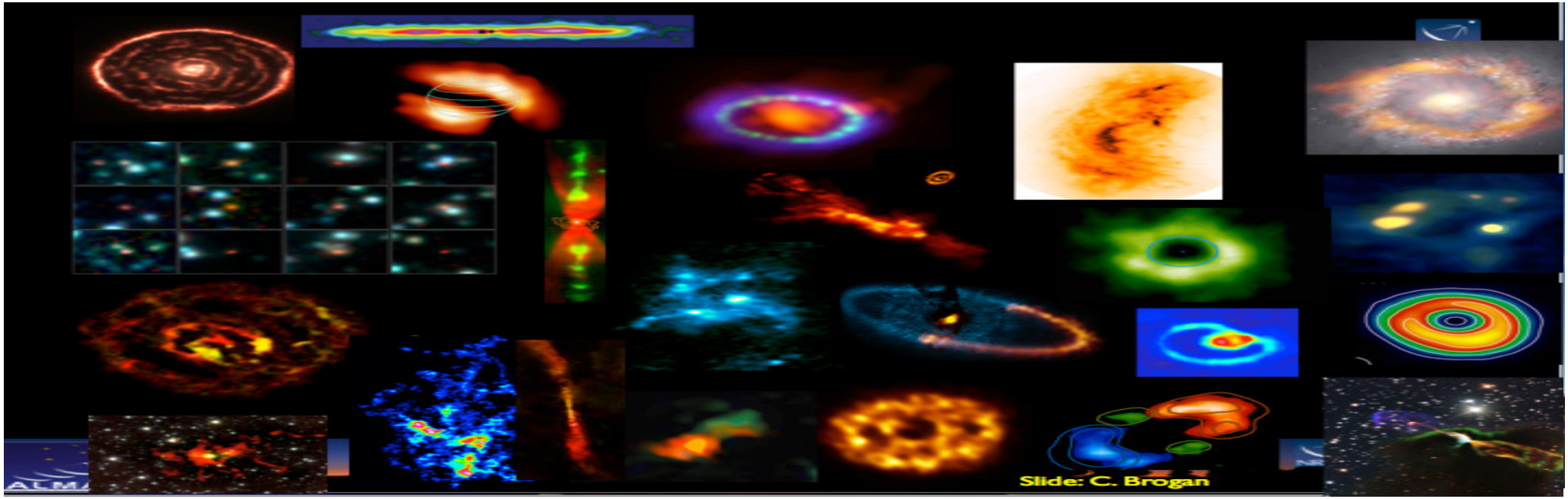
Sustaining Submillimeter Science: New Development



A Short Overview

Al Wootten

ALMA, A WORLDWIDE COLLABORATION

Atacama Large Millimeter/submillimeter Array
Karl G. Jansky Very Large Array

ASAC Recommended Development Paths

- Finish the Scope of ALMA (B1 + B2 +B5 receivers, VLBI capability)
  - Detailed in **ALMA Scientific Specifications and Requirements** (ALMA-90.00.00.00-001-B-SPE)
- ALMA2030
  - 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 imaging.

ALMA's Future

- The original specifications and most construction contracts were let ~15 years ago; those specifications are mostly demonstrated
- Technology has advanced tremendously since
- The community is outlining a new vision to extend ALMA science into the future
- ALMA Development funds enable studies which can underpin that vision
  - Studies are available in the ALMA Memo Series, they are open to community participation
  - SACs and science team combined these into a palette of possible upgrades summarized in 'ALMA2030'
  - Community now engaged in transforming these elements and others into a science-driven vision for the next 5-15 years
- ALMA Development Projects fund upgrades to ALMA to achieve that vision, as they have for Bands 1 (35-52GHz) and 5 (163-211GHz), and will for the remaining Bands and other capital investments

