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NEWSLETTER

Space Telescope Science Institute

Servicing Hubble Robotically

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Figure 1: The caption for this figure is located on page 3.

On March 2, 2002, space shuttle *Columbia* roared into orbit carrying a crew of seven astronauts and a valuable cargo to service and upgrade the *Hubble* on servicing mission SM3B. In five challenging space walks, *Hubble* acquired a new set of solar arrays, a new power control unit, the Advanced Camera for Surveys, and the new cooling system for the Near Infrared Camera and Multi-Object Spectrometer (NICMOS). SM3B was the last successful mission for *Columbia*. On its next flight, eleven months later, a previously unrecognized safety risk in our space transportation system led to the destruction of *Columbia* and the loss of its crew. In January 2004, NASA Administrator Sean O'Keefe paid a visit to the *Hubble* program office at Goddard Space Flight Center to inform us personally that he had decided to discontinue *Hubble* servicing with the space shuttle and to cancel the planned servicing mission SM4. This decision brought to an end one of the most successful programs in NASA history, the linkage of human and robotic space flight to repair, maintain, and technologically advance the *Hubble Space Telescope*.

Or did it…?

The *Hubble* program is populated with talented, creative, and experienced engineers, who have a long-standing reputation for successfully tackling seemingly unsolvable problems. My favorite example is the NICMOS cryocooler, a mechanical cooler that brought back to life a failed instrument that was not originally designed to be cooled mechanically. Of course, at the time the cryocooler idea was suggested, mechanical coolers had a bad reputation, in general. Many people said it could not be done. But the outcome was that NICMOS has resumed its place among the critical tools available to astronomers on *Hubble*, and it has operated reliably for the past 2.5 years with the cryocooler. So it is not surprising that this same team of engineers, working with our partners in the world of human space flight, rapidly developed a concept for accomplishing many of the original objectives of SM4 without the associated human risks of a shuttle mission.

The key element of the new servicing concept is a robot already developed and flight-qualified for use on the *International Space Station* (*ISS*). The robot is named Special Purpose Dexterous Manipulator or "Dextre" for short.

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WINTER [2005]

Gyroscopes

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Three years ago, during the run-up to servicing mission SM3B, we faced a difficult decision about whether to install new gyroscopes on the *Hubble Space Telescope* or mount the NICMOS Cryocooler System (NCS). Doing both was not an option—there was not enough time on the space walks. We opted to install the NCS, allowing *Hubble* to observe supernovae at infrared wavelengths to study the early expansion history of the universe. But the potential early loss of gyroscope guiding troubled me, so I approached Rodger Doxsey about the possibility of guiding in some novel way, as *FUSE* and *IUE* had already demonstrated.

"Rodger," I asked in my half-baked idea voice, "would it be possible to point the telescope with fewer than three operating gyroscopes?"

Rodger's jaw tensed momentarily, his instinctive reaction to a naive question from a child. He quickly recovered his composure, but his reply had all the patience of a mother explaining to her three-year-old why it is a bad idea to poke a stainless steel knife in an electric wall socket.

"Impossible," he said. "Three axes are the minimum needed to define an inertial reference frame in space."

Well, I already knew that much, but I could not help but wonder why the other satellites could make do with less while ours could not. So I pressed. He responded with an impromptu lecture on the *Hubble* guiding system, the intricate ballet by which the magnetometers, gyroscopes, fine guidance sensors, and fixed-head star trackers work in concert to make *Hubble* the most exquisitely pointed telescope in history. If *Hubble* were in Baltimore, it could easily locate Roosevelt's ear on a dime in Washington, D.C. It was a brilliant tour de force, a fascinating lesson that convinced me both that my wish was in vain, and it was an excellent thing that he was in charge of our *Hubble* mission and not me.

Fast-forward two years to February 2003, following the *Columbia* accident. Rodger, Keith Kalinowski, and Larry Dunham (Goddard Space Flight Center) looked anew at what *Hubble* might do with only two working gyroscopes. It had become obvious that the servicing mission SM4 would be delayed, but there were also two other factors causing them to reconsider the pointing algorithm: the new 486 computer installed on SM3A gave *Hubble* vastly more computing power than in the past, capable of handling more complex pointing calculations, and they had talked to the *FUSE* engineers about how the *FUSE* pointing problem was overcome.

A little thought convinced them that if they changed the nature of the pointing algorithm, using the fine guidance sensors to provide information on the missing axis, two gyroscopes might be enough to stabilize the telescope during an observation. Slewing from one target to another was still a problem, as was recovering the guide stars lost after the telescope emerged from the Earth's shadow each orbit, but they figured that the combination of information from the magnetometers with sightings from the star trackers might get the telescope close enough for acquisition.

Thus, the notion of two-gyro guiding with *Hubble* was born.

By now, the Institute and Goddard teams have put together a complete plan for a two-gyro mode and run some tests. High-fidelity simulations indicate that the two-gyro mode telescope-pointing stability will differ little from what it is under three-gyro control—a few milliseconds of arc. The vast majority of our current programs would be unaffected in two-gyro mode. The project team will test the two-gyro mode on *Hubble* itself in February 2005.

We expect each of *Hubble*'s gyroscopes to stop working as its electrical leads age. There is less than a 50/50 chance that *Hubble* will have three working gyroscopes beyond May 2006 under our current mode of operations (three gyroscopes on, one turned off, two dead.) Under two-gyro mode, there is a 50% probability that science operations can continue to October 2007—extending *Hubble*'s scientific lifetime by more than one year. If we were to turn off one of the currently working gyroscopes early and go into two-gyro mode at the start of Cycle 14, say, science operations could even continue through the summer of 2008, providing an important margin for any delays in the servicing mission and continuous scientific results from *Hubble* until it is serviced. Early entry to two-gyro mode would return almost 3,000 orbits of additional observation time over the life of the program, almost 75% of a cycle. Those extra orbits would be an enormous benefit for science.

Entry into two-gyro mode would carry some consequences for our science program, of course, but we are increasingly optimistic that the impact will be small. The major difficulty under two-gyro mode will be in scheduling. With three working gyroscopes, *Hubble* can point at about 80% of the celestial sphere, the other 20% being too close to the Sun. Under two-gyro mode, the solar exclusion zone will grow, and *Hubble* will only be able to point to one half of the remaining sky. This restriction will make it more challenging to schedule programs requiring strict roll angles, and it will be more difficult to schedule target-of-opportunity observations owing to the loss of 60% of the sky at any one time. Nevertheless, the entire sky is accessible at some time during each cycle.

We think we can find workarounds for almost all programs typically scheduled. We are leaning favorably toward early entry into two-gyro mode, although we cannot be sure before the tests in February. The final decision would be made at NASA Headquarters, of course.

We urge *Hubble* users to take seriously our instructions on two-gyro mode in the Cycle 14 *Call for Proposals*. There, we ask proposers to describe the implementation of their observations in two-gyro mode and to discuss the impacts. We will ask the Time Allocation Committee to rank proposals in two lists, one for the baseline three-gyro mode and the other for the two-gyro mode.

Feeling vindicated for my "dumb luck" query three years ago, I wandered into Rodger's office the other day and asked him about one-gyro pointing. This time, his face became thoughtful. He said that it wasn't crazy—this is a big step up for me—but it was not obvious that it could be done either. Ever the optimist, it sounded quite promising to me.

Emboldened, I asked about a *zero-gyro* mode.

With that question, he threw me out of his office. Ω

Servicing Hubble from page 1

It is a two-arm robot with seven degrees of freedom in each arm and a total arm span of about 23 feet. Dextre was designed and built by MacDonald Dettwiler (MD) Robotics of Brampton, Ontario, the same company that built the Remote Manipulator System (RMS) used on almost all shuttle missions and the arm that is used on the *ISS*. Other candidate robots were considered, such as the "Robonaut" being developed at the Johnson Space Center and the "Ranger" from the University of Maryland. However, neither of these alternatives is as ready as Dextre for the robotic servicing mission to *Hubble*.

Within a few short weeks after Mr. O'Keefe's announcement, engineers carried high-fidelity mockups of *Hubble* hardware to Canada. Using the Dextre test facility at MD Robotics and some simple tools that the Dextre could manipulate, they demonstrated that the robot could indeed perform tasks needed to service *Hubble*, whether under human control with a joystick or operating in a fully automated, pre-programmed mode. The Dextre ground test unit was then brought to our cleanroom at Goddard Space Flight Center. There, using instrument simulators, it demonstrated the robotic replacement of the Wide Field and Planetary Camera 2 (WFPC2) by the Wide Field Camera 3 (WFC3), the robotic installation of the Cosmic Origins Spectrograph (COS), the connection of new batteries to the *Hubble* solar arrays, and numerous other tasks planned for the robotic servicing mission. Astronauts Mike Massimino and Claude Nicollier performed the same tasks remotely, operating the Dextre test unit in the Goddard cleanroom from a control console located at Johnson Space Center in Houston.

