

# The Poles of Mars: A Key to Understanding Earth's

by Bruce C. Murray

ANYTHING HAVING TO DO with the United States and space these days is still colored by the Challenger tragedy — not just by the loss of life but by the total disruption of the American space program. It's going to be a long, painful way back — probably three to five years before we can again begin to resume world leadership in civilian space activities. In fact, return to world leadership at all is by no means assured. We might, through mediocre policies, become a second-class spacefaring nation permanently.

The key to our recovery is going to be selection of national goals. We have not had goals for accomplishments in space since John Kennedy announced the Apollo mission 25 years ago, in May 1961. It was completed in 1972. Since that time we have substituted a focus on the *means* (such as the shuttle and the space station) as the *ends*. We talk about what we'd like to build or do but not what it's for or why it's worth the cost either in dollars or, as we now know, in human lives.

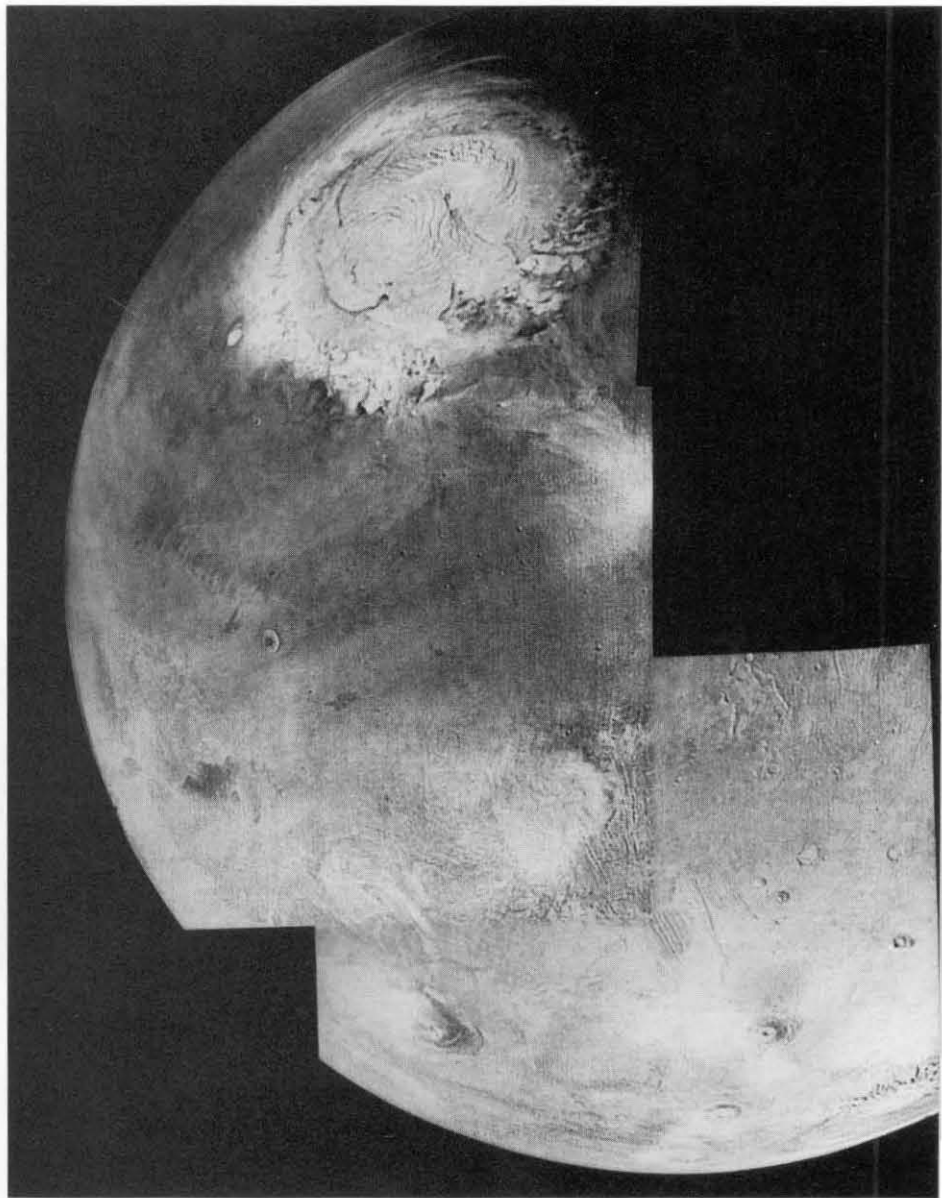
If we are going to be a major spacefaring nation in the future, it will be because we have a collective purpose important enough to bring various elements of the space pro-

