

The Atacama Large Millimeter Array (ALMA)



Kartik Sheth

National Radio Astronomy Observatory

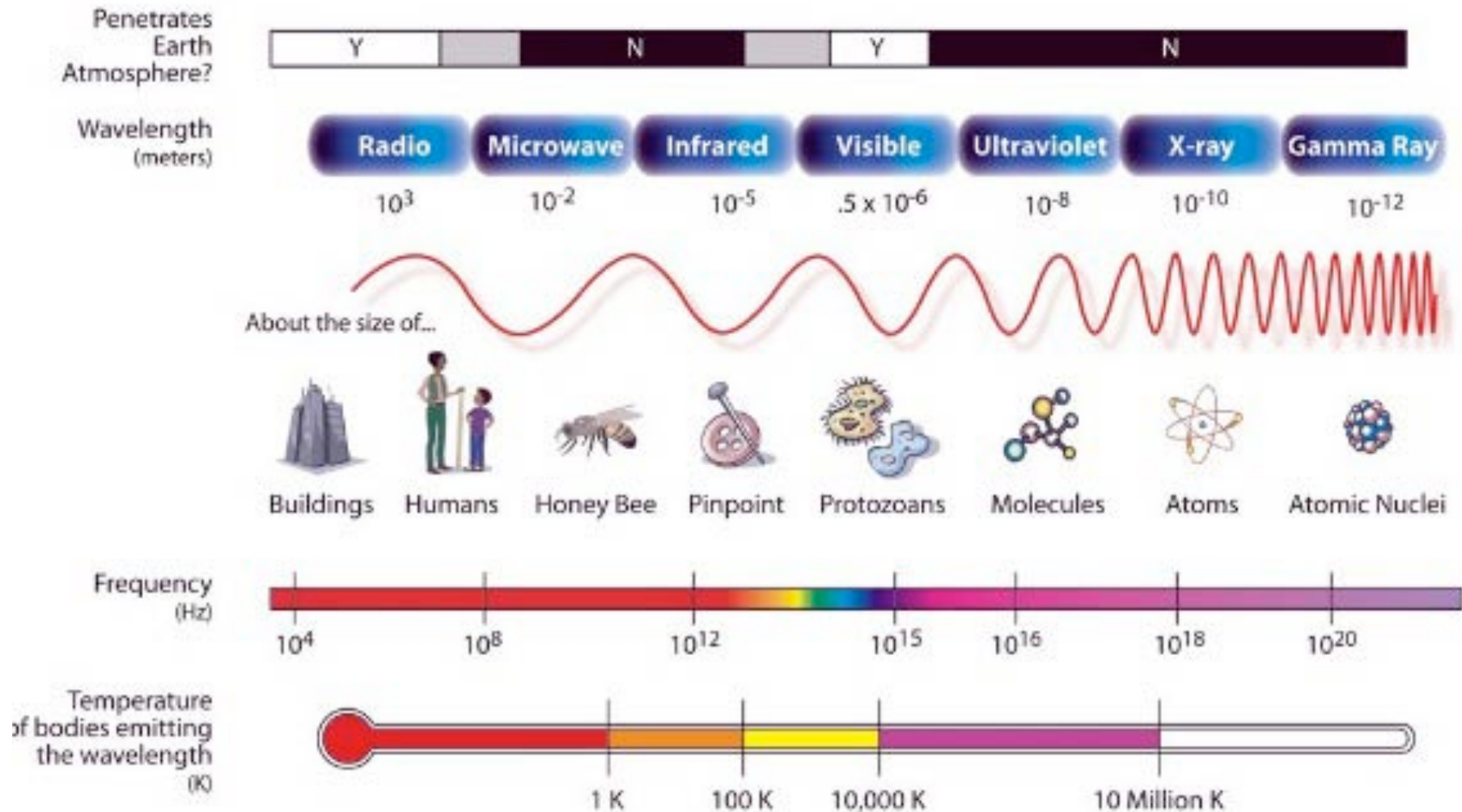
North America ALMA Science Center

Charlottesville, Virginia U.S.

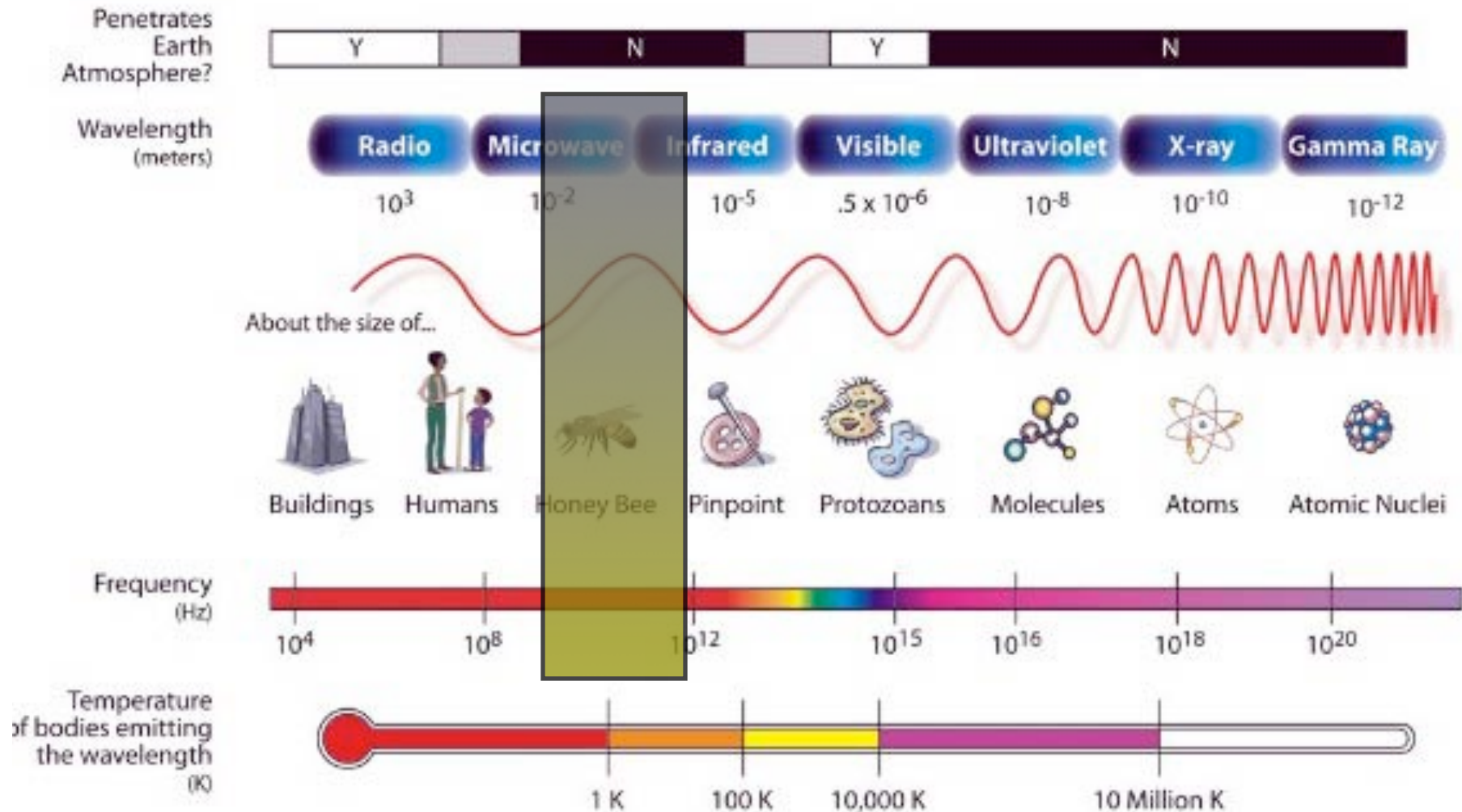
Atacama Large Millimeter/submillimeter Array
Expanded Very Large Array
Robert C. Byrd Green Bank Telescope
Very Long Baseline Array



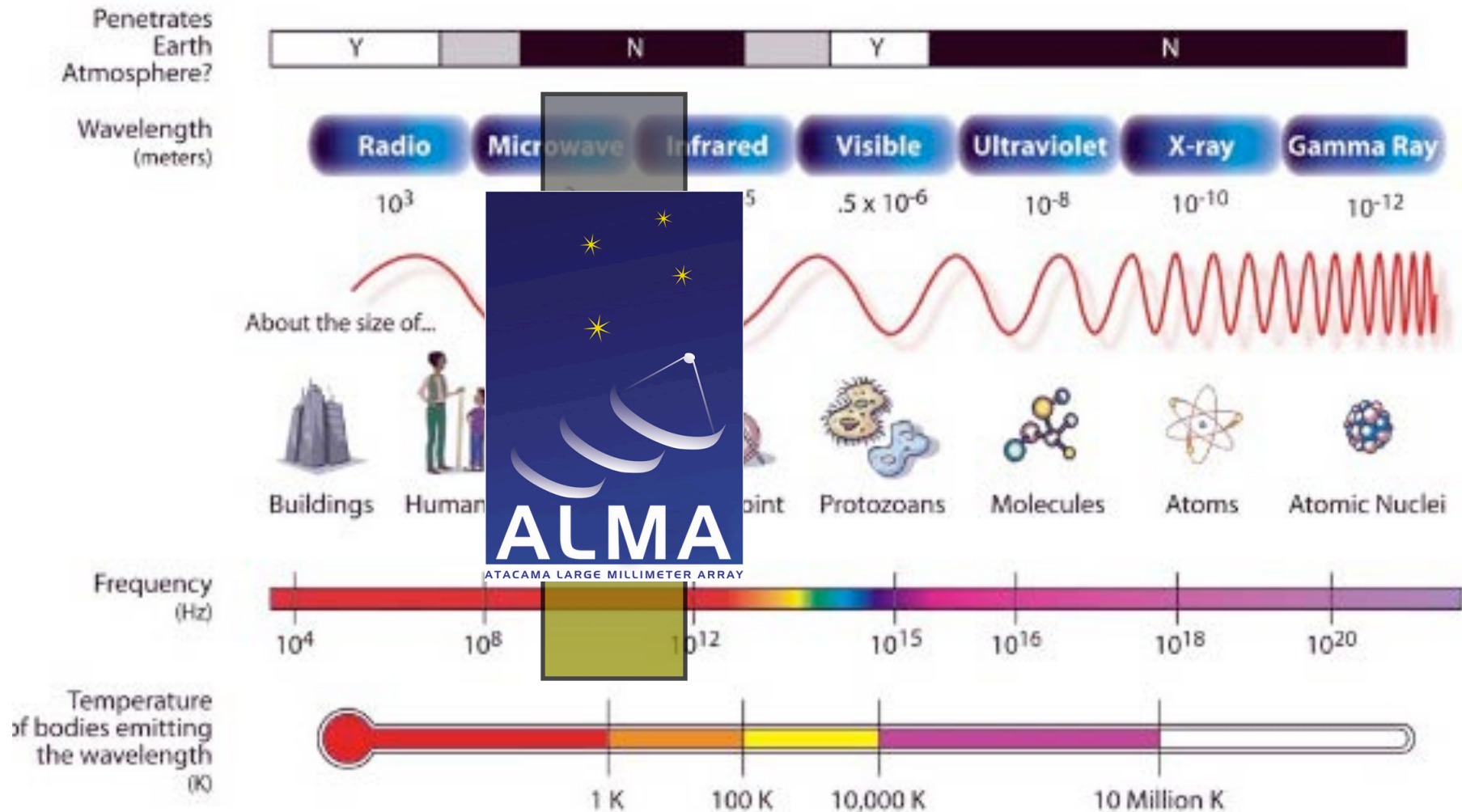
Astronomers see the Light!



Astronomers see the Light!



Astronomers see the Light!

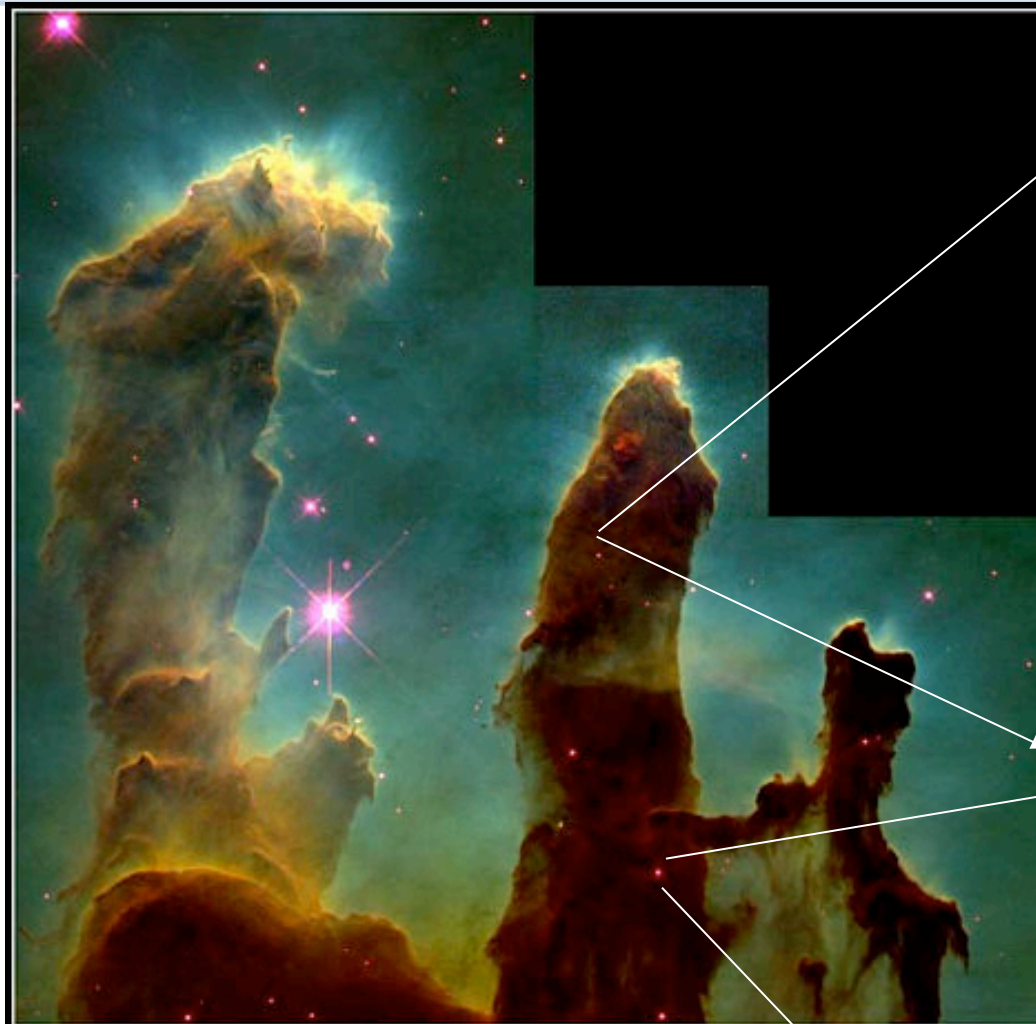




ALMA's bread and
butter science:

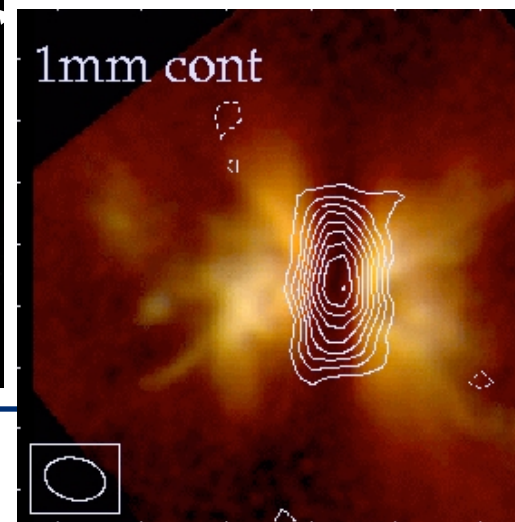
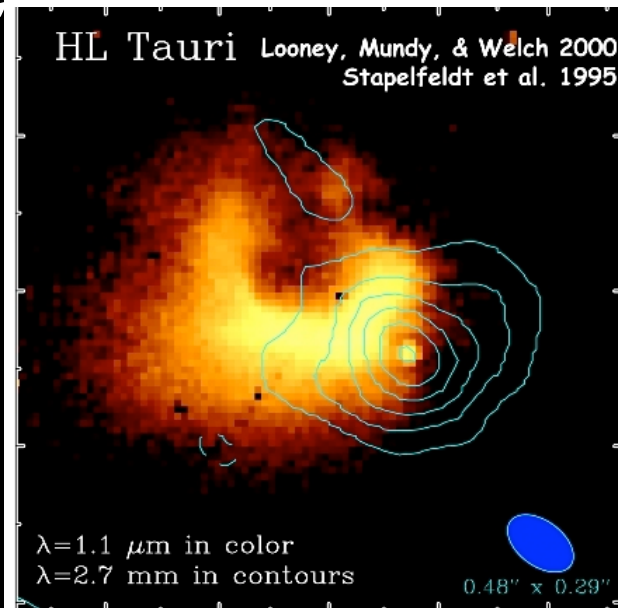
Molecular gas and dust
in the Universe!