At the same time, engineering studies were underway to develop a concept of how Dextre and the *Hubble* payload, including the two new scientific instruments, WFC3 and COS, could be transported to the telescope in orbit.

At the end of its useful life, NASA policy requires that *Hubble* must be safely de-orbited. This entails the launch of a de-orbit propulsion module on an expendable launch vehicle, followed by the autonomous rendezvous and docking (AR&D) of that module with *Hubble*. AR&D is a challenging new technology that has been in development for many years. Several small missions to demonstrate various aspects of AR&D are scheduled for flight over the next few years. A *Hubble* robotic servicing mission would both provide the capability to safely de-orbit the telescope and serve as the first major practical application of the new AR&D technology.

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Figure 1: (Cover Image)

Artist's rendering of the current baseline concept for *Hubble* robotic servicing. The de-orbit module (DM) is attached directly to the aft bulkhead of *Hubble*. Below the DM is the ejection module (EM). The "skirt" configuration at the bottom is made up of solar array panels, which provide electrical power to the EM and DM while they are stacked and offer shade for thermal protection while the instruments are being installed. The remote manipulator arm is shown deployed and attached to Dextre, which is shown in the process of removing WFPC2.

Servicing Hubble from page 3

The technology benefits have great interest for the recently formed Exploration Systems Mission Directorate (ESMD) at NASA Headquarters. Both AR&D and robotic technologies will play major roles in the President's exploration initiative, and the *Hubble* servicing mission would advance the state of the art by an estimated ten years, accelerating the availability of tools for exploration beyond low earth orbit. For this reason, ESMD has been assigned the lead role for *Hubble* robotic servicing, working in partnership with the Science Mission Directorate.

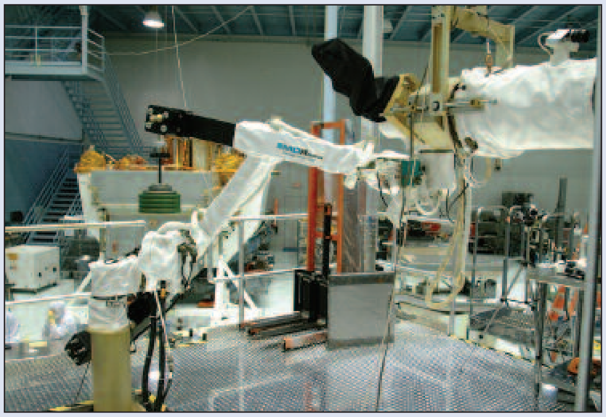

Figure 2: The MD Robotics 1-g test bed for Dextre, shown deployed in the cleanroom at the Goddard Space Flight Center. The test bed is a fully functional, high fidelity representation of one of the two Dextre arms.

In August 2004, Administrator O'Keefe once again paid a visit to the *Hubble* team at Goddard. He expressed great enthusiasm for the possibility of the robotic servicing mission and authorized continuation of work on the concept for a period of approximately one year, culminating in a critical design review late in the summer of 2005. At that time a decision will be made whether or not to proceed with robotic servicing. The scientific community will have a voice in the decision-making process, perhaps through the National Academy of Sciences.

Figure 1 (see cover image) shows an artist's rendition of the robotic mission concept. Two modules would be launched in tandem on either a Delta IV or an Atlas 5 expendable launch vehicle. The de-orbit module (DM), containing the sensors necessary for AR&D, the new *Hubble* batteries, and the propulsion system ultimately needed to de-orbit *Hubble*, attaches to the aft bulkhead of the *Hubble* spacecraft, to the same attachment fittings (the so-called "towel bars") used in prior shuttle-based servicing missions. Below the DM is the ejection module (EM), which houses Dextre, a small-scale version of the shuttle RMS, and the payload destined to go into *Hubble*. The combined stack is almost as large as *Hubble* itself, 25 feet in length with a fully fueled weight of 23,000 lbs.

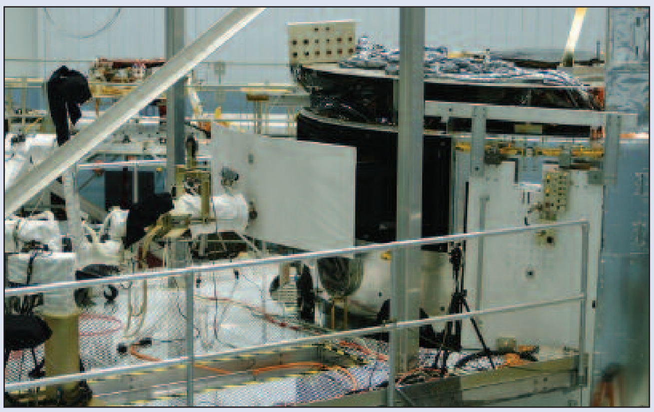

Figure 3: The 1-g test bed for Dextre, shown in the process of robotically inserting a full-scale mockup of WFC3 into the *Hubble* high-fidelity mechanical simulator in the Goddard cleanroom. Because Dextre is designed to operate in zero gravity, the WFC3 mockup has been counterbalanced with cables and weights.

Tentatively, the payload would include, in addition to COS and WFC3, a new set of six gyroscopes (mounted on the exterior of WFC3). Consideration is also being given to include a replacement Fine Guidance Sensor (FGS). Dextre, mounted on the end of the RMS-like arm, would remove COSTAR (Corrective Optics Space Telescope Axial Replacement, which implemented the fix for spherical aberration), WFPC2, and perhaps FGS 2, replacing them with COS, WFC3, and a refurbished FGS. Dextre would then stow the old equipment within the EM.

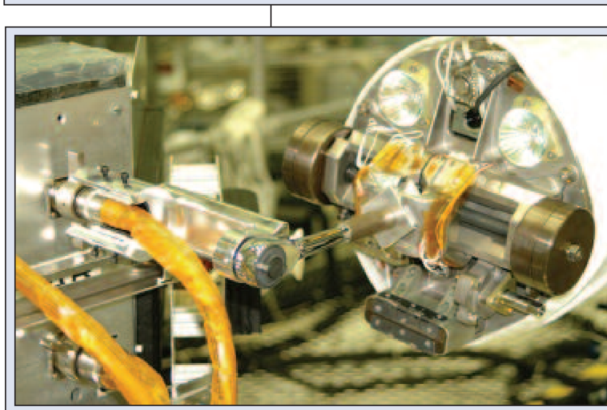

Figure 4: The working end of the Dextre arm in the process of practicing robotic connection and disconnection of a cable harness. The tool being used is a right-angled, motor-driven wrench attached to a custom-designed socket, which can engage the wing tabs of the cable connector and rotate it. The two work lights will illuminate the scene so that the process can be monitored in orbit with small digital cameras attached to the arm.

Since Dextre requires no food, oxygen, or rest, the robotic servicing mission can proceed at a deliberate, mechanical pace. If needed, weeks or months can be allocated to completing the servicing tasks successfully.

When servicing and basic checkout of the equipment are completed, the EM will be ejected from *Hubble*. The DM will remain attached, providing the new battery power that *Hubble* badly needs and later sending *Hubble* on a safe trajectory into the ocean. Simulations by experts on the pointing control system indicate that the DM attached to *Hubble* will not degrade its pointing and jitter performance below current specifications, although slew rates will be slower than they are now.

Most scientists and engineers have been skeptical when they first hear about servicing *Hubble* with a robot.

I certainly was. My own epiphany came when I saw actual demonstrations of a real robotic system, using relatively simple tools we had designed and built in a very short time to open and close doors, to connect and disconnect wiring harnesses, to guide instruments into and out of the *Hubble* high-fidelity mechanical simulator—and to accurately repeat these processes many times both under human and computer control (see Figures 2–5). I had not been aware that the human space flight program had already pioneered the design and development of a robot that was simply waiting for a ride to the *ISS*. It has been our experience that when previously skeptical astronomers first see this system in action, uniformly their response is, "Wow, I didn't know we could do that."

For further information about progress toward a possible robotic servicing mission, check out **http://hubble.nasa.gov.** Ω

Figure 5: An operator in the Goddard clean room controlling Dextre with a joystick. Actual operations will entail a combination of joystick control and pre-programmed, computer-driven operations, initiated by the operator with "go/no-go" commands.

