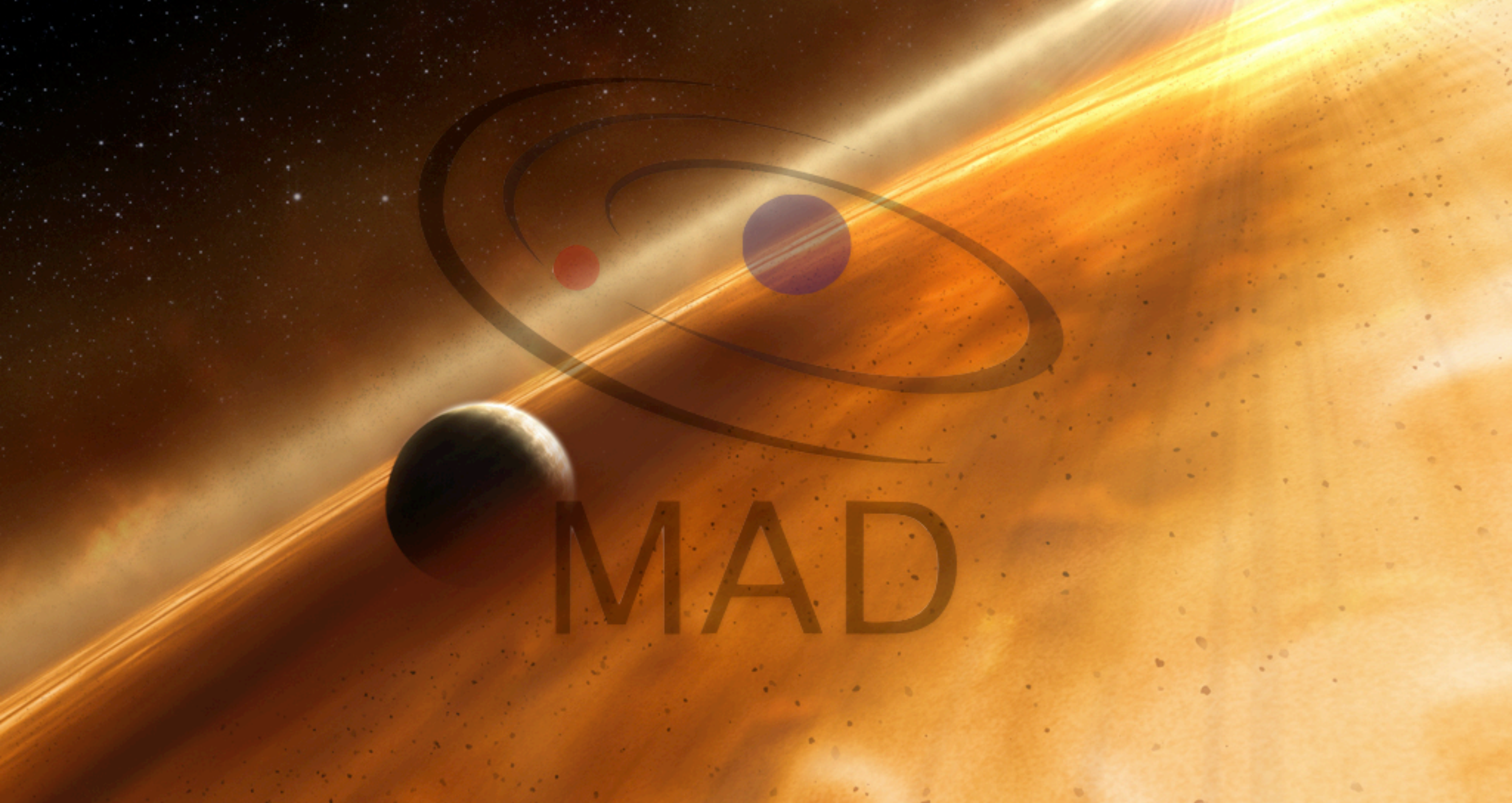
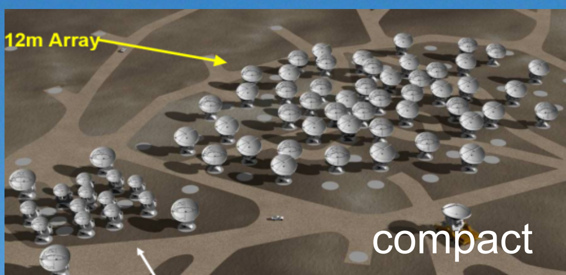
Probing Planetary formation with ALMA



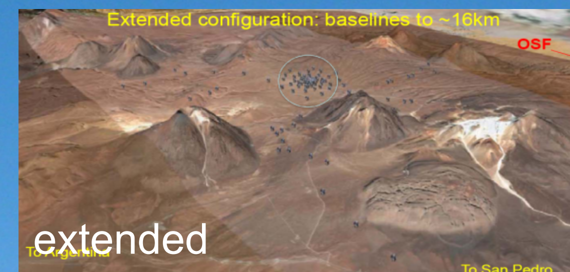
Probing Planetary formation with ALMA

This is ALMA

An array of **66 antennas,**
using *aperture synthesis*, *as a* "zoom telescope"
over the *entire accessible mm/submm* wavelength range



Built to operate
>30 yrs

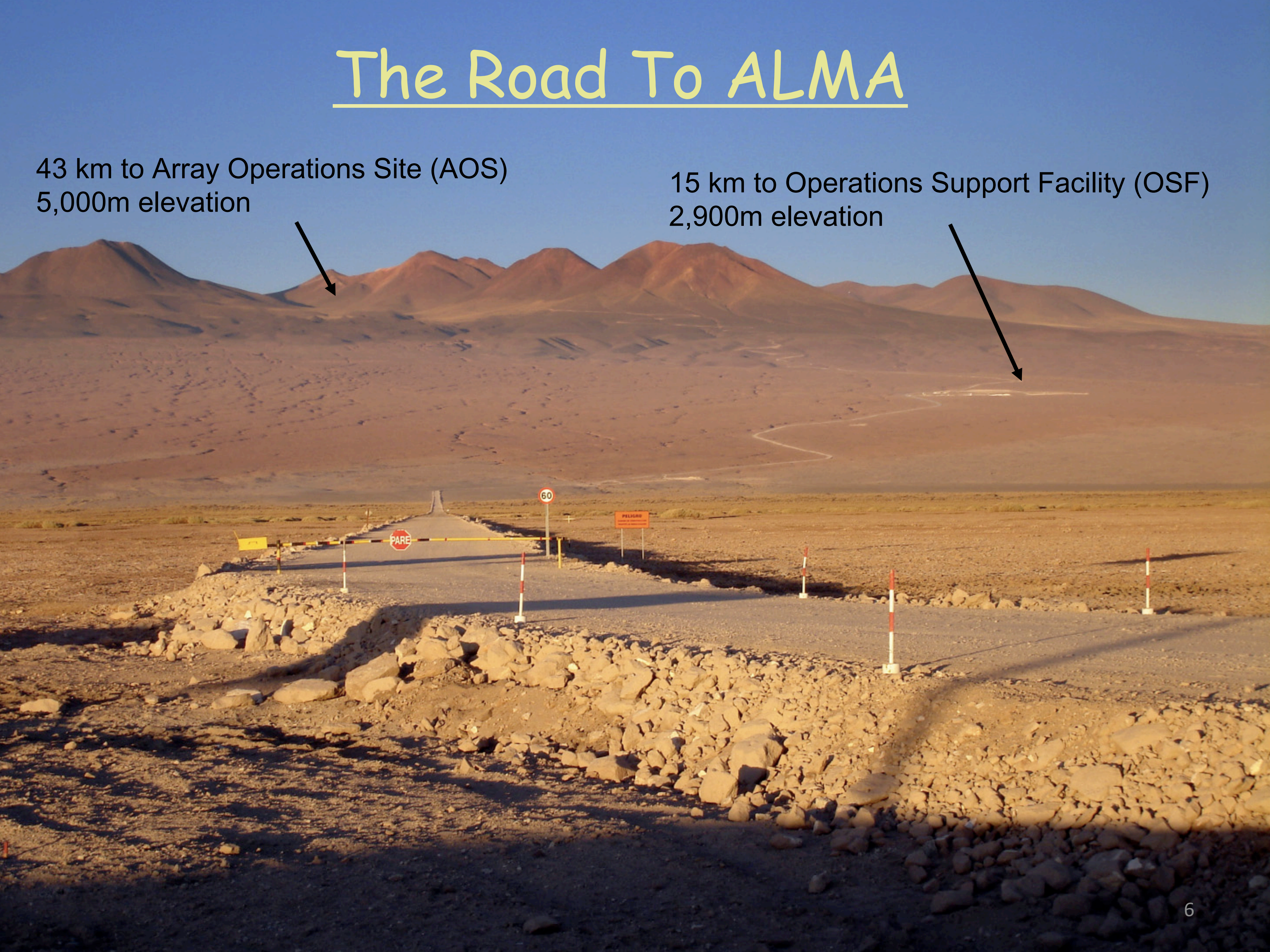



Paulina Rodriguez
11 años
Toconao
1st


ALMA
2nd

Equipment and data flow between ALMA centers

The Road To ALMA



Operations Support Facility (OSF): Technical Building

Full House at the OSF

First EU antenna (Apr 21st)

ALMA at 13 March 2013

- Antennas

• 57 through the integration (AIV) process and ready/used in the array

• 9 in various advanced states of integration and to be delivered by July. Ready for the array in October

- **Equipment and Software:** all delivered
- **Infrastructure complete** except for the residencia
- **Commissioning tests and Science Verification** in progress

- **Early Science started;**

cycle-0 done; cycle-1 started; cycle-2 in preparation

After 2013

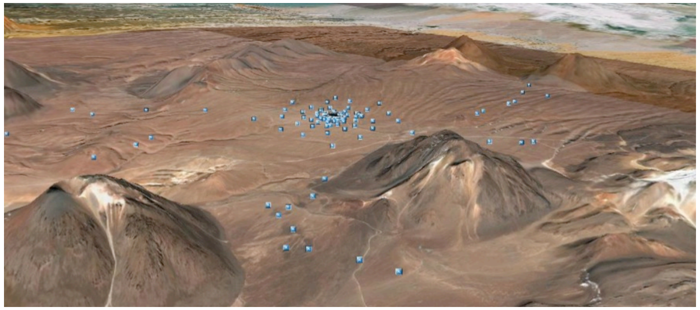
- optimization of the array: long baselines; polarization, etc…
- development program

Full Science Capabilities

ALMA

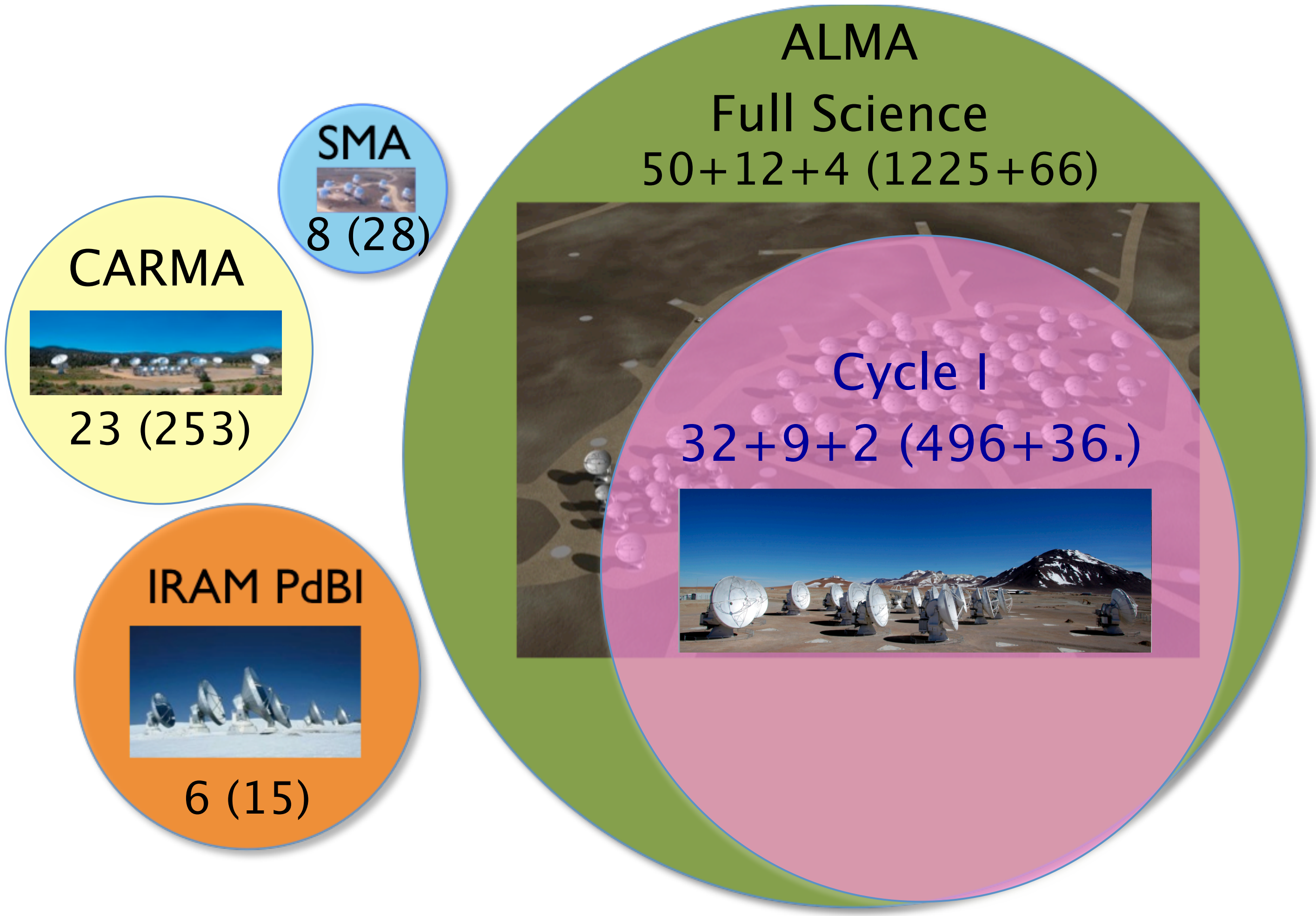
10-100× better sensitivity and resolution than current mm arrays.

