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[2, 2/20/93]

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A PALE BLUE DOT

by Carl Sagan

[3/16/93]

A Pale Blue Dot:

Assume approx. 15 pp. MS/chapter = approx. 10-12 pp. print/chapter:

Length of 38 chapters yields 380-456 pp.
+ pix.
Length of 45 chapters yields 450-540 pp.

2 bks. of about 22 chapters each yield 220-264 pp. each + pix.

Present vol. I: ~250 pp. + pix.

[2A, 2/20/93]

<u>A Pale Blue Dot</u>:

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[4-3-93.atp]

Let's call the Introduction "Wanderers," and here is an introductory paragraph:

We were wanderers from the beginning. We followed the herds in their annual migrations. When there was a drought or an odd long-term chill in the summer air, a premonition of an ice age, we sought a better clime. When we couldn't get on with the other members of our little band, we left to seek a more congenial group elsewhere. For 99.9 percent of the tenure of humans on Earth, we were hunter-gatherers and nomads. When the climate was equable, we managed a good life. We were willing to stay put, to become sedentary, careless, a little overweight perhaps. But no circumstances last forever. And so, even after generations of village or city life, the nomadic urge, the song of the open road still sings within us. It has been, I think, put there by natural selection, an essential element in our survival. You never know what's going to happen. You cannot predict when your life, or your band, or even your species might owe its survival to a restless few, driven by an impulse they can hardly articulate, craving, especially early in their lives, unknown lands and undiscovered regions. Vast migrations of people have occurred -- some voluntary, most involuntary -- that have shaped the human condition. The planet is now all explored. To first approximation, all the various ethnic groups have met each other and interacted. We still flee from war and famine. As the

[4-3-93.atp]

climate changes, there will be vast numbers of environmental refugees. Better conditions will always beckon, and people will ebb and flow around the world. But the lure of new places, unknown, undiscovered, holding untold opportunities, has faded. The Earth is all explored. There seems to be nowhere else to go. Except. . . Maybe it's a little early. Maybe the time is not yet. . . But other worlds beckon.

[Prior to next passage, * * *.]

Introduction

My grandfather was a beast of burden, ~~and I have been to Neptune. [Sort of.]~~

Early in this century, Leib Gruber lived in a small town in the vast Austro-Hungarian Empire in Central Europe. His father sold fish when he could. But times were often hard. As a young man, the only honest work available to Leib was carrying people on his back across the river Bug. The customer, male or female, would mount Leib; he would wade out in a shallow stretch of the river and deliver his burden to the opposite bank. No bridges had been built here, and the draft required of ferryboats was too shallow. Horses or mules might have served the purpose, but they had other uses. That left Leib and a few other young men like him. They had no other uses. There was no other work available. They hired themselves out like [camels or oxen]. They would lounge about the river bank, calling out their prices and praising their drayage virtues to likely customers among the passersby.

I don't think that in all his young manhood Leib had been more than 100 kilometers from his hometown. But then, in ____ [year], he suddenly left -- to avoid a murder rap, according to one family legend -- leaving his young wife behind. How different the great German port cities must have seemed compared to his tiny backwater hamlet, how vast the ocean, how strange the

~~planets.~~

Insert V, p.2

~~We have discovered that every one of them is a world. Not one of them is closely similar to the Earth. We have found dozens of other planets and moons, thousands of asteroids and comets.~~ N.¶ Since the advent of successful interplanetary flight in 1962, we have flown by, orbited, or landed on more than ~~forty~~ sixty new worlds. We have discovered vast volcanic eminences that dwarf the highest mountain on Earth; ancient river valleys on a planet now too cold for running water; ice worlds that have enigmatically melted; a cloud-covered planet with an atmosphere of corrosive acids and a surface temperature above the melting point of lead; uneroded surfaces preserving some of the history of the formation of the solar system over four billion years ago; exquisitely patterned ring systems, revealing the subtle harmonies of gravity; and a world surrounded by an impenetrable cloud of complex organic molecules like those that in the earliest history of our planet led to the origin of life.

We have uncovered wonders undream~~ed~~t of by our ancestors who speculated on the nature of those wandering points of light in the night sky. We have begun to probe the mysteries of the origins of our planet and ourselves. By examining other worlds, by discovering what else is possible, by coming face to face with the alternative fates of worlds more or less like ours, we are beginning to understand better our own world. ~~The unmanned exploration of the solar system initiated by the United States~~

lofty skyscrapers and endless hubbub of his new land. We know nothing of his crossing, but have found the record of the voyage made a few years later by his wife Chaiya -- finally rejoining Leib after he had saved up enough money for her passage. She traveled in the cheapest class on the Batavia, a passenger ship of Hamburg registry. The ship's records indicate that Chaiya could not read or write, knew not a word of English, and had one dollar to her name. She landed, lived in America just long enough to give birth to my mother and her sister, and then died of childbirth fever. In those few years, her name was sometimes anglicized to Clara. My mother named ~~me~~ her first-born after the mother she never knew. Leib remarried and lived to what was then considered a ripe old age.

* * *

By profession, I'm a planetary astronomer. My job is to examine other worlds. It's invigorating, exciting, even magical work for me. And in the last few decades, the United States and the former Soviet Union have accomplished something stunning and historic -- the close-up examination of all those points of light, from Mercury to Saturn, that moved our ancestors to wonder and to science. Insert V ~~We have studied broiling, cratered Mercury; and Venus, a hellhole of a planet. We have scrutinized the stunning rings of the outer planets and their amazingly variegated moons~~.

Every one of these worlds is lovely and instructive. But, so far as we know, they are also desolate and lifeless.

During the Viking mission to Mars, beginning in July 1976, in a certain sense I spent a year on that planet. I lovingly examined the boulders and sand dunes, the reddish sky, the ancient river valleys, the soaring volcanic eminences, the steppes in the polar terrain. But there was no life on that planet -- not a blade of grass, not a mouse, or a beetle, or even, so far as we can tell, a microbe. For one reason or another these worlds have apparently not been graced as our world has with life. Life is a comparative rarity. You can have dozens of worlds and on only one of them does life appear and sustain itself.

~~Travel is broadening. [Have we used this sentence in Cosmos or elsewhere?]~~ We humans have progressed from believing that there were no other worlds besides the Earth, to believing that there were many other worlds in the Solar System, to an ebb and flow of opinion about all of the worlds being inhabited or none of them, to our present, still tentative conclusion that -- in this solar system at least -- we are alone.

Having in all their lives up till then only crossed rivers, Leib and Chaiya graduated to crossing oceans. But they had a great advantage: They knew that on the other side of the waters there would be -- with strange customs, it is true -- real human beings speaking their language, sharing their values, people indeed to whom they were closely related.

In my time we've crossed the Solar System and sent four ships to the stars. Neptune lies a million times farther from Earth than New York is from the banks of the Bug. But there are no distant relatives, no humans, and apparently no life at all waiting for ~~my generation~~ us on those other worlds. We have no letters sent home, by recent emigrés, to help us understand these new lands -- only digital data transmitted at the speed of light by robot emissaries with no feelings at all. These worlds are not much like ours.

No one on Earth is rich enough to pay for the passage, so no one can pick up and leave for Mars or Titan on a whim, or because we're bored, or because we've been accused of a crime and must flee the law. If we humans ever go to these worlds, it will be because a consortium of nation-states believes it to be to the advantage of the human species. Our present circumstances are very different; there are a great many problems pressing in on us and justly competing for the money it takes to send people to the planets.

Of course, the fact that I have gone -- even vicariously, via robots whose missions I helped design -- so much farther than my grandparents is hardly because of any special merit of my own. Rather, it is due to the astonishing pace of technology, the fact that by luck I was alive when we first built the ships to go to other worlds. Through better medical practice, pharmaceuticals, agriculture, contraception, advances in transportation and communications, devastating new weapons of war, inadvertent side effects of industry, and disquieting challenges to long-held world views, science and technology have dramatically changed our lives. Many of us are huffing and puffing to keep up, sometimes only slowly grasping the implications of the new developments. In the ancient human tradition, young people grasp change more quickly than the rest of us -- not just in running personal computers and programming videocassette recorders, but also in accommodating to new visions of our world and ourselves. The current pace of change is much quicker than a human lifetime, so fast as to work to rend the generations asunder. This book is in part about understanding and accommodating to the upheavals ~~changes~~ -- both for good and for ill -- brought on by science and technology. [AD: Doesn't quite work.]

As I've said, the Earth is an anomaly. In all the Solar System, it is, so far as we know, the only inhabited planet. We humans are one among millions of separate species who live on a world burgeoning, overflowing with life. And yet, most species that ever were are no more. After flourishing for 180 million years, the dinosaurs were extinguished. Every last one. There are none left. No species is guaranteed its tenure on this planet. And we've been here for only about a million years, we, the first species that has devised means for its self-destruction. We are rare and precious because we are alive, because we can think. We are privileged to influence and perhaps control our future. I believe we have an obligation to fight for life on Earth -- not just for ourselves, but for all those, humans and others, who came before us, and to whom we are beholden, and for all those who, if we are wise enough, will come after. There is no cause more urgent, no dedication more fitting than to protect the future of our species. Nearly all our problems are made by humans and can be solved by humans. No social convention, no political system, no economic hypothesis, no religious dogma is more important. That is also what this book is about.

[2B, 2/20/93]

A Pale Blue Dot

The spacecraft was a long way from home -- beyond the orbit of the outermost planet and high above the ecliptic (an imaginary plane which we can think of as something like a racetrack in which the orbits of the planets are confined). The ship was speeding away from the Sun at 40,000 miles per hour. But in early February of 1990, it was overtaken by a message from Earth, an unusual and unexpected set of new instructions.

Obediently, it turned its cameras back toward the now-distant planets. Slewing from one spot in the sky to another, it took 60 pictures and stored them on its tape recorder. Then, slowly, in March, April, and May, it radioed the images back to Earth. Each picture was composed of 640,000 individual picture elements (pixels), like the dots in a newspaper wirephoto or a pointillist painting. The spacecraft was 3.7 billion miles away from Earth, so far away that it took each pixel 5½ hours, traveling at the speed of light, to reach us. The pictures would have been returned earlier, but the big ground-based radio telescopes that receive these whispers from the edge of the Solar System had responsibilities to other ships that ply the sea of space -- Magellan, bound for Venus, for example, and Galileo on its tortuous passage to Jupiter.

Voyager 1 was so high above the ecliptic plane because, in 1981, it had made a close pass by Titan, the giant moon of Saturn. Its sister ship, Voyager 2, was dispatched on a different trajectory, within the ecliptic plane, and so she was able to perform her celebrated explorations of Uranus and Neptune. The two Voyager robots have explored four planets and nearly 60 moons. They have opened up most of the planetary part of the Solar System to the human species. They were produced on time, on budget and far exceeded their design specifications. They are triumphs of human engineering and one of the few recent glories of the American space program. They will be in the history books when much else about our era is long forgotten.

The Voyagers were guaranteed to work only until the Saturn encounter. So I thought it might be a good idea, just after Saturn, to have one or both take a last glance homeward. The point of such a picture would not be mainly scientific. I knew that, even from Saturn, the Earth would appear too small for Voyager to make out any detail. Our planet would be just a point of light, not even filling a single pixel, hardly distinguishable from the many other points of light it could see, nearby planets and far-off suns. But I thought that -- precisely because of the obscurity of our world thus revealed -- such a picture might be useful.

Mariners had painstakingly mapped the coastlines of the continents. Geographers had translated these findings into maps and globes. Photographs of portions of the Earth had been obtained by orbiting spacecraft -- giving a perspective like the one you achieve by positioning your eyeball about an inch from a large globe. While almost everyone understands that the Earth is a sphere, all of us somehow glued to it by gravity, the reality of this circumstance did not really dawn until the famous frame-filling Apollo photographs of the whole Earth -- the one taken by the Apollo 17 crew on the last journey of humans to the Moon.

It has become a kind of icon of our age. There's Antarctica at the bottom, and then all of Africa stretching up above it: Ethiopia, Tanzania, and Kenya, where the earliest humans lived. At top right is Saudi Arabia and the Near East, and just barely peeking out at the top is the Mediterranean Sea, around which so much of the modern global civilization emerged. You can make out the blue of the ocean, the yellow of the Sahara and the Arabian deserts, the brown-green of vegetated areas.

And yet there is no sign of humans in this picture. We are too small. There is also no sign of national boundaries. Our statecraft is too insignificant to be seen from this vantage point. The Apollo pictures of the whole Earth conveyed to multitudes something well known to astronomers: On the scale of worlds -- much less stars or galaxies -- humans are feeble and inconsequential, a thin film of life on a single world. The human pretension to centrality and cosmic importance seems laughable from this perspective, our aspirations so out of touch with reality.

It seemed to me that another picture of the Earth, this one taken from a hundred thousand times farther away, might help in further awakening ourselves to our true circumstances. Many in NASA's Voyager Project were supportive. But did we want to take a picture so close to the Sun as to risk burning out the spacecraft's video system? Wouldn't it be better to delay until all the scientific images -- from Uranus and Neptune, if the spacecraft lasted that long -- were taken?

And so we waited -- from 1981 at Saturn to 1989, when both spacecraft had passed the orbits of Neptune and Pluto. At last the time came. But there were some instrumental calibrations that needed to be done first, and we waited a little longer. Although we were in the right spot and the instruments were working, a few project personnel opposed taking this picture. It wasn't science, they said. Then we discovered that the people who devise and transmit the radio commands to Voyager were, in a cash-strapped NASA, being laid off immediately or transferred to other jobs. At the last minute -- actually, in the midst of the Voyager 2 encounter with Neptune -- the NASA Administrator, then Admiral Richard Truly, stepped in and made sure that these images were taken.

So here they are -- a mosaic of squares laid down on top of the planets and a smattering of more distant stars. We were able to photograph not only the Earth but also six of the Sun's nine known planets. Mercury, the innermost planet, was lost in the glare of the Sun, and Mars and Pluto were too small, too poorly lit, and/or too far away. Uranus and Neptune are smeared because of the motion of the spacecraft; these planets are so dim that to record their presence required long exposures. This is what the planets would look like to an alien spaceship entering the Solar System after a long interstellar voyage.

Because of the way that sunlight is scattered off the spacecraft, the Earth seems to be sitting in a beam of light, as if there were some special importance to our small planet. But this is just an accident of geometry and optics. The Sun emits its radiation equitably to all directions in space.

And why that cerulean color? The blue comes partly from the sea and partly from the sky. While water in a glass is transparent, it absorbs slightly more red light than blue light. If you have a kilometer of the stuff, the red light is absorbed out and what gets reflected back to space is mainly blue. Similarly, a short line of sight through air seems perfectly transparent. Nevertheless -- something Leonardo da Vinci excelled at portraying -- the more distant the object, the bluer it seems. The reason is that the air bounces blue light around much better than red light. So the blueness of this dot is due to a deep transparent atmosphere and deep oceans of liquid water. And the white? The Earth on an average day is about half covered with white water clouds. We can explain this pale blueness because we know the Earth well. Whether an alien scientist newly arrived at the outskirts of our solar system could reliably deduce oceans and clouds and a thickish atmosphere is less certain. Neptune, for instance, is blue, but for a wholly different reason. From this distant vantage point, the Earth might not -- even to a very advanced alien being -- seem of particular interest.

But for us, it's different. Look at this pale blue dot. That's here. That's home. That's us. On that dot everyone you love, everyone you know, everyone you ever heard of, every human being who ever was, lived out their lives. Every act of human heroism or betrayal, the sum total of human joy and suffering, thousands of confident religions, ideologies, and economic doctrines, every hunter and forager, every creator and destroyer of civilization, every king and peasant, mother and father, hopeful child, inventor and explorer, moral teacher and corrupt politician, every "superstar," every "supreme leader," every saint and sinner in the history of our species lived there -- on a mote of dust suspended in a sunbeam.

The Earth is a very small stage in a vast cosmic arena. What is the glory and triumph of the greatest conquerors and builders of empires? They were the momentary masters of a fraction of a blue dot. Our posturings, our imagined self-importance, the delusion that we have some privileged position in the Universe, are challenged by this point of pale light. Our planet is a lonely speck in the great enveloping cosmic dark. In our obscurity in all this vastness, there is no hint that help will come from the outside to save us from ourselves. Doing that is up to us.

The Earth is the only world known so far to harbor life. There is nowhere else, at least in the near future, to which our species could migrate. It is a lovely, fragile, finite little planet. But its importance lies only, I think, in what we make of it.

It has been said that astronomy is a humbling and character-building experience. There is perhaps no better technological demonstration of the folly of human conceits than this distant image of our tiny world. To me, it underscores our responsibility to preserve and cherish this pale blue dot, the only home we have.

[2B, 2/20/93]

~~[Alternative position in book (with some modifications): last chapter.]~~

A Universe Not Made for Us

~~[A Universe Not Made for Us?]~~

[Epigraph: from beginning of "Dover Beach."]

It almost never feels like prejudice. Rather, it seems fitting and just -- the idea that, because of an accident of birth, our group (whichever one it is) has an otherwise unmerited central position in the social universe. Among Pharaonic princelings and Plantagenet pretenders, children of robber barons and Central Committee officials, members of confident majorities, obscure sects, and reviled minorities, this self-serving attitude seems as natural as breathing. It is connected with sexism, racism, nationalism, and the other deadly chauvinisms that continue to plague our species. Uncommon strength of character is needed to resist the blandishments of those who assure us that we have an obvious, even God-given, superiority over our fellows.

Since scientists are people, it is not surprising that comparable pretensions and conceits have entered the scientific world view. Indeed, many of the central debates in the history of science seem to be really contests about whether we humans are special. Almost always the going-in position is that we are special, and at the end of the debate it turns out -- in dishearteningly many cases -- that we are not.

Our ancestors lived out-of-doors. They were as familiar with the night sky as most of us are with our favorite television programs. The Sun, the Moon, the stars, and the planets all rose in the east and set in the west, traversing the sky overhead in the process. The motion of the stars was not merely a diversion, eliciting a sense of awe; it was the only way to tell the time of day and the seasons. For hunters and gatherers, as well as for agricultural peoples, knowing about the sky was a matter of life and death. How lucky for us that the Sun, the Moon, the planets, and the stars are part of some elegantly configured cosmic clockwork! Clearly they are put here for our benefit. Who else makes use of them?

And if the celestial bodies rise and set around us, then isn't it wholly evident that we're at the center of the Universe? These bodies -- so clearly suffused with unearthly powers, especially the Sun on which we depend for light and heat -- are circling us, like courtiers attending a king. We might not otherwise have guessed, but the most elementary examination of the heavens reveals that we _are_ special. The Universe seems structured around human beings, created for us. It's difficult to contemplate such a circumstance without experiencing some stirrings of pride. The entire Universe, made for us! We must be really _something_!

This satisfying demonstration of our self-importance, buttressed by daily observations of the heavens, made the geocentrist conceit a transcultural truth -- taught in the schools, built into the language, part and parcel of great literature and sacred scripture. Dissenters were discouraged, sometimes with torture and death. It is no wonder that for the vast bulk of human history, no one questioned it. Aristotle and Plato and almost all the great philosophers and scientists of all cultures over the last 3,000 years bought into this delusion. Many busied themselves figuring out how the Sun, the Moon, the stars, and the planets could be cunningly attached to absolutely transparent, crystalline spheres -- the big spheres, of course, centered on the Earth -- that would explain the complicated motions of the celestial bodies so painstakingly chronicled by generations of astronomers.

And yet -- never mind how many kings, popes, savants and philosophers were convinced of the contrary -- the Earth through all those millennia stubbornly persisted in orbiting the Sun. You might imagine an uncharitable extraterrestrial observer looking down on our species over all that time -- with us excitedly chattering, "The Universe created for us! We're at the center! Everything pays homage to us!" -- and concluding that this must be the planet of the idiots.

But that judgment is too harsh. We did the best we could. There was an unlucky coincidence between common sense observations and what we secretly hoped would be true. We tend not to be especially critical when presented with evidence that seems to affirm our prejudices.

Beginning with Copernicus in the middle fifteenth century, the issue was formally joined. The idea of the Sun rather than the Earth at the center of the Universe was generally treated, in a kind of doctrinal compromise, as a mere computational convenience, not an astronomical reality -- that is, the Earth was really at the center of the Universe, as everybody knew and as the Bible taught; but if you wished to know where Jupiter would be on the second Tuesday of November the year after next, you were permitted to pretend that the Sun was at the center. Then you could calculate away. Many were unhappy with these findings, though, and ~~he was~~

~~Insert from~~ p. 5.

However, when Galileo discovered that Jupiter had a little retinue of moons circling it, and that Mercury and Venus went through phases like the Moon, the Earth-centered Universe began to crumble. By the time Isaac Newton demonstrated that very simple and elegant physics could quantitatively explain all the observed lunar and planetary motions -- provided you assumed the Sun at the center of the Solar System -- the traditional view was overturned. The geocentrist conceit utterly collapsed. Or so it seemed.

It was not until the nineteenth century that direct observations of the stars demonstrated the Earth indeed to be circling the Sun (through the discovery of the "annual parallax" of the stars). But by then scientific geocentrists were ~~dead as~~ extinct.

by the princes of the Church

~~doornails~~. Once most scientists were convinced, ~~informed public~~ opinion swiftly changed. ~~Of course -- like the cardinals who earlier had threatened~~ the aged ~~Galileo~~ astronomer was threatened ~~with~~ with torture if he persisted in teaching the abominable doctrine that the Earth moved ~~--~~, Of course, there were still some who resisted, who tried to prevent the new Sun-centered Universe from becoming known.

X p.

Every other proposal, and there have been a long sequence of them, to remove the human species from cosmic center stage has been resisted, in part for reasons that emotionally all seem rather similar. We crave privilege, emanating not from our works but from our birth, from the mere fact that we were born on this planet or among such-and-such a people. We might call it the anthropocentric -- the "human-centered" -- conceit. If chimps had a cosmology, I bet it would be "chimpocentric," and a dolphin cosmology "delphinocentric." It's an easy mistake to make.

By the seventeenth century there might have been some hope that, even if the Earth is not the center of everything, the Earth is the only planet, the only "world," in the Universe. But telescopic observations of the Moon and the other planets made it clear that they had as much claim to being worlds as the Earth does -- with mountains, atmospheres, ice caps, clouds, and, in the case of Saturn, a dazzling, unheard-of set of circumferential rings. They might be profoundly different from our planet. None might be as clement or as habitable. But the Earth was hardly the only world.

Well, it was then widely held, even if the Earth isn't at the center of the Universe, the Sun is. The Sun is **our** Sun. The Earth is **approximately** at the center of the Universe. In this way some of our pride could be saved. But by the nineteenth century, observational astronomy had made clear that the Sun was but one star among huge numbers, part of a lens-like, self-gravitating assemblage of suns called the Milky Way Galaxy. Far from being at the center of the Galaxy, our Sun with its retinue of tiny planets lies in an undistinguished arc of an obscure spiral arm.

Well, then, at least the Milky Way Galaxy is at the center of the Universe. No, this notion is wrong as well. The Milky Way Galaxy is one of billions, perhaps hundreds of billions of galaxies distinguished neither in mass nor in brightness nor in how its stars are configured. When the expansion of the Universe was first discovered, many people naturally gravitated to the idea that the Milky Way Galaxy was at the center of the expansion, all of the other galaxies running away from us. But we now recognize that astronomers on any galaxy would see all of the other galaxies running away from them; they would -- unless they were very careful -- conclude that they were at the center of the Universe. There is, in fact, no center, at least in three-dimensional space.

Well, even if there are hundreds of billions of galaxies, each with hundreds of billions of stars, maybe none of those other stars has planets. Because planets are small and don't shine by their own light, they're hard to find, even around the nearest star, Alpha Centauri. There was once a popular view that our solar system was formed by the near collision of the ancient Sun with another star, the gravitational tidal interaction pulling out tendrils of sunstuff which condensed into planets. Since space is mainly empty and near stellar collisions exceedingly rare, it was confidently concluded that very few other planetary systems existed -- perhaps only one, around that other star that long ago co-parented the worlds of our solar system. (Early in my astronomical career, I was amazed and disappointed that such a view had ever been taken seriously, and that the absence of evidence for planets was considered evidence for the absence of planets.)

Today quite firm evidence exists for two Earthlike planets orbiting an extremely dense star called a pulsar. (The planets show up in the timing residuals of the beacons of radio waves that the rapidly rotating neutron star casts across the Earth.) And we've found, for more than half the stars like the Sun, that during the first few million years of their lives they're surrounded by great disks of gas and dust out of which planets seem to be forming. Other planetary systems look to be a cosmic commonplace.

Well, if we can't find anything special about our position, maybe there's something special about our motion. Newton and all the great classical physicists believed that the velocity of the Earth in space constituted a "privileged frame of reference." That's actually what it was called. Albert Einstein considered this attitude a remnant of an increasingly discredited Earth chauvinism. It seemed to him that the laws of Nature must be the same no matter what the velocity of the observer. With this as his starting point, he formulated the Special Theory of Relativity. Its consequences are bizarre, counterintuitive, and grossly contradict common sense -- especially at very high speeds. But careful and repeated observations show that the justly celebrated Special Relativity is an accurate description of how the world is made, no matter what our preferences. There are no privileged frames of reference.

Well, even if our position, our motion, and our world are not unique, maybe **we** are. We're different from the other animals. We're specially created. The particular devotion of the Creator of the Universe is evident in us. This position was passionately defended on religious and other grounds. But in the middle nineteenth century Charles Darwin showed convincingly how one species can evolve into another by entirely natural processes, which come down to saving which heredities work and rejecting those that don't. The profound connections of humans with chimpanzees and all the other life forms on Earth has been compellingly demonstrated in the late twentieth century by the new field of molecular biology.

In each age the chauvinist predispositions are challenged in yet another arena of scientific debate -- in this century, for example, in attempts to understand the nature of human sexuality, the existence of the unconscious mind, and the fact that many psychiatric illnesses and character defects may have a molecular origin. But let me skip over these and instead mention some others:

Well, even if we're closely related to some of the other animals, we're different -- not just in degree, but in kind -- on the really important questions: reasoning ability, tool making, religion, ethics, altruism, language, nobility of character. While humans, like all animals, have traits that set them apart -- if this were not true, how could we distinguish one species from another? -- my own sense is that human uniqueness has been exaggerated, sometimes grossly so. (Ann Druyan and I run through the evidence in our book *Shadows of Forgotten Ancestors*.) But because we have not opened up a clear communications channel between the minds of other animals and ourselves, we cannot yet be absolutely sure about some of these traits.

Well, maybe we're not much, maybe we're humiliatingly related to monkeys, but we're the best there is. We're the only really intelligent beings in the Universe. The simple fact is that we are in the earliest stages of looking for extraterrestrial life. We have not found it yet. The question is wide open. If I had to guess -- especially considering our long sequence of failed chauvinisms -- I would guess that the Universe is filled with beings far more intelligent, far more advanced than we are. But this is at best a plausibility argument, not a scientific demonstration. The question is among the most fascinating in all of modern science.

Perhaps the clearest indication that the search for an unmerited privileged position for humans will never fully die is what is called the Anthropic Principle. It would be better named the Anthropocentric Principle. It comes in various forms. The "weak" anthropic principle merely notes that if the laws of Nature had been different, the course of events leading to the origin of humans would never have been taken. Under other imaginary laws, atoms would not hold together, or stars would evolve so quickly that there would be insufficient time for life to evolve on nearby planets, or the chemical elements of which life is made would never have been generated, and so on. If it were an inverse cube instead of an inverse square in the law of gravity, then planets would quickly spiral into their stars and be burned to a crisp. There is no controversy about the weak anthropic principle: Change the laws of Nature, if you could, and a very different Universe would develop -- in many cases, a Universe incompatible with us. The "strong" anthropic principle goes farther, and some of its advocates come close to deducing that the laws of Nature and the values of the physical constants were established <u>so that</u> humans would eventually come to be.

check
[~~Restate.~~] In this way, although in a more sophisticated form, the ancient doctrine that the Universe was made for us is resuscitated.

To me it sounds like playing one hand of bridge, winning the game, knowing that there are ________ [fill in number] possible other hands that I was equally likely to have been dealt. . . and then deducing that there is a god of bridge who has arranged the cards and the shuffle with my victory foreordained from the beginning. [Check with Barrow and Tippler.] We do not know how many other hands there are in the cosmic deck, how many other kinds of universes, laws of Nature, and physical constants that could also lead to life and intelligence and conceits of self-importance. Since we know next to nothing about how the Universe was made -- or even <u>if</u> it was made -- it's difficult to pursue the question constructively. Einstein's formulation was whether God had any choice in creating the Universe. Perhaps there is only a limited set of laws of Nature that go together consistently. Perhaps the Universe is infinitely old and the question of why it is as it is is meaningless.

But if self-congratulatory pretensions even among scientists have now retreated to bastions impervious to experiment (we are unlikely to be creating universes to test the Anthropic Principle anytime soon), then the sequence of battles with human chauvinism would seem to be, at least largely, won. We could not have known beforehand that the evidence would be so repeatedly and

, a college graduate,

thoroughly incompatible with the proposition that the human species is at cosmic center stage. Instead, the debates have been settled decisively in favor of a position that, however painful, can be summarized in a single sentence: There is nothing special about us.

A famous television talk show host confessed to me that he'd never been taught that the Sun was a star.

* * *

No matter what the scientists say, in everyday life we often ignore the evidence. We do not talk about the Earth turning, but rather about the Sun rising and setting. "What a beautiful sunset," we say, or "I'm up before sunrise." We haven't even been able to find a graceful locution to ~~match~~ convey the Copernican insight. We are covert geocentrists. We at the center and everything else circling around us is built into our languages and therefore taught to our children. Polls show that something like 20 percent of American adults do not know that the Earth goes around the Sun. I can find in my undergraduate classes at Cornell University bright students who do not know that the stars rise and set at night, and in a poll of graduating seniors at Harvard University, ___ percent thought that it's hotter in summer because the Earth is then closer to the Sun.

Through science fiction and our educational system, NASA and the role that science plays in society, Americans have much more exposure to the Copernican perspective than the average person on

[3-23-93.at1]

An insert into A Pale Blue Dot:

~~[Footnote:]~~ *The International Astronomical Union has recommended that the definite article be excised in all names of celestial bodies: thus, Sun, Earth, and Moon, instead of the Sun, the Earth, and the Moon. Presumably we should describe the Milky Way as Galaxy, instead of the Galaxy. The intent is admirable -- a real attempt to break loose from ~~of~~ some of our astronomical chauvinisms. But I can't bring myself to do it. In spoken speech, we lose the distinction between our planet and a clump of humus. And such locutions as "Moon goes around Earth; Earth goes around Sun" sound like a literal translation from one of those many languages that lack definite articles. It may be that Western European languages are especially prone to the anthropocentrism of the definite article. But I recognize that my inability to change may be a species of oldfogeyism. ~~[Sic in Amer. Her. Dict.: single word.]~~

[3-23-93.at1]

Insert C for A Pale Blue Dot, [chapter?]; also for the Gifford Lectures:

To its credit, although ~~rather~~ quite belatedly, the Roman Catholic Church has invalidated its 1633 condemnation of Galileo for advocating that the Earth goes around the Sun. Unfortunately, the Church still cannot quite bring itself to see ~~acknowledge that it~~ the significance of its opposition to the thesis that the Earth went around the Sun. ~~made a serious mistake and that it had no right making pronouncements on matters of science, much less threatening and intimidating people who did not agree that the Sun went around the Earth~~. In a 1992 speech Pope John Paul II says, "From the beginning of the Age of Enlightenment down to our own day, the Galileo case has been a sort of 'myth' in which the image fabricated out of the events is quite far removed from reality. In this perspective, the Galileo case was a symbol of the Catholic Church's supposed rejection of scientific progress, or of 'dogmatic' obscurantism opposed to the free search for truth."

~~But he~~ The Pope does though go on to add: "The error of the theologians of the time, when they maintained the centrality of the earth, was to think that our understanding of the physical world's structure was in some way imposed by the literal sense of Sacred Scriptures."

Here indeed considerable progress has been made -- although proponents of other fundamentalist faiths will be distressed to hear from the Pope that Sacred Scripture is not inerrant. ~~but~~

But surely the Holy Inquisition taking the ill and elderly Galileo to check out the instruments of torture in the dungeons of the Church admits just such an interpretation

Earth. It may very well be, then, that more than four and a half centuries after Copernicus, most people on Earth still think that our planet sits immobile at the center of the Universe.

We talk about "the" world, as if our planet were the only one (and "the" Sun and "the" Moon). Maybe it's reassuring. There are eight other planets in this solar system, dozens of moons, thousands of asteroids, and trillions of comets. But that needn't ~~bother~~ diminish us, if ours is "the" world.*

Insert C

Only nine percent of Americans share Darwin's view that human beings (and all the other species of life now on Earth) have slowly evolved through specific natural processes from a succession of simpler and more ancient precursors. Evolution is still being fought -- in the schools, in the courts, and on the question of just how much pain physicians and scientists can inflict on other animals without crossing some ethical threshold. Many of us do not want to believe that other animals have language skills comparable to a human two-year-old, or technologies that humans cannot duplicate, or ~~are~~ may be more willing than we are to suffer so that their fellows will not. Many people are dismissive, even angry, about such claims. One well-known philosopher argues that if intelligent extraterrestrials exist but lack human form, they are not "persons" and need not be given the respect or legal protection that they would otherwise be owed. No matter how smart they are -- this is what the argument seems to come down to -- if they don't look like us, it's okay to slaughter them. Nonhuman intelligence, both on Earth and elsewhere, is another battleground on which the anthropocentric conceit is being tested. ~~If there are other meadows, they are too far away for us to see them -- at least till now~~

These chauvinisms have practical ~~consequences.~~ ~~The~~ Earth ~~is~~ a tiny meadow in a vast, ~~black~~ bleak, empty wasteland. But if ~~If instead~~ ~~were~~ we ~~to~~ imagined ~~it~~ our planet at the center of the Universe and ourselves the reason that the Universe was made, then would we make our best effort to care for our meadow? Human beings are exquisitely dependent on a complex network of relationships with other organisms, many of them quite humble. If we imagined that we were put here to have "dominion" over Nature, would we scrupulously protect those other beings who share this world with us? Are our chances of survival better or worse if we lack the courage to see the Universe as it really is?

Of course, it's not much fun to have a gaggle of scientists incessantly haranguing you with "You're ordinary, you're ~~not~~ unimportant, there's nothing special about you." ~~"You're not important, you're not important."~~ Even unexcitable people might get annoyed with this incantation after a while. Maybe it seems that the scientists are getting some weird satisfaction out of putting humans down. Why can't they find some way in which we're superior? Lift our spirits! In such debates science seems cold and remote, unresponsive to human needs.

But surely we'll never be able to improve our circumstances if we lie to ourselves about what those circumstances are. If we were central and important in the Cosmos, it would be good to know that. Whatever twists and turns along the way, it will all work out. There's a *Deus ex machina* waiting in the wings. But if we are peripheral and insignificant, it is even more important to know *that*. If in error we believed that the world was made for us, we might be much more complacent about the harm we do from greed, inattention, ignorance, or stupidity. If we are what the Universe is about, we may be dangerously negligent about our future.

This is why -- if we humans are not the heroes of the entire cosmic drama -- Copernicus, Galileo, Darwin, Einstein, and the other pioneers of deprovincialization have provided a key public service: They have alerted us to a grave peril, which perhaps can be described as hubris compounded by complacency. Two or three millennia ago, there was no shame in holding that the Universe was made for us. It was a thesis consistent with what we thought we knew. But we have learned much in the interim. Holding such a position today amounts to willful neglect of the evidence, and a shameful resistance to self-knowledge.

These deprovincializations rankle. Even if they do not fully carry the day, they erode confidence, unlike the happy anthropocentric certitudes, rippling with social utility, of an earlier age. Our time is burdened under the cumulative influence of more debunkings of the anthropocentric conceit than any previous historical epoch: We live in the cosmic boondocks. We emerged from the slime. Apes are our cousins. Our thoughts and feelings are not entirely under our own control. There may be much smarter and very different beings elsewhere. And on top of all this, we're making a mess of our planet. Many of us wish this bill of particulars were otherwise. It weighs on us. It has a train of implications. It undermines human confidence. It raises awkward questions about what our responses should be. Some of us may feel called upon to act. But it is much easier to be complacent and hope for the best.

It's hard to be human without feeling some glimmer of resentment about these attacks on human chauvinism. But, it seems to me, the gains from this new perspective far outweigh the losses. We find ourselves, trembling just a little, on the threshold of a vast and awesome Universe, rich in mystery and promise, that utterly dwarfs -- in time, in space, and in potential -- the tidy anthropocentric world of our ancestors. We are peering across billions of light years of space to view the Universe shortly after the Big Bang. We are reading the genetic language in which is written the nature and propensities of every being on Earth. We are peering down into the core of the Earth. We have developed medicines that have saved the lives of billions of people. We have sent dozens of ships to more than sixty nearby worlds, and four spacecraft to the stars. We are right to be proud of our discoveries, and to judge our merit in part by the science that so deflated our pretensions.

Most of these debates were entered into with no thought for their practical implications. Passionate and curious humans wish to understand their actual circumstances, how unique or pedestrian they and their world are, their ultimate origins and destinies. Surprisingly, some of these debates have yielded the most profound practical results. The very method of mathematical reasoning that Isaac Newton introduced to explain the motion of the planets around the Sun has led to most of the technology of our modern world.

But it might have been otherwise. It might have been that the balance lay elsewhere, that humans by and large did not want to know the truth, that they were unwilling to permit challenges to the prevailing wisdom, that they would not spend government or private money to uncover a disquieting Universe. Despite stout resistance in every age, it is very much to the credit of our species that we have allowed ourselves to follow the evidence, to draw conclusions that at first seem so unpalatable and daunting: a Universe not made for us, a Universe so much larger and older that our personal and historical experience is dwarfed and humbled.

There is a related danger. Conceits about the superiority of our position or motion or planet or species are but a step from believing that our particular sex or race or ethnic group has some intrinsic superiority. Many of us humans are still focused on and transfixed by human differences -- men giving

[3-23-93.at1]

Insert X

~~An insert into A Pale Blue Dot~~:

Every time it is suggested that humans, like some ~~many~~ of our close relatives, have a biological propensity for certain behavior -- dominance, ethnocentrism, xenophobia, rape -- the objection is heard that this is a thinly disguised justification for tyranny, ~~and~~ ethnic hatred and sexual violence. Of course the cultural and social environment plays an enormous role, encouraging some predispositions ~~propensities~~ and discouraging others. ~~But~~ A ~~a~~ predisposition is ~~does not mean an inevitability, and the existence of~~ only that -- behavior that can be elicited under some circumstances in some societies. It is not a commandment graven in stone. A ~~a~~ predisposition to hate might very well be balanced by a predisposition to love. But we are afraid to hear that some of our ~~som~~ routine behavior, which can be read about in any newspaper on any given day, has a biological basis. That's just for apes. We want to believe we're above all that.

thanks each day to God that they were not born women, one race characterizing another as "apes" or "devils," nations making fun of one another's customs and languages, one ethnic group ready to make any sacrifice to visit vengeance on another in feuds and vendettas that trace back to the dawn of recorded history. The lesson is very hard to learn. It's as if we're born ready to cast our lot passionately with any random group or circumstance; whoever we're related to or whoever gets to teach us first, we're for them forever, and against all others. Both in understanding how the Universe really works and in designing a society that really works, self-congratulatory conceits constitute a major obstacle.

Insert X

Today we are faced with a sequence of unparalleled crises regarding the global environment, the growth of the world population, [the spread of epidemic diseases?], and matters of simple equity and fairness and respect for those less advantageously circumstanced. And yet we are willing to explore the fine structure of matter, life, the planets, the stars, and the distant galaxies. We are bravely examining what would seem to be the last testable self-congratulatory chauvinism -- the contention that in all this great Universe of a hundred billion galaxies and a billion trillion stars, there is no species so wise, so intelligent, so advanced as we. We may misuse our technology. We may be disastrously short-sighted. Some of us may seek to suppress a truth which does not correspond to our preconceptions. But in our courageous pursuit of the unknown, we may find a saving grace.

The hard truth seems to be this: We live in an immense and ancient universe -- in which, daily, suns are made and worlds destroyed -- while humanity, newly arrived, clings to an obscure clod of rock and metal. There is design without a doubt. But while we are forever hoping to find a Designer, we keep discovering that natural processes can extract order out of chaos. The evidence does not unambiguously reveal a Designer. Maybe there is one, but it certainly has not revealed itself enough to convince even a moderately scrupulous skeptic.

The significance of our lives and our fragile planet is determined then only by our own wisdom and courage. We are the custodians of life's meaning. We would prefer there to be a cosmic Parent who will care for us, forgive us our errors and save us from ourselves. But I believe it is better to ~~know~~ accept a disappointing truth than to embrace a reassuring ~~lie [error?].~~ fallacy. If we long for some cosmic importance, then it is our responsibility, rather than pretending to what we do not yet have, to make ourselves significant.

