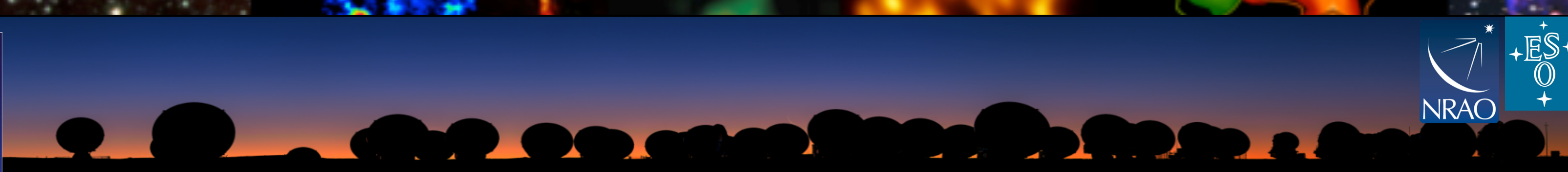
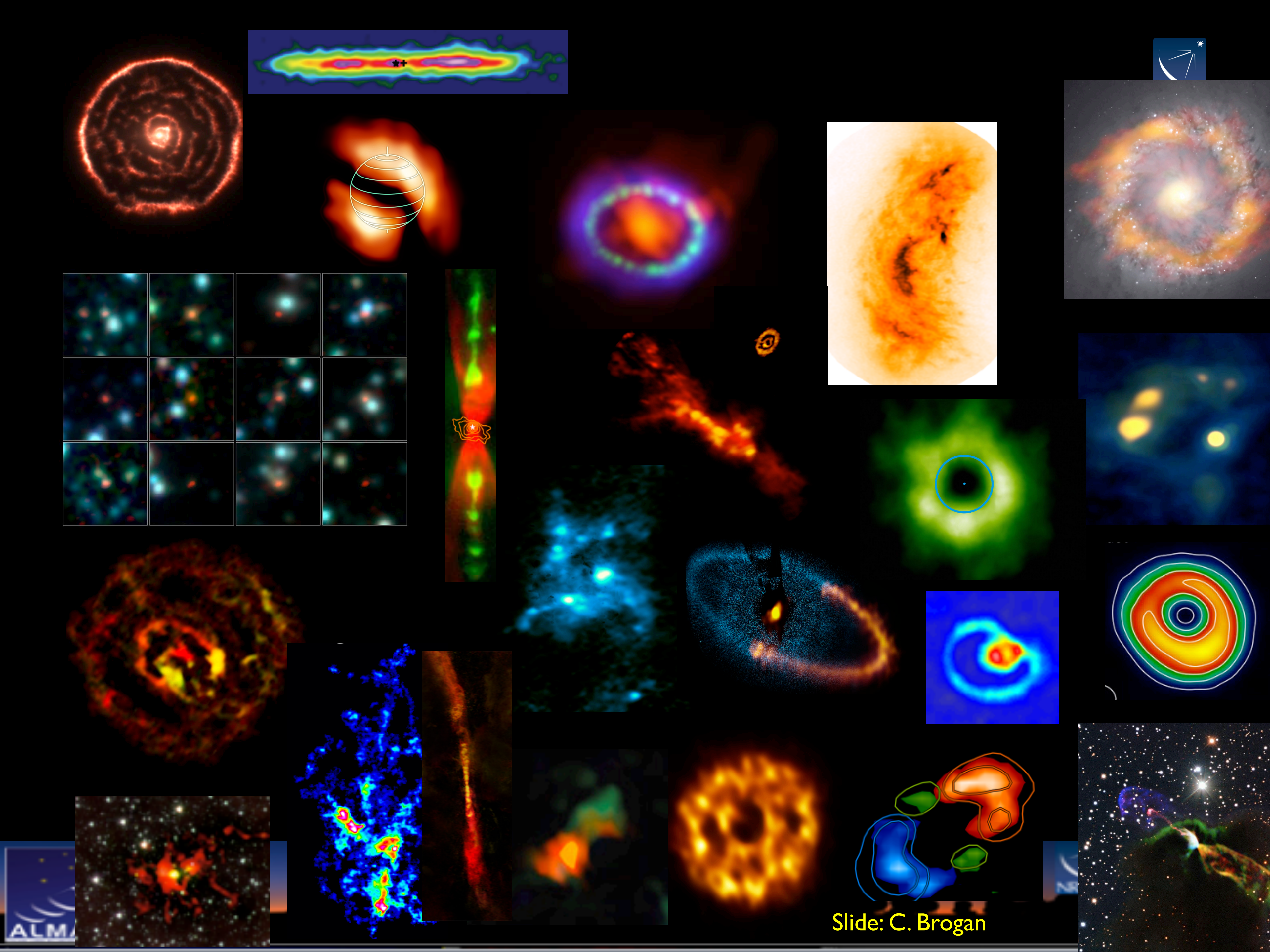
Development Summary (NA+)

Al Wootten




Slide: C. Brogan

ALMA Development Overview

Al Wootten, NRAO

ALMA Development Jargon

- Projects are large efforts, budget >$.2M taking several years, culminating in major new capabilities or improvements
  - Begin with recommendation of ALMA Executive(s), perhaps in response to a Community Call
  - Need approval of ALMA Development Steering Committee, ASAC and recommendation of ALMA Director to ALMA Board
- Studies and small projects are shorter term, lower budget endeavors
  - Normally, Studies are initiated by a Community Call for Ideas
  - May lead to projects, singly or collectively
  - Funding at discretion of ALMA Executives
- Both are guided by a constellation of potential improvements, many listed in a document known as 'ALMA2030'

Progression of ALMA Development Components

ALMA Development Study

Next Gen ALMA Data Viewer	MM/Submm VLBI w/ALMA

↓

ALMA Development Project

CARTA	ALMA Phasing Project

↓

ALMA Enhancement

Implementation/CASA	Cycle 4 VLBI

Progression of ALMA Development Components

ALMA Development Study	
Band 2 Study	Unleashing Large Dataset Science

ALMA Development Project	
Band 2 Prototype Cartridge	ALMA Data Mining Toolkit

ALMA Enhancement	
Band 2 Construction??	ADMIT

Progression of ALMA Development Components

ALMA Development Study	
ALMA B1 Study	Unleashing Large Dataset Science

ALMA Development Project	
ALMA B1 Project, CDR	ALMA Data Mining Toolkit

ALMA Enhancement	
Proposed implementation 2019	ADMIT (Apr 2016)

Current and Past ALMA Development Programs

- Projects from the First (2010, 2011) Calls are now reaching fruition:
  - Band 5 (163-211 GHz) receivers
  - Fiber optic connection from ALMA to the World
  - ALMA Phasing Project (VLB)
  - Several from 2013 Call also reaching implementation
- Studies from a number of Calls nearing completion or, from 2016 Call, beginning now

New NA Studies

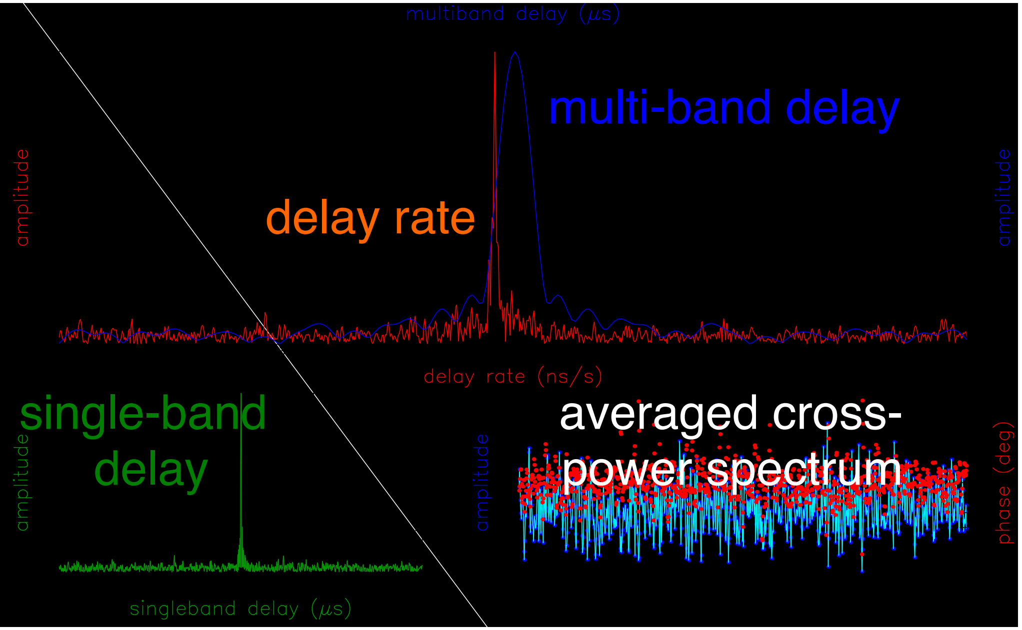
Seven Studies from 33 proposers representing ten institutions fit within the funding envelope and were proposed for North American funding with the consent of the National Science Foundation.

