The Space Telescope's mission in the solar system

The Hubble is not often thought of as a solar system probe, yet over 10% of observing programs accepted so far are solar system studies. David Cherry reports.

The Hubble Space Telescope lifted off aboard the Space Shuttle Discovery on April 24 at 8:34 a.m. amid great rejoicing. Lyman Spitzer, the Princeton professor emeritus called grandfather of the project, was on hand to see the telescope go up. Also at Cape Canaveral were many of the scientists who have devoted years to ensuring success for what James Beggs, NASA Administrator in the early 1980s, once said might be "the most important scientific instrument ever flown."

The telescope—a joint project of NASA and the European Space Agency—is best thought of as an entire observatory. The various instruments in the observatory exploit different wavelength bands within the wide sensitivity range of the central mirror, on which they all depend. The central 94½ inch mirror (2.4 m) is sensitive from the ultraviolet, through the visible band, and into the near-infrared.

The mirror is more exact than any mirror to come from the hand of man. At no point does the mirror depart from the intended figure (curvature) by more than 25-millionths of a millimeter. If the mirror were stretched to fill the extent of the United States from coast to coast, that maximum deviation would only amount to a quarter of an inch! Such perfection has no value for ground-based telescopes. The constantly varying refraction of the atmosphere that causes the stars to twinkle degrades the images formed by telescopes.

Escaping the atmosphere also has other major advantages. It allows the telescope to detect major portions of the spectrum—in the ultraviolet and infrared—that simply do not penetrate the atmosphere, or do so weakly. It also allows very faint sources that are washed out by "sky brightness" to be seen. Sky brightness is a low level of scattered light that illuminates the sky even in the darkest night.

When Lyman Spitzer first proposed a large telescope in Earth orbit in 1946, he identified four objectives for such an instrument: 1) The extent of the universe, 2) the structure of galaxies, 3) the structure of globular clusters, and 4) the nature of other planets. Today the list has not changed much, nor has the order of the priorities. The instrument has been built according to Spitzer's vision, to favor the study of the universe on the largest scale. As this magnificent exemplar of the human spirit goes about its cosmic business, it has a crucial role to play in exposing to view the workings of our own solar system. Its other objectives will be reported in these pages in weeks to come.

The Space Telescope observes the solar system

In several ways, the Space Telescope will provide information about the solar system that is superior to that gathered by the fly-by missions. The quality and variety of its instrumentation is superior to that of the fly-bys; it will be able to track atmospheric and other changing features on the planets over several revolutions; and it can return to its subject again and again over the years. The Space Telescope gives us a presence in the solar system that we have never had.

Unfortunately, these advantages will not yet be available for solar system bodies when observing begins in earnest after testing and calibration. The acquisition, pointing, and tracking system, as explained above, is based upon guide stars. Complicated computer programming is therefore necessary to acquire and track a moving planet or a feature on a planet. This programming has fallen 12 months behind schedule, owing to an unforeseen workload at the Space Telescope Science Institute in programming for the testing and calibration phase that follows launch.

The ephemerides of the solar system bodies (their positions on the sky, as they change hour by hour) have been computerized, but that still leaves the problem of moving back and forth between a planet's or a satellite's ephemeris and the guide stars. The rapid motion and high parallax of Comet Austin at its closest approach to Earth, for example, would require the acquisition of new guide stars about every 15 minutes, and would operate the tracking stability function at its maximum speed of about 0.2 arc seconds of apparent motion per second.

Harold Weaver, an associate astronomer at the institute, reports that the necessary programming may not be complete until the summer of 1991, and even at that point it will still require a period of testing. "I think there is still some hope that we might be able to push completion to an earlier date, however," Weaver said. He is working on methods to obtain some solar system observations before the programming is finished, such as getting snapshots of Comet Austin with very short exposures—0.1 to 0.5 seconds—during which the comet would not move enough to degrade the resolution. There is more than enough sensitivity to make such short exposures worthwhile.

