

# NRAO

an NSF Facility



## National Radio Astronomy Observatory



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



# ALMA's Contributions to Outflows, Winds and Jets



Al Wootten

North American ALMA Science Center

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



# Outline



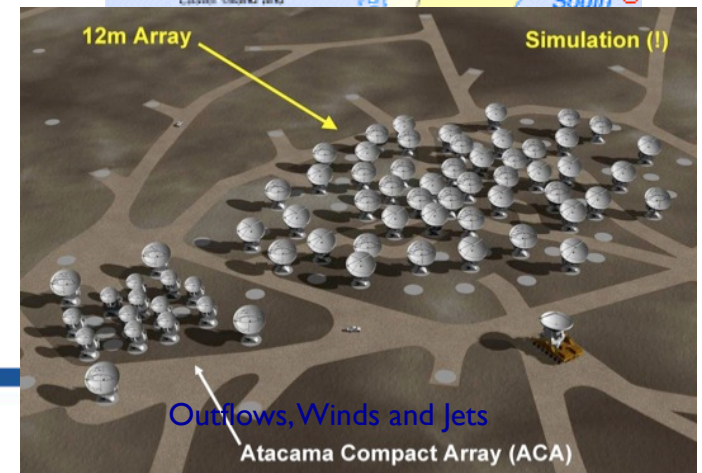
- Current Status of ALMA
- Capabilities of ALMA for studies of outflows, winds and jets
  - Test data – some results, mostly early with few antennas
  - SV data – no jets, winds, outflow data yet
  - Cycle 0 and beyond – stay tuned
    - Cycle I
    - Development (see tomorrow's discussion)





# ALMA Overview

- A global partnership to deliver a transformational millimeter/submillimeter interferometer
  - North America (US, Canada, Taiwan)
  - Europe (ESO)
  - East Asia (Japan, Taiwan)
  - In collaboration with Chile
- 5000m (16,500 Ft) site in Chilean Atacama desert
- Main Array: 50 x 12m antennas
  - + Total Power Array 4 x 12m
  - + Atacama Compact Array (ACA): smaller array of 12 x 7m antennas
- Total shared cost ~1.3 Billion (\$US2006)
  - On budget for completion on time



# Operation Support Facility (OSF) Early 2007, between 1<sup>st</sup> and 2<sup>nd</sup> NAASC Workshops



View from East to West

# Antenna Vendor Areas 2007



**View of Vertex hangar construction**



# Operations Support

## Facility: 9500 ft altitude

15 km from gate on CH23



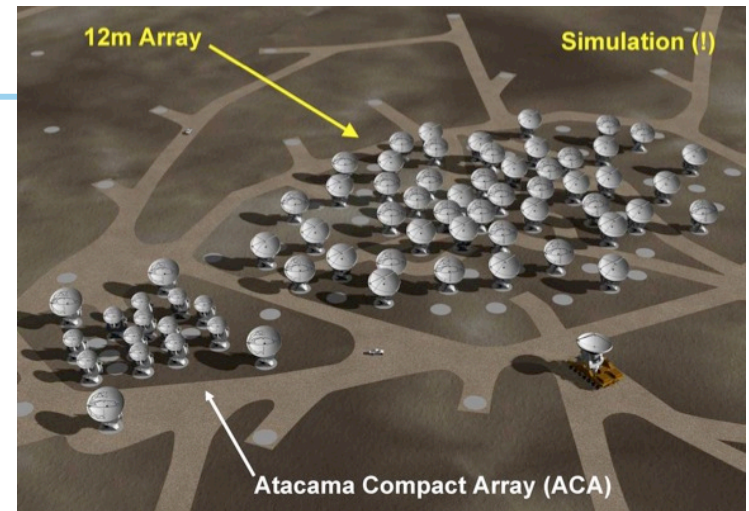
OSF

- Technical Building
  - Completed
  - Warehouse
  - Shops, offices, antenna area
- Camps: House, feed and amuse >500 people
  - ALMA
  - Contractors
- Antenna erection areas
  - VertexRSI (NA)
  - Mitsubishi (JP)
  - Alcatel (EU)
- Temporary Offices

# ALMA Overview

- Baselines up to 15 km ( $0.015''$  at 300 GHz) in “zoom lens” configurations
- Sensitive, precision imaging 84 to 950 GHz (3 mm to 315  $\mu$ m)
- State-of-the-Art low-noise, wide-band SIS receivers (8 GHz bandwidth x 2 polzns)
- Flexible correlators (64 and 16 inputs) with high spectral resolution at wide bandwidth
- Full polarization capabilities
- Estimate .5 TB/day archived

- A resource for ALL astronomers



ALMA will be 10-100 times more sensitive and have 10-100 times better angular resolution compared to current millimeter interferometers

