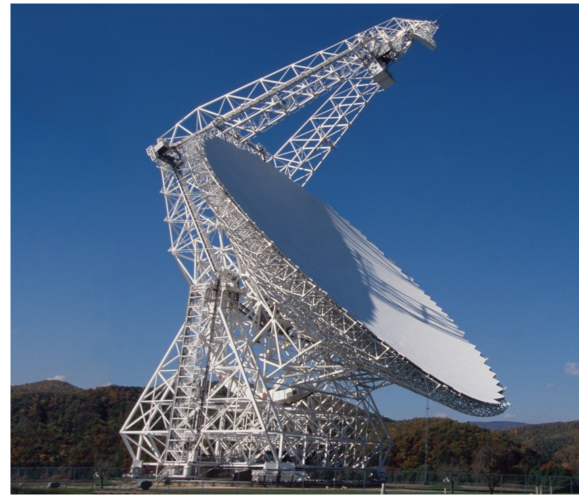
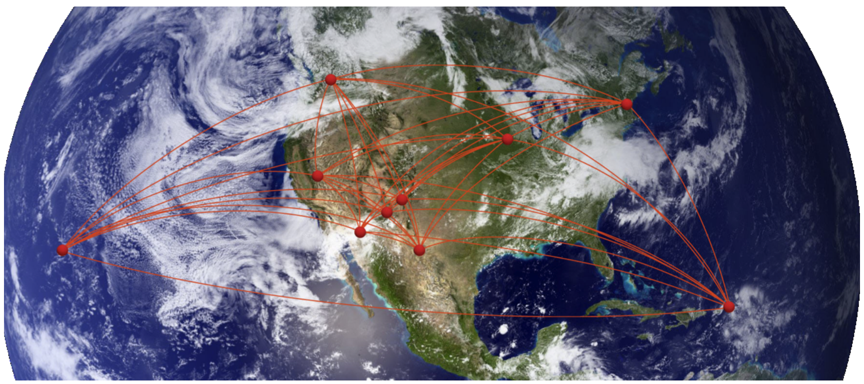
National Radio Astronomy Observatory





Sabrina Stierwalt
ALMA Staff Scientist

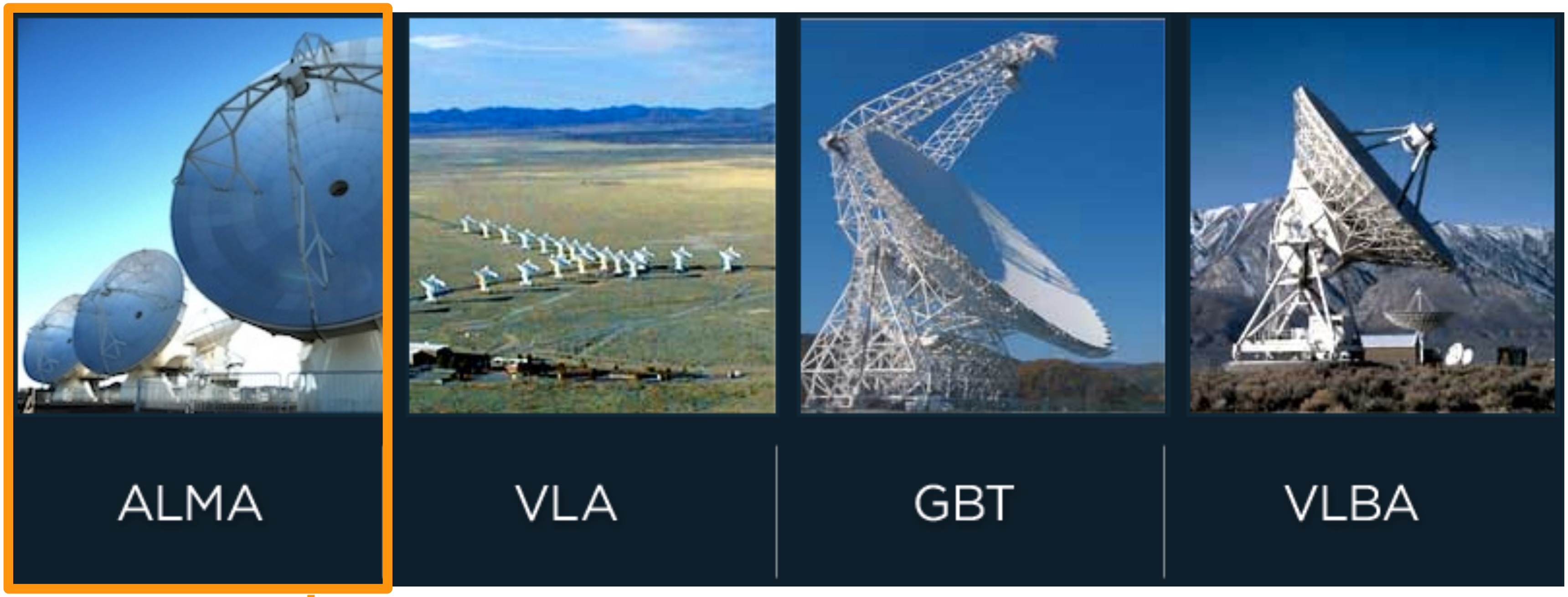
Associated Universities, Inc.

Atacama Large Millimeter/submillimeter Array
Karl G. Jansky Very Large Array
Robert C. Byrd Green Bank Telescope
Very Long Baseline Array

NRAO

NRAO:
One Observatory, Four Facilities

NRAO: One Observatory, Four Facilities



Atacama Large Millimeter/submillimeter Array:
a 66-antenna array in Chile

NRAO:
One Observatory, Four Facilities

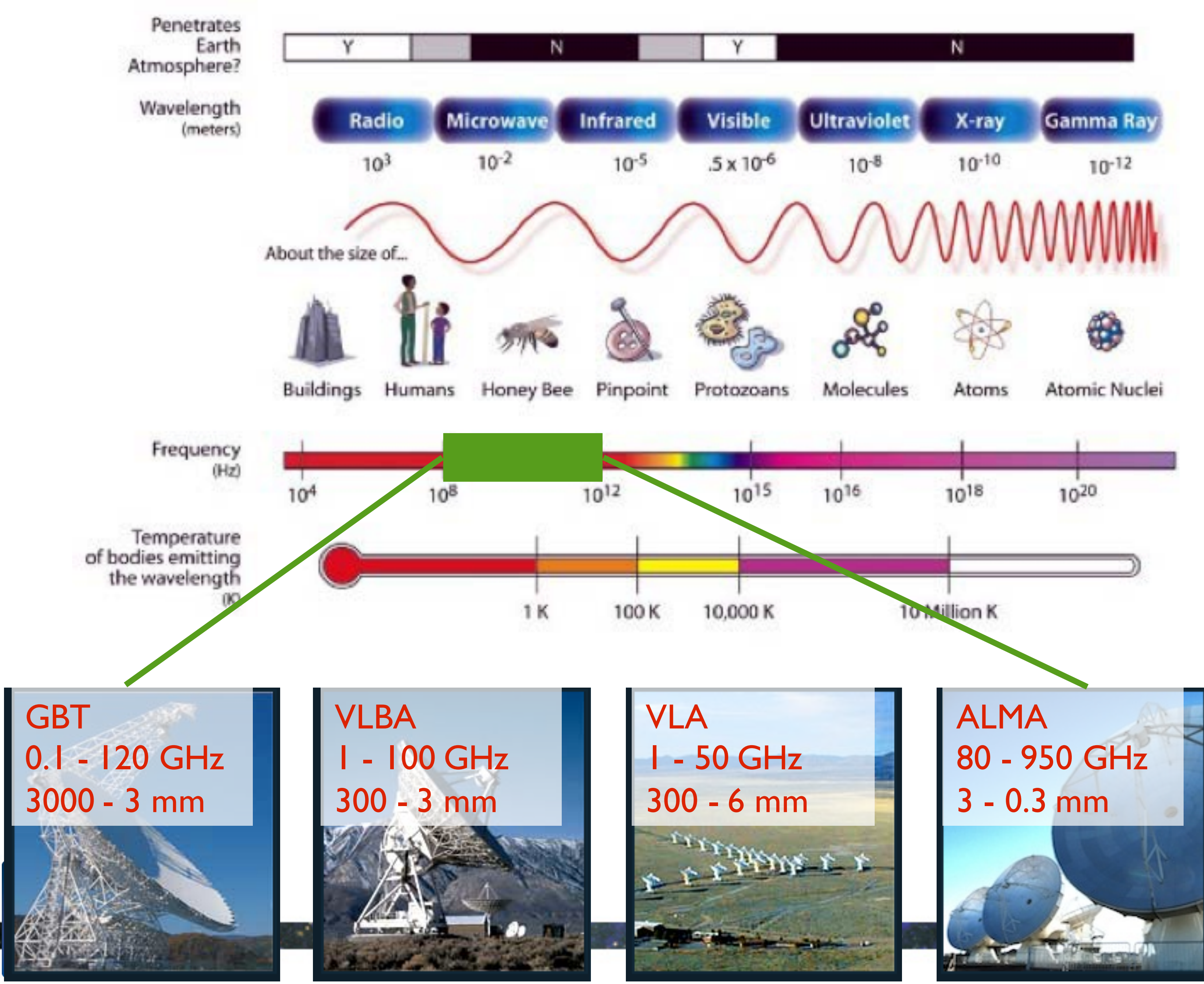
Jansky Very Large Array:
a 27-antenna array in New Mexico

NRAO:
One Observatory, Four Facilities

Robert C. Byrd Green Bank Telescope: world's largest fully steerable radio telescope, in West Virginia

NRAO:
One Observatory, Four Facilities

Very Large Baseline Array:
ten radio antennas spanning 8000 km


Penetrates Earth Atmosphere?
Y
N
Y
N
Wavelength (meters)
Radio
Microwave
Infrared
Visible
Ultraviolet
X-ray
Gamma Ray
10^{3}
10^{-2}
10^{-5}
$.5 \times 10^{-6}$
10^{-8}
10^{-10}
10^{-12}
About the size of...
Buildings
Humans
Honey Bee
Pinpoint
Protozoans
Molecules
Atoms
Atomic Nuclei
Frequency (Hz)
10^{4}
10^{8}
10^{12}
10^{15}
10^{16}
10^{18}
10^{20}
Temperature of bodies emitting the wavelength (K)
1 K
100 K
10,000 K
10 Million K
GBT
0.1 - 120 GHz
3000 - 3 mm
VLBA
1 - 100 GHz
300 - 3 mm
VLA
1 - 50 GHz
300 - 6 mm
ALMA
80 - 950 GHz
3 - 0.3 mm

Broad Science Topics with NRAO Telescopes

- Sun – coronal mass ejections, magnetic field activity
- Solar system, KBOs – atmospheres, astrometry, composition
- Star-forming regions – dust and gas environment, kinematics (infall, outflows, jets), proto-planetary disks, cores, chemistry, feedback, and natal cloud / star interactions
- Exoplanets – direct imaging, gaps in disks, kinematics
- Pulsars – neutron star physics, pulse morphology, gravity, ISM probe
- Galactic structure – spiral arms, bars, global atomic and molecular gas properties
- Nearby galaxies – molecular / atomic gas content and kinematics, dynamics of galaxies at high resolution, star formation, obscured SF, gas flow, astrochemistry
- Galaxy groups and clusters – atomic and molecular gas across systems, star formation efficiency, kinematics, dynamical mass measurements
- Black holes – mass measurements, kinematics
- High redshift galaxies – extragalactic background light, source counts, star formation history and efficiency, evolution of gas content (atomic and molecular)
- Cosmology – H_0 measurement, SZE

What is ALMA?

A global partnership to deliver a revolutionary millimeter/submillimeter telescope array (in collaboration with Chile)

- North America (US, Canada, Taiwan)
- Europe (ESO)
- East Asia (Japan, Taiwan)

66 reconfigurable, high precision antennas

λ ~ 0.3 – 8.6mm. Array configurations between 150 meters and >16 kilometers: 192 possible antenna locations:

- Main Array: 50 x 12m antennas
- Total Power Array: 4 x 12m antennas
- Atacama Compact Array (ACA): 12 x 7m antennas

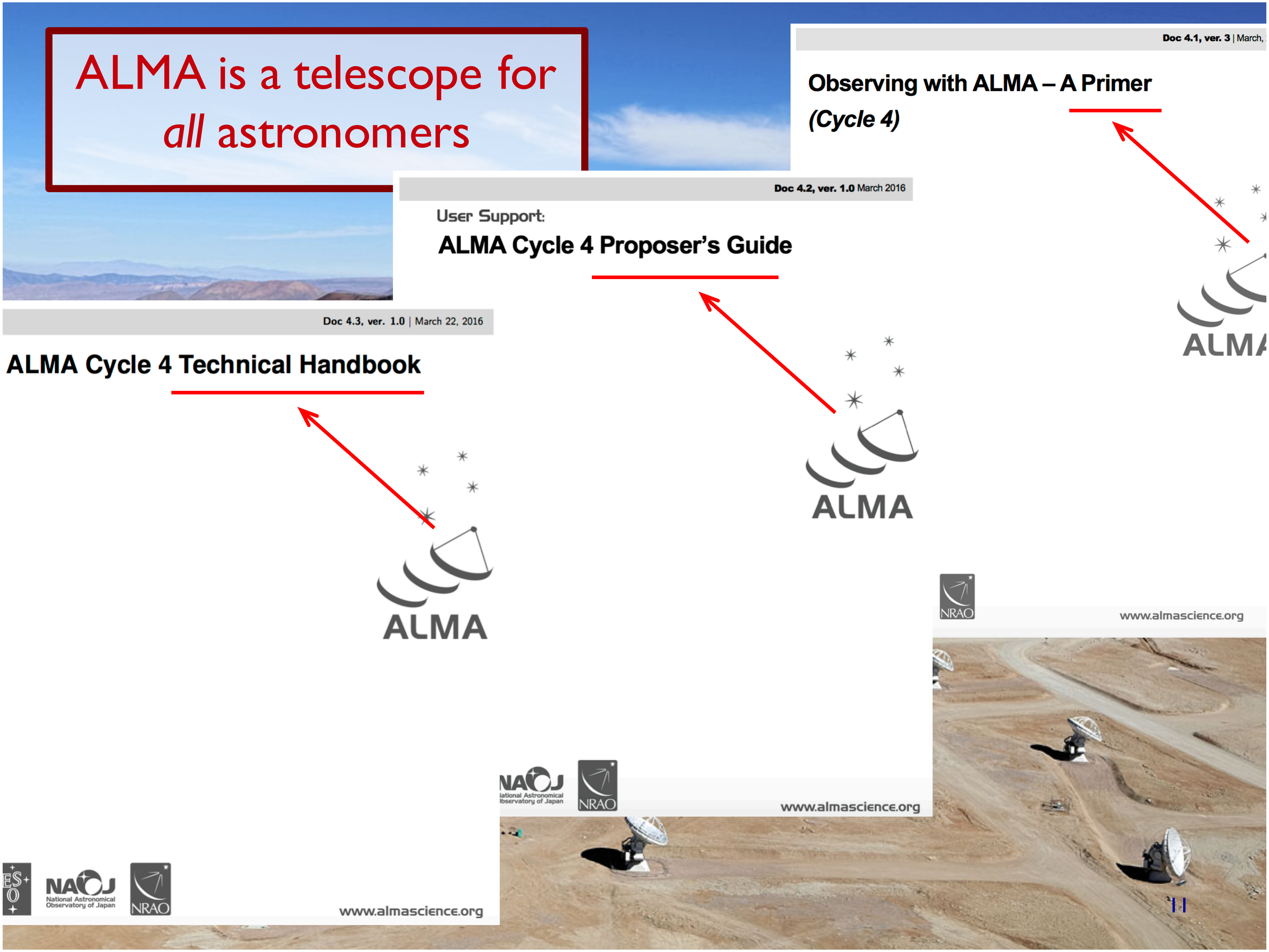
Array Operations Site is located at 5000m elevation in the Chilean Andes

Provides unprecedented imaging & spectroscopic capabilities at mm/submm λ

What is ALMA?

Array configurations between 150 meters and >16 kilometers: 192 possible antenna locations:

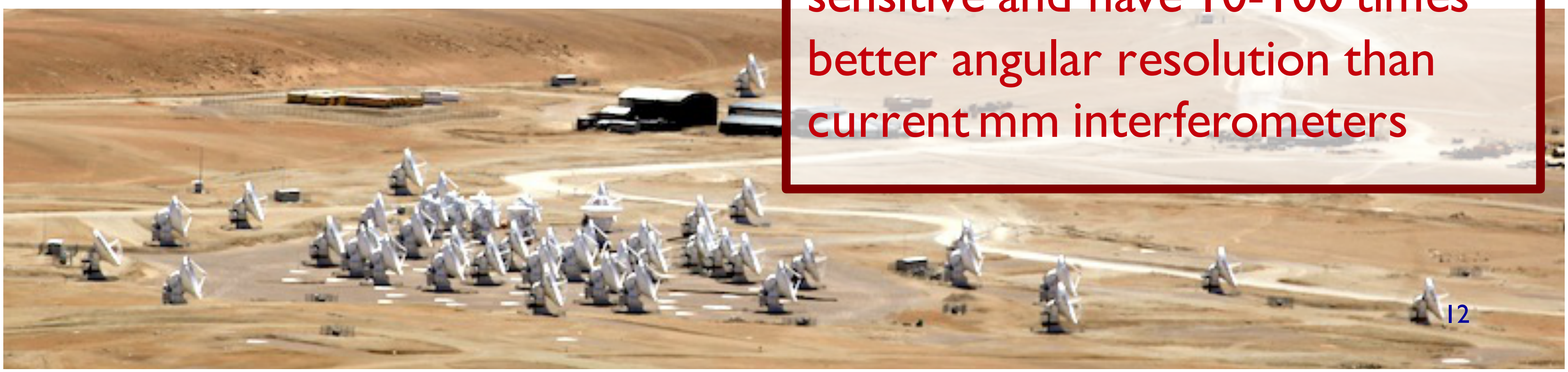
http://youtu.be/YMISe-C8GUs


ALMA is a telescope for *all* astronomers
Doc 4.1, ver. 3 | March,
Observing with ALMA – A Primer (Cycle 4)
Doc 4.2, ver. 1.0 March 2016
User Support:
ALMA Cycle 4 Proposer's Guide
Doc 4.3, ver. 1.0 | March 22, 2016
ALMA Cycle 4 Technical Handbook
ALMA
NAOJ National Astronomical Observatory of Japan
NRAO
ESO
www.almascience.org