The Millimeter /Submm Universe



Gaseous Pillars • M16
PRC95-44a • ST ScI OPO • November 2, 1995
J. Hester and P. Scowen (AZ State Univ.), NASA

HST • WFPC2



courtesy D. Padgett



ALMA Today



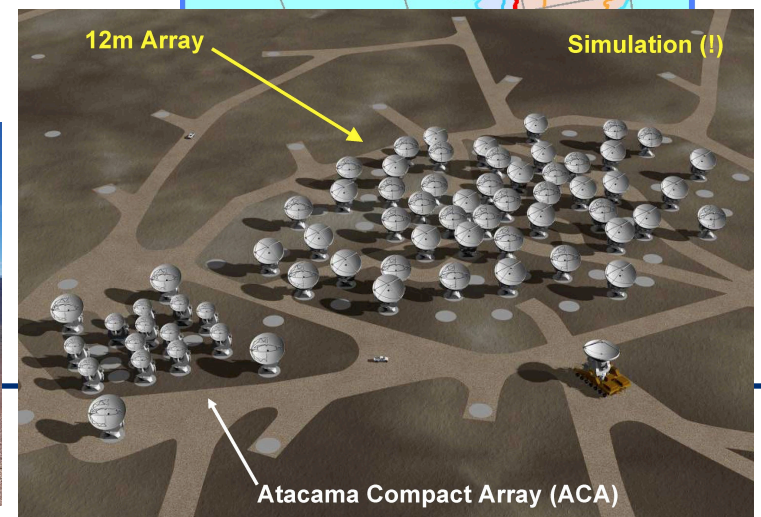
ALMA next year!



The Millimeter /Submm Universe

A transformational new facility
A ground-based Great Observatory!

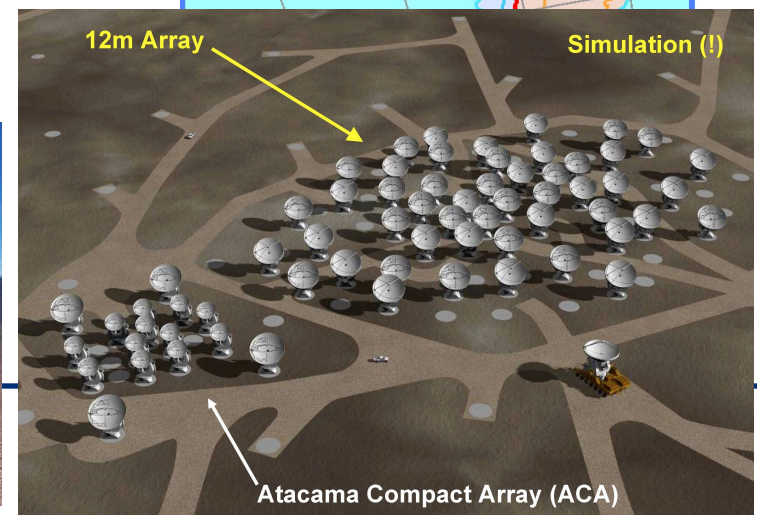
- A Global Partnership: NA + ESO + NAOJ + Chile



The Millimeter /Submm Universe

A transformational new facility
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

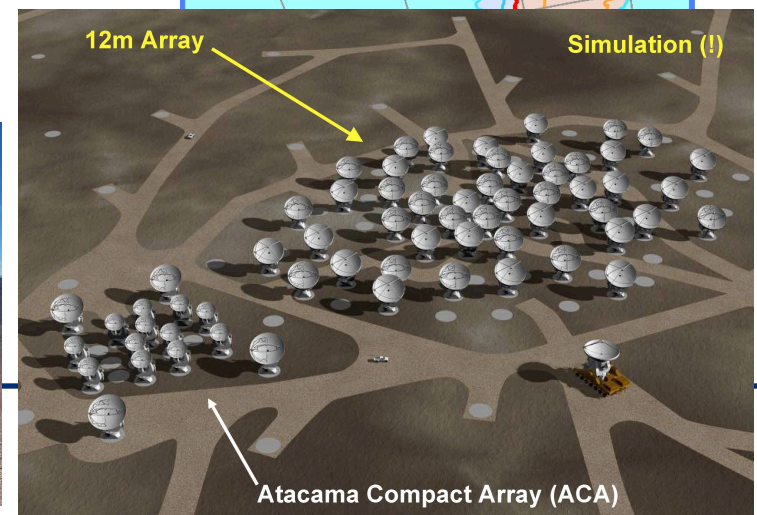


The Millimeter /Submm Universe

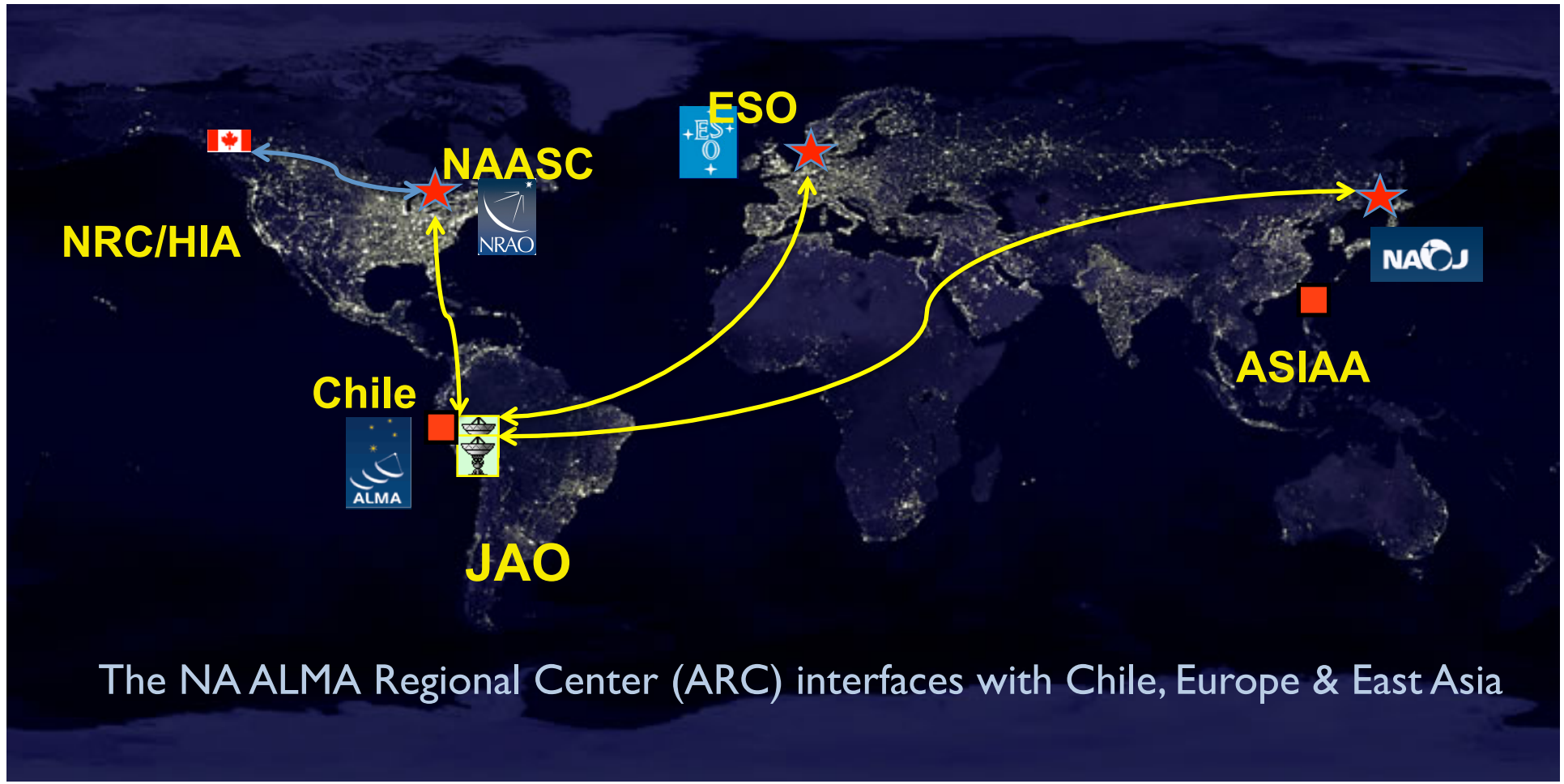
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*Many (most?) advances in astronomy
have come from technological advances*