Study	PI	Institution	Co-Is	Institutions
Digital Correlator and Phased Array Architectures for Upgrading ALMA	Weintroub	Smithsonian Astrophysical Observatory	Weintroub,Baudry, Carlson, Doeleman, Escoffier, Lacasse, Rosenfeld, Rupen	Smithsonian Astrophysical Observatory, U. Bdx, NRC, NRAO
Improving the calibration of atmospheric spectral features in ALMA data	Hunter	NRAO	Hunter,Phillips, Broguiere	JAO, IRAM, NRAO
Pulsars, Magnetars, and Transients with Phased ALMA	Cordes	Cornell University	Cordes, Chatterjee, Crew, Doeleman, Kramer, Lazio, Ransom	MIT/Haystack Observatory, Max Plank, NRAO
ALMA Study Project: Extensions and Enhancements to the ALMA Phasing System	Matthews	MIT	Matthews, Crew, Doeleman, Fish, Hecht	MIT
Feature extraction and visualization of ALMA data cubes through topological data	Rosen	University of Utah	Rosen, Wang, Johnson, Kern, Mills	University of Utah, NRAO
Advanced materials and on wafer chip evaluation for second generation ALMA	Lichtenberger	University of Virginia	Lichtenberger, Lu	University of Virginia
Spectral Resolution and Bandwidth Upgrade of the ALMA Correlator	Lacasse	NRAO	Lacasse, Escoffier, Greenberg, Saez, Treacy, Webber, Baudry, Amestica, Stan	NRAO, retired consultant, JAO, Universite de Bordeaux

Existing Projects Status

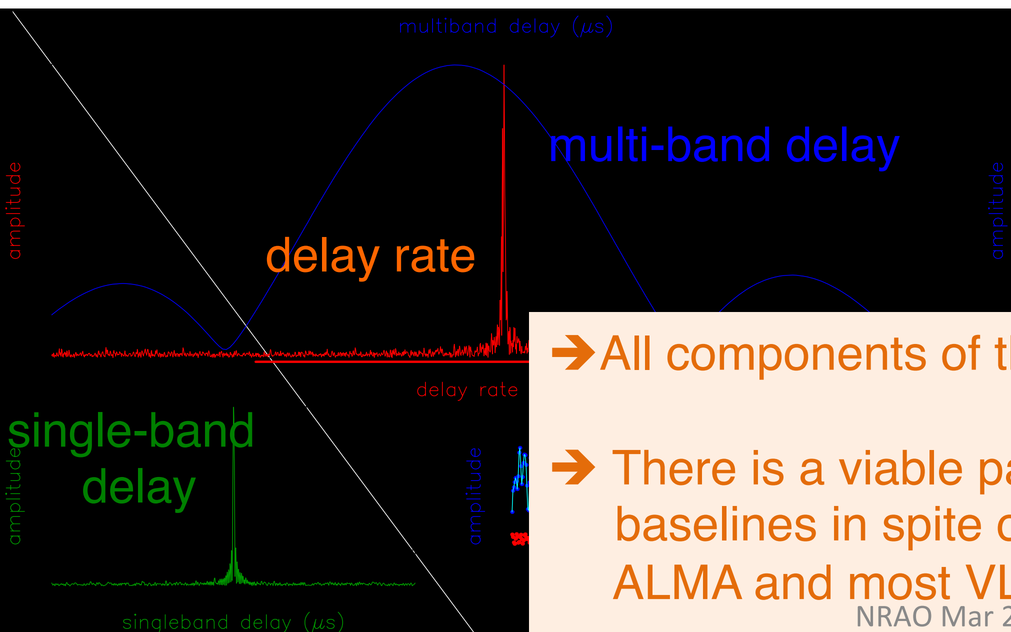
- ALMA Phasing Project (NA)
  - Key science: Test GR using BH Shadow
- ALMA Band 5 Project (EU/NA)
  - Key science: [C II] at z~8-10; Water
- JAO-AOS Fiber Link Project (JAO, NA, Eu)
  - 150km fiber connects AOS to Chilean internet (REU
  - Operational, in testing. Awaiting permits.

APP Project: First Intercontinental VLBI Fringes with ALMA



Phased ALMA – IRAM 30m:
March 30, 2015

- Band 6 (1.3 mm); Source 3C273
- 9770 km baseline



Phased ALMA – VLBA (MK)
(plus 5 other VLBA stations):
August 1, 2015

- Band 3 (3 mm); Source 3C454.3

➔ All components of the APS hardware are working to spec

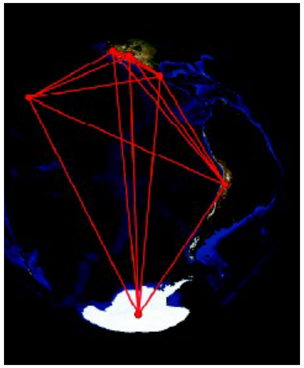
➔ There is a viable path to correlation of VLBI data on ALMA baselines in spite of the different sampling rate used by ALMA and most VLBI sites

Upcoming APP Project Activities

• Offer VLBI capabilities on ALMA to the general community in ALMA Cycle 4

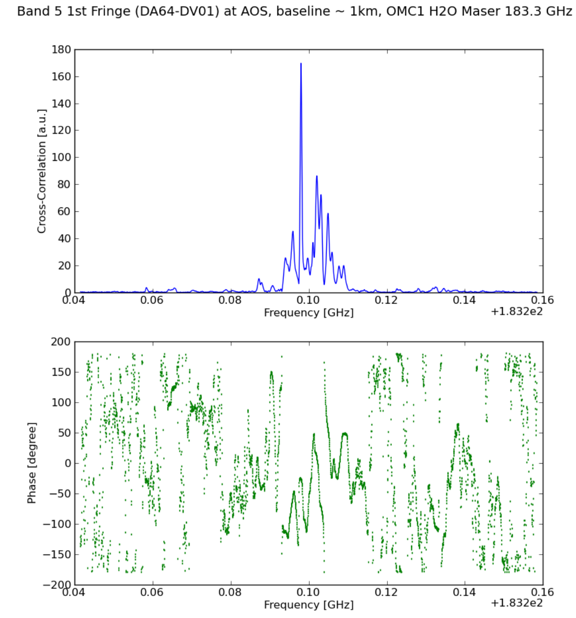
- 3mm:
    - Call for GMVA network proposals was made 1 Feb
    - ALMA proposals complementing these at Cycle 4 deadline
- 1.3mm:
    - Call for EHTC network proposals ca 24 March
    - ALMA proposal complementing these at Cycle 4 deadline

