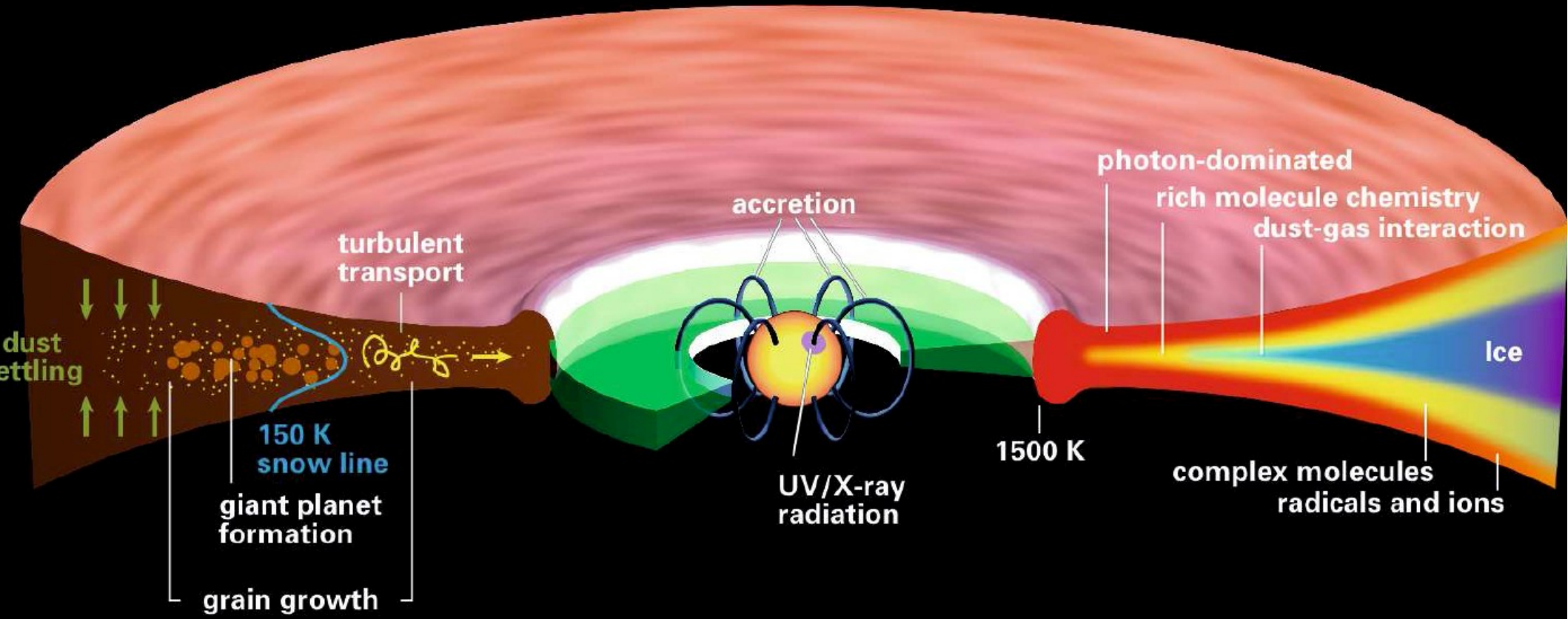
(sub-)mm, high angular resolution observations of protoplanetary disks: PdBI/NOEMA & ALMA

Vincent Pietu (IRAM)

A. Dutrey, S. Guilloteau, L. Reboussin, V. Wakelam, E.di Folco (LAB), E. Chapillon (LAB/IRAM), Y. Boehler (UNAM, Mexico)

Why (sub-)mm interferometry ?

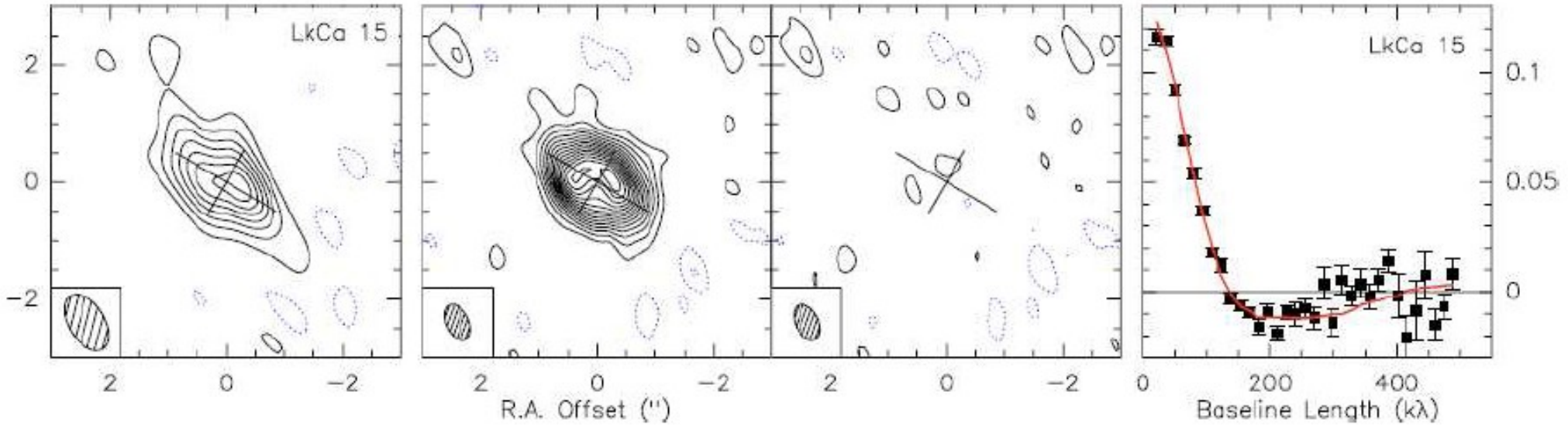
- Protoplanetary disks are (mostly) cold
  - Rotation lines
  - Dust thermal emission
- Protoplanetary disks are dense
  - Optically thick at shorter wavelength
- Protoplanetary disks are small
  - Few arcseconds for the closest



Henning & Semenov 2013

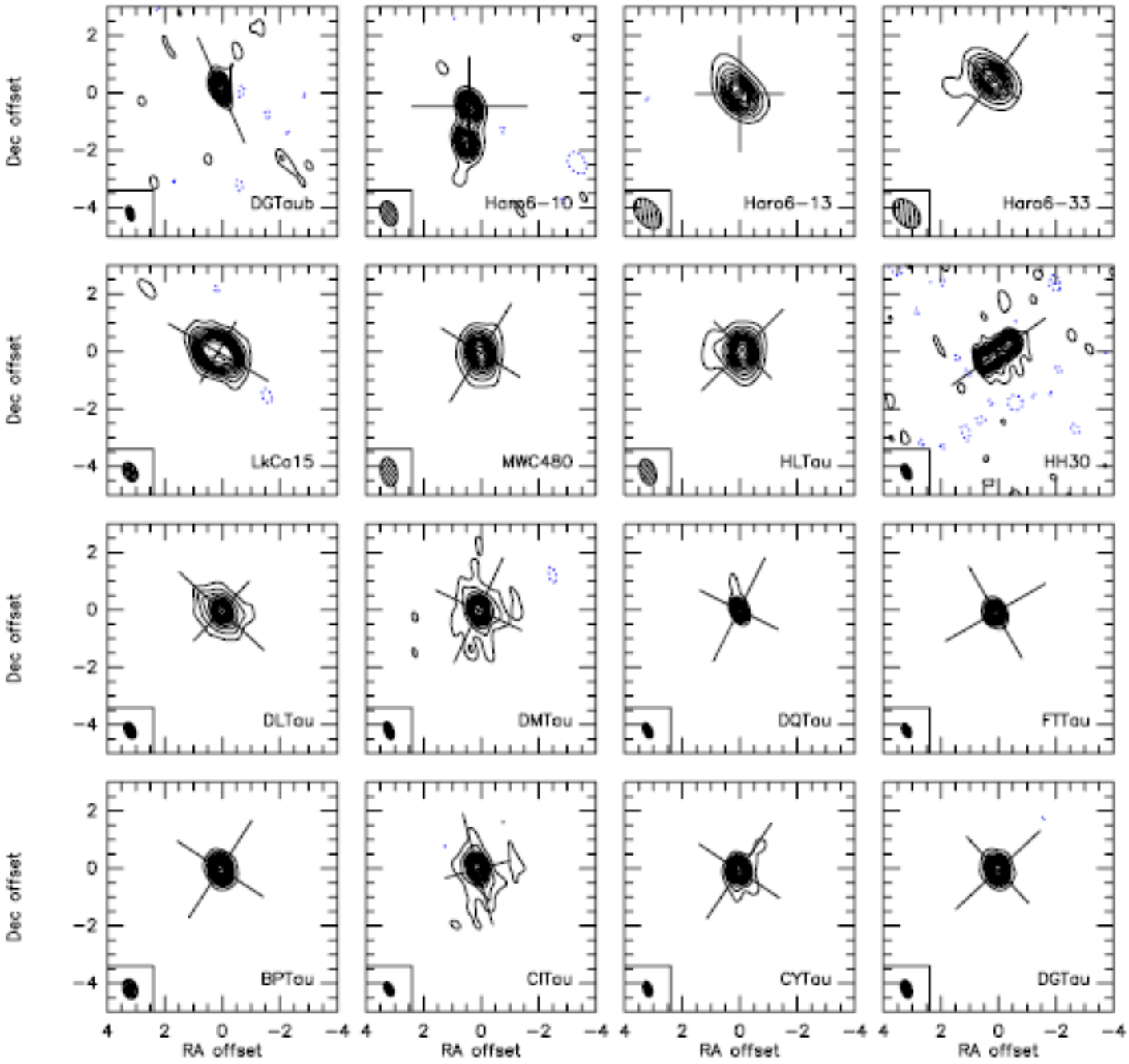
Dust continuum emission

- (mainly) optically thin
- Allowed first direct imaging of cavities within protoplanetary disks



