Beta Pictoris with ALMA

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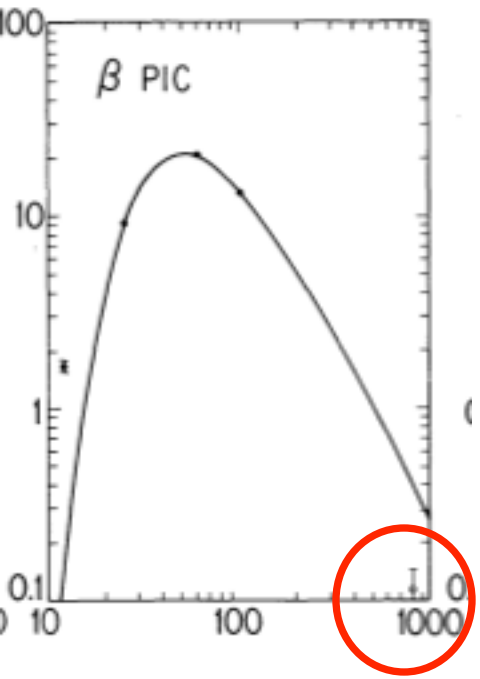
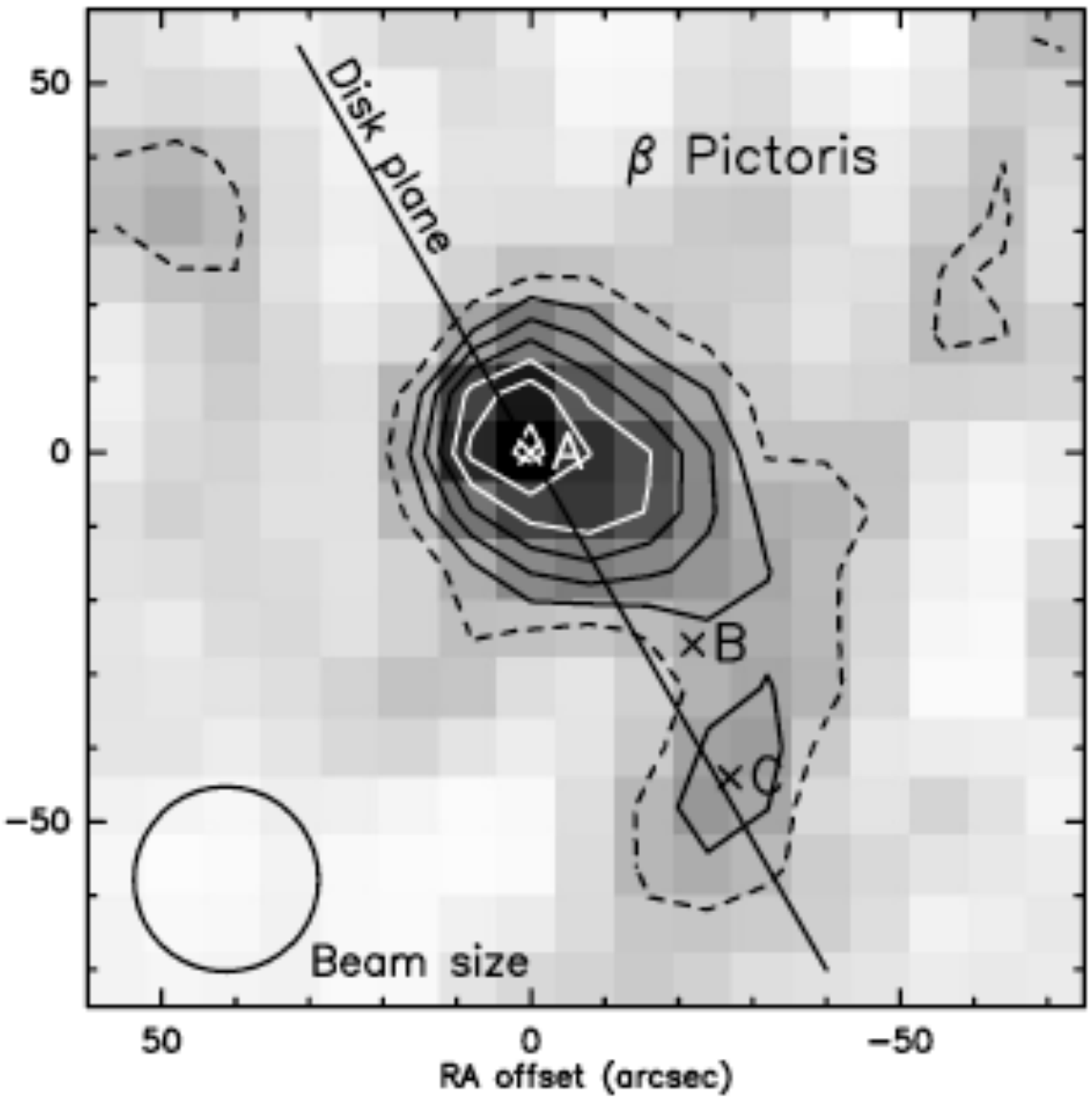
Sub-mm continuum in β Pic – potted history

JCMT (phot)

