2012 ANNUAL REPORT

NRAO

NATIONAL RADIO ASTRONOMY OBSERVATORY

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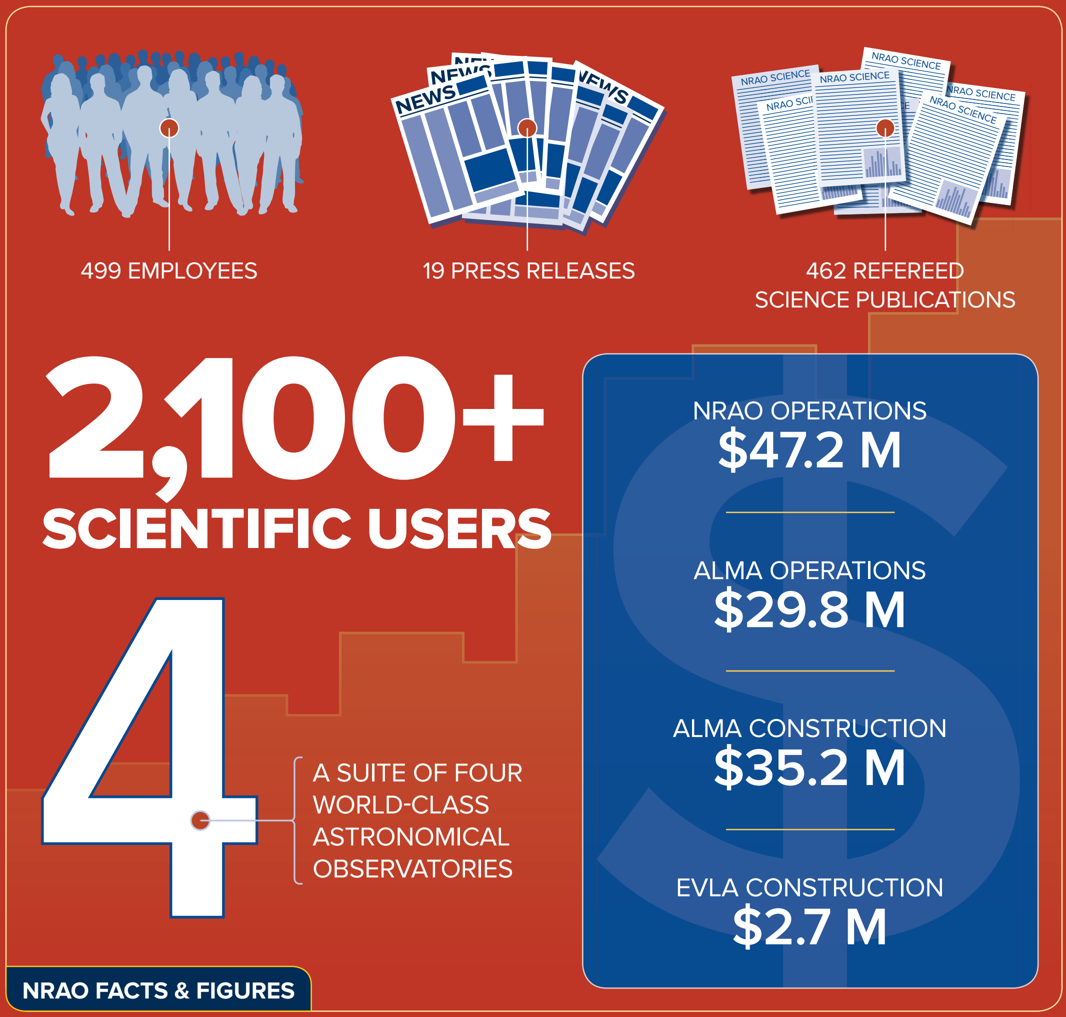
Associated Universities, Inc.

NSF



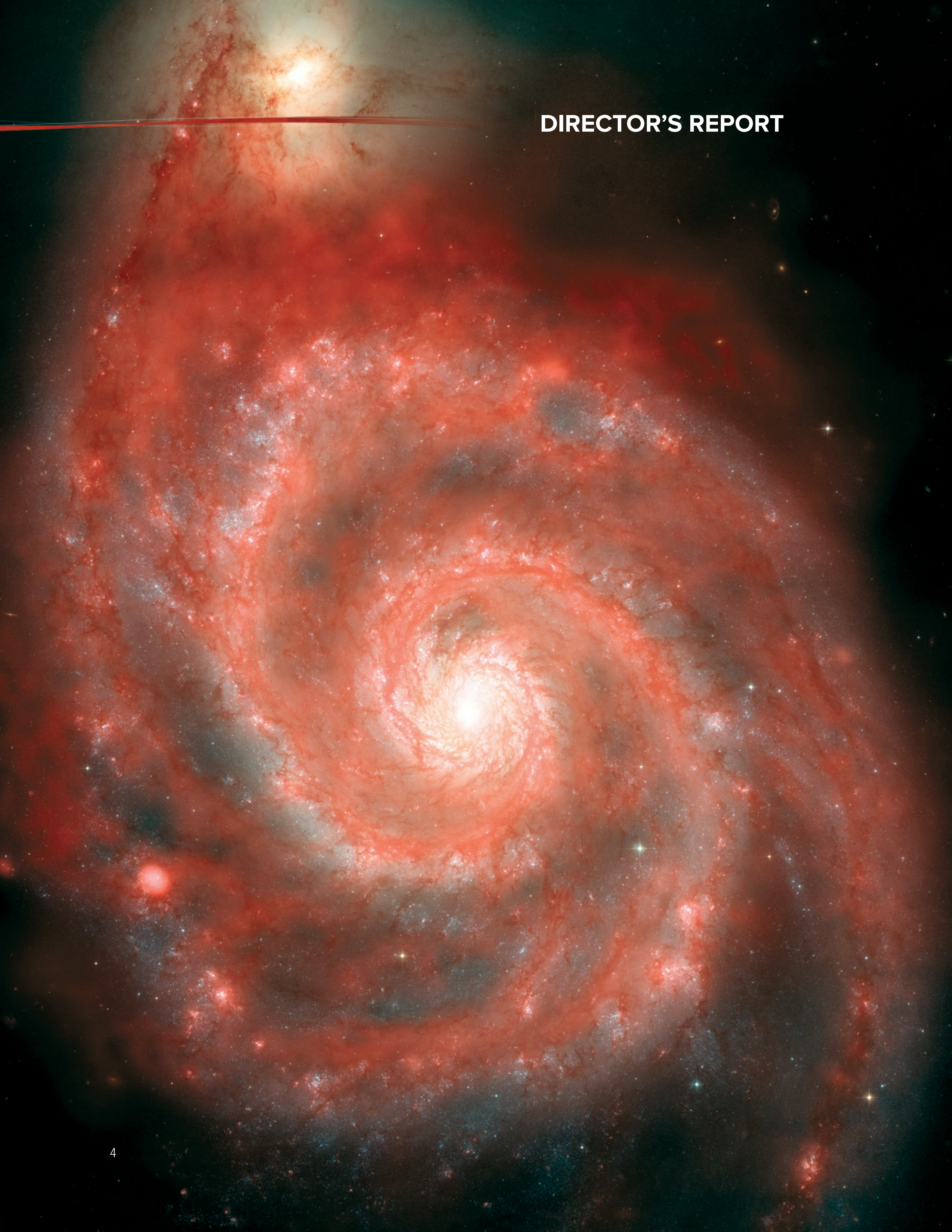
COVER: *The spectacular jets (pink) in this composite radio-visible wavelength image are powered by the gravitational energy of a 2.5-billion-solar-mass black hole located in the core of the elliptical galaxy Hercules A (center), and illustrate the combined imaging power of the recently upgraded NRAO Karl G. Jansky Very Large Array (VLA) and the NASA Hubble Space Telescope (HST). Some two billion light-years away, Hercules A appears ordinary in the visible light seen by HST. But this innocuous-looking galaxy, also known as 3C 348, is the brightest radio-emitting object in the constellation Hercules and one of the brightest extragalactic radio sources in the entire sky.*

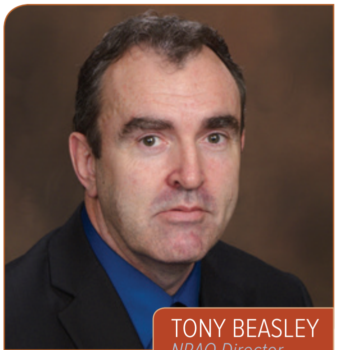
The enormous, optically invisible jets seen in the VLA image span one-and-a-half million light-years and dwarf the visible galaxy from which they emerge. The jets are high-energy plasma beams, subatomic particles and magnetic fields shot at nearly the speed of light from the vicinity of the supermassive black hole. The outer portions of both jets show unusual ring-like structures suggesting a history of multiple outbursts from the black hole. The innermost parts of the jets are not visible because of the extreme velocity of the material: relativistic effects confine all the light to a narrow cone aligned with the jets.

RIGHT: *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. Under construction 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.*

CONTENTS

DIRECTOR'S REPORT





TONY BEASLEY
NRAO Director

I am honored to have been selected as Director of NRAO, and thank Associated Universities, Inc. (AUI) and the National Science Foundation (NSF) for the opportunity to lead the Observatory. This role is both a privilege and a great responsibility, and I look forward to the challenges ahead.

On behalf of the entire astronomy community, I would like to thank my predecessor, Fred K.Y. Lo, for his leadership and recognize the many impressive accomplishments of his decade as NRAO Director. His emphasis on engaging the university community and enabling world-class science for the benefit of the broad astronomy community was prescient and unwavering.

This is both an exciting and challenging era for astronomy. Through the efforts of the Observatory's excellent staff, the NRAO is the preeminent radio astronomy organization in the world. NRAO research facilities and laboratories serve a large fraction of the astronomy community – university faculty, postdocs, graduate and undergraduate students – and deliver added benefits to the public via the Observatory's vigorous education and outreach programs.

NRAO's role in the U.S. and global scientific and technical communities is vital, and each of our research facilities is opening new frontiers and discovery space. The Early Science results from the Atacama Large Millimeter/submillimeter Array are extremely exciting to the community, including many who are new to radio-wavelength observing. The Very Large Array upgrade project will be complete in January 2013, enabling the array to transition to full science operations, and the Green Bank Telescope and the Very Long Baseline Array are engaged in an impressive range of world-class science. The future of our community is the domain of the NRAO Central Development Lab, a national treasure whose staff is conducting research and development that is key to realizing next-generation facilities.

AUI provides the oversight and management skills necessary to ensure the success of these challenging enterprises while maintaining the scientific focus desired by the astronomy community. The active, engaged AUI Board of Trustees is rooted in the research community and vital to our success.

There are, however, significant uncertainties in our present and future. The struggling U.S. and world economies, and the shifting politics here and abroad, will continue to impact science funding for several years. The implementation plan being developed by the NSF – Division of Astronomical Sciences for the Portfolio Review recommendations will also yield challenges. Budget constraints are already forcing difficult decisions about Observatory operations and user community support priorities.

We are, of course, responding to these challenges as constructively as possible, improving efficiency while continuing to deliver strong performance. We focus on making every NRAO research facility a success for our users. The Observatory continues to adapt and evolve, guided by the community's priorities and interests. We are strategically strengthening our technical development program, nurturing the Central Development Lab, and collaborating with universities and industry to realize important new capabilities. We are working daily to improve the user experience, for example, with the Proposal Submission Tool, the Common Astronomy Software Applications package, and the NRAO Archive. We also remain strongly committed to serving the tax-paying public via our outreach and Science, Technology, Engineering, and Mathematics (STEM) education programs.

I am certainly pleased to be back at NRAO, engaged in the Observatory's mission, and privileged to be leading an extraordinary team of professionals who are dedicated to scientific adventure and discovery.

Anthony (Tony) J. Beasley was appointed as NRAO Director by the AUI Board of Trustees effective 21 May 2012. Prior to his arrival at NRAO, Beasley served as the Chief Operating Officer and Project Manager of the NSF-funded National Ecological Observatory Network (NEON), a continental-scale ecological observatory designed to detect ecological change and enable forecasting of its impacts. After receiving his Bachelor's in Physics in 1986 and his Doctorate in Astrophysics in 1991 from the University of Sydney, Beasley joined NRAO as a Postdoctoral Fellow in 1991. He was appointed as a Deputy Assistant Director in 1997, and served as Assistant Director from 1998 to 2000. In 2000, he left NRAO to become Project Manager for the Combined Array for Research in Millimeter-wave Astronomy. In 2004, he returned to NRAO as an Assistant Director and Project Manager for the Atacama Large Millimeter/submillimeter Array in Chile. Beasley joined NEON in 2008.

Created in 1956 by the National Science Foundation (NSF) and Associated Universities, Inc. (AUI), the National Radio Astronomy Observatory (NRAO) designs, builds, and operates the most capable astronomical telescopes and instruments at radio wavelengths. In 2012, 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 was demonstrated by the 9:1 oversubscription for observing time.

At the adjacent centimeter-wavelength range, the updated Jansky VLA has scientific capabilities 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. Early Science observations continued through 2012 as this major upgrade program continued, yielding dramatic new science results that ranged from Galactic protostellar clouds to the molecular gas in early galaxies. As 2013 opened, the Jansky VLA transitioned to full science operation as the world's most capable and versatile centimeter-wave imaging array.

With comparable collecting area and sensitivity to ALMA and the 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 (HI) emission via the innovative Intensity Mapping technique.

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.

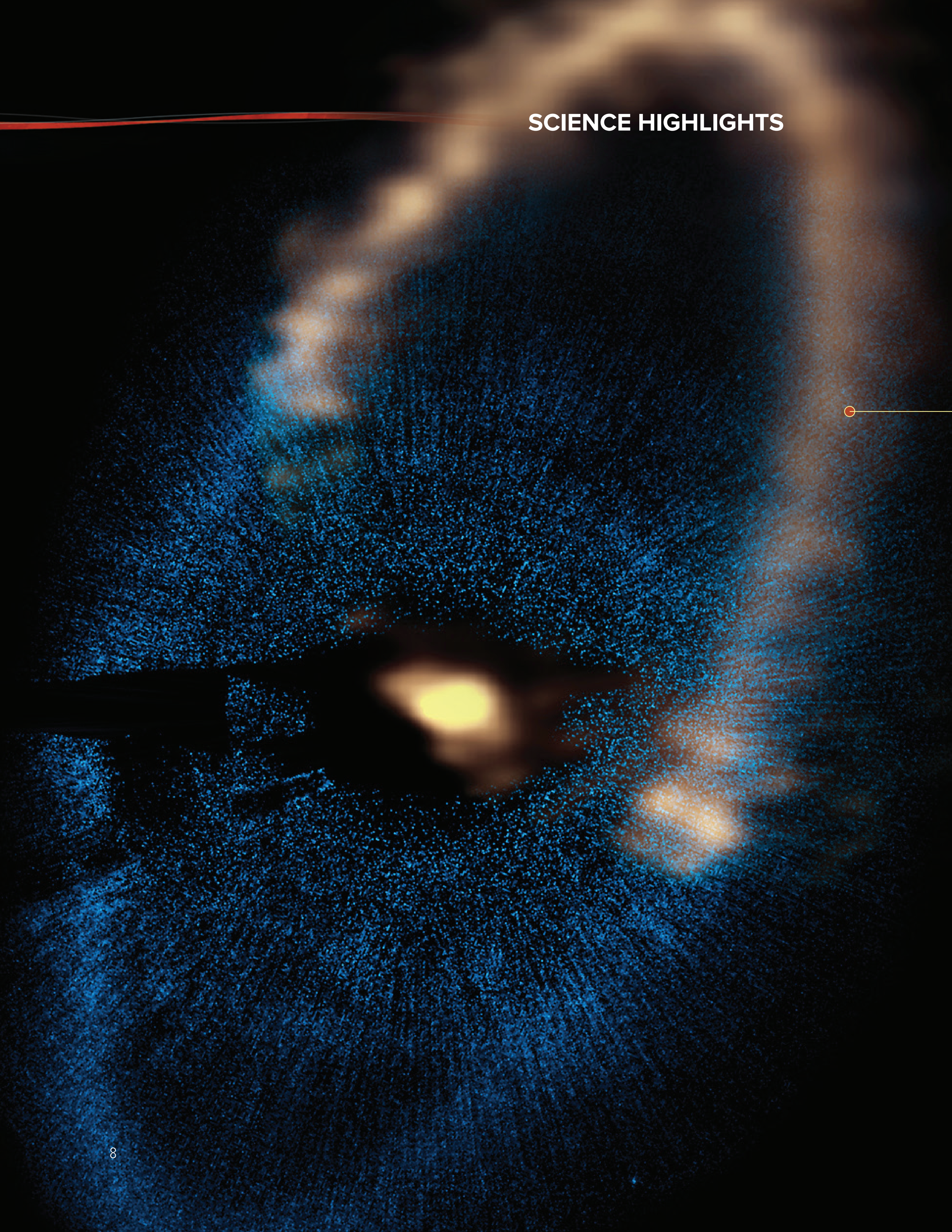
The Central Development Laboratory (CDL) conducts the crucial research and development that continually improves operational NRAO telescopes and helps realize next generation facilities. CDL oversees a science-driven research and development program that supports the astronomy community's highest priority 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 2012 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; the expansion rate of the Universe; and much more.

In addition to research, the NRAO broadly impacts science and society via its education and public outreach programs. For example, the Observatory's 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.



The Fomalhaut Debris & Planetary System

The Fomalhaut debris system surrounding the bright, nearby star Fomalhaut is a natural laboratory for testing planet formation theories. The eccentric debris ring has a semi-major axis of ~140 AU. The inner edge is sharply truncated, which, along with the ring's eccentricity, suggests that a planet is shaping the ring's morphology. Optical images trace micron-sized grains, which are strongly affected by stellar radiation and need not coincide with their parent body population. Observations of millimeter-size grains accurately trace parent bodies, though previous images have lacked the resolution and sensitivity needed to characterize the ring's morphology. Boley et al. acquired observations of the Fomalhaut debris ring using 13 – 15 ALMA antennas and the 350 GHz receivers during Cycle 0 Early Science. Their remarkable data demonstrate that the parent body population is 13-19 AU wide with a sharp inner and outer boundary and that debris confined by shepherd planets is the explanation most consistent with the ring's morphology.

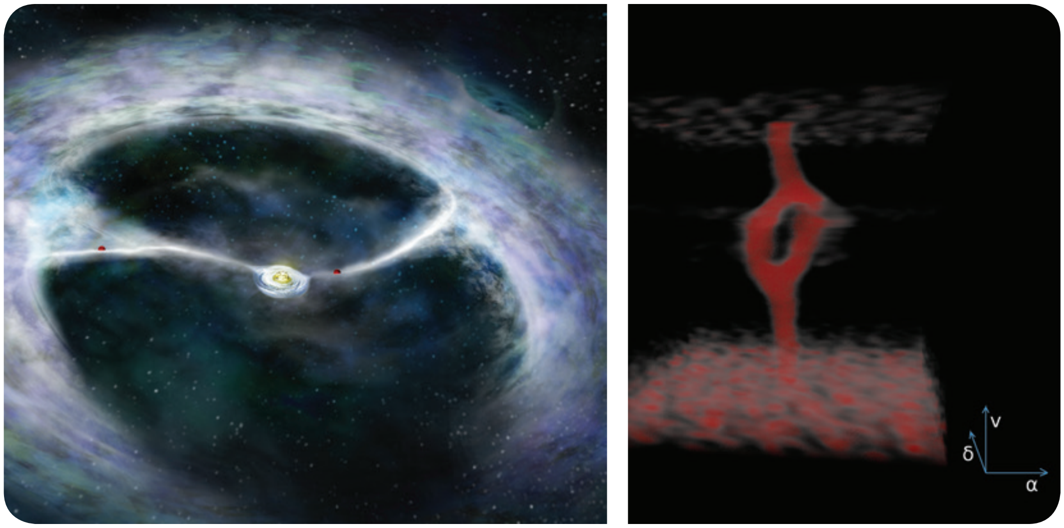
[Left page] *The narrow dust ring around Fomalhaut. [Yellow] ALMA data. [Blue] Hubble Space Telescope data. The star is at the location of the bright emission at ring center. Credit: A.C. Boley (Florida, Sagan Fellow), M.J. Payne, E.B. Ford, M. Shabran (Florida), S. Corder (NRAO-NAASC and W. Dent (JAO), NRAO/AUI/NSF; NASA, ESA, P. Kalas, J. Graham, E. Chiang, E. Kite (UC, Berkeley), M. Clampin (NASA GSFC), M. Fitzgerald (LLNL), and K. Stapelfeldt and J. Krist (NASA JPL).* **[Right]** *The ALMA Array Operations Site in northern Chile.*

Science Team: A.C. Boley (Florida, Sagan Fellow), M.J. Payne (Florida), S. Corder (NRAO-NAASC), W. Dent (JAO), E.B. Ford (Florida), and M. Shabram (Florida).

Publication: *Constraining the Planetary System of Fomalhaut Using High-resolution ALMA Observations,* Astrophysical Journal Letters, 750, L21 (1 May 2012).

Gas Flows through a Protoplanetary Gap

Previous infrared observations of the protoplanetary disk around the young and relatively nearby star HD142527 found an inner disk about 10 Astronomical Units (AU) in radius, surrounded by a large gap and a disrupted outer disk at 140+ AU. This disruption indicates an unseen planetary mass at ~90 AU. Cassasus et al. have used the excellent sensitivity and spatial resolution of ALMA to image dense gas in gap-crossing filaments, along with diffuse CO within the gap. These ALMA data explain how the observed high accretion rate – 7×10^{-9} to 2×10^{-7} solar masses per year – may be maintained, and support dynamical models that suggest the outer disk gas could be channeled by putative protoplanets through gap-crossing bridges feeding the inner disk.



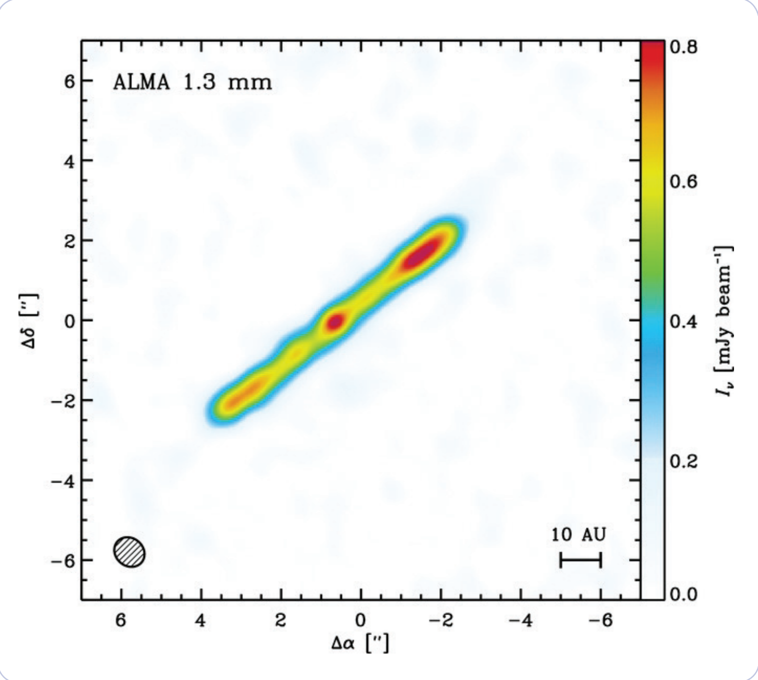
[Left] *Artist's concept of the HD142527 system.* **[Right]** *A 3D view of the HD142527 ALMA Band 7 dataset illustrates the emission distribution on the sky (α ~ right ascension, δ ~ declination) and in velocity-frequency space (vertical axis), enabling detailed study of the gas filament dynamics for this interesting planet-forming system. Data visualizations such as these provide astronomers new tools to explore the phase space of their results and mine their data.*

Science Team: Simon Casassus (Chile), Gerrit van der Plas (Chile), Sebastian Perez M. (Univ Chile), William R. F. Dent (Joint ALMA Observatory, ESO), Ed Fomalont (NRAO), Janis Hagelberg (Chemin des Maillettes), Antonio Hales (Joint ALMA Observatory, NRAO), Andres Jordan (Univ Catolica de Chile), Dimitri Mawet (ESO), Francois Menard (CNRS, Chile), Al Wootten (NRAO), David Wilner (Harvard-Smithsonian Center for Astrophysics), A. Meredith Hughes (UC-Berkeley), Matthias R. Schreiber (Valparaiso), Julien H. Girard (ESO), Barbara Ercolano (Ludwig-Maximillians), Hector Canovas (Valparaiso), Pablo E. Roman (Chile), and Vachail Salinas (Chile)

Publication: *Flows of Gas Through a Protoplanetary Gap*, Nature, 493, 191 (10 January 2013).

The Young Solar System Analog Disk Around AU Mic

MacGregor et al. analyzed 1.3mm ALMA Cycle 0 Early Science observations of the edge-on debris disk around the relatively nearby late-type star AU Mic. Their data reveal two distinct debris emission components: (1) the previously known dust belt that extends to a radius of 40 AU, and (2) a newly recognized, unresolved central peak. The central peak is ~6X brighter than the stellar photosphere. The authors suggest this peak may be dominated by dust emission from an inner planetesimal belt, which is consistent with a lack of emission at $\lambda < 25$ μm and a location less than 3 AU from the star. The cold, outer dust belt appears truncated, reminiscent of a classic Kuiper Belt. The origins of the sharp edge could be from dynamical interactions or may simply represent the initial conditions. These ALMA data show no evidence for asymmetries or substructure that would indicate planet-disk interactions, though the measurement limit of the centroid offset between the outer belt and central peak is still compatible with the presence of a Uranus-like planet.