gram together. I think that this purpose will likely be human travel to Mars in the next century. This logical destiny for humans in space would give sense to a lot of precursor steps — and eventually even to the risks to human life demonstrated by Challenger.

My own research concern is the poles of Mars; they're scientifically interesting and may have some relevance to Earth. But my discussion of the poles here is nested within a larger subject — the exploration of Mars — a subject that really is relevant to all of us and in which we are all, as taxpayers and voters, participants.

Mars, like Earth, has north and south polar caps. It also has seasons, since the spin axis of Mars has the same obliquity (tilt) as that of Earth. Each polar cap is very large at the beginning of spring, reaching equatorward to around 55 degrees latitude at the height of the winter. But in the summer they retreat to tiny caps barely visible from Earth. This seasonal frost that comes and goes at both poles is made of solid carbon dioxide. Underneath this frost, which except for its composition is somewhat analogous to winter snow cover on Earth, lies a permanent, residual polar cap

# Ice Age



made mainly of water ice. The residual cap at the south pole is smaller than that of the north pole, and its carbon dioxide seasonal frost is relatively thin — a few feet in thickness. When the seasonal frost recedes and exposes the residual caps, we see smooth, finely layered terrains with scarps that exhibit dark and light banded deposits. We believe these layers can give us clues to the way in which the residual caps formed — and are still forming.

This layered terrain looks a bit like a French omelet — layer after layer, perfectly made. Since these layers are almost flat, our pictures look like contour maps of that surface. These layers are 50 to 100 feet thick. There may be 30 of them in one stack, making the whole thing about a kilometer in thickness. They're abundantly present at both poles and must have been laid down by global winds. They're very smooth and are made of either dirty ice or icy dirt. Slight differences in the proportions of ice and dirt in each layer end up making them weather a bit differently and possess different albedos, or brightnesses. The layered terrains may include 500 million years of geologic history,

