The Atacama Large Millimeter Array (ALMA)

Kartik Sheth

National Radio Astronomy Observatory

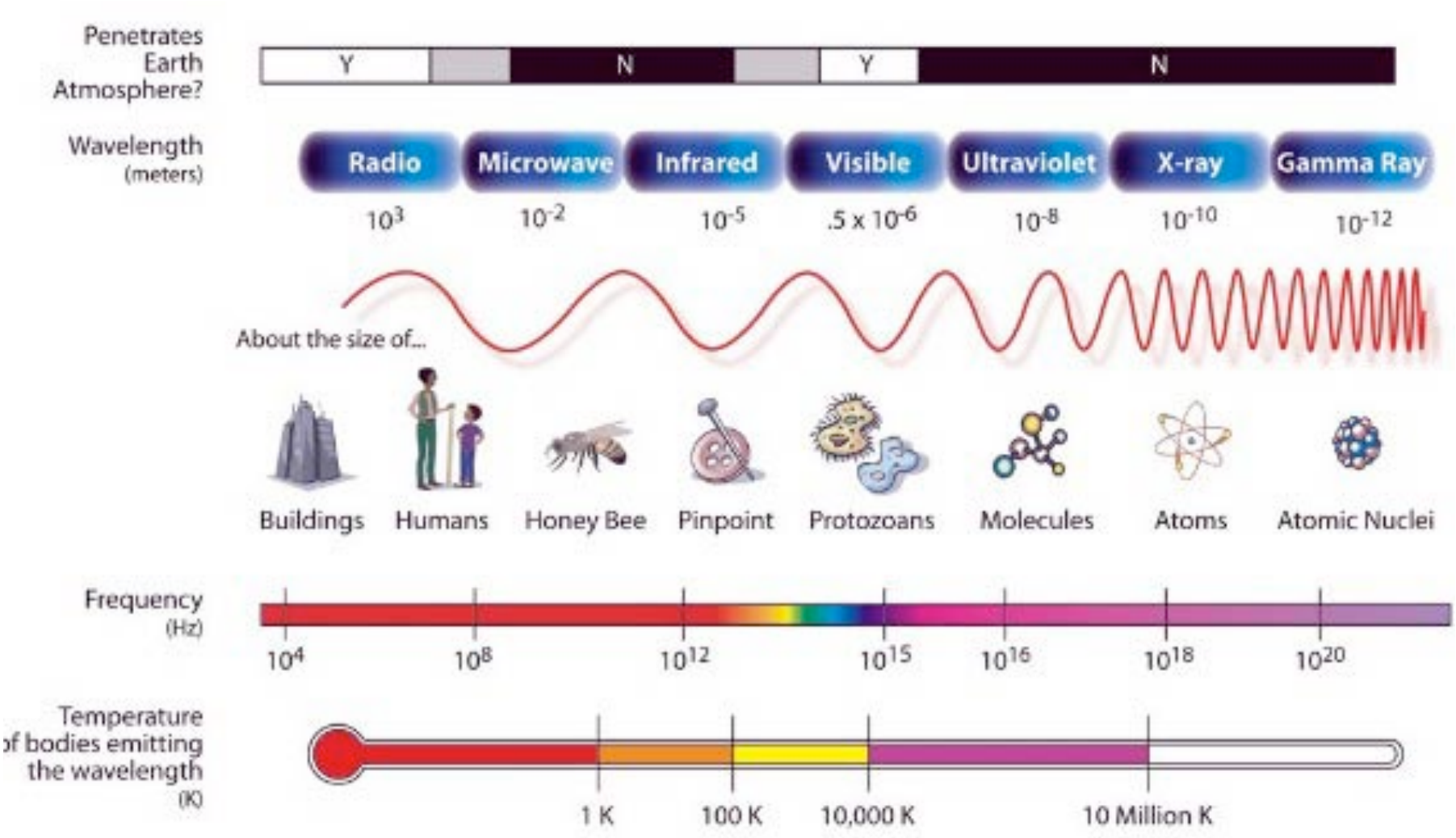
North America ALMA Science Center

Charlottesville, Virginia U.S.

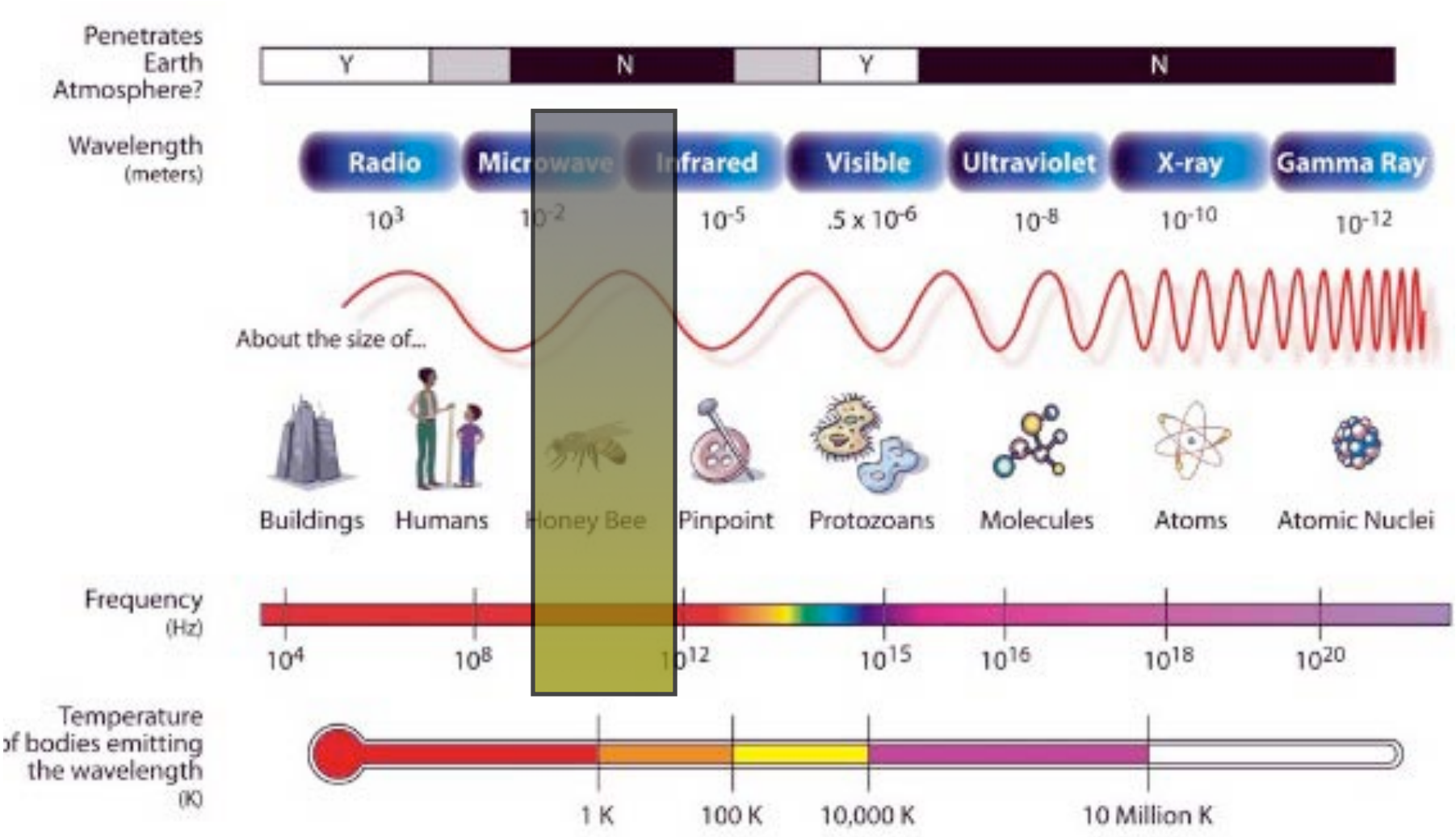
Atacama Large Millimeter/submillimeter Array
Expanded Very Large Array
Robert C. Byrd Green Bank Telescope
Very Long Baseline Array

NRAO

Astronomers see the Light!



Astronomers see the Light!



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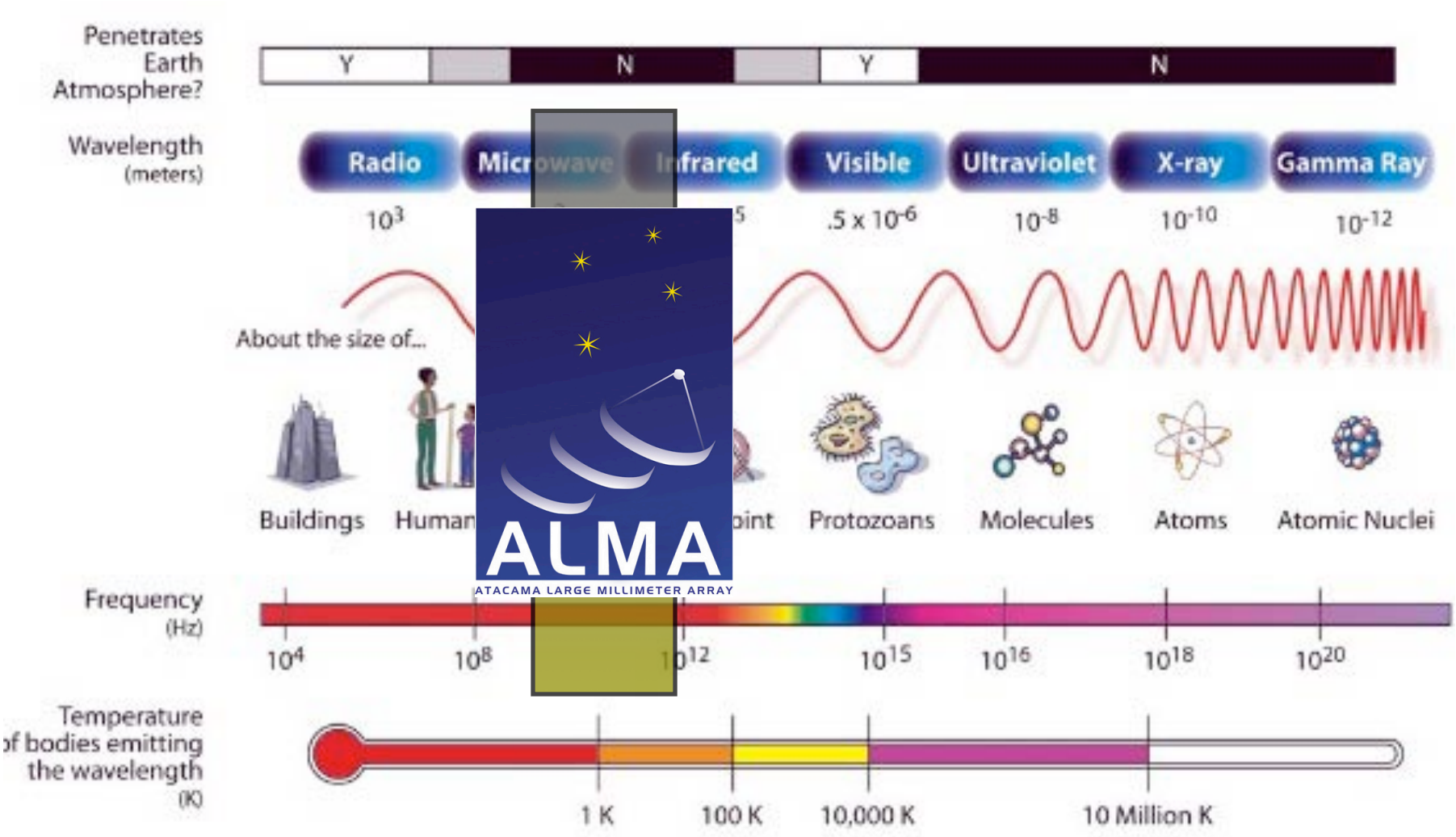
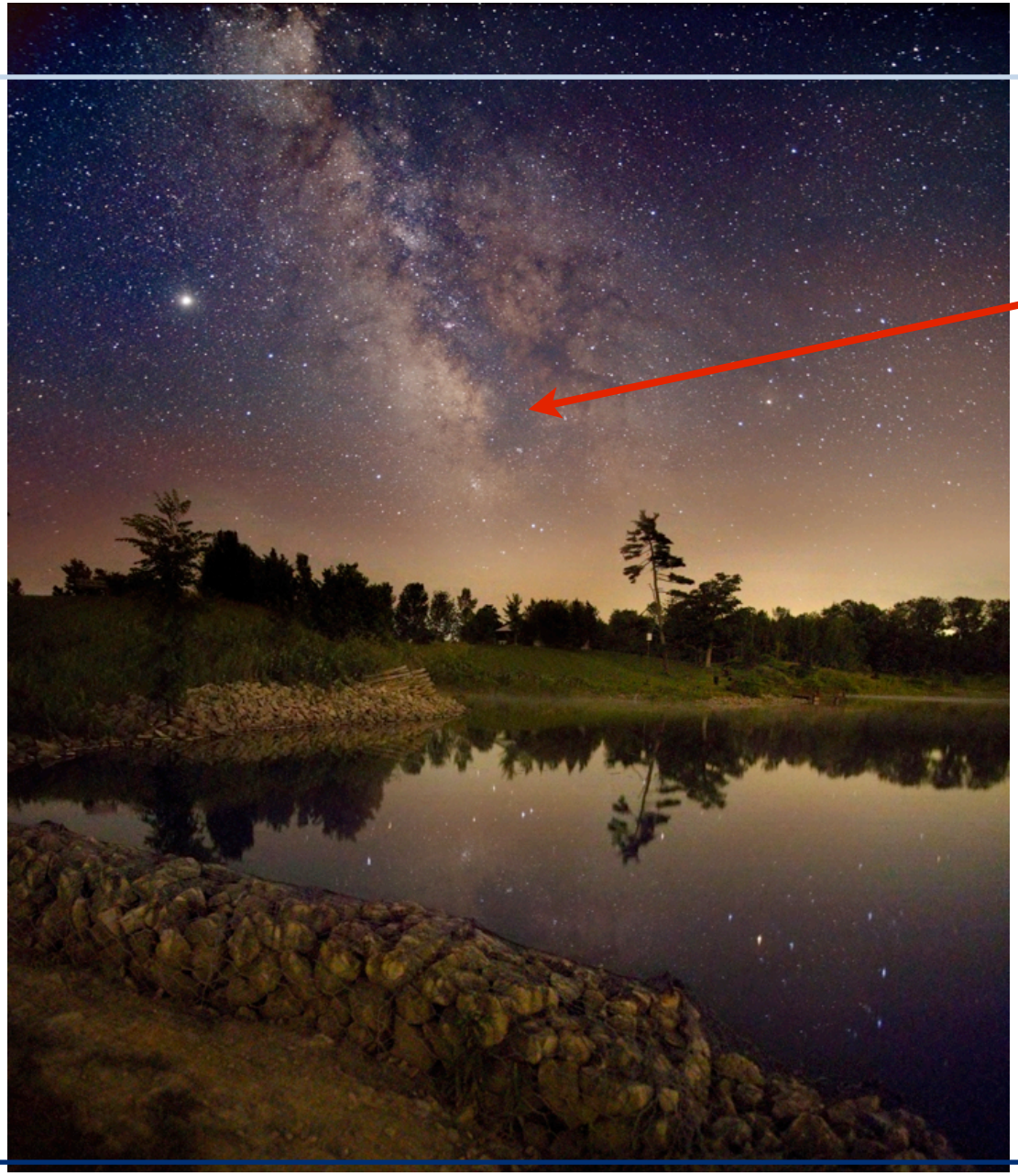