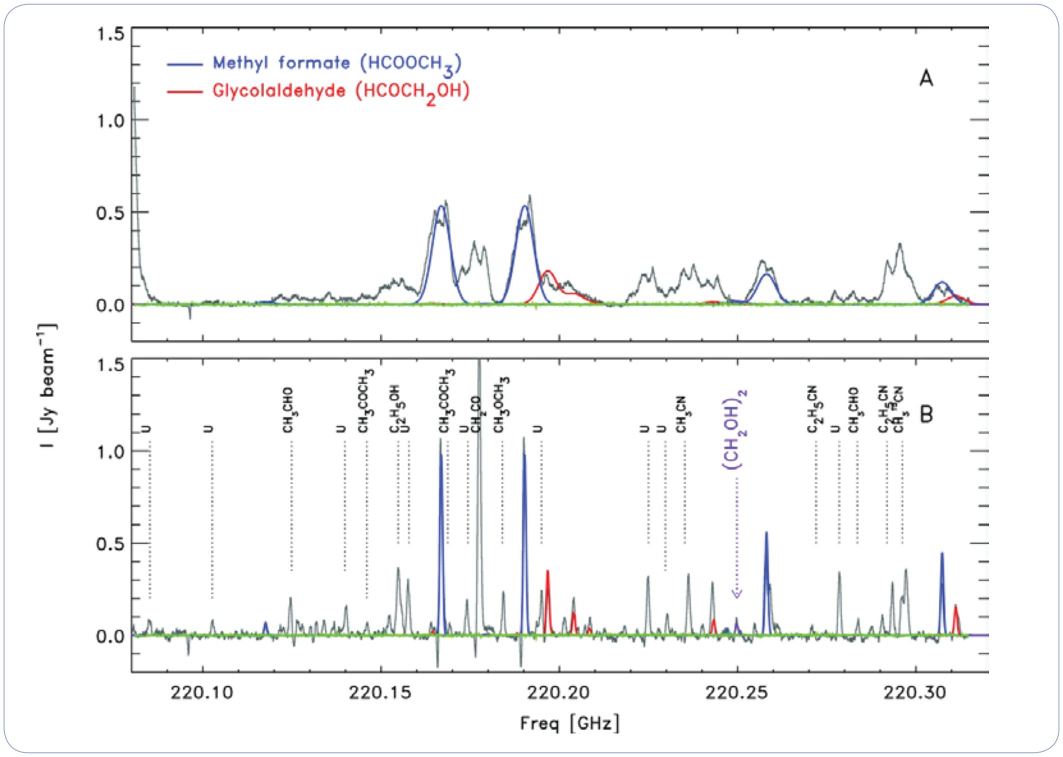
ALMA 1.3 mm continuum emission from AU Mic. The ellipse (lower left) shows the 0.80 × 0.69 arcsec (8 × 7 AU) synthesized beam.

Science Team: Meredith A. MacGregor (Harvard-Smithsonian Center for Astrophysics), David J. Wilner (Harvard-Smithsonian Center for Astrophysics), Katherine A. Rosenfeld (Harvard-Smithsonian Center for Astrophysics), Sean M. Andrews (Harvard-Smithsonian Center for Astrophysics), Brenda Matthews (Herzberg Institute of Astrophysics), A. Meredith Hughes (UC Berkeley), Mark Booth (Herzberg Institute of Astrophysics, Victoria), Eugene Chiang (UC Berkeley), James R. Graham (UC Berkeley, Toronto), Paul Kalas (UC-Berkeley, SETI), Grant Kennedy (Cambridge), and Bruce Sibthorpe (Space Research Organization Netherlands).

Publication: *Millimeter Emission Structure in the First ALMA Image of the AU Mic Debris Disk*, Astrophysical Journal Letters, 762, L21 (10 January 2013).

Detection of Sugars around a Proto-star

Glycolaldehyde ($HCOCH_2OH$) is the simplest sugar and an important intermediate in the path toward forming more complex biologically relevant molecules and understanding their full chemistry. Joergensen et al. present the first detection of 13 transitions of the sugar glycolaldehyde around a solar-type young star, using ALMA observations of the protostellar binary star system IRAS 16293-2422 at 220 GHz and 690 GHz. The glycolaldehyde spectral lines have their origin in warm (200-300 K) gas close to the individual components of the binary. These data also show a tentative detection of ethylene glycol, the reduced alcohol of glycolaldehyde.



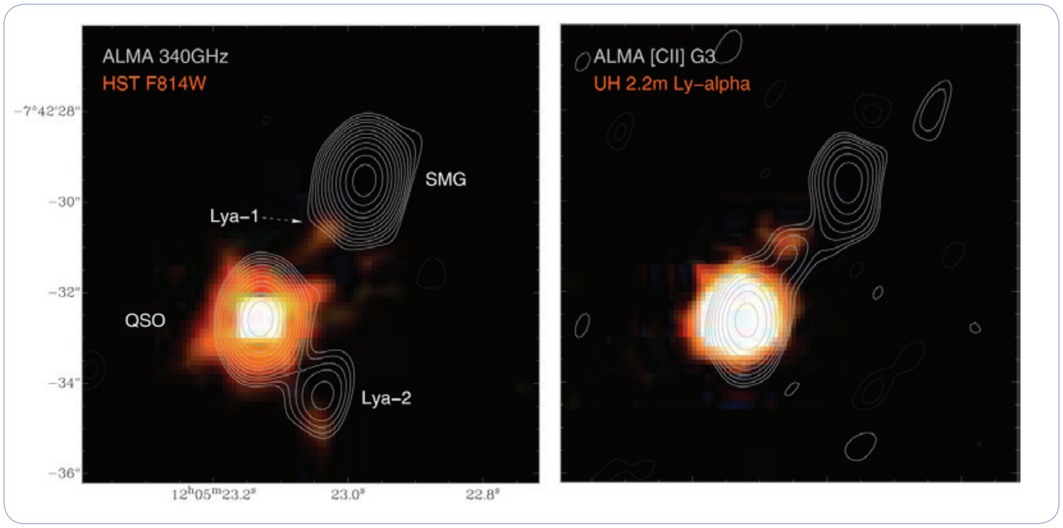
Spectra toward IRAS 16293A (upper) and IRAS 16293B (lower). Model fits of the methyl formate (blue) and glycolaldehyde (red) emission are indicated. The purple line indicates the model fit to the possible ethylene glycol transition. The x-axis represents the frequencies in the system's rest frame. The green line is an indication of the rms level (13 mJy/beam). The narrower lines toward IRAS 16293B enable easier identification of individual spectral lines.

Science Team: Jes K. Jørgensen (Copenhagen), Cécile Favre (Aarhus), Suzanne E. Bisschop (Copenhagen), Tyler L. Bourke (Harvard-Smithsonsian Center for Astrophysics), Ewine F. van Dishoeck (Leiden, Max-Planck-Institut für Extraterrestrische Physik), and Markus Schmalzl (Leiden).

Publication: *Detection of the Simplest Sugar, Glycoaldehyde, in a Solar-type Protostar with ALMA,* Astrophysical Journal Letters, 757, L4 (20 September 2012).

Anatomy of an Extreme Starburst in the Early Universe

Carilli et al. acquired ALMA Cycle 0 Early Science observations and analyzed the [C II] 158 μm fine structure line and thermal dust continuum emission from the archetype extreme starburst/active galactic nucleus (AGN) group of galaxies in the early Universe, BRI 1202–0725 at $z = 4.7$. The group has long been noted for having a closely separated (26 kpc in projection) far infrared-hyperluminous quasar host galaxy and an optically obscured submillimeter galaxy (SMG). This paper examines in detail the ALMA imaging results and describes [C II] emission detections from two Lyα-selected galaxies, demonstrating the relative ease with which ALMA can detect the [C II] emission from lower star formation rate galaxies at high redshift. Imaging of the [C II] emission shows a clear velocity gradient across the SMG, possibly indicating rotation or a more complex dynamical system on a scale ~10 kiloparsecs. There is also evidence in the quasar spectrum and images for a possible outflow toward the southwest, as well as more extended emission between the quasar and the SMG. These results provide an unprecedented view of a major merger of gas-rich galaxies driving extreme starbursts and AGN accretion during the formation of massive galaxies and supermassive black holes within 1.3 Gyr of the Big Bang.



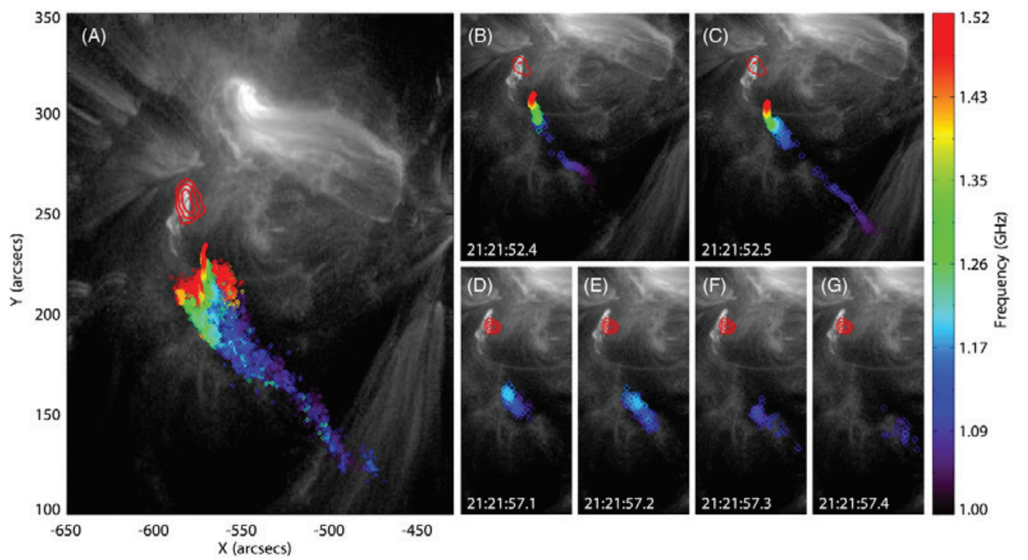
[Left] *Contours show the submillimeter continuum emission from BRI 1202-0725 at 340 GHz at 1.2 × 0.8 arcsec resolution. The rms noise is 0.1 mJy/beam. The color shows a Hubble Space Telescope image from Hu et al. (1996 ApJL, 459, 53). The SMG, quasar, Lyα-1, and Lyα-2 are indicated.* **[Right]** *The integrated [C II] emission in the velocity range 0 to 130 km/s. The color is the Lyα narrowband image from Hu et al. (1996).*

Science Team: C.L. Carilli (NRAO), D. Riechers (Caltech), F. Walter (MPIfA), R. Maiolino (Cavendish Lab), J. Wagg (ESO), L. Lentati (Cavendish Lab), R. McMahon (Univ. Cambridge), A. Wolfe (UCSD).

Publication: *The Anatomy of an Extreme Starburst within 1.3 Gyr of the Big Bang Revealed by ALMA*, Astrophysical Journal, 763, 120 (1 February 2013).

Imaging Magnetic Reconnection on the Sun

Type III radio bursts from the Sun correspond to thermal electron beams propagating in the low corona. The Jansky VLA recently imaged these bursts on timescales ~100 ms. The beams emanate from an energy release site located in the low corona and propagate along a bundle of discrete magnetic loops upward into the corona. The diameter of these loops is less than 100 km. These over-dense and ultra-thin loops reveal the fibrous structure of the Sun's corona. The localized energy release is highly fragmentary in time and space, supporting a bursty reconnection model that involves secondary magnetic structures for magnetic energy release and particle acceleration.



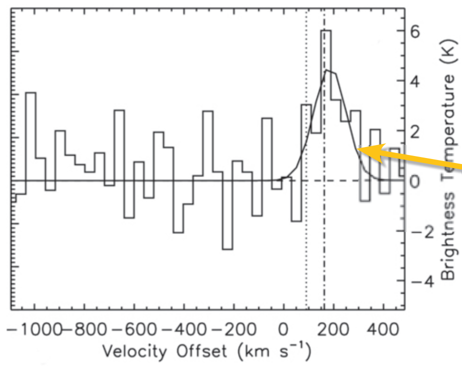
(A) Emission centroids of all type IIIdm bursts observed from 21:20:30 to 21:22:10 UT, colored from blue to red in increasing frequencies, showing electron beam trajectories in projection. Background is the Solar Dynamic Observatory/AIA 131 Å image at 21:22:09 UT. Red contours are the 12 s integrated 12–25 kilo-electron-volt hard X-ray (keV HXR) emission during the second HXR peak (around 21:21:50 UT). Emission centroids of a temporally resolved type IIIdm burst observed from 21:21:52.4 to 21:21:52.6 UT are shown by (B–C) for two successive 100 ms integrations. Another temporally resolved type IIIdm burst from 21:21:57.1 to 21:21:57.5 UT is shown by (D–G) for four successive 100 ms integrations. Red contours are the 12–25 keV HXR source with a 4 s integration closest to the type-IIIdm-burst times.

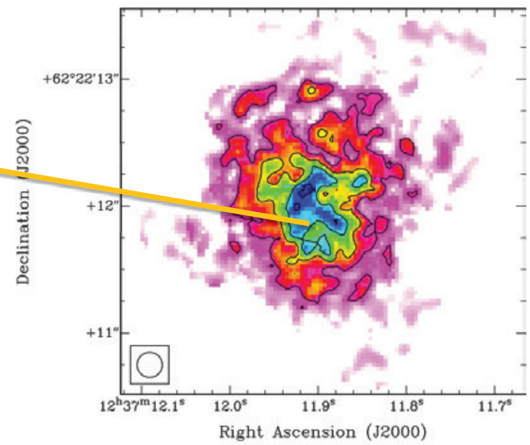
Science Team: Bin Chen (Virginia), T.S. Bastian (NRAO), S.M. Shite (Air Force Research Lab), D.E. Gary (NJ Institute of Technology), R. Perley (NRAO), M. Rupen (NRAO), and B. Carlson (NRC-Canada).

Publication: *Tracing Electron Beams in the Sun's Corona with Radio Dynamic Imaging Spectroscopy,* Astrophysical Journal Letters, 763, L21. (20 January 2013).

Imaging Gas Disks in Early Galaxies

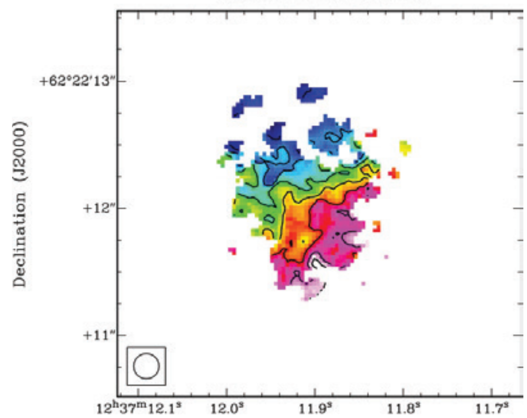
The Jansky Very Large Array has imaged the molecular disk of a galaxy within 1.6 Gyr of the Big Bang at ~ 1 kiloparsec resolution in the hyper-starburst galaxy GN20 (z = 4.0). These observations reveal a rotating disk of molecular gas on a scale of 14 kiloparsec, with a dynamical mass ~5x10[11] $M_{\odot}$. The disk is comprised of massive molecular clumps that are possibly self-gravitating. The gas distribution and dynamics is consistent with a disk formed via cold mode accretion from the intergalactic medium driving the extreme starburst.





[Above] *CO(2-1) spectrum for a GN20 molecular gas clump. The dot-dashed line shows the observed coherent velocity at this clump position; the dotted line shows the model coherent velocity.*

[Above right] *CO(2-1) integrated intensity and* **[bottom right]** *intensity-weighted mean velocity maps for GN20 at a resolution of 0."19. The intensity contours start at, and are in steps of, 15.5 mJy km s^{-1}. The velocity contours are in steps of 100 km s^{-1}, with the contour between the green and orange bands representing the systemic velocity. Positive velocity offsets occur in the south and are shown in shades of orange and pink.*

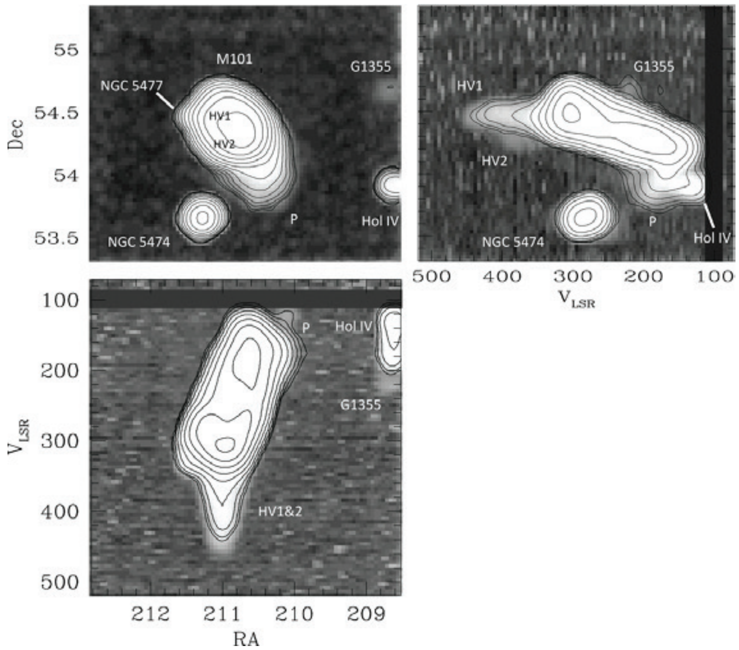


Science Team: J.A. Hodge (MPIfA), C.L. Carilli (NRAO, Cavenish Lab), F. Walter (MPIfA, NRAO), W.J.G. de Blok (ASTRON, Cape Town), D. Riechers (Caltech), E. Daddi (CEA), and L. Lentati (Cavendish).

Publication: *Evidence for a Clumpy, Rotating Gas Disk in a Submillimeter Galaxy at z = 4*, Astrophysical Journal, 760, 11 (20 November 2012).

The Neutral Hydrogen Environment of the M101 Galaxy Group

Mihos et al. used the Green Bank Telescope (GBT) to create a wide field, deep neutral hydrogen (HI) map of the M101 galaxy group. They identified two new HI sources in the group environment, one an extremely low surface brightness, hitherto unknown, dwarf galaxy; the other a starless HI cloud, possibly primordial. Their GBT data show the extended M101 H I envelope is a ~100 kpc tidal loop or HI plume with a mass of ~$10^8 M_\odot$ and a peak column density of N(HI) = 5 x 10^{17} cm^{-2}. While it rotates with the main body of M101, the envelope shows kinematic peculiarities suggestive of a warp or flaring out of the galaxy's rotation plane. The authors also found two new HI clouds near the plume with masses ~$10^7 M_\odot$, likely also tidal in nature. Neither the M101 plume nor the clouds have any extended optical counterparts. They also trace HI at intermediate velocities between M101 and NGC 5474, strengthening the case for a recent interaction between the two galaxies. The kinematically complex HI structure in the M101 group, coupled with the optical morphology of M101 and its companions, suggests that the group is in a dynamically active state.



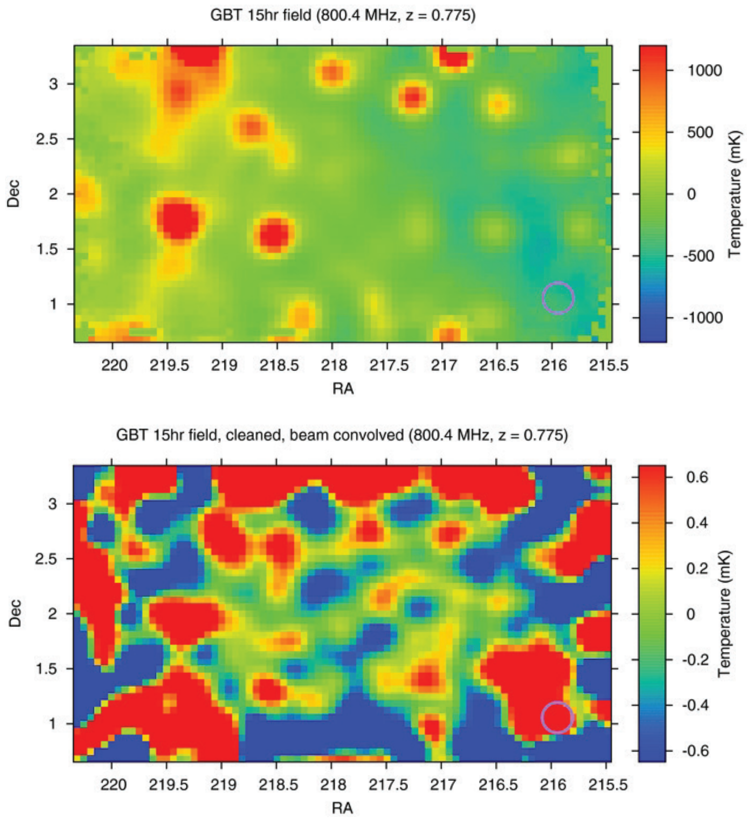
Projected views of the inner, high-sensitivity portion of the M101 data cube. To best highlight diffuse features, peak flux, rather than integrated flux, is plotted along each projected axis. **[Top left]** *HI intensity map. Column density contours are log (NHI) = 18 to 20.5 in steps of 0.25.* **[Top right]** *Declination versus VLSR.* **[Bottom left]** *VLSR versus right ascension. Position-velocity contours run logarithmically from 0.1 to 50 Jy beam–1. The bright bands near VLSR = 100 are channels corrupted by narrowband radio frequency interference. "HV1" and "HV2" refer to high-velocity clouds first identified by van der Hulst & Sancisi (1988, Astronomical Journal, 95, 1354); "P" refers to the southwest HI plume.*

Science Team: J. Christopher Mihos (Case Western), Katie M. Keating (Rincon Research), Kelly Holley-Bockelmann (Vanderbilt, Fisk), D.J. Pisano (WVU), and Namir E. Kassim (NRL)

Publication: *The HI Environment of the M101 Group,* Astrophysical Journal, 761, 186 (20 December 2012).

Neutral Hydrogen Intensity Mapping

Masui et al. present Green Bank Telescope neutral hydrogen (HI) intensity mapping in the range $0.6 < z < 1$, over two fields totaling ~ 41 square degress in the WiggleZ Dark Energy Survey area. These images represent the integrated HI surface brightness of thousands of galaxies over large cosmic volumes. The cross-correlation with the smoothed optical spectroscopic data shows a clear correlation, indicating HI signal on degree-scales. The HI intensity is consistent with optical quasar absorption line measurements for the evolution of the cosmic HI mass density.



Maps of the GBT 15 hour field at approximately the band-center. The purple circle is the FWHM of the GBT beam, and the color range saturates in some places in each map. **[Left]** *The raw map, dominated by synchrotron emission from extragalactic point sources and smoother emission from the galaxy.* **[Below]** *The raw map with 20 foreground modes removed per line of sight. The map edges have visibly higher noise or missing data due to sparse scanning coverage. The cleaned map is dominated by thermal noise.*

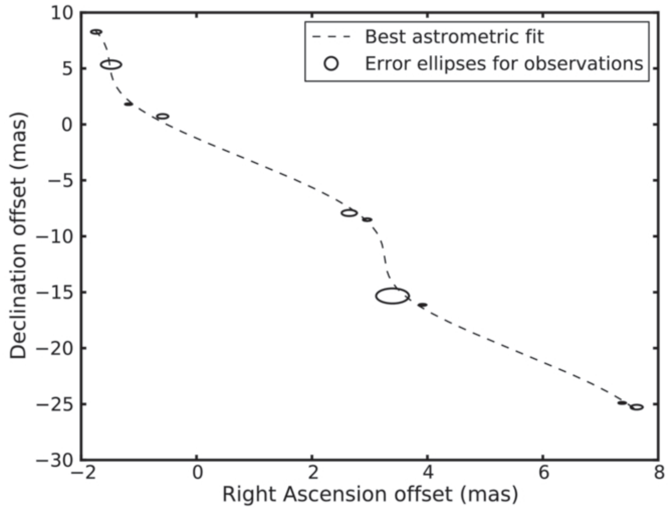
Science Team: K. W. Masui (CITA), E. R. Switzer (CITA, Chicago), N. Banavar (Toronto), K. Bandura (McGill), C. Blake (Swinburne), L.-M. Calini (CITA), T.-C. Chang (ASIAA), X. Chen (National Astronomical Observatories, Chinese Academy of Science; Peking), Y.-C. Li (National Astronomical Observatories, Chinese Academy of Science), Y.-W. Liao (ASIAA), A. Natarajan (Carnegie Mellon), U.-L. Pen (CITA), J. B. Peterson (Carnegie Mellon), J. R. Shaw (CITA), T. C. Voytek (Carnegie Mellon).

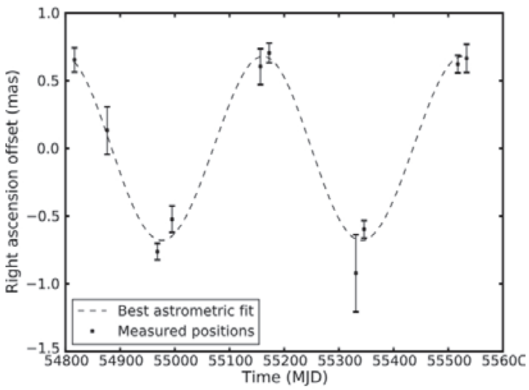
Publication: *Measurement of 21 cm Brightness Flucturations at z ~ 0.8 in Cross-correlation*, Astrophysical Journal Letters, 763, L20 (20 January 2013).

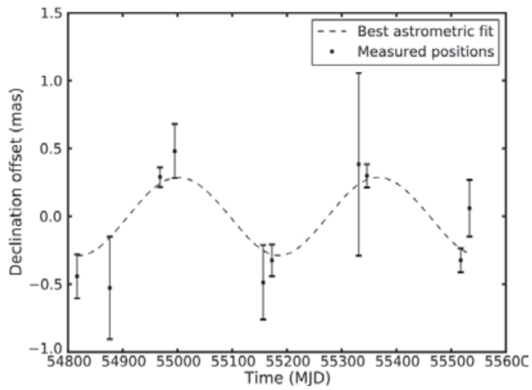
An Accurate Distance and Mass for a Transitional Millisecond Pulsar

Deller et al. use the Very Long Baseline Array to measure a direct parallactic distance to the transitional millisecond pulsar J1023+0038. Variable X-ray emission from this system indicates it is in the crucial, short-lived evolutionary phase of mass transfer from the stellar companion that leads to the high spin-up of the neutral star to generate a millisecond pulsar. From the parallax (0.731 ± 0.022 milli-arcsecond) and proper motion (17.98 ± 0.05 milli-arcsecond/yr), and using previous optical observations, a distance of 1368 parsecs (+42, -39 parsecs), a neutron star mass of 1.71 ± 0.16$M_\odot$, and a 3D space velocity of 126 ± 5 km/s are derived.

