# National Radio Astronomy Observatory

NRAO

## Progress Report FY 2008

# National Radio Astronomy Observatory


# FY 2008 Annual Progress Report

*Cover Image: The outlying regions of M83 are highlighted in this composite image from GALEX (far-UV image in blue, near-UV image in green) and the VLA (HI image in red). Ongoing star formation was discovered remarkably far out in the extended arms. Image credit: NASA/JPL-Caltech/VLA/MPIA*

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# Annual Progress Report

*September 2008*

## Summary

This report describes the major accomplishments of the NRAO during the fiscal year FY 2008 (October 1, 2007 through September 30, 2008), with reference to the plans described in the FY 2008 Program Plan submitted to the NSF at the outset of the fiscal year.

Among many science highlights from the NRAO telescopes over the fiscal year are studies of the detailed composition and structure of the lunar surface using radar echos received with the Green Bank Telescope (GBT) as transmitted by Arecibo; an accurate determination of the distance to the Orion nebula using the VLBA, resulting in a substantial revision from 480 pc to 389 pc, with implications for star formation theory; discovery of the youngest (140 year old) supernova remnant in the Galaxy with the VLA and Chandra; accurate measurement of relativistic spin precession of the eclipsing double pulsar system using the GBT; organic molecule studies with the GBT that distinguishes grain mantle chemistry in Galactic Center from clouds in other parts of the Galaxy; detection of high velocity clouds around the M81/M82 group which are most likely relics of ongoing interactions among galaxies in the group, the detection of which is made possible by the high sensitivity and clean beam of the GBT; the detection and analysis of neutral hydrogen at high redshift (z=2.3) with the GBT; the detection of the integrated Sachs-Wolfe effect with the VLA; and a strong indication from VLA surveys that tidal interactions are responsible for triggering Seyfert activity.

ALMA construction highlights include completion of the Array Operations Site (AOS) Technical Building and the AOS antenna transporter hanger. Vertex Antennas #1 through #7 were delivered to the Operations Support Facility (OSF) in FY 2008. Acceptance testing of Antenna 1 is nearly complete and the measured surface accuracy of the antenna is very good – about 11 μm – in stable nighttime conditions, which is well within specifications. The first antenna transporter has been accepted, and has successfully moved an antenna from the erection facility to an external pad. The first Front End was delivered to the OSF, and several Backend Antenna Articles were shipped to the OSF.

In the EVLA construction project, 17 antennas have been retrofitted to the EVLA design. Production of the Ka-band receiver began, and fringes were obtained between the first pair of receivers. The prototype WIDAR correlator was installed and first fringes were successfully achieved. All L-band feed horns have now been fabricated, and fabrication of the S-band feed horns has begun.

At the North American ALMA Science Center, the ALMA Operations Plan was updated to Version D. Several key staff appointments were made, including a new NAASC Assistant Director, Carol Lonsdale. The CASA offline data reduction software beta release was tested and supported, and tutorials were given at the *Synthesis Imaging Workshop* is Socorro. The public beta release for the "Database for Astronomical Spectroscopy*: Splatalogue*," was issued. The award for SIS development with the University of Virginia Microfabrication Laboratory was approved by the NSF. The third NAASC Science Workshop was held in late September 2008—*"Transformational Science with ALMA: The Birth and Feedback of Massive Stars, within and Beyond the Galaxy."*

At the Green Bank Telescope, astronomical commissioning of the Zpectrometer wideband, high redshift spectrometer took place, as did commissioning of MUSTANG, the 3 mm bolometer camera. Antenna performance was improved through Out-of-Focus holography, traditional Phase-Coherent holography techniques, and servo upgrades. Development of an advanced pulsar backend using a new, agile application of FPGA technology was underway. Construction of a seven-pixel focal plane array for the 18-26 GHz band (the "K-Band FPA") is underway. Lab and telescopes tests of the prototype pixel were

successful. The primary scientific aim of this camera is star formation science via the ammonia and CCS spectral lines.

The emphasis on large observing proposals continues to grow at the VLA and VLBA. At the June deadline, two, new large proposals were received for the VLA and one for the VLBA. The 11th Synthesis Imaging Workshop was held in June and was attended by 150 participants. Approximately 40% of VLA time is now scheduled dynamically. More than 4,000 railroad ties were replaced in CY2007. For the VLBA, progress on the sensitivity upgrade continued. A successful test of 4 Gbps recording on Mark 5C recorders was carried out. The VLBA 22 GHz receiver upgrade, which was conducted in collaboration with the MPIfR, was completed in December 2007, three months ahead of schedule.

The Office of End-to-End Operations (OEO), together with staff in New Mexico Operations, completed processing of an additional 30,000 VLA continuum images and published them to the Virtual Observatory collection. The Data Vault archive interface of NRAO resources (http://archive.nrao.edu) was released this fiscal year. A collaboration with Google Sky was begun. OEO participated in the development of the US Virtual Astronomical Observatory proposal. The CASA beta release was issued in November 2007, followed by Patch 1 in March 2008.

At the Central Development Laboratory (CDL), a new 35 nm gate-length InP pHEMT MMIC of NRAO's design was delivered from Northrop Grumman Space Technology and packaged in a 67-95 GHz low-noise amplifier. The LNA set a record for low noise performance of 23 K between 83 and 87 GHz, and was below 30 K from 78 to 95 GHz. The I(V) characteristics of four NbTiN/Al-AlN/Nb SIS junctions from the University of Virginia Microfabrication Lab were measured and shown to be viable for use in mixers at 385-500 GHz. The UVML continues to make excellent progress on a process to produce NbTiN films for use at 1 THz.

The New Initiatives Office (NIO) staff participated in a number of Square Kilometer Array forums, including the new Science and Engineering Committee (SSEC), European PrepSKA discussions, and US TDP forums. New Initiatives staff and NRAO scientists are working with the community to guide development of the program as the Decadal Survey nears. The NIO worked to establish VLBA funding partnerships, as recommended by the Senior Review. The NIO staff also helped manage the development of the FASR proposal, which was submitted to the NSF ATM division in June.

The Office Education and Public Outreach (EPO) led development of a new NRAO web site, which was introduced in February 2008. The electronic newsletter, eNews, which replaces the quarterly hardcopy newsletter, was introduced in June. The educational outreach program included the Sister Cities student-teacher exchange between Magdalena, New Mexico and San Pedro, de Atacama, Chile, the West Virginia Govenor's School for Math and Science in Green Bank, and the Pulsar Search Collaboratory, an NSF-funded program in which West Virginia high school students will work with a world-wide team of astronomers to reduce pulsar data from the GBT.

In administrative areas, the Management Information Services group was nearing release of the new Electronic Timekeeping system. The Human Resources Group initiated new training programs for Performance Evaluation and Affirmative Action. NRAO engaged a consultant to review and revise our Affirmative Action Plan, including compliance and performance. The Computing and Information Services Division improved network security by enhancing perimeter access policies and by enabling bastion hosts.

# A. Science Highlights in FY 2008

## Measuring the Composition of the Moon

A pure circularly polarized radar signal incident upon the lunar surface will be returned in a mixed polarization state depending on the surface properties. By using the Arecibo radar to transmit a circularly polarized signal and the GBT to receive both reflected circular-polarization states, the detailed structure of the reflecting surface can be measured. This technique was used recently to study the lunar Aristarchus plateau, a block of ancient highland crust that rises 2 km above the surrounding basaltic plains. Its visible surface is dominated by pyroclastics, blankets of fine-grained glass and crystal spheroids formed by eruptions of gas-rich magma during the early phases of lunar basaltic volcanism. The distribution, composition, and glass fraction of the pyroclastics offer clues to the opening stages of lunar volcanism. The data reveal the outlines of a lava-flow complex that covers a significant portion of the plateau and appears to have formed by spillover of magma from a nearby sinuous rille. There is also evidence for a 10 m depth of fine-grained glass as well as numerous patches of rocks, 2 cm and larger, associated with ejecta from the Aristarchus crater. Some of the radar-detected rocky debris is not evident in visible-wavelength images. The new radar data provide a window on the geologic history, resources, and potential hazards of this region.

*Investigators:* Campbell (Smithsonian), Carter (Smithsonian), Hawke (U. Hawaii), Campbell (Cornell), & Ghent (U. Toronto).

## VLBA Measures Parallactic Distance to Orion Nebula Cluster

The parallax and proper motion of the non-thermal radio star GMR A in the Orion Nebula Cluster have been determined using the VLBA. The parallactic distance, 389 parsecs, is considerably smaller than the previous canonical distance of 480 parsecs. This distance change lowers the luminosities of the stars in the cluster by a factor of roughly 1.5, which in turn affects the age spread of pre-main-sequence stars and the agreement between the zero-age main sequence and the temperatures and luminosities of massive stars. By providing a more accurate distance to the Orion Nebula, the VLBA made an important contribution to our general understanding of star formation in this important region.

*Investigators:* K. Sandstrom, J. Peek, G. Bower, A. Bolatto, & R. Plambeck (UC Berkeley).

## Youngest Stellar Explosion in Our Galaxy Discovered

Astronomers have used the VLA and NASA's Chandra X-ray Observatory to discover the youngest supernova remnant in our Galaxy, an object known as G1.9+0.3. They did so by measuring the expansion of the debris from the star's explosion in X-ray and radio images made more than two decades apart (1985 and 2007). To their surprise, the 2007 Chandra image was 16% larger than the 1985 VLA image. This implied a large expansion rate and hence a young age for the supernova remnant. Follow-up VLA observations in 2008 confirmed this expansion. The original explosion that gave rise to G1.9+0.3 occurred only 140 years ago, but it was obscured from view by the dust and gas of the Galaxy.

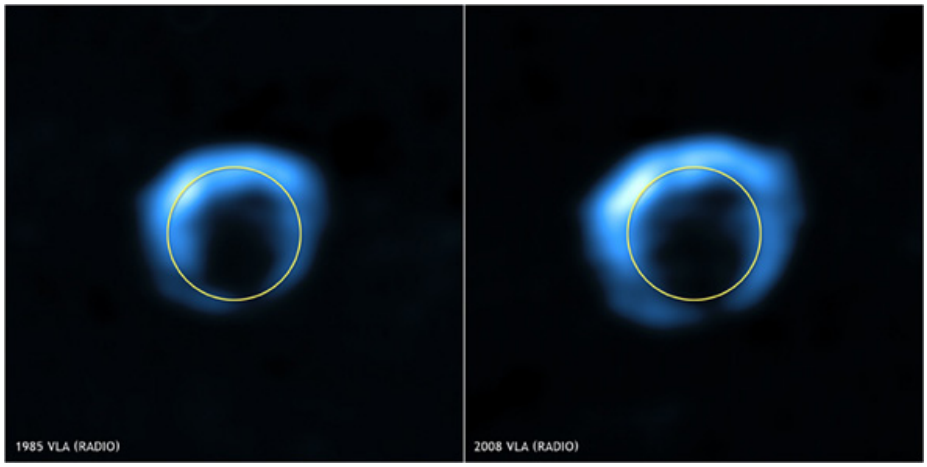


*Figure A.1. False-color VLA Images of G1.9+0.3 in 1985 (left) and 2008 (right). The circle is drawn for size comparison. The clear expansion between 1985 and 2008 indicates that the debris from the original supernova explosion is still expanding very fast and implies a young (140 years) age for G1.9+0.3.*

*Investigators:* Green (Cambridge), Reynolds, Borkowski (NCSU), Hwang, Harrus, & Petre (NASA/Goddard).

## Relativistic Spin Precession in Eclipsing Double-Pulsar System

The double pulsar PSR J0737−3039A/B is the only known pulsar-pulsar system, that is, two neutron stars orbiting each other and both visible as radio pulsars. Unique eclipse phenomena in the double pulsar allowed GBT observers to measure the relativistic spin precession of PSR J0737−3039B to high statistical significance. Relativistic spin precession is similar to the wobbling of a spinning top and induces a motion of the spin-axis orientation around the orbital angular momentum. The precession rate that they measured is in agreement with Einstein's theory of general relativity.

*Investigators:* Breton, Kaspi (McGill), Kramer (Manchester), McLaughlin (WVU and NRAO), Lyutikov (Purdue), Ransom (NRAO), Stairs, Ferdman (UBC), Camilo (Columbia), & Possenti (INAF).

## Organic Molecules at the Center of the Galaxy

Complex organic molecules are very abundant near the Galactic center (GC), where physical conditions such as temperature and density are quite different from those near typical star-forming regions. Despite the difference, the relative abundances of some complex organics are similar in both types of source, suggesting that there might be a universal grain-mantle composition in the Galactic disk. Recent GBT observations of organic molecules in several different GC molecular clouds have shed new light on this issue. The GBT data show a very high abundance of molecules such as $HC_2CHO$, $CH_3CH_2CHO$, and HCCCHO relative to molecular hydrogen, and relative abundances that are quite similar among the GC clouds, even between those forming stars and those that are quiescent. The new data strengthen the suggestion that grain mantles in the GC share a common molecular history. The new data, however, also now clearly distinguish the chemistry of GC molecular clouds from that of the more common star-forming hot cores in the Galactic disk. The environment of the Galactic Center is unusual because of its high level of energetic X-rays, cosmic rays, and shocks. These apparently drive a very interesting chemistry that is able not only to produce complex species in cold environments, but also to distribute them broadly into the gas phase. The GC molecular clouds continue to be among the most promising sources of information on the chemical complexity of the interstellar medium.

*Investigators*: Requena-Torres (CSIC), Martin-Pintado (CSIC), Martin (CfA), & Morris (UCLA)

## New Hydrogen Clouds in the M81 Group of Galaxies

High Velocity Clouds (HVCs) of neutral hydrogen (HI) are common in the sky around the Milky Way and may result from a variety of phenomena, including primordial infall, a galactic fountain, and interaction with satellites. These processes are fundamental to the origin and evolution of the Milky Way and other galaxies, so HVCs have received increasing scrutiny in recent years. The GBT was used to observe HI in a search for HVCs in the M81/M82 galaxy group, a gas-rich system of more than a dozen galaxies with clear signs of tidal interaction. The GBT's superb sensitivity to low-surface-brightness emission resulted in the detection of five previously unknown HI clouds associated with the group.

Based upon the proximity of the clouds to group galaxies in position and velocity, the clouds are most likely relics of ongoing interactions among galaxies in the group. These results are inconsistent with models of primordial HI cloud infall. Work on detailed numerical simulations of the mass distribution and trajectories of the galaxies and newly detected clouds in the M81 group are underway. The ultimate goal of this work is to understand the origin and evolution of extragalactic HI clouds and their relationship to the HVCs in the Milky Way.

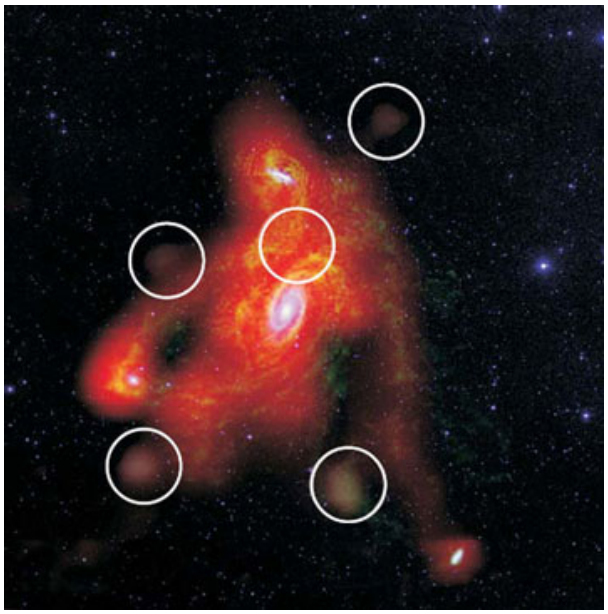

*Figure A.2. Composite radio and optical image of the M81/M82 galaxy group. Orange: GBT HI column-density map from Chynoweth et al (2008). New HI cloud detections are circled and highlighted in white. Yellow: VLA HI column density from Yun et al (1994). Both column-density maps are integrated from -250 to 340 km/s. Blue: Optical image from the DSS.*

*Investigators:* Chynoweth, Holley-Bockelmann (Vanderbilt University), Langston, & Lockman (NRAO).

## Physical Conditions in Star-forming Regions

It is frequently difficult to determine the physical conditions in star-forming regions of external galaxies because emission from the most abundant molecular tracer, CO, is generally dominated by radiative-transfer effects. Less-abundant molecules can be better suited for determining the temperature and density of dense gas, but their emission lines are often quite weak and difficult to study. Recently the GBT was used to measure several transitions of $H_2CO$ in a set of infrared-bright starburst galaxies and derive accurate measurements of the density of molecular hydrogen, $H_2$. The data show a correlation between the infrared luminosity and the derived volume density of $H_2$ consistent with suggestions that the high infrared brightnesses of these galaxies are driven by extreme star-formation activity. Moreover, a

relationship between the infrared luminosity and the derived total mass of dense gas supports the theory that active star formation in infrared-bright galaxies is driven by the amount of material available to form stars.

*Investigators:* Mangum (NRAO) Darling (U. Colorado), Menten (MPIfR), & Henkel (MPIfR).

## GBT Detects Neutral Hydrogen at High Redshift

The $\lambda$ = 21 cm HI absorption spectrum was measured from a damped-Ly$\alpha$ system at $z$ = 2.347 toward which there were optical measurements of Zn and Fe lines. The radio detection of HI was at 424 MHz in absorption against radio continuum from a background QSO. The HI spectrum contains several velocity components that match those in Fe and Zn and allow the abundances of these elements to be estimated along with the spin temperature of the HI. This damped-Ly$\alpha$ absorber appears to contain some gas that is rich in dust and metals and has a relatively large 21 cm optical depth, plus a component poorer in heavier elements and having weaker 21 cm absorption. The absorbing object must have a rather non-uniform interstellar medium.

*Investigators:* Kanekar (NRAO) & Chengalur (NCRA/TIFR)

## NVSS Analysis Reveals Giant Cosmic Void

Investigators analyzing data from the NRAO VLA Sky Survey (NVSS) in the direction of the "cold spot" in the cosmic microwave background (CMB) detected by the WMAP satellite found a dramatic drop in the number of radio sources in that region. They conclude that the drop is caused by a completely empty void with a 140 Mpc radius at a redshift $z \sim 1$ along the line of sight to the "cold spot." The 20 $\mu$K drop in the CMB temperature, they conclude, is due to a lack of matter that would slightly energize CMB photons through the integrated Sachs-Wolfe effect. The size of this void greatly exceeds current expectations from both observations and simulations.

*Investigators:* Rudnick, Brown, & Williams (University of Minnesota).

## VLA Images Indicate That Tidal Interactions Trigger Seyfert Activity

A systematic study of atomic hydrogen (HI) toward nearby Seyfert galaxies revealed that the vast majority show evidence of tidal interactions with gravitationally bound neighboring galaxies, while a matched control sample of inactive galaxies showed few with any evidence of such interactions. The Seyferts in the VLA study show no evidence of interaction at optical wavelengths. This is the first strong evidence for the long-suspected link between tidal interactions and luminous Seyfert activity. The study clearly demonstrates the power of HI imaging to reveal tidal interactions that otherwise would remain invisible.

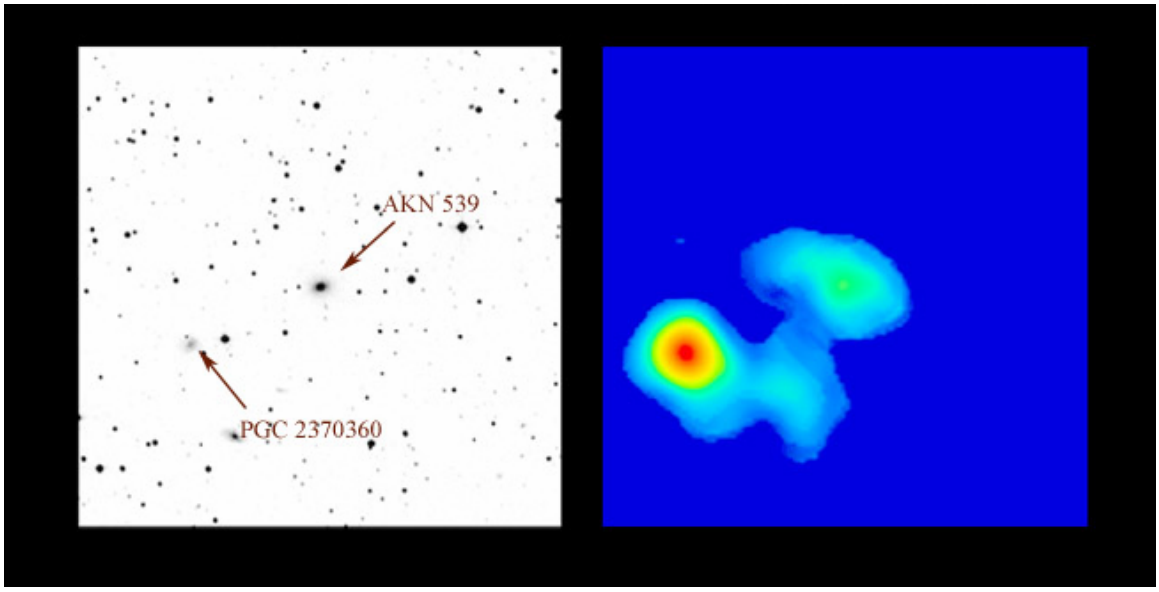


*Figure A.3. Visible-light (left) and radio (right) images of a galaxy pair. The radio image shows gas streaming between two galaxies, AKN 539 and PGV 2370360.*

*Investigators:* Kuo (ASIAA and U. Va.), Lim (ASIAA), Tang (ASIAA and National Taiwan University), & Ho (ASIAA and CfA).

## VLBA Movies Reveal New Details of Cosmic Jets

The MOJAVE (Monitoring of Jets in Active galactic nuclei with VLBA Experiments) survey is making a long-term study of 200 galactic jets and now has released time-lapse movies of 100 jets. The survey includes polarization measurements that are producing valuable information on magnetic fields in the jets. Some of the galaxies have shown surprising behavior, including 3C279, which emitted a bright feature that moved along a straight path for 15 years, then suddenly brightened, showed a change in its magnetic field, and sped off in a new direction. Other galaxies shoot successive bright features that move outward in curved paths, and some jet features break apart unexpectedly.

*Investigators:* The MOJAVE collaboration is led by M. Lister (Purdue).

# B. FY 2008 Technical Highlights

Significant technical achievements during FY 2008 included the following:

- We completed ALMA's Array Operations Site (AOS) Technical Building and the AOS antenna transporter hanger.

- Vertex Antennas #1 through #7 were delivered to the Operations Support Facility (OSF). Acceptance testing of Antenna 1 is nearly complete and the measured surface accuracy of the antenna is very good—about 11 μm—in stable nighttime conditions, which is well within specifications.

- The first Front End was delivered to the OSF, and several Backend Antenna Articles were shipped to the OSF.

- The first quadrant of the ALMA correlator was shipped to Chile, and the second quadrant was completed in Charlottesville.

- Seventeen EVLA antennas have been retrofitted to the EVLA design on schedule. Production of the Ka-band receiver began, and fringes were obtained between the first pair of receivers.

- The prototype WIDAR correlator was installed and first fringes were successfully achieved.

- All L-band feed horns have now been fabricated, and fabrication of the S-band feed horns has begun.

- A new-process 35 nm gate-length InP pHEMT MMIC (Monolithic Microwave Integrated Circuit) of NRAO's design was delivered from Northrop Grumman Space Technology (NGST) and packaged in a 67–95 GHz low-noise amplifier. The lowest measured uncorrected receiver noise temperature is 23 K from 83 to 87 GHz (a new record), below 30 K from 78 to 95 GHz, and below 40 K from 70 to 96 GHz.

- The $I(V)$ characteristics of four NbTiN/Al-AlN/Nb SIS (Superconductor-Insulator-Superconductor) junctions from the University of Virginia Microfabrication Laboratory (UVML) were measured and shown to be viable for use in mixers at 385–500 GHz. An SIS mixer has been designed and will be fabricated using these junctions. The UVML continues to make excellent progress on a process to produce high-quality NbTiN films for use at 1 THz.

- In collaboration with Arizona Radio Observatory we have developed a superconducting 180° IF hybrid covering 4–12 GHz that is small enough to be mounted inside a mm-wavelength sideband-separating mixer block.

- Indium-Phosphide Heterojunction Bipolar Transistors (InP HBTs) from NGST were tested and characterized at cryogenic temperatures. HBTs offer the potential for much better $1/f$ gain stability than HFETs (Heterostructure Field-Effect Transistors) and may be appropriate for second and later stages of low-noise amplifiers (LNAs).

- More than one hundred HFET amplifiers were delivered by the Central Development Laboratory (CDL) for use on all NRAO telescopes.

- A wide variety of custom centimeter- and millimeter-wave MMIC components were designed, tested, and delivered for various projects.

- A tunable, single-conversion, sideband-separating mixer using digital signal processing at baseband was demonstrated with >55 dB sideband separation. The goal is a much-simplified receiver system with digitization as close to the telescope feed as possible.

- First pulsar test results were obtained with the new GBT pulsar backend, which is based on the Berkeley CASPER FPGA (Field-Programmable Gate Array) system technology.

- New feeds were designed and tested for 18–26.5 GHz (GBT K-band focal-plane array) and 12–18 GHz (EVLA), and linear-to-circular-polarization phase shifters were designed and tested for the 8–12 GHz, 12–18 GHz (EVLA), and 75–110 GHz (ALMA) bands. Production of the 2–4 GHz EVLA feed horns is well underway. A broadband (500–4000 MHz) conical sinuous feed has been successfully prototyped for use in the Frequency Agile Solar Radiotelescope (FASR) project.

- An orthomode transducer (OMT) was designed for the 8–12 GHz EVLA band using high-temperature superconducting material, and the HTS structures are being fabricated in Germany. The modified EVLA 1–2 GHz quad-ridge orthomode-transducer prototype now exceeds specifications, samples recently passed laboratory tests conducted at the NRAO, and the production of the digitizers is now fully underway and manufacturing bids have been solicited.

- Samples of the EVLA 3-bit, 4 Gsps digitizers passed NRAO laboratory tests, and production is now fully underway. The local-oscillator round-trip-phase module was shown to meet specifications and is in production. The prototype WIDAR correlator was installed at the VLA site and first fringes have been obtained.

- In a collaboration with Haystack Observatory, test observations at 4 Gbps using loaner Mark 5C recorders and digital backends on 6 VLBA antennas were successful.

- Work at Green Bank on a seven-pixel, dual-polarization, 18–26 GHz focal-plane array is well underway in collaboration with the CDL. A prototype pixel and test dewar have been successfully tested in the lab and in sky tests on the telescope.

- Substantial improvements in both instrument sensitivity and vibrational isolation were made to the University of Pennsylvania's 8×8-pixel, 3 mm wavelength MUSTANG bolometer array on the GBT. Work has begun on expansion to a 16×16 (256 pixel) array in collaboration with NASA and NIST.

- The Precision Array to Probe the Epoch of Reionization (PAPER), led by the University of California at Berkeley, deployed a four-element prototype array in Western Australia and produced an all-sky map near 150 MHz.

# C. ALMA Construction

## Accomplishments and Highlights in FY 2008

The accomplishments and highlights in FY 2008 are described below. Although the work of most of the IPTs is quite integrated with our international partners, this report concentrates on North American progress and deliverables.

### *Management Integrated Product Team (Management IPT)*

FY 2008 has seen both tremendous progress and worrying delays. Highlights of the year include acceptance of the Array Operations Site (AOS) Technical Building (TB) and the delivery of the first front-end and backend systems to Chile together with a two-antenna correlator system and the subsequent end-to-end operation of these by the Assembly, Integration, and Verification (AIV) staff. The Front End (FE) IPT had expected to complete three FEs at the NRAO Technology Center (NTC) and deliver them to the Operations Support Facility (OSF). However, late deliveries of contractor test equipment and unexpected difficulties in getting the beam scanner operational and interpreting the beam-pattern results led to considerable delay. The first FE was delivered to the OSF as an engineering model in May 2008. The second Vertex antenna was lifted by the newly accepted antenna transporter and carried out of the Site Erection Facility (SEF) to allow it to see the sky. Although Vertex's schedule performance in delivering antennas from the northern hemisphere has been excellent, there have been significant delays in the assembly, integration, and testing of these antennas at the OSF. Vertex significantly underestimated the effort needed to complete all of the electrical installation work (since then, much of this work has been relocated to the northern hemisphere); furthermore, an accident involving antenna #1 driving into the man-basket delayed the acceptance by some 2.5 months. In Chile we hired our 100$^{th}$ local employee in July. From an international perspective, there have been significant staff changes with the departure to the ALMA Director, the ALMA Project Manager, and the European Project Manager. All three of these posts have been filled on an interim basis, and a new ALMA Director and Project Manager were named in mid-September 2008.

