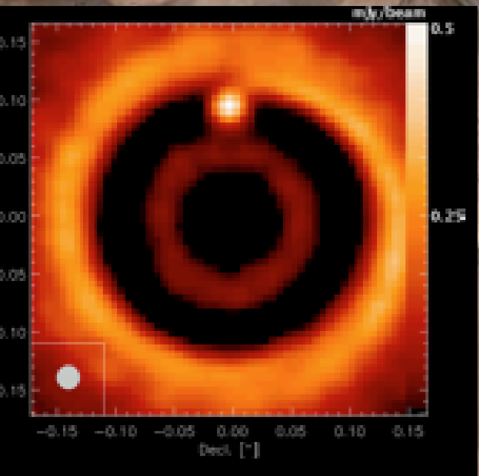
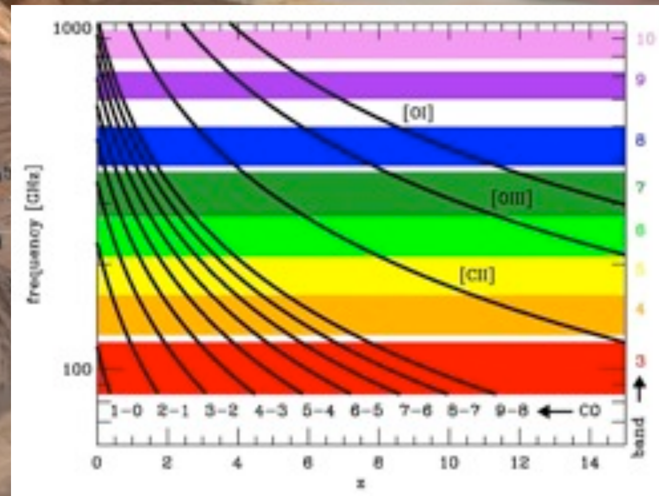
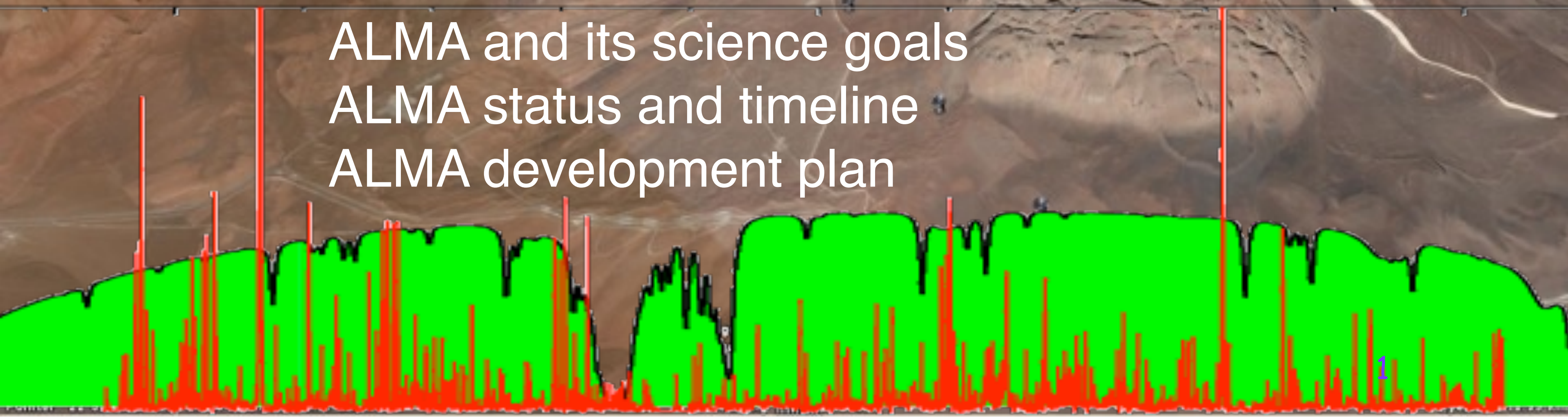
The ALMA Project

Leonardo Testi
ESO

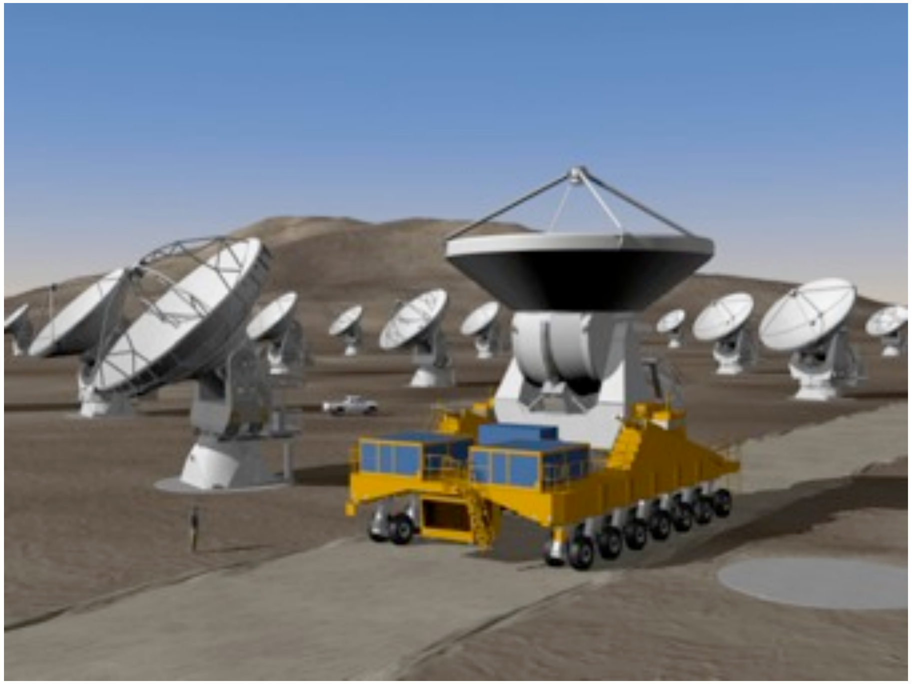




ALMA and its science goals
ALMA status and timeline
ALMA development plan



Atacama Large Millimeter Array



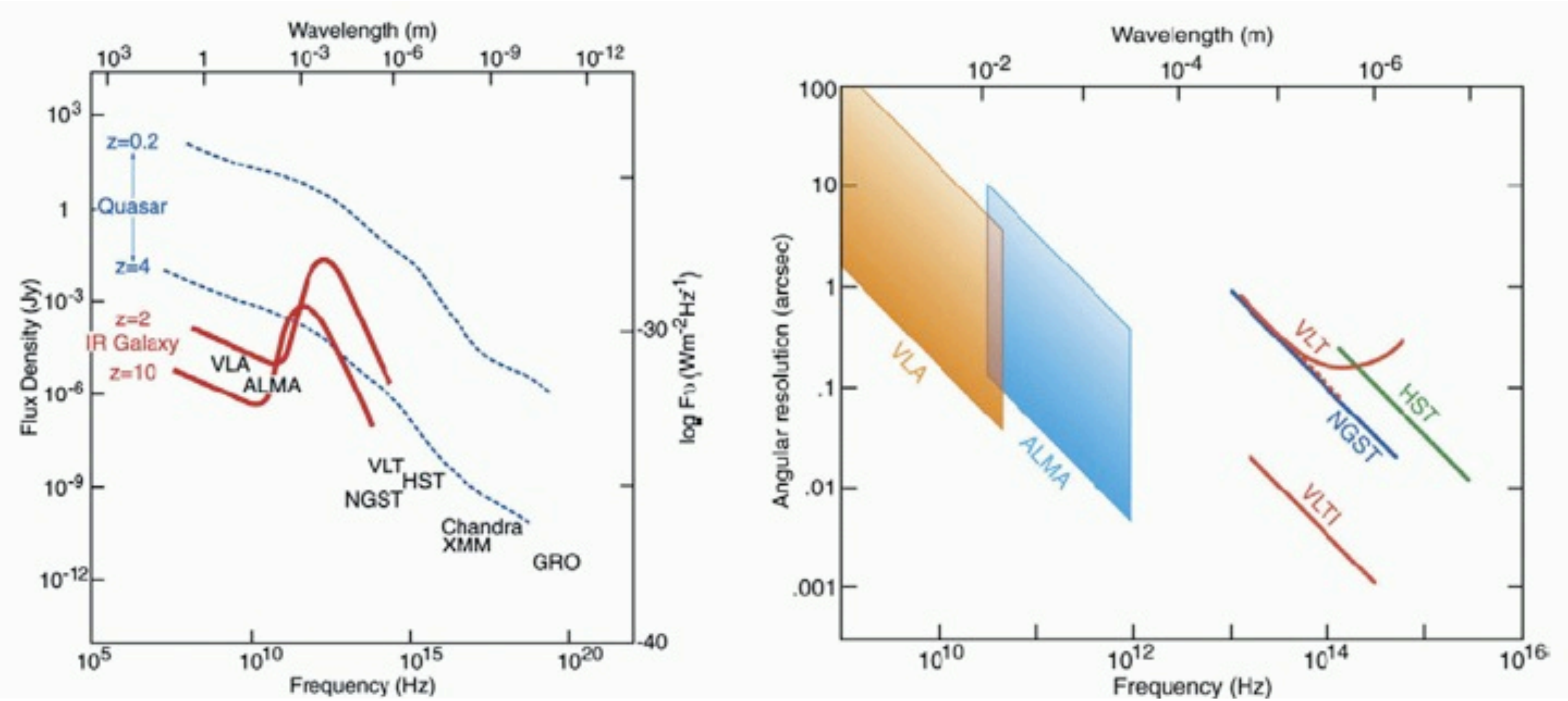
- At least 50x12m Antennas
- Frequency range 30-1000 GHz (0.3-10mm)
- 16km max baseline (<10mas)
- ALMA Compact Array (4x12m and 12x7m)

1. **Detect and map CO and [C II] in a Milky Way galaxy at z=3 in less than 24 hours of observation**
2. **Map dust emission and gas kinematics in protoplanetary disks**
3. **Provide high fidelity imaging in the (sub)millimeter at 0.1 arcsec resolution**

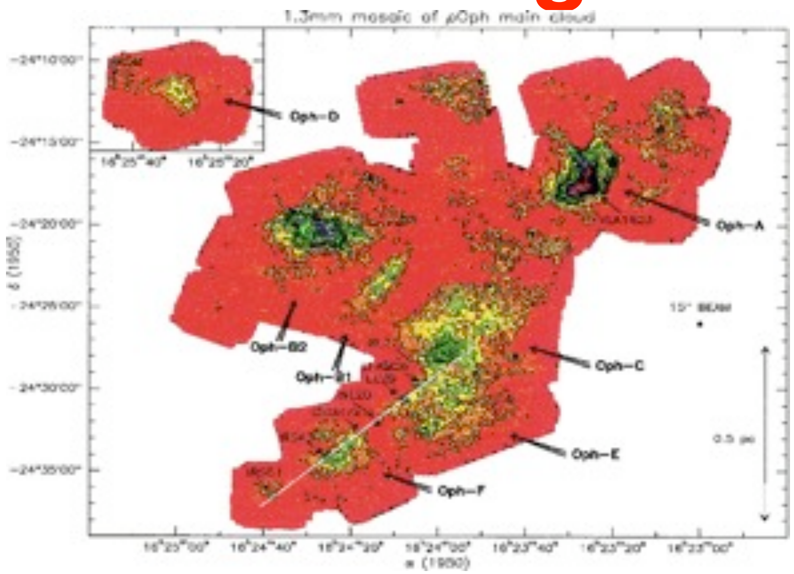
ALMA Science Requirements

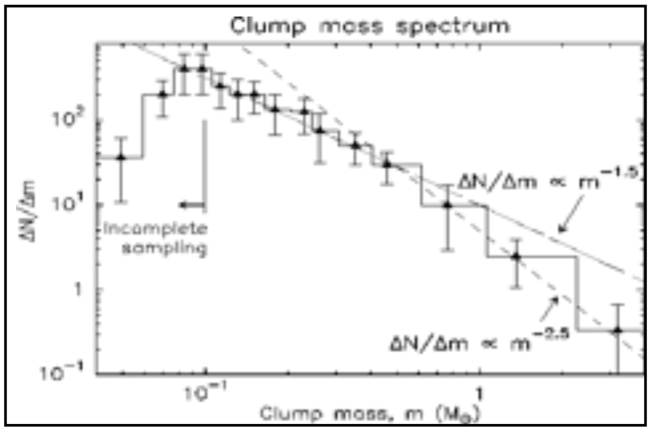
- High Fidelity Imaging.
- Precise Imaging at 0.1” Resolution.
- Routine sub-mJy Continuum Sensitivity.
- Routine mK Spectral Sensitivity.
- Wideband Frequency Coverage.
- Wide Field Imaging Mosaicing.
- Submillimeter Receiver System.
- Full Polarization Capability.
- System Flexibility.

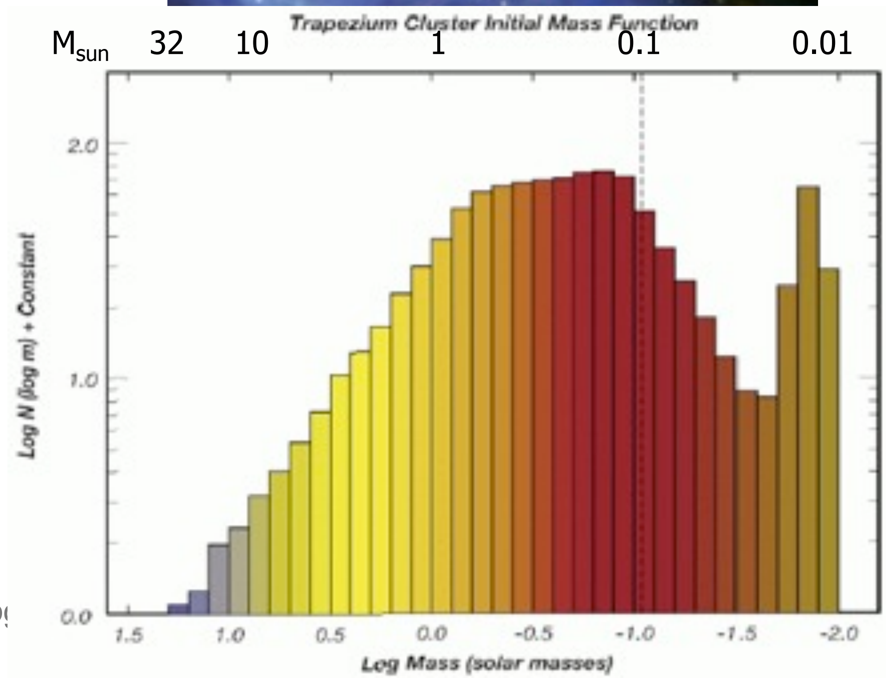
Sensitivity and Resolution



The origin of the stellar IMF

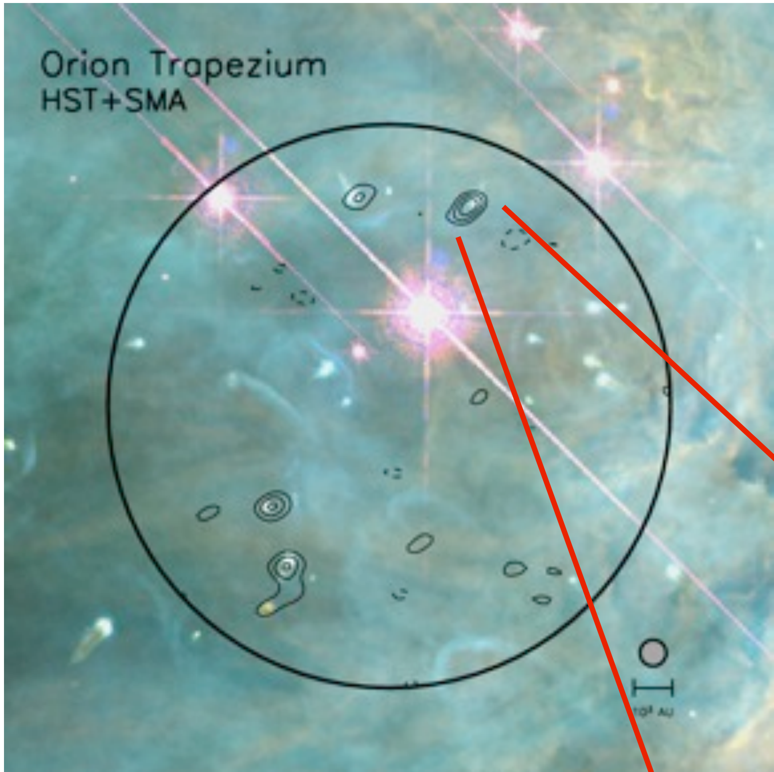






- Clumps MF resembles stellar IMF in local SFRs

Birth of Planets

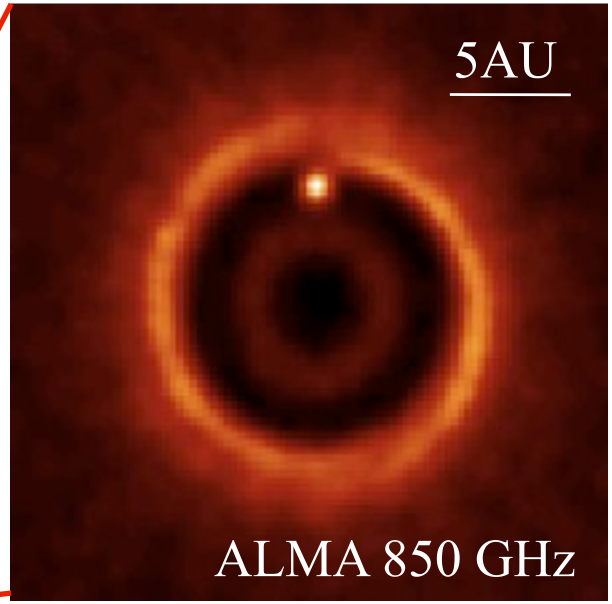


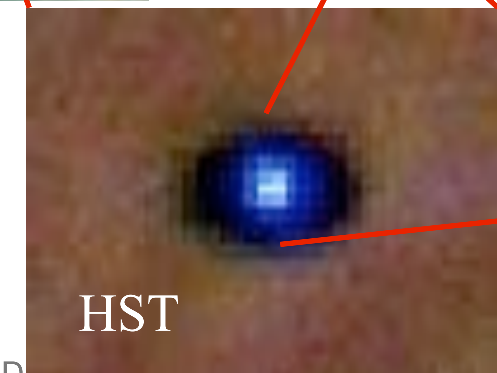
$M_{planet} = M_{Jup}$

$M_{star} = 0.5\ M_{sun}$

Orbiting at 5AU

Distance 50pc





ISM Molecules

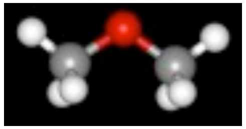
H_2	HD	H_3+	H_2D+					
CH	CH^+	C_2	CH_2	C_2H	*C_3			
CH_3	C_2H_2	C_3H(lin)	c-C_3H	*CH_4	C_4			
c-C_3H_2	H_2CCC(lin)		C_4H	*C_5	*C_2H_4	C_5H		
H_2C_4(lin)	*HC_4H	CH_3C_2H	C_6H	*HC_6H	H_2C_6			
*C_7H	CH_3C_4H	C_8H	*C_6H_6					
OH	CO	CO+	H_2O	HCO	HCO+			
HOC+	C_2O	CO_2	H_3O+	HOCO+	H_2CO			
C_3O	CH_2CO	HCOOH	H_2COH+	CH_3OH	CH_2CHO			
CH_2CHOH		CH_2CHCHO		HC_2CHO	C_5O	CH_3CHO	c-C_2H_4O	
CH_3OCHO	CH_2OHCHO		CH_3COOH	CH_3OCH_3	CH_3CH_2OH	CH_3CH_2CHO		
$(CH_3)_2CO$	$HOCH_2CH_2OH$		$C_2H_5OCH_3$	$(CH_2OH)_2CO$				
NH	CN	N_2	NH_2	HCN	HNC			
N_2H^+	NH_3	$HCNH^+$	H_2CN	HCCN	C_3N			
CH_2CN	CH_2NH	HC_2CN	HC_2NC	NH_2CN	C_3NH			
CH_3CN	CH_3NC	HC_3NH^+	*HC_4N	C_5N	CH_3NH_2			
CH_2CHCN		HC_5N	CH_3C_3N	CH_3CH_2CN	HC_7N	CH_3C_5N?	HC_9N	$HC_{11}N$
NO	HNO	N2O	HNCO	NH2CHO				
SH	CS	SO	SO+	NS	SiH			
*SiC	SiN	SiO	SiS	HCl	*NaCl			
*AlCl	*KCl	HF	*AlF	*CP	PN			
H_2S	C_2S	SO_2	OCS	HCS+	c-SiC_2			
*SiCN	*SiNC	*NaCN	*MgCN	*MgNC	*AlNC			
H_2CS	HNCS	C_3S	c-SiC_3	*SiH_4	*SiC_4			
CH_3SH	C_5S	FeO						

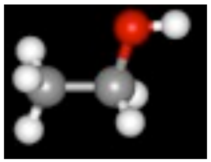
DEMIRM

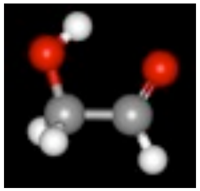
Complex Organic Molecules

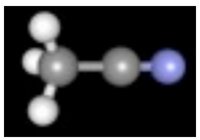
Detected

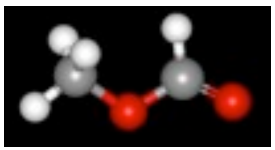

Acetic acid

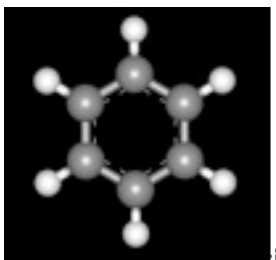

Di-methyl ether

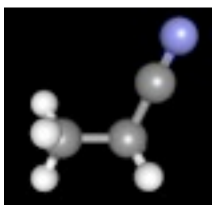

Ethanol


Sugar

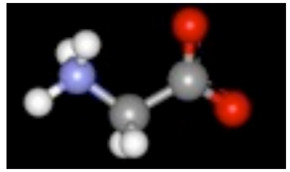

Methyl cyanide

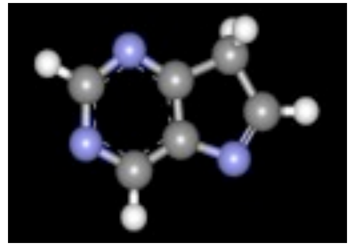

Methyl formate

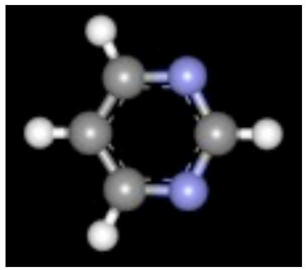

Benzene

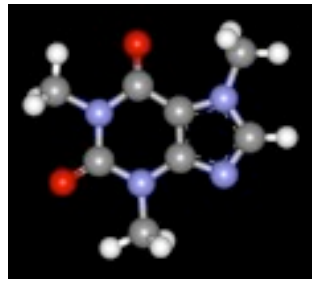

Ethyl cyanide

Not (yet) detected


Glycine


Purine


Pyrimidine


Caffeine

How far does chemical complexity go?
Can we find pre-biotic molecules in Disks?

