VOL [23] ISSUE [02]

NEWSLETTER

Space Telescope Science Institute

The Institute Hosts a Workshop

Matt Mountain, *mmountain@stsci.edu*

Image Credit: Lick Observatory

On November 28–30, 2006, the Institute will host a workshop on astrophysics enabled by NASA's plans to return to the Moon in the next decade. The *stated* issue is whether the exploration initiative poses an opportunity for progress on important problems in astrophysics. The *unstated* question is about the ongoing relationship between space science and human exploration of space: What are the true terms, values, and risks of this relationship? The astronomical community has been challenged to formulate the best possible answers to those underlying questions.

This edition of the Newsletter contains two invited opinion pieces on the issue from Riccardo Giacconi and Bernard Burke. It also reprints an article by Martin Harwit, in which he addresses a relevant question: "How did we get to be so lucky?" The overall goal is to foster reflection on why this workshop is important and timely.

Because of the Institute's unique experience with *Hubble*—an epitome of the scientific benefits of human spaceflight and technologies developed for other purposes—it is both an obligation and a privilege for us to conduct this open, objective discussion about the possibilities for astrophysics enabled by a NASA's commitment to return to the Moon, Mars, and beyond.

In April 1990, the *Space Shuttle Discovery* blasted off from Kennedy Space Flight Center carrying the *Hubble Space Telescope* to orbit. So began a historic and somewhat controversial ride along a tremendous journey of discovery. Today, *Hubble* is an integral part of the modern scientific landscape, serving a community of roughly 7,000 astronomers worldwide, having produced over 5,000 papers in refereed journals, and, in 16 years, having dispensed over $300 million in grants and fellowships. For the public, *Hubble* has become an icon of modern science. What other telescope in history has its images on postage stamps, U-Haul trucks, rock albums, and the walls of almost every school?

Hubble's long journey from Lyman Spitzer's imagination in 1946 to instrument and icon in 2006 would never have been possible without major technical contributions from national programs that the science budget could never afford, including subsidized space transportation, optical and detector technologies, and servicing by astronauts to repair spherical aberration, replace failed hardware, and upgrade instrumentation.

As we look forward to the next decade, or perhaps more importantly, the next Decadal Survey of Astronomy and Astrophysics, are we confident we can "go it alone" in pursuit of our visions—imaging earths around other stars, watching the detailed plight of matter falling into black holes, and hunting for gravitational waves from the Big Bang? If the space science budget is limited—and it obviously is—then only a few endeavors can afford to develop their own technologies and infrastructures. The remainder must adapt to available opportunities, or wait indefinitely in the antechambers of funding. As Martin Harwit concluded, "We cannot, except in rare cases of uncommon importance, ask for support of missions that require capabilities which significantly outstrip commonly available military or industrial capacities."

If the return to the Moon is an opportunity for astronomy, and the science sufficiently compelling, perhaps we can influence aspects of NASA's exploration architecture to help some of our ambitious future science missions become more likely. Ω

FALL [2006]

Astronomical Observatories on the Moon

Riccardo Giacconi

I have been asked to comment briefly on the potential significance of lunar exploration to astronomy. Most of the arguments that I have had the opportunity to read in favor of lunar astronomical observatories are not based on scientific requirements that can be uniquely achieved on the Moon, but rather on arguments of convenience, continuity, serviceability, and cost(!). It is asserted that once a human habitat infrastructure is available on the Moon, astronomical observatories could easily be brought there, or even built there, at low cost. The similarity of these arguments to those we heard in the past concerning the *Space Shuttle* and *International Space Station* (*ISS*) is frightening.

I believe that to answer the question of utilization of a lunar base, one must consider the NASA program as a whole. Most people would agree that NASA has historically been given two tasks: manned exploration of the Solar System and study of the universe by space-borne instrumentation.

It is interesting to note that NASA has invested one-third of its total budget in research—more than the rest of the world combined—and has achieved its greatest successes in planetary robotic exploration and in astronomy. The opening up of new observational windows unimpeded by the absorbing and scattering effects of the atmosphere has contributed to some of the most significant advances in astronomy of the last 50 years.

The other side of NASA's mission—of extending man's presence in the Solar System—has not made significant progress since the Moon landings of the *Apollo* program from 1969 to 1972.

The *Shuttle* program and the *International Space Station* have finally been recognized for the dead ends they are. In fact, the main achievement of the *Shuttle* program has been to service and upgrade the *Hubble Space Telescope*. While a wonderful contribution in itself, it is scarcely an advance in our ability to get to Mars and establish a human base there—the implicit or explicit goal of the manned space program. In fact, very little has been learned in the *Shuttle* or *ISS* programs about the main issues regarding a flight to Mars, such as development of launch vehicles, potential mission profiles, and crew issues, such as long-term exposure to radiation and low gravity.

Since Mars is the most plausible place in the Solar System—it is reachable by humans and offers *in situ* resources to support a permanent base—it should be the goal of our exploration program for the foreseeable future. The limited resources of the NASA manned program should be expended only on items that are programmatically required to achieve this goal. From this point of view, I see the lunar base as a new potential dead end—essentially an *ISS* in a higher and stable orbit—but not contributing significantly to a Mars mission. The argument of possible scientific usefulness to bolster its acceptance in Congress is as devoid of meaning as were the arguments for *ISS*.

The enthusiasm of scientists to take advantage of the "Moon infrastructure" to carry out astronomical observations should be measured competitively and in terms of real costs within the science budget. I would be dismayed if a lunar observatory were to have high priority in the next National Academy of Science's Decadal Astronomy Survey. Ω

Astronomy from the Moon?

Bernard F. Burke, *MIT*

The drivers for the next generation of optical instruments are clear: more collecting area, broad-spectrum coverage, and higher angular resolution. The scientific goals are fundamental, but the technical demands are challenging. Large telescopes are absolutely necessary to gather the trickle of photons from the earliest condensations in the young universe after the era of the cosmic microwave background. *Hubble* has demonstrated the importance of angular resolution for a vast range of astronomical problems, from the study of how planetary systems condense and evolve to the eventual study of Earth-like exoplanets. On the ground, European planning started with an instrument 100 meters in diameter—but it is now shrinking as reality sets in. The American planning target, 30 meters, may well be revised downward. Soon to be in space, the *James Webb Space Telescope* is at an advanced planning stage; at six meters in diameter, it is already proving to be a challenge. As yet, there are no definitive plans for imaging interferometer arrays in space, largely because the technical challenges have been recognized. However, this is a direction that must ultimately be taken.

