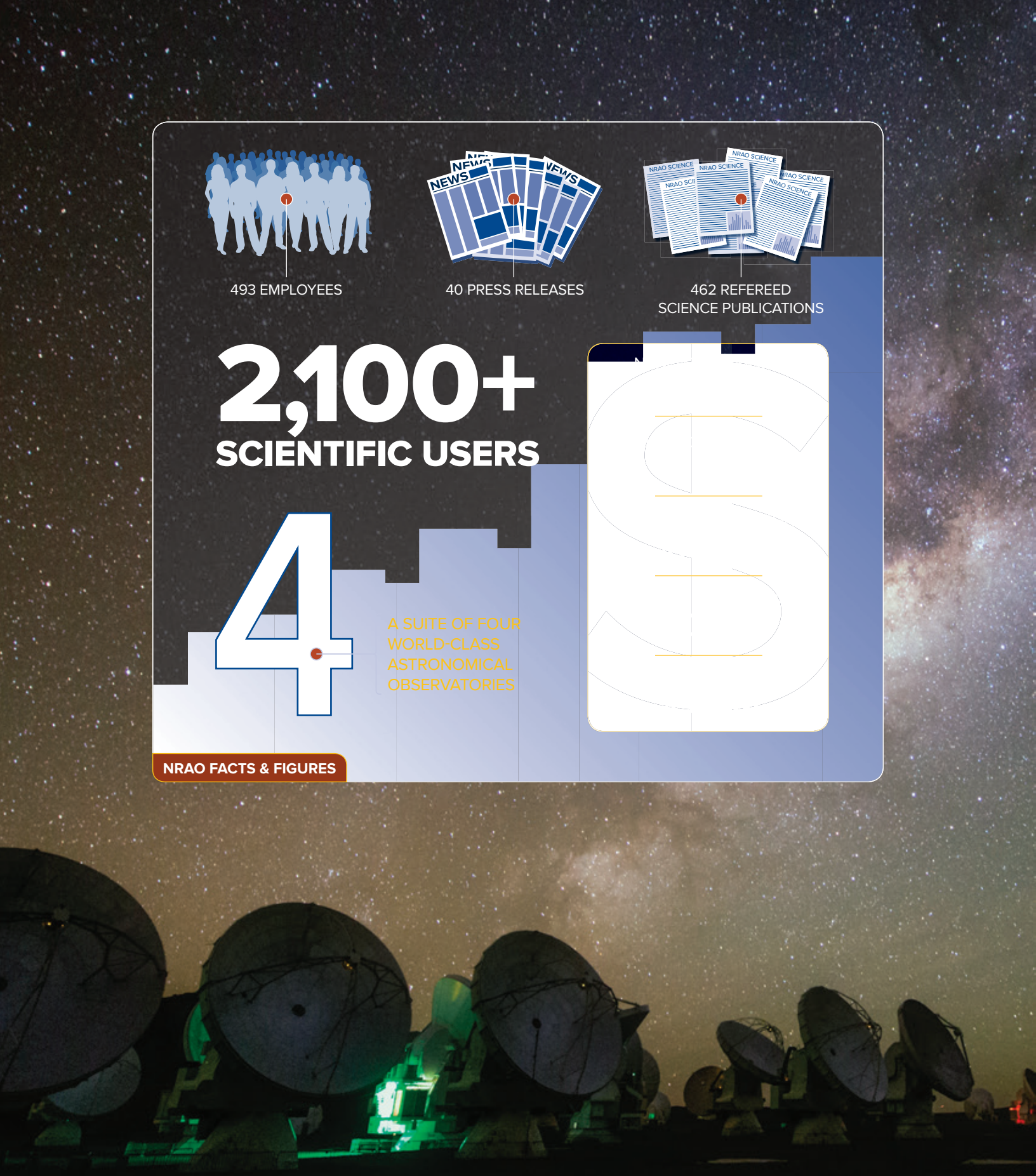
2013 ANNUAL REPORT

NRAO

NATIONAL RADIO
ASTRONOMY OBSERVATORY



493 EMPLOYEES

40 PRESS RELEASES

462 REFEREED SCIENCE PUBLICATIONS

2,100+ SCIENTIFIC USERS

4

A SUITE OF FOUR WORLD-CLASS ASTRONOMICAL OBSERVATORIES

NRAO FACTS & FIGURES

Contents

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

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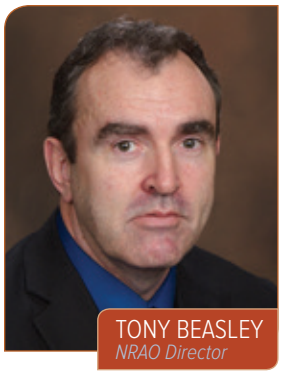
LEFT: *An international partnership between North America, Europe, East Asia, and the Republic of Chile, the Atacama Large Millimeter/submillimeter Array (ALMA) is the largest and highest priority project for the National Radio Astronomy Observatory, its parent organization, Associated Universities, 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.*

DIRECTOR'S REPORT



TONY BEASLEY
NRAO Director

As 2013 came to a close, we looked back on a challenging year with a sense of accomplishment.

An increasing number of astronomers employed NRAO telescopes in their research, and this research yielded a great deal of outstanding new science. We also explored important new technical developments, improved our administrative and support services, and continued to grow our communications with the science community, the public, and other key stakeholders. Our telescope proposal calls this year set new records for the numbers of requests received. We are moving in the direction of pipeline processing of our telescope data streams, a difficult but necessary transition. In March, the Atacama Large Millimeter/submillimeter Array (ALMA) Inauguration was held in Chile, capping more than a decade of work by the National Science Foundation (NSF), our parent organization, Associated Universities, Inc. (AUI), NRAO, and our international partners in Europe and East Asia. Across the Observatory we performed well in all areas, achieved more with less, and did an outstanding job following the plans for 2013 that we laid out the previous year.

We also had some unusually hard times in 2013. The October shutdown of the US Federal government was an unfortunate experience, and although – with the help of the NSF and AUI –most of the worst potential impacts were avoided, the uncertainty of this period will be hard to forget.

The NSF Portfolio Review remains a cloud on the horizon. In 2012, the NSF recommended divestiture of the Green Bank Telescope (GBT) and the Very Long Baseline Array (VLBA). They requested that NRAO seek new partners and sources of funding for these state-of-the-art instruments. During the past year, we have had some success in doing that for both instruments, with new contracts with West Virginia University, renewal with the U.S. Naval Observatory, and interest from other parties. NRAO and AUI remain confident that our efforts to secure partners for the instruments will continue to be successful, and we hope to meet the goals for partnering set by NSF in the coming year. This threat to NRAO facilities is not over, however.

Beyond routine operations, we continue to seek new business and involve ourselves in new initiatives. We are collaborating closely with partners around the world, including institutions in Chile, Germany, China, South Africa, Canada, Mexico, and elsewhere. Discussions are underway about new instruments in which NRAO could participate, with several significant options identified at low, medium, and high radio frequencies. Over the next several years, working closely with AUI and the scientific community, we will endeavor to be the go-to organization for collaborations planning the next generation of astronomical instruments. We are already well advanced in exploring new technologies which might have an enormous impact on the design of these future instruments, including lower-noise amplifiers, phased-array feeds, and more powerful signal detection and correlation systems. There are several good options in front of us for the Next Big Thing.

In the area of outreach, we have undertaken new initiatives in the areas of Citizen Science and a new Very Large Array (VLA) Visitor Center, as we have continued our world-class student programs. We are exploring options for a new all-sky VLA survey, building multi-pixel cameras for GBT, and continuing to develop new astrometric and spacecraft tracking capabilities for VLBA. The rapidly growing U.S. millimeter science community will enjoy more ALMA data as construction ends and full science operations ramp up.

The budget is tight, but we have a remarkable staff and the best facilities and instruments in the world. We are a strong organization, undertaking interesting and important work, and I am incredibly proud of who we are and what we do.

Brief Bio: *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 and rejoined NRAO in May 2012.*


ALMA


VLA

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 2013, NRAO operated a complementary suite of four world-class telescopes, each the world leader in its domain: the international Atacama Large Millimeter/submillimeter Array (ALMA), the Karl G. Jansky Very Large Array (VLA), the Robert C. Byrd Green Bank Telescope (GBT), and the Very Long Baseline Array (VLBA). Observing time on these telescopes is allocated solely on the scientific merit of the proposed research.

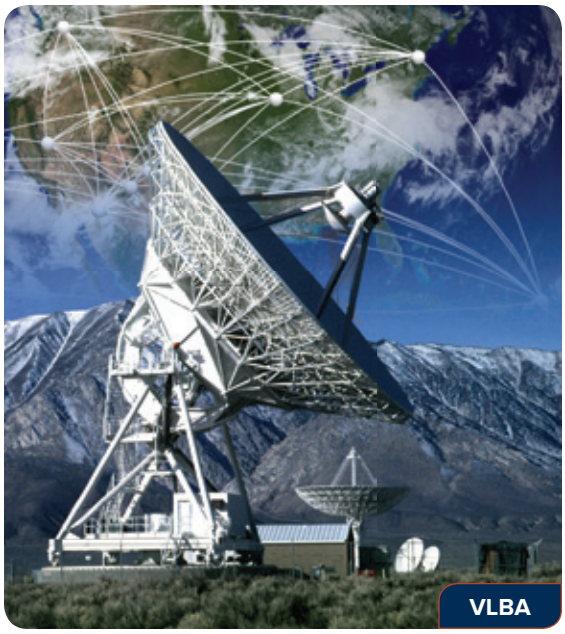
ALMA is the largest ground-based global astronomy endeavor in history. Composed of 66 high-precision antennas on an excellent, 5000m+ elevation site in northern Chile, ALMA is delivering orders of magnitude improvements in millimeter-wavelength sensitivity, frequency coverage, resolution, imaging, and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

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

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


GBT


VLBA

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.

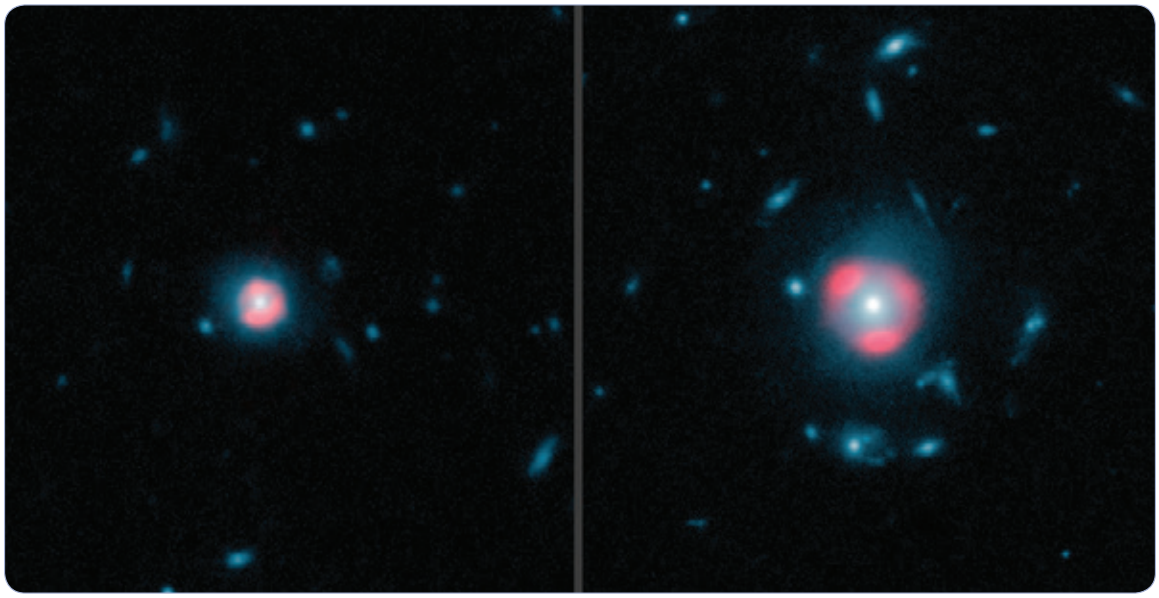
NRAO telescopes are serving the broad and diverse astronomy community and are enabling university researchers to address many of the most fundamental astrophysical questions of our time. Operating individually or synergistically with optical, infrared, and X-ray telescopes, NRAO is opening new frontiers over a broad range of modern astrophysics. The Observatory's 2013 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. NRAO science, technology, engineering, and mathematics (STEM) education programs are introducing numerous young people every year to the excitement and opportunities of STEM careers.

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

Dusty Starburst Galaxies in the Early Universe

Our understanding of galaxy evolution has been revolutionized by the discovery that luminous, dusty starburst galaxies were much more abundant in the early Universe than now. It has, however, been difficult to measure their complete redshift distribution, especially at the highest redshifts ($z > 4$). Vieira (Caltech) et al report on a redshift survey at $\lambda = 3$mm, targeting carbon monoxide line emission from the star-forming molecular gas in the direction of extremely bright mm-selected sources. High-resolution ALMA imaging demonstrates that these sources are strongly gravitationally lensed by foreground galaxies. The authors detect spectral lines in 23 of 26 sources and multiple lines in 12 of these 23 sources, obtaining robust redshifts. At least 10 of the sources are at $z > 4$, indicating that the fraction of dusty starburst galaxies at high redshifts is greater than previously thought. Models of lens geometries in the sample indicate that the background objects are ultra-luminous infrared galaxies, powered by extreme bursts of star formation.



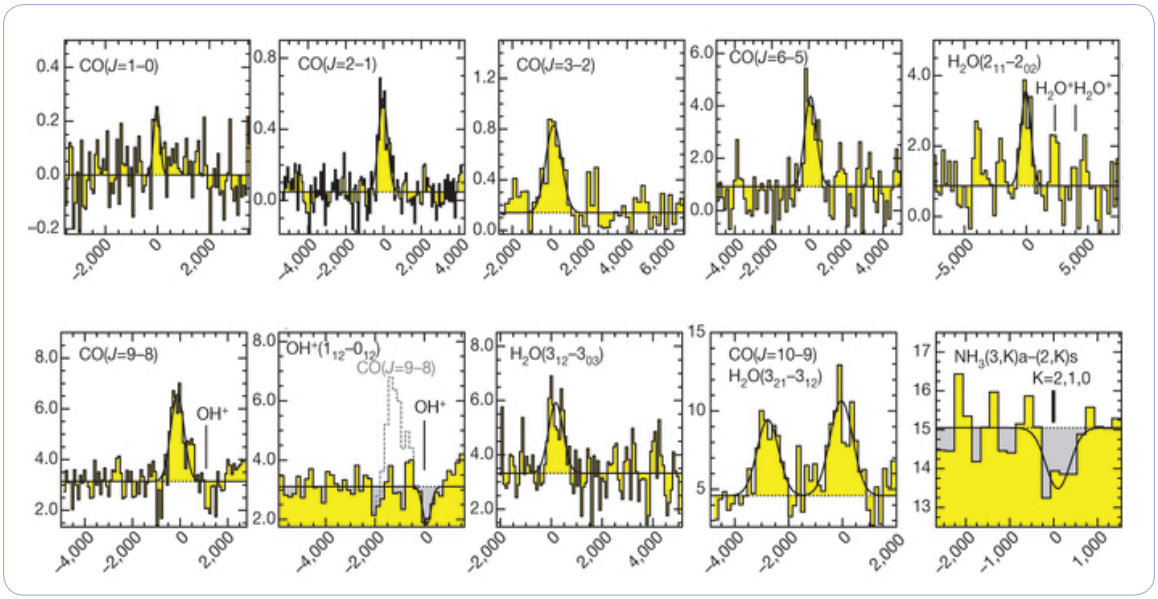
In these frames, a galaxy discovered by the South Pole Telescope has been observed and imaged with ALMA and the Hubble Space Telescope (HST). The massive central galaxy (in blue, seen by HST) bends the light of a more distant, submillimeter-bright galaxy, forming a ring-like image of the background galaxy that is observed by ALMA (red). Radiation from a distant galaxy is deflected due to the gravity of a massive, foreground galaxy, as predicted by Einstein's theory of general relativity. This effect makes the background galaxy appear as multiple magnified images surrounding the foreground galaxy. J. Vieira et al., ALMA (ESO, NAOJ, NRAO), NASA, NRAO/AUI/NSF.

Science Team: J. D. Vieira (Caltech), D. P. Marrone (Arizona), S. C. Chapman (Dalhousie, Cambridge), C. De Breuck (ESO), Y. D. Hezaveh (McGill), A. Weiβ (MPIfR), J. E. Aguirre (Pennsylvania), K. A. Aird (Chicago), M. Aravena (ESO), M. L. N. Ashby (CfA), M. Bayliss (Harvard), B. A. Benson (Chicago), A. D. Biggs (ESO), L. E. Bleem (Chicago), J. J. Bock (Caltech, JPL), M. Bothwell (Arizona), C. M. Bradford (JPL), M. Brodwin (Missouri), J. Carlstrom (Chicago), C. L. Chang (Chicago, Argonne), T. M. Crawford (Chicago), A. T. Crites (Chicago), T. de Haan (McGill), M. A. Dobbs (McGill), E. B. Fomalont (NRAO) et al.

Publication: *Dusty Starburst Galaxies in the Early Universe as Revealed by Gravitational Lensing,* 2013 Nature, 495, 344 (21 March 2013).

The Earliest Extreme Starburst

Massive present-day early-type galaxies likely gained the bulk of their stellar mass and heavy elements through intense, dust-enshrouded starbursts in the most massive dark-matter haloes at early epochs. However, it has been unknown how soon after the Big Bang massive starburst progenitors exist. Now, using a submillimeter color-selection technique, Riechers et al have identified and unambiguously determined the redshift to the earliest (z = 6.34) extreme starburst galaxy, HFLS 3, via observations of multiple molecular and atomic fine-structure lines with the Combined Array for Research in Millimeter Astronomy (CARMA), the Plateau de Bure Interferometer, the VLA, and the Caltech Submillimeter Observatory (CSO). This system represents the formation of a massive galaxy in an extreme starburst within 880 Myr of the Big Bang. These results demonstrate the power of centimeter through sub-millimeter spectroscopy to study the interstellar medium in the earliest galaxies, and determine redshifts for the earliest, highly dust-obscured galaxies.



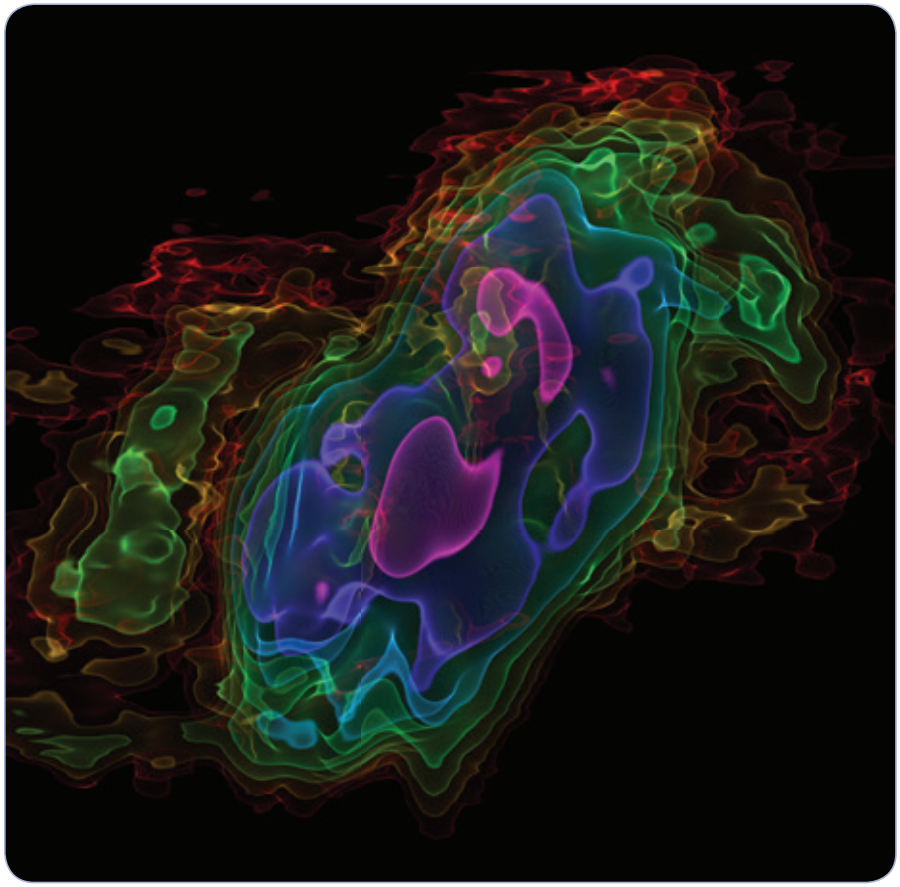
Detailed profiles of carbon monoxide (CO) lines in the spectrum of the galaxy HFLS 3. The line profiles are typically asymmetric relative to single Gaussian fits, indicating the presence of two principal velocity components at redshifts of 6.3335 and 6.3427. At these redshifts, the Universe was just 880 million years old.

Science Team: Dominik A. Riechers (Cornell), C. M. Bradford (Caltech), D. L. Clements (Imperial College), C. D. Dowell (JPL), I. Pérez-Fournon (Universidad de La Laguna), R. J. Ivison (UK ATC, Edinburgh), C. Bridge (Caltech), A. Conley (Colorado-Boulder), Hai Fu (UC-Irvine), J. D. Vieira (Caltech), J. Wardlow (UC-Irvine), J. Calanog (UC-Irvine), A. Cooray (UC-Irvine), P. Hurley (Sussex), R. Neri (IRAM), J. Kamenetzky (Colorado-Boulder), J. E. Aguirre (Pennsylvania), B. Altieri (Herschel Science Centre), V. Arumugam (Edinburgh), D. J. Benford (NASA-Goddard), M. Béthermin (CNRS), J. Bock (Caltech, JPL), D. Burgarella (CNRS), A. Cabrera-Lavers (Centro de Astrofísica de La Palma), S. C. Chapman (Cambridge) et al.

Publication: *A Dust Obscured Massive Maximum-Starburst Galaxy at Redshift 6.3,* 2013 Nature, 496, 329 (18 April 2013).

A Galaxy-scale Molecular Outflow

ALMA has imaged expanding molecular shells in the starburst nucleus of NGC 253 at 50 parsec resolution. The extra-planar molecular gas closely tracks the Hα filaments, and connects to expanding molecular shells located in the starburst region. The molecular outflow rate is 9 Solar Mass ($M_{\odot}$) per year, implying a ratio of mass-outflow rate to star-formation rate of ~3, indicating that the starburst-driven wind limits the star-formation activity and the final stellar content. These observations support the idea that the growth of large galaxies may be limited by strong wind-driven outflows.



A three-dimensional rendering of the carbon monoxide (CO) emission as observed by ALMA in the nearby starburst galaxy NGC 253. The colors in this rendering correspond to the intensity of emission – and therefore the amount of CO – from red (faint) to purple (bright). An animation of this dataset is available online at https://people.ok.ubc.ca/erosolo/post/ngc253_co.mp4. Credit: Erik Rosolowsky, University of Alberta.

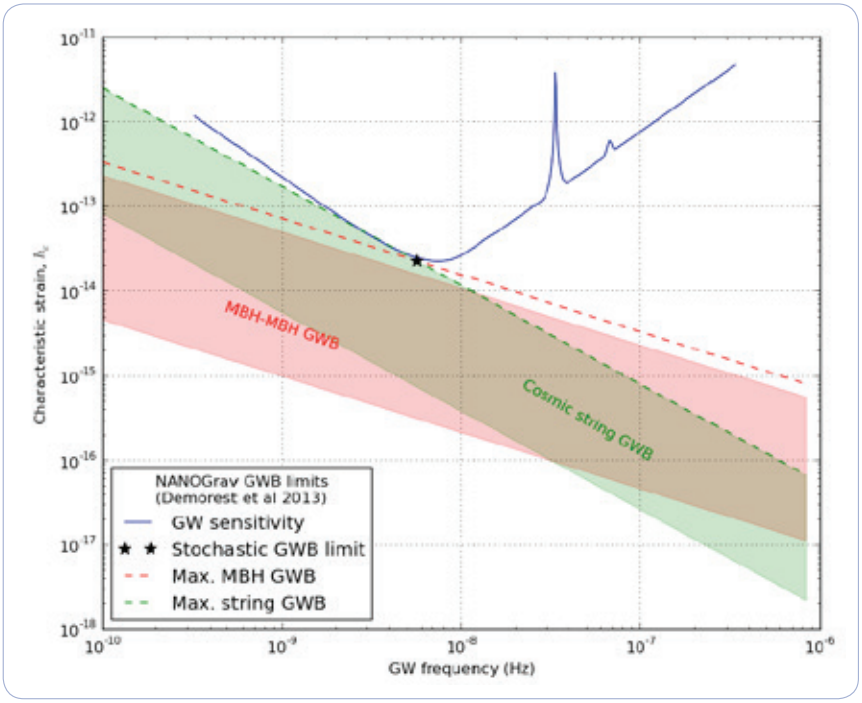
Science Team: Alberto D. Bollato (Maryland), Steven R. Warren (Maryland), Adam K. Leroy (NRAO), Fabian Walter (MPIfA), Sylvain Veilleux (Maryland), Eve C. Ostriker (Princeton), Jürgen Ott (NRAO), Martin Zwaan (ESO), David B. Fisher (Maryland), Axel Weiss (MPIfR), Erik Rosolowsky (British Columbia), and Jacqueline Hodge (MPIfA),

Publication: *Suppression of Star Formation in the Galaxy NGC 253 by a Starburst-driven Molecular Wind,* 2013 Nature, 499, 450 (25 July 2013).

A New Gravitational Wave Detection Limit

The North American Nanohertz Observatory for Gravitational Waves (NANOGrav) team has observed 17 pulsars over about five years using the GBT and the Arecibo Observatory. These data were analyzed using standard pulsar timing models, with the addition of time-variable dispersion measure and frequency-variable pulse shape terms. Sub-microsecond timing residuals are obtained in nearly all cases, and the best rms timing residuals are ~30 to 50 nanoseconds. The authors present methods for analyzing post-fit timing residuals for the presence of a gravitational wave signal with a specified spectral shape. These optimally take into account the timing fluctuation power removed by the model fit, and can be applied to either data from a single pulsar, or to a set of pulsars to detect a correlated signal. These data and methods yield the best upper limit to date on the strength of the nanoHertz-frequency stochastic supermassive black hole gravitational wave background of $h_c\,(1\ \mathrm{yr}^{-1}) < 7 \times 10^{-15}$ (95%).

Gravitational wave (GW) strength, in units of dimensionless strain, versus frequency. The blue line illustrates the NANOGrav experiment sensitivity using five years of data. The maximum sensitivity is for GWs with ~5 year periods. The star symbol shows the maximum allowed level (95% confidence) of a power-law spectrum stochastic GW background. Predicted sources of such a background include unresolved supermassive black hole binaries and cosmic strings. The shaded areas show theoretical predictions for the strengths of these signals; the dashed lines indicate the upper limits derived from the five-year NANOGrav data set.



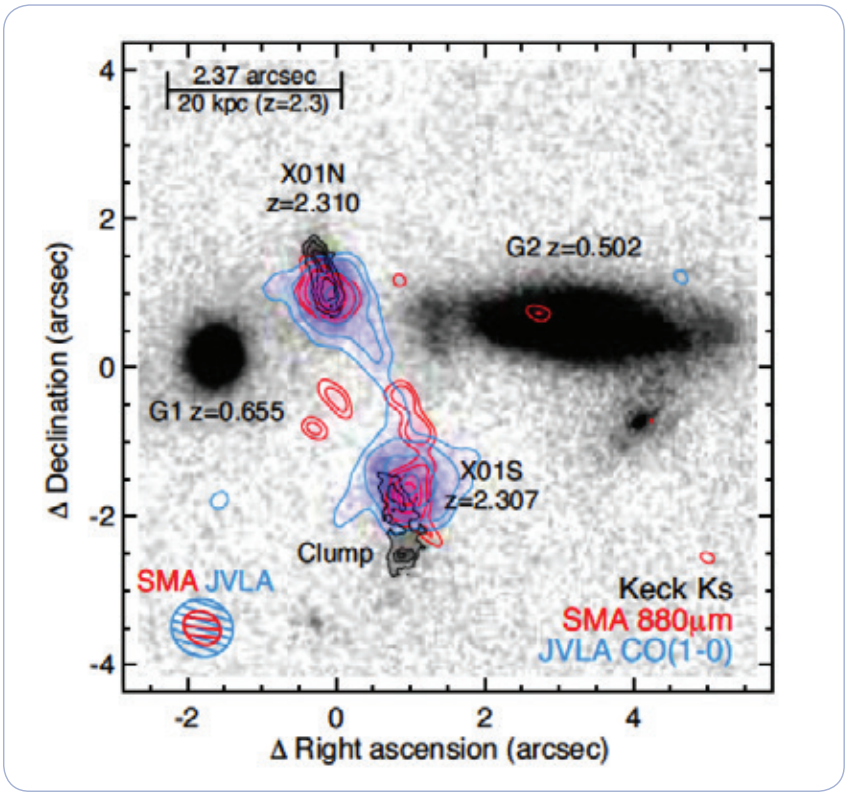
Science Team: P. B. Demorest (NRAO), R. D. Ferdman (McGill), M. E. Gonzalez (UBC), D. Nice (Lafayette), S. Ransom (NRAO), I. H. Stairs (UBC), Z. Arzoumanian (NASA-Goddard, USRA), A. Brazier (Cornell), S. Burke-Spolaor (NASA-JPL), S. J. Chamberlin (Wisconsin-Milwaukee), J. M. Cordes (Cornell), J. Ellis (Wisconsin-Milwaukee), L. S. Finn (Pennsylvania State Univ), P. Freire (MPIfR), S. Giampanis (Wisconsin-Milwaukee), F. Jenet (UT-Brownsville), V. M. Kaspi (McGill), J. Lazio (NASA-JPL), A. N. Lommen (Franklin & Marshall), M. McLaughlin (West Virginia), N. Palliyaguru (West Virginia), D. Perrodin (Franklin & Marshall), R. M. Shannon (CSIRO), X. Siemens (Wisconsin-Milwaukee), D. Stinebring (Oberlin), J. Swiggum (West Virginia), and W. W. Zhu (UBC).

Publication: *Limits on the Stochastic Gravitational Wave Background from the North American Nanohertz Observatory for Gravitational Waves,* 2013 Astrophysical Journal, 762, 94 (10 January 2013).

Rapid Assembly of a Massive Elliptical Galaxy

Previous work has shown that massive elliptical galaxies formed rapidly about ten billion years ago with star-formation rates exceeding several hundred solar masses per year. Fu et al report multi-wavelength high-resolution observations, including CO observations with the VLA and GBT, of the object HXMM01, a rare merger of two massive, submillimeter bright galaxies at z = 2.3 that is forming stars at 2,000 $M_{\odot}$ per year. The observed star-formation efficiency is an order of magnitude greater than that of normal galaxies, and thus the gas reservoir for this star formation will be exhausted in only ~200 million years. At a projected separation of 19 kiloparsecs, the two massive submillimeter galaxies are about to merge and form a passive elliptical galaxy with a stellar mass of ~$4x10^{11}$ $M_{\odot}$. The VLA CO results show a tidal structure, direct evidence for a gas-rich major merger, driving the intense star formation during the rapid formation of the most massive elliptical galaxies by z ~ 1.5.

The highest-resolution images of HXMM01. The background and black contours show a near-infrared camera (NIRC2 at the Keck Observatory) adaptive optics image. The dust continuum emission seen by the Submillimeter Array (SMA, 880 μm, red contours) and the molecular CO emission seen by the VLA (blue contours) are overlaid. The two major components of HXMM01 – X01N and X01S – and the foreground galaxies are labeled. There is also a bridge of material detected between X01N and X01S. The ellipses (lower left) illustrate the beam full-width at half-maximum for the SMA and VLA.

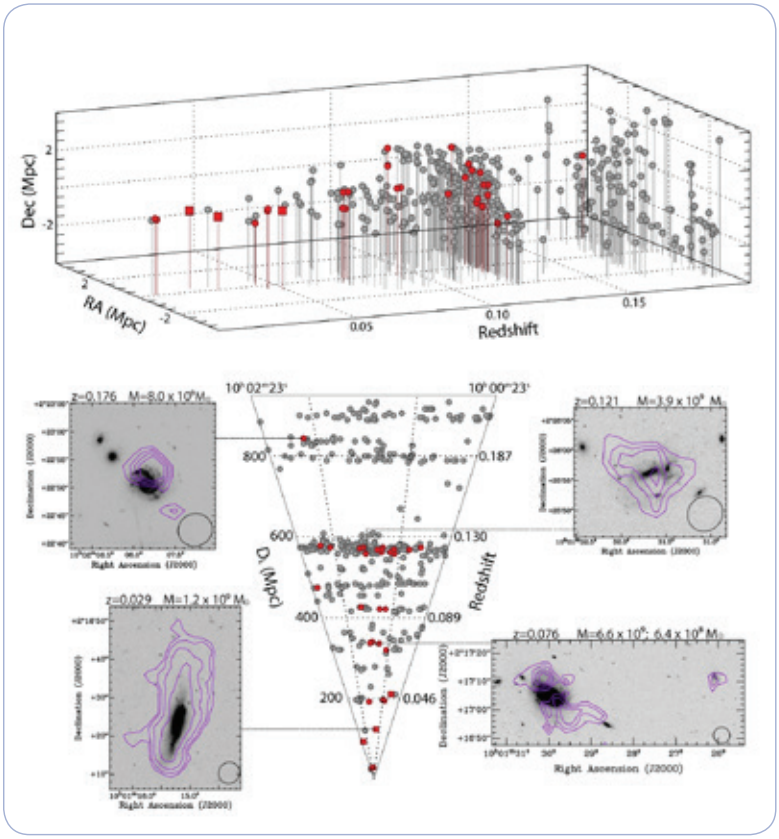


Science Team: Hai Fu (UC-Irvine), Asantha Cooray (UC-Irvine), C. Feruglio (IRAM), R.J. Ivison (UKATC, Edinburgh), D.A. Riechers (Cornell), M. Gurwell (CfA), R.S. Bussmann (CfA), A.I. Harris (Maryland), B. Altieri (Herschel), H. Aussel (CEA-Saclay), A.J. Baker (Rutgers), J. Bock (Caltech, JPL), M. Boylan-Kolchin (UC-Irvine), C. Bridge (Caltech), J.A. Calanog (UC-Irvine), C.M. Casey (IfA), A. Cava (Madrid), S.C. Chapman (Dalhousie), D.L. Clements (Imperial College), A. Conley (Colorado-Boulder), P. Cox (IRAM), D. Farrah (Virginia Tech), D. Frayer (NRAO), R. Hopwood (Imperial College), J. Jia (UC-Irvine), G. Magdis (Oxford), G.Marsden (UBC), P. Martinez-Navajas (IAC, ULL), M. Negrello (INAF), R. Neri (IRAM), S.J. Oliver (Sussex), A. Omont (Paris), M.J. Page (University College London), I. Perez-Fournon (IAC, ULL), B. Schulz (IPAC), D. Scott (UBC), A. Smith (Sussex), M. Vaccari (Western Cape), I. Valtchanov (Herschel), J.D. Vieira (Caltech), M. Viero (Caltech), L. Wang (Sussex), J.L. Wardlow (UC-Irvine) & M. Zemcov (JPL).

Publication: *The Rapid Assembly of an Elliptical Galaxy of 400 Billion Solar Masses at a Redshift of 2.3,* 2013 Nature, 498, 338 (20 June 2013).