### *Site IPT*

During FY 2008 the Site IPT made significant progress with the completion of the AOS TB (Array Operations Site Technical Building) as well as the commissioning of the mechanical, electrical, fire extinguishing, and control systems. Other IPTs have already started installing their deliverables inside the building.

*Figure C.1. A View of the mechanical room.*

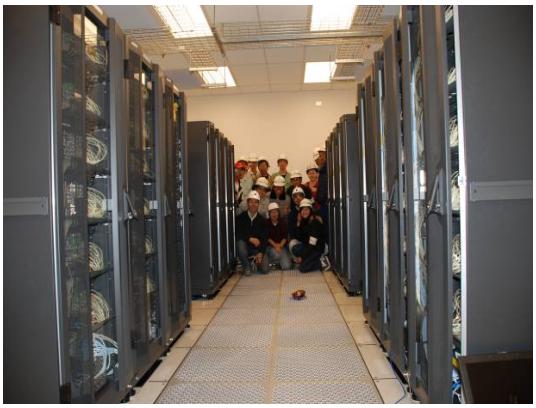

*Figure C.2. ACA Correlator room.*

At the AOS, a hangar to house the antenna transporter was built and the grading of the Central Cluster and Atacama Compact Array (ACA) areas was completed. The procurement of the electrical and fiber-optics materials for the AOS utilities construction has started.

A second external antenna pad was built to test antennas in the Vertex site-erection facility. The second holography tower was erected close to the OSF Technical Facilities building to permit AIV to start with holography testing at the OSF.

*Figure C.3. A View of the AOS Transporter Hangar (left).*

In addition, the NRAO completed the extension of the ALMA Camp at the Operations Support Facility level, an altitude of approximately 9,600 ft., which now may house up to 130 persons.

### *Antenna IPT*

Vertex antennas #1 through #7 were delivered to the OSF in FY 2008. As of early August 2008, acceptance testing for antenna #1 was 95% complete, antenna #2 was 75% complete, antenna #3 was 50% complete, antenna #4 was 25% complete, and antenna #5 was 10% complete. Antennas #6 & #7 have been delivered to the OSF and are in the final stages of integration. Beginning with antenna #4, the deliveries to the OSF have been occurring on schedule at a pace of one antenna every 6–8 weeks.

Although Vertex's schedule performance in delivering antennas from the northern hemisphere has been excellent, there have been significant delays in the assembly, integration, and testing of these antennas at the OSF. Vertex underestimated the effort needed to complete all of the electrical installation work (since then, much of this work has been relocated to the northern hemisphere); furthermore, an accident involving antenna #1 driving into the man-basket delayed the acceptance by some 2.5 months.

The holography campaign on antenna #1 was just completed, with the nighttime stable environment surface being measured at 11 microns rms, which is well within specification.

In July the second Vertex antenna was driven out of the SEF and placed on the newly completed second external antenna pad using the ALMA Antenna Transporter.

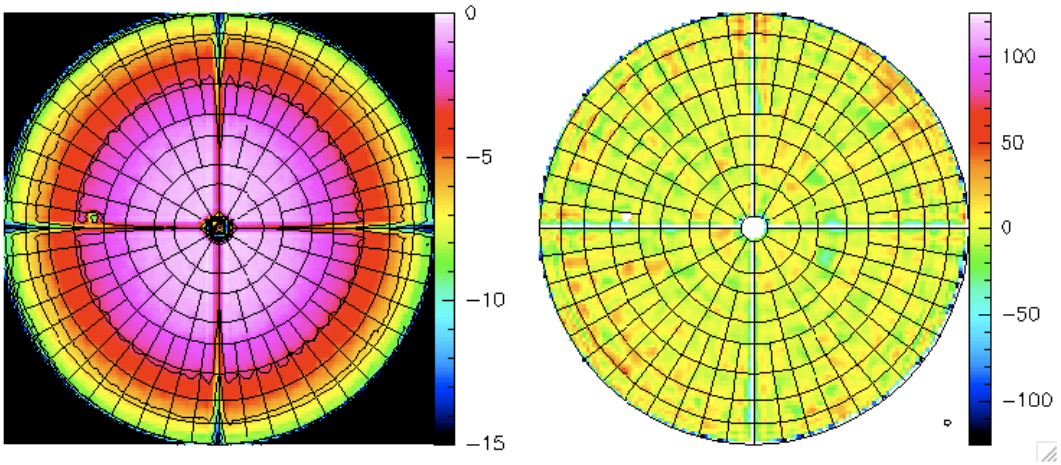


*Figure C.4. Holography map of the Vertex Antenna showing a surface rms of 11.06 microns.*

*Figure C.5. Vertex antenna #2 being brought out of the SEF.*

The nutator design effort completed its critical design review in January, 2008. Design changes required by ALMA lengthened the design phase. Nutator unit #1 is now completing its system-integration phase at the contractor's factory. Acceptance testing is scheduled to begin and complete in Q4 2008, with delivery to the OSF planned for Q1 2009.

The Front-End Handling Vehicle (FEHV) was competitively bid, and the bid evaluation was completed in December 2007. All bids received far exceeded the budget, suggesting that the technical requirements were too stringent. The current prototype FEHV will be used for one year at the OSF for installation of FE equipment in antennas, and then the technical requirements will be revised to reflect actual work conditions and needs, and then re-bid in 2009.

The production Optical Pointing Telescope (OPT) contract was awarded in December 2007. The preliminary design review was held in May 2008 and the critical design review was held in August 2008. Acceptance testing is planned for Q4 2008.

The Front-End Service Vehicle (FESV) was released for bid in June 2008, with proposals received in August 2008 and bid evaluations completed in September 2008. The contract award is planned for Q4 2008.

### *Front End (FE) IPT*

In FY 2008 the Local Oscillator Reference Test Module (LORTM) was delivered as planned to the North American (NA) ALMA Front-End Integration Center (FEIC) along with a unit to be delivered to the OSF to support system integration there. Acceptance and functional testing began on July 14. It was originally planned that this would complete the NA FEIC. However, the plan to increase the rate of FE production resulted in allocation of contingency funds to partially instrument the assembly tilt table as a second test station. It is now planned that this will be ready for operation by the end of the first quarter of 2009, at which time the NA FEIC (revised) will be completed.

The FE IPT expected to complete three Front Ends at the NTC and deliver them to the OSF. However, late deliveries of contractor test equipment plus unexpected difficulties in getting the beam scanner operational and interpreting the beam-pattern results led to considerable delay. The first FE was delivered to the OSF as an engineering model, incompletely tested (because of lack of time and because no LORTM was available) in May 2008, and PAS testing was supported by FE IPT staff. A second FE was assembled and is presently undergoing extensive testing, including commissioning of the entire phase-stability testing process. Some assemblies originally intended to be used in further NA FEIC units were sent to the EA and EU FEICs to accelerate their first-unit production progress.

A second holography system was built and delivered in August 2008.

### *Back End (BE) IPT*

**Antenna Article (AA):** The BE IPT delivered production AAs to the OSF in March and July. The March delivery was delayed from the previous December to allow complete verification testing on the design. With testing largely completed and all major procurements either in place or in process, future AA deliveries that adhere to the Integrated Project Schedule are anticipated.

One subassembly of the AA, the Digitizer Clock (DGCK) Line-Replaceable Unit (LRU), underwent a major design change in FY 2008. The redesign was completed ahead of schedule, and the new LRU has been verified and accepted by the project. Production DGCKs are operational at the ALMA Test Facility (ATF) and OSF.

*Figure C.6. AA analog and digital racks with test stand undergoing PAI in Socorro.*

**Data Receiver Article (DRXA):** The BE IPT delivered thirty-two fully verified production DRXAs to the OSF in July 2008. With testing virtually complete and all major procurements either in place or in process, on-time DRXA deliveries per the Integrated Project Schedule are anticipated.

The BE IPT provided eight additional production DRXAs in FY 2008 for installation in the two-antenna correlators at the ATF and OSF.

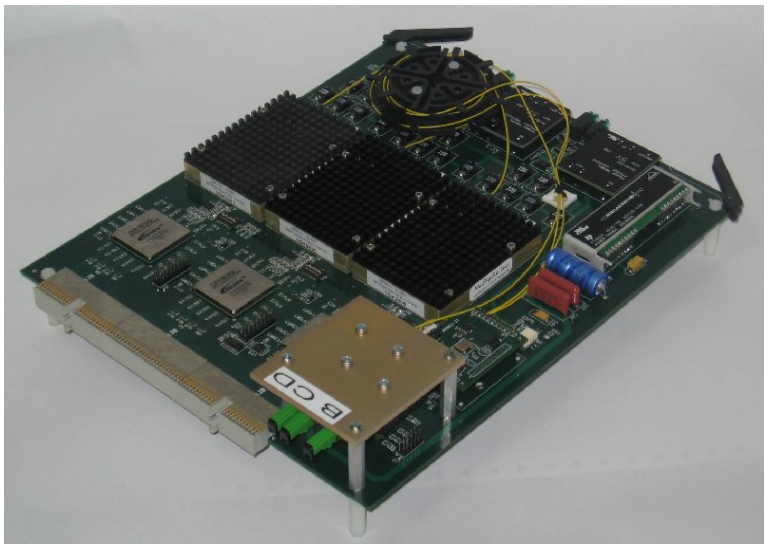

*Figure C.7. The DRXA. A total of 264 will be installed in the Bilateral Correlator.*

**Local Oscillator Photonic Receiver Article (LPRA):** One pre-production LPRA was delivered to the FE IPT for use in FE #1, which is presently operational at the OSF. A second unit was installed in a second FE in April. Three additional units are scheduled for completion in FY 2008. Full verification testing and completion of PAI/PAS handover procedures are scheduled to occur in late 2008. To speed production, a statement of work is being drafted to outsource future LPRA production.

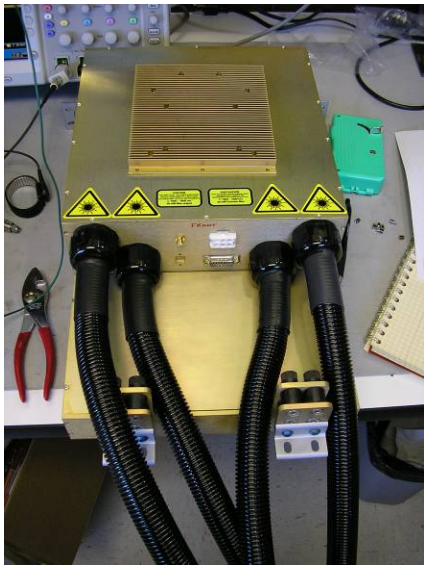

*Figure C.8. The LPRA. Outsourcing of units is needed in order to meet schedules.*

**Central LO Article (CLOA):** Production Central LO racks were not delivered to the OSF in FY 2008 as originally scheduled, largely owing to a delay in receiving the Master Laser from the vendor. The schedule has been restructured to plan for a partially built CLOA to be delivered to the OSF in May 2009.

This set of racks will provide timing for up to sixteen antennas. To accommodate the full complement of sixty-six Bilateral and ACA antennas, completion of the CLOA is scheduled for FY 2010.

**Temporary Central LO:** For the purpose of early end-to-end testing at the OSF, the BE IPT delivered a suitable central timing system in December 2007.

**Test Sets and Equipment:** In North America the BE IPT uses several test stands for PAI acceptance testing of the various products and articles. Duplicates of these test stands were created and provided to AIV. Test stands for the DTS, IFP, PS, and LO (RF) modules underwent PAI/PAS and were delivered to the OSF in December 2007. In March 2008 a duplicate AA test stand was handed off to AIV when the first AA was delivered.


*Figure C 9. LO, IFP, DTS, and PS Test Stands at the OSF.*

### *Correlator IPT*

The first quadrant of the correlator was delivered to Chile and the second quadrant was completed in Charlottesville. The first quadrant of the correlator had been postponed pending completion and checkout of the AOS TB, including power and HVAC checkout, construction and delivery of a second two-antenna correlator for use at the OSF, and development and test of an improved method of enhanced cooling airflow using fan assemblies. During this period, further development of firmware and software, which we had planned to do with the second quadrant, was done with the first quadrant, so there is no net delay. Installation and checkout will continue in the last quarter of CY 2008.

Also during this period, the additional two-antenna correlator (an added task) was delivered and accepted at the OSF. The two-antenna correlator at the ATF was supported, and successful interferometric spectroscopy was accomplished.

### *Computing IPT*

In FY 2008 the ALMA Computing IPT focused on activities at the ATF, along with supporting initial OSF and AOS activities (initial antenna-acceptance activities and procurements), and continued its longer-term development program.

We moved from interferometric demonstrations (first fringes) to routine interferometric observations with automatic fringe and delay tracking in an initial end-to-end system (Observing Tool through the Archive

into CASA for data reduction). The Computing IPT took over ownership of the ATF and has managed it on behalf of all project stakeholders since just before the start of the fiscal year.

CASA was released to the community in a beta release, along with several patches. Starting in July 2008 CASA was released without restriction to the entire community.

### *Systems Engineering and Integration (SE&I) IPT*

**Prototype System Integration (PSI):** During FY 2008 the role of the PSI group changed from leading the effort at the ALMA Test Facility (ATF) to supporting the Computing IPT, which took over ATF management in September 2007. The main activity at the ATF became developing software for dynamic interferometry plus total-power observing and commissioning procedures needed for ALMA in Chile.

PSI staff provided on-site maintenance of the prototype antennas and the front-end cryogenic systems plus general hardware diagnostics. System-level diagnostics were provided by PSI staff in conjunction with Computing and Science IPT members. A particular example where PSI took the lead was in identifying the problem of Walsh switching at high spectral resolutions, which led to the use of LO offsetting. It was then demonstrated how this could be done with no penalty using existing digital filters. PSI staff also developed and tested calibration procedures for the antenna position encoders. The initial definition of a set of acceptance tests for the ALMA System was also provided by PSI.

During this period most of the PSI staff transferred to AIV in Chile, transferred to the Back End IPT, or left the ALMA project. The last PSI task will be to decommission the ATF facility after its planned closing in December 2008.

**Product Assurance (PA):** Two of three open PA positions were staffed during FY 2008 and two new openings were established during this period. The third open position, for European PA, is currently in the procurement process. During FY 2007 the budget was approved and candidates were interviewed. A selection was made early this year, and ESO (European Southern Observatory) is completing its internal hiring process. The selected candidate will be responsible for all ALMA product reviews and acceptance activities originating from the European Union. Another area identified for improvement this year was software quality. A budget request for a Software Quality Engineer was approved, and the position will be located in North America.

To address reporting and evaluation inconsistencies, the PA Team developed criteria and templates to standardize these processes. The initiatives are currently being developed and implemented, with anticipated completion by Q2 2009. The PA Team is currently defining the process and tools needed to facilitate the identification, analysis, and correction of production- and design-related issues within the project. The ALMA standards are being updated to reflect the new processes, templates, and tools.

### *Science IPT*

During FY 2008 the focus of the Science IPT began to shift from pre-commissioning work at the ALMA Test Facility (ATF) led by Project Scientist R. Hills, Deputy Project Scientist A. Peck, and Instrument Scientist R. Laing) and preparation for Chilean commissioning (led by Hills, Peck, and Instrument Scientists D. Emerson and B. Vila-Vilaro) to a full focus on Chile. The Science IPT worked with the Computing and other IPTs at the ATF to evaluate the ALMA system. Particular foci included achieving fringes with the test interferometer, performing total-power observations, evaluating system performance, and producing the first data calibrated with CASA. These functions are essential at the OSF for the evaluation of the production antennas. Several postdoctoral fellows and others from various ALMA centers were trained to use the ALMA system from observational setup through data reduction with CASA. As FY 2008 closed, the first members of the ALMA commissioning team arrived in Chile.

Rainer Mauersberger and Robert Lucas will be starting work in Chile in Q4 of FY 2008. In Q1 of FY 2009 members Antonio Hales (currently an ALMA postdoctoral fellow) and Stuartt Corder (now at Caltech) will begin working with the Commissioning Team in Chile, to be joined by Denis Barkats (also now at Caltech). The NAOJ (National Astronomical Observatory of Japan) has appointed Dr. Tsuyoshi Sawada as ALMA Commissioning Scientist; he will probably arrive in Chile in October.

A success of the Science IPT during FY 2008 was working with the Computing IPT to obtain interferometric data using ALMA schedule blocks generated by the Observing Tool, exporting the data through the ALMA Science Data Model from the ALMA Archive, through data reduction using CASA, including amplitude, phase, and bandpass calibrations as specified in the ALMA Calibration Plan (though still with some prototype hardware).

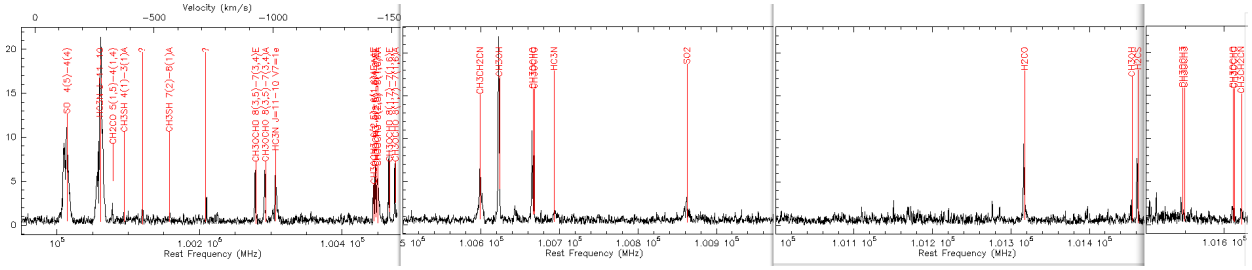


*Figure C.10. A portion of the Orion Hot Core region spectrum was observed at the ATF and calibrated using ALMA software. In this nearly 2 GHz wide spectrum, dozens of spectral lines are identified.*

The Science IPT provides expertise to ALMA project reviews. The Project Scientist ensures that the scientific specifications and requirements of the project are maintained; studying items presented to the Change Control Board constitutes a major part of the job. Many items were studied, discussed with the science advisory committees, and resolved. The ALMA Science team represented ALMA at a number of regional and international meetings throughout the year. Schools introducing young astronomers to ALMA were held in North America, South America, Europe, and Asia. In North America, students at the Synthesis Imaging Workshop in Socorro were introduced to the reduction of millimeter-wave data using CASA. A particular focus was on a workshop "Transformational Science with ALMA: The Birth and Feedback of Massive Stars, Within and Beyond the Galaxy" to be held September 25–27 in Charlottesville. Over 130 participants are expected.

## ALMA Milestones

| Item | Date Planned | Date Accomplished |
|---|---|---|
| **Site IPT** | | |
| 1. Construction of the AOS transporter hangar | 02/2008 | 07/2008 |
| 2. Complete extension of the ALMA Camp to 130 beds | 02/2008 | 04/2008 |
| 3. Call for bid for the power and fiber-optic cables | 03/2008 | 06/2008 |
| 4. Call for bid during late 2007 for the construction of AOS roads, power, and fiber-optics distribution | FY 2008 | 11/2008* |
| **Antenna IPT** | | |
| 1. Vertex antenna #1 accepted at the OSF | 12/2007 | 09/2008* |
| 2. Nutator unit #1 delivered and accepted at the OSF | 06/2008 | Q1 2009 |
| 3. Optical pointing telescope under contract and critical design review completed | 10/2007, 03/2008 | 12/2007, 08/2008 |
| 4. FEHV under contract and critical design review completed | 01/2008, 07/2008 | On hold |
| 5. FESV under contract and | 03/2008, | Q4 2008* |

| Item | Date Planned | Date Accomplished |
|---|---|---|
| critical design review completed | 09/2008 | |
| **FE IPT** | | |
| 1. Complete the NA Front-End Integration Center | 01/2008 | 3/2009 |
| 2. Complete and deliver the first three front ends | CY 2008 | 05/2008, Q1, Q2 2009 |
| 3. Deliver the second holography transmitter and receiver | 02/2008 | 09/2008* |
| **BE IPT** | | |
| 1. Deliver pre-production antenna article 1 and test sets to the OSF | 12/2007 | 03/2008 |
| 2. Deliver temporary Central LO to the OSF, to coincide with the arrival of the test correlator | 12/2007 | 12/2007 |
| 3. Complete hardware and firmware redesign of the digitizer clock LRU per project change request. Update relevant documentation. | 05/2008 | 02/2008 |
| 4. Deliver DRX articles needed to populate the first half of quadrant 1 to the Correlator IPT | 06/2008 | 07/2008 |
| 5. Deliver the first set of Central LO racks to the OSF | 08/2008 | 05/2009 |
| **Correlator IPT** | | |
| 1. Begin assembly and checkout of first quadrant at the AOS TB | 02/2008 | 09/2008 |
| 2. Complete testing of the second quadrant | 11/2007 | 03/2009 |
| 3. Complete assembly of the third quadrant | 06/2008 | 09/2009 |
| **Computing IPT** | | |
| 1. Provide software support (optical pointing, holography, etc.) for the first antenna acceptance in Chile. | Q4 2007 | Q4 2007, ongoing |
| 2. Demonstrate full dynamic interferometry (fringe tracking, delay tracking, phase switching) at the ATF. | Q4 2007 | Q4 2007[1] |
| 3. Demonstrate full end-to-end operability at the ATF, including GUIs, documented procedures, and sufficient diagnostics. | Q2 2008 | Q2 2008 |
| **SE&I IPT** | | |
| 1. PSI: Work with computing and science IPTs to develop dynamic interferometry and other functionality at the ATF. Support this effort with system-level performance diagnostics. | Q2 2008 | 12/2008* |
| 2. PSI: Conduct system performance verification at the ATF or develop verification procedures that will be used later at the OSF | Q2 2008 | 12/2008* |
| 3. PSI: Close down the ATF facility | Q3 2008 | 12/2008* |
| 4. PA**:** Implement the NA, EU, and Chile staffing plans | Q1 2008 | 07/2008 |
| 5. PA**:** Develop reporting criteria and formats to address PA metrics, vendor evaluation reports, audit reports, action-item tracking, and corrective actions | Q4 2007 | 02/2008 |
| **Science IPT** | | |
| 1. Demonstrate early calibration of the production ALMA system during Integration at the Operations Support Facility | Q4 2008 | Q1 2009* |
| 2. Demonstrate aspects of the commissioning plan (e.g. demonstrate phase-stable interferometry, test calibration procedures, exercise correlator modes) on the prototype ALMA system at the ATF. | Q3 2008 | 04/2008 |

Notes:
[1]Phase switching does not yet track antenna delay.
*Projected date.

# D. EVLA Construction

## Accomplishments and Highlights in FY 2008

- Seventeen antennas have been retrofitted to the EVLA design and account for 55.2% of all antenna hours in scientific observations.
- Production of the Ka-band receiver began, and fringes were obtained between the first production pair.
- Production of the gain-slope equalizers began.
- The prototype correlator was installed and on-the-sky tests began; first fringes were successfully achieved.
- All L-band feed horns were fabricated.
- Fabrication of the S-band feed horns began.

In what follows, the accomplishments of the EVLA project in FY 2008 are described under the major elements of the project's work breakdown structure (WBS).

### *Project Management*

Per recommendations of the EVLA Advisory Committee and the AUI Visiting Committee, an integrated schedule was developed to illustrate how the EVLA construction project transitions to operations. It shows how the required software and hardware come together for the first shared-risk science observations. We also used it to develop an EVLA capabilities forecast that will be updated as necessary.

A successful meeting was held at the DRAO (Dominion Radio Astronomy Observatory) in Penticton, BC in February 2008 to review management processes for the WIDAR correlator. The meeting addressed NRAO's concerns about the use of formal management tools in the execution of the WIDAR project, the support of DRAO's funding agency, and the routine involvement of WIDAR project management.

The project management office made semi-annual updates of the project's WBS cost data sheets, risk register, and earned-value analysis. The EVLA change control board evaluated a number of change requests, although not all were approved. Approved requests include outsourcing the production of the junction boxes for the M302/303 utility modules, providing additional funding to fabricate the S-band feed horns, extending a person on the EVLA budget to complete antenna retrofitting, and supplementing the front-end budget to support the production of machined components for EVLA receivers.

### *Systems Integration*

A total of 17 antennas have been outfitted to the EVLA design. In June 2008 the EVLA antennas accounted for 55.2% of all antenna hours used in scientific observations. The mechanical overhaul of the 18$^{th}$ antenna is underway. The antennas continue to be retrofitted at the rate of about six per year.

The production of the M302 and M303 utility modules was started in December 2007. The modules provide a number of functions, including temperature sensors and emergency shutdown capabilities, to the vertex and pedestals rooms of the antennas.

The central LO system was updated to add the timing and clock signals necessary for the WIDAR prototype-correlator tests that began in July 2008.

### *Civil Construction*

The civil-construction group helped the Electronics Division install the equipment racks for the WIDAR correlator. The task included installing the racks, cable tray, and 48V power cables for the racks. The group also implemented the humidity-control features of the HVAC units in the correlator shielded room.

The civil-construction WBS element of the EVLA project will be complete in FY 2009. The only work remaining for civil construction is to install control and alarm wiring for the air conditioning equipment in the shielded room and activate the FM200 gas cylinders in the fire-suppression system of the shielded room once correlator installation is complete.

### *Antennas*

The mechanical overhaul of the antennas is the most visible aspect of the EVLA antenna retrofit. Six overhauls occurred in FY 2008. Fabrication of mechanical components for additional EVLA antennas is ongoing, and fabrication of structural components for additional EVLA antennas is ahead of schedule

Production of the S-band (2–4 GHz) feed horns is well underway. Production orders were placed for the horns' centrifugal castings and fiberglass lamination in February 2008. The assembly and fiberglass lamination of two S-band feed horns has been completed. The horns were installed on EVLA antennas after pattern measurements showed they met design specifications. Lamination of the third S-band horn is underway. The remaining horns will be assembled at the rate of two every seven weeks. A second fixture for assembling the horns was built in the VLA welding shop. Fabrication of the aluminum rings for the S-band horns continues at the VLA site.

The assembly and fiberglass lamination of all L-band (1–2 GHz) feed horns was completed in June 2008.

Two prototype feed horns were fabricated for the Ku-band (12–18 GHz) receiver at the Green Bank machine shop. Pattern measurements were made of the horns in June 2008 at an antenna test range on the New Mexico Tech campus; they showed that the horns meet design specifications.

### *Front End*

Progress on all of the EVLA receiver bands is described in the subsections below.

> **L-band:** The overall design of the L-band (1–2 GHz) quad-ridge orthomode transducer (OMT) was improved. The fin profile of the OMT now gives a return loss that is better than specification plus improved broadband performance overall. Also, a shorting block, instead of shorting pins, will be used in the throat section of the OMT. Simulations show the block gives good performance. It is much easier and cheaper to manufacture than the original pin design. Bids have been solicited for manufacturing the quad-ridge section of the OMT. Production of the OMT will commence once laboratory tests show that the prototype meets performance specifications.
>
> Production of the fully EVLA-compliant L-band receiver has been paced by the development of the OMT. As a matter of priority, engineers have focused on finishing the S- and C-band OMTs so that progress could advance on those receivers. The OMT designs in general are mature, and progress on L band should advance in the near term. Production of the L-band receivers is now scheduled to commence in December 2008.

The mechanical drawings for the new design of the L-band Dewar were completed. A vendor who can supply cast Dewars that comply with the vacuum requirements has been identified. A request for quotation for the prototype Dewars has been submitted.

**S-band:** The design of the new quad-ridge OMT for the EVLA S-band (2–4 GHz) receiver was completed in Green Bank. This effort involved the scaling in frequency of the current designs for the L- and C-band OMTs. The prototype S-band OMT exceeds design specifications. The old VLA L-band Dewar will be reused for the new S-band receiver, and drawings have been made to document the required Dewar modifications. RF components for the prototype receiver are on hand, and its remaining mechanical components are being fabricated. The prototype receiver is scheduled for installation in October 2008.

