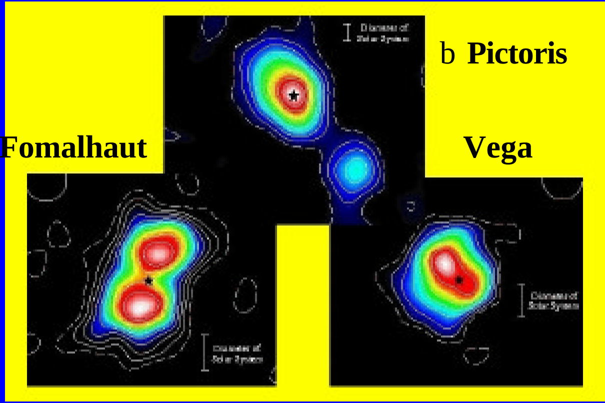
Millimetre observation of pre-planetary disks



Holland et al. (1998)

Nature

JCMT

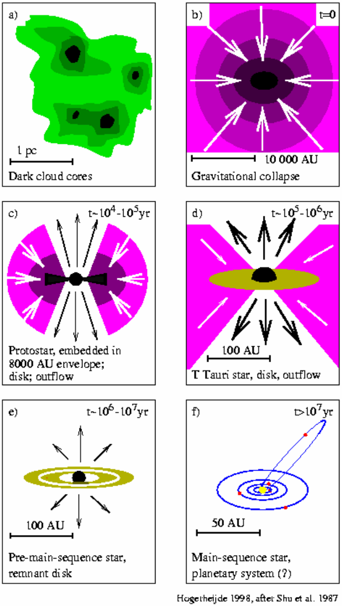
0.85 mm

Chris Wright, Honorary Visiting Fellow, UNSW@ADFA

Prof. Ewine van Dishoeck, Leiden & Dr. Tyler Bourke, CfA

MM observations of pre-planetary disks

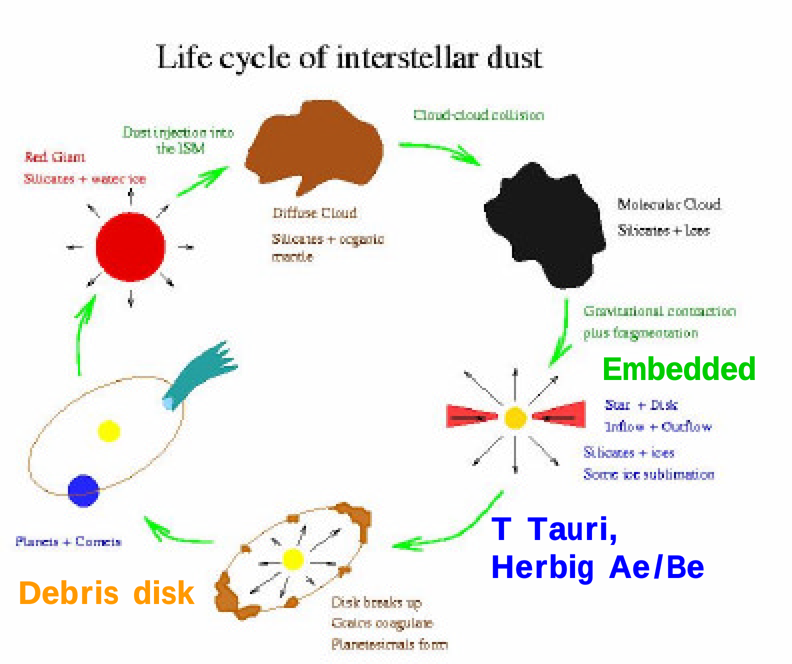
- Aims
  - to study the evolution of the gas and dust through the phases of a young stars life, e.g. from deeply embedded Young Stellar Object to T Tauri and Herbig Ae/Be through to optically revealed main-sequence stars. This will provide information on dust and gas processing, and disk dispersal (planetary 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



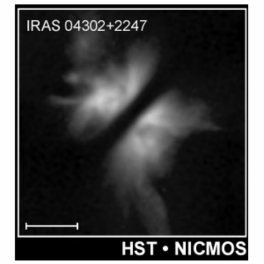
From Michiel Hogerheijde, adapted from Shu et al. (1987)

