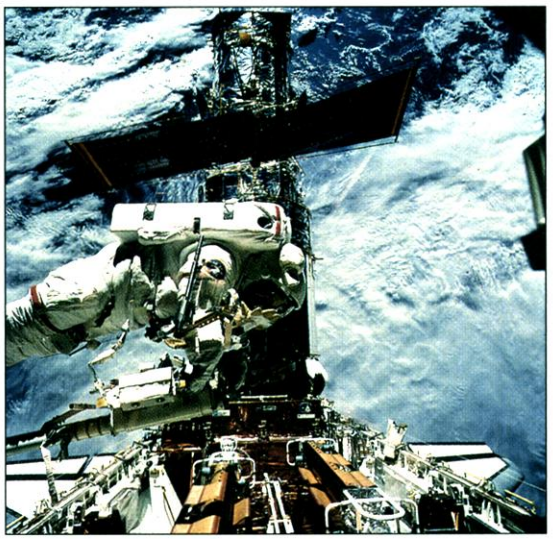
Next month's servicing mission marks NASA's next-to-last planned visit to the Hubble Space Telescope. That has kicked off a lively debate about what's next

Glimpsing the Post-Hubble Universe

The aging Hubble Space Telescope should get a new lease on life early next month after astronauts on the space shuttle carry out extensive repairs and upgrades. But astronomers are tempering their excitement, because NASA plans to turn off the highly successful instrument at the end of the decade after one more servicing mission.

That may seem a long way off, but it's practically next week on the time scale needed to plan major observatories. The Next Generation Space Telescope (NGST) is slated to replace Hubble in 2009, but it will observe in the infrared range, leaving optical and ultraviolet astronomers without a major space-based instrument. Meanwhile, Earth-based telescopes are experimenting with new technologies that could give them an edge over their more expensive space brethren. To avoid being caught short, researchers this spring will start to tackle what scientific questions over the next 2 decades are best answered through space observations—and which technologies are needed to get the job done.

The exercise will also tempt the community to reexamine whether it makes sense to halt operations of a popular and productive observatory. Previous efforts to extend Hubble's life were brushed off by former NASA Administrator Dan Goldin as coming from "Hubble huggers." NASA officials say that servicing Hubble costs too much, and that the $1.3 billion NGST effort is a better use of scarce resources. But Goldin has been replaced by Sean O'Keefe, and Hubble enthusiasts are heartened by the changing of the guard. "Now there's new leadership and lots of interest in finding a way to keep it on line," says Harry Ferguson of the Space Telescope Science Institute (STScI) in Baltimore, Maryland, which manages Hubble.



Long-distance service. A 1993 servicing mission put Hubble back on track for a decade of spectacular science.

It may be hard to convince NASA officials, however, who dismiss the idea as politically and technically impractical. "I'm a Hubble hugger in the ultimate sense," jokes NASA space science chief Ed Weiler, who spent 17 years as the telescope's chief scientist. "I want to hug it in 2010" as a display in the Smithsonian National Air and Space Museum, he says.

Room for service?

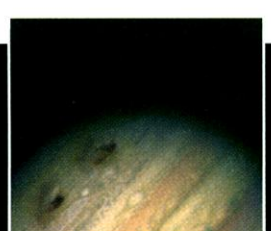
After an embarrassing debut in 1990, when it was launched with a defective mirror, Hubble has been one of the most successful space science projects. Even now, demand for glass time continues to rise, with the biggest surges coming after each servicing mission. The first, in December 1993, fixed the mirror, and two subsequent missions provided huge leaps in Hubble's data-collecting abilities. During the 1999 servicing mission, for example, the shuttle crew replaced six dying or dead gyroscopes, critical for the telescope's pointing accuracy. Astronauts also installed a new main computer, an advanced data recorder, a transmitter, a better guidance sensor, and insulation.