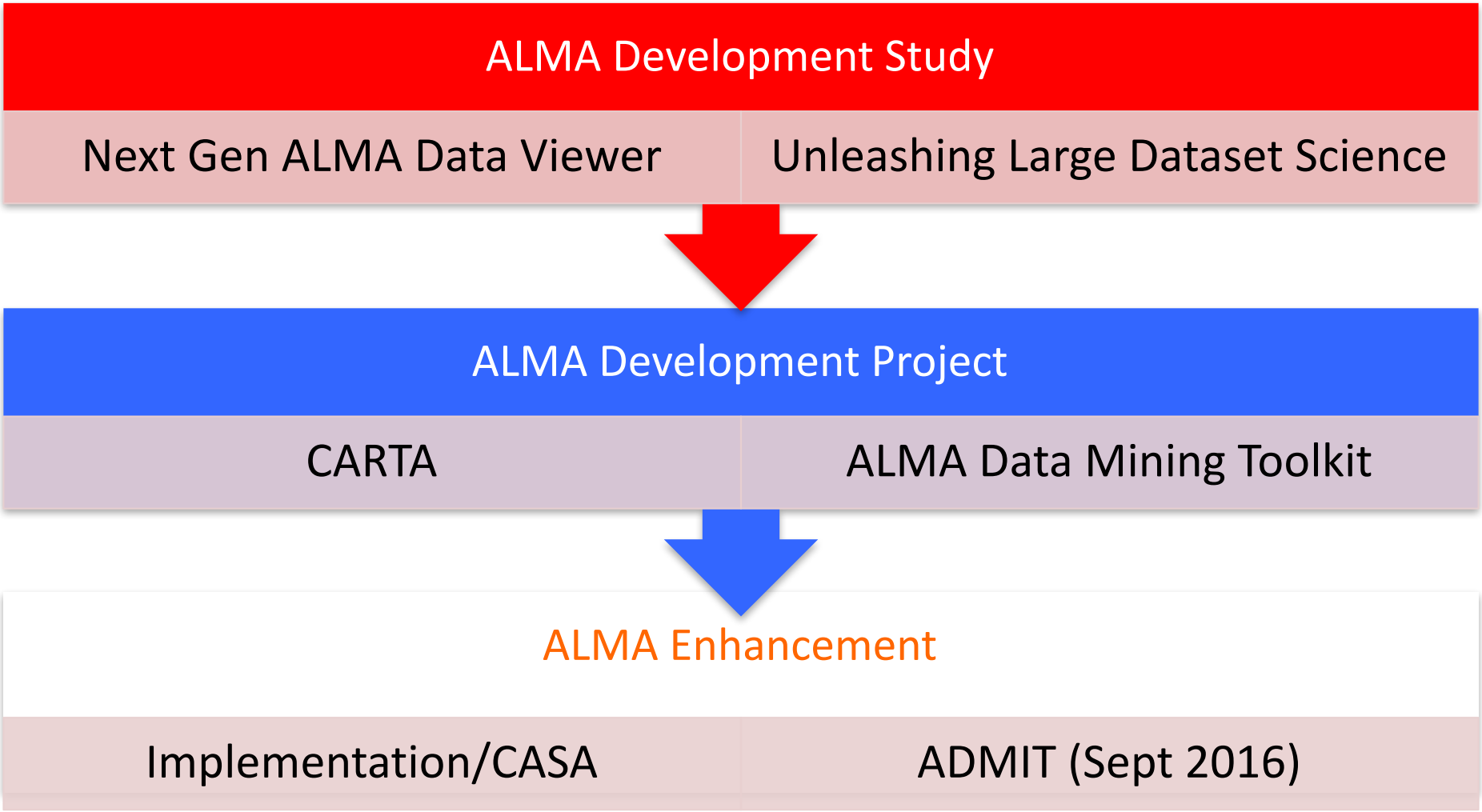
ALMA Development

- ALMA Operations included development funds
  - Ramped up to steady-state level by FY2015
  - First priority was to build to unfunded requirements (receiver bands, VLBI)
- ALMA Integrated Science Team working with the ALMA Science Advisory Committee (ASAC), developed ***PATHWAYS TO DEVELOPING ALMA*** (ALMA2030)
- Using information gleaned from various sources, ***Pathways*** informs discussions leading to assembly of a roadmap for ALMA improvements

ALMA Development Overview

- ALMA Operations comprises many organizations in many countries and many entities participate in Development in parallel but slightly different fashion
- Projects are large pan-ALMA 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 Management Team (JAO, EA, EU, NA), 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'

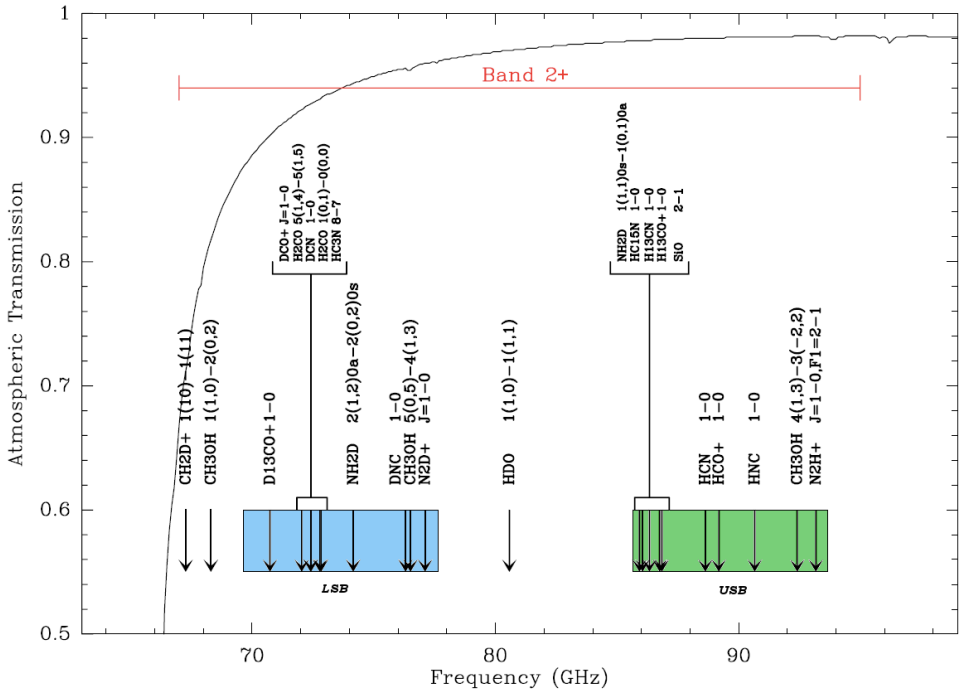
Progression of ALMA Development Components

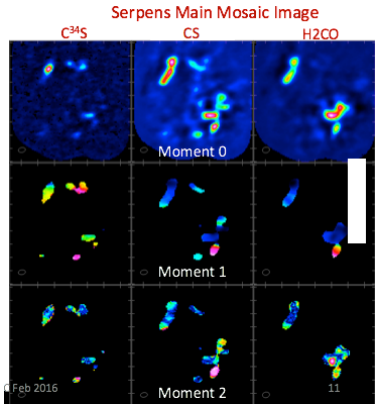


NA Development Program

Current Project Overview

- New ALMA Band 2+ provides new science: ***sensitive*** access to redshifted CO 'desert' and deuterated light molecules passed PDR May
  - *NRAO + NAOJ, suspended*
- ***Correlator Upgrade (not yet approved)***
- Fiber optic connection ALMA to JAO improves PI data delivery
- B3 upgrade to deliver improved TP stability
- Recently delivered ADMIT and CARTA projects for improved archive use
- ALMA Phasing Project (*some elements pending)*

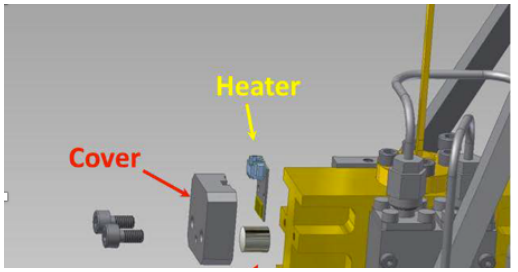




ADMIT products are delivered with data packages, also archived (currently independently)

