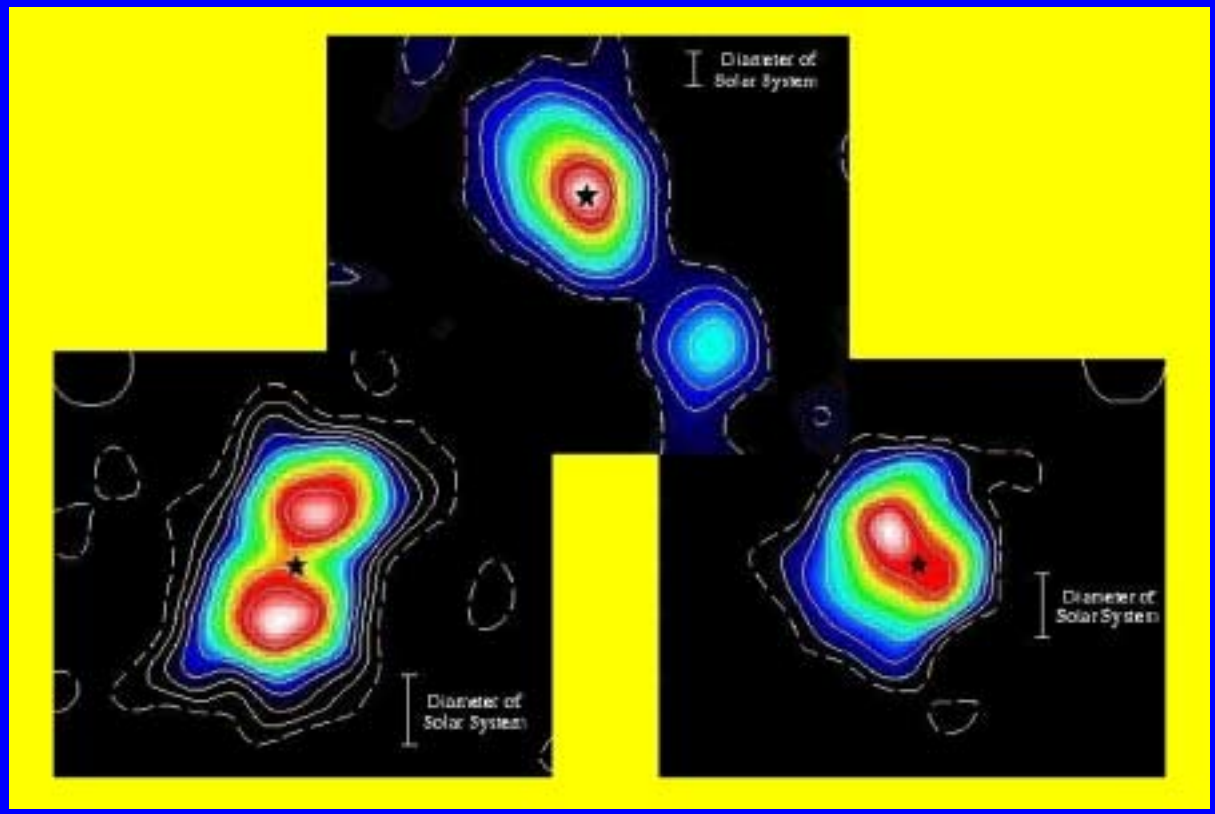
3 mm observations of the TW Hya and HD 100546 pre-planetary disks



Holland et al. (1998)