Pietu et al. 2006

Dual-frequency continuum survey in Taurus

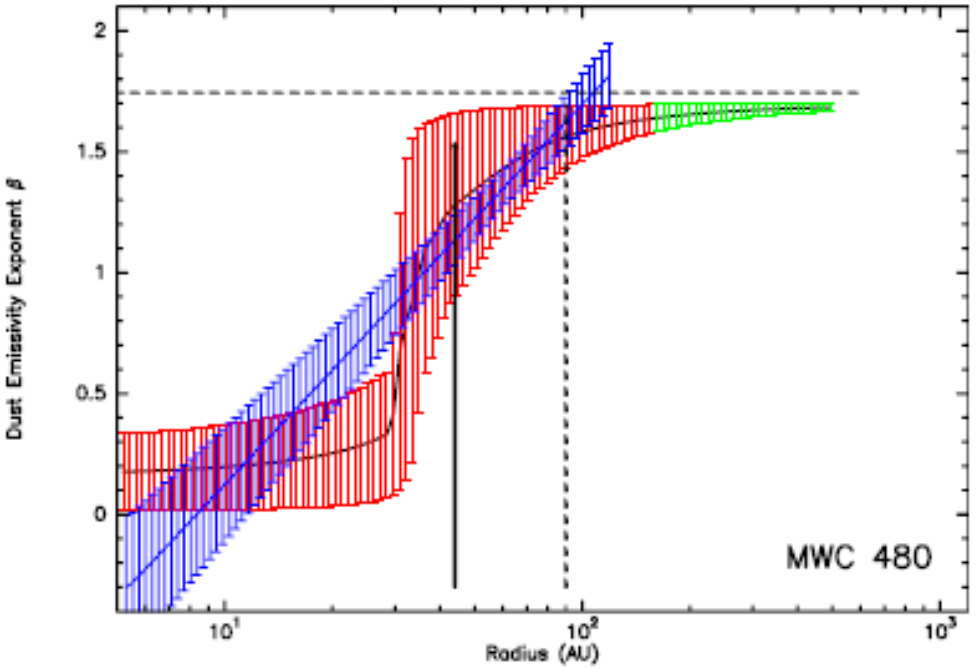


Guilloteau et al. 2011

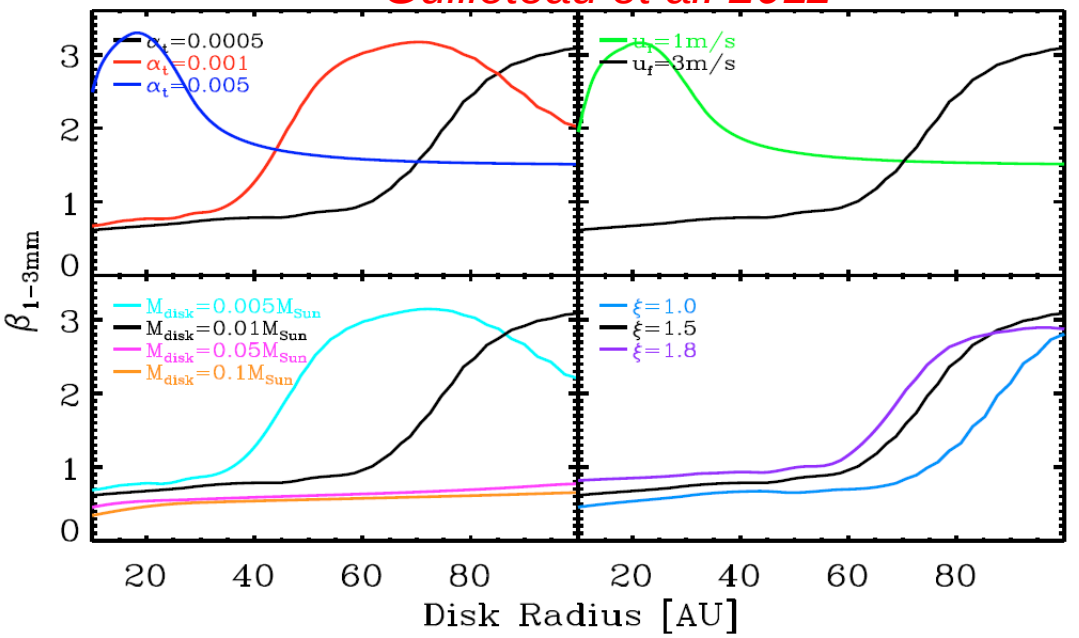
Varial radiation of grain properties

Comparison of brigthness distribution at two frequencies allows to measure radial distribution of dust absorption coefficient spectral index.

Varies from 0 (big grains compared to wavelength) within ~60-80 au to 1.7 (ISM like) outside.

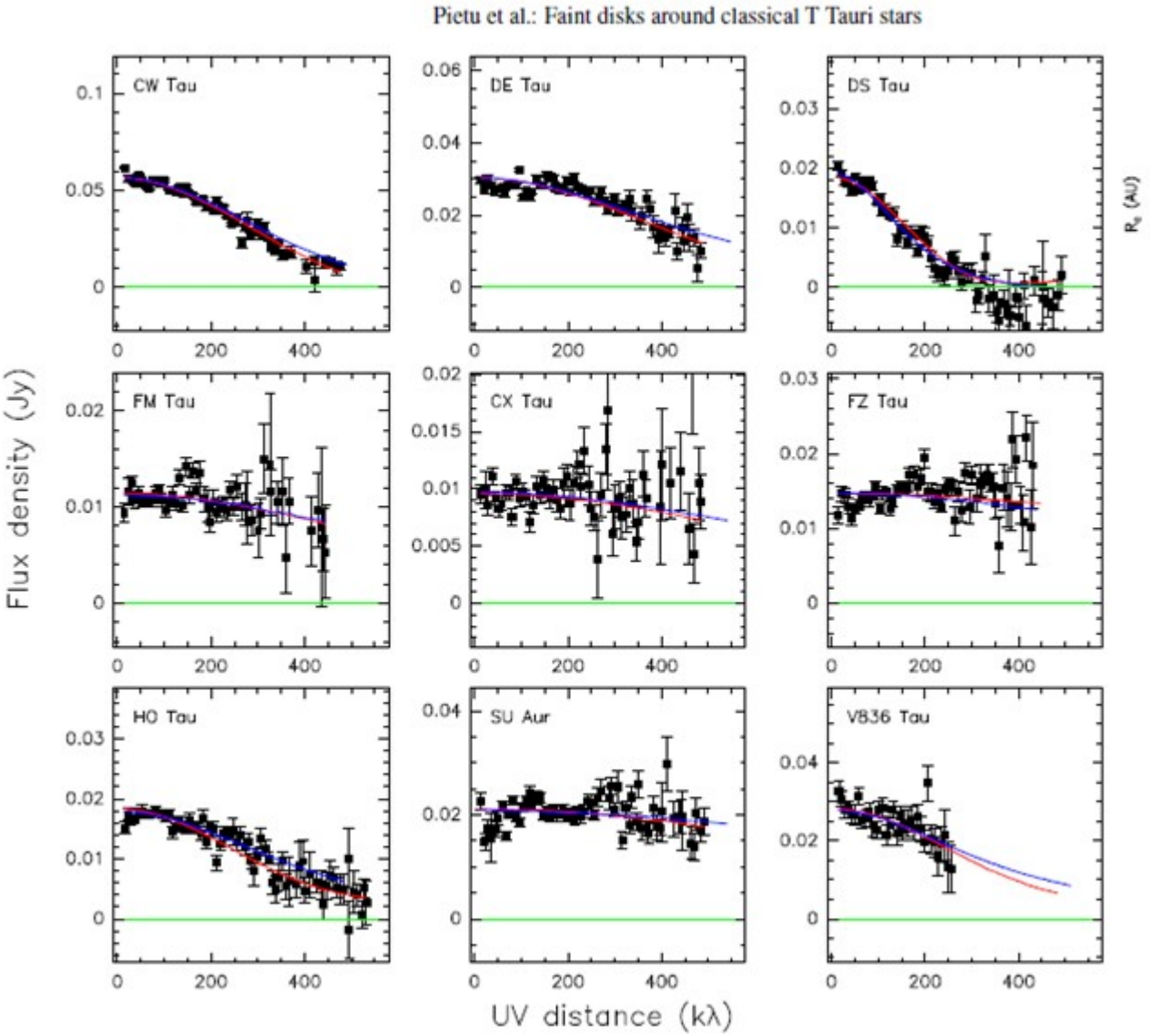


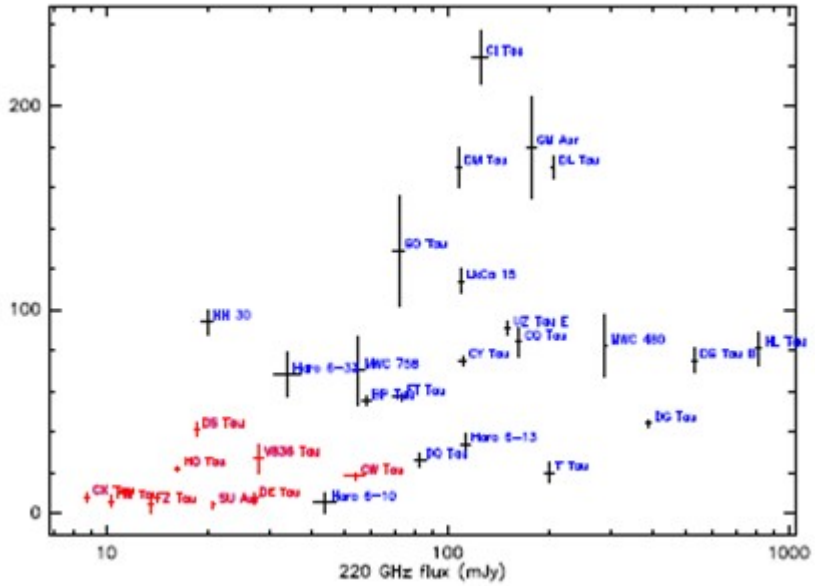
Guilloteau et al. 2011



Birnstiel et al. 2011

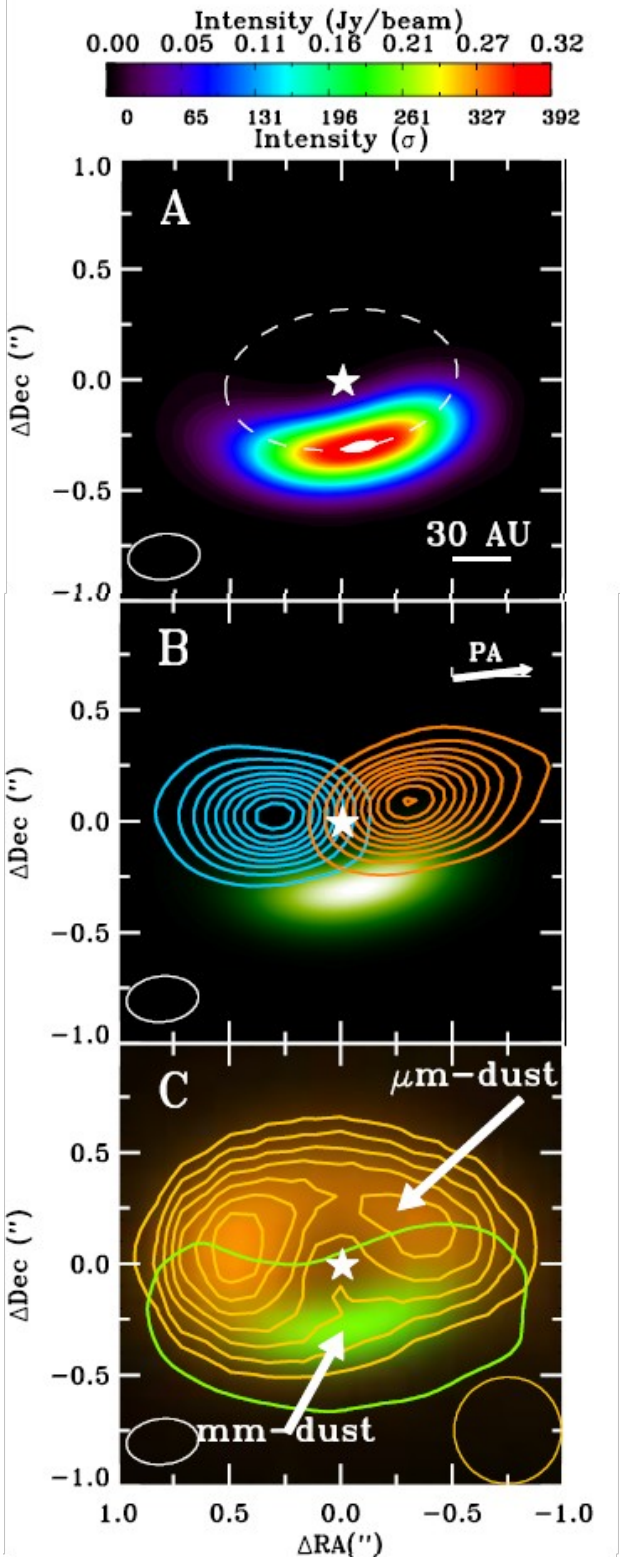
Faint disks are small





- Survey of 9 mm faint disks with PdBI at 220 GHz
- All of them are small, and most are quite dense.

