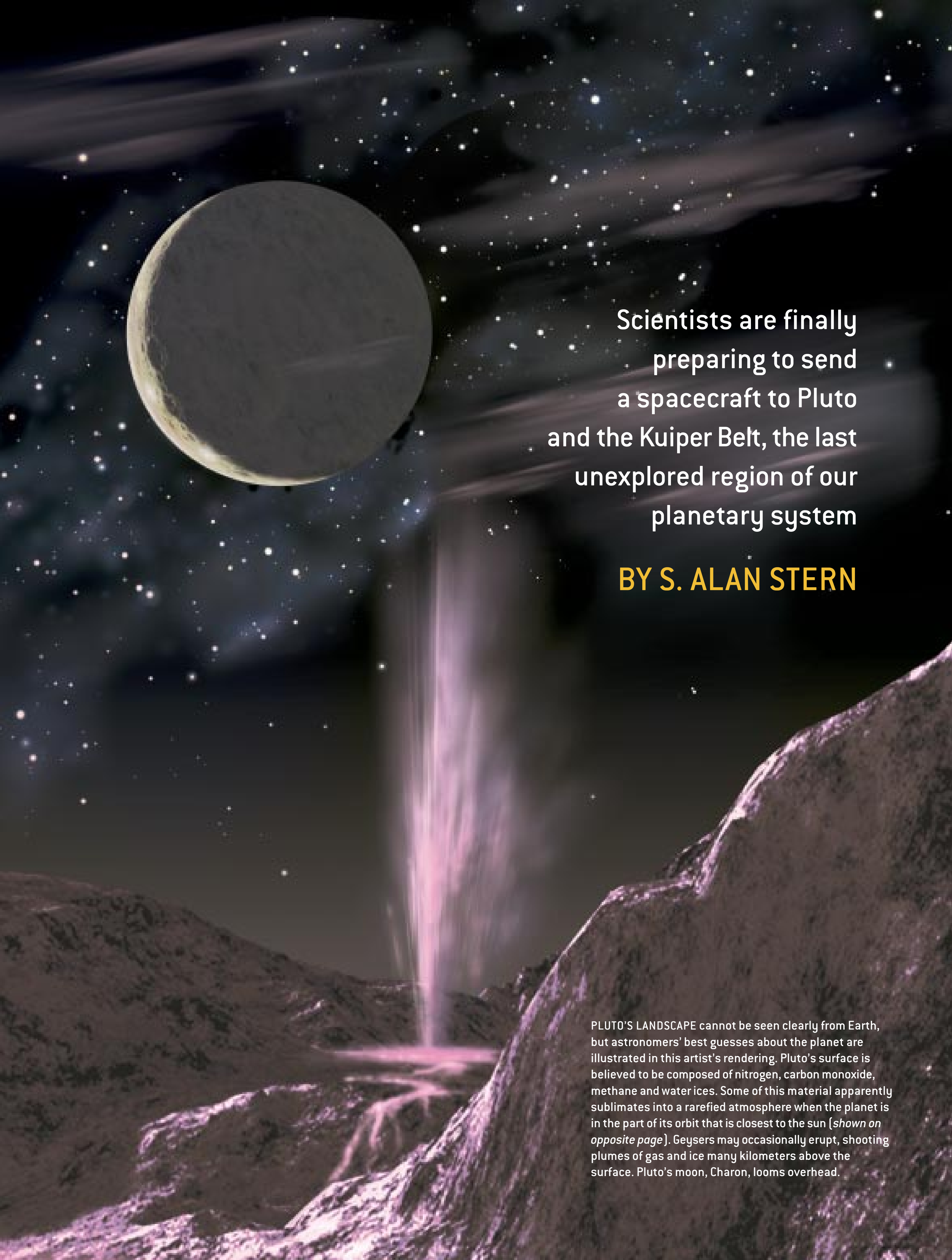
JOURNEY TO THE FARTHEST PLANET

Until about 10 years ago, most planetary scientists considered Pluto to be merely an oddity. All the other planets neatly fit into what astronomers knew about the architecture of the solar system—four small, rocky bodies in the inner orbits and four gas giants in the outer orbits, with an asteroid belt in between. But distant Pluto was an icy enigma traveling in a peculiar orbit beyond Neptune. Some researchers, most notably Dutch-American astronomer Gerard Kuiper, had suggested in the 1940s and



Scientists are finally preparing to send a spacecraft to Pluto and the Kuiper Belt, the last unexplored region of our planetary system

BY S. ALAN STERN

PLUTO'S LANDSCAPE cannot be seen clearly from Earth, but astronomers' best guesses about the planet are illustrated in this artist's rendering. Pluto's surface is believed to be composed of nitrogen, carbon monoxide, methane and water ices. Some of this material apparently sublimates into a rarefied atmosphere when the planet is in the part of its orbit that is closest to the sun (*shown on opposite page*). Geysers may occasionally erupt, shooting plumes of gas and ice many kilometers above the surface. Pluto's moon, Charon, looms overhead.