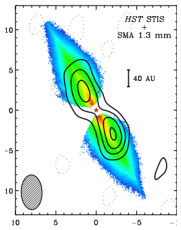


Zuckermann & Becklin 1993



APEX

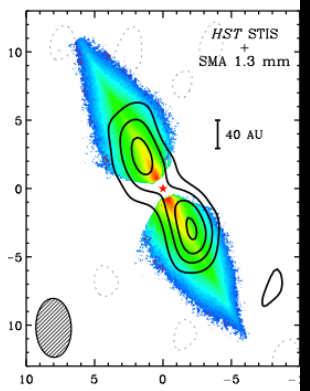
SMA

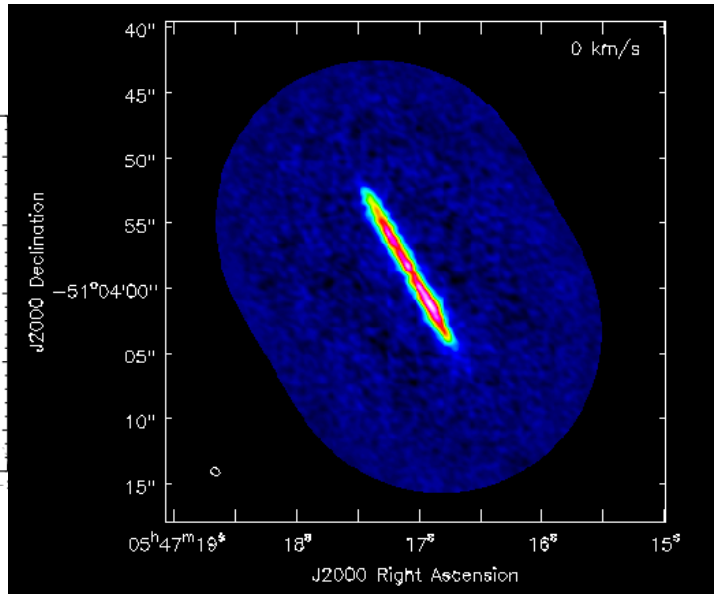


Liseau et al 2003 Wilner et al 2011

ALMA data

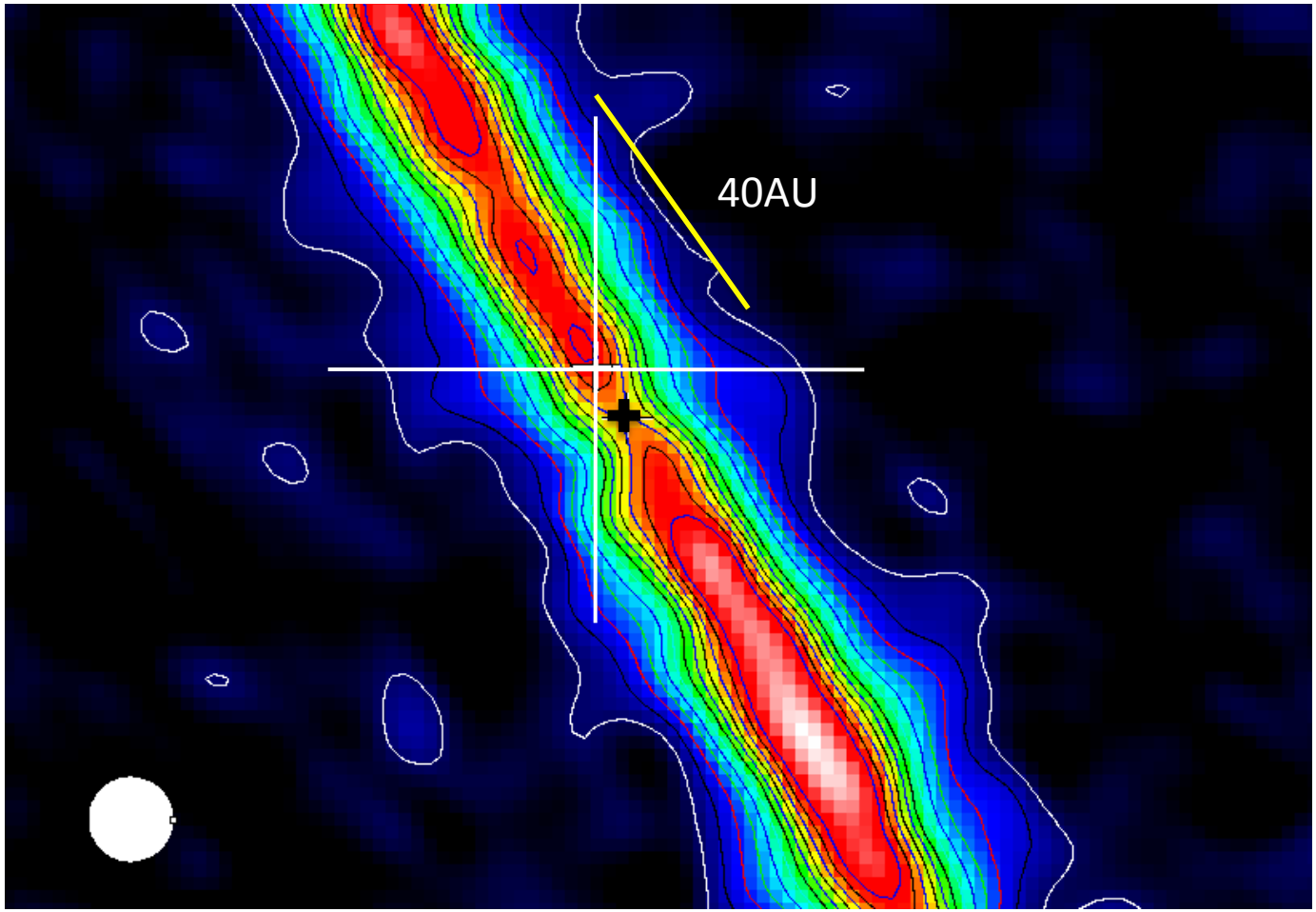
- Project 2011.0.00087.S
- 2-point 'mosaic'
- 1.5 hrs on-source time, ~18 antennas, max baseline ~400m
- Band 7, 345GHz, beamsize 0.7x0.55arcsec (~12AU)
- rms (continuum) = 60 μJy
- Total flux = 61mJy