Pietu et al. 2014



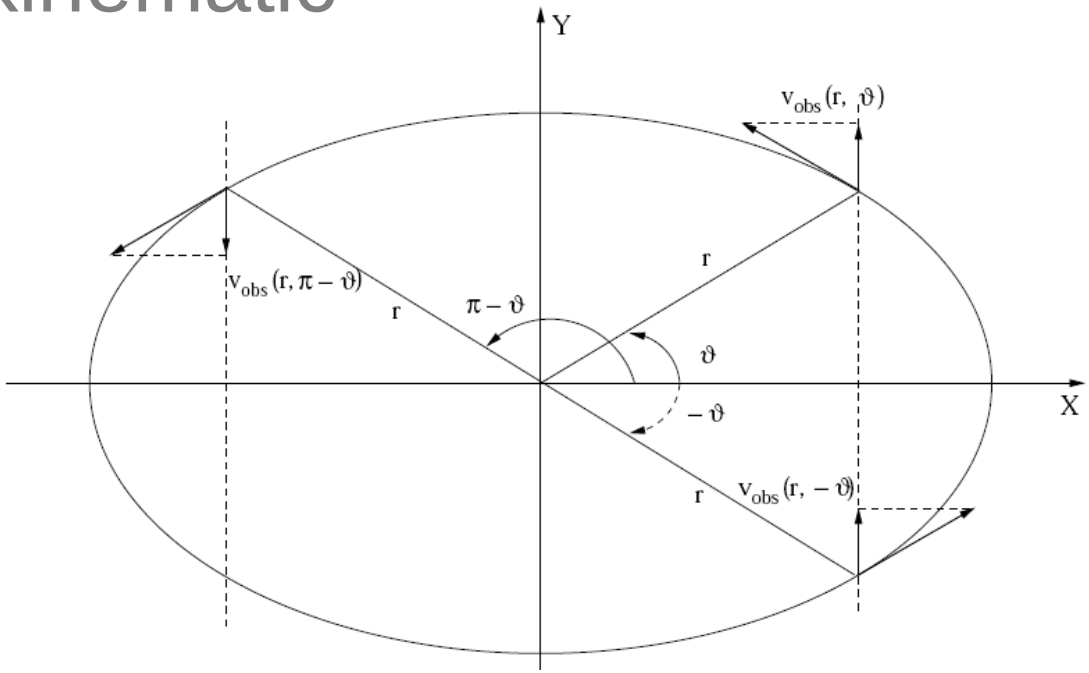
A dust trap ?

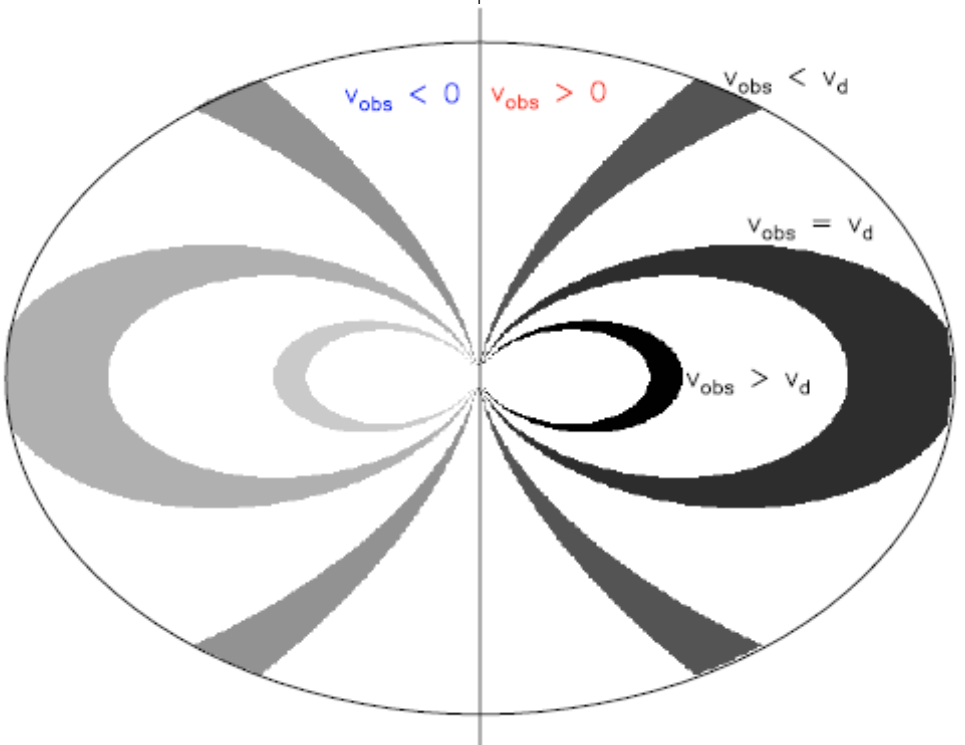
- ALMA B9 observations of IRS48 (Herbig Ae star).
- Asymetry of the dust continuum
- Possibly tracing dust traping in a local pressure extremum

Van der Marel et al 2013, Science

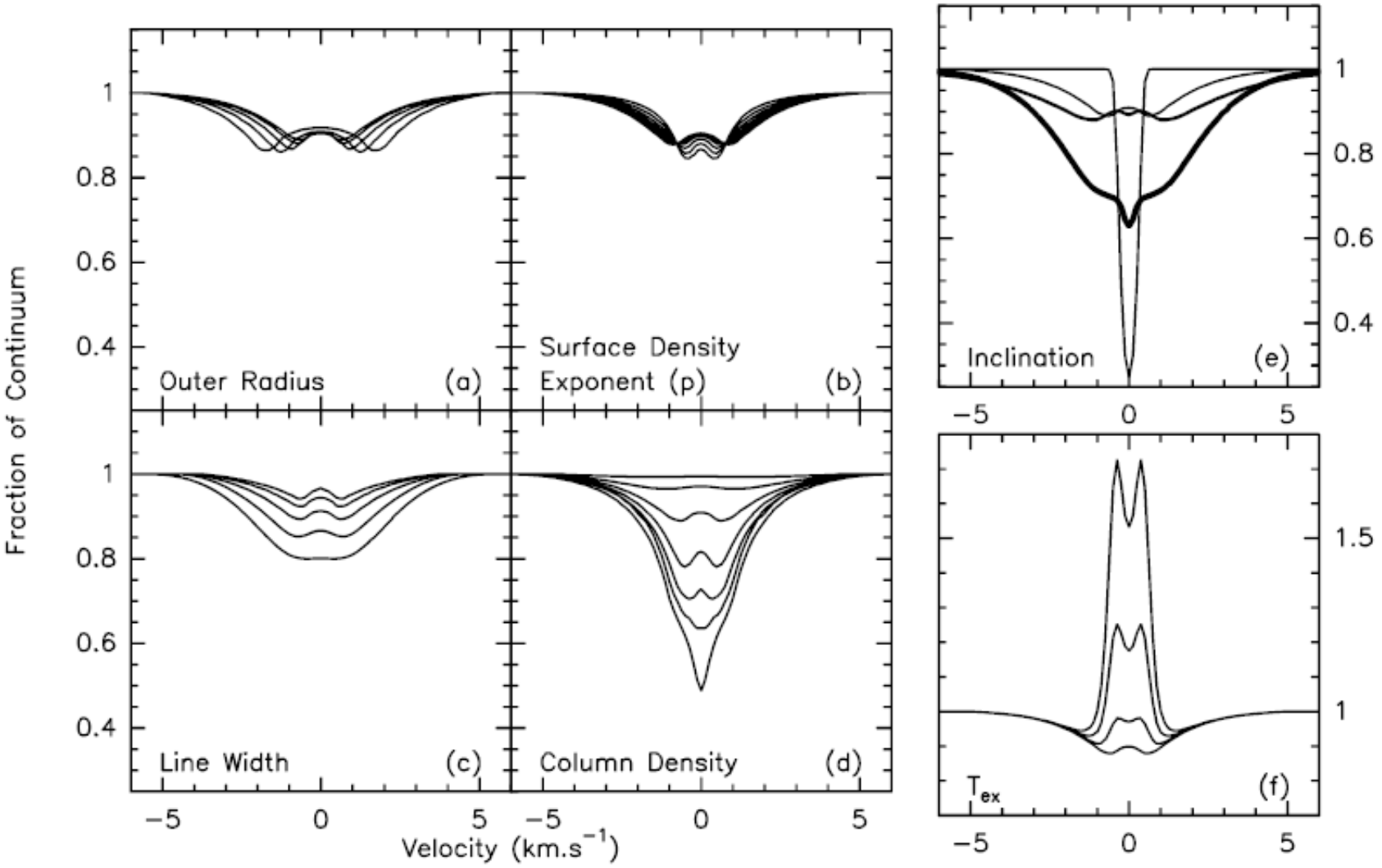
Disk kinematic

- If one consider a geometrically thin disk
- Axisymetric
- In Keplerian rotation
- One obtains the typical shape for the channels.