ALMA Capabilities in a Nutshell…

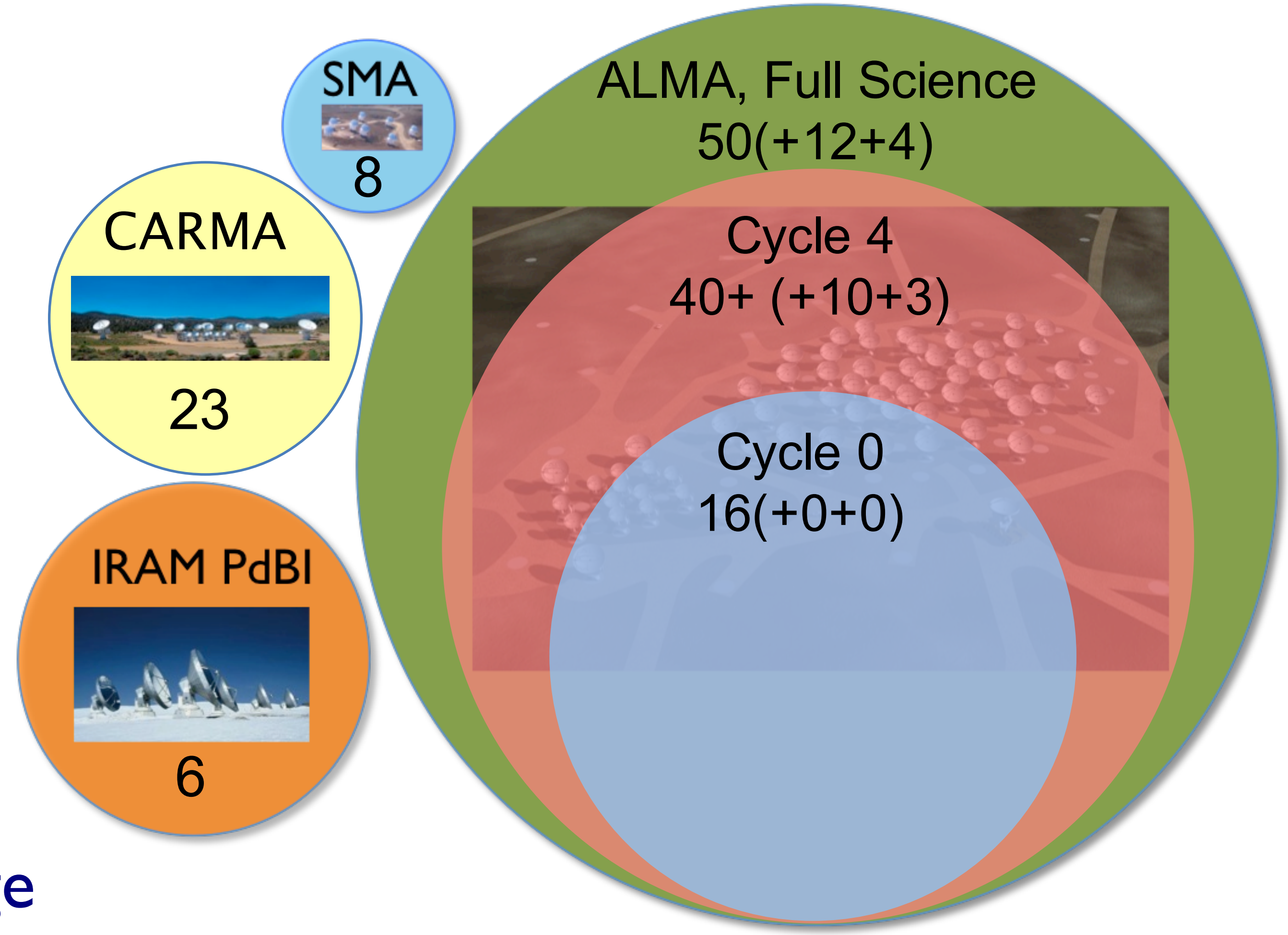
- Angular resolution down to 0.015” (at 300 GHz)
- Sensitive, precision imaging 84 to 950 GHz (3 mm to 315 μm)
- State-of-the-art low-noise, wide-band receivers (8 GHz bandwidth)
- Flexible correlator with high spectral resolution at wide bandwidth
- Full polarization capabilities
- Estimated 1 TB/day data rate
- All science data archived
- Pipeline processing

ALMA will be 10-100 times more sensitive and have 10-100 times better angular resolution than current mm interferometers

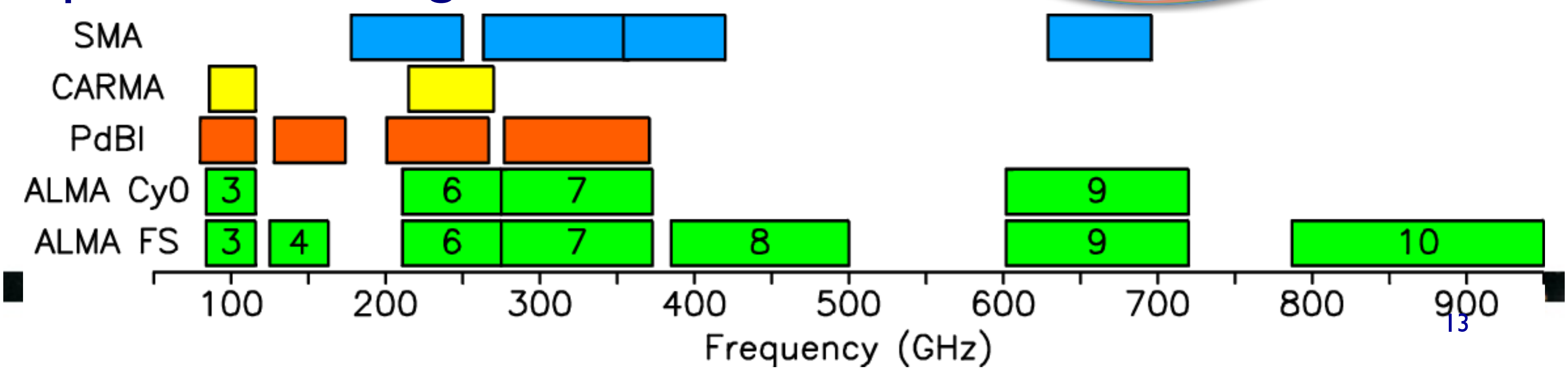


Collecting Area

~ sensitivity



Spectral Coverage



ALMA Current Status

- Construction Project ended in September 2014
- Routine science observing has been out to greater than 10 km baselines (C36-8) thanks to the highly successful Long Baseline Campaigns in 2014 and 2015
- **All 66 antennas accepted**
  - Currently all 66 antennas are at the high site (AOS), of which ~47 on average (up to max ~54) are being used for Cycle 3 observations
  - Some construction and verification items remain to be finished (e.g., wide-field polarization; various observing modes)
- The ACA (Atacama Compact Array) or Morita Array – up to 12x7m antennas and 4x12m antennas for TP observations – has been accepted and is being used for Cycle 3 observations
- More on Capabilities later… however, first on to science!

NRAO

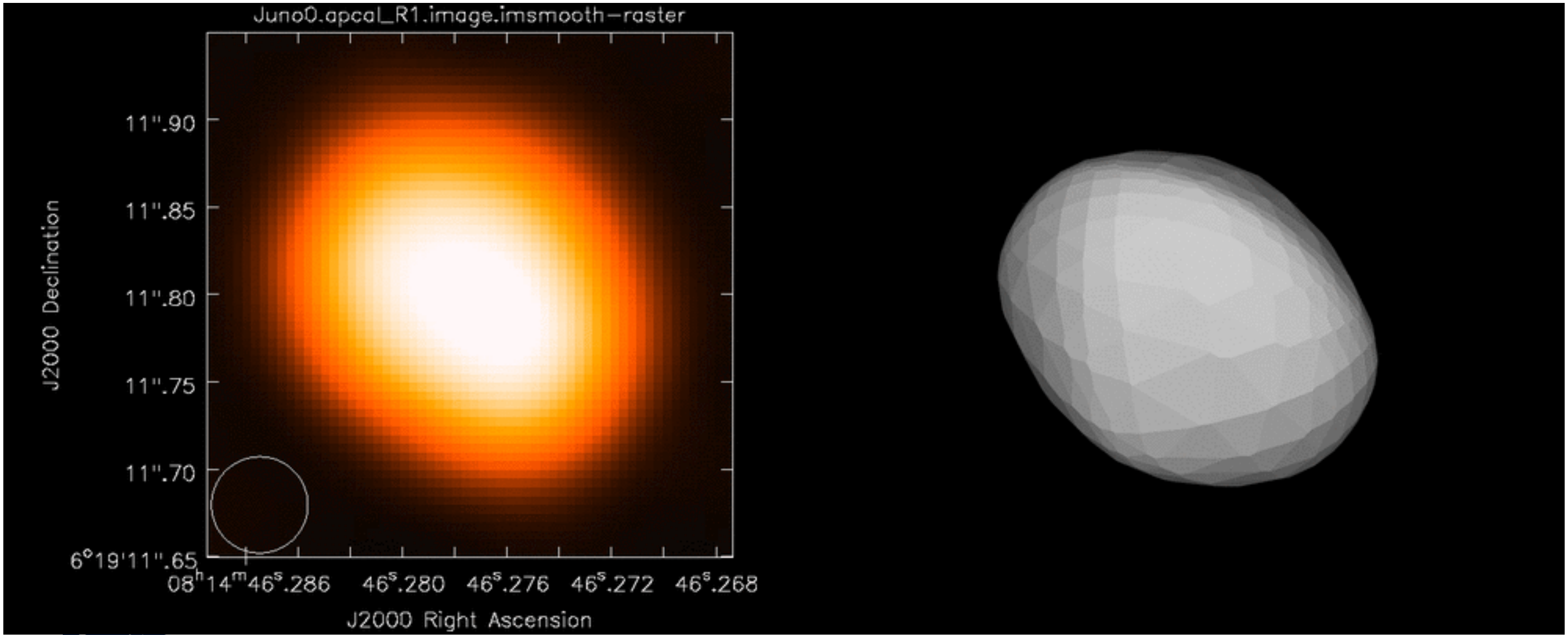
Band 6 Observations of Juno (SV)

Frequency = 233 GHz;

Five consecutive executions over 4.4 hours

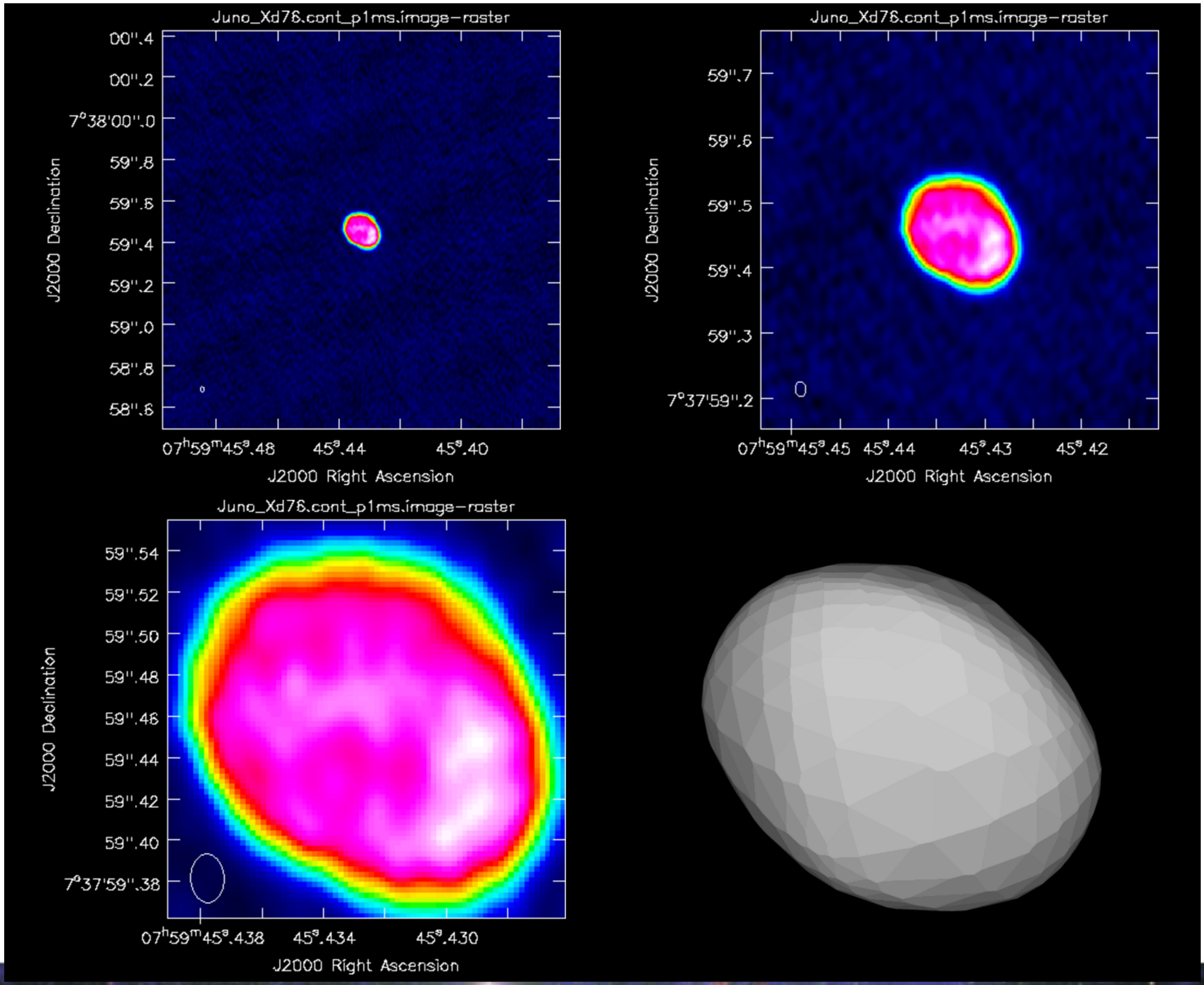
Beamsize ~ 0.04”x0.03” (~60x45 km)

Model: Durech et al. 2010: **Database of Asteroid Models from Inversion Techniques**



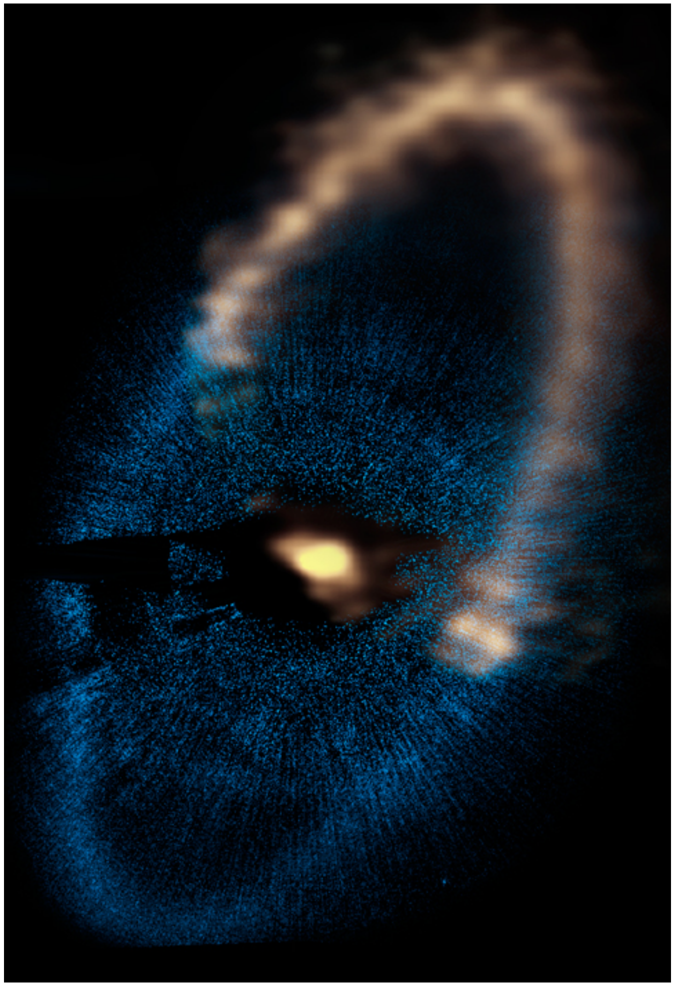
Band 8 Observations of Juno – TEST DATA

Frequency = 409 GHz; Beamsize=0.023" x 0.016" (35x24 km)



Formation of Planetary Systems

- Remarkably thin, sharp-edged Fomalhaut debris disk: 13-19 AU wide
- Two shepherding planets likely corral the disk on either side
- Each exoplanet < 3 Earth masses
- Data acquired with only 15 ALMA antennas