Based on Ehrenfreund 2003

History of Galaxies

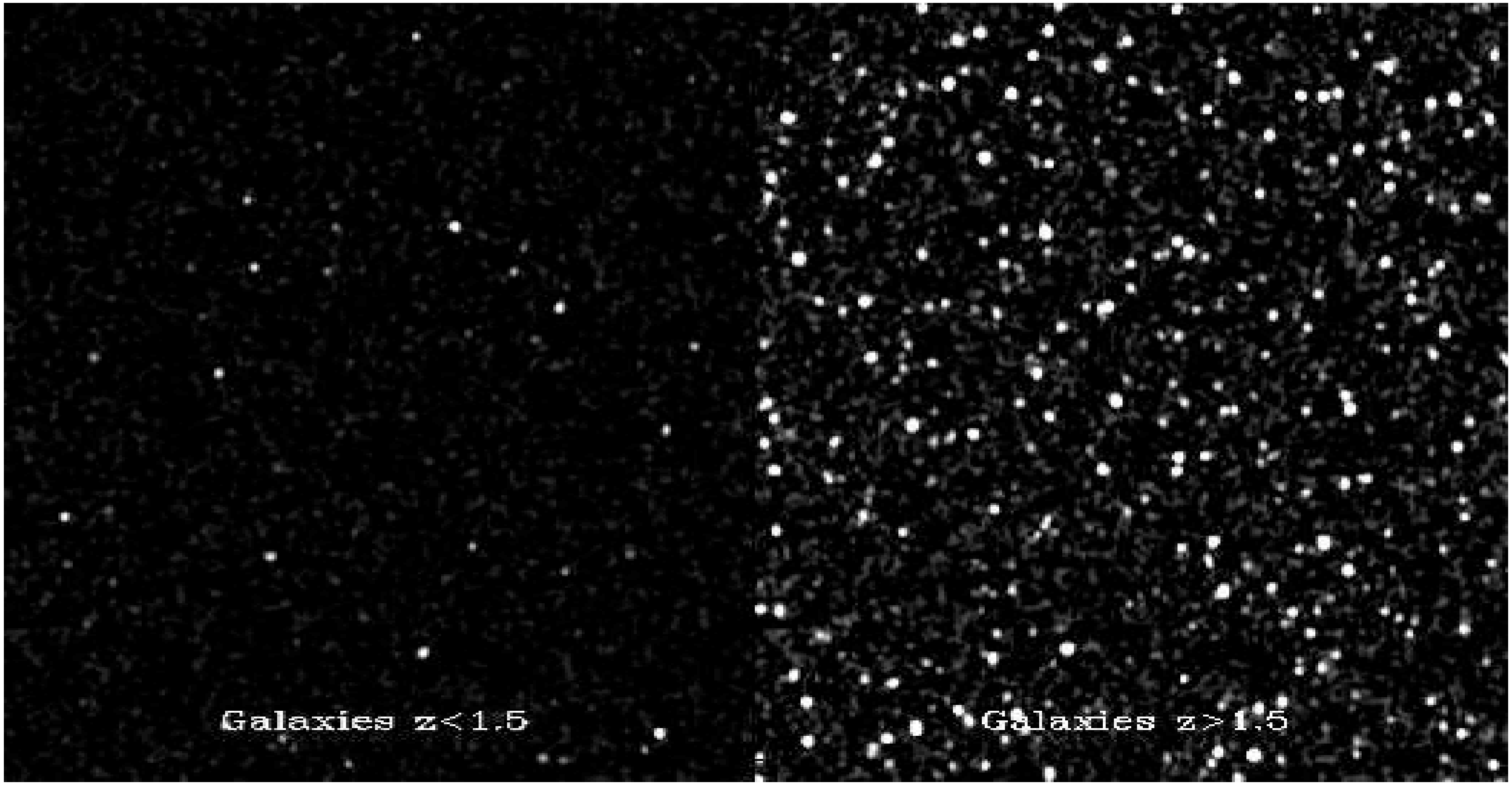
HST

(12 days of integration)

z<1.5 z>1.5

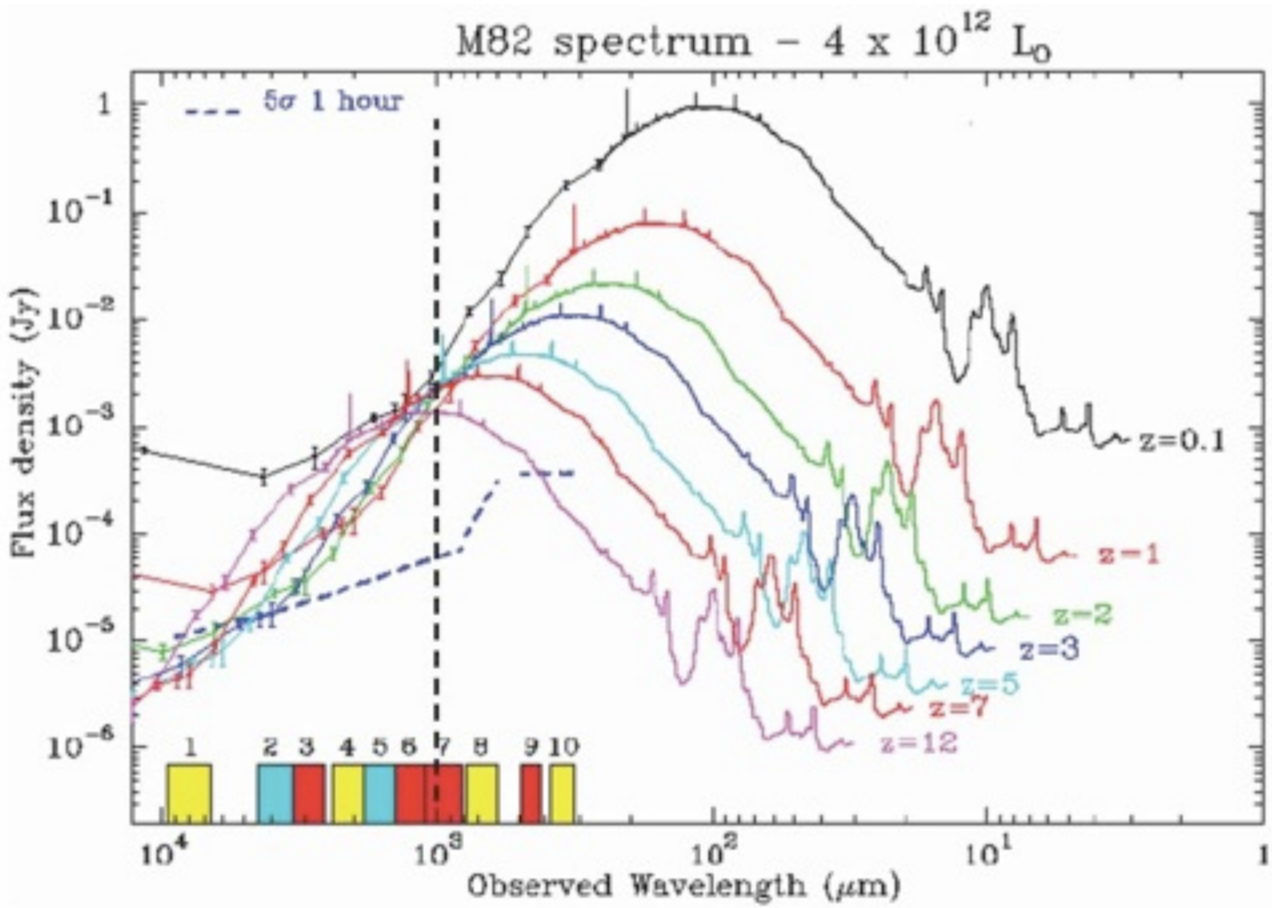
History of Galaxies

ALMA



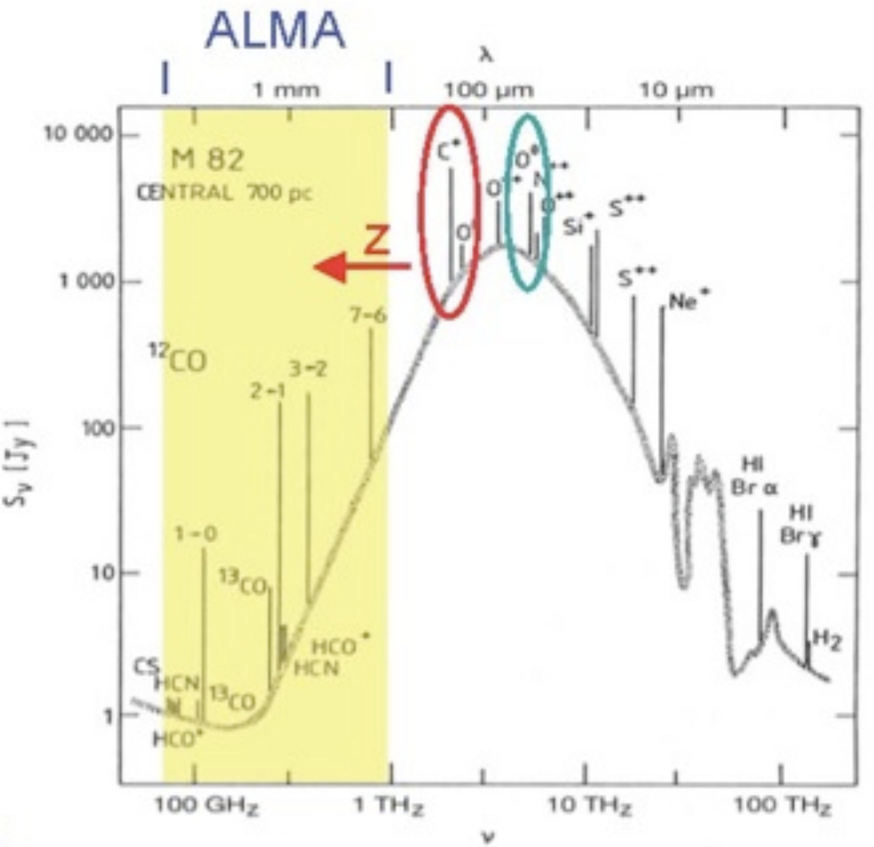
- ALMA will resolve the far infrared background seen by DIRBE and FIRAS

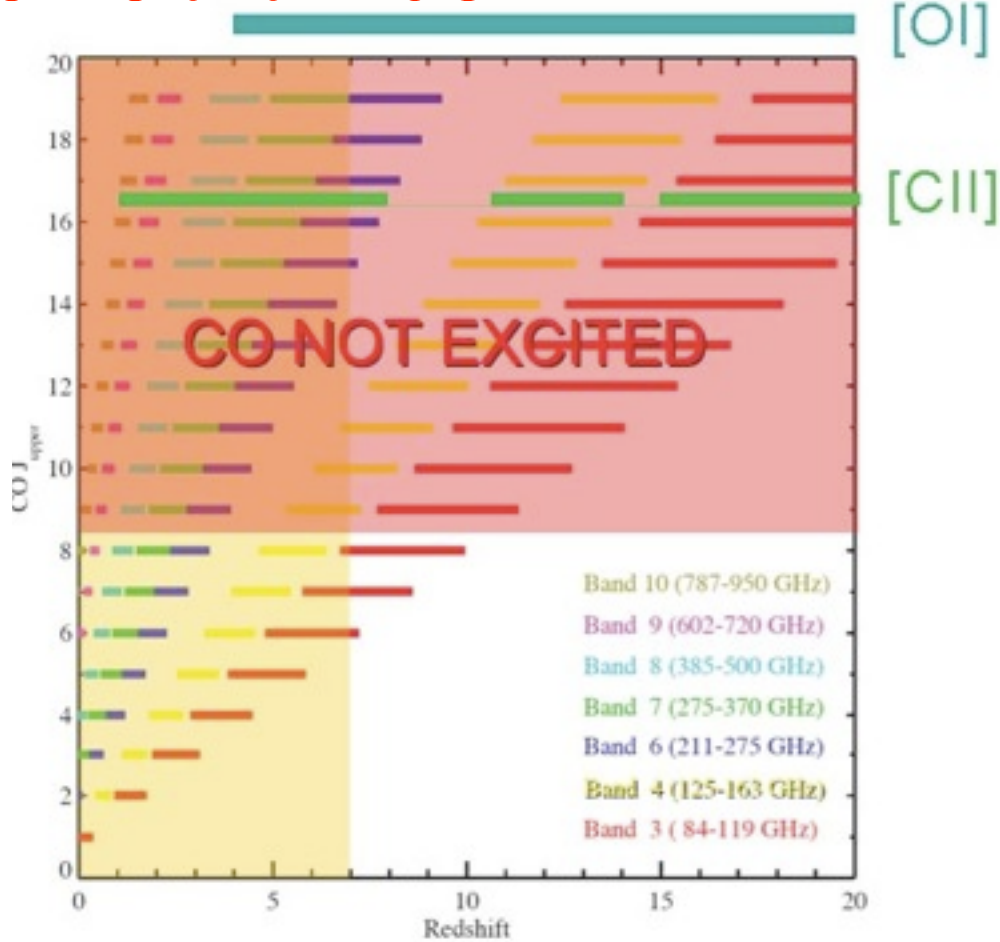
History of Galaxies



- In the (sub-)millimeter the inverse K-correction compensates for the distance as z increases

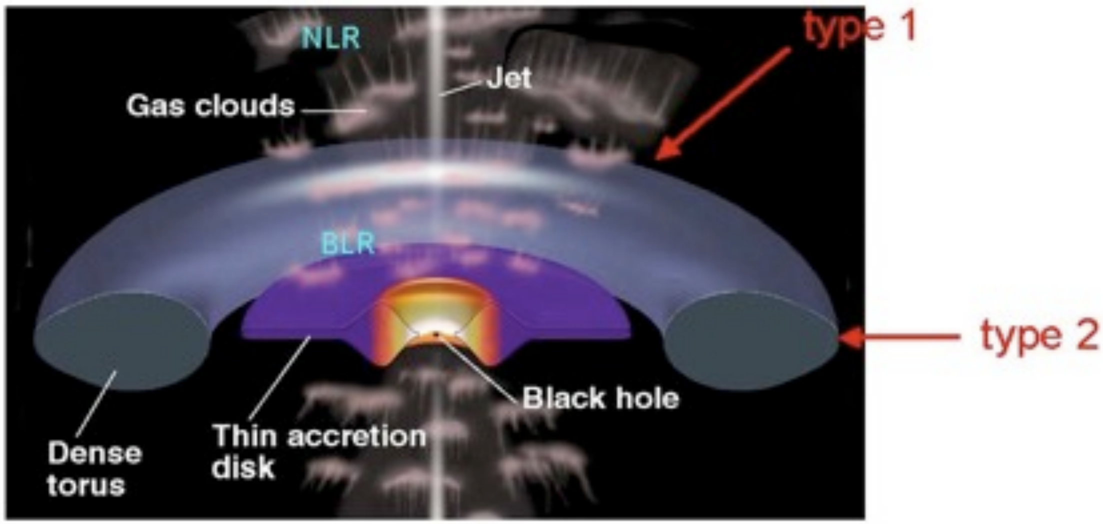
History of Galaxies

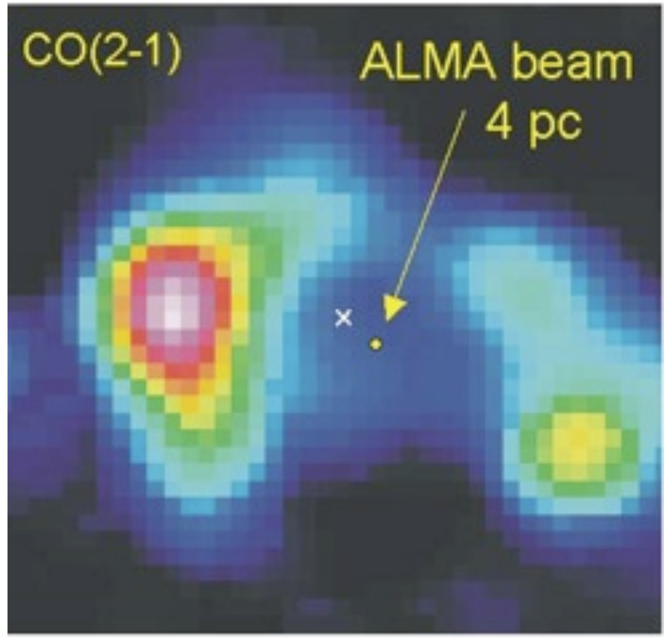




- Measuring redshift (and more) using CO, [CII] or [OI]

The Engine of nearby AGNs



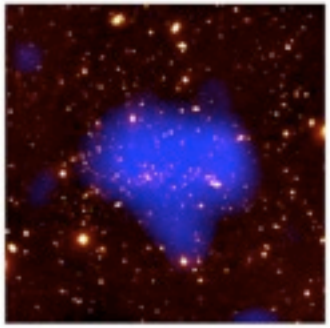
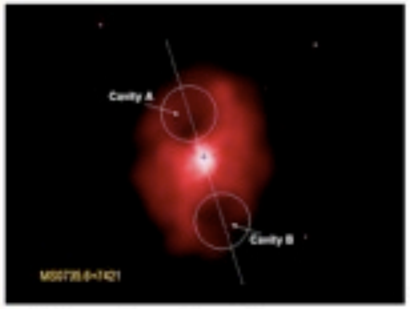
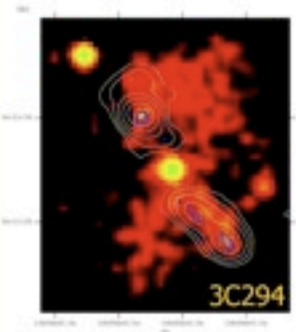
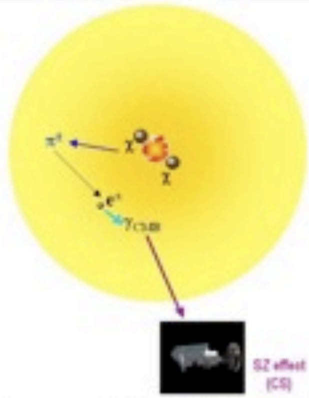
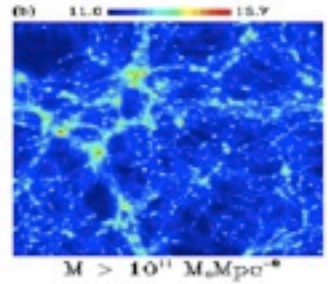


Several (competing) models:

Geometry		Dynamics		Structure	
large ~100 pc	small ~1 pc	rotation	rotation and outflow	cont./diff. medium	clumpy medium
(observed)	(ALMA)	(ALMA)		(ALMA)	

- ALMA will resolve the molecular gas structure and dynamics around nearby AGNs

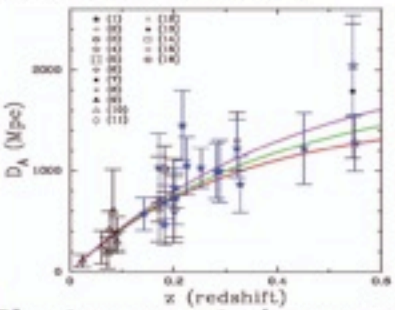
Sources of SZ

Galaxy clusters	AGN jets/cavities	Dark Matter	WHIM
	 	 	

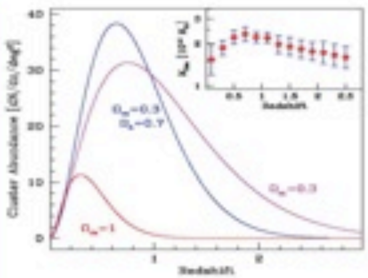
Astrophysical relevance

Galaxy clusters

Hubble diagram



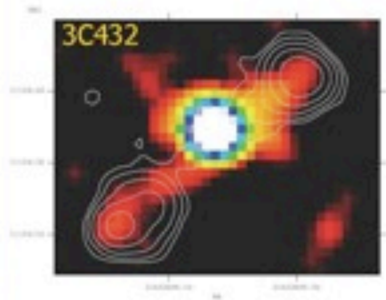
Cluster counts/masses



Cluster velocities

AGN jets/cavities

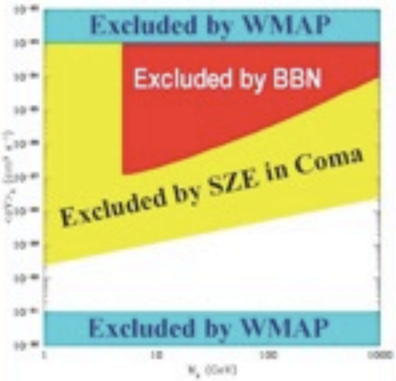
$T_{CMB}(z)$



$$\frac{\Delta T}{F_{IC}} \propto (kT_{CMB})^{-3} \times \gamma_{min}^{-(\alpha-1)} \cdot E_{X\,min}^{-(\alpha-1)/2}$$

DM nature

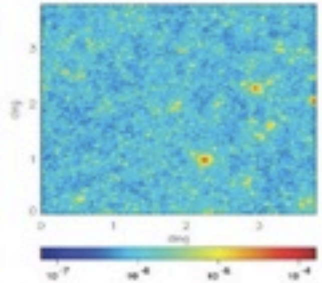
SUSY DM



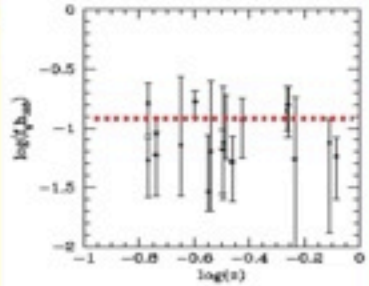
Non-SUSY DM

- MeV DM
- sterile ν
- ...

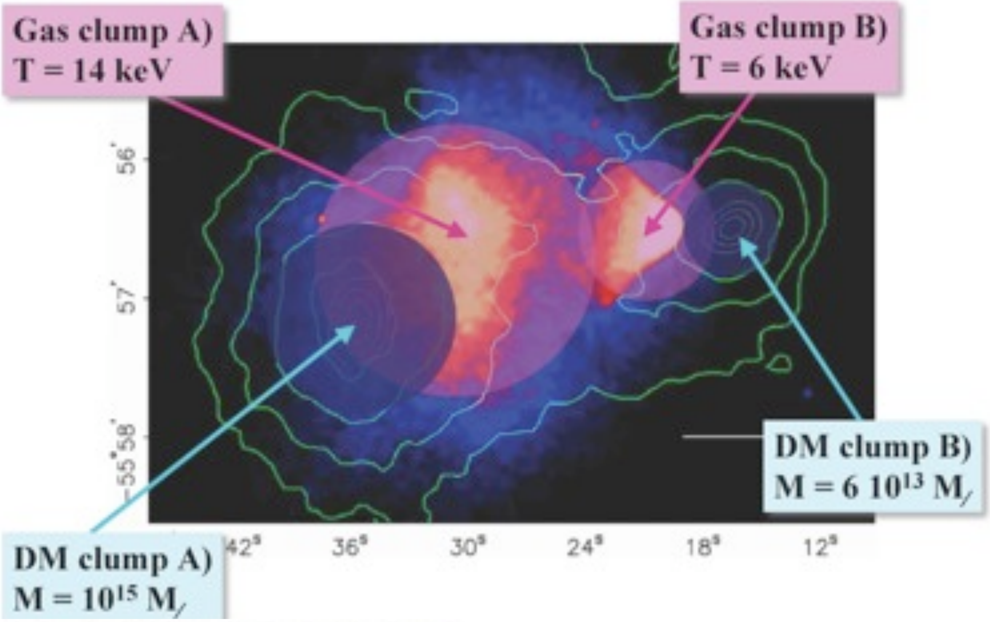
WHIM

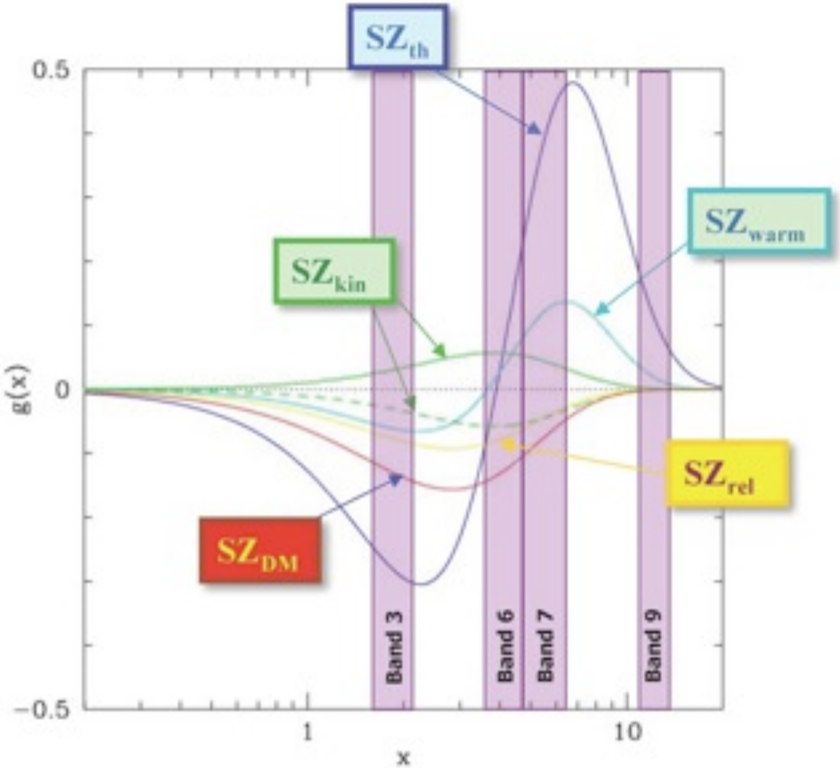


Baryon fraction

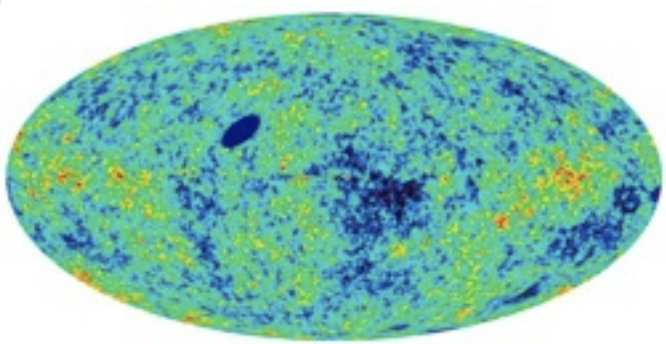


Observing SZ with ALMA





low surface brightness galaxies



- Observing Dark Matter signatures in SZ effect with ALMA

ALMA Science

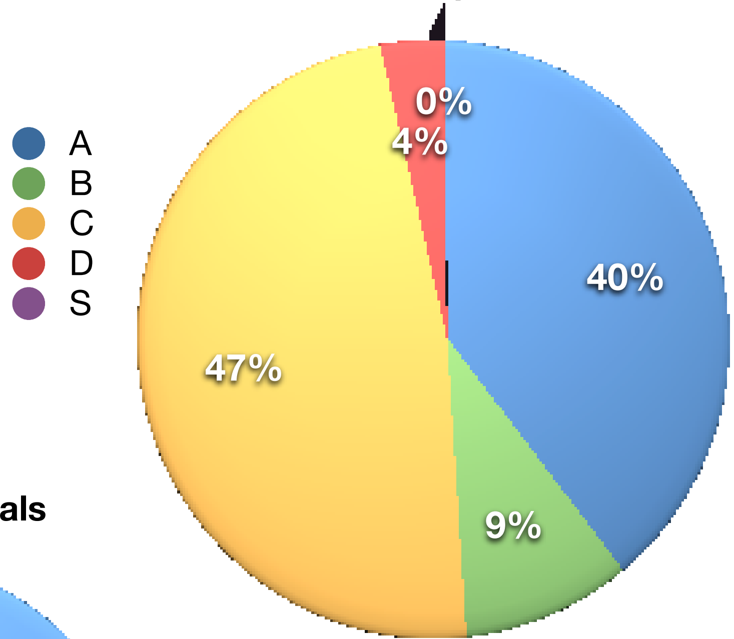
- Star Formation, Proto-planets in nearby disks
- Astrochemistry
- Interstellar medium (Galaxy, Local Group)
- High-redshift deep fields

- *+130 projects in first 3yrs – DRSP 2.0*
  - http://www.eso.org/sci/facilities/alma/science/drsp/

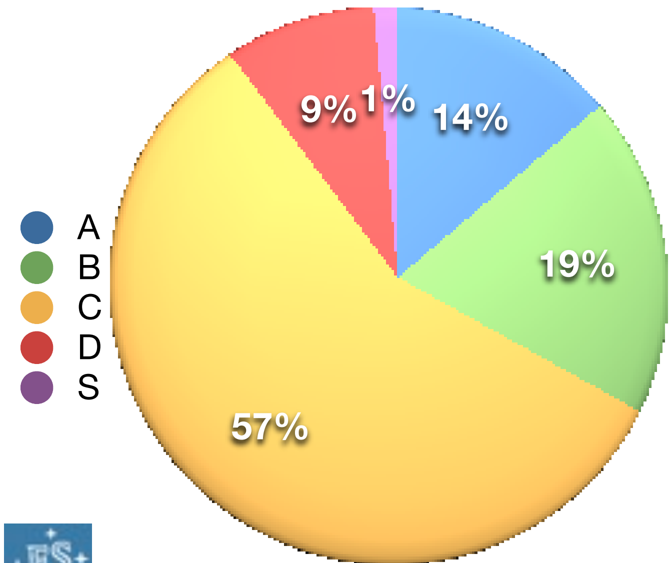
- **ALMA Science is for everyone**
  - High resolution/sensitivity 3D instrument at mm-wl
  - 100% service observing with full dynamic scheduling
  - Complete e2e data flow system
  - Science quality images (cubes) delivered to the users
  - Raw, calibrations, pipeline processed data and recipes in archive
  - Friendly and widespread User Support through ARCs

