Observations of disks with the EVLA: what will it do for you?

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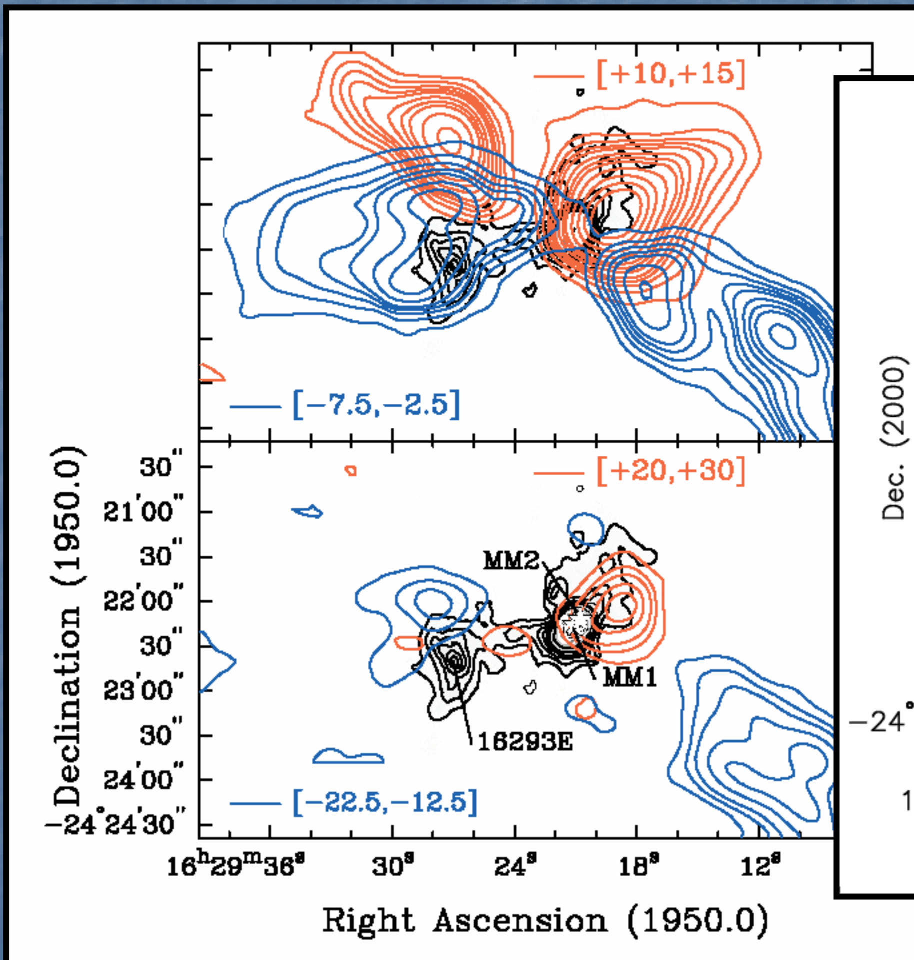
The role of cm-wavelength studies of disks

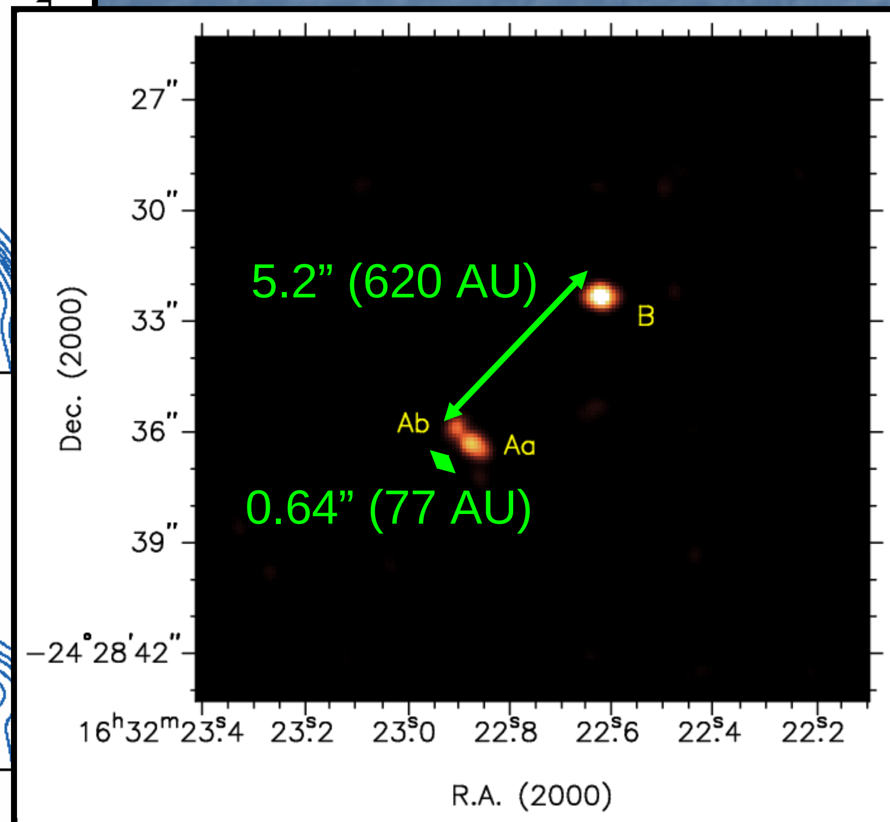
- ALMA will do great things! But source physics sometimes demands cm-wavelength observations:
  - Disks in deeply embedded protostars (submm optically thick)
  - Demonstrating grain growth to cm-sized particles
  - Disk/jet interactions
- Need a very sensitive cm-wavelength telescope to complement ALMA: the Expanded Very Large Array (EVLA)
- The rest of this talk:
  - Recent results from the VLA
  - Technical capabilities of the EVLA
  - Science capabilities of the EVLA
  - Status of the EVLA project