Dent et al 2014

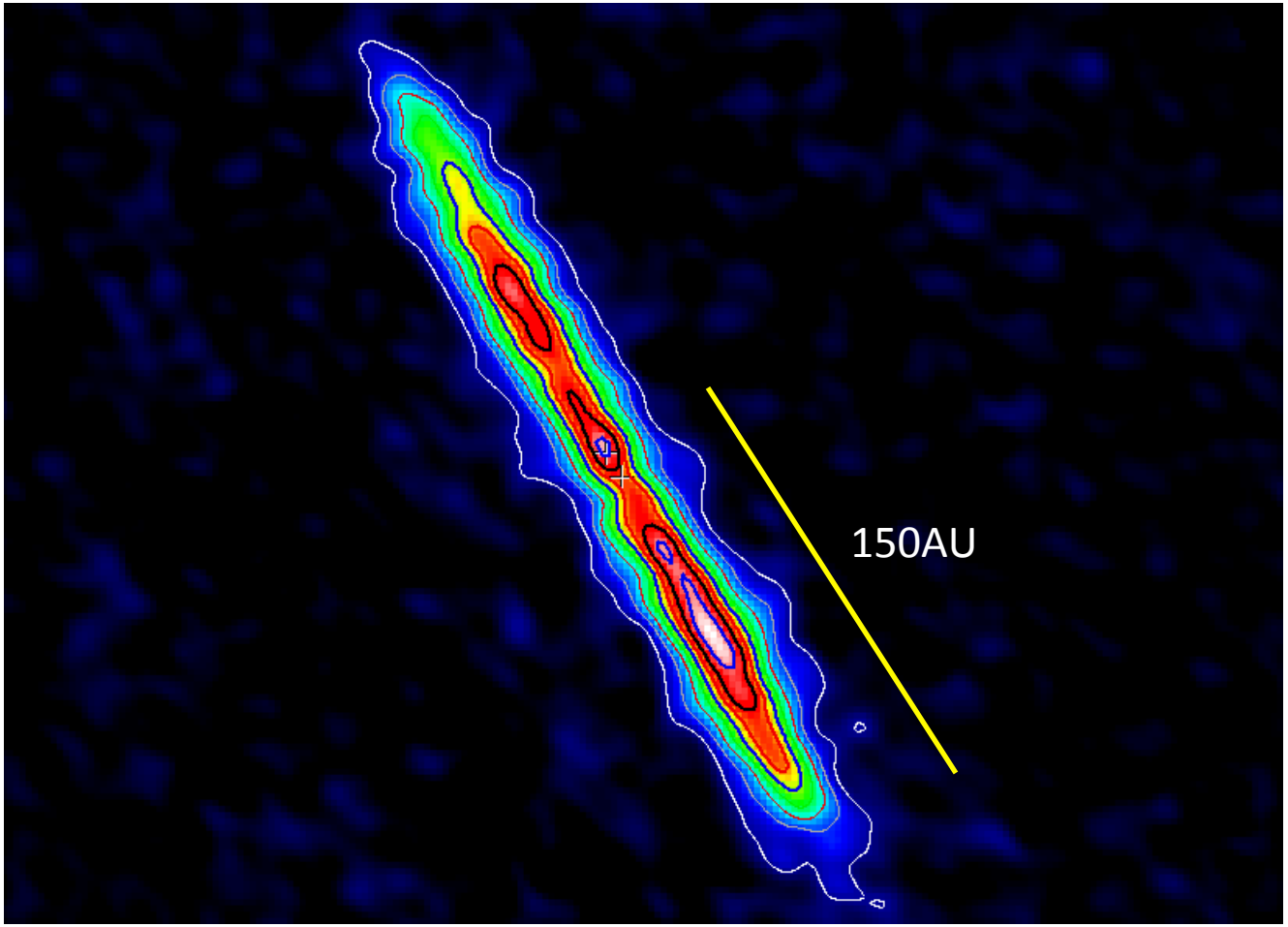
Continuum from inner 50AU?



Photosphere subtracted:
5-sigma lower on planet side

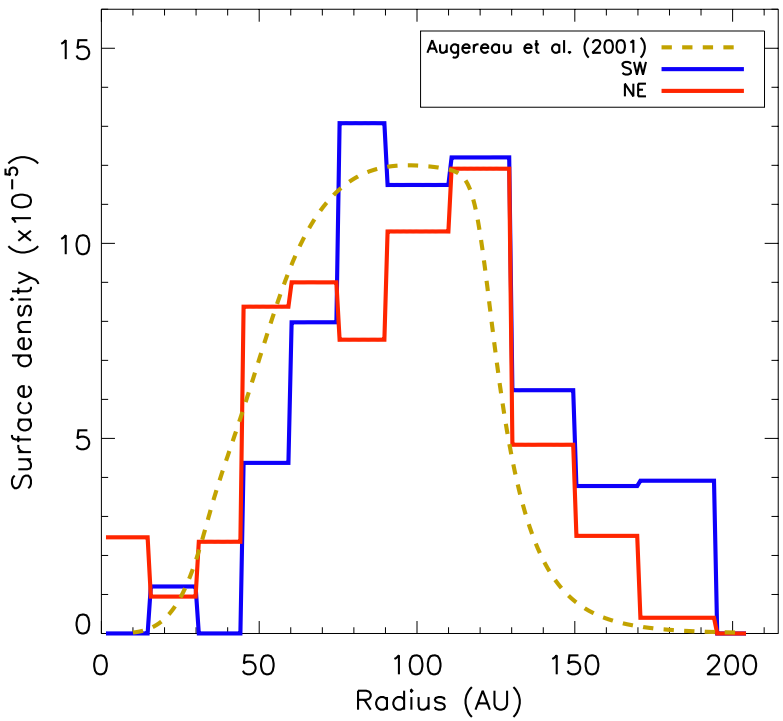
- evidence of planet clearing (?)

Outer 150AU



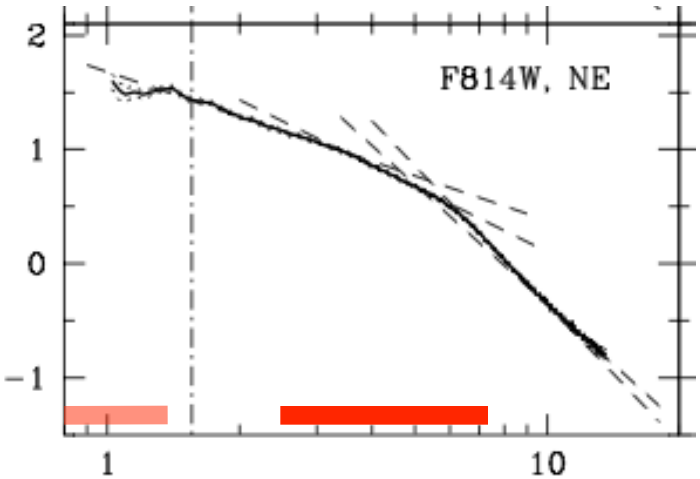
Peaks at +/- 65AU
Asymmetric: ~1.2 flux ratio => mass ratio
Emission to ~150AU