Nature

JCMT

0.85 mm

Chris Wright, Visiting Fellow, UNSW@ADFA

David Wilner & Tyler Bourke, Harvard CfA

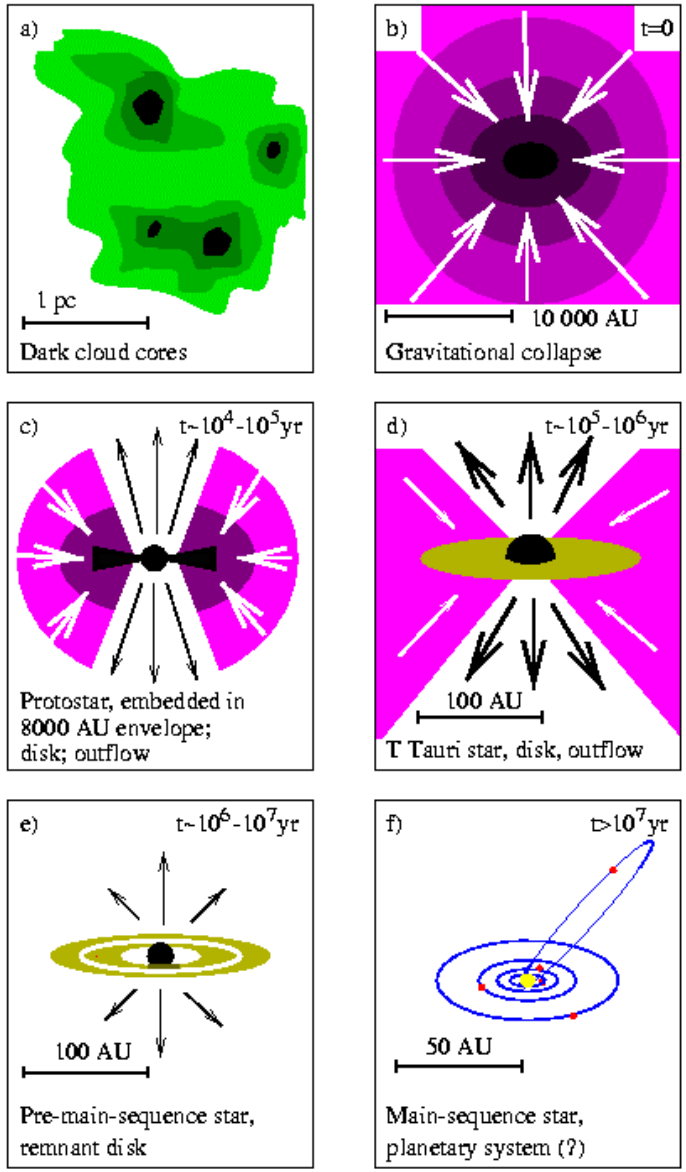
Tony Wong, ATNF

Ewine van Dishoeck & Jes Joergensen, Leiden University

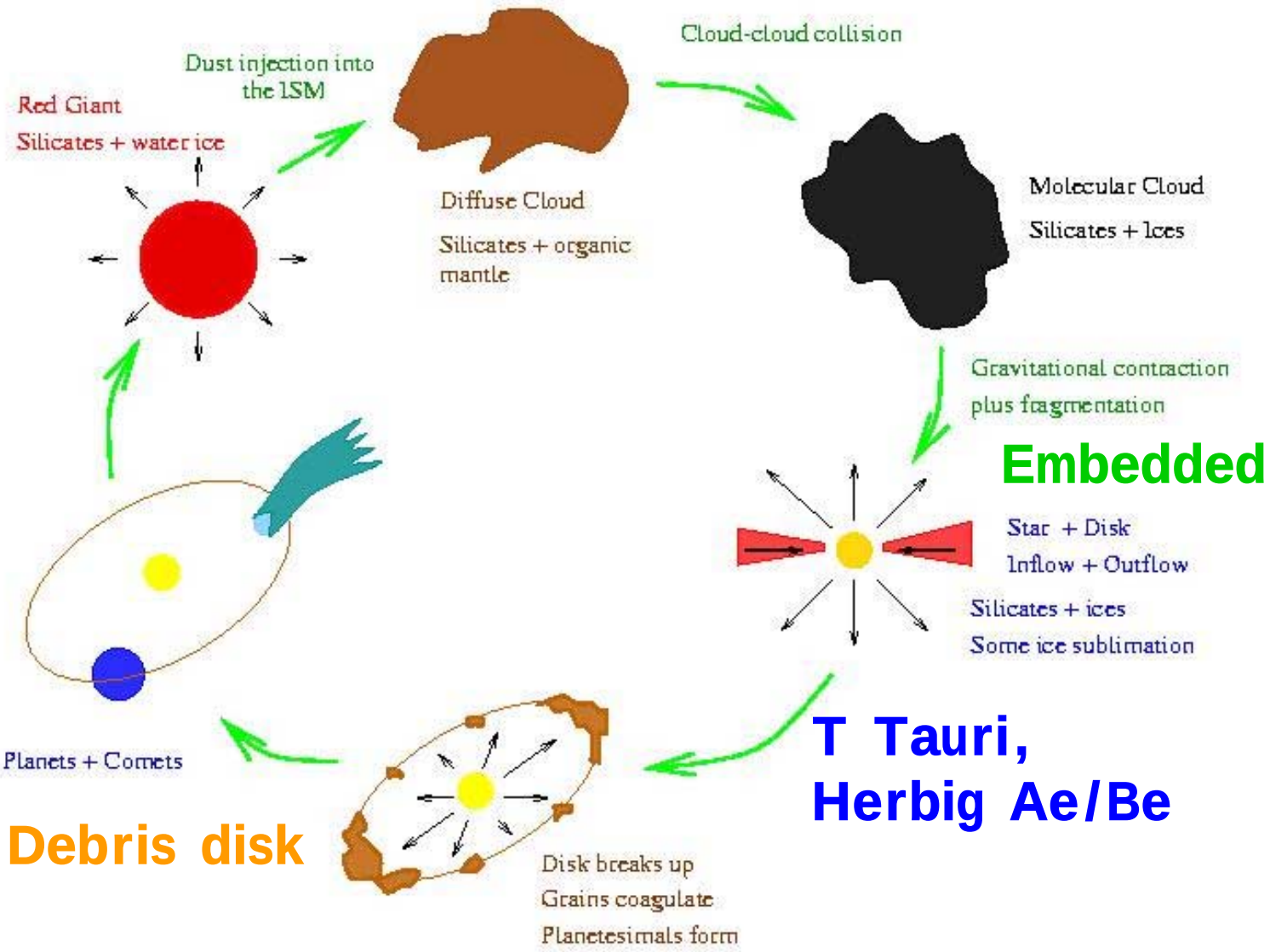
MM observations of pre-planetary disks

- Aims
  - to study the evolution of the gas and dust through the phases of a young stars life, e.g. from deeply embedded Young Stellar Object to T Tauri and Herbig Ae/Be through to optically revealed main-sequence stars. This will provide information on dust and gas processing, and disk dispersal (planetary formation?) timescales.
  - to conduct such a study in the rich southern hemisphere skies, e.g. the Chamaeleon, Corona Australis, Lupus, Vela and Ophiuchus clouds, and compare their processing with that of our solar system

From Michiel Hogerheijde, adapted from Shu et al. (1987)



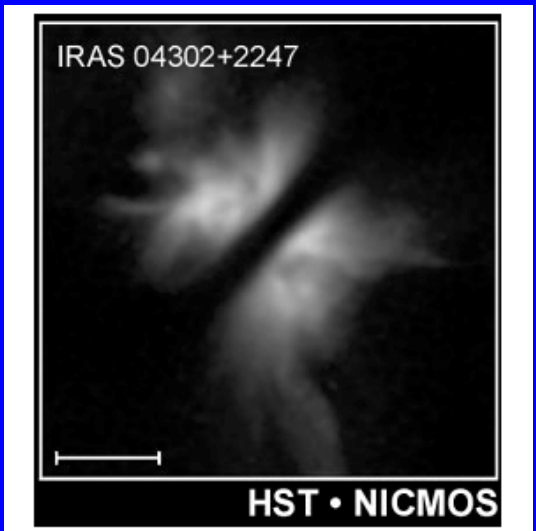
Life cycle of interstellar dust

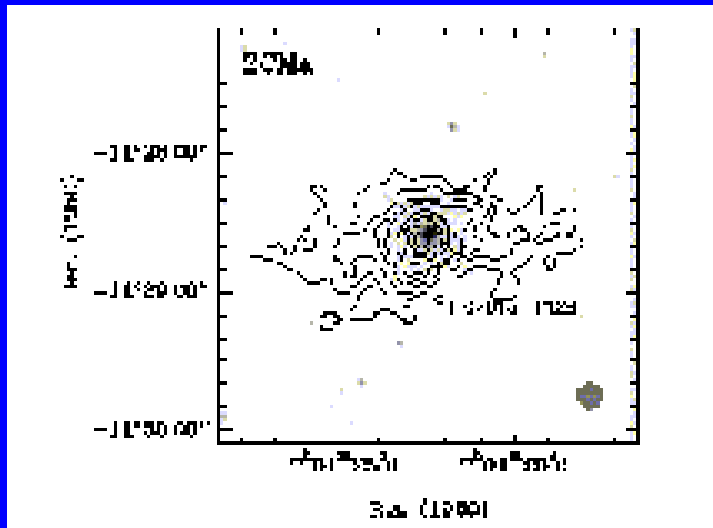


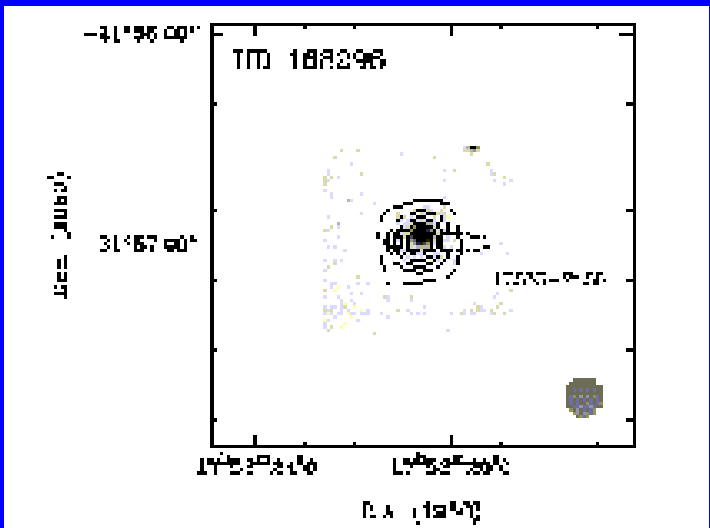
MM observations of pre-planetary disks

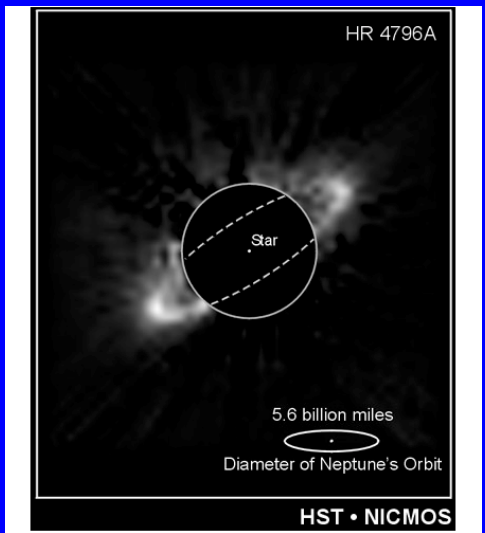
- Methods
  - Millimetre single dish (Mopra) and interferometric (ATCA) spectral line and continuum observations, to obtain gas chemistry, kinematics (infall, outflow, rotation), gas and cold dust spatial distribution
  - Mid-infrared spectroscopic observations of the 10, 20 micron silicate bands (Michelle on UKIRT/Gemini-N, TIMMI2 on ESO 3.6 m, T-ReCS on Gemini-S), to obtain warm dust mineralogy, size, spatial distribution

Images of disk “evolution”