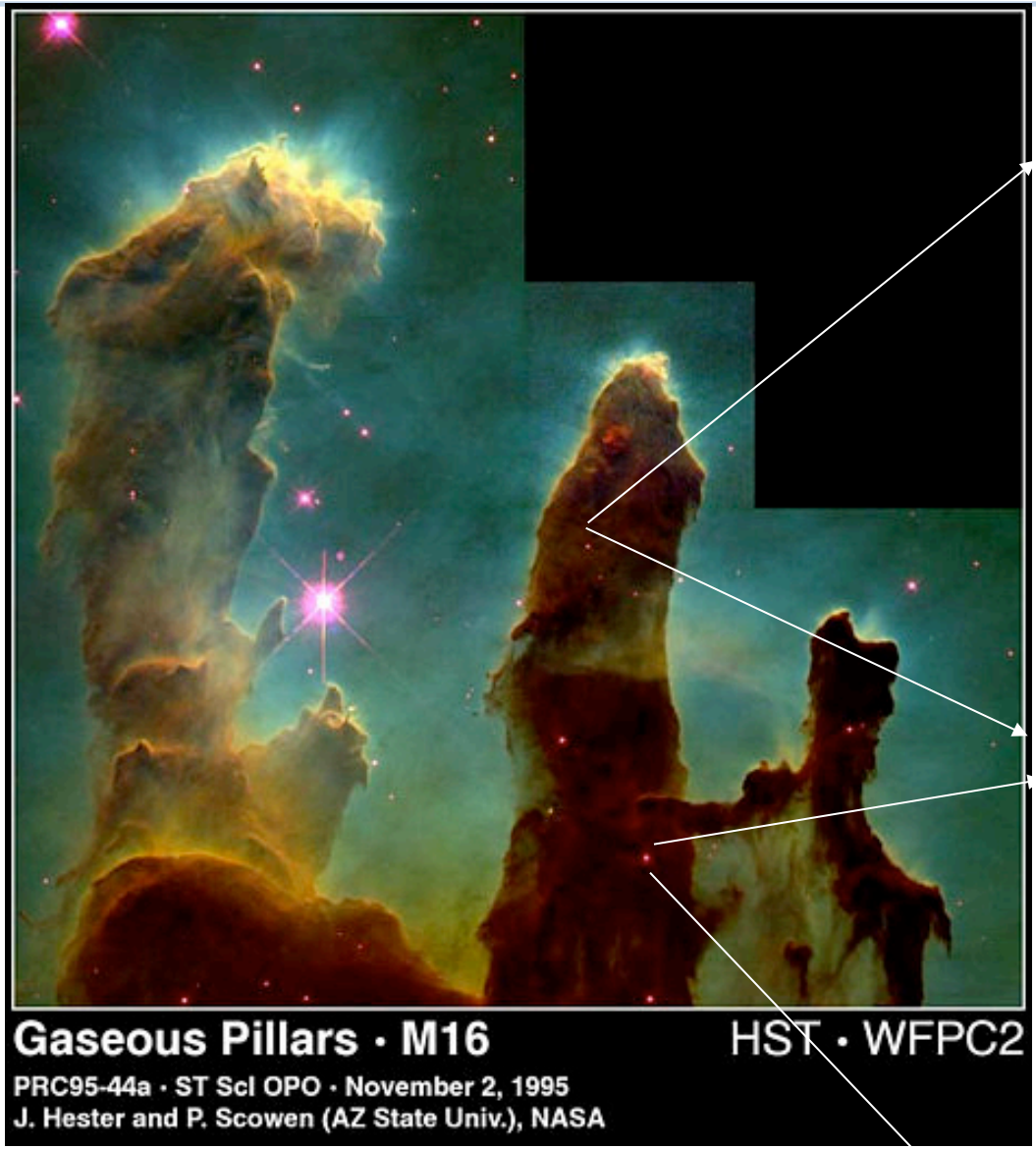


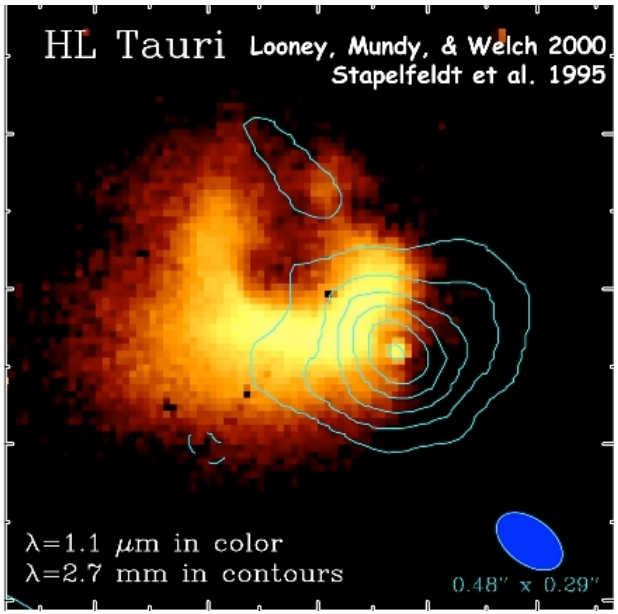
ALMA

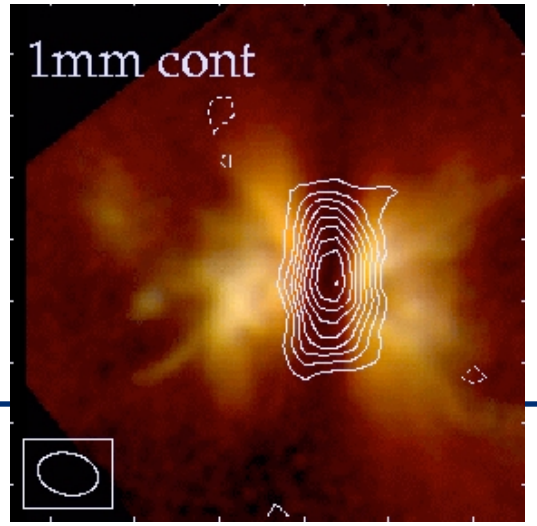
ALMA's bread and butter science:

Molecular gas and dust in the Universe!

The Millimeter /Submm Universe







Courtesy D. Padgett

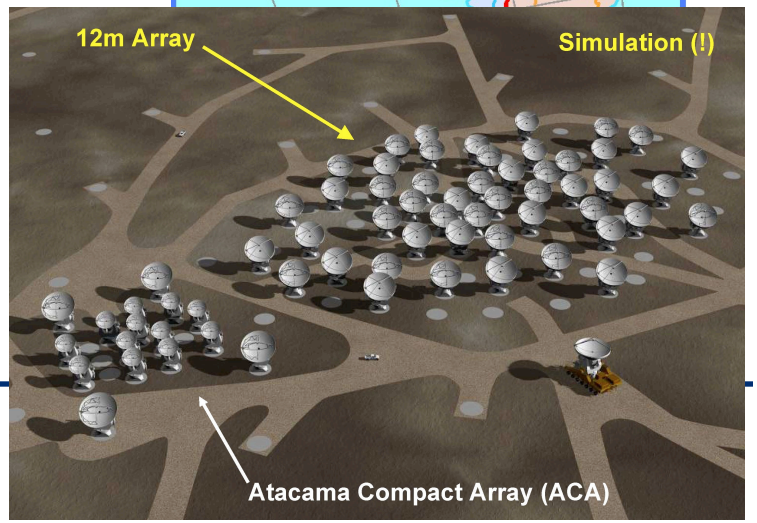
ALMA Today


ALMA next year!

The Millimeter /Submm Universe

A transformational new facility
A ground-based Great Observatory!

- A Global Partnership: NA + ESO + NAOJ + Chile



The Millimeter /Submm Universe

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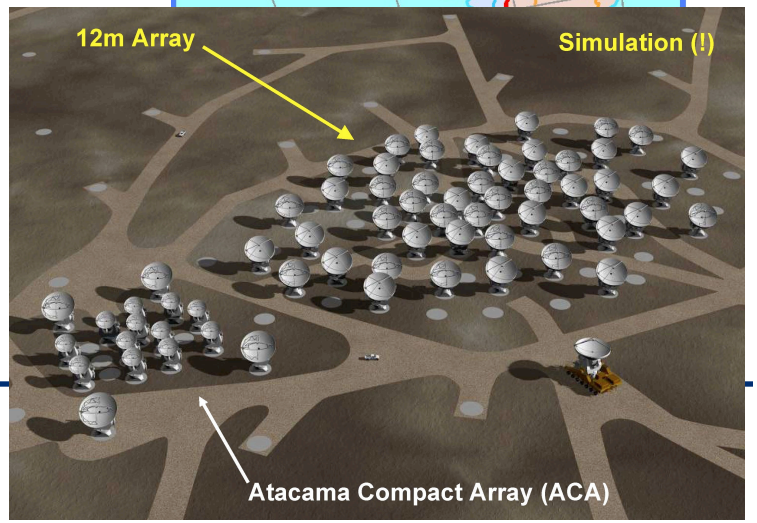
A ground-based Great Observatory!

- A Global Partnership: NA + ESO + NAOJ + Chile
  - At least 50 x 12m antennas (up to 64)
  - + 4x 12m + 12x7m for a compact array
  - x 10-100 times more sensitive!
  - x 10-100 times better resolution!
  - x2 in wavelength coverage and bandwidth



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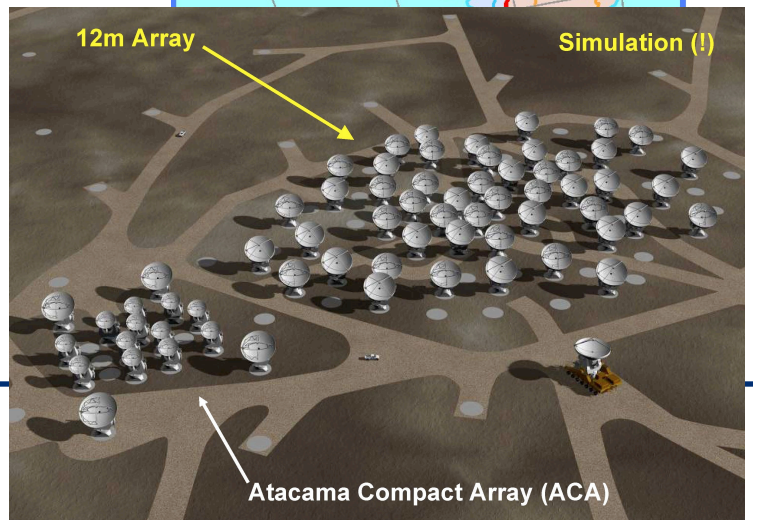
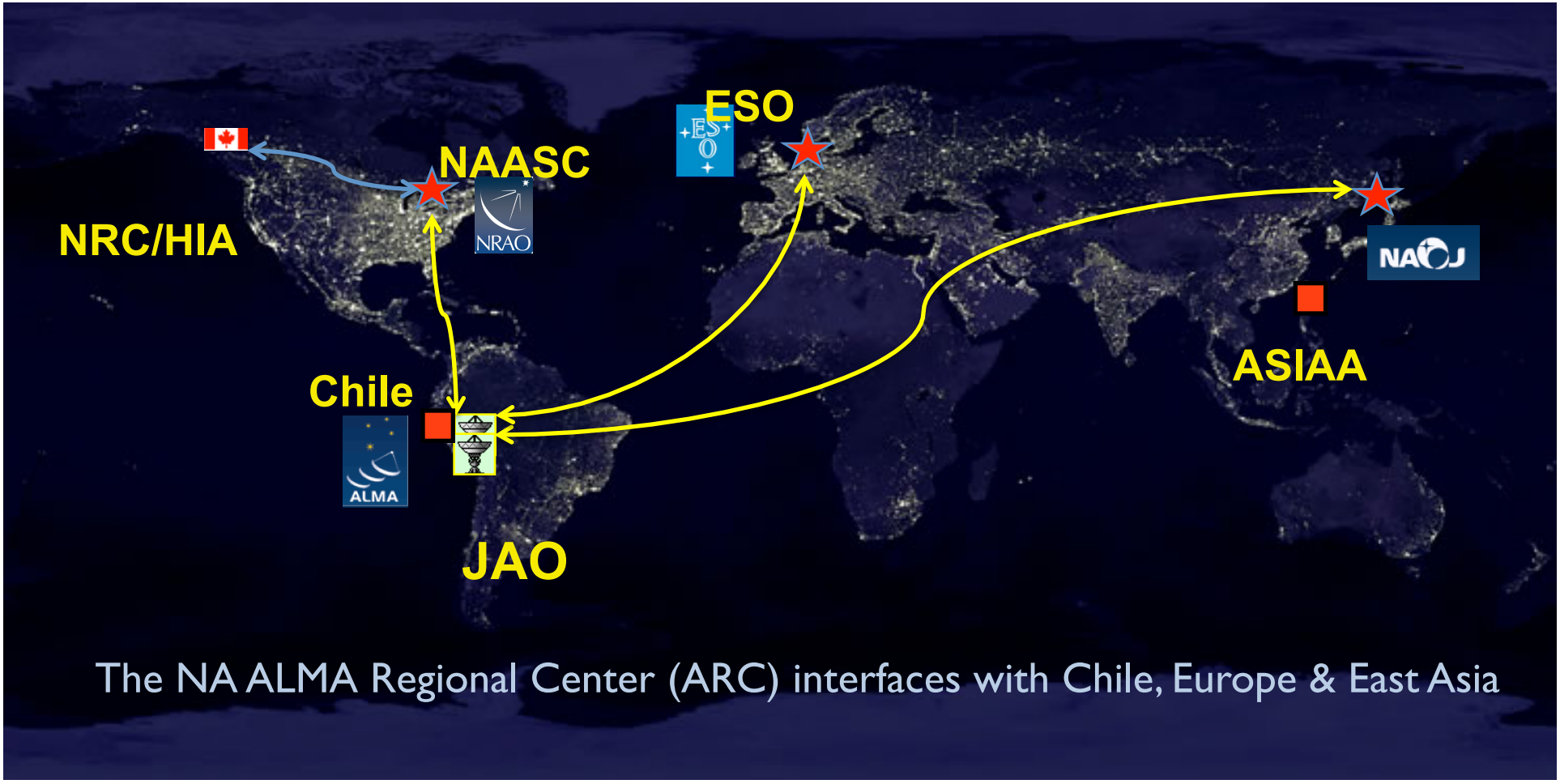
Many (most?) advances in astronomy have come from technological advances



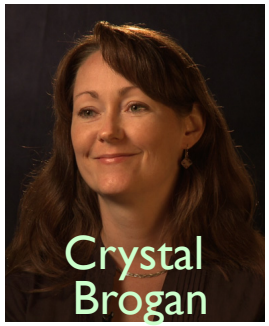
NAASC, NRAO, is the observer's interface to all things ALMA in North Am.

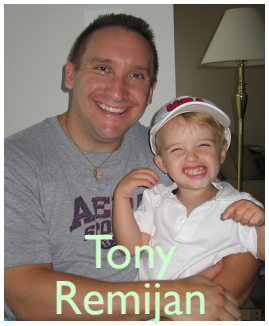


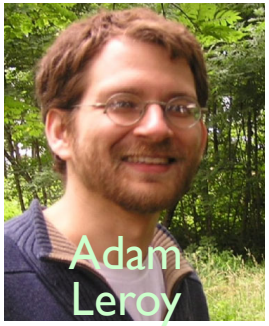
The NA ALMA Regional Center (ARC) interfaces with Chile, Europe & East Asia

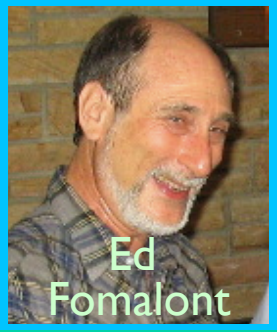
NAASC Science Support

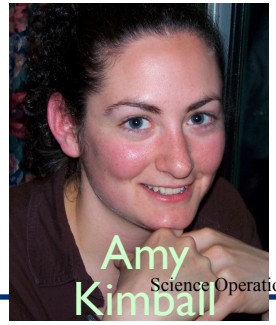
Nuria Marcelino











http://www.nrao.edu/explorer/alma/

ALMA OSF & AOS

OSF: Operations Support Facility
AOS: Antenna Operations Site

Associated Universities, Inc.

NSF

NRAO

ALMA OSF & AOS

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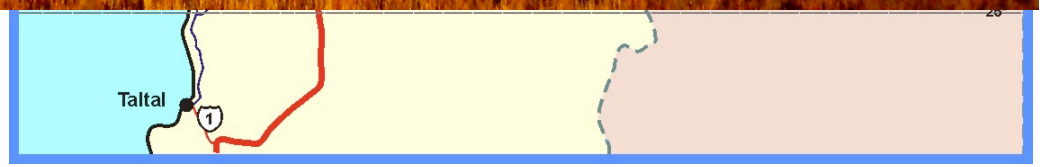

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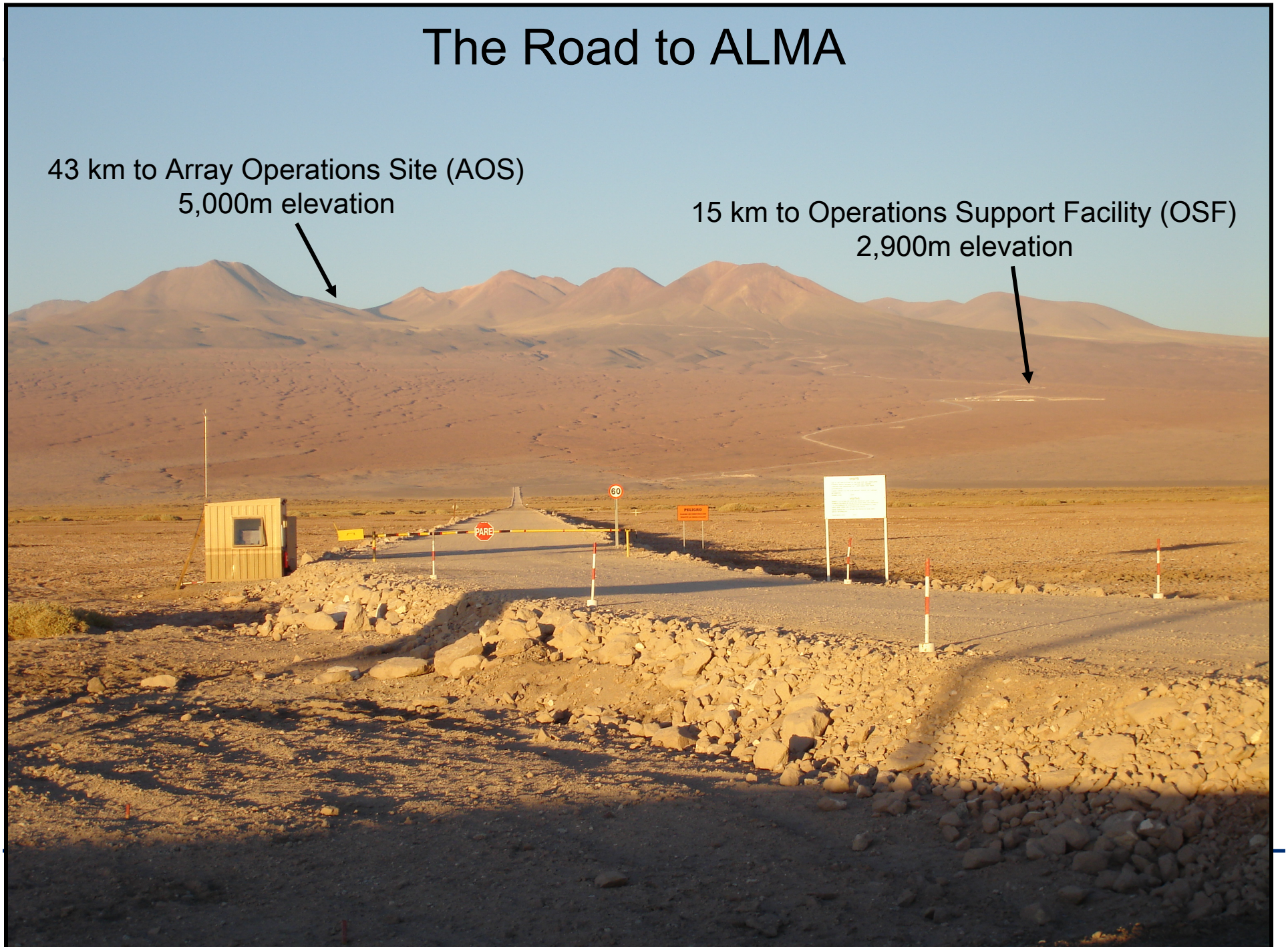
The Road to ALMA