A sample of proposed solar system observations

Out of 162 guest observer proposals accepted by the Space Telescope Science Institute for the first 12-month cycle of observing, 20 are solar system proposals with targets ranging from Earth itself, in one unusual case, to Pluto. There were apparently no proposals accepted for the first cycle that involve the observation of Venus, Mercury, or any of the asteroids. Earth and the Moon are generally not considered as suitable targets, and to point the telescope at the Sun would destroy its detectors. For the same reason, the telescope will not be put at risk by pointing at a full Moon. Descriptions of some of the projects follow.

Mars watch

A program for global monitoring of Mars in selected seasons over a three-year period is the work of Philip B. James of the University of Missouri at St. Louis and his collaborators. They will also map specific regions of the Mars surface in multiple wavelengths with the Planetary Camera. The Space Telescope will permit resolution of Mars near opposition "comparable to Viking approach images," according to James.

Cloud observations during the first and third years will provide information on diurnal changes in the W-shaped cloud complex. Much of the dust storm season will fall in the second year of observations, and James says his program will then study the Hellas and Solis Planum regions, where global and local dust storms originate. James's team plans to study the same seasons in consecutive Mars years to learn about interannual variability. The Mars year is 687 Earth days.

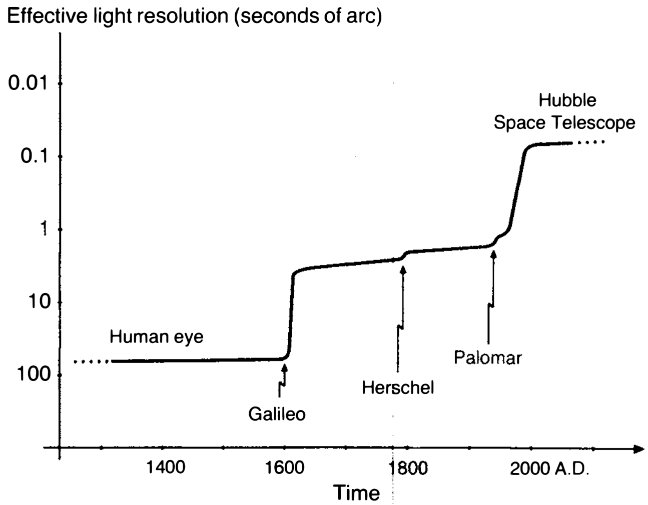
The program will include Planetary Camera imaging with standard blue and red filters like those used to distinguish between surface and atmospheric phenomena on Mars during the Viking mission and in NASA's ground-based Planetary Patrol observations of 1969-1982. Comparability of results is therefore expected. Ozone concentrations, indicative of water abundance, will also be studied.

A new Voyager encounter every year

An ambitious program to analyze the rich array of atmospheric processes on Jupiter and Saturn disclosed by previous observations is headed by Reta Beebe of New Mexico State University at Las Cruces, New Mexico. "The Space Telescope can provide the equivalent of a new Voyager encounter every year," according to Beebe. But it "surpasses Voyager in its multicolor imaging capability, which is required to obtain vertical structure information and to monitor composition and [indications of] atmospheric motions." The Space Telescope, according to Beebe, can actually provide "a continuous record of wind, cloud, aerosol and composition variations spanning significant changes in insolation [rate of solar energy received] and convective activity that will not be mapped by any spacecraft."

FIGURE 1

A revolution in resolving power



The Hubble Space Telescope is the life of the mind improving and extending itself. Its importance can be seen from this graph showing our progress in resolving power. Not since the first general dissemination of telescopes been any such major improvement in resolving power as the Space Telescope promises.

While big Earth-bound telescopes have improved mightily our ability to obtain images of faint objects (light-grasp), their improvement in distinguishing detail (resolving power or resolution) has been modest.

Resolution is given here in seconds of arc of apparent size on the "surface" of the sky. One second of arc is 1/360 of a degree. The diameter of Jupiter seen from Earth is just over 60 seconds of arc.

When the Galileo atmospheric probe descends into Jupiter's atmosphere in December 1995, it will enter between Jupiter latitudes 6.5° and 6.9° North. Beebe states, "It is essential to be able to remotely characterize the local environment in which the probe descends in order to relate the measurements it will make to the Jovian atmosphere at large." It is therefore a high priority of Beebe and her co-investigators to focus on long-term variation of Jupiter's atmosphere between $-10°$ and $+10°$ latitude from the beginning, and to continue to do so at least until the Galileo Orbiter mission ends in 1997.

