Introduction to NRAO and ALMA

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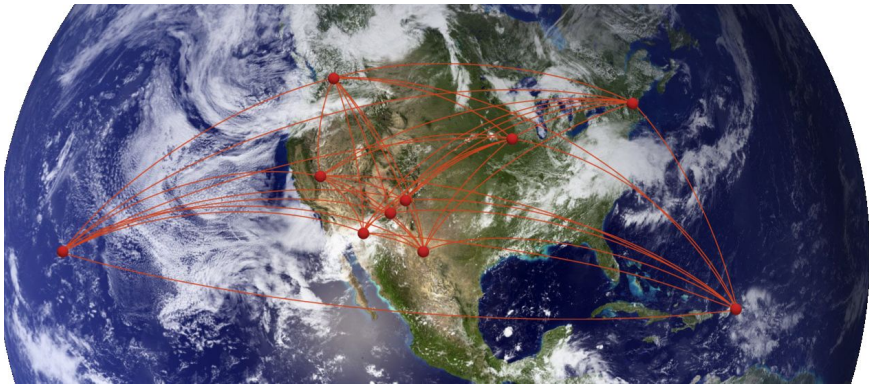


Atacama Large Millimeter/submillimeter Array
Karl G. Jansky Very Large Array
Very Long Baseline Array

NRAO:
One Observatory, Three World Class Facilities

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

NRAO:
One Observatory, Three Facilities

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

Broad Science Topics with NRAO Telescopes

- **Sun** – coronal mass ejections, magnetic field activity, coronal/chromospheric heating
- **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, Sunyaev-Zeldovich Effect, reionization

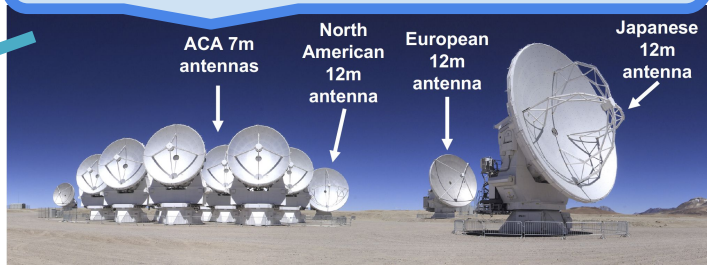
ALMA is a telescope for *all* astronomers

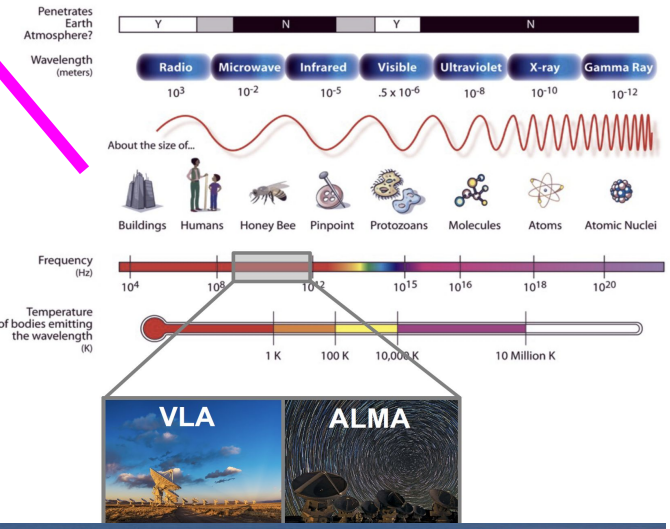
Atacama Large (sub)Millimeter Array

ALMA in a nutshell

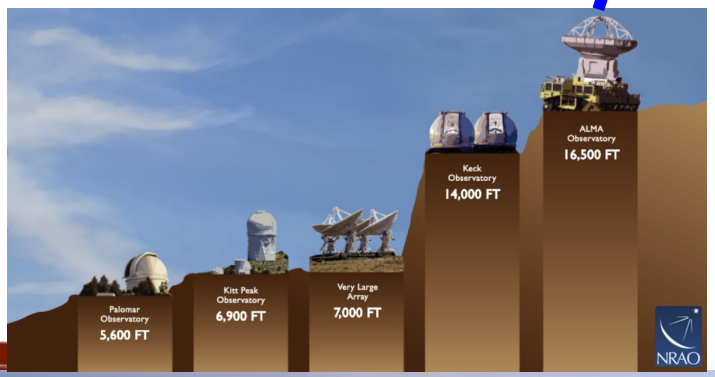
- Chajnantor Plateau, Chile
- ↕≡5 km ~16,500'
- 66 dishes
- λ 3mm - 320μm (84 - 950 GHz)
- 0.012-66"

Main array: 50 x 12m antennas
Compact array (ACA): 12 x 7m antennas
Total Power: 4 x 12m antennas (as single dish)