Planning for a new generation of telescopes should start now, because the thrust toward greater instrumental capability brings with it a set of problems that must be faced: possible failure due to complexity. In this light, a comprehensive comparison of the relative advantages of orbiting telescopes versus lunar-based instruments would be wise. At present, the general attitude of the astronomical community toward instruments on the Moon is "Hell, no, we won't go!" A human presence on the Moon may change this attitude. It is not at all clear that a large, complex instrument at L2 will be more reliable than a human-serviceable instrument on the lunar surface, nor is it clear how much a suite of robots, operating with a three-second time delay, will add to the cost, when compared to the human interaction on the Moon.

After a review of the literature available so far, I have to report that quantitative studies, which address lunar bases in a realistic, comparative way, have not yet been carried out. ESA sponsored a comparative study of optical interferometers, but it only addressed automated instruments. The conclusion—that the Moon presented many uncertainties without offering significant advantages—was correct, in my view, but it did not specifically address the effect of human servicing. The American studies so far have mostly been PowerPoint projects—a start, perhaps, but too speculative to be a justification. On the other hand, the objections to a lunar instrument by orbital enthusiasts have had much the same quality: the dreadful lunar dust (even though the retroreflectors continue to serve well after 30 years of exposure); the fearful moonquakes (ignoring the seismic data that demonstrates that these pose no problem); and the insidious condensing volatiles (most unlikely to be a problem, given the tenuous exosphere of the Moon). There have even been mutterings about lunar gravity, even though that is more likely to be a help than a hindrance.

The experience of the astronomical community with the *International Space Station* has certainly soured the atmosphere between scientists and the manned space flight program. It does not necessarily follow that the same will be true for the future. The political reality is that the Moon is once more a target for exploration. The Exploration Mission Directorate of NASA has established a Lunar Precursor and Robotics Program; this primarily addresses the next ten years or so, preparing the way for a renewed human presence on the Moon. Other nations are joining the lunar club: in addition to the European Space Agency, China, Japan, and probably India, all have mission planning under way. Planetary scientists are making plans to take advantage of the new climate to resume the work on hiatus from 30 years ago. The near-term prospects for astronomy lie with orbiting instruments, but this is the right time to consider what may be possible once the human presence is reestablished on the Moon. Ω

Instrumentation and Astrophysics: How Did We Get to Be so Lucky?

Martin Harwit, *Cornell University*

This has been a fabulous conference, showing the enormous influence that instrumentation is having on the directions we are currently pursuing in astronomy. To see where the future might take us, I thought I might review how we got to be where we are now—how we got to be so lucky.

1. A Golden Age

The exciting discoveries of recent decades have come about through a wealth of new techniques. As we built instruments of ever-greater acuity, we stumbled upon a dazzling range of phenomena that revealed a Universe rich beyond anything we could have imagined. Gamma rays displayed the most violent outbursts witnessed in the Universe. X-rays led to the discovery of extremely hot ionized gases pervading clusters of galaxies. Infrared radiation showed the existence of galaxies undergoing huge bursts of star formation, while radio telescopes revealed radiation emitted long ago, when the Universe was thirty thousand times younger than today (Harwit 1981).

In the spirit of these successes, we press on, knowing that we must continue to probe the Universe in as many ways as we can, to whatever depth we are able. This is the spirit of this conference—it is why we are here. If we knew more about the Universe, we might take a different, more targeted approach, guided to key truths by astrophysical theory. But we know we cannot. Our theorists are supposed to be our bodyguards, protecting us against cosmic surprises. In this we know they are failing. Instead of relying on them, we have opted, rather, for an increasingly heavy barrage of instrumentation to conquer the Universe—a massive straightforward extrapolation of the approach that yielded so many great advances in recent decades. The question is, "Will this approach succeed?" To answer this, we may look at the history of other straightforward extrapolations.

2. Jules Verne

Over the weekend of March 20, 1999, Bertrand Piccard and Brian Jones completed the first circumnavigation of the Earth by balloon. Most remarkable was its prediction a century and a quarter earlier. In 1873, when Jules Verne wrote *Around the World in Eighty Days*, ballooning seemed the most obvious way for flying around the world. Today the flight of the Breitling Orbiter-3 is considered more of a stunt. After 1903 and the flight of the Wright brothers, the airplane took over. Aeronautics underwent a discontinuity. Predictions about the balloon's technological future suddenly were all wrong. The balloon had given way to the airplane.

When we went to the Moon, a flight that Jules Verne had predicted even earlier, in 1865, it involved another discontinuity. Verne wanted to launch his spacecraft with a cannon. The actual flight required rockets—an entirely new technology which had the merits of sufficiently low g-forces that astronauts could survive. The barrel of a cannon to launch humans into space with an accelerating force as low as a tolerable 2g would be a surprising two thousand miles long—perhaps possible, but unwieldy in practice. The cannon had given way to the rocket. The desire to go to the Moon had stayed the same.

Going ahead just as always in the past is not invariably the easiest approach. What is more important is keeping one's ultimate goals clearly in sight, and then taking the technological path of least resistance. Jules Verne had laid out the goals. We just followed a different path—an important lesson to keep in mind.

So much for extrapolation. But there is also a matter of cost.

3. Cost

When our colleagues in high-energy physics began constructing the Superconducting Supercollider, they were extending previously successful accelerator technology. By the time the project was stopped, a huge circular tunnel many miles long had been dug beneath a Texas landscape. Was this their equivalent of a 2000-mile cannon barrel? I have the greatest respect for these physicists. We need to heed their plight to avoid their fate.

The natural question for us becomes, "How much further can present trends in astronomy, and their projections now before the current U.S. "Decadal Review," be continued into the future before we, too, are turned back?"

Astronomical missions that cost more than two billion dollars are beyond the limits of even international collaborations. Yet some of the more ambitious

Continued page 9

ACS Status

Ken Sembach, *sembach@stsci.edu*

The Advanced Camera for Surveys (ACS) is operating normally after a brief hiatus due to a failure in an electronics box this summer. ACS activities were suspended on June 19, 2006, and resumed using backup electronics on July 2. An anomaly review board was established to determine the cause of the problem. The board found that the most likely culprit was a component on a circuit board in one of the low-voltage power supplies that power the ACS's CCD detectors. After the switchover to the backup electronics, the ACS is fully functional, operating as expected, and still delivering the superb image quality expected by the science community and general public.

Images taken immediately after resumption of science activities confirm that the ACS is operating as expected and sending back detailed images of objects in both the distant and nearby universe. (See Figs. 1 & 2.)

As part of the reactivation of ACS, the temperature set-point of the Wide Field Channel (WFC) CCD was lowered from –77° C to –81° C. This change reduced the number of hot pixels and the dark current in the WFC images, improving image quality and the detectability of faint objects. The ACS team is conducting calibrations to fully characterize the instrument in its new state, and is updating the ACS data pipeline as the analyses are completed.