Meanwhile, there is a lesson to be drawn from these scientific debates: Be wary when evidence is adduced of the superiority of our planet, our species, or any subgroup of humans. We are not at our best when so tempted.

IS THERE INTELLIGENT LIFE ON EARTH?

[FROM THE ANNALS OF AN ALIEN LIFE DETECTION MISSION]

[Italicized:]

There are places, in and around our great cities, where the natural world has all but disappeared. You can make out streets and sidewalks, autos, parking garages, advertising signs, monuments of glass and steel, but not a tree or a blade of grass or any animal -- besides, of course, the humans. There are lots of humans. Only if you look up through the skyscraper canyons can you make out a star or a patch of blue -- reminders of what was there long before humans came to be. But the bright lights of big cities bleach out the stars, and even that patch of blue is often gone, tinted brown by technology.

It's not hard, going to work every day in such a place, to be impressed with ourselves. How we have transformed the Earth for our benefit and convenience! But a hundred miles up or down there are no humans (except for an increasingly rare handful in transit). Apart from a thin film of life at the very surface of the Earth, a few intrepid spacecraft, and some radio static, our impact on the Universe is nil. It knows nothing about us.

[End of italics.]

* * *

You're an alien explorer entering the Solar System after a long journey through the blackness of interstellar space. You examine the planets of this humdrum star from afar -- a pretty handful, some gray, some blue, some red, some yellow. You're interested in what kinds of worlds these are, whether their environments are changing, and especially whether there is life and intelligence. You have no prior knowledge of the Earth. You have just discovered its existence.

There's a galactic ethic, let's imagine, about looking but not touching. You can fly by these worlds; you can orbit them; but you are strictly forbidden from landing. Under such circumstances, could you figure out what the Earth's environment is like and whether anyone lives there?

Your first impression on seeing a picture of the whole Earth is white clouds, white polar caps, brownish continents, and some bluish substance that covers two-thirds of the surface. You cannot know beforehand the composition of any of these. When you measure the temperature of this world from the infrared radiation it emits, you find that most latitudes are above the freezing point of water, while the polar caps are below the freezing point. Water is a very abundant material in the Cosmos; polar caps made of solid water would be a reasonable guess, as well as clouds of solid and liquid water. You might be tempted to conclude that the blue stuff is vast quantities -- kilometers deep -- of liquid water. But this suggestion is bizarre, at least as far as <u>this</u> solar system is concerned, because surface oceans of liquid water exist on none of the other worlds. However, when we look in the visible and near-infrared spectrum for telltale signatures of chemical composition, sure enough we find enough water vapor in the air to account for the clouds, and just the amount that must exist because of evaporation if the oceans are in fact made of liquid water.

The spectrometers also reveal that the air on this world is almost one-fifth oxygen, O_2. No other planet in the Solar System has anything close to so much oxygen. Where does it come from? The intense ultraviolet light from the Sun breaks water down into oxygen and hydrogen, and hydrogen quickly escapes to space. This is a source of O_2, sure enough, but it doesn't easily account for so <u>much</u> oxygen. Another possibility is that ordinary visible light is used to break water apart -- except there's no known way to do this without life. If you're a good skeptical scientist, then, the O_2 would be not proof of life, but only the merest hint.

With all that oxygen you're not surprised to discover ozone in the atmosphere, because ultraviolet light makes ozone (O_3) out of oxygen (O_2). The ozone then absorbs dangerous ultraviolet radiation. So if the oxygen is due to life, there's a curious sense in which the life is protecting itself. But this life might be photosynthetic plants. A high level of intelligence is not implied.

When you examine the continents more closely, you find there are, crudely speaking, two kinds of regions. One shows the spectrum of ordinary sorts of rocks and minerals found on many worlds. The other reveals something unusual: a material -- covering vast areas -- that strongly absorbs red light. This pigment is just the sort of thing needed if ordinary visible light was being used to break water apart and account for the oxygen in the air. It's another hint -- this time a little stronger -- of life, not a bug here and there, but of a planetary surface chock full of life. This pigment is in fact chlorophyll; it absorbs in the blue as well as the red, and is responsible for the fact that plants are green. What you're seeing is a densely vegetated planet.

When you look carefully at the infrared spectrum of the Earth, you find many minor constituents of the air. In addition to water, there's carbon dioxide (CO_2), methane (CH_4), and other gases which absorb the heat that the Earth tries to radiate away to space at night. These gases warm the planet. Without them, the Earth would everywhere be below the freezing point of water. You have readily discovered the greenhouse effect.

There's something odd about having methane and oxygen together in the same atmosphere. The laws of chemistry are very clear: In an excess of O_2, CH_4 should be entirely converted into H_2O and CO_2. The process is so efficient that at equilibrium not a single molecule in all the Earth's atmosphere should be methane. In fact, you find one out of every million molecules is methane, an immense discrepancy.

The only possible explanation is that methane is being injected into the Earth's atmosphere so quickly that its chemical reaction with O_2 can't keep pace. What could the source of this methane be? Maybe it's left over from the early history of the Solar System, before the origin of life, but quantitatively this doesn't seem to work. The only alternatives are biological. This conclusion makes no assumptions about the chemistry of life, but merely follows from how hard it is to be so far from chemical equilibrium. In fact, the methane in the Earth's atmosphere arises from such sources as bacteria in bogs, the cultivation of rice, the burning of vegetation, natural gas from oil wells, and -- I'm trying to put this decorously -- bovine flatulence. In an oxygen atmosphere, it _is_ a sign of life.

It's a little disquieting that the intimate intestinal activities of cows should be detectable from interplanetary space when, as we will see, so much of what we consider important and hold dear is not. As an alien scientist flying by the Earth, you would not be able to deduce cows, but you would almost certainly deduce life.

All the signs of life that we've discussed so far are due to comparatively simple forms. Had your spacecraft flown by the Earth a hundred million years ago in the age of the dinosaurs, when there were no humans and no technology, you would still have seen oxygen and ozone, the pigment of chlorophyll, and far too much methane. But your instruments are also finding signs not just of life, but of high technology -- something that couldn't possibly have been detected a hundred million years ago. You are detecting radio transmission from the Earth -- at just the frequencies where radio waves begin to leak out of the Earth's ionosphere, which reflects and absorbs radio waves. The signal is modulated (a sequence of ons and offs). The conclusion that the radio transmission is due to technology on Earth holds no matter what the ons and offs mean. You don't have to decode the message to be sure it <u>is</u> a message. (In fact, the signal is a communications relay from the U.S. Navy to its distant nuclear submarines.)

So as an alien explorer you would know that at least one of the species of beings on Earth has achieved radio technology. Which ones? The ones that make methane, the ones that make oxygen, the ones whose pigment colors the landscape green? Or somebody else, somebody more subtle, somebody not so readily apparent to a flyby spacecraft? To search for this technological species, you might want to examine the Earth in finer and finer detail, seeking, if not the beings themselves, at least their artifacts.

You look first with modest telescopes, so the finest detail you can make out is about one or two kilometers across. At this level of detail, you can make out no strange formations, no obvious signs of life. You observe a dense atmosphere in motion. The abundant water must evaporate and then rain back down on the ground, so there must be running water. The ancient impact craters, apparent on the Earth's nearby Moon, are almost wholly absent. There must then be a set of processes whereby new land is created and then eroded away in much less time than the age of this world. As you look with finer and finer definition you find mountain ranges, river valleys, and many other indications that this planet is geologically active.

There are many places surrounded by vegetation, though, but which are themselves denuded of plants. They look like discolored smudges on the landscape. (Many of them are in fact large cities, but you'd never be able to prove it unless you looked at higher resolution.)

When you examine the Earth at about 100-meter resolution, everything changes. The planet is revealed to be covered with straight lines, squares, rectangles, circles -- of a regularity and complexity that would be hard to explain except by life and intelligence. You would not know what all this was about. Perhaps all you would conclude is that the dominant life forms on the planet have a simultaneous passion for territoriality and Euclidean geometry. You would at this resolution not be able to see them, much less know them.

When you take pictures at a few meters resolution, you find that the crisscrossing straight lines of the cities and the long straight lines that connect the cities seem to be filled with beings a few meters in length -- that at night turn on two bright lights in front so they can see where they're going. The streets of the cities, the roadways of the countryside are clearly built for the benefit of these beings. Some of them, when their workday is done, go to little houses to retire for the night. At last you have detected the source of all the technology, the dominant life form on the planet. You might begin to believe that you were really beginning to understand life on Earth. And perhaps you'd be right. (If the resolution improved just a little further, you would discover tiny parasites that occasionally enter and exit the dominant organisms.)

All the images so far you've taken in reflected sunlight -- that is, on the day side of the planet. But something most interesting is revealed when you photograph the Earth at night. The planet is lit up like a Christmas tree. The brightest region, near the Arctic Circle, is lit by the aurora borealis -- generated not by life, but by protons from the Sun. Everything else you see is due to life. The lights outline the same continents that you can make out in daylight, and many correspond to the cities that you've already mapped. The cities are concentrated near the coastlines. They tend to be sparser in continental interiors. Perhaps the dominant organisms are desperate for seawater (or maybe oceangoing ships were once essential for trade and emigration).

Some of the lights, though, are not due to cities. In North Africa and the Middle East, there are very bright lights in the desert; they are due to the burnoff of oil and natural gas wells. In the Sea of Japan there is a strange, triangular-shaped area of light. In daylight it corresponds to open ocean. This is no city. What could it be? It is in fact the Japanese squid fishing fleet using brilliant illumination to attract schools of squid to their deaths. This pattern of light wanders all over the Pacific Ocean, seeking its prey. What in effect we have discovered here is sushi. It is sobering that odds and ends of life on Earth -- the gastrointestinal habits of ruminants, Japanese cuisine, or the means of communicating with nomadic submarines that carry death for 200 cities -- should be so readily detectable, while so much of our art, literature, science, and compassion are almost wholly invisible. It's a kind of parable for our time.

By this point your expedition to the Earth must be considered highly successful. You've characterized the environment; you've detected life; you've found manifestations of intelligent beings. Surely this planet is worth a longer and more detailed study. That's why you've now inserted your spacecraft into orbit around the Earth.

Looking down on the planet, you uncover new puzzles. All over the planet, smokestacks are putting carbon dioxide and toxic chemicals into the air. So are the beings who inhabit the roadways. But carbon dioxide is a greenhouse gas. As you watch, the amount of it in the atmosphere increases steadily, year after year. The same is true of methane and other greenhouse gases. If this keeps up, the temperature of the planet is going to increase steeply. Another class of molecules being injected into the air are the chlorofluorocarbons. Not only are they greenhouse gases, but they are very efficient in destroying the protective ozone layer.

You look more closely at the center of the South American continent, which -- as you know by now -- is a vast rain forest. Every night you see thousands of fires. In the daytime you find the region covered with smoke. Over the years, all over the planet, you find less and less forest and more and more scrub desert.

You look down on the large island of Madagascar. The rivers are colored brown, generating a vast stain in the surrounding ocean. This is topsoil being washed out to sea at a rate so high that in another few decades there'll be none left. The same thing is happening, you note, in many other places. But no topsoil means no agriculture.

From your orbital perspective, you can see that something has unmistakably gone wrong. The dominant organisms, whoever they are -- who have gone to so much trouble to rework the surface -- are simultaneously destroying their ozone layer and their forests, eroding their topsoil, and performing massive, uncontrolled experiments on their planet's climate. Haven't they noticed what's happening? Are they oblivious to their fate? Are they unable to work together on behalf of the environment that sustains all of them? Perhaps, you think, it's time to reassess the hypothesis that there is intelligent life on Earth.

* * *

[Box:]

A REAL SPACECRAFT LOOKS FOR LIFE ON EARTH

Spacecraft from the Earth have now flown by dozens of planets, moons, comets, and asteroids -- equipped with cameras, instruments for measuring heat and radio waves, spectrometers to determine composition, and a host of other devices. We have found not a hint of life anywhere else in the Solar System. But you might be skeptical about our ability to detect life elsewhere, especially life different from the kind we know. And until recently we had never performed the obvious calibration test: to fly a modern interplanetary spacecraft by the Earth and see whether we could detect ourselves. This all changed on December 8, 1990.

Galileo is a spacecraft designed to explore the planet Jupiter, its moons, and its rings. But to get there the spacecraft had to come close by Venus (once) and the Earth (twice) to be accelerated by the gravities of these planets; otherwise there wasn't enough oomph to get it to where it's going. This permitted us for the first time to look systematically at the Earth from an alien perspective. Galileo passed only 960 kilometers (about 600 miles) above the Earth's surface. Except for pictures showing features finer than 1 kilometer, and the image of the Earth at night -- obtained by other, orbiting spacecraft -- all spacecraft data described in this article were actually obtained by Galileo. Other members of the NASA scientific team who worked with me on Galileo's detection of life on Earth are Drs. W. Reid Thompson, Cornell University; Robert Carlson, JPL; Donald Gurnett, University of Iowa; and Charles Hord, University of Colorado.

~~[CS: Make changes from published copy, next round:]~~

[2B, 2/20/93]

Are We Being Visited? I.

It's still dark out. You're lying in bed, fully awake -- but, you discover, you're utterly paralyzed. You sense someone in the room. You try to cry out. But you cannot. Several small gray beings, less than four feet tall, are standing at the foot of your bed. Their heads are pear-shaped and bald, and large for their bodies. Their eyes are enormous, their faces expressionless and identical. They wear tunics and boots. You hope this is only a dream, but as nearly as you can tell it's really happening. They lift you up and, eerily, they and you slip through the wall of your bedroom and float out into the air, rising high toward a metallic saucer-shaped spacecraft. There, you are escorted into a medical examining room. A larger but similar being -- evidently some kind of physician -- takes over. What follows is even more terrifying.

Your body is probed with certain machines, especially your sexual parts. If you're a man, they may take sperm samples; if you're a woman, they may implant semen or remove ova or fetuses. They may force you to have sex. Afterwards you may be ushered into a different room where hybrid babies, partly human and partly like these creatures, stare back at you. You may be given an admonition about human misbehavior, especially in despoiling the environment; scenes of future devastation are displayed.

Finally, these cheerless gray emissaries usher you out of the spacecraft and ooze you back through the walls into your bed. By the time you're able to move and talk, they're gone.

You may not remember the incident right away; you might find some period of time unaccountably missing. Because all of this seems so bizarre, you're concerned about your sanity; naturally you're reluctant to talk to anyone about it. At the same time the experience is so disturbing that it's hard to keep it bottled up forever. It all pours out when you hear similar accounts, or when you're under hypnosis with a sympathetic therapist, or even when you see a picture of an "alien" in one of the many popular magazines and books on UFOs. Some people say they remember such experiences from early childhood; their own children, they think, are now being abducted by the aliens.

Most Americans seem to believe that we're being visited by aliens in UFOs [1978 Gallup Poll]. In a recent Roper poll of nearly 6,000 American adults, specially commissioned by those who accept the alien abduction story at face value, 18 percent reported sometimes waking up paralyzed, aware of one or more strange beings in the room. Something like 13 percent report odd episodes of missing time, and 10 percent claim to have flown through the air without mechanical assistance. From these results, the poll's sponsors conclude that two percent of all Americans have been abducted, many repeatedly, by beings from other worlds. If aliens are not partial to Americans, the number for the whole planet would be more than a hundred million people. This means an abduction every few seconds. It's surprising that more of the neighbors haven't noticed.

What's going on here? Could all these people be mistaken, or lying, or hallucinating the same or a very similar story? When you talk with them, most seem very sincere, although in the grip of powerful emotions. A few psychiatrists who've examined them find no more evidence of psychopathology than in the rest of us. But could there really be a massive alien invasion, repugnant medical procedures performed on millions of innocent men, women, and children, and humans apparently used as breeding stock over many decades -- and all this not generally known and dealt with by responsible media and the governments sworn to protect the lives and well-being of their citizens?

Why should beings so advanced in physics and engineering -- crossing vast interstellar distances, walking like ghosts through walls -- be so backward when it comes to biology? Why, if the aliens are trying to do their business in secret, wouldn't they perfectly expunge all memories of the abductions? Why are the examining instruments macroscopic and so reminiscent of doctors' offices on Earth? Why go to all the trouble of repeated sexual encounters between aliens and humans? Why not steal a few egg and sperm cells, read the full genetic code, and then manufacture as many copies with as many genetic variations as you like? Even we humans -- who cannot quickly cross interstellar space or slither through walls -- are able to clone cells. The preoccupation with reproduction in these accounts raises a warning flag -- especially considering the uneasy balance between sexual freedom and repression that has always characterized the human condition, and the fact that we live in a time fraught with numerous ghastly accounts, both true and false, of childhood sexual abuse.

The pollsters never actually asked whether their subjects had ever been abducted by aliens; they <u>deduced</u> it: Those who've awakened with strange presences around them, ever unaccountably seemed to fly through the air, and so on, have therefore been abducted. The pollsters didn't even check to see if these occurrences were part of the same or separate incidents. Their conclusion -- that millions of Americans have been so abducted -- seems extremely doubtful. Still, at least hundreds of people, believing they have been abducted, have sought out sympathetic therapists or joined abductee support groups. Others may have similar complaints but, fearing ridicule or the stigma of mental illness, have refrained from speaking up or getting help.

So which is more likely -- that we're undergoing a massive but generally overlooked invasion by alien sexual abusers, or that people are experiencing some internal mental state that they do not understand? Admittedly, we're very ignorant both about extraterrestrial beings, if any, and about human psychology. But if these really were the only two alternatives, which would you pick?

* * *

The phrase "flying saucer" was coined when I was in high school. The newspapers were full of stories about ships from elsewhere in the skies of Earth. It seemed pretty believable to me. There were lots of other stars, many of which presumably had planetary systems like ours. Many stars were as old or older than the Sun, so there was plenty of time for intelligent life to evolve on their planets. A two-stage rocket had just been flown high above the Earth. Clearly we were on our way to the Moon and the planets. Why shouldn't other, older beings be able to travel from their star to ours?

This was only a few years after the bombing of Hiroshima and Nagasaki. So maybe the UFO occupants were worried about us. They wanted to help us. Or maybe they wanted to make sure that we and our nuclear weapons didn't come and bother <u>them</u>. Many people seemed to see these flying saucers -- sober individuals, pillars of the community, police officers, commercial airplane pilots, military personnel. And apart from some harumphs and giggles, I couldn't find any counterarguments. How could all these eyewitnesses be mistaken? What's more, the saucers had been picked up on radar, and pictures had been taken of them. You could see the pictures in newspapers and glossy magazines.

There were even reports about crashed flying saucers and little alien bodies in Air Force freezers in the Southwest. And yet not one adult I knew was preoccupied with UFOs. I couldn't figure out why not. Instead they were worried about Communist China and Soviet nuclear weapons. I wondered if they had their priorities straight.

In college I began to learn a little about how science works, the secrets of its great success, how rigorous the standards of evidence must be if we are really to know something is true, how many false starts and dead ends have plagued human thinking, how our biases can color our interpretation of the evidence, how often belief systems widely held and supported by the political, religious, and academic hierarchies turn out to be not just slightly in error, but grotesquely wrong. I read a book called Extraordinary Popular Delusions and the Madness of Crowds, written by Charles McKay in the middle nineteenth century [examples of topics]; and another by Martin Gardner called Fads and Fallacies in the Name of Science [more examples]. It dawned on me that human fallibility being what it is, there might be some other explanation for flying saucers.

I was interested in the possibility of extraterrestrial life long before I ever heard of flying saucers, and I've remained fascinated long after my early enthusiasm for UFOs waned -- as I understood more about that remorseless taskmaster called the scientific method. Everything hinges on the matter of evidence.

Many people seeing something strange in the sky become excitable and uncritical Some reports are due to psychological aberrations, others to hoaxes. Many UFO photos turn out to be fakes -- small models hanging by thin threads, often photographed in a double exposure.

searchlights or headlights off clouds; reflections of sunlight from shiny surfaces; luminescent organisms (including one case of a firefly lodged between two adjacent panes of glass in an airplane cockpit window); optical mirages and looming; lenticular cloud formations; ball lightning; sun dogs; meteors, including green fireballs; planets, especially Venus; bright stars; and the aurora borealis.

Radar detection of unidentified flying objects has also occurred occasionally. Many of these sightings have been explained as radar reflections from temperature inversion layers in the atmosphere and other sources of radar "signals."

Considering the difficulties involved in tracking down visual and radar sightings, it is remarkable that most of the reported UFOs have been identified as naturally occurring -- if sometimes unusual -- phenomena. It is of some interest that the UFOs which are unidentified do not fall into uniform categories of motion, color, and lighting, but rather run through roughly ~~the same range of these variables as the identified UFOs~~s. ¶ In

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October 1957, Sputnik I, the first Earth-orbiting artificial satellite, was launched. Of 1,178 recorded UFO sightings in America in that year, 701 or ___ %, occurred between October and December. The clear implication is that Sputnik and its attendant publicity ~~was responsible for many UFO sightings~~ played a major role.

Earlier, in July 1952, a set of visual and radar observations of unidentified flying objects over Washington, D.C.

[Broca II, draft 1, 8/12/92]

1975, #29: "Unidentified Flying Objects," in Encyclopedia Americana (New York: Grolier); Americana Annual (New York: Grolier); Bull. Atom. Sci. 23 (6) (1967), 43; The Physics Reader (Cambridge, MA: Harvard Project Physics, 1968); Document 97-818, House Committee on Science and Astronautics (Washington: U.S. Government Printing Office, 1968).

[The following has been transcribed from typescript labelled "Text of article in press in the Encyclopaedia [sp?] Americana, 1975."]

UNIDENTIFIED FLYING OBJECT, a moving aerial or celestial phenomenon, detected visually or by radar but whose nature is not immediately understood. Interest in unidentified flying objects (UFOs) stems from speculation that some of them are the products of civilizations beyond the Earth, and from the psychological insights into contemporary human problems that this interpretation provides.

Insert 2 — Insert p. 7.

¶ ~~Observations~~. ~~Accounts~~ UFOs were ~~Unidentified flying objects have~~ been described variously as rapidly moving or hovering; disc-shaped, cigar-shaped, or ball-shaped; moving silently or noisily; with a fiery exhaust, or with no exhaust whatever; accompanied by flashing lights, or uniformly glowing with a silvery cast. The diversity of the observations suggest~~s~~ed that ~~UFOs~~ they have no common origin and that the use of such terms as UFOs or "flying saucers" serves only to confuse the issue by grouping generically a collection of unrelated phenomena lenticular clouds, ball lightning, sundogs, meteors including green fireballs, and satellites or

On so important a question, the evidence must be airtight. No witness's say-so is good enough. People make mistakes. But essentially all the UFO cases were mere anecdotes, something asserted. There ~~were hoaxes and faked photographs and~~ was the suspicion that the field attracted rogues and charlatans. Insert 2 ~~And~~ There were very many cases in which people honestly reported what they saw, but what they saw turned out to be entirely natural. Some reported UFOs turned out to be unconventional aircraft, conventional aircraft with unusual lighting patterns, meteorological high altitude balloons, luminescent insects, planets seen under unusual atmospheric conditions, reflections of searchlights or headlights off clouds or overcast, optical mirages and looming, rocket boosters reentering the atmosphere~~, and the like~~. One UFO seen by spectacularly thousands of people turned out to be a college fraternity ~~hoax~~ prank -- a piece of cardboard, some candles, and a thin plastic bag that dry cleaning comes in -- put together to make a rudimentary hot air balloon. Insert 1 The alleged evidence ~~was~~ seemed very thin.

Since then, I've been lucky enough to be involved in sending spacecraft to other planets to look for life, and to be involved in listening for possible radio signals sent our way by alien civilizations on planets of distant stars. While we've had a few tantalizing moments, we've not yet found any good evidence for life beyond the Earth. But we're only at the very beginning of the search. New, compelling data might emerge, for all we know, tomorrow. I don't think anyone could be more interested than I am if we're in fact being visited by aliens. It would save me so much time and effort studying extraterrestrial intelligence directly and nearby, rather than at best -- if we're very lucky -- indirectly and at a great distance. (And we would at least be quite sure there was something to study.) My mind, I believe, is open.

But in science, the standards of evidence must be high -- employing the same levels of skepticism as in buying a used car or in judging the quality of analgesics or beer from their television commercials. Skepticism, though, is discouraged in our society. It's hardly taught at all in the schools. Our politics, economics, advertising, and religions (New Age and Old) are awash in credulity. Also, it's no fun to tell nice, sincere, although slightly distraught people that what they saw when I wasn't there was some kind of psychological aberration or error.

The question is whether -- after misapprehended natural events and hoaxes and psychological aberrations are cleared away -- there is a residuum of reliably reported and extremely bizarre cases, especially supported by physical evidence. Is there a signal hiding in all the noise? In my view, no such signal has been demonstrated. There are reliably reported cases which are not exotic, and exotic cases which are not reliably reported. So far as I know, there are no cases -- despite well over a million UFO reports since 1947 -- in which something so strange that it could only be an extraterrestrial spacecraft is reported so reliably that misapprehension, hoax, or hallucination can be reliably excluded.

Over the years I've continued to spend a little time on the UFO problem. I've found that the going-in attitude of many people is highly pre-determined. Some are convinced that eyewitness testimony is reliable, that people do not lie, that hallucinations on such a scale are impossible, and that therefore there must be a long-standing, high-level government cover-up to keep the truth from the rest of us. As government deceit and conspiracies of silence have been exposed on so many other matters, it's hard to argue that a cover-up on this strange subject is impossible, that the government would never hide important information from its citizens. A common argument on why there should be a cover-up is to prevent panic or erosion of confidence in the government.

I was a member of the U.S. Air Force committee that investigated the Air Force's UFO study -- called "Project Bluebook," but earlier and revealingly called "Project Grudge." We found the approach to be lackadaisical, careless, and dismissive. In the middle 1960s, "Project Bluebook" was headquartered at Wright-Patterson Air Force Base in Ohio. They had state-of-the-art technology in file retrieval. You asked for a given case and, somewhat like at the dry cleaner's today, reams upon reams of files made their way past you, until the engine stopped when the file you wanted was before you. But what was <u>in</u> those files wasn't worth much. For example, senior citizens report lights hovering over their small New Hampshire town for more than an hour, and the case is explained as a wing of strategic bombers from a nearby Air Force base on a training exercise. Could the bombers take an hour to pass over the town? No. Did the bombers pass over the town at the time the UFOs were reported? No. Can you explain to us, Colonel, how strategic bombers can be described as "hovering"? No. These slipshod investigations played little scientific role, but they seemingly demonstrated that the Air Force was on the job and that there was nothing to UFO reports.

Of course, this doesn't preclude the possibility that there was another, more serious, more scientific study of UFOs going on elsewhere -- perhaps headed by a Major General rather than a Lieutenant Colonel. I think something like this is even likely, not because I believe that we are being visited but because hiding in the UFO phenomena are data of significant military interest. Certainly if UFOs were as reported -- very fast, very maneuverable aircraft (or spacecraft) -- there is a military interest in finding out how they work. If the UFOs are built by the Soviets, it is the Air Force's responsibility to protect us. If the UFOs are built by extraterrestrials, we can copy the technology and get a big step ahead of the Soviets. But even if you believe that UFOs have nothing to do either with Soviets or extraterrestrials, you have a good reason for following them closely:

The early heyday of UFOs corresponds to the time when the main delivery vehicle for nuclear weapons was being switched from aircraft to missiles. An early and important problem had to do with re-entry -- the return through the bulk of the Earth's atmosphere of a nuclear-armed nosecone. Observations of re-entry could very well tell about U.S. progress in this vital strategic technology, about inefficiencies in the design, and about how an adversary might take defensive measures. Under such circumstances, there very likely were cases in which military personnel were told not to talk about what they had seen, or where seemingly innocent data was suddenly classified top secret or higher. Courageous Air Force officers and civilian scientists thinking back on it years later might very well conclude that the Air Force had a UFO cover-up.

Or consider spoofing. In the strategic confrontation between the United States and the Soviet Union, the adequacy of the defenses was an important issue. If you could find a weakness, it might be the key to "victory" in an all-out war. The way to test your adversary's air defenses is to fly an aircraft into its airspace and see how long it takes for them to notice you. In the 1950s and '60s, the United States had a state-of-the-art radar defense system covering its West and East Coasts, and especially its northern approaches (over which a Soviet missile attack would most likely come). But there was a soft underbelly -- no significant Early Warning System for a southern approach. This is of course information vital for a potential adversary. It immediately suggests a spoof. A few of the adversary's high-performance aircraft zoom out of the Caribbean into U.S. airspace, penetrating, let us say, 500 miles up the Mississippi River until the U.S. air defense radar locks on. Then the aircraft hightail it out of there. There may be combined visual and radar sightings and large numbers of independent reports. What is reported corresponds to no known aircraft. The Air Force can truthfully state that none of its aircraft was responsible. Even if they have been urging a southern Early Warning System, the Air Force is unlikely to admit that Soviet or Cuban aircraft got to St. Louis [check] before anybody noticed.

Here again, we have every reason to expect a high-level technical team investigating the incident, Air Force and civilian observers told to keep their mouths shut, and not just the appearance but the reality of suppression of the data. But again, all of this need have nothing to do with alien spacecraft.

So I'm perfectly prepared to believe that some UFO reports have been classified. But a conspiracy to keep knowledge of alien abductions almost wholly secret for 45 years, with hundreds if not thousands of government employees privy to it, is a remarkable notion. Certainly secrets are routinely kept, even ones of substantial general interest. But the point of such secrecy is to protect the country and its citizens. Here, though, it's different. The alleged conspiracy is to keep from us knowledge of a continuing alien assault on the human species. If aliens really were abducting millions of us, it would be much more than a matter of national security. It would impact the security of all human beings in all countries. Given such stakes, is it plausible that no one in nearly 200 nations would blow the whistle and side with the humans rather than the aliens?

NASA after the end of the Cold War is flailing about, trying to find missions that justify its existence -- particularly a good reason for humans in space. If the Earth were being visited daily by hostile aliens, wouldn't NASA leap on this to augment its funding? If an alien invasion were in progress, why would the Air Force step back from manned spaceflight and launch all its payloads on unmanned boosters? Consider the Strategic Defense Initiative Organization, in charge of "Star Wars." It's fallen on hard times, particularly its objective of basing missile defenses in space. The inability of SDI to protect the United States against a massive missile attack is manifest. But wouldn't we want to have defenses in space if we were facing an alien invasion? The entire post-Cold War posture of the military and civilian space programs of the United States (and other nations) speaks powerfully against the idea that there are aliens among us -- unless, of course, the news is also being kept from those who plan the national defense.

On the other hand, there are those who dismiss the idea of alien visitation out of hand and with great passion, claiming that it's unscientific even to consider the matter. A 1969 report by the National Academy of Sciences, while recognizing that there are reports "not easily explained," concluded that "the least likely explanation of UFOs is the hypothesis of extraterrestrial visitations by intelligent beings." I once helped to organize a public debate at the annual meeting of the American Association for the Advancement of Science between proponents and opponents of the proposition that some UFOs were spaceships; whereupon a distinguished scientist, who in many other matters I revered, threatened to sic the Vice President of the United States on me if I persisted in this madness. ~~(The debate was held and published, the issues were a little better clarified, the sky did not fall, and I did not hear from Spiro T. Agnew.)~~

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It's curious that emotions can run so high on a matter about which we know so little. After all, either hypothesis -- extraterrestrial invasion or an epidemic of hallucinations -- teaches us something we certainly ought to know about. Maybe the reason for such strong feelings is that both alternatives have extremely unpleasant implications.

~~[CS: Make changes from published copy, next round:]~~

[2C, 2/20/93]

Are We Being Visited? II.

The first alien abduction story in the modern genre began with Betty and Barney Hill, a New Hampshire couple -- she a social worker and he a Post Office employee. During a late-night drive in 1961 through the White Mountains of New Hampshire, Betty spotted a bright star-like UFO that seemed to follow them. Because Barney feared it might harm them, they left the main highway for narrow mountain roads. They arrived home two hours later than they had expected. The experience prompted Betty to read a book about UFOs which claimed they were spaceships from other worlds, and that their crews were little men who sometimes abduct humans. Soon after, she had a repetitive nightmare in which she and Barney were abducted and taken aboard the UFO. Barney overheard her describing this dream to friends and volunteer UFO investigators.

Several years later, Barney's psychiatrist referred him to a Boston hypnotherapist, Benjamin Simon, M.D. Betty came to be hypnotized as well. Under hypnosis they separately described a memory of their trip home -- of seeing a UFO, watching it land on the highway, and being taken partly immobilized into the UFO, where little humanoid creatures subjected them to unconventional medical examinations. There are those now who believe that eggs were taken from Betty's ovaries and sperm from Barney, although that isn't part of the original story. The captain showed Betty a map of interstellar space with the ship's routes marked.

Martin S. Kottmeyer has shown that many of the motifs in the Hills' account can be found in a 1953 motion picture, "Invaders from Mars." Barney's account of what the aliens looked like, especially their enormous eyes, emerged in a hypnosis session just twelve days after the airing of an episode of the television series "The Outer Limits" in which such an alien was portrayed. [Gauche Encounters: Badfilms and the UFO Mythos, by Martin S. Kottmeyer.]

Although the case was celebrated, even the few scientists of the time who identified some UFOs with alien spaceships were very wary. The Hills' encounter was, for example, prominent by its absence from the list of cases compiled by James E. McDonald, a University of Arizona atmospheric physicist. McDonald's views were based, he said, not on irrefutable evidence, but because all the alternative explanations proposed seemed to him ~~were worse.~~ even less credible.

I was glad to have an opportunity to spend several hours with Mr. and Mrs. Hill, and with Dr. Simon. There was no mistaking the earnestness and sincerity of Betty and Barney, and their mixed feelings about becoming public figures under such bizarre circumstances. With the Hills' permission, Dr. Simon played for me some of the audiotapes of their sessions under hypnosis. By far my most striking impression was the absolute terror in Barney's voice when he described -- re-lived would be a better word -- the encounter. Simon, while a leading proponent of the value of hypnosis, had not been caught up in the enormous public interest in UFOs. He shared in the royalties of John Fuller's best-seller, Interrupted Journey, on the Hills' experience. If Simon had pronounced their account authentic, the sales of the book might have gone through the roof and his own financial reward been considerably augmented. But he didn't. He rejected instantly the notion that they were lying, or that this was a folie à deux -- a shared delusion in which, generally, the submissive partner goes along with the delusion of the dominant partner. So what's left? The Hills, said their psychiatrist, had experienced a species of "dream." Indeed, many modern "abductees" express serious reservations about whether the stories they are telling really happened.

In 1894 The International Census of Waking Hallucinations was published in London. From that time to this, repeated surveys have shown that 10 to 25 percent of ordinary, functioning people have experienced, at least once in their lifetimes, a vivid hallucination -- hearing a voice, usually, or seeing a form when there's no one there. In some cases these are profound religious experiences. (Probably a dozen times since their deaths I've heard my mother or father, in an ordinary, conversational tone of voice, call my name. They had called my name often during my life with them. I still miss them so much that it doesn't seem strange to me that my brain will occasionally retrieve a kind of lucid recollection of their voices.)

Such hallucinations may occur to perfectly normal people under ordinary circumstances. But there are circumstances in which they can be elicited: by a campfire at night, or under great stress, or by prolonged fasting or sleeplessness or sensory deprivation, or through hallucinogens such as LSD, psilocybin, mescaline, hashish, or alcohol. (Delirium tremens, the dreaded "DTs," is one well-known example.) There are also molecules, like the benzodiazepines (valium, for example), that make hallucinations go away. It is very likely that the normal human body generates substances that cause hallucinations.

These hallucinations have a vivid and palpable reality. Indeed, they are sought out in many cultures. Among the Native Americans of the Western Plains, a young man's future occupation was foreshadowed by the nature of the hallucination he experienced; its meaning was discussed with great seriousness among the elders and shamans of the tribe.

Hallucinations are common. If you have one, it doesn't mean you're crazy. We would surely be missing something important about our own nature if we refused to face up to the fact that hallucinations are part of being human. But none of this makes hallucinations real. Roughly 10 percent of Americans report having seen one or more ghosts. This is more than the number who allegedly remember being abducted, about the same as the number

It makes good evolutionary sense for children to ~~be afraid of~~ have fantasies of ~~imaginary~~ scary monsters. It helps ~~prent~~ prevent defenseless toddlers from wandering too far away from their guardians. But something like "Oh, that's not real; that's just your imagination." Other families may be impatient about fantasizing; it makes running the household and adjudicating disputes at least marginally more difficult. Many children can be discouraged from fantasizing, and grow up thinking it's something shameful. A few parents may not be very clear to the child about the distinction between reality and fantasy, or may even enter into the fantasy. Out of all these contending tendencies, some people grow up with an intact ability to fantasize, and a history, extending well into adulthood, of confabulation. Others conclude that anyone who doesn't know the difference between reality and fantasy is "crazy."

Many abductees report having seen "aliens" in their childhood -- coming in through the window or from under the bed or out of the closet. But children have reported similar stories everywhere in the world -- with fairies, elves, goblins, and a rich variety of imaginary "friends." Are we to imagine two different groups of children -- one who see imaginary earthly beings and the other who see genuine extraterrestrials? Isn't it more reasonable that both groups are seeing the same thing? Most of us remember being frightened at the age of two or so by real-seeming but wholly imaginary "monsters." If we're capable of conjuring up monsters in childhood, ~~-- for good evolutionary reasons, it may be --~~ why shouldn't some of us, at least on occasion, be able to imagine similar things as adults?

* * *

There's a common, although insufficiently well-known, psychological syndrome very much like alien abduction: Many people have experienced sleep paralysis. On falling asleep or when waking up -- just for a few seconds, or maybe for longer periods -- you seem to be paralyzed and acutely anxious. You may feel a weight on your chest, your heartbeat is quick, your breathing labored. You may experience auditory or visual hallucinations -- of people, demons, ghosts, animals, or birds. In the right setting, the experience can have "the full force and impact of reality," according to Robert Baker, a psychologist at the University of Kentucky. Sometimes there's a marked sexual component to the hallucination.

Baker has ~~forcefully~~ argued that these common sleep disturbances are behind many if not most of the alien abduction accounts. Some "abductees" remember the experience without hypnosis; most do not. But hypnosis is an unreliable way to refresh memory (and often elicits false recollections). Many courts have banned its use in criminal investigation. So the fact that people relate alien abduction stories when hypnotized carries little weight. Indeed, there's a danger that subjects are -- at least on some matters -- so eager to please the hypnotist that they sometimes respond to subtle cues of which the hypnotist may be unaware. (Baker and others suggest that some abduction claims are also made by fantasy-prone individuals or hoaxers seeking fame and fortune. There is also the insufficiently examined possibility that these accounts are disguised memories of rape and childhood sexual abuse.)

Even if no known hallucinations were to fit the alien abduction pattern, it is certain that humans commonly hallucinate. But there's considerable doubt about whether extraterrestrials exist and frequently visit our planet. We may argue about details, but the one category of explanation seems much better supported than the other. The main reservation you might then have is: Why do so many people report _this particular_ set of hallucinations? Why little gray beings, and flying saucers, and sexual molestation?

Demons, taught the early Church Fathers, come down from Heaven and have unlawful sexual congress with women. No less a figure than St. Augustine believed that witches were the offspring of these forbidden unions. In his famous Bull of 1484, Pope Innocent VIII declared, "It has come to Our ears that members of both sexes do not avoid to have intercourse with evil angels, incubi, and succubi, and that by their sorceries, and by their incantations, charms, and conjurations, they suffocate, extinguish, and cause to perish the births of women. . ." as well as cause sundry other calamities. [Annemarie de Waal Malefijt, _Religion and Culture_: _An Introduction to Anthropology of_

Religion (Prospect Heights, IL: Waveland Press, 1989) (originally published in 1968 by Macmillan), pp. 286 ff.] With this Bull, Innocent initiated the systematic accusation, torture, and execution of countless "witches" all over Europe. Despite the evenhanded "members of both sexes" in the language of the Bull, as it turned out it was almost entirely women who were so persecuted. Their differences with the Catholic Church notwithstanding, many leading Protestant theologians of the following centuries had nearly identical views.

In his Bull, Innocent commended "Our dear sons Henry Kramer and James Sprenger," who "have been by Letters Apostolic delegated as Inquisitors of these heretical [de]pravities" -- because if "the abominations and enormities in question remain unpunished," the souls of many may be in peril of eternal damnation. It was all being done for their own good.

Innocent appointed Kramer and Sprenger to write a comprehensive analysis, using the full academic armory of the late fifteenth century. With exhaustive citations of Scripture and ancient and modern scholars, they produced the Malleus Maleficarum, the "Hammer of Witches" -- aptly described as one of the most terrifying documents in human history. What it comes down to, pretty much, is that if you're accused of witchcraft, you're guilty. There are no rights of the accused. There is no opportunity to confront your accusers. No one seems to have even considered the proposition that accusations can be made for impious purposes -- jealousy, say, or revenge, or misogyny. The more who, under torture, confessed to witchcraft, the harder it was to maintain that the whole business was mainly fantasy. And the Bible counseled, "Thou shalt not suffer a witch to live." Legions of women were burnt alive.