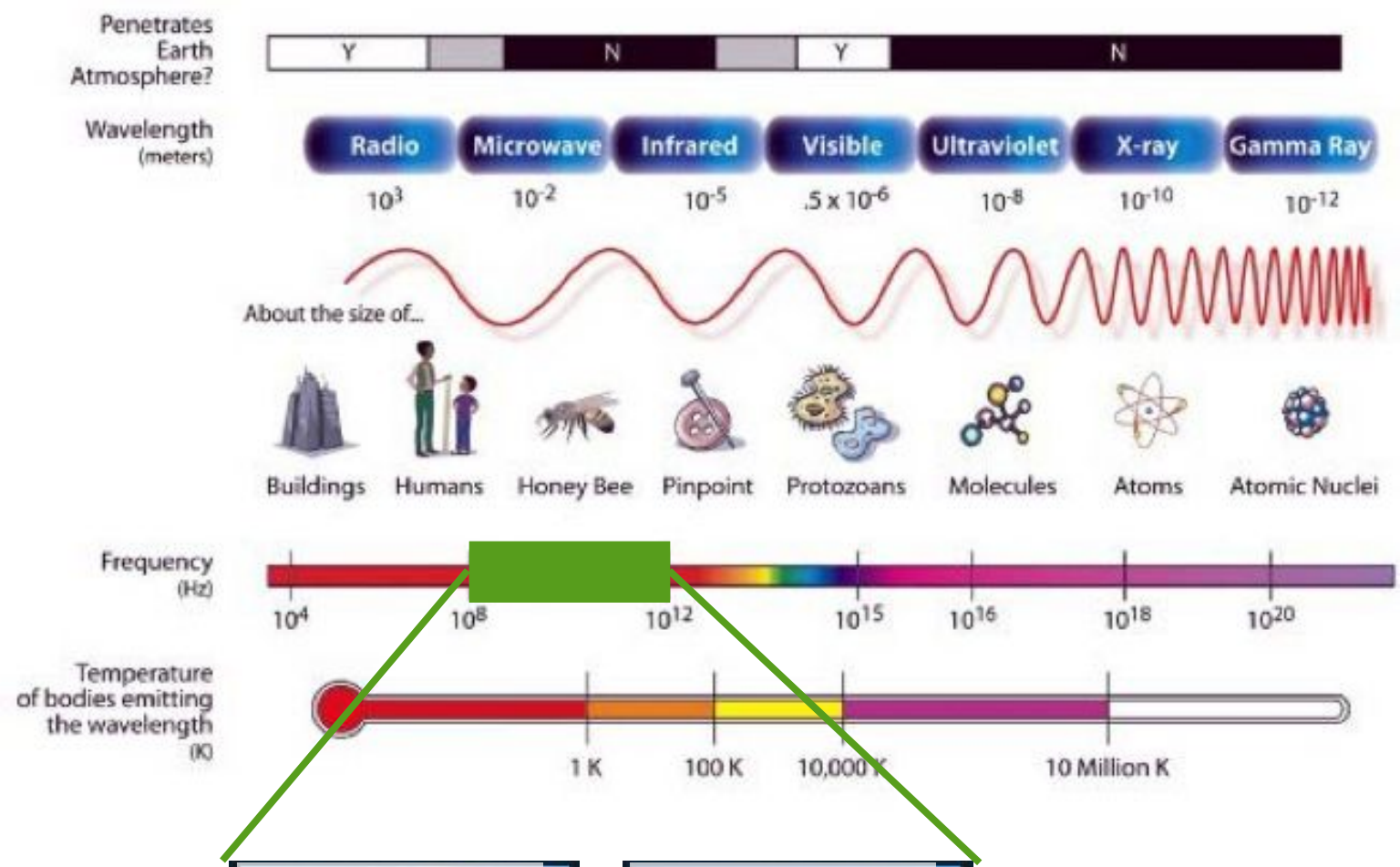




Joint ALMA Observatory global partnership to provide unprecedented imaging and spectroscopic capabilities at mm/submm wavelengths



10 configurations with baselines from 15m to 16.2km
10-100x more sensitive than previous mm arrays


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 x 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


