# The NRAO Annual Progress Summary

# FY 2009


*December 2009*

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# FY 2009 Annual Progress Summary

At the writing of this document, the FY 2009 is complete. This summary gives a brief description of activities that have been reported in the Quarterly Status Updates (QSU) for FY 2009 Quarter 1 (Q1), Quarter 2(Q2) and Quarter 3 (Q3), and Quarter 4 (Q4) spanning October, 2008 through September, 2009. For detailed descriptions of the activities in these quarters, please review the Q1 Quarterly Report and the Q2-4 annotated briefings submitted as Interim Reports to NSF.

In Q2, all reporting documentation was restructured significantly. This impact of the changes affected the Strategic Plan, the Long-Range Plan, Program Plan, Quarterly Reports, and the Annual Progress Report. The changes also added requirements for a Workforce Management Plan and a focus throughout all the documents on infrastructure maintenance and renewal activities at each of the sites. These changes in format and content were put in place to provide a better executive overview, and to allow a more iterative process between the NRAO, AUI and NSF. The changes also focused on providing an integrated view of all the NRAO activities.

As a result of the documentation and date modifications, an update to the Annual Progress Report (this document), which is meant to report activity done on behalf of the Program Plan FY 2009, will be provided concurrently with the Quarterly Status Update Q4 annotated briefing to NSF.

## Science Highlights

A number of significant and stimulating scientific results have been obtained in FY 2009 by observers using the NRAO telescopes. These include the following:

### Very Large Array (VLA)

***VLA, Effelsberg Detect Most Distant Water in Universe:*** Thanks to the effect of a gravitational lens, researchers were able to detect water-maser emission in a quasar at redshift $z = 2.64$, the most distant water yet detected. The initial detection was made using the 100 m Effelsberg telescope. The VLA then was able to detect the water emission in two of the four lensed images of the quasar, confirming that the emission was indeed coming from it. This detection implies that giant water masers may have been more common in the early universe than today. Curiously the object, MG J0414+0534, is a Type 1 quasar seen nearly face-on, implying that the masers may be located in the jet rather than in the disk of the system.

*Investigators: C.M. Violette Impellizzeri, J.P. McKean, A.L. Roy, C. Henkel, and A. Brunthaler (MPIfR); P. Castangia (MPIfR and INAF, Italy); and O. Wucknitz (Argelander-Institut für Astronomie, Bonn).*

***Black Holes Grow Before Galaxy Bulges:*** Early studies of galaxies and their central black holes in the nearby Universe revealed an intriguing linkage between the masses of the black holes and of the central "bulges" of stars and gas in the galaxies. The ratio of the black hole and the bulge mass is nearly the same for a wide range of galactic sizes and ages. For central black holes from a few million to many billions of times the mass of our Sun, the black hole's mass is about one one-thousandth of the mass of the surrounding galactic bulge. This study measured black-hole and bulge masses in several galaxies seen as they were in the first billion years after the Big Bang.

*Investigators: C. Carilli (NRAO), D. Riechers (Caltech), F. Walter (MPIfA), F. Bertoldi (Bonn), K. Menten (MPIfR); P. Cox and R. Neri (IRAM).*

***First Detection of the Zeeman Effect in a 36 GHz Methanol Maser:*** New science capabilities have already been enabled by the EVLA 26-40 GHz receivers. Total of 15 now installed. First detection of the

Zeeman effect in 36 GHz methanol maser- Star-forming region M8E; Line of sight magnetic field: Blos = 31mG. Field is dynamically significant.
*Investigators: A. P. Sarma (DePaul) and E. Momjian (NRAO).*

***Discovery of the Radio Afterglow from the Most Distant Cosmic Explosion:*** Gamma Ray Burst source GRB 090423 has redshift z = 8.3. This GRB is the most distant known object in the Universe. Radio afterglow detected by the VLA; data combined with X-ray and IR data. No conclusive evidence was found to identify the GRB progenitor as a Population III star
*Investigators: P. Chandra (RMC, Canada); D. Frail (NRAO); D. Fox (PSU); S. Kulkarni (Caltech); E. Berger (Harvard); S. B. Cenko (UC Berkeley); F. Harrison (PSU); M. Kasliwal (PSU).*

**Very Long Baseline Array (VLBA)**

***Direct Distance Measurement to a Galaxy in the Hubble Flow:*** The NRAO's Megamaser Cosmology Project, utilizing the VLBA, the GBT, and the Effelsberg telescope, has produced the first direct, geometric distance measurement to a galaxy within the Hubble Flow. This is an important stepping stone toward improving the accuracy of the Hubble Constant to a level sufficient to constrain models of Dark Energy. Multi-year observations of the maser disk in the core of UGC 3789 yielded a geometric distance of 50 Mpc, currently accurate to within 17 percent. Further work will improve the accuracy of this measurement. UGC 3789 is seven times more distant than NGC 4258, the first galaxy whose distance was measured by the maser technique with the VLBA in 1999.
*Investigators: J Braatz (NRAO); M. Reid (CfA); C. Kuo (UVa), K.Y. Lo (NRAO); C. Henkel (MPIfR); I. Zaw (NYU); and A. Tilak (CfA).*

***Milky Way Rotating Faster, More Massive, VLBA Astrometry Shows:*** A long-term VLBA project to map the Milky Way by observing water masers in star-forming regions showed that the Galaxy rotates 15% faster at the solar circle and is 50% more massive than previously believed. This makes the Milky Way as massive as the Andromeda Galaxy. Precision VLBA maps of the spiral-arm pitch angles support a four-arm, rather than a two-arm, structure for the Galaxy. The increased mass raises the likelihood of collisions with other galaxies in the Local Group in the future.
*Investigators: M. Reid (CfA) and K. Menten (MPIfR).*

***Progress in Measurements of the Gravitational Bending of Radio Waves Using the VLBA:*** VLBA used at 43, 23, and 15 GHz to measure gravitational bending of 4 radio sources by the Sun. Independent measurement of PPN $\gamma$ parameter. Separate systematic errors compared to earlier measurements. Measure $\gamma = 0.9998 \pm 0.0003$ (68% confidence level). Agreement with GR prediction $\gamma = 1$. Further improvements to method by factor of ~ 4 possible. Other measurements of $\gamma$ have claimed somewhat higher precisions than this result, but there have been questions about the magnitude of their systematic errors. This approach does not suffer from those errors, and produces a total error of a few parts in ten thousand. Published in Ap.J. 699, 1395 (2009).
*Investigators: E. Fomalont (NRAO), S. Kopeikin (Missouri), G. Lanyi (JPL), J. Benson (NRAO).*

**Green Bank Telescope (GBT)**

***The kinetic temperature of a molecular cloud at redshift 0.9: ammonia in the gravitational lens PKS 1830–211****:* The molecular cloud at $z$ = 0.9 seen in absorption against the radio source PKS1830−211 is the most distant known that can be studied in detail. GBT observations in ten absorption lines of ammonia show that it is not a dark cloud like Taurus, as previously proposed, but is more like the molecular cloud near Sgr B2 near the nucleus of our Galaxy. The absorbing gas is warm: most is around 80 K, but some has a temperature greater than 600 K. This cloud is unique in having a warm, extended, low-density molecular envelope in a spiral arm 4 kpc from the nucleus.
*Investigators: C. Henkel (MPIfR), J.A. Braatz (NRAO), K.M. Menten (MPIfR), & J. Ott (NRAO/CSIRO), 2008.*

***Probing a New Domain in AGN Jet Physics:*** A long-standing problem in AGN physics is that the radiative lifetimes of the synchrotron-emitting electrons are significantly shorter than the time required for these electrons to travel down the jets, where they are observed. The presumption is that some mechanism re-accelerates the particles far from the galactic nucleus. This mechanism might be observable as a variation in spectral index along the jet emission, but this requires measuring the jet at widely spaced frequencies with good angular resolution and high sensitivity, an observational feat that was difficult to accomplish in the past. With the availability of the MUSTANG bolometer array on the GBT, however, it is now possible to acquire sensitive images at 90 GHz with 8.5 arcsec angular resolution. MUSTANG has recently been used to observe two AGN, M87 and Hydra A, and make a comparison with archival VLA data acquired at lower frequencies. The results suggest that the M87 jet shows only small spectral changes along its length providing little evidence of electron aging. The spectrum is curved everywhere, however, indicating a complex history of electron energetics. The Hydra A spectrum, however, shows dramatic changes with position suggesting that particle acceleration slows or stops fairly early in the jet. Hydra A also has a curved spectrum, however, suggesting a similarly complex history of particle loss and resupply.
*Investigators: W. Cotton and B. Mason (NRAO); S. Dicker, P. Korngut, M. Devlin, and J. Aquirre (UPenn); D. Benford, H. Moseley, and J. Staguhn (NASA-GSFC); K. Irwin (NIST), and P. Ade (Cardiff Univ.), submitted to ApJ arXiv:0902.3149.*

***A survey of $C_6H^-$ and $C_6H$ in Carbon Chain Sources in the Galaxy***: The recent discoveries of three carbon chain anions ($C_4H^-$, $C_6H^-$, and $C_8H^-$) in space indicate that large carbon chain anions may be significant reservoirs of negative charge in the interstellar gas. We propose a search for the most conspicuous molecular anion, $C_6H^-$, and its parent radical $C_6H$, in 13 sources to better understand the distribution of this anion and to investigate new sources of long carbon chains and their anions in the Galaxy.
*Investigators: Gupta (Univ. of Texas), H., Gottlieb, C.A., McCarthy, M.C. and Thaddeus (Harvard-Smithsonian CFA and School of Engineering & Applied Sciences, Harvard Univ), P. 2009 ApJ 691, 1494.*