Development Status of Two-Gyro Mode

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The primary task of the *Hubble* gyros is to provide accurate, high-speed information to the pointing-control system in order to meet the jitter specification of 7 milli-arcseconds for the line of sight of the telescope. Current operations of *Hubble* require three working gyros. At the present time, *Hubble* has four functional gyros, two having failed. We have made considerable progress in developing a two-gyro mode, which will allow *Hubble* to continue scientific observations with only two working gyros. In the last several months, we have developed a much better understanding of the scientific performance of the telescope in this mode, and it appears to be less compromised than originally expected.

Over the summer, the pointing-control engineers carried out high-fidelity simulations of the jitter of the telescope in two-gyro mode. The simulator incorporates all the known physical effects, including gyro noise and photon noise in the Fine Guidance Sensors (FGSs), accurate models of the hardware and software processing of the sensor data, and the flight software used in the pointing control system, including timing and quantization effects. The simulator has a complete model of the structural modes of the telescope interacting with the control system. Also, the simulator uses a library of known disturbances challenging the pointing-control system, obtained from on-orbit measurements.

Relative to three-gyro mode, we expect the jitter to increase in two-gyro mode. The jitter will depend on the gyro pair and the brightness of the guide stars (due to greater reliance on fine-pointing information from the FGSs).

The results of the simulations and our analysis of them are contained in the *Two Gyro Handbook*, available at **http://www.stsci.edu/hst/HST_overview/TwoGyroMode**. Table 1 shows the largest jitter (rms in a 60-second interval) seen during the simulations for disturbance periods for the various gyro pairs and levels of brightness of the guide stars. The highlighted column pertains to the most typical guide-star brightness, and the last line in the table shows the results of simulating the current, three-gyro mode. (The typical value for jitter in three-gyro mode during non-disturbance periods is 5–6 milli-arcseconds.)

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Status of Two-Gyro Mode from page 5

As we have modified the Institute scheduling systems to handle two-gyro mode, we have also been able to carry out evaluations of its scheduling efficiency. The main impact is due to the intensive use of the Fixed Head Star Trackers (FHSTs) after slewing the telescope, to reduce the pointing error to the level where the FGSs can acquire the guide stars. The combined requirements for the FHSTs and telescope visibility of the sky can be satisfied for all regions of the sky, but only for about half the number of days possible in three-gyro mode. The *Two Gyro Handbook* has an extensive discussion of the impact on scheduling observations, and the website listed above has tools that can be used to evaluate the situation for any target. While each target will have about half the flexibility for scheduling compared with today, the overall scheduling efficiency will depend on the mix of targets. Scheduling evaluations carried out to date indicate that in two-gyro mode we should be able to schedule about 85–95% the number of orbits we schedule now in three-gyro mode. Maintaining this efficiency for an extended period will require making each observation as flexible as possible, within its science constraints.

Table 1. Jitter Predictions (including disturbances)

Gyro Set	Angle of G_X Axis on Plane of Sky	Maximum Boresight Jitter (mas, 60-second RMS)		
		m_V=9.58	m_V=13.0	m_V=14.5
Two-Gyro F2G-FL Results				
1–2	0.0	9.55	9.76	10.40
1–4	-22.7	10.65	10.86	11.65
1–6	+22.7	11.72	11.91	13.06
2–4	+55.6	12.20	12.30	15.97
2–6	-55.6	12.39	12.47	17.41
4–6	+90.0	12.26	12.49	18.93 (+ LOL)
Three-Gyro Results				
1–2–4		9.73	9.73	9.75

Most jitter will be well below maximum values listed above, even for faint guide stars.

The development of the flight software to support the two-gyro mode is proceeding on schedule at Goddard Space Flight Center. The first flight tests of slews and FHST activities in two-gyro mode were carried out in mid-November 2004 and worked well. These included the first on-board identification of star fields using maps from the FHSTs. In mid-February 2005 there will be a full flight-test of the mode, which will take about three days. It will include extensive calibration observations with the Advanced Camera for Surveys and Near Infrared Camera and Multi-Object Spectrometer to verify the jitter performance and the impact on science observations. Ω

Update on the STIS Situation

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The Space Telescope Imaging Spectrograph (STIS) stopped science operations on August 3, 2004, due to the failure of a power supply within the side-2 electronics, which had powered the instrument since a short circuit blew a fuse, knocking out the side-1 electronics in May 2001. Currently, STIS is in "safe mode," with the instrument and its on-board computer switched off, but with the heaters on, in order to ensure a healthy and stable thermal environment.

The failed unit delivered power to all the mechanisms within STIS, including the aperture wheel, the mode select mechanism (which selects gratings and mirrors for a given observing mode) and the CCD shutter. At the time of the failure, the STIS was in "idle" mode, in which the light path is completely blocked—a precaution to prevent over-illumination of the Multi-Anode Microchannel Array (MAMA) detectors. In the absence of a working power supply, the mechanisms cannot be moved from their current positions, and the instrument is inoperable.

Immediately following the failure, the *Hubble* project office at Goddard Space Flight Center (GSFC) assembled a Failure Review Board including engineers from GSFC, the Institute, Ball Aerospace (where STIS was built), and Interpoint (the builders of the failed power supply). The board conducted a thorough review of all available telemetry to date to identify the most likely cause(s) of the failure, to evaluate possible work-arounds, to recommend further testing to characterize the problem and/or establish whether or not STIS can be returned to use, and to consider any risks of identical failures occurring in other *Hubble* instruments.

The board presented its findings and recommendations on September 16, 2004. Although it made no definitive conclusion as to the root cause, it localized the failure to be within the Interpoint power converter. A similar anomaly had been identified in November 2002 during the pre-launch testing of the *Gravity Probe B*, which used the same type of power converter. Unfortunately, the board did not identify any possible work-arounds to restore STIS operations. Nevertheless, the board proposed four tests developed by engineers and scientists at GSFC and the Institute:

Test 1. Verify the health and viability of the STIS detectors and lamps. This would be useful to know if an attempt to repair STIS would be made in the future.

Test 2. Attempt to reactivate the side-1 electronics. During the last servicing mission, astronauts replaced the blown side-1 fuse. The short circuit might have resolved itself.

Test 3. Verify that the failure in the mechanism power supply still exists.

Test 4. Test whether the STIS control electronics board can be turned on separately while STIS is in safe mode. This test would ensure that certain STIS components can be used to provide additional load during battery capacity tests, which is important to track the health of the batteries aboard *Hubble*. Each test also included a thorough description of all risks and benefits associated with its execution.

The only test currently approved is test 4, which executed successfully on December 9, 2004. Tests 2 and 3 have been disapproved. Senior management at the *Hubble* project office is carefully considering the risks and benefits of executing test 1.

We are sorry to bring you this sad news about STIS, which brought many unique observing capabilities to *Hubble*, including very high-resolution echelle spectroscopy in the ultraviolet and spatially resolved spectroscopy in the ultraviolet and optical. These and other capabilities will not be restored when Wide Field Camera #3 (WFC3) and the Cosmic Origins Spectrograph (COS) are installed in *Hubble*. A steady and high percentage of approved *Hubble* observing programs have used STIS throughout its lifetime. On the positive side, project engineers at GSFC continue to look carefully at possible ways to service STIS during the proposed robotic servicing mission. Ω

ACS and WFPC2 News and Results

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Longevity has its rewards. For an astronomical instrument, such rewards can include the ability to accurately measure proper motions. A team led by Pillar Ruiz-Lapuente has used this attribute of the Wide Field and Planetary Camera 2 (WFPC2) to locate the binary companion to the supernova type Ia (SN Ia) discovered by Tycho Brahe in 1572.[1]

Type Ia supernovae are thought to be produced when there is accretion from a companion star onto a white dwarf. The white dwarf may then be compressed and undergo a thermonuclear explosion. Its companion may often survive and could show evidence of mass loss and a high proper motion due to its binary velocity, which has been transformed into linear motion.

WFPC2 observations and ground-based spectroscopy of stars remaining in the vicinity of Brahe's SN have revealed a star of spectral class G0–G2 with a surface brightness and temperature comparable to the Sun, but with a noticeably lower surface gravity—which is moving rapidly compared to neighboring stars. This is the first time a progenitor companion to a SN Ia has been discovered. Although SNe Ia have been exquisite tools for measuring the geometry of the universe, direct observational evidence on their formation has been largely absent until now. This work suggests that Brahe's SN was a cataclysmic variable before it exploded; it seems these binaries are even more appropriately named than one might have realized. Some science is worth a 400-year wait.

