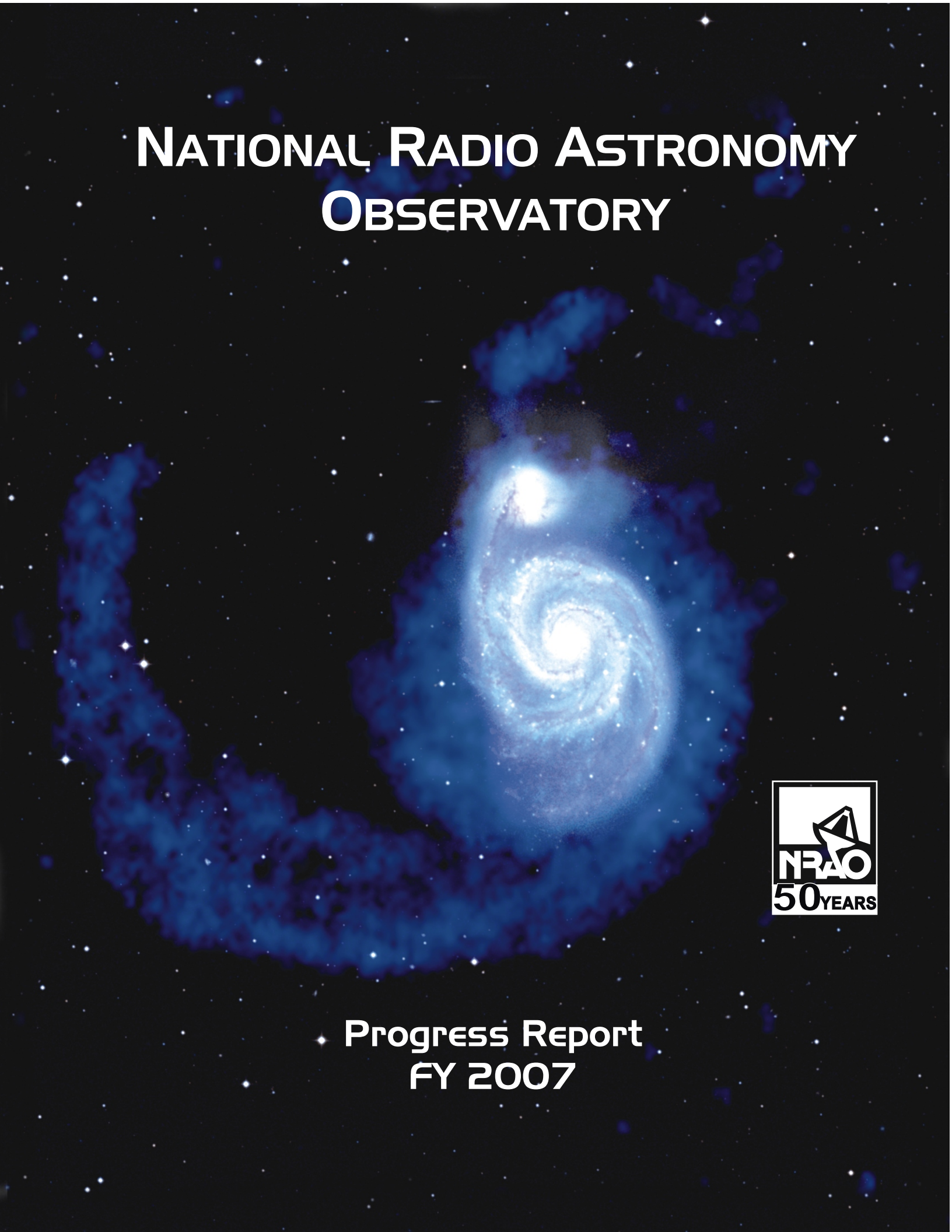
National Radio Astronomy Observatory



NRAO 50 YEARS

Progress Report
FY 2007

National Radio Astronomy Observatory

2007 Annual Progress Report

Cover Image: This image of the spiral galaxy M51, also known as the "Whirlpool Galaxy," and its companion NGC5195 combines observations of neutral Hydrogen emission obtained with the Very Large Array with optical images (R, B) from the Second Palomar Observatory Sky Survey - STScI Digital Sky Survey. The optical data show the emission of stars in these galaxies as well as the dust; the latter can be seen as dust lanes in the spiral arms of M51 itself and in obscuring the eastern (left hand) part of its companion, NGC5195. They also show foreground stars in our own Milky Way galaxy as well as some background galaxies. The spectral-line observations of neutral atomic hydrogen (depicted by bluish hues) yield the distribution, as well as the kinematics, of the neutral Hydrogen gas. The long tidal tail of neutral Hydrogen was shaken loose by the dance of these two galaxies.

Investigator(s): A. H. Rots, A. Bosma, J. M. van der Hulst, E. Athanassoula, P. C. Crane. Image composition: J. M. Uson.

The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.

Table of Contents

Annual Progress Report

September 2007

Summary

The report describes the major accomplishments of the NRAO during the fiscal year FY 2007 (October 1, 2006 through September 30, 2007), with reference to the plans described in the FY 2007 Program Plan submitted to NSF at the outset of the fiscal year.

NRAO 50th Anniversary

The NRAO celebrated the 50th anniversary of its founding by AUI and the NSF with an Observatory-wide all-staff meeting on June 14, which also honored the completion of the ALMA Array Operations Site Technical Building. The symposium "Frontiers of Astrophysics"' held in Charlottesville from June 18–21 brought together nearly 200 scientists to review recent discoveries, provide guidance for future radio facilities and observations, and commemorate major achievements enabled by the NRAO instruments. Participants also attended a reception, an in-depth tour of the NRAO Technology Center, and an optional tour of the GBT. Two Town Hall meetings were held to obtain community input to the Committee on the Future of U.S. Radio Astronomy sponsored by AUI.

Science

A number of significant and stimulating scientific results were obtained by observers using NRAO telescopes during the past fiscal year. These include a determination that Mercury has a molten core, first detection of an interstellar negative ion (C_6H^-), periodic radio outbursts from brown dwarf stars, a highly accurate determination of the distances to T Tauri stars in the Taurus and Ophiuchus star-forming regions, radio observations of a remarkable magnetar, a comprehensive survey of nearby galaxies in neutral hydrogen (HI) to study the process of star formation, a VLBA imaging and polarimetric survey in support of the GLAST mission, and the discovery of giant (~2 Mpc) radio-emitting rings around the galaxy cluster Abell 3376.

During the past year, the NRAO issued a call for large proposals for legacy and key projects, open to all of its telescopes. Following recommendations from our users, up to 50% of available observing time could be made available to large projects that will allow time for significant programs designed to address major questions. Approximately ten projects were selected in this call, with a number of programs chosen for each telescope, including the GBT, VLA, and VLBA. The programs selected address detection of gravitational radiation, using megamasers to measure the Hubble constant and constrain dark energy, the VLA complement to the Chandra Deep Field South, VLBA Mojave/GLAST survey, blazar surveys, star-formation investigations, a comprehensive biomolecule survey, and a radio astrometric planet search.

ALMA Construction

ALMA construction highlights include the completion of the AOS technical building, arrival of the first two Vertex antennas in Chile, and detection of first astronomical fringes between prototype antennas at the ATF. The master agreement between NRAO and NAOJ (Japan) has been signed and work is underway. Local Chilean labor is now being hired under the auspices of NRAO. The NA Front End Integration Center is now established and operational in Charlottesville; all cold-cartridge groups have now delivered working cartridges to the Integration Center. Progress within other IPTs and the overall progress of the project have been excellent during the past year.

EVLA Construction

The EVLA Project is on schedule to complete the retrofitting of 12 antennas in FY 2007. Antennas are now being retrofit at a rate of ~6 per year. The civil-construction work element of the project has been completed with the installation of the correlator shielded room and 48 VDC power plant. The front-end group completed its highest-priority goal of improving the noise and cool-down performance of the L-band orthomode transducer. Final tests of the correlator chip have been successfully completed, and the chip production order has been issued. The old VLA Modcomp control computers have been replaced by the new EVLA Monitor and Control system, which operates both VLA and EVLA systems. An initiative for joint development of software tools with the ALMA project is underway.

Telescope Science Operations

ALMA Operations: The ALMA operations plan and the North American plan for operation of the NAASC were completed and successfully reviewed during the past fiscal year. A memorandum of understanding for Canadian participation in ALMA operations has been drafted. A beta release of the CASA data-analysis system remained on track for this fall. Excellent progress was made in expanding a spectral-line catalog that will be essential for analysis of ALMA data. The University of Virginia Microfabrication Laboratory produced their first AlN tunnel junctions, an essential step toward developing NbTiN conductors for ALMA Band 10.

Green Bank Telescope: The project to replace the GBT azimuth track, a major design and construction project, was completed on time and within budget. As part of the Precision Telescope Control System project, a significantly improved pointing model has been installed that makes use of inclinometer data. First light with the $\lambda = 3$ mm bolometer camera and the first engineering observations were achieved. In addition, first engineering observations with the Zpectrometer wideband spectrometer were conducted. The C-Band (4–6 GHz) receiver was significantly improved, and CICADA, a project for rapid development of advanced FPGA-based backends, was initiated.

Very Large Array: The VLA continued in smooth scientific operation while the EVLA project was underway. The first two journal papers directly utilizing EVLA upgrades were submitted. The Science Advisory Group for the EVLA (SAGE) held its first meeting. The EVLA/VLBA Operations Plan for 2012 was modified to include personnel transitions through the completion of the EVLA project. Approximately 20% of VLA observing time was scheduled dynamically.

Very Long Baseline Array: The VLBA is now a 100% disk-based Mark 5 system for both recording and correlator playback. A sensitivity enhancement project has been initiated that will culminate in a 4 Gbps bandwidth (including backend, recording, and correlator systems) and a more sensitive 22 GHz receiver system. Planning was completed for corrosion repair and rustproofing the St. Croix antenna, and work will commence in the autumn of 2007.

Technical Capability Development

End-to-End (E2E) Operations: FY 2007 completed the first full year of E2E as a new operational unit at NRAO. E2E was an active participant and facilitator in the initiative to join software development for ALMA and the EVLA. The group assumed responsibility for the NRAO Proposal Submission Tool (PST) and Observatory algorithm development. The group developed NRAO archive infrastructure and interfaces, and it directed the population of a VLA image archive using pipeline processing (presently with 45,000 images). The group is also responsible for the CASA and GBTIDL data-reduction systems.

Central Development Laboratory: At the CDL, a redesign of the 18–26 GHz and 26–40 GHz amplifiers successfully met EVLA specifications. The lab produced a total of 117 new or upgraded low-noise amplifiers. A MMIC LNA for ALMA Band 2 (67–90 GHz) was completed. Development work continued on SIS mixers for ALMA Band 6 and Band 10. A 79/104 GHz holography feed for ALMA was successfully completed. CDL engineers completed development of Green Bank Solar Radio Burst Spectrometer systems and were part of a successful collaboration on the PAPER (Precision Array to Probe the Epoch of Reionization) project, including deployments in Green Bank and in western Australia.

New Initiatives

The New Initiatives Office (NIO) has been an active participant in SKA initiatives over the past year, including the recently funded Technology Development Proposal and work on the EVLA, which is a technical pathfinder for the SKA. The NIO staff has also been active in discussions on Space VLBI initiatives such as VSOP-2. Considerable effort has been invested in negotiations with potential partners for operational and development support of the VLBA, as recommended by the Senior Review report. Prospects for success in this area are encouraging. The NRAO is providing infrastructure support for the LWDA on a cost-reimbursement basis. The NRAO is a leading member of the FASR consortium and will likely serve as the managing partner for the construction.

Community Support Programs

Scientific Community Outreach: The Office of Science and Academic Affairs (SAA) has continued an active program of community scientific outreach that includes the REU program, undergraduate co-ops, pre-doctoral fellows, and Jansky and NRAO postdoctoral fellowships. SAA also oversees the proposal review and telescope assignment process. In the past year, the proportion of external members of the VLA scheduling committee has increased substantially. SAA also oversaw a successful call for Large and Legacy proposals on NRAO telescopes.

Spectrum Management: The NRAO continues an active presence in spectrum management at international forums including ITU, IUCAF, and CRAF. The spectrum manager also participated in a number of domestic activities including the NAS CORF, and in filing several comments on FCC dockets.

Education and Public Outreach: The EPO group completely redesigned the Observatory exhibits for science conferences including AAS and IAU meetings. The NRAO organized and chaired an ALMA EPO working group including representatives from each of the Executives. The NRAO wrote the ALMA EPO Development Plan and presented the plan at the Operations Review. The NRAO initiated a program to document ALMA construction in high-definition video and produced a video teaser that was well received. A Sister Cities program between San Pedro de Atacama, Chile and Magdalena, NM was also established. EPO produced a high-quality public brochure, hosted the annual Image Contest, and produced numerous press releases of notable scientific results from NRAO telescopes. The visitor centers in Green Bank and New Mexico hosted a total of over 66,000 visitors in the past year. A number of successful K–12 education programs were also conducted.

Management and Administration

Observatory business and administration groups continued to refine and enhance their capabilities and responsiveness to NRAO staff. The administration group assumed responsibility for Web-Based Business Services in FY 2007 and continued to enhance and stabilize these systems. A new budgeting tool, Microsoft FRx, was adopted. A senior Contracts and Procurement manager was hired. The Human Resources group developed a plan for diversity enhancement at the Observatory. The Observatory HR

group also oversaw the development of HR staff and capabilities in Chile in support of ALMA. The NRAO participated in an NSF Total Business Systems Review (TBSR) in FY 2007. The draft TBSR report indicated that NRAO business services are efficient, well managed, and conform to best practices. An initial observatory strategic plan was developed.

A. Science Highlights in FY 2007

Mercury's Core Molten, Radar Study Shows

A group of scientists lead by Dr. Jean-Luc Margot (Cornell University) used a new high-precision planetary radar technique and discovered that Mercury probably has a molten core, resolving a mystery of more than three decades. The discovery, which used the National Science Foundation's NRAO Robert C. Byrd Green Bank Telescope in West Virginia, the Arecibo Observatory in Puerto Rico, and NASA/Jet Propulsion Laboratory antennas in California, is an important step toward a better understanding of how planets form and evolve.

Whether the core is molten or solid today depends greatly on its chemical composition. To answer the question, the scientists implemented an ingenious, high-precision technique in which they sent a powerful beam of radio waves to bounce off Mercury, then received and analyzed the reflected signal using pairs of ground-based radio telescopes. While similar radar systems have been used in the past to map planetary surfaces, this technique instead measured the rate at which Mercury spins on its axis, with an unprecedented precision of one part in 100,000. By making 21 separate observations, the research team was able to measure minute variations in the planet's spin rate. This was the key to learning whether Mercury's core is solid or molten. Using an understanding of the Sun's gravitational effect on the planet, they realized that the tiny variations in its spin rate would be twice as large if the core is liquid than they would be if Mercury has a solid core. In addition to measuring Mercury's spin rate, their technique also measured the alignment of the planet's axis of rotation 100 times more accurately than previous work.

Investigators: J. L. Margot (Cornell), S. J. Peale (UC, Santa Barbara), R. F. Jurgens, M. A. Slade (JPL), and I. V. Holin (Space Research Institute in Moscow).

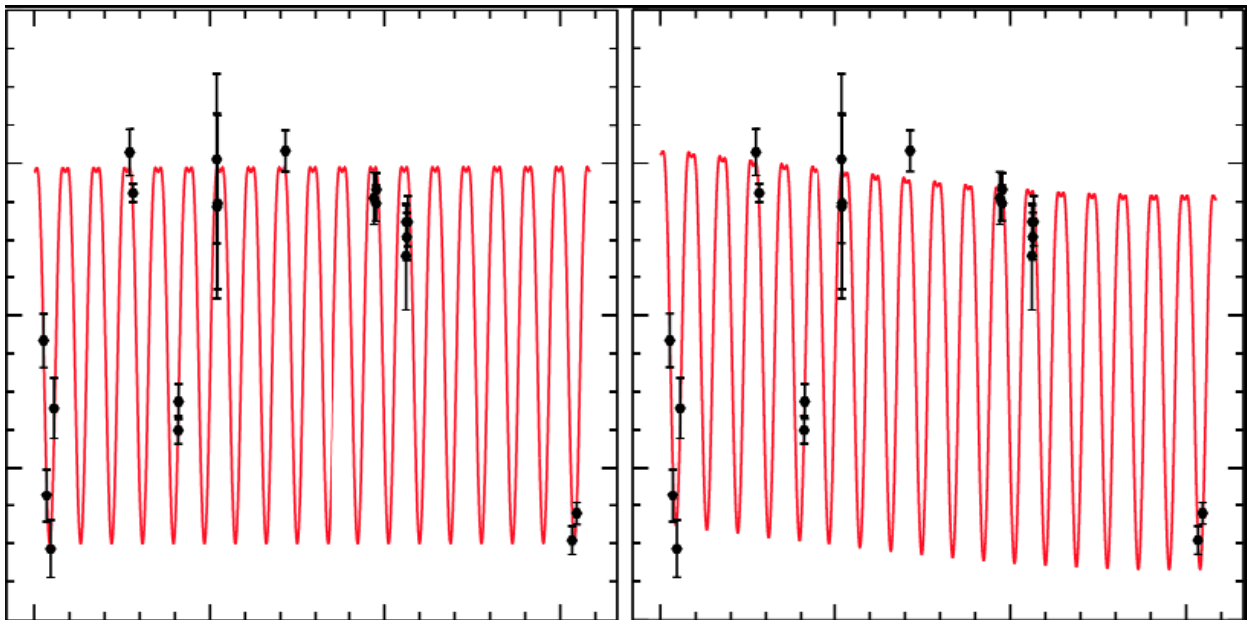


Figure A.1. Mercury's spin-rate deviations from the resonant rate of 3/2 times the mean orbital frequency. Observed data points and their error bars are shown at their respective epochs. The solid line is a numerical integration of the torque equation, the phase of which is dictated by the time of pericenter passage. The left panel shows a one-parameter fit to the data (allowing for 88-day forced librations only,) and the right panel shows a three-parameter fit to the data (allowing for an additional libration component with ~12 year period). Reference: J. L. Margot, S. J. Peale, R. F. Jurgens, M. A. Slade, and I. V. Holin 2007, Science Vol. 316, pp 710–714.

Laboratory and Astronomical Identification of the Negative Molecular Ion C_6H^-

The first negatively charged molecule in space was discovered with the GBT in 2007. While about 130 neutral and 14 positively charged molecules are known to exist in interstellar space, this is the first negative molecule, or anion, to be found. Michael McCarthy (CfA) worked with CfA colleagues Carl Gottlieb, Harshal Gupta (also from the U. of Texas), and Patrick Thaddeus to identify the molecular anion C_6H^-, a linear chain of six carbon atoms plus one hydrogen atom at the end with an extra electron. Such molecules were thought to be extremely rare because the ultraviolet light that suffuses space easily knocks electrons off molecules. The large size of C_6H^-, which is larger than most neutral and all positive molecules known in space, may increase its stability in the harsh cosmic environment. They found C_6H^- in two very different locations—a shell of gas surrounding the evolved red-giant star IRC +10216 in the constellation Leo and the cold molecular cloud TMC-1 in Taurus. The presence of the anion in both regions shows that the chemical processes that form C_6H^- are ubiquitous. It also suggests that other molecular anions are present and will be found in the near future.

Investigators: M. C. McCarthy , C. A. Gottlieb , H. Gupta , and P. Thaddeus (Center for Astrophysics).

Brown Dwarfs Show Beamed, Coherent Radio Emission

Using the VLA, a team of researchers from the U.S. and Europe detected periodic bursts of extremely bright, 100 percent circularly polarized coherent radio emission from two brown dwarfs. These beams of emission sweep Earth with the rotation of the dwarfs to produce periodic pulsar-like bursts of radio emission. Brown dwarfs are enigmatic objects that are too small to be stars but too large to be planets. They are sometimes called "failed stars" because they have too little mass to trigger hydrogen fusion

reactions in their cores, the source of the energy output in larger stars. With roughly 15 to 80 times the mass of Jupiter, the largest planet in our Solar System, brown dwarfs were long thought to exist. However, it was not until 1995 that astronomers found one. The team observed a set of brown dwarfs with the VLA and found that three of the objects emit extremely strong repeating pulses of radio waves. The researchers conclude that electron cyclotron maser emission may be generated over the poles of the objects' large-scale magnetic fields, producing the beams.

Investigators: G. Hallinan, A. Golden, S. Bourke, and C. Lane (National University of Ireland Galway); T. Antonova and G. Doyle (Armagh Observatory); R. Zavala and F. Vrba (U.S. Naval Observatory); Walter Brisken (NRAO); and R. Boyle (Vatican Observatory).

VLBA Determines Distances to Star-Forming Regions With 1 Percent Accuracy

Multi-epoch VLBA observations of T Tauri stars in the Taurus and Rho Ophiuchi star-forming regions have produced trigonometric-parallax measurements yielding the distances of these two important regions accurate to within one percent. The observations also produced measurements of proper motions of individual sources within these regions. Such measurements allow accurate determinations of such basic properties as the masses and luminosities of young stars. Because young stars tend to be surrounded by nebulosities, the radio measurements can be far more accurate than those made by the Hipparchos satellite. The results will improve our understanding of the young stars and of the 3-D structure and dynamics of the star-forming regions.

Investigators: L. Loinard, R. Torres, and L. Rodriguez (UNAM); and A. Mioduszewski (NRAO).

VLBA Reveals the Earliest Structure Resolved in a Nova Explosion

Teams of researchers have used the VLBA and VLA to study the latest burst from the recurrent nova RS Ophiuchi. This system consists of a dense white dwarf with a red-giant companion whose prolific stellar wind dumps material onto the surface of the white dwarf, resulting in powerful thermonuclear explosions. Systems such as RS Ophiuchi are the likely progenitors of Type Ia supernovae. It is important to understand how these systems evolve because astronomers use SNIa as "standard candles" for measuring distances in the universe. RS Ophiuchi produced energetic blasts in 1898, 1933, 1958, 1967, and 1985, but the February 2006 burst was the first to be imaged by the VLBA. Observations revealed the earliest spatially resolved structure in any nova (or indeed supernova) explosion. The observations clearly showed that, contrary to earlier assumptions of spherical explosion symmetry, the ejection is jet-like, collimated by the central binary whose orientation on the sky can be determined. The observers believe the lessons learned from this object can also be applied to supernova explosions and possibly to stellar explosions in general.

Investigators: T.J. Obrien, T.W.B. Muxlow, R.J. Beswick, S.T. Garrington, and R.J. Davis (Jodrell Bank); M.F. Bode (Liverpool John Moores University); R.W. Porcas (MPIfR, Bonn); S.P.S. Eyres (U. Central Lancashire); A. Evans (Keele University) and J. Sokoloski (CfA); M. Rupen (NRAO); A. Mioduszewski (NRAO)

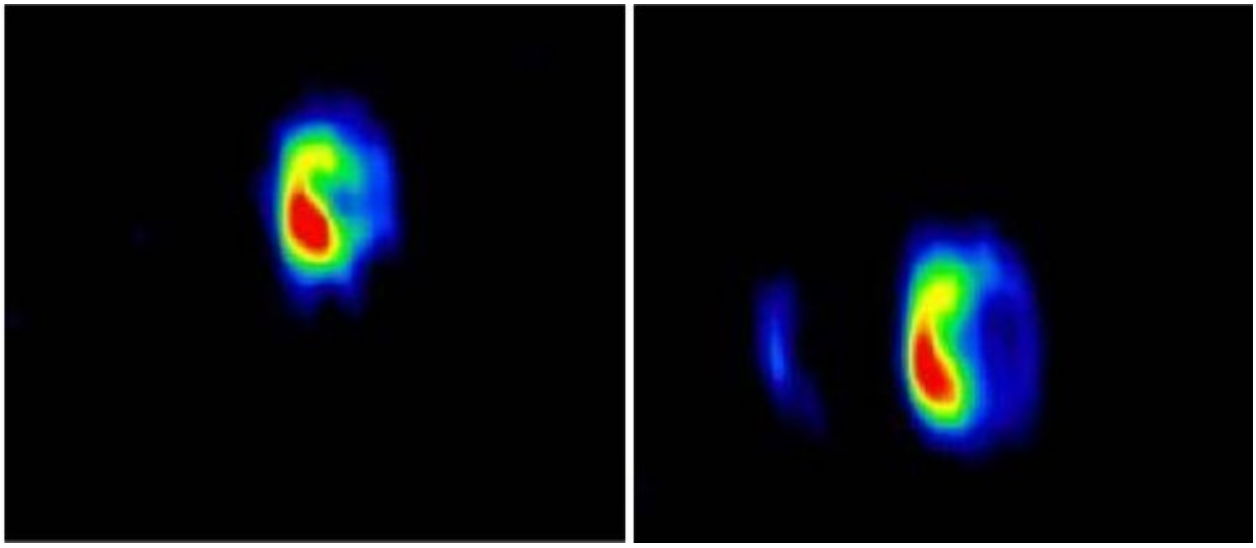


Figure A.2. Radio images of RS Ophiuchi at 21 (left) and 27 (right) days after the outburst, as observed with the VLBA at a wavelength of 18 centimeters. The expanding shell shows radii roughly 27 and 30 times the Earth–Sun distance in these images, matching those expected from X-ray observations of the same object (Sokoloski et al.), assuming a distance of about 5200 light years. The "jet" on the east (left side) is clearly present on day 27 but not on day 21. Such jets have been seen in white-dwarf systems in the past, but never so clearly and so early. In particular, these images give the most precise measurement yet of how soon a jet appears after an outburst. Images from Rupen, Mioduszewski, & Sokoloski; a similar, independent imaging sequence appears in O'Brien et al.