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





Carol
Lonsdale

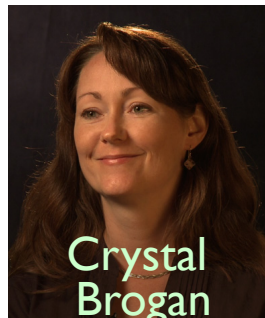
NAASC Science Support



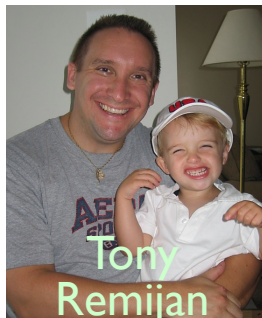
Al
Wooten



Nuria
Marcelino



Crystal
Brogan



Tony
Remijan



Kartik
Sheth



Mark
Lacy



John
Hibbard



Harvey
Liszt



Jim
Braatz



Adam
Leroy



Aaron
Evans



Remy
Indebetouw



Ed
Fomalont



Todd
Hunter



Scott
Schnee

Santiago, October 11-12, 2010



Rachel
Friesen



Amy
Kimball

Science Operations Readiness Review



David
Heninger

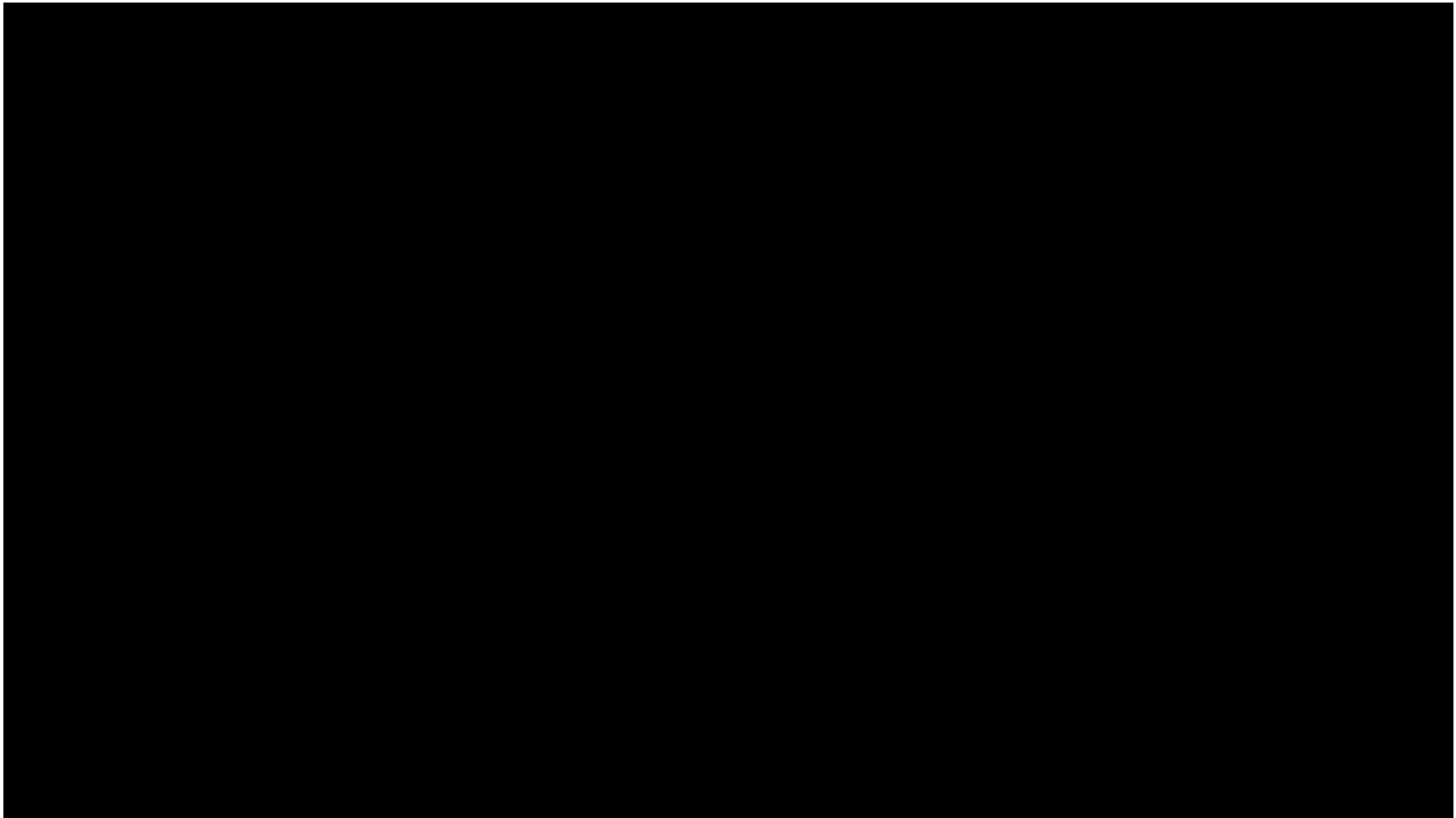


Robin
Pulliam



Stuartt
Corder

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



ALMA OSF & AOS



OSF: Operations Support Facility

AOS: Antenna Operations Site

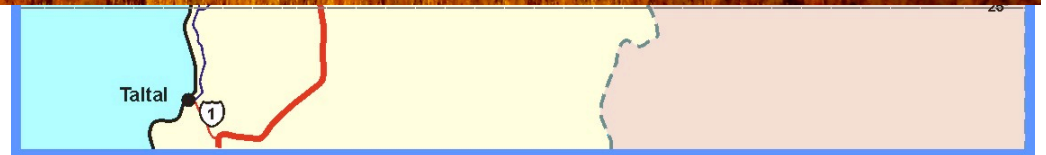


ALMA OSF & AOS



OSF: Operations Support Facility

AOS: Antenna Operations Site



The Road to ALMA

43 km to Array Operations Site (AOS)
5,000m elevation

15 km to Operations Support Facility (OSF)
2,900m elevation

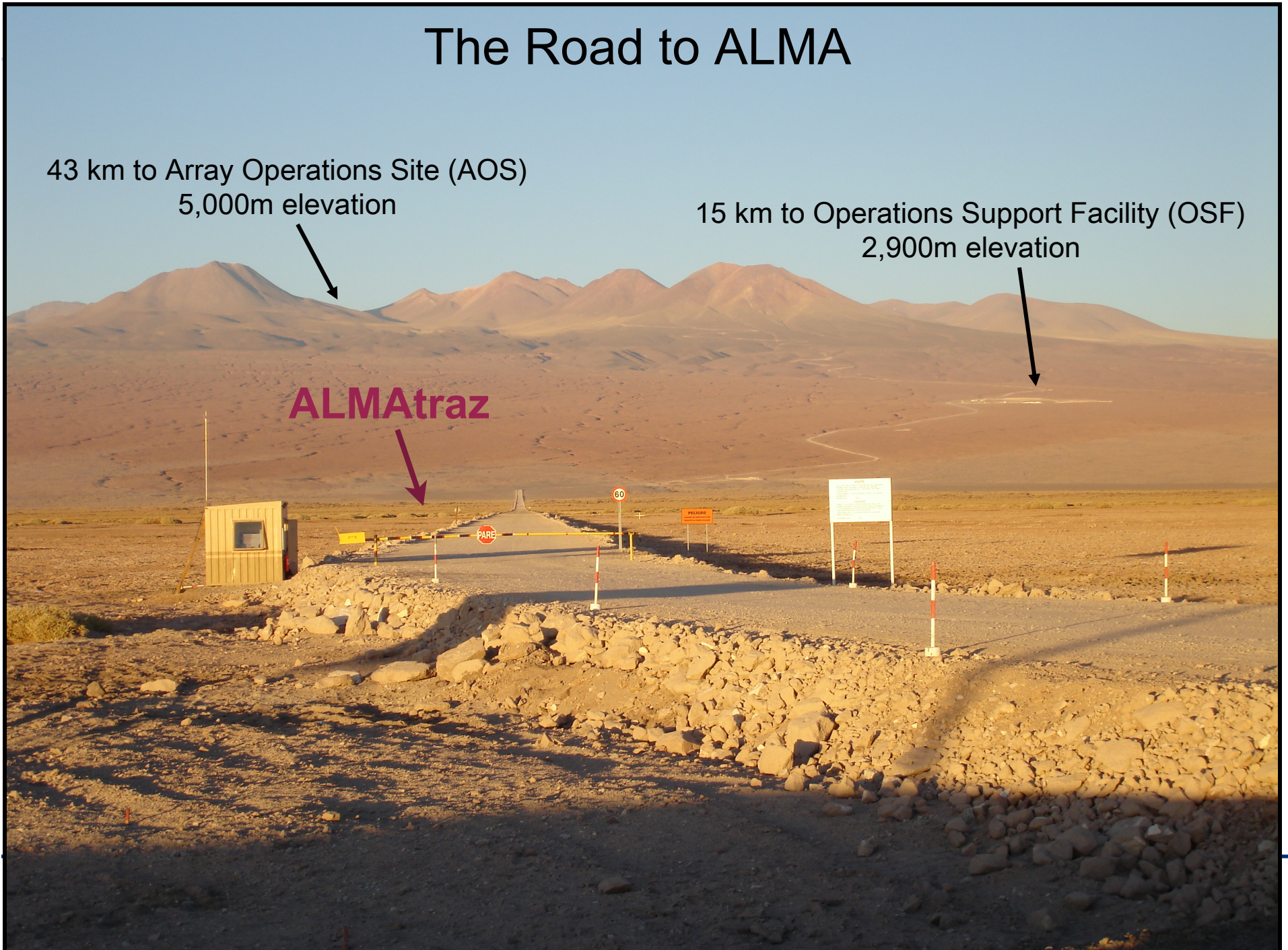


The Road to ALMA

43 km to Array Operations Site (AOS)
5,000m elevation

15 km to Operations Support Facility (OSF)
2,900m elevation

ALMAtraz



Drier is Better!

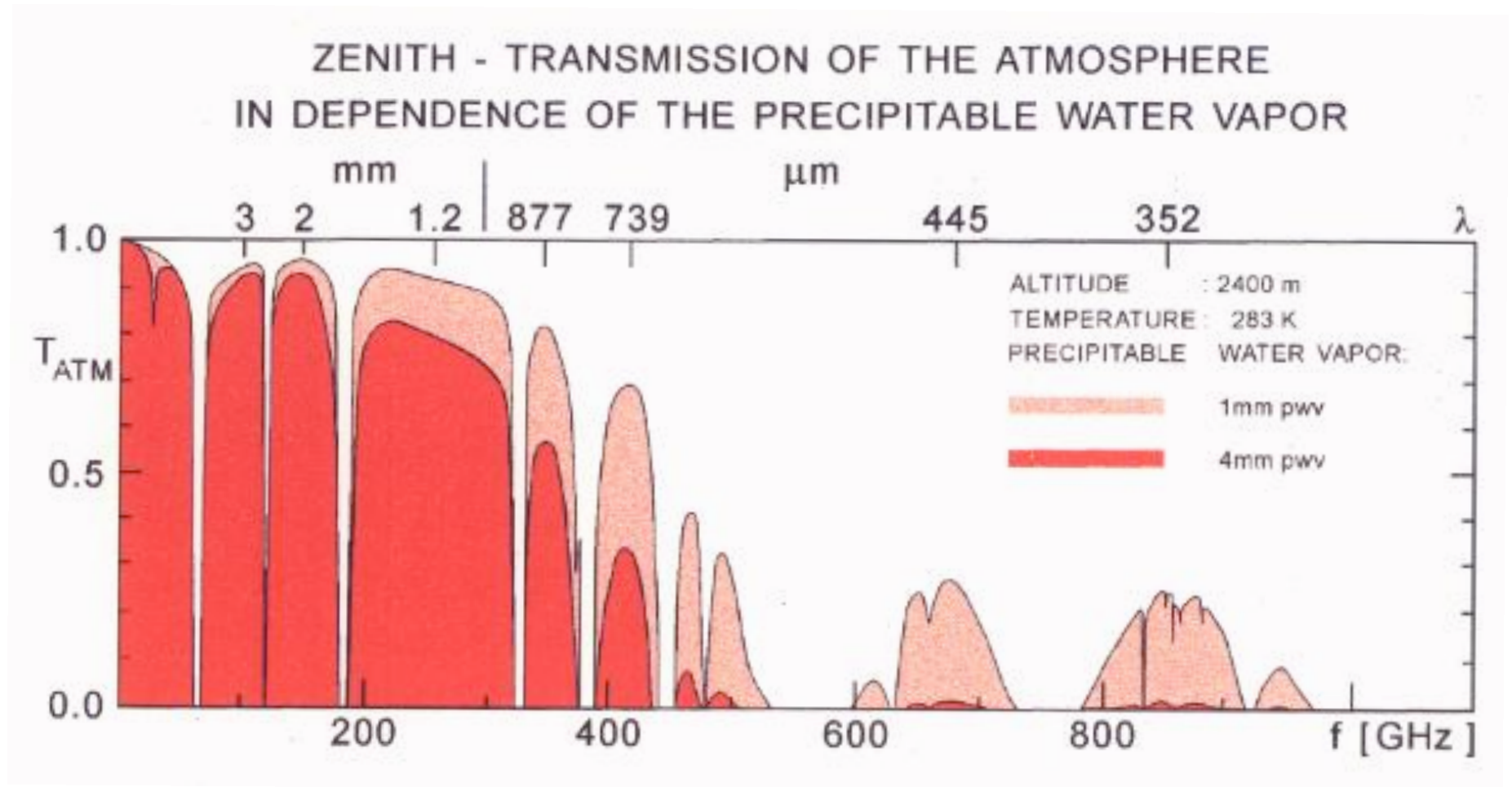
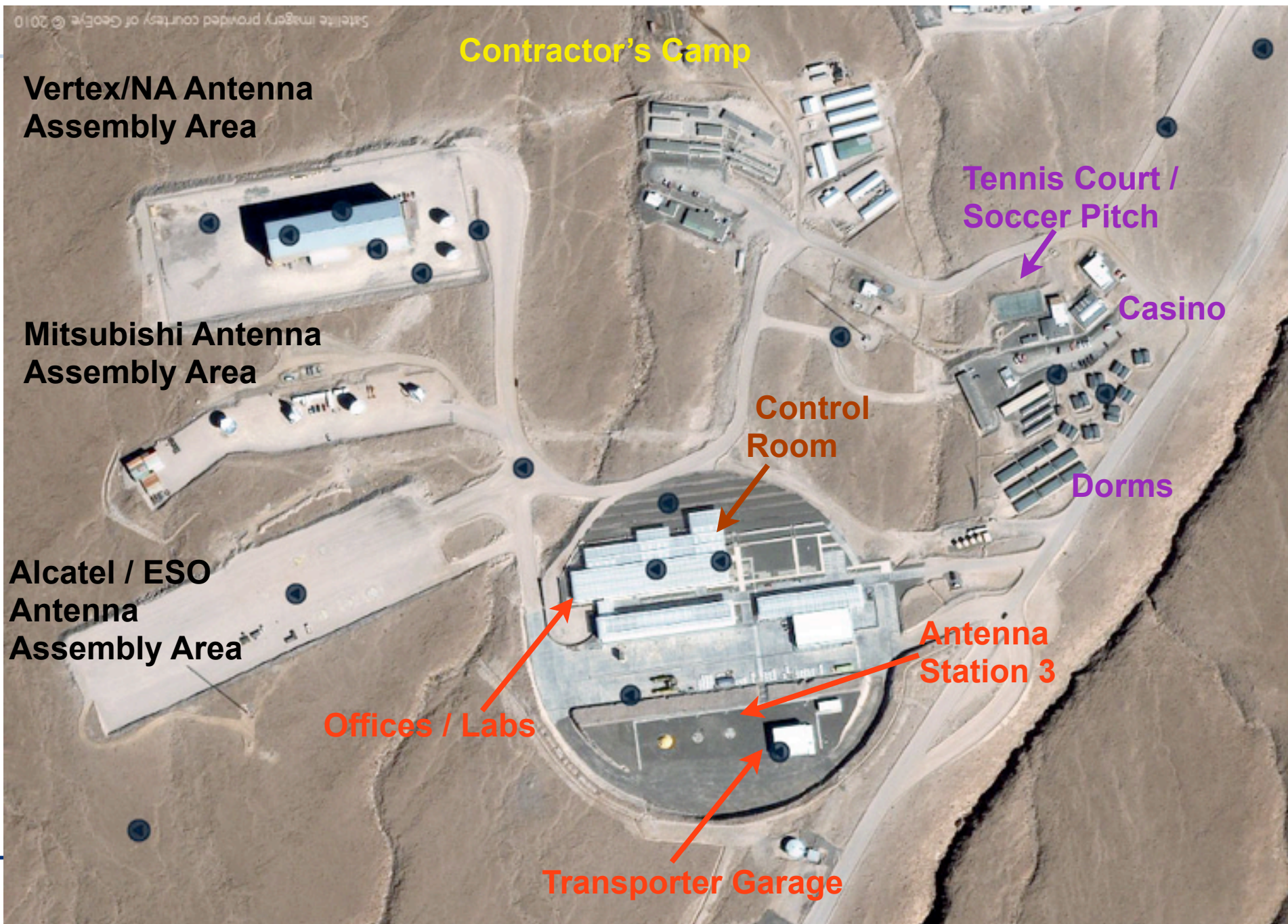
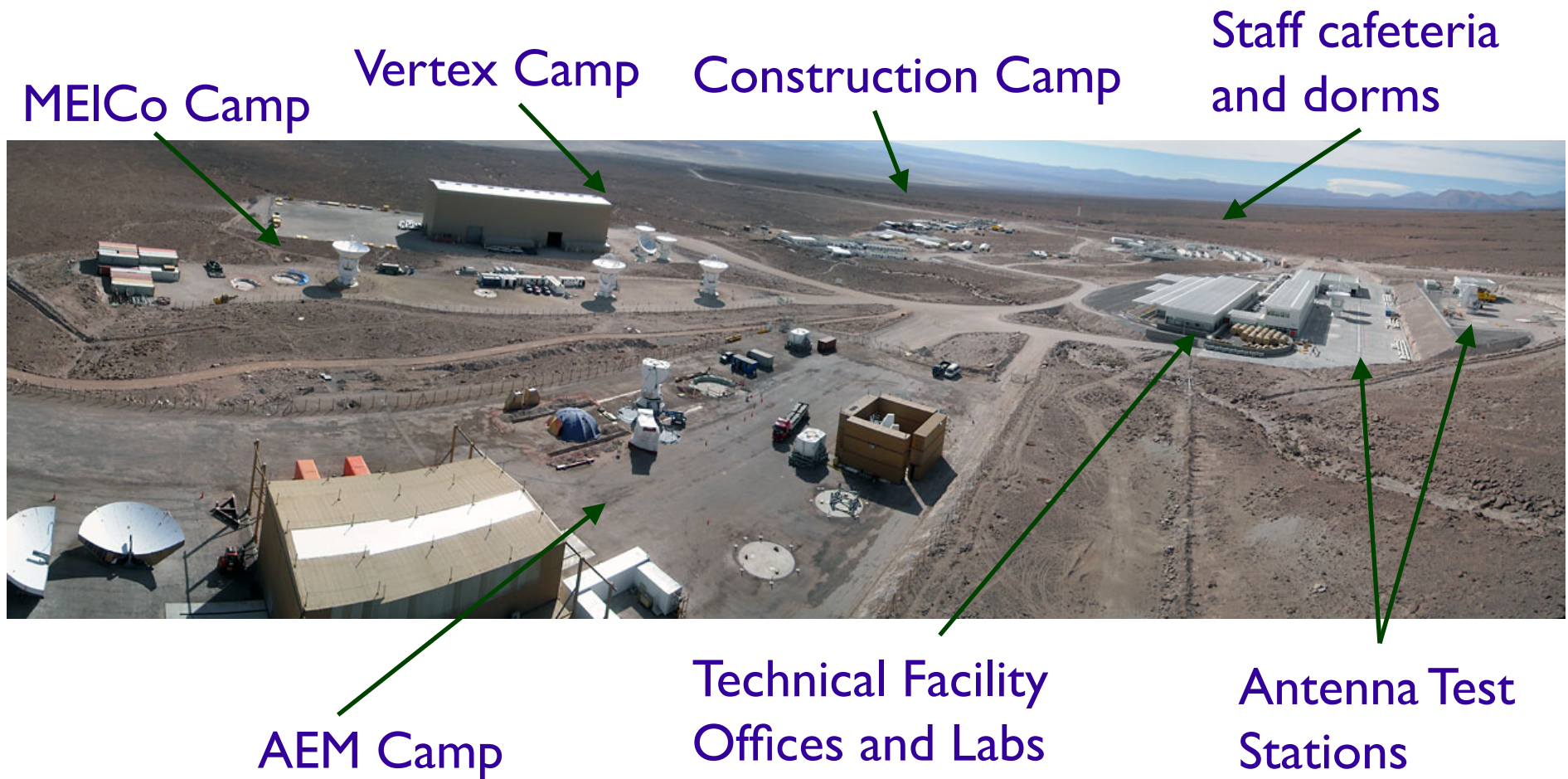


