Program

09:00 - 09:10 Welcome and Overview of the workshop

09:10 - 09:25 Introduction to NRAO/ALMA

09:25 - 10:10 Introduction to Radio Interferometry

10:10 - 10:30 Break

10:30 - 11:00 ALMA Capabilities Overview

11:00 - 12:00 Proposal Preparation I

12:00 - 13:00 Lunch Break

13:00 - 14:40 Proposal Preparation II: ALMA Observing Tool Virtual Demonstration

14:40 - 15:00 Break

15:00 - 16:00 CASA Simulations and Imaging Tutorial

16:00 - 16:45 Proposal Group Work

16:45 - 17:00 Workshop wrap-up and questions

https://forms.gle/j8RxVUUWCMjJYRbF7

NRAO/ALMA Overview

Danielle Lucero
ALMA Ambassador
Virginia Tech

The National Radio Astronomy Observatory (NRAO)

The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.

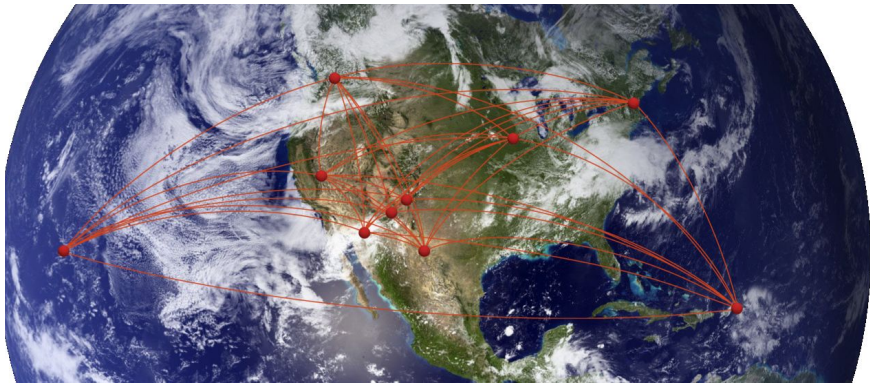
Founded in 1956, the NRAO provides state-of-the-art radio telescope facilities for use by the international scientific community. NRAO telescopes are open to all astronomers regardless of institutional or national affiliation. Observing time on NRAO telescopes is available on a competitive basis to qualified scientists after evaluation of research proposals on the basis of scientific merit, the capability of the instruments to do the work, and the availability of the telescope during the requested time. NRAO also provides both formal and informal programs in education and public outreach for teachers, students, the general public, and the media.

The National Science Foundation (NSF) is an independent federal agency created by Congress in 1950 "to promote the progess of science; to advance the national health, prosperity, and welfare; to secure the national defense..."

AUI collaborates with the scientific community and research sponsors to plan, build, and operate cutting-edge facilities. We cultivate excellence, deliver value, enhance education, and engage the public.