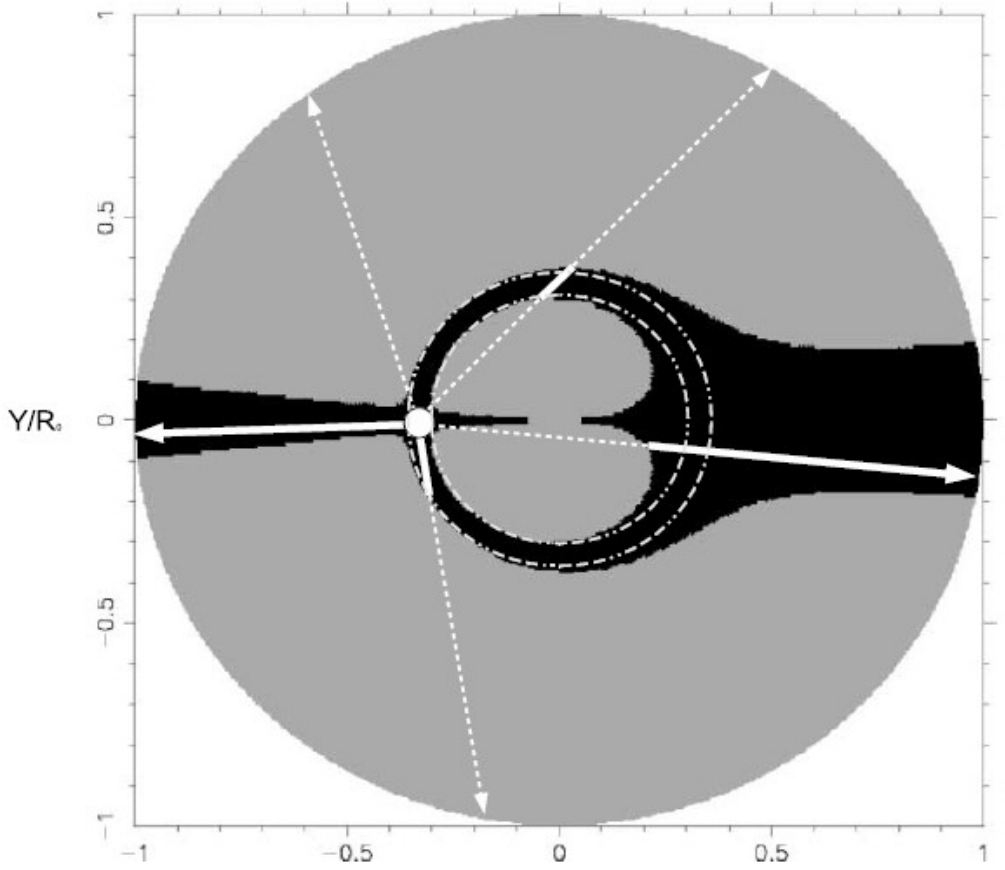


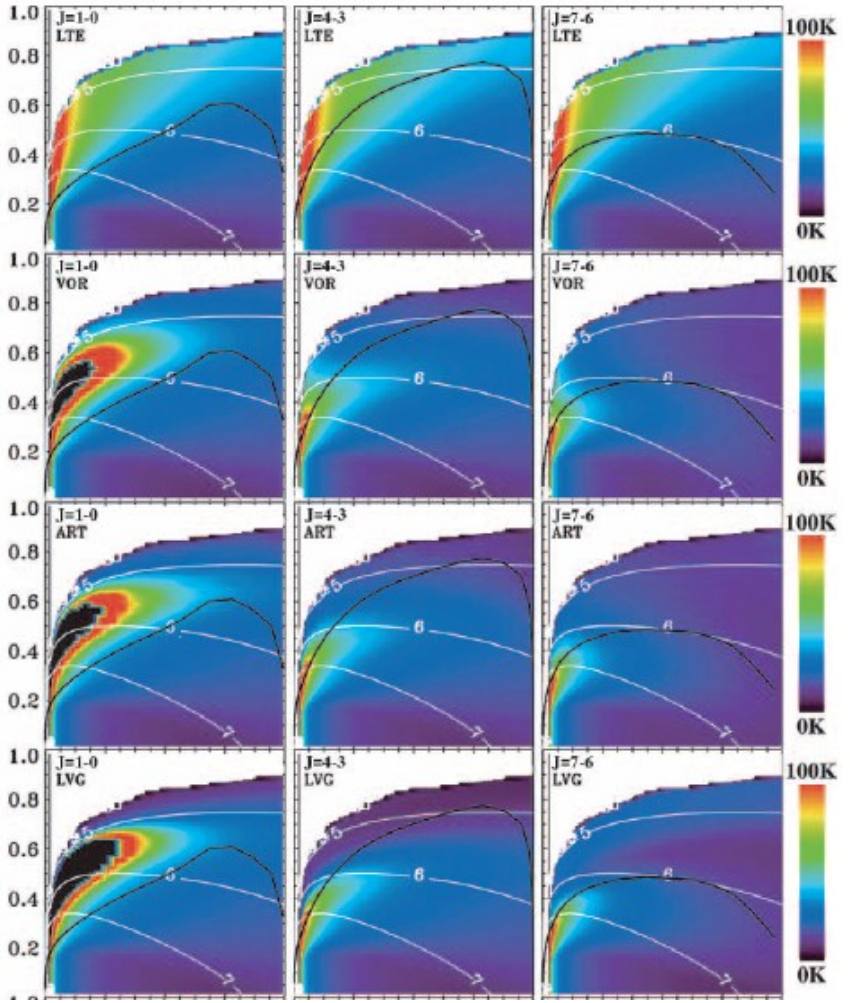
Example: absorption lines

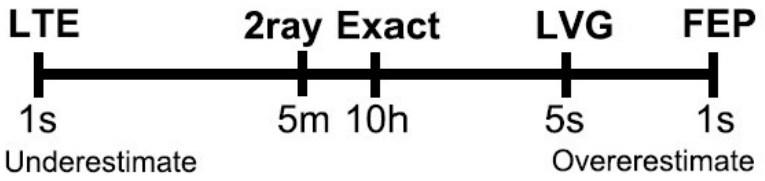


Guilloteau et al. 2006

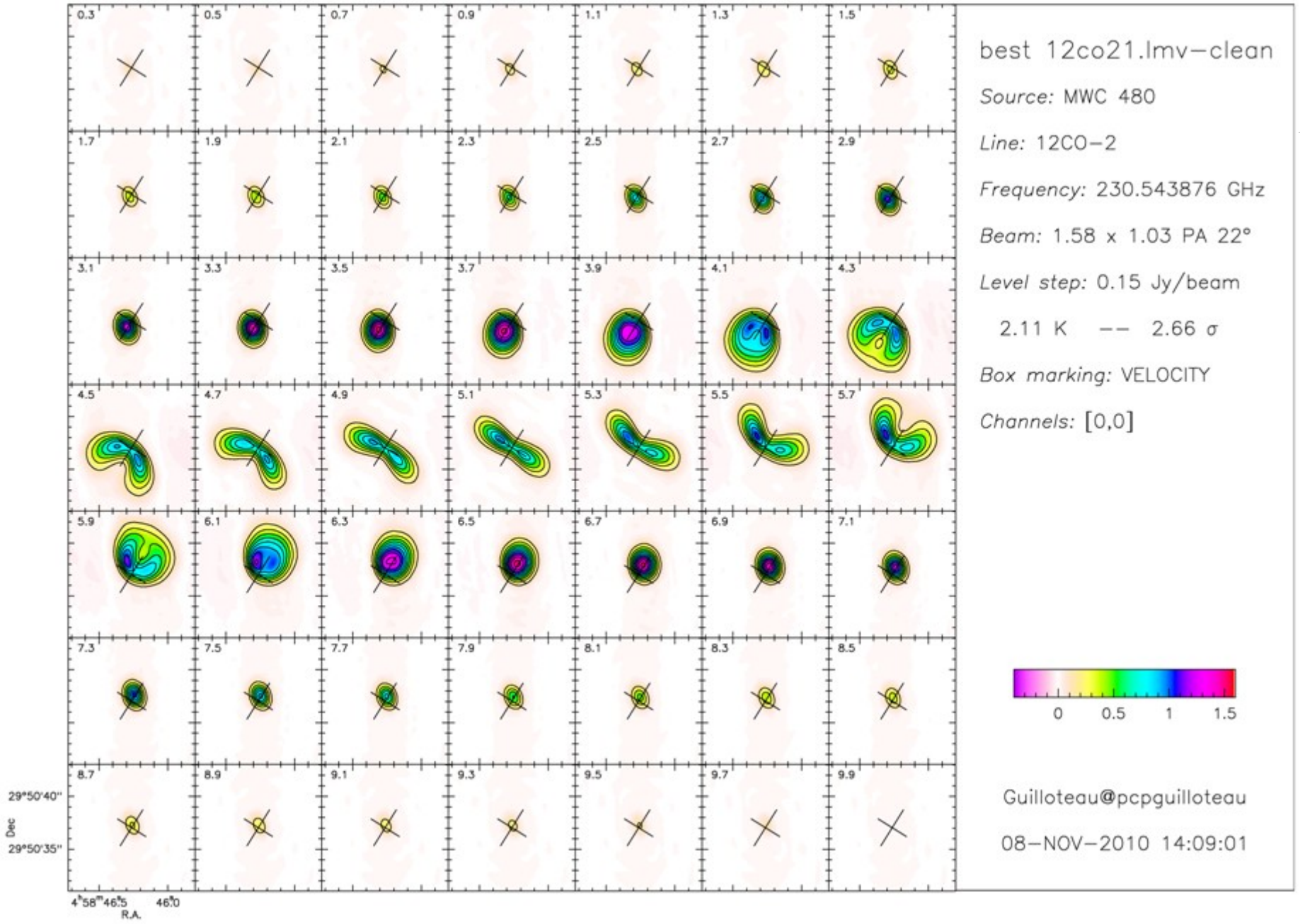
Non Local Thermodynamic Equilibrium







Pavlyuchenkov et al. 2007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best 12co21.lmv-clean
Source: MWC 480
Line: 12CO-2
Frequency: 230.543876 GHz
Beam: 1.58 x 1.03 PA 22°
Level step: 0.15 Jy/beam
2.11 K -- 2.66 σ
Box marking: VELOCITY
Channels: [0,0]
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Guilloteau@pcpguilloteau
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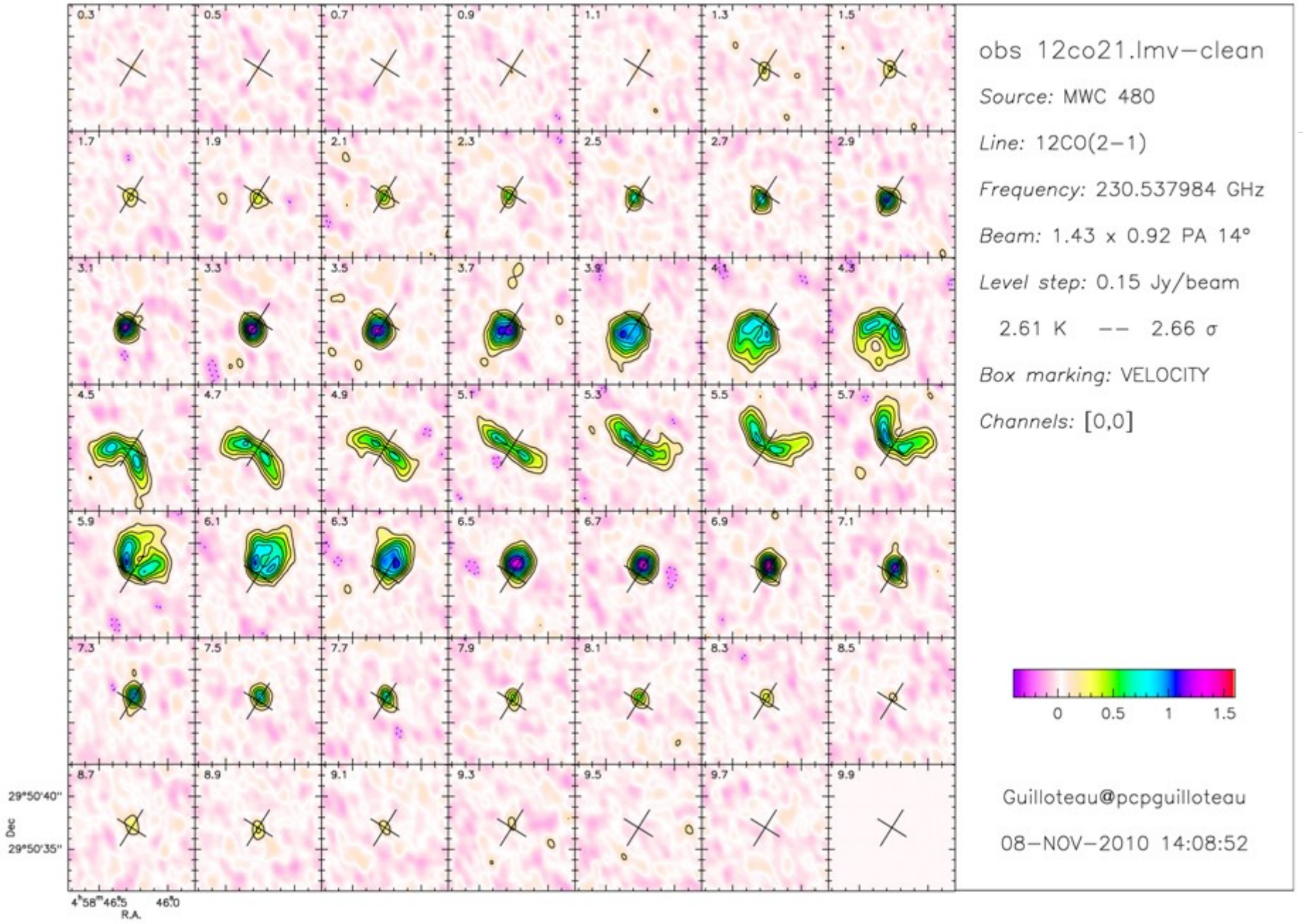
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obs 12co21.lmv-clean
Source: MWC 480
Line: 12CO(2-1)
Frequency: 230.537984 GHz
Beam: 1.43 x 0.92 PA 14°
Level step: 0.15 Jy/beam