A Neutral Hydrogen Pilot Deep Field

The VLA has been used for a deep pilot search for neutral hydrogen in distant galaxies. Part of the Cosmic Evolution Survey (COSMOS) field was observed for 50 hours, and 33 galaxies were detected in neutral hydrogen (HI) to z = 0.2, including three without a previously known spectroscopic redshift. The detections have a range of HI and stellar masses, indicating the diversity of galaxies probed. This pilot study shows that the VLA B-array is the ideal configuration for HI deep fields, and that the VLA is ready to conduct a very deep HI survey, as a key pathfinder for the Square Kilometre Array.



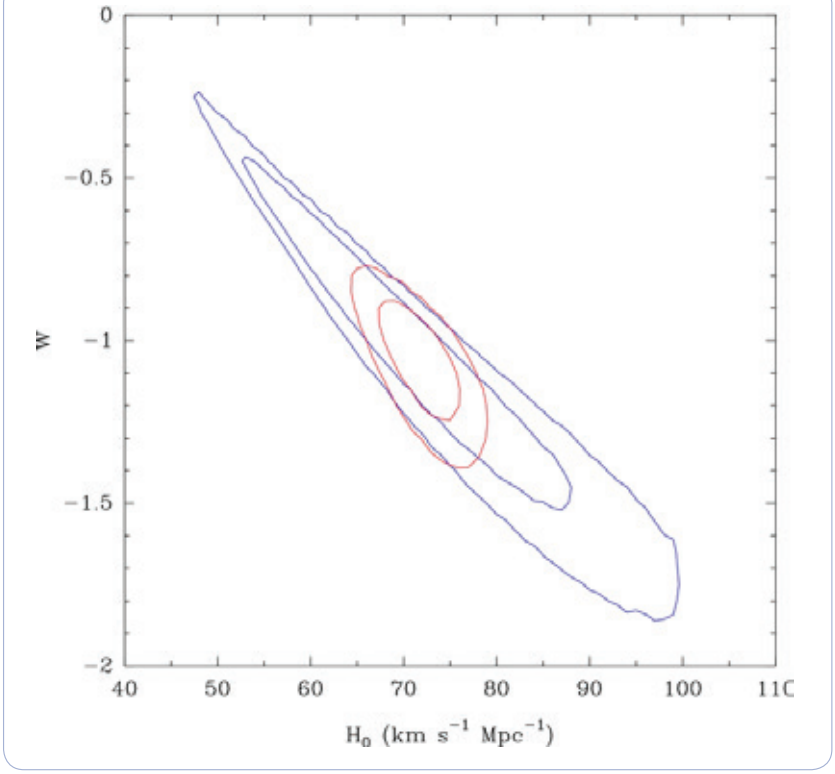
Optical spectroscopic sample and detections by Fernandez et al. in HI. **[Top]** *Three-dimensional (3D) distribution of galaxies in the data cube with the coordinates translated to a linear distance from the pointing center. The gray circles represent the galaxies with known optical spectroscopic redshifts, and the red symbols show the HI detections. The circles are detections with known optical spectroscopic redshifts, while the squares show the three detections without a redshift, where we calculate the redshift from the HI spectrum.* **[Bottom]** *A projection of the 3D plot in R.A.–z with HI distribution maps highlighting the detections. HI emission contours are overlaid on Hubble Space Telescope images (Koekemoer et al. 2007; Massey et al. 2010). From bottom left, moving counterclockwise: an isolated galaxy, a galaxy pair, an ongoing merger, and the highest redshift detection. The opening angle of the pie-diagram is greatly exaggerated for clarity.*

Science Team: Ximena Fernandez (Columbia), J.H. van Gorkum (Columbia), Kelley M. Hess (Cape Town), D.J. Pisano (WVU, NRAO), Kathryn Kreckel (MPIfA), Emmanuel Momjian (NRAO), Attila Popping (ICRAR), Tom Oosterloo (ASTRON, Groningen), Laura Chomiuk (Michigan State), M.A.W. Verheijen (Groningen), Patricia A. Henning (New Mexico), David Schiminovich (Columbia), Matthew A. Bershady (Wisconsin), Eric M. Wilcots (Wisconsin), and Nick Scoville (Caltech).

Publication: *A Pilot for a Very Large Array H I Deep Field,* 2013 Astrophysical Journal Letters, 770, L29 (20 June 2013).

Measuring the Expansion of the Universe

A new geometric maser distance has been estimated to the active galaxy NGC 4258 from 18 epochs of Very Long Baseline Interferometry, and 10 years monitoring the velocities of the 22 GHz masers in NGC 4258, using a telescope suite that included the GBT and VLA. A new model includes both disk warping and confocal elliptical maser orbits with differential precession. The distance to NGC 4258 is now determined to be 7.60 ± 0.17 ± 0.15 Mpc, a 3% uncertainty including formal fitting and systematic terms. The resulting Hubble Constant, based on the use of the Cepheid variables in NGC 4258 to recalibrate the Cepheid distance scale, is H_0 = 72.0 ± 3.0 km s^{-1} Mpc^{-1}.



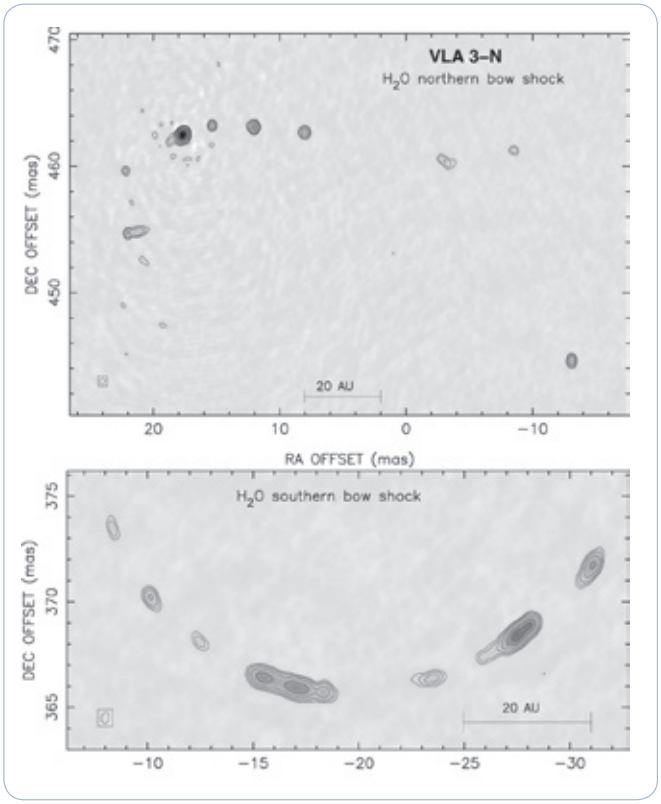
Constraint on dark energy. 2D probability density functions (PDFs) for a constant equation of state of dark energy (w) and H0 with 95% and 68% confidence contours. The blue contours were generated by binning the parameter values from Markov chains from the Wilkinson Microwave Anisotropy Probe (WMAP) 7 year data. The red contours combine the WMAP PDF and the constraint that H0 = 72.0 ± 3.0 km s−1 Mpc−1 from this paper. Fitting a Gaussian to the marginalized one-dimensional PDF for w yields w = −1.06 ± 0.12 (±68% confidence).

Science Team: Liz Humphreys (ESO, CfA), Mark Reid (CfA), Jim Moran (CfA), Lincoln Greenhill (CfA), and Alice Argon (CfA).

Publication: *Toward a New Geometric Distance to the Active Galaxy NGC 4258. III. Final Results and the Hubble Constant,* 2013 Astrophysical Journal, 775, 13 (20 September 2013).

Imaging Protostellar Outflows

Trinidad et al. acquired multi-epoch VLBA observations of the high-mass star-forming region AFGL 2591. Maser emission was detected that was associated with the radio continuum sources VLA 2 and VLA 3, and a water maser cluster, VLA 3-N, was seen. The water maser emission towards the VLA 3-N region shows two bow-shock-like structures separated by ~100 mas (~330 AU). The spatial distribution and kinematics of the water masers in this cluster have persisted over 7 years. The northern bow shock has a somewhat irregular morphology, while the southern bow shock has a remarkably smooth morphology. Proper motions of 33 water maser features were measured, yielding an average proper motion velocity of ~1.3 mas yr^{-1} (~20 km s^{-1}). The morphology and proper motions of this water maser cluster show systematic expanding motions that could imply one or two centers of star formation activity. A detailed model was constructed for the southern structure, proposing two different kinematic models to explain the 3D spatio-kinematical distribution of the water masers: (1) a static central source driving the two bow-shock structures; and (2) two independent driving sources, one of them exciting the northern bow-shock structure, and the other one, a young runaway star moving in the local molecular medium exciting and molding the remarkably smoother southern bow-shock structure. Future observations will discriminate between the two scenarios, in particular by identifying the still unseen driving source(s).



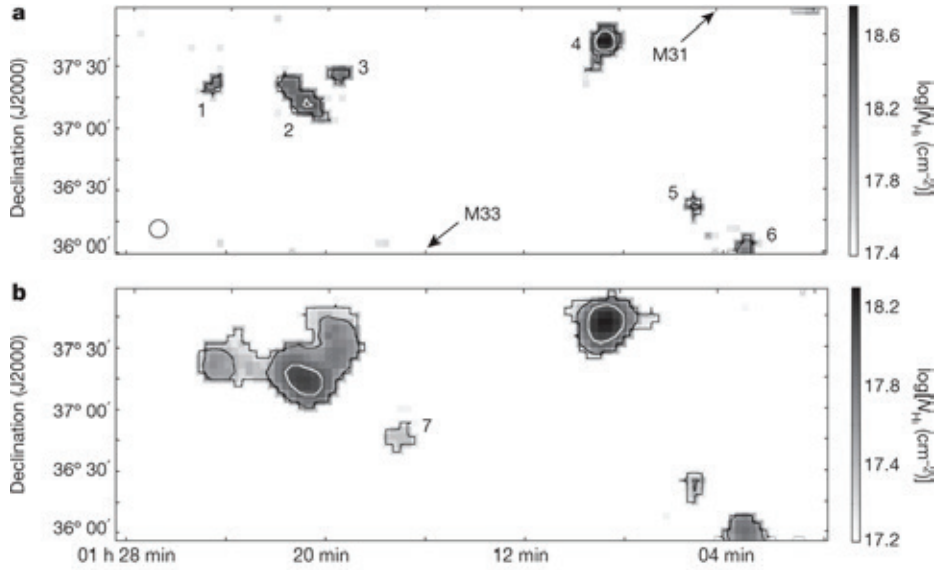
Close-up of the integrated water maser emission in VLA 3-N for the northern (upper panel) and southern (lower panel) bow-shock structures for the first epoch of the VLBA observations on 2 December 2001.

Science Team: M.A. Trinidad (Guanajuato), S. Curiel (UNAM), R. Estalella (Barcelona), J. Canto (UNAM), A. Raga (UNAM), J.M. Torrelles (Barcelona), N.A. Patel (CfA), J.F. Gomez (Andalucía), G. Anglada (Andalucía), C. Carrasco-González (MPIfR) and L. F. Rodríguez (UNAM).

Publication: *Formation and evolution of the water maser outflow event in AFGL 2591 VLA 3-N,* 2013 Monthly Notices of the Royal Astronomical Society, 430, 1309 (1 April 2013).

Observing Intergalactic Neutral Hydrogen

Spiral galaxies must acquire gas to maintain their observed level of star formation beyond the next few billion years. The gas that resides between galaxies may be the source for this material, but our understanding of the state and distribution of this gas is incomplete. Radio observations of the Local Group of galaxies have revealed neutral hydrogen gas extending from the galactic disk of M31 at least halfway to M33. This feature has been interpreted to be the neutral component of a condensing intergalactic filament that would be able to fuel star formation in M31 and M33. Simulations suggest, however, that such a feature could also result from an interaction between both galaxies within the past few billion years. In this *Nature* paper, Wolfe et al. report GBT observations showing that about 50% of the diffuse gas between M31 and M33 is composed of clouds; the remainder is distributed in an extended, diffuse component. These clouds have velocities comparable to those of M31 and M33, and have properties suggesting they are unrelated to other Local Group objects. These GBT observations strongly support the idea of gas accretion from the inter-galactic medium along filamentary structures as the fuel for future star formation in M31 and M33.



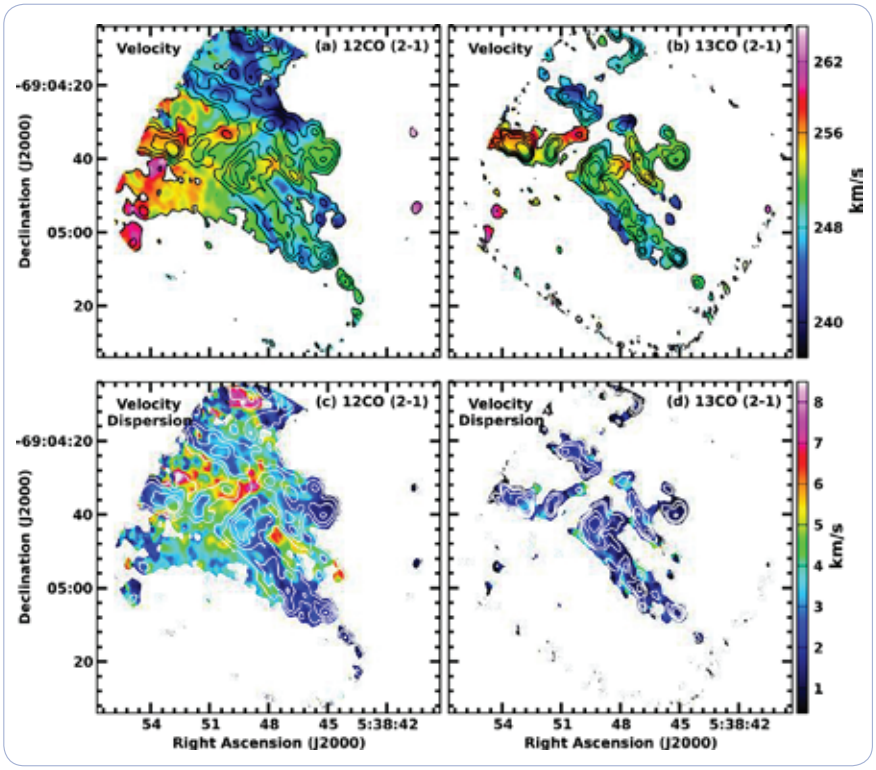
Neutral hydrogen (HI) emission over a 12 deg2 region between the nearby spiral galaxies M31 and M33. (a) A column density map of H I (cm−2) of the portion of the area between M31 and M33, mapped with the GBT in nearly 250 hours of integration. There are six confirmed H I clouds. M31 is to the northwest and M33 to the southeast, as indicated by the arrows. Both galaxies are about five degrees from the respective map edges. (b) The GBT data, smoothed to a 15 arcminute resolution. A seventh cloud is now visible.

Science Team: Spenser A. Wolfe (WVU), D.J. Paisano (WVU, NRAO), Felix J. Lockman (NRAO), Stacy S. McGaugh (Case Western), and Edward J. Shaya (Maryland).

Publication: *Discrete Gas Clouds of Neutral Gas between the Galaxies M31 and M33*, 2013 Nature, 497, 224 (9 May 2013).

Resolving Molecular Cloud Structure

Indebetouw et al. present ALMA observations of 30 Doradus and the highest resolution view of molecular gas in an extragalactic star formation region to date (~0.4 pc × 0.6 pc). The 30Dor-10 cloud, north of R136, was mapped in ^{12}CO 2–1, ^{13}CO 2–1, C^{18}O 2–1, 1.3 mm continuum, the H30α recombination line, and two H_2CO 3–2 transitions. ^{12}CO emission is associated with small filaments and clumps (0.1pc, 10^3 $M_\odot$), including protostars and "pillars of creation" photoablated by intense radiation from R136. Clumps in 30 Dor follow trends in size, line width, and surface density similar to massive clumps in the Milky Way. The consistency of clump masses calculated from dust continuum, CO, and the virial theorem reveals that the CO abundance in 30 Doradus clumps is not significantly different from the Large Magellanic Cloud average, but the dust abundance may be reduced by ~2x.



Images of the mean velocity observed with ALMA and the Atacama Pathfinder Experiment (APEX) for (a) ^{12}CO 2–1 and (b) ^{13}CO 2–1, along with images of the velocity dispersion for (c) ^{12}CO 2–1 and (d) ^{13}CO 2–1.

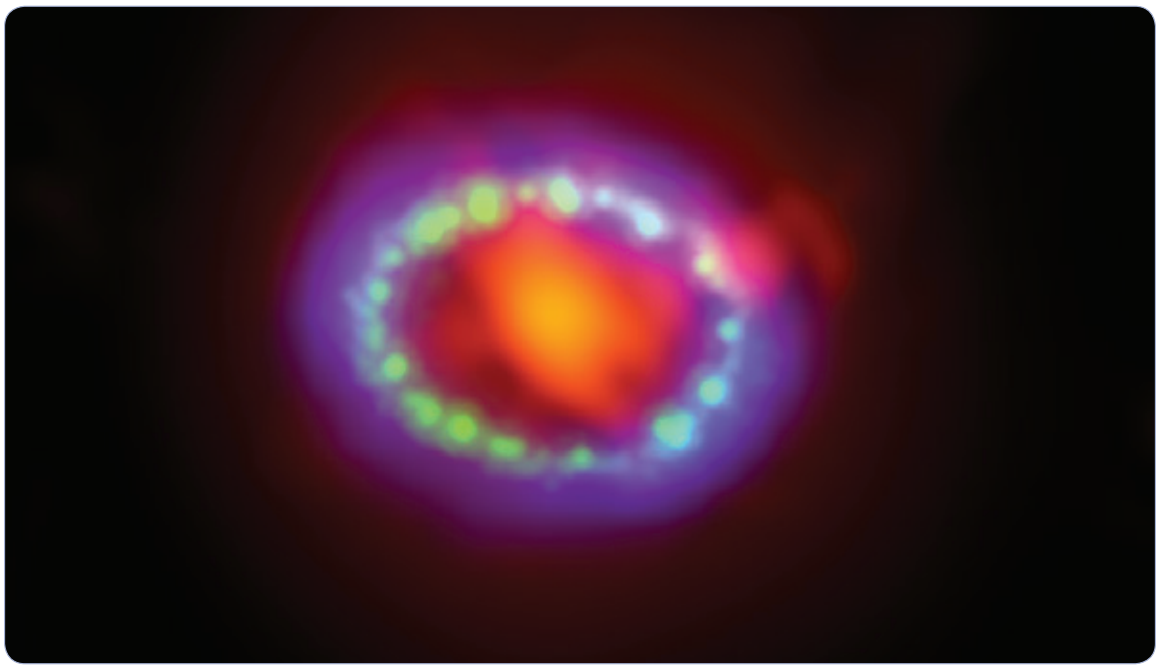
Science Team: Remy Indebetouw (NRAO, Virginia), Crystal Brogan (NRAO), C.-H. Rosie Chen (MPIfR), Adam Leroy (NRAO), Kelsey Johnson (Virginia), Erik Muller (NAOJ), Suzanne Madden (Saclay), Diane Cormier (Heidelberg), Frederic Galliano (Saclay), Annie Hughes (MPIfA), Todd Hunter (NRAO), Akiko Kawamura (NAOJ), Amanda Kepley (NRAO), Vianney Lebouteiller (Saclay), Margaret Meixner (STScI), Joana M. Oliveira (Keele), Toshikazu Onishi (Osaka), and Tatiana Vasyunina (Virginia).

Publication: *ALMA Resolves 30 Doradus: Sub-parsec Molecular Cloud Structure near the Closest Super Star Cluster,* 2013 Astrophysical Journal, 774, 73 (1 September 2013).

A New Window on Supernova Ejecta

ALMA's unprecedented sensitivity and resolution have enabled scientists to identify CO and SiO in the Supernova (SN) 1987A inner ejecta. The C/O clumps in SN1987A contain at least 0.01 $M_{\odot}$ of ^{12}CO, an order of magnitude greater amount than measured in the first few years after the explosion. ^{12}CO has clearly continued to form over the past 25 years. This CO is at T > 14K, and is confined within at most 35% of a spherical volume expanding at 2000 km/sec. The emission is located within 1 arcsecond of the central debris.

ALMA views the full velocity range of emission, unobscured by dust. Doppler tomography will be possible in CO and other molecules (SiO) to probe the spatial, chemical, and kinetic environment within the inner ejecta.



A color composite image of SN 1987A. [Red] The unresolved ^{12}CO 2-1 line emission detected by ALMA. Also shown are the Hα emission (blue) and the [SiI] + [Fe II] 1.644 μm emission (green in the ring; yellow in the ejecta) observed with HST. (Larssonet all 2013).

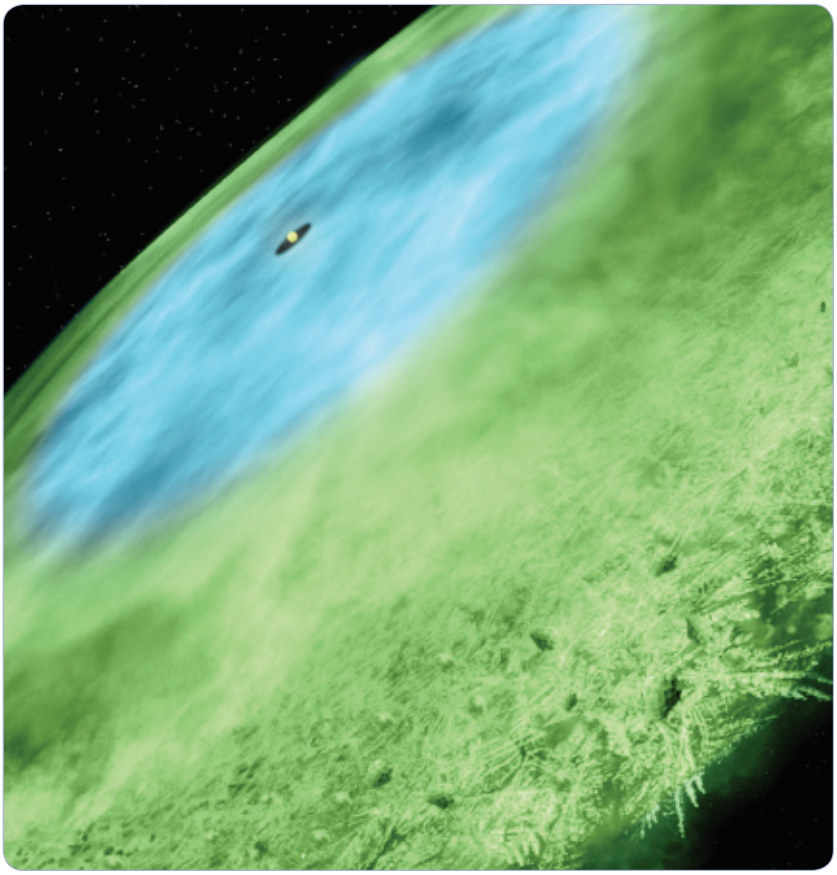
Science Team: J. Kamenetzky (Colorado-Boulder), R. McCray (Colorado-Boulder), R. Indebetouw (Virginia, NRAO), M. J. Barlow (University College-London), M. Matsuura (University College-London), M. Baes (Gent), J.A.D.L. Blommaert (KU Leuven. Vrije), A. Bolatto (Maryland), L. Decin (KU Leuven), L. Dunne (Canterbury), C. Fransson (Stockholm), J. Glenn (Colorado-Boulder) , H. L. Gomez (Cardiff), M.A.T. Groenewegen ((Royal Obs-Belgium), R. Hopwood (Imperial College-London), R.P. Kirshner (Harvard), M. Lakicevic (Keele), J. Marcaide (Valencia), I. Marti-Vidal (Onsala), M. Meixner (STScI), P. Royer (KU Leuven), A. Soderberg (Harvard), G. Sonneborn (NASA-Goddard), L. Staveley-Smith (ICRAR,CAAS-TRO), B. M. Swinyard (University College-London), G. Van de Steene (Royal Obs-Belgium), P.A.M. van Hoof (Royal Obs-Belgium), J. Th. van Loon (Keele), J. Yates (University College-London), G. Zanardo, (CAAS-TRO).

Publication: *Carbon Monoxide in the Cold Debris of Supernova 1987A,* 2013 Astrophysical Journal Letters, 773, L34 (20 August 2013).

The CO Snow Line in a Solar Nebula Analog

ALMA has imaged the CO "snow line" around TW Hya, an analog of the solar nebula. Planets form in the disks around young stars. Their formation efficiency and composition are intimately linked to the protoplanetary disk locations of snow lines of abundant volatiles. The chemical imaging used high spatial and spectral resolution observations of N_2H+, a reactive ion present in large abundance only where CO is frozen out. The N_2H+ emission is distributed in a large ring, with an inner radius that matches CO snow line model predictions. The extracted CO snow line radius of ~ 30 AU is a key parameter in constraining models of the formation dynamics of planetary systems.

Artist concept of the snow line in TW Hydrae showing water-covered ice grains in the inner disk at a distance of 4.5 to 30 AU from the star (blue), and carbon monoxide (CO) ice covered grains in the outer disk beyond 30 AU (green). The transition from blue to green marks the CO snow line. Credit: Bill Saxton and Alexandra Angelich, NRAO/AUI/NSF

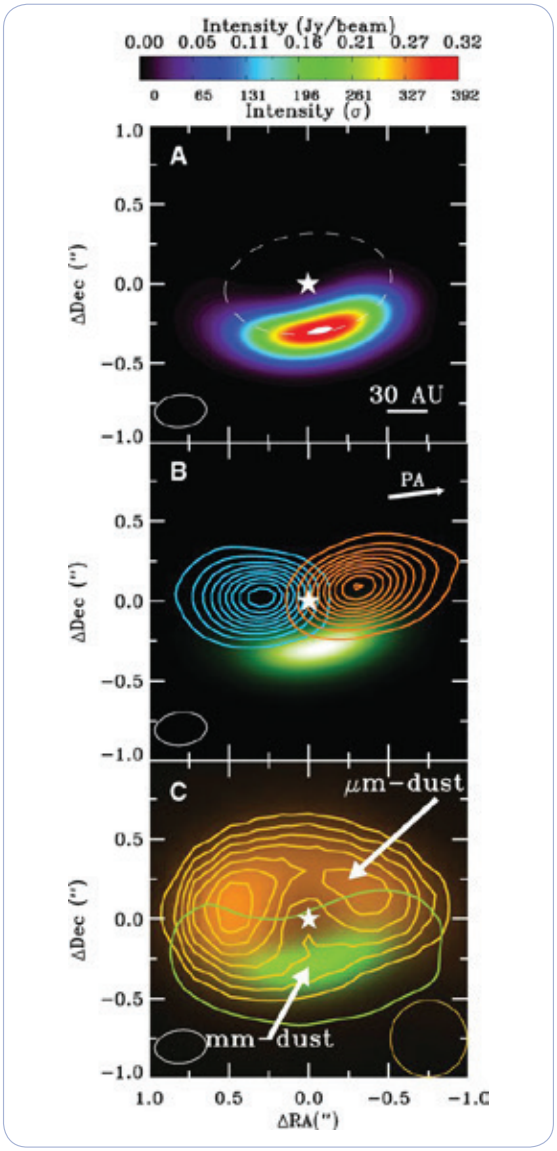


Science Team: Chunhua Qi (CfA), Karin I. Oberg (Virginia), David J. Wilner (CfA), Paolo D'Alesso (UNAM), Edwin Bergin (Michigan), Sean M. Andrews (CfA), Geoffrey A. Blake (Caltech), Michiel R. Hogerheijde (Leiden), Ewine F. van Dishoeck (Leiden, MPIfE)

Publication: *Imaging of the CO Snow Line in a Solar Nebula Analog,* Science, 341, 630 (9 August 2013). Published in Science Express 18 July 2013.

A Dust Trap in a Transition Disk

Though the statistics of discovered exoplanets suggest that planets form efficiently, we still struggle to understand exactly how planets form. There remain fundamental unsolved problems, such as the excessive inward drift of particles in protoplanetary disks during planet formation. Recent planet formation theories invoke dust traps to overcome this problem. Marel et al. report in Science the detection of a dust trap in the disk around the star Oph IRS 48 using ALMA observations. Their $\lambda \sim$ 0.44mm (685 GHz, ALMA Band 9) continuum map shows high-contrast crescent-shaped emission on one side of the star, originating from millimeter-sized grains, whereas both the mid-infrared image (micrometer-sized dust) and the gas traced by the CO 6-5 rotational line suggest rings centered on the star. The difference in distribution of large grains versus small grains/gas can be modeled with a vortex-shaped dust trap triggered by a companion.



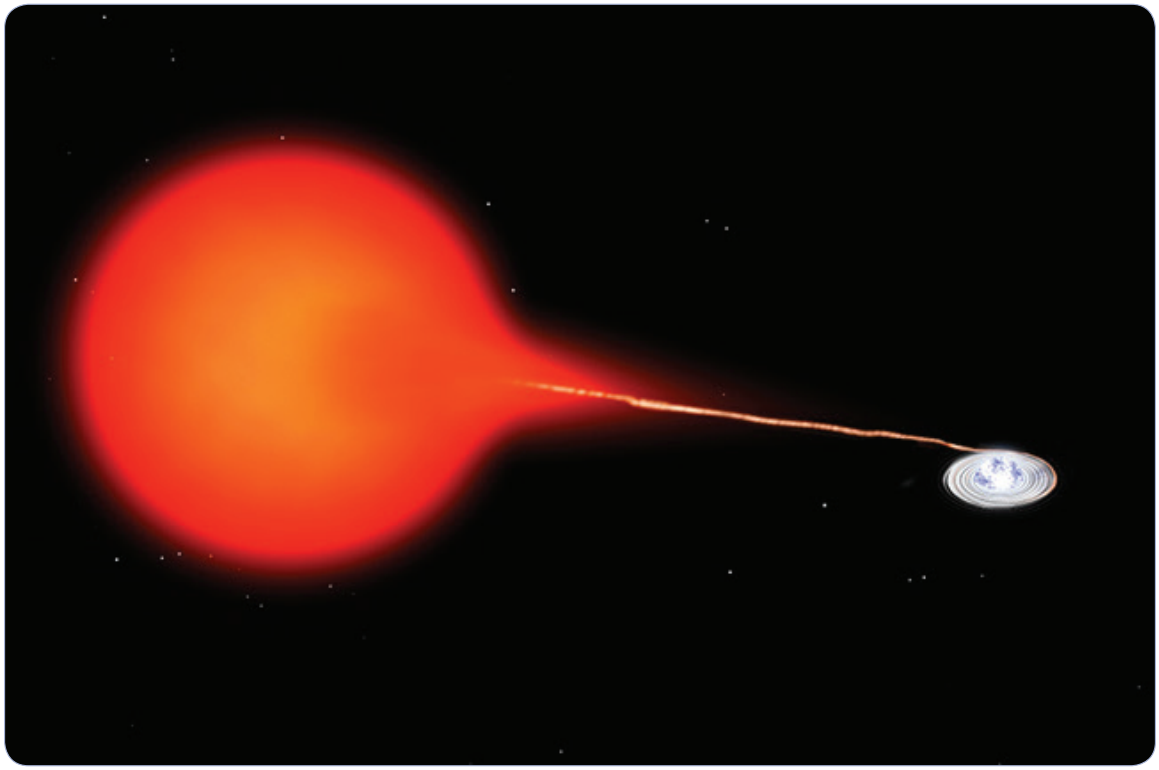
The inclined disk around IRS 48 as observed with ALMA, centered on the star (white star). The ALMA beam is 0.32" × 0.21" (white ellipse, lower left). **(A)** *The 0.44-mm (685 GHz) continuum emission. The 63 AU radius is indicated by a dashed ellipse.* **(B)** *The integrated CO 6-5 emission over the highest velocities in contours, showing a symmetric gas disk with Keplerian rotation at an inclination i = 50°. The green background shows the 0.44-mm continuum.* **(C)** *The Very Large Telescope Imager and Spectrometer for the mid-infrared (VISIR) 18.7-μm emission in orange contours and colors, overlaid on the 0.44-mm continuum in green and the 5σ contour line in green.*

Science Team: Nienke van der Marel (Leiden), Ewine F. van Dishoeck (Leiden, MPIfEP), Simon Bruderer (MPIfEP), Til Birnstiel (CfA), Paola Pinilla (Heidelberg), Cornelis P. Dullemond (Heidelberg), Tim A. van Kempen (Leiden, JAO), Markus Schmalzl (Leiden), Joanna M. Brown (CfA), Gregory J. Herczeg (Kavli Institute-Peking), Geoffrey S. Mathews (Leiden), and Vincent Geers (Dublin Institute for Advanced Studies)

Publication: *A Major Asymmetric Dust Trap in a Transition Disk,* 2013 Science, 340, 1199 (7 June 2013).

Accurate Distance Vindicates Disk Theory

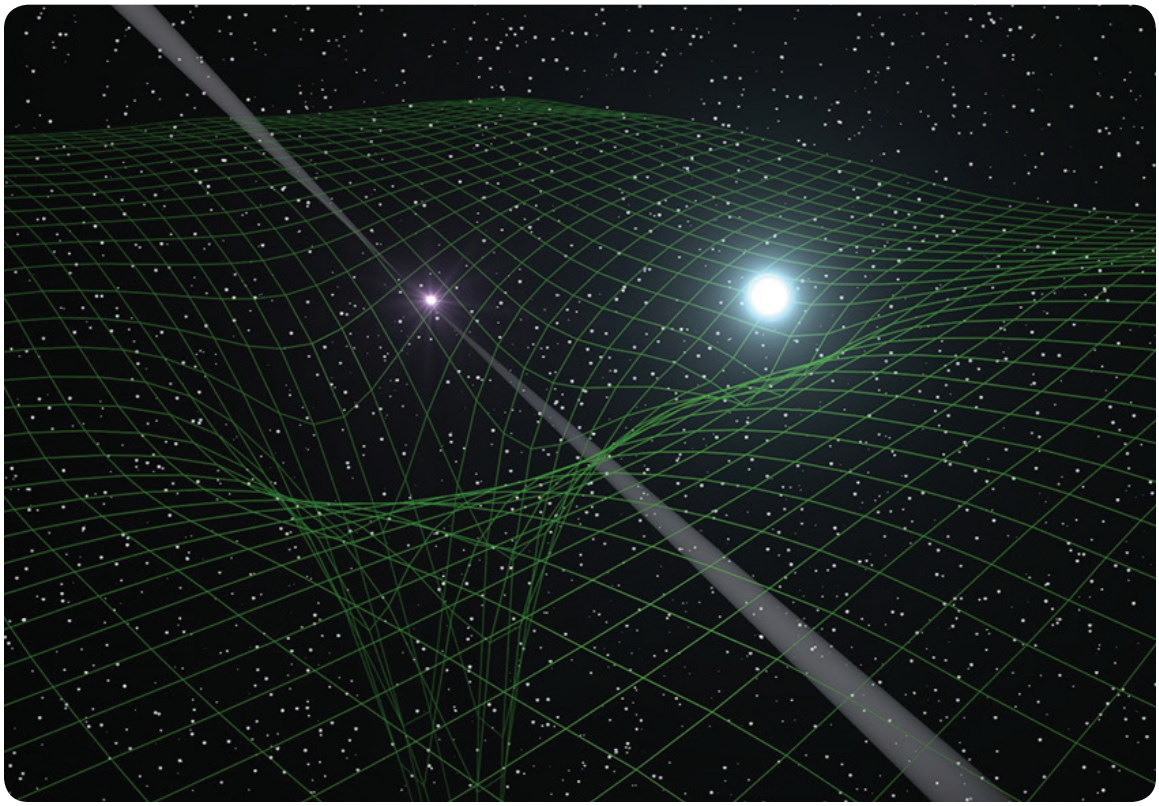
Dwarf novae are white dwarfs accreting matter from a nearby red dwarf companion. Their regular outbursts are explained by a thermal-viscous instability in the accretion disk, which is described by the disk instability model that has since been extended to other accreting astronomical systems. However, the prototypical dwarf nova, SS Cygni, has presented a major challenge to accretion disk theory. At the distance of 159 ± 12 parsecs measured by the Hubble Space Telescope, SS Cygni is too luminous to be undergoing the regular observed outbursts. Using very long baseline interferometric radio observations acquired with the VLBA and the European VLBI Network, Miller-Jones et al. report an accurate, model-independent distance to SS Cygni of 114 ± 2 parsecs. This new distance reconciles the behavior of SS Cygni with our understanding of accretion disk theory. Artist's concept: Bill Saxton, NRAO/AUI/NSF.



