2014 ANNUAL REPORT

NRAO

NATIONAL RADIO
ASTRONOMY OBSERVATORY

485 EMPLOYEES

51 MEDIA RELEASES

535 REFEREED
SCIENCE PUBLICATIONS

PROPOSAL AUTHORS

1425 – NRAO SEMESTER 2014B

1432 – NRAO SEMESTER 2015A

1500 – ALMA CYCLE 2, NA EXECUTIVE

A SUITE OF **FOUR** WORLD-CLASS ASTRONOMICAL OBSERVATORIES

4

FISCAL YEAR 2014

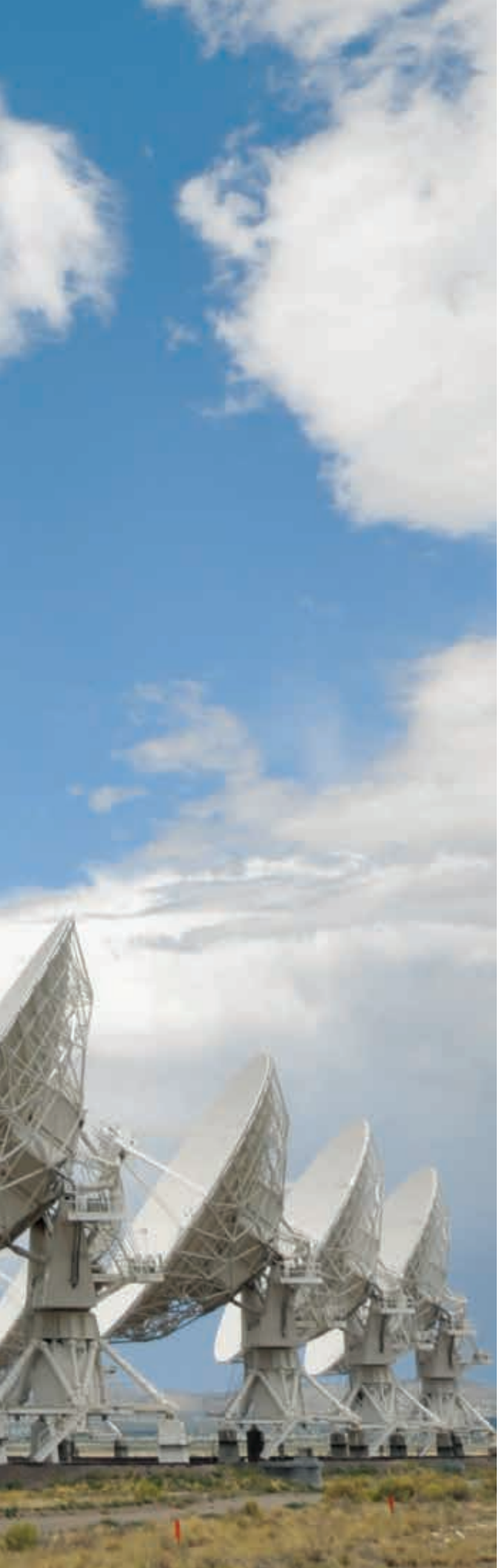
NRAO / ALMA OPERATIONS
$79.9 M

ALMA CONSTRUCTION
$12.4 M

EVLA CONSTRUCTION
$0.1 M

EXTERNAL GRANTS
$4.6 M

NRAO FACTS & FIGURES



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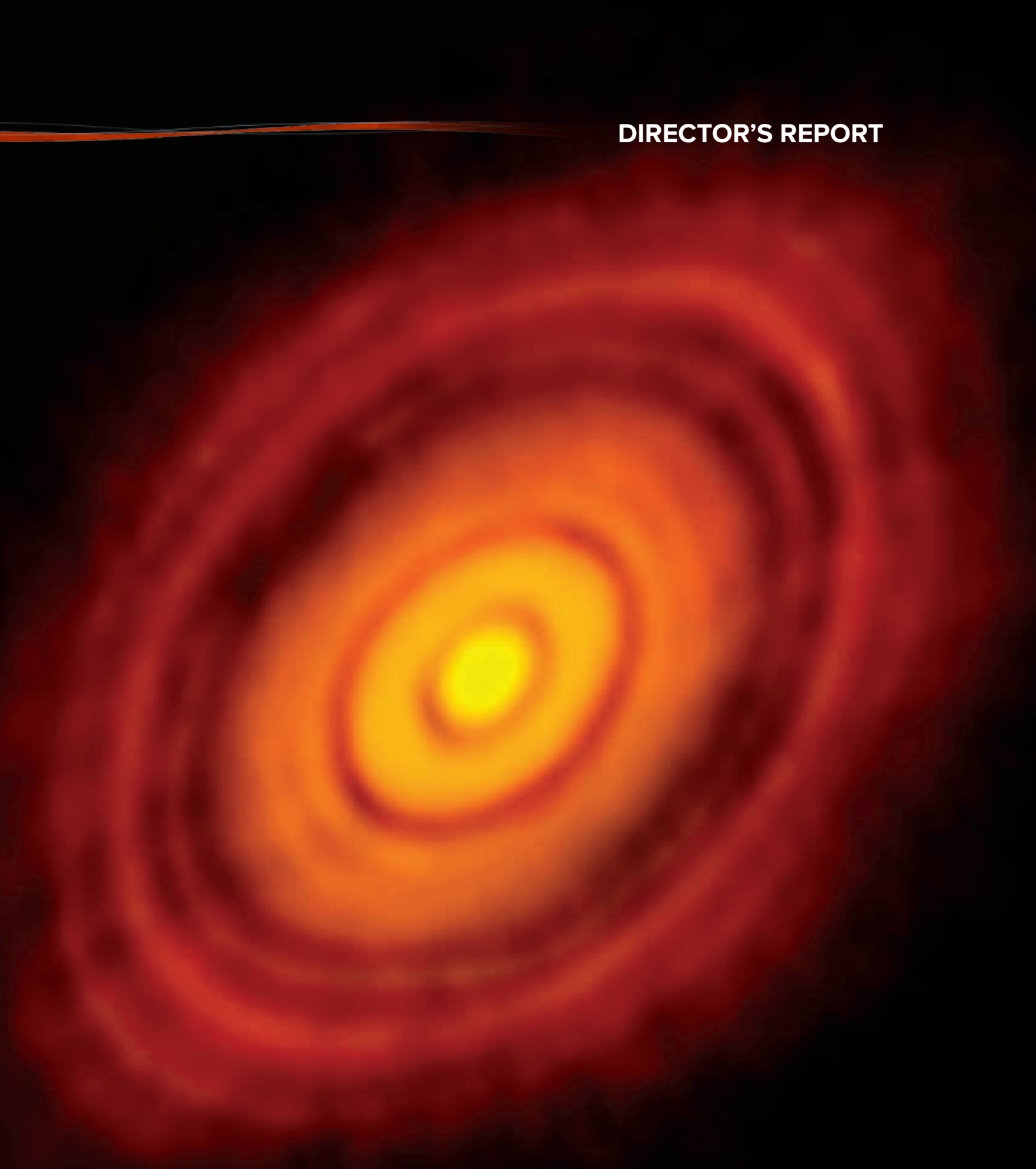
COVER: *An international partnership between North America, Europe, East Asia, and the Republic of Chile, the Atacama Large Millimeter/submillimeter Array (ALMA) is the largest and highest priority project for the National Radio Astronomy Observatory, its parent organization, Associated Universities, Inc., and the National Science Foundation – Division of Astronomical Sciences. Operating at an elevation of more than 5000m on the Chajnantor plateau in northern Chile, ALMA represents an enormous leap forward in the research capabilities of ground-based astronomy. ALMA science operations were initiated in October 2011, and this unique telescope system is already opening new scientific frontiers across numerous fields of astrophysics. Credit: C. Padillo, NRAO/AUI/NSF.*

LEFT: *The National Radio Astronomy Observatory Karl G. Jansky Very Large Array, located near Socorro, New Mexico, is a radio telescope of unprecedented sensitivity, frequency coverage, and imaging capability that was created by extensively modernizing the original Very Large Array that was dedicated in 1980. This major upgrade was completed on schedule and within budget in December 2012, and the Jansky Very Large Array entered full science operations in January 2013. The upgrade project was funded by the U.S. National Science Foundation, with additional contributions from the National Research Council in Canada, and the Consejo Nacional de Ciencia y Tecnologia in Mexico. Credit: NRAO/AUI/NSF.*

DIRECTOR'S REPORT



ABOVE: ALMA image of the young star HL Tau and its protoplanetary disk. This best image ever of planet formation reveals multiple rings and gaps that herald the presence of emerging planets as they sweep their orbits clear of dust and gas. Credit: ALMA (NRAO/ESO/NAOJ); Crystal Brogan, Bill Saxton (NRAO/AUI/NSF).

TONY BEASLEY
NRAO Director

The National Radio Astronomy Observatory (NRAO) telescopes performed well in 2014, and the astronomy community harvested an enormous range of science made possible by National Science Foundation (NSF) support of the Atacama Large Millimeter/submillimeter Array (ALMA), the Karl G. Jansky Very Large Array (VLA), the Robert C. Byrd Green Bank Telescope (GBT), and the Very Long Baseline Array (VLBA).

The North American ALMA construction project was completed in September 2014 after a decade of global effort. The ramp-up to full ALMA science operations continued as the array conducted considerable science. NRAO – North American ALMA Science Center scientists were major contributors to outstanding progress on many technical campaigns that also resulted in stunning science-rich images.

The increasing capabilities of the VLA, GBT, and ALMA have opened a new era in radio surveys. Wide-band systems allow deep searches over enormous cosmic volumes, and pilot CO and HI surveys are underway. VLA continuum surveys are reaching micro-Jansky sensitivity at sub-arcsecond resolution over degree-area fields, providing an unobscured view of the history of star formation history and the evolution of supermassive black holes and cosmic magnetism. ALMA deep fields are informing our understanding of galaxy evolution back to the early Universe, and GBT wide-field cameras are conducting state-of-the-art line and continuum surveys, with science ranging from Galactic star formation to cosmology.

Community-led working groups are planning a new VLA Sky Survey. If approved, this survey will play a major role in the future VLA scientific program. Even when wide-field survey interferometers such as the Australian Square Kilometre Array Pathfinder are online, the VLA will still offer the highest spatial resolution for wide-field surveys.

Inspired by dramatic discoveries from the VLA and ALMA, the community has initiated discussion of a future centimeter-wavelength facility that will enable a quantum leap in imaging thermal emission from the cosmos at milliarcsecond resolution: a next generation Very Large Array (ngVLA). An NRAO-sponsored community workshop to discuss the ngVLA science cases and technical requirements will take place at the January 2015 American Astronomical Society meeting.

Exploring the time-domain will be a key discovery area of increasing community interest as the Large Synoptic Survey Telescope (LSST) comes to life. The improved power of NRAO telescopes is already being deployed to study the variable radio sky, and we are developing operational models and technical capabilities that enable rapid response studies with micro-Jansky sensitivity. If Fast Radio Bursts are real and extragalactic, as some suggest, they will have important implications for cosmology and physics.

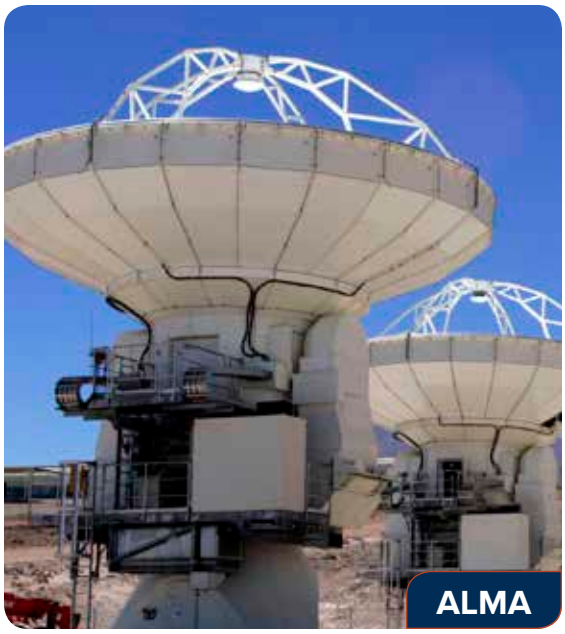
The VLBA continues to reveal the fundamental physics of high-energy phenomena from Galactic X-ray binaries to distant blazars. The community is effectively exploiting the VLBA's new fast response capability to study the early time evolution of Gamma Ray Bursts, steering onto sources within minutes of a high-energy trigger.

We continue to seek operations support for the NRAO telescopes – GBT and VLBA – recommended for divestment by the NSF Portfolio Review. In 2014 we increased the GBT and VLBA operations support levels outside the NSF, and new partnerships are being developed. This situation is not yet resolved, but progress continues.

The NSF process to compete the NRAO management contract resulted in a proposal by Associated Universities, Inc. (AUI) that charts their exciting vision for the Observatory over the next decade. An NSF decision regarding this award is expected in November 2015.

Building on the innovative science being performed with our existing facilities, the NRAO has initiated a community discussion on radio astronomy's future. Our staff are attacking the most difficult problems facing next-generation instruments including Big Data archiving, processing, and analysis; 3D visualization; wide-field, wide-band, high dynamic range polarimetric imaging; massively integrated receiver modules; THz receiver technology; phased array feeds; and more.

Our challenges are many, but so are our opportunities. The NRAO has a remarkable staff and the best telescopes and instruments in the world. We are a strong organization, undertaking interesting and important work, and dedicated to serving our community.

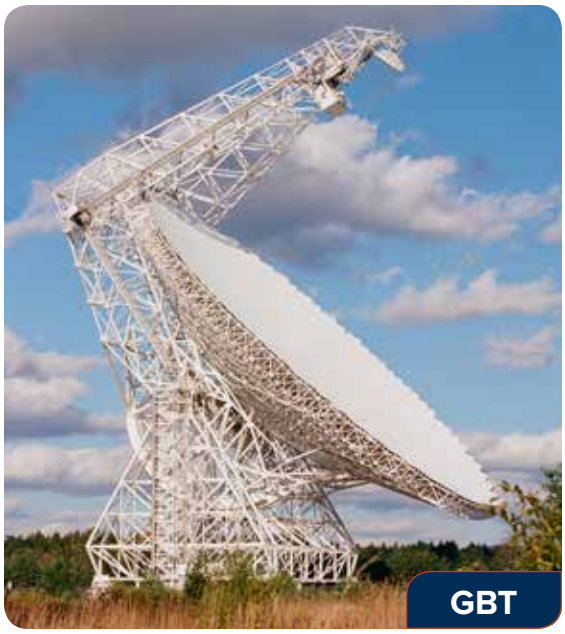


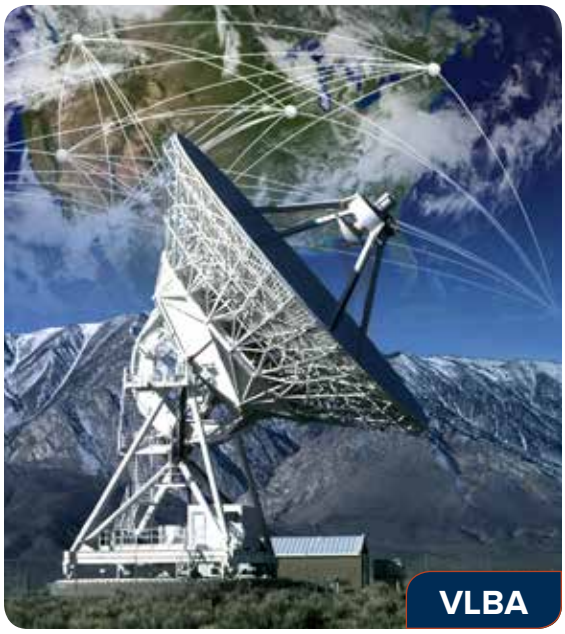
Created in 1956 by the National Science Foundation (NSF) and Associated Universities, Inc., the National Radio Astronomy Observatory designs, builds, and operates the most capable astronomical telescopes and instruments at radio wavelengths. In 2014, NRAO operated a complementary suite of four world-class telescopes, each the world leader in its domain: the international **Atacama Large Millimeter/submillimeter Array (ALMA**), the **Karl G. Jansky Very Large Array (VLA)**, the **Robert C. Byrd Green Bank Telescope (GBT)**, and the **Very Long Baseline Array (VLBA)**. Observing time on these telescopes is allocated solely on the scientific merit of the proposed research.

ALMA is the largest ground-based global astronomy endeavor in history. Composed of 66 high-precision antennas on an excellent, 5000m+ elevation site in northern Chile, ALMA is delivering orders of magnitude improvements in millimeter-wavelength sensitivity, frequency coverage, resolution, imaging, and spectral capabilities. ALMA's capabilities span wavelengths from 9.6 to 0.3 mm (31 – 950 GHz), a key part of the electromagnetic spectrum for observing the first stars and galaxies, directly imaging planetary formation, and studying the energy output from supermassive black holes in starburst galaxies. The first ALMA Early Science programs were completed in 2012, as construction continued. The community's strong interest in ALMA has been repeatedly demonstrated by the substantial over-subscription for its Early Science observing time.

The updated **Jansky VLA** has scientific capabilities at the adjacent centimeter-wavelength range that are comparable to ALMA and that exceed the original VLA capabilities by one to four orders of magnitude. These new capabilities were delivered on schedule and on budget via the Expanded Very Large Array Project, and the array is meeting all of the project's technical specifications and scientific objectives. The Very Large Array transitioned to full science operations in January 2013 as the world's most capable and versatile centimeter-wave imaging array and is yielding dramatic new science results that range from Galactic protostellar clouds to the molecular gas in early galaxies.

With comparable collecting area and sensitivity to ALMA and VLA, the **100m GBT** is the preeminent filled-aperture radio telescope operating at meter to millimeter wavelengths. Its 2.3 acre collecting area, unblocked aperture, and excellent surface accuracy enable a wide range of forefront science, including precision pulsar timing to detect gravitational wave radiation, testing the strong field limit of General Relativity, and observing distant neutral hydrogen emission.





The **VLBA** is the premier dedicated Very Long Baseline Interferometer (VLBI) array. Astrometry with the VLBA has reached the precision of a few micro-arcseconds, supporting distance and proper motion measurements of astronomical objects in the solar neighborhood, across the Milky Way, within the Local Group, and moving with the Hubble flow. When used in conjunction with the phased VLA and the GBT, the resultant High Sensitivity Array (HSA) greatly enhances the sensitivity for VLBI observations and broadens the range of novel scientific research.

The **Central Development Laboratory (CDL)** conducts the crucial research and development that continually improves operational NRAO telescopes and helps realize next generation facilities. CDL oversees a science-driven research and development program that supports the astronomy community's highest priority science goals, such as the detection of gravitational waves via pulsar timing, and the study of the epoch of reionization.

NRAO Headquarters in Charlottesville, Virginia is home to the **North American ALMA Science Center (NAASC)**, Business & Administration, Human Resources, Education & Public Outreach, Program Management, and the Director's Office.

NRAO telescopes are serving the broad and diverse astronomy community and are enabling university researchers to address many of the most fundamental astrophysical questions of our time. Operating individually or synergistically with optical, infrared, and X-ray telescopes, NRAO is opening new frontiers over a broad range of modern astrophysics. The Observatory's 2014 science highlights include advances in our understanding of: proto-planetary disks and extrasolar planet formation; astrochemistry; the early phases of star formation; pulsar physics; molecular gas in early, high-redshift disk and starburst galaxies; high energy physics; the environments of supermassive black holes; the 3D structure of star-forming regions in our Galaxy; the structure of our Galaxy; and much more.

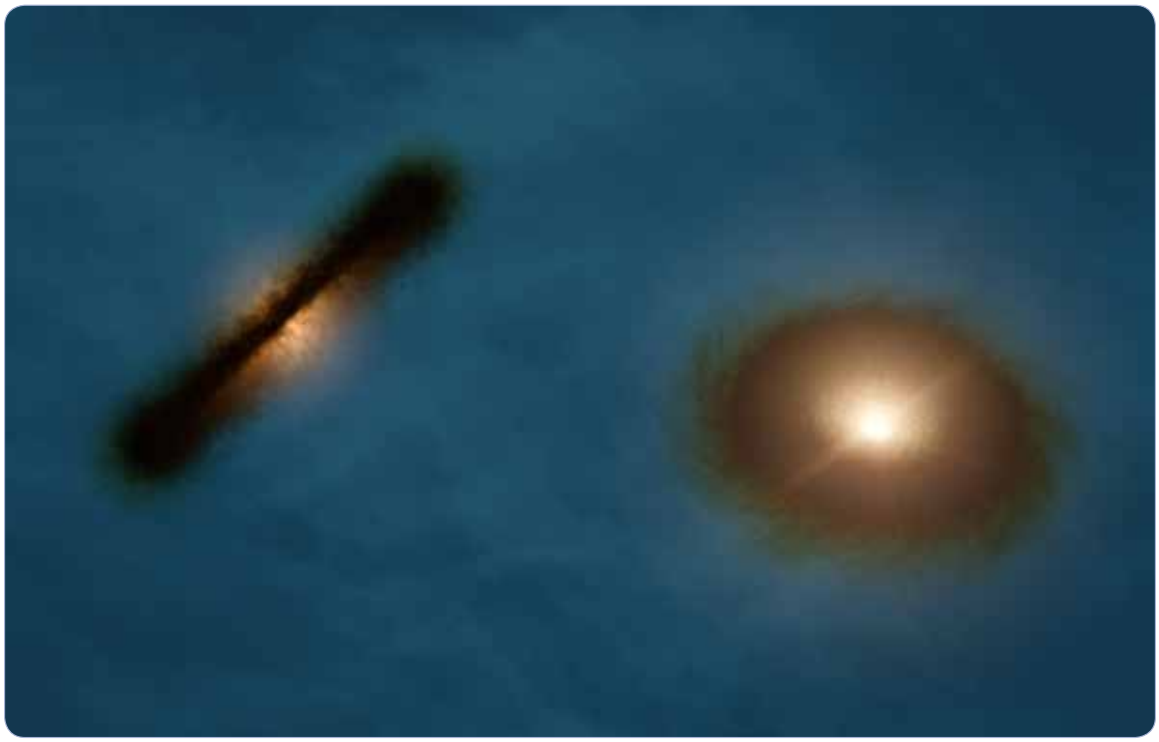
In addition to research, the NRAO broadly impacts science and society via its education and public outreach programs. NRAO science, technology, engineering, and mathematics (STEM) education programs are introducing numerous young people every year to the excitement and opportunities of STEM careers.

After more than five decades of continual improvement under AUI management, the NRAO comprises the nation's core competency in radio astronomy, an invaluable resource for the astronomy community in the U.S. and around the world.

Misaligned Disks in a Young Binary System

Many extrasolar planets follow orbits that differ from the nearly coplanar and circular orbits found in our Solar System. Extrasolar planet orbits may be eccentric or inclined with respect to the host star's equator, and the population of giant planets orbiting close to their host stars suggests appreciable orbital migration. There is no consensus regarding what produces such orbits. Theoretical explanations often invoke interactions with a binary companion star in an orbit that is inclined relative to the planet's orbital plane. Such mechanisms require significant mutual inclinations between the planetary and binary star orbital planes. The protoplanetary disks in a few young binaries are misaligned, but often the measurements of these misalignments are sensitive only to a small portion of the inner disk, and the three-dimensional misalignment of the bulk of the planet-forming disk mass has hitherto not been determined.

Based on millimeter (mm) wave observations of the young binary system HK Tauri with ALMA, Jensen and Akeson report that the protoplanetary disks in this system are misaligned by 60 to 68 degrees, such that one or both of the disks are significantly inclined to the binary orbital plane. Their results demonstrate that the necessary conditions exist for misalignment-driven mechanisms to modify planetary orbits, and that these conditions are present at the time of planet formation, apparently because of the binary formation process.

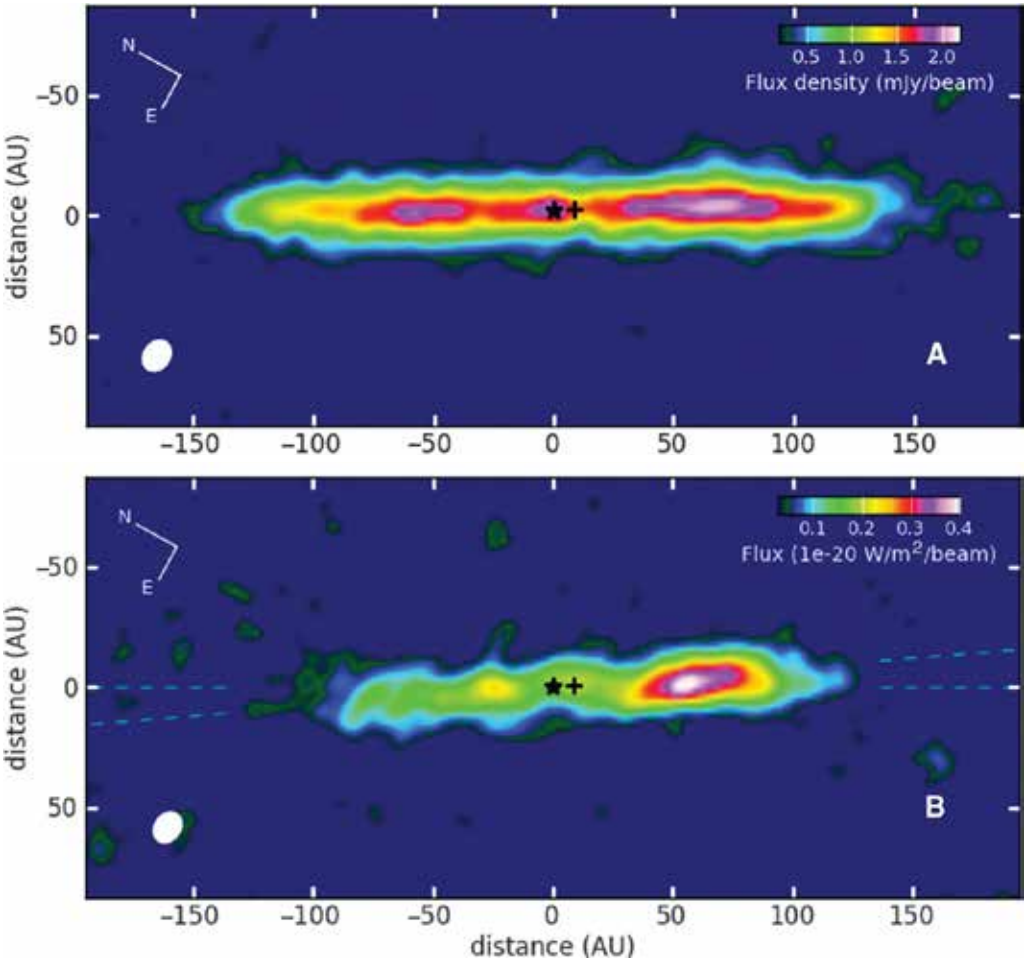


An artist's impression of the misaligned protoplanetary disks around the binary stars in HK Tau. Credit: R. Hurt (NASA/JPL-Caltech/IPAC)

Science Team: Eric L.N. Jensen (Swarthmore) and Rachel Akeson (IPAC/Caltech). Publication: *Misaligned Protoplanetary Disks in a Young Binary Star System,* 2014 Nature, 511, 567 (31 July 2014)

Icy Wreckage in a Nearby Solar System

Protoplanetary disks of dusty debris around young stars are formed by collisions of asteroids, comets, and dwarf planets. ALMA observations of the archetypal debris disk around β Pictoris show that 0.3% of a Moon mass of CO orbits in its debris belt. The gas distribution is highly asymmetric, with 30% found in a single clump 85 AU from the star, in a plane closely aligned with the orbit of the inner planet, β Pic b. CO will dissociate in 100 years so close to the star, implying active CO deposition in the disk. This gas clump likely delineates a region of enhanced cometary collisions, either from a mean motion resonance with an unseen giant planet, or from the remnants of a collision of icy Mars-mass planets.

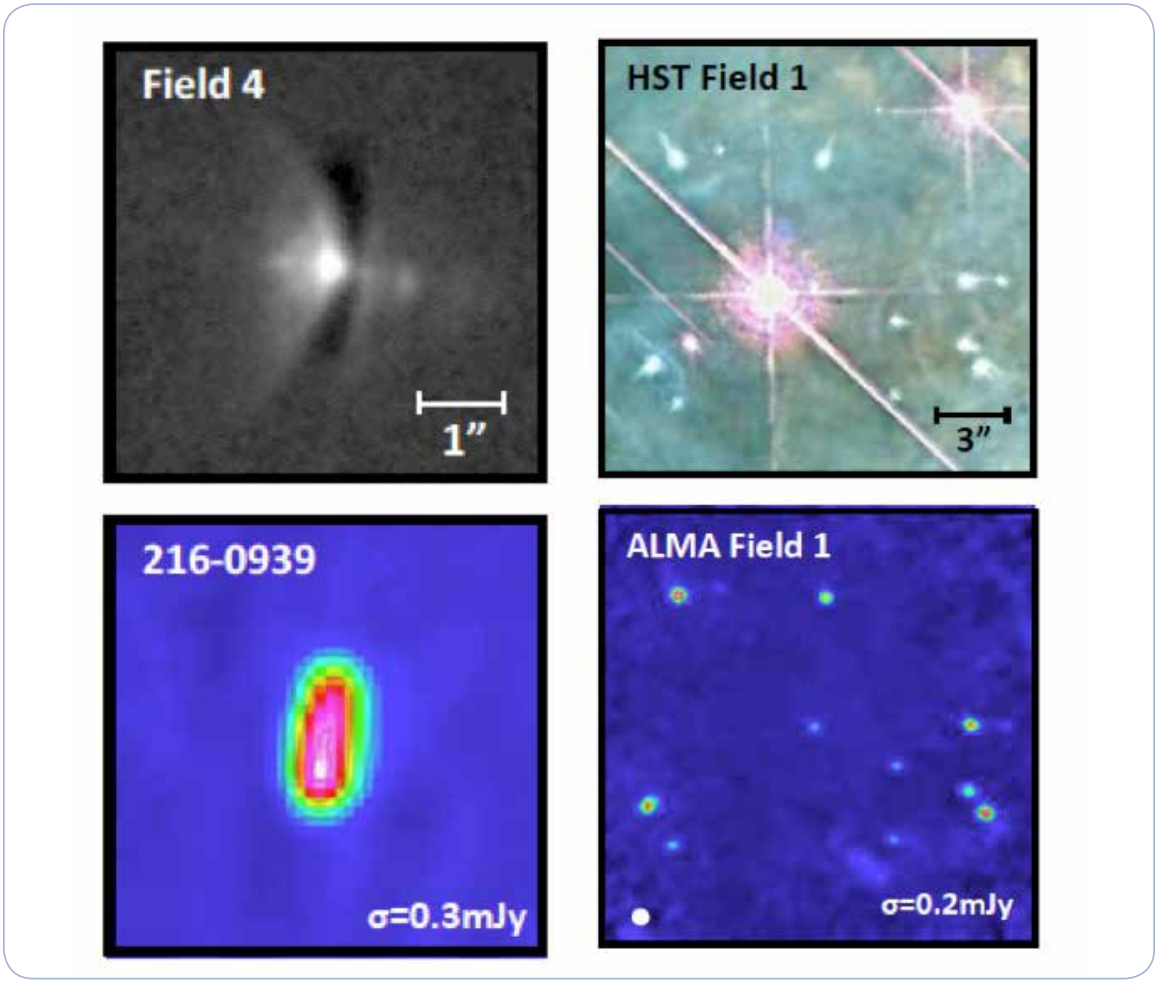


ALMA image of the β Pic dust continuum at 870 mm **[Top]** *and the CO 3-2 emission at 346 GHz* **[Bottom]**.

Science Team: W. R. F. Dent (JAO), M. C. Wyatt (Cambridge), A. Roberge (NASA-Goddard), J.-C. Augereau (Grenoble), S. Casassus (Univ de Chile), S. Corder (JAO), J. S. Greaves (St. Andrews), I. de Gregorio-Monsalvo (JAO, ESO), A. Hales (JAO), A. P. Jackson (Cambridge, Arizona State), A. Meredith Hughes (Wesleyan), A.-M. Lagrange (Grenoble), B. Matthews (NRC, Victoria), and D. Wilner (SAO). Publication: *Molecular Gas Clumps from the Destruction of Icy Bodies in the β Pictoris Debris Disk,* 2014 Science, 343, 1490 (28 March 2014).

Hot Stars Evaporating Disks in Orion

ALMA has imaged the sub-millimeter thermal continuum emission from a large sample of protoplanetary disks in Orion, known as proplyds, seen in Hubble Space Telescope (HST) images as dusty shadows or reflected light. ALMA detects most of these systems, with implied dust masses from 0.3 to 79 $M_{Jupiter}$. An anti-correlation is seen between regions of the most intense ultraviolet interstellar radiation field and the existence of massive proplyd disks, indicating the extreme impact O stars have on their local environments. These results suggest that a rapid dissipation of disk masses likely inhibits potential planet formation in the extreme-UV-dominated regions of OB associations.



[Top] *HST images from Bally et al. (2000, AJ, 119, 2919) of fields observed with ALMA in Cycle 0.* **[Bottom]** *Corresponding ALMA 856 μm observations. Each image is 20 x 20 arcsec.*

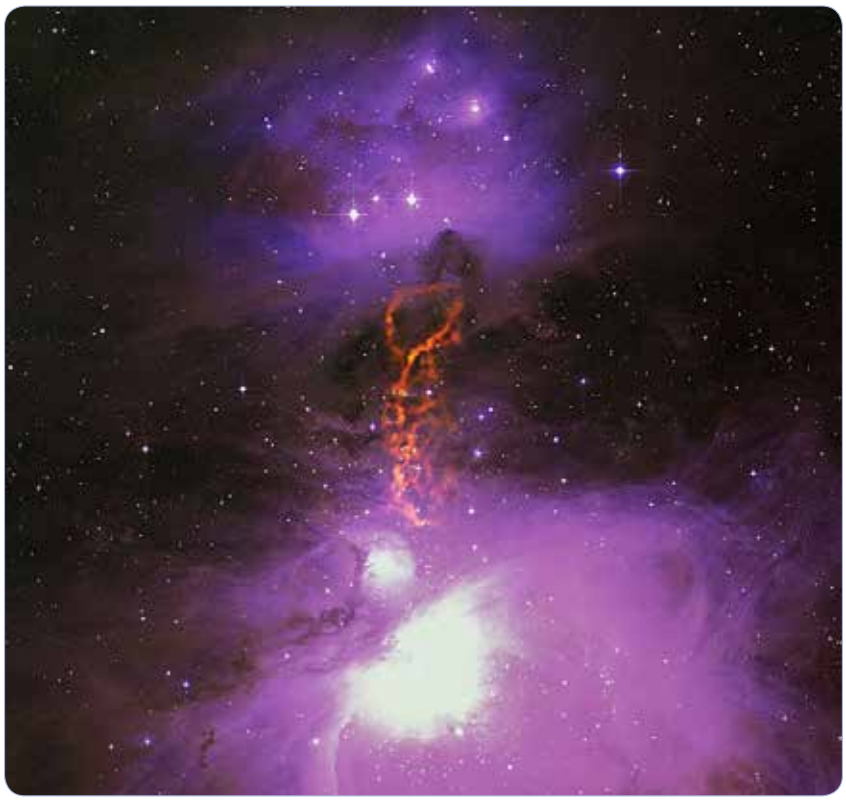
Science Team: Rita K. Mann (NRC), James Di Francesco (NRC, Victoria), Doug Johnstone (NRC, Victoria, JAC), Sean M. Andrews (CfA), Jonathan P. Williams (IfA-Hawaii), John Bally (Colorado), Luca Ricci (Caltech), A. Meredith Hughes (Wesleyan), and Brenda Matthews (NRC, Victoria), Publication: *ALMA Observations of the Orion Proplyds,* 2014 Astrophysical Journal, 784, 82 (20 March 2014).

Pebble-size Particles May Jump-start Planet Formation

The star-forming material in the Orion molecular cloud complex OMC-2/3 is organized into a skein of twisted dust-rich filaments dotted with many dense cores. Thermal continuum emission from the dust can be detected at mm-wavelengths, while the gas temperature in the dense cores has been derived from NH_3 line ratios measured with the VLA and GBT. Thermal emission from dust is modeled as a modified blackbody spectrum with a frequency dependence given by the power-law slope β, the emissivity spectral index. β varies with location in the interstellar medium and with the stage of a protostar's evolution. In molecular clouds and cloud cores it has a typical value of +1.5 to +2.5.

Recent measurements in the 3.3 mm continuum using the MUSTANG bolometer array on the GBT by Scott Schnee et al. show that the filaments are significantly brighter than expected and thus imply a low value of $\beta < 1$. An index this low has been seen previously only in disks around pre-main sequence stars and brown dwarfs, and has been attributed to emission from dust grains with sizes up to a few mm.

These GBT OMC-2/3 results suggest the presence of large grains or pebbles of at least 1 mm, and perhaps as large as 1 cm, in the dense parts of the filament. These grains are much larger than typically found in the diffuse interstellar medium, and this would be the first report of large grains in structures with scales on the order of 1 pc. Although a power-law spectrum has been used successfully to model dust emission from many different environments, the shallow spectral index between 1 and 3 mm could alternatively indicate that a more complex model is needed



A radio – optical composite of the Orion Molecular Cloud Complex and the OMC-2/3 star-forming filament. The orange filaments at image center are the GBT data.

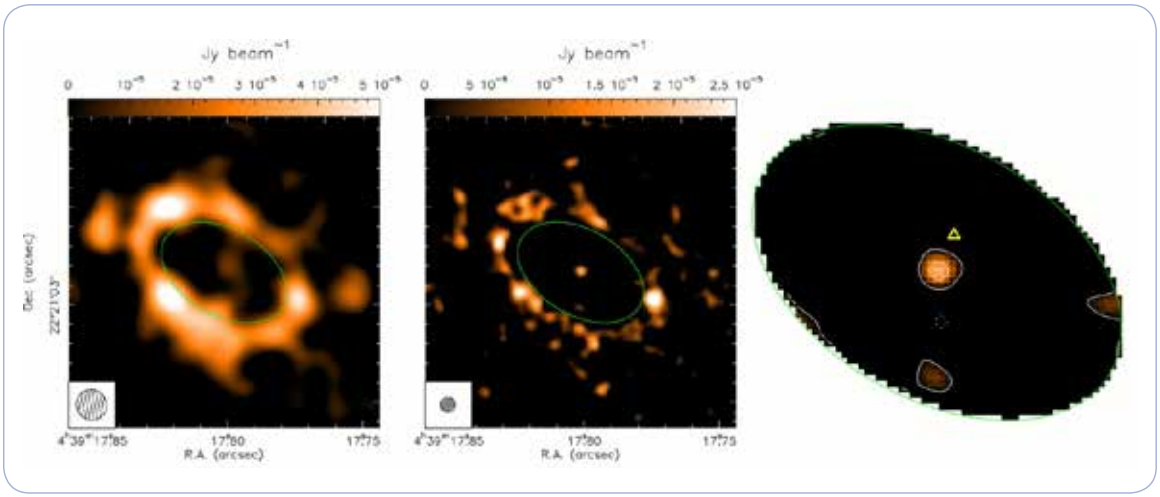
Science Team: S. Schnee (NRAO), B. Mason (NRAO), J. Di Francesco (NRC-Canada, Victoria), R. Friesen (NRAO, Toronto), D. Li (NAO-Chinese Academy of Science, SSI), S. Sadavoy (MPIfA) and T. Stanke (ESO). Publication: *Evidence for Large Grains in the Star-forming Filament OMC-2/3,* 2014 Monthly Notices of the Royal Astronomical Society, 444, 2303 (1 November 2014).

Probing Circumplanetary Disks

Isella et al. acquired VLA observations of the 7 mm continuum emission from the disk surrounding the young star LkCa 15 at an angular resolution of 70 milli-arcseconds that resolve the circumstellar emission on a spatial scale of 9 AU. The continuum emission traces a dusty annulus of 45 AU in radius that is consistent with the dust morphology observed at shorter wavelengths.

The VLA observations also reveal a compact source at the center of the disk, possibly due to thermal emission from hot dust or ionized gas located within a few AU from the central star. No emission is observed between the star and the dusty ring and, in particular, at the position of the candidate protoplanet LkCa 15b.

By comparing the observations with theoretical models for circumplanetary disk emission, the authors find that if LkCa 15b is a massive planet (>5$M_{Jupiter}$) accreting at a rate greater than 10^{-6} $M_{Jupiter}$ yr^{-1}, then its circumplanetary disk is less massive than 0.1$M_{Jupiter}$, or smaller than 0.4 Hill radii. Similar constraints are derived for any possible circumplanetary disk orbiting within 45 AU from the central star. The mass estimates are uncertain by at least one order of magnitude due to the mass opacity uncertainties. Future ALMA observations of this system might be able to detect circumplanetary disks down to a mass of 5 x 10^{-4} $M_{Jupiter}$ and as small as 0.2 AU, providing crucial constraints on the presence of giant planets in the act of forming around this young star.



