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

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Very Long Baseline Array

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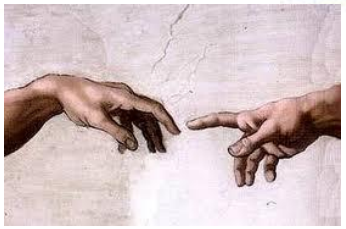
ALMA Development: Origins



- Recognized early in the ALMA project that continuing technical upgrades and development of new capabilities are essential to maintain ALMA as state-of-the-art facility over its projected life of 30+ years
  - ALMA Board agreed that a science driven, long range development plan should be developed
  - Internationally reviewed and adopted ALMA operations budget includes line dedicated to ALMA upgrades
- In 2008-2009, international panel considered wide range of possibilities to extend baseline capabilities of ALMA
  - ALMA North American Science Advisory Committee and counterparts in Europe and East Asia reviewed and commented
  - ALMA Science Advisory Committee (ASAC) reviewed these and indicated their scientific priority

SAC Recommendations

- Matrix of capabilities
- A mix of projects;
  - Short term quickly realizeable projects with maximum science impact
  - Longer term projects promising a high scientific return but requiring development
- Emphasis on
  - Improved sensitivity
  - Greater spatial resolution
  - Increased spectral coverage
  - Field of View
- Some projects in each category fit within short-term possibilities, some long-term

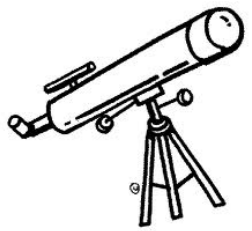
AS2010: New Worlds, New Horizons in Astronomy and Astrophysics

- **Report of the Panel on Radio, Millimeter, and Submillimeter Astronomy from the Ground**
- "**ALMA Development:** The consortium plans a program costing $90 million over a decade, of which $30 million would come from the North American partners. The panel fully supports this plan."
  - Specific mention of new receiver bands, mm VLBI.
- Plan: Call for ideas/studies of development
  - Such a call was issued at ESO in 2010; NRAO and NAOJ 2011.
  - Some development funding from outside these lines
    - ALMA Band 5 initial receiver complement
    - VLB capability as part of Event Horizon Telescope

ALMA Plan: Scope

NAASC

- Key principle: ***program must be driven by science***
- Program focus
  - •Delivery of tangible improvements to ALMA
  - •Alternatively, to fund ALMA-targeted R&D that may lead to improvements
- Projects could be:



– New additions to the array

– Extension of existing capabilities (more sensitivity, wider bandwidth, improved image quality)

– Improvements to existing systems resulting in improved availability

-- Improved infrastructure reducing risk, increased availability, eased or decreased operations cost.

– Improved infrastructure that reduces risks, increases availability, makes operations easier/less expensive

Includes significant enhancements to software

- Timescale for project completion in the range of 3-5 yrs

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Development Life Cycle: Birth as *Studies*

- ***Regional*** discussions overseen by Executives generate initiative
- Targeted exploratory research or feasibility ***studies*** at Executive
  - Includes assessment of opportunities for collaboration
  - Budget line in Ops Plan amounts to ~10% of Development Program
  - ADSC to coordinate calls for Development Studies on 2-3 yr timescales
- Executives present ***proposals*** to ***ALMA Development Steering Committee***, taking into account Joint Alma Observatory recommendations and drawing on results of studies
  - ASAC, drawing on its regional knowledge and scientific expertise, advises ADSC
  - ADSC takes input, recommends prioritization to ALMA Director
- ALMA Director submits proposal for ***ALMA Development Program***, with suggested prioritization, to Directors Council for concurrence and to ALMA Board for approval

ALMA Development Program

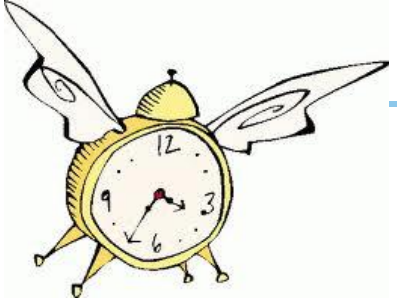
- One program coordinated by ALMA
  - ***Based in partner communities***
  - Contributions in accordance with partnership share 37.5/37.5/25
  - No requirement to balance/share individual projects
  - Overall contributions balanced on timescales of ~5 years

