tainty, criteria intended to weed out unrepresentative or poorly documented craters.

The independent culling of the cratering record of the past 250 million years yielded two rather different data sets. One contained 25 and the other 27 craters, with 20 craters common to both lists. But only 10 of those 20 craters have the same ages in both lists. The problem is in the selection of the best age for a crater from all the possibilities in the literature. The mean age uncertainty of the lists is about 5 million years, but that includes analytical error only. There is obviously additional error. For example, Gosses Bluff crater in Australia had an age uncertainty of 0.5 million years in one list and 3 million years in the other, but its ages differed by 9.5 million years.

The apparent periodicities extracted from the two records differed as well. Sharpton's list yielded a periodicity with a period of 18.5 million years having confidence limits greater than 95%. No period had a significance exceeding the 99% confidence limits, as periods from earlier data sets had, and no period appeared near 30 million years. The Shoemaker and Wolfe list did yield a period of 30 million years with a confidence limit of greater than 95%. But when Sharpton searched for shorter periods, he also found a period of 16 million years that was even more significant.

Sharpton believes that a single cluster of four craters slightly younger than 40 million years plus the tendency of recent craters to have an unduly large representation on the lists accounted for the observed periods. He finds no merit in the recent suggestions that the record may appear so poor because the periodic component is only 50 to 30% of the total, the rest being random impacts. If that were the case, Sharpton said, the assignment of reasonable errors would eliminate the significance of any period. "You can play with statistics forever, but to resolve whether there is any geological significance to it, we need to go to the field."

In the next talk, Peter Schultz of Brown University and Seth Posin of Arizona State University carried the discussion to quite a far distant field. They searched the cratering record of the moon for any signs of periodicity, on the assumption that on an airless, waterless world the cratering record could be more complete. Combining Apollo dating of three craters with counts of craters 20 to 100 meters in diameter in Apollo and Lunar Orbiter images, Schultz and Posin found times when craters larger than 1 kilometer were particularly abundant. The clusters have ages of about 2, 7, 10 to 30, and 60 to 80 million years. Schultz sees this as evidence for clustering, not periodicity. ■

RICHARD A. KERR

Soviet Space Science Opens to the West

Even as prospects are looking up for Soviet-American cooperation in space, the Soviet Union is becoming remarkably more open about its space program; a visit to the Space Research Institute suggests that something more than glasnost *is at work*

IN the spring of 1987, the prospects for Soviet-American cooperation in space appear brighter than they have for years. First, a formal framework is now in place: on 15 April, U.S. Secretary of State George P. Shultz and Soviet Foreign Minister Eduard Schevardnadze signed a new space cooperation agreement during Shultz' visit to Moscow (page 1430).

Second, American space scientists generally seem eager for increased cooperation—especially now, when the Challenger accident has left so many U.S. spacecraft stranded on the ground. The Reagan Administration allowed a previous space cooperation agreement to lapse in 1982 as a protest against the imposition of martial law in Poland; since then, U.S. and Soviet researchers have had to make do with informal, scientist-to-scientist contacts. But with a renewed agreement, say researchers contacted by *Science*, the way has been opened for more substantive collaboration, perhaps culminating in a joint Mars Sample Return mission to bring martian rocks back to terrestrial laboratories—and perhaps even in a joint manned expedition to Mars after the turn of the century.

Finally, the Soviets themselves seem willing. Roald Z. Sagdeev, director of the Space Research Institute in Moscow (abbreviated IKI in Russian), a member of the Soviet Academy of Sciences, and by all accounts the dominant figure in Soviet space science, has repeatedly stressed that a multibillion-dollar Mars Sample Return mission almost demands international cooperation. "It would be very difficult to afford such missions," he said during a recent visit to Stanford University. "Maybe only our two countries could do it—America and Russia. But even in this case, I think there is a great deal of necessity to join efforts."

However, the very fact that the prospects for cooperation look bright makes it all the more important for American space scientists to understand what their Soviet counterparts are up to. Not so long ago, for example, the Soviets would not even announce their missions until they had been successfully launched. But just within the past few years—and in fact, beginning well before the ascendancy of Soviet General Secretary Mikhail Gorbachev in March 1985—their space science programs have begun to operate in an atmosphere of remarkable openness. Western journalists are freely being invited to visit IKI, which manages most of the Soviet space science missions. And Western scientists are freely being invited to place instruments aboard the spacecraft and to help plan the missions.