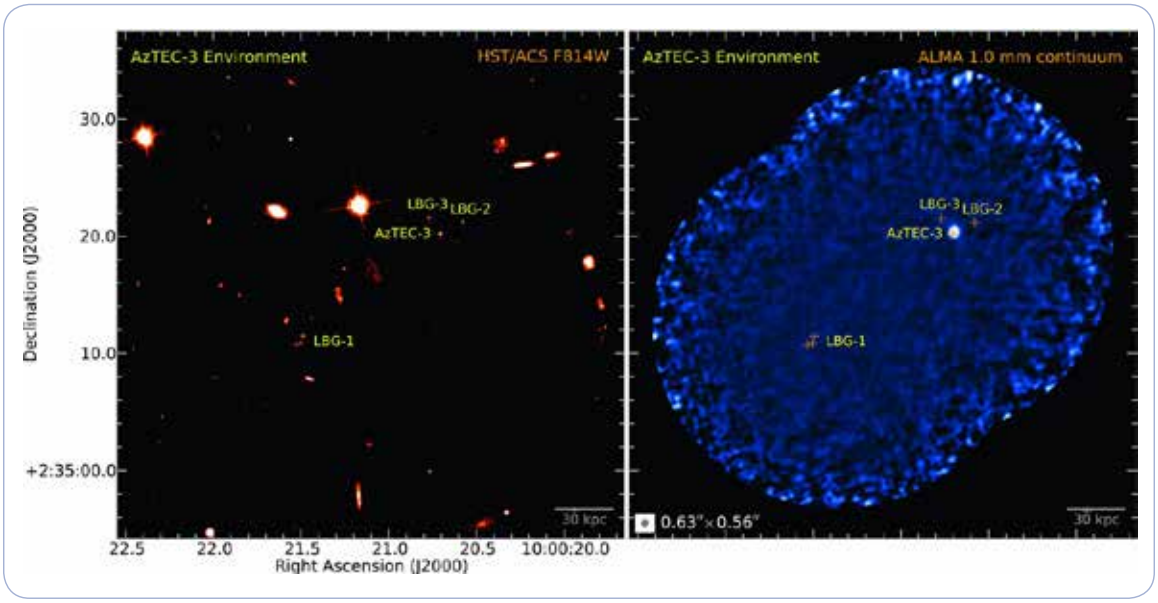
[Left] *1.6 x 1.6 arcsec map of the LkCa 15 continuum disk emission observed at 7 mm obtained by reducing the weights of the complex visibilities measured on the longest baselines to increase the sensitivity of the extended structures. The rms noise is 6.1 μJy beam^{-1} and the synthesized beam is 0.15 arcsec FWHM.* **[Center]** *The 7 mm emission map obtained by adopting natural weighting of the complex visibilities to maximize the angular resolution and the point source sensitivity. The rms noise level is 3.6 μJy beam–1, and the synthesized beam is 0.07 arcsec FWHM. The green ellipse corresponds to an orbital radius of 45 AU and traces the outer edge of the dust-depleted cavity as measured from the observations at 1.3 mm.* **[Right]** *A map of the innermost 45 AU disk region. Contours are plotted at two and four times the noise. The triangle shows the expected position of LkCa 15 b (Kraus & Ireland 2012) assuming the star is located at the peak of the 7 mm emission.*

.Science Team: Andrea Isella (Caltech), Claire J. Chandler (NRAO), John M. Carpenter (Caltech), Laura M. Pérez (NRAO), and Luca Ricci (Caltech). Publication: *Searching for Circumplanetary Disks Around LkCa 15,* 2014 Astrophysical Journal, 788, 129 (20 June 2014).

Imaging the Dynamics of Normal Galaxy Formation

Riechers et al. report ALMA interferometric imaging of [C II] and OH emission toward the center of the galaxy protocluster associated with the z = 5.3 submillimeter galaxy (SMG) AzTEC-3. Strong [C II], OH, and rest-frame 158 μm continuum emission are detected toward the SMG. The [C II] emission is distributed over a scale of 3.9 kpc, implying a dynamical mass of 9.7 x 10^{10} $M_{\odot}$, and a star formation rate (SFR) surface density of 530 $M_{\odot}$ yr^{-1} kpc^{-2}.

This suggests that AzTEC-3 forms stars at SFR surface density approaching the Eddington limit for radiation pressure supported disks. The authors also find that the OH emission is slightly blueshifted relative to the [C II] line, perhaps indicating a molecular outflow associated with the peak phase of the starburst. They also detect and dynamically resolve [C II] emission over a scale of 7.5 kpc toward a triplet of Lyman-break galaxies with moderate UV-based SFRs in the protocluster at ~95 kpc projected distance from the SMG. These galaxies are not detected in the continuum, suggesting far-infrared SFRs of <18–54 $M_{\odot}$ yr^{-1}, consistent with a UV-based estimate of 22 $M_{\odot}$ yr^{-1}. The spectral energy distribution of these galaxies is inconsistent with nearby spiral and starburst galaxies, but resembles those of dwarf galaxies. This is consistent with expectations for young starbursts without significant older stellar populations. This suggests that these galaxies are significantly metal-enriched, but not heavily dust-obscured, "normal" star-forming galaxies at z > 5, showing that ALMA can detect the interstellar medium in "typical" galaxies in the very early Universe. The [CII] 158μm line is fulfilling its potential as a unique tracer of early galaxy dynamics and as a redshift indicator, even for galaxies without extreme starbursts



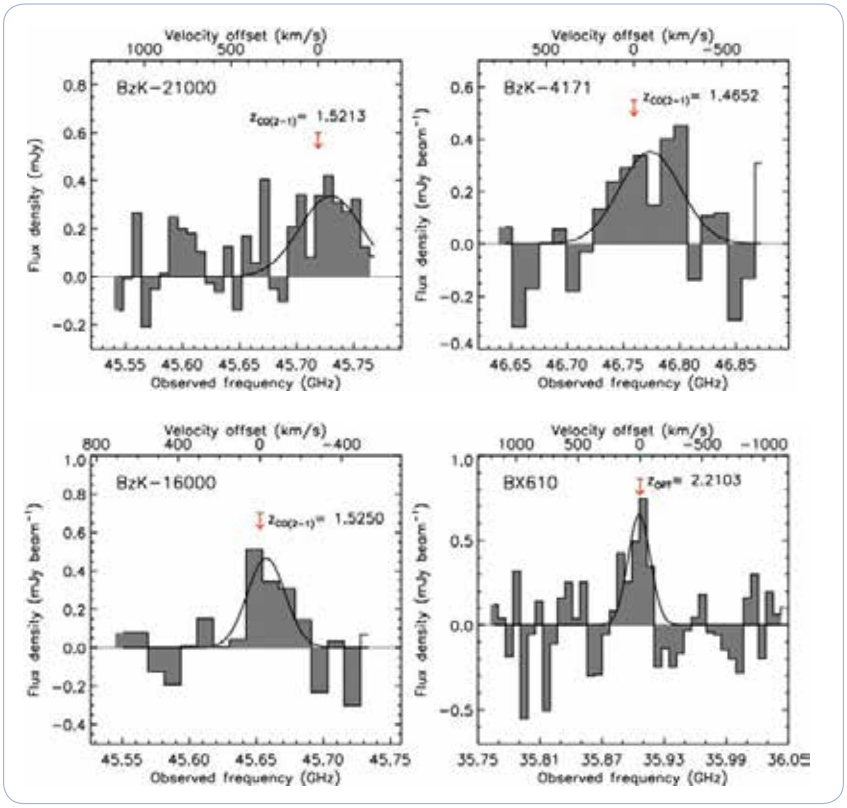
The Hubble Space Telescope F814W (left) and ALMA 1.0 mm continuum image (right, rest-frame 157.7 μm) covering AzTEC-3 at z = 5.3 and five candidate companion Lyman-break galaxies (indicated by plus signs; LBG-1 contains three components). The ALMA synthesized 0.63 x 0.56 arcsec beam is shown in the bottom left of the right panel.

Science Team: Dominik A. Riechers (Cornell), Christopher L. Carilli (NRAO), Peter L. Capak (IPAC), Nicholas Z. Scoville (Caltech), Vernesa Smolcic (Caltech), Eva Schinnerer (MPIfA), Min Yun (Massachusetts), Pierre Cox (ALMA), Frank Bertoldi (Bonn), Alexander Karim (Bonn), and Lin Yan (IPAC). **Publication:** *ALMA Imaging of Gas and Dust in a Galaxy Protocluster at Redshift 5.3,* 2014 Astrophysical Journal, 796, 84 (1 December 2014).

Imaging Massive Star-forming Disk Galaxies

VLA observations have shown that typical star-forming galaxies contain massive reservoirs of cool molecular gas during the peak epoch of cosmic star formation (z ~ 1 to 3). The gas to stellar mass ratio changes from 0.1 in nearby disk galaxies, to greater than 1.0 at z ~ 2. This order of magnitude increase in the molecular baryon fraction drives the increased cosmic star formation rate during the epoch of galaxy assembly.

Aravena et al. present detections of the CO(1–0) emission line with the VLA in a sample of four massive star-forming galaxies at z ~ 1.5 – 2.2. Combining these data with previous CO(2–1) and CO(3–2) detections of these galaxies, the authors study the excitation properties of the molecular gas in their sample sources, finding average line brightness temperature ratios of R_{21} = 0.70 ± 0.16 and R_{31} = 0.50 ± 0.29. These results provide additional support to previous indications of sub-thermal gas excitation for the CO(3–2) line with a typically assumed line ratio R_{31} ~ 0.5. For the galaxy BzK-21000, the authors present spatially resolved CO line maps. At a resolution of 0.18 arcsec (1.5 kpc), most of the emission is resolved out except for some clumpy structure. From this, the authors attempt to identify molecular gas clumps in the data cube, finding four possible candidates. They estimate that < 40% of the molecular gas is confined to giant clumps (~ 1.5 kpc in size) and, thus, most of the gas could be distributed in small fainter clouds or in fairly diffuse extended regions of lower brightness temperatures than our sensitivity limit.



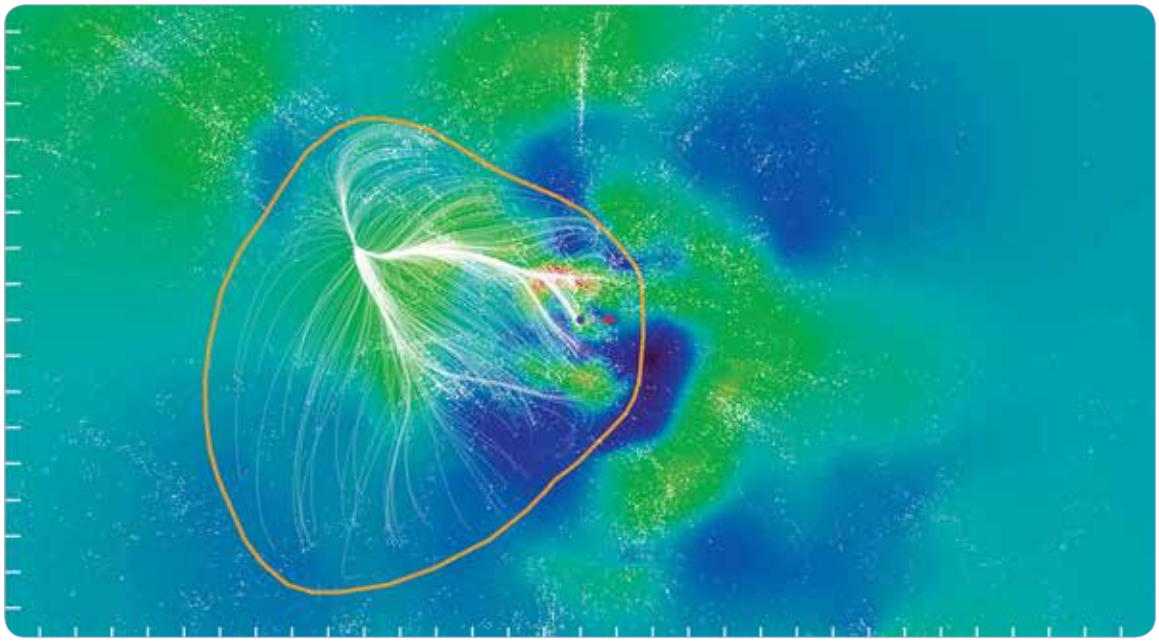
CO(1–0) spectra obtained for the four targets.The BzK-21000 spectra were obtained in a circular 2 arcsec aperture enclosing most of the CO emission. The spectral resolution is ~50 km/sec for BzK-21000, ~60 km/sec for BX610, and ~80 km/sec for BzK-4171 and BzK-16000. The red arrows indicate the frequency of the CO(1–0) line based on the previously determined CO(2–1) redshift (Daddi et al. 2010a). For BX610, the red arrow shows the frequency of the CO(1–0) line using the optical redshift (Erb et al. 2006; Förster Schreiber et al. 2009, 2011).

Science Team: M. Aravena (Diego Portales, ESO), J.A. Hodge (NRAO), J. Wagg (SKA), C.L. Carilli (NRAO, Cambridge), E. Daddi (CEA), H. Dannerbauer (Wien), L. Lentati (Cambridge), D.A. Riechers (Cornell), M. Sargent (Sussex), and F. Walter (MPIfA). Publication: *CO(1-0) Line Imaging of Massive Star-forming Disc Galaxies at z = 1.5-2.2,* 2014 Monthly Notices of the Royal Astronomical Society, 442, 558 (21 July 2014).

A Newly Identified Galactic Supercluster is Home to our Milky Way

Galaxies congregate in clusters and along filaments, and are missing from large regions known as voids. Spectroscopic surveys reveal networks of interconnected structure that lack clear boundaries. Extended regions with a high concentration of galaxies are called superclusters. There is, however, another way to analyze the structure. If each galaxy distance is directly measured, then the peculiar velocity – the line-of-sight departure from the cosmic expansion that arises from gravitational perturbations – can be derived. A map of peculiar velocities can be translated into a map of matter distribution.

Using galaxy peculiar velocities measured out to a distance of ~100 Mpc, many from the GBT, Tully et al. have created a structure map and identified "gravity sheds", analogous to "water sheds", around which velocities diverge. The surface defined by these gravity sheds sets the boundary of local large-scale structure that has separated from the Hubble flow, and hence our home supercluster. The authors find a filamentary lattice that includes the Great Attractor and our previously known supercluster. The region contains 10^5 galaxies, and a total gravitating mass of 10^{17} $M_{\odot}$. The authors have named this filamentary lattice Laniakea, which means "immense heaven" in the Hawaiian language.

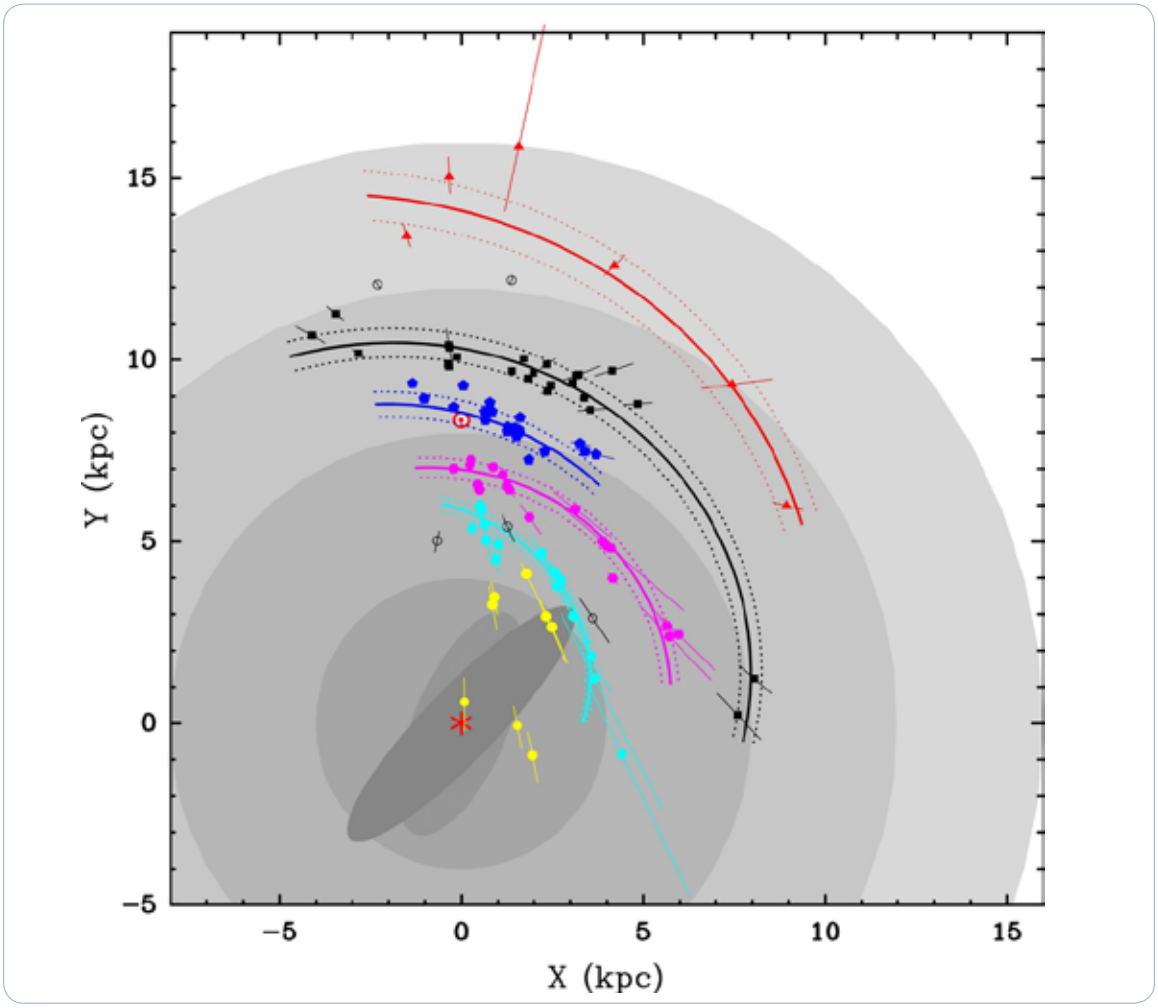


A slice of the Laniakea Supercluster. Colors represent density: red for high densities and blue for voids. White dots are individual galaxies. Velocity flow streams within the region gravitationally dominated by Laniakea are white, while dark blue flow lines are away from the Laniakea basin of attraction. The orange contour encloses the outer limits of these streams, a diameter of ~160 Mpc. Credit: SDvision visualization software by DP at CEA/Saclay, France.

Science Team: R. Brent Tully (IfA), Hélène Courtois (Lyon I), Yehuda Hoffman (Hebrew), and Daniel Pomarède (CEA/Saclay).
Publication: *Mapping the Laniakea Supercluster of Galaxies,* 2014 Nature, 513, 71 (4 September 2014).

Mapping the Milky Way in Unprecedented Detail

Over 100 trigonometric parallaxes and proper motions for masers associated with high-mass stars have been measured by the Bar and Spiral Structure Legacy Survey (BeSSeL). This publication represents a major milestone in VLBA astrometry. These measurements provide strong evidence for the existence of spiral arms in the Milky Way, accurately locating many arm segments and yielding spiral pitch angles ranging from 7° to 20°. The widths of spiral arms increase with distance from the Galactic center. The distance to the Galactic center is 8.34 ± 0.16 kpc, and the circular rotation speed at the Sun is 240 ± 8 km/sec. The rotation curve is nearly flat between Galactocentric radii of = 5 and 16 kpc, and the solar motion component in the direction of Galactic rotation is 14.6 ± 5.0 km/sec.



Plan view of the Milky Way showing the locations of high-mass star forming regions with trigonometric parallaxes measured by the VLBA, VLBI Exploration of Radio Astrometry (VERA), and the European VLBI Network (EVN).

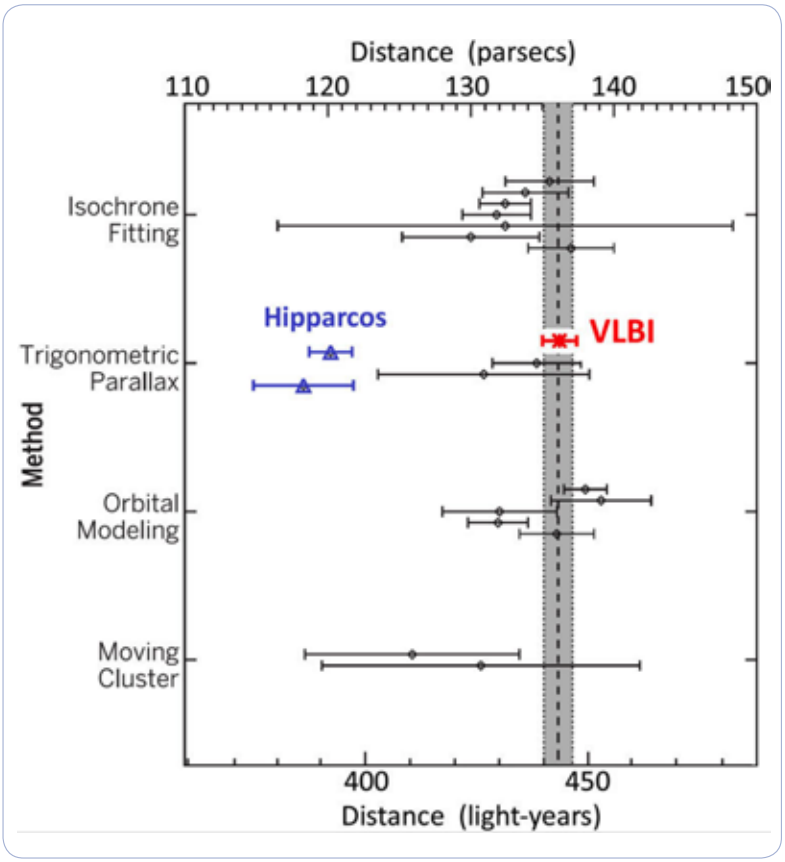
Science Team: M.J. Reid (CfA), K.M. Menten (MPIfR), A. Brunthaler (MPIfR), X.W. Zheng (Nanjing), T.M. Dame (CfA), Y. Xu (Purple Mountain), Y. Wu (MPIfR), B. Zhang (MPIfR), A. Sanna (MPIfR), and M. Sato (MPIfR). Publication: *Trigonometric Parallaxes of High Mass Star Forming Regions: The Structure and Kinematics of the Milky Way*, 2014 Astrophysical Journal, 783, 130 (10 March 2014).

Resolving the Pleiades Distance Controversy

The Pleiades hold an important place in our understanding of stellar evolution. Its hundreds of young stars help to define the zero-age main sequence and serve as templates for determining the physical characteristics of more distant stars. Because many derived physical properties of stars depend on their distance raised to some power, the distance to the Pleiades is an important measurement whose accuracy propagates throughout modern stellar physics.

It was of some concern, therefore, when results from the *Hipparcos* astrometric satellite suggested that the traditional distance to the Pleiades – about 135 pc via multiple techniques – was 10% too high and that the cluster was located only 120 pc away. At the closer distance some stars in the Pleiades would be decidedly peculiar, possibly implying enhanced helium abundances and hinting of serious flaws in our understanding of fundamental stellar evolution.

To resolve the issue a research team led by Carl Melis undertook a campaign of precise radio astrometry on several Pleiades stars that are weak radio sources and measured their annual stellar parallax with respect to a background quasar over ~18 months. Because of the weakness of the radio signal, a telescope network was used that included the VLBA, GBT, Arecibo and Effelsberg. The resultant distances to four stars had uncertainties of 0.5 to 1.1 pc, a 99+% precision. After taking into account that the stars are likely at different depths in the cluster, an effect estimated from the cluster's angular size, the very long baseline interferometry measurements yield a distance for the combined sample of 136.2 ± 1.2 pc. This is the most accurate and precise distance measurement for the Pleiades, and is compatible with most previous measurements, except for the *Hipparcos* satellite.



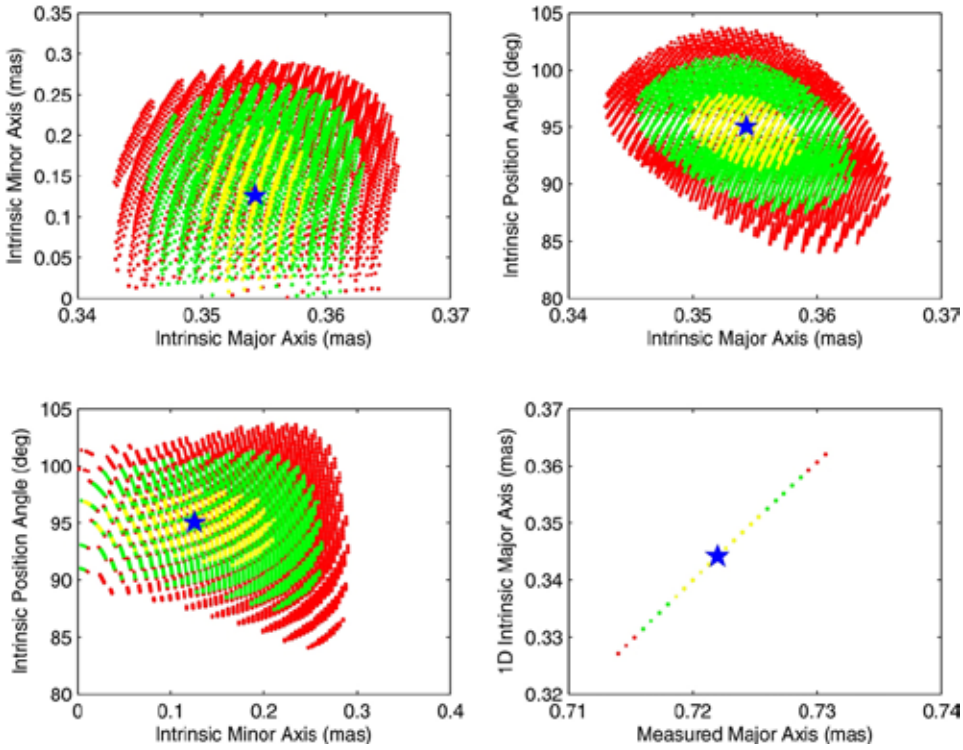
A summary of the Pleiades distance measurements.

Science Team: Carl Melis (UC, San Diego), M.J. Reid (CfA), A.J. Mioduszewski (NRAO), J.R. Stauffer (SSC), and G.C. Bower (UC, Berkeley). Publication: *Toward a VLBI resolution of the Pleiades distance controversy,* 2014 Science, 345, 1029 (29 August 2014).

The Intrinsic Size of Sgr A*

Bower et al. have used the VLBA at a wavelength of 7mm to make the best measurement to date of the intrinsic size and two-dimensional structure of the radio source associated with the Galactic Center black hole, SgrA*. The intrinsic source is modeled as an elliptical Gaussian with major x minor axis size of 35.4 x 12.6 Schwarzschild radii in position angle 95 deg East of North. This morphology can be interpreted in the context of both jet and accretion disk models for the radio emission.

The authors have also placed a maximum peak-to-peak change of 15% in the intrinsic major axis size over five different epochs. Three observations were triggered by detection of near infrared (NIR) flares and one was simultaneous with a large X-ray flare detected by the Nuclear Spectroscopic Telescope Array. The absence of simultaneous and quasi-simultaneous flares indicates that not all high-energy events produce variability at radio wavelengths. This supports the conclusion that NIR and X-ray flares are primarily due to electron excitation and not to an enhanced accretion rate onto the black hole.



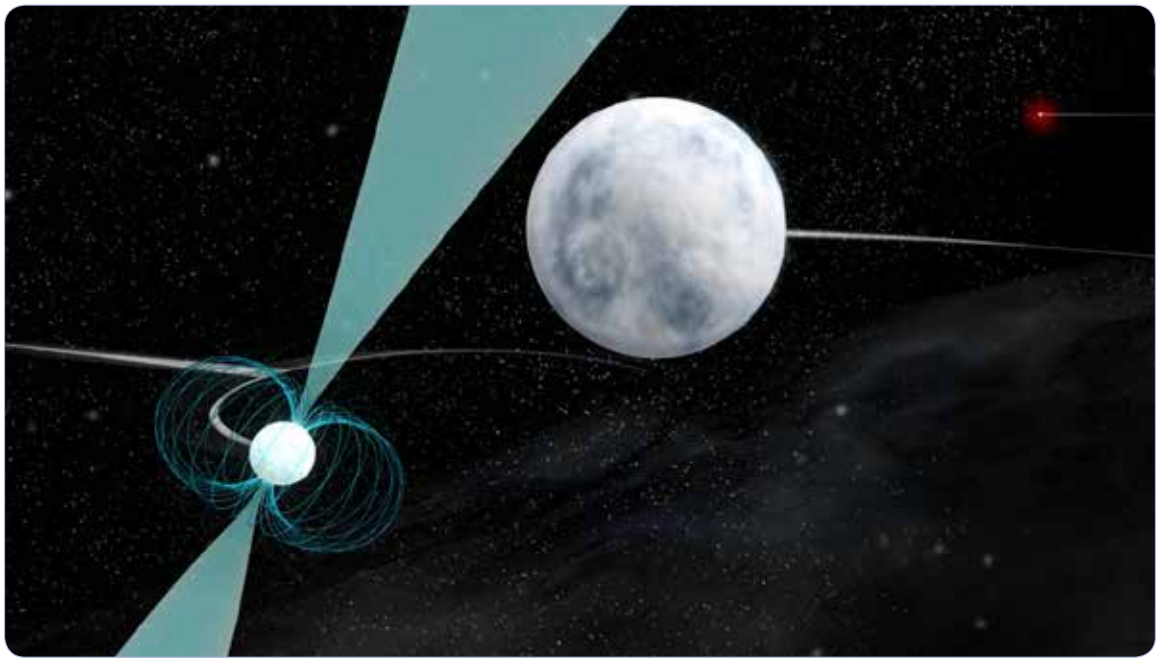
Two-dimensional and one-dimensional intrinsic size estimates for Sgr A. Two-dimensional solutions were obtained through deconvolution of all apparent sizes with the two-dimensional scattering size within the 3σ error surface. Colors show solutions that are <1σ (yellow), between 1 and 2σ (green), and between 2 and 3σ (red). Slices through the parameter space at the position of the best-fit position angle, minor axis, and major axis are shown (upper left, upper right, and lower left, respectively). The blue star indicates the best-fit size. The lower right panel illustrates the intrinsic size determined using only the measured major axis size. The same color-coding applies to this panel. The plots show that the maximum intrinsic minor-axis value never reaches the minimum permitted value for the major axis; that is, the intrinsic source must be elliptical.*

Science Team: Geoffrey C. Bower (Berkeley, ASIAA), Sera Markoff (Amsterdam), Andreas Brunthaler (MPIfR), Casey Law (Berkeley), Heino Falcke (MPIfR, Radboud, ASTRON), Dipankar Maitra (Wheaton), M. Clavel (Paris, CEA Saclay), A. Goldwurm (Paris, CEA Saclay), M.R. Morris (UCLA), Gunther Witzel (UCLA), Leo Meyer (UCLA), and A.M. Ghez (UCLA). Publication: *The Intrinsic Two-Dimensional Size of Sagittarius A*,* 2014 Astrophysical Journal, 790, 1 (20 July 2014).

A Unique Gravitational Laboratory

Gravitationally bound three-body systems show complex orbital interactions, which can constrain the compositions, masses and interior structures of the bodies and test theories of gravity, if sufficiently precise measurements are available. A triple system containing a radio pulsar could provide such measurements, but the only previously known such system, PSR B1620-26 – with a millisecond pulsar, a white dwarf, and a planetary-mass object in an orbit of several decades – shows only weak interactions.

In this paper, Ransom et al. report precision timing and multi-wavelength observations of PSR J0337+1715, the only known millisecond pulsar in a triple system, recently discovered as part of a large-scale pulsar survey with the GBT. Strong gravitational interactions are apparent and provide the masses of the pulsar the two white dwarf companions, as well as the inclinations of the orbits. The unexpectedly coplanar and nearly circular orbits indicate a complex and exotic evolutionary past that differs from those of known stellar systems. The gravitational field of the outer white dwarf strongly accelerates the inner binary containing the neutron star, and the system will thus provide an ideal laboratory to test the strong equivalence principle of General Relativity.

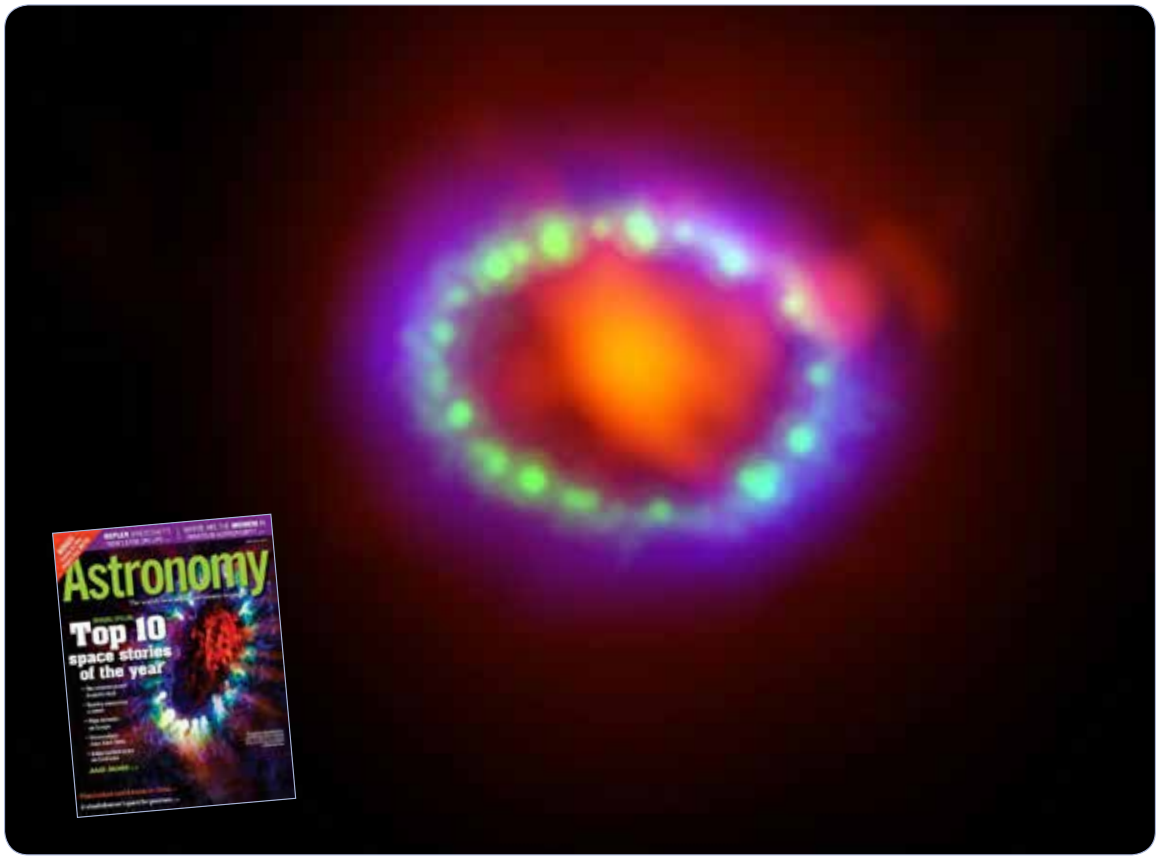


A hot white dwarf (center) orbits a millisecond pulsar (left foreground), each of which orbit another, more distant and cooler white dwarf (top right). Credit: Bill Saxton; NRAO/AUI/NSF

Science Team: S.M. Ransom (NRAO), I.H. Stairs (UBC), A.M. Archibald (ASTRON, McGill), J.W.T. Hessles (ASTRON, Amsterdam), D.L. Kaplan (Wisconsin), M.H. van Kerkwijk (Toronto), J. Boyles (WVU, WKU), A.T. Deller (ASTRON), S. Chatterjee (Cornell), A. Schectman-Rook (Wisconsin-Madison), A. Berndsen (UBS), R.S. Lynch (McGill), D.R. Lorimer (WVU), C. Karako-Argaman (McGill), V.M. Kaspi (McGill), V.I. Kondratiev (ASTRON, Lebedev), M.A. McLaughlin (WVU), J. van Leeuwen (ASTRON, Amsterdam), R. Rosen (NRAO, WVU), M.S.E. Roberts (Eureka, NYU), and K. Stovall (UT-Brownsville, UNM). Publication: *A Milli-second pulsar in a Stellar Triple System,* 2014 Nature, 505, 520 (23 January 2014).

A Supernova Dust Factory

Supernova (SN) explosions are crucial engines driving the evolution of galaxies by shock heating gas, increasing the metallicity, creating dust, and accelerating energetic particles. In 2012, Indebetouw et al. used ALMA to observe SN 1987A, one of the best-observed supernovae, and acquire spatially resolved images at 450μm, 870μm, 1.4mm, and 2.8mm, an important transition wavelength range. The longer wavelength emission is dominated by synchrotron radiation from shock-accelerated particles; the shorter wavelength emission is from the largest mass of dust measured in a supernova remnant (>0.2 $M_{\odot}$). The authors show unambiguously, for the first time, that this dust has formed in the inner ejecta, the cold remnants of the exploded star's core. The dust emission is concentrated to the center of the remnant, so the dust has not yet been affected by the shocks. If a significant fraction survives, and if SN 1987A is typical, supernovae are important cosmological dust producers.



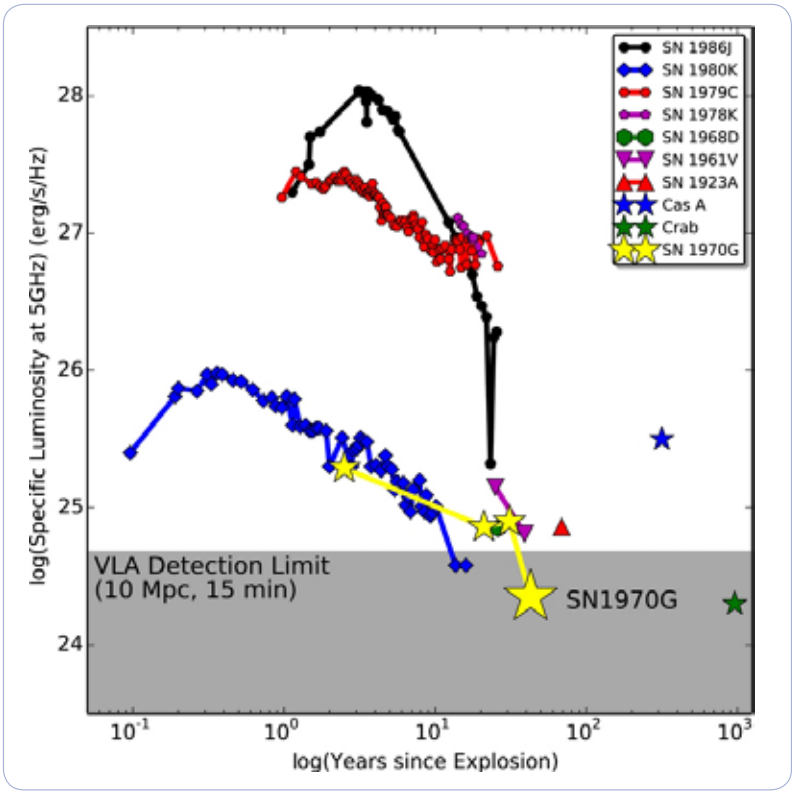
Composite image of SN 1987A. ALMA data (red) shows newly formed dust in the center of the remnant. Hubble Space Telescope (green) and the Chandra X-ray Observatory (blue) show the expanding shockwave. Credit: R. Indebetouw et al., A. Angelich (NRAO/AUI/NSF); NASA/STScI/CfA/R. Kirshner; NASA/CXC/SAO/PSU/D. Burrows et al. Inset: Astronomy Magazine "Top 10 Space Stories of the Year".

Science Team: R. Indebetouw (UVA, NRAO), M. Matsuura (Univ College-London), E. Dwek (NASA-Goddard), G. Zanardo (ICRAR), M.J. Barlow (Univ College-London), M. Baes (Gent), P. Bouchet (CEA_Saclay), D.N. Burrows (PSU), R. Chevalier (UVA), G.C. Clayton (LSU), C. Fransson (Stockholm), B. Gaensler (CAASTRO, Sydney), R. Kirshner (CfA) et al. Publication: *Dust Production and Particle Acceleration in Supernova 1987A Revealed with ALMA,* 2014 Astrophysical Journal Letters, 782, L2 (10 February 2014).