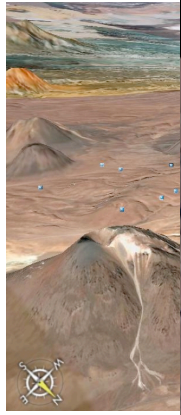
Outflows, Winds and Jets



# Array Operations Site: 16400

feet

43 km from site on CH22 on 51 ft wide road



m-14km  
Antenna to TB  
r  
Is

- Antenna transporter shelter
- Refuge
- No one overnight, few during day



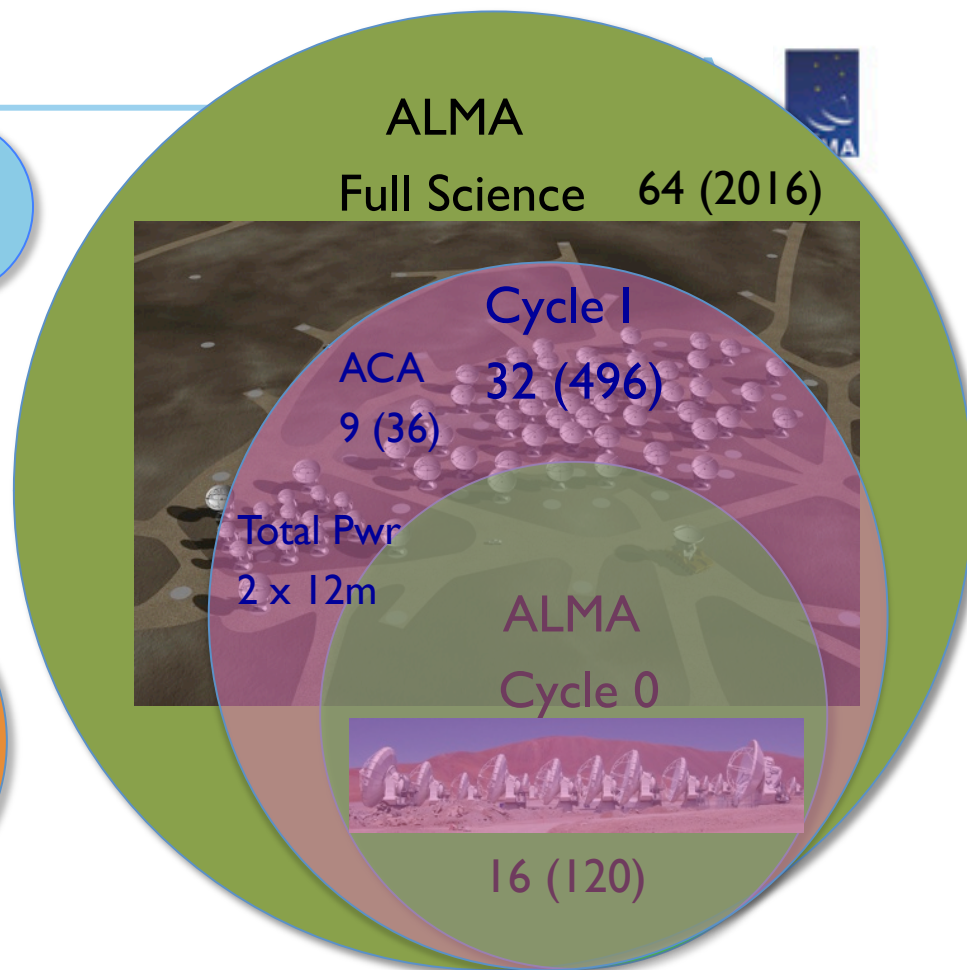
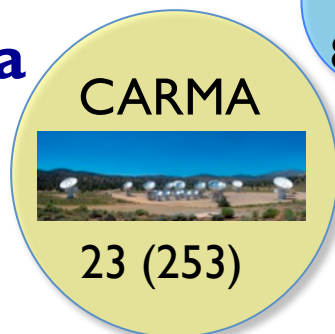
Array Operations Site Technical Building

