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National Radio Astronomy Observatory

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

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Associated Universities, Inc.

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ALMA in the Coming Decade: NA Overview

NA Program Overview April 18, 2013

ALMA seen from the peak of Chajnantor in March 2013 (courtesy M. Lindqvist, Onsala Space Observatory)

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NA ALMA Program Scientist

Atacama Large Millimeter/submillimeter Array

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Organization of Presentation

- Science Drivers for ALMA in the Coming Decade
- Current ALMA Development Studies Program NA
- Current ALMA Development Projects NA
- NA Plan Forward
- EU ALMA Development Studies and Projects
- EA ALMA Development Studies and Projects

NA ALMA Science Priorities

- Sources of science priorities for ALMA, NA development focus:
  - ASAC,ANASAC general categorization (2008-2010)
    - Performance improvements judged according to science criticality, degree of improvement, technical readiness and speed, cost for the development
    - For hardware, completing/upgrading bands figured prominently
    - Phasing project to provide VLB resolution
    - For software, improvements in imaging and usability rank highly
  - Actual NA development study proposals received, reviewed and implemented (2012)
    - 62% involve NA millimeter community partners
    - Science talks, 1st ALMA Development Workshop NA (Mar 2011)
      - (https://science.nrao.edu/facilities/alma/alma2011/program)
    - Studies of Bands 1, 2 and STHz received
    - Upgrades for B6, B3
    - Software: Datarate increase, improved visualizations, VLB software
- Community science priorities: AS2010, particularly RMS panel recs
  - The panel recommends a sustained and substantial program to enhance the NRAO telescope and ALMA capabilities, amounting to $90 million for NRAO and $30 million for the U.S. share for ALMA over the decade.

Summary NWNH/RMS needed Capabilities

- Fast mm/submm Surveys (and fast cm surveys)
- Efficient high resolution imaging at cm/mm wavelengths
- Ultra-high resolution
- Complete wavelength coverage
- Very sensitive cm wavelength coverage
- Solar imaging capabilities

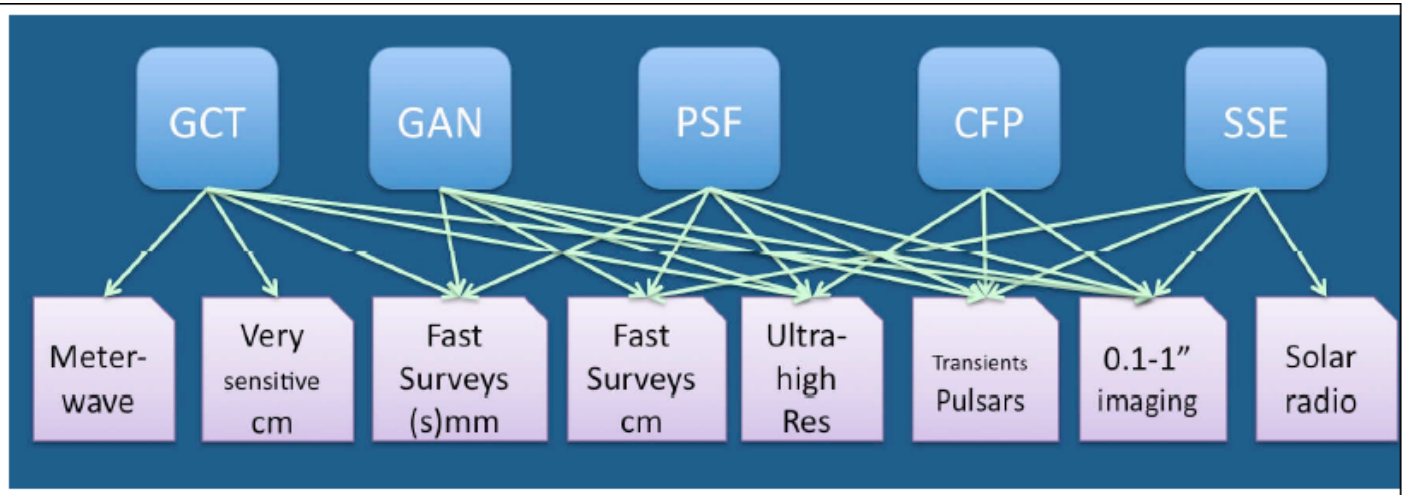


FIGURE 9.6 Mapping of SFP areas to needed RMS capabilities.