XTE J1810–197: A Remarkable Radio-emitting Magnetar

The VLA, VLBA, and GBT have all been used as part of a worldwide effort to study very strong pulses repeating every 5.54 sec from the anomalous X-ray pulsar XTE J1810–197. These pulses represent the first detection of magnetospheric pulsed radio emission from a magnetar and, among other implications, link ordinary radio pulsars and magnetars. Magnetars, of which only a dozen are known, are young neutron stars whose very bright and highly variable X-ray emission is thought to be powered by the decay and reconfiguration of their ultra-strong magnetic fields (10^{14} G). In this respect they differ fundamentally from the ubiquitous radio pulsars (>1700 are now known), since all of the nonthermal radiation detected from the latter ultimately derives from the magnetic braking of the rotation of the neutron star. This is not possible for magnetars, because their X-ray luminosity greatly exceeds the energy loss rate available from the rotational slow-down of the neutron star. Astronomers hope to be able to understand what the physical origin is for this pulsed emission.

Investigators: F. Camilo, J. Halpern, D. Helfand, and N. Zimmerman (Columbia University); S. Ransom (NRAO); and J. Reynolds, J. Sarkissian (ATNF).

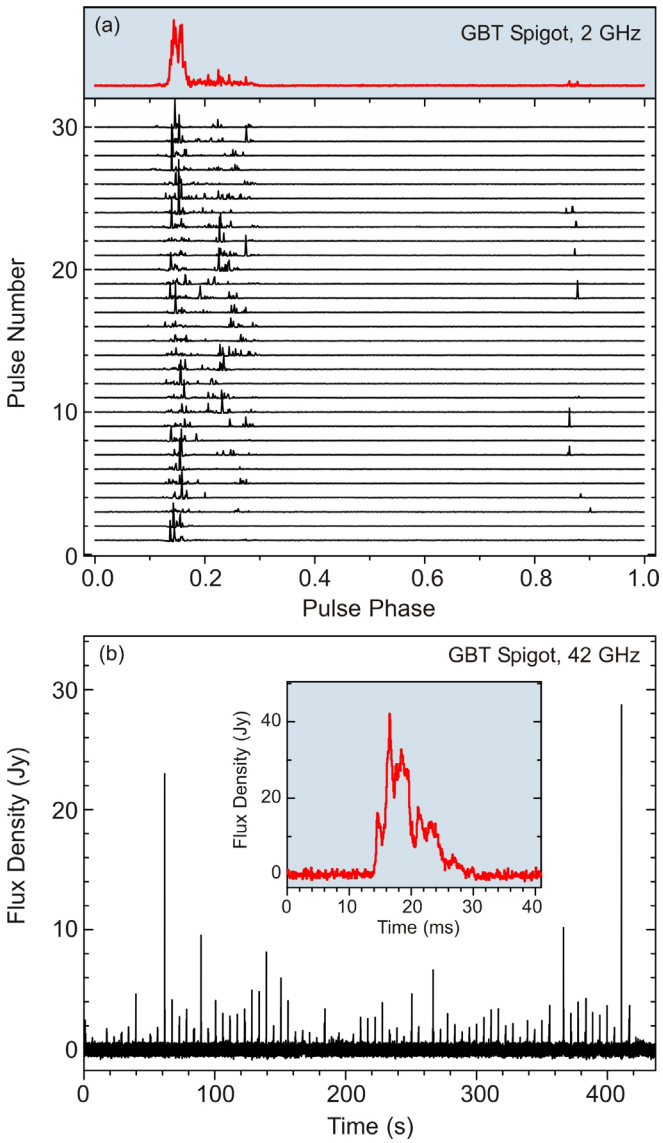


Figure A.3. Single pulses from XTE J1810–197 observed with the GBT using the Spigot spectrometer. Upper panel: Thirty consecutive single pulses (about 220 sec of data) from one observation at 2 GHz, where each row represents the full pulse phase. The sum of all 30 pulses is displayed at the top. Sub-pulses with typical width 10 ms arrive at different phases and gradually build up the average profile which, however, varies from day to day. Lower panel: Train of about 77 consecutive single pulses detected at a frequency of 42 GHz. The inset shows 40ms-long detail of the brightest pulse. Reference: Camilo, F., Ransom, S., Halpern, J., Reynolds, J., Helfand, D., Zimmerman, N., & Sarkissian, J. 2006, Nature, 442, 892.

The HI Nearby Galaxy Survey (THINGS)

Astronomers have completed the largest VLA program dedicated to 21 cm HI observations of the highest quality (6" angular resolution and $\leq$ 5 km s^{-1} velocity resolution) of a sample of 34 nearby galaxies (at distances 3<D<10 Mpc), covering as wide a range as possible of star-formation rate, total mass, absolute luminosity, evolutionary stage, and metallicity. The scientific goal of *The HI Nearby Galaxy Survey (THINGS)* was to obtain a homogeneous set of HI data cubes for a sample of galaxies spanning a wide range in galaxy properties in order to study the processes leading to star formation, the dynamics and structure of the interstellar medium, and the dark-matter distribution, thereby touching on the major issues

related to galaxy evolution. The science return is enhanced as most of the *THINGS* galaxies are featured in the *Spitzer* Infrared Nearby Galaxies Survey (SINGS) and the GALEX Nearby Galaxy Survey (NGS). In fact, high-quality observations from the X-ray through the radio are available at comparable angular resolution for every galaxy.

Investigators: F. Walter (Max Planck Institute for Astronomy), E. Brinks (University of Hertfordshire), W. J. G. de Blok (Mt. Stromlo Observatory), F. Bigiel (Max Planck Institute for Astronomy), R. Kennicutt (Cambridge University),and M. Thornley (Bucknell University)

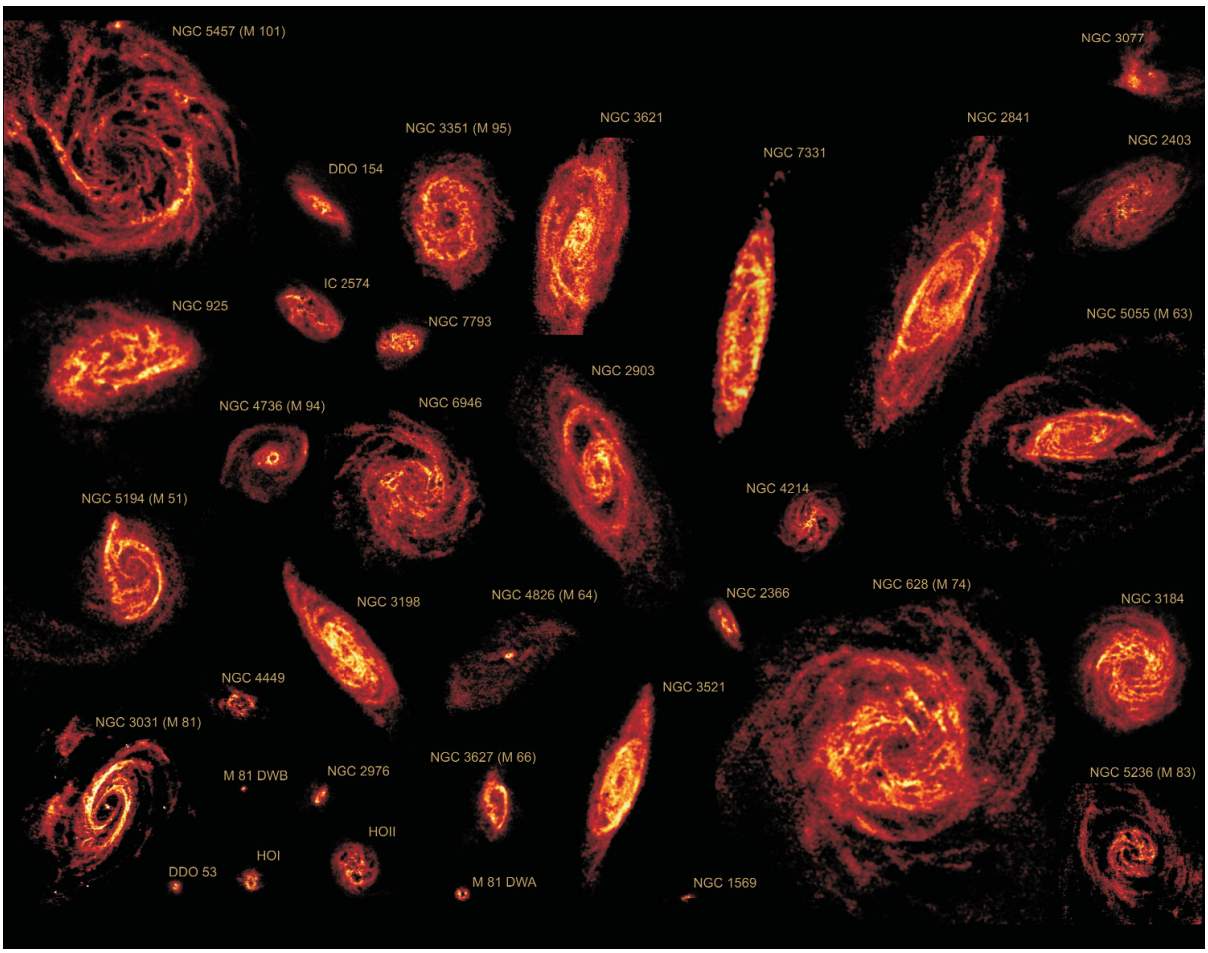


Figure A.4. A composite of the atomic hydrogen surface-density maps of all THINGS galaxies. All images are shown with the correct relative scale so that their HI morphologies can be compared directly (see http://www.nrao.edu/imagegallery/php/level3.php?id=562).

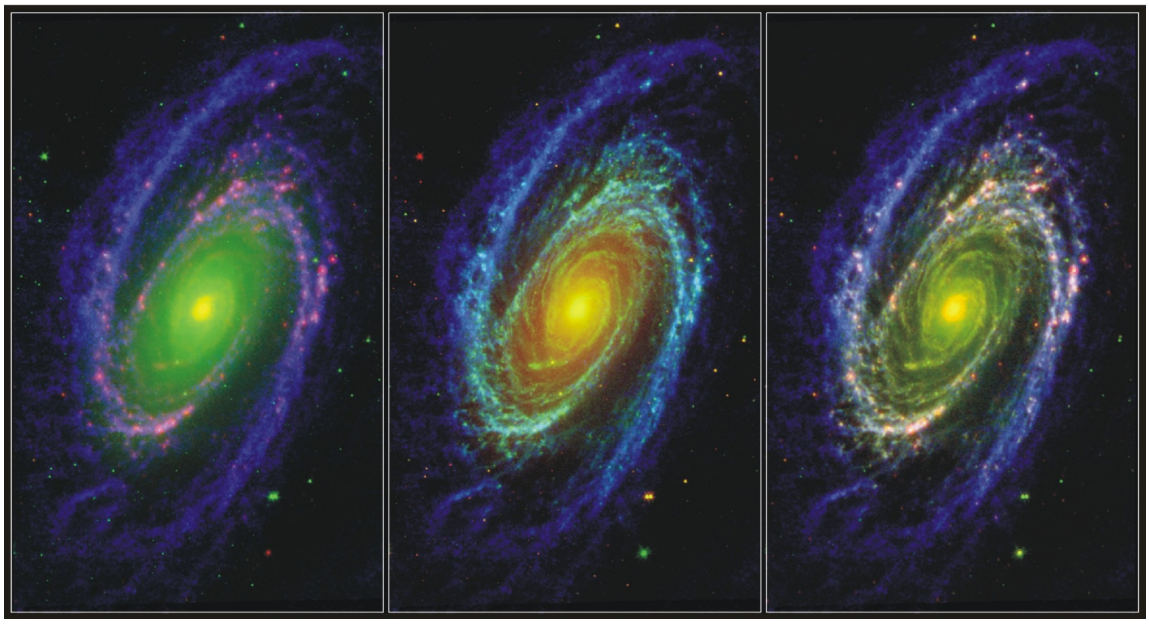


Figure A.5. The spiral galaxy M81—the panels show different overlays of Spitzer near- and mid-infrared images taken from SINGS (PI: R. Kennicutt) and the HI map from THINGS.

VLBA Imaging and Polarimetry Survey Completed in Advance of the GLAST Launch

The VLBA Imaging and Polarimetry Survey, a 5 GHz imaging survey of more than 1100 flat-spectrum extragalactic radio sources, was completed in 2006; during the fourth quarter, the general results of this survey were accepted for publication. Automatic data-reduction and classification algorithms enabled routine production and analysis of these 1100 images so that the survey could be published within months after completion of the observations. A primary goal of the survey was to generate baseline images with milliarcsec resolution of the target active galactic nuclei, most of which should be detected as gamma-ray sources by the Gamma-ray Large Area Space Telescope (GLAST) after its launch in early 2008. In addition, approximately 20 candidate binary black holes were identified and will be followed up with the VLBA.

Investigators: J. F. Helmboldt (UNM), G. B. Taylor (UNM), S. Tremblay (UNM), C. D. Fassnacht (Univ. Calif., Davis), R. C. Walker (NRAO), S. T. Myers (NRAO), L. O. Sjouwerman (NRAO), T. J. Pearson (Caltech), A. C. S. Readhead (Caltech), L. Weintraub (Caltech), N. Gehrels (NASA/GSFC), R. W. Romani (NASA/GSFC), S. Healey (Stanford), P. F. Michelson (Stanford), R. D. Blandford (KIPAC, Stanford), and G. Cotter (Oxford, UK).

Giant, Ring-Like Structures Discovered Around Galaxy Cluster

Researchers using the VLA discovered giant ring-like radio-emitting structures around the galaxy cluster Abell 3376. The structures are believed to trace the elusive shock waves of cosmological large-scale matter flows. This discovery, combined with X-ray observations of the cluster, indicates the probable merger of a large group or small cluster with the main body, supporting the hierarchical-clustering model for the origin of large-scale structure. In addition, the large radio-emitting structures may be acceleration sites where magnetic shocks could boost cosmic-ray particles to energies of 10^{18} to 10^{19} eV.

Investigators: J. Bagchi (IUCAA, Pune, India), F. Durret (Institut d'Astrophysique de Paris), G.B. Lima Neto (Instituto Astronomico e Geofisico, Sao Paulo, Brazil), and S. Paul (U. Wuerzburg, Germany).

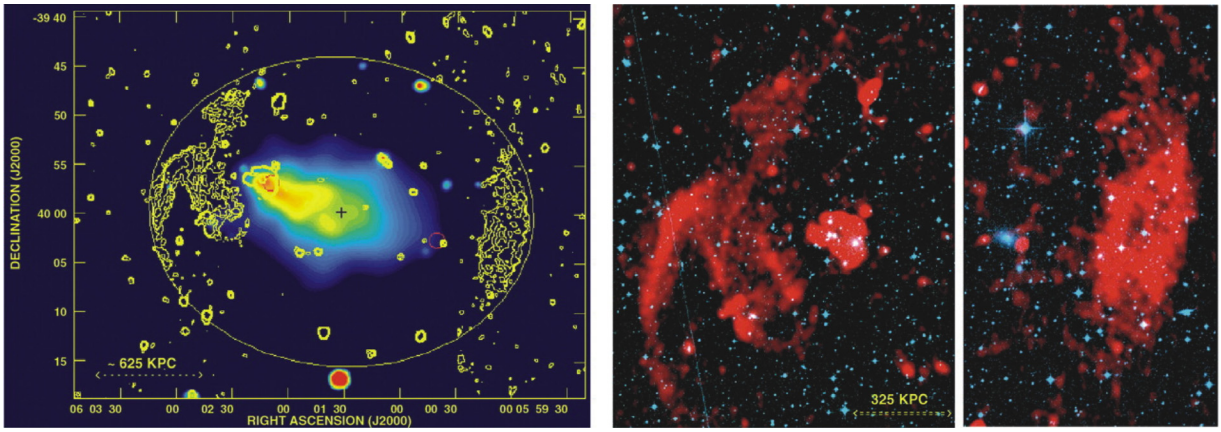


Figure A.6. Left panel: A composite map of radio and X-ray emissions from the galaxy cluster Abell 3376. VLA-observed 1.4 GHz radio emission is shown by yellow contours (0.12, 0.24, 0.48, and 1 mJy per beam; 20 arcsec half-power beamwidth). The yellow ellipse shows an elliptical fit to the peripheral radio structures, and the "+" marks the center of the ellipse. The central color image depicts the thermal X-ray emission detected by the ROSAT PSPC (Position Sensitive Proportional Counter) instrument (12 kilosecond exposure; 0.14 to 2.0 keV-band). The red circles mark the positions of the two brightest cluster galaxies; the brightest elliptical galaxy on the lower right and the second brightest elliptical galaxy associated with the bent-jet radio source MRC 0600–399 near the X-ray peak. Composite images: The VLA 1.4 GHz radio maps (in red) for the eastern (left) and the western (right) radio structures are shown over the red-band Digitized Sky Survey image (in blue).

B. FY 2007 Technical Highlights

Significant technical highlights achieved during FY 2007 included the following:

- A major milestone was reached this year on the way to advanced NbTiN/insulator/Nb tunnel junctions for frequencies above 700 GHz. The University of Virginia Microfabrication Laboratory successfully fabricated SIS junctions with AlN tunnel barriers as required for NbTiN SIS junctions. Junctions with AlN barriers and high critical current densities are required for high-frequency broadband operation.
- The new EVLA Monitor and Control System began regular scientific observations in late June 2007, and the old Modcomp-based system was effectively shut down on June 27.
- Careful research and laboratory measurements on the Q-band (40–50 GHz) GBT receiver uncovered a very weak coupling to Dewar cavity resonances that were a major source of spectral-baseline instabilities in the Ka-band (26–40 GHz) and Q-band receivers. These resonances were very sensitive to ambient temperature, which were affected by the physical size of the Dewar. Adding microwave absorber around the waveguide flanges and other cold components solved the problem. Another source of GBT spectral-baseline instability was crosstalk and reflections in the multi-channel IF system. The addition of a specially designed active power splitter greatly increased channel isolation and essentially eliminated this source of temperature-dependent baseline ripple.
- A redesign of the 18–26 GHz and 26–40 GHz EVLA amplifiers to achieve flat noise and gain at the band edges was successfully completed. That completes the design and development of all EVLA amplifiers covering the 1–50 GHz frequency range. A total of 117 new and upgraded amplifiers,

including L (1–2 GHz), S (2–4 GHz), C (4–8 GHz), K (18–26 GHz), and Q (40–50 GHz) band units, were built for receiver systems on the GBT, VLBA, and EVLA (primary).

- In collaboration with the UC Berkeley CASPER group, engineers, students, and scientists from Green Bank, the CDL, the University of Cincinnati, and West Virginia University have teamed up to design and build a new pulsar backend using state-of-the-art software tools and hardware developed by the CASPER group. These tools and hardware platforms will shorten development time, reduce cost, and lead to faster advances in astronomical signal processing. Engineers in Socorro are also working with this technology.

- The EVLA front-end group achieved its highest-priority goals of improving the noise and cool-down performance of the L-band (1–2 GHz) orthomode transducer (OMT). The OMTs will be fabricated using a precision sand-cast mold, and the first two test articles have been fabricated and delivered to Socorro.

- An 8-element full-Stokes version of the UC Berkeley/NRAO Precision Array to Probe the Epoch of Reionization (PAPER) began operation at the Green Bank Galford Meadow site in mid-August 2006, and a 4-element copy was successfully deployed in Western Australia in July 2007. The full 32-element array is scheduled to go to Western Australia in December 2007.

- Final testing of the EVLA correlator chip was completed and reviewed in a production sign-off critical design review (CDR) in early June 2007. More tests were run at the direction of the CDR committee, and the sign-off for chip production was given in late June.

- The design for a new GaAs power amp for the ALMA Band 3 local oscillator (up to 108 GHz) was completed. Small-signal wafer-probe test results with the revised MMPA75B look good, but the saturated output power measured in package and later in chip form is low by at least 3dB. Investigation of possible causes is underway. Low power was also measured in a package for the Band 3 (92–108 GHz) amplifier from the same wafer lot.

- Scaling the K-band linear- to circular-polarization phase shifter to W-band did not meet ALMA specifications over the 75–110 GHz band. A new W-band design with slot width 0.005 inches instead of 0.009 inches was completed and the fabrication challenge met by the CDL machine shop. The predicted differential phase shift is 90° ± 4° over the 75–110 GHz band. Prototypes at K-band and W-band will be measured to check the design.

- A theoretical investigation of the generation, propagation, and effects of local-oscillator sideband noise on single-ended mixers, both double sideband and sideband-separating, showed that this noise source in ALMA Band 10 is significantly less troublesome than first feared. A paper on this research was presented at the 18th International Symposium on Space Terahertz Technology entitled "Maximizing Signal-to-Noise Ratio in Local-Oscillator Chains for Sideband-Separating Single-Ended Mixers".

- The first set of EVLA 4P IF converters (T301), the modules that upconvert the RF signals from the 327 MHz and 74 MHz receivers to a 1–8 GHz IF, was completed and installed on EVLA antennas.

- The prototype of a new 79 and 104 GHz ALMA holography feed was designed and measured. This feed is designed for higher-than-normal dish edge illumination (–8 dB) and a very tight phase tolerance of ±7.5º across the aperture.

- A new technique for electroforming on aluminum mandrels with pressed-in copper structures was successfully demonstrated. This is necessary to fabricate over 250 waveguide components for the EVLA.

C. ALMA Construction

Accomplishments and Highlights in FY 2007

The accomplishments and highlights in FY 2007 are described below.

Management IPT

Last year saw significant progress on the ALMA project. Highlights include completion of the AOS technical building, the first Vertex antenna is in Chile undergoing acceptance testing, and at the ATF first astronomical fringes have been obtained. Overall progress has been excellent, and the project is beginning to gear up for the production phase.

Considerable work has been carried out on the PMCS to ensure that the Earned Value data are available. For most of the year, this system has been routinely delivering timely and accurate Earned Value data which North America is using to manage the project and which is reported to the NSF on a monthly basis.

The Master Agreement between the NRAO and the NAOJ has been signed, and work is underway. This is the first of two agreements that will secure all the North American components needed to allow NOAJ to complete the ACA and to fully enhance ALMA. After lengthy discussions, an agreement with Taiwan for them to join the North American Partnership is close to conclusion. Like Canada, Taiwan will have the right to compete for North American ALMA time. Under this agreement Taiwan will contribute the cash equivalent of two fully loaded antennas and a pro-rata share of the Operations costs.

The Chile office, with local labor legally under the NRAO, continued its oversight of ALMA human resources activities, including payroll and travel support, and support of the Chilean AIV staff presently being trained in the U.S. and Europe. Other activities performed under the purview of the NRAO were the support of ALMA environmental efforts, import/export responsibilities, and Expatriates. The Chile Office has also been involved in the design of the AUI/NRAO section of the new Santiago ALMA building in Vitacura.