Next month's mission will add a new science instrument, power switching station, and four large, flexible solar arrays that are smaller but will produce 30% more power than the current radiation- and debris-pitted sails. The crew also will install a new cooling system that will reactivate a dormant instrument (see sidebar, p. 1450). The result, say Hubble managers, will be virtually a new observatory. "It's been an excellent value for the money," concludes Steve Beckwith, STScI's director.

But those missions remain technically challenging, and they aren't cheap—$172 million for next month's effort. Planning them requires a

CREDIT: MSFC/NASA

HUBBLE'S HITS



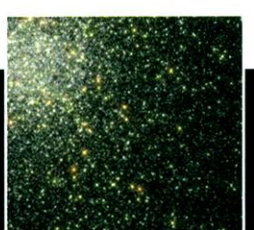
HST Jupiter Imaging Team

Comet Shoemaker-Levy 9: Watched the comet slam into Jupiter and studied its plume and wake. (1994)

Protoplanetary dust disks: Showed that they are common around young stars but often quickly lose their gas. (1993)

C. R. O'Dell/Rice University/NASA

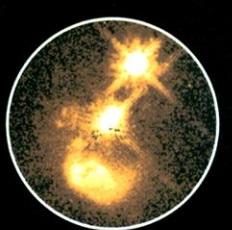
Globular clusters: Showed that those in our galaxy are all roughly the same age. (1991)



R. Gilliland/STScI/NASA

47 Tucanae: Vain search for Jupiter-sized planets in this cluster showed that such planets are much rarer in globular clusters than in the solar neighborhood. (2000)

Quasars: Confirmed that they reside in host galaxies, many of them colliding. (1997)



J. Bahcall, M. Disney/STScI/NASA

standing army of technicians and engineers, plus exhaustive training for the astronauts who carry out the work. And then there's the $500 million price tag for a shuttle flight.

These huge costs led to an agreement in the late 1990s among Congress, NASA, and the White House Office of Management and Budget to halt servicing missions after 2004 and to funnel money into NGST. "If you don't stop servicing Hubble, then NGST won't get started," says Weiler, adding that Hubble's 15-year lifetime has already been extended to 20 years. By then, he says, even servicing missions won't be able to keep Hubble's technology up-to-date. "We could continue to do great science with Hubble," says Weiler. "But I want to do outstanding science. Without unlimited funding, we've got to make tough choices."

Beckwith, however, says the choice isn't necessarily that stark. NASA could conduct a relatively inexpensive repair mission after 2004 that wouldn't entail costly instrument upgrades, he says, and technical advances could cut Hubble's $40 million annual operating costs in half by the end of the decade. Keeping Hubble alive a bit longer would also restore a 1-year overlap between NGST and Hubble that disappeared as the new telescope's launch date has slipped at least a year, he adds.

But Anne Kinney, a senior NASA space science official, says that an overlap is not vital to the agency's research program. And even reduced annual operating costs—not to mention the cost of another servicing mission—would break NASA's limited budget, she and Weiler say. Turning off Hubble "is not a scientific question, it's a political one," concedes Beckwith.

Out in the cold

The voice of researchers remains important, however, in shaping a post-Hubble future. Next month, infrared astronomers will gather in Maryland to discuss their scientific goals and the missions needed to reach them. Optical and ultra-

NGST Aims for Big Advance by Going Back in Time

The Hubble Space Telescope is a hard act to follow. But the designers of the Next Generation Space Telescope (NGST) expect the $1.3 billion instrument to win loud applause by greatly extending Hubble's vision. It should be able to peer back in time to first generations of stars and galaxies, and its sharp eyesight should spot individual stars in nearby galaxies. Their confidence remains unshaken after several years of daunting technical challenges, budget threats, and sometimes difficult negotiations among the U.S., European, and Canadian partners.

Scientists began thinking about NGST in the 1990s as a vehicle for probing the early universe—primarily at infrared wavelengths, which are absorbed by Earth's atmosphere. They are giving it a 6-meter mirror that will provide more than six times the viewing area of Hubble's 2.4-meter mirror. On the other hand, its designers won't have a chance to fix any flaws after its scheduled launch in late 2009 because its location will put it beyond the reach of the space shuttle. Hovering beyond even the faintest wisps of the atmosphere, NGST will peer back in time and "see" the universe when it was between 1 million and a few billion years old. The National Academy of Sciences' most recent decadal panel on astronomy makes it the field's top priority (*Science*, 26 May 2000, p. 1310), and, although NGST's capabilities were scaled back substantially last year to trim costs, another academy review concluded last fall that the revised blueprint remains "a sound approach."