National Radio Astronomy Observatory

Atacama Large Millimeter/submillimeter Array



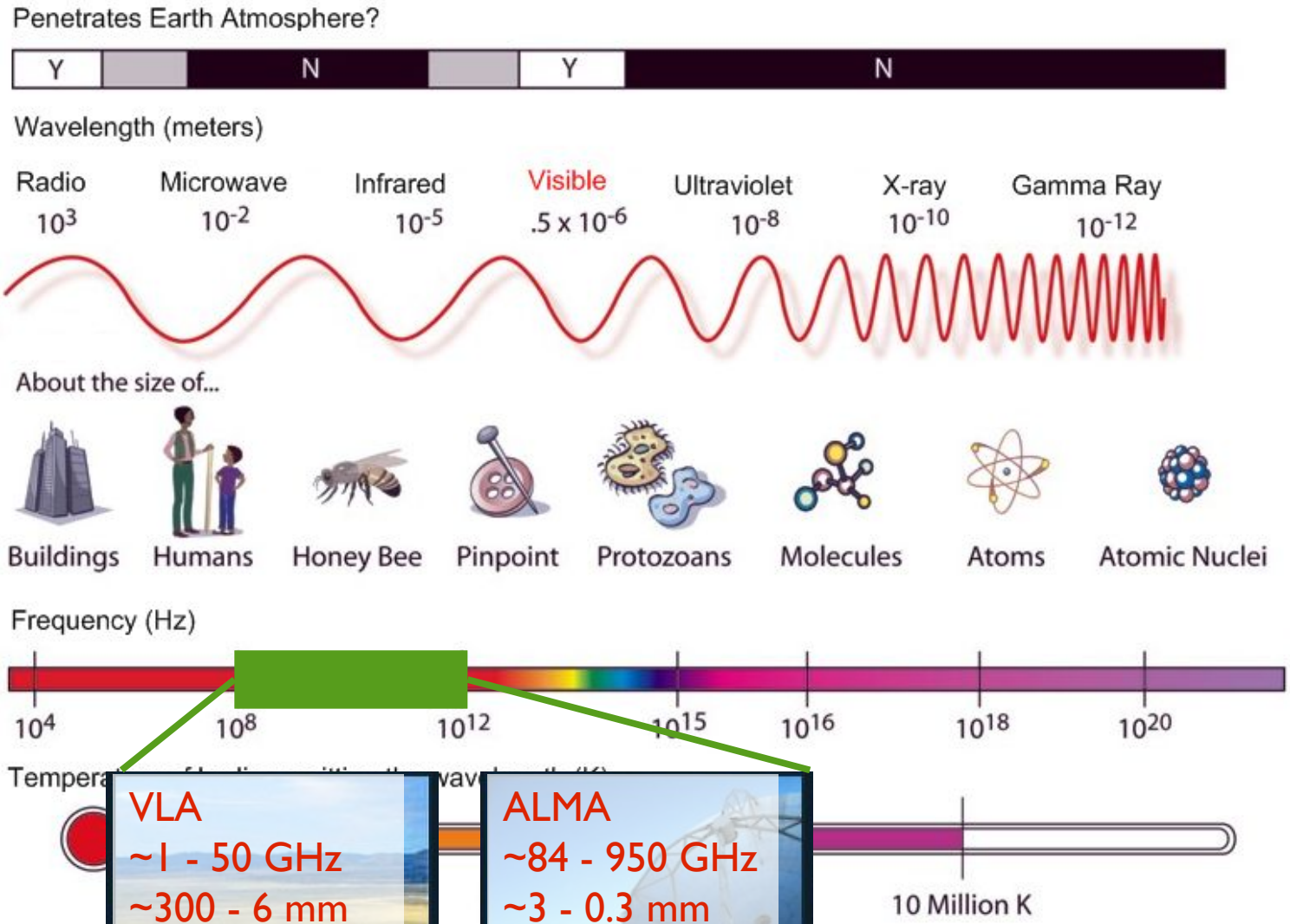
Very Long Baseline Array

Karl G. Jansky Very Large Array

The Green Bank Observatory

Other Affiliated Telescopes and Observatories include the Green Bank Observatory (http://greenbankobservatory.org/). The VLBA was incorporated back into NRAO last year.

The Electromagnetic Spectrum



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
- 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

NRAO:
One Observatory, Three Facilities

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

What is ALMA?

- A global partnership to deliver a revolutionary millimeter/submillimeter telescope array (in collaboration with Chile)
  - North America
  - Europe
  - East Asia

- 66 reconfigurable, high precision antennas λ~ 0.32 – 8.5mm. Array configurations.

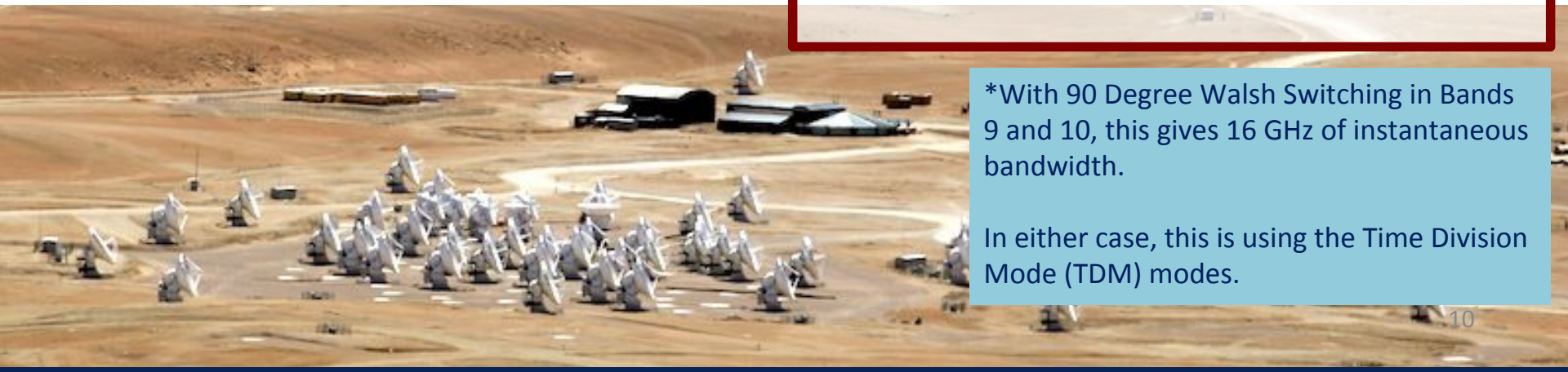
- between 150 meters and >16 kilometers: 192 possible antenna locations:
  - Main Array: 50 x 12m antennas
  - Total Power Array: 4 x 12m antennas
  - Atacama Compact Array (ACA): 12 x 7m antennas
  - TP + ACA (Morita Array).

- Array Operations Site is located at 5000m elevation in the Chilean Andes.
- Provides unprecedented imaging & spectroscopic capabilities at mm/submm λ.

ALMA in a Nutshell...

- Angular resolution down to 0.015” (at 300 GHz).
- Sensitive, precision imaging 84 to 950 GHz (3 mm to 320 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 including circular.
- Estimated 1 TB/day data rate.
- All science data are archived.
- Pipeline processing.