Site IPT

With the acceptance of the AOS Technical Building at the OSF, ALMA is the proud owner of the second-highest steel building on earth (only the Tanggula station on the China–Tibet railway is at a slightly higher elevation). All mechanical and electrical equipment for the AOS TB completion was purchased by the NRAO and delivered to the site, on schedule and under budget, for the contractor to install. In the Antenna Vendors lay-down areas, temporary power generators with a capacity of 1.2 MW were installed as part of the Site Development's deliverables. The expansion of both the ALMA Camp (for our staff) and the Contractor's Camp at the OSF are continuing to plan. At the time of writing we have typically 500 staff on site!

Antenna IPT

The first and second Vertex antennas were delivered to the OSF in FY 2007. Antenna #1 is fully assembled and undergoing formal acceptance testing. Antenna #2 is undergoing final assembly and integration. Antennas #3 and #4 are in various stages of fabrication. Deliveries of Antennas #3 through #25 are expected in accordance with the existing schedule. The Production Nutator contract was awarded in December 2006. The final detailed design is in progress and the critical design review is scheduled for September 2007. Negotiations are proceeding with the preferred bidder for the Production Optical Pointing Telescope, with the contract award anticipated at the end of FY 2007 or very early FY 2008, and with the first unit delivery scheduled for 12 months later. Responsibility for the Front End Handling Vehicle and Front End Service Vehicle deliverables was transferred from the Front End IPT to the Antenna IPT in 2007. Bid documents for the Handling Vehicle were completed and approved in July 2007 and released for bid in August 2007. Proposals are expected in early FY 2008 for both deliverables.

Front End IPT

The NA Front End Integration Center is now operational and the Front End IPT made steady progress toward delivery of the first front end. All cold-cartridge groups have delivered working cartridges to the North American Front-End Integration Center (NA FEIC). The sensitivities of these cold cartridges substantially exceed the performance of any other mm-wave receivers. The test facilities at the NA FEIC were completed except for the challenging Local Oscillator Reference Test Module, whose design was completed in collaboration with the Back End IPT and whose production is in progress under contract; all measurements except long-term phase stability can be made now. Most FE subassemblies and components are now in full production mode. Prototypes of FE local oscillators for Band 4 and Band 8 were delivered to ALMA-J. The holography transmitter/receiver was delivered to the ATF for operational testing and then sent to the OSF to support acceptance of the first antenna.

Backend IPT

The main backend prototype electronics were debugged last fall. This allowed the prototype systems integration process to move from Socorro to the ATF. The successful acquisition of first fringes demonstrated that all BE modules are performing well. The NA Back End IPT (BE IPT) delivered pre-production antenna racks to the Vertex and AEC antennas at the ALMA Test Facility (ATF) in July 2007. After numerous modifications resulting from knowledge gained through Prototype System Integration (PSI), the modules in these racks are very close to what will exist in final production. A major BE IPT achievement in FY 2007 was developing the various product-area test sets that will accompany the BE deliverables to the OSF. Meanwhile the BE IPT placed the order for the production Master Lasers, a pre-production Laser Synthesizer, IF downconverters, Mux/DeMux chips, and Racks, and is in negotiation to place the contract for the production laser synthesizers.

Correlator IPT

The Correlator IPT designed and installed a system of baffles and fans to improve cooling in the Station Rack. Completion of the second quadrant was postponed partially because of this effort (this is nowhere near the critical path as the first quadrant supports 16 antennas). A full complement of Tunable Filter Bank (TFB) cards from the University of Bordeaux was delivered to the NTC for populating the first quadrant. A task was added: a new two-antenna correlator was built to support Prototype System Integration including the TFB cards, which were not supported by the original prototype two-antenna correlator (this also delayed completion of the second quadrant). Good progress was made on verifying, refining, and upgrading the software and firmware.

Computing IPT

The Computing IPT supported project objectives in the PSI laboratory, at the ATF, and in Chile. In the PSI lab low-level support software in support of bench tests (e.g., to provide LabView over the general network and access to monitor/control points) was provided. At the ATF first fringes were achieved, and antenna commissioning software and procedures were accepted by the project for optical pointing and beacon holography. These use the full end-to-end software system (observing tool to Archive). In Chile the computer and network infrastructure was purchased and deployed in conjunction with Chilean IT, and the software was installed and bench tested in anticipation of antenna acceptance. The CASA project was partially managed by the CIPT in 2007 (responsibility at the NRAO shifted to the E2E Operations Division partway through the year). CASA passed its final ALMA test and the Beta version should be released in September 2007 as planned. Also in FY 2007 the Pipeline subsystem passed its first complete (flagging, calibration, and imaging) test using data from several telescopes. In May 2007 the Computing IPT was reviewed by an external NSF panel. While important comments were received (for example, to ensure that CIPT planning reflects overall AIVC priorities), the report was positive overall.

In the fall of last year, PSI activity moved from Socorro to the ATF site. End-to-end system connectivity was demonstrated by interferometry on a tower beacon on February 8, 2007. At 7:13pm on March 2, 2007 both antennas were successfully pointed at Saturn and fringes were seen instantly at 104 GHz; they were tracked for over an hour before the team retired to celebrate. This is a very significant milestone in the ALMA project, and the many people who enabled it deserve congratulations. A second major PSI task was supporting performance verification of the Optical Pointing Telescope and Holography systems at the ATF prior to their being shipped to the OSF for use in antenna acceptance. ALMA Product Assurance ramped up in 2007 with participation in project- and IPT- level reviews including PDRs, CDRs, TRRs, and PPDRs; vendor evaluations prior to procurement and during production by reviewing statements-of-work and quality documentation as well as on-site visits and in-process inspections; and acceptance testing of completed product material.

Science IPT

During FY 2007 considerable transition occurred in the Science IPT. The European Project Scientist post was filled by the European Instrument Scientist until L. Testi assumed the position in May. The Japanese Project Scientist transitioned from Ryohei Kawabe to Koh-Ichiro Morita. Project Scientist Richard Hills (beginning Q1 2008) and his Deputy, Alison Peck (who began Q3 2007), were hired. A. Wootten served as Interim JAO Project Scientist through FY 2007. As construction progressed, the focus of the Science IPT continued to be testing the prototype system in New Mexico under the leadership of Instrument Scientists Emerson, Laing, and Vila-Vilaro. The Science IPT worked with PSI and with other IPTs at the ALMA Test Facility to evaluate the ALMA system. The ALMA Calibration Plan, encompassing particular examples for the various sorts of calibration, was refined; the examples were developed with members of the Computing IPT so that the first instantiations could be realized. The longest-baseline pad locations in ALMA have been proposed, in synergy with the development of the road, power, and fiber-network design for the AOS. Evaluation of the performance of the largest arrays continues; the set was optimized for superb imaging at highest resolution. The Design Reference Science Plan, including the use of ALMA components furnished by Japan, has been completed. ALMA was represented at a number of regional and international meetings through the year. Young astronomers have been introduced to ALMA in schools held on four continents and attended by over 600 persons. In North America, one particular focus was the workshop “Transformational Science with ALMA: Through Disks to Stars and Planets” held in Charlottesville in early June 2007, just after the NRAO 50th Anniversary Symposium.

ALMA Milestones

Item	Date Planned	Date Accomplished
Management IPT		
1. Clean up PMCS data	10/2006	10/2006
2. Complete the agreement between AUI and NINS/NAOJ	Q4/2006	03/2007
3. Support the procurement activities of the Site IPT in an efficient and timely manner	10/2006	10/2006
4. Plan to co-locate the ALMA Central Office and NA Executive offices in a permanent location in Santiago	06/2007	06/2007
Site IPT		
1. Complete construction of the AOS Technical Building	04/2007	06/2007
2. Complete enlarging the ALMA Camp	03/2007	07/2007
3. Complete enlarging the Contractor's Camp	03/2007	12/2006
4. Call for bid for the power and fiber-optic distribution design	11/2006	04/2006
5. Call for bid during mid 2007 for the construction of power and fiber-optics distribution *Rescheduled to FY 2008 because of ESO antenna foundation work*	FY 2008	FY 2008
Antenna IPT		
1. Accept the first Vertex Antenna at the OSF	04/2007	12/2007 est.
2. Place the contract for the ALMA nutators	11/2006	12/2006
3. Place the contract for the ALMA Optical Pointing Telescopes	01/2007	08/2007
FE IPT		
1. Make the NA Front End Integration Center operational	10/2006	05/2007
2. Complete and deliver the first three front ends	10/2007	Ongoing
3. Complete design of the service vehicle and handling equipment *Work transferred to the Antenna IPT*	03/2007	07/2007
4. Deliver the holography transmitter and receiver	11/2006	04/2007
BE IPT		
1. Ship pre-production antenna racks with supporting documentation and acceptance tests to the OSF for the first antenna	Early CY 2007	12/2007 est.
2. Complete testing and documentation of DTS firmware to support the half-transponders and to correct various clock-synchronization problems uncovered during PSI testing	10/2006	02/2007
3. Complete testing of pre-production IF Processor modules	01/2007	04/2007
4. Complete testing of the LORR for the 2 GHz LO Reference	10/2006	03/2007
5. Place order for the Master Laser and Laser Synthesizers	11/2006	04/2007
Correlator IPT		
1. Install a quadrant of the correlator at the AOS TB and make it operational	08/2007	02/2008 est.
2. Ship test-correlator fixtures to Chile and set up support laboratory	08/2007	12/2007 est.
3. Complete assembly and test of the second correlator quadrant	02/2007	10/2007 est.
4. Begin integrated testing of the third correlator quadrant *Rescheduled to allow two 2-antenna correlators to be built first.*	11/2006	01/2008 est.
Computing IPT		
1. Make a major software release, including antenna acceptance software (beacon holography, optical pointing) and ATF first-fringes support.	12/2006	12/2006
2. Procure OSF temporary-building hardware and perform hardware	01/2007	02/2007

Item	Date Planned	Date Accomplished
and software installation.		
3. Make a minor software release, including AIV single-dish software and single-baseline single-field interferometry (unlike first fringes, this is an E2E software system—observing tool to archive).	06/2007	06/2007
SE&I IPT		
1. Re-establish system connectivity at the ATF.	Q4 2006	02/2007
2. Demonstrate two-antenna interferometry on an astronomical source at the ATF.	Q2 2007	03/2007
3. In conjunction with antenna, front-end, and computing IPTs, coordinate and execute the installation and verification of the optical pointing telescope and holography systems at the ATF so that these systems may be sent to AIV in Chile by the end of 2006.	Q4 2006	06/2007
4. Train AIV, CSV, and OPS staff at the ATF.	Q4 2006	10/2006
Science IPT		
1. Demonstrate early calibration of the complete ALMA system during Prototype Systems Integration at the ALMA Test Facility.	Q4 2007	05/2008
2. Deliver version 2.0 of the Design Reference Science Plan, including ALMA components furnished by Japan.	12/2006	04/2007

D. EVLA Construction

Accomplishments and Highlights in FY 2007

In what follows, the accomplishments and highlights of the EVLA project in FY 2007 are described under the major elements of the project's work breakdown structure.

Project Management

A project risk-management plan was developed, and a risk-analysis workshop was held on December 12, 2006. At the workshop, the financial impacts and probabilities of the risks were estimated, and tentative action plans and owners were identified for each risk item. We are actively addressing items that are both high probability and high impact. Other risks are being tracked to determine if they can be retired or if corrective action is required.

Project performance metrics were determined and documented. The cost at the completion of the project was estimated using three different methods advocated by the Project Management Institute. Although results varied among methods, all methods revealed performance issues related to understaffing in the Front End and Monitor & Control elements of the WBS. Measures have or are being taken to address the staffing needs.

The inaugural meeting of the Science Advisory Group for the EVLA (SAGE) was held in Socorro on May 22–23, 2007. The charges to SAGE included defining high-priority observing modes and first-science cases and advertising the scientific capabilities of the EVLA to the astronomical community. The committee will likely submit a report on its findings and recommendations by September 2007.

Systems Integration

The project is on schedule to achieve its program-plan goal of retrofitting 12 antennas (project total) by the end of this fiscal year. As of July 1, 2007 ten antennas were used in routine scientific observations and account for 32.4% of VLA antenna hours, compared to only 3% a year ago. Electronics outfitting of the eleventh EVLA antenna has begun, and mechanical overhaul of the twelfth antenna is underway. The antennas are being retrofitted at the rate of about six per year.

Civil Construction

Assembly of the correlator shielded room is complete, and the room's infrastructure has been installed. The startup of the correlator room's HVAC equipment was completed in December 2006. The FM200 fire suppression and pre-action sprinkler systems were completed and put into operation in December 2006. The −48 VDC power plant for the correlator was delivered to the VLA site in early March 2007, and site personnel completed its installation and startup in late April. The installation of a 225 KVA uninterruptible power supply (UPS) for the EVLA operations area was completed in May 2007. That UPS is now operational. The installation of the UPS and the correlator power plant effectively marks the completion of the civil construction element in the project's WBS.

Antennas

This fiscal year, the mechanical overhaul of four antennas has been completed, and the overhaul of another will be complete before the end of the fiscal year. Fabrication of mechanical components for additional EVLA antennas is ongoing. Fabrication of structural components for additional EVLA antennas is proceeding ahead of schedule.

The production of receiver feed horns is also proceeding ahead of the antenna retrofitting schedule. The fiberglass lamination of the L-band (1–2 GHz) feed horns is ahead of the program-plan goal of completing 20 horns by the end of the fiscal year. The lamination of horns 1 through 21 is complete, and the lamination of horn 22 is in progress. The Ka-band feed horns were fabricated and then tested at the antenna test range in Green Bank. The fabrication of the first S-band (2–4 GHz) feed horn was completed, and its RF performance was evaluated in late June 2007. Designs for the Ku-band (12–18 GHz) feed horn and its mounting tower were completed.

Front End

The front-end group achieved its highest-priority goals of improving the noise and cool-down performance of the L-band (1–2 GHz) orthomode transducer (OMT) and selecting a cost-effective means of fabricating it. Tests conducted in mid 2006 indicated that the OMT could only be cooled to a disappointing 100K over a three-day period. Modifications to the receiver Dewar now allow us to achieve 53K in about 24 hours, which is well within the design goal. The OMTs will be fabricated using a precision sand-cast mold, and the first two test articles have been fabricated and delivered to Socorro. The prototype L-band receiver with the first wideband OMT was installed on an EVLA antenna in November 2006. A series of sensitivity and efficiency measurements were completed. Staffing shortages in the group prevented the L-band receiver from going into full production. The staffing shortages have been addressed, but the long-term impact of the staffing shortage has been to delay the installation of the final EVLA receiver from 2012 into 2013.

The first two C-band (4–8 GHz) OMTs were fabricated, and their cryogenic testing has begun. The receiver temperature across the full bandwidth appears to be within specification, but further testing is needed before mass production can begin. The method and details for mass producing the C-band OMT are basically complete.

The new 2–4 GHz OMT for the EVLA S-band receiver is being developed in Green Bank. This effort involves scaling in frequency the L- and C-band OMTs.
A prototype Ka-band (26–40 GHz) receiver was designed and assembled. Cool-down tests and the RF evaluation of the receiver are underway.

Local Oscillator (LO) Systems

All LO modules are in full production with the exception of the round-trip-phase module. The design of the round-trip-phase module is being modified slightly to address some problems with module component noise.

The operational stability of the L302 frequency synthesizer was improved. The improvements concentrated on the direct digital synthesizer printed-circuit board, the automatic gain-control circuitry and firmware, and the microwave reference inputs to the L302 module.

Fiber Optics

Modules for the digital transmission system, formatter, and de-formatter continue to be built to meet the antenna outfitting schedule.

The original project plan for the EVLA 3-bit 4 Gsps sampler relied on the development of a sampler by the ALMA project. Concerns arose over the cost and suitability of the ALMA design, and an independent design of the sampler, based upon a digitizer chip that is commercially available from Teledyne/Rockwell, was undertaken as a risk-mitigation measure. The Teledyne/Rockwell sampler circuit board was built and shown to meet project performance specifications. However, concerns over the availability and cost of the chip caused us to investigate alternative chips and designs, thus delaying the production of the sampler. Quotations for the production order of the chip were received from multiple vendors. A recommendation of the successful vendor has been submitted to the NSF for approval. The chip order will be placed in the next few months so that chip production and board fabrication can begin.

Junction boxes for optical-fiber connections are needed at each antenna location so that an EVLA antenna can be connected to the optical fiber data-transmission system. All of the 72 junction boxes on the array have been installed, reaching the program-plan goal of completing the installation of the array fiber infrastructure. The completion of the junction boxes will allow more flexibility in locating EVLA antennas in the array after their retrofits are complete.

Intermediate Frequency (IF) Systems

The production of IF modules is keeping pace with the antenna retrofits.

The first set of 4P IF converters (T301), the modules that upconvert the RF signals from the 327 MHz and 74 MHz receivers to a 1–8 GHz IF, was completed and installed on EVLA antennas. The production and installation of the T301s had been delayed by more-pressing priorities, but now their installation should keep pace with the antenna-retrofitting schedule.

The design of the new converter interface module (M301) was completed. The M301 allows computer control of the T301, the LSC IF converter, and the UX IF converter modules. The M301 is now being installed on the EVLA antennas.

The wideband (2 GHz) signal path, including the new gain-slope equalizer in the IF downconverter module, was tested and shown to meet project specifications. Adding an isolation amplifier and installing board covers with RF-absorbing material solved isolation problems in the baseband downconverter.

Correlator

Testing components in the EVLA correlator has been steady and largely successful. The final test of the correlator chip was completed and reviewed in a production sign-off critical design review (CDR) in early June 2007. More tests were run at the direction of the CDR committee, and the sign-off for chip production was given in late June. The chip worked the first time it was tested, although it did take considerable time to reach this conclusion because of socketing problems on the chip's ball-grid array, delays in the fabrication of printed-circuit boards, some test-environment bugs, and the amount of time it took to perform chip testing with the appropriate level of rigor. From a wider perspective, these problems caused a delay in holding the correlator CDR and a subsequent delay in the delivery of the prototype correlator.

Testing the correlator chip also required debugging and testing the baseline board, which contains the correlator chips where the correlations are computed. Many complex functions and data paths on the baseline board are now tested and working, including input-data synchronization and routing, phase generation, long-term accumulator functions, and transmission of data packet frames to the correlator backend computer.

The station board provides delay tracking and digital filtering in the correlator. All data paths on the station board are now tested. Further work is required to test and debug all functions of the board's field-programmable gate array. Meanwhile, modifications to the station board are underway for the next prototype build.

Monitor and Control

A top-level design document for the EVLA Monitor and Control (M&C) Transition System was completed, and a critical design review of the system was held on December 5–6, 2006. A transition system is needed to satisfy the project requirement that the VLA must continue to operate while the EVLA is being built. This means the transition system must be able to control EVLA and VLA antennas, the VLA correlator, and the prototype WIDAR correlator. The review committee found that the requirements for the transition system are complete and that the architecture selected for the system design will satisfy those requirements.

The retirement of the Modcomp-based VLA control system with a rollover to the EVLA M&C Transition System has been the primary focus of the M&C group over the last year. The hardware and software were completed for the visibility pipeline, providing a path by which the output of the VLA correlator is available to the EVLA M&C System. The Interim version of the Data Capture and Format (IDCAF) software is now able to capture the output of the visibility pipeline and form a partial archive record containing visibility data and some, but not all, of the needed metadata. This partial archive record was successfully input to AIPS, demonstrating the complete data path from antennas, through the correlator, to the post-processing software for the EVLA M&C System. Another crucial milestone was achieved with the demonstration of the EVLA M&C System's ability to control the VLA correlator. The

demonstration was facilitated by the installation of the new correlator controller in September 2006. More recently, exclusive operation of the VLA–EVLA hybrid array by the EVLA M&C System, with no assistance from the Modcomp-based VLA control system, has occurred on a regular basis. The EVLA M&C System was used regularly for scientific observations in late June 2007, and the old control system was effectively shut down on June 27.

The main sequence of control and data acquisition within the EVLA M&C System, from control script to VLA-format archive records in the archive, has been demonstrated to work for one subarray for virtually all standard observing modes. Infrequently used features, such as multiple subarrays, single-dish VLBI, and phased-array VLBI, have yet to be implemented completely.

The M302 and M303 utility modules, which are responsible for a variety of functions including emergency stops, fire alarms, and antenna control unit and power resets, have been field tested. The M302 was redesigned based upon the results of the field tests. The redesign is ready for manufacture.

The data throughput and handling requirements of the correlator were determined and documented in NRC–EVLA memorandum No. 027.

Science Support Systems

The overall design of the software's High Level Architecture was completed. Work continues on the architecture's various components, called tools, which include a Proposal Submission Tool, an Observation Preparation Tool, an Observation Scheduling Tool, and an Archive Access Tool. The tools are comprised of models, and the models for Project, Program Block, Scheduling Block, Scan, and Source are all nearly complete. The model for Resources, such as antennas, front ends, and the correlator, is under development. These models will be used by all subsystems in the Science Support System (SSS) and some subsystems in M&C.

The sixth release of the VLA Proposal Submission Tool (PST) was used to submit 33 GBT and 134 VLA proposals for the February 2007 deadline. A significant recent change in the support of the PST is that its continued maintenance, upkeep, and upgrading are now done by Open Sky Software, a software-consulting firm in Austin, TX, under the auspices of the E2E Operations Division. Open Sky supported the PST for the June 2007 proposal deadline.

The Observation Preparation Tool (OPT) now uses the Source, Scan, and Scheduling Block common models, and it supports the definition of scans and the sources that populate them. Local scientific staff began testing the OPT in earnest, allowing very early input on the functionality and look-and-feel of the tool. Another software tool that manages catalogs of sources, including calibrator catalogs, and interacts with the OPT was developed and updated significantly. The tool has been tested outside the Array Operations Center by NRAO staff in Charlottesville. VLA, VLBA, and GBT calibrator catalogs are now available in this tool with a variety of simple query functions.

The initial implementation of the Observation Scheduling Tool (OST), the software that will be used to schedule observations on the EVLA, was completed. The OST will support current-style dynamic scheduling (with VLA OBSERVE files) and new-style dynamic scheduling (using Scheduling Blocks), and it also has built in a number of metrics to gauge performance. The OST was demonstrated to the ALMA software group and was well received. The deployment of an alpha version of the OST, which was to be used in real VLA/EVLA transition observations, was not made because of personnel turnover.

Work on the Archive Access Tool (AAT) has focused on coming to an agreement with ALMA on a common definition for the format of the science archive data. The definition has two parts: the raw binary data itself (the "Binary Data Format", or BDF), and the descriptive metadata (the "Science Data Model", or SDM). A document was written describing how the ALMA and EVLA BDFs differ, and several meetings were held to discuss how they could be reconciled. Additionally, a meeting was held to discuss the ALMA SDM and how it might be modified to support the EVLA.

A document describing the joint development of software tools for proposal submission, observation preparation, scheduling, data archive, and data processing by ALMA, ELVA, and the E2E Operations Division was written and presented to NRAO management. The primary objectives of the document are to provide common software tools for ALMA and EVLA users and to minimize long-term software development and maintenance costs. The document defines responsibilities for software development across the Observatory. Additional, detailed negotiations will be taking place to ensure that short-term project needs and long-term Observatory objectives are adequately addressed. A second document that describes the detailed interactions among various groups will be written and presented to ALMA management for consideration and approval. This second document must be agreed upon before the SSS preliminary design review (PDR) can be held.

The hardware and software for the ESO/ALMA Next Generation Archive System (NGAS) have been installed and are working. The system is being heavily tested so that the EVLA can borrow much of the ALMA archiving software.

Performance on EVLA Milestones

The project's performance on EVLA milestones from the 2007 Program Plan is shown in the Table below.

Performance on EVLA Milestones from 2007 Program Plan

Item	Date Planned	Date Accomplished
1. Develop project performance metrics	10/2006	06/2007
2. Initiate procurement of Ka-band feed horns	10/2006	10/2006
3. Complete design of High-Level Architecture	10/2006	07/2007
4. Complete design of the L-band OMT	10/2006	12/2006
5. Complete M&C critical design review	11/2006	12/2006
6. Complete Science Support Systems PDR	11/2006	03/2008 est.
7. Conduct risk and contingency analyses	12/2006	12/2006
8. Assemble prototype S-band feed horn	12/2006	06/2007
9. Start production of L-band receiver	02/2007	08/2008 est.
10. EVLA Science Advisory Committee meeting	04/2007	05/2007
11. Complete prototype of Ka-band receiver	06/2007	07/2007
12. Start production of 3-bit sampler	06/2007	01/2008 est.
13. Conduct correlator critical design review	06/2007	06/2008 est.
14. Complete installation of array fiber infrastructure	07/2007	06/2007
15. Retrofit a total of 12 antennas to the EVLA design	09/2007	09/2007
16. Conduct on-the-sky tests of prototype correlator	09/2007	07/2008 est.
17. Assemble a total of 20 L-band feed horns	09/2007	06/2007

E. Telescope Operations

E.1. North American ALMA Science Center

Accomplishments and Highlights in FY 2007

The main activities at the North American ALMA Science Center (NAASC) were developing the global ALMA operations plan and the North American plan for the NAASC. Major operations milestones were reached with the submission in Q4 2006 of the NAASC proposal to the NSF and the global ALMA operations plan (AOP) to the ALMA board.

