Should Dying Patients Get Unproved Drugs? (*page 92*)

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SPECIAL REPORT

The Future of EXPLORING SPACE

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- 5 Essential Things to Do Up There

Consciousness
Scientists Debate How Neurons Make Us Aware

Diamond Chips
Sparkling Processors Spin Quantum Logic

Diagnosis to Go
New Portable Microlabs

5 ESSENTIAL THINGS TO DO IN SPACE

Planetary scientists have articulated goals for exploring the solar system

By George Musser

TO A CHILD OF THE SPACE AGE, books about the solar system from before 1957 are vaguely horrifying. How little people knew. They had no idea of the great volcanoes and canyons of Mars, which make Mount Everest look like a worn hillock and the Grand Canyon like a roadside ditch. They speculated that Venus beneath its clouds was a lush, misty jungle, or maybe a dry, barren desert, or a seltzer water ocean, or a giant tar pit—almost everything, it seems, but what it really is: an epic volcanic wasteland, the scene of a Noah's flood in molten rock. Pictures of Saturn were just sad: two fuzzy rings where today we see hundreds of thousands of fine ringlets. The giant planet's moons were gnats, rather than gnarled landscapes of methane lakes and dusty geysers.

All in all, the planets seemed like pretty small places back then, little more than smudges of light. At the same time, Earth seemed a lot larger than it does now. No one had ever seen our planet as a planet: a blue marble on black velvet, coated with a fragile veneer of water and air. No one knew that the moon was born in an impact or that the dinosaurs died in one. No one fully appreciated that humanity was becoming a geologic force in its own right, capable of changing the environment on a global scale. Whatever else the Space Age has done, it has enriched our view of the natural world and given us a perspective that we now take for granted.

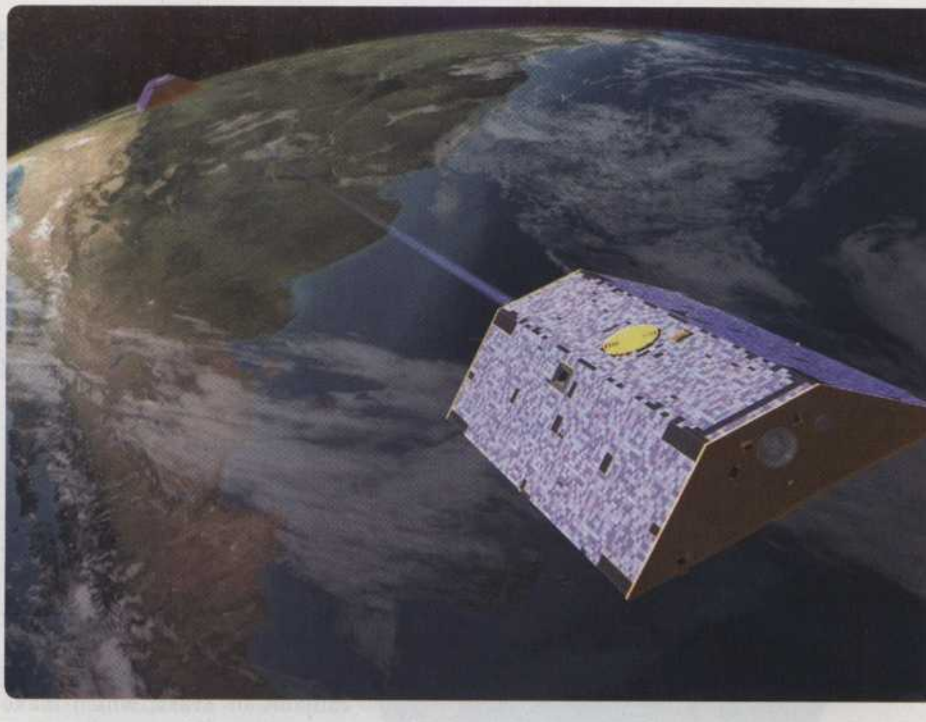
Since Sputnik, planetary exploration has gone through several waxing and waning phases. The 1980s, for instance, might as well have been the dark side of the moon. The present looks brighter: dozens of probes from the world's space programs have fanned out across the solar system, from Mercury to Pluto. But budget cuts, cost overruns and inconsistency of purpose have cast long shadows over NASA. At the very least the agency is going through its most unsettled period of transition since Nixon shot down the Apollo moon missions 35 years ago.