***A Radio Pulsar/X-ray Binary Link:*** Every century several supernova occur in the Milky Way, and one of their products should be young neutron stars. Some fraction of these ought to be visible as radio pulsars, and we expect that there is a total population of several hundred young radio pulsars in the Galaxy. To date, however, only a dozen pulsars with a characteristic age less than 10,000 years have been found, and fewer than 20 pulsars have a firmly-established connection with a supernova remnant (SNR). The recent discovery using the GBT of a pulsar at the center of a SNR is therefore of particular interest, especially as the pulsar has the second-largest known spin-down luminosity (second only to the Crab pulsar) and the SNR is less than one degree from the Galactic Center. The pulsar is visible as a hard X-ray source, and its energy loss is sufficient to power the SNR, which is bright in both the radio and the X-ray. The pulses are highly dispersed, consistent with a location of the SNR at the Galactic

center or somewhat beyond. Considerations of the nebular structure and energetics suggest that the SNR and pulsar have an age of 2-3 thousand years.
*Investigators: Investigators: A. M. Archibald (McGill University), I. H. Stairs (University of British Columbia; Australia Telescope National Facility), S. M Ransom (NRAO), V. M. Kaspi (McGill University), V. I. Kondratiev, D. R. Lorimer, M. A. McLaughlin, J. Boyles, (West Virginia University; NRAO), (West Virginia University; NRAO), J. W. Hessels, J. van Leeuwen (Netherlands Institute for Radio Astronomy; Astronomical Institute Anton Pannekoek), R. Rynch (University of Virginia), M. S. Roberts (Eureka Scientific), F. Jenet (University of Texas, Brownsville), D. J. Champion (ATNF; CSIRO), R. Rosen (NRAO), B. Barlow, B. Dunlap (University of North Carolina, Chapel Hill), R. Remillard (Massachusetts Institute of Technology)*

***Discovery of the Energetic Pulsar J1747–2809 in the Supernova Remnant G0.9+0.1:*** A pulsar recently discovered with the GBT seems to be the first example of this process observed at the important transition between accretion and emergence of the pulsar. The star that is the pulsar's companion was observed to flicker rapidly and have optical behavior typical of an accretion flow. However, since 2002 the star has been in a quiescent state. The discovery of the pulsar by the GBT provides quantitative information on the system and suggest that it is just emerging from the accretion event. Even now, some gas from the star occults the pulsar, giving further evidence that material is still being stripped from the companion star, though at a lower rate than before. This system will allow detailed tests of theories of pulsar and stellar evolution, and may be the missing link in our understanding of milli-second pulsars.
*Investigators: Camilo (Columbia Astrophysics Laboratory), S. M. Ransom (NRAO), B. M. Gaensler (Sydney Institute for Astronomy), D. R. Lorimer (West Virginia University, Morgantown).*

***Discovery of Three Pulsars from a Galactic Center Pulsar Population****:* We report the discovery of three pulsars whose large dispersion measures (DMs) and angular proximity to Sgr A* indicate the existence of a Galactic center population of neutron stars. The relatively long periods (0.98-1.48 s) most likely reflect strong selection against short-period pulsars from radio-wave scattering at the observation frequency of 2 GHz used in our survey with the Green Bank Telescope. One object (PSR J1746–2850I) has a characteristic spindown age of only 13 kyr along with a high surface magnetic field ~4 × 1013 G. It and a second object found in the same telescope pointing, PSR J1746–2850II (which has the highest known DM among pulsars), may have originated from recent star formation in the Arches or Quintuplet clusters given their angular locations. Along with a third object, PSR J1745–2910, and two similar high-dispersion, long-period pulsars reported by Johnston et al., the five objects found so far are 10-15 arcmin from Sgr A*, consistent with there being a large pulsar population in the Galactic center, most of whose members are undetectable in relatively low-frequency surveys because of pulse broadening from the same scattering volume that angularly broadens Sgr A* and OH/IR masers.
*Investigators: Deneva, J. S.; Cordes, J. M.; Lazio, T. J. W.*

***90 GHz Observation of M87 and Hydra A:*** New observations of the active galactic nuclei M87 and Hydra A at 90 GHz made with the MUSTANG array on the Green Bank Telescope at 8.″5 resolution. A spectral analysis is performed combining this new data and archival VLA7 data on these objects at longer wavelengths. This analysis can detect variations in spectral index and curvature expected from energy losses in the radiating particles. M87 shows only weak evidence for steepening of the spectrum along the jet suggesting either re-acceleration of the relativistic particles in the jet or insufficient losses to affect the spectrum at 90 GHz. The jets in Hydra A show strong steepening as they move from the nucleus suggesting unbalanced losses of the higher energy relativistic particles. The difference between these two

sources may be accounted for by the lengths over which the jets are observable, 2 kpc for M87 and 45 kpc for Hydra A.[1]
*Investigators: Cotton, Mason (NRAO), Dicker, Korngut, Devlin, and Aquirre (UPenn), Benford, Moseley, and Staguhn (NASA-GSFC), Irwin (NIST) and Ade (Cardiff Univ.) submitted to ApJ arXiv:0902.3149*

## Observatory Science Operations

Science operations at the NRAO have been largely distributed between the telescope sites until late FY 2009, while some distributed functions have been managed under the Office of End-to-End Operations (E2E). During the first two quarters of FY 2009 the NRAO began planning the transition to an integrated Observatory Science Operations (OSO) organization which is expected to begin operation in FY 2011. A number of OSO sub-working groups were set up in Q2 that were charged with planning the scope of OSO, and implementing a transition strategy between previous science operations and OSO-based science operations. E2E support activities were included among the sub-working groups. During this period of transition to the new organization, E2E will continue as an organization and business unit. In Q4, the organizational structure for OSO within the overall NRAO structure was developed and discussed at the September Assistant Director's face-to-face retreat, resulting in an agreement for the framework of the implementation plan.

During the fiscal year there were several enhancements made to the proposal submission system, including the addition of referee management capabilities and the development of a system-level Application Programming Interface (API) to enable other NRAO software systems to communicate with the proposal system. In Q4, modifications to the Proposal Submission Tool for the first call for EVLA proposals at the October 1, 2009, proposal deadline include enabling reviewers to submit their reviews through the NRAO User Portal rather than via the disparate methods currently employed for the different NRAO telescopes/sites. This new feature will be tested in-house by NRAO staff for EVLA technical reviews in FY 2010 Q1.

The Science Web sub-working group began work on a new web environment that serves as an entry point for critical observing and proposal information for the user community. The Statistics and Metrics working group completed their survey of potential metrics to track, and completed the down-selection to the highest priority ones that will be routinely reported. The implementation of the collection of the new set of metrics into a dashboard will begin in FY 2010 Q4.

In Q4, the OSO Archive & VAO working group continued to make progress in defining the operational requirements for EVLA, GBT and ALMA within the framework of the Archive and VAO strategy. A total of eight archive servers (80TBytes total) have been ordered and received in Socorro to initiate the migration of data from the current servers to NGAS, the ALMA-compliant archive system and now NRAO standard. NRAO applied for, and received a TeraGrid Resource Allocation for compute and storage to evaluate GBT data on September 14, 2009.

In the Science Operations area, two CASA tutorials in Europe were supported (see ALMA Science Operation for additional tutorial information). The Kayako helpdesk was configured in preparation for in-house testing by NRAO staff, based on interactions with the Spitzer and Herschel Observatories, which also use this helpdesk system. It will initially be used for dealing with tickets involving EVLA Observation Preparation, AIPS, and CASA. Testing will begin in FY 2010 Q1. The working group is also evaluating how the NRAO helpdesk will interface with the international ALMA project. Development of

[1] The Astrophysical Journal **701** (2009) 1872

the user portal awaits hiring of an applications developer. Interviews continue for the position. NRAO decided in Q4 to adopt PLONE for the user portal development environment, for synergy with the ALMA archive and other tools.

The Data Processing working group reported that the CASA development was complete to deploy the first production (post-beta) release in Q1 FY 2010. CASA software developments for release version 3.0 included: development of the Science Data Model to Measurement Set filler for both ALMA and the EVLA; improvements in the ALMA data simulator; a generic calibration value application task to provide post-observing corrections to applied values (like clock offsets); imaging support for flanking fields and imaging in non-LSRK velocity frames; improvements to the interactive flagging/visibility plotting GUI tool and the non-interactive flagging tool; interactive specification of regions of interest (e.g., polygons) using the Viewer GUI; investigation of support of the updated MacOS 10.6 operating installation for the release.

## Atacama Large Millimeter/submillimeter Array

Prior to the second quarter, the Atacama Large Millimeter/submillimeter Array (ALMA) quarterly activity was reported directly to the Joint ALMA Office (JAO) and the National Science Foundation (NSF). From the beginning of the second quarter, the activities were reported both to the JAO/NSF, and through the NRAO quarterly reports in order to provide an integrated picture of the NRAO activities.

A major NSF North American (NA) ALMA Schedule Review was held in July. The scope of the review was the prominent components of the U.S.-funded receiver system - specifically the Band 6 receivers, other front-end components, the NA front-end integration center, back-end photonic system - and the Vertex antennas. By agreement with the Herzberg Institute of Astrophysics (HIA) of the National Research Council of Canada, information regarding the Band 3 receivers was provided by HIA and was also included in this schedule review. The review focused on the schedule of NA deliverables and the North America contingency given the schedule, budget, risks and forecast liens on contingency.

In Q4 the results of the NSF NA ALMA Schedule Review was published. It concluded that "The ALMA NA management team is highly capable and taking the appropriate steps to complete their work scope within the approved total project cost…." The final review document is available at: *http://staff.nrao.edu/wiki/pub/ALMA/NSFReview2009-07-15/ALMA_Report0721Changed.pdf.* The first pass of the cost-to-complete exercise is planned for Q1 2010 (October 21-24) at the Management IPT Meeting in Charlottesville, VA.

Site: During this fiscal year, invitations for bid for Array Operations Site (AOS) infrastructure (roads and utilities) work at the AOS have finished successfully. Grading of the central cluster has been completed. The AOS Roads construction contract was awarded and the kick-off meeting with the contractor took place in early July. The AOS utilities (installation of Fiber Optic (FO) and electrical cables) bidding process concluded and is awaiting approval. In Q4, the AOS Roads and Utilities Contracts were approved by the NSF, awarded and the work is under way. These contracts will install the power and fiber optic lines to all antenna stations at the AOS. The contract for the procurement of FO cables was approved and fabrication of the cables has started. These will be delivered in Q1 of FY 2010, on time for the first milestone in the Utilities Contract (Dec 2009).