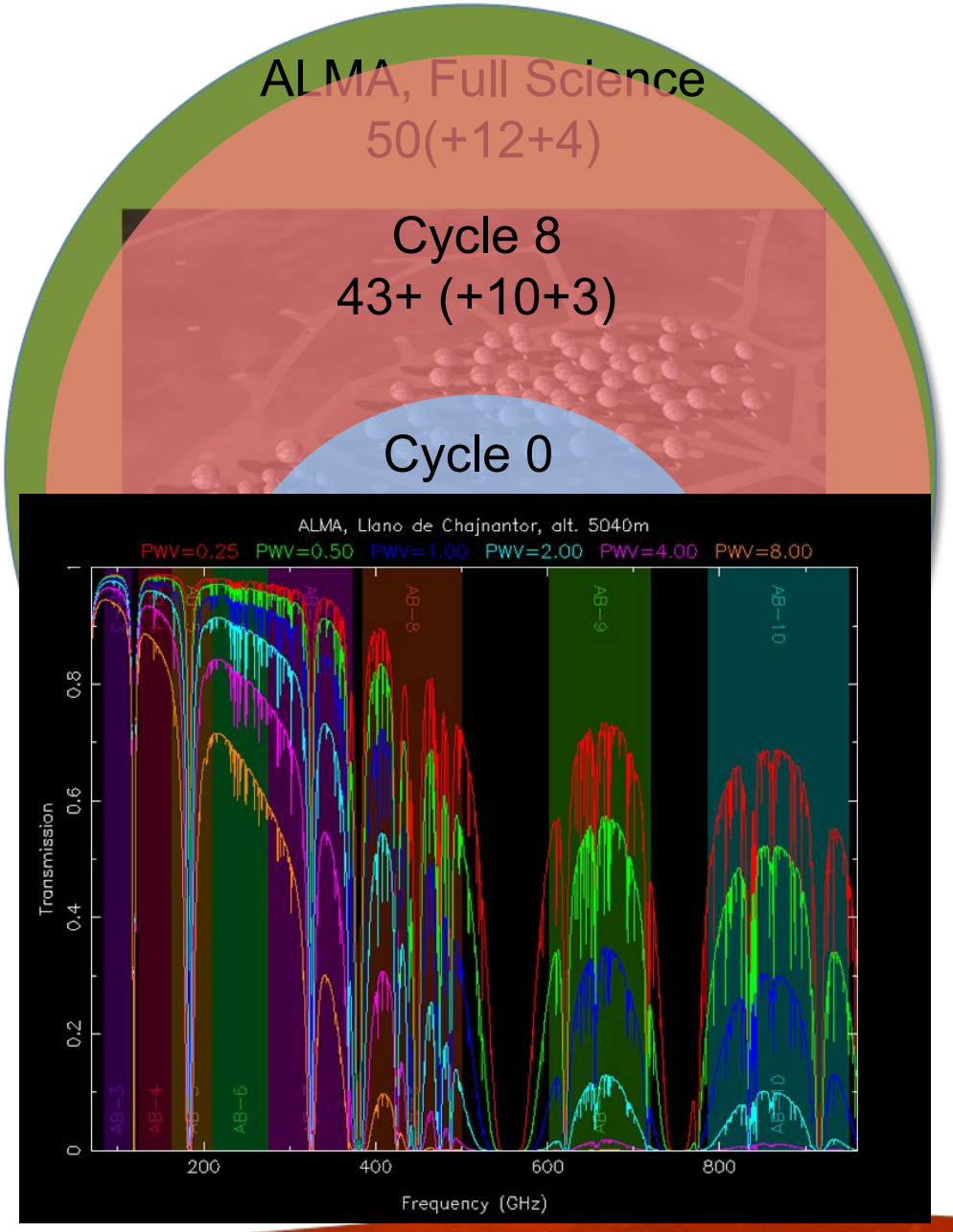
ALMA is10-100 times more sensitive and has 10-100 times better angular resolution than current mm interferometers*



*With 90 Degree Walsh Switching in Bands 9 and 10, this gives 16 GHz of instantaneous bandwidth.

In either case, this is using the Time Division Mode (TDM) modes.

What is ALMA?



Collecting Area

Not only sensitivity but the collecting area (1.6 acres or 6600+ m²) + huge number of baselines provides excellent image fidelity.

Spectral Coverage - Covers

ten atmospheric windows with 50% or more transmission above 35 GHz.