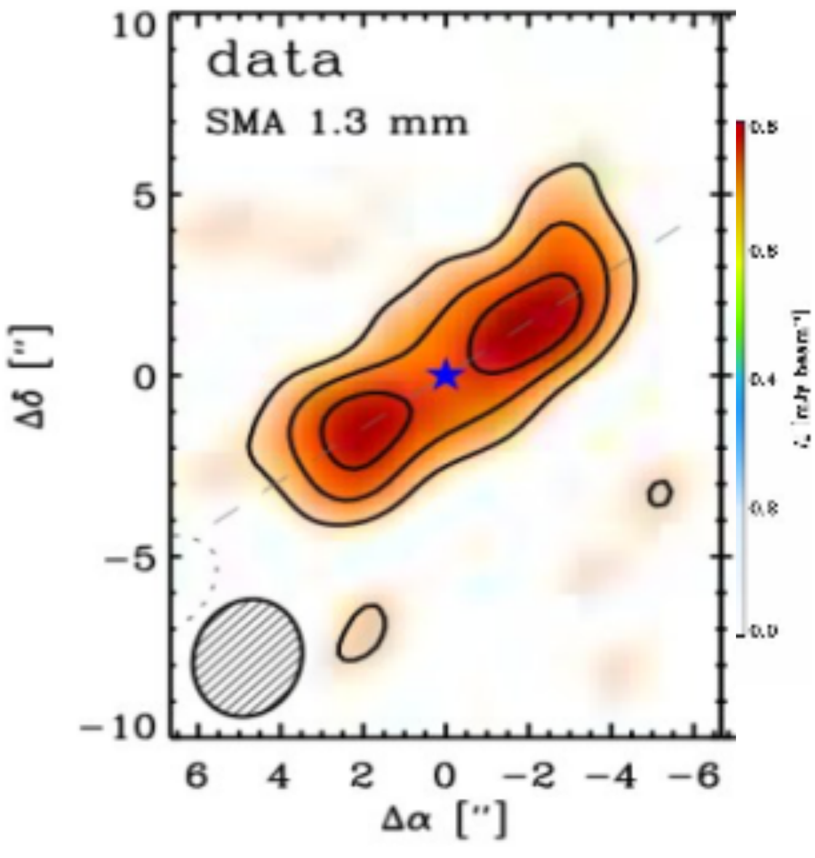


Boley et al. 2012

AU Mic: Young Solar System Analog

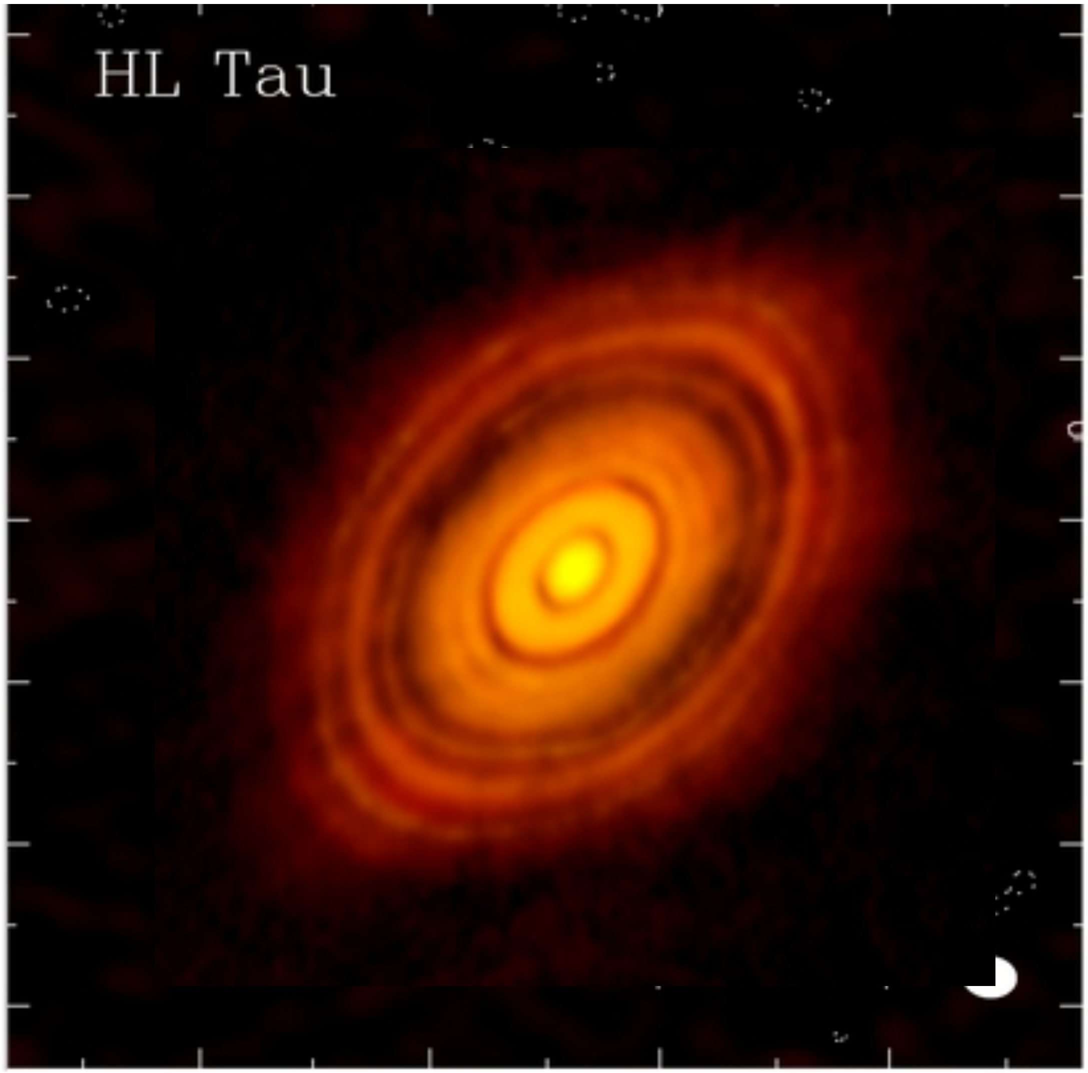
- Two debris emission components
- Central peak: stellar photosphere + asteroid-like belt at a few AU?
- Outer dust belt extends to 40 AU, to break in scattered light profile
  - truncated, reminiscent of classical Kuiper Belt
  - no detectable asymmetries in structure or position: compatible with Uranus-like planet

MacGregor et al. 2013



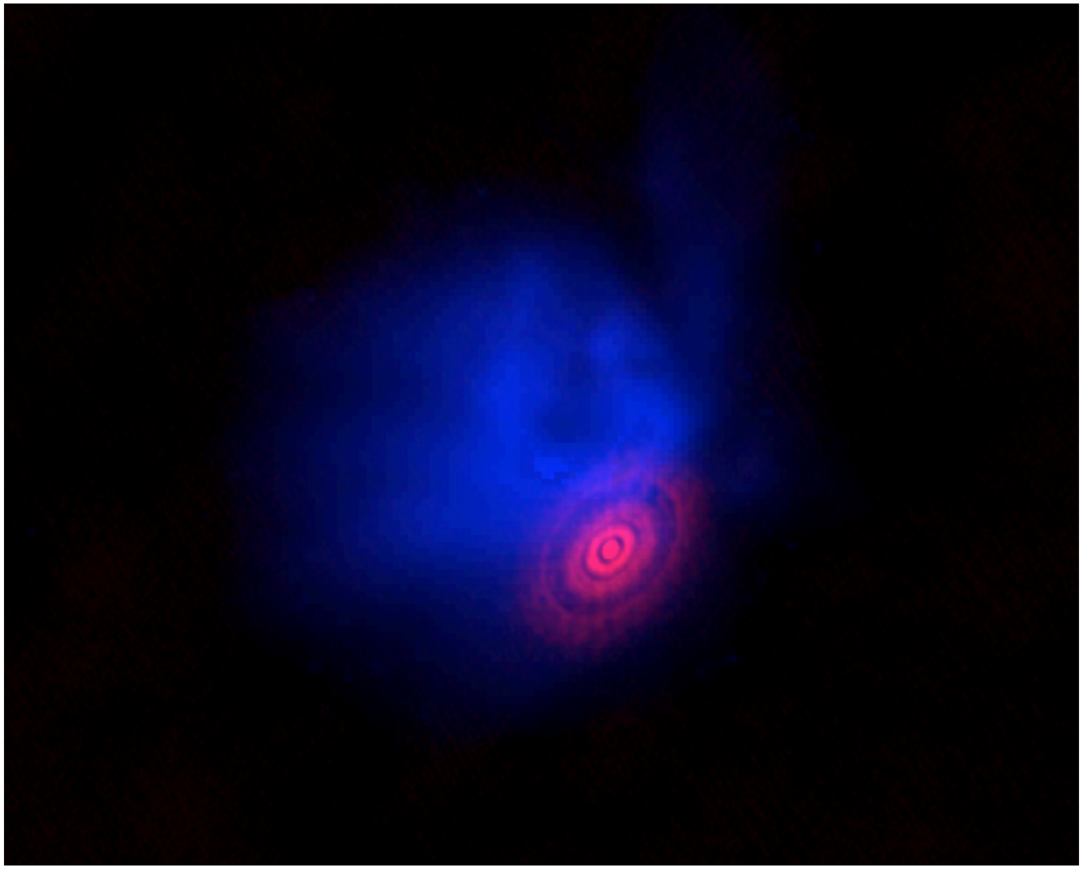
Wilner et al. 2010

ALMA Long Baseline Campaign



ALMA Observation of HL Tau, resolution of ~5AU (35 mas)

Long Baseline Campaign: HL Tau



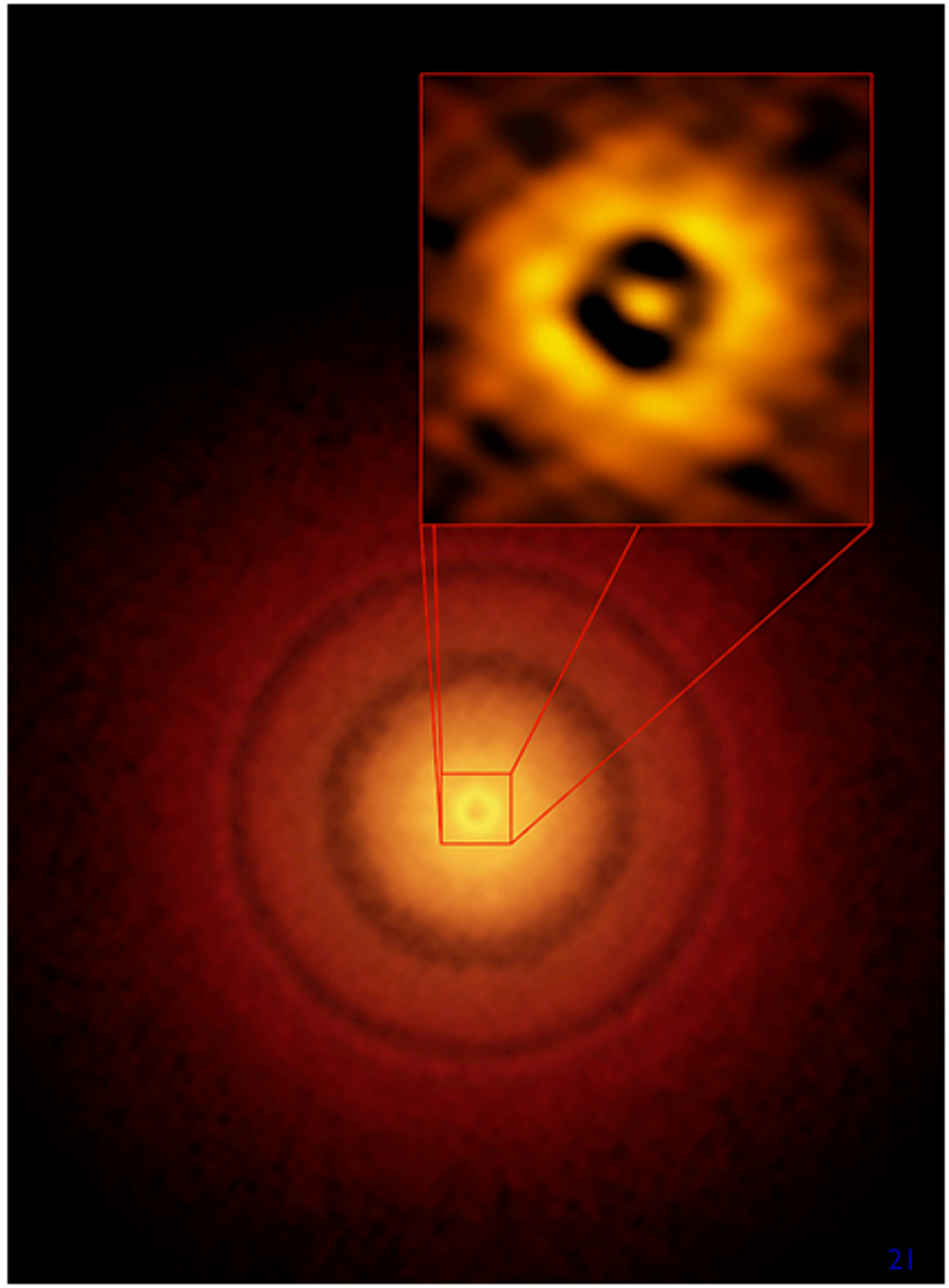
- Complementary to Hubble (blue—scattered light from unseen star).
- Presence of several planets at such a young age is "disturbing" to planet formation theories

HL Tau ALMA Image:
455 Million views

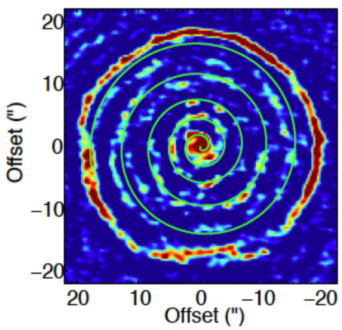
TW Hydrae Press Release out today!

ALMA's better-than Hubble resolution details as small as the Earth's distance from the Sun may be discerned in this young (10Myr) nearby (175 light years) planet forming Sun-like star

Andrews et al. 2016



ALMA Measures Stellar Feedback



Maercker et al 2012

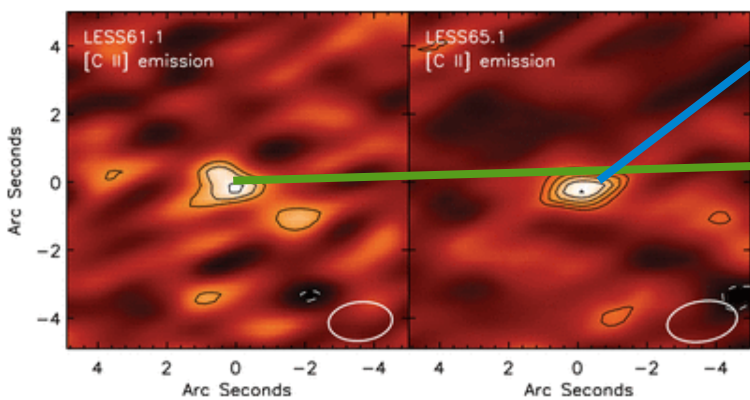
- ALMA's high sensitivity high resolution CO image measures the mass (0.003 M_{sun}) and timescale (200 years) of feedback to the interstellar medium from the AGB star R Sculptoris and reveals the star to be a binary

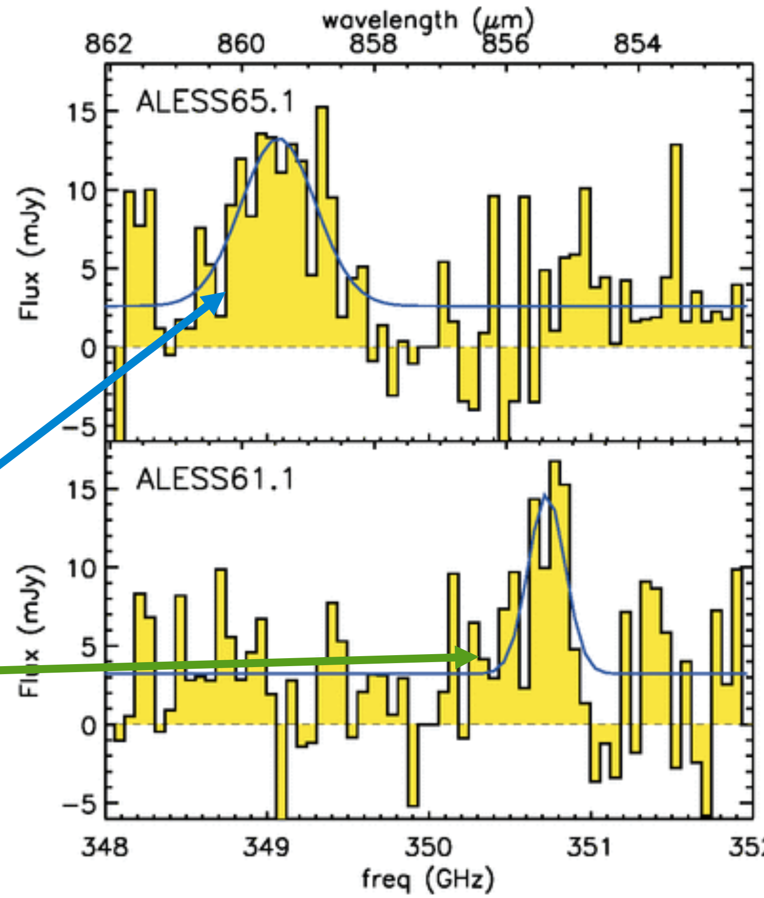
NRAO

Serendipitous [C II] Detection

ALMA 870 μm continuum observations of 100+ submm galaxies resulted in serendipitous detection of [CII] in two galaxies at z ~ 4.4

- Bright end of cooling function evolves strongly between z ~ 0 and 4.4
- Increased interstellar medium cooling at higher z due to higher star formation rates