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ACS and WFPC2 from page 7

NASA's great observatories have turned their collective gaze on the remains of another historical supernova—the one observed by Johannes Kepler in 1604.[2] When this most recent of all known supernovae in our Galaxy appeared alongside Jupiter, Mars, and Saturn in the sky, observers could use only their eyes to study it. Now Ravi Sankrit and William Blair of The Johns Hopkins University have used *Spitzer*, *Chandra*, and *Hubble* to obtain a combined, multi-wavelength image, which reveals a bubble-shaped shroud of gas and dust that is 14 light-years wide and is expanding at 4 million miles per hour (2,000 kilometers per second).

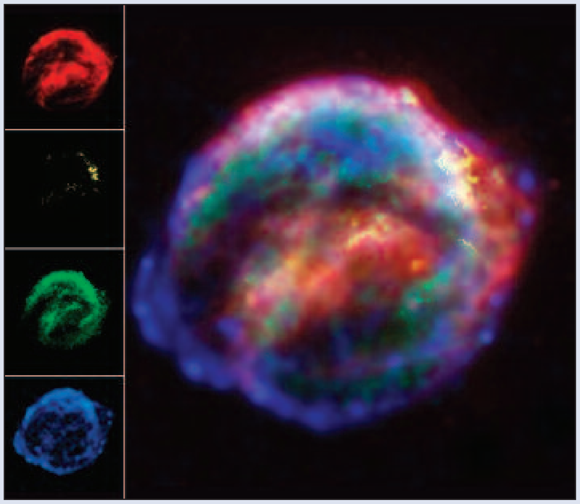

Figure 1: Four hundred years ago, sky watchers—including the famous astronomer Johannes Kepler—were startled by the sudden appearance of a "new" star in the western sky, which rivaled the brilliance of nearby planets. Now, astronomers using NASA's three great observatories—*Spitzer*, *Chandra*, and *Hubble*—have obtained new views of the expanding remains of Kepler's supernova, the most recent such event seen in our Galaxy. In this image, *Chandra* data are shown in blue and green, *Spitzer* data in red, and *Hubble* data in yellow.

http://hubblesite.org/newscenter/newsdesk/archive/releases/2004/29/

Each telescope's view highlights distinct features of the supernova remnant (a fast-moving shell of iron-rich material from the exploded star, surrounded by an expanding shock wave that is sweeping up interstellar gas and dust). The *Hubble* observations used primarily narrow-band filters to detect emission from excited oxygen, hydrogen, and nitrogen. These observations will allow direct studies on the composition, density, and evolution of structures in this complex nebula.

Observers have produced two other spectacular images of nebulae using narrow-band images from the Advanced Camera for Surveys (ACS). The Hubble Heritage team observed NGC 6543, better known as the Cat's Eye Nebula.[3] Yaël Nazé (University of Liège) and Yung-Hua Chu (University of Illinois, Urbana) observed the lesser known, but nonetheless enchanting, NGC 1763 (LMC N44F), which is one of the few known interstellar bubbles produced by the winds off of massive stars.[4] Figure 2 shows the image, taken in the light of hydrogen and sulfur emission, which reveals an object some have called a "celestial geode."

Astronomers have recently used *Hubble* images to study a far more distant subject: the epoch of reionization. This era, now universally believed to lie between $5 < z < 20$, occurred when the ultraviolet (UV) light of the universe ionized the intergalactic hydrogen, lifting a fog that had absorbed UV light since shortly after the Big Bang had begun to cool. In September 2004, a number of groups convened at the Institute, reporting the results of their studies of this epoch, which primarily used the Hubble Ultra Deep Field (UDF). Like the early universe itself, the subject of reionization remains in a bit of a fog. A group led by Andrew Bunker (University of Exeter), using a sample of 50 galaxies in the UDF at $z{\sim}6$, reported that galaxies at this epoch were unlikely to have sufficient UV light to reionize the universe. A team led by Massimo Stiavelli (STScI) claimed that such objects could reionize the universe—if they were much less metal rich than present-day galaxies (a hypothesis widely believed true), and if those galaxies contained proportionally more massive stars than galaxies today (which is a possible consequence of fewer metals). Another team led by Haojing Yan (Spitzer Science Center) and Rogier Windhorst (Arizona State University) reported that a large number of dwarf galaxies at $z{\sim}6$ could provide the necessary UV light to reionize the universe.[5] Results reported by Richard Bouwens (UCSC) for the HUDF NICMOS (Near Infrared Camera and Multi-Object Spectrometer) Treasury team support the contention that faint galaxies dominated this epoch and that these galaxies may have played a large role in the last stages of reionization. Finally, a group led by Sangheeta Malhotra and James Rhoads (STScI) used the HUDF, as well as ACS grism images of the HUDF, to argue that a single "sheet" of galaxies dominated the light in this epoch in the UDF and that the clumpiness in the galactic distribution would strongly affect small-area observations of reionization. While the various groups still disagreed on the exact cause of reionization, they were in agreement that the *James Webb Space Telescope* should be able to provide a definitive answer to the question of when and how reionization was finally brought about.

Figure 2: An image of NGC 6543 taken by the ACS in the light of hydrogen, oxygen, and nitrogen emission lines. Although this nebula, informally known as the Cat's Eye, was one of the first planetary nebula discovered, it remains today among the most complex and spectacular nebulae known.

http://hubblesite.org/newscenter/newsdesk/archive/releases/2004/27/

Although the ACS has become known for the power of its imaging, reduction of the data can be complex due to the strong geometric distortion of its field. Recently, Jay Anderson (Rice University) and Ivan King (University of Washington) completed a study of the geometric distortion of the ACS high-resolution camera (HRC). Their results have been released in the *ACS Instrument Science Report* (*ISR*) *2004-15*.[6] Using multiple images of a dense stellar field, they could solve for the geometric distortion of the HRC to the level of 0.01 pixel. Most users will not observe fields that permit comparable solutions. Fortunately, early indications are that the solution of Anderson and King should be good to a level of perhaps a few hundredths of a pixel when applied directly to other data sets.

The ACS group at the Institute, along with Anderson and King, has been working on further measurements of the geometric distortion of the ACS field and its stability, both for the HRC and the Wide Field Camera. The latest version of MultiDrizzle—a task that both removes cosmic rays and combines ACS exposures using offsets derived from the image headers—incorporates the results of this work. Furthermore, starting on September 22, 2004, the pipeline has been applying MultiDrizzle to associated ACS data sets. The Drizzle parameters used are excellent for a first look at the data and are suitable for many science projects. For more information on MultiDrizzle, see Section 4.5 of the *ACS Data Handbook* or **http://www.stsci.edu/hst/acs/analysis/multidrizzle**.

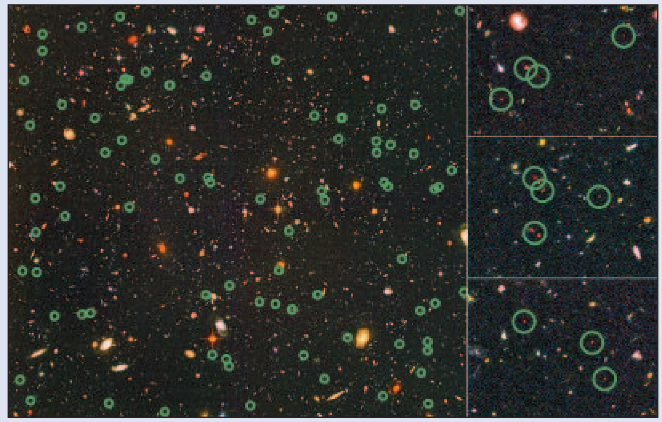

Figure 3: The Hubble Ultra Deep Field (left) and sections of the field enlarged four times (right). The green circles mark objects identified by Yan and Windhorst on the basis of optical and near-infrared photometry to lie in the redshift range $5.5 < z < 6.5$. The ultraviolet radiation from such objects may have been largely responsible for the reionization of the universe.
http://hubblesite.org/newscenter/newsdesk/archive/releases/2004/28/

Coronographic observations of the vicinity of bright sources are an infrequent but important use of the ACS. Flat-fielding is a necessary but difficult aspect of these observations. Due to vignetting by the Lyot stop and the presence of occulting spots, the usual ACS flat fields cannot be used for coronography. ACS coronographic flat-fielding is further complicated by unpredictable motions of the occulting spots, and therefore requires the division of a pixel-to-pixel flat field followed by the removal of a large scale flat reflecting the appropriate positions of the vignetting patterns. In *ACS ISR 2004-16*, John Krist, Jennifer Mack, and Ralph Bohlin report on a technique for overcoming many of these difficulties and creating ACS coronographic flats to better than 2% accuracy on spatial scales of a few or more pixels.[7] This technique has now been implemented into the ACS data-reduction pipeline.