Current NA Timeline

- Call for Studies Nov 2011
  - Includes both hardware and software
  - Better definition of software after Oct 2011 workshop
- 21 Proposals received 13 Feb 2012
  - 14 covered hardware, new bands, increased bandwidth, improved performance of first generation receivers
  - 7 'software' proposals
- Subsequent Call may be issued for early 2013 due date.

Current NA Study Proposals

- 12 PI institutions represented in response
  - 25 institutions overall
  - 11 from NRAO/NRC-HIA/ASIAA
  - Several with partners in ESO
- Total requested funding >$1.5M (3::1 oversubscription)
- External review committee
  - 9 members accepted, going through conflict resolution
  - Goal to accommodate all possible within (~$.5M) budget



Planned NA Timeline II

- Evaluation Completed in March by external-to-NRAO committee
  - ANASAC nominated committee members, chosen in conjunction with NSF
  - NSF will approve committee recommendations
- Kick-off for Studies Spring 2012
- Due end of 2012 (no-cost extension may be sought)
- See https://safe.nrao.edu/wiki/bin/view/ALMA/AlmaDevelopment

Sensitivity, Resolution, FoV

erformance to be improved	development item	degree of improvement	speed/technical difficult	cost	beneficial for
sensitivity	more antenna	add 5 antenna ==> 10%	quick	expensive	all science
	new digital system/2GC	10%	moderate	expensive	all science
	2SB for Band 9	a factor of 2	moderate?	moderate?	all science
	Widening the IF Bandwidth of Band 6	a factor of 2 in a certain case	moderate	moderate($1.6M?)	All science
	receiver development (lower noise): Especially at band 3	10 – 20%?	moderate?	moderate?	all science
angular resolution	longer baseline	a factor of a few	easy/quick but phase stability issues (including atmospheric and LO reference) should be improved as well	expensive?	limited brightest sources
	VLBI	orders of magnitude	easy/quick? LO reference should be improved. A lot of software efforts needed	cheap ($5M?)	Black hole: Sgr A* and very limited sources, 200GHz or higher frequencies AGN Jets at 86GHz and above
field of view	multi-beam receiver	a factor of a few?	long/tough? Enhance correlator power is also required?	expensive?	almost all science (but for compact sources)
	under-illuminated feed	a factor of a few	moderate?	moderate	Solar obs only

Bandwidth, Coverage

spectral coverage	band 2		medium-term	moderate	SZ, redshifted lines, protoplanetary disks, solar
	band 5		medium-term	moderate	redshifted lines, planetary atmosphere
	band 11		long-term/difficult	moderate?	redshifted atomic lines, galaxies?
simultaneous frequency coverage	multi-frequency feed	a factor of a few	moderate? Enhance correlator power is also required (for narrow band observations BLC can accommodate?)	moderate?	almost all science?
	receiver development (wider frquency coverage)	a factor of a few?	moderate? Enhance correlator power is also required to cover whole wide freq. range?	moderate?	ISM, galaxies?
	new digital system/2GC	an order of magnitude? (at high spectral resolution mode)	moderate	expensive	ISM, galaxies?