The ALMA DRSP 2.0

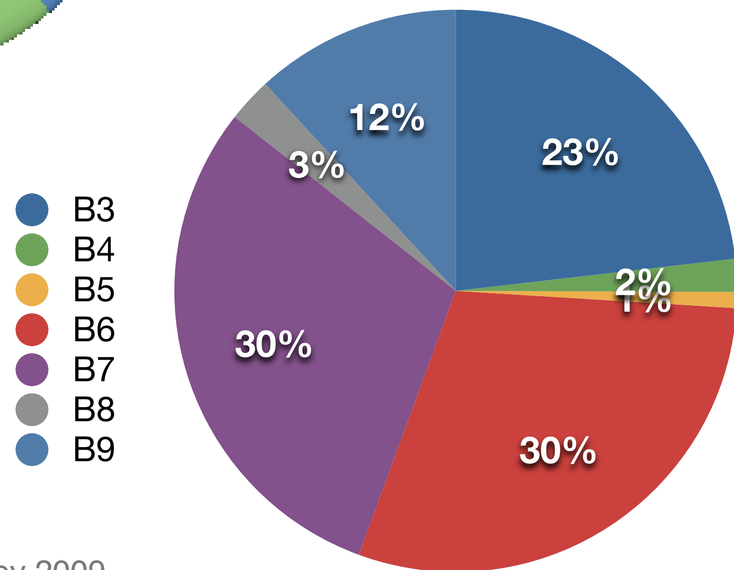
Time Requested



Number of Proposals



Time Requested per Band



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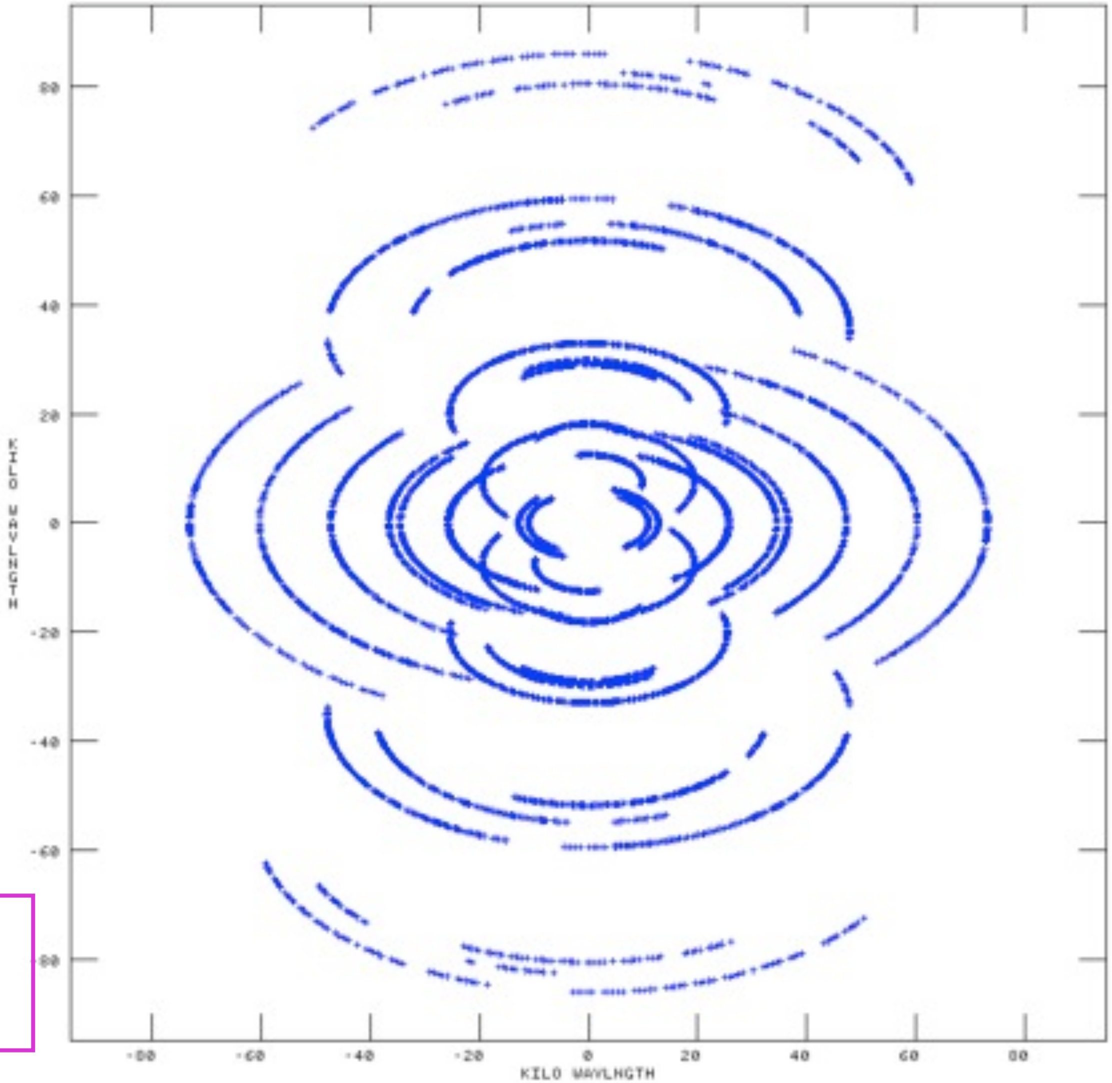
mm Interferometers (u,v) coverage

OVRO mm Array,
6 Antennas

L-configuration
single integration

L-Configuration few
hrs of observations

Final coverage: a
few hrs in both the L
and H configurations



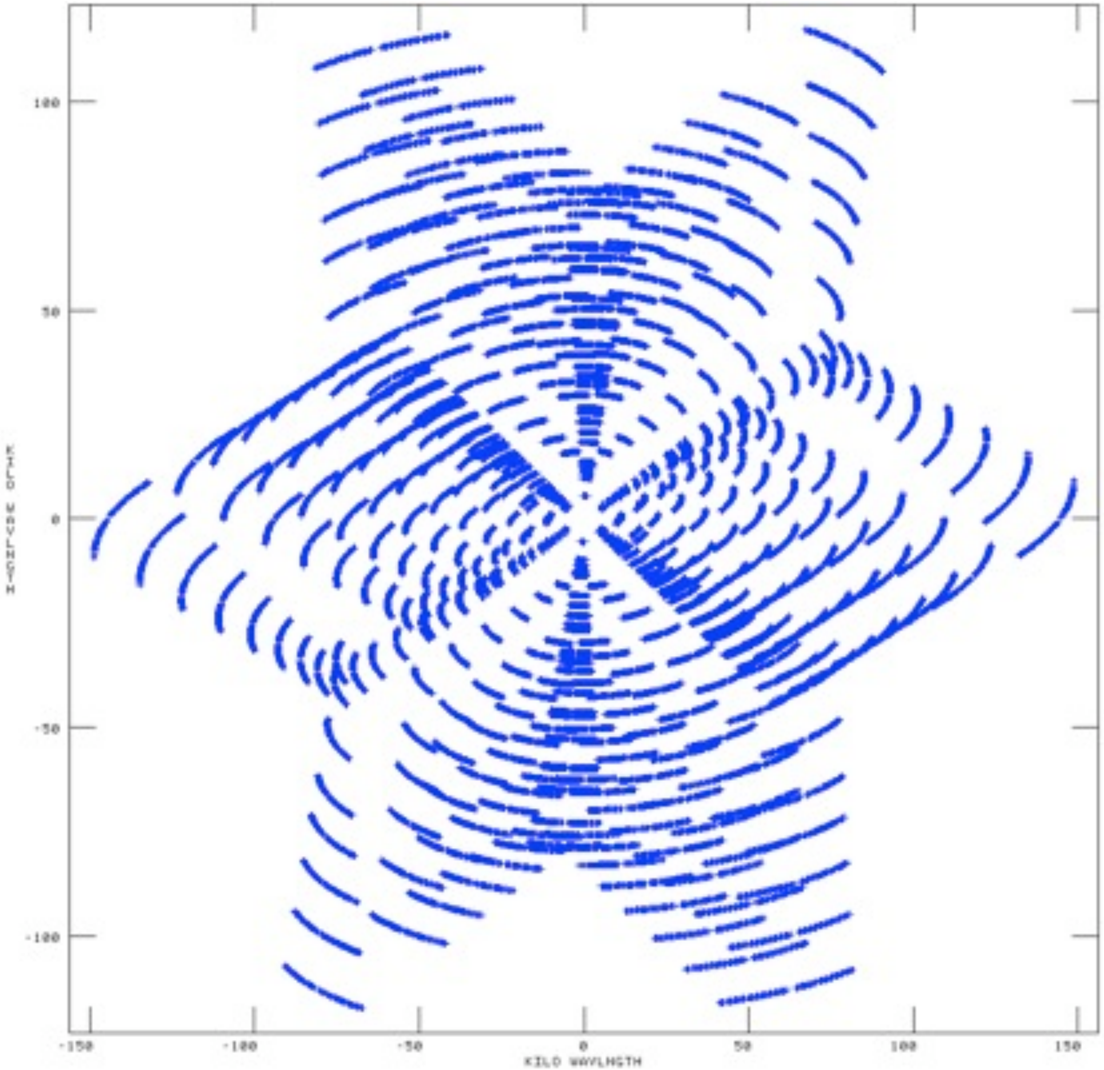
<u>N.B.</u> (u,v) coverage
is not uniform

mm Interferometers (u,v) coverage

Very Large Array,
27 Antennas,
1.5h of observing time!

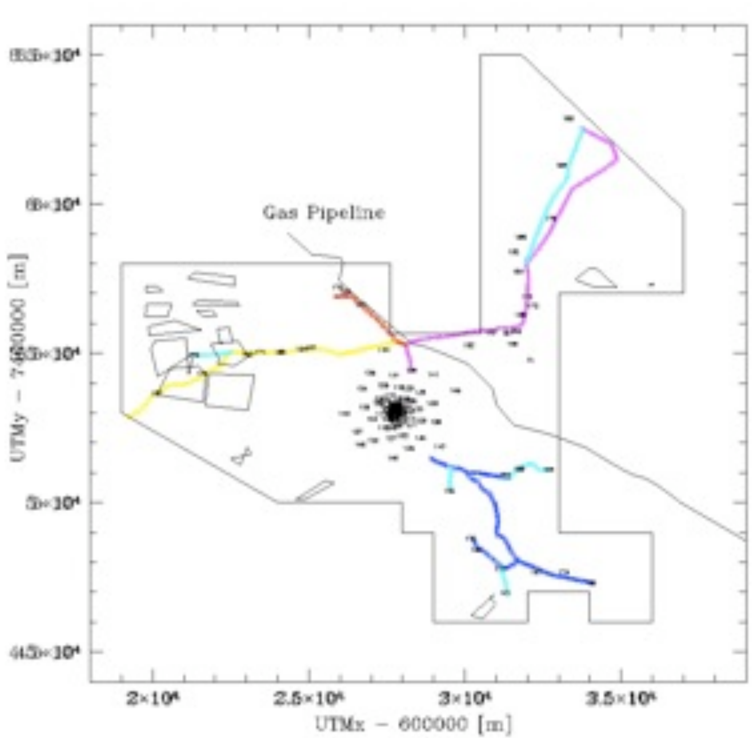
N.B. (u,v) coverage is still not uniform.

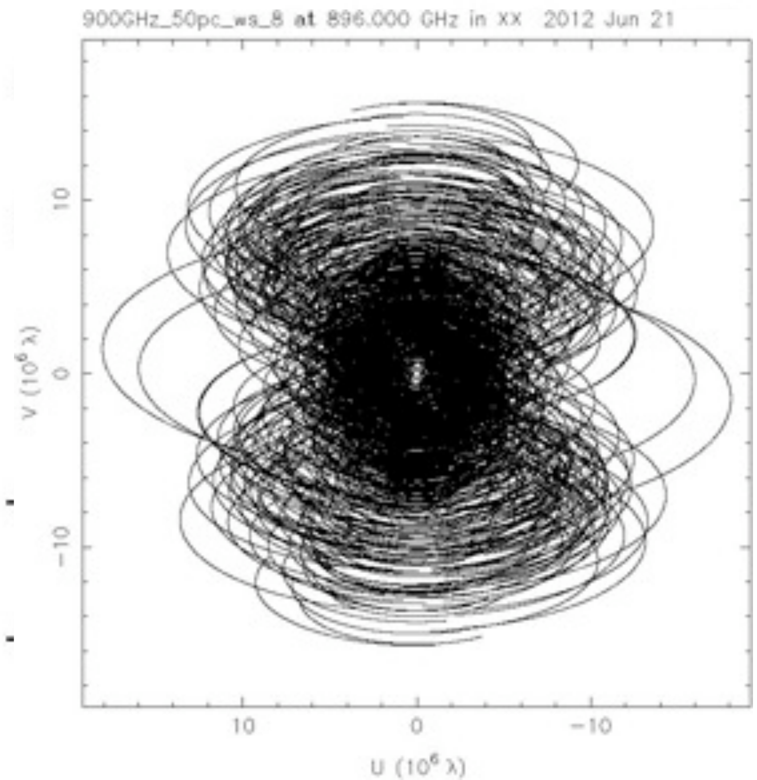
Critical parameters:
- Long baselines
- Short baselines
- Number of (u,v) points
- (u,v) coverage distribution



mm Interferometers (u,v) coverage

- Current mm interferometers offer typically ~10^4 visibility measurements in several hours, the VLA delivers ~10^5 visibilities per hour
- ALMA will improve by almost two orders of magnitude





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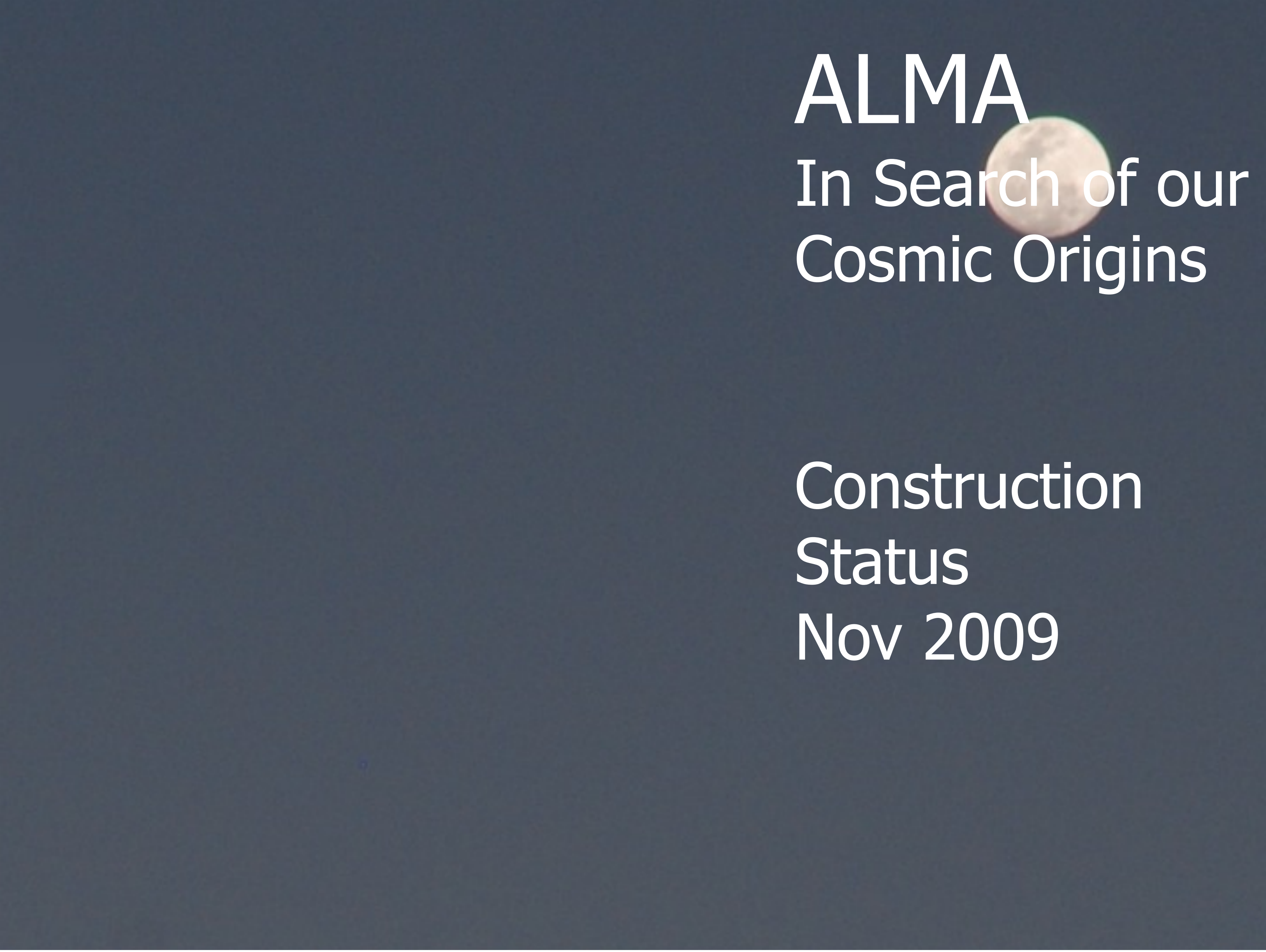
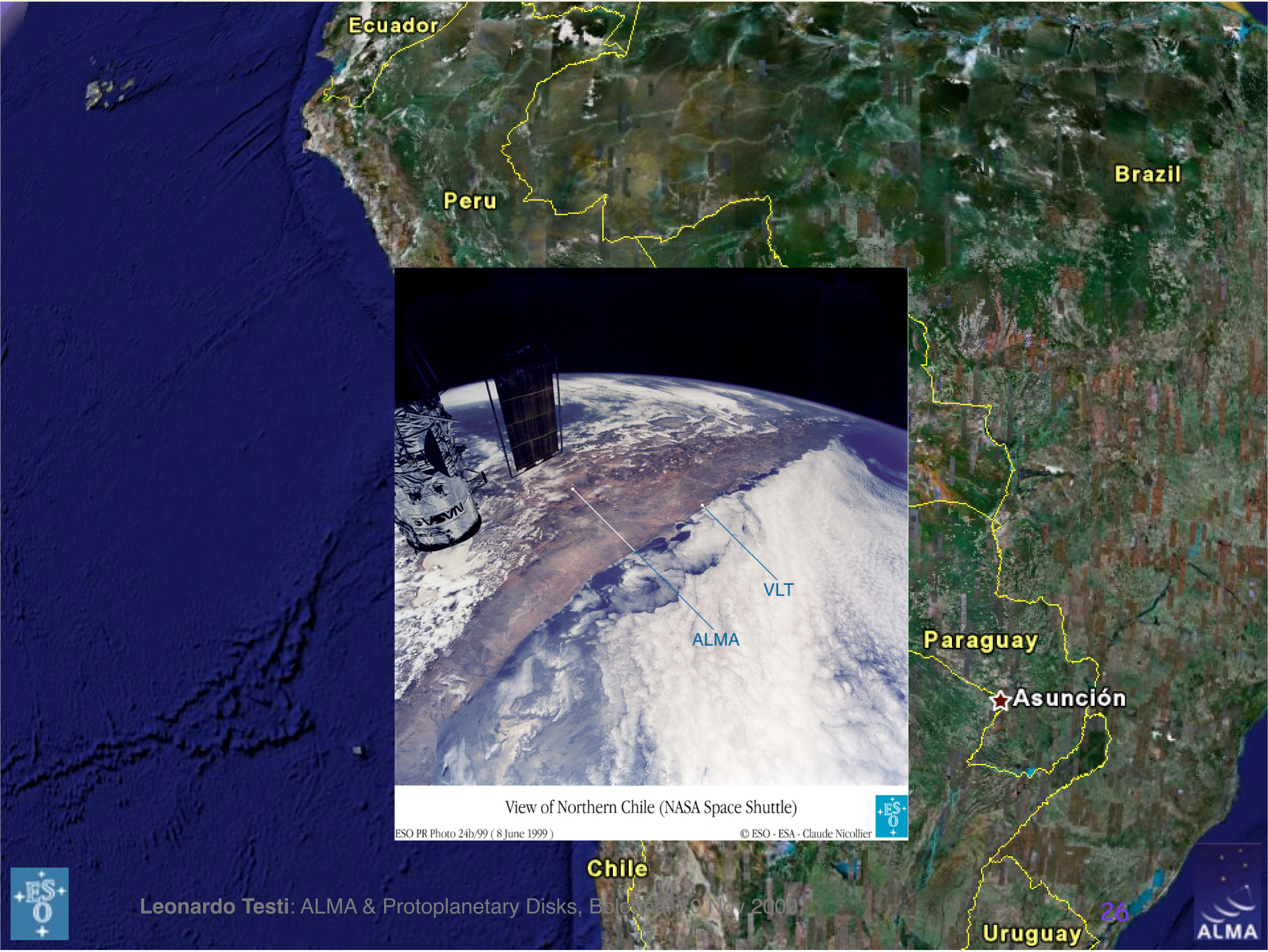
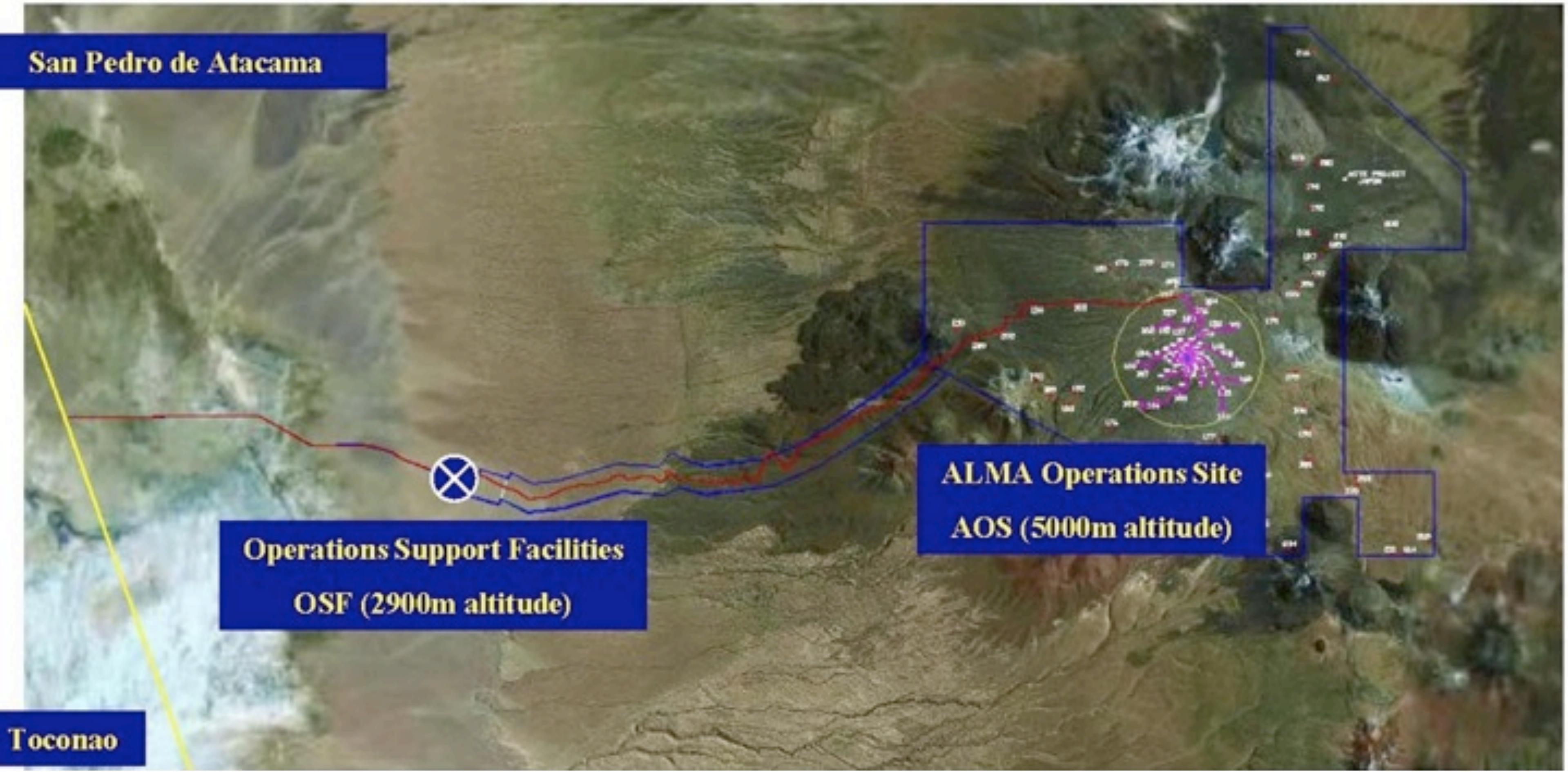
Technical Specifications

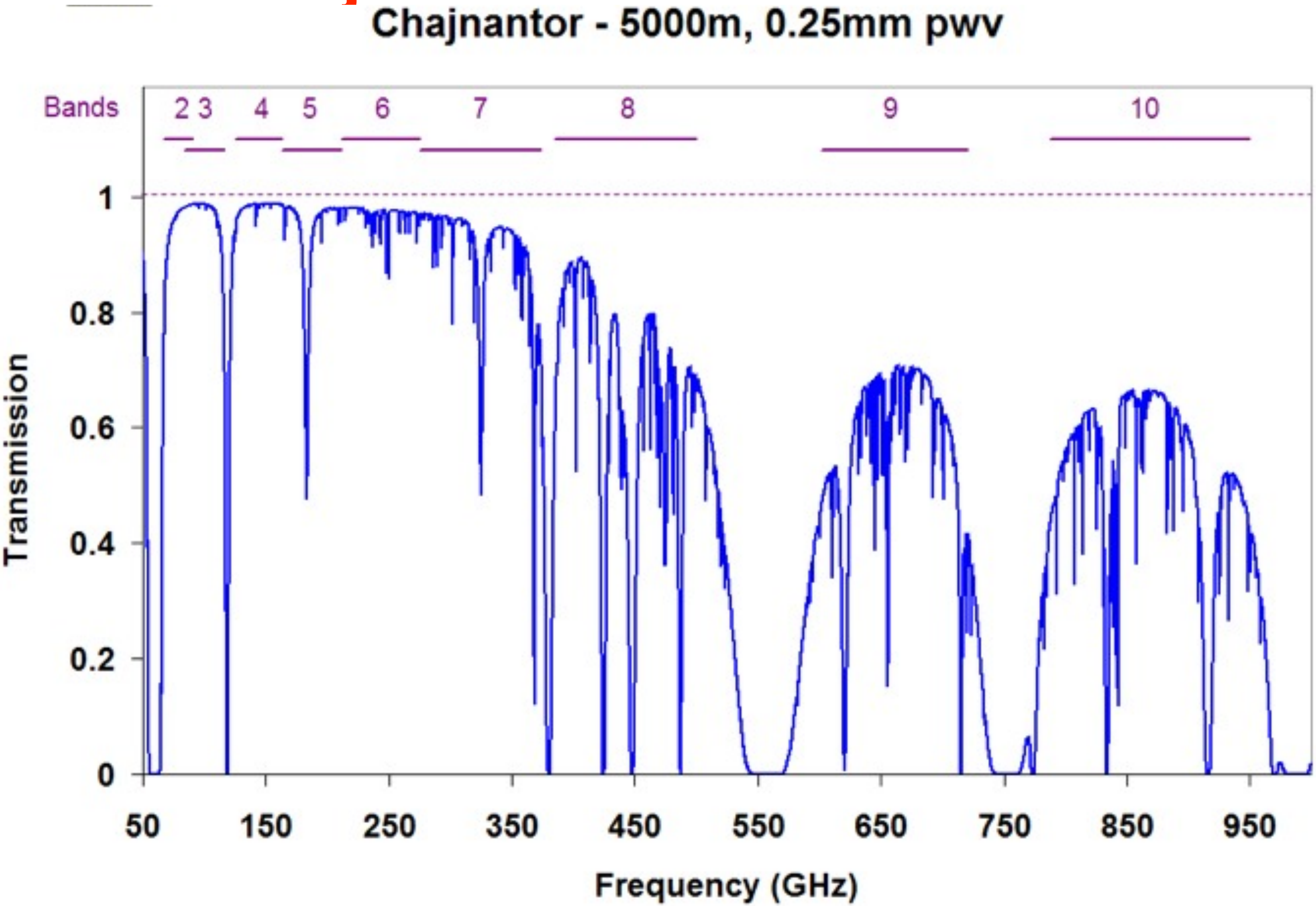
- 54 12-m antennas, 12 7-m antennas, at 5000 m site
- Surface accuracy ±25 μm, 0.6” reference pointing in 9m/s wind, 2” absolute pointing all-sky.
- Array configurations between 150m to ~18km.
- 10 bands in 31-950 GHz + 183 GHz WVR.
- 8 GHz BW, dual polarization.
- Flux sens. 0.2 mJy in 1 min at 345 GHz (median cond.).
- Interferometry, mosaicing & total-power observing.
- Correlator: 4096 channels/IF (multi-IF), full Stokes.
- Data rate: 6MB/s average; peak 60-150 MB/s.
- All data archived (raw + images), pipeline processing.