Science Team: J.C.A. Miller-Jones (Curtin), G.R. Sivakoff (Alberta, Virginia), C. Knigge (Southampton), E.G. Körding (Radboud), M. Templeton (AAVSO), and E.O. Waggen (AAVSO).

Publication: *An Accurate Geometric Distance to the Compact Binary SS Cygnii Vindicates Accretion Disk Theory,* 2013 Science, 340, 950 (24 May 2013)

Einstein Passes Toughest Test Yet



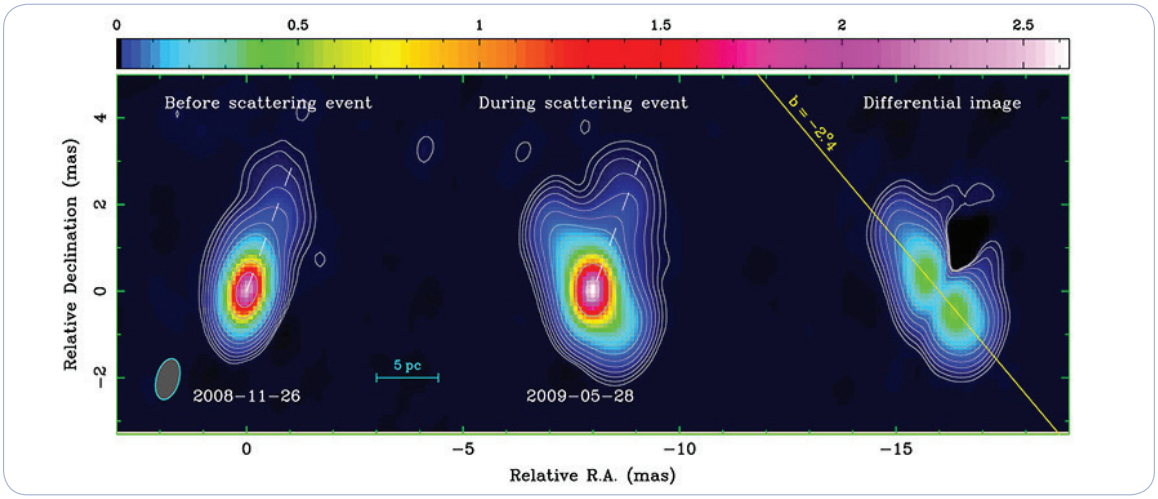
Many physically motivated extensions to general relativity (GR) predict substantial deviations in the properties of space-time surrounding massive neutron stars. Antoniadis et al. report in Science their measurement with the GBT of a 2.01 ± 0.04 $M_{\odot}$ pulsar in a 2.46-hour orbit with a 0.172 ± 0.003 $M_{\odot}$ white dwarf. The high pulsar mass and the compact orbit make this system a sensitive laboratory of a previously untested strong-field gravity regime. Thus far, the observed orbital decay agrees with GR, supporting its validity even for the extreme conditions present in the system. The resulting constraints on deviations support the use of GR-based templates for ground-based gravitational wave detectors. Additionally, the system strengthens recent constraints on the properties of dense matter and provides insight to binary stellar astrophysics and pulsar recycling. Artist's concept: Antoniadis et al.

Science Team: John Antoniadis (MPIfR), Paulo C. C. Freire (MPIfR), Norbert Wex (MPIfR), Thomas M. Tauris (Argelander, MPIfR), Ryan S. Lynch (McGill), Marten H. van Kerkwijk (Toronto), Michael Kramer (MPIfR, Jodrell Bank), Cees Bassa (Jodrell Bank), Vik S. Dhillon (Sheffield), Thomas Driebe (DLR), Jason W. T. Hessels (ASTRON, Amsterdam), Victoria M. Kaspi (McGill), Vladislav I. Kondratiev (ASTRON, Lebedev), Norbert Langer (Argelander), Thomas R. Marsh (Warwick), Maura A. McLaughlin (WVU), Timothy T. Pennucci (Virginia), Scott M. Ransom (NRAO), Ingrid H. Stairs (UBC), Joeri van Leeuwen (ASTRON), Joris P. W. Verbiest (ASTRON, Amsterdam), and David G. Whelan (Virginia)

Publication: *A Massive Pulsar in a Compact Relativistic Binary,* 2013 Science, 340, 397 (26 April 2013).

A Rare Multiple Quasar Imaging Event

The first detection of multiple imaging of an Active Galactic Nucleus (AGN) jet due to refractive foreground scattering in our galaxy has been reported by Pushkarev et al. This rare phenomenon was first predicted several decades ago and is based on the refractive properties of AU-scale electron density enhancements in the ionized component of the Galactic interstellar medium. The predicted effect has now been seen in the low galactic latitude quasar 2023+335, one of a large sample of AGNs being observed by the Monitoring Of Jets in Active galactic nuclei with VLBA Experiments (MOJAVE) project. The strongest event showed a refractive image ~ 1/10th as bright as the primary image on 28 May 2009 at 15 GHz, when the source was undergoing an extreme scattering event. The VLBA image was taken serendipitously during a special phase when a caustic spike associated with the lens edge passed over the source. While the parsec-scale jet of the source normally extends along an angle of -20 degrees, a highly significant multi-component pattern of secondary images induced by strong refraction appears stretched out roughly along the constant galactic latitude line at an angle of +40 degrees. This suggests that the direction of relative motion of the lens is parallel to the galactic plane, as expected for an orbiting cloud.



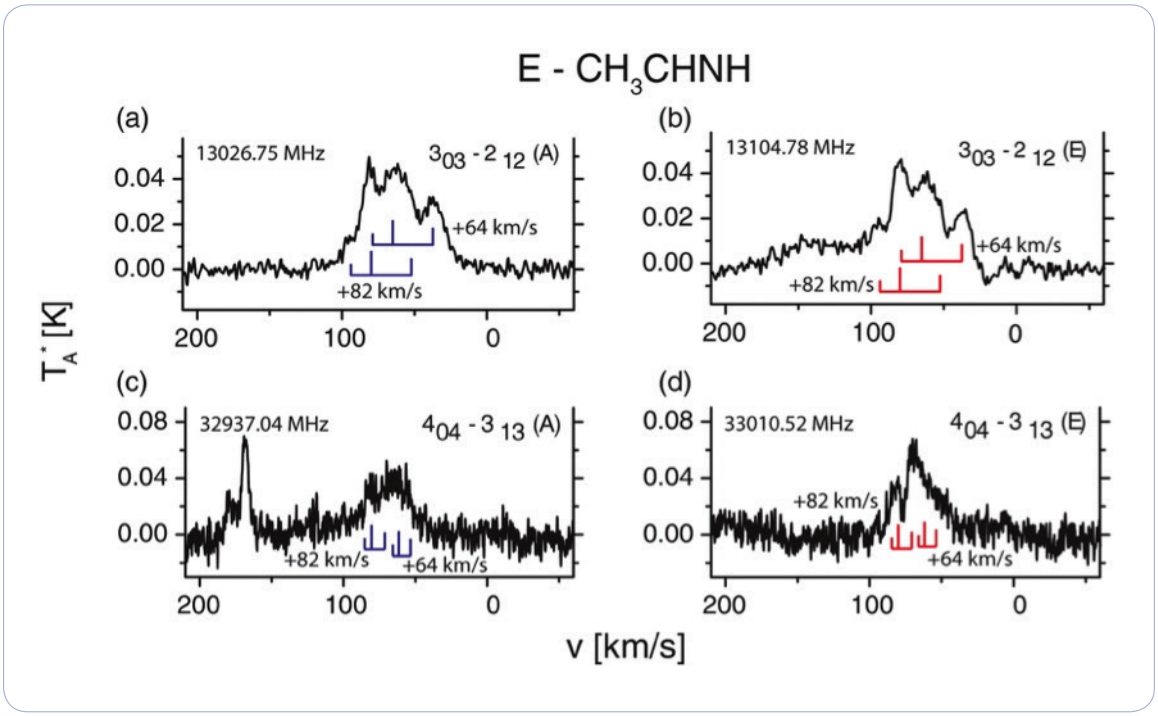
Extraction of the refraction-induced structure from the 15.4 GHz VLBA images of 2023+335. The image on 26 November 2008 (Left) shows a typical parsec-scale morphology represented by a bright core and one-sided jet propagating along the PA ~ −20°. The image taken on 28 May 2009 (Center) shows an unusual brightness distribution, which is a result of multiple imaging of the source. The fitted Gaussian components are superposed on the images as shaded circles/ellipses. The difference image of the two epochs (Right) reveals a quasi-symmetric pattern dominated by two bright components and formed by refraction when the lens edge passes over the source. The pattern of de-magnified secondary images is extended nearly precisely along the line of constant galactic latitude, which is at PA = 40° in this region of the sky (full line). One milliarcsecond corresponds to about 3.5 pc.

Science Team: A.B. Pushkarev (MPIfR, Pulkovo Obs, Crimean Obs), Y.Y. Kovalev (Lebedev, MPIfR), M.L. Lister (Purdue), T. Hovatta (Caltech), T. Savolainen (MPIfR), M.F. Aller (Michigan), H.D. Aller (Michigan), E. Ros (Valencia, MPIfR), J.A. Zensus (MPIfR), J.L. Richards (Purdue), W. Max-Moerbeck (Caltech), and A.C.S. Readhead (Caltech).

Publication: *VLBA Observations of a Rare Multiple Quasar Imaging Event Caused by Refraction in the Interstellar Medium,* 2013 Astronomy & Astrophysics, 555, 80 (July 2013).

Detection of Interstellar Ethanimine

Ethanimine is one of the large interstellar "imines" ever detected. These molecules are important in the formation of larger organic species like amino acids, and finding amino acid precursors is a step closer to understanding our molecular origins in the Universe. The detection of ethanimine is significant because of its possible role in the formation of alanine—one of the twenty amino acids in the genetic code. Observations acquired by Loomis et al for the GBT Prebiotic Interstellar Molecule Survey (PRIMOS) toward the Sagittarius B2 North (SgrB2N) region detected two structural isomers of ethanimine (CH3CH=NH). Shown in the spectrum (below) are the GBT data (black) and a model of the two ethanimine isomers (blue and red).



Interstellar spectra sample from the GBT PRIMOS survey for E-ethanimine transitions. Relative intensity markers are shown where hyperfine splitting is expected, with the A torsional state in blue and the E torsional state in red.

Science Team: Ryan A. Loomis, Daniel P. Zaleski, Amanda L. Steber, Justin L. Neill, Matthew T. Muckle, Brent J. Harris (Virginia); Jan M. Hollis (NASA-Goddard); Phillip R. Jewell (NRAO); Valerio Lattanzi (CfA, Harvard); Frank J. Lovas (NIST); Oscar Martinez, Michael C. McCarthy (CfA, Harvard); Anthony J. Remijan (NRAO); Brooks H. Pate and Joanna F. Corby (Virginia)

Publication: *The Detection of Interstellar Ethanimine (CH_3CHNH) from Observations Taken during the GBT PRIMOS Survey,* 2013 Astrophysical Journal Letters, 765, L9 (1 March 2013).


NRAO
ESO
NAOJ
ALMA

ALMA CONSTRUCTION

Atacama Large Millimeter/submillimeter Array Construction Project

Construction of the Atacama Large Millimeter/submillimeter Array (ALMA) continued but ramped down in 2013. When complete, at the end of Fiscal Year 2014, 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 of more improvement in millimeter-wave sensitivity, frequency coverage, resolution, imaging, and spectral capabilities. ALMA Early Science, underway since October 2011 as construction continued, has already impacted numerous fields of astrophysics and is opening new scientific frontiers.

An international astronomy facility, ALMA 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.

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 JAO. Staff at the AOS is limited to the absolute minimum owing to the harsh, high-elevation environment. A private road connects Chilean Highway 23 to the OSF, at kilometer marker 15, and to the AOS, 43km from the highway. This road is up to 14m wide to accommodate the ALMA Transporter.

Site Construction

The vast majority of ALMA site construction at the OSF and AOS was completed in 2013, including all road construction. The remaining site construction work in Chile is largely associated with the final build out of the extended baseline antenna stations.

Power

The provisioning of electrical power to the northern Chile ALMA site has been challenging. 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. In its place, a standalone power generation plant at the OSF using multi-fuel turbines was selected, designed, and procured. Performance and reliability issues with the system in mid-2013 caused some loss of commissioning and science observing time in 2013. These issues have been resolved, and are no longer expected to materially affect array operations.

Antennas

By the end of 2013, all of the ALMA antenna hardware produced by the North American, European, and East Asian contractors had been received by the JAO in Chile, and the 25 antennas delivered by the North American contractor – VertexRSI, a Texas-based division of General Dynamics SATCOM Technologies – were in routine service. An astigmatism issue with the VertexRSI antennas was investigated in collaboration with the contractor, the JAO, and NA ALMA Construction team, and will be resolved in 2014. All five nutators have been delivered and Acceptance Reviews have been conducted on each. All six Optical Pointing Telescopes have been delivered and on-antenna testing is complete.

The procurement of the 25 North American antennas for ALMA was the largest single procurement in the history of the NSF Astronomical Sciences Division. AUI managed the North American antenna procurement contract, while NRAO oversaw the integration and testing of the antennas that were manufactured and assembled by VertexRSI.

The Mitsubishi Electric Corporation of Japan manufactured the four 12m and twelve 7m antennas of the Atacama Compact Array that are East Asian deliverables to ALMA and are enhancing ALMA's ability to image extended radio sources. The AEM Consortium – Thales Alenia Space, European Industrial Engineering, MT Mechatronics – built the twenty-five 12m antennas that are European deliverables to ALMA.

Fifty-two ALMA antennas were resident at the AOS by the end of 2013.

New Careers for Two ALMA Prototype Antennas

Two of the ALMA prototype antennas have been removed from the NRAO VLA site to commence new careers. The Alcatel – Costamasagna – European Industrial Engineering prototype antenna has been moved to the Arizona Radio Observatory's site on Kitt Peak in southern Arizona and is being installed there to pursue research in the millimeter spectral range. The Vertex prototype antenna is being relocated to the National Science Foundation Summit Station facility in Greenland where it will be operated by the Harvard-Smithsonian Center for Astrophysics in collaboration with the Academia Sinica Institute of Astronomy and Astrophysics in Taiwan.

[Left to right] *The Japanese, North American, and European prototype antennas at the ALMA Test Facility on the site of the Very Large Array in central New Mexico. This facility was occupied from April 2003 through November 2012.*

Correlator

The computational 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 at the NRAO CDL and is housed in the AOS Technical Building. Assembled, tested, and shipped in "quadrants," the last of the four NRAO correlator quadrants was formally accepted by the JAO in December 2012, marking completion of this important delivery, another major NRAO ALMA milestone.

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.

Front Ends

All 27 North American (NA) Front Ends (FEs) have been delivered to Chile: 22 from the NA FE Integration Center, and 5 from the East Asia (EA) Front End Integration Center. The 73 Local Oscillator Warm Cartridge Assemblies, including spares, for ALMA Band 10 (787 – 950 GHz) were also delivered in 2013, per the Goods and Services Agreement with NAOJ.

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	2.40-184	1.84-142	1.42-109	1.09 - 0.80	0.78 - 0.60	0.50 - 0.42	0.38 - 0.32

The ALMA North American deliverables conveyed to the JAO in 2013 also included the seventy-three Band 10 Warm Cartridge Assemblies, the NA Front End Test & Measurement System, and the Band 6 Cartridge Test System.

NRAO engineers and technicians reassembled and commissioned the NA and EA Front End Test & Measurement systems at the JAO, and trained JAO personnel in test and maintenance procedures. These systems provide the ability to diagnose operations or performance issues with the ALMA Front Ends and support some maintenance. Maintenance is characterized as Tier-1, Tier-2, or Tier-3, in order of increasing complexity. Tier-1 maintenance can be handled at the JAO; complex Tier-3 maintenance is the responsibility of NA ALMA Operations in Charlottesville. Much of the Tier-2 maintenance is currently handled by the NA ALMA Operations in Charlottesville, though the intent is to eventually transfer this responsibility to JAO.

The Band 6 Cartridge Test Set was delivered to the OSF; NA personnel assisted in the re-assembly and commissioning of the Cartridge Test System, and trained JAO personnel in test and maintenance procedures.

The National Research Council (NRC) – Herzberg in Canada completed delivery of all Band 3 (84 – 116 GHz) cold cartridges in 2013. NRC – Herzberg also transferred the Band 3 Test & Measurement System to the JAO in a manner analogous to the NRAO transfer of the Band 6 Test & Measurement System.

Procurement of the Front End Handling Vehicles was suspended in mid-2013, but is back on track for completion and delivery by the end of construction.

Back Ends

All NA Back End deliverables have been provided to the JAO, including all Antenna Articles, Data Receiver Articles, Local Oscillator Photonic Receiver Articles, and the Central Local Oscillator Article.

OPERATIONS & DEVELOPMENT

North American ALMA Operations & Development

North American ALMA Operations includes:

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

Photo: Bill Johnson

North American ALMA Science Center

The North American ALMA Science Center (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 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.

Cycle 2 Call for Proposals

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

ALMA received 1382 unique proposals by the close of the Cycle 2 submission process on 5 December, compared to 1131 unique proposals in Cycle 1 and 919 in Cycle 0. The total Cycle 2 time requested was 7314 hours for the array of 12m telescopes, and 3327 hours were requested for the ACA. A total of 1049 individual PIs and 3408 scientists submitted proposals. The fractions of proposals coming from the three ALMA Executives, Chile, and from outside the partnership were similar to Cycle 1: 30% North America; 41% Europe; 20% East Asia; 7% Chile; and 3% Other. There were nearly 1500 unique investigators on proposals submitted from the North American Executive.

The ALMA archive encountered no problems ingesting the large number of Cycle 2 proposals despite the rapid increase in submission rate: 11% of all proposals were submitted in the final hour, and there were almost 600 re-submissions in the final three hours.

The Cycle 2 Review Panels will meet 10-14 March 2014 in London, Ontario, Canada with the final proposal ranking expected in April 2014.

Cycle 1 Science Observations

ALMA Early Science Cycle 1 observations started in January. Also, though the end of Cycle 1 was initially set for October, it was postponed owing to a re-prioritization of the commissioning activities being performed in parallel with science observations. Cycle 1 science observations also proceeded more slowly than expected owing to adverse weather conditions and power generation issues that limited the number of antennas available for science observations. Cycle 1 was further delayed when local labor union workers at the ALMA facilities near San Pedro de Atacama and at the central offices in Santiago, Chile declared a legal strike beginning 22 August. The strike continued for 17 days, when a settlement agreeable to all parties was reached. The process to restore full operational conditions was initiated on 9 September. Cycle 1 science observations were necessarily suspended during the strike and resumed in October.

Owing to these delays, only slightly more than half of Cycle 1 Highest Priority observations were likely to be completed by the end of the cycle. Thus, to avoid impacting the start of Cycle 2, PIs of High Priority Cycle 1 projects were offered the opportunity to designate their projects as eligible for transfer into Cycle 2, if they were uncompleted at the end of Cycle 1.

Power was reliable by the end of the year, and data was flowing for Cycle 1 Early Science again at the expected rates.

Cycle 0 Science Observations

The inaugural ALMA Cycle 0 Early Science observing season was initiated in October 2011 and was completed 1 January 2013. Cycle 0 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 data was delivereed to 107 of the 111 highest-priority projects worldwide. Only three Cycle 0 projects received no data. The Cycle 0 plan was for 500-700 hours of observing time. A total of 1,026 hours were actually used. More than 40 papers have been published from Cycle 0 and/or Science Verification data, and more are in preparation. Many Cycle 0 projects have reached the end of their proprietary period and are available in the ALMA Science Archive.

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 the 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 projects and one international project.

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 Principal Investigators (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 Common Astronomy Software Applications (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.

Transformational Science with ALMA: From Dust to Rocks to Planets – Formation and Evolution of Planetary Systems

From 8-12 April, the NRAO North American ALMA Science Center (NAASC) held its 7th annual science workshop titled *Transformational Science with ALMA: From Dust to Rocks to Planets - Formation and Evolution of Planetary Systems.* More than 150 participants converged on the Big Island of Hawaii to discuss and review a myriad of science topics regarding the formation of planetary systems as observed with the Atacama Large Millimeter/submillimeter Array, including 25+ student researchers and many other early career scientists. Group photo credit: K. Ransom.

A broad range of exciting new science was discussed at the meeting including:

- Improved resolution and sensitivity are unveiling subtle spatial and kinematic asymmetries in disks.
- Disk asymmetry can indicate vorticity in disks, which was proposed as a mechanism to produce dust trapping, which may lead to planet formation.
- Gaps or spiral structures in disks can be a hallmark of planetary sculpting.
- Chemical asymmetries provide clues to physical conditions; the conditions in the planet-forming midplane are of particular interest.
- Deuteration may provide a signpost for the 'snow line' in disks, the regions where molecules may freeze onto grains, providing the building blocks for giant planets and a repository for molecules important to the development of life.
- Subtle kinematic shifts may evidence material flow between inner and outer disk regions capable of shifting material from the snow line and potentially providing atmospheres and oceans for rocky inner planets.
- The newly available sensitivity and resolution are yielding breakthroughs in our understanding of the kinematics, chemistry, composition, structure, and evolution of a range of environments including molecular clouds, protoplanetary disks, debris disks, young planetary systems, and the youngest protostars.

ALMA Development

Having invested ~$1.3B USD to realize the biggest historical advance in ground-based astronomy, it is vital that ALMA maintain and expand its capabilities. The ALMA Operations Plan envisages an ongoing international program of development and upgrades that may include hardware, software, or data analysis tools. With a modest investment, ALMA will continue to lead astronomical research through the 2011-2020 decade and beyond.

North American (NA) ALMA is currently involved in three ALMA Development Projects: (1) a partnership with Europe to build the first post-construction receiver band (Band 5); (2) an international effort to add phasing capability to ALMA; and (3) an effort to improve Internet bandwidth to the ALMA site.

Further, eight Development Studies are underway in response to a NA Call issued in November 2011. These studies are nearing completion and address topics ranging from new receiver design to data analysis and visualization software.

New Call for Development Study Proposals

A new Call for Development Study Proposals was issued 1 May. An informational workshop was held 18 April at NRAO headquarters in Charlottesville, VA to support this new Call. An overview of the current ALMA Development Plan and studies now under way was given and presentations are available on line.

The primary objectives of these studies are to:

- provide groups in North America the opportunity to propose ALMA upgrades that may later be implemented as part of the ALMA Development Plan;
- support the development of conceptual and detailed designs for ALMA upgrades; and
- encourage relevant long-term research and development in areas important for ALMA.

Proposers were requested to submit a Notice of Intent by 17 May, and the proposal deadline date was 12 July.

Nine proposal submissions were received from eight Principal Investigators (PIs) with teams totaling 41 investigators from 17 institutions seeking total funding of $1.23M. A panel of highly qualified members of the astronomical community reviewed the study proposals. To avoid conflict of interest, none of the review panel members was affiliated with NRAO. Panels submitted anonymous grades and rankings. The panel discussed the results of the rankings in a telecon. Six studies fit within the funding envelope and were proposed for North American funding with the consent of NSF. The successful studies are listed in the following Table.

ALMA Development Studies (Title/Primary investigators/Co-Investigators)

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

New Call for Development Projects

Proposers were requested to submit a Notice of Intent by 17 June, and the proposal deadline was 16 August. Eight proposals were submitted by PIs with teams totaling 32 investigators from 11 institutions seeking total funding of $7.01M. Three of these evolved from the previous round of Studies. Five US, three Canadian, and one Taiwanese institution were represented.

An independent panel of highly qualified members of the astronomical community, nominated by the ALMA North American Science Advisory Committee, was assembled with NSF consent. The panel reviewed the project proposals, submitting anonymous grades and rankings. After discussion at a telecon, the five most highly ranked that fit within the $4M funding available were integrated into a proposed program of ALMA Development in North America. NSF consent was received for the funding of the highest ranked proposals, and PIs were notified of their status. The proposed program for ALMA Development in North America was presented to the ALMA Director, the ALMA Development Steering Committee, and to the ALMA Board and its science advisory committee for inclusion in the ALMA Development Plan. The proposals comprising the Program are listed in the following Table.

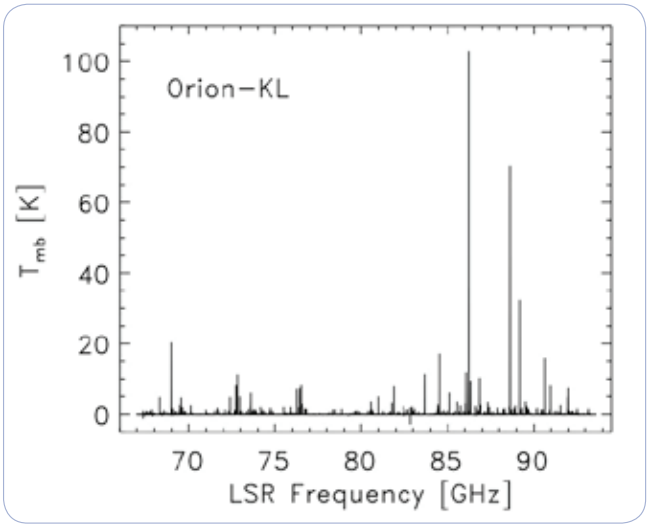
Table 2: ALMA Development Projects (Title/Primary investigators/Co-Investigators)

Design and Testing of a Prototype Band 2 Cartridge	Kamaljeet S. Saini, NRAO	E. Bryerton (Va Diodes), Kieran Cleary (Caltech/JPL), David T. Frayer, Matthew A. Morgan, Marian W. Pospieszalski, , Scott Schnee, Sivasankaran Srikanth (NRAO), Anthony C. S. Readhead (Caltech/JPL), Lorene Samoska (JPL)
Band 3 Cold Cartridge Assembly Magnet and Heater Installation for Deflux Operation	S. Claude, NRC-Herzberg	L. Knee (NRC-Herzberg)
Expansion of the Central LO Article to 5 Subarrays	C. Jacques, NRAO	
ALMA Data Mining Toolkit: ADMIT	L. Mundy, U. Md	Jeff Kern (NRAO), Adam Leroy (NRAO), Leslie Looney (UIUC), Anthony Remijan (NRAO), Amitabh Varshney (Maryland)
The Next Generation LMA Viewer	E. Rosolowsky, U. Alberta	Jeff Kern (NRAO), Gregory Sivakoff (Alberta), Russ Taylor (Calgary/Cape Town)

ALMA Band 2 Workshop

Twenty-five astronomers and students gathered at the North American ALMA Science Center in Charlottesville, VA on 29 May for a one-day workshop devoted to science that would be enabled by equipping ALMA with receivers covering 67-90 GHz, ALMA Band 2. The workshop was available via webcast and several persons attended remotely. Presentations are available at the Workshop website.

No radio interferometers currently operate in this band, though there has been a receiver at the Arizona Radio Observatory 12m antenna on Kitt Peak for many years, and the GBT has recently been equipped with a sensitive 4mm receiver. These receivers, and prospects for a similar design for ALMA, were reviewed in a discussion leading into science drivers for ALMA operation in this band.



This GBT spectrum of Orion KL demonstrates the wealth of spectral lines in the 4mm (ALMA Band 2) window.

One focus of 4mm science concentrates on the fundamental J=1-0 transitions of deuterated molecules that fall into this band. Deuterium becomes enhanced over its cosmic abundance in molecules at low temperatures owing to exchange reactions in ion-molecule chemistry. These lines are therefore good probes of specific cold regions in astrophysical environments. They may be particularly useful when coupled with ALMA's high spatial resolution for identifying cold regions in the mid planes of protoplanetary disks. Similarly, the cold regions probed by these lines provide insights into the conditions in starless cores, which may subsequently evolve to star-centered cores. Of particular interest are those molecules that persist at low temperatures in the gas phase, such as N_2D+ and NH_2D, which were discussed by several speakers.

Important probes of the nearby Universe also lie in the 4mm band, among which the formaldehyde resonance transition figures prominently. Other lines migrate into the window as a function of the redshifts of their host galaxies; the window gives a view into an important period of evolution of the Universe. CO emission shifted to $z \sim 0.6$ provides a window into galaxies during the last ~5 Gyr of evolution, a period in which the tremendous bursts of star formation began to quiet down. ALMA's superior sensitivity and spatial resolution – up to 1 arcsec in Band 2, or about 6 kpc – will be important to our understanding of galaxy evolution.

OPERATIONS & DEVELOPMENT

[Right] *Chilean President Sebastián Piñera and NSF Director Subra Suresh visit the ALMA Array Operations Site for the Inauguration. Credit: C. Padilla, NRAO/AUI/NSF* **[Below]** *Fifty-five antennas from all three major partners in place at the Array Operations Site for the ALMA Inauguration on 13 March. C. Padilla, NRAO/AUI/NSF.* **[Opposite page]** *From the International Space Station, Canadian Space Agency astronaut Chris Hadfield and NASA astronaut Thomas Marshburn congratulate North America and its partners on the Inauguration of ALMA. Credit: NASA/ISS.*

ALMA Inauguration

On 13 March, after nearly three decades of planning, engineering, and construction, representatives from the international astronomical community came together in a remote part of the Chilean Andes to welcome in a new era of discovery with the official ALMA inauguration. The ceremony, which was viewed around the world, conveyed both the excitement of what ALMA will achieve as well as the universal appreciation for the diverse talents that have brought this amazing observatory to fruition.

The staff members at the JAO and the ALMA partners did an excellent job preparing the ALMA Operations Support Facility (OSF) for the event. As invitees mingled with friends and colleagues, visiting VIPs, including outgoing NSF Director Subra Suresh and Chilean President Sebastián Piñera, visited the high elevation AOS to personally inspect the ALMA antennas and get a first-hand "high site" experience.

The inauguration ceremony featured presentations by ALMA Director Thijs de Graauw and NSF Director Suresh, among others. A congratulatory video from U.S. astronaut Tom Marshburn and Canadian astronaut Chris Hadfield, recorded on board the International Space Station as part of Expedition 34 was a highlight.

Closing out the ceremony, President Piñera spoke about the importance of astronomy to Chile and the pride that his nation takes in enabling world-class research. Through a live video feed to the high site, Piñera gave the command to point the array at the Galactic Center, symbolizing the launch of ALMA as the world's premier astronomical observatory.

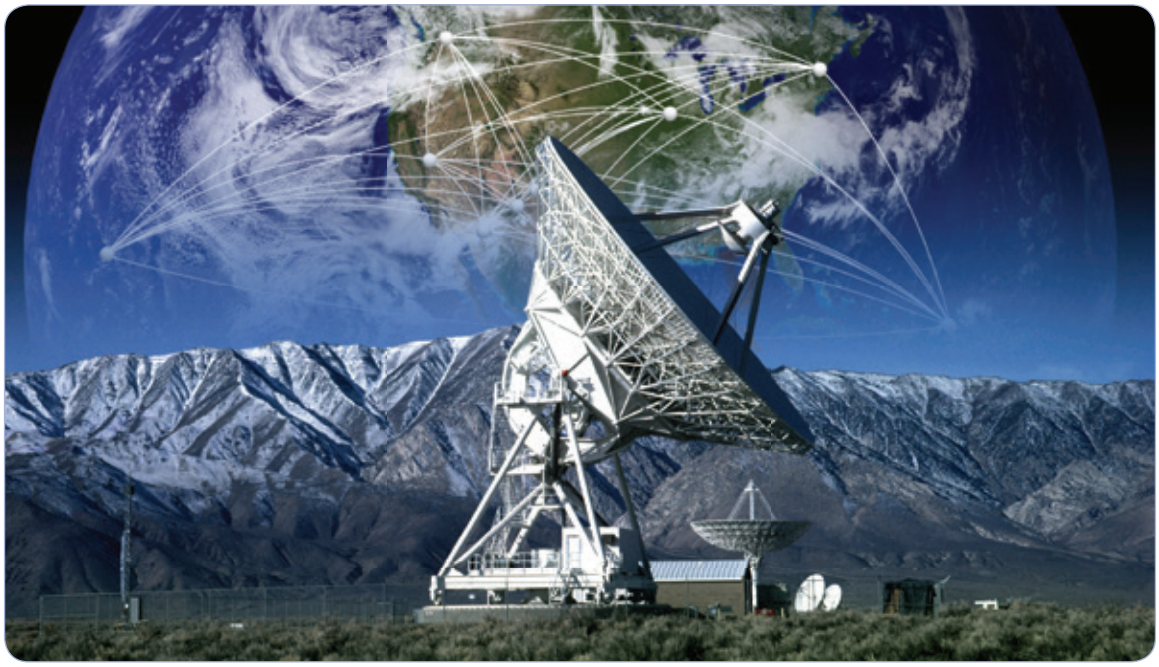
The previous day, more than 50 international reporters, including 12 who traveled with NRAO, attended a press day at the AOS and OSF that included a press conference. The day concluded with an AOS tour, and numerous interviews with scientists and support staff. NRAO's press events started even earlier, with a reception and presentation at an AUI co-sponsored radio astronomy exhibit titled *A New Window on the Universe* located in one of Santiago's busiest metro stations.

This Inauguration was a fitting celebration to mark ALMA's transition from a construction project to an extraordinarily capable, international observatory that is already impacting numerous fields of astrophysics.

Array Science Center: VLA/VLBA Operations & Development

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 Jansky Very Large Array transitioned from the Expanded Very Large Array construction project to full science operations in January 2013 as a radio telescope of unprecedented sensitivity, frequency coverage, and imaging capability. A suite of



new receivers on all 28 antennas, along with a new digital data transmission system and a new Wideband Interferometric Digital Architecture (WIDAR) correlator, provide superb spectral resolution and fidelity over very wide instantaneous bandwidth, enabling astronomers to make full-beam images with very high spatial resolution and dramatically improved continuum sensitivities from 1-50 GHz.

The VLBA is an interferometer of 10 identical antennas with baseline lengths up to 8600 km (Mauna Kea, Hawaii to St. Croix, Virgin Islands). Each VLBA station consists of a 25m antenna and an adjacent control building. Signals are amplified, digitized, and recorded on fast, high capacity recorders. The recorded data are sent from the individual VLBA stations to the correlator in Socorro.

The NRAO Semester 2013B Call for Proposals covered: (a) the VLA observing period 23 August 2013 through 06 January 2014, which corresponded to the CnB, B, and BnA configurations; and (b) all types of VLBA and High Sensitivity Array (HSA) proposals requesting time from 1 August 2013 through 31 January 2014.