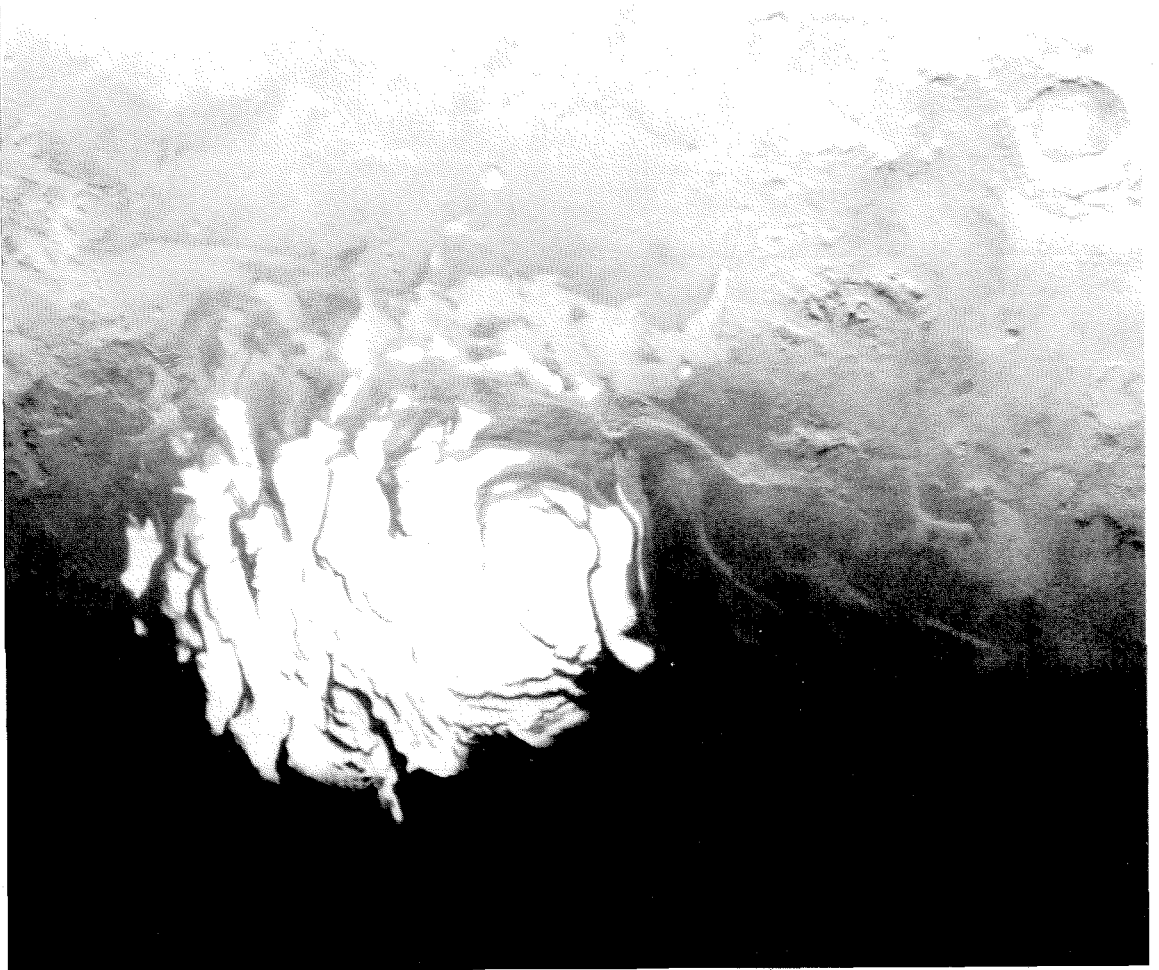
and they are interesting to us because they record global climatic fluctuations on Mars.

Water ice is remarkably stable on Mars because the planet is so cold. Mars is half again as far away from the sun as Earth, and because it doesn't have any oceans to hold in the heat, it experiences extreme temperature fluctuations. In the polar regions a block of ice will evaporate very slowly. It's like putting water ice in an ice cream factory with temperatures low enough to freeze carbon dioxide; it becomes a stable substance that doesn't go anywhere very fast. So even though there might be only 10 to 20 feet of water ice now exposed in the residual caps, it may remain stable for hundreds of thousands of years on Mars.

How do we know that the seasonal "snow" on Mars is carbon dioxide? We know

*The northern polar cap of Mars, shrinking during the late Martian spring, can be seen in this mosaic (three pictures) taken by Mariner 9 August 7, 1972. The picture shows the northern hemisphere almost to the equator.*

*Right: This view of the south polar cap of Mars was imaged by Viking Orbiter 2 on September 29, 1977, when the residual cap had retreated to its nearly minimal size of about 200 km across. Four overlapping wide-field scenes were combined by the Astrogeology Branch of the United States Geological Survey in Flagstaff, Arizona, to produce this computer mosaic.*



*Below: A high-resolution image acquired by Mariner 9 on March 8, 1972 shows in greater detail the largely defrosted "forklike" feature that can also be seen on the right side of the whole south residual cap image at right. The delicate banding of the layered terrain underlying the residual cap is apparent in this frame, which is about 40 km wide.*



from measurements of Mars's atmosphere that, although it's very thin compared to Earth's (about one half of one percent that of Earth's), it's almost all carbon dioxide. Mars has about 30 times more carbon dioxide that

does Earth. Since Mars is so cold, the carbon dioxide will freeze out of the atmosphere slowly at night as the surface radiates heat during the long polar winters when the sun disappears for six months. This forms the huge seasonal cap of carbon dioxide frost. When the sun hits the cold carbon dioxide frost in the spring, the carbon dioxide begins to sublimate into the atmosphere again. The gaseous atmosphere and the surface deposits of solid carbon dioxide are in balance. This was first predicted in 1966 by Robert Leighton, the William L. Valentine Professor of Physics, Emeritus, and confirmed by Mariner 7 in 1969 (partly with a instrument developed by Gerry Neugebauer, the Howard Hughes Professor and professor of physics and director of Palomar Observatory).