Before submission to the NSF, the NAASC plan underwent a number of internal reviews including Canadian participation and a major external review by the ALMA North American Science Advisory Committee (ANASAC). The Operations Working Group (OWG), led by John Hibbard on behalf of the Joint ALMA Office (JAO), developed the AOP. The NSF committee and members of the OWG made visits to the JAO office in Santiago and to the ALMA site.

In Q1 2007 major reviews of the ALMA operations plan were held by an international committee, and the NAASC plan was reviewed by an NSF committee at the end of February near NSF headquarters in Arlington VA. February 27 and 28 saw presentations by the international operations working group. The international panel presented a verbal summary to the attendees at the end of these two days. On March 1 the NAASC/NRAO staff presented the details of North American ALMA operations and presented the NAASC plan on the third day. The NSF panel gave their summary report to the NRAO Director and the NSF at the end of the day.

The overall reaction of both the international and North American panels was that ALMA has a more mature and better-delineated operations plan than any other ground-based observatory and that the basic assumptions and plan are well-founded and justified. It was pointed out that the WBS Excel spreadsheet developed by Hibbard and the OWG is a powerful tool for guiding ALMA operations development and for making real-time adjustments to the plan based on construction project milestones. This WBS has been transferred to the JAO.

Both panels emphasized the importance of the Full Science support functions to fully realize the scientific promise of ALMA. The NSF panel emphasized that the NRAO needs to be prepared for early science to ensure that we deliver the capabilities promised at the appropriate time. They also emphasized the need for adequate user support, both in terms of software and manpower, in order to assist astronomers in the use of the advances and complexities of ALMA.

A final written report from the NSF panel reviewing the NAASC plan was submitted to AUI/NRAO in Q2 2007, with a written response by AUI/NRAO sent to the NSF in Q3. Successful completion of these reviews represents a major milestone for ALMA operations and the NAASC. Passing these reviews gives the funding agencies a road map for planning long-range operations funding and sets the direction for the transition from construction to operations.

Other Goals from the 2006 Program Plan

Canadian Involvement in ALMA Operations

Canadians participated in development of the NAASC plan through telecons and a face-to-face meeting, in all the preliminary reviews of the ALMA operations plan, and in the major external review in Q1 2007. A new Memorandum of Understanding with Canada for ALMA operations is being drafted at the Hertzberg Institute of Astrophysics. It will be discussed and completed in the coming quarter.

Software Testing, Data-Analysis Software

The NAASC continues to support 3.75 FTEs of CASA programmers to develop ALMA user software (see the CASA report).

NAASC staff members have also participated in extensive software testing, including:

- A major (ALPHA) test of the CASA software (written report by D. Shepherd)
- ALMA pipeline software testing (written report by Wilson)
- Testing the ALMA simulator
- Testing the ALMA ObsTool
- Testing in preparation for the CASA BETA release in Q4 2007

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

Work with E2E on Archive and VO tasks

An End-to-end (E2E) working group has been established at the NRAO with NAASC participation to track progress on user-related software at the NRAO and to coordinate among NRAO projects such as the EVLA and ALMA (see the contribution by E2E).

Database Construction

Work continues on the "Splatalogue" spectral-line catalog. Over the last several months the catalog has seen major improvements from overall use and functionality to data reliability. Frank Lovas from the National Institute of Standards and Technology has been working very closely with Anthony J. Remijan, the North American Chair of the ALMA Working Group on Spectral-Line Frequencies. They added more than 229,000 new lines to the catalog, of which over 2000 have been found in astronomical environments. Special search filters were added to the database to reduce the confusion from known atmospheric species and from large molecular species that could not be identified without a dedicated search. This spectral-line catalog is the most complete database of molecular transitions from mm to submm wavelengths.

The NAASC is revising the NRAO ALMA web pages, in particular those related to user interfaces. This will be a high priority for the ALMA EPO hire in 2008.

Community Relations and the ANASAC

The ANASAC remains the primary means of communication between the NAASC and the user community. The ANASAC was reorganized to have a more formal charge-and-response format parallel to that of the ASAC for the ALMA Board. This format ensures that high-priority issues are discussed,

with formal reporting and responses. The first major charge to the ANASAC was to review the NAASC plan prior to submission to the NSF and to consider in detail user-related issues such as the ALMA grants program. ANASAC input to the NAASC plan was invaluable. Regular ANASAC telecons are held.

NAASC members participated in the organization of, and made presentations at, the successful Pan-ALMA science meeting in Madrid in Q4 2006. NAASC members also made ALMA-related presentations at the AAS. Talks on ALMA status and ALMA science were made by NAASC staff at many U.S. and international institutions.

The NAASC workshop "Transformational Science with ALMA: Through Disks to Stars and Planets" was held in June 2007. There were about 80 participants. This meeting continued the successful series of scientific workshops begun in 2006 to promote and refine the scientific use of ALMA. Special thanks to C. Brogan for organizing this interesting meeting. See: http://www.cv.nrao.edu/naasc/disks07/.

UVa Foundry

AlN tunnel junctions: The University of Virginia Microfabrication Laboratory (UVML) made their first AlN (aluminum nitride) tunnel junctions. They had excellent I(V) quality at high current density (30,000 A/cm^2), about 3 times that of an Nb/Al-AlOx/Nb junction of the same I(V) quality.

Mixer design for 900 GHz: The design of an SIS mixer for ~1 THz requires a refinement of the previous design rules. We have been working with the UVML to determine the smallest conductor width and spacing that can be produced reliably with their latest fabrication procedures. The current design study indicates that an extension of the successful ALMA Band 6 mixer design will be feasible using the latest design rules with AlN tunnel barriers and NbTiN conductors.

Education and Public Outreach

ALMA EPO was well represented at international (e.g., IAU), and national (e.g., AAS) meetings by NRAO EPO officers. The advertisement for the first ALMA-specific EPO staff, matrixed to the NRAO EPO division, has been distributed. For more details, see the EPO section.

Personnel

Staffing of the NAASC was relatively constant during FY 2007. The Head Office includes Chris Carilli and John Hibbard. A business manager was added and partial support was added for an administrative assistant. Crystal Brogan remains the only NAASC staff scientist. The NAASC continued support for 3.75 CASA programmers. Partial support was provided for members of the Office of Chilean Affairs.

NAASC Milestones for FY 2007

Item	Date Planned	Date Revised	Date Accomplished
1. Start Operations Budget	01/2006		01/2006
2. NAASC operations plan internal review	10/2006		10/2006
3. NAASC ops plan review by AUI/NRAO	10/2006		10/2006
4. Submit NAASC proposal to NSF	10/2006		10/2006
5. Submit ALMA Operations plan to Board	10/2006		11/2006
6. AOP presentation to the ALMA Board in Madrid	11/2006		11/2006
7. Participate in ObsTool Test 4	01/2007		01/2007
8. NSF panel ALMA site visit	01/2007		01/2007

Item	Date Planned	Date Revised	Date Accomplished
9. ALMA Operations plan sent to external reviewers	01/2007	02/2007	02/2007
10. International review of AOP	02/2007		02/2007
11. NSF Review of NAASC Plan	03/2007		03/2007
12. ALMA external software testing–CASA ALPHA	10/2006	03/2007	03/2007
13. Participate in Pipeline Test 4	01/2007	03/2007	03/2007
14. Respond to NSF budget questions	03/2007		03/2007
15. Transfer AOP document and budget to JAO/Smeback	04/2007		04/2007
16. Spectral-line catalog—organize working group, first meeting in Charlottesville, spring 07	04/2007		04/2007
17. Respond to NSF panel report	04/2007		04/2007
18. Science center visits–CXC, SSC	05/2007		05/2007
19. NAASC Science workshop–Protoplanetary Disks	06/2007		06/2007
20. Participate in CASA Alpha-patch testing	06/2007		06/2007
21. Visit by F. Lovas to help resolve molecular species for Splatalogue (Spectral-Line Catalog)	07/2007		07/2007
22. Antenna 1 AIV Receive at OSF	08/2007		08/2007
23. ANASAC Face-to-Face meeting	08/2007		08/2007
24. Participate in ObsTool Test 5	08/2007	09/2007	09/2007
25. NAASC offline-software testing before beta release	09/2007		08/2007
26. ARC manager meeting at ESO	09/2007		09/2007
27. Participate in Director's ALMA program review	09/2007		09/2007
28. New NAASC science workshop 2008 – topic and SOC	09/2007		09/2007

E.2. Green Bank Telescope (GBT)

Introduction

The Robert C. Byrd Green Bank Telescope (GBT) is the world's premier single-dish radio telescope operating at centimeter–millimeter wavelengths. The GBT is in robust, routine, and effective operation at frequencies up to 50 GHz, and FY 2007 saw first light at 92 GHz (λ = 3mm) with the MUSTANG bolometer array.

The GBT scheduled 6152 hours of observing in FY 2007 out of 8736 possible hours in the year. 1.6% of the scheduled time was lost to weather, and 6.6% to faults. The scope of tasks necessary to support on-going astronomical observations includes site management, business services, physical plant, mechanical engineering, electronic engineering, computing infrastructure, software support, telescope operations, and scientific support.

Accomplishments and Highlights in FY 2007

- Completion of the major azimuth-track refurbishment project to specification, on time and within budget.
- Development of a significantly improved pointing model, directly including inclinometer data.

- Initial engineering observations with the Zpectrometer wideband spectrometer and first light at λ = 3mm with the MUSTANG bolometer array.
- Refurbishment of the C-band (4–6 GHz) receiver resulting in an improvement in system temperature corresponding to a factor of two increase in observing speed.
- Commencement of the "CICADA" (Configurable Instrument Collaboration for Agile Data Acquisition) project for the rapid development of advanced FPGA-based backends.

Approximately 6300 hours of telescope time were scheduled for astronomy during FY 2007. About 1600 hours of the astronomy time went to surveys during the track refurbishment, including a major 350 MHz pulsar drift-scan survey, one of the most sensitive surveys to date. The fraction of observing time in FY 2007 was approximately the same as in FY 2006 when these surveys are included.

Progress toward FY 2007 Program-Plan Objectives

Azimuth-Track Refurbishment

The azimuth-track refurbishment was a major engineering effort culminating in a four-month shutdown of the GBT from May 01 through August 31, 2007 while the entire track between the top of the concrete foundation and the bottom of the wheels was replaced. The telescope remained on the track during this time. Four $1/8^{th}$-arc segments between the wheels were replaced. Then the telescope was driven onto the new sections and the remaining four $1/8^{th}$-arc sections were replaced. During the shutdown a number of transit observing projects were scheduled, including a major (1400 hours) 350 MHz pulsar drift-scan survey, one of the most sensitive pulsar surveys to date. The azimuth-track project was successfully completed on time and on budget.

Ka-band (26–40 GHz) and Q-band (40–50 GHz) Receivers

Refurbishment and commissioning of both the Ka- and Q-band receivers were completed in fall 2006. The Q-band receiver has been released for general use and has good performance and stable baselines between 40 and 49 GHz. The Ka-band receiver still suffers from some baseline instability and has not reached its full potential as a correlation receiver. However, it can be used as a beam-switched receiver with the GBT spectrometer and the Caltech Continuum Backend, and it has been released for these uses. Investigations into the problems associated with using the Ka-band receiver as a correlation receiver are ongoing. They should considerably improve receiver performance for all types of observing and allow use of the wideband Zpectrometer, which requires a correlation receiver. Additionally, this work will pave the way for future work on any W-band receivers for the GBT. The improved Ka-band receiver will be tested at the start of FY 2008.

Zpectrometer for Ka-band

The Zpectrometer is a wideband analog spectrometer constructed by a team at the University of Maryland headed by Prof. Andy Harris. (The Zpectrometer was described in detail in the 2006 Annual Progress Report.) It was completed on time and on budget during FY 2007 and was commissioned on the telescope. The instrument worked well, but science verification was hampered by the issues with the Ka-band receiver described above. As a result, astronomical commissioning of the instrument has been delayed until FY 2008.

Mustang

Mustang (formerly "The Penn Array"), a 64-pixel, λ = 3mm bolometer array (described in the 2006 progress report) underwent initial engineering commissioning in FY 2007. The receiver and all GBT interfaces worked well on the telescope. The instrumental noise was high initially, but the University of Pennsylvania team achieved a breakthrough, significantly reducing the noise levels in the system and increasing the number of useful detectors very close to the full 64. The cryogenic performance of the receiver was not optimum during the fall commissioning tests, but further work appears to have improved this as well. Further tests and early science observations are planned for FY 2008, with a goal of releasing the instrument for general observers, in collaboration with the P.I., in FY 2009.

Refurbished C-band (4–6 GHz) Receiver

The C-band receiver was upgraded with a new refrigerator that is more reliable and has greater cooling capacity. The refrigerator upgrade lowered the system temperature across the receiver's band to 15–20 K, an improvement from the 22–30 K temperature before the modifications. This yields roughly a factor of two reduction in integration time needed to reach a given noise level. We also improved the receiver's baseline performance by eliminating most coaxial interconnections and using shorter transmission lines in the room-temperature portion. Commissioning of the refurbished receiver is scheduled for the start of FY 2008. C-band is being used as a test bed for possible future enhancements to other receivers.

Dynamic Scheduling

Work on the new dynamic scheduling system for the GBT was slowed by the heavy workload for the GBT's high-frequency receivers. Nonetheless the overall project plans are now complete, and testing and programming have begun on the scheduling algorithms. The project underwent a number of reviews over the fiscal year—two internal to the NRAO and one external conceptual design review. Overall the reviews were quite favorable, and the suggested changes are being implemented.

Continued Telescope Performance Improvements

The Precision Telescope Control System (PTCS) project focused on upgrades to the GBT servo system, antenna trajectory improvements, creating a new pointing model, and recharacterizing the track after the azimuth-track replacement. The upgrades to the antenna trajectory and servo system will improve the performance of the antenna when "nodding" between beams (e.g. for Ka- and Q-band observing) and when performing complex scan patterns such as daisy-petal scans. Owing to limited resources, performance upgrades for these systems were limited to improving the slow-speed motion of the telescope. An improved pointing model that directly incorporates inclinometer data was developed. The length scales and relative magnitudes of the various contributions to reflector surface error were characterized via the analysis of scans across the Moon. Mathematical simulations of traditional holography demonstrated both the utility and limitations of the technique. They will provide a useful guide for reducing small-scale surface errors.

RFI Mitigation

The GBT RFI-monitoring station was completed during FY 2007. Its omnidirectional antennas covering 100 MHz to 3 GHz are useful for monitoring RFI at the GBT and for developing RFI-excision techniques. Work started on refurbishing the 20m telescope for a collaboration with Brigham Young University to use the antenna as an array-feed test platform. The array feeds will be coupled with

adaptive signal processing for RFI removal. Finally, development of a user-friendly database with all known RFI at the Green Bank site was begun, with a completion scheduled in FY 2008.

Future Instrumentation

As a result of the future-instrumentation workshop held at the end of FY 2006, Green Bank has begun work on two new large projects—CICADA and the K-band focal-plane array.

CICADA, the Configurable Instrument Collaboration for Agile Data Acquisition, explores the development of new back ends using reconfigurable off-the-shelf hardware platforms and software tools that allow rapid design, verification, and deployment of astronomical signal-processing systems. Its current focus is on developing FPGA-based hardware and software for observations using the GBT and the 43m telescope. The program is a collaboration among the NRAO, U.C. Berkeley, the University of Cincinnati, West Virginia University, Xilinx, Inc, and others. The first three instruments for the project are the next-generation pulsar backend for the GBT, a prototype transient detector for the 43m telescope, and a spectrometer/pulsar processor for the 43m telescope. All three instruments are scheduled for completion in FY 2008.

The K-band (18–26 GHz) focal-plane array remained in the planning stage for FY 2007. Current plans call for an 8-element array to be built using existing GBT back ends (e.g. the GBT spectrometer) and to be developed and installed on the telescope by FY 2010. The K-band focal-plane array project is a collaboration between the Green Bank site and NRAO's Central Development Laboratory.

Non-programmatic Funded Projects

The NRAO and Lincoln Laboratories continued operation of the 43m telescope under their cooperative agreement to measure the properties of the Earth's ionosphere using bistatic radar techniques.

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

The Solar Radio Burst Telescope, the refurbished 14m antenna at Green Bank, had a successful 3rd year of operation during FY 2007.

E2E Operations

Green Bank staff worked closely with NRAO's End-to-end (E2E) group. In particular, Green Bank staff worked with the E2E team on the GBT dynamic-scheduling project, future data-reduction software, and the proposal submission tool. We also worked with the E2E division to develop a new User Database schema that will be shared across all NRAO sites. The Green Bank Software Development Division also organized a site-wide meeting of all software engineers to facilitate communication among the sites. Finally, Green Bank staff participated in a number of reviews for the E2E team.

Work for other NRAO Divisions

Green Bank staff worked on projects for two other NRAO divisions during FY 2007. The Green Bank Software Development Division developed a new Business Office System that will be used by all NRAO sites for tracking guest services (lodging, transportation coordination, concessions, etc.). Deployment is scheduled for the beginning of FY 2008. The ALMA bias boxes (35) were tested and built at Green Bank.

A summary of performance against milestones in FY 2007 for all GBT projects is provided in Table E.2.1. It includes both original milestones and intermediate milestones identified throughout the year.

GBT Milestones for FY 2007

Item	Date Planned	Date Accomplished
Azimuth Track Refurbishment		
1. Work Plan and schedule complete	10/2006	10/2006
2. First 24 wear and base plates manufactured	01/2007	03/2007
3. Final 24 wear and plates manufactured	03/2007	04/2007
4. All components on site	03/2007	04/2007
5. Refurbishment starts	04/2007	04/2007
6. Refurbishment complete	08/2007	09/2007
7. Telescope performance restored	08/2007	09/2007
Zpectrometer		
1. Lab tests complete	10/2006	10/2006
2. Zpectrometer installed on telescope	10/2006	10/2006
3. Commissioning tests complete	12/2006	12/2006
4. Science validation complete	05/2007	Moved to FY08
MUSTANG (Penn Array Receiver)		
1. In-progress review	08/2006	08/2006
2. Lab tests complete	02/2005	09/2006
3. Engineering commissioning commences	02/2005	09/2006
4. Document commissioning results	01/2007	03/2007
5. Science validation complete	05/2007	Moved to FY08
Dynamic Scheduling		
1. Stage I (Concept development) complete	04/2007	06/2007
2. Proposal Review	06/2007	06/2007
3. Stage II (Proof of concept) complete	09/2007	Moved to FY08
Precision Telescope Control System		
1. Trajectory generation and servo improvements complete	12/2006	08/2007
2. PLC interlock system installed	08/2007	09/2007
3. Small-scale surface errors characterized	08/2007	07/2007
4. Upgrade of pointing model with new track terms	09/2007	09/2007
5. Laser rangefinder V2 development complete	09/2007	Moved to FY08

E.3. Very Large Array (VLA)

The VLA scheduled 6195 hours of observing in FY 2007 out of 8736 possible hours in the year. 1.3% of schedule time was lost to weather, and 6.2% to faults. The scope of tasks necessary to support on-going astronomical observations includes site management, business services, engineering services, electronic engineering, computing infrastructure, software support, telescope operations, and scientific support.

Accomplishments and Highlights in FY 2007

Observing and User Programs

The VLA Large Proposal deadline in October 2006 resulted in approval of four large proposals, one for A configuration and three for B-configuration. The A-configuration proposal was executed in summer 2007; the other proposals await the B-configuration session that will occur in the first quarter of FY 2008.

The VLA/VLBA Proposal Selection Committee (PSC) was modified to incorporate more outside (non-NRAO) members. Previously, this committee typically had one non-NRAO member and six from NRAO. For the proposal deadlines in February 2007 and June 2007 (evaluation meetings in April and August), the PSC was expanded to include five and six outside members (together with five NRAO members), respectively. With this change, the PSC has taken a slightly more active role in proposal evaluation beyond strictly following the referee grades.

The web-based Proposal Submission Tool was modified slightly in response to user recommendations early in FY 2007, and then was turned over to the NRAO E2E Operations Division.

EVLA Transition

Except for a few items such as the round-trip-phase module, all EVLA electronics modules are in full production mode and are being installed in retrofitted EVLA antennas as they are modified in the Antenna Assembly Building. At the end of FY 2007, 12 EVLA antennas had been returned to VLA operations for routine observing with the operational VLA. Generally, these antennas contain operating receivers at L-band (1.2–2 GHz), C-band (4–8 GHz), X-band (8–8.8 GHz), K-band (18–26.5 GHz), and Q-band (40–50 GHz). Two more VLA antennas are being retrofitted, so nearly half of the antennas in the operational VLA will be using the new EVLA electronics and fiber-optic systems at the end of FY 2007.

The combination of VLA and EVLA antennas in the operational array results in unavoidable complexities in observing and data reduction. Astronomers have been informed of these complexities and the steps needed to maximize scientific use of their data by the frequently updated "EVLA Returns" web site at http://www.vla.nrao.edu/astro/guides/evlareturn/ .

The first VLA proposals were called for in the extended frequency ranges enabled by the new EVLA electronics. A special C-band call made in April 2007 emphasized total-intensity imaging in the D and A configurations; the wideband EVLA orthomode transducers needed for high polarization purity over a very wide bandwidth are not yet available. Eight proposals focusing on hydroxyl lines near 6.0 GHz and methanol lines near 6.7 GHz were approved, and all were completed by the end of FY 2007. In addition, two K-band proposals were observed in the new frequency range between 18 and 20 GHz.

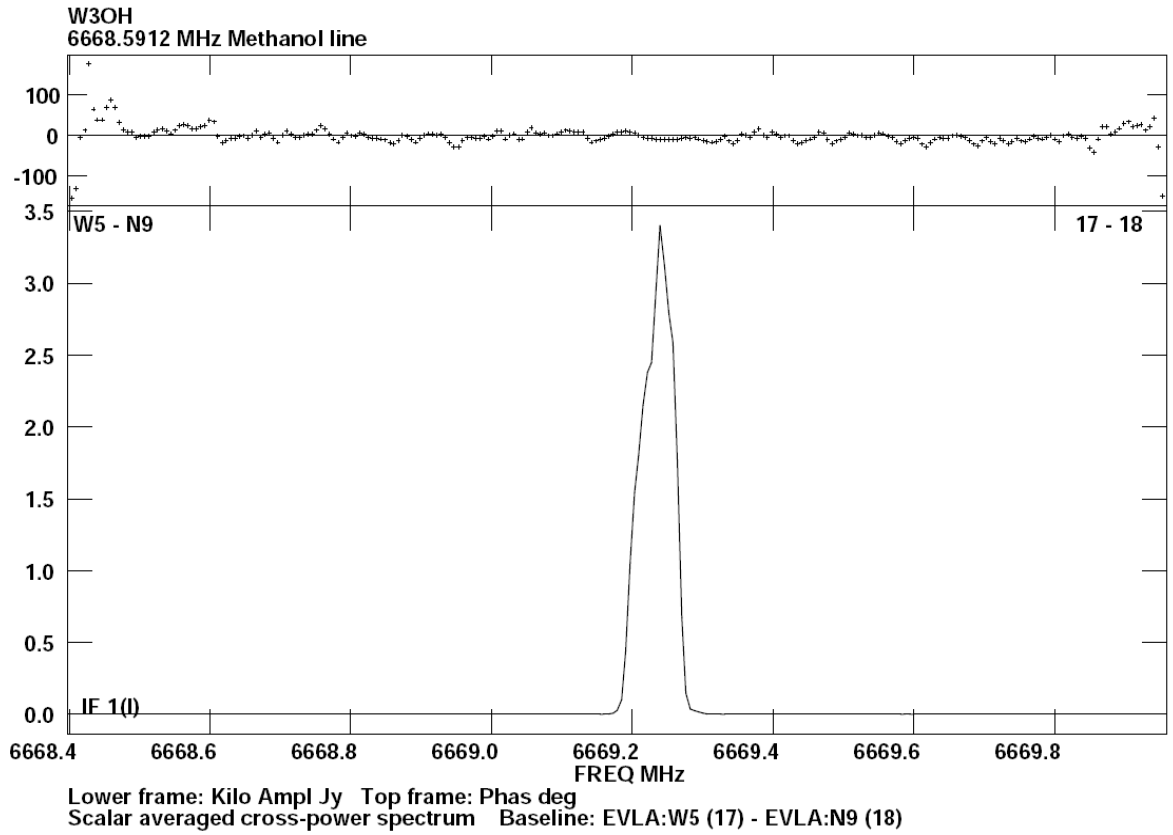


Figure E.3.1. The amplitude (bottom) and phase (top) from a test observation of the 6.7 GHz methanol line in W3–OH on a single baseline between two EVLA antennas. The wider tuning capability demonstrated by these tests led to the first science observations using the new tuning capability of the EVLA in the 4–8 GHz band.

