Space Telescope: A Saga of Setbacks

Astronomers worry about aging components and sluggish software

By RON COWEN

On March 27, if all goes well, astronaut Steve Hawley will maneuver a robot arm to gingerly lift a 43-foot cylinder from its berth in the cargo bay of the shuttle Discovery. Latches will unlock, two tightly rolled panels of solar cells on opposite sides of the cylinder will unfurl like window shades, and current will begin to course through the instrument's complex circuitry. The robot arm will then release its grasp and the shuttle will back away, leaving the cylinder in orbit 370 miles above Earth. By remote command, an aperture cover at the cylinder's top will swing open, and for the first time, starlight unclouded by Earth's turbulent atmosphere will strike a high-precision mirror that scientists finished polishing in 1981.

At that moment, the world's highest-resolution optical telescope will make its heavenly debut — seven years after its original launch date and nearly two decades after scientists began designing it.

"Future historians may one day look back on the 1990s as the decade that revolutionized our understanding of the universe," says astronomer Stephen P. Maran, who will direct some of the telescope's observations at NASA's Goddard Space Flight Center in Greenbelt, Md. "The Hubble Space Telescope will be remembered as the instrument that first cracked open the window."

But the project should also be remembered for its many setbacks, contends Robert C. Bless of the University of Wisconsin-Madison, who will work with the telescope's high-speed photometer. "When the space telescope reaches orbit and begins sending back exciting new images of the universe, it may be tempting to put aside the problems encountered along the way," Bless wrote in the winter 1988-89 ISSUES IN SCIENCE AND TECHNOLOGY. "That would be a mistake, for only if NASA recognizes the problems caused by its current policies will space science regain its lost vigor."

Successful deployment of the Hubble Space Telescope — an aging explorer that nonetheless should reveal extraordinarily faint objects, give remarkable clarity to images of brighter stars and detect ultraviolet light that cannot penetrate Earth's atmosphere — will climax a long and problem-plagued journey from drawing board to orbit. Dogged by delays ever since Congress approved its funding in 1977, the device — actually five observing instruments (see sidebar) that feast on light from a single reflecting telescope — was first set for launch in late 1982. Software and instrument problems pushed that date back to August 1986. Then, in early January of 1986, NASA rescheduled the launch for October to allow more time for testing equipment. Within weeks of that announcement, the Challenger shuttle exploded, prompting NASA to put further shuttle flights on hold.

Many scientists, including space telescope officials, view the latter delay as a mixed blessing for the project, arguing that the software for scheduling the telescope's thousands of observations couldn't have performed adequately in 1986. But even after NASA upgraded the software and resumed shuttle flights, military and research missions critically dependent on launch timing continued to preempt the telescope's deployment. As a result of the many delays and some still-unresolved software problems, researchers and the public may get less from the $2 billion satellite than originally promised.

Some scientists worry that the aging equipment, now nearly as old as the telescope's planned 15-year lifetime in space, could fail before all the key observations are made. Intensifying those worries is the inefficiency of the scheduling software, which might rob astronomers of half their potential observation time, Bless and others say.

"We're launching a telescope with 1970s technology," says astronomer Robert Brown of the Space Telescope Science Institute (STScI) in Baltimore, the university cooperative that coordinates software and research aspects of the mammoth project. In the years since the telescope's initial planning, advances in observatory design, temperature control and optics have — perhaps inevitably — led to increasingly sensitive ground-based telescopes and light detectors, narrowing the technology gap between the space telescope and its counterparts on Earth. While the space telescope retains much of its observational superiority as well as its vantage point for detecting ultraviolet light that never reaches Earth, it might well have benefited from some of the interim advances, Brown says.

The unprecedented telescope "was built with the NASA philosophy that big is beautiful," says STScI spokesman Eric Chaisson, who notes that its size and intricacy have complicated and slowed the project. Bless and others say NASA would have been wiser to send up some of the observational equipment years ago on simpler, single-instrument missions. According to Bless, the photometer and spectrographs don't require the complex and costly high-resolution mirror to achieve most of their goals. If NASA had launched them earlier on separate missions, he says, researchers could already have analyzed a wealth of data.