IRAS16293–2422

- IRAS 16293–2422: two outflows, at least two protostars:



JCMT: Stark et al. (2004)

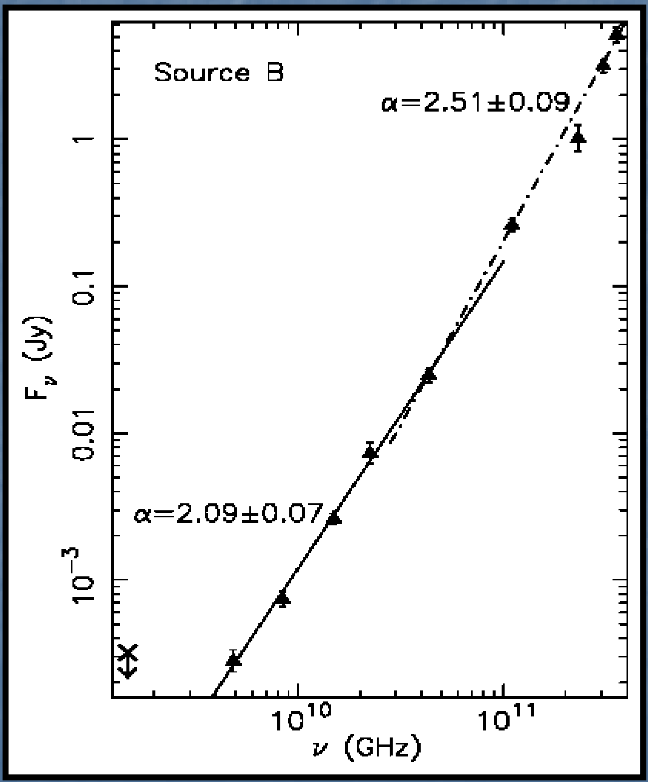


SMA: Chandler et al. (2005)

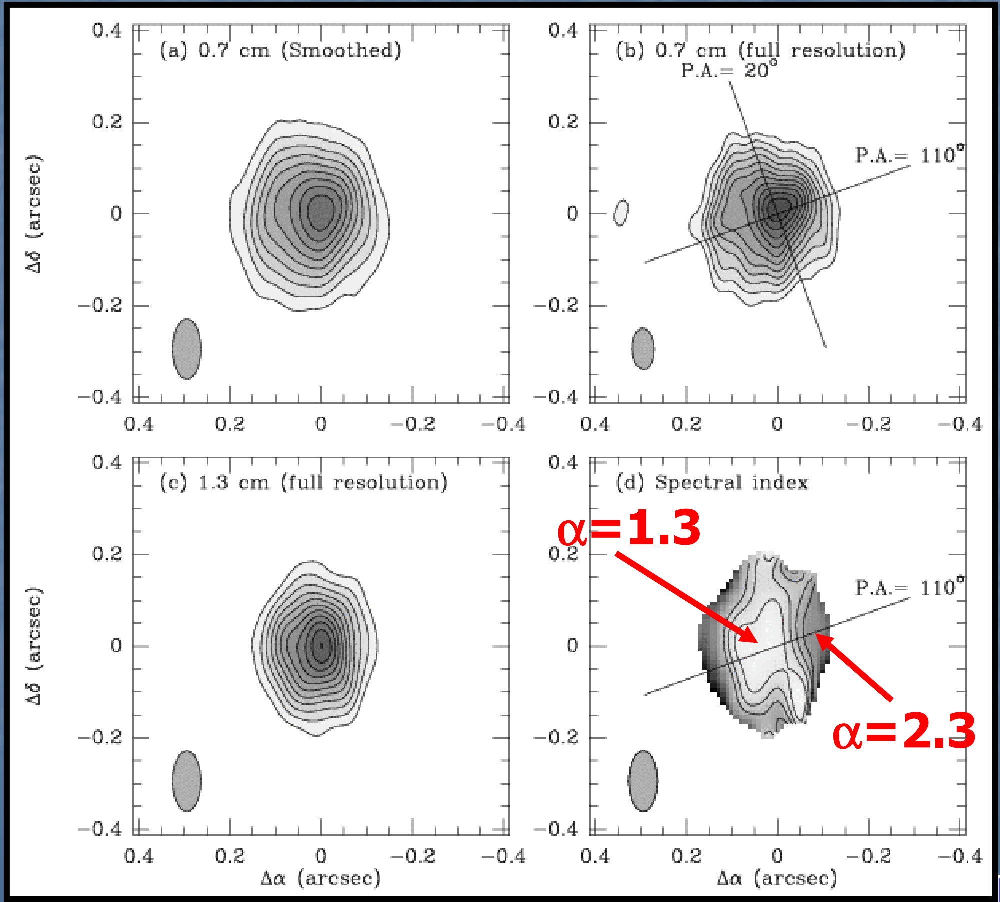
IRAS16293B

- Optically-thick dust, plus extended, optically-thin envelope?
  - ν^2 even at 8 GHz
  - Peak T_B~200–400 K on size scales 5–20 AU