"NASA continues to wrestle with its own identity," says Anthony Janetos of the Pacific Northwest National Laboratory, a member of a National Research Council (NRC) panel that scrutinized NASA's Earth observation program. "Is it about exploring space? Is it about human exploration, is it about science, is it about exploring the outer universe, is it about exploring the solar system, is it about the space shuttle and station, is it about understanding this planet?"

In principle, the upheaval should be a happy occasion. Not only are robotic probes flying hither and yon, the human space program is no longer drifting like a spent rocket booster. President George W. Bush set out a clear and compelling goal in 2004—namely, to plant boots in lunar and Martian soil. Though controversial, the vision gave NASA something to shoot for. The trouble is that it quickly turned into an unfunded mandate, forcing the agency to breach the "firewall" that had traditionally (if imperfectly) shielded the science and human spaceflight programs from each other's cost overruns. "I presume it is not news to you that NASA doesn't have enough money to do all the things it's being asked to do," says Bill Claybaugh, director of NASA's Studies and Analysis Division. Cash doesn't exactly flow like liquid hydrogen at space agencies in other countries, either.

NRC panels periodically take a step back and ask whether the world's planetary exploration programs are on track. The list of goals that follows synthesizes their priorities.

1 Monitor Earth's Climate



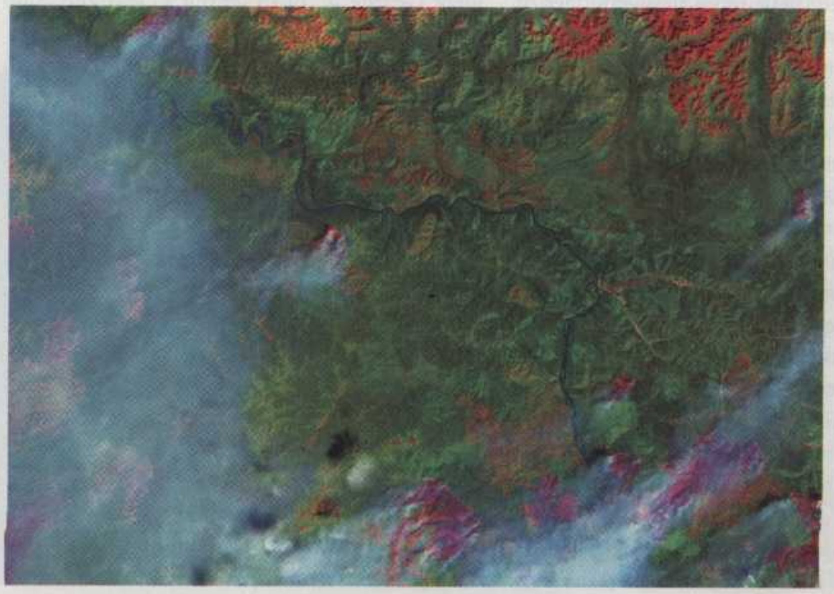
▲ TWIN SATELLITES of the Gravity Recovery and Climate Experiment (GRACE), which detect the gravitational distortions caused by the movement of water, are already past their original planned lifetime.

Amid all the excitement of buggying around Mars and peeling back the veil of Titan, people sometimes take the mundane yet urgent task of looking after our own planet for granted. NASA and the National Oceanic and Atmospheric Administration (NOAA) have really let it slide. In 2005 Janetos's NRC panel argued that the "system of environmental satellites is at risk of collapse." The situation then deteriorated further. NASA shifted $600 million over five years from Earth science to the shuttle and space station. Meanwhile the construction of the next-generation National Polar-Orbiting Operational Environmental Satellite System ran seriously over budget and had to be downsized, stripping out instruments crucial to assessing global warming, such as those that measure incoming solar radiation and outgoing infrared radiation.