2.61 K -- 2.66 σ
Box marking: VELOCITY
Channels: [0,0]
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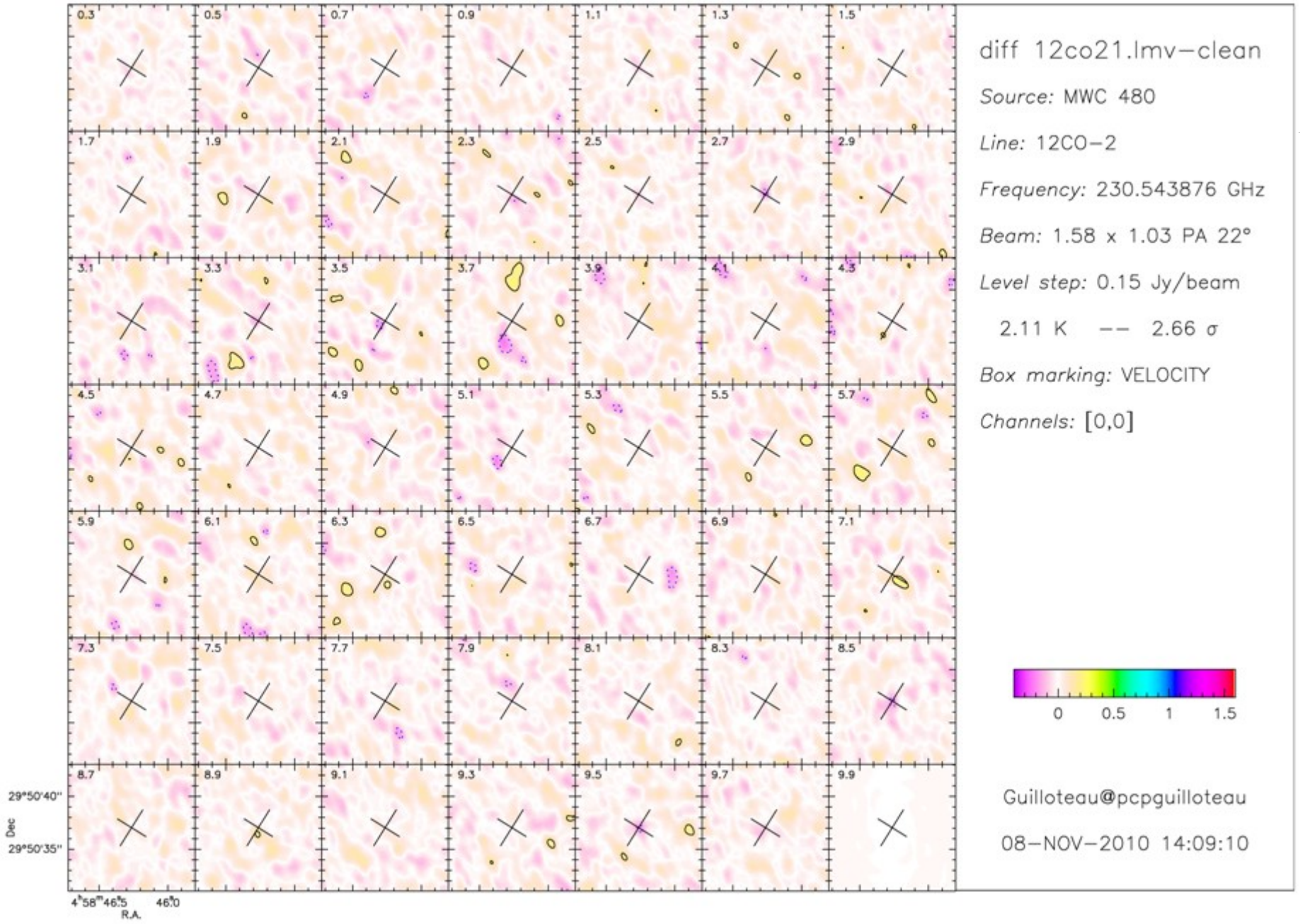
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diff 12co21.lmv-clean
Source: MWC 480
Line: 12CO-2
Frequency: 230.543876 GHz
Beam: 1.58 x 1.03 PA 22°
Level step: 0.15 Jy/beam
2.11 K -- 2.66 σ
Box marking: VELOCITY
Channels: [0,0]
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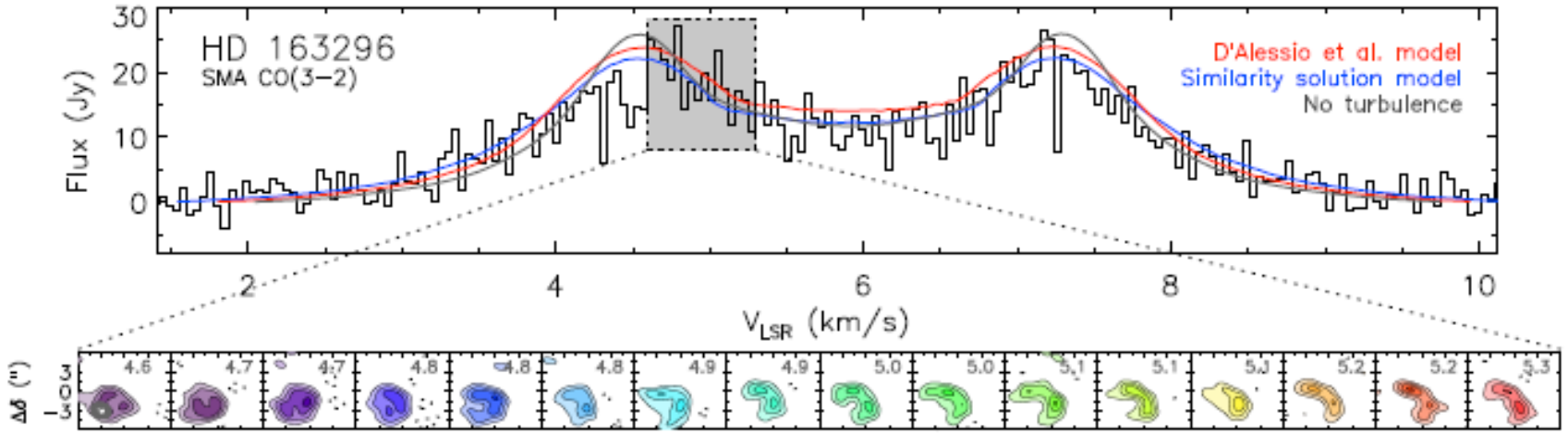
Guilloteau@pcpguilloteau
08-NOV-2010 14:09:10

Measuring the turbulence

- Local line width:

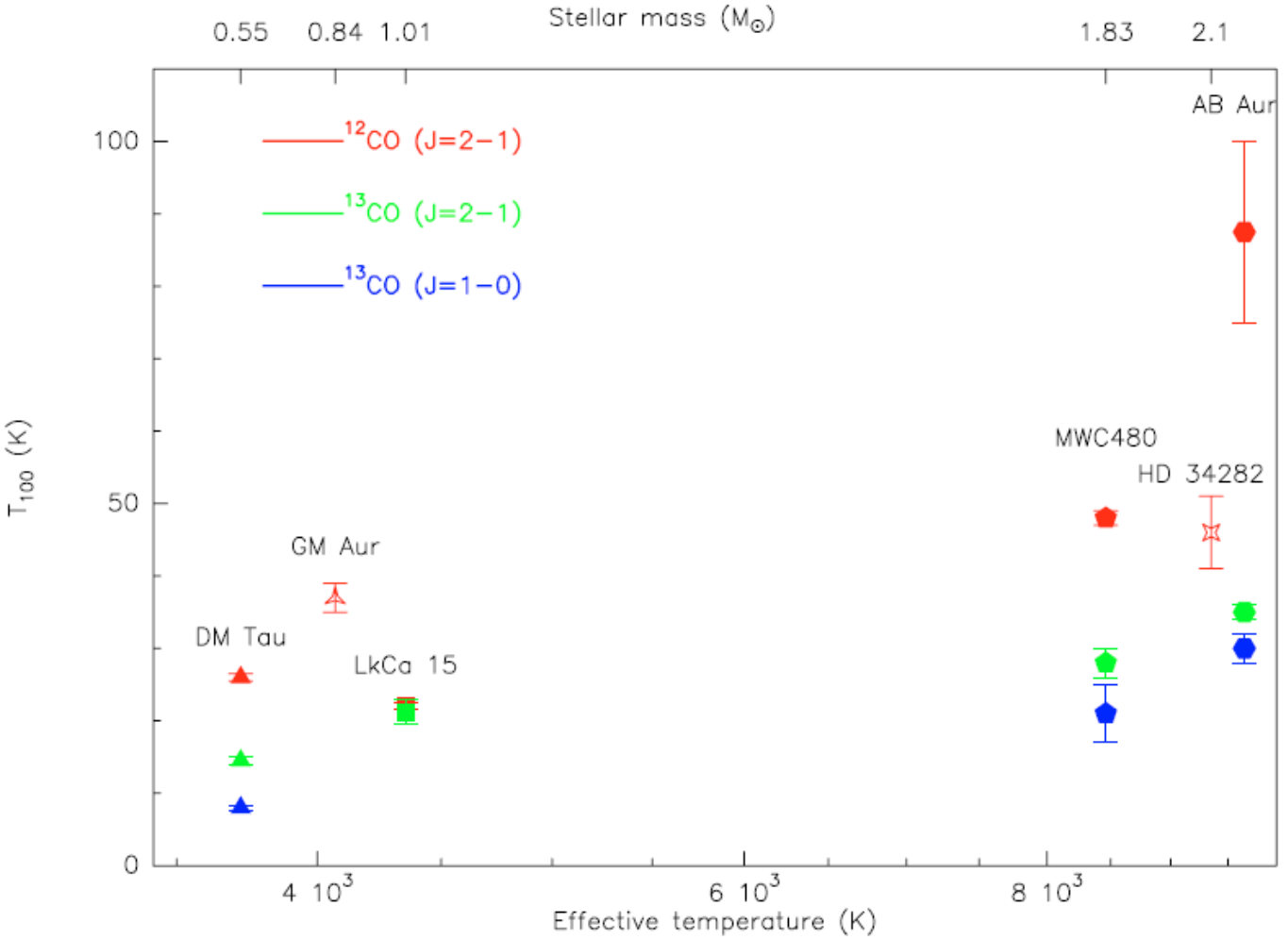
$$\Delta V(r) = \sqrt{\frac{2kT(r)}{\mu m_H} + \delta V_{\mathrm{tu}}(r)^2}$$

- More precise if using a heavy molecule
- Requires a good knowledge of the temperature structure and a good spectral resolution.
- 0.3 km/s (0.4 Mach number)