Astrometric fits to the J1023+0038 very long baseline interferometry data of Deller et al. **[Right]** *Motion relative to the reference position over the two years of observations, with the best fit shown by the dashed line.* **[Below]** *The parallax signature in right ascension (proper motion subtracted).* **[Below Right]** *The parallax signature in declination (proper motion subtracted).*





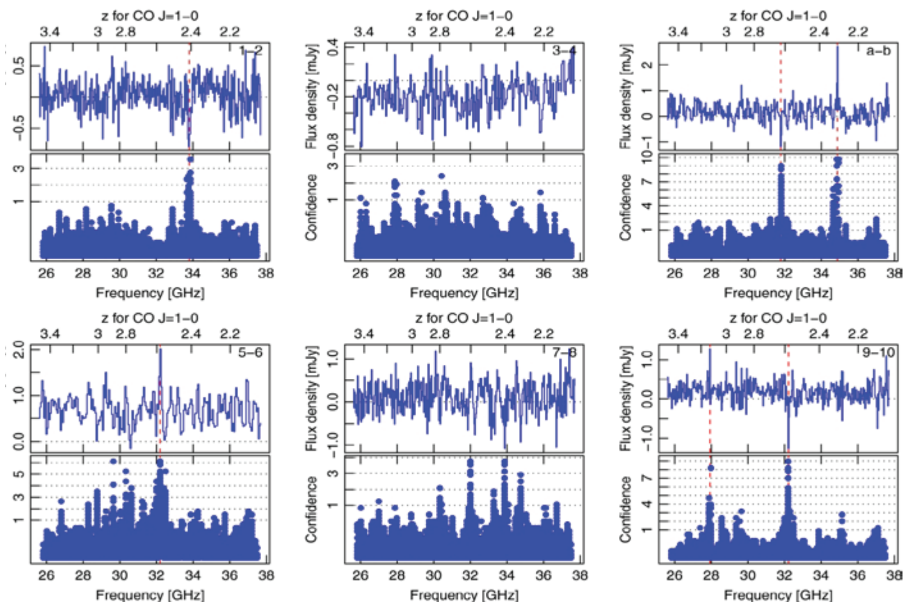


Science Team: A. T. Deller (ASTRON), A. M. Archibald (McGill), W. F. Brisken (NRAO), S. Chatterjee (Cornell), G. H. Janssen (Jodrell Bank), V. M. Kaspi (McGill), D. Lorimer (West Virginia), A. G. Lyne (Jodrell Bank), M. A. McLaughlin (West Virginia), S. Ransom (NRAO), I. H. Stairs (British Columbia), and B. Stappers (Jodrell Bank).

Publication: *A Parallax Distance and Mass Estimate for the Transitional Millisecond Pulsar System J1023+0038*, Astrophysical Journal Letters, 756, L25 (10 September 2012).

Blind Detections of CO in Distant Galaxies

The Herschel Space Observatory has identified large samples of gravitationally lensed, very dusty, far-infrared luminous star-forming galaxies, but optical redshifts are difficult to obtain for these objects owing to dust obscuration. The Zpectrometer ultra-wide bandwidth spectrometer on the 100-meter diameter Green Bank Telescope has become a powerful tool to measure these redshifts and study molecular gas properties in early galaxies. Nine new redshifts are reported that were obtained via measurements of the carbon monoxide ground state rotational transition ($^{12}C^{16}O$, J=1-0) with the Zpectrometer on the Green Bank Telescope. Analysis of CO line widths and luminosities provides a method for finding approximate gravitational lens magnifications μ from spectroscopic data alone, yielding μ ~ 3-20. Corrected for magnification, most galaxy luminosities in this sample are consistent with an ultra-luminous infrared galaxy classification, but three are candidate hyper-luminous infrared galaxies (LIRGs) with luminosities greater than 10^{13} $L_{\odot}$.



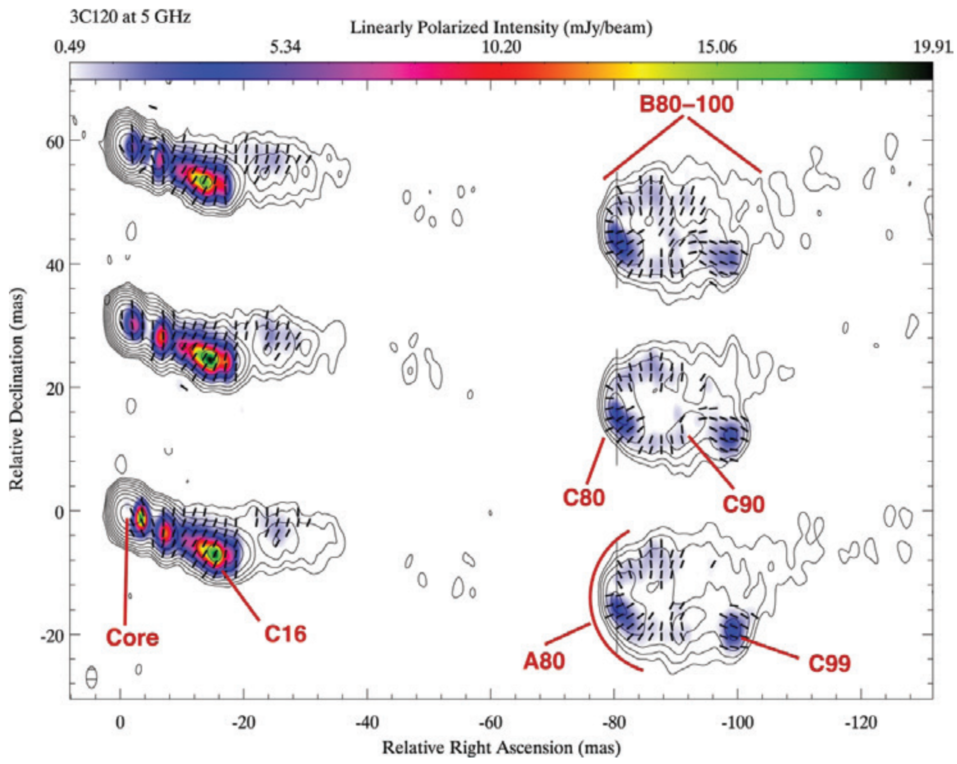
Spectra and detection confidence plots for targets. **[Upper panels]** *Difference spectrum for each pair.* **[Lower panels]** *Detection confidence. Coherent columns of dots indicate detections that are insensitive to binning parameters. Vertical dashed lines mark detections or tentative detections.*

Science Team: A.I. Harris (Maryland), A.J. Baker (Rutgers), D.T. Frayer (NRAO), I. Smail (Durham), A.M. Swinbank (Durham), D.A. Riechers (Caltech), P.P. van der Werf (Leiden), R. Auld (Cardiff), M. Baes (Gent), R.S. Bussmann (Harvard-Smithsonian Center for Astrophysics), S. Buttiglione (INAF) et al.

Publication: *Blind Detections of CO J = 1–0 in 11 H-ATLAS Galaxies at z = 2.1-3.5 with the GBT/Zpectrometer*, Astrophysical Journal, 752, 152 (20 June 2012).

The Violent Environment of Radio Galaxy Jets

3C120 is a canonical radio jet powered by a supermassive black hole that is a very active and powerful emitter of radiation at all observed wavebands. Multi-frequency, high-sensitivity observations of 3C 120 recently acquired by Agudo et al. with the Very Long Baseline Array (VLBA) show relativistic motion for most components in a parsec-scale jet. One component of the jet (C80) appears stationary. These VLBA data are interpreted via a model that includes a recollimation shock, effectively a standing-wave, that is collimating the large scale jet into a narrow channel that propagates out to 100 kiloparsecs.



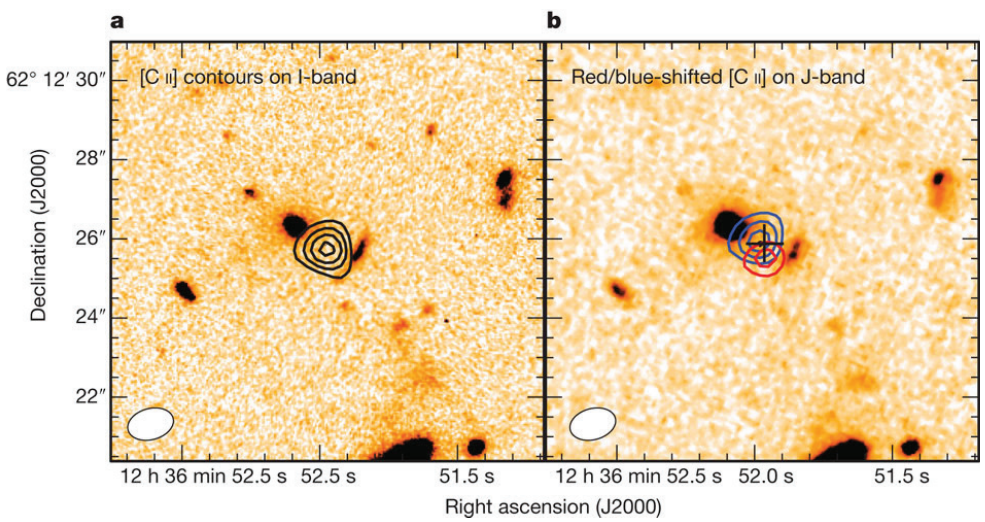
3C 120 VLBA image sequence of 3C 120 at 5 GHz taken on 2009 Dec 14, 2010 Mar 14, and 2010 Jun 21 (top to bottom). Vertical separations are proportional to the time difference between epochs. Gray-scale images (linear scale at top) show the linearly polarized intensity. Black sticks indicate the polarization electric vector position angle, uncorrected for Faraday rotation.

Science Team: I. Agudo (Andalucia, Boston), J.L. Gómez (Andalucia), C. Casadio (Andalucia), T.V. Cawthorne (Central Lancashire), M. Roca-Sogorb (Andalucia).

Publication: *A Recollimation Shock 80 mas from the Core in the Jet of the Radio Galaxy 3X 120: Observational Evidence and Modeling*, Astrophysical Journal, 752, 92 (20 June 2012).

Extreme Star Formation in the Early Universe

HDF850.1 was the first optically obscured, distant extreme starburst 'submillimeter galaxy' discovered. For more than a decade, and despite significant efforts, no counterpart was found at shorter wavelengths, and it was not possible to determine its redshift, size, or mass. Now Walter et al. report a redshift of z = 5.183 for HDF850.1 determined from a millimeter-wave molecular line scan using the NRAO Jansky Very Large Array and the Plateau de Bure interferometers. This places HDF850.1 in a galaxy overdensity at z ~ 5.2, only 1.1 billion years after the Big Bang. This redshift is significantly higher than earlier estimates and higher than those of most of the hundreds of submillimeter galaxies identified to date. The source has a star-formation rate of 850 solar masses per year, and is spatially resolved on scales of 5 kiloparsecs, with an implied dynamical mass of about 1.3×10^{11} solar masses, a significant fraction of which is present in the form of molecular gas. Despite the accurate redshift and position, a counterpart emitting optical or near infrared starlight is still not seen.



(a) [C II] contours on a deep I-band Hubble Space Telescope (HST) image that covers the Lyman-α line and ultraviolet continuum at z = 5.183. [C II] contours show the averaged emission over 700 km s−1. A Gaussian fit to the emission gives a size of 5.7 ± 1.9 kpc at z = 5.183. The underlying continuum emission (not shown) is also extended on the same scales. (b) The blue and red contours indicate the approaching and receding [C II] emission relative to the systemic redshift of z = 5.183. The color is a deep HST J-band image. The cross indicates the rest-frame 158-μm continuum emission peak.

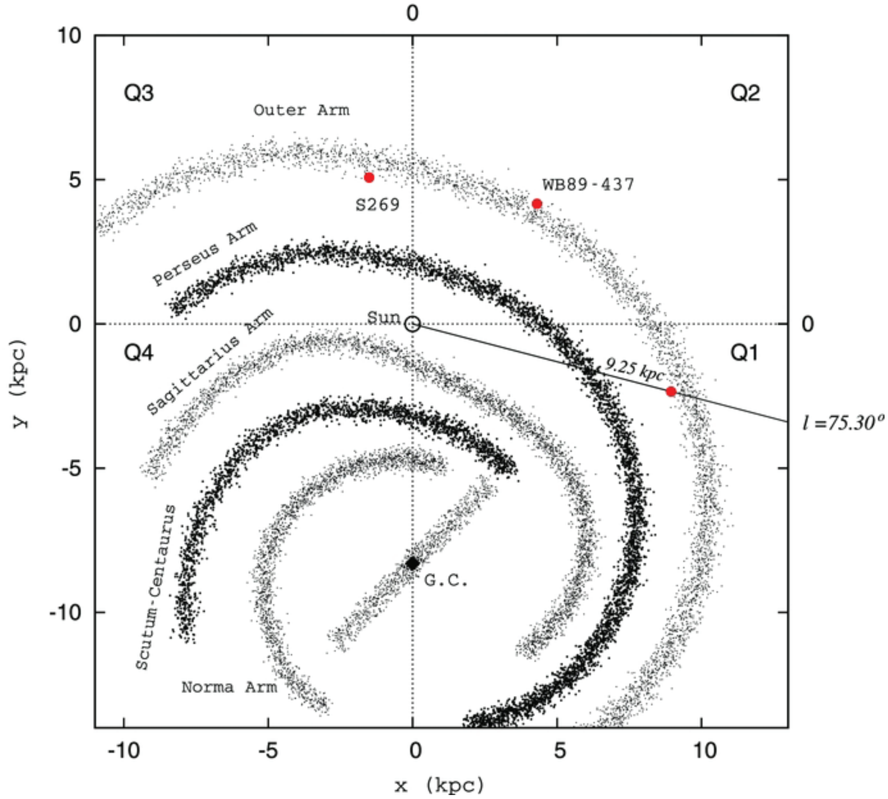
Science Team: F. Walter (Max-Planck-Institut für Astronomie), R. Decarli (Max-Planck-Institut für Astronomie), C. Carilli (NRAO, Cambridge), F. Bertoldi (Bonn), P. Cox (IRAM), E. da Cunha (Max-Planck-Institut für Astronomie), E. Daddi (CEA Saclay), M. Dickinson (NOAO), D. Downes (IRAM), D. Elbaz (CEA Saclay), R. Ellis (Caltech), J. Hodge (Max-Planck-Institut für Astronomie) et al.

Publication: *The intense starburst HDF 850.1 in a galaxy overdensity at z ≈ 5.2 in the Hubble Deep Field*, Nature, 486, 233 (14 June 2012).

Mapping the Milky Way in 3D

As part of a long-term program that is employing the extraordinary astrometric accuracy of the Very Long Baseline Array to accurately map the structure and kinematics of the entire Milky Way, Sanna et al. have measured the parallax for a water maser in a high mass star-forming region, yielding a heliocentric distance of 9.25 kilo-parsecs (kpc) and placing it in our Galaxy's Outer Arm. G75.30+1.32 lies 200 parsecs above the Galactic plane and is associated with a substantial HI enhancement at the border of a large molecular cloud. At a Galactocentric radius of 10.7 kpc, G75.30+1.32 is in a region of the Galaxy where the disk is significantly warped toward the North Galactic Pole. While the star-forming region has an instantaneous Galactic orbit that is nearly circular, it displays a significant motion of 18 km/s toward the Galactic plane. These results, when combined with two previous maser studies in the Outer Arm, yield a pitch angle of 12° for a large section of the arm extending from the first quadrant to the third.

The positions of the Outer Arm sources previously measured with trigonometric parallaxes are labeled, together with the distance and Galactic longitude of the new measurement.

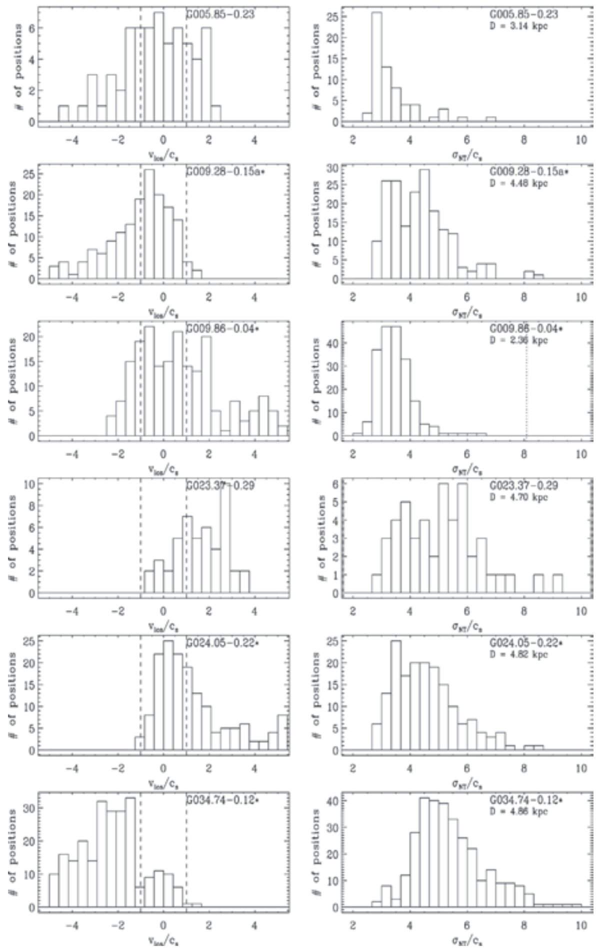


Science Team: A. Sanna (Max-Planck-Institut für Radioastronomie), M.J. Reid (Harvard-Smithsonian Center for Astrophysics), T.M. Dame (Harvard-Smithsonian Center for Astrophysics), K.M. Menten (Max-Planck-Institut für Radioastronomie), A. Brunt haler (Max-Planck-Institut für Radioastronomie), L. Moscadelli (Istituto Nazionale di Astrofisica), X.W. Zheng (Nanjing), Y. Xu (Purple Mountain Observatory).

Publication: *Trigonometric Parallaxes of Massive Star-forming Regions. IX. The Outer Arm in the First Quadrant*, Astrophysical Journal, 745, 82 (20 January 2012).

The Earliest Phases of Star Formation

Infrared Dark Clouds (IRDCs) are believed to be the birthplaces of rich clusters and thus contain the earliest phases of high-mass star formation. Ragan et al. have earlier used the Green Bank Telescope and Very Large Array to map the ammonia (NH_3) emission in six IRDCs to measure their column density and temperature structure. In this study, they investigate the kinematic structure and energy content of these IRDCs. They find that these IRDCs display organized velocity fields, with only localized disruptions due to embedded star formation. The local effects seen in NH_3 emission are not high-velocity outflows but rather moderate (few km/s) increases in the line width, with maxima near or coincident with the mid-infrared emission tracing protostars. These line width enhancements could be the result of infall or outflow. Not only is the kinetic energy content insufficient to support the IRDCs against collapse, but the spatial energy distribution is inconsistent with a scenario of turbulent cloud support. The authors conclude that the velocity signatures of the IRDCs in their sample are due to active collapse and fragmentation, augmented in some cases by local feedback from stars.



IRDC kinematics summary. **[Left column]** Histograms of the centroid velocity in units of the sound speed. Vertical dashed lines indicate the transition between subsonic and supersonic. **[Right column]** Histograms of the non-thermal velocity dispersion. All values are supersonic by at least a factor of two.

Science Team: Sarah E. Ragan (Michigan, Max-Planck-Institut für Astronomie), Fabian Heitsch (North Carolina), Edwin A. Bergin (Michigan), and David Wilner (Harvard-Smithsonian Center for Astrophysics).

Publication: *Very Large Array Observations of Ammonia in Infrared-Dark Clouds. II. Internal Kinematics*, Astrophysical Journal, 746, 174 (20 February 2012).

ALMA TRANSPORTER

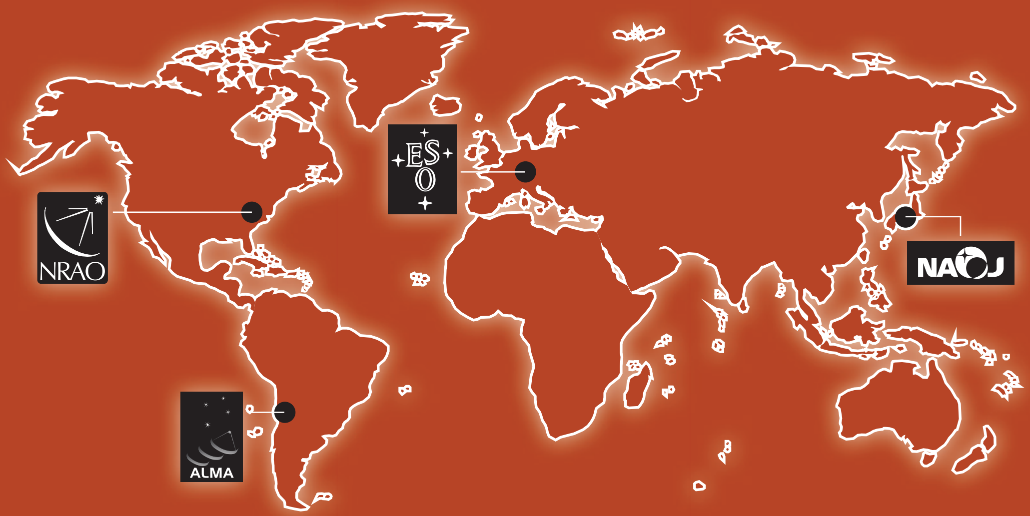
Construction continued in 2012 on two new, state-of-the-art radio-wavelength interferometers, each representing an enormous leap forward in capabilities for the astronomy community: the Atacama Large Millimeter/submillimeter Array (ALMA) and the Expanded Very Large Array (EVLA).

Atacama Large Millimeter/submillimeter Array Construction Project

When complete, ALMA will include fifty 12m antennas in an extended interferometric array, plus twelve 7m antennas and four 12m antennas in a compact array, operating at frequencies from 80 – 900 GHz at more than 5,000m elevation in northern Chile. Among the largest advances in astronomy, ALMA will achieve an order of magnitude more improvement in millimeter-wave sensitivity, frequency coverage, resolution, imaging, and spectral capabilities. ALMA is already impacting numerous fields of astrophysics and opening new scientific frontiers, enabling astronomers to study the first stars and galaxies, directly image the disks in which planets are formed, and probe regions of our Universe that are optically dark but shine brightly in the millimeter portion of the electromagnetic spectrum.

ALMA construction began in late 2003 and made substantial progress throughout 2012. When construction is complete in 2013, ALMA will consist of 66 precise, high-tech antennas on a site that is one of the best in the world for astronomical research. Providing capabilities that complement those of other research facilities, the international science community will use ALMA synergistically with other world-class observatories of the coming decade, such as the Jansky Very Large Array, the James Webb Space Telescope, and the Large Synoptic Survey Telescope.

ALMA, an international astronomy facility, is a partnership of East Asia, Europe and North America in cooperation with the Republic of Chile. ALMA is funded in East Asia by the National Institutes of Natural Sciences of Japan in cooperation with the Academia Sinica in Taiwan, in Europe by the European Organisation for Astronomical Research in the Southern Hemisphere (ESO) and in North America by the U.S. National Science Foundation (NSF) in cooperation with the National Research Council of Canada (NRC) and the National Science Council of Taiwan. ALMA construction and operations are led on behalf of East Asia by the National Astronomical Observatory of Japan (NAOJ), on behalf of Europe by ESO, and on behalf of North America by the NRAO, which is managed by AUI.



A NEW GENERATION OF RADIO INTERFEROMETERS

ALMA Construction

The three 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 Joint ALMA Observatory. 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.

Major civil construction at the AOS in 2012 included additional antenna foundations, roads that link the antennas and the AOS Technical Building, and infrastructure of the electrical and fiber optic network.

ALMA OPERATIONS SUPPORT FACILITY

The provisioning of electrical power remains to the northern Chile site has been a challenge. The original plan to connect ALMA to the public electricity grid had to be abandoned owing to difficulties with energy supply negotiations and changed fuel market conditions. Instead, a standalone power generation plant at the OSF using multi-fuel turbines was selected and designed, and procurement began in 2009. This power system was delivered and installed at the ALMA OSF and AOS in 2012.

All 67 km of the roads at the AOS were accepted by the JAO on 5 December. Arbitration with the dismissed AOS Utilities contractor was resolved in AUI's favor on 30 May, avoiding a potential $5M claim. The new AOS Utilities contract is in place and will provide electrical power and fiber optic cables to each station by July 2013.

ALMA Antennas

In November, North America delivered the last of the twenty-five, precision 12m diameter dishes that comprise its share of antennas for ALMA, an important milestone in the construction project. The NSF provided the funding to build the 25 North American antennas that are North American deliverables to ALMA, the largest single procurement in the history of the foundation's astronomy division. AUI managed the North American antenna procurement contract, while NRAO oversaw the integration and testing of the antennas, which were manufactured and assembled by VertexRSI, a Texas-based division of General Dynamics SATCOM Technologies. Each antenna's pedestal and dish structure components were shipped separately to the JAO site in northern Chile, and assembled in an enormous hangar building built by General Dynamics at the Operations Support Facility (OSF) specifically for this purpose.

Once an antenna is assembled on-site, it undergoes Assembly, Integration, and Verification (AIV) activities at the OSF. Upon completion of AIV, antennas are moved via the ALMA Transporter to the AOS and integrated into the operational array. By the end of 2012, the 25 VertexRSI antennas had been accepted by the JAO, and 20 VertexRSI antennas were at the AOS.

[Top Image] *The ALMA Array in May 2012. (J. Guarda, ALMA)* **[Bottom image row]** *North American ALMA Antenna 25 at the ALMA site in northern Chile. (General Dynamics SATCOM Technologies, Bill Johnson).*

The Mitsubishi Electric Corporation (MElCo) of Japan manufactured the four 12m and twelve 7m antennas of the Atacama Compact Array (ACA) that are East Asian deliverables to ALMA and are enhancing ALMA's ability to image extended radio sources. By the end of 2012, the 16 MElCo antennas had been accepted the JAO in Chile, and 14 MElCo antennas were at the AOS.