The Semester 2014A Call for Proposals covered: (a) the VLA observing period 14 February 2014 through 8 September 2014, corresponding to the A and D configurations; and (b) all types of VLBA and High Sensitivity Array (HSA) proposals requesting time from 1 February 2014 through 31 July 2014.

Both single pointing and mosaics with discrete, multiple field centers were supported. Data rates up to 20 MB/s (72 GB/hour) were available to all users via the 2013B Call, and up to 6 MB/s (216 GB/hour) via the 2014A Call. All VLA antennas employed electronics and receiver systems throughout 2013 that provided continuous frequency coverage from 1-50 GHz in the following observing bands: 1-2 GHz (L-band); 2-4 GHz (S); 4-8 GHz (C); 8-12 GHz (X); 12-18 GHz (Ku); 18-26.5 GHz (K); 26.5-40 GHz (Ka); and 40-50 GHz (Q).

New Mexico Operations continued to offer shared risk programs to the NRAO user community for those who like to push the capabilities of the VLA beyond those offered for general use.

The Shared Risk Observing program provided users access to capabilities that are not yet well tested. Capabilities offered under the VLA Shared Risk Observing program in 2013 included: correlator dump times as short as 50 ms; the 3-bit sampler system with the C/X/Ku-band receivers; and the new low frequency system (230-470 MHz, P-band).

The continuing Resident Shared Risk Observing (RSRO) provided access in to extended VLA capabilities that required additional testing, in exchange for a period of residence to help commission those capabilities. Capabilities under the 2013 RSRO program included: correlator dump times shorter than 50 ms; data rates above 60 MB/s and up to 140 MB/s; use of recirculation in the correlator; more than 3 sub-arrays; on-the-fly (OTF) interferometric mosaicking; and complex phased array observations (e.g., pulsar and complex VLBI observing modes).

A new low frequency VLA receiver system was developed in collaboration with the Naval Research Laboratory. Twenty antennas were outfitted with this system by the start of the B configuration, and all 27 antennas were outfitted by the start of A configuration. Use of this low frequency system for Stokes I continuum observations at P-band (230 to 470 MHz) was available through the Shared Risk Observing program.

A primary concern of New Mexico Operations is 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.

A New Sky Survey with the Very Large Array

In the 20 years since the initial observations were made for the *NRAO VLA Sky Survey (NVSS)* and the *Faint Images of the Radio Sky at Twenty-Centimeters (FIRST) Survey*, these pioneering programs have defined the state-of-the-art in centimeter radio sky surveys and produced a steady stream of excellent science. Given the enhanced capabilities of the Jansky Very Large Array (VLA), NRAO initiated discussion with the astronomy community in 2013 regarding the scientific potential of new centimeter-wavelength sky surveys.

The astronomy community recognized that several of the high priority science goals of the 2010 decadal survey *New Worlds, New Horizons in Astronomy and Astrophysics* could be addressed by a new VLA sky survey. At the May *Radio Astronomy in the LSST Era* symposium held at NRAO headquarters in Charlottesville, many scientists expressed keen interest in employing the VLA to conduct new, wide-area centimeter wavelength sky surveys in support of multi-wavelength synoptic surveys using existing and future facilities, such as the Large Synoptic Survey Telescope (LSST).

Thus, NRAO formally announced a VLA Sky Survey (VLASS) initiative in 2013 to explore the science and technical opportunities of a new centimeter-wavelength survey. The plan is for all VLASS data to be made available immediately to the North American community.

Call for White Papers

In early September, NRAO announced an open call for community white papers on the VLASS concerning survey science goals, techniques, development areas, and overall design. The 18 community white papers and abstracts submitted for the VLASS will form the basis for discussion and presentations at a workshop to be held 5 January 2014 at the winter American Astronomical Society (AAS) meeting. The submitted white papers covered topics ranging from transients to lensing to polarization, covering our Galaxy to the far reaches of the Universe and everything in between.

In early October, NRAO announced an open call for nominations of individuals to serve on the VLASS Science Organizing Committee (SOC). The SOC was charged with review of the white papers received from the community, with organization of the January 2014 AAS workshop, and with setting up the community-based Science Survey Group (SSG) that will carry out the survey definition.

The VLASS Science Organizing Committee members appointed in December include:

Stefi Baum (RIT, *Chair*)
Tracy Clarke (NRL)
Jackie Hodge (NRAO)
Eric Murphy (IPAC)
Aneta Siemiginowska (CXC/SAO)
Alicia Soderberg (Harvard)
Rick White (STSCI)
Shami Chatterjee (Cornell)
Jim Condon (NRAO)
Karl Menten (MPIfR)
Steven Myers (NRAO, *ex-officio*)
Vernesa Smolcic (Zagreb)
Michael Strauss (Princeton)

A community-led Science Survey Group (SSG) was created to define the science program and key components of VLASS, with NRAO supporting its technical definition and implementation. Science Survey Group members were selected to represent the diverse interests of potential VLASS users, including those from multiple wavelength regimes, colleagues who have expertise in sky survey planning and oversight, and those with interest in relevant science areas. The NRAO, along with the SSG, will develop the technical design of the survey and implement it on the array.

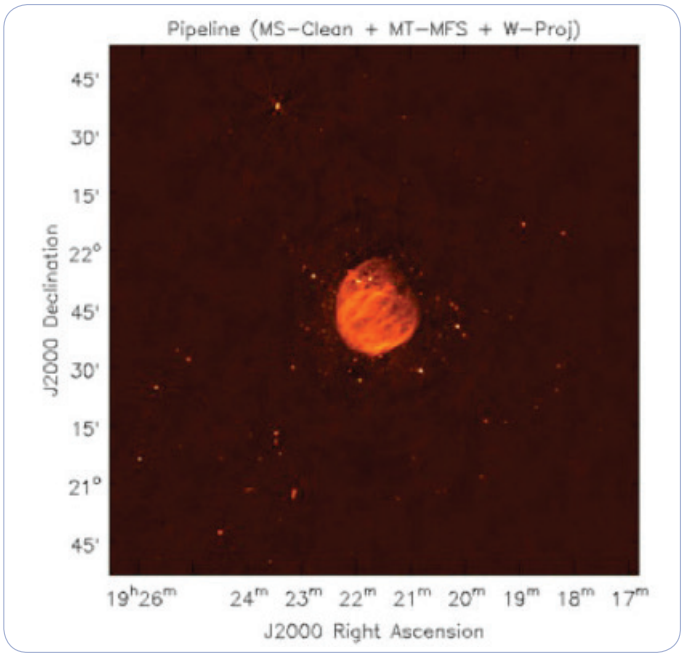
The SSG Governing Council includes the following community members:

Co-Chairs: Stefi Baum (RIT) and Eric Murphy (IPAC)
Programmatics Co-Chairs: Jim Condon (NRAO), Rick White (STScI)
Galactic Co-Chairs: Cornelia Lang (Iowa), Rachel Osten (STScI)
Extragalactic Co-Chairs: Jackie Hodge (NRAO), Gordon Richards (Drexel)
Transients & Variability Co-Chairs: Gregg Hallinan (Caltech), Ashley Zauderer (CfA)
Communication/Education/Outreach Co-Chairs: Susana Deustua (STScI), TBA
Technical WG Co-Chairs: Casey Law (UC Berkeley), Steve Myers (NRAO)
At-large Councilors: Niel Brandt (Penn State), Jim Cordes (Cornell), Mark Dickinson (NOAO), Tracy Clarke (NRL), Joe Lazio (JPL), Sui Ann Mao (Wisconsin), Michael Strauss (Princeton)

VLA Calibration Pipeline

Starting with the D-configuration in 2013, all VLA observations are being run through an automated calibration pipeline. All pipeline-calibrated scheduling blocks undergo quality assurance checks by NRAO staff, after which observers may request a calibrated CASA measurement set for download. The first pipeline-reduced data were delivered to the PI of a VLA project on 30 January, and the pipeline continued to run 24 hours/day reducing VLA observations.

While the calibration pipeline is optimized for Stokes I continuum observations, it can also work for some spectral line observing set-ups as well with minor modifications. The pipeline scripts, with instructions for installation and operation, are available for download at *https://science.nrao.edu/facilities/vla/data-processing/pipeline*.

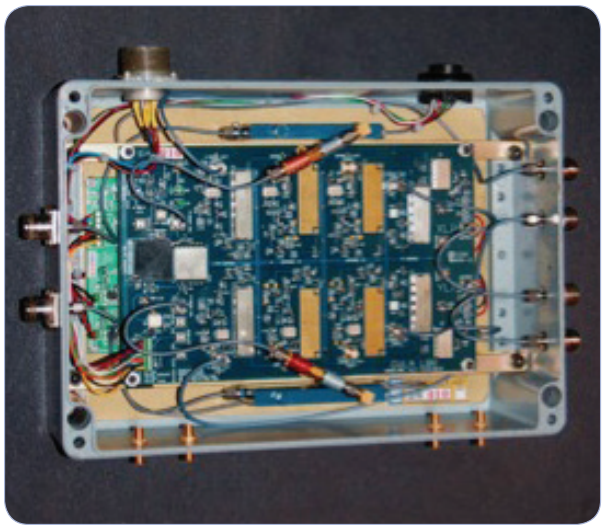


A typical L-band image made from data flagged and calibrated by the VLA calibration pipeline. The rms noise in this image of G55.7+3.4 is just 12.2 μJy/beam. Differences in the source structure and/or source flux density between data reduced via the pipeline and data reduced manually are dominated by the uncertainty in the deconvolution process, not the calibration and flagging (image courtesy Urvashi Rao).

The pipeline is based on CASA tasks and python scripts. The pipeline includes automated radio frequency interference (RFI) flagging and identification of system issues, but in some cases extra flagging may be necessary before self-calibration and imaging.

The pipeline heuristics have been developed by NRAO staff and validated through comparisons with expert, hand calibration and imaging. In all cases, the images produced from the pipeline-calibrated data compare well with those made using manually reduced data. The accompanying sample L-band image of the supernova remnant G55.7+3.4 made using data calibrated and flagged by hand and via the pipeline. The heuristics of the VLA calibration pipeline are continuing to be developed, and options for supporting different types of reprocessing will become available in the coming months. Feedback on the pipeline output is welcome, and may be provided through the pipeline department of the NRAO Helpdesk.

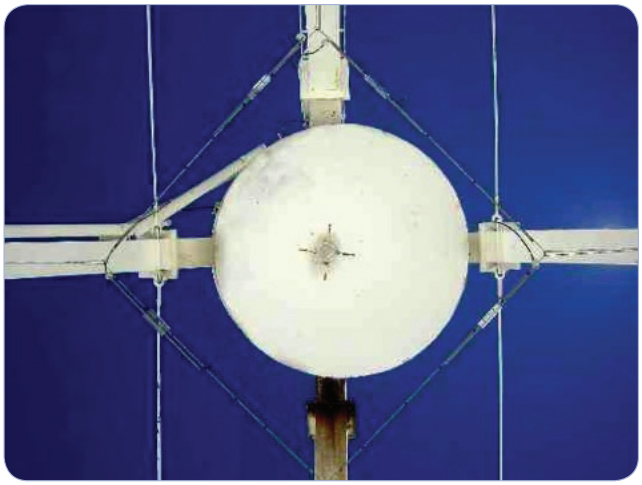
Low Frequency VLA Receivers



In collaboration with the Naval Research Laboratory (NRL), new low-frequency receivers were successfully installed at the VLA in 2013 to replace the legacy 74 MHz and 327 MHz VLA receivers. The new "low band" receivers take advantage of the much wider bandwidths now available at the VLA and the improved interference environment below 85 MHz created by the elimination of low frequency analog TV channels. Twenty-eight receivers were funded by NRL and the NRAO. Receivers in all 27 antennas have been installed, commissioned, and are actively used for scientific observations. EVLA Memo 175 *Low Band Receiver Performance* describes the laboratory performance of the low band receiver and also the in-array performance of the P-Band system.

Prototype Low-Band VLA Feeds

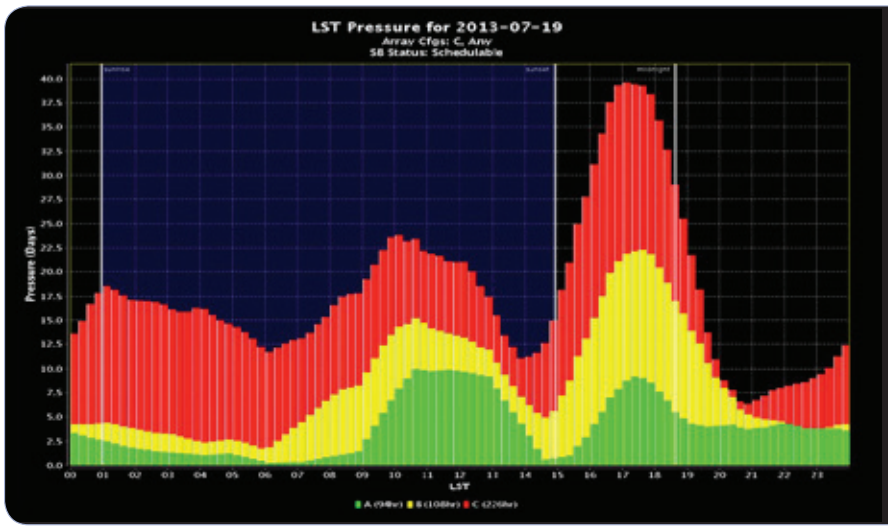
The legacy dipole feeds for the 54-86 MHz frequency range interfere with beam polarization at higher frequencies. As a result, they are only mounted on the antennas for special campaigns. The low-band feed development project was tasked with prototyping and testing a new low-band feed that will produce minimal adverse effects on higher frequency observing, enabling the feeds to be mounted permanently. A design was produced, called the Modified J-Pole (MJP). The project had mixed success, reducing high frequency polarization perturbations at the expense of some reduction in the low-band frequency sensitivity.



Four Modified J-Pole feeds on a VLA antenna.

After testing, it was concluded that the design was not ready for a critical design review. A decision was made to retain the Erickson dipoles, deployable in campaign mode, for the foreseeable future. The response and cross-polarization of the traditional Erickson feeds was improved significantly in a concurrent development process.

The VLA Pressure Histogram



Pressure histogram for Schedule Blocks in the VLA dynamic queue on Friday, 19 July 2013, aggregated by the scheduling priority (A, B, or C) assigned by the NRAO Time Allocation Committee. The total hours per priority are also displayed. Local Sidereal Times (LSTs) between sunrise and sunset are shaded blue. The LST at local midnight is also shown.

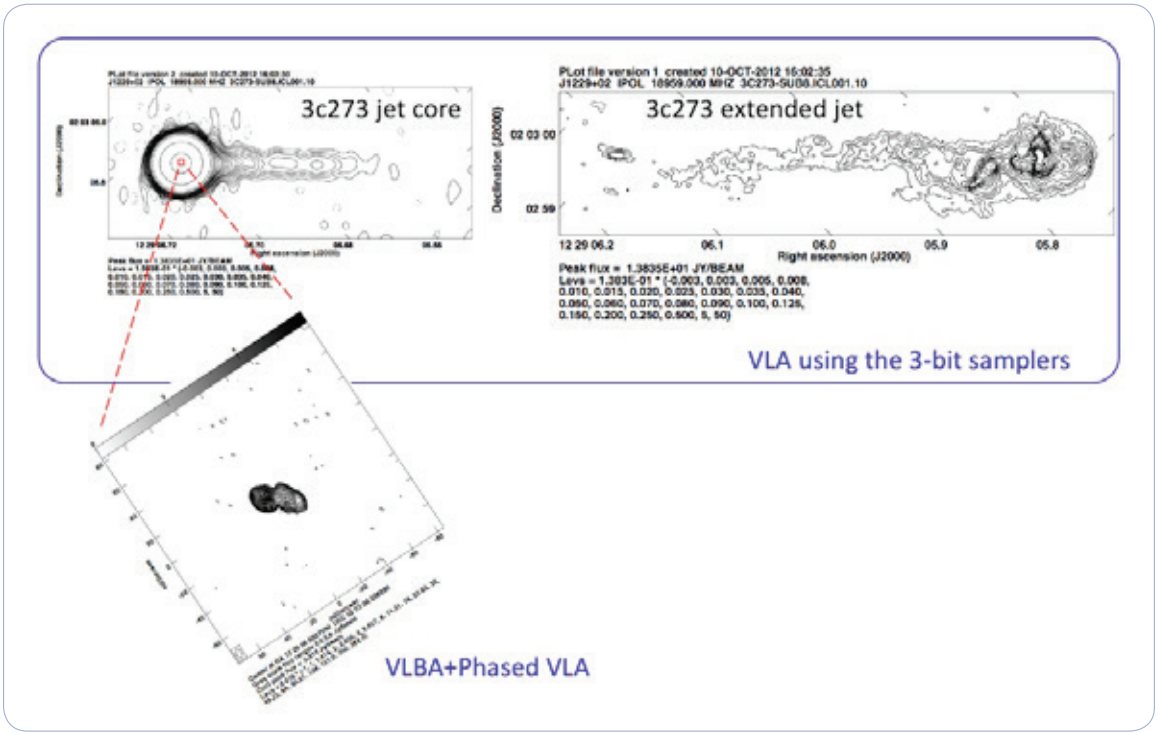
The VLA is dynamically scheduled. Information from approved proposals flows to the Observation Preparation Tool (OPT). Astronomers use the OPT to specify sources to be observed, instrumental setups, timing information, and weather constraints, all packaged as a Scheduling Block (SB). SBs carry the scheduling priority of A (almost certain), B (best effort), or C (filler) assigned to them by the NRAO Time Allocation Committee (TAC). After vetting by NRAO staff, SBs are entered into the dynamic queue.

NRAO staff use the Observation Scheduling Tool (OST) to examine the current weather conditions and the SBs in the queue. The OST then applies heuristics to select the optimal SB from the queue and send it off for observation. Dynamic scheduling enhances science data quality and the array's ability to discharge time-sensitive science. But it can leave astronomers puzzled about the chances that their SBs will be selected for observation.

For this reason, every Friday, VLA operations staff post a "pressure histogram" for the dynamic queue. The OST heuristics include SB attributes under astronomer control, specifically its duration, weather constraints, observing bands, and range of starting Local Sidereal Times (LSTs). Guided by the weekly histogram, some astronomers might wish to use the OPT to adjust the attributes of their SBs. Most weekdays between about 8 a.m. and 5 p.m. Mountain Time the array is unavailable for science because of maintenance and development activities. This histogram is updated every Friday at http://www.aoc.nrao.edu/~schedsoc/FridaysPressureHistogramVLA.png

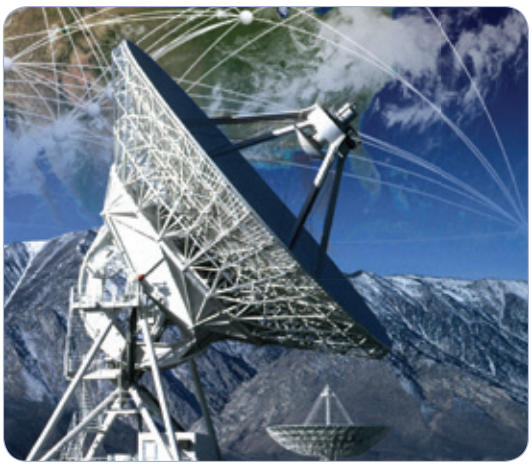
Very Long Baseline Interferometry Capability Returns to VLA

For the first time since the old VLA correlator was decommissioned in early 2010, it became possible in 2013 to include the phased VLA in Very Long Baseline Interferometry (VLBI) observations. A first example of such a mode made use of the VLA and ten Very Long Baseline Array (VLBA) antennas. Both the VLBA and VLA were configured to observe with 2 full-polarization baseband channels of 128 MHz each, corresponding to the widest bandwidths the VLBA can offer. The image below was constructed from 15 minutes of test data. The upper images show the arcsecond scale jet as observed with the VLA. The inset is the milli-arcsecond scale VLBI jet observed simultaneously with the VLBI array. On 2 February, the VLBA and phased VLA began making scientific observations of distant black holes. Some of the upcoming observations will include the orbiting Russian RadioAstron VLBI antenna.



Rapid Response with the VLBA

In recent years, several space and ground-based observatories with wide-field imaging capabilities have been routinely surveying the dynamic sky. Satellites such as Swift and Fermi, and precursors to the Large Synoptic Survey Telescope and the Square Kilometre Array such as the Panoramic Survey Telescope and Rapid Response System (Pan-STARRS), the Palomar Transient Factory, and the Low Frequency Radio Array can detect transient astronomical events in real or near-real time and generate alerts to trigger sensitive, narrow-field instruments such as the VLBA. Follow-up capabilities are ever more critical to the science goals of characterizing and localizing these fast events.



With these goals in mind, a new VLBA capability was added that enables trigger observations on time scales as short as 10 minutes. This new capability has been available since NRAO Semester 2013A as part of the Resident Shared Risk Program. The long baselines of the VLBA can provide milli-arcsecond imaging, precise localizations, and robustness to radio frequency interference that are not possible with any other instrument.

One VLBA program (P.I. Keith Bannister) is using this capability to confirm detection and conclusively associate short-duration radio pulses from Gamma-Ray Bursts (GRBs) occurring within 15 minutes of a Swift satellite trigger. These short-pulses were first detected using the Parkes 12m telescope as single dispersed pulses for two GRBs, with flux densities of 7 Jy and dispersion measures in excess of Galactic values (Bannister et al. 2012, ApJ, 757, 38). If such detections are confirmed they can provide an important tool to study GRBs and the intergalactic medium.

The VLBA rapid response capability as currently implemented supports follow-up observations in times as short as 5 minutes after a trigger at times when there are no observations running on the array. Notices from the Gamma-ray Coordinates Network containing preliminary locations and basic information for the events are automatically received at the Array Operations Center in Socorro, NM. Events matching the given science case are used to generate VLBA schedules and an email notification to the array operators, who make the decision to observe based on the available array time. The astronomer is responsible for the event selection and schedule generation, for which the observatory can provide support during the development process.

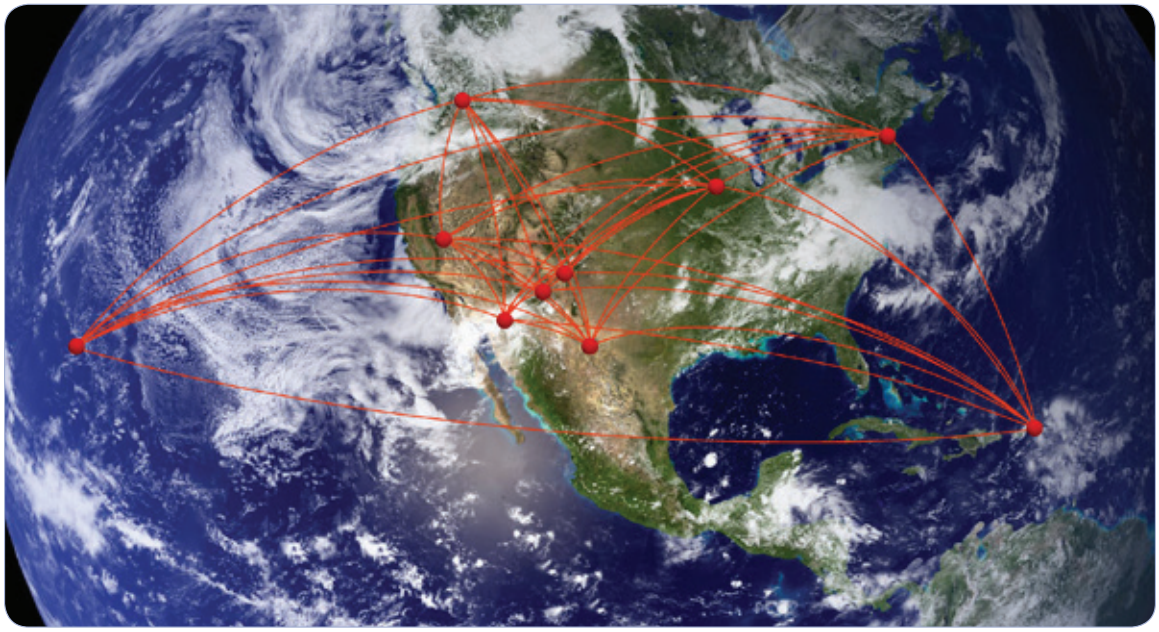
Multiple science programs will benefit from this new VLBA rapid response capability. Examples include imaging changes in SgrA* in response to strong IR flares, fast-evolving X-ray binaries, short-lived flare stars, and much more.

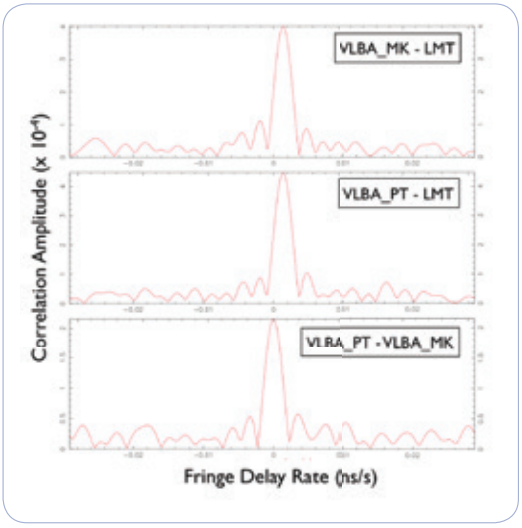
DiFX Software Correlator

On 23 December 2009, the Distributed FX (DiFX) software correlator became the sole correlator used by NRAO to process VLBA data. Since then development of this correlator has continued. A new release, version 2.2, was announced 12 June and shortly thereafter adopted. In addition to numerous operational improvements, this version added improved support for the VDIF data format – used by the VLA and an increasing number of VLBI antennas globally – which remains an area of continued development. Substantial improvements have also been made in the processing of geodetic data, including more flexible processing of mixed sidebands, and formal support for "zoom bands" which allow processing of mismatched baseband channels. DiFX can also now be compiled without reliance on the Intel Integrated Performance Primitives (IPP) library. This will result in reduced performance but will vastly simplify use on non-Intel architectures and in cases where IPP is not available.

Key developers of DiFX and its supporting libraries span the globe: the Netherlands Institute for Radio Astronomy, US Naval Observatory, Haystack Observatory, NASA – Goddard Spaceflight Center, University of Western Australia, Curtin University, Australia Telescope National Facility, Max Planck Institut für Radioastronomie, Korea Astronomy and Space Science Institute, Institute of Astronomy & Astrophysics Academia Sinica, and NRAO.

VLBI Fringe Detections between the VLBA and the Large Millimeter Telescope





[Top] *A map of the relative locations of the antennas involved in the successful 2013 Very Long Baseline Interferometry (VLBI) test between the Large Millimeter Telescope (LMT) and several VLBA stations.* **[Above Left]** *The Large Millimeter Telescope (LMT), at the summit of Volcan Sierra Negra (4600m elevation) in Mexico. Credit: Instituto Nacional de Astrofísica, Óptica y Electrónica and the University of Massachusetts* **[Above Right]** *VLBI fringe detections obtained 26 June between the LMT in Mexico and VLBA sites in the US at Mauna Kea, Hawaii (MK) and Pie Town, New Mexico (PT).*

An international team of US and Mexican scientists has completed a successful Very Long Baseline Interferometry (VLBI) test between the Large Millimeter Telescope Alfonso Serrano (LMT) and several VLBA stations. The LMT is a 50m diameter millimeter-wave telescope at the summit of Volcan Sierra Negra at an elevation of 4600m. Because of its high elevation and geographical location, the LMT promises to be a scientifically important addition to the VLBA at 3mm and to the Event Horizon

Telescope (EHT) project at 1.3mm. As a first step toward full LMT participation in these networks, the team assembled a full VLBI system at the LMT, consisting of an IF downconverter – to process the IF from the facility 3mm Red Shift Search Receiver – a VLBI Digital Backend, and a Mark5b VLBI recorder. Because a hydrogen maser could not be installed for this test, a precision quartz oscillator, which has stability comparable to a hydrogen maser on integration times shorter than 10 seconds, was used as the fundamental VLBI frequency reference.

Robust and clear VLBI fringe detections were obtained 26 June between the LMT and VLBA sites at Mauna Kea and Pie Town. These detections confirm that the LMT facility 3mm receiver has phase stability characteristics suitable for VLBI, and that the LMT can deliver significant added sensitivity to the VLBA. These successful tests pave the way for high sensitivity VLBI projects at 3mm wavelength that will target, among other objects, AGN and astronomical masers. At 1.3mm wavelength, in conjunction with the EHT, the LMT will add important capability to efforts aimed at resolving and imaging the black hole event horizons of SgrA* and M87.

Building on these tests, the team plans a permanent installation of a hydrogen maser and instruments that will allow the LMT to participate fully in Global VLBI observations. Institutes involved in the test include: Haystack Observatory, University of Massachusetts, NRAO, the Instituto Nacional de Astrofísica Óptica y Electrónica, and the Smithsonian Astrophysical Observatory.

The Sun rises over a 25-meter dish antenna of the Very Long Baseline Array, our collection of ten identical radio dish antennas working together as one telescope. The VLBA antennas are placed across the Northern Hemisphere from Hawai'i to St. Croix in the U.S. Virgin Islands, and together they form a dedicated array 5,351 miles across.

OPERATIONS & DEVELOPMENT

NRAO Calls for Proposals

The NRAO published two Calls for Proposals for the GBT, the VLBA/High Sensitivity Array (HSA), and the VLA in calendar year 2013: the Semester 2013B Call for Proposals was released 3 January for the 1 February deadline; and the NRAO 2014A Call for Proposals was released 8 July for the 1 August deadline. At each deadline, proposers requested time on the GBT, the VLBA/High Sensitivity Array (HSA), and/or the 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
- Star formation
- Galaxies (continuum)
- Active Galactic Nuclei
- Energetic transients and pulsars
- Interstellar medium
- 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 for Semester 2013B, NRAO received 354 proposals by 1349 unique authors, with 956, 392, and 227 proposers competing for time on the VLA, GBT and VLBA/HSA, respectively. Eight Science Review Panels (SRPs) evaluated the proposals on the basis of scientific merit; NRAO staff reviewed the proposals for technical feasibility. Reviews were completed in October and then reconciled by the Time Allocation Committee (TAC) during its meeting 15-17 April at Associated Universities, Inc., in Washington, D.C. The TAC consists of the chairs of the SRPs and was charged with recommending a science program for Semester 2013B to the NRAO Director. The *recommended program* was reviewed and approved on 6 May. A disposition letter was sent to the principal investigator and co-investigators of each proposal on 17 May. A TAC report containing information for proposers and observers, including statistics and telescope pressure plots, was released the same day. The approved science program was also posted to the NRAO science website.

At the 1 August submission deadline for Semester 2014A, NRAO received a record 450 proposals by 1526 unique authors, with 1146, 401, and 247 proposers competing for time on the VLA, GBT, and VLBA/HSA, respectively. Eight Science Review Panels (SRPs) evaluated the proposals on the basis of scientific merit. NRAO staff also reviewed the proposals for technical feasibility. Reviews were completed in September and then reconciled by the TAC during a 28 October telecon and a face-to-face meeting 4-5 November at NRAO in Charlottesville, VA. The TAC consists of the chairs of the SRPs and was charged with recommending a science program for Semester 2014A to the NRAO Director. The recommended program was reviewed and approved on 18 November. A disposition letter was sent to the principal investigator and co-investigators of each proposal on 25 November. A TAC report containing information for proposers and observers, including statistics and telescope pressure plots, was released the same day. The approved Semester 2014A science program was posted to the NRAO science website. For each approved proposal in the science program, the Proposal Finder Tool will provide access to its authors, title, abstract, and approved hours.

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

OPERATIONS & DEVELOPMENT

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 (λ3.0m – 2.6mm) operating range.

Located in the National Radio Quiet Zone 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.

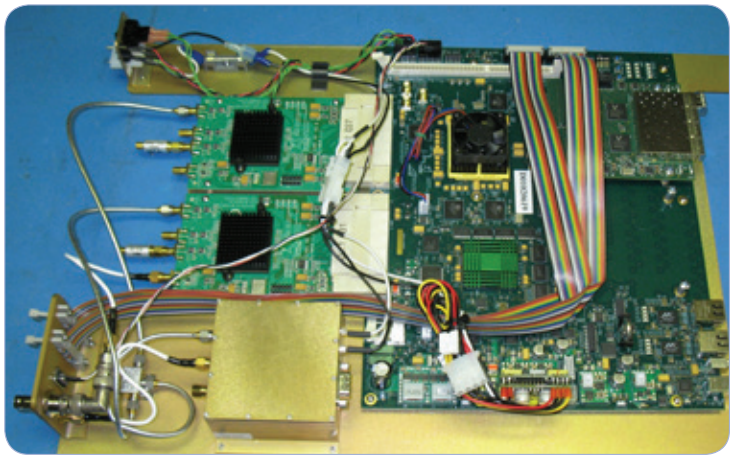
Science for the GBT ranges from understanding black holes through detecting gravitational waves, imaging the earliest galaxies, and searching space for the precursors of life. The GBT's flexibility and ease of use means it can rapidly respond to new ideas from the scientific community. It has a collecting 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.

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.

Versatile Green Bank Astronomical Spectrometer

With funding from the NSF Advanced Technologies and Instrumentation program, the Versatile Green Bank Astronomical Spectrometer (VEGAS) collaboration is building a new GBT backend to replace the existing spectrometer and spectral processor, instruments based on 20-year-old technology. An FPGA-based spectrometer, VEGAS is being developed by the University of Berkeley, the Collaboration for Astronomy Signal Processing and Electronics Research (CASPER) consortium, and NRAO.



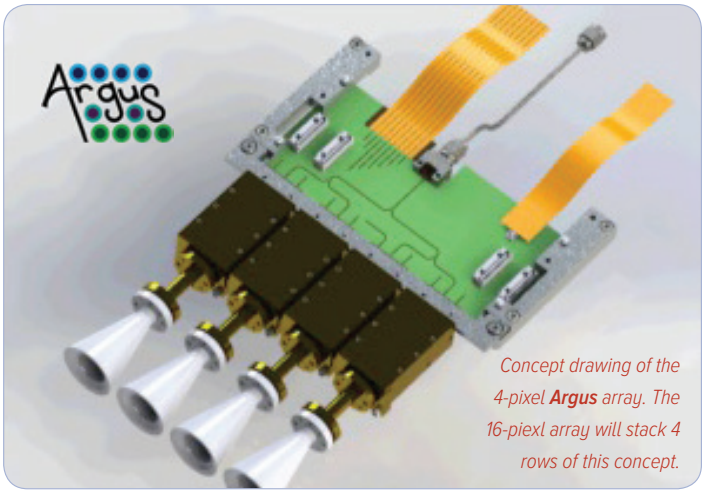
The new backend will provide vastly improved dynamic range, higher time resolution for off-line RFI excision and rapid maps, and greatly improved observations of multiple lines through the ability to create high frequency resolution sub-bands, modes crucial for the exciting GBT astrochemistry studies. The instrument will permit GBT focal plane array instruments to reach their full science potential by providing significantly increased bandwidth for the individual feeds. The instrument will also provide an instantaneous 10 GHz bandwidth vital for both detection of highly redshifted lines such as CO and for millisecond pulsar searches in the Galactic Center.

First light with the instrument was achieved on schedule in 2012. Development of further scientific instrument modes, as well as its associated data taking and data reduction software, continued through 2013. Delivery of the VEGAS instrument proved challenging and required more NRAO resources for project completion than anticipated. As a result, while the most difficult to implement modes were completed in 2013, final delivery of all modes will occur in 2014, at which time the instrument will be available for scientific use.