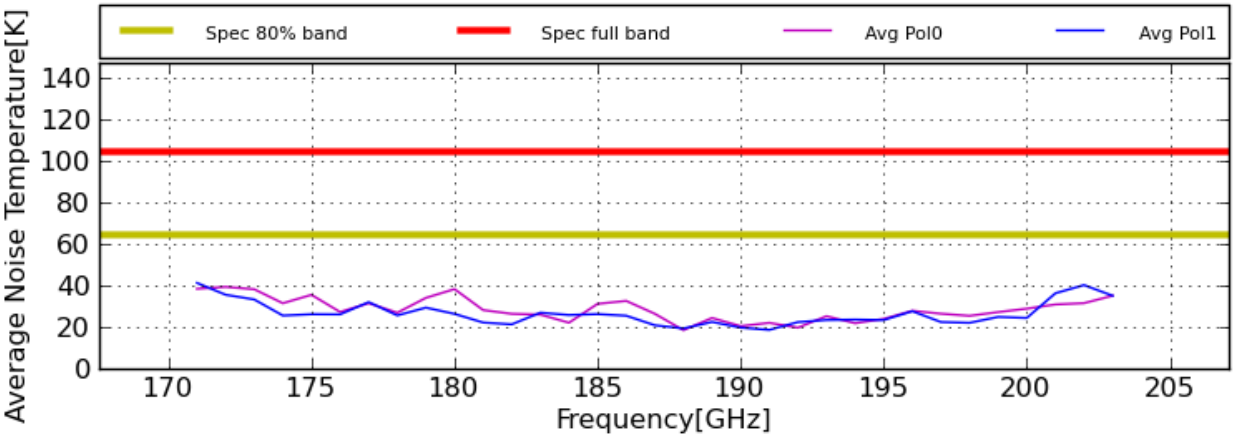
Outstanding Tasks:



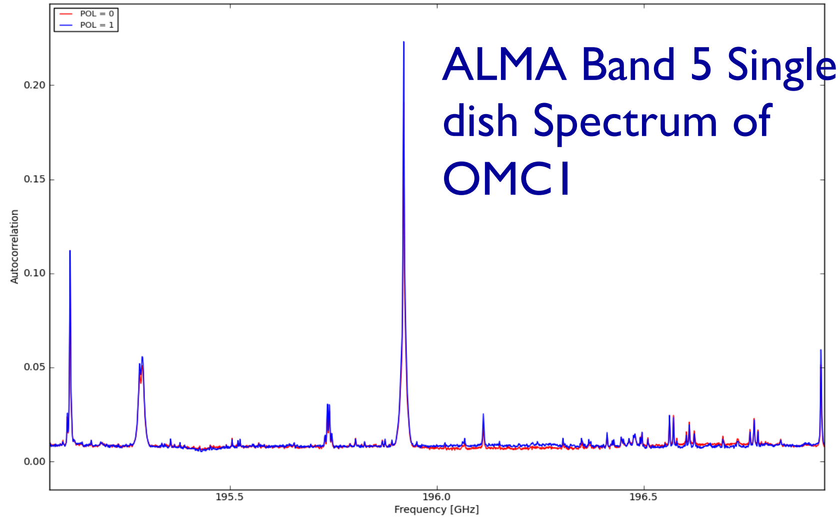
• Additional testing of PolConvert capability
• Correlation of full VLBI data sets
• Imaging and closure analysis of VLBI observations
• Preparation of documentation on use of APS for science observations

Band 5 Project





- Tuning range 163-211 GHz
- Key science:
  - C^+ 158 micron line z~8-10.6
  - Imaging 183 GHz H_2O, isotopologues
- Development and construction ESO, RAL, NOVA, Onsala, NRAO
  - NRAO: Last multipliers shipped 2015 Sep 30
- Some installed, final receiver (of 73) expected Q2 2017.



Initial Stages: New Bands 1, 2, Upgrades

Band 1 (35-50(52)GHz)

- Key science: SZ effect, free-free emission, large grains in protoplanetary disks
- Collaboration of EA, CL, NA
- Project Prototype under construction

Band 2 (67-90(94)GHz)

- Key science: Deuterated species, high redshift (MW CO J=3-2@z=3) and complex molecules
- Project (NA): Under construction, 16 GHz bandwidth
- Study (Eu): Potential combination of B2&3 for 67-116GHz tuning range

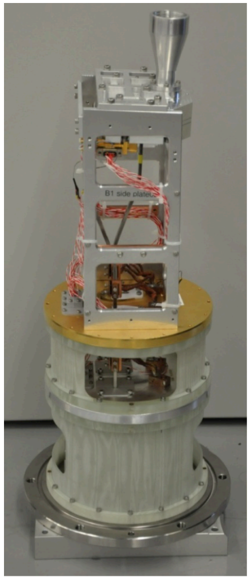
Additional Projects and Studies

- Improve sensitivity B3 (NA), B6 (NA), B9 (EU), B10 (NA), 'B11' (EA)
- Improved digital system for simpler design, eventually higher bandwidth (Eu)

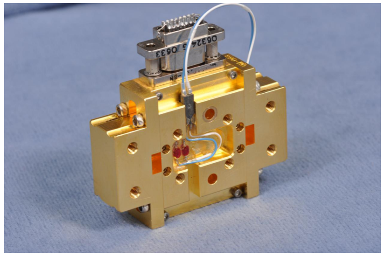
Bandwidth: Note B9, B10 already present 16 GHz/polzn to correlator; B6 presents 10 GHz, prototype B2 also presents 16 GHz

ALMA Band 1

Cartridge



NRAO LNA



EA/Taiwan Project with

NRAO supplied LNA (right)

OMT developed by HIA

Feedhorn designed by U. Chile

CDR and project review were held on Jan 19-20, 2016 at ASIAA

- ***Panel sought redesign of down-converter***

- CDR close out items:

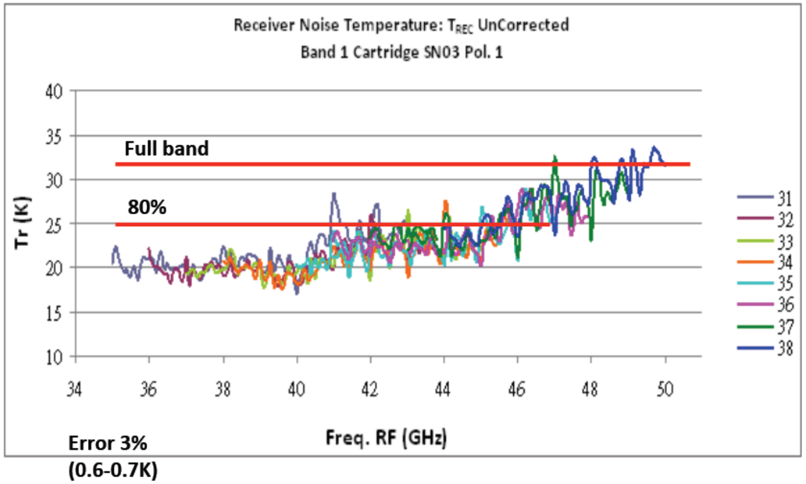
  To plan the down-converter design review

  To update the project management plan

  To update the safety assessment report incl. safety compliance matrix and safety

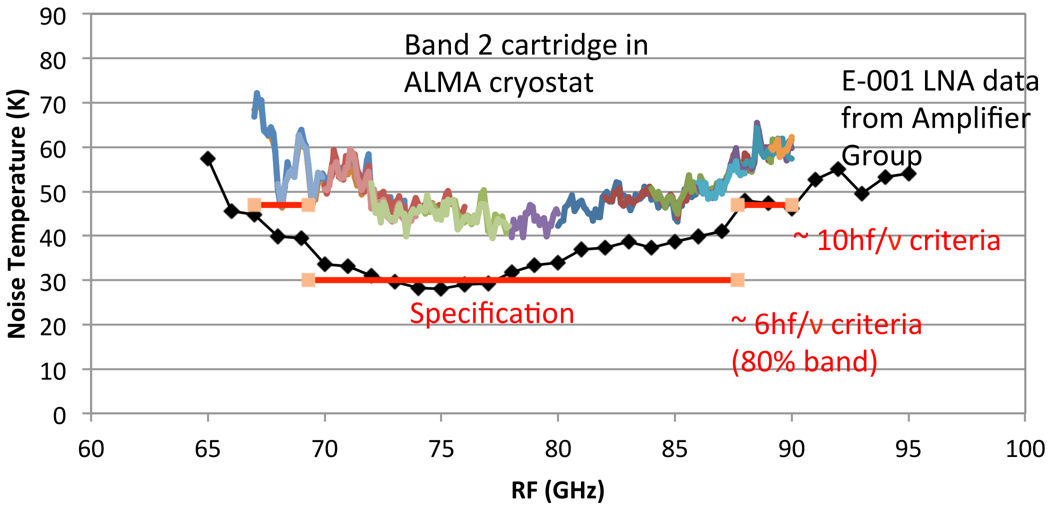
- "Down-converter review" will be held in late 2016, before the MRR