At the same time, the Soviets have committed themselves to an exceptionally vigorous space science program, especially when it comes to their flagship planetary missions. Western observers agree that the Soviets' recent VEGA mission to Halley's comet was scientifically and technically impressive by any standard. Moreover, the Soviets' Phobos mission (page 1428), due for launch in the summer of 1988, is only the first in a series of increasingly ambitious missions to Mars, a series that may well culminate in a Mars Sample Return mission by the late 1990s. "You can sense a buoyancy there [among Soviet space scientists]," says one recent visitor from the United States. "They act as if they are on a fast track, as if they have a green light through the year 2000. The contrast with the mood at NASA [the National Aeronautics and Space Administration] is black and white."

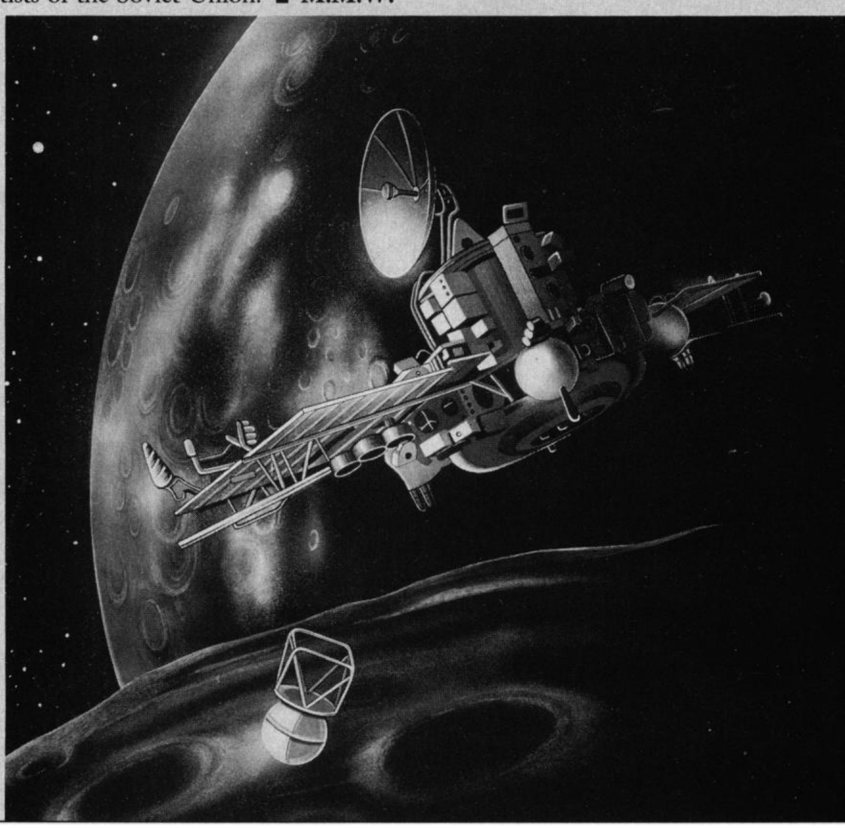
That contrast has only been underscored by the successful test launch of the Soviets' Energia booster on 15 May. The Energia, which can place as much as 100,000 kilograms of payload into orbit with a single launch—three times the payload of the space shuttle—rivals the Americans' now-defunct Saturn 5 in lift capacity and is currently the most powerful rocket in the world. Among its possible payloads are new and larger manned space station modules, as well as advanced planetary missions.

Close Encounter

In the spring of 1989, if all goes according to plan, a chunky, bottom-heavy spacecraft will drift by the martian moon Phobos at a distance of some 50 meters. During the 15-minute encounter it will photograph details on the 27-kilometer diameter moon with a resolution of 6 centimeters. It will use an infrared laser to vaporize patches of Phobos' surface, which is thought to consist of tarry, carbonaceous material that has remained chemically and isotopically unchanged since the origin of the solar system; it will then use an onboard mass spectrometer to analyze the vapor as it comes boiling off. The spacecraft will operate a separate ion gun in much the same way, blasting loose the first few atomic layers of the surface in a search for elements implanted over the eons by the solar wind.