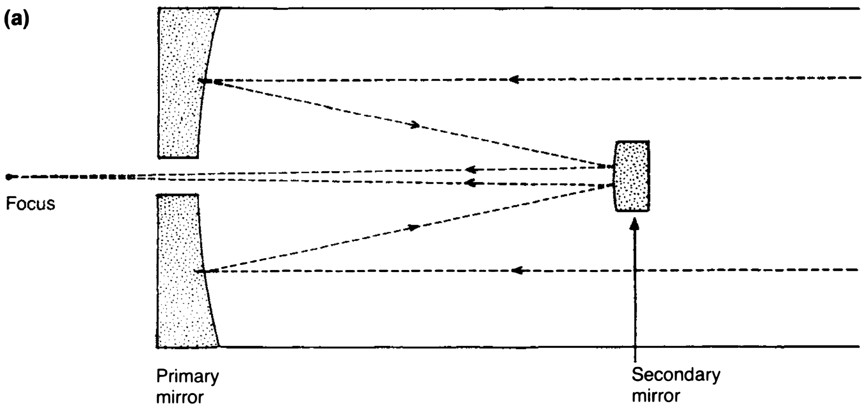
Outer planets in the ultraviolet

An ultraviolet survey of the outer planets from Jupiter to Neptune, including Saturn's moon Titan, is led by Laurence Trafton of the University of Texas at Austin. Trafton plans to "survey the far ultraviolet emission spectrum for each of these bodies, to locate sources of intense auroral emission and obtain their spectra, and to study the charged particle environments of these bodies." He hopes to obtain an understanding of the interaction between their atmospheres and their charged particle environments. The survey will obtain spectra with about the same spectral resolution as is available on the International Ultraviolet Explorer (IUE), but with a sensitivity 1,000 times greater, by using the Faint Object Spectrograph.

A prime target for Trafton will be Jupiter's auroral emission near the region where the flux tube from Io is attached (see **Figure 4**). The flux tube is a plasma structure capable of transmitting mega-ampere currents, and is oppositely

FIGURE 2
Design of the Space Telescope

(a)



The Space Telescope employs the well-known Cassegrain design (a). Incoming light is focused by the primary mirror onto the secondary, whence it passes through a hole in the center of the primary to the focal plane beyond. This is also seen in (b) within the general architecture of the telescope. The science instruments and supporting equipment are modular, and can be serviced or replaced in space.

(b)