- Baselines to ~**15 km** (0.015" at 300 GHz) in "zoom lens" configurations
- Sensitive, precision imaging 84 to 950 GHz (3 mm to 315 μm)
- State-of-the-art low-noise, wide-band SIS receivers (8 GHz bandwidth per polarization)
- Flexible correlator with high spectral resolution at wide bandwidth
- Full polarization capabilities



NRAO

Collecting Area & Baselines



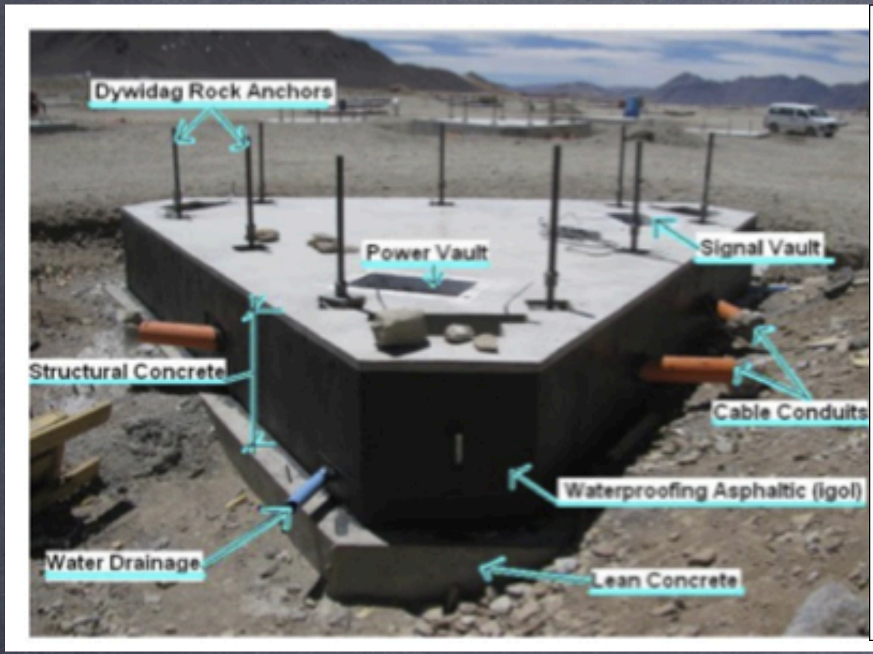
Circles Show Collecting Area (sensitivity)

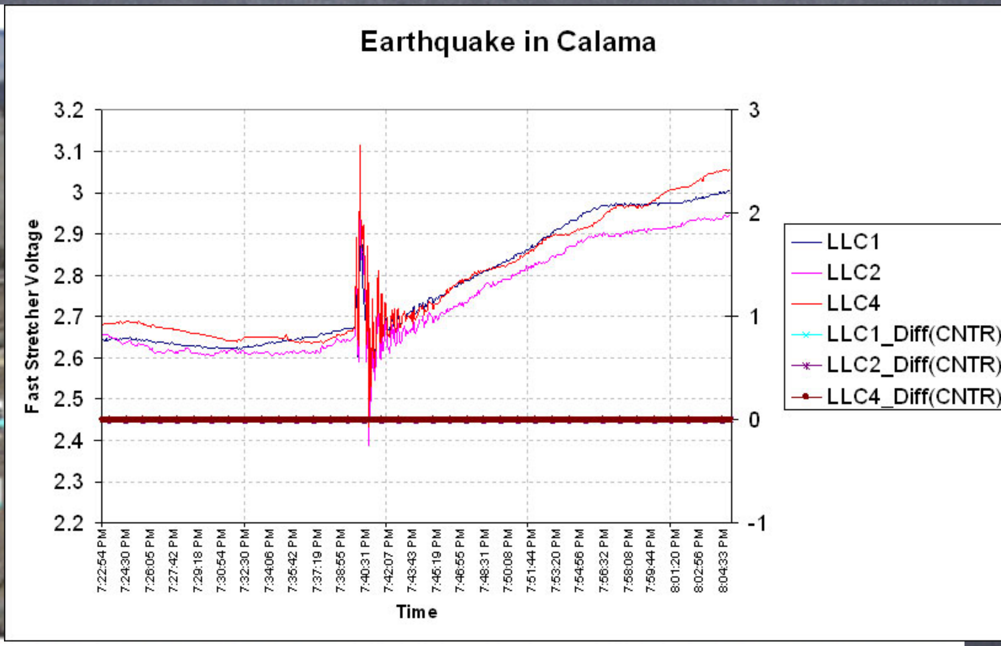
Captions give # of antennas and # of baselines (fidelity)

MAD

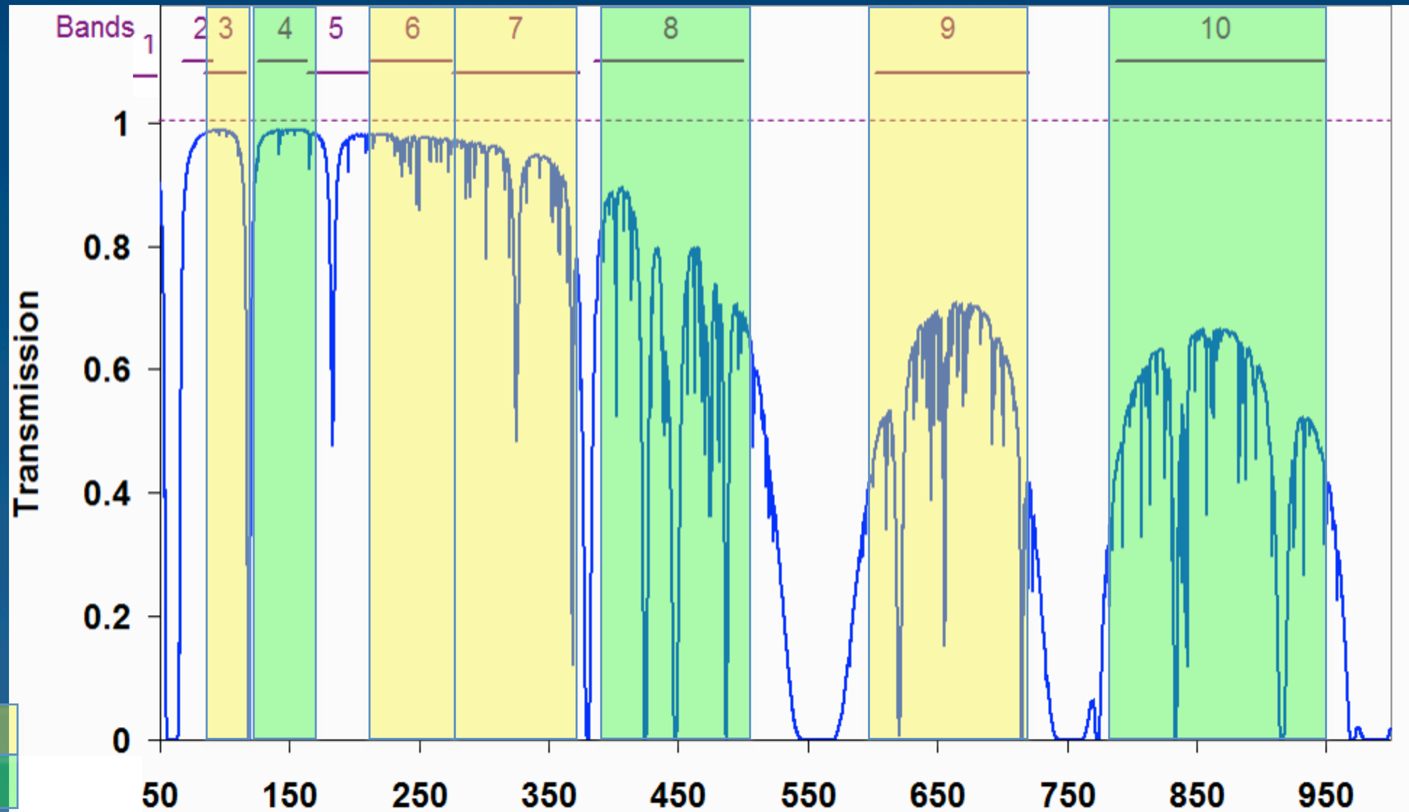
	BUS	Number Rings/ Panels	Panel Mate- rial	Quad type[1]	Cabin	Drive System[2]	Metrology System[3]
Vertex	CFRP Al Invar	8/264	Al	+	Steel	Gear	4 linear displacement sensors + 1 two-axis tiltmeter (above the az-imuth bearing)
Melco 12m	CFRP	7/205	Al	+	Steel	Direct	Reference Frame metrology
Melco 7m	Steel	5/88	Al	+	Steel	Direct	Thermal (main dish), Reference Frame metrology
AEM	CFRP Invar	5/120	Nickel Rhodium	x	CFRP	Direct	86 thermal sensors + 2 tiltmeters in yoke arms