We think there is also excess solid carbon dioxide in the Martian south polar region, because Mars's carbon dioxide atmospheric pressure seems to be regulated by the temperature at the poles. Imagine a laboratory experiment to illustrate this: If we have a bell jar in which we can regulate and measure the temperature and pressure from outside, we

can stick a block of carbon dioxide in, evacuate the bell jar, and set the temperature at 143 degrees Kelvin — the average temperature at the Martian pole. That is the temperature of a bright substance at Mars's poles that reflects most of the light, averaged over the year. When we let the carbon dioxide gas sublimate from the block of carbon dioxide come into equilibrium with that temperature and then measure the pressure in the bell jar, it turns out to be one half of one percent of the Earth's atmospheric pressure. This is exactly the pressure of the carbon dioxide atmosphere on Mars!

So the atmospheric pressure on Mars is governed by this solid carbon dioxide at the poles. The Earth's atmosphere, mostly nitrogen, behaves differently. Since there's no solid nitrogen on the surface, our atmospheric pressure is not governed by the surface temperature. But on Mars it is, and that's a key to the global variations recorded in the layered terrains. The Martian atmosphere has changed drastically and periodically as a consequence of the change in the polar temperature.

But there's also dust in the layered terrains. Where does it come from? We know that there's lots of dust in the Martian atmosphere because Mariner 9 arrived there in 1971 during a dust storm; we practically couldn't see the planet. Decades of telescopic studies from Earth had shown that a global dust storm usually occurs when the planet gets closest to the sun. (Mars has a moderately eccentric orbit). We think that near the equator, the hottest place on the planet, temperatures get so high that vertical dust devils start to swirl up from convection — just as in Earth's dry deserts in the summer. There's no moisture, so this very dry dust gets sucked up, creating much dust in the atmosphere where it absorbs the sun's heat. The dust in the atmosphere gets hotter and hotter, heats the atmosphere, and the process takes off, ending up as a global dust storm. It's an unstable process for a while but is turned off when the dust finally spreads globally and gets carried up to the poles. So the source of the dust in the polar layered terrains is the equatorial areas, driven annually by the year's hottest conditions. The sink of the dust is in the polar regions, where the average annual conditions are much colder and residual water ice caps provide a permanent trap.

If there is a solid seasonal cap on the

poles, and the atmospheric carbon dioxide is regulated by the solid deposit on the surface, the pressure on Mars ought to change significantly over the year. Viking landers on Mars in 1976 and 1978 conducted measurements showing that indeed the Martian atmosphere has a 20- to 30-percent annual variation in pressure simply because of the seasonal freezing out and sublimating of carbon dioxide in the two caps. But to explain these smooth layers that formed over thousands of years, we're looking for a longer term variation that could cause the conditions on Mars to vary over long periods of time.

For example, the amount of eccentricity of Mars's orbit varies. It has 100,000-year fluctuations and million-year fluctuations from the combined effect of Jupiter and Saturn tugging on Mars's orbit. When Mars's orbit is very eccentric, the planet gets much closer to the sun at perihelion, and the heating increases. When the eccentricity is small, the differential seasonal heating will be minimal.

Another effect, which we also have on Earth, is the precession of the spin axis. This will cause the hemisphere that happens to lean toward the sun at perihelion to alternate

*Smoothly eroded layered terrain at 75° south latitude is displayed in this Mariner 9 high-resolution image. The nearly horizontal layers are estimated to be 20 to 50 meters thick. The overall dimension of the frame is about 30 km across.*



back and forth over a period of 50,000 years. This periodicity, called the equinoctial period, will also cause a global climatic fluctuation in dust production.