1950s that perhaps Pluto was not a world without context but the brightest of a vast ensemble of objects orbiting in the same region. This concept, which came to be known as the Kuiper Belt, rattled around in the scientific literature for decades. But repeated searches for this myriad population of frosty worlds came up empty-handed.

In the late 1980s, however, scientists determined that something like the Kuiper Belt was needed to explain why many short-period comets orbit so close to the plane of the solar system. This circumstantial evidence for a distant belt of bodies orbiting in the same region as Pluto drove observers back to their telescopes in search of faint, undiscovered objects beyond Neptune. By the 1980s telescopes were being equipped with electronic light detectors that made searches far more sensitive than work done previously with photographic plates. As a result, success would come their way.

In 1992 astronomers at the Mauna Kea Observatory in Hawaii discovered the first Kuiper Belt object (KBO), which was found to be about 10 times as small as and almost 10,000 times as faint as Pluto [see "The Kuiper Belt," by Jane X. Luu and David C. Jewitt; Scientific American, May 1996]. Since then, observers have found more than 600 KBOs, with diameters ranging from 50 to almost 1,200 kilometers. (Pluto's diameter is about 2,400 kilometers.)

And that's just the tip of the iceberg, so to speak. Extrapolating from the small fraction of the sky that has been surveyed so far, investigators estimate that the Kuiper Belt contains approximately 100,000 objects larger than 100 kilometers across. As a result, the Kuiper Belt has turned out to be the big brother to the asteroid belt, with far more mass, far more objects (especially of large sizes), and a greater supply of ancient, icy and organic material left over from the birth of the solar system.

It is now clear that Pluto is not an anomaly. Instead it lies within a vast swarm of smaller bodies orbiting between about five billion and at least eight billion kilometers from the sun. Because this far-off region may hold important clues to the early development of the solar system, astronomers are keenly interested in learning more about Pluto, its moon, Charon, and the bodies making up the Kuiper Belt. Unfortunately, the immense distance between this region of the solar system and Earth has limited the quality of observations. Even the exquisite Hubble Space Telescope, for example, shows only blurry regions of light and dark on Pluto's surface. And although the Pioneer, Voyager and Galileo spacecraft have provided scientists with marvelous close-up images of Jupiter, Saturn, Uranus and Neptune, no space probe has ever visited the Pluto-Charon system or the Kuiper Belt.

Recognizing the importance of this region of the solar system, scientists have urged NASA to put Pluto on its planetary exploration agenda for more than a decade. In response, the space agency has studied mission concepts ranging from houseboat-size, instrument-laden spacecraft similar to the Cassini probe (now on its way to Saturn) to hamster-size craft carrying just a camera. In the late 1990s NASA settled on a midsize concept called Pluto-Kuiper Express that would be built by the Jet Propulsion Laboratory in Pasadena, Calif. But the projected cost of that mission quickly rose toward $800 million, which was considerably more than NASA wanted to invest. As a result, the agency scrapped Pluto-Kuiper Express in the fall of 2000.

But this cancellation didn't go down easily. Scientists, space exploration advocates and schoolchildren flooded NASA with requests to reconsider, and the agency did so, but with a twist. Rather than restarting the expensive Pluto-Kuiper Express, NASA launched a competition among universities, research labs and aerospace companies for proposals to explore Pluto, Charon and the Kuiper Belt at lower cost. Never before had NASA allowed industry and universities to compete to lead a mission to the outer solar system. Given the novelty of such a competition, NASA made it clear that if none of the proposals could accomplish the specified scientific measurement objectives by 2020, and for less than $500 million, then the agency was under no obligation to choose *any* of them.

Last November, after a grueling selection process, NASA picked our team, called New Horizons, to carry out the Pluto–Kuiper Belt mission. New Horizons is led by my institution, the Southwest Research Institute, based in San Antonio, Tex., and the Applied Physics Laboratory (APL) at Johns Hopkins Univers- ity. A team of scientists from more than a dozen universities, research institutions and NASA centers is deeply involved in planning the scientific observations. The Southwest Re- search Institute will manage the project, be in charge of the mission team and be responsible for the development of the scientific instruments. APL will build and operate the New Horizons spacecraft. Ball Aerospace, the NASA Goddard Space Flight Center and Stanford University will build portions of the instrument payload, and JPL will be responsible for spacecraft tracking and navigation.