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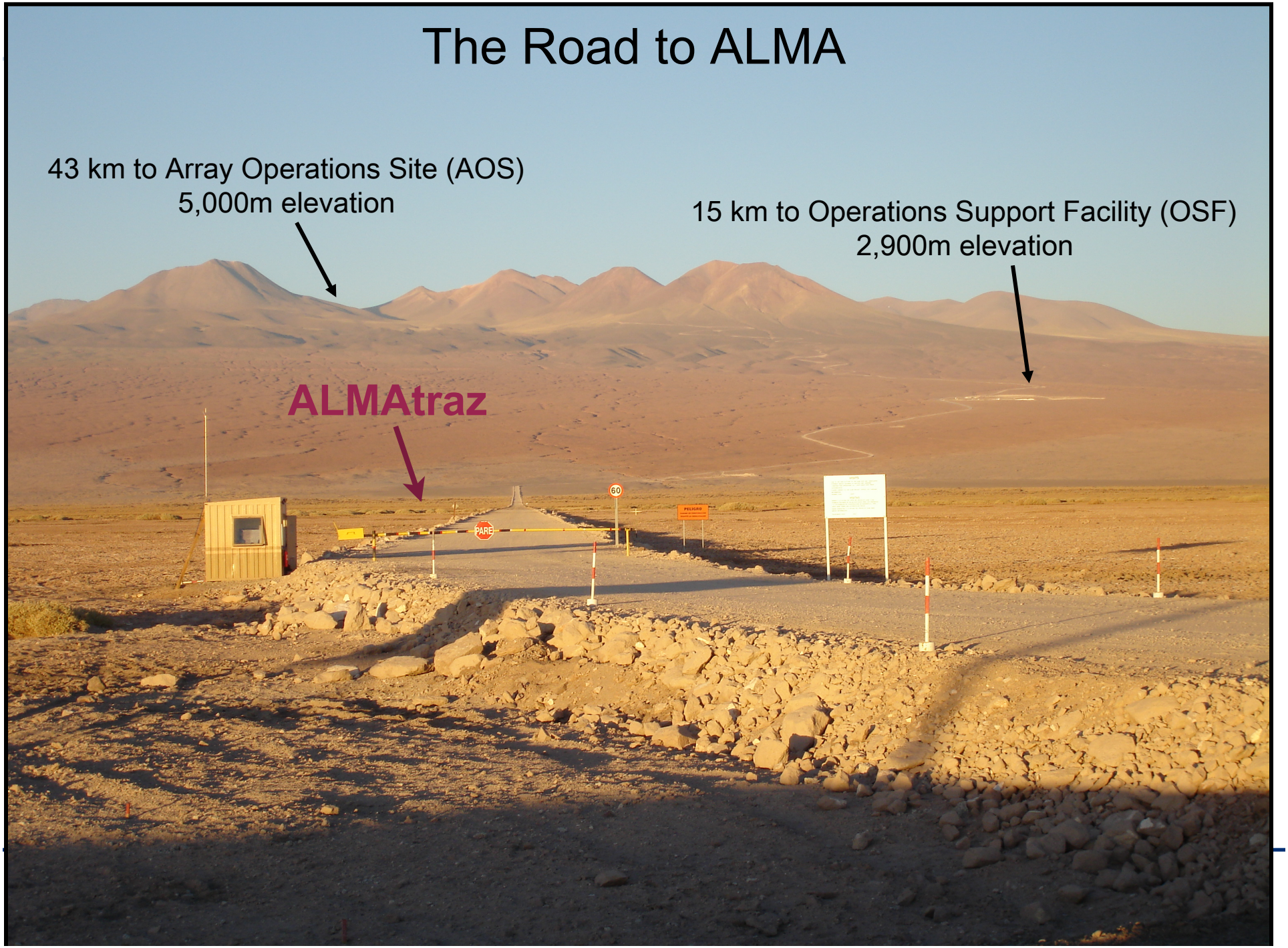


Drier is Better!

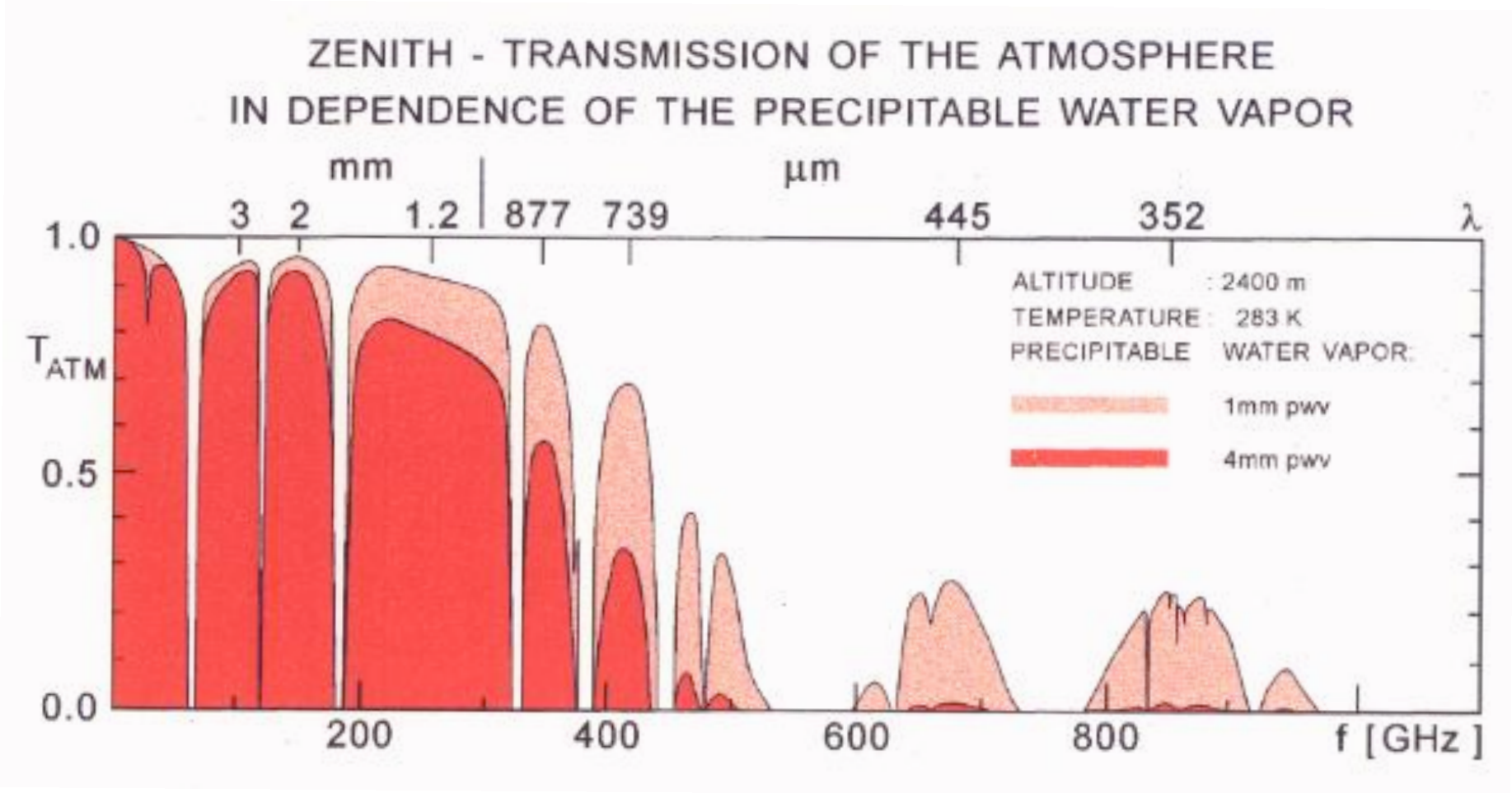
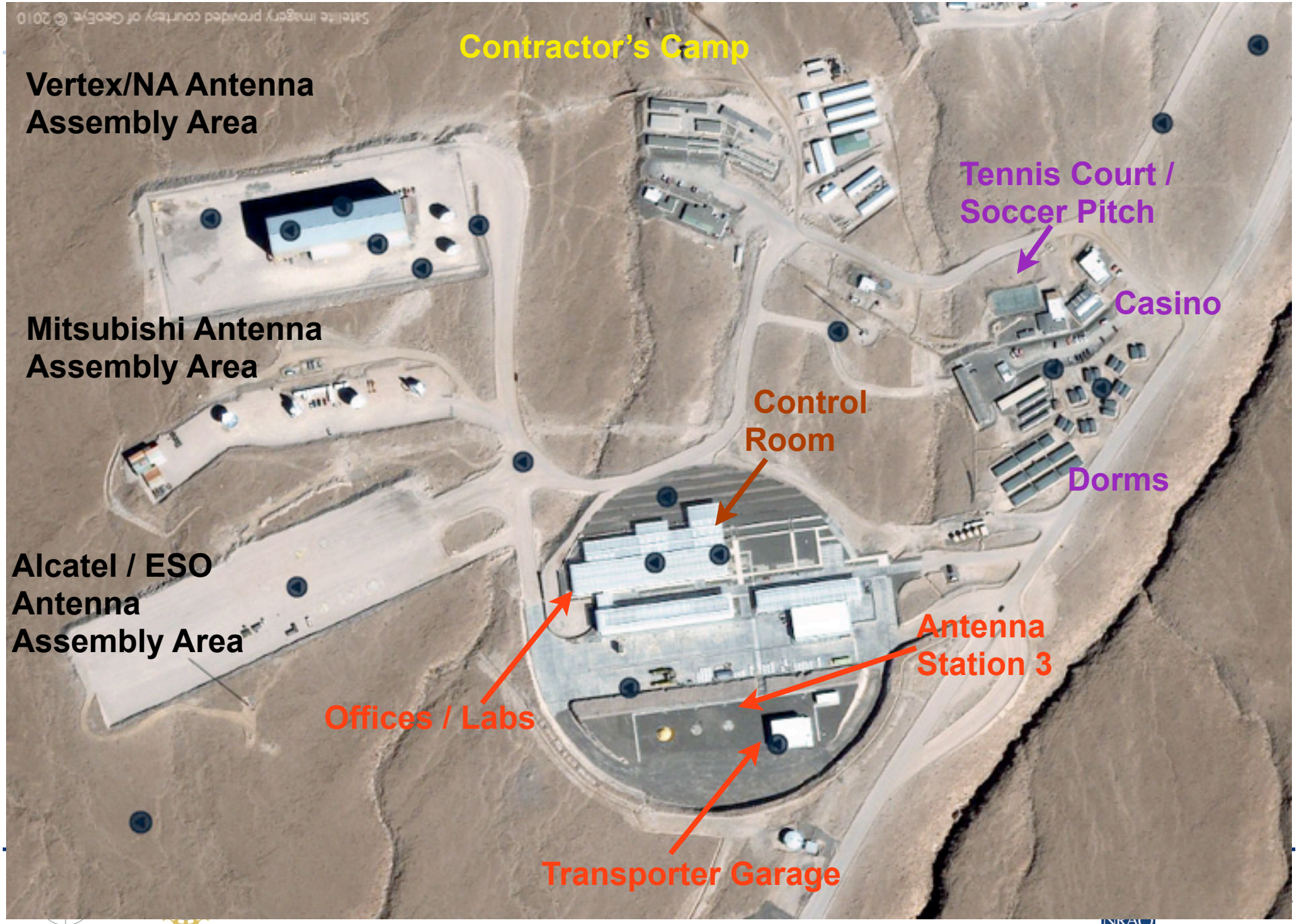
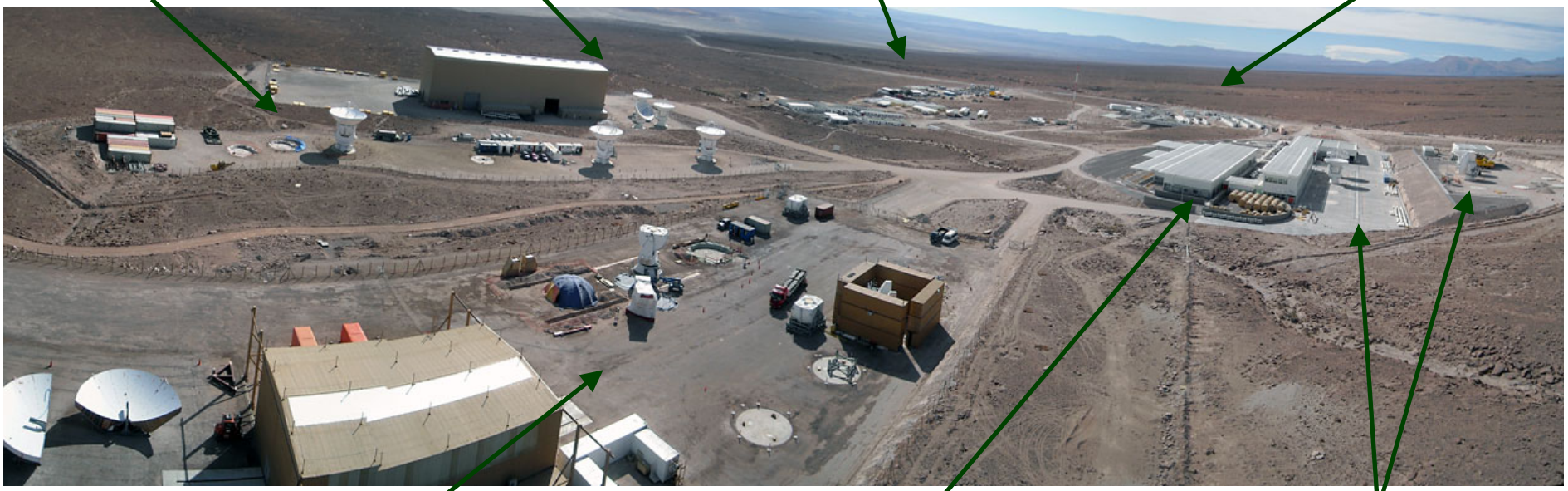


Figure from Arizona Radio Observatory


Contractor's Camp
Vertex/NA Antenna Assembly Area
Tennis Court / Soccer Pitch
Casino
Mitsubishi Antenna Assembly Area
Control Room
Dorms
Alcatel / ESO Antenna Assembly Area
Antenna Station 3
Offices / Labs
Transporter Garage

Current Shape of the OSF

Seen from the holography tower



The High Site - AOS

AOS: The Antenna Operations Site

Comparison to current arrays

Telescope	altitude (feet)	diam. (m)	No. dishes	A (m^2)	ν_{max} (GHz)
NMA	2,000	10	6	470	250
CARMA	7,300	3.5/6/10	23	800	250
IRAM PdB	8,000	15	6	1060	250
SMA	13,600	6	8	230	650
ALMA	**16,400**	**12**	**54**	**6100**	**950**
ACA	**16,400**	**7**	**12**	**490**	**950**
EVLA	*7,050*	*25*	*27*	*13250*	*43*

Comparison

- **Collecting Area**

Comparison

- **Collecting Area**

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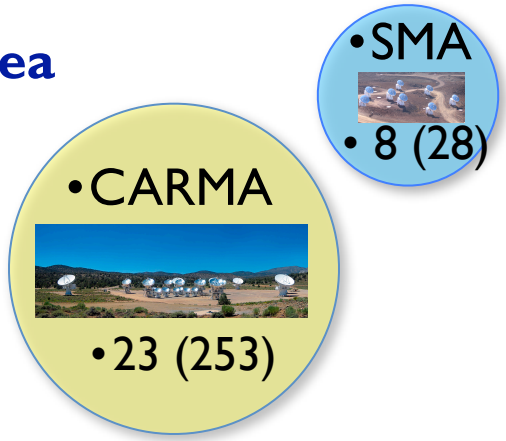
- **Collecting Area**



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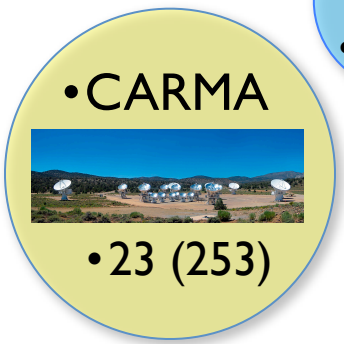

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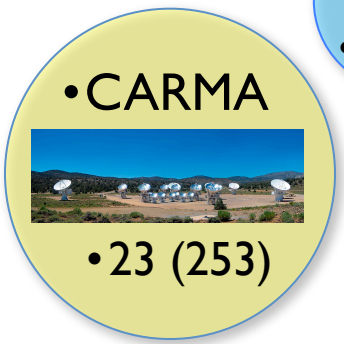

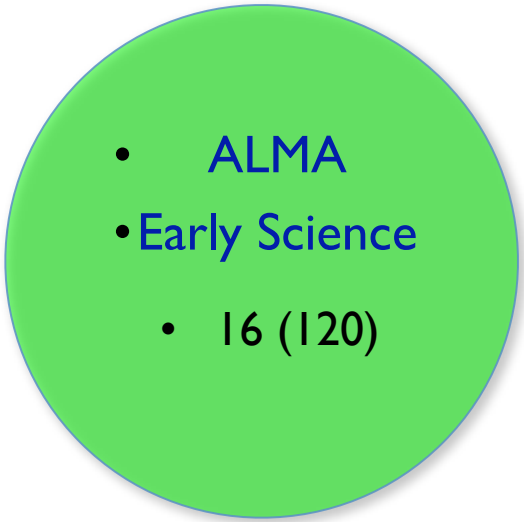

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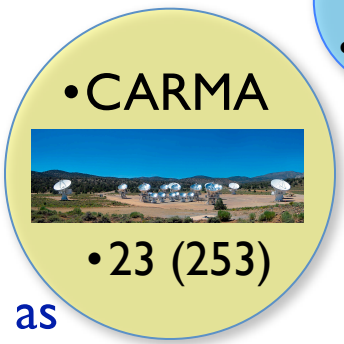
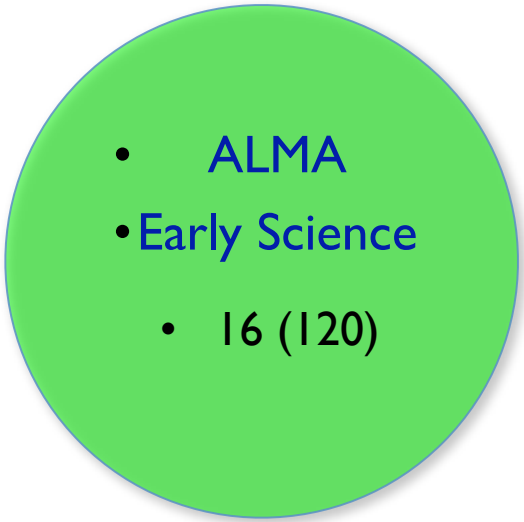