But there's something else going on on Mars that affects the poles themselves, and which is even more important. As I mentioned earlier, Mars's axis is tilted about the same amount as Earth's is — about 24 degrees — so the planet has the same kind of seasons we have. But Jupiter and Saturn wreak enormous havoc on this obliquity, as well as on its orbit, over time. About 700,000 years ago it was tilted only 16 degrees — more straight up and down. Since the poles were not tilted as much toward the sun in summer, they remained much colder. That means that the average temperature and pressure of the atmosphere went down too. At that time the pressure was about 40 percent of what it is now.

On the other hand, about 800,000 years ago the opposite happened: The axis was pulled more over on its side, leaning at an angle of 33 degrees. At this tilt the poles got *more* heat than normal. The pressure of the atmosphere must have been six to eight times what it is now. This has been going back and forth periodically over 100,000-year and million-year cycles — not exactly the same periods as the eccentricity, but similar. This obliquity variation will strongly affect the dust storms, but even more important it will affect the capacity of the polar ice "sink" to capture the dust and create layers. So, in the variation in obliquity we have the mechanisms to explain to some extent how these layers may have formed. But we still have to understand much more of the details.

Mars is a planet that's very sensitive to sunlight; its climate fluctuates very easily. This isn't true on Earth because much of the heat absorbed from sunlight stays in the oceans and is mediated over thousands of years by a very complex, long-term exchange of heat with the atmosphere. So even though some climatic processes on Earth are similar to those on Mars, there is no such direct relationship on Earth to the short-term changes that exist on Mars.

We do have ice ages on Earth. We're in one right now — the Pleistocene — which began about 3 million years ago. Actually, we're in a brief warm period, but it's still an ice age, a phenomenon that has happened only rarely over geologic time. There was another about 250 million years ago, which

was the end of the Permian and another at the end of the Precambrian about 700 million years ago. There have been other smaller scale ice ages, but these three were the worldwide ones that stand out in the geologic record.

What causes ice ages to occur? Most of the Earth's geologic history has not had ice ages. But we probably wouldn't even be here except for this climatic anomaly. The whole development of *Homo sapiens*, and *Homo erectus* who preceded him, was tied to climatic change and effects of the ice age. But we don't know what causes ice ages to occur. Two categories of possibilities have been debated for a long time. One category suggests that something peculiar happened on the Earth itself. For example, an excessive amount of vulcanism may have thrown a lot of particulates high into the atmosphere and cooled the planet. Or perhaps two plates of the Earth's crust came together in some strange way that disturbed the oceans sufficiently to change the climate. Somehow, a chance activity of the Earth's surface or interior must have triggered ice ages.

The other theory postulates instead that something peculiar happened to the sunlight. Perhaps the sun occasionally gets a little cooler and doesn't radiate so much heat, and this triggers an ice age. Because the climatic record on Earth is mixed up, it will probably never be possible to confidently determine from a terrestrial record alone whether the cause of ice ages is internal or external.

But Mars is clearly a much more sensitive indicator of solar activity. Suppose the sun for some reason did cool down 3 million years ago. Because its effect on Mars would be far stronger than its effect on Earth, there should be a record of it in those layered polar terrains. On the other hand, if there is no record there of reduced solar heating starting 3 million years ago, then our ice ages must have resulted from an internal process of Earth. Mars may well provide the solution to the puzzle of ice ages. But how do we find out? We will have to go to Mars.