VLA
~1 - 50 GHz
~300 - 6 mm

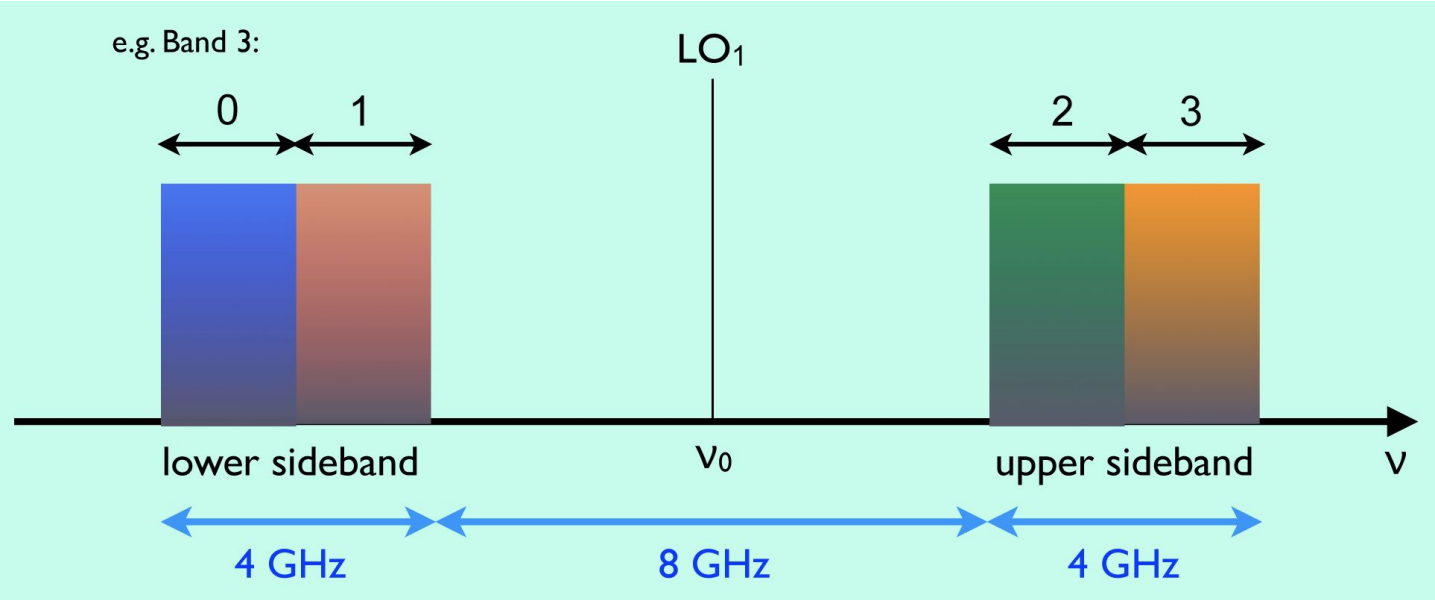

ALMA
~84 - 950 GHz
~3 - 0.3 mm

ALMA Vocabulary

- **Antenna -** the radio dish and its associated structure.
- **Baseline -** an imaginary line between two antennas. The larger number of unique distances, the better.
- **Receiver -** the instrument where the signals are collected.
- **Correlator -** a powerful computer that cross-correlates the signals from each antenna's receiver.
- **Beam size -** the approximate angular resolution (in arcseconds). This is related to the baseline distances.
- **Sensitivity -** the minimum signal needed (usually in order to detect your weakest line at 3σ). This depends on the beam size. Increasing sensitivity increases required observing time.
- **Visibilities -** the Fourier transform of sky brightness detected by all baselines.

ALMA Vocabulary

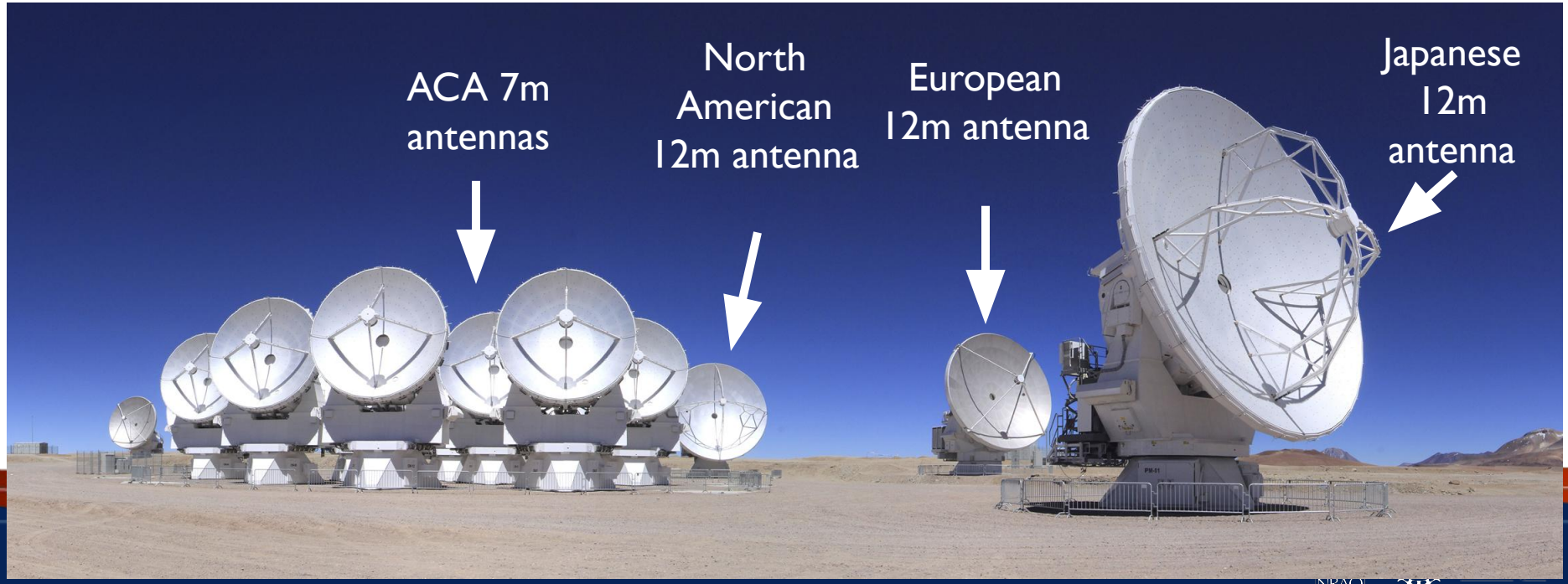
- **Band -** a specific frequency range observed at ALMA (Bands 3-10 are currently available)
- **LO -** (local oscillator) the central frequency between the two sidebands separated from each by 4 GHz
- **Sideband -** two 2 GHz frequency ranges (**basebands**) in which you can place your spectral windows
- **Spectral window -** a range of frequencies set by the proposer that contains the targeted spectral lines or continuum