A Midlife Crisis for Supernova 1970G

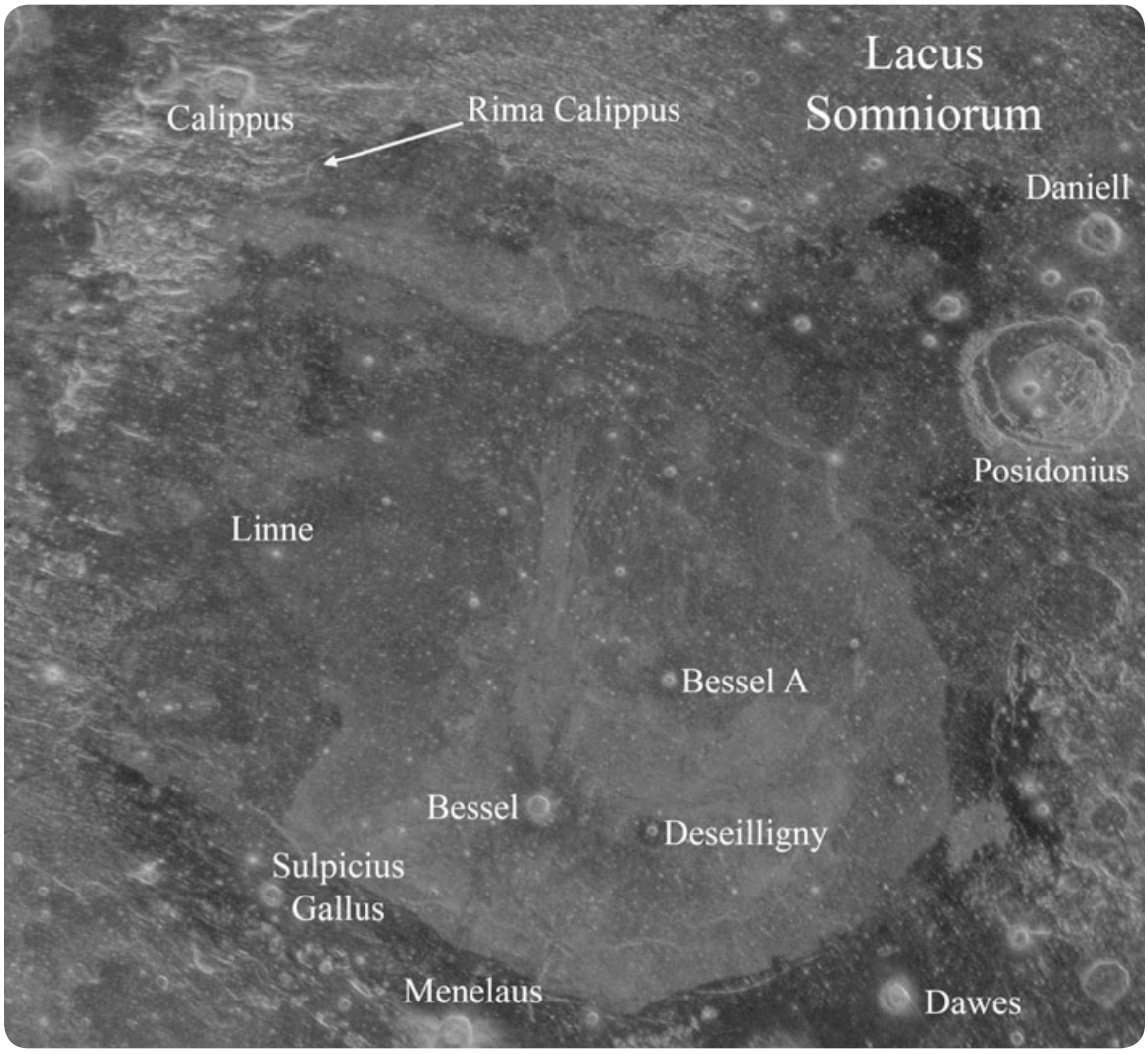
As the shock from a supernova (SN) expands, the mass-loss history we are able to probe is extended, providing insight to rapid timescale processes that govern the end states of massive stars. While supernovae (SNe) transition into remnants on timescales of decades to centuries, observations of this phase are currently limited. Dittmann et al. present VLA observations of SN 1970G, serendipitously observed during the monitoring campaign of SN 2011fe, which shares the same host galaxy. Using the VLA and a deep Chandra X-ray exposure, the authors recover this middle-aged SN and resolve it from its associated H II cloud. They find that the flux density of SN 1970G has changed significantly since it was last observed: the X-ray luminosity has increased by ~3x, and the radio flux is significantly lower, just 27.5 μJy at 6.75 GHz, a level now detectable, given the recent VLA upgrade. These changes suggest that SN 1970G has entered a new stage of evolution toward a SN remnant, and we may be detecting the turn-on of the pulsar wind nebula. Deep radio observations of additional middle-aged SNe will provide a statistical census of the delicate transition period between SN and remnant.

Radio light curves at 5 GHz of supernovae more than 25 years old. SN 1970G (yellow) is probing a new regime in the mass loss history of the end-of-life high mass stars, as well as probing the regime bridging supernovae (left) with supernova remnants (right).



Science Team: J.A. Dittmann (CfA), A.M. Soderberg (CfA), L. Chomiuk (Michigan State), R. Margutti (CfA), W.M. Goss (NRAO), D. Milisavljevic (CfA), and R.A. Chevalier (Virginia). Publication: *A Mid-life Crisis? Sudden Changes in Radio and X-Ray Emission from Supernova 1970G,* 2014 Astrophysical Journal, 788, 38 (10 June 2014).

Radar Imaging of the Moon



Bi-static radar imaging of central and northern Mare Serenitatis – conducted with the Arecibo Observatory transmitting and the GBT receiving – has improved our ability to discriminate the Moon's volcanic complexes, tectonic features, and regolith properties. The Arecibo-GBT radar images acquired and described by Campbell et al. in their paper reveal flow-unit boundaries, channels, and lobes unseen via other remote sensing methods. Comparison of the 12.6 cm and 70 cm radar data implies a rough or block transition zone between the mare regolith and the intact bedrock, and an average regolith thickness of 10 m, with a T_iO_2 content of 2-3%. A localized pyroclastic deposit associated with Rima Calippus has been identified based on its low radar echo strength. A 250 km east-west trending feature in northern Mare Serenitatis suggests a large graben flooded by late-stage mare flows.

Science Team: Bruce A. Campbell (Smithsonian), B. Ray Hawke (Hawaii-Manoa), Gareth A. Morgan (Smithsonian), Lynn M. Carter (NASA-Goddard), Donald B. Campbell (Cornell), and Michael Nolan (Arecibo). Publication: *: Improved Discrimination of Volcanic Complexes, Tectonic Features, and Regolith Properties in Mare Serenitatis from Earth-based Radar Mapping,* 2014 Journal of Geophysical Research: Planets, 119, 313 (February 2014).


NRAO
ESO
NAOJ
ALMA

ALMA CONSTRUCTION

Atacama Large Millimeter/submillimeter Array Construction Project

September 2014 marked the end of the Atacama Large Millimeter/submillimeter Array (ALMA) construction and a full transition to ALMA Operations. ALMA now includes fifty 12m antennas in an extended interferometric array, plus twelve 7m antennas and four 12m antennas in a compact array, operating at a wide range of millimeter and submillimeter frequencies at more than 5,000m elevation in northern Chile. Among the largest advances in astronomy, ALMA has achieved an order of magnitude of more improvement in millimeter-wave sensitivity, frequency coverage, resolution, imaging, and spectral capabilities. ALMA Early Science, underway since October 2011, continued throughout 2014 and has already impacted numerous fields of astrophysics and opened new scientific frontiers.

ALMA, an international astronomy facility, is a partnership of the European Organisation for Astronomical Research in the Southern Hemisphere (ESO), the U.S. National Science Foundation (NSF) and the National Institutes of Natural Sciences (NINS) of Japan in cooperation with the Republic of Chile. ALMA is funded by ESO on behalf of its Member States, by NSF in cooperation with the National Research Council of Canada (NRC) and the National Science Council of Taiwan (NSC) and by NINS in cooperation with the Academia Sinica (AS) in Taiwan and the Korea Astronomy and Space Science Institute (KASI).

ALMA construction and operations are led by ESO on behalf of its Member States; by the National Radio Astronomy Observatory (NRAO), managed by Associated Universities, Inc. (AUI), on behalf of North America; and by the National Astronomical Observatory of Japan (NAOJ) on behalf of East Asia. The Joint ALMA Observatory (JAO) provides the unified leadership and management of the construction, commissioning and operation of ALMA.

The ALMA facilities in Chile constitute the Joint ALMA Observatory (JAO): the Array Operations Site (AOS) at 5,100m elevation on the Chajnantor plain near San Pedro de Atacama in northern Chile; the Operations Support Facility (OSF) at 2,900m elevation just 28km from the AOS; and the JAO Santiago Central Offices (SCO) in Chile's capital. The OSF is the operations center for the JAO. Staff at the AOS is limited to the absolute minimum owing to the harsh, high-elevation environment. A private road connects Chilean Highway 23 to the OSF, at kilometer marker 15, and to the AOS, 43km from the highway. This road is up to 14m wide to accommodate the ALMA Transporter.

Administrative close out of the ALMA Construction Project was initiated in 2014, including a concerted effort to formally conclude the remaining Final Acceptance of all North American deliverables by 30 September 2014. The North American Project Office (NAPO) led a coordinated effort with ESO and NAOJ / ASIAA to prepare and present a comprehensive Acceptance Package to the JAO.

As the 30 September deadline approached, a major, ongoing technical investigation and several incomplete work elements remained, including an investigation into the Vertex antenna surface accuracy, the delivery of four Front End Handling Vehicles, completion of the Site Development punch list, procurement/delivery of six (6) general purpose utility vehicles, and a few remaining administrative close out tasks.

The NAPO and the relevant ALMA Integrated Product Teams prepared a detailed estimate of the resources and time required to complete the required work and determined there were sufficient funds. Thus, AUI / NRAO requested and received a six-month, No-Cost Extension for the period 1 October 2014 – 31 March 2015.

Antenna Surface Accuracy

NRAO and the JAO carried out holography measurements on the 25 antennas delivered by Vertex / General Dynamics to evaluate surface accuracy under all operational conditions. An astigmatic surface error pattern was observed under some conditions, though at the highest frequencies (ν > 800 GHz) and in extreme cold weather (T < -15° C). NRAO and Vertex have jointly carried out investigations designed to identify and mitigate the root causes of the astigmatism.

AUI President Receives North American-Chilean Chamber of Commerce Award

In a ceremony held on 22 October in New York City, AUI President Ethan Schreier received the Distinguished Scientist of the Year award from the North American – Chilean Chamber of Commerce in recognition of the work AUI and NRAO have done in Chile for ALMA. Other awardees included Roberto Angelini Rossi, the President of Empresas Copec S.A., who was recognized as a Distinguished Corporate Leader; and John Dinges, Godfrey Lowell Cabot Professor of Journalism at Columbia, who was recognized as a Distinguished Honorary Chilean.

[Left to right] *Mario J. Paredes, Chamber President; Roberto Angelini Rossi; Juan Gabriel Valdés, Chilean Ambassador to the U.S.; Ethan Schreier; and John Dinges.*

The administrative closure process was initiated in June 2014 with the final, NRAO/ESO and NRAO/NAOJ balancing of accounts, and was essentially completed by 30 September. The few remaining administrative close out tasks were performed during the No-Cost Extension, including: (a) JAO Final Acceptance of North American deliverables; (b) preparation of a Final Financial Statement; (c) remittance of residual Project funds to the NSF; (d) preparation of an asset capitalization plan to the NSF; (e) preparation of the NA ALMA Construction Project Final Report; and preparation of a Project Outcomes Statement. All administrative closure tasks will be complete by 30 June 2015.

ALMA OPERATIONS & DEVELOPMENT

North American ALMA Operations

Photo: Bill Johnson

North American ALMA Operations includes:

- Science Operations at the North American ALMA Science Center (NAASC)
- The NA share of the ALMA Development Program
- The NA share of Offsite Technical Support undertaken outside Chile
- Activities of the AUI/NRAO Office of Chilean Affairs (OCA)
- The North American (NA) share of ALMA Operations in Chile
- Education & Public Outreach (EPO) programs and Diversity initiatives.

North American ALMA Science Operations

The NAASC is located at the NRAO headquarters in Charlottesville, Virginia and is responsible for supporting the scientific use of ALMA by astronomers in North America. The NAASC has three management groups – the Telescope Support Group (telescope-facing), the User Support Group (user-facing, ALMA-specific), and the Science User Support (SUS) Group, which reports to the Observatory's Science Support & Research department and is matrixed to the NAASC. SUS is the NRAO-wide science operations group that unifies common support programs across the NRAO. The NAASC specifies its requirements for science operational support, and contributes staff into this pool, which can then be effectively leveraged for economy of scale and uniformity of approach.

Telescope Support Group

The NAASC Telescope Support Group (TSG) provides support for JAO operations from NA and via temporary deployments to Chile. The NAASC provides domain-expert assistance to the JAO Extension of Capabilities effort (EOC) in areas where the NAASC has key expertise that is missing or understaffed at the JAO. In Fiscal Year 2014, the NAASC provided 25+ months of EOC support deployed to Chile. The NAASC also supported an extended visit to the JAO by an expert sabbatical visitor (Christine Wilson, McMasters University). NA EOC contributions included investigations and reports on calibration stability, single dish commissioning, band-to-band and bandwidth transfer, spectral scans, and software acceptance. The NAASC also provided 13 Astronomer-on-Duty (AoD) shifts or "turnos" and 6 EOC shifts over the year.

Additional JAO operations support was provided in bi-annual software acceptance testing of all ALMA operations software subsystems. Subsystem Scientists and regional Cognizant Leads for each software subsystem and international ALMA working group were also provided. The NAASC provided three subsystem scientists – CASA, helpdesk, and science portal – and ten Cognizant Leads and served on eight Working Groups. The testing, characterization, and feedback to the pipeline subsystem and development of the pipeline operations plan for Cycle 1 and 2 data was a particularly significant effort. NAASC involvement was crucial to the successful deployment of the calibration pipeline in 2014. The NAASC staff provided most of the support for the Quality Assurance 2 script generator, which is critical for the manual reduction effort.

User Support Group

The NAASC User Support Group is responsible for direct support of the NA ALMA user community. User support responsibilities in 2014 included support of the Cycle 2 Call for Proposals. The NAASC sponsored six community training events – two webinars and four community day events – reaching 120+ scientists. Three additional ALMA outreach events were held after the Cycle 2 proposal deadline, in conjunction with other major science meetings.

During the Cycle 2 proposal season, the NAASC supported 195 helpdesk tickets and created 24 knowledgebase articles. National Research Council – Canada scientists provided additional after-hours helpdesk support in the final week leading up to the proposal deadline. The NAASC provided the NA community with continuous helpdesk coverage in the 36 hours leading up to the proposal deadline. The 1381 submitted Cycle 2 proposals– the most for a single call for any observatory – included 418 proposals from NA-affiliated PIs. NAASC assigned Contact Scientists to 136 NA-supported Cycle 2 projects, and continued Contact Scientist support of 78 Cycle 1 projects. Contact Scientist duties include assisting PI projects with the review of their Phase 2 products (observing scripts), with updates on project status, answering questions on observing strategies and data products, and assisting with data reduction and analysis for visiting PI teams.

Science User Support

NA ALMA Ops supported several programs for students and scientific professionals in 2014.

The Student Observing Support (SOS) Program is funded by NA ALMA and managed by Science Support & Research (SSR) department. A total of 41 applications requesting $1,080,523 were received from NA graduate and undergraduate students associated with successful ALMA Cycle 2 Early Science observing proposals. Fifteen awards were made, amounting to $407,021.

The NAASC provided travel and expert science support for 13 Data Reduction visitors and provided partial support for a sabbatical visitor who assisted with EOC tasks. NA ALMA also funded four Reber pre-doctoral Fellows.

Cycle 1 Science Operations

ALMA observations for Cycle 1 Early Science (ES) began 1 January 2013 and continued through to 31 May 2014. Cycle 1 was the second ES period made available to the international ALMA community for PI science on a “best efforts” basis, i.e., completion of the 66-element array and the commissioning and delivery of the full ALMA capabilities was the highest priority activity.

Cycle 1 PI observing was originally planned to start in January 2013 and span 10 months. However, a decision was made to spend several months giving priority to commissioning and improvements to infrastructure and overall system stability, and to extend Cycle 1 from the end of October 2013 to the end of May 2014.

Further engineering and commissioning activities took place in February 2014 – when good weather is less likely – including the annual maintenance of the switchgears and transformers that cannot be performed during regular array use, and work on the technical building that requires the correlator and central Local Oscillator to be powered off and a major annual upgrade of the ALMA software.

After resuming Cycle 1 ES observations at full priority on 30 October 2013, it became clear that the completion percentage of High Priority projects for Cycle 1 would be less than for Cycle 0 due to the reduced amount of time available for ES observations (6 months at nominal priority versus the originally planned 10 months). The completion percentage of Cycle 1 High Priority projects was estimated to be ~60% (compared to ~80% for Cycle 0) with projects requiring high frequencies and/or the most extended configurations remaining mostly incomplete. In compensation, the JAO allowed PIs of Cycle 1 High Priority projects to designate their projects as eligible for transfer into Cycle 2, should they remain incomplete at the end of Cycle 1.

A Cycle 1 Status Report was produced by the JAO with contributions from the North American, East Asian, and European ARCs and published at the ALMA Science Portal on 7 March. This report describes the status of Cycle 1 as of this date, the progress in observing the 196 approved Cycle 1 projects, the state of data reduction for these projects, the 2014 ALMA configuration schedule, and an analysis of the expected project completion likelihood.

Cycle 2 Call for Proposals

The ALMA Cycle 2 Call for Proposals was published 24 October 2013, inviting members of the astronomy community to propose scientific programs to be scheduled on ALMA beginning in June 2014 and continuing for 17 months. About 2000 hours of 12-m Array time and Atacama Compact Array (ACA) time were expected to be available for Cycle 2 projects and high priority projects transferred from Cycle 1.

ALMA received 1382 unique proposals by the close of the Cycle 2 submission process on 5 December 2013, a considerable increase beyond the 1131 and 919 unique proposals received in Cycle 1 and Cycle 0, respectively. The total Cycle 2 time requested was 7314 hours for the array of 12m telescopes; 3327 hours were requested for the ACA. A total of 1049 individual PIs and 3405 scientists submitted proposals. The fractions of Cycle 2 proposals coming from the three ALMA Executives, Chile, and from outside the partnership was similar to Cycle 1: 30% North America; 41% Europe; 20% East Asia; 7% Chile; and 3% Other. There were nearly 1500 unique investigators on proposals submitted from the North American Executive.

Eleven ALMA Review Panels (ARPs), each comprising seven Science Assessors, reviewed the Cycle 2 proposals. To ensure as even a workload as practical for each ARP, the proposals were distributed as follows across the five ALMA scientific categories:

1. Cosmology and the high redshift Universe (2 ARPs);
2. Galaxies and galactic nuclei (3 ARPs);
3. Interstellar medium, star formation and astrochemistry (3 ARPs);
4. Circumstellar disks, exoplanets, and the Solar System (2 ARPs); and
5. Stellar evolution and the Sun (1 ARP).

Science Assessors were selected based on their scientific expertise, taking into account regional balance. The resulting regional distribution of the ARP members closely matched the nominal ALMA regional shares of the observing time. The 11 ARP Chairs also served on the ALMA Proposal Review Committee (APRC), together with an ARP member acting as Chilean representative, and the APRC Chair, Françoise Combes (Observatoire de Paris), who did not belong to any ARP.

Four Science Assessors initially evaluated each proposal (Stage 1) and a ranked list was built on the basis of these scores. The top 70% of the proposals in this ranking proceeded to Stage 2, as did proposals with a large dispersion in their Stage 1 scores.

At Stage 2, the ARPs met face-to-face 10-13 March in London, Ontario, Canada to discuss and rank all proposals assigned to them that were still under consideration, taking into account the technical assessments conducted by ALMA staff. On 14 March, the APRC reviewed the single ranked list resulting from the merging of the individual ARP rankings, with particular attention given to proposals involving duplicated observations. Based on scientific merit, the APRC identified 35 proposals to be assigned Grade A, making them eligible for carry-over to Cycle 3 if they cannot be completed in Cycle 2. The JAO built a list of 318 Grade B proposals and a list of 160 Grade C proposals to be used as “fillers” when conditions do not permit Grade A or B observations. The Directors’ Council and the Chilean representative endorsed this scientific program, which is available via the ALMA Science Portal. Notifications regarding each proposal were emailed to all Principal Investigators on 9 April.

The estimated execution time of the 353 Grade A and B projects is 1700 hours of 12m Array time; an additional 470 hours are expected to be required to complete carried-over Cycle 1 projects. The Cycle 2 Grade C projects account for an additional 800 hours of estimated execution time. Fifty-three of the 353 Grade A and B projects include ACA observations; 27 of the 160 Grade C projects include ACA observations. Their ACA execution time is expected to be 812 hours for the Grade A and B projects, and 495 hours for the Grade C projects. Twenty proposals that would have qualified for scheduling based on their scientific rank were rejected on technical grounds.

A detailed report on the outcome of the ALMA Early Science Cycle 2 proposal review process is available at the ALMA Science Portal.

Cycle 2 Science Operations

Cycle 2 Early Science observing began, on schedule, on 3 June. The ALMA pipeline processing capability became the principal means of data calibration and flagging for PI Cycle 2 science on 17 September. ARC scientists around the globe manually reduced all previous ALMA data. For North American projects, data reduction is managed and conducted by NAASC staff scientists at NRAO Headquarters in Charlottesville and in Victoria, Canada, and at the JAO in Santiago, Chile. A team of engineers and scientists has been developing the automated pipeline to handle the majority of projects. Some non-standard cases will continue to require manual reduction. The pipeline currently handles flagging and calibration while the imaging step continues to be done manually. An imaging pipeline is also under development.

ALMA was moved into an extended array configuration in September, including baselines up to 15.2 km, as part of a campaign to develop strategies for executing user observations using the array's full extent. The array was moved into a compact configuration for the resumption of Cycle 2 Early Science in early December.

Revolution in Astronomy with ALMA – The 3rd Year

Nearly 300 astronomers from around the world gathered 8-11 December 2014 in the heart of Tokyo, Japan for a science conference titled *Revolution in Astronomy with ALMA - The 3rd Year.* Numerous recent ALMA results were presented and discussed, including early results from the 2014 Long Baseline Campaign. The science program filled four full days and included excellent sessions presenting new ALMA science on topics in: (a) Cosmology and High Redshifts; (b) Circumstellar Disks, Exoplanets, Solar System; (c) Stellar Evolution and the Sun; (d) Frontiers of ALMA Capabilities; (e) Galaxies and Galactic Nuclei; (f) Interstellar Medium, Star Formation, and Astrochemistry. A conference summary provided by Christine Wilson (McMaster) and final remarks by Tetsuo Hasegawa (NAOJ) concluded the meeting. The Tokyo meeting presentations will comprise a volume of the Astronomical Society of the Pacific conference series.

Many of these ALMA science results were also presented at the 225th American Astronomical Society meeting in Seattle, Washington in early January 2015, at which plans for public release of a number of datasets in early February were presented.

NAASC Evolution 2014 Workshop

The NRAO North American ALMA Science Center (NAASC) held its 8th annual science workshop – *Transformational Science in the ALMA Era: Multi-wavelength Studies of Galaxy Evolution* – from 4-7 August. More than 110 scientists from 22 countries converged on Charlottesville, Virginia to explore multi-wavelength approaches to four central themes of galaxy evolution using current and future research facilities:

- the mass assembly history of galaxies, and the formation and evolution of galactic structure;
- the evolution of the interstellar medium and star formation over cosmic time;
- the role of large scale structure and environment; and
- the role of AGN in galaxy evolution.

A broad range of new and exciting science from ALMA and across the electromagnetic spectrum was discussed at this NAASC workshop. Major sessions in the four-day science program included: (a) Evolution of the Interstellar Medium and Star Formation over Cosmic Time; (b) Mergers, Starbursts and Star Formation; (c) Star Formation and the Assembly of Galaxies; (d) Role of Active Galactic Nuclei in Galaxy Evolution; (e) Surveys of Galaxies from the Submillimeter to HI; (f) Star Formation in Extreme Environments and the Role of Environment in Galaxy Evolution; and (g) C+: The New Workhorse for Submillimeter Studies of Galaxy Evolution.

The presentations from this NAASC science workshop are available at the NRAO science website.

Cycle 3 Call for Proposals

The JAO published an ALMA Cycle 3 Pre-announcement on 8 December, informing the community of the plans for this next cycle of Early Science observing. This pre-announcement noted that the Call for Proposals would be issued 24 March 2015 with an anticipated deadline for proposal submission of 23 April 2015.

The anticipated capabilities for ALMA Cycle 3 include:

- At least thirty-six 12-m antennas in the main array, and ten 7-m antennas (for short baselines) and two 12-m ACA antennas for making single-dish maps
- Receiver bands 3, 4, 6, 7, 8, 9, & 10 ($\lambda \sim$ 3.1, 2.1, 1.3, 0.87, 0.74, 0.44, and 0.35 mm)
- Baselines up to 2 km for Bands 8, 9 and 10
- Baselines up to 5 km for Band 7
- Baselines up to 10 km for Bands 3, 4, & 6
- Both single field interferometry and mosaics
- Spectral-line observations with all Arrays and continuum observations with the 12m Array and the 7m Array.
- Polarization (on-axis, continuum in Band 3, 6 and 7, no ACA, no mosaics, no spectral line, no circular polarization)
- Mixed correlator modes (both high and low frequency resolution in the same observation)

The expectation is that all PIs will be notified of the results of the ALMA Cycle 3 proposal review process in August 2015. Cycle 3 science observing is expected to begin in October 2015 and end in September 2016. As with Cycles 0, 1, and 2, time will be reserved for engineering and commissioning work to realize the full suite of ALMA capabilities.

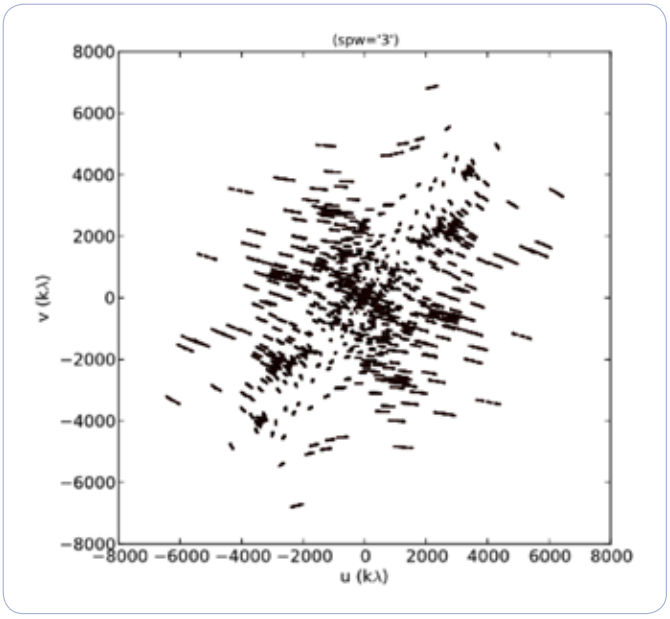
Extension and Optimization of Capabilities

A new group – *Extension and Optimization of Capabilities (EOC)* – was formed in early 2014 to lead and increase ALMA's instrumental opportunities. Anthony Remijan was appointed to lead this group, as Program Scientist (Extension and Optimization); Catherine Vlahakis became the Deputy Program Scientist (Extension and Optimization). NAASC scientists were critical participants in EOC activities in 2014 and several spent considerable periods of time supporting EOC activities, such as the Long Baseline Campaign, at the JAO in Santiago and in northern Chile. Beginning 1 April 2014, ALMA transitioned to a cadence of two weeks of Early Science observations, followed by one week of focused EOC activity.

Long Baseline Campaign

The approximate resolutions that can be achieved with the longest ALMA baselines are 60 mas at 100 GHz, 25 mas at 250 GHz and 17 mas at 350 GHz, though these can vary by ~20% depending on the imaging parameters. Until 2014, ALMA configurations included baselines from 100 m to ~1.5 km, with limited testing of a ~3 km baseline in 2013. To test the highest angular resolution capability of ALMA using baseline lengths of up to ~15 km at selected frequencies, the three-month period from September to November was dedicated to the 2014 ALMA Long Baseline Campaign (LBC). The major goal of the LBC was to develop the technical capabilities and procedures needed to offer ALMA long baseline array configurations for future science observations.

Since many of the distant antenna pads had not been previously powered or occupied, a coordinated effort was made from April to August 2014 to prepare a sufficient number of antenna stations beyond 2 km from the array center. The configuration process began with an initial test in late August when a single antenna was moved out to a 7 km baseline. The nominal LBC configuration consisted of 21-23 antennas on baselines between 400 m and 15 km and was available from the end of September until mid-November, with the two longest baselines being added in mid-October. In addition, typically 6-12 antennas were available on baselines less than 300 m that were useful for imaging the more extended sources. Thus, the total number of antennas used for the LBC ranged from 22-36 depending on the date and observing band.



The uv distribution for the ~1 hour ALMA Band 6 observations of 3C138 acquired during the 2014 Long Baseline Campaign.

The ALMA LBC achieved an increase of a factor of ~6 in maximum baseline length (~15 km) compared to previous test observations and a factor of ~10 increase compared to previous ALMA science observations (a factor or ~100 smaller beam area). The ALMA LBC enabled long baseline (up to ~15 km) antenna configurations to be made available for science observations. This fulfills a major ALMA goal to accurately image sources at mm and submm wavelengths with resolutions of tens of milliarcseconds and, together with ALMA's high sensitivity, opens up significant new discovery space.

North American ALMA Development Studies

The primary objectives of the ALMA Development Studies are: (a) to provide North American groups the opportunity to propose ALMA upgrades that may be implemented via the ALMA Development Plan; (b) to support the development of conceptual and detailed designs for ALMA upgrades; and (c) to encourage long-term research and development in technical fields key to ALMA.

North America issued a Call for Proposals for ALMA Development Studies on 1 May 2013, with proposals due 12 July 2013. Nine submissions were received from eight PIs with teams totaling 41 investigators from 17 institutions seeking total funding of $1.23M. Five PIs were from NRAO; four PIs were from other entities, including one from Academia Sinica Institute for Astronomy and Astrophysics (ASIAA) in Taiwan, and one from the National Research Council – Herzberg in Canada. An expert panel reviewed the proposals. To avoid conflict of interest, none of the review panel members was affiliated with NRAO.

Six Development Studies fit within the funding envelope and were proposed for North American funding with NSF consent (Table 1). The tasks associated with these Development Studies were initiated in February 2014, were in progress throughout the remainder of 2014, and will finish no later than March 2015.

Table 1: ALMA Development Studies (Title/Principal Investigators/Co-Investigators)

Advanced Solar Observing	**T. Bastian, NRAO**	B. Chen (NJIT), B. De Pontieu (LMSAL), G. Fleishman (NJIT), A. Hales (NRAO), H. Hudson (USB, Glasgow), R. Hills (MRAO), G. Hurford (UCB), S. Krucker (UCB, FHNW), M. Shimojo (NAOJ), S. Wedemeyer (Oslo), S. White (AFRL), Y. Yan (NAO/CAS)
2nd Generation Band 10 Receiver	**A. Kerr, NRAO**	J. Mangum, S. Pan, E. Bryerton, J. Effland (NRAO), A. Lichtenberger (UVA), M. Morgan, M. Pospieszalski, K. Saini, S. Srikanth (NRAO)
Community Science Tool Development	**A. Leroy, NRAO**	T. Robitaille (MPIA), E. Rosolowsky (UB-Alberta), M. Turk (Columbia), A. Ginsburg (ESO), C. Beaumont (Hawaii)
2nd Generation Band 6 Receiver	**A. Kerr, NRAO**	J. Mangum, S. Pan, E. Bryerton, J. Effland (NRAO), A. Lichtenberger (UVa), M. Morgan, M. Pospieszalski, K. Saini, S. Srikanth (NRAO)
Millimeter Camera	**S. Claude, NRC-Herzberg**	J. Di Francesco, D. Henke (NRC-Herzberg)
Calibration Refinements for ALMA Imaging	**T. Wilson, NRL**	H. Schmidt, K. Stewart, I. Adams (Naval Research Laboratory)

North American ALMA Development Projects

North America issued a Call for Studies of Proposed ALMA Development Upgrades 3 June 2013, with proposals due 16 August 2013. Eight submissions were received, submitted by PIs with teams totaling 32 investigators from 11 institutions seeking total funding of $7.01M. Three of these evolved from the previous round of ALMA Development Studies. Five U.S., three Canadian, and one Taiwanese institution were represented in the proposals.

An independent panel nominated by the ALMA North American Science Advisory Committee (ANASAC) and assembled with NSF consent reviewed the proposals. The highest-ranked proposals that fit within the $4.0M funding envelope were integrated into a proposed program of ALMA Development in North America. NSF consent was received for the funding of these five highest-ranked proposals, and all PIs were notified of their status.

In early 2014, the proposed program for ALMA Development in North America was presented to the ALMA Director, the ALMA Development Steering Committee, and to the ALMA Board and its science advisory committee for inclusion in the ALMA Development Plan. The proposals comprising the ALMA Development Program are listed in the following Table-2.

Three ALMA Development Projects funded via a previous Call for Proposals made substantial progress toward completion in 2014. The ALMA Optical Link Project established a complete pathway for data transmission via fiber from the AOS at Chajnantor to the JAO offices in Santiago. A positive review of the ALMA Phasing Project was held in mid-December. And the first of the ALMA Band 5 receivers (163-211 GHz) will arrive at the ALMA Operations Support Facility (OSF) in spring 2015.

Table 2: ALMA Development Projects (Title/Principal Investigators/Co-Investigators)

Design and Testing of a Prototype Band-2 Cartridge	**Kamaljeet S. Saini (NRAO)**	E. Bryerton (Virginia Diodes), Kieran Cleary (Caltech/JPL), David T. Frayer, Matthew A. Morgan, Marian W. Pospieszalski, Scott Schnee, Sivasankaran Srikanth (NRAO), Anthony C. S. Readhead (Caltech/JPL), Lorene Samoska (JPL)
Band 3 Cold Cartridge Assembly Magnet and Heater Installation for Deflux Operation	**S. Claude (NRC-Herzberg)**	L. Knee (NRC-Herzberg)
Expansion of the Central LO Article to 5 Subarrays	**C. Jacques (NRAO)**	(none)
ALMA Data Mining Toolkit: ADMIT	**L. Mundy (Maryland)**	Jeff Kern (NRAO), Adam Leroy (NRAO), Leslie Looney (UIUC), Anthony Remijan (NRAO), Amitabh Varshney (Maryland)
The Next Generation ALMA Viewer	**E. Rosolowsky (Alberta)**	Jeff Kern (NRAO), Gregory Sivakoff (Alberta), Russ Taylor (Calgary/Cape Town)

NA ALMA Offsite Hardware Technical Support

The NA ALMA offsite hardware maintenance team comprises several group in Charlottesville with responsibility for a wide range of ALMA hardware in 2014: Front End (components as well as test and measurement systems); Band-6 cold cartridge; Front End Local Oscillator (warm cartridge assembly and cryogenic multipliers), Photonics (central Local Oscillator modules and antenna articles), Correlator, and Antenna. The Back End group resides in Socorro (antenna articles, data receiver articles, and some of the central LO articles). These key operational activities support the operations and maintenance of the ALMA telescope. These groups built, repaired, tested, and shipped a wide range of hardware to the OSF in 2014 and provided a range of hardware maintenance support.

NA ALMA Offsite Software Technical Support

The NA ALMA Offsite Software Technical Support Group provided support throughout 2014 for the ALMA Baseline Correlator and Central Electronics Monitor and Control System, for Data Formation and Scheduling Block Execution, Dynamic Scheduling (in commissioning in FY14), CASA Programming Support and Development, and Data Pipeline Development. These activities are supported by NA ALMA Operations and matrixed to the Data Management & Software department for management and execution.

Photo by Carlos Padilla, NRAO/AUI/NSF

VLA OPERATIONS & DEVELOPMENT

VLA Operations & Development

NRAO continued to offer a suite of robust and scientifically powerful observational capabilities on the VLA, designed and tailored to address the highest priority scientific needs of the general community. In telescope operations, considerable effort was invested in ensuring that the array was calibrated, maintained, and performing optimally. A small number of upgrade projects were implemented to improve performance in key areas, including antenna pointing, receiver stability, and digital sampler reliability and performance.

New VLA Sky Survey

A new VLA Sky Survey (VLASS) is in the planning stages, with the community-led working groups designing both deep and wide components of this next-generation mega-survey in the radio. If approved, this survey will play a major role in the scientific program at the VLA in the coming years. Even with the advent of wide field survey interferometers like Australian Square Kilometre Array Pathfinder (ASKAP) and MeerKAT, the VLA will still provide by far the highest spatial resolution for wide field surveys.

Next Generation Very Large Array

Building on the exciting science that is being performed with our existing facilities, the NRAO has initiated a long-term, community discussion on the future of radio astronomy. We are planning a workshop at the January 2015 American Astronomical Society meeting focused on science with a next generation VLA – an instrument with roughly an order of magnitude higher sensitivity and resolution than the current VLA, operating from 1 to 100 GHz. This facility will open a new window on radio imaging of thermal emission at milliarcsecond resolution.

VLA Operations

NRAO continued to offer three types of observing programs to VLA users in 2014: General Observing (GO), Shared Risk Observing (SRO) and Resident Shared Risk Observing (RSRO). Increases in observing capabilities were offered in Semesters 2014B and 2015A. The following capabilities were moved into GO in Semester 2015A: P-Band Stokes I continuum observing, correlator recirculation, mixed 3-bit and 8-bit samplers, and correlator dump times as short as 50 msec. On-the-fly mosaicking was successfully tested and offered through the SRO program in Semester 2015A. In addition, the operation of phased VLA modes, sub-arrays, and fast correlator dumps were stabilized.

All array reconfigurations completed successfully. The length of the D-configuration was reduced by one week; the DnC and C reconfigurations occurred on schedule.

An evaluation of moving array operations to Socorro for evening and night shifts was completed that will guide future efforts to operate the VLA remotely.

VLA Upgrade and Enhancement Projects

Antenna Control Unit Replacement: The VLA Antenna Control Unit (ACU) Critical Design Review was delayed into early 2014 owing to the October 2013 Observatory shutdown. A second prototype ACU was installed in a VLA antenna in March 2014. Various problems with the prototype design were identified during the CDR and subsequently confirmed by operational tests of the first and second prototypes in the field. Scientific evaluation of these two prototypes was mostly completed, but given the problems evident (self-generated RFI, system reliability, pointing accuracy and settling time), and the need for key scientific

staff to work on VLA Ionospheric and Transient Experiment (VLITE), this work was re-prioritized and not completed in 2014. Design modifications are being investigated and will be implemented and tested in a production version in 2015.

4-Band Feed Development: Tests of the Modified J-Pole (MJP) feeds showed promising results as far as system sensitivity and bandwidth were concerned, but the build-up of static charge due the feed mount was found to damage the receivers. A new mount was designed and has been installed with MJP feeds on six antennas; detailed testing will begin when the array is again in its extended configurations in 2015.

C-Band and L-Band Thermal Gap Retrofits: New thermal gaps were installed on 3 VLA C-Band receivers, and 6 VLA L-Band receivers.

Card Cage Upgrades: New card cages were installed on 48 VLA front ends.

3-bit Sampler Upgrade: Hittite 3-bit sampler assemblies were installed on two VLA antennas. Performance was as expected, and better than most of the legacy Teledyne sampler assemblies. The replacement of 112 poorly performing sampler boards requires ~$1.1M, but a reasonable option is to replace the worst Teledyne samplers (which are discontinued chips) with the Hittite chips (which are still commercially available). The latter approach will be adopted in 2015, enabled by external funding.

API Hardware Upgrade: The existing VLA Atmospheric Phase Interferometer (API), built from aging and inflexible parts and increasingly a challenge to maintain, is being upgraded. In 2014, a second baseline for the interferometer was installed, and the API output was integrated into VLA operations, and the full four-element system has been tested.

VLA Operational Enhancements

Improved Referenced Pointing: The ability to specify a different reference antenna or sub-band was implemented within the online software in 2014, but has not been exposed to users, or used in any other way in the system. Scientific testing of this item was delayed due the redirection of effort to VLITE. However, other enhancements to referenced pointing were implemented in 2014, including improved robustness to misbehaving antennas or electronics, along with the implementation of multi-sub-band phasing (necessary for most phased-array observations). The existing method of referenced pointing works in most cases.

Tipping Scans: The implementation of tipping scans on the VLA was identified at the beginning of 2014 as potentially being severely impacted by the need to divert key scientific staff to VLITE. In addition, the loss of scientific and programming staff at the beginning of the year further impacted the delivery of this item. By the end of 2014, tipping scans were supported in the observing system, but testing was blocked because scheduling blocks including TIP scans would not validate in the OPT. The testing and analysis of TIP scan data will continue into 2015. Since turning on the Wideband Interferometric Digital Architecture (WIDAR) correlator, the VLA has used weather data and atmospheric models as a proxy, and will continue to do so until tipping scans are fully commissioned. The impact of the lack of tipping scans is that any high frequency observations for which a primary flux density calibrator is not observed at a similar elevation to the target has an increased uncertainty in its absolute flux density scale by a few percent.

Improved Switched Power Calibration: Switched power measurements at all bands and for all antennas were stabilized during 2014, in preparation for commissioning and documenting their use for calibration in CASA in 2015.

Pipeline Heuristic Development: Considerable progress was made on the development of VLA pipeline heuristics in 2014. The heuristics for handling weak calibrators were defined conceptually, and successfully tested on high frequency data. The technique has the potential to be more generally applicable, though further CASA development is needed to associate frequency to gain calibration solutions instead of spectral window IDs. This development is planned for CASA 4.4. Improved L-Band RFI flagging techniques were investigated, and found that improvements can be made when tailored to specific observing set-ups.

VLA Maintenance and Renewal

Nine VLA antennas were overhauled in 2014. The planned azimuth bearing replacement did not take place because of personnel challenges in the Antenna Mechanics group, and the diversion of resources to work on failing VLBA wheel assemblies. A total of 2500 cross ties and three antenna pads were replaced in 2014.

A proposal for the future of the VLA VAX building was developed that recommends demolition of the structure. The VLA Activity Center transformer was replaced and preventive maintenance was performed on 90 VLA site transformers and the hatch gear.