The Science Advisory Group for the EVLA (SAGE) was created and held its first meeting in May 2007. This committee will provide advice on the first observing modes to be implemented with the EVLA and the first science to be done during the VLA–EVLA transition.

The venerable Modcomp control computers of the VLA were removed from service in June 2007, after various versions of the Modcomps had controlled the VLA for a third of a century. An interim version of the EVLA control software now operates both the old VLA antennas and the new EVLA antennas with the old VLA correlator. Achievement of this major milestone allows software and telescope operations personnel to focus on the new EVLA system.

The EVLA/VLBA Operations Plan for 2012 was modified. It now contains an extensive plan for an Array Science Center as well as a complete analysis of the year-by-year personnel requirements for operations of the EVLA and the VLBA through every year of the EVLA transition, until 2012. This plan is being used to assess the possibilities for a more integrated Science Center across the NRAO, including (at least) all of its scientific interferometers.

Dynamic Scheduling

An experiment with dynamic scheduling proceeded beyond just scheduling filler time. Approximately 20% of all VLA observing time was allocated by dynamic scheduling in FY 2007. All scheduling "gaps"

in the interstices between larger programs allocated by the Proposal Selection Committee and all regular monitoring programs now are allocated dynamically.

Infrastructure

Four azimuth bearings replaced on VLA antennas were sent out for evaluation. Two were found suitable for reworking, a third was too worn to be reworked, and the fourth is under evaluation. Delivery time for reworked bearings has increased substantially, to as much as 18 months. Since only one refurbished bearing is on hand and is reserved for emergencies, no azimuth bearings were replaced during FY 2007.

The original VLA analog tachometers are being replaced with digital tachometers as the antennas receive their EVLA retrofits. Five antennas have received these digital tachometers. The digital tachometers are less expensive and provide better pointing than the analog versions, and they are required for the new Antenna Control Unit (ACU). The ACU prototype was scheduled for completion in March 2007 but was delayed to August 2008 because day-to-day maintenance and the EVLA schedule have priority.

The track maintenance crew was increased from skeleton staffing of four individuals to six in FY 2007. (Since pairs of men do much of the work, a crew of five would be quite inefficient.) The crew focused on retrofitting the track intersections near antenna stations, with much more robust concrete structures replacing the standard wooden ties. The seasonal nature of this work requires planning on a Calendar Year basis, not a Fiscal Year basis. A total of 3,300 ties were replaced during Calendar Year 2006. About 1,500 ties were replaced before September in 2007, and we expect to meet the milestone of 4,000 ties by the end of Calendar Year 2007.

A frozen 31DEC06 release of the Astronomical Image Processing System (AIPS) software was made, and the daily updated 31DEC07 version of AIPS was initiated. Virtually all observers rely on AIPS for VLA and VLBA data analysis. During CY 2006 a total of 1398 unique IP addresses downloaded copies of AIPS and/or accessed the remote-download site. Several AIPS tasks were modified to allow data from the VLA/EVLA transition array to be processed successfully by all astronomers.

Communications between the VLA site and the Array Operations Center (AOC) had been limited to the use of only two T1 data lines (1.7 Mbps each) plus a third line for voice. This restricted the ability of both ALMA and EVLA engineers and scientists to troubleshoot modules at the VLA site 50 miles from the AOC, particularly for problems that arose at short notice. NRAO infrastructure funding was used to implement a 150 Mbps OC-3 line between the VLA and AOC in December 2006. Annual costs for operating this line are shared by VLA/VLBA Operations, EVLA Construction, ALMA, and the Long Wavelength Development Array. This wider-bandwidth link enabled a successful electronic real-time VLBI experiment to be carried out in FY 2007, connecting a VLA antenna and one in Westford, MA to the correlator at Haystack Observatory.

VLA Milestones from FY 2007 Program Plan

The table below reproduces the list of major FY 2007 milestones for the VLA from the 2007 NRAO Program Plan along with the performance on those milestones. Most milestones were accomplished on or near schedule. Key deviations were (1) the delay in obtaining refurbished azimuth bearings, caused by a large increase to 18 months in the manufacturer's quoted turnaround time for refurbished bearings, and (2) deferral of a project to improve the VLA antenna control, since the servo group focused on keeping EVLA antenna retrofits on schedule. The highest-priority additional capability from last year's program plan was accomplished: implementation of a 150 Mbps OC-3 link between the VLA and the AOC.

VLA Milestones for FY 2007

Item	Date Planned	Date Accomplished
1. Return the 6th EVLA antenna to VLA	10/2006	09/2006
2. Freeze AIPS version 31DEC06, begin 31DEC07	12/2006	12/2006
3. Complete the new VLA ACU prototype	03/2007	Deferred to FY08
4. Offer the new frequency coverage of EVLA antennas	06/2007	05/2007
5. Obtain 3 refurbished azimuth bearings for stock	06/2007	Delayed, 18-month delivery time
6. Decommission the Modcomp computers	06/2007	06/2007
7. Return the 11th EVLA antenna to VLA	08/2007	08/2007
8. Replace 4,000 railroad ties	12/2007	On schedule
9. Install ~5 digital tachometers on VLA antennas	09/2007	09/2007
Additional capabilities:		
10. Acquire 150 Mbps link from the VLA to the AOC		12/2006

E.4. Very Long Baseline Array (VLBA)

The VLBA scheduled 3849 hours of observing in FY 2007 out of 8736 possible hours in the year. 6% of scheduled time was lost to weather, and 3.9% to faults. The scope of tasks necessary to support on-going astronomical observations includes site management, business services, engineering services, electronic engineering, computing infrastructure, software support, telescope operations, and scientific support.

Accomplishments and Highlights in FY 2007

Observing and User Programs

The VLBA continued to perform scientific observing for about 50% of the wall-clock hours in FY 2007, or 65% if scaled to the sustainable data rate of 128 Mbps. Since the observing rate is limited by the disk supply, the "wall clock" observing rate is likely to remain fairly steady in the future. We are likely to "spend" any extra recording capability by doing more observing at 256 Mbps and 512 Mbps, as requested by more than 70% of our proposals. Small amounts of funding were made available by the GLAST LAT team at Stanford and UNM to support a higher data rate for the VLBA Imaging Polarimetry Survey, and by Purdue University for a higher data rate for the MOJAVE active-galaxies project; the additional disk modules bought by this funding were transferred to VLBA Operations for future use. Approximately 70% of all VLBA observing programs in FY 2007 were scheduled dynamically, with the projects on the telescope determined 1–3 days in advance, depending on forecast weather and array conditions.

The VLA/VLBA Proposal Selection Committee (PSC) added six members by the August 2007 meeting.

Four large VLBA proposals from the October 2006 deadline were accepted and began observations in FY 2007. Two are VLBA-only projects that image active galactic nuclei at regular intervals, and both are connected to the upcoming launch of the Gamma-ray Large Area Space Telescope (GLAST). The others use the VLBA's unique astrometric capabilities to search for extrasolar planets and to probe cosmological parameters by measuring geometric distances to extragalactic water megamasers. These last two projects involve the GBT and will start late in FY 2007 as the GBT comes back on line after its azimuth-track replacement. Several previous VLBA large proposals were completed in FY 2007.

A VLBA student stipend program was initiated; it is similar to the long-running and successful GBT program. In its first round during FY 2007, stipends were awarded to three different U.S. graduate students to support them in their thesis work making use of VLBA observations.

The NRAO signed an agreement for collaborative observations with the GLAST mission. Although this agreement covers all NRAO telescopes, the VLBA is probably the most important telescope for observing GLAST gamma-ray sources.

Mark 5 Recording System

In FY 2007 we acquired several more Mark 5 playback units, resulting in a total of 17 units on the VLBA correlator. When this milestone was reached, the last tape drives at the VLBA correlator were removed, and the VLBA is now a 100% Mark 5 system. The total disk-module capacity for the VLBA is now approximately 562 Terabytes, which corresponds to about 975 hours (33 days) of scientific observing at 128 Mbps on all 10 VLBA antennas. The actual observing capacity is considerably lower because of lag times required for module shipment in two directions, modules waiting to be recorded or correlated, and the use of extra observing antennas (e.g., the VLA and the GBT).

The advent of the Mark 5 system enabled the NRAO to combine the formerly separate jobs of telescope operator and correlator operator in FY 2007. This saves the salary of one operations position and also increases the number of hours that the correlator can be run. It also reduces the turnaround time for disk modules and increases the sustainable VLBA data rate for a given disk supply.

In order to increase the total bandwidth of the VLBA, the NRAO had planned to upgrade two Mark 5A recorders to Mark 5B systems in FY 2007. However, while developing a long-term plan for reaching 4 Gbps (see the next subsection), we concluded that Mark 5B recorders are not on the direct path to that high data rate. Therefore, this upgrade was cancelled in favor of development for the long-term plan. During FY 2007 the NRAO began a collaboration with Haystack Observatory and Conduant Corp. to develop a Mark 5C recorder capable of recording 4 Gbps and completed specifications for the Mark 5C.

Sensitivity Enhancements

It has long been recognized that the VLBA is "sensitivity starved" by its limited bandwidth and relatively small 25m dishes; even compared with the older VLA, the effective observing bandwidth is 3–6 times lower and the total collecting area is 2.7 times lower. This relatively low sensitivity has been the primary reason for implementing the High Sensitivity Array, which incorporates the VLA, GBT, and sometimes Effelsberg and Arecibo for the subset of VLBA observations that require the highest sensitivity.

New technologies have the potential to make the VLBA much more scientifically productive by increasing its maximum and sustainable data rates to 4 Gbps from the current maximum (sustainable) rates of 512 (128) Mbps. In FY 2007 we developed a plan for a VLBA bandwidth expansion project that has three components: (1) a VLBA digital back end capable of delivering 4 Gbps or more, (2) a new VLBI recording system capable of recording 4 Gbps, and (3) a new correlator capable of processing 4 Gbps. In collaboration with the Center for Astronomy Signal Processing and Electronics Research (in Berkeley), Haystack Observatory, and South Africa, we began designing a new digital back-end for the VLBA, making the maximum use of hardware and techniques from the EVLA project. We began a collaboration with Haystack Observatory and Conduant Corp. to design of the new 4 Gbps recorder. We installed a software correlator developed at Swinburne University (Australia) and detected first VLBA fringes with that correlator at data rates ranging from 128 Mbps to 512 Mbps. Late in FY 2007 we

acquired new CPU capacity for the Mark 5 playback systems at the VLBA hardware correlator that should enable them to be used in a new software correlator for the VLBA.

Late in FY 2006 we began a collaborative program with the Max Planck Institut fűr Radioastronomie and the NRAO Central Development Laboratory to replace the relatively old 22 GHz amplifiers at the VLBA stations. The new amplifiers and contemporaneous improvements in antenna calibration have enabled us to improve the sensitivities of the newly equipped VLBA stations by at least 30%. Six of the ten VLBA stations are now equipped with the new amplifiers.

International VLBI

The VLBA continued to participate in Global centimeter and millimeter VLBI sessions during FY 2007, and it is the anchoring set of antennas for the High Sensitivity Array. We explored the possibility of establishing a more formal International VLBI Network (IVN) but have not yet reached a formal agreement globally. The MPIfR contribution to the VLBA 22 GHz upgrade is a positive sign in developing a more international approach to VLBI.

Infrastructure

Tiger-team maintenance visits were made to Fort Davis and Brewster in FY 2007. A visit was made to the Hancock station to install a reshaped subreflector that had been removed from Brewster in FY 2006 and to repair the Hancock azimuth rail. An analysis in FY 2006 showed that St. Croix was in serious need of corrosion repair and rustproofing, including repainting the entire antenna structure. St. Croix was removed from service late in FY 2007 to begin these repairs, which should be completed in FY 2008. The St. Croix repairs had been delayed by funds being shifted to GBT azimuth track maintenance and repairs; in return the St. Croix repainting was funded by the settlement of the GBT track warranty claim. An originally scheduled major maintenance visit to Owens Valley was delayed until FY 2008 because of the antenna-mechanic workload necessitated by refurbishing St. Croix while also maintaining the schedule for retrofitting VLA antennas to EVLA antennas.

The drives used on the VLBA Focus Rotation Mounts (FRM) are no longer supported by the manufacturer, and replacement parts are unavailable. A temporary solution has been developed to remove one of the rotation motors from each antenna and use them as spares. This solution has been implemented on 8 of the 10 VLBA antennas, including two antennas that were modified in FY 2007. A long-term solution is being developed to replace both the VLBA and VLA FRM systems. The plan is to replace the focus and rotation motors with standard frame motors and to replace the drive/controllers with new digital electronics. This will increase performance while minimizing the cost. In FY 2007 a prototype system was procured and is now running standalone in the laboratory.

Several VLBA Antenna azimuth-drive wheel axles have failed because of a design flaw and are being replaced by more robust wheel assemblies during maintenance visits. Twelve out of twenty azimuth-drive wheel assemblies have been replaced so far. In FY 2007 both wheel assemblies were replaced at Fort Davis, including one replacement on an emergency basis after a failure just before Christmas; in addition, one azimuth-drive wheel assembly was replaced at Brewster.

Key AIPS modifications that assist VLBA data analysis have improved astrometric calibration of the array in support of the increasing number of important astrometric observations that are being carried out, as well as acquisition and implementation of improved geometric models that are available only after data correlation is completed.

VLBA Data Archive

Caretaking of the VLBA data archive was transferred to the NRAO E2E Operations Division during FY 2007. A large fraction of users are now downloading their data directly from the on-line archive rather than requesting shipment of data on magnetic media.

Performance on VLBA Milestones from the FY 2007 Program Plan

The table below summarizes key VLBA milestones listed in the FY 2007 Program Plan and performance on those milestones. Several milestones were late or deferred by a combination of overoptimism (large proposal observations and student grants), expanded scope of the St. Croix repairs (beginning repairs and deferring Owens Valley maintenance), and changes in plans (Mark 5 upgrades).

VLBA Milestones for FY 2007

Item	Date Planned	Date Accomplished
1. Conversion of HSA to Mark 5	10/2006	10/2006
2. Correlator achieves 17 Mark 5 inputs, last tape drives discarded	12/2006	12/2006
3. Publish plan and budget for VLBA to reach 4 Gbps in 2011	04/2007	04/2007
4. Initial VLBA student observing grants awarded	01/2007	05/2007
5. First observations for new VLBA large proposals	01/2007	06/2007
6. SC rustproofing project begins	05/2007	09/2007
7. Prototype a new VLBA FRM system	09/2007	07/2007
8. Upgrade two Mark 5A recorders to Mark 5B	09/2007	Cancelled
9. Maintenance visits to FD, OV, and BR	09/2007	OV deferred
10. Completion of three large proposals from FY 2005/06	09/2007	09/2007

F. Scientific and Technical Support Services

F.1. End-to-End (E2E) Operations

NRAO End to End Operations (E2E) was initiated as a formal organizational entity in April 2006, so the FY2007 Program Plan described the initial mission, direction, and activities for the division's launch. By the end of the year, the role and activities of E2E had been substantially developed, and this is reflected in the content of the Annual Progress Report.

Accomplishments and Highlights in FY 2007

The accomplishments and highlights herein reflect the first full year of End to End Operations as an organizational unit. E2E Operations is dedicated to broadening access to NRAO facilities, increasing science impact and throughput, and optimizing investments in software and end-to-end user support. Since its formal inception in April 2006, formative work has included identifying roles and responsibilities, startup funding, building channels of communication, and identifying opportunities for shared technical development. For example, one area of focus has been to ensure that science products are available for much of the existing archived data from NRAO telescopes, making the archived data easier to access, and making more extensive use of National Virtual Observatory (NVO) protocols and services.

There were two major organizational advances in spring 2007. First, a cooperative software-development plan was established between EVLA and ALMA NA to focus and combine efforts more strongly. This involved the agreement to formally combine development teams for scheduling, to bring together the various groups working on pipeline heuristics so those methods are shared between telescopes, and to work with ALMA EU to determine how all of NRAO's telescopes (including ALMA) can share a common mechanism for submitting proposals and preparing observations. Although there are many details to be worked out, the principles of the agreement will provide a refreshed framework for moving forward as One Observatory. Second, the question of how to revitalize algorithm development at the NRAO was examined, specifically in the context of how the NRAO will ensure that the algorithm development challenges presented by EVLA and ALMA are met. As a result, algorithm R&D workshops will be conducted over the next three to five years, with the first to be held in November 2007.

By summer 2007 the NRAO was actively participating in the development of the emerging National Virtual Observatory (NVO) facility at both technical and managerial levels. The continued use and refinement of the VLA data-processing pipeline had resulted in more 45,000 new VLA images covering more than 8000 sky positions. These were readied for publication to the NRAO archive and published as a collection to the NVO. The Proposal Submission Tool (PST) and its underlying database of astronomical users was transitioned from EVLA computing, upgraded, and is being prepared for mid-September release on the new NRAO portal, http://my.nrao.edu. Substantial progress was made on establishing a single-dish archive for both spectral-line and continuum observations, which began in earnest for current GBT observations as well as archival 12m and 43m telescope data. An alpha site representing new designs and information flows is being prepared as part of the NRAO Web Transformation Project, a joint effort between EPO and E2E which will result in a new NRAO web site.

Strategic alliances were also established throughout this period. E2E Operations now regularly collaborates with the University of Virginia (UVa) Astronomy and Computer Science departments, the UVa Center for Computational Science, the West Virginia University Physics and Computer Science departments, North Carolina Agricultural & Technical State University, and the Pittsburgh Supercomputer Center. Discussions are beginning with the National Center for Supercomputing Applications (NCSA) about hosting NRAO data and pipelines on the high-performance TeraGrid. E2E Operations also aggressively pursued non-programmatic funding in the areas of data visualization, proposal management, scientific communities of practice, pulsar archiving, algorithm development and exploration at the petascale, and involving minorities in scientific and computational opportunities at the NRAO. Three proposals were declined and the rest are pending. E2E Operations will continue to pursue appropriate opportunities for external funding related to advanced computation.

Management & Administration Milestones

Item	Date Planned	Date Accomplished
1. Strategic alliances for external funding established	09/2006	09/2006
2. External funding plan established	09/2006	09/2006
3. Initial proposals for external funding developed and issued	12/2006	12/2006
4. **External funding**: Prepare proposal for computational science REUs	04/2007	Deferred FY08
5. Oversight for March 2006 external CASA tests	03/2007	03/2007
6. Begin regular biweekly E2E email communications	04/2007	04/2007
7. Begin regular biweekly E2E in-person meetings	04/2007	04/2007

Item	Date Planned	Date Accomplished
8. Complete CASA beta plan	04/2007	04/2007
9. Prepare demos for Users Committee	05/2007	05/2007
10. New front page for http://e2e.nrao.edu published	06/2007	06/2007
11. Participate in GBT Dynamic Scheduling System conceptual review	06/2007	06/2007
12. Determine feasibility of partnership for NSF PAARE diversity program for research in computational physics/astronomy with minority-serving institutions	07/2007	07/2007
13. Create NRAO alpha web-site specifications with EPO; hold kickoff meeting with NRAO webmasters and outside design contractors	08/2007	07/2007
14. Participate in EVLA Advisory Committee meeting	09/2007	09/2007
15. Release http://my.nrao.edu dashboard for astronomers, begin receiving NRAO proposals using new interface	09/2007	09/2007
16. First draft of E2E Strategic Plan complete	09/2007	09/2007

Algorithm Development Milestones

Item	Date Planned	Date Accomplished
1. Plan initiative to revitalize algorithm development at the NRAO completed (with Fomalont, McKinnon/EVLA)	06/2007	06/2007
2. Relationship established with the Pittsburgh Supercomputer Center to help the NRAO with algorithm development	06/2007	06/2007
3. **External funding:** Submit proposal to NSF OCI for petascale applications in conjunction with the University of Virginia and supported by the Pittsburgh Supercomputing Center	07/2007	07/2007
4. Create project charter for algorithm development; establish and promote core values to distinguish algorithm R&D from software implementation	09/2007	09/2007

NRAO Participation in the National Virtual Observatory (NVO) Project

Item	Date Planned	Date Accomplished
1. Conduct Fall 2006 joint meeting of NRAO/NVO	12/2006	01/2007
2. DAL service reference code in Java (DALServer)	07/2006	02/2007
3. Promote Cone Search to Proposed Recommendation (PR)	03/2007	03/2007
4. Draft chapters for NVO Book	12/2006	04/2007
5. Concept and scope for Simple Image Access (SIA) V2	05/2007	05/2007
6. IVOA interoperability meeting (China)	05/2007	05/2007
7. Promote Simple Spectral Access (SSA) to PR	12/2006	06/2007
8. Edited chapters for NVO Book	07/2007	07/2007
9. Summer 2007 NVO team meeting (Tody/Radziwill)	07/2007	07/2007

Item	Date Planned	Date Accomplished
10. Revised SIA specification for PR	08/2007	08/2007
11. SSA V1.1 working draft including Grid functionality	09/2007	
12. Initial working draft and prototyping for SIA V2	09/2007	
13. Initial working draft Table Access Protocol	05/2007	05/2007
14. Concept and data model for handling time-series data	05/2007	05/2007
15. IVOA interoperability workshop (Cambridge UK)	09/2007	09/2007
16. Concept for handling SEDs and spectral aggregates	05/2007	05/2007
17. High-level plan for NRAO data center in place	06/2007	06/2007

NRAO Archive Infrastructure & Interfaces

Item	Date Planned	Date Accomplished
1. Acquire and install ESO/NGAS Archive Software	01/2006	09/2006
2. Integrate NGAS into existing NRAO science data archive	09/2006	09/2006
3. Document role of archive facilities in NRAO Integrated Science Center vision, including envisioned physical and application architectures	09/2006	03/2007
4. Updates to SIAP image server	11/2006	12/2006
5. Complete VO–Google Pre-prototype	12/2006	01/2007
6. Complete VO–Google Beta	04/2007	05/2007
7. Devise archive-index schema and replication scheme; resolve data integrity issues in current NRAO archive	04/2007	07/2007
8. Determine release date for Archive v2.0	03/2007	05/2007
9. Complete transfer of GB 43m telescope data to disk	12/2007	04/2007
10. Set up rsync between GB and CV to archive GBT data to transfer data daily to archive disks.	03/2007	07/2007
11. Generate index files for current (trimester 07A) GBT data before summer shutdown.	08/2007	06/2007
12. Develop database schema for the archive index files	06/2007	07/2007
13. Develop search parameters for advanced searches of single-dish spectral-line data.	06/2007	06/2007
14. Generate automated script to load the index file data into the archive index database	06/2007	06/2007

NRAO Proposal Infrastructure & Interfaces

Milestones	Date Planned	Date Accomplished
1. Develop transition plan	09/2006	11/2006
2. Transfer NRAO PST & Database to E2E Operations	12/2006	02/2007
3. Successful maintenance of PST in first E2E-managed deadline	06/2007	06/2007

Milestones	Date Planned	Date Accomplished
4. Work with ALMA EU (ObsPrep subsystem) to ensure that NRAO PST development over the next 12–18 months is scoped properly to ensure commonality with ALMA	06/2007	06/2007
5. Complete PST performance improvements; ready for internal integration testing	05/2007	07/2007
6. Conduct user-acceptance testing for upgraded PST	08/2007	08/2007
7. Conduct user-acceptance testing for new Proposal Handling System	09/2007	09/2007
8. Release PST upgrade; begin receiving new proposals using upgraded interface	09/2007	09/2007
9. Successful management of October 2007 NRAO proposal deadline with upgraded software	09/2007	09/2007

Data Processing (CASA/GBTIDL) Milestones

Milestones	Date Planned	Date Accomplished
1. Integrate CASA/GBTIDL milestones into upcoming quarterly reports	09/2006	12/2006
2. Conduct internal EVLA CASA Tests	12/2006	12/2006
3. Conduct/provide scientific oversight for external ALMA CASA Tests	03/2007	03/2007
4. Prepare detailed schedule for September CASA Beta	03/2007	04/2007
5. CASA Beta-release plan finalized	04/2007	04/2007
6. CASA Alpha-release Patch 1	06/2007	07/2007
7. CASA ALMA ARC Tutorials (ESO Garching)	07/2007	07/2007
8. CASA Alpha-release Patch 2	08/2007	08/2007
9. CASA Beta release scheduled	09/2007	09/2007

NRAO Pipeline Infrastructure & Interfaces

Milestones	Date Planned	Date Accomplished
1. Start working through past VLA archive data with AIPS pipelines to generate science products	10/2006	09/2006
2. Requirements for pipeline improvements set	09/2007	11/2006
3. First half of VLA archive processed via pipeline	06/2007	06/2007
4. Summary statistics and report on VLA/VLBA pipeline in AIPS	09/2006	02/2007
5. Process in place for a data analyst to pipeline and archive straightforward VLA/VLBA observations within two weeks of data availability	01/2007	04/2007

F.2. Central Development Laboratory

The Central Development Laboratory (CDL) designs, develops, fabricates, and supplies unique components, in particular low-noise amplifiers, MMIC circuits, cryogenic mixers, passive electromagnetic components, digital data-processing systems, and specialized receivers for other NRAO facilities: ALMA, the VLA, VLBA, GBT and EVLA, as well as other projects and activities, such as FASR and WMAP, for the astronomy community.