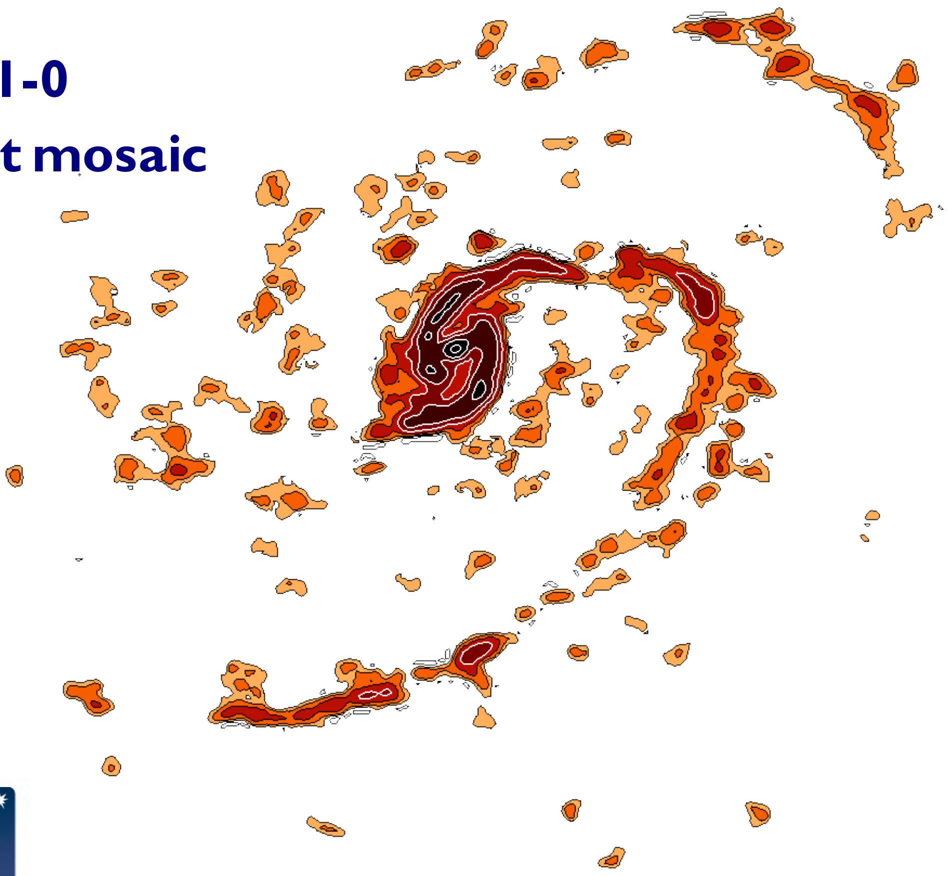
Swinbank et al. 2012

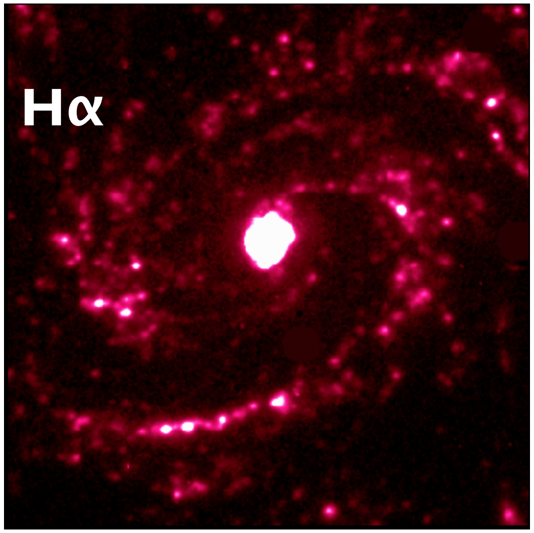
ALMA Images Nearby Galaxies

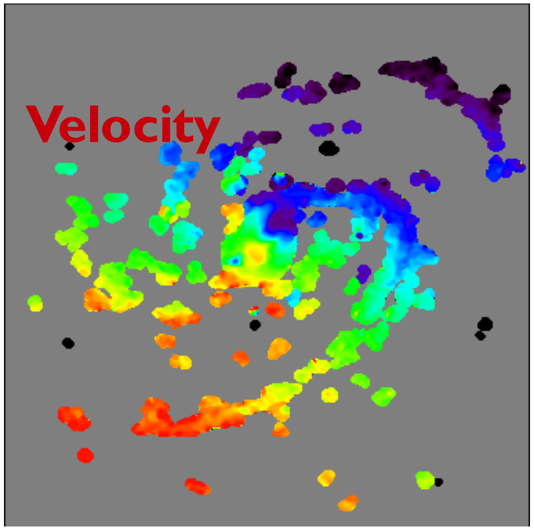
Science verification imaging of M100

CO 1-0

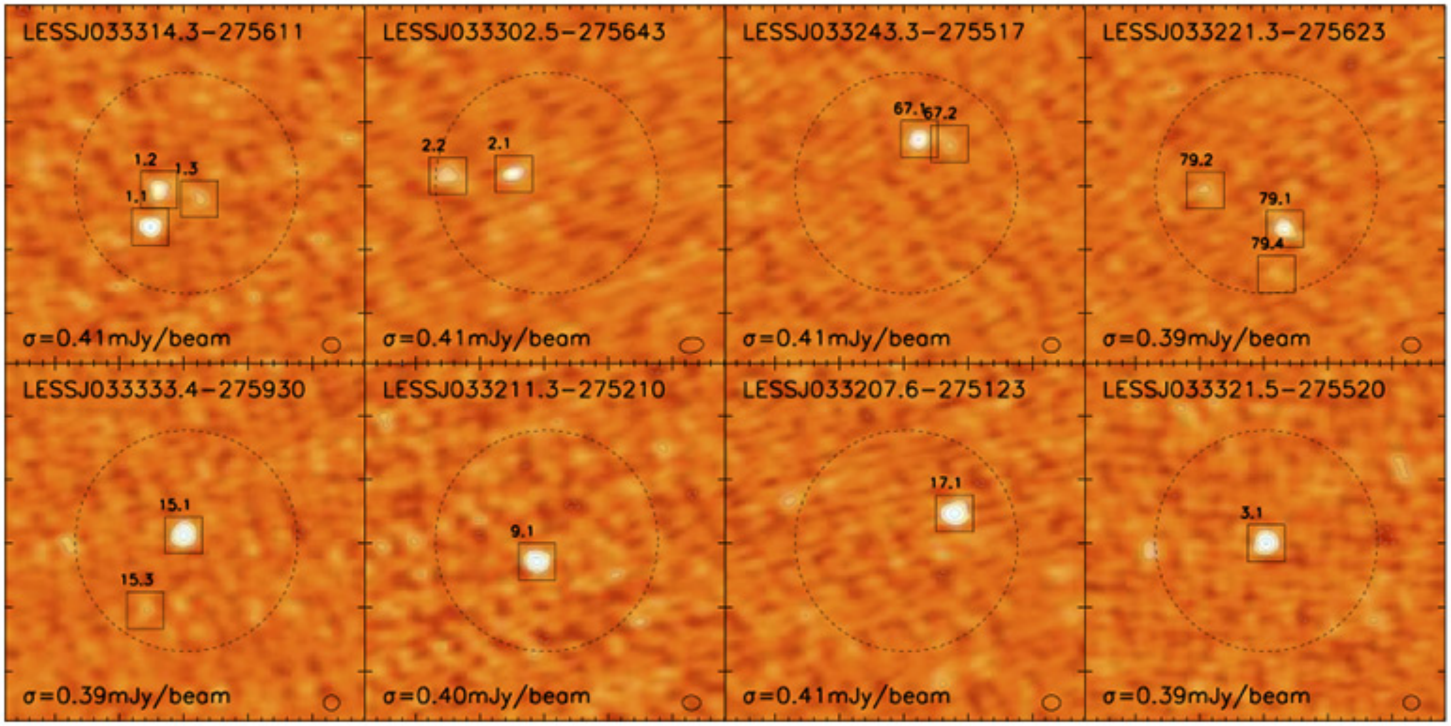
47-pt mosaic







Resolving High-z Submm Galaxies



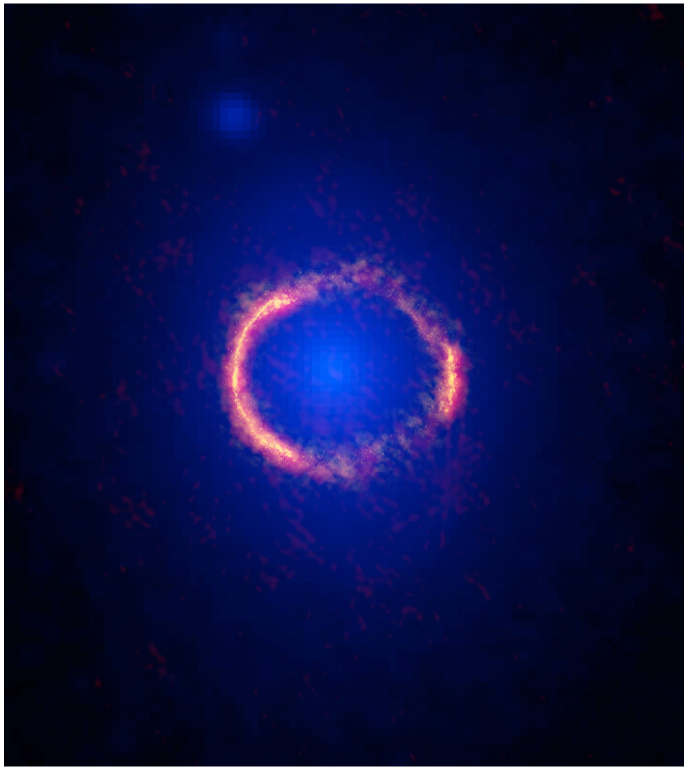
Hodge et al. 2013

- 126 submm sources observed with ALMA at 870 μm
- 2x deeper, 10x higher angular resolution than previous surveys
- **99 sources detected in 88 fields, integration time ~120 sec**
- Significant multiplicity (35-50%) found at 0.2” resolution

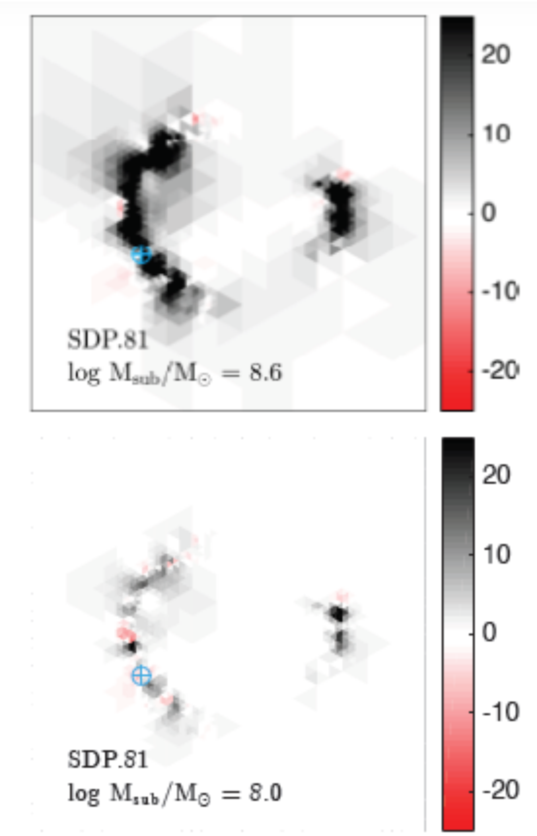
Resolving High-z Submm Galaxies

SDP.81

- Foreground galaxy acts as a gravitational lens
- Lensed galaxy at z ~ 3
- Observed as part of the long baseline campaign (baselines out to 15 km)
- 23 mas resolution achieved

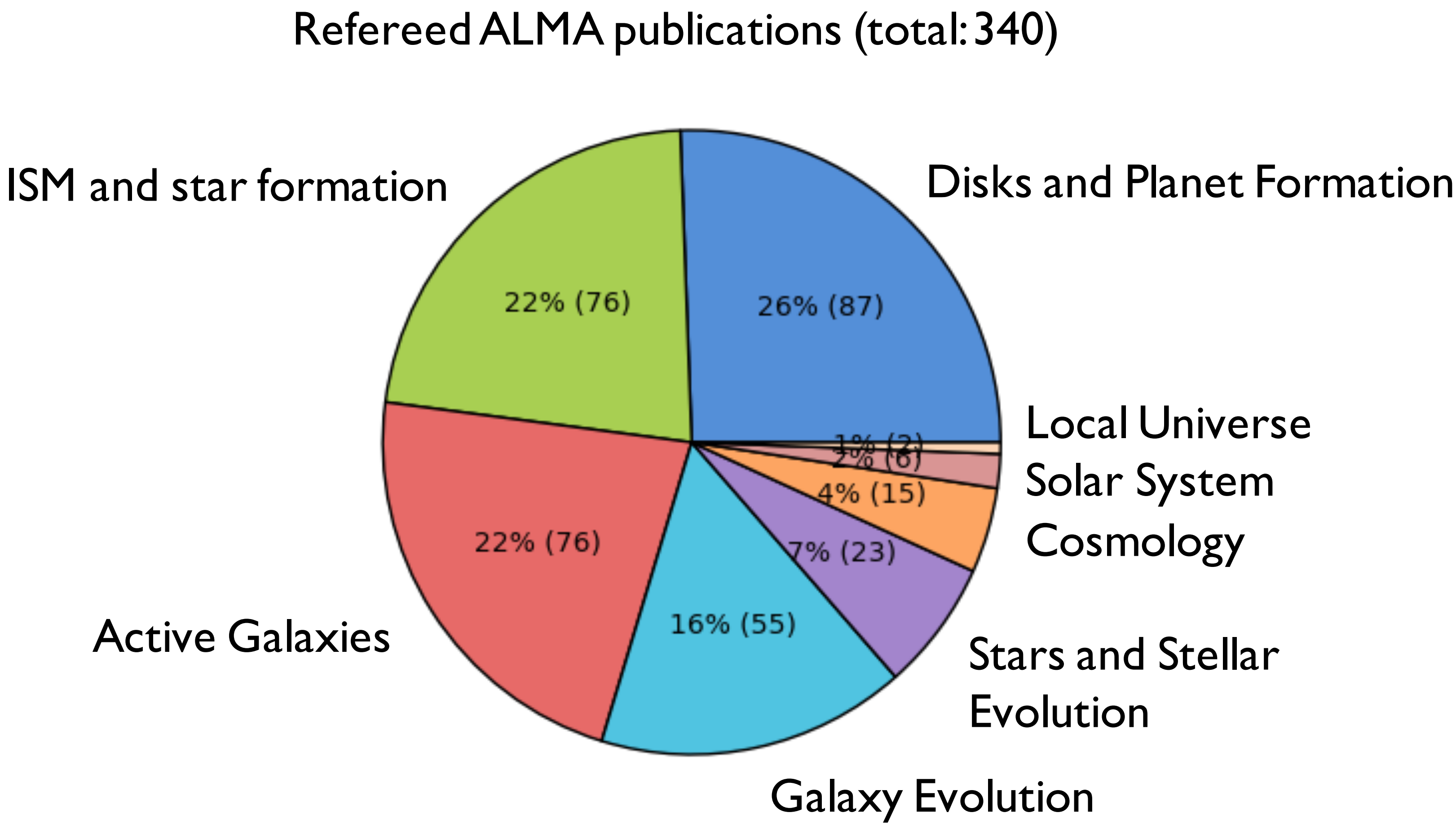


Looking for subhaloes in SDP.81. (Hezaveh et al 2016)



Recent ALMA Results

340 ALMA Publications to date



Half a Decade of ALMA: Cosmic Dawns Transformed

20-23 September 2016, Indian Wells, CA (near Palm Springs)

More information: http://go.nrao.edu/ALMA5years

SOC

- Crystal Brogan (NRAO, USA)
- John Carpenter (JAO, Chile)
- Vivien Chen (National Tsing Hua University, Taiwan)
- Aeree Chung (Yonsei University, Korea)
- Pierre Cox (JAO, Chile)
- Michiel Hogerheijde (Leiden University, Netherlands)
- Daisuke Iono (NAOJ, Japan)
- Kirsten Kraiberg Knudsen (Chalmers University, Sweden)
- Dan Maronne (University of Arizona, USA)
- Munetake Momose (Ibaraki University, Japan)
- Karin Oberg (Harvard University, USA)
- Eva Schinnerer (MPIA, Germany)
- Leonardo Testi (ESO, Germany)
- Christine Wilson (McMaster University, Canada)
- Al Wootten (NRAO, USA)
- Franz Bauer (PUC)

NRAO

ALMA Development Program

- Goals
  - Incorporate development ideas from the NA ALMA community into the ALMA Development Program
  - Support development of conceptual and detailed designs for new or upgraded ALMA Observatory capabilities
  - Support ALMA-relevant, long-term R&D
- Upgrades progress through three phases:
  1) Conceptual study
  2) Prototype/pre-production
  3) Full production and implementation
- Priorities are science-driven

ALMA Development Program

- Call topics of particular interest are
  - Focal Plane Arrays
  - Phased Array Feeds
  - Increased ALMA bandwidth
- North American ALMA Partners and the North American radio astronomy community at-large are eligible to participate in the Program
- Collaborations are encouraged
- Your participation is welcome and appreciated
  - There will be a special Splinter Session at the June AAS meeting in San Diego
- Please direct your questions to Bill Randolph, Program Manager

  (wrandolp@nrao.edu)

The Green Bank Telescope in 2016

Next GBT, VLA, VLBA/HSA/VLBI proposal deadline is

August 01, 2016 at 5pm EST

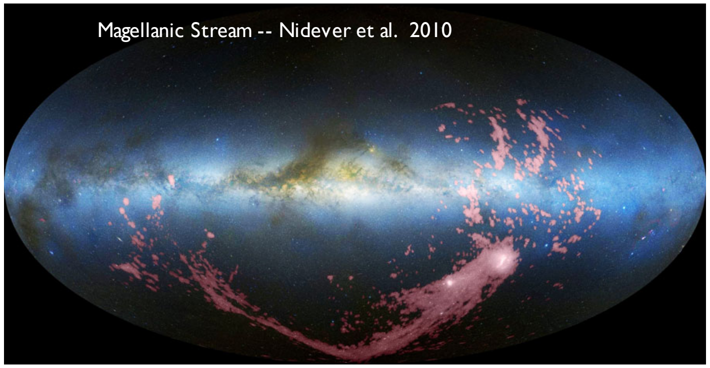
which is for semester "17A" (Feb 2017 – Aug 2017 observations)

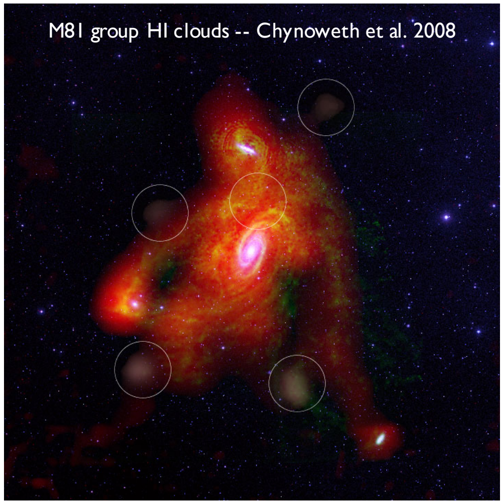
NRAO

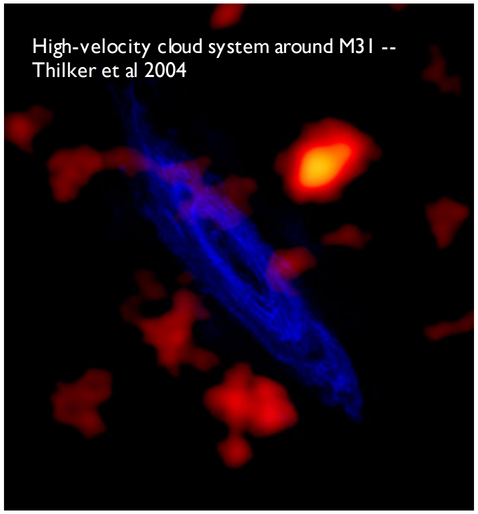
GBT Studies of faint HI -- unequalled sensitivity

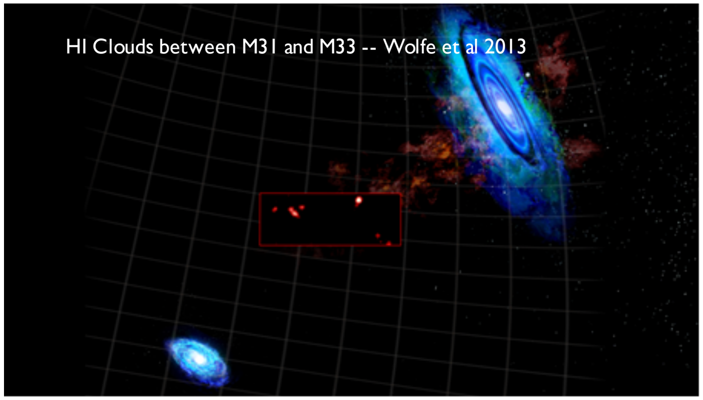
GBT offers ability to detect HI to $N_{HI} \sim 10^{17}\ cm^{-2}$

- Interactions
- Outflows from winds and fountains
- Cool gas accretion







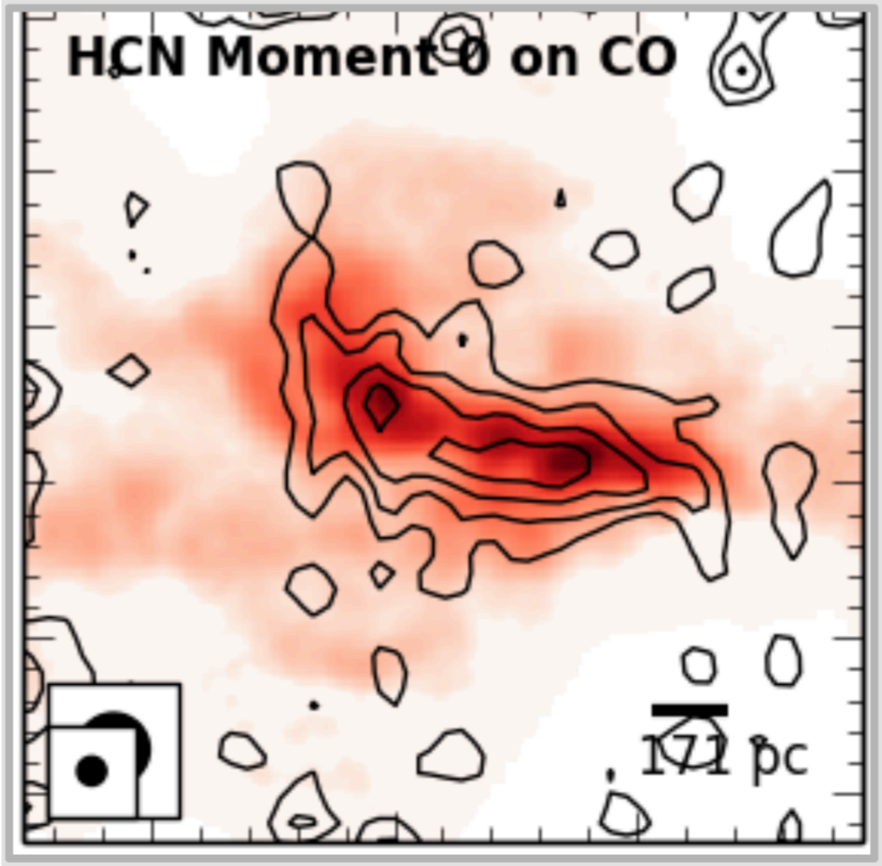


NRAO

GBT maps dense molecular gas in nearby galaxies

Starburst Galaxy M82

- HCN and HCO+ map the dense molecular gas most closely linked to star formation
- Observed simultaneously at 4 mm over ~15 hours