Quality, Accuracy of Data

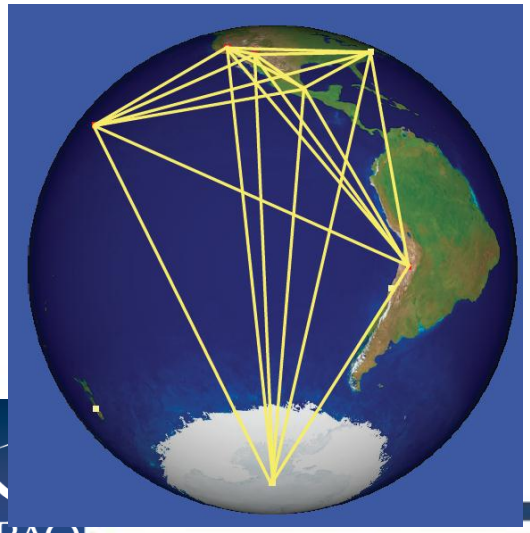
imaging quality	more antenna	add 5 antennas ==> 2 times fidelity	quick	expensive	targets with extended structures
	more 7m antenna	?	moderate?	expensive?	targets with extended structures
	software development	??	all	moderate?	all science
accuracy of amplitude	improved calibration device	???	difficult?	??	ISM?
accuracy of phase	improved atmospheric correction	???	difficult?	??	almost all science which requires high angular resolution
accuracy of polarization	improved calibration device	???	difficult?	??	star formation, ISM
flexibility	more subarrays (two more LO reference systems)	a factor of a few?	moderate	moderate($6 20k?)	transient objects(gamma ray bursts, cometary ejection events, solar flares)
usability	software development	??	long term	moderate	all science

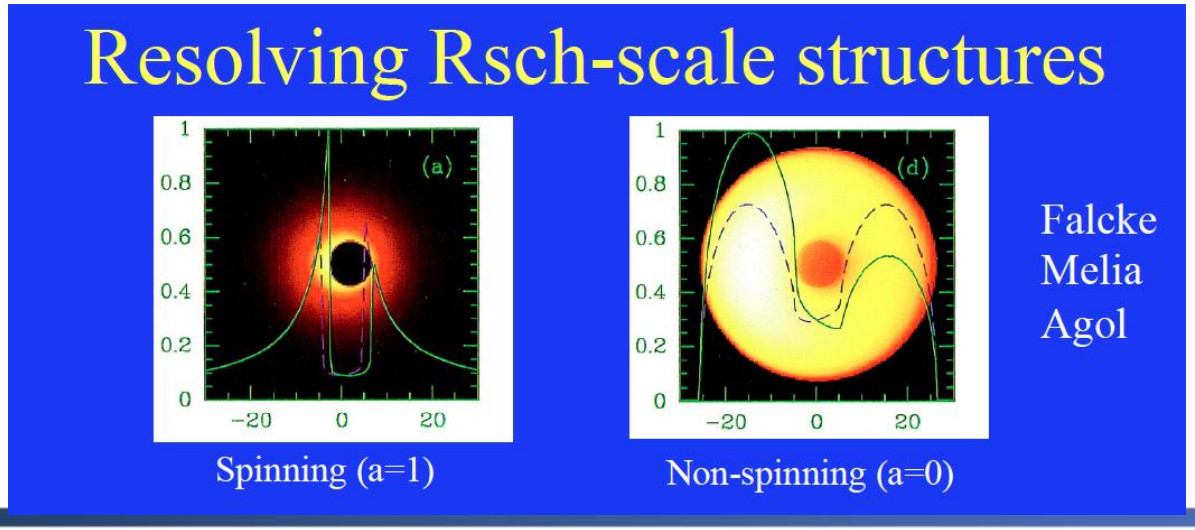
Current Status of ALMA Plan

- Projects in detailed planning but not yet ALMA Development Plan elements
  - Fiber OSF-Calama (link from ALMA to the world)
  - Complete set of band 5 receivers
  - VLBI capability