VLA Sky Survey Planning (VLASS)

In the two decades since observations were acquired for the *NRAO VLA Sky Survey (NVSS)* and the *Faint Images of the Radio Sky at Twenty-Centimeters (FIRST),* these pioneering programs have defined the state-of-the-art in centimeter radio sky surveys and produced a steady stream of excellent science. Given the enhanced capabilities of the Jansky VLA and its successful debut of full science operations in January 2013, NRAO initiated an initiative to discuss the scientific potential of new centimeter-wavelength sky surveys.

High priority science goals of the 2010 decadal survey *New Worlds, New Horizons in Astronomy and Astrophysics* can be addressed by a new VLA sky survey, and many scientists have expressed keen interest in employing the VLA to conduct new, wide-area synoptic surveys in support of multi-wavelength sky surveys using existing and future facilities, such as the Large Synoptic Survey Telescope (LSST). Thus, NRAO launched a NRAO VLA Sky Survey (VLASS) initiative to explore the science and technical opportunities of a new centimeter-wavelength survey. A Science Survey Group (SSG) was chartered to define the science program and key components of VLASS, with NRAO supporting its technical definition and eventual implementation. The plan is for all VLASS data to be available immediately to the astronomical community. The community-led SSG was formed in summer 2013 and issued a call for white papers to provide critical input regarding survey science goals, techniques development, and design.

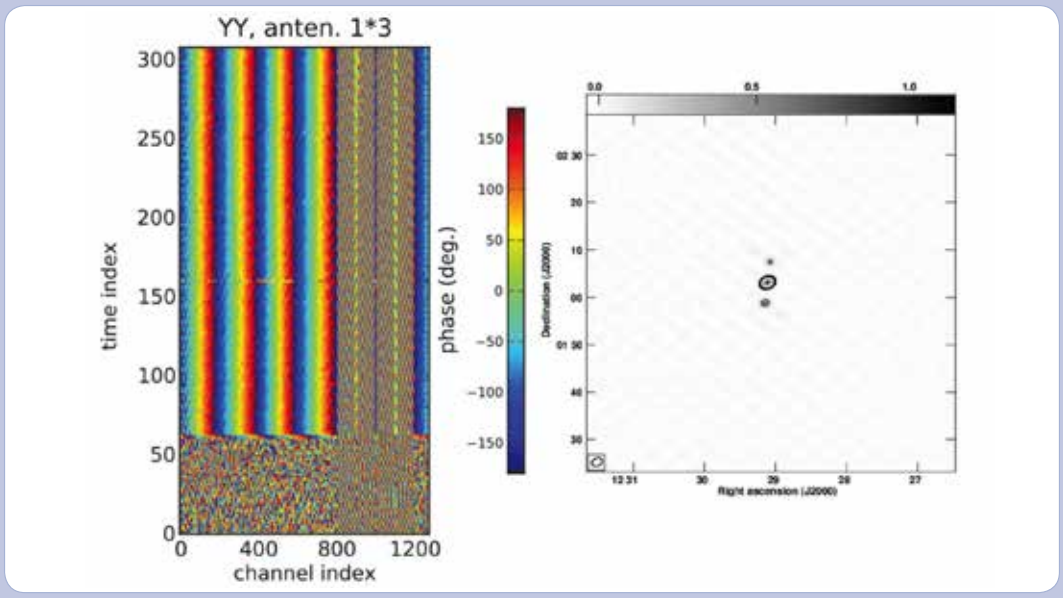
A daylong Workshop titled *NRAO Very Large Array Sky Survey Science Planning* was organized at the AAS meeting in Washington D.C. on Sunday, 5 January 2014. This Workshop enabled broad discussion of the scientific potential of new centimeter-wavelength sky surveys and was attended by more than 50 interested members of the community. This Workshop enabled community members to learn about the VLA and its survey capabilities, participate in discussion of survey science priorities, and provide input on survey planning.

4th VLA Data Reduction Workshop

Photo by Brian Kent

A full house of 31 scientists attended the 4th VLA Data Reduction Workshop that took place 27 - 31 October at the NRAO New Mexico Array Science Center (NMASC) in Socorro. The workshop assisted observers with the data reduction challenges posed by the increased flexibility and complexity of the VLA. During the workshop, observers reduced their own VLA data using hardware provided by NRAO and with NRAO staff experts present for consultation. Presentations by NRAO Socorro staff covered the Common Astronomy Software Applications (CASA) package and the latest developments in data reduction techniques. This advanced workshop, unlike the Synthesis Imaging Workshops, targeted experienced radio-wavelength observers, scientists with prior experience and working knowledge of the Astronomical Image Processing System (AIPS), CASA, or MIRIAD.

Photo by Bob Fugate



VLITE First Fringes

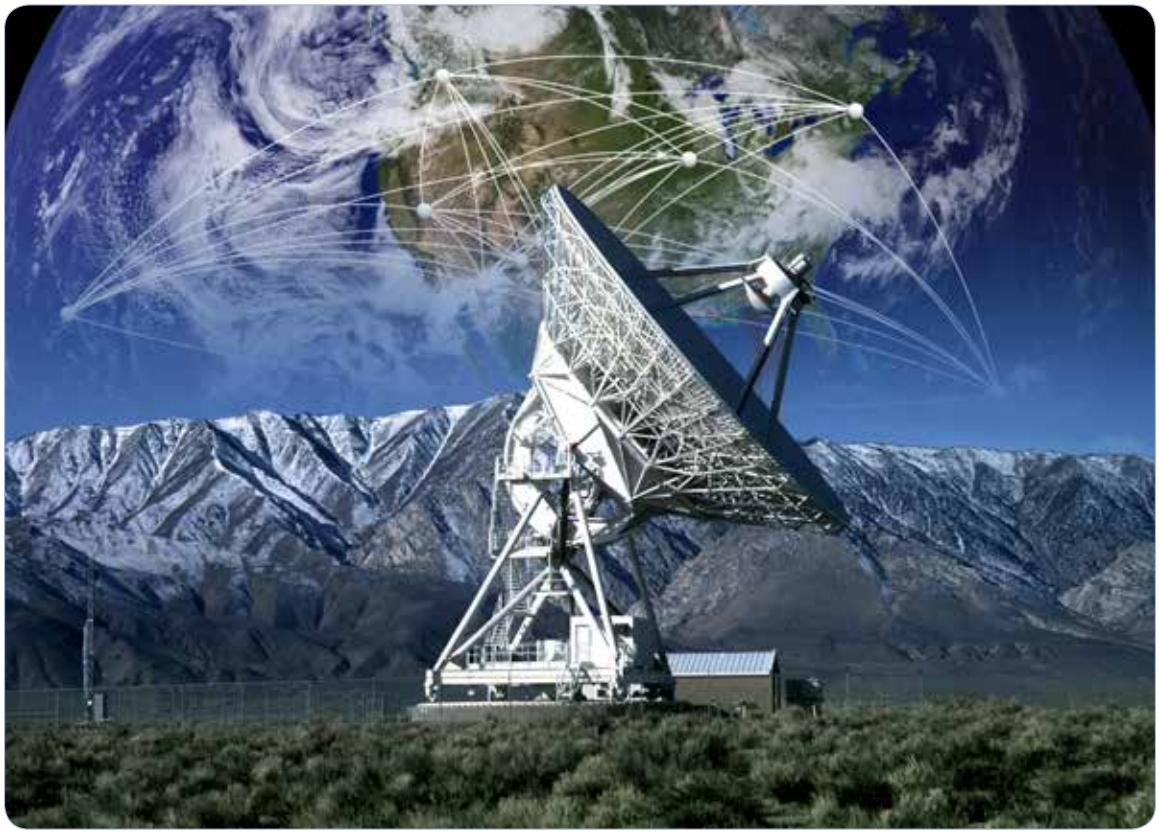
The Naval Research Laboratory (NRL) and NRAO successfully teamed to obtain first fringes on the VLA Low Frequency and Ionosphere Transient Experiment (VLITE) in 2014. VLITE is a 10-antenna commensal system continuously accessing 64 MHz from the new 236-492 MHz Low Band system. Its backend includes dedicated samplers, fiber optics, and a DiFX-based software correlator. By harvesting data from the VLA prime focus, VLITE can provide 5000+ hours of "free" observing time a year, effectively making the VLA "two telescopes in one". VLITE is a multi-year project commencing this fall, and could pave the road towards a VLA Low Band Observatory, or LOBO system, in the future.

VLITE became sentient on 17 July, soon after the first antennas came on line. The left side of the figure (above) shows the phase of the cross-correlation function as a function of time (vertical) and frequency (horizontal) between VLITE antennas 1 and 3, corresponding to VLA antennas 14 and 23, after the quasar 3C273 enters the field-of-view. The length of the scan is about 10 minutes, and the ~6.5 fringes seen across the 64 MHz bandwidth (λ~1 meter) correspond to a residual delay error of ~100 nsec. Since then, more antennas have been added and simple images of calibrators – including 3C273 (see Figure, right side), made from five antennas – are starting to emerge.

VLITE has two main scientific drivers, and one ethereal one. The first is to provide continuous, near real-time monitoring of ionospheric waves over the VLA. VLITE is significantly more sensitive to tiny fluctuations in ionospheric total electron content than GPS, opening a new field of ionospheric remote sensing. The second scientific goal is a continuous, blind search for astronomical transients, both fast (pulsars and fast radio bursts) and slow (supernovae, gamma-ray bursts, etc.). VLITE plays to the strength of transient observations by accessing a wide field-of-view (~5 square degrees) nearly continuously. Finally, VLITE challenges the paradigm of targeted observations catering to a priori science. Its exploration-driven model seeks to reinforce the value of serendipity in a landscape increasingly dominated by perceived "transformational" science goals.

VLITE is an NRL-funded project supported by NRAO; Namir Kassim is the PI.

VLBA OPERATIONS & DEVELOPMENT



VLBA Operations

VLBA operations emphasized stabilizing and documenting existing capabilities, and improving the array's ease-of-use and reliability. VLBA science operations emphasized Large / Key Science Projects, especially those that made effective use of the array's unique astrometric capabilities. In addition to a regular infrastructure maintenance and renewal program, upgrade projects focused on retiring legacy hardware and software systems.

NRAO continued to offer three types of observing programs to VLBA users in 2014: General Observing (GO), Shared Risk Observing (SRO) and Resident Shared Risk Observing (RSRO). Science operations focused on completing verification tests of the dual Roach Digital Back End (RDBE) system, stabilizing existing operations using the new backends, and documenting the dual RDBE system for users. NRAO – New Mexico Operations took over responsibility for VLBI operations at the GBT, solving problems associated with communications, software version control, and more, and a number of initiatives resulted in a significantly more stable VLBA + Y27 operation compared with last year, including additional system monitoring, automated observe file production, and completion of the calibration path for VLA system temperature data.

In addition, increasing the compatibility of HSA observing set-ups on the various partner stations of the High Sensitivity Array (HSA) enabled new spectroscopic observing modes to be offered through the SRO and RSRO programs in 2015A compared with 2014A, and a new opportunity arose to offer the combination of VLBA and the Large Millimeter Telescope (LMT) for 3mm VLBI for 2015A through the RSRO program. Support of the 2014B semester Call For Proposal (CfP) was successfully completed.

VLBA Upgrade and Enhancement Projects

An interface box was designed, built, and installed in the laboratory to enable the VLBA antenna control (VME) computers to communicate with legacy hardware. Testing of the interface box took place in the lab test rack, pending completion of the software needed to interface to an antenna. Testing in a VLBA antenna will take place in 2015.

The schedule for the re-integration of Mark 5A recorders from the VLBA sites as playback units for the VLBA correlator was brought forward to enable dual correlations in preparation for a VLBA observing surge in February 2014 and to take advantage of availability of key personnel who would be unavailable later in the year due to VLITE. As a result, all projects using the legacy observing system were transitioned to using the RDGEs by the start of 2014, well ahead of schedule. Eight of the VLBA Mark 5A recorders, and the Green Bank Mark 5A recorder, were removed and shipped to Socorro, and integrated into the VLBA correlator. The number of playback drives is now 21, with one spare, and dual correlation is now in routine operation.

The spare VLBA C-Band receiver was completed and tested. Two of the ten VLBA antennas contain pre-production C-Band receivers, but the performance of these receivers is comparable with the production receivers in the field, so there was no need to upgrade them to the production design.

VLBA Capability Enhancements

The VLBA can be operated as a stand-alone interferometer, in combination with other NRAO telescopes (phased VLA and the GBT), and as the foundation to the High Sensitivity Array (HSA). Eight-channel phased VLA ("Y27") was enabled and offered as a Shared Risk capability for Semester 2015A.

Enhancements to non-RSRO stations of the HSA require effort and associated priority from other observatories. NRAO worked with Effelsberg in 2014 to enable Digital Downconverter compatible observing modes to improve the spectroscopic capabilities of the HSA. In addition, the LMT acquired a maser, and in collaboration with Haystack Observatory, performed the first LMT astronomical 3mm VLBI observations with the VLBA. As a result of these successful observations, NRAO was able to offer the LMT as a new participant in the HSA for 3mm observing for Semester 2015A.

VLBA Maintenance and Renewal

Two antennas received major overhauls. At North Liberty, Iowa, the VLBA Tiger Team replaced both azimuth wheel assemblies, installed the T450 total power monitor upgrade, and the servo motor upgrade, in addition to regular scheduled maintenance. At Hancock, New Hampshire, the Tiger Team replaced two azimuth wheel assemblies and installed the T450 total power monitor upgrade, in addition to the usual overhaul tasks.

GBT OPERATIONS & DEVELOPMENT

GBT Operations & Development

The Robert C. Byrd Green Bank Telescope (GBT) is the world's premiere single-dish radio telescope at meter to millimeter wavelengths. Its 100-meter diameter collecting area, unblocked aperture, excellent surface, and unique site offer the scientific community unrivaled capabilities across the telescope's 0.1 –116 GHz (λ 3.0m – 2.6mm) operating range.

Located in the National Radio Quiet Zone (NRQZ) and the West Virginia Radio Astronomy Zone, the GBT has the best protection of any U.S. observatory from many forms of man-made radio frequency interference. The Observatory's location in a lightly populated valley in the Monongahela National Forest, surrounded by extensive ranges of mountains, provides further protection from interfering signals.

Science for the GBT ranges from understanding black holes through detecting gravitational waves, imaging the earliest galaxies, and searching space for the precursors of life. The GBT's flexibility and ease of use means it can rapidly respond to new ideas from the scientific community. It has a collecting area and sensitivity comparable to ALMA and the VLA and thus excellent response to point sources, such as pulsars. But as a filled aperture it also has the highest possible sensitivity to extended low surface-brightness emission of the kind associated with comets, molecular clouds, and distortions of the cosmic microwave background. The GBT also joins the VLBA for interferometric observations to provide a critical threshold of sensitivity for the highest angular resolution studies. The single focal plane is ideal for rapid, wide-field imaging using multi-pixel cameras. It thus serves as the wide-field imaging complement to ALMA and the VLA.

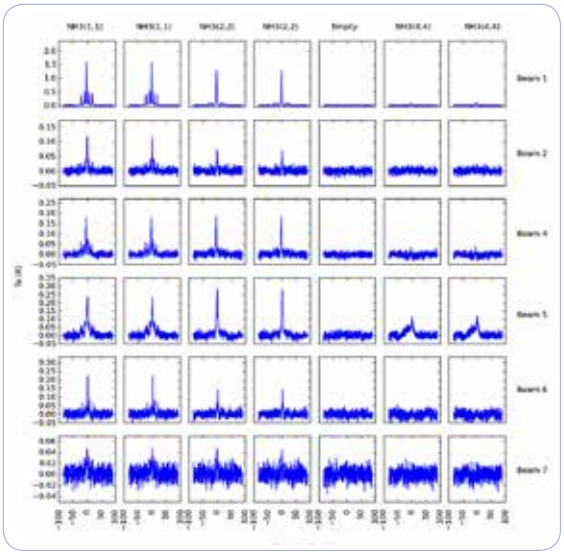
The GBT was designed to allow ready upgrades and changes to all aspects of its hardware and software. A specialty or PI-driven instrument can be installed on the telescope with relative ease, making it feasible for an individual or group of researchers to outfit the telescope to meet their particular science goals. The GBT also has a vigorous development program in collaboration with college and university groups to take advantage of the latest technology and provide our user community with a constantly improving facility.

The largest concern facing the GBT is the 2012 NSF Portfolio Review Committee recommendation that NSF-AST divest from GBT by 2017. NRAO and AUI continue to actively seek partners for the GBT.

Versatile GBT Astronomical Spectrometer

The next-generation spectrometer for the GBT – the Versatile GBT Astronomical Spectrometer (VEGAS) – was released for shared risk science in 2014, providing major new capabilities for the community. VEGAS offers larger bandwidths, more spectral windows, better dynamic range, higher time resolution, and better support for multi-beam instruments than the previous suite of spectral line backends at the GBT.

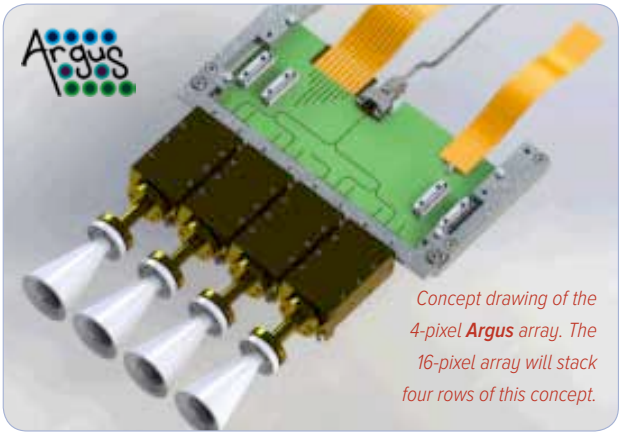
The figure demonstrates some of these capabilities: it shows 42 spectra of the ammonia lines in the Galactic HII region W3, acquired with seven beams of the K-band Focal Plane Array (KFPA). Previously, the KFPA was limited to one spectral window per beam when all seven beams were used. VEGAS can provide up to eight spectral windows to all seven beams simultaneously.



The first shared risk GBT – VEGAS science users arrived 10 March and worked with scientific staff to set up, test, and debug their observations. VEGAS became the default spectral line backend for Semester 2014B observations at the GBT.

VEGAS was built by the CICADA collaboration, which includes NRAO-Green Bank and the Center for Astronomy Signal Processing and Electronics Research (CASPER) at the University of California, Berkeley. VEGAS was funded by the NSF – Advanced Technologies and Instrumentation (NSF-ATI) program (Award 1006509, PI: Dan Werthimer).

ARGUS



*Concept drawing of the 4-pixel **Argus** array. The 16-pixel array will stack four rows of this concept.*

In 2014, a group led by Stanford University began the construction of a 16-pixel, 90-116 GHz traditional feed horn array, funded through the NSF-AST Advanced Technologies and Instrumentation program. The GBT is the best telescope in the world for molecular line studies in the 70-100 GHz band. The proposed camera would capitalize on that fact by using the GBT sensitivity to create, for example, an on-the-fly image of cometary molecules. Development of the instrument continued in 2014, and commissioning is planned for winter 2014 – 2015. The ARGUS cryostat, warm electronics and feeds were completed. However, the ARGUS module delivery and IF/LO have been delayed into 2015 owing to multiple project delays outside NRAO's control. These delays will likely further delay commissioning.

Multiplexed Squid TES Array at Ninety GHz (MUSTANG)

A group led by the University of Pennsylvania began building a new 81-98 GHz bolometer array in 2013 known as the Multiplexed Squid TES Array at Ninety GHz (MUSTANG). This array is assembled from new frequency-domain microwave SQUID multiplexers recently developed by National Institute of Standards and Technology (NIST) and contoured feed horns. Due to the small size of the array (32-64 pixels), it will not provide a significant increase in the overall GBT sensitivity and mapping speed. The array will, however, provide a more stable array than currently available and the infrastructure needed to install the full 200+ pixel MUSTANG2 system which, if funded, will provide more than two orders-of-magnitude increase in the GBT mapping speed.

The project was scheduled to be complete in 2014. However, delays in NIST delivery of the detectors for the instrument have resulted in delays from its original schedule. Due to the schedule lapse, the NRAO initiated bi-weekly meetings with the University of Pennsylvania team, and monthly meetings with the Program Management Department and NRAO management, to monitor progress and control costs. MUSTANG commissioning is planned for 2015.

Maintenance

Routine telescope front-end and back-end maintenance continued, including cold head and compressor maintenance for the cryogenic receivers, repair of failed parts in the front ends, servo and LO-IF systems, and the maintenance and repair of fiber optic connections. Antenna mechanics also performed some remedial grinding in the GBT elevation axle. The mechanics removed the GBT azimuth wheel bearing caps and cleaned, inspected, and filled with new oil all 32 of the telescope wheel bearings. A total of ~36,000 pounds of steel and motors were removed and reinstalled, in addition to the regular and scheduled summer maintenance for all site antennas.

The GBT track is ten years old and is showing signs of wear. In 2014 NRAO began a program of inspecting the track pieces and ordered several to be ready in case replacement is necessary. The bronze impregnated Teflon barrier between the base plate and wear plate was replaced in each track piece.

Working with colleagues from the federal Sugar Grove, WV facility, NRAO continued to administer all Federal Communications Commission applications within the National Radio Quiet Zone (NRQZ). NRAO also monitored the West Virginia Radio Zone, a 10-mile radius around the GBT. In 2014, the Observatory signed a new Memorandum of Understanding with the National Security Agency for continuing to oversee the NRQZ.

Hosted Instruments

The following instruments were hosted at the NRAO – Green Bank in 2014, supported by other facility collaborators, and funded outside the NSF Cooperative Service Agreement.

Precision Array to Probe the Epoch of Reionization: Green Bank is the northern site and development/test facility for the Precision Array to Probe the Epoch of Reionization (PAPER) telescope, the Hydrogen Epoch of Reionization Array (HERA) prototype operated by a partnership that includes University of California, Berkeley and the University of Virginia. This partnership operates an identical array in the Karoo desert of South Africa.

Solar Radio Burst Spectrometer: The 45-ft telescope, previously transformed into a ground station for the Japanese Highly Advanced Laboratory for Communications and Astronomy (HALCA) satellite, is functioning as a Solar Radio Burst Spectrometer, providing dynamic spectra of solar radio bursts during daylight hours at Green Bank and giving the Frequency Agile Solar Radiotelescope (FASR) team its first data.

Low Frequency All-Sky Monitor: This University of Texas, Brownsville project will consist of four phased dipole arrays, separated by several thousand kilometers. One of this telescope's first arrays was installed on the Green Bank site in 2014 owing to the low RFI in the NRQZ and the available NRAO – Green Bank infrastructure.

Magnetometers for Undergraduate Research and Education: West Virginia University has installed a magnetometer at Green Bank as part of the University of California-led Magnetometers along the Eastern Atlantic Seaboard for Undergraduate Research and Education (MEASURE) project to study magnetosphere dynamics.

West Virginia Geospatial Information Network: A reference GPS sensor for the West Virginia Geospatial Information Network is installed on site in Green Bank.

RadioSkynet: Skynet is a distributed network of robotic telescopes operated by students, faculty, and staff at the University of North Carolina at Chapel Hill. The network began operation in January 2006 with the opening of the six Panchromatic Robotic Optical Monitoring and Polarimetry Telescopes (PROMPT) telescopes in Chile. Since then, several more telescopes in the U.S. and Europe have been integrated into the network. The NRAO – Green Bank 20m telescope is the only radio telescope within the network. In 2014, the RadioSkynet telescope refurbishment was completed and telescope operations were initiated. A commensal project to RadioSkynet on the NRAO – Green Bank 20m telescope is searching for Fast Radio Bursts. The project is a collaboration of Virginia Tech, West Virginia University, and NRAO.

RadioAstron: The 140ft telescope in Green Bank is in use as an Earth downlink station for the RadioAstron satellite.

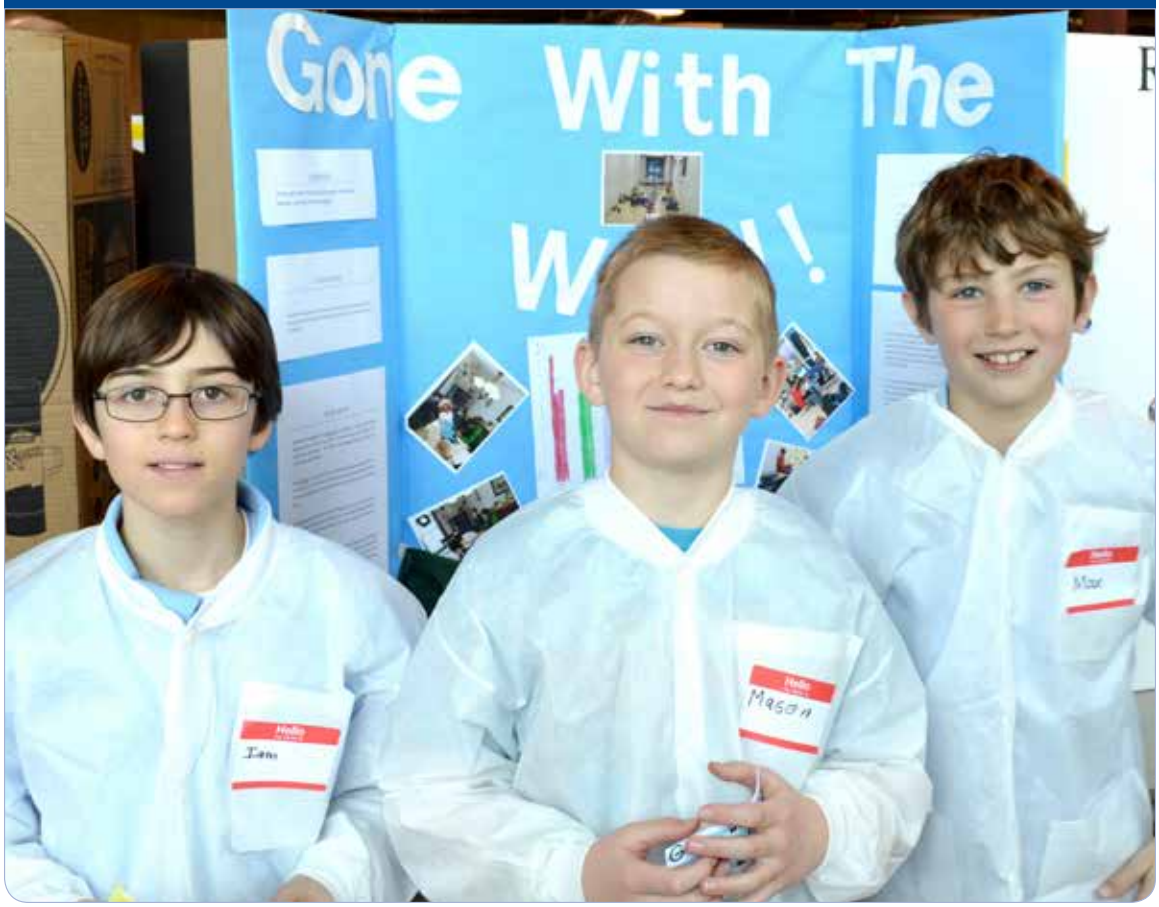
GBT OPERATIONS & DEVELOPMENT

NRAO–Green Bank Hosts a Science Fair

On Tuesday, 8 April, 125 local students in grades 3-12 set up their posters and experiments to participate in the Pocahontas County Science Fair that was hosted by NRAO – Green Bank. Volunteer support from NRAO staff made the event a great success. Their efforts began this winter when they ventured out to the schools to motivate students to participate in the science fair and later to assist students in developing "investigable" questions for their projects.

During the fair itself, 23 NRAO staff assisted with project judging and led engaging activities as students cycled through the daylong event. Astronomy activities included the portable Star Lab and an Exhibit Hall scavenger hunt. The GBT Design Challenge was a team-building engineering activity where students used spaghetti, marshmallows, gumdrops, and toothpicks to build a tall structure that could support weight. Finally, the electronics activity involved building play-doh "Squishy Circuits" with the younger students and soldering with the older students.

Parents and family members were invited to the event and visited throughout the day to visit the projects and participate in the activities. The local Board of Education provided transportation for the students. The science fair was an effective vehicle for fostering community engagement and good will, and a great day for young scientists living in and near Green Bank.



NRAO CALLS FOR PROPOSALS

The NRAO published two Calls for Proposals for the GBT, the VLBA/HSA, and the VLA in 2014: (a) the Semester 2014B Call for Proposals was released 3 January with a submission deadline of 3 February; and (b) the Semester 2015A Call for Proposals was released 7 July with a submission deadline of 1 August.

The NRAO proposal evaluation and time allocation process is panel-based. Members of the scientific community review proposals based on their scientific merit via eight Science Review Panels (SRPs):

- Solar System, Stars & Planetary Systems (SSP)
- Star Formation (SFM)
- Normal Galaxies, Groups, and Clusters (NGA)
- Extragalactic Structure (EGS)
- Energetic Transients and Pulsars (ETP)
- Interstellar Medium (ISM)
- Active Galactic Nuclei (AGN)
- High Redshift and Source Surveys (HIZ)

Each SRP comprises six members: a Chair and five panelists. The term of an SRP member is normally two years.

The annual February proposal deadline typically applies to requests for time from 1 August through 31 January, and the annual August proposal deadline applies to requests for time from 1 February through 31 July.

NRAO received 350 proposals at the February Semester 2014B submission deadline from 1425 unique authors, with 987, 474, and 288 proposers competing for time on the VLA, GBT and VLBA/HSA, respectively. Eight Science Review Panels (SRPs) evaluated the proposals on the basis of scientific merit; NRAO staff reviewed the proposals for technical feasibility. Reviews were completed in March and then reconciled by the Time Allocation Committee (TAC, see Appendix C) during an 11 April teleconference and a 22-23 April face-to-face meeting in Socorro, NM. The TAC consists of the chairs of the SRPs and was charged with recommending a Semester 2014B science program to the NRAO Director. The recommended program was reviewed and approved on 2 May. A TAC report containing information for proposers and observers, including statistics and telescope pressure plots, was released the same day.

NRAO received 375 new proposals for the August Semester 2015A submission deadline from 1432 unique authors, with 1051, 358, and 258 proposers competing for time on the VLA, GBT, and VLBA/HSA, respectively. The proposals were reviewed for scientific merit by eight Science Review Panels (SRPs) and for technical feasibility by NRAO staff. Reviews were completed in September and then reconciled by the TAC during a 9 October teleconference and a 21-22 October face-to-face meeting in Green Bank, WV. The TAC recommended a Semester 2015A science program to the NRAO Director that was reviewed and approved on 5 November. A disposition letter was sent to the Principal Investigator and Co-investigators of each Semester 2015A proposal on 13 November, within the window for funding applications to the NSF Astronomy and Astrophysics Grants (AAG) program. A TAC report containing information for proposers and observers, including statistics and telescope pressure plots, was released the same day. Semester 2015A proposers were also able to request time via new joint opportunities with the Hubble Space Telescope (HST) and Swift missions. Up to 30 HST orbits and 300 Swift kiloseconds (ksec) were available at Semester 2015A. Proposers requested 97 HST orbits and 14 orbits were approved; proposers requested 253.5 Swift ksec and 54 ksec were approved.

The approved Semester 2014B and 2015A science program are available at the NRAO science website. For each approved proposal in these science programs, the Proposal Finder Tool provides access to its authors, title, abstract, and approved NRAO hours.

NRAO welcomes community feedback on its process for telescope time allocation via the Proposal Review department of the Observatory's Helpdesk.

DATA MANAGEMENT AND SOFTWARE

The Data Management and Software (DMS) Department encompasses the resources of the three NRAO science centers: the North American ALMA Science Center (NAASC) in Charlottesville, the Array Science Center in Socorro, and Green Bank Science Operations. The software division contains the staff responsible for all software development within DMS. The Scientific Information Services Division is similar to the software division for staff working in Information Services areas directly related to telescope and observatory specific processes as well as observatory wide support for Archive, Scientific Computing Infrastructure and Wide Area Networks.

Software Development

Initial steps were taken in 2014 towards modernizing the NRAO Archive and its user interface, the Archive Access Tool (AAT). This work is informed by the ALMA archive tool design. Based on internal and external user requirements, an AAT architecture was developed and a prototype AAT was demonstrated. A production version will be delivered in 2015.

The Common Astronomy Software Applications (CASA) package is developed by NRAO, ESO, and NAOJ and is used for the offline reduction and analysis of both ALMA and VLA data. Full support is provided for ALMA and VLA but almost any data that can be written in uvfits format can be imported and reduced in CASA.

The ALMA CASA pipeline was commissioned in 2014 and began processing Cycle 1 and Cycle 2 data at the JAO, with a focus on calibration of standard modes of observing. While development of calibration heuristics for additional modes continues, the focus has shifted to imaging. Heuristics of the VLA scripted pipeline were integrated in 2014, leading to an ongoing project to implement the CASA pipeline as the VLA production pipeline.

Development of CASA, the NRAO post-processing software, continued to emphasize support for the VLA and ALMA. CASA 4.2.1 provided optimizations in many parts of the system and improved data visualization capabilities. The development schedule for CASA 4.3 was changed due to packaging and release problems at the end of the CASA 4.2 cycle. In an effort to accommodate all critical stakeholder needs, the scope of the CASA 4.3 cycle was revised and split into two deliverables. An intermediate release, CASA 4.2.2 offered the most pressing functionality for ALMA Cycle 2, specifically, improved handling of data weights, and was delivered in 2014. An expanded CASA 4.3 release, including initial refactored imaging, will be released in January 2015.

The Proposal Submission Tool (PST), Proposal Handling Tool (PHT), and the Observation Prep Tool (OPT) were all updated as planned to support the VLA Semester 2014B and 2015A Calls for Proposals and observing.

A prototype standalone web application was developed and demonstrated as a reprocessing interface. Its goal is to allow astronomers to submit simple reprocessing requests to the VLA and ALMA pipelines, using the NRAO cluster. It will be delivered into production in 2015 and further developed to support more complex requests.

ALMA System Software

Dynamic scheduling was tested and implemented as a production service at the JAO. Work continues on improving it based on experience with science observing.

The original QuickLook application was deemed unusable due to performance and usability issues. A new QuickLook application was written and tested successfully at the OSF in August.

The Science Operations IPT re-prioritized fast scanning as a major deliverable and this capability was delivered in 2014. ALMA observing efficiency was improved by parallelizing setup and shutdown rather than with scan sequences, as originally envisioned. This system software deliverable resulted in ~6 minutes saved per ALMA observation.

The full data rate (60 MB/s) delivery by the ALMA correlator was verified in early 2014. Additional low-priority correlator modes – 2x Nyquist, 3x3 and 4x4 bit modes – were de-scoped by Science Operations IPT to focus effort on sub-arrays.

The ALMA Phasing Project (APP) correlator software was delivered and successfully tested during two missions to the OSF. All APP features were verified and the readiness of the system for the Hardware Acceptance Review was established.

VLA and VLBA System Software

Significant DMS effort was invested in VLA and VLBA support for commissioning and observing in Semesters 2014A and 2014B. The VLA and VLBA system software was updated to support new capabilities and the migration of capabilities from Resident Shared Risk Observing to General Observing. Modes added or improved in 2014 included phase binning mode, various VLA Y27 modes for VLBI, and VLA pulsar mode. Data rates exceeding 300 MB/sec were achieved on the VLA. Additionally, the Proposal Submission Tool and Proposal Handling Tool were updated to support the new capabilities. The software work to enable full on-the-fly mosaic mode was completed. The new wideband VLBA observing system was stabilized in 2014.

GBT System Software

The remaining requirements for integration of the GBT data into the NRAO archive were completed in 2014. GBT data is now available via the archive.

The GBT Monitor and Control system was modified to use data streaming to support the high data rates expected with the Versatile GBT Astronomical Spectrometer (VEGAS). A data viewer capability was requested by GB scientists and was developed using the streaming capabilities. This reduced the need to include streaming in Astrid in the near term. Higher priority work diverted resources from data streaming so effort was prioritized to deliver data streaming on the Monitor & Control system, which was required to support eventual changes to Astrid.

A CASA version GBT imaging pipeline was delivered in 2014. Performance improvements in support of VEGAS data rates were included by integrating data streaming and parallelizing the pipeline processes. This work will continue through 2015. The activity to complete the GBT pipeline parallelization was delayed due to VEGAS commissioning and shared-risk observing support and resource constraints.

Scientific Information Services

The alignment of Scientific Information Services to focus on high-performance computing (HPC), science data storage, and the prompt delivery of observed data products, has allowed for clear delineation of complementary support responsibilities with Computing Information Systems (CIS), with accountability of support to DMS. The expansion of archive, network communications, and HPC capacity is executed in close cooperation with the individual telescope operations and observer supporting initiatives, to facilitate ever-increasing instrument science capabilities. Several initiatives were completed in 2014 that improved the observer experience, such as enabling account association and single sign-on between ALMA and MyNRAO accounts, and access to NRAO cluster resources for data re-processing.

In 2014, multiple Archive and HPC systems were added, most notably those needed to support the ALMA pipeline in Chile and the full complement of data processing capacity at the NAASC. As anticipated, the VLA upgrade resulted in a substantial increase in the fidelity and size of VLA observations, pressuring observers' personal computer resources. In cases where sufficient capacity was not available, NRAO enabled access to cluster computing resources and high speed storage, by leveraging existing MyNRAO user accounts and established access policies.

SIS staff successfully tested the staging and execution of CASA jobs on University of Virginia (UVA) resources. While this additional capacity is not yet required, it informs future strategies to employ Genesis2/Globus (XSEDE) and Slash2/DataSupercell (PSC) in support of access to national compute resources when needed. In addition to these initiatives, UVA has granted NRAO access to its new Tier 3 Data Center for the hosting of public science data products with 250 TeraBytes of storage.

With the increasing data products size, the move to Gigabit/second communications access to all major NRAO sites is complete, with 1 Gigabit/s in Charlottesville and New Mexico, and 10 Gigabit/s to Green Bank. To manage these resources, NRAO is leveraging PerfSonar for performance analysis, and investing in the Bro Network Security monitoring tool for improved visibility into traffic payload in and out of NRAO.

Photo by Carlos Padilla

SCIENCE SUPPORT AND RESEARCH

Science Support and Research (SSR) is the science interface of the Observatory to the user community. SSR is an Observatory-wide department that coordinates, aligns, and manages the collective efforts of staff from Charlottesville (CV), Socorro (SO), and Green Bank (GB). SSR is organized into three divisions: Telescope Time Allocation, Science User Support, and Science & Academic Affairs.

The Telescope Time Allocation (TTA) division manages proposal preparation, submission, evaluation, and time allocation for the VLA, VLBA, and GBT, and associated activities. It uses staff from across the observatory, and is supported by tools and databases that are developed and maintained by the Data Management & Software department. This was the fourth year of a process where the community evaluates the science merit of all proposals submitted each semester through a panel-based system, and makes recommendations regarding time allocations through the Telescope Allocation Committee (TAC). As an international project, ALMA manages its time allocation process through the JAO and the NAASC.

Science User Support (SUS) is the user facing component of NRAO operations and comprises three broad functional areas of responsibility: (a) community support, (b) science data processing, and (c) science software support. The initial emphasis is on Observatory-wide tasks that have an immediate impact on users: a uniform science portal, an integrated helpdesk, and a unified science website.

Science & Academic Affairs (SAA) supports the research activities of NRAO scientific staff and related activities, including: (a) travel related to research and other professional activities; (b) review and promotion of scientific staff; (c) recruitment and hiring of scientific staff; (d) postdocs and mentoring; (e) colloquia and the annual Jansky Lectureship; and (f) student and visitor programs.

Jansky Fellowship Program

The NRAO Jansky Fellowship program provides outstanding opportunities for research in astronomy. Jansky Fellows formulate and carry out investigations either independently or in collaboration with others within the wide framework of interests of the Observatory. The program is open each fall to candidates with interest in radio astronomy instrumentation, computation, and theory, and prior radio experience is not required. Multi-wavelength projects leading to a synergy with NRAO instruments are encouraged. Three new Jansky Fellows joined NRAO in fall 2014: Chat Hull, Brent McGuire, and Sarah Burke Spolaor.

Chat Hull completed his Ph.D. at the University of California, Berkeley, where he focused on instrumentation and astronomical research. Along with his adviser, Dick Plambeck, Chat tested, installed, and commissioned the dual-polarization millimeter receiver system at the Combined Array for Research in Millimeter Astronomy (CARMA), and then used the system to perform the Telescope Array Doing Polarization (TADPOL) survey, the largest interferometric survey to date of dust polarization in low-mass protostellar cores. As a Jansky Fellow, Chat will keep a foot in the technical and the astronomical camps by working to characterize the ALMA polarization system more fully, and by using that system to understand how magnetic fields affect the star formation process at the scales of protostellar envelopes, circumstellar disks, and beyond. Chat will take his Jansky Fellowship at the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts.

Brett McGuire completed his Ph.D. at Caltech in the department of Physical Chemistry. His research focuses on prebiotic astrochemistry at the interface of laboratory physical chemistry and observational astronomy. Brett has experience in laboratory astrophysics and also observational astronomy having observed with the Caltech Submillimeter Observatory (CSO), CARMA, and the GBT. During his tenure as a Jansky Fellow, he plans to explore laboratory studies of astrophysical ices, the likely birthplace of these molecules, in the far-IR (THz) region with the objective of applying

these measurements to observations of protoplanetary disks and complex molecular clouds. Brett will divide the first year of his Fellowship between Caltech and NRAO Charlottesville before moving to Charlottesville to complete his Fellowship in 2015. He will collaborate with University of Virginia scientists in the chemistry and astronomy departments.