Meanwhile, the spacecraft will release two landers, letting Phobos' feeble gravity pull them slowly to the surface. The smaller of the two, a beach ball–sized sphere carrying an accelerometer, an x-ray fluorescence spectrometer, and several other instruments, is known as the hopper: by using a set of leglike rods it will be able to flip itself across the moonscape to sample as many as ten different sites. The larger device, known as the long-term automated lander, will touch down, drive a spike-like probe into the surface underneath, and settle in for at least a year of independent data-gathering; in addition to reports on Phobos' temperature, seismology, and surface composition, its radio transmissions to Earth will provide a beacon for precision analysis of Phobos' orbit, and perhaps for sensitive new tests of Einstein's general theory of relativity.

Finally, as the encounter draws to a close—and as an identical spacecraft waiting in a higher orbit prepares either to repeat the process at Phobos or perhaps to go on to Mars' other moon, Deimos—the spacecraft will drift back into its permanent orbit around Mars. Once there it will turn its attention to the particles and fields environment of the planet, to the mineralogy and thermal dynamics of the martian surface, to the structure and composition of Mars' atmosphere, and to a wide-ranging battery of instruments aimed at the sun. All in all the spacecraft and its twin will operate in the vicinity of Mars for some 260 days, returning their streams of data to scientists from France, Germany, Finland, Hungary, the United Kingdom, the United States, and roughly a dozen other nations—and, of course, to the scientists of the Soviet Union. ■ **M.M.W.**



Max-Planck-Institut für Aeronomie/Marianne Schmidt

So once again, what is going on? Where are the Soviets headed with their space science program? And what do they hope to get out of collaboration with the United States—or, for that matter, with anyone?

It should be said at the outset that the Soviets are hardly strangers to foreign collaboration in their space missions. This year marks the 20th anniversary of their cooperative agreement with France, for example. Through their Interkosmos organization they have flown satellites (and cosmonauts) from a variety of Soviet bloc and nonaligned nations. Nonetheless, their contacts with the Western space science community have expanded dramatically in the past few years, not least because the Soviets are eager to tap into the expertise of that community.

Alec A. Galeev, head of IKI's space plasma physics division and a longtime associate of Sagdeev, frankly conceded as much during a recent interview with *Science* at IKI: "The main motivation from our side is to use the advancement of some of our colleagues in certain directions, to use their advanced instrumentation," he said. "Also, with our limited resources, we can do more [through cooperation]."

Galeev's point is echoed by European and American scientists who have worked with the Soviets in the past. What the Soviets have to offer the West is a guaranteed series of launch opportunities, they point out. Indeed, the Soviet leadership seems to rank space exploration as a symbol of national prowess right alongside the Soviet Olympic teams, the Bolshoi Ballet, and the May Day parades through Red Square. For three decades now, the Kremlin has shown itself willing to support a systematic series of launches to the moon, to Venus, and now to Mars. If anything, that support has gotten stronger under Gorbachev.

However, the Soviet space science program does operate under some real constraints. One, apparently, is money. Soviet officials are reluctant to talk about budgets; even when figures are available, the systems are so different that dollar-ruble comparisons are almost meaningless. (For example, Soviet spacecraft are turned out assembly-line fashion in a factory, whereas American and European spacecraft are more like custom-built sports cars; at the same time, the spacecraft themselves are paid for out of the factory's budget, which means that IKI only has to pay for the instrumentation.) Nonetheless, the budget envelope for space science does seem to loom as a real issue at IKI. "Certainly we couldn't have done a whole VEGA by ourselves," says Galeev.

A closely related problem is manpower. Western observers credit Sagdeev with bringing together a first-rate team of researchers at his institute. Nonetheless, the Soviet space science community is still quite small by Western standards. A 1982 study of the Soviet Academy of Sciences prepared for the Department of Defense by Texas A&M University counted only 150 scientists in IKI and only 37 in the Vernadsky Institute, which is roughly analogous to the U.S. Geological Survey and which is where much of the work on planetary geophysics is done. Moreover, these are the two largest concentrations of space scientists in the country. (In contrast to the West, relatively little basic research is conducted in Soviet universities.) "They're overworked," says Louis Friedman, who is executive director of the Pasadena-based Planetary Society, a 100,000-member space interest group, and who is a frequent visitor to IKI. "They're having to rush around to meet the 1988 schedule [for the Phobos launch]. It's a tense time, with a lot of deliverables that have to come together all at once." Friedman finds it significant that the Soviets are not preparing a mission for the Mars launch window in 1990: "They just couldn't do it."