Observers should consult the ACS website (**http://www.stsci.edu/hst/acs/**) for the most recent information on instrument performance, including instrument science reports (ISRs) that describe the calibration results in detail. Recent ISRs include (1) new information about relative astrometry within ACS visits, (2) policies and procedures for targets subject to unpredictable outbursts when using the Multi-Anode Microchannel Array detectors, (3) wavelength and flux calibrations of the PR130L and PR200L prisms, and (4) effective point-spread functions for WFC photometry.

We are pleased to announce the availability of a new web-based ACS bulletin board, which we hope will make it easier for observers to share and find information about constructing ACS observations and analyzing ACS data. The bulletin board can be accessed from the ACS website. Ω

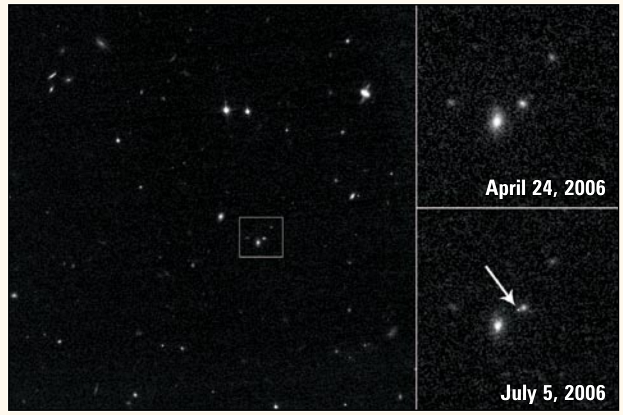


Figure 1: Supernova images from April and July 2006, illustrating the ACS is fully restored and operating normally. *Hubble* periodically revisits about 20 distant galaxy clusters on a cosmic "fishing trip" to find Type Ia supernovae (Perlmutter: GO–10496). Left: a rich galaxy field containing a cluster of galaxies 9 billion light-years away (redshift $z = 1.4$). In April 2006, no supernova is evident in the field. Lower right: In July 2006, ACS images a supernova in a field galaxy 1 billion light-years closer ($z = 1.2$) than the cluster.

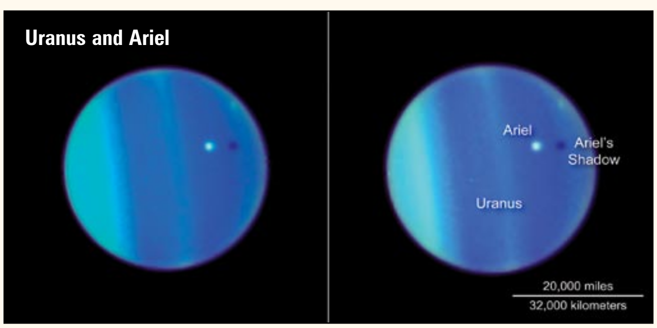


Figure 2: A July 2006 ACS image of a moon of Uranus traversing the face of the planet accompanied by its shadow. The white dot is the icy moon Ariel, which is 700 miles in diameter. The moon is casting a shadow onto the cloud tops of Uranus (black dot). Such transits are rare for Uranus because its spin axis and the poles of the orbits of its moons lie nearly in the planetary orbital plane. As a result, the necessary configuration for transits—satellite orbits aligned edge-on to the Sun—occurs only every 42 years.

Update on STIS Data Enhancement Program

Paul Goudfrooij, *goudfroo@stsci.edu*

After the Space Telescope Imaging Spectrograph (STIS) became inoperative in August 2004, the Institute's STIS team established a "data enhancement program," which was endorsed by the Space Telescope Users Committee and the *Hubble* project at NASA's Goddard Space Flight Center. The focus of the program is to finalize the calibrations and documentation and ensure that the archive of existing STIS data is suitable for high-level, high-accuracy science. A detailed description of the program is available through the STIS instrument website at **http://www.stsci.edu/hst/stis** under "STIS Closeout Calibration." The STIS team and the Archive Branch at the Institute will also enhance the retrieval of STIS data from the *Hubble* archive after the STIS data have been fully recalibrated and stored.

Most calibration aspects of the data enhancement program are finalized and implemented in the on-the-fly-recalibration (OTFR) pipeline. Observers interested in the details of a particular calibration should consult the STIS website for the most up-to-date information, including instrument science reports (ISRs) and other items in the document archive, such as Space Telescope Analysis Newsletters (STANs). The following is a summary of recent calibration updates, with references.

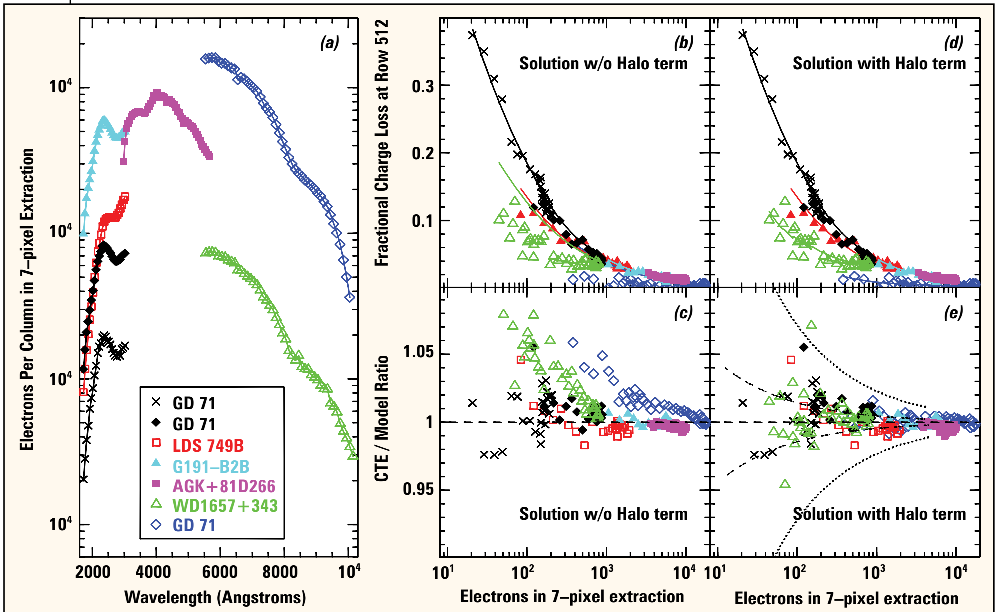


Figure 1: The impact of the new CTE correction algorithm for STIS CCD spectra. Panel (a): Smoothed flux standard star spectra used to determine the functional form of the CTE loss of the STIS CCD in spectroscopic mode. The legend links the symbols with the standard stars used. Panel (b): Fractional charge loss at the central row of the CCD versus extracted signal level. Symbols as in panel (a). The smooth curves represent the predictions of the previous CTE model for those data. Panel (c): The ratio of measured CTE values and the model predictions shown in panel (b) versus signal level. Panel (d): Same as panel (b), but now using the new CTE model. Note the much better fit to the green and dark blue symbols (i.e., the data beyond 7500 Å). Panel (e): Same as panel (c), but now using the new CTE model. For reference, the dashed lines represent the uncertainty due to Poisson noise associated with the binned spectra shown in panel (a) as a function of signal level, while the dotted lines represent the Poisson error associated with a resolution element of unbinned spectra.