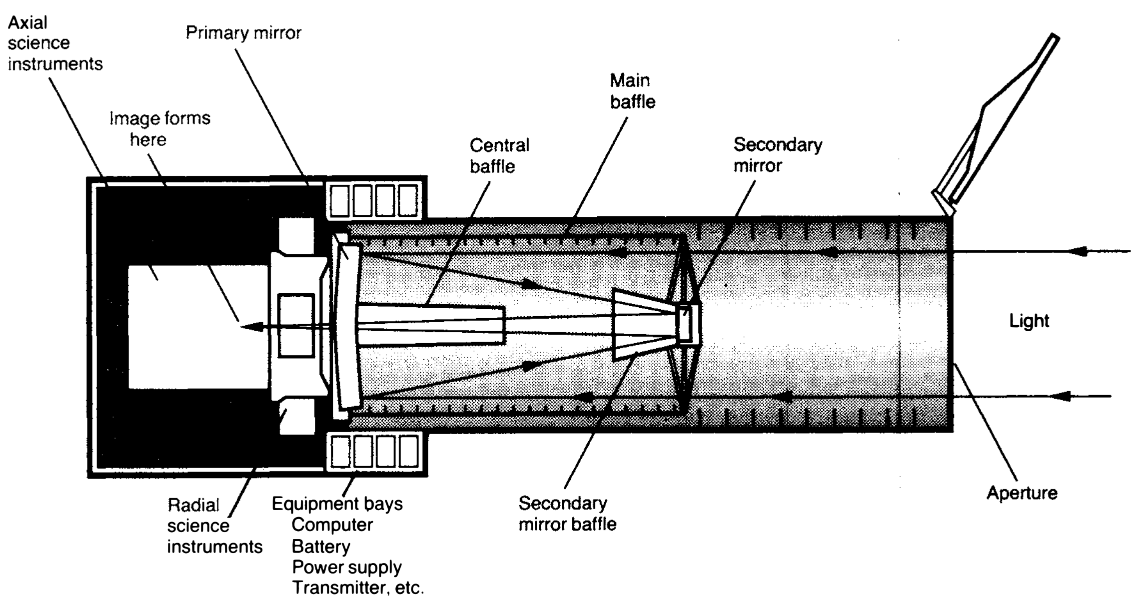
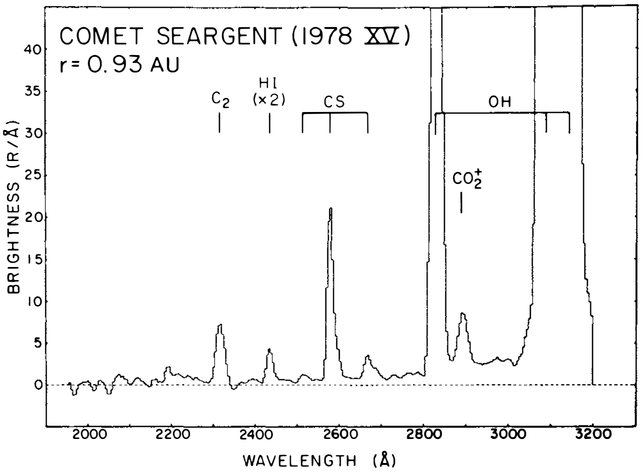


FIGURE 3

What ultraviolet spectra reveal



Source: P.D. Feldman, "Ultraviolet Spectroscopy of Comae," in *Comets*, Laura L. Wilkening, ed. (1982).

The Space Telescope is well equipped to produce images and spectra in the ultraviolet. The ultraviolet portion of the spectrum is rich in lines that disclose the composition of the emitting body. On this spectrogram of Comet Seargent, obtained by the International Ultraviolet Explorer, the chemical identities of the peaks (or "lines") are provided.

The identifications are based upon laboratory the wavelengths these chemical species emit when excited. From left to right they are: molecular carbon, neutral atomic hydrogen, carbon sulfide, ionized carbon dioxide, and the hydroxyl radical.

charged on its inside and outside. He writes that here "emission is suspected to be especially strong because of strong Birkeland currents predicted between Jupiter and Io. The High Resolution Spectograph will have the spatial resolution to locate such emission and test the theory that predicts it. "

Excitation of atmospheres: Io and Titan

The excitation of atmospheres is the subject of a program to observe Jupiter's Io and Saturn's Titan in the near and far ultraviolet. The principal investigator is John T. Clarke of the University of Michigan. Evidence is strong for a substantial atmosphere on Io, according to Clarke. What is not known, he says, is whether this atmosphere is a function of vapor pressure equilibrium that depends on solar energy, or whether it is produced by volcanic plumes. Io's atmosphere is interesting in itself, and is also important in a larger picture. Jupiter is surrounded by a giant plasma torus, and Io orbits Jupiter within this torus (see Figure 5). Since the torus exhibits long-term stability, how is plasma supplied to the torus? It is thought that the neutral gases of Io's atmosphere may be the source, and initially become charged through electron impact dissociation, excitation, and ionization.

Another interesting study of Titan addresses the mystery of its North-South albedo contrast. The principal investigator is Peter H. Smith of the University of Arizona. The 25% contrast in blue light was first discovered when Martin Tomasko, also of the University of Arizona, and Smith analyzed Pioneer data. This program proposes to discover whether the contrast is seasonal, a permanent feature, or is correlated with the solar cycle, and at what depth the contrast is produced. The surface of Titan is obscured by clouds and haze, according to Smith. The albedo contrast is therefore due to variations in the properties of the clouds and haze.