"NASA put all its eggs in one basket, but not all equipment needs such precision," Bless says. Science is the loser, he contends, because the weight of the instrument-laden space telescope restricts it to a low orbit. A single-instrument satellite could reach geosynchronous orbit some 22,300 miles above Earth, allowing observations of the heavens to continue unimpeded during 85 to 90 percent of the orbiting time, he says. In contrast, Earth will partially block the view of the low-orbiting space telescope 40 percent of the time. Nonetheless, Bless thinks the telescope will produce spectacular data. He estimates, for example, that its photometer will analyze starlight images with 100 to 200 times the resolution of the most sophisticated Earth-based devices.

Several NASA officials, including Goddard project scientist Albert Boggess, say the project's management structure has further complicated matters. NASA distributed the responsibilities for manufacturing and installing equipment between two main contractors. And two separate NASA centers preside over the telescope, each equally involved in putting the pieces together. Goddard oversees operation of the device, while Marshall Space Flight Center in Huntsville, Ala., coordinates equipment development and repairs. "NASA's internal organization – having two centers – made it difficult to communicate," says STScI's Brown.

But perhaps the most serious management problems came with the development of the ground-based software known as SOGS (for science operations ground system), designed to both schedule and record telescope observations during the mission. As a software package, SOGS met specification standards set by NASA officials. But those standards, formulated without input from researchers who will use the instruments, didn't account for the details and quirks of the telescope's five light-detecting instruments. Though recently upgraded, the $70 million system still has a basic problem: It can schedule astronomical observations in order of priority, but trouble develops when it plans too far ahead.

In order to schedule each observation requested by astronomers, the software places a marker in its calendar of events, explains Rodger Doxsey, chief of computer operations at STScI. Because SOGS methodically checks and compares the amounts of free time between all markers before scheduling the next observation, the need for more computer time increases at an unacceptably high rate as the number of markers increases, Doxsey says. This and other problems have forced NASA to develop a second ground-based system, known as SPIKE, that can sketch out flexible plans for up to a year's worth of observations. Three months in advance of actual observations, SPIKE will feed week-long segments of the master plan to SOGS, which will then formulate a detailed schedule.

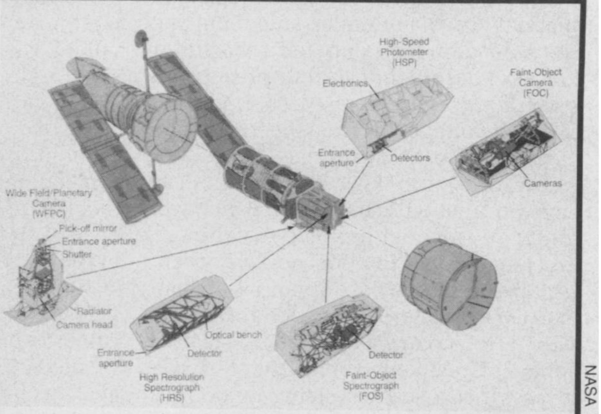
Doxsey calls SPIKE "nearly operational," but even so, the scheduling process remains inefficient. SOGS "is not smart enough," he says, to condense a lengthy observation or to expand a short one so that it fits into the 95 minutes of observation time available during a single orbit. Thus, SOGS could leave the telescope idle for several precious minutes between observations instead of arranging for continuous viewing.

Doxsey estimates that the SOGS/SPIKE combination now takes one-half day to schedule a day's worth of observations – a significant improvement over the past rate but still falling short of the one-third-day goal.

Such delays disturb astronomers because the mechanical functions of the telescope's detectors and the restrictions imposed by a low orbit already remove large chunks of observing time. For starters, the telescope typically needs several minutes to shift its orientation from star A to star B. Once the telescope reorients, its precision pointing system takes another 15 minutes to locate and track "guide stars" so that it can fix the position of the star under study. Observation time is further reduced at certain times in the orbit because some of the sensitive light detectors (such as the charge-coupled devices on the wide-field/planetary camera) cannot point directly at the intense light of the sun. Astronomers lose still more observation time because the telescope avoids looking in the direction of the moon or the Earth; light scattered from these bodies can distort star images.