ASAC Development matrix (Mar 2010)

Orange: NA Development study targeting this received

Green, Blue: NA, EU (may be out of date)

performance to be improved	development item	degree of improvement	speed/technical difficulti	cost	beneficial for	Note
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	Three CO isotopes simultanuously
	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	
spectral coverage	band 1		medium-term	moderate ($4M for the first five sets)	SZ, redshifted lines, protoplanetary disks, solar	Q band (31-50GHz)
	band 2		medium-term	moderate	SZ, redshifted lines, protoplanetary disks, solar	
	band 5		medium-term	moderate	redshifted lines, planetary atmosphere	163-211GHz European deliverable (6 cartriges)
	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?	
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($620k?)	transient objects(gamma ray bursts, cometary ejection events, solar flares)	
usability	software development	??	long term	moderate	all science	

NA Development Studies

- First NA Call November 2011
  - 21 submissions were received involving 77 investigators from 26 institutions
  - Reviewed by external panel with representatives of NA partners
  - Eight highest ranked Study Proposals funded with available funds
  - Studies now in final months
- Primary aims of these studies are to:
  - give groups in North America the opportunity to propose ALMA upgrades that may later be implemented as part of the ALMA Development Plan;
  - support the development of conceptual and detailed designs for ALMA upgrades; and
  - encourage relevant long-term research and development in areas important for ALMA.

NA ALMA Development Studies

Study	PI	Lead Institution	Collaborating Institution	Funding
2nd generation Receiver for Band 6	A. Kerr	NRAO	U. Virginia	$84.045
Design Study Band 2 Cartridges	E. Bryerton	NRAO	U. Arizona	98,119
Ultra-wideband Quantum Limited Amplifiers	D. Woody	CalTech		92,498
Unleashing Large Dataset Science	L. Mundy	U. Maryland	U. Illinois	34,320
A Visualization Portal for ALMA Data	E. Rosolowsky	U. British Columbia	U. Calgary	73,438
ALMA Band 1 Receiver Development	P. Ho	ASIAA	HIA, U. Chile, NRAO	100,000
Mm/submm VLBI with ALMA	J. Kern	NRAO	MIT, Haystack	0
Increase the ALMA Data Rate	B. Glendenning	NRAO		0

ALMA Band 1 (Ho)