Mapping Pluto

The Space Telescope will provide a view of Pluto "almost equivalent to a naked-eye view of the Moon from Earth," according to University of Colorado astronomer Alan Stern, the principal investigator of a program to map Pluto's entire surface. Pluto, now 2.7 billion miles from Earth, was not included in the just completed Voyager 2 grand tour of the planets, and has appeared as scarcely more than a point of light until now (see **Figure 5**).

Stern's team will map the planet with the WF/PC and Faint Object cameras, with emphasis on the ultraviolet and infrared for best resolution. The result will be a Mercator projection composed of 50 picture elements. Pluto, whose linear diameter is 2,315 km, has an angular diameter of 0.2 arc seconds when seen from Earth. The Faint Object Camera in its high-resolution mode has a resolution of 0.022 arc seconds, although the mapping will not quite have the indicated resolution for other reasons. Stern believes the mapping project may lay the basis for future missions to Pluto.

Spectroscopic studies from ground-based telescopes indicate the likelihood of bright polar caps and a thin surface layer of methane frost interspersed with dark spots, Stern says. It is thought that Pluto has an atmosphere of methane when it is closer to the Sun, which then turns into methane snow as the planet recedes in its 248-year elliptical orbit.

Exceptional solar system objects

Today we still know the inventory of solar system objects only to about the 16th magnitude. Who knows what "interesting new objects or even new types of objects may be discovered" and studied by the Space Telescope? It is Benjamin Zellner—mentioned above in connection with the study of the Mars satellites—who asked that question. Zellner is the principal investigator of a unique program to search all of the images obtained by the telescope for previously unknown bodies. He points to the question of where comets may originate in the distance range between Saturn and Neptune, and to the possibility that another major planet exists.

Nearly all Space Telescope images of more than three minutes' exposure will be examined by the institute's Observation Support System within hours after they are made. The examination will include a check for trails made by moving objects—trails that could reduce the usefulness of the image.

A tour of the Hubble science instruments

The instruments associated with the Space Telescope accomplish imaging, photometry (measurements of brightness), spectroscopy (peaks and valleys of an object's brightness, wavelength by wavelength), and astrometry (measurement of star positions).

What are these instruments? The Wide Field and Planetary Camera (WF/PC) is really two cameras in one. In the Wide Field mode, it has the largest field of view of the telescope's imaging instruments, yet it would take ten snapshots in this mode to cover a band across the middle of the Moon. In the Planetary mode, the WF/PC zeroes in on a smaller field of view with greater resolution. Here it can image the full disk of Jupiter with the clarity of the Voyager probes about five days before nearest approach.

The Faint Object Camera (FOC), built by the European Space Agency, has an even smaller field of view (and is sensitive to a narrower spectral range) but achieves the highest resolution.

The telescope has the pointing and tracking accuracy consistent with this tremendous resolving power, an accuracy that would allow someone atop the Empire State Building in New York City to lock onto a dime on top of the Washington monument in Washington D.C., 210 miles away! The telescope is expected to point within 0.01 arc seconds of its target, and hold the target, if necessary, for 24 hours with a deviation no more than 0.007 arc seconds, yet the telescope orbits the Earth about once every 90 minutes.

The measure of resolving power is the amount of field of view, in arc seconds, that is included in one pixel. The pixels (picture elements) are the tiny photon buckets arrayed in the plane that film occupies in a conventional camera. The array is called a charge-coupled device (CCD).

The High Resolution Spectrograph (HRS), for use only in the ultraviolet, can sample extremely narrow wavelength ranges, and take exposures as short as .05 seconds to analyze processes with rapid variability.

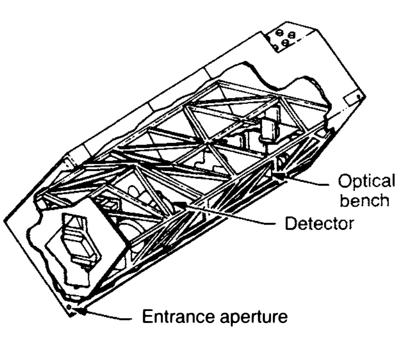
The Faint Object Spectrograph (FOS) sacrifices spectral resolution in favor of greater light-gathering power when the subject is faint.