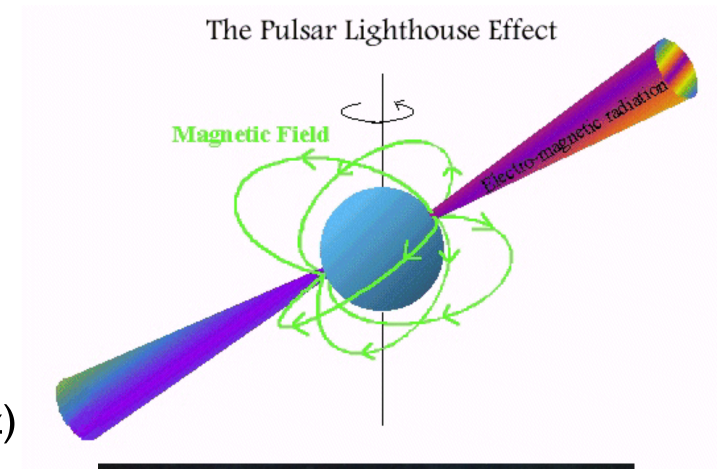
Kepley, Leroy, Frayer + 2014

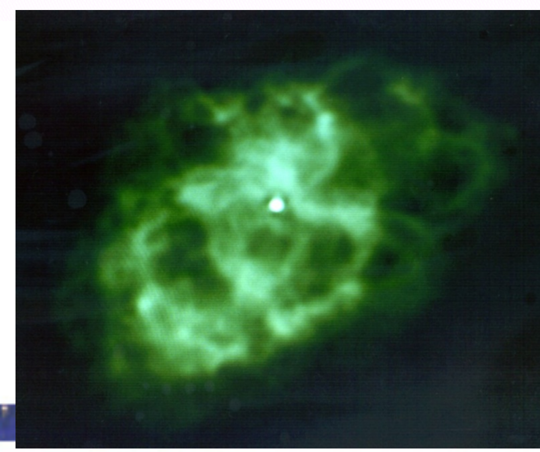
The GBT remains the world's premier pulsar observatory

(Quiet Zone, collecting area, receivers, detectors, sky coverage)

The Pulsar Renaissance:

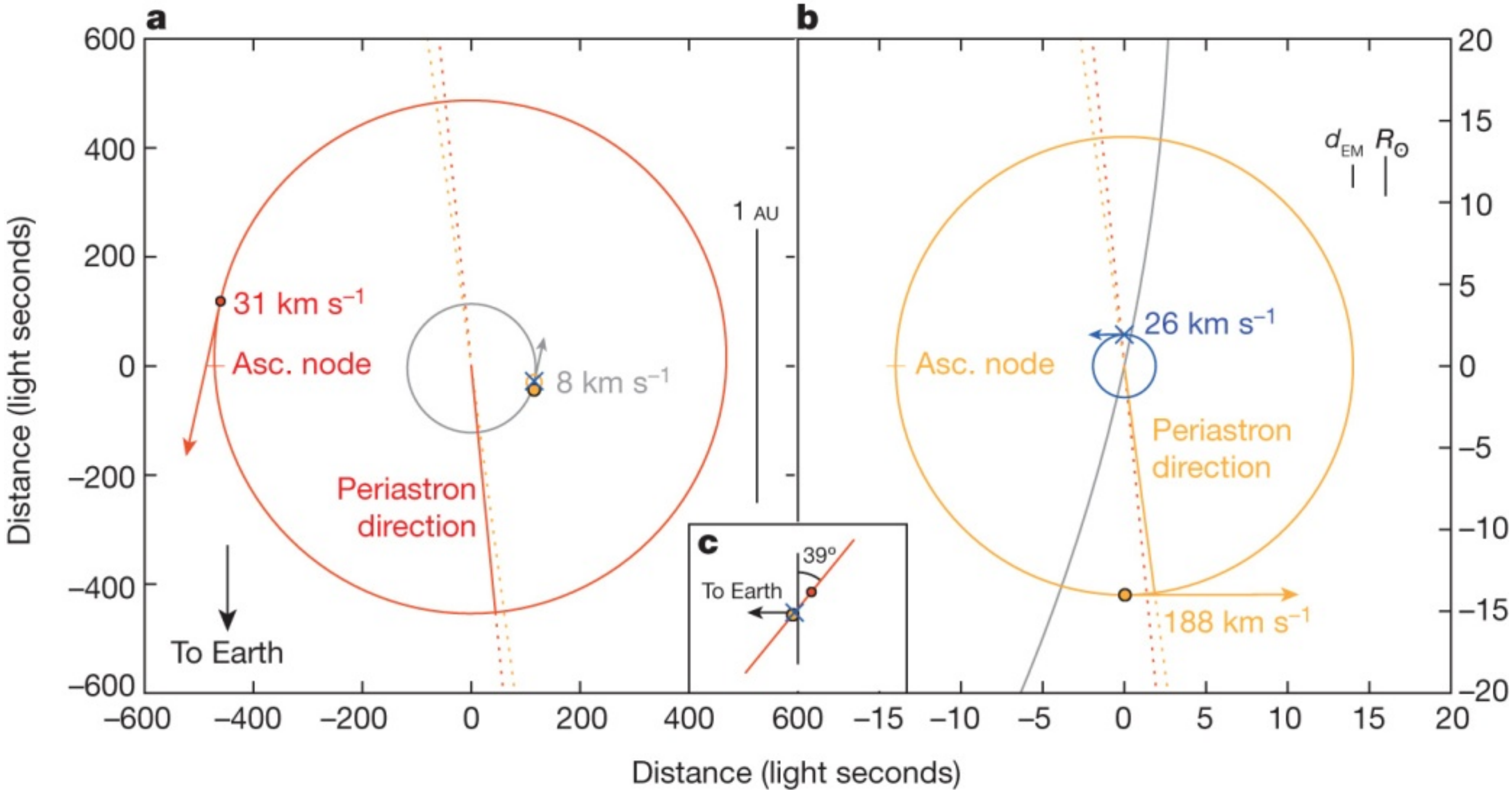
- Fastest Pulsar
- Most Massive Pulsar
- Pulsars in Globular Clusters
- Tests of General Relativity
- Relativistic Spin Precession
- Pulsar in a three-body system
- Coolest white dwarf star (a diamond as big as the Ritz)





GBT Discovery of a Pulsar in a Triple System

Ransom et al. Nature (2014)



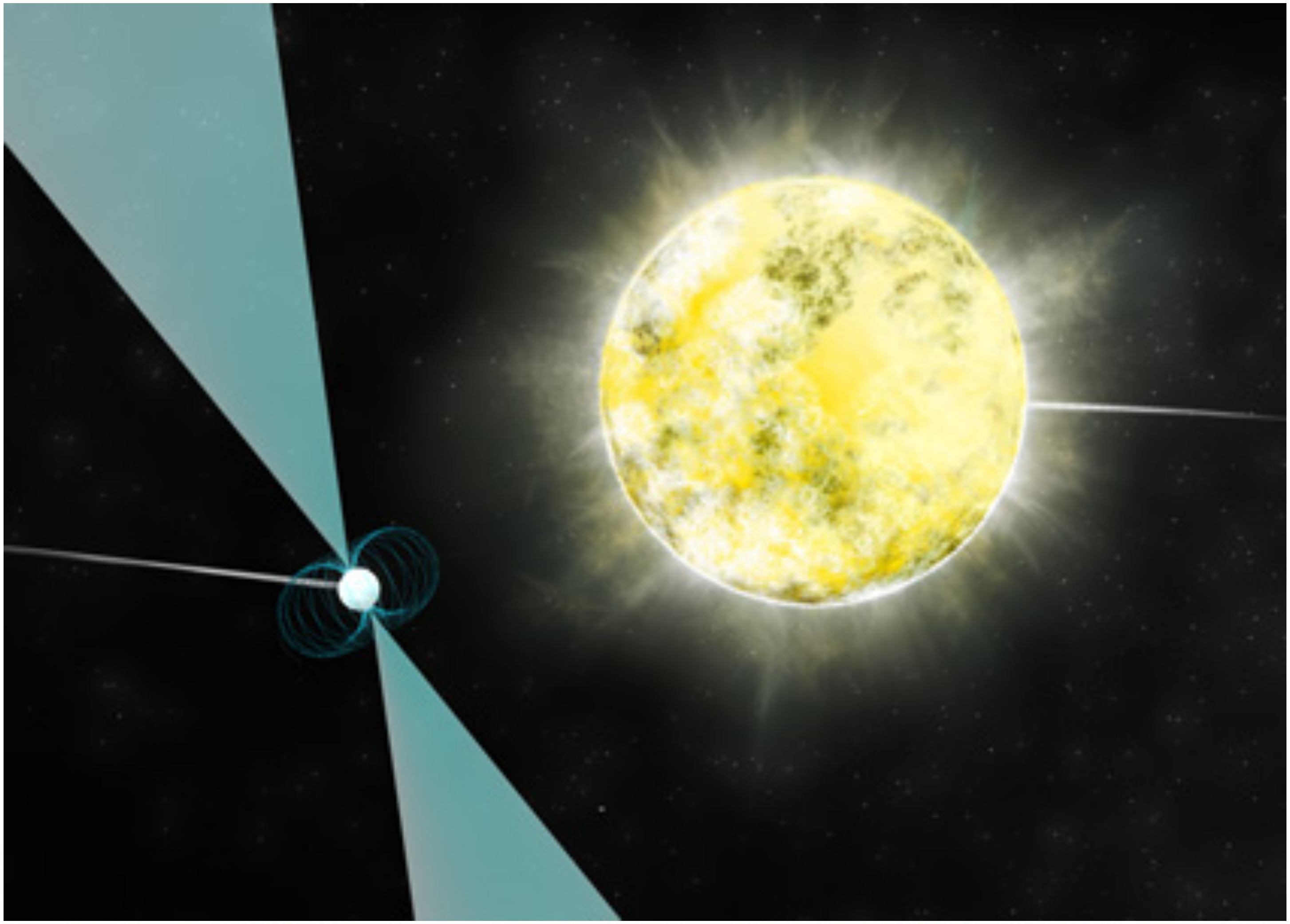
Masses: 1.4378(13), 0.19751(15), 0.4101(3) $M_\odot$
Angle between orbital planes: 1.20(17)x10^{-2} deg

Testing the Equivalence Principle

NRAO

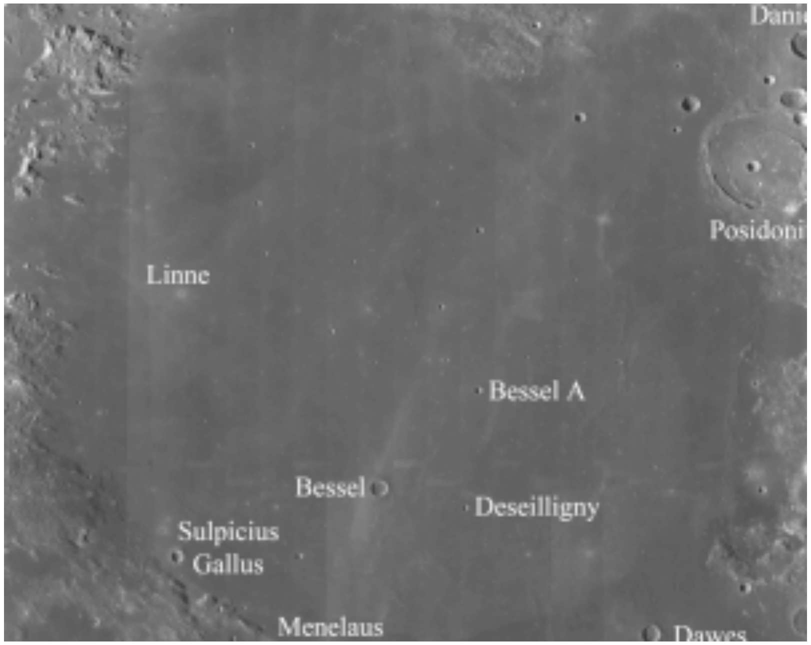
A Solid Carbon "Diamond" Star Orbiting a Pulsar

Kaplan et al. (2014)

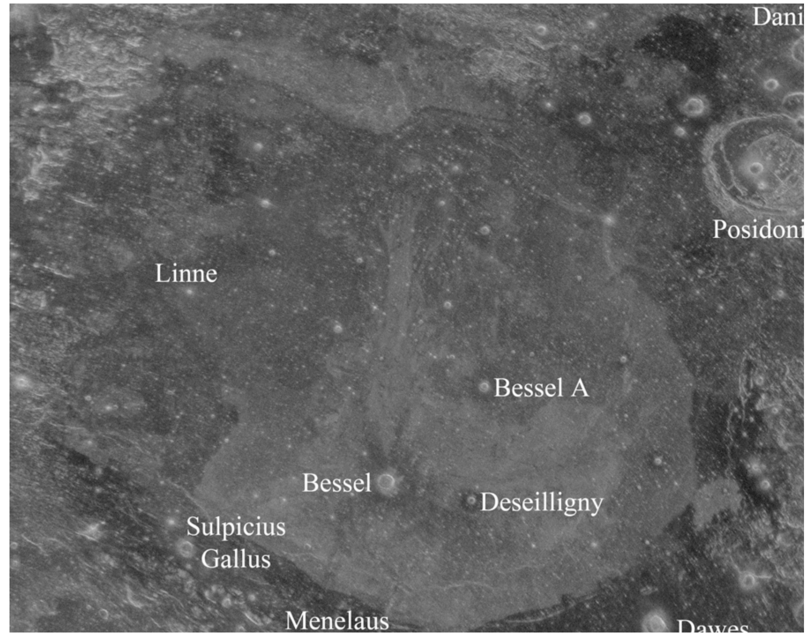


GBT Bi-static radar studies with Arecibo

Campbell, B.A. et al. 2014 JGR-P



Optical



70cm radar

"The 70 cm backscatter differences provide a view of mare flow-unit boundaries, channels, and lobes unseen by other remote sensing methods."
-- Campbell, B.A. et al. JGR-P 2014

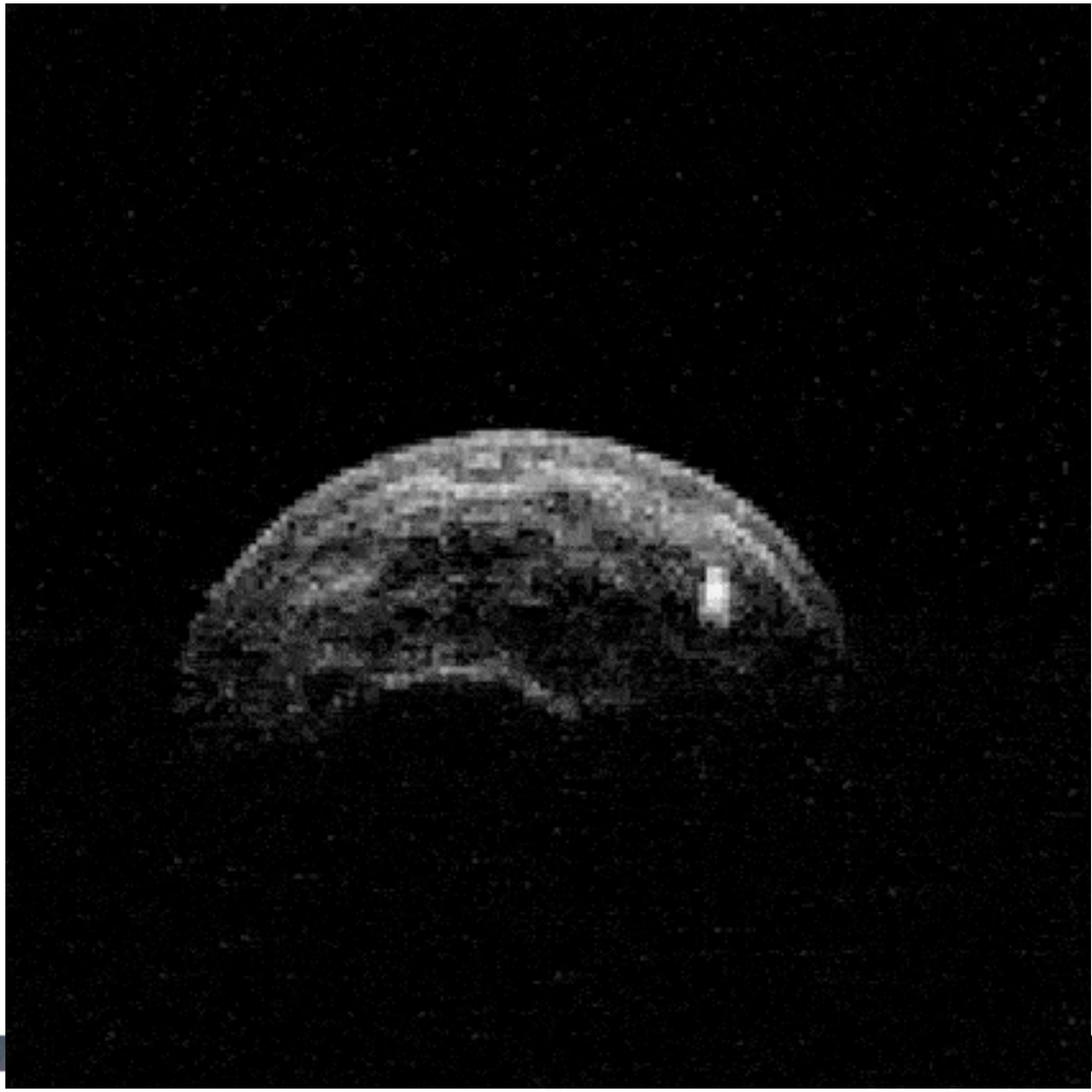
New GBT radar backend in 2014 from JPL

NRAO

Asteroid 2004 BL86
DSS/Goldstone - GBT Radar

GBT Radar Tracks NEAs

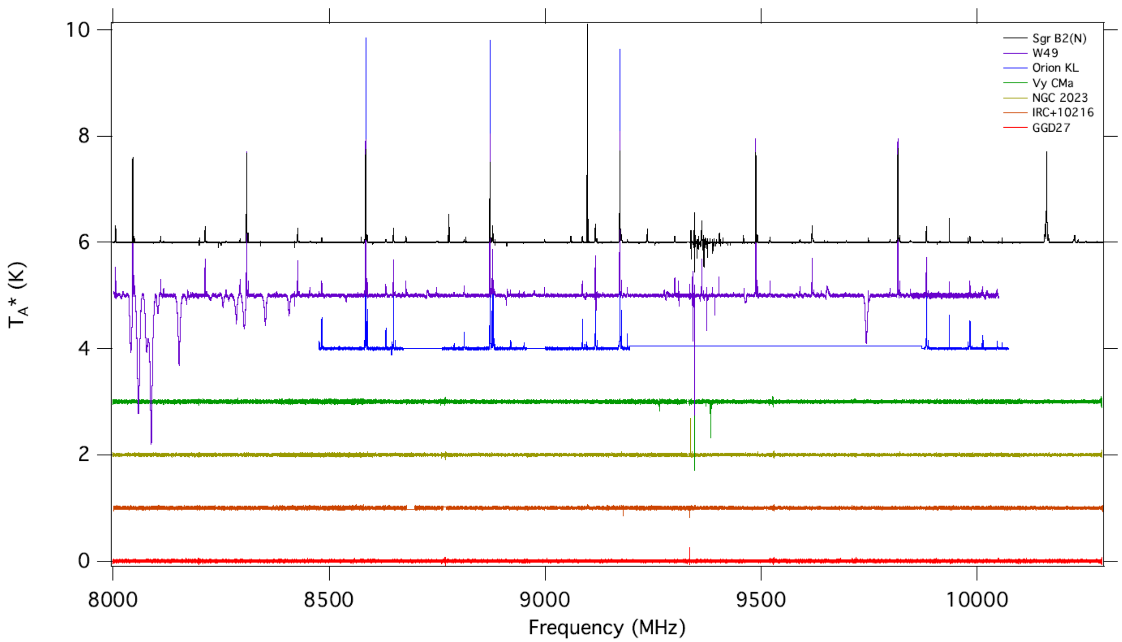
- Observed in Jan 2015
- 4 meters resolution
- NEA passing by at 4 x the distance to the Moon
- It has a moon!