Cryogenic HFET Development

The CDL is the recognized leader of cooled HFET (Heterostructure Field-Effect Transistor, sometimes called HEMT) amplifier design and construction for radio astronomy. In FY 2007 the CDL provided more than 100 HFET amplifiers for use on all NRAO telescopes and for others in the radio-astronomy community and elsewhere. The CDL redesigned several amplifiers to improve their performance.

Accomplishments and Highlights in FY 2007

Amplifier Development—A redesign of the 18–26 GHz and 26–40 GHz EVLA amplifiers to achieve flat noise and gain at the band edges was successful. That completes the original task to design and develop all EVLA amplifiers covering the 1–50 GHz frequency range. In addition, some changes were introduced in the 2–4 GHz and 4–8 GHz amplifier assembly and bonding schedules to improve noise performance. Furthermore, a redesign of the 1–2 GHz amplifier body was completed and a redesign of the 2–4 GHz amplifier body is in progress. Both were done to reduce some parasitic effects on the amplifier performance. Good progress has been achieved in developing state-of-the-art cryogenic InP HFET amplifiers for ALMA Band 1 (31.3–45 GHz) and Band 2 (67–90 GHz) receivers.

Amplifier Research—We continued research on noise properties of SiGe and InP heterostructure bipolar transistors (HBTs), in particular in the study of their cryogenic noise properties and their possible applications in total-power radio-astronomy receivers. Although these devices are not expected to offer the noise performance of InP HFETs, especially at cryogenic temperatures, they could in principle offer an order-of-magnitude lower 1/f-like gain fluctuations that currently set the minimum switching frequency of broadband continuum receivers, improve radiometer sensitivity, and perhaps lower cost.

A picture of the PC/LabView-based amplifier noise-measurement system, built to replace the 25-year-old Apple II/ADIOS system, is shown below. This system is operational, and capable of handling all routine LNA measurements and performance documentation. An inexpensive piece of commercial software was added which allows the old HP8510 Network Analyzers to transfer data directly to PCs for storage and printing. Further user interface enhancements to the system will be implemented in FY 2008.

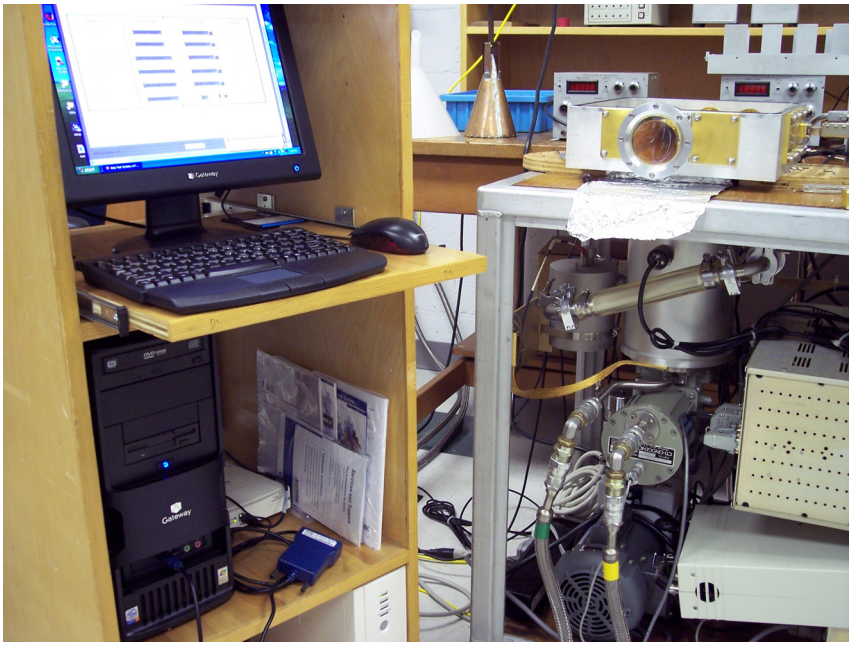


Figure F.2.1. This picture shows the new PC-based noise-measurement system that replaces the old Apple II-based hardware, allowing for data compatibility with modern hardware and software. Commercial data-acquisition modules from National Instruments connect to the PC via USB, replacing the twenty year old NRAO-built ADIOS (Apple II compatible) modules.

A total of 117 new and upgraded amplifiers, including L (1–2 GHz), S (2–4 GHz), C (4–8 GHz), K (18–26 GHz), and Q (40–50 GHz) band units were built for receiver systems on the GBT, VLBA, and EVLA (primary). All requested EVLA production is either on or ahead of schedule. In addition, work has been carried out to repair and test ten Cosmic Background Imager (CBI) Ka-band (26–40 GHz) amplifiers.

Amplifier Design and Development Milestones

Item	Date Planned	Date Accomplished
1. Refine the designs for 18–26 and 26–40 GHz	Ongoing	
2. Demonstrate state-of-the-art performance in ALMA Band 1 and Band 2	Ongoing	
3. Study the cryogenic noise properties of HBTs	Ongoing	
4. Keep pace with EVLA receiver needs	On schedule	Ahead of schedule
5. Further improvements to the PC-based amplifier test system	12/07	

MMIC Development

The CDL continues to develop a wide variety of custom centimeter- and millimeter-wave Monolithic Millimeter-Wave Integrated Circuit (MMIC) components. A MMIC-based approach for the front ends holds the promise of more compact, lightweight receivers and possible cost savings for large array receivers. This will have a positive impact on many fronts, from cryogenics and power distribution to antenna structure and maintenance operations, as well as improved impedance match, gain slopes, and even optical parameters, such as beam spacing and field of view.

Accomplishments and Highlights in FY 2007

Revise DSN front-end modules for wider bandwidth—In collaboration with JPL, we revised the existing dual-channel 26–40 GHz MMIC downconverter design for the Deep Space Network Array to provide extended bandwidth.

Differential LNA for balanced feeds—Extensive effort has been put into designing the differential MMIC LNA for balanced feeds. Some progress has been made, but the combination of specifications on input impedance, noise temperature, and dynamic range are proving to be most challenging. A serious design will have to wait for the appropriate MMIC wafer run to come along.

Integrated wideband LNA–feed package—New insights into the high-order behavior of ultra-wideband mixers make this approach less desirable than originally thought for decade-bandwidth systems. We still intend to explore it for other applications, but its priority has been reduced. Instead, we are exploring ways of more closely integrating LNAs with feeds and OMTs for lower noise.

GaAs W-band (75–110 GHz) power-amplifier development—The design for a new GaAs power amp for ALMA Band 3 (up to 108 GHz) was completed. Small-signal wafer-probe test results with the revised MMPA75B are good. However, the saturated output power measured in package and later in chip form is low by at least 3dB. Similarly, low power was measured in a package for the Band 3 (92–108 GHz) amplifier from the same lot. We are investigating possible causes. The 70nm GaAs wafer run was delayed by unforeseen problems with the new process at the MMIC foundry (BAE systems.) The process has been revised, and a new discrete-transistor wafer started that has already been shown to be free of the problem. A MMIC run is now scheduled to enter fabrication in October 2007.

Evaluate InP HBTs for use in cryogenic amplifiers—InP HBT amplifiers may offer order-of-magnitude lower 1/f-like gain fluctuations, thus improving broadband radiometer sensitivity. We have received sample devices from Northrop Grumman Space Technology (NGST) and are preparing to perform cryogenic evaluation on these devices. This effort may lead to low-noise amplifier chains with much lower gain fluctuations than those currently available, resulting in much improved broadband radiometers.

MMIC VCO development—This is a joint R&D effort of the NRAO CDL and ASIAA, Taiwan to develop low-cost, low-power alternatives to Yig-Tuned Oscillators (YTOs) for local oscillators. The wideband MMIC HBT Voltage-Controlled Oscillators (VCOs) designed by Dr. Chiong of ASIAA during his stay at the NRAO were fabricated by WIN Semiconductors Corp. and samples were delivered to the NRAO for on-wafer testing. This VCO covers the band required for the ALMA Band 10 LO driver. Using this MMIC VCO, an all-MMIC LO driver was designed to fit into a 0.75" x 0.90" x 1.03" package containing the VCO, warm multipliers, amplifiers, mixers, and filters needed to drive the cold frequency multipliers for Band 10. The LO driver block has been machined and is ready to be assembled.

67–90 GHz MMIC LNA development—We have received model parameters for a 35nm InP HFET for the new NGST 35nm InP process. This gate length is shorter than that of any previously successful device, enabling operation at higher frequencies. We were asked to contribute designs for the next run of this process. Using the model data, we converted the s-parameters to a circuit model and converted the frequency-dependent noise parameters to a temperature-dependent (Pospieszalski) noise model. A 67–95 GHz MMIC LNA for ALMA Band 2 was designed in this process with predicted 20K noise at cryogenic temperature, compared to about 30K for older processes. The fabrication run is underway.

Other Projects:

As part of the development of ALMA local oscillators for Band 10, we investigated more closely the generation, propagation, and effects of LO sideband noise on single-ended mixers, both double sideband and sideband separating. A paper on this research was presented at the 18th International Symposium on Space Terahertz Technology entitled "Maximizing Signal-to-Noise Ratio in Local-Oscillator Chains for Sideband-Separating Single-Ended Mixers". A high-school intern assisted with some of the signal-to-noise measurements in this paper. This theory will help considerably with the design of the Band 10 local oscillator, which will be used to pump a sideband-separating mixer after large multiplication factors.

We submitted an internal proposal to develop a small K-band (18–26 GHz) focal-plane array (~7 pixels) receiver for the GBT using Lockheed Martin settlement funds. Funding was tentatively approved by the Director contingent on a more detailed implementation plan. This receiver is being designed for easy expansion to a larger array (about 50 elements maximum) and to serve as a template for focal-plane arrays for other bands (*e.g.*, λ = 3mm). The project will be carried out jointly by engineers at CDL and GB.

MMIC Design and Development Milestones

Item	Date Planned	Date Accomplished
1. Design/Revise DSN front-end modules for wider bandwidth	09/2006	08/2006
2. Develop differential LNA for balanced feeds	04/2008	
3. Develop integrated wideband LNA–feed package	04/2008	
4. Design and test GaAs W-band (75–110 GHz) power amplifiers to improve reliability of millimeter-wave LOs	04/2008	
5. Evaluate InP HBTs for use in cryogenic amplifiers.	06/2008	
6. Package and test ALMA Band 10 (787–959 GHz) driver module using MMIC VCO	09/2007	
7. Design ALMA Band 2 (67–90 GHz) LNA MMIC using NGST 35nm InP HEMT process	05/2007	05/2007

Millimeter- and Submillimeter-Wave Receiver Development

In addition to the ALMA Band 6 (211–275 GHz) receiver development reported in the ALMA section, work continues at the CDL on the following millimeter and submillimeter technical-development projects: 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 2007

350 μm (780–950 GHz) Heterodyne-Receiver Technology Development—This project is being done in collaboration with the University of Virginia Microfabrication Laboratory (UVML). At present, no heterodyne receivers for the 350 μm atmospheric window can achieve the nearly quantum-limited sensitivity that niobium SIS receivers provide below ~600 GHz. Success in this work would enable the NRAO to provide the best possible receivers for ALMA Band 10 and at higher frequencies. The goal is to produce reliable, repeatable, inexpensive, quantum-limited receivers using recently developed SIS mixer fabrication technology. We reached a major milestone this year on the way to advanced NbTiN/insulator/Nb tunnel junctions for frequencies above 700 GHz—the UVML successfully fabricated SIS junctions with AlN tunnel barriers as required for NbTiN SIS junctions. Junctions with AlN barriers

and high critical current densities are desirable for high-frequency broadband operation. The I–V characteristic of a two-junction array is shown below:

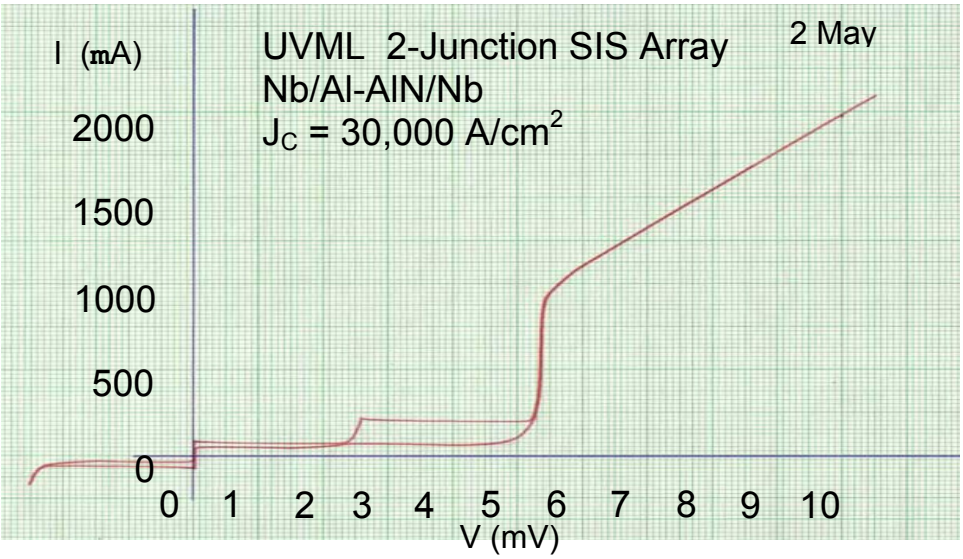


Figure F.2.2. I-V curve of a UVML Nb/Al–AlN/Nb two junction array. Junction diameter ~ 1.7μm. This achieves the level of non-linear operation needed for high-performance SIS mixers.

Balanced SIS Mixer Development—Our work on balanced mixers is funded primarily by the Arizona Radio Observatory of the University of Arizona (UAZ).

Balanced mixers have three desirable characteristics for radio-astronomy receivers: (1) immunity to LO sideband noise, (2) ~50 times lower LO-power requirement, and (3) 3 dB greater dynamic range. Six blocks for a 211–275 GHz balanced SIS mixer with a superconducting IF hybrid have been received. The mixers were designed at the NRAO and fabricated by the UAZ as part of our collaboration on ultra-low-noise receivers for the Submillimeter Telescope. The NRAO will install chips and the superconducting hybrids and send the mixers to the UAZ for evaluation. The next step towards the ultimate low-noise SIS receiver is to develop a balanced sideband-separating SIS mixer with very low noise and low LO power requirement. We have completed the design of a 211–275 GHz balanced sideband-separating SIS mixer with a superconducting hybrid. Such mixers will be essential for future coherent mm/submm focal-plane and beam-forming-array receivers.

385–500 GHz SIS mixer—This is a joint effort between the NRAO and UVa to develop a new 385–500 GHz beam-lead SIS mixer. The NRAO is providing mixer designs and the UVa foundry is fabricating devices. This work will explore the use of both Nb and NbTiN materials for submm SIS mixers. An initial mixer design was completed, but the project was put on hold awaiting funds and engineering resources. Recently, the Arizona Radio Observatory of the University of Arizona has expressed interest in supporting this effort as part of our collaboration on ultra-low-noise receivers for the Submillimeter Telescope. A new design based on the newly developed a Nb/Al–AlN/Nb technology is in progress.

Other Project—Very-Low-Loss Passive Front-End Components

Recently there has been interest in using high-temperature-superconducting circuits in two applications: (1) very high Q band-stop filters for interference excision at the GBT and (2) to lower the loss of the feed and polarizer or 90-degree hybrid at the input of VLA receivers. It seems likely, however, that unplated copper conductors can be as effective as the high-temperature superconductor in these applications

except, perhaps, for interference filters, which require very high-Q resonators. The resistivity of copper decreases by more than an order of magnitude between room temperature and ~30 K. We measured copper samples on Duroid and Cuflon circuit board and found a DC resistance ratio of ~50 between room temperature and 4 K. Using the simple skin-loss formula, that gives a factor of ~7 reduction in loss at microwave frequencies. If it is possible to reduce conductor loss in the front end by this amount, the input loss will be reduced to essentially that of the connectors. An experiment is currently being designed to measure the losses of copper, aluminum, and gold-plated copper circuits at room temperature and cold.

Superconducting Millimeter-Wave Receiver Development Milestones

Item	Date Planned	Date Accomplished
350 µm Receiver Technology Development		
1. Demonstrate SIS junctions with AlN barrier	07/2007	05/2007
2. Demonstrate NbTiN/insulator/Nb tunnel junction	12/2007	
Balanced SIS Mixer Development		
1. Complete first balanced SIS mixer with superconducting IF hybrid	09/2007	
2. Complete first balanced sideband-separating mixer	03/2008	
Other Mixer Development		
1. 385–500 GHz SIS mixer Development	12/2007	

Electromagnetics

The CDL is responsible for most of the Observatory's electromagnetic development. In FY 2007 we designed and tested several new components for the EVLA, GBT, and ALMA.

Accomplishments and Highlights in FY 2007

A prototype of a new ALMA holography feed was designed and measured. This feed will be used in the holography receiver for measuring ALMA antennas at 79 and 104 GHz. It is designed to provide flatter amplitude and phase patterns than an earlier feed. The far-field patterns of two sets of the 79 GHz and 104 GHz ALMA holography feeds were measured in the Green Bank indoor anechoic range. The illumination taper at the edge of the main reflector of the ALMA antenna for the feeds varies between −7.5 dB and −8.0 dB. The maximum phase variation across the reflector is ±7.5º.

Design of the EVLA 12–18 GHz feed was completed. Analysis shows the feed has an average illumination taper of −12 dB at the edge of the subreflector and a return loss better than −25 dB in the 12–18 GHz band, which meets EVLA requirements.

The development of a dual-frequency 345/800 MHz prime-focus feed for the GBT is in progress. An existing 600 MHz short-backfire antenna feed was configured to model the new 345 MHz and 800 MHz feeds. Measurements of these configurations showed that the gain/system temperature of the dual-band feed varied between 0.5 and 1 compared to the single-band feed at 345 MHz and between 0.55 and 0.73 at 800 MHz. Further work is required to improve the performance of the dual-band feed.

Figure F. 2.4. EVLA 2–4 GHz feed under test at the outdoor antenna test range at the AOC.

Development work on the EVLA 2–4 GHz feed was completed. A scaled version of the EVLA 4–8 GHz feed for 2–4 GHz would result in an aperture diameter of 44 inches for the 2–4 GHz feed, which would not fit in the available space. A new feed design with an aperture diameter of 42 inches was developed and evaluated. The measured patterns agree with theory, and the illumination taper is −12.8 dB at the edge of the subreflector. Cross-polarized sidelobes are below −27 dB. The measured return loss is −19 dB at 2.0 GHz and better than −30 dB for frequencies above 2.2 GHz. The photos above show the feed being tested at the outdoor antenna range at the Array Operation Center (AOC) in Socorro, NM.

The first design of a corrugated rectangular K-band prototype phase shifter, a scaled version of the W-band phase shifter, did not meet specifications over the intended 17.0–25.0 GHz (75–110 GHz) band. The W-band phase shifter of this design has corrugations with slot width 0.009 inches on one set of walls. A new W-band design with slot width 0.005 inches was completed. A picture of the mandrel of the 75–110 GHz phase shifter is shown below. Analysis with Microwave Studio predicts a differential phase shift of 90° ± 4° over the 75–110 GHz band. Prototypes at K band and W band will be fabricated and measured to check the design.

Figure F.2.5. Mandrel of the 75–110 GHz phase shifter with vane thickness 0.005 inches machined in the NTC machine shop. After electrodeposition of a thick copper layer, the mandrel will be dissolved, leaving in place its 3-dimensional negative.

VSWR measurements were performed on the production feeds for the EVLA Ka band (26–40 GHz) front ends. The return loss is better than –25 dB on all 27 feeds that were measured.

S. Srikanth presented a paper titled "A New Broadband Short-Backfire Antenna as a Prime-Focus Feed: Single and Dual Band" at the IEEE AP-S International Symposium 2007 in Honolulu, HI.

Electromagnetic Support Milestones

Item	Date Planned	Date Accomplished
1. Measure the 79 /104 GHz ALMA holography feeds	06/2007	05/2007
2. Design the EVLA 12–18 GHz feed	06/2007	04/2007
3. Develop a dual-band 345/800 MHz feed for the GBT	09/2007	
4. Build and measure the EVLA 2–4 GHz feed	07/2007	06/2007
5. Prototype, fabricate, and measure a 75–110 GHz phase shifter at 17–25 GHz	09/2007	

Green Bank Solar Radio Burst Spectrometer (GB/SRBS)

The Green Bank Solar Radio Burst Spectrometer (GB/SRBS) is an instrument for detecting solar radio emissions with sufficient temporal and spectral resolution to probe a wide variety of active solar phenomena at the base of the corona. It consists of radio spectrometers that provide continuous frequency coverage from 10–2500 MHz. It provides a basic research tool in solar radiophysics for use by the wider community, remedies the lack of an important component of the U.S. Space Weather effort, and provides a platform for research and development work on broadband antennas, feeds, and receivers needed for new instruments such as the Square Kilometer Array (SKA) and the Frequency Agile Solar Radiotelescope (FASR).

Accomplishments and Highlights in FY 2007

The completed GB/SRBS has been in full operation since early FY 2007. The system is in routine operation over the frequency range 10–1000 MHz using an analog spectrometer. Data continue to be archived in Charlottesville. Research to improve the bandwidth and noise performance of the feed/amplifier system continues for application to FASR. A major upgrade to the GB/SRBS has also been completed. The low-frequency antenna work has been delayed until fall 2007.

Green Bank Solar Radio Burst Spectrometer (GB/SRBS) Phase III Milestones

Item	Date Planned	Date Accomplished
1. 10–80 MHz, dual polarization, four crossed dipoles, new digital spectrometer*	09/2005	
2. 80–300 MHz, dual polarization, log-periodic on 45-foot telescope, new digital spectrometer*	11/2006	01/2007
3. 300–2500 MHz, dual polarization, 45-foot telescope with log-periodic feed, new digital spectrometer*	11/2006	01/2007

Note:
* A new digital spectrometer will extend the range to 2500 MHz. The prototype is complete and construction of field units is pending upgrade funds.

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

This is a collaborative project of the NRAO CDL, the UVa Astronomy Department, and the Radio Astronomy Laboratory at UC Berkeley to measure the predicted step in the cosmic background amplitude caused by neutral hydrogen at the Epoch of Reionization. A prototype array has been deployed in Green Bank and a larger version is being planned for Western Australia.