The High Speed Photometer (HSP) measures brightnesses, and for rapidly varying sources, it can sample brightness 100,000 times per second.

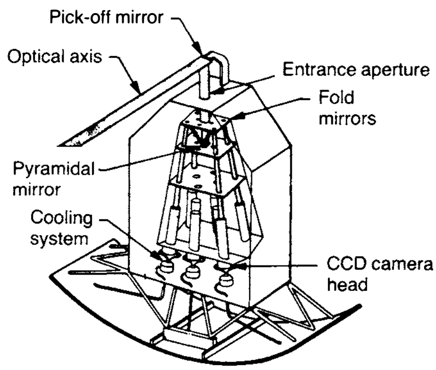
The three Fine Guidance Sensors (FGS) enable the telescope to find its way within small regions of the sky. To fix the telescope's aim, two of the sensors must lock onto guide stars while the telescope orbits—stars that are specified in the computerized *Guide Star Catalog*, of 19 million entries. The third sensor is for astrometry.

Testing and calibration is expected to last well into the fall of 1990. The world waits expectantly.

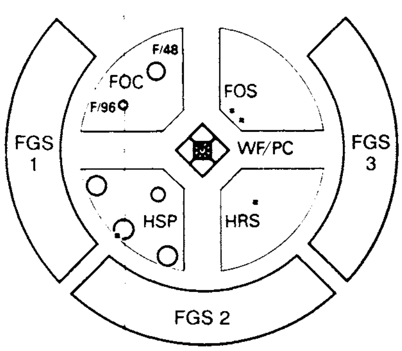
(a) High resolution spectrograph



(b) Wide field/Planetary camera



(c)

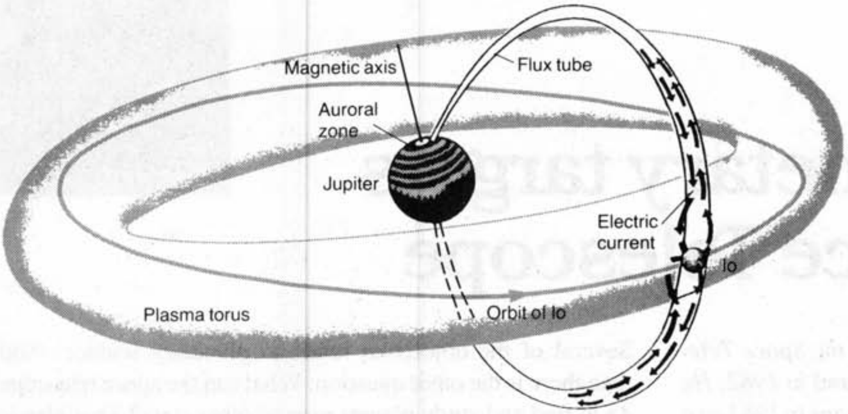


Four of the science instruments are stowed axially (see Figure 2(b)). Each is about the size of a telephone booth. The High Resolution Spectrograph (HRS) shown in (a) is one of the four. The two remaining science instruments, the Wide Field/Planetary Camera (WF/PC) shown in (b) and the Fine Guidance Sensors (FGS), are stowed radially.

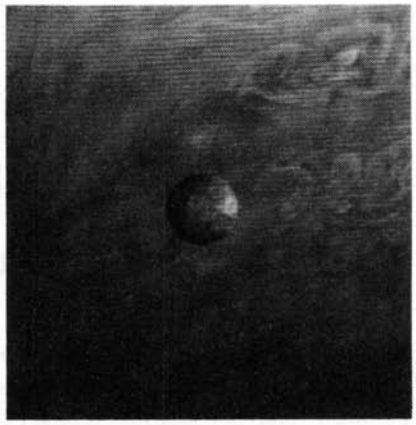
All of these instruments share the focal plane (c), about the size of a dinner plate. In its center, the square is the image area of the Wide Field Camera (2.6 × 2.6 minutes of arc). The smaller square within it is that of the Planetary Camera (1.1 × 1.1 arc min, just enough to get all of the largest planetary disk—Jupiter's—in one exposure).