CREDIT: ESA

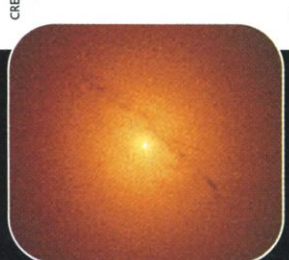
Time traveler. The Next Generation Space Telescope hopes to glimpse the early universe.

NASA will contribute about $1 billion for the mirror, instruments, spacecraft systems and integration, and launch. European contributions will total some $250 million to build the spacecraft platform and 50% of the three instruments. Canada will chip in $50 million for half of one instrument. "We hope to have the details worked out by the fall," says Sergio Volonté, the European Space Agency's (ESA's) coordinator for astronomy and fundamental physics. In exchange, European astronomers will receive at least 15% of NGST's observing time, and Canada will get 5%. Although use of the telescope will be governed by peer review, European researchers now receive a similar percentage of time on Hubble despite having made a far smaller contribution to its cost.

NASA's Anne Kinney says that U.S. negotiators had wanted to launch NGST aboard Europe's Ariane rocket and do the bulk of the spacecraft work in the United States. But under ESA bookkeeping practices, France—which developed Ariane—would have received sole credit for the contribution. So the ESA-built platform will be shipped to the United States, integrated with other components, and launched aboard a U.S. Atlas rocket. The parties must still tackle less pressing details such as sharing communications and ground facilities. "Most of the issues are resolved," adds Kinney.

This spring NASA will choose a U.S. prime contractor for NGST. And proposals for the spacecraft's instruments are due 5 March. **–A.L.**

With reporting by Daniel Clery.

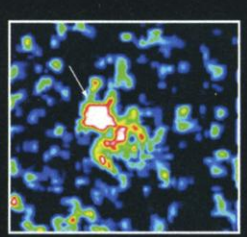


K. Gebhardt, T. Lauer/STScI/NASA

Supermassive black holes: Discovered that they dwell in the cores of most galaxies. (1997)

Hubble Constant: Measured the expansion rate of the universe with an uncertainty of only about 10%. (2001)

Gamma ray bursts: Helped show that they reside in galaxies that are forming stars at high rates. (1997)

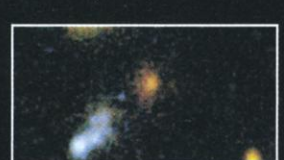


K. Sahu et al./ STScI/ NASA

R. Williams/STScI/NASA

Hubble Deep Field: Deepest-ever optical/ultraviolet/infrared image of the universe showed galaxies when the universe was less than a billion years old. (1996)

High-redshift supernovae: Most-distant exploding stars ever observed gave further evidence of an accelerating universe. (1998)



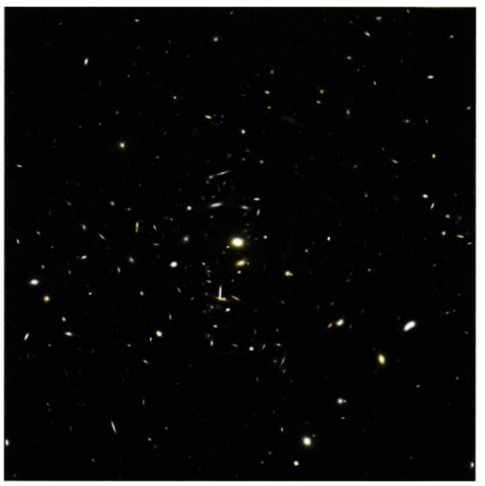
A. Riess/STScI/NASA

A Hot New Camera—and a Chilly Revival

Next week's service call to the Hubble Space Telescope should double the pleasure of astronomers. Not only will astronauts install a spiffy new camera, but they will resurrect an older instrument that sputtered to a premature shutdown.