**C-band:** Interim C-band (4–8 GHz) receivers are being built to meet the antenna retrofitting schedule. The interim receivers are fully EVLA compliant but do not have their wideband OMTs.

The installation of the first full-bandwidth C-band OMT in the receiver on antenna 2 in May marked the start of production of these OMTs. The wideband receiver is performing well. The bulk fabrication of the OMTs is underway, and they will be installed on the receivers at the rate of about one antenna per month beginning in August.

The OMT is combined with a 90-degree hybrid coupler to convert linear polarization into circular. For this to work, the cables between the OMT and hybrid must be phase matched and the hybrid must function reliably at cryogenic temperatures. These issues have been resolved.

**X-band:** The overall design of the X-band (8–12 GHz) receiver will be determined by the type of OMT used in it. A conventional waveguide-style OMT is under development at the Central Development Laboratory and is scheduled for completion in October 2008. The waveguide OMT may cause the receiver to be too large, so an alternative four-probe planar-style OMT is being developed by the engineering staff in Green Bank. The prototype of this OMT is nearly complete, and a Dewar assembly for it is being built so that it can be tested in Green Bank. Preliminary test data show that the OMT is providing acceptable performance for this type of design. The main concern with the planar OMT is its noise contribution may be too large.

**Ku-band:** The RF and mechanical design of the Ku-band (12–18 GHz) receiver is complete. The OMT, phase shifter, and square-to-rectangular waveguide transition were scaled from K-band.

**Ka-band:** The production of the Ka-band (26–40 GHz) receivers was started with the installation of a receiver on antenna 4 in May 2008. We recorded fringes with this receiver by tuning it to frequencies in the band edges that overlapped with K- and Q-band frequencies on other antennas in the array. The second Ka-band receiver was installed on Antenna 5 in August and fringes were obtained between the first production pair. Additional receivers will be installed in the array at the rate of about one per month.

**K-band and Q-band:** The installation of EVLA-compliant K-band (18–22 GHz) and Q-band (40–50 GHz) receivers continues to keep pace with the antenna retrofitting schedule.

### *Local Oscillator (LO) and Intermediate Frequency (IF) Systems*

Modules for the LO and IF systems of the EVLA continue to be built to meet the antenna retrofitting schedule. Some modules require retrofits for hardware upgrades and RFI mitigation. The module retrofits will be made so as not to interrupt the antenna retrofitting schedule.

The wideband upgrade of the T304 baseband downconverter modules began. It includes installing wideband filters, gain-slope equalizers, and total-power detectors in the T304 modules. Currently, EVLA antennas in the array use the EVLA's narrowband (1 GHz) signal path. The full capability of the EVLA's wideband (2 GHz) signal path cannot be exploited until the WIDAR correlator arrives. The gain-slope equalizers were ordered early in FY 2008 and were delivered to the NRAO in January.

The L352 round-trip-phase module was shown to meet specifications, and it was placed into production in February 2008. Six modules have been produced, but a subtle phase-wrap error has since been discovered in the module's firmware. A solution to this problem is being implemented in the firmware now, and full production will resume by November.

### *Fiber Optics*

Modules for the digital transmission system (DTS), formatter, and deformatter continue to be built to meet the antenna retrofitting schedule. The deformatters are actually being built ahead of schedule to accommodate testing of the prototype WIDAR correlator.

The order for the 3-bit, 4 Gsps digitizers was placed in late FY 2007, and engineering samples of the digitizer were received in June 2008. The samples recently passed laboratory tests conducted at the NRAO, and the production of the digitizers is now fully underway. The remaining digitizers in the order are expected to arrive in late September. The digitizers will be installed in sampler modules and will then be installed in antennas beginning November 2008.

### *Correlator*

The correlator chip manufacturer, iSine, delivered all 12,000 chips by April. Most were sent to MuAnalysis, a company specializing in integrated-circuit qualification, failure analysis, and screen testing, for device qualification to relevant standards well in advance of final board production.

The primary circuit boards in the correlator are the station board and the baseline board. The station board provides delay tracking and digital filtering for the correlator. The baseline board contains the chips that compute the correlations. The station board was tested and 14 pre-production boards were built. They are undergoing tests in Penticton. Testing of and design changes to the baseline board were completed. The fabrication of 14 more pre-production boards is underway. Six are scheduled for delivery in October, and the final eight will be delivered about a month later, after the first six are tested satisfactorily.

All 16 equipment racks for the WIDAR correlator were installed at the VLA site by the end of July 2008. The high-speed data cables connecting the correlator boards will be installed by the end of August.

A prototype correlator was installed at the VLA in June. It is being used for on-the-sky tests to verify that it works as a correlator with all the necessary functions in place. A "first fringes" observation with the prototype was successfully carried out. The tests are scheduled to occur through September 2008. The correlator critical design review should be complete by November, pending the successful completion of these tests.

### *Monitor and Control*

The EVLA Monitor and Control (M&C) group focused on three areas over the past year: additional capabilities for the EVLA antenna M&C system, maintenance of the transition observing system, and work on the EVLA correlator M&C system.

The additional capabilities of the EVLA antenna M&C system include new software for the module interface boards, the L350 central reference generator module, the L351 master offset generator, the L352 round-trip-phase modules, the M301 downconverter interface module, and the antenna control unit.

Maintenance of the transition observing system included new software and scripts that allow users to submit concatenated OBSERVE files for observing in separate VLA and EVLA sub-arrays during dynamically scheduled observations. A new release of the Alert Server improved alert handling within the EVLA operators' software. Two new standard releases of the EVLA Operators Software were made. The first added three new screens: a total-power detector screen, an EVLA antenna power-supply screen, and a power-supply screen for all EVLA antennas. The second included changes to the Alerts Screen, making it compatible with the latest version of the Alerts Server.

There was a considerable amount of work on the WIDAR M&C system. DumpTrig and delay-and-phase models were implemented for the station board and tested satisfactorily. Support for the correlator's module interface board was added for the new baseline board phased-array design. The graphical user interface for the correlator's retiming, crossbar, and phasing boards was completed. The core engine for Intelligent Diff was completed. The framework for correlator backend software was enhanced, including the incorporation of a head node for the compute-node processes.

A minimal version of the Science Data Model (SDM) has been incorporated into the data capture and format (DCAF) module of the M&C system. DCAF captures science metadata while observing scripts are executed, reformats them, and stores them in a set of tables that is the SDM. These data are then written to a staging area where they are ingested by the next-generation archiving system (NGAS) together with binary data from the correlator. This is a preliminary system intended for use in on-the-sky tests of the prototype correlator (PTC). However, it is now routinely being run on metadata from VLA observations. Our version of the SDM is also being used by ALMA at the ALMA Test Facility (ATF). A compatible version of the Binary Data Format (BDF) is also supported and has been tested with simulated data from the correlator subsystem. This combination of the SDM metadata and binary data has been successfully loaded into CASA using the same software filler that is being used by ALMA at the ATF. In preparation for on-the-sky testing of the PTC, a new NGAS server has been installed at the VLA. This is a smaller archive system that is intended as a staging area for science datasets.

An agreement between ALMA and EVLA on the BDF was written. The final version of the document defining the general SDM has also been a joint effort. EVLA personnel made extensive comments on the draft prepared by ALMA. The final version is scheduled for publication in September.

### *Science Support Systems (SSS)*

Over the past year, the SSS group concentrated on providing new tools for EVLA observing, primarily in the Observation Preparation Tool (OPT). The OPT consists of three main components: one for configuring instrumentation, one for maintaining catalogs of target sources and calibrators, and one for putting together actual observing programs. NRAO staff scientists have been testing each of these components. The instrument-configuration component is ready for use with EVLA antennas and the VLA correlator. The source-catalog component is also ready for use.

An expert-user interface for manipulating EVLA antenna electronics was made available within the OPT. Most users will be shielded from this part of the application. Expert users, though, will be able to tune each local oscillator independently and will eventually have access to all hardware switches.

A model and user interface for the VLA correlator is being added to support VLA Ka-band observing.

The "parminator" (a web-based interface used by operators to maintain many of the parameters essential to the operation of the EVLA) was completed, and the operators were trained to use it. The parminator supports some new parameters, has a much more rigorous error-checking and handling mechanism, and allows for batch input from a file, which is vital for pointing and baseline results.

A document describing the joint development of software tools for proposal submission, observation preparation, scheduling, data archiving, and data processing by ALMA, ELVA, and E2E was written in FY 2007. A more detailed document describing the interactions among the various Observatory groups in software development was planned as a joint effort. However, joint software development has been difficult because the projects are at different stages in their schedules and their limited resources have been devoted to achieving their own critical milestones. This second document was to have been written prior to the SSS design review (DR), but the DR will now proceed without it in November 2008.

Personnel assigned to the Observation Scheduling Tool (OST) were partially diverted to developing and maintaining Observatory-wide web pages, delaying the OST alpha release to December 2008.

### *EVLA Milestones from the 2008 Program Plan*

The project's performance on EVLA milestones from the 2008 Program Plan is listed below.

**EVLA Milestones for FY 2008**

| Item | Date Planned | Date Accomplished |
|---|---|---|
| 1. Start production of the M302/303 utility modules | 10/2007 | 12/2007 |
| 2. Start production of the gain-slope equalizers | 10/2007 | 11/2007 |
| 3. Relocate the deformatter racks to the new correlator room | 10/2007 | 09/2007 |
| 4. Complete the joint definition of the binary data format | 10/2007 | 04/2008 |
| 5. Develop a detailed plan for joint software development | 11/2007 | Joint task |
| 6. Start production of the Ka-band receiver | 11/2007 | 05/2008 |
| 7. Start production of the L352 round-trip-phase modules | 11/2007 | 11/2008* |
| 8. Fabricate prototype S-band OMT | 11/2007 | 12/2007 |
| 9. Fabricate prototype Ku-band feed horn | 12/2007 | 01/2008 |
| 10. Complete the joint definition of the Science Data Model | 12/2007 | 09/2008 |
| 11. Start production of the C-band OMT | 12/2007 | 05/2008 |
| 12. Start production of the 3-bit, 4 Gsps sampler | 01/2008 | 06/2008 |
| 13. Start production fabrication of the S-band feed horns | 01/2008 | 02/2008 |
| 14. Complete design of a waveguide-style X-band OMT | 02/2008 | 10/2008* |
| 15. Complete fabrication of the L-band feed horns | 02/2008 | 06/2008 |
| 16. Conduct science support systems (SSS) design review | 03/2008 | 11/2008* |
| 17. Conduct the correlator critical design review | 06/2008 | 11/2008* |
| 18. Make the alpha release of observation scheduling tool | 06/2008 | 12/2008* |
| 19. Conduct on-the-sky tests of the prototype correlator | 07/2008 | 07/2008 |
| 20. Complete prototype S-band receiver | 07/2008 | 10/2008* |
| 21. Start production of the L-band receiver | 08/2008 | 12/2008* |
| 22. Retrofit a total of 17 antennas to the EVLA design | 08/2008 | 08/2008 |

*Projected date.

# E. Telescope Operations

## E.1. North American ALMA Science Center (NAASC)

### Accomplishments and Highlights in FY 2008

The main NAASC activities in FY 2008 were: (1) updating the ALMA Operations Plan (AOP) and budget to version D; (2) making key NAASC appointments, including the new NAASC Assistant Director C. Lonsdale, the North American ALMA EPO Program Officer J. Stoke, and the NAASC Commissioning & Science Verification Liaison A. Remijan. Joint UVa/NAASC hires A. Evans and R. Indebetouw joined the NAASC staff in FY 2008; (3) testing, developing, and supporting several Beta Releases of the CASA offline software system, including the first fully open public release; (4) sponsoring the public beta release of the "Database for Astronomical Spectroscopy: *Splatalogue"*; (5) the NSF approving a subaward request for the University of Virginia Microfabrication Laboratory (UVML) to support SIS mixer development; and (6) holding the third NAASC Science Workshop *"Transformational Science with ALMA: The Birth and Feedback of Massive Stars, within and Beyond the Galaxy"*.

### Progress toward the FY 2008 Program Plan

#### *NAASC Science Operations*

The NAASC supports both internationally approved ALMA "core" operations as well as North American (NA) support operations outside the project-defined "core" elements. The former are organized through the NA ALMA Regional Center (ARC), and includes international project coordination and support tasks such as commissioning support, observing preparation, direct observing support (Astronomer On Duty in Chile and Quality Assurance), and post-observation support (offline software and archive). Activities beyond these core tasks include organizing the Canadian contribution to NA ALMA Operations, Community Development, and NA ALMA EPO.

At the start of FY 2008, NAASC personnel included Assistant Director C. Carilli, NA ARC Manager J. Hibbard, ALMA CASA subsystem scientist C. Brogan and a quarter-share of astronomer Steve Myers for CASA Science Support, a fraction of administrative assistant J. Neighbours, 0.5 FTE of business support, and a small fraction of the NA Project Manager A. Russell for help with the NA ALMA Development effort and overall NA coordination. James di Francesco (HIA/NRC) served as the Canadian ALMA Operations representative.

Several staff members joined NAASC Operations in FY 2008. Carol Lonsdale will replace NAASC AD Chris Carilli at the start of FY 2009 as he moves to the post of Observatory Chief Scientist. Also joining were joint NRAO/UVa hires Remy Indebetouw (October 2007) and Aaron Evans (January 2008). Anthony Remijan was recruited to serve as the ARC Commissioning and Science Verification (CSV) Liaison (June 2008). A second CSV liaison is still being recruited.

**International Coordination:** NAASC staff updated the ALMA Operations Plan (AOP) and budget to version D, incorporating the comments from the international panel that reviewed version C in February 2007. Corresponding changes were made to the NAASC plan and budget, incorporating comments from the North American panel review from March 2007. The ALMA Board accepted AOP version D in November 2007. The ARC manager worked with the new JAO (Joint ALMA Observatory) budget manager and the head of Technical Services to clarify the reasoning, justification, and methodologies used in developing the AOP, and to work towards developing the 2009 Chilean Operations plan and budget.

The Science Operations Integrated Project Team (IPT) was formed, following the recommendation of the AOP review panel. This group includes all three regional ARC Managers and key JAO staff. Its main charge is to implement the AOP. It met biweekly during the year and face-to-face each quarter. This group defined ARC CSV staffing requirements and turno guidelines, Operations software commissioning needs, ALMA helpdesk requirements, and ARC archive implementation plans. International search committees were set up to recruit the first group of JAO Operations Astronomers, and six were hired.

**Canadian Partnership:** The Canadians are a contributing partner with the NRAO in the international ALMA project. The "Memorandum of Understanding" (MOU) between NRAO/AUI and NRC/HIA was revised and has been signed by NRAO and forwarded to HIA/NRC for signature. Under this agreement, Canadian contributions to ALMA Operations activities taking place in Chile or as part of Board-approved ALMA development will be in cash, while contributions to ALMA core support (including hardware and software maintenance and repair) can be in kind.

**Software Testing:** In FY 2008, NAASC staff members participated in extensive software testing, including:

- Pre-release testing of the CASA software for the Beta release (October 2007)
- Pre-deployment testing of the CASA helpdesk (October 2007)
- ALMA Pipeline User Test 5.0 (December 2007)
- ALMA Archive User Test 1.0 (January 2008)
- Pre-release testing of the CASA software for the Beta release Patch 1 (March 2008)
- Pre-release testing of the CASA software for the Beta release Patch 2 (June 2008)
- Testing the ALMA simulator for CASA Beta release Patch 2 (June 2008)
- ALMA ObsTool User Test 5.0 (June 2008)
- Pre-release testing of the CASA software for the Beta release Patch 3 (September 2008)

Participation of NAASC staff is meant to ensure readiness of the software for early science and to familiarize NAASC staff with the software.

The Common Astronomy Software Applications (CASA) is the offline data reduction and analysis software package being jointly developed for ALMA and EVLA[1]. The NAASC science support of the CASA software system is quite extensive and is led by ALMA CASA Subsystem Scientist C. Brogan. Brogan represents ALMA on the "CASA Cabal", the group of NRAO scientists charged with prioritizing software development targets and organizing software testing, releases, and tutorials. The NAASC supports (with EVLA) the CASA Project Scientist S. Myers to manage the CASA Cabal. He also generated release notes and FAQs and upgraded the ALMA Cookbook at each major release. The Beta releases of the CASA software are of particular importance. The first Beta release in November 2007 was to volunteers from the regional ALMA scientific advisory committees, the NRAO users committee, and EVLA science advisory committees. This release was for a limited number of platforms and to a limited number (about 25) of users. A helpdesk and triage system was established for this release and supported primarily by NAASC personnel. Beta release Patch 1 occurred in March 2008, in preparation for the NRAO Synthesis Imaging Workshop. The Patch 2 release occurred as scheduled shortly after the Synthesis Imaging workshop, in July 2008. This release was made available for twice the number of platforms, and was the first fully open public release. Preparations and testing for the Patch 3 release were underway at the close of the fiscal year. At this time, CASA functionalities encompass many high-level ALMA requirements, such as mosaicing, inclusion of zero spacing flux, single-dish processing,

[1] The ALMA share of CASA software development is supported under "ALMA Technical Support," while scientific testing of CASA against ALMA requirements is a core support item in the NA ARC. CASA software development activities are described elsewhere in this document.

interactive cleaning, interactive and automatic data editing, and fully scriptable task-based interface through ipython. CASA is now available for download to any interested parties from http://my.nrao.edu.

**Commissioning and Science Verification (CSV) Support:** NAASC scientists take part in CSV as a means to train for ALMA operations. In FY 2008 this involved taking part in turno staffing of the ALMA Test Facility in Socorro. This activity includes prototype-antenna and software testing and debugging, to gain familiarity with the system and train for eventual work in Chile, and testing the functionality of CASA to import and analyze real ALMA data. Key achievements include producing the first interferometric spectrum and obtaining single-antenna spectra of the SiO maser line at 86 GHz to test spectral-line pointing of individual antennas. In FY 2008 four NAASC personnel (Carilli, Brogan, Indebetouw, and Remijan) participated. NAASC staff also participated in monthly meetings of the Science IPT, considering the scientific impact of issues arising during the constructon project, such as array configuration, receiver characteristics, polarization requirements, and the like.

**User Support:** Training of external users commenced in FY 2008 with two major CASA tutorials sponsored in part by the NAASC. The first was a two-day tutorial held in mid-October in Socorro for representatives from the NA, EU, and EA ARCs, ALMA commissioning personnel, and EVLA scientific staff to train User Support Specialists for CASA. The second was held as part of the NRAO Synthesis Imaging Summer School in June 2008. At this second tutorial, about 50 workshop participants used CASA to reduce VLA HI spectral-line, VLA continuum polarization, and BIMA millimeter CO line data.

NAASC staff participated in "lessons learned" sessions on science-user support, archive support, and helpdesk implementation, at STScI (Hibbard, February 2008), the Spitzer Science Center (Evans, extended visit in spring 2008), and ESO (Hibbard, June 2008). A. Evans reviewed the NAASC Science User web pages. R. Indebetouw provided CASA testing, helpdesk support, and extensive development input to the CASA ALMA simulator, enabling its inclusion in the CASA Beta Patch 2 release in July 2008.

**Community Relations and the ANASAC:** The ALMA North American Science Advisory Committee (ANASAC) remains the primary means of communication between the NAASC and the user community, and it is an important resource to the NA members of the ALMA Science Advisory Committee (ASAC). This year, the ANASAC was reorganized to have a more formal charge-and-response format parallel to that of the ASAC for the ALMA Board. The ANASAC provided written inputs on ALMA "user grants," pre-ALMA science initiatives, the NA aspect of the ALMA development program, and the disposition of the NA ALMA prototype antennas. It also reviewed its membership and Terms of Reference.

The ANASAC organized and set the scientific program for the 3rd NAASC Science Workshop *"Transformational Science with ALMA: The Birth and Feedback of Massive Stars Within and Beyond the Galaxy"*, held in Charlottesville in September 2008. This meeting continues the successful series of scientific workshops begun in 2006 to promote and refine the scientific use of ALMA. Owing to the strong initial response, the meeting venue was changed to accommodate ~130 participants (compared to ~85 for past NAASC Science Workshops).

NAASC staff provided material for and gave presentations to a number of committees throughout the year, including the ASAC, the NRAO Visiting Committee, the NRAO User Committee, the AUI Milkey committee, and the AUI co-operative agreement review panel. They also hosted face-to-face meetings of both the ANASAC and the ASAC.

NAASC staff attended meetings and gave science talks featuring discussions of the potential for ALMA. At the 211th AAS meeting in Austin TX, Carilli participated in the NRAO Town Hall, Remijan gave a presentation on *Splatalogue*, and Brogan gave a plenary talk on "Massive Star Birth and the promise of ALMA" to a packed crowd. Other visits included the Naval Research Lab (Carilli), the Harvard Sackler

Cosmology symposium (Carilli), an ESO workshop on 3D Visualization (Hibbard), a CCAT workshop "Spectrometry with CCAT: Science and Instrumentation Opportunities" (Brogan), Peking University (Evans), and the *63rd International Symposium on Molecular Spectroscopy* (Remijan). Brogan and Evans gave talks at the Bilateral China-US Workshop on Radio Astronomy held in Beijing, China. Finally, Carilli and Brogan gave lectures at the NRAO Synthesis Imaging Summer School in Socorro.

**Education and Public Outreach:** For most of the year, the NRAO EPO office represented ALMA at national (e.g., AAS) meetings, in NRAO EPO materials, and on the ALMA EPO Working Group. They supervised the shooting of a documentary on the ALMA project and planning for the International Year of Astronomy. For more details, see the EPO section of this report.

John Stoke, formerly of STScI, joined NRAO as the NA ALMA EPO Program Officer. John assumed responsibility for NA representation on the ALMA EPO Working Group starting with the face-to-face meeting in August 2008 in Charlottesville, and he spent the last quarter reviewing the international and NRAO ALMA web pages, particularly those related to user interfaces. He also developed a comprehensive NA ALMA EPO short-term plan including U.S., NA, Chilean, and International activities. This position was filled much later than expected, so many of the activities described in the FY 2008 Program Plan will be carried out in FY 2009.

### *ALMA Special Projects*

This business unit supports work that is viewed by the NRAO as critical to ALMA's success but is not delineated in the AOP as part of the international operations functions. It currently includes two projects: (1) SIS mixer development and (2) the molecular and atomic spectral-line database *Splatalogue*.

**SIS Mixer Development:** The international project has recognized that ALMA operations must support continuing R&D for SIS mixer development. State-of-the-art SIS mixers are key to the unprecedented sensitivities that will be achieved with the ALMA receivers. Future developments in SIS mixer technology will bring substantial improvements to ALMA receivers, particularly for ALMA Bands 9 and 10. The Band 9 mixer being provided by the construction project will be a double-sideband system, which is not ideal for spectral-line identification, and only one SIS mixer ever built meets the demanding specifications for Band 10. Thus improving receivers for these bands is a high priority for the ALMA development program. The ultimate goal is a low-noise wideband SIS mixer for 780–950 GHz ($\lambda$ = 350 μm). One of only two existing SIS foundries in the U.S., the University of Virginia Microfabrication Laboratory (UVML) has developed a very stable and repeatable process for making Nb-based SIS mixers and is a critical resource for U.S. astronomy and for ALMA. Recently, the UVML demonstrated stable, small area SIS junctions with AlN tunnel barriers and also reproducible thin films of NbTiN with high superconducting critical temperature, both of which are believed to be essential to successful receivers for Band 10.

The FY 2008 Program Plan proposed that the NAASC would support the UVML to continue development of Nb/Al-AlN/NbTiN SIS junctions. However, the new 5-year NRAO-UVML support contract was delayed by the National Science Board's resolution NSB/CPP-07-34 on December 6, 2007 requiring that AUI competitively bid technology-development initiatives associated with the operation of ALMA. In June the NSF approved a subaward request for the UVML to continue its development of the new technology for Band 10 and also to manufacture and supply replacement SIS mixer chips for ALMA. The subaward is for five years. Late in the FY 2008 an MOU between the NRAO and the UVa was signed, and the accompanying contractual structure between the parties was solidified.

**Splatalogue:** The NAASC has supported the construction of the "Database for Astronomical Spectroscopy: *Splatalogue*" that is now the world's most complete database of molecular transitions from mm to submm wavelengths. This database is essential for the full utilization of ALMA as a spectral-line

instrument. A. Remijan led this work on behalf of the NAASC. The "beta" release of *Splatalogue* occurred on February 1 (http://www.splatalogue.net). The release demonstrated the capabilities of the database to search through all available line catalogs and introduced a new catalog to the community, the Spectral Line Atlas of Interstellar Molecules (SLAIM; F.J. Lovas). It included a complete list of frequencies of H, He, and C recombination lines, added newly detected transitions to the Lovas list of detected astronomical transitions, and provided a limited sample of species (about 200 out of 650) for which the quantum numbers in all four major catalogs were resolved. It reports the line-strength and energy levels in all useful astronomical units, and provides the community with NRAO-recommended rest frequencies for molecular transitions.

Feedback was sent to the ALMA Working Group on Spectral Line Frequencies, and updates and corrections continued throughout the year. Remijan traveled to universities and observatories operating instruments in the radio to submm regimes to introduce and demonstrate *Splatalogue*.

### *Office of Chilean Affairs (OCA)*

The OCA is a small office in Santiago, Chile, that handles the legal and business affairs of AUI/NRAO, including representation of ALMA to the Republic of Chile for AUI and support for JAO staff. In the FY 2008 Program Plan, we anticipated that this office would transfer from the ALMA Construction project to the NAASC budget as operations activities ramped up. As part of updating the AOP from version C to D, it was decided that this office should remain focused on construction issues until 2011, at which time it will transfer into NA operations. Therefore there was no OCA activity within the NAASC this year.

### *ALMA Technical Support*

This business unit provides technical support to the ALMA Observatory. In FY 2008 this only involved support for the ALMA-specific development of the CASA offline software system. The NAASC shares this support with the EVLA, with the NAASC share accounting for 3 FTEs of effort from six scientific programmers and software developers. These developers generated the software to meet the ALMA offline subsystem requirements, responded to bug reports, and supported the CASA work described above (CASA beta releases and patches, tutorials, CASA tests, the ALMA simulator development).

### *ALMA Development Support*

This business unit supports North American development efforts. No activity was planned for FY 2008, apart from development discussions with the ANASAC, ASAC, and at the NAASC Science Workshops.

### *ALMA Chilean Operations*

The major NAASC budget element is for the NA fraction of the operations costs of the Joint ALMA Observatory (JAO) in Chile, accounting for 66% of the expended NAASC budget in FY 2008. JAO Operations activities are reported monthly to the ALMA Board. A main achievement in FY 2008 was the hiring of key operations staff including: an interim Director (T. de Graauw), the Head of Technical Services (R. Prestage), the first contingent of the Array Operations Group (manager, deputy, and operators) and their deployment to the ATF in Socorro for training, and the first six operations and systems astronomers into the Department of Science Operations. Other major accomplishments include participation in CSV activities at the ATF, the acceptance of the Operations Support Facility; the acceptance and first use of the Antenna transporter; setting up key operations contracts for operations support, such as catering, cleaning, facility maintenance, security, safety, etc.

Compared to the original plan (as described in the ALMA Operations Plan, version D), the JAO spent less than budgeted, due to a much shallower hiring profile (56 operations staff in post at the end of FY 2008 compared to the AOP plan of 85). This results in a savings to NAm of ~$740k over the FY.

### *NAASC Milestones from the 2008 Program Plan*

The project's performance on NAASC milestones from the 2008 Program Plan are listed below. All milestones concerning the UVML work are reported in Section F.2 of this report.