Although use of WFPC2 is winding down, work to obtain a final accurate calibration of this instrument continues. Recently, Inge Heyer and collaborators examined WFPC2 zeropoints obtained by different groups through several approaches, and reported the results in *WFPC ISR 2004-10*.[8] They found that the absolute uncertainty of WFPC2 zeropoints is currently between 0.02 and 0.04 magnitudes, with some dependence on the filter, although in one case an error of 0.07 magnitudes may be present. Since Poisson statistics would have allowed an accuracy of better than 1%, they conclude that systematic terms still dominate the WFPC2 absolute magnitude calibration.

The *ACS* and *WFPC2 Instrument Handbooks* both have undergone revisions for Cycle 14. The new handbooks reflect our current understanding of the instruments and include calibrations and insights obtained during the past year. They can be accessed at the webpages of the respective instruments.[9,10] As always, we recommend that users regularly check the ACS and WFPC2 webpages for the latest information. For questions, send email to the Institute Help Desk at *help@stsci.edu*. Ω

1 http://hubblesite.org/newscenter/newsdesk/archive/releases/2004/34/
2 http://hubblesite.org/newscenter/newsdesk/archive/releases/2004/29/
3 http://hubblesite.org/newscenter/newsdesk/archive/releases/2004/27/
4 http://hubblesite.org/newscenter/newsdesk/archive/releases/2004/26/
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8 http://www.stsci.edu/instruments/wfpc2/Wfpc2_isr/wfpc2_isr0401.html
9 http://www.stsci.edu/hst/acs/documents/
10 http://www.stsci.edu/instruments/wfpc2/

James Webb Space Telescope Status

P. Stockman, *stockman@stsci.edu*, **and M. Stiavelli,** *mstiavel@stsci.edu*

The *Webb* project progressed over the last several months, undergoing important reviews, including the preliminary design reviews for the Near Infrared Camera (NIRCam) and the Mid-Infrared Instrument (MIRI) and the requirements review for the ground systems. The instrument design reviews were successful, paving the way for the production of the engineering test units. On the optics front, the manufacture of primary mirror segments is in full swing with the successful shipping of three additional beryllium blanks (the material for the six primary mirror segments).

SWG focus on NIRSpec

The Webb Science Working Group (SWG) met in October 2004 at the European Aeronautic Defence and Space Company (EADS) in Ottobrun near Munich. EADS is the prime contractor for the Near Infrared Spectrograph (NIRSpec), which was the meeting focus. The instrument design is maturing and on track to meeting its requirements. The micro-shutter arrays, which are being developed at Goddard Space Flight Center for use as the NIRSpec multi-object slit selection mechanism, are also making good progress. The NIRSpec mercury-cadmium-telluride detectors, which Rockwell Scientific is developing, are also coming along well.

Hans Walter Rix joined the SWG as the NIRSpec science team representative.

Ground systems requirement reviews

The ground systems for the *Webb* mission, including the Science & Operations Center (S&OC) passed their systems requirements review in October 2004. The review encompassed all aspects of *Webb* operations from launch and early commissioning to routine science operations—which entails science proposal selection, development of the command loads, their uplink to the spacecraft, downlink of science data, and delivery of calibrated data to the astronomers. While the development of the S&OC systems will not begin for another year, this review was an important milestone, laying the groundwork for studies of optimizing the scientific return from the *Webb* mission while managing observatory resources wisely, including station-keeping fuel, on-board data storage, and downlink contacts.

Webb primer

We have developed a primer or "mini-handbook" for astronomers interested in using or calibrating *Webb* instruments. The primer describes science goals, the observatory, and its components. It also discusses the natural backgrounds relevant for *Webb* and how they can affect field selection. For those interested in comparing capabilities with *Hubble* and *Spitzer*, the primer describes the four *Webb* instruments and their expected sensitivities. It highlights *Webb*'s main observational capabilities, as well as the capabilities of *Hubble* that are not supported by *Webb*.

The primer is available at: **http://www.stsci.edu/jwst/docs/handbooks**.

New *Webb* emblem

The *Webb* project has developed a new emblem for the mission identifying the three partner space agencies (NASA, European Space Agency, and Canadian Space Agency) and symbolically refers to the segmentation of the primary and the complexity of the L2 orbit. Ω

The Mid-Infrared Instrument for Webb

G. H. Rieke, *grieke@as.arizona.edu*, **G. S. Wright, T. Böker, E. F. van Dishoeck, T. P. Greene, M. Meixner, M. Ressler, & C. Waelkens**[1]

The capabilities of the *James Webb Space Telescope* become even more phenomenal as one observes further into the thermal infrared. The telescope will be limited in sensitivity only by the faint glimmer of the zodiacal background out to 10 μm. This wavelength is right at the peak of the thermal emission of ground-based telescopes. Instruments on those telescopes must peer through a million times higher glare, reducing their sensitivity by three orders of magnitude in comparison with *Webb*. The *Webb* self-emission at longer wavelengths remains far, far below the foreground glare on the ground. Operation in space also avoids the atmospheric absorption bands that seriously hamper ground-based astronomy in the deep thermal infrared.

The promise of *Webb* in the thermal infrared was recognized from its inception ("we also recommend that it be operated as a powerful general-purpose observatory, serving a broad range of scientific programs over the wavelength range $\lambda \sim 0.5$–20 μm": *HST and Beyond*) and by subsequent reviews ("Having [*Webb*'s] sensitivity extend to 27 μm would add significantly to its scientific return.": McKee-Taylor decadal survey). Therefore, NASA, a nationally funded consortium of European institutes, and the European Space Agency (ESA) have combined efforts to provide a powerful thermal infrared capability in the form of the Mid-Infrared Instrument (MIRI).

Table 1. Basic operating modes of MIRI, and their characteristics.

Mode	Wavelengths	Spectral Resolution	Field of View	Comments
Imaging	5.6, 7.7, 10, 11.3, 12.8, 15, 18, 21, and 25.5 μm	R ~ 5 typical	1.9x1.4 arcmin	Mix of broad and narrow filters
Coronography	10.65, 11.3, 16, and 24 μm	R=10	25x25 arcsec	
Low-resolution spectroscopy	5–11 μm	R=100	5x0.6 arcsec slit	Prism
Medium-resolution spectroscopy	5–28.5 μm	R~2000	3.5x3.5 to 7x7 arcsec	Integral field unit

The MIRI provides imaging, coronagraphy, and low- and moderate-resolution spectroscopy over the spectral range 5 to 27 μm (with a goal to extend to 28.5 μm). These capabilities are summarized in Table 1.

The imaging will be diffraction limited at all wavelengths, i.e., image widths (λ/D) of 0.2 arcsec at 5.6 μm, up to 0.9 arcsec at 25.5 μm. Table 2 lists examples of the MIRI sensitivity levels for point sources. From 5 to 10 μm, the imaging sensitivity is 50 times greater than that of *Spitzer*. For very deep exposures in cosmological fields, the high angular resolution with MIRI resolves the background into individual galaxies, allowing penetration far beyond the confusion limit for smaller telescopes.

As a result of its versatility and sensitivity, the MIRI contributes to virtually all areas of emphasis in the *Webb* science planning. For example:

The first galaxies and quasars. Figure 1 compares the spectra of a new galaxy ("first light," slightly reddened by a damped Lyman-α foreground galaxy) with an older one and a quasar, all placed at high redshift ($z = 15$). The three spectral energy distributions (SEDs) are sufficiently similar in the range of the Near Infrared Camera (NIRCAM) that surveys with that instrument will have

Continued page 12

MIRI from page 11

Table 2. Examples of MIRI Performance. All values are 10 standard deviations in 10,000 seconds.

Imaging, 5.6μm (μJy)	Imaging, 12.8μm (μmJy)	Imaging, 21μm (μJy)	R ~ 3000 Spectroscopy, 9.2μm (10^{-20} W m^{-2})	R ~ 2000 Spectroscopy, 22.5μm (10^{-20} W m^{-2})
0.19	1.4	8.6	1.0	6.0

difficulty distinguishing them. With the addition of MIRI data at 5.6 and 7.7 μm, the colors of first-light objects diverge from the others, and they can be properly identified.