In the Malleus, Kramer and Sprenger declared that "devils. . . busy themselves by interfering with the process of normal copulation and conception, by obtaining human semen, and themselves transferring it." The offspring of these demonic unions are also, when they grow up, visited by devils -- although not all witches are created in this way. And witches were well-known to fly through the air. There is no spaceship, but most of the essential elements of the alien abduction story are here. On this matter, in this age, there were almost no skeptics. Everyone believed.

Accounts with similar elements occur in cultures around the world. In Genesis we hear of angels who are sexually attracted to "the daughters of men." In ancient Greece and Rome, there are innumerable stories about gods appearing to women as bulls or swans or showers of gold and impregnating them. There were skeptics in those days too, like Cassius whose position is reported by Plutarch in his Brutus: "Our senses, being credulous, and therefore easily abused. . . are induced to imagine they see and conjecture that which in truth they do not." But hardly anyone took them seriously. St. Teresa of Avila reported a vivid sexual encounter with an angel, as did many other women who were sanctified by the Catholic Church.

In 1645 a Cornish teen-ager, Anne Jeffries, was found groggy, crumpled on the floor. Much later, she recalled being attacked by half-a-dozen little men, carried paralyzed to a castle in the air, seduced, and returned home. She called the little men fairies. They returned to torment her. The next year she was arrested for witchcraft [Katherine Briggs, An Encyclopedia of Fairies (Pantheon, 1976)]. Fairies traditionally have magical powers, and can cause paralysis by the merest touch. The ordinary passage of time is slowed in fairyland. Fairies are somehow reproductively impaired, so they have sex with humans and carry off babies from their cradles -- sometimes leaving a fairy substitute, a "changling." If Anne Jeffries had known about aliens rather than fairies, and UFOs rather than castles in the air, would her story have been distinguishable from the one "abductees" tell?

In his 1982 book The Terror That Comes in the Night: An Experience-Centered Study of Supernatural Assault Traditions, David Hufford describes an executive, a university-educated man in his mid-thirties, who recalls a summer he spent as a teenager in his aunt's house. One night, after seeing mysterious lights in the harbor, he fell asleep. But from his bed he witnessed a white and glowing figure climbing the stairs, entering his room, and saying -- not especially ominously -- "That is the linoleum."

Sometimes the figure was an old woman; sometimes it changed into an elephant. Sometimes he was sure he was dreaming; other times he was sure he was awake. Pressed down into his bed, he was immobilized and unable to move or cry out. His heart was pounding. He was short of breath. Something similar happened on many consecutive nights. This experience occurred before alien abductions were widely described. If the executive had known about alien abductions, would his old woman have had a larger head and bigger eyes?

The folklorist Thomas E. Bullard argues that "abduction reports sound like rewrites of older supernatural encounter traditions with aliens serving the functional roles of divine beings." He concludes: "Science may have evicted ghosts and witches from our beliefs, but it just as quickly filled the vacancy with aliens having the same functions. Only the extraterrestrial outer trappings are new. All the fear and the psychological dramas for dealing with it seem simply to have found their way home again, where it is business as usual in the legend realm where things go bump in the night" [(J. Amer. Folklore 102 (1989), pp. 147-170).]

Is it possible that people in all times and places occasionally experience vivid, realistic hallucinations, often with sexual content -- with the details filled in by the prevailing cultural idioms, sucked out of the Zeitgeist? When everyone knows that gods regularly come down to Earth, we hallucinate gods; when everyone knows about demons, it's incubi and succubi; when fairies are widely believed, we see fairies; and when the old myths fade and we begin thinking that alien beings are plausible, then that's where our hypnogogic imagery tends. Snatches of song or foreign languages, images, and stories that we witnessed in our childhood can be accurately recalled decades later without any conscious memory of the source. In our everyday life, we effortlessly incorporate cultural motifs and norms and make them our own.

Today aliens are the subject of innumerable science fiction stories and novels (including one of my own). UFOs are a regular feature of weekly newspapers dedicated to falsification and mystification. One of the highest-grossing motion pictures of all time is about aliens very like those described by abductees. Alien abduction stories were comparatively rare until 1975, when a credulous network dramatization of the Hills case was aired; another leap into public prominence occurred after 1987, when a purported first-hand account with a haunting cover painting of an "alien" became a best-seller. It is striking how similar many of the abduction accounts are now, and how little we hear lately about incubi and fairies. (Where have they all gone?) But it might not be altogether surprising that in our time and society, short, gray aliens with breeding programs on their minds are what Americans mainly reach for when they must describe these hallucinations.

Far from being global, the alien abduction stories are dissappointingly local. They hardly transcend American culture.

In other countries, bird-headed, insect-headed, robot, and blond and blue-eyed aliens are reported. This will probably decline as the American short gray motif becomes better publicized worldwide. ~~Currently there are striking differences of opinion between U.S. and European students of alien abductions.~~

Long before the terms "flying saucer" or "UFOs" were invented, science fiction was replete with "little green men" and "bug-eyed monsters." Somehow little aliens with big heads (and eyes) have been with us for a long time, going back to the fictional Martians of H. G. Wells. The typical reported modern extraterrestrial is small, with disproportionately large head and eyes, undeveloped facial features, no eyebrows or genitals, and smooth gray skin. It looks to me eerily like a fetus in roughly the twelfth week of pregnancy. Why so many of us might be obsessing on fetuses, and imagining them attacking us, is an interesting question.

Of course, as enthusiasts for extraterrestrial visitations are quick to remind me, there's another interpretation of these historical circumstances: Perhaps, they say, aliens have always been visiting us, poking at us, stealing our sperms and eggs, impregnating us. In earlier times we understood them to be gods, demons, or fairies; only now do we realize that it's aliens who've been diddling us all these millennia. But then why are there virtually no reports of flying saucers before 1947?

The University of Washington psychologist Elizabeth Loftus has found that people can easily be made to believe they saw something they didn't. In a typical experiment, subjects will view a film of a car accident. When questioned about what they saw, they're casually given false information. For example, a stop sign is off-handedly referred to when there wasn't one in the film. Many subjects then dutifully recall seeing a stop sign. When the deception is revealed, some vehemently disagree, stressing how clearly they remember the sign. The greater the time lag between viewing the film and being given the false information, the more people let their memories be tampered with. There is considerable evidence that vivid but wholly false recollections can be induced by a few cues and questions, especially in the therapeutic setting. These facts suggest that on alien abduction matters -- where interviews typically occur years after the alleged event -- therapists must be very careful that they do not accidentally implant the stories they elicit and recount.

"There's nothing in my background that prepared me" for the alien abduction story, says one psychiatrist who takes it at face value. "It's completely persuasive because of the emotional power of these experiences." But have the hypnotists and psychotherapists working with "abductees" made conscientious attempts to steep themselves in the body of knowledge on human hallucinations and perceptual malfunctions? Why do they believe these witnesses but not those who report, with comparable conviction, encounters with gods, demons, angels, and fairies? Are all deeply felt stories true?

How can further progress be made? Those treating abductees might explain to their patients that hallucinations are normal. They might bear in mind that no patient can be wholly uncontaminated by the aliens in popular culture. They might take scrupulous care not subtly to lead the witness.

I'm surprised that there are psychiatrists and others with at least some scientific training, who know the imperfections of the human mind, but who dismiss the idea that these accounts are some species of hallucination. I'm even more surprised by claims that the alien abduction story is a challenge to our grip on reality, or constitutes support for mysticism. Even if we take the cases at face value, their remarkable aspects -- slithering through walls and so on -- would be a tribute to advanced alien technology, not a vindication of witchcraft.

No one would be happier than I would if we had real evidence of extraterrestrial life. But the issue comes down to the quality of the evidence. Proponents of alien abductions do not ask us to believe on faith, but rather on the strength of their evidence. Surely it is our duty to examine the purported evidence closely and skeptically. <u>No</u> anecdotal claim -- no matter how sincere, no matter how deeply felt, no matter how exemplary the lives of the attesting citizens -- carries much weight on so important a question. As for the older UFO cases, anecdotal accounts are subject to irreducible error. This is not a criticism of those who claim abductions or of those who interrogate them. It is merely a statement of human fallibility.

Where is the physical evidence? Some abductees allege that aliens stole fetuses from their wombs. This is something that would surely cause a stir among gynecologists, midwives, obstetrical nurses -- especially in an age of heightened feminist awareness. But not a single medical record has been produced substantiating such claims.

Some abductees say that tiny metallic implants were inserted into their bodies -- high up their nostrils, for example. But no such implants have been confirmed by physicists as of unearthly manufacture. There are no metals from the transuranic "island of stability," where many physicists think there might be a new family of chemical elements unknown on Earth. There are no components made of unusual isotopes. There is no hint of cunning machinery far beyond current technology. No abductee has filched a page from the captain's logbook, or a strange examining instrument, or taken an authentic photograph of the interior of the ship, or come back with detailed scientific information not hitherto known on Earth. These failures surely tell us something.

For 45 years we've been told by proponents of the extraterrestrial hypothesis that physical evidence -- not disturbed soil but real alien technology -- was in hand. The analysis would be released momentarily. It's 45 years later and we're still waiting. Where are the articles published in the refereed scientific literature, in metallurgical journals, in publications of the Institute of Electrical and Electronic Engineers, in Science or Nature? Such a discovery would be momentous. If there were real artifacts, physicists and chemists would be fighting for the privilege of discovering that there are aliens among us -- who use, say, wholly unknown alloys, or materials of extraordinary tensile strength or ductility or conductivity. The practical implications of such a discovery -- never mind the confirmation of an alien invasion -- would be immense. Discoveries like this are what scientists live for. Their absence must tell us something. Occasionally there's a mysterious appearance of alleged classified documents from decades ago attesting to crashed saucers and small aliens and government conspiracy. But we never even hear about (much less see) artifacts smuggled out of secret warehouses. Why not? The simplest explanation is that they don't exist. Keeping an open mind is a good thing -- but, as the space engineer James Oberg has said, not so open that your brains fall out. Not all claims have equal merit. But of course we should be open to good new evidence.

If indeed the bulk of the alien abduction accounts are really about hallucinations, don't we have before us a matter of supreme importance -- touching on our limitations, the ease with which we may be misled, the fashioning of our beliefs, and perhaps even the origins of our religions? There is genuine scientific paydirt in UFOs and alien abductions -- but it is, I think, of a distinctly terrestrial nature.

* * *

[Box:]

Aliens and the Big Bang

It is my practice to send early drafts of my articles to experts in the field -- both those who might agree with me and those who might not. I always find that the piece is improved as a result. Errors of fact are corrected, implications that I've missed are drawn, better anecdotes are suggested, and infelicities of style are corrected. For these two chapters on alien abductions, it seemed to me that there are no real experts, but I sent copies to about a dozen people who had written on this contentious subject.

One of the most interesting responses was from an author and therapist who has worked with abductees, and argued fervently that we really are being visited by honest-to-goodness extraterrestrials. There is not a word of substantive criticism in his letter -- nothing about how I described the abduction experience and nothing about how I attempted to explain it. He complains that I have "no idea of the extent of the evidence, the weight of the literature, or the range and thoroughness of the work in the field." He compares my writing about alien abduction to his writing about the Big Bang. He has no credentials in cosmology, he suggests, perhaps never even having seriously studied the subject, and therefore his opinions on the matter are worthless. He invites me to draw the same conclusion about my opinions on alien abduction.

But how, I wondered, would he proceed if he were seriously about to write an article on the Big Bang? Surely it would be insufficient to discuss his own emotional predispositions, whether he finds the theory congenial or upsetting, and the like. He would have to discuss the evidence. He would have to describe the spectroscopic data supporting a mutual recession of the galaxies, the black body microwave background radiation, and the ratio of hydrogen to helium in interstellar space. These are the standard pieces of evidence for Big Bang cosmology, and this evidence, separately and collectively, is the reason that the theory is well-accepted by the tumultuous and argumentative community of cosmologists.

If you wished to be a skeptic on the subject, you would perhaps argue that there is another explanation for the background radiation, or that some terrible error has been made in the ground-based and space-borne measurements of the background radiation. You would have to take account of the fact that hundreds of scientists in a dozen nations have carried out independent studies, all of which show the same unmistakable signature of the now wan remnant of the great fireball that began the Universe, or at least its present incarnation. Any skeptic might devise an independent experiment to see if she too reaches the same conclusion. But she could not dismiss the evidence as inappropriately anecdotal. A dedicated skeptic can go to the laboratories and observe the meter readings. Not only are all the measurements consistent with a certain so-called "black body curve" quantitatively determining how intense the radio waves are at each frequency, but they all agree within the probable error about what the present temperature of the background radiation is (about 2.7° above absolute zero). Everything depends on the quality of the evidence.

The situation is very different for alien abductions. There are no meter readings. There are only stories. The skeptic cannot go out and examine the aliens, but is restricted to listening to accounts from a population that is contaminated by books, magazines, and television programs telling and retelling the same story. Despite this, by no means are all the accounts of aliens similar. There is nothing like one curve specified by a single temperature on which all the observations converge. The evidence for the mutual recession of the galaxies, the black body background radiation, and the abundance of helium are not just vaguely consistent with a Big Bang, but quantitatively, reliably, and repeatedly consistent with it.

This does not mean that there aren't a few competent astronomers who are skeptical about Big Bang cosmology. It is one of the strengths of science that every issue is open to debate. But the scientific skeptics of Big Bang cosmology understand that they must provide alternative explanations of the present quantitative evidence for the Big Bang, and show that these alternative explanations make fewer demands on what we do not know, are more parsimonious with their assumptions, more consistent with the rest of our knowledge. So far, no such alternative explanation has been forthcoming. The situation is very different in the alien abduction controversy.

Box at very end of "Visited" II

Order in sequence shown.

~~[3-23-93.at1]~~ ¶ An abbreviated version of the foregoing two chapters appeared in Parade magazine on March 7, 1993. Here, without comment, is a sampling of critical comments from the public:

9 • In the Bible it talks about terrestrial and celestial bodies. This is not to say that God is out for sexual abuse on people or that were crazy.

10 • Sagan refuses to take seriously the witnesses' reports of anything that twentieth-century science can't explain.

12 • When alleged scientists conspire to censor and intimidate those who endeavor to offer new insightful hypotheses on conventional theories. . . they no longer should be considered scientists, but merely the insecure, self-serving impostors that they apparently are. . . In the same token, must we also still suppose that J. Edgar Hoover was a fine FBI director, rather than the homosexual tool of organized crime he was?

11 • My friend Frankie ~~[Franky?]~~ wants me to bring back an ashtray or a matchbook, but I think these visitors are probably much too intelligent to smoke.

20 • Some of these ~~beams [~~beings~~?]~~ are capable of intercepting the spiritual body when it is traveling.

3 • How many human females who had the misfortune of being raped had the foresight to take from their attacker an ID card, a picture of the rapist, or anything else which could be used as evidence as to an alleged rape?

22 • The aliens can stay a step or two ahead of the thinking of scientists, and know how to leave insufficient clues behind that would satisfy the Sagan types, until society is better prepared

mentally to face up to it all. . . Perhaps you share the view that what's going on with respect to UFOs and aliens, if deemed real, would be too traumatic to think about. However. . . they've shown themselves until back some 5,000-15,000 years or more ago when they were here for extended periods, spawning the god/goddess mythology of all cultures. The bottom line is that in all that time they haven't taken over Earth; they haven't subjected us or wiped us out.

2
6

24 • I have at least 20 reasons why Carl Sagan's and other evolutionist's ideas about evolution are not scientific. Their assumptions are mere hallucinations, not one bit better than hallucinations regarding the existence of extraterrestrial aliens.

25 • The explosion that people saw was hydrogen fuel from a star cruiser, the landing sight was to be Northern California. . . The people on that star cruiser looked like Mr. Spock from the <u>Star</u> <u>Trek</u> TV series.

13 • Your conclusion that large numbers of people in this country, perhaps as many as five million, are all victims of an identical mass hallucination is asinine.

14 • If there is no reason to take the matter of alien visitation seriously, why is it the most highly classified subject in the U.S. government?

15 • Science has become the "magic that works." The UFOlogists are heretics to be excommunicated or burned at the stake.

[3-23-93.at1]

29 • I hope that I never feel so superior that I cannot acknowledge that Creation is not limited to myself, but encompasses the Universe and all its entities.

4 • I can't believe you would publish Carl Sagan's UFO crap, which is just more of what our government want the public to believe.

1 • I wonder how some of our fellow animals may describe their encounters with us. They see a large hovering object making a terrible noise above them. They begin to run and feel a sharp pain in their side. Suddenly they fall to the ground. . . Several man-creatures approach them carrying strange looking instruments. They examine your sexual organs and teeth. They place a net under you and then let it take you in the air with a strange device. After all the examinations, they then clamp a strange metal object to your ear. Then, just as suddenly as they had appeared, they are gone. Eventually, muscle control returns, and the poor disoriented creature staggers off into the forest, not knowing that what just transpired was a nightmare or a reality.

16 • If I were a betting man, I would give you odds that your mailbox will overflow with stories such as I just related. I suspect that the psychic brings forth these demons and angels, lights and circles as a part of our development. They are part of our nature.

[3-23-93.at1]

26 • Sagan is now the top authority and debunker of UFO for the U.S. gov't.

5 • This is a grotesquely challenging arena. . . I studied UFOs for over 20 years. Finally I became quite disenchanted by the cult and the cult fringe groups.

6 • I am a 47-year-old grandmother who has been the victim of this phenomena since early childhood. I do not -- nor have I ever -- accepted it at face value. I do not -- nor have I ever -- claimed to understand what it is. . . I would gladly accept a diagnosis of schizophrenia, or some other understood pathology, in exchange for this unknown. . . The lack of physical evidence is, I fully agree, most frustrating for both victims and researchers. Unfortunately, the retrieval of such evidence is made extremely difficult by the manner in which the victims are abducted. Often I am removed either in my nightgown (which is later removed) or already naked. This condition makes it quite impossible to hide a camera. . . There is another form of physical evidence you neglected to mention in your article; this being bodily marks, scars, and physical abnormalities still unexplained by the medical community. I have awakened with deep gashes, puncture wounds, scooped out tissue, eye damage, bleeding from the nose and ears, burns, and finger marks and bruises which persist for days after the event. I have had all of these examined by qualified physicians but none have been satisfactorily explained. I am not into self-mutilation; these

are not stigmata. . . Please be aware that the majority of abductees claim to have had no interest in UFOs previously (I am one), have no history of childhood abuses (I am one), have no desire for publicity or notoriety (I am one), and, in fact, have gone to great lengths to avoid acknowledging any involvement whatsoever, assuming he or she is experiencing a nervous breakdown or other psychological disorder (I am one). Agreed, there are many self-proclaimed abductees (and contactees) who seek out publicity for monetary gain or to satisfy a need for attention. I would be the last to deny these people exist. What I do deny is that ALL abductees are imagining or falsifying these events to satisfy their own personal agendas.

2 • I was sexually abused as a child. In my recovery I have drawn many "space beings" ~~[correctly transcribed?]~~ and have felt many times I was being overpowered, held down, and the sensation of having left my body to float around the room. None of the abductee accounts really come as a surprise to someone who has dealt with childhood sexual abuse issues. . . Believe me, I would much rather have blamed my abuse on a space alien than have to face the truth about what happened to me with the adults I was supposed to be able to trust. It's been driving me crazy to hear some of my friends speak of their memories that imply they have been abducted by aliens. . . I keep saying to them that this is the ultimate victim role in which we as adults have no power when these little gray men come to us in our sleep! This is not real.

[3-23-93.at1]

The ultimate victim role is the one between an abusive parent and the victimized child.

28 • Hynosis prepares the mind for the invasion of demons, devils, and little gray men. God wants us to be clothed and in our right minds. . . Anything your "little gray men" can do, Christ can do better!

21 • I am having communication with an alien being. This communication started early in 1992. What else can I say?

7 • UFOs don't exist. I think that requires an eternal energy source, and this doesn't exist. . . I have spoken with Jesus.

23 • Homo sapiens ~~[Underlined in original?]~~ was genetically fashioned, created initially to be substitute laborers and domestics for the SKY-LORDS (DINGIRS/ELOHIM/ANUNNAKI).

27 • The answer to these aliens from outer-space is simple. It comes from man. Man using drugs on people. In mental institutions all over the country, there are people who have no control over their emotions and behavior. To control these people, they are given a variety of antipsychotic drugs. . . If you have been drugged often. . . you will begin to have what is called "bleedthroughs." This will be flash images popping into your mind of strange-looking people coming up to your face. This will begin your search for the answer of what the aliens were doing to you. You will be one of the thousands of UFO abductees. People will call you crazy. The reason for the strange creatures you are seeing is because Thorazine distorts the vision of your

subconscious mind. . . The writer was laughed at, ridiculed, had his life threatened [because of presenting these ideas].

18 • You, sir, are in a position to do one of two things: Know about the abductions and be covering them up, or feel that because you have not been abducted (perhaps they are not interested in you) they do not occur.

• ~~You, a great scientist who is praised by Extraterrestrials, know nothing about them. . .~~ The commentary
6 on the Parade magazine is very destructive, and it enjoys scaring society, I beg you to think more openly because our intelligent beings from outer spaces do exist and they are our creators. . . I too was an abductee. To be honest, these dear beings have done me more good than bad. They have saved my life. . . The trouble with Earth beings is that they want proof, proof, and proof!

19 • A treason suit [was filed] against the President and Congress of the United States over a treaty made with aliens in the early '40s, who had later shown themselves to be hostile. . . The treaty agreed to protect the secrecy of the aliens in return for some of their technology.

17 • [Several readers wrote to say that aliens were devils sent by Satan, who is able to cloud our minds. One proposes that the Satanic purpose is to make us worried about an alien invasion, so that when Jesus and his angels appear over Jerusalem we will be frightened rather than glad.] I do hope you will not dismiss me, [she writes,] as another religious crackpot. I am quite normal

3/30/93

~~A Pale Blue Dot.~~

~~There were many thoughtful and constructive responses that I received to this article. Others were not. Here is a sampling from them:~~

30 "In 1977 an heavenly being spoke to me about an injury to my head that happened in 1968"

31 A letter from a man who has had 24 separate encounters with "a silent hovering saucer-shaped vehicle" and who has ~~"have"~~ experienced an ongoing development and amplification of such mental functions as clairvoyance, telepathy, and the challenging of universal life energy for the purpose of healing"

[3-23-93.at1]

and well-known in my own little community.

32 • Over the years I have seen and talked to "ghosts," been visited (though not yet abducted) by aliens, seen 3-dimensional heads floating by my bed, heard knocks on my door. . . These experiences seemed as real as life. I have never thought of these experiences as anything more than what they certainly are: my mind playing tricks on itself. [From a letter received by The Skeptical Inquirer; reference Kendrick Fraser.]

1,7

[4-3-93.atp]

In "The Triumph of Voyager," here is a new first sentence for the first paragraph:

They opened the Solar System for the human species, trailblazing a path for our descendants. [And then pick up "Their names were Voyager 1 and Voyager 2. . ."]

[2A, 2/20/93]

The Triumph of Voyager

Bottom p. 2 first?

~~"Robots have changed history." This sentence sounds a little out of place at the end of the twentieth century -- something you'd be prepared to believe for the end of the twenty-second century, say, but not now. Robots don't seem to play much of a role in our lives just yet. Certainly there are manufacturing robots and data processing systems that have increased efficiency and put people out of work. But we don't much think about particular robots, robots with names and personalities, heroic robots. There are such robots, though, and I want in this chapter to talk about a famous robot couple.~~

Their names are Voyager 1 and Voyager 2. They were launched in August and September 1977 from Cape Canaveral, Florida bound for the planets and the stars. In the next dozen years, they provided our first detailed, close-up information about many new worlds -- some of them previously known only as fuzzy disks in the eyepieces of ground-based telescopes, some merely as points of light, and many entirely unknown before the Voyagers discovered them. Before Voyager, we were almost wholly ignorant about most of the planetary part of the Solar System.

~~They will change history, it seems to me, because,~~ W when all is said and done, they will have taught us about the uniqueness and fragility of our world, about the variety of other worlds, and about the origin and fate of the Solar System. ~~-- and because~~ T they were the ships that first explored some of the homelands of our remote descendants. These two spacecraft have opened most of the Solar System -- both in extent and in mass -- to the human species.

United States launch vehicles are not powerful enough to get a spacecraft this quickly to the outer~~most~~ Solar System by rocket propulsion alone. So *Voyager 2* took advantage of a rare lining-up of the planets: A close fly-by of Jupiter accelerated it on to Saturn, Saturn on to Uranus, Uranus on to Neptune, and Neptune on to the stars. (The last opportunity for such a game of celestial billiards presented itself during the Presidency of Thomas Jefferson. But we were then only at the horseback, canoe, and sailing ship stage of exploration.)

Since adequate funds were unavailable, NASA's Jet Propulsion Laboratory (JPL) only could afford to build a spacecraft that would work reliably as far as Saturn. Beyond that, all bets were off. But because of the brilliance of the engineering design -- and the fact that the JPL engineers who told the spacecraft what to do got smarter faster than the spacecraft got dumb -- both *Voyagers* went on to explore Uranus and Neptune, and are still radioing data back from deep interplanetary space.

We tend to hear much more about the splendors returned than the ships that brought them, or the shipwrights. It has always been that way. Even those history books enamored of the voyages of Columbus do not tell us much about the builders of the Niña, Pinta, and Santa Maria, or even about the principle of the caravel. These spacecraft, their designers, builders, navigators, and controllers are examples of what science and engineering, set free for well-defined peaceful purposes, can accomplish. Those scientists and engineers are role models for an America seeking excellence and international competitiveness. They should be on our stamps.

At each of the four giant planets -- Jupiter, Saturn, Uranus, and Neptune -- Voyager studied the planet, its rings, and its moons. At Jupiter, in 1979, Voyagers 1 and 2 braved a dose of trapped charged particles 1,000 times what it takes to kill a human being; and in all that radiation discovered the rings of the largest planet, the first active volcanos outside Earth, and a possible underground ocean on an airless world -- among a few hundred other major findings. At Saturn, in 1980 and 1981, the two spacecraft survived a pummeling by tiny ice particles as they plummeted through previously unknown rings, ~~and~~ discover~~ed~~ing not a few, but thousands of them. They examined ~~Saturnian rings,~~ icy moons recently melted through unknown causes, and a large world with an apparent ocean of liquid hydrocarbons surmounted by clouds of organic matter. On January 25, 1986, Voyager 2 entered the Uranus system and reported a procession of wonders. The encounter lasted only a few hours, but the data faithfully relayed back to Earth have revolutionized our knowledge of the aquamarine planet, its more than 15 moons, its pitch black rings, and its belt of trapped high-energy charged particles. At Neptune on [date], Voyager 2 swept through the Neptune system and observed in the dim sunlight kaleidoscopic cloud patterns and a moon with a bizarre surface and plumes of fine organic particles swept up by the (very) thin air. These spacecraft have returned four trillion bits of information to Earth, the equivalent of about 100,000 encyclopedia volumes. (I described the Voyager encounter with the Jupiter system in Cosmos. I'll try to say a little about the Saturn, Uranus, and Neptune encounters below.)

Because we are stuck on Earth, we are forced to peer at distant worlds through an ocean of distorting air. It is easy to see why our spacecraft have revolutionized the study of the Solar System: We ascend to the stark clarity of the vacuum of space, and there approach our objectives, flying past them or orbiting them or landing on their surfaces. These worlds will be -- unless we are so foolish as to destroy ourselves first -- as familiar to our descendants as the neighboring states are to those who live on Earth today.

Voyager and its brethren are prodigies of human inventiveness. Just before Voyager 2 was to encounter the Uranus system, the mission design had scheduled a final course correction, a short firing of the on-board propulsion system to position Voyager correctly as it flew among the moons. But the course correction proved unnecessary. The spacecraft was already within 200 kilometers of its designed trajectory after a voyage along an arcing path five billion kilometers long. This is roughly the equivalent of throwing a pin through the eye of a needle 50 kilometers away, or firing your target pistol in New York and hitting the bull's eye in Dallas.

Lodes of planetary treasure were transmitted back to Earth by the radio antenna aboard Voyager; but Earth is so far away that by the time the signal was gathered in by radio telescopes on our planet, the received power was only 10^{-16} watts (fifteen zeros after the decimal point). This weak signal is to the power emitted by an ordinary reading lamp as the size of an atom is to the distance from the Earth to the Moon.

The spacecraft were designed, assembled, and operated by JPL. The mission was conceived during the late 1960s, first funded in 1972, but was not approved in its final form (including encounters with Uranus and Neptune) until after the 1979 Jupiter flyby. The two spacecraft were launched by a nonreusable Titan/Centaur booster configuration. Weighing about a ton, a Voyager would fill a good-sized living room. Each spacecraft draws about 400 watts of power -- considerably less than an average American home -- from a generator that converts radioactive plutonium into electricity. (If it had to rely on solar energy, the power available would decline quickly as the ship ventured farther and farther from the Sun. If not for nuclear power, Voyager would have returned no data at all from the outer Solar System, except perhaps for Jupiter.)

The instrument that measures interplanetary magnetic fields is so sensitive that the flow of electricity through the innards of the spacecraft would generate spurious signals. As a result, this instrument is placed at the end of a long boom stretching out from the spacecraft. With other projections, it gives _Voyager_ a slightly porcupine appearance. Two cameras, infrared and ultraviolet spectrometers, and an instrument called the photopolarimeter are on a scan platform; the platform swivels so these instruments can point toward a target world. The spacecraft antenna must know where Earth is if the transmitted data are to be received back home. The spacecraft also needs to know where the Sun is and at least one bright star, so it can orient itself in three dimensions and point properly toward any passing world. It does no good to be able to return pictures over billions of miles if you can't point the camera.

Each spacecraft cost about as much as a single modern strategic bomber. But unlike bombers, _Voyager_ cannot, once launched, be returned to the hangar for repairs. As a result, the spacecraft's computers and electronics are designed redundantly. When _Voyager_ finds itself in trouble, the computers use branched contingency tree logic to work out the appropriate course of action. If that doesn't work, the robot radios home for help.

As the spacecraft journeys increasingly far from Earth, the round-trip light (and radio) travel time also increases, approaching twelve hours by the time Voyager is at the distance of Neptune. Thus, in case of emergency, the spacecraft needs to know how to put itself in a safe standby mode while awaiting instructions from Earth. As the spacecraft ages, more and more failures are expected, both in its mechanical parts and its computer system, although there is no sign, even now, of a serious memory deterioration, some robot Alzheimer's disease. When an unexpected failure occurs, special teams of engineers -- some of whom had been with the Voyager program since its inception -- were assigned to "work" the problem. They would study the underlying basic science and draw upon their previous experience with the failed subsystems. They would do experiments with identical Voyager spacecraft equipment that was never launched, or even manufacture a large number of components of the sort that failed in order to gain some statistical understanding of the failure mode.

In April 1978, almost eight months after launch, an omitted ground command caused Voyager 2's on-board computer to switch from the prime radio receiver to its backup. During the next ground transmission to the spacecraft, the receiver refused to lock onto the signal from Earth. A component called a tracking loop capacitor had failed. After seven days in which Voyager 2 was out of contact, its fault protection software commanded the backup receiver to be switched off and the prime receiver to be switched back on. Mysteriously, the prime receiver failed moments later. It never recovered. Voyager 2 was now fundamentally imperiled. ~~Although the primary receiver had failed~~d, ~~t~~The on-board computer foolishly commanded the spacecraft to use ~~it~~ the failed primary receiver. There seemed to be no way for the human controllers on Earth to get Voyager to revert to the backup receiver. Even worse, the backup receiver would be unable to receive the commands from Earth -- because of the failed capacitor. Some mission controllers were convinced that all was lost. Finally, after a week of ~~sullen~~ obdurate unresponsiveness to all ~~commands~~ instructions, instructions to switch automatically between receivers were accepted and programmed into the on-board computer. And during that week the JPL engineers had designed an innovative command frequency control procedure to make certain essential ~~commands~~ orders comprehensible to the damaged backup receiver.

This meant the engineers were now able to communicate, at least a little bit, with the spacecraft. Unfortunately the backup receiver now turned giddy, becoming extremely sensitive to the stray heat dumped when various components of the spacecraft powered up or down. Over the following months the JPL engineers designed and conducted a series of tests that let them thoroughly understand the thermal consequences of most operational modes of the spacecraft on ~~the spacecraft's~~ its ability to receive commands from Earth. The backup-receiver problem was entirely circumvented. It was this backup receiver that acquired all the commands from Earth on how to gather data in the Jupiter, Saturn, Uranus, and Neptune systems. The engineers had saved the mission. (But to be on the safe side, during most of Voyager's subsequent flight a nominal data-taking sequence for the next planet to be encountered was always in residence in the on-board computers.)

Another heart-wrenching failure occurred just after Voyager 2 emerged from behind Saturn (as seen from the Earth) in August 1981. The scan platform had been moving rapidly -- quickly pointing here and there among the rings, moons, and the planet itself during the time of closest approach. Suddenly, the platform jammed. A stuck scan platform obviously means a severe reduction in future pictures and other key data. The scan platform is driven by gear trains called actuators, so first the JPL engineers ran an identical copy of the flight actuator in a simulated mission. The ground actuator failed after 348 revolutions; the actuator on the spacecraft had failed after 352 revolutions. The problem turned out to be a lubrication failure. Plainly, it would be impossible to overtake Voyager with an oil can.

The engineers wondered whether it would be possible to restart the failed actuator by alternately heating and cooling it, so that the thermal stresses would cause the components of the actuator to expand and contract at different rates and un-jam the system. After gaining experience with specially manufactured actuators on the ground, the engineers jubilantly found that this procedure started the scan platform up again in space. More than this, they devised techniques to diagnose any imminent actuator failure early enough to work around the problem. Voyager 2's scan platform worked perfectly in the Uranus and Neptune systems. The engineers had saved the day again.

Voyager 1 and 2 were designed to explore the Jupiter and Saturn systems only. It is true that their trajectories would carry them to Uranus and Neptune, but officially these planets were never contemplated as targets for Voyager exploration: The spacecraft were not supposed to last that long. Because of the need to pass close to Titan, Voyager 1 was flung by Saturn on a path that could never encounter any other known world; it is Voyager 2 that flew on to Uranus and Neptune with brilliant success. At these immense distances, sunlight is getting progressively dimmer, and the spacecraft's transmitted radio signals to Earth are getting progressively fainter. These were predictable but still very serious problems that the JPL engineers and scientists also had to solve.

Because of the low light levels at Uranus and Neptune, the Voyager television cameras were obliged to take longer time exposures. But the spacecraft was hurtling so fast through, say, the Uranus system (at about 35,000 miles per hour) that the image would have been smeared or blurred. To overcome this, the entire spacecraft had to be moved during the time exposures to compensate for the motion, like panning in the direction opposite yours while taking a photograph of a street scene from a moving car. This may sound easier than it is: You have to compensate for the most casual of motions; at zero gravity, the mere start and stop of the on-board tape recorder that's registering the image can jiggle the spacecraft enough to smear the picture. This problem was solved by commanding the spacecraft's little rocket engines (called thrusters), machines of exquisite sensitivity, to compensate for the tape-recorder jiggle at the start and stop of each sequence by turning the entire spacecraft just a little. To compensate for the low received radio power at Earth, a new and more efficient digital encoding algorithm was designed for the cameras, and the radio telescopes on Earth were joined together with others to increase their sensitivity. Overall, the imaging system worked, by many criteria, better at Uranus than it did at Saturn or even at Jupiter.

Voyager may not yet be done exploring. There is, of course, a chance that some vital subsystem will fail tomorrow, but in terms of the radioactive decay of the plutonium power source, the two *Voyager* spacecraft should be able to return data to Earth until roughly the year 2015. By then they will have traveled more than a hundred times the Earth's distance from the Sun, and may have penetrated the heliopause, the place where the interplanetary magnetic field and charged particles are replaced by their interstellar counterparts; the heliopause is one definition of the frontier of the Solar System.

Voyager has become a kind of intelligent being -- part robot, part human. It extends the human senses to far-off worlds. For simple tasks and short-term problems, it relies on its own intelligence; but for more complex tasks and longer term problems, it turns to another, considerably larger brain -- the collective intelligence and experience of the JPL engineers. This trend is sure to grow. The *Voyagers* embody the technology of the early 1970s; if such spacecraft were to be designed in the near future, they would incorporate stunning improvements in artificial intelligence, in data-processing speed, in the ability to self-diagnose and repair, and in the capacity for the spacecraft to learn from experience. In the many environments too dangerous for people, the future belongs to robot-human partnerships that will recognize the two *Voyagers* as antecedents and pioneers. This is another reason for their historical importance.

The *Voyager* spacecraft came in at cost, on time, and vastly exceeding both their design specifications and the fondest dreams of their builders. These machines do not seek to control, threaten, wound, or destroy; they represent the exploratory part of our nature, set free to roam the Solar System and beyond. This kind of technology, ~~its findings~~ the treasures it uncovers freely ~~revealed~~ available to all humans everywhere, has been, over the last few decades, one of the few activities of the United States admired as much by those who find our policies uncongenial as by those who agree with us on every issue. Missions to the planets are one of those things -- and I mean this not just for the United States, but for the entire human species -- that we do best. We are tool makers, and the right tools, wisely chosen, can vastly improve our prospect.

"No Small Rapture":

Voyager at Titan

I know a world, midway in size between the Moon and Mars, where the upper air is rippling with electricity pouring in from a giant ringed planet; where the perpetual brown overcast is tinged an odd burnt orange; and where the stuff of life falls out of the skies onto the unknown surface below. This world is so far away that light takes over an hour to get there from the Sun. Spacecraft from Earth take years. We have examined it in reflected sunlight, probed its surface with radar, and investigated it close-up with robot spacecraft. Much about it is still a mystery -- including whether it holds great oceans. We know just enough, though, to recognize that within our reach is a place where some of the processes are today working themselves out that long ago led to the origin of life on Earth.

The oldest known fossils date to about 3.6 billion years ago. Of course, the origin of life had to have happened well before that. But 4.3 or 4.2 billion years ago the Earth was being so ravaged by the final stages of its formation that life then could not yet have come into being; indeed, massive collisions were melting the surface and turning the oceans into steam. So there's a fairly narrow window around 4 billion years ago in which our most distant ancestors arose.

The first living things were far less capable than the most humble microbe alive today, perhaps just barely able to make crude copies of themselves. But natural selection, the evolutionary process first coherently described by Charles Darwin, is so powerful that from such simple beginnings there can emerge all the richness and beauty of the biological world of which we are a part.

Those first living things were made of pieces, parts, building blocks which had to come into being on their own -- that is, driven by the laws of physics and chemistry. The building blocks of all life on Earth are called organic molecules, molecules based on carbon. Of the stupendous number of possible organic molecules, only a very few are used at the heart of life. The two most important kinds are the amino acids, the building blocks of proteins, and the nucleotides, the building blocks of the nucleic acids.

Just before the origin of life, where did these molecules come from? There are only two possibilities: from the outside or from the inside. We know that vastly more comets and asteroids were hitting the Earth then than do so now, and that these small worlds are rich storehouses of complex organic molecules. But here I want to talk about homemade, not imported, goods: the organic molecules generated in the air and waters of the early Earth.

Unfortunately, we don't know very much about the composition of the early atmosphere, and organic molecules are far easier to make in some atmospheres than in others. There couldn't have been much oxygen, because oxygen is generated by green plants and there weren't any green plants yet. There was probably more hydrogen, because hydrogen is very abundant in the Universe and escapes from the upper atmosphere of the Earth into space (because it's so light) better than any other atom. We can imagine what various early atmospheres were, duplicate them in the laboratory, supply some energy and see what organic molecules are made -- and, indeed, such experiments have over the years been very provocative and promising. But our ignorance of initial conditions limits the relevance of such experiments.

What we need is a real world whose atmosphere still retains some hydrogen-rich gases, a world in other respects something like the Earth, a world in which the organic building blocks of life are being generated in our own time, a world we could go to to seek our own beginnings. There is only one such world in the Solar System. This world is Titan, the big moon of Saturn.*

The Voyager spacecraft tod us that the atmosphere of Titan is composed mainly of nitrogen, N_2, as is the Earth's today. Its other principal constituent is methane, CH_4, the starting material from which carbon-based organic molecules are generated there. There's about ten times more air on Titan than there is on the Earth today, but the early Earth may well have had a denser atmosphere. Ultraviolet light from the Sun is falling on

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*There could have been none; we're very lucky. The others have too much hydrogen, or not enough hydrogen, or no atmospheres at all.