Consequently, the two dozen satellites of the Earth Observation System are reaching the end of their expected lifetimes before their replacements are ready. Scientists and engineers think they can keep the satellites going, but there is a limit. "We could hold out, but we need a plan now," says Robert Cahalan, head of the Climate and Radiation Branch at the NASA Goddard Space Flight Center. "You can't wait till it breaks."

If a satellite dies before relief arrives, gaps open up in the data record, making it difficult to establish trends. For instance, if a newer instrument discovers that the sun is brighter than its predecessor found, is it because the sun really brightened or because one of the instruments was improperly calibrated? Unless satellites overlap in time, scientists may not be able to tell the difference. The venerable Landsat series, which has monitored the surface since 1972, has been on the fritz for years, and the U.S. Department of Agriculture has already had to buy data from Indian satellites to monitor crop productivity. For some types of data, no other nation can fill in.

▼ LANDSAT 7 IMAGE, taken at multiple wavelengths, shows fires in Alaska and the Yukon in 2004. A failure in 2003 hobbled the satellite, and the entire program has been on budgetary drip-feed for more than a decade.



The NRC panel called for restoring the lost funding, which would pay for 17 new missions over the coming decade, such as ones to keep tabs on ice sheets and carbon dioxide levels—essential for predicting climate change and its effects. The root issue, though, is that climate observations fall somewhere in between routine weather monitoring (NOAA's specialty) and cutting-edge science (NASA's). "There's a fundamental problem that no one is charged with climate monitoring," says climatologist Drew Shindell of the NASA Goddard Institute for Space Studies. He and others have suggested that the U.S. government's scattered climate programs be consolidated in a dedicated agency, which would own the problem and give it the focus it deserves.

ACTION PLAN

- **Fund the 17 new satellites proposed by the National Research Council over the next decade (estimated cost: $500 million a year)**
- **Found a climate agency**

2 Prepare an Asteroid Defense

Like climate monitoring, guarding the planet from asteroids always seems to fall between the cracks. Neither NASA nor the European Space Agency (ESA) has a mandate to stave off human extinction. The closest they come is NASA's Spaceguard Survey, a $4-million-a-year telescope observing program to scan near-Earth space for kilometer-size bodies, the range that can cause global as opposed to merely regional destruction. But no one has done a systematic search for region destroyers, an estimated 20,000 of which come within striking range of our planet. No Office of Big Space Rocks is standing by to evaluate threats and pick up the red phone if need be. It would take 15 years or longer to mount a defense against an incoming body, assuming that the technology were ready to go, which it isn't. "Right now the U.S. doesn't have a comprehensive plan," says aerospace engineer Larry Lemke of the NASA Ames Research Center.

This past March, at Congress's request, NASA published a report that could serve as the starting point for such a plan. By its analysis, searching for 100- to 1,000-meter bodies could largely piggyback on the Large Synoptic Survey Telescope (LSST), an instrument that a consortium of astronomers and companies (most famously Google) is now working on to scan the sky for anything that moves, blinks or winks. A report last month by the LSST project itself estimates that the scope, as currently designed, should find 80 percent of the bodies over one decade of operation, from 2014 to 2024. With an extra $100 million of fine-tuning, it could net 90 percent of them.

Like any Earth-based instrument, though, the LSST has two limitations. First, it has a blind spot: bodies that are either just ahead or just behind Earth in its orbit—the most dangerous ones—can be observed only at dusk or dawn, when they are easily lost in the sun's glare. Second, the instrument can estimate the mass of asteroids only indirectly, based on how bright they are. Limited to visible light, the estimates are good only to a factor of two: a big but dark asteroid can masquerade as a small but bright one. "That difference could matter a lot if we actually decided there was a mitigation required," NASA's Claybaugh says.

▲ **NOT A SIGHT YOU WANT TO SEE: An asteroid of the dinosaur-killing sort would reach from sea level to the cruising altitude of commercial airliners.**

THREATENING ASTEROIDS

Dinosaur killers, 10 kilometers across, hit every 100 million years on average. Globally devastating asteroids, one kilometer or larger, come every half a million years or so. City destroyers, 50 meters across, strike perhaps once a millennium.