Fiber Optic Project

Design & Testing of a Prototype 67-95GHz Cartridge



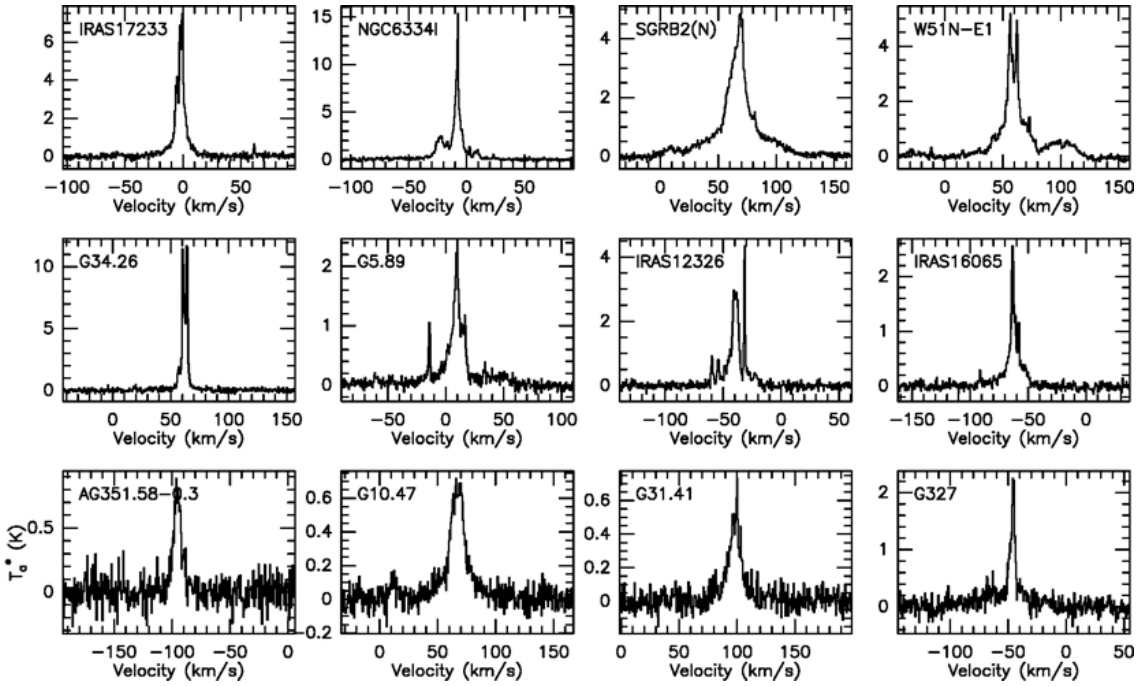
Band 3 CCA Heater Installation for Deflux Operation

Three Projects continue during FY2017.

EU Development Program

Current Project Overview

- New ALMA Band 5 (163-211 GHz) provides new science:
  - Follow the Water!
    - 183 GHz water line
  - [CII] at 8.0 < z < 10.65
  - Consortium of GARD, NOVA, NRAO, ESO, NAOJ
  - Public Data available (SV)
- ALMA Alarm System
- ALMA B2+3 ***(pending review)***
  - ***67-116 GHz one cartridge***
  - ***Prototype PDR Nov '17***