λ=3cm 3mm



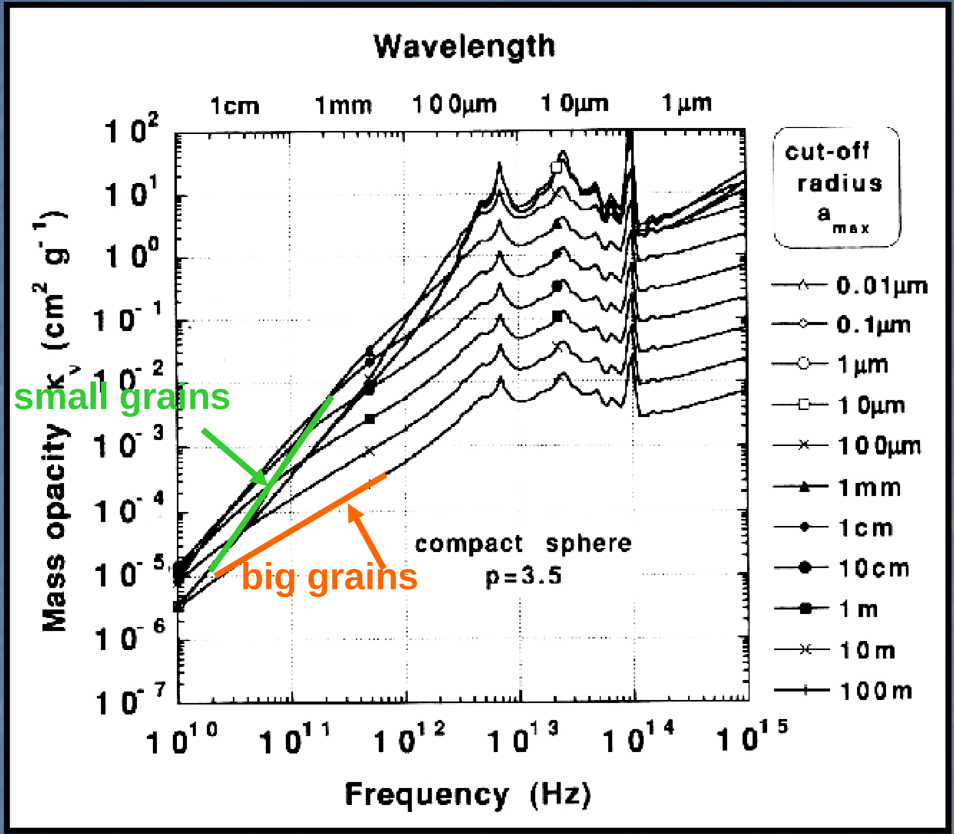
Chandler et al. (2005)



Loinard, Chandler et al. (2007)

Grain growth

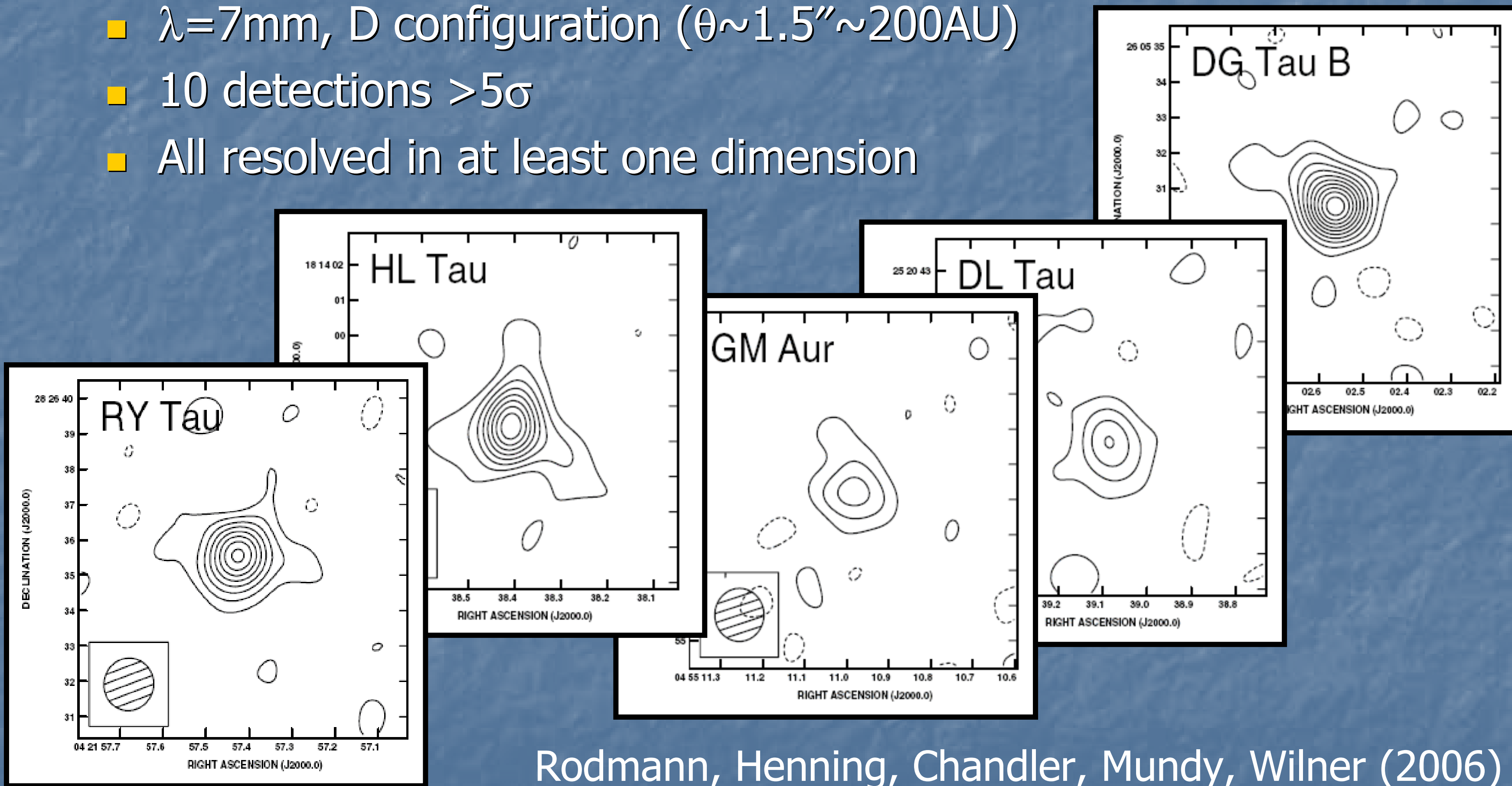
- Miyake & Nakagawa (1993)