The Spaceguard Survey has found just over 700 kilometer-size bodies, none posing a threat over the coming centuries. The rate of discovery is tapering off, suggesting the survey has found about 75 percent of the total.

The chance of an impactor among the remaining 25 percent is small, but the consequence would be large. Statistically, the risk amounts to an average death toll of 1,000 people a year. Smaller ones kill maybe 100 a year on average.

To plug these holes, the NASA team also considered building a $500-million infrared space telescope and putting it in its own orbit around the sun. It could pick up essentially every threat to Earth and, by studying bodies at multiple wavelengths, pin down their mass to within 20 percent. "If you want to do it right, you want to go to the infrared in space," says planetary scientist Donald Yeomans of the Jet Propulsion Laboratory (JPL), a co-author of the report.

The other question is what to do if an asteroid is on its way. A rule of thumb is that to divert an asteroid by one Earth radius, you need to change its velocity by one millimeter per second, one decade in advance, by either hitting it, nuking it, pushing it or towing it gravitationally. In 2004 ESA's Near-Earth Object Mission Advisory Panel recommended doing a trial run. Known as Don Quijote, the proposed $400-million mission would fire a 400-kilogram projectile into an asteroid and watch what happens.

The debris thrown out by the impact would exert a force on the asteroid via the rocket effect, but no one knows how strong it would be. Finding out is the whole point of the mission. "You can find out whether the kinetic impactor strategy would work or not," says Alan Harris of the German Aerospace Center in Berlin. Scientists would choose a body on a distant orbit so that

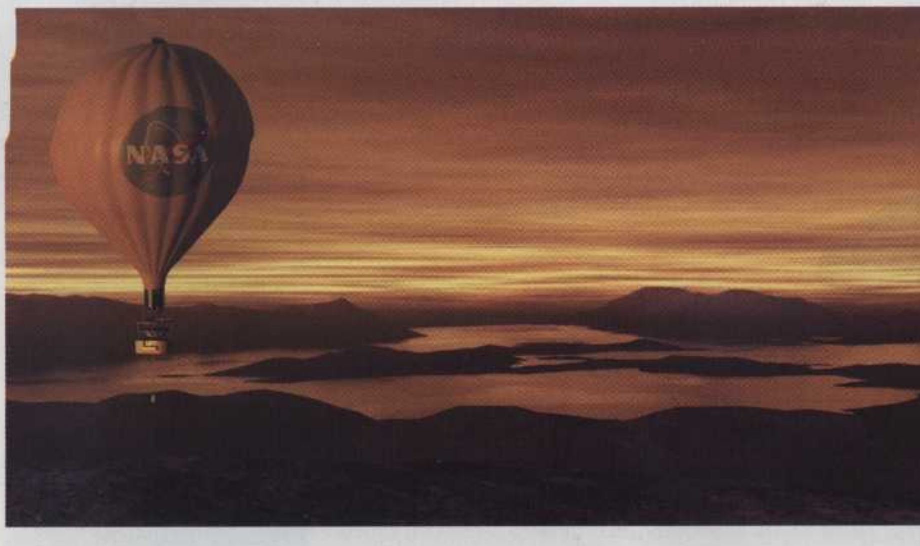
◄ **THY ASTEROID IS SO GREAT, and my spaceship is so small. But given enough time, even a modest rocket can steer a big rock out of harm's way.**

a snafu could not end up putting it on a collision course with Earth.

This past spring ESA completed a set of feasibility studies—and promptly shelved them for lack of money. It would take a joint effort with NASA or the Japan Aerospace Exploration Agency (JAXA), or both, to make the plan happen.