The first antenna station, pad A106 (close to the AOS Technical Building), was finished and the first antenna transported to the AOS was installed on it on September 17, 2009. The AOS Technical building acceptance has been granted in August 2009; only the JAO's final signature of acceptance is pending.

Antenna: The ALMA Antenna IPT reported that a conditional acceptance agreement for the first and second Vertex antenna were signed, Antennas #1 and #2 were relocated to the Operations Support Facility (OSF), and that the Assembly Integration and Verification (AIV) team completed integration of the Front End and Back End electronics on Antenna #1. On Antenna #2, the all sky pointing was accepted fully since the new tilt meters allow the specified two-second settling time to be met. The main conditional acceptance clauses are completion of the maintenance verification (planned to be done shortly on unit DV04), offset pointing & tracking, and acquisition of more data on the surface to allow a better extrapolation of the data to the most extreme cold temperatures that antennas will face.

On September 29, 2009 the third Vertex antenna was conditionally accepted and was relocated to the OSF Technical Facility. Submission of the test report and request for full JAO acceptance of the Vertex antenna surface error requirement is expected in Q1 FY2010 (October 2009). NRAO and Vertex agreed that Antenna 8 would be outfitted with the additional temperature sensors desired for further investigations of the surface accuracy vs. temperature performance. However, because of the success with holography experiments on Antenna 3 and the excellent analysis and modeling performed, it is not expected that a special holography campaign will have to be performed on Antenna 8. Instead, this antenna is expected to go through AIV test and integration where the surface will be set using the standard AIV process. Vertex antenna 1 will be moved to the AOS in early Q1 (October) to allow AIV to continue to move forward toward meeting their goal of three antennas at the AOS by the end of the calendar. ALMA succeeded in placing the first antenna at the AOS on September 17, 2009, which is the first step towards achieving phase closure before the end of calendar year 2009.

The Maintainability Verification Testing on antenna 4 was completed in August. The outcomes primarily required revisions to the maintenance procedures and are being closed out by Vertex. It is expected this will be fully complete by November 2009. The first optical pointing telescope underwent Preliminary Acceptance In-House (PAI) in Tucson and is now in Chile for acceptance testing.

Front End: Milestones in 2009 included the Preliminary Acceptance In-house (PAI) for the eighth Band 6 cartridge delivery (SN10) and the Band 3 Manufacturing Readiness Review (MRR; held 2/12/09). In addition, the Operational Readiness Review (ORR) of the NA Front End Integration Center (NA-FEIC) was held in Charlottesville, April 16–17, 2009. The procurement of an additional front-end test set will allow Band 6 production to increase its throughput to meet the target of completing all cold cartridges by the end of 2011. However, the cross polarization performance of the cartridges still does not meet the specification. In the interim it was agreed until July to continue to accept cartridges with a waiver on the cross polarization requirement and to plan to retrofit once the issue is understood. Testing of Band 6 cartridge SN11 was completed. The first phase of the automated Warm Cartridge Assembly noise test software was also completed. This reduces the test time for one key test from four hours to forty minutes and will relieve a great deal of pressure on the test facilities.

In Q4, acceptance testing for the second NA FE began, and beam scans for all 4 bands were completed. The Project Management Control System (PMCS) team and the Regional Project Managers and IPTs are working to resolve issues related to the shortage of subassemblies and components to be delivered to the FEICs. Their status is continuously monitored and corrective actions are requested. Assembly and upgrade of the FEIC's second Intermediate Frequency (IF) Processor chassis is complete, and integration of the test racks for the second test system has begun. When completed early in 2010, this will significantly increase the throughput of the NA FEIC and provide backup in case of equipment problems.

Also, in Q4 a major breakthrough in Band 6 mixer yield occurred with the determination that the production batch of commercial IF hybrids were of a modified design which did not work properly at cryogenic temperatures, and this was causing nearly half of the tested mixers to be rejected for poor image separation. A new design IF hybrid which works properly when cooled has greatly increased acceptance, so that the rate of mixer production appears to be no longer an issue. The procurement of an additional cartridge test set for Band 6 will allow the increase of its throughput to meet the target of completing all cold cartridges by the end of 2011. The cross polarization performance of the cartridges still does not meet the specification. Investigation of this continued with verification of the test system on a standard gain horn and measurement of Band 6 horns manufactured to the same print by different fabricators. In the interim it has been agreed to continue to accept cartridges with a waiver on the cross polarization requirement and to plan to retrofit once the issue is understood. Eleven Band 6 cartridges have been completely tested. Warm Cartridge Assembly (Front End Local Oscillator) noise screening was implemented and accepted as sufficient testing to allow shipping WCAs directly to Integration Centers rather than to cartridge manufacturers for noise verification.

The FE LO group is now considered to be in full production mode for bands 3, 6, 7, and 9, nearly in production for Band 4, and still developmental for Bands 8 and 10. The Front End Critical Design Review (CDR) was scheduled for the next quarter, and preparation of documentation including that for remaining sub-assembly CDRs commenced.

Back End*:* The first two production laser synthesizers and both production master lasers have arrived in Charlottesville. The first master laser locked immediately and the lock appeared very robust. They were integrated in the central LO article (CLOA) racks. Antenna Articles 1 and 2 were installed in antennas at the OSF. The production contract for LO Photonic Receivers (LPRs) was also placed; S/N 104 subsequently passed PAS testing was installed in EU-FE#1 at RAL. Provisional acceptance in-house (PAI) testing on Back End Antenna Article # 5 was completed in Socorro in February.

The Central Local Oscillator Article1 (CLOA1) was shipped from North America in late June 2009. Reintegration and installation occurred in July and early August, and acceptance testing was successfully carried out by the NRAO staff in August and September. The CLOA1 provides the LO reference for the array and can support up 16 antennas, once Line Length Corrector and Sub-Array Switch Line Replaceable Units (LRUs) 9-16 arrive in 2010. A review and formal handover will occur in October 2009.

In Q4, additional Fiber Stretcher Assemblies for use in the remaining Line Length Corrector (LLC) LRUs in CLOA1 were submitted for NSF approval. In addition, the first 9 of 25 Production LO Photonic Receivers (LPRs) were received in Charlottesville. LO Photonic Articles began to arrive from the integration vendor and are undergoing testing, and a successful Manufacturing Readiness Review (MRR) is anticipated in early October at which point Articles 11 through 25 will begin integration. A delay in delivery to Front End Integration Centers has occurred, however, due to a manufacturing defect in the fiber optic cable harnesses. Antenna Articles continue to be integrated and shipped on schedule from Socorro. In addition to this work in North America, staff have been travelling to Chile to aid AIV in acceptance testing and installation. Future acceptance and installation is expected to be wholly performed by AIV staff.

During Q4, the Single Dish Timing Rack (SDTR), an additional Central LO source for the antenna testing at OSF was delivered on schedule, and Antenna Article (AA) 4 was installed in an antenna at the OSF. Antenna Articles (AA) 8-11 were shipped to Chile. AA's 12-15 were completed in anticipation of shipment. A third quadrant's worth of Data Receiver (DRX) Articles were delivered to the Correlator

Integrated Product Team (IPT). One quadrant, 64 articles, remains to be delivered by the Back End IPT, currently estimated for Q2 FY 2010.

Correlator: In Q4, detailed checkout of the 67 defined modes for correlator operation continued, using artificially-generated test signals. Approximately 35% of the modes have been thoroughly verified, including the signal-to-noise ratio improvement from 4-bit and oversampling modes. The first astronomical observations were made with Quadrant 1 of the 64-antenna correlator. Quadrant 2 was installed at the AOS TB and acceptance testing began. Quadrant 3 began integrated testing in the correlator laboratory in Charlottesville, VA, and the construction of Quadrant 4 started.

Computing: Most of the effort in Q4 went towards the development of the next releases of both CASA (R. 3.0) and the ALMA (R. 7) software (see OSO section). Patch 6.1.1 was released, which had support for the AOS Central LO. The production optical telescope software was tested successfully in Chile, although later than planned due to hardware delays.

Science: In Q4, the Science IPT continued to scientifically test the calibration and interferometric software tools implemented by the Computing IPT on the production ALMA system during initial Commissioning at the Array Operations Site. Interferometry at the OSF progressed, culminating in the demonstration of interferometric pointing. Antenna PM03 was moved to the AOS and calibration and other software tools were tested. Pointing and refined holography established that Vertex antennas meet pointing and surface accuracy specifications over an extrapolated range of temperatures. A review of Commissioning and Science Verification plans was held September 2-3. ANASAC met in Charlottesville to discuss ALMA development and other topics at the end of September in conjunction with the NAASC science workshop.

Science Operations/North American ALMA Science Center (NAASC): In FY 2009 two releases of the Common Astronomy Software Applications (CASA) were completed and a tutorial provided for 25 Santiago ALMA scientific staff (see OSO section). The software was tested in Chile in June re-established dynamic fringes (with computer control of delays) for the first time (this had previously been routine at the Antenna Test Facility (ATF)). The software for the production optical telescope was integrated into this high-level software. The CASA pre-release was successfully used in two tutorials in Garching, Germany and National Astronomical Observatory of Japan (NAOJ), with generally positive feedback. During this time period, NAASC also selected the Kayako helpdesk system product for baseline testing and over fifty helpdesk queries were supported through the helpdesk to date.

In Q4, in preparation for Science Operations Implementation Plan review the Science Operations IPT met in Green Bank in August. The NAASC Implementation Plan, the JAO/DSO and ARC Coordinated Activities Plan were written, and contributions made to all other documents, including the ALMA Project Plan. Presentations were given at the Sept 28-30 review in Santiago on ALMA from the users perspective, ALMA Science Operations Software, and the NAASC. Work began on the revision to the ALMA Operations Plan.

The first NAASC Commissioning and Science Verification (CSV) liaison scientist began duties in Chile including shifts at the OSF. A thermal analysis of holography data for the characterization of the surface of the Vertex antennas was performed. The NAASC's second CSV liaison scientist joined in September and will begin a three month tour in Chile in January 2010. Three new scientist positions have been advertised.