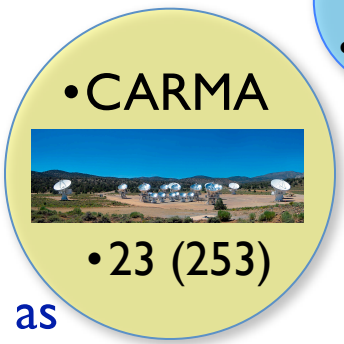
- Sensitivity goes as collecting area
- Imaging complexity goes as # of baselines

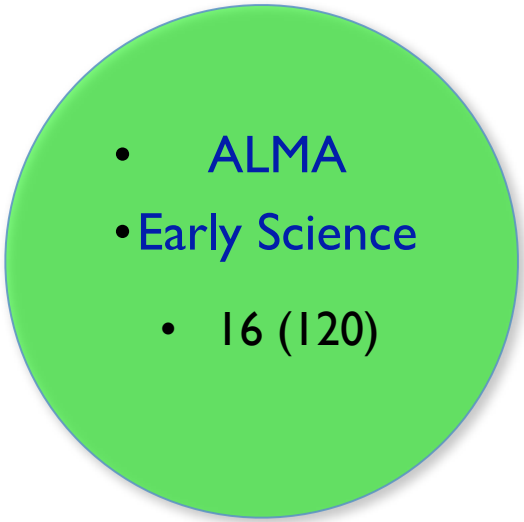


Comparison

NAASC

- **Collecting Area**

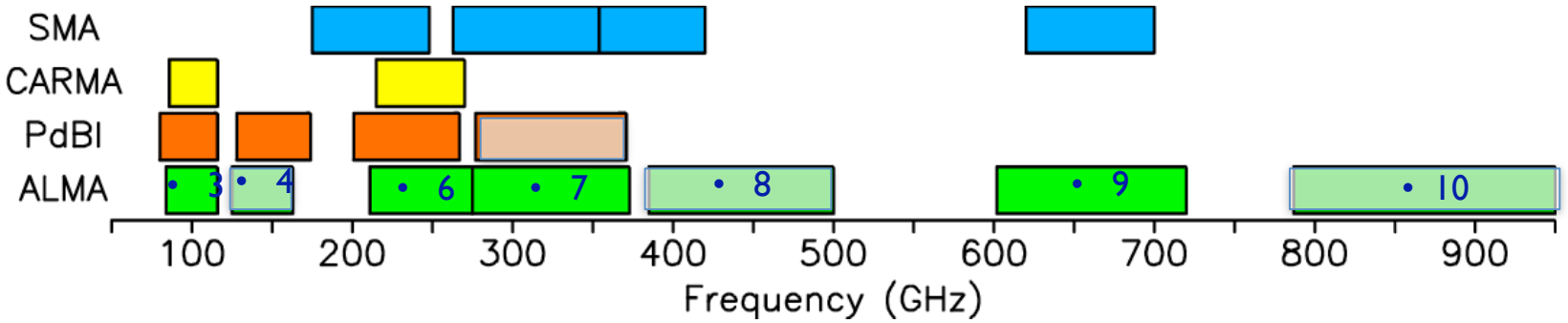




➢ Sensitivity goes as collecting area

➢ Imaging complexity goes as # of baselines

- **Spectral Coverage**



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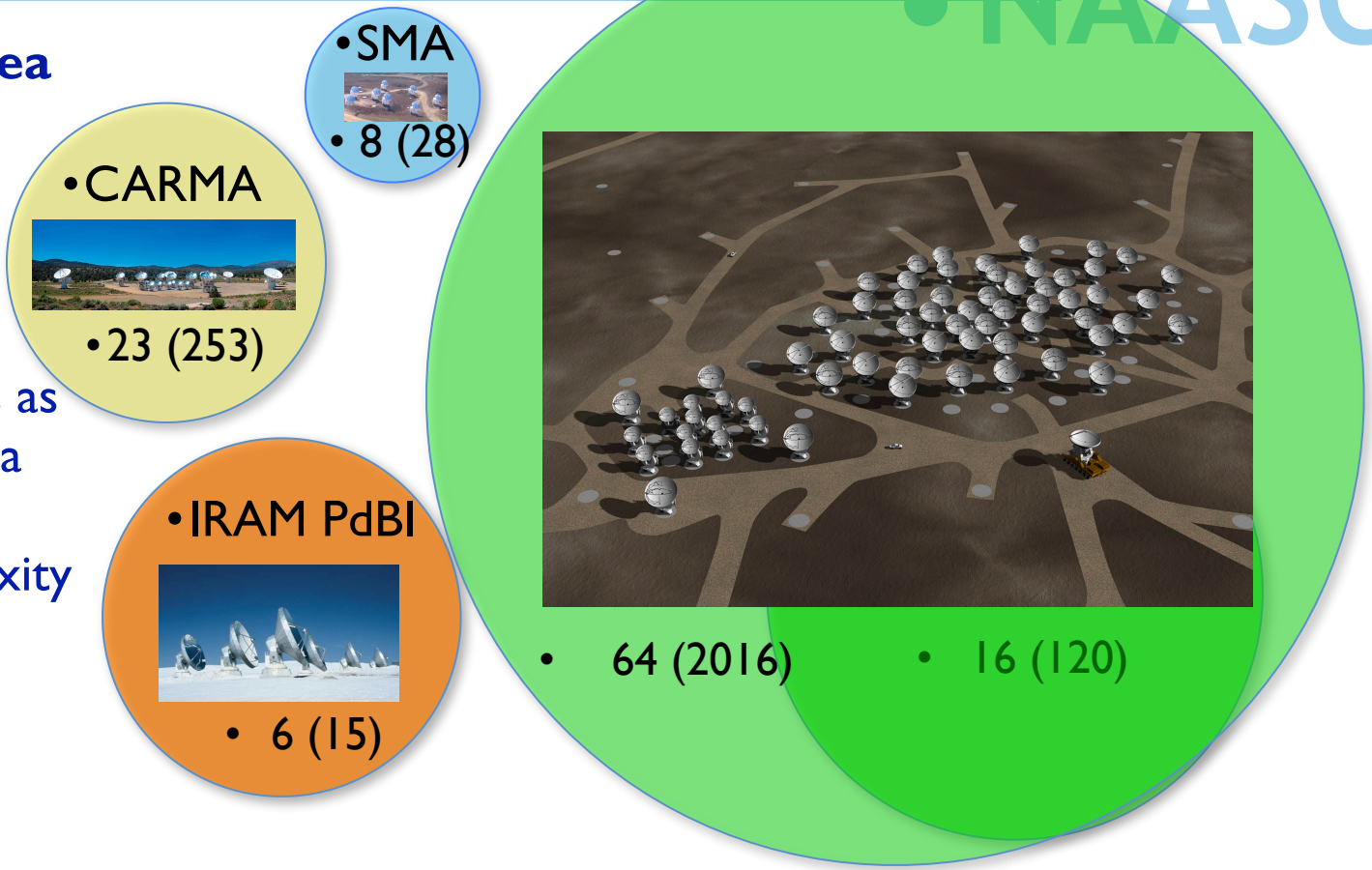

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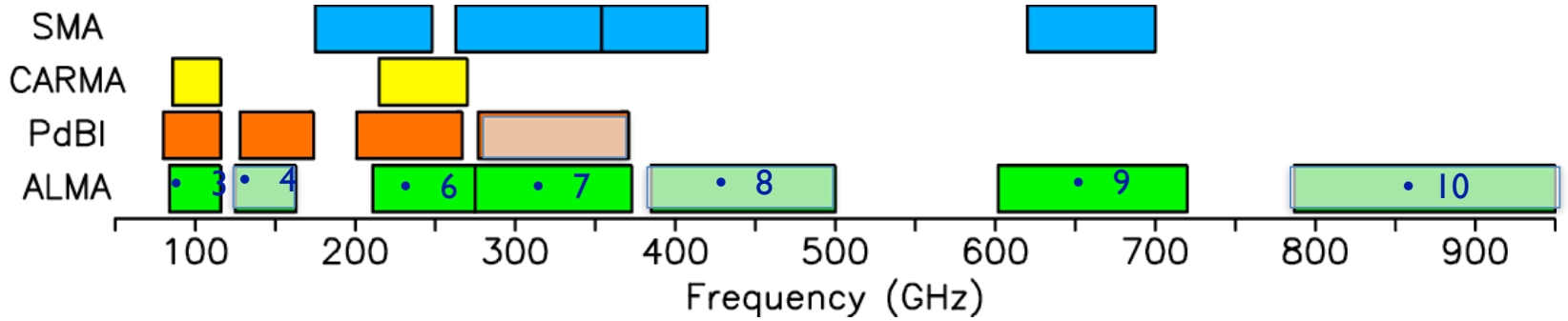
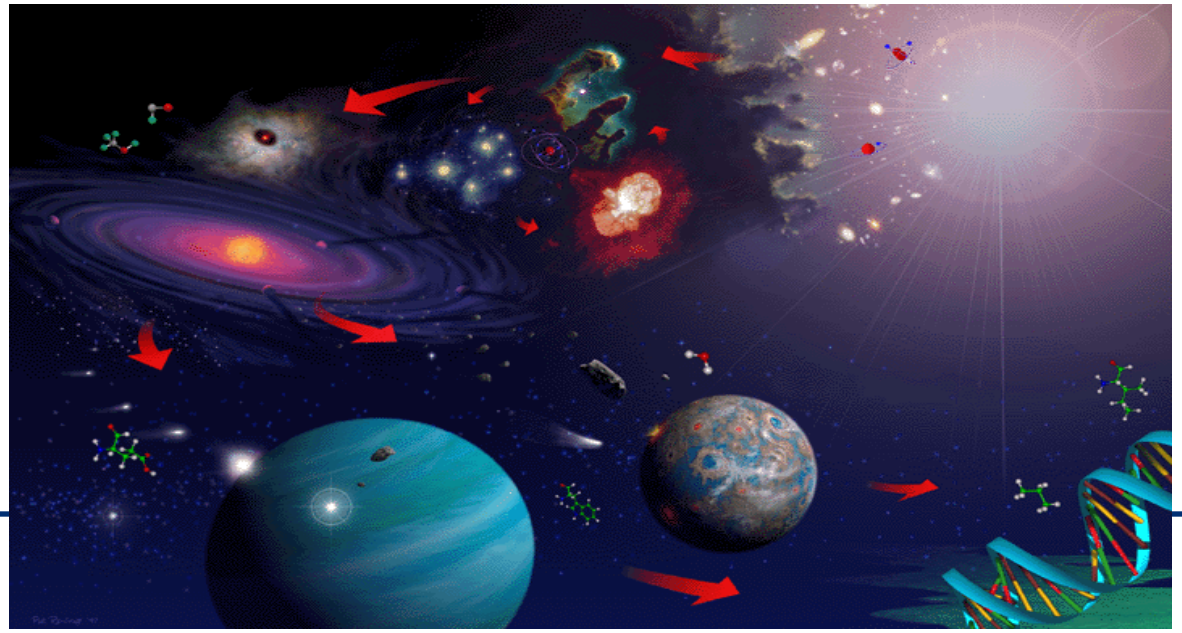
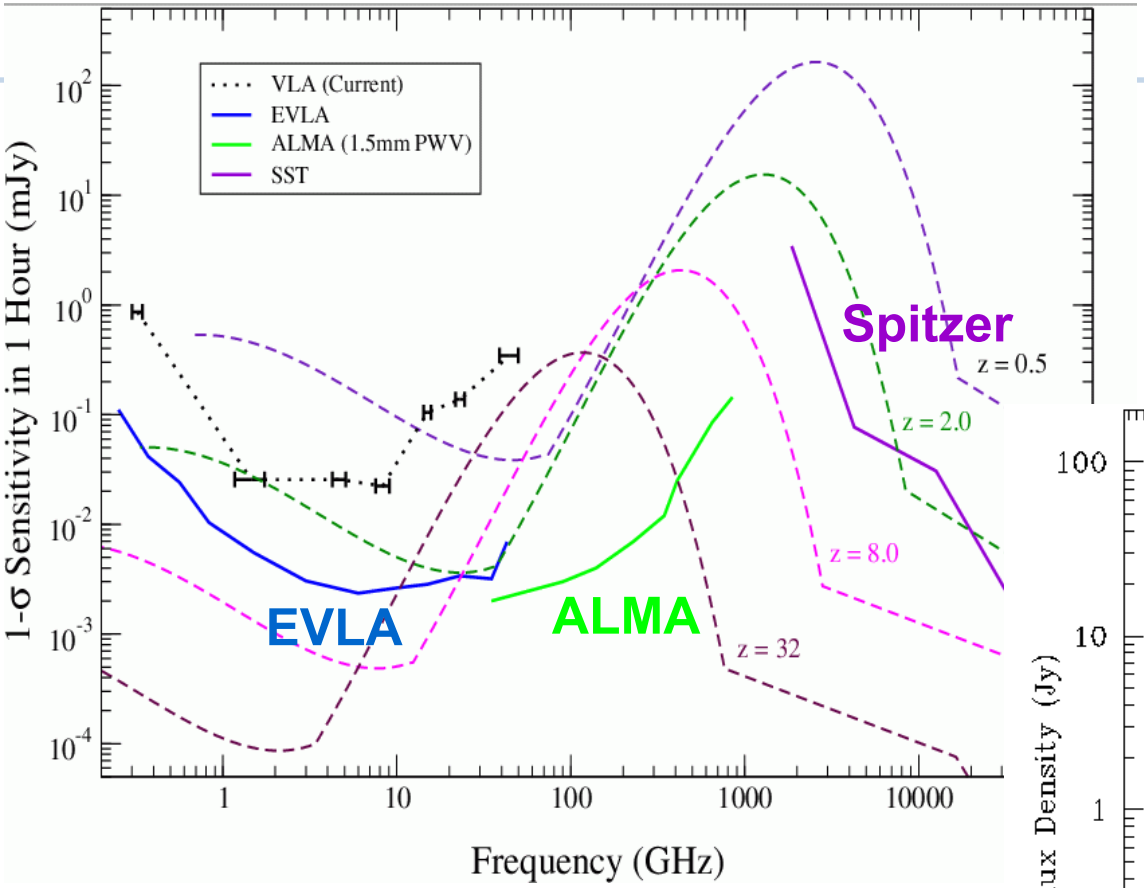


The Main SCIENCE Drivers of ALMA

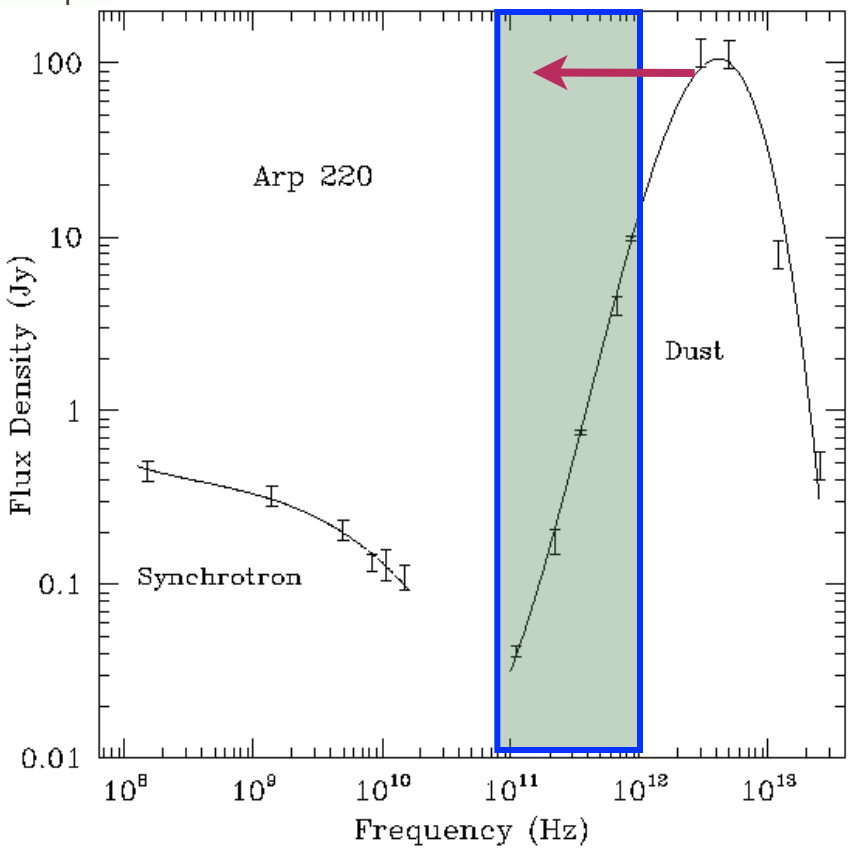
- ★ Origins of Galaxies: Molecular gas in the Milky Way 10 Gyr ago (at z = 3) in less than 24 hours of observation.
- ★ Origins of Planetary Systems & Planets: Gas kinematics in a solar-mass protostellar/ protoplanetary disk at a distance of 150 pc.
- ★ Exquisite Sensitivity & Resolution: Precise images at an angular resolution of 0.1" at 0.1% peak brightness.