Argus

Cometary radio astronomy is currently very challenging because of the need for good angular resolution observations of very low surface brightness molecular lines in the 3mm band, from objects that can cover a wide field and change on time scales of an hour. To provide the requisite observing capability, Stanford (PI Sarah Church), the University of Maryland, and Caltech have begun construction of a 16-pixel "comet camera" for 85-116 GHz. This instrument, known as *Argus*, will be "plug compatible" with the existing IF system and the new VEGAS spectrometer. NRAO's role in 2013 was to provide GBT infrastructure and optics information to Stanford as requested. The project remains on track for testing in 2014.

The Argus array architecture is designed as a scalable technology pathfinder for larger arrays, and 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. In addition to comets, *Argus* will address a range of high impact science, including star-formation and cores, the interstellar medium, astro/bio-chemistry, and filamentary structure in molecular clouds.

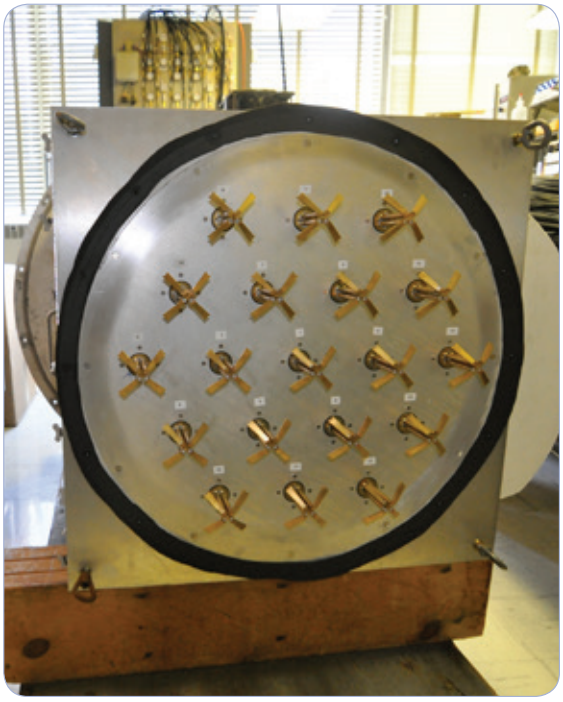


*Concept drawing of the 4-pixel **Argus** array. The 16-piexl array will stack 4 rows of this concept.*

Multiplexed Squid TES Array at Ninety GHz

The Multiplexed Squid TES Array at Ninety GHz (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 of the original MUSTANG bolometer array. MUSTANG 1.5 is a collaboration of the University of Pennsylvania, the National Institute of Standards and Technology (NIST), and NRAO. This instrument development project encountered several challenges in FY 2013, including delay in the delivery of the NIST detectors and difficulties in the backend readout electronics. The detector's delivery to NRAO – Green Bank is now expected in 2014.

A Wide-Field GBT Focal Plane Array Beamformer



Brigham Young University (BYU), West Virginia University, and NRAO were awarded a major NSF Advanced Technologies and Instrumentation (ATI) grant in 2013 to develop a digital signal processing system for a new wide-field L-band receiver for the GBT. At optical wavelengths, the advent of multi-pixel detectors revolutionized astronomical science. Radio telescopes have lagged behind in pixel-count for technical reasons, but dedicated efforts have been underway for more than a decade to close some of this ground.

Several telescopes worldwide currently use clusters of horn-type feeds to create multiple image pixels, but at radio frequencies the resulting pixels are widely separated on the sky and the field-of-view is discontinuous. A more sophisticated approach to increasing the field of view is to build a type of focal plane array known as a "phased array." This is an array of antenna elements in the focal plane of the telescope, in which the relative phases and amplitudes of the respective signals feeding the elements are weighted and combined in such a way that the effective radiation pattern of the array is reinforced in a desired direction and suppressed in undesired directions.

With a modern digital backend it is possible to perform this process in a parallel fashion so that multiple beams can be formed on the sky. Development of phased array feeds is proceeding at a number of radio observatories worldwide, and in particular a pioneering program at NRAO has grown out of early work by Rick Fisher in the mid-1990s.

Research and development of phased arrays at NRAO in recent years has focused on multiple-element wideband dipole front-end receivers. A strong collaboration between NRAO and BYU led to progress on the design of the dipole elements, electronics and signal transport, and beam forming algorithms. NRAO implemented robust fiber optic transmission capability between the GBT and the control building in 2013 for high element-count phased array receivers.

OPERATIONS & DEVELOPMENT

The NSF-ATI grant is supporting development of a digital back end and post processing system for the Focal L-Band Array for the GBT (FLAG) receiver. All results to date from FLAG have been produced using narrow instantaneous bandwidth data acquisition systems, with beam forming done in post-processing. A complete science grade instrument requires a real-time broadband signal processing system for array calibration, beam forming, correlation, and pulsar and transient searching.

The project is a collaboration between BYU (signal processing, calibration, beam forming, RFI mitigation algorithm development, analog-digital subsystems interface), and West Virginia University (science goals, algorithm and back end programming work, commissioning). NRAO staff provide support to ensure seamless integration into the GBT electronics and control systems. The project is expected to span three years.

FLAG will increase telescope survey speed relative to existing single-pixel instruments by a factor of 3-5. This receiver will push the GBT survey capability to a new state-of-the-art and will enable significant new science. FLAG's high sensitivity and wide field-of-view will also open up a new parameter space for studies of the transient radio sky, particularly for bright but rare transients such as the newly recognized and likely extragalactic population of fast radio bursts.

NRAO and the US Federal Government Shutdown

Owing to a US Federal Government shutdown, NRAO was required to temporarily suspend its North American operations and close all of its North American facilities from Friday evening, 4 October until Friday morning, 18 October 2013.

NRAO Site Directors identified a skeleton staff to maintain the security, safety, and integrity of NRAO facilities, telescopes, and systems during the shutdown; but no science observing occurred at the VLA, VLBA, or GBT during this period. ALMA operations at the Joint ALMA Observatory in Chile were unaffected, but no user support was available from the NRAO North American ALMA Science Center.

NRAO personnel, other than the skeleton staff, were on furlough. They could not report to NRAO facilities or conduct Observatory business from home. The NRAO Archives, including the ALMA Science Archive, were not accessible. Persons planning to visit an NRAO site during this time were required to reschedule their visits. Up-to-date information regarding the Observatory's operations status was made available by the skeleton staff via the NRAO websites.

A budget agreement reached by the US Congress enabled the NSF to reopen 17 October. The NSF requested that AUI/NRAO restart North American operations at the earliest possible time at the VLA, VLBA, and GBT. With the assistance of NSF and AUI, the Observatory restarted full operations, including science observing, on 18 October.

SCIENCE SUPPORT AND RESEARCH

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

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 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, though SSR will soon review the time allocation process to consider ways in which elements of the ALMA time allocation process can be effectively integrated and managed.

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

Science & Academic Affairs (SAA) supports the research activities of NRAO scientific staff and related activities, 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.

Karl G. Jansky Lectureship

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

The 48th annual Jansky Lecture was given in 2013 by Prof. Charles Bennett, Alumni Centennial Professor of Physics and Astronomy and a Johns Hopkins University Gilman Scholar, and was entitled *A Tour of the Universe*.

Prof. Bennett received his B.S. degree in Physics and Astronomy from the University of Maryland. He received his Ph.D. in Physics at MIT under Prof. Bernie Burke, working on large radio surveys with the 300 ft telescope in Green Bank, WV and follow-up "snapshot" observations at the VLA. He joined the scientific staff of the NASA Goddard Space Flight Center in 1984 and later became the Infrared Astrophysics Branch Head, and then a Senior Scientist for Experimental Cosmology and a Goddard Senior Fellow. Dr. Bennett became a professor at the Homewood campus of the Johns Hopkins University in January 2005.

For the last two decades, Dr. Bennett has led the Wilkinson Microwave Anisotropy Probe (WMAP) mission. WMAP, launched in June 2001, quantified the age, content, history, and other key properties of the Universe with unprecedented accuracy and precision. Previous to his work on WMAP, Dr. Bennett was the Deputy PI of the Differential Microwave Radiometers instrument

and a member of the Science Team of the Cosmic Background Explorer (COBE) mission. The scientific results from this work included the first detection of variations across the sky of the temperature of the cosmic microwave background radiation.

Dr. Bennett is currently building the Cosmology Large Angular Scale Surveyor (CLASS), a microwave background instrument to search for the B-modes from inflationary gravitational waves. CLASS will be sited near ALMA in Chile. Bennett has also been active in defining the Wide-Field Infrared Survey Telescope (WFIRST) mission, and is member of the Euclid and the Subaru Prime Focus Spectrograph teams.

Dr. Bennett has received several awards and honors, including the 2012 Gruber Cosmology Prize, 2010 Shaw Prize in Astronomy, the 2009 Comstock Prize in Physics, the 2006 Harvey Prize, and the 2005 Henry Draper Medal. He twice received the NASA Exceptional Scientific Achievement Medal, once for COBE and once for WMAP. He also received the NASA Outstanding Leadership Medal for WMAP. Dr. Bennett is a member of the National Academy of Sciences and the American Academy of Arts and Sciences.

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. Two new Fellows joined the program in 2013.

Betsy Mills completed her Ph.D. with Mark Morris at UCLA on studies of the Galactic Center. She has performed groundbreaking work on warm, dense gas in molecular clouds in the inner few parsecs of the Galaxy. As a Jansky Fellow, Betsy worked to build a complete picture of the physical conditions in the Galactic Center gas from the largest to the smallest scales. She works from the Array Science Center in Socorro, NM.

Jackie Hodge was a postdoc at the Max Plank Institute for Astronomy working with Fabian Walter, having obtained her Ph.D. from UC-Davis having worked with Robert Becker on the Faint Images of the Radio Sky at Twenty-Centimeters (FIRST) survey. She is an expert on centimeter and millimeter observations of galaxy formation at high redshift, with extensive VLA and ALMA experience. As a Jansky Fellow, she is using the growing capabilities of ALMA, along with the VLA, to work toward a more comprehensive understanding of the build-up of galaxies over cosmic time. Jackie works at the North American ALMA Science Center in Charlottesville, VA.

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. Two Postdoctoral Fellows joined NRAO in 2013.

Jennifer Donovan Meyer, a new NAASC post-doc, earned her Ph.D. in Astronomy at Columbia University with Jacqueline van Gorkom. Her dissertation focused on the evolution of early-type galaxies and the role in that process played by neutral atomic hydrogen (HI). Following her dissertation, Jen worked with Jin Koda at Stony Brook University on a survey of nearby spiral galaxies observed in CO (1-0) using combined data from the CARMA interferometer and the Nobeyama 45-meter single dish telescope. On her way to NRAO, she spent a couple months at Columbia to work on a new survey of HI-selected dwarf galaxy candidates. The common thread that ties her interests together is the understanding of the gas conditions necessary for star formation to occur in and around galaxies, from the potentially rejuvenated outskirts of early-type galaxies, to the booming centers of spiral galaxies, to tiny blue dwarf systems.

Drew Brisbin arrived at NRAO as a North American ALMA Science Center (NAASC) post-doctoral fellow in September 2013. He completed his Ph.D. under the supervision of Gordon Stacey at Cornell University. Drew's primary scientific focus has been on understanding galaxy evolution in terms of star formation and metallicity, with a focus on systems at $z > 1$. This work has largely relied on observations from Herschel and the Redshift(z) Early Universe Spectrometer (ZEUS) at the Caltech Submillimeter Observatory, and most recently, ALMA. Drew hopes to continue this work and also gain a greater understanding of how Active Galactic Nuclei influence star formation in the nearby Universe. Drew is excited to join the NAASC team and become an insider on the largest and most sensitive submillimeter/millimeter telescope. He is also enthusiastic about the emphasis NAASC puts on outreach and hopes to contribute to relating astronomy to the broader community.

IAU Symposium 303: *The Galactic Center: Feeding and Feedback in a Normal Galactic Nucleus*

IAU Symposium 303 was organized by NRAO scientific staff and was held in Santa Fe, New Mexico, USA 30 September – 4 October with 164 participants from around the world. This is perhaps the largest gathering of scientists in the series of Galactic Center workshops that have taken place over the past three decades.

This IAU Symposium featured 65 talks and 82 posters. The symposium's scientific highlights included the discussion of recent, high-resolution, multi-wavelength large scale surveys of molecular gas in the central molecular and dust zones of our Galaxy, as well as nearby Milky Way analogs. ALMA and VLA results were featured and provided the most detailed views of these regions. Studies of stellar populations revealed the latest results on stellar orbits around Sgr A* and a new class of compact dusty gas clouds. One of these clouds – known as G2 – is on a trajectory that allows possible accretion onto the supermassive nuclear black hole Sgr A*. A variety of theoretical models were proposed to explain the G2 event, as well as the general accretion and jet formation in the vicinity of Sgr A*. The large-scale gamma-ray emission (Fermi Bubble) was discussed in the context of possible past and current energetic activity in the Galactic Center, and the role of the magnetic field was emphasized.

Future observing opportunities were a topic of great interest, including monitoring G2 and Sgr A* across much of the electromagnetic spectrum, and at very high resolution, via the Event Horizon Telescope. Finally, plans for future workshops on the detailed physics of galactic nuclei were also discussed, including the August 2014 Committee on Space Research (COSPAR) Scientific Assembly in Moscow, Russia, a workshop at the August 2015 IAU General Assembly in Hawaii, USA, and plans for a 2016+ Galactic Center IAU Symposium in South Korea, Japan, or Australia.

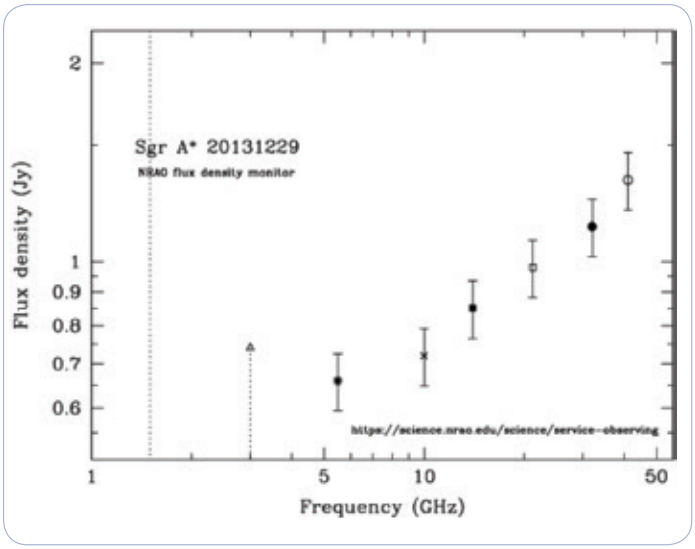
Monitoring the Galactic Center and the G2 Gas Cloud

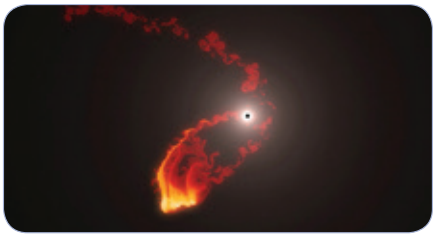
In October 2012 NRAO announced a service program to observe the encounter of the G2 gas cloud encounter with SgrA* in the Galactic Center, undertaking bi-monthly VLA monitoring observations through and after the expected closest approach encounter in mid-2013.

The VLA monitoring data are being obtained under project code TOBS0006, and the raw data are available through the NRAO Archive. Photometry, calibrated visibility data, and some images are posted at the NRAO Service Observing web page (https://science.nrao.edu/science/service-observing).

Multiple epochs of an anticipated 13 observations were obtained in 2013 in the VLA A, B, and D configurations. The measurements are consistent with no changes in flux density for Sgr A* within the measurement errors for the higher frequency bands. For the lower frequency bands only upper limits can be derived from the D configuration data, owing to the extended structure around Sgr A*.

The figure plots the measured flux densities of Sgr A* for Q, Ka, K, and Ku bands as function of time with their 10% error bars. Also shown is the maximum visibility flux density at L-band for baselines longer than 4.6kλ: these comprise the baselines that





[Above] *This simulation shows the future behavior of the G2 gas cloud now approaching Sgr A*, the supermassive black hole at the center of the Milky Way. X-ray emission from the cloud's tidal interaction with the black hole is expected sometime this spring. Credit: ESO/MPE/M.Schartmann.* **[Left]** *A sample of the G2 cloud encounter VLA data from B-configuration, acquired on 29 December 2013. Only upper limits are available for the flux density of SgrA* at the lowest frequencies.*

overlap between A and D configuration, and do include emission from SgrA-West, but should be less affected by the extended structure surrounding SgrA* that dominates the emission at the lower frequency bands in the compact configurations. The photometry and calibrated visibility data can be found on the Service Observing web page.

NRAO will continue to monitor the flux density of Sgr A* in 2014. New monitoring measurements will be made available as soon as possible through the Service Observing web page at the NRAO science website and through The Astronomer's Telegram.

The Galactic Gas Supply: Neutral Hydrogen in the Local Universe

Recent observations in the UV and 21cm lines have provided evidence that very low-level amounts of neutral gas may be common around galaxies and in galaxy groups. Theoretical arguments suggest that such gas might arise from a number of sources including cold mode accretion and galaxy interactions, and may be a trace constituent of much larger amounts of gas.

To explore this topic, a workshop on *The Galactic Gas Supply* was held at NRAO – Green Bank 29-31 May. The workshop focused on recent observational and theoretical work on the existence and properties of very low column density neutral hydrogen in the local Universe, including:

- The extreme edges of gaseous galaxy disks
- The neutral component of intergalactic and circumgalactic gas
- Galaxy growth through accretion of neutral gas, and
- The relationship of faint neutral gas to other components

More than 30 people participated in the two and one-half days of presentations and late night discussions. The participants and program are on-line at: https://science.nrao.edu/science/meetings/2013/HI17/galactic_gas_supply

NRAO Summer Student Program in 2013

NRAO welcomed 28 summer research interns to Socorro, Green Bank and Charlottesville in 2013, the 54th class in the Observatory's summer student program.

The program runs 10-12 weeks each summer, from early June through early August. At the end of the summer, participants present their research results at a student seminar and submit a written report. These projects often result in publications in scientific journals. Financial support is available for students to present their summer research at an American Astronomical Society meeting, generally at the winter meeting following their appointment. In addition to their research, students take part in other activities, including social events and excursions, and an extensive lecture series that covers many aspects of radio astronomy and astronomical research. Students also collaborate on their own observational projects using the VLA, VLBA, and/or GBT. Jeff Mangum leads the NRAO summer student program. NRAO scientific staff members Amy Mioduszewski, David Frayer, and Jeff Mangum lead and coordinate the summer student program in Socorro, Green Bank, and Charlottesville, respectively.

There are three types of Summer Student programs available. The Research Experiences for Undergraduates (REU) program is for undergraduates who are citizens or permanent residents of the United States or its possessions, and is funded by the National Science Foundation.

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

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

The students who participated in the 2013 program, their NRAO advisors, and their research projects are each listed below.

Socorro

Lorraine Bowman is a graduate student studying Physics at New Mexico Tech. Lorraine worked with Juergen Ott and David Westpfahl on *Power Law Structure of the ISM: HI, CO, and IR Lacunarity and Fractal Dimension Analysis in Nearby Galaxies*.

Rick Cosentino is a graduate student studying Physics at New Mexico Tech. Rick worked with Bryan Butler on *Simulations of Outer Planets Atmospheric Dynamics and Circulation*.

Ryan Duffin is a rising second year studying Astrophysics and Computer Science at the University of Virginia. Ryan worked with Minnie Mao on *Large Radio Sources Hosted by Spiral Galaxies*.

Jacob Jencson is a rising senior studying Astronomy, Physics, and German at the Ohio State University. Jacob worked with Miller Goss on *21-SPONGE: Searching for the Warm Neutral Medium in the Milky Way*.

Kara Kundert is a rising junior studying Astrophysics and Electrical Engineering at Oberlin College. Kara worked with Urvashi Rau and Sanjay Bhatnagar on *Evaluating the VLA L-Band Primary Beam Models in the Context of Wide-Field Imaging*.

Julia Mayeshiba is a rising senior studying Astronomy and Physics at the University of Wisconsin at Madison. Julia worked with Frazer Owen and Urvashi Rau on *Quantifying Deep-Imaging Limits with the VLA*.

Samuel Mellon is a rising junior studying Physics and Music at Westminster College. Samuel worked with Laura Perez on *Study of the Outflow and Disk Surrounding a Post-Starburst FU-Orionis Star*.

Green Bank

Kyle Blanchard is a rising junior studying Physics and Astrophysics at the University of California at Berkeley. Kyle worked with John Ford on the *Transient Search Receiver*.

Ryan Bossler is a rising senior studying Astronomy, Physics, Philosophy, and German at the University of Wisconsin at Madison. Ryan worked with Alyson Ford on *The Effects of Energetic Events in the Milky Way's Nucleus on HI Gas in the Lower Halo*.

Susan Schmitz is a rising junior studying Physics, Astronomy, Mathematics, and Spanish at the University of Iowa. Susan worked with Amanda Kepley on *Magnetic Fields in the Irregular Galaxy NGC 1156*.

Chris Thibodeau has a bachelor's degree in Astrophysics from Towson University. Chris worked with Jay Lockman on *Green Bank Telescope Observations of a Milky Way Satellite*.

Olivia Wilkins is a rising junior studying Chemistry, Mathematics, and Physics at Dickinson College. Olivia worked with Toney Minter on *HI Absorption Towards Pulsars*.

Charlottesville

Ajamu Abdullah is a rising senior studying Physics at Howard University. Ajamu worked with Aaron Evans on *Dissecting Luminous Starburst Galaxy Mergers*.

Laiya Ackman is a rising junior studying Astronomy, Physics, and Feminist Gender and Sexuality Studies at Wesleyan University. Laiya worked with Jen Donovan Meyer on *Probing the Rejuvenation of NGC 2685*.

Daniel Calem is a rising second year studying Astronomy at the University of Virginia. Daniel worked with Bob Dickman on *Searching for the Signature of Cold Dark Matter (CDM)*.

Ekene Elodimuor is a rising senior studying Computer Science at Howard University. Ekene worked with Aaron Evans on *Dissecting Luminous Starburst Galaxy Mergers*.

Norland Hagen is a rising sophomore studying Geology and Astronomy at the University of Montana. Norland worked with Arielle Moullet on *Interpreting Thermal Lightcurves of Rocky Solar-System Bodies*.

Anna Ho is a rising senior studying Physics, Astronomy, and Science Writing at MIT. Anna worked with Scott Ransom on *Rotation Measures for Globular Cluster Pulsars as a Unique Probe of the Galactic Magnetic Field*.

Jennifer Kadowaki is a rising senior studying Physics at the University of California at Los Angeles. Jennifer worked with Adam Leroy on *Recombination Line Emission in Nearby Mergers*.

Jared Keown is a rising senior studying Physics at the University of Louisville. Jared worked with Scott Schnee on *Correlating Physical and Chemical Properties in Starless and Protostellar Cores*.

Nicholas Kern is a rising junior studying Astrophysics and Physics at the University of Michigan. Nick worked with Jeff Mangum on *Imaging the Spatial Density within Starburst Galaxies*.

Adrian Lucy is a rising senior studying Astrophysics and History of Science at the University of Oklahoma. Adrian worked with Al Wootten and Nuria Marcelino on *Study of Deuteroammonia in the Orion Molecular Cloud*.

Sinclaire Manning is a rising senior studying Physics and Spanish at Howard University. Sinclaire worked with Aaron Evans on *Dissecting Luminous Starburst Galaxy Mergers*.

Adrian Mead is a rising third year studying Astrophysics and Mathematics at the University of Virginia. Adrian worked with John Tobin on *Examining the Initial Conditions of Star Formation Through Dense Gas Kinematics*.

Zaarah Mohamed is a rising sophomore studying Physics and Philosophy at Case Western Reserve University. Zaarah worked with Kim Scott and Kartik Sheth on *Evolution in the Interstellar Medium of Luminous Infrared Galaxies Since z = 1*.

Diana Powell is a rising junior studying Astrophysics, Physics, and French at Harvard University. Diana worked with Kartik Sheth and Kim Scott on *The Influence of Bars in Triggering Star Formation at High Redshift*.

Sierra Smith is a graduate of James Madison University with Bachelors and Masters degrees in History with a concentration on science history. Sierra worked with Ellen Bouton and Ken Kellermann on *Open Skies: The Story of NRAO*.

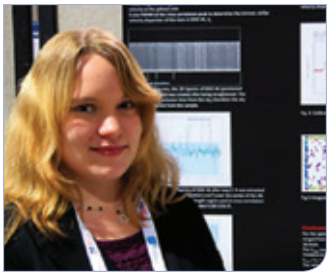
Aara'L Yarber is a rising sophomore studying Physics and Art at Howard University. Aara'L worked with Aaron Evans on *Dissecting Luminous Starburst Galaxy Mergers*.

NRAO at the 221st American Astronomical Society Meeting (Long Beach)

More than 300 AAS attendees heard brief presentations from Tony Beasley (NRAO Director, below left), Rachel Akeson (IPAC/Caltech), and Dominik Riechers (Cornell) at the NRAO Town Hall Tuesday evening.







The NRAO booth in the Long Beach Convention Center exhibit hall was busy throughout the AAS meeting, providing an excellent location for NRAO scientific staff to meet and converse with scientists from other institutions.

University of Arizona astronomer Daniel Marrone (above left) presented a talk on "ALMA Observations of the Brightest Starbursts in the Universe", one of 6 speakers in an ALMA Special Session that was "standing room only."

On Tuesday afternoon, the NRAO Education & Public Outreach team engaged students from Long Beach-area middle and high schools in an interactive activity about radio frequency interference (above center).

Fifteen NRAO Summer Students presented their research results at the Long Beach AAS meeting, including Sarah Wood (University of Tennessee, above right), who worked with Megan Johnson on the stellar kinematics and HI distribution of the dwarf galaxy DDO 46.

NRAO scientist Alison Peck led a group of current and potential users through a tutorial on processing ALMA and VLA data with the CASA software package.

2012 Summer Student AAS Presentations

Fifteen of the 2012 NRAO Summer Student program participants presented the results of their research projects at the January 2013 American Astronomical Meeting in Long Beach, CA. The table below lists these presentations along with the session title, the paper number in the session, and the complete author list.

Monday, 7 January 2013	
Elliptical and Spiral Galaxies	***146.20. Plateau de Bure Arcsecond Whirlpool Survey (PAWS): Multiscale Analysis of the ISM in the Whirlpool Galaxy***. S. Pardy; A.K. Leroy; E. Schinnerer, J. Pety; D. Colombo
Pulsars, Neutron Stars	***154.11. A New Method for Measuring the Rotation Measures of Millisecond Pulsars in the Globular Cluster Terzan 5*** A. Ho; S.M. Ransom; P. Demorest
Starburst Galaxies	***157.07. Imaging the Spatial Density Within Starburst Galaxies*** R. Smullen; J.G. Mangum; J.K. Darling; C. Henkel; K. Menten
Tuesday, 8 January	
Computation, Data Handling, Image Analysis	***240.04 Polarization Monitoring Using the EVLA*** K. Weil; S.T. Myers
Dwarf and Irregular Galaxies	***242.05. Inside Out: The Stellar Kinematics and HI Map of DDO 46*** S. Wood; M.C. Johnson; D.A. Hunter
Star Formation	***251.04. The Properties and Potential of XUV-Disks*** M. Gallagher; J. Munoz-Mateos; K. Sheth ***251.16. Modeling the Infall of Gas onto Class 0 Protostars*** A. Osler; J.J. Tobin
The Milky Way, The Galactic Center	***254.07. The Survey of 44GHz Methanol Masers and Star Formation Towards the Galactic Center*** A. Walker-LaFollette; L. Sjouwerman; Y. Pihlstrom
Wednesday, 9 January	
AGN, QSO, Blazars	***339.35. ALMA and Jansky VLA Observations of Highly Luminous Obscured Quasars: Synchrotron Ages of Young Radio Jets*** R. Smith; C.J. Lonsdale; M. Lacy; J.J. Condon; A.E. Kimball
Instrumentation, Ground and Airborne	***345.24. Raido and Optical Telescopes for School Students and Professional Astronomers*** L. Hosmer; G. Langston; S. Heatherly; A.P. Towner; J. Ford; R.S. Simon; S. White; K.L. O'Neil; J. Haipslip; D. Reichart
Molecular Clouds, HII Regions, Interstellar Medium	***349.05. Physical Temperature Measurements of L1551 from NH3*** A.P. Towner; L. Hosmer; G. Langston
	349.11 Determining the X-Factor of M82 Z. Edwards; J. Ott; D.S. Meier
	349.21. Correlating Physical and Chemical Evolution in Starless Cores N. Brunetti; S. Schnee; R. Friesen
Surveys and Large Programs	***352.10. Broadband Screening for Interstellar Species: Additional Laboratory Measurements and Interstellar Detection of Ethanimine (CH_3CHNH) in Sgr B2(N) Using GBT PRIMOS Survey Data*** R. Loomis; D. Zaleski; A. Steber; J. Neill; M.T. Muckle; B.J. Harris; N. Seifert; B. Pate; V. Lattanzi; O. Martinez; M.C. McCarthy; A.J. Remijan
Thursday, 10 January	
Radio Surveys of Galactic Clouds	***413.02. The Green Bank Telescope H II Region Discovery Survey IV. Helium and Carbon Recombination Lines*** T. Wenger; T.M. Bania; D.S. Balser; L.D. Anderson

NRAO at the 222nd American Astronomical Society Meeting (Indianapolis)

ALMA: A New Window on the Universe

NRAO Director Tony Beasley presented an invited plenary session talk at the 222nd American Astronomical Society in Indianapolis, Indiana on Tuesday 4 June 2013.

Director Beasley's presentation reviewed ALMA's origins and history, current technical capabilities, and described its primary scientific goals. Innovative aspects of ALMA's design, construction, operation, and governance were highlighted throughout this talk, including the key roles of the NRAO North American ALMA Science Center in Charlottesville, Virginia and the Joint ALMA Observatory in Chile. Director Beasley also described the development of the state-of-the-art technologies that is enabling the highest impact science, as well as the status of science operations and numerous research results from the Cycle 0 and Cycle 1 Early Science opportunities. The Director concluded his plenary talk by describing the vision for the Development Program that will maintain ALMA's capabilities at the forefront of modern astronomy.

Proposal & Observing Prep with NRAO Telescopes

NRAO scientific staff hosted a three-hour Splinter Session on Tuesday, 4 June 2013 at the summer American Astronomical Society meeting in Indianapolis to assist users with proposal preparation for the next Call for Proposals for all NRAO facilities, including the GBT, VLA, VLBA, and ALMA. This Session guided new users in how to create proposals for each of the NRAO telescopes and included overviews of new capabilities these telescopes are bringing to the scientific community. The Session also included interactive walk-throughs of the proposal preparation tools for each facility, and guided, hands-on tutorials hosted by NRAO scientific staff. No previous experience was necessary to attend and benefit from the Session: new and potential users were encouraged to attend.

3rd VLA Data Reduction Workshop

The third VLA Data Reduction Workshop took place 8-12 April at the Pete V. Domenici Science Operations Center in Socorro, NM. The aim of this workshop was to assist observers with the challenges posed by the vastly increased flexibility and complexity of the VLA. The focus was on reducing data taken in the wide-band Wideband Digital Interferometric Architecture (WIDAR) correlator modes available to the observing community since 30 September 2011. During the workshop observers were able to reduce their own data using hardware provided by NRAO while staff experts were present for consultation. Presentations by local staff also covered the Common Astronomy Software Applications (CASA) package and the latest developments in data reduction techniques.

This was an advanced workshop, and unlike the biannual NRAO Synthesis Imaging Workshop, was not intended for scientists new to radio interferometry. Prior experience with the Astronomical Image Processing System (AIPS), CASA, or Miriad software packages was required.

2013 Grote Reber Medal Awarded to James Moran

The Grote Reber Foundation announced that Professor Jim Moran was the recipient of the 2013 Grote Reber Gold Medal. Moran is the Donald H. Menzel Professor of Astrophysics at Harvard University and a Senior Radio Astronomer at the Smithsonian Astrophysical Observatory (SAO), where he has spent his entire career. He also holds a position as Concurrent Professor of Astronomy at Nanjing University and previously served as Chair of the Harvard Department of Astronomy and Associate Director of SAO.

Moran did his undergraduate work at the University of Notre Dame and received his Ph.D. from MIT in 1968. He has previously received the AAS Newton Lacy Pierce Prize, was the joint recipient of the 1971 Rumford Medal of the American Academy of Arts and Science, and was the 1996 NRAO Jansky Lecturer. He is a member of the US National Academy of Sciences and the American Academy of Arts and Sciences. He is a coauthor of a widely used reference book, *Interferometry and Synthesis in Radio Astronomy*. In 1962, he participated in one of the earliest NRAO summer programs, which permanently hooked him on radio astronomy as a career.

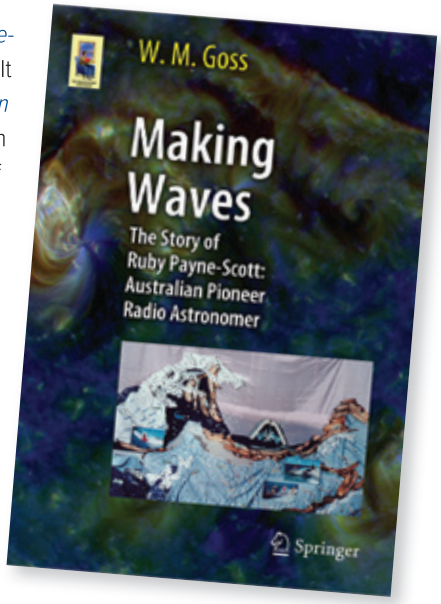
The Grote Reber Medal is awarded annually for significant and innovative contributions to radio astronomy. Moran is being recognized for his pioneering work in the development and application of spectroscopic Very Long Baseline Interferometry. For his Ph.D. dissertation, Moran made the first images of maser spots. Later he extended this work to use various molecular masers as tracers of the structure and magnetic fields in the envelopes of late type stars and massive protostars. He continued on to study water vapor, methanol, and silicon monoxide masers in the envelopes of both late-type stars, as well as massive protostars.

Moran also played a key role in the design and application of the VLBA for spectroscopic observations. In 1994, he led an international group of collaborators and students to use the VLBA to image the masers in the Seyfert galaxy NGC 4258, which convincingly demonstrated that the spots trace an early Keplerian accretion disk around a supermassive black hole. This work provided definitive and direct evidence for the existence of supermassive black holes and the first direct geometric distance estimate to a galaxy independent of the traditional multi-step extragalactic distance ladder.

The VLBA measurement of the distance to NGC 4258 of 7.2±0.5 Mpc was the most precise extragalactic distance measurement at that time, and has played an important role in the calibration of the Cepheid distance scale based on observations of Cepheid variables in NGC 4258. Accurate knowledge of the extragalactic distances is a key factor in establishing the equation of state of dark energy as well as being an essential prerequisite for the determination of the age, energy density, geometry, and evolution of the Universe. Moran was also the director of the Submillimeter Array (SMA) on Mauna Kea during its construction phase. Among other projects, he used the SMA to study the accretion flow in the black hole in the center of our galaxy, Sgr A*.

The 2013 Grote Reber Medal was awarded to Moran on 8 July in Turku, Finland, during the European Week of Astronomy and Space Science.