Titan as it did on the primitive Earth. Beams of electrons trapped in the magnetic field of giant Saturn fall on the upper air of Titan, just as charged particles from the solar wind fell on the primitive Earth.

But no world is a perfect replica of any other, and there is at least one important respect in which Titan is very different from the primitive Earth: Being so far from the Sun, its surface is extremely cold, far below the freezing point of water, around 180° below zero Centigrade. So while the Earth at the time of the origin of life was, as now, mainly ocean-covered, there can be no oceans of liquid water on Titan. The low temperatures give an advantage as well, though, because they mean that once molecules are synthesized on Titan, they stick around. The higher the temperature, the faster molecules fall to pieces. On Titan the molecules that have been raining down like manna from heaven for the last 4 billion years might still be largely unaltered, deep-frozen in their earliest state, awaiting the chemists from Earth.

* * *

The invention of the telescope in the seventeenth century led to the discovery of many new worlds. In 1610 Galileo first spied the four large moons of Jupiter. Forty-five years later, the celebrated Dutch physicist, Christianus Huygens, discovered a point of light moving about the planet Saturn and named it Titan -- not because he thought it remarkably large, but because in Greek mythology the generation which preceded the Olympians, and that included the god Saturn, was called the Titans. It was a dot of light gleaming in reflected sunlight a billion miles away. From the time of its discovery, when European men wore long curly wigs, to World War II, when American men cut their hair down to stubble, almost nothing more was discovered about Titan except the fact it had a curious, tawny, orangish or brownish color. Ground-based telescopes could just barely make out some enigmatic detail. The Spanish astronomer, Comas Solá, reported at the turn of the twentieth century faint variable markings on Titan that he thought to be clouds. It was a minor controversy.

In a way, I grew up with Titan. I did my doctoral thesis at the University of Chicago under the guidance of Gerard P. Kuiper, the man who discovered that Titan had an atmosphere. Kuiper was Dutch and, in a way, in a direct line of intellectual descent from Christian Huygens. In 1944, while making a spectroscopic examination of Titan, he was astonished to find the characteristic spectral features of the gas methane. When he pointed the telescope at Titan, there was the signature of methane as well. When he pointed it away, not a hint of methane. But moons are not supposed to have atmospheres, and the Earth's Moon certainly does not (or at least nothing to speak of). Titan could retain an atmosphere, Kuiper realized, even though its gravity was less than Earth's, if the temperature in its upper atmosphere were very low. The molecules simply aren't moving fast enough for large numbers of them to achieve escape velocity and trickle away to space.

If you wanted to learn more about Titan, you could also measure the polarization of sunlight reflected off it. Ordinary sunlight is unpolarized. Joseph Veverka, now a fellow faculty member at Cornell University, was my graduate student at Harvard University. In his doctoral work, around 1970, he measured the polarization of Titan and found that it changed as the relative positions of Titan, the Sun, and the Earth changed. But the change was very different from that exhibited by, say, the Moon. Veverka concluded that the character of this variation was consistent with clouds or haze on Titan.

So, by the early 1970s we knew, as a kind of legacy from Huygens, that Titan had a dense methane-rich atmosphere, and that it is probably enveloped by a reddish cloud veil or aerosol haze. But what kind of cloud was red? We knew that the irradiation (by ultraviolet light from the Sun or by protons and electrons) of mixtures of methane and other gases produced complex organic molecules, some of which were red. It was therefore not a daring hypothesis to propose, as I did at the time, that the Titan haze layer is composed at least in part of complex organic molecules. By the early 1970s my colleague Bishun Khare and I had been doing experiments at Cornell in which we irradiated methane-rich atmospheres with charged particles and were making a kind of reddish or brownish solid that would coat the interior of our reaction vessel. It seemed to me very likely that if methane-rich Titan had brownish clouds, that those clouds might be similar to what we were making in the laboratory. We called this stuff tholin. While at the beginning we had very little idea what it was made of, it clearly consisted of complex organic molecules.

I want to stress that the word "organic" here carries no implication of biological origin; following long-standing chemical usage dating back more than a century, it merely refers to molecules based upon carbon (excluding a few very simple carbon-based molecules such as carbon monoxide, CO, and carbon dioxide, CO_2). Since life on Earth is based on organic molecules, and since there was a time before there was life on Earth, there must have been some process which made organic molecules on our planet before the advent of life. Something similar, I thought, might be happening on Titan today, and have some relevance to the origin of life.

The epochal event in our understanding of Titan was the arrival in 1980 and 1981 of the Voyager 1 and Voyager 2 spacecraft in the Saturn system. Threading its way past moon after moon, skirting the edge of the magnificent ring system, Voyager 2 left the Saturn system on a trajectory that would take it -- immensely successfully, as it turned out -- to Uranus and

Neptune. But to make a close fly-by of Titan, Voyager 1 had to forego the option of a rendezvous with the worlds beyond. ~~Titan was considered so important an objective that we were willing to sacrifice much to study it. [Redundant?]~~ The ultraviolet, infrared, and radio instruments gathered in a treasure-trove of data. We learned the pressure and temperature from the surface to high up in the atmosphere. We discovered a variety of simple organic molecules present as gases, mainly hydrocarbons and nitriles. Hydrocarbons are molecules composed of carbon and hydrogen atoms only, and are familiar to us as constituents of natural gas, petroleum, and waxes. Nitriles are molecules with a carbon and nitrogen atom attached in a particular way. The best known of these is HCN, hydrogen cyanide, a deadly gas for humans. But hydrogen cyanide is implicated in the steps that on Earth led to the origin of life. Finding these simple organic molecules in the upper atmosphere -- even if present only in a part per million or a part per billion -- is tantalizing.

So we now know that the atmosphere of Titan is composed primarily of nitrogen and methane, and that among the minor atmospheric constituents are nine organic molecules, the most complex of which have four carbon and/or nitrogen atoms. Moreover, Voyager discovered a large region of energetic electrons and protons surrounding Saturn, trapped by the planet's magnetic field. During the course of its orbital motion around Saturn, Titan bobs in and out of this magnetosphere. Thus it is natural to try irradiating a mixture of nitrogen and methane, simulating the atmosphere of Titan, with ultraviolet light or charged particles to see what more complex molecules can be made.

With W. Reid Thompson playing a key role in our laboratory at Cornell, we've simulated Titan's manufacture of organic gases. We cause high-energy electrons, like those that Saturn conveys to Titan, to irradiate a laboratory mixture of nitrogen and methane at very low pressures, simulating the altitude where the electrons are stopped. We make a large variety of different organic gases, the most complex with 6 or 7 carbon and/or nitrogen atoms. These product gases seem to be on their way to forming tholins, the organic solids also made in such experiments. We know that the simplest hydrocarbons on Titan are manufactured by ultraviolet light from the Sun. But for all the other gas products, those made most readily in the laboratory correspond to those discovered by Voyager on Titan, and in the proper abundances. The next most abundant gases that we find in the laboratory will be looked for in future studies of Titan.

We had hoped for a break in the weather as Voyager 1 approached Titan. A long distance away, it appeared only as a tiny circle; at closest approach, our camera's field of view was filled by a tiny piece of Titan. If there had been a break in the haze and clouds of Titan only a few miles across [check], we would have had a chance to see details on its hidden and enigmatic surface. But there was no hint of a break. This world is socked in. No one knows what its surface looks like.

But from Voyager and other measurements from the vicinity of the Earth, we know a fair amount about the orangish-brown haze particles that obscure the surface: which colors of light they like to absorb, which colors they pretty much let pass through them, and how much they bend the light that does pass through them. These "optical properties" will depend, of course, on the composition of the haze particles.

When we irradiate a simulated Titan atmosphere with electrons, we make a particular reddish-brown powder that we call Titan tholin. In collaboration with Edward Arakawa of Oak Ridge National Laboratory in Tennessee, we've measured the optical properties of Titan tholin. It turns out to be a dead ringer for the real Titan haze. No other candidate material matches the optical constants of Titan. [Figure.] So we can fairly claim to have bottled the haze of Titan [same phrasing in _Cosmos_?] -- formed high in its atmosphere, slowly falling out, and accumulating in vast amounts on its surface. What is this stuff made of?

It's very hard to know the exact chemical composition of a complex chemical solid. For example, the chemistry of coal -- where there's a powerful economic motive to understand exactly what it's made of -- is still not well understood. But there are some things that we do know about Titan tholin. We find it to be an extremely complex organic material containing many of the something about its composition. The average density of Titan lies between the density of ice and the density of rock. Both ice and rock are abundant on nearby worlds, with some of them made purely of ice. If the surface of Titan is icy, a high-speed impact will melt the ice. Thompson and I estimate that any given spot on Titan's surface has a better than 50-50 chance of having once been melted, with an average lifetime of the impact melt of about a thousand years.

This makes for a very different story. The origin of life on our planet about four billion years ago seems to have happened in the oceans and shallow tide pools. All life on Earth is made mainly of water, and it plays an essential physical and chemical role. It's hard for us water-besotted creatures to imagine life without water. If the tholins had been mixed into liquid water -- even for only a thousand years -- the surface of Titan may be much further along towards the origin of life than we thought.

I hope I haven't made it seem that we understand everything about Titan. In fact, we understand pitifully little and are lucky to have gotten that far. This was brought home forcefully to me at a recent scientific symposium on Titan held in Toulouse, France and sponsored by the European Space Agency (ESA). While oceans of liquid water are impossible on Titan, oceans of liquid hydrocarbons are not. Clouds of methane (CH_4), the most abundant hydrocarbon, are expected not far above the surface. Ethane (C_2H_6), the next most abundant hydrocarbon, must condense out at the surface in the same way that water vapor becomes a liquid near the surface of the Earth, where the temperature drops below the freezing point. Vast oceans of liquid hydrocarbons should have accumulated over the lifetime of Titan. They would lie far beneath the haze and clouds, but that doesn't mean they would be inaccessible to us -- because radio waves readily penetrate through the atmosphere of Titan and its suspended fine particles.

In Toulouse, Duane O. Muhleman of the California Institute of Technology described to us the very difficult technical feat of transmitting a set of radio pulses from a radiotelescope in the Mohave desert, having them reach Titan, penetrate through to its surface, be reflected back into space, and then travel back to Earth -- where the by now feeble signal is detected by an array of radiotelescopes near Socorro, New Mexico. Great. But if Titan were covered with hydrocarbon oceans, Muhleman wouldn't have seen a thing. Liquid hydrocarbons are black to radio waves. All right, you might say, so Titan has oceans and continents, and it was a continent that reflected back the signals from Earth. And indeed, Muhleman sees Titan with his giant radar system when he's looking at some parts of Titan, but not for others. But then you run into another problem:

The orbit of Titan around Saturn is not a perfect circle. It's noticeably squashed out, or elliptical. If Titan has extensive hydrocarbon oceans, the giant planet Saturn around which it orbits will raise substantial tides on Titan, and the resulting tidal friction will circularize the orbit of Titan in much less than the age of the Solar System. In a 1982 scientific paper called "The Tide in the Seas of Titan," Stanley Dermott, now at the University of Florida, and I argued that for this reason Titan must be either an all-ocean or an all-land world. Otherwise the tidal friction in places where the ocean is shallow would take its toll. A few lakes or islands might be permitted, but anything more and Titan would have a very different orbit than the one we see. We have, then, three scientific arguments -- one saying the world is almost entirely covered with hydrocarbon oceans, another saying almost all continents and no oceans, and a third saying that you have to choose; you can't have abundant oceans and abundant land both. It will be interesting to see what the answer turns out to be.

What I've just told you is a kind of scientific progress report. Tomorrow there might be a new finding that clears up these mysteries and contradictions. Maybe there's something wrong with Muhleman's radar results, although it's hard to see what it might be: His system tells him he's seeing Titan when it's nearest, when he ought to be seeing Titan. Maybe there's something wrong with Dermott's and my calculation about the tidal evolution of the orbit of Titan, but experts have been unable to find any errors so far. And it's hard to see how ethane can avoid condensing out at the surface of Titan. Maybe, despite the low temperatures, over billions of years there's been a change in the chemistry; maybe some combination of comets impacting from the sky and volcanoes and other tectonic events, helped along by cosmic rays, can congeal liquid hydrocarbons, turning them into some complex organic solid that reflects radio waves back to space. Or maybe something that reflects radio waves is floating on top of the ocean; but liquid hydrocarbons are very underdense: All known organic solids, unless incredibly frothy, would sink like a stone in the seas of Titan.

Should we expect an icy surface covered with a deep layer of tholins, a hydrocarbon ocean with at most a few organic-encrusted islands poking up here and there, or something quite different that we haven't yet been clever enough to figure out? This isn't just an academic question, because there's a real spacecraft being designed to go to Titan. In a joint NASA/ESA program, sometime after the turn of the century, if all goes well, a spacecraft called Cassini will be injected into orbit around Saturn. Each time the spacecraft comes close to Titan, the moon will be examined by an array of instruments, including radar which, because it will be so close to Titan, will be much more sensitive and be able to resolve many more details on Titan's suface than Muhleman's pioneering system. It's also possible that regions of transparency in the haze and cloud will be found in the near infrared, and that maps of the hidden surface of Titan will be in our hands sometime early in the twenty-first century.

Cassini is also carrying an entry probe, fittingly called Huygens, which will detach itself from Cassini and plummet into Titan's atmosphere. A great parachute will be deployed and the instrumented package will slowly settle through the organic haze down into the lower atmosphere, perhaps through the methane clouds, and settle gently onto the surface. It will examine organic chemistry as it descends, and on the ground as well.

Nothing is guaranteed. But the mission is technically feasible, hardware is being built, an impressive coterie of specialists, including many young European scientists, are at work on it, and all the nations responsible are committed to it. Perhaps it will actually come about. Perhaps winging across the billion miles of intervening interplanetary space we will, in the not too distant future, begin receiving news about how far along the path to life Titan has come.

When Huygens contemplated Galileo's work, he mused that it must have been "with no small rapture" that the moons of Jupiter had first been ~~discovered~~ spied through the telescope. And we know from Huygen's own writings the rapture that he felt in his astronomical findings, not the least of which was his discovery of Titan. We have, in a little over three centuries, moved from the discovery of Titan as a point of light circling Saturn to our finding that it is a tantalizing world, strangely similar -- except for the fact that it is stuck out there, a billion miles from the Sun -- to the primitive Earth. When, in the future, our flybys make a radar map of the unknown surface of Titan, when our entry probes slowly sink through the organic haze, when our landers begin returning imaging and chemical data from the surface of Titan, we will once again experience, no less than Galileo and Huygens, the rapture of seeing a new ~~another~~ world for the first time.

[Broca II, draft 1, 8/12/92]

1983, #9: Foreword to *The Planets*, B. C. Murray, ed. (A *Scientific American* Book) (San Francisco: W. H. Freeman).

Our ancestors looked up into the night sky, and of the thousands of shimmering points of light they noticed five that seemed out of the ordinary. Unlike all the other stars, these five changed their relative positions through the course of months. They wandered, in a regular but complex pattern, from constellation to constellation. It was hard to tell what these wandering stars -- or indeed the other so-called "fixed" stars -- really were. It must have been a topic of protracted speculation and debate.

Insert W

~~Eventually the names of gods became attached to them:~~ The faint, fast-moving one that was never far from the Sun ~~was~~ the Romans named Mercury, after the messenger of the gods; the most brilliant of them was named Venus, after the goddess of beauty; the blood red one was named Mars, after the god of war; ~~the bright yellowish slow-moving one was called Jupiter, after the king of the gods;~~ and the faint slowest-moving of the five was named Saturn, after the god of time. These metaphorical allusions were the best our ancestors could do: They had no scientific instruments beyond the naked eye, and they were confined to the Earth. But in the five centuries since the time of Copernicus, there has been a revolution of historic proportions in our understanding of the nature of these wandering points of light that we now call

[2A, 2/20/93]

An American Ship at the Frontiers of the Solar System:

Voyager at Uranus and Neptune

Before we invented civilization, our ancestors lived mainly in the open, out under the sky. Before we devised artificial lights and atmospheric pollution and modern forms of nocturnal entertainment, we watched the stars. There were practical calendrical reasons, of course, but they weren't the only reason. Even today, the most jaded city-dweller can be unexpectedly moved when encountering, sometimes by accident, a clear night sky studded with thousands of stars. When it happens to me, even after all these years, it still takes my breath away. As a child, before you know anything about the nature and distance of the stars, you can feel a sense of awe. In every culture, the night sky and the religious impulse were connected.

Our ancestors, watching the stars, soon noticed five of them that did more than rise and set in stolid procession among the so-called "fixed" stars; these five also slowly wandered with respect to the other stars. Today we call them planets, which is the Greek word for wanderers. We know now that the planets are not stars but are rather other worlds, gravitationally bound to the Sun and, like our own world, reflecting its light back to space. Sharing the odd apparent motion of the planets were the Sun and Moon, making seven wandering bodies in all.

~~It was apparent~~ to the ancients ~~that~~ these seven bodies were important, and they named them after gods -- not any old gods,

, the chief gods, the ones who tell other gods what to do.

Insert W

but the main gods. One of the planets, bright and slow-moving, was named by the Babylonians after Marduk, by the Norse after Odin, and by the Romans after Jupiter, in each case the ~~chief~~ king of the gods. ~~local deity~~.

¶ The number seven began to acquire mystic significance. When it got to be time to design the week -- a period of time, unlike the day, month, and year, with no intrinsic astronomical significance -- it was given seven days, each named after one of the seven anomalous lights in the night sky. We can readily make out the remnants of this convention. Sunday and Monday are clear enough. Tuesday through Friday are named after the Norse gods: Wednesday is Odin's (or Wodin's) day, which would be more apparent if we pronounced it as it is spelled; Thursday is Thor's day; Saturday is from the Roman god Saturn. This collection of seven, seven days and seven worlds -- the Sun, the Moon, and the five wandering planets -- entered the perceptions of people everywhere as an eternal verity.

It was, therefore, with a real sense of surprise that people heard in 1781 about a new planet, discovered with the telescope. That there were new planets to be found and that humans had invented the means to do so were both considered remarkable. The discovery was not even made by a professional astronomer but by William Herschel, a musician whose family had come to Britain with the family of another anglified German, the reigning monarch, King George III. It became Herschel's wish to name the planet George ("George's Star," actually), but posterity has been wiser. Instead, the planet that Herschel discovered is called Uranus, after the ancient sky god who was Saturn's father and Jupiter's grandfather. We no longer count the Sun and Moon as planets, and we now understand that the Earth is just one of the planets. Thus, Uranus is the seventh planet in order from the Sun (Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, Pluto) and the first planet unknown to the ancients.

As the years passed and the quality of astronomical instruments improved, we began to learn more about Uranus. What reflects the dim sunlight back to us is no solid surface, but atmosphere and clouds -- just as for Jupiter, Saturn, and Neptune. Far below, under crushing pressures, there may be a rocky surface something like the Earth's. The upper atmosphere is composed mainly of hydrogen and helium, the two simplest gases. Methane and other hydrocarbons are also present. Deeper in the atmosphere, below the visible clouds, there are enormous quantities of ammonia and, especially, water.

Uranus is lying on its side as it goes around the Sun. in the 1990s, the south pole is heated by the Sun, and it is this pole that Earthbound observers now see when they look at Uranus. It takes Uranus 84 Earth years to go once around the Sun. So in the 2030s, the north pole will be sunward, and in 84 years the south pole will be pointing to the Sun again. In between, astronomers on Earth will look mainly at equatorial latitudes. All the other planets spin much more upright in their orbits. 7

~~But Uranus' axis is tilted 97 degrees.~~ No one knows the reason for this anomaly; the most promising suggestion is that sometime in the early history of Uranus, billions of years ago, it was struck by a rogue planet, about the size of the Earth, in a highly eccentric orbit. Such a collision, if it ever happened, must have worked much ~~havoc~~ tumult in the Uranus system; ~~and~~, for all we know, there may be other ~~signs~~ vestiges of that ancient havoc still left for us to see. But Uranus' ~~is very far away, and it is difficult to learn much about it from the Earth.~~ remoteness guards its mysteries.

In 1977, a team of scientists led by James Elliot, then of Cornell University, discovered the rings of Uranus. The scientists were flying over the Indian Ocean in a special NASA airplane to witness the passage of Uranus in front of a distant star. (Such passages, or occultations, as they are called, happen from time to time, because Uranus slowly moves with respect to the distant stars.) The observers were surprised to find that the star winked on and off several times just before it passed behind Uranus, then several times more just after it emerged. Since the patterns of winking on and off were the same ~~(or symmetric)~~ before and after occultation, this finding (and subsequent work) has led to the discovery of nine very thin, very dark rings surrounding the planet, giving it the appearance of a bull's eye in the sky.

Surrounding the rings, Earthbound observers understood, were the orbits of the five known moons of Uranus: Miranda, Ariel, Umbriel, Titania, and Oberon. They are all named after characters in Shakespeare's A Midsummer Night's Dream and The Tempest, and in Alexander Pope's The Rape of the Lock. Two of them were discovered by Herschel himself. The innermost of these five moons, Miranda, was discovered as recently as 1948 by my teacher G. P. Kuiper. I remember how great an achievement the discovery of a new moon of Uranus was considered back then. The infrared light emitted by the five moons subsequently revealed the spectral signature of ordinary water ice on their surfaces, and no wonder -- Uranus is so far from the Sun that it is no brighter there at noontime than it is shortly after sunset on Earth. Any water of course will be frozen.

A revolution in our understanding of the Uranus system -- the planet, its rings, and its moons -- began on January 24, 1986. On that day, after an epic journey of 8½ years, the Voyager 2 spacecraft ~~flew~~ sailed through the Uranus system very near to Miranda, piercing the bull's eye in the sky. Uranus' gravity then flung the spacecraft on to Neptune. The spacecraft returned 4,300 close-up pictures of the Uranus system and a wealth of other data.

Uranus is surrounded by an intense radiation belt, electrons and protons trapped by the planet's magnetic field. On the Earth the magnetic and the geographical poles are quite close together, but on Uranus the magnetic axis and the axis of rotation are tilted away from each other by some 60 degrees. No one yet

flat

understands why: Perhaps we are catching Uranus in a reversal of its north and south magnetic poles, as periodically happens on Earth. The planet is emitting much more ultraviolet light than it is receiving from the Sun, perhaps generated by charged particles striking its upper atmosphere. From a vantage point in the Uranus system, the spacecraft examined a bright star winking on and off as the rings of Uranus passed by. Many new rings were thereby found. From the vantage point of Earth, the spacecraft passed behind Uranus, and so the radio signals it was transmitting back home penetrated the Uranian atmosphere and probed it to a considerable depth -- to below its methane clouds. A vast and deep ocean, perhaps 8,000 kilometers thick, of superheated liquid water is inferred by some.

But among the principal glories of the Uranus encounter were the 4,300 pictures. With the two television cameras on the spacecraft, we discovered 10 new moons, determined the length of the day in the clouds of Uranus (about 17 hours), and studied about a dozen full rings and many apparently incomplete ones. The most spectacular pictures were those returned from the five previously known moons of Uranus, especially the smallest of them, Miranda. Its surface is covered with fault valleys, parallel ridges, sheer cliffs, low mountains, impact craters. The turmoil so evident on its surface is unexpected for a small, cold, icy world so distant from the Sun. Perhaps the surface was melted and reworked in some long-gone epoch when a gravitational resonance between Uranus, Miranda, and Ariel pumped energy from the nearby planet into Miranda's interior. Or perhaps the turmoil is connected with the primordial collision that is thought to have knocked Uranus over. Or perhaps Miranda has once been utterly destroyed, dismembered, blasted into many pieces by a giant collision. But if the collision was of the right energy, it could have demolished Miranda but not driven the pieces out of Miranda's orbit. The fragments, slowly colliding and gravitationally attracting one another, may have reaggregated into just such a jumbled, patchy, unfinished~~-looking~~ appearance as Miranda shows us today.

There are other signs of a reworking of the surfaces of these worlds. They are mainly colorless, ranging from gray/brown for Ariel to pitch black for the rings and the newly discovered interior moons. It seems likely that the charged particles in the Uranian radiation belt have played a major role in destroying molecules responsible for color on the surfaces of the moons and generating a kind of carbon black from snows that once contained methane.

For me, there is something almost eerie about the pictures of dusky Miranda, because I can remember so well when it was only a faint point of light almost lost in the glare of Uranus, discovered through great difficulty by dint of the astronomer's skills. In only half a lifetime it has gone from an undiscovered world to an exotic place whose ancient and idiosyncratic secrets have been at least partially revealed. The pace of discovery is breathtaking -- and continuing.

* * *

We are completing the preliminary reconnaissance of the solar system in which we live. Our robot emissaries are visiting worlds whose very existence was unknown to most of the humans who have ever lived.

Neptune was the final port-of-call in Voyager 2's grand tour of the Solar System. Usually, it is thought of as the penultimate planet, with Pluto as the outermost. But because of Pluto's stretched-out, elliptical orbit, Neptune has lately been the outermost planet and will remain so until the year 1999. Neptune is so far away that, in its sky, the Sun appears as little more than an extremely bright star. Typical temperatures in its upper clouds are about -400°F, or -240°C, precisely because it is so far from the warming rays of the Sun. It lives on the edge of interstellar night.

How far? It's so far away from the Earth that it cannot be seen with the naked eye. It's so far away that it has~~n't~~ yet to complete~~d~~ a single trip around the Sun since its discovery in 1846. (It takes so long to circuit the Sun because its orbit is so vast, 23 billion miles around, and because the force of the Sun's gravity at that distance is comparatively weak.) It's so far away that it takes light -- faster than which nothing can go -- six hours [check] to get from Neptune to Earth. ~~I mean far out~~.

When Voyager 2 raced through the Neptune system in 1989, its cameras, spectrometers, particle and field detectors, and other instruments were feverishly examining the planet, its moons, and its rings in rapid succession. The planet itself -- like its cousins Jupiter, Saturn, and Uranus -- is a gas giant. Neptune is four times bigger than the Earth. When we look down on its cool, austere blueness, we are seeing only atmosphere and clouds -- no solid surface. The atmosphere is made mainly of hydrogen and helium, with a little methane and traces of other hydrocarbons. There may also be nitrogen. The bright clouds, which seem to be methane crystals, are poised above thick, deeper clouds of unknown composition. The ~~blue~~ azure color ~~is~~ seems so appropriate to a planet named for the god of the sea, ~~-- is due partly to the scattering of sunlight by air molecules (the same process that makes the skies of the Earth blue), and partly to the absorption of red light by methane gas~~. From the motion of the clouds we find fierce winds, approaching the speed of sound. A great dark spot was discovered, ~~oddly~~ curiously at almost the same latitude as the Great Red Spot on Jupiter. If there is any solid surface, it lies far deeper than any of our instruments have yet been able to probe. There probably is a rocky and metallic Earthlike object buried at the core of Neptune. The planet's magnetic field seems tied to the deep interior, so we know how fast the interior rotates.

This is a blue, dimly lit, chilly, stormy, and remote world -- but, despite all that, Neptune, it turns out, has much to teach us about our own planet.

Surrounding Neptune (like the other three gas giants) is a system of rings, each composed of innumerable orbiting objects ranging in size from the fine particles in cigarette smoke to small trucks. Like the rings of other planets in the Solar System, those of Neptune appear to be evanescent~~; natural~~, because gravity and solar radiation ~~processes~~ would disrupt them in less than the age of the Solar System. This suggests that rings were made more or less "recently" and are not relics from primordial times. But how can rings be made?

~~There are also many moons surrounding the giant planets, and every now and then, by chance, one of the multitude of comets that sweep through the outer Solar System must collide with a small moon.~~ The resulting debris -- ejected from the moon but not so fast-moving as to escape from the planet's gravity -- may form, for a time, a new ring. ~~When we examine the small moons in the Solar System, we find that a number of them have craters almost big enough for the impact responsible to have fractured and splintered the moon. Other, more massive, impacts~~ must have occurred and ~~must have wholly demolished moons -- the fragments of disintegration perhaps, for a time, forming a ring.~~

~~Insert 1 fr When Worlds Collide, p. 4~~

~~Insert 2 fr When Worlds Collide, p. 4~~

~~Redundant; Asteroids?~~

Insert * Worlds Collide, p. 5

The American planetary ~~scientist~~ geologist Eugene Shoemaker, of the U.S. Geological Survey, proposes that many moons in the outer Solar System have been annihilated and reformed more than once in the 4.5 billion years since the Sun and the planets condensed out of the interstellar gas and dust. The picture that is emerging from the Voyager sweep through the outer Solar System is of worlds whose placid and lonely vigils are spasmodically interrupted by catastrophes from space -- and of worlds reforming from rings and other debris, ~~rising~~ reconstituting themselves like phoenixes from their own ashes.

The biggest moon in the Neptune system is called Triton. It has an atmosphere, somewhat similar to Titan's; but, because the atmosphere and haze are much thinner, we can see Triton's surface. We find a wondrously variegated landscape. This is a world of ice -- methane ice, nitrogen ice, probably underlain by more familiar water ice and rocks. There are impact basins, which seem to have been flooded by the liquefied ice before refreezing; impact craters; long crisscrossing valleys; vast fields of freshly fallen snow; puckered terrain that resembles the skin of a cantaloupe; and more or less parallel, long, dark streaks that seem to have been blown by the wind, despite the thinness of Triton's atmosphere (about 1/10,000th ~~thinner than~~ the thickness of the Earth's atmosphere).

In some places the snow is as bright and white as freshly fallen Antarctic snows (and may offer a skiing experience unrivaled in all the Solar System). Elsewhere there is a tint to the snows, ranging from pink to brown. Here is one possible explanation: Freshly fallen snows of nitrogen, methane, and simple hydrocarbons are irradiated by ultraviolet light from the distant Sun and by electrons trapped in the magnetic field of Neptune, through which Triton plows. We know from experiments in our laboratory at Cornell and elsewhere that such irradiation will convert the snows to complex, dark, reddish organic sediments -- nothing alive, but composed of some of the same molecules that were involved in the origin of life on Earth some 4 billion years ago.

In local winter, the snows fall from the sky just as on Earth (although our winters, mercifully, are about 25 times shorter). Through the spring, they are slowly transformed, more and more reddish organic molecules building up in them. By summertime, the snows have evaporated and migrated halfway across the planet to the winter hemisphere. But the reddish, organic molecules do not vaporize and are not transported -- they are covered over by new snows, irradiated, and the next summer there is more and darker lag deposit. As time goes on, substantial amounts of organic matter are built up on the surface of Triton, which probably accounts for its variegated color markings.

The streaks begin in small, dark source regions, perhaps when the warmth of spring and summer heats the volatile snows below the surface. These vaporize and come pouring out like geysers, blowing off the less-volatile surface snows and dark organics. Winds at very low speeds carry the dark organics downwind to create the streaks.

Our understanding of Triton is in its earliest stages, but it seems very clear that we see, all jumbled together on the same world, a record of a tumultuous last 4 ~~changes occurring on time scales between centuries and~~ billion~~s~~ ~~of~~ years.

* * *

The <u>Voyager</u> spacecraft are bound for the stars. They are on escape trajectories from the Solar System, barrelling along ~~At~~ at almost a million miles a day, ~~they are speeding toward the stars~~. The gravitational fields of Jupiter, Saturn, Uranus, and Neptune have flung them at such high velocities that they are destined ultimately break the Sun's hold on them ~~to leave the Solar System~~ altogether. Have they left the Solar System yet? It depends very much on how you define the boundary of the Sun's realm ~~Solar System~~. If it's the orbit of the outermost good-sized ~~big~~ planet, then the <u>Voyager</u> spacecraft are already long-gone ~~have left the Solar System~~; there are no Neptunes ~~that lie~~ undiscovered. If we mean the outermost planet, it may be that there are other planets far beyond Neptune and Pluto; if so, <u>Voyager</u> <u>1</u> and <u>Voyager</u> <u>2</u> are still within the Solar System. If you define the outer limits ~~boundary~~ of the Solar System as the heliopause -- where the wind from the Sun gives way to the wind from the stars -- then <u>Voyager</u> has not yet left the Solar System, although it may do so in the next few decades. But if your definition of the edge of the Solar System is the place where the Sun's gravity can no longer hold worlds in orbit about it, then the *Voyagers* will not leave the Solar System for millennia.

Weakly held by the Sun's gravity in every direction in the sky, is ~~a great~~ an immense horde of trillions of comets, in what astronomers call the Oort Cloud. *Voyager* will not pass through the Oort Cloud for another 20,000 years. Then, at last, broken free of the gravitational shackles that bind her to the Sun, completing her long goodbye to the Solar System, *Voyager* will make for the open sea of interstellar space. Only then will Phase 2 of her mission begin.

These spacecraft will wander for ages in the calm, cold blackness of interstellar space -- where, it turns out, there is essentially nothing to erode them ~~no erosion~~. Once out of the Solar System, the surfaces of the spacecraft will remain intact for a billion years or more, as the *Voyagers* circumnavigate the center of the Milky Way galaxy.

We do not know whether there are other spacefaring civilizations in the Milky Way. And if they do exist, we do not know how abundant they are. But there is at least a chance that some time in the remote future one of the *Voyagers* will be intercepted and examined by an alien craft.

As each *Voyager* left Earth for the planets and the stars, it carried along with it a golden phonograph record encased in a golden, mirrored jacket containing, among other things: greetings in 5~~8~~9 human languages and one whale language; a 12-minute sound essay including a kiss, a baby's cry, and an EEG record of the meditations of a young woman in love; 116 pictures, digitally encoded, on our science, our civilization, and ourselves; and 90 minutes of the Earth's greatest hits -- Eastern and Western, classical and folk, including a Navajo night chant, a Pygmy girl's initiation song, a Peruvian wedding song, a Japanese *shakuhachi* piece, Bach, Beethoven, Mozart, Stravinsky, Louis Armstrong, and Chuck Berry's ~~singing~~ "Johnny B. Goode."

Space is so empty that there is virtually no chance that *Voyager* will ever enter another solar system, even if every star in the sky is accompanied by planets. The instructions on the record jackets, written in what we believe to be readily comprehensible scientific hieroglyphics, can be read, and the contents of the records understood, only if alien beings, somewhere in the remote future, find *Voyager* in the depths of interstellar space. Since both *Voyagers* will circle the center of the Milky Way Galaxy essentially forever, there is plenty of time for the records to be found -- if there's anyone out there to do the finding.

We cannot know how much of the records they would understand. The hypothetical aliens are bound to be very different from us -- independently evolved on another world. Are we really sure they could understand our message? Every time I feel these concerns stirring, though, I reassure myself: Whatever the incomprehensibilities of the Voyager record, any extraterrestrial that finds it will have another standard by which to judge us. Each Voyager is itself a message. In their exploratory intent, in the lofty ambition of their objectives, in their utter lack of intent to do harm, and in the brilliance of their design and performance, these robots speak eloquently for us.

But being much better scientists and engineers than we -- otherwise they would never be able to find and retrieve the silent spacecraft in interstellar space -- perhaps they would have no difficulty understanding. Perhaps they would recognize the tentativeness of our society, the mismatch between our technology and our wisdom. Have we destroyed ourselves since launching Voyager, they might wonder, or have we gone on to greater things?

Or perhaps the records will never be intercepted. Perhaps no one in 5 billion years will ever come upon them. Five billion years is a long time. In 5 billion years, everyone we know and love will be gone, all humans will have become extinct or evolved into some other beings, no human artifacts will remain on Earth, the continents will have been unrecognizably altered or destroyed, and the Earth itself will have been reduced by the evolution of the Sun to a charred cinder.

Far from home, untouched by these ~~distant~~ remote events, the Voyagers, preserving the songs of a world that is no more, will fly on.

* * *

[Box:]

"Go, Voyager, Go!"

[Italics:] On Sunday, August 27, 1989, just after Voyager 2 had successfully encountered the Neptune system, the scientists and engineers at JPL were given a "wrap party." Chuck Berry, one of the fathers of rock 'n' roll and the only living American composer to be represented on the Voyager Interstellar Record, performed a rousing rendition of "Johnny B. Goode" on the grand steps of Building 180, JPL's administrative hub. ~~At the same party, organized by Ann Druyan and The Planetary Society,~~ I ~~gave the~~ was pleased to provide the warm-up for Mr. Berry with the following "Benediction for Voyager 2": [end of italics]

Every human culture has its rites of passage. They mark the transition from one stage of life to another. We are gathered here to celebrate Voyager's rite of passage. A machine designed, built, and operated here at the Jet Propulsion Laboratory has broken free of the Sun's gravity, explored most of the worlds of the Solar System, and is now on its way to the great, dark ocean of interstellar space. It carries a phonograph record of greetings, pictures, and the world's great music to any beings who might encounter it there.

The men and women responsible are gathered here. You are heroes of human accomplishment. Your deeds will be remembered in the history books. Our remote descendants may live on some of the worlds first revealed to us by Voyager. If so, they will look back on you as we used to look back on Christopher Columbus.

Voyager left a planet blighted and imperiled by nuclear weapons, climatic change, poverty, and injustice. The species that launched her was a danger to itself. But Voyager has given us a stirring cosmic perspective. We have seen evidence of the destruction and reconstitution of worlds. We have witnessed the early building blocks of life assembling themselves. But we have not found a trace, not a hint, of life itself. Voyager reminds us of the rarity and preciousness of what our planet holds, of our responsibility to preserve life on Earth.

If we are capable of such grand, long-term, benign, visionary, high-technology endeavors as Voyager, can we not use our technological gifts and long-term vision to put this planet right?

Perhaps the Neptune fly-by marks not just Voyager's rite of passage but the beginning of our own: the binding up of the peoples and nations and generations to take care of one another, to cherish the Earth, and bravely to venture forth -- in the footsteps of Voyager -- to the planets and the stars.

[2A, 2/20/93]

The Skies of Other Worlds

The blue of a cloudless May morning, the reds and oranges of a sunset at sea have roused humans to wonder, to poetry, and to science. No matter where on Earth we live, no matter what our language, customs, or society, we share a sky in common. Most of us <u>expect</u> that cerulean blue and would be stunned to wake up one sunrise to find a cloudless sky that was black or green. (Inhabitants of Los Angeles and Denver recently have grown accustomed to brown skies, and the citizens of Seattle and Buffalo have long been used to gray ones -- but even they still consider blue to be the planetary norm.)

And yet there <u>are</u> worlds with black or green skies, and the color of the sky characterizes the world. Plop me down on any planet in the Solar System, let me -- without sensing the gravity, without glimpsing the ground -- take a quick look at the Sun and sky, and I can pretty much tell you where I am. That familiar shade of blue, interrupted here and there by fleecy white clouds, is a signature of our world. If there ever is a true flag of Earth, this should be its color.

Birds fly through it, clouds are suspended in it, humans admire and routinely traverse it at almost the speed of sound. Light from the Sun and stars flutters through it. But what <u>is</u> the sky? What is it made of? How much of it is there? Where does all that blue come from? If it is a commonplace for all humans, if it typifies our world, surely we should know something about it. What is the sky?

In August 1957, for the first time, a human being got above the blue and looked around -- when David Simons, a retired Air Force officer and physician, became the highest human in history. He piloted a balloon to an altitude of over 100,000 feet (30 kilometers) and through his windows glimpsed a different sky. Now a professor at the University of California Medical School in Irvine, Dr. Simons recalls a dark, deep purple sky. He had reached the transition region in the atmosphere where the blue of ground level is being overtaken by the perfect black of space.

Since Simons' almost forgotten flight, people of many nations have flown above the atmosphere. It is now clear from repeated and direct human (and robotic) experience that in space the daytime sky is black. The Sun shines brightly on your spaceship. The Earth below you is brilliantly illuminated. But the sky above is black as night.

Clearly, the daylight sky -- all that blue -- is somehow connected with the air. If you look more closely at the Earth from space, you see it surrounded by a thin band of blue. It's as thick as the lower atmosphere; indeed, it <u>is</u> the lower atmosphere. At the top of that band you can see the sky fading into the blackness of space. This is the transition zone that Simons entered.

We see the blue in daylight because sunlight is bouncing off the air around and above us. On a cloudless and moonless night, the sky is black because there is no sufficiently intense source of light to be reflected off the air. Somehow, the air preferentially bounces blue light down to us. How?

The light from the Sun comes in many colors -- violet, blue, green, yellow, orange, red, corresponding to light of different wavelengths. (A wavelength, we recall, is the distance from crest to crest as the wave travels through air or space.) Violet and blue light have the shortest wavelengths; orange and red light have the longest wavelengths. What we perceive as color is how our eyes and brains read the wavelengths of light. (We might just as naturally read wavelengths of light as, say, heard musical tones rather than seen colors -- but that's not how our senses evolved.)

When all those rainbow colors of the spectrum are mixed together, as in sunlight, they seem almost white. These different wavelengths travel together in 8 minutes across the intervening 93 million miles (150 million kilometers) of space between the Sun and Earth. The lightwaves hit the atmosphere, which is made mostly of nitrogen and oxygen molecules. Some waves are reflected by the air back into space, and some are bounced around in the air before the light reaches the ground, where they can be detected by a passing eyeball. This bouncing around of lightwaves in the atmosphere is called "scattering."