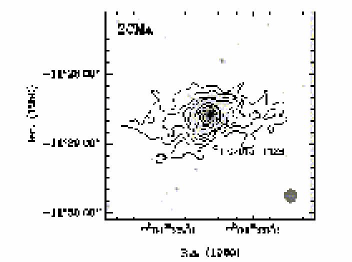
MM observations of pre-planetary disks

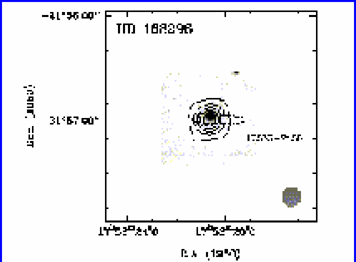
- Methods
  - Millimetre single dish (Mopra) and interferometric (ATCA) spectral line and continuum observations, to obtain gas chemistry, kinematics (infall, outflow, rotation), gas and cold dust spatial distribution
  - Mid-infrared spectroscopic observations of the 10, 20 micron silicate bands (Michelle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

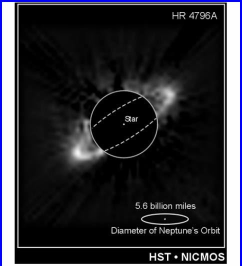

Life cycle of interstellar dust
Cloud-cloud collision
Dust injection into the ISM
Red Giant
Silicates + water ice
Diffuse Cloud
Silicates + organic mantle
Molecular Cloud
Silicates + Ices
Gravitational contraction plus fragmentation
Embedded
Star + Disk
Inflow + Outflow
Silicates + ices
Some ice sublimation
T Tauri,
Herbig Ae/Be
Disk breaks up
Grains coagulate
Planetesimals form
Planets + Comets
Debris disk

Images of disk “evolution”