- a << λ ⇒ β=2 (ISM); a >> λ ⇒ β=0 (e.g., planet)
- Very important to separate optical depth from β
- Need high spatial resolution and long-λ

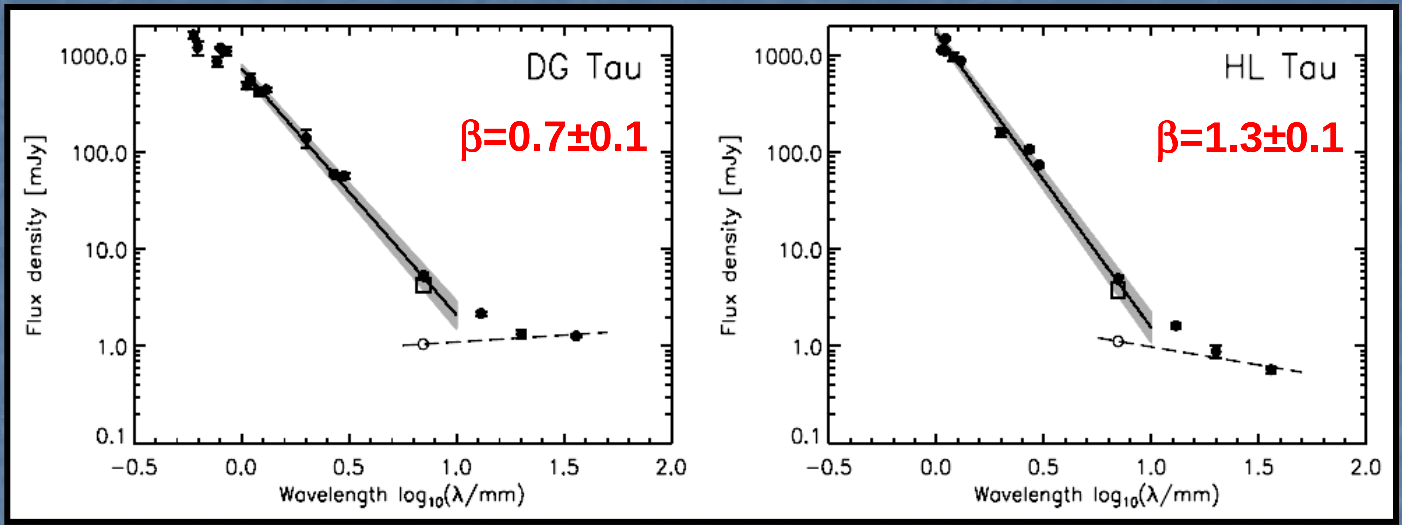
VLA 7mm continuum

- 14 low-mass PMS stars in Taurus-Auriga region
  - λ=7mm, D configuration (θ~1.5"~200AU)
  - 10 detections >5σ
  - All resolved in at least one dimension