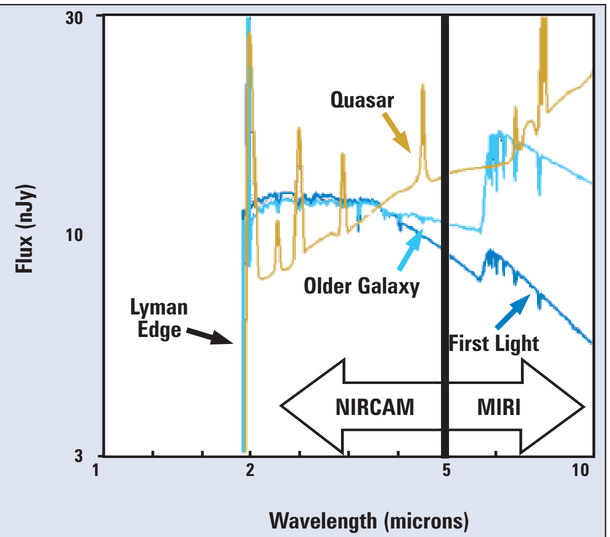


Figure 1: Confirming first-light galaxies requires MIRI. At the resolution of the NIRCam filters, all three SEDs are very similar (for the quasar, due to the contribution of emission lines). They are readily distinguished with MIRI data.

The SED and emission-line properties of quasars have shown a remarkable uniformity to beyond $z = 6$. Although little evolution in source properties seems to have occurred since $z = 6$, we would expect substantial evolution since their epoch of formation. As ever more distant quasars are discovered, MIRI will be needed to probe their characteristics to search for such evolution. Given the strong Lyman forest absorption, the accessible spectral range for studying the first quasars will be limited to the rest-frame ultraviolet for NIRCam and the Near Infrared Spectrograph (NIRSpec). The continuum and emission-line properties of these sources in the MIRI wavelength range (rest-frame near ultraviolet, visible, and near-infrared) will help substantially in the comparisons with quasars at lower redshift.

Formation of planetary systems. Stars are formed and the seeds for planets planted in cold cloud cores that are opaque in the visible and near infrared. A key to understanding the conditions leading to the formation of life is to understand how volatile and organic materials are collected and processed in protoplanetary disks. Observing these materials requires spectroscopy through the interstellar absorption "windows" between 4 and 8 μm and 13 and 17 μm. An example is shown in Figure 2. The line profile of the absorption near 6.85 μm indicates that ices are being observed within the protoplanetary disk, rather than in the foreground interstellar medium.

The higher spectral resolution (some 30 times greater than in Figure 2) and sensitivity of MIRI will allow much more precise identifications of these materials, will identify gaseous and solid phases, and will probe modifications due to the environment. It will also extend studies to a large enough sample of protoplanetary disks to examine how conditions vary from one to another, and to low luminosity sources similar to the solar nebula.

Evolution of planetary systems. Debris disks are the results of collisions between planetesimals that inject finely divided material into the circumstellar region, where it is warmed to temperatures high enough that it can be readily detected in the mid- and far-infrared. Debris disks are the most visible manifestation of a planetary system because they dominate its surface area. *Spitzer* is revealing that debris disks come in a huge variety. A few have been found that are dominated by small grains, which have very short lifetimes within the system, falling into the star due to Poynting-Robertson drag or being expelled altogether through photon pressure or the stellar wind. These observations indicate that some systems are dominated by recent, catastrophic collisions between bodies at least the size of large asteroids. The behavior is analogous to current theories for the formation of the planets in the solar system, thought to be characterized by large collisions for tens of millions of years. An example, placed at about 40 million years, is the event that tore material from the early Earth, which eventually consolidated into the Moon.

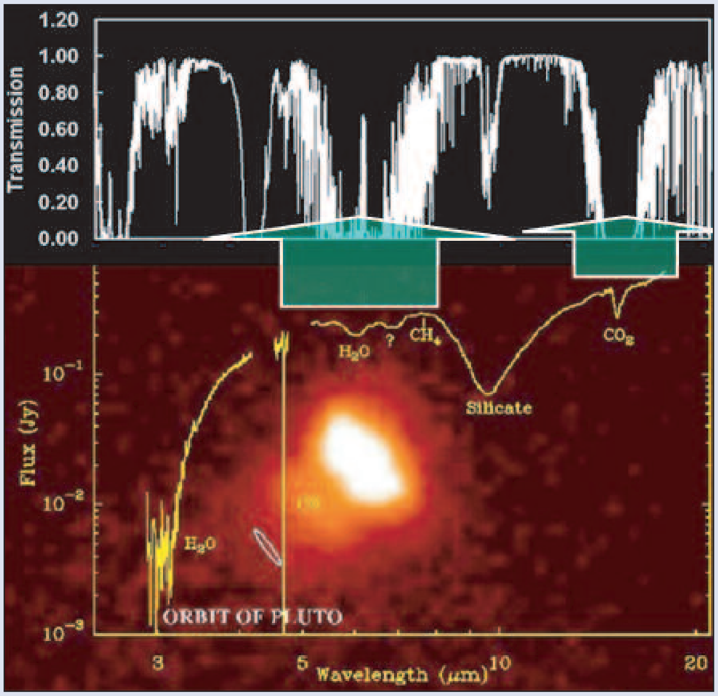


Figure 2: Spectrum and image of CRBR 2422.8-3422 (lower panel), by Pontoppidan et al. (**http://www.spitzer.caltech.edu/Media/releases/ssc2004-20/ssc2004-20c.shtml**). The shape of the feature marked with "?" indicates that it arises in the nearly edge-on protoplanetary disk. The upper panel shows the atmospheric transmission from a dry site. The shaded arrows show the relatively transparent regions in the interstellar medium. There is a rough anti-coincidence between atmospheric and interstellar windows, emphasizing the importance of space data to probe important prebiotic organic materials.

To understand the variety in debris disks being revealed by *Spitzer*, there is a pressing need to obtain detailed images of a large number of them. *Spitzer*'s 85-cm aperture is a serious handicap for this goal. With only a few exceptions, such images are inaccessible from the ground because of the low surface brightnesses of these relatively faint, extended structures. The gains in resolution and sensitivity offered by MIRI are necessary to advance to this goal. In addition, MIRI will often be able to directly detect the massive planets hypothesized to control the structure of debris disks. Figure 3 is a demonstration of the potential revolutionary increase in information we will achieve with MIRI images of nearby systems. In addition, positionally resolved spectra with the MIRI integral field unit (IFU) spectrometer will allow detailed study of grain properties within these systems.

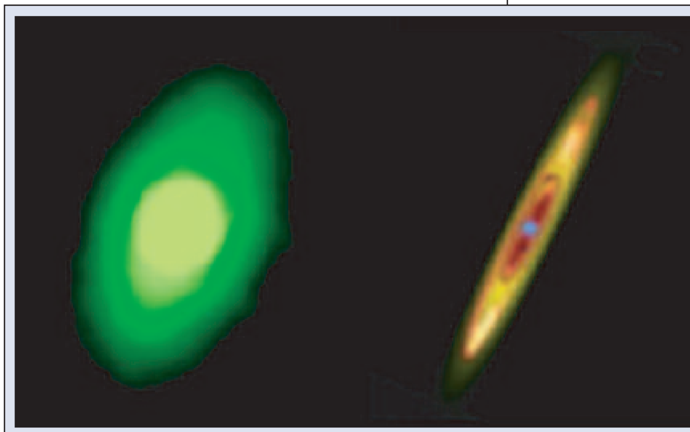


Figure 3: MIRI brings unique capabilities to observing nearby planetary systems. In this illustration, the *Spitzer* image at 24 μm of the nearby debris system around Fomalhaut (left) shows for the first time the warm diffuse dust within 100 AU of the star. The projected MIRI image (right) is based on a dynamical model of the similar Vega system. It shows two massive planets, and clearings in the debris system they have created, as well as resonant structures in the outer debris system also maintained by these planets.

Design of MIRI

Figure 4 shows the overall layout of MIRI. The carbon-fiber-reinforced-plastic (CFRP) hexapod legs isolate the instrument from the *Webb*-integrated science instrument module. A solid hydrogen cryostat (not shown) is used to cool the instrument and focal planes to ~7 K.

The telescope focal plane is divided to feed both the imager and the spectrometers. A portion of the imager focal plane is used for the coronagraphs and for the slit for the low-resolution

MIRI from page 13

spectrometer. The low-resolution spectrometer operates by inserting a zero-deviation dispersing prism into the beam. Three of the coronagraphs are based on quadrant phase plates, which allows observation arbitrarily close to the central object (at reduced rejection). The rejection of the light from the central source with these devices is similar to that with classical occulting coronagraphs far enough from the field center that either approach can be used. Because the phase plates are not achromatic, these three devices have only about a 10% spectral range each. The fourth (operating at 24 μm) is a classical occulting device.