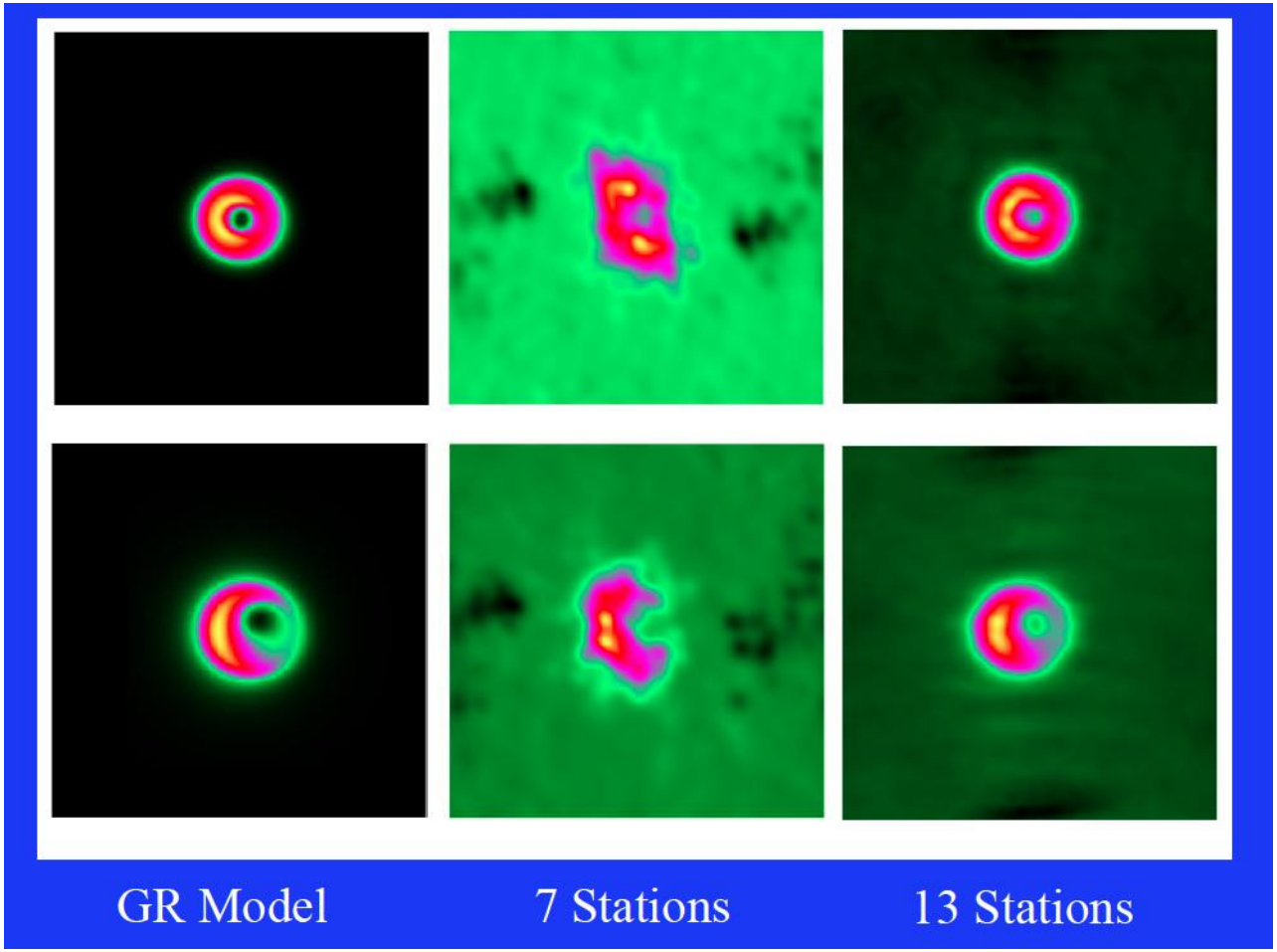
ALMA in a ~300 GHz VLB Network

- Phasing ALMA
  - Single most important objective for EHT.
  - Increases resolution by x2, sensitivity by x10.
  - Allows detection in 10s to all other EHT sites.
  - SgrA* is nearest and largest angular size Black Hole R_{Sch}~10μas; scattering lessened at submm wavelengths