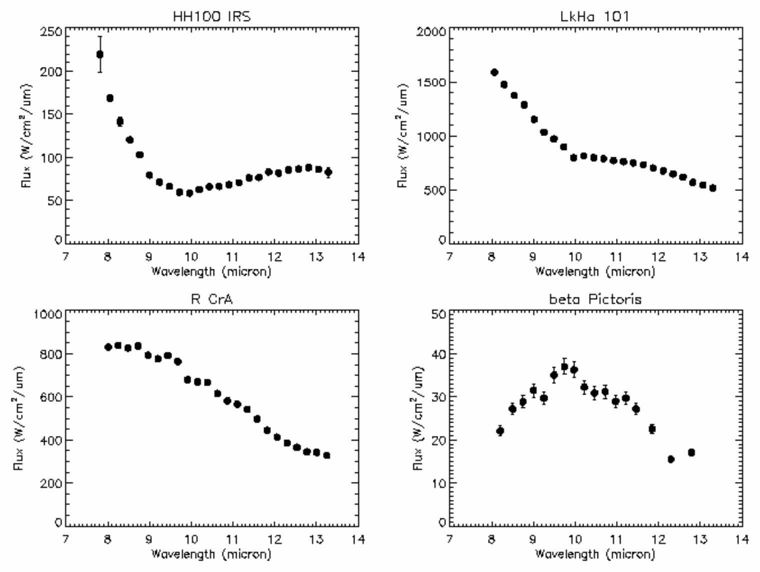




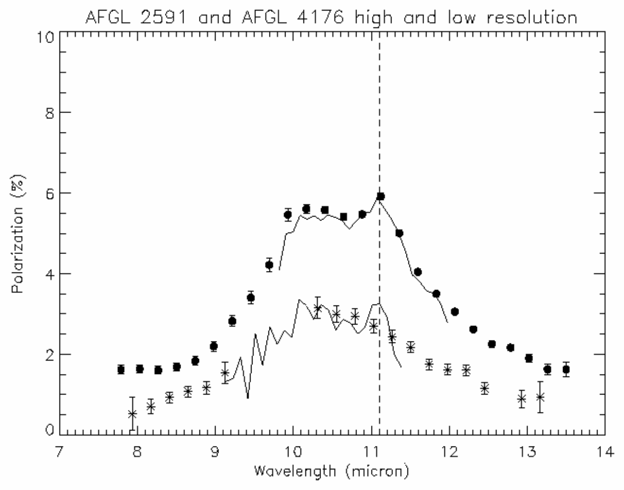




The “evolution” of the 10 μm silicate band



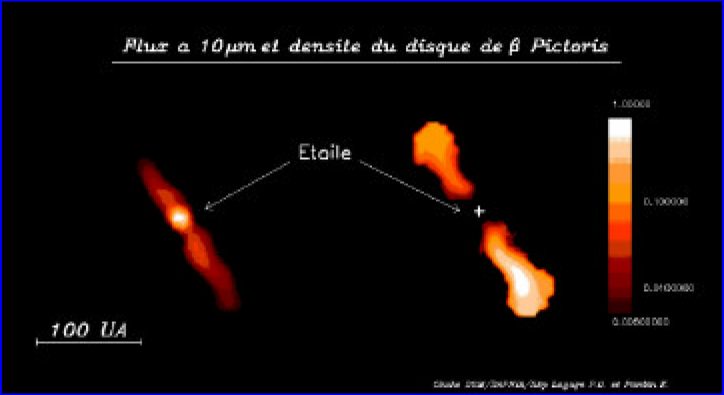
Michelle - Prospects for High Resolution Spectropolarimetry



History 1

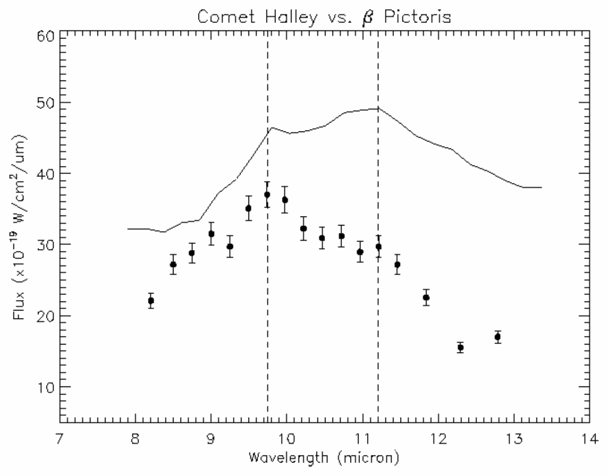
- 1984, Aumann et al. used IRAS to detect excess dust emission at 15, 60 and 100 μm toward the main sequence star Vega (α Lyrae)
- A search of IRAS database conducted, and further detections like β Pictoris reported, e.g. Aumann (1985), Sylvester et al. (1996)
- Ground-based follow-up imaging and spectroscopy⇒ dust distributed in a so-called “debris” disk, in some cases with warps and gaps indicative of a planetary system

12 μm image of β Pictoris



- Age about 20 Myr, cf. 4.5Gyr for the Sun
- Disk extent more than 100 AU
- Depletion and warp at < 40 AU $\rightarrow$ at least one planet

AAT Observations of β Pictoris and Comet Halley



Sitko et al. (1999) - “To understand better how β Pic and other main sequence stars with debris disks evolved into their present state, we need to investigate their evolutionary precursors.”