TW Hya

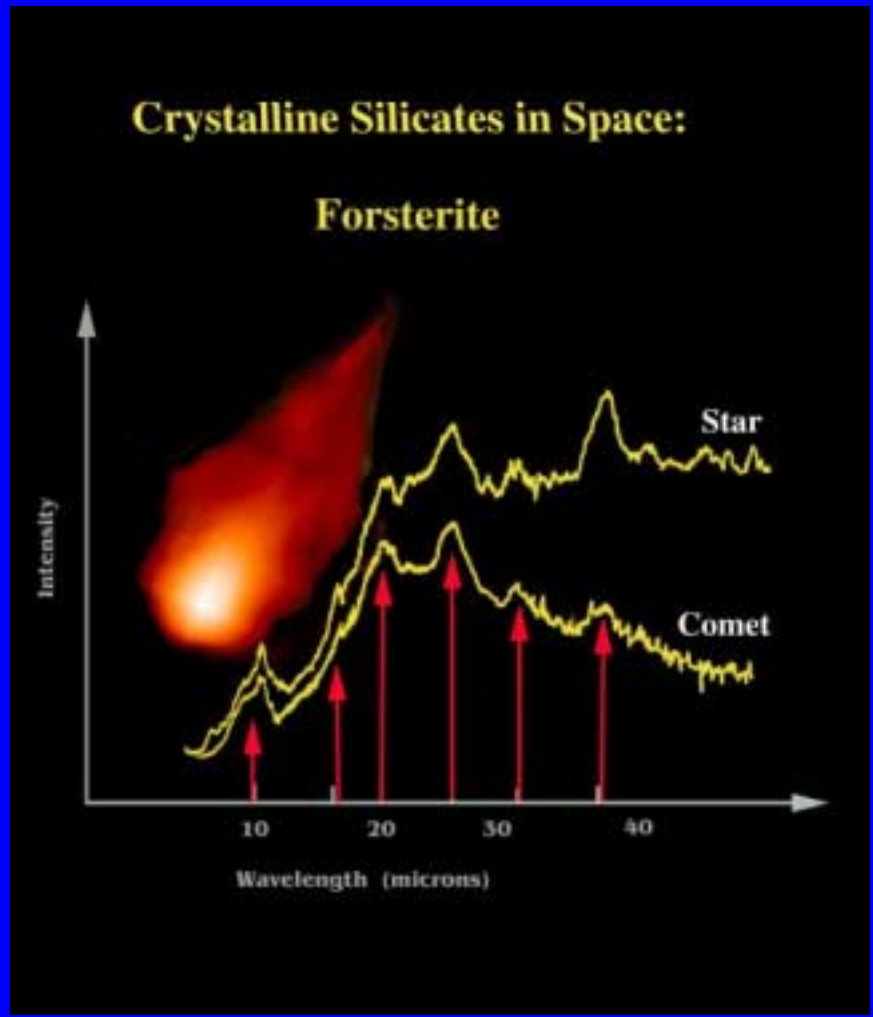
- At 50 pc the TWA is the closest known region of recent star formation
- Well studied TT star
  - make detailed comparisons
- TW Hya has Sun-like properties
  - ~0.5 Msun, ~0.5 Lsun
- Age ~ 5-20 Myr
- Disk radius ~ 5 arcsec

HD 100546

- Dust spectrum very similar to that of Comet Hale-Bopp
  - processing very similar to our solar system
- Not well studied, e.g. no molecular data
  - chance to find something NEW!
- ~2.5 Msun, ~30 Lsun
- Age ≥ 10 Myr, d~100 pc
- Disk radius ~ 5 arcsec

HD 100546 and Comet Hale-Bopp

- Solar system comet = HD 100546 extrasolar disk = mixture of crystalline and amorphous silicates
  - **short lifetime of dust - needs replenishment**
- Grady et al. (1997)
  - **“star-grazing comets”**



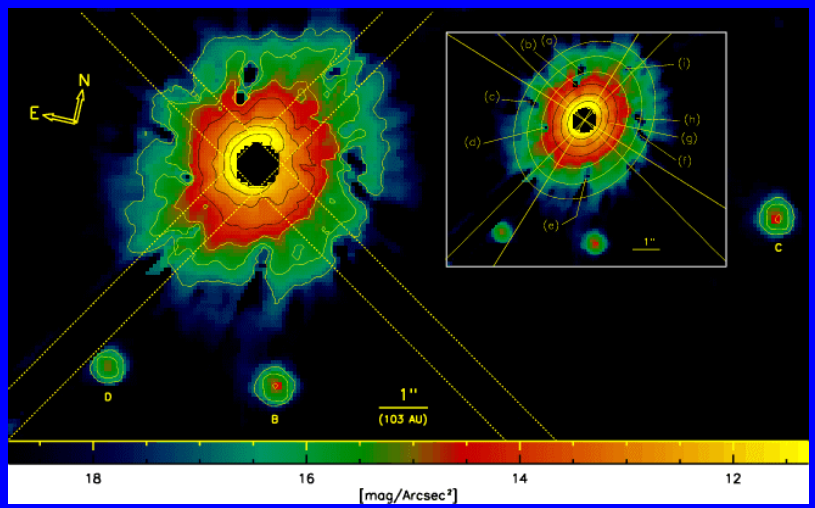
Malfait et al. (1998) - ISO

But …….

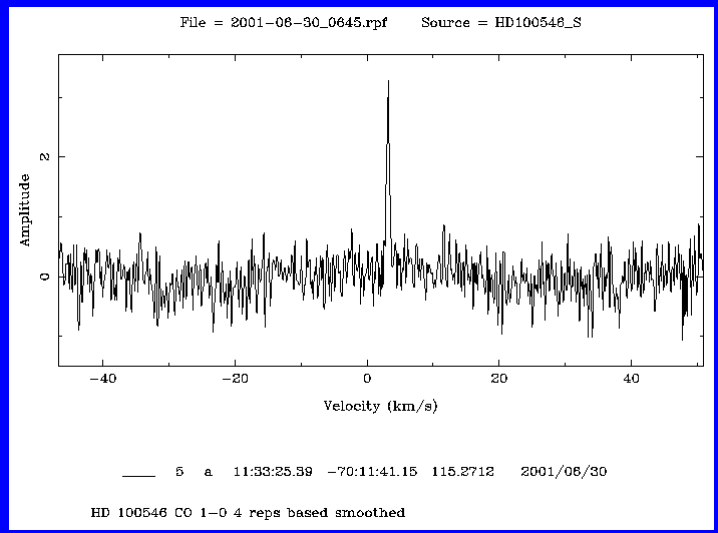
- Whilst gas was detected and imaged toward the younger phases, no mm molecular emission was detected toward the debris disks - where is the gas?
  - Depleted by planet formation, dissociated, frozen out or beam diluted by single dish?
- Liseau & Artymowicz (1998):
  - “the testing of [these alternatives] has to await the advent of the new generation of millimeter interferometers in the southern hemisphere”