ALMA
In Search of our
Cosmic Origins
Construction
Status
Nov 2009


Ecuador
Peru
Brazil
Paraguay
Asunción
Chile
Uruguay
VLT
ALMA
View of Northern Chile (NASA Space Shuttle)
ESO PR Photo 24b/99 (8 June 1999)
© ESO - ESA - Claude Nicollier
ALMA


San Pedro de Atacama
Operations Support Facilities
OSF (2900m altitude)
ALMA Operations Site
AOS (5000m altitude)
Toconao

Chajnantor Plateau - 5000m



ALMA Receivers

ALMA Band	Frequency Range	Receiver noise temperature		Mixing scheme	Receiver technology
		T_{Rx} over 80% of the RF band	T_{Rx} at any RF frequency		
1	31.3 – 45 GHz	17 K	28 K	USB	HEMT
2	67 – 90 GHz	30 K	50 K	LSB	HEMT
3	84 – 116 GHz	37 K	62 K	2SB	SIS
4	125 – 169 GHz	51 K	85 K	2SB	SIS
5	163 - 211 GHz	65 K	108 K	2SB	SIS
6	211 – 275 GHz	83 K	138 K	2SB	SIS
7	275 – 373 GHz*	147 K	221 K	2SB	SIS
8	385 – 500 GHz	98 K	147 K	DSB	SIS
9	602 – 720 GHz	175 K	263 K	DSB	SIS
10	787 – 950 GHz	230 K	345 K	DSB	SIS

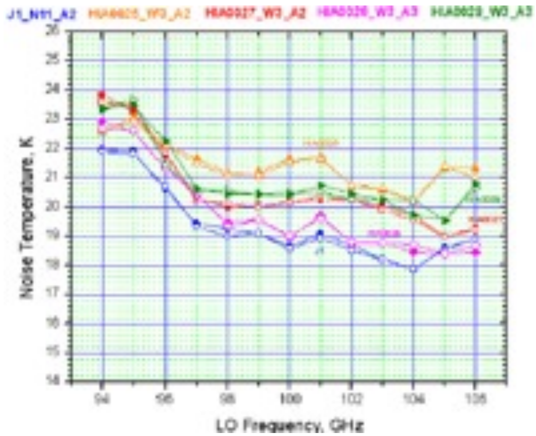
* - between 370 – 373 GHz T_{rx} is less then 300 K

- Dual, linear polarization channels:
  - Increased sensitivity
  - Measurement of 4 Stokes parameters
- 183 GHz water vapour radiometer:
  - Used for atmospheric path length correction

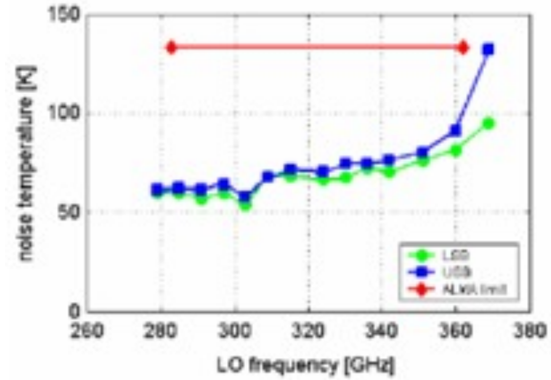
★ Japanese contribution all telescopes plus ACA

★ EC funded 6 receivers ALMA-Herschel sinergy

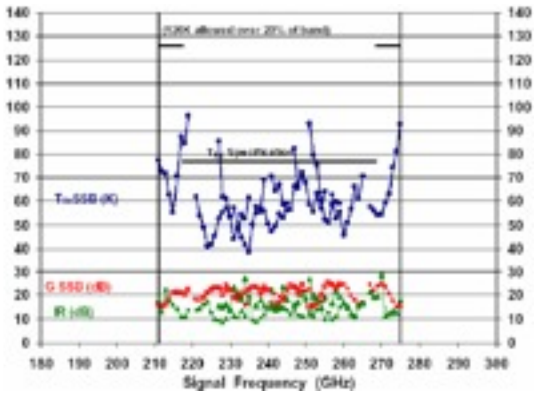
ALMA Receivers



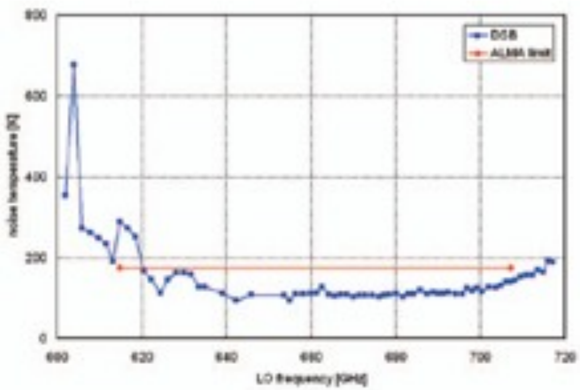
Band 3 ("3mm")



Band 7 ("850μm")



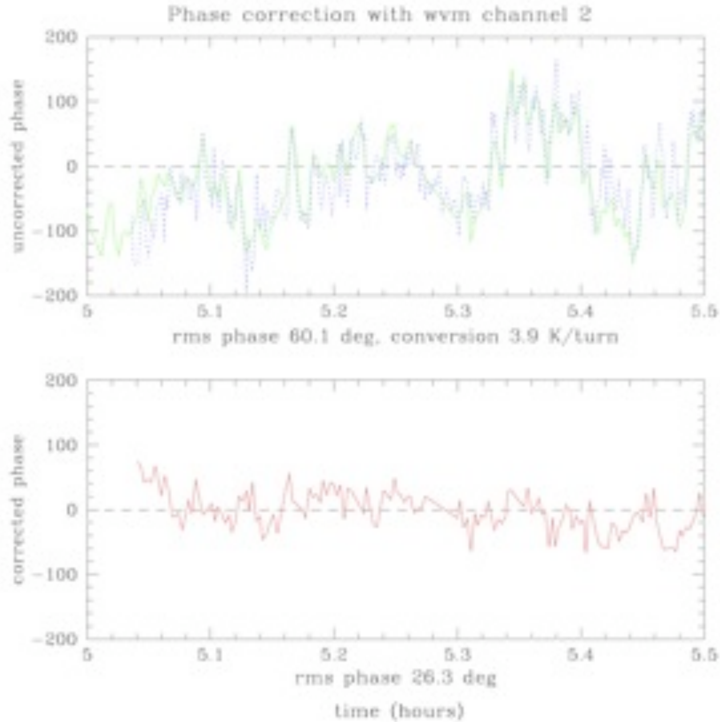
Band 6 ("1mm")

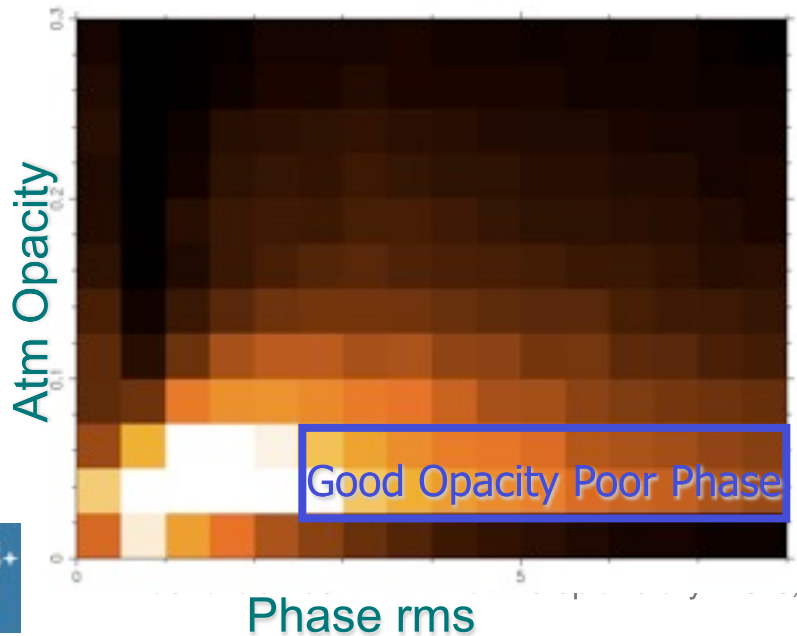


Band 9 ("450μm")

✦ Water Vapour Radiometers

- All ALMA antennas will be equipped with water vapour radiometers observing the 183GHz atmospheric water line.

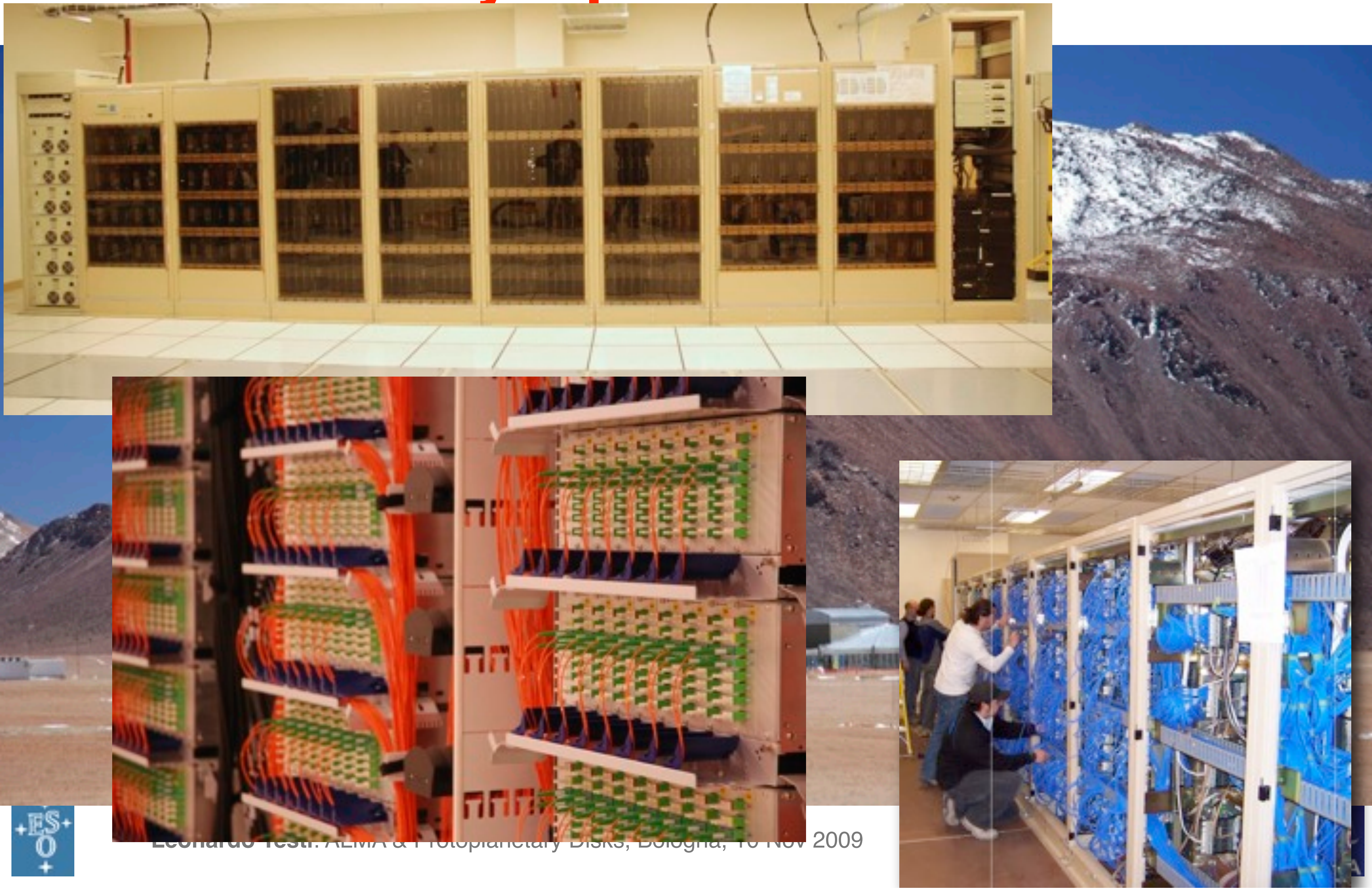




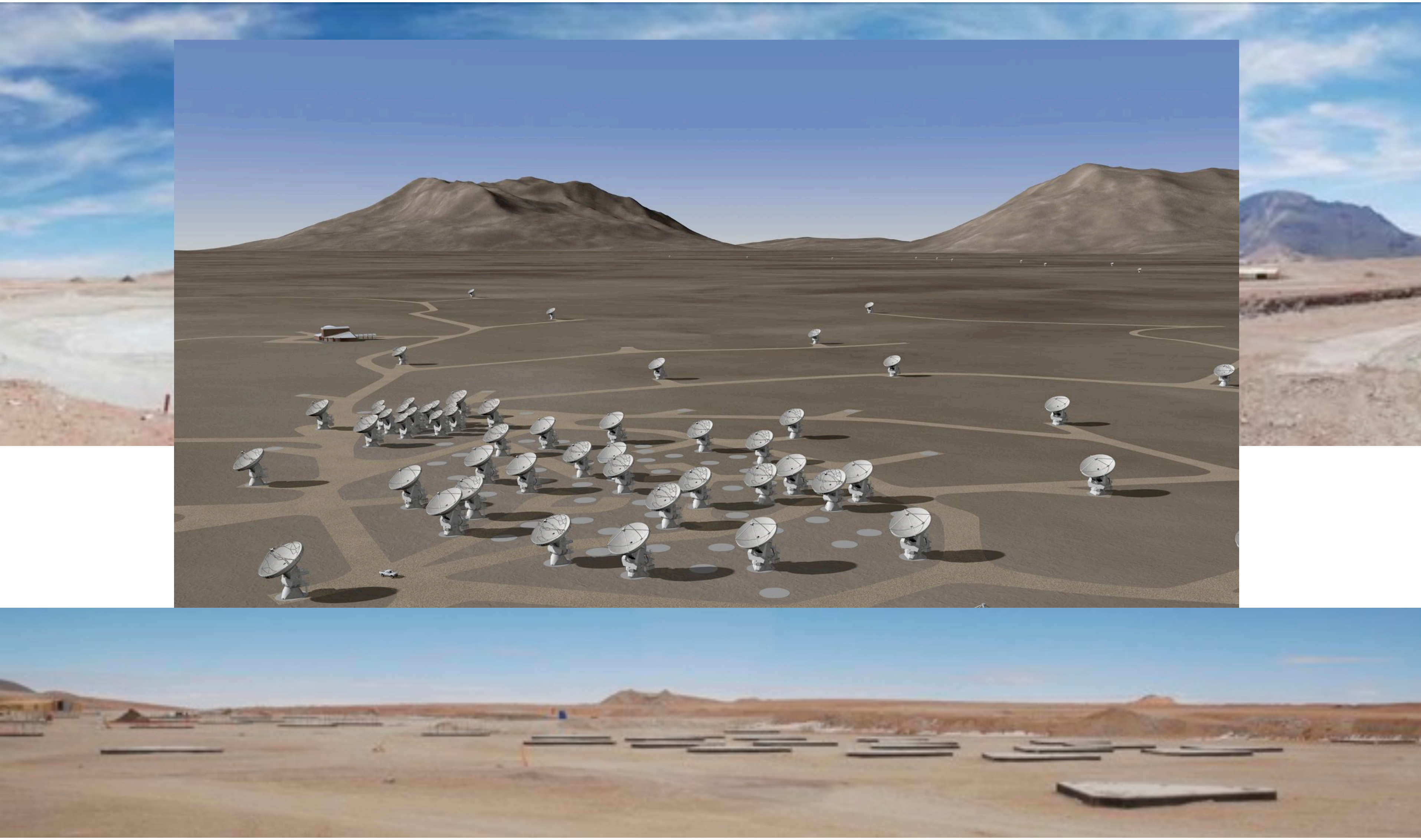
WVRs track phase on 1s timescales along the same path (within 3-10 arcmin) as the astronomical signal from the source (complementary to fastswitching: ≥10s and few degs)

-Improve Sensitivity and Fidelity
-Allow to increase switch time

Array Operations Site

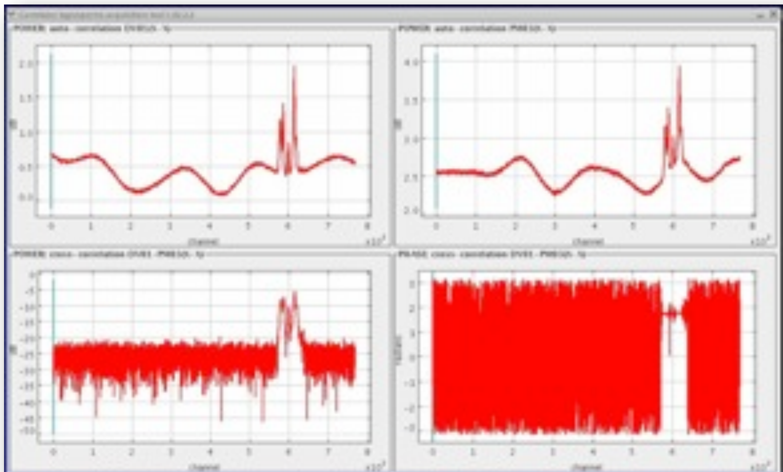


Array Operations Site



Operations Support Facility - 2900m

First Fringes at OSF

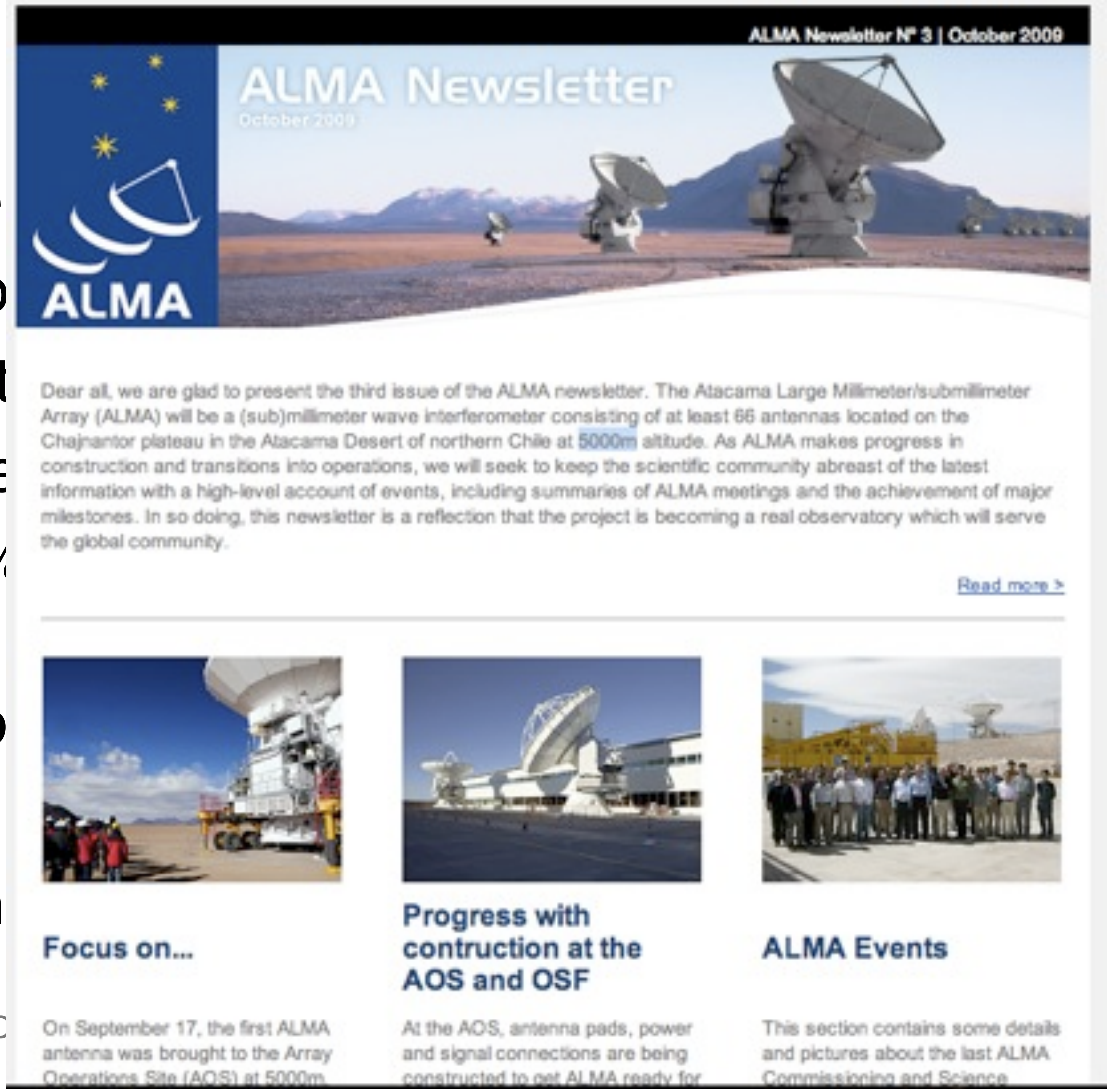


First antenna at 5000m

ALMA CSV, Early and Full Science

- CSV Team
  - Sci IPT plus Ops Astr.
  - Community involveme
  - SV is NOT an early op
- Early Science: 16 ants, at
  - We expect to issue the
- Science Operations >75%
  expected in 2012
- Formal end of constructio

- ALMA is hiring and lookin


ALMA Newsletter N° 3 | October 2009

ALMA Newsletter

October 2009

ALMA

Dear all, we are glad to present the third issue of the ALMA newsletter. The Atacama Large Millimeter/submillimeter Array (ALMA) will be a (sub)millimeter wave interferometer consisting of at least 66 antennas located on the Chajnantor plateau in the Atacama Desert of northern Chile at 5000m altitude. As ALMA makes progress in construction and transitions into operations, we will seek to keep the scientific community abreast of the latest information with a high-level account of events, including summaries of ALMA meetings and the achievement of major milestones. In so doing, this newsletter is a reflection that the project is becoming a real observatory which will serve the global community.

Read more >

Focus on...