Imaging Model

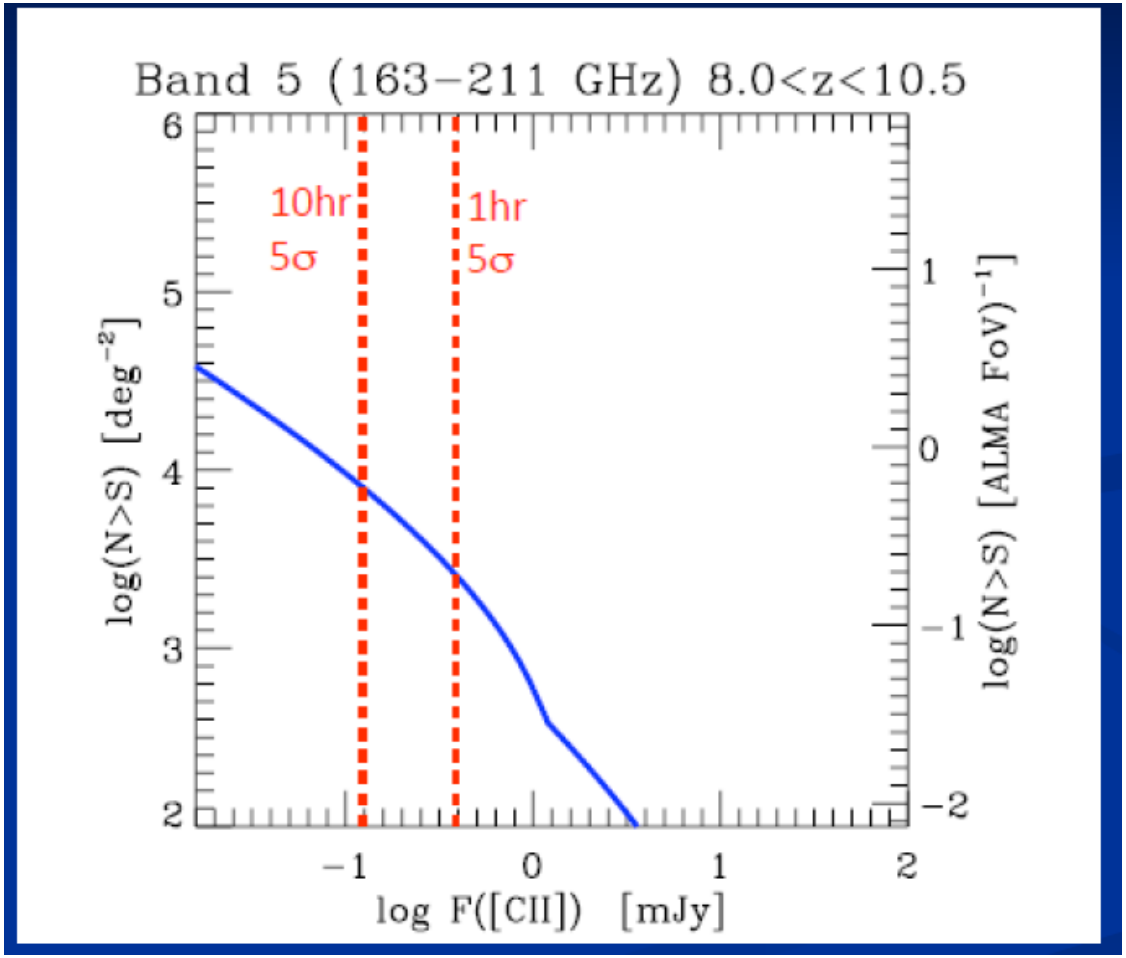


ALMA 'Band 5'

Thanks to R. Laing

- Specifications
  - Covers 163 – 211 GHz
  - TSSB < 65 K over 80% of the band; < 108 K over full band
  - Dual Polarization
  - Standard ALMA receiver requirements
- Key Science
  - Key Science 1: Earliest Galaxies, redshifted [C II] at 8<z<10.5
  - Key Science 2: Water in (proto)planetary systems
    - Moderate excitation183 GHz line may be observed at high dry ALMA site through the atmosphere
      - High resolution followup of Herschel results
    - $H_2{}^{18}O$ line at 203 GHz