# ALMA in Context

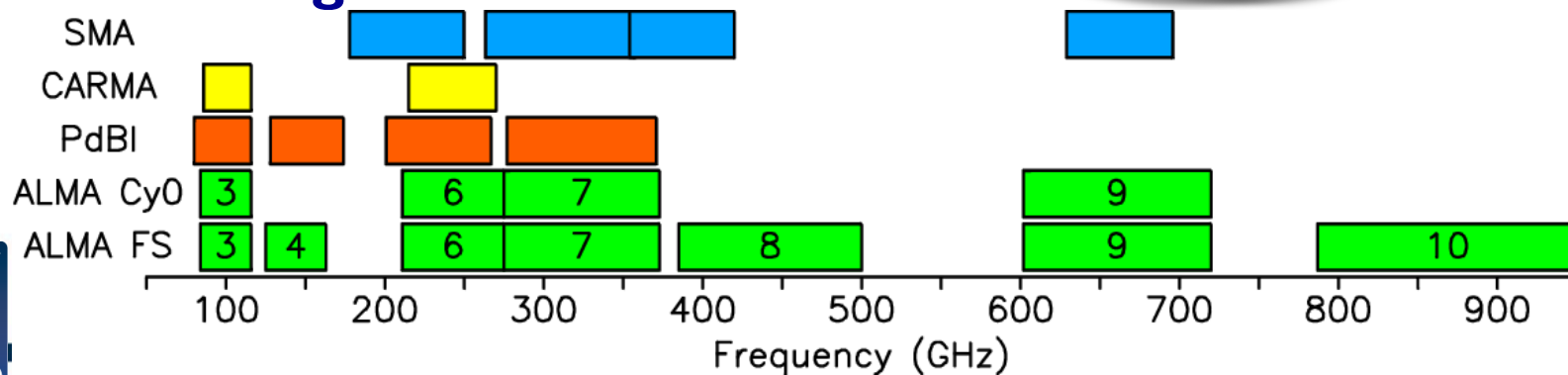
## Collecting Area

# of Antennas  
(# of baselines)

- Sensitivity goes as collecting area
- Image fidelity goes as # of baselines



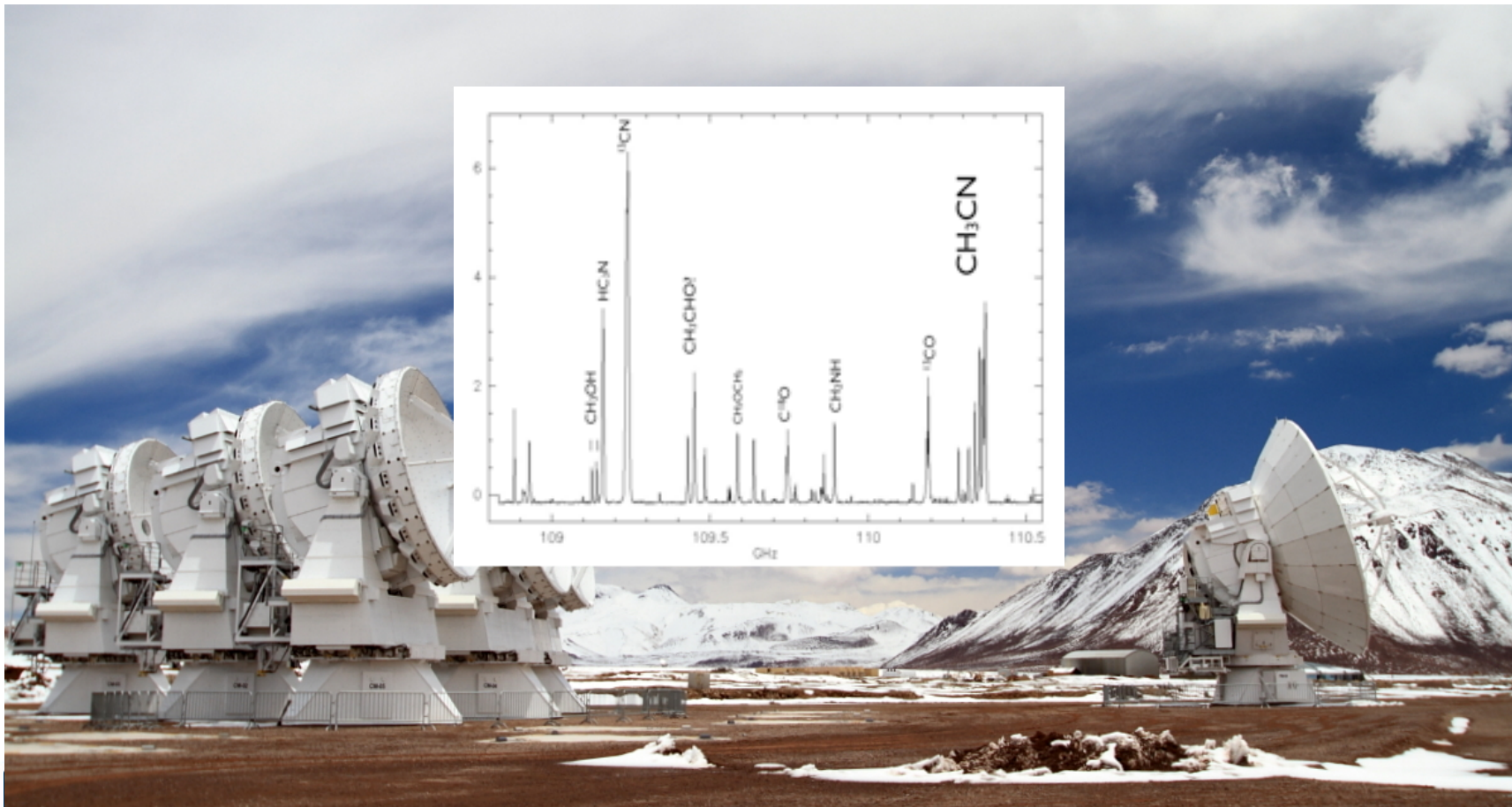
## Spectral Coverage



Outflows, Winds and Jets

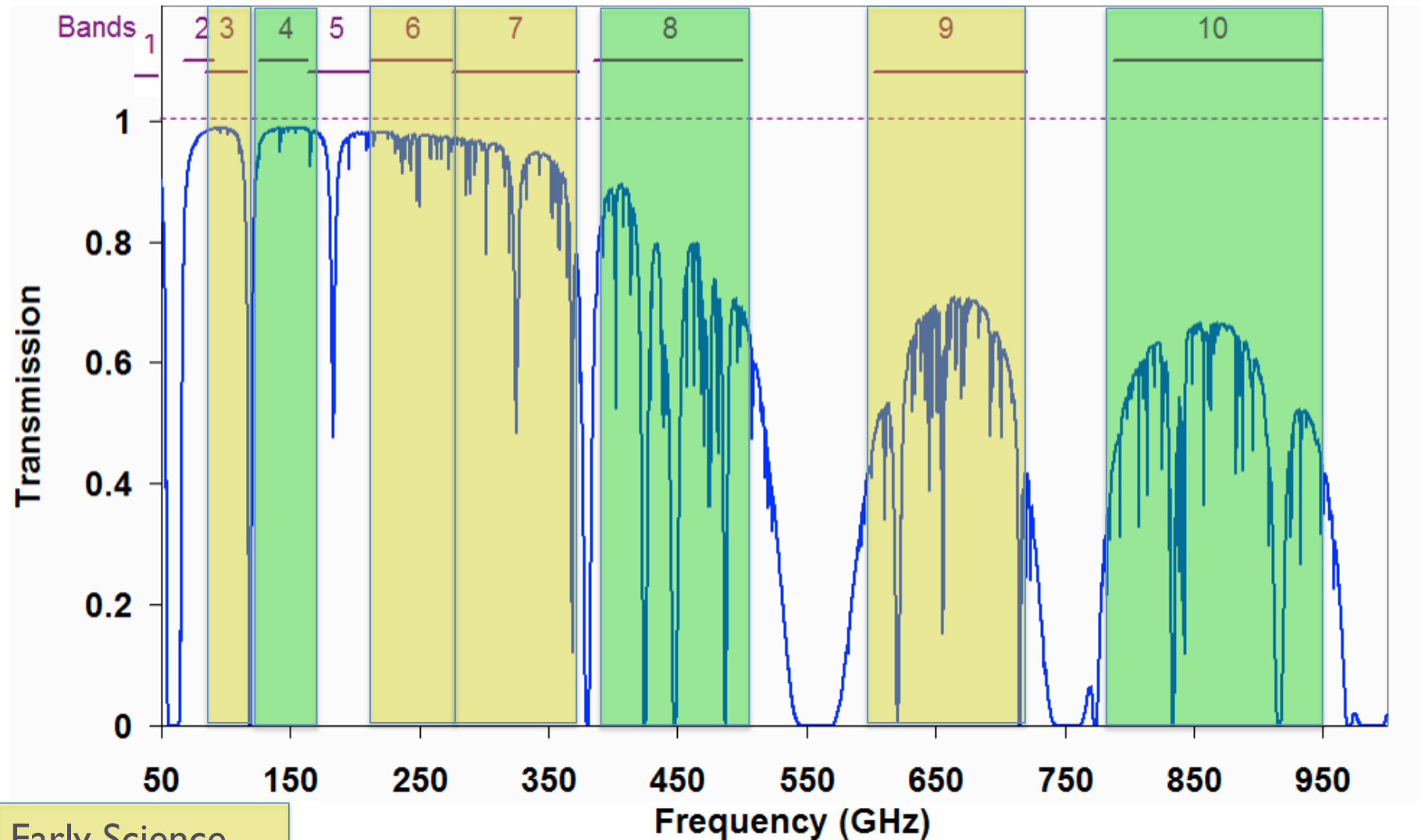


# ACA: Short Spacings





# ALMA Receiver Bands

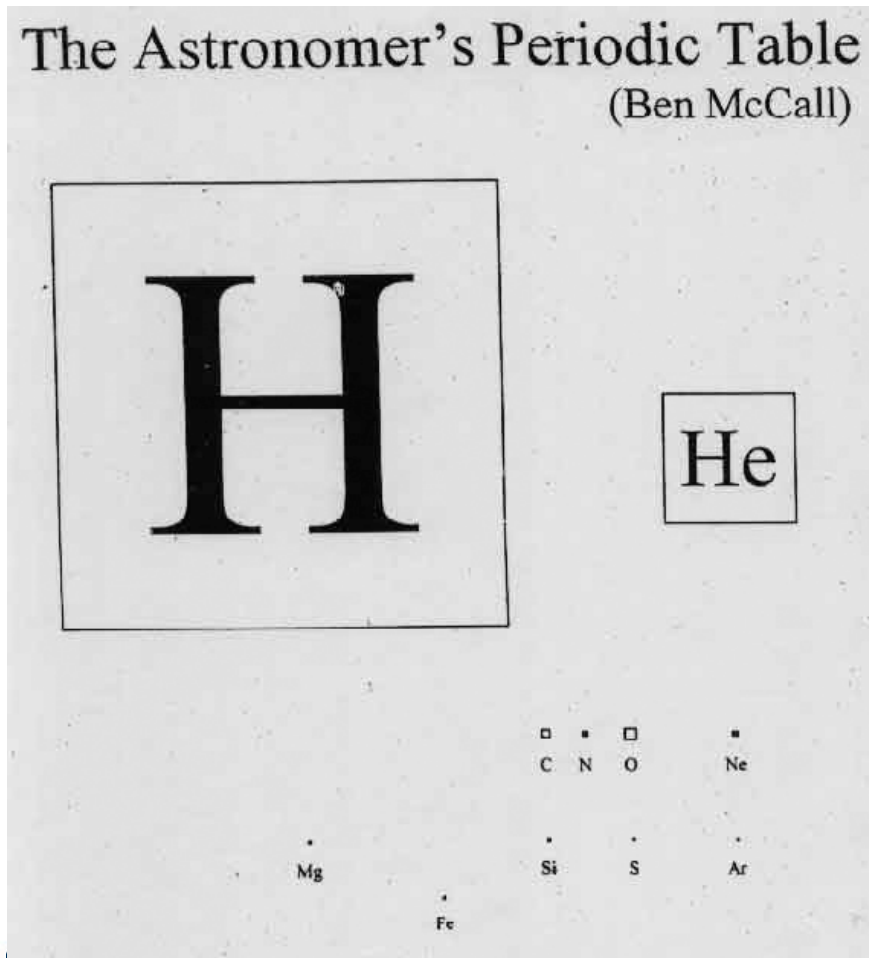


Early Science

Full Operations

Outflows, Winds and Jets

# The Birth of Chemical Complexity



When chemistry got interesting

( $\text{H}_3^+$ ,  $\text{H}_2\text{D}^+$ ,  $\text{H}_2$ , HD notwithstanding)

ALMA should be able to monitor the creation of

- O ([O I], [O III], OH,  $\text{H}_2\text{O}$ )
- C ([C I], [C II], CO, CH,  $\text{CH}^+$ ,  $^{13}\text{C}$ )