ALMA Basics: Antennas

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

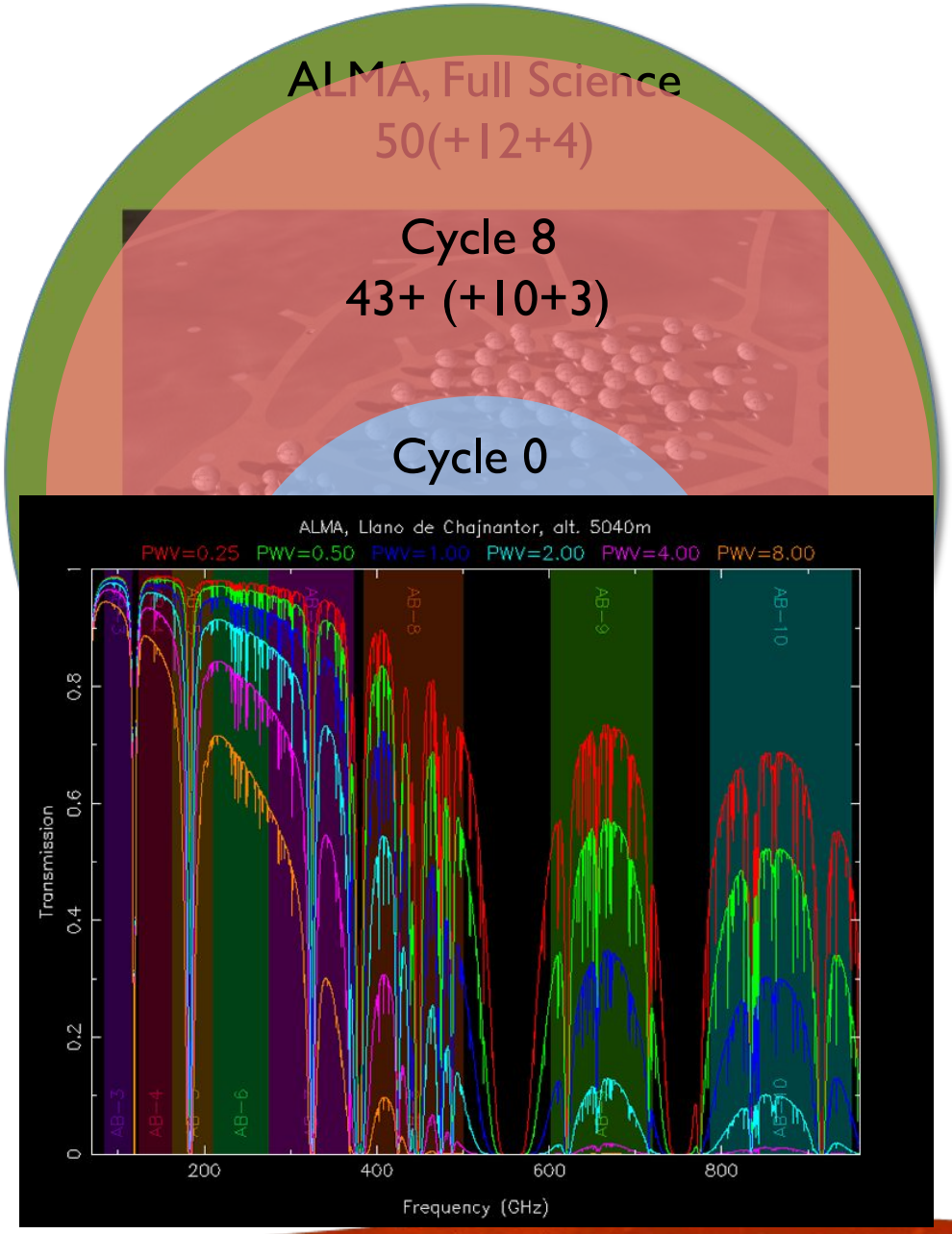
Complementary! → Sensitive to emission on different spatial scales



