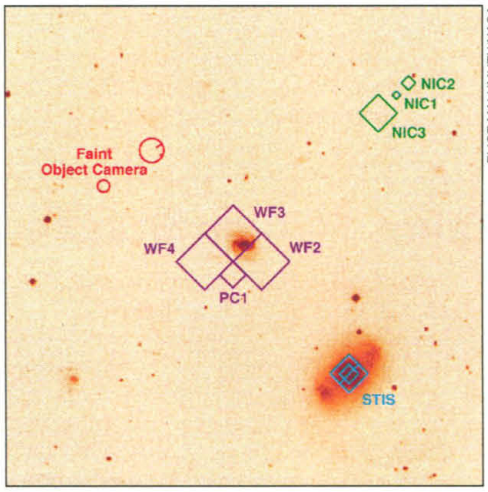
SPACE SCIENCE

The Clearest View: Hubble Telescope to Get an Upgrade

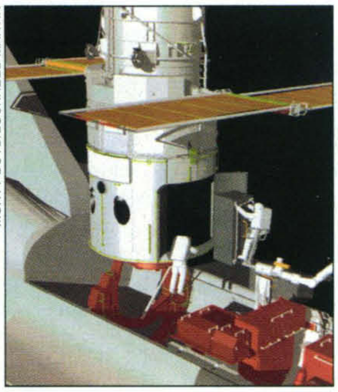
The orbiting Hubble Space Telescope has been fueling new findings in astronomy for more than 6 years, but if all goes as planned, the pace of discovery will soon become even faster. On 14 February, space-walking astronauts are scheduled to install two new instruments aboard the Hubble, securing astronomers' best view yet of the cosmos. One instrument, NICMOS (Near Infrared Camera and Multi-Object Spectrometer), will gather and analyze wavelengths of light never before seen from space, opening Hubble's eye to sights that may include planets circling other suns and the earliest objects to form in the universe. The other, STIS (Space Telescope Imaging Spectrograph), can gather spectral data from hundreds of different objects simultaneously, so new findings should come even faster than before. It all adds up to "new kinds of science," says STIS principal investigator Bruce Woodgate of the Goddard Space Flight Center in Greenbelt, Maryland.

This new view has been a long time coming. The $125 million STIS and $105 million NICMOS "essentially were canceled three or four times" since they were conceived 12 years ago, says NICMOS principal investigator Rodger Thompson of the University of Arizona. The instruments were originally scheduled to fly earlier, he says, but suffered major delays after the Challenger disaster and the discovery of the flaw in the Hubble mirror. Then, tight NASA budgets nearly killed the projects several times. But team scientists say there's a silver lining to the delays. Although the final instruments have smaller detectors and fewer accessories than in the original plans, astronomical advances over the past dozen years have yielded new questions for them to probe, such as the number of galaxies with black holes at their cores, Thompson says. "We can be much more sophisticated in our science," he says. "Many of the things we want to look at we wouldn't have known about if we'd gone earlier."

The instruments—each encased in a refrigerator-sized container that fits into the instrument bays of the three-story telescope—do their work with a series of mirrors, prisms, gratings, and detectors. Light from the telescope's main mirror is reflected into the instruments, which can either record images directly or use gratings and slits to separate the light into individual wavelengths, just as a raindrop splits light into a rainbow. State-of-the-art detectors will then record the data for transmission to Earth.



ELIOT MALUMUTH/NASA



MONTY BOYD/LOCKHEED MARTIN

Star search. After two new instruments are installed into the Hubble telescope (artist's view, *left*), all four instruments will be able to scan different parts of the sky simultaneously *(above)*.

The mission itself should be much like the 1993 Hubble repair mission, when astronauts removed one instrument and installed corrective optics, says Steve Hawley, an astronomer and astronaut who helped deploy the telescope in 1990. This time, Hawley will capture the Hubble with a robotic arm from inside the space shuttle. After the telescope is secured in the shuttle's cargo bay, Hawley's space-walking colleagues—one of them riding the robotic arm as Hawley maneuvers it—will remove two instruments, the Goddard High-Resolution Spectrograph (GHRS) and the Faint Object Spectrograph (FOS), and replace them with STIS and NICMOS. The 1993 mission went so smoothly that "people are inclined to think, 'Well, shoot. This must be pretty easy,' " says Hawley. But it's not as simple as it might look on television, he says: "I worry people don't appreciate how hard this really is."