Making Waves: Ruby Payne-Scott, Australian Pioneer Radio Astronomer



A new book by NRAO scientist Miller Goss – *Making Waves: The Story of Ruby Payne-Scott: Australian Pioneer Radio Astronomer* – was published in 2013 by Springer. It is an abbreviated, partly re-written edition of *Under the Radar – The First Woman in Radio Astronomy: Ruby Payne-Scott* (Goss & McGee, Springer, 2010). This new edition addresses a general readership interested in historical and sociological aspects of astronomy and presents the biography of Ruby Payne-Scott (1912-1981). As the first female radio astronomer, and one of the first people in the world to consider radio astronomy, she made classic contributions to solar radio physics. She also played a major role in the design of the Australian government's Council for Scientific and Industrial Research radars, which were in turn of vital importance in the Southwest Pacific Theatre in World War II. These radars were used by military personnel from Australia, the United States, and New Zealand. From a sociological perspective, her career offers many examples of the perils of being a female academic in the first half of the 20th century. Complemented by many historical photographs, the book offers fascinating insights into the beginnings of radio astronomy and the role of a pioneering woman in astronomy.

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, ESO, NAOJ, the Commonwealth Scientific and Industrial Research Organisation – Australia Telescope National Facility (CSIRO–ATNF), and the Netherlands Institute for Radio Astronomy (ASTRON). 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.

CASA is the most common software package used for ALMA and VLA data processing. 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, and its capabilities have steadily improved.

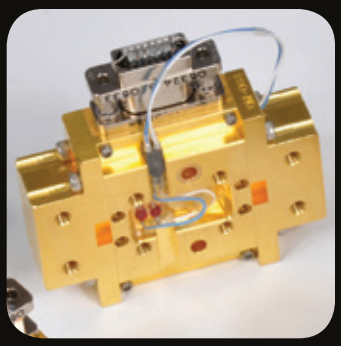
A major CASA Review was held 5-6 March in Socorro, NM with external and internal representation on the panel.


DV-10

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 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.



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

Prototype amplifiers for ALMA Band 1 were developed covering the 32-52 GHz frequency range. These amplifiers exhibited less than 20 K noise temperature everywhere across the band and had a minimum noise temperature of about 10 K at the band center. Two amplifiers were delivered to the Academia Sinica Institute for Astronomy and Astrophysics (ASIAA) team in Taiwan for incorporation into the prototype Band 1 cartridge that is under development. As additional development support to ASIAA team, hermetic dewar transitions covering the same frequency range were also developed. The work initiated in FY 2012 on ALMA Band 2 amplifiers resulted in deliveries of amplifiers for the GBT and for the University of Arizona 67- 90 GHz receivers. These amplifiers all had less than 50 K noise temperature over 67-88 GHz with a minimum noise temperature of about 25 K at the band center. An upgrade of the amplifiers used in the VLBA 3 mm wave receiver using CRYO3 NGST devices was also developed. A test amplifier covering the frequency range of 75-115 GHz was further evaluated, demonstrating the feasibility of an amplifier with less than 50 K noise temperature over the entire frequency range and with a minimum noise of about 30 K. These results have put the performance of NGST CRYO3 devices based amplifiers practically at par with the 35 nm Monolithic Millimeter-wave Integrated Circuit (MMIC) amplifiers, offering a competitive alternate solution if schedule and/ or funding limitations prevent use of the modern but relatively expensive MMIC technology.

Some vital improvements to CDL instrumentation were completed, including a new YIG power supply was designed and built, and the DC characteristic measurement system was completed.

Research work on the general noise properties of microwave transistors and on amplifiers incorporating various technologies – including commercial CMOS and SiGe Heterojunction Bipolar Transistor (HBT) – resulted in four conference publications and several publications.

Several iterations of SiGe HBT cryogenic amplifiers have been built using the devices purchased from ST Microelectronics through JPL. Measurements reveal that the best of these devices are comparable to the state-of-the-art InP Heterojunction Field Effect Transistors (HFETs) from the CRYO3 wafer in the low cm-wave range. However, results from multiple wafer runs show an unexpected variation in noise temperature, despite consistent current gain and other model parameters amongst wafers, calling into question the anticipated repeatability of these devices. In addition, the aluminum pad plating on these commercial devices leads to some new challenges with regard to the construction of amplifiers. Use of traditional gold bond-wire is not recommended due to the formation of “Purple Plague” ($AuAl_2$) and our experiments have confirmed that 1% Si-doped aluminum bond wire, the industry standard for this metal system, has two orders of magnitude higher loss at cryogenic temperatures than that of pure metal.

Measurements on the latest wafer of 35 nm InP HFET MMICs were completed and showed that their noise performance in the low 3 mm band was comparable to the best chip-and-wire amplifiers built using CRYO3 devices.

Millimeter & Sub-millimeter Detectors

Single-ended mixers with AlN barriers on Si membrane substrates with beam leads were successfully fabricated for the 385-500 GHz frequency range and met the ALMA Band 8 specifications. These mixers are now deployed on the Submillimeter Telescope (SMT). Balanced mixers have been successfully tested, and after extensive measurements, some excess loss has been attributed to the superconducting 180-degree IF hybrid. A balanced Band 6 mixer was also fabricated and tested. In this case as well, some excess loss was observed and attributed to the superconducting 180-degree IF hybrid. A 4 K test set is being constructed to characterize the loss of the suspect superconducting 180-degree IF hybrids.

Despite a spate of high-vacuum equipment failures in early 2013, and the resulting delays due to repairs and recalibration of the affected processes, Nb/Al-AlN/Nb junctions of the desired size and critical current density and with excellent I(V) characteristics were fabricated and a batch of Band 6 mixer chips was fabricated.

Superconductor-Insulator-Superconductor (SIS) junctions based on NbTiN for frequencies above ~700 GHz require AlN tunnel barriers to obtain the high critical current densities necessary at higher frequencies. With the 2013 success of SIS junctions with AlN barriers, and earlier successful deposition of NbTiN films at University of Virginia Microfabrication Laboratory (UVML), work was initiated on NbTiN SIS junctions for use above 1 THz.

Next Generation Receivers

Cryogenic measurement of the S-Band triangular Digital Ortho-Mode Transducer was delayed owing to issues with the test horn required for this measurement and problems with the Collaboration for Astronomy Signal Processing and Electronics (CASPER) development environment. Cost estimates of the corrugated horn used for on-the-sky Y-Factor measurements were much higher than projected. Consequently, a simpler non-corrugated horn construction is being investigated. The back-end processing software needed for the measurement is being ported to a new National Instruments platform for improved reliability, and the necessary ancillary interfaces are being designed.

The unformatted digital fiber-optic link was completed and tested extensively with excellent performance. These results were published in the June 2013 *The Publications of the Astronomical Society of the Pacific*.

Measurements on the W-Band Local Oscillator Distributor were delayed by an oscillation problem with the existing package. Troubleshooting is ongoing to address the problem but should the existing package prove to be unrepairable, a new package design is being created to resolve the problem.

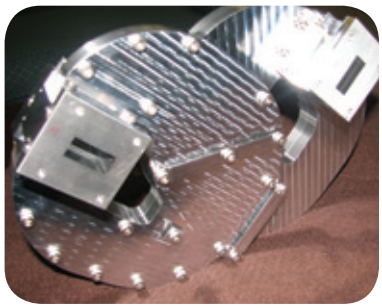
The fourth iteration of the Flex Thermal Transition was characterized, but the results were still not satisfactory. Significant new knowledge was gained about the thermal properties and loss characteristics as a result of these experiments. Several previously unknown issues – problems relating to channel isolation, ground loops, and cavity coupling from the "open" transmission line structures – were seen. These problems pose significant obstacles in the way of an optimum design and consequently, this approach is being abandoned.

The 67-93 GHz Integrated I/Q down-converter module was measured successfully and performed well, in agreement with predictions.

The 1/10th scale-mode of the 100-1000 GHz ridged horn was fabricated and shipped for testing at National Institute of Standards and Technology (NIST) using the 1 mm coax calibration standards that are prohibitively expensive and unavailable at NRAO. Progress at NIST has been very slow under this contract, and measurements were further delayed by the October 2013 government furlough.

Electromagnetic Development

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.



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

A C-band (4-8 GHz) secondary focus corrugated feed horn was designed and built for the Shanghai 65-m telescope. Field patterns measured in the E- and H-planes yielded an average illumination taper of -17.5 dB at the subreflector edge, compared with the desired illumination taper of -17 dB. Cross-polarization

measured in the diagonal planes was better than -27 dB at 4-8 GHz and measured patterns showed good circular beam symmetry. The measured phase center location (distance from the feed aperture) varied from 29.8" at 4 GHz to 41.8" at 8 GHz. This variation can be compensated by offsetting the telescope secondary. Return loss was better than 18 dB in the 4-8 GHz band. This feed horn was installed on the 65m antenna and initial measurements indicate efficiency as predicted.

Measurements on the Q-band (33-50 GHz) turnstile OMT developed for ALMA Band 1 were completed and return loss was better than 20 dB from 33-52 GHz. Insertion loss was about 0.3 dB for a gold plated OMT at room temperature. The corresponding, estimated loss at 15 K is about 0.12 dB, which could be further reduced by trimming the length of the OMT arms. Three OMTs were measured and exhibited consistent performance.

An E-band (67-90 GHz) OMT, also based on turnstile junction, was developed for ALMA Band 2 cartridge, and three units were fabricated. The machining took longer than anticipated, indicating that the manufacturability limits of this design are being approached. Preliminary measurements have been completed using a WR-10 calibration kit and indicate that the OMT meets its design requirements, but further refined measurements are planned using WR-12 calibration standards.

Progress has been made with the development of broadband corrugated feed horns. Electromagnetic simulations indicate that the bandwidth of such feed horns may be increased to 2.4:1 by improving cross-polarization at the high end of the band and return loss at the low end. Development of an optimized spline feed horn continues.

Development of an 800 MHz short backfire antenna feed with corrugations on the main reflector was completed. Measurements of far-field patterns indicate lower spillover on the GBT.

Reflectionless Filter Patent

Filters are used in almost all electronic systems to define the operating frequency range and prevent unwanted, out-of-band energy from propagating to downstream components. This is important to improve dynamic range, suppress spurious signals and image bands, and limit interactions between high- and low-frequency components. In conventional filter structures, however, this is accomplished by reflecting the stop-band portion of the spectrum back to the source, which can sometimes cause problems of its own, usually through interaction with frequency-converting elements like multipliers or mixers. These issues are increasingly important as technology trends toward broader-bandwidth components and more tightly integrated systems.

A recent patent issued by the US Patent and Trademark Office to Matt Morgan, a research engineer at the CDL, concerns a novel circuit structure comprising a "Reflectionless Filter," wherein the stop-band energy is absorbed internally rather than being reflected back to the source. In microwave terminology, the input impedance is theoretically constant at all frequencies (pass-band, stop-band, and transition-band). This prevents the build-up of out-of-band standing waves and eliminates interactions between components operating at different frequencies. It also makes them cascadable, so that small filtering elements may be placed at multiple points throughout the signal path to optimize sensitivity and dynamic range.

These filters, which can be low-pass, high-pass, band-pass, band-stop, and even multi-band, are very easy to implement and have a number of advantages in addition to the reflectionless property for which they were developed. Despite exhibiting a third order, inverse Chebyshev response, all elements of a single type – resistor, inductor, or capacitor – have the same value, no matter what the order of the filter. Not only does this simplify design, fabrication, and tuning, it limits the required elements to more nominal values that extend the applicable frequency range for a given technology. The filter response is also more stable with respect to component variation (e.g., with temperature) than conventional filters. Finally, despite containing resistive elements, the insertion loss of these filters in the pass-band is nominally zero, and is degraded less by low-Q components than their conventional filter counterparts.

Characterizing Cosmic Dawn

In 2013, the CDL continued its collaboration with the US 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.

The Hydrogen Epoch of Reionization Arrays (HERA) road map is a strategy for achieving this goal that proposes building a staged sequence of 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. The construction and evaluation of 70 receivers and 70 amplifiers were completed for PAPER in 2013. An environmental chamber capable of maintaining 16 receiver modules at a constant operating temperature was developed and eight field units were fabricated and tested. The CDL staff also coordinated the construction of 70 array elements in Green Bank, each consisting of an antenna and ground reflector along with 70 connectorized custom length cables between the antenna elements and the respective chambers. All of this instrumentation was packaged and shipped to South Africa for deployment in late 2013 to increase the PAPER array size to 128 elements, leaving only 12 elements yet to be deployed. CDL support of the PAPER engineering array in Green Bank continues.

Lunar University Node for Astrophysics Research (LUNAR)

LUNAR is a grant from the NASA Lunar Science Institute to develop instrumentation for lunar-based research. This collaboration with University of Colorado continued on the conceptual design of the proposed Explorer-class Dark Ages Radio Explorer (DARE) mission to measure the hydrogen signature of the early universe. CDL staff is involved in the development of the antenna and front-end electronics, along with defining the precision flux calibration methodology. In 2013, CDL deployed the next generation Engineering Prototype in Green Bank for long-term ground-based observations and instrument verification.

HFET Amplifier Production

In 2013, the CDL Amplifier Group continued to produce and repair amplifiers for NRAO VLA, VLBA, GBT, ALMA and other research institutions: Combined Array for Research in Millimeter Astronomy, Arecibo, Max Planck Institute für Radioastronomie, University of Arizona, University of Pennsylvania, Shanghai Observatory, and University of Washington. This production and delivery include these 97 amplifiers: six 230-470 MHz, thirty-eight 1-2 GHz, eleven 2-4 GHz, ten 4-8 GHz, eight 8-12 GHz, six 12-18 GHz, four 26-36 GHz, one 26-40 GHz, four 38-50 GHz, two 32-52 GHz, six 65-90 GHz and one 80-95 GHz.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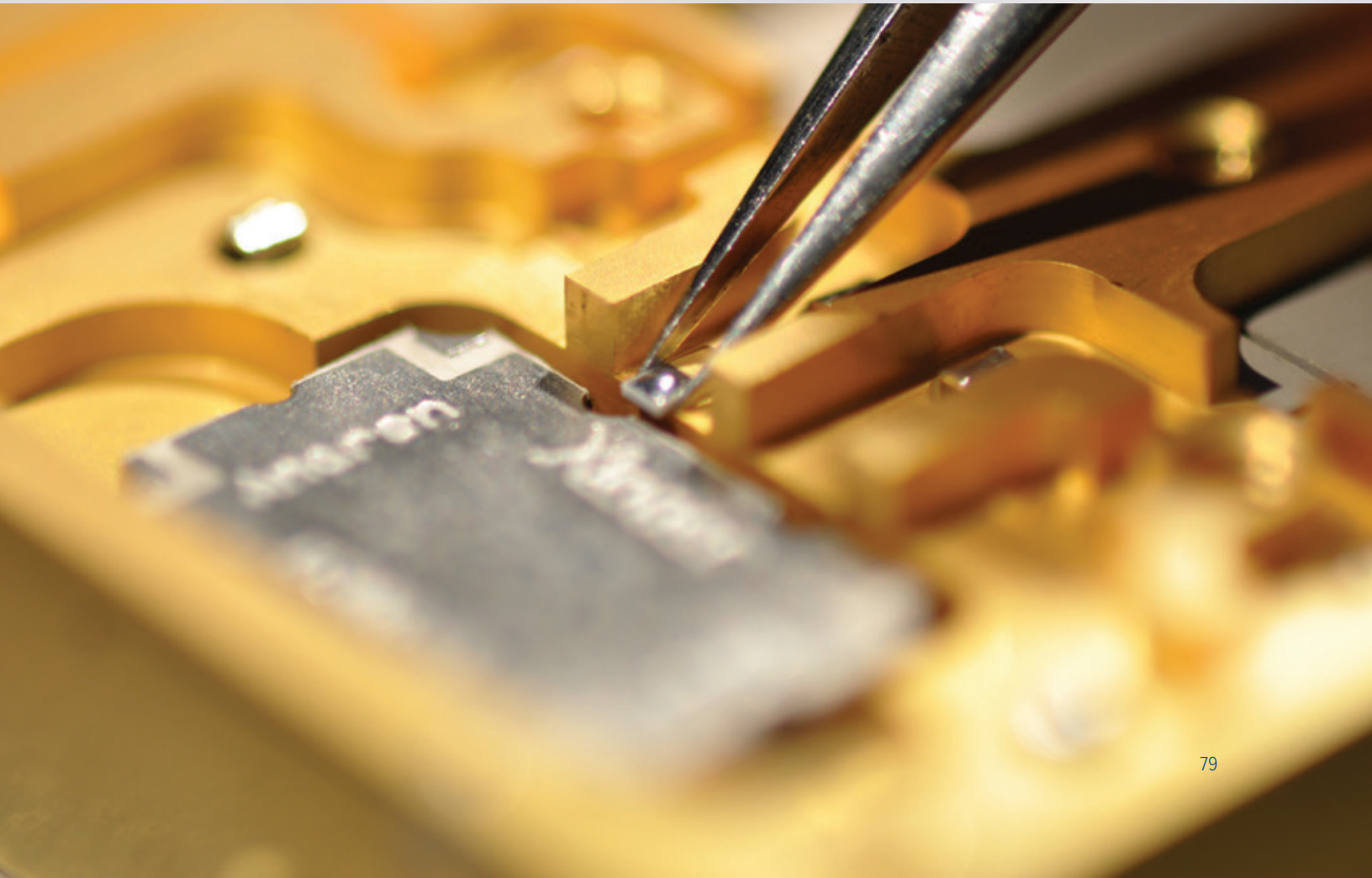

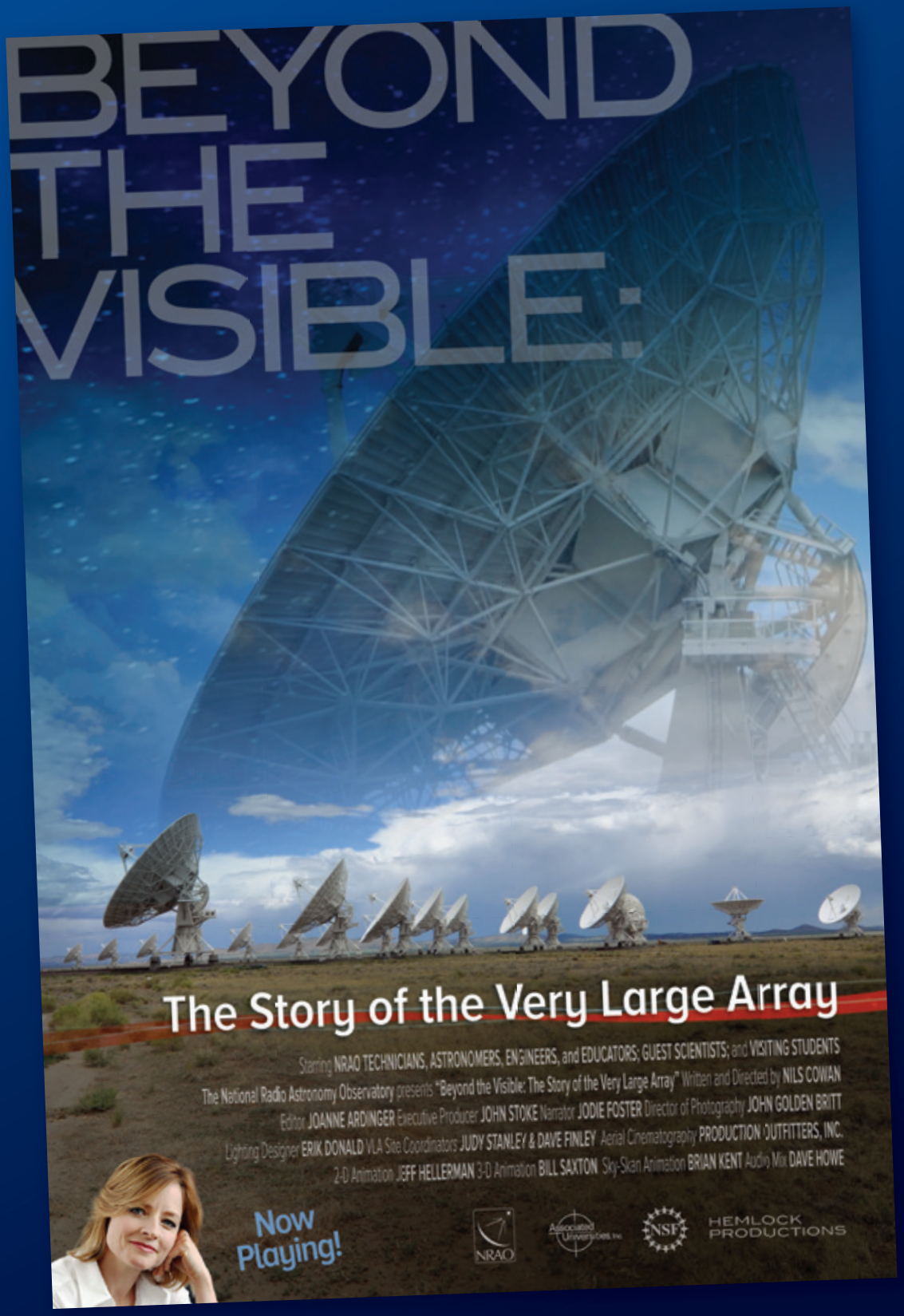
BEYOND THE VISIBLE:
The Story of the Very Large Array
Starring NRAO TECHNICIANS, ASTRONOMERS, ENGINEERS, and EDUCATORS; GUEST SCIENTISTS; and VISITING STUDENTS
The National Radio Astronomy Observatory presents "Beyond the Visible: The Story of the Very Large Array" Written and Directed by NILS COWAN
Editor JOANNE ARDINGER Executive Producer JOHN STOKE Narrator JODIE FOSTER Director of Photography JOHN GOLDEN BRITT
Lighting Designer ERIK DONALD VLA Site Coordinators JUDY STANLEY & DAVE FINLEY Aerial Cinematography PRODUCTION OUTFITTERS, INC.
2-D Animation JEFF HELLERMAN 3-D Animation BILL SAXTON Sky-Skan Animation BRIAN KENT Audio Mix DAVE HOWE
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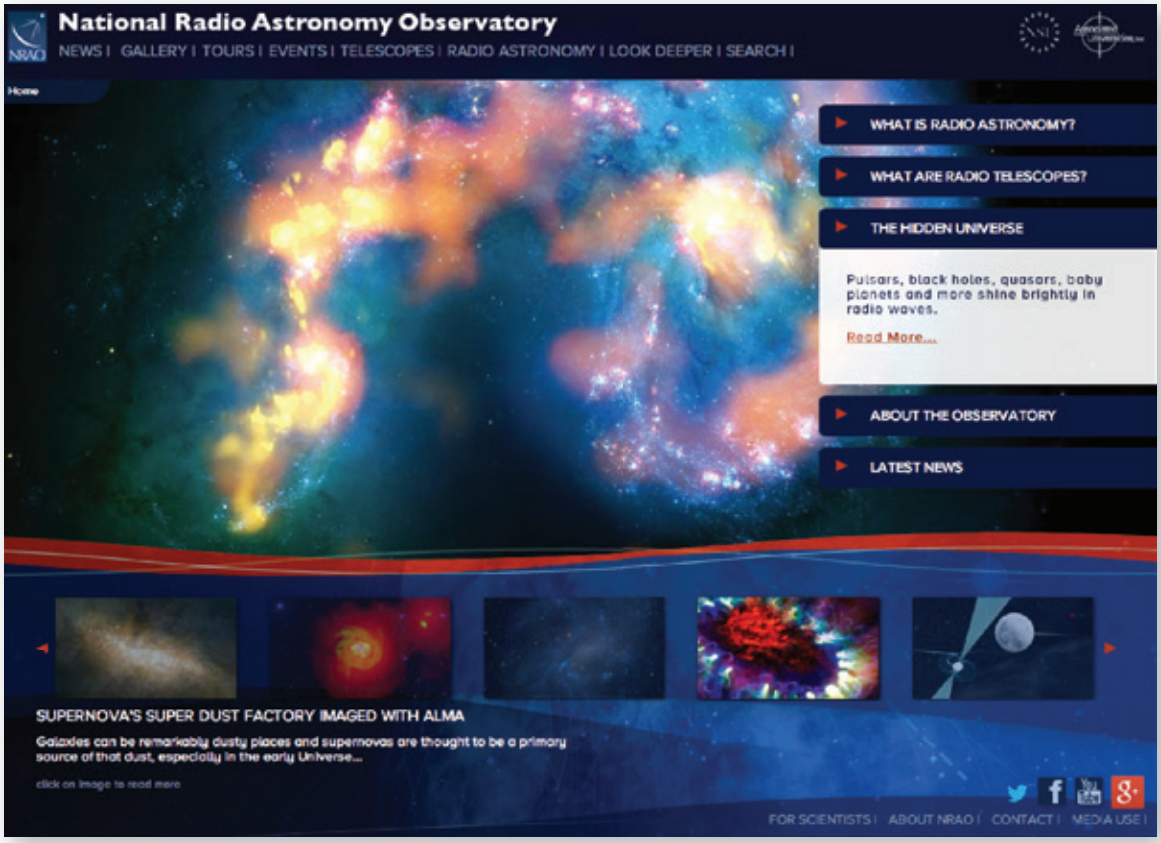
The Education & Public Outreach (EPO) department had a productive 2013, expanded its staffing to its full planned complement, and executed several high-impact projects.

News & Public Information

The Internet is the primary means for NRAO to communicate with a national audience. The Observatory unveiled a new public website at https://public.nrao.edu in 2013. This site features a clean, clear, contemporary 'app-like' design that works well on tablets as well as computers, and uses a modern content management system to enable easy, rapid content modification by EPO staff regardless of geographic location. New 2013 content includes a virtual tour of the NRAO Green Bank facilities – added to existing tours of ALMA and the VLA – a 700-element media gallery, and an improved "contact us" facility that enables topical questions to be routed to the correct EPO staff member for processing. During 2013 the NRAO Facebook and Twitter audiences steadily grew.



In addition to communicating directly to the public, NRAO communicates indirectly via 'natural amplifiers' in the print, broadcast, and online media, leveraging audiences developed by others. During 2013, EPO engaged the National Educational Television Association to distribute the ALMA documentary completed in 2012, *Into Deepest Space: The Birth of the ALMA Observatory*, via satellite uplink to PBS stations nationwide. EPO conducted a direct-mail promotional campaign to all 157+ PBS stations and arranged for a second uplink opportunity. The program was accessed over 600 times by PBS stations during these opportunities.

EPO hired a new Public Information Officer for ALMA and GBT in 2013, and increased the quantity and range of press releases and media announcements. Rich media content accompanied news releases, including videos, illustrations, and animations. The EPO creative team produced several public VLA image releases, including a compelling radio-optical composite image of the Hercules A galaxy for which EPO obtained observing time on the Hubble Space Telescope. EPO collaborated with the US Fish & Wildlife Service on naming W50 supernova remnant as the Manatee Nebula, and the EPO-produced radio-optical composite image was published on the front page of the New York Times' Science Times section.

EPO improved the reach of NRAO news by engaging a full-service media support service to expand our linkages to the national and international news media. This service tracks electronic and print press mentions of NRAO and its telescopes, and allows creation of media lists tailored to specific topics, such as engineering. EPO also created a dedicated list of 300+ science reporters who receive our releases directly. A new 'Tip Sheet' product was developed, each of which bundles smaller stories of potential interest to bloggers and others interested in smaller 'tidbits' of NRAO news.

The EPO team contributed, in coordination with the NSF Office of Legislative and Public Affairs, to the March ALMA Inauguration and associated events in Chile. A dozen North American journalists were escorted to the Inauguration, which included special press events and tours, and special opportunities to meet with NSF and NRAO officials. EPO provided the script read by astronauts aboard the International Space Station in a video shown during the inauguration, and created print publications and a video disc for dignitaries.

Throughout the year, EPO escorted multiple media visits to ALMA, Green Bank, and the VLA, including CBS News *60 Minutes* and National Geographic. Several science stories were delivered to the Space Telescope Science Institute for their *ViewSpace* network of astronomy displays in museums and visitor centers.

STEM Education

Traditionally, NRAO science, technology, education, math (STEM) education activities have centered on providing direct access to radio telescopes and associated technology and data to students and teachers, as well as educational exhibits and tours to learners who visit our Green Bank and VLA facilities. Those efforts continue. In 2013, NRAO embarked on a new strand of STEM education endeavor, recruiting and hiring a STEM Education Development Officer, a position funded with AUI corporate funds. This new position will seek opportunities for national STEM impact through such means as K-16 curriculum, citizen science projects, and geographically dispersed student science projects.

The Green Bank Science Center and the VLA Visitor Center enjoyed upgrades and exhibit repairs, offering tours and a rich schedule of events. Grant funding from the WV state tourism agency enabled promotion of visits to Green Bank. Improvements to the visitor center offerings in 2013 included upgrading the Green Bank Science Center's computer lab

with new computers, installation of outdoor walking tour signs at the VLA, the new Bracewell Radio Sundial at the VLA, and improved public highway VLA signage along US Highway 60.

NRAO continued to offer an Overnight Educational Field Trip program in Green Bank for schools, universities, and scouts, featuring student-conducted research using the 40-foot telescope. This program was fully subscribed. Green Bank welcomed a wide range of groups for multi-day educational events.

EPO produced a new high-definition interpretive film for the VLA Visitor Center, *Beyond the Visible: The Story of the Very Large Array*. The 24-minute production is narrated by actress Jodie Foster and depicts many of the people whose STEM careers enable the VLA to be a cutting-edge facility. The VLA Visitor Center auditorium was also upgraded with a new, solid-state digital HD video player.

EPO initiated development of the Skynet Jr. Scholars program, an educational research experience that connects rural 4H Clubs nationwide with the newly renovated and automated-for-remote-control Green Bank 20-meter telescope. Students observe celestial objects in the radio and optical, using Skynet network telescopes operated by University of North Carolina (UNC) – Chapel Hill. This program is a collaboration among NRAO, 4H, UNC–Chapel Hill, and The University of Chicago Yerkes Observatory. The 20-meter telescope had an L-band receiver installed during 2013, enabling HI spectroscopy.

Improving teachers' ability to teach in STEM areas is important. NRAO offers teaching resources and training, including StarLab portable planetariums, in NM and WV. NRAO also provided professional development opportunities for teachers through the Chautauqua short course program, in NM and WV.

Enrolling undergraduate students as presenters to K-12 classrooms and civic organizations is the objective of the new Space Public Outreach Team program inaugurated via NASA Space Grant funding in West Virginia in 2013.

Educational gaming is a promising area of non-traditional STEM learning. EPO has commissioned and is collaborating with an external educational game developer on the creation of an online ALMA Operations game, in which players will make decisions about how to optimize the mix of activities at an astronomical observatory to maximize its science output.

MANAGEMENT & ADMINISTRATION

Organization

A Director, a Deputy Director, an Associate Director and nine Assistant Directors form the senior management team that leads an NRAO staff of 493 persons. The NRAO organization consists of departments, which are made up of divisions, which consist of groups. The NRAO organization is designed to emphasize Observatory-wide management and coordination in key areas, including Program Management, Data Management and Software, and Science Support.

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

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

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

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

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

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

MANAGEMENT & ADMINISTRATION

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.

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

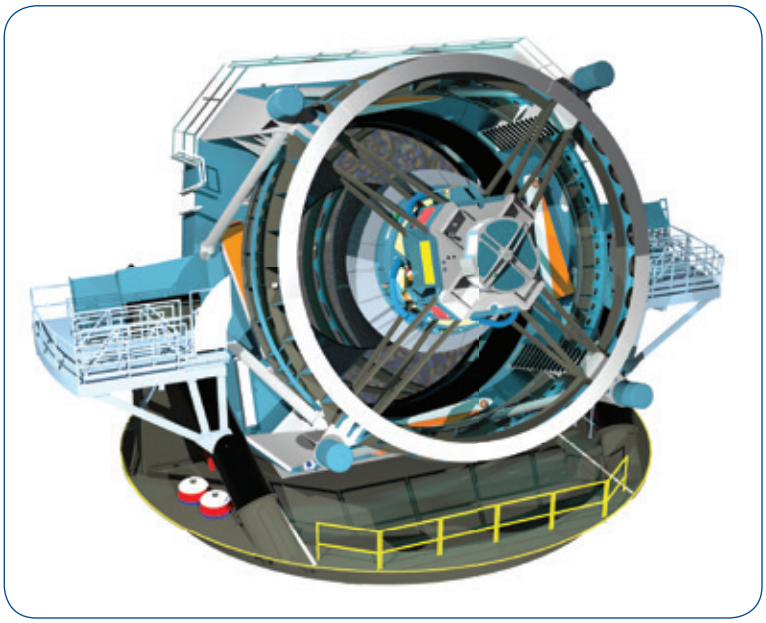
The Program Management (PM) Department led by Assistant Director **Lory Wingate** provides program and project management support and systems engineering services to NRAO project leaders and PIs. The key PM Department goals are to provide visibility, transparency, and consistency in reporting within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

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

New Initiatives Office

The New Initiatives Office (NIO) pursues, develops, and manages strategic partnerships and collaborations with academic, government, and non-profit organizations. Among the core NIO activities envisioned during 2013 were managing and expanding the partnerships to sustain the scientific operations and unique technical capabilities of the VLBA and GBT, including the Lebedev Institute of the Russian Academy of Sciences (FIAN), and the Shanghai Astronomical Observatory (SHAO). Partnership agreements with two other sister observatories in China were also explored.

In addition, in 2013 NIO continued its efforts to convene and lead the radio astronomical community in beginning a study of the science and technology case for a major new radio instrument. A workshop, *Radio Astronomy in the Large Synoptic Survey Telescope (LSST) Era*, was organized by NRAO and held in May 2013. This workshop dovetailed nicely with NRAO's first full year as an institutional LSST partner, as did various activities of the NRAO Director, a member of the project's Association of Universities for Research in Astronomy (AURA) Management Council for LSST, and the Head of NIO, who is the NRAO institutional representative to the LSST Board.



Credit: LSST

While no new partnerships delivering additional operations funds for the VLBA were established during 2013, preliminary meetings with NASA representatives to discuss spacecraft tracking for the space agency were held.

The Event Horizon Telescope (EHT) concept was to be formalized in 2013 by a Letter of Intent signed by the NRAO Director and representatives of a number of other institutions, outlining the structure of the EHT partnership to be led by Haystack Observatory, and supporting a proposal to accelerate the implementation of phased array operations with ALMA. Technical progress on the latter task during 2013 was good.

During 2013, NRAO delivered a C-band receiver Front End for the SHAO 65m radio telescope, and signed an additional contract to deliver a flexible digital backend suitable for both spectral line and continuum sources, including pulsars. This year also saw the signing of broad Memorandum of Understanding for cooperation between NRAO and the Xinjiang Astronomical Observatory, which is planning to build a 110m radio telescope in the Uighur Autonomous Region of western China, and the National Astronomical Observatory, which is building the radio Five-hundred-meter Aperture Spherical Telescope (FAST).

The year 2013 saw ongoing scientific observations with NRAO telescopes involving Russia's RadioAstron VLBI spacecraft. Meetings of the restructured RadioAstron International Science Council (RISC) continued, and its formal guest observer program began. The Observatory anticipates the continued participation of the GBT, VLA, and VLBA in the RadioAstron scientific program, via its normal proposal process.

Negotiations for a multi-year usage contract to make the Green Bank 140ft antenna (which is no longer supported by NSF funds) available as a second downlink station for RadioAstron astronomical data were successfully concluded in early 2013, following State Department approval of a Commodity Jurisdiction Request submitted by the Observatory to permit the observations. The 140ft antenna was refurbished in early 2013 and downlink of RadioAstron observational data during VLBI runs began in September. Use of the 140ft antenna permits VLBI observations between RadioAstron and a set of ground-based antennas in the western hemisphere considerably more powerful and extensive than the radio telescopes that must be used when RadioAstron is within line-of-sight view of the original Pushchino downlink station.