By pioneering less expensive ways to build and operate a spacecraft to explore the outer solar system, New Horizons sat-

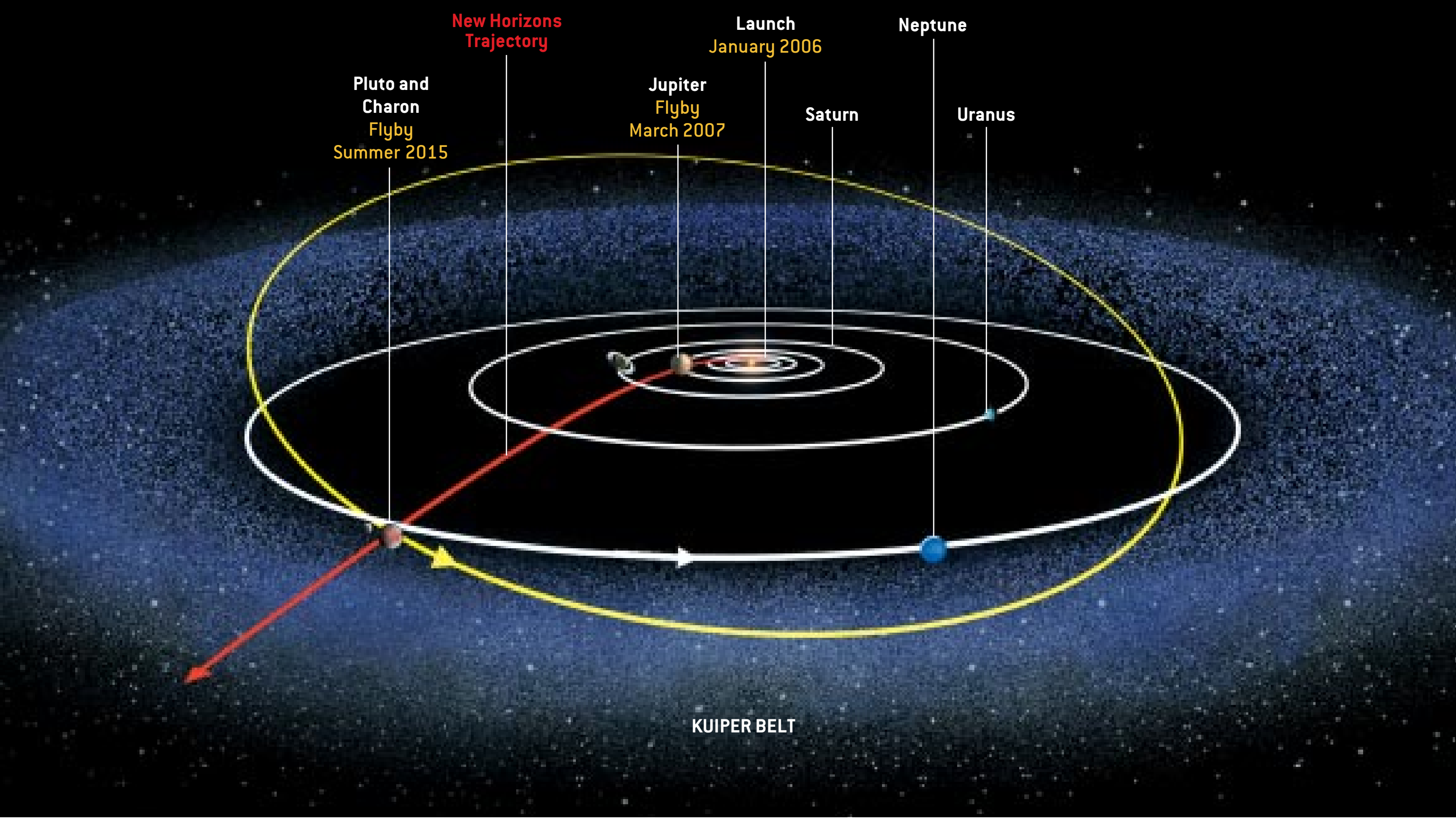
Overview/*New Horizons*

- Astronomers have recently learned that Pluto is not an anomaly, as once believed, but the brightest of a vast ensemble of objects orbiting in a distant region called the Kuiper Belt. Scientists want to explore Pluto and the Kuiper Belt objects because they may hold clues to the early history of the planets.
- Pluto and its moon, Charon, are also intriguing in their own right. The two bodies are so close in size that astronomers consider them a double planet. In addition, Pluto has a rapidly escaping atmosphere and complex seasonal patterns.
- NASA has chosen a team called New Horizons to build a spacecraft that would study Pluto, Charon and several Kuiper Belt objects during a series of flyby encounters. If its funding is approved by Congress, the spacecraft could be launched in 2006 and arrive at Pluto as early as 2015.

EDWIN FAUGHN (*preceding pages*)

OUTWARD BOUND

THE JOURNEY TO PLUTO could take less than 10 years if the New Horizons spacecraft is launched in 2006. Traveling along the planned trajectory (*red line*), New Horizons would head initially for a Jupiter flyby that would use the planet's gravity to slingshot the craft toward Pluto (*yellow orbit*). After investigating Jupiter in 2007 and the Pluto-Charon system in 2015, the probe would go on to reconnoiter several of the icy bodies in the Kuiper Belt.