**NAASC Milestones for FY 2008**

| Item | Date Planned | Date Accomplished |
|---|---|---|
| 1. Advertise for Scientist 4 (CSV liaison) | 10/2007 | 10/2007 |
| 2. Advertise for Scientist 5 (CSV liaison) | 10/2007 | 10/2007 |
| 3. CASA tutorials for beta testers (Socorro) | 10/2007 | 10/2007 |
| 4. Start ARC participation in AIV/CSV to train for operations (ATF trips) | 10/2007 | 10/2007 |
| 5. CASA beta release | 10/2007 | 11/2007 |
| 6. Participate in Pipeline Test 5 | 11/2007 | 12/2007 |
| 7. Advertise for Scientist 6 (CASA) | 04/2008 | 12/2007 |
| 8. Spectral-line catalog beta release | 12/2007 | 02/2008 |
| 9. Science center visits – Herschel | 11/2007 | Canceled |
| 10. Start NA Development Planning (charges to ANASAC & ASAC) | 04/2008 | 01/2008 |
| 11. New ALMA EPO hire | 04/2007 | 03/2008 |
| 12. Testing for CASA beta patch 1 | 03/2008 | 03/2008 |
| 13. New NAASC hire: CSV Liaison Scientist No. 1 | 04/2008 | 03/2008 |
| 14. Software testing: CASA beta release, patch 1 | 06/2008 | 05/2008 |
| 15. Release CASA ALMA simulator to community (web-based form) | 01/2008 | Canceled |
| 16. Release of CASA ALMA Simulator (CASA tasks) | 07/2008 | 06/2008 |
| 17. Software testing: CASA beta release, patch 2 | 09/2008 | 05/2008 |
| 18. Software testing: ObsTool Test 5 | 02/2008 | 06/2008 |
| 19. Update Offline software cookbook | 10/2008 | 06/2008 |
| 20. CASA tutorials (at NRAO Synthesis Imaging School) | 04/2008 | 06/2008 |
| 21. CASA beta release, patch 2 | 10/2008 | 07/2008 |
| 22. Complete MOU with Canada for ALMA Operations | 10/2007 | 08/2008 |
| 23. ANASAC face-to-face meeting in Charlottesville | 08/2008 | 09/2008 |
| 24. 3rd NAASC Science Workshop | 05/2008 | 09/2008 |
| 25. New NAASC hire: CSV Liaison Scientist No. 2 | 12/2007 | readvertise |
| 26. Software testing: ObsTool Test 6 | 08/2008 | delayed |
| 27. Advertise for Archive Tech 1 | 06/2008 | delayed |
| 28. ARC participation in CSV at OSF | 05/2008 | delayed |
| 29. Decision on NA ALMA archive – buy or outsource | 05/2008 | delayed |
| 30. Participate in Pipeline Test 6 | 05/2008 | delayed |

## E.2. Green Bank Telescope (GBT)

### Introduction

The Robert C. Byrd Green Bank Telescope (GBT) is the world's premiere single-dish radio telescope operating at centimeter-millimeter wavelengths. The GBT is in robust, routine, and effective operation at frequencies up to 50 GHz, ($\lambda \geq 6$ mm), and initial 90 GHz ($\lambda = 3$ mm) operations have commenced with the MUSTANG bolometer array camera.

### Accomplishments and Highlights in FY 2008

- Astronomical commissioning of the Zpectrometer wideband spectrometer and the MUSTANG bolometer array
- Further development and beta testing of the new dynamic scheduling system (DSS)
- Major antenna performance improvements, including servo upgrades and increased surface efficiency via traditional holography and out-of-focus holography
- Development and initial tests of an advanced pulsar backend using a new, agile approach to FPGA development
- Commencement of work on a seven-pixel dual-polarization K-band focal-plane array (KFPA) in collaboration with the CDL.

Acceleration of the antenna-performance project and the KFPA made use of funds resulting from the azimuth-track settlement.

Each of these activities is described in more detail below, with a complete list of milestones in the following table.

### Progress toward FY 2008 Program-Plan Objectives

#### *Zpectrometer for Ka band (26–40 GHz)*

The Zpectrometer is a wideband analog spectrometer constructed by a team at the University of Maryland headed by Prof. Andy Harris. This instrument was described in detail in the FY 2007 Program Plan. The Zpectrometer was completed and underwent initial engineering commissioning in FY 2007. Astronomical commissioning and science verification was completed in FY 2008, and the instrument has been released for shared-risk observing in FY 2009.

#### *MUSTANG*

FY 2008 was an exciting year for MUSTANG (formerly called the Penn Array), the GBT's first $\lambda = 3$ mm instrument, as engineering commissioning was completed and MUSTANG began the transition to a full user instrument. Both instrumental sensitivity and vibrational isolation were improved substantially over the previous season. The initial monitor-and-control software for MUSTANG was completed, replacing NASA's interim java-based software used for commissioning, so the instrument is ready for shared-risk observing beginning in FY 2009. During this period the GBT is expected to have its present ~10% aperture efficiency at 3 mm; even so, the its effective collecting area is equal to that of the next-largest millimeter facility and a wealth of unique science observations are possible. Initial tests utilizing MUSTANG as an out-of-focus (OOF) holography instrument in FY 2008 indicate that this array could quickly produce GBT surface maps for active-surface control in real time.

MUSTANG was designed with a larger bolometer array in mind. The current Dewar and electronics can accommodate a 16×16 (256 pixel) array. In FY 2008 we worked with NASA and NIST to begin the upgrade.

### *Dynamic Scheduling System (DSS)*

The GBT has a limited form of dynamic scheduling in which high-frequency and low-frequency projects are paired over two days, and the high-frequency observers choose which day they will use. Optimal use of the GBT for high-frequency observing requires full dynamic scheduling, and the DSS project to enable this was initiated in FY 2007. Work continued in FY 2008 with the most significant accomplishment being a four-month test on the GBT of the DSS algorithms and beta-version software.

### *Continued Telescope Performance Improvements*

The goal of the Precision Telescope Control System (PTCS) project is to enable full $\lambda = 3$ mm operation of the antenna. Progress on the PTCS project ramped up again in FY 2007, and that momentum continued through FY 2008, augmented by three new engineers supported by the azimuth track settlement funds. Work focused on three main areas: servo improvements, out-of-focus (OOF) holography, and traditional holography. The servo team completed the PLC interlock upgrade project, improved the servo command trajectory, and improved the tracking at low azimuth rates by adding a friction compensator.

The OOF holography team developed a staff-operable routine that can obtain and analyze the data needed to correct thermal deformations of the telescope. Both holography teams moved forward in using the MUSTANG out-of-focus maps combined with traditional Q-band maps to provide fast, accurate surface corrections, a significant move toward making "real-time" corrections to the GBT surface. The traditional holography team also identified the location for a new, permanently mounted, holography receiver and made the final, iterative determination of precise actuator zero-points at the end of FY 2008.

### *CICADA/Next Generation Pulsar Backend*

As a result of the September 2006 Future Instrumentation Workshop, Green Bank initiated a new development program in FY 2007 called CICADA (Configurable Instrument Collaboration for Agile Data Acquisition). The initial instrument developed for the GBT will be the "next generation" pulsar back end. This instrument is described in the FY 2008 Program plan. The engineering of an initial (filter bank only) version of the back end was completed in FY 2008. Shared risk release of the first observing mode (800MHz, Full stokes) occurred at the end of FY 2008. The testing and commissioning of additional modes system will be done in early FY 2009, and the initial version should be released during that time.

Also as part of the CICADA program, in FY 2008 we performed the conceptual design study for an advanced spectrometer to make full use of the K-band focal plane array described below.

### *K-band (18–26 GHz) Focal-Plane Array (KFPA)*

The combination of high sensitivity, unblocked aperture, and wide field-of-view of the GBT is ideally matched to focal-plane array receivers. Large spectroscopic focal-plane arrays at centimeter and millimeter wavelengths will bring a powerful new set of scientific capabilities to the GBT, both as a stand-alone instrument and in combination with the EVLA and ALMA interferometers. In collaboration with the CDL we began work on an initial seven-element K-band (18–26 GHz) focal-plane array, supported via a combination of operations and azimuth track settlement funds. A complete description of this instrument is in the FY 2008 Program Plan. During FY 2008 we made significant progress on this instrument, with the development of the full science plan, initial work on the software data-reduction

pipeline, and full development of the first beam of the array. The first beam will be commissioned in early FY 2009, and the array should be ready for commissioning by FY 2010.

### *University Collaborations*

We continue to provide limited amounts of staff effort to assist a variety of university groups with experiments that take advantage of Green Bank facilities and the unique National Radio Quiet Zone. Examples include collaborations with West Virginia University to develop pulsar instrumentation for the 43 m as part of the CICADA program, a wideband receiver for pulsar tomography built by students at the Raman Research Institute, and collaboration with Brigham Young University to develop advanced RFI-mitigation techniques. This last project will use the 20 m telescope as a test bed for array feeds on large reflectors coupled with adaptive signal processing for RFI removal.

### *Externally Funded Projects*

The NRAO and Lincoln Laboratories continued operation of the 43 Meter Telescope under memorandum of agreement to measure the properties of the Earth's ionosphere using bistatic radar.

PAPER, the Precision Array to Probe the Epoch of Reionization, is a joint project developed by the University of California at Berkeley with NRAO collaboration. PAPER had another successful year at the Green Bank site. The project is currently being transported to its final destination in Australia.

The Solar Radio Burst Spectrometer, which uses the refurbished 14m antenna at Green Bank, obtained funding from the NSF ATM division for an additional five years of operation. During 2008 it also had a successful fourth year of operation.

### *Work with other NRAO Telescopes and Divisions*

Green Bank staff collaborated with NRAO's Office of End-to-End (E2E) Operations in FY 2008 to take maximum advantage of E2E work. In particular, Green Bank staff worked hand-in-hand with the E2E team on the GBT dynamic scheduling project, future data-reduction software plans, and the proposal submission tool.

Green Bank staff also worked on projects for ALMA and the EVLA in FY 2008. For ALMA, Green Bank staff provided technical design, prototyping, testing, repair, and support for the ALMA bias boxes; provided engineering support for the ALMA foundation work; built a Band 6 Dewar, and provided station pins and panels, parts for the front-end bias system, and a number of other parts for ALMA telescopes. For the EVLA, Green Bank staff built a variety parts for the L-, C-, S-, X-, Ku-, K-, and Ka-band receivers, from the feeds themselves to feed towers, OMTs, and test fixtures. Additionally, one of the Green Bank microwave engineers was a part of the EVLA microwave team for all of FY 2008.

### *GBT Milestones from the 2008 Program Plan*

The table below summarizes performance against milestones from the 2008 Program Plan for all GBT projects, including both original milestones and intermediate milestones identified throughout the year.

**GBT Milestones for FY 2008**

| Item | Date Planned | Date Accomplished |
|---|---|---|
| **Dynamic Scheduling System** | | |
| 1. Complete trial run of new scheduling algorithms | 04/2008 | 09/2008 |
| 2. Incorporate feedback from trial run into system design | 08/2008 | FY 2009 |

| Item | Date Planned | Date Accomplished |
|---|---|---|
| **Zpectrometer** | | |
| 1. Astronomical commissioning complete | 05/2008 | 05/2008 |
| **MUSTANG** | | |
| 1. Commence second-year commissioning observations | 12/2007 | 12/2007 |
| 2. Acquire MUSTANG data with GBT-standard M&C software | 01/2008 | 03/2008 |
| 3. Acquire first science data with MUSTANG | 03/2008 | 02/2008 |
| **Precision Telescope Control System** | | |
| 1. Traditional holography hardware and telescope preparations complete | 01/2008 | 05/2008 |
| 2. Traditional holography deployment and engineering tests | 05/2008 | 09/2008 |
| 3. Out-of-focus holography: advanced algorithm prototyping | 05/2008 | 07/2008 |
| 4. Out-of-focus holography: advanced algorithm deployed | 09/2008 | 07/2008 |
| 5. Servo upgrades and PLC interlocks upgrade complete | 06/2008 | 07/2008 |
| 6. Servo performance improvements for low-speed tracking | 09/2008 | 07/2008 |
| **CICADA (FPGA Development) Program** | | |
| 1. Incoherent pulsar backend prototype complete | 01/2008 | 04/2008 |
| 2. Incoherent pulsar backend deployed | 06/2008 | 09/2008 |
| 3. Advanced Spectrometer design document complete | 05/2008 | 08/2008 |
| **K-band (18–26 GHz) Focal Plane Array** | | |
| 1. Project initiation | 10/2007 | 10/2007 |
| 2. Scientific requirements complete | 12/2007 | 12/2007 |
| 3. Conceptual design review | 03/2008 | 03/2008 |

## E.3. Very Large Array (VLA)

### Accomplishments and Highlights in FY 2008

#### *Observing and User Programs*

The three large VLA proposals emphasizing the C and D configurations that were mentioned in the FY 2008 Program Plan were considered by our review process, as promised. Two, both focused on HI in dwarf galaxies, were accepted and are receiving observing time. The June 2008 deadline resulted in three new large proposals (1 VLBA and 2 VLA), which will be reviewed in August. As of the June 2008 deadline, large proposals may be submitted with ordinary proposals under the regular trimester system.

As yet, we have not found it necessary to abandon the regular VLA configuration rotation pattern.

The 11$^{th}$ Synthesis Imaging Workshop was held successfully in June and attended by nearly 150 people.

#### *EVLA Transition*

As promised in the FY 2008 Program Plan, the VLA now consists of a majority of EVLA-configured antennas: as of late July 2008, 16 EVLA antennas are operating in the array. Antenna retrofits are on schedule to meet the goal of having the 17$^{th}$ EVLA antenna returned to the array by the end of FY 2008.

The prototype WIDAR correlator was delivered in June, and "on-the-sky" tests began in early July.

As of late July, 16 (rather than 15) EVLA antennas offer users wider tuning capabilities at L (1–2 GHz), C (4–8 GHz) and K (18–26.5 GHz) bands than their VLA counterparts.

### *Dynamic Scheduling*

We have exceeded the stated Program Plan goal of scheduling ~20% of the VLA's observing time dynamically; approximately 40% of the VLA's time is now dynamically scheduled. Doing so is important since it allows us to optimize science returns during the VLA/EVLA transition and to prototype our scheduling process for eventual EVLA operations.

### *Infrastructure*

Slightly more than 4000 railway ties were replaced during CY 2007 as planned, and the anticipated intersection repairs were carried out.

New Mexico Tech is now scheduled to begin connecting the Domenici Science Operations Center—DSOC (formerly the Array Operations Center) to the university chiller loop sometime this fall. The exact scheduling is now in the hands of the university physical plant, which is responsible for the operational integrity of the DSOC's heating and cooling system and for carrying out the connection process, so we will no longer track this item as a milestone.

As planned, AIPS version 31DEC07 was frozen and made available to the user base. Daily updates of version 31DEC08 were initiated.

We remain on schedule to replace the azimuth bearing on Antenna 28 by the end of FY 2008. The antenna began its mechanical overhaul (the first stage of its EVLA upgrade) on July 2. Ten digital tachometers have been installed on EVLA antennas, and the eleventh will be installed on Antenna 28 in September.

### *VLA Milestones from the 2008 Program Plan*

The following table reproduces the list of major FY 2008 milestones for the VLA, as given in the 2008 Program Plan, together with the performance on those milestones. Most milestones were accomplished on or near their planned dates. Variances are addressed in the text above.

**VLA Milestones for FY 2008**

| Item | Date Planned | Date Accomplished |
|---|---|---|
| 1. Return the 13th EVLA antenna to the VLA | 11/2007 | 12/2007 |
| 2. Freeze AIPS version 31DEC07, begin version 31DEC08 | 12/2007 | 12/2007 |
| 3. Replace 4,000 railroad ties in CY 2007 | 12/2007 | 12/2007 |
| 4. Offer wider frequency coverage with 12 EVLA antennas | 06/2008 | 05/2008 |
| 5. Replace one azimuth bearing (provisional) | 09/2008 | 09/2008 |
| 6. Return the 17th EVLA antenna to the VLA | 09/2008 | 08/2008 |
| 7. Install the 11th digital tachometer on an EVLA antenna | 09/2008 | 09/2008 |
| 8. Connect AOC to the NM Tech chiller loop (provisional) | 09/2008 | 09/2008 |

Notes:
4, 5, 6, 7, and 8. Still on track for completion on or before planned dates, as of July 2008.
8. Schedule subject to change by New Mexico Tech Facilities Management. See text.

# E.4. Very Long Baseline Array (VLBA)

## Accomplishments and Highlights in FY 2008

### *Observing and User Programs*

The FY 2008 Program Plan discussed four large VLBA programs. All four were initiated as planned.

The Program Plan also called for the start of GLAST-related collaborative observations in April 2008. Most involve radio observations concurrent with the satellite's survey mission or triggered by gamma-ray outbursts. The start of these observations was delayed as the GLAST launch date slipped. GLAST was finally launched on June 11, and NASA intends to begin releasing data under its collaborative program in August. At that point we expect to begin supporting coordinated radio observations. GLAST has recently been renamed the Fermi Gamma-ray Space Telescope.

### *Mark 5 Recording System*

The FY 2008 Program Plan noted that Mark 5C development was still in the planning stages and did not provide any additional details. Since then, three Mark 5C units were purchased and installed at the VLBA correlator to facilitate testing of the prototype digital backends (see *Sensitivity Enhancements* below). Motherboards on ten VLBA playback units were upgraded to allow use with the software correlator.

### *Sensitivity Enhancements*

Notable progress in the VLBA sensitivity upgrade was made relative to the baseline given in the FY 2008 program plan. The upgrade is funded by the settlement of the warranty claim on the GBT track.

We have verified that the VLBA software correlator can process VLBA data at a sustainable rate of 128 Mbps; the upgraded correlator has been shown to do the same at 512 Mbps.

We also collaborated with Haystack Observatory to obtain successful 4 Gbps test observations using loaner Mark 5C and digital backends provided by Haystack to six VLBA antennas. However, delivery of our order for prototype VLBA digital backends is four months late as the result of problems experienced by the contractor. The prototypes are now expected in August 2008.

The upgrade of all ten VLBA 22 GHz receivers, conducted in collaboration with the Max Planck Institut für Radioastronomie, was completed in December 2007, three months ahead of schedule.

### *Infrastructure*

The FY 2008 Program Plan presciently noted that the increasing failure rate of our 1990's-vintage hydrogen masers might cause the VLBA to run out of spare masers at some point during FY 2008. This in fact occurred midway through the fiscal year, and emergency Observatory funds were used to purchase a replacement. The new maser arrived and was placed in service in March 2008.

As indicated in the FY 2008 Program Plan, the Focus Rotation Mount (FRM) drive-replacement program made little progress, owing to funding limitations.

The maintenance site-visit schedule presented in the FY 2008 Program Plan, and its associated subreflector and azimuth drive wheel assembly replacement program, had to be modified to accommodate

critical maintenance and repair needs that arose after the start of the fiscal year. (This is not uncommon, and such flexibility is an integral part of the VLBA's operational model.) Two primary factors drove changes in the activities planned for FY 2008: (1) The Saint Croix rustproofing/painting campaign took longer and cost more than originally envisioned; as a result, some mechanical overhaul items for this antenna, including replacement of the subreflector and azimuth wheel assemblies, were deferred to a site visit now planned for the beginning of FY 2009. (2) Replacement of the Fort Davis elevation bearing (cited in the Program Plan as a desirable activity if funding were available) became a critical priority after the bearing showed signs of incipient failure in February 2008.

As a result of these developments, wheel assemblies on the North Liberty, Owens Valley, and Pie Town antennas were replaced as planned, but the replacement of the St. Croix azimuth-wheel assembly and subreflector were deferred until October 2008. The work at the first two sites was carried out as part of dedicated Tiger Team visits, whereas the Pie Town wheel assembly work (and other major maintenance work during the remainder of FY 2008) is being done on maintenance days by Socorro personnel; this avoids taking the antenna out of service. The Tiger Team maintenance visit to Los Alamos planned for FY 2008 has been deferred owing to the need to repair the Fort Davis elevation bearing.

### *VLBA Milestones from the 2008 Program Plan*

The following table is the list of major FY 2008 milestones for the VLBA, as given in the 2008 Program Plan, together with the performance on these milestones. Schedule variances are discussed above.

**VLBA Milestones for FY 2008**

| Item | Date Planned | Date Accomplished |
|---|---|---|
| 1. Production 128 Mbps correlation with the software correlator | 11/2007 | 02/2008 |
| 2. Completion of St. Croix rustproofing | 12/2007 | 12/2007 |
| 3. Completion of the 22 GHz receiver upgrade | 02/2008 | 12/2007 |
| 4. First observing for the collaborative GLAST program | 04/2008 | 08/2008 |
| 5. First digital backend board for the LBA | 04/2008 | 09/2008 |
| 6. Install refurbished subreflector at St. Croix | 09/2008 | 10/2008 |
| 7. Major maintenance visits to OV, LA, NL, and SC | 09/2008 | 07/2008 |
| 8. Replace four azimuth drive wheel assemblies | 09/2008 | 10/2008 |

Notes:
4. Delayed by NASA launch-date slippage. Launch occurred June 11, 2008.
5. Delayed by contractor board delivery.
6 and 8. St. Croix mechanical maintenance repair slipped by one month to October 2008 (start of FY 2009) because of the unexpectedly costly painting/rustproofing campaign in December 2007 and because of unplanned replacement of the Fort Davis antenna elevation bearing (see text above).
7. PT work is being done out of Socorro; LA postponed to support FD (see text).
8. Three wheel assemblies replaced as of 06/2008 (see text).

# F. Scientific and Technical Support Services

## F.1. End-to-End Operations (OEO)

### Introduction

The Office of End-to-End Operations (OEO) has as its primary goal broadening access to NRAO facilities and resources through continued application of the "One Observatory" philosophy. To do this, OEO works in the areas of archive and pipeline operations, proposal operations, data processing, and other site-specific software areas that have the potential to broaden access when implemented more globally. OEO focuses on successful technology transfer from development to operations, taking an integrated approach that recognizes the dynamic interactions between researchers and the systems they use for scientific investigation.

### Accomplishments and Highlights in FY 2008

OEO work in FY 2008 included incrementally advancing archive and pipeline operations, proposal operations, and the National Virtual Observatory (NVO) project through standards development and involvement in facility planning. Several data-processing milestones were also achieved for the EVLA and ALMA this year, including the beta release and first public release of CASA in July.

Processing of the VLA data archive yielded an additional 30,000 historical continuum images that were published to the Virtual Observatory (VO) collection, bringing the total number contributed by the NRAO to over 125,000. Continuing to bridge the gap between E2E and education and outreach, the NRAO also launched its first collection of radio skymarks to Google Sky. This broadened access to the Observatory's radio images to over 4 million users in January 2008. The first end-to-end view of NRAO resources (including data, observations, proposal cover sheets, and pipeline-processed images) was presented in the release of the Data Vault archive interfaces at http://archive.nrao.edu in May 2008. Archive infrastructure continued to develop in the background to support these new information access points, and the strategic alliance with the National Center for Supercomputer Applications (NCSA) continued. Using the NCSA for long-term data curation was shown to be an extremely promising option, with costs on the order of 10% what it would take for the NRAO to support such services independently.

In FY 2008 the NRAO supported three proposal deadlines: October 2007, February 2008, and June 2008. Enhancements to the proposal submission system included improved preparation of submitted proposals for refereeing, additional instruments on both the VLA and GBT, and the major addition of electronic submission capabilities for the VLBA and HSA. Nearly 600 proposals were processed in total.

#### *Archive and Pipeline Operations*

OEO continued the VLA data-processing pipeline, adding 30,000 new images at 6,000 new sky positions by the end of the reporting period. The VLA Archive Survey now holds 72,839 new continuum images along with calibrated data files of 15,590 unique sky positions. These were included in the NRAO archive and the VO, bringing NRAO's total contribution to the VO to more than 125,000 unique images. A prototype design for the interface between the EVLA correlator and the archive was also completed during this time, and extensive work transitioning the NGAS-based archive system for ALMA into routine operation in Socorro took place. Also at this time, the "Archive 2.0" project concluded a proof-of-concept free-text search for telescope data and provided the foundations for the Data Vault interfaces that were released in May 2008. In Q4 2007 the data archive added support for image queries to over 125,000 images drawn entirely from VLA and VLBA survey projects, introduced easy web access to GBT data

through 2006, produced an early version of free-text search queries for VLA and VLBA data, and made substantial improvements to metadata integrity, particularly for GBT data.

All NRAO information products are catalogued in a central registry and made available through the Data Vault at http://archive.nrao.edu. The Data Vault now searches across the VLA, VLBA, and GBT using new services implemented under the framework developed this year. The search system provides access to many data products including GBT scheduling blocks, VLA and GBT proposal cover sheets, pipeline-processed images, and initial representations of sources in Google Sky. The collection of proposal data and monitor data will expand in 2009.

The NRAO began collaborating with Google in January 2008 to integrate NRAO science press-release-quality images into Google Sky and to investigate that application as an interface to the data archive and other services. Creating a Google Sky prototype for NRAO radio images involved creating "skymarks" in Keyhole Markup Language (KML), which is understood by the Google application. To complement the new NRAO web, the Data Vault adopted a new framework for improved look-and-feel and ongoing integration of value-added services such as Google Sky, the Spectral Line Search Engine (SLiSE), proposal information, etc. Through this framework, the interaction between the Data Vault free-text search capabilities and existing archive tools and services became clear. In June 2008, summer students began investigating tag-based semantic searching based on SIMBAD and NED taxonomies for the data archive, and integration of 140 Foot and 12 Meter Telescope data. Their contributions are very promising and will be tested and rolled out into the Data Vault for public use by early 2009.

### *Proposal Operations*

The proposal submission tool (PST) successfully handled over 150 VLA and GBT proposals per submission period for the October 1, 2007 and February 1, 2008 proposal deadlines. Additional validation rules and minor improvements to the GUI significantly reduced the number of user complaints compared to the prior proposal submission. The capability to assign incoming proposals to review categories was also integrated. The PST successfully handled 223 VLA, VLBA/HSA, and GBT proposals for the June 2, 2008 deadline. This was the first time that VLBA/HSA proposals could be submitted electronically, and the majority of VLBA/HSA proposers opted to use the new system. The NRAO will require that all proposals be submitted electronically as of the October 1, 2008 deadline.

### *NRAO Participation in the National Virtual Observatory (NVO) Project and Virtual Astronomical Observatory (VAO) Operations*

Over the past year the main focus of NRAO involvement in the VO has continued to emphasize development of VO standards and technology. With the expected transition of the NVO to the US Virtual Astronomical Observatory (USVAO) in 2009, we anticipate that this will change. The NRAO will continue to be a leader in developing VO infrastructure and standards, but as the NVO transitions to an operational facility and becomes the USVAO, the emphasis will shift to integrating VO technology into NRAO operations to provide useful facilities for the NRAO and the broader US user communities.

NRAO participation in VO technology and standards development over the past year has included leading ongoing development of the IVOA Table Access Protocol (TAP), the Simple Spectral Access Protocol (SSAP), and the second-generation Simple Image Access Protocol (SIAV2), which together will provide advanced capabilities for accessing most astronomical data via the VO. SSAP and the associated Spectrum Data Model both reached the level of an IVOA Recommendation in late 2007. With the VO data-access protocols now reaching maturity, attention has started to shift to data analysis with the VO and integration of observatory data processing with the VO, with the development of a design for a general multiwavelength, scalable applications framework for observatory and VO data processing and analysis. The NRAO participated in production of a book documenting the research and development

phase of NVO, published in February 2008. Finally, the NRAO participated in developing the plans for the USVAO and writing the proposal to operate the VAO that was submitted to the NSF in April 2008. If funded, the NRAO will be a partner in the operations of the VAO.

### *Data-Processing Development/CASA*

Several data-processing milestones were reached for the EVLA and ALMA this year, including the initial beta release of Common Astronomy Software Applications (CASA) and two update patches in the winter and spring, culminating in a release to public testers in July. CASA was utilized in many of the tutorials for the June 2008 synthesis-imaging school in Socorro.

CASA Beta Patch 1 was completed in March 2008. This included polarization calibration and imaging, basic image analysis (math, statistics, etc.), and model subtraction from (*u,v*) data. It also included many improvements for existing applications. The release included 64-bit distributions for Linux RHEL 4 and 5. CASA Beta Patch 2 in June contained enhancements that were used in the summer school, including greater flexibility in calibration solutions, improvements to task parameter scoping, plotxy improvements, major reworking of imaging tasks, and improvements to the ALMA simulator. Particularly important for both ALMA and the EVLA is importing the (very rich) raw-data format being adopted by both projects. It is critical that the telescope formats for the EVLA and ALMA are the same (with some telescope-specific fields/tables) so each telescope can easily leverage software developed to support the other. Releases will be made quarterly. Each candidate release is exercised thoroughly by a group of testers that includes astronomers from outside the NRAO. The problems found are used to correct the current release and to provide development targets for subsequent releases.