mm dust continuum – a model



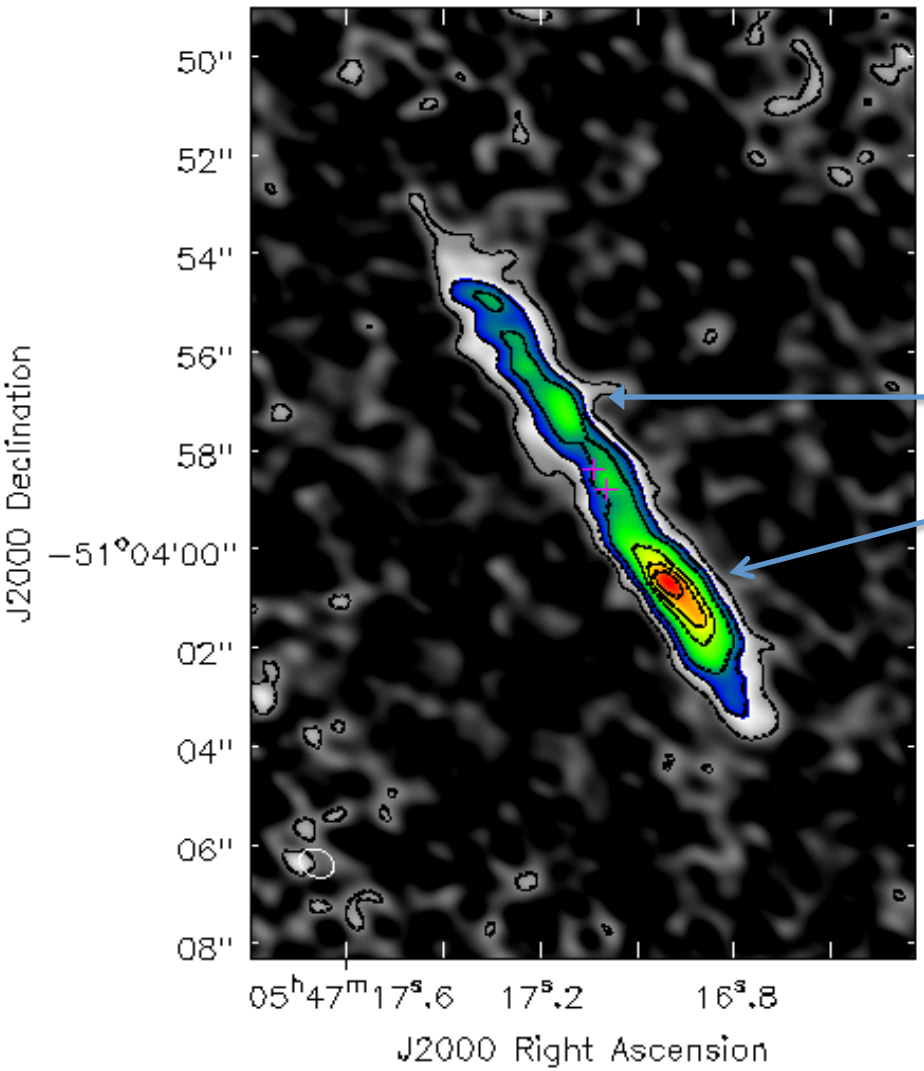
Fitting symmetric edge-on dust rings to NE and SW emission indicates a dust belt:

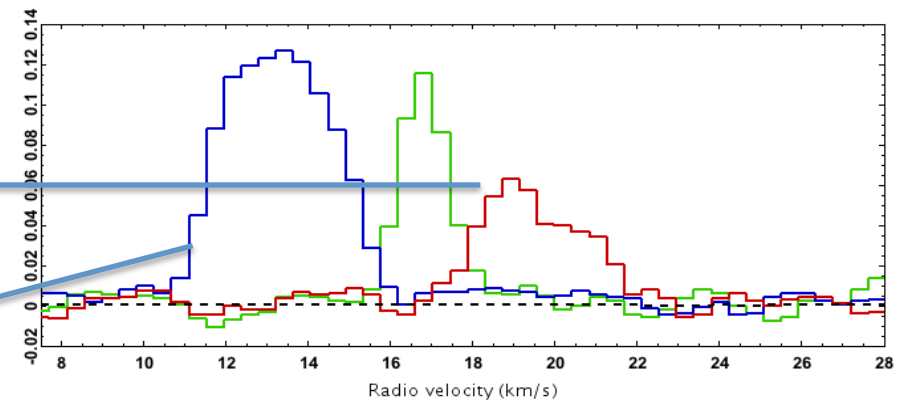
- Inner radius 50AU
- Maybe some extra component at <20AU (NE)
- Outer radius ~150AU (less sharp)
- Extra component on SW side at 80AU (radius)



Golimowski et al 2006

New detection of mm CO





CO mass ~2.10^{20}kg (LTE)

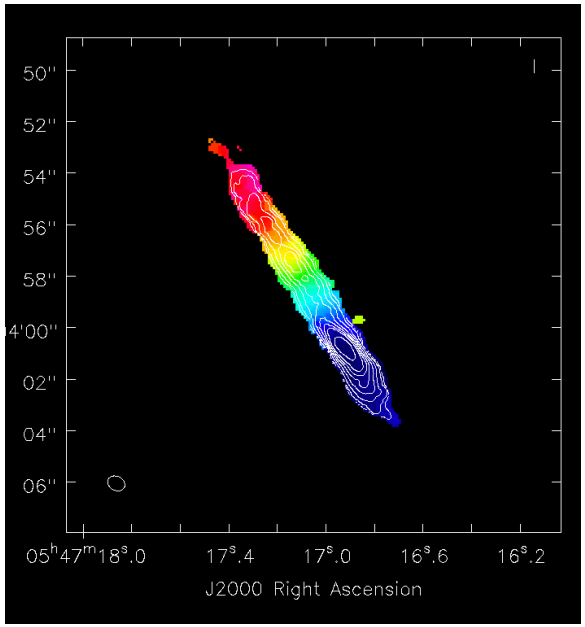
Optically thin disk =>

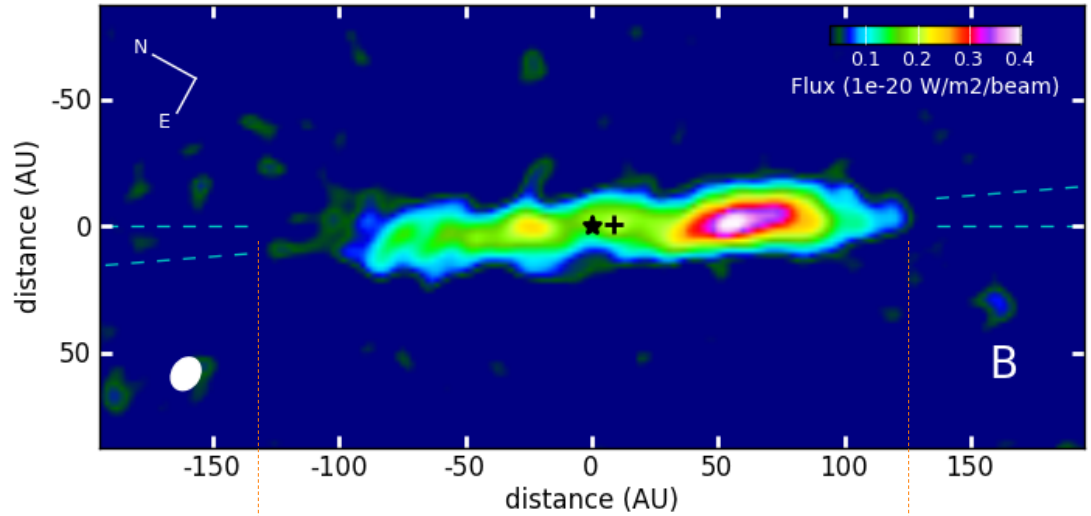
CO has short lifespan (~120yrs)