A third constraint is the Soviet Union's own technical limitations, particularly when it comes to advanced electronics. In some cases, of course, the factories do quite well. On both VEGA and Phobos the cameras use charge-coupled device detectors originally developed for the Soviet military. But overall, industrial capability is quite erratic by Western standards. It is no accident that the onboard data processing for VEGA and Phobos was developed by the Hungarians, who have been much more successful at mastering modern electronics and computer technology than the Soviets themselves.

The upshot of all this is that Sagdeev and his colleagues are using foreign collaboration to leverage their strength: by offering space on their missions, they get first-rate instrumentation and the participation of first-rate scientific talent for little more than the cost of integrating the instruments on their spacecraft.

At the same time, however, cooperation does require a certain level of frankness and trust. Why should anyone cooperate if they do not know what the other side is doing? Arne Richter of the Max-Planck Institute in Lindau, one of the first West Europeans (aside from the French) to work with the Soviets, recalls what it was like in the early days of planning for VEGA and Phobos: "I would come back from IKI and tell my colleagues about it, and all I was allowed to say was, 'A spacecraft of some type is going at some time to an interesting celestial body, and here are some experiments we can do.' I could only refer to Phobos as 'Mission F'."

Richter's co-workers were as frustrated as he was. And they were not the only ones. "We felt embarrassed that we couldn't talk to our colleagues [in other countries]," says Galeev. "We couldn't see any reason to do all this in secret. Also, we have limited resources and we don't want to duplicate other missions. So we have to talk to others about their plans. But then we need to tell them *our* plans. We need the trust of our colleagues." Added to that, says Galeev, he and his associates were acutely aware of what their isolation from the West was costing them in terms of scientific credibility. Their papers were slow to be published—not least because they lacked sophisticated computers to reduce their data—and even slower to be translated. Moreover, Soviet travel restrictions meant that the Russians seldom had a good representation at international meetings. The result was that few scientists outside the Eastern Bloc seemed to know or care what the Soviets were up to.


M. Mitchell Waldrop

Academician Roald Z. Sagdeev.

Thus the thaw. It seems to have had no precise beginning. Experienced Western scientists say that in retrospect they had noticed it developing for years. But whenever it began, the VEGA mission to Venus and Halley's comet was clearly the watershed. Consisting of two identical spacecraft launched in December 1984, VEGA involved international collaboration on an unprecedented scale for the Soviets, with investigators from more than a dozen countries participating in some two dozen experiments—including one American experiment, a dust detector placed on board by John Simpson of the University of Chicago at Sagdeev's personal invitation.

From the beginning, moreover, the mission was conducted in a glare of publicity reminiscent of the Voyager encounters at NASA's Jet Propulsion Laboratory. The launches themselves were televised live. And for the Halley's comet enounter, in March 1986, Sagdeev invited a contingent of American and European journalists to IKI to cover the events as they happened, with scientists standing by to offer instant interpretations as the images appeared on the video monitors. (Among the visiting journalists was Richard A. Kerr, whose account appeared in the 18 April 1986 issue of *Science*, page 320).

Norman Ness, director of the Bartol Research Institute at the University of Delaware, a principal investigator on the U.S. Voyager project, and one of the four Americans invited to be interdisciplinary scientists on Phobos, was deeply impressed by the change. Open communications among scientists was one thing, but the level of publicity offered with VEGA went well beyond that. "Sagdeev took an enormous risk with VEGA," he says. The Kremlin, after all, is not noted for being tolerant of highly visible failures.

On the other hand, the risk may not have been as great as it appeared. Aside from the fact that the VEGA mission included two identical spacecraft, which automatically provided each instrument (and each spacecraft) with a backup, it seems highly unlikely that Sagdeev could have put so much of the Soviet Union's prestige on the line without Kremlin approval. And in any case, by the time the two VEGAs arrived at Halley's comet, Gorbachev had become General Secretary; Sagdeev's public approach to space science was sheltered under the wider umbrella of *glasnost*. (When *Science* asked Sagdeev himself why he had gone public with VEGA, he simply said, "*Glasnost* has to apply to space exploration as well. We were especially proud that we were able to contribute in our field of activity to a general framework of what he [Gorbachev] is doing for our society.")