A summary of considerations and open issues regarding spectral line OTF mapping with ALMA was produced and distributed to a working group. A prototype summary page for ALMA proposal submission was developed. A NAASC sabbatical visitor has prototyped a web site based on mediapedia (which is used by Wikipedia), to support demonstrations of the use of validated CASA scripts and developed prototype 'CASApedia' script tutorial site. In Q4 a NAASC CASA post-doc started and will work on scientific use of CASA especially for heterogeneous imaging.

The ALMA archive and data rate requirements planned for the NRAO Data Center in Charlottesville were evaluated. In addition, the 4th NAASC workshop "Assembly, Gas Content and Star Formation History of Galaxies" was held on September 21-24, 2009. There were over 170 participants, including more than 60 students and postdocs. In preparation for Early Science and full science operations, the expected SED for the MilkyWay at various redshifts with the 24 hour ALMA sensitivities were recalculated. The NAASC team also prepared for and held the ANASAC face-to-face meeting on September 25. Agenda material included background material for the ALMA Science Advisory Committee (ASAC) charges on ARC preparedness, the ALMA development program, and the ALMA proposal review process.

Special Projects: Work continued at the Central Development Laboratory (CDL) towards a 350-μm Superconductor–Insulator–Superconductor (SIS) mixer. At the University of Virginia Microfabrication Laboratory (UVML), high quality AlN SIS junctions with very high critical current density were demonstrated in the last year. Key to a highly stable production process is an accurate determination of the thickness of the AlN barrier during deposition, accomplished by ellipsometry. Discussions are under way with an ellipsometer manufacturer to obtain a wide-spectrum instrument to replace the current monochromatic one whose accuracy is marginal for this work. Also at UVML, work continues on the fabrication of high quality NbTiN for use above ~700 GHz. The Hot deposition system ordered 12/2008 is almost ready for delivery. Site acceptance is complete and the system should be delivered in Q1 FY2010 (December). Essential to the NbTiN development is the ability to measure the properties of the superconducting films at 4 K. A method is being developed for measuring test circuits using a cryogenic wafer prober. This will allow on-wafer measurements of the specific capacitance of the $SiO_x$ layers, and the penetration depth and loss of the superconductors, which are difficult to measure after the devices are detached from their parent wafer.

While UVML develops the new materials and fabrication processes, the CDL is prototyping the 350-μm mixer at half the frequency (440 GHz) to optimize a new mixer design using silicon membranes and gold beam leads. The first wafer of 500 GHz SIS mixers has been completed at UVML and is awaiting initial DC measurements. Balanced and single-ended mixer blocks have been fabricated at the CDL. Membrane LO couplers and quadrature hybrids for these mixers have been fabricated and satisfactorily tested.

The cryogenic test system for SIS mixers at 440 GHz is nearly complete. This includes the DC bias and IF components, optics, and LO and signal sources. An ellipsoidal mirror design is complete and has been sent to our collaborators at the Arizona Radio Observatory for fabrication.

In another development area, updates and maintenance continue for Splatalogue, the spectral line database. An international technical workshop was planned for October in Cologne, Germany, to work towards consensus on line database support for the community, in support of ALMA proposals and data analysis. Requirements for a subset of the database for use in offline tools (the OT and CASA) are sought at the workshop.

ALMA Development Support: In Q4, colleagues from the Herzberg Institute, Canada, prepared a journal paper on the science case for the development of ALMA Band 1. Involvement with the processes of the Astronomy Decade Review continued with responses to calls for information.

NA ALMA EPO: NAASC Education and Public Outreach (EPO) to the science community during the fiscal year included attendance at several conferences. In particular, NAASC was a sponsor of the 2009 Center for Chemistry in the Universe Workshop: "Advancing Chemical Understanding through Astronomical Observations", and the Taipei meeting: "Millimeter and Submillimeter Astronomy at High Angular Resolution." NAASC also successfully obtained grant funding to assist 13 young researchers in attending the Taipei meeting to learn about mm interferometry. In Q4, EPO published a press release for the transport of the first antenna to the ALMA high site. In the areas of Science Media Services and Outreach, EPO fulfilled requests for NRAO ALMA High Definition (HD) video footage by documentary producers, and conducted video interviews in collaboration with outside video producers.

In the area of Science, Technology, Engineering, and Mathematics (STEM) education for ALMA, the NA ALMA EPO group participated in ALMA EPO IPT meeting at the OSF, 8-10 September. ALMA booklets are now part of the Williams College astronomy curriculum (cf. Prof. Jay Pasachoff). The group also acquired virtual field trip webcast studio equipment and an astronomy visualization system. In addition, ViewSpace displays were acquired for use in the Green Bank and New Mexico visitor centers.

EPO participated in several activities in support of NRAO Chile over the year. These included plans for a video shoot of the antenna move, organization of a series of workshops to train teachers on how to use software to support the teaching of astronomy in classes, and organization of the logistics (institutions participating, program of activities and attendance of public) for the IYA'09 cornerstone project "Galilean Nights." The NA ALMA EPO group participated in the most relevant science fair for schools in Chile (organized by EXPLORA each year in Santiago), and participated in the regional version of this fair in Valdivia (and sponsored the awards). The group redesigned the logo of NRAO Chile. The group also offered public lectures on Astronomy, NRAO, and ALMA.

Office of Chilean Affairs (OCA): The OCA continues its support and management of NA expatriates working in Chile. OCA has reviewed and signed new ALMA Local Staff contracts on behalf of the NA Executive, designated as the sole employer of local staff for ALMA in Chile. In Q4 three new expats arrived, bringing the total number of employees for which OCA provides ALMA with legal, payroll and travel support to 179.

Two defibrillator units were installed in the Santiago offices as requested by the Joint Health and Safety committee managed by the OCA. OCA has also provided extensive legal support to the NA Executive on Chilean labor-related matters, especially now on union matters. OCA continues the management of the joint health and safety committee and transmits its suggestions to the ALMA administration. OCA has provided the legal and institutional support for contracts and procurements for ALMA Construction including those described in the Site IPT section, namely AOS Roads Construction Contract, AOS Utilities – Electrical and FO cables installation contract, Fiber Optic Cable supply and Contractors' Camp expansion. Related to the Sodexho contract (Catering, Cleaning and Maintenance), improvements were introduced in the catering services provided at the Contractors camp and changes were introduced in lodging services in order to accommodate the ALMA new access control system and lodging management. Monthly reports were issued to Conama (environmental authority), related to flora/fauna and archaeological follow-ups. OCA personnel participated in the environmental analysis related to the temporary power supply system that will remain as backup after Operations commences.

## Very Large Array/Expanded Very Large Array

The EVLA construction project continued on schedule, and detailed planning for commissioning and early science proceeded during FY 2009. The installation of the Wideband Interferometric Digital Architecture (WIDAR) correlator is scheduled for completion in Q1 CY2010. The conversion of antennas to the EVLA design is scheduled to be complete in Q3 CY2010. The last EVLA receiver will be installed in late CY2012. The critical path to project completion currently runs through the conversion of the antennas to the EVLA design and will move to receiver production at the start of FY 2011. In Q4, the project management office completed and initiated a plan to transition personnel off the EVLA construction project budget.

Site: The civil construction work element of the project was completed in FY 2009 with the installation of the correlator shielded room and 48 VDC power plant. A new performance specification and design for the EVLA weather station was completed as a replacement for the old VLA weather station modules, which are not compatible with the interface to the new fiber-optic based EVLA systems. Hardware procurement is contingent on funding. A redesigned Focus Rotation Mount (FRM) Brake power supply module is in production, and will replace the old, obsolete units. Parts for 10 of 28 antennas have been procured. In Q4, the site was able to procured two new site pickup trucks under the ARRA program.

Antenna: Mechanical overhauls of the 20th, 21st, and 22nd EVLA antennas were converted to the EVLA design. The antenna conversion schedule was interrupted by the failure of a pinion gear in an azimuth gearbox of EVLA antenna 5. The replacement of the gearbox and the azimuth bearing caused a one month schedule delay, but antenna conversions are scheduled for completion as planned in Q4 FY 2010. As part of an accelerated risk mitigation process completed in Q4, all of the antenna gear boxes were inspected and the oil was changed in each. The drive and backlash gearboxes were also swapped to even out wear load. At the completion of the inspection, only 3 of 56 AZ gearboxes showing additional serious wear; these will be repaired. No EL gearboxes showed serious wear. The EVLA construction project achieved the program plan goal of converting 23 antennas to the EVLA design by the end of FY 2009.

Front End: The front-end group completed its highest priority goal of improving the noise and cool-down performance of the L-band orthomode transducer. The 20$^{th}$ EVLA antenna was outfitted with interim L and X-band receivers, and fully EVLA-compliant C, K, and Q-band systems. The first fully EVLA-compliant S-band (2-4 GHz) receiver was installed in EVLA antenna in January. During Q4, 20 S-band (2-4 GHz) feed horns were fabricated. The fabrication of the S-band feed horns appears in the Front End portion of the project's work breakdown structure. The completion of the horn fabrication is a program plan goal for FY 2010 and should occur in early April 2010. The horns are being completed well in advance of the S-band receiver deployment schedule. The on-antenna performance of prototype Ku-band (12-18 GHz) receiver exceeds design specifications. The X-band receiver is the last receiver to be installed on the EVLA antennas. The OMT design will be selected in Q1 FY 2010 so that receiver production can commence in Q2.

Local Oscillator/Intermediate Frequency Systems (LO/IF): L301 frequency synthesizer, the L353 LO reference transmitter, the L304 LO reference receiver, and the T305 baseband controller were completed in FY 2009. Production of other LO/IF modules continues to keep pace with the antenna conversion schedule. Installation of the second set of frequency synthesizers, which is used in the wide band signal path of the EVLA, was started. In conjunction with the high speed samplers (see the fiber optics discussion), these synthesizers enable observations at 8 GHz bandwidth per polarization. The synthesizer installation is being done well in advance of the sampler installation. To date, synthesizers

have been installed in three antennas, with a future installation rate expected to be one antenna per month.