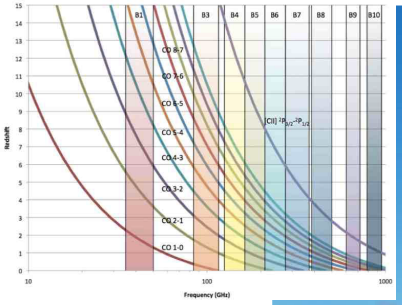


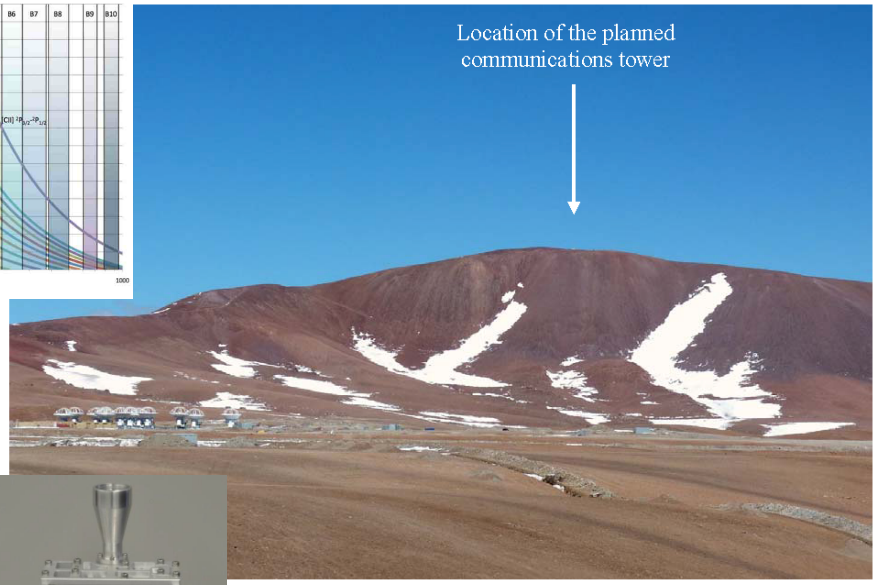
SEPIA/Apex data Wyrowski+ 2017

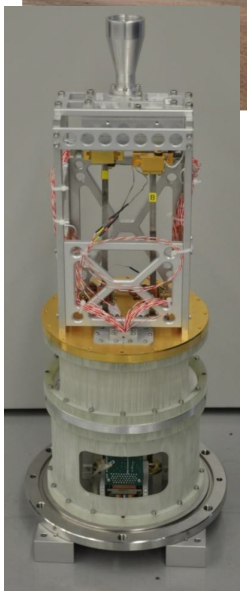
EA Development Program

Current Project Overview

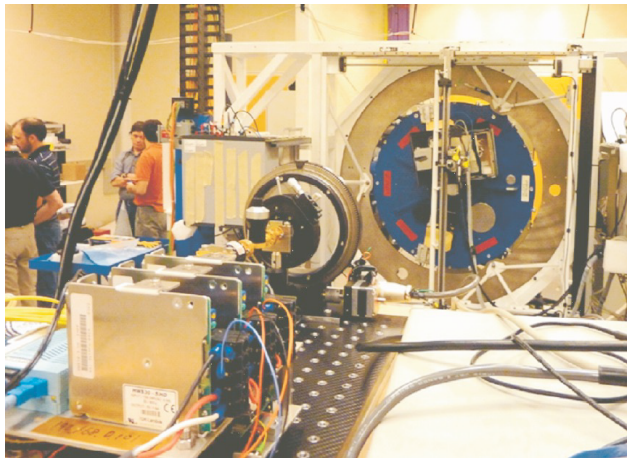
- Band 1 (35-51 GHz) enables new science:
  - Optically thin dust in disks
  - High z CO
  - T_{rx} ~25K; ASIAA, with NAOJ, U of Chile, NRAO, HIA; available ca 2020
- GPU Spectrometer for TP (w/KASI)
- Band 5 Integration and Testing
- Band 2, 2+3 optics
- Artificial Calibration Source
  - Beacon at Chajnantor
  - 100 GHz delivered
  - 230/345 GHz 2018
- High Critical Current Density (Jc) SIS Junction Device Development (esp Wideband RF/IF and THz devices)







Band 1 Receiver



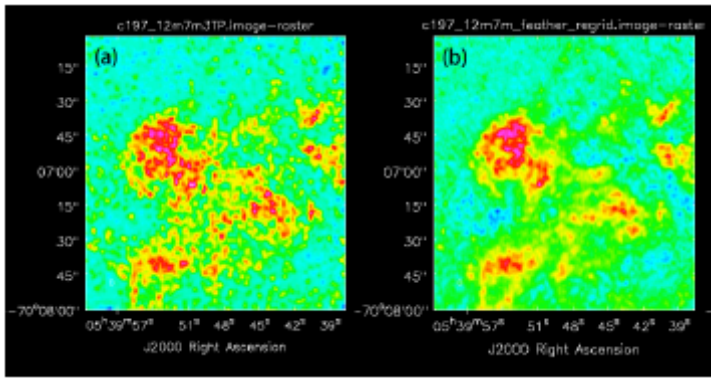
ACS acceptance at OSF

NA Development Program

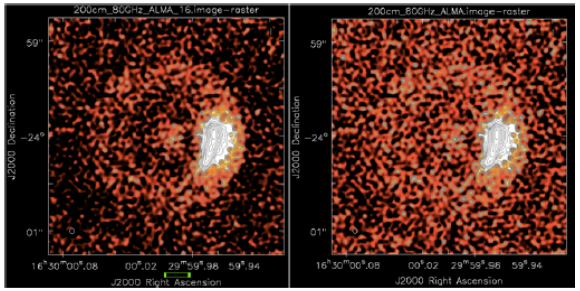
Cycle 4 Study Overview

Acting on ALMA2030 vision:

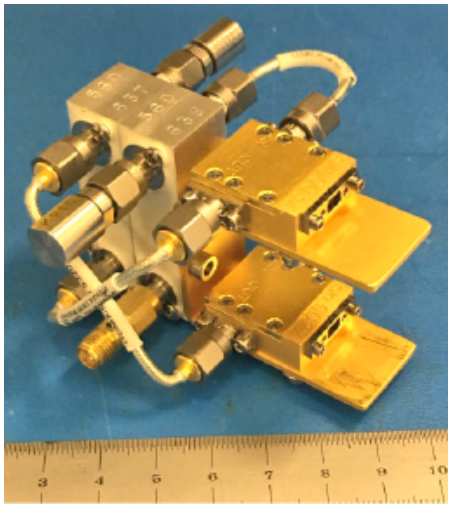
- Increasing receiver sensitivity, bandwidth
  1. Upgraded ALMA B3 mixer block - Henke
  2. 2nd generation SIS receiver development -Kerr
- Expanding ALMA's processing bandwidth
  1. Upgrade of Backend Antenna Article to match correlator upgrade - Ford
- Improved data use
  1. Improved interactive CLEAN
  2. Improved imaging with combined arrays
- Maximizing point source sensitivity and resolution
  1. Weak source and spectral line VLBI



Total Power Map to Visibilities (TP2VIS)
a) Joint deconvolution b) Current mode



A protoplanetary disk simulation: r: current bandwidth l: upgraded 2x BW.



Development of 2nd Generation SIS Receivers for ALMA: Prototype balanced B6 amplifier 4-12 GHz

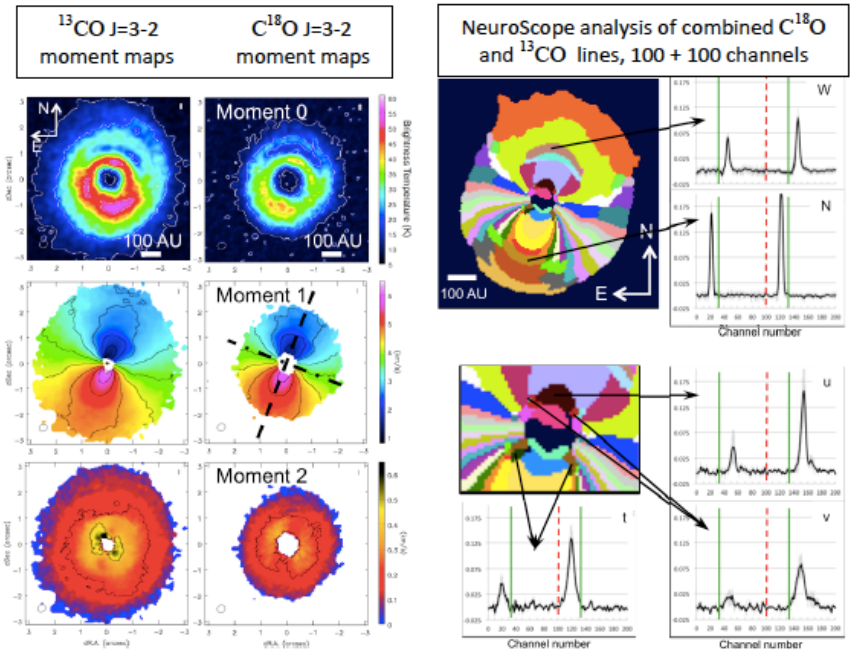
Six Cycle 4 Studies underway.