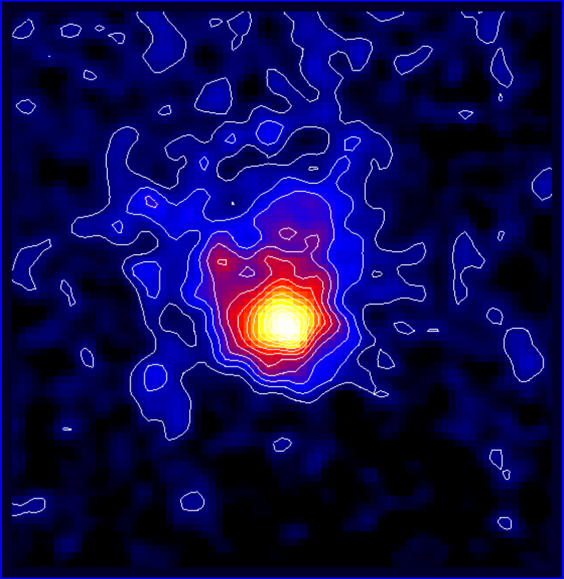
Comet Hale-Bopp

AAT NIMPOL

11.5 μm

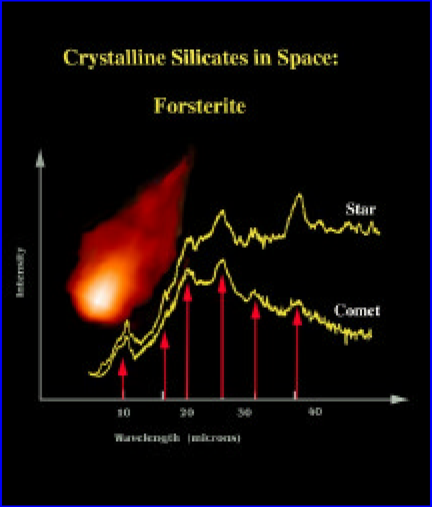
August 1996

3.6 AU



HD 100546 and Comet Hale-Bopp

- Comet = disk =crystalline/amorphous silicate mixture
  - **short lifetime of dust - needs replenishment**
  - **infalling/colliding comets**
- Crystalline silicates not seen in ISM
- Crystallised in disk before comet formation
  - **How?**



History 2

- But what about the gas?
- Searches conducted for molecular emission
  - Embedded YSOs by Hogerheijde (1998), Padgett et al. (1999)
  - T Tauri stars by Sargent & Beckwith (1991), Zuckerman et al. (1995)
  - Herbig Ae/Be stars by Mannings & Sargent (1997)
  - Debris disks by Liseau & Artymowicz (1998), Coulson et al. (1998), Greaves et al. (2000)

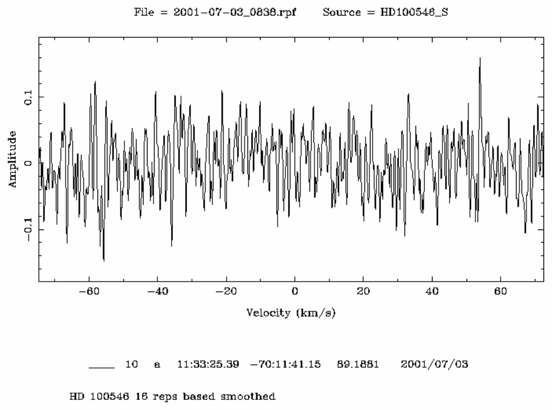
But …….

- 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"

The gas content of planet building disks

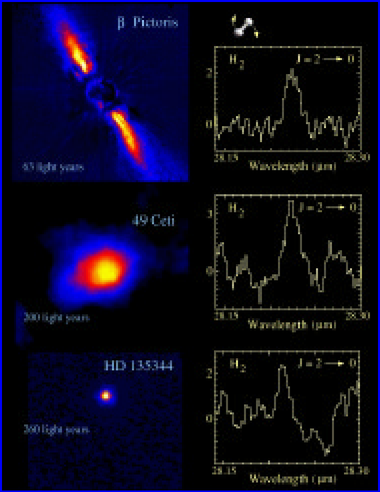
HD 100546 HCO+ Mopra

- Little or no gas detected around so-called “debris” disks using ground-based instrumentation
  - **e.g. HD100546, known for its “solar-system-like” dust properties**
  - **But where is the gas?**



Molecular hydrogen in disks

- CO and other molecules not previously found in “debris” disks
- Used up in planet formation, frozen out, dissociated, or beam dilution?
- But these gases are only trace constituents - what about H_2?
- ISO observations
  - **Jovian planet formation can occur on timescales up to 20 Myr**