If all goes as planned, NICMOS will be the first space-based instrument to analyze near-infrared light, which is obscured by Earth's atmosphere and therefore can't be seen clearly from the ground. Infrared light passes through the dusty shrouds that often surround newborn stars and planets, however, so NICMOS may give astronomers a chance to see planets orbiting other suns.

STIS will record the wavelengths currently covered by FOS and GHRS—from the visible to shorter than the deepest blue our eyes can see—but with higher resolving power and a wider view than previous Hubble spectrographs, which had only a single peephole and could record data from only a small area at a time. STIS essentially lets astronomers peer through a crack in the door: A long slit projects light onto a rectangular array of detectors that can record the spectra of more than 500 points in space at once, so data on large objects and the motions of stars and gas clouds can be collected up to 500 times faster than before, says Goddard's Woodgate.

That efficiency will help astronomers answer questions requiring massive amounts of data, such as whether black holes lurk at the center of most galaxies and play an important role in their formation. This idea gained support this month with the release of FOS data showing that in half-a-dozen nearby galaxies, star velocities increase dramatically as they whirl around the galactic center (*Science*, 24 January, p. 476). Now, "we want to take a more systematic census of galaxies to see if it's actually true," says Richard Green of the National Optical Astronomy Observatories in Tucson, Arizona, a member of the STIS team. With STIS, the team will be able to record stellar velocities across an entire galaxy in a single observation—and so examine nearly 20 galaxies in just one year.

The galaxies in the Hubble Deep Field are a tempting target for both instruments. This nondescript point of sky became one of the most studied in astronomy when the Wide Field Planetary Camera 2 (WFPC2) pointed at it for 10 days straight in December 1995, producing an image of the faintest—and most distant—galaxies ever seen. The picture and follow-up observations from other telescopes have allowed scientists to piece together a rough history of galaxy formation (*Science*, 20 December, p. 2006). But astronomers hope STIS and NICMOS will fill in major gaps in the story.

By seeing near-infrared light, NICMOS will be able to pick up the light emitted by older, cooler stars, revealing more details of how stars and galaxies age. At the other end of the spectrum, STIS will gather ultraviolet light from galaxies relatively nearby, which will give astronomers their most detailed look at the young stars in these galaxies. NICMOS may also make the Deep Field even deeper. As the universe expands, light from objects moving away from Earth is stretched to longer wavelengths in a phenomenon called redshift. NICMOS will be able to spot galaxies so distant that even their shortest wavelengths are redshifted into the infrared. While the most distant objects currently known in the Deep Field are at redshifts of between 4.5 and 5.5—more than 11 billion light-years away—"I think we could see objects up to [a redshift of] 14—if they exist," says Thompson. That would be equivalent to peering 12 billion years or even more into the past.

In addition to installing STIS and NICMOS, the Discovery crew will update Hubble's original tape recorder with a larger digital recorder that will allow STIS, NICMOS, WFPC2, and the Faint Object Camera to collect data simultaneously. While one instrument is pointed at a target, the other three will scan the adjacent sky for hard-to-find objects, such as brown dwarves—small, dim cousins of stars that some astronomers think make up the "dark matter" affecting the motions of galaxies. But Richard Terrile of NASA's Jet Propulsion Laboratory in Pasadena, California, says there's no telling what else these "serendipity scans" might turn up: "We can expect to be surprised. Reality always seems to be more exciting than we can predict."

–Gretchen Vogel

PLASMA PHYSICS

ITER Review Team Takes Bullish Stance

SAN DIEGO—A large team of U.S. fusion researchers last week began poring over the latest blueprints for a massive international machine designed to demonstrate fusion power and provide plasma physicists with an exciting new facility. The review of the $10 billion International Thermonuclear Experimental Reactor (ITER) was prompted by controversy over the reactor's design and the shrinking U.S. fusion budget.