NA Development Program

Cycle 5 Study Overview

Acting on the ALMA2030 vision:

- Increasing receiver sensitivity, bandwidth
  - *2nd Generation SIS Receiver Development* - Kerr
- Expanding ALMA's processing bandwidth
  - *Quantum-Limited Very-Wideband 4-Kelvin RF and IF Amplifiers for ALMA* - Noroozian
- Improved data characterization
  - *Neural Network Analysis of ALMA Datasets* - Merenyi
- Full-field primary beam models will be developed for use in imaging software
  - *Full-Mueller Mosaic Imaging with ALMA*, PI Sanjay Bhatnagar



Neural Network analysis highlights departures from Keplerian disk motion in HD142527

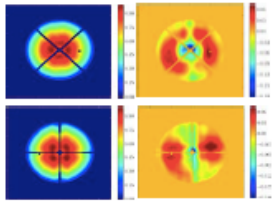


Figure 2A: The average real and imaginary parts of DA (top row) and DV antennas (bottom row) [Kundert et al, 2016]

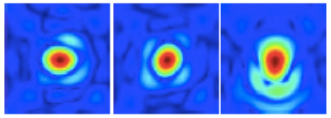


Figure 2B: Range of antenna-to-antenna variations in PB derived from aperture illuminations shown in Fig. 2A.

Imaging with different antennas

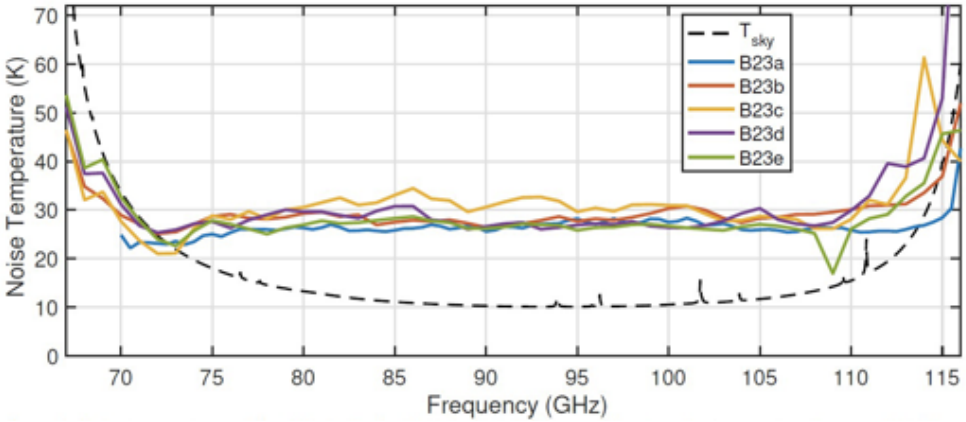
Four Cycle 5 Studies Commence FY2018.

EU Development Program

Study Overview

Acting on the ALMA2030 vision:

- SIS Junction Technology Development (Belitsky, GARD)
- Evolution of the ALMA Observing Tool (Bridger, UKATC)
- Band 2+3 (ESO, INAF, UManc, NAOJ, RAL,
- UChile)
  - Passive Component
  - InP MMIC LNAs for ALMA Band 2+3
  - Band 2+3 Prototype (internal; ongoing)
- Digitization and Digital Signal Processing for 16GHz on-sky bandwidth (Alain Baudry)
- Digital ALMA Front End
- 2SB upgrade for Band 9 (NOVA, Baryshev)
- Solar Observations (pending ALMA Memo)
- XClass/MAGIX integration in CASA
- ARTIST prototype interface



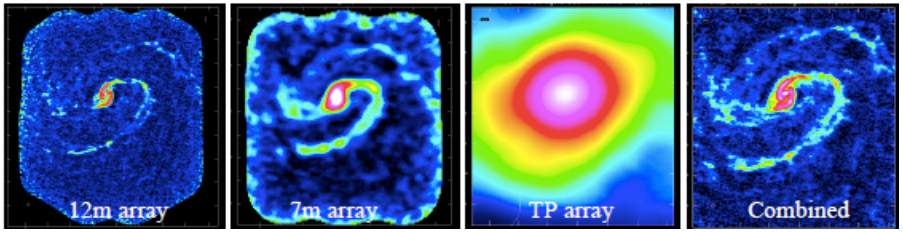
B2+3 LNA performance (Cuadro-Calle et al. 2017)

EA Development Program

Study Overview

Acting on the ALMA2030 vision:

- ALMA Calibration Source
  - Calibration at bands 3,6,7
- High Critical Current Density (Jc) SIS Junction Device Development (including Wideband RF/IF and THz devices)
- GPU Spectrometer for Total Power array (with KASI)
  - Supplements the ACA correlator
  - Separates auto-correlationfrom cross-correlation, maintaining 32-bit quantization and eliminating re-quantization loss in the decimation.