Incorporating some improvements identified during the summer school, the CASA Beta Release became available for public testing in July 2008. Members of the user community who login to NRAO Interactive Services at http://my.nrao.edu will see an option to forward them to the CASA Beta Release. A CASA Advisory Group (CAG) is being formed to facilitate close and productive relationships between the CASA scientists and the development team, and several members of the user community have already registered to become part of this group. The short-term goal for late 2008 is to develop Beta Patch 3, tentatively scheduled for October 15 release. CASA must be prepared to support initial shared-risk science observations at the EVLA in Q4 2009.

### *Other Developments*

OEO also supported software activities in Green Bank, focusing on (1) scheduling algorithms and technical mechanisms for communicating with users of the Dynamic Scheduling System (DSS) and (2) integrating high-performance FPGA computing into operations as part of the Green Bank Ultimate Pulsar Processing Instrument (GUPPI). GUPPI, a component of the CICADA FPGA development program, saw first light with the GBT on 17 April 2008, observing the pulsar B1824–24. It will first be available as an expert-user instrument and later fully integrated into the GBT system as a common-user backend (expected for FY 2009).

For the DSS, the task of creating the simplest end-to-end system for executing scheduling was completed on schedule in late 2007. OEO staff remained involved in this project through its first live test with real observers in the summer and fall of 2008, and OEO will continue to grow and develop the software for scheduling algorithms and communications with users as the DSS becomes fully operational in 2009.

*End-to-End Operations Milestones from the 2008 Program Plan*

**Management & Administration Milestones for FY 2008**

| Item | Date Planned | Date Accomplished |
|---|---|---|
| 1. First Draft of the E2E Strategic Plan | 10/2007 | 03/2008 |
| 2. E2E and EPO release new NRAO web site | 12/2007 | 02/2008 |
| 3. E2E Strategic Plan Formalized (to working version) | 03/2008 | 07/2008 |
| 4. Detailed Design Formalized (to working version) | 08/2008 | — |
| 5. Deliver management-analytics dashboard to NRAO managers | 09/2008 | 09/2008 |
| 6. Participate in Integrated Science Center development | Ongoing | 05/2008 |

**Algorithm Development Milestones for FY 2008**

| Item | Date Planned | Date Accomplished |
|---|---|---|
| 1. Send at least two developers to the AstroGPU conference | 11/2007 | 11/2007 |
| 2. Hold first NRAO Algorithm R&D Workshop | 11/2007 | Canceled |
| 3. Begin NRAO memo series for algorithm development | 12/2007 | 12/2007 |
| 4. Design complete for parallelizing CASA | 03/2008 | Deferred until FY 2009 |
| 5. Hold second NRAO Algorithm R&D Workshop | 05/2008 | Canceled |
| 6. Circulate relevant algorithm R&D publications to working group online; facilitate active collaboration (Note: through memos.nrao.edu) | 08/2008 | Deferred to 12/2008 |

Note: Items 2 and 5 were canceled owing to budget constraints.

**NRAO Participation in the NVO Project Milestones for FY 2008**

| Item | Date Planned | Date Accomplished |
|---|---|---|
| 1. IVOA Note—Table Access Protocol (TAP) design analysis | | 09/2007 |
| 2. IVOA interoperability workshop (Cambridge, UK) | 09/2007 | 09/2007 |
| 3. SSA protocol becomes IVOA Recommendation | | 11/2007 |
| 4. Spectrum data model becomes IVOA Recommendation | | 11/2007 |
| 5. NVO/Opticon data-analysis architecture updated | 10/1007 | 01/2008 |
| 6. NVO Book published | 12/2007 | 02/2008 |
| 7. Preparation of quality assurance program for NVO software development (created for VAO proposal in Spring 2008) | 08/2008 | 04/2008 |
| 8. VAO proposal submitted to the NSF | 04/2008 | 04/2008 |
| 9. Draft IVOA Table Access Protocol specification | 03/2008 | 05/2008 |
| 10. IVOA Note—Simple Image Access V2 design analysis | | 05/2008 |
| 11. IVOA Interoperability workshop (Trieste, Italy) | 05/2008 | 05/2008 |
| 12. First draft of applications framework system interfaces | 05/2008 | 07/2008 |

**NRAO Archive Infrastructure & Interfaces Milestones for FY 2008**

| Item | Date Planned | Date Accomplished |
|---|---|---|
| 1. First release of new NRAO archive interface | 10/2007 | 11/2007 |
| 2. Publish VLA images to Virtual Observatory | 10/2007 | 11/2007 |
| 3. Retrofit archive authentication to upgraded user database | 10/2007 | 11/2007 |
| 4. Pipeline to generate calibrated SDFITS data for GBT/12 m/140 ft telescopes | 12/2007 | Deferred |
| 5. Pipeline to generate preliminary calibrated, averaged dataset for the VLA (Sjouwerman) | 12/2007 | 12/2007 |
| 6. Edit the Spectral Line Search Engine (SLiSE) to query the single-dish spectra database and make it available to users | 12/2007 | Deferred until 12/2008 |
| 7. VLA/EVLA observing-script archive available | 03/2008 | 03/2008 |
| 8. NRAO archive presents data, observing scripts, and other supplemental information together for all operational telescopes | 09/2008 | 05/2008 |

Note: (4) Deferred in favor of the KFPA pipeline

**NRAO Proposal Infrastructure & Interfaces Milestones for FY 2008**

| Item | Date Planned | Date Accomplished |
|---|---|---|
| 1. Manage the October 2007 NRAO proposal deadline with upgraded software | 10/2007 | 10/2007 |
| 2. Release first version of the internal proposal-handling system | 10/2007 | 10/2007 |
| 3. Integrate the VLBA into the proposal system | 01/2008 | 01/2008 |
| 4. Shift management of individual configurability for telescopes to people possessing the expertise at telescope sites | 05/2008 | Deferred (budget ) |
| 5. Develop action plan for the VLA/EVLA transition in the proposal system | 06/2008 | 06/2008 |
| 6. Observing summary analytics reports available online | 09/2008 | 09/2008 |

**Data Processing (CASA/GBTIDL) Milestones for FY 2008**

| Item | Date Planned | Date Accomplished |
|---|---|---|
| 1. CASA beta release | 10/2007 | 11/2007 |
| 2. Data Processing Helpdesk in place and functional | 12/2007 | 01/2008 |
| 3. Pipeline for calibrated GBT (Note: canceled owing to design changes compelled by KFPA pipeline development) | 12/2007 | Canceled |
| 4. Rationalize plan for single-dish data analysis | 02/2008 | 07/2008 |
| 5. Complete 64-bit distribution of CASA | 03/2008 | 03/2008 |

**NRAO Pipeline Infrastructure & Interfaces Milestones for FY 2008**

| Item | Date Planned | Date Accomplished |
|---|---|---|
| 1. Publish available collection of VLA images to the VO | 10/2007 | 11/2007 |
| 2. Add polarization enabling in the antenna file | 10/2007 | 10/2007 |
| 3. Upgrade infrastructure for continued processing | 10/2007 | 03/2008 |
| 4. Complete VLA editing/self-calibration pipeline | 03/2008 | 09/2008 |
| 5. Begin processing joint VLA/Chandra sources | 03/2008 | 09/2008 |
| 6. Bind single-dish pipeline to NRAO archive and spectral-line search engine | 05/2008 | Prototype due 12/2008 |
| 7. Begin processing joint VLA/Spitzer sources | 06/2008 | 09/2008 |
| 8. Investigate VLA reduction of spectral-line data and of C/D-configuration data | 09/2008 | 08/2008 |

## F.2. Central Development Laboratory (CDL)

The mission of the CDL is to design, develop, fabricate, and supply unique components and specialized receivers for the NRAO telescopes—ALMA, the VLA, VLBA, GBT, and EVLA—as well as other projects and activities for the astronomy community. This year our efforts continued with superconducting mixer development, HFET-amplifier-based receivers, Monolithic Microwave Integrated Circuit (MMIC) development, electromagnetic structures such as feeds and polarizers, the GBT K-band Focal Plane Array (KFPA), the solar monitor, the Frequency Agile Solar Radiotelescope (FASR), and the Precision Array to Probe the Epoch of Reionization (PAPER) project.

### *Cryogenic HFET Development*

The CDL is the recognized leader of cooled HFET (Heterostructure Field-Effect Transistor) amplifier design and construction for radio astronomy use. In FY 2008 the CDL produced more than one hundred HFET amplifiers for use on all NRAO telescopes, for others in the radio-astronomy community, and for other research areas. CDL staff also redesigned several amplifiers to improve their performance.

### Accomplishments and Highlights in FY 2008

**Amplifier Research and Development:** The cryogenic evaluation of TRW Cryo-3 devices was completed. The design/redesign of cryogenic amplifiers using Cryo-3 TRW devices for the EVLA, the VLBA, and the GBT were also completed with the development of wideband EVLA 18–26.5 GHz and 26.5–40 GHz amplifiers. The performance of these amplifiers is shown in Figures F.1 and F.2. Other work includes redesigning the 2–4 GHz amplifier body to reduce some parasitic effects and redesigning the EVLA 12–18 GHz amplifier with a waveguide instead of K-connector input, at the request of the EVLA receiver engineers. All EVLA designs are now in production. In addition, a version of the NRAO standard 8–18 GHz design that actually covers 5–20 GHz has been demonstrated. The performance of two of these is shown in Figure F.3.

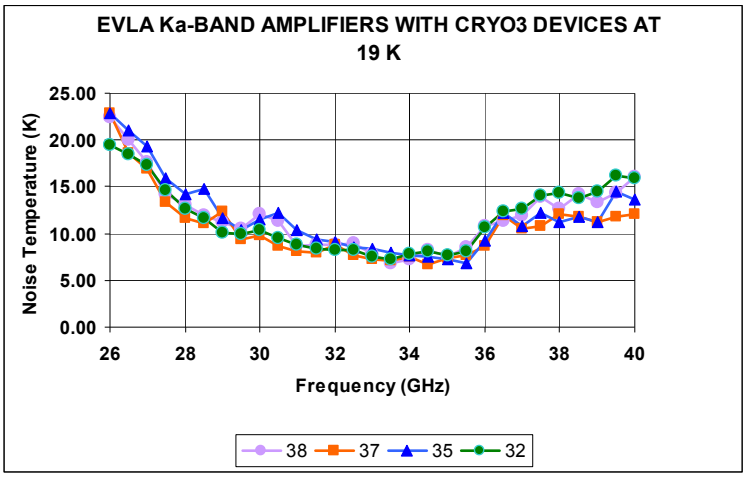


*Figure F.1. Noise temperatures of several Ka-band amplifiers measured at cryogenic temperatures.*

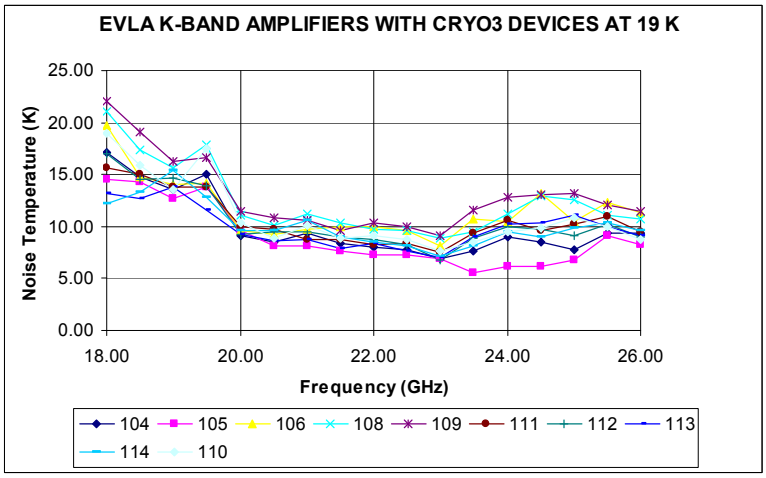


*Figure F.2. Noise temperatures of several K-band amplifiers measured at cryogenic temperatures.*

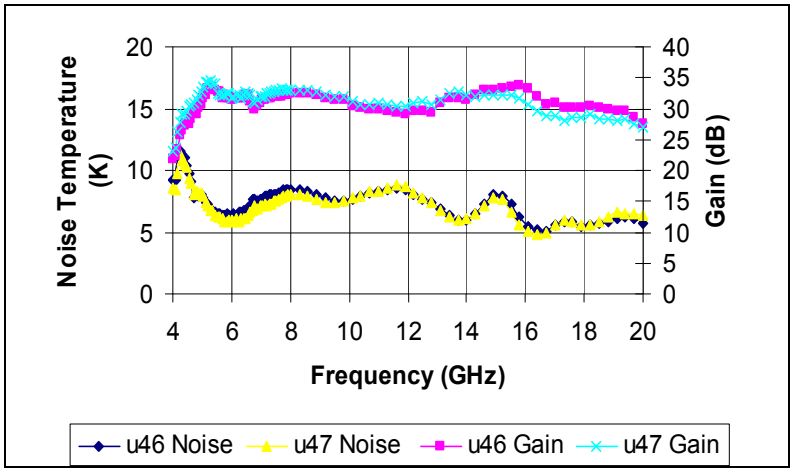


*Figure F.3. Gain and noise of two 5-20 GHz amplifiers measured at cryogenic temperatures.*

Demonstration amplifiers for ALMA Band 1 (31–45 GHz) and Band 2 (67–90 GHz) receivers have been designed. Experimental evaluation awaits the availability of technician time.

Research on noise properties of heterostructure bipolar transistors (HBTs) and CMOS MOSFETs continued. This ongoing effort may lead to low-noise amplifier chains with much lower $1/f$ gain fluctuations than those currently available, resulting in significantly improved broadband radiometers.

**Amplifier Production:** 124 new and upgraded amplifiers, including L- (1–2 GHz), S- (2–4 GHz), C- (4–8 GHz), K- (18–26 GHz), and Q-band (40–50 GHz) units were built for receiver systems on the GBT, VLBA, and EVLA. All required EVLA production is on or ahead of schedule. In addition, nine Cosmic Background Imager (CBI) Ka-band (26–40 GHz) amplifiers were repaired and tested this year.

The PC/LabView-based noise-measurement system is operational and making all routine LNA (low-noise amplifier) measurements and performance documentation. Software enhancements will be added as needed.

**Amplifier Design, Development, and Production Milestones for FY 2008**

| Item | Date Planned | Date Accomplished |
|---|---|---|
| 1. Production of amplifiers for EVLA, VLBA, and GBT receiver needs | Ongoing | Ongoing |
| 2. Demonstrate state-of-the-art performance in ALMA Band 1 (31.3–45 GHz) and Band 2 (67–90 GHz) | 07/2008 | On hold |
| 3. Study the cryogenic noise properties of HBTs | Ongoing | Ongoing |
| 4. Further improvements to amplifier cryogenic test system | 07/2008 | Ongoing |
| 5. Redesign of EVLA 12–18 GHz amplifier (waveguide instead of K-connector input) | 06/30/08 | 05/08/08 |
| 6. Evaluation of TRW Cryo-3 devices to determine noise, signal, and DC properties at cryogenic temperatures | 12/31/07 | 12/31/07 |
| 7. Design/redesign of cryogenic amplifiers using Cryo-3 TRW devices for the EVLA, VLBA, and GBT | 12/31/07 | 12/31/07 |
| 8. New amplifier test system development | 06/30/06 | 12/31/07 |

Note to Table: tasks 5–8 were added after the FY 2008 Program Plan was written

### *Monolithic Microwave Integrated Circuit (MMIC) Development*

A MMIC-based approach for front ends promises more compact, lightweight receivers and a possible cost savings for large array receivers. A wide variety of custom centimeter- and millimeter-wave components have been developed at the CDL in FY 2008. Some of these designs will be used in ALMA, the GBT, and the EVLA.

## Accomplishments and Highlights in FY 2008

**GaAs W-band (75–110 GHz) Power-amplifier Development:** Revised amplifier designs for ALMA Bands 3, 4, 7, 8, 9, and new designs for Band 10 have been completed based on the latest nonlinear 70 nm process models available from BAE Systems. Fabrication began in February 2008 and was completed in June 2008. RF testing at the foundry took place in July 2008, with excellent on-wafer test results for small-signal gain and impedance match. Delivery of the first 220 of the 1000 chips ordered is expected in August 2008. Packaged-device power-output tests will take place in September 2008.

**Cryogenic Performance of InP Heterojunction Bipolar Transistors:** InP HBTs were obtained from Northrop Grumman Space Technology (NGST) for cryogenic characterization at the CDL. They were packaged in a coolable test fixture and their DC properties were measured as a function of temperature. A 10–20% increase in current gain (β) was measured at 20 K versus room temperature with an associated slight decrease in transconductance ($g_m$). These data show that InP HBT amplifiers will operate at cryogenic temperatures. However, the noise performance of these particular HBTs will not improve as much as HFETs do upon cooling. The fairly low β means that high base-current shot noise will limit use of these HBT amplifiers to later gain stages rather than the initial low-noise amplification in a receiver. Other types of HBTs, such as SiGe, have shown large increases in noise performance, perhaps comparable to that of InP HFETs. Continuing effort will focus on obtaining or designing HBT amplifiers with better noise performance and characterizing their gain stability when cold.

**Cryogenic Noise Calibration:** Several MMIC K-band LNAs were packaged and tested cold (see Figure F.4). The measured noise output and stability of the lowest-power LNA have shown that it is a suitable noise calibration source for the GBT K-band Focal Plane Array (KFPA). Dissipated power at the expected operating bias point is about 7mW, for an average thermal load of 3.5mW at 50% duty cycle. As shown in Figure F.5, it has a flatter noise output than the current generation of noise calibration devices, in which noise diodes are operated warm and their output injected into the Dewar through coaxial cable. Stability on time scales of a few hours was measured to be within a few percent, likely limited by the stability of the DC bias supplies. This more easily integrated calibration module should help not only the KFPA but also future large-*N* focal-plane arrays, such as a λ = 3 mm FPA.

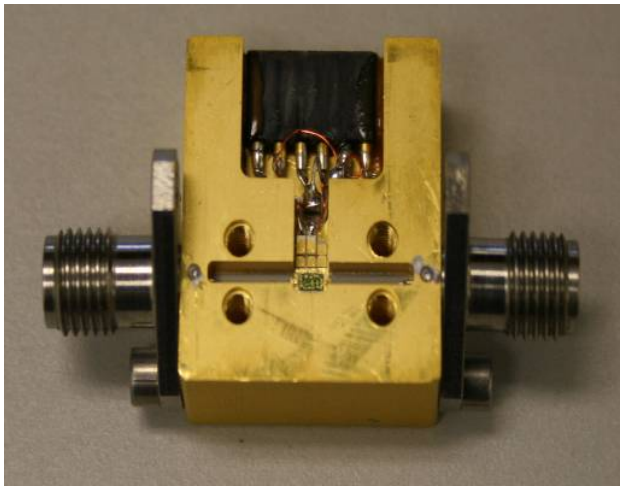

*Figure F.4. Photograph of the assembled module used to test MMIC LNAs as noise calibration sources. The MMIC is connected to 2.92 mm SMA input and output connectors through 50-ohm microstrip lines on Alumina substrates. In the actual GBT KFPA receiver, the MMIC will be packaged in a waveguide module integrated with a dual 25 dB coupler to both receiver channels.*

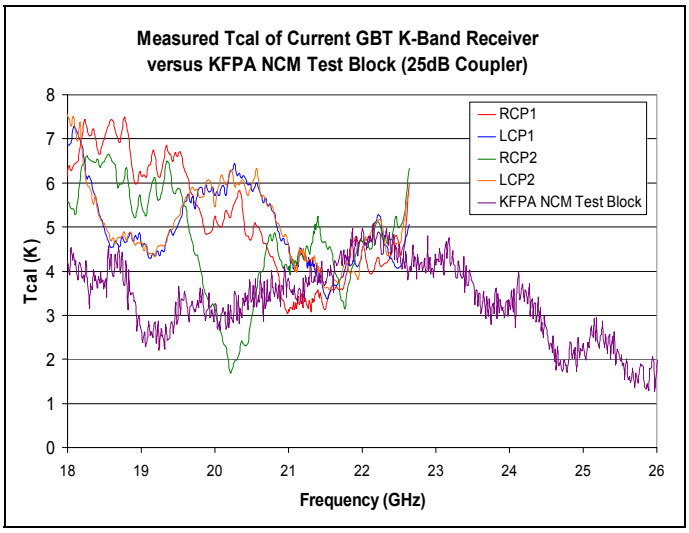


*Figure F.5. Measured injected noise in the current GBT low-band (18–22.5 GHz) K-band receiver together with the measured noise source proposed for the GBT KFPA scaled by a 25 dB coupler.*

**Differential LNA for balanced feeds and integrated wideband LNA-feed package:** Extensive effort has been put into designing this MMIC. Some progress has been made, but the combination of specifications on input impedance, noise temperature, and dynamic range are proving to be the most challenging. A serious design will have to wait for the appropriate MMIC wafer run. Funding for experimental wafer runs such as these may become available through the new Keck Institute for Space Studies at Caltech. We plan to pursue this development with them at a workshop in July 2008.

**Advanced Compact Integrated Receivers:** An R&D project to develop techniques for highly integrated front ends for future telescopes is being initiated at the CDL. The first concept to be explored is a digital sideband-separation/polarization-separation backend technique. This is a single downconversion sideband-separating receiver in which the upper and lower sidebands are reconstructed digitally after downconversion. Proof-of-concept lab experiments using a narrow IF bandwidth of 50 MHz have confirmed that USB/LSB image separation > 55 dB can be achieved by digitizing two quadrature-phase signal paths and recombining them in a digital hybrid. The next step, building an L-band implementation, is targeted at also achieving similar polarization separation for a single-dish antenna and is expected to be tested on the GBT.

**K-band Focal Plane Array:** Prototyping of the single-pixel modules continues. Initial tests in the lab and on the GBT were conducted in August and early September 2008.

**Wafer-Probe Station:** Significant effort has been put into upgrading the CDL's manual wafer-probing capabilities, which will facilitate future MMIC research and development. The probe station now has a dedicated Vector Network Analyzer, permitting calibrated two-port *s*-parameter measurements up to 50 GHz. Additional wafer probes and precision micromanipulators allow scalar measurements in the WR-12 (60–90 GHz), WR-10 (75–110 GHz), WR-8 (90–140 GHz), and WR-5 (140–210 GHz) waveguide bands.

**Sub-mm MMIC Amplifier Development:** Two new experimental MMIC designs were submitted for a 35 nm gate-length InP pHEMT wafer run at NGST, in collaboration with JPL. A photograph of the first new chip, a 67–95 GHz low-noise amplifier, is shown in Figure F.6. Figures F.7 and F.8 show the measured cold (17.5 K) performance for the packaged amplifier. The lowest measured uncorrected receiver noise temperature is 23 K from 83 to 87 GHz. This is believed to be the record low noise temperature for an amplifier in this frequency range. The noise temperature is below 40 K from 70 to 96 GHz. This MMIC LNA can be used for the ALMA Band 2 receivers as well as for GBT $\lambda = 3$ mm receivers, such as a $\lambda = 3$ mm Focal Plane Array (FPA).

The second 35 nm MMIC design is a 275–375 GHz power amplifier capable of driving an SIS mixer directly. It is currently being evaluated at the Jet Propulsion Laboratory.

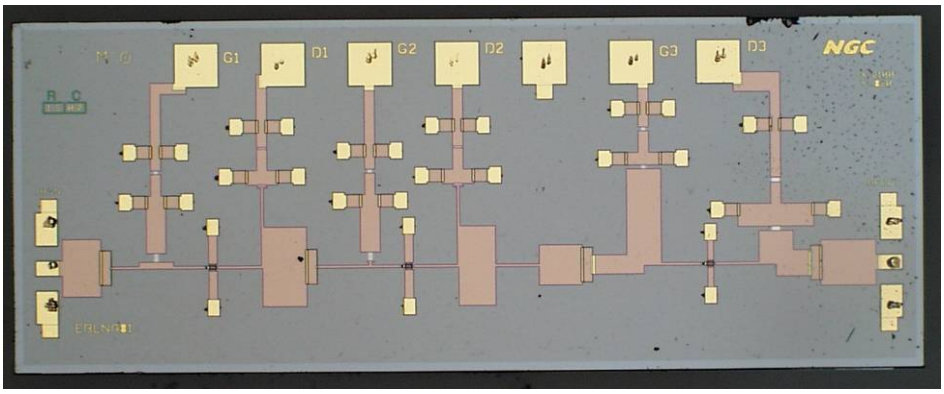


*Figure F.6. Photograph of the 67–95 GHz MMIC LNA. Chip size is 2.10 mm × 0.80 mm× 0.05 mm.*

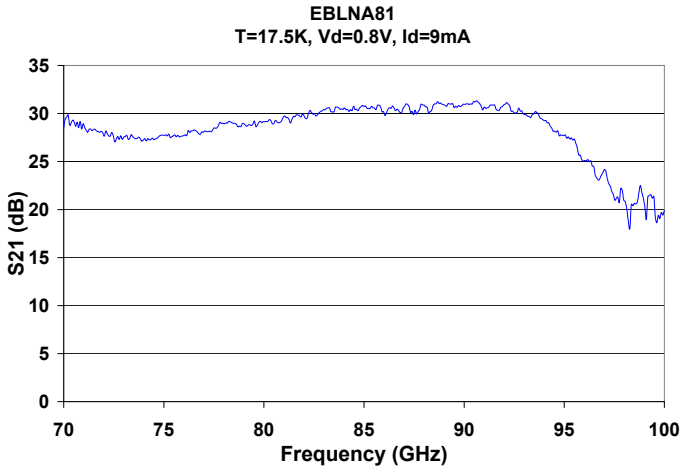


*Figure F.7. Measured gain of the 67–95 GHz MMIC LNA at 17.5 K*

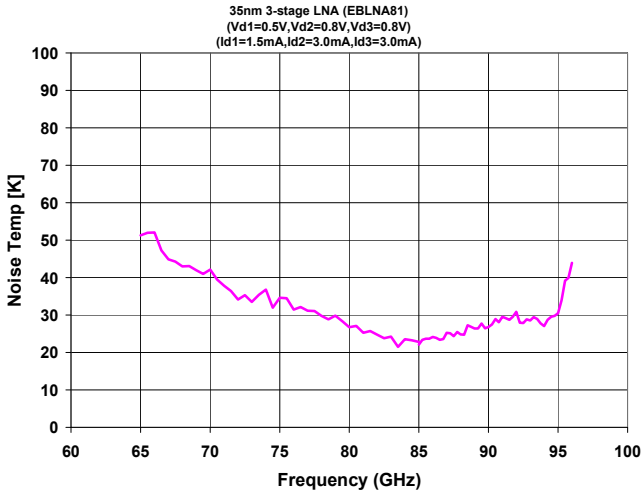


*Figure F.8. Measured noise temperature of the 67–95 GHz MMIC LNA at 17.5 K*

**MMIC Design and Development Milestones for FY 2008**

| Item | Date Planned | Date Accomplished |
|---|---|---|
| 1. Complete 70 nm GaAs pHEMT wafer run | 02/01/08 | 06/25/08 |
| 2. Complete initial study and identify fabrication process for active baluns | 06/01/08 | 05/01/08 |
| 3. Test new 35 nm InP pHEMT MMIC designs | 09/30/08 | 07/08/08 |
| 4. Complete cryogenic DC measurements on HBTs | 09/01/08 | 12/13/07 |
| 5. Develop cryogenic HBT noise model | 03/01/08 | 12/13/07 |
| 6. Begin fabrication of HBT test amplifiers | 06/01/08 | 12/13/07 |
| 7. K-band Spectroscopic Focal Plane Array for the GBT | 07/01/09 | Ongoing |
| 8. MMIC VCO development | 06/01/08 | 08/01/07 |
| 9. Design and test GaAs W-band (75–110 GHz) power amplifiers using the 70 nm GaAs pHEMT to improve reliability of millimeter-wave local oscillators | 12/01/08 | 07/31/08 |
| 10. Evaluate InP HBTs for use in cryogenic amplifiers. | 06/01/08 | Ongoing |
| 11. Develop cryogenic noise calibration modules | 08/31/08 | 07/01/08 |
| 12. Develop differential LNA for balanced feeds and integrated wideband LNA-feed package | 12/01/08 | Ongoing |

Notes:
8. This task was canceled because our study showed that the performance of the MMIC VCOs is inferior to commercially available YIG oscillators.
9-12. These tasks were added after the FY 2008 Program Plan was written.