Sarah Burke Spolaor received her Ph.D. at Swinburne University of Technology (Melbourne, Australia) in 2010 and then took a postdoc at Caltech. She is an expert on fast radio bursts (FRB). She has extensive pulsar and FRB research experience having used the Parkes radio telescope and the VLA. As a Jansky Fellow based at the NRAO facilities in Socorro, Sarah will undertake research in the topics of radio transients and gravitational-wave astronomy. She will be exploiting the excellent sensitivity and angular resolution of the NRAO interferometric facilities to explore the radio sky on sub-second timescales. She will also be continuing research that aims to discover and characterize electromagnetic emission from binary systems of supermassive black holes in the Universe.

Postdoctoral Fellows

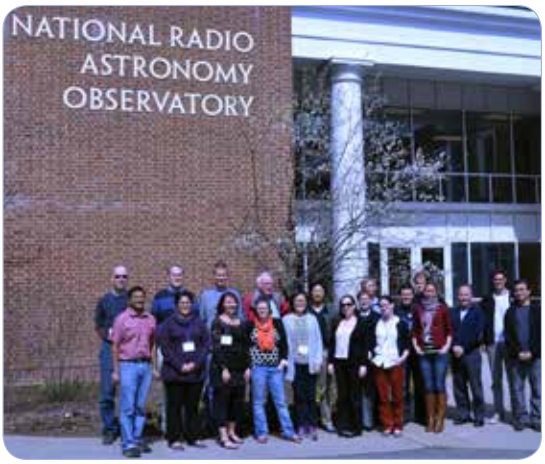
NRAO offers a Postdoctoral Fellow program that provides the opportunity for hands-on training in areas of technical expertise and observatory operations, in addition to offering excellent research opportunities with NRAO facilities.

Amanda Kepley joined the NAASC in September 2014 following a two-year stint as an NRAO Postdoctoral Fellow at the GBT. Her research focuses on understanding the physical properties of the gas responsible for fueling the evolution of galaxies by using radio observations of nearby (d < 10 Mpc) galaxies. Recently, she used the new 4mm receiver on the GBT to make the deepest map ever of the star-forming gas in the nearby galaxy M82, which was published in the Astrophysical Journal Letters and featured in an NRAO press release in 2014.

As an ALMA Cycle 1 PI, Amanda is working on the first spatially resolved study of the molecular gas fueling the starburst in the low-metallicity starburst galaxy II Zw 40. These observations will lead to a better understanding of how stars form in low metallicity systems like those found in the early Universe. On the technical side, Amanda has had the opportunity to participate in EVLA commissioning efforts as a resident shared risk observer and led the early astronomical commissioning efforts for VEGAS, the new GBT backend. Amanda is looking forward to opportunities available as a NAASC postdoc to become an expert ALMA user. She received her Ph.D. in astronomy from the University of Wisconsin – Madison with Eric Wilcots and worked with Kelsey Johnson as a postdoc at the University of Virginia.

NRAO Postdoctoral Symposium

The annual NRAO Postdoctoral Science Symposium was held on Monday-Tuesday, 7-8 April 2014 at the Observatory's facilities in Charlottesville, Virginia. This symposium brings together the resident and non-resident Jansky Fellows and NRAO postdocs to highlight their current research, share ideas, and establish collaborations. The symposium covers a wide range of current topics. This year's speakers described new research into the physics of comets, pulsars, protoplanetary disks, binary star formation, the intergalactic medium, dwarf galaxies, massive black holes, galaxy evolution, and the early Universe. Local NRAO scientific and engineering staff also attend.



Attendees at the 2014 NRAO Postdoc Symposium

Dr. Andrew Baker, a former NRAO Jansky Fellow and a professor at Rutgers University, was the symposium's Keynote Speaker in 2014. Dr. Baker's talk – "Dusty Star-forming Galaxies at High Redshift" – discussed recent results on the redshift distributions, evolutionary states, and detailed internal properties of such galaxies, as well as what can be learned from lensed galaxies about intervening mass distributions. He also provided a personal perspective on where ALMA might be able to make the most significant contributions over the next few years.

14th Synthesis Imaging Workshop

The 14th Synthesis Imaging Workshop took place 13-20 May and was attended by 152 scientists from 20 countries. Held on the campus of the New Mexico Institute of Mining and Technology (NMT) and at the NRAO Domenici Science Operations Center in Socorro, the Workshop featured lectures, data reduction tutorials, and observation preparation tutorials. Other events included a reception, workshop dinner, visits to the Magdalena Mountains and the Bosque del Apache, and a popular tour of the VLA.

More than half the participants were graduate students. Scientific and engineering staff, postdocs, undergraduates, and faculty also attended. The participants spent one afternoon learning the important considerations for observing and how to prepare for VLA and ALMA observations. There were also two full days of data reduction tutorials. Participants could choose tutorials using VLA, VLBA, Long Wavelength Array (LWA), and/or ALMA data. The datasets and a guide to reducing them in CASA are online at the NRAO science website.

The 2014 Synthesis Imaging Workshop presentations and lectures are also available at the NRAO science website. NRAO and AUI provided logistical and financial support and a majority of the lecturers. Lecturers from the Naval Research Lab, the Netherlands's ASTRON, the Harvard-Smithsonian Center for Astrophysics, New Mexico Tech, the University of New Mexico, and the Square Kilometre Array also supported the Workshop. New Mexico Tech provided the use of their facilities, and the Physics Department provided key support. The University of New Mexico and the Institute of Geophysics, Planetary Physics, at Los Alamos National Laboratory also provided financial support.

NRAO Astronomer Elected as AAAS Fellow

Felix J. "Jay" Lockman, an NRAO astronomer based in Green Bank, was named a Fellow of the American Association for the Advancement of Science (AAAS) in 2014. Jay was honored for his "significant studies of neutral hydrogen in our galaxy and others, including the discovery of the 'Lockman Hole,' and for service to U.S. radio astronomy." The Lockman Hole is an area of the sky near the constellation Ursa Major that has a remarkably low concentration of neutral atomic hydrogen. This makes it a useful window on the distant universe for certain X-ray and ultraviolet observations. Lockman received his Ph.D. from the University of Massachusetts, Amherst, in 1979 and began work at NRAO in 1978.

The tradition of AAAS Fellows began in 1874. Election as a AAAS Fellow is an honor bestowed upon AAAS members by their peers. New Fellows were presented with an official certificate and a gold and blue rosette pin at the February 2014 AAAS Annual Meeting in Chicago.

U.S. – China Workshop on Radio Astronomy Science & Technology

The 3rd U.S. - China Workshop on Radio Astronomy Science and Technology was held 19-21 May at NRAO – Green Bank. Attendees focused on developing collaborations between Chinese and U.S.-based scientists and engineers in Very Long Baseline Interferometry (VLBI), pulsars, gravity waves, the Epoch of Reionization, neutral hydrogen, precision astrometry, Fast Radio Bursts, low frequency and solar radio astronomy, phased array feeds, digital technologies, spectrum management, and Radio Frequency Interference excision.

Particular attention was given to new research opportunities with: the 65m radio telescope near Shanghai; the Five-Hundred-Meter Aperture Spherical Telescope (FAST); the Chinese Spectral Radioheliograph (CSRH); a 110m fully-steerable radio telescope in western China (QTT); the Chinese Space Millimeter-Wavelength VLBI Array.

This Green Bank workshop, which followed from a Memoranda of Understanding between NRAO and Shanghai Astronomical Observatory (SHAO) and between NRAO and the National Observatories Astronomy China (NOAC), was organized by NRAO and SHAO and built on the two previous joint workshops held in China in 2008 and 2013.

Karl G. Jansky Lectureship

The Karl G. Jansky Lectureship is an honor established by the AUI trustees to recognize outstanding contributions to the advancement of astronomy. First awarded in 1966, it is named in honor of Karl G. Jansky who, in 1932, first detected radio waves from a cosmic source.

The 49th annual Jansky Lecture was given in 2014 by Dr. Jill Tarter, the Bernard Oliver Chair for the Search for Extraterrestrial Intelligence (SETI) at the SETI Institute in Mountain View, California, and the former Director of the Center for SETI Research. Dr. Tarter has pioneered methods for searching for extraterrestrial intelligence using radio techniques, as she is also a leader in the emerging field of astrobiology.

Dr. Tarter received a Bachelor of Engineering Physics with Distinction from Cornell and went on to receive her Masters and Ph.D. degrees in Astronomy from the University of California at Berkeley. She is credited with coining the term "brown dwarf" to refer to substellar objects that fail to achieve hydrogen burning in their cores. She served as Project Scientist for NASA's SETI program, the High Resolution Microwave Survey. The SETI Institute was founded in 1984; Dr. Tarter was one of its founding members and continues to serve as a trustee. Following the termination of funding for NASA's SETI program in 1993, she served in a leadership role to secure private funding to continue the search, serving as Director of Project Phoenix under the auspices of the SETI Institute.

Dr. Tarter has received numerous awards in recognition of her achievements, including a Lifetime Achievement Award by Women in Aerospace in 1989. She was named a Fellow of the American Association for the Advancement of Science in 2002 and a Fellow of the California Academy of Sciences in 2003; she received the Adler Planetarium Women in Space Science Award in 2003; and was named one of the 100 most influential people in the world by Time Magazine in 2004.

Dr. Tarter is deeply involved in the education of future citizens and scientists. In addition to her scientific leadership at NASA and the SETI Institute, she has been the Principal Investigator for two curriculum development projects funded by NSF, NASA, and others: the *Life in the Universe* series of science teaching guides for grades 3-9, and *Voyages Through Time,* an integrated high school science curriculum on the fundamental theme of evolution. Dr. Tarter is a frequent speaker at science teacher meetings and museums/science centers, bringing her commitment to science and education to teachers and the public.

NRAO Astronomer Receives Prestigious Bruce Gold Medal

Kenneth Kellermann, a senior scientist at the NRAO in Charlottesville, Virginia, was the recipient of the Astronomical Society of the Pacific's (ASP) 2014 Catherine Wolfe Bruce Gold Medal, the society's highest honor. This award recognizes Kellermann's lifetime achievements in founding radio astronomy as a major branch of global astronomy and for contributing to both the development of modern cosmology and to the invention of Very Long Baseline Interferometry (VLBI).

Kellermann earned his S.B. in physics from the Massachusetts Institute of Technology in Cambridge in 1959 and his Ph.D. in physics and astronomy from the California Institute of Technology in Pasadena in 1963. He was one of the first to use the Owens Valley Radio Observatory interferometer to study both galactic and extragalactic radio sources. He did his postdoctoral research at Australia's Commonwealth Scientific and Industrial Research Organization (CSIRO) Division of Radiophysics, where he studied planets as well as radio galaxies with the then-new Parkes Radio Telescope.

Kellermann joined the NRAO in 1965. During his tenure, he served as NRAO's acting assistant director for Green Bank Operations, chief scientist, and head of the observatory's New Initiatives Office. He has also held a concurrent appointment as research professor of astronomy at the University of Virginia. During 1978 and 1979, while on leave from NRAO, Kellermann served as director of the Max Planck Institute for Radio Astronomy in Bonn, Germany.

Starting in the late 1960s, Kellermann – along with Barry Clark, Marshall Cohen, and other colleagues – led the development of VLBI. Their efforts soon enabled astronomical observations with a resolution of 0.01 arc second. Kellermann later led the effort to design and build the VLBA. He has also been an advocate for using radio telescopes in space in conjunction with terrestrial telescopes to achieve even greater resolution. He also was involved in the ongoing international project to develop the Square Kilometre Array.

Summer Student Program

NRAO welcomed a large class of 30 research interns to Socorro, Green Bank and Charlottesville in 2014, the 55th class in the Observatory's summer student program.

The program runs 10-12 weeks each summer, typically early June through early August. At the end of the summer, participants present their research results at a student seminar and submit a written report. These projects often result in publications in scientific journals. Financial support is available for students to present their summer research at an American Astronomical Society meeting, generally the winter meeting following their appointment. In addition to research, students take part in social events, excursions, and an extensive lecture series on radio astronomy and astronomical research. Students also collaborate on their own observational projects using the VLA, VLBA, and/or GBT.

Management and oversight of the NRAO summer student program transitioned from Jeff Mangum to Alison Peck in 2014. NRAO scientific staff members Amy Mioduszewski and David Frayer lead and coordinate the summer student program in Socorro and Green Bank, respectively.

Three types of summer student programs are available at NRAO. The NRAO *Research Experiences for Undergraduates (REU)* program is for undergraduates who are citizens or permanent residents of the U.S. or its possessions, and is funded by the NSF Research Experiences for Undergraduates (REU) program.

The *NRAO Undergraduate Summer Student Research Assistantship* program is for undergraduate students or graduating college seniors who are U.S. citizens, are from an accredited U.S. undergraduate program, or are otherwise eligible to work in the U.S. This program primarily supports students or research projects that do not meet the REU guidelines, such as graduating college seniors, some foreign undergraduate students, or projects involving pure engineering or computer programming.

The *NRAO Graduate Summer Student Research Assistantship* program is for graduate students who are citizens or permanent residents of the U.S. or its possessions, enrolled in an accredited U.S. graduate program, or otherwise eligible to work in the U.S.

Sixteen, ten, and four NRAO summer students participated in the 2014 program and were based in Charlottesville, Socorro, and Green Bank, respectively. Each student's educational status in summer/fall 2014 and their NRAO research project and scientific staff mentor(s) are summarized in the following paragraphs.

Charlottesville

Aaron Beaudoin was a rising senior studying Astronomy at the University of Illinois at Urbana-Champaign. Aaron worked with Morgan McLeod at the CDL on *The ALMA Front End Test and Measurement System.*

Christopher Bochenek was a rising junior studying Physics and Math at the University of Chicago. Christopher worked with Scott Ransom and Paul Demorest on *Basic Physics with Pulsars.*

Andrew Burkhardt entered graduate school in Astronomy at the University of Virginia in fall 2014. Andrew worked with Tony Remijan and Al Wootten on *NH_2OH Toward the Shocked Outflow Region L1157-B1 and CH_3CHO Toward Orion KL.*

Tierra Candelaria was a rising senior studying Math and Physics at The College of Idaho. Tierra worked with Scott Schnee and John Tobin on *Temperature, Density, and Kinematics of Dense Cores in Taurus.*

Niklaus Dollhopf was a rising junior studying Physics and Astronomy at the University of Virginia. Klaus worked with Tony Remijan and Al Wootten on *NH_2OH Toward the Shocked Outflow Region L1157-B1 and CH_3CHO Toward Orion KL.*

Cathleen Gross was a rising junior studying Applied Physics and Math at the College of St. Benedict. Cathleen worked with Christophe Jacques at the CDL on *The ALMA Photonic Local Oscillator Chain.*

Ben Holland was a rising sophomore studying Engineering and Applied Physics at the Colorado School of Mines. Ben worked with Alison Peck on *Constraining the Orbits of Supermassive Binary Black Holes.*

Evgeniya Kravchenko was a graduate student at the Astro Space Center of Lebedev Physical Institute in Moscow, Russia. Evgeniya worked with Bill Cotton on *VLA Rotation Measure Synthesis at High Frequencies.*

Tamar Lambert-Brown was a rising sophomore studying Physics and Computer Science at the University of Maryland. Tamar worked with Aaron Evans on *Dissecting Luminous Starburst Galaxy Mergers*.

Kristen Luchsinger was a rising senior studying History of Math and Science at St. John's College. Kristen worked with Mark Lacy on *Optimizing Selection of Quasars and High Redshift Radio Galaxies in Deep Near-Infrared Fields.*

Myles McKay was a rising junior studying Physics at South Carolina State University. Myles worked with Sabrina Stierwalt and Kartik Sheth on *Comparison Of Alma And Spitzer Data Of Molecular Gas And Dust In The Nuclear Ring And Black Hole Of NGC 1097.*

Moiya McTier was a rising senior studying Astrophysics and Mythology at Harvard College. Moiya worked with Drew Brisbin on *Probing the Physical Conditions of a Compact Starburst Galaxy.*

Michelle Nowling was a rising junior at Lone Star College – North Harris. Michelle worked with Arielle Moullet on *Winds in the Middle Atmosphere of Venus: Determining Temporal and Spatial Variations with ALMA Data.*

Brianna Thomas was a rising sophomore studying Math at Howard University. Brianna worked with Alison Peck and Jacqueline Hodge on *A Pipeline for Ultra-High-Resolution Imaging of Radio Sources.*

Daniel Wavle was a rising senior studying Physics and Astronomy at Indiana University. Daniel worked with Jennifer Donovan Meyer and Adam Leroy on *Starburst-Driven Galaxy Outflows.*

Aara'L Yarber is a rising junior studying Physics and Atmospheric Science at Howard University. Aara'L worked with Kartik Sheth, Dana Balser, and Sarah Wood on *Bulge to Total Evolution over Last 7 Gyr in COSMOS.*

Green Bank

Devin Cody was a rising sophomore majoring in Physics/Computer Science at Yale University. Devin worked with John Ford on *Low Frequency Dipole Antenna*.

Sara Denbo was a rising sophomore majoring in Astrophysics at Michigan State University. Sara worked with Alyson Ford on *The Effects of the Galactic Centre Wind on HI Clouds in the Milky Way*.

Ryan Endsley was a rising senior majoring in Physics/Math/Philosophy at Washington University in St. Louis. Ryan worked with Jay Lockman on *Neutral Clouds in the Milky Way's Hot Halo*.

Gabriel Ortiz-Pena rising junior majoring in Astronomy/Astrophysics at Pennsylvania State University. Gabriel worked with Richard Prestage on *RFI Mitigation and Pulsar Timing*.

Socorro

Jonathan Barnes was a rising senior majoring in Physics at Norfolk State University. Jonathan worked with Betsy Mills on *How Dense are Galactic Center Clouds?*

Aspen Clements was a rising junior majoring in Chemistry/Physics at the University of Nebraska at Kearney. Aspen worked with Betsy Mills on *Picturing Sgr B2: The Distribution of Molecules in the Most Actively Star-forming Cloud in the Milky Way.*

Hansung Gim was a graduate student in Astronomy at the University of Massachusetts–Amherst. Hamsung worked with Emmanuel Momjian on *The Nature of Sub-micro-Jy Sources in the CHILES Continuum Survey.*

Julia Gross was a graduate student in Astrophysics at Columbia University. Julia worked with Emmanuel Momjian on *A Blind Search for HI in Volumes at Different Redshift.*

Gia Johnson was a rising senior majoring in Mathematics/Physics and Chemistry at Adams State University. Gia worked with Minnie Mao, Frazer Owen, and Emmanuel Momjian on *Probing the Nether Regions of a Spiral DRAGN.*

Kara Kundert was a rising senior majoring in Astronomy and Physics at the University of Michigan–Ann Arbor. Kara worked with Urvashi Rao on *Evaluating the Effects of ALMA's Heterogenous Beams on Imaging.*

Rebecca Levy was a rising junior majoring in Astronomy, Physics, and French at the University of Arizona. Rebecca worked with Juergen Ott, David Meier, and Annie Hughes (Max Planck Institute for Astronomy) on *The Distribution of Dense Molecular Gas in the Large Magellanic Cloud.*

Matthew Rickert was a graduate student in Physics and Astronomy at Northwestern University. Matthew worked with Juergen Ott and David Meier on *The Energetic Sources that Emit Water Maser Emission in the Galactic Center.*

Viviana Rosero was a graduate student in Physics at New Mexico Tech. Viviana worked with Mark Claussen on *Deep Radio Continuum Observations of Massive Protostars: A Search for Jets.*

Alexander Teachey was a rising Senior majoring in Physics/Math at CUNY Hunter College. Alexander worked with Juergen Ott, Betsy Mills, and David Meier on *Ammonia Masers: What are They?*

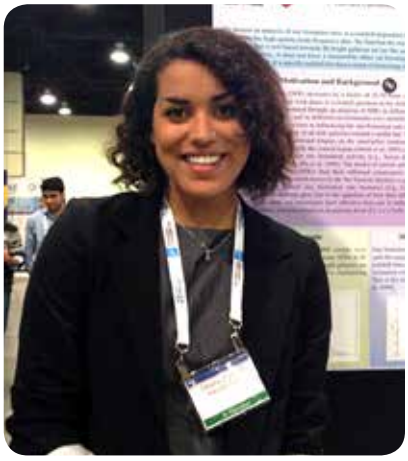
Summer Student AAS Presentations

Nineteen of the 2013 NRAO Summer Student program participants presented the results of their research projects at the January 2014 American Astronomical Meeting in Washington, D.C. The table below lists these presentations along with the session title, the paper number in the session, and the complete author list.

Monday, 6 January 2014	
Novae, Cataclysmic Variables, Evolved Stars	***(154.11) Evidence for Non-thermal Radio Emission from a Classical Nova - V1723 Aql***. SY. Zheng; J.L. Sokoloski; M.P. Rupen; J. Weston; L. Chomiuk; A.J. Mioduszewski; K. Mukai; M.I. Krauss; N. Roy; T. Nelson
Pulsars & Neutron Stars	***(153.18) Rotation Measures of Globular Cluster Pulsars as a Unique Probe of the Galactic Magnetic Field*** A. Ho; S.M. Ransom; P. Demorest
Tuesday, 7 January 2014	
AGN, QSO, Blazars Poster	***(250.21) Large Radio Sources Hosted by Spiral Galaxies (aka: The Wrong Type of Host!)*** R. Duffin; M. Mao; F.N. Owen
Computation, Data Handling, & Image Analysis	***(255.07) Quantifying Deep-Imaging Limits of the VLA*** J. Mayeshiba; J. Mayeshiba; U. Rau; F.N. Owen
Evolution of Galaxies	***(246.02) Probing Star Formation in Polar Ring Galaxy NGC 2685*** L. Ackman; J. Donovan Meyer; J. Muñoz-Mateos ***(246.27) The Influence of Bars in Triggering Star Formation Since z=1*** D. Powell, K. Sheth, K. Scott
Star Formation	***(244. 03) New Star Formation in NGC 3690*** A. Abdullah ***(244. 04) Stacking Spectra of High Critical Density Tracers in ALMA Cycle 0 Observations of the Antennae Galaxies*** J. Kadowaki; A.K. Leroy; L. Barcos; C. Lee; B.C. Whitmore; C.L. Brogan; J.E. Hibbard; K.E. Johnson; R. Chandar; G.C. Privon; A.S. Evans; A.J. Remijan; K. Sheth ***(244.13) Infall as a Function of Position and Molecular Tracer in L1544 and L694*** J.A. Keown; S. Schnee; T.L. Bourke; R. Friesen
Starburst Galaxies	***(252.02) Imaging the Spatial Density Within Starburst Galaxies M82 and Arp220*** N.S. Kern; J.G. Mangum; J.K. Darling; C. Henkel; K. Menten
The Solar System	***(247.17) Interpreting the Thermal Lightcurve of Iapetus at 1.3mm*** N. Hagen; A. Moullet; M.A. Gurwell
HAD VI: History of Astronomy	***(209.05) Radio Frequency Interference and the National Radio Astronomy Observatory*** S. Smith

Wednesday, 8 January 2014	
Dwarf & Irregular Galaxies	***(355.17) Magnetic Fields in the Irregular Galaxy NGC1156*** S. Schmitz; A.A. Kepley; R. Beck; C.C. Lang; E.M. Wilcots
Young Stellar Objects	***(347.09) Study of the Outflow and Disk surrounding a Post-Outburst FU-Orionis Star*** S.N. Mellon; L.M. Perez
Thursday, 9 January 2014	
Molecular Clouds, HII Regions, Interstellar Medium	***(454.06) Evolution of the ISM at z < 1*** Z. Mohamed ***(454.07) Examining the Initial Conditions of Star Formation Through Dense Gas Kinematics*** A.T. Mead; J.J. Tobin; R. Smith (***454.11) Investigation of Interstellar Formation Routes Using Molecular Abundance Ratios of C3H2O Isomers*** R.A. Loomis; C.H. Johnson; A.J. Remijan ***(454.32) Power Law Structure of the Interstellar Medium: Fractal Dimension of the HI, CO and mid-IR in Nearby Galaxies*** L. Bowman; J. Ott; D. Westpfahl ***(454.38) NH2D in Orion KL: Results from ALMA, EVLA, and IRAM*** A.B. Lucy; A. Wootten; N. Marcelino

NRAO REU Student Awarded Chambliss Medal



Diana Powell, a 2013 REU student at NRAO, was awarded a Chambliss Astronomy Achievement Medal for her research and poster presentation at the 223rd AAS meeting in January 2014 in Washington D.C. The Chambliss medals recognize exemplary research by undergraduate and graduate students who present at a AAS poster session meeting. Diana was one of six undergraduate students awarded this honor at the 223rd AAS meeting.

Diana worked with Kartik Sheth and Kim Scott at the NRAO in Charlottesville during summer 2013, studying the influence of bars in triggering star formation in galaxies over the last half of cosmic history. By measuring the star formation rate (SFR) in a sample of nearly 2000 galaxies from $0 < z < 1$, Diana was able to show that there are no obvious differences in the SFRs between barred and unbarred galaxies at any epoch. She concluded that while bars may enhance star formation in specific regions of galaxies, as seen in nearby objects, they do not contribute significantly to the SFR averaged over an entire galaxy. She also discovered that for low redshift, infrared-bright galaxies, the SFR increases with decreasing mass, implying that high mass galaxies turn off their star formation at earlier times.

Diana graduated from Harvard in 2014 with plans to attend graduate school in astronomy and pursue research in either exoplanets or star formation. Diana is also interested in becoming an advocate for the involvement of scientists in policy.

NRAO at the 2014 AAS Meetings

NRAO actively participated in the winter and summer American Astronomical Society (AAS) meetings in 2014. The winter AAS meeting was held Sunday, 5 January through Thursday, 9 January 2014 at the Gaylord National Convention Center near Washington D.C. The summer AAS meeting was held Sunday, 1 June through Thursday, 5 June 2014 at the Westin Copley Place in downtown Boston, Massachusetts.

More than 300 attendees attended the NRAO Town Hall on Tuesday evening, 7 January. After an opening reception, Director Tony Beasley updated the AAS membership regarding: (a) ALMA construction progress; (b) science opportunities and development programs at ALMA, VLA, GBT, and VLBA; (c) recent science results from across NRAO; and (d) technical development for the next generation of radio astronomy research facilities. The NRAO Town Hall concluded with an audience question & answer session.

The NRAO booth in the AAS meeting exhibit hall at both the Gaylord Convention Center exhibit hall in January and at the Westin Copley Place in June was busy and provided an excellent venue for NRAO scientific staff to meet and converse with scientists from other institutions.

Given the enhanced capabilities of the Jansky VLA, NRAO organized a daylong AAS Workshop on Sunday, 5 January, titled *NRAO Very Large Array Sky Survey Science Planning*. This workshop extensively discussed the scientific potential and potential design of new centimeter-wavelength sky surveys with the community.

NRAO organized a three-hour Splinter Session – *Proposing for NRAO Instruments* – on Tuesday, 7 January to assist members of the community, especially new users, interested in proposing for observations with the GBT, VLA, and VLBA. This session opened with an overview of NRAO telescope capabilities and the NRAO observing proposal process. A hands-on session followed that enabled community members to work on GBT, VLA, and/or VLBA observing proposals on their own laptops. NRAO scientific staff assisted and answered questions.

Joe Lazio (JPL) and NRAO scientists organized a AAS meeting Splinter Session – *Telescopes for Cosmic Dawn and 21 cm Cosmology* – that immediately followed the NRAO Town Hall on Tuesday evening, 7 January. This session continued and broadened the discussion of U.S. plans for future telescopes designed to track the transition of the Universe from a neutral to an ionized state during Cosmic Dawn using the highly redshifted 21 cm line from neutral hydrogen. Topics of discussion included the status and future plans for telescopes with U.S. involvement, and the full range of science cases that can be conducted at low radio frequencies.

NRAO sponsored and participated in the early Sunday evening Undergraduate Orientation at the winter (5 January) and summer (1 June) AAS meetings. Local Education & Public Outreach (EPO) events were sponsored by AUI and the AAS at the winter and summer AAS meetings. Each of these EPO events brought ~ 200 local young people to the AAS meeting exhibit hall, enabling them to visit the AUI and NRAO exhibits, and engage in discussions with AUI staff and NRAO scientists about radio astronomy.

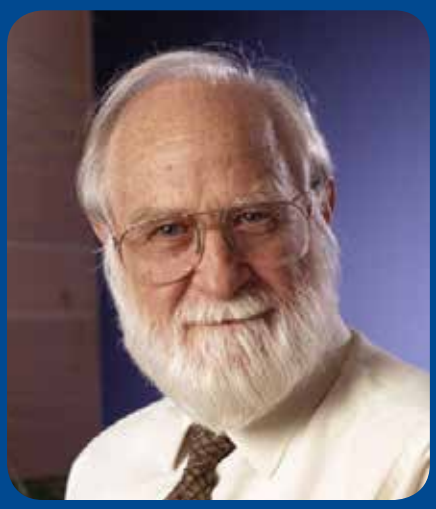
NRAO, in partnership with AUI, the National Society of Black Physicists, and the Committee for Status of Minorities in Astronomy co-sponsored an AAS session at the winter meeting titled *Astronomy Across Africa – A New Dawn*. Organized by Kartik Sheth (NRAO), Andrew Baker (Rutgers), and Joseph Lazio (JPL), this session introduced AAS members to cutting-edge multi-wavelength facilities that are or will be operating across the African continent, such as the Southern African Large Telescope (SALT), High Energy Stereoscopic System, African Very Long Baseline Interferometry Network, the Square Kilometre Array, and others.

Sarah Blyth (Cape Town) discusses Legacy Science Surveys with the MeerKAT in the Astronomy Across Africa session at the January 2014 AAS meeting.

Speakers from Africa and the U.S. discussed on-going science activities. After an overview of astronomy across Africa by Ted Williams (Director, South African Astronomical Observatory), Ilani Loubser (UNW-Potchefstroom) reviewed the latest scientific results from SALT, Sarah Blyth (Cape Town) discussed new results from the KAT-7 array (pre-cursor to MeerKAT) and MeerKAT legacy science surveys. Aaron Parsons (UC Berkeley) reviewed the results from their on-going exploration of the epoch of reionization with Precision Array to Probe the Epoch of Reionization (PAPER) and the proposed Hydrogen Epoch of Reionization Array (HERA). Sheth (NRAO) discussed U.S.–Africa student and faculty exchange programs that are helping to build the next generation of scientists. J.C. Mauduit described the activities of the IAU Office of Astronomy Development across Africa. The session ended with remarks from Takalani Nemaungani of South Africa's Department of Science and Technology on the vision for U.S.–Africa astronomy partnerships.

This session will lead to further collaborations and scientific exchanges between the U.S. and Africa. Given the new radio facilities rising across the African continent and the long-standing partnership and new initiatives between NRAO and South Africa, the NRAO aims to be a leader in U.S.–Africa collaborative activities.

Grote Reber Medal Awarded to Ron Ekers



The 2014 Grote Reber Gold Medal for innovative and significant contributions to radio astronomy was awarded to former NRAO Very Large Array Director, Ron Ekers, during the 31st URSI General Assembly in Beijing, China in August 2014. Ekers is currently a CSIRO Fellow at the Australia Telescope National Facility and Adjunct Professor at Curtin University in Perth. Ekers was recognized for his many pioneering scientific and technical investigations, including the first determination of the radio galaxy luminosity function, the precise measurement of the deflection of radio waves by the Sun, and his role in creating high-resolution images of the radio emission from the Galactic Center. The Reber Medal was established by the Trustees of the Grote Reber Foundation to honor the achievements of Grote Reber and is administered by the Queen Victoria Museum in Launceston, Tasmania.

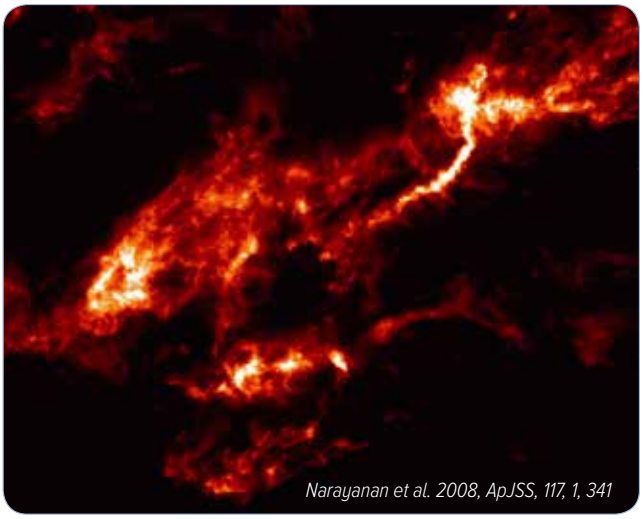
MegaSAGE

The MegaSAGE – Surveying the Agents of Galaxy Evolution – consortium studies the life cycle of matter that drives the evolution of galaxies, focusing on the Magellanic system and the detailed interplay of gas, dust, newly forming and evolved dying stars. This study has included surveys with Spitzer and Herschel, and detailed ongoing studies with other instruments. ALMA is revolutionizing our understanding of dense gas in the Universe, and is a primary focus for these Magellanic studies.

The 7th annual MegaSAGE project meeting was held at the NRAO Headquarters in Charlottesville, Virginia 2-5 September and featured discussions of ongoing projects as well as future proposal planning and discussion. Fifty scientists from 25 institutions in North American, Europe, South America, Africa, and Asia participated in the 2014 MegaSAGE meeting, which included four full days of presentations, breakout sessions, as well as a conference dinner.

Filamentary Structure in Molecular Clouds

Filamentary structure in clouds has been observed dating back many years. In addition, numerical hydrodynamic and magneto-hydrodynamic simulations of molecular clouds over the past ~15 years have consistently shown that filamentary structure is always present, and may be produced by turbulence and self-gravity. Recent Herschel observations of nearby dust clouds have highlighted that the dense gas is distributed predominantly in filaments. Filamentary structure may be ubiquitous in the internal structure of all molecular clouds and may be preferential formation sites of the dense cores that eventually collapse to form stars.


Narayanan et al. 2008, ApJSS, 117, 1, 341

If such filamentary structures were universal in all molecular clouds with low and high mass star formation, then the entire paradigm of cloud formation and evolution leading to star formation would be placed on a framework that centers on cloud condensation into filaments and filament fragmentation into cores. Filaments and embedded cores may also develop simultaneously, as suggested by some numerical simulations. It will be important for observational studies of star formation in molecular clouds to delineate the conditions, including magnetic fields, and the time sequence for the formation and evolution of dense filaments and cores within them.

A two-day workshop that included review talks, contributed papers, posters and panel-audience discussion was held at NRAO Headquarters in Charlottesville, Virginia, 10-11 October that discussed the evidence for the picture described above and formulated future investigations to verify whether such filamentary structure is universal and to study the physical conditions and evolution of such structures.

TECHNOLOGY

The NRAO Central Development Lab (CDL) continues to be the world-leader in cryogenic microwave circuit technology, supporting the evolution of NRAO's existing facilities and providing the technology and expertise required for the next generation of radio astronomy instruments. This is accomplished through development of multiple enabling technologies: low noise amplifiers, millimeter and sub-millimeter detectors, optics, and electromagnetic components, digital signal processing, and new receiver architectures including cryogenic phased array feeds. The CDL has a long history as a world leader in each of these fields. CDL staff have developed and produced these critical components and subsystems not only for NRAO telescopes, but also for the worldwide astronomical community. CDL research and development projects seek to develop technologies necessary for the long-range objectives of the Observatory and advance the state-of-the-art in mission related technologies.

Phased Array Feed Development

The L-Band cryogenic phased array receiver was tested on the GBT for the first time in late December 2013. This test included new fiber optics between the control room and the GBT prime focus, updated monitor and control and data acquisition software, and repaired cryogenic low-noise amplifiers. The observing included mapping Virgo A and detection of the 21cm spectral line in NGC 6822. Following testing, offline cross-correlation and beam forming of the data was completed, including a composite 7-beam map of Virgo A. Unfortunately, the system temperature of the formed beams was higher than expected. The GBT has longer focal length and thus higher spillover noise contribution for individual phased array feed (PAF) elements, but the circuit and full-wave electromagnetic model had predicted that this noise would be adequately suppressed in the beam forming process. An intensive effort was begun to isolate and resolve this data/model discrepancy in the model or in the instrumentation.

Development of new hardware continued during the period that the observing and data analysis was underway. A new digital downconverter will increase the processed bandwidth 100-fold. A Roach2-based digital receiver is being developed to capture the data and perform as a polyphase filter bank on the front half of a real-time correlator/beamformer being developed by Brigham Young University / West Virginia University. A new low-noise amplifier has been designed based on a previous NRAO S-band design and will be prototyped and tested in 2015.

A new release of PAF software, with improved user interface and real-time analysis capability was demonstrated.

Integrated Receiver Development

Cryogenic measurements on the S-band triangular Digital Ortho-Mode Transducer (DOMT) were completed using a non-corrugated, truncated feedhorn. Results were encouraging, though the tests revealed a spurious baseline ripple in the measurement as an artifact of the calibration procedure. This is likely due to impedance mismatch presented to the orthogonal mode by the waveguide-tapered calibration standards used. With these lessons learned, new measurements and calibration procedures are being considered for future work to address this issue; however, for efficiency the decision has been made to delay this work until after the real-time FPGA backend (also needed for other Integrated Receiver Development experiments) is completed.

One possible calibration problem solution would be to use external, quasi-optical polarization standards, in which case a more compact and higher-frequency DOMT version would be developed to better facilitate our experiments. Early work leading up to these experiments led to the conclusion that on-the-sky measurements were not practical, as the equipment was cumbersome to put on the roof. A plan to complete the measurements indoors using a liquid nitrogen cold bath was implemented instead.

An oscillation problem on the W-Band Local Oscillator distributor was solved, and final testing was completed. These measurements will inform future designs that utilize this concept, as it is now possible to extrapolate with confidence the level

of temperature-phase drift that can be expected for a given length distribution chain and design the system accordingly. The LO distribution concept is being incorporated successfully into the PAF integrated converter described above.

CDL successfully tested the circuit flexible thermal transition with low loss up to 40 GHz.

The unformatted fiber-optic link concept has been extended this year into multi-channel designs, which introduce new challenges with regard to parallel-channel re-timing and synchronization. A six-channel optical receiver to FPGA interface with the necessary re-timing buffers was built and successfully tested and will allow for the demonstration of the polarization isolation of DOMT using FPGA in 2015.

Construction of a 40-channel integrated analog-digital-photonic converter has begun that uses many of the concepts developed for the PAF program. The complete receiver will comprise five "blades" of eight channels each. The first of these blades has been completed and successfully tested. An alternate approach to the channel synchronization problem is being pursued by the developers of the PAF backend in Green Bank, wherein the re-timing buffers are internal to the FPGA.

NIST delivered the promised return-loss measurements on the 1/10th scale model of the 100-1000 GHz ridged horn, and CDL engineeers are following up with beam pattern measurements at the indoor antenna range in Green Bank. Results acquired in 2014 compare favorably with predictions.

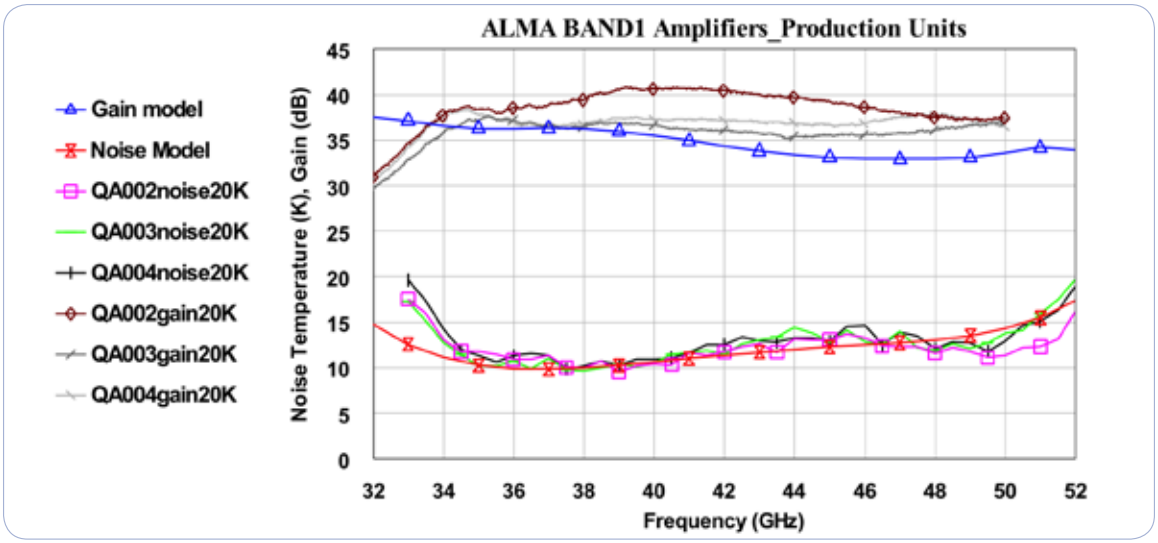
An effort to commercialize the IRD-developed Reflectionless Filter technology had a promising start in 2014. A wafer was procured with a number of initial designs, some 200 of which have already been sold to a commercial customer and much more interested received in response to CDL advertising. CDL has also begun working toward long-term licensing of this technology to a commercial partner.