Moreover, the telescope must interrupt observations during the 15 percent of its orbit when it passes through the South

Nuts and bolts



NASA

Three major systems serve as the nuts and bolts of the space telescope: the support systems module; an assortment of light-detecting instruments and guidance sensors; and the optical telescope assembly itself.

The support systems module will provide the power, communications, pointing ability and other operational assistance. Stacked within it are four main components: the light shield, which contains the telescope's aperture door and internal baffles to catch stray light; the forward shell, which has the main attachments for the craft's two solar panels and antennas; a doughnut-shaped electronics section; and an aft shroud enclosing the light-detecting instruments.

Light reflected from the telescope's 94.5-inch primary mirror can be intercepted by any of five light-detecting instruments and three fine-guidance sensors. Two of the radially positioned guidance sensors will locate and track an object targeted for observation while the third pinpoints the positions of neighboring objects.

The chief workhorse of the light-detecting instruments is the **wide-field/planetary camera,** mounted behind the primary mirror. In its wide-field mode, the camera will image large, faint objects, including galaxies, clusters of galaxies, and quasars. Its smaller-aperture mode will survey large, bright objects – particularly planets – with a precision rivaling past flyby missions of the inner planets.

The four other light detectors encircle the primary mirror. The **faint-object camera** has a smaller field of view and is more sensitive to ultraviolet light than the planetary camera. Taking full advantage of the telescope's high-resolution optics, it will count individual photons to image the dimmest objects detectable with the telescope – including 29th-magnitude stars – at the highest angular resolution.

The **faint-object spectrograph** will measure the spectra of dim bodies at both ultraviolet and optical wavelengths. It will examine the structure and composition of quasars, comets and galaxies, including active galactic nuclei.

The **Goddard high-resolution spectrograph** is the only device on the craft that operates solely in the ultraviolet. Designed for insensitivity to visible light, it enables detection of faint ultraviolet emissions from stars producing intense visible light. This spectrograph can detect objects about 1,000 times dimmer than those spotted by previous space-borne detectors. Because its aperture lets in more light and resolves it into finer increments, it should analyze spectra in greater detail than its faint-object counterpart.

The simplest instrument on board, the **high-speed photometer,** contains no moving parts. Dependent on the telescope's pointing accuracy, this device will measure the total amount of light from an object and note brightness fluctuations on a time scale as precise as ten-millionths of a second. The photometer can detect rapidly spinning neutron stars or other compact objects, as well as gather detailed data on their flares.

– R. Cowen

Atlantic Anomaly, a region over Brazil where the Earth's radiation belt comes close enough to the satellite to interfere electronically with data collection. And about 40 percent of the time, Earth itself will block the telescope from observing any particular star. All this means the space telescope will at best detect starlight during only about 35 percent of its time in orbit.

In the first six months of orbit, with software still in need of debugging and scientists still unaccustomed to operating the telescope in space, that number may drop to 20 percent, Doxsey estimates. Later, after the operation becomes more routine, observation time should increase. "It's not unusual for observations to become much more efficient after we learn where we can trim off minutes and seconds," notes Peter Stockman, associate director of STScI.

Aside from eating up observation time, limitations inherent in SOGS and other ground-based software may hamper the use of certain instrument features as well as prevent observations of variable stars and the structural details of planets. For instance, the telescope's high-resolution spectrograph can adjust its exposure on the spot – like a camera with an electronic light meter – according to the light intensity of the star or galaxy under study. But the software cannot account for a shorter or longer exposure than the one preset. As a result, Doxsey says, researchers cannot take advantage of the spectrograph's variable exposure feature.

"We will be looking at more modern software that will come later, which will allow more complex observations," Stockman says. "But [for] now we probably have to simplify observations of planets." For example, observations of rapidly moving planetary phenomena, such as Jupiter's Great Red Spot, will have to wait, he says, because the system cannot track them without smearing the image.

Further complications spring from the communications system that will convey messages back and forth between ground-based scientists and the telescope, says Bless. NASA uses the Tracking and Data Relay Satellite System (TDRSS) for relaying messages to and from low-orbit satellites such as the space telescope. But with military and other satellites also competing for TDRSS time, telescope scientists can expect access to the system only about 15 to 20 percent of the time. This will limit their real-time observations, forcing the satellite to store some data on tape. And storage capacity is sorely limited. According to Doxsey, the telescope's computers can hold about one-sixth the data storable in a typical personal computer.