System Noise Temperature:
CCA SN03 WCA SN03 Pol1

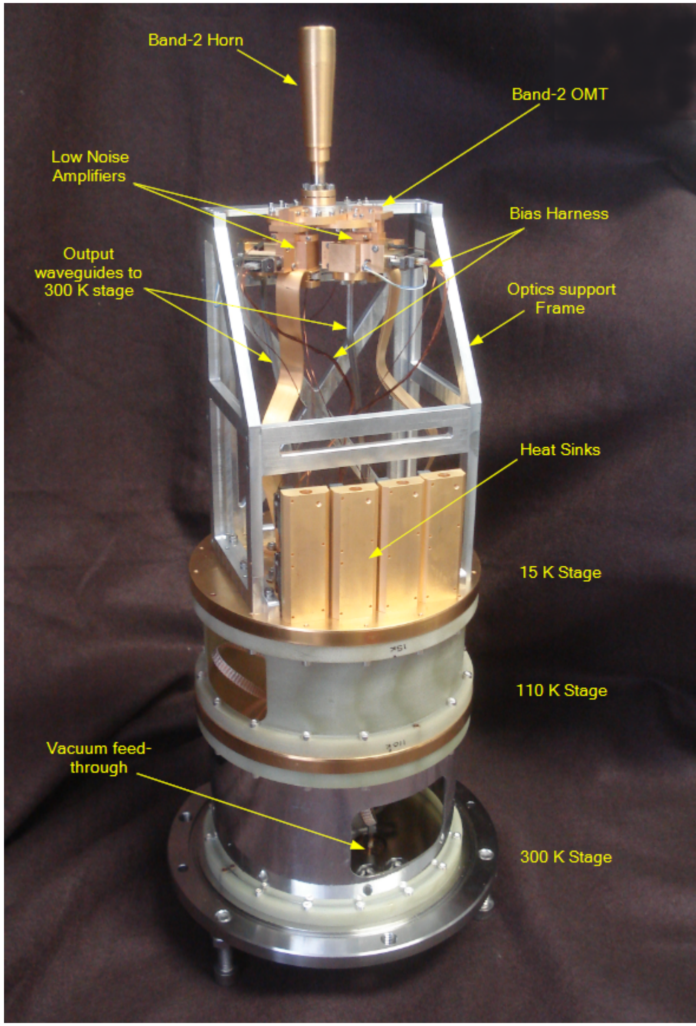


ALMA Band 2: NRAO

Pol-0 Noise Temperature



- Cartridge built and tested with temporary NRAO design
- Awaiting CRAL MMIC based LNAs for testing and possible incorporation into design
- Some optics features to be addressed
- Note that there is also a EU B2+3 study with some NAOJ involvement.



ALMA Subarray Expansion

- **Central LO Expansion to 5 Sub-arrays Project:**
  - Commissioning tests and acceptance being planned.
  - Expected to be available for engineering use soon.

Band 3 Magnet and Heater Project

- CNRC has proposed heater circuits to deflux Band 3 cartridges. Chosen option:
  - 1. Modify the bias box to re-route the heater circuit lines to unused lines in the Band 3 cartridges. Pol0 and Pol1 heater circuits would both become functional.
- Stability improvement expected
- First unit to be shipped to JAO.

2. Removal of hysteresis in PIV curves.

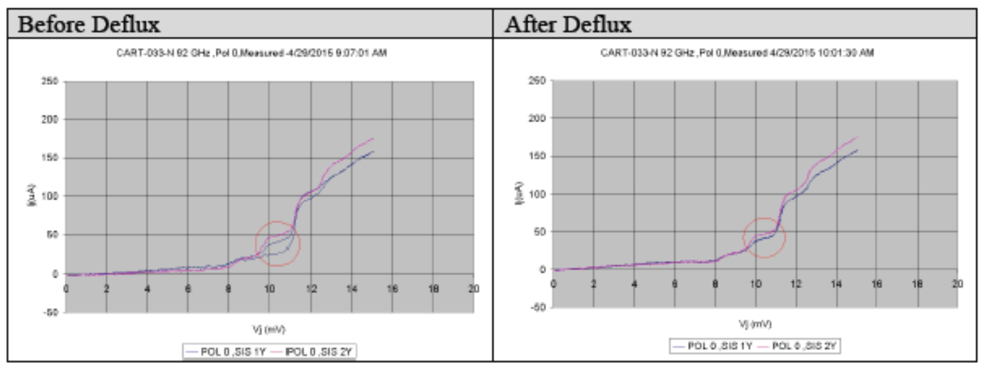
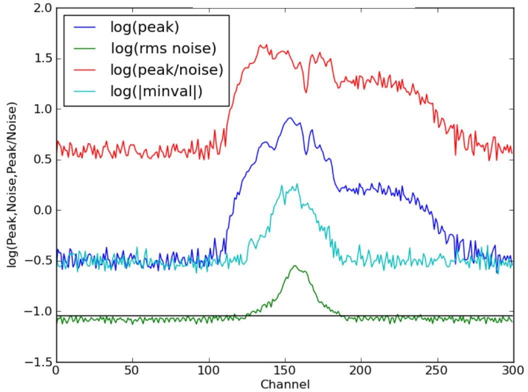


Figure 4: Hysteresis Disappears

ADMIT

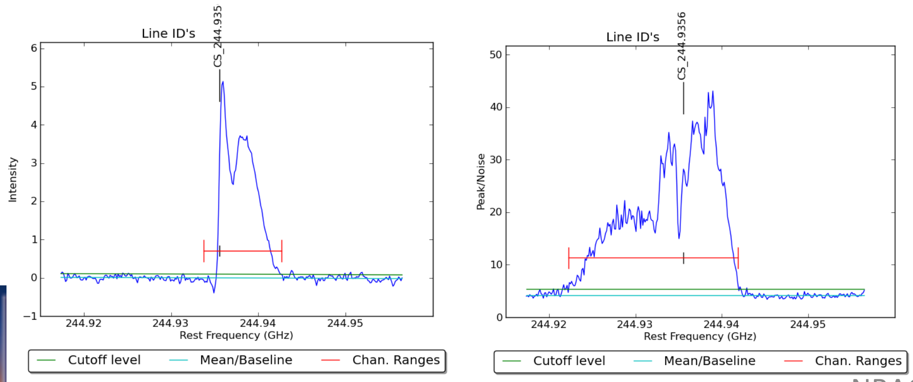
- Operates on data cubes only; cubes can be FITS or casa image format
- Compatible with CASA environment and utilizes CASA routines where possible
- Products are self-documenting with XML; compatible with future ingestion by a database

Each data cube get a full set of products
See: admit.astro.umd.edu/admit-M4 and click on and xxx.admit directory