Communications Office

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The NRAO presence at the winter American Astronomical Society (AAS) meeting – 6-10 January 2013, Long Beach, CA – included an NRAO Town Hall, NRAO and AUI exhibits, an ALMA Special Session (*Cosmic Dawns: ALMA Early Science Commences*), an NRAO CASA Tutorial (*Processing ALMA and VLA Data with CASA*), as well as sponsorship and participation in the undergraduate orientation and public outreach events. The NRAO presence at the summer AAS meeting – 2-6 June 2013, Indianapolis, IN – featured an invited plenary session by Director Tony Beasley, *The Atacama Large Millimeter/submillimeter Array: A New Window on the Universe*. The summer meeting also included NRAO and AUI exhibits, a Splinter Session (*Proposal and Observing Preparation with NRAO Telescopes*), as well as sponsorship and participation in the undergraduate orientation and public outreach events. Proposals for an NRAO Town Hall and an ALMA Special Session for the January 2014 AAS meeting at National Harbor, MD were submitted and accepted. NRAO and AUI will also participate as exhibitors and sponsors of the undergraduate reception and orientation.

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

The Communications Office edited and published the monthly NRAO electronic newsletter, *eNews*, each issue of which was distributed to 8,000+ scientists around the world. COM published a 2012 NRAO Annual Report and managed the high-level content at the NRAO science website (*http://science.nrao.edu*) and the NRAO internal website (*http://inside.nrao.edu*). The *2013 NRAO Research Facilities* brochure was published in January.

COM and DMS collaborated on the NRAO exhibit at the International Conference for High Performance Computing, Networking, Storage, and Analysis conference – 17-22 November 2013, Denver, CO – an annual gathering of 10,000+ scientists, engineers, software developers, CIOs, and IT administrators from universities, industry, and government agencies.

COM worked with Director's Office and staff across the Observatory to prepare NRAO reports, briefings, and support materials for NSF and for the 2013 Users Committee.

Spectrum Management Office

The Spectrum Management Office was responsive to and involved with both domestic and international spectrum management issues in 2013.

The Observatory filed comments in 2013 with the Federal Communications Commission (FCC) regarding repacking of the UHF TV broadcast bands, an attempt by the FCC to liberate spectrum below 800 MHz for use by broadband mobile wireless. Incumbent TV stations are being encouraged to share or give up their channels in exchange for compensation from income derived from a future auction of the freed spectrum. This will affect the radio astronomy continuum observing band in channel 37 at 608-614 MHz, but not in any way that is obvious. The band could be moved, shared, eliminated, or made useless by the physical encroachment of cell phone use and infrastructure operating in nearby bands. NRAO noted that other allocations at 327 MHz and 1420 MHz constrain the range over which the 608-614 MHz band might usefully be moved and noted the substantial cost of modifying the 10 existing VLBA receivers. The VLA is not foreseen to operate at 500-1000 MHz owing to the design of its optics.

The Iridium mobile-satellite (satellite phone) operator has caused interference in the 1610.6-1613.8 MHz protected radio astronomy band since its inception in the late 1990's. Iridium is about to launch a new generation of satellites that will operate at somewhat lower frequencies closer to the upper edge of the radio astronomy band and has indicated that it expects to generate harmful interference to radio astronomy despite having taken precautionary measures in the design of its new spacecraft. Iridium suggested a schedule-based coordination process that would provide limited interference-free use of the band for radio astronomy upon three-day advance notice, and so with a substantial impact on NRAO's current practice of dynamically scheduling its observing to make optimal use of prevailing weather conditions.

Several agenda Items to be considered at the 2015 World Radio Conference (WRC-15) have a bearing on radio astronomy operations. Via the Radiocommunication Sector (ITU-R) Working Party 7D (astronomy) and IUCAF, the scientific committee on frequency allocations for radio astronomy and space science, the NRAO spectrum manager attended and provided input documents for meetings in Geneva dealing with AI 1.18 (a new allocation to vehicular radar, to fill in the remaining portions of the 76-81 GHz band not yet allocated to radar) and another larger group that is trying to identify global allocations to mobile wireless (i.e., similar to the UHF TV band repacking noted above).

The NRAO Spectrum Management Office represented the Observatory and the radio astronomy community at the following meetings in 2013:

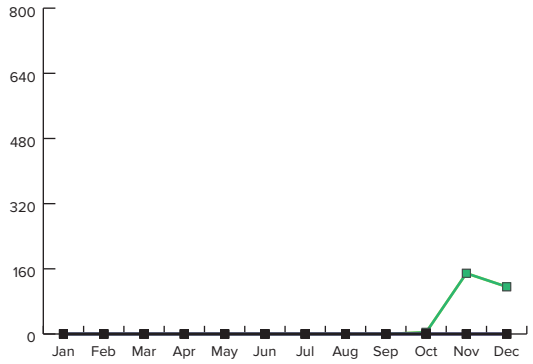
- April, CRAF (Zurich): pan-European frequency-coordination analog of the Committee on Radio Frequencies.
- April, Working Party 7D (Geneva): the regular radio astronomy group.
- May, National Spectrum Manager's Association (Washington).
- May, CORF (Washington): the US National Academy's frequency coordination group.
- September: Working Party 7D (Geneva), along with its immediate parent body, Study Group 7 (SG7).
- September (Geneva): a meeting on the future of the international time system (leap-second).

PERFORMANCE METRICS

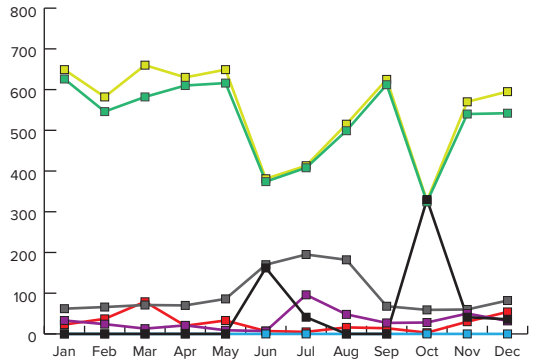
VLA photograph by Knate Myers

Observing Hours

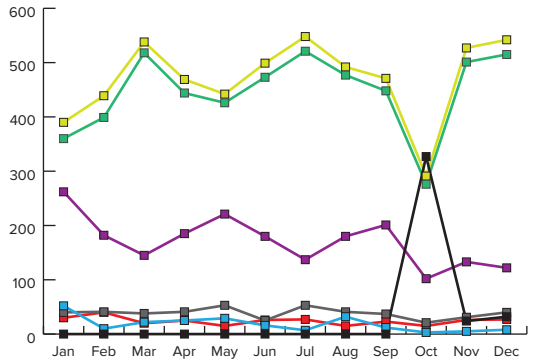
ALMA



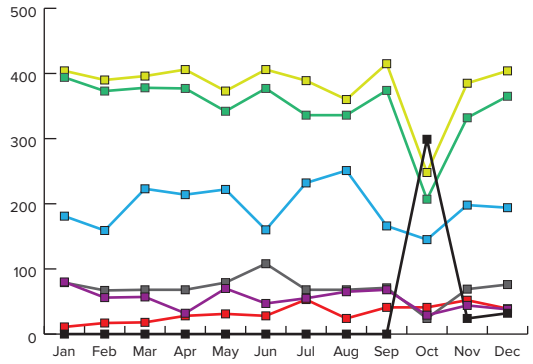
GBT



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.

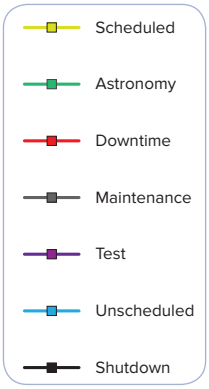
Maintenance: Actual hours of scheduled service of infrastructure, structure, electronics, and software.

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

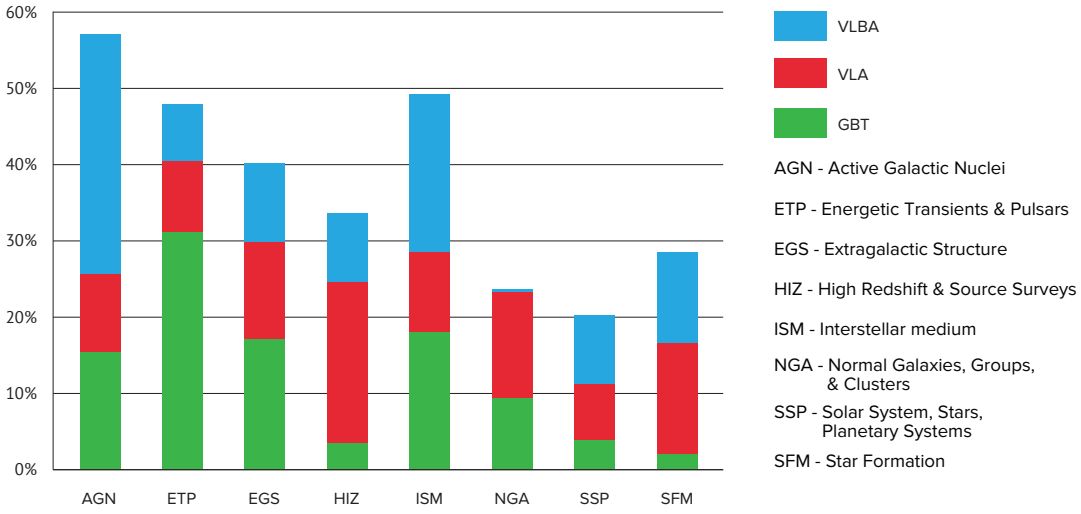
Unscheduled: Actual idle hours owing to gaps between observing programs that cannot be scheduled and to predicted, extended inclement weather.

Shutdown: Actual shutdown hours, usually for a holiday. Other major shutdowns occur for major equipment work, such as GBT structural painting. In 2013, the US Federal government closure was responsible for the unusual October 2013 shutdown hours at the GBT, VLA, and VLBA.

*Scheduled observing time = [Astronomy hours + Downtime hours]

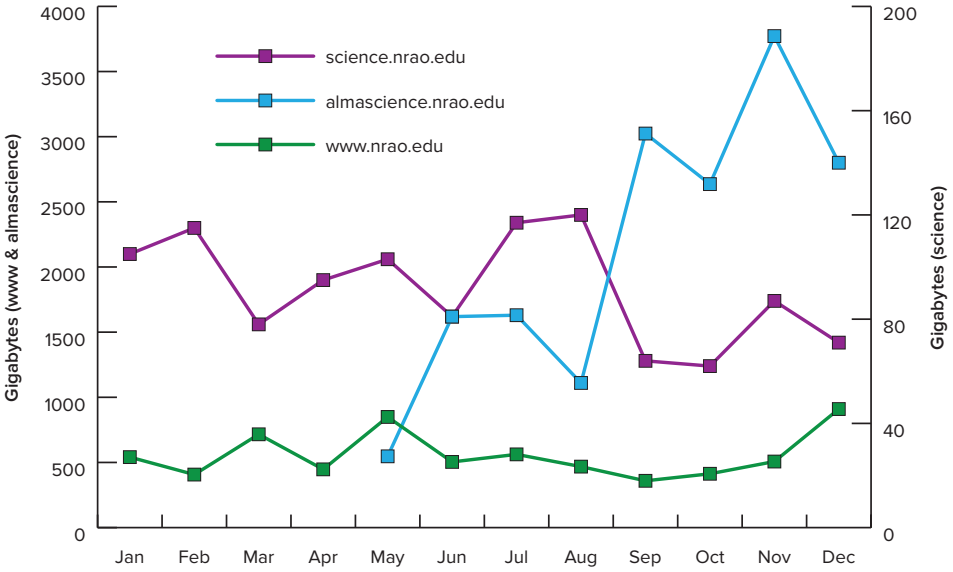


Observing Hours by Science Category



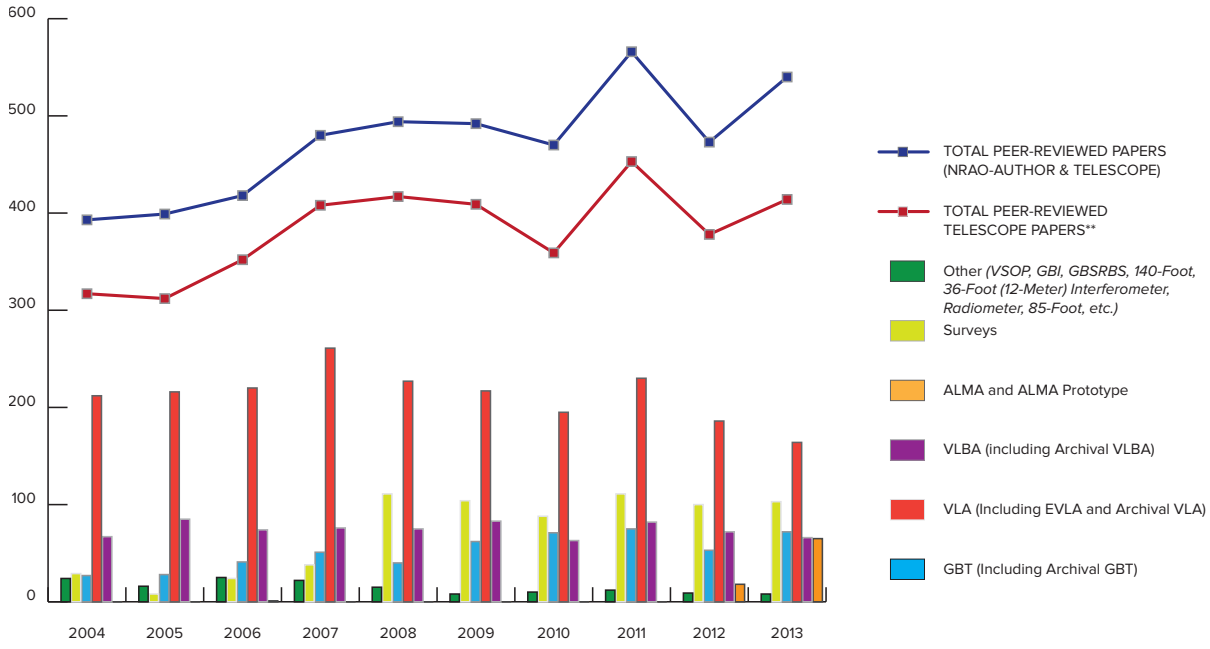
Observing hours for each of the GBT, VLA, and VLBA are tracked in the eight science categories that are included in the NRAO proposal evaluation and time allocation process:

NRAO Website Volume



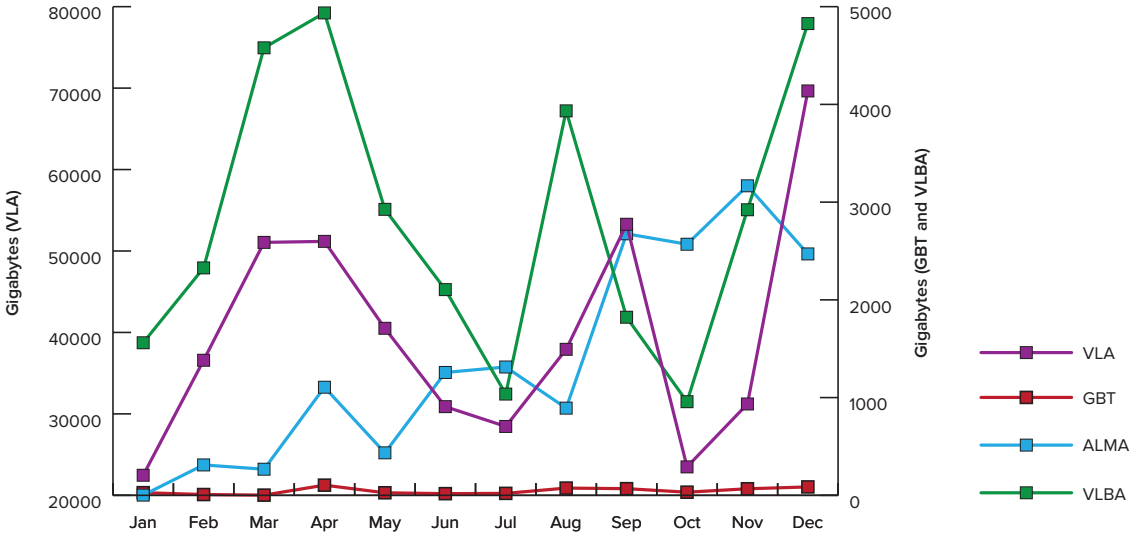
The almascience.nrao.edu website volume reflects activity by scientists interested in submitting observing proposals or seeking other professional astronomical information about ALMA. The science.nrao.edu website volume reflects activity by scientists interested in submitting observing proposals or seeking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

Refereed Telescope and Author Papers



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

Science Data Archive Volume



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

APPENDIX A: PUBLICATIONS

2013 NRAO TELESCOPE AND AUTHOR REFEREED PUBLICATIONS

Abdo, A. A.; Ajello, M.; Allafort, A.; Baldini, L.; Ballet, J.; Barbiellini, G.; Baring, M. G.; Bastieri, D.; Belfiore, A.; Bellazzini, R.; Bhattacharyya, B.; Bissaldi, E.; Bloom, E. D.; Bonamente, E.; Bottacini, E.; Brandt, T. J.; Bregeon, J.; Brigida, M.; Bruel, P.; Buehler, R.; Burgay, M.; Burnett, T. H.; Busetto, G.; Buson, S.; Caliandro, G. A.; Cameron, R. A.; Camilo, F.; Caraveo, P. A.; Casandjian, J. M.; Cecchi, C.; Çelik, Ö.; Charles, E.; Chaty, S.; Chaves, R. C. G.; Chekhtman, A.; Chen, A. W.; Chiang, J.; Chiaro, G.; Ciprini, S.; Claus, R.; Cognard, I.; Cohen-Tanugi, J.; Cominsky, L. R.; Conrad, J.; Cutini, S.; D'ammando, F.; De Angelis, A.; Decesar, M. E.; De Luca, A.; Den Hartog, P. R.; De Palma, F.; Dermer, C. D.; Desvignes, G.; Digel, S. W.; Di Venere, L.; Drell, P. S.; Drlica-Wagner, A.; Dubois, R.; Dumora, D.; Espinoza, C. M.; Falletti, L.; Favuzzi, C.; Ferrara, E. C.; Focke, W. B.; Franckowiak, A.; Freire, P. C. C.; Funk, S.; Fusco, P.; Gargano, F.; Gasparrini, D.; Germani, S.; Giglietto, N.; Giommi, P.; Giordano, F.; Giroletti, M.; Glanzman, T.; Godfrey, G.; Gotthelf, E. V.; Grenier, I. A.; Grondin, M.-H.; Grove, J. E.; Guillemot, L.; Guiriec, S.; Hadasch, D.; Hanabata, Y.; Harding, A. K.; Hayashida, M.; Hays, E.; Hessels, J.; Hewitt, J.; Hill, A. B.; Horan, D.; Hou, X.; Hughes, R. E.; Jackson, M. S.; Janssen, G. H.; Jogler, T.; Jóhannesson, G.; Johnson, R. P.; Johnson, A. S.; Johnson, T. J.; Johnson, W. N.; Johnston, S.; Kamae, T.; Kataoka, J.; Keith, M.; Kerr, M.; Knödlseder, J.; Kramer, M.; Kuss, M.; Lande, J.; Larsson, S.; Latronico, L.; Lemoine-Goumard, M.; Longo, F.; Loparco, F.; Lovellette, M. N.; Lubrano, P.; Lyne, A. G.; Manchester, R. N.; Marelli, M.; Massaro, F.; Mayer, M.; Mazziotta, M. N.; Mcenery, J. E.; Mclaughlin, M. A.; Mehault, J.; Michelson, P. F.; Mignani, R. P.; Mitthumsiri, W.; Mizuno, T.; Moiseev, A. A.; Monzani, M. E.; Morselli, A.; Moskalenko, I. V.; Murgia, S.; Nakamori, T.; Nemmen, R.; Nuss, E.; Ohno, M.; Ohsugi, T.; Orienti, M.; Orlando, E.; Ormes, J. F.; Paneque, D.; Panetta, J. H.; Parent, D.; Perkins, J. S.; Pesce-Rollins, M.; Pierbattista, M.; Piron, F.; Pivato, G.; Pletsch, H. J.; Porter, T. A.; Possenti, A.; Rainò, S.; Rando, R.; Ransom, S. M.; Ray, P. S.; Razzano, M.; Rea, N.; Reimer, A.; Reimer, O.; Renault, N.; Reposeur, T.; Ritz, S.; Romani, R. W.; Roth, M.; Rousseau, R.; Roy, J.; Ruan, J.; Sartori, A.; Saz Parkinson, P. M.; Scargle, J. D.; Schulz, A.; Sgrò, C.; Shannon, R.; Siskind, E. J.; Smith, D. A.; Spandre, G.; Spinelli, P.; Stappers, B. W.; Strong, A. W.; Suson, D. J.; Takahashi, H.; Thayer, J. G.; Thayer, J. B.; Theureau, G.; Thompson, D. J.; Thorsett, S. E.; Tibaldo, L.; Tibolla, O.; Tinivella, M.; Torres, D. F.; Tosti, G.; Troja, E.; Uchiyama, Y.; Usher, T. L.; Vandenbroucke, J.; Vasileiou, V.; Venter, C.; Vianello, G.; Vitale, V.; Wang, N.; Weltevrede, P.; Winer, B. L.; Wolff, M. T.; Wood, D. L.; Wood, K. S.; Wood, M.; Yang, Z. "The Second Fermi Large Area Telescope Catalog of Gamma-Ray Pulsars" The Astrophysical Journal Supplement Series 208: 17 (59 pp), 2013

Adebahr, B.; Krause, M.; Klein, U.; Wężgowiec, M.; Bomans, D. J.; Dettmar, R.-J. "M 82 - A radio continuum and polarisation study. I. Data reduction and cosmic ray propagation" Astronomy and Astrophysics 555: 23 (17 pp), 2013

Ai, Mei; Zhu, Ming; Xiao, Li; Su, Hong-Quan "Properties of the UCHII region G25.4NW and its associated molecular cloud" Research in Astronomy and Astrophysics 13: 935-944, 2013

Akiyama, Kazunori; Takahashi, Rohta; Honma, Mareki; Oyama, Tomoaki; Kobayashi, Hideyuki "Multi-Epoch VERA Observations of Sagittarius A*. I. Images and Structural Variability" Publications of the Astronomical Society of Japan 65: 91 (13 pp), 2013

Alberts, Stacey; Wilson, Grant W.; Lu, Yu; Johnson, Seth; Yun, Min S.; Scott, Kimberly S.; Pope, Alexandra; Aretxaga, Itziar; Ezawa, Hajime; Hughes, David H.; Kawabe, Ryohei; Kim, Sungeun; Kohno, Kotaro; Oshima, Tai "Submm/mm galaxy counterpart identification using a characteristic density distribution" Monthly Notices of the Royal Astronomical Society 431: 194-209, 2013

Aleksić, J.; Antonelli, L. A.; Antoranz, P.; Asensio, M.; Backes, M.; Barres De Almeida, U.; Barrio, J. A.; Bednarek, W.; Berger, K.; Bernardini, E.; Biland, A.; Blanch, O.; Bock, R. K.; Boller, A.; Bonnefoy, S.; Bonnoli, G.; Borla Tridon, D.; Bretz, T.; Carmona, E.; Carosi, A.; Carreto Fidalgo, D.; Colin, P.; Colombo, E.; Contreras, J. L.; Cortina, J.; Cossio, L.; Covino, S.; Da Vela, P.; Dazzi, F.; De Angelis, A.; De Caneva, G.; De Lotto, B.; Delgado Mendez, C.; Doert, M.; Domínguez, A.; Dominis Prester, D.; Dorner, D.; Doro, M.; Eisenacher, D.; Elsaesser, D.; Ferenc, D.; Fonseca, M. V.; Font, L.; Fruck, C.; García López, R. J.; Garczarczyk, M.; Garrido Terrats, D.; Gaug, M.; Giavitto, G.; Godinović, N.; González Muñoz, A.; Gozzini, S. R.; Hadamek, A.; Hadasch, D.; Herrero, A.; Hose, J.; Hrupec, D.; Jankowski, F.; Kadenius, V.; Klepser, S.; Knoetig, M. L.; Krähenbühl, T.; Krause, J.; Kushida, J.; La Barbera, A.; Lelas, D.; Leonardo, E.; Lewandowska, N.; Lindfors, E.; Lombardi, S.; López, M.; López-Coto, R.; López-Oramas, A.; Lorenz, E.; Lozano, I.; Makariev, M.; Mallot, K.; Maneva, G.; Mankuzhiyil, N.; Mannheim, K.; Maraschi, L.; Marcote, B.; Mariotti, M.; Martínez, M.; Masbou, J.; Mazin, D.; Meucci, M.; Miranda, J. M.; Mirzoyan, R.; Moldón, J.; Moralejo, A.; Munar-Adrover, P.; Nakajima, D.; Niedzwiecki, A.; Nieto, D.; Nilsson, K.; Nowak, N.; Orito, R.; Paiano, S.; Palatiello, M.; Paneque, D.; Paoletti, R.; Paredes, J. M.; Partini, S.; Persic, M.; Pilia, M.; Prada, F.; Prada Moroni, P. G.; Prandini, E.; Puljak, I.; Reichardt, I.; Reinthal, R.; Rhode, W.; Ribó, M.; Rico, J.; Rügamer, S.; Saggion, A.; Saito, K.; Saito, T. Y.; Salvati, M.; Satalecka, K.; Scalzotto, V.; Scapin, V.; Schultz, C.; Schweizer, T.; Shore, S. N.; Sillanpää, A.; Sitarek, J.; Snidaric, I.; Sobczynska, D.; Spanier, F.; Spiro, S.; Stamatescu, V.; Stamerra, A.; Steinke, B.; Storz, J.; Sun, S.; Surić, T.; Takalo, L.; Takami, H.; Tavecchio, F.; Temnikov, P.; Terzić, T.; Tescaro, D.; Teshima, M.; Tibolla, O.; Torres, D. F.; Toyama, T.; Treves, A.; Uellenbeck, M.; Vogler, P.; Wagner, R. M.; Weitzel, Q.; Zandanel, F.; Zanin, R.; Longo, F.; Lucarelli, F.; Pittori, C.; Vercellone, S.; Bastieri, D.; Sbarra, C.; Angelakis, E.; Fuhrmann, L.; Nestoras, I.; Krichbaum, T. P.; Sievers, A.; Zensus, J. A.; Antonyuk, K. A.; Baumgartner, W.; Berduygin, A.; Carini, M.; Cook, K.; Gehrels, N.; Kadler, M.; Kovalev, Yu. A.; Kovalev, Y. Y.; Krauss, F.; Krimm, H. A.; Lähteenmäki, A.; Lister, M. L.; Max-Moerbeck, W.; Pasanen, M.; Pushkarev, A. B.; Readhead, A. C. S.; Richards, J. L.; Sainio, J.; Shakhovskoy, D. N.; Sokolovsky, K. V.; Tornikoski, M.; Tueller, J.; Weidinger, M.; Wilms, J. "The simultaneous low state spectral energy distribution of 1ES 2344+514 from radio to very high energies" Astronomy and Astrophysics 556: 67 (28 pp), 2013

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Antoniadis, John; Freire, Paulo C. C.; Wex, Norbert; Tauris, Thomas M.; Lynch, Ryan S.; Van Kerkwijk, Marten H.; Kramer, Michael; Bassa, Cees; Dhillon, Vik S.; Driebe, Thomas; Hessels, Jason W. T.; Kaspi, Victoria M.; Kondratiev, Vladislav I.; Langer, Norbert; Marsh, Thomas R.; Mclaughlin, Maura A.; Pennucci, Timothy T.; Ransom, Scott M.; Stairs, Ingrid H.; Van Leeuwen, Joeri; Verbiest, Joris P. W.; Whelan, David G. "A Massive Pulsar in a Compact Relativistic Binary" Science 340: 448 (10 pp), 2013

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Bergin, Edwin A.; Cleeves, L. Ilsedore; Gorti, Uma; Zhang, Ke; Blake, Geoffrey A.; Green, Joel D.; Andrews, Sean M.; Evans, Neal J., Ii; Henning, Thomas; Öberg, Karin; Pontoppidan, Klaus; Qi, Chunhua; Salyk, Colette; Van Dishoeck, Ewine F. "An old disk still capable of forming a planetary system" Nature 493: 644-646, 2013

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Bhattacharyya, B.; Roy, J.; Ray, P. S.; Gupta, Y.; Bhattacharya, D.; Romani, R. W.; Ransom, S. M.; Ferrara, E. C.; Wolff, M. T.; Camilo, F.; Cognard, I.; Harding, A. K.; Den Hartog, P. R.; Johnston, S.; Keith, M.; Kerr, M.; Michelson, P. F.; Saz Parkinson, P. M.; Wood, D. L.; Wood, K. S. "GMRT Discovery of PSR J1544+4937: An Eclipsing Black-widow Pulsar Identified with a Fermi-LAT Source" The Astrophysical Journal 773: L12 (6 pp), 2013

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APPENDIX A: PUBLICATIONS

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APPENDIX A: PUBLICATIONS

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APPENDIX A: PUBLICATIONS

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APPENDIX A: PUBLICATIONS

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Weiß, A.; De Breuck, C.; Marrone, D. P.; Vieira, J. D.; Aguirre, J. E.; Aird, K. A.; Aravena, M.; Ashby, M. L. N.; Bayliss, M.; Benson, B. A.; Béthermin, M.; Biggs, A. D.; Bleem, L. E.; Bock, J. J.; Bothwell, M.; Bradford, C. M.; Brodwin, M.; Carlstrom, J. E.; Chang, C. L.; Chapman, S. C.; Crawford, T. M.; Crites, A. T.; De Haan, T.; Dobbs, M. A.; Downes, T. P.; Fassnacht, C. D.; George, E. M.; Gladders, M. D.; Gonzalez, A. H.; Greve, T. R.; Halverson, N. W.; Hezaveh, Y. D.; High, F. W.; Holder, G. P.; Holzapfel, W. L.; Hoover, S.; Hrubes, J. D.; Husband, K.; Keisler, R.; Lee, A. T.; Leitch, E. M.; Lueker, M.; Luong-Van, D.; Malkan, M.; Mcintyre, V.; Mcmahon, J. J.; Mehl, J.; Menten, K. M.; Meyer, S. S.; Murphy, E. J.; Padin, S.; Plagge, T.; Reichardt, C. L.; Rest, A.; Rosenman, M.; Ruel, J.; Ruhl, J. E.; Schaffer, K. K.; Shirokoff, E.; Spilker, J. S.; Stalder, B.; Staniszewski, Z.; Stark, A. A.; Story, K.; Vanderlinde, K.; Welikala, N.; Williamson, R. "ALMA Redshifts of Millimeter-selected Galaxies from the SPT Survey: The Redshift Distribution of Dusty Star-forming Galaxies" The Astrophysical Journal 767: 88 (16 pp), 2013

Weisskopf, Martin C.; Tennant, Allyn F.; Arons, Jonathan; Blandford, Roger; Buehler, Rolf; Caraveo, Patrizia; Cheung, Chi C.; Costa, Enrico; De Luca, Andrea; Ferrigno, Carlo; Fu, Hai; Funk, Stefan; Habermehl, Moritz; Horns, Dieter; Linford, Justin D.; Lobanov, Andrei; Max, Claire; Mignani, Roberto; O'dell, Stephen L.; Romani, Roger W.; Striani, Edoardo; Tavani, Marco; Taylor, Gregory B.; Uchiyama, Yasunobu; Yuan, Yajie "Chandra, Keck, and VLA Observations of the Crab Nebula during the 2011-April Gamma-Ray Flare" The Astrophysical Journal 765: 56 (10 pp), 2013

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Zaritsky, Dennis; Salo, Heikki; Laurikainen, Eija; Elmegreen, Debra; Athanassoula, E.; Bosma, Albert; Comerón, Sébastien; Erroz-Ferrer, Santiago; Elmegreen, Bruce; Gadotti, Dimitri A.; Gil De Paz, Armando; Hinz, Joannah L.; Ho, Luis C.; Holwerda, Benne W.; Kim, Taehyun; Knapen, Johan H.; Laine, Jarkko; Laine, Seppo; Madore, Barry F.; Meidt, Sharon; Menendez-Delmestre, Karin; Mizusawa, Trisha; Muñoz-Mateos, Juan Carlos; Regan, Michael W.; Seibert, Mark; Sheth, Kartik "On the Origin of Lopsidedness in Galaxies as Determined from the Spitzer Survey of Stellar Structure in Galaxies (S4G)" The Astrophysical Journal 772: 135 (16 pp), 2013

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Zauderer, B. A.; Berger, E.; Margutti, R.; Pooley, G. G.; Sari, R.; Soderberg, A. M.; Brunthaler, A.; Bietenholz, M. F. "Radio Monitoring of the Tidal Disruption Event Swift J164449.3+573451. II. The Relativistic Jet Shuts Off and a Transition to Forward Shock X-Ray/Radio Emission" The Astrophysical Journal 767: 152 (6 pp), 2013

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Zhao, Yinghe; Lu, Nanyao; Xu, C. Kevin; Gao, Yu; Lord, S.; Howell, J.; Isaak, K. G.; Charmandaris, V.; Diaz-Santos, T.; Appleton, P.; Evans, A.; Iwasawa, K.; Leech, J.; Mazzarella, J.; Petric, A. O.; Sanders, D. B.; Schulz, B.; Surace, J.; Van Der Werf, P. P. "A Herschel Survey of the [N II] 205 μm Line in Local Luminous Infrared Galaxies: The [N II] 205 μm Emission as a Star Formation Rate Indicator" The Astrophysical Journal 765: L13 (6 pp), 2013

Zhelenkova, O. P. "Investigation of radio sources with the virtual observatory tools: Results and problems" Astronomische Nachrichten 334: 882-886, 2013

Zhelenkova, O. P.; Soboleva, N. S.; Majorova, E. K.; Temirova, A. V. "Identification and properties of host galaxies of RCR radio sources" Astrophysical Bulletin 68: 26-39, 2013

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Zhou, Ming; Wang, Jiancheng "A New Result on the Origin of the Extragalactic Gamma-Ray Background" The Astrophysical Journal 769: 153 (6 pp), 2013

Zhu, H.; Tian, W. W.; Torres, D. F.; Pedaletti, G.; Su, H. Q. "A Kinematic Distance Study of the Planetary Nebulae-Supernova remnant-H II Region Complex at G35.6-0.5" The Astrophysical Journal 775: 95 (9 pp), 2013

Zhu, Lei; Zhao, Jun-Hui; Wright, M. C. H.; Sandell, Göran; Shi, Hui; Wu, Yue-Fang; Brogan, Crystal; Corder, Stuartt "Subarcsecond Observations of NGC 7538 IRS 1: Continuum Distribution and Dynamics of Molecular Gas" The Astrophysical Journal 779: 51 (17 pp), 2013

Zhuravlev, V. I.; Popov, M. V.; Soglasnov, V. A.; Kondrat'ev, V. I.; Kovalev, Y. Y.; Bartel, N.; Ghigo, F. "Statistical and polarization properties of giant pulses of the millisecond pulsar B1937+21" Monthly Notices of the Royal Astronomical Society 430: 2815-2821, 2013

Zwaan, Martin A.; Kuntschner, Harald; Pracy, Michael B.; Couch, Warrick J. "The cold gas content of post-starburst galaxies" Monthly Notices of the Royal Astronomical Society 432: 492-499, 2013

APPENDIX B: EVENTS & MILESTONES

2 January
NRAO Semester 2013B Call for Proposals opens

7-10 January 2013
221st *AAS meeting*
NRAO Town Hall
NRAO Exhibit
Special Session: *Cosmic Dawns: ALMA Early Science Commences*
Splinter Session: *Processing ALMA and VLA Data with CASA*
Summer Student presentations
Undergraduate Orientation sponsor & exhibitor
Local EPO event sponsor & participant
Long Beach, California

9-12 January
U.S. National Committee – Union of Radio Science National Radio Science Meeting
University of Colorado – Boulder
Boulder, Colorado

1 February
NRAO Semester 2013B Call for Proposals submission deadline

5 February
NRAO Community Day
Universidad de Guanajuato
Guanajuato, Mexico

14-15 February
AUI Board of Trustees meeting
Washington, D.C.