The AEM Consortium – Thales Alenia Space, European Industrial Engineering, MT Mechatronics – is building twenty-five 12m antennas that are European deliverables to ALMA. By the end of 2012, 17 AEM antennas had been accepted by the JAO in Chile, and 13 AEM antennas were at the AOS. The last EU antenna will be delivered in July 2013 and is expected to be through AIV in October 2013.

A NEW GENERATION OF RADIO INTERFEROMETERS

ALMA Correlator

The heart of the extended Array is its correlator, a dedicated supercomputer and digital data processor capable of more than 10^{16} operations per second that was designed and built by the scientists, engineers, and technicians at the NRAO Central Development Lab (CDL). Assembled, tested, and shipped in "quadrants," the last of the four correlator quadrants was formally accepted by the JAO on 20 December, marking completion of this important delivery, another major NRAO ALMA milestone.

Technician Juan Carlos Gatica checks electronics on the ALMA correlator while using supplemental oxygen at the high-altitude site (Carlos Padilla, NRAO/AUI/NSF).

The ALMA correlator's 134 million processors continually combine and compare faint celestial signals received by as many as 50 ALMA antennas. The correlator can also accommodate up to 14 of the 16 ACA antennas. At the correlator's maximum capacity of 64 antennas, there are 2,016 antenna pair combinations, and as many as 17 quadrillion calculations every second.

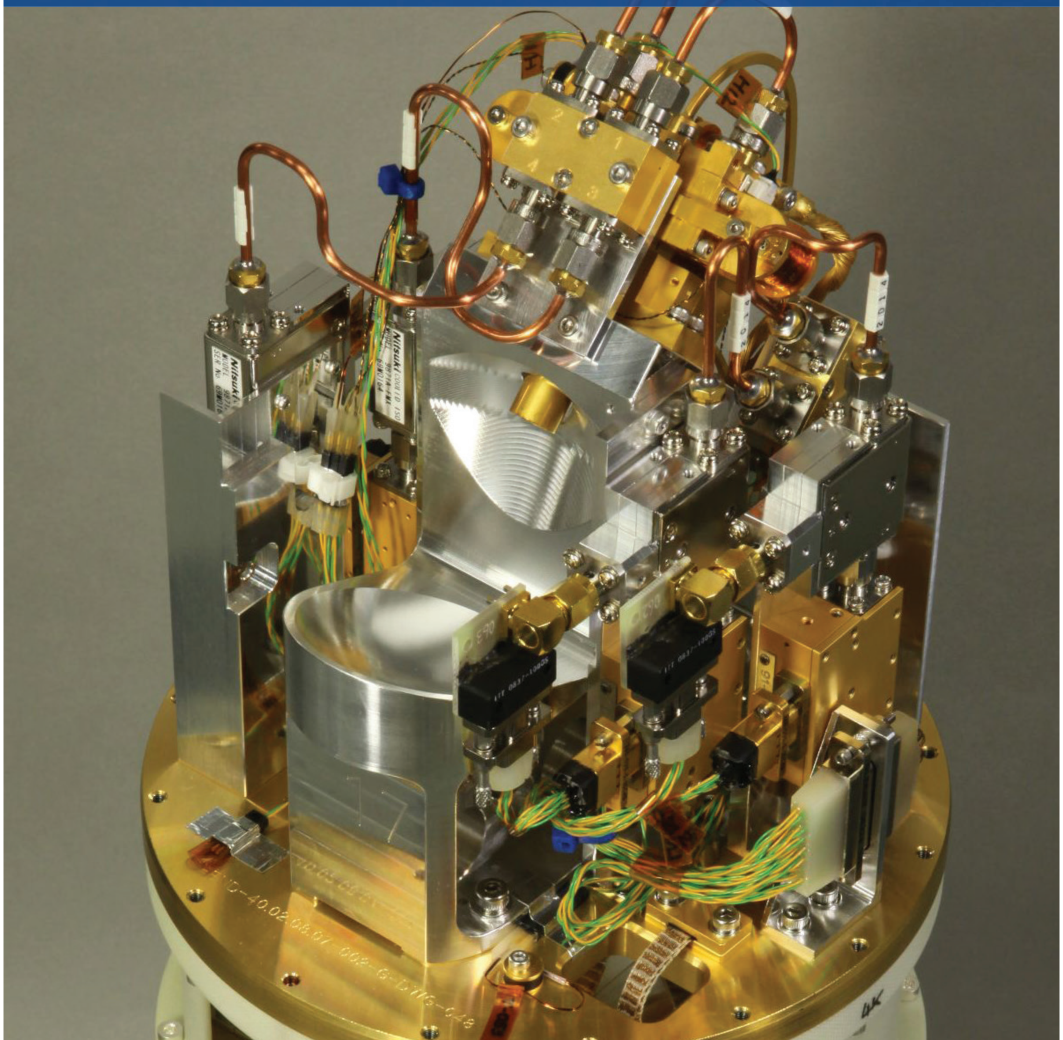
The correlator is housed in the AOS Technical Building, the highest-altitude high-tech building in the world. At 5,100m elevation, the air is thin, so twice the normal airflow is necessary to cool the correlator, which draws 140 kilowatts of power. Computer disk drives will not work reliably in thin air, so the correlator and its associated computers must be diskless. Seismic activity is common in Chile, so the correlator had to also be designed to withstand the vibrations associated with earthquakes.

The NRAO ALMA correlator is one of two such systems in the ALMA complex. A second ALMA correlator, designed and built by Fujitsu and delivered by the NAOJ, provides independent correlation of the 16 antennas in the ACA, except when select ACA antennas are combined with the 50 more widely dispersed main array antennas.

ALMA Front End & Back End Assemblies

The electronics and ancillary hardware along the signal path from the antenna feed horn to, and including, the receiver is termed the antenna "front end." By the end of 2012, the ALMA North American Front End Integration Center (FEIC) at the NRAO CDL in Charlottesville, Virginia had completed, tested, and shipped to the OSF 27 ALMA Front End assemblies, including 22 from the NA FEIC and 5 from the East Asia FEIC. All 27 Front Ends were accepted by the JAO as of 4 January 2013. Each of these Front End assemblies was fully functional in the specified four ALMA frequency bands: Band 3, Band 6, Band 7, and Band 9. Front End deliveries from North America were aided by a 15 June U.S. State Department ruling that the ALMA Front Ends were not subject to ITAR export control. Delivery of the final European Front End is expected in February 2013.

ALMA Receiver Bands



Band #	3	4	5	6	7	8	9	10
Frequency Range (GHz)	84-116	125 - 163	163 - 211	211 - 275	275 - 373	385 - 500	602 - 720	787 - 950
Wavelength Range (mm)	3.57-2.59	2.40-1.84	1.84-1.42	1.42-1.09	1.09 - 0.80	0.78 - 0.60	0.50 - 0.42	0.38 - 0.32

The Band 3 (84-166 GHz) and Band 6 (211-275 GHz) receiver cartridges were also North American deliverables, and production for both bands was completed in 2012. The last Band 6 cold cartridge assembly was delivered from the CDL on 16 August.

ALMA Back Ends

Installation and testing of the final stage of the ALMA Central Local Oscillator was completed in August 2011. This Local Oscillator provides critical timing signals for up to 66 antennas and four sub-arrays, and its delivery to the AOS represents the achievement of a major North America ALMA construction milestone.

A NEW GENERATION OF RADIO INTERFEROMETERS

Expanded Very Large Array Construction Project

Begun in 2001, the Expanded Very Large Array (EVLA) Construction Project was completed at the end of 2012, on time, on budget, and having met all of the project's original technical and scientific specifications. The EVLA Project has created a centimeter-wavelength radio telescope of twenty-seven 25m-diameter antennas with much greater sensitivity, very broad continuous frequency coverage, and excellent imaging capabilities.

The EVLA was designed to explicitly address four primary science themes:

- measuring the strength and topology of cosmic magnetic fields;
- imaging young stars and massive black holes in dust-shrouded environments;
- following the rapid evolution of energetic phenomena; and
- studying the formation and evolution of star, galaxies, and Active Galactic Nuclei.

The primary observational goals of the EVLA Project included: (a) complete frequency coverage from 1 to 50 GHz; (b) continuum sensitivity improvement by up to an order of magnitude (nearly two orders of magnitude in speed) by increasing the bandwidth from 100 MHz to 8 GHz per polarization; and (c) implementation of a new correlator that can process the large bandwidth with a minimum of 16,384 spectral channels per baseline. All of these goals have been met.

A comparison of key EVLA performance parameters with those of the original VLA is provided in Table 1.

Table 1: EVLA Performance Goals

Parameter	VLA	EVLA	Factor
Continuum Sensitivity* (1-σ, 9 hr)	10 μJy	1 μJy	10
Maximum BW in each polarization	0.1 GHz	8 GHz	80
Number of frequency channels at max. BW	16	16,384	1024
Maximum number of frequency channels	512	4,194,304	8192
Coarsest frequency resolution	50 MHz	2 MHz	25
Finest frequency resolution	381 Hz	0.12 Hz	3180
Number of full-polarization sub-correlators	2	64	32
Log (Frequency Coverage over 1-50 GHz)	22%	100%	5

*1 Jansky = 1 Jy = 10^{-26} W/(m^2 – Hz)

The primary contribution of the EVLA Project's Canadian partner was the Wideband Interferometric Digital ARchitecture (WIDAR) Correlator, which performs the requisite digital correlation of the very wideband signals from the EVLA radio interferometer. The EVLA data are digitally filtered by the WIDAR correlator and decimated into lower rate "sub-bands" that are separately cross-correlated and integrated before being seamlessly stitched together to yield the final wideband spectrum. The WIDAR correlator was formally accepted from the National Research Council Hertzberg Institute of Astrophysics (NRC-HIA) on 28 September. NRC-HIA continued to provide WIDAR support through the end of 2012.

WIDAR CORRELATOR

A NEW GENERATION OF RADIO INTERFEROMETERS

All VLA antennas are now outfitted with eight receivers providing continuous 1 to 50 GHz frequency coverage: 1-2 GHz (L-Band), 2-4 GHz (S-Band), 4-8 GHz (C-Band), 8-12 GHz (X-Band), 12-18 GHz (Ku-Band), 18-26.5 GHz (K-Band), 26.5-40 GHz (Ka-Band), and 40-50 GHz (Q-Band). The 3-bit sampler system that enables up to 8 GHz of simultaneous bandwidth at high frequencies was installed and placed in operation.

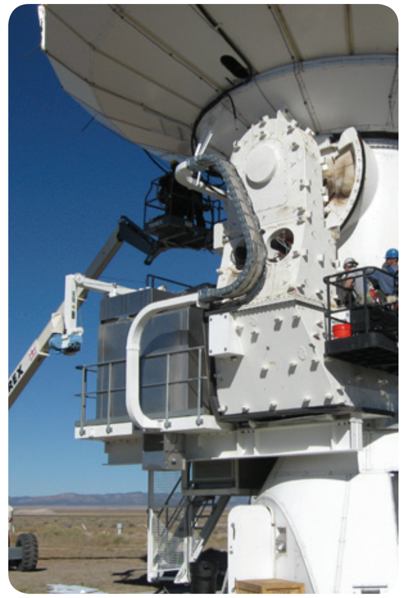
The Jansky VLA entered full science operations in January 2013.

The NSF provided the primary funding for the EVLA Construction Project, with additional contributions from the National Research Council in Canada, and the Consejo Nacional de Ciencia y Technologia in Mexico.

OPERATIONS & DEVELOPMENT

A multiwavelength composite of the interacting galaxies NGC 4038/4039, the Antennae, including: (a) centimeter-wavelength radio data from the Very Large Array (blues); (b) visible wavelength imagery from the Hubble Space Telescope and Cerro Tololo Inter-American Observatory (whites and pinks); and (c) a selection of current star-forming regions, as observed by the Atacama Large Millimeter/submillimeter Array (orange and yellows), showing detail surpassing all other views at millimeter and submillimeter wavelengths. NRAO/AUI/NSF; ALMA (ESO/NAOJ/NRAO); HST (NASA, ESA, and B. Whitmore (STScI)); J. Hibbard, (NRAO/AUI/NSF); NOAO/AURA/NSF.

North American ALMA Operations



North American (NA) 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 NA share of ALMA Operations in Chile
- A broad outreach program including Education & Public Outreach (EPO) and Diversity initiatives

The major North America (NA) ALMA Operations goals are to: (a) complete commissioning; (b) make ALMA a research facility for the entire astronomy community; (c) develop and improve ALMA; and (d) integrate NA ALMA Operations within NRAO.

After an extensive search, Phil Jewell was appointed Assistant Director for NA ALMA Operations, effective 22 October. This key position oversees the NA ALMA Science Center (NAASC) and the ALMA Development program, coordinating the ALMA maintenance program, and is the face of ALMA to the NA scientific community.

North American ALMA Science Center (NAASC) Science

The NRAO–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 is the interface for the science community to ALMA. The NAASC staff also assists with support of ALMA operations in Chile, and plays a key role in the research and development activities that support future capability upgrades of the ALMA.

The North American ALMA Regional Center (NA ARC) is a subset of the NAASC, concentrating on the internationally agreed ALMA core functions. The ALMA international partners in East Asia and Europe support similar ALMA Regional Centers. In North America, the ARC is a partnership between NRAO, the National Research Council of Canada (NRC), supported by the Millimeter Astronomy Group at the Herzberg Institute of Astrophysics in Canada, and the National Science Council of Taiwan.

The inaugural ALMA Cycle 0 Early Science observing season ended 1 January 2013 and produced a wealth of excellent data and spectacular science results, many of which have already reached publication. Cycle 0 data were observed and processed on a best efforts basis, and 107 of the 111 highest-priority projects were delivered data worldwide. Only three Cycle 0 projects received no data, and another is still being reduced. The Cycle 0 plan was for 500-700 hours of observing time. A total of 1,026 hours were actually used. To date, about 40 papers have been published from Cycle 0 and/or Science Verification data, and more are in preparation.

For the North American partners – US, Canada, Taiwan – 36 of the 38 highest priority projects received all of the requested Cycle 0 data. One Cycle 0 project was cancelled; one received no data. Three filler projects were also executed. A total of 326 observing hours were allocated to NA high priority projects, and 21 hours were allocated to filler projects.

NAASC staff reduced 29% of the total 337 schedule blocks in Cycle 0. The JAO reduced 35%; Europe and East Asia each reduced 18%. The mean delivery time of Cycle 0 data in North America was half that of any other region. NAASC staff also processed and delivered six Chilean and one international project.

A total of 1133 science proposals were submitted for ALMA Early Science Cycle 1. Seventy-eight science assessors from around the world evaluated these proposals. The most promising proposals were selected as those most likely to be completed using the ALMA Cycle 1 capabilities. PIs were notified 16 November 2012 of the outcome of the Proposal Review Process. The 196 highest-priority projects span five broad science categories: (1) cosmology and the high redshift Universe; (2) Galaxies and galactic nuclei; (3) interstellar medium, star formation, and astrochemistry; (4) circumstellar disks, exoplanets, and the solar system; and (5) stellar evolution and the Sun. Cycle 1 science observing began January 2013.

Throughout 2012, NAASC scientists provided significant support to the Joint ALMA Observatory (JAO) in Chile for: (a) on-site Astronomy-on-Duty shifts; (b) Commissioning & Science Verification; and (c) data reduction and quality assurance.

NAASC scientists also provided extensive support to members of the North American and Chilean user community for schedule block preparation and Help Desk support, and were Contact Scientists for NA ALMA PIs. NAASC scientists reduced every Cycle 0 schedule block for the North American community. A new, searchable ALMA Science Archive was delivered by the NAASC team, which also invested considerable time in CASA and ALMA pipeline testing. A comprehensive Cycle 0 survey was conducted to seek input from the community regarding future users service improvements and priorities.

The NAASC hosted and/or participated in a broad range of in-person and on-line science conferences, data reduction workshops, proposal preparations tutorials, and ALMA training events for the community. These included: an ALMA Special Session at the January AAS meeting in Austin; the 6th NAASC science workshop – *Outflows, Winds and Jets: From Young Star to Supermassive Black Holes* – in Charlottesville, VA 3-6 March; an inaugural proposal preparation webinar 11-12 June; and the *First Year of ALMA Science* conference, 12-15 December, in Puerta Varas, Chile. A complete list of these community events is included in Appendix B.

ALMA Development

The ALMA Operations Plan envisages an ongoing program of development and upgrades that may include hardware, software, or data analysis tools. In 2012, construction of the first post-construction receiver bands, phasing hardware, and new data analysis tools has commenced in NA partially under a program of Development Studies submitted in response to a November 2011 Call. Twenty-one Development Studies submissions were received from 77 investigators representing 26 institutions. After review by an external panel, eight proposals were funded.

Three ALMA Development Projects were also funded in 2012: (1) Band 5 Local Oscillator Production, led by NRAO; (2) Fiber Optic Connectivity, led by JAO; and (3) ALMA Phasing Project, led by MIT – Haystack. Numerous collaborators are involved in these development projects.

A new Call for Development Studies will be issued 1 May 2013 and will be followed by a new Call for Development Projects on 3 June 2013. Funding of $1M is expected for the Development Studies in this Call; and $1.63M is expected for the Development Projects.

ALMA Cycle 0 Early Science

The ALMA Cycle 0 Early Science Call for Proposals (CfP) was issued 30 March 2011 with a 30 June 2011 proposal submission deadline. From the 919 proposals submitted, 113 high priority and 51 filler projects were accepted, with an estimated execution time of ~800 hours.

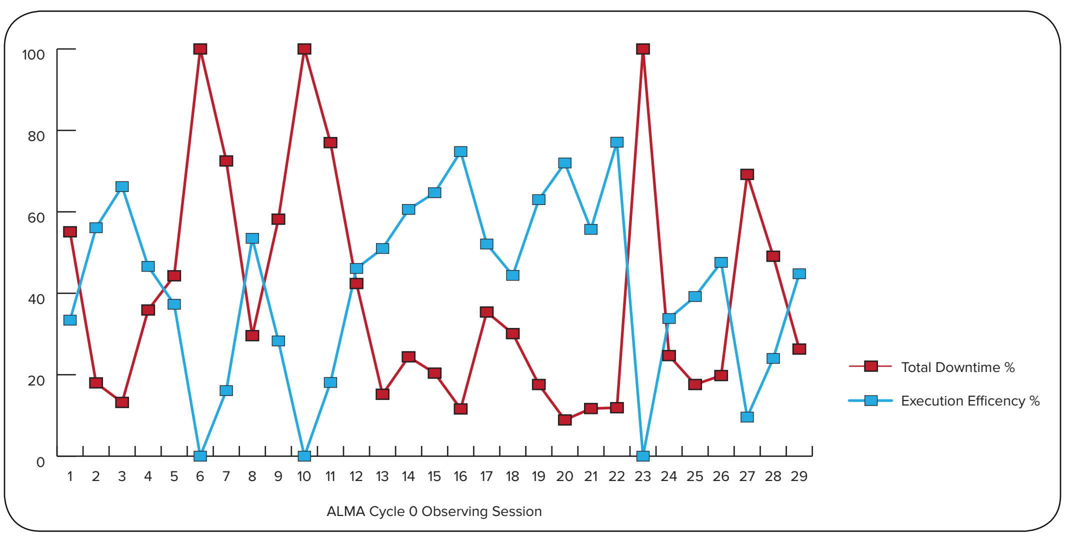
ALMA Cycle 0 observations were initiated 30 September 2011. Observations were conducted in 5-7 day sessions every two weeks, with 12-16 hour shifts from late afternoon until morning. During each observing session several activities took place in addition to the science observations, such as observatory calibrations and calibrator surveys.

At the time of the CfP, it was anticipated that the array would begin in the extended configuration (maximum baselines of ~400m). However, due to challenging weather conditions, Cycle 0 was initiated in the compact configuration (maximum baselines of ~125m). This change was announced to ALMA observers via email and the ALMA Science Portal.

After three months of observations, it was realized that while the data quality was excellent, the project completion rate was lower than planned, owing to a lower than expected execution efficiency, the loss of two of the first ten observing sessions due to poor weather and technical problems, and other factors. The Cycle 0 observing period was thus extended to 1 January 2013, with a planned shutdown in September 2012 for a correlator upgrade. Near the end of the observing season, some daytime observing was made available to increase the completion rate of high priority projects.

At completion, Cycle 0 consisted of 29 observing sessions; three sessions were lost due to weather and technical problems. Two of the 113 high priority projects selected for Cycle 0 were cancelled, leaving 111 high priority projects to be observed: 108 (97%) high priority projects received some data, 98 (88%) completed some of their science goals, and 77 (69%) completed all of their science goals.

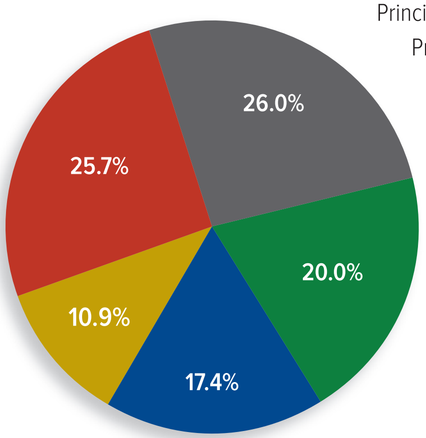
Execution Efficiency and Downtime Percentages



Execution efficiency (blue) and total downtime for weather and technical problems (red) for the 30 ALMA Cycle 0 observing sessions.

ALMA Early Science Cycle 1 Proposal Process

A total of 1133 science proposals were submitted for ALMA Early Science Cycle 1. Seventy-eight science assessors from around the world evaluated the expected scientific value of these proposals. The most promising proposals of each ALMA region – North America, Europe, East Asia, and Chile – were selected as those most likely to be completed using the ALMA Cycle 1 capabilities, after their technical feasibility was confirmed by fifteen technical assessors from the Joint ALMA Observatory and the three ALMA Regional Centers.



Principal Investigators were notified on 16 November of the outcome of the Proposal Review Process. The 196 highest-priority projects cover a wide range of science and are distributed across the five broad ALMA science categories:

- Galaxies and galactic nuclei
- Cosmology and the high redshift Universe
- Interstellar medium, star formation, and astrochemistry
- Stellar evolution and the Sun
- Circumstellar disks, exoplanets, and the solar system.

Offsite Technical Support

A key feature of ALMA operations model is that the Executives continue to maintain, repair, and improve the hardware and software they delivered during construction. This is essential to ensure that experts from each subsystem are retained and continue to be efficiently available to ALMA. Software support includes: (a) ALMA common software, (b) correlator, (c) dynamic scheduling, (d) Monitor & Control, (e) CASA, (f) pipeline, (g) Project Tracker, and others. Hardware support includes: (a) cold cartridges, (b) Local Oscillator (LO) assemblies, (c) board-level repair, (d) photonic LO system, and (e) the data transmission system.

Office of Chilean Affairs

The NRAO/AUI Office of Chilean Affairs (OCA) in Santiago, Chile was founded in 1998 to support the interests of AUI and NRAO in Chile, particularly North American participation in ALMA. The OCA responsibilities include: (1) executing procurement, contracts and fiscal activities, including payroll, in Chile for the JAO; (2) employing "Local Staff Members (LSMs)" for ALMA; and (3) performing additional activities in Chile on behalf of AUI/NRAO. The first two of these responsibilities are funded by JAO Chile Operations; the third includes activities funded via the NAASC.

The OCA represents AUI/NRAO in Chile, handling legal and business matters, representing ALMA to the Republic of Chile, and supporting JAO. This support includes implementing actions initiated by JAO, such as purchase orders, contracts, import/export, travel reimbursements, pay orders, accounts payable, and assuming legal responsibilities for ALMA Chilean staff.

In 2012, the OCA provided 300 ALMA LSMs and international staff with legal, payroll, and travel support. OCA also provided the legal and institutional support for numerous contracts and procurements for ALMA Construction and Operations. Multiple reports were issued by OCA to the Chilean environmental authority – Comision Nacional del Medio Ambiente (CONAMA) – related to flora, fauna, and archaeological site follow-up. Catering, cleaning, and maintenance contracts were re-bid due to price changes.

ALMA Operations in Chile

The NA Executive share of ALMA Operations in Chile is 37.5%. The European and East Asian Executive shares of ALMA Operations in Chile are 37.5% and 25.0%, respectively.

This direct appropriation for JAO operations in Chile represents the single largest NA ALMA expense. It includes the NA share of all monies spent in Chile to operate ALMA, including those for: (a) the Chilean-based staff, (b) on-site maintenance, (c) the JAO Santiago Central office headquarters, and the OSF and AOS in northern Chile; fees paid to the Chilean science agency that oversees ALMA in Chile (CONICyT); land concession fees; and ALMA committee support.

Array Science Center: VLA/VLBA Operations

Staff located at the Array Science Center in Socorro, New Mexico support VLA and VLBA operations for the NRAO user community. All user-facing science support is matrixed through the Science Support & Research (SSR) Department. All telescope-facing support is managed through New Mexico operations.

The VLA averaged ~60% efficiency in 2012. With the completion of the EVLA, the goal is to return to the traditional VLA average of ~70% efficiency by the end of 2014. The VLBA efficiency continues to average ~50%.

New VLA capabilities for the 2013A and 2013B semesters included flexible tuning of sub-band spectral line windows using the 8-bit samplers (enabling up to 2 GHz total bandwidth), use of the 3-bit samplers at higher frequencies in a mode suitable for wide-band continuum and extragalactic lines and line searches, use of up to three independent sub-arrays, and a phased array capability for Very Long Baseline Interferometry.

The new VLA operational model includes providing calibrated visibility data for Stokes I continuum and enabling access to NRAO computing facilities. The primary goals are to increase ease-of-use, reduce the time to publication, and expand the novice user base.

VLA pipeline products undergo quality assurance review by NRAO staff. About 80% of schedule blocks ran successfully through the pipeline by the end of 2012, and about 20% of projects downloaded the pipeline-calibrated data.

In 2012, the Jansky VLA initiated a program of bi-monthly monitoring observations in advance of the expected encounter in mid-2013 of the G2 cloud with SgrA* in the Galactic Center. These raw data are made available through the NRAO Archive. Photometry, calibrated visibility data, and some images are available on-line. Four epochs of an anticipated 13 were obtained in 2012.