### *Millimeter- and Sub-millimeter-Wave Receiver Development*

Work continues at the CDL to advance the state of art in millimeter- and sub-millimeter-wave receiver technology. These efforts include $\lambda$ = 350 μm (780–950 GHz) heterodyne receiver technology development, balanced SIS mixer development, and a new SIS mixer design for 385–500 GHz.

## Accomplishments and Highlights in FY 2008

**University of Virginia Foundry Support:** A longstanding collaboration between the NRAO and the University of Virginia Microfabrication Laboratory (UVML) has resulted in the development of broadband tunerless mixers used by ALMA for Bands 3 and 6. IRAM (Institute for Millimeter Radio Astronomy, Grenoble, France) has used the UVML as a backup for its own foundry for ALMA Band 7. Current work with the UVML includes:

(1) A project to develop reliable SIS mixer technology for the $\lambda$ = 350 μm band.
(2) A joint project with Arizona Radio Observatory to develop balanced sideband-separating SIS mixers for 385–500 GHz and 780–950 GHz.
(3) Production of an additional ALMA Band 6 wafer to support the entry of Japan into ALMA.
(4) In conjunction with (1), the UVML will be under contract on a standby basis to supply additional ALMA wafers if they are required to complete the construction project or to recover from an unexpected loss of receivers (*e.g.*, in case of damage from atmospheric lightning).

However, the new 5-year NRAO-UVML support contract was delayed by the National Science Board's resolution NSB/CPP-07-34 on December 6, 2007 requiring that AUI competitively bid technology-development initiatives associated with the operation of the ALMA. Several SIS mixer-development projects were put on hold by this delay. The new contract was approved by the NSF on June 4.

**λ = 350 μm (780–950 GHz) Heterodyne Receiver Technology Development:** This project is being done in collaboration with the UVML. The ultimate goal is a low-noise wideband SIS mixer for the λ = 350 μm band. During this period UVML developed a process to produce high-quality NbTiN films for use in a λ = 350 μm mixer and has produced small-area AlN tunnel junctions with good quality at critical current densities as high as 30,000 A/cm$^2$. Figure F.9 shows the *I*(*V*) characteristics of four NbTiN/Al-AlN/Nb SIS junctions of different areas.

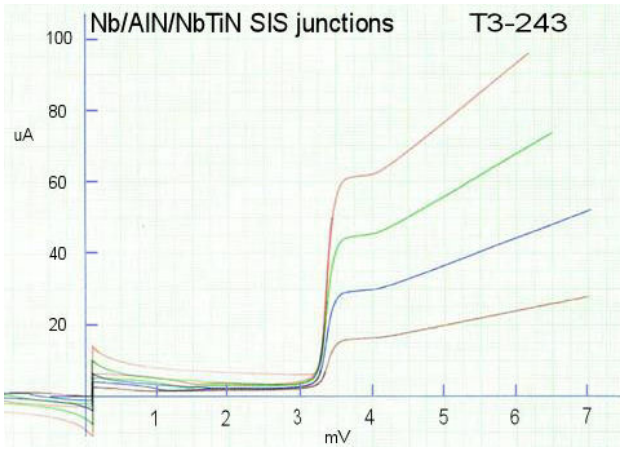


*Figure F.9. I(V) characteristics of four NbTiN/Al-AlN/Nb SIS junctions.*

For operation above ~300 GHz, the quartz substrates used in most SIS mixers would be too thin to handle. The UVML has developed a process for making superconducting circuits on thin silicon membranes 3 μm thick with gold beam leads for mechanical support and electrical connections.

**385–500 GHz SIS Mixer Development:** This work is a major step on the way to a λ = 350 μm receiver. Following the recent successful development at the UVML of AlN tunnel junctions with high current density and good *I*(*V*) characteristics, a 385–500 GHz SIS mixer has been designed and will be fabricated using Nb/Al-AlN/Nb junctions.

**Balanced SIS Mixer Development:** A critical component of a balanced mixer is a 180° IF hybrid that separates the downconverted signal from the LO sideband noise. We have developed a superconducting 180° IF hybrid covering 4–12 GHz that is small enough to be mounted inside the mixer block (Fig. F.10). An additional advantage of this hybrid is that it will enable a balanced SIS mixer to operate from a single bias supply. This project is being done in collaboration with Arizona Radio Observatory.

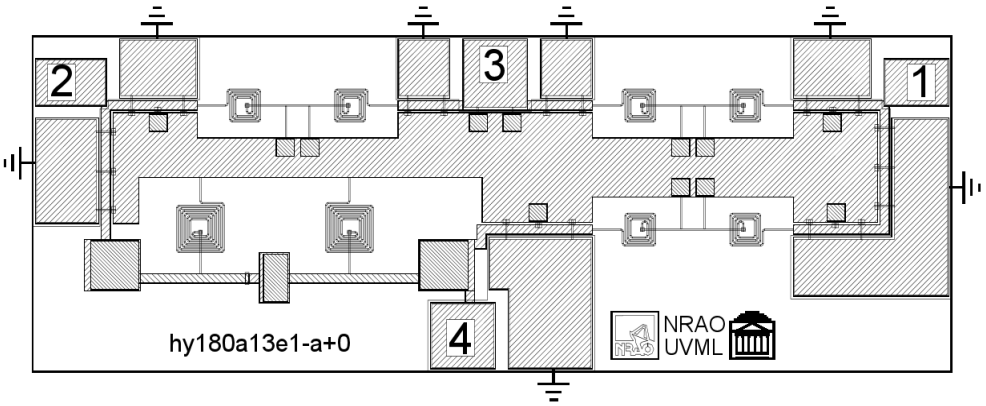


*Figure F.10. Superconducting 4–12 GHz 180° hybrid on a quartz chip. Dimensions: 1.42 × 0.51 mm.*

**Balanced and Sideband-Separating SIS Mixer Development:** This project is being done in collaboration with Arizona Radio Observatory and was delayed in part by the delay of the UVML support contract mentioned above.

**Superconducting Millimeter-Wave Receiver Development Milestones**

| Item | Date Planned | Date Accomplished |
|---|---|---|
| 1. First measurements of NbTiN properties | 12/01/07 | Delayed by NSB |
| 2. Complete initial mixer design for λ = 350 μm mixer | 03/01/08 | Delayed by NSB |
| 3. Complete λ = 350 μm signal & LO sources | 06/01/08 | Delayed by NSB |
| 4. Design λ = 350 μm optics | 05/01/08 | Delayed by NSB |
| 5. Complete initial 500 GHz mixer design | 12/01/08 | 05/01/08 |
| 6. Fabricate 500 GHz mixer | 10/30/08 | Ongoing |
| 7. Demonstrate first 230 GHz balanced mixer | 03/01/08 | Delayed by NSB |
| 8. Demonstrate NbTiN/insulator/Nb tunnel junction | 12/01/07 | 09/17/07 |

Note:
8. This task was added after the FY 2008 Program Plan was written.

### *Electromagnetics*

The CDL is responsible for most of the Observatory's electromagnetic development. In FY 2008 we continued to design and test new components for the EVLA, GBT, and ALMA. A brief description of progress is given below.

### Accomplishments and Highlights in FY 2008

A new K-band (18–26.5 GHz) feed was developed for the GBT focal-plane-array receiver. The outer diameter of the feed is 3.5 inches, resulting in a beam spacing of three half-power beamwidths. The average illumination taper at the edge of the subreflector is −12 dB.

Design of X-band (8–12 GHz) and Ku-band (12–18 GHz) phase shifters was completed. The new X-band design yields a differential phase shift of 90±5.5º. This design is 1.3 inches shorter than the scaled version of the Ka-band (26.5–40 GHz) phase shifter. At Ku band, the phase shifter is 0.7 inches shorter than the scaled design.

Development of the Ku-band feed was also finished. This is a linear-taper horn with an inside diameter of 12.3 inches at the aperture and length of 33.6 inches. The average illumination taper at the edge of subreflector is −12 dB and the return loss is better than −25 dB in the 12–18 GHz band. Measurements of the feed were carried out at the Socorro antenna range. The results agree well with the design goals.

A 75–110 GHz corrugated phase shifter with a slot width of 0.005 inches has been developed. This phase shifter is shown in Figure F.11. The insertion loss of the phase shifter is about 0.4 dB. The measured phase difference, shown in the Figure F.12, is 90±6º between 75 and 106 GHz.

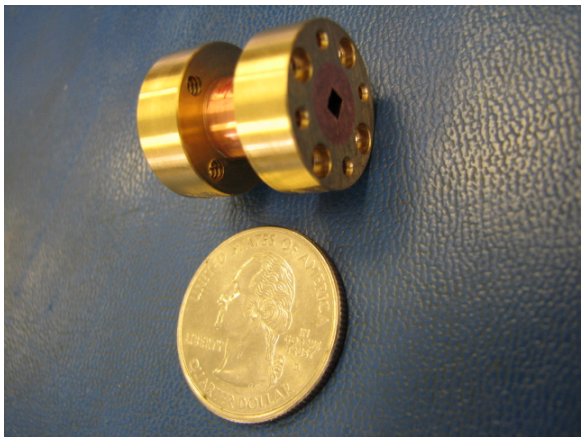

*Figure F.11. Corrugated phase shifter for 75–110 GHz.*

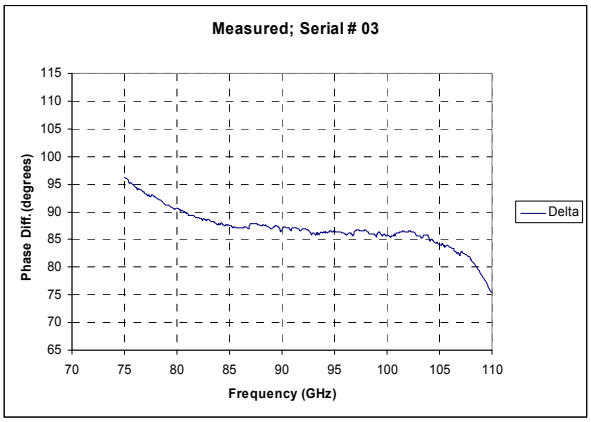


*Figure F.12. Phase difference between two linear polarizations.*

Development of the dual-band 342/800 MHz feed for the GBT was put on hold by a shift of priorities.

Work continues on designing and prototyping the EVLA X-band (8–12 GHz) OMT. The development of the Ku-band (12–18 GHz) phase shifter is in progress.

**Electromagnetic Support Milestones for FY 2008**

| Item | Date Planned | Date Accomplished |
|---|---|---|
| 1. Design and develop 8–12 and 12–18 GHz polarizers for the EVLA | 09/30/08 | Ongoing |
| 2. Develop a 75–110 GHz phase shifter | 03/31/08 | 03/31/08 |
| 3. Develop a 342/800 MHz feed for the GBT | 09/30/08 | On hold |
| 4. Develop a 3:1 bandwidth feed | 10/01/08 | Ongoing |
| 5. Evaluate the EVLA 12–18 GHz feed | 06/30/08 | 06/13/08 |
| 6. Develop an 18–26.5 GHz feed for the KFPA receiver | 11/15/07 | 01/31/08 |
| 7. Design transitions for EVLA Ku band (12–18 GHz) | 03/31/08 | 03/31/08 |

Note:
Tasks 6 and 7 were added after the FY 2008 Program Plan was written.

### *Precision Array to Probe the Epoch of Reionization (PAPER)*

The development of PAPER continues in collaboration with UC Berkeley and other groups. The project goal is to remove foreground sources from the data with sufficient precision to reveal spatial power patterns caused by density and ionization fluctuations in the neutral hydrogen present during the "dark ages" of the universe. In July 2008 the NSF ATI program awarded funding for deployment of PAPER in Western Australia; NRAO's share will support graduate students and equipment procurements.

## Accomplishments and Highlights in FY 2008

A major milestone was achieved in July 2007 when a four-element pathfinding array was deployed in Western Australia. This work culminated in an all-sky map, shown in Figure F.13, demonstrating better than 1 Jy/beam sensitivity. This work was presented at the URSI and AAS meetings in January 2008.

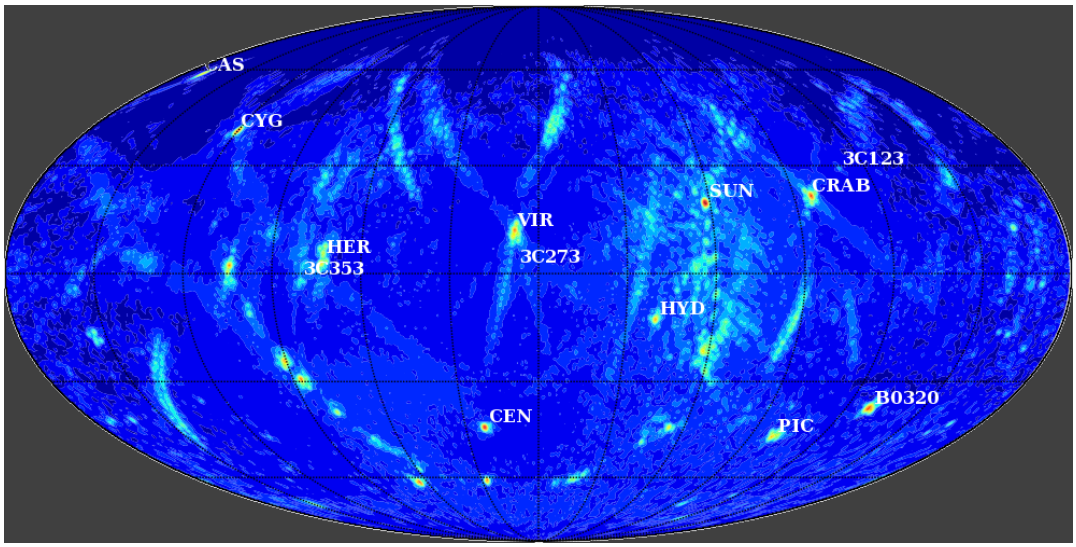


*Figure F.13. A Mollweide projection of the radio sky as measured by the four-element PAPER pathfinding array deployed in Western Australia (July 2007). The map is confusion limited to about 1 Jy/beam. Image courtesy of A. Parsons (U.C. Berkeley).*

Two independent methods have been devised to measure the beam pattern of the PAPER antenna. The first makes use of strong continuum astronomical sources but requires an entire antenna assembly to be rotated periodically. A second method was developed to measure the pattern *in situ* using the downlink signals from low-earth-orbiting satellites operating near 137.5 MHz. An example pattern is shown in Figure F.14. Both total-intensity and differential methods were developed and successfully demonstrated in the field. This work was presented at the January 2008 URSI Meeting.

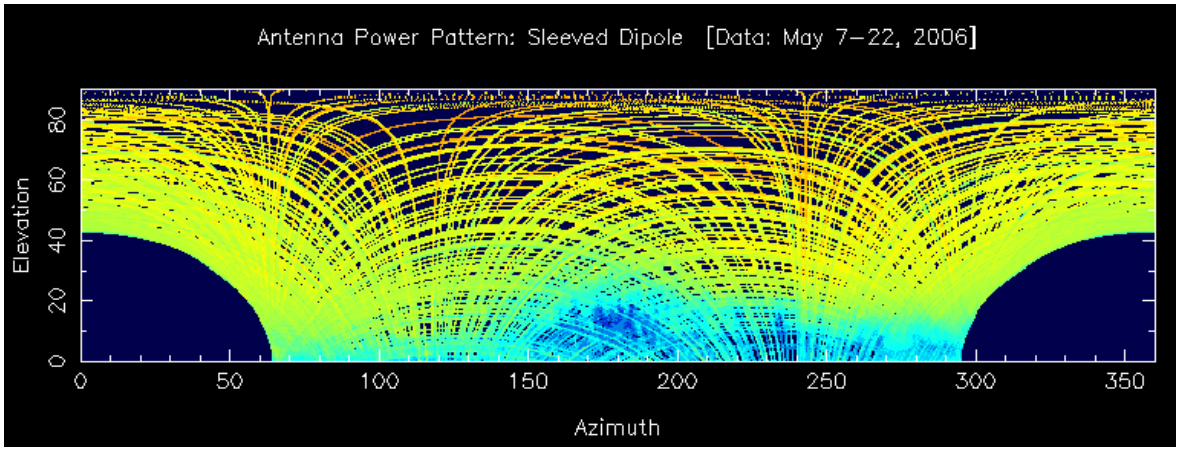


*Figure F.14. Example of an antenna's power pattern measured in situ using satellite downlink signals at 137.5 MHz. The antenna is a north-south oriented sleeved dipole of the type used in PAPER. This false-color plot shows normalized power ranging from 0 dB (red) to -45 dB (dark blue) over the hemisphere. The blind spot toward the north is due to the antenna's latitude on the Earth and the satellite's orbital inclination. Signal blockage by the local terrain is visible toward the west.*

An eight-element system was deployed on a 300 m diameter circle in January 2008. The 16-element prototyping array in Green Bank is currently under construction with a scheduled completion date of early July 2008 (delayed from early May by a shop backlog). The 32-port, full-Stokes correlator is still under development by our collaborators at Berkeley. This system will remain operational throughout the course of the PAPER project.

Plans are in place to build and deploy a 32-element array in Western Australia beginning in October 2008. This is a result of a shift in the long-term plan. Industrial contracts for fabricating array components are now under negotiation. This will be the first step toward building the 128- or 256-element Epoch-of-Reionization detection array scheduled for completion in 2010 (pending additional NSF support).

**Precision Array to Probe the Epoch of Reionization (PAPER) Milestones for FY 2008**

| Item | Date Planned | Date Accomplished |
|---|---|---|
| 1. Complete precision calibration efforts of the PAPER RF system | 12/01/08 | Ongoing |
| 2. Measure power patterns and polarization properties of in situ antennas at 137 MHz | 07/01/08 | 03/01/08 |
| 3. Estimate the ionospheric total electron content (TEC) | 12/01/08 | Ongoing |
| 4. Complete the sixteen-element array in Green Bank | 07/30/08 | Ongoing |
| 5. Characterize the prototype two-by-two close-packed array | 07/01/08 | 01/03/08 |
| 6. Outsource functional components of PAPER-WA | 08/01/08 | Ongoing |
| 7. A 4-element pathfinder array in Western Australia | 07/15/07 | 07/31/07 |
| 8. 32-element array in Western Australia | 10/15/08 | Ongoing |

Note: Tasks 7 & 8 were added after the FY 2008 Program Plan was written.

### *Green Bank Solar Radio Burst Spectrometer (GB/SRBS)*

The Green Bank Solar Monitor is a high-performance instrument designed to receive solar radio emissions in the 5–1200 MHz band with adequate temporal and spectral resolution to probe a wide variety of active solar phenomena originating in the base of the corona. The system has been operational for several years as a prototype, with data being archived at the NRAO in Charlottesville for direct access

by researchers over the Internet. However, it is currently being upgraded to improve calibration and signal-processing efficiency. A small NSF grant will permit continuous operation of the solar monitor over the next five years.

### Accomplishments and Highlights in FY 2008

The system is currently down for a major upgrade to the signal-processing path. The original subsystems are being combined under one backend control system. This work is directed toward archiving a uniform data-acquisition environment and improving reliability as we move into a more active part of the solar cycle. Various functional spares are also being constructed to reduce repair downtime. Operation is scheduled to resume on August 1, 2008. The low-frequency antenna work has been delayed, pending additional funds.

**Green Bank Solar Radio Burst Spectrometer (GB/SRBS) Milestones for FY 2008**

| Item | Date Planned | Date Accomplished |
|---|---|---|
| 1. Complete a suite of low-frequency antennas | 07/01/08 | On hold |
| 2. Implement the prototype digital sweeping backends | 07/01/08 | On hold |
| 3. Install wide-bandwidth hybrids for 70–250 MHz and 250–2000 MHz | 07/01/08 | On hold |
| 4. 10–80 MHz, dual polarization, four crossed dipoles, new digital spectrometer | 09/30/08 | On hold |

Note: Task 4 was added after the FY 2008 Program Plan was written.

## *Frequency Agile Solar Radiotelescope (FASR)*

### Accomplishments and Highlights in FY 2008

The FASR project is currently in the design and development phase. In FY 2008 a highly optimized broadband (500–4000 MHz) sinuous feed was developed for use with the FASR A and B reflector antennas. A photograph of this feed is shown in Figure F.15. All characteristics of this feed are in good agreement with a theoretical analysis. This work was presented at a recent URSI meeting.

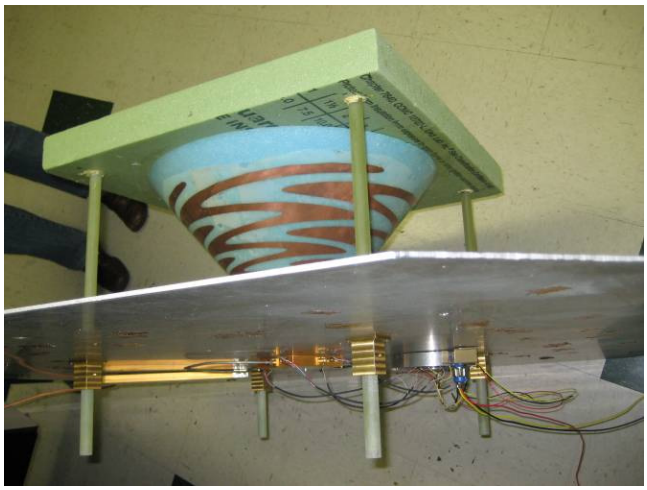

*Figure F.15. Photograph of the prototype sinuous feed with integrated amplifiers (second generation).*

A cooled version of this feed is being developed for other astronomical applications requiring wide instantaneous bandwidth and low noise. Preliminary work to characterize the dielectric properties of rigid foam has already been completed. A Dewar is currently being refurbished for use in measuring the thermal conductivity of the rigid foam samples at cryogenic temperatures.

A technical evaluation of broadband analog fiber links for the FASR LO and IF optical transmission system has been carried out. The analysis revealed that it would be feasible and economical to implement a wideband IF transmission scheme for FASR A, covering 3–22 GHz, given systems recently developed by several manufacturers. The fiber link's frequency response, return loss, noise figure, gain compression, dispersion nulling, and group delay were all measured on a bench using a 1 m patch cord and a 5-km-long fiber spool, and they agreed with the manufacturer's data sheet and technical literature.

The full proposal for FASR was submitted to the NSF by AUI on June 2, 2008. Planning has begun for the FASR Design and Development period, which began on July 1, 2008. A proof-of-concept breadboard for the wideband FASR-B feed with integrated amplifier (300–3000 MHz) was completed and evaluated on the Green Bank 43 Meter Telescope with satisfactory results. Work has already begun on a rugged prototype version.

**Frequency-Agile Solar Radiotelescope (FASR) Development Milestones**

| Item | Date Planned | Date Accomplished |
|---|---|---|
| 1. Complete sinuous-antenna study | 07/01/08 | 06/01/08 |
| 2. Complete sinuous feed with amplifier covering 0.3–3.0 GHz | 07/01/08 | 06/01/08 |
| 3. Evaluate prototype high-frequency sinuous feed | 07/01/08 | Ongoing |
| 4. Evaluate proof-of-concept cryogenic sinuous feed | 12/01/08 | Ongoing |
| 5. Complete proof-of-concept FASR-C station | 07/01/08 | Ongoing |

### *Electrochemistry Laboratory*

The Chemistry Lab's primary functions are (1) to provide precision, functional gold surface finishes on various microwave components and (2) to produce copper electroformed pieces, which are usually complex microwave components with internal structures that cannot be readily machined.

The lab also provides various specialized services, such as copper plating the internal surfaces of stainless-steel waveguide. This technique combines the thermal isolation of stainless steel with the low microwave losses of copper, and it is essential in cryogenic receiver construction.

## Accomplishments and Highlights in FY 2008

An online tracking system for plating jobs was initiated in October 2007, and since its inception 140 "job numbers" have been assigned. The commercial value of our gold plating over the past year exceeds $200,000. We plated approximately 385 grams of pure (bondable) and alloy (bright) gold. The volume of work continues to accelerate as ALMA and EVLA both move into production, with recent deliveries of plated components exceeding $20,000 per month in commercial plating value.

Our old copper-electroforming production process relied on a commercial chemistry formulation that is no longer available. We retired that process and established a new tank and system using a currently available process in mid-April 2008. Various test pieces since then have yielded very bright and uniform copper growth at current densities from 20–70 Amps/square foot (ASF) of mandrel area. It is very clear that careful handling of the bath chemistry, rotating the mandrel in the tank, and optimized air agitation

will allow us to electroform consistently at 30–50 ASF, which means 10–15 days to complete a piece (3 to 4 times faster than before) with excellent finishing. This capability is demonstrated in the four recently electroformed K-band (18–26 GHz) phase shifters for the EVLA, shown in Figure F.16. Our next steps are (1) assemble a second small electroforming system for evaluating copper plating chemistries and experimenting with higher ASF and (2) set up multiple rotators in the first system to handle three pieces at once to increase production.

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*Figure F.16. EVLA K-band phase shifters electroformed using the new process.*

# G. New Initiatives

## G.1. The Square Kilometer Array (SKA)

### Accomplishments and Highlights in FY 2008

The international management of the SKA program underwent considerable change in FY 2008. The International SKA Steering Committee (ISSC) was replaced by the SKA Science and Engineering Committee (SSEC), a new international oversight group, in recognition of the change from long-term planning to more detailed science and engineering work. After the last ISSC meeting in Manchester, UK in October 2007, the first SSEC meeting was held in Perth, Australia in April 2008. In conjunction with this shift, the new SKA Program Development Office occupied offices at the University of Manchester early in 2008 and hired a new Project Engineer. An NRAO scientist took over as chair of the SSEC in mid-2008, and another US scientist took on the role of SSEC Project Scientist.

A key element of the SKA development program was publication of a document that presented a draft set of performance specifications for the SKA. The specifications and schedule were divided among SKA-low (tens to hundreds of megahertz observing frequency), SKA-mid (a few hundred megahertz to a few gigahertz), and SKA-high (a few gigahertz to a few tens of gigahertz) components in recognition of the different technologies and timescales for the different elements. NRAO scientists played a role in producing the specifications, and two other NRAO scientists were on the review committee assessing the specifications document. Many US scientists believe that the specifications document presents an overly ambitious schedule and has modified performance parameters enough that some of the key SKA science goals will not be attainable. These issues are critical for the decadal-survey working group for the US SKA Consortium, which includes three NRAO members and is considering the form of the SKA Program that will be submitted to the US decadal committee in the next year.

The PrepSKA proposal submitted to the European Community Framework Program 7 activity was approved, and PrepSKA work commenced in 2008. The primary focus so far has been staffing the Central Design and Integration Team in Manchester. Concurrently, the US Technology Development Program (TDP) began its work on optimizing antennas, wideband receivers, and work packages for the mid- and high-frequency SKA segments; and the first meeting of the Antennas Working Group took place in March 2008. The NRAO is performing simultaneous work on phased-array feeds (not emphasized in the funded TDP) for the mid-frequency SKA. The NRAO also is a key participant in developing one of the low-frequency arrays that may be a first step toward a low-frequency SKA—the Precision Array for Probing the Epoch of Reionization (PAPER) is under development by a team led by UC Berkeley with significant contributions from the NRAO in antenna development and measurement. A four-element pathfinding array for PAPER has been deployed and tested in Western Australia. Further details are found in the Central Development Laboratory portion of this document.

The NRAO has played a major role in the SKA Calibration Working Group, particularly with respect to developing algorithms for wide-field imaging at low and intermediate observing frequencies. We expect that implementing and testing such algorithms on the EVLA will be important to demonstrating the capability for successful scientific data analysis with the SKA.

## G.2. Space VLBI

### Accomplishments and Highlights in FY 2008

The NRAO played a major role preparing the "SAMURAI" Mission of Opportunity proposal to NASA for support of the Japanese VSOP-2 mission centered on the Astro-G spacecraft. The proposal had two primary science goals: (1) studying jet formation and collimation in blazars and (2) measuring geometric distances to galaxies containing $H_2O$ megamasers for improved determination of the Hubble constant. Funding was requested to prepare the VLBA operations and correlator to support VSOP-2, and for support of VLBA operations in the years 2013–2015. The NASA evaluation panels found only strengths in the science program, with low cost and technical risks, and hence rated the proposal as "Category I," the highest category eligible for funding. Unfortunately, the Selection Committee chose not to fund it.