[C II] Detectable in Many Systems



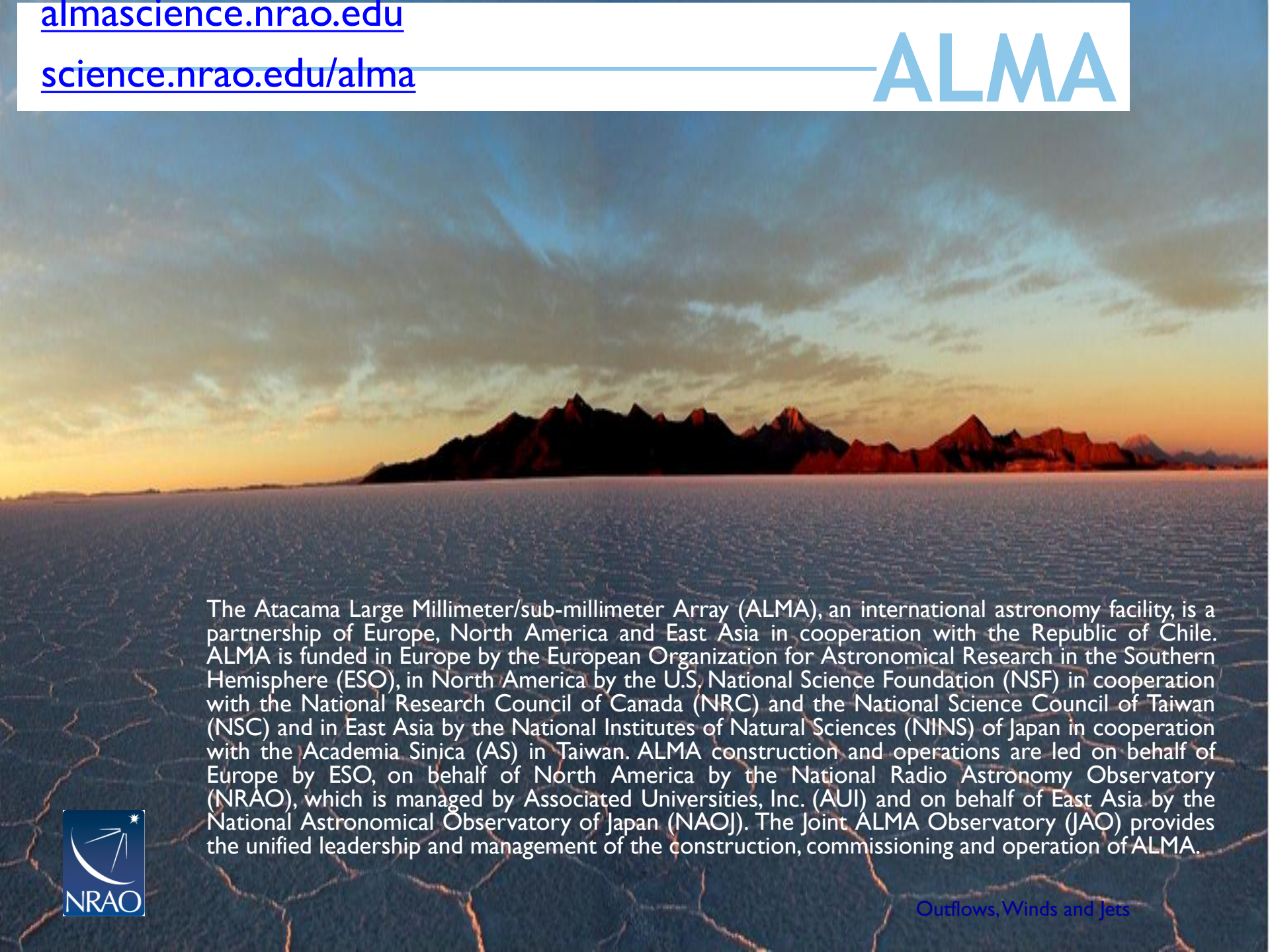
Possible Schedule

- VLB phasing by ~2014
- Band 5 construction by SRON, partners by 2016
- ALMA cost through 2016 ~37% of $46M potential budget.

almascience.nrao.edu

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.

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