- A revision of the correction for imperfect charge transfer efficiency (CTE) for spectroscopic CCD data, including treatment of the effect of the extended point-spread function in the red part of the spectrum. Note that the amplitude of CTE loss can be quite significant for STIS CCD spectra of faint sources: losses of 10–25% are not uncommon, especially during the last few years of STIS operations. The new CTE algorithm calibrates the STIS flux with a precision within about 1.5% over the full wavelength range covered by the spectroscopic CCD modes. This means that the flux precision of calibrated STIS CCD spectra is now limited by Poisson noise, *not by CTE loss* (ISR 2006-01 and ISR 2006-03). The impact of the new CTE algorithm is illustrated in Figure 1.

- A significantly improved flux calibration for the STIS objective prism mode (ISR 2005-01).
- A calibration of wavelength-dependent aperture corrections for the first-order, low-resolution charge-coupled device (CCD) spectroscopic modes, when used with slits less than two arcsec wide (STAN 2005-12).
- A full revision of the flux calibration for the first-order, medium-resolution spectroscopic modes (ISR 2006-04).
- A determination of the spectroscopic point-spread function across the spectrograph slit for the first-order CCD modes (ISR 2006-02).
- A final revision of the wavelength-dependent time dependence of the sensitivities of the first-order spectroscopic modes and the imaging modes (STAN 2006-10).
- A verification of the quality of the dispersion solutions for the first-order spectroscopic modes that use the CCD or the far ultraviolet Multi-Anode Multichannel Array detectors.
- New and comprehensive flux calibrations for the echelle modes of STIS. This includes updates for wavelength-dependent aperture corrections, wavelength-dependent time dependence of the sensitivity, order-dependent spectrum extraction locations, a correction for offsets of the mode-select mechanism and echelle grating, and their associated blaze shifts. (STAN 2006-10). The significant improvement of the new echelle flux calibration is illustrated in Figure 2.

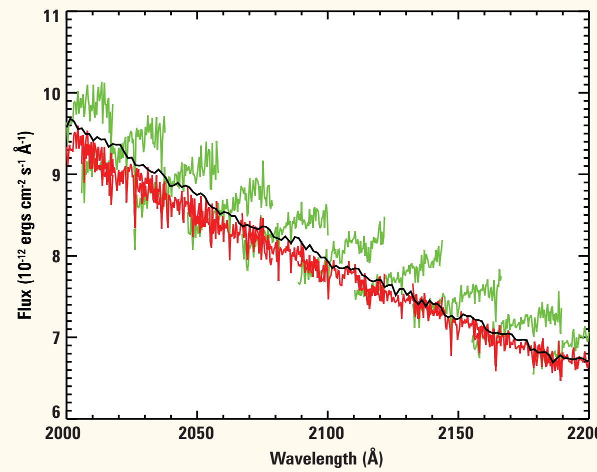


Figure 2: Illustration of the significant improvement allowed by the new Echelle flux calibration. The figure shows a spectrum of a flux standard star observed in May 2004 using the E230M grating at central wavelength 1978 Å. The spectrum calibrated with the old blaze shift correction is shown in green. Note the ~10% flux offset between adjacent orders. The spectrum calibrated with the new blaze correction is shown in red, which reduces this error to less than about 1%. For reference, the spectrum of this star was taken with the Faint Object Spectrograph and is shown in black.

- A major update to the trace table reference files for all three detectors within STIS. (Trace tables describe the shape of the projection of point-source spectra onto the detector.) The new trace tables include a correction for a recently discovered slow rotation of the traces with on-orbit time (STAN 2006-10).
- New software that incorporates an improved interpolation algorithm for the extraction of one-dimensional spectra from spatially resolved two-dimensional data. The new algorithm is based on wavelet interpolation, and can significantly reduce the amplitude of the "scallop-like" features that arise in extractions of spectra with a spatial coverage of only a few CCD pixels along the spectrograph slit, for grating modes in which the trace is tilted significantly relative to the CCD pixel array (STAN 2006-10).
- New software to correct relevant columns in photometry tables derived from STIS CCD imaging observations for the time-dependent effect of imperfect CTE (STAN 2006-10).
- A new set of association rules for STIS spectral data that did not have automatic wavelength calibrations made during the observations. A small subset of STIS data was taken in this mode, where principal investigators were allowed by the STIS team to insert their own wavelength calibration exposures in their Phase II proposal. Up to now, these so-called "GO wavecals" were not automatically associated with the corresponding science datasets during archive retrievals. These new associations have now been defined and will be made available in OTFR data over the next few months (STAN 2006-10).
- A new set of association rules for STIS data taken in the G750L and G750M spectral modes. Since these modes exhibit significant fringing (see ISR 1998-19), principal investigators were urged to insert so-called "fringe flat" exposures in their Phase II proposals. Up to now, these exposures were not automatically associated with the corresponding science datasets during archive retrievals. This association has now been enabled (STAN 2006-10).

The STIS team and the Archive Branch at the Institute have started a comprehensive effort to recalibrate all STIS data in the *Hubble* archive, using all calibration improvements implemented within the STIS data-enhancement program. When complete, the final set of calibrated STIS data will be stored in the *Hubble* archive.

The presence of a fixed archive of calibrated STIS data will have several benefits relative for the OTFR pipeline. For example, fully calibrated STIS data will be available for preview purposes. More data-retrieval processing power will be available for OTFR requests of the currently active *Hubble* instruments.

For answers to any questions regarding STIS, please send email to the Institute help desk at *help@stsci.edu*. Ω

Webb Status

Peter Stockman, *stockman@stsci.edu*

Since NASA revised the project plan a year ago, *Webb* has remained on schedule for a launch in June 2013.

Axsys Technologies has machined most of the 18 primary mirror blanks and sent them to Tinsley Laboratories for polishing—the last stage in the production cycle. The polishing process is slow, even with parallel lines operating at Tinsley, and includes cryogenic tests to ensure that the proper figure is reached at operating temperature. Polishing and testing all 21 blanks, including 3 spares, will take four years.

The scientific instrument teams are completing their critical design reviews. They have begun building engineering models for preliminary tests, and ordering parts with long lead times for the flight instruments, which will be delivered to NASA in 2009.