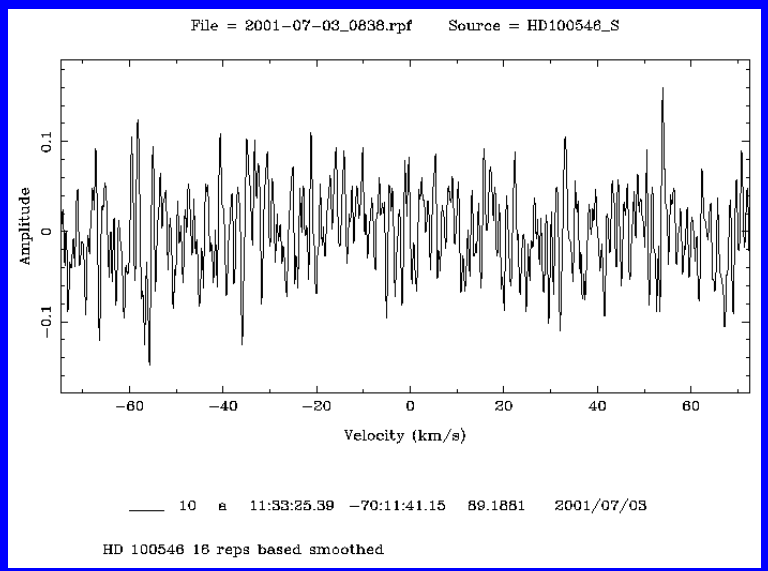
Mopra observations of HD 100546

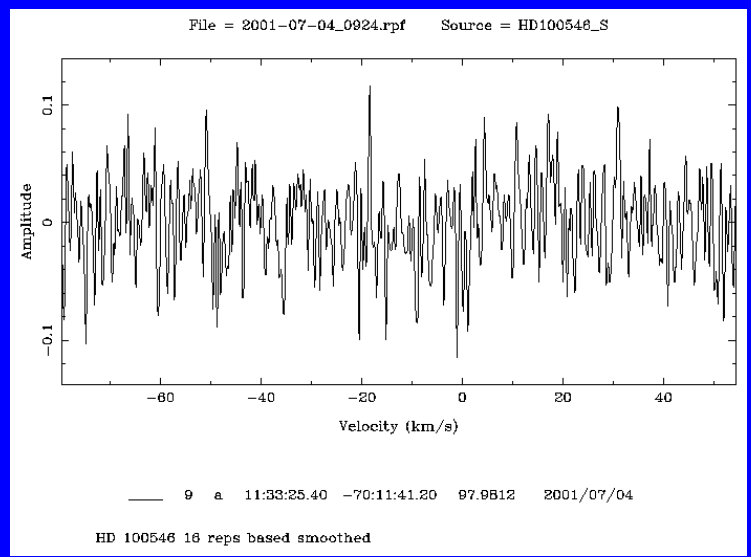
Augereau et al. (2001) HST 1.6 μm



DC 296.2-7.9

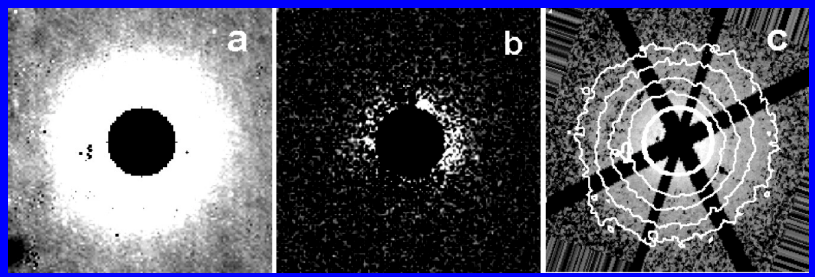




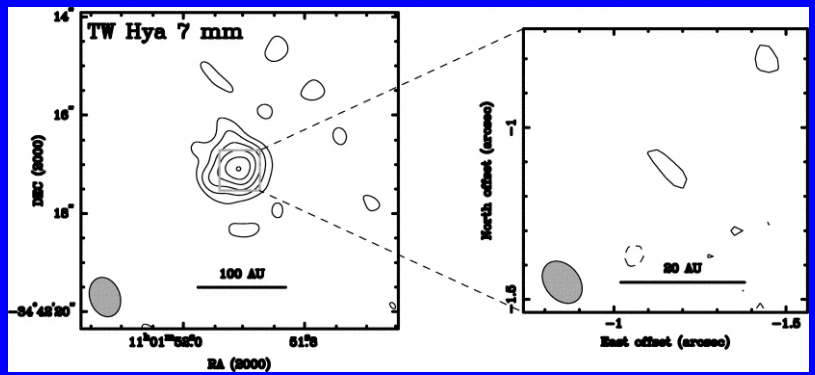


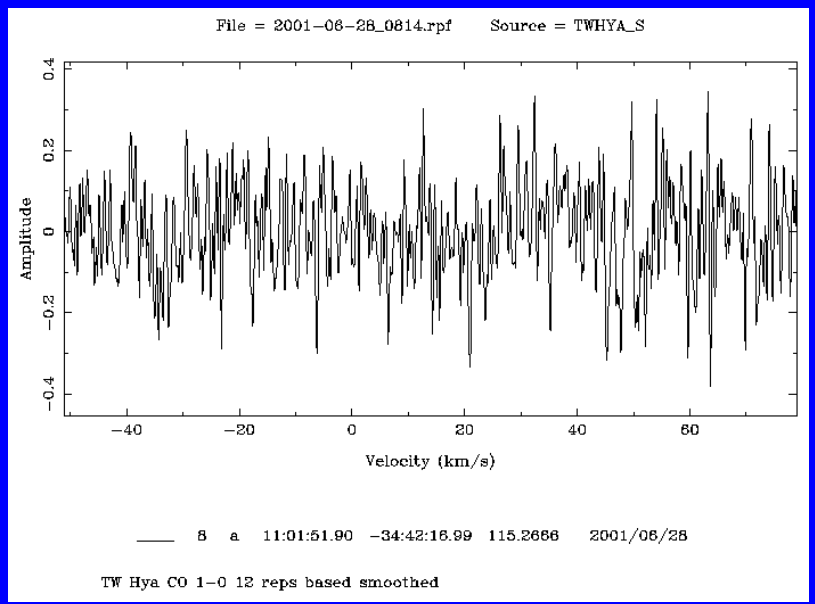
Mopra observations of TW Hya

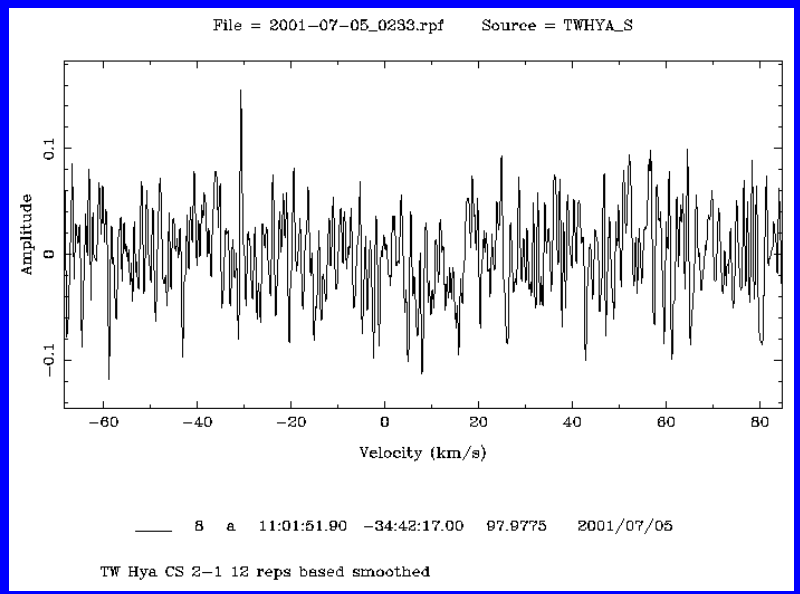
Trilling et al. (2001) 1.65 μm
- face-on disk