Fiber Optics: The high speed (3-bit, 4Gsps) samplers in the EVLA's Fiber Optic System enable high bandwidth (8 GHz per polarization) observations. Although the prototype version of the demultiplexer used in the sampler was shown to work in the summer of 2007, subsequent versions of the vendor's demultiplexer have not performed satisfactorily. After over a year of investigation into the problem, work on the current demultiplexer design was suspended, and an external review was held on October 13, 2009 to select an alternate design. A new design, based on a field programmable gate array (FPGA) – a technology that was not available as recently as a year ago – was selected, and the detailed design of the sampler is underway. Currently, the sampler installation is expected to commence in Q3 FY 2010 with installation complete in late 2011. This sampler installation plan should not adversely impact the overall project schedule.

Correlator: Final tests of the correlator chip have been successfully completed and the chip production order has been issued. A subset of the final correlator, WIDAR-0, was installed at the VLA site, and was used for system integration tests. First fringes were recorded with WIDAR-0 in March 2009. The production order for the WIDAR baseline boards was placed in June, and 22 of the 128 station boards have been delivered to the EVLA. A test version of the WIDAR's configuration mapper software with a graphical user interface was released. The VLA correlator is scheduled to be replaced by the WIDAR correlator in January 2010. The delivery of WIDAR's station boards should be complete in November 2009, and all baseline boards should be delivered by March 2010. All WIDAR crossbar boards were delivered and installed in August 2009. Sufficient number of boards are on hand now for early science observations.

Monitor and Control Systems: The old VLA Modcomp control computers have been replaced by the new EVLA Monitor and Control system, which operates both VLA and EVLA systems. In Q4 development for Monitor and Control Systems was focused on systems integration of WIDAR. The old VLA API modules are not compatible with the new EVLA monitor and control system so new API interface modules have been completed and will be installed in Q1 2010. The SCR driver cards are obsolete and in need of replacement, and so a program has been started to address long-term reliability. The prototype SCR driver card used in the VLA Antenna Control Unit has passed initial bench testing, and antenna testing will begin in January 2010.

Science Support Systems (SSS): The new web-based Observation Preparation Tool (OPT) was released. A SSS readiness review for shared risk observing held in June. The review committee found that SSS is well positioned to support EVLA shared risk observing (SRO) and did not believe that SSS posed a significant risk to the SRO schedule. The committee also found that the overall design of the SSS applications seemed sound, and the processes used to implement the software were generally good. The committee recommendations include devoting more attention to refining the specific SSS requirements for SRO and defining software acceptance processes (by non-SSS team members) within the EVLA project. Development of software for user tools continued on track to support commissioning and early science in Q2 FY 2010.

EVLA Science Operations: Over most of the year, EVLA Science Operations commissioning focused on testing and system integration of the WIDAR correlator. Emphasis was on correlator configurations that will be made available for EVLA Early Science in March 2010 and included user documentation and modifications to the Proposal Submission Tool to accommodate observations with WIDAR. A call for EVLA proposals was made on September 15.

VLA Operations: 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 VLA completed planned moves in January and February from A to BnA and from BnA to B. Additional moves in FY 2009 included B to CnB, CnB to C, and C to DnC configurations.

## Very Long Baseline Array

The VLBA underwent standard maintenance at the Saint Croix site in mid-November, 2008. Two additional maintenance tiger team visits to Kitt Peak, Arizona, and Mauna Kea Hawaii were deferred to the fourth quarter due to late release of funding. In addition to the maintenance activities, the VLBA sensitivity enhancement development program continued toward its goal of demonstrating a 4 Gbps data rate. Funding for this program is from non-programmatic sources. During this fiscal year, the DiFX software correlator, which will replace the hardware correlator, was completed and is undergoing tests. The goal is to replace the hardware correlator by the end of Q1 FY 2010. Tests comparing DiFX with the VLBA hardware correlator have been highly successful, with data from the two correlators agreeing in amplitude to (0.4%±1.7%), and in phase to (0.1°±1°). High-speed digital back ends and new, high-speed recording system were also developed and installed.

In addition to maintenance and enhancement activity, considerable effort has been invested in negotiations with potential partners for operational and development support of the VLBA, as recommended by the NSF Senior Review Report of 2006. The National Astronomical Observatory of Japan submitted a preliminary proposal to their funding agency for a joint VLBA/VERA astrometry program that includes funding to support VLBA operations. Substantive discussions also occurred between NASA and the Max Planck Institut für Radioastronomie regarding operations funding of the VLBA. A UNAM proposal to CONACyT was submitted this fiscal year and approximately 2.5 million pesos ($190K) awarded, with about $160K available for procurement of VLBA equipment connected with the sensitivity enhancement project. The exact balance of purchases between disks, recording units, and central processing unit (CPU) for the software correlator will be set for maximum scientific impact for the Mexican partners and the rest of the user community.

Discussions between NASA, USNO, and the NSF also resulted in a draft Memorandum of Understanding (MOU) for a partnership in the operation of the VLBA. The MOU was iterated and reviewed by legal counsel by each partner. The NASA partnership is contingent on equipping the VLBA with 33 GHz receiver systems; this would be available from ARRA funds. In Q4, an operations plan was drafted which lays out concepts for issues such as telescope time allocation, procedures for communication, data delivery, priorities, and responsibility for carrying out different activities. This document is intended to be one of several documents (e.g., interface requirements) supporting execution of the MOU. At year's end, the MOU was not yet approved.

## Green Bank Telescope

Site: During FY 2009 Green Bank (GB) Operations enlarged the site data storage capabilities to accommodate the more massive data files being created by GBT observers. This has been long-requested by the pulsar astronomers and others whom have been acquiring large data sets from their scans and observations. Internal network speeds have been increased within the GB facility, allowing large data transfers to occur more efficiently and without affecting other network traffic on site.

A design was completed and the materials procured for a new warehouse to be built in the GB shops area. This new facility, shared by the shop and plant maintenance divisions will allow for moving of materials stored in the shop work area to a more secure and suitable location (away from work zones), and for the indoor storage of materials for both divisions.

During the year Green Bank participated in writing three broadband internet access grant applications under the federal government economic stimulus program. Two of the grants were submitted by community organizations, and the third is still being crafted. In addition to providing much-needed broadband access to the Observatory, the proposed network fibers will provide broadband internet access to the local schools, library and the community.

Also during this fiscal year, the Green Bank facility hosted the "Advancing Chemical Understanding through Astronomical Observations" workshop, with approximately 80 participants from around the world and co-hosted the fifth bi-annual NAIC/NRAO School on Single Dish Radio Astronomy in Arecibo, Puerto Rico.

Antenna: The Green Bank telescope engineers and mechanical shop designed and fabricated a track cover system for the GBT in the first quarter. These covers travel between the GBT trucks and provide protection for the new GBT azimuth track as well as improve traction of the GBT azimuth wheels in wet and slippery weather conditions.

In Q3, the summer telescope maintenance was carried out, which included telescope painting, receiver maintenance, and track maintenance on the GBT. The summer maintenance season was extended into September to allow for more of the GBT structure, including some surface panels, to be painted. The structural inspection was concluded in Q4 and the structure was deemed to be holding up well. A few areas of corrosion were identified and re-welding or added material returned the areas to original design strength.

Development:
*Infrastructure Improvements*: The holography project of the Precision Telescope Control System (PTCS) program, designed to improve the surface accuracy of the GBT, made significant improvements to the surface during the fiscal year. During the year the PTCS team provided the first large (2-degree, 200 column) 11.7 GHz holography maps of a geostationary satellite. Small-scale surface error initial corrections were subsequently applied, bringing the r.m.s. surface error to 300 microns. This is an interim milestone in a series of surface smoothness improvements, with an ultimate PTCS performance goal of 220 microns averaged across the dish.

The servo system replacement project in the PTCS program held a design review in May, 2009. The panel's report validated the technical solutions for the digital servo, offering some suggestions of points to monitor for system maintainability. The panel suggested that the schedule should be revised to reflect the information gained from earlier task completion durations to predict better the duration of remaining project tasks. This rescheduling activity was commenced in Q4. During that time development of a new digital servo system also continued along with the construction of new motor and encoder interface circuit boards.

The GBT Dynamic Scheduling System (DSS) project went through a design review in the first quarter of FY 2009. The results of that review, along with the beta tests which were run in FY 2008 were incorporated into a new plan for the system. Work continued at a rapid pace at the close of FY 2009, and DSS was poised for release at the beginning of FY 2010.

*Camera Development:* MUSTANG, the GBT's 90 GHz bolometer array, received a new 100 pixel array from National Institute of Standards and Technology (NIST) in mid-September and testing began with encouraging initial results. Basic offline data reduction pipeline capabilities were completed in September and were ready for the upcoming high-frequency observing season.

The first pixel of the 7-pixel,18-26 GHz K-Band Focal Plan Array (KFPA), was installed on the GBT in Q1-Q2 for comparison tests with the current K-Band receiver, and a successful external review was conducted afterward. In Q4, all items necessary to build the receiver for the KFPA, except the LO doubler and distribution system, were delivered. Testing of the individual components was completed, and the Monitor and Control (M&C) hardware was built tested and a mechanical housing built. The M&C software, which provides the interface to the hardware was written and tested with all available devices.

*Digital Signal Processing*: The Configurable Instrument Collection for Agile Data Acquisition (CICADA) program continued in FY 2009. This is a project for rapid development of advanced, FPGA-based signal processing systems. The majority of the effort on this program was devoted toward development of a new pulsar backend, GUPPI, the Green Bank Ultimate Pulsar Processing Instrument. GUPPI has been offered as an "expert" tool for select astronomers and the first use by outsiders was well received. By the end of FY 2009 phase I, the incoherent filterbank (or "search") modes of GUPPI were complete, and work began in phase II of the instrument, the coherent de-dispersion (or "timing") modes.

## Central Development Laboratory

At the Central Development Laboratory (CDL) during FY 2009, work continued in the areas of Amplifier Production and Development, Advanced Receiver Development, Submillimeter-Wave Receiver Development, and Electromagnetic Support.