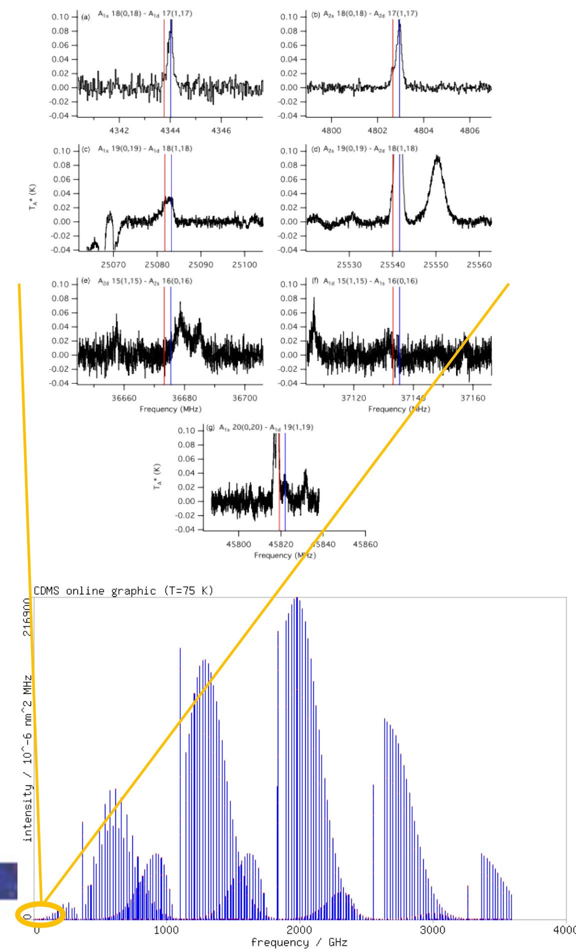


Investigating Prebiotic Organic Chemistry at Centimeter Wavelengths
The GBT PRIMOS Survey

Centimeter-wave observations are a powerful tool for the identification of new molecules:

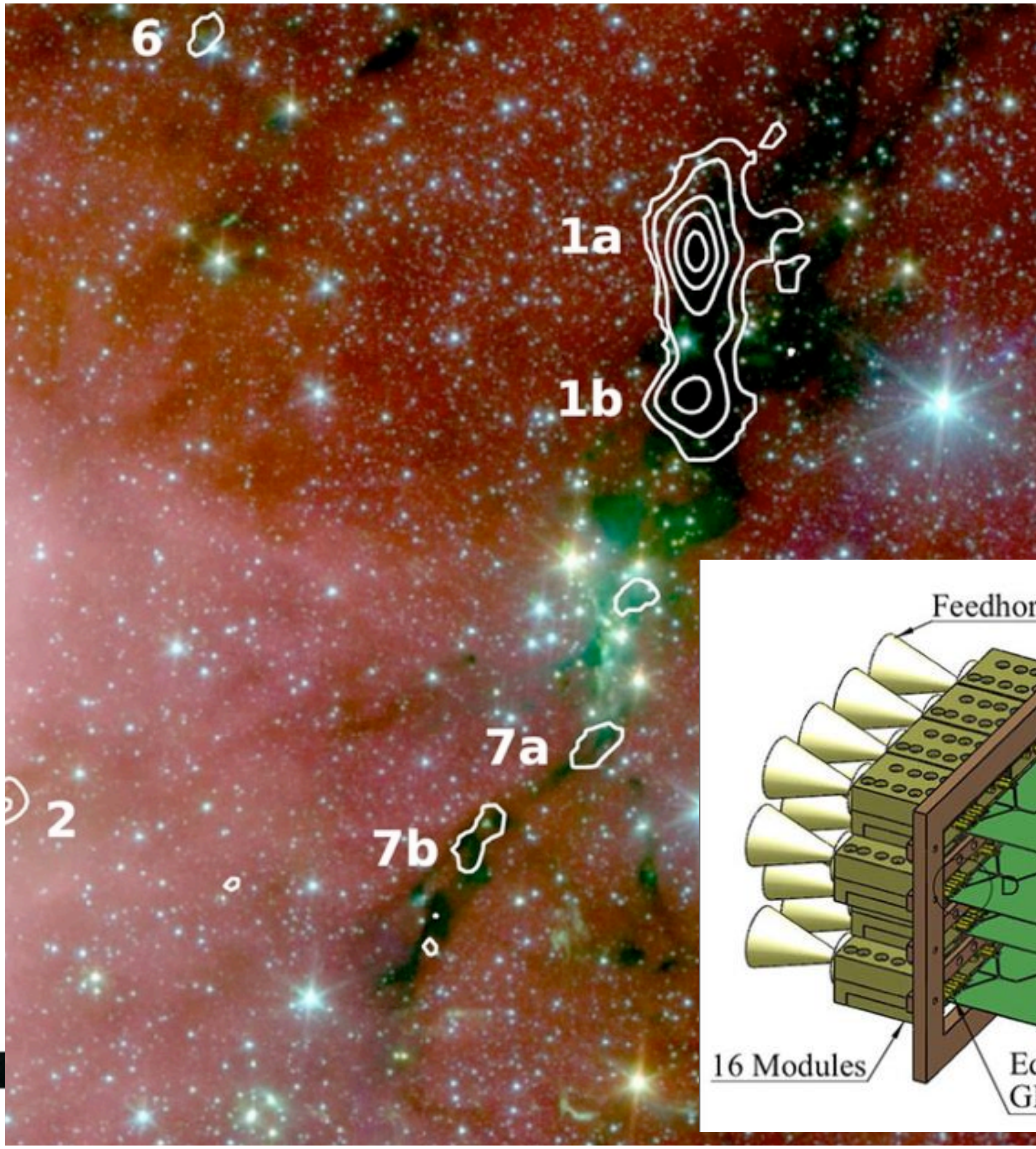
- Spectral line survey of molecular cloud SgrB2N
- At least 1-2 new molecule detections a year come from PRIMOS for the last 7 years
- Low line density makes definitive detections possible with fewer lines. Observations at mm/submm wavelengths suffer too much line confusion given the complexity of spectra of even the simplest asymmetric top molecules.



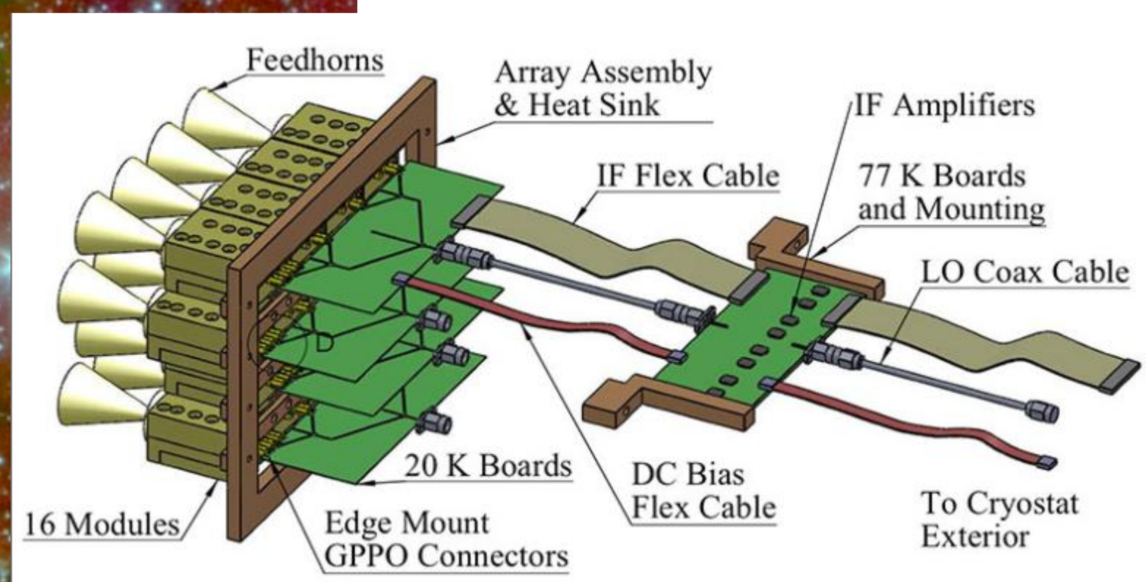


NRAO

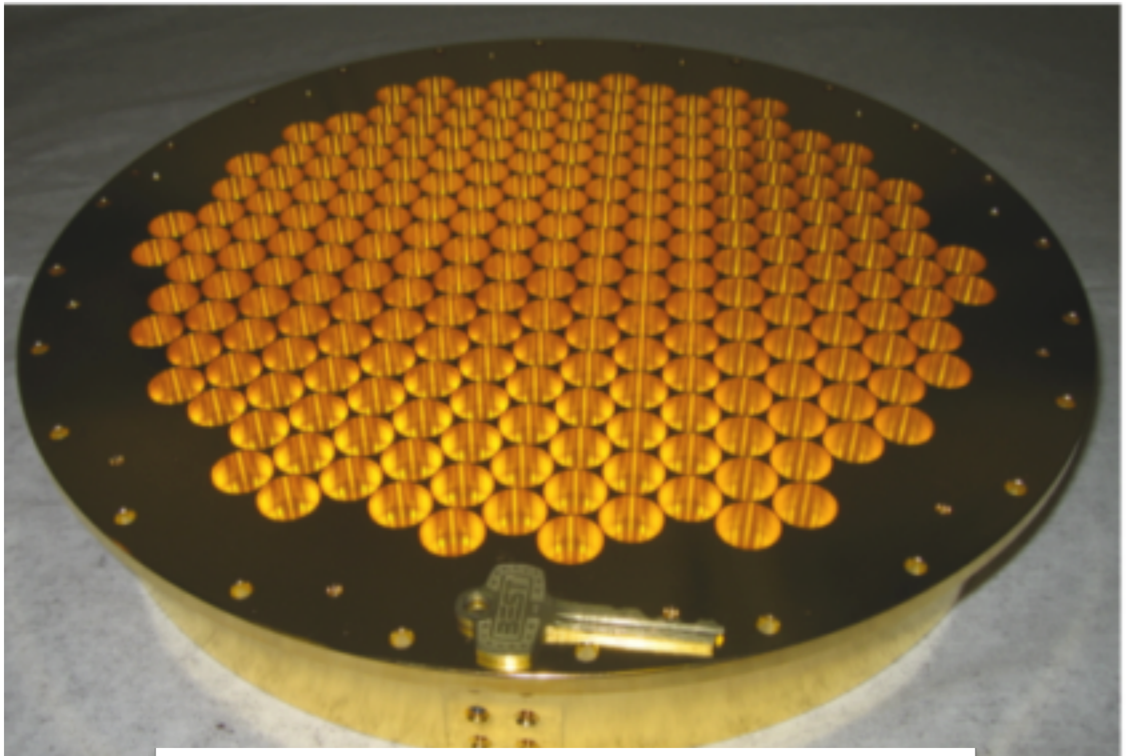
ARGUS – 8" GBT spectroscopy at 3mm



- 16 element scalable 75-115 GHz FPA
- Stanford/CIT-JPL/UMd/Miami/NRAO (NSF grant to Stanford)



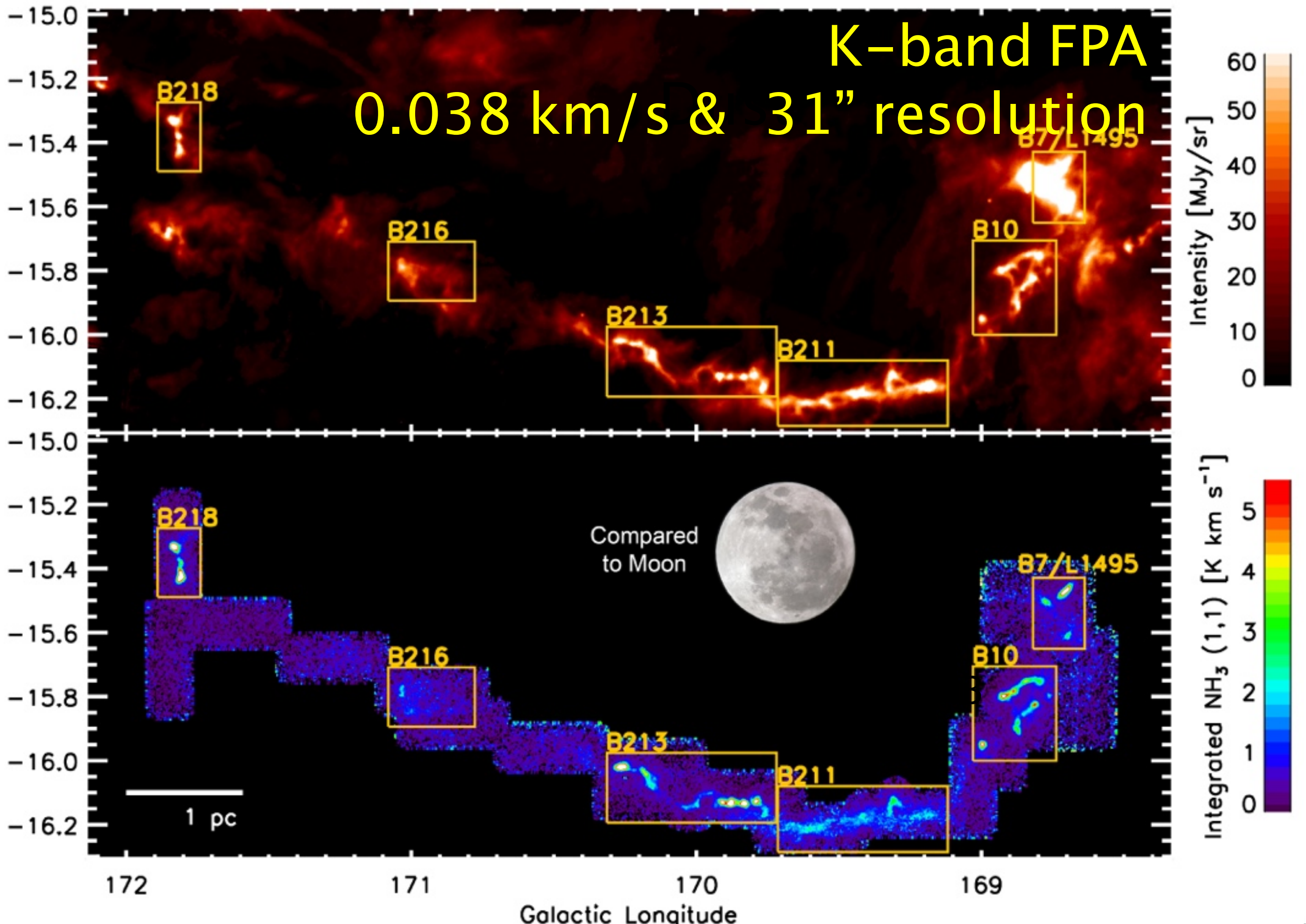
GBT MUSTANG - 2 (NSF grant to Univ Penn)



223 pixels
>4' FOV
35x faster than MUSTANG

Star Formation in a Filament in Taurus Molecular Cloud

Deep ammonia observations over 3 degrees (8pc cloud)



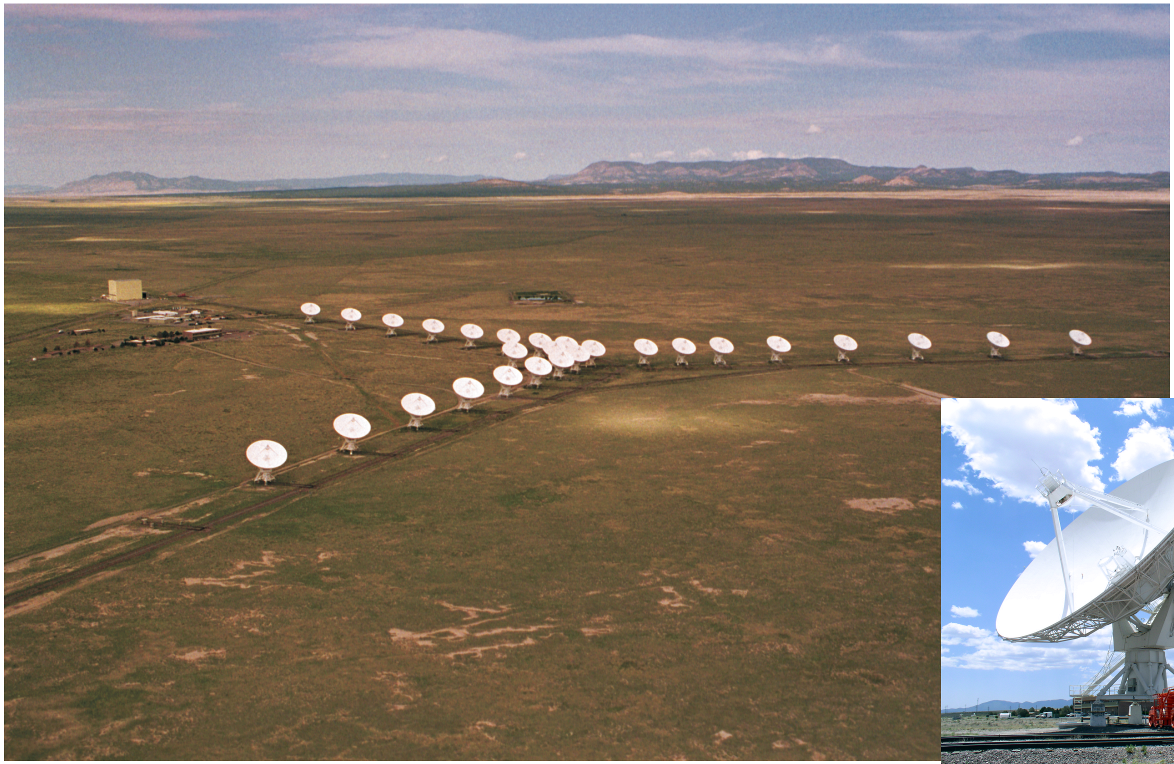
Seo et al. 2015 ApJ 805, 185

The Karl G. Jansky Very Large Array

Atacama Large Millimeter/submillimeter Array
Karl G. Jansky Very Large Array
Robert C. Byrd Green Bank Telescope
Very Long Baseline Array

The (Jansky) VLA

- 27x25m antennas (antennas in the shape of a Y) reconfigurable on baselines 35m to 36km
- located in New Mexico at 2100m altitude



Angular Resolution

- With reconfiguration of the antennas, the array can vary its spatial resolution by a factor of ~40.
- Configuration sequence: D (B_{max}~ 1 km) → C → B → A (B_{max}~ 36 km).
- Reconfiguration every ~4 months.
- Hybrid configurations (DnC, CnB, BnA) extend for about 2 weeks in between regular configurations.
- The August 1, 2016 deadline is for the C and D configurations.