- N ([N II], NH,  $\text{N}_2\text{H}^+$ )

And monitor important isotopes of these elements; many are created as byproducts of the evolution of lower mass stars which begin to pollute the ISM by  $z \sim 5.5$

At high  $z$ , spectra are compressed by  $(1+z)$ .

## Sensitivity, Resolution

- ALMA can reach 1 mJy/beam in a minute (1 km s<sup>-1</sup>)
- Excellent imaging
  - Atmospheric correction
  - Hundreds of baselines
- 16ms time resolution for interferometric observations
- Provides e.g. possibility of tracking the physical and chemical evolution of shocks accompanying winds, jets and flows



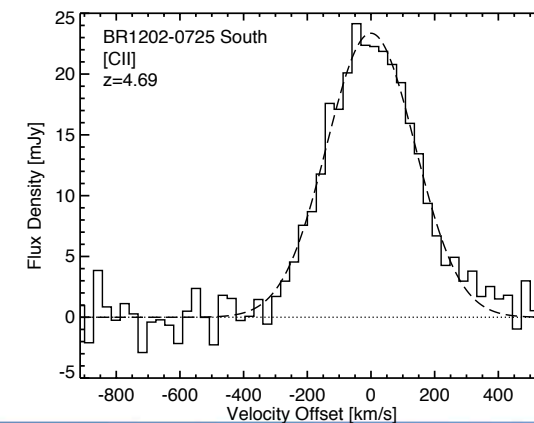
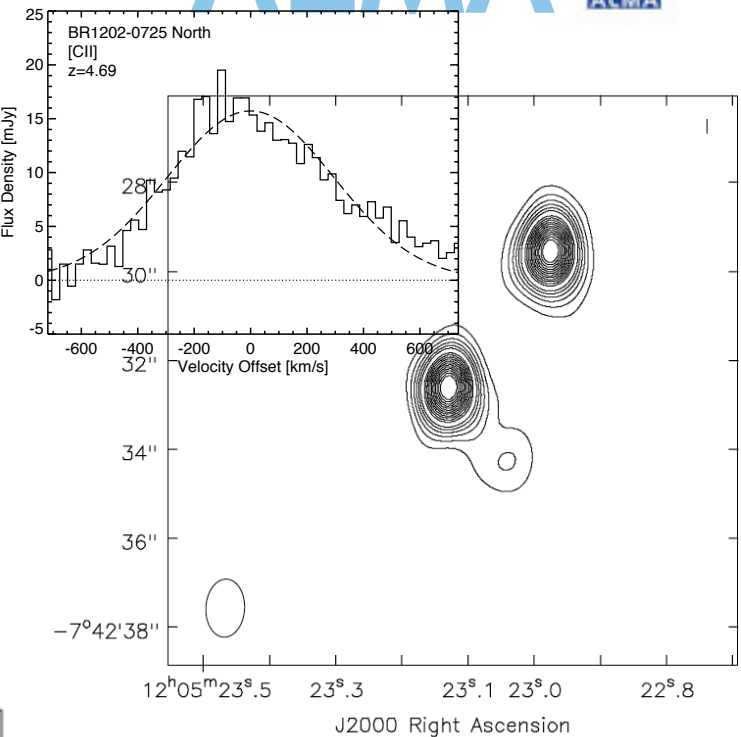
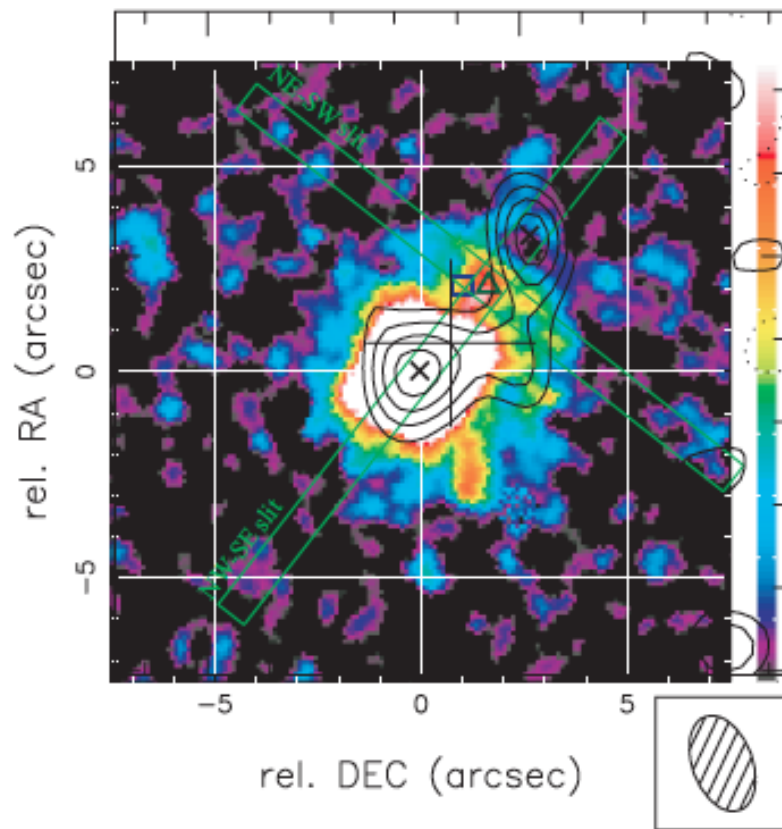
## Bottom Line: 30 Sep C0 ES began