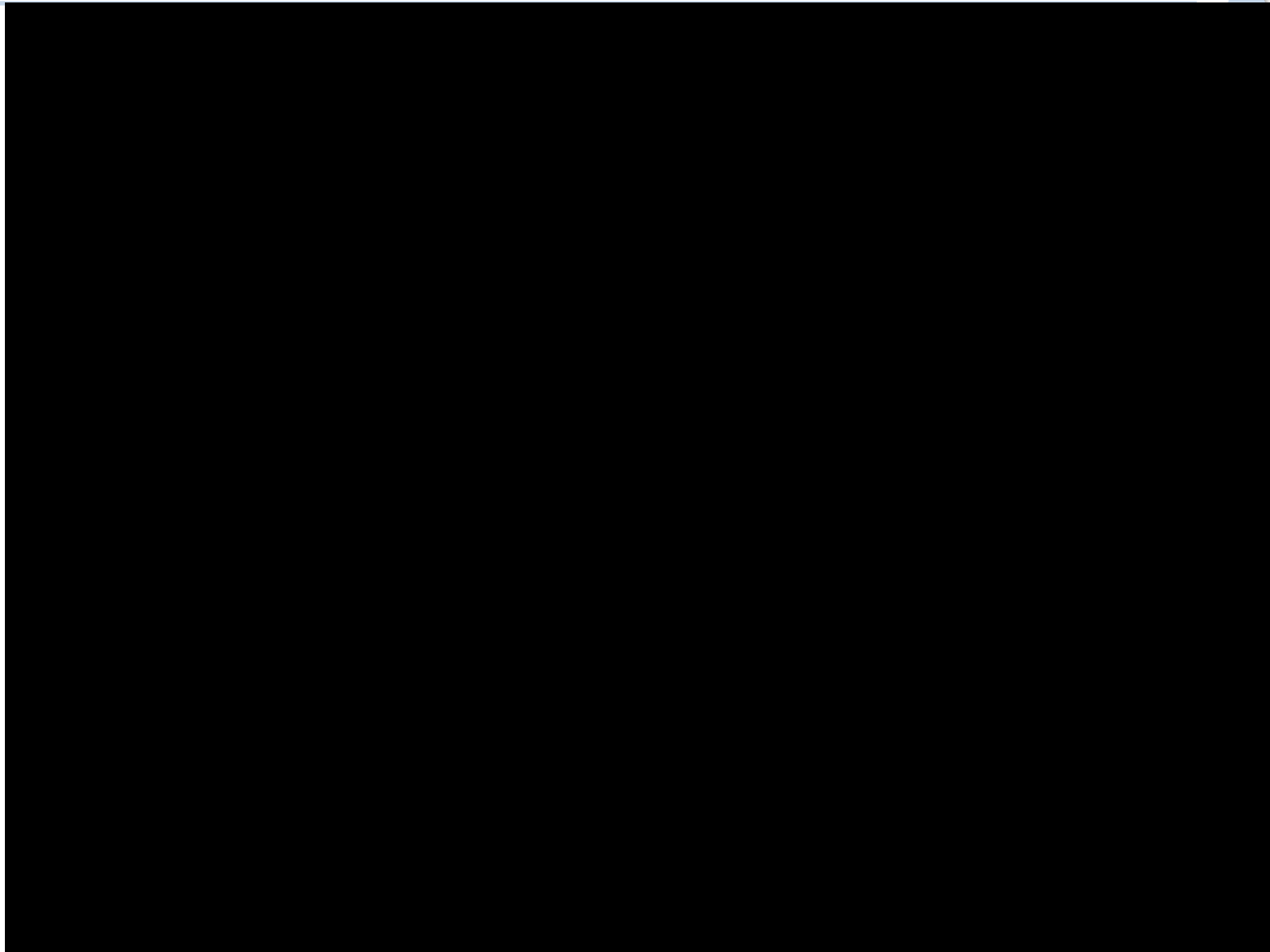
Figure from Arizona Radio Observatory



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
<i>EVLA</i>	<i>7,050</i>	<i>25</i>	<i>27</i>	<i>13250</i>	<i>43</i>

Comparison

• NAASC

- **Collecting Area**



Comparison

• NAASC

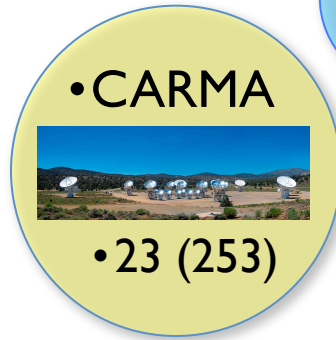
- **Collecting Area**



Comparison

• NAASC

- **Collecting Area**



Comparison

• NAASC

- **Collecting Area**

• SMA



• 8 (28)

• CARMA



• 23 (253)

• IRAM PdBI



• 6 (15)

Comparison

• NAASC

- **Collecting Area**

• SMA



• 8 (28)

• CARMA



• 23 (253)

• IRAM PdBI



• 6 (15)

- ALMA
- Early Science
- 16 (120)

Comparison

• NAASC

- **Collecting Area**

• SMA



• 8 (28)

• CARMA



• 23 (253)

➤ Sensitivity goes as
collecting area

➤ Imaging complexity
goes as # of
baselines

• IRAM PdBI



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• ALMA

• Early Science

• 16 (120)

Comparison

• NAASC

• Collecting Area

• SMA
• 8 (28)

• CARMA



• 23 (253)

➤ Sensitivity goes as
collecting area

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goes as # of
baselines

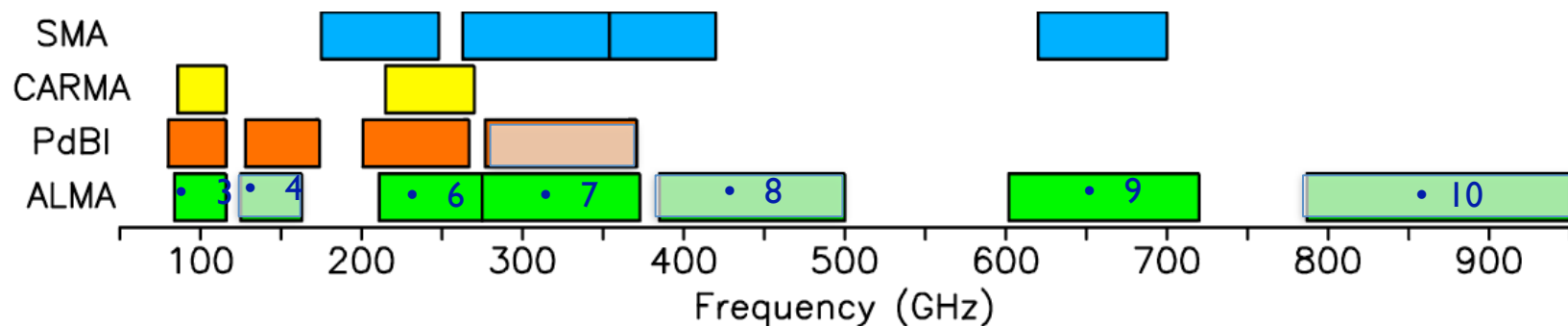
• IRAM PdBI



• 6 (15)

• ALMA
• Early Science
• 16 (120)

• Spectral Coverage



Comparison

• Collecting Area

• SMA



• 8 (28)

• CARMA



• 23 (253)

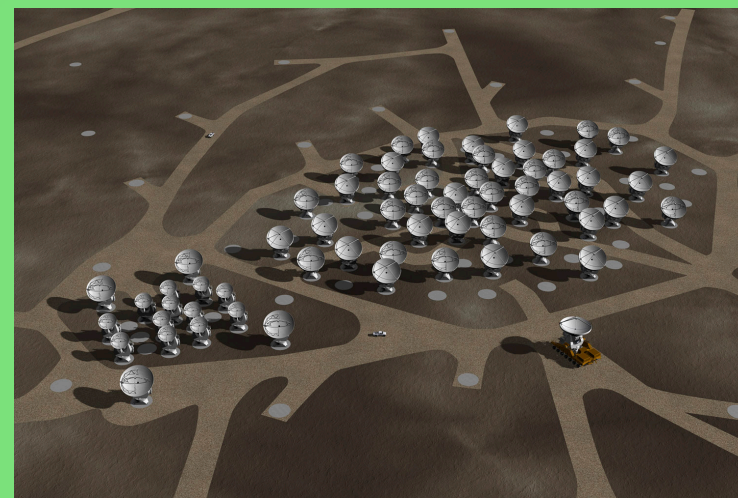
• IRAM PdBI



• 6 (15)

➤ Sensitivity goes as
collecting area

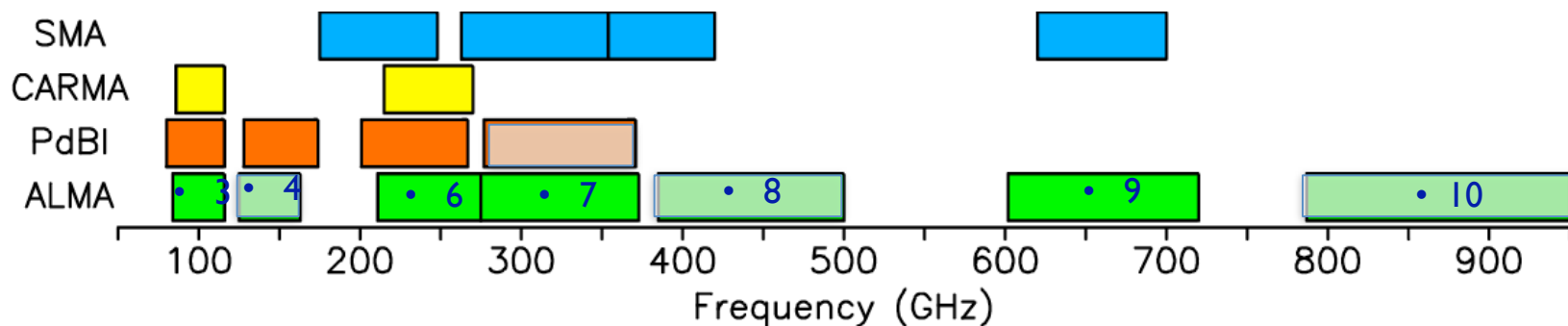
➤ Imaging complexity
goes as # of
baselines



• 64 (2016)

• 16 (120)