In purely political terms, of course, Gorbachev and his colleagues have every reason to publicize their space missions. As many U.S. observers have pointed out, not without a touch of envy, a vigorous space research program allows the Soviets to be seen as the champions of peaceful uses of space at a time when the Reagan Administration seems committed to pursuing the Strategic Defense Initiative. (In this context it is significant that Sagdeev serves as Gorbachev's adviser on the U.S. Strategic Defense Initiative.)

"The VEGA encounter was terribly instructive," says Friedman. "I went into that room and I must have heard 20 languages. I saw all these scientists standing around—French, West Germans, Hungarians. And I thought to myself, 'God, Sagdeev is brilliant. He's got all these people working for him for free, and here he is getting all the credit from the whole world for the science on Halley's comet. Now, that's *leadership*.' Why can't we be that smart?"

If VEGA was a propaganda triumph, however, it was certainly not just propaganda. From a scientific and technical stand-point, in fact, it represented a major step forward for the Soviets—albeit a step taken with a characteristic measure of caution.

On the cautious side, Sagdeev and his colleagues planned VEGA as a outgrowth of their long exploration of Venus. In that sense Halley's comet was basically a target of opportunity, an interesting object that happened to be in the vicinity of Venus at the right time. The twin VEGA spacecraft themselves were the last of the most recent Venera series, which had begun in 1975 with Venera 9 and 10, and which had continued with a new pair of probes being sent to Venus every 2 or 3 years. (Earlier Venus missions in the 1960s had used a less capable spacecraft.) Moreover, VEGA was in keeping with the Soviets' essentially conservative strategy with the Veneras: use the same basic spacecraft as long as possible, while upgrading the scientific instrumentation step by step on each successive mission. In the pre-VEGA years that strategy had produced such highlights as the first photographs of the venusian surface, relayed from landing craft dropped by Venera 9 and 10 in 1975; and the first imaging radar maps of the surface, produced by Venera 15 and 16 in 1983. For VEGA, the first task of the twin spacecraft was to swing by Venus on the way to Halley's comet and to drop a pair of French-built balloons into the upper atmosphere; once there, the two balloons drifted among the venusian cloud tops for more than a day, radioing back a detailed profile of Venus' high-altitude temperatures, pressures, and wind dynamics.

However, the coma of gas and dust surrounding an active comet is a profoundly different place from the calm environs of Venus, especially when the coma is encountered at 78 kilometers per second. And for that very reason, VEGA's meeting with Halley's comet demanded something more than one-step-at-a-time improvements. It demanded wide-angle and narrow-angle cameras capable of imaging the cometary nucleus from a distance of 10,000 kilometers. It demanded onboard control systems to keep the spacecraft stable and on course; an onboard data acquisition system able to handle the data stream from the cameras, the magnetometers, the mass spectrometers, and all the other instruments; and an onboard radio transmission system capable of beaming all that data back to Earth at 65,536 bits per second before the spacecraft could be destroyed by dust. (It was not.) The encounter demanded an international network of Soviet, European, and American radio telescopes to track the spacecraft. And it demanded a sophisticated system of data analysis and data distribution on the ground just to get the information into the hands of the waiting scientists.

As already mentioned, the technical challenge of the VEGA encounter was no small part of the reason that the Soviets invited foreigners to participate. Nonetheless, as Arne Richter of the Max-Planck Institute points out, the Soviets' achievement was real. By carrying VEGA to such a successful conclusion, he says, the Soviets proved to the world—and to themselves—that they could indeed handle a world-class planetary mission and all its associated infrastructure. In a real sense, that achievement was as important as the science itself.

All of these lessons have been incorporated into the Phobos mission. Indeed, leaving aside the fact that one spacecraft is going to Mars while the other went to a comet, Phobos is striking for its continuity with VEGA. The Phobos spacecraft incorporates

Technology Transfer Is the Issue in Space Cooperation

In working out the new Soviet-American space cooperation agreement, signed in Moscow on 15 April, one of the two most troublesome issues for the negotiators was technology transfer: the suspicion that high-grade sensors, computers, and other scientific technology will inevitably find their way into the Soviet military machine. [The other issue was the U.S. federal budget: the White House refused to let the National Aeronautics and Space Administration (NASA) even talk about missions that are not already approved. Thus, NASA had to turn down a Soviet proposal to commit to a joint Mars Sample Return mission.]