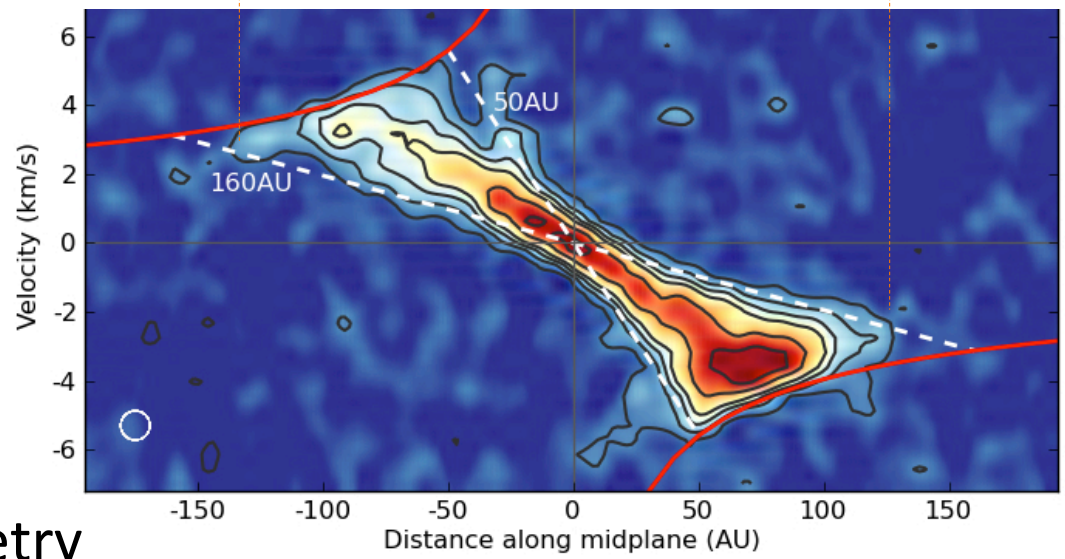
=> recently produced

Source: icy comet collisions

CO velocity shifts – PV diagram





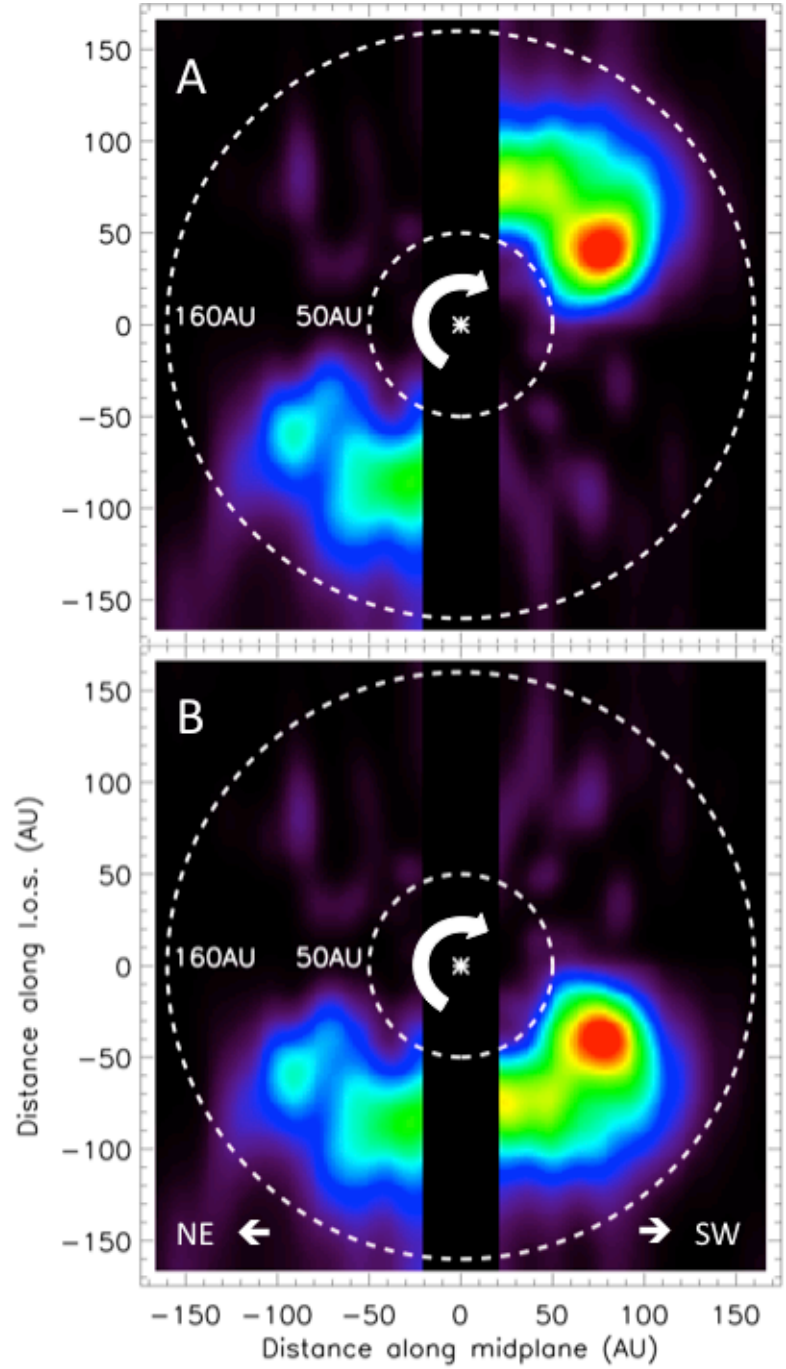


- In orbital motion
- Gas belt from 50-160AU
- No CO inside 50AU
- Factor of 2 NE-SW asymmetry

Where is the CO?