- AOS: 27 antennas, repowering after engineering period
  - 6 are 7m antennas; 21 are transitioning to ES extended
    - Net change of 12
  - 10 (2x7m) at OSF in ALV; 38 ‘accepted’ by project, of 66
  - Capable; some issues with equipment readiness
  - Expect pads for extended configuration by year-end.
- All antennas four bands (42 Front Ends in Chile)
  - Some have B4 (2mm), B8 (.6mm), B5 (1.6mm)
- First datasets: ongoing delivery to PIs
- Planning advanced for Cycle I



# Test 1

- Data not high resolution, require deconvolution.
- Exam BR1202-0725 but is not a jet.
- 1.5 hr observation
  - Sensitive
  - A
  - [C II] agrees with Hi-J CO
  - 3<sup>rd</sup> source flux 1.4 mJy seen in Subaru image





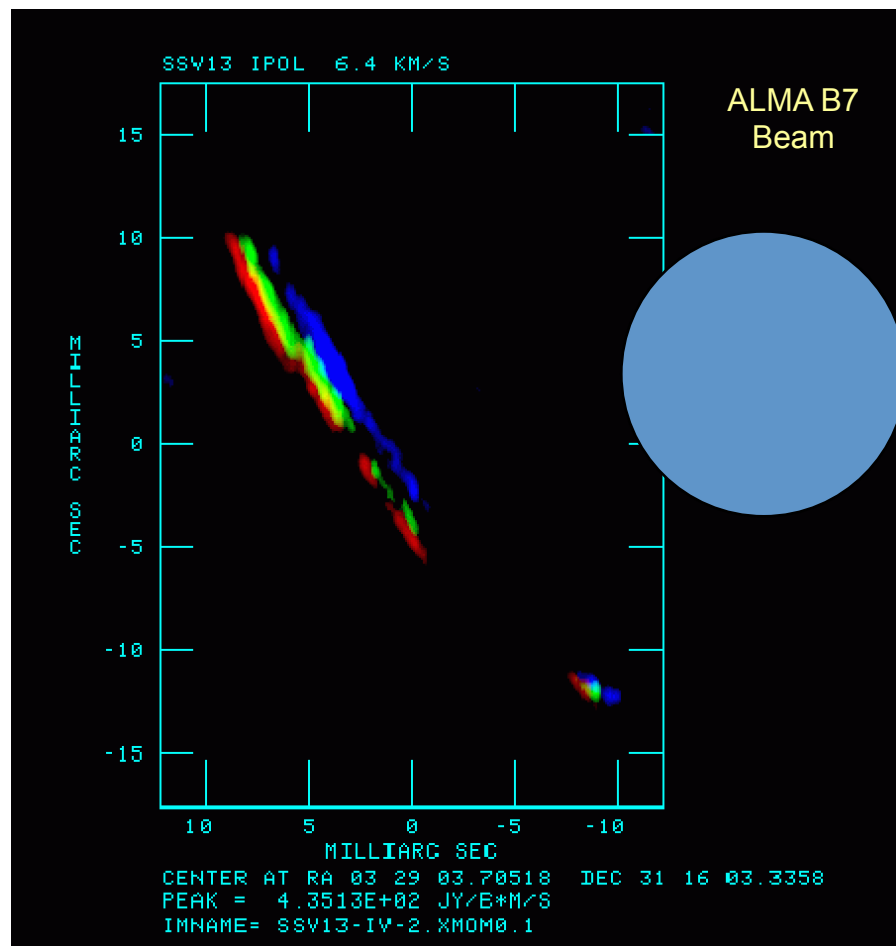
# 30 Sep Cycle 0 ES



- Correlator/Spectral Modes
  - Both ACA and 32 element correlators functioning.
  - Final quadrants of 64 element correlator to be installed Sept 12
  - Imminent CSV demonstration: combination of data
- Scientific Verification Data: Eight Datasets Released (and one datum):
  - 1: **TW Hya: Band 7**, high spectral resolution (casaguide).  
Band 3, Band 6.
  - 2: **NGC3256: Band 3**, low spectral resolution (casaguide).
  - 3: **Antennae galaxies: Band 7**, high spectral resolution, mosaic (casaguide). Band 6
  - 4: **M100 Band 3**, low spectral resolution.
  - 5: **SgrA\* Band 6**, recombination lines.
  - 6: **Proof of Concept of Response to Targets of Opportunity:**  
The GRB 110715A (detected)



# Resolution: Proper Motion, Shock Structure in Dense Clouds



Masers near SVS13;  $1\text{mas}=0.34\text{AU}$   
Blue Epoch I, Green Epoch III, Blue Epoch IV  
Wootten, Marvel, Claussen and Wilking

Winds, jets and outflows interact with local media at shocks; masers can trace these.