ALMA abilities

Collecting Area

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



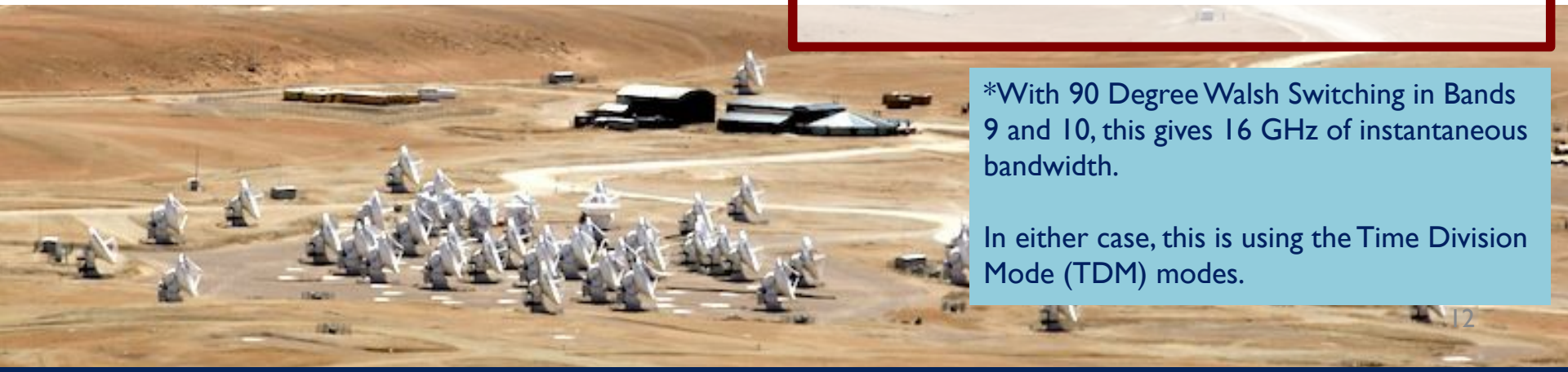
Spectral Coverage - Covers ten atmospheric windows with 50% or more transmission above 35 GHz

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

In short…

- 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 archived
- Pipeline processing

ALMA is 10-100 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.

Did You Know? In *Cycle 8* ALMA can…

…resolve molecular structures in M83:	
clouds of excited CO(J=3-2) gas across the central 400 pc of M83 at 6pc resolution	*in 1.7 hours*
…detect the ISM in high-redshift galaxies:	
dust emission in a "normal" 10^{11} $L_\odot$ galaxy between z=1 and z=6	*in 4.3 hours*
…reveal the behavior of solar system objects:	
obtain wind patterns in the atmosphere of Mars with 300 km resolution	*in 26 minutes*
measure Kuiper Belt Object sizes from their thermal emission	*in 48 minutes*
…survey Galactic Clouds and star forming regions:	
measure the polarization of dust in 30 protostars in a single star-forming region	*in 3 hours*
…reveal the nature of planetary disks around nearby stars:	
detect a dust disk gap induced by a Jupiter-mass planet at 120 pc	*in 2 hours*
…measure stellar activity from low-mass to high-mass stars:	
investigate heating mechanisms of red giant stars	*in 5 minutes*
…study black holes and their environments, near and far:	
measure black hole mass of NGC 4526 from molecular gas kinematics	*in 42 minutes*
…trace the formation of galaxy clusters, cosmic structure:	
survey clustering in a sample of 23 Lyman-α Blobs (LABs) at z=3.1	*in <1 hour*

ALMA is a Telescope for all Astronomers

- ALMA is an open skies telescope – anyone can propose for time!
- Support includes easy to use website + documentation + pipeline data products + proposal and data reduction workshops
- You don't have to be a radio/mm astronomer to use ALMA data!

Documentation

Call for Proposals

Documentation supporting the current ALMA Call for Proposals – **Cycle 6**. 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

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Additional Slides

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)
- The ACA (Atacama Compact Array) or Morita Array – up to 12x7m antennas and 4x12m antennas for TP observations – is currently being used for Cycle 7 observations
- More on Capabilities later… however, first on to science!

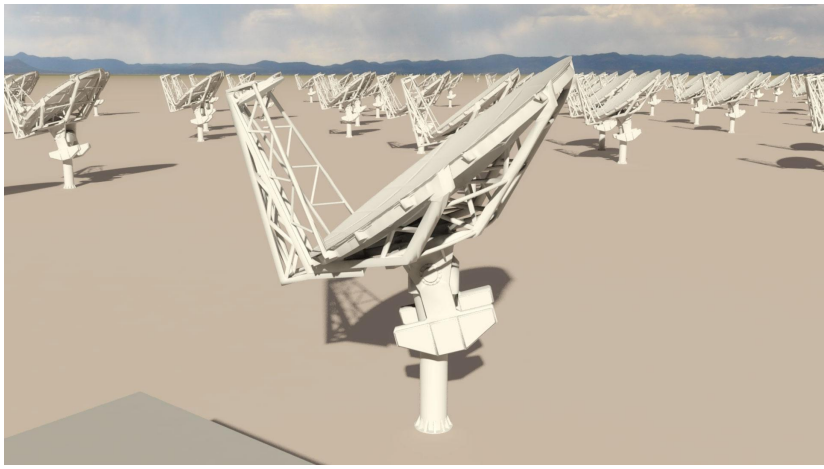
What is ALMA?