NRAO continued to offer shared-risk observing options for those who wanted to push the capabilities of the VLA beyond those offered for general use: the "Shared Risk Observing" and "Resident Shared Risk Observing" (RSRO) programs. A new low-band system is available at the VLA via the RSRO program. Sixteen RSRO participants assisted with the Jansky VLA during semesters 2012A and 2012B. Two RSRO participants worked on the VLBA Mark4 data format and analysis procedures for multiple-phase-center observations.

A primary concern was the Portfolio Review Committee recommendation that NSF divest from VLBA by 2017. NRAO/AUI are continuing to actively pursue partners for the VLBA. If NSF does divest from the VLBA, the amount of time available for proposals from non-partner institutions may be severely limited or non-existent.

VLBA operations were focusing on stabilizing and standardizing operation of the VLBA + 27 antenna VLA array, and the full transition to the digital downconverter (DDC) and Mark 5C recording system.

VLA/VLBA Development

NRAO telescopes are platforms for continued innovation and test beds for new instruments that flow from consultation with the user community and NRAO scientific staff. Now that the EVLA Construction Project is complete, the VLA

Development focus is shifting to the consideration of multiple, smaller high and low frequency hardware, software, and data processing enhancement projects.

The multi-year VLBA Sensitivity Upgrade Project came to completion in 2012. This project brought multiple new capabilities to the VLBA, including: (a) a new digital corrector (DiFX), (b) a switch to digital recording, (c) increased data rates of up to 2 Gb/sec, and (d) new low noise, wide bandwidth receivers. These capabilities enable massively multiplexed imaging, 3X improved continuum sensitivity.

2012 NRAO Calls for Proposals

The NRAO Semester 2012B Call for Proposals was released 6 January for the 1 February deadline; the NRAO Semester 2013A Call for Proposals was released 9 July for the 1 August deadline.

NRAO has fully migrated from a trimester-based proposal cycle to a semester-based proposal cycle, with each semester lasting six months. The annual proposal submission deadlines are 1 February and 1 August. At each deadline, proposers may request time on the GBT, the VLBA, and/or the Jansky VLA.

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
- Energetic transients and pulsars
- Galaxies (continuum)
- Active Galactic Nuclei
- Interstellar medium
- Star formation
- Galaxies (line)
- High redshift and source surveys

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

The 1 February deadline typically applies to requests for time from 1 August through 31 January, and the 1 August deadline applies to requests for time from 1 February through 31 July. Details about proposal submission, proposal evaluation, and time allocation are available at the NRAO science website, http://science.nrao.edu.

At the 1 February submission deadline, NRAO received 322 proposals by 1040 unique authors, with 758, 323 and 131 proposers competing for time on the Jansky VLA, GBT and VLBA/High Sensitivity Array (HSA), respectively. Eight SRPs evaluated the proposals for scientific merit. The proposals were also reviewed for technical feasibility by NRAO staff. Reviews were completed in April and then reconciled by the Time Allocation Committee (TAC) during a 25-27 April meeting in Charlottesville. The TAC, which consists of the SRP chairs, recommended a science program for Semester 2012B to the NRAO Director that was reviewed and approved 18 May. A disposition letter was sent to each principal investigator and co-investigator 31 May.

At the 1 August submission deadline, NRAO received 420 proposals by 1415 unique authors, with 966, 418, and 288 proposers competing for time on the VLA, GBT, and VLBA/HSA, respectively. SRP and NRAO technical reviews were completed in October and reconciled by the TAC during a 29-31 October meeting. The TAC recommended a Semester 2013A science program to the NRAO Director that was reviewed and approved 26 November. A disposition letter was sent to the Principal Investigator and Co-Investigators of each proposal 29 November.

OPERATIONS & DEVELOPMENT

VLA Becomes the Karl G. Jansky Very Large Array

Astronomers and officials from around the globe gathered on the high desert of New Mexico on 31 March to officially bestow a new name on the Very Large Array (VLA) and mark its transformation into a new and more powerful tool for science: the Karl G. Jansky Very Large Array, honoring the founder of radio astronomy.

To celebrate the decade-long effort to bring the VLA, first dedicated in 1980, up to today's technological state of the art, NRAO Director Fred K.Y. Lo was joined by Ethan Schreier, President of Associated Universities, Inc.; James Ulvestad, Director of the Astronomical Sciences Division of the National Science Foundation; representatives of U.S. Senator Tom Udall and U.S. Rep. Steve Pearce; and astronomers and officials from the U.S., Canada, Mexico, Europe, China, Australia, and Japan. The event formally inaugurated the new name, and recognized those who worked on the project.

The new name was selected following a call for public submissions that netted 23,331 suggestions submitted by 17,023 people from more than 65 countries. The new name was one of 16,223 unique names submitted.

Upon a command from the NRAO Director, the twenty-seven antennas of the Jansky VLA turned toward a set of dwarf galaxies for the official first observation by the renamed facility, and the beginning of a new era of NRAO science.

GBT Operations and 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 full 0.1–116 GHz (l 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 US 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.

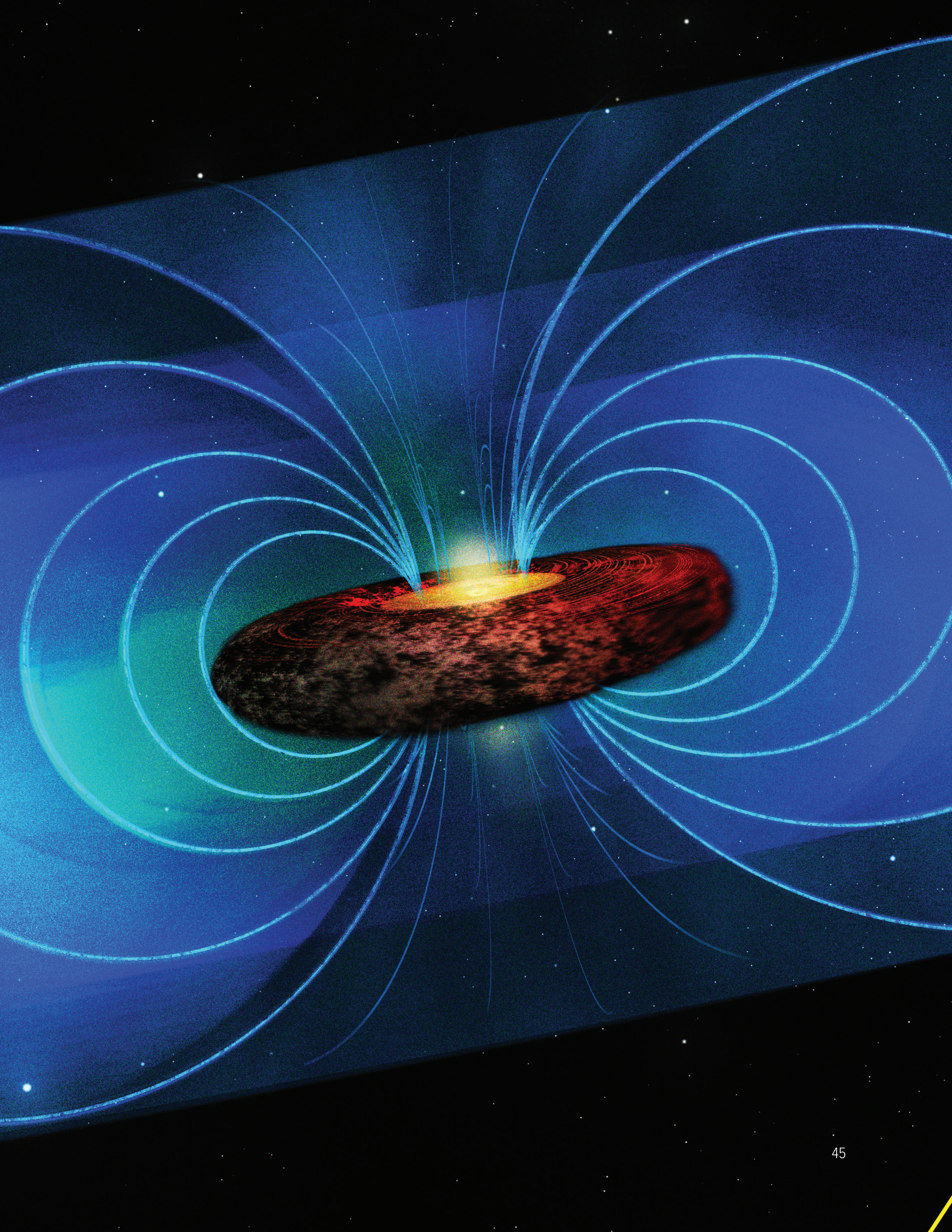
Science for the GBT ranges from understanding black holes through detecting gravitational waves, imaging the earliest galaxies, and searching space for the precursors of life. The GBT's flexibility and ease of use means it can rapidly respond to new ideas from the scientific community. It has a collecting area and sensitivity comparable to the Atacama Large Millimeter/submillimeter Array (ALMA) and the Karl G. Jansky Very Large Array (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 Very Long Baseline Array (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 largest concern facing the GBT is the 2012 Portfolio Review Committee recommendation that NSF-AST divest from GBT by 2017. NRAO/AUI is actively seeking partners for the GBT. However even if significant partners are found, NSF divestiture from the GBT will make the amount of time available for proposals from non-partner institutions non-existent or severely limited.

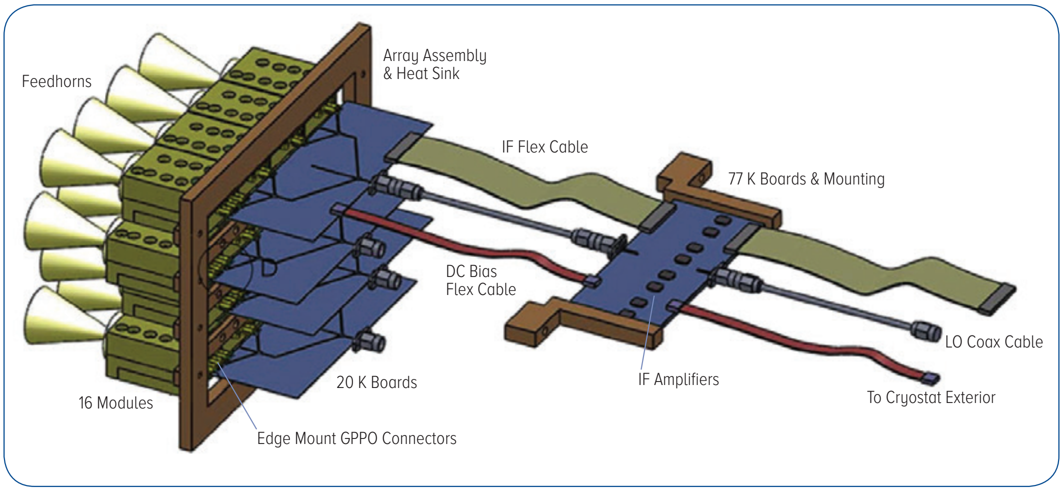
All GBT receivers were available for the Semester 2012A and Semester 2012B Calls for Proposals, from 290 MHz through 99 GHz. Available observing modes were spectral line (including cross-polarization), continuum, pulsar, and VLBI/VLBA. The VLBA back end with Mark5A disk recorder became available in 2 Gps mode on the GBT at the end of 2012. The 67-93.5 GHz (4mm) dual feed receiver went into general science operation in 2012. New amplifiers significantly reduced the system temperature, resulting in excellent performance across the band.

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. Development projects underway in 2012 are summarized below.

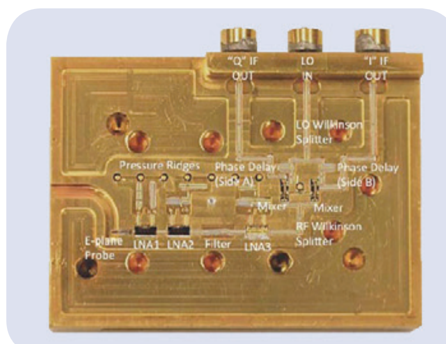
An FPGA-based spectrometer for the GBT, VEGAS (the Versatile Green Bank Astronomical Spectrometer) is being developmed by the University of Berkeley, the CASPER consortium, and the NRAO. Commissioning of the first observing modes for the VEGAS began in 2012. The remaining modes will be released in 2013, and VEGAS will be fully commissioned by the end of 2013.



ARGUS is a 16-pixel W-band (75-115.3 GHz) focal plane array is being developed for millimeter spectroscopy. The ARGUS development team includes scientists from Stanford, Caltech, JPL, Univ. Miami, Univ. Maryland, and NRAO. The array architecture is designed as a scalable technology pathfinder for larger arrays. The array's modular construction allows for the repair and easy replacement of malfunctioning or poorly performing elements. The ARGUS array fielded on the GBT will vastly improve mapping speeds and allow rapid surveys of substantial areas of the sky with high spectral resolution. ARGUS will address a wide-range of high-impact science: star-formation and cores, the interstellar medium, astro/bio-chemistry, filamentary structure in molecular clouds, and comets. Commissioning is scheduled for fall 2014.



[Above] *A concept drawing of ARGUS, a 16 pixel W-Band array. Mounting hardware to attach the array to the cryostat is not shown.* **[Right]** *The interior of a prototype receiver module, showing the components and their cavities. The input radio-frequency signal is via WR10 waveguide on the left.*



The Multiplexed Squid TES Array at Ninety GHz (MUSTANG) is a 64-pixel bolometer array that has been commissioned on the GBT. MUSTANG 1.5 is a prototype of a successor instrument that is under development and features 40-60 [TES + feedhorn] pixels, provides 30-50x the mapping speed and 4x the field-of-view. MUSTANG 1.5 is a collaboration of the Univ. Pennsylvania, NIST, and NRAO, and will be commissioned on GBT in fall 2013.

The Focal L-band Array for the GBT (FLAG) is a 19-element L-band phased array feed with a target system temperature of 20K that will also function as a pathfinder to a larger array. FLAG is a collaboration of Brigham Young Univ. and NRAO, and its initial commissioning run is scheduled for June 2013.

An 800 MHz array of 8-9 feedhorns operating at 700-945 MHz is in development as a collaboration of the University of Wisconsin, Academia Sinica Institute of Astronomy and Astrophysics (ASIAA), and NRAO. The primary science goal of this array is HI intensity mapping. Single pixel tests are scheduled for summer 2013, with a design review in August 2013.

SCIENCE SUPPORT & 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: (1) Telescope Time Allocation, (2) Science User Support, and (3) Science & Academic Affairs.

Telescope Time Allocation manages proposal preparation, submission, evaluation, and time allocation for the VLA, VLBA, and GBT, and associated activities. It uses staff from CV, SO, and GB, and is supported by tools and databases that are now developed and maintained by the Data Management & Software department. The past year, 2012, was the second year of a process wherein 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.

Science & Academic Affairs supports the research activities of NRAO scientific staff and related activities, specifically: (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; (f) student and visitor programs.

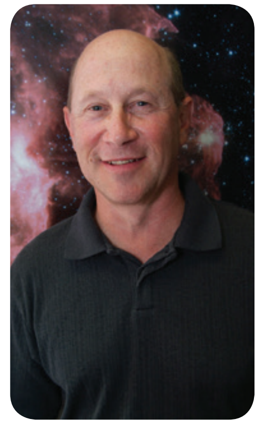
2012 NRAO Summer Students. **[Top]** Charlottesville, VA. **[Center]** Green Bank, WV. **[Bottom]** Socorro, NM.

NRAO received 167 applications for its summer 2012 internship program, and 25 summer student interns started in June in Socorro, Green Bank, and Charlottesville. The NSF Research Experiences for Undergraduates (REU) program supported 18 undergraduate students; the NRAO Undergraduate and Graduate Summer Student progams supported another seven undergraduate and graduate students. This was the 53rd year of the NRAO Summer Student Research Program, which has graduated more than 1,000 students since its inception. Fifteen of the 2012 NRAO summer students presented the results of their research projects at the January 2013 American Astronomical Meeting in Long Beach, CA.

In 2012, the Student Observing Support Program allocated its full budget target of $125,274 for NRAO semester 2012B; the Program allocated $124,599 to 11 proposals for Semester 2012A.

Visiting Astronomers in 2012 included Andreas Brunthaler (Max-Planck-Institut für Radioastronomie), who completed a one-year visit to Socorro. Christopher Stockdale (Marquette) visited Socorro for two months (June-July); D.J. Pisano (WVU) began a two-month visit to GB in June; and Paul Martini (Ohio State) started a one-year visit to the NAASC in June. Leslie Looney (Illinois) began a one-year visit to the NAASC in July; David Roberts (Brandeis) started a five-month visit to Socorro in August; Vernesa Smolcic (Argelander) and Sergei Gulyaev (Auckland) each visited Socorro for a week in Sep; Robert Mutel (Iowa) started a 3.5 month Socorro visit in September.

2012 Karl G. Jansky Lectureship



The Karl G. Jansky Lectureship is an honor established by the AUI trustees to recognize outstanding contributions to 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 47th annual Jansky Lecture was given in 2012 by Dr. Mark J. Reid of the Smithsonian Astrophysical Observatory and was entitled *Measuring the Cosmos*. Dr. Reid was honored for his pioneering work in Very Long Baseline Interferometry (VLBI) as applied to numerous key problems in astrophysics. Dr. Reid presented his Jansky Lecture in Charlottesville, VA on 2 November 2012; in Green Bank, WV on 5 November; and in Socorro, NM on 30 November.

Reid has been a world leader in the development and application of VLBI. He is widely recognized as the father of ultra-high precision VLBI astrometry, and he has used these techniques to answer some of the most important questions in astrophysics. Most recently, Reid's studies of maser emission from star forming regions has led to a detailed understanding of our Galaxy's three-dimensional structure. This work has revised the Galactic rotation velocity, re-defining the mass of the Milky Way. Reid has also played a key role in the first direct measurements of proper motions of Local Group galaxies – a technique that has the potential to revolutionize our understanding of the mass distribution within the Local Group and its Dark Matter content.

The First Year of ALMA Science

Nearly 200 astronomers converged on Puerto Varas, Chile 12 - 15 December for a conference titled *The First Year of ALMA Science* that discussed the many cutting-edge results emerging from ALMA Early Science data. The conference Science Organizing Committee, chaired by Leonardo Testi, crafted a program that demonstrated the breadth of ALMA's impact on astrophysics and featured major oral presentation sessions on the evolution of galaxies, the interstellar medium and star formation, the high-redshift Universe, solar system and protoplanetary disks, the local Universe, stellar evolution, and the future of ALMA science. Twice-daily poster sessions proved lively and helped maximize the conference's scientific impact. Ryohei Kawabe (NAOJ) and Al Wootten (NRAO) chaired a discussion session on the future of ALMA development and science on the final afternoon, and Neal Evans (Univ. Texas) wrapped up the conference with an excellent summary of the many presentations and posters. Though the conference focused on ALMA observational results, it also included presentations and discussions on related theory, as well as relevant complementary data from the VLA, VLBA, GBT, Herschel Space Observatory, Combined Array for Research in Millimeter Astronomy, Submillimeter Array, and the Institut de Radioastronomie Millimétrique.

2012 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. Three new Fellows joined the program in 2012.

Michal Drahus is hosted by Caltech as a Jansky Fellow. Michal received his Ph.D. in Astronomy and Astrophysics from the University of Goettingen. His interest is the properties of comets investigated with the modern tools of submillimeter astronomy. In particular, using time-resolved spectroscopy of cometary emission lines, he has studied the rotational dynamics and compositional structure of the nuclei of short-period comets. As a Jansky Fellow, he will extend this program to all classes of comets, with the ultimate goal to better understand the formation, evolution, and decay of these bodies. Michal is also excited about the new possibilities that have been recently opened for his research by ALMA.

Laura Pérez is taking her Jansky Fellowship at the NRAO in Socorro, New Mexico. Laura received her Ph.D. in Astrophysics from Caltech. Her research focuses on characterizing the environments where planets form: proto-planetary disks. As a Jansky Fellow she plans to exploit the high spatial resolution capabilities of the next generation of radio interferometers, the Jansky VLA and ALMA, to study several questions related to planet and star formation. She is currently studying one of the first steps toward planet formation: the growth of dust grains to pebbles inside proto-planetary disks, employing multi-wavelength observations that include Jansky VLA measurements. She will also study transitional disks, thought to be intermediate systems were planets might have already formed. She is very excited about her ALMA Cycle 0 observations that will study a sample of these objects to understand the origin of the observed cavities in transitional disks.

Chris Hales received his Ph.D. from Sydney University, and is taking his Jansky Fellowship at the NRAO in Socorro, New Mexico. During his Fellowship, Chris is using new radio polarimetry statistics to measure magnetic fields in three key environments: Galactic supernova remnants, the intra-cluster medium of galaxy clusters, and the intergalactic medium in the filaments of large scale structure. Chris proposes to use these observations to investigate properties of cosmic rays and turbulence, and to probe the origins of magnetism in galaxies and clusters using the techniques of radio astronomy and polarization.

2012 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 exciting research opportunities with NRAO facilities. Three Postdoctoral Fellows joined NRAO in 2012, working in areas directly related to the new capabilities provided by the Jansky Very Large Array and the Very Long Baseline Array.

Minnie Mao completed her Ph.D. at the University of Tasmania, where she has focused on studying the cosmic evolution of radio sources in the Australia Telescope Large Area Survey (ATLAS). Minnie plans on using the Jansky VLA, VLBA, and ALMA to understand the role of Active Galactic Nuclei (AGN) in the formation and evolution of galaxies, investigate different accretion modes, and disentangle star formation and AGN activity. Minnie has an extensive background in radio interferometry, and will be helping to develop and test the Jansky VLA calibration pipeline while in Socorro.

Walter Max-Moerbeck received his Ph.D. from Caltech, where he studied the high-energy emission mechanism in blazars through monitoring of large blazar samples at gamma ray and radio wavelengths. At NRAO Walter plans to develop the enhanced statistical analysis tools needed to understand further the relationship between radio and gamma ray emission from blazars, as well as using the Jansky VLA and VLBA for high resolution monitoring and imaging. While in Socorro he will also help to commission new capabilities on the VLBA.

Huib Intema received hi Ph.D. from Leiden University and was a Jansky Fellow at NRAO-Charlottesville, where his research focused on merging galaxy clusters, and proto-clusters associated with high redshift radio galaxies. Huib has also developed special data reduction techniques for wide-field calibration and imaging at low frequencies with direct application to Giant Meterwave Radio Telescope and Westerbork Synthesis Radio Telescope data. In Socorro he plans to extend these studies to the Jansky VLA, while helping to develop the wide-field, wide-band imaging and automated flagging algorithms needed to deliver the full capabilities of the telescope.

Common Astronomy Software Applications package

The Common Astronomy Software Applications (CASA) package strives to deliver the best calibration and imaging algorithms for ALMA, including single dish capabilities, and the VLA.

The CASA package can process both interferometric and single dish radio-wavelength astronomical data. CASA is developed by an international consortium of scientists, under the guidance of NRAO, based at the European Southern Observatory (ESO), the National Astronomical Observatory of Japan (NAOJ), the Commonwealth Scientific and Industrial Research Organisation – Australia Telescope National Facility (CSIRO–ATNF), the Netherlands Institute for Radio Astronomy (ASTRON), and NRAO. The CASA infrastructure consists of a set of C++ tools bundled together under an iPython interface as a set of data reduction tasks. This structure provides flexibility to process the data via task interface or as a python script. In addition to the data reduction tasks, many post-processing tools are available for even more flexibility and special purpose reduction needs.

Significantly improving ALMA observing efficiency was a major 2012 focus and the ALMA specification has been achieved. The latest CASA release is 4.0.1. CASA releases are downloaded by ~ 1500 unique IP addresses per release.

A major CASA Review is planned for 5-6 March 2013 in Socorro, NM with external and internal representation on the panel.

2012 NRAO Postdoctoral Symposium


Postdoctoral Fellows Symposium

The 8th NRAO Postdoctoral Fellows Symposium was held at the Domenici Science Operations Center in Socorro 26-28 March. This annual event brings together all the NRAO postdocs, including the non-resident and resident Jansky Fellows, to highlight their current research, share ideas, and establish collaborations. There were 25 participants this year, including 15 NRAO postdocs. Keynote speaker and former NRAO Jansky Fellow, Yancy Shirley (University of Arizona), presented an exciting talk on *Bolocam Galactic Plane Survey: A census of embedded star formation in the Milky Way*. EVLA Project Scientist Rick Perley gave a review talk on the Jansky VLA capabilities, scientific prospects, and possibilities in the near future before a tour to the telescope site. With spontaneous participation and interaction, an impressive diversity of the presentation topics – from asteroids and comets to star formation in high redshift galaxies, and adequate time for social events – the three-day 2012 symposium was a great success.

Synthesis Imaging Workshop

The 13th NRAO Synthesis Imaging Workshop was held 29 May – 5 June in Socorro, NM. Most of the workshop was held at the Workman Center on the campus of the New Mexico Institute of Mining and Technology. The data reduction tutorials were partially held at NRAO's Domenici Science Operations Center. There were four days of lectures, two days of data reduction tutorials, and two afternoons of observation preparation tutorials. Other events included a reception, workshop dinner, hikes of the Magdalena Mountains and the Bosque del Apache, and a popular tour of the Jansky VLA.

There were 156 registered participants from 20 countries. Over half (71%) the participants were graduate students; scientific and engineering staff (13%), postdocs (8%), undergraduates (6%) and faculty (2%) also attended.

The observation preparation tutorials were new. Students spent two afternoons 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 and/or ALMA data. The ALMA datasets were new: CO and HCO+ observations of the nearby T Tauri star TW Hydra; and a mosaic of the NGC 4038/39 Antennae interacting galaxy pair. The datasets and a CASA guide to reducing them are at http://casaguides.nrao.edu/.

Fourteen of the 24 lecturers were from NRAO. The other lecturers were from National Research Council Canada, the Netherlands's ASTRON, Harvard-Smithsonian Center for Astrophysics, New Mexico Tech, University of New Mexico, Purdue University, and Caltech.

There was a special treat on the last day of the workshop: the transit of Venus. All the participants were provided solar glasses and telescopes were set up outside the Science Operations Center and the Etscorn Observatory on the New Mexico Tech campus.