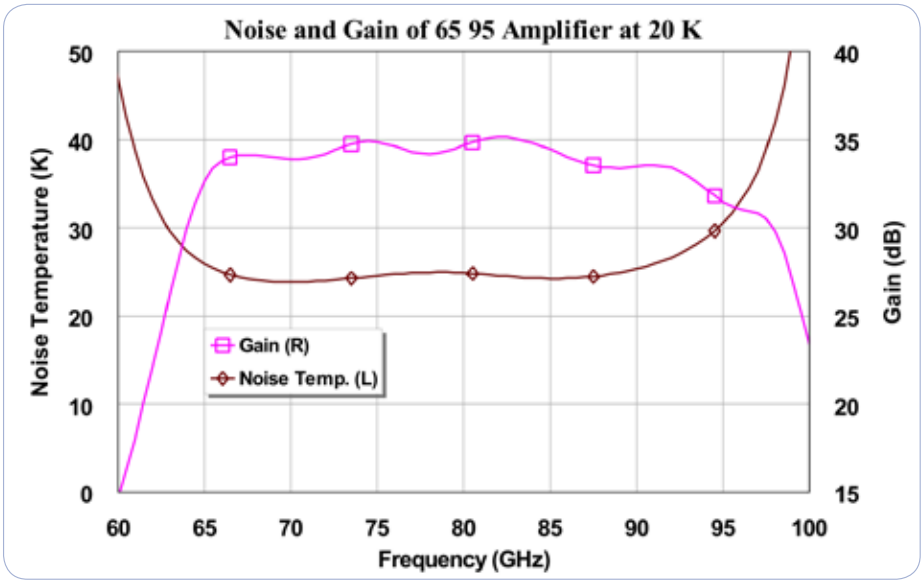
Low Noise Amplifiers

A production run of ALMA Band-1 low-noise cryogenic amplifiers revealed excellent repeatability of performance and very good agreement with model prediction (Figure-1). Four amplifiers are to be delivered to ASIAA for the development of prototype Band-1 cartridges. A new version of an ALMA Band 2 amplifier with optimal noise and gain performance has been developed, and the prototype assembled. It is expected to demonstrate less than 30 K noise temperature from 65 to 95 GHz with a gain of ~35 dB (Figure 2). A 75 – 115 GHz amplifier with optimal noise and gain performance has been designed, and work on a prototype was initiated. The performance of Next Generation Space Telescope (NGST) cryo3 devices is practically on par with Monolithic Millimeter-wave Integrated Circuit (MMIC) 35 nm amplifiers, therefore offering a competitive alternative in case schedule and/or funding limitations prevent the use of the more modern but relatively expensive technology.

The CDL Amplifier Group continued to produce and repair Heterojunction Field Effect Transistor (HFET) amplifiers for the VLA, VLBA, GBT, and ALMA, and for other astronomical research institutions, including the Combined Array for Research in Millimeter Astronomy (CARMA), Arecibo Observatory, Max Planck Institute for Radio Astronomy, the University of Arizona, the University of Pennsylvania, the University of Washington, Shanghai Observatory, the Naval Research Laboratory, Onsala Observatory (Sweden), Metsahovi Observatory (Finland), Torun Observatory (Poland), and the Instituto Nationale di Astrofisica (Italy). In 2014, this work resulted in the delivery of 118 HFET amplifiers to institutions around the globe, including: fifty 1-2 GHz, eight 2-4 GHz, eleven 4-8 GHz, eight 8-12 GHz, five 12-18 GHz, five 26-36 GHz, two 26-40 GHz, twelve 38-50 GHz, three 34-52 GHz, four 65-90 GHz and three 80-95 GHz amplifiers.

CDL also completed the production of six of the planned eight ALMA Band-6 Superconductor-Insulator-Superconductor (SIS) mixers in 2014, though mixer chip yields were lower than planned.





[TOP] *Figure 1: Cryogenic performance of three ALMA Band 1 amplifiers compared with model prediction.* **[LEFT]** *Figure 2: Expected performance of ALMA Band 2 amplifier.*

Millimeter & Submillimeter Detectors

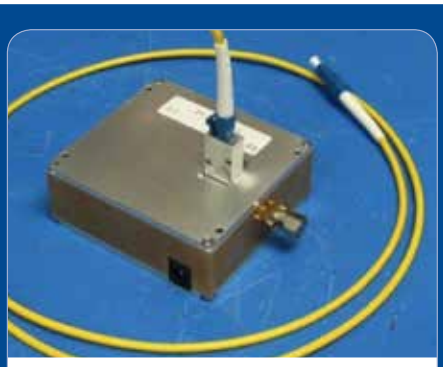
Under an ALMA Development Program grant, work was initiated on an improved, second generation SIS receiver for ALMA Band 6. The main improvements will be in the mixer itself and in the IF preamplifier. The mixer will use Nb/Al-AlN/Nb junctions in place of the current Nb/Al-AlOx/Nb junctions, allowing a wider RF bandwidth and lower receiver noise. The preamplifier will use balanced amplifiers in place of the current single-ended amplifiers, which will allow a flatter noise temperature across the full 4-12 GHz IF band.

Under another ALMA Development Program grant, work has begun on an improved, second-generation SIS receiver, with sideband separation, for ALMA Band 10. The initial phase of this work consists of demonstrating a lower-frequency design at 385-500 GHz that incorporates the new technology required for Band 10: beam-lead mixer chips on thin Si membranes, AlN tunnel barriers, and SIS junctions with NbTiN electrodes. This has yielded good mixers with beam-lead membrane chips and junctions with AlN barriers and NbTiN electrodes. Future work will combine these elements into working mixers, initially at the lower frequency, then at Band 10.

Progress on these two detector development projects has been slower than initially planned owing to a significant delay in production of SIS junctions at the University of Virginia Microfabrication Laboratory (UVML) caused by equipment failures and loss of key personnel. Good quality SIS junctions are again being produced at UVML, but a one-year time extension was requested for these projects.

The ring-centered waveguide flange, proposed by Kerr and Srikanth, has been included in the new IEEE P-1785.2 standard on Waveguides for Millimeter and Submillimeter Wavelengths. An informal group of NRAO, University of Virginia, and Virginia Diodes, Inc. engineers evaluated the quality of the ring-centered interface and compared it with the old MIL Spec UG-387 interface and its commonly-used improved derivatives, with which the new flange is fully compatible. The results were published at the IEEE International Microwave Symposium and the IEEE Automatic Radio Frequency Techniques Group Conference, and demonstrated the clear superiority of the new design over the previous designs.

Patent Issued to NRAO CDL Engineers



Prototype Integrated Receiver using the new unformatted fiber optic link. Credit: NRAO/AUI/NSF.

A transformative patent was issued to Matt Morgan and Rick Fisher of the NRAO CDL in Charlottesville, Virginia in 2014. Entitled *Statistical Word Boundary Detection in Serialized Data Streams,* this innovative development makes it possible to transmit digital data over optical fiber, or any data link, with far less overhead in the front-end than conventional digital data links would allow.

Conventional digital links rely on rather elaborate data formatting and packetization at the transmit end to enable decoding at the receive end. By using the statistical properties of the noise omnipresent in all radio telescope observations, management of the data link can be deferred entirely to the receive end, off the telescope, with no prior formatting of the data at the transmitter, reducing the size, power dissipation, and RFI generated by the digital electronics inside the telescope.

These improvements facilitate the construction of large-format integrated focal plane arrays with the stability afforded by early digitization and digital data transmission. That stability enhances the longevity of calibrations for digitally corrected receivers, such as Phased Array Feeds, and may prove crucial for the very high-dynamic range imaging that is key to future planned radio astronomy facilities.

Although the initial theoretical basis for the technique assumed a background spectrum of Gaussian-distributed white noise, laboratory experiments have shown that the data link is very robust in the presence of real-world signals, such as RFI, over a wide range of operating conditions. The same hardware could be applied to a broad range of sampled data streams, such as scientific and medical instrumentation, and especially imaging applications where the data rates are very large. Whether active or passive, these systems all rely on the extraction of a signal of interest from a noisy background with maximum speed and fidelity, and with minimum overhead at the sensor node.

For similar reasons, this technique would also apply to radar and sonar systems, commercial and military, and to security screening platforms. It could also be used in industrial environments for process monitoring and product inspection. In each of these cases, the development described in this patent effectively provides system designers with an “ADC on a fiber” to incorporate in their applications for improved performance.

Optics and Electromagnetic Development

A corrugated linear taper Ku-band (12-18 GHz) secondary focus feed horn for the Shanghai 65-meter telescope was designed, built and characterized by measurement. The horn has an aperture of 8.5" (inside diameter), a length of 19" and has three sections. The average illumination taper in the E- and H-planes is -15.8 dB at the edge of the subreflector. Cross polarization measured in the diagonal plane is 23 dB at 18 GHz and below -30 dB from 12-17 GHz. Measured return loss is better than 25 dB with the radome, and below 30 dB without the radome. The phase center lies about 14" inside the feed horn at 15 GHz, and total travel is ±2.8".

A wideband feed horn for 4-8 GHz was developed, fabricated, and measured for the improved GBT C-band receiver. This is a corrugated linear taper horn with a 28.25" aperture and length of 47.3." The horn is fabricated out of five sections. The measured average illumination taper is -14.8 dB in the H-plane and -15.5 dB in the E-plane. Cross polarization in the diagonal plane is below -25 dB in the 4-8 GHz band. The phase center is 38.4" inside the feed horn measured from the aperture plane. Input return loss is better than 20 dB. A preliminary test on the GBT showed the system meets the performance specifications.

Work on the ALMA Band 2 optics continued. The combination of a corrugated feed horn with a lens at the 300 K window couples the beam waist of the horn to that of the telescope.

A 67-90 GHz OMT developed for the ALMA Band 2 cartridge was measured with calibration. Return loss was found to be better than 18 dB over the required bandwidth. Further optimization required a minor modification to the tuning stub in the turnstile junction. After incorporating this change, measurements were repeated and the return loss improved to better than 20 dB.

Measurements were carried out on a number Ku-band orthomode transducers based on Boifot junctions. One of these OMTs was installed on the SHAO Ku-band receiver.

Digital Signal Processing

The bulk of the 2014 effort of the Digital Signal Processing Group was divided between the ALMA Phasing Project (APP) and the Precision Array for Probing the Epoch of Reionization (PAPER) project Smart Networked ADC Processor (SNAP). Some effort was also expended supporting the ALMA Correlator and Phased Array Feed research and development.

For SNAP, several design iterations at both the schematic and board level were required to arrive at a mutually agreeable design. The design for the initial prototype was submitted for manufacturing.

For the APP, all hardware required for proof-of-concept were configured and tested in Charlottesville, delivered to Chile, and installed. This included 12 custom-designed Phasing Interface Cards (PICs), associated power supplies and cables, as well as three custom-designed timing signal level converter cards. The operation of these deliverables at the module level was confirmed on site. Firmware for the microprocessor and gateware for the FPGA on the PIC were completed. Updates to the correlator's FPGA-based summing logic and timing event distribution logic were also completed.

Only minor effort was required to support the ALMA Correlator, primarily discussions with the software group in efforts to understand bugs uncovered during their development of new correlator features.

Low Frequency Radiometry

In collaboration with J. Hewitt (MIT) and MIT graduate student A. Neben, CDL staff characterized the beam pattern of Murchison Widefield Array (MWA) tiles and PAPER antennas in 2014 using the ORBCOMM satellite. An MWA Tile with a beam-forming network was deployed in Green Bank for beam-mapping measurements using the ORBCOMM downlink data acquisition system developed by R. Bradley. Several months of data were acquired for several beam pointings and calibration measurements taken with a reference dipole in place of the Tile. The data has been used by the MWA collaboration to help characterize sources of pointing and polarizations errors.

An upgraded low frequency log-periodic antenna was deployed near the Green Bank solar radio burst monitor site. An amplifier and mounting bracket were fabricated while the monitor was being repaired and upgrade: the low frequency system will be incorporated into this upgrade.

Working in collaboration with NRAO-GB engineer J. Ford, the all-digital, ROACH-based system was completed and the design of the multiplexer, used to interface the RF from all three channels onto a fiber optic cable, was completed. RF measurements taken after the upgrade will be used to set the levels at the multiplexer that are required by the data acquisition system.

A Dark Ages Radio Explorer (DARE) prototype radiometer consisting of the biconical dipole antenna with ground reflector, low noise balun, receiver, and digital data acquisition system was developed at the CDL with the assistance of University of Colorado graduate student B. Nhan (mentored by CDL scientist R. Bradley). The system was deployed in Green Bank for field tests. Data taken by the prototype over the 40-120 MHz band will also be used to study accuracy limits on sky spectrum measurements caused by the ionosphere.

The Precision Array to Probe the Epoch of Reionization (PAPER) team at an array element in Green Bank, West Virginia.


4K

EDUCATION & PUBLIC OUTREACH

The Education and Public Outreach (EPO) department provides major components of the public's return-on-investment by marshaling observatory resources in support of Science, Technology, Education, and Math (STEM) education, and informing the interested public about the observatory, its facilities, and the latest technical and scientific achievements of its staff and users.

EPO continued to operate the popular Green Bank Science Center (GBSC) and VLA Visitor Center (VLAVC) public exhibits and tours program. Attendance at the GBSC was 36,791 and at the VLAVC 15,855 during FY 2014. These attendance figures were undoubtedly reduced by the October 2013 federal government shutdown, which closed both the GBSC and VLAVC. Special Green Bank tours were provided to a wide range of educational and tourist groups.

Special community events were organized in Green Bank, including a regular schedule of planetarium shows, lab tours, etc. Numerous overnight educational field trip programs were hosted for schools, universities, and scouts in Green Bank, each of which featured student-conducted research using the 40-foot telescope. EPO staff provided local astronomy teaching resources (and training in their use), including the use of StarLab portable planetariums, in New Mexico and West Virginia. Professional development opportunities for teachers included the Chautauqua Short Course classes in New Mexico and West Virginia. A monthly series of public events were hosted at the VLA, including guided tours on the first Saturday of each month. Charlottesville EPO staff actively participated at the USA Science and Engineering Festival in DC 26-27 April, interacting with thousands of attendees. The March 2014 VLA Open House saw reduced attendance owing to the National Park Service's decision not to open the nearby Trinity Test Site.

Skynet Jr. Scholars (SJS): NRAO conducted a series of workshops with professional educators, to develop and pilot-test the curriculum for SJS youth activities, and created a series of development workshops for 4H leaders.

West Virginia Governor's School: NRAO – Green Bank again hosted a cohort of rising 8th grade students for an intense, two-week educational experience.

VLA Visitor Center Film: A new VLA film – *Beyond the Visible* – premiered at the Visitor Center in 2014 and has received three industry awards: an Interpretive Media Award from the National Association for Interpretation; a Cine Golden Eagle award from the Council on International Nontheatrical Events; and a Bronze Telly Award, which honors film and video productions, groundbreaking online video content, and outstanding local, regional, and cable TV commercials and programs. **Beyond the Visible** tells the behind-the-scenes story of the operation and scientific achievements of the VLA since its dedication in 1980. With spectacular ground and aerial footage, the movie depicts many of the unsung heroes of the NRAO technical staff who keep the telescope working, as well as scientists who use the VLA for science and discovery. The VLA film was shot on location under the supervision of Director Nils Cowan of Hemlock Productions in Seattle, and edited by Joanne Ardinger. NRAO Assistant Director for Education and Public Outreach, John Stoke, served as Executive Producer. The online version of the film includes closed captions for the hearing-impaired in English and Spanish. An interactive kiosk version of the on-line VLA Explorer Virtual Tour was created for the visitor center exhibit hall.

Feasibility Studies for a new VLA Visitor Center: EPO commissioned an economic feasibility and impact analysis for a new VLA Visitor Center. The results suggest that an annual attendance of 35,000-45,000 is achievable, and that a center with a 5,000 sq. ft. exhibit hall and associated visitor amenities is optimal.

STEM Role Models: Exposure to role models, the work they do, and the rich environments in which they function, can give students a model to emulate. NRAO participated in several STEM career development days sponsored by community organizations in Charlottesville, including one sponsored by Dominion Virginia Power and another carried out in coordination with the national Hour of Code event. Funded by the WV Space Grant Consortium, the new WV SPOT (Space Public Outreach Team) trained West Virginia undergraduate students to become STEM presenters to grade school students.

ALMA Operations Online Interactive Role Playing Game: In collaboration with a contracted outside educational game developer, and in consultation with NRAO – ALMA operations experts, development began in 2014 of an online role playing game in which players will be challenged to make real-time choices that determine ALMA scientific success.

ALMA Featured in Major Media

A lengthy and well-produced program segment titled *ALMA: Peering Into Our Universe's Past* was initially broadcast in the U.S. on the popular CBS News program *60 Minutes* on Sunday evening, 9 March. The *60 Minutes* program is among the most successful in U.S. television history, and the audience for the ALMA segment was measured to be 10.6 million viewers. This excellent ALMA program is available at the CBS News website (http://www.cbsnews.com).

NRAO public information officer Charles Blue and the Education & Public Outreach media team shepherded this program to completion, in collaboration with the NAASC and NRAO/AUI-Chile scientists and staff, several of whom appear on-camera in the *60 Minutes* segment.

ALMA was also featured in the April edition of National Geographic magazine. NRAO arranged, with kind assistance from the Joint ALMA Observatory, for a photographer to spend a month at the ALMA site in northern Chile, and for the writer to visit. An online version of the article (http://www.nationalgeographic.com/cosmic-dawn) includes excellent time-lapse video.

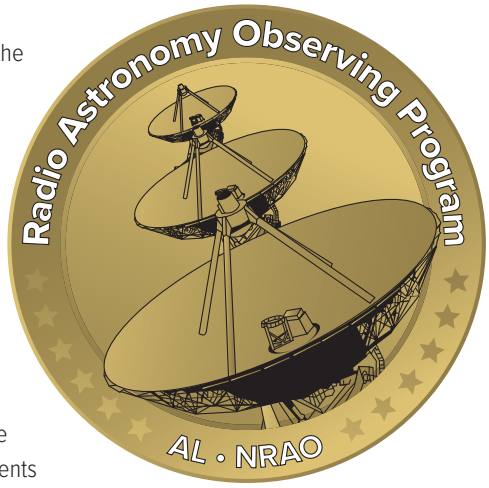
ALMA Launches Website for Children

ALMA Kids (http://kids.alma.cl) is a new mini-website created in 2014 especially for children. The colorful site aims to familiarize them with astronomy, expand their understanding of the Universe, and help them appreciate the contribution of the ALMA. The content of this new ALMA educational space includes comics, discoveries explained in simple words, videos, and games, all within a playful design.

This website offers Spanish and English versions and was launched on 27 May as part of the Santiago Student Science and Technology Fair in Chile. At the fair, children of all ages, from preschool to high school, exhibited the scientific projects they completed in public schools in the district of Santiago. At ALMA's booth, visitors learned about astronomy and the functioning of the largest radio telescope in the world. There were opportunities to take photographs with Talma, the main character in the virtual tour on the ALMA Kids website.

NRAO Partners with Astronomical League

The largest coalition of amateur astronomy organizations in the world, the Astronomical League (AL), and NRAO have teamed up, with support from AUI, to begin a new astronomy badge program. Unlike traditional AL observing programs, the new Radio Astronomy Observing Program (RAOP) encourages explorers of all ages to gaze to the cosmos and "see" the invisible radio Universe.



The RAOP is designed to introduce and encourage observations in the radio part of the electromagnetic spectrum, as well as the construction of radio telescopes and observing instruments. RAOP focuses on five major observing projects: (a) space weather, (b) the Sun, (c) Jupiter, (d) meteors, and (e) Galactic radio sources. Each of the projects can be completed using NRAO or other professional radio telescopes, or instruments built by individuals or the RAOP teams.

Projects range from beginner to advanced levels, and are open to amateur astronomers, K through college educators, and learners of all ages. The AL will award participants a RAOP bronze certificate for completing a single observing project, or a RAOP silver certificate and pin for completing two projects. The AL will award the RAOP gold certificate and pin to those who complete four observing projects.

The RAOP can help bring together educators and amateur astronomers to address critical needs in STEM education. The U.S. Federal STEM 5-Year Strategic Plan calls for the U.S. to "increase and sustain youth and public engagement in STEM by supporting a 50% increase in the number of U.S. youth who have an authentic STEM experience each year prior to completing high school." In addition, the Next Generation Science Standards call for the integration of engineering practices in K-12 science learning. Amateur astronomers are known for their excellent education and public outreach work, and through the AL's 10,000+ members, and collaboration with NRAO, the new RAOP will work to address these national priorities.

Milky Way Explorer Debuts

A cloud of gas, that may or may not have a star embedded in the middle, is falling into the supermassive black hole in the center of our Milky Way Galaxy. It's a once-in-a-lifetime chance for astronomers to watch our malnourished black hole eat, and a perfect time to put that into context for you in an exciting new interactive adventure: the Milky Way Explorer, online at: https://public.nrao.edu/explorer/milkyway/TheMilkyWayExplorer.php

Join the astronomers who are on a quest to understand our Galaxy and the Universe we inhabit. They will tell you about the mysteries they are trying to solve, their favorite objects in space, and their excitement about finally getting to watch our Galaxy's black hole feed.

The NRAO EPO will continue to add new videos to this unique tour, so keep orbiting the Milky Way Explorer for updates.

MANAGEMENT & ADMINISTRATION

Organization

The NRAO organization consists of departments, which are made up of divisions, which consist of groups. This organization is designed to emphasize Observatory-wide management and coordination in key areas, including Program Management, Data Management and Software, and Science Support.

Phil Jewell continued as Assistant Director for North America (NA) ALMA. Beginning in 2013, this key position assumed management responsibility for the ALMA construction project. Jewell also oversees the NA ALMA Science Center and the ALMA Development program, coordinates the ALMA maintenance program, and is the face of ALMA to the North American scientific community. Jewell also continued in a part-time role as Deputy Director.

The New Mexico Operations Department, based in Socorro and led by Assistant Director **Dale Frail**, includes all NRAO staff engaged in the operation, maintenance, calibration, performance, and further development of the scientific capabilities of the Jansky VLA and the VLBA.

The West Virginia Operations Department, based in Green Bank and led by Assistant Director **Karen O'Neil**, includes all NRAO staff engaged in the operation, maintenance, calibration, performance, and further development of the scientific capabilities of the GBT. West Virginia operations are also a major resource for education and public outreach, including the Green Bank Science Center. The Observatory's laboratories, utilities, and support facilities also make it an attractive location for independent research experiments.

Assistant Director **Tim Bastian** leads the Science Support & Research (SSR) Department. SSR is responsible for the Observatory's scientific interface to the NRAO user community. This Observatory-wide department coordinates, aligns, and manages the collective efforts of scientific staff in Charlottesville, Socorro, and Green Bank.

The Data Management and Software (DMS) Department led by Assistant Director **Brian Glendenning** manages data archiving at NRAO, including access, distribution, provisioning, and operation. DMS manages the data reduction pipeline infrastructure implementation and technical operation; high-performance computing platform definition, acquisition, and operation; and network provisioning to the external community and between sites. DMS also has primary responsibility for all user-facing and telescope software.

Located in Charlottesville, the CDL supports the evolution of NRAO's existing facilities and provides the technology and expertise needed to the build the next generation of radio astronomy instruments. The CDL team, led on an interim basis by **Robert Dickman**, accomplishes this through development of the enabling technologies: low-noise amplifiers, millimeter and submillimeter detectors, optics and electromagnetic components, including feeds and phased arrays.

Assistant Director **John Stoke** leads the Education and Public Outreach (EPO) team that provides major components of the public's return-on-investment, marshaling NRAO resources in support of Science, Technology, Engineering, and Math (STEM) education. EPO also informs the science-interested public about the Observatory, its facilities, and the latest technical and scientific achievements of its users and staff.

MANAGEMENT & ADMINISTRATION

Based in Charlottesville and led by Associate Director **Steven Geiger**, the Administration Services Department provides administrative and human resources management and non-programmatic services to NRAO including: business services; contracts and procurement; environmental safety and security; management and information systems; and technology transfer.

Faye Giles and Shirley Franks jointly lead the Human Resources (HR) Department that supports the needs of the Observatory's domestic and international staff. Ms. Giles is the HR Manager and Diversity Officer; Ms. Franks is the Manager for Compensation & HR Information Systems (HRIS). They provide professional and administrative expertise in HR areas including employment/recruitment/hiring, employee relations, diversity, succession planning, training, regulatory compliance, compensation, HR information systems, the AUI benefits interface for NRAO staff, and the HR interface to the Observatory's substantial international and local staff in Chile that support ALMA.

The NRAO/AUI Office of Chilean Affairs (OCA) supports the interests of the Observatory and its parent organization, AUI, in Chile, particularly the North American participation in the ALMA project. Led by Assistant Director **Eduardo Hardy**, OCA provides ALMA with legal, payroll, and travel support, and provides the legal and institutional support for numerous contracts and procurements for ALMA Construction and Operations in Chile.

With ALMA construction completing, the Office of Chilean Affairs was divided in 2013 into NRAO-Chile and AUI-Chile components, with NRAO-Chile activities, led by Assistant Director Eduardo Hardy. **Stuartt Corder** was promoted to Joint ALMA Observatory Deputy Director of ALMA.

The Program Management (PM) Department led by Assistant Director **Lory Wingate** provides program and project management support and systems engineering services to NRAO project leaders and PIs. The key PM Department goals are to provide visibility, transparency, and consistency in reporting within NRAO and externally to NSF and outside partners or customers, identify and provide resources for program management and systems engineering needs across all NRAO projects, review new projects for alignment in supporting the Observatory's long-range strategic goals, and compile deliverables.

The Communications Office (COM) led by **Mark Adams** is attached to the Director's Office and is responsible for communicating NRAO science, accomplishments, priorities, and plans to the science community, in collaboration with NRAO scientific staff. COM personnel also collaborate with staff across the Observatory to improve internal communication, and assist the Director's Office in communicating NRAO accomplishments to external stakeholders such as the NSF and the U.S. Congress. Led by Robert Dickman, the **New Initiatives Office** is also attached to the Director's Office and facilitates Observatory-wide development and management of strategic partnerships and collaborations with academic, government, and non-profit organizations. The NRAO Chief Scientist, **Chris Carilli**, also reports to the Director's Office.

Program Management Department

In 2014, the NRAO Program Management Department (PM) shifted from an initial implementation phase to operating, auditing, and optimizing. PM continued to provide qualified, formally trained and experienced program and project managers, and systems engineers. These individuals provide direct support to projects as requested by principal investigators and project leaders, and consulting support for all other projects or activities on an as requested basis. PM also continued to enhance its decision support capabilities. Analytics derived from systems used by PM, such as Sharepoint and the PM Shared Access database, ensure that prior to new work being undertaken, impacts to NRAO's existing work are well understood and new work is aligned with NRAO strategic goals and objectives. PM uses these tools to perform its four primary areas of PM responsibility: proposal development, ensuring best practices in management of projects/managing projects, development of program and grant documentation, and providing analytics for NRAO executive decision support.

Standards

Program Management / Systems Engineering processes, tools, templates, and techniques are available to all NRAO staff. A PMD – Standard Operating Procedures (SOP) document is being developed and will be distributed in 2015.

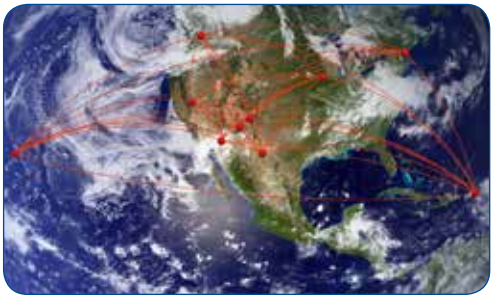
Process Audit

Each existing process underwent informal process auditing in 2014 to assess process integrity and quality including proposal development, project management, documentation, and analytics and decision support. Process optimization opportunities will be reviewed in 2015 and changes documented during the SOP development.

In collaboration with Computing & Information Services (CIS), PM actively pursued and implemented a solution to the Sharepoint browser incompatibility issue, which resolved the inability to use a workflow in the tool. Working closely with Fiscal, Management Information Systems, and Human Resources, PM obtained higher quality project charging information, critical to the success of project performance. In addition, PM assisted in developing a cost model for proposals to ensure a consistent, transparent approach.

New Initiatives Office

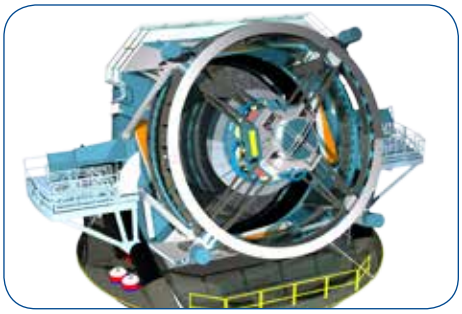
The New Initiatives Office (NIO) facilitates strategic partnerships and collaborations with academic, government, and non-profit organizations. Core NIO activities in 2014 included continuing to develop and further expand partnerships that sustain the scientific operations and unique technical capabilities of the VLBA and GBT.



VLBA and GBT Sustaining Activities

As NSF's plans for recompeting the management of NRAO became clarified in 2014, the NRAO Director took direct responsibility for discussions involving the potential support of these instruments by NASA and other Federal agencies. These discussions have begun to focus on a number of specific applications, and will continue into 2015.

Large Synoptic Survey Telescope



Credit: LSST

The head of NIO has served as NRAO's institutional representative on the Large Synoptic Survey Telescope (LSST) Board, and in 2014 also served as Treasurer of the LSST Corporation (LSSTC) and Chair of the LSSTC audit and finance committee. The Committee was significantly expanded and the level of financial expertise broadened in 2014.

RadioAstron

The Head of NIO serves as the NRAO institutional representative on the RadioAstron International Science Council, and attended the Council's annual meeting in August, which was held alongside the Committee on Space Research meeting. The RadioAstron downlink receiving station, which employs the NRAO 140-foot antenna in Green Bank, has worked well since beginning operations in late 2013 and has significantly enhanced the science reach of the RadioAstron spacecraft. NIO helped develop a Memorandum of Understanding with the Lebedev Physical Institute – the scientific home for RadioAstron – that simplifies access to NRAO's radio telescopes for well-reviewed proposals already approved by RadioAstron's international time allocation committee.

Xinjiang Astronomical Observatory

Xinjiang Astronomical Observatory (XAO) is pursuing plans to build a 110-meter diameter radio telescope in QiTai County in western China. Following the signature of an MOU between NRAO and XAO in late September 2013, NRAO continued to develop this relationship, and is concluding a contract with XAO to provide radio astronomical consulting services. In addition, NRAO recently hosted a visit by XAO management and engineering personnel to the CDL and to Green Bank.

Spacecraft Tracking & Astrophysical Research into Gigahertz Astronomical Transient Emission

In 2014, the University of Texas - Rio Grande Valley (UTRGV) requested NRAO develop a Memorandum of Understanding for collaboration with the University's Spacecraft Tracking and Astrophysical Research into Gigahertz Astronomical Transient Emission (STARGATE) Project. STARGATE is a cooperative effort between the Space Exploration Technologies Corporation (SpaceX) and the University of Texas system. NIO drafted an MOU proposing mutual collaboration in a number of technological and educational areas.

Communications Office

The NRAO Communications office organized the NRAO presence at the winter American Astronomical Society (AAS) meeting – 5-9 January 2014, Washington, D.C. – including a day-long VLA Sky Survey Workshop on Sunday, a two-hour NRAO Town Hall on Tuesday evening, as well as NRAO and AUI participation in the meeting's multi-day exhibition.

NRAO also sponsored and hosted two Splinter Sessions at the January 2014 AAS meeting. Proposing for NRAO Instruments was a three-hour session on Tuesday afternoon that assisted members of the community, especially new users, in proposing for the

GBT, VLA, and/or VLBA. The *Telescopes for Cosmic Dawn and 21 cm Cosmology* Splinter Session was held immediately after the NRAO Town Hall. It continued and broadened NRAO's discussion with the community about U.S. plans for future telescopes capable of tracking the Universe's transition from a neutral to an ionized state during cosmic dawn using the highly redshifted 21 cm line of neutral hydrogen. NRAO also actively participated in the undergraduate orientation Sunday evening, and the Tuesday afternoon local public outreach events organized by the AAS and sponsored by AUI.

The NRAO presence at the summer AAS meeting – 1-5 June 2014, Boston, MA – included NRAO and AUI exhibits, as well as participation in an undergraduate orientation and local public outreach events organized by the AAS and sponsored by AUI.

Two science symposia were prepared and presented to the broader science community at the 2014 Annual Meeting of the American Association for the Advancement of Science (AAAS) –13-17 February 2014, Chicago – with speakers from NRAO and across the astronomy community: (1) *From Dust and Gas to Disks and Planets* (180 minutes, 6 speakers); and (2) *New Millimeter-Wavelength Insights into Galaxy Evolution in the Early Universe* (90 minutes, 3 speakers).

The Communications Office (COM) continued to edit and publish the monthly NRAO electronic newsletter, eNews, each issue of which was distributed to 8,500+ persons around the world. COM published a 2013 NRAO Annual Report and managed the high-level content at the NRAO science website and the NRAO Intranet. The 2014 NRAO Research Facilities brochure was published in January 2014, immediately prior to the winter AAS meeting.

COM and CIS collaborated on the NRAO exhibit at the International Conference for High Performance Computing, Networking, Storage, and Analysis conference – 16-21 November 2014 in New Orleans, Louisiana – an annual gathering of 10,000+ scientists, engineers, software developers, CIOs, and IT administrators from universities, industry, and government agencies.

COM worked with Director's Office and staff across the Observatory to prepare NRAO reports, briefings, and support materials for NSF and for the 2014 Users Committee, which met in Charlottesville, VA 28-30 May, and the 2014 Visiting Committee, which met in Socorro, NM 24-25 April. COM also collaborated with Director's Office and the Observatory's management team to improve internal communications across the Observatory.

Spectrum Management Office

The NRAO Spectrum Management Office was responsive to and involved in domestic and international spectrum management issues in 2014 that are relevant to the NRAO science mission and observatories.

National Spectrum Management

The Iridium satellite phone system is in the process of renewing its operating license and designing a new generation of satellites. Iridium has generated strong interference into the 1612 MHz OH band since its inception and the situation has deteriorated as the Iridium operating frequency range has been allowed to extend downward, closer to the OH band. NRAO prepared extensive background materials to guide national negotiations between NSF, Arecibo, and Iridium, in the expectation that interference-free observing will be the norm in the near future.

The Federal Communication Commission (FCC) is in the process of re-defining the TV broadcast bands to open more spectrum for wireless broadband. This is reflected in several complicated regulatory proceedings that affect radio astronomy operations in the protected band 608 – 614 MHz – TV channel 37 in the U.S., TV channel 38 in Europe – and perhaps eventually at much

lower frequencies as the remaining broadcasters are re-packed into the lower reaches of the TV broadcast spectrum. NRAO filed FCC comments as issues develop, in the hope of preserving channel 37 as a clean observing band.

The use of vehicular and other 76 - 86 GHz radars is beginning to proliferate. The U.S. has yet to adopt operating rules for car radars, which eventually will operate in multiples of 4-8 on every vehicle, hence by the billions over the country. Unfettered radar operation will cause severe interference problems for millimeter-wave astronomy up into the harmonics at 230 GHz. NRAO has filed several comments in FCC proceedings with the eventual goal of establishing coordination zones around observatories. NRAO coordinated VLBA observations in Owens Valley with an airborne 75 and 84 GHz communications system being tested by Google over Utah.

The NRAO Spectrum Manager participated in 2014 meetings of the National Spectrum Managers Association, Committee on Radio Frequencies, and the monthly telecons led by NSF in preparation for meetings at the International Telecommunication Union – Radiocommunication (ITU-R) Sector in Geneva, Switzerland.

International Spectrum Management

The NRAO spectrum manager attended four meetings at the ITU-R in Geneva in preparation for the World Radio Conference in November 2015. Multiple issues were under discussion in the international spectrum management community in 2014, as described below.

Wireless avionics manufacturers want to lighten aircraft and improve onboard communications by eliminating wiring. Spectrum at 4.2 – 4.4 GHz has been identified for this purpose, but Boeing and Airbus are hoping for additional spectrum near 23 GHz that would put extreme pressure on nearby frequency bands allocated to astronomy. Fortunately for radio astronomy, this effort has stumbled in proving compatibility with other commercial services.

Synthetic aperture radar users are interested in widening an allocation at 9.3 – 9.9 GHz for Earth mapping. Future illuminations of radio observatories by commercial radar operators will be curtailed, but some details are unclear and some classified systems may not participate.

Additional spectrum may be made available for radars at 76 – 81 GHz. The question is the uses to which the 77 – 81 GHz band will be put. In the meantime, NRAO is participating in discussions to establish a record of studies of projected interference, which could be used by national administrations to establish coordination zones for the protection of radio observatories. In any case, prospects are dim for continued 4mm radio astronomy observations at sites that have direct line-of-sight to major cities.

The Joint ALMA Observatory Headquarters in Santiago, Chile hosted the 2014 Inter-Union Committee on the Allocation of Frequencies (IUCAF) Spectrum Management School 11-14 April. The sessions were well attended, with participation and lectures by ALMA and AUI staff, foreign and local enrollees, and Chilean regulators from Subsecretaría de Telecomunicaciones de Chile (SUBTEL). The NRAO spectrum manager is the Vice-Chair of the IUCAF, helped organize the April 2014 IUCAF spectrum management school in Santiago, Chile and delivered several lectures at the school.


ALMA

Observing Hours

All telescope time for each of ALMA, GBT, VLA, and VLBA is characterized in the following categories: Scheduled, Maintenance, Test, Unscheduled, or Shutdown. The sum of these categories is the total number of available hours each month: 720 hours in a 30-day month, and 744 hours in a 31-day month. Scheduled science operations time is either Astronomy or Downtime.

The observing hours for each NRAO telescope are divided into the following seven categories:

Scheduled: Planned hours of observing time for peer-reviewed science proposals

Scheduled = [Astronomy + Downtime]

Astronomy: Actual hours of observing time for peer-reviewed science proposals

Downtime: Hours lost during scheduled observing time for peer-reviewed science proposals

Downtime: Hours lost during scheduled* observing time for peer-reviewed science proposals.

Maintenance: Actual hours of scheduled service of infrastructure, structure, electronics, and software.

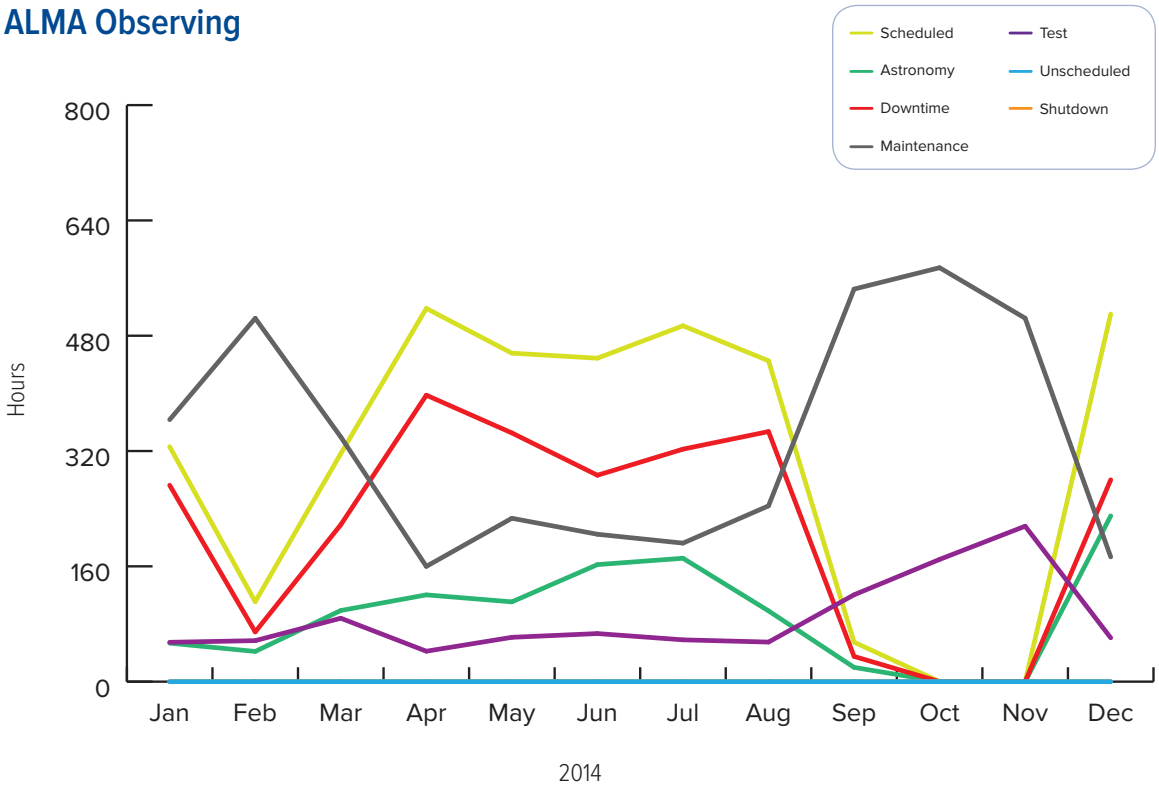
Test: Actual hours for test observations rather than peer-reviewed science proposals.