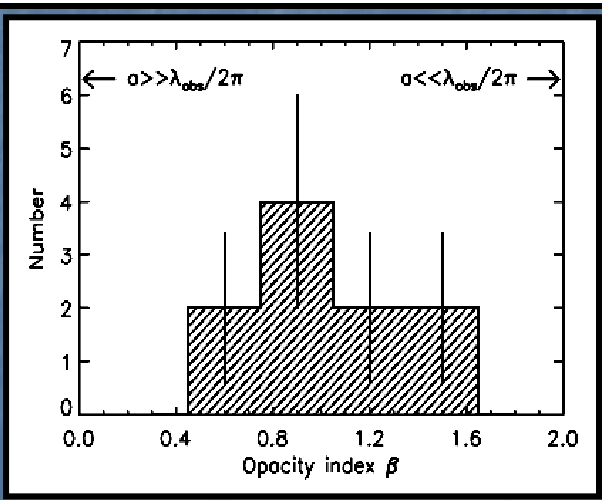


Rodmann, Henning, Chandler, Mundy, Wilner (2006)

Grain growth to cm-sized particles



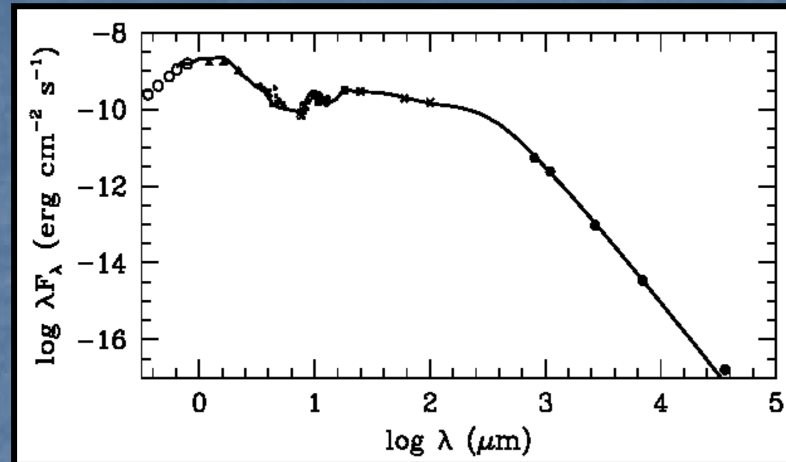
- Apply corrections for RJ and free-free emission
- Find 0<β<2
- Similar results observed for Herbig Ae stars (Natta et al. 2004)

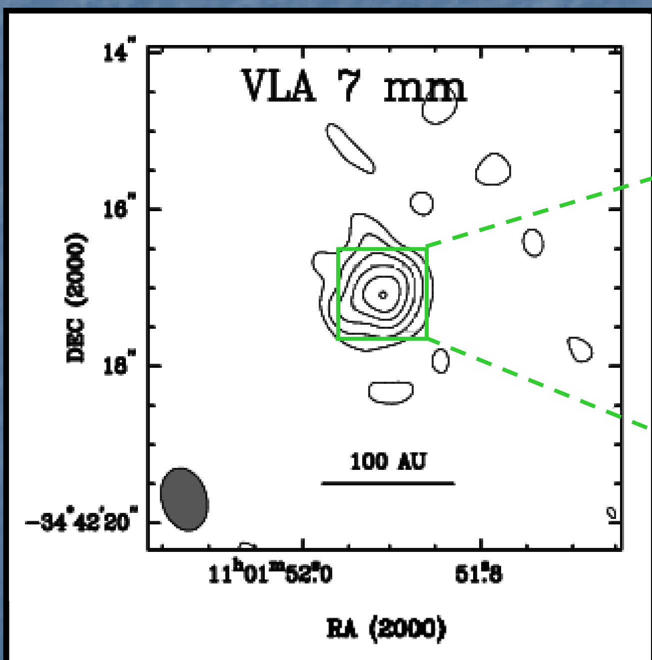


The case of TW Hya: pebbles

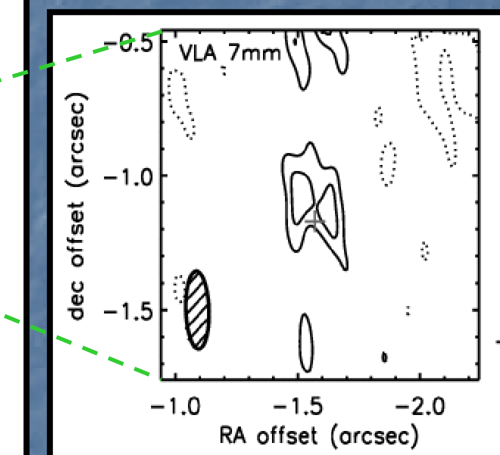
- SED suggested an inner hole

(Calvet et al. 2002)





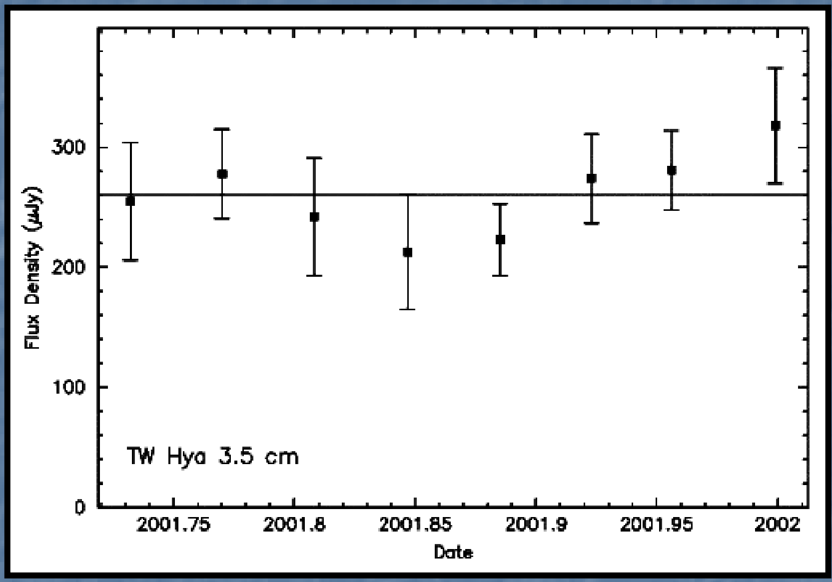
Wilner et al. (2000)