DON DIXON

isfied NASA's conditions: the total mission cost is $488 million, including more than $80 million in budgeted reserves, and the spacecraft may arrive at Pluto as early as the summer of 2015. Furthermore, New Horizons would fly more instruments and return about 10 times as much observational data as the canceled Pluto-Kuiper Express mission would have delivered and would do so for less money.

The launch of New Horizons, however, is not yet a sure thing: in February, President George W. Bush removed the $122 million needed for the mission from NASA's budget for the 2003 fiscal year. But my colleagues and I are hopeful that Congress, which mandated NASA to select and begin the mission to Pluto and the Kuiper Belt, will reinstate funding for the construction of the craft. If so, New Horizons would be much more than the first mission to Pluto. During its journey, the spacecraft would also fly by and study Jupiter and its moons, and after flying by Pluto-Charon, the probe would go on to reconnoiter several KBOs at close range.

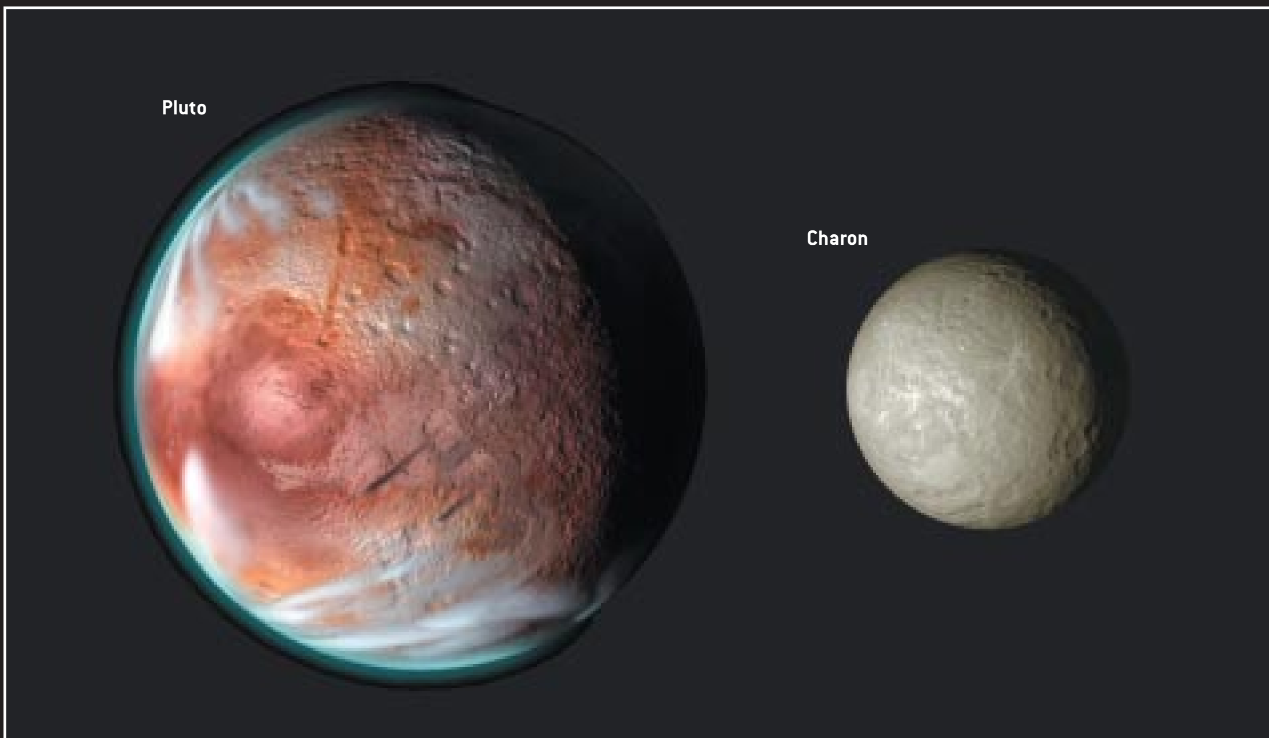
An Archaeological Dig in Space

WHY ARE ASTRONOMERS so interested in studying Pluto-Charon and the Kuiper Belt? I can summarize only a few of the reasons here. For one, the size, shape, mass and general nature of the Kuiper Belt appear to be much like the debris belts seen around other nearby stars, such as Vega and Fomalhaut. Researchers, including myself, have used computer modeling techniques to simulate the formation of the KBOs almost five billion years ago as the planetary system was coalescing from a whirling disk of gas and dust. We found that the ancient Kuiper Belt must have been approximately 100 times as massive as it is today to give rise to Pluto-Charon and the KBOs we see. In other words, there was once enough solid material to have formed another planet the size of Uranus or Neptune in the Kuiper Belt.