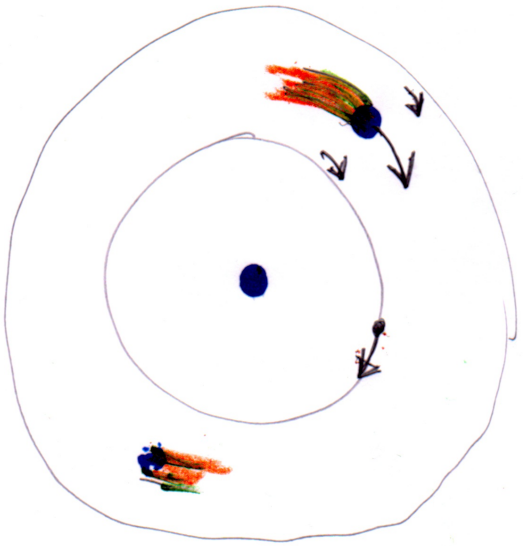
Re-projections of CO to face-on view

- Assumes Keplerian rotation
- Location of gas near zero velocity cannot be determined
- Line-of-sight locations have near/far ambiguity

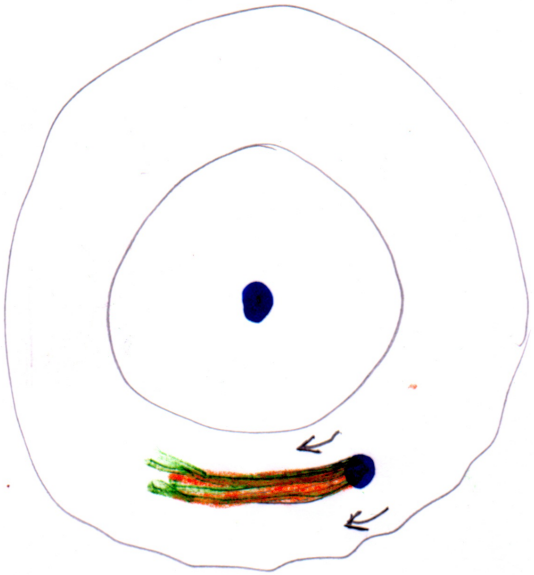


Explanations for the CO clump(s) and tail(s)

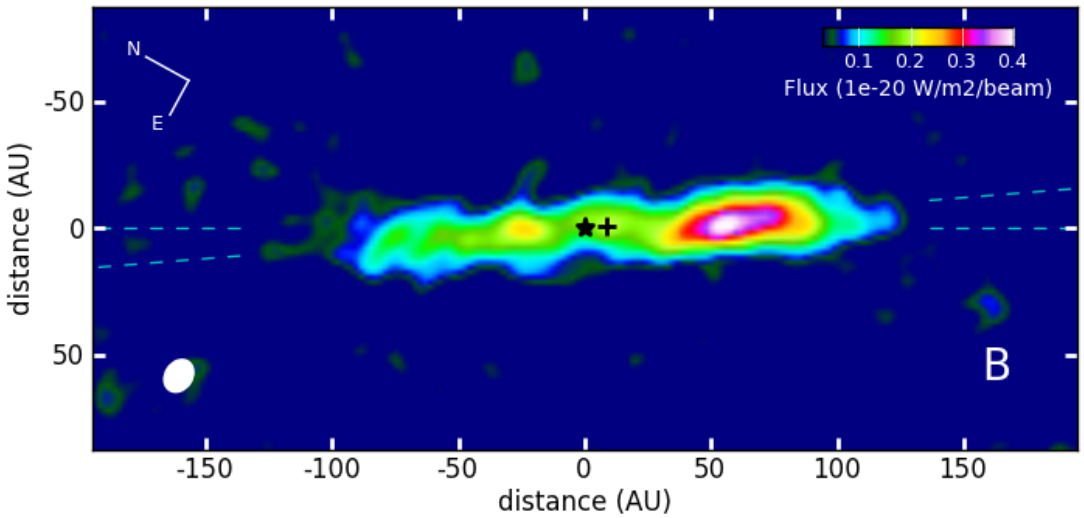
(A) Enhanced collisions in resonances with an unseen planet. Resonances move through the disk with the synodic period. 'Tail' length is given by the CO dissociation time / synodic period.

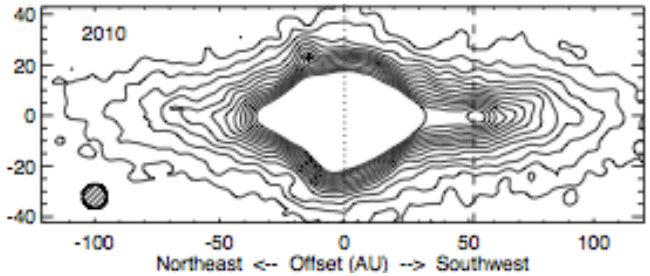


(B) A single collision of massive planets. The collision point is stationary. The 'tail' length is given by the CO dissociation time / sidereal period (ie longer than (A))