Slated for rescue is the Near-Infrared Camera and Multi-Object Spectrometer (NICMOS). Installed in February 1997, NICMOS peered through dust at objects otherwise hidden from Hubble's view. But an accidental contact in the cooling system caused the camera's solid-nitrogen refrigerant to boil away, shutting NICMOS down by January 1999.

The daring fix looks and acts like the minirefrigerator in a college dorm room. "Refilling nitrogen in orbit isn't easy, so we figured out how to cool the camera mechanically," says project scientist Ed Cheng of NASA's Goddard Space Flight Center in Greenbelt, Maryland. The 90-kilogram cryocooler—built by Creare Inc. of Hanover, New Hampshire—will circulate compressed neon gas that expands within the existing NICMOS plumbing, driven by half-centimeter turbines whirling 7000 times per second. The vibration-free system should chill NICMOS to a frigid 70 kelvin for many years, Cheng says.



Sharp arcs. Large detectors in Hubble's new Advanced Camera for Surveys will capture stunning views of gravitationally distorted galaxies, this simulation predicts.

CREDIT: ACS TEAM

Expect hotter results from the Advanced Camera for Surveys (ACS), which astronauts will slide into the slot occupied by Hubble's last original instrument, the Faint Object Camera. Pictures from ACS will cover twice as much area on the sky as those from Hubble's workhorse, the Wide Field and Planetary Camera 2. Moreover, the camera's imaging chips are three to five times as efficient and its vision twice as sharp. Those gains will have a dramatic impact, says lead scientist Holland Ford of Johns Hopkins University in Baltimore, Maryland: "After 1 or 2 years in orbit, ACS will have detected more faint stars and galaxies than all of Hubble's previous instruments combined."

Astronomers will use ACS to survey wide patches of the distant universe. Such studies should write the book on how clusters of galaxies have evolved, Ford says. ACS images of the eerie distortions of space caused by massive clusters, called gravitational lenses, may reveal magnified images of the first galactic building blocks less than a billion years after the big bang. Further, surveys of the outermost solar system should expose a host of faint icy objects beyond Neptune and Pluto, within the poorly understood Kuiper belt. ACS also boasts a high-resolution camera for even sharper images of small patches, such as the cores of galaxies and dusty disks around young stars, and a detector for spotting ultraviolet light from hot stars, aurorae on Jupiter and Saturn, and other energetic objects. A small disk will block nearly all light from bright central sources for certain studies.

"Everybody and his brother wants to use this camera," says astronomer Richard Ellis of the California Institute of Technology in Pasadena. The competition is already fierce even by Hubble's stingy standards. In the first round of proposals for observing time on ACS, just one of every 20 requests made the cut.

–ROBERT IRION

violet scientists will hold a similar discussion in April at the University of Chicago. "We are thinking ahead more than a decade," says Robert Kennicutt of the University of Arizona in Tucson, who is helping to organize the Chicago meeting. But scientists hoping to rally support for a fast-track payload will be disappointed, Kennicutt warns: "This is not an effort to shoehorn a new mission into NASA's planning cycle."

Coming up with a cohesive plan is particularly pressing for researchers who use the ultraviolet and optical wavelengths that will not be a part of NGST's portfolio. Although smaller missions are on the drawing board, NASA has no plans right now for a major space telescope to serve their needs.

Meeting participants are expected to weigh the relative merits of exploring a range of scientific topics, including the nature of the intergalactic medium, the precise distance among galaxies, extrasolar planets, and the identification of fainter galaxies to understand galactic evolution. "It is real easy to define exciting problems," says Kennicutt. "It's more difficult to ask how many will still be cutting edge in a decade." Getting a firm grip on the scientific issues is vital, says Kinney. "Scientists tend to think in terms of facilities; from NASA's point of view, we need to know what science questions are important."