The Precision Array to Probe the Epoch of Reionization (PAPER): This collaboration with UC Berkeley succeeded in providing single polarization data using the Green Bank 16-element engineering array in January and February, and dual-polarization data in Q2. In Q3, 32 additional antennas, ground screens, and receivers were fabricated and the preliminary results from the PGB-16 array were obtained. The preliminary results included wide field sky maps with <100 mK RMS noise and initial measurements of the power spectrum. It was recently decided to move the initial deployment of PAPER to South Africa for two reasons: 1) to help the Mileura Widefield Array (MWA) project by staying out of their way during this very critical time for them; and 2) our correlator engineer is in South Africa and this is a critical time for us to develop a 64 station, dual-polarization, ROACH-based correlator. PAPER plans to revisit the site question once 64 stations are deployed. Eventually CDL staff plan to collaborate with the MWA group as we move toward the next generation instrument (HERA II).

Amplifier Production and Development: In FY 2009 demonstration low-noise amplifiers for ALMA Band 1 (31–45 GHz) and Band 2 (67–90 GHz) receivers were completed. The delivery of amplifiers for the GBT K-band focal plane array project was completed. 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 in the 1-2 GHz, 2-4 GHz, 4-8 GHz, 4-12 GHz, 8-18 GHz, and 18-26 GHz ranges. The deliveries of 18-26 GHz and 38-50 GHz amplifiers in support of Korean Very Long Baseline Interferometer (VLBI) network, Message Passing Interface (MPI) Receiver Group, and Jet Propulsion Laboratory (JPL) Defense Switched Network (DSN) are on schedule.

Advanced Receiver Development: This year, a revised L-band Digital Sideband Separating Mixer (DSSM) was tested on the GBT, and the design of an X-Band Digital Ortho-Mode Transducers (DOMT-X) was completed, with fabrication in progress. Also, the design of a DSSM with integrated digitizers was completed, and fabrication is in progress. In the area of analog/digital/photonic receiver integration, the downconverter for testing the X-Band DOMT-X is in micro-assembly.

An algorithm has been developed for word-boundary detection of Gaussian-distributed, white-noise data streams at the receive end of the link. An analysis of the algorithm's performance shows that word boundaries can be detected with very high statistical certainty in a short time, even in the presence of real-world non-Gaussian signals such as RFI, and non-white spectra due to gain slopes. This should permit using very simple digital data sample stream transmission without formatting and deformatting electronics, reducing expense and heat dissipation. An Electronics Division Technical Note (EDTN #213) describing this work has been released.

Millimeter and Submillimeter-wave Receiver Development: In this area, development of 500 GHz balanced and single-ended mixer blocks moved to fabrication, and a 500 GHz drop-in hybrid was successfully tested. The cryogenic test system for SIS receivers at 500 GHz is now nearly complete. This includes the DC bias and IF components, optics, and LO and signal sources. An ellipsoidal mirror design is complete and has been sent to our collaborators at the Arizona Radio Observatory for fabrication. A proposed submillimeter waveguide interface (flange) has much greater alignment precision than the standard UG-387 type of flange while being backward compatible with the old standard. Initial measurements in collaboration with the University of Virginia show greatly improved repeatability of the new design. The first wafer of 500 GHz SIS mixers was completed and is ready for DC testing, and a 500 GHz balanced and single-ended mixer blocks was completed. Components are now being installed in mixer blocks.

Electromagnetic Support: In this area, a new X-band (8-12 GHz) OMT was developed. Two designs of Ku-band (12-18 GHz) phase shifters were measured and evaluated. A longer design was chosen for the EVLA Ku-band receiver because of its better performance. An optics design for the 385-500 GHz receiver was completed. Other work included completion of a design for an X-band phase shifter, transitions for the EVLA, the measurement of transmission (at S-band) and reflection (at X-band) coefficients of a VLBA dichroic reflector, and the preliminary design of wide band C- and Ka-band feeds for the VLBA.

Frequency-Agile Solar Radiotelescope (FASR): Prototyping began in January 2009 with design of the FASR band B system. In Q3 a prototype of the FASR B field board was completed. Terminal impedance measurements on the wide band FASR B antenna were also completed during FY 2009.

## New Initiatives

The New Initiatives Office (NIO) has been an active participant in Square Kilometre Array (SKA) programs throughout FY 2009, including the recently-funded Technology Development Proposal and work on the EVLA, which is a technical pathfinder for the SKA. In Q4, detailed responses to Astro2010 questions were submitted by the US SKA Consortium (SKA) and NRAO (North America Array). The NRAO participated in preliminary discussions and the face-to-face meeting of the Funding Agencies tiger team on the SKA schedule and final negotiations were concluded for a long-term collaboration visit to South Africa by an NRAO scientist, to facilitate cooperation in digital design, algorithm development, and SKA commissioning.

For Lunar Radio Astronomy (LRA), the NRAO designed and built a rugged, dual-polarization dipole reference antenna, completely encapsulated in PVC tubing, for 137 MHz (HI at redshift z=9.3) and is examining planar ground screen with fan-fold deployment mechanism for robust deployment on the lunar surface. The NIO staff has also been active in discussions on Space VLBI initiatives such as VSOP-2, but the Japanese mission has been under cost/technical review and is on hold pending results. The NRAO is providing infrastructure support for the Long Wavelength Array (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, if funded.

## Education and Public Outreach

The NRAO Office of Education and Public Outreach (EPO) acquired extensive high-definition video and high-resolution digital images from the air and the ground in Green Bank during mid-October 2008. New high-quality video B-roll was produced from this material and from the similar VLA video shoot that took place in the previous month. These video B-roll products were made available to the media, and EPO fulfilled several requests for NRAO HD video footage by broadcast documentary producers. EPO also produced video for the NRAO website and posts for YouTube celebrating the discovery, by a West Virginia high school student participating in the NRAO's Pulsar Search Collaboratory, of a pulsar-like object. The NRAO 2009 Calendar was also produced, which featured the 2008 Image Contest prizewinners and a selection of other high-quality images from the on-line Gallery.

More than 400 guests participated in a Community Open House held in Green Bank on October 26, 2008 and enjoyed a day of science demonstrations, lectures, activities, and behind-the-scenes tours of the Green Bank electronics lab, machine shop, and the GBT. Open House events took place at the VLA on 3 October, 2008, in Socorro 14-17 October, 2008 (Enchanted Skies Star Party), and in Green Bank on 25 October, 2008. An additional event in Socorro occurred on 26 September, the M Mountain Fly-In. NRAO had a booth there and the event was attended by over 500 people. EPO also hosted the Northern Virginia Astronomy Club "Almost Heaven" Star Party in Green Bank.

Press releases were written and distributed for ALMA, GBT, VLA and VLBA, including releases that described key ALMA achievements, those that described new science, and those that described a major new NRAO-university partnerships, such as the Q1 announcement of the partnership with the *Center for Chemistry in the Universe*. In Q4, a press release on the transport of the first ALMA antenna to the high site was published.

The NRAO displays for science community outreach underwent an inexpensive but major re-design, and new multimedia content was created for use with the new displays at the January 2009 American Astronomical Society (AAS) meeting in Long Beach, CA. A very successful NRAO Town Hall at the Long Beach AAS meeting was held. A new brochure that describes all NRAO research facilities was written and published. An ALMA media prospectus was designed and released. In Q4, the NRAO donated an "Itty Bitty Radio Telescope" to the National Air and Space Museum (NASM), on the national mall. It will be used in educational programs conducted in and adjacent to the museum's new optical observatory on the plaza outside the museum. This will be the beginning of more extensive collaborations with NASM.

A new on-line program to celebrate the 50th anniversary of the successful NRAO summer student program was conceived and prototyped in collaboration with scientific staff. This program debuted in early 2009. A Discovery Channel film crew visited the VLA and Pete V. Domenici Science Operations Center for a feature on "Cosmic Collisions," which aired in January. EPO completed its planning in Q1 and Q2 for NRAO participation in the International Year of Astronomy 2009, which included several

Global Cornerstone Projects: Quiet Skies/Dark Skies Awareness, 100 Hours of Astronomy, Portal to the Universe, and 365 Days of Astronomy.

Consultation continued on the draft script for a European Organization for Astronomical Research in the Southern Hemisphere (ESO) sponsored ALMA planetarium show. In Q4, the ALMA EPO IPT meeting gathered EPO representatives from the ALMA executives and the JAO, along with the ALMA director, for several days of discussions. Important topics discussed included planning for the April 2010 press/VIP event at the JAO, planning for a visitor center at the JAO, policies on joint press releases, EPO conceptual "building blocks," and branding.

Work continued on the development of a modern, unified, and visually compelling NRAO brand that incorporates our recently adopted new logo, including a comprehensive style and design guide. The design of "One Observatory" exhibits for the GB Science Center and the VLA Visitor Center was initiated.

Over the year, EPO focused heavily on Science, Technology, Engineering and Math (STEM) education. Activities included the West Virginia Governor's School for Math & Science two week Science Camp in Green Bank with 56 rising high school freshmen; the NSF-funded Pulsar Search Collaboratory: 2nd cadre of teachers and students included 28 student leaders, with 12 teachers participating in summer workshops in Green Bank; RET (Research Experiences for Teachers) hosted two teachers during July-August in Green Bank. Green Bank also hosted a National Youth Science Camp Tour – 120 rising college freshmen from every state in the US, plus Puerto Rico. An Educational Research in Radio Astronomy Camp organized by UNC welcomed ~20 college and high school students for a one-week residential research camp in Green Bank. School groups and scouts came to Green Bank for overnight 40-foot telescope observing field trips from Oil City (PA) High School, Charlottesville High School, Virginia Cub Scouts, Black Diamond Girl Scout Council, West Virginia University, and Mt. Vista (VA) Governor's School.

## Communications

In Q3 2009, EPO was divided into two offices with separate ADs and line management groups (but with some shared resources): EPO and Communications. The Office of Communication focuses on communications with external stakeholders, the science community, and the NRAO staff. EPO focuses on disseminating NRAO's discoveries to the general public, which includes educational programs. One of the first tasks in FY 2009 for Communications was to provide a scientist-oriented web. The scientist-oriented web at NRAO must serve users whose radio astronomy knowledge and scientific interests span a wide range, from new users to experts. Prior to implementation of the new science web, an extensive review of the design, structure, navigation, and content of science websites at comparable observatories (e.g., HST, Chandra, Spitzer, ESO, NAOJ, NOAO etc.) was conducted. A beta site for the construction and test of the new NRAO science web site was then created. The design, structure, and content of the new web site home page, and the landing pages for ALMA/NAASC, GBT, VLBA, and EVLA were completed in Q4 and reviewed with the OSO Working Group. In collaboration with the NRAO web masters, Stefan Witz and Pat Murphy, tests were conducted of the Joomla, Zope, and Drupal content management systems.