Unscheduled: Actual idle hours owing to gaps between observing programs that cannot be scheduled and to predicted, extended inclement weather.

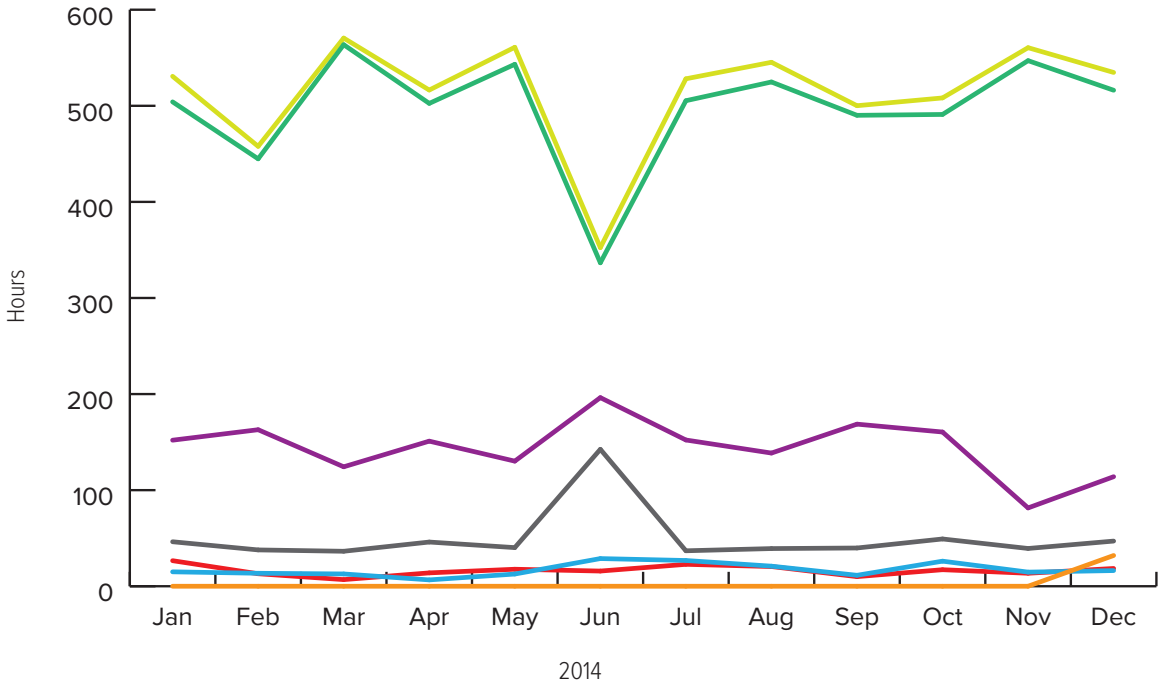
Shutdown: Actual shutdown hours, usually for a holiday. Other major shutdowns occur for major equipment work, such as GBT structural painting.

VLA photograph by Knate Myers

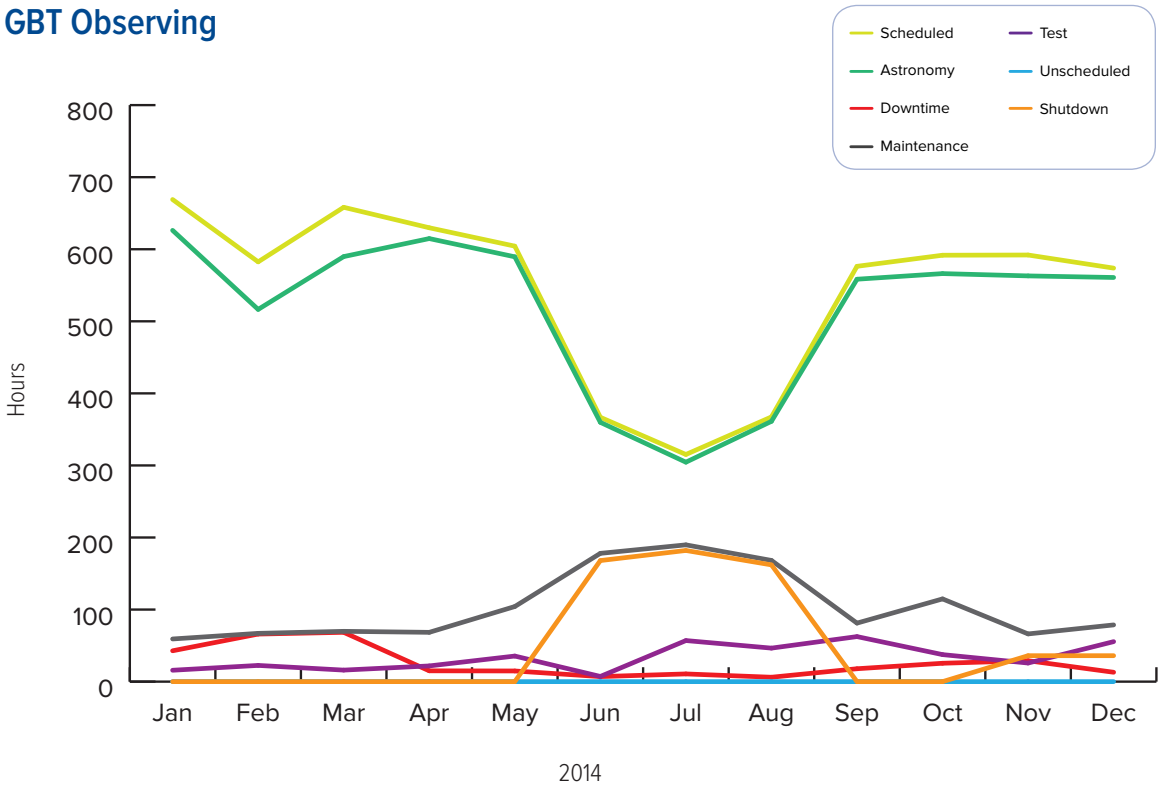
ALMA Observing



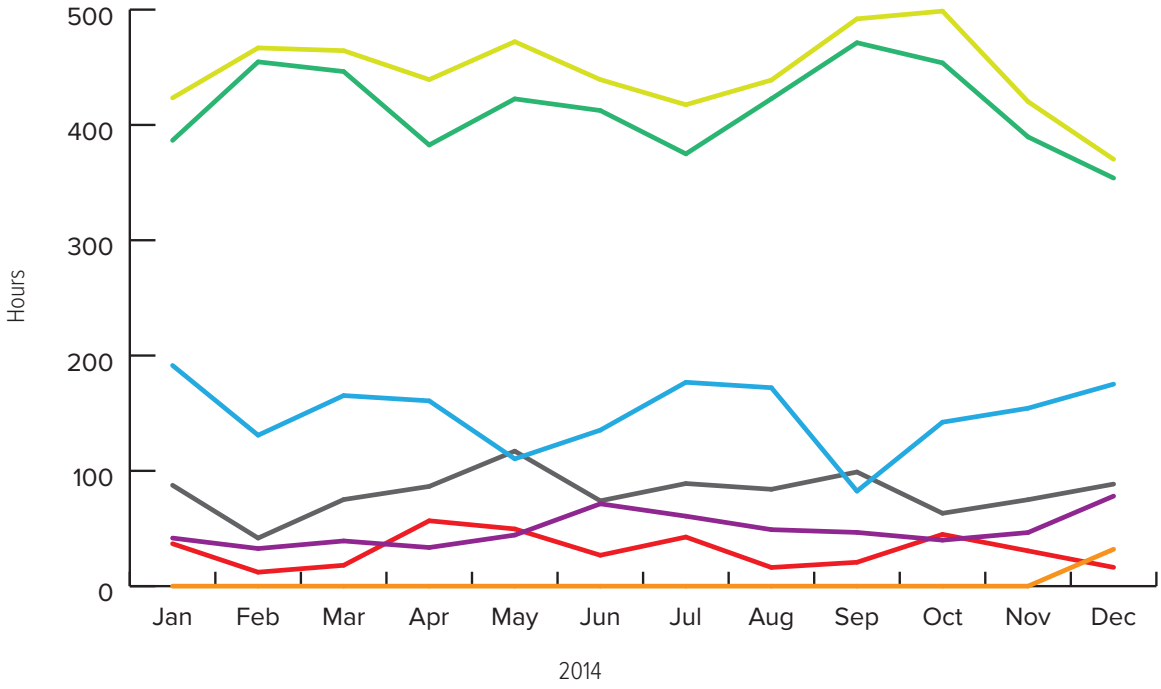
VLA Observing



GBT Observing



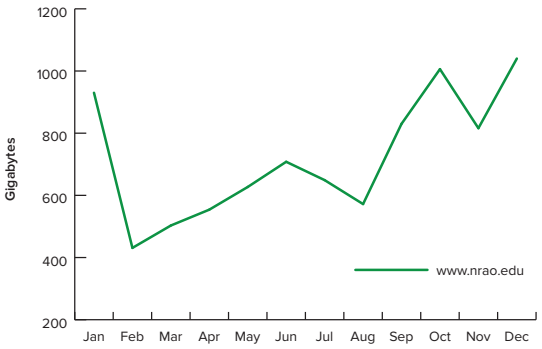
VLBA Observing

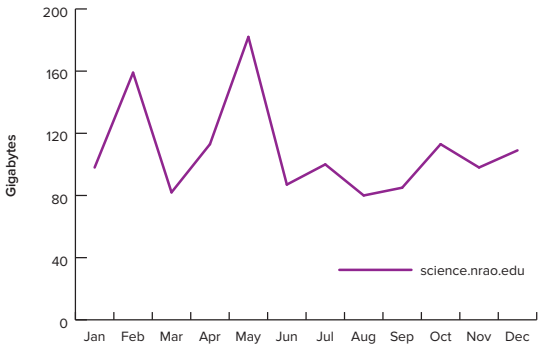


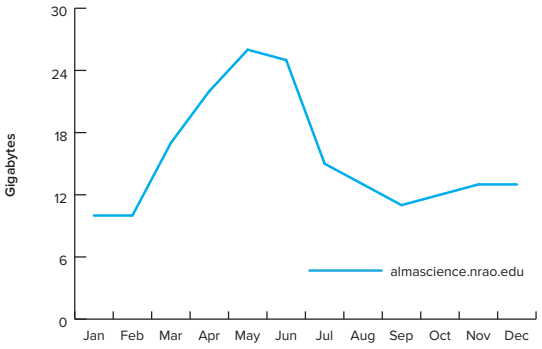
Observing Hours by Science Category

Observing hours for each of the GBT, VLA, and VLBA are tracked in the eight science categories that are included in the NRAO proposal evaluation and time allocation process:

NRAO Website Volume

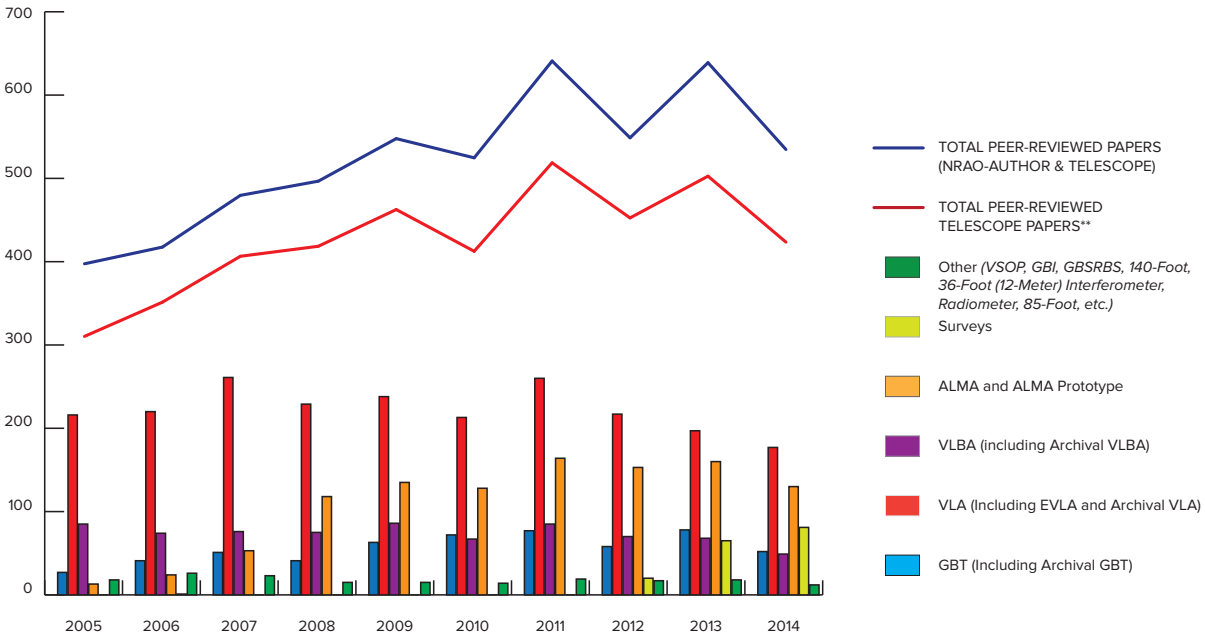






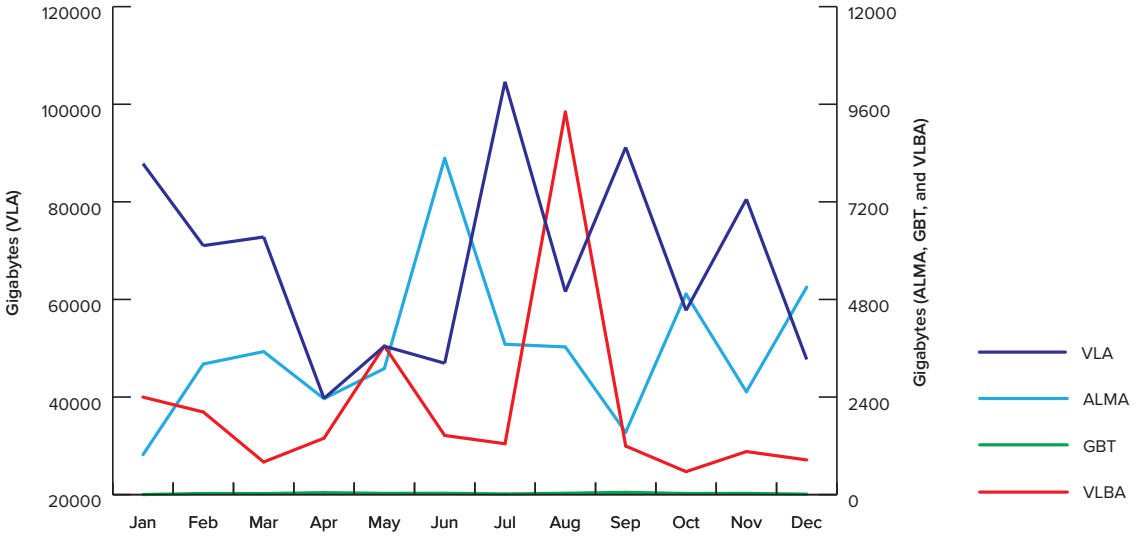
The almascience.nrao.edu website volume reflects activity by scientists interested in submitting observing proposals or seeking other professional astronomical information about ALMA. The science.nrao.edu website volume reflects activity by scientists interested in submitting observing proposals or seeking other professional astronomical information about GBT, VLA, and VLBA. The *www.nrao.edu* website volume reflects activity for press releases and other online public information.

Refereed Telescope and Author Papers



Total Peer-Reviewed NRAO-Author and Telescope Papers: Peer-reviewed publications that include NRAO telescope data, plus peer-reviewed publications by NRAO staff based on non-NRAO telescope data. **Total Peer-Reviewed Telescope Papers**: Peer-reviewed publications that include NRAO telescope data. **Other:** Peer-reviewed publications based on data from NRAO telescopes other than ALMA, VLA, VLBA, and GBT.

Science Data Archive Volume



The GBT science data archive was released to the community 1 October 2012. Most scientists, however, directly access their GBT data from the local disks in Green Bank rather than from the NRAO Science Archive.

APPENDIX A: PUBLICATIONS

2014 NRAO TELESCOPE AND AUTHOR REFEREED PUBLICATIONS

Aasi, J.; Abadie, J.; Abbott, B. P.; Abbott, R.; Abbott, T.; Abernathy, M. R.; Accadia, T.; Acernese, F.; Adams, C.; Adams, T.; Adhikari, R. X.; Affeldt, C.; Agathos, M.; Aggarwal, N.; Aguiar, O. D.; Ajith, P.; Allen, B.; Allocca, A.; Amador Ceron, E.; Amariutei, D.; Anderson, R. A.; Anderson, S. B.; Anderson, W. G.; Arai, K.; Araya, M. C.; Arceneaux, C.; Areeda, J.; Ast, S.; Aston, S. M.; Astone, P.; Aufmuth, P.; Aulbert, C.; Austin, L.; Aylott, B. E.; Babak, S.; Baker, P. T.; Ballardin, G.; Ballmer, S. W.; Barayoga, J. C.; Barker, D.; Barnum, S. H.; Barone, F.; Barr, B.; Barsotti, L.; Barsuglia, M.; Barton, M. A.; Bartos, I.; Bassiri, R.; Basti, A.; Batch, J.; Bauchrowitz, J.; Bauer, Th. S.; Bebronne, M.; Behnke, B.; Bejger, M.; Beker, M. G.; Bell, A. S.; Bell, C.; Belopolski, I.; Bergmann, G.; Berliner, J. M.; Bersanetti, D.; Bertolini, A.; Bessis, D.; Betzwieser, J.; Beyersdorf, P. T.; Bhadbhade, T.; Bilenko, I. A.; Billingsley, G.; Birch, J.; Bitossi, M.; Bizouard, M. A.; Black, E.; Blackburn, J. K.; Blackburn, L.; Blair, D.; Blom, M.; Bock, O.; Bodiya, T. P.; Boer, M.; Bogan, C.; Bond, C.; Bondu, F.; Bonelli, L.; Bonnand, R.; Bork, R.; Born, M.; Boschi, V.; Bose, S.; Bosi, L.; Bowers, J.; Bradaschia, C.; Brady, P. R.; Braginsky, V. B.; Branchesi, M.; Brannen, C. A.; Brau, J. E.; Breyer, J.; Briant, T.; Bridges, D. O.; Brillet, A.; Brinkmann, M.; Brisson, V.; Britzger, M.; Brooks, A. F.; Brown, D. A.; Brown, D. D.; Brückner, F.; Bulik, T.; Bulten, H. J.; Buonanno, A.; Buskulic, D.; Buy, C.; Byer, R. L.; Cadonati, L.; Cagnoli, G.; Calderón Bustillo, J.; Calloni, E.; Camp, J. B.; Campsie, P.; Cannon, K. C.; Canuel, B.; Cao, J.; Capano, C. D.; Carbognani, F.; Carbone, L.; Caride, S.; Castiglia, A.; Caudill, S.; Cavaglià, M.; Cavalier, F.; Cavalieri, R.; Cella, G.; Cepeda, C.; Cesarini, E.; Chakraborty, R.; Chalermsongsak, T.; Chao, S.; Charlton, P.; Chassande-Mottin, E.; Chen, X.; Chen, Y.; Chincarini, A.; Chiummo, A.; Cho, H. S.; Chow, J.; Christensen, N.; Chu, Q.; Chua, S. S. Y.; Chung, S.; Ciani, G.; Clara, F.; Clark, D. E.; Clark, J. A.; Cleva, F.; Coccia, E.; Cohadon, P.-F.; Colla, A.; Colombini, M.; Constancio, M., Jr.; Conte, A.; Conte, R.; Cook, D.; Corbitt, T. R.; Cordier, M.; Cornish, N.; Corsi, A.; Costa, C. A.; Coughlin, M. W.; Coulon, J.-P.; Countryman, S.; Couvares, P.; Coward, D. M.; Cowart, M.; Coyne, D. C.; Craig, K.; Creighton, J. D. E.; Creighton, T. D.; Crowder, S. G.; Cumming, A.; Cunningham, L.; Cuoco, E.; Dahl, K.; Dal Canton, T.; Damjanic, M.; Danilishin, S. L.; D'antonio, S.; Danzmann, K.; Dattilo, V.; Daudert, B.; Daveloza, H.; Davier, M.; Davies, G. S.; Daw, E. J.; Day, R.; Dayanga, T.; De Rosa, R.; Debreczeni, G.; Degallaix, J.; Del Pozzo, W.; Deleeuw, E.; Deléglise, S.; Denker, T.; Dent, T.; Dereli, H.; Dergachev, V.; Derosa, R.; Desalvo, R.; Dhurandhar, S.; Di Fiore, L.; Di Lieto, A.; Di Palma, I.; Di Virgilio, A.; Díaz, M.; Dietz, A.; Dmitry, K.; Donovan, F.; Dooley, K. L.; Doravari, S.; Drago, M.; Drever, R. W. P.; Driggers, J. C.; Du, Z.; Dumas, J.-C.; Dwyer, S.; Eberle, T.; Edwards, M.; Effler, A.; Ehrens, P.; Eichholz, J.; Eikenberry, S. S.; Endrőczi, G.; Essick, R.; Etzel, T.; Evans, K.; Evans, M.; Evans, T.; Factourovich, M.; Fafone, V.; Fairhurst, S.; Fang, Q.; Farinon, S.; Farr, B.; Farr, W.; Favata, M.; Fazi, D.; Fehrmann, H.; Feldbaum, D.; Ferrante, I.; Ferrini, F.; Fidecaro, F.; Finn, L. S.; Fiori, I.; Fisher, R.; Flaminio, R.; Foley, E.; Foley, S.; Forsi, E.; Fotopoulos, N.; Fournier, J.-D.; Franco, S.; Frasca, S.; Frasconi, F.; Frede, M.; Frei, M.; Frei, Z.; Freise, A.; Frey, R.; Fricke, T. T.; Fritschel, P.; Frolov, V. V.; Fujimoto, M.-K.; Fulda, P.; Fyffe, M.; Gair, J.; Gammaitoni, L.; Garcia, J.; Garufi, F.; Gehrels, N.; Gemme, G.; Genin, E.; Gennai, A.; Gergely, L.; Ghosh, S.; Giaime, J. A.; Giampanis, S.; Giardina, K. D.; Giazotto, A.; Gil-Casanova, S.; Gill, C.; Gleason, J.; Goetz, E.; Goetz, R.; Gondan, L.; González, G.; Gordon, N.; Gorodetsky, M. L.; Gossan, S.; Goßler, S.; Gouaty, R.; Graef, C.; Graff, P. B.; Granata, M.; Grant, A.; Gras, S.; Gray, C.; Greenhalgh, R. J. S.; Gretarsson, A. M.; Griffo, C.; Groot, P.; Grote, H.; Grover, K.; Grunewald, S.; Guidi, G. M.; Guido, C.; Gushwa, K. E.; Gustafson, E. K.; Gustafson, R.; Hall, B.; Hall, E.; Hammer, D.; Hammond, G.; Hanke, M.; Hanks, J.; Hanna, C.; Hanson, J.; Harms, J.; Harry, G. M.; Harry, I. W.; Harstad, E. D.; Hartman, M. T.; Haughian, K.; Hayama, K.; Heefner, J.; Heidmann, A.; Heintze, M.; Heitmann, H.; Hello, P.; Hemming, G.; Hendry, M.; Heng, I. S.; Heptonstall, A. W.; Heurs, M.; Hild, S.; Hoak, D.; Hodge, K. A.; Holt, K.; Holtrop, M.; Hong, T.; Hooper, S.; Horrom, T.; Hosken, D. J.; Hough, J.; Howell, E. J.; Hu, Y.; Hua, Z.; Huang, V.; Huerta, E. A.; Hughey, B.; Husa, S.; Huttner, S. H.; Huynh, M.; Huynh-Dinh, T.; Iafrate, J.; Ingram, D. R.; Inta, R.; Isogai, T.; Ivanov, A.; Iyer, B. R.; Izumi, K.; Jacobson, M.; James, E.; Jang, H.; Jang, Y. J.; Jaranowski, P.; Jiménez-Forteza, F.; Johnson, W. W.; Jones, D.; Jones, D. I.; Jones, R.; Jonker, R. J. G.; Ju, L.; K, Haris; Kalmus, P.; Kalogera, V.; Kandhasamy, S.; Kang, G.; Kanner, J. B.; Kasprzack, M.; Kasturi, R.; Katsavounidis, E.; Katzman, W.; Kaufer, H.; Kaufman, K.; Kawabe, K.; Kawamura, S.; Kawazoe, F.; Kéfélian, F.; Keitel, D.; Kelley, D. B.; Kells, W.; Keppel, D. G.; Khalaidovski, A.; Khalili, F. Y.; Khazanov, E. A.; Kim, B. K.; Kim, C.; Kim, K.; Kim, N.; Kim, W.; Kim, Y.-M.; King, E. J.; King, P. J.; Kinzel, D. L.; Kissel, J. S.; Klimenko, S.; Kline, J.; Koehlenbeck, S.; Kokeyama, K.; Kondrashov, V.; Koranda, S.; Korth, W. Z.; Kowalska, I.; Kozak, D.; Kremin, A.; Kringel, V.; Krishnan, B.; Królak, A.; Kucharczyk, C.; Kudla, S.; Kuehn, G.; Kumar, A.; Kumar, P.; Kumar, R.; Kurdyumov, R.; Kwee, P.; Landry, M.; Lantz, B.; Larson, S.; Lasky, P. D.; Lawrie, C.; Lazzarini, A.; Le Roux, A.; Leaci, P.; Lebigot, E. O.; Lee, C.-H.; Lee, H. K.; Lee, H. M.; Lee, J.; Lee, J.; Leonardi, M.; Leong, J. R.; Leroy, N.; Letendre, N.; Levine, B.; Lewis, J. B.; Lhuillier, V.; Li, T. G. F.; Lin, A. C.; Littenberg, T. B.; Litvine, V.; Liu, F.; Liu, H.; Liu, Y.; Liu, Z.; Lloyd, D.; Lockerbie, N. A.; Lockett, V.; Lodhia, D.; Loew, K.; Logue, J.; Lombardi, A. L.; Lorenzini, M.; Loriette, V.; Lormand, M.; Losurdo, G.; Lough, J.; Luan, J.; Lubinski, M. J.; Lück, H.; Lundgren, A. P.; Macarthur, J.; Macdonald, E.; Machenschalk, B.; Macinnis, M.; Macleod, D. M.; Magana-Sandoval, F.; Mageswaran, M.; Mailand, K.; Majorana, E.; Maksimovic, I.; Malvezzi, V.; Man, N.; Manca, G. 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APPENDIX A: PUBLICATIONS

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APPENDIX B: EVENTS & MILESTONES

3 January
NRAO Semester 2014B Call for Proposals opens

5-9 January
223rd AAS meeting
National Harbor, MD
NRAO Town Hall
VLA Sky Survey Workshop
NRAO Exhibit
Splinter Session: *Telescopes for Cosmic Dawn & 21 cm Cosmology*
Splinter Session: *Proposing for NRAO Instruments*
Summer Student Presentations
Undergraduate Orientation Sponsor & Exhibitor
Local EPO Event Sponsor & Participant

13-14 January
NSF FY 2014 Program Review
Charlottesville, Virginia

17 January
Jansky Lecture: Charles L. Bennett
A Tour of the Universe
Socorro, New Mexico

17 January
29th New Mexico Symposium
Socorro, New Mexico

21 January
Jansky Lecture: Charles L. Bennett
A Tour of the Universe
Charlottesville, Virginia

22 January
Jansky Lecture: Charles L. Bennett
A Tour of the Universe
Green Bank, West Virginia

3 February
NRAO Semester 2014B Call for Proposals deadline

13-14 February
AUI Board of Trustees meeting
Washington, D.C.

14 February
American Association for the Advance of Science
Chicago, Illinois
NRAO-sponsored science symposium: *From Dust and Gas to Disks and Planets*

15 February
American Association for the Advance of Science
Chicago, Illinois
NRAO-sponsored science symposium New Millimeter-wavelength Insights into Galaxy Evolution in the Early Universe

10 March
Versatile GBT Astronomical Spectrometer (VEGAS) released for shared-risk science

7-8 April
NRAO Postdoctoral Symposium
Charlottesville, Virginia

10 April
AUI Executive Committee meeting
Washington, D.C.

24-25 April
NRAO Visiting Committee
Socorro, New Mexico

13-20 May
14th Synthesis Imaging School
Socorro, New Mexico

19-21 May
3rd China-U.S. Workshop on Radio Astronomy Science and Technology: Emerging Opportunities
Green Bank, West Virginia

28 May
ALMA North American Science Advisory Committee (ANASAC)
Charlottesville, Virginia

29-30 May
NRAO Users Committee
Charlottesville, Virginia

31 May
ALMA Cycle 1 science observations ended
Joint ALMA Observatory, Chile

1 June
ALMA Cycle 2 science observations began
Joint ALMA Observatory, Chile

1-5 June
224th AAS meeting
Boston, MA
NRAO Exhibit
Undergraduate Orientation Sponsor & Exhibitor
Local EPO Event Sponsor & Participant

19-20 June
AUI Board of Trustees meeting
Charlottesville, Virginia

20-21 June
NRAO Community Day
University of Illinois at Urbana-Champaign

22-26 June
70th International Symposium on Molecular Spectroscopy
Champaign-Urbana, Illinois

7 July
NRAO Semester 2015A Call for Proposals open

1 August
NRAO Semester 2015A Call for Proposals deadline

4-7 August
Transformational Science in the ALMA Era: Multi-wavelength Studies of Galaxy Evolution
Charlottesville, Virginia

16-23 August
XXXIth URSI General Assembly and Scientific Symposium
Beijing, China

2-5 September
MegaSAGE (Surveying the Agents of Galaxy Evolution)
Charlottesville, Virginia

11 September
AUI Executive Committee meeting
Washington, D.C.

11-12 September
NSF Large Facilities Workshop
Ballston, Virginia

24 September
CASA 4.2.2 Release

8-9 October
ALMA Science Advisory Committee
Charlottesville, Virginia

10-11 October
Filamentary Structure in Molecular Clouds
Charlottesville, Virginia

16-17 October
AUI Board of Trustees meeting
Socorro, New Mexico

27 October
Jansky Lecture: Jill Tartar
Are We Alone? Searching for Intelligent Life Beyond Earth
Charlottesville, Virginia

27-31 October
4th VLA Data Reduction Workshop
Socorro, New Mexico

30 October
Jansky Lecture: Jill Tartar
Are We Alone? Searching for Intelligent Life Beyond Earth
Green Bank, West Virginia

7 November
Jansky Lecture: Jill Tartar
Are We Alone? Searching for Intelligent Life Beyond Earth
Socorro, New Mexico

7 November
NRAO Community Day
46th Division of Planetary Science Meeting
Tucson, AZ

4 December
AUI Executive Committee meeting
Washington, D.C.

8 December
ALMA Cycle 3 Pre-Announcement
Joint ALMA Observatory, Chile

8-11 December
Revolution in Astronomy with ALMA – The 3rd Year
Tokyo, Japan

10-11 December
NSF FY 2015 Program Review
Charlottesville, Virginia

APPENDIX C: ADVISORY COMMITTEES

Users Committee & ALMA North American Science Advisory Committee

The Users Committee is a scientific advisory group that provides input to NRAO on issues that affect the Observatory's scientific productivity and user relations and advises NRAO on matters of concern to those whose research is dependent on the Observatory's research facilities. The Committee also provides advice on scientific, technical, operational, and development issues relating to the astronomical community's current and future use of NRAO research facilities and makes recommendations that maximize the Observatory's scientific productivity and improve its effectiveness for the user community.

To perform these duties, the members of the Committee consult widely with current and potential NRAO users and communicate their requirements, recommendations, issues, and concerns to the Observatory.

The Committee delivers an annual report to the NRAO Director that summarizes the Committee's recommendations and concerns. In recent years, the Committee has become increasingly active in advising the Observatory between formal meetings. This is a valuable role that NRAO welcomes and encourages.

This year, as ALMA began to focus more on science operations and construction was completed, NRAO integrated the ALMA North American Science Advisory Committee (ANASAC) as a subcommittee of the Users Committee. Established in February 2003, the ANASAC has four primary charges:

- Advise the NRAO Director on issues relating to the scientific use of ALMA, including scientific and technical requirements for ALMA, user support, preparatory programs with existing facilities, and/or providing access to new facilities in Chile, science with ALMA during the construction and commissioning stage, definition and preparation for the NAASC, priorities for ALMA Chilean operations and the ALMA development plans.

- Provide a conduit between the NRAO and the NA scientific community for dissemination of information pertaining to the status and progress of the ALMA construction project and operations.

- Provide input to the NA ASAC members on charges given to the ALMA Science Advisory Committee (ASAC) by the ALMA Board.

- Carry out other tasks as may be requested by the NRAO Director.

The long-term plan is that the ANASAC will include the four North American representatives to the ASAC, a Taiwan representative, and any other Users Committee members interested in ALMA. Periodic teleconferences between the ANASAC and NRAO will continue, and the ANASAC will conduct an annual face-to-face meeting in conjunction with the annual Users Committee meeting.

Gregg Hallinan was the Chair for the 2014 Users Committee. Joseph Lazio was the Deputy Chair in 2014 and will be the 2015 Users Committee Chair.

The 2014 Users Committee members, their home institution, and the last year of their term of service follow. Members who also serve on the ANASAC or the ASAC are indicated.

Alberto Bolatto (ANASAC/ASAC)
University of Maryland, 2014

Daniela Calzetti (ANASAC)
University of Massachusetts, 2014

John Carpenter (ANASAC/ASAC)
Caltech, 2015

Shami Chatterjee
Cornell University, 2016

Laura Chomiuk
Michigan State University, 2016

Sarah Church
Stanford University, 2014

Helene Courtois
University Lyon France, 2014

Mark Devlin
University of Pennsylvania, 2014

Sheperd Doeleman (ANASAC)
MIT Haystack Observatory, 2015

Gregg Hallinan, Chair
Caltech, 2015

Fredrick "Rick" Jenet
University of Texas, Brownsville, 2014

Francisca Kemper (ANASAC)
Institute of Astronomy & Astrophysics, Academia Sinica, 2014

Joseph Lazio, Deputy Chair
JPL/Caltech, 2016

Dan Marrone (ANASAC)
University of Arizona, 2015

James Miller-Jones
Curtin University, 2015

Karin Öberg (ANASAC)
Harvard University, 2015

Ue-Li Pen
CITA – University of Toronto, 2014

Dick Plambeck (ANASAC/ASAC)
University of California, Berkeley, 2015

Dominik Riechers
Cornell University, 2016

Eva Schinnerer
Max-Planck-Institut für Astronomie, 2014

Douglas Scott (ANASAC/ASAC)
University of British Columbia, 2014

APPENDIX C: ADVISORY COMMITTEES

AUI Visiting Committee

The AUI Visiting Committee is appointed by the AUI Board of Trustees to review the management and research programs of the Observatory. The bi-annual Visiting Committee meetings are held at alternating NRAO sites. Edwin Bergin was the chair for the 2014 Visiting Committee. The Committee's bi-annual face-to-face meeting was held at the NRAO Domenici Science Operations Center in Socorro, New Mexico 24 – 25 April 2014. The 2014 Visiting Committee members, their home institution, and their last year of their term of service follow.

Edwin Bergin, Chair
University of Michigan, 2018

Katherine Blundell
Oxford University, 2018

Xiaoyu Hong
Shanghai Astronomical Observatory, 2016

Ryohei Kawabe
National Astronomical Observatory of Japan, 2016

Elizabeth A. Lada
University of Florida, 2014

Malcolm Longair
University of Cambridge, 2014

Maura McLaughlin
West Virginia University, 2016

Suzanne Staggs
Princeton University, 2016

Greg Taylor
University of New Mexico, 2018

Dan Werthimer
University of California – Berkeley, 2018

Time Allocation Committee

The persons listed below served on the NRAO Time Allocation Committee (TAC) for Semesters 2014B and 2015A. The scientific purview of each TAC member is indicated.

Semester 2014B

Jessica Rosenberg
Extragalactic Structure (EGS)
George Mason University

Bob Zavala
Solar System, Stars, and Planetary Systems (SSP)
US Naval Observatory

Mike Eraculous
Active Galactic Nuclei (AGN)
Pennsylvania State University

Andrew Baker
Normal Galaxies, Groups, and Clusters (NGA)
Rutgers University

Tom Bania
Interstellar Medium (ISM)
Boston University

Susana Lizano
Star Formation (SFM)
Universidad Nacional Autonoma de Mexico

Dave Sanders
High Redshift and Source Surveys (HIZ)
University of Hawaii

Joe Lazio
Energetic Transients and Pulsars (ETP)
Jet Propulsion Laboratory

Semester 2015A

Jeremy Darling
Extragalactic Structure (EGS)
University of Colorado

Bob Zavala
Solar System, Stars, and Planetary Systems (SSP)
U.S. Naval Observatory

Matt Malkan
Active Galactic Nuclei (AGN)
University of California Los Angeles

Andrew Baker
Normal Galaxies, Groups, and Clusters (NGA)
Rutgers University

Roland Kothes
Interstellar Medium (ISM)
Dominion Radio Astrophysical Observatory

Susana Lizano
Star Formation (SFM)
Universidad Nacional Autonoma de Mexico

Dave Sanders
High Redshift and Source Surveys (HIZ)
University of Hawaii

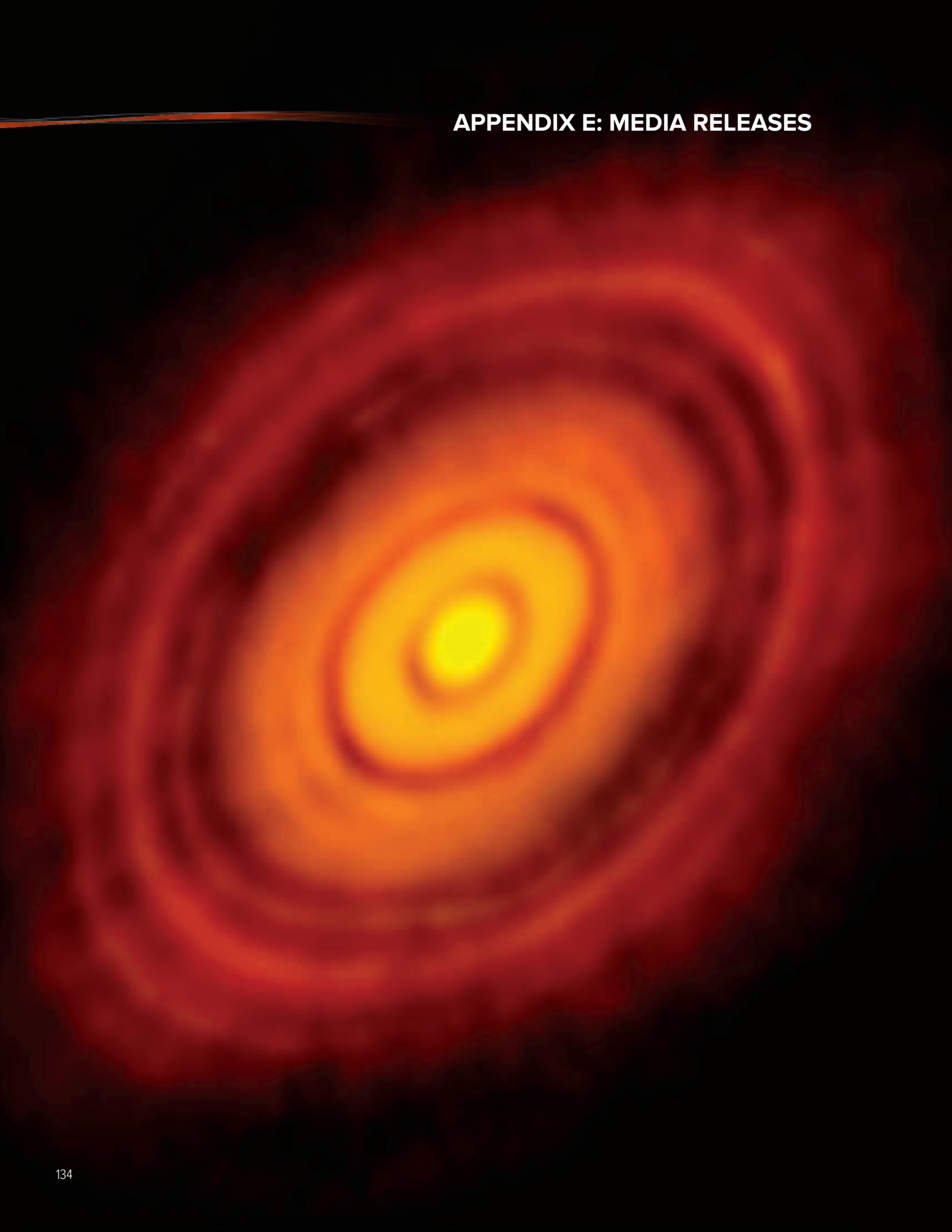
Joe Lazio
Energetic Transients and Pulsars (ETP)
Jet Propulsion Laboratory

APPENDIX D: FISCAL YEAR 2014 FINANCIAL SUMMARY

(all figures are $k USD)

Functional Work Breakdown Structure Element	GBT	VLA	VLBA	ALMA	GB Ops	NM Ops	HQ & CV Ops	CDL & Other	Solar Radio Burst Spectrometer	RET/REU	ALMA-C	EVLA-C	External Grants	Total
Administrative Services	$110.0	$2,023.5	$723.5	$921.4	$2,678.9	$2,020.1	$7,609.6	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$16,087.0
Development Programs	$573.1	$0.0	$0.0	$3,568.4	$411.2	$0.0	$654.2	$2,397.0	$0.0	$0.0	$0.0	$0.0	$0.0	$7,604.0
Director's Office	$0.0	$0.0	$0.0	$2,829.3	$251.6	$207.3	$3,766.9	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$7,055.1
Science Operations	$692.5	$125.4	$45.7	$5,110.9	$107.0	$850.4	$5,810.6	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$12,742.5
Telescope Operations	$4,224.8	$8,104.9	$4,699.2	$18,859.6	$351.6	$88.4	$109.3	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$36,437.9
SPO-4 Solar Radio Burst Spectrometer	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$35.8	$0.0	$0.0	$0.0	$0.0	$35.8
CSA-4 - RET/REU	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$40.3	$0.0	$0.0	$0.0	$40.3
ALMA Construction	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$12,389.0	$0.0	$0.0	$12,389.0
EVLA Construction	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$135.5	$0.0	$135.5
External Grants	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$4,559.0	$4,559.0
Grand Total	$5,600.4	$10,253.9	$5,468.5	$31,289.6	$3,800.3	$3,166.2	$17,950.5	$2,397.0	$35.8	$40.3	$12,389.0	$135.5	$4,559.0	$97,086.0

APPENDIX E: MEDIA RELEASES

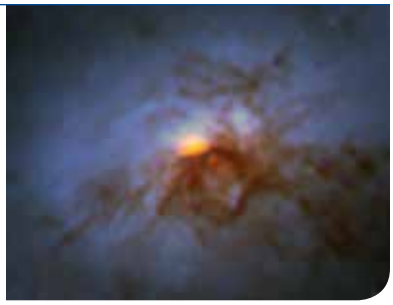


Media Releases of 2014

Complete text for all NRAO media releases is available at https://public.nrao.edu/news/pressreleases.