https://almascience.nrao.edu/about-alma/atmosphere-model

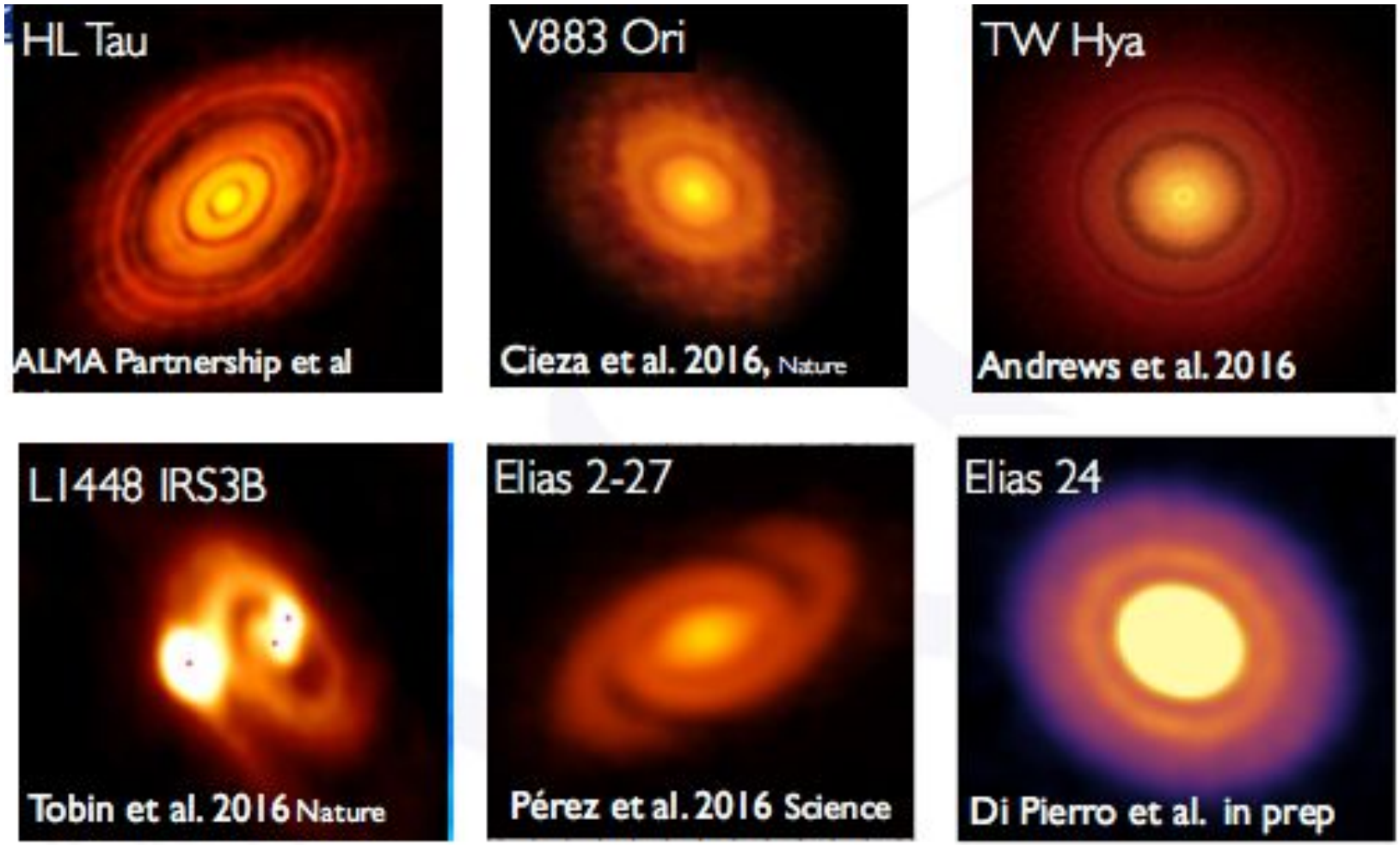
ALMA Current Status

- Construction Project ended in September 2014.
- Routine science observing has been out to **greater than 16 km baselines (C43-10)** 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 ~66) are being used for Cycle 8 observations.
  - Some construction and verification items remain to be finished (e.g., wide-field polarization; various observing modes, etc...).
- The ACA (Atacama Compact Array) or Morita Array – up to 12x7m antennas and 4x12m antennas for TP observations – is currently being used for Cycle 8 observations.

- More on Capabilities later… however, first on to science!

ALMA Science Highlights: Protoplanetary Disks

Protoplanetary Disks: With ALMA

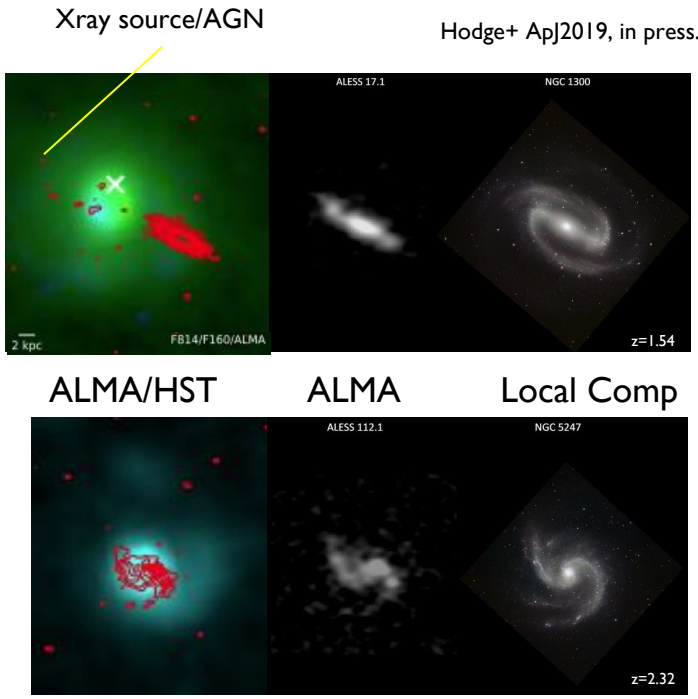


Composite image courtesy J. Carpenter / A. Wootten (ALMA / NRAO)

ALMA Images Nascent Galaxy Structure

ALMA 0.07" (0.5kpc) imaging of rest-frame FIR emission from 6 SMGs at z~1.5 < z < 4.9

- Robust sub-kpc structure on underlying exponential disks (FWHM ~few kpc).
- Often poor correlation with HST: ALMA seeing heavily dust-obscured cores only.
- Structures suggest spiral arms, edge-on nuclear emission (bars).



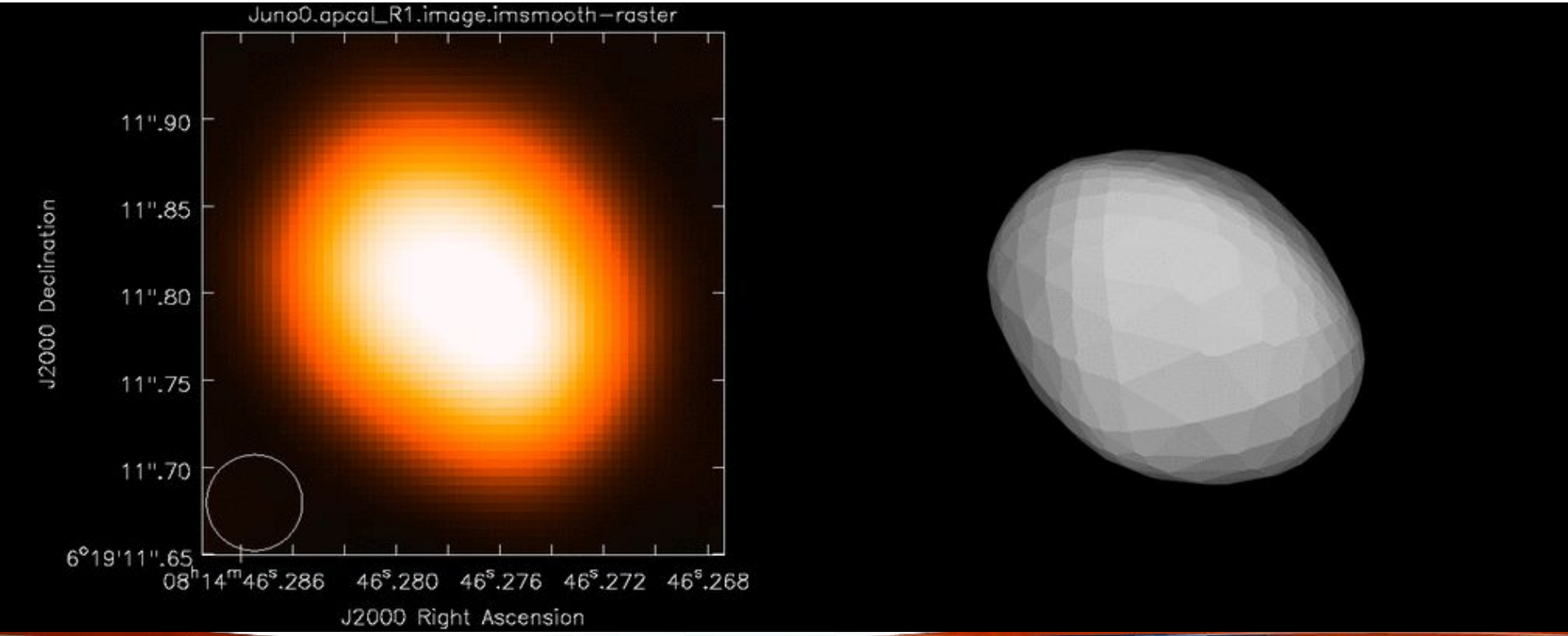
ALMA Science Highlights: Solar System

Band 6 Observations of Juno: Frequency = 233 GHz (Science Verification)