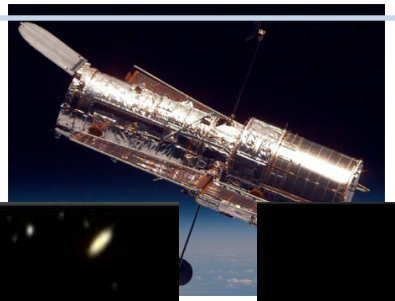
Detect high-z galaxies as easily as those at z~0.5

SED peak shifts to ALMA as z increases

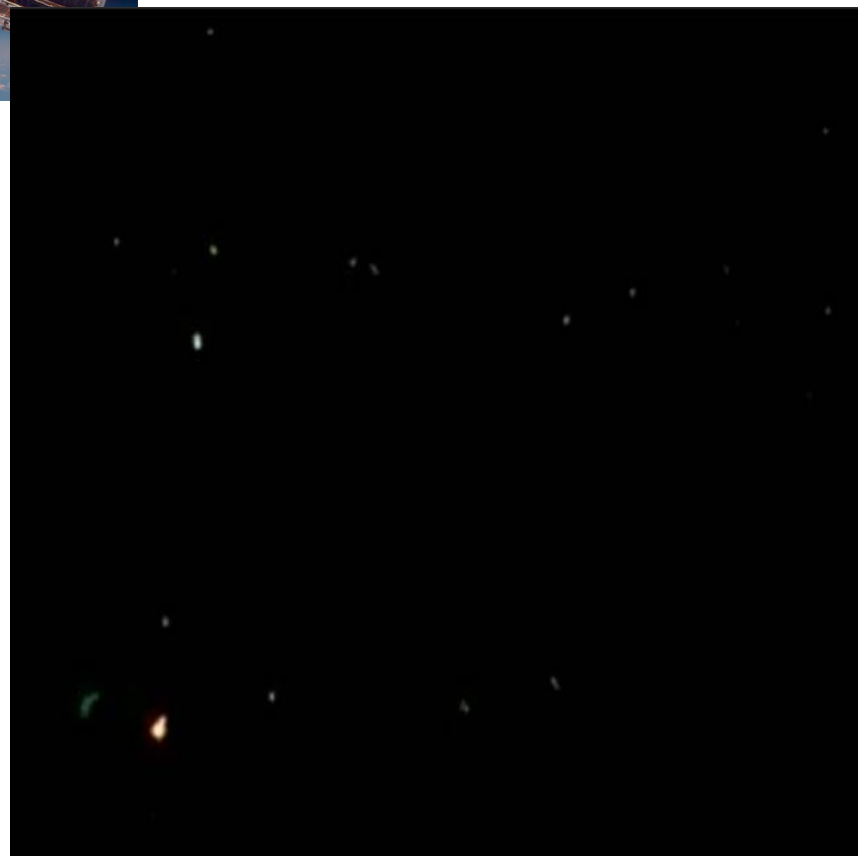


The Power of ALMA!

What Hubble Sees:



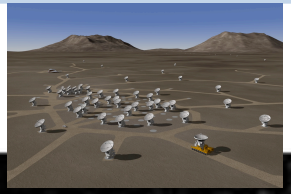
HDF Nearby Galaxies

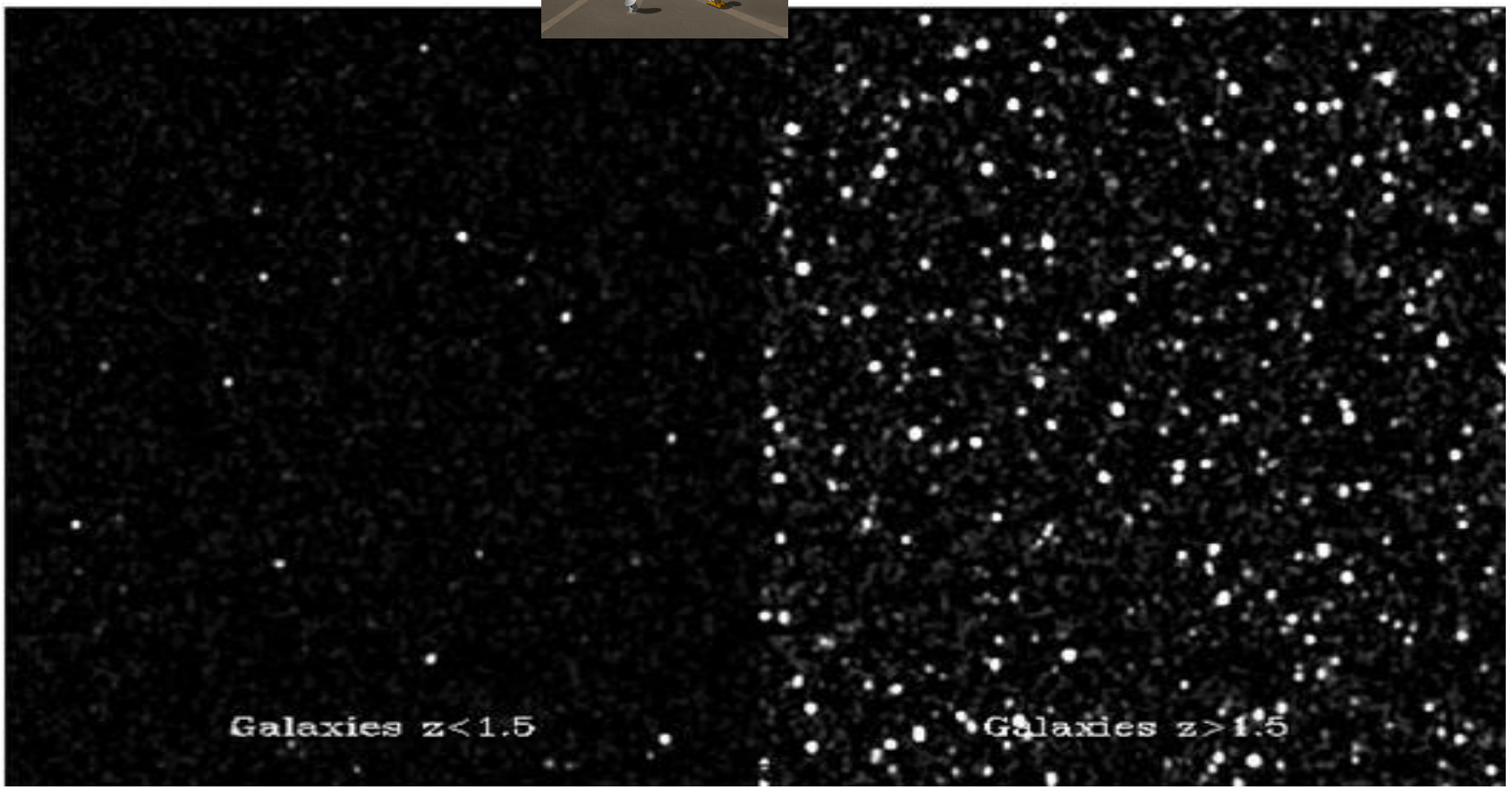


HDF Distant Galaxies
z > 0.5

The Power of ALMA!

What ALMA will see:





HDF Nearby Galaxies

HDF Distant Galaxies
z > 0.5

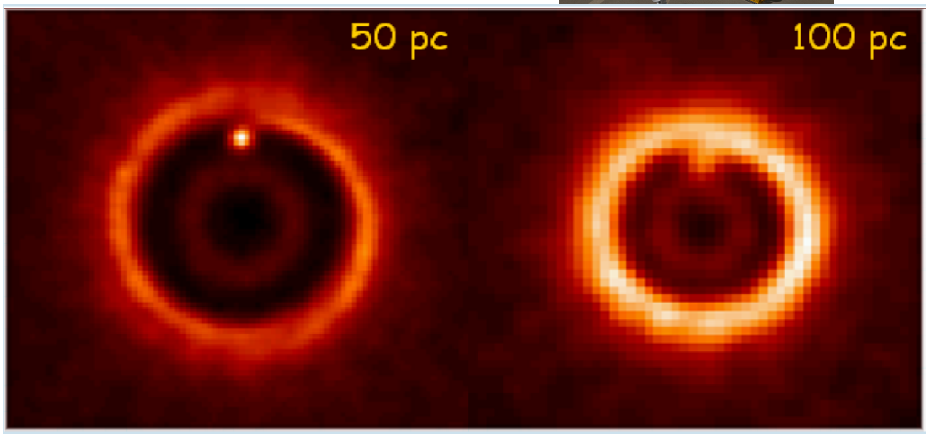
ALMA & Planets!

Simulation of a 950 GHz dust emission from a Jupiter at 0.5 solar mass star at 5 AU

Disk mass ~ Butterfly star in Taurus

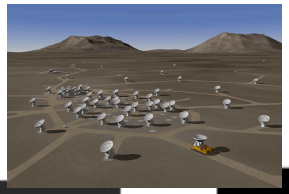
8 hr integration, 10 km baselines

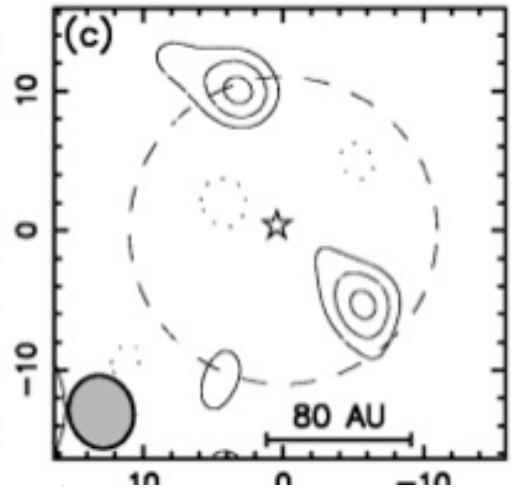
What ALMA will see:

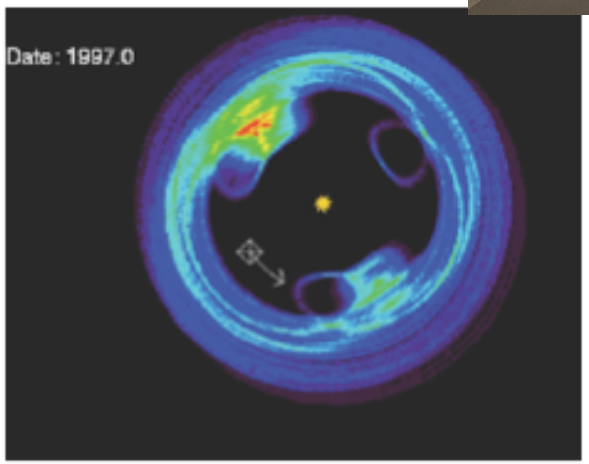


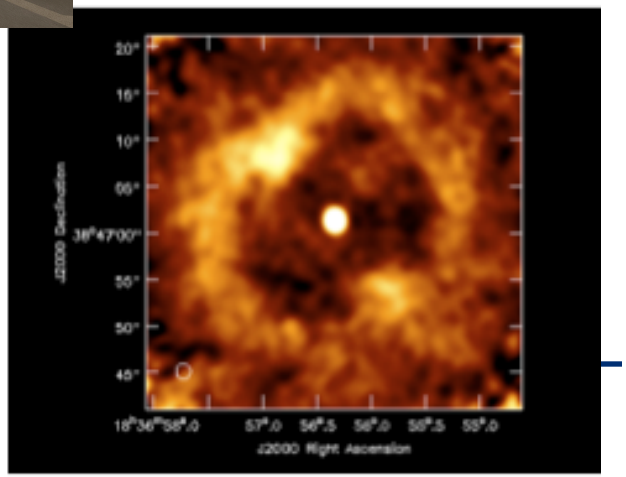
Wolf & D'Angelo 2005

Similar simulation for the Vega debris disk

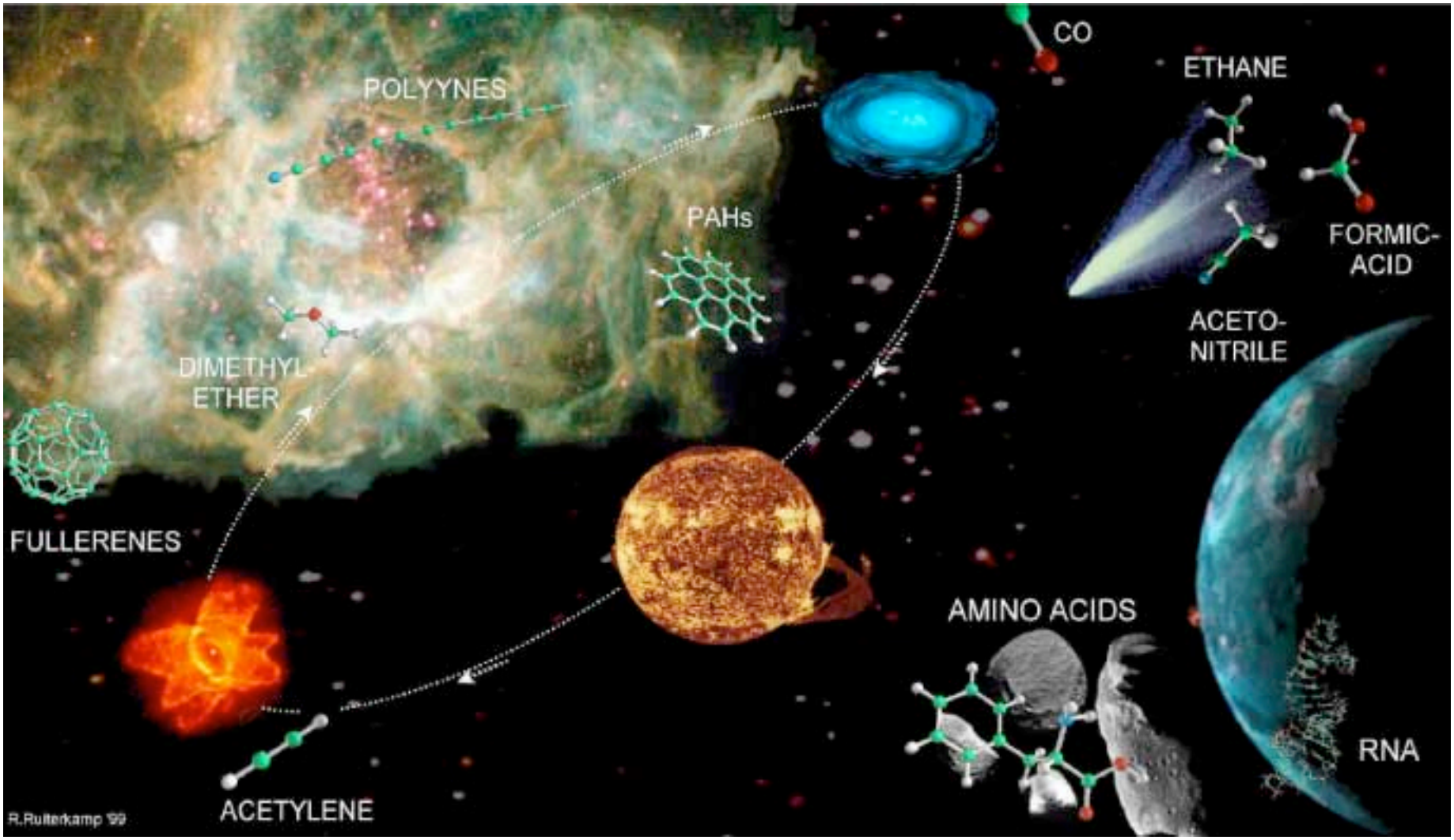








ALMA & Chemistry!

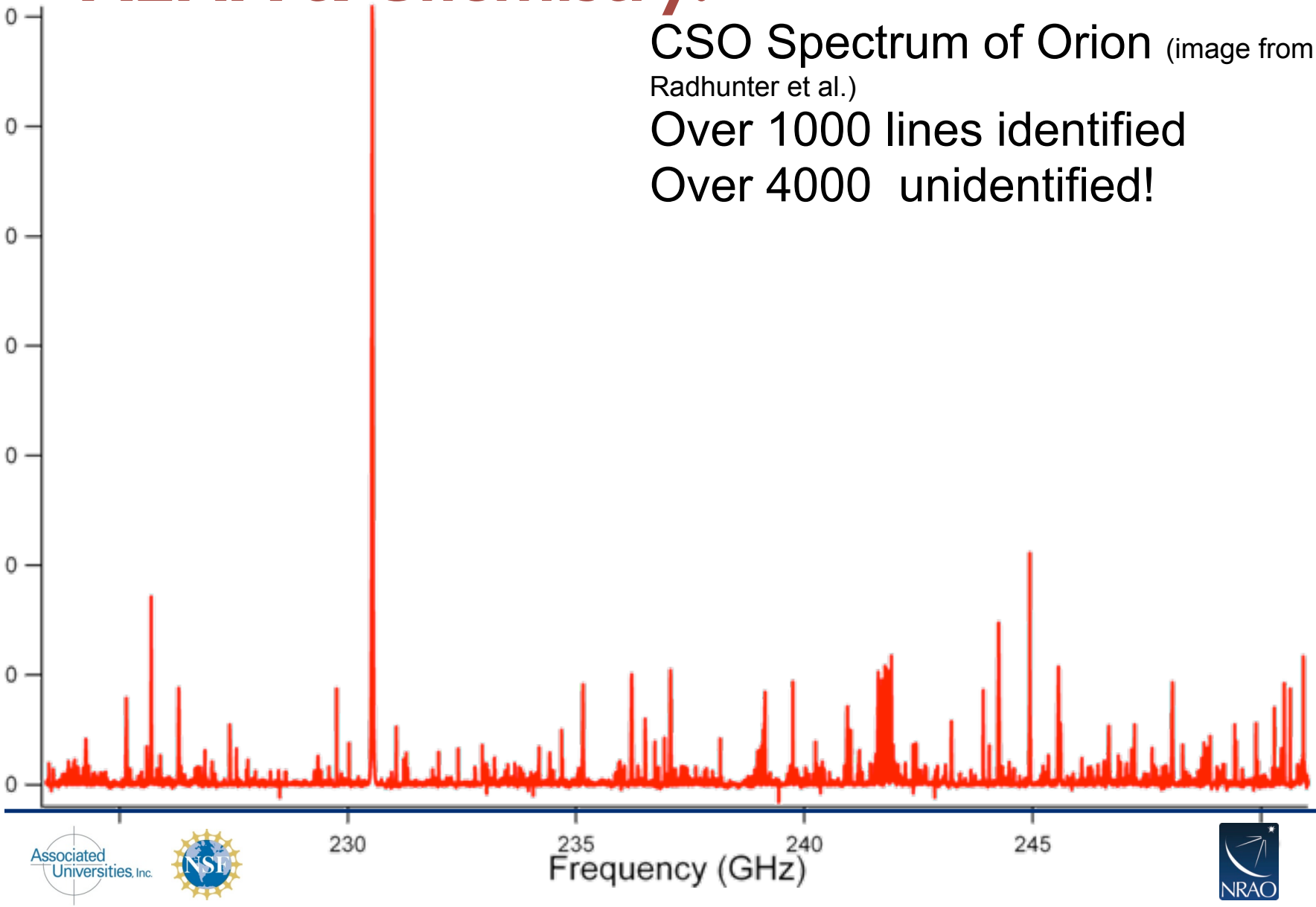


ALMA & Chemistry!