On September 17, the first ALMA antenna was brought to the Array Operations Site (AOS) at 5000m

Progress with contruction at the AOS and OSF

At the AOS, antenna pads, power and signal connections are being constructed to get ALMA ready for

ALMA Events

This section contains some details and pictures about the last ALMA Commissioning and Science

ALMA Science

- Star Formation, Proto-planets in nearby disks
- Astrochemistry
- Interstellar medium (Galaxy, Local Group)
- High-redshift deep fields

- *+130 projects in first 3yrs – DRSP 2.1*
  - http://www.eso.org/sci/facilities/alma/science/drsp/

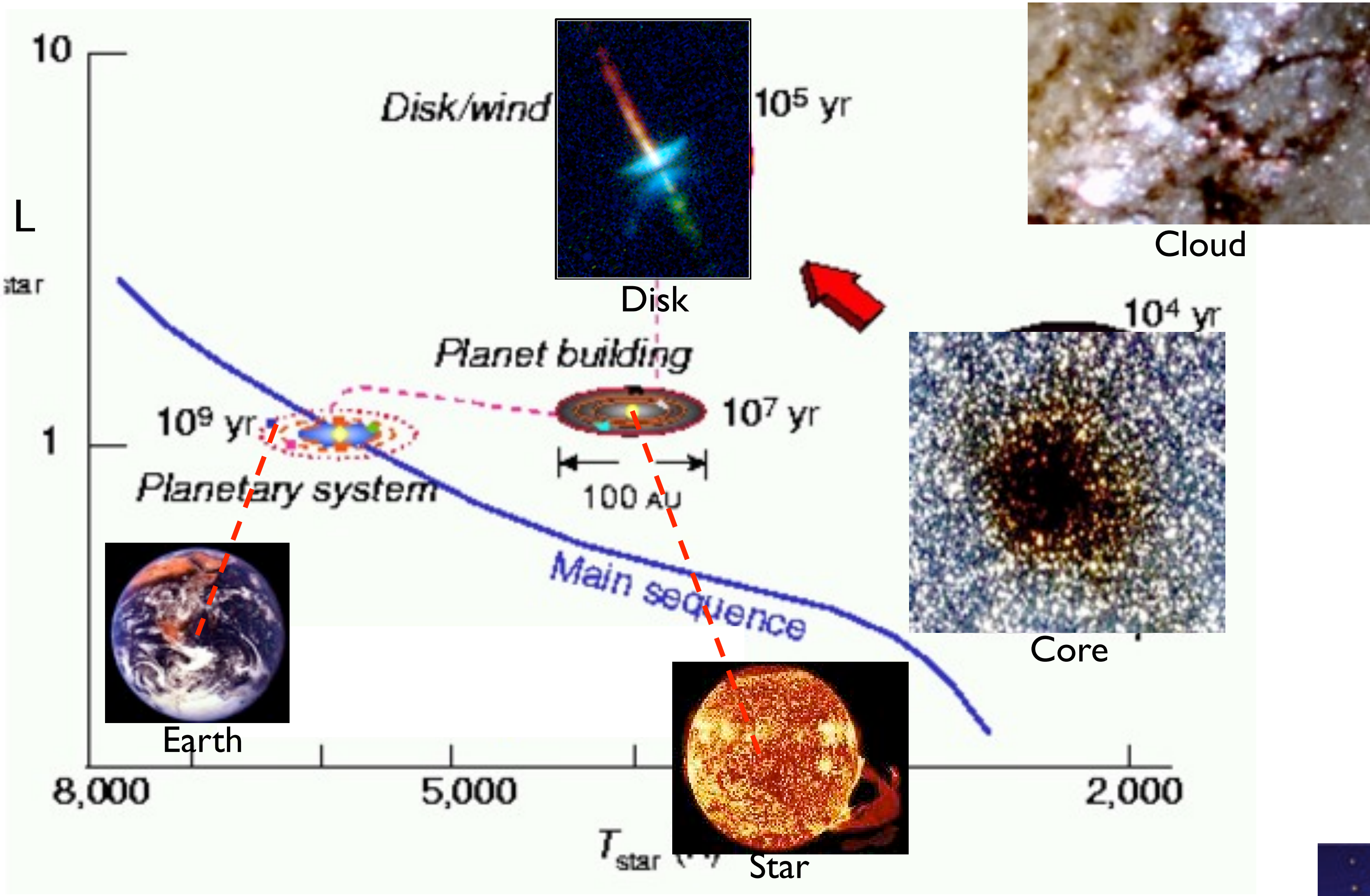

Your proposal here
2010

Protoplanetary Disks
Observing the dawn of planetary systems with ALMA

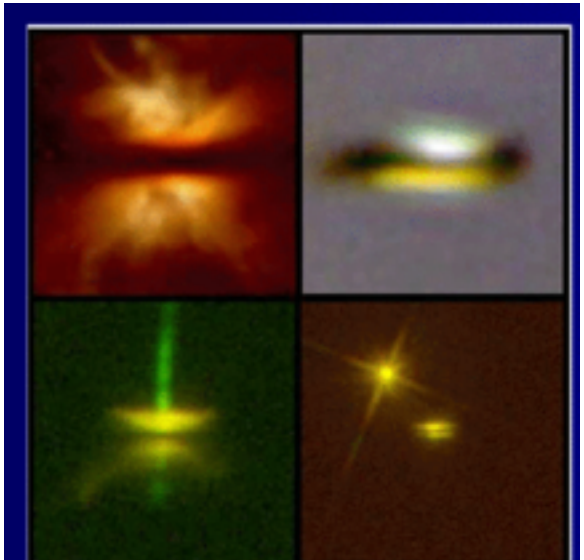
Leonardo Testi (European Southern Observatory)

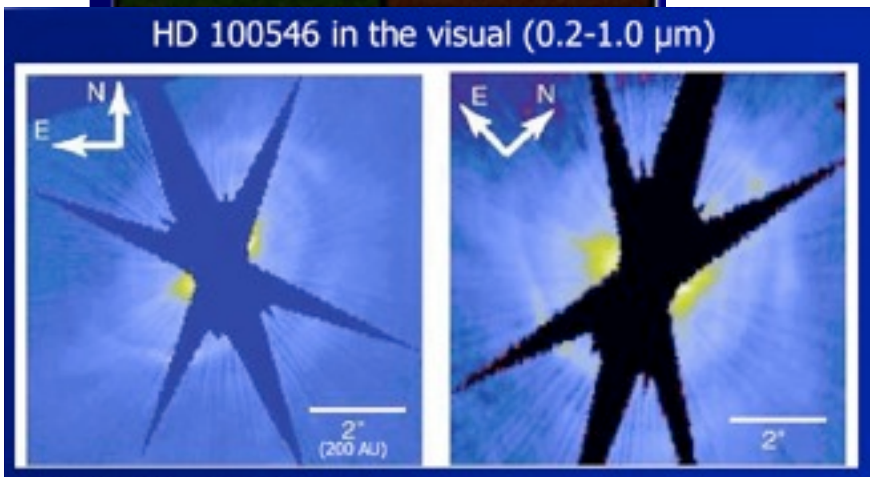
- Structure of Circumstellar Disks
- Millimeter Continuum Emission from Disks
- Molecular Lines Emission from Disks
- Teasers and advanced topics

From Cores to Stars and Planetary Systems

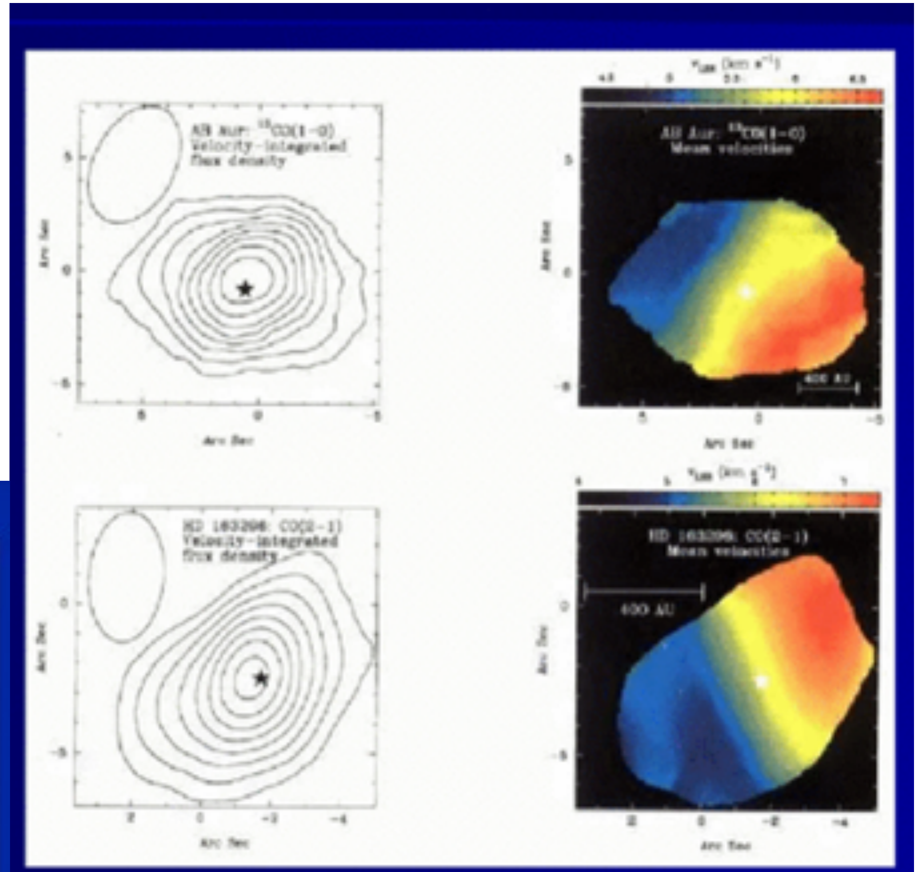


Disks at different wavelengths





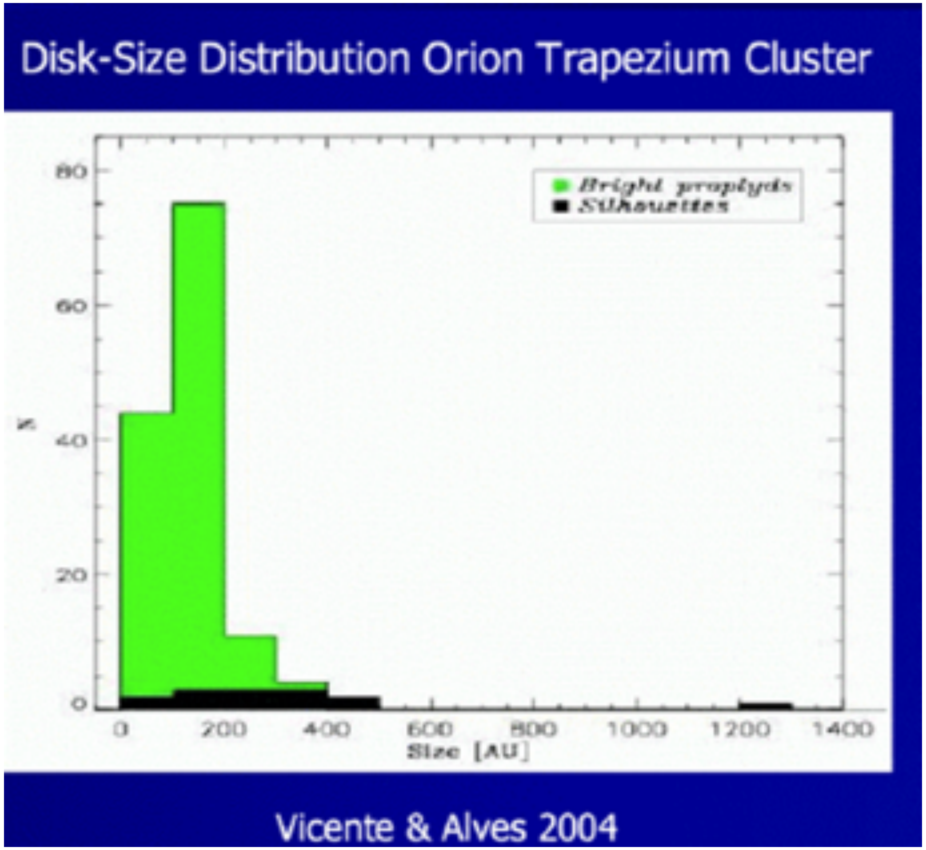
Grady et al. 2001, AJ 122, 3396



Mannings & Sargent 1997, ApJ 490, 792

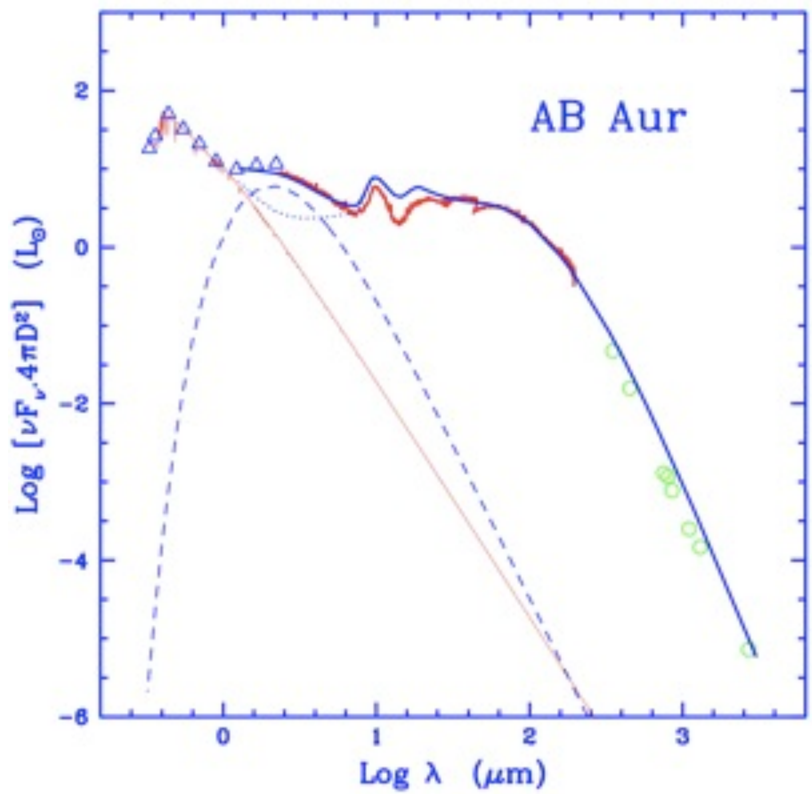
Physical sizes

- Few hundred AUs
  - From scattered light
  - Mm continuum
  - CO mm lines

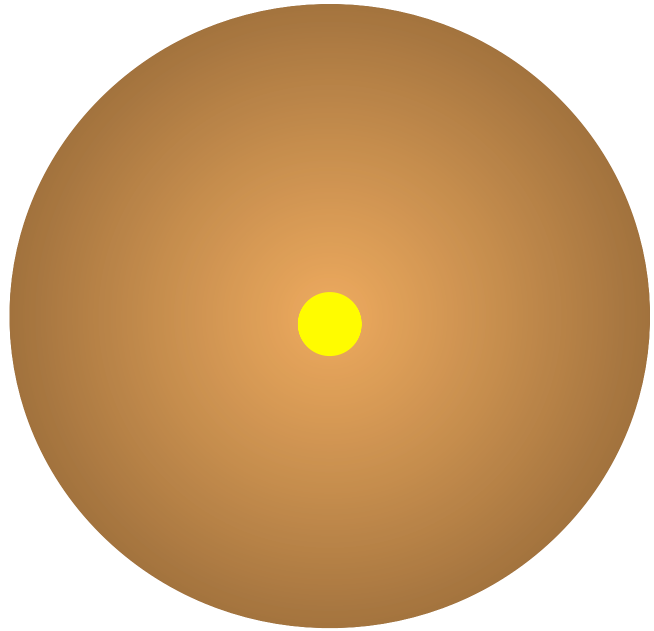


SED and Infrared Excess

- Cirsumstellar disks in the PMS phase are optically thick (except at λ≥mm)
- Disks dominate the emission beyond 1-2μm
- The shape of the SED depends on the disk structure



(sub)mm continuum emission



$$F_\nu = \frac{cos\theta}{D^2} \int_{r_i}^{r_o} B_\nu(T_d)(1 - e^{-\tau_\nu}) 2\pi r dr$$

$$T_d \sim r^{-q}$$

$$\tau_\nu \propto \Sigma(r)\kappa_\nu \qquad \Sigma(r) \propto r^{-p} \qquad \kappa_\nu \propto \kappa_o \nu^\beta$$

Masses: (sub)mm continuum emission

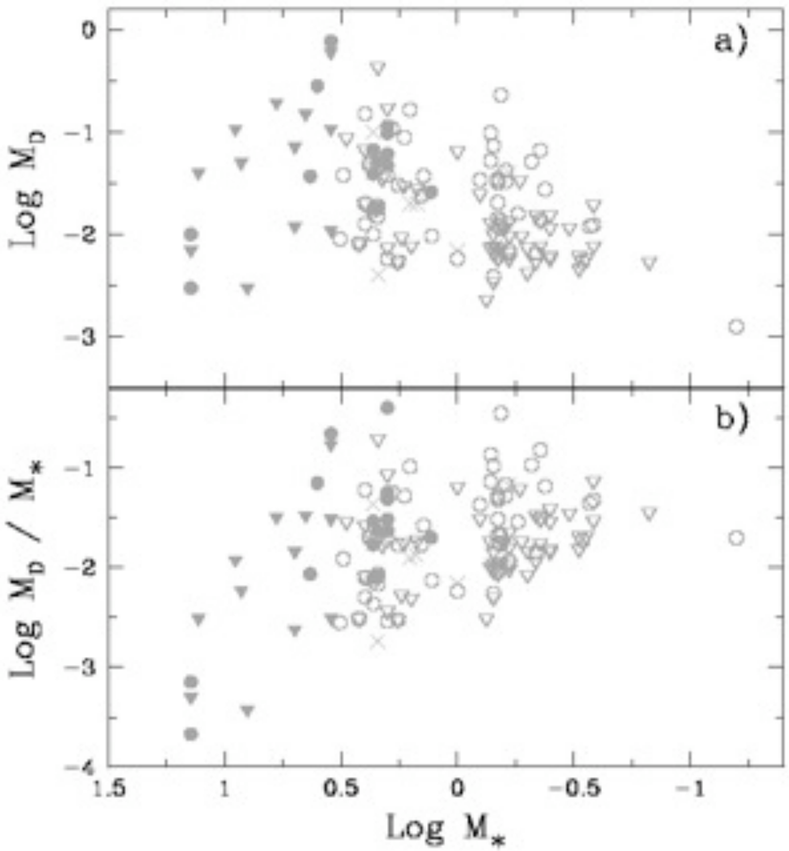
- $M_D \sim 0.01\text{-}0.1$ Msun
- $M_D/\text{Mstar} \sim 0.03$

- $F_{1mm} \sim B_n(T)\ k_{1mm}\ M_D$

$$F_\nu = \frac{cos\theta}{D^2} \int_{r_i}^{r_o} B_\nu(T_d)(1 - e^{-\tau_\nu}) 2\pi r dr$$

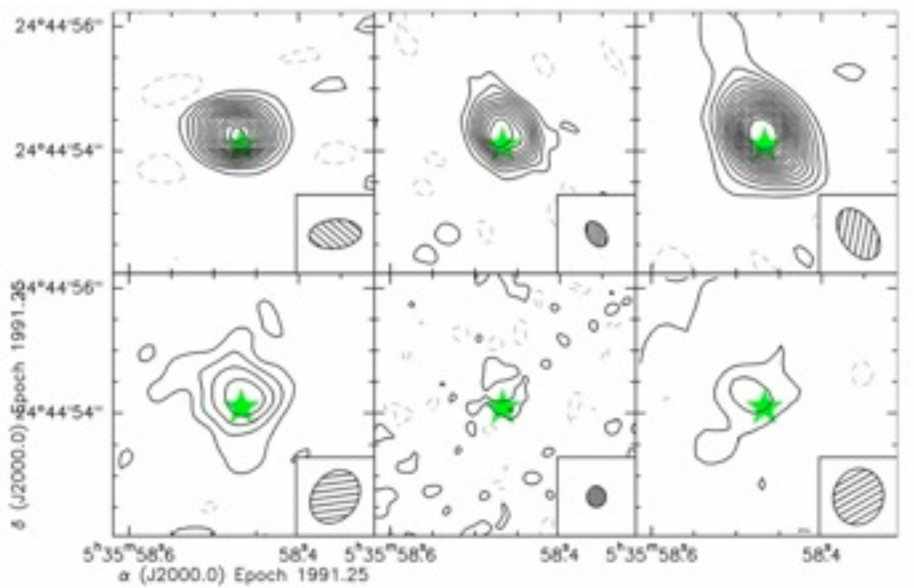
$$T_d \sim r^{-q}$$

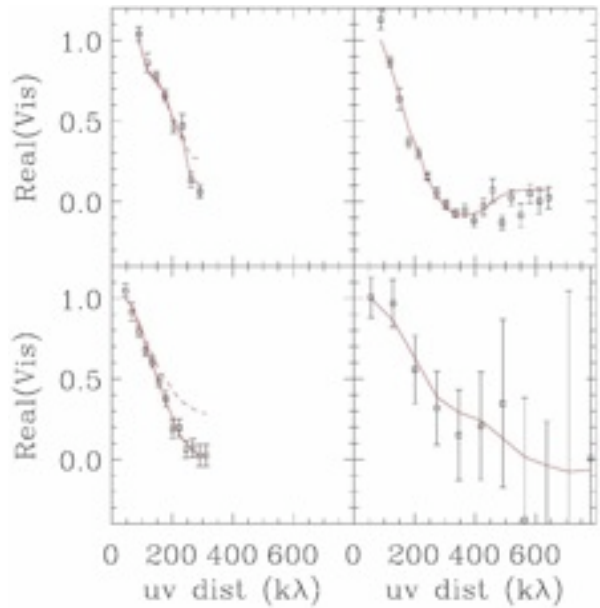
$\tau_\nu \propto \Sigma(r) \kappa_\nu$ $\Sigma(r) \propto r^{-p}$ $\kappa_\nu \propto \kappa_o \nu^\beta$



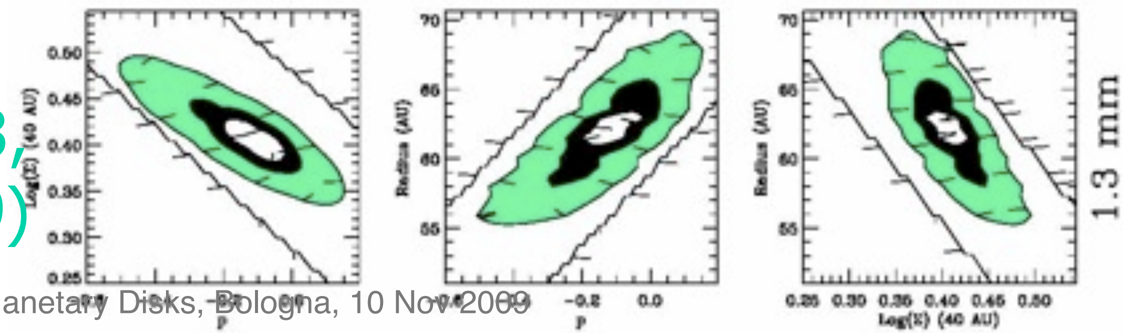
Radial density profiles

- High resolution mm continuum observations allow to derive the dust column density as a function of radius



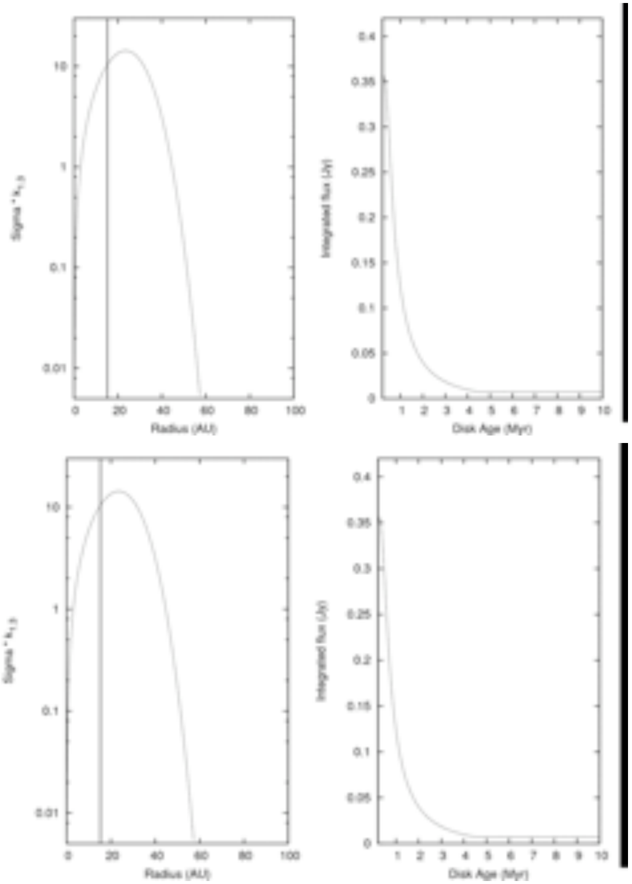


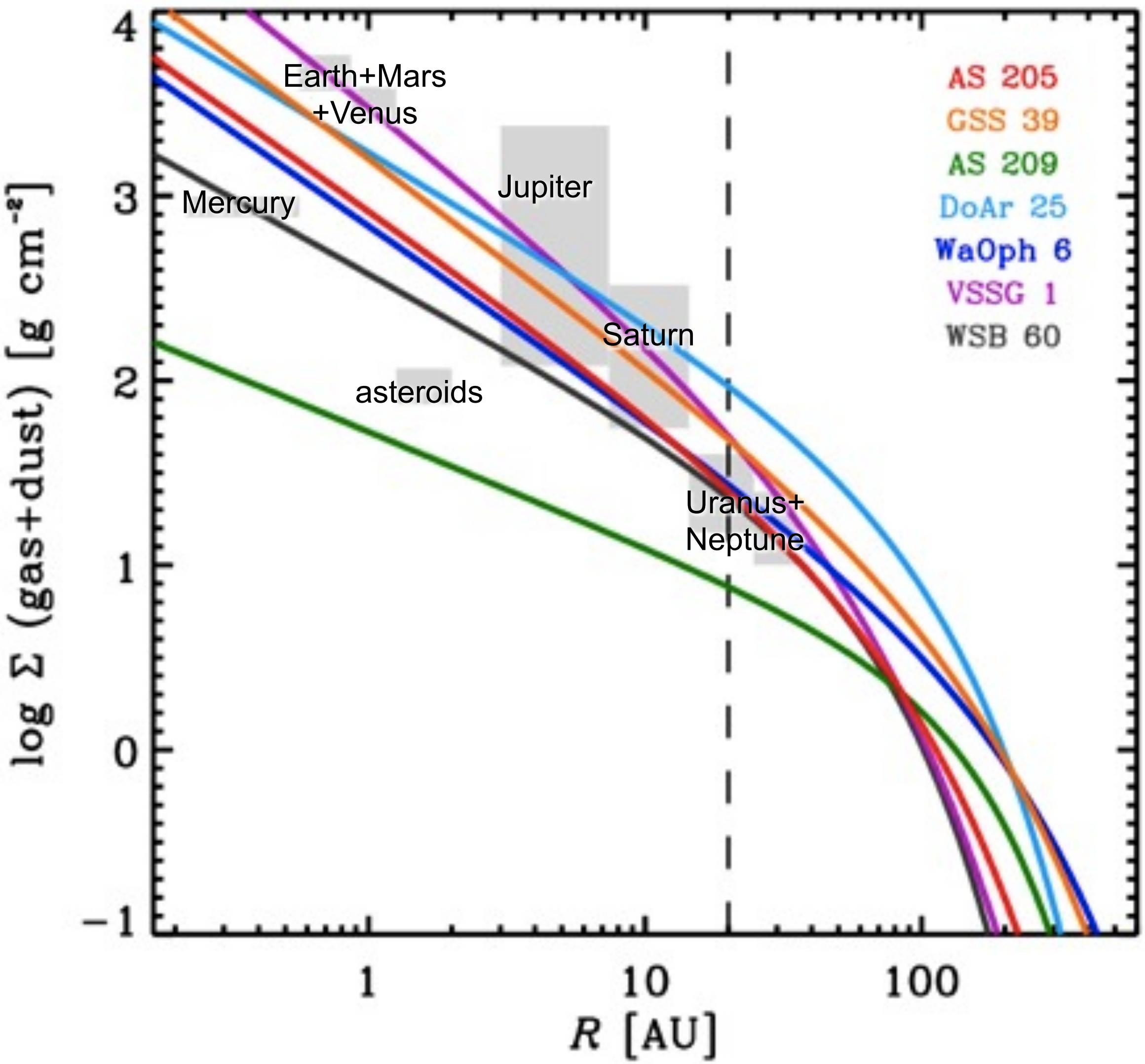
CQTau SMA/PdB/VLA
$\Sigma \sim r^{-p}$; p~-0.1
(Testi et al. 2001, 2003, Banzatti, LT et al. 2009)



Viscous disks

- Advanced topic:

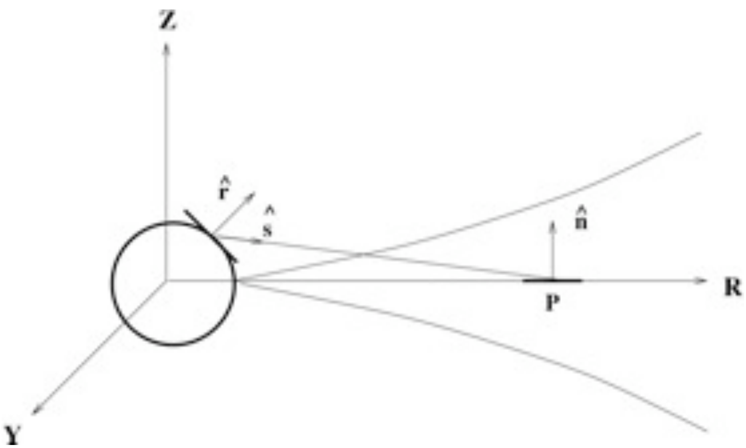


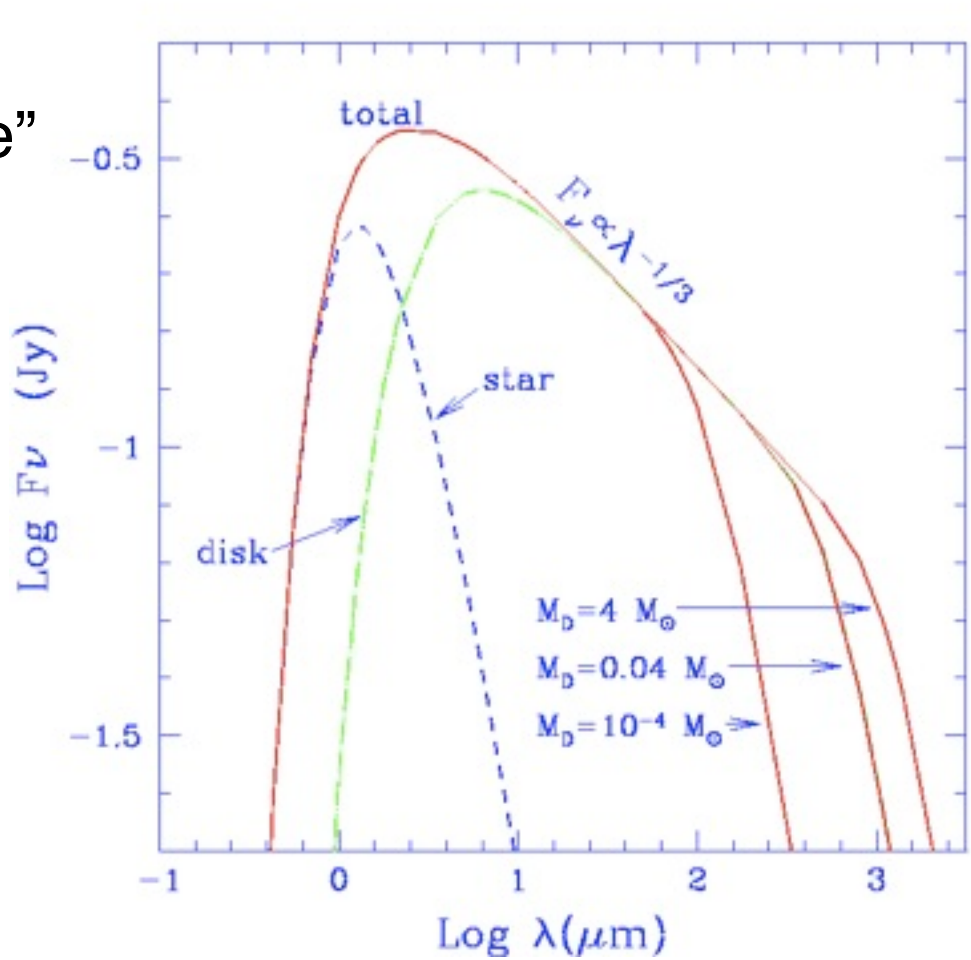


(Isella et al. 2009

Fflat accretion disk

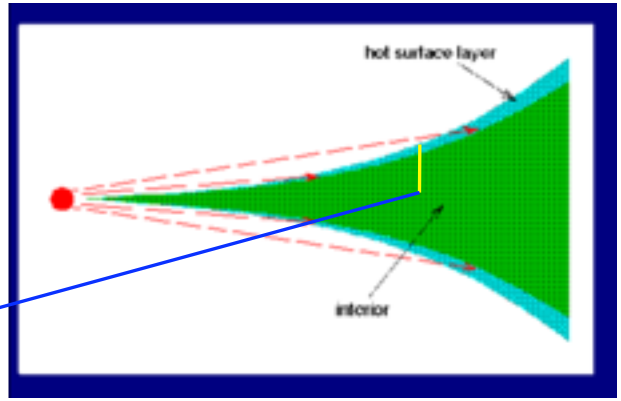
- Geometrically thin disks (in z):
  - Too cool to be "passive"
  - Too "active" to be consistent with measured accretion rates

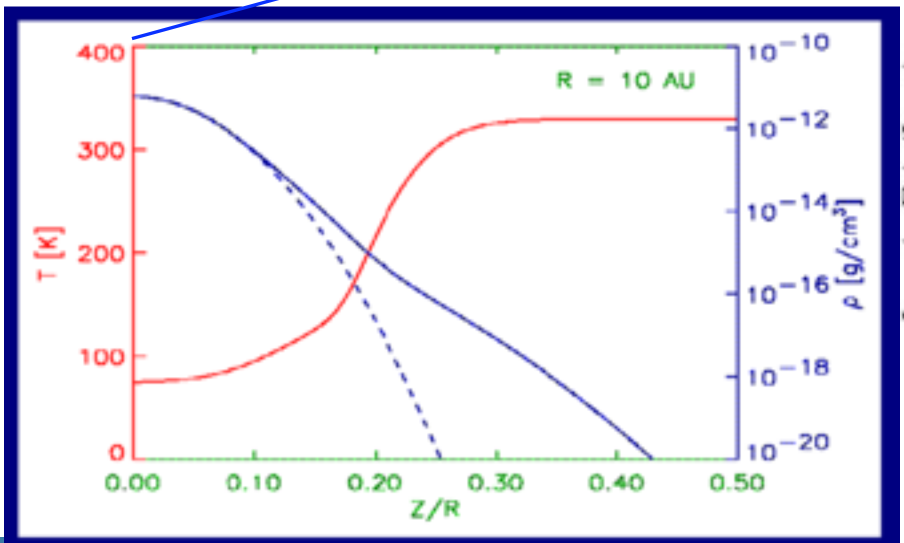


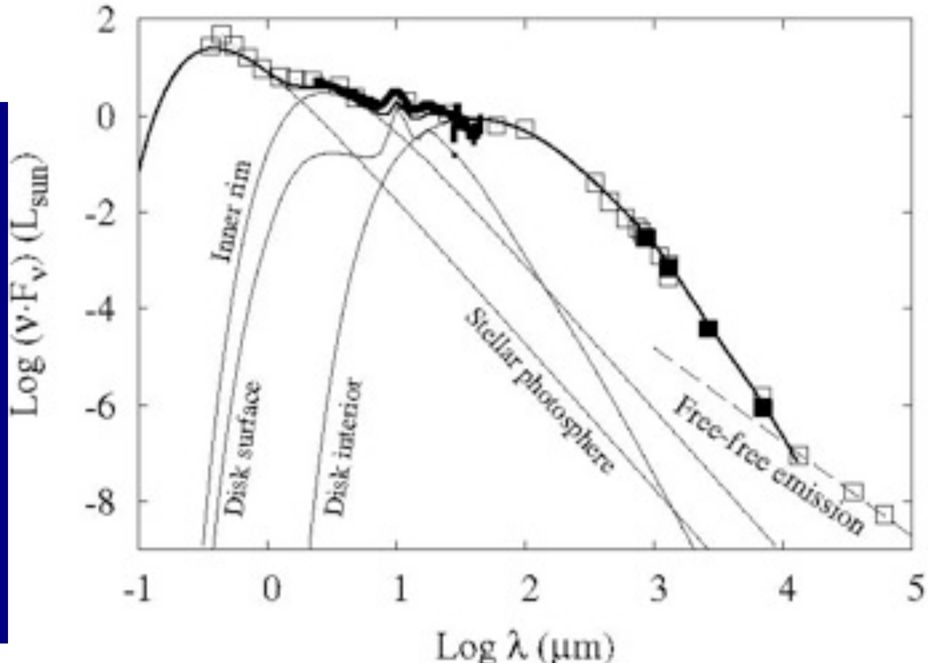


“Flared” disks

- Two components:
  - An optically thin surface layer (atmosphere)
  - A cool, optically thick inner layer which contains most of (~all) the mass

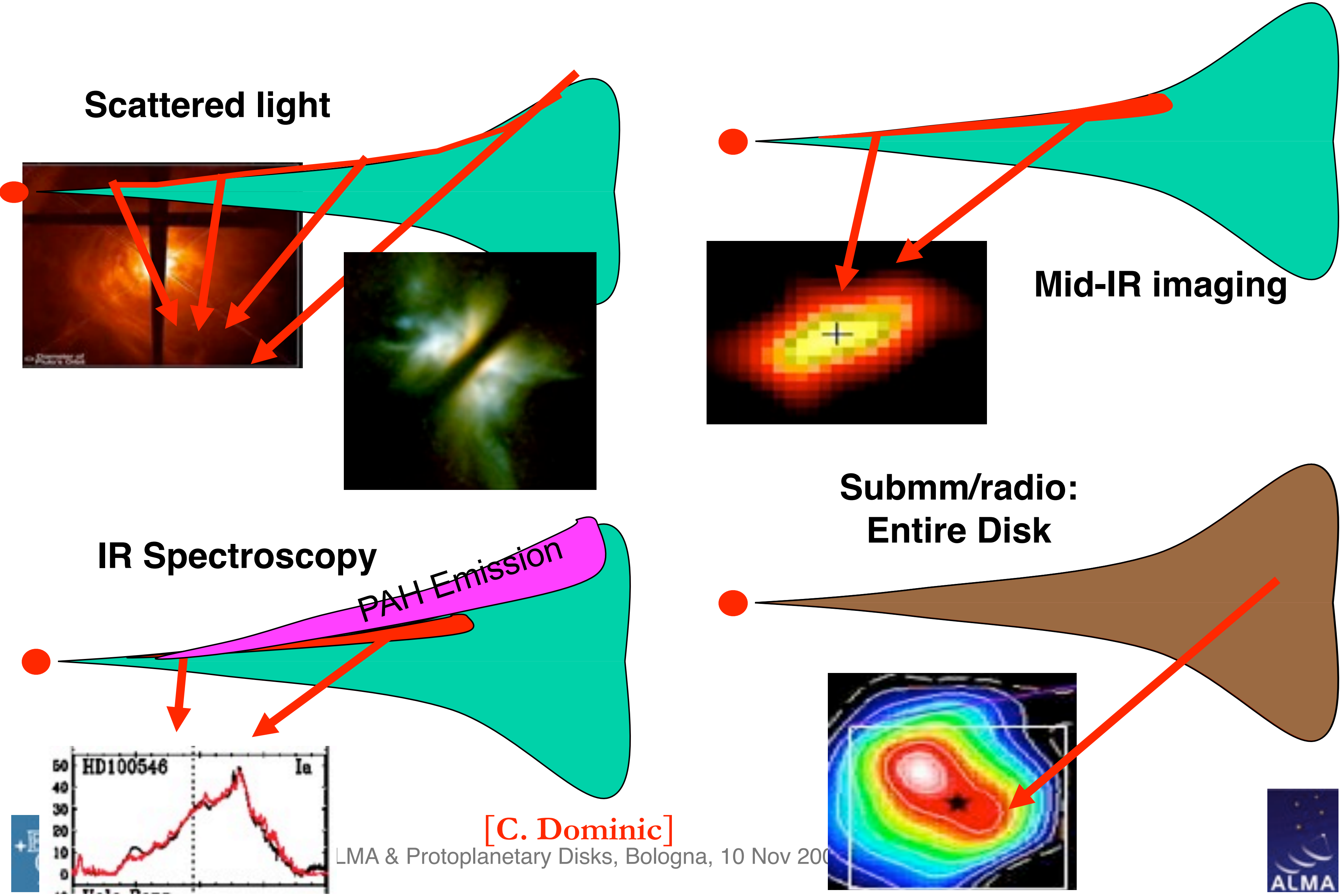






(Isella et al. 2007)

Which observations probe what?



Molecular gas

- Gas has to dominate the disk mass
  - From geometry : **H/R ~ 0.1 at 1 AU**

$$\frac{1}{\rho}\frac{\partial p}{\partial z} \sim \frac{p}{\rho z} = -\frac{GM_* z}{R^3}$$

$$\rho(z) = \rho(0)\ exp(-z^2/2H^2)$$

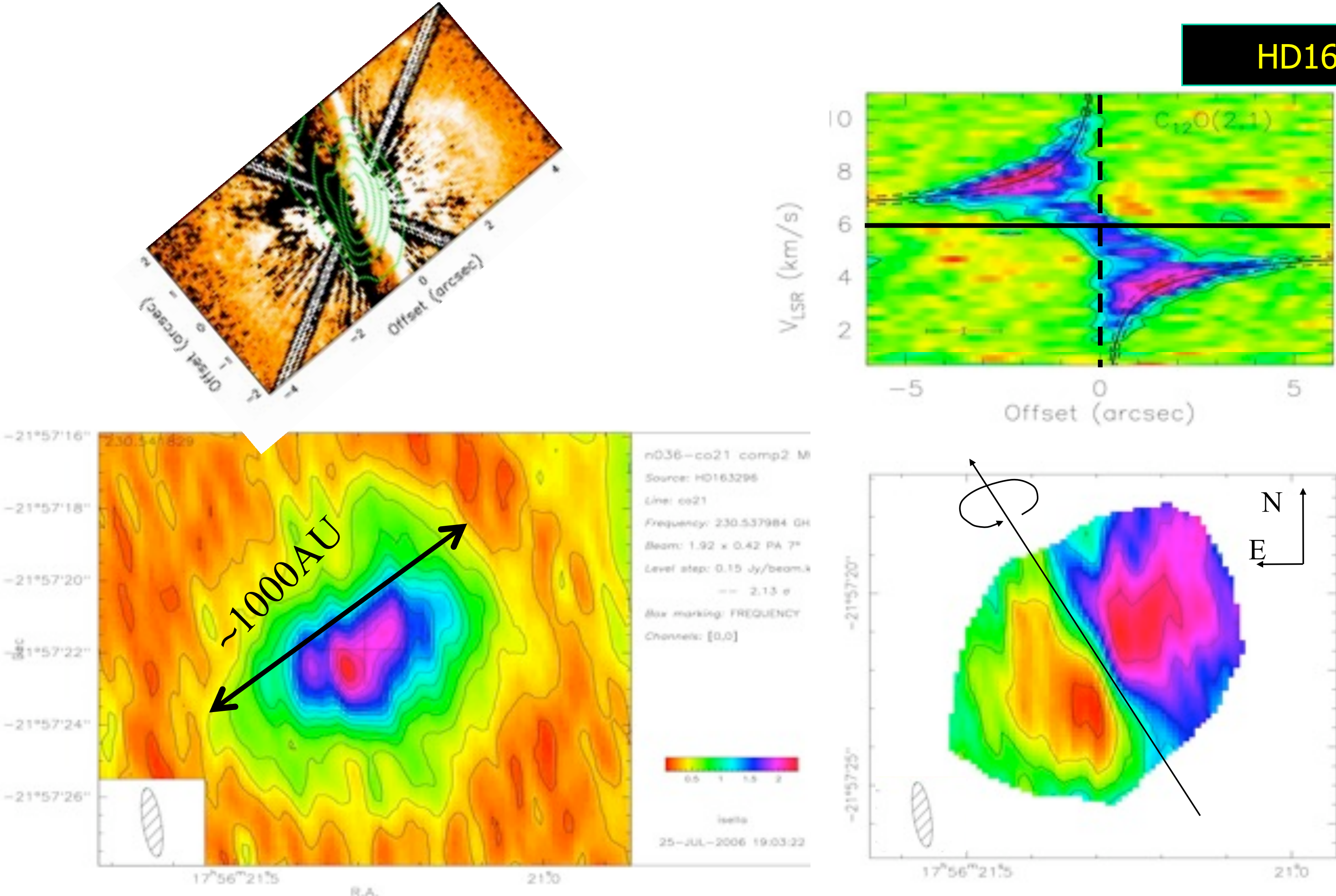
$$H/R = (T_d/T_g)^{1/2}\ (R/R_*)^{1/2}$$

$$T_g = \frac{GM_*\mu}{kR_*}$$

- Direct measurements:
  - Cold gas CO, … (outer disk)
  - Warm gas H_2, CO, H_2O(?) (inner disk)
  - Indirect: Accretion and Jets

Outer disks structure and kinematics

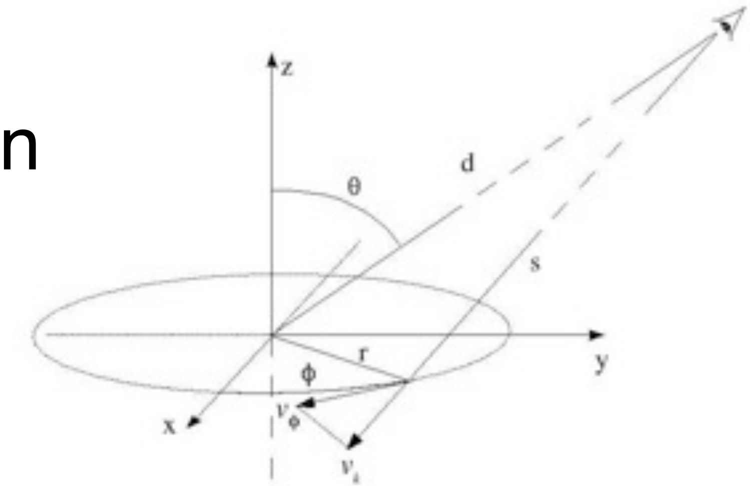
HD163296



(Isella et al 2007)

Molecular gas

- Calculation of the CO emission assuming thermalised gas



$$I_\nu = \int_0^\infty S_\nu(s) e^{-\tau_\nu}(s) K_\nu(s) ds$$

$$\tau_\nu(s) = \int_0^s K_\nu(s') ds' \qquad K_\nu^d(s) = \rho(s) \cdot k_\nu \qquad K_\nu^{CO}(s) = n_l(s) \cdot \sigma_\nu(s)$$

$$n_l(s) = \chi_{CO} \frac{\rho(s)}{m_0} \cdot \frac{g_l \, e^{-E_l/kT_{CO}(s)}}{Z(T_{CO}(s))}$$

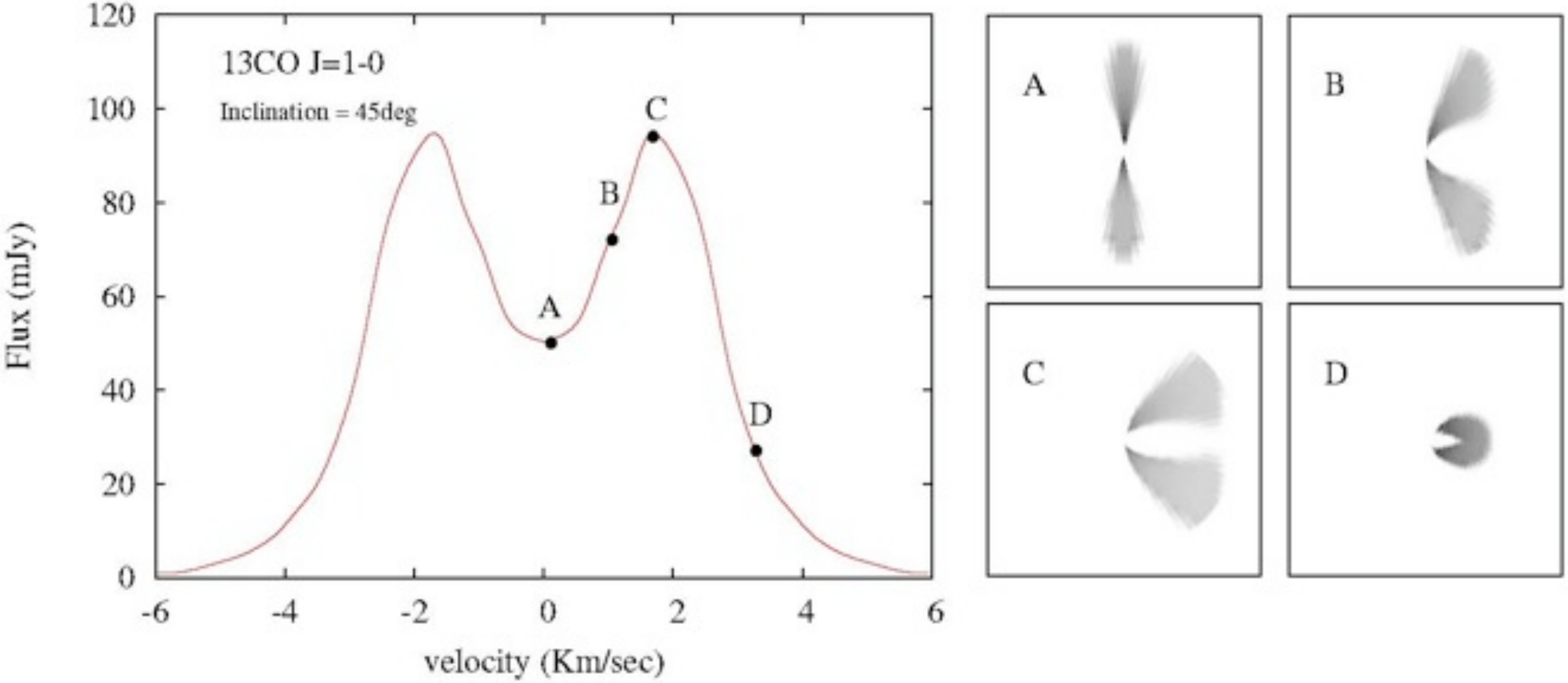
$$S_\nu(s) = B_\nu(T_{CO}(s)) = \frac{2h\nu^3}{c^2} \frac{1}{\exp(h\nu/kT_{CO}(s)) - 1}$$

$$T_{CO}(r) = T_{CO}(r_0)(r/r_0)^{-q}$$

(Isella et al. 2007)

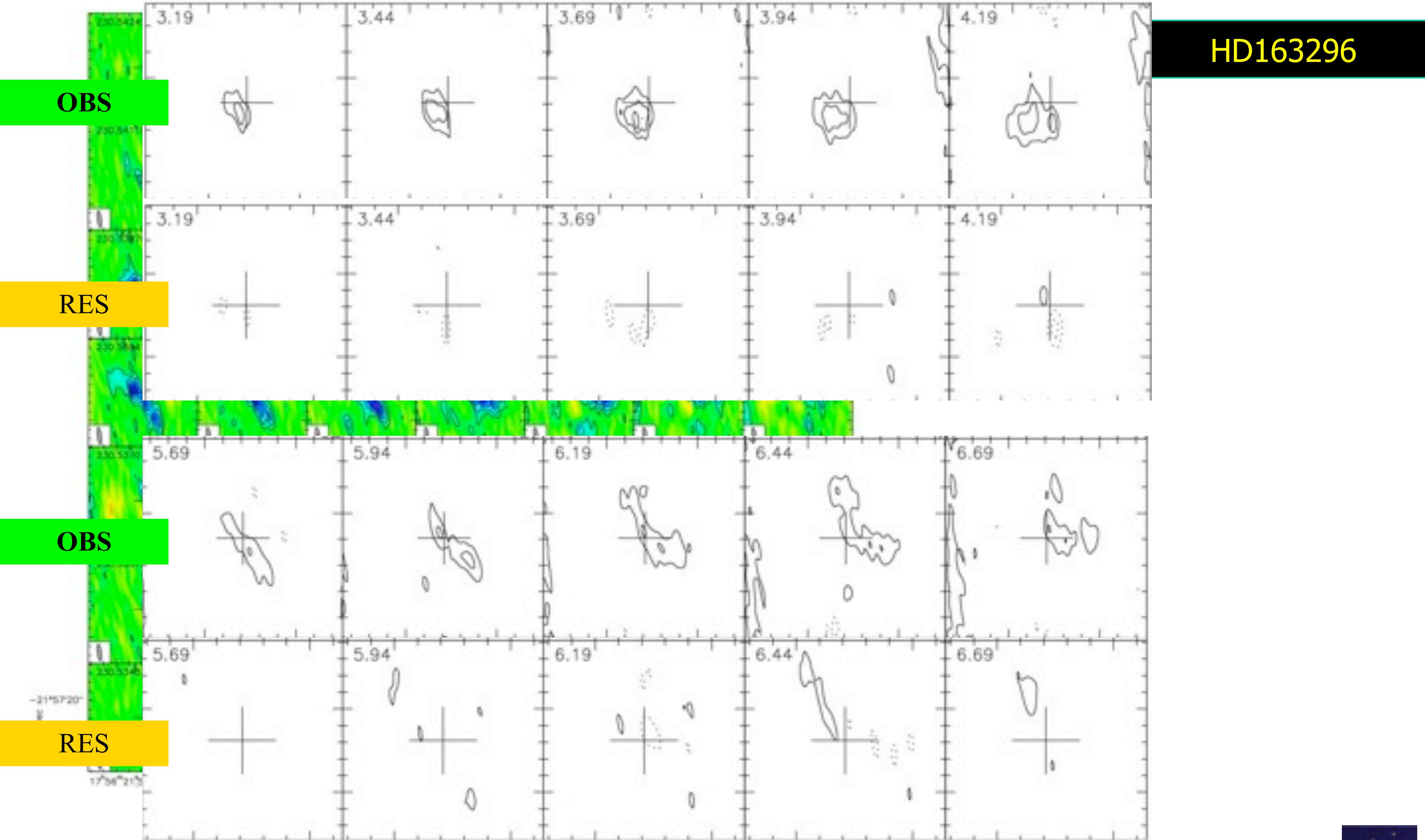
Molecular gas

✦ Simulated CO profiles and maps



(Isella et al. 2007)

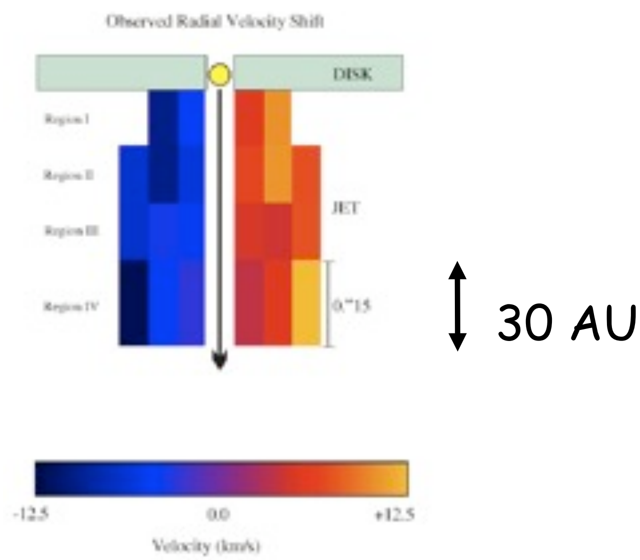
Outer disks structure and kinematics



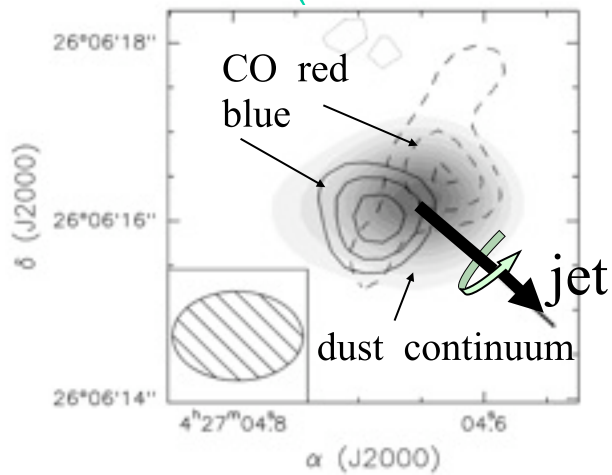
(Isella et al. 2007)

Gas properties and evolution

- Kinematics
  - Disk-outflow interaction
  - Possible evidence for non keplerian motions
- Physical properties
  - Temperature, density structure
  - Abundance, gas to dust ratio
- Chemical properties
  - Formation of complex molecules
  - Chemical differentiation in different regions of the disk