Five consecutive executions over 4.4 hours

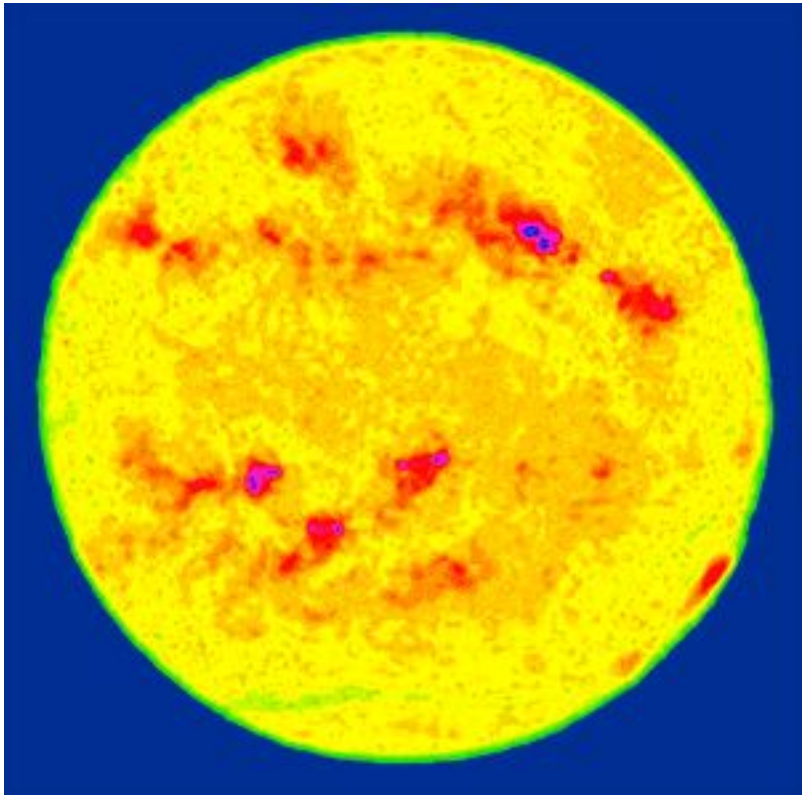
Beamsize ~ 0.04”x0.03” (~60x45 km)

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



ALMA Image of Juno (ALMA Partnership, Hunter et al. 2015)

ALMA can observe a wide variety of phenomena on the Sun.



©ALMA (ESO/NRAO/NAOJ)

The antennae were designed specifically so that the Sun's strong radiation would not affect its instruments.

- The structure of the quiet solar atmosphere.
- Coronal holes (where vast solar winds originate because of diverging magnetic fields).
- Solar active regions.
- Active and quiescent filaments.
- Energetic phenomena, like filament eruptions and flares.

ALMA can observe a wide variety of phenomena on the Sun.

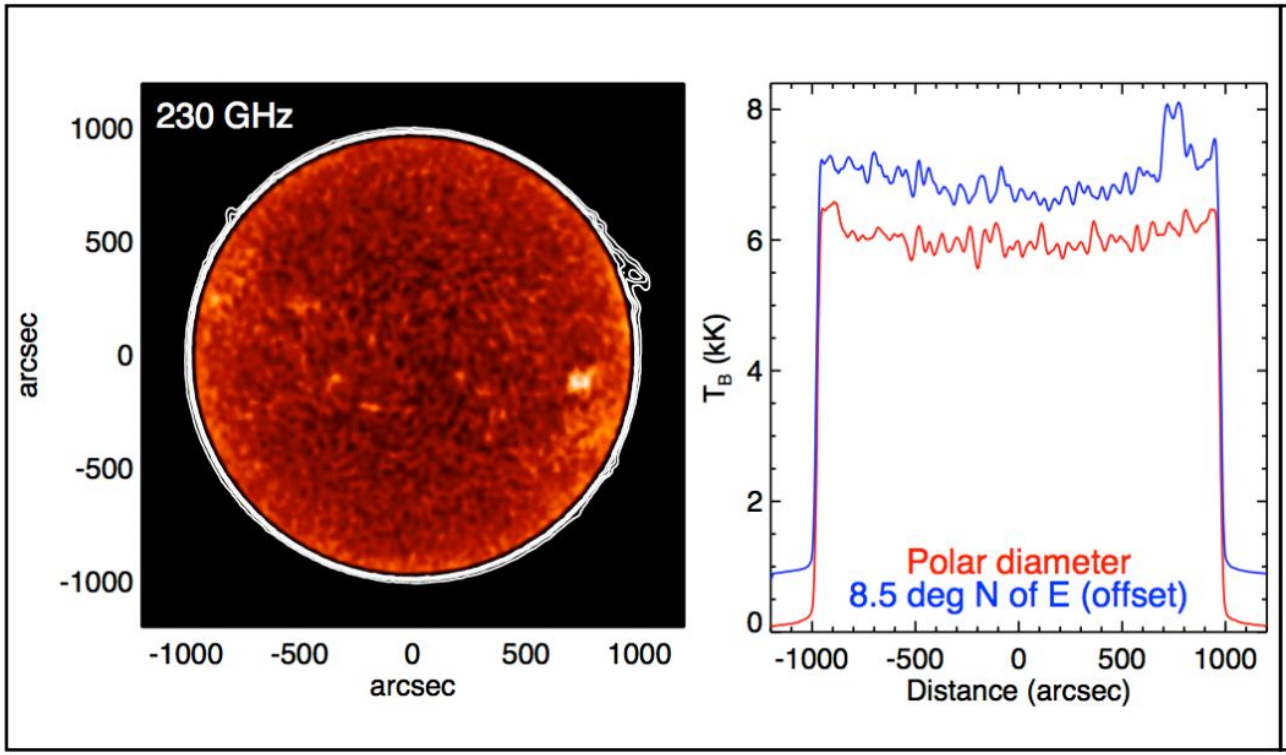
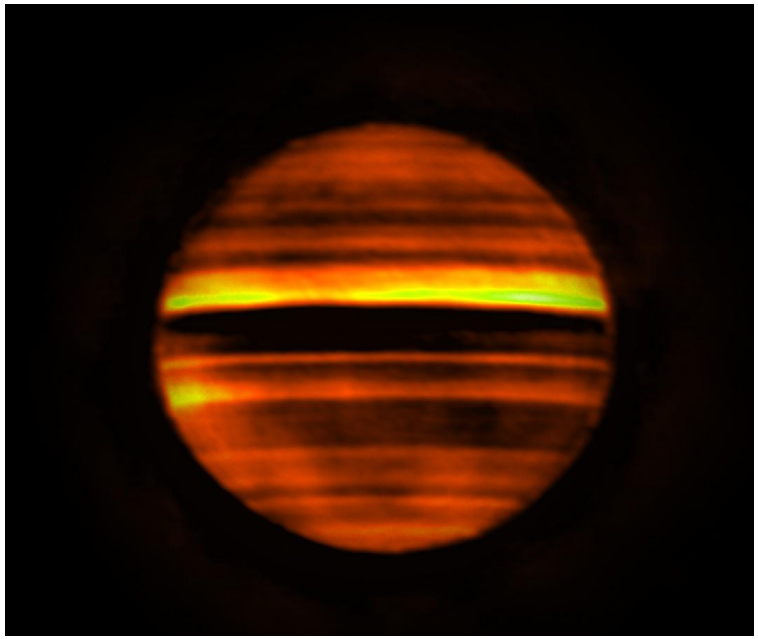