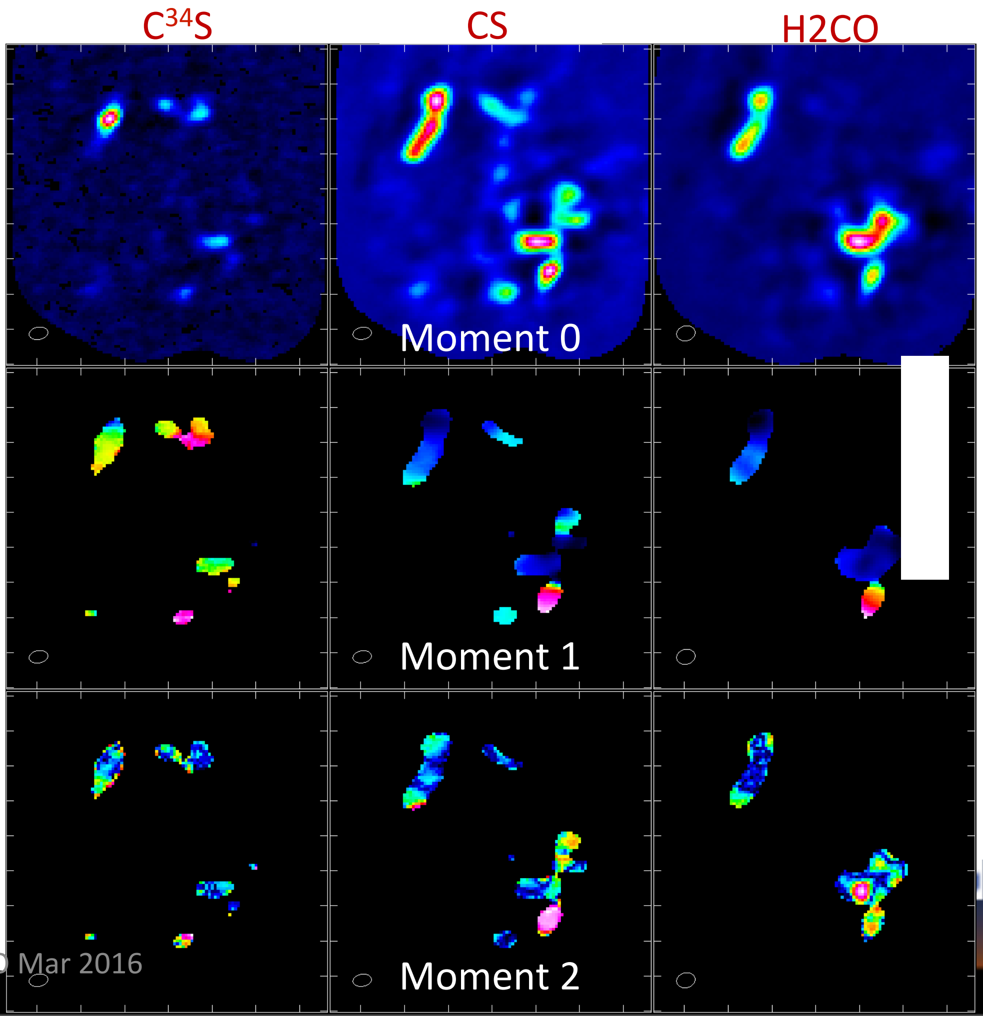
Spectra based on peak flux and noise in each channel

Blue and green spectra highlight impact of missing flux



Two spectra used in line ID of CS J=5-4

Serpens Main Mosaic Image



ADMIT

Two modes of Operation:

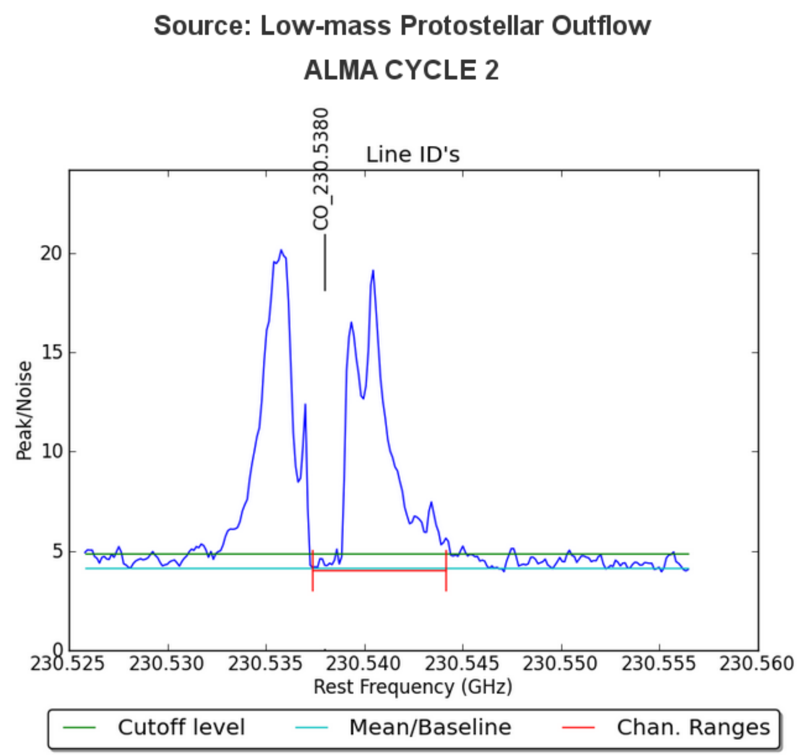
- In-line (pipeline mode producing standard set of products):
  - ADMIT runs after QA2 and before archive ingestion (ideally as a pre-step to the archive ingest process) – details being worked with ALMA Project
  - ALMA archive user can select to download ADMIT tarball (20-40Mb)
    - XML, PNG, and HTML files; limited FITS files – details to be decided with ALMA Project
  - Browser-based viewer allows user inspect products once downloaded
  - ADMIT summary XML file allows user to recreate the ADMIT products

- Off-line (user created data products):
  - The ADMIT Toolkit "add-on" available from the CASA download page
  - Flow-model for creating and re-creating products - viewable in the browser
  - Environment for expanded exploration of data sets:
    - Principle component analysis of emission
    - Overlap integrals
    - Comparisons across multiple windows and multiple sources
    - New tools for examining large data cubes

ADMIT

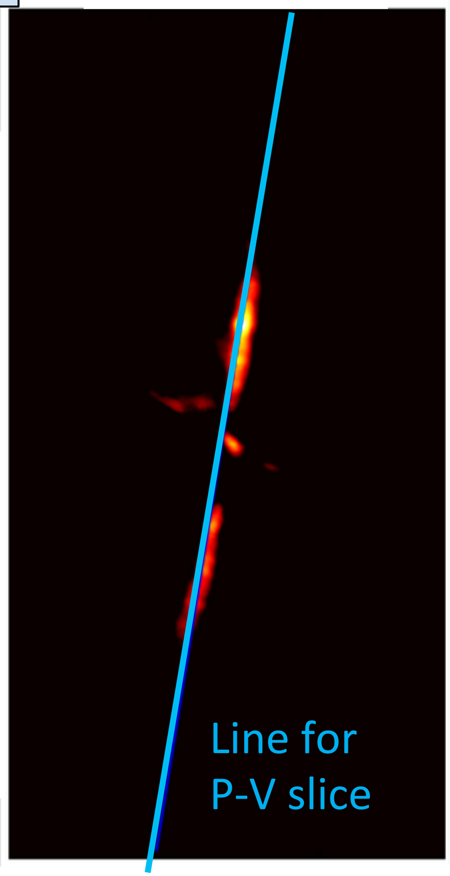
- Automated line ID which allows line-based operations: moment maps, PV slices, etc
- Pipeline produces set products for users which can be determine by ALMA
- Users can create their own custom products locally, which can be applied across sources

Conservative automated line ID: do no bad ID

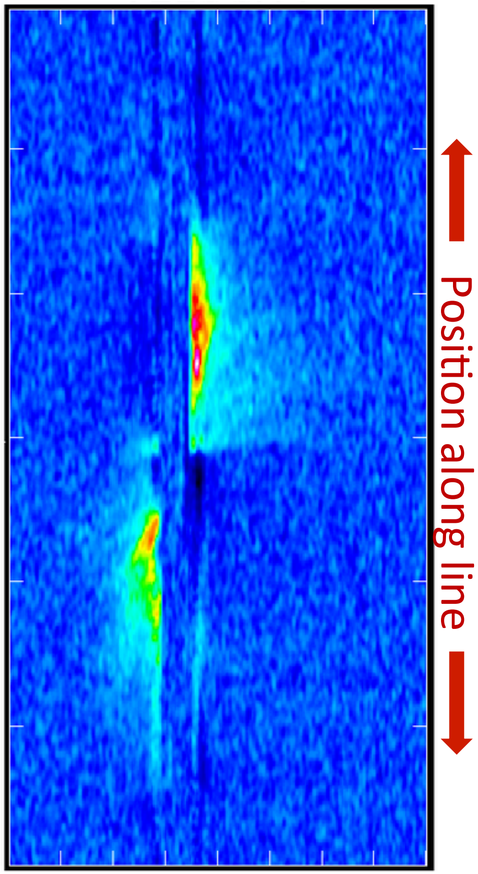


Spectrum: peak emission over noise per channel

Moment 0



Position-Velocity Slice



Identified lines

frequency	formula	transition	velocity	fwhm	startchan	endchan
230.53800	CO	2-1	1.200E+01	3.503E+00	100	155

ADMIT

Timeline for Science users:

- November 2015: Requested start date for testing of Cycle 3 data from imaging pipeline at ARCS.
  - Needed for robustness testing against operational products in April 2016
  - Allows interaction with interested scientists to verify/improve products