The same simulations also revealed that large planets like Neptune would have naturally grown from the KBOs in a very short time had nothing disturbed the

DISTANT WORLDS

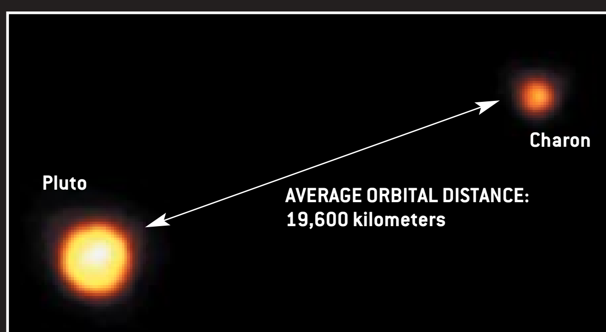
ASTRONOMERS ARE INTERESTED in obtaining close-up views of Pluto and its moon, Charon, depicted here in an artist's rendering (*top*) based on the current knowledge of the two bodies. Because the Pluto-Charon system is so far from Earth, even the Hubble Space Telescope shows only blurry images of the two bodies (*bottom*).



The relative sizes of Pluto and Charon are drawn to scale, but the distance between them is not.

KEY FACTS

Diameter of Pluto: 2,400 kilometers
Diameter of Charon: 1,200 kilometers
Average distance of Pluto-Charon from sun: 5.9 billion kilometers
Orbital period around sun: 248 years
Average distance between Pluto and Charon: 19,600 kilometers
Orbital period of Charon around Pluto: 6.39 days
Rotation periods of Pluto and Charon: 6.39 days
Surface composition of Pluto: Nitrogen, carbon monoxide, methane and water ices
Surface composition of Charon: Water ice and possibly other compounds



DON DIXON (*artist's rendering*); NASA/ESA/ESO (*Hubble image*)

region. Clearly, something disrupted the Kuiper Belt at about the time Pluto was formed, but we do not yet know the cause of the disturbance. Perhaps it was the formation of Neptune near the belt's inner boundary. Did the planet's gravitational influence somehow interrupt the creation of another gas giant farther out? And if so, why didn't the formation of Uranus frustrate the birth of Neptune in the same way? Perhaps instead it was the gravitational influence of a large population of planetary embryos—rocky bodies thousands of kilometers across—moving rapidly through the Kuiper Belt billions of years ago after they were ejected by Uranus and Neptune from their formation zones. Or perhaps it was something else altogether. Whatever the cause, the Kuiper Belt lost most of its mass, and the growth of bodies in the region was suddenly arrested.

The KBOs are remnants of that ancient planet-building process and therefore hold extremely important clues to the formation of the outer solar system. Exploring Pluto and the Kuiper Belt is the equivalent of conducting an archaeological dig into the history of the outer solar system—a place where researchers can get a valuable glimpse of the long-gone era of planetary formation.

Furthermore, although our knowledge of Pluto and Charon is meager, what we do know indicates that they offer a scientific wonderland of their own. For one, Charon is surprisingly large—its diameter is about 1,200 kilometers, or about half of Pluto's. Because the two bodies are so close in size, Pluto-Charon can be considered a double planet. No other planet in our solar system falls into this category—the diameters of most satellites are just a few percent of the diameters of their parent planets. But because astronomers have discovered many double asteroids and double KBOs in recent years, there is now little doubt that binary objects like Pluto-Charon are common in our solar system and most likely in others. Yet we have never visited a binary world.

We are eager to know how a system such as Pluto-Charon could form. The prevailing theory is that Pluto collided with another large body in the distant past and that much of the debris from this impact went into orbit around Pluto and eventually coalesced to form Charon. Because it appears that a similar collision led to the creation of Earth's moon, the study of Pluto and Charon is expected to shed some light on that subject as well.

Researchers also want to know why Pluto and Charon are so different in appearance. Observations from Earth and the Hubble Space Telescope show that Pluto has a highly reflective surface with distinct markings that indicate the presence of expansive polar caps. In contrast, Charon's surface is far less reflective, with indistinct markings. And whereas Pluto has an atmosphere, Charon apparently does not. Is the sharp dichotomy between these two neighboring worlds a result of divergent evolution, perhaps because of their different sizes and compositions, or is it a consequence of how they originally formed? We do not know.

Also intriguing is the fact that Pluto's density, size and surface composition are strikingly similar to those of Neptune's largest satellite, Triton. One of the great surprises of Voyager 2's exploration of the Neptune system was the discovery of ongoing, vigorous volcanic activity on Triton. Will Pluto also display such activity? Will the KBOs as well? Our present-day knowledge of planetary processes suggests that they should not, but Triton's activity was not expected either. Perhaps Triton is showing us that we do not yet understand the nature of small worlds. By exploring Pluto and the KBOs, we expect to gain a better comprehension of this fascinating class of bodies.