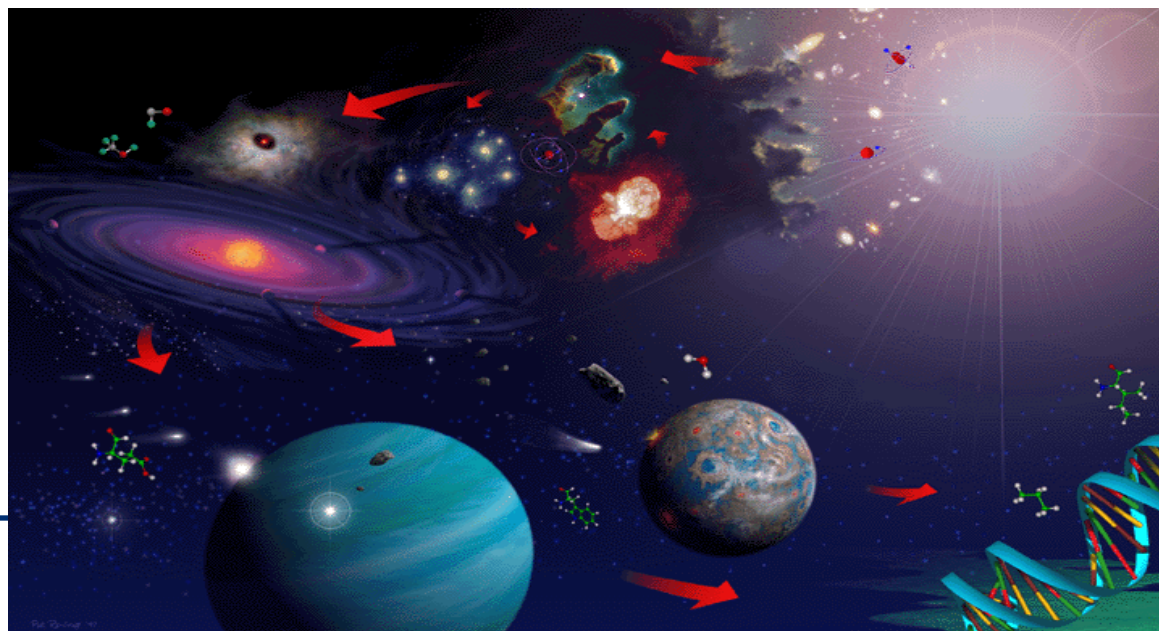
• Spectral Coverage

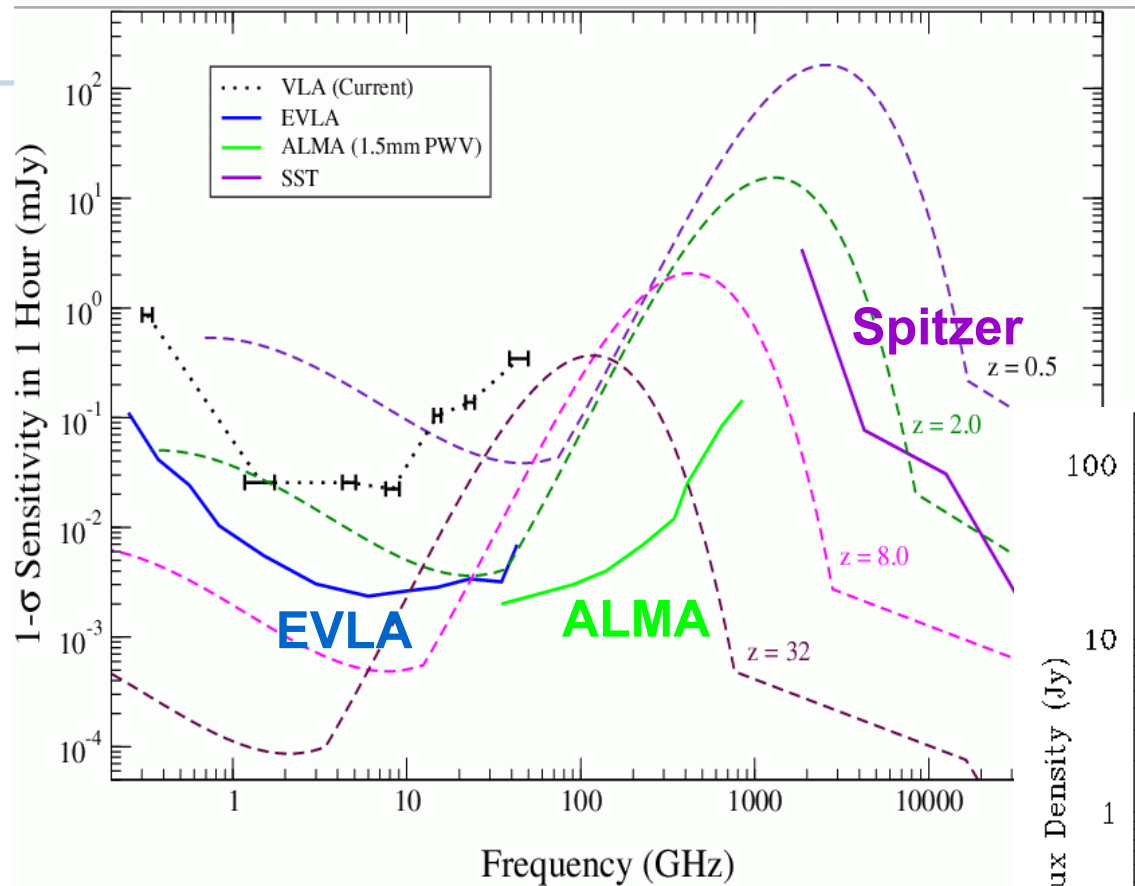


The Main SCIENCE Drivers of ALMA



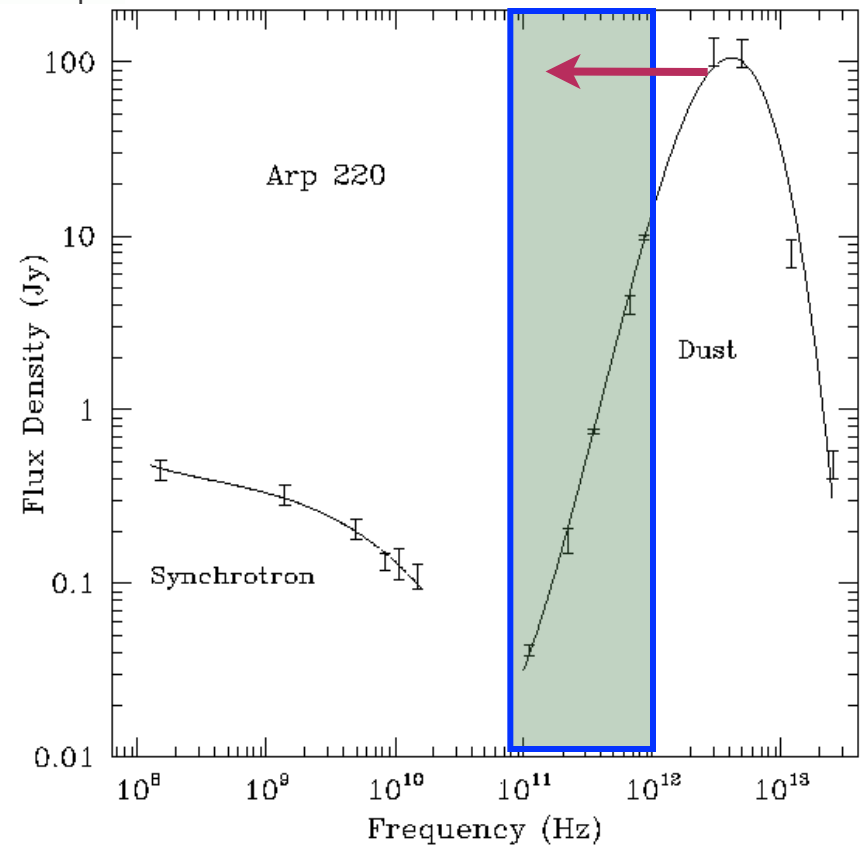
- ★ **Origins of Galaxies:** Molecular gas in the Milky Way 10 Gyr ago (at $z = 3$) in less than 24 hours of observation.
- ★ **Origins of Planetary Systems & Planets:** Gas kinematics in a solar-mass protostellar/ protoplanetary disk at a distance of 150 pc.
- ★ **Exquisite Sensitivity & Resolution:**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





Detect high- z galaxies as easily as those at $z \sim 0.5$

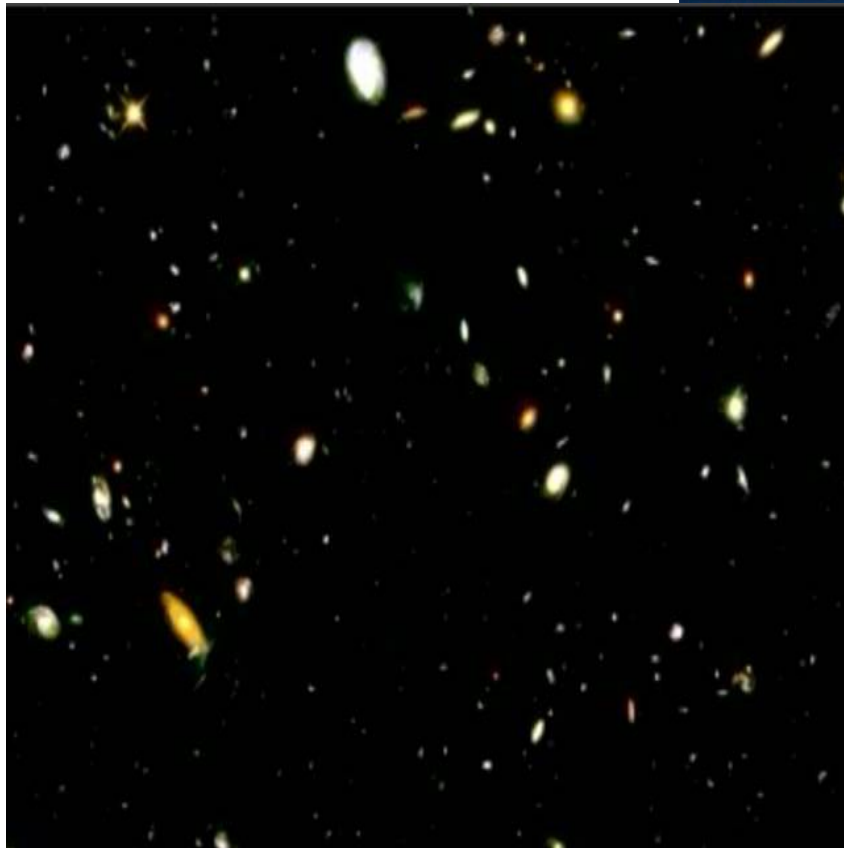
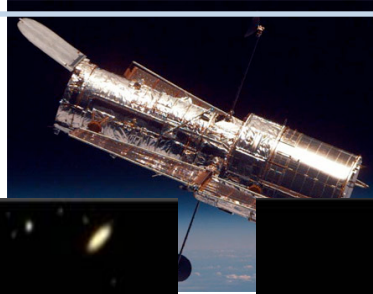
SED peak shifts to ALMA as z increases



The Power of ALMA!



What Hubble Sees:



HDF Nearby Galaxies

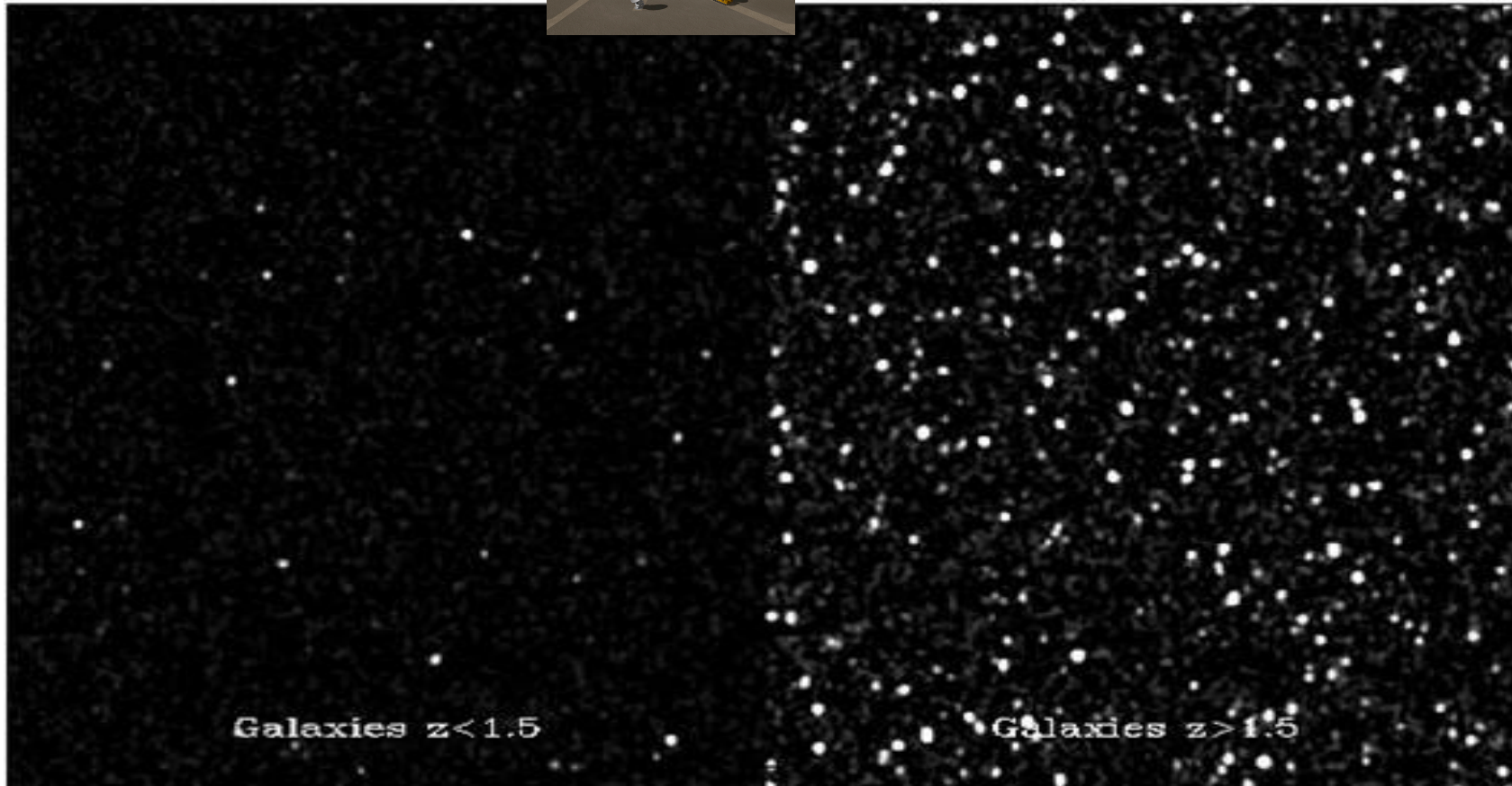
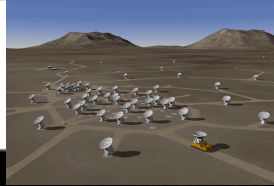


HDF Distant Galaxies
 $z > 0.5$

The Power of ALMA!



What ALMA will see:



HDF Nearby Galaxies

HDF Distant Galaxies
 $z > 0.5$

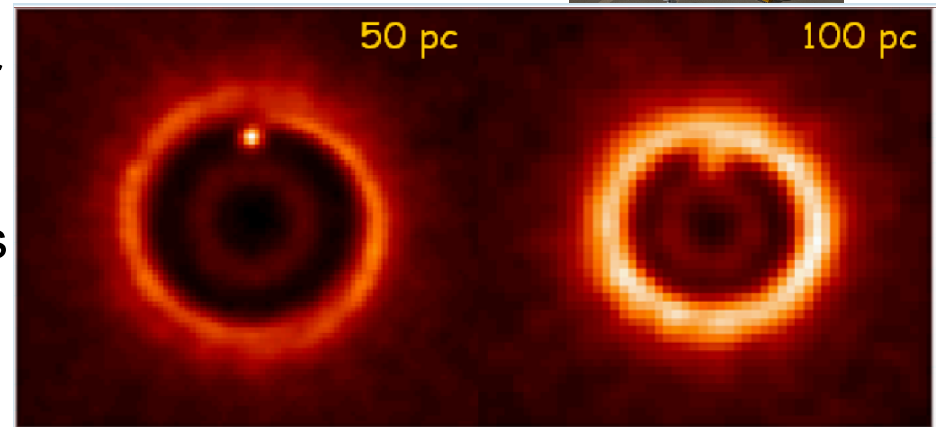
ALMA & Planets!

What ALMA will see:

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

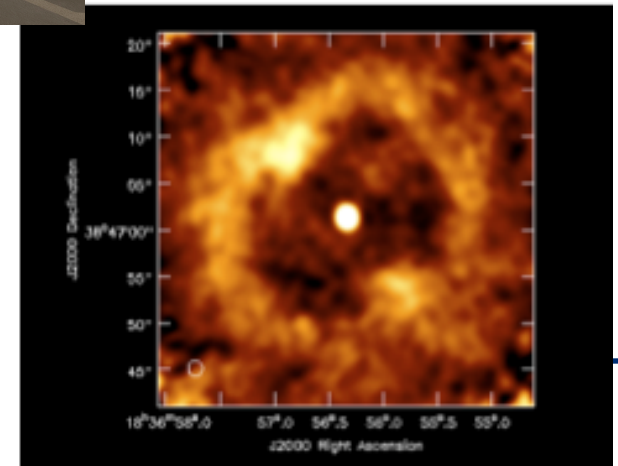
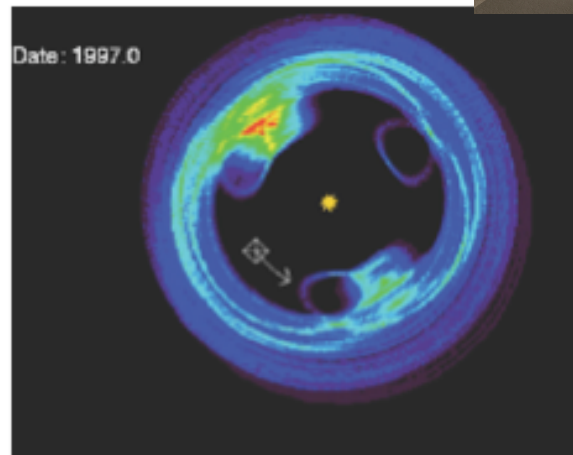
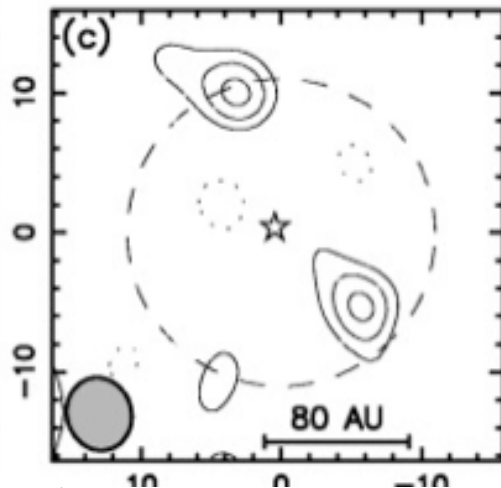
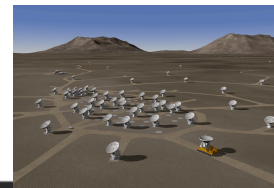
Disk mass ~ Butterfly star in Taurus