- TBD: Deployment of ADMIT pipeline within ALMA to create products for archive ingestion.
  - Date and final design to be decided in discussion with the ALMA project

- May 1 2016: Delivery of completed software system
  - End of funded ALMA Development Project is April 30, 2016
  - Contract requires delivery of all software and documentation
  - Options for continued support will be explored with ALMA/NRAO

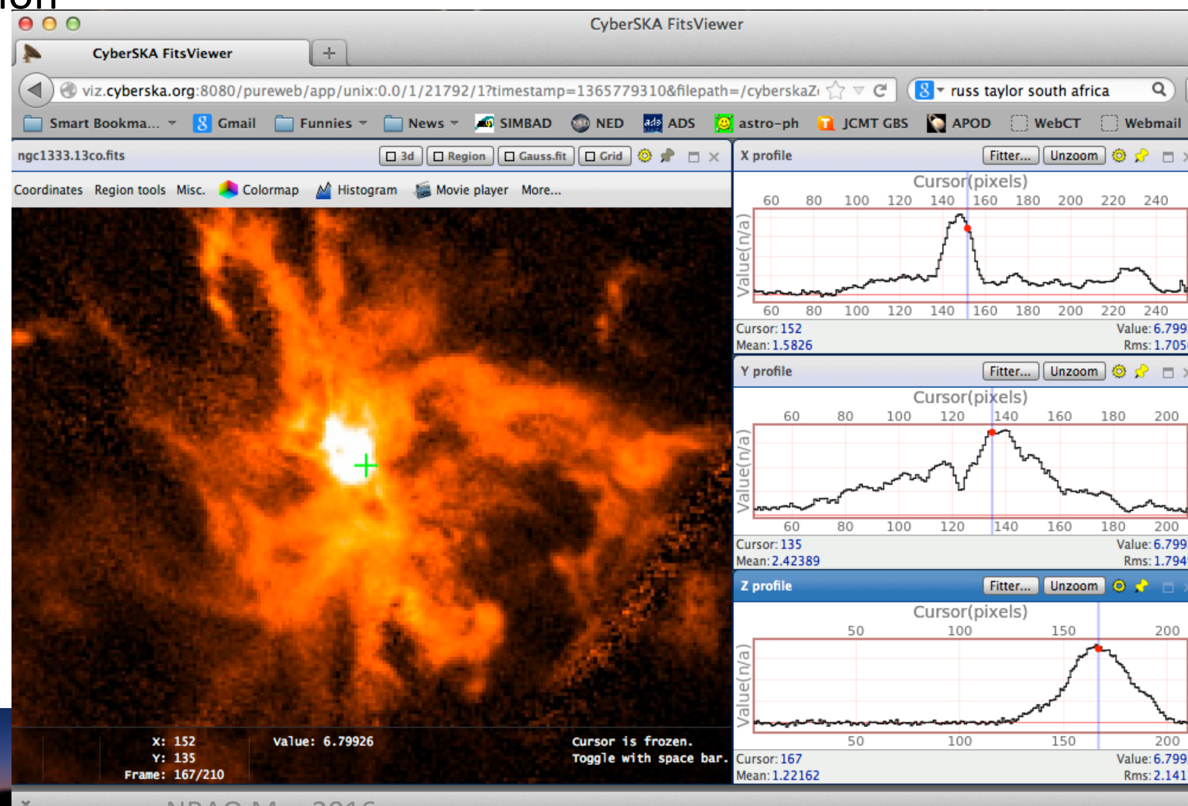
Archive Enhancement- II

- CARTA: Cube Analysis and Rendering Tool for Astronomy (also known as the "Next Generation ALMA Viewer")
  - Designed to navigate and analyze large data cubes as a replacement for the CASA image viewer tool
  - Operates stand alone or as web-server co-located with archive
  - Provides scripted interaction

October 2015 -- Beta testing and design review. Email Erik Rosolowsky (rosolowsky@ualberta.ca) if you would like to participate.

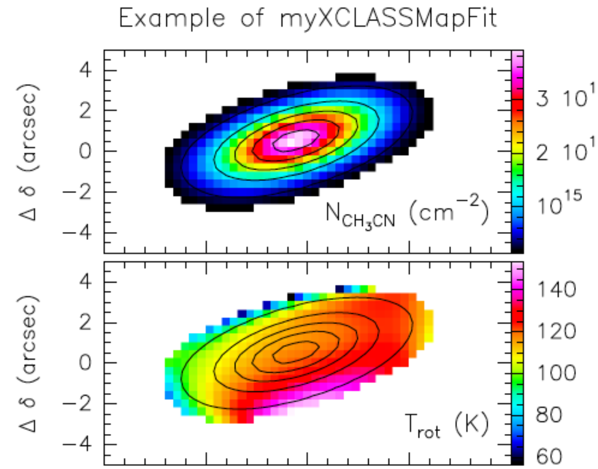
2016 -- Installation into ALMA archive and distribution with CASA.

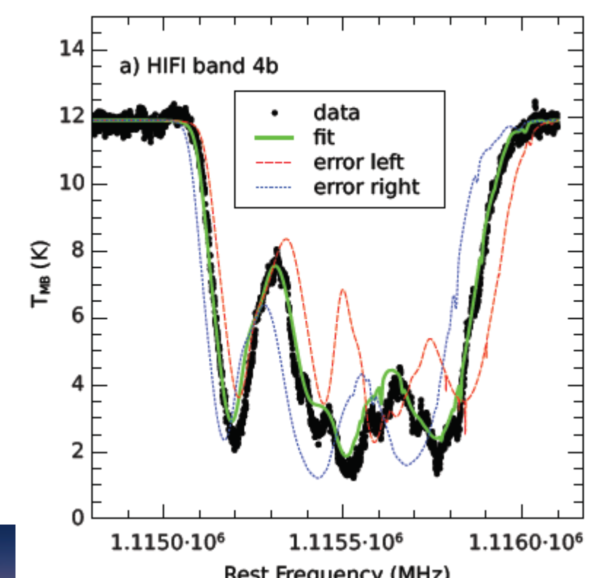
NA- Development
University of Calgary & NRAO



Archive Enhancement- III

- XCLASS (eXtended CASA Line Analysis Software Suite)
  - Functions for modeling interferometric and single dish data including the myXCLASS program which calculates synthetic spectra by solving radiative transfer including dust attenuation and finite source size
  - MAGIX (Modeling and Analysis Generic Interface for eXternal numerical codes): Provides an easy interface between existing codes (like myXCLASS, RADEX, RADMC-3D or LIME) and an iterating engine that attempts to minimize deviations of the model results from available observational data and providing corresponding error estimates





EU Development
Uni Köln, Allegro, Niels Bohr Institut
Also see Möller, Endres, Schilke (2015)

Correlator Upgrade Performance Enhancements Lacasse, PI

- X4-8 ***enhancement in frequency resolution***.
  - Spectral resolution for every mode increases by a factor of four to **eight** for integration times of 128 msec and greater. For example, from Table 2 of the correlator specification (next slide) (http://edm.alma.cl/forums/alma/dispatch.cgi/documents/docProfile/100591)
  - Broader band coverage at high resolution
- ***Time resolution enhancement*** for auto and cross products
- ***Higher sensitivity or shorter observing times*** can be obtained using 4-bit x 4-bit modes and/or double Nyquist mode (95% efficiency versus 85% including the effect of the 3-bit sampler). This is equivalent to adding about 8 antennas to the array or cutting integration times down by 12%! See comparison of modes 2 and 53 on the next slide…note bandwidth restrictions.
- ***Potential for subsequent upgrade to 2x16GHz processsing.***