Antenna Foundations

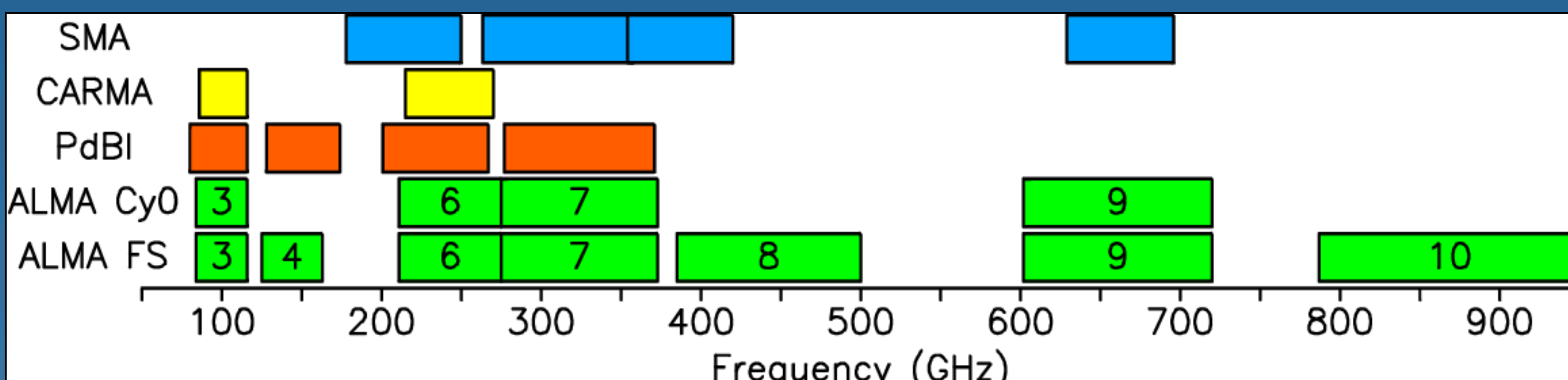




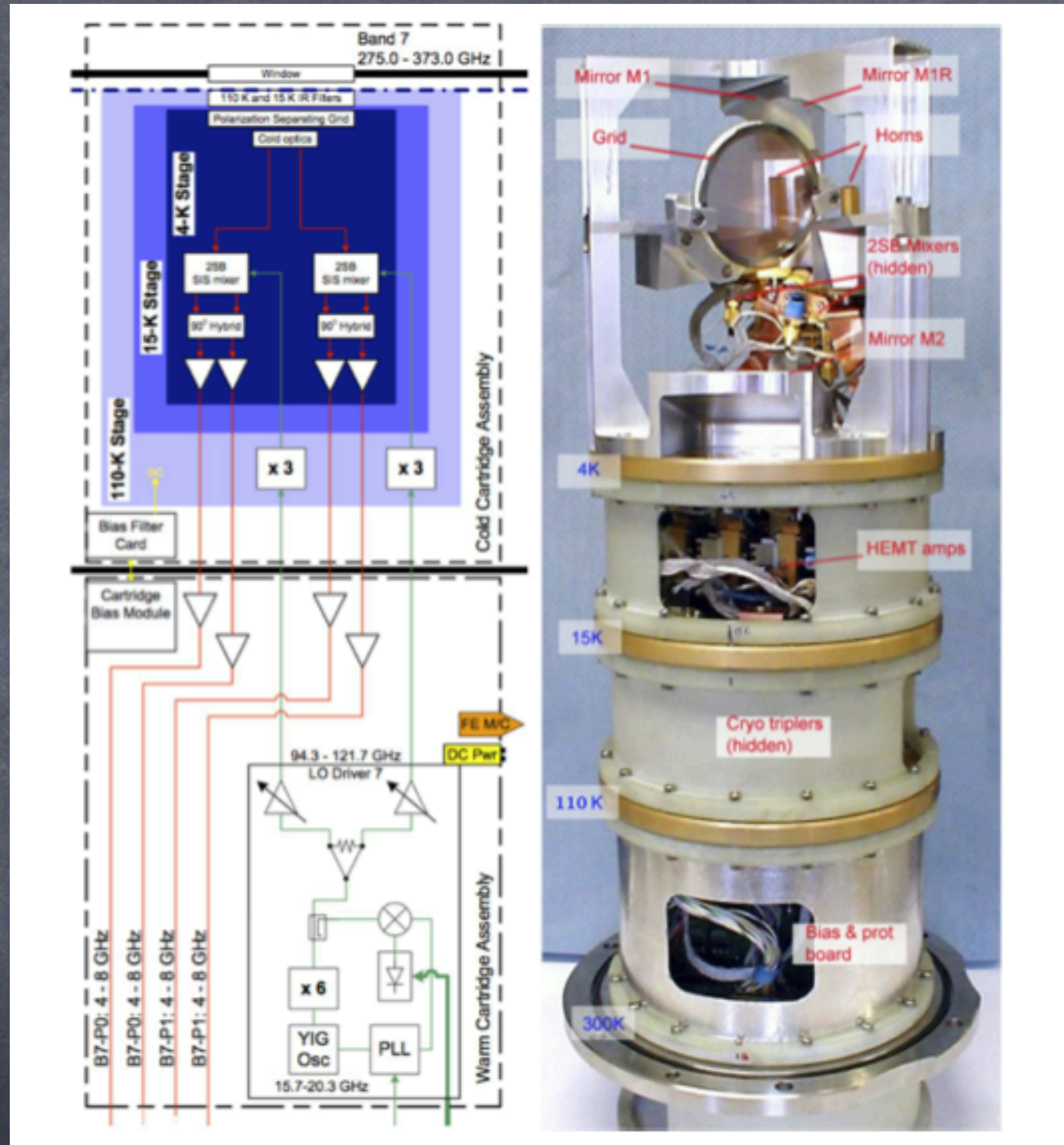
MAD



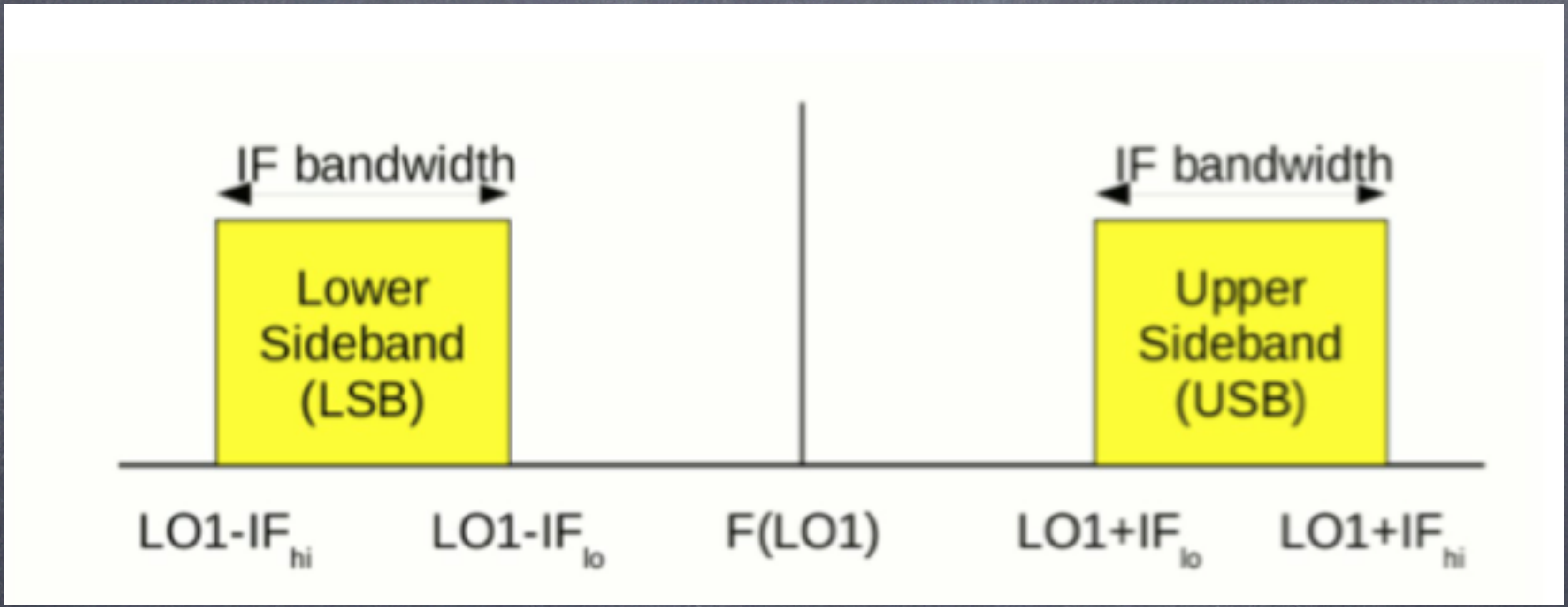
Early Science (now)
Full Operations



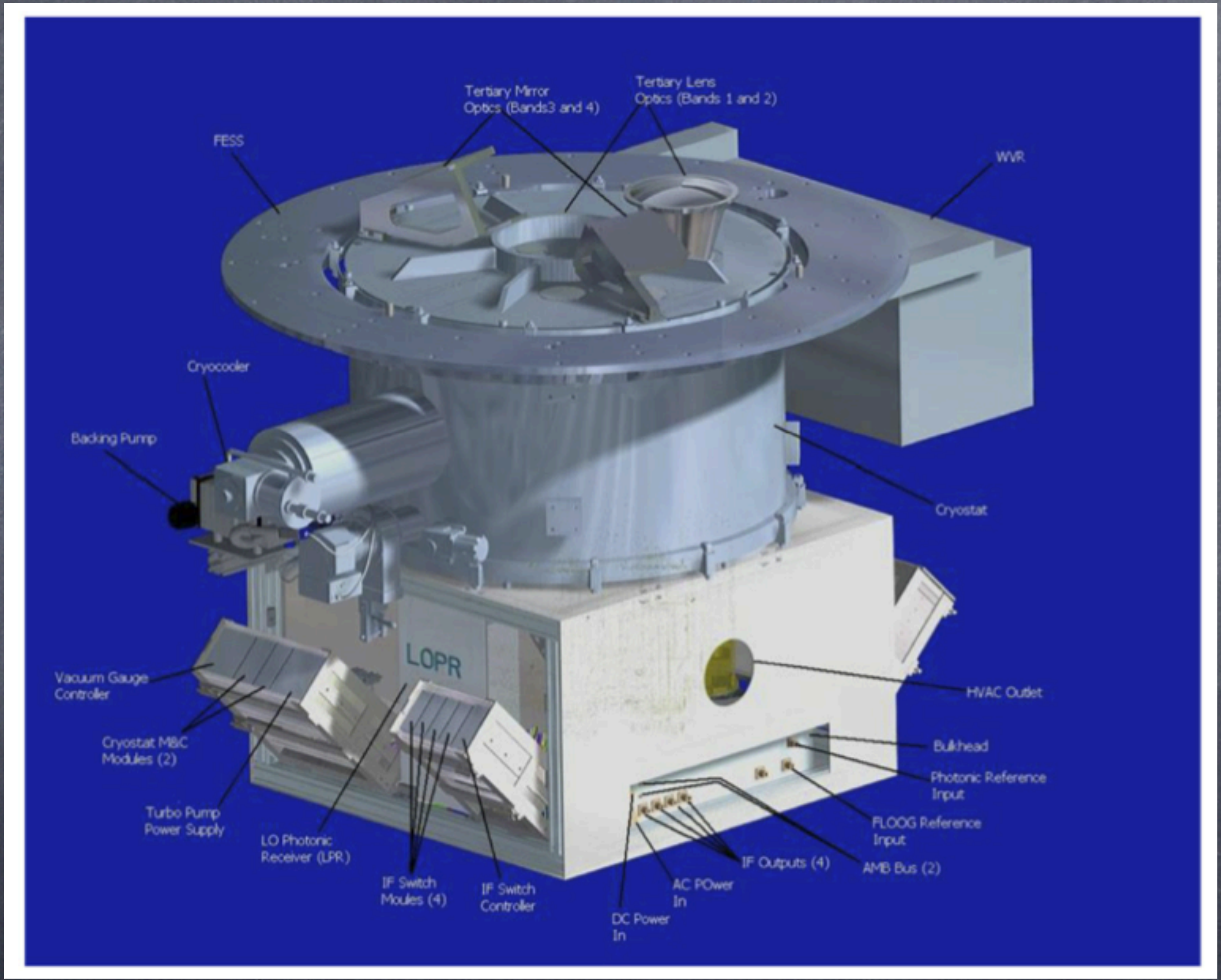
Extreme Altiplano winter…

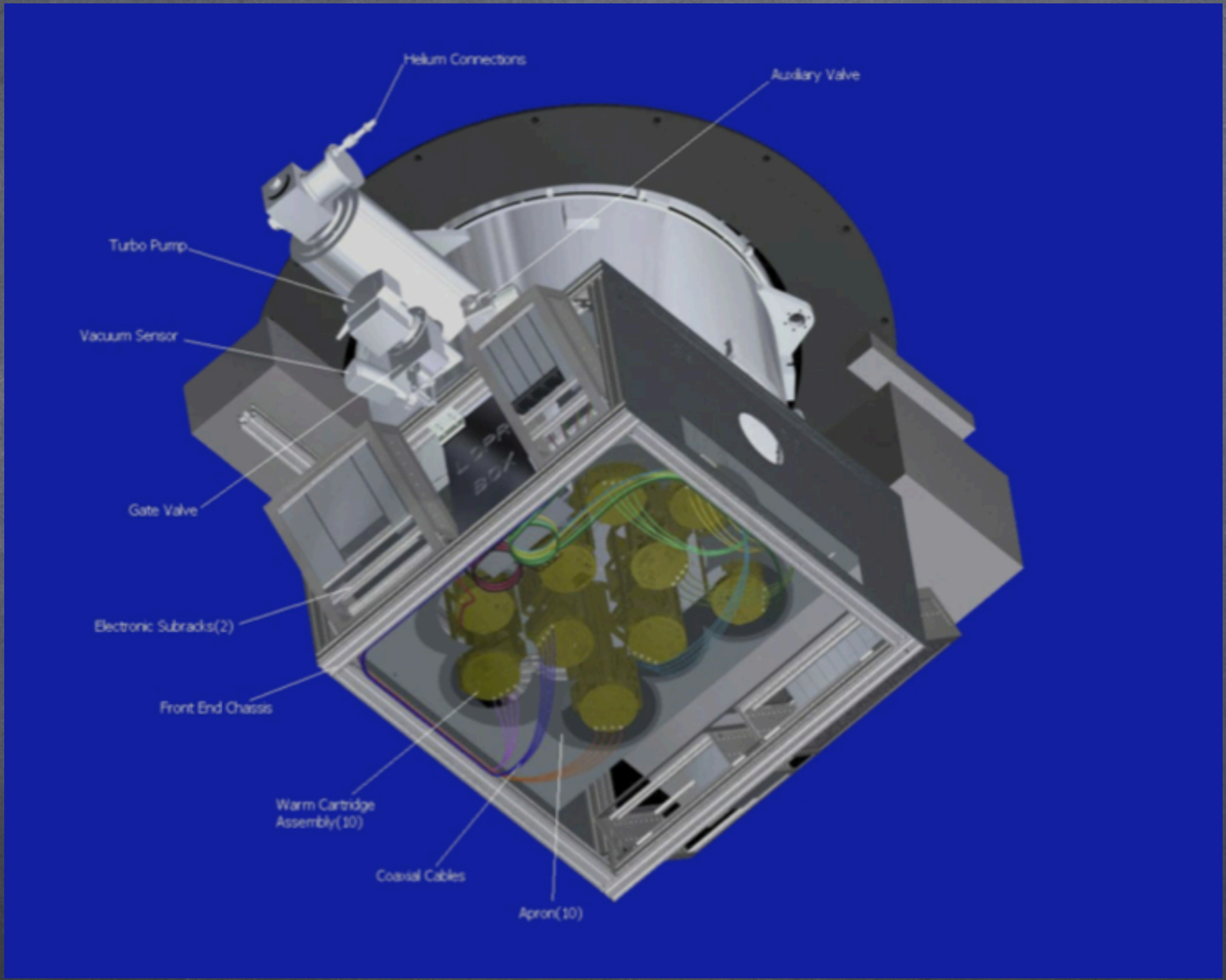

Band 7
275.0 - 373.0 GHz
Window
110 K and 15 K IR Filters
Polarization Separating Grid
Cold optics
4-K Stage
15-K Stage
110-K Stage
2SB SIS mixer
2SB SIS mixer
90° Hybrid
90° Hybrid
x 3
x 3
Bias Filter Card
Cold Cartridge Assembly
Cartridge Bias Module
FE M/C
DC Pwr
94.3 - 121.7 GHz
LO Driver 7
x 6
YIG Osc
PLL
15.7-20.3 GHz
B7-P0: 4 - 8 GHz
B7-P0: 4 - 8 GHz
B7-P1: 4 - 8 GHz
B7-P1: 4 - 8 GHz
Warm Cartridge Assembly
Mirror M1
Mirror M1R
Grid
Horns
2SB Mixers (hidden)
Mirror M2
4K
HEMT amps
15K
Cryo triplers (hidden)
110 K
Bias & prot board
300K

2SB receivers

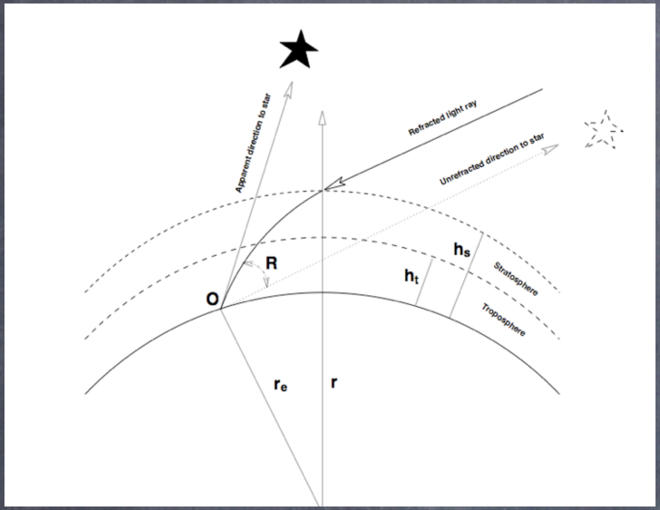


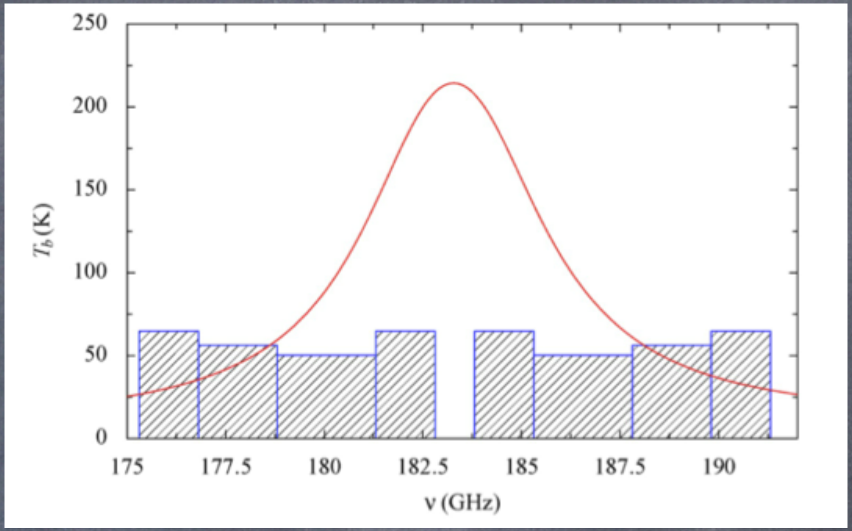
ALMA Cryostat

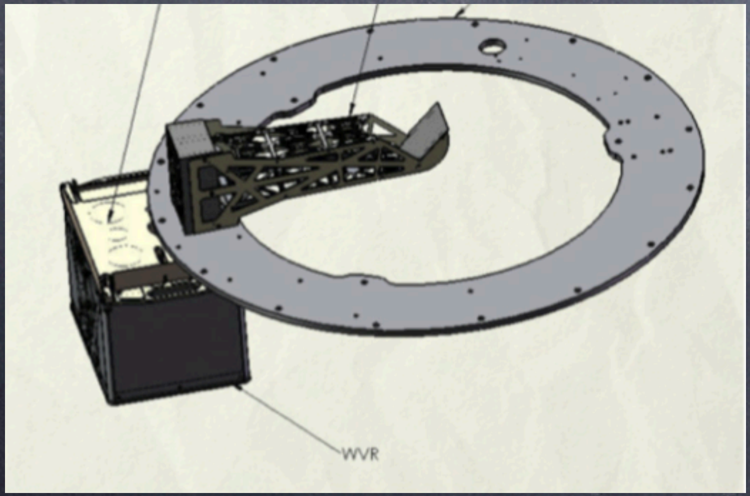


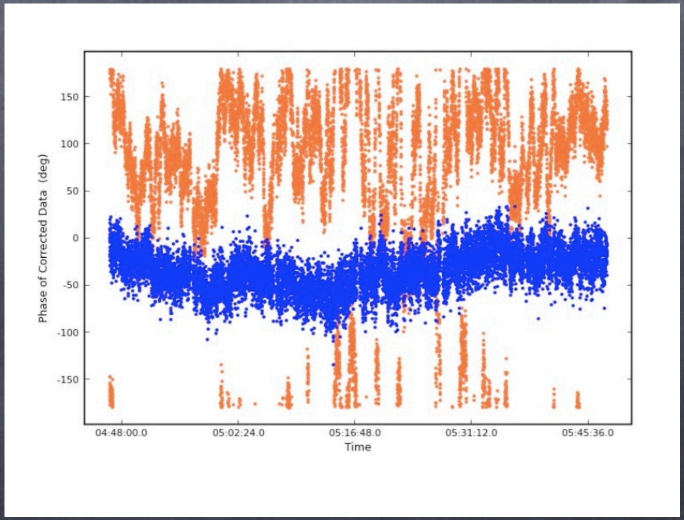

Helium Connections
Auxiliary Valve
Turbo Pump
Vacuum Sensor
Gate Valve
Electronic Subracks(2)
Front End Chassis
Warm Cartridge
Assembly(10)
Coaxial Cables
Apron(10)