Water masers observed over four epochs encompassing 50 days (22 GHz, VLBA). Several of the masers define an arc structure about 5AU in length. This consistently moved at a rate of 0.023 mas/day, or 13.6 km/s. Including the radial velocity offset, a space velocity of 13.7 km/s is calculated at an inclination of 6 degrees from the plane of the sky.

These structures apparently represent water emission from interstellar shocks driven by the outflow from SVS13.

*ALMA, VLBA, JVLA can provide images of chemistry in action in shocks such as this.*

# Key to Understanding Shocks:

High  $T_B$  sensitivity at high resolution, 1 min

Band	Frequency	Primary Beam (FOV; ")	Largest Scale (")	Continuum Sensitivity (mJy)	Compact		Most Extended	
					Angular Resolution (")	$\Delta T_{\text{line}}$ (K)	Angular Resolution (")	$\Delta T_{\text{line}}$ (K)
<i>Band 1</i>	<i>31.3 - 45 GHz</i>							
<i>Band 2</i>	<i>67 - 90 GHz</i>							
<i>Band 3</i>	<i>84 - 116 GHz</i>	56	37	0.05	3.18	0.07	0.038	482
<i>Band 4</i>	<i>125 - 163 GHz</i>	48	32	0.06	2.5	0.071	0.03	495
<i>Band 5</i>	<i>163 - 211 GHz</i>	35	23					
<i>Band 6</i>	<i>211 - 275 GHz</i>	27	18	0.10	1.52	0.104	0.018	709
<i>Band 7</i>	<i>275 - 373 GHz</i>	18	12	0.20	1.01	0.167	0.012	1128
<i>Band 8</i>	<i>385 - 500 GHz</i>	12	9	0.40	0.86	0.234	0.01	1569
<i>Band 9</i>	<i>602 - 720 GHz</i>	9	6	0.69	0.52	0.641	0.006	4305
<i>Band 10</i>	<i>787 - 950 GHz</i>	7	5	1.1	0.38	0.940	0.005	

To be developed in the future.

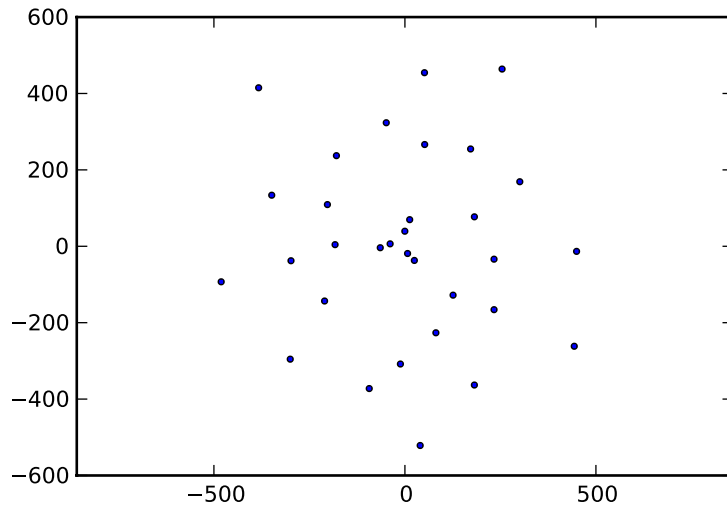
Available for early science.



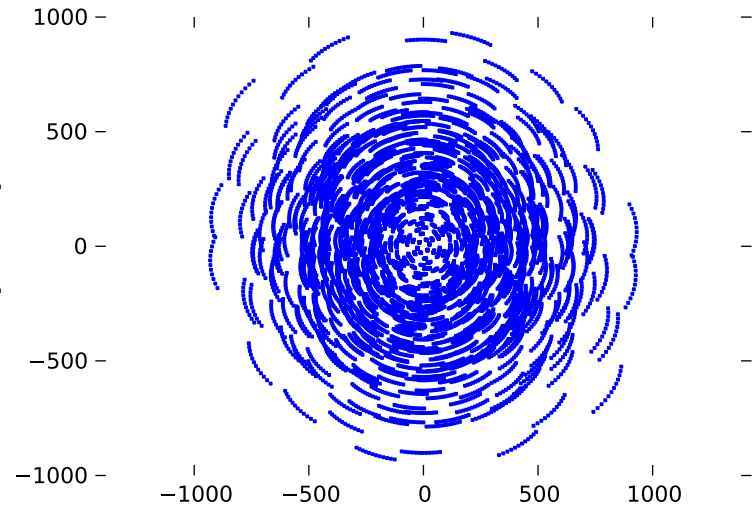
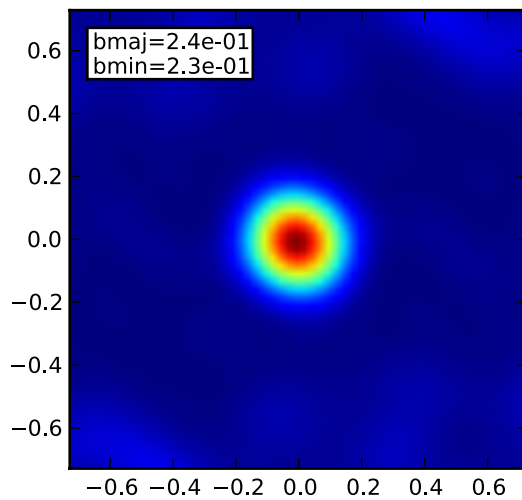
# Looking Forward: Cycle 0 and Cycle I

- Cycle 0
  - Completion rate of projects is lower than planned
    - 16+ datasets delivered
  - Cycle 0 observing period will be extended until the end of 2012.
    - Time fraction devoted to ES will increase
    - Will allow completion of nearly all Cycle 0 projects
    - May result in completion of some fraction of ‘filler’ projects
  - This extension will not delay completion of the array.
- Cycle I
  - Information regarding the capabilities and timeline for ALMA Early Science Cycle I to be released April 2012.
  - Deadline is expected to be in July 2012
  - Start of Cycle I observations at the beginning of 2013.