(Bacciotti et al 2002)



(Testi et al.2002)

Gas properties and evolution

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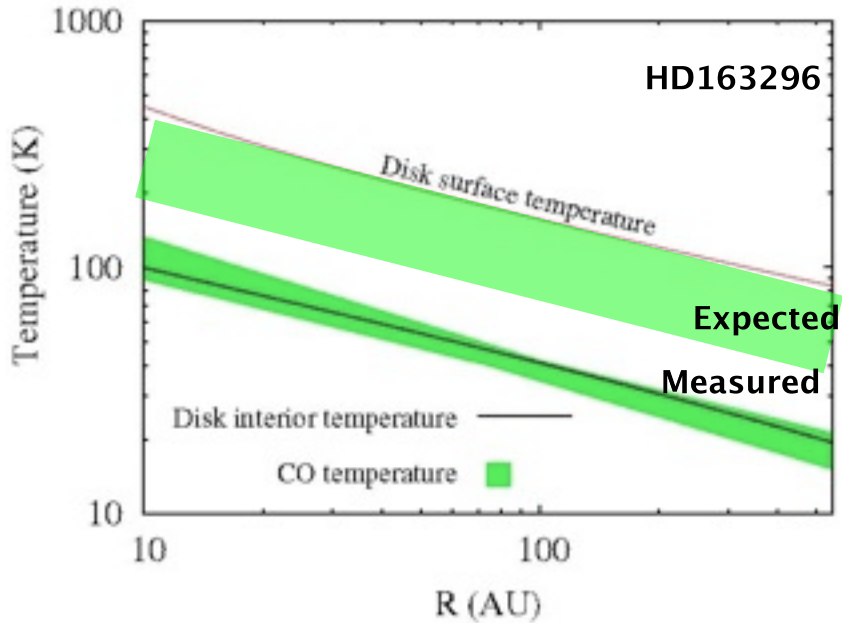


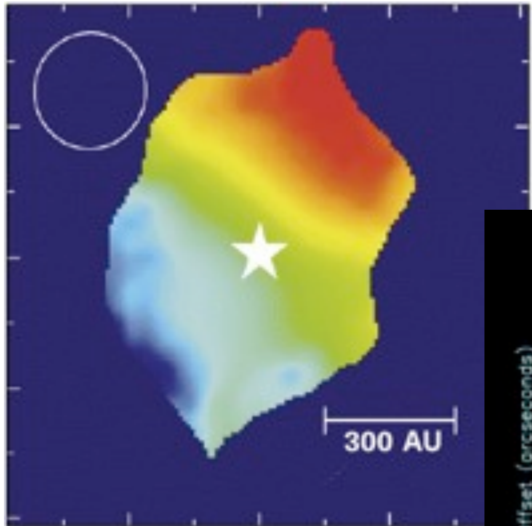
CO isotopes depletion factors:

$^{13}CO \Rightarrow \sim 10$ $([^{13}CO]/[H_2] \sim 10^{-7})$

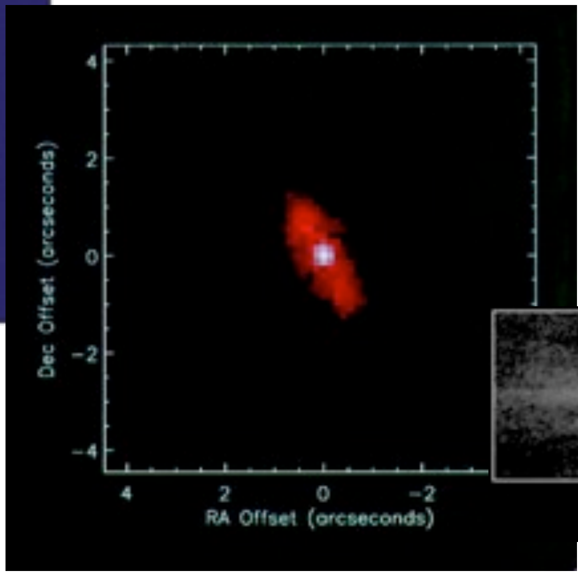
$C^{18}O \Rightarrow >60$

Disk Evolution

- There is evidence that disk evolution and planet formation systems may occur on timescales of a few million years



MWC 480
Young gaseous disk – 6 Myrs
CO(2-1): Mannings et al 1997

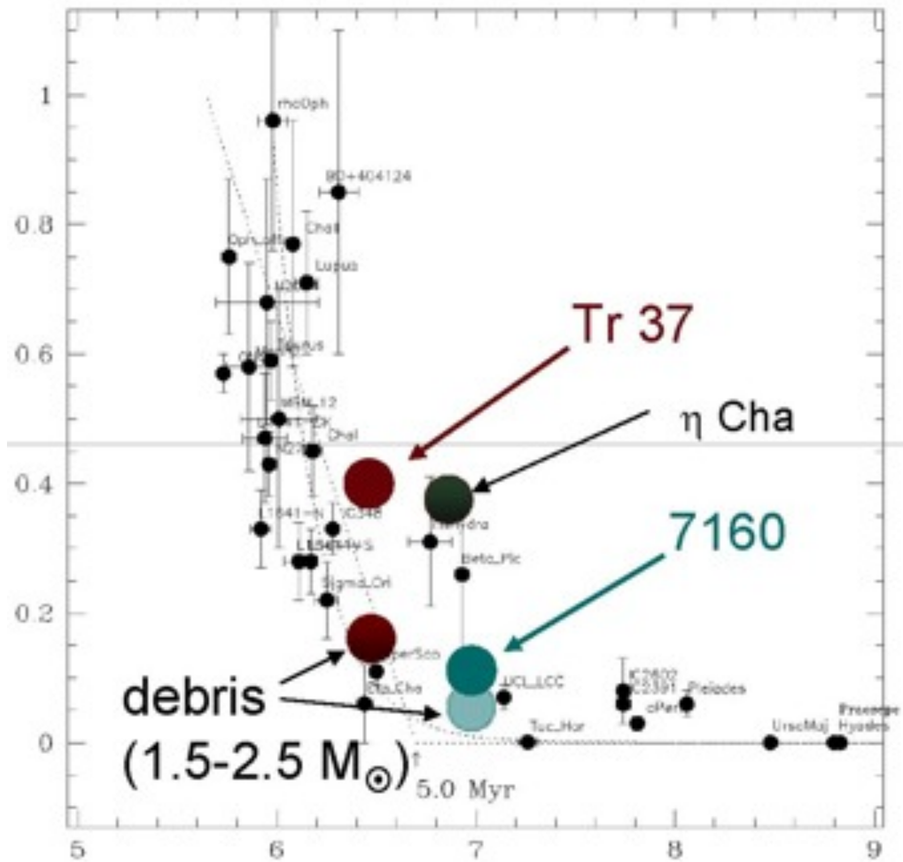


HR 4796 A
Evacuated inner disk – 15Myr
MID-IR: Koerner et al. 1998

ß Pic
Debris disk – 100 Myrs
Scattered light: Burrows et al. 1995

Inner disk clearing

- Evolution of the fraction of infrared excess sources in clusters
- In 1-2Myr 50% of the sources have lost teir inner disk
- Debris disks begin to appear at 5-10Myr



From dust to planets

Observations provide constraints to models that bridge the "gap"

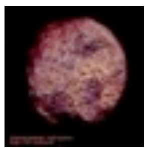
Directly observable through IR and mm observations

?

Exo-planets

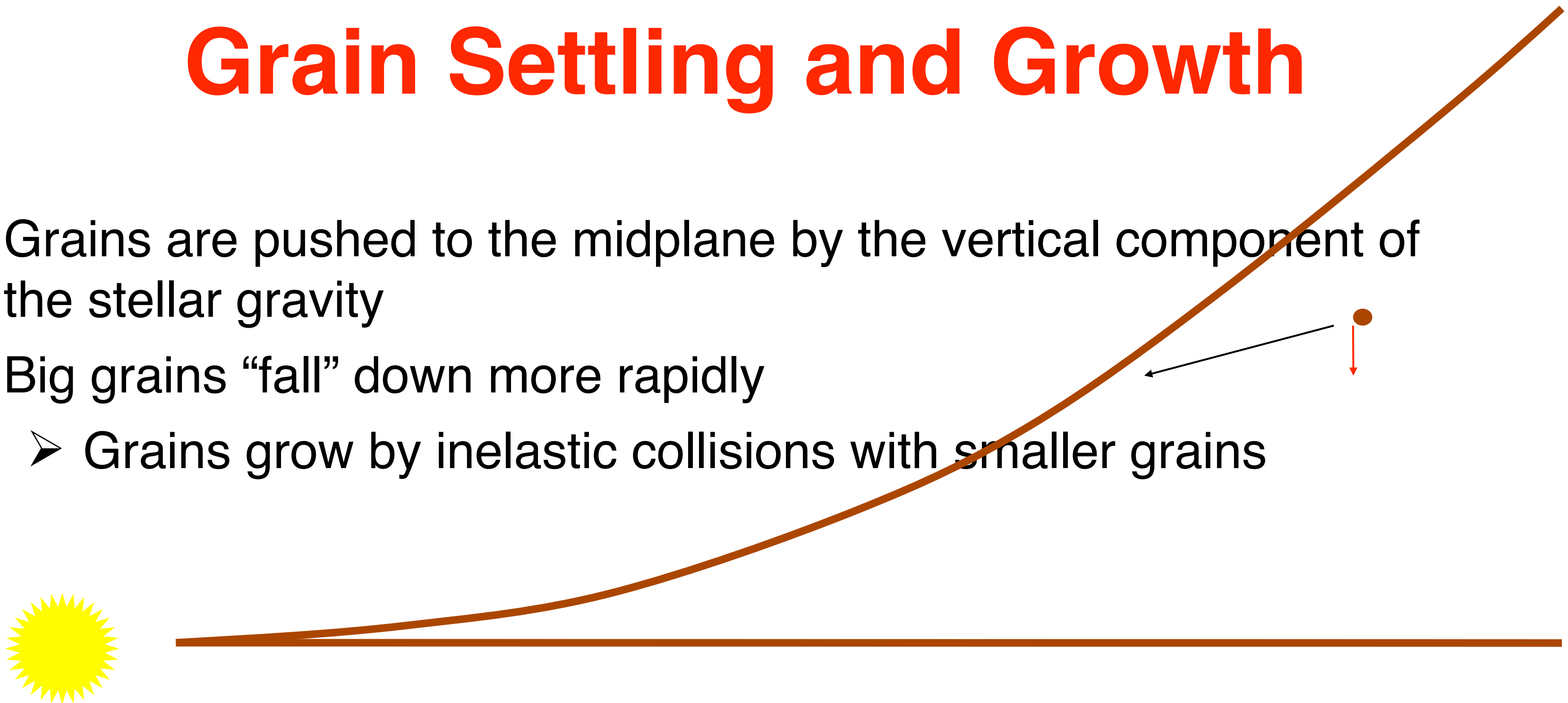
Solar system constraints (but only 1 object! And 4.5 billion years ago!)

1μm — 1mm — 1m — 1km — 1000km



Grain Settling and Growth

- Grains are pushed to the midplane by the vertical component of the stellar gravity
- Big grains "fall" down more rapidly
  - Grains grow by inelastic collisions with smaller grains



- The process is very fast and rapidly produces a vertical stratification of grain properties
- Turbulence, mixing and destructive collisions have to slow down this process
  - Need to maintain the "flaring" (SED)
  - Big grains are present also in the disk atmosphere

Circumstellar disks @ mm-λ

- At long wavelegths the thermal emission from dust grains in circumstellar disks becomes optically thin
- mm observations are a powerful (in most cases the only) probe of the dust population on the disk midplane
- The observed millimeter spectral energy distribution depends “only” on the number, temperature and emissivity of dust grains
  - Assuming a grain mixture at a defined temperature, the measured flux at a given wavelength is proportional to the total dust mass
  - Measuring the continuum emission from dust grains at several wavelengths we can set constraints also on the combination of the dust properties ad the disk structure
  - With the aid of appropriate disks models and of spatially resolved images of disks it is possible to constrain the geometry and physical properties of the dusty disks

(sub)mm continuum emission

$$F_\nu = \frac{\cos\theta}{D^2}\int_{r_i}^{r_o} B_\nu(T_d)(1-e^{-\tau_\nu})2\pi r dr$$

$$T_d \sim r^{-q}$$

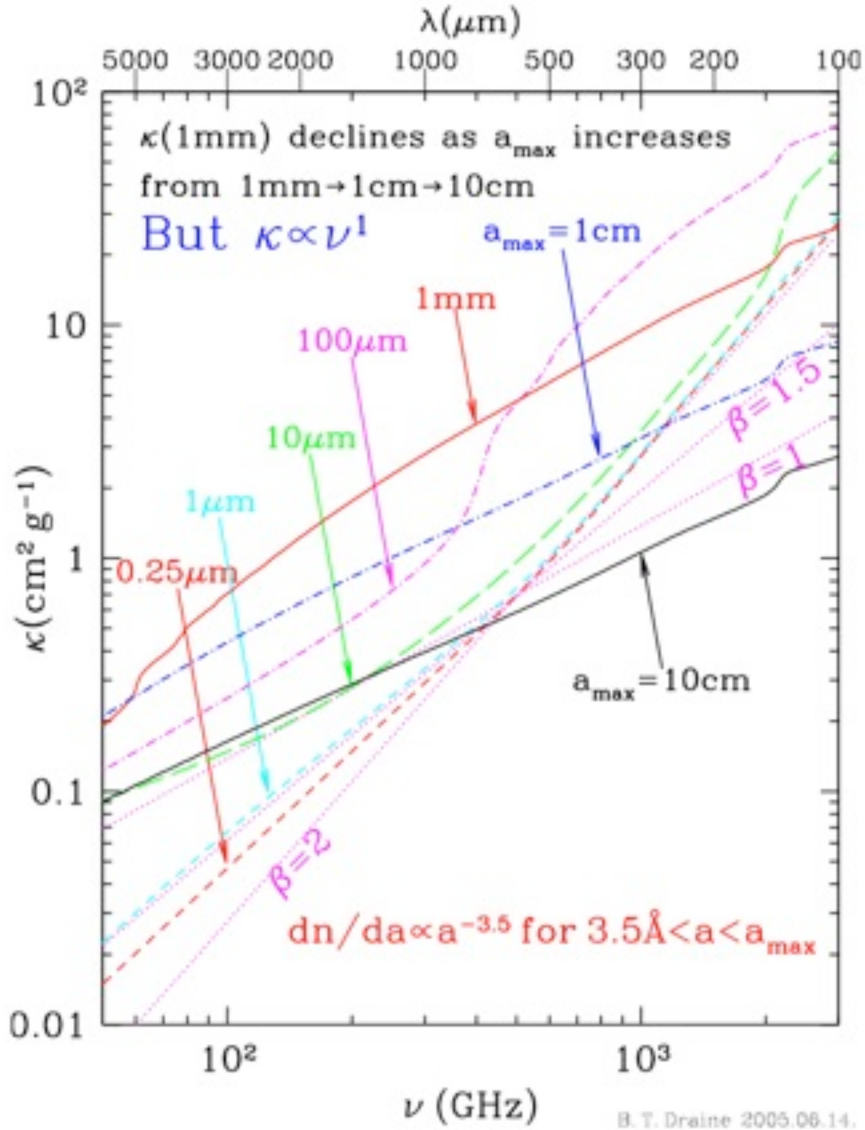
$\tau_\nu \propto \Sigma(r)\kappa_\nu$ $\Sigma(r)\propto r^{-p}$ $\kappa_\nu \propto \kappa_o \nu^\beta$

$\tau_\nu \ll 1$ $T_d \approx$ const.

$F_\nu \sim \kappa_\nu\ B_\nu(T_d)\ M_d$

$F_\nu \sim \kappa_\nu\ \nu^2\ T_d\ M_d$

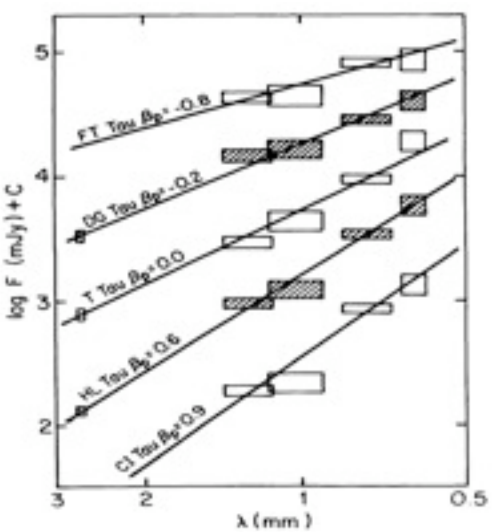
$F_\nu \sim \nu^{2+\beta}$



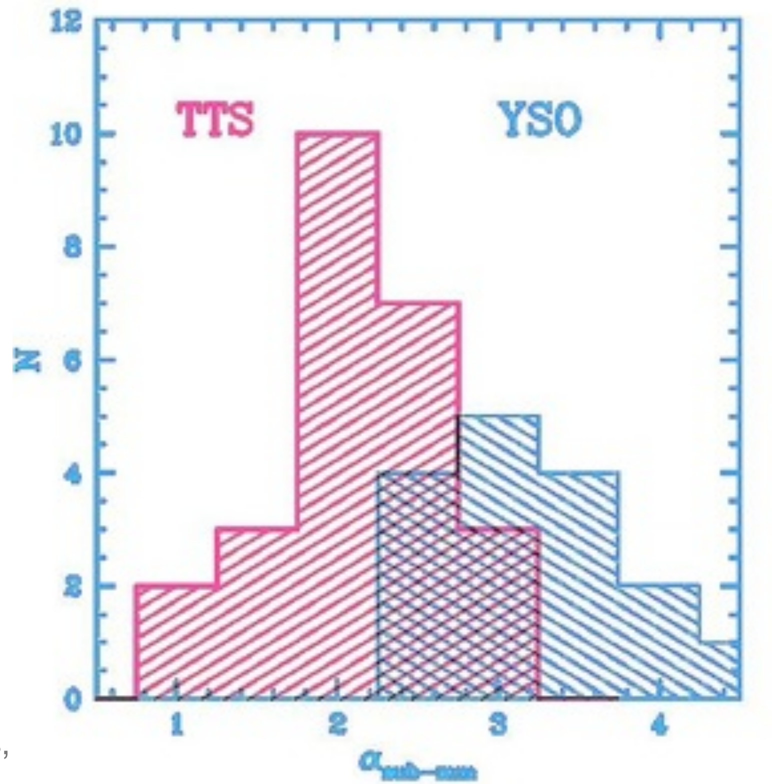
(Draine 2005)

Evolution of dust in disks

- Search for the presence of large (cm-size) grains
- The basic idea is to search for mm spectra that approach the black body spectrum
  - limit for optically thick disk or grey dust (size>>λ)
- $[F_\nu \sim \nu^\alpha; \alpha=2+\beta; \kappa_\nu \sim \nu^\beta]$



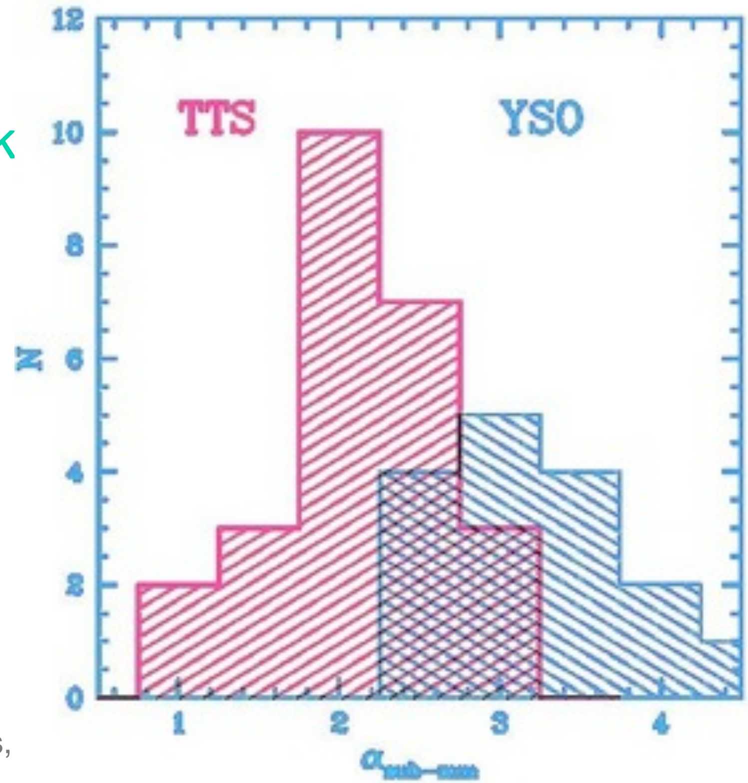
Single dish α_{sub-mm}
(Beckwith & Sargent 1991)



Evolution of dust in disks

- Search for the presence of large (cm-size) grains
- The basic idea is to search for mm spectra that approach the black body spectrum
  - limit for optically thick disk or grey dust (size>>λ).
- $[F_\nu \sim \nu^\alpha; \alpha = 2+\beta; \kappa_\nu \sim \nu^\beta]$

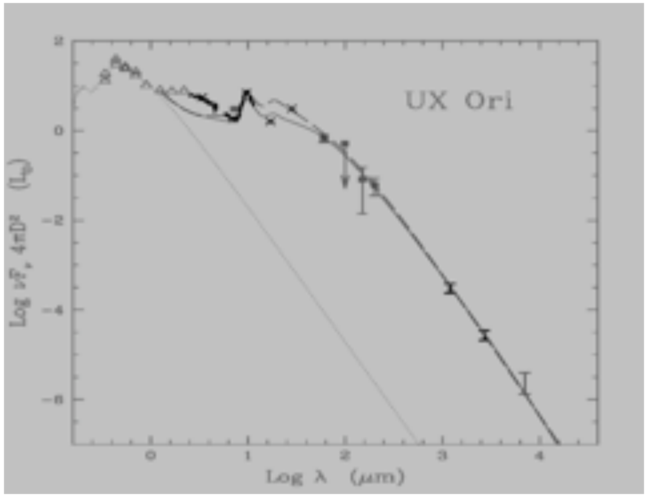
- Disks may be optically thick
- Need to go to longer λ
- Worry about free-free
- Need to resolve disks
- Need to use disk models



Single dish α_{sub-mm} (Beckwith & Sargent 1991)

Evolved dust in HAe disks

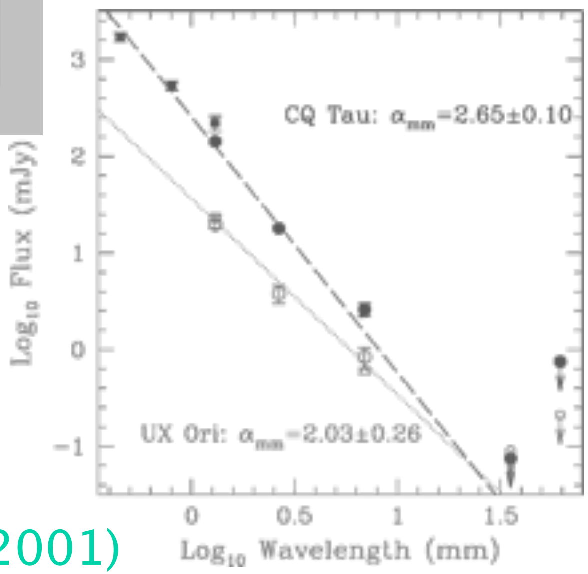
- 1 to 7 mm observations with OVRO/PdBI and the VLA

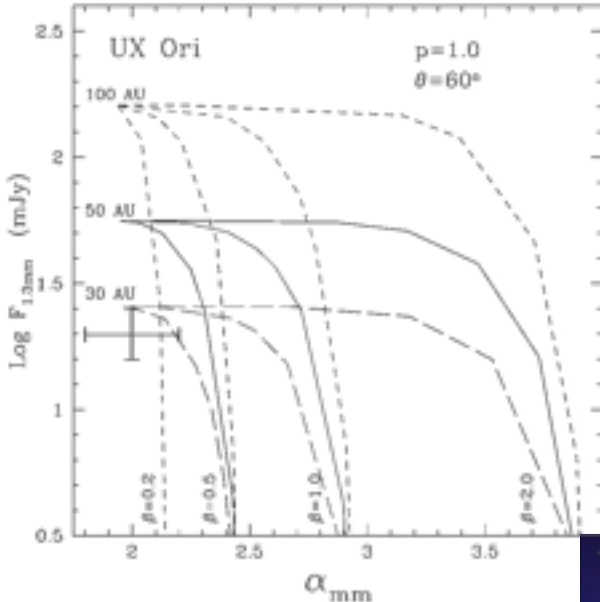


1. Very small, optically thick, ISM grains disk
2. Large disk with very large (few cm size) grains

PdBI 1.2 & 2.7 mm
VLA 7mm and 3.6cm

α_{mm}~2.0; β~0.1
a ≥ 10cm (Testi et al. 2001)





Evolved dust in HAe disks

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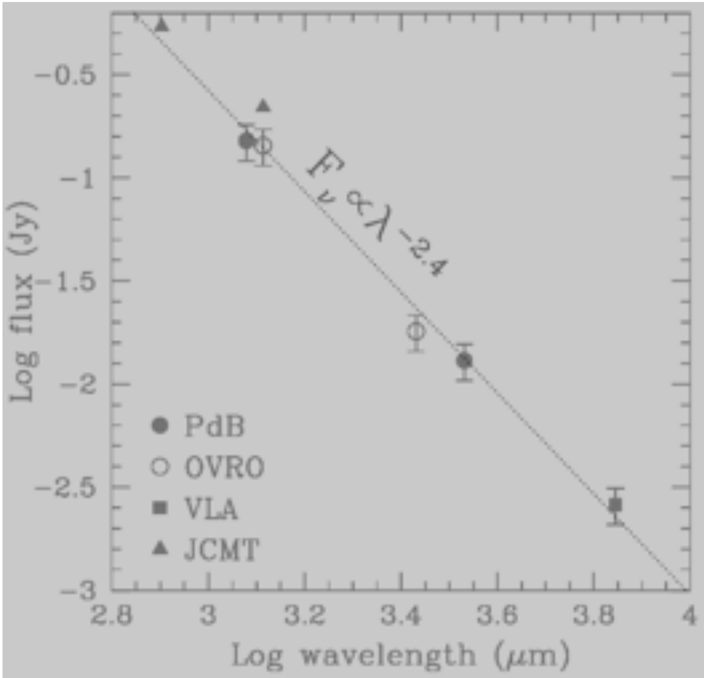
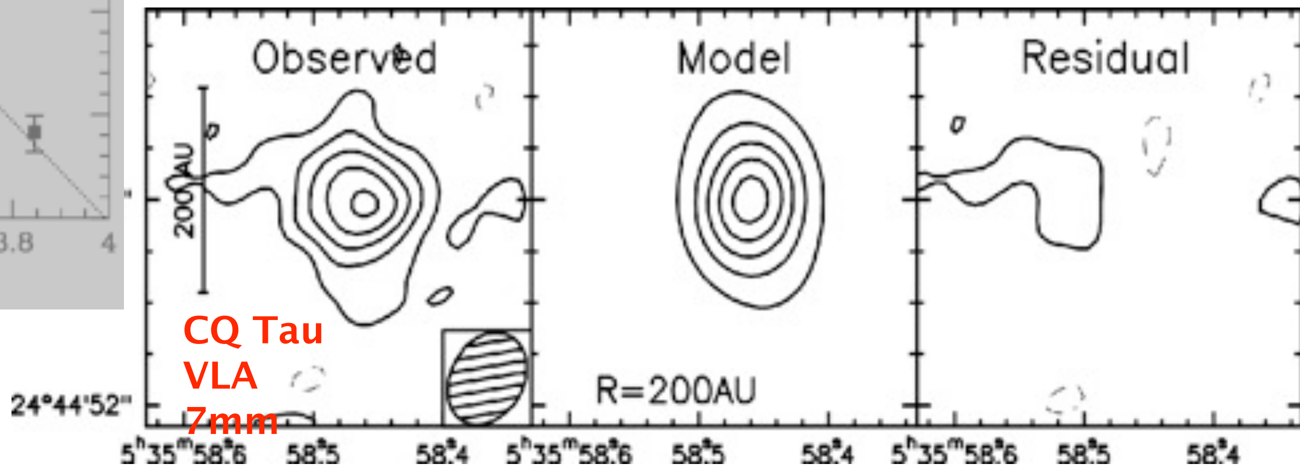