Water Vapor Correction







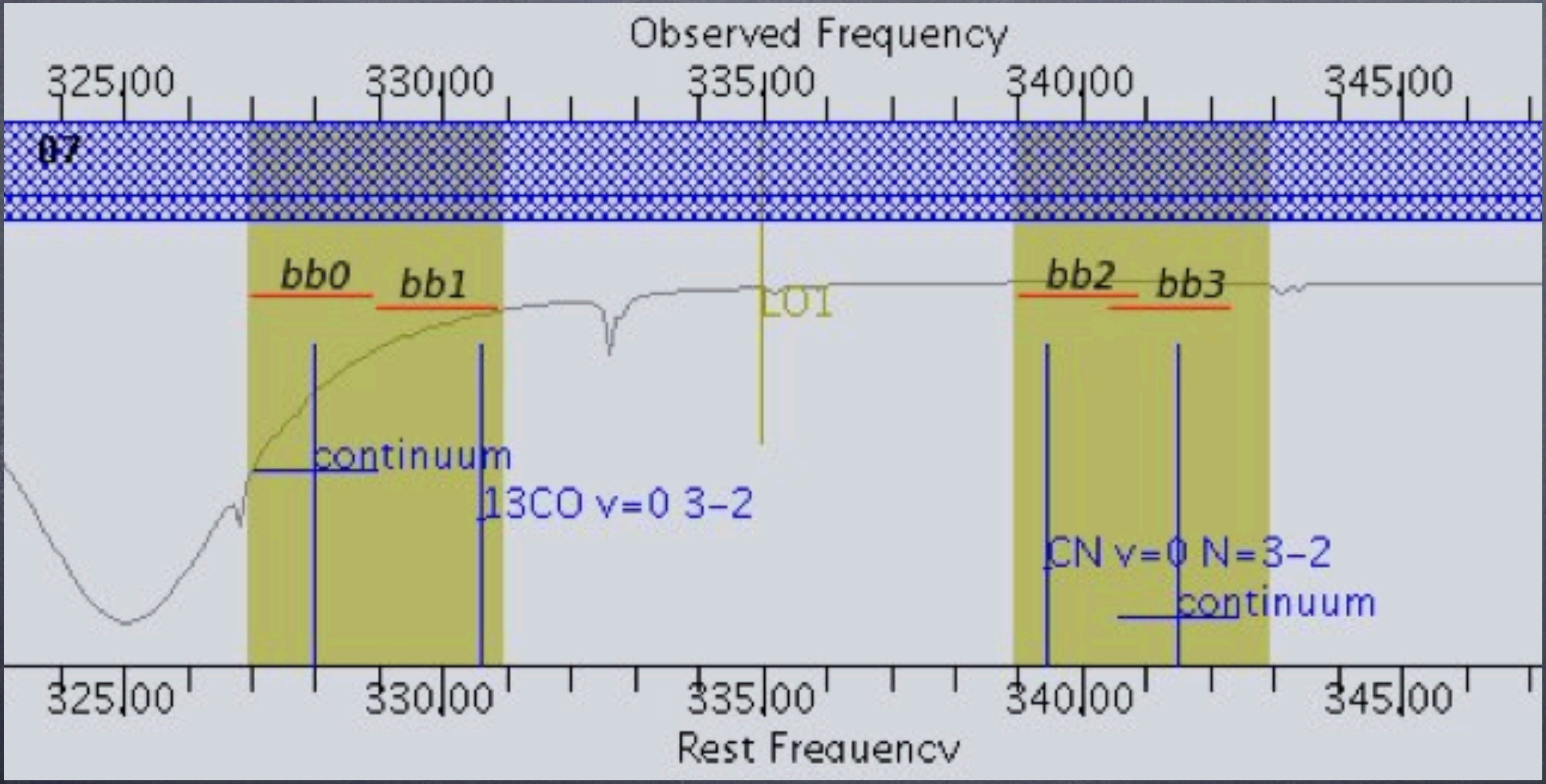


ALMA Correlator

Correlator Setups

Nominal Bandwidth (MHz)	Usable bandwidth (MHz)	Usable channels	Channel spacing (MHz)	Correlator mode
2000	~1875	~120	15.6	TDM
2000	1875	3840	0.488	FDM
1000	938	3840	0.244	FDM
500	469	3840	0.122	FDM
250	234	3840	0.0610	FDM
125	117	3840	0.0305	FDM
62.5	58.6	3840	0.0153	FDM

Spetral Setups



Popular Setups

Band	Species/transition	Frequency	Sideband	bandwidth	spw
3	HCO+ 1-0	89.188	LSB	62.5	1
	HCN 1-0	88.632	LSB	62.5	2
	CH_3OH/H_2CO	101.293/101.333	USB	125	3
	contin	101.3	USB	2 GHz/TDM	4
6	contin	231.6	USB	2 GHz/TDM	1
	^{12}CO 2-1	230.538	USB	125	2
	$C^{18}O$ 2-1	219.560	LSB	250	3
	^{13}CO 2-1	220.399	LSB	125	4
7 (a)	contin	343.800	LSB	2 GHz/TDM	1
	^{12}CO 3-2	345.796	LSB	250	2
	HCO+ 4-3	356.743	USB	500	3
	HCN 4-3	354.505	USB	500	4
7 (b)	^{12}CO 3-2	345.796	USB	62.5	1
	contin	344.8	USB	2 GHz/TDM	2
	^{13}CO 3-2	330.588	LSB	62.5	3
	contin	331.6	LSB	2 GHz/TDM	4
9	^{12}CO 6-5	691.472	USB	500	1
	CS 14-13	685.436	USB	500	2
	H_2S	687.303	USB	500	3
	$C^{17}O$ 6-5	674.009	LSB	500	4

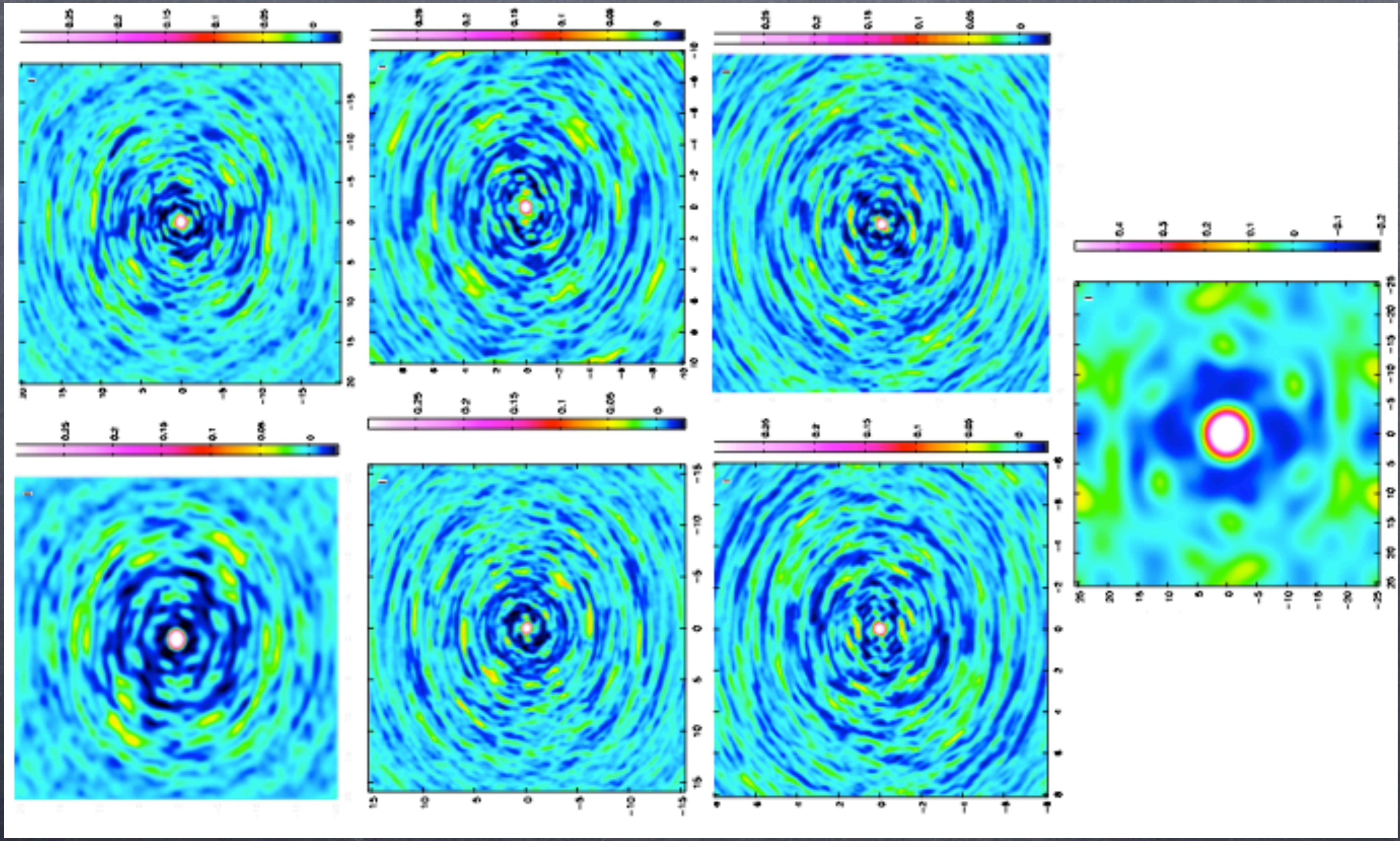
Maximum Angular Scales (MAS)

$$\theta\ (\mathrm{arcsec}) \simeq 1.2 \frac{\lambda}{BL_{max}} = \frac{74200.}{BL_{max}(\mathrm{meter}) \times \nu(\mathrm{GHz})}$$

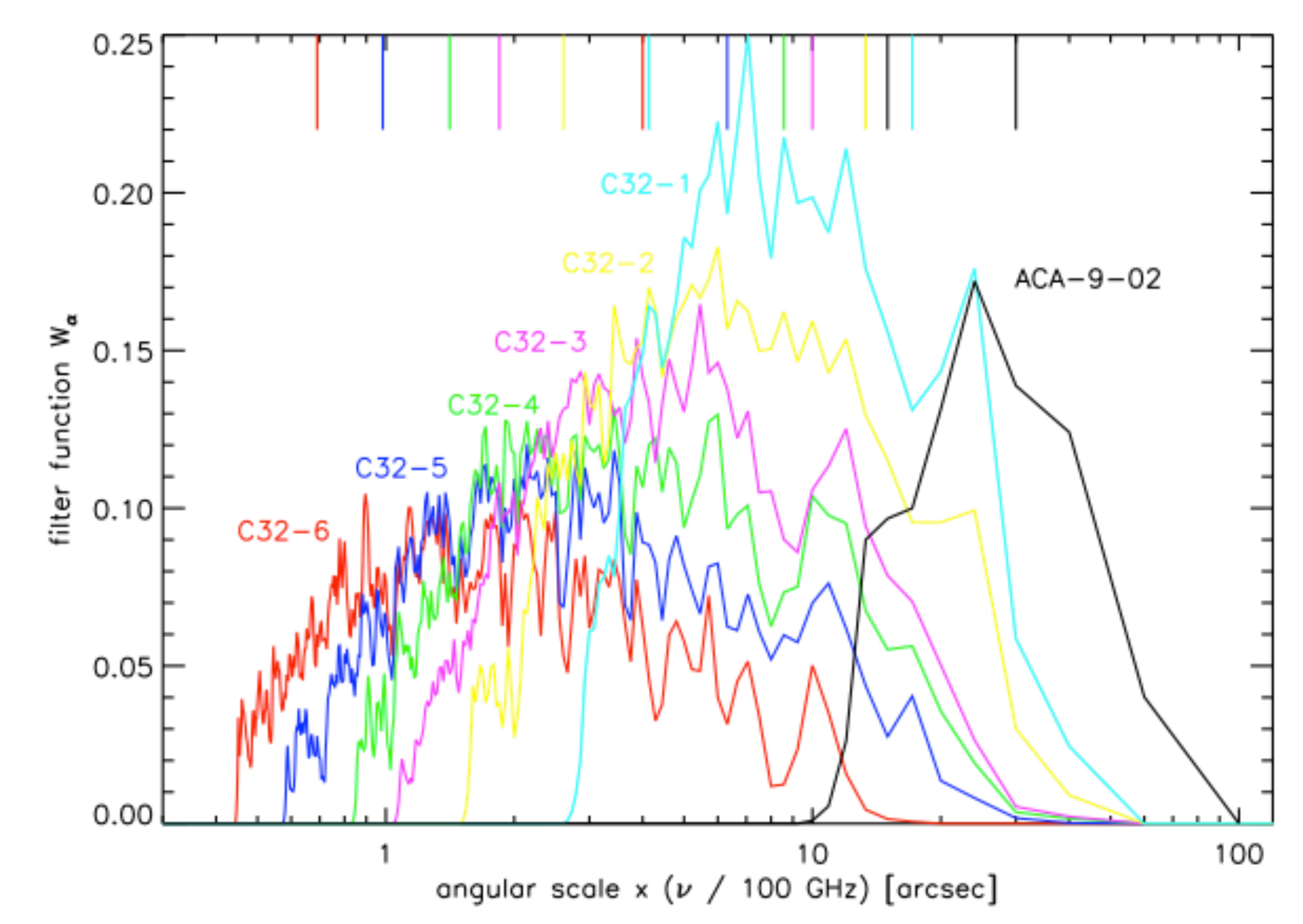
$$\mathrm{MAS}\ (\mathrm{arcsec}) \simeq 0.6 \frac{\lambda}{BL_{min}} = \frac{37100.}{BL_{min}(\mathrm{meter}) \times \nu(\mathrm{GHz})}$$

Band	Freq	C32-1		C32-2		C32-3		C32-4		C32-5		C32-6	
	GHz	AR	MAS	AR	MAS	AR	MAS	AR	MAS	AR	MAS	AR	MAS
3	100	3.7″	25″	2.0″	25″	1.4″	17″	1.1″	17″	0.75″	14″	0.57″	8.6″
6	230	1.6″	11″	0.89″	11″	0.61″	7.6″	0.48″	7.6″	0.33″	6.2″	0.25″	3.7″
7	345	1.1″	7.1″	0.59″	7.1″	0.40″	5.0″	0.32″	5.0″	0.22″	4.1″	0.16″	2.5″
9	675	0.55″	3.6″	0.30″	3.6″	0.21″	2.6″	0.16″	2.6″	0.11″	2.1″	0.08″	1.3″