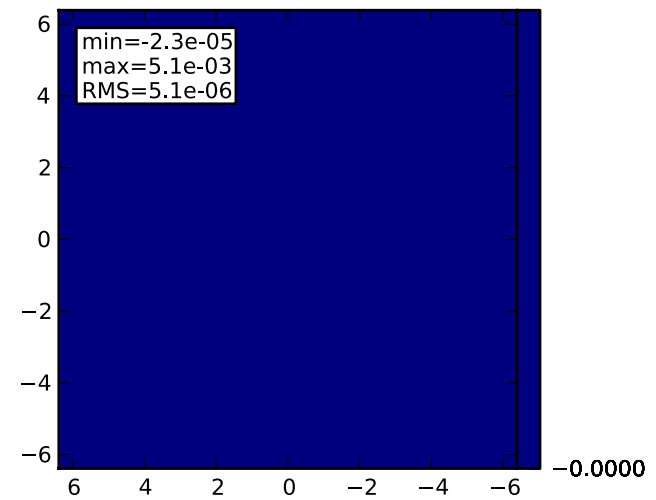
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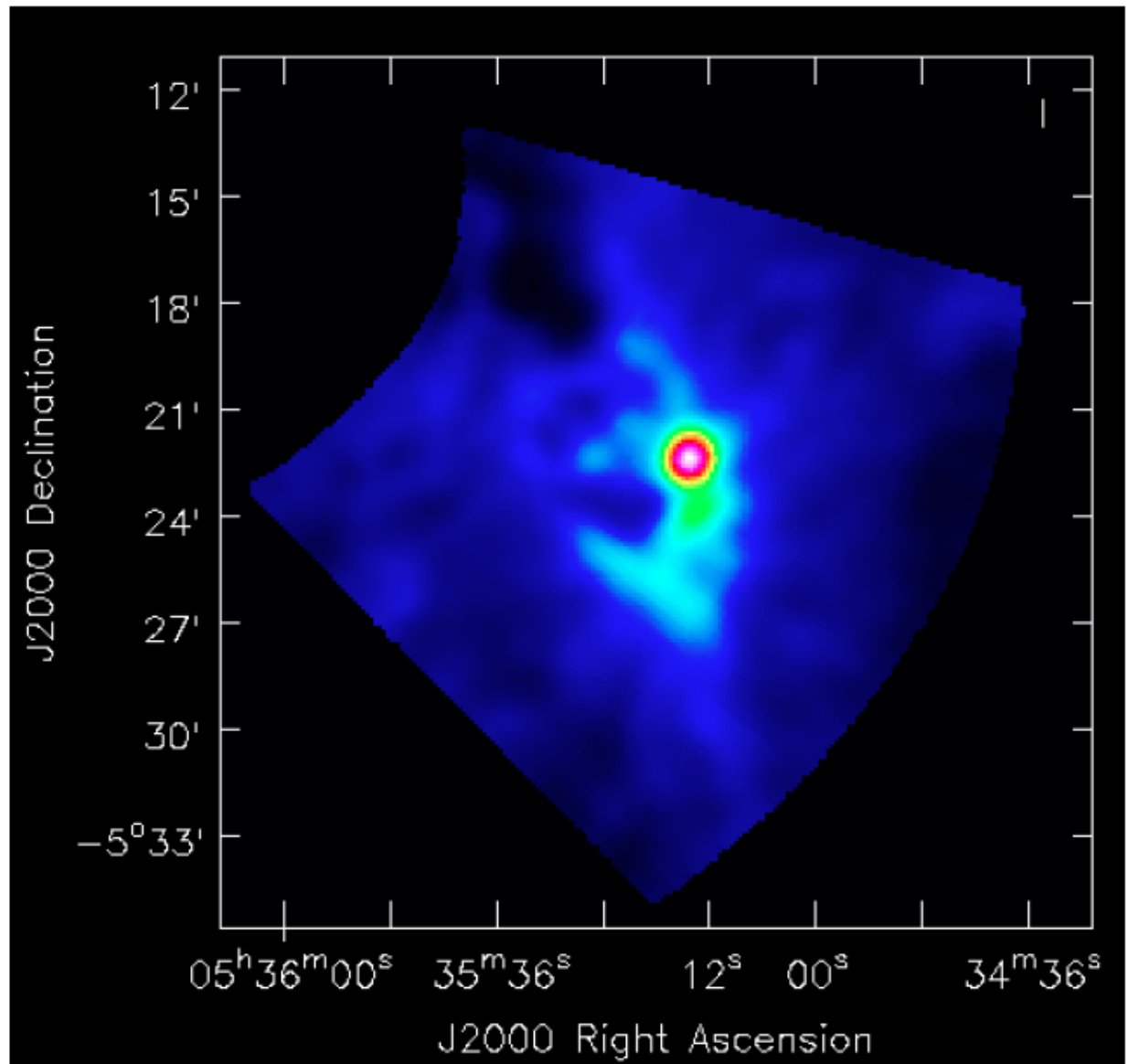
[illegible]

# Orion $^{12}\text{CO}$ 1-0

64 row map

Took 52 mins

(of which 34 were  
on sky and 18  
were overheads)