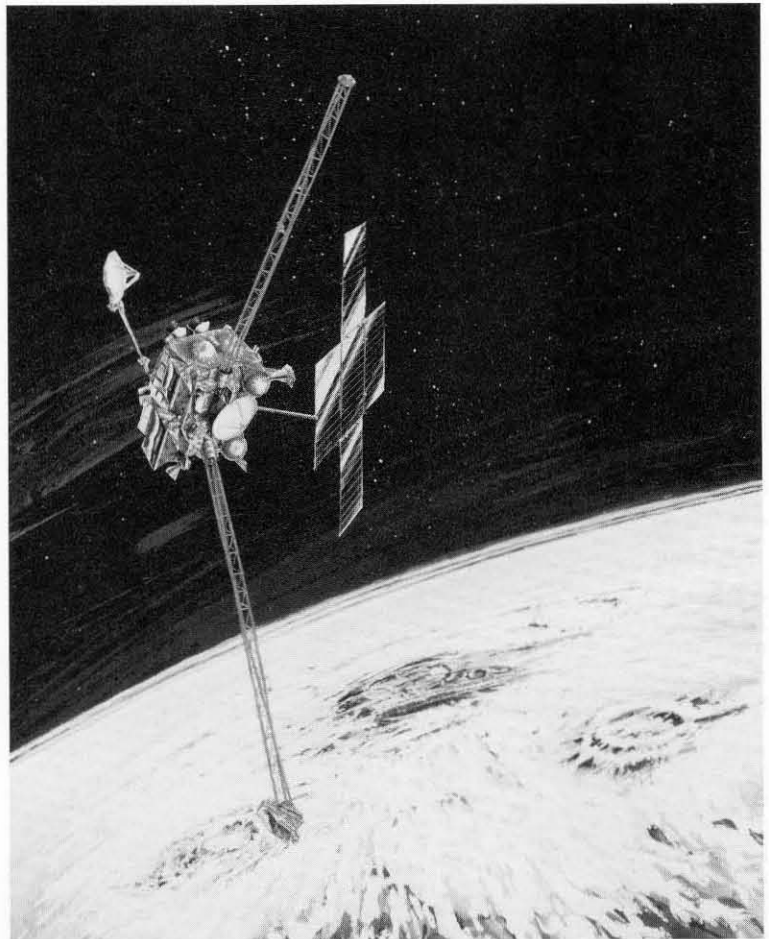
Mars and Earth get together on the same side of the sun once every 25 months. The next three times this happens — in 1988, 1990, and 1992, there will be some new launches of spacecraft for exploration there by Earth's robots. First, in early 1989 two Soviet spacecraft will rendezvous with Mars's moonlet Phobos. These spacecraft will come within a few hundred feet of the surface of

Phobos and try to measure its composition with lasers and a number of other instruments. Then, two landers will be projected onto the surface to measure directly what Phobos is made of. We're very interested in this moon because it's one of the darkest objects in the solar system. In some ways it's like the nucleus of Halley's Comet, and it may well contain organic materials with a record going far back in time. Then the two spacecraft will go into orbit around Mars itself. It's an ambitious mission, which requires big launch vehicles, so it's fortunate that the Soviets are trying to do it instead of us right now. They're using two large rockets of the same class that launched our Viking and Voyager spacecraft.

After that the next visit to Mars is supposed to be an American one — a single spacecraft called Mars Observer. It will orbit 500 km from the surface and include radar measurement of the altitudes of Martian features. It will also measure how light is emitted and reflected from the polar deposits to try to determine their chemical composition. Also planned is an experimental camera to return extremely high-resolution pictures. G. Edward Danielson, member of the professional staff of the Division of Geological and Planetary Sciences, is developing this camera along with Andrew Ingersoll, professor of planetary science, and Michael Malin, PhD 1976 (now professor of planetary science at Arizona State University). This remote-sensing mission was supposed to be launched by the space shuttle in 1990. NASA now feels, however, that the shuttle will still not be adequate for the task. They might use a Titan 3 rocket, or the mission may slip until 1992. But there will be an American presence at Mars in the next decade.

The Soviet Union is on a roll and is doing some very good things in interplanetary space — ambitious missions with great big rockets and sophisticated spacecraft. They have announced the objectives of the Phobos mission in advance, as they did with their previous successful mission to Halley's Comet, which had originally dropped balloons and landers into Venus's atmosphere. The Soviets encouraged international participation in that mission, and this will continue, with the Phobos undertaking including several American investigators.