But not all waves are equally scattered by the molecules of air. Wavelengths that are much longer than the size of the molecules are scattered less. Wavelengths that are closer to the size of the molecules are scattered more. (You can see the same thing in water waves scattered by the pilings of piers). The shorter wavelengths -- those that we sense as violet and blue light -- are more efficiently scattered than the longer wavelengths -- those that we sense as orange and red light. When we look up on a cloudless day and see the blue sky, we are witnessing the preferential scattering of the short waves in sunlight. This is called Rayleigh scattering, after the English physicist who offered the first coherent explanation of it. Cigarette smoke is blue for just the same reason: The particles that make it up are about as small as the wavelength of blue light.

The red of the sunset is what's left of sunlight after the blue is scattered away. Since the atmosphere is a thin shell of gas surrounding the solid Earth, sunlight must pass through a longer path of air at sunset (or sunrise) than at noon. Since the violet and blue waves are scattered even more efficiently during their now-longer path through the air, what we see when we look toward the Sun are the other waves of sunlight -- the ones not efficiently scattered -- especially the oranges and reds. A blue sky makes a red sunset. (The Sun at noon seems yellowish partly because it puts out slightly more yellow light, and partly because some blue light is scattered out of the sunbeams.)

It is sometimes said that scientists are unromantic, that their passion to figure out robs the world of beauty and mystery. But is it not stirring to understand how the world actually works -- that white light is made of colors, that color is the way we perceive ~~measures~~ the ~~length~~ wavelength of light, ~~lightwaves~~, that transparent air reflects light, that in so doing it discriminates among the waves, and that the sky is blue for the same reason that the sunset is red? It does no harm to the romance of the sunset to know a little bit about it.

Since most simple molecules are about the same size (roughly a hundred millionth of an inch), the blue of the Earth's sky doesn't much depend on what the air is made of -- as long as the air doesn't <u>absorb</u> the light. Oxygen and nitrogen molecules don't absorb visible light; they only bounce it away in some other direction. But other molecules gobble up the light. Oxides of nitrogen -- produced in automotive engines and in the fires of industry -- are a source of the murky brown coloration of smog. Oxides of nitrogen (made from oxygen and nitrogen) <u>do</u> absorb light. Absorption, as well as scattering, can color a sky.

So now let's take a quick survey of the daytime skies of some other worlds in our Solar System. The planet Mercury, the Earth's Moon, and many other natural satellites going around the planets are <u>small</u> worlds; and, with little gravity, they are unable to retain their atmospheres -- which instead trickle off into space. The near vacuum of space then reaches the ground.

Light from the Sun strikes their surfaces unimpeded, neither scattered nor absorbed along the way. Their skies are black, even in full daylight. In the Solar System, all moons have black skies (except Titan of Saturn and perhaps Triton of Neptune, which are big moons with atmospheres), and all asteroids as well.

Venus has about 100 times more air than Earth. The air isn't mainly oxygen and nitrogen as here -- it's carbon dioxide. But carbon dioxide doesn't absorb visible light either. What would the sky look like from the surface of Venus if Venus had no clouds? With so much atmosphere in the way, not only would violet and blue waves be scattered but all the other colors as well -- green, yellow, orange, red. But the air is so thick that blue light never makes it to the ground; it is scattered back by successive bounces higher up. Thus, the light that does reach the ground should be strongly reddened -- like an Earth sunset all over the sky. Sulfur in the high clouds will slightly yellow this color. Pictures taken by the Soviet _Venera_ landers confirm that the skies of Venus are orange.

Mars is a different story. It is a smaller world than Earth, with a much thinner atmosphere. In fact, the pressure at the surface of Mars is about that at the altitude in the Earth's stratosphere to which Simons rose. So we might expect the Martian sky to be purple-black. The first color picture from Mars was obtained by the American _Viking 1_ lander in July 1976 -- the first spacecraft successfully to touch down on the surface of the Red Planet. The digital data were dutifully radioed from Mars back to Earth, where the color picture was assembled by computer. To the surprise of all the scientists and nobody else, the first picture released showed the Martian sky to be a comfortable, homey blue -- impossible for a planet with so insubstantial an atmosphere. Something had clearly gone wrong.

The picture on your color television set is a mixture of three monotone images, each in a different color of light -- red, green, and blue. To get the right color, you or your set needs to mix or balance these three images correctly. If you turn up the intensity of, say, blue, the picture will eventually appear too blue. Any picture returned from space requires similar color balance. Considerable discretion is sometimes left to the computer analysts in deciding this balance. The *Viking* analysts were not planetary astronomers, and with this first color picture from Mars they simply mixed the colors until it looked "right." We are so conditioned by our experience on Earth that "right," of course, means a blue sky. The color of the picture was soon corrected -- under the supervision of James B. Pollack of NASA's Ames Research Center, using color calibration standards onboard the spacecraft -- and the resulting picture showed no blue sky at all but rather something between ochre and pink. Again, hardly purple-black. [Duplicate of *Cosmos*?]

But this *is* the right color of the Martian sky. Much of the surface of Mars is desert -- and red because the sands are rusty.

There are occasional violent sandstorms, which lift fine particles from the surface high into the atmosphere. It takes a long time for the particles to fall out, and before the sky has cleaned itself, there is another sandstorm. Since rusty particles are always suspended in this sky, future generations of humans, born and living out their lives on Mars, will consider that salmon color to be as natural and familiar as we consider our homey blue. (And, from a single glance at the sky, they'll probably be able to tell how long it has been since the last big sandstorm.)

The planets in the outer part of the Solar System -- Jupiter, Saturn, Uranus, and Neptune -- are of a different sort. These are huge worlds with giant atmospheres made mainly of hydrogen and helium. Their solid surfaces are so deep inside that no sunlight penetrates there at all. Down there, the sky is black, but with no promise of a sunrise -- a perpetual starless night, perhaps illuminated on occasion by a bolt of lightning. But higher in the atmosphere, where the sunlight reaches, a much more interesting vista awaits. On Jupiter, above a high-altitude haze layer composed of ammonia (rather than water) ice particles, the sky is blue-black. Farther down, in the blue sky region, are gorgeous multicolored clouds of unknown composition. (The candidate materials include sulfur, phosphorus, and complex organic molecules.) Still farther down, the sky will appear red-brown, except that these clouds are of varying thickness, and

1,10

[4-3-93.atp]

Insert P into "Skies of Other Worlds," last page (p. 9): Uranus and especially Neptune have an uncanny, austere blue color through which clouds -- some of them a little whiter -- are carried by high-speed winds on these worlds.

✓ 1,10

[4-3-93.atp]

Insert Q into "Skies of Other Worlds," last page (p. 9): The conventional understanding is that the absorption by methane and the scattering of sunlight by the deep atmosphere accounts for the blue colors on these planets. But recent analyses of Voyager data show these causes to be insufficient. Apparently very deep -- maybe in the vicinity of the hypothesized clouds of hydrogen sulfide -- there is an abundant blue substance. So far no one has been able to figure out what it might be. Again, blue materials are quite rare in Nature. As always happens in science, as the old mysteries are dispelled, new ones arise. But sooner or later we'll find out the answer to this one, too.

Balnes: blue chromophore?

where they are very thin, you might see a patch of blue. Still deeper, we approach perpetual night. Something similar is true on Saturn, but the colors there are much more muted.

Insert P ~~At Uranus,~~ sunlight reaches a comparatively clean atmosphere composed mainly of hydrogen and helium but also rich in methane. Long paths of methane absorb yellow and especially red light and let the green and blue light filter through. A thin hydrocarbon haze removes a little blue. Insert Q ~~So the skies of Uranus are blue-green. At Neptune, the colors are similar, but deeper~~.

It is now almost possible to assign color combinations -- based on the hues of clouds and sky -- to every planet in the Solar System. Perhaps they will one day adorn the flags of distant human outposts, when the new frontiers are sweeping toward the stars.

[2A, 2/20/93]

Volcanos of Other Worlds

All over the world, you can find a kind of mountain with one striking and unusual feature. Any child can recognize it: The top seems ~~squared~~ sheared off. If you climb to the summit or fly over it, you discover that the mountain has a hole or crater at its peak. In some mountains of this sort, the craters are small; in others, they are almost as large as the mountain itself. Occasionally, the craters are filled with water. Sometimes they're filled with a more amazing liquid: You tiptoe to the edge, and see vast, glowing lakes and fountains of fire within the crater interior. These holes in the tops of mountains are called calderas, after the word "caldron," and the mountains on which they sit are known, of course, as volcanos, after Vulcan, the Roman god of fire.

A typical volcanic mountain looks safe enough. Vegetation runs up its sides. Hamlets or shrines nestle at its base. Terraced fields may decorate its flanks. And yet, without warning, after centuries of lassitude, the mountain may explode and rivers of molten rock come pouring down its sides. The eruptions of Mt. St. Helens or Mt. Pinatubo are recent reminders, but examples can be found throughout history. In 1902, a hot, glowing volcanic cloud swept ~~off~~ down the slopes of Mt. Pelée and killed 30,000 people in the city of St. Pierre in the Caribbean island of Martinique. The eruption of Mt. Vesuvius in the first century buried in ash the hapless inhabitants of Pompeii and Herculaneum and killed the intrepid naturalist Pliny the Elder as he ~~set out to explore its mysteries~~ made his way up the side of the volcano, intent on arriving at a better understanding of its inner workings. The Mediterranean island of Santorini is in reality the only part above water of the rim of a volcano now inundated by the sea. The explosion of the Santorini volcano in the late fifteenth century B.C. may, some think, have destroyed the great Minoan civilization on the nearby island of Crete and changed the balance of power in early classical civilization.

Really major volcanic explosions can punch enormous quantities of matter -- mainly fine droplets of sulfuric acid -- into the stratosphere. There, they reflect sunlight back to space and cool the Earth. This has happened recently with Mt. Pinatubo, and disastrously in 1815-16 after the eruption of the Indonesian volcano Mt. Tambora, which resulted in the ~~disastrous~~ famine-ridden "year without a summer." Studies of volcanic effects on the climate have led to the discovery of nuclear winter and provide important tests of our ability to use sophisticated computer models to predict future climate change.

Volcanos have naturally been regarded with fear and awe. When medieval Christians viewed the eruption of Mt. Hekla in Iceland and saw churning fragments of soft lava suspended over the volcano, they imagined they were seeing the souls of the damned awaiting entrance into Hell. Indeed, the glowing red lakes and sulfurous gases within the summit caldera of Hekla were once thought to be a real glimpse into the underworld and a confirmation of folk beliefs in Hell (and, its concomitant ~~by symmetry~~, in

/ 1, 11

[4-3-93.atp]

Insert P into "Volcanos of Other Worlds," revision 2A, p. 3: Once the volcano is fully built, the molten lava no longer spewing up into the caldera, then it becomes just like any other mountain, slowly eroding because of rainfall and windblown debris and, eventually, the movement of continental plates across the Earth's surface. "How many years can a mountain exist before it is washed to the sea?" asked Bob Dylan in the ballad "Blowing in the Wind." The answer depends on which planet we're talking about. For the Earth, it's about ten million years.

Heaven).

A volcano is, in fact, an aperture to an underground ~~land~~ realm much vaster than the surface of the Earth -- and far more hostile. The lava that erupts from a volcano is liquid rock -- rock raised to its melting point, generally around 1000°C. The lava emerges from a hole in the Earth; as it cools and solidifies, it generates and then remakes the flanks of a volcanic mountain. This observation implies that the interior of the Earth is extremely hot. Indeed, seismic evidence shows that, only a few hundred kilometers beneath the surface, the entire Earth is at least slightly molten. The interior of the Earth is hot, in part, because radioactive elements there, such as uranium, give off heat as they decay; and partly because the Earth retains some of the original heat formed in its formation, when many small worlds fell together by their mutual gravity to make the Earth.

The molten rock, or magma, rises through fissures in the surrounding heavier solid rocks. We can imagine vast subterranean caverns filled with glowing, red, hot, bubbling, viscous liquids that shoot up toward the surface if a suitable channel is by chance provided. The magma, called lava as it pours out of the summit caldera, does indeed arise from the underworld.

Insert P

In November 1971, NASA's Mariner 9 arrived at Mars to find the planet completely obscured by a global dust storm. Almost the only features to be seen on Mars were four circular spots rising out of the reddish murk. But there was something peculiar about them: They had holes in them. As the storm cleared, we were able to see quite unambiguously that we had been viewing four huge volcanic mountains penetrating through the dust, each capped by a great summit caldera.

After the storm had dissipated, the true scale of these volcanos became clear. The largest -- appropriately named Olympus Mons, or Mt. Olympus, after the home of the Greek gods -- is more than 25 kilometers (roughly 15 miles) high, dwarfing not only the largest volcanic mountain on the Earth but also the largest mountain of any sort, Mt. Everest, which stands 9 kilometers above the Tibetan plateau. There are about 20 large volcanos on Mars, but none so massive as Olympus Mons, with a volume about 100 times greater than that of the largest volcano on Earth, Mauna Loa in Hawaii.

By counting impact craters (made by small impacting asteroids, and ~~very different~~ readily distinguished from summit calderas) on the flanks of the volcanos, estimates of their ages can be derived. Some Martian volcanos turn out to be a few billion years old, although none dates back to the very origin of Mars, about 4.5 billion years ago. But some, including Olympus Mons, are comparatively ~~youngsters~~ new -- perhaps only a few hundred million years old. It is clear that enormous volcanic explosions occurred early in Martian history, providing, perhaps, an atmosphere much denser than the one Mars holds today. What would the planet have looked like if we could have visited it then?

It is, I suppose, even possible -- although there is no evidence either way -- that Olympus Mons, the largest volcano we know about for certain in the Solar System, will again one day be active. Volcanologists, a patient sort, would doubtless welcome the event.

In 1990-92 [check] the Magellan spacecraft returned astonishing data about the landforms of Venus. In a near-polar orbit, Magellan's radar waves penetrated the cloud, reached the surface, reflected back to space, and were recorded by Magellan before the data were relayed back to Earth. From these data, maps of almost the entire planet, with resolutions better [check] than 1 kilometer, were obtained. Much of the geology of Venus is unlike anything seen on Earth or anywhere else. Planetary geologists give these landforms names, but that doesn't mean we understand how they're formed.

The surface temperature of Venus is almost 470°C (900°F) -- which means that the rocks on Venus are much closer to their melting points than are the rocks at the surface of the Earth. The ~~temperature boost you~~ additional heat that must ~~give~~ be provided from below to melt surface rocks is much less than on Earth. Although some large volcanic forms seem to have been discovered, the entire surface of Venus is, in a sense, volcanic terrain -- formed from molten rock. (But you could also say this about the Earth, because a mighty

[3-23-93.atl]

Insert B into "Volcanos of Other Worlds":

¶ The surface of Venus as revealed by <u>Magellan</u> ~~was~~ is very young. There are so few impact craters that everything older than about 500 million years must have been wiped out~~.~~ -- on a planet 4.5 billion years old. There is only one plausible agent of erosion: vulcanism. All over the planet there are craters, mountains, and other geological features that have been ~~inundated~~ swamped by seas of lava that well~~ing~~ up from the inside, ~~inundating pre-existing features~~ and then freez~~ing~~e solid. Some scientists believe that until about 500 million years ago the surface of Venus was almost entirely devoid of any landforms. Streams and oceans of molten rock were pouring out of the interior all over the planet, filling in and covering over all relief. Had you plummeted down through the clouds in that ancient time, the surface would have been pretty uniform and featureless. ~~at~~ At nighttime the landscape would have been eerily glowing ~~everywhere~~ from the red heat of molten lava. In this view the great internal heat engine of Venus, which supplied copious amounts of magma to the surface until about 500 million years ago, has now turned off. The heat engine has run down.

plate tectonic engine has formed the continents out of the near-molten interior [check].)

Insert B

Even more unexpected than the great Martian volcanos or the surface of Venus is what awaited us when the _Voyager 1_ spacecraft encountered Io, the innermost of the four large moons of Jupiter, in March 1979. There we found a strange, small, multicolored world positively awash in volcanos. As we watched in astonishment, eight active plumes poured gas and fine particles up into the sky. The largest, now called Pele, projected a fountain of material 300 kilometers into space. By the time _Voyager 2_ arrived at Io, four months later, Pele had turned itself off, but six of the other plumes were still active, at least one new plume had been discovered, and another caldera, named Surt, had changed its color dramatically.

The colors on the surface of Io, even though exaggerated in NASA's color-enhanced images, are like none elsewhere in the Solar System. The currently favored explanation is that the volcanos of Io are driven not by upwelling molten rock, as on the Earth, but by upwelling sulfur dioxide and molten sulfur. Various forms and compounds of sulfur have indeed been detected on the surface of Io and in nearby space -- the volcanos blow some of the sulfur off Io altogether. These findings have suggested to some an underground sea of liquid sulfur that issues to the surface at points of weakness, generates a shallow volcanic mound, trickles downhill, and freezes, its final color determined by its temperature when it erupted.

There are places on Mars that have changed very little in a billion years. On Io, in a century, much of the surface will be reflooded, filled in or washed away by new volcanic flows. Maps of Io become quickly obsolete.

A volcano, in one sense, represents the insides of a planet gushing out, a wound that eventually heals itself by cooling. But different worlds have different insides. The discovery of liquid-sulfur vulcanism on Io was a little like finding that an old acquaintance, when cut, bleeds green blood. You had no idea such differences were possible. We are naturally eager to find additional signs of vulcanism on other worlds. On Europa, the second of the large moons of Jupiter, while there are no volcanic mountains at all, molten ice -- liquid water -- seems to have gushed to the surface through an enormous number of crisscrossing dark markings before freezing. The satellite's <u>surface</u> temperature is near -150°C, the Sun being 25 times dimmer at Europa than at Earth. Among the moons of Saturn, we have seen signs that liquid water has gushed up from the interior, wiping away impact craters, although we have never seen anything that might plausibly be an ice volcano in either the Jupiter or Saturn systems.

The volcanos of other worlds provide a stirring spectacle. They enhance our sense of wonder, our joy in the beauty and diversity of the cosmos. But these exotic volcanos perform another service as well: They help us to understand better the volcanos of our own world. When we discover vast volcanic eminences on a geologically quiet Mars; when we find an object melted not by the heat of radioactive decay, as on Earth, but by gravitational tides exerted by nearby worlds; when we find sulfur rather than silicate vulcanism; and when we begin to wonder, out in the Saturn system, whether we might be viewing a kind of water or ammonia vulcanism -- then we are learning what else is possible. Knowing the alternatives is a help if you have any ambition to preserve ~~understand and improve~~ your own neighborhood.

Waves

You're sitting in the bathtub, and the faucet is dripping. Once every second, say, a drop falls into the tub and generates a little wave that spreads out in a circle. You watch as it approaches the sides of the tub, and note that it's reflected back into the water. But now the wave is weaker, and after one or two more reflections, you can't make it out anymore. New waves are arriving at your end of the tub, each generated by another drip of the faucet. The "frequency" of the waves is simply how often they pass your vantage point -- in this case, one wave every second. It's the same as the drip rate. The "wavelength" of the waves is simply the distance between successive wave crests -- in this case, maybe [check] 10 centimeters (about 4 inches). But if a wave passes every second, and they are ten centimeters apart, the speed of the waves is 10 centimeters per second. The speed of a wave, you conclude, is the frequency times the wavelength.

Bathtub waves and ocean waves are two-dimensional waves; they spread out as circles on the surface of the water. Sound waves, on the other hand, are three-dimensional waves, spreading out in the air in all directions from the source of the sound. In the wave crest, the air is compressed a little; in its wake, the air is a little less dense. Your ear detects these waves. The more often they come (the higher the frequency), the higher is the pitch you hear.

Musical tones are only a matter of how often the sound waves strike your ears. Middle C is how we describe 263 sound waves reaching us every second. What would be the wavelength of Middle C? If sound waves were directly visible, how far would it be from crest to crest? At sea level, sound travels at about 340 meters per second (about 700 miles per hour). Just as in the bathtub, the wavelength will be the speed of the wave divided by its frequency, or about 1.3 meters for Middle C -- the height of a ten-year-old [check].

The human ear is not a perfect detector of sound waves. There are frequencies (fewer than 20 waves arriving per second) that are too low for us to hear, although whales communicate readily with such low tones. Likewise, there are frequencies (more than 20,000 waves arriving every second) that are too high-pitched for human adults to detect, although dogs have no difficulty (and respond when called by a whistle at such frequencies). There are realms of sound -- a million waves per second, say -- that are, and always will be, unknown to direct human perception. Our sense organs, as superbly adapted as they are, have fundamental limitations.

Light waves are similar to sound waves. They are three-dimensional, have a frequency, a wavelength, and a speed (the speed of light). But, astonishingly, they do not require a medium, like water or air, to propagate in. Light reaches us from the Sun and the distant stars, even though the intervening space is a nearly perfect vacuum. In space, astronauts without a radio link cannot hear each other, even if they are a few centimeters apart. But they can see one another perfectly well. Take away all the air in your room and you will be unable to hear an acquaintance complain about it, although you will have no difficulty seeing him flailing and gasping.

For ordinary visible light -- the kind our eyes are sensitive to -- the frequency is very high, about 600 trillion waves striking your eyeballs every second. [Because the speed of light is 30 billion centimeters a second (186,000 miles per second), the wavelength of visible light is about 0.00005 centimeters -- much too small for us to see if the waves themselves were somehow illuminated.]

Just as different frequencies of sound are perceived by humans as different musical tones, so different frequencies of light are perceived as different colors. Red light has a frequency of about 460 trillion waves per second, and violet light about 710 trillion waves per second. Between them are the familiar colors of the rainbow. Every frequency corresponds to a color. Just as there are sounds too high-pitched and too low-pitched for us to hear, so there are frequencies of light, or colors, outside our range of vision. They extend to much higher frequencies (around a billion billion [I know, I know. I can't help it. That's how many there are.] waves per second for gamma rays) and to much lower frequencies (less than one wave per second for long radio waves). Running through the spectrum of light from high frequency to low frequency are broad swaths called gamma rays, X-rays, ultraviolet light, visible light, infrared light, and radio waves. These are all waves that travel through a vacuum. Each is as legitimate a kind of light as ordinary visible light is. We are prejudiced towards visible light, because that's the only kind of light to which our eyes are sensitive. But if our bodies could transmit and receive radio waves, early humans might have been able to communicate with each other over great distances; if the same were true of X-rays, our ancestors might have peered usefully into the hidden interiors of plants, people, other animals, and minerals. So why didn't we evolve eyes sensitive to these other frequencies of light?

Any material you choose likes to absorb light of certain frequencies, but not others. A different substance has a different preference. There is a natural resonance between light and chemistry. Some frequencies, like gamma rays, are indiscriminately gobbled up by virtually all materials. If you had a gamma ray flashlight, the light would travel about the length of a football field before being mostly absorbed by the air along its path. So gamma rays from space, traversing a much longer path through the Earth's atmosphere, would be entirely absorbed before they reached the surface of the Earth. Down here on Earth, it's very dark in gamma rays. If you want to see gamma rays from the center of the Galaxy, say, you must move your instruments into space. Something similar is true for X-rays, ultraviolet light, and most infrared frequencies.

On the other hand, most materials absorb visible light much less efficiently. Air, for example, is generally transparent to visible light. So one reason we see at visible frequencies is that this kind of light gets through the atmosphere. Gamma ray eyes would be of limited use in an atmosphere which makes things pitch black in gamma rays. Natural selection knows better.

The other reason we see in visible light is because that's where the Sun puts out most of its energy. A very hot star emits most of its energy in the ultraviolet. A very cool star puts out most of its energy in the infrared. But the Sun, in many respects an average star, puts out most of its energy in the visible. Indeed, to remarkably high precision, the human eye is most sensitive at the exact frequency in the yellow part of the spectrum where the Sun is brightest.

Might the beings of some other planet see at some very different frequencies? This seems not at all likely. Virtually all cosmically abundant gases tend to be transparent in the visible and opaque at nearby frequencies. Virtually all stars put out a significant amount, if not most, of their energy at visible frequencies. There might be occasional exceptions, but in general the beings of other worlds will probably see at very much the same frequencies as we do.

Grass absorbs red and blue light, reflects green light, and so appears green to us. We could draw a picture of how much light is reflected at different colors. Something that absorbs blue and reflects red light appears to us red; something that absorbs red light and reflects blue appears to us blue. We see an object as white when it reflects light roughly equally in different colors. But this is also true of gray materials and black materials. The difference between black and white is not one of color, but one of how much light they reflect. The terms are relative, not absolute. Perhaps the brightest natural ~~object~~ material ~~[word?]~~ is freshly fallen snow. But it only reflects about 75 percent of the sunlight falling on it. Perhaps the darkest material that we come into contact with -- black velvet, say -- reflects only a few percent of the light that falls on it. "As different as black and white" is a conceptual error: Black and white are fundamentally the same thing; the difference is only in the relative amounts of light reflected, not in their color. Surprisingly, this fact seems to be commemorated in some languages. "Black" derives from the Anglo-Saxon blaece, and "white" from the nearly identical Anglo-Saxon blac (for example, "bleach," "bleak," "blanch," "blank," and the French "blanc"). [Check not word-for-word from Dragons of Eden.]

White and black are relative terms. Among humans, most "whites" are not as white as a white refrigerator and most "blacks" are not as black as black velvet. The amount of light that human skin reflects (the reflectivity) varies widely from individual to individual. Skin pigmentation is produced mainly by an organic molecule called melanin, which the body manufactures from tyrosine, an amino acid common in proteins. In the United States there are very few people whose skin is actually white or black; almost everyone's skin color is brown, reflecting somewhat more light towards the red end of the spectrum than towards the blue. It makes no more sense to call individuals with high melanin contents "colored" than it does to describe individuals with low melanin contents "bleached." Albinos suffer from a hereditary disease in which melanin is not made; their skin and hair are milky white, and the irises of their eyes are pink. Albino animals are rare in Nature because their skins provide little protection against solar radiation, and because they lack protective camouflage.

It is only at visible and immediately adjacent frequencies that any significant differences in skin reflectivity exist. People of Northern European ancestry and people of Central African ancestry are equally black in the ultraviolet and in the infrared, where almost all organic molecules, not just melanin, absorb much of the light that falls on them. Only in the visible, where many molecules are transparent, is the anomaly of white skin even possible. Over most of the spectrum, all humans are black.

Sunlight is composed of a mixture of waves with frequencies corresponding to all the colors in the visible spectrum. There is slightly more yellow light than red or blue light, which is partly why the Sun looks yellow. All of these colors fall on, say, the petal of a rose. So why does the rose look red? Because all colors other than red are preferentially absorbed in the petal. The mixture of lightwaves strikes the rose and the waves are bounced around helter skelter below the surface of the petal. As with a surface wave in the bathtub, after every bounce the wave is weaker. But blue and yellow waves are absorbed at each reflection more than red waves. The net result after many reflections is that more red light is reflected back to the observer's eye than any other color, and we perceive the beauty of a red rose. In blue or violet flowers exactly the same thing happens, except now red and yellow light is preferentially absorbed after the multiple reflections and blue or violet light is preferentially reflected.

There's a particular organic pigment responsible for the absorption of light in such flowers as roses and violets. It's called anthocyanin. Remarkably, a typical anthocyanin is red when placed in acid, blue when placed in an alkaline solution, and violet when placed in water. Thus, roses are red because they contain anthocyanin and are slightly acid; violets are blue because they also contain anthocyanin and they are not acidic. (I've been trying to use these facts in a bit of doggerel, but with no success.)

Blue pigments are generally rare in nature. The rarity of blue rocks on Earth, and blue surface material on other planets, is an illustration of this fact. Blue pigments have to be fairly complicated; the anthocyanins are composed of about 20 atoms heavier than hydrogen arranged in a particular pattern.

The major evolutionary reason for the coloration of flowers is to attract pollinating insects. The colors of the rose and the violet are there for sexual reasons. But not all the action is going on in the visible part of the spectrum, because pollinating insects -- bees, for example -- are also sensitive at ultraviolet frequencies where humans cannot see. In the near-ultraviolet, many flowers have garish patterns to attract insects -- the equivalent of signs saying "free eats" or "bees welcome." [Duplicated?]

Living things have inventively put color to use -- to absorb sunlight and, through photosynthesis, to make food out of air and water; to remind mother birds where the gullets of their fledglings are; to interest a mate; to attract a pollinating insect; for camouflage and disguise; and, at least in humans, out of a delight in beauty. But all this is possible only because of the physics of stars, the chemistry of air, and the elegant machinery of the evolutionary process which has brought us into such superb harmony with our physical environment.

[2A, 2/20/93]

The Man in the Moon

Today we know the Moon as a place, a small world, rocky, cratered, airless, and waterless, that has actually been trod by humans. But for most of history -- before spacecraft, before telescopes, before we had begun to emerge from magical thinking -- the Moon was an enigma with a function. (In an old Persian story, a wise man is asked which is more useful, the Sun or the Moon. "The Moon," he answers, "because the Sun shines in the daytime, when it's light out anyway.") The Moon's waxing and waning -- from crescent to full to crescent to new -- was widely understood as a celestial metaphor of death and rebirth. It was connected with the reproductive cycle of women, which has very closely the same period -- as the word "menstruation" (Latin <u>mensis</u> = month) reminds us. Almost no one knew that the Moon was a world.

What do we actually see when we look up at the Moon with the naked eye? We see a configuration of irregular bright and dark markings -- not a close representation of any familiar object. However, if we examine world myth and folklore, we find many images ~~imagined to exist~~ seen in the Moon: a woman weaving, an elephant jumping off a cliff, a girl with a basket on her back, a rabbit, a woman pounding tapa cloth.

But the most common image by far is the Man in the Moon. ~~whose~~ The associated folklore depicts the Moon ~~not~~ as something not mysterious, but ~~rather as something~~ prosaic. In children's books and elsewhere, the Man in the Moon is often drawn simply as a face set in a circle, not too different from the bland "happy face" of two dots and an upturned arc. ~~that one sees on metal buttons distributed by corporations seeking to improve their public image.~~ You need only look up at night, though, to see that there is little similarity to a face.

Consider the two regions of the Moon that we see with the naked eye. One is the brighter forehead, cheeks, and chin; the other is the darker eyes and mouth. The former -- when we examine it to much higher precision than we possibly can with the naked eye -- turns out to be the ancient, cratered highlands, dating back to almost 4.5 billion years. The dark features are younger flows of basaltic lava that welled up a few hundred million years after the Moon was formed, many of them as a result of the impacts of enormous asteroids or comets. The Man in the Moon is in fact a record of ancient catastrophes -- all of which occurred before humans, before mammals, before vertebrates, and possibly before life on Earth. It is a characteristic conceit of our species to put a human face on random cosmic violence.

But why should cultures all over the world, probably for most of human history, put a man in the Moon when there is none there?

Humans, like other primates, are a gregarious lot. We enjoy one another's company. We're mammals, and parental care for the young is essential for the continuance of the species. Infants readily recognize human faces soon after birth. The parent smiles at the child, the child smiles back, and an essential bond is enhanced. By the time we grow up, we have seen an enormous number of faces and are keenly attuned to them.

But this has an inadvertent consequence, because the pattern-recognition machinery in our brains is so efficient in extracting a face from a clutter of other details that we sometimes see faces where there are none. We assemble disconnected patches of light and dark and unconsciously <u>try</u> to see a face. The Man in the Moon is one result. There are many others.

Sometimes it's a geological formation, such as the Old Man of the Mountain in New Hampshire. We recognize that this is not some supernatural sculpture but the consequence of erosion and collapse of a rock face. Anyway, it doesn't look much like a face anymore.

Occasionally, a vegetable or a pattern of wood grain or the hide of a cow resembles a human face. There is a celebrated eggplant that closely resembles Richard Nixon (see illustration). But few of us deduce from this divine or extraterrestrial intervention. We recognize that there are large numbers of eggplants in the world and that, if there are enough of them, sooner or later we will come upon one that looks a little like a human face.

When the face is of a religious personage -- as, for example, a tortilla purported to exhibit the face of Jesus (see illustration) -- believers tend to deduce the hand of God. ~~then there is usually a pause before pronouncing judgment.~~ Still, it seems unlikely that a miracle is being worked on so evanescent a medium, and, considering how many tortillas have been pounded out since the beginning of the world, it would be surprising if a few didn't have ~~look~~ vaguely familiar features. (These cases are very different from that of the so-called Shroud of Turin, which shows something too close to a human form to be a natural object misapprehended and which is now proved to be not the death shroud of Jesus, but a pious hoax from the fourteenth century, a time when the manufacture of fraudulent religious relics was a thriving home handicraft industry.)

In our day, the most arresting of such discoveries accompany the spacecraft exploration of other worlds. Around the time of the Apollo lunar landings, many non-experts -- amateur astronomers, flying saucer zealots, and writers for aerospace magazines -- pored ~~[3/18/93: correct spelling sic (assuming Amer. Her. Dict. remains our arbiter)]~~ over the photographs, searching for anomalies that NASA scientists and astronauts had overlooked. Soon there were reports of enormous Latin letters and Arabic numerals inscribed on the lunar surface, pyramids, highways, crosses, glowing UFOs, and, it was ominously asserted, the long shadows of ballistic missiles, probably Soviet, aimed at Earth. All have turned out to be natural lunar geological formations misunderstood by the analysts, internal reflections in hand-held cameras, and the like.

The experience provides fair warning that, for a complex terrain sculpted by unfamiliar processes, amateurs examining photographs at the very limit of resolution may be in trouble. Their hopes and fears, the excitement of possible discoveries of great import, may overwhelm the usual skeptical and cautious approach of science.

Venus is a world with a stifling, scorching, poisonous atmosphere entirely obscured by clouds. If we examine the available surface images, an occasional peculiar landform will swim into view -- as, for example, a portrait of Joseph Stalin discovered by American geologists analyzing Soviet orbital radar imagery (see illustration). No one maintains, I gather, that unreconstructed Stalinists had doctored the magnetic tapes or that the former Soviets were engaged in engineering activities of unprecedented and hitherto unrevealed scale on the surface of Venus -- where every spacecraft to land has been fried in an hour. The chances are overwhelming that this feature, whatever it is, is due to geology and not to biology or engineering.

Mars is a magnificent world, exhibiting vast volcanic mountains, ancient river valleys, and stacked plates in the polar regions resembling a pile of discarded poker chips. It is much more clement than Venus, although the Viking landers provided no compelling evidence for life on Mars. With 100,000 available photographs, it is not surprising that claims have been made over the years about something unusual on Mars. There is, for example, a cheerful "happy face" sitting inside a Martian impact crater 8 kilometers (5 miles) across, with a set of radial splash marks outside, making it look like the conventional representation of a smiling Sun (see illustration). But no one claims that this has been engineered by an advanced Martian civilization, perhaps to attract our attention. We recognize that, with big and little objects falling from the sky and with the surface rebounding and reconfiguring itself after each impact, many different patterns will be formed all over the planet. It is not surprising that occasionally we come upon something like a face. With our brains programmed for this from infancy, the face leaps out at us.

There are a number of small mountains on Mars that resemble pyramids. There is even a cluster of them -- the biggest a few kilometers across at the base -- all oriented in the same direction. Is it fair to deduce Martian pharaohs? Not really. On a small scale, similar features are known on the Earth, especially in Antarctica. Some of them would come up to your knees. They are called <u>dreikanters</u>, from a German word meaning three sides. It is improbable that they are manufactured by an otherwise undetected race of miniature Egyptians living in the Antarctic wasteland. They are, in fact, produced by wind erosion -- the action of fine particles picked up by strong winds blowing mainly in the same direction and, over the years, sculpting what once were irregular hummocks into nicely symmetrical pyramids.

On Mars, there is evidence of winds much fiercer than any ever experienced on Earth, ranging up to half the speed of sound. Vast sandstorms are commonplace. Over millions of years of evolution of the Martian landscape, it would not be too surprising if a few features -- even very large ones -- were sculpted by aeolian processes into the forms we see.

There is a place on Mars called Cydonia, where a great stone face a kilometer in size stares unblinkingly up at the sky (see illustration). It is an unfriendly face but recognizably human. In some representations, it could have been sculpted by Praxiteles. It lies in a landscape where many low hills have been molded into odd forms, perhaps by some mixture of ancient mudflows and subsequent wind erosion. From the number of impact craters nearby, the face looks to be at least tens of millions and perhaps billions of years old.

It has intermittently over the past decade attracted some attention both in the United States and in the Soviet Union. The headline that appeared in Weekly World News for November 20, 1984, was "Soviet Scientist's Amazing Claim: Ruined Temples Found on Mars. Space Probe Discovers Remains of 50,000-Year-Old Civilization." The revelations are attributed to an anonymous source and a~~llude to~~ describe discoveries made by a nonexistent Soviet space vehicle.

But the story of the "face on Mars" is almost entirely an American one. It was found by one of the Viking orbiters in 1976 [1977?]. There was an unfortunate dismissal of the feature as a trick of the lighting by a project official, which led later to the accusation that NASA was covering up the discovery of the millennium. Some engineers and computer specialists, some of them employed by NASA, on their own time worked to enhance the image to better understand what it might be. They suspected it might prove to be something spectacular. But that's permissible in science, even encouraged -- as long as your standards of evidence are high. Many of them were fairly cautious and should be commended for advancing the subject. Others were less restrained, deducing not only that the face was a genuine, monumental sculpture of a human being, but identifying a nearby city with temples and fortifications. From quite spurious arguments, one of them believed he had shown that the monuments had a particular astronomical orientation -- not now, though, but millions of years ago, from which it followed that only in that remote epoch were all these wonders constructed. But many millions of years ago there were no human beings on Earth.

An American ~~science~~ writer compares the Martian face to "similar faces. . . constructed in civilizations on Earth. The faces are looking up at the sky because they're looking up to God." Is it a remnant of an ancient, long-extinct human civilization on Mars? Might they have come to Earth and initiated life here? Or at least human life? Could it have been constructed by alien visitors stopping on Mars for a brief interlude? Was it left for us to discover? What does it imply about human evolution? Many deep questions are elicited.

When we know only a little about this face, it is hard to stare at it for very long without being roused to tremulous speculation. When we know a little more, it grows less enigmatic.

The surface area of Mars is almost 150 million square kilometers. The area covered by the Martian "sphinx" is about one square kilometer. Is it so astonishing that one postage-stamp-sized patch in 150 million should look a little funny -- especially given our penchant, since infancy, for finding faces? When we examine the neighboring jumble of hillocks, mesas, and other complex surface forms, we recognize that the face is akin to many other features on Mars that do not at all resemble a human face. Why this resemblance? Would some ancient Martians rework only this mesa (well, maybe a few others) and leave all the others unimproved by monumental sculpture? Shall we conclude that other blocky mesas are also sculpted into the form of faces, but not faces known on Earth? Surely the burden of proof is on the shoulders of those who believe the "face" is artificial.

If we look more carefully at the image, we see that a strategically placed "nostril" -- one that ~~ma~~ adds much to the impression that we are indeed looking at a face -- is in fact ~~a bit of~~ a black point corresponding to lost data in the radio transmission from Mars to Earth. When we examine other pictures under different lighting conditions, we find that the face is not nearly so symmetrical as it seems at first glance. Despite our shortness of breath and the beating of our hearts, this Martian sphinx looks natural -- not artificial, not a dead ringer for a human face -- and probably was sculpted by slow geological process over millions of years.

But my assessment might be wrong. It's hard to be sure about a world that we've seen so little of. Maybe aeolian erosion cannot produce pyramidal forms of such colossal dimensions on Mars, for example. All of these features deserve closer attention with higher resolution. Much more detailed photos of the "face" would surely settle issues of symmetry and settle the debate between geology and sculpture. Small impact craters found on or near the face can settle fairly definitively the issue of its age. In the unlikely case that the nearby features were really once a city, that fact should be obvious on closer examination. Even if these claims are highly improbable -- as I think they are -- they are worth a look. Unlike the UFO situation, we have here the opportunity for a definitive experiment. The hypothesis is very much falsifiable. (And if it's not, after much more careful scrutiny, falsified, the significance of course could be very great.) I hope that forthcoming American and Russian missions to Mars, which include orbiters with high-resolution television cameras, will make a special effort -- among the hundreds of other scientific questions to answer about Mars -- to look much more closely at what some people call the pyramids, the face, and the city.

I think it is fair to say that scientists' minds are open when exploring new worlds. If we knew what we would find there, it would be unnecessary to go. There is no telling what we will ~~be~~ find ~~found~~ in future missions to Mars or to the other fascinating worlds in our neck of the cosmic woods. But skepticism must be a part of exploration, or we will lose our way. Extraordinary claims require extraordinary evidence.

The Gift of _Apollo_

For the first time in my life, I saw the horizon as a curved line. It was accentuated by a thin seam of dark blue light -- our atmosphere. Obviously, this was not the "ocean" of air I had been told it was so many times in my life. I was terrified by its fragile appearance.