The first meeting of the VSOP-2 International Science Council (VISC-2) was held in May 2008, in conjunction with a European meeting on VSOP-2 key science. VISC-2 presently has two NRAO members. A structure and charter were adopted for the VISC-2, officers were elected, and discussions were held on scientific policies and the role of international partners. Since the NASA SAMURAI proposal was rejected, the NRAO will be unable to participate in VSOP-2 without an additional source of funding. Discussions with our colleagues in Japan have been ongoing and have increased in urgency.

The Russian Radioastron space VLBI mission now is scheduled for launch in 2009. The NRAO has participated only informally by attending several teleconferences and by consulting with the Radioastron team regarding some of the key technical elements of Space VLBI.

## G.3. VLBA Partnerships

### Accomplishments and Highlights in FY 2008

The NSF Senior Review report released late in FY 2006 recommended developing external funding sources for the VLBA to cover approximately half of the direct operating costs of the VLBA by 2011. Responsibility for developing the requested VLBA partnerships was transferred to the New Initiatives Office early in FY 2007. The VSOP-2 work described above is part of one prospective partnership.

In FY 2007 two primary scientific partnerships were established for the VLBA: (1) a general cooperative agreement with the Max Planck Institut für Radioastronomie (MPIfR) and (2) a collaborative observing agreement with the Gamma-ray Large Area Space Telescope (GLAST) now know as the Fermi Gamma-ray Space Telescope. In FY 2008 the VLBA completed a project funded by the MPIfR to increase the sensitivity of the VLBA 22 GHz receiver systems by more then 30%. In addition, the GLAST mission received the first collaborative proposals for the VLBA and other NRAO telescopes. Approximately 300 hours of VLBA time were awarded, with the first observations taking place shortly after the June 2008 launch of GLAST.

NRAO/AUI was a co-investigator on the Trans National Access portion of the Radio Net proposal to the European Community Framework Program 7 opportunity. This proposal, submitted in early FY 2008, requested four years of funding at 50,000 Euros/year for operation of the VLBA in support of Global VLBI Network observations. The outcome of the proposal is in final negotiation; it is expected to yield VLBA funding of approximately 50,000 Euros/year for three years.

The VLBA successfully observed the Phoenix spacecraft en route to Mars on nine occasions in May 2008 and determined the spacecraft position relative to background quasars and to multiple Mars-orbiting spacecraft. This demonstration was part of a potential partnership under discussion with NASA for

accurate navigation of interplanetary spacecraft. Position accuracies were derived as a function of the separation between Phoenix and the reference source, with a best accuracy of < 25 microarcseconds (30 m at a Mars distance of 1.9 AU) when Phoenix and a Mars orbiter were in the same antenna beam, just before Phoenix reached Mars in late May. We hope to improve the accuracy by a factor of 2–3 with a better understanding of systematic errors. Preliminary results were presented to the head of the NASA Planetary Science Division at a meeting in late June.

## G.4. The Frequency Agile Solar RadioTelescope (FASR)

### Accomplishments and Highlights in FY 2008

The Frequency Agile Solar Radiotelescope (FASR) is a prospective facility designed to address solar, heliospheric, and space-weather physics. The project was developed by a partnership under AUI management that includes the NRAO and a number of universities: NJIT, UC Berkeley, University of Michigan, University of Maryland, and Caltech. The proposed site of the instrument is Caltech's Owens Valley Radio Observatory. In anticipation of the submission of a construction proposal, a letter of intent was signed by the FASR partners in 2007, followed by a teaming agreement in early 2008. In January 2008 a preliminary proposal for FASR construction was submitted to the Mid-Sized Infrastructure (MSI) Opportunity program sponsored by the NSF Division of Atmospheric Science (ATM). In March the FASR team was invited to submit a full proposal for construction to the MSI program. The proposal was submitted for review in June.

In parallel with submission of the preliminary and full proposals to the MSI Opportunity, ongoing design and development phase (DDP) activities were supported by an NSF/ATM award to the NRAO. They include (1) developing the FASR operations and maintenance plan, (2) a significant descope and rescope of the instrument in advance of the proposals to the MSI Opportunity program, (3) software and data-management planning, (4) systems design, including specific design of analog and digital subsystems and their interfaces, (5) designing and prototyping the ultra-broadband feeds and integrated first-stage broadband amplifiers required by FASR, (6) evaluating ultrabroadband (>20 GHz) fiber-optic links required by FASR, (7) evaluating correlator architectures and their costs, and (8) developing a prototype digital filter bank for evaluation with the FASR prototype analog system. If the FASR project is funded, FASR DDP activities, which are funded through FY 2009, will dovetail with construction ramp-up.

**New Initiatives Milestones for FY 2008**

| Milestones | Date Planned | Date Accomplished |
|---|---|---|
| 1. Funding start for the US SKA TDP | 11/2007 | 11/2007 |
| 2. Complete evaluation of collaborative GLAST proposals | 01/2008 | 12/2007 |
| 3. Submission of VSOP-2 MoO proposal | 01/2008 | 01/2008 |
| 4. Agreement on management model for international SKA | 01/2008 | 01/2008 |
| 5. Sign MOU for one major partner for VLBA | 06/2008 | See notes |
| 6. Begin 33 GHz implementation on VLBA (provisional) | 09/2008 | See notes |
| 7. SKA Program submission to decadal committee (provisional) | 09/2008 | See notes |

Notes:
5 and 6. The most-likely candidate for the first VLBA MOU is NASA, but agreement was delayed by frequent NASA reorganization and budget issues. Absent a NASA agreement, the related 33 GHz implementation has not occurred. The second-most-likely candidate is the VSOP-2 mission; since the rejection of the VSOP-2 MoO proposal, we are now discussing a direct partnership with Japan.
7. The US decadal committee does not yet exist, so there is no forum for submission of SKA material.

# H. Community Support Programs

## H.1. Scientific Community Outreach

The Office of Science and Academic Affairs (OSAA) focuses on those activities that provide services to the wider astronomical community outside the NRAO, with the goal of fostering a strong US radio community. They include research programs to employ undergraduates (NSF REU program and engineering co-op students), graduates (Junior Fellows), and post-graduates (Jansky Fellows, NRAO Postdoctoral Fellows, and Research Associates). The OSAA also manages the peer-review process for allocating telescope time on all NRAO telescopes. As part of this process, funding is available for travel to the telescope, student research support, as well as computing and page-charge support. In addition, a healthy and active US radio community is supported though the funding of University-led hardware and software projects, NRAO staff community service, and the organization of science meetings.

| Mission Activity | FY 2008 Completed Milestones | Delivery Date |
|---|---|---|
| Undergraduate Programs | Successful NSF REU/RET Proposal | 12/12/07 |
| Undergraduate Programs | Research programs for 24 summer students (8 Socorro, 4 GB, 12 in CV) | 08/11/08 |
| Undergraduate Programs | Five Engineering Co-op Students | 09/30/08 |
| Graduate Programs | Seven Pre-doctoral Fellows | 09/30/08 |
| Graduate Student Research support | Supported ~20 Student Observing Proposals | 09/30/08 |
| Graduate Student Research support | Internship visits for ~10 students | 09/30/08 |
| Postgraduate Programs | New hires and continuation of Jansky Fellows postdoctoral program | 03/01/08 |
| Oversight of the NRAO proposal review and the telescope time assignment process. | Joint GLAST/NRAO Agreement. | 02/28/08 |
| Oversight of the NRAO proposal review and the telescope time assignment process. | Drafted Proposal Process review charge | 01/18/08 |
| Oversight of the NRAO proposal review and the telescope time assignment process. | Oversee status and data release of Large Projects | 02/05/08 |
| Scientific Meetings | NRAO Scientific Staff Retreat Meeting | 04/11/08 |
| Scientific Meetings | US/China Bilateral Astronomy Meeting | 04/25/08 |
| Scientific Meetings | NRAO Postdoctoral Symposium | 04/28/08 |
| Outside Scientific Visitors | Eight short-term or sabbatical visitors | 09/30/08 |

## H.2. Spectrum Management

Domestically, the NRAO spectrum manager gave presentations at the twice-yearly meetings of the NAS CORF (National Academy of Sciences Committee On Radio Frequencies). The NRAO helped to draft and co-signed a joint letter organized by KPNO on behalf of the tenants of Kitt Peak and other telescopes around Tucson whose observing environment stands to be affected by construction and operation of the DHS (Department of Homeland Security) border fence (the Secure Border Initiative, SBI) in Arizona. The NRAO also filed its own comments with the SBI. The NRAO filed comments with the State of New Mexico regarding possible placement of a high-voltage power line across the Plains of San Agustin, carrying power from wind farms to be located elsewhere in the state. No FCC comments were filed.

Internationally, the spectrum manager participated in ITU-R (International Telecommunications Union-Radio) activities including the World Radio Conference 2007 held in Geneva and contributed to the ongoing meetings of US and International Working Party 1A (spectrum engineering) and Study Group 1 (spectrum management), WP7D (radio astronomy), and SG7 (science services). The NRAO is spear-heading an effort to achieve wider (ITU-R) recognition of Radio Quiet Zones. The NRAO spectrum manager was offered an interim membership in IUCAF, subject to approval at the 2009 IAU General Assembly.

## H.3. Education and Public Outreach (EPO)

The Office of Education and Public Outreach (EPO) communicates what the Observatory does and why it is important via a wide range of programs, activities, services, and publications that feature NRAO science and technology. The target audiences are the scientific community, teachers and students, and the public. EPO programs incorporate the most recent scientific results from the GBT, VLA, and/or VLBA, discuss the scientific promise of the EVLA and ALMA, and describe how radio astronomy complements and connects to astronomical research in other wavebands.

### *Science Community Outreach*

EPO organized NRAO exhibitions at three major science meetings: (a) the January 2008 American Astronomical Society (AAS) meeting in Austin, including an NRAO Town Hall and AUI/NRAO reception; (b) the February 2008 American Association for the Advancement of Science (AAAS) meeting in Boston, the first time the NRAO has exhibited at this major science venue; and (c) the June 2008 joint meeting of the AAS and Astronomical Society of the Pacific (ASP) in St. Louis. The NRAO co-sponsored the ASP meeting, which focused on U.S. planning for the International Year of Astronomy 2009 (IYA 09).

An electronic Newsletter, NRAO eNews, was designed and debuted in June 2008, transforming the Newsletter from a quarterly, hardcopy publication delivered by postal mail to 2,000 subscribers into a monthly, electronic publication delivered via e-mail and the Internet to 4,000 subscribers. An annual eNews archive will be published in hard copy for institutional subscribers beginning in January 2009.

The 2007 AUI/NRAO Image Contest awarded prizes to eight astronomical images in October 2007. The 4$^{th}$ annual AUI/NRAO Image Contest was announced in April; the submissions deadline is 3 September 2008. The popular NRAO 2008 Calendar was produced and distributed. This calendar features the prize-winning entries from the previous year's AUI/NRAO Image Contest.

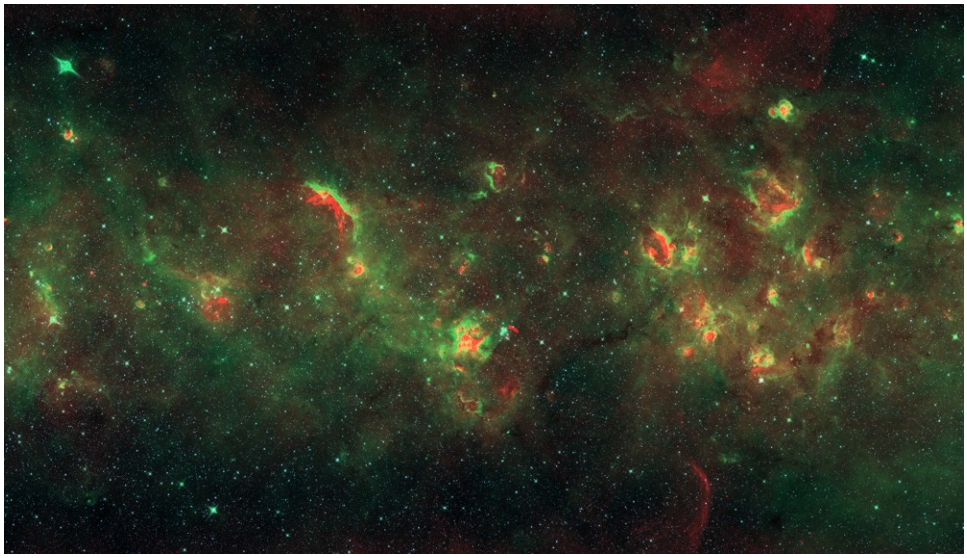


*Figure H.1. First Prize, 2007 AUI/NRAO Image Contest: "Birth and Death in the Milky Way. A VLA-Spitzer panorama of the Milky Way in Scutum and Aquila. Image by Rick White (STScI), Bob Becker (IGPP/LLNL & UC-Davis), and David Helfand (Columbia)*

## *Public Outreach*

Visitation to the Green Bank Science Center increased by 8.3% in CY 2007 to 48,291 persons, including a 12% increase in commercial tour-group visitation. The Science Center applied for and received $41K in Matching Advertising Partnership Program funds from the West Virginia Tourism Commission. The VLA Visitor Center saw 20,147 visitors in CY 2007, an increase of 2.4% over CY 2006. The VLA Open House events in October 2007 and April 2008 each drew more than 500 visitors. The VLA Visitor Center Auditorium remodel was completed in March.

A completely redesigned NRAO web site debuted 25 February 2008. This redesign incorporates an improved structure, a more compelling visual style, content management tools, and presentation of the NRAO as "One Observatory." The first EPO webcast covered GBT's participation in the NASA Phoenix Mars Lander mission on May 25 May. EPO and Allegheny Mountain Radio completed 26 short programs for the *Cosmic Radio* program and podcasts that debuted in January 2008.

The NRAO distributed 21 news releases as of July 11 in FY 2008. Fifteen of these releases described research results; the GBT, VLA, and VLBA were featured in 6, 4, and 5 of these releases, respectively. Other releases described major technical achievements (e.g., ALMA construction progress) and non-research news (e.g., the 2008 Jansky Lectureship). A January 2008 news release that described how "Smith's Cloud" will collide with the Milky Way garnered major media attention, including astronomer interviews on National Public Radio and CBC Radio. EPO also produced and distributed multiple local releases describing, for example, the VLA public tours and the Charlottesville Open House.

Major Community Open House events were held in Green Bank (October 2007) and Charlottesville (April 2008), hosting 600 and 920 guests, respectively, including many K–12 educators and young people. Guests at both locations enjoyed numerous exhibits, educational games and activities, and talks about NRAO science and technology. In association with the 2008 AAS meetings, EPO participated in free public-outreach events (Astro-Zone) for the Austin and St. Louis area public, and the similar two-day Family Science Fun Days outreach events at the Boston AAAS meeting.

Santiago-based FilmoSonido continued documenting the ALMA project via high-definition video with two multi-day visits (October 2007 and April 2008) to the OSF, the AOS, and San Pedro de Atacama. In collaboration with the NRAO, Charlottesville-based Paladin Media Group conducted and filmed interviews with ALMA scientists, engineers, and senior managers. A 4.5-minute high-definition ALMA trailer was completed for the January 2008 AAS meeting, and a 16-minute short feature that broadly describes ALMA science and technology debuted at the February 2008 AAAS meeting.

*Figure H.2. The first VertexRSI production antenna at the Operations Support Facility in Chile.*

### *Teachers and Students*

The NSF-funded *Pulsar Search Collaboratory* program got underway in January 2008. Through this innovative, three-year program, teachers and students will assist a worldwide team of astronomers in discovering new pulsars. The project will introduce students to computational mathematics and distributed-computing applications while engaging them in authentic scientific research. Thirty-five high school students, four undergraduate students, and fifteen teachers participated in this joint NRAO-West Virginia University program in July 2008.

Three-day intensive residential Chautauqua programs took place in Green Bank and Socorro, continuing a 20+ year NRAO tradition of serving undergraduate science faculty. The West Virginia Governor's School for Math and Science was hosted in Green Bank again in summer 2008, providing an in-depth research experience for sixty rising 8$^{th}$ graders, encouraging their interest in science, technology, engineering, and mathematics careers. The *StarQuest* star party continued as an annual and successful Green Bank event with 200+ attendees. Four high-school teachers are participating in the 2008 NRAO Research Experiences for Teachers (RET) program, two in Socorro and two in Green Bank. Over 2,000 students took part in the Green Bank education programs through extended or overnight field trips in the past year.

The *Sister Cities* program continued, sponsoring educational and cultural programs connecting the San Pedro de Atacama, Chile and Magdalena, NM communities. Two Magdalena high-school seniors will spend the southern hemisphere 2008 spring semester in Chile; and two San Pedro students will attend the Magdalena High School during the northern hemisphere fall 2008 semester. Periodic videocons between classrooms in San Pedro and Magdalena are scheduled to provide educational opportunities between annual exchange visits.

*Figure H.3. The students and teachers of the West Virginia Governor's School for Science & Mathematics.*

### *Program Development & Management*

The EPO team met in Green Bank for its annual planning meeting on December 3 and 4. The main topics were the EPO Strategic Plan and the new EPO website design, structure, and content.

A proposal was submitted to the International Year of Astronomy (IYA) 2009 Program Committee for a national *Quiet Skies* program that would be an integral component of the *Dark Skies Awareness* global cornerstone project. We also partnered with the STScI Office of Public Outreach and other observatories to propose a Virtual Astronomy Observatory EPO program to the NSF. The EPO section for the renewal of the AUI Cooperative Agreement (2010–2015) proposal was prepared and submitted.

Taylor Johnson joined the NRAO on October 1, 2007 as our WWW Content Specialist and Senior Web Designer. John Stoke arrived at the NRAO on August 4, 2008 to be the ALMA EPO Program Officer.

### *Education and Public Outreach Milestones from the 2008 Program Plan*

The performance on the EPO milestones from the 2008 Program Plan is shown in the following table.

**Education and Public Outreach Milestones for FY 2008**

| Item | Date Planned | Date Accomplished |
|---|---|---|
| 1. Complete Science Community Outreach Plan | 10/2007 | 09/2008 |
| 2. Award 2007 Image Contest Prizes | 10/2007 | 10/2007 |
| 3. Publish NRAO Newsletter | 10/2007, 01/2008 04/2008, 07/2008 | 10/2007, 01/2008 04/2008, 07/2008 |
| 4. Publish NRAO 2008 calendar | 12/2007 | 12/2007 |
| 5. AAS exhibitions (Austin, St. Louis) | 01/2008, 06/2008 | 01/2008, 06/2008 |
| 6. Announce 2008 Image Contest | 01/2008 | 01/2008 |
| 7. AAAS exhibition (Boston) | 02/2008 | 02/2008 |
| 8. SPIE exhibition (Marseilles) | 06/2008 | canceled |
| 9. ESOF2008 exhibition (Barcelona) | 07/2008 | canceled |
| 10. 2008 Image Contest deadline | 09/2008 | 09/2008 |

| Item | Date Planned | Date Accomplished |
|---|---|---|
| 11. New NRAO website home page | 12/2007 | 02/2008 |
| 12. New EPO website | 12/2007 | 02/2008 |
| 13. New Science/observer website | 03/2008 | 02/2008 |
| 14. New Internal website | 07/2008 | Transferred |
| 15. NRAO Community Open House (GB) | 10/2007 | 04/2008 |
| 16. Publish first image release | 12/2007 | 01/2008 |
| 17. Distribute ALMA high-def video | 01/2008 | 02/2008 |
| 18. NRAO Community Open House (CV) | 04/2008 | 04/2008 |
| 19. Publish CY 2007 Annual Report | 08/2008 | Canceled |
| 20. Initiate *Cosmic Radio* distribution | 11/2007 | 01/2008 |
| 21. Sister Cities exchange (SOC, Chile) | 12/2007 | 08/2008 |
| 22. Gadgets & Gizmos (GB) | 05/2008 | 06/2008 |
| 23. Astronomy Institute (GB) | 06/2008 | Canceled |
| 24. RET teachers arrive (GB, SOC, CV) | 06/2008 | 06/2008 |
| 25. Chautauqua (GB, SOC) | 07/2008 | 07/2008 |
| 26. Master of Science Teaching (SOC) | 07/2008 | FY 2009 |
| 27. SARA conference (GB) | 07/2008 | 07/2008 |
| 28. StarQuest IV Star Party (GB) | 07/2008 | 07/2008 |
| 29. GLOBE Workshop (GB) | 08/2008 | 08/2008 |
| 30. WV Gov School for Science & Math (GB) | 08/2008 | 08/2008 |
| 31. Install One Observatory exhibits | 04/2008 | FY 2009 |
| 32. Install *ViewSpace* | 02/2008 | FY 2009 |
| 33. Complete VLAVC marketing plan | 04/2008 | 11/2008 |
| 34. Submit VLA VC exhibits proposal | 05/2008 | 11/2008 |
| 35. Complete EPO Strategic Plan | 10/2007 | 01/2008 |
| 36. Complete IYA 2009 planning | 09/2008 | 10/2008 |

Notes:
3. Transitioned to a monthly electronic publication in June 2008.
8, 9. Exhibitions canceled owing to M&S and travel budget constraints.
14. Responsibility for the internal NRAO web site was delegated to CIS.
15. Open House date changed to take advantage of Astronomy Day.
19. Canceled owing to M&S budget constraints.
21. Community interest in a student exchange motivated the date change.
23. NASA funding no longer available.
26. Rescheduled to FY 2009 in cooperation with co-sponsor NM Tech.
31. Delayed by M&S budget constraints. Design to be completed November 2008. Installation will be contingent on FY 2009 funding.
32. Delayed by M&S budget constraints and monitor RFI issues.

# I. Management and Administration

## I.1. Administration

### Observatory Business Services (OBS) Overview

The Observatory Business Services division provides management and support for budget development and analysis, contracts and procurement, facilities, and general administration and business matters for Charlottesville operations and Observatory-wide requirements. The OBS division has made advances in all functional areas with specific accomplishments and status updates detailed below.

#### *Budget and Business Analysis*

During FY 2008 the first multi-year budgeting and staffing forecasts were developed for FY 2009 through FY 2015. The models performed well but require intensive maintenance to maintain consistency as assumptions are changed. To address this level-of-effort issue, we developed a plan to transition from the secure shared-server budget development process using change-tracking Excel workbooks to the web-based Microsoft FRx software application. Conceptually the software meets the need; however, the FRx application is proving to have its own level-of-complexity and level-of-effort issues. The learning curve is steeper than anticipated, and the available time required is insufficient for FY 2008 implementation.

Significant progress has been made in modeling the Indirect Cost rate, Management Fee allocations, and Direct Allocation Cost reallocations. This modeling is very useful for "what if?" planning scenarios.

#### *Grants Administration*

During FY 2008 grants administration was centralized under one dedicated person within Observatory Business Services. This has enabled a more comprehensive approach to grants administration and led to improved customer satisfaction. To further improve the program, the Grants Administrator has completed the first course in a certificate series for federal grants administration.

#### *Charlottesville Facilities*

During FY 2008 several projects were planned to update the appearance and material condition of offices at the Edgemont Road facility and the availability of restroom facilities at the NRAO Technology Center. Below is a review of the project status.

Edgemont Road

1. Office renovations and space reconfiguration. Three offices were renovated and an additional three offices were created through the conversion of a large conference room.

2. Server-room electrical distribution and backup power. A scalable uninterruptible power supply (UPS) was installed in the server room early in FY 2008. This 20 KW UPS has shored up the power backup capacity to continue server operations during periods of intermittent power, limit the potential for data loss, and ensure an orderly and systematic shutdown of server services. Shortcomings of the electrical distribution system will not be addressed during this fiscal year owing to budget constraints and higher-priority infrastructure projects.

NRAO Technology Center (NTC)

1. Third-floor restroom. The design-build project to convert the existing men's room into two separate restrooms is in the proposal phase with local contractors. This project addresses the need for additional women's restroom facilities at the NTC. Work on this project is expected to begin before the end of the fiscal year.

2. Surge protection. The surge-protection project has been sidelined while the contractor reschedules the power-consumption data-gathering run. The contractor's original study was conducted in the summer of FY 2007; however, the contractor lost the data set and must conduct another study. This project will be continued into FY 2009.

3. Interior Offices. The increasing population at the NTC has led to a critical shortage of adequate office space. Funding has been secured for this project and a request for proposals is being prepared for release to local contractors. This project will not be completed before the end of FY 2008.

### *Contracts and Procurement (CAP)*

The Contracts and Procurement Division is responsible and accountable for all AUI/NRAO procurement actions in accordance with NRAO procurement policy and federal regulations. CAP activities include generating purchase orders; executing purchase orders; ensuring supplier compliance with delivery, pricing, and terms and conditions; and issuing change orders. CAP also creates and negotiates the supplier's agreement/contract. CAP continues to ensure a high level of communication and service between the NRAO procurement staff and ALMA management and IPTs, NSF program directors, and the NSF Division of Acquisition and Cooperative Support staff.

During FY 2008 CAP implemented procurement changes to P2P (the Procure to Pay program) and created a new Source and Pricing Justification Form to streamline and improve turnaround times for purchases. These changes also resolved issues identified by the NSF TBSR (Total Business Systems Review). Training is now in process.

**Procurement Activity:** FY 2008 presented continued challenges for the procurement staff in terms of procurement complexity, challenges in supplier's negotiations, and an increase in the number of user-generated requirements. The total purchase-order activity had only a slight increase, but ALMA procurements have increased the complexity of the RFP and contracting processes, as well as their dollar values. The number of Procurements requiring NSF approval was projected to increase by 59%. CAP acquired NSF's pre-approval for ten of the forecasted procurements, thereby reducing the reviews and approval times by 35 days for these ten items. We will be seeking pre-approval for additional items. In addition, CAP is starting to develop local and Observatory-wide preferred-vendors lists.

**Procedure Manuals:** CAP has drafted updates to the Procurement Manual and has created a Purchasing-Card Manual. Both documents had preliminary reviews and are back at CAP for modification. As a result of the new Source and Pricing Justification Form, those changes have already been implemented and are incorporated into the Procurement Manual. CAP is also creating a new Import/Export Procedures Manual.

**Contracts:** CAP has developed and implemented a new multi-year Master Agreement strategy for large supplies and services agreements. CAP is also updating all NRAO terms and conditions, some of which haven't been updated since 1992. After Bill Porter's departure, a majority of his contracts administration functions were transferred to CAP. CAP has also been engaged in the reviews of non-programmatic funded opportunities for both the NRAO and AUI.

**Career-path/Training development:** The Buyer's career path is being re-evaluated and expanded. Five of the seven Buyers have completed their CPP (Certified Purchasing Professional) exams, and a sixth has completed her third of four modules to become a Certified Purchasing Manager.

An off-site CAP training session was conducted to inform personnel on CAP, NRAO, and industry information on contracts and acquisition, and there was an external guest speaker on subcontracting and unique terms and conditions.

### *Management Information Systems (MIS) Division Overview*

The Management Information Systems Division provides Observatory-wide business-systems support to all areas of Observatory operations including payroll, human resources, general ledger, accounts payable, business computer (Windows-based and SQL), and computer hardware. MIS is also responsible for providing financial reporting via business systems, user support, and enhancements along with upgrades for business computer systems. The NRAO utilizes the Oracle J.D.Edwards (JDE) EnterpriseOne business software as its Enterprise Resource Planning software. FY 2008 MIS accomplishments include:

- Selection and development of the Electronic Timekeeping (ETK) system to be used by the NRAO. The ETK system is custom written with the JDE toolset, web-based, and will be fully integrated with the JDE business software. The system is scheduled for deployment in September/October 2008.
- MIS Disaster Recovery Initiative. During FY 2008 MIS implemented disaster-recovery hardware that gives real-time mirroring of the JDE business-software database server. In the event of hardware or other failure of the primary server, the disaster-recovery server can by operational in less than one hour. The disaster-recovery area is in an RFI-shielded area and is located in a different building from the primary server. Other redundant machines (Web servers) required to access JDE are located in the same disaster-recovery area.
- Hiring an MIS System Administration I employee for Configurable Network Computing (CNC) duties within MIS. This position is cost effective and replaces the services from a third-party contractor. The CNC administrator duties include installation and administration of the MIS web server and portal servers, JDE updates, database administration, security, and disaster recovery.
- Installation of the JDE Electronics Funds Transfer (EFT) for Accounts Payable. EFT will enable the NRAO Accounts Payable to make funds transfer payments from the JDE business software without the issuance of a hard-copy check while retaining all normal business processes within the JDE business software.
- Further physical-security measures for the MIS business servers. Access control to the MIS server room and Disaster Recovery room has been changed from hard-key access to a proximity-card access system with full logging capabilities. Cameras are installed in both server rooms. After-hours controlled access to the primary server room floor/wing has also been implemented.
- Updates to the JDE business software. Payroll and operating-system updates have been implemented throughout the year.