28 February – 1 March
ALMA Data Reduction Workshop
Charlottesville, Virginia

11 March
AUI Executive Committee meeting
Santiago, Chile

19-20 March
Science with ALMA Band 11
University of Oxford, U.K.

8-12 April
Transformational Science with ALMA: From Dust to Rocks to Planets
Kona, Hawaii

8-12 April
3rd *VLA Data Reduction Workshop*
Socorro, New Mexico

18 April
ALMA in the Coming Decade: A Development Workshop
Charlottesville, Virginia

23-25 April
National Science Foundation Large Facilities Operations Workshop
Socorro, New Mexico

29 April–1 May
NRAO Postdoc Symposium
Green Bank, West Virginia

1-2 May
Users Committee Meeting
Charlottesville, Virginia

6-8 May
Radio Astronomy in the LSST Era
Charlottesville, Virginia

13 - 17 May
2nd *China-U.S. Workshop on Radio Astronomy Science & Technology*
Shanghai Astronomical Observatory
Shanghai, China

21-22 May
NRAO Budget Summit
Charlottesville, Virginia

29 May
ALMA Band 2 Science Workshop
Charlottesville, Virginia

29-31 May
Galactic Gas Supply Workshop
Green Bank, West Virginia

3-6 June
222nd *AAS meeting*
NRAO Exhibit
Invited plenary presentation by NRAO Director Tony Beasley:
The Atacama Large Millimeter/submillimeter Array: A New Window on the Universe
Splinter Session: *Proposal & Observing Preparation with NRAO Telescopes*
Undergrad Orientation sponsor & exhibitor
Local EPO event sponsor & participant
Indianapolis, Indiana

14-16 June
2nd *Annual Space Race Rumpus*
Green Bank, West Virginia

20-21 June
AUI Board of Trustees meeting
Morgantown, West Virginia

8 July
NRAO Semester 2014A Call for Proposals opens

10-13 July
Star Quest X
Green Bank, West Virginia

10-17 July
7th NAIC-NRAO Single Dish School
Arecibo Observatory, Puerto Rico

14-17 July
Society of Amateur Radio Astronomers (SARA) Conference
Green Bank, West Virginia

1 August
NRAO Semester 2014A Call for Proposals submission deadline

2-6 September
Collaboration for Astronomy Signal Processing and Electronics Research (CASPER) Meeting
Jodrell Bank Observatory
University of Manchester, U.K.

9 September
2014 Jansky Fellow Program
Announcement

9 September
VLA Sky Survey Call for White Papers

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

17 September
ALMA Cycle 2 Pre-announcement

27-28 September
NRAO Community Day at Howard University
Washington, D.C.

30 September – 4 October
IAU Symposium 303 – The Galactic Center: Feeding and Feedback in a Normal Galactic Nucleus
Santa Fe, New Mexico

7 October
NRAO Community Day
AAS – Division for Planetary Sciences Meeting
Denver, CO

9 October
NRAO Community Day
University of Wisconsin-Madison
Madison, Wisconsin

17-18 October
AUI Board of Trustees meeting
Albuquerque, New Mexico

28-29 October
NRAO Community Day
NASA – Goddard Space Flight Center
Silver Springs, Maryland

24 October
ALMA Cycle 2 Call for Proposals
Released

31 October
NRAO Community Day
Infrared Analysis and Processing Center
California Institute of Technology
Pasadena, California

1 November
NRAO Community Day
University of Texas – Austin
Austin, Texas

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

5 December
ALMA Cycle 2 Call for Proposals Submission Deadline

APPENDIX C: ADVISORY 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 astronomical community's current and future use of NRAO research facilities and makes recommendations that maximize the Observatory's scientific productivity and improve its effectiveness for the user community.

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

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

Aneta Siemiginowska was the Chair for the 2013 Users Committee; Gregg Hallinan was the Co-Chair.

In collaboration with the Observatory, the Committee reviewed and adopted an updated description of the Committee's formal charge. The 2013 Committee members, their home institution, and their term of service follow.

Shami Chatterjee
Cornell University
2013 – 2016

Laura Chomiuk
Michigan State University
2013 – 2016

Sarah Church
Stanford University
2011 – 2014

Helene Courtois
University Lyon France
2011 – 2014

Mark Devlin
University of Pennsylvania
2011 – 2014

Mark Heyer
University of Massachusetts
2010 – 2013

Fredrick "Rick" Jenet
University of Texas, Brownsville
2011 – 2014

Jeremy Darling
University of Colorado – Boulder
2012 – 2015

Sheperd Doeleman
MIT Haystack Observatory
2012 – 2015

Gregg Hallinan, Co-Chair
Caltech Astronomy
2012 – 2015

Joseph Lazio
JPL/Caltech
2013 – 2016

James Miller-Jones
ICRAR Curtin University
2012 – 2015

Karin Öberg
Harvard-Smithsonian, CfA
2012 – 2015

Dominik Riechers
Cornell University
2013 – 2016

Gordon Richards
Drexel University
2010 – 2013

Aneta Siemiginowska, Chair
Harvard-Smithsonian, CfA
2010 – 2013

David J. Thompson
NASA – Goddard Space Flight Center
2010 – 2013

Ue-Li Pen
CITA – University of Toronto
2011 – 2014

Eva Schinnerer
Max-Planck-Institut für Astronomie
2011 – 2014

Michael Skrutskie
University of Virginia
2010 – 2013

Visiting Committee

The Visiting Committee is appointed by the AUI Board of Trustees to review the management and research programs of the Observatory and meets bi-annually at alternating NRAO sites. The next Visiting Committee meeting will take place in spring 2014 in Socorro, New Mexico. The Committee members for this meeting are listed below.

Edwin Bergin, (Chair)
University of Michigan
2018

Katherine Blundell
Oxford University
2018

Xiaoyu Hong
Shanghai Astronomical Observatory
2016

Ryohei Kawabe
Nobeyama Radio Observatory
2016

Elizabeth A. Lada
University of Florida
2014

Malcolm Longair
University of Cambridge
2014

Maura McLaughlin
West Virginia University
2016

Suzanne Staggs
Princeton University
2016

Greg Taylor
University of New Mexico
2018

Dan Werthimer
UC Berkeley
2018

APPENDIX C: ADVISORY COMMITTEES

ALMA North American Science Advisory Committee (ANASAC)

Established in February 2003, the ALMA North American Science Advisory Committee (ANASAC) has four primary mandates:

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

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

(c) Provide input to the NA ASAC members on charges given to the ASAC by the ALMA Board.

(d) Carry out other tasks as may be requested by the NRAO Director.

The NRAO Director appoints ANASAC members from the North American astronomy community. About one-third of the membership rotates off each year and is replaced. Appointments are typically for three-year terms. The North American members of the ALMA Science Advisory Committee members are also members of the ANASAC. The ANASAC holds an annual face-to-face meeting and teleconferences approximately every two months.

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

Shep Doeleman
MIT Haystack Observatory
2015

Kelsey Johnson
University of Virginia
2014

Francisca Kemper
ASIAA
2014

Leslie Looney
University of Illinois
2013

Dan Marrone
University of Arizona
2015

Michael Mumma
University of Maryland/GSFC
2013

David Neufeld
Johns Hopkins University
2013

Karin Oberg
Harvard Smithsonian – CfA
2015

Rachel Osten
Space Telescope Science Institute
2013

Dick Plambeck
University of California, Berkeley
2015

Douglas Scott
University of British Columbia
2014

Time Allocation Committee

The persons listed below served on the NRAO Time Allocation Committee (TAC) for Semesters 2013B and 2014A. The scientific purview of each TAC member is indicated.

Semester 2013B

Mary Putman
Extragalactic Structure (EGS)
Columbia University

Stephen White
Solar System, Stars, and Planetary Systems (SSP)
University of Maryland

Mike Eraculous
Active Galactic Nuclei (AGN)
Pennsylvania State University

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

Tom Bania
Interstellar Medium (ISM)
Boston University

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

Nick Scoville
High Redshift and Source Surveys (HIZ)
California Institute of Technology

James Cordes
Energetic Transients and Pulsars (ETP)
Cornell University

Semester 2014A

Mary Putman
Extragalactic Structure (EGS)
Columbia University

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

Mike Eraculous
Active Galactic Nuclei (AGN)
Pennsylvania State University

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

Tom Bania
Interstellar Medium (ISM)
Boston University

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

Grant Wilson
High Redshift and Source Surveys (HIZ)
University of Massachusetts – Amherst

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

APPENDIX D: FINANCIAL SUMMARY

(all figures are $k USD)

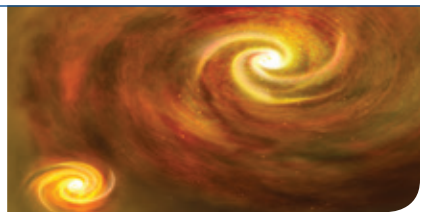
Functional Work Breakdown Structure Element	GBT	VLA	VLBA	ALMA	GB Ops	NM Ops	HQ & CV Ops	CDL & Other	Solar Radio Burst Spectrometer	RET/REU	ALMA-C	EVLA-C	External Grants	Total
Administrative Services	$85.7	$1,994.6	$662.7	$14,570.5	$2,160.6	$2,358.1	$16,694.0	$0.0						$38,526.2
Development Programs	$774.1	$66.2	$114.5	$1,683.4	$294.6	$0.0	$746.6	$2,410.4						$6,089.8
Director's Office	$0.0	$0.0	$0.0	-$2,231.7	$366.8	$116.4	$3,942.3	$0.0						$2,193.8
Science Operations	$710.7	$877.2	$110.7	$6,813.8	$660.2	$859.0	$4,112.4	$0.0						$14,143.9
Telescope Operations	$3,564.5	$7,890.0	$4,258.6	$10,894.5	$258.9	$100.4	$56.9	$0.0						$27,023.9
SPO-4 Solar Radio Burst Spectrometer									$31.2					$31.2
CSA-4 – RET/REU										$227.0				$227.0
ALMA Construction											$11,945.0			$11,945.0
EVLA Construction												$745.8		$745.8
External Grants													$3,837.1	$3,837.1
Grand Total	$5,135.0	$10,828.0	$5,146.5	$31,730.6	$3,741.1	$3,433.9	$25,552.3	$2,410.4	$31.2	$227.0	$11,945.0	$745.8	$3,837.1	$104,763.8

APPENDIX E: MEDIA RELEASES

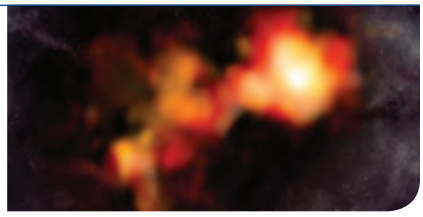
The NRAO Education and Public Outreach team issued 40 media releases in 2013, including 34 press releases, 5 announcements, and 1 media tip sheet. Thirty-one of the media releases described exciting new science conducted with NRAO telescopes. Science results from ALMA, VLA, VLBA, and GBT were featured in 12, 10, 6, and 8 releases, respectively. Each 2013 NRAO media release is briefly described below.

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

New Studies Give Boost to Binary Star Formation Theory
(31 December)
Using the new capabilities of the upgraded VLA, scientists have discovered previously unseen binary companions to a pair of very young protostars.

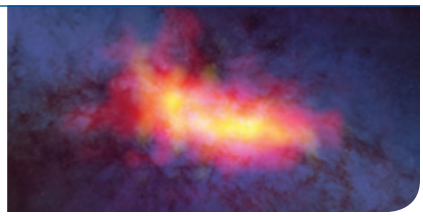


Starless Cloud Cores Reveal Why Some Stars Are Bigger
(20 December)
Massive stars – those at least eight times the mass of our Sun – present an intriguing mystery.



New System Makes the VLA Two Telescopes in One
(10 December)
The VLA will get a new system allowing it to continuously monitor the sky to study the ionosphere and detect short bursts of radio emission from astronomical objects.

Hidden Details Revealed in Nearby Starburst Galaxy
(9 December)
Using the new, high frequency capabilities of the GBT, astronomers have captured never-before-seen details of the nearby starburst galaxy M82.



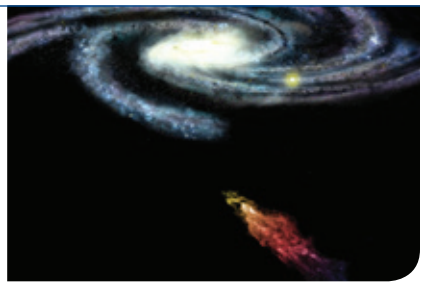
Tip Sheet: Science, engineering, and technology milestones
VLBI between West Virginia and Shanghai and the world's first radio sundial.

APPENDIX E: MEDIA RELEASES

Infant Galaxies Merging Near 'Cosmic Dawn'
(21 November)
Astronomers using the combined power of ALMA and NASA's Hubble Space Telescope have discovered a far-flung trio of primitive galaxies nestled inside an enormous blob of primordial gas nearly 13 billion light-years from Earth.

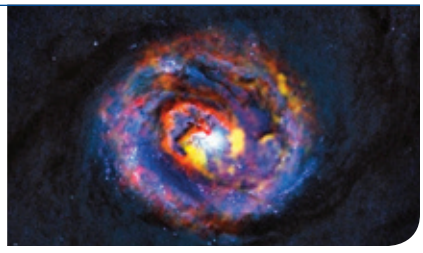
Surprising Image Provides New Tool for Studying a Galaxy
(14 November)
Astronomers studying gas halos around nearby galaxies discovered that one of their subjects is not a single galaxy, but two, superimposed on the sky and masquerading as one.

Magnetic Force Field Shields Giant Gas Cloud
(31 October)
Doom may be averted for the Smith Cloud, a gigantic streamer of hydrogen gas that is on a collision course with the Milky Way Galaxy.



ALMA Reveals Ghostly Shape of Coldest Place in Universe
(24 October)
At a cosmologically crisp one degree Kelvin, the Boomerang Nebula is the coldest known object in the Universe.

ALMA Observes Two Supermassive Black Holes
(21 October)
Two teams of researchers using the ALMA telescope have made remarkably detailed observations of supermassive black holes caught in the act of ingesting matter and converting it into powerful jets of particles and energy.

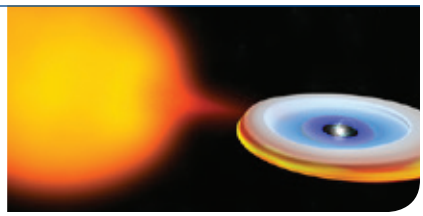


Announcement: New Film about Very Large Array
(4 October)
The NRAO has released a new 24-minute film about the recently renovated Karl G. Jansky Very Large Array radio telescope. The film is narrated by Academy Award-winning actress Jodie Foster, star of the 1997 Warner Brothers film, "Contact," which was filmed in part at the VLA.

Announcement: Final Antenna Delivered to ALMA
(1 October)
The final ALMA antenna is delivered to the Joint ALMA Observatory.

Announcement: Charles Bennett Receives 2013 Jansky Lectureship
(26 September)
AUI and NRAO award the 2013 Jansky Lectureship to Charles Bennett.

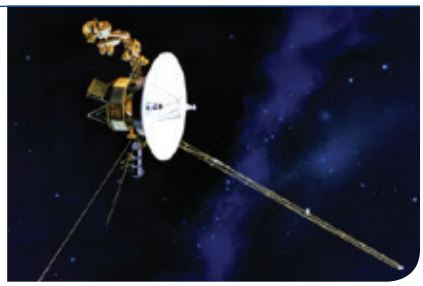
Jekyll & Hyde Star Morphs from Radio to X-ray Pulsar and Back
(25 September)
Neutron star morphs from radio to X-ray pulsar and back again.



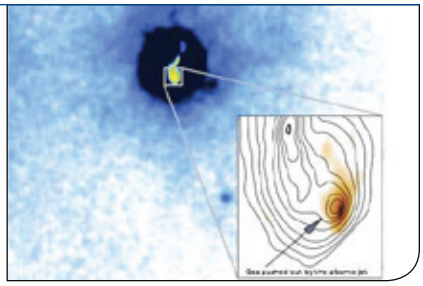
Announcement: AUI and WVU Sign $1M Agreement with NRAO
(19 September)
AUI and NRAO signed an agreement with West Virginia University to use the GBT.

APPENDIX E: MEDIA RELEASES

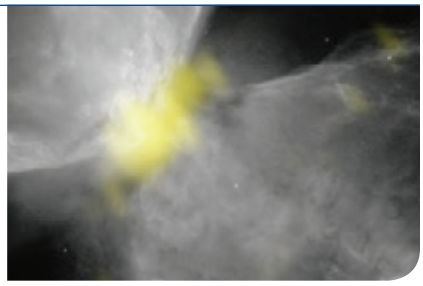
Voyager 1 Spotted from Earth
(12 September)
Earlier this year, the National Science Foundation's Very Long Baseline Array telescope turned its gaze to NASA's famed Voyager 1 and captured an image of this iconic spacecraft's faint radio signal.



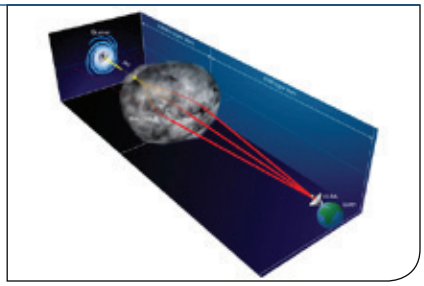
Powerful Jets Blowing Material Out of Galaxy
(5 September)
Astronomers using a worldwide network of radio telescopes have found strong evidence that a powerful jet of material propelled to nearly light speed by a galaxy's central black hole is blowing massive amounts of gas out of the galaxy.



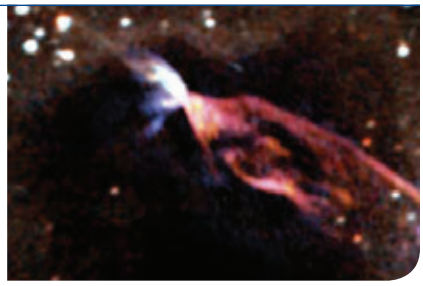
ALMA Opens Another Window on the Universe
(2 September)
ALMA astronomers successfully used the new Band 8 receivers to observe the distribution of atomic carbon in a planetary nebula dubbed NGC 6302.



Gas Cloud Causes Multiple Images of Distant Quasar
(28 August)
For the first time, astronomers have seen the image of a distant quasar split into multiple images by the effects of a cloud of ionized gas in our own Milky Way Galaxy.

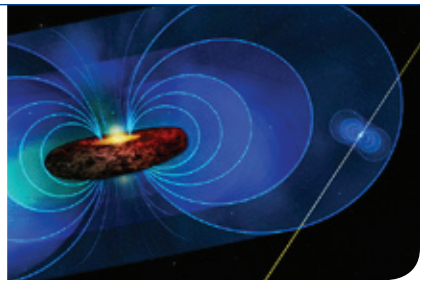


Starbirth Surprisingly Energetic
(20 August)
While observing a newborn star, astronomers using ALMA discovered twin jets of matter blasting out into space at record-breaking speed.

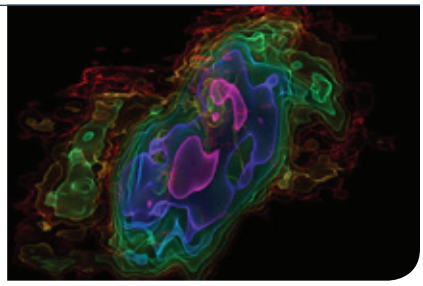


NRAO Telescope Reborn
(15 August)
The trailblazing 43 Meter Telescope in Green Bank, West Virginia, has been given new life as one of only two Earth stations for the Russian-made RadioAstron satellite, the cornerstone of astronomy's highest-resolution telescope.

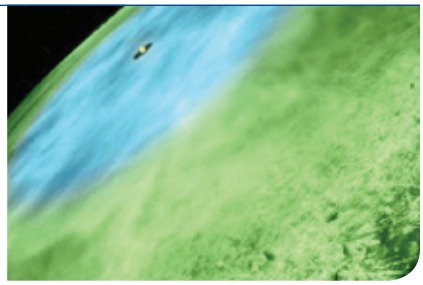
Pulsar Helps Astronomers Explore Milky Way's Core
(14 August)
Astronomers have made an important measurement of the magnetic field emanating from a swirling disk of material surrounding the black hole at the center of our Milky Way Galaxy.



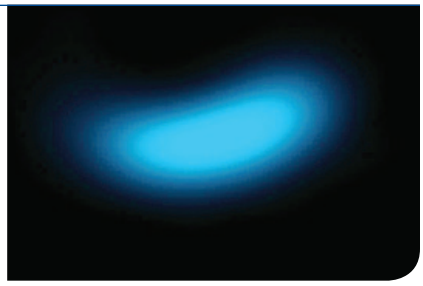
Starburst to Star Bust
(24 July)
The cosmic fireworks that characterize a starburst galaxy can abruptly fizzle out after only a relatively brief period of star formation, and astronomers want to know why.



Snow Falling Around Infant Solar System
(18 July)
The sight of a snowfall can thrill children, but the first-ever snow line seen around a distant star gives astronomers an even greater thrill because of what it reveals about the formation of planets and our Solar System's history.

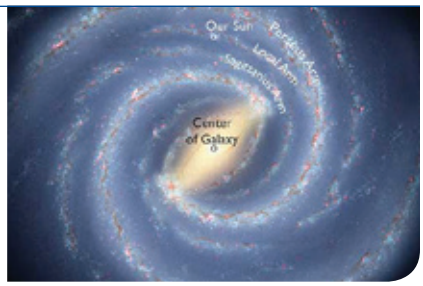


Dust Trap around Distant Star
(6 June)
Based on a treasure trove of recent discoveries, astronomers now know that planets are remarkably plentiful in our galaxy and may be common throughout the Universe.

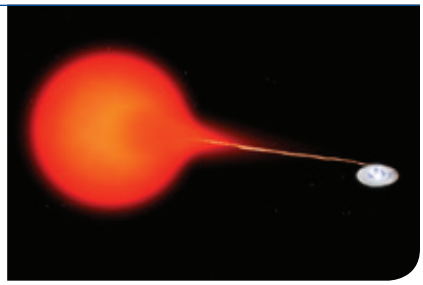


APPENDIX E: MEDIA RELEASES

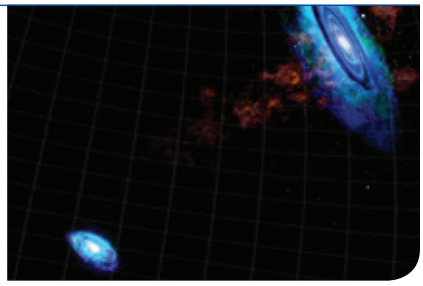
Earth's Milky Way Neighborhood Gets More Respect
(3 June)
Our Solar System's Milky Way neighborhood just went upscale.



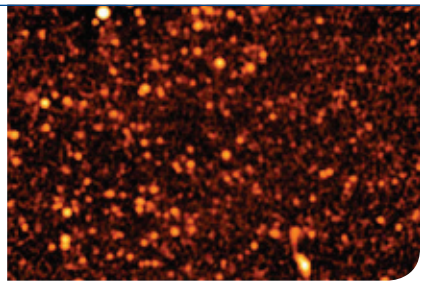
Accurate Distance to Dwarf Nova
(23 May)
Sometimes astronomy is like real estate – location, location, location.



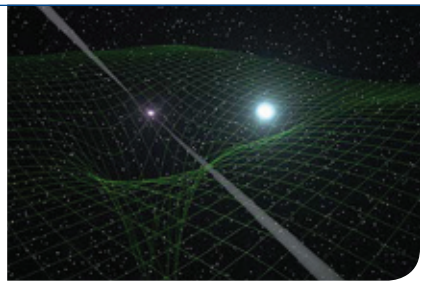
Clouds Among Our Galactic Neighbors
(8 May)
In a dark, starless patch of intergalactic space, astronomers have discovered a never-before-seen cluster of hydrogen clouds strewn between two nearby galaxies, Andromeda and Triangulum.



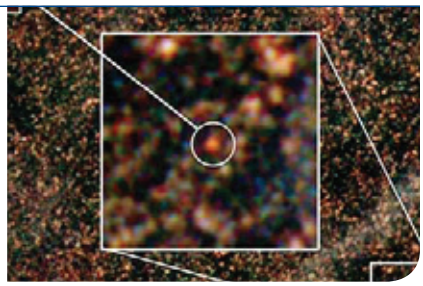
VLA Images the Distant Universe
(30 April)
Staring at a small patch of sky for more than 50 hours with the ultra-sensitive VLA, astronomers have for the first time identified discrete sources that account for nearly all the radio waves coming from distant galaxies.



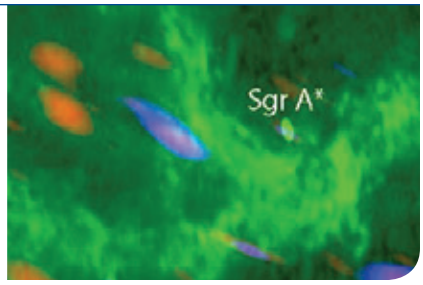
Einstein's Gravity Theory Passes Toughest Test Yet
(25 April)
A strange stellar pair nearly 7,000 light-years from Earth has provided physicists with a unique cosmic laboratory for studying the nature of gravity.



Massive Star Factory Churned in Universe's Youth
(17 April)
Astronomers using a worldwide collection of telescopes have discovered the most prolific star factory in the Universe, surprisingly in a galaxy so distant that they see as it was when the Universe was only six percent of its current age.

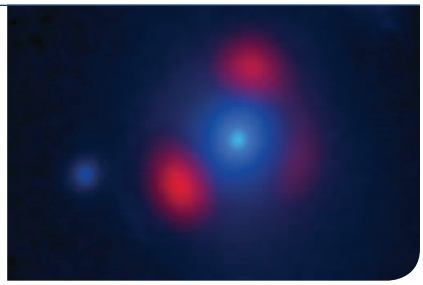


ALMA Sees Stars Forming Near Galaxy Core
(4 April)
Astronomers using ALMA have discovered signs of star formation perilously close to the supermassive black hole at the center of the Milky Way Galaxy.

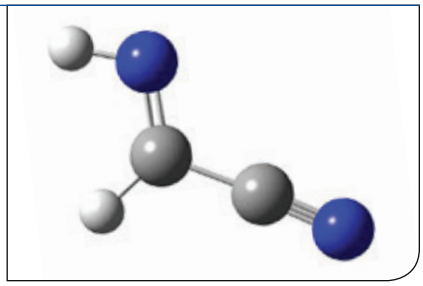


Announcement: ALMA Inauguration
(13 March)
ALMA was officially inaugurated today in a ceremony that brought together representatives from the international astronomical community.

ALMA Finds 'Monster' Starburst Galaxies
(13 March)
Astronomers using ALMA have discovered starburst galaxies earlier in the Universe's history than they were previously thought to have existed.

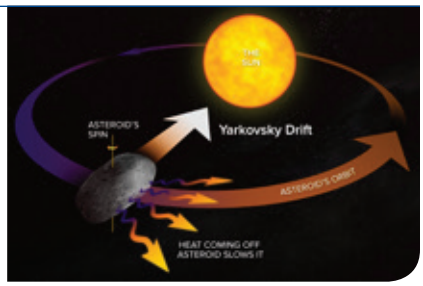


Icy Cosmic Start for Amino Acids and DNA
(28 February)
Using new technology at the telescope and in laboratories, researchers have discovered an important pair of prebiotic molecules in interstellar space.

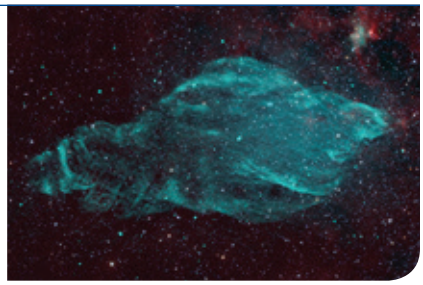


APPENDIX E: MEDIA RELEASES

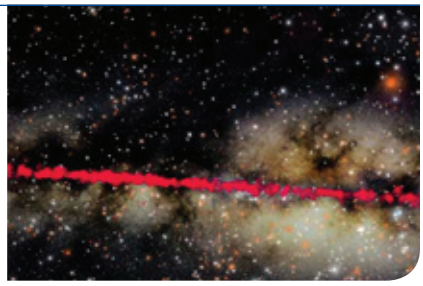
Getting the Right Spin on a Close-Passing Asteroid
(11 February)
The record-setting close approach of an asteroid on 15 February is an exciting opportunity for scientists, and a research team will use NRAO and NASA telescopes to gain a key clue that will help them predict the future path of this nearby cosmic neighbor.



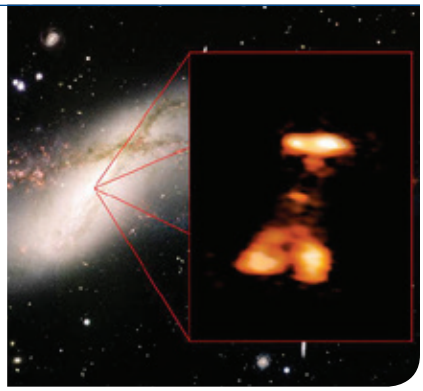
Microquasar Makes a Giant Manatee Nebula
(19 January)
A new view of a 20,000-year old supernova remnant demonstrates the upgraded imaging power of the VLA and provides more clues to the history of this giant cloud that resembles a beloved endangered species, the Florida Manatee.



Mapping the Milky Way
(9 January)
Astronomers have discovered hundreds of previously-unknown sites of massive star formation in the Milky Way, including the most distant such objects yet found in our home Galaxy.



Massive Outburst in Neighbor Galaxy
(7 January)
The surprising discovery of a massive outburst in a neighboring galaxy is giving astronomers a tantalizing look at what likely is a powerful belch by a gorging black hole at the galaxy's center.



ALMA Sees Star and Planets Grow Together
(2 January)
Astronomers have used the ALMA telescope to get their first glimpse of a fascinating stage of star formation in which planets forming around a young star are helping the star itself continue to grow, resolving a longstanding mystery

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 Division of Astronomical Sciences
ASTRON	Netherlands Institute for Radio Astronomy
ATI	Advanced Technologies Instrumentation
ATLAS	Australia Telescope Large Area Survey
ATNF	Australia Telescope National Facility
AU	Astronomical Unit
AUI	Associated Universities, Incorporated
AURA	Association of Universities for Research in Astronomy
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
CLASS	Cosmology Large Angular Scale Surveyor
cm	centimeter
COBE	Cosmic Background Explorer
COM	Communications Office
CONAMA	La Comisión Nacional del Medio Ambiente (Chile)
CONIcyT	Comisión Nacional de Investigación Científica y Tecnológica (Chile)
COSMOS	Cosmic Evolution Survey
COSPAR	Committee on Space Research
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSO	Caltech Submillimeter Observatory
CV	Charlottesville, VA
DARE	Dark Ages Radio Explorer
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
EHT	Event Horizon Telescope

EPO. . . . . Education and Public Outreach
ESO. . . . . European Southern Observatory
EVLA . . . . . Expanded Very Large Array
FASR . . . . . Frequency-Agile Solar Radiotelescope
FAST . . . . . Five hundred meter Aperture Spherical Telescope
FCC. . . . . Federal Communication Commission
FE . . . . . Front End
FEIC . . . . . Front End Integration Center
FIAN . . . . . Russian Academy of Science
FIRST . . . . . Faint Images of the Radio Sky at Twenty centimeters
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
GRB . . . . . Gamma Ray Burst
GUPPI . . . . . Green Bank Ultimate Pulsar Processing Instrument
GW . . . . . Gravitational Waves
Gyr . . . . . Gigayear
HBT. . . . . Heterojunction Bipolar Transistor
HERA . . . . . Hydrogen Epoch of Reinonization Array
HFET. . . . . Heterojunction Field Effect Transistor
HR. . . . . Human Resources
HSA. . . . . High Sensitivity Array
HST. . . . . Hubble Space Telescope
IAU . . . . . International Astronomical Union
IPT . . . . . Integrated Product Team
IRDC . . . . . Infrared Dark Cloud
ITAR . . . . . International Traffic in Arms Regulations
JAO. . . . . Joint ALMA Observatory
JPL . . . . . Jet Propulsion Laboratory
kHz . . . . . kiloHertz
Kpc . . . . . kiloparsec
LMT. . . . . Large Millimeter Telescope
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

APPENDIX F: ACRONYMS

mm . . . . . millimeter
MMIC . . . . . Monolithic Millimeter-wave Integrated Circuit
MPIfR . . . . . Max Planck Institut für Radioastronomie
MS . . . . . Magellanic Stream
Myr . . . . . Megayear
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
NANOGrav . . . . . North American Nanohertz Observatory for Gravitational Waves
NASA . . . . . National Aeronautics and Space Administration
NEON . . . . . National Ecological Observatory Network
NGST . . . . . Next Generation Space Telescope
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
NVSS . . . . . NRAO Very Large Array Sky Survey
NWNH. . . . . 2010 Decadal Survey report: *New Worlds, New Horizons*
OCA . . . . . Office of Chilean Affairs
OMT . . . . . OrthoMode Transducer
OPT. . . . . Observation Preparation Tool
OSF. . . . . Operations Support Facility (ALMA, Chile)
OST. . . . . Observation Scheduling Tool
PAF . . . . . Phased Array Feed
Pan-STARRS . . . . . Panoramic Survey Telescope and Rapid Response System
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
RISC . . . . . RadioAstron International Sciences Council
rms . . . . . root mean square
RSRO . . . . . Resident Shared Risk Observing
SAO. . . . . Smithsonian Astrophysical Observatory
SB. . . . . Schedule Block
SCO . . . . . Santiago Central Office

SHAO . . . . . Shanghai Astronomical Observatory
SIS . . . . . Superconductor–Insulator–Superconductor
SKA. . . . . Square Kilometre Array
SMA . . . . . Submillimeter Array
SMG . . . . . Submillimeter Galaxy
SMT . . . . . Submillimeter Telescope
SOC . . . . . Science Organizing Committee
SOS. . . . . Student Observing Support
SRP. . . . . Science Review Panel
SSG. . . . . Science Survey Group
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
UVML . . . . . University of Virginia Microfabrication Laboratory
WV . . . . . West Virginia
VA. . . . . Virginia
VAO. . . . . Virtual Astronomical Observatory
VEGAS . . . . . Versatile Green Bank Astronomical Spectrometer
VLA . . . . . Very Large Array
VLASS. . . . . Very Large Array Sky Survey
VLBA. . . . . Very Long Baseline Array
VLBI . . . . . Very Long Baseline Interferometry
WFIRST. . . . . Wide-Field infrared Survey Telescope
WIDAR . . . . . Wideband Interferometric Digital Architecture Correlator
WMAP. . . . . Wilkinson Microwave Anisotropy Probe
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