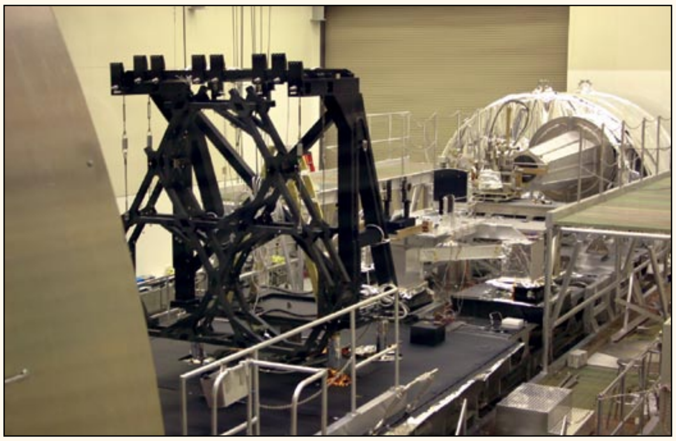


Figure 1: Prototype, three-segment portion of the *Webb* primary mirror backplane prior to cryogenic testing at the X-ray Calibration Facility at Marshall Space Flight Center. Each hexagon is approximately 1.2 m flat-to-flat.

NASA is verifying the performance of the new technologies for *Webb* under flight-like conditions. After enduring the strong acceleration, harsh vibrations, and acoustics of launch, followed by continuous exposure to radiation, cryogenic temperatures, and vacuum, *Webb*'s components and systems will have to function properly for ten years. The sunshield material and detector technologies (HgCdTe, Si:As) were verified in spring 2006. Over the summer, the primary mirror segments passed final testing, showing no permanent deformations after exposure to realistic vibrations and acoustics, while mounted in a flight-like structure. The electronics for the near-infrared detectors (HgCdTe) also passed. The programmable Multi-Slit Array (MSA) for the near-infrared spectrograph passed all except the acoustic tests, during which 5% of the slits jammed. Acoustic resonances in the membrane that supports the slits are the probable cause. The development team is pursuing two possible solutions—a finer support structure for the membrane and additional support only during launch—and will test these fixes in fall 2006.

In August 2006, Northrop Grumman Space Technology began to test the cryogenic stability of a 1/6th portion of the backplane for the *Webb* primary mirror (Fig. 1). The goal of this testing is confidence in the design and manufacturability of the full-scale backplane and the structure to support the instruments. The testing location is the X-ray Calibration Facility at Marshall Space Flight Center, which has been modified to provide temperatures below 30 K. In the initial phase, the test article was repeatedly cycled between room temperature, a holding temperature of 50 K, and the operating temperature of 30 K. The effect on piston distortion was monitored continuously, using a novel interferometer invented by Babak Saif at the Institute and 4-D Technology Corporation in Tucson, AZ. The interferometer is sensitive to distortions at the 5–10 nm level, with a bandwidth of 5 Hz. Preliminary analysis of the 14 TB of data accumulated in this testing indicates that the backplane sample successfully meets the stability criteria agreed upon by NASA and the independent optics review team.

Three other technologies must pass their verification tests by the end of 2006, with results to be reported at the non-advocate review of the *Webb* project in January 2007. Those technologies are cryogenic heat switches, wavefront sensing and control, and the cryocooler for the mid-infrared instrument.

When all these verification tests are completed satisfactorily, the project will have shown that the major technologies are in hand for the *Webb* mission. Ω enterprises we now have in mind will hit this barrier if we expect to launch them in the foreseeable future. The main downfall of the Superconducting Supercollider was its cost.

Many among us still remember LDR, the Large Deployable Reflector for submillimeter astronomy, proposed a couple of decades ago for launch into space. We still have not built it, and if we did, today, it would certainly still break the bank. It too was too costly for its time, with its 10- to 30-meter aperture, depending on who was talking, and its demanding technology. Our aims in submillimeter astronomy, however, have not been stopped by this setback. Our goals are still firmly in place. Submillimeter astronomy is healthy and going forward.

4. The Rise in Data Rates

A further challenge today is the enormous rise in data rates. We keep building increasingly large detector arrays, with higher sensitivities, dynamic ranges, and spectral, spatial, and time resolution. Many space missions now on the drawing boards could ideally use gigabyte per second transmission rates. But our telemetry systems are a thousand times slower. This is a real worry.

We speak with confidence of compressing data to reduce the transmission problem. On currently planned missions, the projected data gathering rates already exceed the transmission rate by one or two orders of magnitude. First we build an instrument to collect huge amounts of data, then we throw most of it away. Where observations are marred by varieties of cosmic-ray glitches or other unpredictable sources of noise, data compression is likely to be wasteful.

We speak with similar confidence about laser-based telemetry. But these systems do not yet exist, and I know of no astronomer who has proposed building a large light collector—a laser receiving station—at an ideal cloudless site optimized solely to receive the torrent of data we expect soon to be reaching us from an armada of spacecraft at the second Lagrangian point, L2. If we are serious about gathering massive data streams in space, we will need far higher capacity transmission systems. A laser transmitter at L2 would require a one-meter dish—which is not much, but it would also need 0.1 arcsecond pointing stability so its beam would not wander too far around the receiving station on the ground. Ideally, three such receiving stations would need to be deployed around the globe for continuous data reception.

Most astronomers assume that all such problems will soon be overcome. I am not so confident. To see why, we need to look at the origins of our past successes—just how we got to be so lucky—so we might once again take a path of least resistance as we move ahead.

5. Brief Recapitulation of the History of Radio Astronomy

Let us begin by recollecting how some of our prime advances and discoveries came about:

Radar was one of the most powerful weapons systems developed during World War II. Invented just before the onset of hostilities and further developed throughout the conflict, radar enabled British and German intelligence to see the approach of enemy aircraft long before they had crossed the English Channel. Fighter planes could be scrambled in time, and the approaching airplanes shot down.

On two successive mornings in the winter of 1942, an alert shook up defense forces all over England. Years later, James Stanley Hey, in charge of trouble shooting the British wartime radar network, reported on this incident in a 1946 letter to the journal *Nature*. He wrote (Hey 1946): "It is now possible to disclose that, on one occasion during the War, Army equipments observed solar radiation of the order of [a hundred thousand] times the power expected from the Sun…this abnormally high intensity…occurred on February 27 and 28, 1942…the main evidence that the disturbance was…of solar origin was obtained by the bearings and elevations measured independently by the [radar] receiving sets, sited in widely separate parts of Great Britain…[Hull, Bristol, Southampton, Yarmouth]…"

Unknown to the British, the observatory at Meudon had detected strong solar flares at the time, and it soon became evident that solar radio emission was enhanced during periods of solar activity.

Shortly after the War, Hey and his coworkers also discovered that the galaxy now catalogued as Cygnus A emits an enormous radio flux.