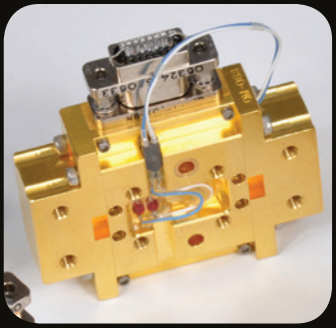
NRAO and AUI provided logistical and financial support and the majority of the lecturers. New Mexico Tech, particularly the Physics Department, provided their facilities and support. The University of New Mexico and the New Mexico Consortium at Los Alamos National Laboratory also provided financial support.

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.

Low Noise Amplifiers

The CDL has for the past 30 years provided NRAO and the astronomical community with the world's lowest noise amplifiers from 0.1-115 GHz. These low-noise amplifiers (LNAs) have not only been responsible for the high sensitivity and success of the VLA, GBT, VLBA, and ALMA, but they have been used by nearly every other astronomical instrument requiring cm-wave low-noise amplifiers built in the last 30 years, including Wilkinson Microwave Anisotropy Probe (WMAP), Combined Array for Research in Millimeter Astronomy (CARMA), Degree Angular Scale Interferometer (DASI), Cosmic Background Imager (CBI), Planck, and many others. The CDL continues to explore the limits of low-noise performance, so that future cm-wave and mm-wave instruments can be pushed to their ultimate sensitivity. In 2012, CDL developed new cryogenic LNAs for ALMA Band 1 ($\lambda \sim$ 7mm) and Band 2 ($\lambda \sim$ 4mm) using "chip-and-wire" technology with 80nm gate length InP transistors. In addition, the CDL has collaborated with Caltech and the NASA – Jet Propulsion Laboratory to demonstrate record low-noise performance for ALMA Band 2 using an advanced 35nm gate length InP MMIC process.



Cryogenic LNAs designed and produced at CDL are used in astronomical instruments around the world.

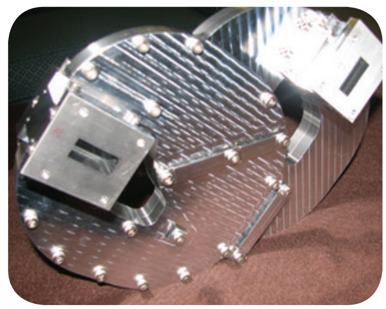
Millimeter and Sub-millimeter Receivers

CDL continued to play a major role in ALMA operations and development throughout 2012. This included delivery of the final Band 6 (λ ~ 1.2mm) receiver inserts, final local oscillator modules, and the final integrated receivers to the Atacama site.

The current generation of ALMA millimeter and sub-millimeter Superconductor-Insulator-Superconductor (SIS) receivers is the result of lengthy development at the CDL in collaboration with the University of Virginia Microfabrication Laboratory (UVML). This includes the introduction of niobium-based superconducting circuits for radio astronomy, development of wideband SIS mixer circuits and the use of sideband-separating SIS mixers that were pioneered at the CDL. In 2012, the CDL and UVML successfully demonstrated 385-500 GHz SIS mixers using AlN barriers. AlN barriers will allow the use of superconducting electrodes to support quantum-limited SIS mixers up to 1 THz and potentially beyond.

Electromagnetic Components and Optics

The design of the receiver optics and electromagnetic components – feeds, orthomode transducers (OMTs), polarizers, and phase shifters – is crucial to the sensitivity, beam quality, and polarization purity of NRAO's instruments. The CDL designs and builds these critical passive electromagnetic components. OMTs based on Boifot junctions have been in use in several NRAO receivers. The typical bandwidth ratio of this OMT is ≤1.5:1. This OMT has pins at the entry to the side ports and a septum in the main port that rejects the unwanted polarization. The CDL has developed an alternative simpler and wider-band turnstile-junction OMT, with no pins or septum. In 2012, CDL demonstrated and built this new turnstile junction OMT for the 11-18 GHz GBT galactic center pulsar receiver and for ALMA Band 1 (λ~ 7mm). This design is currently being scaled for use in ALMA Band 2 (λ~ 4mm).



An OMT designed and fabricated by the CDL for the Green Bank Telescope pulsar receiver.

Phased Array Feeds

To increase the speed at which large areas of the sky can be surveyed, it would be hugely beneficial to more fully populate and sample the focal plane of large radio telescopes. To determine if this can be done without sacrificing raw sensitivity is the long-term goal of this CDL research effort. A successful collaboration with Brigham Young University culminated in 2012 with demonstrating a world record low system noise of 35K for a phased array feed (PAF) at L-band (1.4 GHz) using a cryogenic PAF on the Green Bank 20m telescope. The effort will continue into 2013 with the goal of demonstrating this array on the GBT.

Digital Signal Processing

Essentially all new instrumentation development requires advanced digital signal processing (DSP). NRAO has a long tradition of providing complex DSP instrumentation for its telescopes, including the ALMA correlator that completed delivery in 2012, the Versatile Green Bank Astronomical System (VEGAS) backend for the GBT that initiated operations in 2012, the Green Bank Ultimate Pulsar Processing Instrument (GUPPI) pulsar searching/timing backend that supported innovative science throughout the year, and the VLBI Digital Backend. In 2012, CDL initiated an upgrade of the ALMA correlator to support phasing ALMA for Very Long Baseline Interferometry, enabling its participation in the Event Horizon Telescope.

Advanced Integrated Receivers

The extreme demands of future instrumentation and facilities, such as large-format focal plane arrays and the Square Kilometre Array, require innovative receiver architectures. These new designs must realize substantial improvements in cost, compactness, and power dissipation, while expanding the parameter space in either bandwidth or field-of-view, with little or no compromise in system noise temperature.

Following a path outlined in an Astro2010 Decadal Survey whitepaper, the CDL embarked in 2012 on the development of a highly integrated receiver beginning at the antenna feed terminals or waveguide, and ending in a digital data stream that may be delivered to any number of numerical signal processors. The signal will be digitized very close to the antenna output and sent via optical fiber to the central processing facility. Conventional electromagnetic polarization splitters will be largely replaced by much more accurate digital signal processing, and multiple frequency conversions will be replaced by a single mixer with high-isolation digital sideband separation. The precision of digital signal manipulation will be complemented by the stability of end-to-end electronic integration that breaks down the traditional barriers between analog, digital, and fiber optic subsystems. The result will be a high performance, compact, radio astronomy receiver with unusually smooth spectral baselines and low systematic errors after calibration.

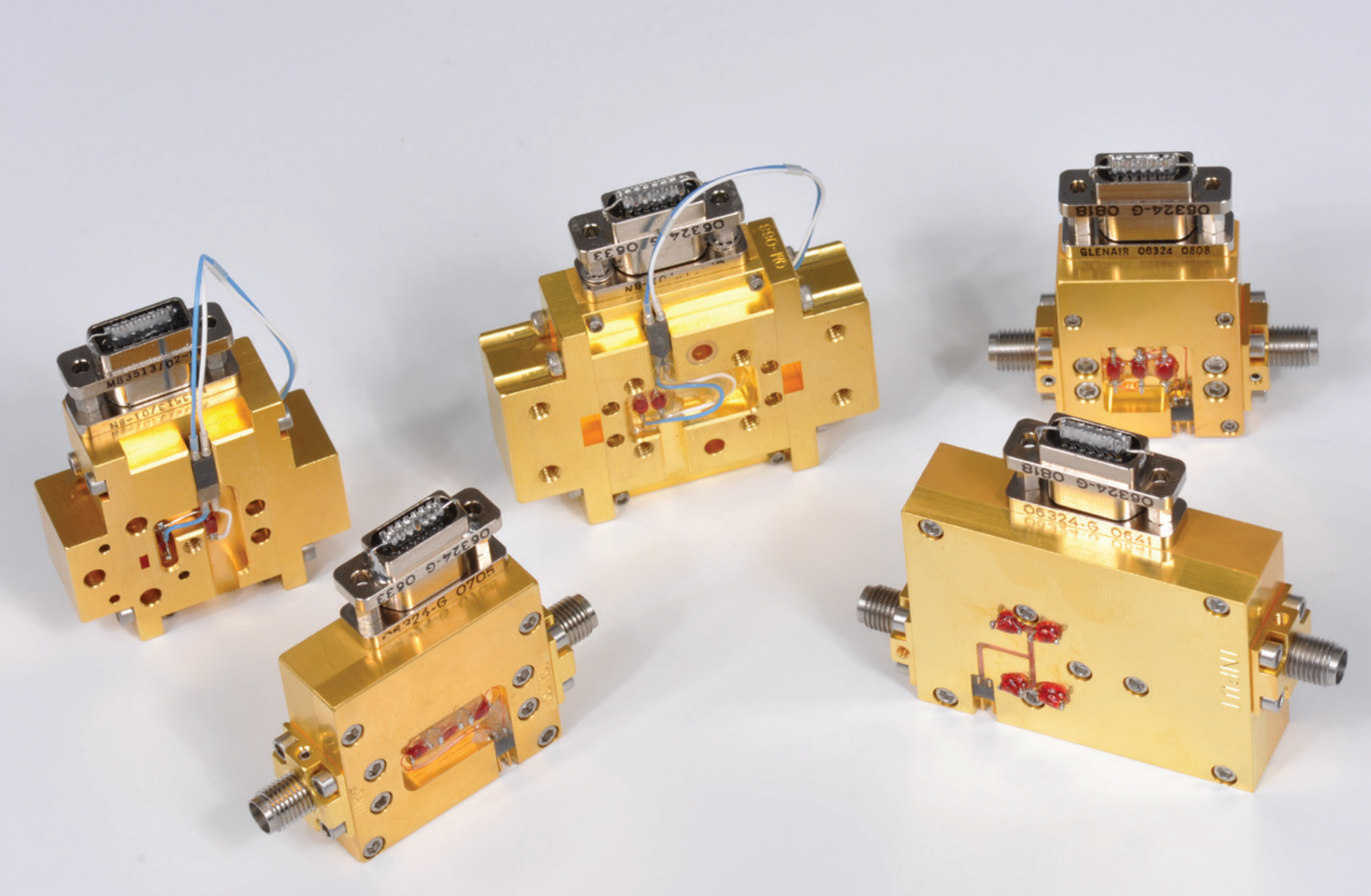
Characterizing Cosmic Dawn

In 2012, the CDL continued its collaboration with the community to formulate the next-generation North American low-frequency research facility. The emergence of the first stars and their host galaxies from the fabric of the largely featureless infant Universe is a key scientific goal endorsed by the Astro2010 Decadal Survey.

Senior CDL Research Engineer Rich Bradley instructs South African students on instrument operation and assembly during the PAPER deployment.

The Hydrogen Epoch of Reionization Array (HERA) road map is a strategy for achieving this goal that proposes building a staged sequence of instruments that will enable scientists to reveal and model the physical processes that led to the contemporary Universe. The CDL is a major institutional partner in HERA and is devoting scientific, technical, and managerial expertise to ensure its success. The Precision Array for Probing the Epoch of Reionization (PAPER) – a partnership between NRAO and UC-Berkeley, the University of Virginia, the University of Pennsylvania, and Square Kilometre Array (SKA) South Africa – is one of two HERA instruments under development.

A major NSF-AST grant was awarded to NRAO and its collaborators in 2012 to fund the expansion of PAPER from 64 to 128 antennas at the SKA South Africa reserve near Carnarvon.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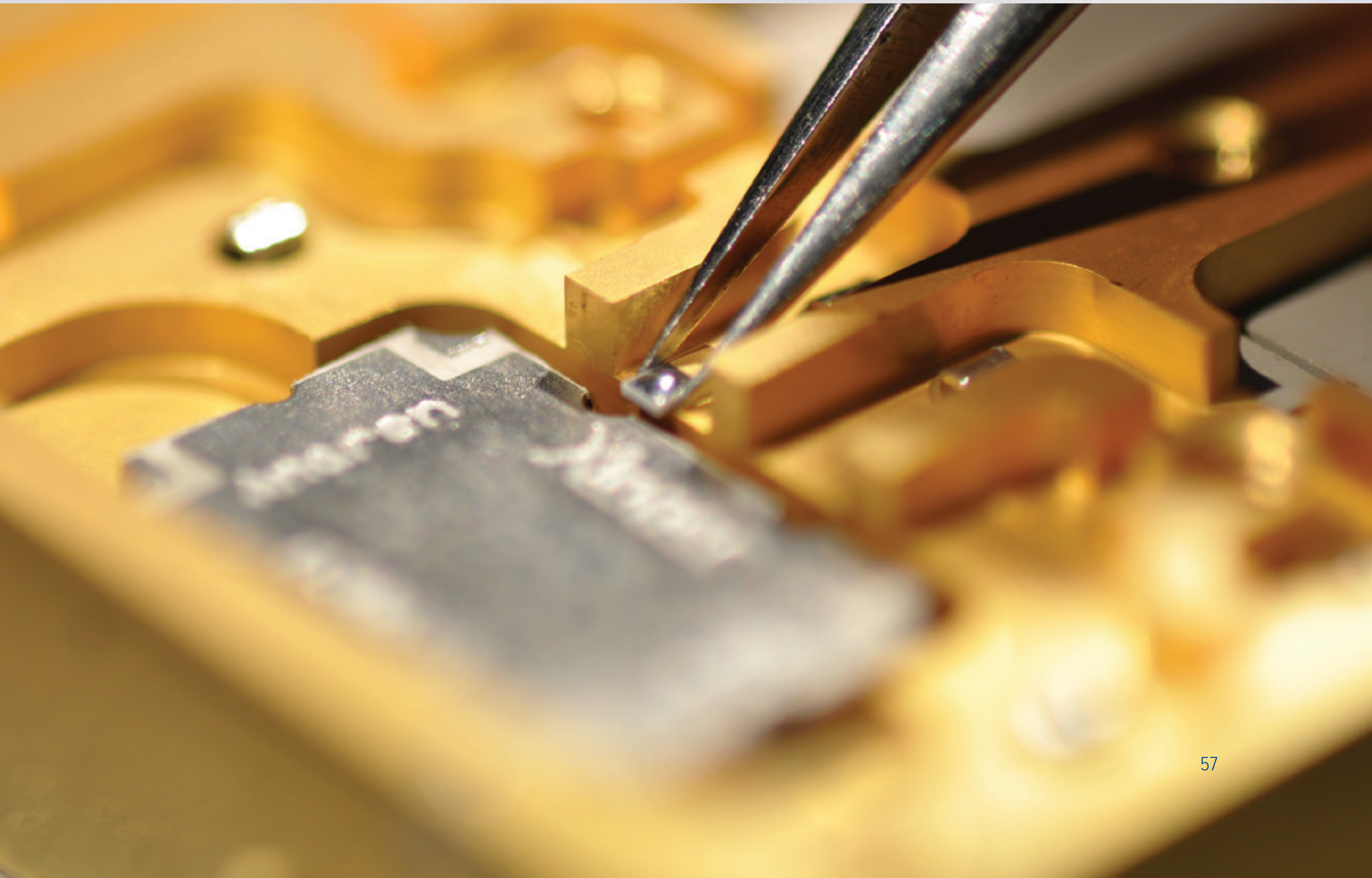


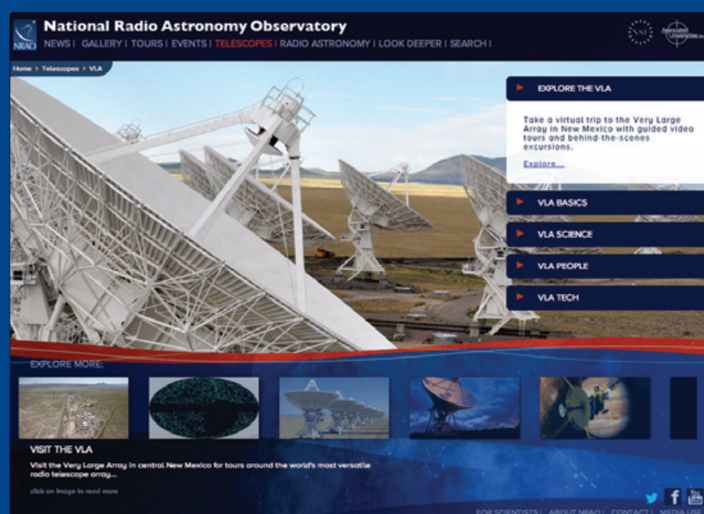
EDUCATION & PUBLIC OUTREACH

Education and Public Outreach (EPO) strives to inform the public nationwide about NRAO by communicating to sizeable audiences with NRAO news and other interesting information. EPO cultivates relationships with science and technology communicators with sizeable audiences to do the same, and supports them in doing so.

EPO seeks to contribute to the national science, technology, engineering, and mathematics (STEM) education effort by making NRAO resources accessible for use by students and teachers, and by offering genuine research experiences using large radio telescopes.

The past year has been very productive. A new EPO website (public.nrao.edu) is on track to debut in late 2013. The number of press releases was up 36% over 2011 and increasingly featured enhanced media. Several spectacular VLA images were also released. The NRAO social media audience increased, with Twitter and Facebook activity up 73% and 108%, respectively. The ALMA public television documentary was broadcast on multiple PBS stations across the US. A new Public Information Officer was hired for ALMA and GBT.

A new STEM curriculum development pilot project funded by AUI is underway in collaboration with the University of Colorado ¬Boulder and the University of Arizona. The grant-funded Pulsar Search Collaboratory expanded the geographic range of its participants, and the Radio Skynet Jr. Scholars STEM program, also grant-funded, was initiated. A new Education Specialist was hired for Green Bank, and an AUI-funded STEM Education Development Officer was hired in Charlottesville.



In honor of the VLA's re-dedication as the Karl G. Jansky Very Large Array, the NRAO Education and Public Outreach team launched the VLA Explorer, the latest in our Explorer series of interactive video tours. Like its cousin, the ALMA Explorer, the VLA Explorer showcases dozens of exclusive videos acquired and edited by EPO to educate the general public about the engineering, astronomy, STEM careers, and operations of this unique radio telescope observatory. Both these and future Explorers are built in HTML5 for improved cross-platform stability (including mobile devices) and the ease of adding new and updated stops. Also, a new, full-color interpretive walking tour was installed on the VLA site, featuring key STEM topics, such as the electromagnetic spectrum, and new images from the VLA. A new interpretive film for the VLA Visitor Center, narrated by Jodie Foster, was completed and will debut in October, 2013.


ROBO.KIT

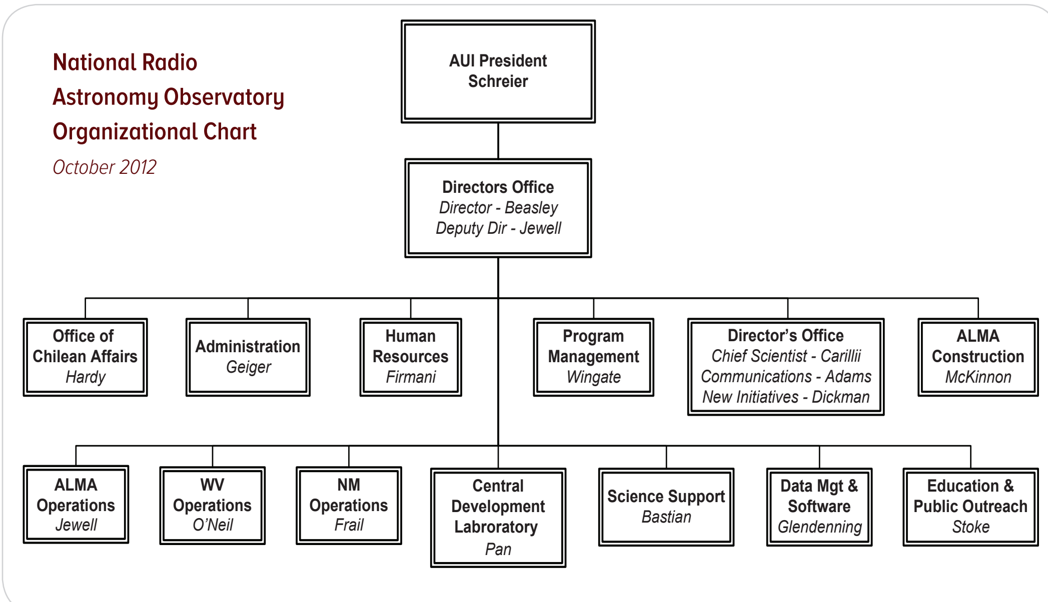
MANAGEMENT TEAM & ORGANIZATION

KARL G. JANSKY VERY LARGE ARRAY

Observatory Organization

A Director, a Deputy Director, an Associate Director and nine Assistant Directors form the senior management team that leads an NRAO staff of 499 persons.

A new, simpler Observatory organization was adopted in October: departments are made up of divisions, which are made up of groups. The Observatory Development & Programs management layer was removed. Site development programs now report to their respective Site Assistant Directors, and the Central Development Laboratory (CDL) again reports to the Director's Office. Day-to-day reporting and work assignment responsibilities for most NRAO employees were not impacted by the new organization, which emphasizes Observatory-wide management and coordination in key areas, including Program Management, Data Management and Software, and Science Support.



The AUI Board of Trustees unanimously voted at their February meeting to appoint Anthony (Tony) J. Beasley as NRAO Director, effective 21 May. Beasley succeeded Fred K.Y. Lo as Director.

Phil Jewell took on the role of North American (NA) ALMA Director in 2012. This key position 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 continues in a part-time role as Deputy Director.

Mark McKinnon is the Assistant Director for ALMA Construction and is responsible for the completion of all ALMA construction tasks for the North American Executive, including the production and delivery of the NA antennas, integrated front ends, front end and back end components, the Front End Handling Vehicles, the correlator, roads at the Array Operations Site in Chile, and construction software releases.

MANAGEMENT TEAM & ORGANIZATION

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; 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 by Assistant Director **Shing-Kuo Pan**, 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.

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.

Assistant Director **James Firmani** leads the Human Resources (HR) Department that supports the needs of Observatory's domestic and international staff. The core areas of HR responsibility include: compensation, diversity, employment, employee relations, the HR information systems, and AUI benefits support for NRAO staff.

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.

Lory Wingate, Director of the Program Management (PM) Department, which 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. NRAO Chief Scientist, **Chris Carilli**, also reports to the Director's Office.

NSF – AST PORTFOLIO REVIEW

In 2011, the NSF Division of Astronomical Sciences (NSF-AST) initiated a Portfolio Review, with the goal of maximizing progress on the science described in the *Astro2010* report –*New Worlds, New Horizons (NWNH)* – by balancing the recommendations for new facilities, instrumentation and programmatic enhancements with the capabilities enabled by existing facilities, grants programs, and other activities. A 17-person Portfolio Review Committee (PRC) was created in mid-2011 that included Daniel Eisenstein (Harvard) as Chair, and Joe Miller (Lick Observatory) as Vice-Chair.

NSF-AST established four conditions for the Portfolio Review:

1. All AST-funded facilities, grants programs, and other activities should be considered together with the *Astro2010* recommendations. The Review should be forward-looking and focus on the potential of all facilities, programs, and activities for delivering the desired capabilities and not on past performance.
2. The review should assume budget scenarios through 2025 provided by NSF-AST and consider the costs of delivering existing capabilities and programs, as well as new facilities, as determined by the *Astro2010* estimating processes.
3. The Review could not reopen debate on the *Astro2010* recommendations and science program.
4. The PRC had to take into consideration the national and international astronomy landscape, and the consequences of its recommendations for domestic and international partnerships, as well as for the state of the profession.

The Committee's recommendations, published in a 16 August 2012 Report, included that the NRAO Green Bank Telescope (GBT) and Very Long Baseline Array (VLBA) be fully divested from the NSF-AST portfolio of research facilities by 2017, with no further NSF funding.

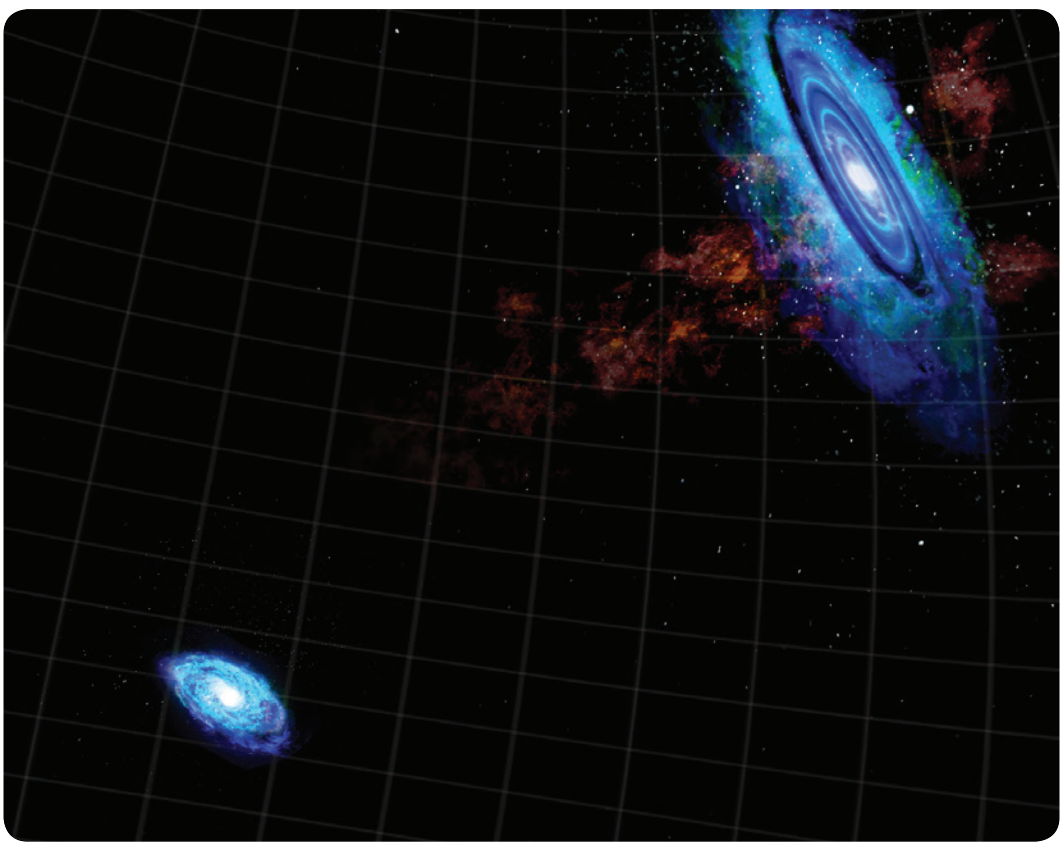
AUI and NRAO recognize and acknowledge the need to retire obsolete facilities to make way for the state-of-the-art. However, both the GBT and the VLBA remain the state-of-the-art, world leaders in their domains, and have crucial capabilities that cannot be provided by other facilities.