8 hr integration, 10 km baselines

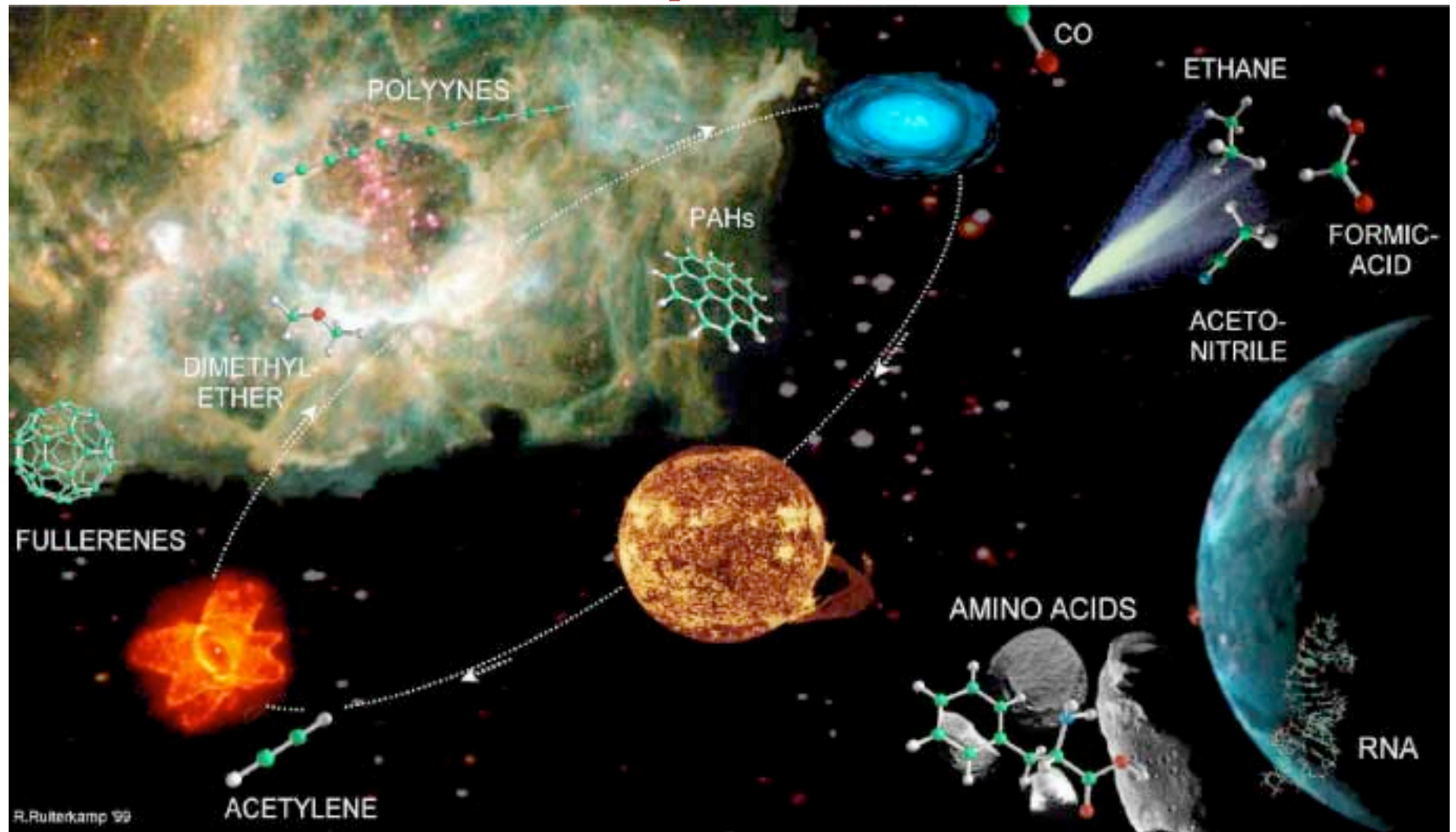


Similar simulation for the Vega debris disk

Wolf & D'Angelo 2005



ALMA & Chemistry!

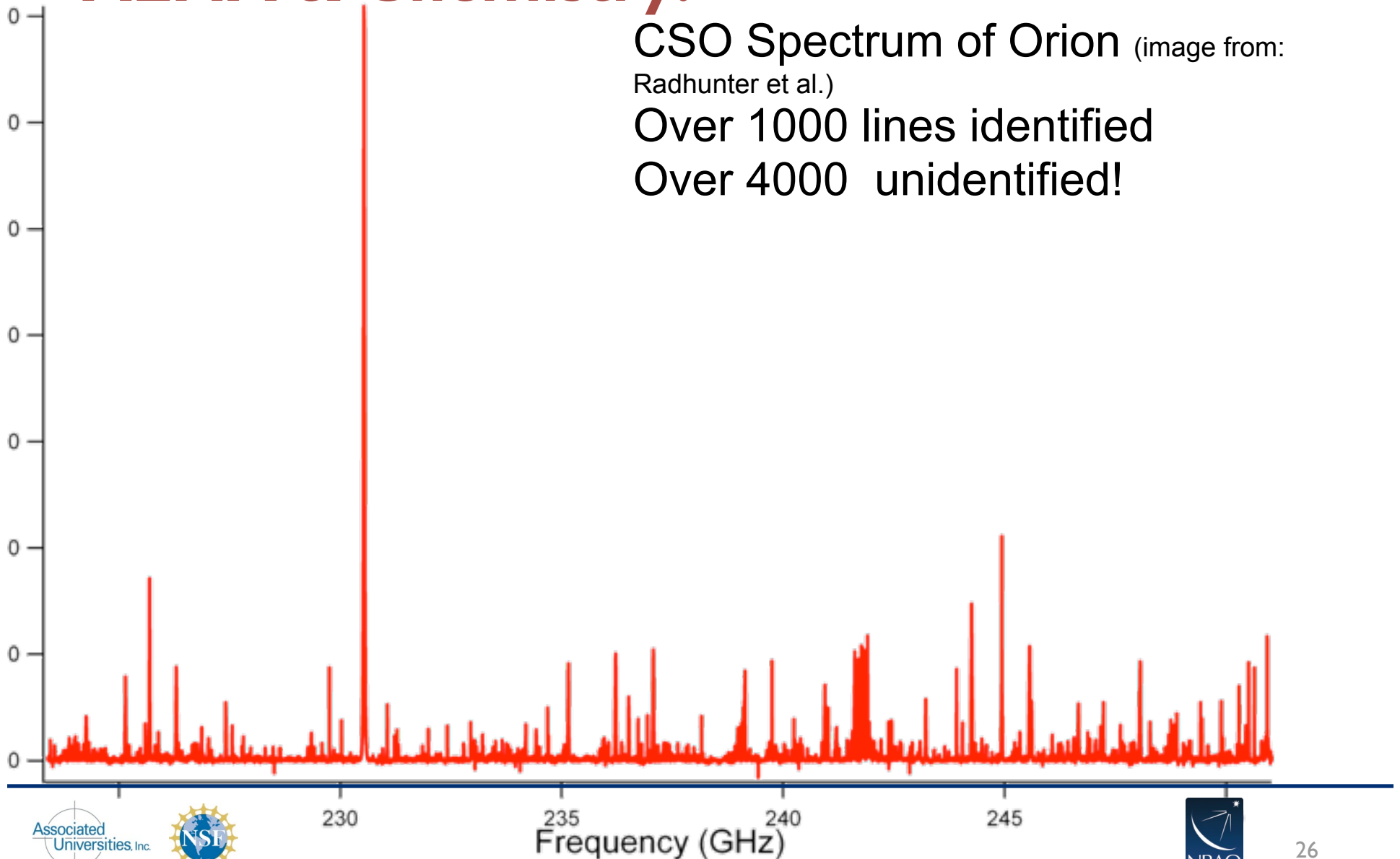


ALMA & Chemistry!

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

Over 1000 lines identified

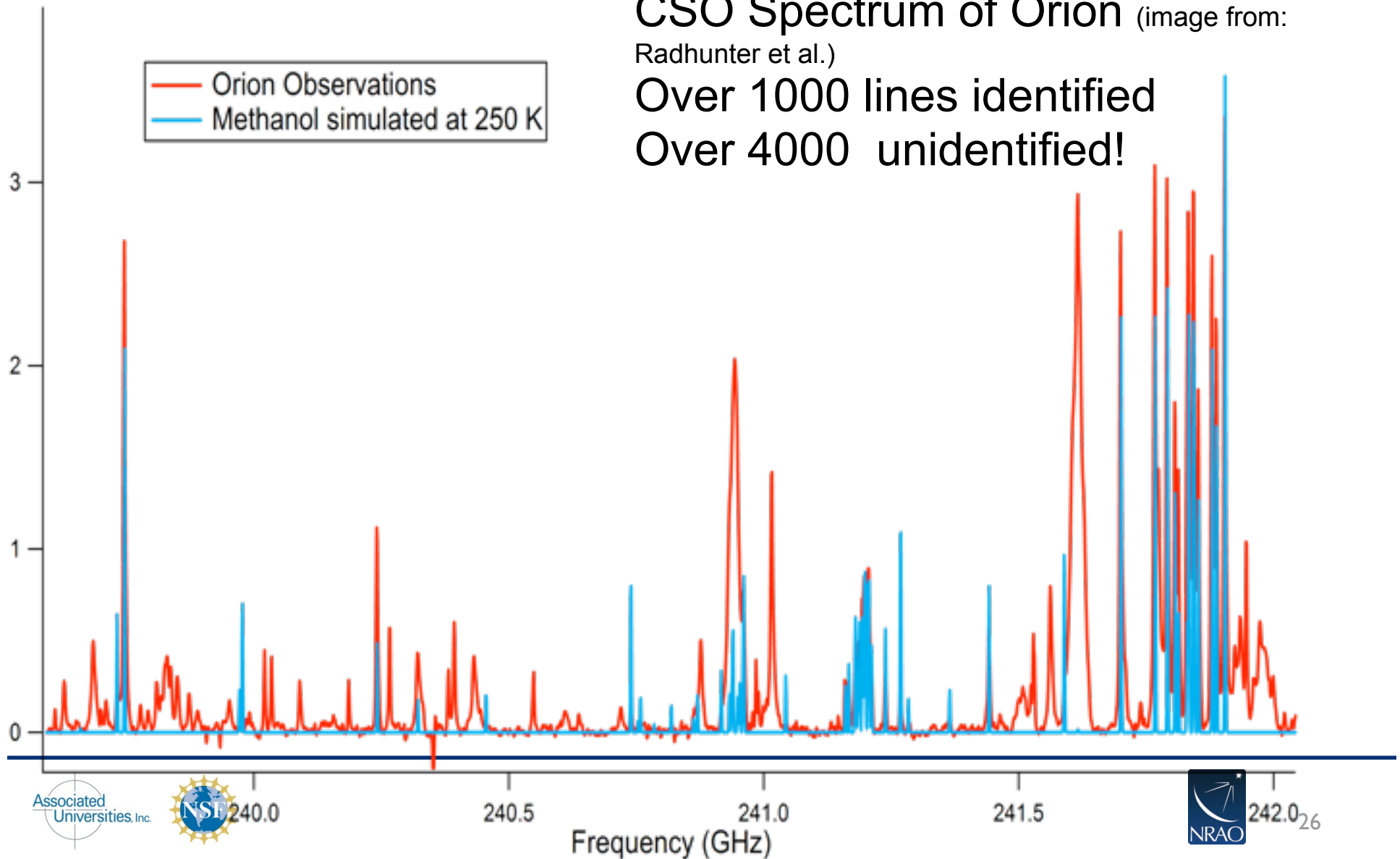
Over 4000 unidentified!



ALMA & Chemistry!

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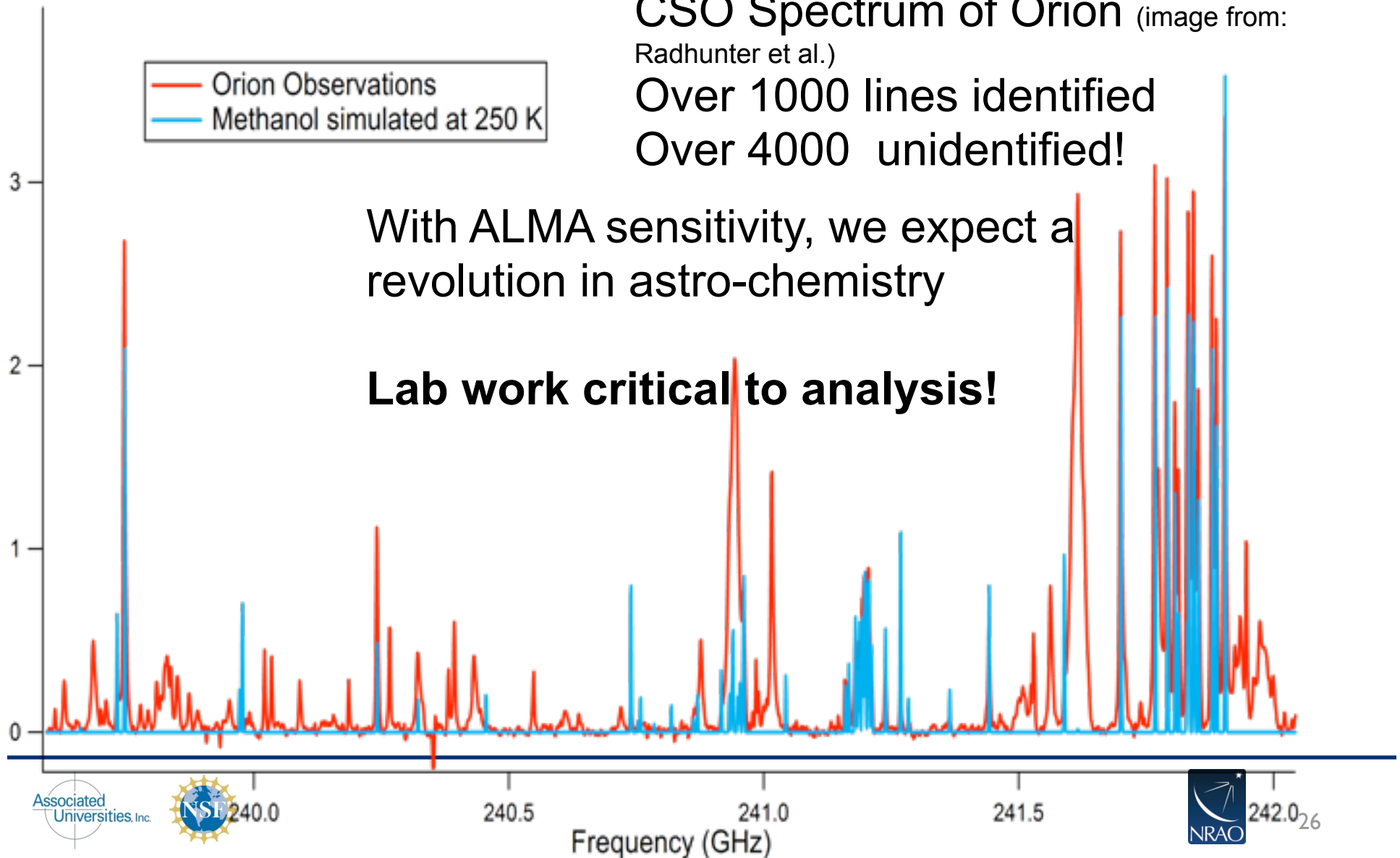
ALMA & Chemistry!

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

Over 1000 lines identified
Over 4000 unidentified!

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

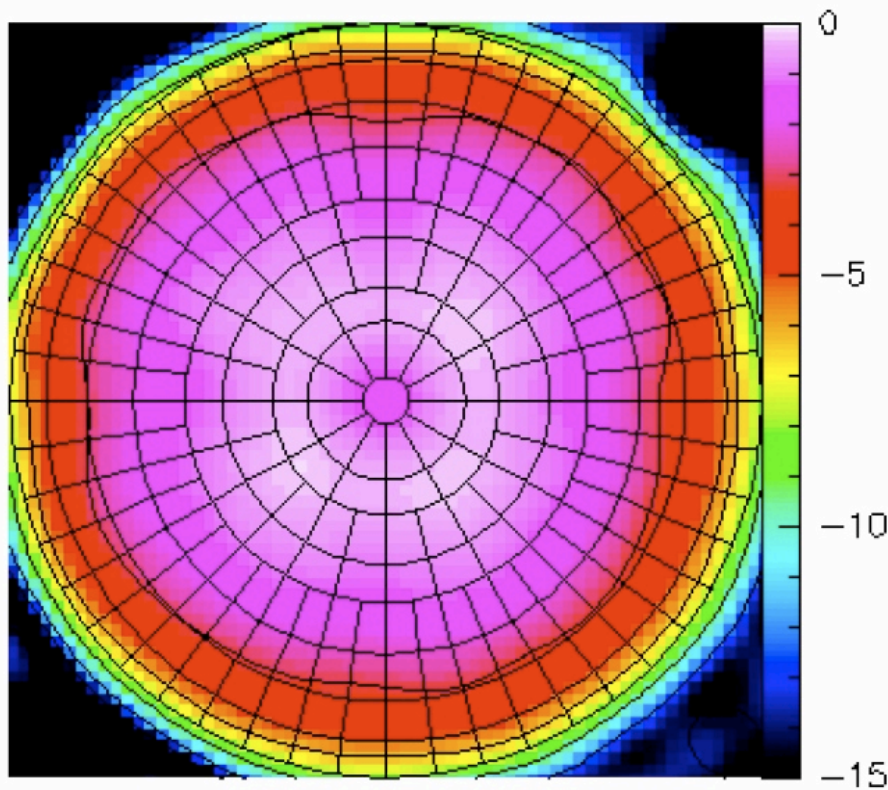
Pushing Technology!