-- Ulf Merbold, West German space shuttle astronaut

It's a sultry night in July. You've fallen asleep in the armchair. Abruptly, you startle awake, disoriented. The television set is on, but not the sound. You strain to understand what you're seeing. Two ghostly white figures in coveralls and helmets are softly dancing under a pitch-black sky. They make strange little skipping motions, which propel them upward amid barely perceptible clouds of dust. But something is wrong. They take too long to come down. Encumbered as they are, they seem to be flying -- a little. You rub your eyes, but the strange tableau persists.

Of all the events surrounding _Apollo_ _11_'s landing on the Moon on July 20, 1969, my most vivid recollection is its dreamlike quality. Yes, it was an astonishing technological achievement and a triumph for the United States. Yes, the astronauts -- Neil Armstrong, Buzz Aldrin, and Mike Collins, the last keeping solitary vigil in lunar orbit -- displayed death-defying courage. Yes, as Armstrong said as he first alighted, this was an historic step for the human species. But if you turned off the sound, with its deliberately mundane and routine chatter, and stared into that black-and-white television monitor, you could glimpse that we humans had ~~once again~~ entered the realm of myth and legend.

We knew the Moon from our earliest days. It was there when our ancestors descended from the trees into the savannahs, when we learned to walk upright, when we first devised stone tools, when we domesticated fire, when we invented agriculture and built cities and set out to subdue the Earth. Folklore and popular songs still celebrate a connection between the Moon and love. The word "month" and the second day of the week are both named after the Moon. Especially when we lived out-of-doors, it was a major -- if oddly intangible -- presence in our lives.

The Moon was a metaphor for the unattainable: "You might as well ask for the Moon," they used to say. For most of our history, we had no idea what it was. A spirit? A god? A thing? It didn't look like something big far away, but more like something small nearby -- something the size of a plate, maybe, hanging in the sky a mile above our heads. Ancient Greek philosophers debated the proposition "that the Moon is exactly as large as it looks" (betraying a terrible confusion between linear and angular size). Walking on the Moon would then have seemed a screwball idea; it made more sense to imagine somehow climbing up into the sky on a ladder or on the back of a giant bird, grabbing the Moon, and bringing it down to Earth. But nobody ever did.

It was not until a few centuries ago that the idea of the Moon as a place, a quarter of a million miles away, gained wide currency; we're new at figuring out what worlds are and how they work. And in that brief flicker of time, we've gone from the earliest steps in understanding the Moon's nature to actually walking on its surface. We calculated how objects move in space; liquefied oxygen from the air; invented big rockets, telemetry, reliable electronics, inertial guidance, and much else. Then we sailed out into the sky.

The Moon is no longer unattainable. A dozen humans, all Americans, made those odd skipping motions they called "moonwalks" on the crunchy, cratered, ancient gray lava -- beginning on that July day in 1969. But since 1972, no one from any nation has ventured there. Indeed, none of us has gone anywhere since the glory days of Apollo except into low Earth orbit -- like a toddler who takes a few tentative steps outward and then, breathless, retreats to the safety of his mother's skirts.

Once upon a time, we soared into the Solar System. For a few years. Then we hurried back. Why? What happened? What was Apollo really about?

The scope and audacity of John Kennedy's May 25, 1961 message to a joint session of Congress on "Urgent National Needs" -- the speech that launched the Apollo program -- dazzled me. We would use rockets not yet designed and alloys not yet conceived, navigation and docking schemes not yet devised, in order to send a man to a world not yet explored -- not even in a preliminary way, with robots -- and we would bring him safely back, and we would do it before the decade was over. This confident pronouncement was made before any American had even achieved Earth orbit.

As a newly minted Ph.D., I actually thought all this had something centrally to do with science. But President Kennedy did not talk about discovering the origin of the Moon, for example, or even about bringing samples of it back for study. All he seemed to be interested in was sending someone there and bringing him home. Kennedy's science advisor, Jerome Wiesner, later told me he had a deal with the President: If the President did not claim that Apollo was about science, then he, Wiesner, would support it. So if not science, what?

There were arguments about "spinoffs," contentions that Apollo was a way to pump American technology. They boiled down to something like this: "Give us $25 billion to put people on the Moon, and we'll throw in Tang, a free cardiac pacemaker, and a stickless frying pan." But anybody could see that if we were after orange-juice substitutes or pacemakers or frying pans -- or even mainframe computers -- we could invent them directly; we didn't have to spend $25 billion and send people to the Moon in the process.

I kept asking. The Apollo program is really about politics, I was told. This sounded more promising. Nonaligned nations would be tempted to drift toward the Soviet Union if it was ahead in space exploration, if the U.S. showed insufficient "national vigor." I didn't follow. Here was the United States, ahead of the Soviet Union in virtually every area of technology -- the world's economic, military, and, on occasion, even moral leader -- and Indonesia would go Communist because Yuri Gagarin beat John Glenn to Earth orbit? What's so special about space technology? Suddenly I understood.

Sending people to orbit the Earth or robots to orbit the Sun requires rockets -- big, reliable, powerful rockets. Those same rockets can be used for nuclear war. The same technology that transports a man to the Moon can carry a nuclear warhead halfway around the Earth. The same technology that puts an astronomer and a telescope in Earth orbit can also put up a laser "battle station." Even back then, there was talk in military circles, East and West, about space as the new "high ground," about the nation that "controlled" space "controlling" the Earth. Of course strategic rockets were being tested on Earth. But heaving a ballistic missile with a dummy warhead to a target zone in the middle of the Pacific Ocean doesn't buy much glory. Sending people into space, though, captures the imagination of the world. You wouldn't spend the money to launch astronauts for this reason alone, but of all the ways of demonstrating rocket potency, this one works best.

There were six more missions after Apollo 11, all but one of which successfully landed on the lunar surface. Apollo 17 was the first to carry a scientist. As soon as he got there, the program was canceled. The first scientist and the last human to land on the Moon were the same person. The program had already served its purpose that July night in 1969. The half-dozen subsequent missions were just momentum.

Apollo was not mainly about science. It was not even mainly about space. Apollo was mainly about ideological confrontation and nuclear war -- often described by such euphemisms as world "leadership" and national "prestige." Nevertheless, good space science was done. We now know much more about the composition, age, and history of the Moon and the origin of the lunar landforms. We have made progress in understanding where the Moon came from. (The best current idea is that it was generated from the debris in the collision of a small planet on an errant orbit with the Earth around 4.5 billion years ago.) More important, Apollo provided an aegis, an umbrella under which brilliantly engineered robot spacecraft were dispatched throughout the Solar System, making that preliminary reconnaissance of dozens of worlds. The offspring of Apollo have now reached the planetary frontiers.

If not for Apollo -- and, therefore, if not for the political purpose it served -- I doubt whether the historic

American expeditions of exploration and discovery throughout the Solar System would have occurred. Something similar is true for the pioneering Soviet efforts in solar system exploration, including the first landings of robot spacecraft on another planet.

Apollo conveyed a confidence, energy, and breadth of vision that did capture the imagination of the world. That too was part of its purpose. It inspired an optimism about technology, an enthusiasm for the future. If we could go to the Moon, what else was now possible? Even those who were not admirers of the United States readily acknowledged that -- whatever the underlying reason for the program -- the nation had, with Apollo, achieved greatness.

When you pack your bags for a big trip, you never know what's in store for you. The Apollo astronauts on their way to and from the Moon photographed their home planet. It was a natural thing to do, but it had consequences that few foresaw. For the first time, the inhabitants of Earth could see our world from above -- the whole Earth, the Earth in color, the Earth as an exquisite white and blue world set against the vast darkness of space. Those images have awakened our slumbering planetary consciousness; they provide incontestable evidence that we all share the same vulnerable planet -- our only home in the entire Solar System. They remind us of what is important and what is not. The Saudi Arabian astronaut Prince Sultan Salman al-Saud, after his observations of the Earth from the Discovery shuttle in 1985, recalled: "The first day or so, we all pointed to our countries. The third or fourth day, we were pointing to our continents. By the fifth day, we were aware of only one Earth."

We may have found that perspective just in time, just as our technology threatens the habitability of our world. Whatever the reason we first mustered the Apollo program, however mired in Cold War nationalism it was, the inescapable recognition of the unity and fragility of the Earth is its clear and luminous dividend, the unexpected gift of Apollo. What began in deadly competition has led us to see that global cooperation is the essential precondition for our survival.

Travel is broadening. It's time to hit the road again.

~~1987, #6:~~ "Explorers," ~~Parade, November 22, 1987 (cover article), 4-6.~~ Excerpted, November 20, 1987, by Associated Press in Chicago Sun-Times, Baltimore Sun, Arkansas Gazette, Staten Island Advance, Fort Worth Star-Telegram, Chicago Tribune, Las Vegas Review-Journal, Syracuse Post-Standard, Modesto Bee, Winston-Salem Journal, Miami News, and many other newspapers. Excerpted in "Launch Heard Around the Country," by Aaron Epstein, Ft. Wayne (IN) News-Sentinel, January 30, 1988; Detroit Free Press, January 31, 1988, 1B, 7B. Reprinted in The 1989 Information Please Almanac (Boston: Houghton Mifflin, 1989), 350-351. Reprinted in Muy Interesante (Mexico City) as "Seguiremos Siendo Exploradores," October 1988, 12-16.

[Heading (at point in article signaled below by {*}:]

"The visions we present to our children shape the future. They become self-fulfilling prophecies. Dreams are maps."

~~[Text (quotation marks omitted):~~]

I know where I was when the space age began. In early October 1957, I was a graduate student at the University of Chicago, working toward a doctorate in planetary astronomy. The previous year, when Mars was the closest it ever gets to Earth, I had been at the McDonald Observatory in West Texas, peering through the telescope and trying to understand something ~~of~~ about what our neighboring world is like. But there had been dust storms on

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[4-3-93.atp]

Insert Q into "Explorers," p. 2:

I'd even bet some physics friends at the University of Chicago around 1955 that we would be walking on the Moon by 1980. [Audiotape: "asterisk" (i.e., footnote):] I also bet that we would be on Mars by 1990. Not even close.

both planets, and Mars was 40 million miles away. When you're stuck on the surface of the Earth, those other worlds are tantalizing but inaccessible.

I was sure that someday spaceflight would be possible. I knew something about Robert Goddard and V-2 rockets and Project Vanguard and even Soviet pronouncements earlier in the 1950s about their ultimate intentions to explore the planets. Insert A But despite all that, Sputnik 1 caught me by surprise. I hadn't imagined that the Soviets would beat the United States to Earth orbit, and I was startled by the large payload (which, American commentators claimed, must have been reported with a misplaced decimal point). Here the satellite was, beeping away, effortlessly circling the Earth every 90 minutes, and my heart soared -- because it meant that we would be going to the planets in my lifetime. The dreams of visionary engineers and writers -- Tsiolkovsky, Goddard, von Braun, H. G. Wells, Edgar Rice Burroughs -- were about to be fulfilled.

~~This year is the 30th anniversary of~~ Sputnik 1 was the first artifact of the human species to orbit the Earth. Five years later, the United States launched ~~It is also the 25th anniversary of~~ Mariner 2, the first spacecraft to explore another planet. These two achievements -- one Soviet, the other American -- mark a new age of exploration, a new direction for our species: the extension of the human presence to other worlds.

We have always been explorers. It is part of our nature. Since we first evolved a million years or so ago in Africa, we have wandered and explored our way across the planet. There are now humans on every continent -- from pole to pole, from Mount Everest to the Dead Sea -- on the ocean bottoms and occasionally in residence 200 miles up in the sky. [Some of this to introduction?]

The first large-scale migration from the Old World to the New happened during the last ice age, around 11,500 years ago, when the growing polar ice caps shallowed the oceans and made it possible to walk on dry land from Siberia to Alaska. A thousand years later, we were in Tierra del Fuego, the southern tip of South America. Long before Columbus, people from Borneo settled Madagascar, off the African coast; Indonesians in outrigger canoes explored the Western Pacific; and a great fleet of ocean-going junks from Ming Dynasty China crisscrossed the Indian Ocean, established a base in Zanzibar, rounded the southern tip of Africa, and entered the Atlantic Ocean. In the eighteenth and nineteenth centuries, American and Russian explorers, traders, and settlers were racing ~~west and east~~ across two vast continents to the Pacific. This exploratory urge has clear survival value. It is not restricted to any one nation or ethnic group. It is an endowment that the human species holds in common.

At just the time when the Earth has become almost entirely explored, other worlds beckon. The nations that have pioneered this new age of exploration are the former Soviet Union and the United States -- motivated nationalistically, of course, but serving as well as the vanguard of our species in space. Their combined achievements ~~(see box, next page)~~ are the stuff of legend. We humans have sent robots, then animals, and then ourselves above the blue skies of Earth into the black interplanetary void. The footprints of 12 of us are scattered across the lunar surface, where they will last another million years. We have flown by some 40 new worlds, many of them discovered in the process. Our ships have set gently down on scorching Venus and chilly Mars -- returning images of their surfaces and searching for life. Once above our blanket of air, we have turned our telescopes into the depths of space and back on our small planet to see it as one interconnected and interdependent whole. We have launched artificial moons and artificial planets, and have sent four spacecraft ~~on their way~~ to the stars.

Bob: Pls. reproduce box

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From the standpoint of a century ago, these accomplishments are breathtaking. From a longer perspective, they are mythic. If we manage to avoid self-destruction, so that there are future historians, our time will be remembered in part because this was when we first set sail for other worlds. In the long run, as we straighten things out here, there will be more of us up there. There will be robot emissaries and human outposts throughout the Solar System. We will become a multiplanet species.

We are not motivated by gold or spices or slaves or a passion to convert the heathen to the One True Faith, as were the European explorers of the fifteenth and sixteenth centuries. Our goals include exploration, science and technology, national prestige, and a recognition that the future is calling. There is a very practical reason as well: We can take better care of the Earth (and its inhabitants) by studying it from space and by comparing it with other worlds.

But whatever our reasons, we are on our way. We advance by fits and starts; there are detours and failures of nerve. The long-term trend, though, is clear: It is getting cheaper and easier to go into space, ~~and there is progressively~~ more for us to do there.

Only a handful of nations have access to space at the moment, but their number is increasing. Russia, despite daunting problems, is maintaining a vigorous space program. France and China are now lifting commercial payloads for a profit. Japan and the European Space Agency, in 1986, mustered their first, extremely successful missions into interplanetary space. There will be other spacefaring nations in the next few decades. Others may lose their determination and their vision, as did Portugal, which trailblazed the great sailing-ship voyages of discovery and then gradually sank into obscurity. ~~Unhappily -- astonishingly -- the United States may become the first nation to back off from the exploration of space~~.

* * *

[Following Explorers, p. 5]

[Broca II, draft 1, 8/12/92]

~~1986, #87: "On the Prehistory of the Planetary Society," The Planetary Report 6 (2) (January/February), 4-5.~~

¶ The American programs of space exploration has had its ups and downs as well.

On November 13, 1971, the American spacecraft Mariner 9 was successfully injected into orbit around Mars -- the first spacecraft in human history to orbit another planet. But Mars was enveloped in a global dust storm, as the American and foreign news media dutifully reported before leaving the Jet Propulsion Laboratory for more urgent business.

By January, the dust storm began to clear and extraordinary vistas of Mars were transmitted, including the largest volcanic mountains known in the Solar System, ancient river valleys on a planet now bone dry, a profusion of strange albedo markings on the surface, and clear evidence of geological stratification, at least in the polar terrain.

Eventually 7,329 pictures were acquired. Those of us privileged to participate in this extraordinary mission felt that the human species was exploring a wondrous new world; we were confident that many others would share our excitement. We were also aware that since such projects are supported by the American people, it is only proper that the public see what they are paying for.

So the Offices of Public Information at JPL and at NASA Headquarters called the media back. Individual scientists did so as well. I called -- or tried to call -- every television and print reporter I could think of. But with only a few exceptions, the answer was the same: Mariner 9 had achieved orbit in November 1971; this was now January of the following year. These findings weren't "news." We should have arranged for the pictures to be available when the reporters were at JPL months before. And anyway, the public -- ~~now~~ recently saturated with Apollo footage -- just wasn't interested in exploring other worlds.

Although things were a little better in 1976 with the two Viking landings on Mars, many of us felt that the reportage was again grossly inadequate for the drama of the first successful landings on Mars, the first search for life on another planet, and especially for the stream of exquisite pictures -- ideal for the visual medium of television. There was a widespread underestimate, it seemed to me, of the intelligence and adventuresome spirit ~~of adventure~~ of the American public. (This experience was a principal motivation for what eventually became the Cosmos television series.)

~~This~~ was often ~~reflected~~ heard when planetary scientists would ~~talk to~~ call on members of Congress or the Executive Branch. I can remember, in the early and very shaky days of the Galileo project, entering the office of a key committee member of Congress (a Republican), and finding a picture of Jupiter on the wall. Well, at least this one ought to be easy, I thought. But I was mistaken. Yes, members of Congress or their aides might be interested in planetary exploration; they might understand its symbolic, historical, scientific, and practical values. But unfortunately the American public wasn't the least interested in planetary

¶ Wariness about public support

exploration, I was told. In the Congressman's entire district there were only three people who had chosen to write on Galileo, and two of them were below voting age. There was no industry in the district that would produce components for Galileo. The Congressman felt he could vote against the wishes of the leadership of his party only on a few, carefully selected occasions. This was not one of them.

But this issue really crystallized for me in December 1977 when I was asked to discuss the space program -- and astromony more generally -- with then President Jimmy Carter and Vice President Walter Mondale and their families, one evening at the Vice President's residence on the grounds of the U.S. Naval Observatory.

Since such Presidential briefings must be rare, I felt it was my responsibility to treat the subject of astronomy and space sciences as evenhandedly as I could, and resist the temptation to lay stress on my own particular interests. But the Viking mission was still ongoing, the pictures spectacular, and I was repeatedly detained on my way to the Crab Nebula and beyond by Presidential interest in Mars. How definitive were the apparently negative results on life? Why had we landed in such dull places when there were such exciting places all over the planet? Hadn't we heard of "nothing ventured, nothing gained?" I found myself in the unlikely posture of pleading caution and fiscal responsibility to a President caught up in an exploratory

1,15

[4-3-93.atp]

[For a combined chapter which begins with "Explorers," has some on the prehistory of the Planetary Society, and will end with a piece from the Goldin/Sagan dialogue; this will be insert A (we tried a previous one which I didn't like; I'm going to do it again) on p. 4 of what used to be "On the Prehistory of the Planetary Society":]

[(Later on audiotape:) You will see on the page in which this insert A is going ("On the Prehistory of the Planetary Society," p. 4) there are a circled few sentences. That should be inserted in insert A, right after the place where I talk about ". . . means there must be many millions of others who share their concerns."]

[Insert A:]

This organization, based in Pasadena, California, is a public membership organization which is the largest space-interest group in the world, with members mainly in the United States but also on seven continents, including Antarctica, and in over 100 countries. In its early days it was one of the fastest-growing major organizations in America. It is devoted to planetary exploration and the search for extraterrestrial life. It has trained Latin American teachers in planetary science; sponsored worldwide student contests; given maps of Mars to American high schools; supported trailblazing research in the radio search for extraterrestrial intelligence, in the detection of near-Earth asteroids, and in the design and testing of balloon and rover exploratory vehicles for Mars. It has been a voice for international cooperation in space. And it has had some notable successes (as well as some failures) in supporting key NASA programs in spacecraft exploration of the Solar System and the radio search for extraterrestrial intelligence. The mere fact that so many people are so passionately involved with the subject itself has political influence. It tends to counteract some of the concerns so often encountered in Washington -- "I of course understand the importance of these things, but unfortunately the public doesn't." Well, it turns out that a significant fraction of the public does. The Society has far outpaced the most optimistic expectations that Bruce Murray -- then director of the Jet Propulsion Laboratory -- and I had in mind when, in 1977, we discussed -- at first very casually -- organizing such a society. If there are 100,000 people who pay dues and keep up their memberships, then there must be many millions of others who share their concerns.

But not everyone does. Some people see the space program as a succession of catastrophes -- seven brave Americans killed on a mission whose main function was to launch a communications satellite that could have been launched without risking any people at all; a billion-dollar telescope launched with a nearsighted lens; a spacecraft to Jupiter whose main antenna -- essential for returning data to Earth -- would not unfurl. Some people cringe every time NASA talks about space exploration, when it describes sending astronauts 200 miles up in a tin can that goes nowhere. Some people look at the space program as a stalking horse for the military and grandiose plans to put weapons into space despite the fact that an orbiting weapon is a sitting duck. And NASA, at least until recently, has shown all the symptoms of an aging, arteriosclerotic bureaucracy. There is considerable merit in many of these criticisms. But they should not obscure the enormous practical and historical significance of the space program.

The justification for sending humans on expensive and dangerous missions that could be done just as well by robots is, at the very least, a dubious proposition. It is often justified on the grounds that only "manned" missions (and, the counterpoint thought is almost never mentioned explicitly, the risks involved) can maintain public interest. I believe this opinion, widespread in some quarters, shows real contempt for the citizens on whose behalf the program is presumably being carried out. Manned spaceflight aside, there is a surprisingly wide range of justifications for the space program. Some people resonate more with some parts of the program than with others: [And then we pick up on the Goldin/Sagan dialogue.]

passion -- easy to come by when discussing Mars.

My hosts were knowledgeable and hospitable. After I finished -- satisfactorily in the realm of the galaxies -- the President took me aside.

"You know, you ought to write a few more books to really get people interested in planetary exploration. Then we could do some really exciting missions."

"But Mr. President," I protested, "you only need write your name at the bottom of a single piece of paper and we could have a rover mission to Mars."

Mr. Carter only smiled.

The clear lesson from such experiences was that the future of planetary exploration, at least in the United States, might very well depend on the perception by politicians and the media of public interest in the subject, and this is the path that for me led to The Planetary Society. Insert A The Society's extraordinary success -- as well as many other lines of evidence, including the appearance of Saturn on the covers of Time and Newsweek, the success of Cosmos, ABC's Nightline devoting whole programs to live coverage of the Voyager encounters, and much else -- demonstrates very clearly, I think, enormous public interest in, and support for, the exploration of the planets. This is even more true of the search for extraterrestrial intelligence.

~~These concerns were very much on my mind when in 1979 Bruce~~ ~~then Director of the Jet Propulsion Laboratory,~~ ~~Murray~~ Jr. ~~and I discussed -- at first very casually -- a new~~

[Broca II, draft 1, 8/12/92]

[1/1/93 Vita:] 1992, #36: Dan Goldin and Carl Sagan: A Dialogue on the Future of Planetary Exploration, Beckmann Auditorium, California Institute of Technology, Pasadena, CA, December 4, 1992. Reported in "Speaking Up: Noteworthy Addresses in the Southland," Los Angeles Times, December 11, 1992; "Goldin Criticizes Space Bureaucracy at Town Meeting," Space News, December 14-20, 1992, 22.

[2/20/93 audiotape: also, Engineering and Science (California Institute of Technology), Winter 1993, in press.]

[From preliminary copy, Engineering and Science, pp. 30, 31; quotation marks omitted:]

[CS:]

~~There's a range of justifications. People resonate differently. Let me talk a little about space in general, not just NASA programs.~~ Communications satellites link up the planet. Meteorological satellites predict the weather, saving many billions of dollars worth of crops every year. Military-reconnaissance and treaty-verification satellites make the planet more secure. Satellites, especially a new generation soon to be deployed, ~~those that are coming along~~, monitor the health of the global environment and check out the greenhouse effect, the depletion of the ozone layer, and new dangers we haven't even thought about yet. All of those are immensely practical and cost-effective.

Then there's the matter ~~issue~~ of exploration. Humans for 99 percent of our history were hunter-gatherers. We wandered. We followed the game. Exploration is built into us. And just at the moment when the planet is all explored, save perhaps for under the ocean, the planets open up as a goal for exploration. Many people feel this in a strong, emotional way -- one could even call it religious, in the sense that they have difficulty justifying it rationally.

And there are the deep questions that each society, one way or another, asks -- the origin of life; the origin of our planet; the origin, nature, and fate of the Universe. I think you'd have to be made out of wood not to wonder, at least a little, about those questions. Through folklore, religion, superstition, or science, every human culture has invested some of its resources in answering those questions. So it is reasonable for us who can, for the first time, actually find out some of the answers to make such an ~~this~~ investment as well.

If you mix those three together -- the directly practical, the zest for exploration, and the answering of questions of origins -- I think you'll catch a sense of what motivates many ~~a lot~~ of people about space. And one last thing. ~~-- the vision of the future that's offered up to young people in our society is almost universally dismal -- something like guys with automatic weapons on bombed-out post-nuclear-war highways.~~ ~~What aspect of our society, in the natural course of doing business, offers a~~

hopeful vision of the future? It's the space program, offering ~~It's~~ new worlds, new exploration. It's something that young people can be motivated by, that can help guide their lives, make them work hard and study science. That's worth a great deal ~~whole lot~~. I think NASA, despite all ~~of~~ its problems and its ossified bureaucracy, is a stunning ~~fantastic~~ bargain. ~~And I'd like to wrap up this evening's discussion by saying that, after listening carefully to Dan's answers to this wide variety of questions, I think that NASA headquarters finally has got a breath of fresh air.~~

* * *

Other missions continuing the mythic tradition need to be approved: a spacecraft that will keep pace with a comet in its orbit around the Sun; an advanced X-ray observatory; the Cassini mission to Titan, a world whose air is filled with organic molecules of the sort that, 4 billion years ago, led to the origin of life on Earth; a radio telescope that can look back in time to glimpse the Universe shortly after it began; and, especially, a set of robot explorers of Mars, culminating in the first human footfall on another planet (see "Let's Go to Mars Together," Parade, February 2, 1986). These missions should be international -- accepting proffered Soviet cooperation, broadening the scientific and engineering talent involved, reducing the costs to any one nation, and helping to bring our world together while exploring others. Such an objective has been endorsed by every U.S. President but one since the dawn of planetary exploration (see box, preceding page). And all this would cost a small fraction of the multitrillion-dollar bill for the technically dubious Star Wars program ("The Leaky Shield," Parade, December 8, 1985).

It has been my good fortune to have participated, from the beginning, in this new age of exploration; to have worked with those glistening Mariners, Apollos, Pioneers, Vikings, and Voyagers in their journeys between the worlds, a technology that harmed no one, that even America's adversaries admired and respected; to have played some part in the preliminary reconnaissance of the Solar System in which we live. I feel the same joy today in these exploratory triumphs that I did ~~30 years ago~~ when Sputnik 1 first circumnavigated the Earth, when our expectations of what technology could do for us were nearly boundless.

But since that time, something has soured. The anticipation of progress has been supplanted by a foreboding of technological ruin. I look into my children's ~~daughter's~~ eyes and ask myself what kind of future we are preparing for our children. We have offered them visions of a future in which -- unable to read, to think, to invent, to compete, to make things work, to anticipate events -- our nation sinks into lethargy and economic decay; in which ignorance and greed conspire to destroy the air, the water, the soil, and the climate; in which we permit a nuclear holocaust. The visions we present to our children shape the future. It matters what those visions are. Often they become self-fulfilling prophecies. Dreams are maps.

I do not think it irresponsible to portray even the direst futures; if we are to avoid them, we must understand that they are possible. But where are the alternatives? Where are the dreams that motivate and inspire? Where are the visions of hopeful futures, of times when technology is a tool for human well-being and not a gun on hair trigger pointed at our heads? Our children long for realistic maps of a future they (and we) can be proud of. Where are the cartographers of human purpose?

Continuing, cooperative planetary exploration cannot solve all our problems. It is merely one component of a solution. But it is practical, readily understood, cost-effective, peaceful, and stirring. It is our responsibility, I believe, to create a future worthy of our children, to fulfill the promise made decades ago by Sputnik 1 and Mariner 2, to open up the Universe to those intrepid explorers from planet Earth.

* * *

[8/29/92: Above, bottom of page 3: ". . . Their combined achievements (see box, next page) are the stuff of legend. . ." Page 7, top: ". . . Such an objective has been endorsed by every U.S. President but one since the dawn of planetary exploration (see box, preceding page). . ." But no boxes appear in photocopy supplied.]

* * *

[In bold print beneath biographical squib:]

FOR MORE INFORMATION

To learn more about the exploration of the Solar System and the search for extraterrestrial life, readers may wish to write

1,21

[Broca II, draft 1, 8/12/92]

1990, #13: "Exploring Other Worlds and Protecting This One: The Connection," ~~The Planetary Report 10 (1) (January/February 1990), 4-7. Reprinted in Science Fiction, Science Fact, and You (New York: Amsco School Publications), in press. Excerpted in 1991 Information Please Almanac (Boston: Houghton Mifflin, 1990), 326-327.~~

~~[Epigraph (italicized in TPR):]~~

"For the first time in my life, I saw the horizon as a curved line. It was accentuated by a thin seam of dark blue light -- our atmosphere. Obviously, this was not the 'ocean' of air I had been told it was so many times in my life. I was terrified by its fragile appearance." -- Ulf Merbold, ~~West~~ German space shuttle astronaut

[Figure captions:]

"Tropical storm Xina draws clouds into its vortex as it builds strength north of the Hawaiian Islands. Such cyclonic storms are common to planets with atmospheres."

"The ozone hole over Antarctica, caused by human-made chemicals released into the atmosphere, is only one of several threats to Earth's environment discovered, in part, through planetary studies. This image, made from data taken by the Nimbus 7 satellite, shows the extent of the hole (dark purple) on October 5, 1989."

"Venus' clouds enshroud a world of broiling surface temperatures. The greenhouse effect on Venus helped alert us to the dangers of the increasing greenhouse on Earth."

"Cyclonic storms form on Mars as well as on Earth. By studying weather patterns on other planets, we gain insight into similar processes on our own planet."

"Scientists attempting to understand Mars' global dust storms realized that a nuclear war might produce similar effects on Earth, and so helped to develop the concept of 'nuclear winter.'"

"In stable air over a calm ocean, cellular clouds such as these grow through slow, convective motion. This image was taken from the shuttle <u>Discovery</u> over Ascension Island in the Atlantic Ocean. The intricate, changing patterns of Earth's weather can be affected by human activities."

~~[Text (quotation marks omitted):]~~

The <u>Apollo</u> images of Earth from space revealed plainly the fragility and vulnerability of our lovely little world, and powerfully assisted the coming of age of a global ecological consciousness. Such pictures by themselves may be worth the whole cost of the space program, because their meaning has reached so many. But what is not so widely understood is how much vital and urgent information we have gained about our own world from robotic exploration of other worlds.

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[4-6-93.at2]

Insert B into 1990:13, "Exploring Other Worlds and Protecting This One," p. 3:

An art fancier who knows only Egyptian tomb paintings, a courtier who knows only blue jeans, a philosopher who knows only one philosophy, a [and then we pick up "linguist. . ."].

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[4-6-93.at2]

Insert C into 1990:13, "Exploring Other Worlds and Protecting This One," p. 3:

What once seemed the only way the world could be, turns out to be somewhere in the middle of a vast range of alternatives. When we look at those other worlds, we can understand what the consequences are of having too much of one thing or too little of another.

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[4-6-93.at2]

Insert D into 1990:13, "Exploring Other Worlds and Protecting This One," p. 3:

Suppose, for example, that we have a three-dimensional general circulation computer model of the Earth's climate that purports to be able to predict what the Earth will be like if there's more of one gas or less of another. The model does very well at predicting the present climate, but is it reliable in rather different climatic regimes? One way to test this program is to apply it to the climates of other planets. Can it predict the structure of the atmosphere on Mars and the climate there, the weather? Or on Venus? If it were to fail in these test cases of other planets, we would be right in mistrusting it when it makes predictions for our own planet. In fact, climate models now in use do very well in predicting from the principles of physics the climates on Venus and Mars.

[4-6-93.at2]

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Insert A into 1990:13, "Exploring Other Worlds and Protecting This One," p. 3:

When we look down at Earth from orbital altitudes, we see a lovely, fragile planet floating in the black vacuum. As you journey further away, as the Apollo astronauts did, you see it shrink in apparent size, so many of its features and aspects that dominate our daily lives gradually becoming invisible. You're struck by how self-contained this world is. An occasional hydrogen atom leaves; a pitter-patter of cometary dust arrives. And of course there's sunlight generated in the immense thermonuclear engine deep in the Sun's interior and racing away from the Sun in all directions. The Earth intercepts a little bit of it, and that provides nearly all the light and heat on Earth. But apart from that, this little world is on its own. From the surface of the Moon you can see it, perhaps as a crescent, even its continents now indistinct. And from the vantage point of the outermost planet it is a mere point of light.

Back in Earth orbit, you can see why there is no longer such a thing as a local environmental problem. Even from this perspective it's hard to make out national boundaries. But even if we could, it's clear that molecules don't carry passports. Industrial poisons, greenhouse gases, and substances that attack the protective ozone layer do not -- doubtless out of ignorance

[4-6-93.at2]

-- respect national boundaries; they are oblivious of the notion of national sovereignty. And so, because of the vast, almost mythic powers of our technology (and the prevalence of short-term thinking) on continental, even planetary scales -- by industrial and radioactive wastes [I'm taking some of this from 1987:1, "The Planetary Perspective," p. 1]; acid rain; deforestation and erosion; depletion of the ozone layer; and global warming -- we are beginning to pose a danger to ourselves. It is clear at a glance that if many of these problems are to be solved, they will have to be solved by many nations acting in concert for a long time. It is a minor irony of our times that spaceflight -- conceived in the cauldron of nationalist rivalries and hatreds -- brings with it, in the natural process of doing business, a stunning transnational vision. You spend even a little time contemplating the Earth from orbit and the most deeply ingrained nationalisms begin to fade. They seem the squabbles of microbes on a marble [better metaphor?]. The Earth is one world.

Insert A

If we are stuck on one world, we are limited to ~~a single~~ case; we do not know what else is possible. Then like a Insert B linguist who knows only English, or a physicist who knows about gravity only from falling bodies on Earth, our insights are narrow, ~~and~~ our predictive abilities severely circumscribed. But when we explore other worlds, our perspective widens. Insert C We gain a new understanding of worlds in general, and ~~including~~ our own in particular.

The ~~Robotic~~ exploration of other worlds has ~~already~~ opened our eyes in many fields of Earth science, including the study of volcanoes, earthquakes, ~~and~~ weather and climate. It may turn out to have profound implications for biology, because all life on Earth is built on a common biochemical master plan. The discovery of a single extraterrestrial organism -- even something as humble as a bacterium -- would revolutionize biology. But the connection between exploring other worlds and protecting our own is most evident in the study of Earth's climate and the burgeoning threat to the climate that our technology now represents. Insert D Other planets provide vital ~~important~~ insights about what dumb things not to do to Earth.

Three environmental ~~catastrophes, or~~ potential catastrophes, have been uncovered accidentally, mainly in the last two decades: ozonosphere depletion, greenhouse warming, and nuclear winter. ~~I want briefly to sketch some of the ways in which planetary exploration aided and deepened these findings.~~

~~Thinning Ozone Shield~~

It was disquieting to discover that an inert material with all sorts of practical functions -- it serves as the working fluid in refrigerators and air conditioners, as propellant for deodorants and other products in aerosol cans, and as lightweight foamy packaging for fast foods, to name only a few -- can pose a danger to life on Earth. Who would have figured it?

The molecules in question are called chlorofluorocarbons (CFCs). They are extremely chemically inert, which means they are invulnerable -- until they find themselves up in the ozone layer, where they are dissociated by sunlight. The chlorine atoms thus liberated deplete the ozone and let more ultraviolet light from the Sun reach the ground.

This increased ultraviolet intensity ushers in a ghastly procession of potential consequences involving not just skin cancer but weakening of the human immune system and, most dangerous of all, ~~the destruction of~~ possible harm to agriculture and of photosynthetic ~~micro~~organisms at the base of the food chain and on which most life on Earth depends.

The principal manufacturer of this material, the Dupont company (which gave it the brand name Freon) -- after years of pooh-poohing the concern of environmentalists, after taking out full-page ads in newspapers and scientific magazines claiming that the uproar all came from wild extrapolations from inadequate data, that nobody had actually demonstrated any peril -- that company has now announced that it will rapidly phase out all its CFC production. The precipitating event seems to have been the discovery in 1986 by British scientists of a hole in the Antarctic ozone layer. There is now good evidence of thinning of the ozone layer at other latitudes as well.

Who discovered that CFCs posed a threat to the ozone layer? Was it the Dupont Corporation exercising corporate responsibility? No~~pe~~. Was it the Environmental Protection Agency protecting us? No~~pe~~. Was it the Department of Defense defending us? No~~pe~~. It was two ivory-tower, white-coated university ~~students~~ scientists working in 1974 on something else -- Sherwood Rowland and Mario Molina of the University of California, Irvine. Not even an Ivy League university. Fundamental research. Scientists following their own interests.

Their work used reaction rate constants of chemical reactions involving chlorine and other halogens, determined in part with NASA support. Why NASA? Because Venus has chlorine and fluorine molecules in its atmosphere -- as discovered by U.S. spacecraft and ground-based observations -- and planetary aeronomers ~~[sic in TPR: astronomers?]~~ wanted to understand what's happening there.

~~Thank You, Venus~~

Confirming theoretical work on ozone depletion was soon done with a big computer model by a group led by Michael McElroy at Harvard. How is it they had all these branching networks of halogen chemical kinetics in their computer ready to go? Because

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[4-6-93.at2]

Insert E into 1990:13, "Exploring Other Worlds and Protecting This One," p. 6:

But simple organic molecules ought to be there, because of the impact of organic-rich meteorites from the nearby asteroid belt.

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[4-6-93.at2]

Insert F into 1990:13, "Exploring Other Worlds and Protecting This One," p. 6:

The _Viking_ microbiology experiments found that organic matter carried to Mars and sprinkled with Martian surface dust is quickly oxidized and destroyed. The materials in the dust do the destruction on molecules like hydrogen peroxide -- which is used as an antiseptic because it kills microbes in the same way.

they too were working on the halogen chemistry of the atmosphere of Venus. Venus helped make and helped confirm the discovery that the Earth's ozone layer is in danger. ~~(Such serendipity, by the way, is found in many discoveries in science.)~~ There is an absolutely unexpected connection between the atmospheric photochemistries of two planets, and suddenly a very practical result emerges from the most blue-sky, abstract kind of work, understanding the upper atmosphere of Venus.

There is also a Mars connection to ozone depletion on Earth. With Viking we found the surface of Mars to be lifeless and remarkably deficient even in simple organic molecules. Insert E This deficiency is widely understood as due to the lack of ozone in the Martian atmosphere. Insert F Ultraviolet light from the Sun strikes the surface of Mars unimpeded by any ozone layer; if any organic matter were there, it would be quickly destroyed by ~~solar~~ the ultraviolet light itself or ~~the~~ its oxidation products, like hydrogen peroxide ~~of solar ultraviolet light~~. Thus part of the reason that the topmost layers of Mars are antiseptic is that Mars has an ozone hole of planetary dimensions -- all by itself a ~~possibly~~ useful cautionary tale for us, who are busily thinning and making holes in our ozone layer.

~~CO_2 and the Greenhouse Effect~~

~~Now let's look at~~ Global warming is predicted to follow ~~from~~ from the increasing greenhouse effect, which ~~derives~~ is caused largely ~~from~~ by carbon dioxide generated by the burning of fossil fuels -- but also from the

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[4-6-93.at2]

Insert G into 1990:13, "Exploring Other Worlds and Protecting This One," p. 7:

Hansen has developed one of the major computer climate models and applied it to predict what will happen to our climate as the greenhouse gases continue to build up. He has been in the forefront of testing these models on ancient climates of the Earth. (During the ice age, it is interesting to note, more carbon dioxide is correlated with higher temperatures, and vice versa.) He has collected a very wide range of data from the last many decades to see what is actually happening to the global temperature, and to compare it to the predictions of what <u>should</u> have happened. He has courageously testified before Congress in the face of a politically-generated order from the White House Office of Management and Budget (this was in the Reagan years) to exaggerate the uncertainties and to minimize the conclusions. His calculation of by how much the explosion of the Philippine volcano Mt. Pinatubo will temporarily reduce the Earth's temperature (by about a half degree Centigrade) was right on the money. He has been a force in convincing governments that global warming is something to be taken seriously.

How did Hansen get interested in the greenhouse effect in the first place? My doctoral thesis was mainly about explaining the high radio brightness of Venus in terms of a very hot surface, and showing that a very large amount of carbon dioxide with some water vapor might explain such high temperatures via the greenhouse effect. There were a number of scientists who were skeptical about this notion (and the surface temperature of Venus is so high that skepticism is certainly merited). A few years later, Hansen wrote his doctoral thesis (at the University of Iowa in 1965?) in which he agreed that the surface is hot, but proposed a different mechanism for heating it (from the interior rather than by sunlight), but with greenhouse gases playing the same role. The Pioneer 12 mission to Venus in 1978 dropped entry probes into the atmosphere of Venus which showed directly that the greenhouse effect -- the surface heated by sunlight and the heat retained by the blanket of air -- was the operative cause. I was lucky. But it's Venus that got Hansen thinking about the greenhouse effect. I know of many other instances where scientists who cut their teeth on the atmospheres of other worlds are making important and highly practical discoveries about this one. The planets are an excellent training ground -- requiring both breadth and depth of knowledge -- for future students of the Earth.