Researchers will also try to mesh their plans with the growing capabilities of ground-based telescopes. Those on the ground cannot compete with the cold and clear conditions of space when it comes to gathering infrared, x-ray, and ultraviolet wavelengths, and that fact is unlikely to change for a long time. But thanks to new technologies—such as adaptive optics—Earth-bound telescopes are starting to rival some of the best of Hubble's images in the optical realm. And ground observations are a lot less expensive.

"In some parts of the visible spectrum, there's not necessarily an advantage to a space telescope," Kennicutt says. But there is no consensus on when or whether those advances will equal or supercede space-based instruments. "There is a gray area when it comes to the visible, and [there is] quite a divergence of opinion," he adds.

For example, adaptive optics can monitor how the atmosphere distorts the image of a single bright star and compensate for the entire field by making minute adjustments to the mirror. The latest technique makes use of an artificial "star" created by a spot of laser light shot high into the sky. Recent pictures from the European Southern Observatory's Very Large Telescope atop Cerro Paranal, Chile, are even sharper than some Hubble images. But that clarity fades for wider fields.

Although some astronomers say wide-field optical imaging from space will retain an advantage over ground-based mirrors, the University of Arizona's Roger Angel says that ground-based technologies are catching up at telescopes such as the W. M. Keck Observatory atop Mauna Kea in Hawaii. At Keck, a series of lasers shot into the atmosphere allow researchers to adjust their mirrors to compensate for atmospheric effects over wider fields. Developing accurate lasers has proved problematic, but they are improving, says Angel. In fact, some ground-based astronomers soon expect to be able to capture images of extrasolar planets (*Science*, 25 January, p. 616). "The space-based guys always need to be looking over their shoulders," he adds.

Technology bridge

The outcome of this horse race between ground-based adaptive optics and space-based technologies will play a key role in NASA's decision on which missions to fund. "We need a hard-nosed discussion of the

technology for the future," says Kinney. Agency managers are pondering a 2004 initiative to come up with better and lighter mirrors, detectors, coatings, and other technologies. So far, such long-term vision has suffered from near-term budget troubles. A NASA proposal to spend some $5 million in 2003 on solar sails and lightweight optics was shot down by White House budget officials to cover cost overruns in other programs. But NASA officials say they are confident that O'Keefe will prove amenable to spending money on long-term technologies for space telescopes.

Telescopes of every wavelength need bigger and lighter optics. But the details differ. Ultraviolet instruments, for example, require greater precision in their optics because of the shorter wavelengths; mirror contamination, which absorbs those shorter wavelengths, also poses a major threat. Infrared astronomy demands low temperatures, to reduce the amount of contaminating heat and light. And x-ray astronomy requires higher precision and multiple mirrors; the current use of cone-shaped mirrors is limited because increasing their size does not rapidly increase light collection. Harley Thronson, NASA's chief astronomy technologist, says that better detectors are essential for all wavelengths, pegging total research and development costs at $30 million to $40 million a year.

Meanwhile, NASA managers say they want to keep close tabs on advances in ground-based astronomy. The 2004 initiative, adds Thronson, might include collaboration with the National Science Foundation, which oversees ground-based telescopes.

Such cooperation would no doubt please the White House, which pushed unsuccessfully last year to combine the two agencies' largely separate efforts under one roof. Coordinating technologies could be a first step toward determining which missions are best met by space- or ground-based instruments. "Hubble has been king of the hill for so long, it's hard to think of a different direction," says Angel. With Hubble's demise in sight, however, the time may be ripe for a new approach.