The NRAO exhibition at the International Astronomical Union General Assembly (IAU GA) in Rio de Janeiro, Brazil (3-14 August 2009) provided an excellent opportunity to present and discuss NRAO capabilities and opportunities with many of the 2100+ astronomers from around the world who attended, including numerous young South American scientists. The NRAO exhibition at the International Conference for High Performance Computing, Networking, Storage & Analysis (SC09) will

mark our debut in this forum as an exhibitor and is a collaboration of the Communications and the Computing Information Systems teams. The SC09 conference will be at the Oregon Convention Center (Portland, Oregon) 14-20 November 2009, with an expected attendance of ~ 10,000 scientists, engineers, software developers, CIOs, and IT administrators from universities, industry, and government agencies. Exhibit re-design, program and NRAO Town Hall planning was initiated for the next American Astronomical Society (AAS) meeting, which will be held 3-7 January 2010 in Washington D.C. A record AAS meeting attendance of ~ 3500 scientists is expected.

## Spectrum Management

In FY 2009, the NRAO Spectrum Manager provided a document which will form the basis of a new coordination agreement between the Scientific Committee on Frequency Allocations for Radio Astronomy and Space Science (IUCAF) and the Space Frequency Coordination Group (SFCG) regarding notification of radio astronomy interests when new high powered earth sensing/mapping radars are planned. Work on another version of this document was finalized in connection with a new International Telecommunication Union Radiocommunications Sector (ITU-R) Report on the received power levels required to damage a radio astronomy receiver.

The Spectrum Manager also provided to ITU-R a document seeking protection of the 6.7 GHz methanol line from a possible new fixed-service allocation to the High Altitude Platform Systems (HAPS). Many compatibility issues of concern to radio astronomy were discussed at the ITU-R, especially the interference generated by use of power lines for broadband connection and impending proliferation of so-called cognitive radios which opportunistically seek to take advantage of "unused" spectrum.

In Q3 the NRAO filed a comment with the Federal Communications Commission (FCC) regarding protection of passive spectrum users in a possible, future, less heavily regulated spectrum allocation regime. In Q4, NRAO filed reply comments with FCC responding to a request from Toyota which would greatly increase the emitted power levels of 76 GHz vehicular radars (see ALMA Spectrum Management). These radars could burn out a radio astronomy receiver if directed toward an antenna while at a radio astronomy site.

Following a similar approach to that made last year to WildBlue, the NRAO Spectrum Manager wrote to HughesNet reminding them of their ongoing obligation under FCC rules to notify NRAO of satellite broadband installations within the National Radio Quiet Zone (NRQZ) as part of geographic area licensing. Vendors have generally ignored this obligation but both WildBlue and Hughes are now coordinating their installations with the Quiet Zone office in Green Bank.

At the behest of the NRAO Spectrum Manager, the NSF Spectrum Manager, acting through the Interdepartment Radio Advisory Committee (IRAC), received U.S. National Telecommunications and Information Administration (NTIA) approval of an intra-governmental request to the FCC for enlargement of the coordination zone at the VLA site for operation of unlicensed TV Broadcast Band White Space Devices.

The NRAO spectrum manager formally became a member of IUCAF at the IAU General Assembly in Rio.

Green Bank: During this Fiscal year, the Green Bank RFI Group and NRQZ administration processed hundreds of applications for satellite terminals from the West Virgina State Lottery. New software for NRQZ administration is under consideration. The RFI Group is continuing to compute 14 GHz coverage maps in order to facilitate coordination with transmitters installed within the Quiet Zone

under geographic area licensing, for instance home satellite broadband internet connections. Modelling of the antenna patterns of these stations is underway. Spectrum plots of RFI were updated and archived.

The GB RFI Group also continues to collaborate with the US Navy and Virginia Tech in terrain-modeling propagation calculations covering the Quiet Zone. If this preliminary program is successful, further studies will be done. The RFI Group continues to locate more local telephone company wireless modems and is working on having these removed by the local telecommunications company, Frontier Communications.

VLA & VLBA: VLA management is continuing to work with the New Mexico State Land Office (SLO) to protect the EVLA site from detrimental RFI produced by new high-voltage power transmission lines that would cross the Plains of San Augustin to distribute power generated by new wind farms. A mechanism to establish a buffer zone around the array was identified in a February meeting with the SLO and is now being pursued.

Coordination with military testing of GPS L3 frequencies continued, along with coordination between VLBA stations near the Canadian border and temporary Canadian military use of frequencies near the Ku band (14.5 and 15.3 GHz) allocations to radio astronomy. A new azimuthally swept RFI monitor was implemented. Technical analysis and discussions started with AirCell to reduce the VLBA-Pie Town impact of a proposed 11 GHz cellular base station-fiber optic portal link. AirCell is one of several companies that provide broadband internet connectivity to commercial airlines using a narrow slice of the 900 MHz cell phone spectrum. Communications between airlines and cell phone towers require Internet gateway links to cell towers, and where fiber is unavailable the links must be completed using microwave transmission.

During Q4, another survey of the VHF and UHF Radio Frequency (RF) environment at the EVLA site was completed in order to assess the impact of the change-over to digital TV in June 2009. The EVLA site L-band environment was reviewed in order to provide a list of suitable target emitters for EVLA correlator testing. In addition, a high-sensitivity survey was performed of the 1612 MHz OH RF environment, providing results (showing GLONASS and IRIDIUM satellite channel re-allocations) to the international radio astronomy community.

ALMA: The NRAO Spectrum Manager filed FCC comments responding to Toyota's petition to allow higher-power 76 GHz radars on US motor vehicles; this issue has long-range implications for spectrum management in Chile, where regulations tend to follow the US in such matters. The NRAO Spectrum Manager attended a Committee on Radio Frequencies (CORF) meeting in Santiago to discuss various compatibility and interference issues with the ALMA project. The NRAO Spectrum Manager also assisted ALMA Back End designers in characterizing requirements for ALMA module shielding and RF emissions.

## Science and Academic Affairs

The NRAO's Office of Science and Academic Affairs (SAA) oversee the scientific staff and community scientific outreach. During FY 2009, the SAA continued an active program of community scientific outreach that included the visiting scientist, summer student, pre-doctoral fellow, Jansky and NRAO postdoctoral, graduate and undergraduate intern and co-op, and Research Experience for Undergraduates (REU) programs. SAA also oversees the proposal review and telescope assignment process, as well as the library and historical archives.

The SAA participated in and helped coordinate submissions to the Astronomy 2010 Decadal Survey, and submitted a response to a January deadline for Notices of Intent to the National Science Foundation for proposals to the Major Research Equipment Program (MRI). A new program announcement for the 2010 Jansky Fellowship Program was posted to the web page in Q4 and advertised in the AAS Job Register, the Women in Astronomy Newsletter, and in the Physics Today online publication. The deadline for application is November 2, 2009.

SAA conducted the annual evaluation of the research and community service for all of the NRAO research staff as part of the Scientific Staff Performance Appraisal. Performance in research and community service is judged via several broad categories relative to other staff members in the same career track. In addition to the annual salary review, in Q4 the SAA also conducted a review of FY 2009 research travel spending for all NRAO scientific staff.

The Observatory Science Council (OSC) was reconstituted and its charge revised to emphasize participation in scientific planning and evaluation of NRAO facilities and projects, based on the NRAO mission and long range vision established in the NRAO impact statement submitted to A2010. In Q4, the Council reviewed the MRI-R2 proposals, and submitted their scientific review to the Director's Office. They also met and discussed possible post-reviews of the A2010 white papers. The OSC chair and SAA Assistant Director are formalizing a charge-response format for the OSC.

## Computer & Information Services

This year, Computer & Information Services (CIS) partnered with the NRAO's Office of End-to-End Operations (E2E) to install and evaluate an NRAO-wide observer support helpdesk solution (Kayako SupportSuite). A test release of the NRAO-wide observer support helpdesk solution (Kayako SupportSuite) was provided late in the fiscal year.

An NRAO-wide working group was initiated to address the challenge presented by the Science Data Archive and access over the next 3-5 years. 8 TeraBytes of user storage was installed in Green Bank. A large disk storage system was installed for GBT science data (250 TB). Hosting of ~4TB of VLA survey data for LITTLE THINGS (Local Irregulars That Trace Luminosity Extremes The HI Nearby Galaxy Survey) to support the distributed analysis of science data product was implemented. In Q3, CIS initiated a NRAO-ALMA Archive and VAO Science Operations review. The purchase of an initial eight NGAS systems for the Science Data Archive in Socorro and CV to support the EVLA (~80TBytes) was completed in Q4. The upgrade circuit order for the Green Bank WAN link to DS3 (45Mbps) speeds was placed with a scheduled go-live date of October 2009. An ARRA funding request for Gigabit link is underway in conjunction with West Virginia University.

CIS executed a Content Management System review with selection of Plone (in alignment with ESO/ALMA) and selected it as the Observatory's Content Management System. CIS completed Observatory-wide user cyber security and data sensitivity security awareness training. CIS also successfully addressed a "pain point" for observers requesting time on the NRAO instruments by alignment of observer account schemes for the Proposal Submission Tool, the GBT Dynamic Scheduler, and the BOS visitor support systems.

## Observatory Management Services

Observatory business and administration groups continued to refine and enhance their capabilities and responsiveness to NRAO staff. In Q4, Electronic Time Keeping (ETK) became available to NRAO Staff. This included the transition of NRAO Payroll from paper timesheets to ETK. Phase-in of payroll processing utilizing time card information was entered in ETK. The phase in required training of all

payroll staff regarding payroll process changes, assistance of the payroll staff in developing required reports to assist with payroll review, and assistance in testing the ETK environment and processing. Implementation was completed for electronic funds transfer (EFT) payments (in lieu of checks) for employee travel reimbursements for employees located at the Green Bank and Charlottesville sites.