Mode Table Changes

Mode #	Number of sub-channel filters	Total Bandwidth	Number of Spectral Points		Spectral Resolution (KHz)		Correlation	Sampling	Sensitivity (x 0.96)
			Current	Proposed	Current	Proposed			
1	32	2 GHz	8192	65536	244	30.5	2-bit x 2-bit	Nyquist	0.88
19	32	2 GHz	4096	32768	488	61	2-bit x 2-bit	Twice Nyquist	0.94
38	32	2 GHz	2048	16384	976	122	4-bit x 4-bit	Nyquist	0.99
2	16	1 GHz	8192	65536	122	15.25	2-bit x 2-bit	Nyquist	0.88
20	16	1 GHz	4096	32768	244	30.5	2-bit x 2-bit	Twice Nyquist	0.94
39	16	1 GHz	2048	16384	488	61	4-bit x 4-bit	Nyquist	0.99
53	16	1 GHz	1024	8192	976	122	4-bit x 4-bit	Twice Nyquist	0.99
3	8	500 MHz	8192	65536	61	7.625	2-bit x 2-bit	Nyquist	0.88
21	8	500 MHz	4096	32768	122	15.25	2-bit x 2-bit	Twice Nyquist	0.94
40	8	500 MHz	2048	16384	244	30.5	4-bit x 4-bit	Nyquist	0.99
54	8	500 MHz	1024	8192	488	61	4-bit x 4-bit	Twice Nyquist	0.99
4	4	250 MHz	8192	65536	30	3.75	2-bit x 2-bit	Nyquist	0.88
22	4	250 MHz	4096	32768	61	7.625	2-bit x 2-bit	Twice Nyquist	0.94
41	4	250 MHz	2048	16384	122	15.25	4-bit x 4-bit	Nyquist	0.99
55	4	250 MHz	1024	8192	244	30.5	4-bit x 4-bit	Twice Nyquist	0.99
5	2	125 MHz	8192	65536	15	1.875	2-bit x 2-bit	Nyquist	0.88
23	2	125 MHz	4096	32768	30	3.75	2-bit x 2-bit	Twice Nyquist	0.94
42	2	125 MHz	2048	16384	61	7.625	4-bit x 4-bit	Nyquist	0.99
56	2	125 MHz	1024	8192	122	15.25	4-bit x 4-bit	Twice Nyquist	0.99
6	1	62.5 MHz	8192	65536	7.6	0.95	2-bit x 2-bit	Nyquist	0.88
24	1	62.5 MHz	4096	32768	15	1.875	2-bit x 2-bit	Twice Nyquist	0.94
43	1	62.5 MHz	2048	16384	30	3.75	4-bit x 4-bit	Nyquist	0.99
57	1	62.5 MHz	1024	8192	61	7.625	4-bit x 4-bit	Twice Nyquist	0.99
25	1	31.25 MHz	8192	65536	3.8	0.475	2-bit x 2-bit	Twice Nyquist	0.94
58	1	31.25 MHz	2048	16384	15	1.875	4-bit x 4-bit	Twice Nyquist	0.99

A New Correlator for ALMA
Weintroub, PI

- Next Generation Correlator:
  - The correlator architecture will be FX, as opposed to XF or FXF.
  - Future available bandwidth will be 16 GHz per sideband per polarization
  - Though the analog bandwidth may be sub-divided arbitrarily, it is far preferred to sample as large a sub-band as possible with the highest speed ADCs available
  - The ADCs or samplers will remain at the antennas as presently the case with ALMA with digital data sent over fiber
  - Fine spectral resolution is needed in many science projects
  - Reduce the required power and size of the ALMA correlator
  - Integrate natively features such as phased array recording for VLBI and pulsar work
  - ngVLA synergies possible

Comparison

Telescope	Algorithm	Antennas	BW/poln	SpRes	Efficiency	Time res	Sample Rate
			(GHz)	kHz (1)		(ms)	Gsps
ALMA	FXF	64	8	3.8	0.85 to 0.98	1, 16	4
ACA	FX	16	8	3.8		16	
ALMA-2	FXF	64	16	0.475	0.95 to 0.99	1, 2, …, 16	8
NextGenALMA	FX	66	16	0.001	0.96*	?	16
SMA	ASIC XF	8	8	25			0.204
SMA	SWARMFX	8	8	150			4.6
EVLA	WIDAR FXF	27	8	0.122			4
IRAM	WIDEX XF	8	3.6	39			4
IRAM	NOEMA FXF	12	3.6	39			8
CARMA	XF	15	4	31			1

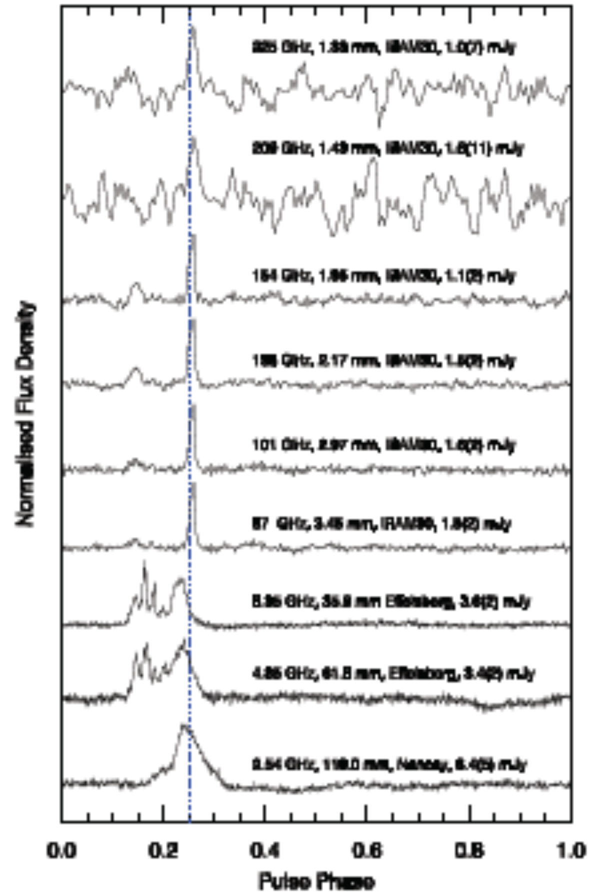
Note unknown cost in software effort of implementation of NextGenALMA

Improving the calibration of atmospheric spectral features in ALMA data
Hunter, PI

- Problem: Coarse resolution (TDM) calibration (31MHz resolution) dilutes instrumental calibration of narrow atmospheric lines, giving poorer calibration
- Proposition: finer resolution calibration through TelCal application alleviates this
  - Apply the proper quantization correction to atmospheric calibration scans obtained in high spectral resolution mode (FDM)
  - Use these data to compute system temperature spectra at higher spectral resolution

Pulsars, Magnetars, and Transients with Phased ALMA
PI: Cordes

- Pulsars near SgrA* are of compelling interest; there are probably many but scattering in the turbulent GC medium limits detection at low frequencies
- Magnetar J1745-2900 (0.1 pc from SgrA*) suggests scattering is variable
  - Its pulses have been seen to 295 GHz
- Study will develop two software modules to provide a capability parallel to that available on the VLA for broadband fast phased array observations



ALMA Study Project: Extensions and Enhancements to the ALMA Phasing System
PI: Matthews

- Study comprises four components:
  - Extension of phasing capabilities, now offered for B3 (90 GHz) and B6 (240 GHz), to B7 (345 GHz)
    - SMA, JCMT, SMT, APEX, Pico Veleta, Plateau de Bure, potentially SPT and LMT
  - Development of correlation techniques to compensate for the mismatch in sampling rates between ALMA and other VLBI stations
  - Optimization of ALMA baseband delay application to avoid unnecessary decorrelation losses
  - Exploration of data reduction and analysis pathways for experiments utilizing phased ALMA data
- Among the deliverables will be a cookbook describing recommended calibration and analysis procedures for VLBI data that include phased ALMA as a participating station

Feature extraction and visualization of ALMA data cubes through topological data
PI: Rosen

- A feasibility study for applying forms of data analysis and visualization never before tested by the ALMA community
- A contour tree-based TDA (topological data analysis) will be used to improve upon existing data cube analysis and visualization