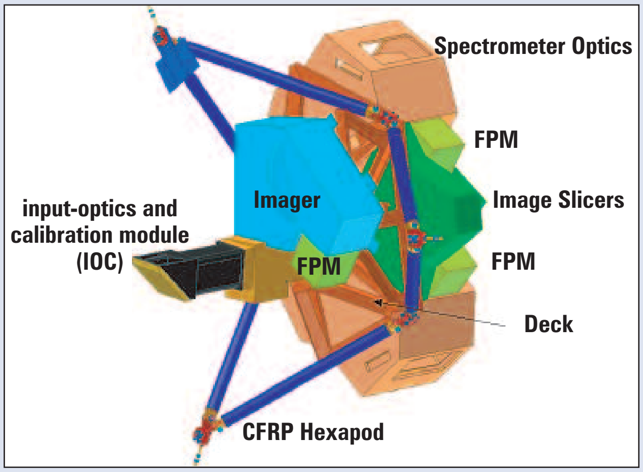


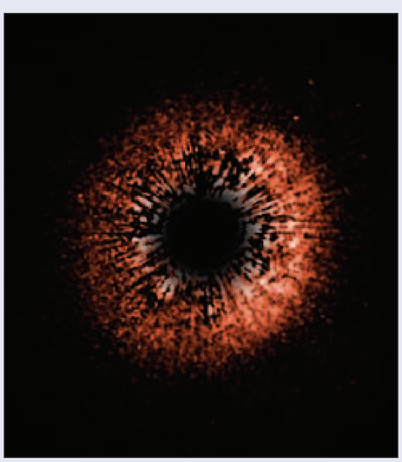
Figure 4: Overall design of the MIRI. Light is received from the telescope by a pick-off mirror in the input optics and calibration module.

The fore-optics for the moderate-resolution spectrometer divide the light in the field spectrally into four ranges, using dichroic filters. An IFU optimized for each wavelength range slices the image of the field and delivers it to the spectrometer optics. The IFUs have total fields ranging from 3.5 x 3.5 arcsec (at the short wavelengths) to 7 x 7 arcsec. These fields are co-aligned, so a single set of spectra applies to the same pointing on the sky. The spectrometer has four sections; the outputs of two spectrometer sections are brought to a single detector array. Each spectrometer section has three gratings, and all the gratings are operated at fixed angles so they can be brought into the beam on simple rotary actuators. The dispersions and blaze angles are selected to give a full spectrum from 5 μm to the cutoff of the detectors at 28–29 μm in three exposures.

The MIRI focal planes are Si:As impurity band conduction devices similar to those being used successfully on *Spitzer*, but much larger. They are of 1024 x 1024 format with read noise of $<$ 20 electrons. They have quantum efficiency $>$ 50% between 5 and 27 μm.

More information about the MIRI is posted at **http://ircamera.as.arizona.edu/MIRI**. Ω

[1] MIRI draws on the expertise of the following organizations: Ames Research Center, USA; Astron, Netherlands Foundation for Research in Astronomy; CEA Service d'Astrophysique, Saclay, France; Centre Spatial de Liège, Belgium; Consejo Superior de Investigaciones Científicas, Spain; Danish Space Research Institute; Dublin Institute for Advanced Studies, Ireland; EADS Astrium, Ltd., UK; Institute d'Astrophysique Spatiale, France; Instituto Nacional de Técnica Aerospacial, Spain; Institute of Astronomy, Zurich, Switzerland; Jet Propulsion Laboratory, USA; Laboratoire d'Astrophysique de Marseille (LAM), France; Lockheed Advanced Technology Center, USA; Max-Planck-Insitut für Astronomie (MPIA), Heidelberg, Germany; Observatoire de Paris, France; Observatory of Geneva, Switzerland; Paul Scherrer Institut, Switzerland; Physikalishes Institut, Bern, Switzerland; Raytheon Vision Systems, USA; Rutherford Appleton Laboratory (RAL), UK; Space Telescope Science Institute, USA; Toegepast-Natuurwetenschappelijk Ondeszoek (TNO-TPD), Netherlands; U.K. Astronomy Technology Centre (UK-ATC); University College, London, UK; University of Amsterdam, Netherlands; University of Arizona, USA; University of Cardiff, UK; University of Cologne, Germany; University of Groningen, Netherlands; University of Leicester, UK; University of Leiden, Netherlands; University of Leuven, Belgium; University of Stockholm, Sweden, Utah State University, USA.



Hubble Captures Evolving Planetary System

This is a false-color view of a planetary debris disk encircling the star HD 107146, a yellow dwarf star very similar to our Sun, though it is much younger (between 30 and 250 million years old, compared to the almost 5 billion years age of the Sun). The star is 88 light-years away from Earth. This is the only disk to have been imaged around a star so much like our own.

http://hubblesite.org/newscenter/newsdesk/archive/releases/2004/33/

Image Credit: NASA, ESA, D.R. Ardila (JHU), D.A. Golimowski (JHU), J.E. Krist (STScI/JPL), M. Clampin (NASA/GSFC), J.P. Williams (UH/IfA), J.P. Blakeslee (JHU), H.C. Ford (JHU), G.F. Hartig (STScI), G.D. Illingworth (UCO-Lick) and the ACS Science Team.

News from the Multi-mission Archive at Space Telescope

R. Somerville, *somerville@stsci.edu*, **for the MAST team**

As of November 1, 2004, the archive contained over 20 Terabytes of data (21.2 Tb). Over the past three months, an average of about 13 Gb per day of new data have been archived at MAST, and about 43 Gb of data per day on average have been retrieved. Median retrieval times for *Hubble* and *Far Ultraviolet Spectroscopic Explorer* (*FUSE*) data have remained at around 0.7 hours (1.4 hours for on-the-fly recalibration requests, 0.5 hours for others).

New look for MAST web interface

We have updated the MAST web pages to make the site more attractive and easier to use. We have applied a more consistent page layout from mission to mission and have created a tutorial page to explain how to use the site and where to find things. We welcome your comments on the new site. Please send them to *archive@stsci.edu*.

MAST distributes the first full public release of *GALEX* data

MAST began distributing data products from the *GALEX* (*Galaxy Evolution Explorer*) satellite in late November of 2004. This distribution continued with four sub-releases through December 2004. The first sub-release, called “GR1a,” consisted of image products for the Medium Imaging Survey and Nearby Galaxy Survey. Subsequent sub-releases GR1b-d included image products from the All-sky Imaging Survey (GR1b) and Deep Imaging Survey (GR1c). Release GR1d consisted of spectroscopic products for the Medium and Wide Spectroscopic Surveys. Users can access *GALEX* data from the MAST website at **http://galex.stsci.edu**. Click on “Search” on the left menu to initiate a search using either a “MAST-style” search form or a customized search form based on structured query language (SQL). You can download data file by file via your browser or, for an entire dataset, via ftp (file transfer protocol). MAST plans to release refined search and cross-correlation tools for *GALEX* early in 2005.

Virtual observatory news

Institute staff continue active participation in National Virtual Observatory (NVO) development activities. In September 2004, we led the organization of the first NVO Applications Software Development Summer School, in which 40 graduate students, post-docs, and software developers spent a week learning about NVO tools and technology at the Aspen Center for Physics. We also successfully proposed for a special session on NVO-enabled research at the January 2005 American Astronomical Society (AAS) meeting in San Diego. The proposed agenda included several talks featuring results from student projects at the summer school. The San Diego AAS meeting was also chosen as the venue for the NVO project’s first substantial public software release (details at **http://us-vo.org**). NVO developments were featured in many of the talks and posters at this year’s ADASS Conference (October, Pasadena), including new VO-compatible features of MAST. International VO collaboration centered on the “interoperability” meeting held in Pune, India, in September. Ω

The Caroline Herschel Visitor Program

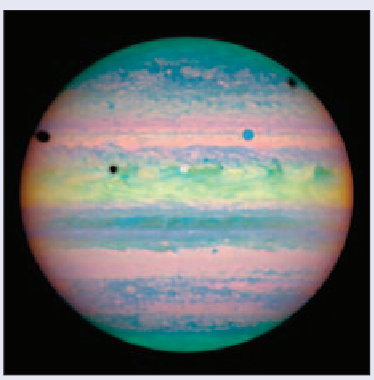
A. Nota, *nota@stsci.edu*

Caroline Herschel was an extraordinary woman of science. In her honor, the Space Telescope Science Institute has created the Caroline Herschel Visitor Program to enhance the representation of women and minority colleagues at the Institute. This program has been designed with two goals in mind: providing a stimulating and productive environment for distinguished women and minority scientists to spend time at the Institute working and lecturing on their scientific projects and providing active mentoring to the Institute's junior scientists, especially women and other underrepresented groups.