Wilner et al. (2000) 7mm





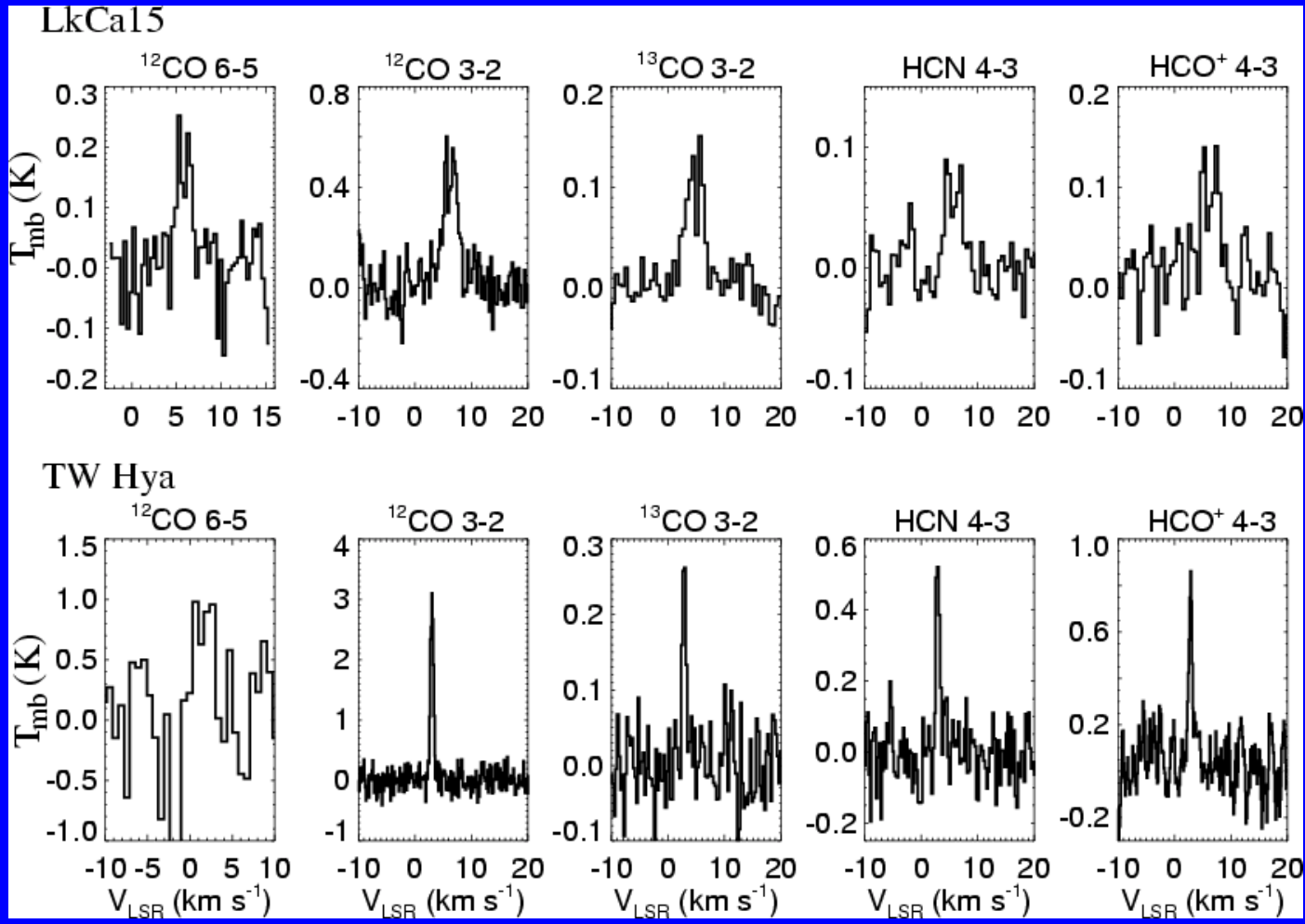


TW Hya

JCMT

Multi species and transition

van Zadelhoff et al. (2001, A&A, 377 566)



Only "warm" gas, T~50 K, traced by higher J transitions is detected towards TW Hya ⇒ Little cold gas present!

Mopra observations of “relic” disks

Mopra observations of "relic" disks

Star	RA J2000	Dec J2000	Distance pc	Cloud	Sp. Type	Age Myr	Disk	Silicate	CO 1 0	HCO 1 0	CS 2 1
TW Hya	11 02	-34 12	60±16	TWA	K7Ve	5 20	Y IR,mm	Y ex LRS,gnd	Y 1+8		Y 8+1
HD 100546 SAO 251157	11 33	-70 12	103,190	DC296.2-7.8	B8Vne	≥10	Y IR,mm	Y ex LRS,190	Y 8 Y 1 Y 1+1	Y 8+8	Y 8+8
HD 107139 SAO 223370	12 21	-18 13		8X Cen (EV Tau?)	F5,G3/5p			Y 190	Y 1		
HD 139614 SAO 226057	15 41	-42 30	81,151,157	Lupus	A2,A7Ve	-		N 190	Y 1		
HD 142527 SAO 226388	15 57	-42 19	200	Isolated Lupus?	G0,F6III F7IIIe	0.1		Y e LRS,190	Y 1+1 Y 1	Y 8	Y 5+8?
HD 142666 SAO 183856	15 57	-22 02	116,190		A3,A8Ve A7V	-		Y e,LRS 190,gnd	Y 1	Y 1	
HD 163296 SAO 185966	17 56	-21 57	122,160	ρ Oph?	A0,A0-7e,A7e A1Ve,A3Ve A0/2Vep+sb	5	Y opt,mm	Y ex,LRS 190,gnd	Y 1		
HD 165052	18 06	-11 55		CrA	F5V			Y e LRS	Y 1		
HD 212283 SAO 213783	22 21	-31 51			F3/5V			Y e LRS	Y 1	Y 8+8	

Mopra (i.e. single dish) conclusions

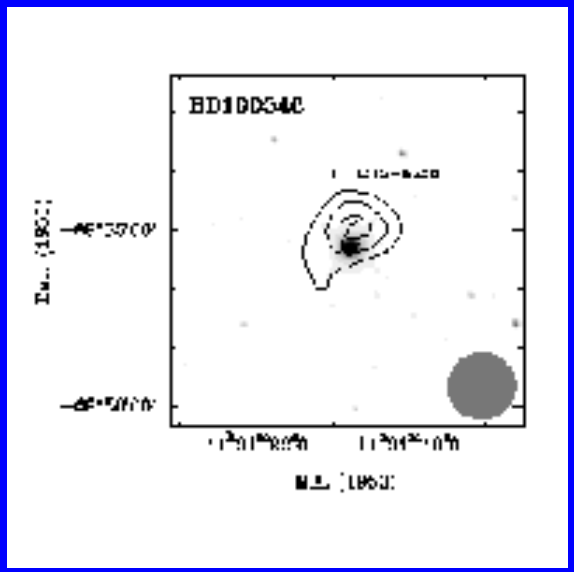
- CO 1-0 detected toward 3 objects
  - HD 100546, where it is extended and associated with the molecular cloud in which the object lies
  - HD 142527 ditto ⇒ need for **interferometer** to reveal small-scale emission
  - HD 163296, where the signature of disk rotation can be discerned, but interpretation is aided by pre-existing **interferometer** observations
- No other detections of CO 1-0, HCO+ 1-0 or CS 2-1 were made. This might indicate that cold gas (say ≤ 50 K) is not a significant component of many disks, **OR**
- Simply need an **interferometer** to see it!

ATCA 3 mm observations

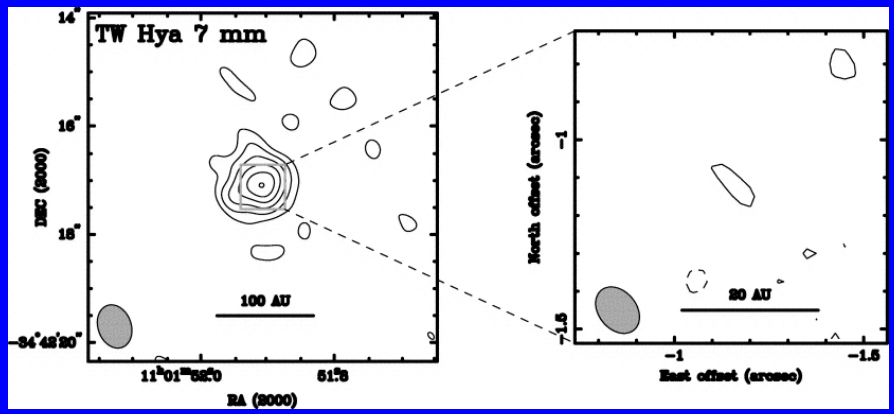
Henning et al. (1998)