GBT

If implemented by NSF-AST, these recommendations would leave the US astronomy research community in a substantially weakened position. US leadership in radio astronomy would diminish, critical scientific capabilities that cannot be replaced with other existing open-access facilities in the US or elsewhere would be surrendered, and there would be a reduction of the university community's ability to train outstanding young scientists and engineers. A wide range of research programs that address high priority science themes would be prematurely terminated. Radio wavelength access for university faculty and students across the US would be severely reduced as over-subscription rates at the remaining facilities increased. Innovative GBT and VLBA instrument development programs underway or planned would be left unfinished, including development that sustains university instrumentation labs, fosters the next generation of radio wavelength instrumentation builders, and improves the science impact of existing NRAO telescopes.

The NRAO mission mandates the operation and development of forefront facilities. When NRAO facilities are no longer world leading, they are decommissioned. Thus, over the past two decades NRAO has retired several major observing facilities from the NSF funding portfolio, including the Green Bank Interferometer, the 140 Foot Telescope, and the 12 Meter Telescope. In addition, NRAO has secured partnership operations funding for the VLBA that amounts to a significant fraction of the total operations costs, and NRAO is actively seeking similar partnerships for the GBT.

NSF-AST is developing an implementation for the Portfolio Review recommendations that will be published in late 2013. Based on discussions with NSF and input from the broader community, AUI has developed alternatives to the divestment options recommended by the PRC that will continue the important work of these facilities while also benefiting all astronomy. AUI and NRAO continue to seek additional partnerships and alliances to support operations and the NRAO mission.

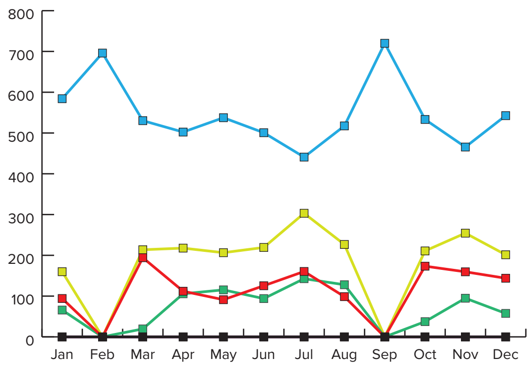


[Above] *The gas "bridge" between M31, right, and M33 (Bill Saxton, NRAO/AUI/NSF).*

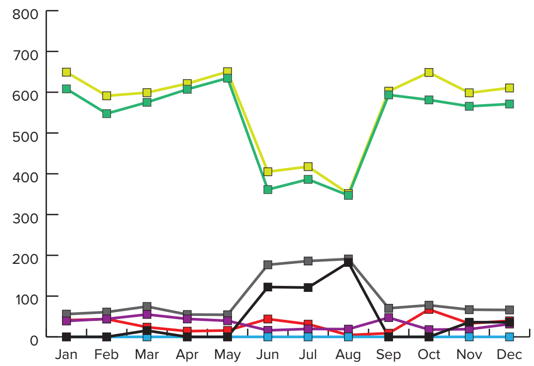
GBT

Observing Hours for 2012

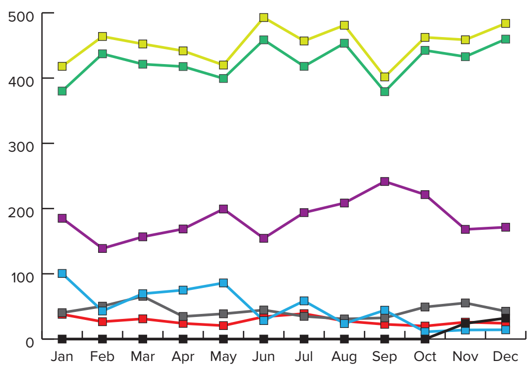
ALMA



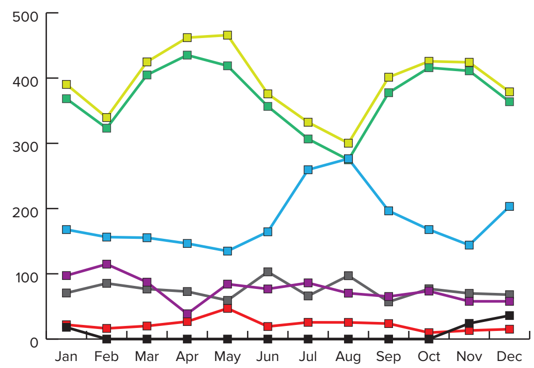
GBT



VLA



VLBA



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.

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

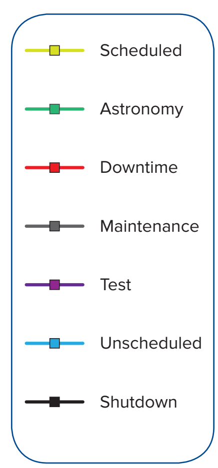
Downtime: Hours lost during scheduled observing time for peer-reviewed science proposals. Thus, Scheduled observing time = [Astronomy hours + Downtime hours]

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

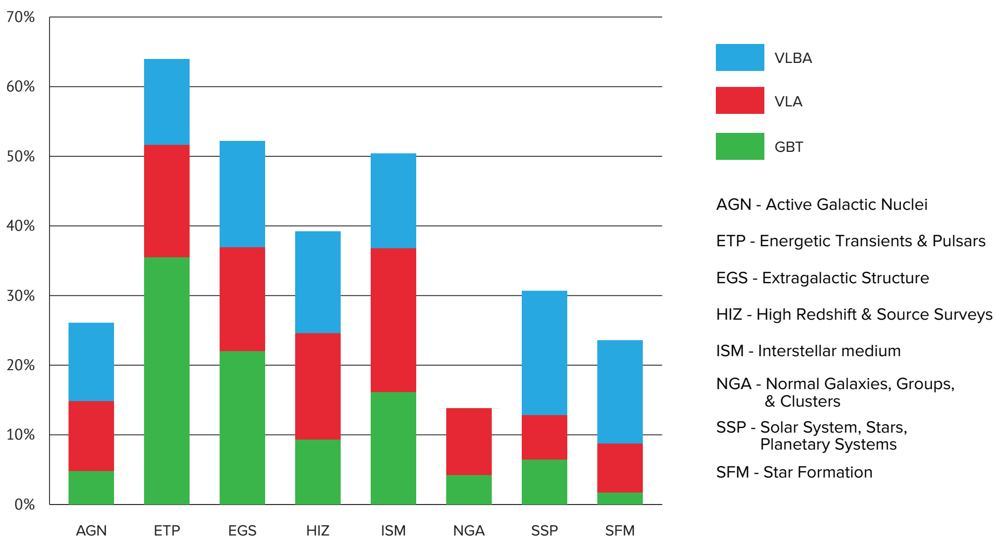
Test: Actual hours for test observations, rather than peer-reviewed science proposal observing.

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 or the VLA correlator installation.

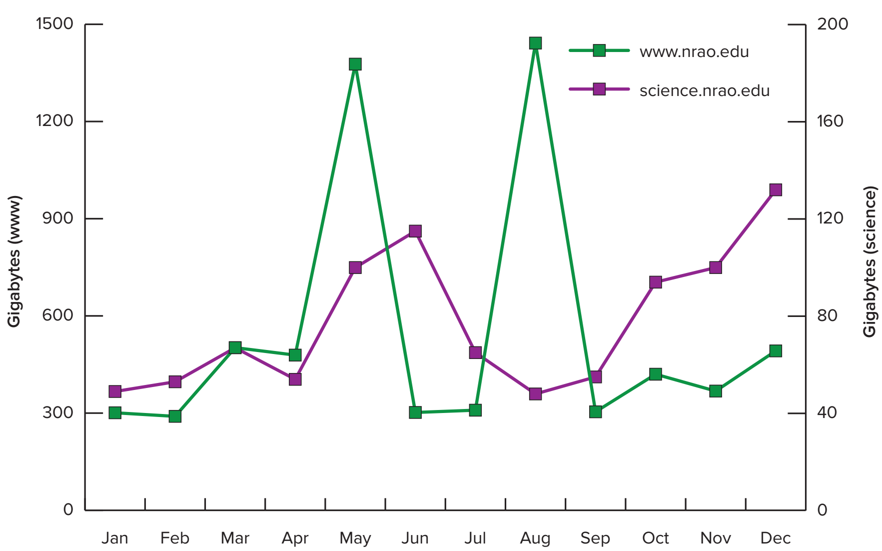


Observing Hours by Science Category



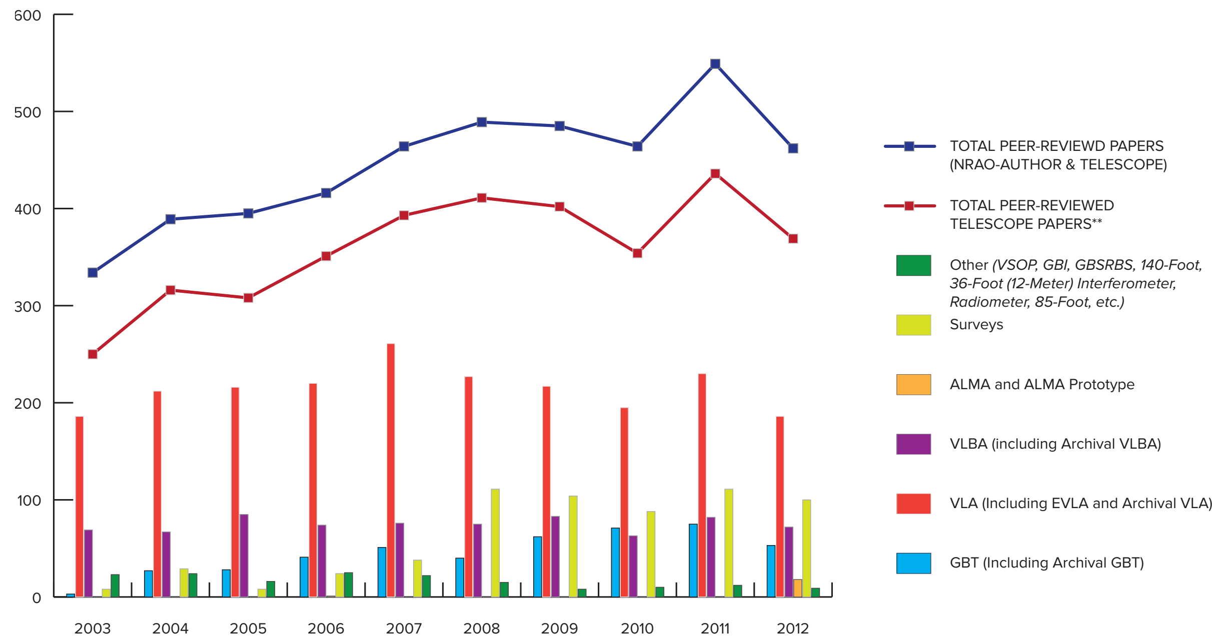
Observing hours for each of the GBT, VLA, and VLBA are tracked in the eight science categories that are included in the NRAO proposal evaluation and time allocation process.

NRAO Website Volume Served



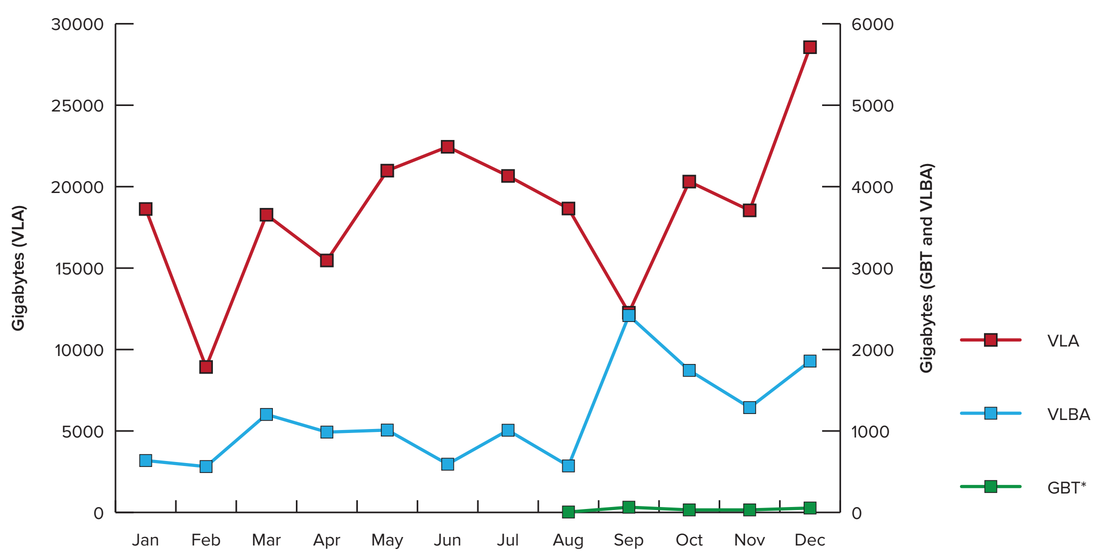
The www.nrao.edu website volume reflects activity for press releases and other online public information. The science.nrao.edu website volume reflects activity by scientists interested in submitting observing proposals or seeking other professional astronomical information about NRAO telescopes and facilities.

Refereed NRAO Telescope and Author Papers



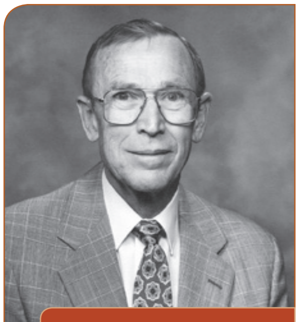
Total Peer-Reviewed NRAO-Author and Telescope Papers: *Peer-reviewed publications that include NRAO telescope data, plus peer-reviewed publications by NRAO scientific staff based on non-NRAO telescope data.* **Total Peer-Reviewed Telescope Papers:** *Peer-reviewed publications that include NRAO telescope data.* **Other:** *Peer-reviewed publications based on data from VLBI Space Observatory Program (VSOP), the Green Bank Interferometer (GBI), 140-Foot Telescope, 36-Foot (12-Meter) Interferometer, Green Bank Solar Radio Burst Spectrometer (GBSRBS), 85-Foot, etc.*

NRAO 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 science archive.

DAVE S. HEESCHEN (1926-2012)


DAVE HEESCHEN

It is with great regret that we report the death of our friend and colleague, former NRAO Director Dave Heeschen on Friday, 13 April 2012.

Dave is recognized as an outstanding scientist, an inspirational leader, and a giant in radio astronomy. During his time as NRAO Director, he built the Observatory into a world-leading organization that offered the science community access to state-of-the-art research facilities.

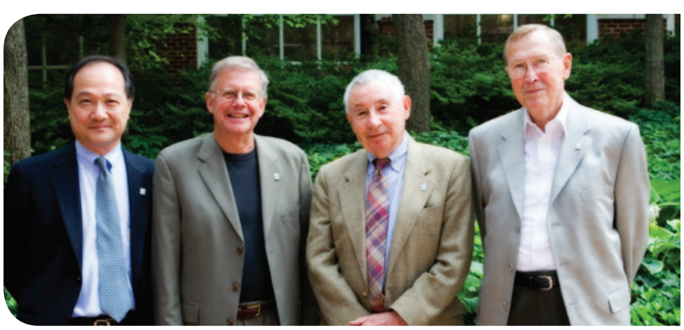
Dave began his association with Associated Universities, Inc. (AUI) during the early planning process for a national radio astronomy facility. He was an ardent supporter of the national observatories concept and became the third NRAO employee, beginning work 1 July 1956, five months prior to the signing of the AUI contract with the National Science Foundation to build and operate the Observatory. He served as Chair of the NRAO Astronomy Department, as Acting Director from 1961-1962, and as Director from 1962-1978.

Between his arrival at NRAO and the end of his time as Director, NRAO grew from an idea into the world center for radio astronomy. Under his leadership the 140-foot and 300-foot telescopes and the interferometer were completed in Green Bank, West Virginia, and the 36-foot telescope was built in southern Arizona. Probably Dave's greatest achievement was to obtain the authorization for and oversee the design and construction of the Very Large Array (VLA) in New Mexico. When he stepped down as Director, VLA construction was nearly complete, science observations were underway, and planning had begun for the Very Long Baseline Array.

Following his resignation as Director, Dave eagerly resumed his research on radio galaxies and AGN, but responded to requests to serve as Assistant Director for Tucson Operations, Assistant Director for Socorro Operations, and as Acting Project Manager during the initial work on the Green Bank Telescope. He retired from NRAO in December 1991, but continued to pursue his research and to advise on NRAO projects.

Born in Davenport, Iowa in 1926, Dave received his B.S. from the University of Illinois in 1949, and a Ph.D. in astronomy from Harvard in 1955. He received numerous honors and awards throughout his long career, including the Distinguished Public Service Award from the National Science Foundation, and the Alexander von Humboldt Senior Scientist Award. He was a member of the National Academy of Sciences, the American Academy of Arts & Sciences, and the American Philosophical Society. After retiring, Dave enjoyed time with his family and pursued his non-astronomical interests, including sailing with his friends and family, and amateur radio.

A memorial to celebrate the life of Dave Heeschen was held at NRAO on May 14.



[Left to right] *Fred Lo, Paul Vanden Bout, Morton Roberts, and Dave Heeschen: Charlottesville, September 2009.* **[Right]** *Dave Heeschen speaking at the 1980 dedication of the Very Large Array.*

APPENDIX A: PUBLICATIONS

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APPENDIX B: EVENTS & MILESTONES

8 – 12 January
219th American Astronomical Society meeting
Austin, TX
NRAO Town Hall
Special Session: *ALMA Cycle 0 Early Science and Capabilities for Cycle 1 Science*
Splinter Session: *Proposing to Use NRAO Telescopes*
Summer Student presentations
Undergraduate Orientation sponsor
Local Education & Public Outreach event sponsor
NRAO Exhibition

6 January
NRAO Semester 2012B Call for Proposals opens

1 February
NRAO Semester 2012B Call for Proposals submission deadline

17 February
American Association for the Advancement of Science (AAAS) Annual Meeting
Science Symposium organized by NRAO: *Pulsars: Astronomical Gifts That Keep on Giving*
Vancouver, British Columbia, Canada

19 February
American Association for the Advancement of Science (AAAS) Annual Meeting
Vancouver, British Columbia, Canada
Science Symposium organized by NRAO: *New Frontiers in the Radio Universe*

22 February – 1 March
2nd EVLA Data Reduction Workshop, Socorro, NM

23 – 24 February
AUI Board of Trustees meeting, Washington, D.C.

28 February – 1 March
NRAO Business Managers meeting, Charlottesville, VA

3 – 6 March
Outflows, Winds and Jets: from Young Star to Supermassive Black Holes
North American ALMA Science Center
Science Workshop
Charlottesville, VA

19 – 20 March
Visiting Committee Site Visit
Charlottesville, VA

26 – 28 March
NRAO Postdoc Symposium
Socorro, NM

30 March
Jansky Very Large Array Dedication
VLA site, NM

1 – 3 April
Global Properties of HI in Galaxies Workshop
Green Bank, WV

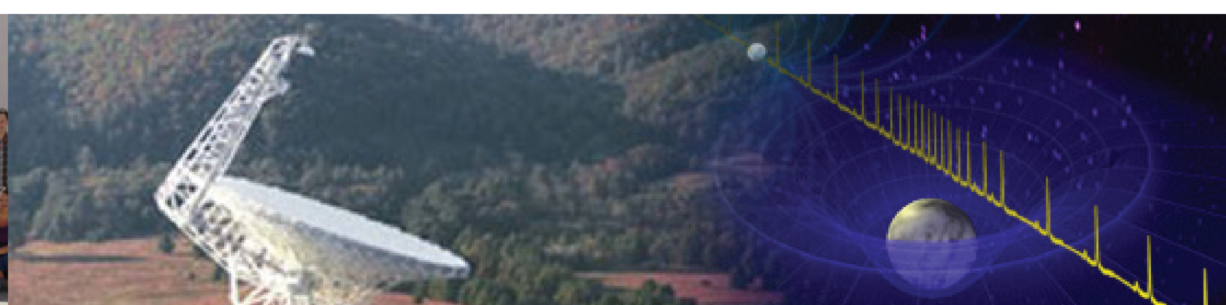
18 April
AUI Executive Committee meeting
Washington, D.C.

24 – 26 April
NSF Large Facilities Operations Workshop
Michigan State University

15 May
ALMA Cycle 1 Early Science Notice of Intent Deadline

16 – 17 May
Visiting Committee Meeting
Green Bank, WV

21 May
New NRAO Director Anthony (Tony) J. Beasley
Charlottesville, VA



21 – 22 May
Users Committee Meeting, Socorro, NM

29 May – 5 Jun
Synthesis Imaging Workshop
Socorro, NM

31 May
ALMA Cycle 1 Call for Proposals opens

10 – 14 June
220th American Astronomical Society meeting
Anchorage, AK
Special Session:
ALMA Early Science Results & Opportunities
Undergraduate Orientation sponsor
Local Education & Public Outreach event sponsor
NRAO Exhibition

11 – 12 June
NRAO Proposal Planning Webinar

14 – 15 June
AUI Board of Trustees meeting
Ithaca, NY

2 – 20 July
Santa Fe Cosmology Workshop
Santa Fe, NM

9 July
NRAO Semester 2013A Call for Proposals opens

12 July
ALMA Cycle 1 Call for Proposals deadline

19 – 20 July
AUI Management Review
Arlington, VA
National Science Foundation

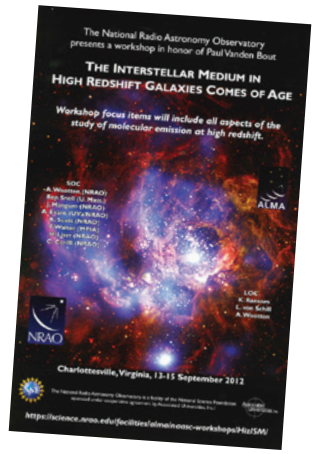
1 August
NRAO Semester 2013A Call for Proposals deadline

13 – 18 August
CASPER Workshop
Green Bank, WV

20 – 31 August
International Astronomical Union XXVIII General Assembly
Beijing, China

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

13 – 15 September
The Interstellar Medium at High Redshift Galaxies Comes of Age
Charlottesville, VA



18 – 19 October
AUI Board of Trustees meeting
Charlottesville, VA

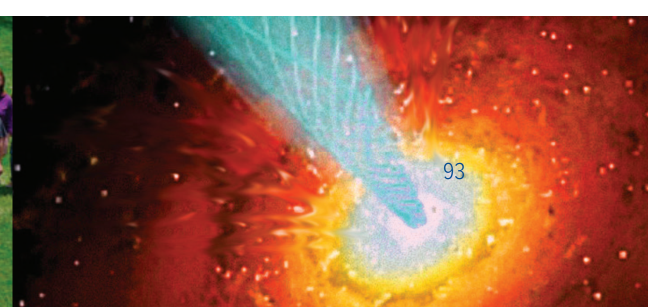
28 – 31 October
Molecular Spectroscopy in the Era of Far-IR Astronomy
Atlanta, GA

2, 5 and 30 November
47th Karl G. Jansky Lecture
Dr. Mark Reid (Harvard-Smithsonian Center for Astrophysics)
Charlottesville, VA; Green Bank, WV; Socorro, NM

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

6 – 7 December
National Science Foundation Program Review
Arlington, VA

12 – 15 December
The First Year of ALMA Science
Puerto Varas, Chile



APPENDIX C: COMMITTEES

Users 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 astronomy community's use of NRAO research facilities and makes recommendations that maximize the Observatory's scientific productivity and improve its effectiveness. The Users Committee holds an annual face-to-face meeting in the spring and periodic teleconferences. The current members of the committee, their home institution, and their last year of service follow.

Edwin Bergin
University of Michigan
2012

Helene Courtois
University Lyon France
2014

Mark Devlin
University of Pennsylvania
2014

Eric Feigelson
Pennsylvania State University
2012

Mark Heyer
University of Massachusetts
2013

Fredrick Jenet
University of Texas, Brownsville
2014

Sarah Church
Stanford University
2014

Jeremy Darling
University of Colorado – Boulder
2015

Sheperd Doeleman
MIT Haystack Observatory
2015

Gregg Hallinan
Caltech Astronomy
2015

Hiroshi Imai
Kagoshima University
2012

James Miller-Jones
ICRAR Curtin University
2015

Karin Öberg
Harvard-Smithsonian, CfA
2015

Gordon Richards (Co-Chair)
Drexel University
2013

Aneta Siemiginowska
Harvard-Smithsonian, CfA
2013

David J. Thompson
NASA – Goddard Space
Flight Center
2013

Ue-Li Pen
CITA – University of Toronto
2014

Eva Schinnerer
Max-Planck-Institut für Astronomie
2014

Michael Skrutskie
University of Virginia
2013

David Wilner (Co-Chair)
Harvard-Smithsonian, CfA
2012

Visiting Committee

To assist the AUI Board of Trustees and provide a wide spectrum of expertise, a Visiting Committee composed of leading scientists in the areas of interest to NRAO is charged with the task of reviewing and appraising the work carried out under AUI's management. The Committee members are appointed by the AUI Board of Trustees and include distinguished scientists from public and private, national and international scientific communities external to AUI facilities. The Committee conducts bi-annual meetings at alternating NRAO sites. The current members of the committee, their home institution, and their last year of service follow.

George Helou, Chair
Caltech
2013

Pierre Cox
IRAM
2013

Timothy Heckman
Johns Hopkins University
2012

Xiaoyu Hong
Shanghai Astronomical Observatory
2015

Ryohei Kawabe
Nobeyama Radio Observatory
2015

Robert C. Kennicutt
University of Cambridge
2012

Elizabeth A. Lada
University of Florida
2013

Malcolm Longair
University of Cambridge
2013

Maura McLaughlin
West Virginia University
2015

Suzanne Staggs
Princeton University
2015

APPENDIX C: COMMITTEES

ALMA North American Science Advisory Committee

The ALMA North American Science Advisory Committee (ANASAC) advises NRAO on issues relating to the scientific use of ALMA, including science requirements, user support, preparatory programs with other facilities, and/or providing access to new facilities in Chile, science during construction and commissioning, priorities for Chilean operations and development plans. The ANASAC is a conduit between NRAO and the North American community for disseminating information regarding ALMA construction and operations. ANASAC members are appointed from the North American astronomy community. The ANASAC holds an annual face-to-face meeting and teleconferences about every two months. The current members of the committee, their home institution, and their last year of service follow.