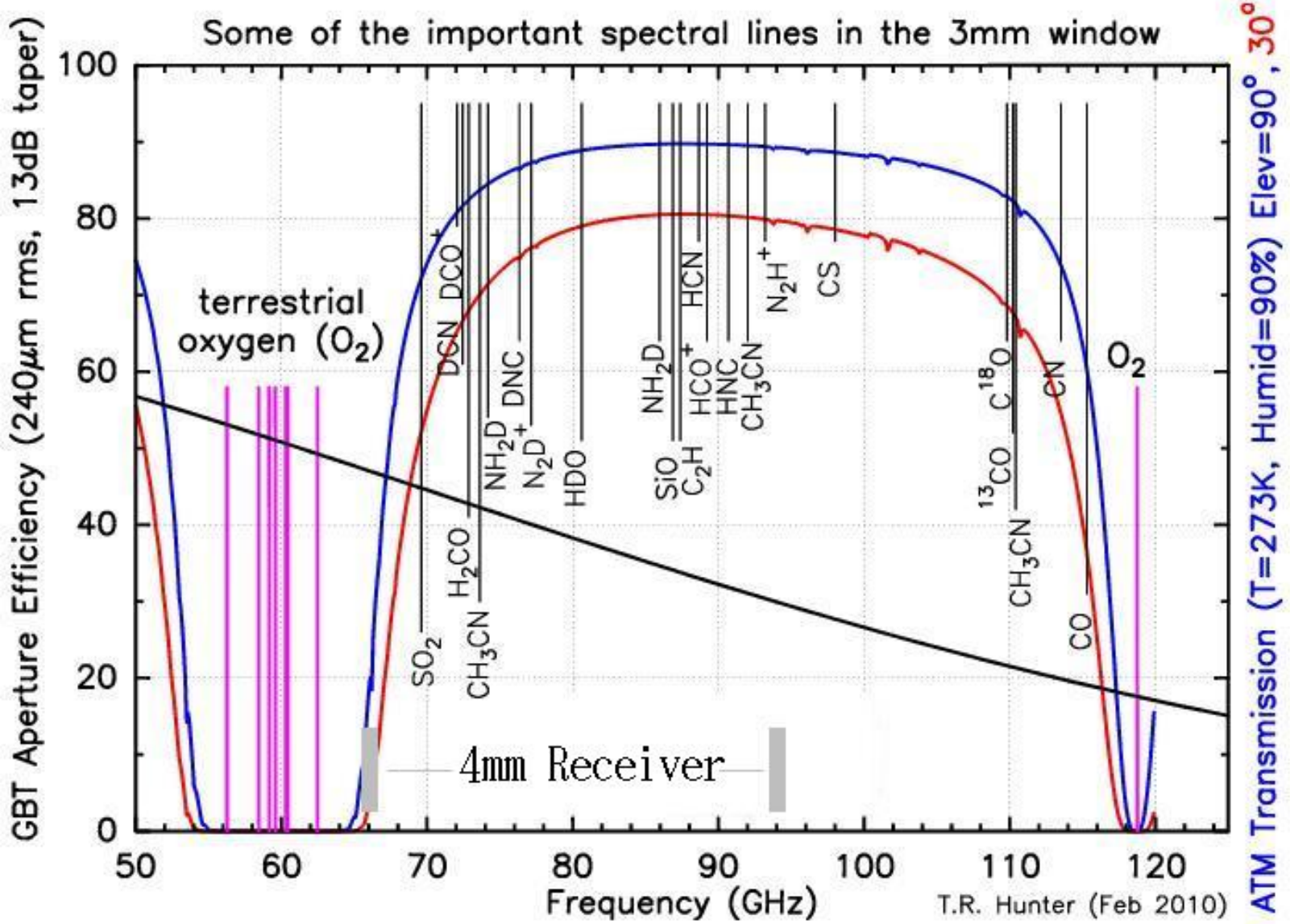
- Downselect meeting: 33-52 GHz
- Key drivers:
  - evolution of grains in protoplanetary disks (PSF Q2: *What is the nature of the planet-forming environment?*)
  - Highly redshifted galaxies (*GCT Q2, Q4: How do baryons cycle in and out of galaxies and what do they do while they are there? Q4:What are the first objects to light up the universe and when did they do it?)*
- Secondary Drivers
  - Distant galaxies, and galaxy clusters (i.e., the Sunyaev-Zel'dovich Effect; reshifted molecules), very small dust grains in the ISM, pulsar wind nebulae, radio supernovae, X-ray binaries, the Galactic Center (i.e., Sgr A*), dense cloud cores, complex carbon-chain molecules, masers, magnetic fields in the dense ISM, jets and outflows from young stars
- Complement to VLA, which has larger effective area over most of the band
  - S. Hemisphere
  - Broader beam, better sensitivity to extended structures.