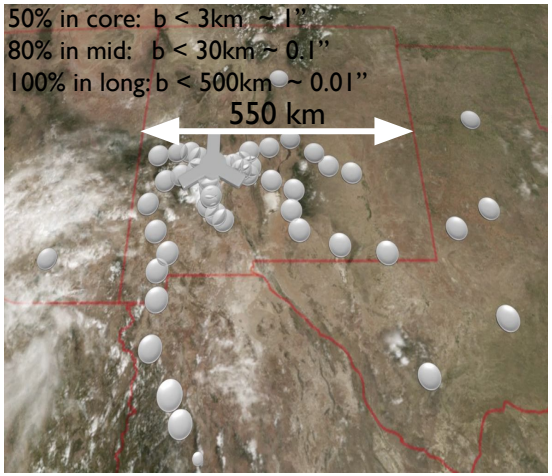
- Array configurations between 150 meters and >16 kilometers: 192 possible antenna locations:

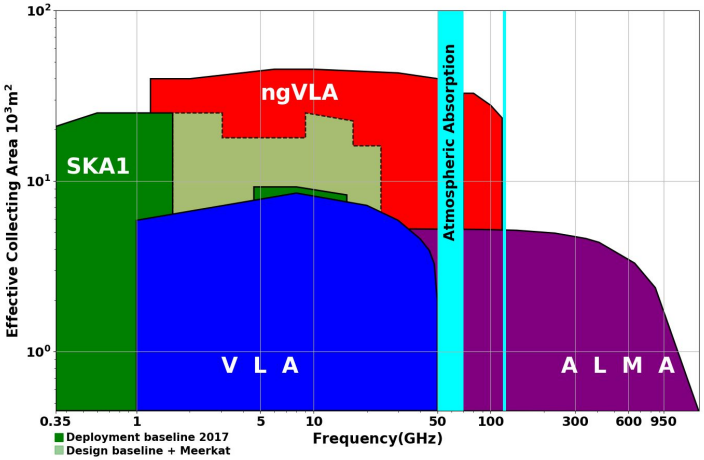
- http://youtu.be/YMISe-C8GUs

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)







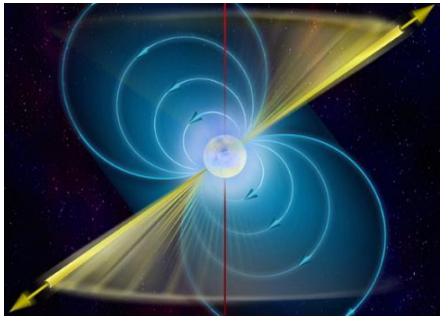
Complementary suite from meter to submm arrays for the mid-21st century

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

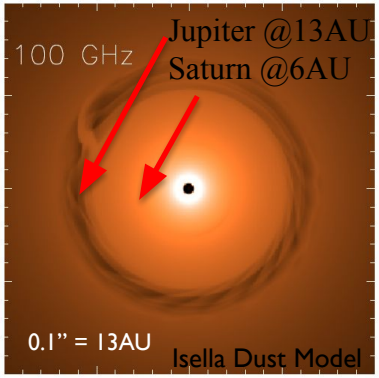
https://science.nrao.edu/futures/ngvla

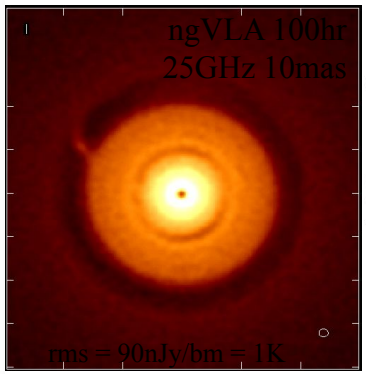
ngVLA Key Science Mission
(ngVLA memo #19)

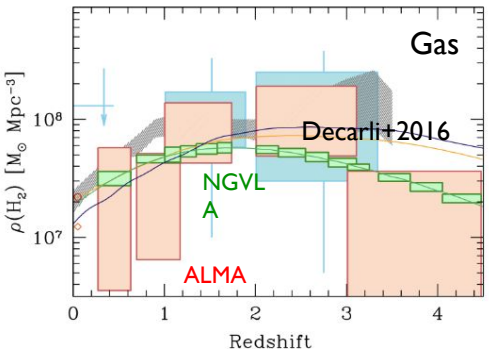
- Unveiling the Formation of Solar System Analogues
- Probing the Initial Conditions for Planetary Systems and Life with Astrochemistry
- Charting the Assembly, Structure, and Evolution of Galaxies Over Cosmic Time
- Using Pulsars in the Galactic Center as Fundamental Tests of Gravity
- Understanding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