According to officials who worked closely with the U.S. negotiating team, the Defense Department representatives were particularly sensitive to the possibility of technology transfer. As a result, the agreement is quite bland on the specifics, calling for little more than the exchange of data between various missions and the coordination of mission schedules. It carefully avoids proposing that researchers from one side fly instruments and other hardware on the other side's spacecraft. And even with that restriction, each mission suggested for cooperation will first have to pass through a painstaking process of interagency review.

In principle, however, officials say that the agreement could provide a framework for more substantive collaboration. The agreement was deliberately designed so that the 16 proposed cooperative missions are listed only in an appendix, which can be changed through a routine exchange of diplomatic notes without the need to renegotiate the whole document. But first, someone is going to have to resolve the original question: How real is the threat of technology transfer?

"It's an issue with a valid basis of concern," concedes General Lew Allen, director of NASA's Jet Propulsion Laboratory, who recently headed a national study on the technology transfer issue and who was instrumental in drawing up the new space cooperation agreement. "Some people exaggerate the problem—but then, some people are cavalier." In general, however, he thinks that certain kinds of hardware exchanges are definitely possible. Consider the Western European instruments being flown on the Soviets' Phobos mission, for example: "I wouldn't worry about it . . . The kind of access the Soviets get on the instruments there would not allow them to use the technology for military purposes."

There is little doubt where the Soviets themselves stand on the issue. "I think this [technology transfer] is purely an artificial obstacle," said Roald Z. Sagdeev, head of the Space Research Institute, in a recent interview with *Science* in Moscow. "I don't see any technology in this area which could harm the military balance." Conceding that not everyone sees things that way, however, he has proposed one scenario for a joint Mars Sample Return that would involve no technology transfer at all: "Both sides are having separate launches," he explained. "One brings return rocket to the surface of Mars, and the other is bringing rover. And then this rover will be moving towards return rocket while doing in situ measurements. . . . It will be able to bring samples to return rocket, and then the interface is maybe a little bit more than a handshake." NASA is taking Sagdeev's proposal quite seriously in its own analysis of the mission. Nonetheless, agreement for collaboration on this scale is clearly a long way in the future. As scientists on both sides have often pointed out, the real problem is not technology at all, but the deeply entrenched attitudes of suspicion and hostility between the two countries. ■ **M. M. W.**

all the technical advances that had been mastered in the early mission. The project continues with the tradition of international collaboration—often with the same collaborators who worked on VEGA. It even follows up on VEGA's pioneering small-body research: the tiny satellite Phobos, like the icy nucleus of Halley's comet and indeed, most of the other comets and asteroids in the solar system, is thought to consist of primitive, relatively undisturbed material dating back to the origin of solar system.

It is true that Phobos is the first of a new generation of spacecraft—in essence, a modernized Venera that has been optimized for the environment of Mars. But even that fact expresses continuity: in the 1960s the Soviets flew mission after mission to the moon; in the 1970s they turned their attention just as resolutely to Venus; and now, for the late 1980s and 1990s, they are preparing a series of missions for Mars.

"We make analogy with agriculture, extensive versus intensive," Sagdeev explained to *Science*. "[Our program] is probably more intensive." There are many arguments for making it so, he says: "Cost efficiency—since after you build spacecraft, is much better suited to perform same type of mission. Redundancy—eventually every experiment would work. Also, it provides a kind of logic—even without knowing the details, what can be the next step, each mission is providing additional questions for the next mission. And also, to avoid unnecessary duplication of America's program, which during the last decade was wide-ranging reconnaissance of the solar system."

Of course, as Sagdeev's colleague Galeev points out, the intensive approach does have its drawbacks. Boredom, for example: "Maybe I'm not a specialist," he told *Science*, "but I couldn't see a big difference between [the results of] the different landers. . . . Is growing opinion we should stop for awhile our Venus research. Maybe is time to do something else."

Moreover, as Sagdeev himself admits, the Soviet approach is as much a matter of inertia as of logic. Soviet factories, even spacecraft factories, tend to be very production oriented. The managers like to keep stamping out items one after the other. Moreover, the Soviet system, even in science, is highly segmented, which means that the scientists have had no direct say in how the spacecraft are designed. "We had spacecraft designed for Venus," says Galeev. "So it was very difficult to get spacecraft for other planets . . . We can influence design of spacecraft only by discussion."