Yet another of Pluto's alluring features is its bizarre atmosphere. Although Pluto's atmosphere is about 30,000 times less dense than Earth's, it offers some unique insights into the workings of planetary atmospheres. Whereas Earth's atmosphere contains only one gas (water vapor) that regularly undergoes phase transitions between solid and gaseous states, Pluto's atmosphere contains three: nitrogen, carbon monoxide and methane. Furthermore, the current temperature on Pluto varies by about 50 percent across its surface—from about 40 to about 60 kelvins. Pluto reached its closest approach to the sun in 1989. As the planet moves farther away, most astronomers believe that the average surface temperature will drop and that most of the atmosphere will condense and fall as snow. Pluto may well have the most dramatic seasonal patterns of any planet in the solar system.

What is more, Pluto's atmosphere bleeds into space at a rate much like a comet's. Most of the molecules in the upper atmosphere have enough thermal energy to escape the planet's gravity; this extremely fast leakage is called hydrodynamic escape. Although this phenomenon is not seen on any other planet today, it may have been responsible for the rapid loss of hydrogen from Earth's atmosphere early in our planet's history. In this way, hydrodynamic escape may have helped make Earth suitable for life. Pluto is now the only planet in the solar system where this process can be studied.

An important connection between Pluto and the origin of life on Earth is the presence of organic compounds, such as frozen methane, on Pluto's surface and water ice in its interior. Recent observations of KBOs show that they, too, probably harbor large quantities of ice and organics. Billions of years ago such objects are believed to have routinely strayed into the inner part of the solar system and helped to seed the young Earth with the raw materials of life.

A Grand Tour Indeed

GIVEN SO MANY compelling scientific motivations, it is not hard to understand why the planetary research community wants to send a spacecraft to Pluto and the Kuiper Belt. And given the romance and adventure of exploring uncharted worlds, it is not surprising that so many citizens and grade school children have also become excited about this mission to new frontiers.

NASA's request for Pluto–Kuiper Belt mission proposals specified three top priorities for scientific observations. First, the craft must map the surfaces of Pluto and Charon with an average resolution of one kilometer (in contrast, the Hubble Space Telescope cannot do better than about 500-kilometer resolution when it views Pluto and Charon). Second, the probe must map the surface composition across the various geologic provinces of the two bodies. Third, the craft must determine the composition and structure of Pluto's atmosphere, as well as its escape rate. NASA also outlined a list of lower priorities, including the measurement of surface temperatures and the search for additional satellites or rings around Pluto. The agency also required that the spacecraft accomplish the same objectives for at least one KBO beyond Pluto.

When NASA selected our proposal late last year, it stated that the New Horizons mission offered both the best scientific return and the lowest risk of schedule delays and cost overruns. This was, in part, because of the robust capabilities of the spacecraft we proposed and the ex-

THE AUTHOR

S. ALAN STERN is a planetary scientist and the principal investigator of NASA's New Horizons mission to Pluto and the Kuiper Belt. He has participated in and led numerous space experiments and flies aboard NASA F-18s and other high-performance aircraft to conduct high-altitude airborne astronomical research. Stern received his Ph.D. in planetary science and astrophysics from the University of Colorado in 1989. He is director of the Southwest Research Institute's department of space studies in Boulder, Colo.

perience of our team-member institutions at delivering space missions on schedule and at or below cost.

The New Horizons spacecraft we designed is lean, with a planned mass of just 416 kilograms (917 pounds)—heavier than the early Pioneer probes but lighter than the Voyagers. This mass includes the hydrazine maneuvering propellant that will be used to adjust the craft's trajectory in flight. Most of the spacecraft's subsystems, such as its computers and its propulsion-control system, are based on designs used in the APL's Comet Nucleus Tour (CONTOUR) probe, which is scheduled to launch this July on a multiple comet flyby mission. The use of CONTOUR's designs reduces New Horizons's costs and lowers the risk of both technical and schedule problems. Almost all our spacecraft subsystems include spare equipment to increase reliability on the long flight to Pluto and the Kuiper Belt.

The spacecraft will carry four instrument packages. A mapping and compositional spectroscopy package, PERSI, will make observations in the visible, ultraviolet and infrared parts of the spectrum. PERSI's infrared imaging spectrometer will be essential for mapping the composition and physical state (including temperature) of the surface ices on Pluto and Charon. A radio-science instrument dubbed REX will probe Pluto's atmospheric structure and gauge the average surface temperatures of Pluto and Charon (on both the daysides and nightsides of the bodies) by measuring the intensity of the microwave radiation striking the spacecraft's 2.5-meter-wide radio dish. A third instrument suite, PAM, consists of charged-particle detectors designed to sample material escaping from Pluto's atmosphere and to determine its escape rate. The fourth instrument is LORRI, a high-resolution imager that will supplement PERSI's already formidable mapping capabilities. At closest approach, PERSI's global maps of Pluto-Charon and the KBOs will have an average resolution of one kilometer. But LORRI, which will image selected regions, will be able to detect objects 20 times as small!