Configuration	A	B	C	D
B_{max} (km[1])	36.4	11.1	3.4	1.03
B_{min} (km[1])	0.68	0.21	0.035[5]	0.035
	Synthesized Beamwidth θ_{HPBW}(arcsec)[1,2,3]			
74 MHz (4 band)	24	80	260	850
1.5 GHz (L)	1.3	4.3	14	46
3.0 GHz (S)[6]	0.65	2.1	7.0	23
6.0 GHz (C)	0.33	1.0	3.5	12
8.5 GHz (X)[7]	0.23	0.73	2.5	8.1
15 GHz (Ku)[6]	0.13	0.42	1.4	4.6
22 GHz (K)	0.089	0.28	0.95	3.1
33 GHz (Ka)	0.059	0.19	0.63	2.1
45 GHz (Q)	0.043	0.14	0.47	1.5

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The VLA

- Nine Frequency Bands
  - Eight cryogenic bands, covering 1 – 50 GHz. Utilizes cassegrain subreflector.
  - One uncooled, prime-focus band, covering 50 – 450 MHz.

- Up to 8 GHz instantaneous bandwidth
  - Provided by two independent dual-polarization frequency pairs, each of up to 4 GHz bandwidth per polarization.
  - All digital design to maximize instrumental stability and repeatability.

- Full polarization correlator with 8 GHz instantaneous BW
  - Provides 64 independent 'sub-correlators', and 16384 spectral channels.
  - Many specialized operations modes (burst, pulsar binning, phased arrays …)

Full Frequency Coverage with Outstanding Performance

There are eight cassegrain focus systems, and one prime focus system.

Band (GHz)		SEFD (Jy) (27 antennas)
.05 -- .45	P	~60
1-2	L	13
2-4	S	9.5
4-8	C	8.5
8-12	X	8.1
12-18	Ku	8.1
18-26.5	K	13
26.5-40	Ka	22
40-50	Q	45

Eight feeds around the cassegrain secondary focus ring.

Basic Features of the 'WIDAR' Correlator

The correlator's basic features (not all implemented yet):

- **64 independent full-polarization subbands**
  - Each can be tuned to its own frequency, with its own bandwidth (128 MHz to 31.25 kHz) and spectral resolution (from 2 MHz to .12 Hz)
- **100 msec dump times with 16384 channels and full polarization**
  - Faster if spectral resolution, BW, or number of antennas is decreased.
- **Up to 8 sub-arrays**. Maximum to date is three.
- **Phased array capability** with full bandwidth – for pulsar and VLBI applications. Two different subarrays can be simultaneously phased.
- **Special pulsar modes**: 2 banks of 1000 time bins, and 200 msec time resolution (all spectral channels), or 15 msec (64 channels/sp.window). Undergoing testing; See RSRO.

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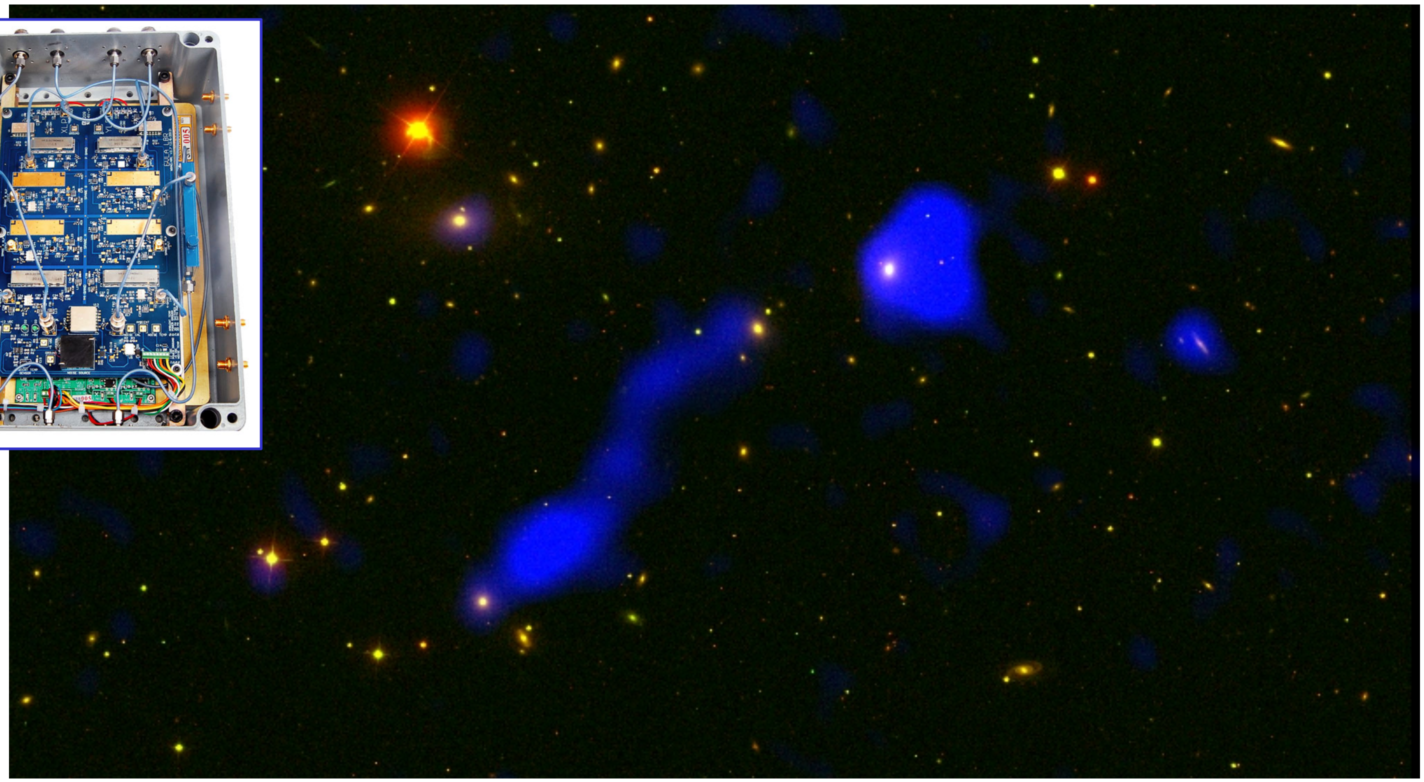
Two Telescopes in One

VLITE (VLA Ionospheric and Transient Experiment)

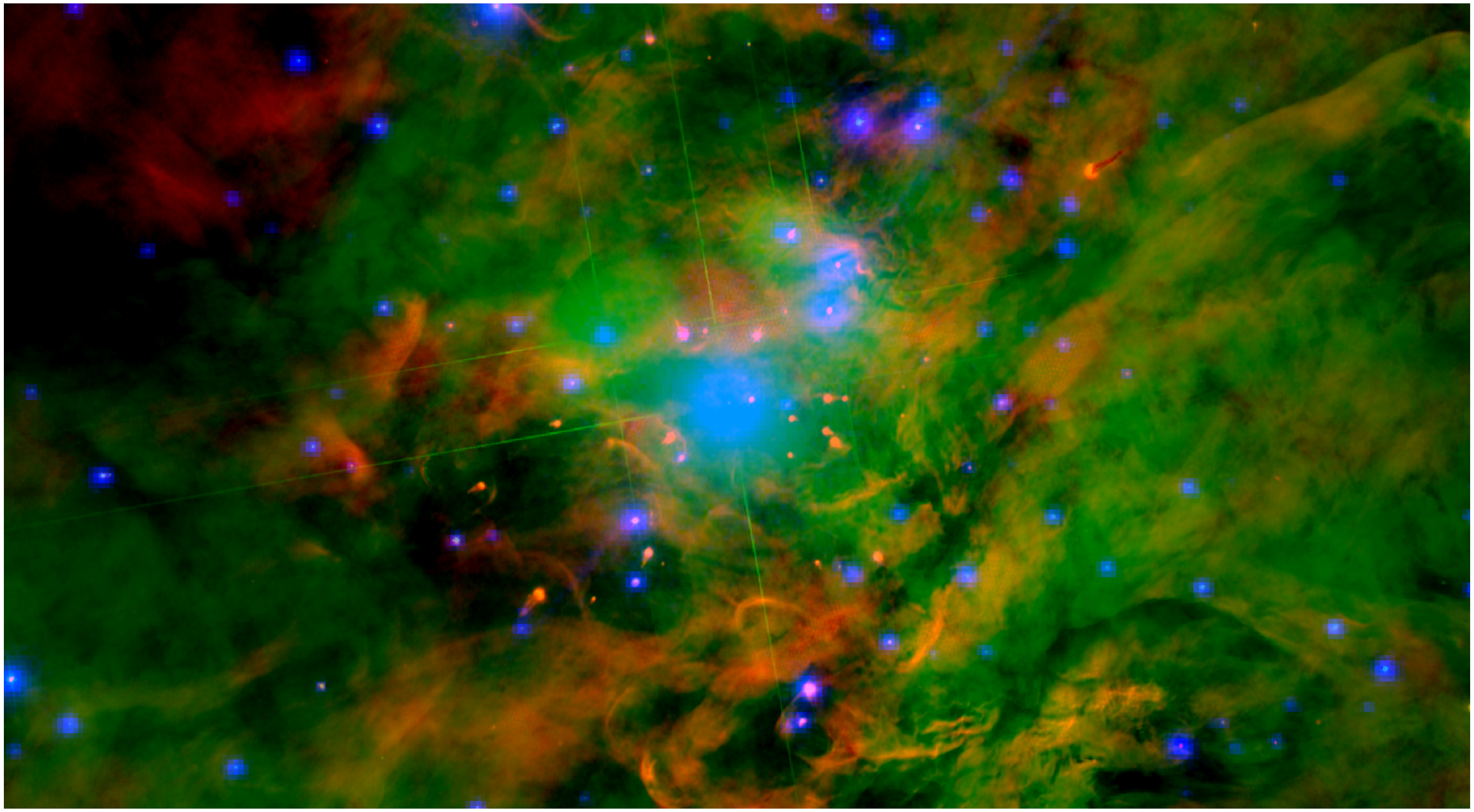


A VLITE pipeline-processed image of the giant radio galaxy IC 711 in the galaxy cluster Abell 1314

Credit: Radio (blue) from VLITE on the NRAO VLA.
Optical (red and green) from the Sloan Digital Sky Survey.
U.S. Naval Research Laboratory/Dr. Tracy Clarke

Time-Domain Astronomy

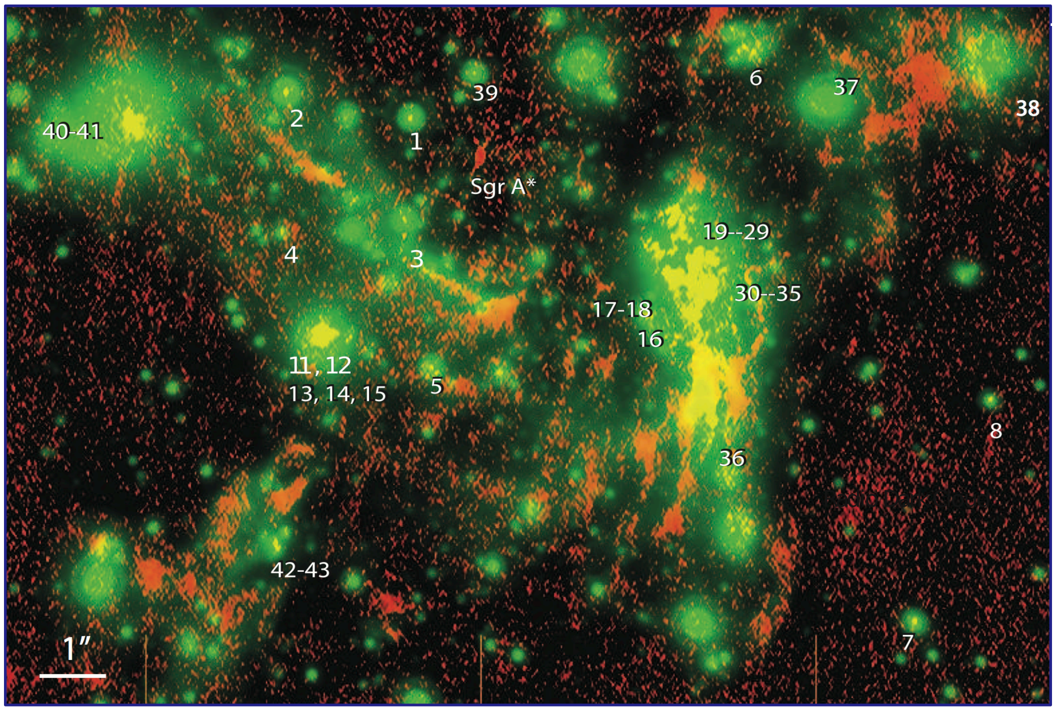
A multiwavelength study of the Orion nebula searches for young stellar variability



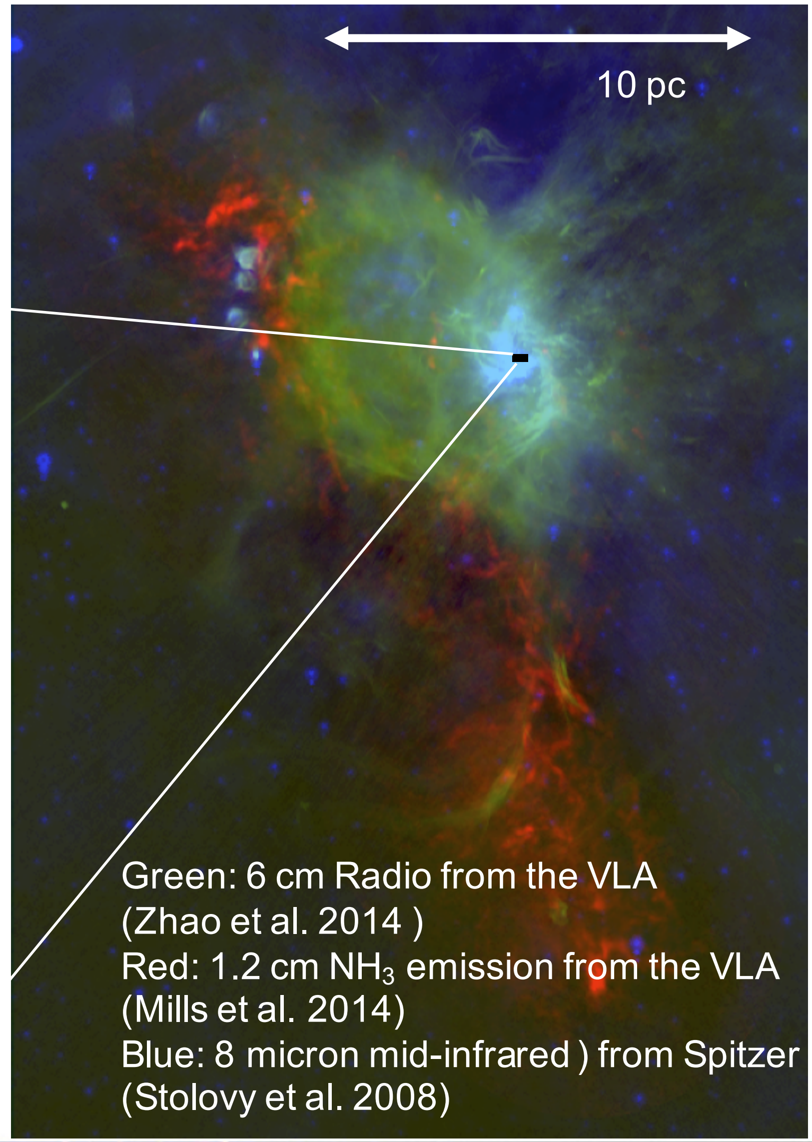
Credit: Red: VLA 6 cm continuum, J. Forbrich et al.
Green: Optical data, Hubble Space Telescope, Robberto et al. 2013
Blue: X-rays, Chandra, Getman et al. 2005

A Sensitive view of the Invisible Universe

Ionized and molecular gas around the supermassive black hole in the center of our Galaxy



Red: 7mm radio VLA observations
Green: 3.8 um adaptive optics image from the VLT
(Yusef-Zadeh et al. 2014)



Green: 6 cm Radio from the VLA
(Zhao et al. 2014)
Red: 1.2 cm NH_3 emission from the VLA
(Mills et al. 2014)
Blue: 8 micron mid-infrared) from Spitzer
(Stolovy et al. 2008)

Capabilities of Interest (for 2016B) General Observing (GO)

- Full 8 GHz bandwidth with 16384 spectral channels – 2 MHz spectral resolution (full pol), 1 MHz resolution (Stokes I)
- All 64 subband pairs can be separately tuned, and set to any of 128, 64, 32, 16, … , 0.03125 MHz widths.
- Up to 16384 spectral channels (no recirculation), or up to 1,048,576 (with recirculation)
- Three simultaneous, fully independent subarrays using standard 8-bit continuum setups
- Mix 3-bit and 8-bit modes.
- Phased Array (for VLBI).