ALMA Band 2 (67-90 GHz) (Bryerton)

- For continuum, science goals are similar to those for Band 1
- No interferometric capability currently exists in most of this band anywhere. The fundamental, J = 1→ 0 transitions of the deuterium analogs of common, abundant interstellar molecules are unique to this band, including DCO+, DCN, and N_2D^+. Studies of such species are crucial to our understanding of the evolution of cores in molecular clouds, and hence to star formation.
  - Molecular spectroscopy of complex organic molecules and pre-biotic molecules in the ISM and comets: key for studying the conditions from which life eventually forms. (*NWNH: Frontiers of Knowledge: The Chemistry of the Universe and the Origin of Life*
  - Evolution of grains in protoplanetary disks (PSF Q2: *What is the nature of the planet-forming environment?*)
    - Cold gas in circumstellar disks: Where is the snow line?
  - Redshifted CO, HCN at intermediate redshifts, where strong evolution occurs (*GCT Q2, Q4: How do baryons cycle in and out of galaxies and what do they do while they are there? Q4: What are the first objects to light up the universe and when did they do it?)*

Workshop planned for end of May (Eu), June (NA) to define science case.

- ALMA Band 2


Some of the important spectral lines in the 3mm window
GBT Aperture Efficiency (240μm rms, 13dB taper)
ATM Transmission (T=273K, Humid=90%) Elev=90°, 30°
terrestrial oxygen (O_2)
SO_2
DCN
DCO^+
H_2CO
CH_3CN
NH_2D
DNC
N_2D^+
HDO
SiO
C_2H
NH_2D
HCO^+
HCN
HNC
CH_3CN
N_2H^+
CS
^{13}CO
CH_3CN
$C^{18}O$
CN
CO
O_2
4mm Receiver
Frequency (GHz)
T.R. Hunter (Feb 2010)

Development of ultra-wideband quantum limited amplifiers for mm/submm receiver frontends: Woody

- New paramp design for ALMA band 3, 84-116 GHz Design & Simulation
  - Current work on the paramp in the 9-14 GHz range yields noise temperatures <3.4 photons corresponding to <16 K single sideband at 100 GHz, a factor of two smaller than the current band 3 specification.
  - Possibly could cover Band 2 & 3 in same device
- Instrumental gains
  - Sensitivity
  - Calibration targets weaker, closer to source
  - Increase in simultaneous bandwidth to >40 GHz
    - More spectral lines
    - Potential for continuum sensitivity increase
- Enabled science
  - SZ in galaxy clusters (increased sensitivity)
  - Star formation in the Milky Way (access to many lines)
  - Survey of Molecular Gas and Dust in Submillimeter Galaxies (large band=> large z coverage)
  - Molecular Absorption lines at high redshifts

ALMA Band 6 Upgrade (Kerr)

- Range 211-275 GHz designed ~10 years ago
- Production pressures on as-built B6 resulted in elevated receiver noise temperature when the receiver is tuned for simultaneous observation of a group of molecules in the range 219-231 GHz; these include the important ^{12}CO and ^{13}CO lines. Current IF: 5.5 GHz cannot cover both in broad-lined sources simultaneously.
- Could now build balanced sideband-separating mixers
  - Cover entire 4-12 GHz IF, more uniform response
  - Will reject LO sideband noise
  - AlN junctions for higher critical current density to improve receiver noise at edges of band, thereby reducing system noise temperature up to 45% in best

Mm/submm VLB with ALMA: Software (Kern)

- Software to enable new observing mode with ALMA
- CASA provides no data reduction support for VLB
  - Needs include support for mixed polarization bases
  - Advanced fringe fitting
  - Features being developed at Haystack within Haystack Observatory Postprocessing System
- Deliverables
  - List of CASA functionalities needed to provide VLB support
  - Detailed Development Plan
  - Collaborative development model