SEST

1.3 mm



Wilner et al. (2000) VLA 7 mm

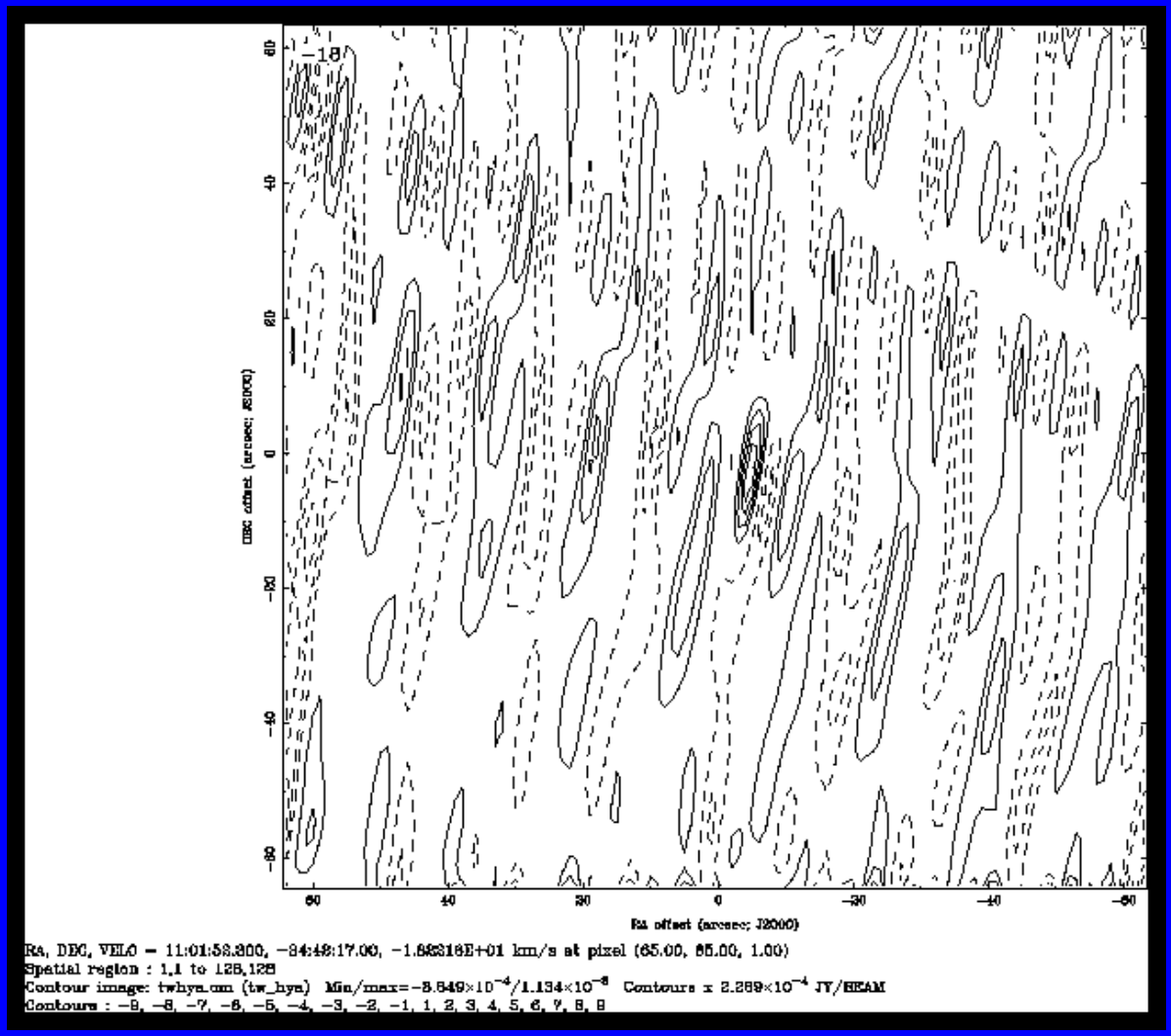


- 2 “interesting” objects selected
  - **HD 100546 and TW Hya in HCO+ 1-0 transition**
- Expected 3 mm continuum fluxes are ~0.1 Jy for HD 100546 and ~0.07 Jy for TW Hya

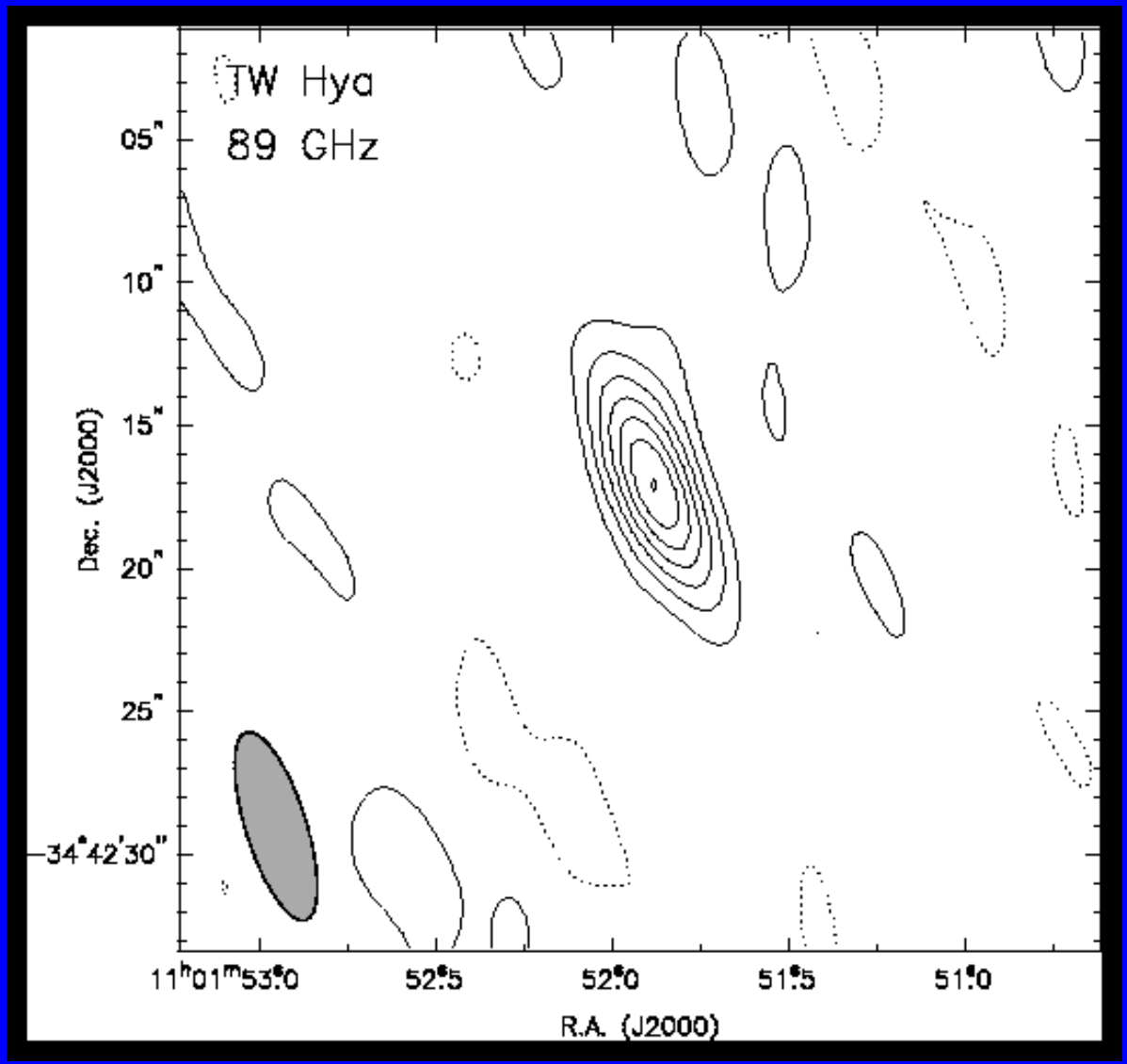
ATCA (CA02,03,04) parameters

- October 2001- EW 352 (baselines 45.9, 76.5, 122.4 m) -day
- May/June 2002- EW 352 -day/night
- August 2002 - 750D (60, 165 225 m) - day/night
- Correlator configured for narrow (16 MHz) and broad (128 MHz) bands, 256 and 32 channels respectively
- Obs. Freq. 89.188518 GHz, HCO+ J=1-0 (3.4 mm)
- Synthesized beams 6.9x2.1 (TW) and 3.2x2.2 arcsecs (HD)
- Phase and pointing calibrators B1144-379 for TW Hya, B1057-797 for HD 100546
- Primary flux calibrator Mars, secondary 1101-325 for TW Hya and 1105-680 for HD 100546
- Bandpass calibrators 3C 279, 0537-441, 1921-293