The Caroline Herschel Visitor Program is intended for distinguished women and minority scientists from the international astronomical community who are committed to mentoring junior colleagues. We will offer them a scientific base for a sabbatical period or long research leave, typically 1–3 months. We will invite them to participate fully in the life of the Institute, including events organized by our mentoring program and membership in short-term committees.

We believe the Caroline Herschel Visitor Program will bring fresh perspectives from other international institutions to the Institute and provide benefits both to the visitors and the Institute scientific staff as a whole. We are delighted to report that the program has already generated considerable interest.

The Institute will host the first Caroline Herschel Visitor in spring 2005. If you are interested, please contact the Science Division Head, Antonella Nota (*nota@stsci.edu*). Ω



Hubble Spots Rare Triple Eclipse on Jupiter

At first glance, Jupiter looks like it has a mild case of the measles. Five spots—one colored white, one blue, and three black—are scattered across the upper half of the planet. Closer inspection by NASA's *Hubble Space Telescope* reveals that these spots are actually a rare alignment of three of Jupiter's largest moons—Io, Ganymede, and Callisto—across the planet's face. In this image, the telltale signatures of this alignment are the shadows [the three black circles] cast by the moons. Io's shadow is located just above center and to the left; Ganymede's on the planet's left edge; and Callisto's near the right edge. Only two of the moons, however, are visible in this image. Io is the white circle in the center of the image, and Ganymede is the blue circle at upper right. Callisto is out of the image and to the right.

http://hubblesite.org/newscenter/newsdesk/archive/releases/2004/30/

Image Credit: NASA, ESA, and E. Karkoschka (University of Arizona)

Caroline Lucretia Herschel

J. J. O'Connor and E. F. Robertson[1]

Caroline Herschel was the daughter of Isaac Herschel and Anna Ilse Moritzen. She was the sister of William Herschel. Caroline's father was a man with no formal education, who tried hard to give his four sons and two daughters a good education in music, philosophy and astronomy. Caroline's mother disapproved of learning in general and although she reluctantly accepted that her four sons should have some education, she strongly opposed her daughters doing anything other than the household chores.

After the French occupation of Hannover, Germany, in 1757, Isaac was occupied fighting the French and so was not at home. William escaped to England, where he became a music teacher, and Caroline was left under the control of her mother, who kept her fully occupied with household chores. In 1760, Isaac returned home in poor health and Caroline essentially lived the life of a servant until he died in 1767. The death of her father seems to have made Caroline realize that she had to take some control of her own life.

In 1766, William became an organist in Bath, and in 1772, Caroline joined him there. Caroline had always been very close to her brother William and, after arriving in Bath, she trained as a singer, receiving lessons from her brother. William taught Caroline more than musical skills. He began to teach Caroline English and mathematics, while he himself became more and more involved with astronomy.

Caroline helped William with his musical activities and looked after him while he spent many hours with his new hobby constructing telescopes. Slowly, Caroline turned more and more towards helping William with his astronomical activities, while he continued to teach her algebra, geometry, and trigonometry. In particular, Caroline studied spherical trigonometry, which would be important for reducing astronomical observations.

Astronomy changed from a hobby to a profession for William in 1781 when he achieved fame by discovering the planet now named Uranus. King George III gave William a £200 per year salary, which was less than generous, but sufficient to allow him to become a full-time astronomer. William gave Caroline a telescope with which she began to make observations, in particular searching for comets by making methodical sweeps of the sky.

Caroline found much less time than she expected to make her own observations, as she became fully involved helping William with his astronomical projects. By day Caroline would work on the results obtained from William's observations of the previous night. She carried out the lengthy calculations necessary to reduce William's data with remarkable accuracy. In fact, only when William was away from home was Caroline able to spend much time with her own program of research. On 1 August 1786, Caroline discovered her first comet, which was described by some as the "first lady's comet." This discovery brought Caroline a certain degree of fame, and articles were written about her. In 1787, King George III gave Caroline a £50 per year salary as assistant to William. In total, Caroline discovered eight comets between 1786 and 1797. She then embarked on a new project of cross-referencing and correcting the star catalogue, which had been produced by Flamsteed.

Caroline returned to Hannover after William's death in 1822. During his lifetime, all her energies had been directed towards helping her brother in his astronomical work, but now she turned to help his son, John Herschel. Certainly this help was not given in the same way as a personal assistant, but rather now as independent researcher producing a catalogue of nebulae to assist John in his astronomical work. She completed her catalogue of 2,500 nebulae and, in 1828, the Royal Astronomical Society awarded her its gold medal for this work.

She was now a celebrity in the world of science and many scientists, including Gauss, visited her. Caroline Herschel received many honors for her scientific achievements. Together with Mary Somerville, she was elected to honorary membership of the Royal Society in 1835 as the first honorary women members. She was also elected a member of the Royal Irish Academy in 1838. A minor planet was named Lucretia in 1889 in Caroline Lucretia Herschel's honor—a fitting tribute to one who had contributed so much, yet had so little personal ambition that she disliked praise directed towards her, lest it detract from her brother William. Ω

[1] Adapted from **http://www-groups.dcs.st-and.ac.uk/~history/Mathematicians/Herschel_Caroline.html** with the permission of the authors.

HUBBLESITE *hubbub*

Comments pulled from the HubbleSite mailbag.

"This is just so informative, and the photo gallery is amazing. Thank you for providing this site. I will recommend it to any of the students at the school where I work." ***-Anonymous***

"Why can't we send the Hubble to a new sight, like Mars or Venus. Or even farther out in space?" ***-Anonymous***

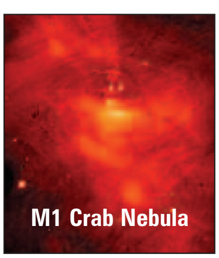
"WOW!! So much information and all the images to boot! I can't think of any better way to keep the public at large engrossed in astronomy than by keeping an archive of the most awe inspiring images at their fingertips AND providing clear, concise information about them while still keeping the explanations non technical." ***-South Africa***

With more than a million visitors a month, HubbleSite.org issued to a steady stream of e-mail from the public. People take time to express admiration for the images, pose science questions, and offer their own theories about the cosmos.

"Fascinating! I simply love your website, especially the video corner. I am charmed by the Orion Nebula movie clip." ***-Anonymous***

"I am 57 years old, and it is my hope and desire that the Hubble, that Greyhound Bus in the sky, continues to share its bounty with us and our youth. One day, I hope they will understand just how fortunate they are to those of you who had the knowledge, skills and dedication to present such a gift to the world." ***-Anonymous***

"Is it just me or does there appear to be the bust of a person or skeleton wearing a large antique hat and a toothy smile right in the middle of this image?" ***-Anonymous***



A Baby Galaxy in a Grown-Up Universe

Scientists using NASA's *Hubble Space Telescope* have measured the age of what may be the youngest galaxy ever seen in the universe. By cosmological standards it is a mere toddler, seemingly out of place among the grown-up galaxies around it. Called I Zwicky 18, it may be as young as 500 million years old (so recent an epoch that complex life had already begun to appear on Earth). Our Milky Way galaxy by contrast is over 20 times older, or about 12 billion years old, the typical age of galaxies across the universe. This "late-life" galaxy offers a rare glimpse into what the first diminutive galaxies in the early universe look like.

http://hubblesite.org/newscenter/newsdesk/archive/releases/2004/35/

Image Credit: NASA, ESA, Y. Izotov (Main Astronomical Observatory, Kyiv, UA) and T. Thuan (University of Virginia)

Contact STScI:

The Institute's website is: `http://www.stsci.edu`

Assistance is available at *help@stsci.edu* or 800-544-8125. International callers can use 1-410-338-1082.

For current *Hubble* users, program information is available at:

`http://presto.stsci.edu/public/propinfo.html`.

The current members of the Space Telescope Users Committee (STUC) are:

David Axon, RIT	Karen Meech, IfA
Martin Barstow, U. of Leicester	Peter Nugent, LBL
Martin Elvis, Harvard-Smithsonian	C. Robert O'Dell, U. Vanderbilt
Debbie Elmegreen (chair), Vassar C.	Regina Schulte-Ladbeck, U. Pittsburgh
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To record a change of address or to request receipt of the Newsletter, please send a message to *address-change@stsci.edu.*

Space Telescope European Coordinating Facility

ST-ECF Newsletter

The Space Telescope—European Coordinating Facility publishes a newsletter which, although aimed principally at European Space Telescope users, contains articles of general interest to the *HST* community. If you wish to be included in the mailing list, please contact the editor and state your affiliation and specific involvement in the Space Telescope Project.

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