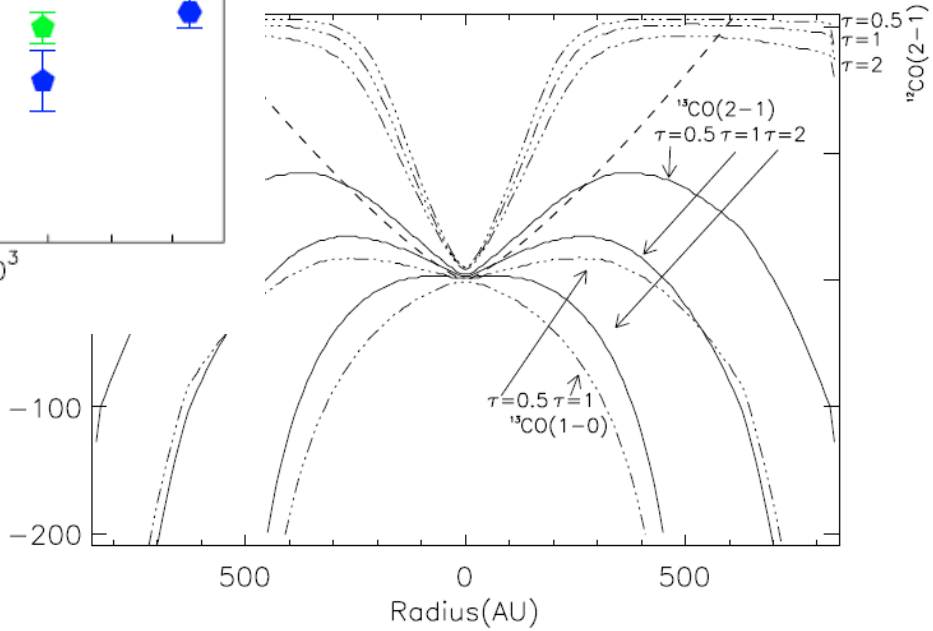


Hughes et al. 2011, Guilloteau et al. 2012

Measurement of the vertical temperature gradient

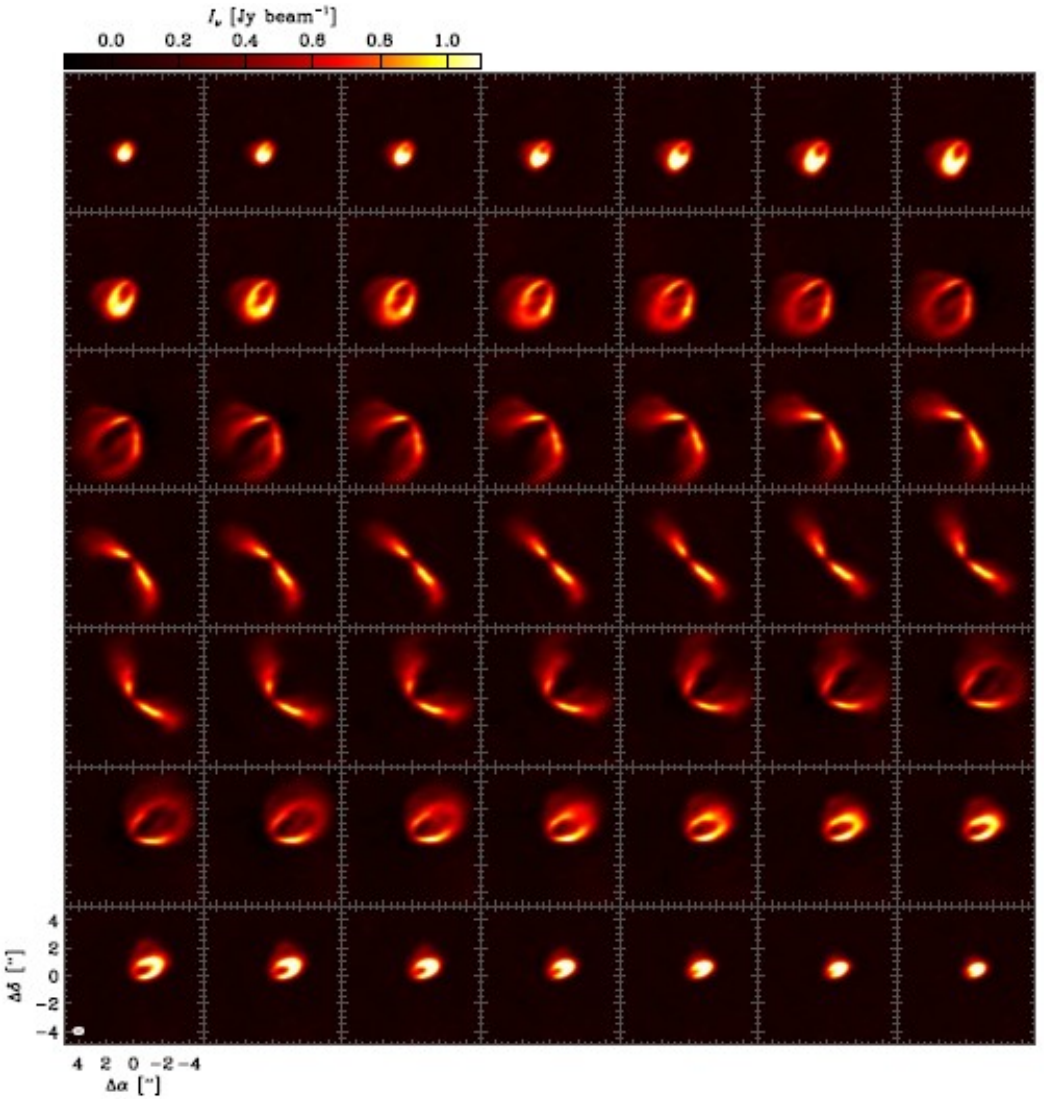


- Hotter surface
- But also hotter interior
- Also evidenced by less CO depletion due to freeze-out



Pietu et al 2007

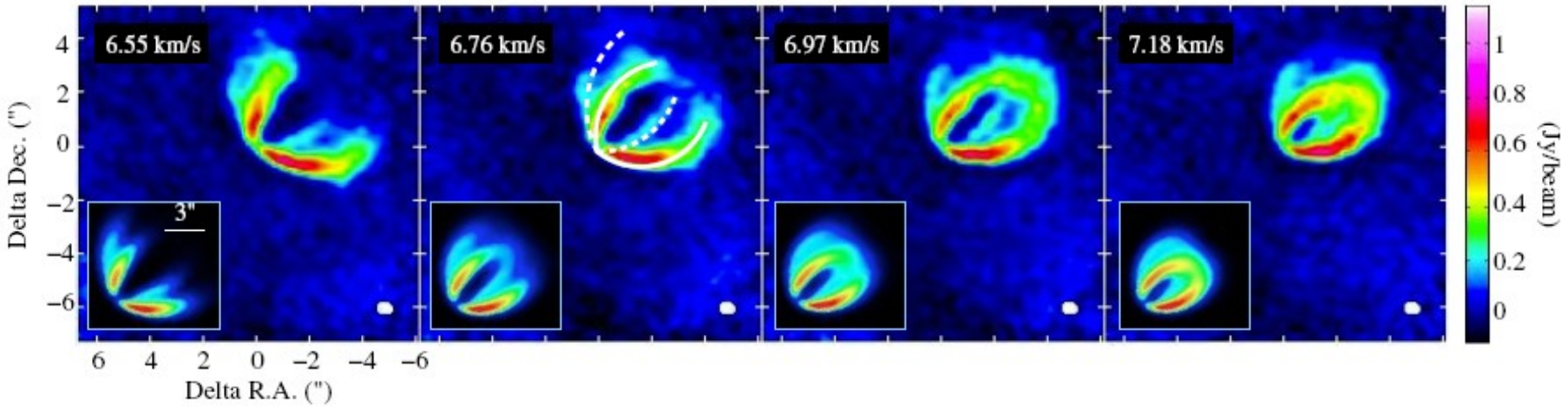
CO vertical distribution



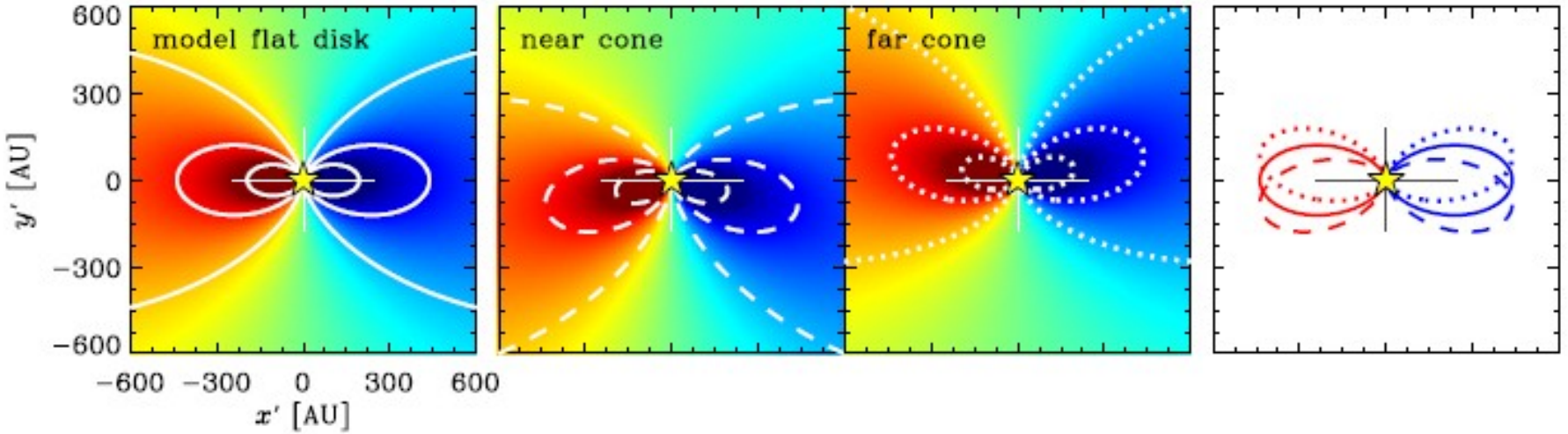
- HD163296
- ALMA Science Verification data
- One sees two disks