The Soviets were planning to go back to Venus in 1992 but have changed their minds and have decided to focus on Mars instead.



What they're going to do on Mars are things we *thought* about doing, but didn't do, 10 years ago. Now the Soviets, instead of us, plan to send a mission specifically to land on Mars in 1992. An orbiting spacecraft will probably rocket-propel several six-foot-long, bullet-shaped probes backward from the spacecraft's direction of motion, a maneuver that will slow them down sufficiently for them to fall onto the surface of Mars. They will still crash at high speed, but they will be designed to do that. In the backs of these probes would be scientific instruments, such as cameras, chemical analysis instruments, seismometers, and so on, that can survive that kind of impact. In the layered terrains that I have just discussed these instruments could gather information both chemically and with imaging.

In addition the Soviets plan to float balloon-mounted electronic cameras in Mars's atmosphere to obtain high-resolution traverses across the surface. This is really difficult to do, because the atmosphere of Mars at the zone they're planning to observe is 50 times less dense than the atmosphere of Venus, where they flew balloons with their

*Mars Observer, a remote-sensing mission to study the planet's geology and climate, under way at Caltech's Jet Propulsion Laboratory, will be launched early in the 1990s.*



*On the dry lake bed at Edwards Air Force Base a team from JPL and Caltech conducts a flight test of a Montgolfiere balloon with a segmented payload and drag rope, which might be used to keep a balloon's height constant above the Martian terrain.*

Vega mission. It will be a very ambitious surface exploration mission preparing for more precise ideas of where to send future missions — both automated and manned. I have been working with Caltech students and with a group at JPL to develop such special balloons and miniature cameras. I hope there may be an opportunity for some American participation in this Soviet mission — or perhaps eventually we will be ready to fly such devices ourselves.

What we really need on Mars is to be able to move around. We could do this with rovers containing artificial intelligence run remotely from Earth. These could, for example, make an autonomous decision not to drive over a cliff and fall down a crevasse and would have arms to collect samples. They could take these samples to another location, to a different rocket vehicle, which could fire itself back out and eventually return to Earth. This sort of robotic sample-return mission has been studied for years by the U.S. and by the Soviets.

The Soviets have indicated an interest in flying such a mission as early as 1996, and there have been discussions about the U.S. taking the rover portion and the Soviets doing the sample-return part. Perhaps we could collaborate on the surface of Mars, which might be a first step toward collaborating on the surface of Earth. A rendezvous of robots on Mars's surface seems to be a lesser problem for the technology transfer people, because the robots talking to each other on Mars will probably not reveal any state secrets. Of course, such an ambitious joint mission has not yet been accepted and it may never be, but at least the Soviets have the momentum to do it. The question is whether we have the will to get back in the act and do it. Fortunately, the proposed rover can be launched by the new, large, automated seven-segment rocket that the Air Force has on order. By 1996 we could probably spring one or two of them loose for Mars. So we could probably still manage to do this despite the delay following the shuttle disaster.

In the longer range, of course, humans will go to Mars. History has shown that humans will explore anyplace they can get to. One reason they'll go to Mars is that the other planets are not suitable for human habitation. Venus is much too hot; Jupiter is surrounded by lethal radiation; Mercury's vacuum surface experiences 10 times the searing sunlight of the Moon; and Saturn and beyond is just too far. Mars is the right place to go. It even contains ice, which might provide oxygen and water for later expeditions. I'm sure the Soviets have been thinking about this for some time, and fortunately now our own government is finally doing some studies. A manned mission to Mars is something that could actually happen soon after the turn of the century — even a joint mission between the U.S. and the Soviet Union. It's something either country *could* do by itself, but that would take longer and cost more. What better way could there be for the two superpowers to demonstrate their commitment to long-term coexistence — and collaboration?

I believe that Mars is the place where the action is going to be for a long time. Humans very likely *will* go to Mars in the first quarter of the next century, and among the areas they will investigate are the poles, where they will elucidate geological records, pertinent not just to Mars but to the Earth itself.

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