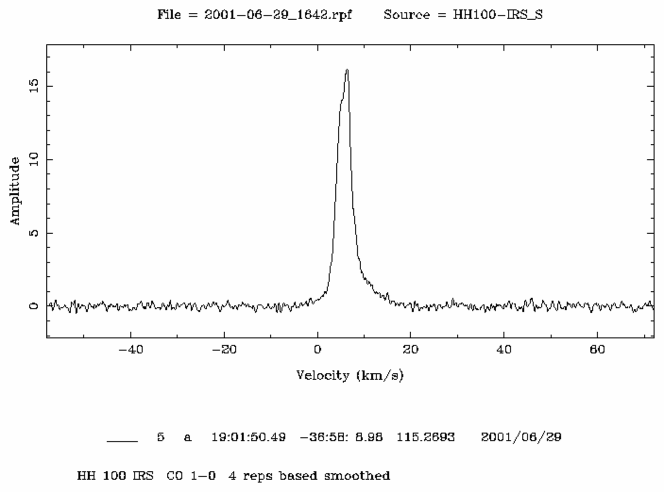
Thi et al. (2001), Nature

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 42	60±16	TWA	K7Ve	5 20	Y IR,mm	Y ex LRS gnd	Y 4+8		Y 8+4
HD 100546 SAO 251457	11 33	-70 12	103,190	DC296.2-7.9	B9Vne	≥10	Y IR,mm	Y ex LRS,ISO	Y 8 Y 1 Y 1+4	Y 8+8	Y 8+8
HD 107439 SAO 223370	12 21	-49 13		SX Cen (RY Tau?)	F5,G3/5p			Y ISO	Y 4		
HD 139614 SAO 226057	15 41	-42 30	84,151,157	Lupus	A2,A7Ve	-		N ISO	Y 4		
HD 142527 SAO 226389	15 57	-42 19	200	Isolated Lupus?	G0,F6III F7IIIe	0.1		Y e LRS,ISO	Y 4+4 Y 4	Y 8	Y 5+8?
HD 142666 SAO 183956	15 57	-22 02	116,180		A3,A8Ve A7V	-		Y e,LRS ISO gnd	Y 4	Y 4	
HD 163296 SAO 185966	17 56	-21 57	122,160	ρ Oph?	A0,A0-7e,A7e A1Ve,A3Ve A0/2Vep+sh	5	Y opt,mm	Y ex,LRS ISO gnd	Y 4		
HD 165088	18 06	-44 55		CrA	F5V			Y e LRS	Y 4		
HD 212283 SAO 213783	22 24	-34 54			F3/5V			Y e LRS	Y 4	Y 8+8	

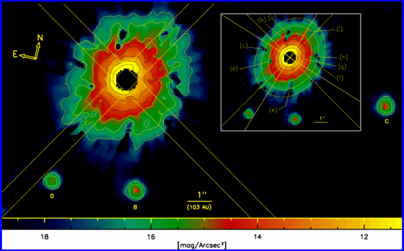
Mopra observations of HH100 IR

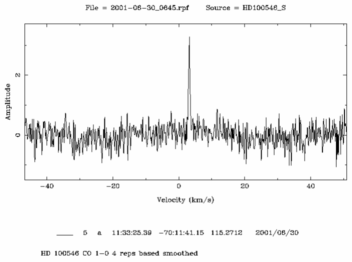


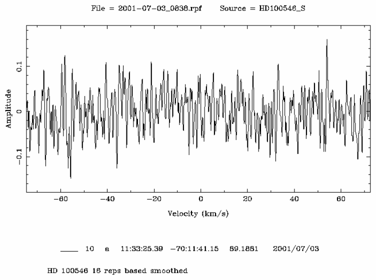
A deeply embedded Young Stellar Object

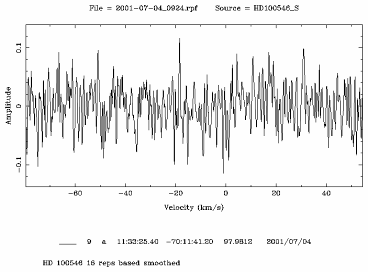
Mopra observations of HD 100546

Augereau et al. (2001) HST 1.6 µm

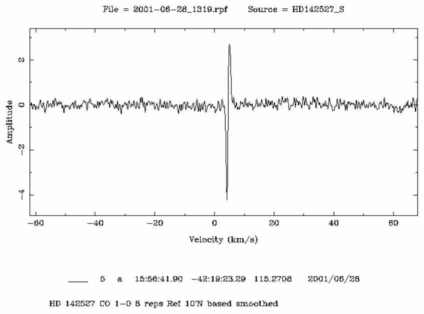


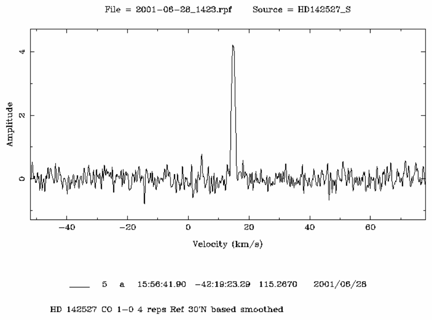






Mopra observations of HD 142527



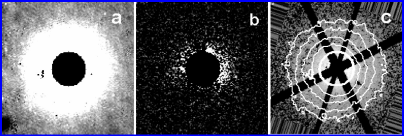


- Thought to be an isolated Herbig AeBe star
- CO 1-0 detected on a scale of tens of arcminutes, but probably not “bound” to the object, e.g. disk or outflow
- But star is definitely associated with a molecular cloud