In the Environmental Safety and Security area, FY 2009 saw completion of several site inspections, including the VLA site maintenance building in January; the Green Bank semi-annual cafeteria inspection in January and annual fire extinguisher inspection in February, and the annual chemical inventory update concluded in March. The NRAO Technology Center (NTC) completed its FEIC (Front End Integration Center) OSHA inspection (internal) in August. ALMA system safety reviews continue on schedule. ALMA conducted all routine safety committee meetings and evacuation drills on time. A face to face meeting of the Executive Safety Managers was held in Chile where the 2008 NSF safety review defects and actions list was reviewed. The report on findings of the review is to be delivered to ALMA Board in October.

The Human Resources group developed the new Workforce Management Plan during FY 2009. The Observatory HR group also oversaw the implementation of a new web-based recruitment system in March. Manager training was conducted at each facility location between the months of April and June. The web-based system supports the job requisition, posting, position description, application tracking, and candidate evaluation and selection processes. The system will also offer supervisor self-service in the recruitment and selection processes. It will also play an important role in supporting NRAO recruitment and employment of females and minorities.

HR initiated the annual performance evaluation process in March. In support of the NRAO Diversity Plan and AUI Broadening Participation Action Plan, manager and employee training sessions were conducted in April and May to assist employees in preparing a more effective self-evaluation, and to assist managers in providing effective feedback. The training also included FMLA for employees and managers. On-site training was provided at the Charlottesville, Green Bank, Socorro and VLA locations. A live video link was provided for NRAO staff in Chile and a webcast was provided for the VLBA operators. The NRAO completed the annual performance evaluation process (PEP) in FY 2009 3rd quarter.

The Research and Development Survey is a combination maturity curve and benchmark survey conducted annually. The survey covers cash compensation - base salaries and bonuses - for scientists and engineers. This is the first year of NRAO participation in the survey and marks the final key step in completing the exempt staff market pricing project. The annual salary review process that began in July, ended in September. In addition, the annual medical plan rate renewal process was conducted, which included the development and solicitation of bids for a new dental plan provider and benefits consulting firm. The final decision meetings were conducted in October for the dental provider and a new provider (Delta Dental) was selected for implementation in January 1, 2010. The decision process for the benefits consulting firm was made in the first quarter of FY 2010.

A new employment and diversity manager was hired in Q4. This marks the formal establishment of a dedicated diversity manager in the Observatory. The first major task for this manager is to oversee the development, and execute a diversity action plan that supports the NRAO Diversity Plan and the AUI Broadening Participation Action Plan. Meetings were also held to prepare for NRAO diversity support for Howard University during the 2009-2010 school years. For the third consecutive year, NRAO was Awarded 2009 Best Diversity Company by the readers of Diversity Careers in Engineering & Information Technology magazine.

## Acronyms

| Acronym | Definition |
|---|---|
| AAS | American Astronomical Society |
| AA | Antenna Article |
| AGN | Active Galactic Nucleus, or Active Galactic Nuclei |
| AIPS | Astronomical Image Processing System |
| AIV | Assembly Integration and Verification (AIV) |
| ALMA | Atacama Large Millimeter/submillimeter Array |
| ANASAC | ALMA North American Science Advisory Committee |
| AOS | Array Operations Site (ALMA, Chile) |
| API | Application Programming Interface |
| ARRA | American Recovery and Reinvestment Act of 2009 |
| ARC | ALMA Regional Center |
| ASAC | ALMA Science Advisory Committee |
| ATF | Antenna Test Facility, ALMA Test Facility |
| AUI | Associated Universities, Incorporated |
| CASA | Common Astronomy Software Application |
| CDL | Central Development Laboratory |
| CDR | Critical Design Review |
| CfA | Center for Astrophysics |
| CICADA | Configurable Instrument Collaboration for Agile Data Acquisition |
| CIS | Computing and Information Services |
| CLOA | Central LO article |
| CORF | Committee on Radio Frequencies |
| CPU | Central processing unit |
| CSIRO | Commonwealth Scientific and Industrial Research Organization (Australia) |
| CSV | Commissioning and Science Verification (ALMA) |
| DiFX | DIstributed FX correlator |
| DOMT-X | Digital Ortho-Mode Transducers |
| DRXA | Data Receiver Articles |
| DSN | Defense Switched Network |
| DSO | Joint ALMA Operations (JAO) Department of Science Operations |
| DSS | Dynamic Scheduling System |
| DSSM | Digital Sideband Separating Mixer |
| E2E | End-to-End |
| EFT | Electronic Funds Transfer |
| EPO | Education and Public Outreach |
| ESO | European Organisation for Astronomical Research in the Southern Hemisphere |
| ETK | Employee Timekeeping System |
| EVLA | Expanded Very Large Array |
| FASR | Frequency-Agile Solar Radiotelescope |
| FCC | Federal Communications Commission |
| FE | Front End |
| FEIC | Front End Integration Center |
| FO | Fiber Optic |
| FPA | Focal-Plane Array |
| FPGA | Field-programmable Gate Array |
| FRM | Focus Rotation Mounts |
| FY | Fiscal Year (October 1 through September 30) |
| GB | Green Bank, WV |
| Gbps | Giga-bits per second |
| GBT | Green Bank Telescope |

| Acronym | Definition |
|---|---|
| GHz | Gigahertz |
| GSPS | Giga-Samples Per Second |
| GUI | Graphical user interface |
| GUPPI | Green Bank Ultimate Pulsar Processing Instrument |
| HAPS | High Altitude Platform Systems |
| HD | High Definition |
| HEMT | High-Electron-Mobility Transistor |
| HIA | Herzberg Institute of Astrophysics |
| HR | Human Resources |
| IAU GA | International Astronomical Union (IAU) General Assembly (GA) |
| IDL | Interactive data language |
| IEEE | Institute of Electrical and Electronics Engineers |
| IF | Intermediate Frequency |
| IPT | Integrated Product Team |
| IRAC | Interdepartment Radio Advisory Committee |
| IRAM | Institut de Radioastronomie Millemétric |
| ITU-R | International Telecommunication Union-Radio communications Sector |
| IUCAF | Scientific Committee on Frequency Allocations for Radio Astronomy and Space Science |
| JAO | Joint ALMA Office |
| JPL | Jet Propulsion Laboratory |
| KFPA | K-Band Focal Plan Array |
| LLC | Line Length Correctors |
| LO | Local Oscillator |
| LO/IF | Local Oscillator/Interim Frequency Systems |
| LPR | LO Photonic Receivers |
| LRA | Lunar Radio Astronomy |
| LRU | Line Replaceable Unit |
| LWDA | Long Wavelength Array (see LWA) |
| M&C | Monitor and Control |
| Mbps | Mega-bits per second |
| MHz | Megahertz |
| mm | millimeter |
| MMIC | Monolithic Millimeter-wave Integrated Circuit |
| MOU | Memorandum of Understanding |
| MPI | Message Passing Interface |
| MPIfR | Max Planck Institut für Radioastronomie |
| MRI | Major Research Instrumentation |
| MRR | Manufacturing Readiness Review |
| μas | Micro-arcsecond |
| μJy | microJansky |
| MUSTANG | Multiplexed SQUID/TES Array for Ninety Gigahertz |
| MWA | Mileura Widefield Array |
| NA | North American |
| NAASC | North American ALMA Science Center |
| NA-FEIC | NA Front End Integration Center |
| NAOJ | National Astronomical Observatory of Japan |
| NASA | National Aeronautics and Space Administration |
| NASM | National Air and Space Museum |
| NIO | New Initiatives Office |
| NIST | National Institute of Standards and Technology |
| NRAO | National Radio Astronomy Observatory |

| Acronym | Definition |
|---|---|
| NRQZ | National Radio Quiet Zone |
| NSF | National Science Foundation |
| NTC | NRAO Technology Center (Charlottesville, VA) |
| NTIA | U.S. National Telecommunications and Information Administration |
| OCA | Office of Chilean Affairs |
| OMT | OrthoMode Transducer |
| OPT | Observation Preparation Tool |
| ORR | Operational Readiness Review |
| OSC | Observatory Science Council |
| OSF | Operations Support Facility (ALMA, Chile) |
| OSHA | Occupational Safety and Health Administration |
| OSO | Observatory Science Operations |
| PAI | Preliminary Acceptance In-house |
| PAPER | Precision Array to Probe the Epoch of Reionization |
| PAS | Bands for passive systems |
| PEP | Performance evaluation process |
| PMCS | Project Management Control System |
| PST | Proposal Submission Tool |
| PTCS | Precision Telescope Control System |
| PVC | Polyvinyl chloride, (IUPAC Poly(chloroethanediyl)) commonly abbreviated PVC |
| Q | Fiscal Quarter |
| QSU | Quarterly Status Update |
| OTF | On-the-fly |
| R&D | Research and Development |
| RET | Research Experiences for Teachers |
| REU | Research Experiences for Undergraduates |
| RF | Radio Frequency |
| RFI | Radio-Frequency Interference |
| SAA | Science & Academic Affairs |
| SCR | Silicon-controlled rectifier |
| SDTR | Single Dish Timing Rack |
| SFCG | Space Frequency Coordination Group |
| SIS | Superconductor–Insulator–Superconductor |
| SKA | Square Kilometre Array |
| SLO | New Mexico State Land Office |
| SNR | SuperNova Remnant |
| SQUID | Superconducting Quantum-Interference Device |
| SRO | Shared risk observing |
| SSS | Science Support Systems |
| STEM | Science, Technology, Engineering, and Mathematics |
| TBytes | TeraBYTES per SECond) Trillion bytes per second. |
| UNAM | Universidad Nacional Autonoma de Mexico |
| UHF | Ultra-High Frequency |
| USNO | United States Naval Observatory |
| UVa | University of Virginia |
| UVML | University of Virginia Microfabrication Laboratory |
| VAO | Virtual Astronomical Observatory |
| VHF | Very High Frequency |
| VLA | Very Large Array |
| VLBA | Very Long Baseline Array |
| VLBI | Very Long Baseline Interferometry |

| Acronym | Definition |
|---|---|
| VSOP-2 | VLBI Space Observatory Program (2nd generation) |
| WIDAR | Wideband Interferometric Digital Architecture |
| WRC | World Radiocommunication Conference |