ACTION PLAN

- Extend asteroid search to smaller bodies, perhaps using a dedicated infrared space telescope
- Deflect an asteroid in a controlled way as a trial run
- Develop an official system for evaluating potential threats



▲ **HOT-AIR BALLOON is ideally suited to getting around Titan. A plutonium power source throws off enough waste heat for a 12-meter balloon carrying 160 kilograms of instruments and cruising at an altitude of 10 kilometers.**

3 Seek Out New Life

Before Sputnik, scientists thought the solar system might be a veritable Garden of Eden. Then came the fall. Earth's sister worlds proved to be hellish. Even Mars bit the dust when the Mariner probes revealed a cratered moonscape and the Viking landers failed to find even a single organic molecule. But lately the plausible venues for life have multiplied. Mars is looking hopeful again. Outer-planet moons, notably Europa and Enceladus, appear to have vast underground seas and plenty of life's raw materials. Even Venus might have been covered in oceans once.

For Mars, NASA is taking a follow-the-water approach, looking not for organisms per se but for signs of past or present habitability. Its latest mission, Phoenix, took off in August and should touch down toward the middle of next year in the unexplored northern polar region. It is not a rover but a fixed lander with a robot arm capable of digging down a few centimeters to study shallow ice deposits. The agency's next step is the $1.5-billion Mars Science Laboratory (MSL), a car-size rover scheduled for launch in late 2009 and landfall a year later.

Gradually, though, scientists will want to return to the direct search for living things or their remains. In 2013 ESA plans to launch the ExoMars rover, equipped with a Viking-like chemistry lab and, crucially, a drilling platform able to go two meters down—which should be deep enough to get past the toxic surface layers to where organic material might have survived.

Unfortunately, the trail then goes cold. Most planetary scientists' single highest priority—not just for the search for life but for solar system exploration generally—is to bring some Martian rocks and dirt back to Earth for analysis. Even a little bit would go a long way toward unraveling the planet's history, as the Apollo samples did for the moon. NASA's budget woes pushed back the multibillion-dollar mission to 2024 at the earliest, but over the summer a glimmer of light reappeared when the agency began to consider modifying MSL to store samples for eventual collection.

For Europa, scientists' priority is an orbiter to measure how the satellite's shape and gravitational field respond to tides raised by Jupiter. If a sea lies within, the surface will rise and fall by 30 meters; if not, by only one meter. Magnetic readings and ground-penetrating radar could also dowse the ocean, and cameras would map the surface in preparation for an eventual lander and driller.

For Titan, a natural follow-up to the ongoing Cassini mission would be an

▶ **EXOMARS is the European Space Agency's Mars rover, scheduled to land in 2014. Carrying a drilling platform and biology laboratory, it will resume the direct search for life, on hold since the Viking landers of the mid-1970s.**

TIBOR BALINT (top); ESA (bottom)

orbiter plus a surface sampler. Titan's Earth-like atmosphere opens up the possibility of a hot-air balloon, which could dip down every now and then to grab rocks and dirt. The goal, says Jonathan Lunine of the University of Arizona, would be to "analyze the surface organics to see if there are systematic trends that suggest the start of self-organization, which is how most origins-of-life people think life began on Earth."

This past January, NASA finally began to study these missions seriously. The agency plans to choose between Europa and Titan next year, so that a $2-billion probe could fly in about a decade. The body that doesn't make the cut will have to wait yet another decade.

In the end, it may turn out that life on Earth is unique after all. Disappointing, no doubt, but it would not mean the whole effort had been a waste. "I see astrobiology more broadly than just looking for life," says Bruce Jakosky, director of the Center for Astrobiology at the University of Colorado. It is also about figuring out how varied life can or cannot be, what its preconditions are, and how lifelessness begat life four billion years ago on our planet. Thus, the search is not just about finding companionship in the cosmos. It is about divining our own origins.