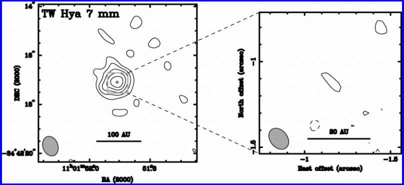
Mopra observations of TW Hya

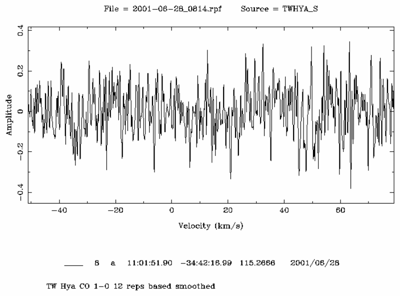
Trilling et al. (2001) 1.65 µm

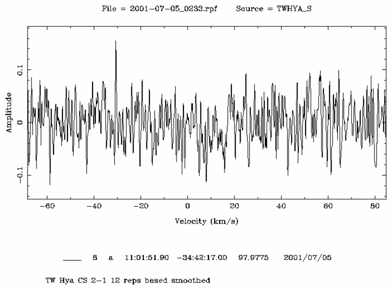
- face-on disk



Wilner et al. (2000) 7mm





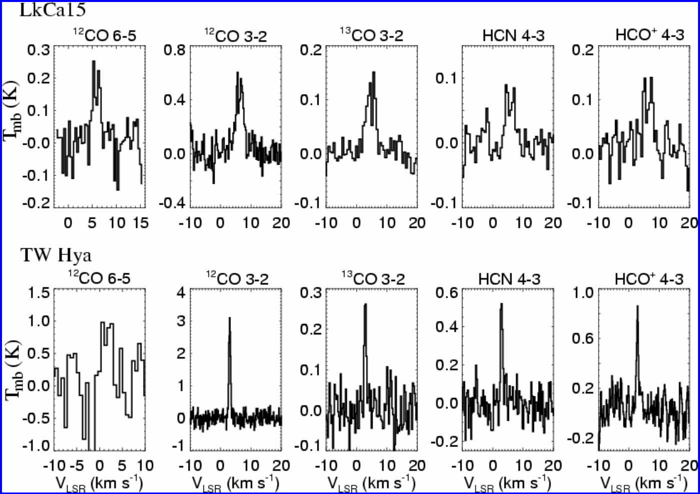


TW Hya

JCMT

Multi species and transition

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



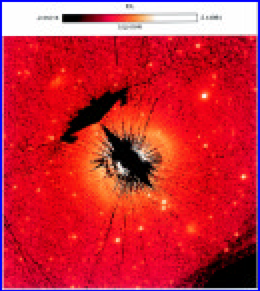
Only "warm" gas, T~50 K, traced by higher J transitions is detected towards TW Hya Þ Little cold gas present!

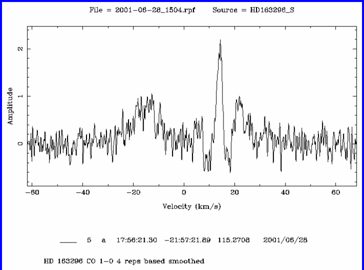
Mopra observations of HD 163296

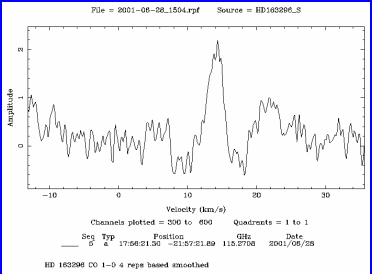
Grady et al.