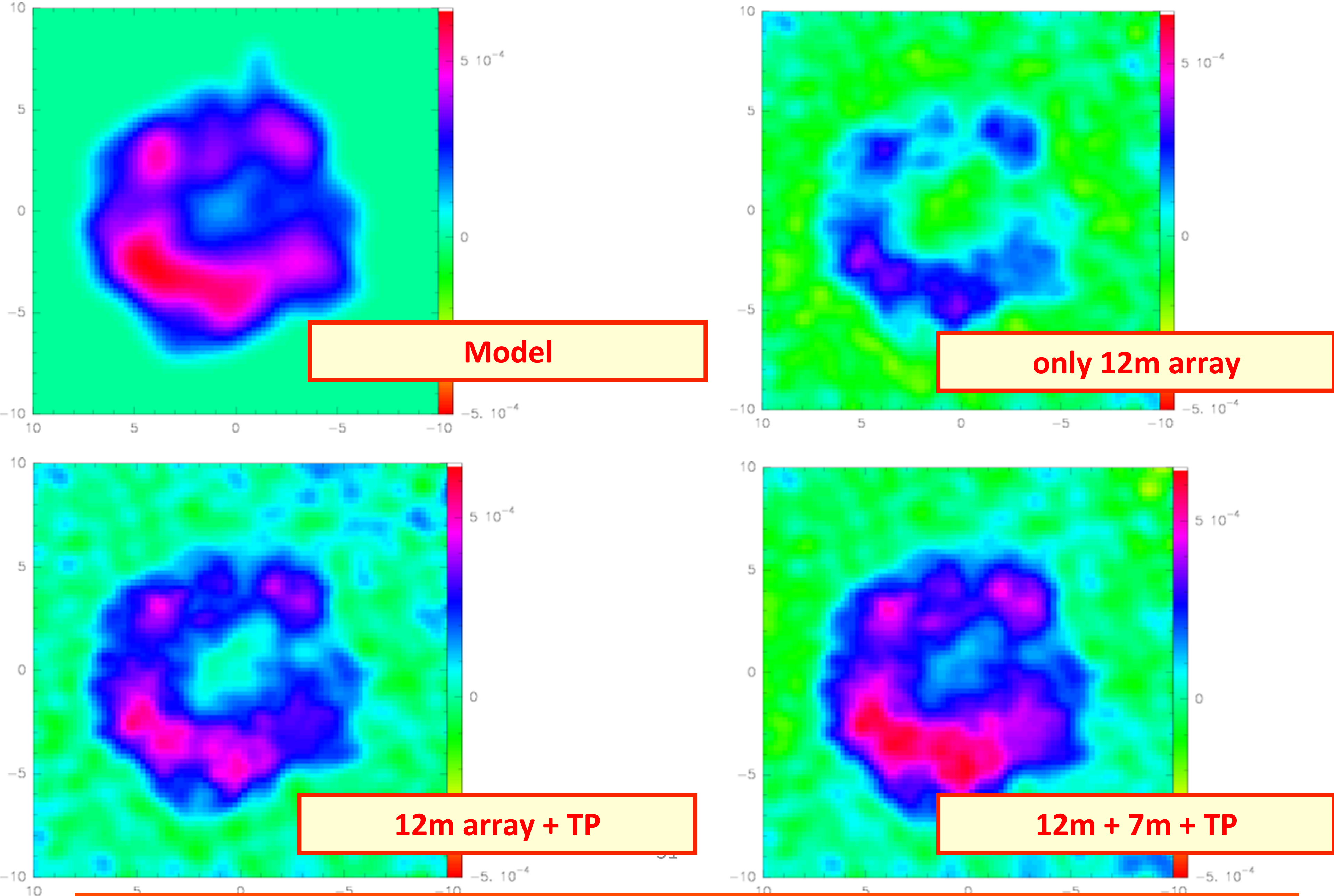
Cycle 1 Synthesised Beams



Filter Functions



ACA-Simulations: Debris Disk



ALMA Sensitivities

$$\sigma_S = \frac{2\,k\,T_{sys}}{\eta_q \eta_c A_{eff} \sqrt{N(N-1)\,n_p\,\Delta\nu\,t_{int}}}. \qquad (8.5)$$

The various symbols are

- A_{eff} – effective area. This is equal to the geometrical area of the antenna multiplied by the aperture efficiency (η_{ap}). The latter is given by the Ruze formula i.e. $\eta_{ap} = R_0 \exp(-16\,\pi^2\sigma^2/\lambda^2)$ where σ is the rms surface accuracy of the antenna – the specification of 25 μm and 20 μm for the 12-m and 7-m antennas respectively is currently used[3]. R_o is equal to 0.72. See Table 8.3 for values of antenna efficiencies and effective areas in various ALMA bands
- η_q – quantization efficiency. A fundamental limit on the achievable sensitivity is set by the initial 3-bit digitization of the baseband signals. This is equal to 0.96
- η_c – correlator efficiency. Although this depends on the correlator (64-input or ACA) and correlator mode, this is currently fixed at 0.88. For the 12-m Array at Cycle 1, this is fine as all the available modes during Cycle 1 will have this efficiency. For the ACA, the efficiency *will* depend on the mode, but as the ASC is currently not mode-aware, the same factor of 0.88 has been assumed for the time being[4]
- N – number of antennas. This defaults to 32 for the 12-m and nine for the 7-m Array
- n_p – number of polarizations. $n_p = 1$ for single polarization and $n_p = 2$ for dual and full polarization observations

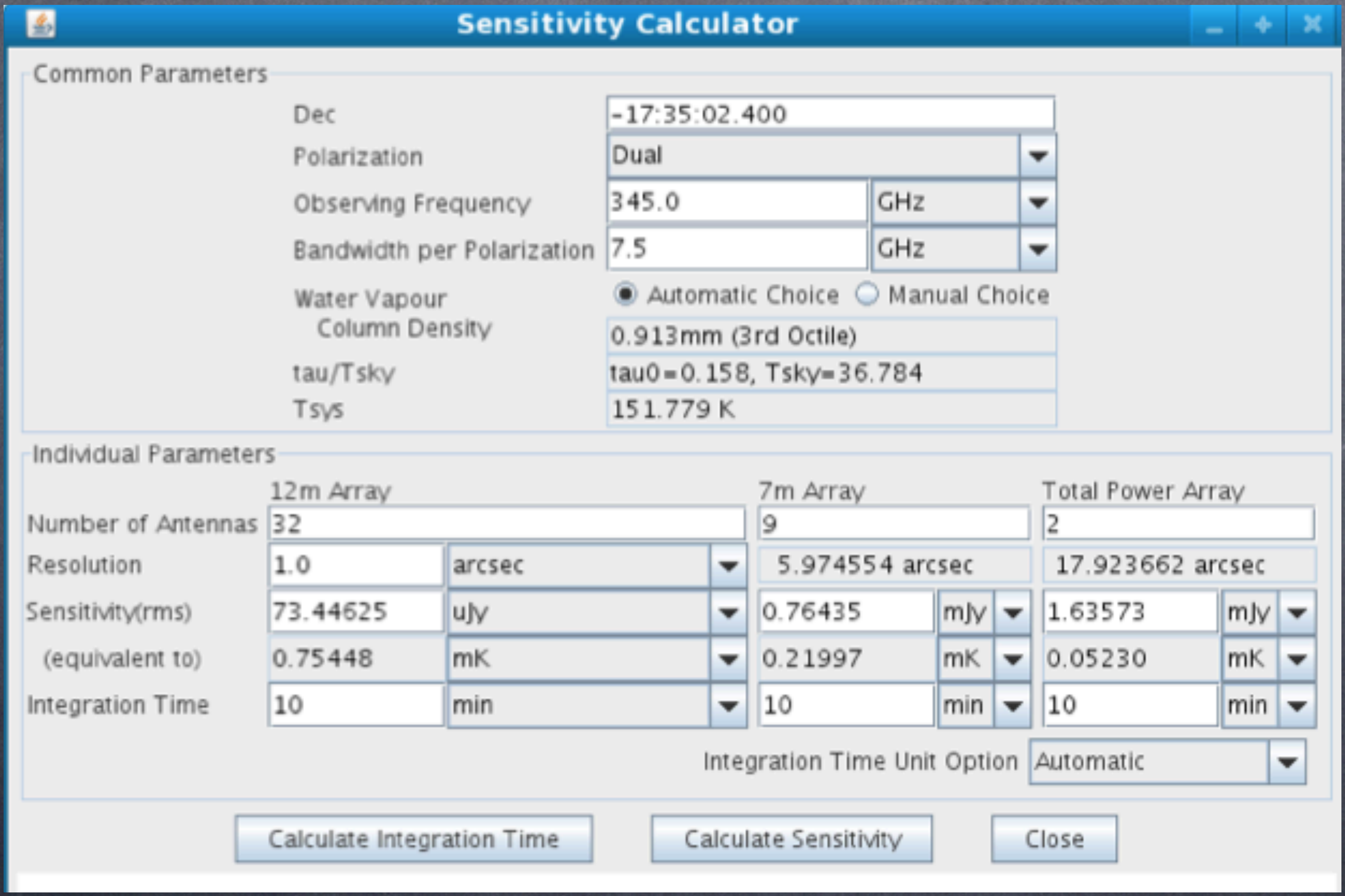
ALMA Tsys

$$T_{\rm sys} = \frac{1+g}{\eta_{\rm eff} e^{-\tau_0 \sec z}} \left(T_{\rm rx} + \eta_{\rm eff} T_{\rm sky} + (1-\eta_{\rm eff}) T_{\rm amb} \right) \quad (8.1)$$

The various terms are

- $T_{\rm rx}$ – receiver temperature
- $T_{\rm sky}$ – sky temperature
- $T_{\rm amb}$ – ambient temperature (ground spillover)
- g – sideband gain ratio. For bands 1 and 2 (Single Sideband; SSB) and 3-8 (Sideband Separating; 2SB), $g = 0$. For these bands there is no contribution to the system temperature as the image sideband is either filtered out (SSB) or separated in the receiver (2SB). Bands 9 and 10 are Double Sideband (DSB) receivers and the correlated signal includes noise from both sidebands; therefore $g = 1$
- $\eta_{\rm eff}$ – the coupling factor, or forward efficiency. This is equal to the fraction of the antenna power pattern that is contained within the main beam and is currently fixed at 0.95
- $e^{-\tau_0 \sec z}$ – the fractional transmission of the atmosphere, where τ_0 is equal to the zenith atmospheric opacity and $\sec z$ is the airmass at transit i.e. zenith angle (z) equals zero degrees.

ALMA Sensitivity Calculator



ALMA Science Data Model

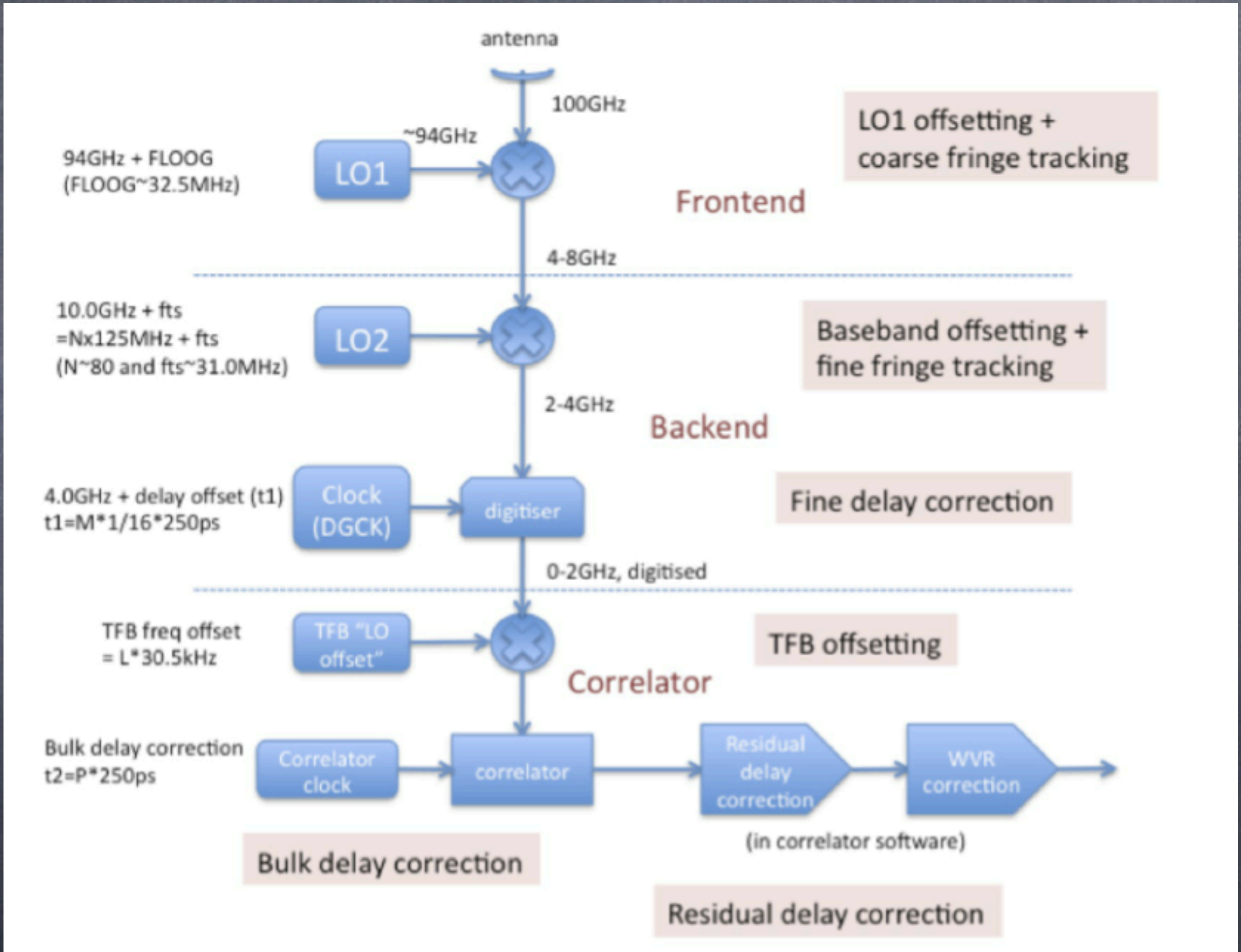
SDM Tables		
Referenced:		
Main		
Antenna	Field	SpectralWindow
ConfigDescription	Pointing	State
DataDescription	PointingModel	Station
ExecBlock	Receiver	Subscan
Feed	Scan	SwitchCycle
Not referenced:		
AlmaRadiometer	Focus	SBSummary
Annotation	FocusModel	Source
CalDevice	FreqOffset	SourceParameter
DelayModel	GainTracking	SpaceCraftOrbit
Doppler	Holography	SysCal
Ephemeris	Polarization *(required in MS)*	WVMCal
Sometimes referenced:		
Beam	required for single dish or mosaicked data	
CorrelatorMode	required for correlators; not allowed for others	
SquareLawDetector	required for total power or noise detectors; not allowed for others	

ALMA Calibration

- Long-Term: All-sky Pointing (including Band relative offsets), Baseline Vectors, Cable Delay, Focus Models, Antenna Characteristics

- Short-Term: Offset Pointing, Bandpass, Phase fluctuations (WVR), Gain (Amplitude & Phase), Flux, Receiver Temperature, System Temperature, Sideband Ratio and Absolute Flux Calibration