ALMA Explorer: Virtual Tour of Revolutionary Telescope Now in Spanish
(23 December) Spanish speakers can now experience the thrill of exploring the Universe with ALMA. To bring the public to this remote yet amazing location, the National Radio Astronomy Observatory (NRAO) has launched the Spanish-language version of its popular *ALMA Explorer* website.

'Perfect Storm' Quenching Star Formation around a Supermassive Black Hole
(17 December) High-energy jets powered by supermassive black holes can blast away a galaxy's star-forming fuel, resulting in so-called "red and dead" galaxies: those brimming with ancient red stars yet containing little or no hydrogen gas to create new ones. Astronomers using ALMA have discovered that black holes do not have to be nearly so powerful to shut down star formation.



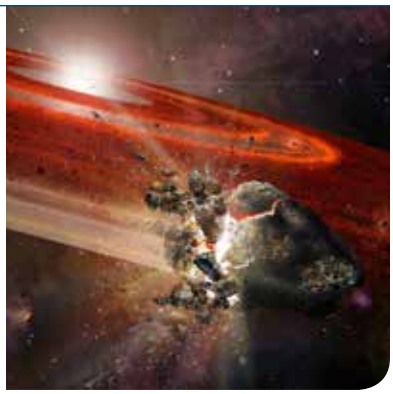
Astronomy in Chile Educator Ambassadors Program Initiated
(12 December) If you have a love of astronomy, a thirst for travel, and a desire to share this passion with others, apply to become one of the first participants in the Astronomy in Chile Education Ambassadors Program (ACEAP). This program, which is beginning its inaugural year, will bring amateur astronomers, planetarium personnel, and astronomy educators of all levels to several of the U.S.-funded astronomy facilities in Chile.

Revolution in Astronomy with ALMA Conference
(12 December) Astronomers from around the world met in Japan to discuss the latest ALMA scientific results. ALMA began Early Science operations in late September 2011 and approximately 170 papers based on its findings have been published in refereed journals since that time. The conference covered a broad range of science topics: the Solar System, the formation of stars and planets, galaxies, galaxy evolution, astrochemistry, and cosmology. Presentations, posters, and discussions focused on the data being collected by ALMA and the extraordinary new images it has provided.

APPENDIX E: MEDIA RELEASES

Pluto-Size Objects Kick Up Dust around Adolescent Star

(11 December) Astronomers using ALMA may have detected the dusty hallmarks of an entire family of Pluto-size objects swarming around an adolescent version of our own Sun. By making detailed observations of the protoplanetary disk surrounding the star HD 107146, astronomers detected an unexpected increase in the concentration of millimeter-size dust grains in the disk's outer reaches. This surprising increase may be the result of Pluto-size planetesimals stirring up the region, causing smaller objects to collide and blast themselves apart.



New VLA Observing System Completed, Begins Scientific Operations

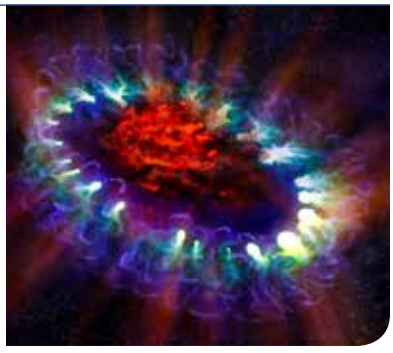
(9 December) A new system that makes the VLA two telescopes in one has been completed and its scientific operations are underway. The new system, called VLITE – VLA Ionospheric and Transient Experiment – allows the VLA to continuously monitor the sky to study the Earth's ionosphere and detect short bursts of radio emission from astronomical objects.

Strange Galaxy Perplexes Astronomers

(2 December) With the help of citizen scientists, a team of astronomers has found an important new example of a very rare type of galaxy that may yield valuable insight on how galaxies developed in the early Universe. The new discovery technique promises to give astronomers many more examples of this important and mysterious type of galaxy.

ALMA Observations of Supernova 1987A is 'Top Space Story'

(2 December) As announced at the American Astronomical Society's January 2014 meeting and published in the Astrophysical Journal Letters by Remy Indebetouw, striking observations with ALMA captured, for the first time, the remains of a recent supernova brimming with freshly formed dust. This result was selected by the editors of Astronomy magazine as one of the "Top 10 space stories of 2014." The artist impression created by Alexandra Angelich was specially featured as the magazine's January 2015 cover image.

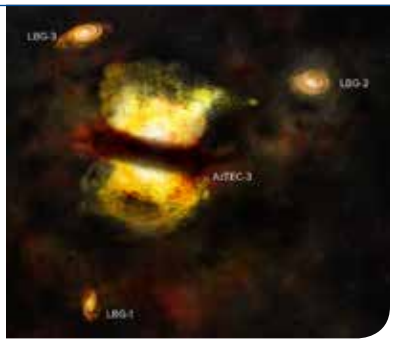


VLA Visitor Center Film Earns Prestigious Media Award

(20 November) The VLA visitor center film, *Beyond the Visible: The Story of the Very Large Array,* received an Interpretive Media Award from the National Association for Interpretation. The award was presented to the film's Executive Producer, John Stoke, of the National Radio Astronomy Observatory (NRAO) in a ceremony at NAI's national workshop in Denver, CO, on Wednesday.

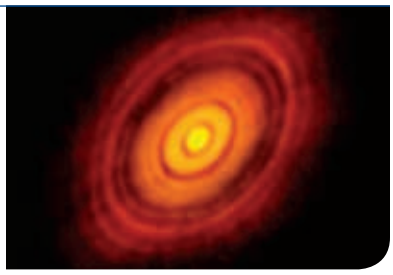
Best Evidence Yet for Galactic Merger in Distant Protocluster

(10 November) Nestled among a triplet of young galaxies more than 12.5 billion light-years away is a cosmic powerhouse: a galaxy that is producing stars nearly 1,000 times faster than our own Milky Way. This energetic starburst galaxy, known as AzTEC-3, together with its gang of calmer galaxies may represent the best evidence yet that large galaxies grow from the merger of smaller ones in the early Universe, a process known as hierarchical merging. An international team of astronomers observed these remarkable objects with ALMA.



Birth of Planets Revealed

(6 November) Astronomers have captured the best image ever of planet formation around an infant star as part of the testing and verification process for the high-resolution capabilities of ALMA. This revolutionary new image reveals in astonishing detail the planet-forming disk surrounding HL Tauri, a Sun-like star located approximately 450 light-years from Earth in the constellation Taurus.

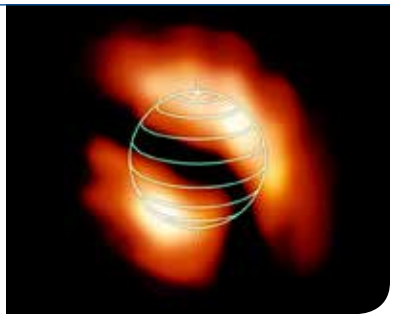


Planet-forming Lifeline Discovered in a Binary Star System

(29 October) Scientists using ALMA have detected a streamer of dust and gas flowing from a massive outer disk toward the inner reaches of a binary star system. This never-before-seen feature may be responsible for sustaining a second, smaller disk of planet-forming material that otherwise would have disappeared long ago.

Organic Molecules in Titan's Atmosphere Are Intriguingly Skewed

(22 October) While studying the atmosphere on Saturn's moon Titan, scientists discovered intriguing zones of organic molecules unexpectedly shifted away from its north and south poles. These misaligned features seem to defy conventional thinking about Titan's windy atmosphere, which should quickly smear out such off-axis concentrations. This discovery, made via a brief three-minute "snapshot" ALMA observation, may help astronomers better understand the processes that shape this world's complex chemistry.



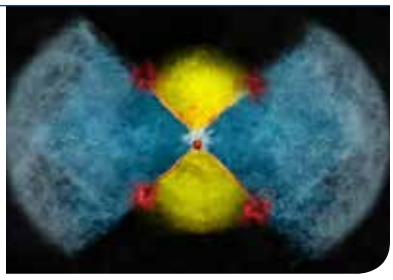
APPENDIX E: MEDIA RELEASES

Milky Way Ransacks Nearby Dwarf Galaxies

(15 October) Astronomers using the GBT, along with data from other large radio telescopes, have discovered that our nearest galactic neighbors, the dwarf spheroidal galaxies, are devoid of star-forming gas, and that our Milky Way Galaxy is to blame. These new radio observations, which are the highest sensitivity of their kind ever undertaken, reveal that within a well-defined boundary around our Galaxy, dwarf galaxies are completely devoid of hydrogen gas; beyond this point, dwarf galaxies are teeming with star-forming material.

Radio Telescopes Unravel Mystery of Nova Gamma Rays

(8 October) Detailed images acquired with the VLA, VLBA, and other radio telescopes have pinpointed the locations where a stellar explosion called a nova emitted gamma rays, the most energetic form of electromagnetic waves. The discovery revealed a probable mechanism for the gamma-ray emissions, which mystified astronomers when first observed in 2012.



NRAO 'Milky Way Explorer' Tours the Solar System

(26 September) Imagine seeing the Sun, planets, and a myriad other objects in our Solar System as you have never seen them before – in invisible radio light! That is the experience you will get through the National Radio Astronomy Observatory's (NRAO) newly released Solar System installment of its popular Milky Way Explorer, an online tour of our interstellar neighborhood guided by the actual astronomers who explore it using radio waves.

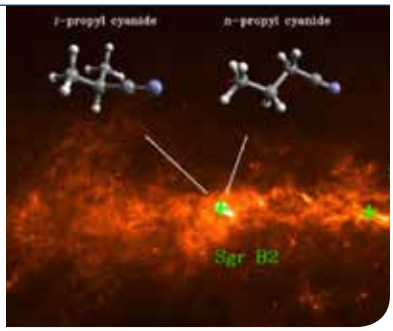
NRAO Media Tip Sheet

(September 2014) Science, engineering, and technology milestones

1. ALMA Finds that Organic Molecules are Branching Out: A new organic molecule with a "branched" structure was found by ALMA, offering greater hope that amino acids may one day be detected in interstellar space.

2. VLA Reveals Details of Still-Forming Planetary System: VLA mapped the structure of a disk of dust surrounding a young star, revealing a pair of gaps in the disk where new planets are likely forming.

3. New NRAO Patent for Radio Synthesizer: New frequency synthesizer helps astronomers "tune in" to the cosmos.

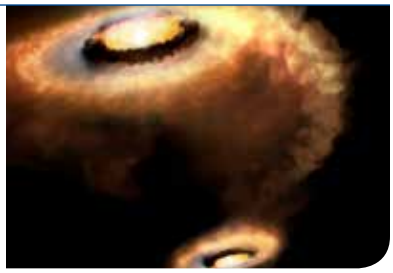


ALMA Extends Its Arms

(24 September) ALMA has successfully tested an antenna in the most extended configuration of the array yet, producing the longest baseline ever achieved with the array. This advance became possible once the first of ALMA's three extended arms was successfully powered up for the first time, and opens up the possibility of greatly extending ALMA's capabilities. With longer baselines, the ability of a radio telescope to see fine detail increases, allowing astronomers to uncover much more information about objects observed in the Universe.

Infant Solar System Shows Signs of Windy Weather

(22 September) Astronomers using ALMA have observed what may be the first-ever signs of windy weather around a T Tauri star, an infant analog of our own Sun. This may help explain why some T Tauri stars have disks that glow weirdly in infrared light while others shine in a more expected fashion.

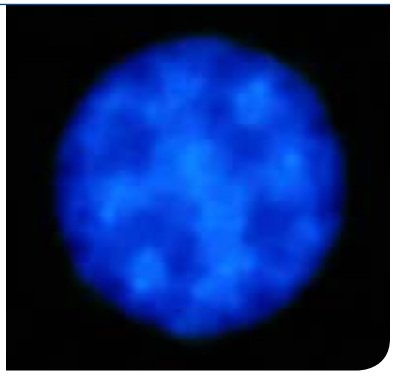


Explaining the Dearth of Elliptical Galaxies

(16 September) Galaxy mergers are quite common throughout the history of the Universe and for decades astronomers believed that these cosmic collisions led primarily to the formation massive elliptical galaxies. New observations with ALMA and a bevy of other radio telescopes provide the first direct evidence that merging galaxies can instead produce disk galaxies – the cosmic cousins of our own Milky Way.

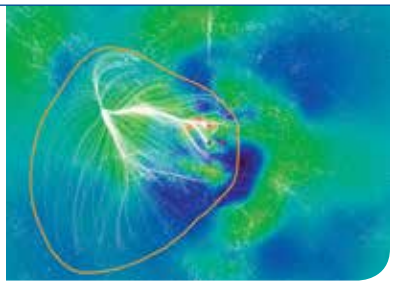
ALMA Achieves New Observing Capabilities

(10 September) ALMA has reached a major milestone by extending its vision fully into the realm of the submillimeter, the wavelengths of cosmic light that hold intriguing information about the cold, dark, and distant Universe. This achievement, which was marked by the completion of ALMA's High Frequency Observing Campaign, opens an entirely new window on the Universe for ALMA and goes beyond its existing capabilities with the Band 9 receivers. It also is a critical step in the telescope's commissioning process, which brings its full capabilities to bear and makes them available to the international astronomical community.



Newly Identified Galactic Supercluster Is Home to the Milky Way

(3 September) Astronomers using the GBT have determined that our own Milky Way galaxy is part of a newly identified ginormous supercluster of galaxies, which they have dubbed "Laniakea," which means "immense heaven" in Hawaiian. This discovery clarifies the boundaries of our galactic neighborhood and establishes previously unrecognized linkages among various galaxy clusters in the local Universe.



APPENDIX E: MEDIA RELEASES

SETI, Astrobiology Pioneer Awarded Jansky Lectureship

(2 September) Associated Universities, Inc. (AUI), and the National Radio Astronomy Observatory (NRAO) have awarded the 2014 Karl G. Jansky Lectureship to Dr. Jill C. Tarter, of the SETI Institute. The Jansky Lectureship is an honor established by the trustees of AUI to recognize outstanding contributions to the advancement of radio astronomy. Dr. Tarter is being honored for her role in pioneering methods of searching for extraterrestrial intelligence and for her leadership in the emerging field of astrobiology.

Radio Telescopes Settle Controversy Over Distance to Pleiades

(28 August) Astronomers have used the VLBA, a worldwide network of radio telescopes, to resolve a controversy over the distance to a famous star cluster – a controversy that posed a potential challenge to scientists' basic understanding of how stars form and evolve. The new work shows that the measurement made by a cosmic-mapping research satellite was wrong.

Pebble-Size Particles May Jump-Start Planet Formation

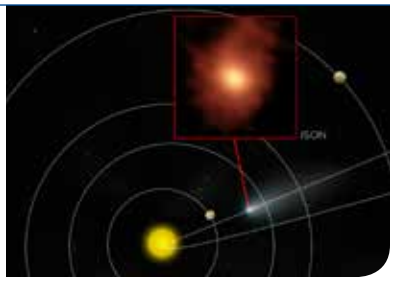
(28 August) Rocky planets like Earth start out as microscopic bits of dust tinier than a grain of sand, or so theories predict. Astronomers using the GBT have discovered that filaments of star-forming gas near the Orion Nebula may be brimming with pebble-size particles – planetary building blocks 100 to 1,000 times larger than the dust grains typically found around protostars. If confirmed, these dense ribbons of rocky material may well represent a new, mid-size class of interstellar particles that could help jump-start planet formation.

Best View Yet of Merging Galaxies in the Distant Universe

(26 August) An international team of astronomers using ALMA, the VLA, and other telescopes has obtained the best view yet of a collision between two galaxies when the Universe was only half its current age. To make this observation, the team also enlisted the help of a gravitational lens, a galaxy-size magnifying glass, to reveal otherwise invisible detail.

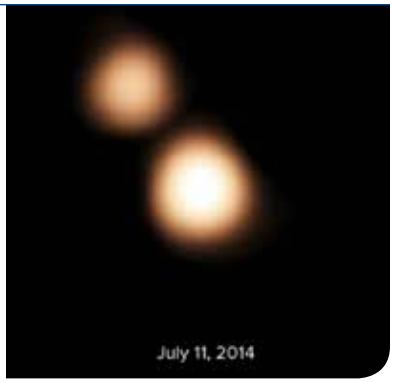
Comets Forge Organic Molecules in Their Dusty Atmospheres

(11 August) An international team of scientists has used ALMA to make incredible 3D images of the ghostly atmospheres surrounding comets ISON and Lemmon. These new observations provide important insights into how and where comets forge new chemicals, including intriguing organic compounds.



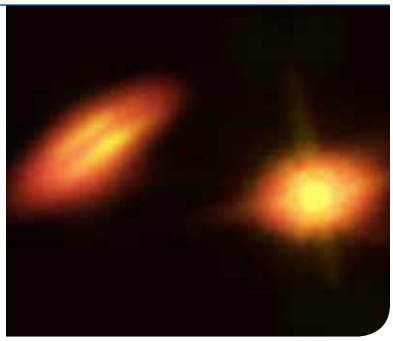
Guiding NASA's New Horizons Spacecraft

(5 August) Astronomers using ALMA are making high-precision measurements of Pluto's location and orbit around the Sun to help NASA's New Horizons spacecraft accurately home in on its target when it nears Pluto and its five known moons in July 2015. The New Horizons team made use of ALMA data, together with newly analyzed visible light measurements stretching back to Pluto's discovery, to determine how to perform the first course correction for targeting. This maneuver helped ensure that New Horizons uses the minimum fuel to reach Pluto, saving as much as possible for a potential extended mission to explore Kuiper Belt objects.



Young Binary Star System May Form Planets with Weird and Wild Orbits

(30 July) Unlike our solitary Sun, most stars form in binary pairs – two stars that orbit a common center of mass. Though plentiful, binaries pose a number of questions, including how and where planets form in such complex environments. While surveying a series of binary stars with ALMA, astronomers uncovered a striking pair of wildly misaligned planet-forming disks in the young binary star system HK Tauri. These results provide the clearest picture ever of protoplanetary disks around a double star and could reveal important details about the birth and eventual orbit of planets in a multiple star system.



NRAO Media Tip Sheet

(June 2014) Science, engineering, and technology milestones

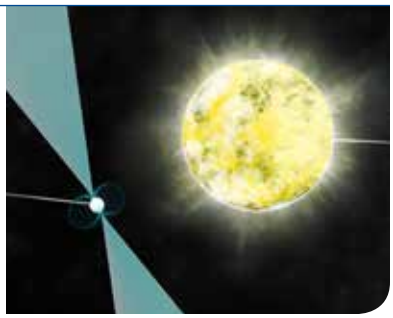
1. VLBA Helps Measure Expansion in the Current Universe: The VLBA and other radio telescopes tracked the motion of 429 distant celestial objects to better calculate how fast the Universe is expanding.

2. Measuring the Starting Point for Star Formation: Scientists using the new capabilities of the VLA have made a difficult, sensitive temperature measurement that sets the starting point for the beginning stage of star formation.

3. Radio Astronomy 'RATs' Celebrate 25th Anniversary at Green Bank: The Radio Astronomy Team (RATs), a high school group from Grosse Pointe, Michigan, celebrated its 25th anniversary at the NRAO in Green Bank, WV.

Remarkable White Dwarf Star Possibly Coldest, Dimmest Ever Detected

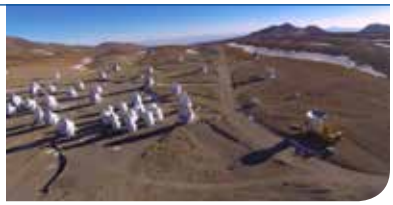
(23 June) A team of astronomers has used the GBT and VLBA, as well as other observatories to identify possibly the coldest, faintest white dwarf star ever detected. This ancient stellar remnant is so cool that its carbon has crystallized, forming, in effect, an Earth-size diamond in space.



APPENDIX E: MEDIA RELEASES

Final ALMA Antenna Arrives on the Chajnantor Plateau

(16 June) The 66th and final ALMA antenna has completed its long journey and arrived on the Chajnantor Plateau in northern Chile on Friday, 13 June 2014.



A Gigantic Explosion Buried in Dust

(11 June) Using ALMA, a team of researchers reports the first-ever detection of molecular gas – the fuel for star formation – in two galaxies that were previously rocked by gamma ray bursts (GRBs), the brightest explosions in the Universe. These new observations revealed that the molecular gas was concentrated toward the centers of the galaxies, while the GRBs occurred in unusual environments that were surprisingly bereft of gas yet rich in dust.

ALMA Upgrade to Supercharge Event Horizon Telescope

(4 June) Scientists recently upgraded ALMA by installing an ultraprecise atomic clock at the telescope's very high-elevation Array Operations Site, home to the observatory's supercomputing correlator. This upgrade will eventually allow ALMA to synchronize with a worldwide network of radio astronomy facilities collectively known as the Event Horizon Telescope.

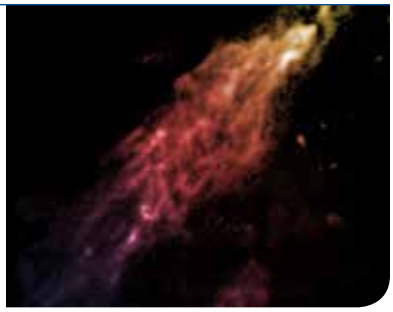
A Violent, Complex Scene of Colliding Galaxy Clusters

(3 June) Astronomers using the VLA and the Chandra X-Ray Observatory have produced a spectacular image revealing new details of violent collisions involving at least four clusters of galaxies. Combined with an earlier image from NASA's Hubble Space Telescope, the new observations show a complex region more than 5 billion light-years from Earth where the collisions are triggering a host of phenomena that scientists still are working to understand.

ALMA Observatory Launches Website for Children

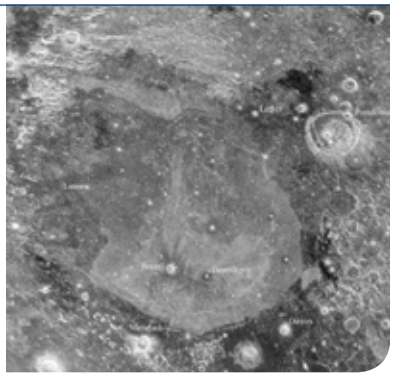
(27 May) ALMA Kids is a new mini-site created especially for children. The colorful site aims to familiarize them with astronomy, expand their understand of the Universe, and help them appreciate the contribution of ALMA. The content of this new ALMA educational space includes comics, discoveries explained in simple words, videos, and games, all within a playful design.

Failed Dwarf Galaxy Survives Galactic Collision
(23 May) Like a bullet wrapped in a full metal jacket, a high-velocity hydrogen cloud hurtling toward the Milky Way appears to be encased in a shell of dark matter, according to a new analysis of data from the GBT. Astronomers believe that without this protective shell, the high-velocity cloud known as the Smith Cloud would have disintegrated long ago when it first collided with the disk of our Galaxy.



NRAO Astronomer Receive Prestigious Catherine Wolfe Bruce Gold Medal
(15 May) Kenneth Kellermann, Ph.D., senior scientist at the National Radio Astronomy Observatory (NRAO) in Charlottesville, Va., is the recipient of the Astronomical Society of the Pacific's 2014 Catherine Wolfe Bruce Gold Medal, the society's highest honor. He is being recognized for his lifetime achievements in founding radio astronomy as a major branch of global astronomy and for contributing to both the development of modern cosmology and to the invention of Very Long Baseline Interferometry.

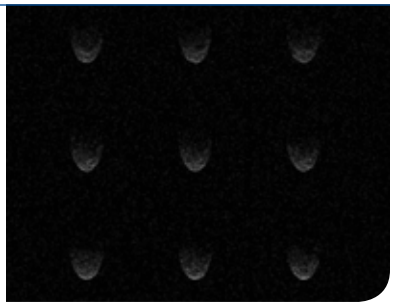
New Radar Images Uncover Remarkable Lunar Features
(14 May) New images of Earth's Moon reveal more than can be seen with the naked eye, thanks to the combined efforts of the two largest radio telescopes of their kind: the GBT and the Arecibo Observatory in Puerto Rico. To make these images, radar signals beamed from Arecibo's powerful transmitter penetrated far below the Moon's dusty surface. The signals then rebounded back and were picked up by the sensitive receivers on the GBT. This observing technique, known as bistatic radar, has been used to study many objects in our Solar System, including asteroids and other planets.



NRAO Media Tip Sheet
(May 2014) Science, engineering, and technology milestones

1. GBT Makes Arecibo Connection to Image Asteroid: The GBT and Arecibo combine to make radar images of a rapidly fleeing asteroid.

2. Global Telescope Array Links Successfully with GBT: The GBT successfully linked with a network of mm-wave telescopes, giving a powerful boost to the Global Millimeter VLBI Array.



APPENDIX E: MEDIA RELEASES

NRAO, WVU Expand Broadband Data Network

(9 April) Two of West Virginia's premier research institutions, the NRAO in Green Bank and West Virginia University (WVU) in Morgantown, have inaugurated a new super high-speed broadband data network to bolster collaboration and scientific research between these two education-focused organizations.

Introducing Our New Milky Way Explorer

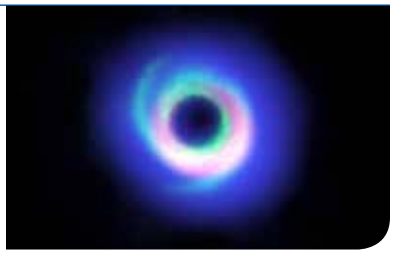
(2 April)

A cloud of gas, that may or may not have a star embedded in the middle, is falling into the supermassive black hole in the center of our Milky Way Galaxy. It's a once-in-a-lifetime chance for astronomers to watch our malnourished black hole eat, and a perfect time to put that into context for you in an exciting new interactive adventure: the Milky Way Explorer.

NRAO Media Tip Sheet

(March 2014)

Science, engineering, and technology milestones



1. Astronomers Make Best Measurement Yet of Distance to Galactic Center: The VLBA and other radio telescopes have made the most accurate measurement yet to the Milky Way Galaxy's center.

2. VEGAS Is a Good Bet to Study the Cosmos: A recent GBT upgrade will help astronomers understand star formation, the evolution of the Universe, and the origin of molecules essential for life.

3. Protoplanetary Disks 'Bulge' in Complex and Asymmetrical Ways: ALMA has studied two massive protoplanetary disks and discovered an essential step in planet formation.

'Death Stars' in Orion Blast Planets before They Even Form

(10 March) The Orion Nebula is home to hundreds of young stars and even younger protostars known as proplyds. Many of these nascent systems will go on to develop planets, while others will have their planet-forming dust and gas blasted away by the fierce ultraviolet radiation emitted by massive O-type stars that lurk nearby. A team of astronomers has used ALMA to study the often deadly relationship between highly luminous O-type stars and nearby protostars in the Orion Nebula.

Icy Wreckage in A Nearby Solar System

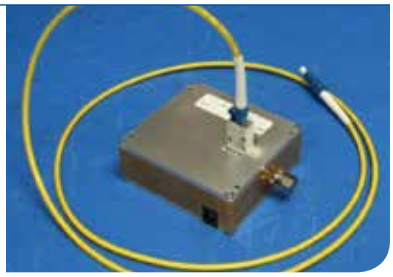
(5 March) Astronomers using ALMA have discovered the splattered remains of comets colliding together around a nearby star; the researchers believe they are witnessing the total destruction of one of these icy bodies once every five minutes. The "smoking gun" implicating this frosty demolition is the detection of a surprisingly compact region of carbon monoxide gas swirling around the young, nearby star Beta Pictoris.

NRAO Media Tip Sheet

(February 2014) Science, engineering, and technology milestones

1. Extended Radio Emission from Merging Galaxy Clusters: GBT may have detected the faint but telltale signs that modest clumps of galaxies are merging into unimaginably huge galaxy clusters.

2. Innovation Promises Big Boost to Data Transmission: A new device created by NRAO engineers may improve the way digital data is transferred over any data link.



3. From Dust and Gas to Disks and Planets: New radio and mm-wave observations are piercing the dusty veil surrounding newborn stars and studying the birth of solar systems.

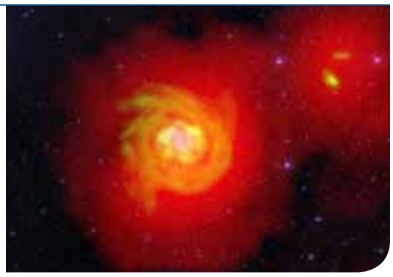
4. Galaxy Evolution in the Early Universe: New mm-wave telescopes are painting a much clearer picture of the early Universe.

Starbursting in the Galaxy M82

(3 February) Messier 82 (M82) is the closest galaxy that is undergoing a rapid burst of star formation, or starburst. A new VLA radio image reveals fresh information about the central 5200 light-years of the galaxy.

A River of Hydrogen

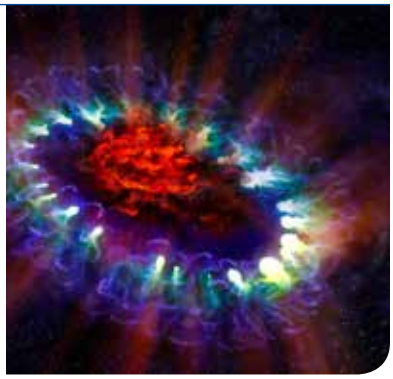
(27 January) Using the GBT, astronomer D.J. Pisano from West Virginia University has discovered what could be a never-before-seen river of hydrogen flowing through space. This very faint, very tenuous filament of gas is streaming into the nearby galaxy NGC 6946 and may help explain how certain spiral galaxies keep up their steady pace of star formation.



Dwarf Galaxies Give Clues to Origin of Supermassive Black Holes

(6 January) Poring through data from a large sky survey, astronomers have found more than 100 small, dwarf galaxies with characteristics indicating that they harbor massive black holes feeding on surrounding gas. The discovery confounds a common assumption that only much larger galaxies hold such monsters, and may help resolve the question of how such black holes originated and grew in the early Universe.

A Supernova's Super Dust Factory



(6 January) Galaxies can be remarkably dusty places and supernovas are thought to be a primary source of that dust, especially in the early Universe. Direct evidence of a supernova's dust-making capabilities, however, has been slim and cannot account for the copious amount of dust detected in young, distant galaxies. Striking new ALMA observations capture, for the first time, the remains of a recent supernova brimming with freshly formed dust. If enough of this dust makes the perilous transition into interstellar space, it could explain how many galaxies acquired their dusty, dusky appearance.

Pulsar in a Stellar Triple System Makes Unique Gravitational Laboratory

(5 January) Astronomers using the GBT have discovered a unique stellar system of two white dwarf stars and a superdense neutron star, all packed within a space smaller than Earth's orbit around the Sun. The closeness of the stars, combined with their nature, has allowed the scientists to make the best measurements yet of the complex gravitational interactions in such a system.

Pluto-Size Objects Kick Up Dust around Adolescent Star
(11 December)

Astronomers using ALMA may have detected the dusty hallmarks of an entire family of Pluto-size objects swarming around an adolescent version of our own Sun. By making detailed observations of the protoplanetary disk surrounding the star HD 107146, astronomers detected an unexpected increase in the concentration of millimeter-size dust grains in the disk's outer reaches. This surprising increase may be the result of Pluto-size planetesimals stirring up the region, causing smaller objects to collide and blast themselves apart.

APPENDIX F: ACRONYMS

Acronym	Definition
AAS	American Astronomical Society
AAAS	American Association for the Advancement of Science
AAG	NSF Astronomy and Astrophysics Grants
AAS	American Astronomical Society
AAT	Archive Access Tool
ACA	Atacama Compact Array
ACEAP	Astronomy in Chile Education Ambassadors Program
ACU	Antenna Control Unit
AGN	Active Galactic Nuclei
AIPS	Astronomical Image Processing System
AL	Astronomical League
ALMA	Atacama Large Millimeter/submillimeter Array
ANASAC	ALMA North American Science Advisory Committee
AoD	Astronomer on Duty
AOS	Array Operations Site
API	Atmospheric Phase Interferometer
APP	ALMA Phasing Project
APRC	ALMA Proposal Review Committee
ARC	ALMA Regional Center
ARP	ALMA Review Panels
ASIAA	Academia Sinica Institute for Astronomy and Astrophysics
ASC	Array Science Center
ASKAP	Australian Square Kilometer Array Pathfinder
ASP	Astronomical Society of the Pacific
AST	NSF Division of Astronomical Sciences
ASTRON	Netherlands Institute for Radio Astronomy
AU	Astronomical Unit
AUI	Associated Universities, Incorporated
AURA	Association of Universities for Research in Astronomy
BeSSeL	Bar and Spiral Structure Legacy Survey
BYU	Brigham Young University
CARMA	Combined Array for Research in Millimeter Astronomy
CASA	Common Astronomy Software Applications
CASPER	Collaboration for Astronomy Signal Processing and Electronics Research
CDE	Community Day Event
CDL	Central Development Laboratory
CDR	Critical Design Review
CfP	Call for Proposals
CICADA	Configurable Instrument Collaboration for Agile Data Acquisition
CIS	Computing Information Systems
COM	Communications Office
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSO	Caltech Submillimeter Observatory
CSRH	Chinese Spectral Radioheliograph
CV	Charlottesville, Virginia
DARE	Dark Ages Radio Explorer
DMSD	Data Management & Software Department
EGS	Extragalactic Structure
EOC	Extension of Capabilities
EPO	Education and Public Outreach
ES	Early Science
ESO	European Organisation for Astronomical Research in the Southern Hemisphere
ETP	Energetic Transients and Pulsars
EVN	European VLBI Network
FASR	Frequency-Agile Solar Radiotelescope
FAST	Five hundred meter Aperture Spherical Telescope
FCC	Federal Communications Commission
FIRST	Faint Images of the Radio Sky at Twenty centimeters
FPGA	Field Programmable Gate Array
FRB	Fast Radio Bursts
FWHM	Full Width at Half Maximum
GB	Green Bank, West Virginia
GBT	Green Bank Telescope
GHz	Gigahertz
GO	General Observing
HALCA	Highly Advanced Laboratory for Communications and Astronomy
HERA	Hydrogen Epoch of Reinonization Array

Acronym	Definition
HFET	Heterojunction Field Effect Transistor
HIZ	High Redshift and Source Surveys
HPC	High Performance Computing
HR	Human Resources
HSA	High Sensitivity Array
HST	Hubble Space Telescope
IEEE	Institute of Electrical and Electronics Engineers
IfA	Institute for Astronomy
IPAC	Infrared Processing and Analysis Center
IPT	Integrated Product Team
IRD	Infrared Doppler Instrument
ISM	Interstellar Medium
ITU-R	International Telecommunication Union – Radiocommunication
IUCAF	Inter-Union Committee on the Allocation of Frequencies
JAO	Joint ALMA Observatory
JPL	Jet Propulsion Laboratory
kHz	kiloHertz
KASI	Korea Astronomy and Space Science Institute
KFPA	K-band Focal Plane Array
Kpc	kiloparsec
LBC	Long Baseline Campaign
LMT	Large Millimeter Telescope
LNA	Low Noise Amplifier
LO	Local Oscillator
LOBO	Low Band Observatory
LSST	Large Synoptic Survey Telescope
LWA	Long Wavelength Array
MEASURE	Magnetometers along the Eastern Atlantic Seaboard for Undergraduate Research and Education
MeerKAT	Karoo Array Telescope
MegaSAGE	Surveying the Agents of Galaxy Evolution
MHz	Megahertz
MMIC	Monolithic Millimeter-wave Integrated Circuit
MOU	Memorandum of Understanding
MPIfR	Max Planck Institut für Radioastronomie
MPIfA	Max Planck Institut für Astronomie
MWR	Murchison Widefield Array
µJy	microJansky
MUSTANG	Multiplexed SQUID/TES Array at Ninety Gigahertz
NA	North American
NAASC	North American ALMA Science Center
NAOC	National Astronomical Observatories, Chinese Academy of Sciences
NAOJ	National Astronomical Observatory of Japan
NANOGrav	North American Nanohertz Observatory for Gravitational Waves
NAPO	North American Project Office
NASA	National Aeronautics and Space Administration
NGA	Normal Galaxies, Groups, and Clusters
NGST	Next Generation Space Telescope
ngVLA	Next Generation Very Large Array
NINS	National Institutes of Natural Sciences
NIO	New Initiatives Office
NIR	Near Infrared
NIST	National Institute of Standards and Technology
NM	New Mexico
NMT	New Mexico Institute of Mining and Technology
NMASC	New Mexico Array Science Center
NRAO	National Radio Astronomy Observatory
NRC	National Research Council
NRL	Naval Research Laboratory
NRQZ	National Radio Quiet Zone
NSF	National Science Foundation
NSC	National Science Council Canada
NVSS	NRAO Very Large Array Sky Survey
NWNH	New Worlds, New Horizons
OCA	Office of Chilean Affairs
OMT	OrthoMode Transducer
OPT	Observation Preparation Tool
OSF	Operations Support Facility

APPENDIX F: ACRONYMS

Acronym	Definition
PAF	Phased Array Feed
PAPER	Precision Array for Probing the Epoch of Reionization
pc	parsec
PHT	Proposal Handling Tool
PI	Principal Investigator
PIC	Phasing Interface Cards
PROMPT	Panchromatic Robotic Optical Monitoring and Polarimetry Telescopes
PST	Proposal Submission Tool
QSO	Quasi-Stellar Objects
QTT	Qitai Radio Telescope
RAOP	Radio Astronomy Observing Program
REU	Research Experiences for Undergraduates
RFI	Radio-Frequency Interference
RISC	RadioAstron International Sciences Council
rms	root mean square
RSRO	Resident Shared Risk Observing
SALT	South African Large Telescope
SAO	Smithsonian Astrophysical Observatory
SCO	Santiago Central Office
SETI	Search for Extraterrestrial Intelligence
SFM	Star Formation
SFR	Star Formation Rate
SHAO	Shanghai Astronomical Observatory
SIS	Superconductor–Insulator–Superconductor
SJS	Skynet Jr. Scholars
SKA	Square Kilometre Array
SMG	Submillimeter Galaxy
SNAP	Smart Networked ADC Processor
SOS	Student Observing Support
SRO	Shared Risk Observing
SRP	Science Review Panel
SSG	Science Survey Group
SSP	Solar System, Stars & Planetary Systems
SSR	Science Support and Research
STARGATE	Spacecraft Tracking and Astrophysical Research Into Gigahertz Astronomical Transient Emission
STEM	Science, Technology, Engineering, and Mathematics
STScI	Space Telescope Science Institute
SUS	Science User Support
TAC	Time Allocation Committee
TADPOL	Telescope Array Doing Polarization
THz	TeraHertz
TSG	Telescope Support Group
TTA	Telescope Time Allocation
UBC	University of British Columbia
UCLA	University of California, Los Angeles
UNM	University of New Mexico
US, USA	United States of America
USNO	United States Naval Observatory
UTRGV	University of Texas - Rio Grande Valley
UVML	University of Virginia Microfabrication Laboratory
VA	Virginia
VEGAS	Versatile Green Bank Astronomical Spectrometer
VERA	VLBI Exploration of Radio Astronomy
VLA	Very Large Array
VLASS	Very Large Array Sky Survey
VLBA	Very Long Baseline Array
VLBI	Very Long Baseline Interferometry
VLITE	VLA Ionospheric and Transient Experiment
WIDAR	Wideband Interferometric Digital Architecture Correlator
WMAP	Wilkinson Microwave Anisotropy Probe
WV	West Virginia
WV SPOT	West Virginia Space Public Outreach Team
WVU	West Virginia University
XAO	Xinjiang Astronomical Observatory

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