The larger square is surrounded by four quadrants. The apertures for each axial instrument are located in a different quadrant (FOC, FOS, HRS, HSP). Each of the three Fine Guidance Sensors has a segment of the surrounding horseshoe.

FIGURE 4
Planetary aurorae



Anthony Peratt/LANL



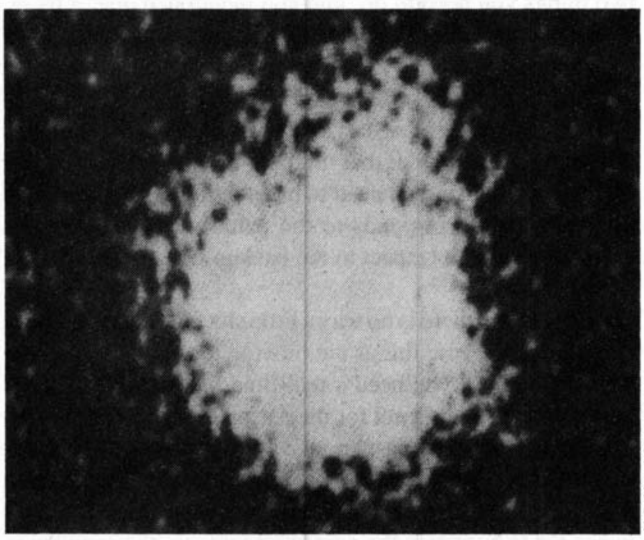
JPL/NASA

An ultraviolet survey of the outer planets from Jupiter to Neptune will probe these planets' atmospheres in relation to their charged particle environments. This spectrographic study will look especially for sources of intense auroral emission.

Jupiter's charged particle environment includes the plasma torus that surrounds it, and within which Jupiter's nearest moon, Io, orbits. It also includes the flux tube that joins Io to Jupiter's magnetic poles. The flux tube is a plasma structure, oppositely charged on the inside and outside, capable of carrying mega-ampere electric currents. Intense auroral emission is expected to be found around Jupiter's north magnetic pole.

At right: Io passes before mighty Jupiter. This Voyager 2 image has a resolution of about 125 miles. Hubble's Planetary camera will obtain even better images of Jupiter, with a resolution of about 95 miles.

FIGURE 5
First map of Pluto



U.S. Naval Observatory

Our ignorance of Pluto is shown in the poor resolution of this 1978 ground-based photo, on which Pluto's satellite Charon was first discovered (the bump at 1 o'clock). The Space Telescope will provide a view of Pluto "almost equivalent to a naked-eye view of the Moon from Earth," according to Alan Stern. Stern leads a team that will map Pluto's entire surface, a project of great value to any future missions to this least known planet.

Zellner's project calls for the addition of a routine by which any such trails found in potentially interesting portions of the sky are reported to the Minor Planet Center in Cambridge, Massachusetts for followup. Any short trail—indicating a slow-moving object—that is out of the ecliptic plane is "likely to represent an unknown object of substantial interest," he says. More discriminating criteria must be used within the ecliptic to screen out ordinary asteroids and comets.

In the case of compelling discoveries, Zellner's program calls for breaking the telescope's schedule to obtain images of the find. Zellner does not expect such discoveries very often—certainly not more than once a year. If they *were* more frequent, he says, "that fact itself would represent one of the more significant discoveries of the Space Telescope."

Beyond the Hubble

Again and again, astronomers planning observations point out the superiority of the Hubble Space Telescope to earlier instruments. But the Hubble is not the last word. There are numerous proposals for additional telescopes of advanced design in Earth orbit or on the Moon. The Space Telescope Science Institute itself sponsored a workshop in September 1989 entitled, "The Next Generation: a 10-16 meter UV-Visible-IR Successor to the Hubble Space Telescope," and while the Hubble was being lifted into orbit, the International Astronomical Union had a colloquium under way on "Observatories in Earth Orbit and Beyond."