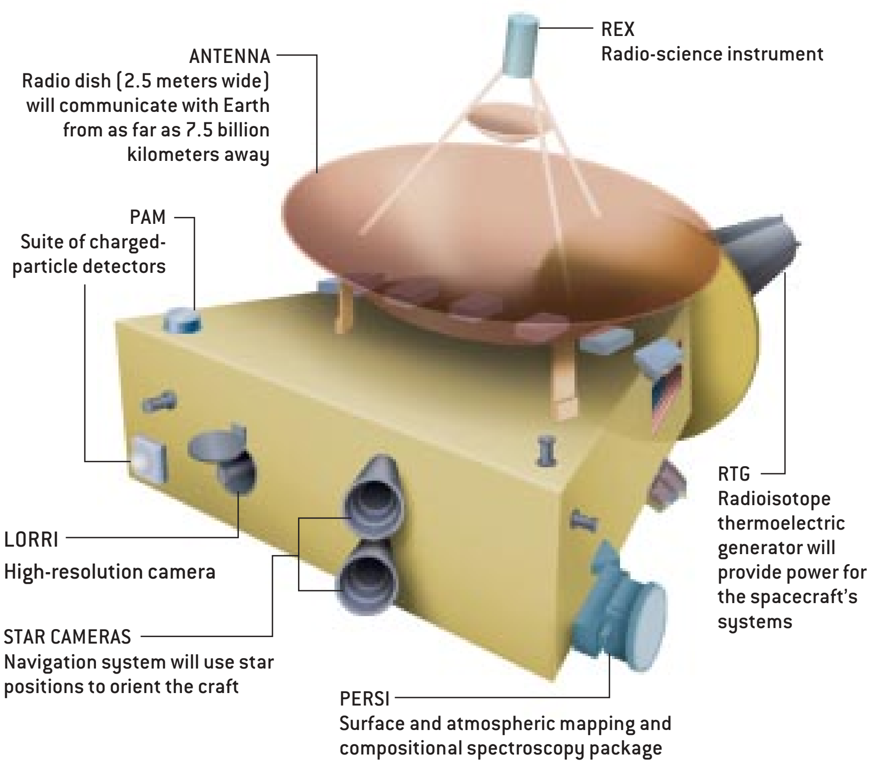
If all goes as planned, the spacecraft will be launched in January 2006, heading initially for a flyby of Jupiter that will use the planet's gravity to slingshot the craft toward Pluto [*see illustration on page 59*]. During its Jupiter flyby, New Horizons will conduct an intensive four-month study of the planet's intriguing system of more than 20 moons, as well as its auroras, atmosphere and magnetosphere. Thanks to the gravitational assist from Jupiter, the spacecraft can reach the Pluto-Charon system as early as 2015. (The exact arrival date depends on the launch vehicle selected by NASA and the precise day we launch in January 2006.)

For much of the long cruise from Jupiter to Pluto, New Horizons will slumber in electronic hibernation. Turning off unneeded systems and reducing the amount of contact with the craft lowers the chance of equipment failures and drastically decreases mission operations costs. During this hibernation the craft will continuously transmit a simple status beacon to Earth; if an unexpected problem develops, our ground-control team will respond. Once each year the craft will be awakened for about 50 days to thoroughly test the systems, make course corrections and calibrate its scientific instruments.

Unlike earlier plans for a quick flyby of Pluto-Charon, New Horizons will begin its study of Pluto-Charon six months before its closest approach to the planet. Once the craft is about 100 million kilometers from Pluto—about 75 days before closest approach—its images of the planet will be better than those of the Hubble Space Telescope, and the results will improve with each passing day. In the weeks before closest approach, our mission

NEW HORIZONS SPACECRAFT

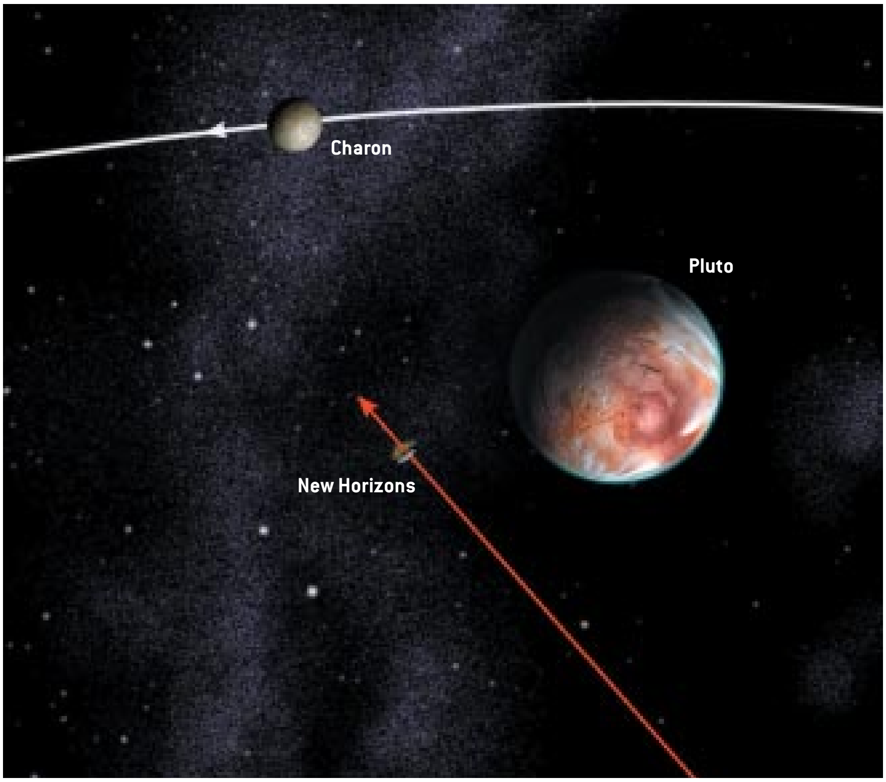
TO EXPLORE Pluto, Charon and the Kuiper Belt objects, the proposed craft will carry four instrument packages, called REX, PAM, PERSI and LORRI.