Edwin Bergin
University of Michigan
2014

Alberto Bolatto
University of Maryland
2014

Daniela Calzetti
University of Massachusetts
2014

John Carpenter, Chair
Caltech
2013

Richard Crutcher
University of Illinois
2013

Alyssa Goodman
Harvard-Smithonian CfA
2012

Kelsey Johnson
University of Virginia
2014

Francisca Kemper
ASIAA
2014

Leslie Looney
University of Illinois
2013

Amy Lovell
Agnes Scott College
2014

Michael Mumma
University of Maryland/GSFC
2013)

David Neufeld
Johns Hopkins University
2013

Rachel Osten
Space Telescope Science Institute
2013

Deborah L. Padgett
IPAC
2012

Douglas Scott
University of British Columbia
2014

Gordon Stacey
Cornell University
2012

Jonathan Williams
University of Hawaii
2012

David Wilner
Harvard-Smithonian CfA
2012

Time Allocation Committee

All observing proposals for the VLA, VLBA, and GBT submitted to NRAO by the community are evaluated by one of eight Science Review Panels (SRPs). The SRP produces a rank-order list of these observing proposals that is based on scientific merit. The NRAO Time Allocation Committee (TAC) consists of the eight SRP Chairs. The TAC cross-reconciles the individual SRP rankings, considers large proposals, and recommends observing time allocations for each semester on the VLA, VLBA, and GBT. The TAC meets face-to-face semi-annually, once for each NRAO observing semester. The following persons served on the NRAO TAC for Semesters 2012B and 2013A. The scientific purview of each member is indicated.

Mary Putman
Extragalactic Structure
Columbia University

Stephen White
Solar System, Stars, and Planetary Systems
Kirtland Air Force Base/ University of Maryland

Mike Eraculous (2013A only)
Active Galactic Nuclei
Pennsylvania State University

Richard Mushotsky (2012B only)
Active Galactic Nuclei
NASA – Goddard Space Flight Center

Russ Taylor
Normal Galaxies, Groups, and Clusters
University of Calgary

Mark Reid
Interstellar Medium
Harvard-Smithsonian Center for Astrophysics

Lee Mundy
Star Formation
University of Maryland

Nick Scoville
High Redshift and Source Surveys
California Institute of Technology

James Cordes
Energetic Transients and Pulsars
Cornell University

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	$1,150.2	$2,510.6	$725.5	$11,003.4	$2,097.5	$2,702.4	$5,926.4	$1,499.3						$27,615.3
Development Programs	$581.5	$1,730.7	$1,017.3	$1,849.6	$0.8	$0.0	$1.7	$2,851.0						$8,032.7
Director's Office	$0.0	$15.4	$0.0	$1,268.2	$99.5	$0.5	$1,903.1	$663.7						$3,950.5
Science Operations	$1,330.5	$1,710.3	$372.0	$5,999.6	$208.1	$83.5	$780.9	$2,180.6						$12,665.6
Telescope Operations	$4,688.1	$6,425.8	$3,509.9	$9,754.9	$211.6	$181.3	$74.6	($5.5)						$24,840.6
SPO-4 Solar Radio Burst Spectrometer									$32.3					$32.3
CSA-4 – RET/REU										$234.6				
ALMA Construction											$35,231.3			$35,231.3
EVLA Construction												$2,786.4		$2,786.4
External Grants													$4,600.1	$4,600.1
Grand Total	$7,750.2	$12,392.8	$5,624.8	$29,875.7	$2,617.6	$2,967.7	$8,686.9	$7,189.2	$32.3	$234.6	$35,231.3	$2,786.4	$4,600.1	$119,989.5

APPENDIX E: PRESS RELEASES

NRAO Education and Public Outreach issued 18 news releases and one image release in 2012. Each of these science and image releases is briefly recapped in this Appendix. Twelve of these NRAO news releases described exciting new science conducted with NRAO telescopes. Science results from ALMA, Jansky VLA, VLBA, and GBT were featured in six, three, two, and three of these science news releases, respectively.

Iconic Telescope Renamed to Honor Founder of Radio Astronomy

10 January

The world's most famous radio telescope will become the "Karl G. Jansky Very Large Array" to honor the founder of radio astronomy, the study of the Universe via radio waves naturally emitted by objects in space. The National Radio Astronomy Observatory (NRAO) announced the new name for the National Science Foundation's Very Large Array (VLA) at the American Astronomical Society's meeting in Austin, Texas. The new name will become official at a rededication ceremony at the VLA site in New Mexico on March 31.

Image: Karl G. Jansky (NRAO/AUI/NSF).

ALMA Early Science Result Reveals Starving Galaxies

11 January

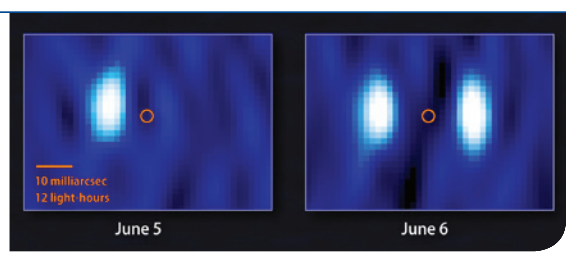
Astronomers using the partially completed ALMA observatory have found compelling evidence for how star-forming galaxies evolve into 'red and dead' elliptical galaxies, catching a large group of galaxies right in the middle of this change.

An artist's concept of an active supermassive black hole and its jet, with outflow of star-forming gases. (Wolfgang Steffen, Cosmovision; Marscher et al., NRAO/AUI/NSF).

VLBA, RXTE Team Up to Pinpoint Black Hole's Outburst

12 January

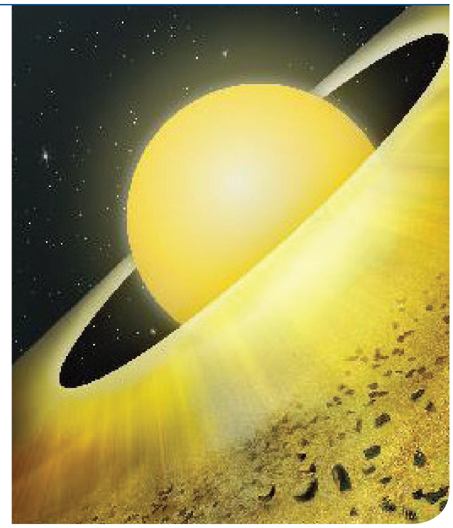
Astronomers have gained an important clue about a ubiquitous cosmic process by pinpointing the exact moment when gigantic "bullets" of fast-moving material were launched from the region surrounding a black hole. They made this breakthrough by using the ultra-sharp radio "vision" of the National Science Foundation's Very Long Baseline Array (VLBA), along with NASA's Rossi X-ray Timing Explorer (RXTE) satellite, to study an outburst from a system including a black hole and its companion star in 2009.



Black Hole H1743-322 Launches a Jet (NRAO, GSFC/NASA).

From Earth's Water to Cosmic Dawn: New Tools Unveiling Astronomical Mysteries
17 February

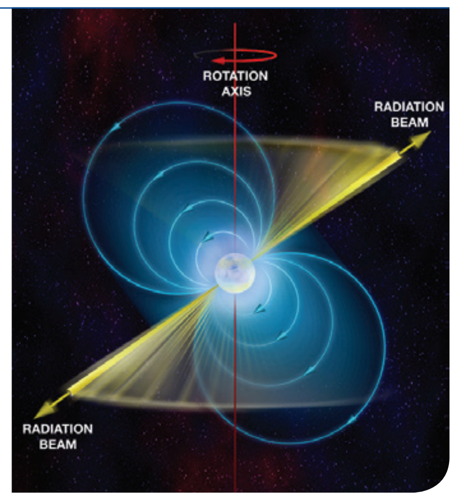
Two new and powerful research tools are helping astronomers gain key insights needed to transform our understanding of important processes across the breadth of astrophysics. The Atacama Large Millimeter/submillimeter Array (ALMA), and the newly expanded Karl G. Jansky Very Large Array (VLA) offer scientists vastly improved and unprecedented capabilities for frontier research.



Artist's Conception of Dusty Disk Around Young Star TW Hydrae (Bill Saxton, NRAO/AUI/NSF).

Pulsars: The Universe's Gift to Physics
19 February

Pulsars, superdense neutron stars, are perhaps the most extraordinary physics laboratories in the Universe. Research on these extreme and exotic objects already has produced two Nobel Prizes. Pulsar researchers now are poised to learn otherwise-unavailable details of nuclear physics, to test General Relativity in conditions of extremely strong gravity, and to directly detect gravitational waves with a "telescope" nearly the size of our Galaxy.



Pulsars are spinning neutron stars (Bill Saxton, NRAO/AUI/NSF).

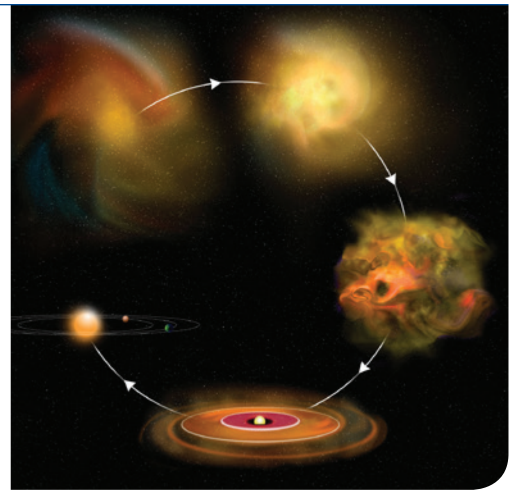
Anthony Beasley Appointed Director of NRAO
24 February

Anthony J. Beasley has been appointed as the next Director of the National Radio Astronomy Observatory (NRAO), according to Ethan J. Schreier, President of Associated Universities, Inc. (AUI). Beasley will succeed Fred K.Y. Lo, who has been NRAO Director since 2002.

Anthony J. Beasley (NRAO/AUI/NSF).

Astronomers Get Rare Peek at Early Stage of Star Formation
14 March

Using radio and infrared telescopes, astronomers have obtained a first tantalizing look at a crucial early stage in star formation. The new observations promise to help scientists understand the early stages of a sequence of events through which a giant cloud of gas and dust collapses into dense cores that, in turn, form new stars.



New observations show 'pristine' example of second stage of star formation shown in this graphic. (Bill Saxton, NRAO/AUI/NSF).

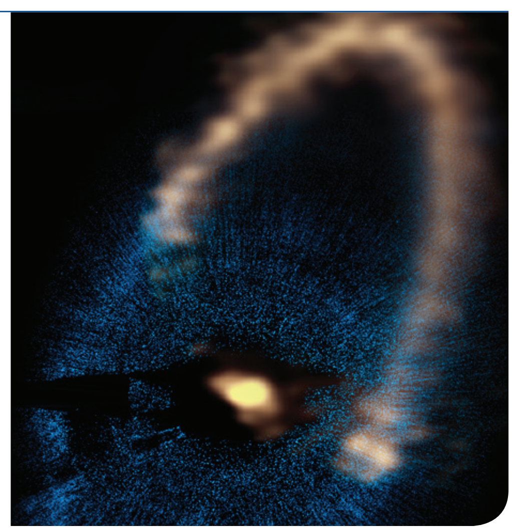
Famous Radio Telescope Officially Gets New Name
31 March

Astronomers and officials from around the globe gathered on the high desert of New Mexico Saturday to officially bestow a new name on the world's most famous radio telescope and to mark its transformation into a new and vastly more powerful tool for science. The iconic Very Large Array (VLA) now is the Karl G. Jansky Very Large Array, honoring the founder of radio astronomy.

NRAO Director Fred Lo, at podium, commands the start of first official observation of the Jansky VLA. Seated: Erica Sichler, Rep, Pearce's office; Ethan Schreier, AUI President; James Ulvestad, NSF Astronomical Sciences Division Director. (Dave Finley, NRAO/AUI/NSF).

ALMA Reveals Workings of Nearby Planetary System
12 April

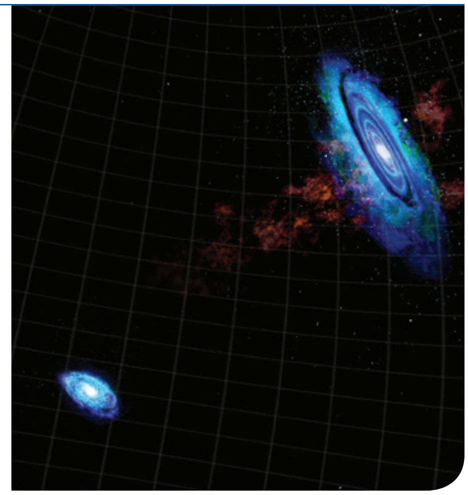
A new observatory still under construction has given astronomers a major breakthrough in understanding a nearby planetary system that can provide valuable clues about how such systems form and evolve. The scientists used the Atacama Large Millimeter/submillimeter Array (ALMA) to discover that planets orbiting the star Fomalhaut must be much smaller than originally thought.



Fomalhaut dust ring: ALMA image in yellow; Hubble Space Telescope image in blue.

Neighbor Galaxies May Have Brushed Closely, Astronomers Find
11 June

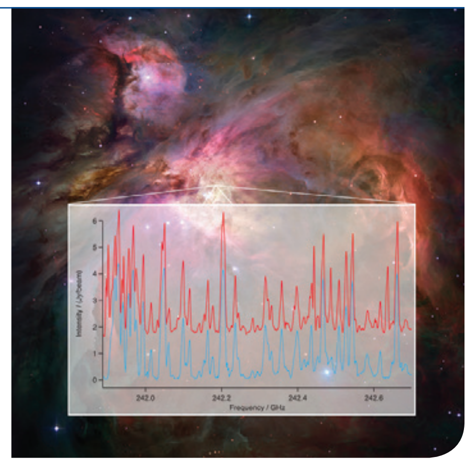
Two of our Milky Way's neighbor galaxies may have had a close encounter billions of years ago, recent studies with the National Science Foundation's Green Bank Telescope (GBT) indicate. The new observations confirm a disputed 2004 discovery of hydrogen gas streaming between the giant Andromeda Galaxy, also known as M31, and the Triangulum Galaxy, or M33.



The gas "bridge" between M31, right, and M33 (Bill Saxton, NRAO/AUI/NSF).

Astrochemistry Enters a Bold New Era with ALMA
20 September

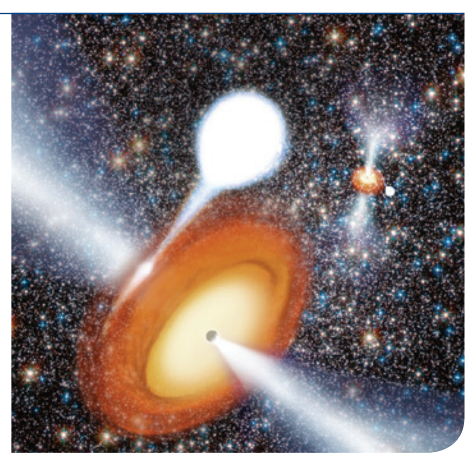
Combining the cutting-edge capabilities of the ALMA telescope with newly-developed laboratory techniques, scientists are opening a completely new era for deciphering the chemistry of the Universe. A research team demonstrated their breakthrough using ALMA data from observations of the gas in a star-forming region in the constellation Orion.



Laboratory (blue) and ALMA (red) spectra of ethyl cyanide overlaid on a Hubble Space Telescope image of the Orion Nebula.

Surprising Black-Hole Discovery Changes Picture of Globular Star Clusters
3 October

An unexpected discovery by astronomers using the National Science Foundation's Karl G. Jansky Very Large Array (VLA) is forcing scientists to rethink their understanding of the environment in globular star clusters, tight-knit collections containing hundreds of thousands of stars.



Artist's conception of a black hole in a globular cluster (Benjamin de Bivort; Strader et al.; NRAO/AUI/NSF).

NRAO Scientist Named Editor of Respected Astronomy Journal

19 November

Jeffrey Mangum, a scientist at the National Radio Astronomy Observatory (NRAO) headquarters in Charlottesville, Virginia, has been appointed Editor of the *Publications of the Astronomical Society of the Pacific* (PASP), a peer-reviewed scientific journal. The tenth editor in PASP's 125-year history, Mangum will continue in his position on the NRAO's scientific staff, where he has worked full time since 1994.

Final North American ALMA Antenna Delivered

20 November

After an odyssey of design and construction stretching across more than a decade, North America has delivered the last of the twenty-five 12-meter-diameter dish antennas that comprise its share of antennas for the international ALMA telescope.

The final North American ALMA Antenna heads up to the Array Operations Site in Chile (NRAO/AUI/NSF, Carlos Padilla).

Image Release: A Radio-Optical View of the Galaxy Hercules A

29 November

Spectacular jets powered by the gravitational energy of a supermassive black hole in the core of the elliptical galaxy Hercules A illustrate the combined imaging power of two of astronomy's cutting-edge tools, the Hubble Space Telescope's Wide Field Camera 3, and the recently upgraded Karl G. Jansky Very Large Array (VLA) radio telescope in west-central New Mexico.

Credit: NASA, ESA, S. Baum and C. O'Dea (RIT), R. Perley and W. Cotton (NRAO/AUI/NSF), and the Hubble Heritage Team (STScI/AURA).

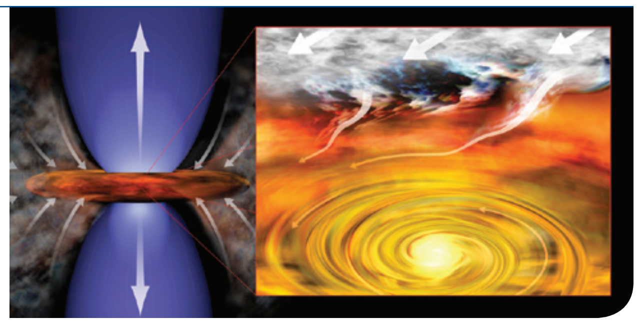
Brown Dwarfs May Grow Rocky Planets
30 November

Astronomers using the Atacama Large Millimeter/submillimeter Array (ALMA) have for the first time found that the outer region of a dusty disk encircling a brown dwarf contains millimeter-sized solid grains like those found in denser disks around newborn stars. The surprising finding challenges theories of how rocky, Earth-scale planets form, and suggests that rocky planets may be even more common in the Universe than expected.

Artist's conception of dusty disk around a brown dwarf [ALMA (ESO/NAOJ/NRAO)/M. Kornmesser (ESO)].

Astronomers Discover and "Weigh" Infant Solar System
5 December

Astronomers have found the youngest still-forming solar system yet seen, an infant star surrounded by a swirling disk of dust and gas more than 450 light-years from Earth in the constellation Taurus.



Artist's conception of infant solar system: young star pulls material from surroundings into rotating disk (right); generates outflowing jets of material (left) (Bill Saxton, NRAO/AUI/NSF).

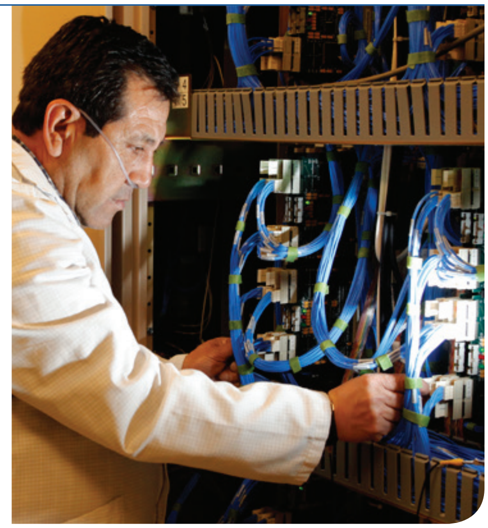
Microquasar Found in Neighbor Galaxy, Tantalizing Scientists
12 December

For the first time, astronomers have found a microquasar – a black hole devouring material from a companion star – in a galaxy beyond our own Milky Way. The object, pumping out X-rays and bright bursts of radio waves, was found in the Andromeda Galaxy, 2.5 million light-years from Earth.

The Andromeda Galaxy (M31): Crosshairs show location of microquasar (Robert Gendler, © 2005, with permission, http://www.robgendlerastropics.com).

Powerful Supercomputer Makes ALMA a Telescope
21 December

One of the most powerful calculating machines known to the civilian world has been installed and tested in a remote, high-altitude site in the Andes Mountains of northern Chile, marking one of the major remaining milestones toward completion of the most elaborate ground-based telescope in history, the Atacama Large Millimeter/submillimeter Array (ALMA).



Technician Juan Carlos Gatica checks electronics on the ALMA correlator while using supplemental oxygen at the high-altitude site (Carlos Padilla, NRAO/AUI/NSF).

APPENDIX F: ACRONYMS

Acronym	Definition
AAS	American Astronomical Society
ACA	Atacama Compact Array
AGN	Active Galactic Nucleus
AIV	Assembly, Integration, and Verification
ALMA	Atacama Large Millimeter Array
ANASAC	ALMA North American Science Advisory Committee
AOS	Array Operations Site (ALMA, Chile)
ARC	ALMA Regional Center
ASIAA	Academia Sinica Institute for Astronomy and Astrophysics
AST	NSF Divisional of Astronomical Sciences
ASTRON	Netherlands Institute for Radio Astronomy
ATLAS	Australia Telescope Large Area Survey
ATNF	Australia Telescope National Facility
AUI	Associated Universities, Incorporated
BE	Back End
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
CBI	Cosmic Background Imager
CDL	Central Development Laboratory
CfP	Call for Proposals
cm	centimeter
COM	Communications Office
CONAMA	La Comisión Nacional del Medio Ambiente (Chile)
CONIcyT	Comisión Nacional de Investigación Científica y Tecnológica (Chile)
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CV	Charlottesville, VA
DASI	Degree Angular Scale Interferometer
DDC	Digital Downconverter
DiFX	DIstributed FX correlator
DMSD	Data Management & Software Department
DSP	Digital Signal Processing
EAR	Export Administration Regulations
EPO	Education and Public Outreach
ESO	European Space Observatory
EVLA	Expanded Very Large Array
FASR	Frequency-Agile Solar Radiotelescope
FE	Front End
FEIC	Front End Integration Center
FLAG	Focal L-Band Array for the Green Bank Telescope
FPGA	Field-programmable Gate Array
FWHM	Full Width at Half Maximum
FY	Fiscal Year (October 1 through September 30)

GB. . . . . .Green Bank, WV
Gbps . . . . .Giga-bits per second
GBT. . . . . .Green Bank Telescope
GHz. . . . . .Gigahertz
GUPPI . . . . .Green Bank Ultimate Pulsar Processing Instrument
HERA . . . . .Hydrogen Epoch of Reinonization Array
HR. . . . . .Human Resources
HAS. . . . . .High Sensitivity Array
IAU . . . . .International Astronomical Union
IPT . . . . .Integrated Product Team
IRDC . . . . .Infrared Dark Cloud
ITAR . . . . .International Traffic in Arms Regulations
JAO. . . . . .Joint ALMA Office
JPL . . . . .Jet Propulsion Laboratory
kHz . . . . .kiloHertz
Kpc . . . . .kiloparsec
LNA. . . . . .Low Noise Amplifier
LO . . . . .Local Oscillator
LSM. . . . . .Local Staff Members
LSST . . . . .Large Synoptic Survey Telescope
LWA. . . . . .Long Wavelength Array
mas. . . . . .micro-arcsecond
MHz . . . . .Megahertz
MIT . . . . .Massachusetts Institute of Technology
mm . . . . .millimeter
MPIfR . . . . .Max Planck Institut für Radioastronomie
MS . . . . .Magellanic Stream
μJy . . . . .microJansky
MUSTANG. . . . . .Multiplexed SQUID/TES Array at Ninety Gigahertz
NA. . . . . .North American
NAASC .North American ALMA Science Center
NAOJ . . . . .National Astronomical Observatory of Japan
NASA . . . . .National Aeronautics and Space Administration
NIST . . . . .National Institute of Standards and Technology
NM . . . . .New Mexico
NRAO . . . . .National Radio Astronomy Observatory
NRC . . . . .National Research Council of Canada
NRL. . . . . .Naval Research Laboratory
NRQZ . . . . .National Radio Quiet Zone
NSF. . . . . .National Science Foundation
NUFO . . . . .National User Facilities Organization
NWNH. .2010 Decadal Survey report: New Worlds, New Horizons
OCA . . . . .Office of Chilean Affairs
OMT . . . . .OrthoMode Transducer
OPT. . . . . .Observation Preparation Tool

Acronym	Definition (continued)
OSF	Operations Support Facility (ALMA, Chile)
PAF	Phased Array Feed
PAPER	Precision Array for Probing the Epoch of Reionization
pc	parsec
PI	Principal Investigator
PMD	Program Management Department
PRC	Portfolio Review Committee
PST	Proposal Submission Tool
R&D	Research and Development
REU	Research Experiences for Undergraduates
RFI	Radio-Frequency Interference
RSRO	Resident Shared Risk Observing
SCO	Santiago Central Office
SIS	Superconductor–Insulator–Superconductor
SKA	Square Kilometre Array
SMA	Submillimeter Array
SMG	Submillimeter Galaxy
SOS	Student Observing Support
SRP	Science Review Panel
SSR	Science Support and Research
STEM	Science, Technology, Engineering, and Mathematics
submm	submillimeter
SUS	Science User Support
TAC	Time Allocation Committee
THz	TeraHertz
US	United States of America
USNO	United States Naval Observatory
WV	West Virginia
VA	Virginia
VAO	Virtual Astronomical Observatory
VEGAS	Versatile Green Bank Astronomical Spectrometer
VLA	Very Large Array
VLBA	Very Long Baseline Array
VLBI	Very Long Baseline Interferometry
WIDAR	Wideband Interferometric Digital Architecture Correlator
WMAP	Wilkinson Microwave Anisotropy Probe
WV	West Virginia
WVU	West Virginia University

ALMA OPERATIONS SUPPORT FACILITY

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NRAO - Green Bank

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NRAO - Pete V. Domenici Science Operations Center

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