De Gregorio et al. 2013, Rosenfeld et al 2013

CO vertical distribution



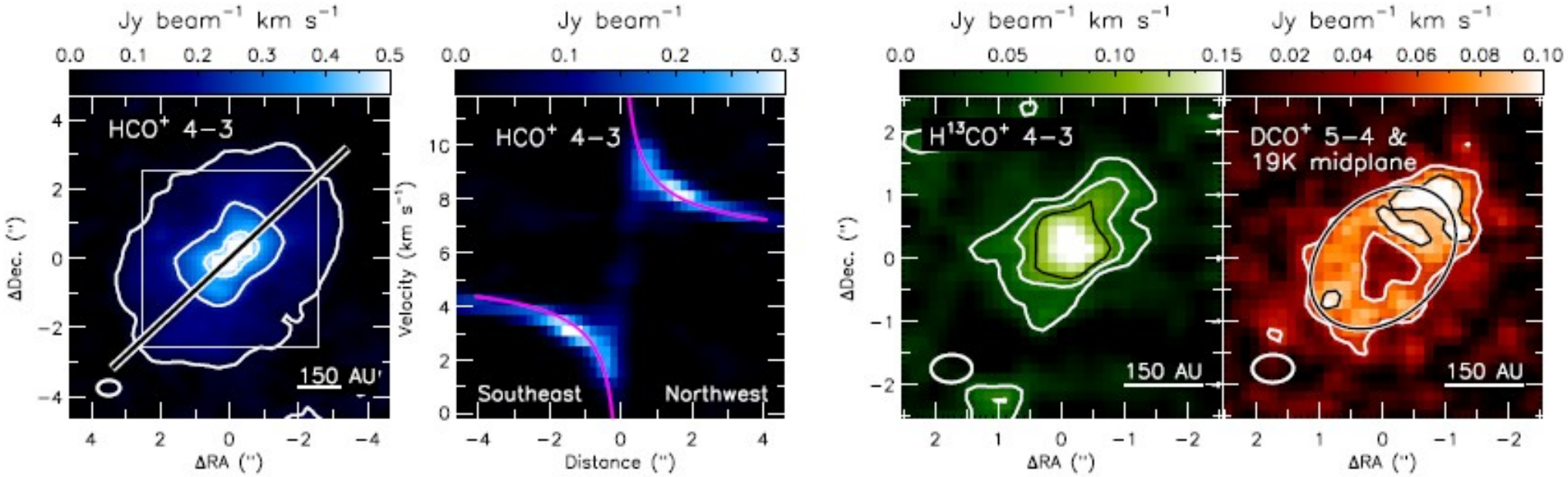
De Gregorio et al 2013



Rosenfeld et al 2013

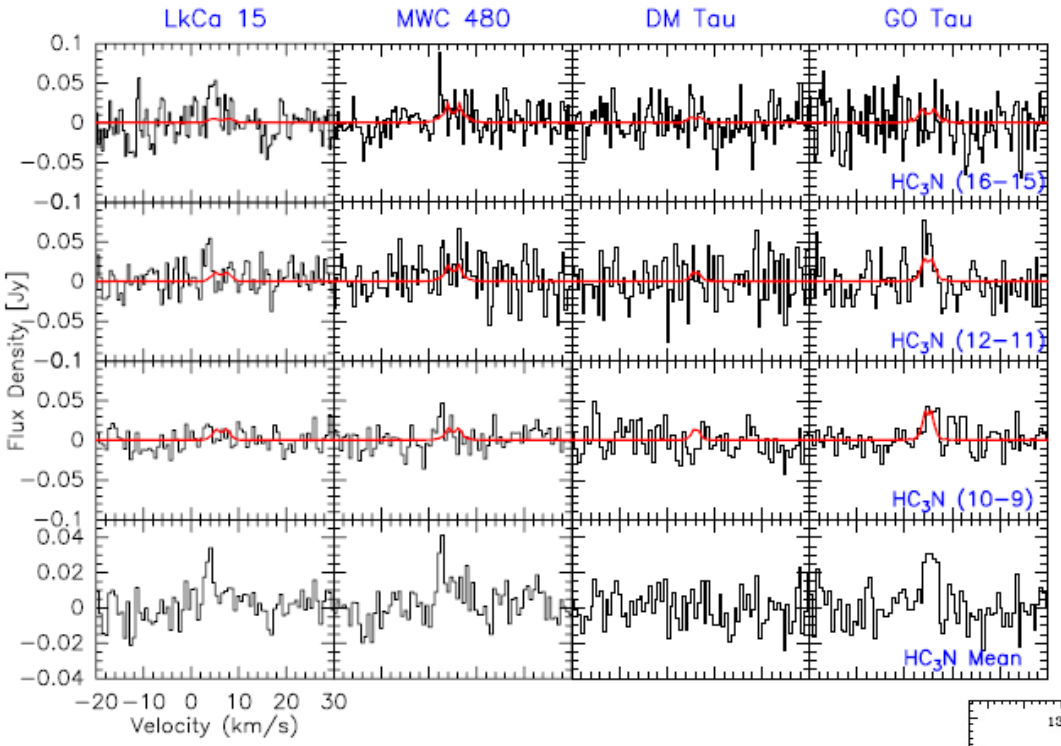
CO snowline

- Snowline corresponds to the region below which water condensates
- Found using $^{13}CO(2-1)$ by *Qi et al 2011*.
- DCO^+ confined in a ring where temperature 19< T < 21 K. (no H_2D^+ if hotter, no CO if colder).