Disk resolved at mm wavelengths:

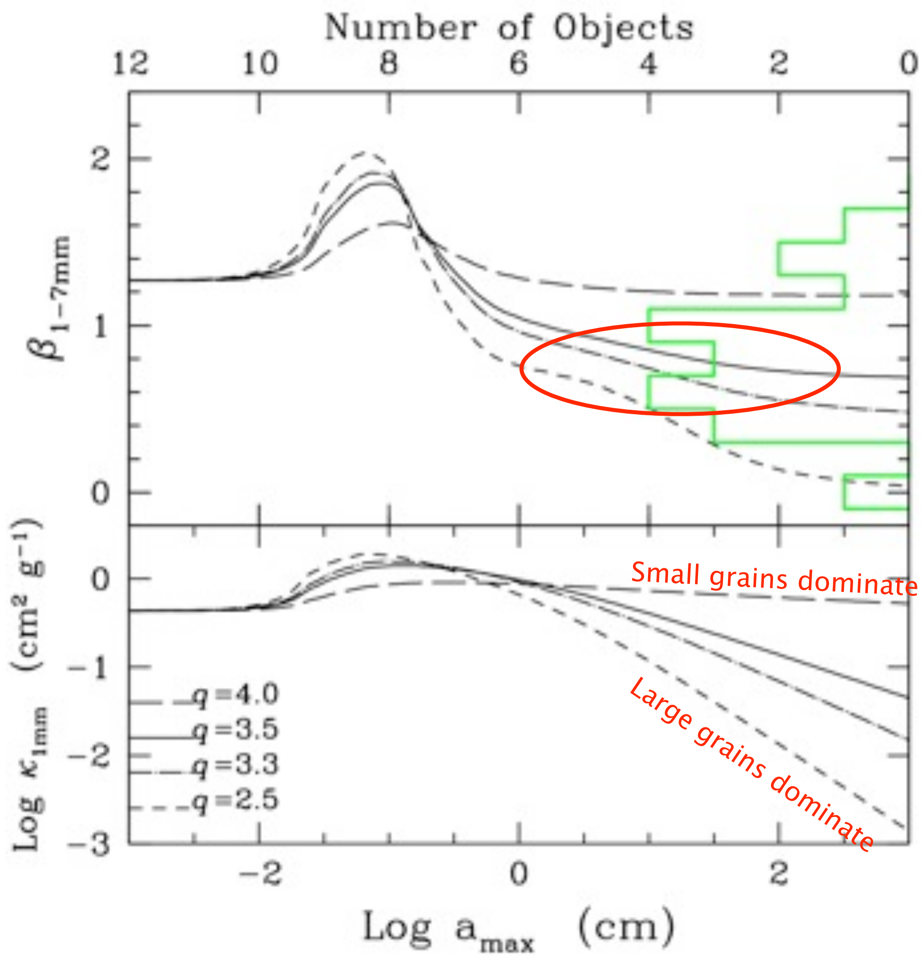
- **Disk size**
- **Surface density profile**
- **Dust emissivity index**



α_{mm}~2.4; p~1.5; β~0.6 (Testi et al. 2003)

β, grain sizes, k and disk masses

- Grain size distributions with very large upper cutoff explain the observed low values of β
- Opacity and mass is dominated by the upper end of the distribution
- Using the appropriate dust opacity coefficients: $M_{dust} \sim 10^{-2/-3} M_{sun}$ => original disk mass 0.1-1 M_{sun}
- Size distribution need to be cut at "observed" size



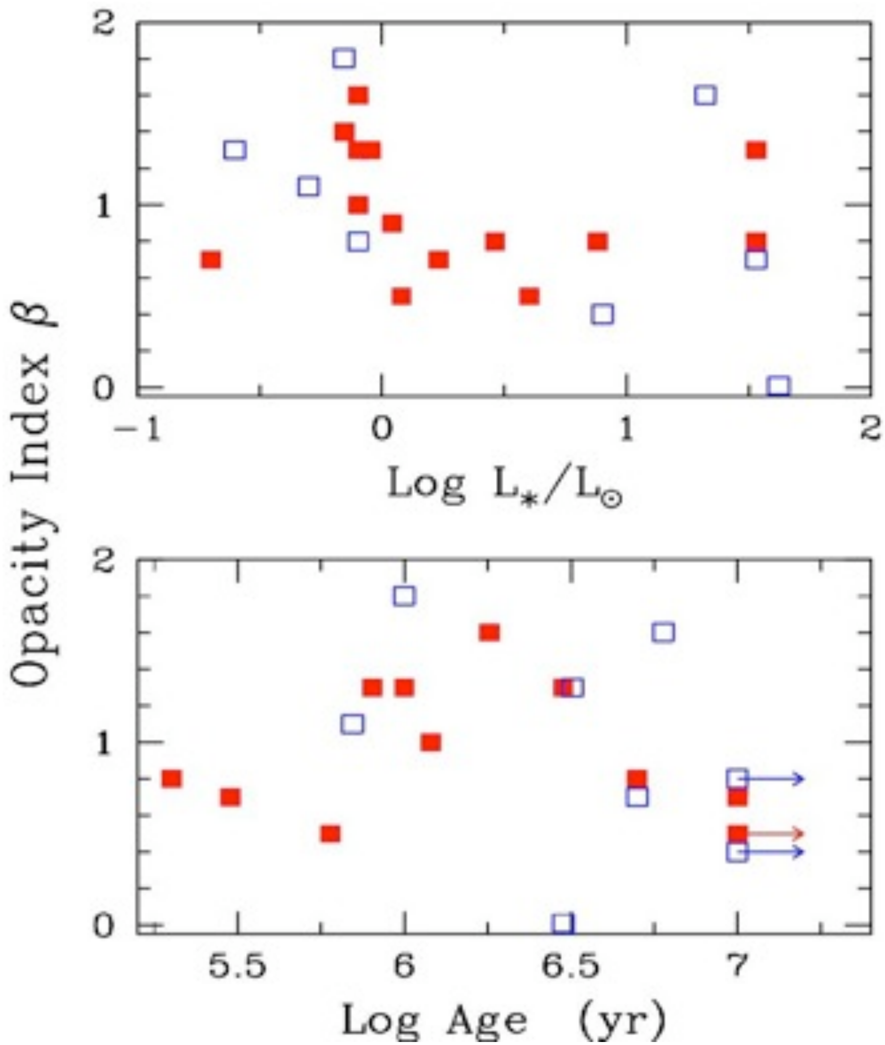
Data:
HAe (Testi et al. 2001; 2003; Natta et al. 2004)
TW Hya (Wilner et al. 2000;Calvet et al. 2002)
TTauri stars (Rodmann et al. 2005)

(Natta & LT 2004; Natta, LT, et al. PPV)

Large grains in HAe and TTS systems

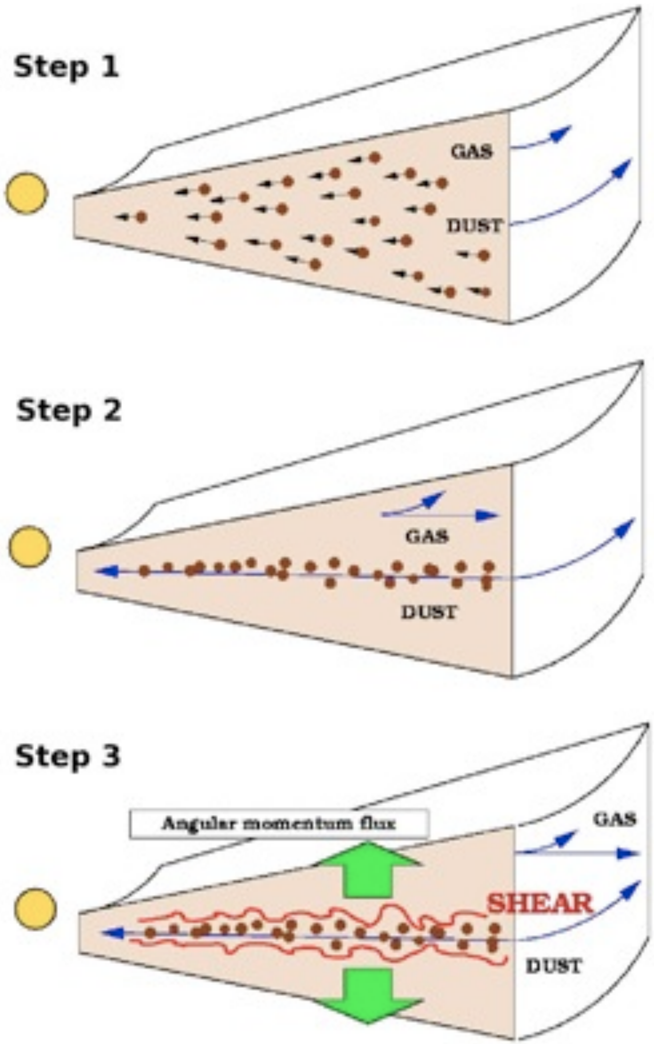
- Values of β range from 1.8 to 0.1 (from ISM grains to pebbles)
- No obvious correlation with stellar properties
- No obvious correlation with age
- No obvious correlation with disk surface grains
- ???
- Caveat: "large disks" small, biased samples

Data:
HAe (Testi et al. 2001; 2003; Natta et al. 2004)
TW Hya (Wilner et al. 2000;Calvet et al. 2002)
TTauri stars (Rodmann et al. 2005)

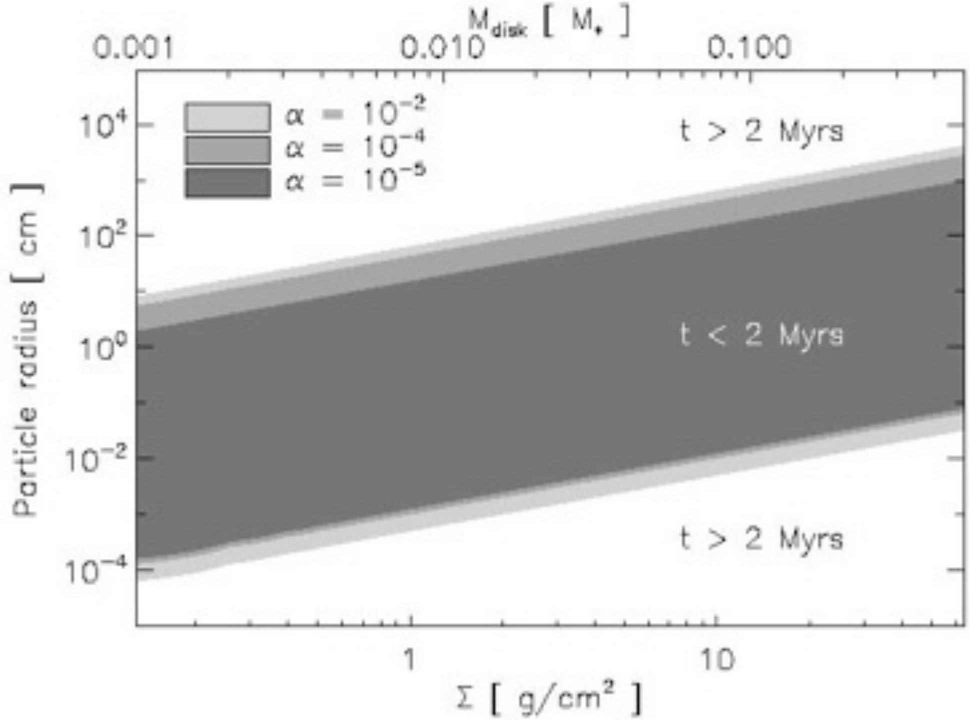


(Natta, LT, et al. PPV)

Pebbles should not survive in disks!

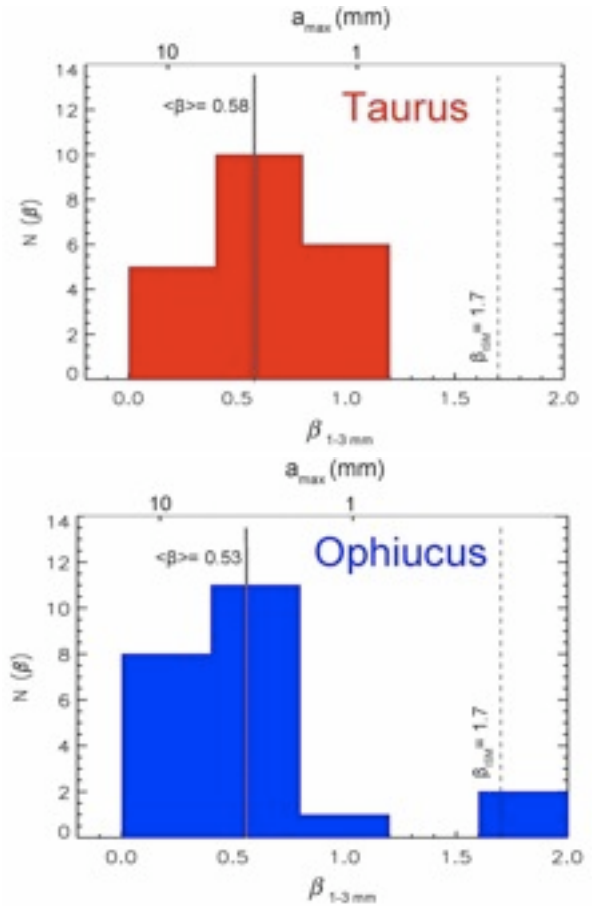


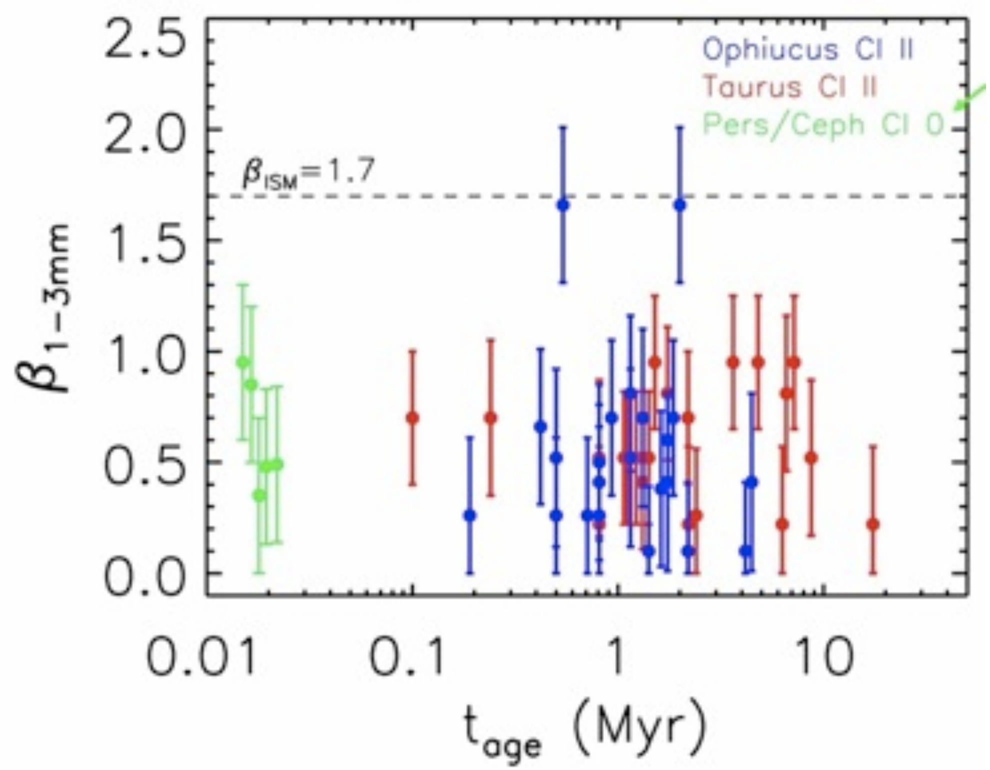
(Brauer et al. 2007)



- Radial drift of mm-cm size particles at r~100AU can be very fast
- Viscosity, porosity, gas/dust ratio
- Trapping in disk patterns
  - Vortices, spiral arms…

Deep survey for large grains in Tau/Oph

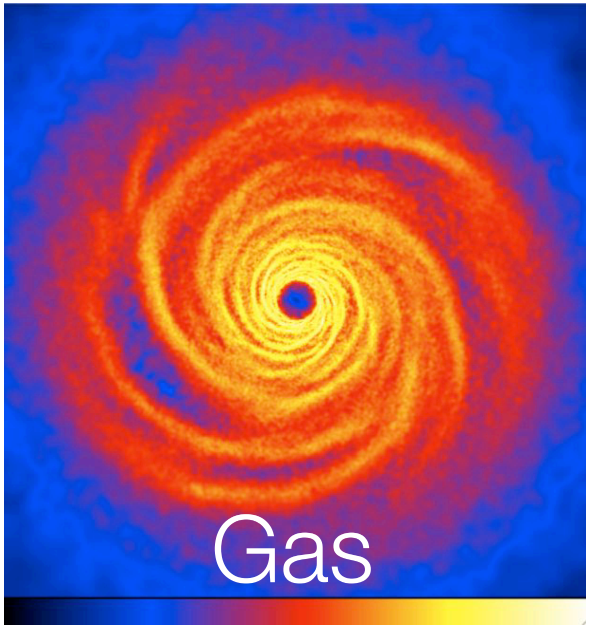


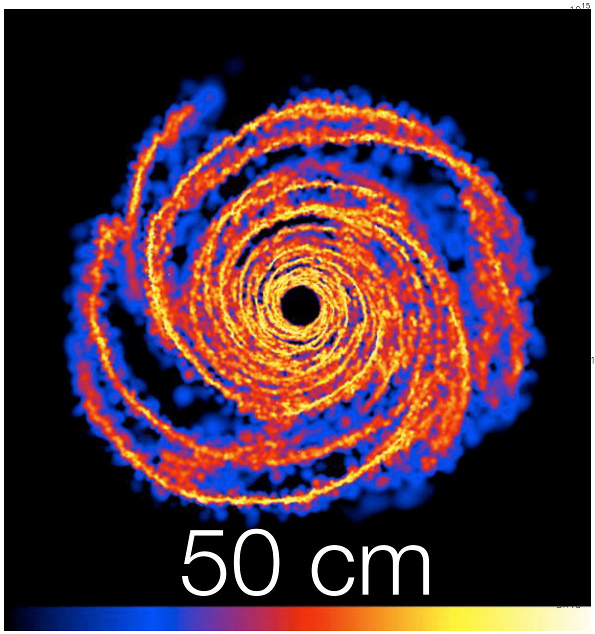


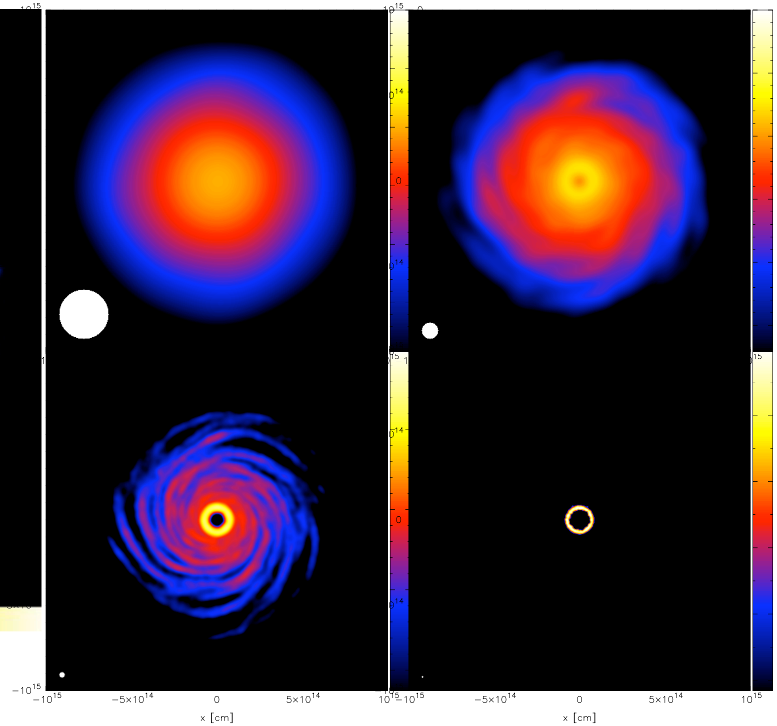
- Large PdBI, ATCA & VLA survey to measure the long wavelengths emission from disks; 43 single, well characterized young stars
- Most disks have low values of β: early growth, slow evolution

(Ricci, LT, et al. 2009; 2010)

Gas density maxima and grain trapping



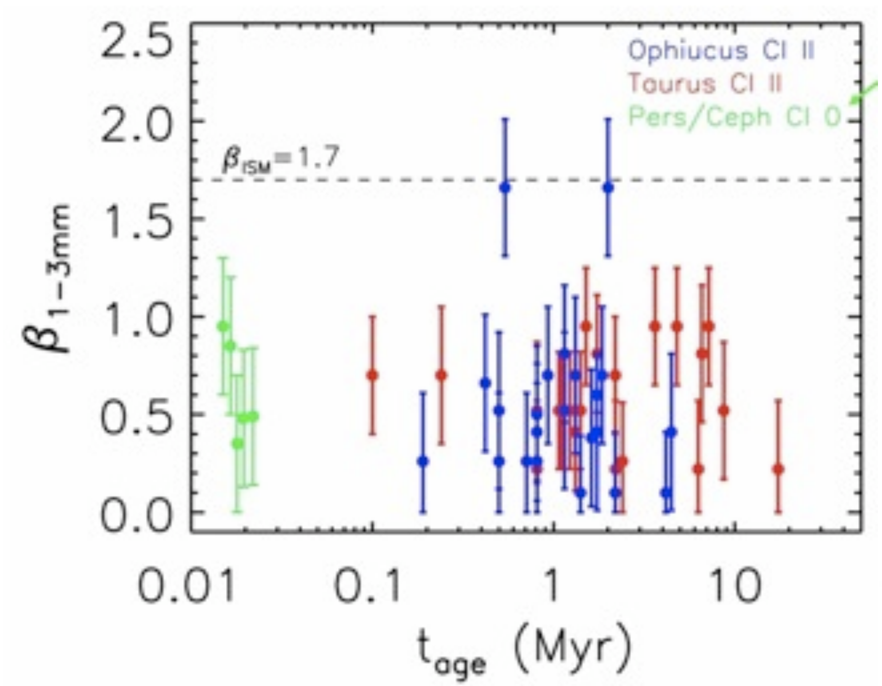




- Particles that are not tightly coupled with the gas tend to move towards pressure maxima
- Pressure maxima in the gas can be caused by various process. e.g. in the simulations of Lodato, Rice et al. this is caused by gravitational instabilities

State of the Art & Future Directions

- Grains grow and settle in disks around all type of PMS objects
- Grain evolution can be very fast as we see highly processed grains around objects of all ages between 1 and 10 Myr
- It is difficult to derive a consistent picture of grain evolution because different observations probe different regions of the disks and samples are still small



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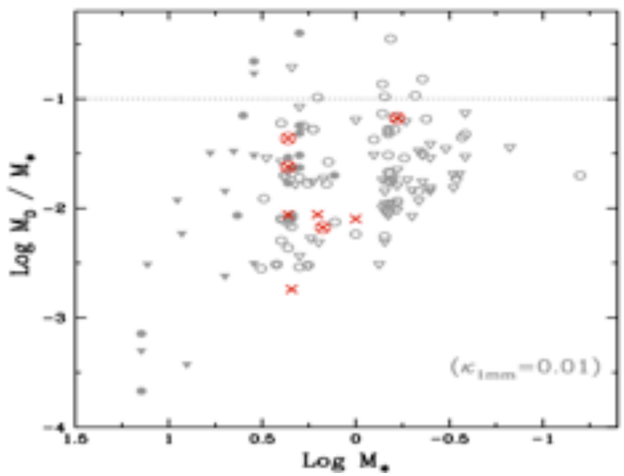
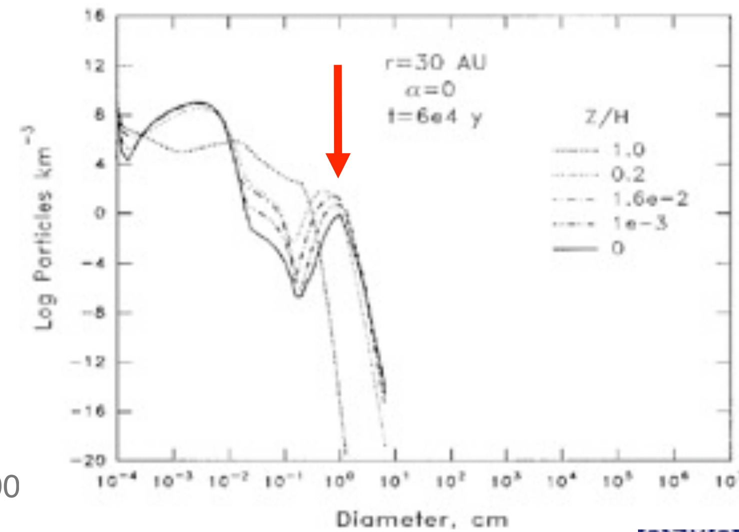
  - Large bodies, if present, do not dominate the solid mass of the disk up to 5-10 Myr
- Growth to pebbles is very fast, but converting a significant mass to 1m-size planetesimals seems more difficult (or requires more time)
  - ~~Or perhaps we are just observing the odd beasts?~~





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- Timescale for settling and growth: is dust evolution occurring in Class 0/I phase?
  - Early planet formation? Grain trapping?
- Large grains should be dragged to the central star on very short timescales, why do we see them at all?
  - Resolve the radial dependence of Grain Growth in disks