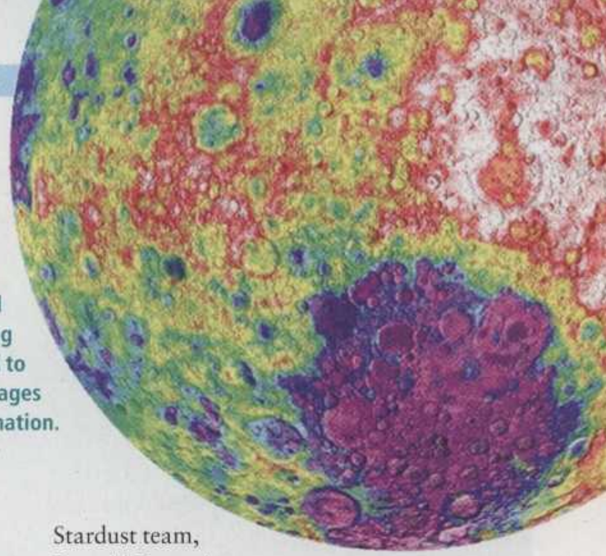
ACTION PLAN

- Get Martian sample return on track
- Gear up for returning to Europa and Titan

4 Explain the Genesis of the Planets

Like the origin of life, the origin of the planets was a complex, multistage process. Jupiter was the first-born and the guiding hand for the rest. Did it build up slowly, like the other planets, or did it take shape in a single gravitational whoosh, like a small star? Did it form farther from the sun and move inward, as its anomalously high levels of heavy elements suggest—in which case it might have flicked lesser worlds out of its way? NASA's Juno orbiter to the giant planet, scheduled for launch in 2011, might provide some answers.

Those concerned with planet formation also want to follow up the Stardust mission, which returned samples last year from the coma of dust that surrounds a solid comet nucleus. "We have just scratched the surface," says the head of the Stardust team, Donald Brownlee of the University of Washington. "Stardust showed that comets were terrific collectors of early solar system materials from the entire solar nebula. These materials were then packed in ice and stored for the age of the solar system. Stardust has found fabulous things from the inner solar system, from extrasolar sources and even perhaps busted-up Pluto-like objects, but the sample is limited." JAXA is planning a direct sampling of a comet nucleus itself.



▶AITKEN BASIN (*purplish blotch*) on Earth's moon, considered the biggest hole in the solar system, is 2,500 kilometers across and 12 kilometers deep. Pinning down its age is crucial to unraveling the late stages of planet formation.

▲HAYABUSA ASTEROID SAMPLER is an innovative (if trouble-plagued) probe that could serve as a model for a comet nucleus sample return mission—which planet formation experts consider crucial. ▼

Earth's moon is another place to do some cosmoarchaeology. It has long been the Rosetta stone for understanding the impact history of the early solar system, connecting the relative ages provided by crater counts with the absolute dating of Apollo and Russian Luna samples. But the landers of the 1960s visited a limited range of terrains. They did not reach the Aitken basin, a continent-size crater on the far side, whose age may indicate when planet formation truly ended. NASA is now considering a robot to bring back a sample from there. It could run about half a billion dollars.

One oddity of the solar system is that the asteroids of the main asteroid belt apparently formed before Mars, which in turn formed before Earth—suggesting that a wave of planet formation swept inward, perhaps instigated by Jupiter. But does Venus fit the progression? "There's no information," says planet formation expert Doug Lin of the University of California, Santa Cruz. "There's just *no* information." Between its acidic clouds, oceanic pressures and oven-cleaning temperatures, Venus is not exactly the friendliest environment for a lander. An NRC panel in 2002 recommended sending a balloon, which could touch down just long enough to collect samples and then repair to a cooler altitude to analyze them or forward them to Earth. The Soviet Union sent balloons to Venus in the mid-1980s, and the Russian space agency—which otherwise has fallen off the face of the earth when it comes to planetary exploration—now has plans for a new lander.

Studies of the origin of the planets overlap quite a bit with studies of the origins of life. Jakosky puts it thus: "Venus sits at the inner edge of the habitable zone. Mars sits at the outer edge. Earth sits in the middle. And understanding the differences between those planets is central to asking about life beyond our solar system."

ACTION PLAN

- **Return samples from a comet nucleus, the moon and Venus**

5 Break Out of the Solar System

Two years ago the venerable Voyager space probes went through a funding scare. NASA, desperate for money, said it might have to shut them down. The ensuing public outcry kept them going. Nothing that human hands ever touched has gone as far as Voyager 1: as of press date, 103 astronomical units (AU)—that is, 103 times as far from the sun as Earth is—and picking up another 3.6 AU every year. In 2002 or 2004 (scientists disagree), it entered the mysterious multilayered boundary of the solar system, where outgoing solar particles and inflowing interstellar gases go mano a mano.