[Now we go to p. 8. . .]

buildup of other infrared-absorbing gases (oxides of nitrogen, methane, those same CFCs, and some other molecules). Some of the most important recent work on global warming has been done by James Hansen and his colleagues at the Goddard Institute for Space Sciences, a NASA facility in New York City.

Insert G

Hansen and his colleagues point out that over the last hundred years the five warmest years in terms of average global temperature have been in the 1980s. If their current projections prove correct, and world temperatures continue to be driven up by the increasing levels of carbon dioxide and other gases in Earth's atmosphere, then 1990 will be the warmest year in the last 120,000.

Some of the consequences projected by various climatologists to the middle and end of the next century include the conversion of the Soviet Ukraine and the American Midwest, the breadbasket of the world, to something approaching scrub deserts. The slow volume expansion of sea water, the melting of glacial and polar ice, and later the collapse of the West Antarctic ice sheet would cause the inundation of every coastal city on the planet. Now that's serious. Mitigating this warming will be very expensive.

~~Hansen has played a major role before committees of the House and Senate, convincing them to take the threat of global warming seriously.~~ How did Hansen get involved with the issue of Earth's climatic future in the first place? As a graduate student at the University of Iowa he wrote a doctoral thesis that attempted (mistakenly, we now know) to disprove the contention that Venus was hot because of a massive greenhouse effect there. Venus got Hansen thinking about the greenhouse effect.

Those who are skeptical about carbon dioxide greenhouse warming might profitably note the massive greenhouse on Venus, ~~where~~ The atmosphere is primarily carbon dioxide, the surface pressure is about 90 times that on Earth, and the surface temperature is about 900 degrees Fahrenheit (480 degrees Celsius). No one proposes that Venus' ~~runaway~~ greenhouse effect was caused by Venusians who burned too much coal, drove fuel-inefficient autos, or cut down their forests. My point is different. ~~That's not the point. But~~ The climatological history of our planetary neighbor, an otherwise Earthlike planet on which the surface became hot enough to melt tin or lead, is worth considering -- especially by those who say that the increasing greenhouse effect on Earth will be self-correcting, that we don't really have to worry about it, or -- you can see this in the publications of some ~~extreme~~ rightwing political publications -- that the greenhouse effect itself is a "hoax."

~~Nuclear Winter~~

Nuclear winter is the predicted darkening and cooling of the Earth, mainly from fine smoke particles injected into the atmosphere from the burning of cities and petroleum facilities that would follow even a ~~"small" nuclear~~ global thermonuclear war. #

There has been a vigorous scientific debate on just how serious nuclear winter ~~is likely to~~ may be. The debate has now ~~largely~~ converged. ~~Most~~ All three-dimensional general circulation

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[4-6-93.at2]

Insert H into 1990:13, "Exploring Other Worlds and Protecting This One," p. 9:

predict that the resulting global temperature will be lower than in the worst of the Pleistocene ice ages. The consequences for our global civilization -- especially through the collapse of agriculture -- seem very dire. Although it is hard to be certain about such things, a case can be made that nuclear winter played some role in convincing the nuclear-armed nations -- especially the Soviet Union -- of the futility of nuclear war. Nuclear winter was first named and calculated [and then we pick up]. . .

Insert H

models ~~now get nearly the same answer, provided they use the same starting conditions.~~ ~~That answer is close to the results first announced~~ in 1982/1983 by a team of five scientists, to which I'm proud to belong. They were given the acronym ~~called~~ TTAPS (for Richard P. Turco, Owen B. Toon, Thomas Ackerman, James Pollack, and myself). Of the five TTAPS scientists, three are nearly full-time planetary scientists, and the other two have published many papers in planetary science.

The earliest intimation of nuclear winter came during the <u>Mariner 9</u> mission to Mars, when there was a global dust storm and we were unable to see the surface of the planet; the infrared spectrometer on <u>Mariner 9</u> found the high atmosphere to be warmer and the surface colder than it ought to have been. We sat down and tried to calculate how that could come about. Eventually this line of inquiry led us from dust storms on Mars to nuclear winter on Earth.

~~Planetary Perspective~~

Planetary science provides a global perspective, a ~~big~~ wide interdisciplinary picture that is ~~turns out to be~~ very helpful in discovering ~~finding~~ and attempting to defuse ~~define~~ these looming ~~climate~~ environmental catastrophes. When you cut your teeth studying other worlds, you develop a point of view about what else is possible. ~~-- one very useful in understanding this world~~. There are probably other such catastrophes still to be uncovered. When they emerge, I think it likely that planetary science will ~~play an important role in discovering and assessing them~~ be playing an important part.

When I look at the evidence, ~~I find~~ it seems to me that planetary exploration is of the most practical and urgent utility for us here on Earth. Even if we were not concerned about exploration, even if we ~~did not~~ didn't have a nanogram of adventuresome spirit in us, even if we were only concerned for ourselves in the narrowest sense, planetary exploration would ~~be~~ constitute a superb investment. ~~NASA ought to make this case.~~

September 6, 1988, 1C, 2C. Reprinted in Space Flight News (U.K.), September, 1988, 20-23. Excerpted in "Space Race Shaping Up as International Effort," by Vince Kohler, Montreal Gazette, September 27, 1988. Reprinted as appendix in "Reflections on the Presidential Moon/Mars Initiative," by Carl Sagan, Planetary Society Background Paper No. 1 (Pasadena, CA: The Planetary Society, 1989).

[The following has been transcribed from an enlarged photocopy of the Parade article. The copy includes three boxes but no illustrations.]

Mars

In the darkened auditorium of the National Academy of Sciences in Washington, D.C., the five of them -- veterans of many space missions -- reminisced about the silent movie being projected on the big front screen. With an easy, self-mocking humor, they described the design of the compatible docking module, the separate launches from Cape Canaveral, Florida, and Tyuratam in the U.S.S.R., the dangerous rendezvous, the triumphant crawling through the air locks to visit one another, the exchange of gifts, the camaraderie, and their separate returns to Earth. Occasionally, a little shyly, they would put an arm around each other. Many in the audience were struck by the mutual affection and respect of Lt. Gen. Thomas Stafford, U.S. Air Force, former commander at Edwards Air Force Base, where high-performance aircraft are tested [and later Air Force Vice Chief of Staff], and Maj. Gen. Alexei

Leonov, Soviet Air Force, the first human to "walk" in space. As the film ended and the lights came on, there arose from the sedate audience of engineers and scientists a sound I have rarely heard -- an ovation of such a timbre and intensity that you knew something deeply felt had been touched in that hard-bitten and tough-minded audience.

Maybe it was possible after all, you got to thinking. (This was 1985, in the height of the Cold War). Maybe these two nations could work together in their common interest. Perhaps they could set aside a little of the mutual paranoia and propaganda, to say nothing of their 55,000 nuclear weapons. We've been conditioned to think that in the "real" world it could never happen, that it's too good to be true. But it had happened in World War II, against a common enemy, and in a small way it had happened in July 1975, with the Apollo/Soyuz linkup that we were celebrating.

That linkup, I knew, had its genesis, in large part, in an idea proposed by Parade back in January 1966. Affirming in an open letter to President Lyndon Johnson that space should be a territory for peaceful exploration, not a battleground, Parade proposed that an American astronaut and a Russian cosmonaut orbit the Earth together in a two-man capsule -- a demonstration of superpower cooperation that would transcend political differences. The response at the time -- from readers and newspaper editors alike -- was overwhelmingly positive. Six years later, in May 1972, President Nixon and Premier Kosygin signed an agreement providing for U.S.-Soviet cooperation in exploring space for peaceful purposes, leading to the 1975 Apollo/Soyuz linkup.

Now, here they were, the veterans of that contact between alien civilizations, describing a mission whose accomplishments, apart from some worthwhile science, were chiefly in the cause of human understanding. There was a hunger in that audience -- as there ~~is~~ was throughout the world -- a longing for the two nations to do something together for a change, something on behalf of the human species, something that would touch greatness. Our powers are so great and our accomplishments so feeble. ~~Think of what we could do together.~~ As the five astronauts and cosmonauts were given relief maps of the Kasei Vallis region of Mars, you heard another stirring ovation, and again the thought arose unbidden: Maybe it was possible after all.

* * *

¶ Tantalizing and majestic, Mars is the world next door, the nearest planet on which an astronaut or cosmonaut could safely land. Although it is sometimes as warm as a New England October, Mars is a chilly place, so cold that some of its thin carbon dioxide atmosphere freezes out at the winter pole. ~~There are pink skies, fields of boulders, sand dunes,~~ and ~~vast extinct volcanos that dwarf anything on Earth, a great canyon that would cross most of the United States, sandstorms that sometimes reach half the speed of sound, strange bright and dark markings on the surface, mountains shaped like pyramids, and other enigmas.~~

1984, #33: "The Case for Mars," Discover 5 (9) (September), 26. Reprinted in L'Europeo, in press. Reprinted in Ark Foundation Peace Anthology (Emeryville, CA), in press. Reprinted in Peacemakers (Seattle: Press for Peace), in press.

[The following has been transcribed from a typescript dated July 20, 1984.]

~~Just next door is another world, tantalizing and majestic.~~

¶ It is the nearest planet whose surface we can see with a small telescope. It is the planet, in all the Solar System, most like the Earth. There have been only two fully successful major missions to Mars: Mariner 9 in 1971, and Vikings 1 and 2 in 1976. They revealed a world of wonders: a deep rift valley on Mars that would stretch from New York to San Francisco; ~~immense and ancient volcanic mountains, the largest of which towers 80,000 feet above the average altitude of the Martian surface, almost three times the height of Mount Everest~~; an intricate layered structure in and among the polar ices, probably a record of past climatic change on Mars; bright and dark streaks painted down on the surface by windblown dust, providing high speed weather maps of Mars over the past decades and centuries; vast globe-girdling dust storms that provided the first clues on nuclear winter, the possible climatic catastrophe that might be triggered by the soot and dust generated by a nuclear war on Earth; and enigmatic surface markings and regularly arrayed

1,116

[4-3-93.atp]

[Now we have a chapter called, for the moment, "Let's Go to Mars Together". . . Let's just call it "Mars," as in the Table of Contents. And in 1984:33, "The Case for Mars" II, which is an insert into there, there's an insert D, which follows:]

Or perhaps 4 billion years ago on Mars -- when conditions were warmer and wetter and the atmospheric pressure higher -- life arose on Mars, as it did in the same epoch on Earth, proliferated, evolved, spread to many locales on the planet, and then, as the climate changed, as the atmosphere thinned, as the soil became dessicated, as the last oceans and lakes dried up, life on Mars became extinct. In that case -- subsurface, safely protected from the ultraviolet radiation that today fries the surface of the red planet -- there may be the chemical or fossil remains of that early life. Perhaps in a rock face exposed by a landslide, or in the banks of an ancient river valley, or in the polar, laminated terrain, key evidence for life on another planet, life different from ours, is waiting.

pyramids on a high plateau -- by no means indicative of some ancient civilization on Mars, but nevertheless worth looking into in further detail. There are hundreds of sinuous channels dating back a billion years or so, and clearly indicating a previous epoch of more benign and Earthlike conditions than prevails in the tenuous and frigid carbon dioxide atmosphere today. There is evidence of abundant near-surface liquid water in the past, ~~great~~ lakes and, perhaps, vast oceans ~~and hints of acrifers [sic in typescript: "aquifers"?], and perhaps even underground lakes, today~~. The "life detection" experiments on Viking were designed to detect only a certain subset of conceivable biologies; the experiments were biased to find the kind of life about which we know. Nevertheless, the fact that no signs of life were determined by a variety of different experiments at two sites 5,000 kilometers apart on a planet marked by global aeolian transport is at least strongly suggestive that Mars may be, today at least, a lifeless planet. But if Mars _is_ lifeless, we have two planets, of virtually identical age, evolving next door to each other in the same solar system: Life evolves and proliferates on one, but not on the other. Why? This is the classic scientific circumstance of the experiment and the control. ~~Or perhaps life~~

Insert D

~~The scientific rewards from further exploration of the Martian atmosphere, surface, and interior are obvious. And there are distinct practical benefits: A better understanding of Mars leads to a better understanding of our own small planet.~~

But ~~there is~~ another reason to explore Mars. Although it is ~~difficult to justify in any detail, many people feel it deeply. There is an exploratory, open-road, outward-bound spirit that has marked us from our hunter-gatherer days. The detailed exploration of an unknown world -- by sophisticated robots, but especially by human beings -- resonates with something profoundly felt in many of us.~~ Insert F, next p. Consider, for example, roving, microbe-free, smart robots, landing in the safe but dull places and wandering to view close-up some of that profusion of Martian wonders. Television images of new terrain and new wonders could grace our home television sets every day for more than a year. The surface area of Mars is almost exactly equal to the land area of the Earth: It provides an ample arena for a new age of exploration.

~~And what of human missions to Mars? Because of their cost,~~ they are very hard to justify on grounds of science. But I could imagine circumstances in which it might be done for other reasons. Suppose the people of the Earth are one day fortunate enough to discover new leaders in Washington and Moscow dedicated to a new beginning; and to seal that new beginning they embark on a dramatic joint enterprise -- something like the Apollo program but with cooperation, not competition, the goal. Major space missions could also ease the transition in the aerospace industry from the present frenzy of military preparations to more benign activities. Could we muster a mission to Mars with human crews for the sorts of money repeatedly allocated for weapons systems?

1, 16

[4-3-93.atp]

[Then in old 1986:8, "Let's Go to Mars Together," p. 5, insert E:]

And new technologies look as if they will permit us to experience what it would be like on Mars without actually going there, until the operators can put a human presence on Mars. If you are the operator, you are helmeted and gloved. You turn your head to the left, the cameras on the Mars rover turn to the left. You take a step forward, the rover walks forward. You reach out your arm to pick up something shining in the soil, the robot arm does likewise. The only difficulty is that this must occur in incredible slow motion, because the round trip travel time of the commands from Earth to Mars and the data from Mars to Earth might take half an hour or more. If the controller was in orbit around Mars or on one of its small satellites, Phobos or Demos, the interaction could occur in real time. Also, the data sent back from Mars could be used in virtual reality. Regions of Mars would be thoroughly characterized in your helmet and gloves and boots. You would walk in an empty room on the Earth, but to you it would be as if you were on Mars, pink skies, fields of boulders, sand dunes stretching to the horizon, enigmatic landforms -- all an exact copy of what is on Mars, from the safety of a virtual reality salon [better word?] in your hometown.

[4-3-93.atp]

No, sending humans to Mars must have a different justification. In the 1980s, it seemed to me a coherent justification was for these two nations that had put the entire planet at risk to show that they could do something cooperatively, something on behalf of the human species, a high-technology endeavor that would give hope to people all over the planet. We imagined a kind of Apollo program in reverse, in which cooperation, not competition, was the objective, in which the two leading spacefaring nations would together lay the groundwork for a major advance in human history -- the eventual settlement of another planet.

~~[extracted from "The Gift of Apollo" (2, 2/20/93)]~~

~~[An insert:]~~ Insert O

But why Mars? Why not return to the Moon? It's much closer, and we've proved we know how to send people there.

Yes, but I'm concerned that the Moon is a long detour, if not a dead end. We've been there. We've even brought some of it back. People have seen the Moon rocks, and, for reasons that I believe are fundamentally sound, they are bored by the Moon. It is a static, airless, waterless, dead world.

Mars, by contrast, has weather, dust storms, its own moons, ~~immense~~ volcanoes, ~~seasonally varying~~ polar ice caps, enigmatic landforms, and ancient river valleys indicating that massive climatic change has occurred on a once-Earthlike world. ~~Mars~~ It ~~also~~ holds some prospect of past or possibly even present life. None of this is true for the Moon. Nor is the Moon an especially desirable test bed or way station for Mars. The Martian and lunar environments are very different, and the Moon is as distant from Mars as is the Earth. The machinery for Martian exploration can ~~better~~ at least equally well be tested in Earth orbit, or on near-Earth asteroids, or on the Earth itself.

Among these many wonders and delights are the channels. The surface of Mars is covered with hundreds of ancient river valleys, carved out in a more clement time when liquid water flowed across the Martian landscape. Not only were there rivers then, but also lakes and (possibly) oceans. When, in 1976, the two Viking landers set down on Mars, no sign of life was uncovered -- no footprints, no artifacts, no trees or bushes or desert coneys or microbes, not even so much as a complex organic molecule. But what seems certain is that a billion years ago, when the waters flowed, the chances of life were much greater on that wetter and warmer Mars. If we could wander down one of the sinuous valleys and examine the geological stratifications in the banks, we might discover much -- about climate change and the origin and evolution of life, and about the comparative developments of sister worlds.

Mars beckons, a storehouse of scientific information -- important in its own right but also for the light it may cast on the environment of our own planet. If Mars once had abundant liquid water, what went wrong? How did an Earthlike world become so parched, frigid, and comparatively airless? Is there something here we should know about our own planet?

Insert D

We humans have been this way before. The ancient explorers ~~Christopher Columbus~~ would have understood the call of Mars. But mere scientific exploration does not require a human presence. We can always send smart robots. They are far ~~much~~ cheaper, they don't talk back, ~~and you can take more~~ you can send them to much more dangerous places, and you don't risk human lives. Insert E

Insert F

any one nation would be still smaller.

But why a joint mission to Mars? Why not jointly feed the hungry in sub-Saharan Africa, or do water reclamation projects in Bangladesh? The United States and the Soviet Union could, if they chose, together help house, educate, provide medical care for, and make increasingly self-reliant every citizen of the planet. But the U.S. and the U.S.S.R. have no such precedent; they have been obsessed by the pursuit of short-term competitive advantages. The political realities, sadly, are that a joint mission to Mars, like Apollo/Soyuz, is well within the realm of practical possibility, while many worthy and more mundane activities are not. Not yet. But a major cooperative success in space can serve as an inspiration and spearhead for joint enterprises on Earth.

~~Moreover, space missions have an important subsidiary advantage: They~~ Such a program would use precisely the same aerospace, electronics, rocket, and even nuclear technologies as ~~does~~ did the nuclear arms race. There is a perception, enunciated most clearly by President Dwight Eisenhower in his farewell address, that the marriage of high technology and the military establishment creates an arms-race juggernaut that is almost impossible to turn off and that may destroy us all. An alternative program using the same industries and some military skills for peaceful purposes might be a very good thing; it is foolish to have powerful vested interests -- jobs, careers, profits, dividends --

mainly dependent upon a continuing arms race. Expeditions to the planets use the same high technology, and the traditional military virtues of organization and valor, in a humane and benign cause.

Voyages by humans to Mars simultaneously engage many different constituencies: technological, scientific, exploratory, military, and industrial, as well as the many who wish to see significant, balanced cooperation between the United States and the Soviet Union. Some people feel the lure of Mars simply as the future calling. A joint Mars project excites both visionaries and practical engineers, crosses national and ideological boundaries, and even -- as I discovered at a meeting of scientists and world religious leaders in Italy -- has a powerful and ecumenical religious appeal. There is, it seems, a tide rising.

House-Senate Joint Resolution 236, spearheaded by Sen. Spark Matsunaga of Hawaii, was passed by both houses of Congress and signed into law by President Reagan on October 30, 1984 (Public Law 98-562). It explicitly describes joint U.S./Soviet activities in space as an alternative to "an arms race in space, which is in the interest of no one." Subsequent resolutions proposed in the Senate by Matsunaga discuss "joint East-West Mars-related activities, including an unmanned Mars sample return and all activities that might contribute to an international manned mission to Mars."

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[4-3-93.atp]

[In 1984:33, "The Case for Mars," insert G, p. 4:]
We succeeded in interesting Soviet scientists in such a joint endeavor. Roald Sagdeev, then director of the Institute for Space Research of the Soviet Academy of Sciences in Moscow, was already deeply engaged in international cooperation on Soviet robotic missions to Venus, Mars, and Halley's Comet, long before the idea was fashionable. The use of the Soviet _Mir_ space station and the _Saturn V_-class Soviet launch vehicle _Energiya_ made cooperation attractive to the Soviet organizations that manufactured these items of hardware and that were otherwise having difficulty justifying their wares. Through a sequence of arguments, the end of the Cold War being chief among them, then-Soviet President Mikhail S. Gorbachev was convinced. At the 198x Washington summit, Gorbachev -- asked what was the most important joint activity by which the two countries could make a clear change in their relationship -- unhesitatingly replied, "Let's go to Mars together."

But the Reagan Administration was not interested. Cooperating with the Soviets, using Soviet technology that was more advanced than American technology, making some American technology available to the Soviets, sharing credit, providing an alternative for the arms manufacturers -- these were not to their liking. The offer was turned down. Mars would have to wait.

[4-3-93.atp]

But in only a few years times have greatly changed. The Soviet Union is no more. The Cold War is over. The argument about the importance of the two nations working together has lost at least some of its force. Other nations -- especially Japan and the European Space Agency -- have become spacefaring nations. There are other just and pressing demands on the discretionary budgets of all these nations.

But the _Energiya_ heavy-lift vehicle and the _Mir_ space station still exist. Despite considerable political turmoil, the Russian space program continues vigorously. Cooperation between Russia and America in space is accelerating. U.S. astronauts will visit _Mir_. Russian cosmonauts will fly on a shuttle. An American instrument is to be carried by a Soviet space vehicle to Mars. Russian scientists are experimenters on the American Mars _Observer_ orbiter. The American and Russian capabilities in space science and technology mesh, interdigitate. Cooperation between the two programs is a marriage made in heaven -- but one still surprisingly difficult to consummate. The first human mission to Mars is now probably too expensive for any one nation to pull off. But a cooperative venture among the United States, Russia, Japan, the European Space Agency -- and perhaps other nations, such as China -- makes sense.

~~Astonishingly, the answer seems to be yes.~~

The symbolism seemed so apt.

~~Those rusting Viking landers represent a symbolic first presence of the human species on another planet. They are reminders of what else is possible for us.~~ The same technology that propels apocalyptic weapons from continent to continent could also enable the first human voyage to another planet, ~~By no means is such a mission to Mars the only -- or in my opinion even the best -- use of the money we could save if we stepped back from the brink of nuclear annihilation. But under certain circumstances, it might represent~~ providing a ~~real~~ choice of fitting mythic power: to embrace either the planet named after, or the madness ascribed to, the ancient god of war.

Insert G

cosmonauts on a close approach to Mars is much easier and just possibly might be launched by 1992. The date is significant -- it is the 75th anniversary of the Russian Revolution.

But 1992 is also the 500th anniversary of Christopher Columbus' discovery of what came, propitiously, to be called the New World. Whatever the original motivations were for the age of exploration that Columbus ushered in, the net result has been, in a painful historical process now nearing completion, the linking of the continents, the unification of the world. What could be more fitting for 1992 than the initiation of an international program for the exploration and eventual settlement of another New World? Perhaps by 1992 the nations would merely begin assembling in low Earth-orbit the components of the spacecraft that will take the first humans to Mars. By 1992, the U.S. Space Station is supposed to be ready.

If we take this path, there will come a time -- perhaps ~~at~~ in the first decade or two ~~the dawn~~ of the new century and the new millennium -- when ~~the~~ an interplanetary spacecraft will be assembled in Earth orbit, the progress in full view on the evening news. Astronauts and cosmonauts, hovering like gnats, will guide and mate the prefabricated parts. The day will come when the ship is tested and ready, boarded by its international crew, and boosted to escape the Earth's gravity. For the whole of the voyage to Mars and back, the lives of the ~~American~~ crew members will depend on each other, ~~their Soviet counterparts and vice versa~~, a microcosm of the actual situation down here on Earth. Perhaps the first joint manned (and womanned) mission will be only a flyby of Mars. ~~Perhaps~~ Robot vehicles will ~~then (or earlier)~~, with aerobraking, parachutes and retrorockets, have gently set down on the Martian surface to collect samples and return them to Earth. But eventually ~~-- around 2001 if we wish it --~~ humans will set foot on the planet Mars. It is only a matter of when.

According to solemn treaty, signed in Washington and Moscow on January 27, 1967, and ratified by the Senate and the President, no nation may lay claim to part or all of another planet. Nevertheless -- for good historical reasons that Columbus would have understood well -- people are concerned about who first sets foot on Mars. If this really worries us, we can arrange for the ankles of the ~~American and Soviet commanders~~ crew members to be tied together as they alight in the gentle Martian gravity.

~~But there would be much to do besides making symbolic gestures.~~ The crews would acquire new and previously sequestered samples, in part to search for life, in part to understand the past and future of Mars and Earth. They would experiment, for later expeditions, on extracting water, oxygen, and hydrogen from the hydrated rocks and sand and from the underground permafrost -- to drink, to breathe, to power their machines and, as rocket fuel, for the return to Earth. They would test out Martian materials for eventual bases and settlements on Mars.

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[4-3-93.atp]

Insert N into 1986:8, "Let's Go to Mars Together," p. 12: Once some of us are out there on the planets, living off the land, bringing up new generations of humans on other worlds, something will have changed forever in human history. In the long term we will have bases and homesteads on asteroids and moons throughout the Solar System, until, tiptoeing through the Oort Cloud, comet to comet, we will be on our way to the stars. This is of course a very long-term enterprise. We may not see the first footfall of humans on another planet in our lifetimes. It does not imply abandoning the Earth; the Earth is not a disposable planet, and for a very long time into the future only a small fraction of the human species will be out there. But in the long run, unless we destroy ourselves, we will go. The Universe extends, for all practical purposes, forever. After a brief hiatus in our global, technical civilization, we will resume our ancient nomadic way of life. Our remote descendants, arrayed on many worlds throughout the Solar System and beyond, will look back to our time as a key nexus in the development of our species and will remember those who made it possible. [Use this to end chapter? To end book?]

peaceful, more cooperative, more forward-looking, and more humane planet Earth." -- Thomas Paine, Chairman, U.S. National Commission on Space and former NASA Administrator, at the American Institute of Aeronautics and Astronautics/Planetary Society Conference, "Steps to Mars," Washington, D.C., July 16, 1985

* * *

BOX:

Astronauts: Envoys of Mankind

In the 1967 Outer Space treaty, the United States and the Soviet Union pledge not to introduce nuclear or other weapons of mass destruction in Earth orbit or on any other celestial body. The treaty prohibits military bases or weapons testing of any sort on the Moon and planets. The nations are to "facilitate and encourage international cooperation" in the scientific exploration of the Moon and planets and "shall regard astronauts as envoys of mankind." Joint activities on other planets are explicitly encouraged by Article 1 of the treaty, which reads in its entirety: "The exploration and use of outer space, including the Moon and other celestial bodies, shall be carried out for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development, and shall be the province of mankind."

* * *

BOX:

What You Can Do

The 100,000-member Planetary Society has been a leading advocate of joint human exploration of Mars. This organization is entirely membership-supported. For further information about the Society and its Mars Fund, write:

• The Planetary Society, Dept. P, 65 N. Catalina Ave., Pasadena, CA 91106.

Letters about joint human exploration of Mars should be sent to the National Commission on Space, which is currently preparing a recommendation to the President about future U.S. space exploration:

• National Commission on Space, Dept. P, 490 L'Enfant Plaza East, S.W., Washington, DC 20024.

Readers also may write to:

• Sen. Slade Gorton, Chairman, Subcommittee on Science, Technology, and Space, U.S. Senate, Room Hart 427, Washington, DC 20510

• Rep. Bill Nelson, Chairman, Subcommittee on Space Science and Applications, U.S. House of Representatives, Room 2321

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[4-3-93.atp]

[Now we go to what used to be called "Why Send Humans to Mars," your 1991:4, now called (and let's make the appropriate changes of titles in the Table of Contents) "Can We Justify a Human Mission to Mars?": insert I:]

Ever since the United States beat the Soviet Union to the Moon, a coherent justification for humans in space has been lacking. Presidents and Congressional committees became puzzled about what to do about the manned space program. What was it for? Why did we need it? But the exploits of the astronauts and moon landings had excited -- and for good reason -- large numbers of people all over the world. It would be a betrayal of these people and a rejection of that great American technological achievement to back off from manned space flight. Also, the first law of bureaucracy is to guarantee the continuance of the bureaucracy. Left to its own devices, without clear instructions from above, NASA gradually devolved into a program that would maintain jobs and perquisites of power. Pork barrel politics became an increasingly powerful motivator. NASA had lost its way.

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[4-3-93.atp]

[Now insert H:]

And yet the Space Exploration Initiative, despite clear direction from the top, went exactly nowhere. Four years after it was mandated, it does not even have an office at NASA dedicated to it. Small and inexpensive lunar robotic missions -- that otherwise might well have been approved -- were canceled by Congress because of guilt by association with SEI. What went wrong?

One problem is the time scale. SEI extended. . .

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[4-3-93.atp]

[Insert J:]

Third, the program was conceived exclusively in nationalist terms. Cooperation with other nations was not fundamental to the design or execution of the program. Vice President Quayle, who had some nominal responsibility for space, justified the space station as a demonstration that the United States was "the world's only superpower." But since the Soviet Union had an operational space station that was a decade or so ahead of the United States, Mr. Quayle's argument proved difficult to follow.

[~~Broca~~ II, draft 1, 8/12/92]

Can We Justify A Human Mission to Mars?

~~1991, #4: "Why Send Humans to Mars?," Issues in Science and Technology, Spring 1991, 80-85.~~

Insert I

On July 20, 1989, the twentieth anniversary of the Apollo 11 landing on the Moon, President Bush announced a long-term direction for the U.S. Space Program. Called the Space Exploration Initiative (SEI), it proposed a sequence of goals that includes a space station, a return of humans to the Moon, and then the first landing of human beings on Mars. In a ~~more recent~~ later statement, Mr. Bush ~~has~~ set 2019 as the target date for the first footfall on that planet. Insert H

~~SEI has been criticized first with regard to continuity of commitment. It extends~~ five or so presidential terms of office into the future, assuming the average presidency is one and a half terms. That makes it easy for a President to attempt to commit his successors, but leaves in ~~question~~ considerable doubt how reliable such a commitment might be.

Second, there ~~is~~ was concern about whether NASA, which had recently experienced great difficulty lifting a few astronauts 200 miles above the Earth -- as well as other well-publicized problems -- ~~can~~ could safely send astronauts on an arcing year-long trajectory to a destination 100 million miles or more away.

Insert J

And finally, there ~~is~~ was the question of where, in terms of practical politics, the money ~~is~~ was supposed to come from. The costs for SEI have been variously estimated, ranging as high as

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[4-3-93.atp]

[Insert L:]

For all these reasons, SEI was a non-starter. It was stillborn. There was no effective attempt by the Bush Administration to spend political capital to get SEI going.

The lesson to me seems clear: There may be no way to send humans to Mars in the comparatively near future -- despite the fact that it is entirely within our technological capability. If we are able to go, the mission must be international from the beginning, with costs and responsibilities equitably shared; the cost must be made much less; the time from approval to launch must fit within practical political time scales; and NASA must demonstrate a significant improvement in its recent ability to muster pioneering exploratory missions with human crews safely, on time, and on budget. If it were possible to imagine such a mission for less than $100 billion, and for approval to launch taking less than 15 years, maybe such a mission would be feasible. (In terms of cost, this would represent only a small fraction of the budget of the present spacefaring nations over the interval of time suggested.) And it's beginning to look as if both this budget and this time scale might be practical.

But the cheaper and quicker the mission is, necessarily the more risk we must be willing to take with the lives of the astronauts and cosmonauts aboard. And no budget, no timeline can be really reliable when we attempt to do something on such a grand scale that has never been done before. The more leeway we ask, the greater is the cost and the longer it takes to get to Mars.

It's not enough to go to Mars because some of us have dreamt of doing so since childhood, because it seems to us the obvious long-term exploratory goal for the human species. If we're talking about spending this much money, we must justify the expense. And if we cannot do so, we should not go.

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[4-3-93.atp]

[Insert K into 1991:4, p. 2:]

~~So~~ whether you pre-emplace supplies from Earth and only launch humans to Mars if the supplies are safely landed; whether you plan to use Martian materials to generate oxygen to breathe, water to drink, and rocket fuel and propellants to get home; whether you land using the thin Martian atmosphere for deceleration;

$500 billion.

No. 11 ~~I would like to stress that it is~~ Of course, it's impossible to estimate costs before you have a mission design. And the mission design depends on such matters as the size of the crew; the extent to which you take mitigating steps against possible solar and cosmic radiation hazards, or zero gravity; and what risks you consider acceptable with the lives of those men and women on board. Other relevant uncertainties

Segment K

are the amount of redundancy in equipment; the extent to which you want to use closed ecological systems or just depend on the food, water, and waste disposal facilities you've brought with you from Earth; the design of roving vehicles for the Martian landscape; and what technology you carry to test the ability to live off the land for later voyages.

Clearly, these issues powerfully affect cost, and until they are decided it is absurd to accept any figure for the cost of the program. On the other hand, it ~~is~~ was equally clear that the program ~~will~~ would be extremely expensive. Segment L

~~The Call of Mars~~

For me, Mars has been calling since childhood. Voyages to other worlds seem to me the natural continuation of the long history of human exploration. The Earth itself, except for the sea bottoms, is now all explored. At this same moment, our technology permits us to go to other worlds. So of course that's where we'll go, sooner or later.

In the long term, self-sustaining human communities on other worlds would be a step more significant than the colonization of the land by our amphibian ancestors some 500 million years ago, and the descent from the trees by our primate ancestors some 5 to 10 million years ago. It would be a transforming event in human history, in the history of life on Earth. But that doesn't mean it has to happen today. It will also be a transforming event if it happens 100 years from now.

I have been advocating human missions to Mars with some vigor since 1984. With the Planetary Society's "Mars Declaration" it became clear that a stunningly ecumenical group of American leaders also supported such a program, and after a short time we found that the Soviets were embracing it as well. Human exploration of Mars is prominent in the 10 stated long-term technological goals of the U.S.S.R., and President Gorbachev on a number of occasions has announced that he would like to pursue it jointly with the United States.

What I had in mind, in the height of the Reagan "evil empire" days, was to establish a common constructive goal for the nuclear superpowers as a means of binding the two nations together, and sharing a purpose of truly historic proportions. The trouble is that the world has not remained static. New developments have emerged. The first is that the U.S. and Soviet economies are in much worse shape than was generally recognized in the Reagan years, and either nation's ability to spend

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enormous amounts of money on such a goal is now a relevant question.

Also, a joint human mission to Mars was promoted as a way of creating a shared and worthy goal for the two Cold War adversaries; but the Cold War is now over. In fact, U.S./Soviet relations have recently been at their warmest point since the end of World War II. The two nations still have some 55,000 nuclear weapons between them, though, 25,000 of which are in hair-trigger readiness; and it is therefore possible that benign shared objectives extending decades into the future are still very important for the well-being of the global civilization.

I don't believe that the increased budgetary problems and the thawing of the Cold War are significant enough changes to actually scuttle the case for going to Mars. But they do work, at least incrementally, to weaken the argument.

¶ ~~My own chief misgiving is that~~ There are now other matters -- clear, crying national needs -- that cannot be addressed without major expenditures; while, at the same time, there is an extremely limited discretionary federal budget. Such matters include the disposal of chemical and radioactive wastes, energy efficiency, alternatives to fossil fuels, declining rates of technological innovation, the collapsing urban infrastructure, the AIDS epidemic, homelessness, malnutrition, infant mortality, education -- there is a painfully long list, and money is needed to address all of these matters, which endanger the well-being of

1,17?

[4-3-93.atp]

Insert M; "I'll indicate where it goes":

(I can't get it out of my head -- that with the money stolen in the U.S. Savings and Loan scandal, we could have gone to Mars and opened a new kind of future for the human species.)

the nation.

Nearly every one of these matters could cost hundreds of billions of dollars, or more, to address. Indeed, alternatives to the fossil-fuel economy clearly represent a global multitrillion-dollar investment, if we can do it. And every now and then there are unexpected little fiscal perturbations provided by private and public corruption, such as the savings and loan scandal. M

~~Saving Money~~

If there were 20 percent more discretionary funds in the U.S. federal budget, or those of other nations, I probably would not feel so worried about advocating such enormous expenditures in space. If there were 20 percent less, I don't think the most diehard space enthusiast would be advocating anything like ~~SEI~~ a human mission to Mars. If, to take a more extreme example, half the people in the Sudan are in immediate danger of starvation, a conscientious board of directors of the Khartoum Art Museum will not be advocating increased government expenditure to purchase art -- no matter how convinced they are of the social benefits of art. You can have life without art, but not vice versa. Surely there is some point at which the national economy is in such dire straits that sending people to Mars is unconscionable. The only difference there might be between me and other enthusiasts for human missions to other worlds is where we draw the line. But surely such a line exists, and every participant in such a debate should stipulate where that line should be drawn, what fraction of the ~~GNP~~ gross national product for space is too much.

If we're talking about a relatively minor increment to the NASA budget in order to accomplish SEI, then perhaps it's inappropriate to make zero-sum arguments. But if we advocate, say, $300 billion spent for SEI, that's $300 billion unavailable for other pressing national needs. That amount is essentially the present NASA budget devoted exclusively to SEI for the next 20 years. If the cost of SEI is to be added on, then we're talking about doubling the NASA budget.

So if we are convinced that sending humans to Mars is important for the human future, the key to getting there is to save money. For example, some propose that with alternative technologies and more lenient bureaucratic restrictions, quick, dirty, and incredibly cheap missions of humans to the Moon and Mars are possible. In the review panels I'm familiar with -- including the White House/National Space Council "Blue Ribbon" Committee on the President's Human Exploration Initiative, as it was then (November 1989) called -- such proposals have been thought stimulating but somewhere between unconvincing and specious. Nevertheless, there might be new technologies, missed by a hidebound NASA, that could produce enormous savings. If such technologies are mature and accessible, they may be critical in sending humans to Mars in the next few decades.

Failing this, the only way for the United States to go is to do it cooperatively. NASA would then commit to something like SEI, but scale back substantially on such technologies as space stations and heavy-lift vehicles, where substantial capability is in hand in other countries -- especially, the Soviet Union. If the cost of going to Mars were shared equally among, say, the Soviet Union, the European Space Agency, Japan, and the United States, the cost for each nation might become low enough for the project to be feasible. Without such cooperation, the program may remain wholly infeasible.

I must confess to being perplexed by those who assert that such cooperation can never be accomplished, or if it can, we will not save any money because of interface and communications problems. If this is the only way we can get to Mars, we should be devoting substantial technical, bureaucratic, and social resources to finding ways to resolve such difficulties. If the Cold War could be made to wind down, if some semblance of true democracy could be introduced in Eastern Europe, we can solve interface and communications problems.

~~The Standard Justification~~

But beyond discussions of costs, even reduced costs, we must also identify benefits. And since there are major and valid social and environmental demands on the discretionary federal budget, it seems to me that advocates of ~~SEI~~ such a mission have to address

~~1,16~~ OR 1,17

[4-6-93.at2]

1991:4, "WHY SEND HUMANS TO MARS?" (PP. 8, 9)

[There's a place -- maybe it's in "Explorers" -- where we're talking about the alleged spinoff benefits of NASA. I listed some technologies -- cardiac pacemakers, stickless frying pans -- that allegedly were produced by NASA technology, but they weren't. Add: ballpoint pens.]

[After the pacemaker remark, put:] (I had the opportunity A to talk with the inventor of the cardiac pacemaker, who himself almost had a coronary in describing to me the injustice of giving NASA the credit for his invention.)

[And let's add the following:]

Of course it would be impossible for so much new B technology to be developed as is necessary for NASA and not to have some spillover into the general economy, some inventions useful down here. There have been some, but they hardly justify doing what NASA does. We could see the same thing in the waning days of the Reagan-era Star Wars office. X-ray lasers on orbiting battle stations will help develop laser surgery, it was argued. If we need laser surgery, I say, by all means let's allocate the funds for it. But leave Star Wars out of it. Spinoff justifications for a government program constitute a clear admission that that program can't stand on its own two feet, cannot be justified by the purpose under which it was advertised.

The argument is specious for other reasons as well, one of which is that Teflon technology preceded Apollo. The same is true of cardiac pacemakers, ballpoint pens, and other purported spinoffs of the Apollo program. A But the central point here is that if there are some technologies that we urgently need, then spend the money on developing them. Why go to Mars to do it?