Accomplishments and Highlights in FY 2007

Work on PAPER is in progress. A fully operational eight-element full-Stokes array was successfully deployed at the Green Bank Galford Meadow site in mid-August 2006. It consists of eight portable sleeved-dipole elements on ground screens that are connected to a central correlator via coaxial cable. The dipoles, active baluns, transmission-line drivers, and receivers were developed by students at the NRAO–UVa Instrumentation Program. The size of the Western Australia array has been increased to 32 elements. Initial deployment of a 4-element pathfinding array in Western Australia began in July 2007. Deployment of the entire 32-element array is scheduled for December 2007.

Precision Array to Probe the Epoch of Reionization (PAPER) Milestones

Item	Date Planned	Date Accomplished
1. Eight element full-Stokes array in Green Bank	06/2006	08/2006
2. Major upgrade to instrumentation subsystems	07/2007	05/2007
3. 16-element prototype array operating in the 100–200 MHz band in Green Bank	10/2007	
4. 4-element pathfinding array in Western Australia	07/2007	07/2007
5. 32-element array in Western Australia	12/2007	

Electrochemistry Laboratory

In FY 2007 the Electrochemistry Lab plated approximately 210 grams of gold in support of ALMA construction, amplifier production, and various GBT projects. That represents a gold value of about $4200 and an estimated job cost of $65,000 if done commercially.

Development work is progressing on new electroforming techniques to be used for more than 250 waveguide components for the EVLA. Demonstration pieces have been completed that indicate electroforming on aluminum mandrels with pressed-in copper structures will be possible. A new alkali copper process has been added, aiding in the production of high-quality electroformed components. A number of complex electroformed pieces have now been completed, with excellent results. Regular production jobs have included electroforming microwave components, internal waveguide plating, plating amplifier and mixer bodies, and plating the usual assortment of mounting plates, brackets, and straps. Items have been supplied to all NRAO sites and projects, including ALMA.

G. New Initiatives

G.1. The Square Kilometer Array (SKA)

Accomplishments and Highlights in FY 2007

The revised U.S. work plan for the SKA Technology Development Program (TDP) was negotiated within the U.S. SKA Consortium, including its two NRAO members, and submitted to the National Science Foundation (NSF) in January 2007. The NRAO is an unfunded collaborator in this work plan. The NSF notified the PI at Cornell University that the proposal would be funded for four years at a level of approximately $12 million, compared to the request for $19 million spread over five years. The proposers were requested to emphasize Work Package 1, focusing on the cost and performance of antennas, feeds, and receivers, instead of Work Package 2, the overall systems work. An agreement was reached regarding the nature of NRAO work cooperating with the TDP team in areas such as improvement of the noise performance of wideband receivers.

The European radio-astronomy community submitted the "PrepSKA" proposal for SKA infrastructure and system development to the Seventh Framework Programme (FP7) funding opportunity within the European Community. The PrepSKA proposal was for funding at a level of about 9 million Euros, comparable to the funding awarded for the U.S. TDP proposal. PrepSKA focuses on overall system design for the SKA by means of a Central Development and Integration Team to be hosted at the University of Manchester. The NRAO participated in face-to-face meetings and telecons for the preparation of the PrepSKA proposal, which is intended to interact closely with the TDP proposal as well as various meter/centimeter interferometers presently under development in Australia, South Africa, the Netherlands, and the U.S.. The European team has been notified that PrepSKA was evaluated very highly, and final funding negotiations are in progress.

NRAO technical development has focused on ALMA and the EVLA Construction Project. The EVLA is a clear technical and scientific pathfinder for the SKA, especially in the areas of signal transmission, local-oscillator system design, and wide-field broadband imaging. Therefore NRAO participation in the SKA program during the year emphasized programmatic development. Two scientists represent the NRAO in the U.S. SKA Consortium; one is the Vice Chair of the International SKA Steering Committee (ISSC) and the other was elected to an unexpired ISSC term during the year. NRAO staff members have participated in various working groups and committees of the international SKA project as well as in the preparation of the new agreements for the operation of the SKA Project Development Office (SPDO) and for the relationship between the SPDO and the host institute at the University of Manchester. An important programmatic accomplishment is a growing international consensus that the SKA is a "program" rather than as a single monolithic telescope, and that the high-frequency component of the SKA (from a few GHz to 25 GHz) is likely to be developed and constructed somewhat later than the low-frequency (below 300 MHz) and mid-frequency (300 MHz to a few GHz) components. In September 2007 the NRAO co-sponsored a meeting on the implementation plan for the SKA, with a primary goal of developing a U.S. consensus view that can be presented to the U.S. decadal review committee.

The NRAO participated in review-committee meetings for the NASA Deep Space Network "Analysis of Alternatives" (including a large number of ~12m antennas as the preferred alternative) and the Mileura Widefield Array; both of these initiatives have potential impact on the scientific and technical development of the SKA.

G.2. Space VLBI

Accomplishments and Highlights in FY 2007

The second Japanese Space VLBI project, VSOP–2 (Astro-G) was approved by the Japanese Aerospace Exploration Agency (JAXA) in FY 2006 and confirmed in FY 2007, with launch scheduled for 2012. A key component of VSOP–2 is the development of a tracking-station network to downlink data at 1 Gbps and to supply an accurate clock and local oscillator for the spacecraft. NRAO efforts focused on participation in four technical meetings to produce a common design for stations to be developed by all international agencies, in contrast to the VSOP mission that included five tracking stations of three different designs. The last of these meetings was hosted by NRAO in Green Bank in August 2007.

A network of at least four tracking stations is desirable, including two each in the Northern and Southern Hemispheres. The nominal plan includes a station in Japan, one in Spain built around the old Yebes 14m telescope, and Southern Hemisphere stations at sites most likely located in Chile, South Africa, or Australia.

NASA released a draft Research Announcement for Small Explorer proposals in June 2007. It includes provisions for proposing for Mission of Opportunity (MoO) support for participation in a non-US-led mission. This is likely to be one of two primary avenues by which NRAO can participate in VSOP–2, since the NRAO is not otherwise funded for either tracking-station construction or VLBA operations. In particular, the science return of VSOP–2 will be reduced drastically if the VLBA cannot participate. In FY 2007 the NRAO and JPL combined to form a VSOP–2 Proposal Working Group in order to develop the MoO proposal, and the first teleconferences were held to communicate with that working group.

The Russian Radioastron Space VLBI mission has again been advertised for launch in 2008. In view of Radioastron's inability to maintain announced launch dates, a very high orbit that makes scientific imaging unimpressive, and a lack of funding for participation, the NRAO has participated only informally by attending several teleconferences and by consulting with the Radioastron team regarding postprocessing software.

G.3. VLBA Partnerships

Accomplishments and Highlights in FY 2007

The NSF Senior Review report released late in FY 2006 recommended developing external funding sources for the VLBA to cover approximately half of its direct operating costs by 2011. Responsibility for developing these VLBA partnerships was transferred to the New Initiatives Office early in FY 2007. The Space VLBI work described above is part of one such partnership, as are the agreements with the GLAST mission and the MPIfR 22 GHz collaboration, both described in the VLBA section. Discussions were held with other potential partners, including NASA Headquarters, various NASA missions, the U.S. Naval Observatory, the European VLBI Network, and Swinburne University in Australia.

G.4. The Long Wavelength Array (LWA)

Accomplishments and Highlights in FY 2007

First funding for developing the Long-Wavelength Array (LWA) for radio astronomy and ionospheric research was received by the University of New Mexico (UNM) in FY 2007. The LWA, planned to

operate from 10 MHz to 88 MHz, involves a consortium including the UNM, U.S. Naval Research Laboratory, University of Texas at Austin, and Los Alamos National Laboratory. The NRAO acts as a host for the predecessor Long-Wavelength Development Array (LWDA) at the VLA site and participates in various LWA planning groups. NRAO development work for the LWDA and LWA largely consists of infrastructure support at the VLA site, with costs reimbursed by UNM. In FY 2007 a 16-antenna LWDA station made its commissioning observations and produced a 24-hr movie of the sky at 80 MHz. Observations also were made with a single antenna 300 meters from this 16-antenna station, using the longer baseline to reduce source confusion. Tests of many LWDA components for possible RFI were carried out in the NRAO interference test facility at the VLA. LWA personnel monitored several locations at or near the VLA site for freedom from external RFI, and they are currently focusing on a location near the end of the VLA North arm as a possible site for the central core of the future LWA.

G.5. The Frequency Agile Solar RadioTelescope (FASR)

Accomplishments and Highlights in FY 2007

Funding for design and development of FASR was received from the NSF Atmospheric Sciences (ATM) division in late FY 2006. The FASR Operations and Maintenance Plan was developed to clarify the long-term costs of operating this new facility. In support of this study, the FASR Reference Instrument was defined and a Software and Data Management Plan was developed. The FASR Operations and Maintenance Plan was reviewed and accepted by the NSF in June 2007.

A Letter of Intent was signed in 2007 that forms the FASR Consortium. The Consortium is a partnership of the AUI, NRAO, and several university partners, including Caltech (the proposed site of the instrument), the New Jersey Institute of Technology, the University of Michigan, UC Berkeley, and the University of Maryland. The Consortium will be responsible for construction of the instrument, with the NRAO playing the role of managing partner.

The project is moving forward with design and prototyping, preliminary site evaluation, and preparation of a detailed plan for construction. We expect to submit the construction proposal to the NSF in FY 2008.

H. Community Support Programs

H.1. Scientific Community Outreach

The Office of Science and Academic Affairs (SAA) focuses on activities that provide services to the wider astronomical community outside the NRAO, with the goal of fostering a strong U.S. radio community. These activities include research programs to employ undergraduates (NSF REU program and engineering co-op students), graduate students (Junior Fellows), and PhDs (Jansky Fellows, NRAO Postdoctoral Fellows, and Research Associates). The SAA also manages the peer-review process for the allocation of observing time on all NRAO telescopes. As part of this process, funding is provided for travel to the telescope, student research support, and computing and page-charge support. In addition to these activities, a healthy and active U.S. radio community is supported though the funding of University-led hardware and software projects, NRAO staff community service, and the organization of science meetings. SAA milestones for FY 2007 are listed below.

Mission Activity	FY 2007 Completed Milestones	Date Accomplished
Undergraduate Programs	Research programs for 22 summer students (6-Socorro, 6-GB, 10-CV)	08/2007
Undergraduate Programs	Engineering Co-op Students (3-Socorro, 1-GB, 1-CV Pre-Undergrad)	09/2007
Graduate Programs	Supported 7 Pre-doctoral Fellows	09/2007
Graduate Student Research support	Increased funding and eligibility for student observing support program.	10/2006
Graduate Student Research support	Created new graduate student internship program for short visits.	10/2006
Postgraduate Programs	New hires and continuation of Jansky Postdoctoral Fellows Program	03/2007
Oversight of the NRAO proposal review & the telescope time assignment process.	Large or Legacy-type Proposal Call for all of NRAO telescopes.	05/2007
Oversight of the NRAO proposal review & the telescope time assignment process.	Increased outside membership on the VLA/VLBA Scheduling Committee	01/2007
Oversight of the NRAO proposal review & the telescope time assignment process.	Updated policy for PhD students	05/2007
Scientific Meetings	New Mexico Symposium	10/2006
Scientific Meetings	2007 NRAO Postdoctoral Symposium	04/2007
Scientific Meetings	NRAO 50th Anniversary Symposium	06/2007
Scientific Meetings	From Disks to Stars and Planets	06/2007
Scientific Meetings	2007 NAIC/NRAO Single Dish School	07/2007
Outside Scientific Visitors	Supported seven short-term or sabbatical visitors.	09/2007

H.2. Spectrum Management

Internationally, the spectrum manager participated in ITU–R activities leading up to WRC07, including meetings of Working Party 1A (spectrum engineering) and Study Group 1 (spectrum management), WP7D (radio astronomy), and SG7 (science services) as well as the Conference Preparatory Meeting. ITU–R adopted an NRAO-originated Recommendation on sharing between radio astronomy and earth-exploration satellites at 94 GHz and a revised Question on the effects of wireless power transmission. The spectrum manager participated in meetings of IUCAF and CRAF, respectively the international (ICSU-sponsored) and European (ESF) groups representing radio astronomy, and served as English-language editor for the CRAF newsletter.

Closer to home, the spectrum manager participated in domestic ITU–R support groups, attended meetings of the NAS Committee On Radio Frequencies and the National Spectrum Managers Association, lectured at "Spectrum Management for National Defense," and organized a session on RFI excision for the North American URSI meeting in Ottawa. The NRAO filed comments in four FCC dockets on topics ranging from tank level penetrating radar at 80 GHz to the use of Ku-band uplinks by vehicle-mounted earth stations. The spectrum manager assists New Mexico personnel in coordinating the use of 611 MHz medical telemetry devices in hospitals around the Iowa VLBA antenna and advises Green Bank personnel on reformulating NRAO policy for supporting local compliance with the West Virginia Zoning Act.

H.3. Education and Public Outreach (EPO)

The Education and Public Outreach (EPO) Division communicates what the Observatory does and why it is important via a wide range of programs, activities, press releases, and publications that feature NRAO science and technology. The target audiences are the scientific community, the media, and the public. The EPO Division collaborates with the E2E Operations and Science and Academic Affairs divisions to improve the impact and visibility of the NRAO in the scientific community. The EPO Division also seeks to improve scientific understanding and literacy among the public, and to improve awareness and understanding of the NRAO mission and science in the media.

Astronomical Community

EPO represented the NRAO at science-community meetings and completely redesigned the Observatory's exhibits so that they better convey our science and technology. The NRAO participated for the first time as an exhibitor at an IAU General Assembly (Prague, August 2006). NRAO exhibits also brought the Observatory's science and technology to the Seattle (January 2007) and Honolulu (June 2007) AAS meetings, the NRAO 50th anniversary science conference (June 2007), and the NAASC workshop (June 2007). EPO organized the NRAO Town Hall at the winter AAS meeting.

ALMA EPO

An ALMA EPO Working Group was organized by the NRAO to foster international collaboration between the Executives and the JAO, define a global ALMA EPO program, and provide ALMA EPO oversight. The NRAO chaired this Working Group and organized face-to-face meetings in Prague (August 2006), Madrid (November 2006), and Tokyo (May 2007), and bi-weekly telecons. ALMA EPO communication and cooperation have been established. The NRAO wrote the ALMA EPO Development Plan that provides a vision and path for a coordinated international program, and it contributed to the Policies & Procedures document. The international and North American ALMA brochures were revised and widely distributed. The NRAO initiated a program to document ALMA via high-definition video, filming the first VertexRSI antenna's transport to the OSF (March–Apr 2007). A video teaser was produced and presented at the Honolulu AAS meeting, and it has been widely distributed. EPO is writing a script for a longer ALMA video of broader scope that targets the public and the media.

Online Outreach / WWW

EPO and the E2E Operations Division initiated a project to design and implement a more organized, attractive, and accessible NRAO web presence. Initial design contracts were let for web design, and an alpha demo site that will include a new home page, observer/science pages, and EPO pages is in preparation. A WWW content position is being added to the EPO staff.

Chile

EPO helped organize and lead, with the AUI/NRAO Chile office, an AUI-funded *Sister Cities* educational and cultural exchange program connecting Magdalena, NM and San Pedro de Atacama, Chile. This program brought the teachers and students of these communities together for new learning opportunities in culture, language, and science. The communities and schools in both hemispheres enthusiastically embraced these opportunities. Two Chilean teachers and the San Pedro Mayor visited New Mexico for two weeks in Jan–February 2007, participating in classes, community events, and field trips. Magdalena teachers visited San Pedro de Atacama for two weeks in July 2007.

Sergio Cabezon, a journalist with extensive experience relevant to the NRAO mission in Chile, was hired into the AUI/NRAO Santiago office full-time in May. Cabezon's responsibilities include documenting ALMA, improving the NRAO's visibility with the Chilean public and media, promoting AUI/NRAO in Chile, organizing events, assisting with the redesign of the NRAO Chile website, coordinating NRAO EPO activities in Chile with ESO and the JAO, and assisting with media coordination for the international astronomy seminar being organized by the Chilean Foreign Ministry.

Agreements with astronomy departments at the Universidad de Chile and U. Catolica were drafted and reviewed, and they are now being extended to include the engineering departments. These agreements enable academic bi-directional visits of students, postdoctoral fellows, and faculty between the U.S. and Chile, and they provide Chilean astronomers access to facilities and use of the NRAO ARC, schools, and symposia. The engineering component of these agreements is increasingly relevant as both universities are developing PhD programs in astronomical instrumentation. The agreements with both universities will be ready for the NRAO Director's signature in September.

Image Contest

The 2006 AUI/NRAO Image Contest yielded several visually compelling science images for EPO publications. The 2007 Image Contest is underway; EPO is proactively contacting and encouraging submitters.

News / Media

The NRAO has distributed 18 press releases to date in FY 2007. Nine of these described scientific research results. The GBT, VLA, and VLBA were featured in 3, 6, and 2 of these releases, respectively. (Some press releases described research conducted with multiple NRAO telescopes). Other releases described major technical achievements, such as first fringes with the ALMA prototype antennas, and non-research news, such as the 2007 Jansky Lectureship. EPO also produced and distributed local releases describing, e.g., the VLA public tours and the Charlottesville Open House. EPO initiated discussion with NSF–OLPA about hosting joint press conferences at the NSF or the National Press Club in Washington D.C.

Education

Three-day intensive residential Chautauqua programs took place in Green Bank and Socorro this summer, continuing a 20-year NRAO tradition of serving undergraduate science faculty. The weeklong Education Research in Radio Astronomy (ERIRA) workshop also returned this summer to GB. ERIRA is a cooperative effort of the NRAO, the University of Chicago, and the University of North Carolina that provides tours and observing projects for high school and undergraduate students. The West Virginia Governor's School for Math and Science was hosted in GB again in 2007, providing an in-depth research experience for sixty rising 8th graders, encouraging their interest in science, technology, engineering, and mathematics careers. A one-week NASA-funded teacher institute was held in July, this program's fifth year and the 21st consecutive year of K–12 teacher professional development at NRAO. The *StarQuest* star party continued as an annual Green Bank event with 160+ attendees. GLOBE (Global Learning and Observations to Benefit the Environment) is a worldwide hands-on K–12 school-based science and education program that debuted at Green Bank in 2007. GLOBE students, teachers, and scientists collaborate on inquiry-based investigations of the environment and contribute scientific measurements to an international database. The core teacher-program experience in Green Bank is scientific research on the 40-foot telescope. Student programs are often overnight or multi-night visits on-site. More than 2,000 students have taken part in the Green Bank education programs in the past year. Two teachers from the

2006 Research Experiences for Teachers (RET) program presented their research at the January AAS meeting in Seattle.

The *Navigators* program trains volunteers from the Society of Amateur Radio Astronomers to bring engaging presentations about science, radio astronomy, and the NRAO to school and civic groups in their home communities. EPO is conducting a pilot *Navigators* program and is seeking grant funding to significantly expand this program's reach and impact.

With funding by the Corporation for Public Broadcasting, EPO developed 26 three-minute radio shows titled *Cosmic Radio* that are being marketed nationwide. Each program is supported by content and background on the WWW.

Publications

A new full-color NRAO brochure for the public was published in December 2006. This popular brochure is an effective vehicle for communicating the NRAO mission and science to a wide range of audiences. EPO updated the ALMA, EVLA, GBT, and VLBA brochures for the astronomy community and published a popular high-quality 2007 NRAO calendar that showcases the AUI/NRAO Image Contest prizewinners. Two new full-color large-format science posters were published for the January 2007 AAS meeting to serve the educators attending this joint meeting with the American Association of Physics Teachers (AAPT). To improve communication with the scientific community, the January 2007 Newsletter was distributed to all AAS individual and institutional members.

Science and Visitor Centers

44,570 persons visited the Green Bank Science Center in 2006, and the number of visiting school groups increased. Revenue increased by 11%. The NRAO convened a panel of tourism and marketing professionals in February to evaluate the Center's marketing efforts and offer recommendations for updating our marketing plan. The panel recommended that Green Bank Science Center marketing focus on the group travel market and the captive audience. A new marketing campaign has been developed to reflect this focus, and an advertising grant proposal was submitted to the West Virginia Tourism Commission to support a campaign targeting school groups, the commercial group-travel market, and the captive audience of visitors traveling to Pocahontas County. The VLA Visitor Center saw 19,674 visitors in 2006, and revenue increased by 13.3%. EPO is revising its marketing plan for the VLA Visitor Center and will review its plans to fund and build a more capable and attractive visitors facility at the VLA. EPO is working with the University of Virginia to develop plans for a Charlottesville-based Science Center and assisted with a major private fund-raising event in May.

Community Relations

The 2nd annual NRAO Charlottesville Open House on November 5, 2006 was attended by more than 900 members of the public, including many educators and young people. Ninety NRAO staff, family, and community volunteers donated their time. Scientific and EPO staff volunteered to judge science fairs and provide science class presentations in Socorro, Magdalena, Green Bank, and Charlottesville. A poster and lecture series at the New Mexico Tech Library last fall celebrated the NRAO 50th anniversary, as did our participation in *Cosmic Carnival*, a joint Astronomy Day event with the Albuquerque Astronomical Society.

EPO Milestones for FY 2007

Item	Date Planned	Date Accomplished
1. New NRAO public brochure available	05/2006	12/2006
2. NRAO Newsletter to printer (October 2006 issue)	09/2006	09/2006
3. Announce AUI/NRAO Image Contest winners	10/2006	10/2006
4. Complete Sister Cities agreement	11/2006	11/2006
5. Science Bowl 2006 (Green Bank)	11/2006	11/2006
6. NRAO Community Open House (Charlottesville)	11/2006	11/2006
7. ALMA EPO Working Group face-to-face meeting (Madrid)	11/2006	11/2006
8. Select two images for poster production	11/2006	11/2006
9. Complete NRAO exhibit redesign	12/2006	12/2006
10. Virtual pressroom operational	12/2006	11/2007 est.
11. Publish NRAO 2007 calendar	12/2006	12/2006
12. NRAO Newsletter to printer (January 2007 issue)	12/2006	12/2006
13. Two new posters complete	12/2006	12/2006
14. Submit VLA Visitor Center proposal to New Mexico Legislature	01/2007	01/2008 est.
15. Announce 3rd annual AUI/NRAO Image Contest	01/2007	01/2007
16. Initiate *Cosmic Radio* distribution	02/2007	10/2007 est.
17. VA Piedmont Regional Science Fair (Charlottesville)	03/2007	03/2007
18. NRAO Newsletter to printer (April 2007 issue)	03/2007	03/2007
19. Complete ALMA EPO Development Plan	03/2007	03/2007
20. Complete two new large-format color posters	04/2007	12/2007 est.
21. EPO / PR position in Chile filled	05/2007	05/2007
22. ALMA EPO Working Group face-to-face meeting (Tokyo)	05/2007	05/2007
23. Complete WWW Project Plan	05/2007	05/2007
24. Submit Pulsar Search Collaboratory proposal to NSF	05/2007	05/2007
25. Complete ALMA high-definition video teaser	05/2007	05/2007
26. AAS meeting exhibition (Honolulu, HI)	05/2007	05/2007
27. RET participants arrive (Green Bank)	06/2007	06/2007
28. Sister Cities program visits Magdalena, NM	06/2007	01/2007
29. Submit proposal for new VLA outdoor exhibits	06/2007	06/2007
30. Chautauqua (Green Bank)	06/2007	06/2007
31. Educational Research in Radio Astronomy (Green Bank)	06/2007	06/2007
32. Sister Cities program visits San Pedro de Atacama, Chile	06/2007	06/2007
33. NRAO Newsletter to printer (July 2007 issue)	06/2007	07/2007
34. Society of Amateur Radio Astronomers (Green Bank)	07/2007	07/2007
35. StarQuest IV Star Party (Green Bank)	07/2007	07/2007
36. Chautauqua (Socorro)	07/2007	07/2007

Item	Date Planned	Date Accomplished
37. NASA/NRAO Joint Institute (Green Bank)	07/2007	07/2007
38. GLOBE workshop (Green Bank)	07/2007	07/2007
39. WV Governor's School for Math & Science (Green Bank)	07/2007	07/2007
40. GEAR UP Camp (Green Bank)	08/2007	08/2007
41. IAU Commission 55 Communicating Astronomy with the Public conference	09/2007	
42. ASP EPO Conference	09/2007	
43. Submit NRAO image for the 2008 AAS calendar	09/2007	
44. Produce NRAO/Radio Astronomy *ViewSpace* program	09/2007	
45. 3rd annual AUI/NRAO Image Contest deadline	09/2007	

Notes:
1. Completing the new brochure required significantly more iterations with the graphic designer and printer than had been expected.
10. The Virtual Pressroom will go live with the new EPO website in fall 2007.
16. *Cosmic Radio* distribution begins 10/2007.
20. Images will be selected for new posters from the 2007 AUI/NRAO Image Contest prizewinners.
22. This ALMA EPO Working Group meeting was held immediately prior to the ALMA Science Advisory Committee meeting where the ALMA EPO Development Plan was briefed and discussed.
23. This WWW Project is a collaboration of the EPO and E2E divisions.
28. The Sister Cities program was able to start much more quickly than had been expected.
29. The proposal for new outdoor exhibits at the VLA has been deferred to early 2008.
41. The IAU CAP 2007 meeting will define the International Year of Astronomy–2009 program and is being held October 8–11, 2007 in Athens.
44. Higher priorities at the NRAO and STScI have delayed the start of this task to spring 2008.