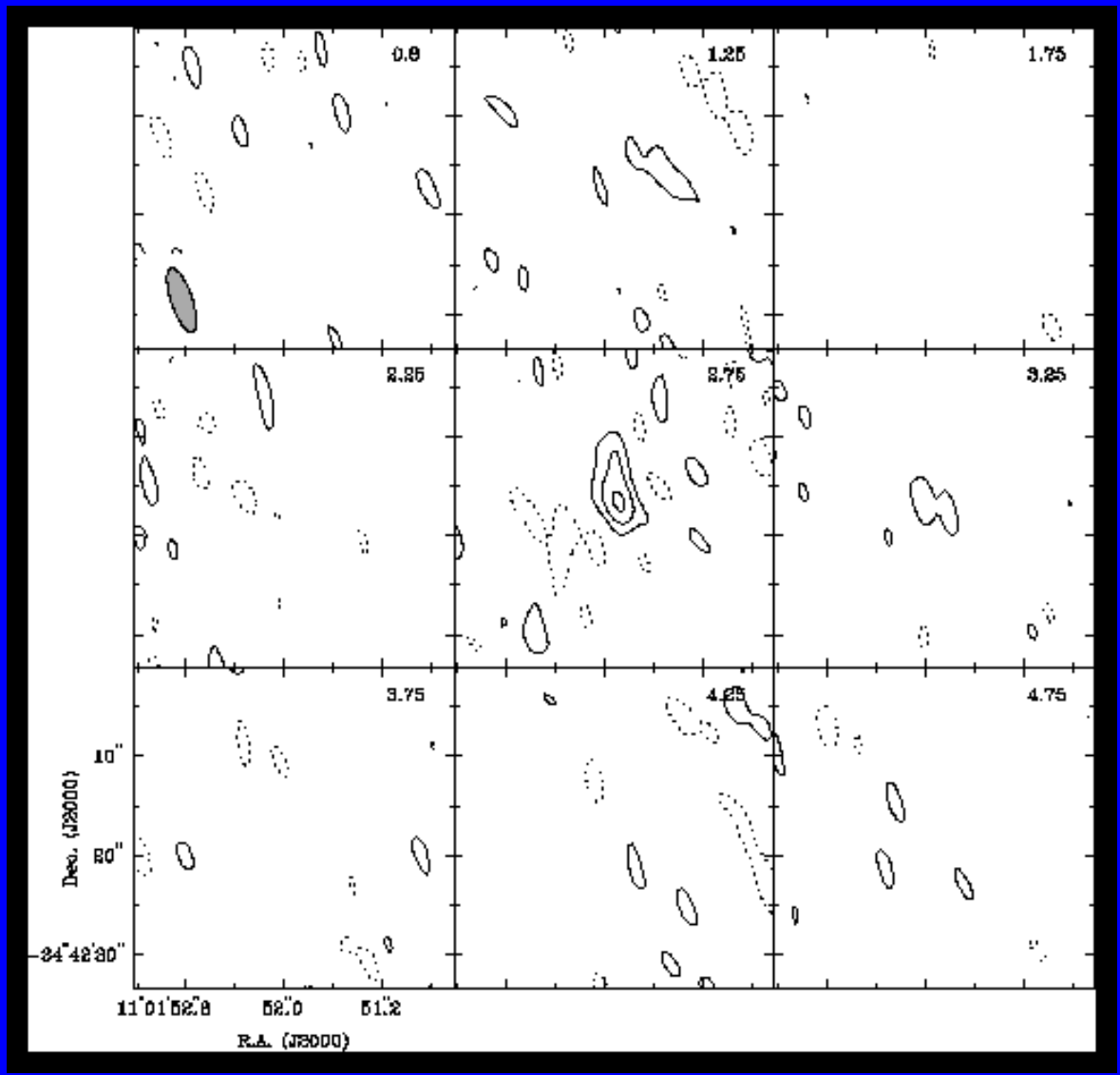
TW Hya October 2001



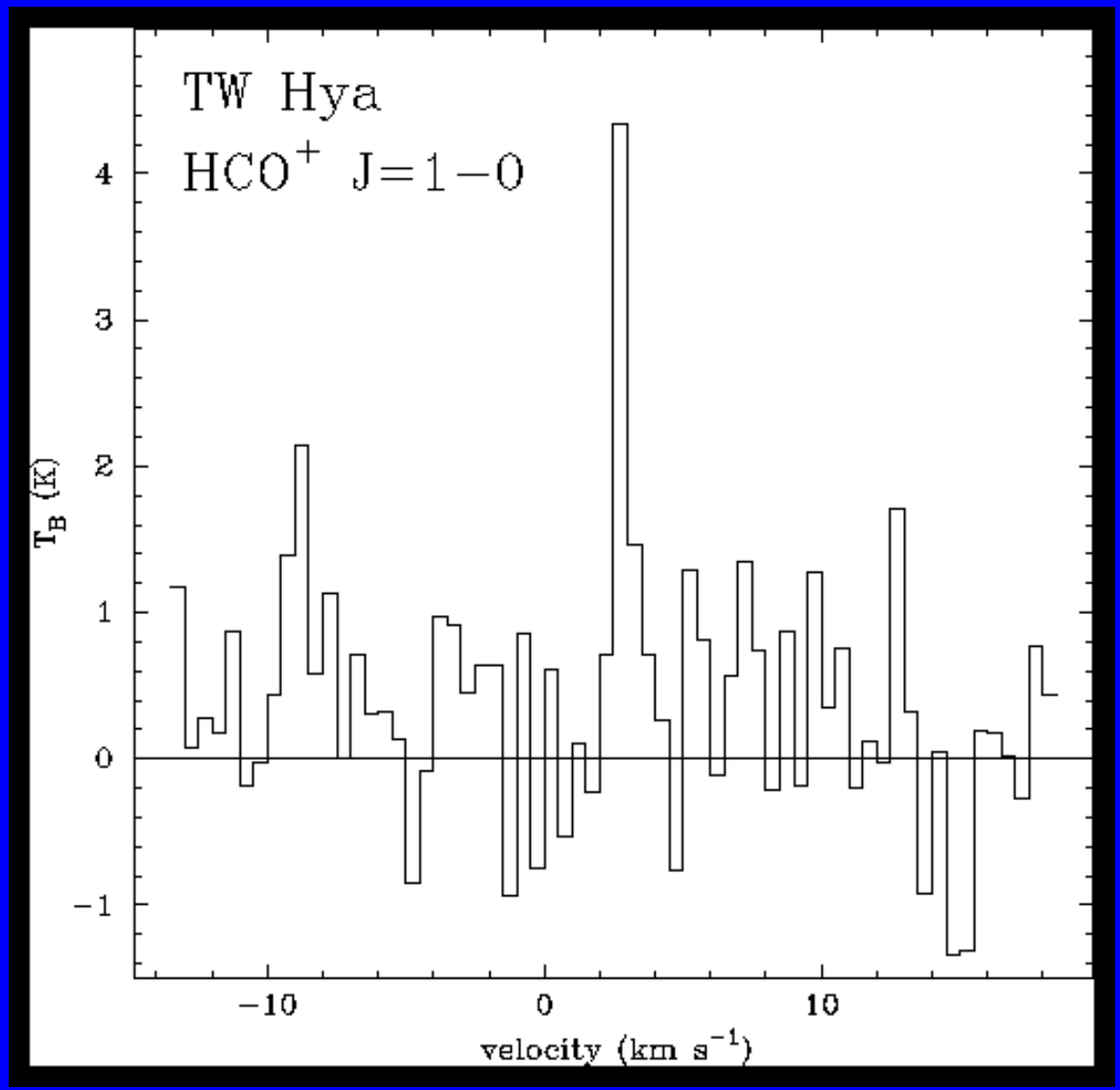
TW Hya 3.4 mm continuum - 2002



TW Hya HCO+ line image - 2002



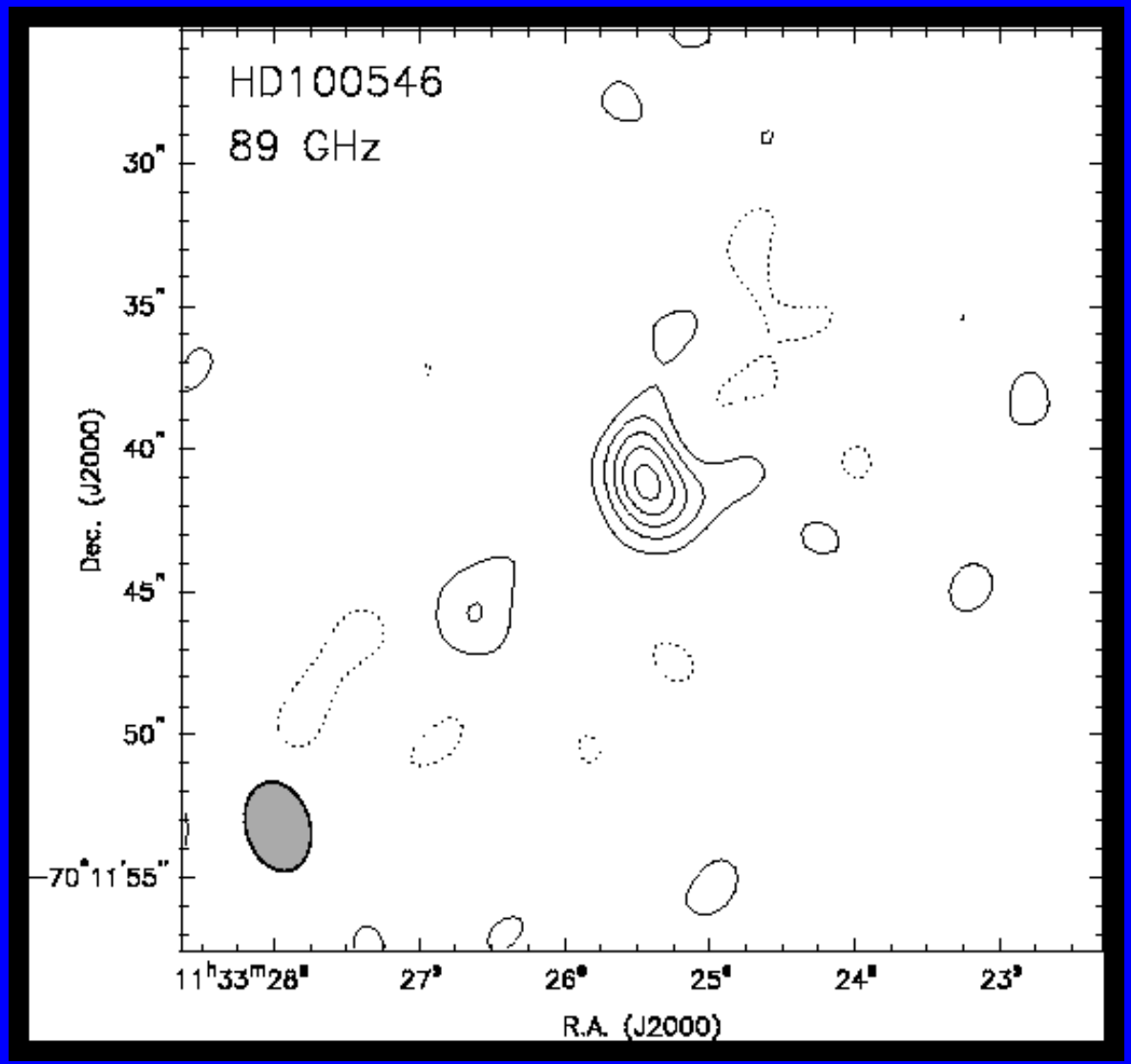
TW Hya HCO+ 1-0 spectrum - 2002



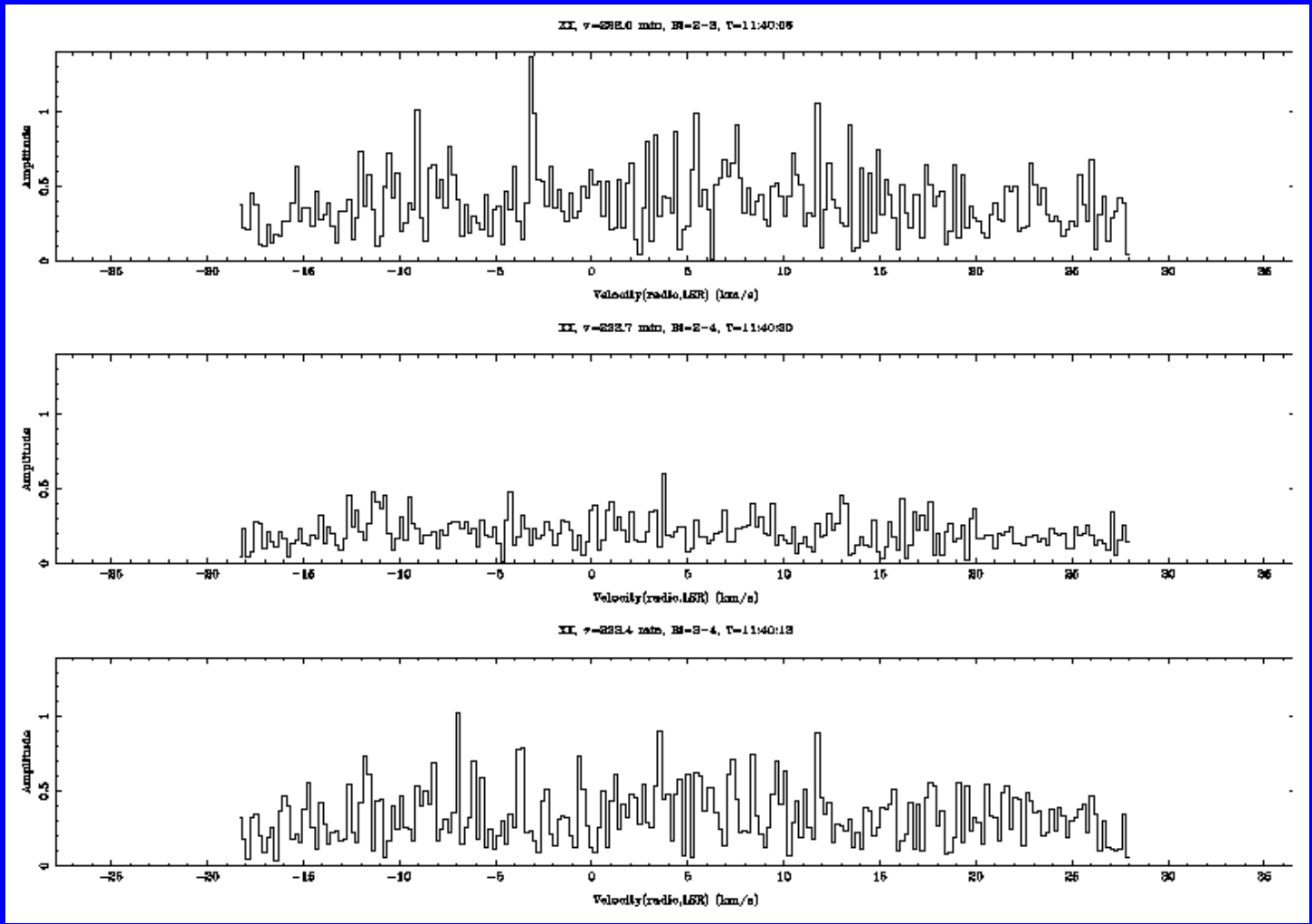
TW Hya results

- Detected in both line and continuum
  - **first interferometric detection of molecular emission**
- Continuum emission is unresolved
  - **flux agrees well with expectation based on SED up to 7mm**
  - **Evidence for big grains, i.e. mm to cm sized, e.g. Calvet et al. (2002)**
- Line emission resolved
  - emission from warm upper layer near the surface of a flaring disk, heated by stellar and interstellar radiation (van Zadelhoff et al. 2001)
- Line very narrow, consistent with face-on disk
- The “Rosetta Stone for our understanding of the evolution and dissipation of protoplanetary disks”

HD 100546 3.4 mm continuum -2002



HD 100546 line emission?



HD 100546 results

- Clearly detected in continuum emission
  - flux consistent with extrapolation from 1.3 mm
  - SED now able to be well modelled
    - **geometry, grain sizes (as for TW Hya)**
- Tentative second source
  - along p.a. of disk major axis from scattering data
- Tantalising line emission, but need more data
  → very important observation to answer the question “Where is the gas?”

ATCA 3 mm recommendations

- The ATCA is a **TERRIFIC** mm interferometer! But….
- CO 1-0 115 GHz would have been nice…..
- Observe at night! Conditions were much better!
- Use one correlator channel for continuum and other for spectral line (broad and narrow band)
- Be sure of your source barycentric velocity as frequency has to be corrected in schedule file
- Find a good strong phase calibrator (if possible)
- Should continue to support Mopra as a training and “extended structure” instrument. Only six weeks of community use per year…..