CSO Spectrum of Orion (image from: Radhunter et al.)

Over 1000 lines identified

Over 4000 unidentified!



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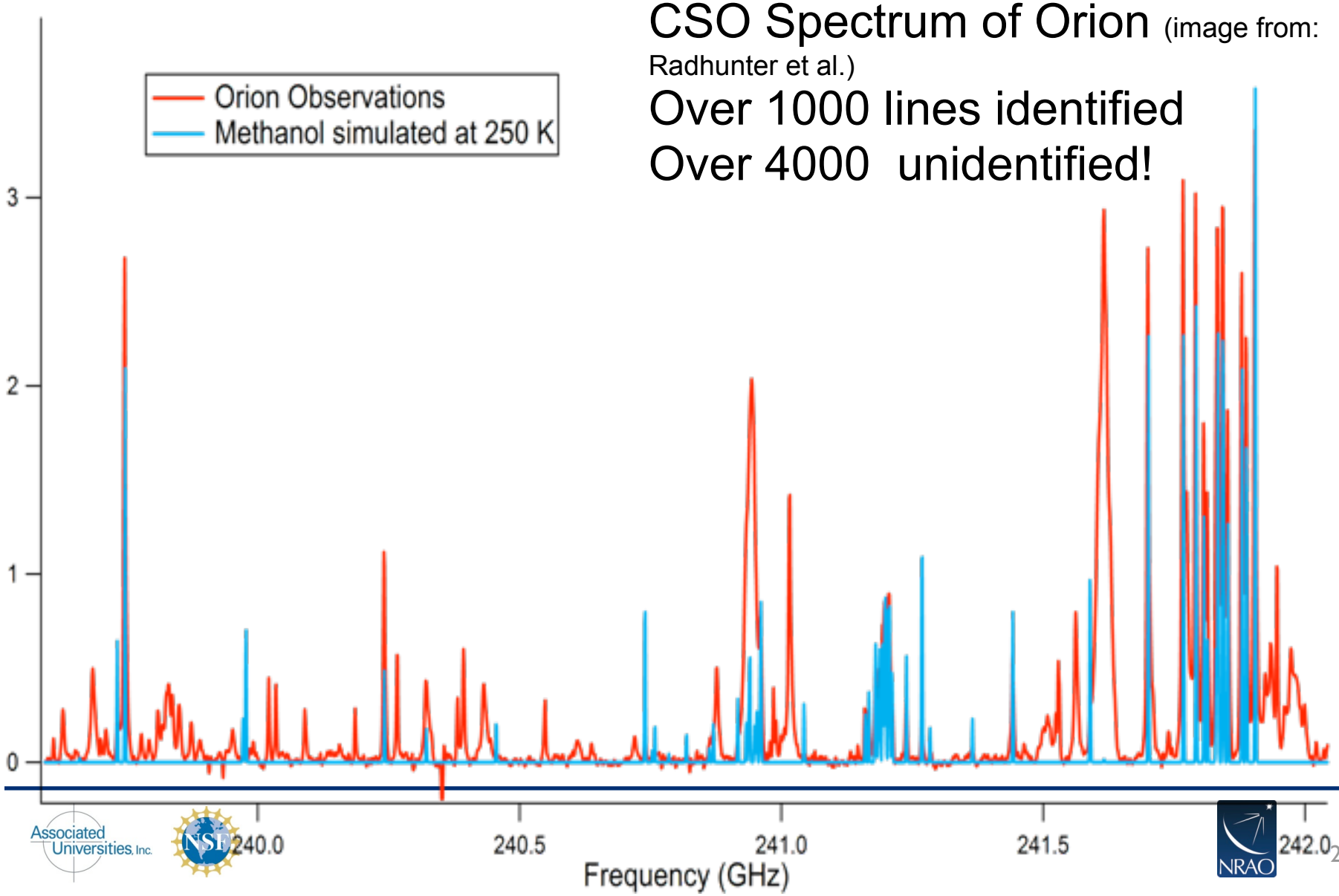

ALMA & Chemistry!

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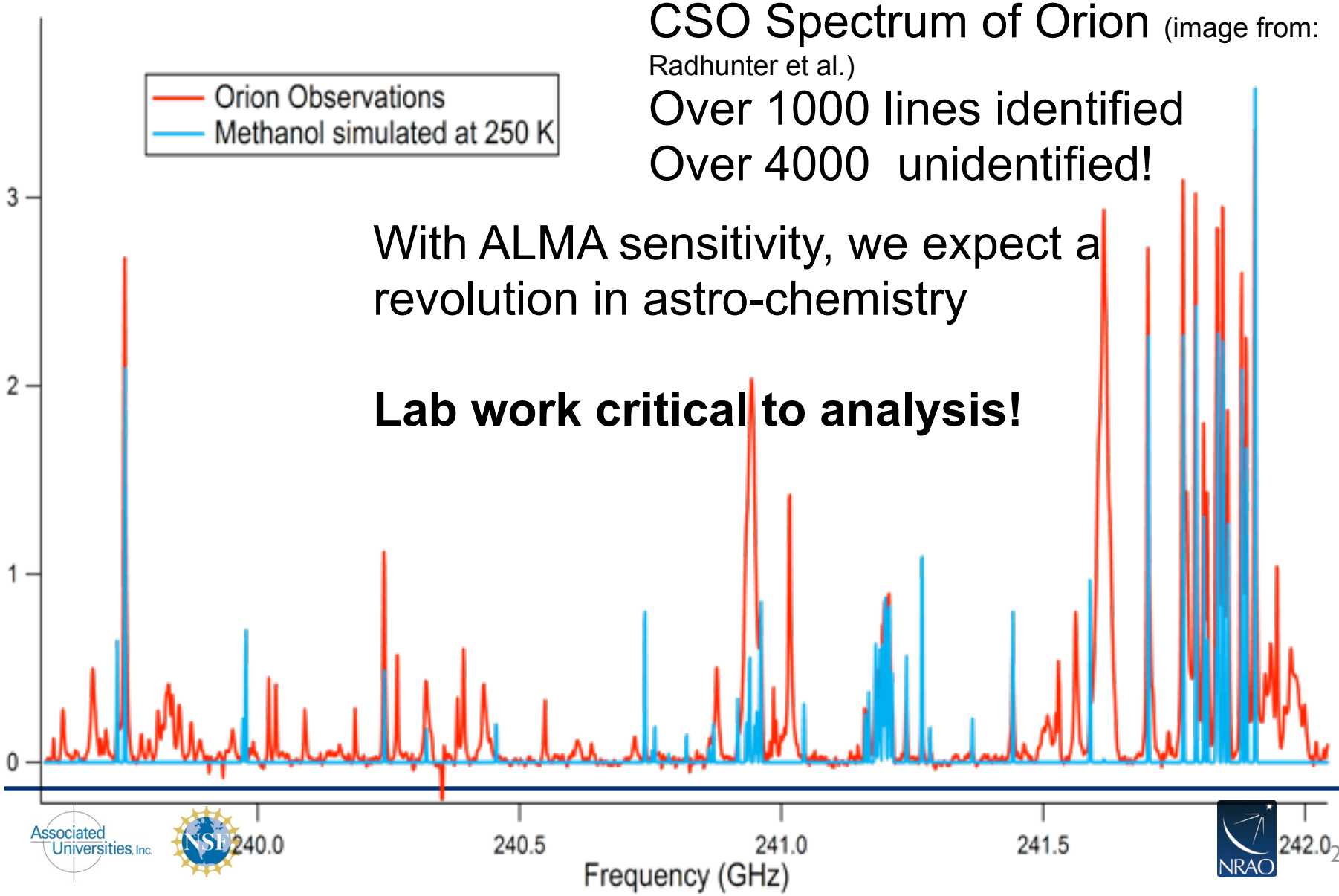
With ALMA sensitivity, we expect a revolution in astro-chemistry

Lab work critical to analysis!



Pushing the Limits of Discovery!

- Requires:
  - High Fidelity Imaging
  - Routing sub-mJy / mK spectral sensitivity
  - Wide frequency coverage
  - Wide Field mosaicking
  - Sub-millimeter capability
  - Full polarization capability
  - Flexibility in hardware and software w/ technological advances

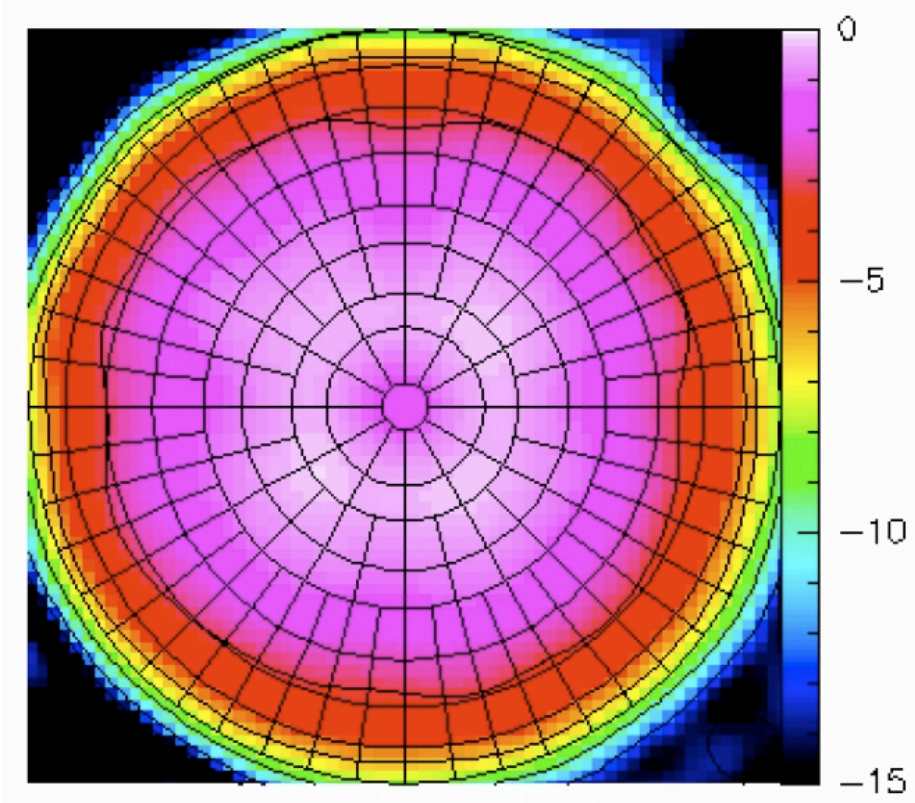
- 100x sensitivity of current telescopes
- 100x resolution -- better than Hubble!
- 2x wider frequency and bandwidth coverage

Pushing Technology!

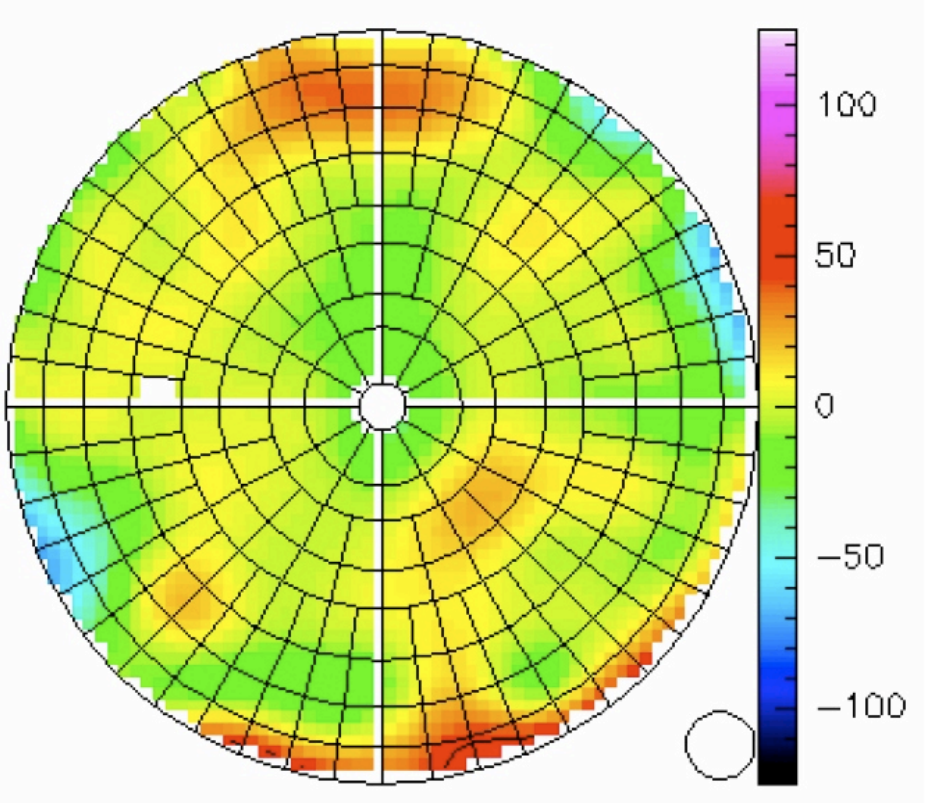
- Antenna design
  - < 15μm surface accuracy over 12m surface
  - Fast pointing and settle times
  - Performance in some harsh weather conditions

Astronomical Holography

3C279 at 81° elevation



- Illumination



- Surface

Teams Trained for Panel Setting

Pushing Technology!

- Cryogenics / Electronics / Optics / Correlator:
  - Dewars need to be maintained at 4K at the site for 66 antennas!
  - Receivers are completely electronically tunable.
  - Line-lengths corrections require 10 femtoseconds accuracy over 10 km for coherent interferometry at THz frequencies!
  - Digitize & process at a rate of 1.7×10^{16} operations per second!

BAND 4 BAND 8

Correlator First Quadrant at AOS

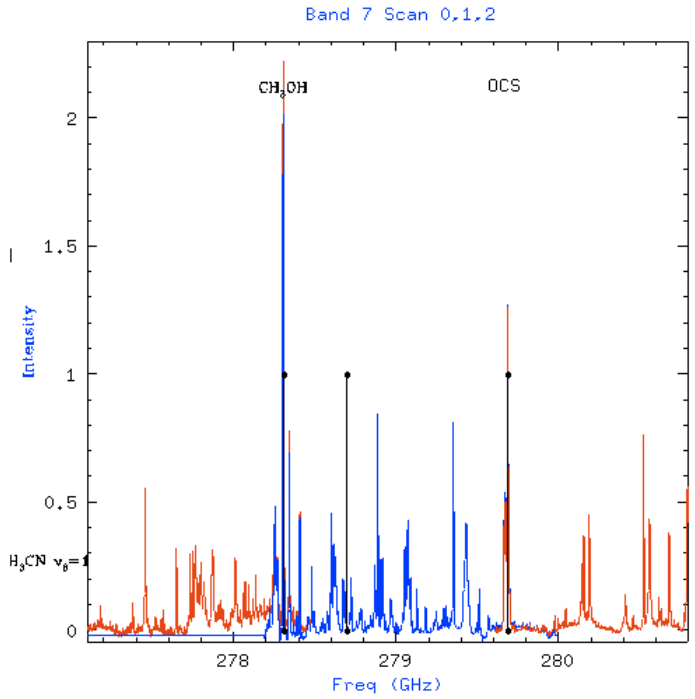
Pushing Technology!

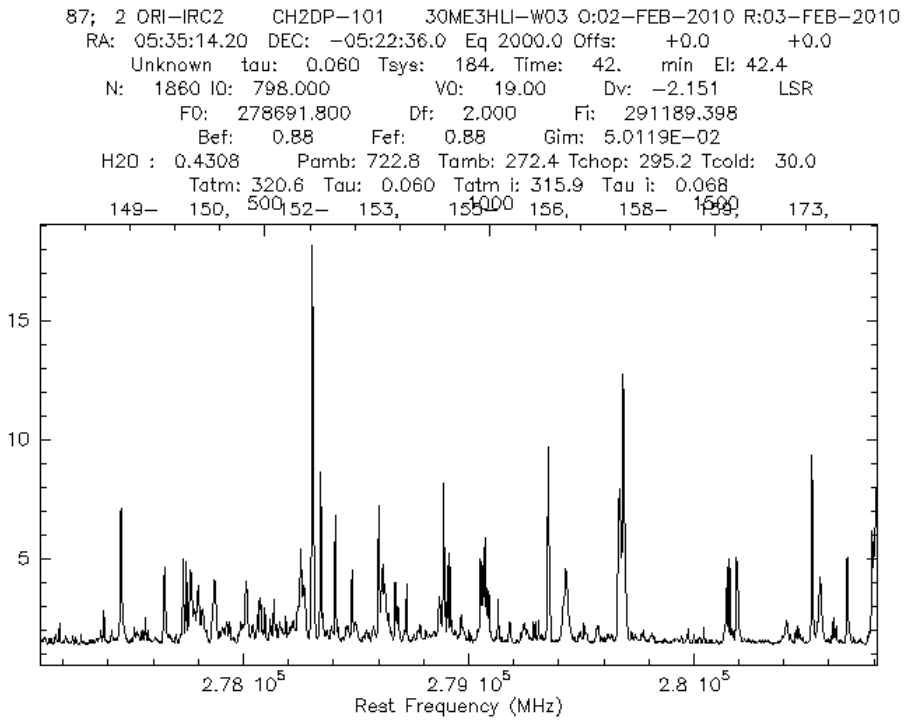
- Material Science / Solid State physics
- (Charlottesville: NRAO's National Technology Center CDL + UVA Micro-fabrication Lab)

  - State of the art SIS junctions
    - Low noise temperature ~ few x quantum limit
    - Broadest RF and IF bandwidths (8 Ghz!)
    - Largest use of superconducting technology!