But Voyager was designed to study the outer planets, not interstellar space, and its plutonium batteries are running down. NASA has long had a mind to dispatch a dedicated probe, and an NRC report on solar physics argued in 2004 that the agency should start working toward that goal.

The spacecraft would measure the abundance of amino acids in interstellar particles to see how much of the solar system's complex organics came from beyond; look for antimatter particles that might have originated in miniature black holes or dark matter; figure out how the boundary screens out material, including cosmic rays,

GETTY IMAGES

Right Stuff?

Scientists have a wide range of attitudes toward human spaceflight. Some think it incompatible with, even inimical to, scientific goals. Others think the two not only compatible but essentially the same thing—for them, curiosity-driven science and because-it's-there exploration are two sides of the same exploratory urge. Others think that humans will eventually want to leave the planet, out of either desire or desperation, even if the time has not yet come.

Whatever their views, researchers agree on several basic points. First, although astronauts can conduct useful science in space and on the moon and Mars, the cost of sending people greatly outweighs the scientific benefit. That may change in the future, as robots reach their limits, but for now a human program must be decided on its other merits; it is not primarily a scientific project. NASA administrator Michael Griffin has said explicitly that the moon/Mars initiative is not about science, although science gains by piggybacking on it.

Second, the space agency needs to respect the firewall between robotic missions and human missions, because the goals of these two wings of the space program are, for now, so distinct. Third, government initiatives and private flight each have something to contribute. With the retirement of the shuttle and then the International Space Station, Earth orbit can increasingly be left to the private sector, freeing NASA and other agencies to stay at the cutting edge.

Finally, if the nations of the world do send astronauts into space, they should at least give the travelers something worthy and inspiring to do. For most researchers, the space station, at least in its present form, does not count. Mars does. The moon is still hotly debated. —*G.M.*

CRUNCHING THE NUMBER$

NASA's budget is **$16.8 billion,** about **0.6 percent** of the total federal budget. Three fifths goes to human spaceflight, a third to science (for the planetary probes as well as space telescopes to explore the broader universe) and the rest to aeronautics.

The agency projects the new moon shot will run about **$100 billion** over the next decade. The Apollo program cost about the same.

This money comes from phasing out the shuttle and space station. President George W. Bush has retracted his earlier promise of a few extra billions, forcing a **20 percent cut** in the science program. Numerous missions have been canceled or put off.

NASA administrator Michael Griffin estimates that if the agency's budget just keeps up with inflation, astronauts could land on Mars in the **late 2030s**.

SCI AM

A Visual Summary

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which may affect Earth's climate; and see whether nearby interstellar space has a magnetic field, which might play a crucial role in star formation. The probe could act as a miniature space telescope, making cosmological observations unhindered by the solar system's dust. It might investigate the so-called Pioneer anomaly—an unexplained force acting on two other distant spacecraft, Pioneer 10 and 11—and pinpoint where the sun's gravity brings distant light rays to a sharp focus, as a test of Einstein's general theory of relativity. For good measure, scientists could aim the probe for a nearby star such as Epsilon Eridani, although it would take tens of thousands of years to get there.

Getting the thing hundreds of AU out within the lifetime of a researcher (and of a plutonium power source) would mean boosting it to a speed of 15 AU a year. The options boil down to large, medium and small—propelled, respectively, by an ion drive powered by a nuclear reactor, an ion drive powered by plutonium generators, or a solar sail.

The large (36,000-kilogram) and medium (1,000-kilogram) missions were honed in 2005 by teams led, respectively, by Thomas Zurbuchen of the University of Michigan at Ann Arbor and by Ralph McNutt of the Johns Hopkins University Applied Physics Laboratory. The small option seems the most likely to fly. ESA's Cosmic Vision program is now considering a proposal from an international team of scientists led by Robert Wimmer-Schweingruber of the University of Kiel in Germany. NASA might join in, too.