Complete Flux Recovery using 12m+7m+TP

Immediate Future

- Projects
  - Next: Follow many steps in Principles of ALMA Development,
    - Correlator Upgrade, APP probably to Board late 2017.
    - ALMA Band 2+ or B2+3 probably to Board 2018.
- Studies
  - New Calls every three years at ESO (2019), probably FY2019 in NA, yearly discussions in EA
- ALMA 2030

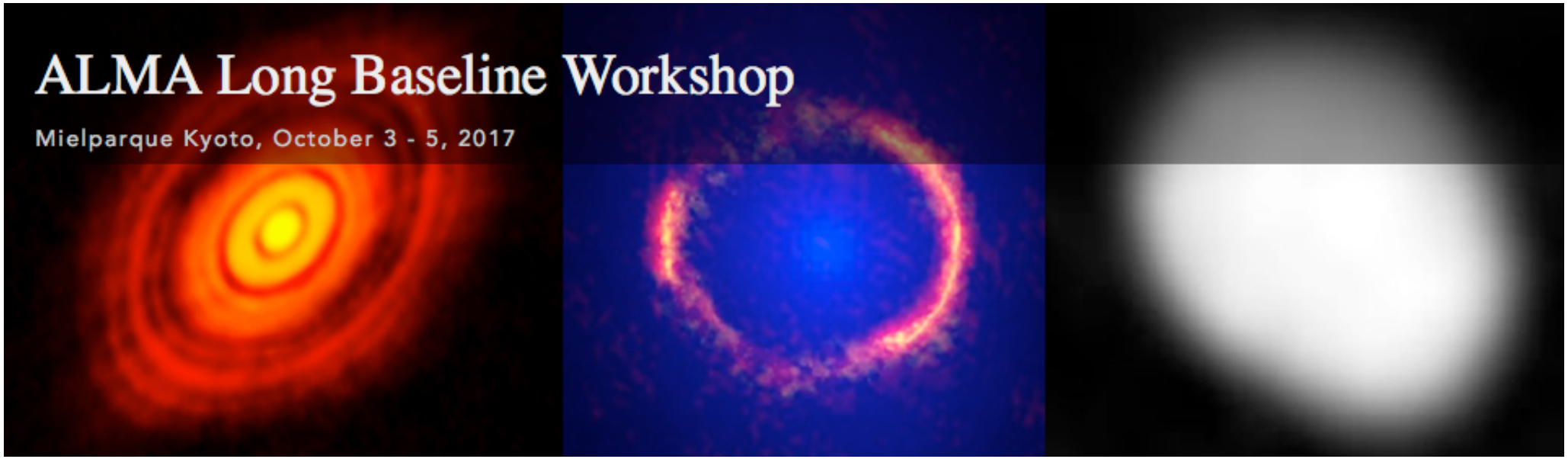
ALMA Development Vision

- The ALMA Development Working Group shall propose a science-driven vision for the medium (5 years) to longer term (5 to 15 years) development of ALMA
- Two new Science Drivers were identified:
  - Disks & Planets: The ability to explore the chemical composition and evolution of disks, including around planets, down to scales of 1 AU
  - First Galaxies: The ability to investigate the early universe from the formation of metals(first stars) to the peak of star formation and to identify the first galaxies and image their surroundings

Development Priorities

To Realize the Vision

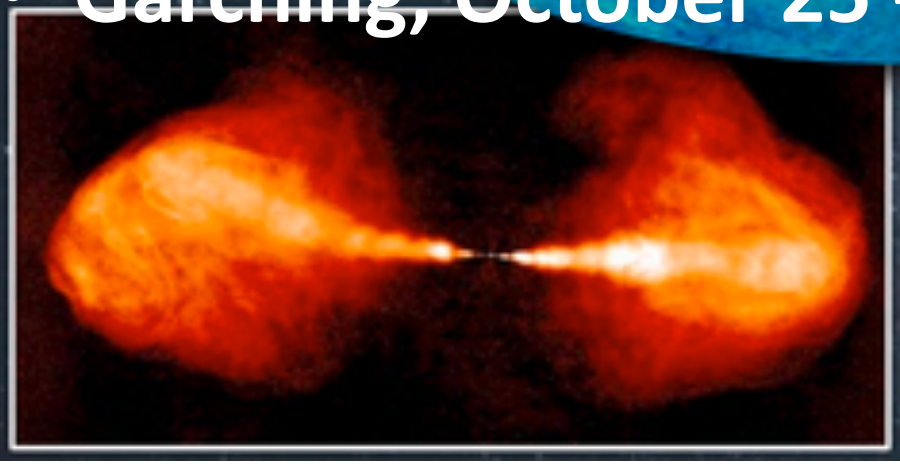
- Broader IF bandwidth; upgrade components
  - Spectrometer and digitizer upgrades
  - Receiver upgrades (B6/7, B3, B9)
  - Results:
    - Better continuum sensitivity
    - Improved spectral coverage, sensitivity
- Additional antennas, longer baselines, focal plane arrays
  - Beyond basic Development
  - Improved spectral sensitivity and imaging
  - Wide field imaging

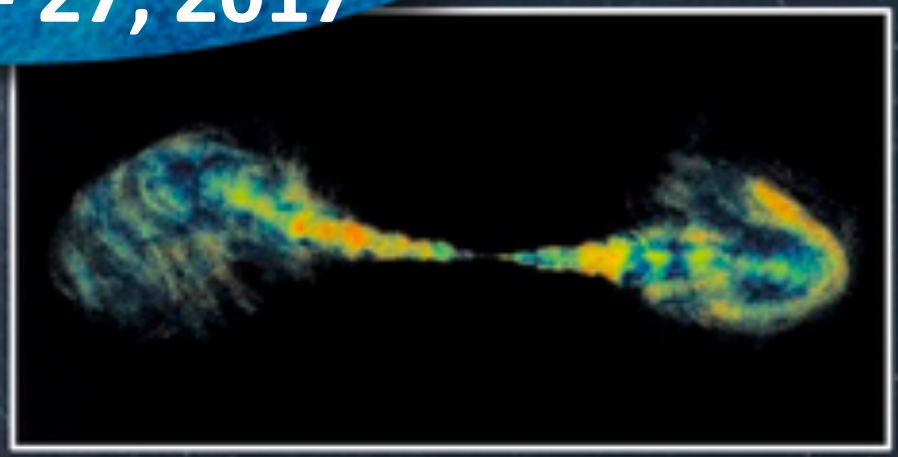


- Mielparque Kyoto, October 3 - 5, 2017
- Register by 1 September
- Web http://alma-intweb.mtk.nao.ac.jp/~diono/meetings/longBL2017/

Polarization Workshop

- **Submm/mm/cm QUESO Workshop 2017:**
- **Centimetre-Sub-Millimetre Q&U (and V) European Southern Observatory Workshop**
- **Garching, October 25 - 27, 2017**





AtLAST

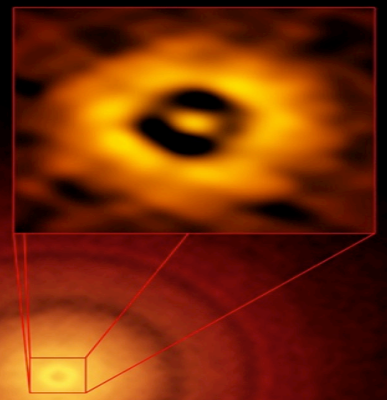
- **Atacama Large-Aperture Submm/mm Telescope (AtLAST)**
- **ESO-HQ, Garching b. München, Germany**
- **January 17-19, 2018**

Magnetic Fields or Turbulence: Which is the critical factor for the formation of stars and planetary disks?