Right after the War, also, Martin Ryle gathered discarded British military radar equipment to set up a radio astronomy research group at Cambridge; Bernard Lovell did the same at Manchester; and Jan Oort used former German radar equipment to start a radio astronomy program in The Netherlands.

Thus was radio astronomy born. The next twenty-five years would revolutionize astrophysics with discoveries of quasars, cosmic masers, pulsars, superluminal sources, and the microwave background.

6. The Age of the Rockets

Let me turn to a different story. Over a period of a dozen years starting in the early 1930s, Wernher von Braun and a huge army of technical experts had painstakingly learned how to build the powerful military V-2 rockets with which Hitler hoped to win the War. In 1945, the U.S. military captured

Continued page 10

Instruments and Astrophysics
from page 9

many of these rockets and brought them home for testing. Onboard the test flights, Richard Tousey and Herbert Friedman of the U.S. Naval Research Laboratory placed the first ultraviolet and X-ray sensors to conduct observations of the Sun.

The V-2s became the basis for America's post-war rocket-astronomical discoveries and also the foundation on which an entire U.S. rocket industry would arise.

The Soviet Union had similarly gathered their own German experts and had also begun to develop a powerful rocket industry. With the launch of Sputnik in 1957, they exhibited an impressive ability to accurately place satellites into Earth orbit, and showed that their rockets could now reach any place on Earth with great precision and presumably with significant nuclear warheads. The high ground of space gave them the ultimate means of surveillance anywhere on Earth.

To counter this advance, the United States created a crash program to develop both more powerful rockets and exquisitely incisive surveillance techniques. The Space Race of the 1960s had begun!

7. The Military as Pioneering Astronomers

This race, though in the public's mind a contest to reach the Moon first, was far more a scramble to gain military ascendancy. Perhaps the most phenomenal discovery this brought about came in 1968. So secret was the finding that it remained classified till 1973.

You may recall the Atmospheric Test Ban Treaty, signed in the Kennedy–Khrushchev era, which had finally banned the testing of nuclear bombs above ground to eliminate the radioactive fallout they created. The problem the treaty posed was that an antagonist could learn a great deal about the yield of a weapon tested underground by sensing the seismic waves it generated.

The United States worried that the Soviet Union might strive to seek greater secrecy by exploding their test devices not underground, but surreptitiously, at great distances out in space. To detect such bursts, the U.S. designed the "Vela" project. It involved several gamma-ray sensing satellites in Earth-orbit, stationed so at least one satellite would always be positioned to detect a nuclear explosion anywhere in space.

The first gamma-ray burst the Vela satellites detected must have been a tremendous shock to the military. And then others followed, one every few months. Once the military realized that these bursts were not due to Soviet nuclear bombs, but to unimaginably vaster explosions somewhere out in space, they declassified them and published their findings in the *Astrophysical Journal Letters* (Klebesadel et al. 1973). The news stunned the astronomical community. It has taken us twenty-five years to decide the bursts are extragalactic and their power is staggering.

8. Theorists Play the Same Game

Astronomical observers were not alone in working with military support. Throughout World War II and the Cold War, theorists were heavily involved (Thorne 1994).

Physicists and astrophysicists who have straddled the fence between academic and military work read like a Who's Who of theorists: J. Robert Oppenheimer in 1939 had done seminal work on neutron stars and black holes. Hans Bethe that same year explained how stars shine by converting hydrogen into helium. Edward Teller similarly had made important contributions to astrophysics before the War. John Archibald Wheeler pioneered the study of black holes. All were major figures on the American nuclear bomb projects. In Nazi Germany, the young astrophysicist Carl Friedrich von Weizsäcker had worked toward a German atomic bomb under Werner Heisenberg. In the Soviet Union, Yakov Borisovich Zel'dovich, perhaps the most prolific theoretical astrophysicist of the post-war era, was deeply involved in the design of Soviet nuclear bombs. And the father of the Soviet hydrogen bomb, Andrei Dmitrievich Sakharov, who later became celebrated for his efforts at establishing world peace, also made fundamental contributions to cosmology. Accompanying these giants came an army of less well-known theorists who worked on inflation, gamma-ray bursts, supernovae, and other outbursts of interest to astronomers—and to the military, which, in the classified sphere, funded a good fraction of the basic theory, as well as experiments to determine cross-sections needed to calculate stellar opacities and nuclear reaction rates in stars, needed incidentally also for designing nuclear weapons.

9. The Inconspicuous Military Influence

The military's efforts, however, have not always been this obvious, and most of us tend to remain unaware of the true extent to which they pervade virtually all aspects of our work. Europeans, in particular, tend to be under the impression that military influences are largely an American phenomenon. But the *Infrared Space Observatory*, the most successful infrared astronomical mission of the decade, launched by the European Space Agency in 1995, is a clear counter example. The infrared camera on board, constructed primarily in France, had a detector array especially constructed for the mission by the French defense establishment. The Short Wavelength Spectrometer, built primarily in The Netherlands, incorporated previously classified infrared detectors provided through the efforts of a co-investigator at the U.S. Air Force. Yet most of the many hundreds of astronomers who have carried out observations with these instruments remain unaware of those contributions, and would heatedly deny that this space mission had any military ties. *SIRTF*, of course, will have vastly greater sensitivity than *ISO* and incomparably larger detector arrays—all military hand-me-down devices.

10. Ground-Based Optical Astronomy

Our ground-based colleagues worldwide have similarly benefited from adaptive optics now installed on all the most powerful optical telescopes (courtesy of our hosts here at Livermore).

Long shrouded in military secrecy and researched at significant cost to the U.S. defense establishment, these techniques have in recent years been made available to the astronomical community worldwide. A large international user community is now in place, advancing the art in a field of significant military interest.

11. The Role of Astronomers

If we now ask how we in astronomy have come so far, we must truthfully answer, somewhat like Isaac Newton, and say, "By standing on the shoulders of military/industrial giants."

The role that we astronomers have played in all these efforts has been to build upon technical advances wrought by others. This is quite natural. In typical years, Department of Defense and Department of Energy budgets for research and development have exceeded the astronomy and space science research budgets of NASA and the NSF, combined, by least an order of magnitude. These larger-scale efforts have been central to our success. Industrial research particularly on computing, which lies at the heart of the 3-D approach—the topic of this meeting—has also played a major role. Where military or industrial support did not exist and we had to go ahead on our own, progress has been much slower. That is why the Gravitational Probe GP-B has already taken more than thirty years to develop. Neither industry nor the military have had an interest in general relativity. Nor have they shown an interest in interferometers placed in space. So, we might have to start out in interferometry in space by solving a whole range of technical problems of formation flying and station keeping. These are expensive propositions. Our limited astronomy budgets may not stretch sufficiently far, and we cannot expect these budgets to greatly increase. This means that we cannot, except in rare cases of uncommon importance, ask for support of missions that require capabilities which significantly outstrip commonly available military or industrial capacities. Gravitational wave detection is one of these few urgent exceptions. Hence we are deeply involved in the LIGO project. But should we, for example, spend our own limited budgets on devising and perfecting laser telemetry or delicate station-keeping systems in space? If others will build these for us because they have practical industrial or military applications, our path of least resistance might be to wait for such technologies to eventually arrive. These are choices we should be considering as we plan astronomy's future.