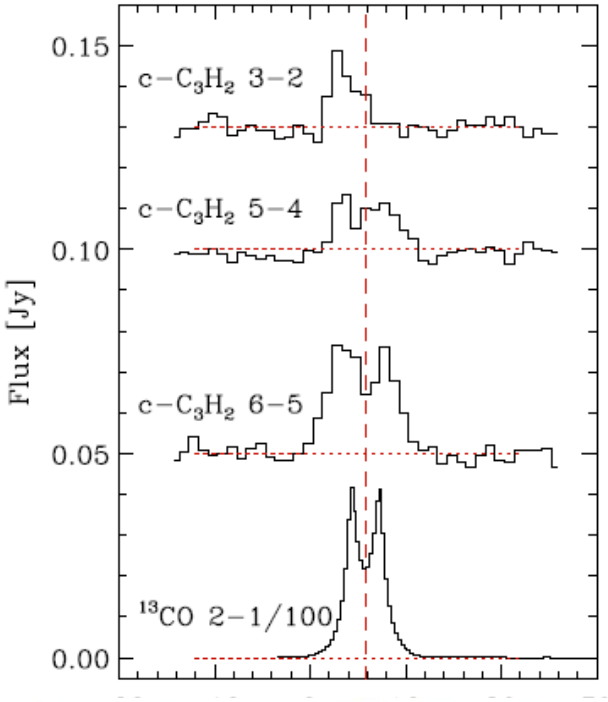


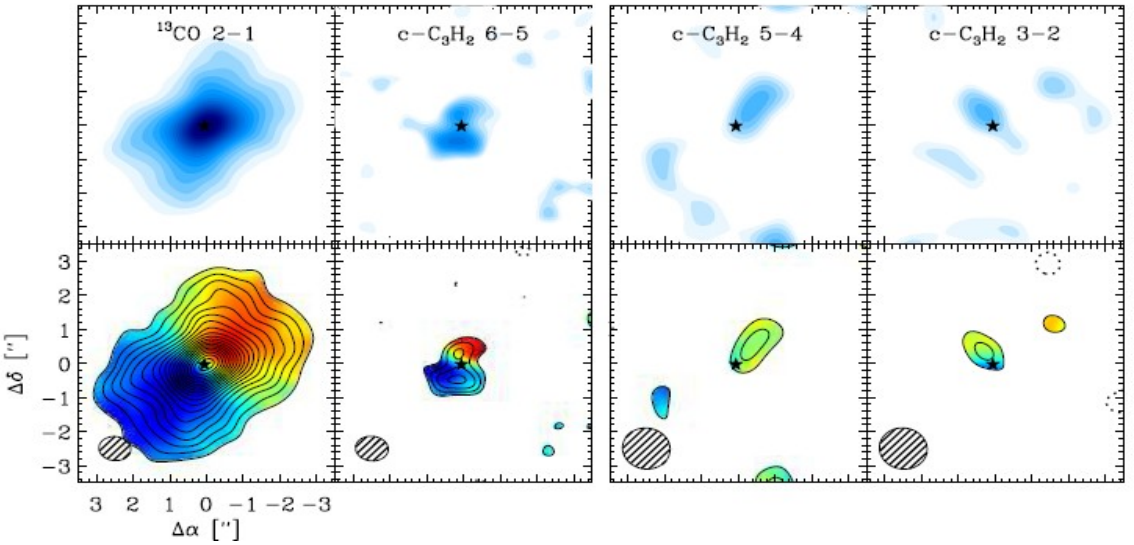
HD163296: *Matthews et al. 2013*

Detection of HC_3N and c-C_3H_2



Chapillon et al. 2012

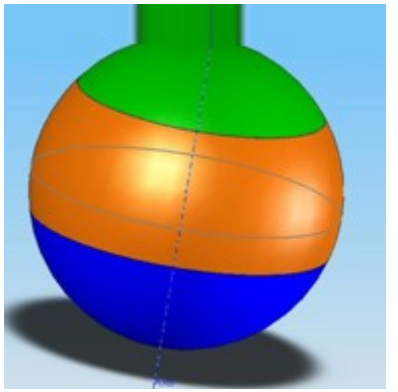


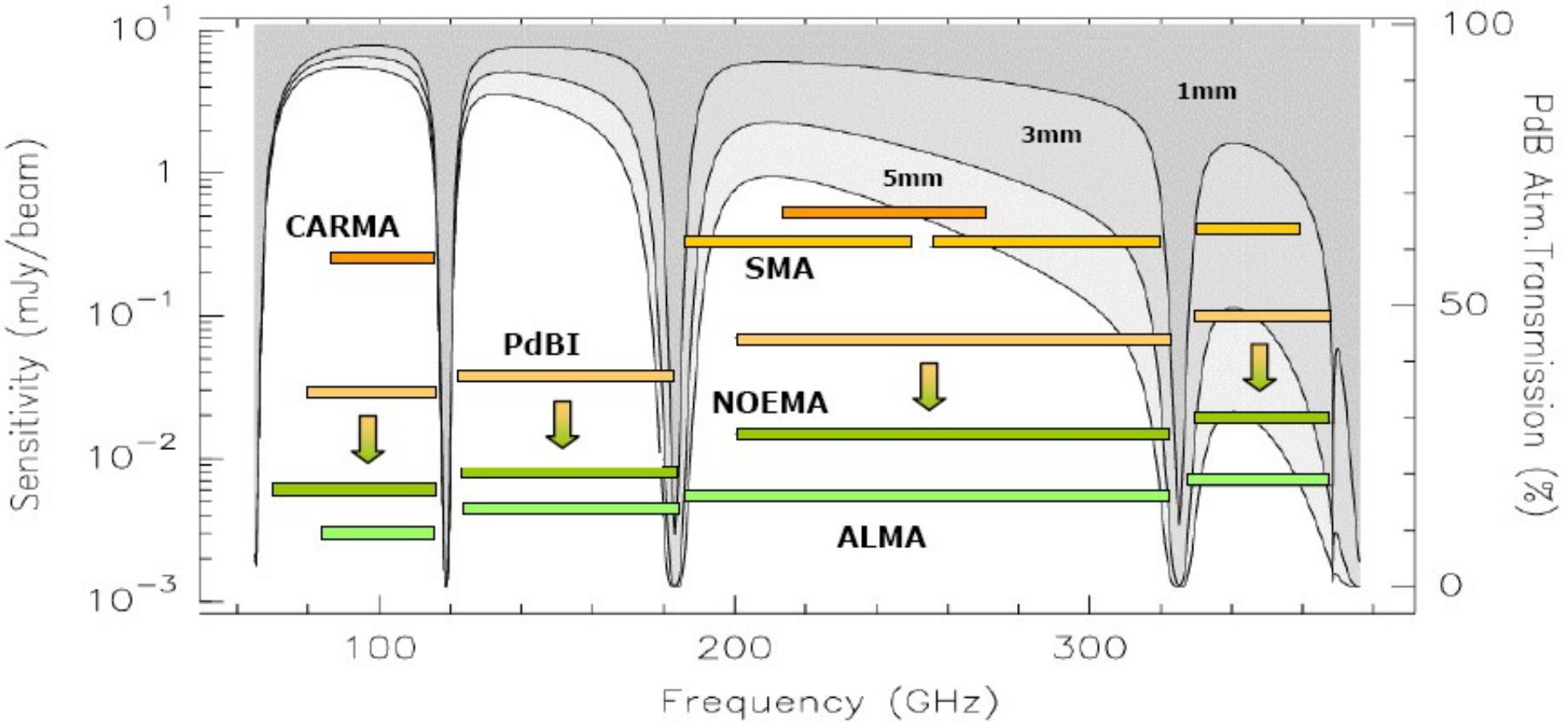


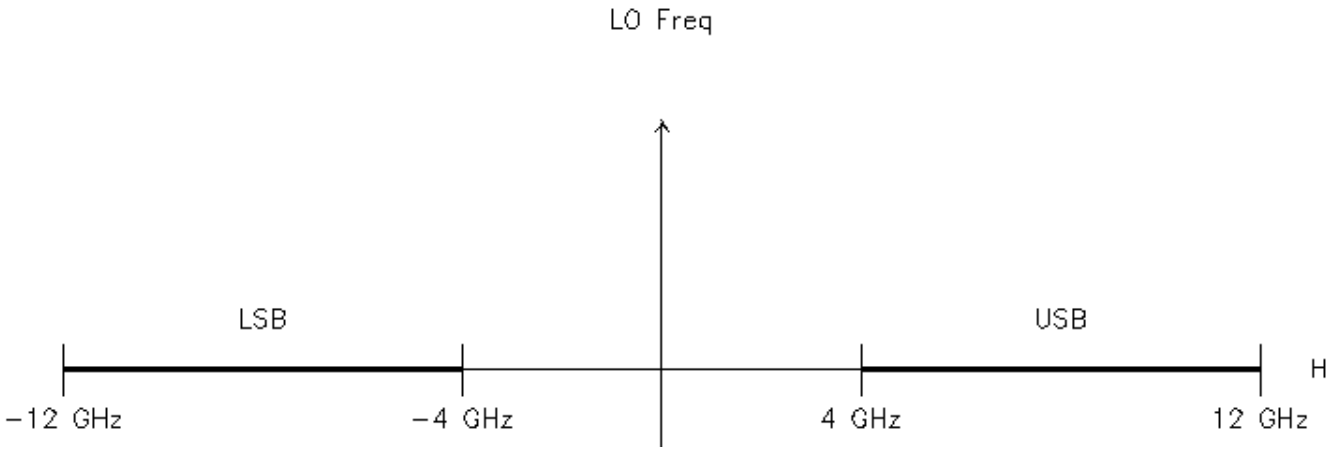
TW Hya
Qi et al. 2013

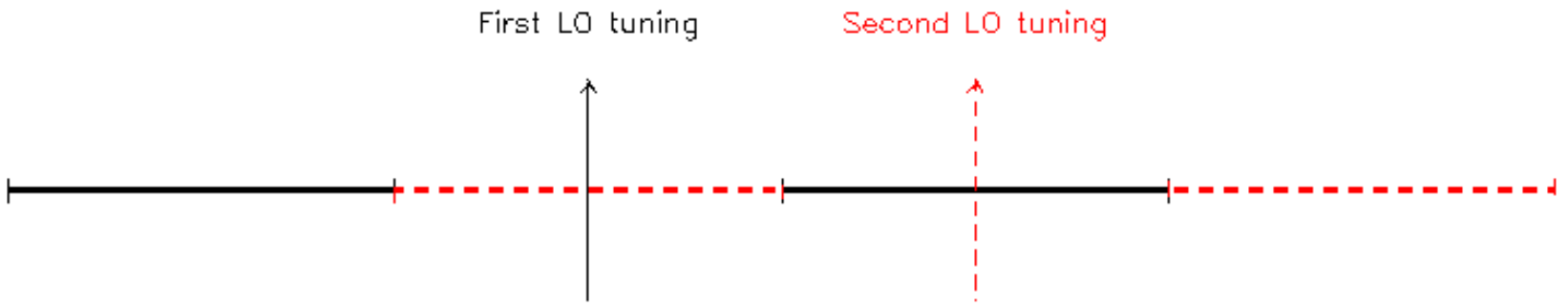
NOEMA

- Double the number of antenna at PdB from 6 to 12
- Extension of the baselines from 0.8 to 1.6 km
- Increase of IF bandwidth from 8 to 32 GHz

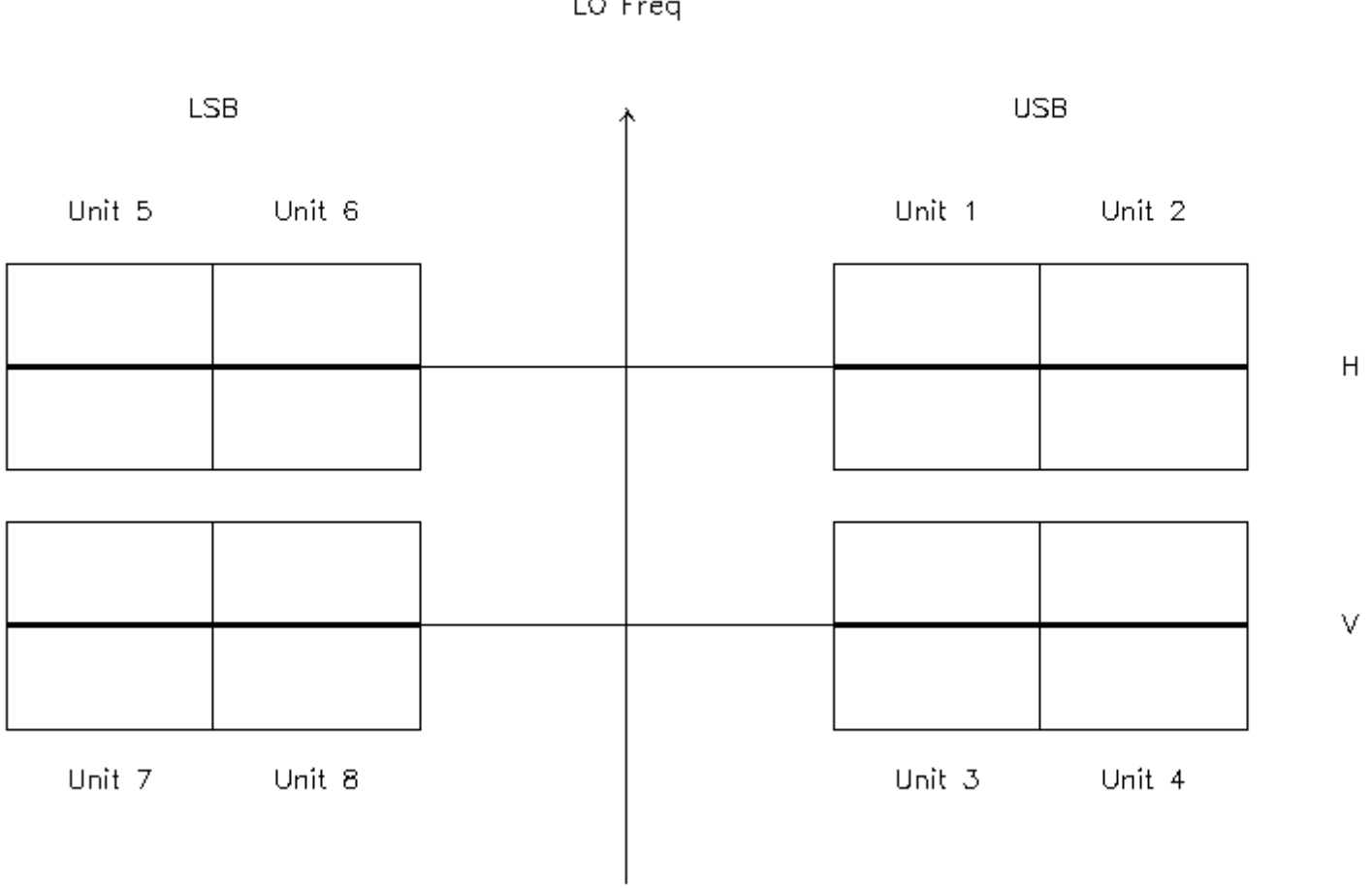








NOEMA RF Band Specifications				
Band	NOEMA-1	NOEMA-2	NOEMA-3	NOEMA-3
RF Frequency (GHz)	**72**-116	127-179	200-276	275-373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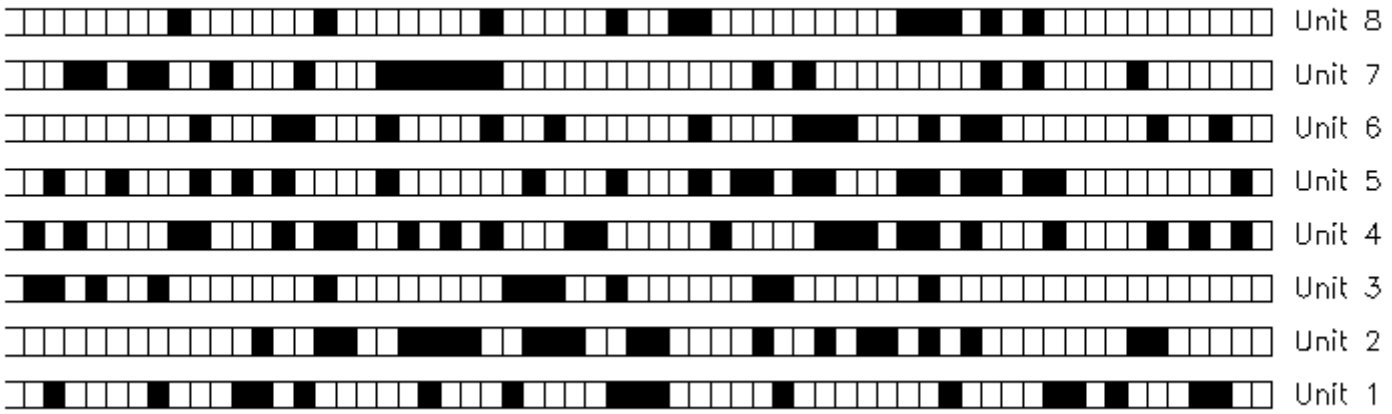
USB
Unit 5
Unit 6
Unit 1
Unit 2
H
V
Unit 7
Unit 8
Unit 3
Unit 4

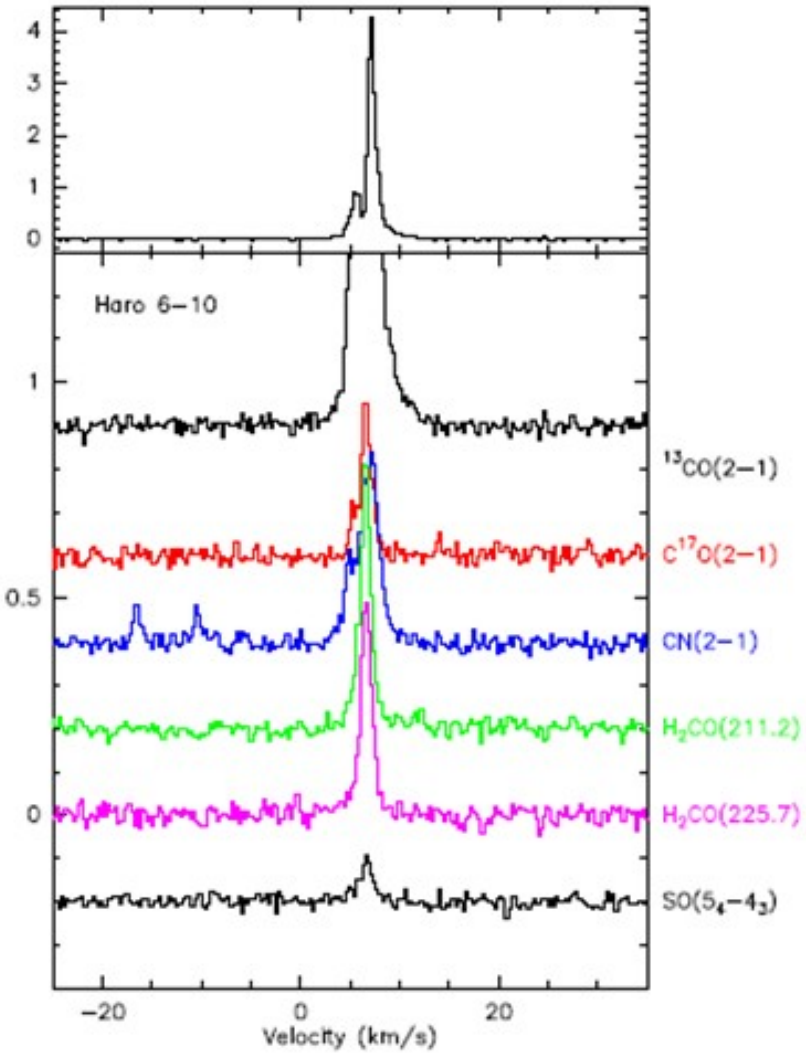

Unit 8
Unit 7
Unit 6
Unit 5
Unit 4
Unit 3
Unit 2
Unit 1

NOEMA and ALMA: what's next ?

- Sensitivity is the limiting factor
  - We want to study fainter features
  - We want to go to high angular resolution
- NOEMA and ALMA will provide sensitivity
- Self-calibration helps a lot
- Survey aspects instrumental in understanding physical processes
- Wide-frequency coverage to allow efficient multiplexing (up to complete spectral surveys).

“Chemistry” survey

- One can have a taste of future surveys with ALMA/NOEMA by looking at what's recently been done with IRAM/30m thanks to EMIR and FTS.
- ^{13}CO, CN, H_2CO, SO in 40 sources (*Guilloteau et al. 2013*)
- HCO^+, HCN, C_2H, SO, CS, $H^{13}CO^+$ in 30 sources (*Reboussin et al. In prep*)



Exciting time ahead

Thank You for Your Attention