Be that as it may, the Soviet program is now committed to Mars through the turn of the century. And indeed, Mars is an eminently reasonable choice: not only is it the most Earth-like of the planets, offering a host of unanswered questions about its climate and geologic history, but it has popular appeal—a not inconsiderable factor even in the Soviet Union. A manned expedition to Venus, with its 750 K surface temperatures, is inconceivable. But a manned mission to Mars is quite conceivable. "This is why many people in our country are interested in Mars research," says Galeev. "[The public] can understand why we should send people there—to prove that we can have life outside our planet."

Granted that the Soviet Union is unlikely to send cosmonauts to Mars anytime soon—although the Salyut and Mir space stations have certainly given them a great deal of experience in long-duration spaceflight—the scientists at IKI and the Vernadsky Institute have nonetheless mapped out a series of increasingly more ambitious pathfinding missions for the interim. The detailed sequence is still in flux. But the first, obviously, will be Phobos in 1988. Next will come Mars 1992, which may well involve an exploration of the surface with an instrument package wafted from point to point by a French-built balloon. Subsequent missions will carry penetrators, rodlike devices that will be dropped from high altitude to probe the subsurface rocks; rovers that will wander across the martian boulder fields; and perhaps even "moles," devices that will burrow down into the planet-wide layer of permafrost.

And finally, of course, as a last step before the first (hypothetical) manned expedition, there will come the Mars Sample Return—the mission that Sagdeev thinks is such a natural candidate for Soviet-American collaboration. ■ **M. MITCHELL WALDROP**

High-Temperature Superconductor Hints

During the past several weeks, several groups have reported tantalizing "drops" in the resistivity of their samples when cooled to about 240 K. The sudden decreases were taken as indicating the possible presence of superconductivity at this high temperature. Now, two sets of researchers are claiming to have seen the resistivity disappear altogether (that is, to below the sensitivity of their instruments) in the same temperature range. Although still short of proof of superconductivity, the new evidence adds to the expectation that a new high-temperature ceramic oxide superconductor will be identified soon. Additional evidence comes from a third group, which says it has magnetic data supporting high-temperature superconductivity.

Ideally, to verify superconductivity, researchers want to observe a vanishing resistivity and a substantial Meissner effect (magnetic flux expulsion from the interior of a specimen) that are reproducible in several samples whose properties do not change with thermal cycling between high and low temperatures.

Ching-Wu (Paul) Chu, who heads a group at the University of Houston that is collaborating with researchers at the Lockheed Palo Alto Research Laboratory and the National Magnet Laboratory, told the National Science Board late last month that the group had seen the disappearance of the resistivity in just one sample of a ceramic oxide of undisclosed composition at 225 K. Moreover, the behavior survived thermal cycling for a period of 2 weeks before the material lost its putative superconductivity. Thermal cycling is necessary for a Meissner effect measurement, and the researchers were able to detect a small effect of less than 1%, suggestive of a small volume fraction of high-temperature superconductor in the sample.

Investigators at the University of California at Berkeley have also observed a vanishing resistivity at about 230 K, once again in a ceramic oxide of undisclosed composition but one that is not dramatically different from that of the rare earth–barium–copper–oxygen compounds that become superconducting between 90 and 100 K. According to Berkeley's Alex Zettl, the sample remains resistanceless on warming until 292 K (or 66°F, a warm spring day). But, after further heating followed by cooling, the resistivity no longer vanishes. By way of explanation, Zettl says it is possible that thermal cycling disrupts tiny filaments of superconductor embedded in a mostly nonsuperconducting sample.

Finally, at Energy Conversion Devices, a Troy, Michigan, company, scientists have magnetic evidence for superconductivity up to 280 K in samples containing fluorine in place of some of the oxygen. The resistivity vanishes (becomes too small to measure) at 155 K, but anomalies in the temperature dependence of the magnetization occur at the higher temperature. According to Stephen Hudgens, the samples consist of at least four ceramic phases. The speculation is that the so-far unidentified superconducting phase is present in too small a volume fraction to give a measurable Meissner effect. ■ **ARTHUR L. ROBINSON**