Recent Band7 (345 GHz) Spectrum of Orion

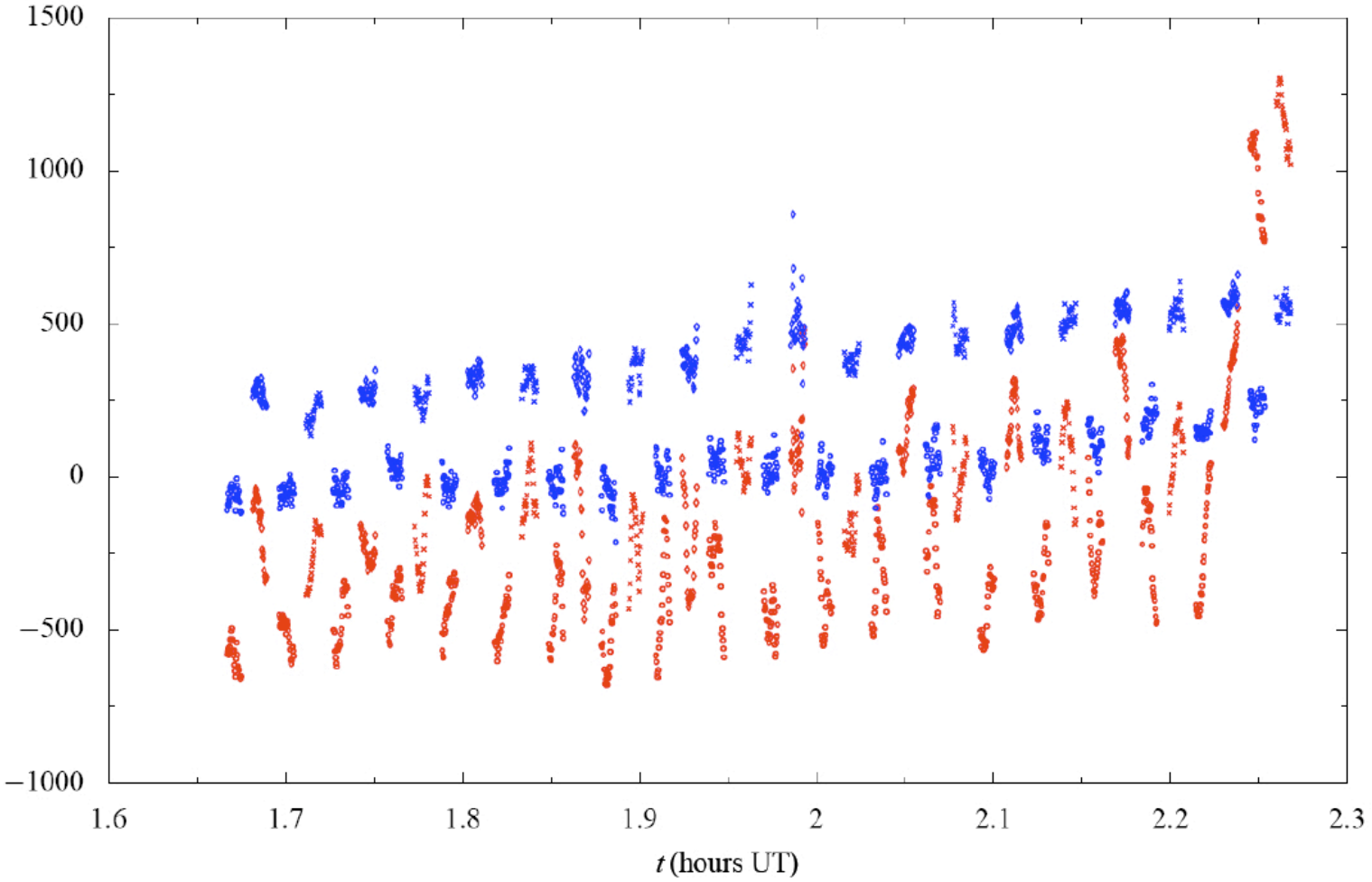
Comparison with IRAM 30m





Water Vapor Correction

Cycling between 3C273, 3C279, Pluto; blue=corrected

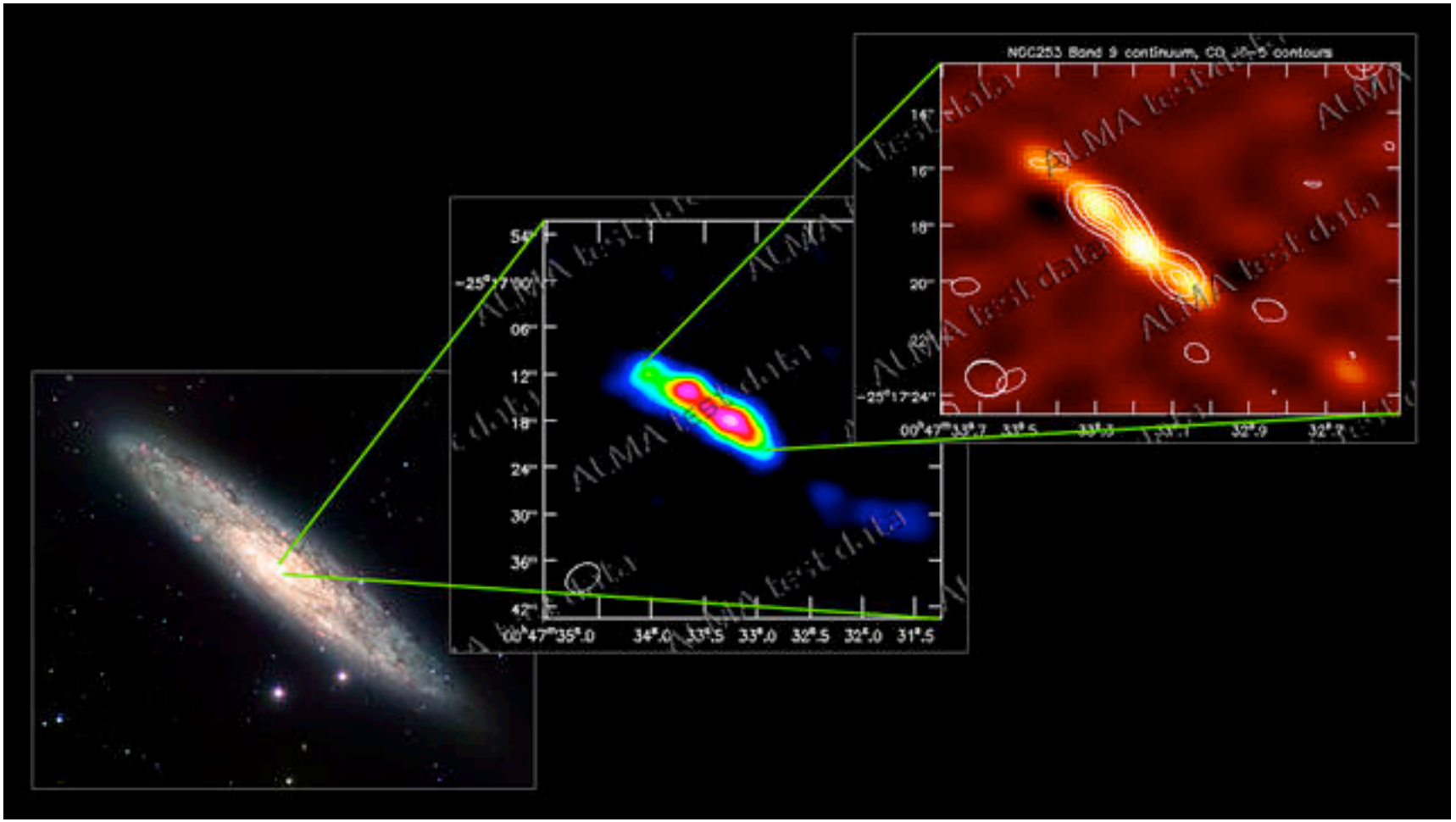


Software vs Hardware!

- Software / Computing
  - New releases every 6 months for control software
    - C++, Java, Python
  - Reduction Analysis Software - CASA (scriptable)
    - casaguides.nrao.edu
    - Parallelization challenges ahead
  - Data Archive
    - Mirrored at each ARC
    - NA users will use NAASC archive to submit re-processing requests
    - Visitors expected every week to the NAASC

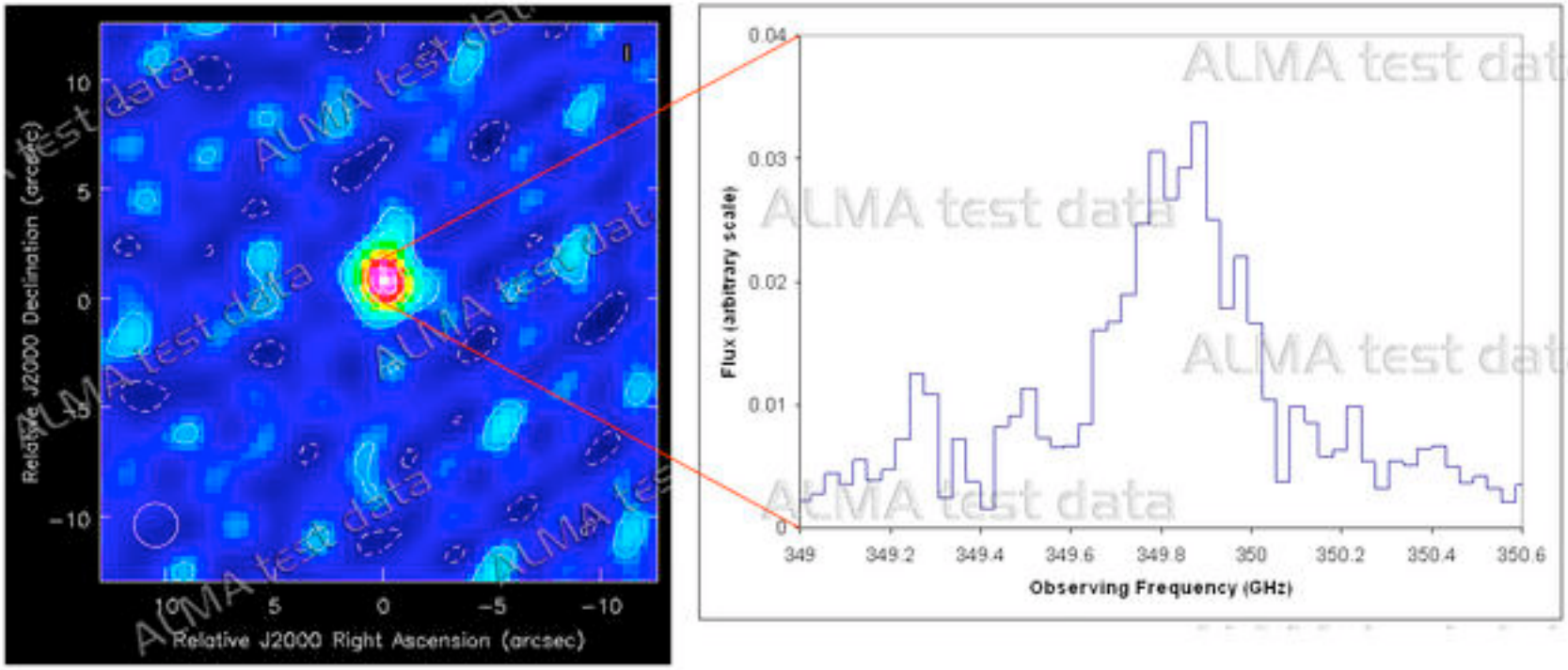
ALMA is HERE and it "works"!

ALMA is HERE!



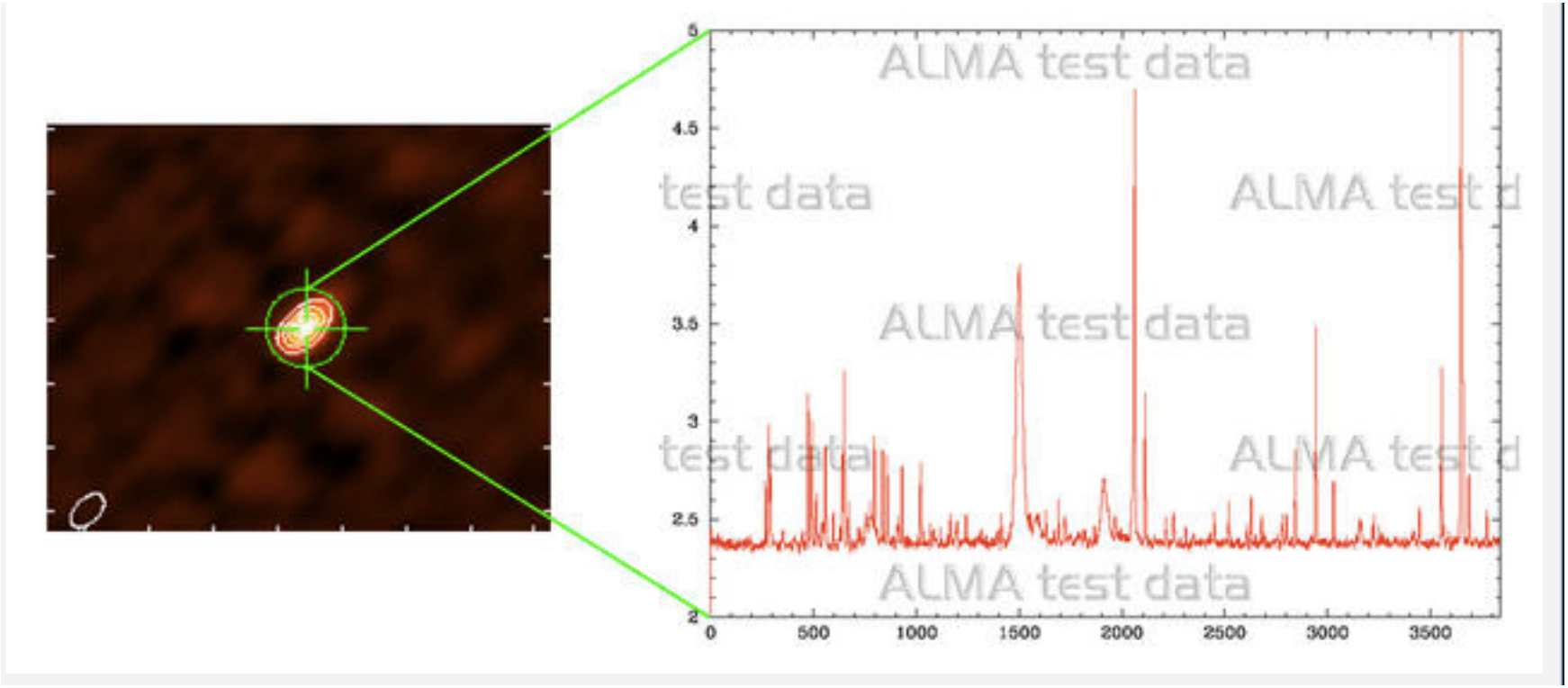
NGC 253 - Band 3: CO (2-1) and Band 7: Continuum + CO(6-5)

ALMA is Here!



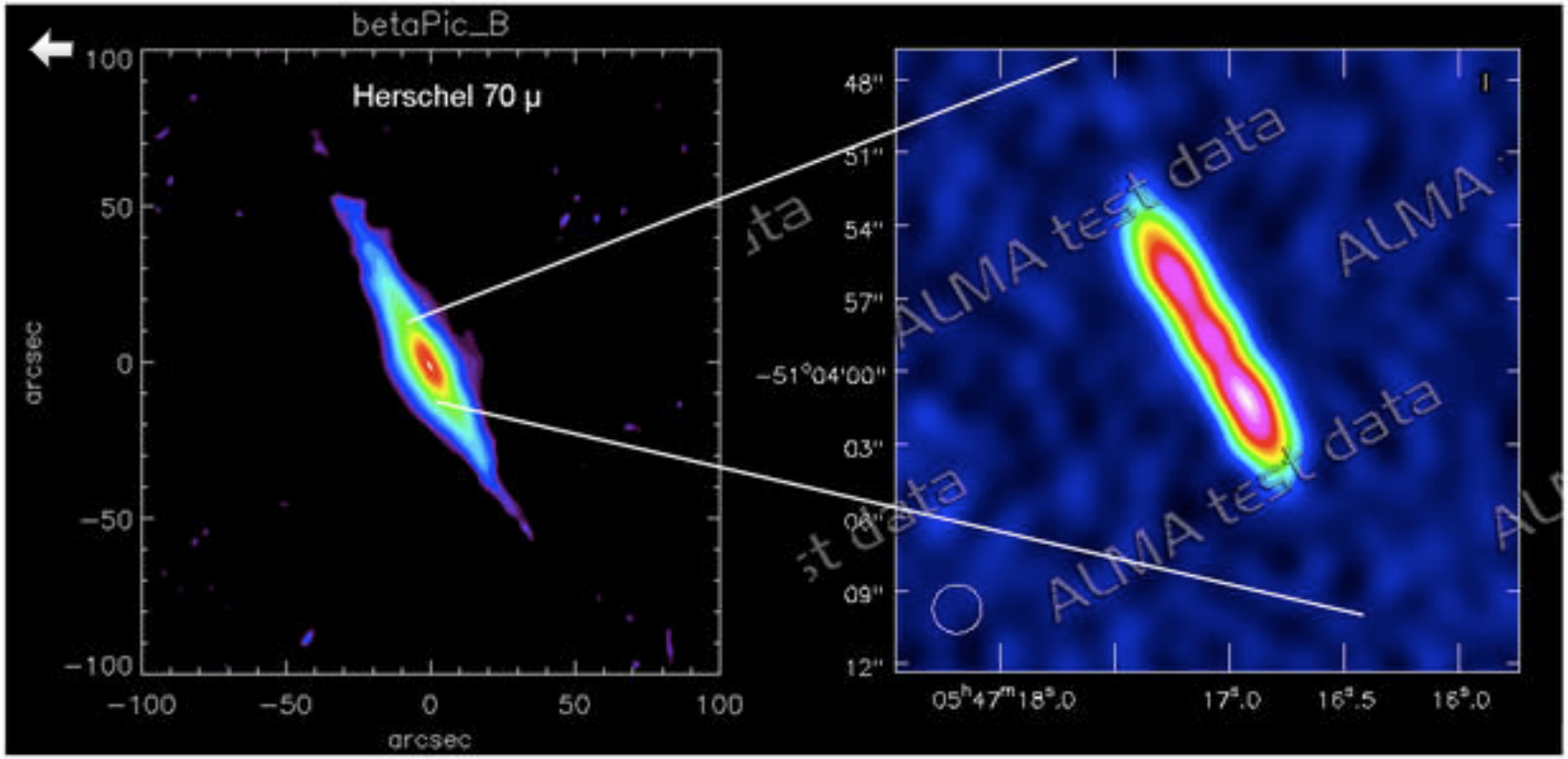
Ionized Carbon (CII @ 158 microns) detected in 1 hr on BRI 0952-0115 at z=4.43

ALMA is Here



Hot core of G34.26+0.15 at 3mm - lots of molecular lines detected

ALMA is Here



Beta Pic disk: Herschel on left and 870 micron dust emission from ALMA!