- Antenna design
 - $< 15\mu\text{m}$ surface accuracy over 12m surface
 - Fast pointing and settle times
 - Performance in some harsh weather conditions

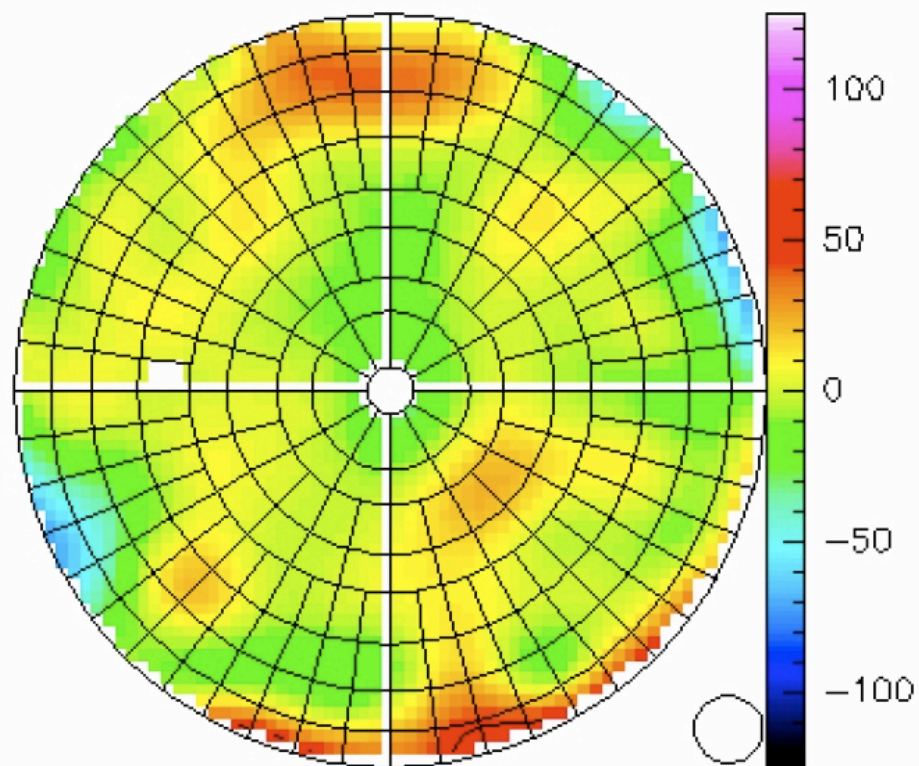


Astronomical Holography

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!





Correlator First Quadrant at AOS

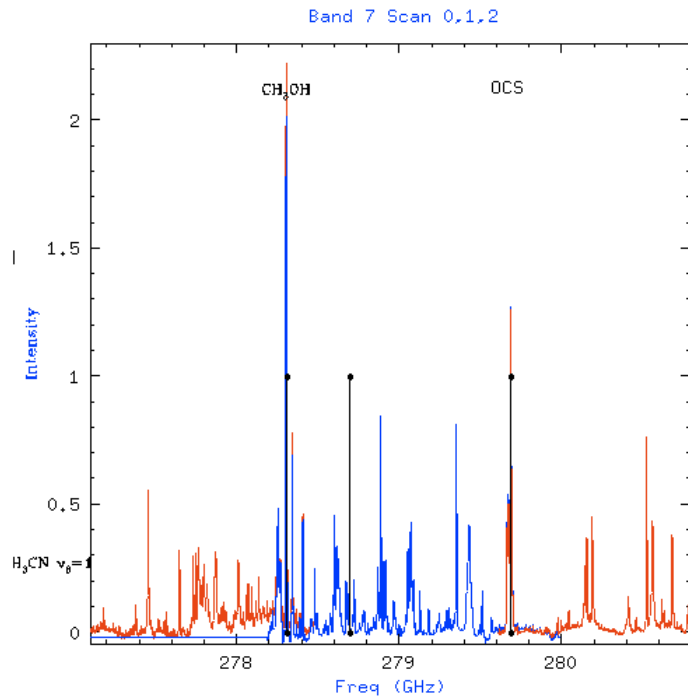


Pushing Technology!

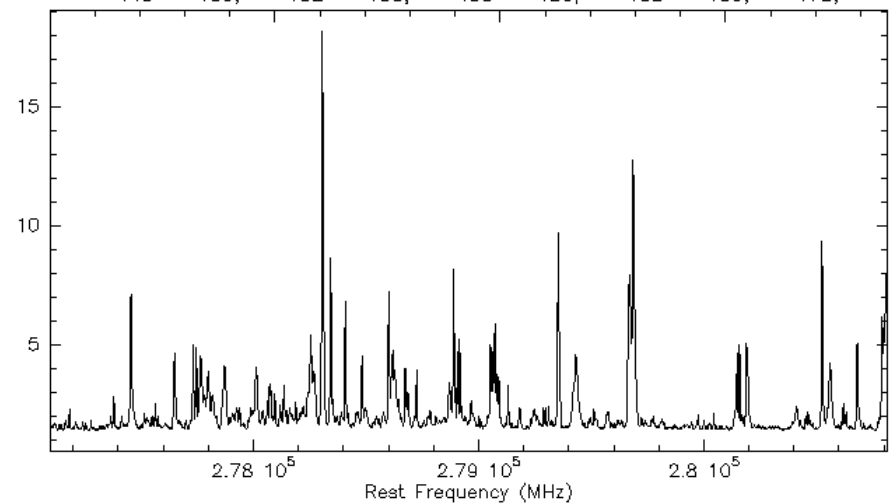
- Material Science / Solid State physics
- (Charlottesville: NRAO's National Technology Center CDL + UVA Micro-fabrication Lab)
- State of the art SIS junctions
 - Low noise temperature \sim few \times quantum limit
 - Broadest RF and IF bandwidths (8 GHz!)
 - Largest use of superconducting technology!

Recent Band7 (345 GHz) Spectrum of Orion

Comparison with IRAM 30m

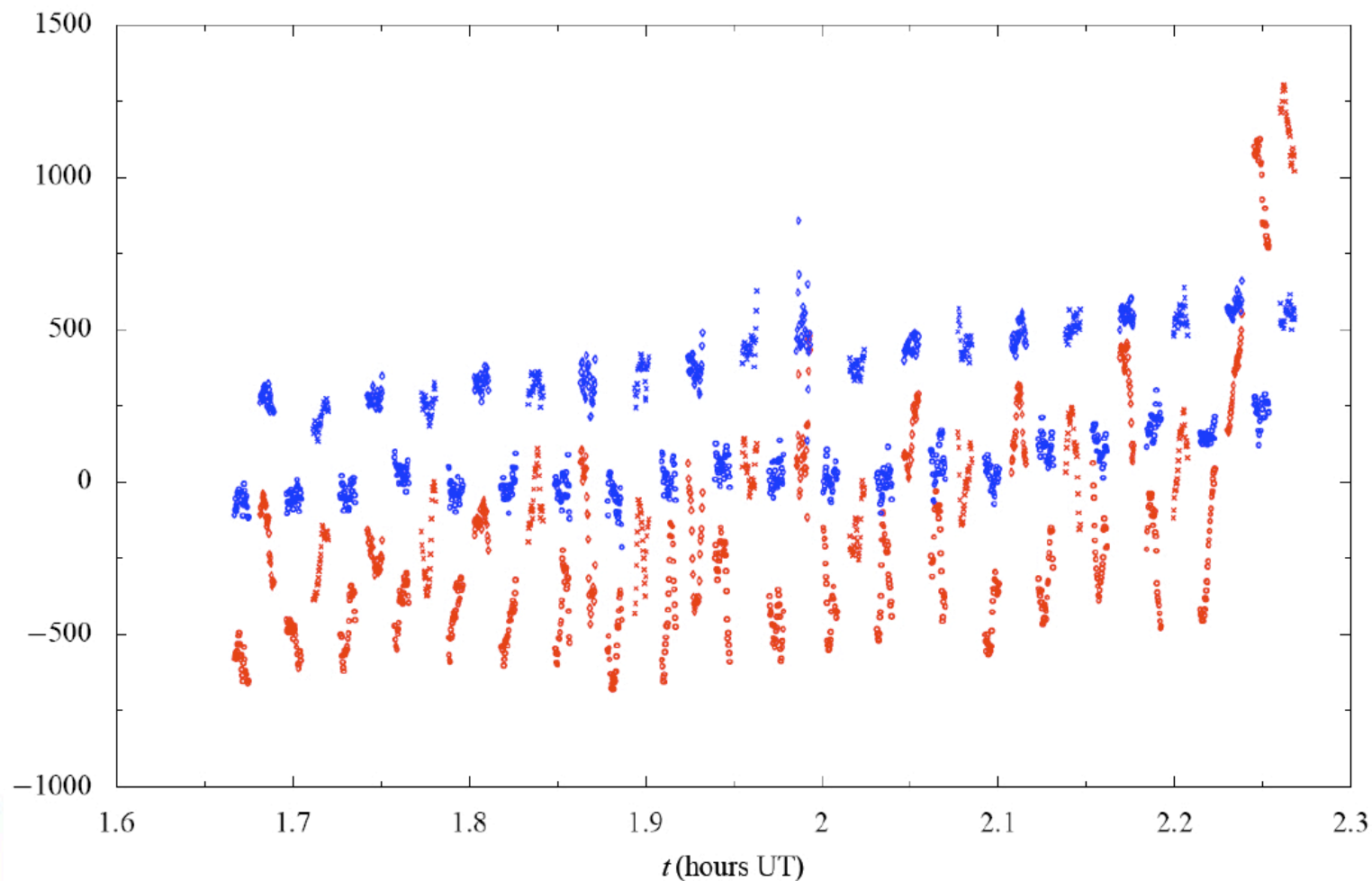


87; 2 ORI-IRC2 CH2DP-101 30ME3HLI-W03 O:02-FEB-2010 R:03-FEB-2010
RA: 05:35:14.20 DEC: -05:22:36.0 Eq 2000.0 Offs: +0.0 +0.0
Unknown tau: 0.060 Tsys: 184. Time: 42. min El: 42.4
N: 1860 IQ: 798.000 V0: 19.00 Dv: -2.151 LSR
FO: 278691.800 Df: 2.000 Fi: 291189.398
Bef: 0.88 Fef: 0.88 Gim: 5.0119E-02
H2O : 0.4308 Pamb: 722.8 Tamb: 272.4 Tchop: 295.2 Tcold: 30.0
Tatm: 320.6 Tau: 0.060 Tatm i: 315.9 Tau i: 0.068
149- 150, 500, 152- 153, 155, 1000 156, 158- 159, 173,



Water Vapor Correction

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



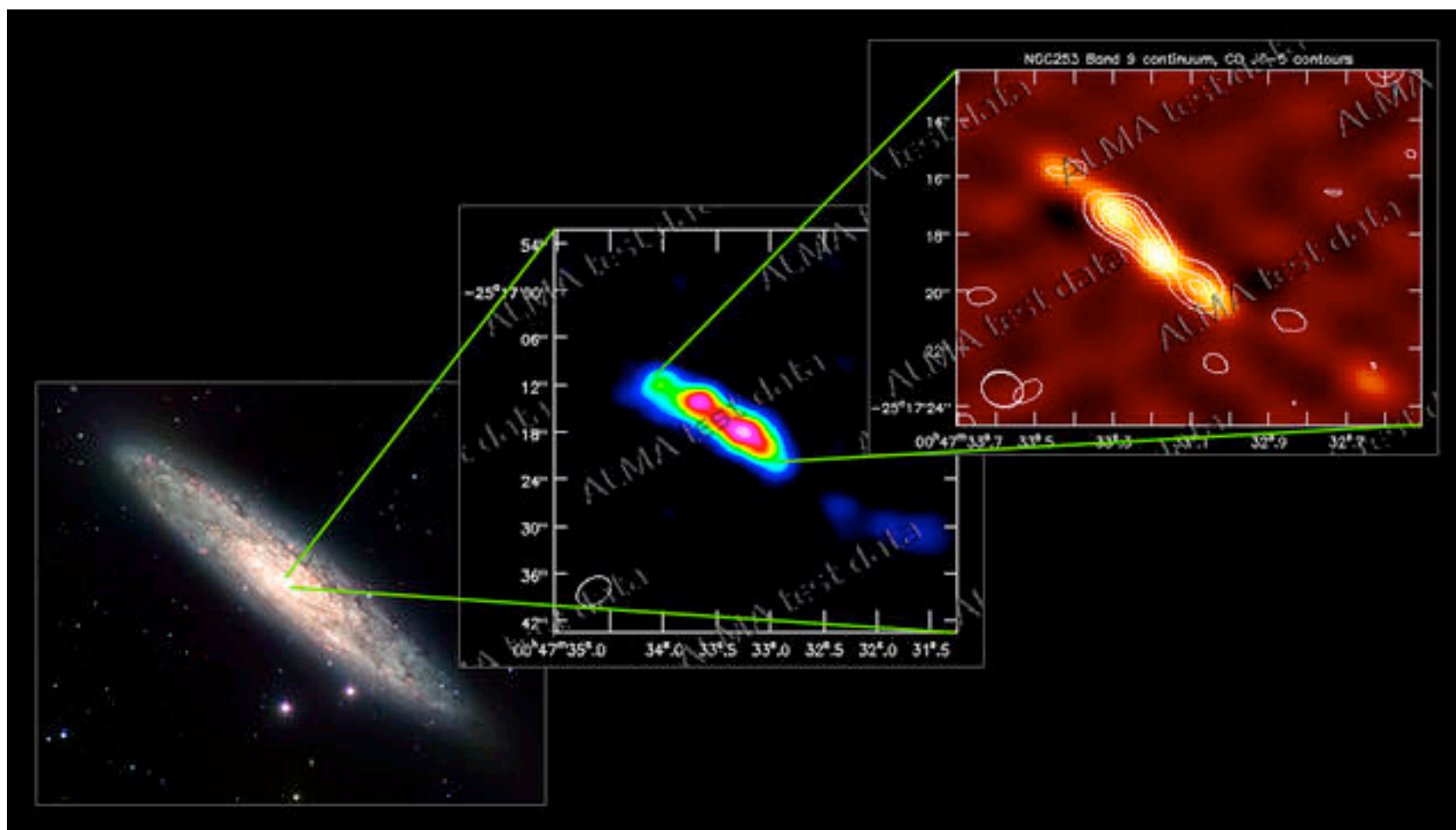
Software vs Hardware!

- 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”!