CO clump coincident with mid-IR dust clump

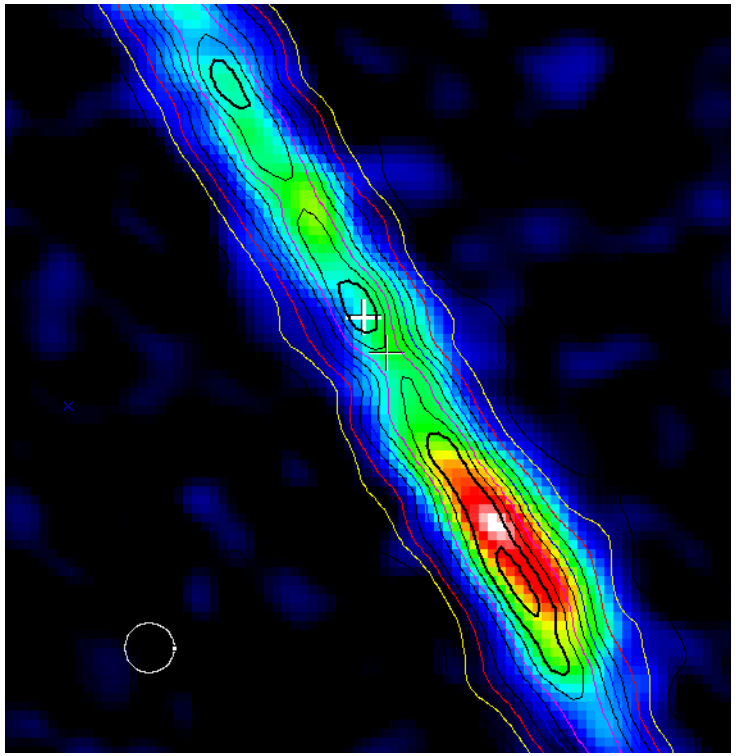




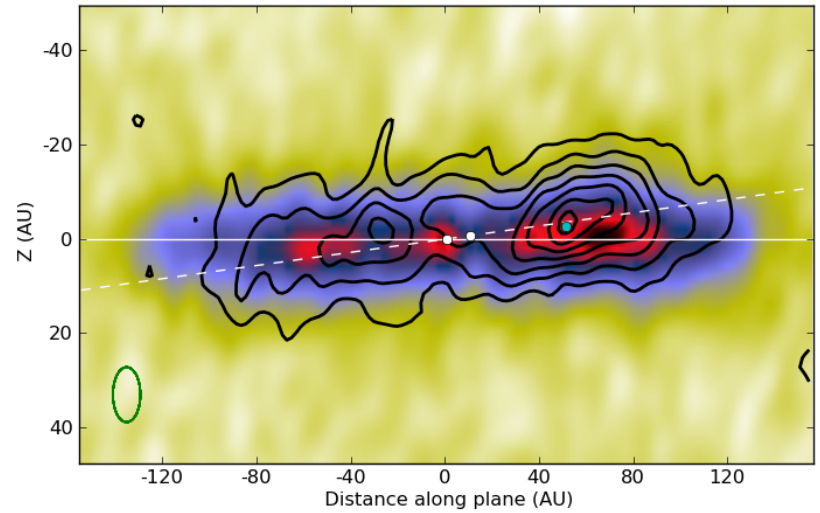
Telesco et al 2005

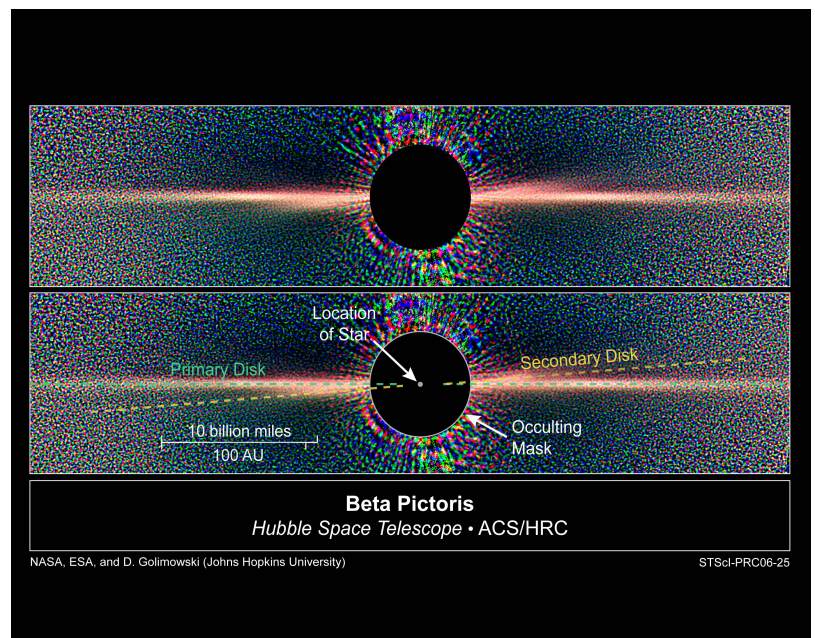
… which may be moving (Li et al 2012)

Disk vertical structure



CO vs. mm dust





=> CO appears to lie mostly in inclined or 'secondary' disk

Golimowski et al 2006

CO model

- 60-130AU ring
- Total mass ~$2x10^{20}$kg ($3x10^{-5}M_e$)
- Highly asymmetric (2-3x brighter in SW)
- Photodissociation timescale ~130yr (orbit ~700yr)

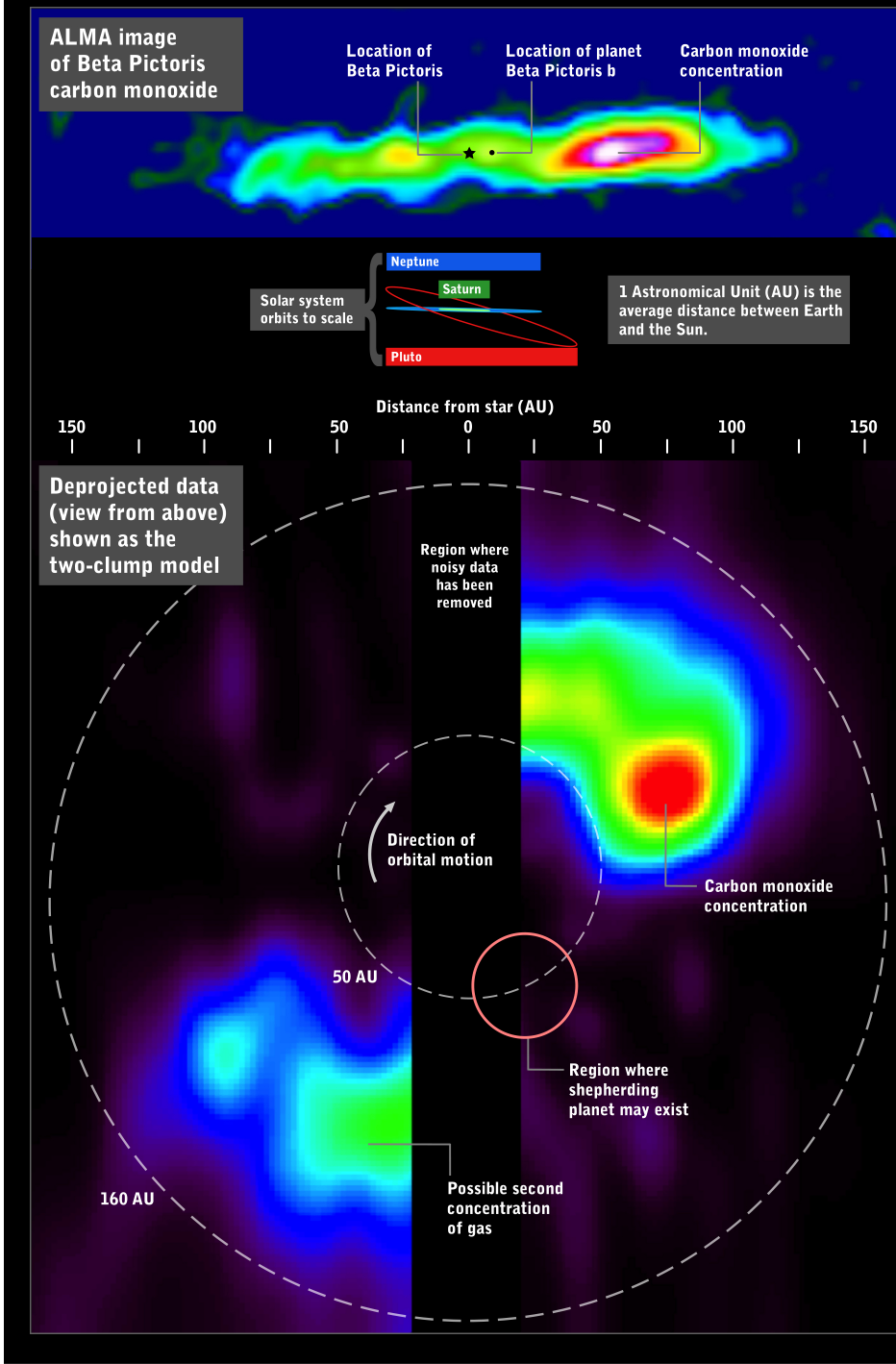
- Comets: mostly H_2O. CO fraction not well known – maybe 10%?
- Continuous replenishment, ~10^{19}kg/yr of icy bodies
- ~$1M_{Jupiter}$ in 10Myr (!)