Figure 26: *The left panel shows a 230 GHz (band 6) image of the Sun on 7 December 2016. In order to emphasize structure on the disk, the 230 GHz image color display ranges from 5300 to 7400 K. Low-level contours are plotted at 300, 600, 1200, and 2400 K in order to show features above the limb. The right panel shows disk profiles through the Poles and on a diameter through the active region in the southwest quadrant, but with the blue curve offset by 800 K in order to show structure in both. (Credit: ALMA (ESO/NAOJ/NRAO; S. White et al., 2017, SoPh, 292, 88)*

ALMA Millimeter Wavelength Images of Jupiter

de Pater+ arXiv:1907.11820

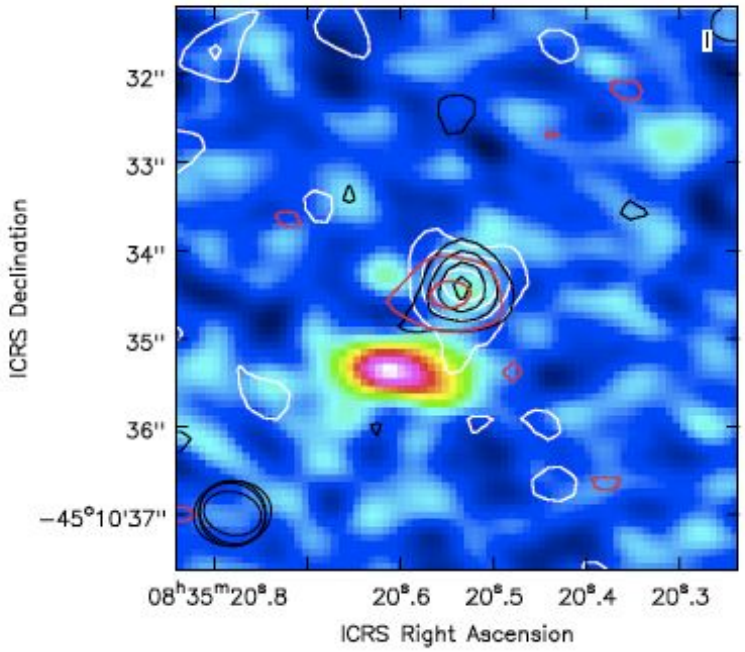
- Jupiter at 1.3mm (mosaic of 17 pointings)
  - NH_3 dominates opacity, so the image can provide its 3 dimensional distribution.
  - High brightness indicates lower NH_3 abundance.
  - Dark areas indicate higher atmospheric opacity.
- Imaged days after an outbreak in the South Equatorial Belt
  - Favored model: Eruptions triggered by energetic plumes via moist convection at base of water cloud, bringing up NH_3.



Science Highlight (2)

ALMA Images Vela Pulsar

- ALMA Development Study results on pulsar observations are now available for download through the Science Verification page of the ALMA Science Portal.
  - Successful measurement of pulsar profiles were achieved on Vela.
- Detections in non-time resolved mode were made on Vela, SgrA* magnetar, and Crab pulsar.
  - Vela pulsar was detected in ALMA Bands 3, 4, 6 and 7 (see B7 image)
  - Extended structure seen in B7 may be a counter-jet protruding from the pulsar