Timeline & Board Statement

May 2009	Fringes between 2 antennas at OSF
Late 2009	Commissioning Began with 3-element array at AOS
Nov 12, 2009	Phase closure with 3 antennas!
2010-2012	Commissioning and Science Verification
Nov 2010	Observing with 8 antennas!
Jan 2011	Call for *Science Verification*
Mar 31 2011	**Early Science Proposals**
Jun 30 2011	**Deadline for ES proposals**
Late 2011	Start of ES observations

*** Off-line data reduction (NO AUTOMATED PIPELINE)**

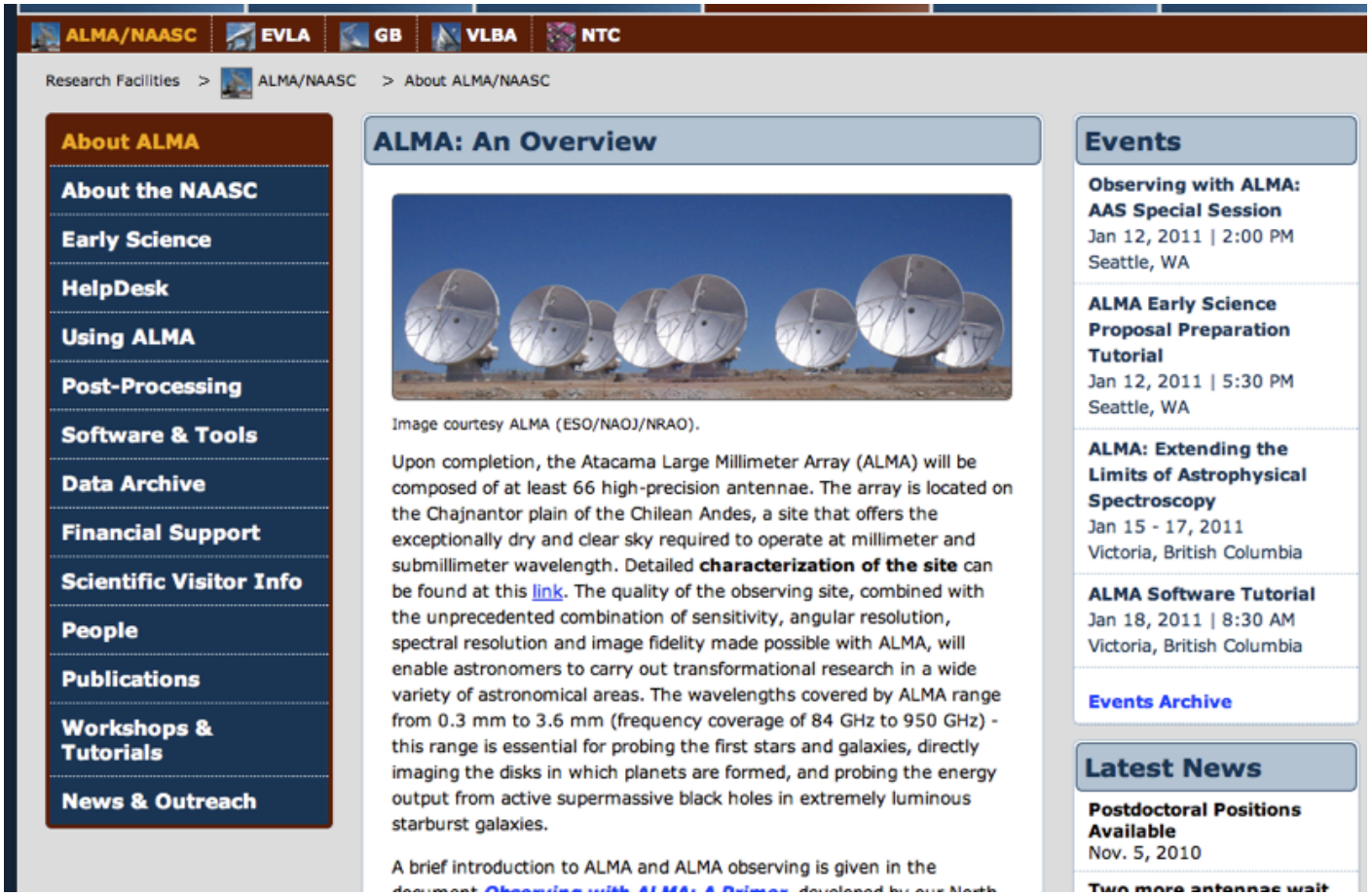
ALMA Early Science

- Early Science proposals with LIMITED capability (compared to full ALMA)
  - First Call for Proposals covers first 9 months of observing
  - NA gets a third of available of the time (~200 of 600 hrs)
  - 16 antennas with 4 bands (3,6, 7 and 9)
  - ~250m baselines (~ 0.4" at highest frequencies)
  - Subset of observing modes
  - 21 correlator setups
- NOTE: 16 ants = limited UV-coverage so careful w/ imaging projects
- Large surveys, large maps may be difficult especially in Early Science (CCAT)
- Blind redshift surveys for high-z ~ 1 hr per source at ES

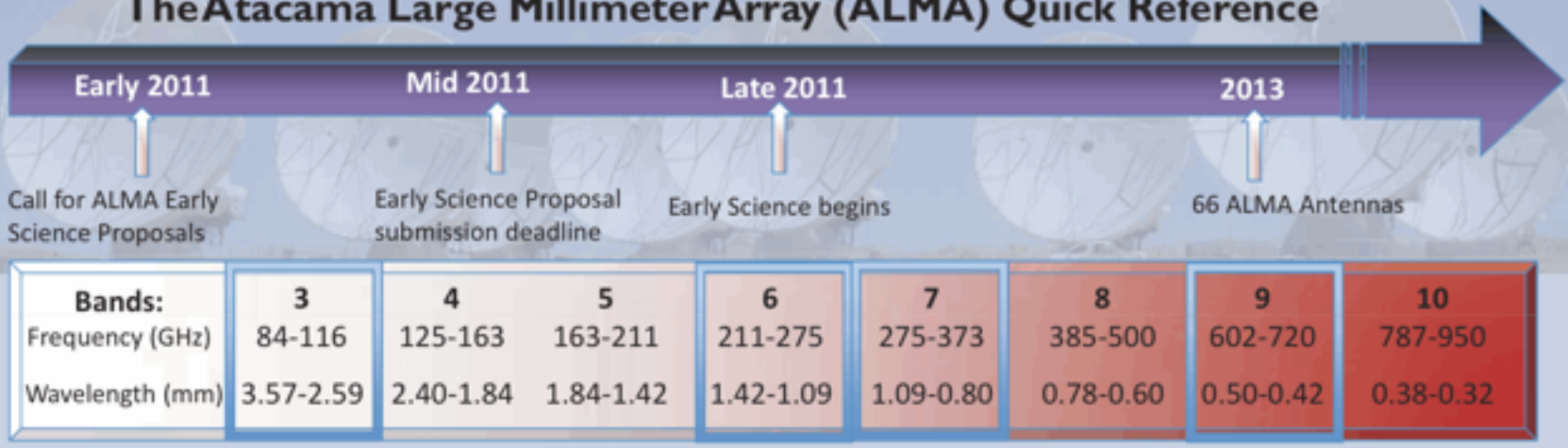
ALMA is already the most powerful mm/submm telescope!

What you need to know?

- ALMA One-Stop Webpage: http://science.nrao.edu/alma
- ALMA Primer & Mousepad



The Atacama Large Millimeter Array (ALMA) Quick Reference



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

	Early Science	Array Completion
Antennas	≥16 x 12m	At least 54 x 12m & 12 x 7m
Bands	Bands 3, 6, 7, 9	Bands 3, 4, 6, 7, 8, 9 & 10
Maximum Bandwidth	16 GHz (2 polarizations x 8 GHz)	
Correlator Configurations	21 (0.02 – 40 km/s)	71 (0.01 – 40 km/s)
Maximum Angular Resolution	$0.02'' \left(\frac{\lambda}{1\ \text{mm}}\right) \left(\frac{10\ \text{km}}{\text{Max Baseline}}\right)$	
Max Baseline	250m (may achieve 500m)	15 km
Continuum Sensitivity (60 sec, Bands 3–9)	~0.2 – 4.2 mJy	~0.05 – 1 mJy
Spectral Line Sensitivity (60 sec, 1 km/sec, Bands 3–9)	~30 – 250 mJy	~ 7 – 62 mJy

Sensitivity Calculator: http://science .nrao.edu/alma/tools.html

NRAO ALMA ESO NAOJ

What you need to know?

- ALMA One-Stop Webpage: http://science.nrao.edu/alma
- ALMA Primer & Mousepad
- ALMA Helpdesk
- ALMA Observing tool to prepare / submit proposals
  - ALMA Sensitivity Calculator & Splatalogue (available inside OT)
- ALMA Simulator in CASA to simulate observations (Basic CASA)

How you can be involved…

Current job advertisements:

https://careers.nrao.edu
http://hr.almaobservatory.org/jobs/opportunities/

Propose for Science Verification

Organize Community Days

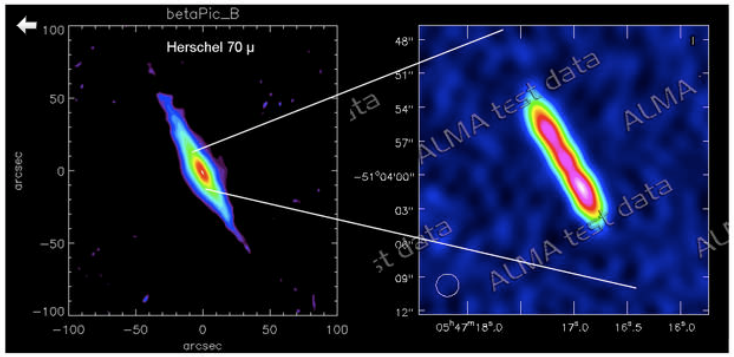
Propose during Early Science

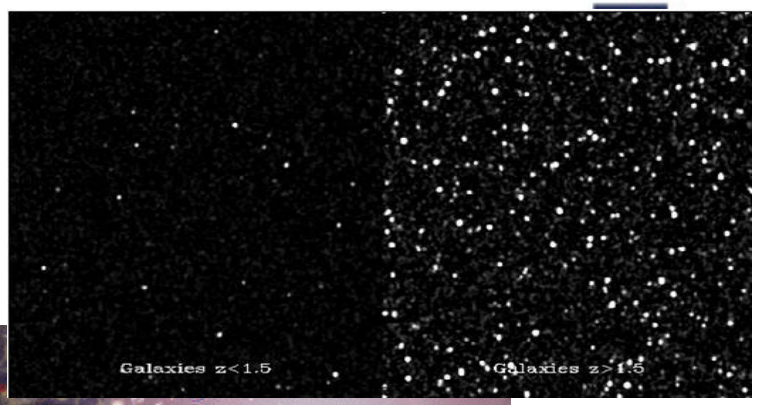
Visit NAASC after getting data

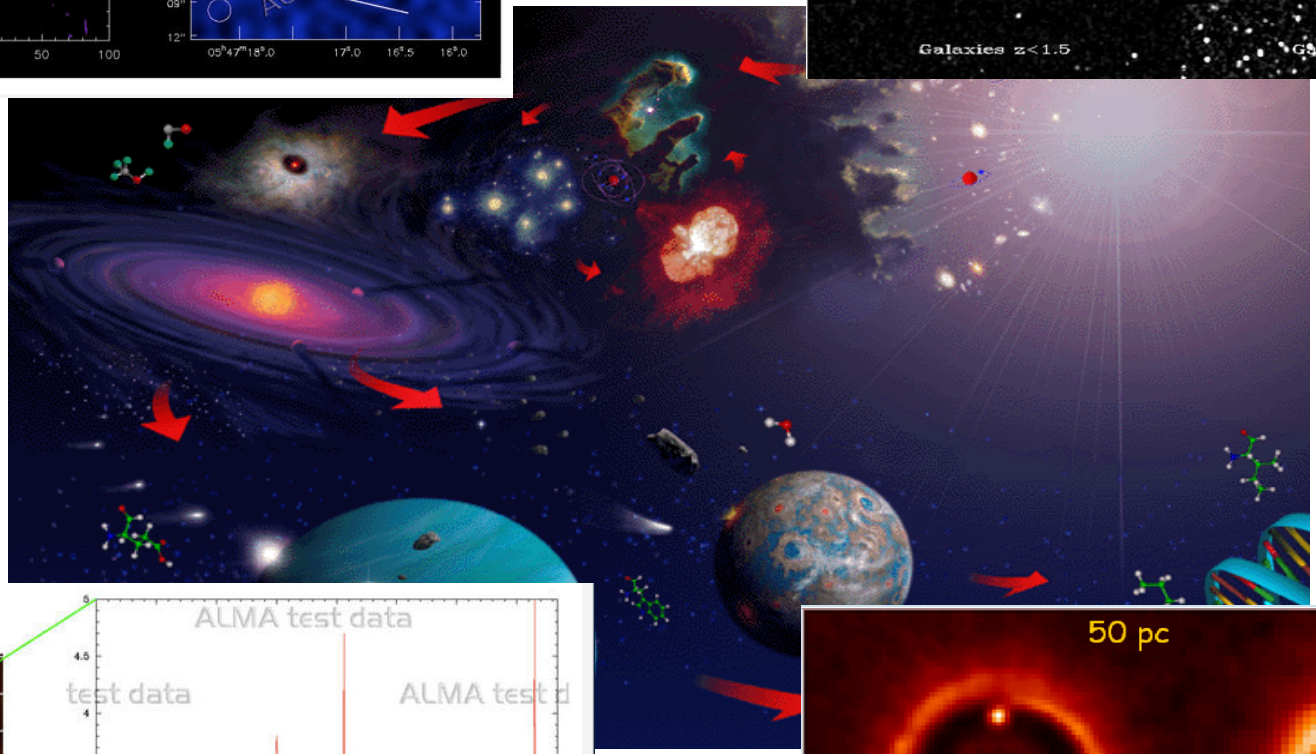
Sabbatical program for visitors with mm/submm expertise in Chile

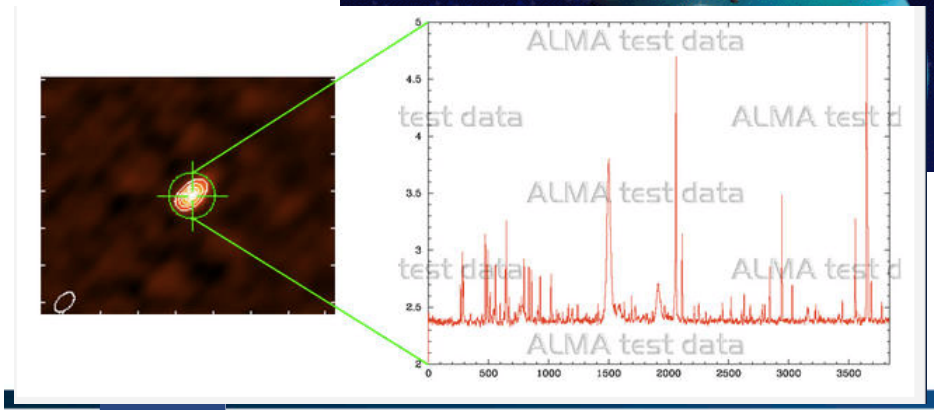
Events in the next few months

- Feb 24-25: Charlottesville, NRAO
- Mar 7: Philadelphia (U. Penn)
- Mar 11: Santa Fe, NM (Following "New Horizons" Conference)
- Mar 15-16: Pasadena (Caltech)
- Apr 18: Baltimore (STScI)
- Apr 20: Boston (Harvard - CfA)
- Apr 26-27: Charlottesville, NRAO
- May 2-3: Gainesville (U. Florida)
- May 9-10: Iowa City, (U. Iowa)
- May 9-10: Charlottesville, NRAO
- May 12-13: Tucson (U. Arizona / NOAO)
- May 23-24: Boston (AAS)
- May 27: New York City (Columbia)


betaPic_B
Herschel 70 μ
arcsec
ALMA test data
ALMA


Galaxies z<1.5
Galaxies z>1.5




ALMA test data
test data
ALMA test data
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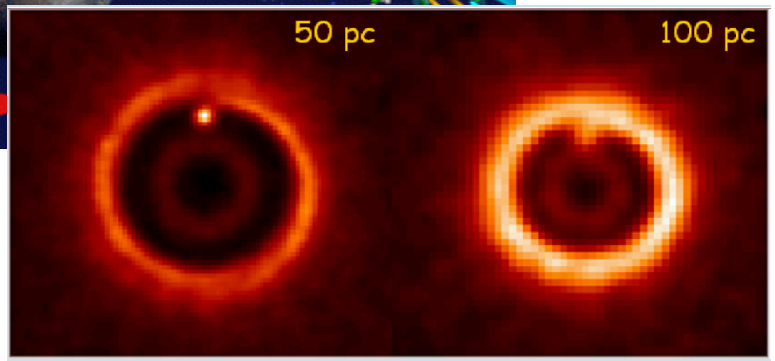
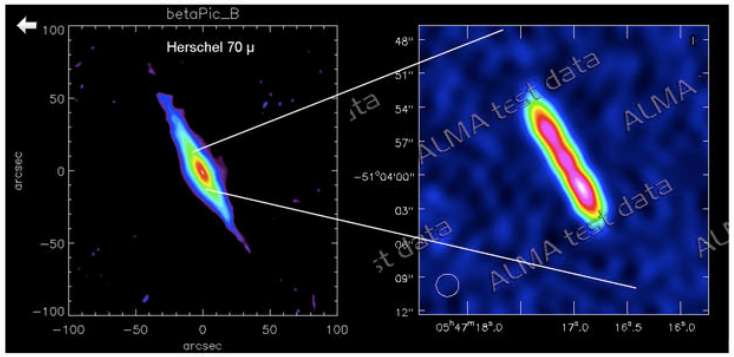
ALMA test data


50 pc
100 pc



ALMA will be a revolutionary telescope, a great observatory for understanding our ORIGINS