J2000 Right Ascension

J2000 Right Ascension



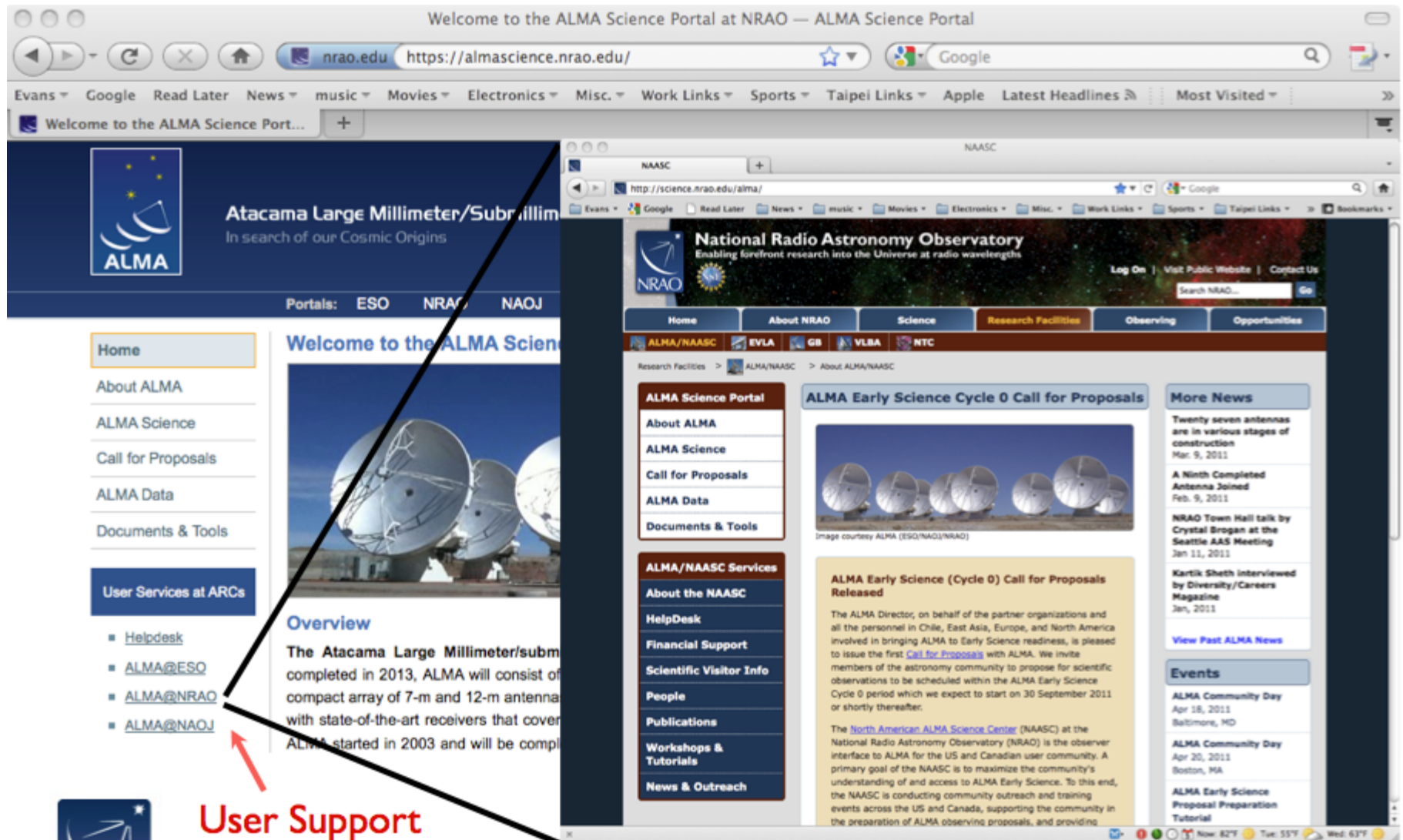
# Cycle I Capabilities (Proposed)

- Mosaics: 150 pointings/schedule block
- Program considerations
  - Target of Opportunity
  - Director's Discretionary Time
  - Scheduling sharpness only 1-2 weeks
  - No large programs
  - No project transferral to Cycle 2

# NRAO User Support

<http://almascience.nrao.edu>

NAASC 



ALMA Science Portal

Atacama Large Millimeter/Submillimeter

In search of our Cosmic Origins

Portals: ESO NRAO NAOJ

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Overview

The Atacama Large Millimeter/submillimeter Array (ALMA) is a ground-based radio astronomy observatory located in the Atacama Desert of northern Chile. The array consists of 66 radio telescopes, each with a diameter of 12 meters, arranged in a Y-shape. The array was completed in 2013 and is currently in operation. The array is designed to observe the universe at millimeter and submillimeter wavelengths, which are the longest wavelengths of the electromagnetic spectrum that can be observed from Earth. The array is the most powerful and sensitive radio telescope ever built, and it is capable of observing the universe at the highest resolution ever achieved. The array is the result of a collaboration between the European Southern Observatory (ESO), the National Radio Astronomy Observatory (NRAO), and the National Astronomical Observatory of Japan (NAOJ). The array is the largest and most sensitive radio telescope ever built, and it is capable of observing the universe at the highest resolution ever achieved. The array is the result of a collaboration between the European Southern Observatory (ESO), the National Radio Astronomy Observatory (NRAO), and the National Astronomical Observatory of Japan (NAOJ).

ALMA Science Portal

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ALMA Early Science Cycle 0 Call for Proposals

ALMA Early Science (Cycle 0) Call for Proposals Released

The ALMA Director, on behalf of the partner organizations and all the personnel in Chile, East Asia, Europe, and North America involved in bringing ALMA to Early Science readiness, is pleased to issue the first [Call for Proposals](#) with ALMA. We invite members of the astronomy community to propose for scientific observations to be scheduled within the ALMA Early Science Cycle 0 period which we expect to start on 30 September 2011 or shortly thereafter.

The [North American ALMA Science Center](#) (NAASC) at the National Radio Astronomy Observatory (NRAO) is the observer interface to ALMA for the US and Canadian user community. A primary goal of the NAASC is to maximize the community's understanding of and access to ALMA Early Science. To this end, the NAASC is conducting community outreach and training events across the US and Canada, supporting the community in the preparation of ALMA observing proposals, and providing

More News

Twenty seven antennas are in various stages of construction  
Mar. 9, 2011

A Ninth Completed Antenna Joined  
Feb. 9, 2011

NRAO Town Hall talk by Crystal Brogan at the Seattle AAS Meeting  
Jan. 11, 2011

Kartik Sheth interviewed by Diversity/Careers Magazine  
Jan. 2011

View Past ALMA News

Events

ALMA Community Day  
Apr. 18, 2011  
Baltimore, MD

ALMA Community Day  
Apr. 20, 2011  
Boston, MA

ALMA Early Science Proposal Preparation Tutorial



User Support

Outflows, Winds and Jets



[almascience.nrao.edu](http://almascience.nrao.edu)  
[science.nrao.edu/alma](http://science.nrao.edu/alma)

ALMA

The Atacama Large Millimeter/sub-millimeter Array (ALMA), an international astronomy facility, is a partnership of Europe, North America and East Asia in cooperation with the Republic of Chile. ALMA is funded in Europe by the European Organization for Astronomical Research in the Southern Hemisphere (ESO), in North America by the U.S. National Science Foundation (NSF) in cooperation with the National Research Council of Canada (NRC) and the National Science Council of Taiwan (NSC) and in East Asia by the National Institutes of Natural Sciences (NINS) of Japan in cooperation with the Academia Sinica (AS) in Taiwan. ALMA construction and operations are led on behalf of Europe by ESO, on behalf of North America by the National Radio Astronomy Observatory (NRAO), which is managed by Associated Universities, Inc. (AUI) and on behalf of East Asia by the National Astronomical Observatory of Japan (NAOJ). The Joint ALMA Observatory (JAO) provides the unified leadership and management of the construction, commissioning and operation of ALMA.



Outflows, Winds and Jets