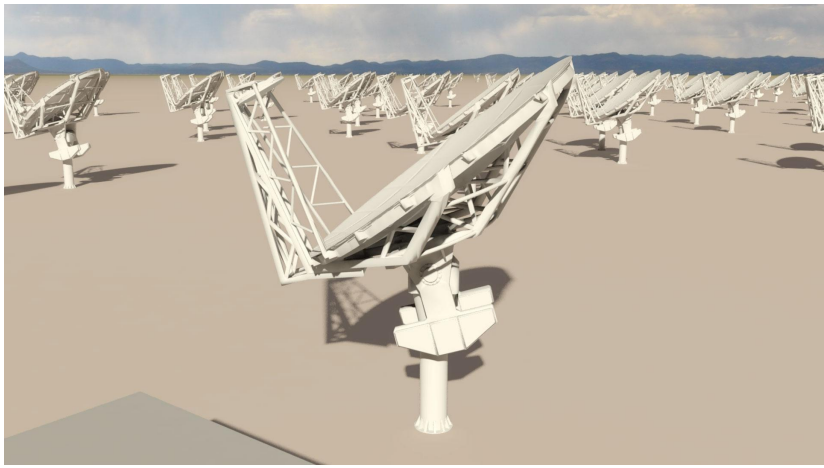
Vela Pulsar, ALMA B3,4,6 (contours) on B7 image; an extended structure, preliminarily detected in ground-based observations, may be a counter-jet protruding from the pulsar. (Mignani+, 2017)

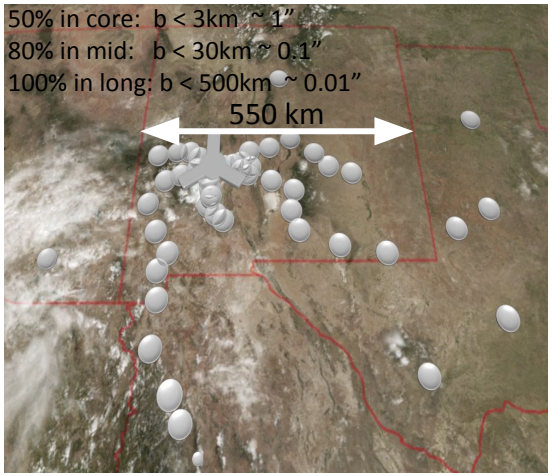
NAASC Sources of Support

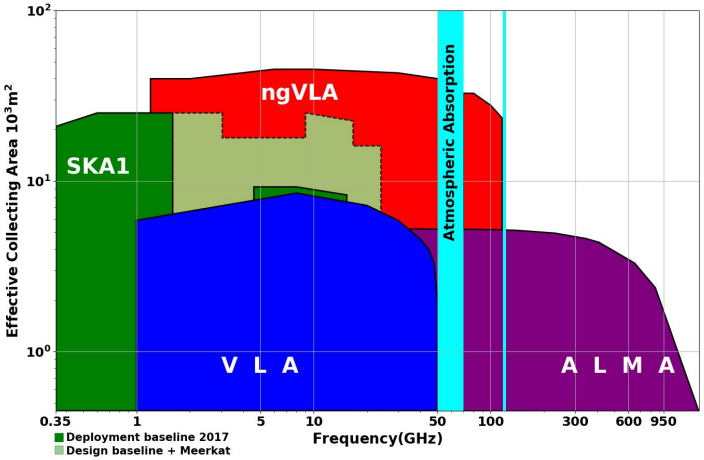
- **ALMA Helpdesk:** User support is a priority so questions are usually answered within 48 hours (with around the clock staffing in the week leading up to the proposal deadline) - https://help.almascience.org
- **Student Observing Support:** Successful ALMA proposals will be invited to apply for up to $35k to support undergraduate or graduate student involvement - https://science.nrao.edu/opportunities/student-programs/sos
- **NAASC Financial Support for Workshop/Conferences:** The NAASC invites scientists to apply for funding in support of upcoming conferences and workshops. - https://science.nrao.edu/facilities/alma/community1/NAASC-Conference-and-Workshop-Support
- **Page Charges:** Upon request NRAO covers page charges for authors at US institutions when reporting results from ALMA/VLA - https://library.nrao.edu/pubsup.shtml
- **Face-to-face Visitor Support:** Upon request NRAO will cover the travel expenses of up to 2 people from 2 teams per week to come to the NAASC to get support for data reduction, proposal preparation, etc… We also have long term visitor support as well - https://science.nrao.edu/facilities/alma/visitors-shortterm
- **ALMA Ambassadors:** You too can become an ALMA Ambassador. For program eligibility visit - https://science.nrao.edu/facilities/alma/ambassadors-program

A next-generation Very Large Array (ngVLA)

- Scientific Frontier: ***Thermal imaging at milli-arcsec resolution***
- Sensitivity/Resolution Goal:
  - ***10x effective collecting area & resolution of JVLA/ALMA***
- Frequency range: ***1.2 –116 GHz***
- Located in Southwest U.S. (NM+TX) & MX, centered on VLA
- Baseline design under active development
- Low technical risk (reasonable step beyond state of the art)







Complementary suite from meter to submm arrays for the mid-21st century

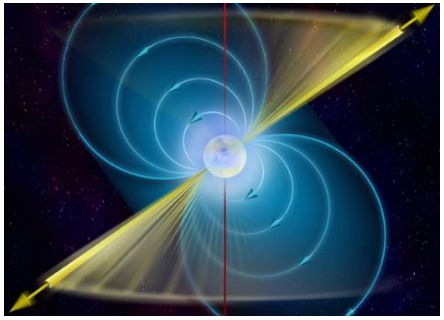
- **< 0.3cm:** ALMA 2030
- **0.3 to 3cm: ngVLA**
- **> 3cm:** SKA

https://science.nrao.edu/futures/ngvla

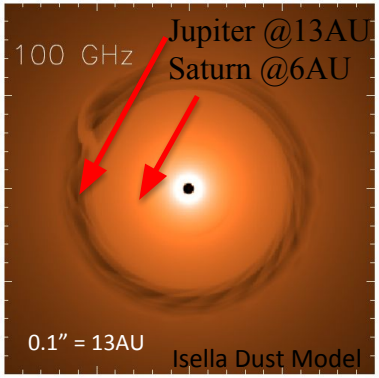
ngVLA Key Science Mission

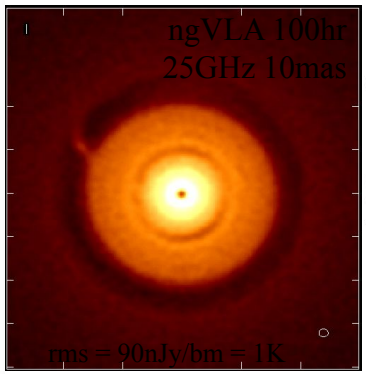
(ngVLA memo #19)