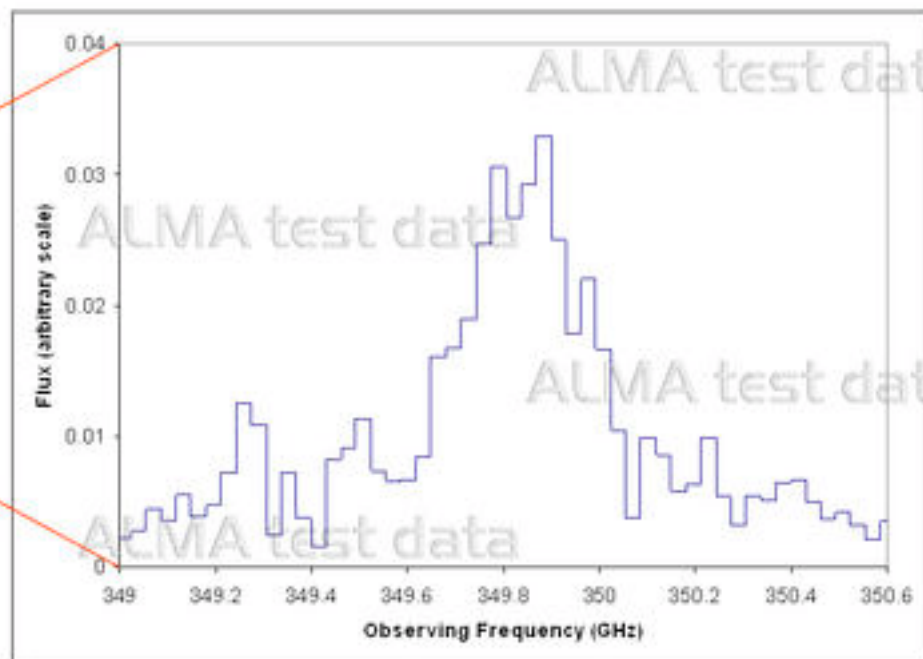
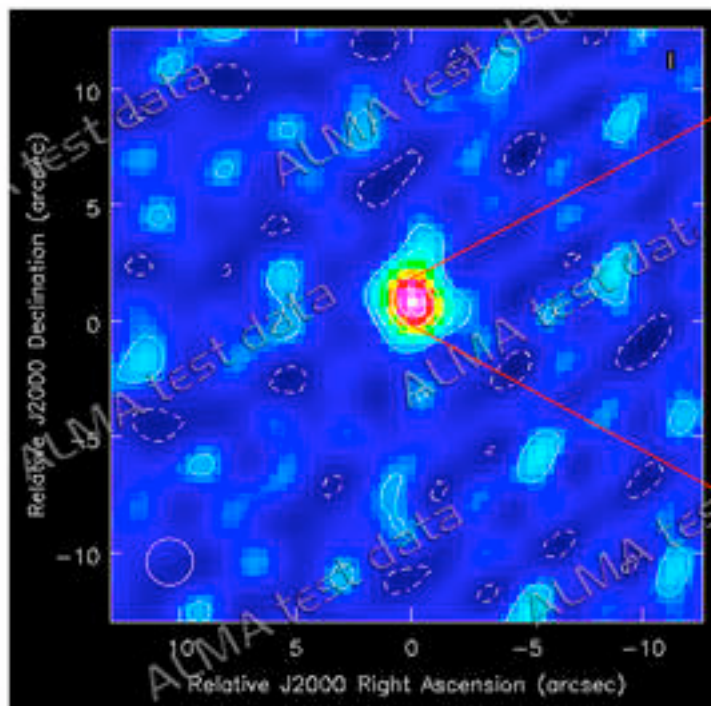


ALMA is HERE!



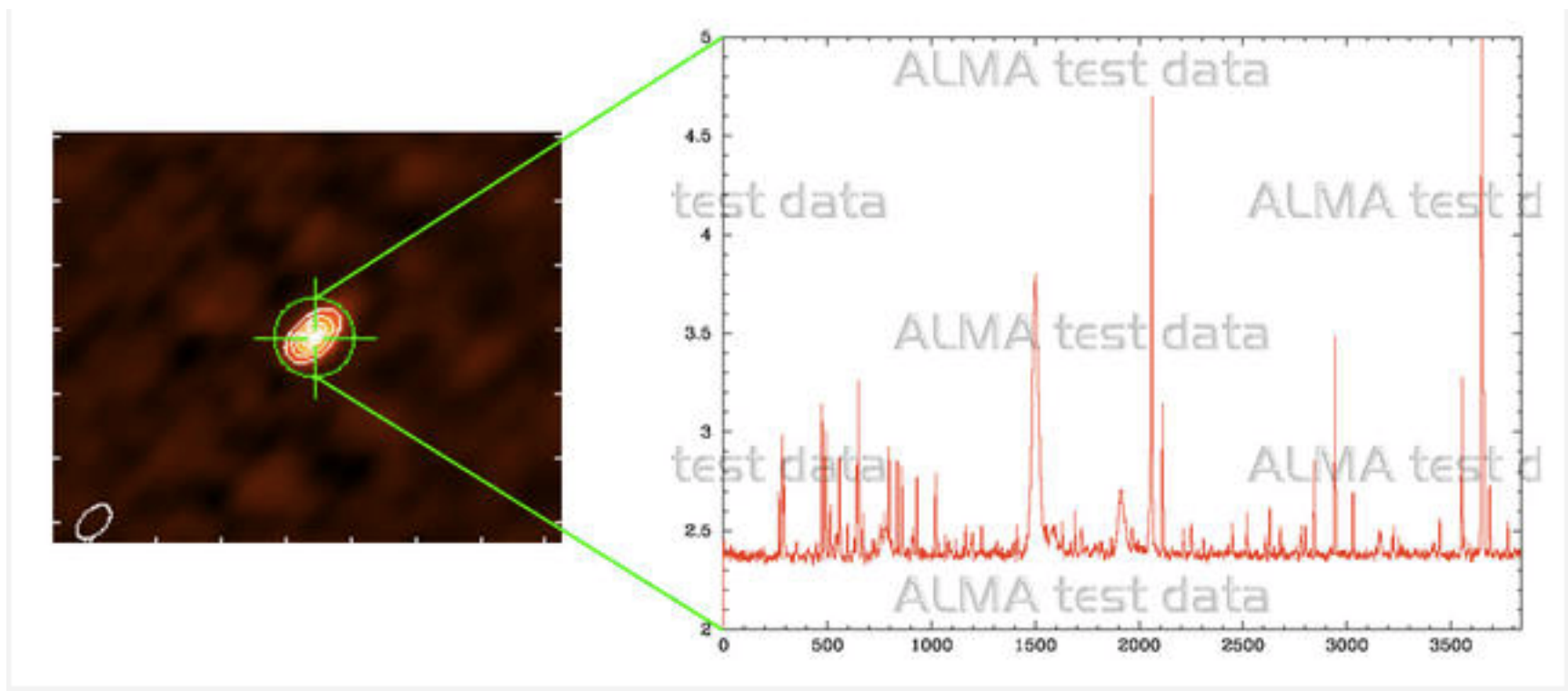
NGC 253 - Band 3: CO (2-1) and Band 7: Continuum + CO(6-5)

ALMA is Here!



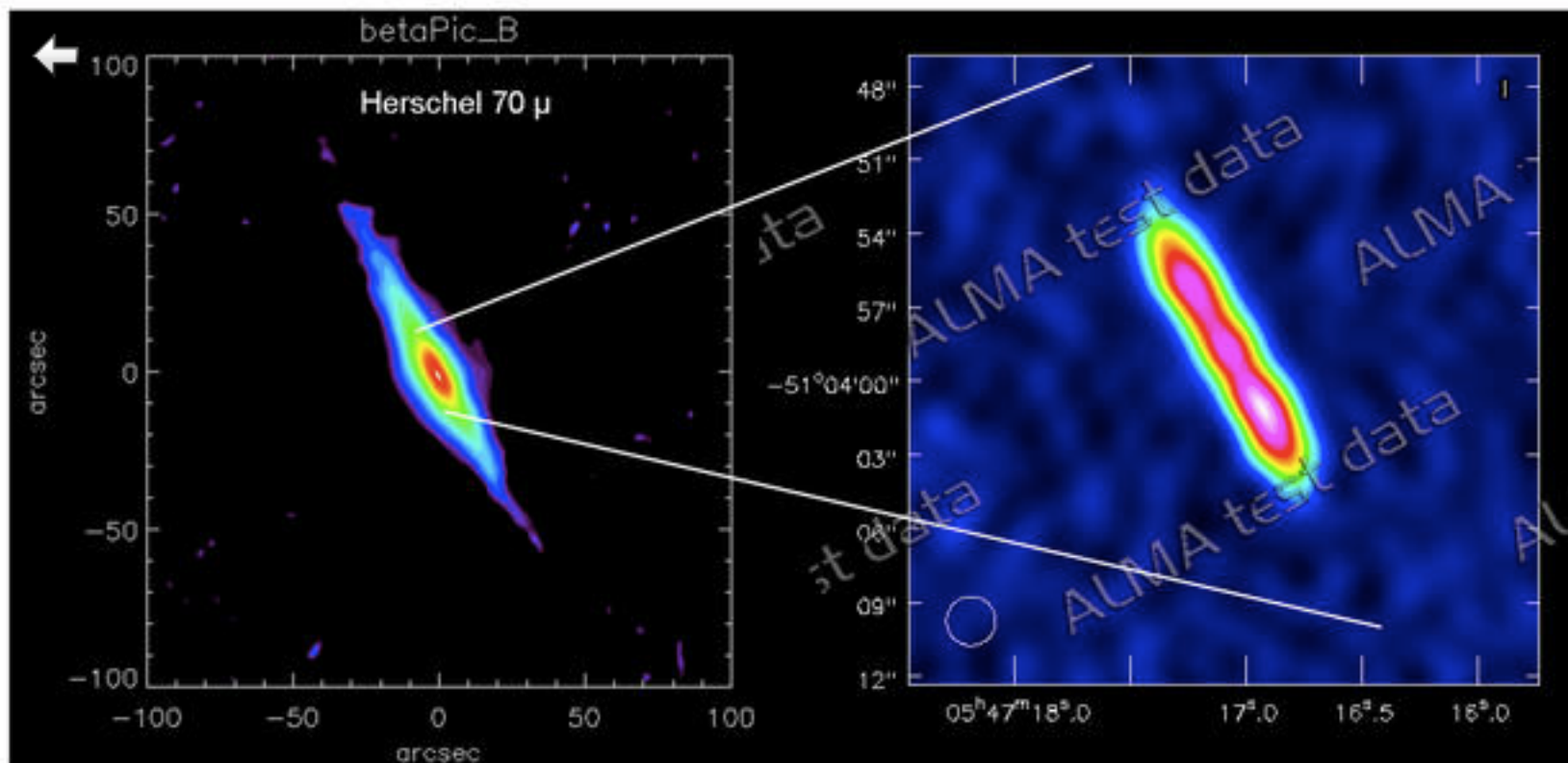
Ionized Carbon (CII @ 158 microns) detected in 1 hr on BRI
0952-0115 at $z=4.43$

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 screenshot displays the ALMA/NAASC website interface. At the top, a navigation bar includes links for ALMA/NAASC, EVLA, GB, VLBA, and NTC. Below this, a breadcrumb trail reads: Research Facilities > ALMA/NAASC > About ALMA/NAASC.

About ALMA

- About the NAASC
- Early Science
- HelpDesk
- Using ALMA
- Post-Processing
- Software & Tools
- Data Archive
- Financial Support
- Scientific Visitor Info
- People
- Publications
- Workshops & Tutorials
- News & Outreach

ALMA: An Overview




Image courtesy ALMA (ESO/NAOJ/NRAO).

Upon completion, the Atacama Large Millimeter Array (ALMA) will be composed of at least 66 high-precision antennae. The array is located on the Chajnantor plain of the Chilean Andes, a site that offers the exceptionally dry and clear sky required to operate at millimeter and submillimeter wavelength. Detailed **characterization of the site** can be found at this [link](#). The quality of the observing site, combined with the unprecedented combination of sensitivity, angular resolution, spectral resolution and image fidelity made possible with ALMA, will enable astronomers to carry out transformational research in a wide variety of astronomical areas. The wavelengths covered by ALMA range from 0.3 mm to 3.6 mm (frequency coverage of 84 GHz to 950 GHz) - this range is essential for probing the first stars and galaxies, directly imaging the disks in which planets are formed, and probing the energy output from active supermassive black holes in extremely luminous starburst galaxies.

A brief introduction to ALMA and ALMA observing is given in the document [Observing with ALMA: A Primer](#), developed by our North

Events

- Observing with ALMA: AAS Special Session**
Jan 12, 2011 | 2:00 PM
Seattle, WA
- ALMA Early Science Proposal Preparation Tutorial**
Jan 12, 2011 | 5:30 PM
Seattle, WA
- ALMA: Extending the Limits of Astrophysical Spectroscopy**
Jan 15 - 17, 2011
Victoria, British Columbia
- ALMA Software Tutorial**
Jan 18, 2011 | 8:30 AM
Victoria, British Columbia

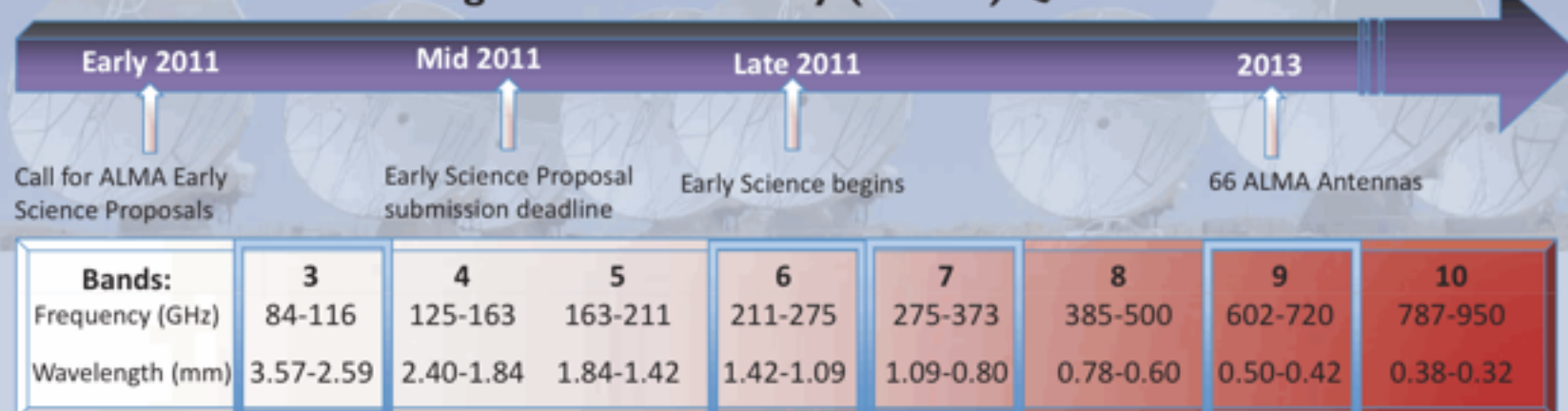
[Events Archive](#)

Latest News

- Postdoctoral Positions Available**
Nov. 5, 2010
- Two more antennas wait**



The Atacama Large Millimeter Array (ALMA) Quick Reference



	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>





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

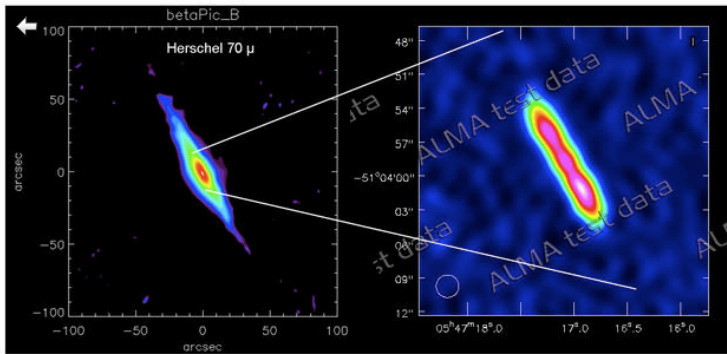
Visit NAASC after getting data

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)



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