12. A Societal Connection

Astronomy is a luxury that society can afford only when it has provided people with life's primary needs—food, shelter, security. This is why we see astronomy flourishing precisely where society has produced equipment we can adapt and adopt. In recent decades, security has played a dominant role, and so we inherited sensitive detection techniques, sophisticated computers, and powerful launch vehicles. But increasingly, preoccupations in the United States have shifted to health and the environment. To the extent that our search for the origins of life fits into astronomy, we may expect that tools developed for medical and biotechnologies would, in the next few decades, provide insights into the most primitive organisms and their macromolecular components. We may have to search for these deep in the oceans, or far beneath the surface of the earth, where the hyperthermophiles reside, or look for trace constituents in carbonaceous chondrites, or fossils in ancient terrestrial rocks, or the atmospheres of extrasolar planets. The next generation of astronomers could be dedicating itself to a vast search for the origins of life using tools totally foreign to most of us today but common, by then, to biomedical industry. This might be one way to follow a path of least resistance. It might not be the path we would be planning today—but then, many of the most-striking astronomical advances of recent decades were not planned by us either.

13. Return to the Decadal Review

As far as data-intensive efforts go, the 3-D approach we are discussing at this meeting may persist as the prime thrust of research for some time to come. The deciding factor will be the directions that industrial and military research take. As long as Moore's law, with its doubling of computing capabilities every eighteen months continues to hold, the 3-D approach will flourish. When we reach the point where this law breaks down, or limitations on data transmission rates are reached, we should be ready to take a long hard look at our discipline's future. This may not be too many years from now.

Continued page 12

Instruments and Astrophysics from page 11

14. Summary

Our field as a whole cannot get out too far ahead of technologies developed by others to meet basic societal needs.

All the generations of scientists who preceded us shared in one certainty, namely that society could provide them only with limited support, and that they would have to make use of whatever tools were ready at hand to forge a new view of the cosmos. Where they asked for more than society could easily afford, progress inevitably was slow and often faltered. It is up to us to find the necessary means. This may involve steady progress as currently planned in 3-D instrumentation, or perhaps radically new directions—discontinuities that may ultimately prove more useful in unpredictable ways.

As long as people all over the world continue to invent new ways to improve their lot, new technologies will also open up for our search through the Universe. If we remain sufficiently astute to take advantage of these, to learn more about the Cosmos and answer questions that generations of people have posed since antiquity, we will be both serving society and working with means that society can afford. This is how we've succeeded these past few decades. That's how we came to be so lucky!

I thank the organizers of this conference for their generous invitation to attend. I am pleased to also acknowledge research support from NASA. Ω

References

Harwit, M. 1981, *Cosmic Discovery—The Search, Scope and Heritage of Astronomy*, Basic Books, New York.

Hey, J.S. 1946, "Solar Radiations in the 4–6 meter Radio Wavelength Band," *Nature* 157, 47.

Klebesadel, R.W., Strong, I.B. & Olson, R.A. 1973, "Observations of Gamma-Ray Bursts of Cosmic Origin," *Astrophysical Journal* 182, L85.

Thorne, K.S. 1994, *Black Holes & Time Warps—Einstein's Outrageous Legacy*, W. W. Norton & Co, New York.

Reprinted with the permission of the author and the publisher; from *Imaging the Universe in Three Dimensions: Astrophysics with Advanced Multi-Wavelength Imaging Devices.* ASP Conference Series, Vol. 195, 2000 W. van Breugel & J. Bland-Hawthorn, eds.

ANTENNAE GALAXIES NGC 4038/4039

http://hubblesite.org/newscenter/newsdesk/archive/releases/2006/46

This new NASA *Hubble Space Telescope* image of the Antennae galaxies is the sharpest yet of this merging pair of galaxies. During the course of the collision, billions of stars will be formed. The brightest and most compact of these star birth regions are called super star clusters.

The two spiral galaxies started to interact a few hundred million years ago, making the Antennae galaxies one of the nearest and youngest examples of a pair of colliding galaxies. Nearly half of the faint objects in the Antennae image are young clusters containing tens of thousands of stars. The orange blobs to the left and right of image center are the two cores of the original galaxies and consist mainly of old stars criss-crossed by filaments of dust, which appears brown in the image. The two galaxies are dotted with brilliant blue star-forming regions surrounded by glowing hydrogen gas, appearing in the image in pink.

The new image allows astronomers to better distinguish between the stars and super star clusters created in the collision of two spiral galaxies. By age dating the clusters in the image, astronomers find that only about 10 percent of the newly formed super star clusters in the Antennae will survive beyond the first 10 million years. The vast majority of the super star clusters formed during this interaction will disperse, with the individual stars becoming part of the smooth background of the galaxy. It is however believed that about a hundred of the most massive clusters will survive to form regular globular clusters, similar to the globular clusters found in our own Milky Way galaxy.