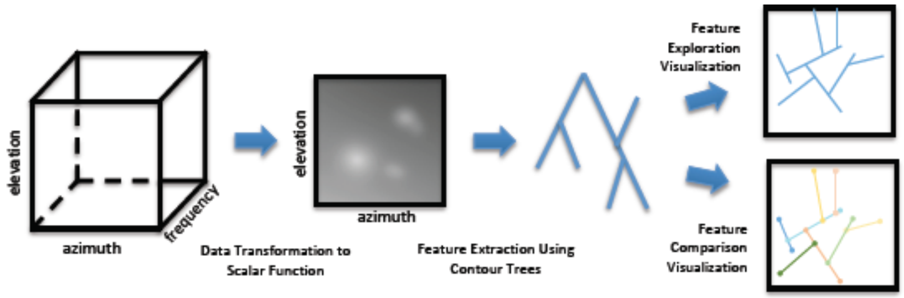
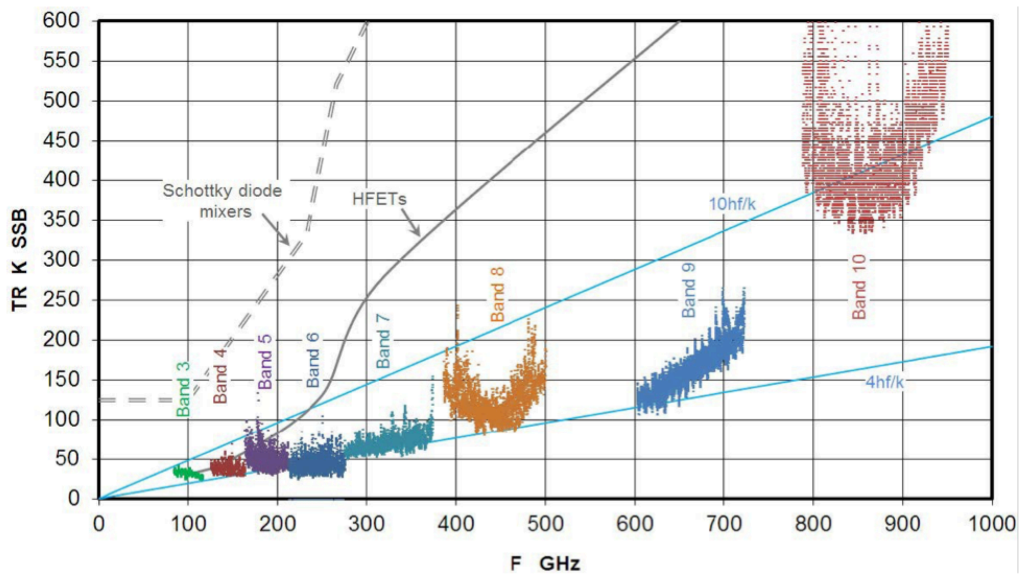


Figure 2: Overview of proposed approach.

Advanced materials and on wafer chip evaluation for second generation ALMA
PI: Lichtenberger

- Investigate an alternative materials deposition technology to realize high gap, all NbTiN SIS mixer devices
  - Incorporating such devices into B9, B10 at ALMA or superTHz mixers should markedly improve performance.
- Investigate an all-wafer SIS device I-V characterization screening technique
  - Allows screening of wafer before proceeding to labor and time-intensive detailed characterization

Single-sideband receiver noise temperature vs frequency for typical ALMA SIS receivers. Bands 3-8 have sideband-separating mixers and Bands 9 and 10 have double-sideband mixers. The performance of the upper half of band9 and the entire band10 could be improved substantially with high energy gap NbTiN/AlN/NbTiN mixers.



Status of Studies

- 2010 Call
  - Preparations for ALMA B5 Full Production - done => **Production Project**
  - Upgrade Options for ALMA B9 – done => **more R&D continuing**
  - Options for upgrading the instantaneous bandpass – done => **New Study**
  - Phasing up ALMA for mm-VLBI – done => **APP Project + ERC + New Study**
  - Design and components for ALMA B2/3 – done => **New Study+**
  - Scientific opportunities for supra-THz – done => **to focus on SD prototype**
- 2013 Call
  - Develop new digitizers design to improve bandwidth – **in progress (Sep29)**
  - Optimization/upgrade of cryocoolers - **in progress (Review mid-Oct)**
  - Data analysis software – **in progress (Review Oct/Nov)**
  - mm-VLBI operations concepts – done => **Board WG**
  - Advanced design and prototypes for ALMA B2+3 – **in progress**
  - Solar observing modes - **in progress**

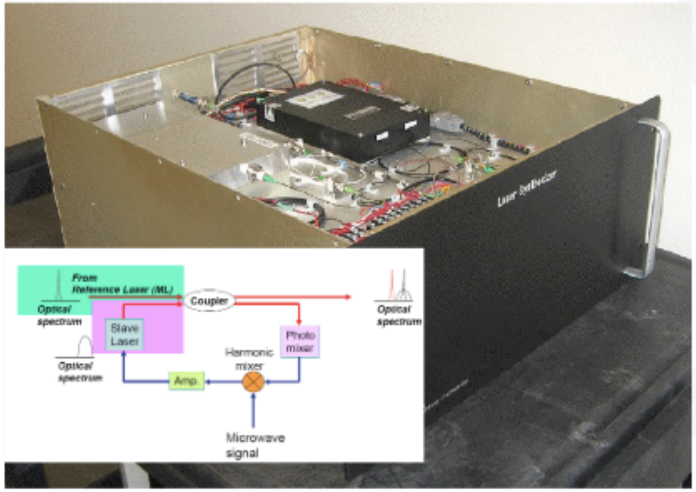
Status of Studies

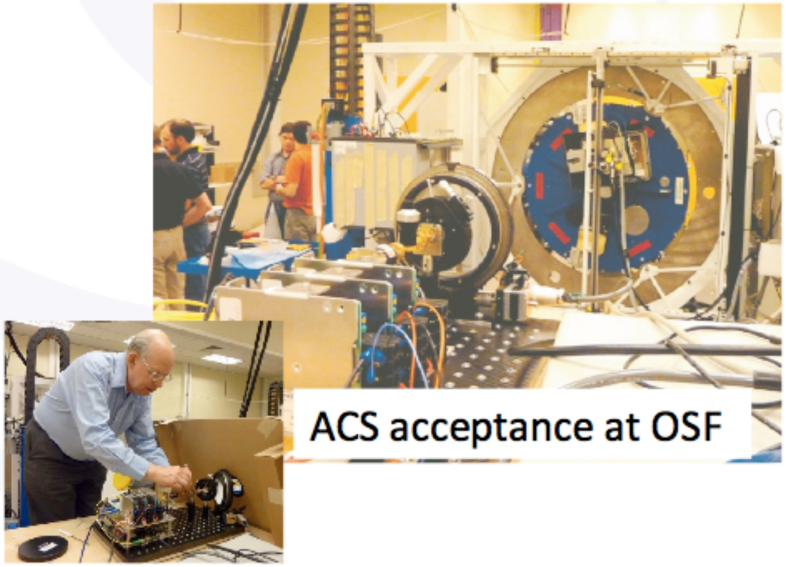
- AOS Artificial Source
- Total Power Spectrometer (w/ KASI)
- High Critical Current Density SIS Junction Device
  - Aimed at THz receivers
- Multi-beam for ASTE (w/ KASI)
  - Ultra-wideband SIS mixers from 300 to 500 GHz (TBC) (and spectrometer)
  - Up to 4 beams

Artificial Calibration Source

- 100GHz frequency range source has been delivered.
- 230/345GHz being developed and will be delivered by 2018

Photonic signal generator: MZM-LS





NAOJ Development

A ROAD MAP FOR DEVELOPING ALMA

ASAC Recommendations for ALMA 2030

- Finish the Scope of ALMA (B1 + B2 receivers, VLB capability)
  - Detailed in **ALMA Scientific Specifications and Requirements** (ALMA-90.00.00.00-001-B-SPE)
- Recommended development paths (ASAC)
  - 1. Improvements to the ALMA Archive: enabling gains in usability and impact for the observatory.
  - 2. Larger bandwidths and better receiver sensitivity: enabling gains in speed.
  - 3. Longer baselines: enabling qualitatively new science.
  - 4. Increasing wide field mapping speed: enabling efficient mapping.
- What are the NRAO/ALMA objectives?
  - Augment ALMA scientific capabilities while benefitting NRAO goals.
  - E.g. B2 has clear complementarities with ngVLA (and GBT).
  - Next Generation Correlator also has clear complementarities with ngVLA.

Enhancing ALMA

- ALMA is exceptional in
  - Providing submillimeter sky access (a unique interferometer at the highest frequencies).
  - ALMA's resolution is highest in these highest bands
- High frequency weather is extremely limited (<15% of time concentrated in austral winter)
- Our goal should be to enhance access to these exceptional capabilities?