- 6-9 Feb 2018, National Tsing Hua University, Hsinchu, Taiwan
- Discussions on all aspects of star and planetary disk formation, such as
  - Magnetic field and turbulence measurements
  - Molecular cloud structure and dynamics
  - Formation of protoplanetary disks
  - Chemical contents of molecular cores and disks
  - Star formation efficiency

- http://events.asiaa.sinica.edu.tw/workshop/20180206/index.php

NRC·CNRC



New Horizons in Solar Systems

A Joint NAASC-NRC Conference
Victoria, BC, May 2019

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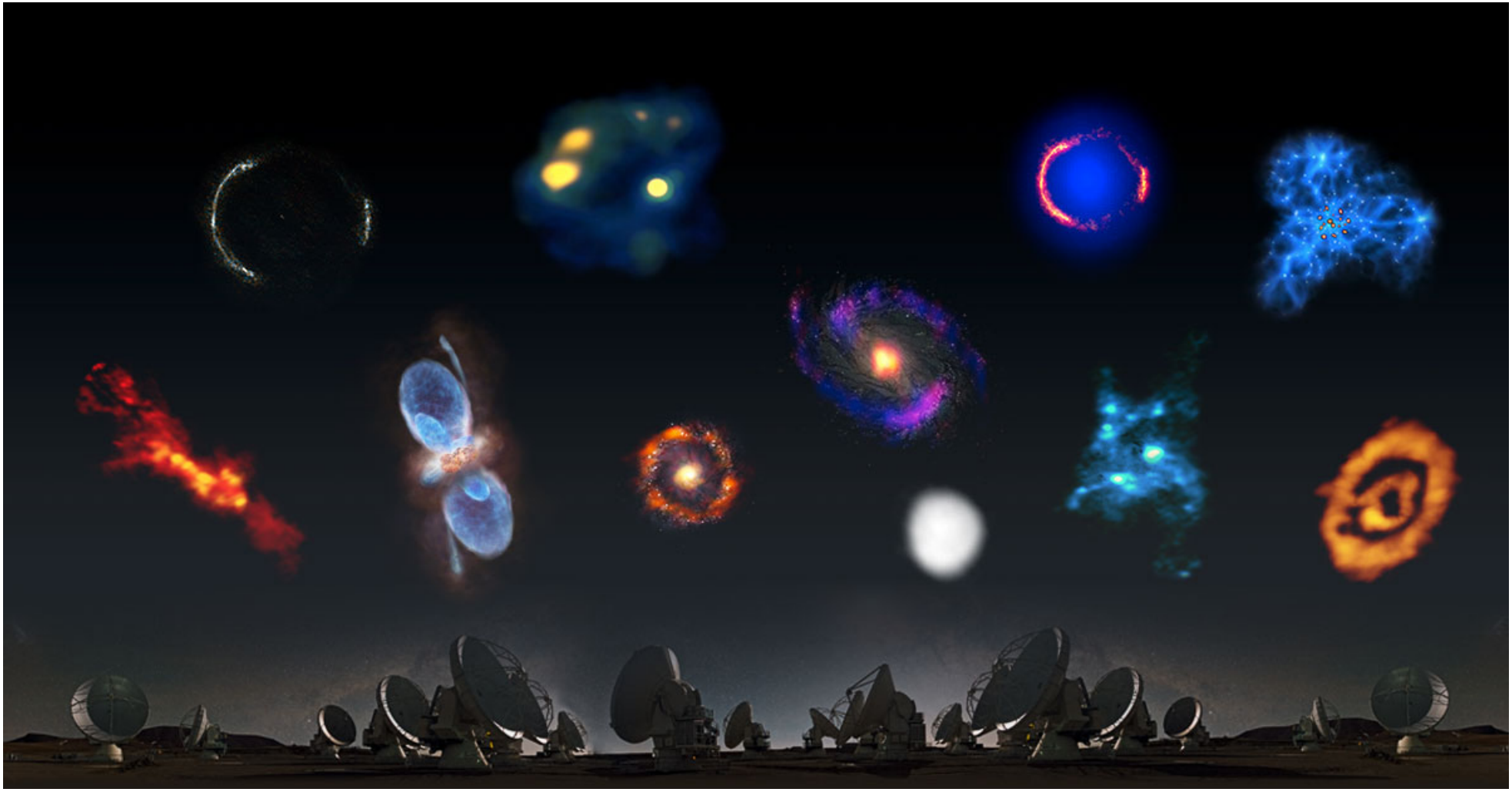