Downconversion and Fringe Tracking



Disk Studies with ALMA

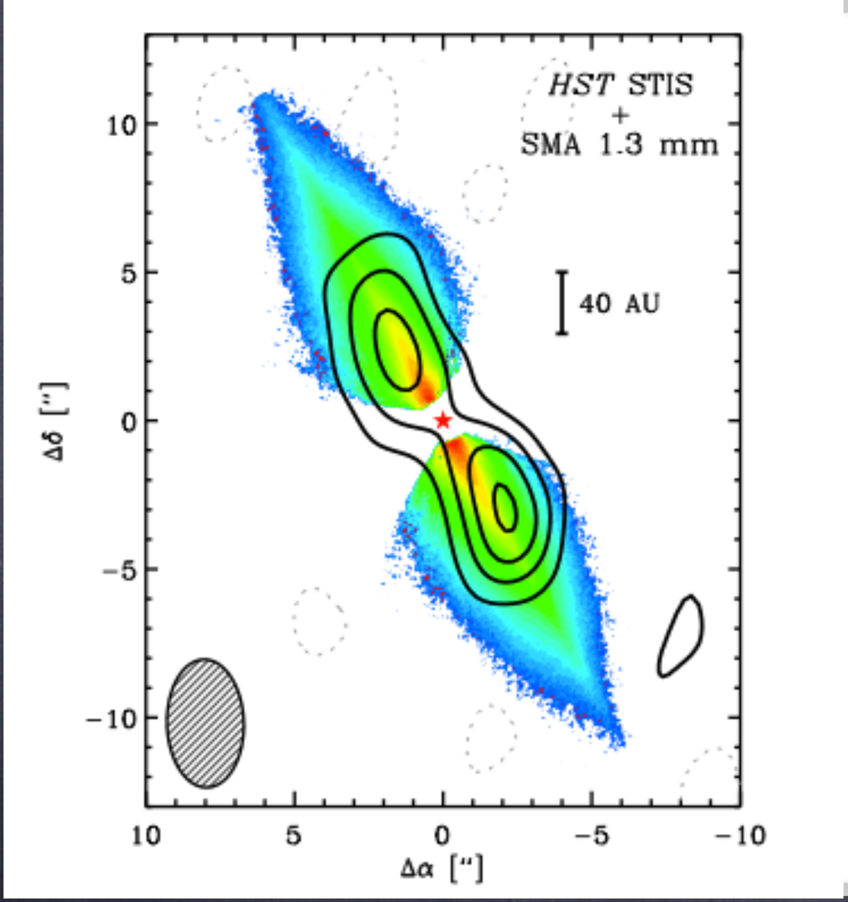
- ALMA Science Goal
- Cycle 0 results

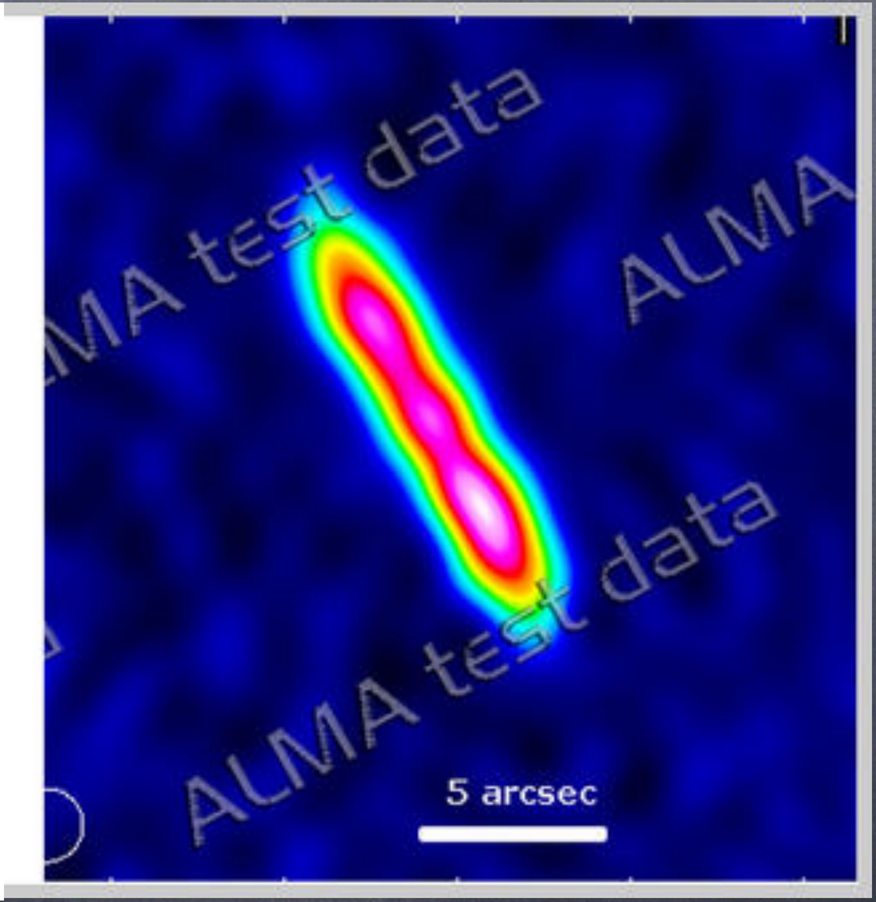
1. Image the redshifted dust continuum emission from evolving galaxies at epochs of formation as early as z=10;
2. Trace through molecular and atomic spectroscopic observations the chemical composition of star-forming gas in galaxies throughout the history of the Universe;
3. Reveal the kinematics of obscured galactic nuclei and Quasi-Stellar Objects on spatial scales smaller than 300 light years [SCI-90.00.00.00-00380-00];

Image gas rich, heavily obscured regions that are spawning protostars, protoplanets and pre-planetary disks;

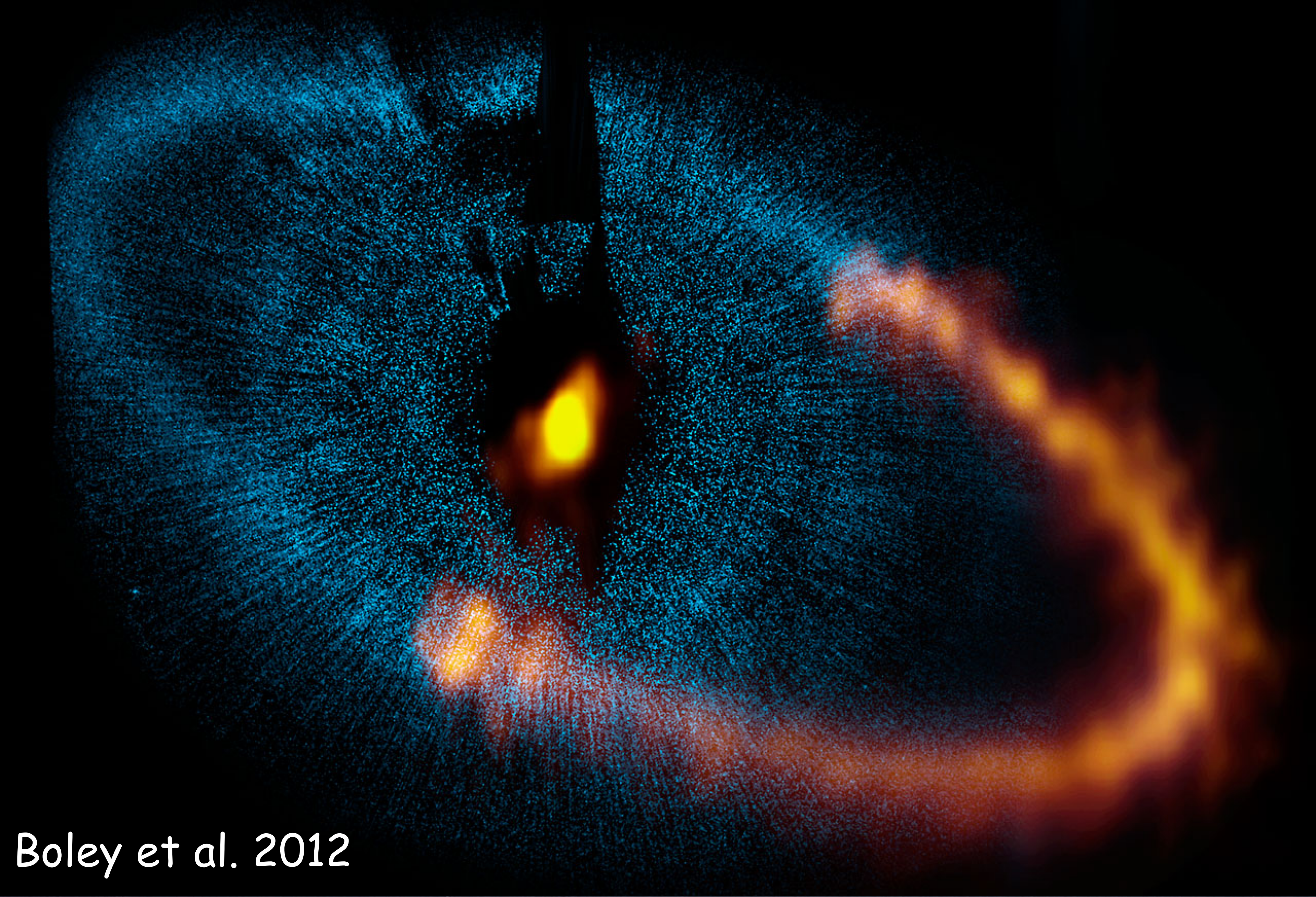
5. Reveal the crucial isotopic and chemical gradients within circumstellar shells that reflect the chronology of invisible stellar nuclear processing;