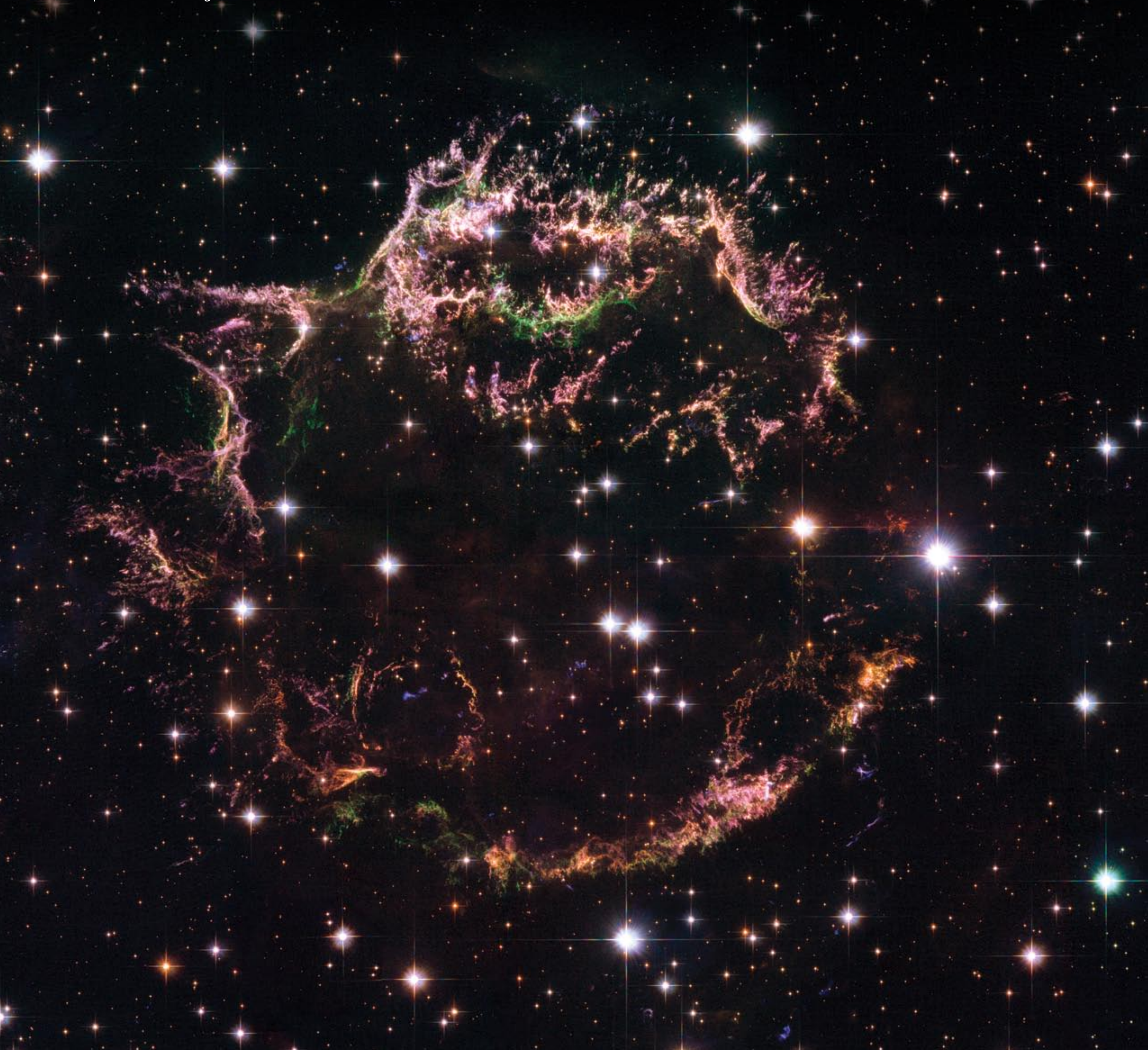
A new image taken with NASA's *Hubble Space Telescope* provides a detailed look at the tattered remains of a supernova explosion known as Cassiopeia A (Cas A). It is the youngest known remnant from a supernova explosion in the Milky Way. The new *Hubble* image shows the complex and intricate structure of the star's shattered fragments.

The image is a composite made from 18 separate images taken in December 2004 using *Hubble's* Advanced Camera for Surveys, and it shows the Cas A remnant as a broken ring of bright filamentary and clumpy stellar ejecta. These huge swirls of debris glow with the heat generated by the passage of a shockwave from the supernova blast. The various colors of the gaseous shards indicate differences in chemical composition. Bright green filaments are rich in oxygen, red and purple are sulfur, and blue are composed mostly of hydrogen and nitrogen.

A supernova such as the one that resulted in Cas A is the explosive demise of a massive star that collapses under the weight of its own gravity. The collapsed star then blows its outer layers into space in an explosion that can briefly outshine its entire parent galaxy. Cas A is relatively young, estimated to be only about 340 years old. *Hubble* has observed it on several occasions to look for changes in the rapidly expanding filaments.

SUPERNOVA REMNANT CASSIOPEIA A

http://hubblesite.org/newscenter/newsdesk/archive/releases/2006/30



Extraterrestrial Fireworks

NASA's *Hubble Space Telescope* has captured an image of a cosmic explosion that is quite similar to fireworks on Earth. In the nearby galaxy, the Small Magellanic Cloud, a massive star has exploded as a supernova, and begun to dissipate its interior into a spectacular display of colorful filaments. The greenish-blue supernova remnant, E0102, resides 50 light-years away from the edge of a bright glowing massive star-forming region.
http://hubblesite.org/newscenter/newsdesk/archive/releases/2006/35/

Image Credit: *NASA, ESA,* and the Hubble Heritage Team (*STScI/AURA*)

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:

Martin Elvis (chair), Harvard-Smithsonian CfA, *elvis@cfa.harvard.edu*

David Axon, RIT
Martin Barstow, U. of Leicester
Eric Emsellem, CRAL
Laura Ferrarese, HIA
Peter Garnavich, U. Notre Dame
Jean-Paul Kneib, OAMP
David Koo, UCSC
Mario Mateo, U. of Michigan
Pat McCarthy, OCIW
Phil Nicholson, Cornell U.
C. Robert O'Dell, U. Vanderbilt
Alvio Renzini, INAF
Abi Saha, NOAO
Regina Schulte-Ladbeck, U. Pittsburgh
Tomasso Treu, UCSB
Monica Tosi, OAB
Marianne Vestergaard, U. of Arizona
Donald G. York, U. Chicago

The Space Telescope Science Institute Newsletter is edited by Robert Brown, *rbrown@stsci.edu*, who invites comments and suggestions.

Technical Lead: Christian Lallo, *clallo@stsci.edu*
Contents Manager: Sharon Toolan, *toolan@stsci.edu*
Design: Krista Wildt, *wildt@stsci.edu*

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.

Richard Hook *(Editor)*

Space Telescope–European Coordinating Facility
Karl Schwarzschild Str. 2
D-85748 Garching bei München
Germany
E-Mail: *rhook@eso.org*

Contents:

Institute News

Calendar

Cycle 15

Open enrollment period for all benefits plans of AURA employees . . . . . . Nov. 6–17, 2006
Parent & Daughter Evening under the Stars, 6–9 p.m. . . . . Nov. 17, 2006
Workshop: Astrophysics Enabled by the Return to the Moon . . . . Nov. 28–30, 2006
Cycle 16 deadline for proposals . . . . Jan. 26, 2007
Institute Visiting Committee . . . . Feb. 27– Mar. 1, 2007
Telescope Allocation Committee . . . . Mar. 19–23, 2007
ESA Symposium: The Impact of HST on European Astronomy, at ESTEC, Noordwijk, Netherlands.
(D. Macchetto is Chairman of SOC.) . . . . May 29–June 1, 2007

SPACE TELESCOPE SCIENCE INSTITUTE

NON PROFIT
U.S. POSTAGE
PAID
PERMIT NO. 8928
BALTIMORE, MD

3700 San Martin Drive, Baltimore, Maryland 21218

STScI N-02-06