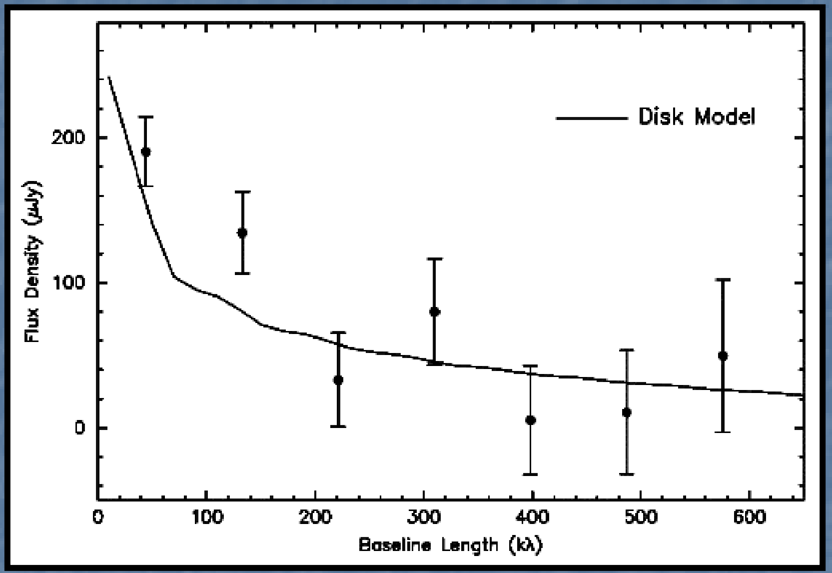


Hughes et al. (2007)