## Fiscal Division Overview

The primary objectives of the NRAO Fiscal Division are strategic financial support for business and operational planning, supporting the Observatory in all major financial functions, and meeting all external and internal audit and reporting requirements. During FY 2008 the Fiscal Division achieved substantial progress toward the planned objectives below.

### *External and Internal Audit*

The NRAO received exceptional results pertaining to the FY 2007 OMB A-133 and Financial Statement Audit completed by an external audit firm. The *"Auditor's Report"* cited an "Unqualified Opinion" and the *"OMB A-133 Report"* cited no findings or questioned costs. Additionally, the external auditors issued no Management Letter Comments pertaining to the Fiscal Department and noted that all prior-year Management Letter Comments had been cleared.

### *Automated Clearing House (ACH) Payments*

The Fiscal Division plans to implement ACH payment for employee travel reimbursements by September 30, 2008. The process is currently in the testing phase to ensure all electronic file requirements are met. Expansion of ACH payments to all vendors is targeted to begin in the second quarter of FY 2009.

#### *Employee Benefit and Fringe Allocation*

During FY 2008 the Fiscal Department designed an Observatory-wide "leave pool" to allocate employee leave costs to individual projects and departments based on an established rate applied to the respective labor costs. The leave pool has been established in a test environment, and the established date to incorporate into production is September 30, 2008.

The re-design of the "fringe pool" to allocate fringe benefits more efficiently has been targeted for the first quarter of FY 2009.

### *Cross-Training Matrix and Succession Planning*

A "cross-training matrix" for the Fiscal division was developed in FY 2009 to classify all individual fiscal responsibilities and identify the person cross-trained in that function.

Additionally, a "succession plan" will be developed in the second quarter of FY 2009 to identify individuals targeted to assume responsibilities of retiring employees.

## Environment, Safety, & Security (ES&S) Overview

### *Environmental Protection*

In FY 2008 the ES&S Department developed site-specific program requirements for asbestos management at the VLA and Green Bank sites. In addition, an asbestos survey at the Charlottesville site was completed and the report was submitted. We have implemented a program to ensure that hazardous wastes from the Charlottesville chemistry lab are properly disposed of.

### *Safety in the Workplace*

During FY 2008 the NRAO Environment Safety & Security Manual was completely rewritten to be a web-based on-line manual that complies with OSHA requirements. The new manual is very specific regarding duties of employees and NRAO management. This fiscal year we began implementing an inspection program for the VLBA sites, and it will be continued into FY 2009. Also, during FY 2008 we began implementing an arc flash electrical-safety program at the VLA and Green Bank sites. It will be complete this fiscal year, including purchase of special personal protective equipment for workers. Another major safety initiative implemented during FY 2008 is the new NRAO-administered commercial drivers-license program at the VLA. This year the new program has already saved several thousand

dollars, and it will continue to save for years to come. The ES&S Department continued to support ALMA with system safety reviews and participated in the acceptance and verification processes for antennas and associated equipment. This effort will continue through FY 2009.

### *Secure Facilities*

During FY 2008 the card-access system at the Edgemont Road facility was expanded to the NTC and Green Bank facilities, making employee access at all Eastern facilities easy while protecting staff from outside intruders. We also installed security cameras and recording systems at the Edgemont Road facility. As money is available during FY 2009, similar systems will be installed at all other NRAO facilities. Already this new system resulted in trespassing charges regarding a potentially dangerous intruder at the Edgemont Road facility.

## Human Resources (HR) Overview

The HR Division, in partnership with NRAO management, ensures a qualified, diverse, and highly motivated workforce focused on achieving the strategic goals of the Observatory through the development of cost-effective and results-oriented human-resource programs, policies, and practices**.**

International growth through the ALMA Observatory in Chile and the continued upgrading of existing telescopes in the United States to maintain NRAO's forefront science are pushing the HR Division to redefine its operations and structure to support an increasingly diverse global organization.

### *Human Resources Information Systems*

The Human Resources Information System (HRIS) provides the resource to meet the Observatory's informational needs. This year, HR supported refinements of the employee self-service module and assisted MIS in the selection and implementation of an electronic timekeeping (ETK) system.

### *Compensation and Benefits*

Following NRAO's growth as an international organization and in support of its Diversity Plan, a Senior Compensation Analyst position was opened and, in March 2008, filled. Since then, the Analyst has planned and delivered performance-evaluation training to NRAO supervisors and managers, implemented a process of reviewing all salary actions to ensure that appropriate and equitable compensation decisions are being made by managers, assisted the ALMA Director and JAO HR Manager in improving the compensation process for Chilean local staff, created a job description and evaluation process, and is analyzing NRAO jobs and pay scales across the Observatory. One of her most important objectives is researching the findings in Mercer's 2007 salary benchmarking report that showed more than half of NRAO employee salaries fall below market by more than 15 percent. The greatest obstacle in correcting the equity shortfall will be NRAO's continued funding limitations.

NRAO benefits continue to be strong recruitment and retention tools. Given NRAO's below-market compensation (equity) levels, maintaining a strong, affordable benefits program is critical to our ongoing success. NRAO's four-tier premium schedule for the employee portion of the medical insurance plan gives employees a stake in medical-plan cost management while reducing the medical-insurance cost burden for employees in lower-paying jobs.

### *Employment*

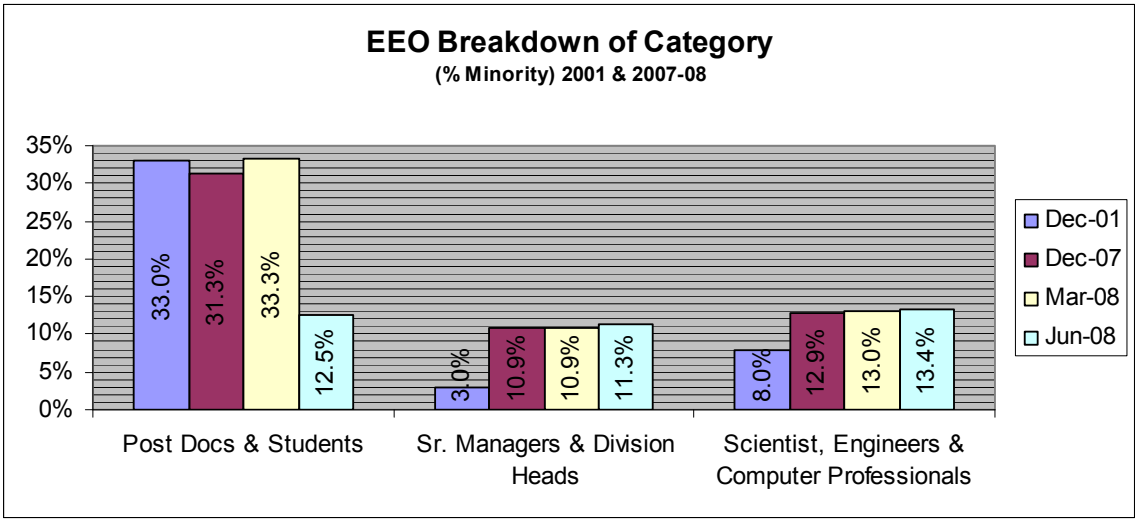
HR reorganized in 2007 and devoted two people to its employment function. This change has enabled the NRAO to focus more energy on expanding its diversity outreach efforts, support international-staff hiring for ALMA, and transfer scientific-staff hiring from OSAA to HR. Improving hiring-process efficiency, accuracy, and analysis was a key objective and is being addressed through the FY 2009 implementation of an Internet-based resume-management and applicant-tracking system. The system will allow instant access to applicant resumes for HR and hiring managers along with providing the NRAO with the ability to report on the results and effectiveness of its diversity hiring.

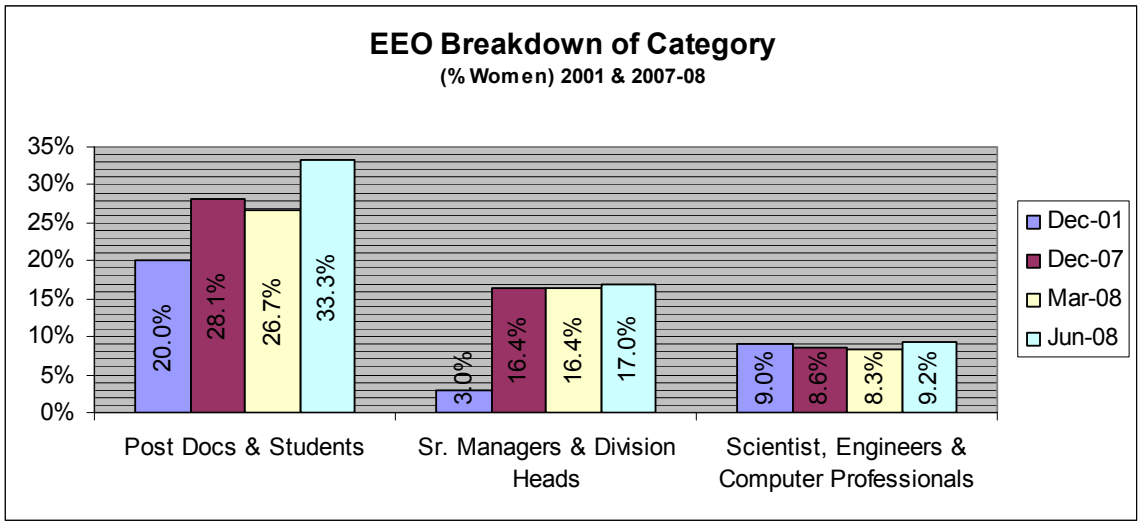
NRAO's outsourcing of its Affirmative Action Plan (AAP) to GEMS Group (Cornelia Gamlen) last year allowed NRAO management to obtain a credible third-party review of its compliance and performance related to its AAP. Following the completion of NRAO's 2007 AAP, Ms. Gamlen conducted management meetings to brief NRAO management on the 2007 Plan and training on the AA regulations and their role and responsibilities under the AAP.

### *Diversity*

The NRAO Diversity Plan was developed in July 2007. Over the course of the year, HR assisted NRAO and its management team in hiring one tenured minority astronomer, promoted three females to three key management positions, promoted females and minorities to higher-level positions, expanded its recruiting drive to reach more minorities and females, and received recognition by the Diversity Careers in Engineering and IT Magazine as a top diversity employer for 2007 and 2008.

The following two charts provide the statistics on minorities and women employees at NRAO, respectively. Three job categories are shown: (Postdocs and Students), (Senior Managers and Division Heads), and (Scientists, Engineers, and Computer Professionals). Within each job category, the percentage as a total of all employees are plotted at four epochs, a benchmark date of December 2001, and at three quarters over the past fiscal year - December 2007, March 2008, and June 2008.






### *Training and Development*

As noted above, HR delivered two supervisor and management training courses over the past year. The first involved Performance Evaluation Program training for supervisors and mangers. The training was conducted by a professional trainer who traveled to all three domestic sites with NRAO's HR Manager and Senior Compensation Analyst. A session was digitally recorded to provide the training to people who could not attend the training sessions and for new managers. Executive-level managers also received training in NRAO's Affirmative Action Plan by an outside consultant. Both training programs support NRAO's Diversity Plan by enabling our supervisors and managers to improve their ability to evaluate employee performance and for executive management to understand how to improve NRAO diversity hiring while maintaining compliance with AA and EEO regulations.

### *ALMA/JAO HR*

Two significant accomplishments occurred in ALMA/JAO HR during the past year.

The first involved reorganizing the interface between NRAO HR and JAO HR. The NRAO HR Manager led an effort that included the direct involvement of the ALMA Director, JAO HR Manager, ALMA HR Advisory Group, the NRAO Director, and AUI to establish clear levels of responsibility for JAO HR and NRAO HR. The results of the group's efforts enabled JAO HR to operate more efficiently and effectively.

The second involved clarifying the JAO's Chilean Local Staff compensation system and supporting the existing JAO HR Manager when the new ALMA Director began his duties in March 2008. Again, working closely with key executives and the NRAO Senior Compensation Analyst, the NRAO HR Manager led the effort to resolve these important issues.

## I.2. Computing and Information Services (CIS)

### Accomplishments and Highlights in FY 2008

#### *Headquarters Computing*

The CIO (Chief Information Officer) position was filled in January 2008 at the Assistant Director level to oversee Observatory-wide Information Technology (IT) vision, strategy, architecture, and coordinated delivery of relevant solutions and services. Key Observatory projects included expanding the pulsar data-processing cluster in Charlottesville, which required upgrading the local data-center power infrastructure. In addition, multiple upgrade projects were successfully executed such as replacing end-of-life wide-bed printers used for graphics, increasing storage on the central filer, and replacing multiple tape-backup systems with a single 20 TByte integrated solution supporting multiple client platforms.

#### *Security*

There were three computer-security incidents during FY 2008; the root cause in all cases involved exploiting vulnerabilities of internal systems by non-trusted external hosts. This risk has now been mitigated by enforcing improved network perimeter access policies and enabling bastion hosts through which users must authenticate before reaching internal systems. Two NRAO staff members attended the annual NSF-sponsored summit on security; and a multi-layered data-security policy was developed, communicated, and adopted.

#### *Common Computing Environments*

A major overhaul of the "Gold Book" of user-centric documentation was undertaken and completed to improve self-help support and standard communication of services across all NRAO sites. Key system upgrades have been initiated including Exchange 2007, the adoption of Red Hat Enterprise Linux version 5.2, and limited deployment of Office 2007.

Windows XP continues to be supported with the release and deployment of SP3. While we continue to evaluate Vista, we have maintained a moratorium on its installation within the NRAO until we have more confidence in the supportability and value to the user of this upgrade path.

#### *Information Infrastructure (Web Services)*

Major progress was made in conjunction with EPO towards the re-architecture of the NRAO external web presence with the release of the new www.nrao.edu portal in February 2008. Work continues to augment this interactive user-centric front end with a more extensive content-management engine. The division of web services into internal and external content has greatly facilitated the consolidation, protection, and management of mission-critical information. The web-reliability initiative has yielded an appreciable improvement in the stability and manageability of our web platforms. In addition, the CIS collaboration with the Library to develop and deploy the web-based NRAO Papers bibliography service has markedly increased the efficiency of gathering, tracking, and accessing important scientific-impact data.

#### *Networking and Telecommunications*

The major ongoing network project initiated in FY 2008 is the re-bid of our General Services Administration (GSA)-related telecommunications contract associated with the "Networx" program. This contract has many more options than the previous one, so opportunities for consolidating other services to this contract will be pursued to provide better value to the NRAO and AUI. CIS also provides web

meeting, audio conferencing, international and domestic toll-free service, and calling cards to our employees under this program. In addition to providing the lowest service-rates available, this consolidation results in easier telephony expense management and reporting with consequently lower overhead for the Observatory.

The NRAO is a sponsored participant in the Internet2 from all major locations. The communication requirements for the GBT, EVLA, and ALMA are on the verge of a step-function rise in data-production rates, and we continue to work with the project sponsors on requirements for remote observation and data analysis, as well as bandwidth needs of video conferencing and data sharing with the wider community. To facilitate secure external access via the VPN, a new Access Control Server was installed.

### *Video and collaboration*

Migration to high-definition video and content tele-presence systems was initiated this year as a result of the recent cost reduction in this technology. This service continues to add substantial value to the NRAO for inter-site research collaborations, with prime examples stemming from joint initiatives between the Central Development Lab and construction projects at other sites and institutions.

### *Computing and Information Services Milestones from the 2008 Program Plan*

The performance on the CIS milestones from the 2008 Program Plan is shown in the following table.

**CIS Milestones for FY 2008**

| Item | Date Planned | Date Accomplished |
|---|---|---|
| 1. New VPN concentrator available | 10/2007 | 02/2008 |
| 2. Web reliability initiative | 12/2007 | 12/2007 |
| 3. Replace wide-bed printers | 12/2007 | 12/2007 |
| 4. "Gold Book" upgrade | 01/2008 | 01/2008 |
| 5. Upgrade storage on the central disk filer | 01/2008 | 03/2008 |
| 6. Install new computer-room power conditioning | 02/2008 | 02/2008 |
| 7. Upgrade the Exchange server (hardware and software) | 03/2008 | 08/2008 |
| 8. System-administrators meeting in Charlottesville | 04/2008 | 05/2008 |
| 9. Deploy Microsoft Office 2007 (initial) | 05/2008 | 08/2008 |
| 10. Web-content management overhaul | 05/2008 | 02/2008 |
| 11. Begin deployment of new Linux (RHEL5) | 05/2008 | 05/2008 |
| 12. Data security plan roll-out (Tier 1 and 2 users) | 05/2008 | 07/2008 |
| 13. Integrated 20 TB library to back up all critical platforms | 05/2008 | 05/2008 |
| 14. Survey NRAO for service priorities for the 5-year plan | 06/2008 | 05/2008 |
| 15. Develop and deploy the NRAO Papers bibliography service | 07/2008 | 07/2008 |
| 16. Re-bid the Wide Area Network contract | 08/2008 | Ongoing |

Note: Several targets were developed during the year in response to events that could not be foreseen for inclusion in the plan for the fiscal year.

# Appendix

| Acronym | Definition |
|---|---|
| AA | Affirmative Action, Antenna Article |
| AAP | Affirmative Action Plan |
| AAS | American Astronomical Society |
| ACA | Atacama Compact Array |
| ACH | Automated Clearing House |
| AIPS | Astronomical Image Processing System |
| AIV | Assembly, Integration, and Verification |
| ALMA | Atacama Large Millimeter Array |
| AlN | Aluminum Nitride |
| ANASAC | ALMA North American Scientific Advisory Committee |
| AOC | Array Operations Center (Socorro, NM) |
| AOP | ALMA Operations Plan |
| AOS | Array Operations Site (ALMA) |
| ARC | ALMA Regional Center |
| ASAC | ALMA Scientific Advisory Committee |
| ASF | Amperes per Square Foot |
| ASP | Astronomical Society of the Pacific |
| ATF | ALMA Test Facility |
| ATI | Advanced Technologies and Instrumentation |
| ATM | Atmospheric Sciences (NSF division) |
| AUI | Associated Universities, Incorporated |
| BAE | British Aerospace Engineering |
| Band 1 | 31.3–45 GHz |
| Band 2 | 67–90 GHz |
| Band 3 | 84–119 GHz |
| Band 4 | 125–163 GHz |
| Band 6 | 211–275 GHz |
| Band 7 | 275–373 GHz |
| Band 8 | 385–500 GHz |
| Band 9 | 602–720 GHz |
| Band 10 | 787–950 GHz |
| BDF | Binary Data Format |
| BE | Back End |
| C band | 4–8 GHz |
| CAP | Contracts And Procurement |
| CASA | Common Astronomy Software Applications |
| CASPER | Center for Astronomy Signal Processing and Electronics Research (Berkeley) |
| CCAT | Cornell-Caltech Atacama Telescope |
| CDL | Central Development Laboratory (Charlottesville, VA) |
| CICADA | Configurable Instrument Collaboration for Agile Data Acquisition |
| CIS | Computing and Information Services |
| CLOA | Central Local-Oscillator Article (ALMA) |
| CNC | Configurable Network Computing |
| CO | Carbon Monoxide |
| CORF | Committee On Radio Frequencies (NAS) |
| CSV | Commissioning and Science Verification (ALMA) |

| Acronym | Definition |
|---|---|
| CV | Charlottesville |
| CY | Calendar Year |
| DC | Direct Current |
| DCAF | Data Capture and Format |
| DDP | Design and Development Phase |
| DGCK | Digitizer Clock |
| DHS | Department of Homeland Security |
| DRAO | Dominion Radio Astronomy Observatory |
| DRXA | Data Receiver Article |
| DSS | Dynamic Scheduling System (GBT), Digital Sky Survey |
| DTS | Digital Transmission System |
| E2E | End-to-End |
| EA | East Asia |
| EFT | Electronic Funds Transfer |
| EPO | Education and Public Outreach |
| ES&S | Environment, Safety, and Security (NRAO department) |
| ESO | European Southern Observatory |
| ETK | Electronic Time Keeping |
| EU | Europe |
| EVLA | Expanded Very Large Array |
| FAQs | Frequently Asked Questions |
| FASR | Frequency-Agile Solar Radiotelescope |
| FD | Fort Davis, TX (VLBA station) |
| FE | Front End |
| FEIC | Front-End Integration Center |
| FEHV | Front-End Handling Vehicle |
| FESV | Front-End Service Vehicle |
| FPGA | Field-Programmable Gate Array |
| FRx | Microsoft Financial Reporting software |
| FTE | Full-Time Equivalent |
| FY | Fiscal Year |
| GaAs | Gallium Arsenide |
| GB | Green Bank |
| GB/SRBS | Green Bank/Solar Radio Burst Spectrometer |
| Gbps | Giga bits per second |
| GBT | Green Bank Telescope |
| GBTIDL | GBT Interactive Data Language |
| GC | Galactic Center |
| GHz | Gigahertz |
| GLAST | Gamma-ray Large-Area Space Telescope |
| GLOBE | Global Learning and Observations to Benefit the Environment |
| Gsps | Giga samples per second |
| GUI | Graphical User Interface |
| GUPPI | Green Bank Ultimate Pulsar Processing Instrument |
| HBT | Heterostructure Bipolar Transistor |
| HFET | Heterostructure Field-Effect Transistor |
| HI | Neutral Hydrogen |
| HIA | Herzberg Institute of Astrophysics |
| HR | Human Resources |

| Acronym | Definition |
|---|---|
| HVAC | Heating, Ventilation, and Air Conditioning |
| HVC | High Velocity Cloud |
| IAU | International Astronomical Union |
| IF | Intermediate Frequency |
| IFP | IF Processor |
| InP | Indium Phosphide |
| IPT | Integrated Product Team |
| ISSC | International SKA Steering Committee |
| IT | Information Technology |
| ITU-R | International Telecommunications Union–Radio |
| IUCAF | International Committee for radio-astronomy frequency allocations |
| IYA 09 | International Year of Astronomy 2009 |
| $I(V)$ | Current $I$ as a function of Voltage $V$ |
| IVOA | International Virtual Observatory Alliance |
| JAO | Joint ALMA Observatory, Joint ALMA Office |
| JDE | J. D. Edwards (business software) |
| JPL | Jet Propulsion Laboratory |
| K | Kelvins (temperature) |
| K band | 18–26.5 GHz |
| Ka band | 26.5–40 GHz |
| KFPA | K-band Focal-Plane Array |
| KPNO | Kitt Peak National Observatory |
| Ku band | 12–18 GHz |
| KW | KiloWatt |
| L band | 1–2 GHz |
| LA | Los Alamos VLBA station |
| LNA | Low-Noise Amplifier |
| LO | Local Oscillator |
| LORTM | Local Oscillator Reference Test Module |
| LPRA | Local-oscillator Photonic Receiver Article |
| LRU | Line-Replaceable Unit |
| M&C | Monitor and Control |
| M&S | Materials and Supplies |
| Mbps | Mega bits per second |
| MHz | Megahertz |
| MIS | Management Information Systems |
| mm | Millimeter |
| MMIC | Monolithic Microwave Integrated Circuit |
| MoO | Mission of Opportunity |
| MOU | Memorandum of Understanding |
| Mpc | Megaparsec |
| MPIfR | Max Planck Institut fűr Radioastronomie |
| MSI | Mid-Sized Infrastructure Opportunity (NSF program) |
| μm | micrometer, micron |
| MUSTANG | Multiplexed SQUID/TES Array for Ninety Gigahertz |
| NA | North American / Not Applicable / Not Available |
| NAASC | North American ALMA Science Center |
| NAOJ | National Astronomical Observatory of Japan |
| NAS | National Academy of Sciences |

| Acronym | Definition |
|---|---|
| NASA | National Aeronautics and Space Administration |
| Nb | Niobium |
| NbTiN | Niobium Titanium Nitride |
| NCSA | National Center for Supercomputing Applications |
| NED | NASA/IPAC Extragalactic Database |
| NGAS | Next-Generation Archive System |
| NGST | Northrop Grumman Space Technology |
| NJIT | New Jersey Institute of Technology |
| NL | North Liberty VLBA station |
| NIST | National Institute of Standards and Technology |
| nm | nanometer |
| NOAO | National Optical Astronomy Observatory |
| NRAO | National Radio Astronomy Observatory |
| NRC | National Research Council (Canada) |
| NSB | National Science Board |
| NSF | National Science Foundation |
| NTC | NRAO Technology Center (Charlottesville) |
| NVO | National Virtual Observatory |
| NVSS | NRAO VLA Sky Survey |
| OBS | Observatory Business Services |
| OCA | Office of Chilean Affairs |
| OEO | Office of End-to-End Operations |
| OMT | Orthomode Transducer |
| OOF | Out Of Focus (holography technique) |
| OPT | Observation Preparation Tool , Optical Pointing Telescope |
| OSAA | Office of Science and Academic Affairs |
| OSF | Operations Support Facility (ALMA) |
| OST | Observation Scheduling Tool |
| OV | Owens Valley, CA (VLBA station) |
| PA | Product Assurance |
| PAI | Product Acceptance In-house |
| PAPER | Precision Array to Probe the Epoch of Reionization |
| PAS | Product Acceptance at Site |
| pHEMT | pseudomorphic High Electron Mobility Transistor |
| PLC | Programmable Logic Controller |
| PS | Power Supply |
| PSI | Prototype System Integration |
| PST | Proposal Submission Tool |
| PTCS | Precision Telescope Control System (GBT) |
| Q | Quarter |
| Q band | 40–50 GHz |
| R&D | Research and Development |
| RET | Research Experiences for Teachers (NSF program) |
| REU | Research Experiences for Undergraduates (NSF program) |
| RF | Radio Frequency |
| RFI | Radio-Frequency Interference |
| RFP | Request For Proposal |
| S band | 2–4 GHz |
| SAA | Science and Academic Affairs (NRAO) |

| Acronym | Definition |
|---|---|
| SDM | Science Data Model |
| SBI | Secure Border Initiative |
| SC | Saint Croix, VI VLBA station |
| SE&I | System Engineering and Integration |
| SEF | Site Erection Facility |
| SG | Study Group |
| SIA | Simple Image Access protocol |
| SiGe | Silicon/Germanium |
| SIMBAD | SIMBAD astronomy archive |
| SIS | Superconductor–Insulator–Superconductor |
| SKA | Square Kilometer Array |
| SOC | Socorro, Scientific Organizing Committee |
| SSAP | Simple Spectral Access Protocol |
| SSEC | SKA Science and Engineering Committee |
| SSS | Science Support Systems |
| STScI | Space Telescope Science Institute |
| TAP | Table Access Protocol |
| TB | Technical Building (ALMA), TeraByte |
| TDP | Technology Development Program (SKA) |
| TEC | Total Electron Content (of the ionosphere) |
| U band | 12–18 GHz |
| UPS | Uninterruptable Power Supply |
| URSI | International Union of Radio Science |
| USVAO | United States Virtual Astronomical Observatory |
| UVa | University of Virginia |
| VAO | Virtual Astronomical Observatory |
| UVML | University of Virginia Microfabrication Laboratory |
| VCO | Voltage-Controlled Oscillator |
| VISC-2 | VSOP-2 International Science Council |
| VLA | Very Large Array |
| VLBA | Very Long Baseline Array |
| VLBI | Very Long Baseline Interferometry |
| VO | Virtual Observatory |
| VPN | Virtual Private Network |
| VSOP-2 | VLBI Space Observatory Program (VSOP) successor |
| W band | 68–117 GHz |
| WA | Western Australia |
| WBS | Work Breakdown Structure |
| WIDAR | Wideband Digital Interferometric Architecture (EVLA correlator) |
| WRC07 | World Radio Conference 2007 |
| WWW | World-Wide Web |
| X band | 8–12 GHz |