GENERAL INFORMATION

- The spacecraft has a design mass of 416 kilograms (917 pounds) and is about the size of a small lifeboat.
- On the journey to Pluto, the probe will reach a top speed of about 70,000 kilometers per hour.
- The craft's computers will be able to store 48 gigabits of data and transmit the information to Earth at up to 770 bits per second from Pluto (16,000 bits per second from Jupiter).

JUAN VELASCO



FLYBY of PLUTO by the New Horizons spacecraft will reach its climax at closest approach, when the craft may come as near as a few thousand kilometers from the planet's surface. The flyby is shown from a perspective within Charon's orbit around Pluto and slightly above the orbital plane.

team will be able to map Pluto-Charon in increasing detail and observe phenomena such as Pluto's weather by comparing the images of the planet over time. And using LORRI's high-resolution imaging capabilities, we will get "zoom-lens" views of Pluto and Charon that will help us decide which geologic features are worthy of special scrutiny. During the day of closest approach, when New Horizons may come as near as a few thousand kilometers from Pluto, PERSI will obtain its best maps of the entire sunlit faces of Pluto and Charon. Meanwhile LORRI will focus on producing higher-resolution maps of dozens of smaller areas on these bodies.

Once the spacecraft passes Pluto, it will turn around and map the planet's nightside, which will be softly illuminated by the reflected moonlight from Charon. And the spacecraft's antenna will receive a powerful radio beam from Earth passing through Pluto's atmosphere. By measuring the refraction of this radio beam, we will be able to plot the temperature and density profile of Pluto's atmosphere from high altitude down to the surface.

After the Pluto-Charon encounter, New Horizons will almost immediately maneuver to begin a series of what we hope will be three or more similar flybys with ancient KBOs over the next five years. The exact number of encounters will depend on how much propellant is left in the spacecraft after the Pluto flyby.

Now—or Never?

THE NEW HORIZONS mission promises to revolutionize our knowledge of both the Pluto-Charon system and the Kuiper Belt. But the potential for discovery will be lost if the mission is not launched in 2006. Because of the changing alignment of the planets, after 2006 the spacecraft will no longer be able to accelerate toward Pluto by swinging past Jupiter. If this window is missed, NASA would have to wait until 2018 for Jupiter to be in the right place again, delaying any encounter until the mid-2020s at the earliest.

By that time Pluto will be hundreds of millions of kilometers farther from the sun and significantly colder than it is today. Because of a combination of Pluto's extreme polar tilt and its motion around the sun, more than four million kilometers of terrain—much of the planet's southern hemisphere—will by then be covered in a dark polar shadow, thereby preventing it from being observed. Also, it is likely that virtually all the planet's atmosphere will have condensed by then, closing off any opportunity to study it until the 23rd century, when the atmosphere should again rise as the planet makes its next close approach to the sun.

New Horizons represents a thrilling return to first-time exploration for NASA's planetary program: for the first time since 1989, when Voyager 2 flew by Neptune, a spacecraft will train its instruments on a new world. The mission offers a scientific bonanza of proportions reminiscent of NASA's historic explorations. And by selecting New Horizons through competitive bidding, NASA reduced costs to dimes on the dollar compared with recent missions to the outer solar system.

If Congress approves the development funding to complete the New Horizons spacecraft, the exploration of Pluto-Charon and the Kuiper Belt will commence with a series of flyby encounters beginning just over a dozen years from now, in the summer of 2015. In supporting this project, the U.S. will at last complete the basic reconnaissance of our solar system that it began in the 1960s with the historic Mariner missions to Venus and Mars. SA

MORE TO EXPLORE

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Information about Pluto and Charon is available at **seds.lpl.arizona.edu/nineplanets/nineplanets/pluto.html**

Details of the New Horizons mission are available at **pluto.jhuapl.edu** and **www.plutomission.com**

DON DIXON