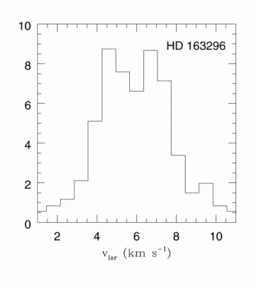
HST STIS

(2000 ApJ 544 895)









Mannings & Sargent

OVRO

CO 2-1

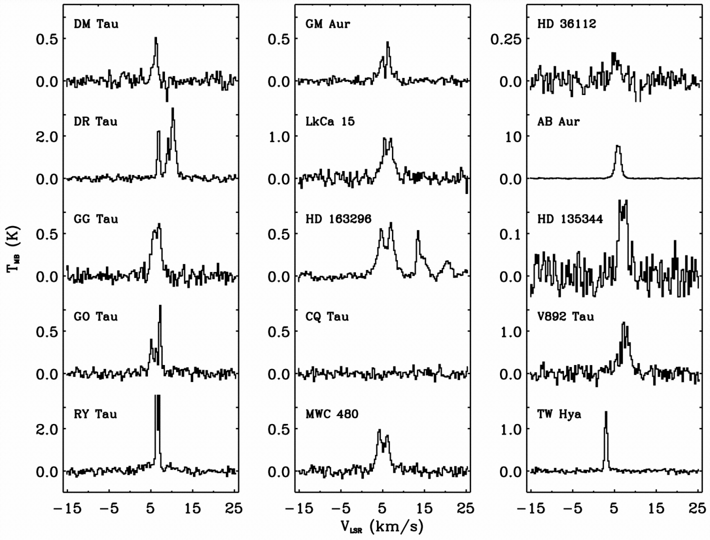
(1997 ApJ 490 792)

HD 163296

JCMT

CO 3-2

Thi et al. (2001, ApJ, 561 1074)



Higher J transitions, which trace warmer gas, are less affected by unrelated emission nearby or along the line-of-sight

Mopra conclusions

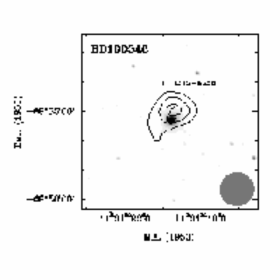
- CO 1-0 detected toward 3 objects
  - HD 100546, where it is extended and associated with the molecular cloud in which the object lies
  - HD 142527 ditto ⇒ need for interferometer to reveal small-scale emission
  - HD 163296, where the signature of disk rotation can be discerned, but interpretation is aided by pre-existing interferometric 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, e.g. TW Hya.

ATCA 3 mm observations

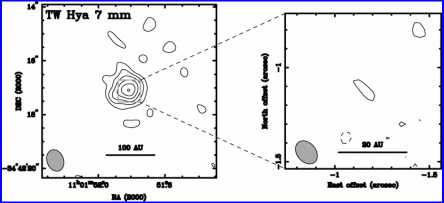
Henning et al. (1998)

SEST

1.3 mm



Wilner et al. (2000) VLA 7 mm

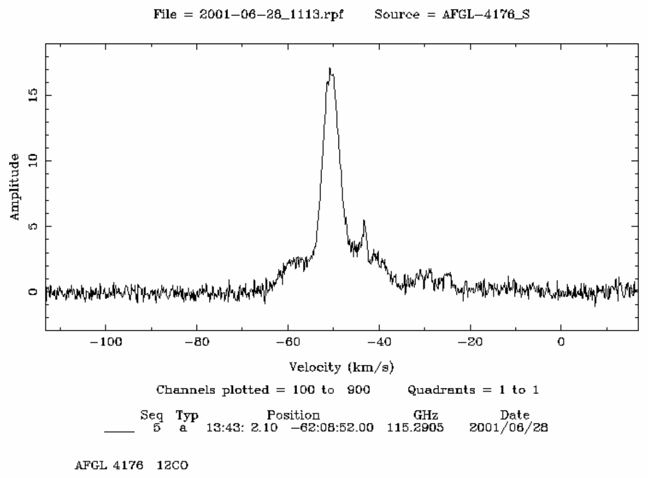


- 2 “interesting” objects selected (before Mopra data)
  - **HD 100546 and TW Hya in HCO+ 1-0 transition**
- Expected 3 mm continuum fluxes are 0.1 Jy for HD 100546 and 0.07 Jy for TW Hya

ATCA 3 mm recommendations

- ATCA data not yet processed! A learning experience….
- CO 1-0 115 GHz would have been preferred if available
- 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)
- To ATNF - continue to support Mopra as a training and “extended structure” instrument. Six weeks of community use per year is not enough!