–ANDREW LAWLER

NEUROSCIENCE

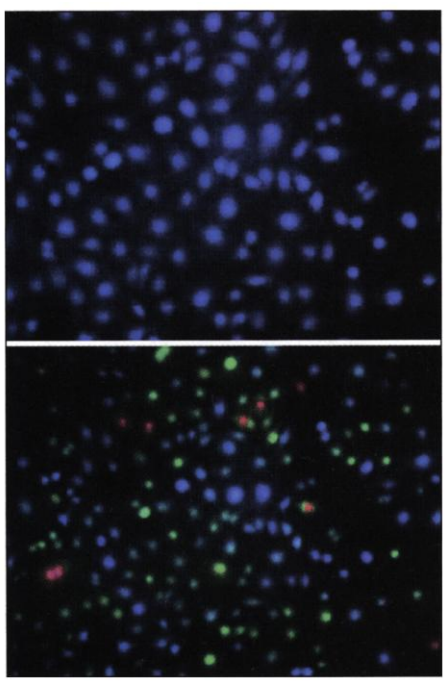
How Neurons Know That It's C-c-c-c-cold Outside

A newfound mint receptor and a cold-sensitive balance of ion movements can each send the chilling message

Mouthwash and chewing gum makers advertise that their minty products feel and taste cool. It's not just a metaphor. To a cold-sensitive neuron, menthol, the active ingredient in mint, might just as well be ice. Until recently, however, researchers didn't have a good grasp of how nerve cells transmit cold sensations. Now a spate of papers published this month offers two answers. Sometimes specialized menthol sensors do the job; other times neurons choreograph the movement of ions in response to cold in the absence of a specific receptor. Researchers suspect that the two mechanisms operate in concert, either in separate populations of cells or together in the same neurons.

Fifty years ago, researchers discovered that some nerve endings react both to cold temperatures and menthol. That meant that menthol could be used to identify cold-sensitive neurons, says neuropharmacologist David Julius of the University of California, San Francisco. These neurons should be mirror images of neurons that are sensitive both to hot temperatures and capsaicin, the chemical that gives chili peppers their sting. In 1997 Julius identified a receptor that registers both types of heat sensations, and since then he's turned his attention from the oven to the freezer. "Is there a bona fide menthol receptor?" he wondered. If so, "what does it look like, and is it [also] a cold receptor?"

Last year work by Gordon Reid's group at the University of Bucharest, Romania, pointed to the existence of such a receptor. The team observed a flow of ions into certain neurons when stimulated by cold and found that exposure to menthol increased that flow—exactly the behavior one would expect if a cold- and menthol-sensitive receptor were at work. That receptor would likely be a channel in the cell membrane that allows ions to flow into the cell and activate the neuron when it gets cold. (Because they looked at only the electrical characteristics of the current, the researchers did not identify any specific neural receptors.) They were a bit perplexed, however, as the new findings seemed to contradict the team's earlier work suggesting that menthol stimulated neurons not by allowing ions to flow into the cell but by preventing ions from leaving the cell.



Cool customers. Neurons expressing the newfound receptor relax at room temperature (top) but fill with calcium ions at 15°C (bottom). Color changes from blue to green to red as the ion concentration inside the cell increases.

CREDIT: PEIER *ET AL., CELL*, PUBLISHED ONLINE 11 FEBRUARY 2002

The new observations, by three independent research groups, support both mechanisms. Two teams cloned proteins that appear to be the long-sought cold receptor. Under cold temperatures, the proteins shuttle positive ions into the cells. The third team reports that cooling blocks a protein channel through which positive ions leak back out of the cell, trapping extra charge inside the neuron. "They're both going on," Reid says of the two mechanisms, but "the relative importance of the two is still open."

In search of a channel responsive to cold, Julius and his colleagues isolated menthol-sensitive neurons from the faces of rats. Even in the face, which is particularly sensitive to cold, only about 10% to 15% of neurons responded to the cooling compound. After verifying that cold temperatures also stimulated the cells, the researchers inserted various genes expressed by those cells into other cells that don't normally register cold or menthol. One gene opened up a new world of sensations for the cells, making them respond to low temperatures as well as the minty chemical, the group reports online 11 February in *Nature*. The gene encodes a receptor that they named, straightforwardly enough, CMR1, for cold and menthol receptor. The team found that the receptor is present primarily in small-diameter neurons, which typically play a role in sensing pain.

A second group, led by Ardem Patapoutian of the Scripps Research Institute in La Jolla, California, and Stuart Bevan of