Visualization: Software

- *Unleashing the Science in Large ALMA Datasets (Mundy)* Develop the software infrastructure and tools to enable science-driven mining and visualization of sets of large image cubes. The overall goal is to give scientists the tools to derive science from large ALMA data cubes in an intuitive way.
  - Deliverables from this study will be a series of memos on the methodologies, evaluations and outcomes in the technical areas
- *A Visualization Portal for ALMA Data (Rosolowsky)* Develop a visualization portal on the web that will be the hub of data exploration for ALMA.
  - Deliverables include: Portal with collaborative tools; distributed data management, user & group access management, metadata access for MS and FITS; search capability; Plane-based visualization tool for all ALMA image data formats (CASA and FITS), including profiles along all axes, and multi-party access.
  - See CYBERSKA

Improving the Data Rate: Software (Glendenning)

- At the beginning of operations, the construction project will deliver to the observatory a system which on average is delivering just over 1% of the capabilities of the correlator, and even the peak data rate will only be 12% of the correlator capability.
- NAASC Memo 110: a straightforward extrapolation from the accepted Cycle 0 proposals would require a factor of three increase in the average data rate.
- Deliverables:
  - Sample science cases that would be enabled by high data-rate observing
  - A baseline data rate evolution scenario for both the average and peak data rates.
  - One or more scenarios to significantly advance the data rate faster than baseline within the Operations funding line
  - Describe the technical impacts and strategy in the following areas: Management, LAN upgrades, wide area network upgrades, data processing needs, archiving needs, CASA/pipelining needs, impact on ACS and other systems

ALMA Development Projects NA

- Band 5 LO (see science case for B5, one of the bands dropped in March 2000, after subsequent ASAC ranking of band importance)
- ALMA Phasing Project: Beamforming ALMA for VLBI and pulsar observations
  - Primary motivation is extremely high resolution imaging of AGN, especially Sgr A* and M87
  - Science case for more general VLB phasing in draft
  - Not a part of construction since Feb 2004 System Review
- Landline internet connection to the Chilean backbone (increased reliability and throughput from site to SCO and beyond).

ALMA Development Projects

Project	PI	Lead Institution	Collaborating Institutions(s)	Value
Band 5 Local Oscillator Production	E. Bryerton	NRAO	ESO, SRON, GARD (CCAs)	$3,328,718.
Fiber Optic Connectivity	J. Ibsen	JAO	Contractor	$1,854,002
ALMA Phasing Project (APP)	S. Doeleman	MIT, Haystack	NRAO, MPIfR, NAOJ, ASIAA, Onsala, U. Concepcion	$516,800*
APP Implementation	S. Doeleman	MIT, Haystack	JAO	$400,000

*ALMA Development Funds Only; an additional $4M provided by NSF/MRI; Implementation costs excluded.

- 62% of total Studies funding allocated to collaborating institutions
- 45% of total Project funding allocated to collaborating institutions

Upgrade of ALMA's Digital Highway

Fiber Connection OSF-Santiago

- Progress
  - Contract signed on 2012 November 9 – AUI, Silica Networks, Telefonica
  - Meets/exceeds technical requirements
  - Contract timeline consistent with project plan – completion by end of 2013
- Benefits
  - Increased potential for ALMA Science: Can provide factor 25 data rate increase (8x Ops plan requirement)
  - Benefits other Chajnantor Working Group observatories
  - Cost Savings to operations $0.5M/yr; breakeven in 4 yrs
  - Reliability: Will include redundancy via link through Argentina at no extra cost
  - Remote operations facilitated

ALMA Development Program: 2013

- Workshop in Tokyo with ASAC February; regional NA workshop April
- All Development Calls include NA partners, selection by external review
  - Emphasis on scientific merit
  - Selection to conclude by September 2013
- New Call for Development Studies 1 May
  - Current round of Studies nearing completion
  - Coordinated with East Asia and Europe
  - Preceded by Workshop 18 April
  - Two year period
  - Total funding $1M, projects may seek up to $200K.
- Call for Projects 3 June
  - Total funding $1.63M available

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