- 7mm emission is resolved by the VLA

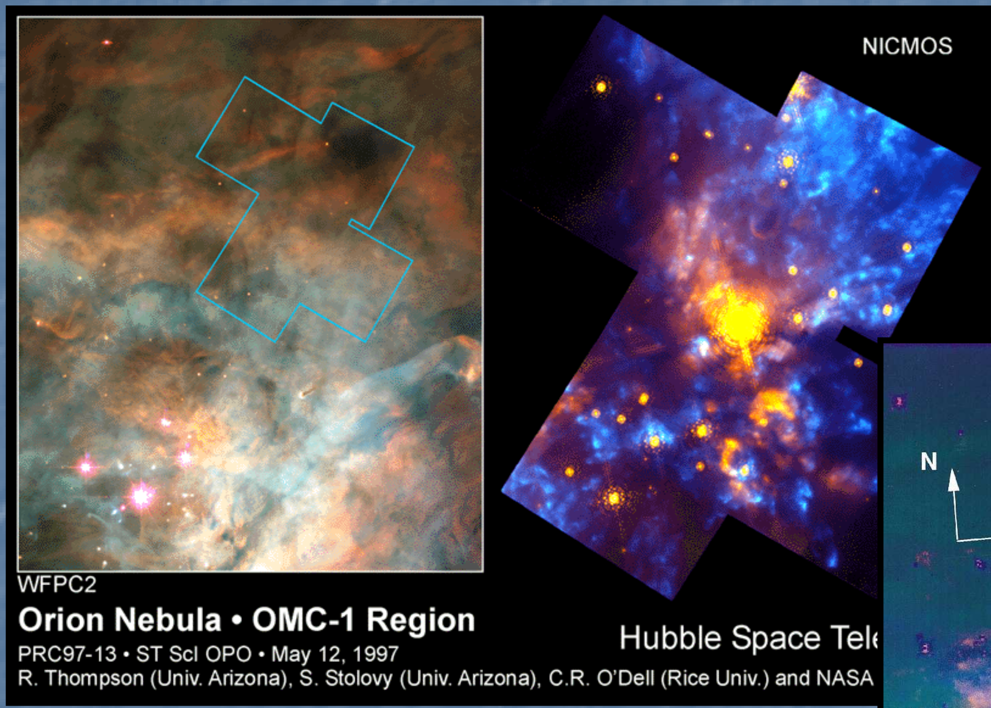
3.5cm emission may even be dust

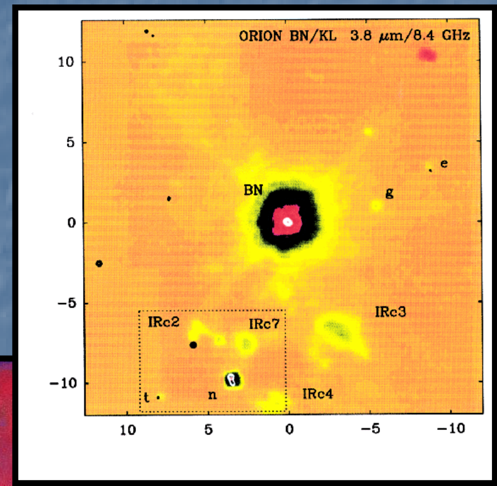


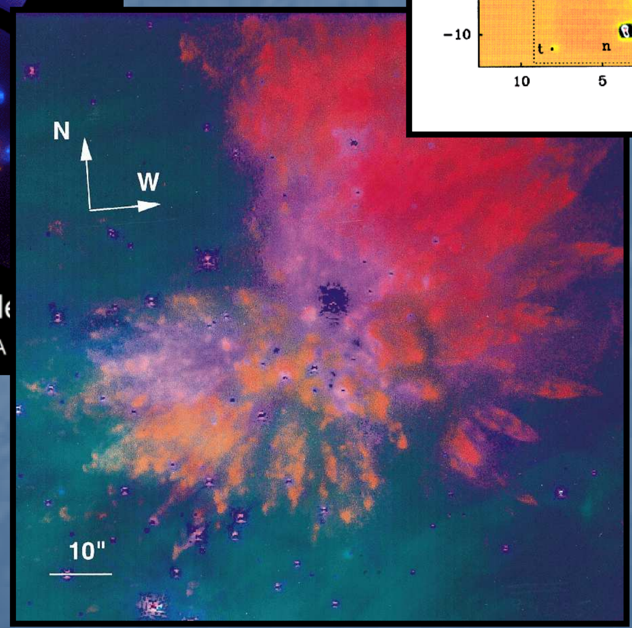


- Flux is not variable
- 3.5cm emission is resolved, consistent with disk model
- T_B~10K
- Pebbles may already be forming in the TW Hya disk
- Wilner et al. (2005)