Science Verificaton : Beta Pict

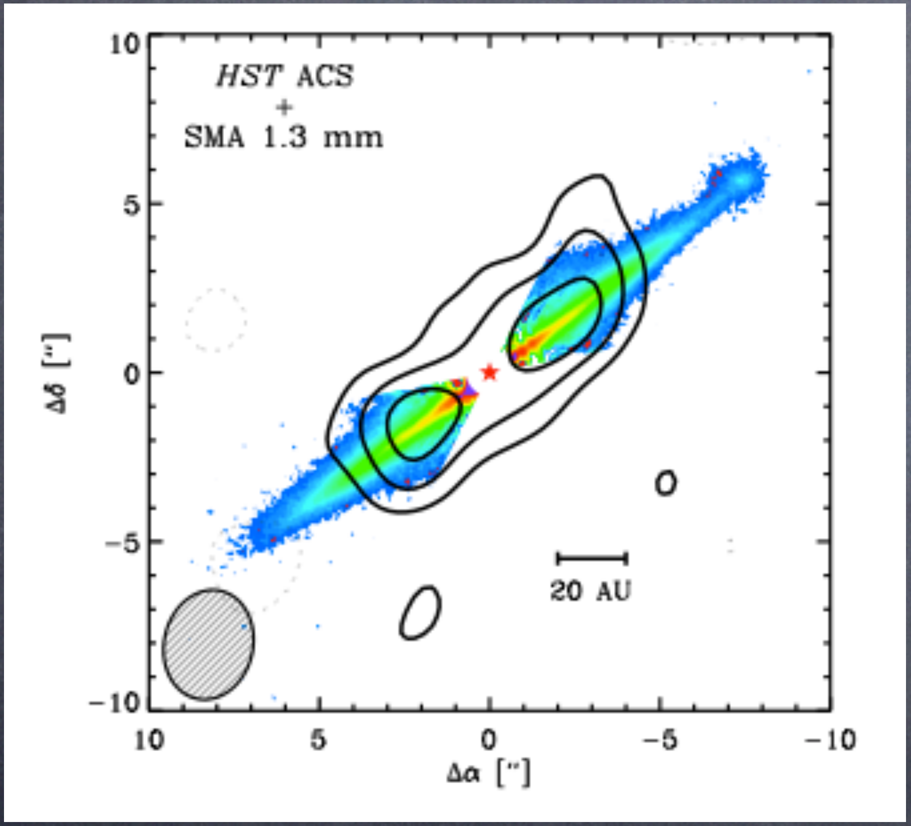




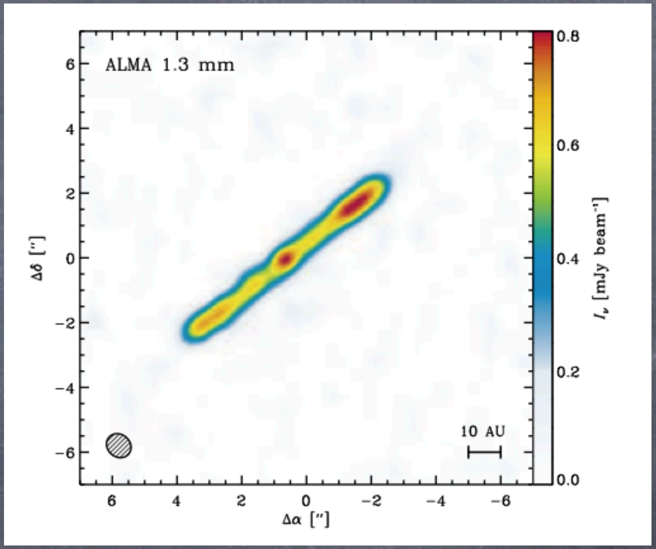
Wilner et al 2011 -SMA


Boley et al. 2012

AU Mic Debris disk

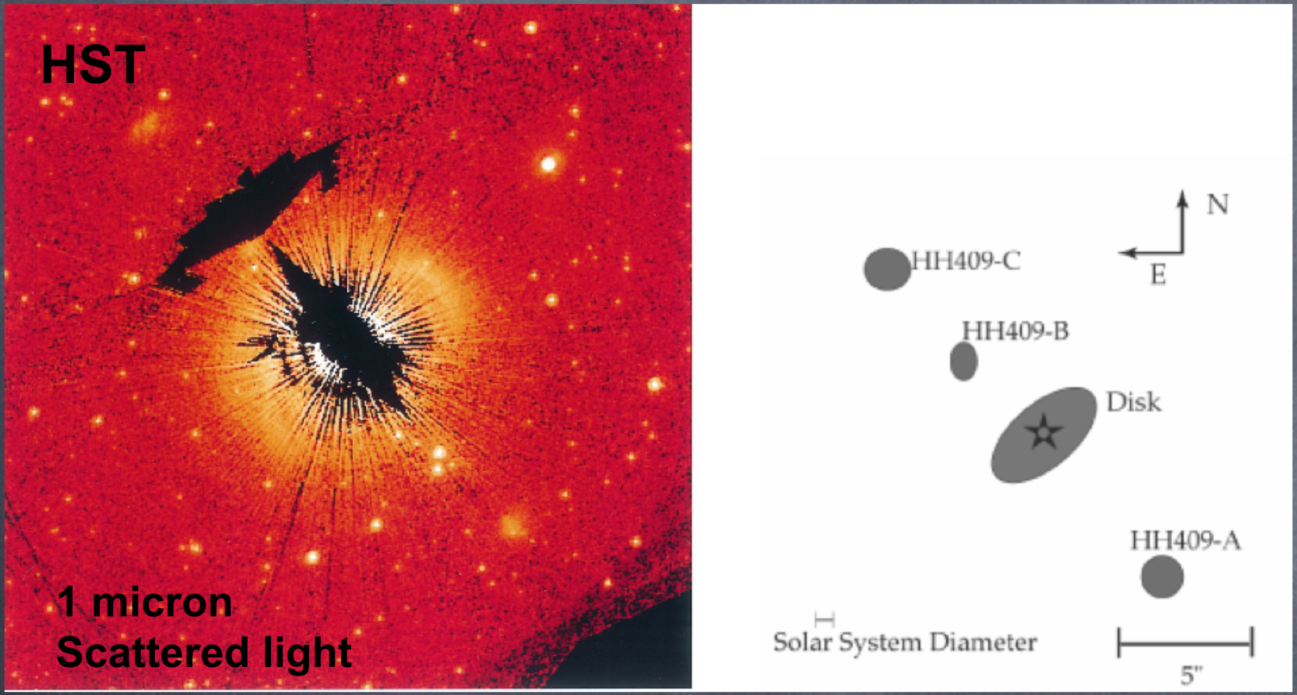


Wilner et al 2012 -SMA

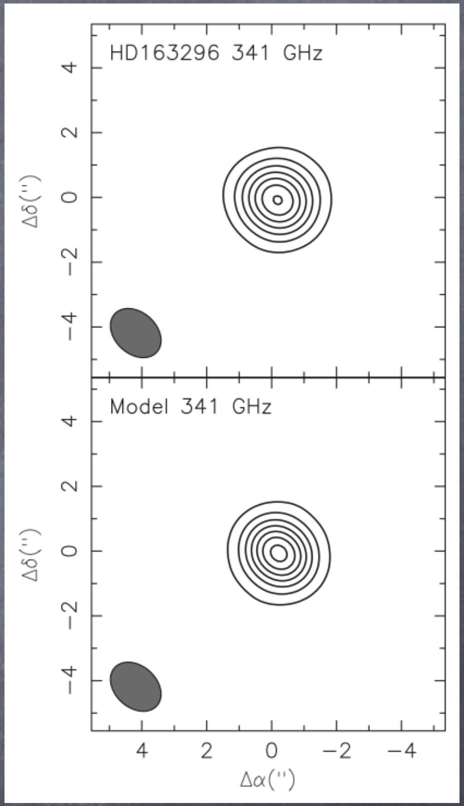


MacGregor et al 2012

HD163296 previous works: dust



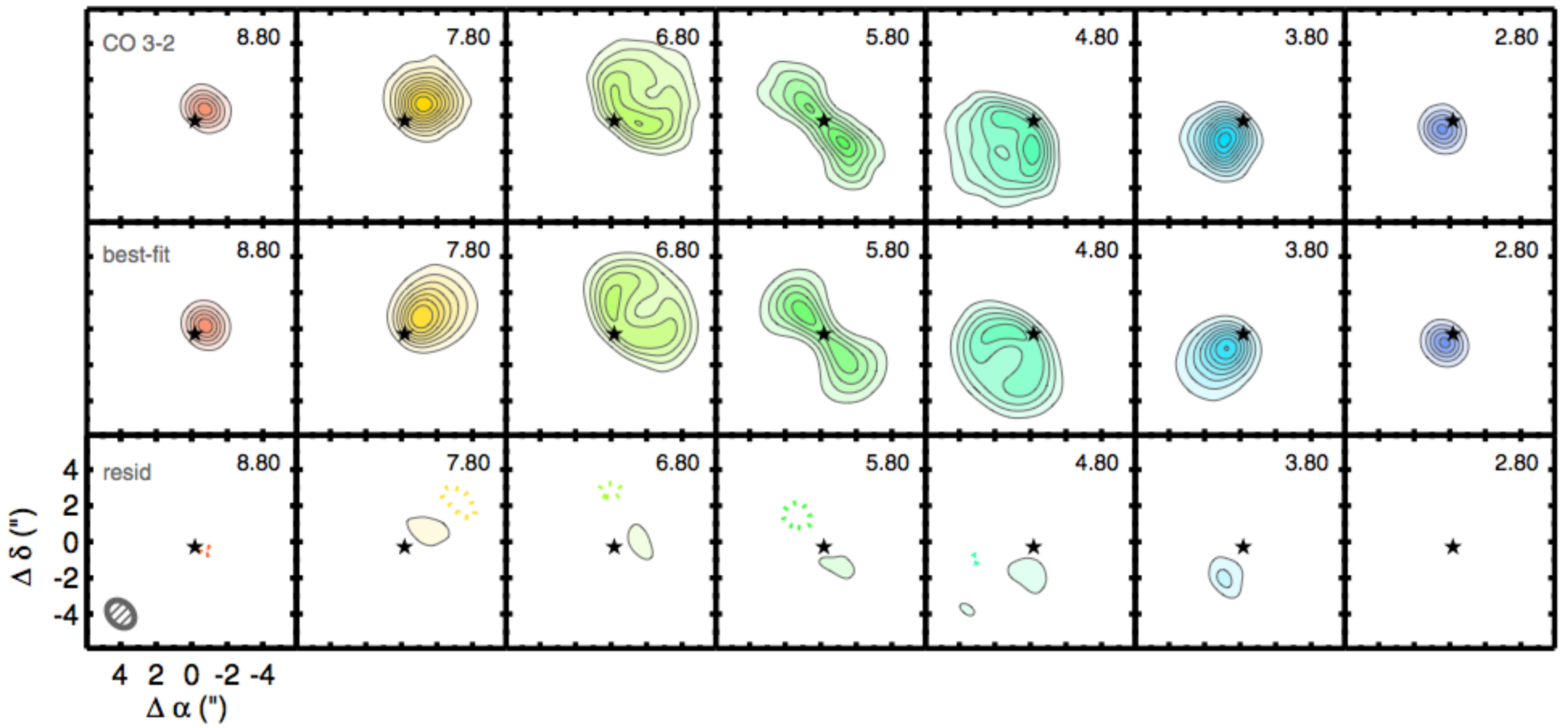
Grady et al. 2000



SMA; Qi et al. 2012

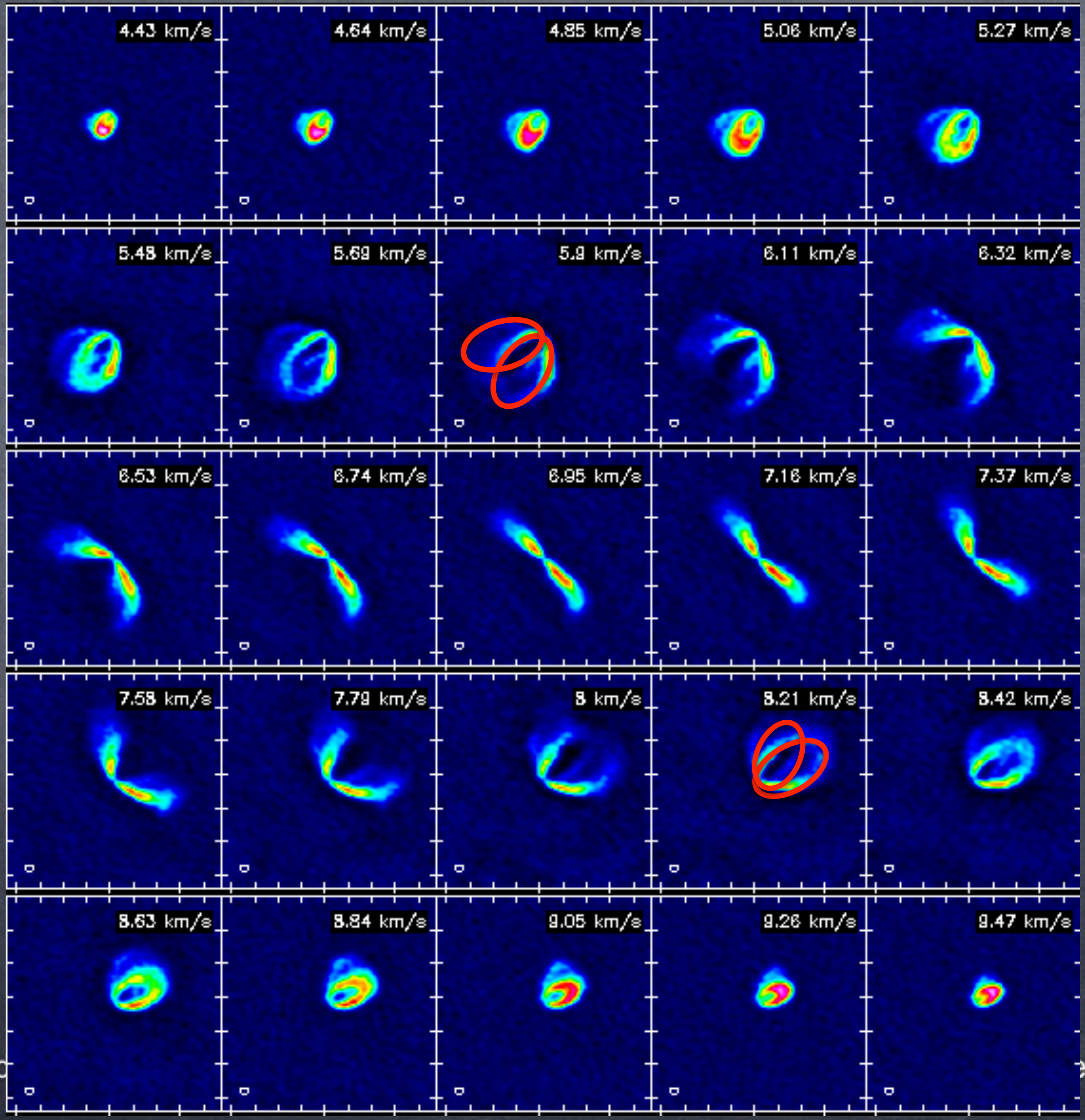
The first year of ALMA Science, (Puerto Varas, Chile 2012)

HD163296 previous works: gas



CO(3-2) SMA data; Qi et al. 2012

HD163296 with ALMA: CO(3-2) gas structure



HD163296 model for the continuum

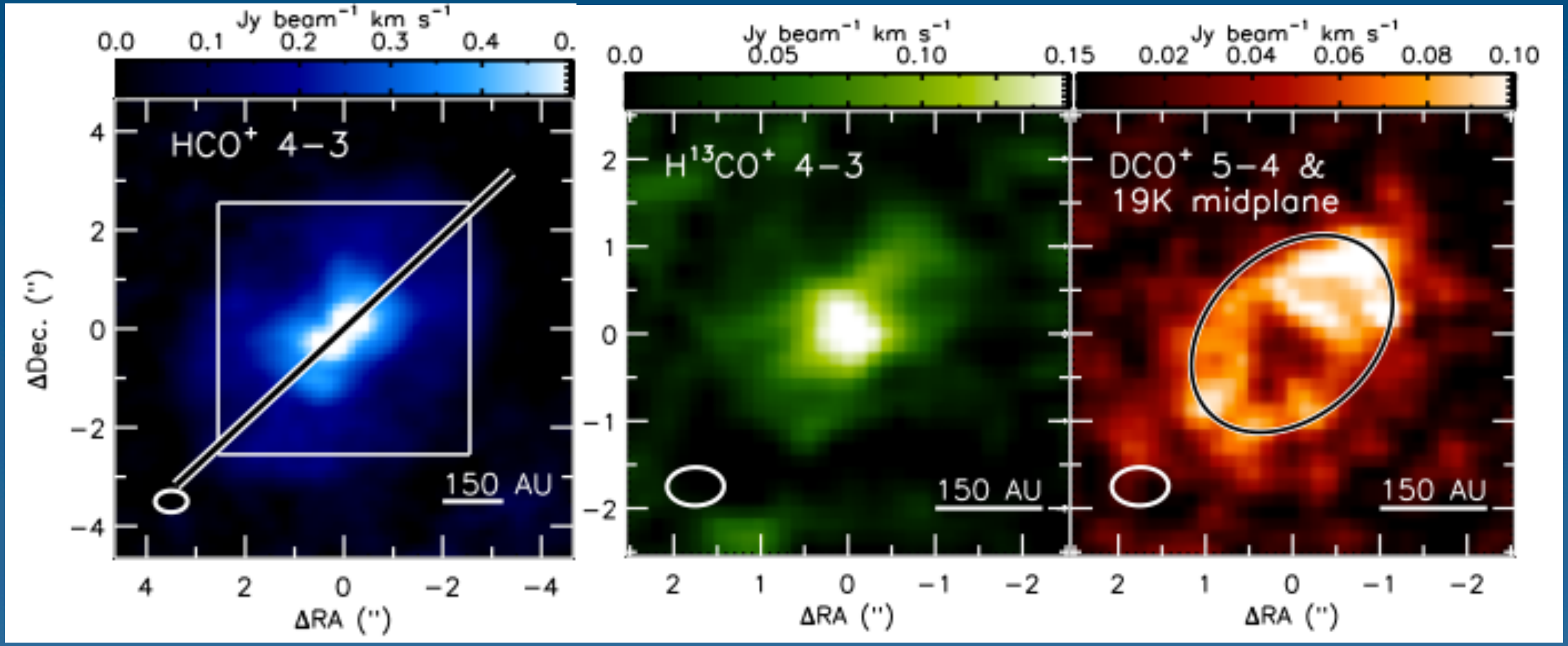
MCFOST models (Pinte et al. 2006, Tilling et al. 2011)

Tapered-edge density profile:

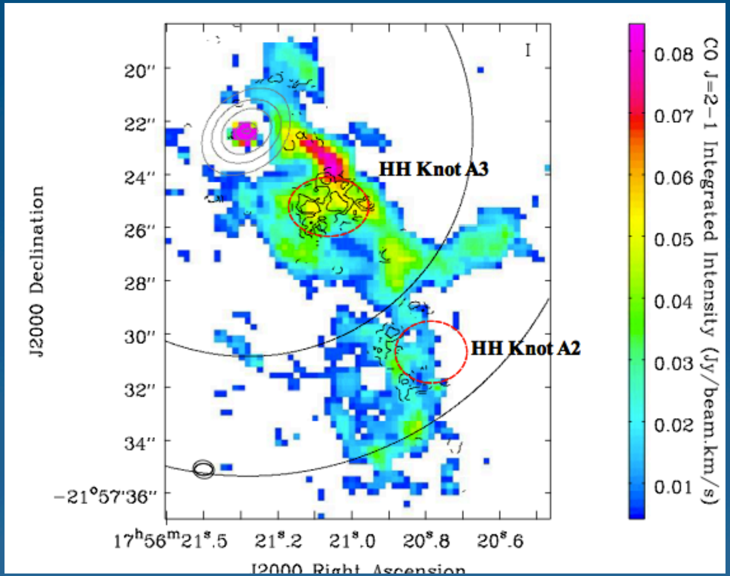
$$\Sigma_{acc}(R) = \Sigma_C \left(\frac{R}{R_C}\right)^{-\gamma} \exp\left[-\left(\frac{R}{R_C}\right)^{2-\gamma}\right],$$

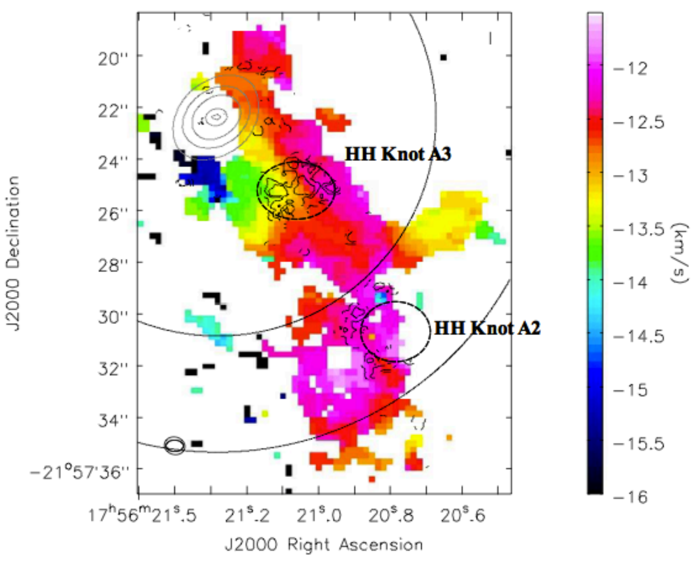
- γ parameter controls the radial variation of the surface density
- Naturally accounts for discrepancy observed between smaller continuum disk sizes and much larger CO gas disk sizes.