A solar sail 200 meters across could carry a 500-kilogram spacecraft. After launch from Earth, it would first swoop toward the sun, going as close as it dared—just inside Mercury's orbit—to get flung out by the intense sunlight. Like a windsurfer, the spacecraft would steer by leaning to one side or the other. Just before passing Jupiter's orbit, it would cast off the sail and glide outward. To get ready, engineers need to design a sufficiently lightweight sail and test it on less ambitious missions first.

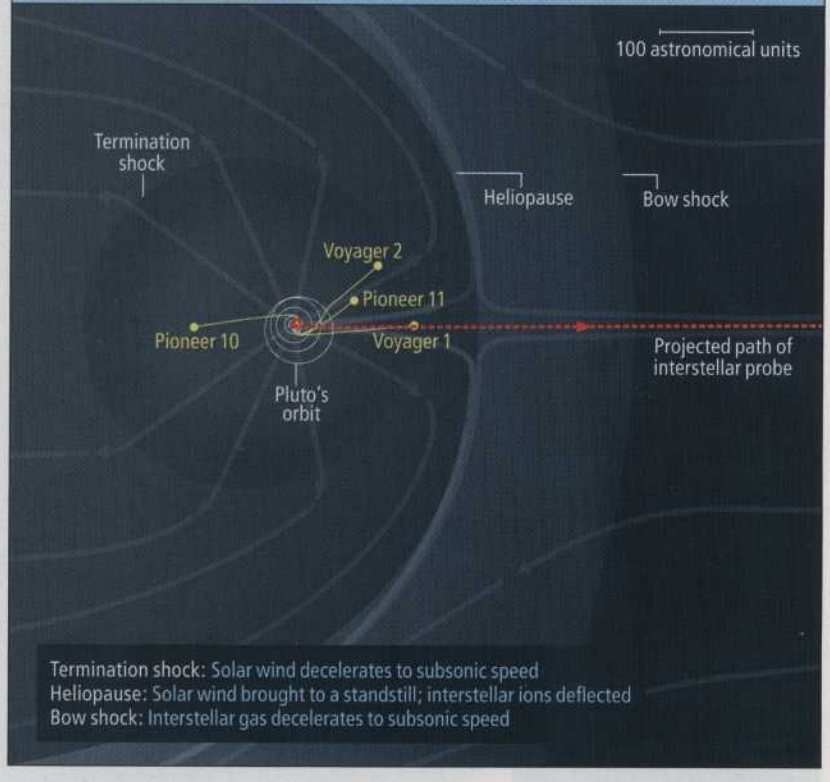
"Such a mission, be it ESA- or NASA-led, is the next logical step in our exploration of space," Wimmer-Schweingruber says. "After all, there is more to space than exploring our very, very local neighborhood." The estimated price tag is about $2 billion, including three decades' operating expenses. Studying the other planets has helped humans figure out how Earth plugs into a grander scheme, and studying our interstellar environs would do the same for the solar system at large.

ACTION PLAN

- Begin developing and testing technology for an interstellar probe ■

THE OUTER LIMITS

▼ An interstellar probe would explore the boundary region of the solar system, where gas flowing out from the sun pushes back the ambient interstellar gas. It would have the speed, endurance and instruments that the Pioneer and Voyager probes never did.



▼ SOLAR SAIL is a big mirror (typically Mylar) that captures the momentum in sunlight. An interstellar probe needs one with a density of one gram per square meter, compared with 20 g/m^2 for current sails, but engineers think it doable.

➡ MORE TO EXPLORE

Current positions of the Voyagers and Pioneers can be seen at **http://heavens-above.com/solar-escape.asp**

NASA's report on the asteroid threat is available at **http://neo.jpl.nasa.gov/neo/report2007.html.** For a critique, see **www.b612foundation.org/press/press.html**

NASA administrator Michael Griffin discusses the agency's future at **aviationweek.typepad.com/space/2007/03/human_space_exp.html**

National Research Council reports are available at **www.nap.edu/catalog/11937.html** (life on Mars), **11820.html** (Earth sciences), **11644.html** (science budget), **11135.html** (solar physics) and **10432.html** (solar system).