The limited storage capacity will also force scientists to send relatively small command packages, he notes. "Using the TDRSS should not be a problem at first, but we'll have to see how things shape up later [when observations become more frequent]," Doxsey says.

Maintenance of the elaborate and aging equipment may pose problems unforeseen by the telescope's developers. Astronomers and designers originally assumed shuttle crews would replace, repair or readjust telescope components every 18 months or so. "Built into the design concept for the 15-year mission was that the shuttle would service the space telescope," Brown says. "Batteries were meant to be changed, and at least 50 'boxes' of major equipment, worth about $1 million each, were meant to be replaced or checked. We thought the shuttle would run a number of times every year," providing plenty of opportunities for sending up emergency repair missions. But in the years since the Challenger explosion, NASA has drastically reduced the number of shuttle launches on its schedule, and it now requires about 12 months' notice to plan a repair mission. The agency has tentatively set the first such mission for late 1993 – nearly four years after the telescope's launch.

Even if they function without a hitch, some components of the space telescope no longer rate state-of-the-art status, notes STScI's Stockman. The faint-object spectrograph, for instance, contains two detectors that share a one-dimensional array of diodes to record the intensity of light at particular wavelengths. Two-dimensional arrays since developed, Stockman says, could measure 20 to 40 spectra in the time it takes this spectrograph to record a single star spectrum.

Some features of the telescope's wide-field/planetary camera – actually two cameras in one – also worry scientists. While testing equipment several years ago, researchers discovered that when the telescope operates in a vacuum environment, a thin film of material, apparently from moisture-absorbing surfaces, condenses on its chilliest components – which happen to be the camera's four light detectors. The condensing material, transparent to visible light but opaque to ultraviolet, may reduce the detectors' already-low sensitivity to ultraviolet light.

Every few months, to rid detectors of the film before taking the next series of ultraviolet measurements, scientists will warm the camera from -90°C, its normal operating temperature, to -30°C. Though the four-hour warm-up should do the trick, telescope scientists remain mystified by the film. "We're not sure what the material is," says NASA's Boggess. Some researchers worry that the unknown contaminant might cause unexpected complications.

The multitude of setbacks, coupled with advances in ground-based equipment, have tempered earlier claims regarding the extent of the telescope's observational superiority. While NASA initially boasted that the space telescope could see astronomical objects seven times as distant as those detected by ground-based telescopes, that assertion "was overselling," says Chaisson. The telescope's resolving power in visible light, about 0.1 arc-second (comparable to what's needed to distinguish a car's right headlight from its left at a distance of 2,500 miles), is indeed about 10 times the average resolving power of today's ground-based telescopes. But that may be changing. Last March, the New Technology Telescope in La Silla, Chile, significantly narrowed that gap when it briefly achieved a resolution of 0.36 arc-second, says Raymond N. Wilson, chief optician of the European Southern Observatory, headquartered in Garching, West Germany.

The New Technology Telescope relies on a feedback system, called active optics, to achieve its resolving power. The computer-driven system counteracts gravity's distorting effect on mirror shape as the telescope rotates. Larger-diameter telescopes now under construction will further rival the space telescope at optical wavelengths, Wilson says. In addition, researchers are experimenting with more complex feedback systems, known as adaptive optics, to adjust mirrors for rapid changes in Earth's turbulent atmosphere – the chief stumbling block to improving resolving power on the ground.

What, in retrospect, can NASA learn from the frustrations encountered in building the world's most expensive telescope?

"If you choose a complicated way to run something, you have more complications," Boggess says.

Brown asserts that the main lesson is the importance of getting early input from the people – in this case astronomers – who will actually use the instrument. Instead, he says, NASA's planning procedure was "like writing a symphony by giving passages of the score to different instruments: Everyone has rehearsed separately in little music rooms, but they've never played together. So people run around making sure that music in one room matches with music from another. . . . The space telescope [components] have never tried out the symphony together."

Come March, astronomers may hear that symphony at last. Balancing their apprehensions with the prospect of viewing faint stars, hidden black holes and the nuclei of young galaxies, they'll be hoping the telescope provides more than just an overture. □