The first year of ALMA Science, (Puerto Varas, Chile 2012)

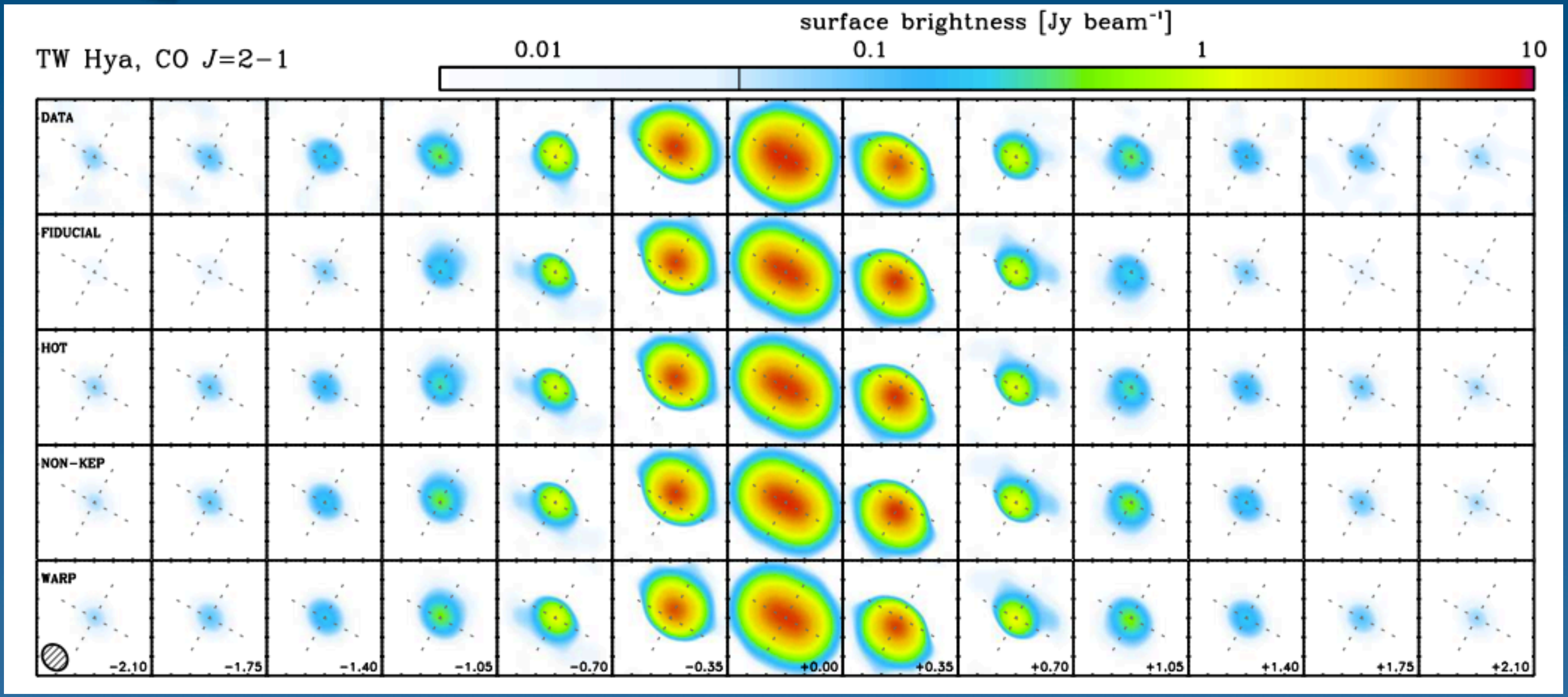


Matthews et al, *submitted*

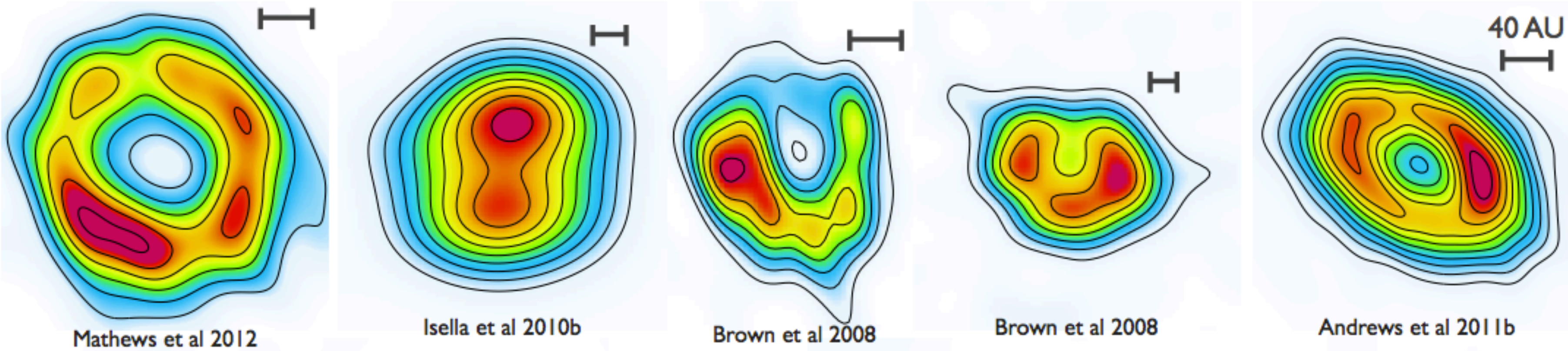




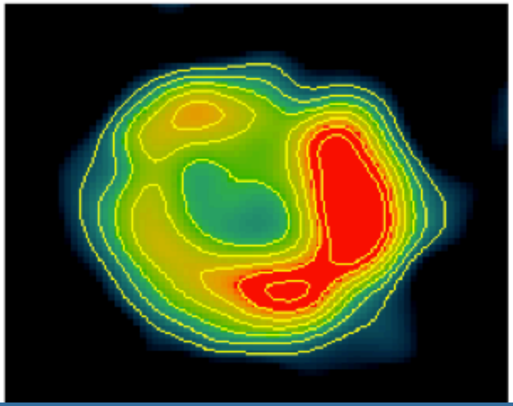
Klaassen et al, *submitted*

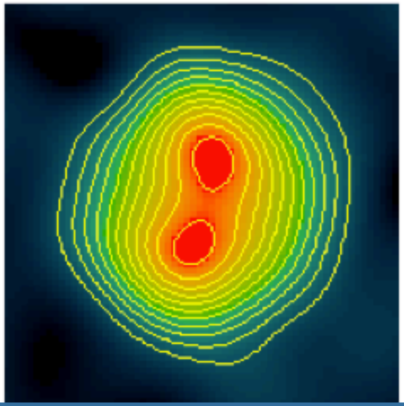

TW Hya, CO J=2−1
surface brightness [Jy beam^{-1}]
0.01
0.1
1
10
DATA
FIDUCIAL
HOT
NON−KEP
WARP
−2.10
−1.75
−1.40
−1.05
−0.70
−0.35
+0.00
+0.35
+0.70
+1.05
+1.40
+1.75
+2.10

Millimeter-wave Observations reveal cavities in Transitional Disks



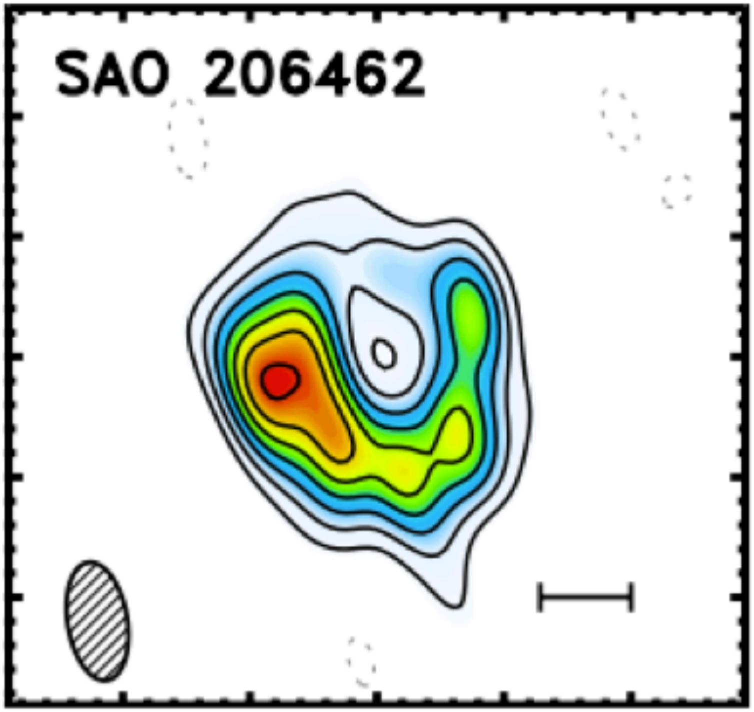
LkHa 330



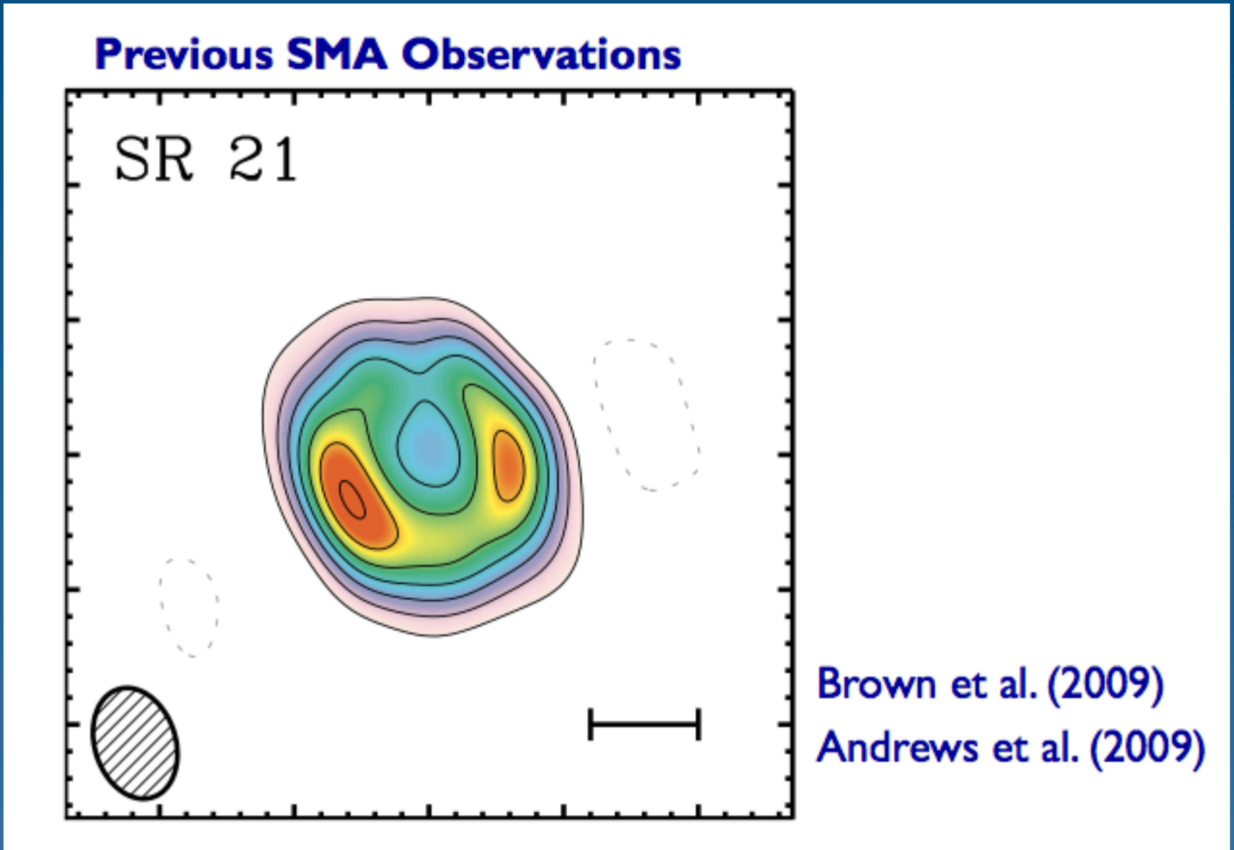


UX Tau

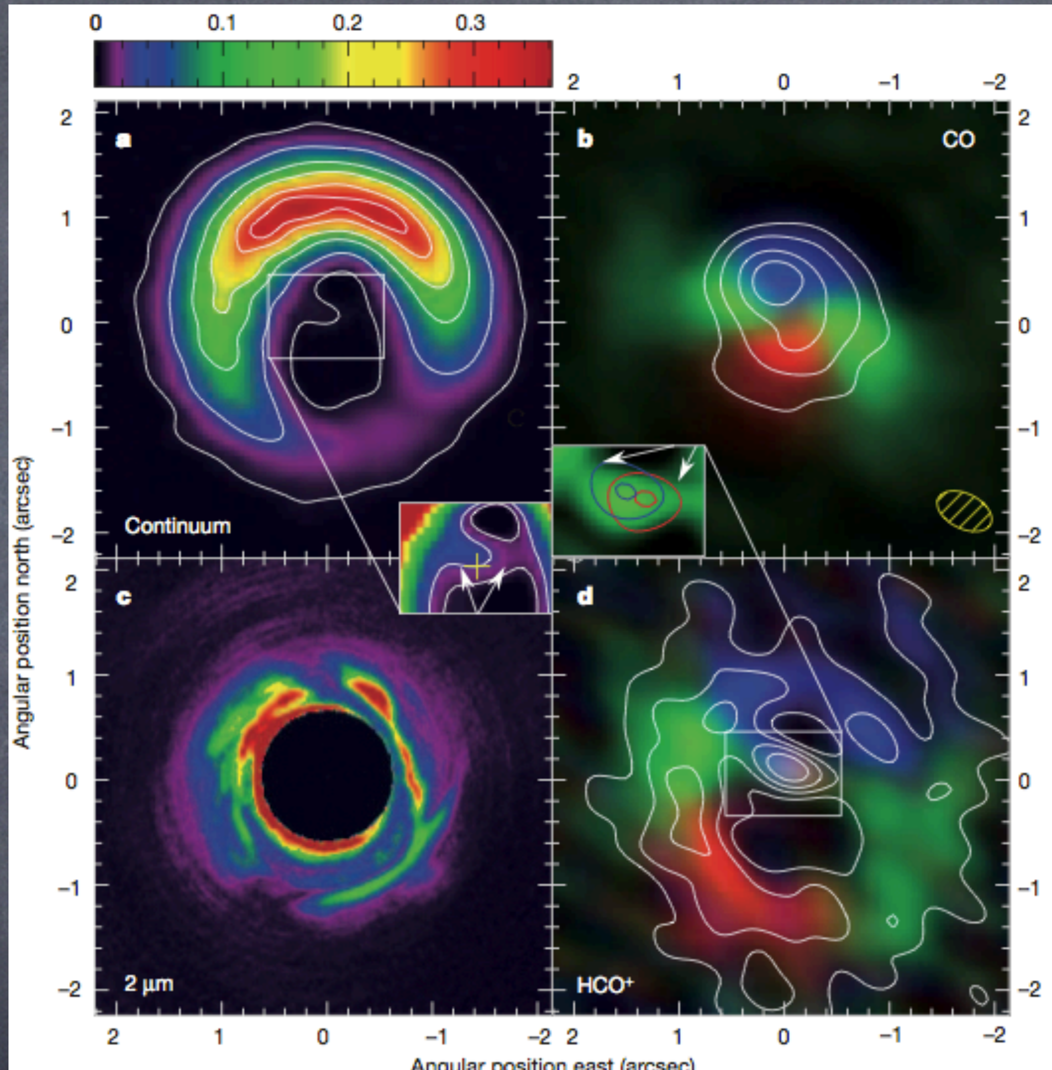
Previous SMA Observations



Brown et al. (2009)
Andrews et al. (2011)



Cycle 1 project to trace different CO isotopes



Casassus et al 2013, Nature

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- Visionary scientists and engineers,
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- And steady funding

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