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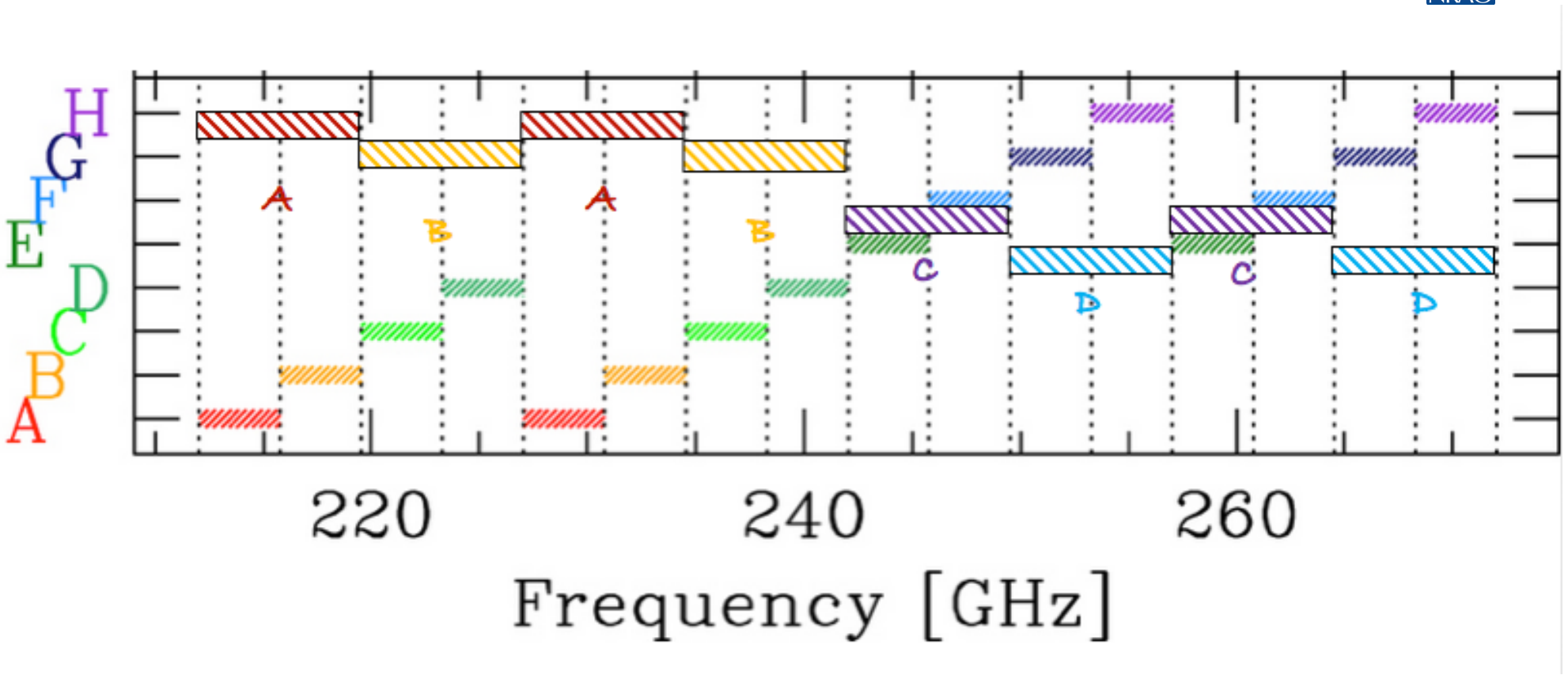
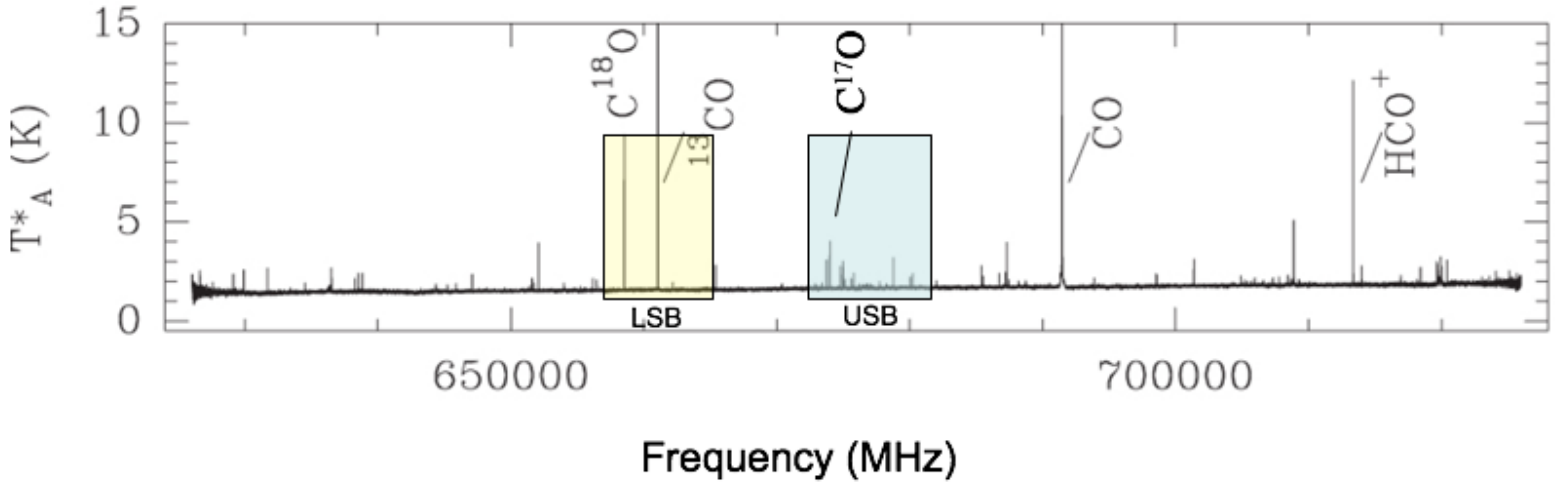
Upgraded Correlator, IF, Halves Spectral Search Settings



Upgraded ALMA Correlator needs *only four* settings to cover Band 6; currently *eight* tunings (Lettered, left) are needed to cover the frequencies of the [C II] line at redshifts of 6 to 8 in the ALMA ASPECS spectral scan of the Hubble UltraDeep Field.

Adapted From Walter et al. 2016

Upgraded Correlator Nets More Lines



- Many CO isotopomers fall within a part of the Herschel HEXOS spectral scan in a portion of ALMA Band 9 (611-720 GHz) showing the spectral grasp of the current baseline correrlator (8 GHz x 2 polarizations) compared to that from the upgraded correlator (2 x 8GHz x 2 polarizations). From Tahani et al. 2016.
- For high resolution, ALMA's current configuration provides 58 MHz spectral windows, only ~70 km/s at 300 GHz. With the correlator upgrade, one could achieve the same resolution over ~550 km/s.