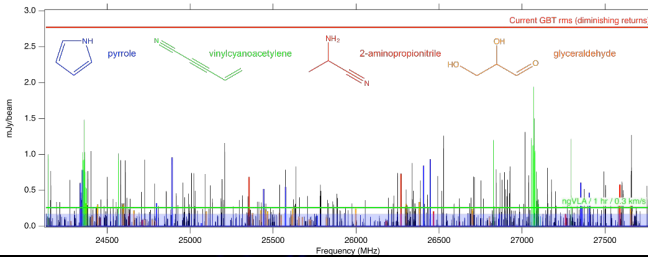


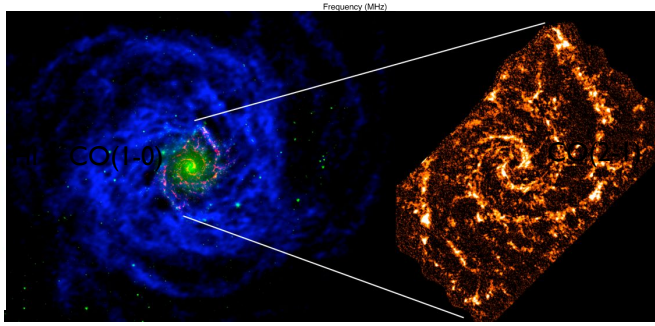
Highly synergistic with next-generation ground-based OIR and NASA missions.









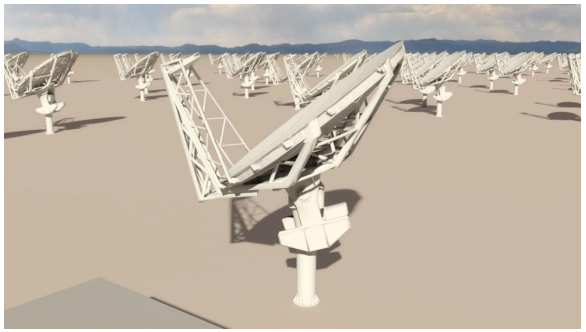


Current Reference Design Specifications

(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

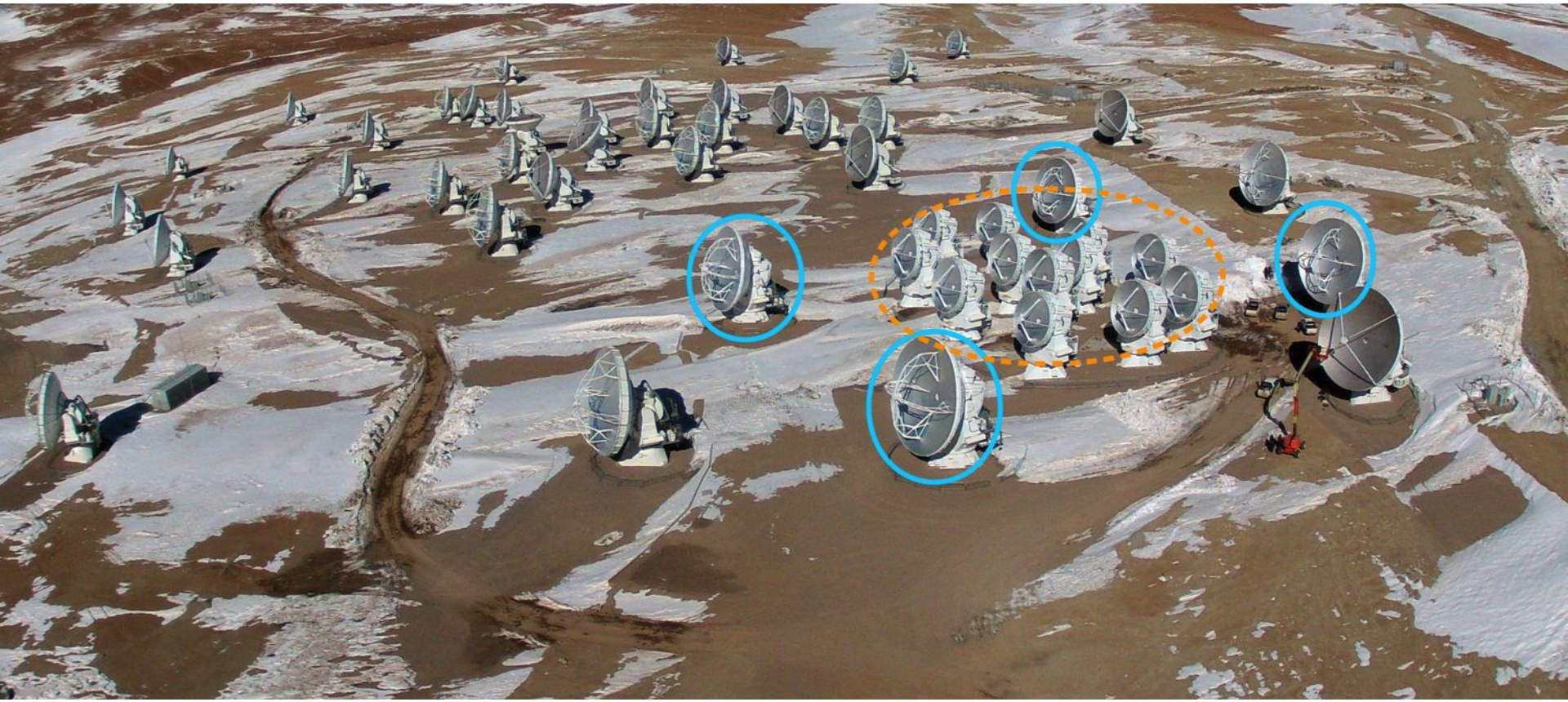
- Continuum Sensitivity: ~0.1uJy/bm @ 1cm, 10mas, 10hr => T_B ~ 1.75K
- Line sensitivity: ~21.5uJy/bm @ 1cm, 10 km/s, 1", 10hr => T_B ~ 35mK