¶B Then there is education, an argument that has proved very attractive in the White House. Doctorates in science peaked somewhere around the time of Apollo 11, maybe even with the proper phase lag after the beginning of the Apollo program. The cause-and-effect relationship is perhaps ~~not~~ undemonstrated but it's not implausible. But so what? If we are interested in improving education, is going to Mars the best route? Think of what we could do with $100 billion in terms of teachers' training and salaries, school laboratories and libraries, scholarships for disadvantaged students, research facilities, and graduate fellowships. Is it really true that the best way to promote science education is to go to Mars?

Another argument is that ~~SEI~~ human missions to Mars will give the military-industrial complex something approaching worthy work, thereby diffusing the temptation to use its considerable political muscle to exaggerate external threats and pump up defense funding. The other side of this coin is that by going to Mars we maintain a standby technological capacity that might be important for future military contingencies. Of course, we might simply ask those

, alluded to earlier,

guys to do something directly useful for the civilian economy. But as we saw with Grumman buses and Boeing/Vertol commuter trains, the aerospace industry experiences real difficulty in producing competitively for the civilian economy.

There are other justifications offered ~~for SEI~~. It is argued that the ultimate solution to world energy problems is to strip-mine the Moon down to a depth of a few microns, return the solar-wind-implanted Helium-3 back to Earth, and use it in fusion reactors. What fusion reactors? Even if this were possible, it is a technology 50 or 100 years away. Our energy problems need to be solved at a less leisurely pace.

Even stranger is the argument that we have to send human beings into space in order to solve the population crisis ~~on Earth~~. But 250,000 more people are born than die every day -- which means that we would have to launch 250,000 people per day into space to maintain the present world population. This appears to be somewhat beyond NASA's present capability.

Finally, there is a set of less tangible arguments, many of which, I freely admit, I find attractive and resonant. The idea of an emerging cosmic perspective, of understanding our place in the Universe, of a highly visible program affecting our view of ourselves -- this might have extremely important benefits for us in clarifying the fragility of our planetary environment and in recognizing the common peril and responsibility of all the nations and peoples of Earth. ~~The first~~ ~~SEI~~ would provide exciting, as I argued above,

And human missions to Mars

exploratory, adventure-rich, and hopeful prospects for young people who are ordinarily provided by the mass media and by the incompetence and corruption of politicians with the most dismal view of what their future might be.

I've also mentioned the importance -- somewhat diminished with the end of the Cold War, but still very great -- of binding the spacefaring nations ~~United States and the U.S.S.R.~~. in a grand, long-term common endeavor.

And then there's ~~is~~ the "because-it's-there" argument: Mt. Everest explored by robots would have aroused minimal public enthusiasm, but when humans first conquered it, that was another story. Maybe. But robotic technology is going to make enormous progress in the next few decades. Imagine, for example, comprehensive data from several sites on Mars used to construct a Martian virtual reality -- so that many people on Earth could have the visual and tactile sensation of walking on and exploring Mars. With appropriate data processing, it is possible that robotic missions will, by 2019, generate public appeal fully competitive with human missions.

Another argument, used by President Bush, suggests that it is human destiny, manifest destiny, or maybe just American destiny to go to other worlds. Well, it's a very brave person who claims to know what is written in the book of destiny. This is essentially a religious argument, and not everyone is an adherent of ~~this~~ the faith.

When I run through such a list and try to add up the pros and cons, bearing in mind the other urgent demands on the federal budget, to me it all comes down to this question: Can the sum of a large number of individually inadequate justifications and some powerful but intangible justifications add up to an adequate justification?

I don't think any of the items on my list of purported justifications is demonstrably worth $500 billion or even $100 billion, certainly not in the short term. On the other hand, every one of them is worth something and if I have 10 items and each of them is worth $~~5~~10 billion, maybe it adds up to $~~5~~100 billion. If we can be clever about reducing costs and making true international partnership work, the justifications become more compelling. I don't know how to do this arcane calculus, but ~~it seems to me~~ that this is the kind of issue we ought to be addressing.

~~Steps for the Here-and-Now~~

Until a national debate on this topic has transpired, until we have a better idea of the rationale and the cost/benefit ratio of ~~SEI~~ human missions to Mars, what should we do? My suggestion is that we pursue ~~R&D~~ research and development projects that can be justified on their own merits or their relevance to other goals, ~~and~~ but that can also contribute to human missions to Mars ~~[sic in published article~~] should we eventually decide to go. Such an agenda would include:

• U.S. astronauts on the Soviet space station Mir for joint flights of gradually increasing duration, aiming at one to two years.

• Reconfiguration of the proposed U.S. space station Freedom to study the long-term effects of the space environment on humans, and make maximum use of knowledge gained from Mir.

• Early implementation of a rotating or tethered "artificial gravity" module on Mir or Freedom.

• Enhanced studies of the Sun, including a distributed set of probes in ~~heliocentric~~ orbit about the Sun, to monitor solar activity and give the earliest possible warning to astronauts of hazardous solar flares.

• Development of a nonreusable heavy-lift vehicle. Present launchers cannot even duplicate the successes of the 1976 Viking and the 1977 Voyager missions, and the shuttle is inadequate and unsafe as the workhorse for ~~SEI.~~ such a Mars mission.

• U.S./~~Soviet~~ Russian and multilateral development of Energiya technology for the U.S. and international space programs. Although the United States is unlikely to depend primarily on a Soviet booster rocket, Energiya has roughly the lift of the Saturn V that sent the Apollo astronauts to the Moon. The United States let the Saturn V assembly line die, and it cannot readily be resuscitated. ~~The U.S.S.R.~~ Russia is eager to sell Energiya technology for hard currency.

• Vigorous pursuit of joint projects with NASDA (the Japanese space agency) and Tokyo University; the European Space Agency; and ~~GLAVCOSMOS [GLAV-COSMOS?]~~ (the ~~Soviet~~ Russian Space Agency) ~~and the U.S.S.R. Academy of Sciences~~; along with Canada and other nations. In many cases these should be equal partnerships, not the United States calling the shots. They could range from joint working groups for choosing landing sites on Mars to joint missions in low-Earth orbit. One of the chief objectives should be to build a tradition of cooperative competence.

• Technological development -- using state-of-the-art robotics and artificial intelligence -- of rovers, balloons, and aircraft for the exploration of Mars, and implementation of the first international rover/return sample mission.

• Vigorous pursuit of new technologies such as constant-thrust propulsion to get us quickly to Mars; this may be essential if the radiation or microgravity hazards make one- to two-year flight times too risky.

• Intensive study of near-Earth asteroids, which may provide preferable intermediate-timescale goals for human exploration than does the Moon.

• A greater emphasis on science -- including the fundamental sciences behind space science, and the thorough reduction and analysis of data already obtained -- by NASA and other space agencies.

These ~~The above~~ recommendations add up to a tiny fraction of the full cost of a human mission to Mars, ~~SEI~~, but if implemented, they would help us to make accurate cost estimates and better assessment of its ~~SEI's~~ dangers and benefits. They would permit us to maintain a vigorous pace toward human missions to Mars without prematurely committing to the specific hardware of those missions. Most, perhaps all, of these recommendations have strong justifications, even if we were sure we were unable to send humans to any other planet in the next few decades.

In the meantime, the most important step we can take toward Mars is to make significant progress on Earth. Achieving even modest improvements in the serious social, economic, and political problems that our global civilization now faces could release enormous resources, both material and human, for furthering space exploration and other worthy goals.

exploration, turning hatred and suspicion into cooperation suggests a hopeful answer.

During the Washington summit last December, General Secretary Gorbachev was asked what could be done to heal the wounds that divide our two nations. His immediate answer was a joint U.S./Soviet human expedition to Mars. With prior and subsequent endorsements of the idea by leading Presidential candidates of both parties, a bill passed by the House to begin establishing the bureaucratic machinery for joint Mars exploration, and a stunningly ecumencial range of American leaders signing the Mars Declaration, there seems to be a chance of actually achieving this dream in the next two decades.

There's plenty of housework to be done here on Earth, and our commitment to it must be steadfast. But we're the kind of species that needs a frontier. Every time humanity stretches itself, turns a new corner, it receives a jolt of productive vitality that can last for centuries or millennia.

There's a new world next door. And we know how to get there.

1991, #6: "When Worlds Collide," _Parade_, March 3, 1991, 4-6. Reprinted in _SIRS_ (Social Issues Resource Series) _Science Series_: _Physical Science_, in press. Reprinted in _Abril_ (Rio de Janeiro), in press.

[Photograph captions:]

"Sometime in the 21st century: As a small asteroid passes nearby, it is greeted by explorers from Earth. An astronaut peers into a large crater produced by an ancient collision. If an asteroid this size or larger were to hit the Earth, the consequences would be catastrophic. There are, however, steps we can take to prevent it. (Painting by Don Davis.)"

"Mimas, a moon of Saturn. The impact that excavated the large crater Herschel nearly blew Mimas to bits. (_Voyager 1_ photograph.)"

"The rings of Saturn seen be _Voyager 1_. Ring material may have been produced when moons were shattered in collisions with comets."

"A collision between a rocky and an organic-rich asteroid in the main asteroid belt. A few of the fragments may eventually strike the Earth, where they are called meteorites. (Painting by William K. Hartmann.)"

[Heading above title on page 4, in all caps:] "The Beginnings and Ends of Worlds"

~~[Text of article; quotation marks omitted:]~~

There's something funny about Saturn. When, in 1610, Galileo used the world's first astronomical telescope to view the planet -- then the most distant world known -- he found ~~something very peculiar. There~~ what seemed to be an appendage on either side. ~~which~~ He likened them to "handles" and other astronomers to "ears." The Cosmos holds many wonders, but a planet with jug ears ~~was~~ is perplexing. Galileo went to his ~~death~~ grave with this bizarre matter unresolved.

As the years passed, observers found the "ears" dwindling and then reasserting themselves. Eventually, it became clear that what Galileo had discovered was a thin ring, which surround~~ed~~s Saturn at its equator but touche~~d~~s it nowhere. In some years, because of the changing positions of Earth and Saturn in their orbits, the ring had been seen edge-on and seemed to disappear. In other years, it had been viewed more face-on, and the "ears" grew bigger. But what ~~was it~~ does it mean that there's a ring around Saturn? A flat, solid plate with a hole cut out for the planet to fit into?

We now know that the rings of Saturn are a vast horde of tiny worlds, each on its separate orbit, each bound to Saturn by the giant planet's gravity. In size, these worldlets range from particles of fine dust to houses. They are spaced out in an exquisite set of concentric rings first revealed in their true majesty by the two <u>Voyager</u> spacecraft in their 1980/81 flybys. In our century, the

Art Deco rings of Saturn have become emblematic of the future.

In the late 1960s, at a scientific meeting, I was asked to summarize the outstanding problems in planetary science. One, I offered, was the question of why, of all the planets in the Solar System, only Saturn had rings. This, it turns out, is a nonquestion. No one then knew that <u>all</u> <u>four</u> giant planets in our Solar System -- Jupiter, Saturn, Uranus, and Neptune -- in fact have rings.

Each ring-system has distinctive features. Jupiter's rings are tenuous and made mainly of dark particles the size of those in cigarette smoke. The bright rings of Saturn are composed mainly of frozen water and could be described as made of snowballs or ice balls; ~~Saturn has~~ there are thousands of separate rings; here some twisted, exhibiting strange, dusky, spokelike markings that form and dissipate. The dark rings of Uranus seem to be composed of elemental carbon and organic molecules -- something like charcoal or chimney soot; Uranus has nine main rings, a few of which sometimes seem to "breathe," expanding and contracting. Neptune's rings are the most tenuous of all, varying so much in thickness that, when detected from Earth, they appear only as partial arcs and not complete circles. Each ring-system displays an ~~austere~~ its own, appropriately unearthly beauty.

How do rings form? One possibility ~~is connected~~ has to do with ~~the~~ tides: If an errant world passes close to a planet, its near side is gravitationally pulled toward the planet more than its tied to the deep interior, so we know how fast the interior rotates.

This is a blue, dimly lit, chilly, stormy, and remote world -- but, despite all that, Neptune, it turns out, has much to teach us about our own planet.

Surrounding Neptune (like the other three gas giants) is a system of rings, each composed of innumerable orbiting objects ranging in size from the fine particles in cigarette smoke to small trucks. Like the rings of other planets in the Solar System, those of Neptune appear to be evanescent~~; natural~~, because gravity and solar radiation ~~processes~~ would disrupt them in less than the age of the Solar System. This suggests that rings were made more or less "recently" and are not relics from primordial times. But how can rings be made?

~~There are also many moons surrounding the giant planets, and every now and then, by chance, one of the multitude of comets that sweep through the outer Solar System must collide with a small moon.~~ The resulting debris -- ejected from the moon but not so fast-moving as to escape from the planet's gravity -- may form, for a time, a new ring. ~~When we examine the small moons in the Solar System, we find that a number of them have craters almost big enough for the impact responsible to have fractured and splintered the moon.~~ Other, more massive, impacts must have occurred and ~~must have~~ wholly ~~demolished~~ moons ~~-- the fragments of disintegration perhaps, for a time, forming a ring.~~

Insert 1 to When Worlds Collide, p. 4

~~Insert 2 to When Worlds Collide, p. 4~~

~~Redundant; Asteroids~~

far side; if it comes close enough, it can literally be torn to pieces. Another possibility, emerging from the Voyager reconnaissance of the outer Solar System, is this: Rings are made when worlds collide and moons are smashed to smithereens. Both possibilities ~~must~~ may have played a role.

The space between the planets is traversed by an odd collection of rogue worldlets, each of them in orbit about the Sun. A few are as big as a county or even a state; many more have surface areas like those of a village or town. They're called asteroids and comets. The distinction isn't quite clear since old comets, their ices evaporated, look very much like asteroids. There are more little ones than big ones, and they range in size down to particles of dust. Some of them travel on long, stretched-out elliptical paths, which make them cross the orbit of one or more planets.

Quote 1 from An American Ship ... p. 10

~~Quote 2 from An Amer...~~ ~~p. 10~~

Occasionally, there~~is~~'s a ~~moon~~ world in the way. ¶ The collision can shatter and pulverize both the interloper and the region of the moon that's hit. ~~The resulting debris~~ It is made of whatever the colliding bodies were made of, but usually more of the "target" moon than the impacting interloper. If the colliding worlds are icy, the net result will be rings of ice particles; if they are made of organic molecules, the result will be rings of organic particles (which will slowly be processed by radiation into carbon). All the mass in the rings of Saturn could have resulted from the pulverization of one icy moon. The disintegration of smaller moons can account for the ring-systems of the three other giant planets.

Insert ✱ Worlds Collide, p.5

The American planetary ~~scientist~~ geologist Eugene Shoemaker, of the U.S. Geological Survey, proposes that many moons in the outer Solar System have been annihilated and reformed more than once in the 4.5 billion years since the Sun and the planets condensed out of the interstellar gas and dust. The picture that is emerging from the Voyager sweep through the outer Solar System is of worlds whose placid and lonely vigils are spasmodically interrupted by catastrophes from space -- and of worlds reforming from rings and other debris, ~~rising~~ reconstituting themselves like phoenixes from their own ashes.

The biggest moon in the Neptune system is called Triton. It has an atmosphere, somewhat similar to Titan's; but, because the atmosphere and haze are much thinner, we can see Triton's surface. We find a wondrously variegated landscape. This is a world of ice -- methane ice, nitrogen ice, probably underlain by more familiar water ice and rocks. There are impact basins, which seem to have been flooded by the liquefied ice before refreezing; impact craters; long crisscrossing valleys; vast fields of freshly fallen snow; puckered terrain that resembles the skin of a cantaloupe; and more or less parallel, long, dark streaks that seem to have been blown by the wind, despite the thinness of Triton's atmosphere (about 1/10,000th ~~thinner than~~ the thickness of the Earth's atmosphere).

In some places the snow is as bright and white as freshly fallen Antarctic snows (and may offer a skiing experience

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[4-3-93.atp]

An insert into "When Worlds Collide":

A few pages earlier [than p. 12] we refer to Eugene Shoemaker. Let's put in "of the U.S. Geological Survey."

Unless it is very close to its planet, a shattered moon (or at least a fair fraction of it) gradually reaccumulates. The pieces, roughly still in the same orbit about the planet, fall together helter-skelter -- what used to be a piece of the inside is now on the outside, and vice versa. The resulting surfaces might look very odd. Miranda, one of the moons of Uranus, shows disconcertingly jumbled surface features and may have had such an origin. Insert from An Amer. Ship, p. 11. ~~In fact, individual small moons may have been destroyed and reconstituted several times early in the 4.5 billion-year history of the Solar System -- phoenixes repeatedly rising from their own ashes, recycled worlds.~~

On the other hand, a moon that's very close to a planet and gets pulverized cannot reform -- the gravitational tides of the nearby planet prevent it. The resulting debris, once formed and spread out into a ring-system, might be very long-lived.

These ideas~~, derived from Voyager data and championed mainly by Eugene Shoemaker of the U.S. Geological Survey, are~~ are supported by the appearance of a number of satellites in the Solar System. Phobos, the inner moon of Mars, has a large crater named Stickney; Mimas, an inner moon of Saturn, has a big crater named Herschel. These craters -- like those on our own Moon and, indeed, as seen on worlds throughout the Solar System -- are produced by collisions. An interloper smashes into a bigger world and makes an immense explosion at the point of impact. A bowl-shaped crater is excavated, and the smaller impacting object is destroyed. If the interlopers that dug out the Stickney and Herschel craters were only a little larger, they would have had enough energy to blow Phobos and Mimas to pieces. These moons barely escaped the cosmic wrecking ball.

Every time a world is smashed into, there's one less interloper in the Solar System. The very fact that many such collisions have occurred means that rogue worldlets have been largely used up. Those that are on circular trajectories around the Sun, those that don't intersect the orbits of any other worlds, will be unlikely to smash into a planet. Those on elliptical trajectories, those that cross the orbits of other planets, will sooner or later collide or be gravitationally ejected from the Solar System. The planets almost certainly accumulated from worldlets which in turn had condensed out of a great flat cloud of gas and dust surrounding the Sun -- the sort of cloud that can now be seen around nearby younger stars. So, in the early history of the Solar System before collisions cleaned things up, there should have been many more worldlets than we see today.

Indeed, there is clear evidence for this in our own backyard: If we count up the interloper worldlets in our neighborhood in space, we can estimate how often they'll hit the Moon. If we assume there has always been a similar population of interlopers, we can calculate how many craters there should be on the Moon. The number we figure is much less than the number we see on the Moon's ravaged highlands, ~~so~~ The unexpected profusion of craters on the Moon speaks to us of an earlier epoch when the Solar System was in wild turmoil, churning with worlds on collision trajectories. Four billion years ago, the lunar impacts seem to have been hundreds of times more frequent than they are today; and 4.5 billion years ago, when the planets were aggregating and forming, collisions happened perhaps a billion times more often than in our comparatively placid era.

What about the Earth? Why isn't it pockmarked and disfigured like the nearby Moon? Our world must have been pummeled from space like all those others. There are few impact craters left on Earth today, because of efficient erosion by air and water and the great internal engine that moves continents and crinkles up mountain ranges. The most satisfactory explanation of the origin of our own Moon, using knowledge of its chemistry derived from the Apollo missions, is that it was formed more than 4 billion years ago, when a world the size of Mars struck the Earth and spewed out debris, most of which then gradually reaccumulated -- atom by atom, boulder by boulder. Much of the Earth's rocky mantle was reduced to dust and hot gas and blasted into space. If that unknown impacting world had been only a little larger, the result would have been the fragmentation of the Earth. Perhaps there once were other worlds in our Solar System -- good citizens, minding their own business -- hit by some demon worldlet and utterly demolished, and of which today we

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[4-3-93.atp]

Insert R into "When Worlds Collide," p. 8:

The first main-belt asteroid, Gaspara, was photographed by the Galileo spacecraft in 1991 on its tortuous journey to Jupiter. It seems misshapen because its gravity is too low to collapse the odd projection into a sphere. We may be seeing here a world fragmented by past collisions, pieces broken off. Indeed, there are those who think that Gaspara is a double asteroid, two pieces of identical. . . [End of audiotape dated 4/3/93; sentence not continued on fractional successor tape dated 4/5.]

have not even an intimation.

Four billion years ago, our Solar System was a violent and dangerous place in which the chaos may have been relieved by much more flamboyant ring-systems than grace the planets today. If they had moons, the Earth, Mars, and the other small planets may then have been adorned by their own ring-systems.

Today, some of the dwindling supply of worldlets are called asteroids; some, comets; others, small moons. But these are arbitrary categories -- real worldlets may breach these human-made partitions. Some asteroids are rocky, others metallic, still others rich in organic matter. None is bigger than 1,000 kilometers across. They are found mainly in a belt between the orbits of Mars and Jupiter. Astronomers used to think these "main-belt" asteroids were the remains of a demolished world, but another idea is now more fashionable: The Solar System may once have been filled with asteroids, many of which went into building the planets. Only in the asteroid belt near Jupiter did the gravity of this most massive planet prevent the nearby worldlets from coalescing into a new world. Perhaps the asteroids, instead of representing a world that once was and is no more, are the pieces of a world destined never to form.

Going down to about kilometer size, there may be several million asteroids, but that's still far too few, in the enormous volume of interplanetary space, to cause any serious ~~hazard~~ to spacecraft on their way to the outer Solar System. ~~No one has~~

Insert R

, ~~to~~ two pieces in identical orbits.

~~ever photographed an asteroid up close. But the Galileo spacecraft, on its long trajectory to Jupiter, is scheduled to encounter the main-belt asteroid Gaspra on October 29 of this year. No one knows what we will find.~~

Main-belt asteroids mostly stay at home. To investigate them, we must go and visit them. Comets, on the other hand, sometimes come and visit us, as Halley's comet did in 1910 and 1986. Comets are made mainly of ice, plus smaller amounts of rocky and organic material. When heated, the ice vaporizes, forming the long and lovely tails blown outward by the solar wind and the pressure of sunlight. After many passages by the Sun, the ice is all evaporated, sometimes leaving a dead, rocky, and organic world. But sometimes the remaining particles spread out in the comet's former orbit, generating a debris trail around the Sun.

Some disintegrating comets have orbits that cross the Earth. Every time a bit of cometary fluff the size of a grain of sand enters the Earth's atmosphere at high speed, it burns up, producing a momentary trail of light that Earthbound observers call a meteor or "shooting star." But its beauty should not deceive us: There is a continuum that connects these shimmering visitors to our night skies with the destruction of worlds.

A few asteroids now and then give off little puffs of gas or even form a temporary tail, suggesting that they are in transition between comethood and asteroiddom. There are small moons going around the planets that are probably captured asteroids or comets; the moons of Mars and the outer satellites of Jupiter may be in this category. Such bodies aren't spherical, because they are too small; only in large bodies is the gravity enough to make mountains and other projections collapse of their own weight, rounding the world. Gravity smooths down everything that sticks out too far. And, indeed, when we infer their shapes by spacecraft imaging or by ground-based nonphotographic techniques, almost always we find lumpy, irregular, potato-shaped worldlets.

There are about 150 known asteroids whose paths take them near the Earth. They are called, appropriately enough, "near-Earth" asteroids. Almost all of them are only a few kilometers across or smaller and take one to a few years to make one circuit around the Sun. About 10 percent of them, sooner or later, are bound to hit the Earth -- with devastating consequences. But in astronomy, "sooner or later" encompasses billions of years. A 10-kilometer asteroid or comet hit the Earth 65 million years ago and seems to have been responsible for the extinction of the dinosaurs and most other species of life then on Earth, ~~perhaps~~ probably by an "impact winter" -- climatic change induced by collision debris in the high atmosphere, and akin to nuclear winter. ~~Every hundred million years or so, the Earth receives such a catastrophic impact; every hundred thousand years or so, our planet is hit by a body bigger than 1 kilometer across; and every century or so, there's a much smaller collision -- no more powerful than the explosion of a~~

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[4-3-93.atp]

Insert T into "When Worlds Collide," p. 11:

Many near-Earth asteroids, like many main-belt asteroids, are rocky objects. A few are mainly metal, and it has been suggested that enormous financial returns might be implied if we could move such an asteroid into orbit around the Earth and then systematically mine it. Some are rich in organic matter, apparently preserving for us material from the earliest history of the Solar System -- of the sort which fell on the primitive Earth and contributed to the origin of life. Two near-Earth asteroids (see figures) have been found by [Steven? Stephen] Ostro of the Jet Propulsion Laboratory to be double. Perhaps a larger world has broken in two as it passed through the strong gravitational tides of a planet like Jupiter, but more interesting is the possibility that two worlds on similar orbits made a gentle collision and stuck, a process which may have been key to the building of planets and the Earth. The near-Earth asteroids have much to teach us.

~~large nuclear weapon.~~ It might be a good idea for us to know a little more about near-Earth asteroids.

Insert T

Sometimes, we hear about an asteroid making a "near miss" of the Earth. (Why do we call it a "near miss"? A "near hit" is what we really mean.) But then we read a little more carefully, and it turns out that its closest approach to the Earth was some hundreds of thousands or millions of kilometers. That doesn't count -- that's too far away, farther even than the Moon. But if we had an inventory of all the near-Earth asteroids, including those considerably smaller than a kilometer across, we could project their orbits into the future and predict which ones are potentially dangerous. There are an estimated 6,000 of them bigger than half a kilometer across, of which we have actually observed only a few percent.

~~It may not be beyond our ability to bring a large rocket~~ motor to the surface of an errant asteroid and alter its trajectory just enough so it misses the Earth. This is a much better idea than the alternative -- blowing an asteroid to smithereens with a 20-megaton nuclear weapon and hoping that each smithereen burns up while entering the Earth's atmosphere. But ~~we must first know where the asteroid is and where it's headed. In fact, we're not doing a very good job in looking for them~~.

¶ One of the two most successful search programs for near-Earth asteroids has been under way for nearly two decades at Palomar Observatory, under the direction of Eleanor "Glo" Helin of NASA's

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[4-3-93.atp]

Insert S into "When Worlds Collide," p. 12:

Recently the third search program has been organized at the University of Arizona, where David Rabinowitz [check spelling] has begun to find many more small objects near the Earth -- smaller than about 100 meters across -- than almost anyone had suspected.

Jet Propulsion Laboratory; partial support for her research has been contributed by members of the Planetary Society~~, a private organization in Pasadena, California~~. (The other program has been carried out by Eugene and Carolyn Shoemaker.) Insert 5 A much more comprehensive search should be mustered, building on the work of these pioneers.

The near-Earth asteroids have evocative mythological names: Orpheus, Hathor, Icarus, Adonis, Apollo, Cerberus, Khufu, Amor, Tantalus, Aten, Midas, Ra-Shalom, Phaethon, Quetzalcoatl. But there's one of special interest (discovered by Helin), that 's called "Z." ~~doesn't yet have a name~~. ~~(It used to be called 1982DB and now has the numerical designation 4660. Helin, its discoverer, is in the process of choosing a name, with help from Planetary Society members.)~~ In general, it's much easier to get onto and off of near-Earth asteroids than the Moon. "Z" ~~Asteroid 4660~~ is one of the easiest to land on and return home from.

Some humans (all from the former Soviet~~s~~ Union) have already been in space for periods longer than the entire round-trip time to "Z" ~~Asteroid 4660~~. The rocket technology to get there already exists. It's a much smaller step than going to Mars or even than returning to the Moon. It's real exploration of a truly new world, rather than the monotonous orbiting of the Earth at low altitude that is sometimes passed off as space "exploration." ~~And it might not be too soon to start practicing getting to these worldlets and diverting their orbits, should the hour of need ever arrive.~~

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[4-3-93.atp]

Insert U into "When Worlds Collide," p. 13:

[* * *; then:]

The new field of near-Earth asteroids seems forward-looking, constructive, potentially providing deep insights into the origins of our world and ourselves, and possibly of enormous commercial value. And if such objects routinely collide with the Earth and if there's some chance -- even a very small chance -- of a catastrophic collision, our own survival might depend on understanding these objects. It is a natural thought that it might not be too soon to start practicing getting to these worldlets and diverting their orbits, should the hour of need ever arise. Certainly we should be mounting a comprehensive search and characterization of all of them able to do our species harm.

But this aspect of the subject has begun to worry me. I'm concerned that there is a booby-trap in this subject, that we must be very slow and very cautious, and even that there are some technologies that it may be better not to develop. Let me explain:

[New paragraph.]

One of many possible future ~~space~~ missions to "Z" ~~leaves Earth on Christmas Eve of the year 2000~~, takes 10 months to get ~~from~~ there from Earth, ~~to this asteroid~~, spends 30 days there, and then requires only three weeks to return home. ~~, arriving home on Christmas Eve of 2001~~. ~~There are many other possible mission designs, some less demanding on the rocket technology~~. We could ~~do it~~ visit "Z" ~~(earlier and easier)~~ with robots, or -- if we're up to it -- with humans. We could examine this little world's shape, constitution, interior, past history, organic chemistry, cosmic evolution, and possible tie to comets. We could bring samples back for examination at leisure in Earthbound laboratories. We could investigate whether ~~there are~~ commercially valuable resources -- metals or minerals -- ~~on the asteroids~~ there. If we are ever going to send humans to Mars, near-Earth asteroids provide a convenient and appropriate intermediate goal -- to test out the equipment and exploratory protocols while studying an almost wholly unknown little world. Here's a way to get our feet wet again ~~as we~~ when we're ready to re-enter the vast cosmic ocean.

* * *

Insert U

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[4-3-93.atp]

Insert U into "Between Enemies" (which is just a continuation of "When Worlds Collide"), p. 1:

START II is agreed to in principle, although not yet ratified.

[Broca II, draft 1, 8/12/92]

[1/1/93 Vita:] 1992, #32: Between Enemies, Bulletin of the Atomic Scientists 48, May 1992, 24-26. Excerpted in "The World Must Take a Tough Stance on Limiting Nuclear Arms," by Frank Rutter, Vancouver (BC) Sun, May 9, 1992; in "No More Doomsday: Good Ideas About the Future of Nuclear Weapons," Syracuse Post-Standard, May 18, 1992; and in other newspapers.

Our long nuclear nightmare has ended. Or at least, that's the prevailing view. Launchers and warheads are being destroyed, ~~deMIRVing has been announced~~, nuclear testing is down, the Soviet Union is no more, ~~and leading ex-Soviet weapons scientists are, it is said, being offered jobs by the United States~~. The Looking Glass command-and-control aircraft have been mothballed, and the Russians, they say, are taking United States cities off their targeting lists. (The United States has offered no comparable reassurance.) President George Bush proposes reducing the U.S. arsenal below 5,000 warheads and President Boris Yeltsin sees him and raises him -- or rather, lowers him, suggesting half that number. Insert ¶ ~~At least as far as talk goes, w~~ We are witnessing an arms race in reverse.

In light of all this, the dangers of global thermonuclear war are, in almost everyone's estimation, much reduced. ~~But there are still over 50,000 nuclear warheads in the world -- maybe over 60,000. Under the Intermediate-Range Nuclear Forces Treaty, boosters have been retired or destroyed, while warheads~~

~~have been recycled or stored, perhaps for a rainy day. To the best of my knowledge, not a single warhead has yet been destroyed or permanently incapacitated. Don't break out the champagne yet.~~

The U.S. defense budget, still nearly $300 billion a year, is the most obvious source of funding for the urgent domestic problems that have been allowed to fester over four decades of the Cold War. ~~(The U.S. tab for the Cold War is about $10 trillion -- enough to buy everything in the United States except for the land.)~~ Almost all Americans would agree that some U.S. military force, still formidable by world standards, should be preserved for national security. But -- in light of such problems as declining productivity, severe educational deficits, toxic waste, homelessness, inadequate health care, the collapsing infrastructure, AIDS, ozone layer depletion, and global warming -- unless we change our way of doing things, there may not be much left that's worth defending.

All bureaucracies attempt to maintain themselves when their primary mission fades. They invent new tasks, preferably urgent ones, and the resulting inertia becomes especially high when jobs and profits are at risk. The Defense Department, with its laboratories and contractors, tends to inflate possible future perils. The statues of Lenin have not yet been melted down, and already we hear that there may be grave dangers from breakaway ex-Soviet republics, or from fundamentalist Muslims, or China, or -- under certain circumstances -- from Israel. The Japanese are

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[4-3-93.atp]

INTO "BETWEEN ENEMIES," PA

Insert A′ into "Between Enemies," p. 3:

Since there are many fewer large asteroids than small ones, run-of-the-mill collisions with the Earth will be by small objects. ~~But~~ [insert B′] [insert B′: ~~?~~] ~~a~~ A million megatons of TNT is 100 times the explosive yield of all the nuclear weapons on the planet, simultaneously exploded. The destructive energy latent in a large near-Earth asteroid dwarfs anything the human species can get its hands on.

increasingly depicted as a menace. How realistic are these fears, and how large a defense establishment is needed to offset them? And how much of these alleged dangers is a frantic search for some replacement, even if short-term, for our former Cold War adversary?

A credible, sufficiently dangerous enemy is a great convenience for politicians unable to deal with proliferating domestic problems and potential discord. And if such an enemy doesn't exist, it's usually easy enough to arrange for one.

Many methods are being proposed to maintain the weapons establishment -- maybe weaponeers can teach school, or make trains, or interdict drugs while preserving their military aegis. One particularly instructive search for a new enemy can be found in the weapons laboratories' and the Defense Department's Strategic Defense Initiative Organization's recent interest in near-Earth asteroids. ~~asteroids and comets~~.

Insert A'

The inner Solar System is filled with small worlds, some of which intercept the Earth's orbit. It is easy to show that sooner or later one of these objects will hit the Earth, as has ~~happened -- with catastrophic consequences -- in the past.~~ The longer the wait, the more devastating the impact. On average, once a millennium there will be an impact event equivalent to the largest nuclear weapons explosion; every 10,000 years, one that might have global climatic effects; and every million years, an impact event equivalent to a million megatons of TNT that would

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[4-3-93.atp]

Insert C′ into "Between Enemies," p. 3:

Some 50,000 people die every year in the United States alone from highway accidents, and hundreds of thousands from the effects of alcohol and tobacco. Amortized over the waiting time, asteroidal collision does not seem very worrisome.

work a global catastrophe, killing a significant fraction of the human species. Insert B' In 100 million years, as I've said, you can bet on something like the Cretaceous-Tertiary event that seems to have extinguished all the dinosaurs and most of the other species of life on Earth. ~~perhaps by an "impact winter" -- analogous to nuclear winter, but still more severe.~~

However, in this grisly actuarial calculus the equivalent number of annual deaths worldwide is at most in the thousands. With effects amortized, it might be argued that this is far from our most pressing problem. Insert C' If a big impact happens, though, it would be an unprecedented human disaster.

Along parallel and only weakly interacting tracks, the planetary science community and the military, aware of the foregoing scenarios, have been pursuing these questions: how to monitor all sizable near-Earth interplanetary objects, how to characterize their physical and chemical nature, how to predict which ones may be on a future collision trajectory with Earth, and finally, how to prevent a collision from happening. In the early 1980s, some in the U.S. weapons establishment argued that the Soviets might use near-Earth asteroids as first-strike weapons; the alleged plan was called "Ivan's Hammer." Countermeasures were needed. But maybe it wasn't a bad idea for the U.S. to develop something similar.

There are two methods of prevention currently being discussed. First, a nuclear weapon of unprecedented yield might blast the asteroid or comet into fragments that would disintegrate and atomize on entering the Earth's atmosphere. This method might require nuclear weapons of 100,000 megatons or more (the highest-yield nuclear weapon ever exploded is about 60 megatons).

Since there is no theoretical upper limit to the yield of a thermonuclear weapon, there are those in the weapons laboratories who consider such impact prevention as not only a stirring challenge but also as a way to unite continuing nuclear weapons development with a permanent seat on the save-the-Earth bandwagon.

Another approach under more serious discussion is less dramatic but still useful as a way of maintaining the weapons establishment -- a plan to place comparatively low-yield nuclear weapons on or near an errant object and explode them ~~near perihelion~~ (generally at its closest to the Sun), to deflect ~~the object's trajectory~~ it away from the Earth. This procedure also offers a way to deal with a suddenly detected long-period comet on imminent collision trajectory with the Earth. The comet would be intercepted with a small asteroid in a game of celestial billiards.

The ~~only~~ problem, it seems to me, is that if you can deflect an object away from ~~collision with~~ the Earth, you can also deflect an object not ~~on an impact trajectory~~ impacting on collision trajectory so it does collide with the Earth. Both cases -- disintegration ~~and~~ or deflection of the asteroid -- require developing technologies of mass destruction many orders of magnitude more

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[4-3-93.atp]

Insert D′ into "Between Enemies," p. 6:

It's no use saying that all technologies can be used for good or for ill. That is certainly true, but when the "ill" becomes sufficiently apocalyptic, we may have to set limits on which technologies may be developed. (In a way we do this all the time, because we can't afford to develop all technologies. Some are favored and some are not.)

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[4-3-93.atp]

Insert E′ into "Between Enemies," [p. __]:

If such a technology were developed, can any international safeguards be imagined that have a reliability commensurate with the risk?

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[4-3-93.atp]

Insert F′ into "Between Enemies," p. 6:

The openness of scientific discovery and the closed nature of the nuclear weapons establishment are fundamentally incompatible.

dangerous than those that now exist. Insert D'

Can we humans be trusted with world-destroying technologies? If we must wait a million years for a significant fraction of the human population to be killed by an impact, isn't it more likely that in much less time this technology will get into the hands of a Hitler or a Stalin, some misanthropic sociopath, some victim of ethnic violence bent on revenge, someone in the grip of unusually severe testosterone poisoning, or technicians incompetent or insufficiently vigilant in handling the controls and safeguards? Insert F ~~The risks seem far greater than the potential benefits.~~ stet

Tracking asteroids and comets is prudent, it's good science, and it doesn't cost much. But, knowing our weaknesses, why would we even consider developing a technology today to disintegrate or deflect small worlds? Job security in the military establishment? An emotional need to justify nuclear weapons by those with guilty consciences? Shall we imagine the technology in the hands of many nations, each providing checks and balances against misuse by another? Insert E'

This impact prevention enterprise also poisons the waters for space exploration. Insert F' ~~The recent appointment of a former Strategic Defense Initiative Organization (SDIO) official to head the NASA office in charge of human missions to the planets may be the merest of coincidences, but it is not reassuring. Neither is this~~ In January~~'s cancellation of~~ 1993, NASA's pioneering Comet Rendezvous and Asteroid Flyby mission was cancelled -- the same month that a classified

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[4-3-93.atp]

Insert G′ into "Between Enemies," [p. __]:

Meanwhile, near-Earth asteroids, and means for altering their orbits, are gathering a great deal of attention. There is some sign that officials in the Department of Defense and the weapons laboratories are beginning to understand that there may be real dangers in planning to push asteroids around. Civilian and military scientists have met to discuss the subject. Many people also, on first hearing about the asteroid danger, think of it as a kind of Chicken Little fable; Goosey-Lucy [?], newly arrived, is communicating the urgent news that the sky is falling. The tendency to instantly dismiss the prospect of any catastrophe which we have not personally witnessed is in the long run potentially very dangerous. But in this case it is an ally of prudence.

I like to think that our history among the near-Earth asteroids will be something like this: From the Earth we discover them, plot and monitor their orbits, and measure their sizes, rotation rates, and composition. We send robotic spacecraft to fly by a few selected objects, to orbit them, to land on them, and eventually to return surface samples to laboratories on Earth. Eventually we send humans there (who will, incidentally, have a rollicking good time: you can make a standing broad jump of ten kilometers or more into the sky, and lob a baseball into orbit around the asteroid). Fully aware of the dangers, we make no attempts to alter the trajetories of these worldlets until the potential for misuse of world-altering technologies becomes much less than it is today. That might take a very long time. Eventually, cautiously, scrupulously careful to attempt nothing on asteroids that could cause a major catastrophe on Earth, we begin to learn how to move the small worlds around. Eventually we learn to insert small asteroids filled with precious and industrial metals into Earth orbit. Gradually we develop the technology to deflect a large asteroid or comet that might in the foreseeable future hit the Earth, while as carefully building safeguards against misuse. The statistics indicate that we can wait a very long time -- decades certainly, probably centuries to millennia -- with no urgent need for such technology. If we play our cards right, we can pace what we can do up there to what we are doing down here. The two of course are deeply connected.

called Clementine,

SDIO mission to an asteroid was announced. (this mission, ~~may also~~

it has been suggested, may

serve as a way to circumvent the Anti-Ballistic Missile Treaty's restrictions on testing Star Wars hardware.)

external

Doubtless other dangers will be discovered or concocted that have the effect of preventing too steep a reduction in the military-weapons establishment. In the ancient scientific tradition, such claims ought to be looked at with the keenest skepticism.

The end of the Cold War permits the reconstruction of our global civilization away from weapons of mass destruction, away from massive conventional firepower, and toward solutions for such urgent problems as poverty, overpopulation, the deteriorating global environment, education, and social justice. We Americans find ourselves unexpectedly between enemies. This is an opportunity that has not come often in this century. It arrives not a moment too soon.

Insert G!

on separate p. for another chapter.