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.

During the fiscal year, the OBS division enhanced its business model by extending its offerings in all areas with the emphasis on providing more capabilities to the customer base and thus elevating the level of administration support across the Observatory. The OBS division has made significant strides in all functional areas with specific advancements detailed below.

Budget & Business Analysis

During FY 2007 the multi-year budgeting and staffing process began with forecasts of FY 2008 and FY 2009 budgets and initial staffing plans for the ALMA and EVLA construction projects. To strengthen budget-analysis activities, the NRAO is transitioning from secure shared-server budget development and change-tracking applications using Excel-based spreadsheets to a web-based Microsoft FRx software application. By tying general-ledger-based transaction detail to budget forecasts, the FRx software gives budget managers and business managers a more robust forecasting and analysis tool to support budget stakeholders.

Models were developed for rapid recalculation of the Indirect Cost rate, Management Fee allocations, and Direct Allocation Cost reallocations to react in a timely manner to budget scenarios. The use of the JD Edwards financial-reporting application data was extended through the generation of standard data output sets utilizing the Data Access Studio capability. These internally developed report formats effectively speed data-analysis processing and the importing of key data elements into higher-level models.

Contracts & Procurement

Efforts continue to ensure a high level of communication and service between the NRAO procurement staff and ALMA construction management and IPTs, NSF Program Directors, and the NSF Division of Acquisition and Cooperative Support staff. In addition, the NRAO introduced on-site training for procurement, import/export, and contracting to improve end-user knowledge, reduce processing time, and increase transparency in the procurement process. We have recently hired a Senior Contracts & Procurement Manager to enhance collaboration and oversight of the ALMA and EVLA procurements in FY 2008.

Procurement activity—FY 2007 presented continued challenges for the procurement staff in terms of procurement complexity and an increase in the number of user-generated requirements. Total procurement activity is projected to increase by 23% over FY 2006, including an 8% increase in purchase orders and a 54% increase in credit-card volume.

Career-path development—To better serve its customers and provide a more coherent buyer career path, Contracts & Procurement established a career-development matrix. Combining education benchmarks, practical experience, and certification goals, the matrix provides the procurement staff with a clear, written explanation of development and advancement expectations. This allows Contracts & Procurement management to focus constrained training resources where they can best serve the needs of the individual and Observatory alike.

Grants Administration

The rise in the number and complexity of grants has led to establishing one full-time equivalent position to administer the non-programmatic funded grants received by the Observatory as well as grants made by the Observatory. With one person fully dedicated to grants administration, Observatory Business Services can devote more attention to processing, budgeting, and tracking grants through their lifecycles.

In order to promote a more seamless administrative environment, OBS staff members have realigned some of their position tasks to better utilize their skills sets and experience. The combination of changes in the division of labor and additional training has given us the ability to provide a backup person for nearly every task performed within the division. This ensures that administrative tasks can be attended to during periods when primary staff members are away on travel, training, illness, or vacation.

Charlottesville Facilities

Edgemont Road

Hydronic piping system replacement—The Edgemont Road facility underwent a much-needed full system replacement. Key among the eight-month project tasks was the replacement of the 40+ year-old hydronic piping, 61 wall-mounted fan coil units, and the two penthouse air-handling units.

Office and workspace renovations—As part of the hydronic piping project, the aged grid ceiling had to be damaged or destroyed in areas where ceiling access was necessary. This afforded an opportunity to update the existing ceilings with a newer and more flexible lay-in ceiling system. At the same time, we renovated twenty-eight offices by repairing walls, painting, and replacing carpet, where appropriate. Dilapidated soundproofing materials were removed and walls were repaired in the server room.

Student rooms—To improve the summer-student education experience at the NRAO headquarters, we renovated and reconfigured two large offices. Old metal desks and wooden desks were replaced with ergonomically designed furniture to provide large horizontal work surfaces at the correct height for computer keyboards and flat-screen displays.

NRAO Technology Center (NTC)

Electronic access-control system—The access-control system installed at the NTC provides 24-hour access control to the exterior of the facility and selected interior labs. It is compatible with systems already installed at the Edgemont Road facility and the Socorro Array Operations Center.

Central fire detection and reporting system—This system detects, announces, and reports suspected fires and water intrusion via local alarms and phone-based alerts. An important feature of the system is the ability to notify key managers and technicians of after-hours situations that require immediate attention to avert system or facility damage.

Facility upgrades—To accommodate the increased power load requirements of the Front End Integration Center a number of upgrades were made at the NTC:

- Rework of selected power distribution panels
- Installation of an additional 200 amp 480 volt line and disconnect
- Large-scale uninterruptible power supply for the two 50 KW motor generators.

Grinding Shop exhaust system—A fan, hood, and related ductwork were installed to remove potentially harmful airborne particulates generated from grinding and cutting operations.

Human Resources Overview

The Human Resources 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**.**

The 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 a global organization. NRAO's new HR Manager is leading this change by focusing his staff on specific HR work and developing their knowledge and skills. His effort also demonstrates HR's support of NRAO's Diversity Plan since his staff is composed primarily of females and minorities.

Human Resources Information Systems

The Human Resources Information System (HRIS) provides the resource to meet the Observatory's informational needs. Last year saw the successful implementation and staff training of the PeopleSoft system. Future efforts will include refinements of the Employee Self-Service module and implementation of an electronic timekeeping (ETK) system.

In support of ALMA, the HR Division assisted the JAO Human Resources staff in selecting an HRIS system to support the employment of Chilean local staff. In an effort to build understanding and support from NRAO staff in related functional areas, the HR Manager is opening lines of communication between employees who support NRAO's HRIS system (PeopleSoft) and ALMA's (Meta4).

Compensation and Benefits

The 2007 salary benchmarking report confirmed that more than half of NRAO employee salaries fall below market by more than ten percent, which data have been discounted by 5% on the assumption that salaries are lower for employers in Charlottesville, Green Bank, and Socorro. Although we must be concerned with limited budget increases in managing employee salaries, salary compression is eroding the NRAO's ability to attract and retain qualified employees. In trying to keep NRAO grade structures in line with budget pressure from NSF, salary grades have been increased by a fraction of the amount recommended by the compensation consultants. This has also contributed to the salary compression problem.

NRAO's growth into the international market with ALMA is driving the need to hire more employees from major metropolitan areas that have the skills required to succeed. NRAO also faces compensation and benefit pressure from ESO in hiring international staff members and getting our employees to work in Chile for short- and long-term assignments.

The new human resources manager has begun taking action to reverse this trend by focusing more on competitive market salaries for new hires, employee promotions, and salary actions. He will be hiring a senior compensation analyst beginning in fiscal year 2008 to help develop and execute a strategy to establish competitive compensation programs and process for the Observatory.

The benefits plans of the Observatory continue to be strong recruitment and retention tools. The strength of the benefits program has helped offset NRAO's below-market compensation. In recent years the NRAO initiated a four-tier premium schedule for the employee portion of the medical insurance plan. The goal was to give employees a stake in medical-plan cost management and redistribute the medical-insurance cost burden based on salary level. This action also placed more pressure on NRAO's compensation compression since it lowered employee take-home pay.

Employment

The employment function is undergoing a significant change in HR to support the growing demand for services. The demand for technical and scientific staff, diversity hiring, and supporting the ALMA hiring

ramp-up can no longer be a part of one's job in HR. Roy Norville will be dedicating all of his time to employment along with Fonda Bryant, who will devote the majority of her time to employment matters.

Although hiring is the primary objective in employment, it is critical that NRAO and JAO employment policies, procedures, and processes are documented and communicated. This includes working with SAA on developing and documenting the processes and procedures for hiring Scientific Staff, assignment of duties, annual performance review, and periodic review for promotion. This is a major goal for HR employment from the NRAO Director.

Limited staff resources in HR make it a challenge to accomplish the above goals and will require thought and action to improve efficiency in the hiring process and find alternative means of support. The outsourcing of NRAO's Affirmative Action Plan in 2007 was one such step that can be replicated. A major improvement would be moving from a paper-driven employment process to one that is electronic. This requires an ongoing investment in technology and will be continuously pursued by HR to find a means of bringing such a system to the NRAO and possibly ALMA.

Diversity

The NRAO Diversity Plan was developed in July 2007 and includes goals for the remainder of 2007 and 2008. The HR Division will play a key role in advancing the plan throughout the Observatory. The Diversity Committee's membership was expanded to improve geographic and demographic diversity. The Committee met in June and will meet every quarter to assist in furthering the implementation of the Plan.

Training and Development

In support of NRAO's Diversity Program, the HR Division will make training an active part of its operations. Pending the availability of funds, NRAO plans to deliver the following training in fiscal year 2008: employment practices and law for supervisors, sexual-harassment prevention training (mandatory), diversity awareness for all employees, leadership development for senior management, and to support professional membership and certification for the employees.

The NRAO Director has also established the goal of collaborating with SAA in the development of a knowledge-transfer program that supports senior members of the Scientific Staff training and mentoring junior staff members.

ALMA/Chilean HR

The hiring of Joanna MacKenzie (JAO HR Manager) and Pamela Rivera (JAO Senior Human Resources Representative) has provided NRAO HR with the experience and knowledge needed to provide the JAO with the strong HR presence it had lacked. HR's biggest challenge in the coming year is to support the ALMA hiring ramp-up in Chile. To meet this challenge, Joanna MacKenzie will be given authority and oversight in Chilean HR operations, where appropriate, to improve efficiency. NRAO HR will provide oversight and support for these operations. NRAO's HR Manager will provide the oversight.

Management Information Systems (MIS) Division Overview

The FY 2007 accomplishments include completing the deployment and maintenance plans for the Web-Based Business Systems (WBBS) program. The implementation of these business services (payroll, general ledger, employee self-service, human resources, procure-to-pay) with supporting hardware began

in November 2004, and all high-priority systems with the exception of electronic timekeeping were complete by August 2006.

For the WBBS initiative, the NRAO completed service reviews and trouble-ticket processing last year to improve Procurement Service, Payroll, and Human Resources as our highest-priority service drivers. The WBBS architecture upgrade progressed according to schedule and required transition from proprietary hardware and databases to industry-standard Intel/Windows computing platforms.

As part of the above migration, Administration assumed responsibility for Management Information Systems in December 2006. This included overall management for the long-term operations and maintenance of the WBBS after disbanding the Program Management Office. We stabilized operations and maintenance costs by hiring on-site J. D. Edwards support staff and establishing a short-term contract for CNC hardware maintenance.

Fiscal Division Overview

The NRAO has continued efforts to maintain a solid financial and reporting system that exceeds all internal and external audit requirements. In an environment of increasing financial complexity and audit overview, the NRAO made excellent progress towards improving electronic processing and maintaining financial data integrity during the current fiscal year.

Progress toward FY 2007 Program-Plan Objectives

The NRAO established added training and education to ensure stability and maturity associated with the newly implemented Web-Based Business System that includes a new JD Edwards Payroll module. Added review and cost/benefit analysis will be devoted to determining the efficiency of printing payroll checks and year-end W-2 Statements in-house versus contracting for such services.

The NRAO implemented detailed policies and procedures to safeguard and accurately report the financial assets to include Work-in-Process (WIP) efforts during the past fiscal year. In addition, revisions to the travel manual to include locality-based per diems and an update to the Procurement Manual were completed and await NRAO management and AUI review/approval.

The NRAO completed its first Procurement Card audit via the NRAO/AUI Internal Audit plan to evaluate and improve the effectiveness of our risk management and controls. Management will continue to pursue efforts for risk assessment and vulnerabilities to determine audit areas for the future.

Environment, Safety & Security Overview

Environmental Protection

In the past year, ES&S focused efforts on replacing waste-oil tanks at both the Socorro and Green Bank facilities. This effort addressed findings of the environmental audit. In Socorro, ES&S led the efforts to complete a site-wide asbestos survey to identify and ultimately manage the asbestos materials in place.

Safety in the Workplace

Revision of the Observatory Occupational Safety Program began in FY 2007 to clarify the roles and responsibilities of all affected personnel at every level and to provide safety education and awareness training appropriate to the level of the employee. Currently the manual is scheduled for completion at the

end of FY 2007. The manual details the requirements for compliance with OSHA regulations. In FY 2007 ES&S initiated an employee safety committee for the Charlottesville site. This committee has proven beneficial in identifying employee concerns as well as playing an active role in the implementation of the new smoke-detection and alarm system. ES&S continued to support the ALMA project with System Safety reviews and participated in the acceptance and verification process for antenna components.

Secure Facilities

As part of the ES&S objectives to protect staff and visitors and to preserve personal and government property from damage or loss, ES&S has assisted in the installation of a card-access system at the NTC. This system eliminates the need for exterior door keys and is completely compatible with the existing card-access system implemented at Edgemont Road.

I.2. Computing and Information Services (CIS)

Accomplishments and Highlights in FY 2007

Security

There were four security incidents during FY 2007; all were localized and there were no serious consequences. Two NRAO staff members attended the NSF summit on security. In response to some widely publicized (external) incidents where personal data were lost or stolen, a data-security policy was developed and adopted.

Common Computing Environments

Completion of the on-line hardware and software inventory was a major step forward. It facilitated the upgrade of commodity computer hardware, and it has been an effective tool for containing the costs of commercially licensed software.

The new Windows operating system (Vista) was introduced during the year. We must plan the migration to the new architecture carefully to ensure that we can provide assistance and that critical third-party software is available. Although we are actively involved in evaluating Vista, we have adopted a moratorium on its introduction within the NRAO until we are more fully prepared.

Networking and Telecommunications

The communication link between the VLA and the AOC was upgraded to provide enhanced support for EVLA development. The link between NRAO Charlottesville and the UVa connects the NRAO to the wide-area backbones; it also carries GBT data to the community. This link was successfully upgraded. A further enhancement has been delayed by the UVa.

Several network improvements were made in Green Bank. The Ethernet switch and associated cabling were upgraded in the Science Center. The network bandwidth to the 140ft (43m) telescope was upgraded to 1 Gbps. The upgrade of network infrastructure on the GBT concludes a two-year effort to upgrade and modernize the whole campus network, including the replacement of all of the 10-year-old Ethernet switches.

Video

A new video hub was deployed and used successfully to provide video for the 50th Anniversary celebrations, including live video of the ribbon cutting at Chajnantor. This hub will enable us to offer additional video communication services both within the NRAO and between the NRAO and its construction partners.

CIS Milestones for FY 2007

Item	Date Planned	Date Accomplished
1. Increase network connectivity in Charlottesville	10/2006	10/2006
2. Increase network connectivity between Socorro and the VLA	12/2006	11/2006
3. Deploy the inventory database of computer equipment [a]	10/2006	12/2006
4. Adopt a data-security policy [b]	10/2006	04/2007
5. System administrators meeting in Green Bank [c]	04/2007	08/2007
6. Upgrade of the central disk filer in Socorro [d]	04/2007	09/2007
7. Decision on unified login profiles	01/2007	02/2007
8. Install network monitor	12/2006	12/2006
9. Deploy Symantec Anti-virus 10	12/2006	12/2006
10. Authenticated outgoing mail	12/2006	12/2006
11. Install service-interruption notification facility in Charlottesville	01/2007	01/2007
12. Upgrade Exchange Server	04/2007	04/2007
13. Moratorium on deployment of Vista adopted	04/2007	04/2007
14. Upgrade of networking in Green Bank Science Center	04/2007	04/2007
15. Deploy video hub	06/2007	06/2007
16. Upgrade network to 140ft telescope to 1 Gbps	07/2007	07/2007
17. Appointment of webmasters	07/2007	07/2007
18. Deployment of new GBT network infrastructure	09/2007	09/2007
19. Acquisition of modern network switch on GBT	09/2007	09/2007
20. New VPN concentrator available	09/2007	09/2007

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

a) The facility was essentially ready as predicted but not completely available for general use.
b) Delayed awaiting administrative approval.
c) Delayed by conflicting priorities and schedules of many individuals. The meeting did go ahead as planned.
d) Delays caused by incorrect delivery and acceptance issues with the hardware.

Appendix

Acronym	Definition
AAPT	American Association of Physics Teachers
AAS	American Astronomical Society
AAT	Archive Access Tool
ACA	Atacama Compact Array
ACU	Antenna Control Unit
AIPS	Astronomical Image Processing System
AIV	Assembly, Integration, and Verification
AIVC	Assembly, Integration, Verification, and Commissioning
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
ASIAA	Academica Sinica Institute of Astronomy and Astrophysics
ASP	Astronomical Society of the Pacific
ATF	ALMA Test Facility
ATM	Atmospheric Sciences (NSF division)
ATNF	Australia Telescope National Facility
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 8	385–500 GHz
Band 10	787–950 GHz
BDF	Binary Data Format
BE	Back End
BR	Brewster, NH (VLBA station)
C-band	4–8 GHz
CAP	Communicating Astronomy with the Public (IAU)
CASA	Common Astronomy Software Applications
CASPER	Center for Astronomy Signal Processing and Electronics Research (Berkeley)
CDL	Central Development Laboratory (Charlottesville, VA)
CDR	Conceptual Design Review
CfA	Center for Astrophysics
CICADA	Configurable Instrument Collaboration for Agile Data Acquisition
CIPT	Computing Integrated Product Team (ALMA)
CIS	Computer and Information Services
CNC	Configurable Network Computing
CRAF	Committee on Radio Astronomy Frequencies

Acronym	Definition
CSV	Commissioning and Science Verification (ALMA)
CV	Charlottesville
CXC	Chandra X-ray Center
CY	Calendar Year
DAL	Data Access Language
DSN	Deep-Space Network (NASA)
DTS	Digital Transmission System
E2E	End-to-End
EPO	Education and Public Outreach
ERIRA	Education Research in Radio Astronomy
ES&S	Environment, Safety, and Security (NRAO)
ESF	European Science Foundation
ESO	European Southern Observatory
ETK	Electronic TimeKeeping
EU	Europe
EVLA	Expanded Very Large Array
FASR	Frequency-Agile Solar Radiotelescope
FD	Fort Davis, TX (VLBA station)
FE	Front End
FEIC	Front-End Integration Center
FPGA	Field-Programmable Gate Array
FRM	Focus Rotation Mount
FRx	Microsoft Financial Reporting software
FTE	Full-Time Equivalent
FY	Fiscal Year
G	Gauss
GaAs	Gallium Arsenide
GALEX	Galaxy Evolution Explorer (ultraviolet observatory)
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
GHz	Gigahertz
GLAST	Gamma-ray Large-Area Space Telescope
GLOBE	Global Learning and Observations to Benefit the Environment
Gsps	Giga samples per second
HBT	Heterostructure Bipolar Transistor
HEMT	High Electron-Mobility Transistor
HFET	Heterostructure Field-Effect Transistor
HI	Neutral Hydrogen
HR	Human Resources
HRIS	Human Resources Information System
HST	Hubble Space Telescope
HVAC	Heating, Ventilation, and Air Conditioning
IAU	International Astronomical Union
ICSU	International Council for Science
IF	Intermediate Frequency

Acronym	Definition
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
I(V)	Current I as a function of Voltage V
IVN	International VLBI Network
IVOA	International Virtual Observatory Alliance
JAO	Joint ALMA Office
JAXA	Japanese Aerospace Exploration Agency
K	Kelvins (temperature)
K-band	18–26.5 GHz
Ka-band	26.5–40 GHz
keV	kilo electron-Volt
Ku-band	12–18 GHz
KVA	KiloVolt Ampere
KW	KiloWatt
L-band	1–2 GHz
LAT	Large-Area Telescope (GLAST)
LNA	Low-Noise Amplifier
LO	Local Oscillator
LORR	Local-Oscillator Reference Receiver
LWA	Long-Wavelength Array
LWDA	Long-Wavelength Development Array
M&C	Monitor and Control
MHz	Megahertz
mm	Millimeter
MMIC	Monolithic Microwave Integrated Circuit
MoO	Mission of Opportunity
Mpc	Megaparsec
MPIfR	Max Planck Institut fűr Radioastronomie
ms	millisecond
μm	micrometer
MUSTANG	Multiplexed SQUID/TES Array for Ninety Gigahertz
Mux	Multiplexer
NA	North American / Not Applicable / Not Available
NAASC	North American ALMA Science Center
NAOJ	National Astronomical Observatory of Japan
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
Nb	Niobium
NbTiN	Niobium Titanium Nitride
NCAT	North Carolina Agricultural and Technical State University
NCSA	National Center for Supercomputing Applications
NCSSM	North Carolina School of Science and Mathematics
NGAS	Next-Generation Archive System

Acronym	Definition
NGST	Northrop Grumman Space Technology
NINS	National Institute of Natural Sciences (Japan)
nm	nanometer
NRAO	National Radio Astronomy Observatory
NSF	National Science Foundation
NTC	NRAO Technology Center (Charlottesville)
NVO	National Virtual Observatory
OBS	Observatory Business Services
OCI	Office of Cyber Infrastructure (NSF)
OLPA	Office of Legislative and Public Affairs
OMT	Orthomode Transducer
OPS	Operations
OPT	Observation Preparation Tool
OSHA	Occupational Safety and Health Administration
OSF	Operations Support Facility (ALMA)
OST	Observation Scheduling Tool
OV	Owens Valley, CA (VLBA station)
OWG	Operations Working Group
P-band	327 MHz
PAARE	Partnerships in Astronomy & Astrophysics Research and Education (NSF)
PAPER	Precision Array to Probe the Epoch of Reionization
PC	Personal Computer
PDR	Preliminary Design Review
PI	Principal Investigator
PLC	Programmable Logic Controller
PMCS	Project Management Control System
PPDR	Pre-Production Design Review
PR	Proposed Recommendation, Public Relations
PSC	Proposal Selection Committee
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
ROSAT	Roentgen Satellite (X-ray observatory)
rsync	software that synchronizes remote data sets
S-band	2–4 GHz
SAA	Science and Academic Affairs (NRAO division)
SDM	Science Data Model
SAGE	Science Advisory Group for the EVLA
SC	Saint Croix, VI (VLBA station)
SE&I	System Engineering and Integration
SED	Spectral Energy Distribution

Acronym	Definition
SG	Study Group
SIA	Simple Image Access
SIAP	Simple Image Access Protocol
SiGe	Silicon/Germanium
SINGS	Spitzer Infrared Nearby Galaxies Survey
SIS	Superconductor–Insulator–Superconductor
SKA	Square Kilometre Array
SPDO	SKA Project Development Office
SSA	Simple Spectral Access
SSC	Spitzer Science Center
SSS	Science Support System
STScI	Space Telescope Science Institute
TB	Technical Building (ALMA), TeraByte
TDP	Technology Development Program (SKA)
TFB	Tunable Filter Bank
THINGS	The HI Nearby Galaxy Survey
TRR	Test Readiness Review
U-band	12–18 GHz
UAZ	University of Arizona
UNM	University of New Mexico
UPS	Uninterruptable Power Supply
URSI	International Union of Radio Science
UVa	University of Virginia
UVML	University of Virginia Microfabrication Laboratory
VCO	Voltage-Controlled Oscillator
VDC	Volts, Direct Current
VERTEX	VertexRSI (antenna supplier)
VLA	Very Large Array
VLBA	Very Long Baseline Array
VLBI	Very Long Baseline Interferometry
VO	Virtual Observatory
VPN	Virtual Private Network
VSOP	VLBI Space Observatory Program
VSOP–2	VSOP successor
W-band	68–117 GHz
WBBS	Web-Based Business Systems
WBS	Work Breakdown Structure
WIDAR	Wideband Digital Interferometric Architecture (EVLA correlator)
WIP	Work In Progress
WRC07	World Radio Conference 2007
WWW	World-Wide Web
X-band	8–12 GHz
YTO	Yig-Tuned Oscillator