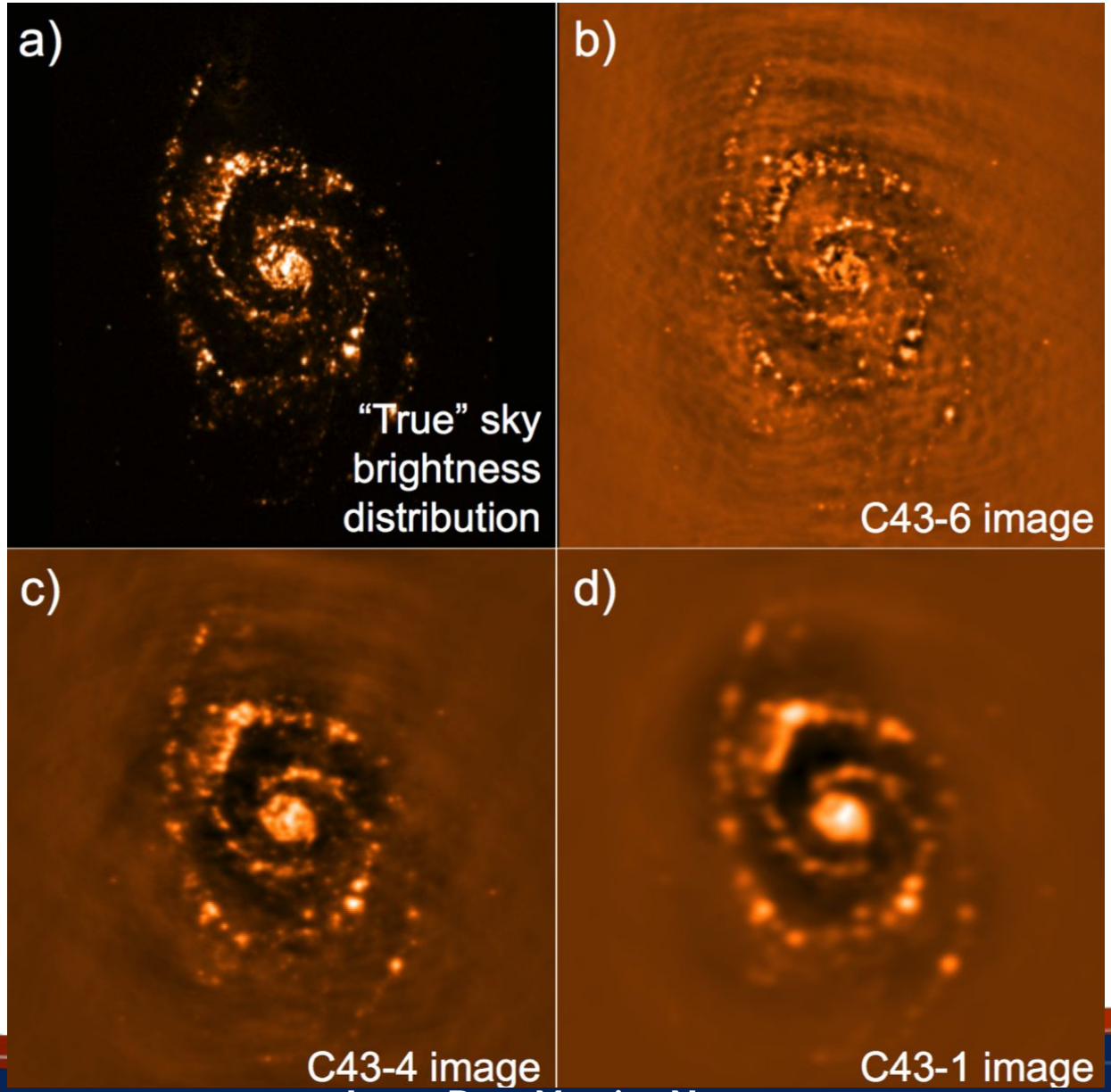
Receiver Configuration

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

ALMA Telescopes



Spatial Filtering



Morita Array

The Morita Array is named in remembrance of Koh-Ichiro Morita, a professor at the NAOJ Chile Observatory who was one of the world's renowned scientists in the field of aperture synthesis. He made a great contribution to designing the configuration of 16 antennas composing the Atacama Com- pact Array (ACA) manufactured by Japan, as well as to realizing high-resolution and high-quality imaging at millimeter/submillimeter wavelengths to further enhance the performance of ALMA.