The sweeping review is likely to give ITER a green light, say panel members, despite concerns that the design may not be adequate to reach the ultimate goal of a self-sustaining fusion burn. Even skeptics on the panel say they are confident that the machine can be made to work despite the thorny technical hurdles facing designers. "If it's a question of thumbs up or down, I'm definitely putting my thumbs up for ITER," says Richard Hazeltine, head of the Institute for Fusion Studies at the University of Texas, Austin, and a critic of the program. Indeed, bringing the fusion community together is a central element of the review, requested by the Department of Energy (DOE), which will examine cost, design, and objectives and is expected to take another 3 months to complete. "This is deliberately set up to make sure we don't miss anything," says John Sheffield, director for energy technology programs at DOE's Oak Ridge National Laboratory in Tennessee and chair of DOE's fusion science advisory panel, which met here last week.

Sheffield's team must wrestle with divergent opinions on the validity of theoretical models for the ITER design, including the new turbulence model proposed by two Texas researchers that raises doubts about the machine's ability to create an extended fusion reaction (*Science*, 6 December, p. 1600). Program supporters tend to downplay the debate as simply the latest example of the traditional tension between theorists, who look for reasons why a design will fail, and experimentalists, who believe they can make the design meet its goals. "We are confident ITER will work," says Paul Rutherford, a Princeton University theoretical physicist who chaired an ITER technical advisory committee that recently reviewed the detailed design. While it would be nice to have a good theoretical model, he says, "we do not see one that would compete with the current empirical model—at least, not right now."

THE COST OF ITER
(in 1997 dollars)

Category	Estimated Cost
Preconstruction	$539 million*
Construction	$8043 million
Construction Support	$1133 million
Research	$400 million
TOTAL	$10.115 billion**
Annual Operating Cost	$500 million

* Includes personnel.
** Excludes contingency reserve and infrastructure costs.
SOURCE: RAYTHEON

For ITER's director, Robert Aymar, the problem is not with the design, but with the balance between the two camps. He complains that U.S. theoreticians have too much influence within the community.

Although the review panel seems likely to back the project, insiders say that its report will probably urge the ITER staff to make better use of both theory and existing data. "We're lacking a lot of physics," says John Lindl, scientific director of Lawrence Livermore National Laboratory's inertial-confinement fusion program. "But things can be done to resolve these issues," he adds, without delaying construction.

Reviewers also are likely to cast a skeptical eye on the machine's ultimate goal of sparking a self-sustaining fusion burn. Ignition "is slipping out of the vocabulary, [but] it's a minor retreat," says Hazeltine. Even if the machine doesn't reach ignition, ITER supporters point out, controlled fusion could still be achieved for extended periods by continuously pumping power into the chamber. Adds Nermin Uckan, who leads Oak Ridge's ITER effort, "People are being cautious about ignition. It would be nice, but it is not the end-all."

DOE officials have asked Sheffield's group to complete the study by 1 May. But even if it gives ITER a glowing report card, the United States will play no more than a minor role in ITER construction and operation. Anne Davies, who directs DOE's fusion program, told the advisory panel on 22 January that U.S. participation cannot exceed its current annual level of roughly $50 million, and that a U.S. site for ITER is out of the question. Japan's government, by contrast, recently asked the Diet for funding to study potential sites in that country, while Italy is making a bid to use European Union funding set aside for economic development to pay for at least a portion of the 60% or more of the construction costs to be borne by the host. ITER supporters hope construction can begin as early as 1998, with start-up by 2008.

But while the United States may be only a small financial actor in the project, its participation could be crucial. A U.S. pullout, warn its supporters, could spook European and Japanese politicians. With this in mind, ITER managers spent 2 days briefing the advisory panel on the painstaking engineering and science behind their 1500-page detailed design, which was completed in December. The exercise was intended to arm U.S. officials with enough information to head off attempts by financially pressed legislators to pull out of the project. "It takes a carpenter to build a house, but even a jackass can knock it down," says one advisory committee member.

ITER's advocates hope that the review will end the quiet warfare over how best to spend diminishing federal dollars on fusion. In the past, critics have argued that the project could divert money from domestic plasma research. "There was a time when there was a feeling that ITER could eat us up," says Hazeltine. "Now, we're all trying to sing the same song, since there is the possibility that plasma physics could die." That somber thought, it seems, is concentrating the minds of empiricists and theorists alike.

–Andrew Lawler