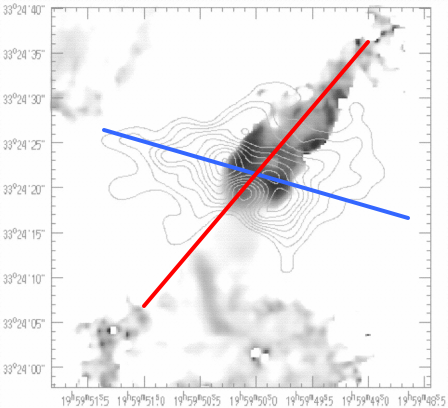
Mopra observations of the AFGL 4176 outflow



- **AFGL 4176 high velocity CO wings on either side of line core Þ bipolar outflow**

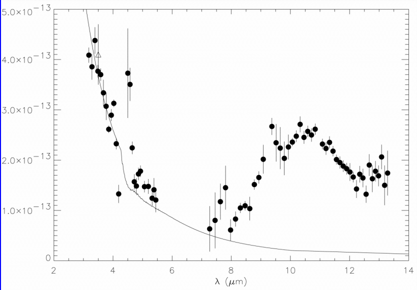
K3-50 Bipolar Outflow and Disk

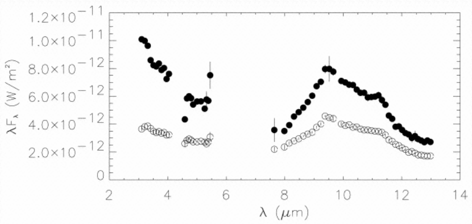
- Via mid-IR polarisation data two magnetic field components were discovered
  - **one from cold dust lies in the plane of the rotating gas (HCO+) toroid**
  - **the other from warmer dust is aligned with the radio jet and bipolar molecular outflow**



Howard et al. (1997 ApJ 477 738)

Mid-Infrared Spectra

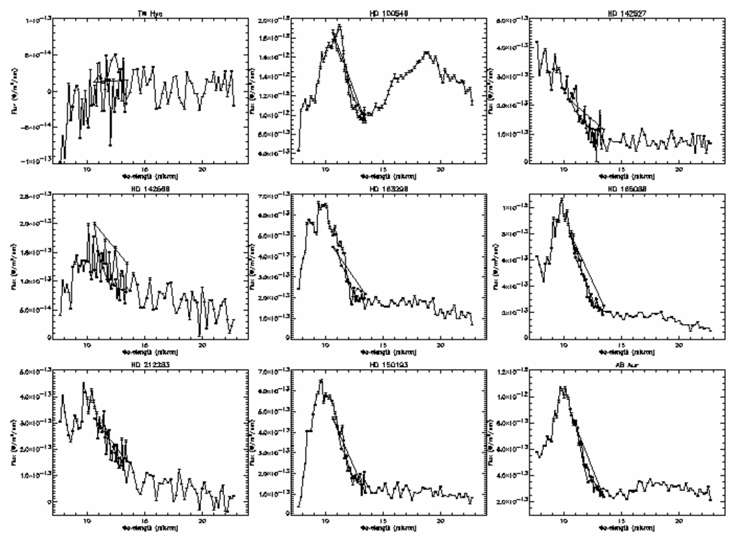




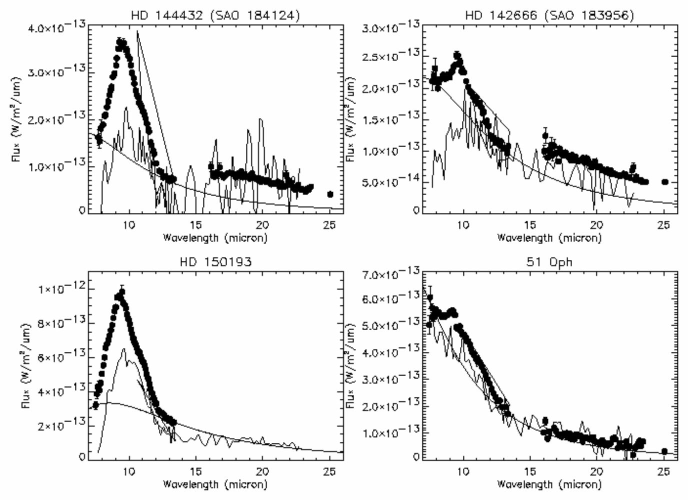
- TW Hya
- Sitko et al. (2000)
-

HD 163296
HD 31648
Sitko et al. (1999)

IRAS LRS Spectra of “Vega-like” stars



Ground based spectra of “Vega-like” stars



Sylvester et al. (1996, MNRAS 279 915)