- CO clump = enhanced collisions (higher velocity, higher density)
  - 2:1 resonance with Saturn-mass planet at ~60AU *OR*
  - Remains of collision of ~Mars mass bodies in last ~Myr
- Clump seen clearly in CO because of short gas lifespan

Summary of results

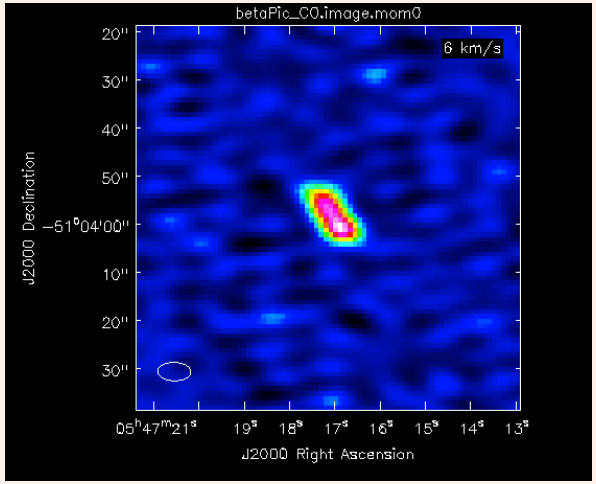
- CO is recently-released (secondary)
- in broad 50-160AU belt
- in plane of inner planet
- highly clumped (unlike dust)
- formed by enhanced cometary collisions
- either resonance with unseen planet or single (~Mars) collision
- CO photodissociation gives [CII] observed by Herschel
- CO can stabilise atomic lines

➢ maybe all debris disks have CO



Future observations with ALMA

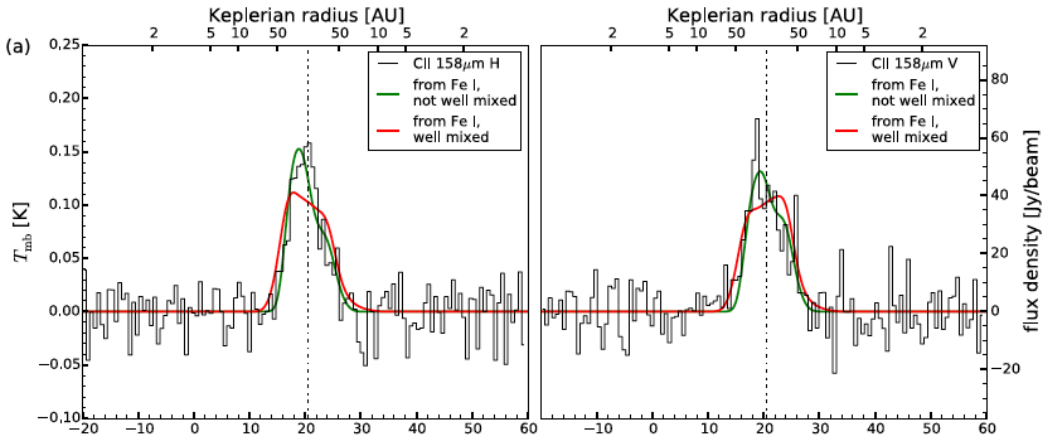
1) Higher resolution and different transition

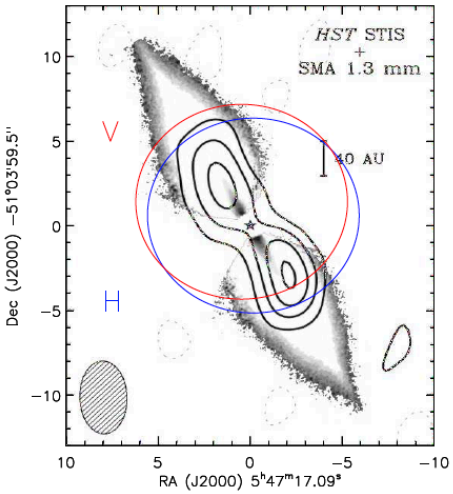


New ALMA Cycle 1 data in band 6 (ACA only so far) also shows CO J=2-1 with a 2-1/3-2 ratio consistent with Tex=20K (same as UV temperature from Roberge etal 2006).
=> CO mass ~$2x10^{20}$ kg

To come (cycle 2): configuration C32-6 (1.5km) => 0.25" resolution

(near) future observations with ALMA





[CII] from Herschel HIFI (Cataldi et al 2014)

=> Cycle 2 project: CI at 492GHz

Photodissociation product of CO
Maybe reconcile CO, [CII] and CI … ?

Other potential ALMA projects?

- Other lines (HCN, CH_3OH, ^{13}CO…)
- Higher resolution (but needs lots of time)
- Inner dust?
- CO clump motion?
- dust clearing compared with beta Pic b motion?
- dust spectral index