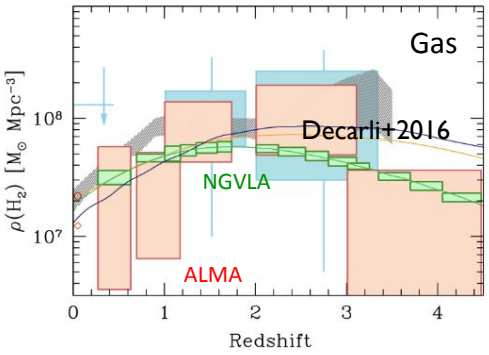
- ***Unveiling the Formation of Solar System Analogues***
- ***Probing the Initial Conditions for Planetary Systems and Life with Astrochemistry***
- ***Charting the Assembly, Structure, and Evolution of Galaxies Over Cosmic Time***
- ***Using Pulsars in the Galactic Center as Fundamental Tests of Gravity***
- ***Understanding the Formation and Evolution of Stellar and Supermassive BH's in the Era of Multi-Messenger Astronomy***

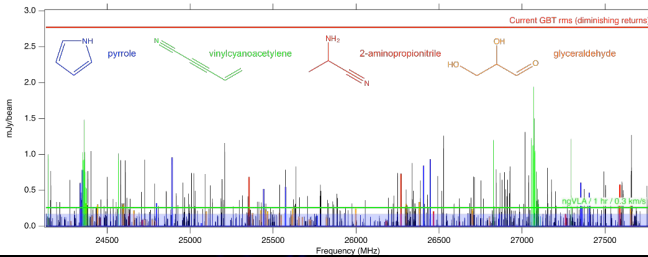


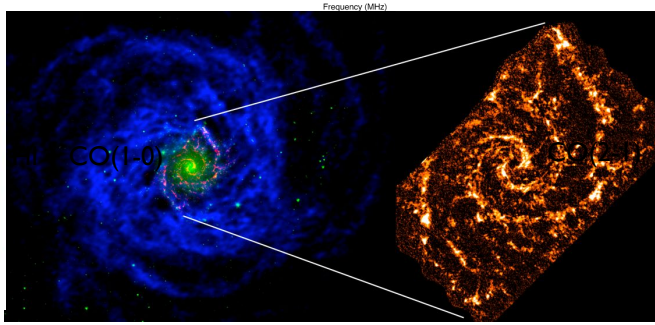
Highly synergistic with next-generation ground-based OIR and NASA missions.







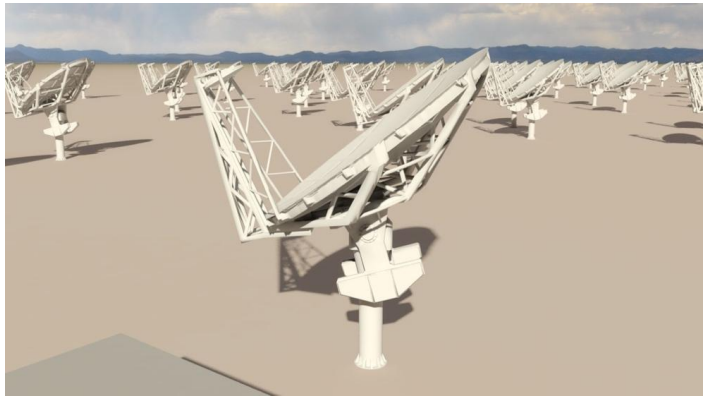




Current Reference Design Specifications (ngVLA Memo #17)

- 214 18m offset Gregorian (feed-low) Antennas
  - Supported by internal cost-performance analysis
- Fixed antenna locations across NM, TX, MX
  - ~1000 km baselines being explored
- 1.2 – 50.5 GHz; 70 – 116 GHz
  - Single-pixel feeds
  - 6 feeds / 2 dewar package
- 19 6m short spacing array + 4 18m in TP mode to fill in (*u, v*) hole

- Continuum Sensitivity: ~0.1uJy/bm @ 1cm, 10mas, 10hr => T_B ~ 1.75K
- Line sensitivity: ~21.5uJy/bm @ 1cm, 10 km/s, 1”, 10hr => T_B ~ 35mK



Receiver Configuration

Band #	Dewar	f_L GHz	f_M GHz	f_H GHz	f_H: f_L	BW GHz
1	A	1.2	2.35	3.5	2.91	2.3
2	B	3.5	7.90	12.3	3.51	8.8
3	B	12.3	16.4	20.5	1.67	8.2
4	B	20.5	27.3	34.0	1.66	13.5
5	B	30.5	40.5	50.5	1.66	20.0
6	B	70.0	93.0	116	1.66	46.0

Atacama Large Millimeter/submillimeter Array
In search of our Cosmic Origins

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Documentation

Call for Proposals

Documentation supporting the current ALMA Call for Proposals – **Cycle 7**. Documents from previous Cycles are provided here.

Document	Description
ALMA Proposer's Guide	Contains all pertinent information regarding the ALMA Call for Proposals
ALMA Technical Handbook	A comprehensive description of the ALMA observatory and its components
ALMA Users' Policies	The long-term core policies for use of the ALMA and ALMA data by the science community
Observing With ALMA - A Primer	Introduction to interferometry and how to use ALMA
ALMA Proposal Template	LaTeX format. Recommended but not mandatory
ALMA Proposal Review Process	The latest version of the ALMA Principles of the ALMA Proposal Review Process

Contents

ALMA is a telescope for *all* astronomers

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public.nrao.edu

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