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Capabilities of Interest (for 2016B)
Resident Shared Risk Observing (RSRO)

- Access to extended capabilities that require more testing
  - In exchange for a period of residence
- Correlator dump times < 50 msec
  - Including as short as 5 msec for transient detection
- Frequency averaging in the correlator
- Data rates above 60 MB/s
- P-band (230-470 MHz) polarimetry and spectroscopy
- 4-band (58-84 MHz) commissioning and testing
- Pulsar observations
- More than 3 subarrays with the 8-bit samplers
- Subarrays with the 3-bit samplers
- Complex VLBI observing modes with the phased array

Next Generation Very Large Array

Killer Gap: *Thermal imaging on milliarcsecond scales at λ ~ 0.3cm to 3cm*

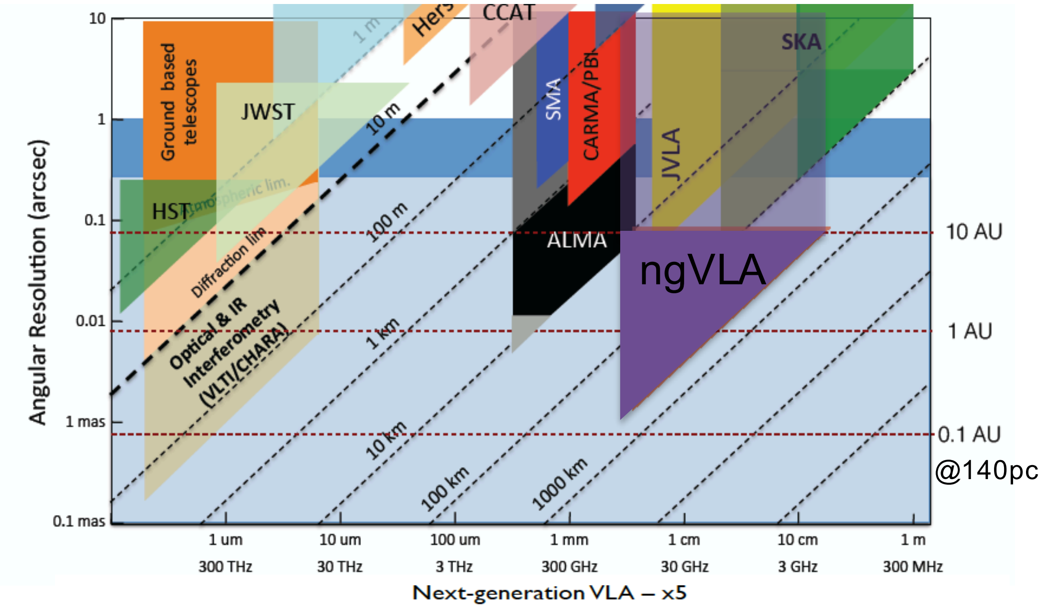
Notional Specifications

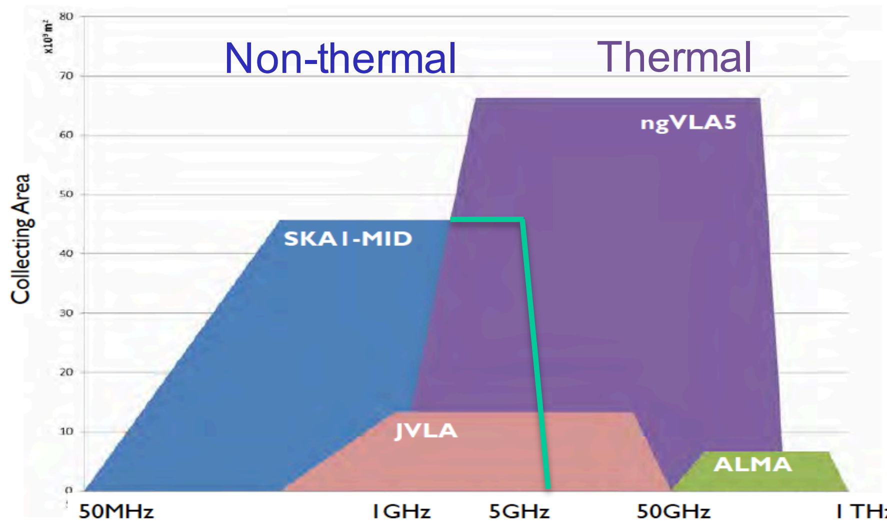
- Collecting area: spec = 5x VLA; goal = 10x VLA
- Frequency range: 1– 50 GHz + 70–115 GHz
- Configuration: 50% to 3km; 40% to 200km; 10%? to 3000km

Killer Gap: Opening parameter space

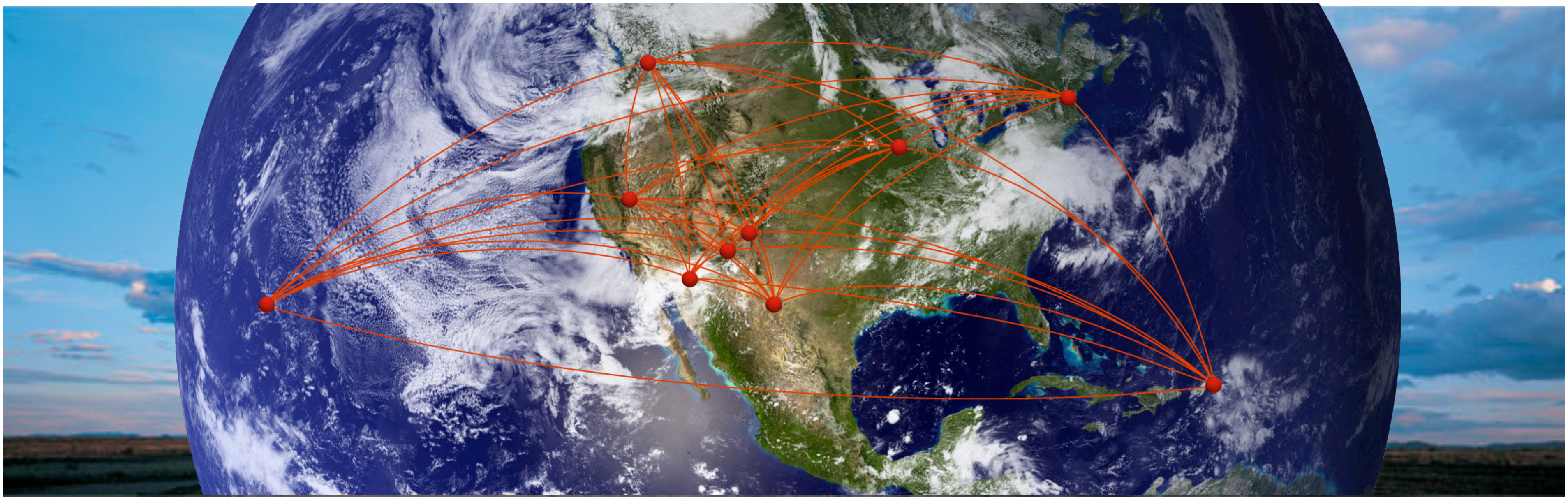
Order of magnitude improvements

- Resolution ~ 15mas @ 1cm (180km)
- Sensitivity ~ 0.2uJy (1cm, 10hr, 8GHz)
- T_B ~ 1K @ 15mas, 1cm





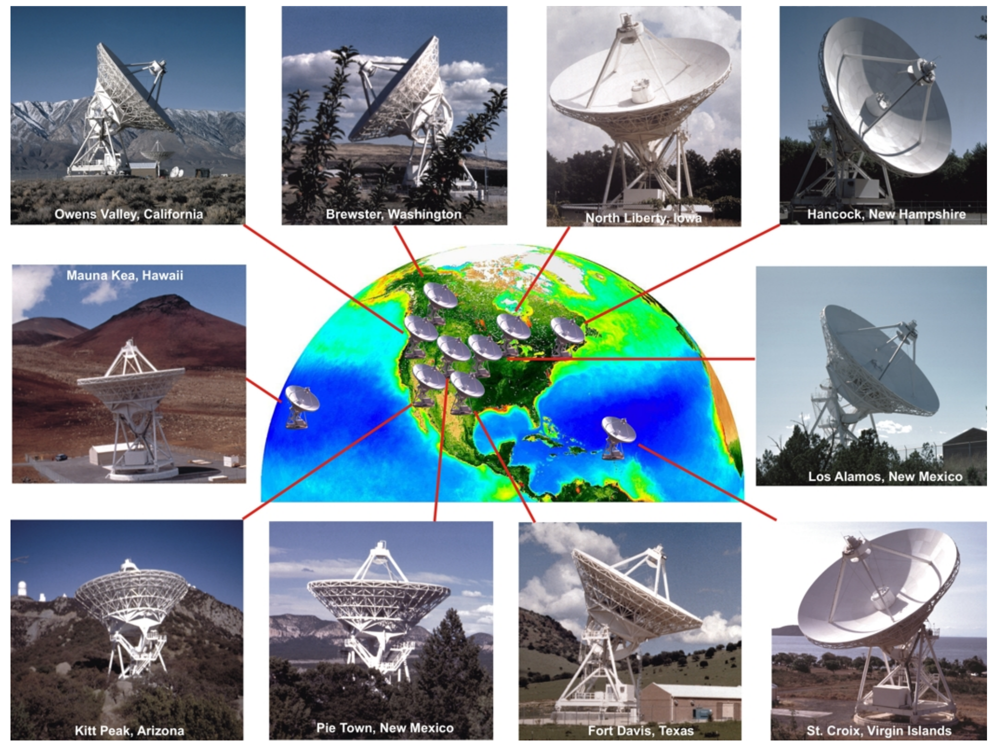
The Very Long Baseline Array



Atacama Large Millimeter/submillimeter Array
Karl G. Jansky Very Large Array
Robert C. Byrd Green Bank Telescope
Very Long Baseline Array

The VLBA

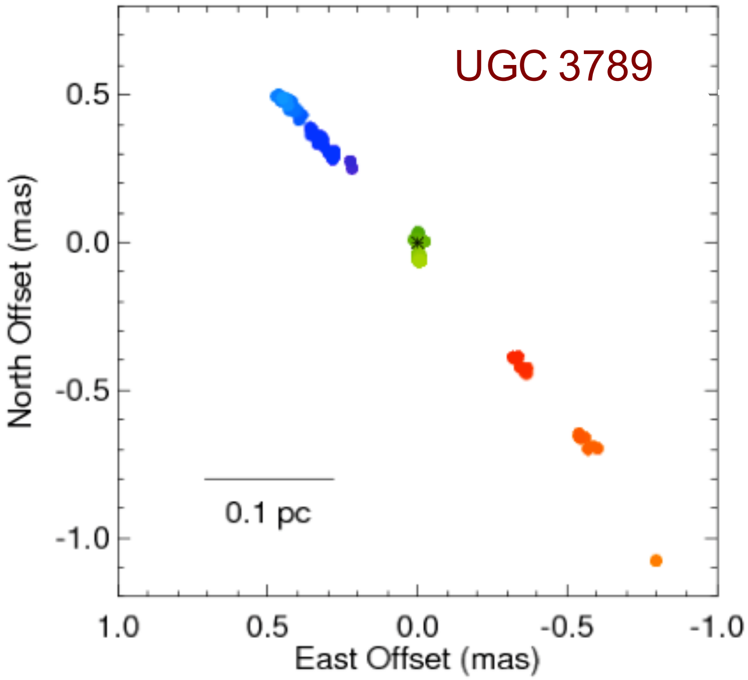
- A dedicated VLBI array
- 10 identical 25-m antennas.
- Spanning Mauna Kea to St. Croix
- Baselines 200 to 8600 km
- Frequencies 310 MHz to 90 GHz
- Sensitive to compact structures with $T_b > 10^5$ K
- Software correlator, DiFX



Resolution!

- 25 *milli* arcsecond at 330 MHz.
- 80 *micro* arcsec at 90 GHz.

- 1 mas is
  - 0.1 AU at 100 pc (Galactic)
  - 10 AU at 10 kpc
  - 1000 AU at 1 Mpc (Extragal)
  - 5 pc at 1 Gpc

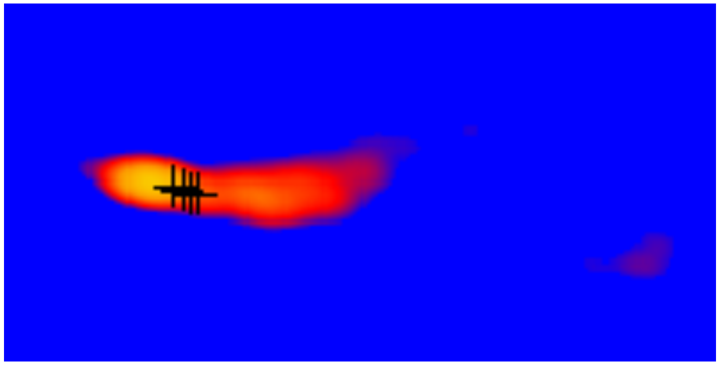


The Megamaser Cosmology Project
(Braatz et al.)

Mapping H_2O maser disks in AGNs
to measure H_0 and determine SMBH masses

Fast Response & Monitoring

- Dedicated array
- Targets of Opportunity
- Monitoring



AGN 1222+216

Example: The MOJAVE project (Lister et al.)

Examining the evolution of AGN jets and their magnetic fields, and the medium into which the jets are expanding

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Astrometry

- Astrometry: parallax and proper motions.
  - Instrumental stability with long baselines
  - < 0.1 mas positions are routine
  - 0.01 mas demonstrated in some cases
  - Allows 1% distance measurements at 1 kpc

Example: Distance to Pleiades (Melis et al. 2014)

$d = 136.2 \pm 1.2$ pc (1%)

Astrometry

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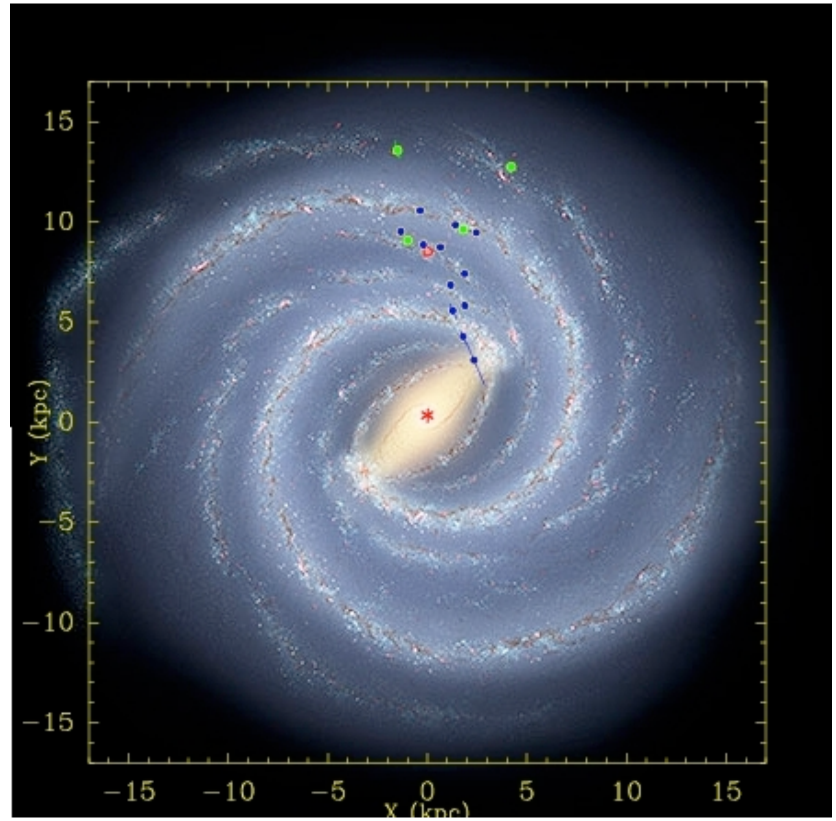

Example: BeSSeL (Reid et al. 2014)

Mapping Galactic structure and measuring fundamental parameters by measuring parallaxes and proper motions of SF regions

R_0 = 8.4 ± 0.6 kpc
Θ_0 = 254 ± 16 km/s

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VLBA Frequency bands and Sensitivity

λ(cm)	ν(GHz)	σ(μJy/beam) in 8 hrs at 2Gbps
90 cm	0.312 - 0.342	266*
50 cm	0.596 - 0.626	681*
21 cm	1.35 - 1.75	10-12
13 cm	2.15 - 2.35	12
6 cm (upgrade)	3.9 - 7.9	6-9
4 cm	8.0 - 8.8	11-15
2 cm	12.0 - 15.4	18
1 cm	21.7 - 24.1	18-22
7 mm	41.0 - 45.0	40
3 mm	80.0 - 90.0	180†

- 2 Gbps recording delivers a bandwidth of 256 MHz with two polarizations.
- 90 cm band assumes 32 MHz of bandwidth.
- 50 cm band assumes 4 MHz of bandwidth.

* Narrower bandwidths

† 8 stations

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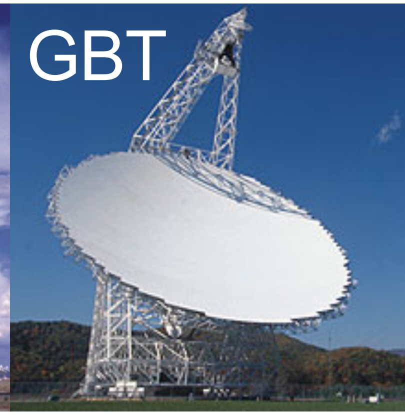
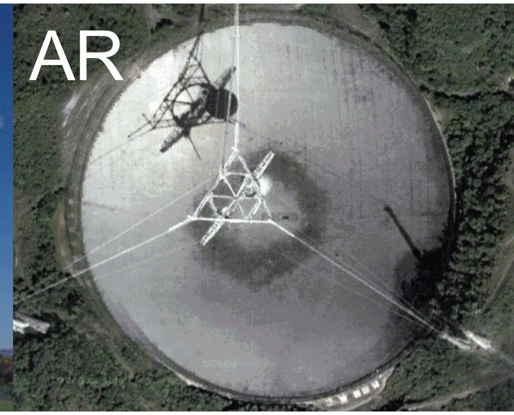
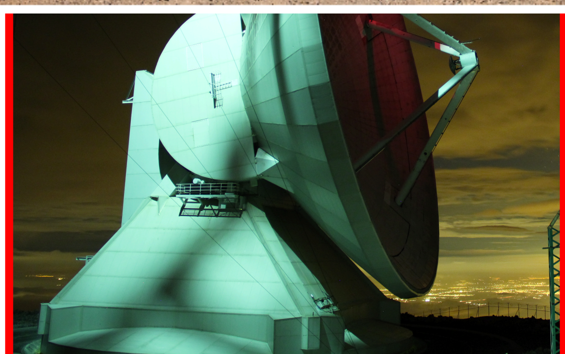
The High Sensitivity Array (HSA):
To boost the sensitivity of the VLBA by an order of magnitude





The High Sensitivity Array at 3mm

VLBA+LMT+GBT offered under the VLBA RSRO program



Important Links

NRAO Help Desk

https://help.nrao.edu

VLA Observational Status Summary

go.nrao.edu/vla-oss

VLA Exposure Calculator

https://obs.vla.nrao.edu/ect/

Proposal Submission Tool

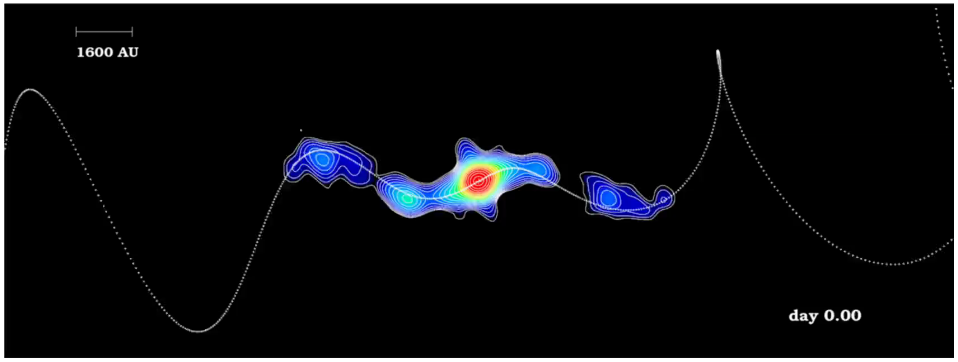
my.nrao.edu

CASA– data reduction software

http://casa.nrao.edu/

VLA Calibration Pipeline

https://science.nrao.edu/facilities/vla/data-processing/pipeline



SS433 at 26 GHz (0.095”; 520 AU resolution)
Credit: Miodusweski & Miller-Jones, EVLA demo science