Massive protostars: Source I in Orion



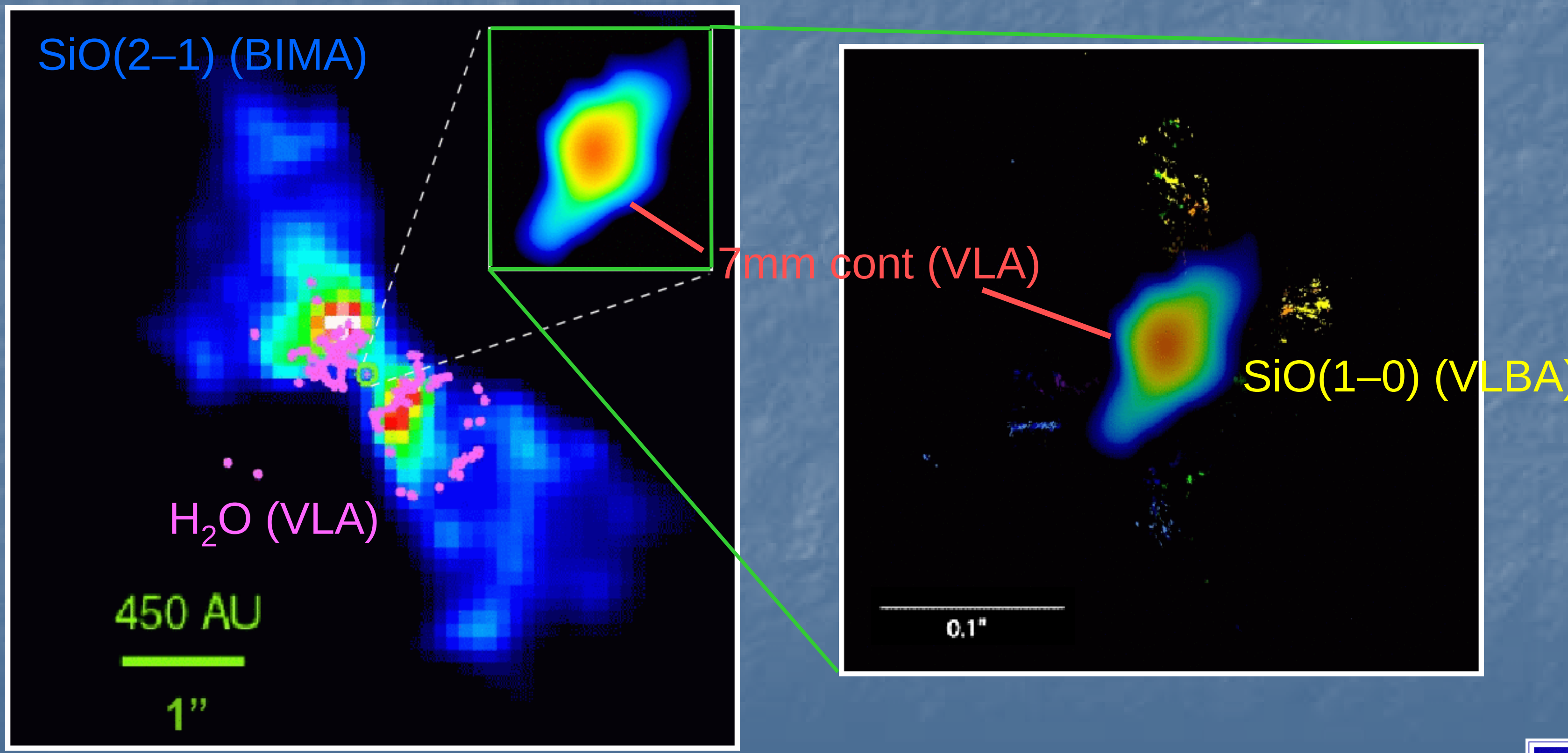




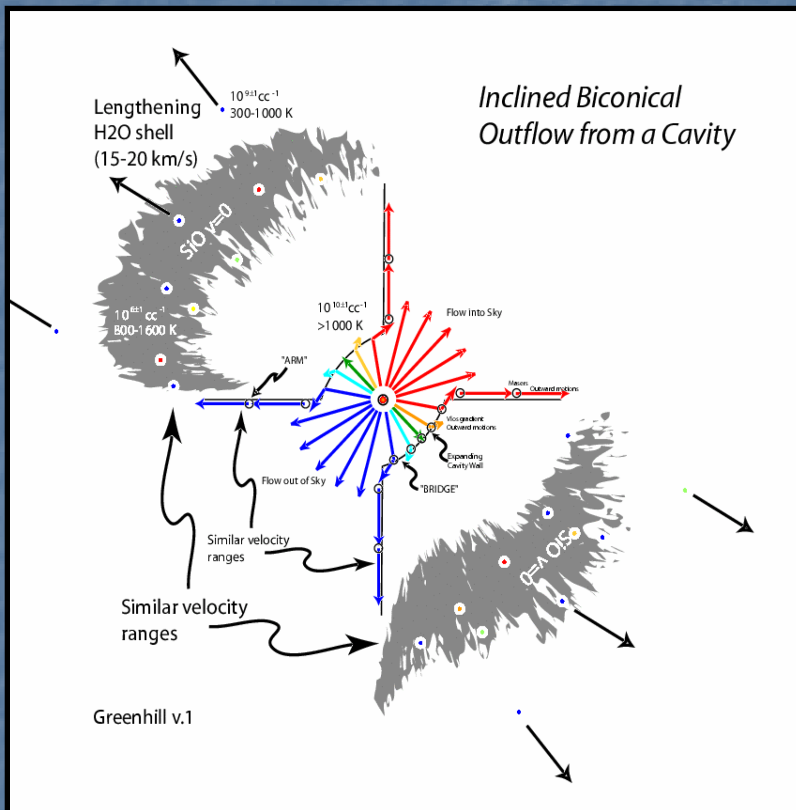
Explosive event centered close to radio Sources “I” and “n”; $L_{bol} \sim 10^5 L_\odot$

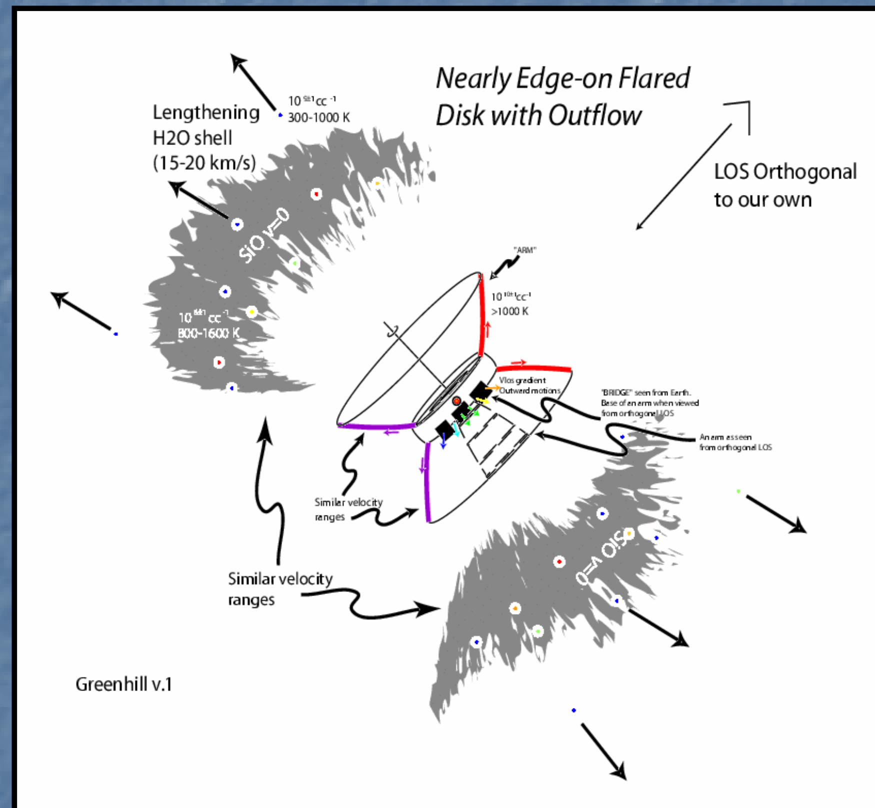
The KaLYPSO (Kleinmann-Low Young ProtoStellar Object) project

- VLA, VLBA, and MERLIN are being used to measure the 3-D dynamics of the disk/wind interaction
- See Lynn Matthews' poster



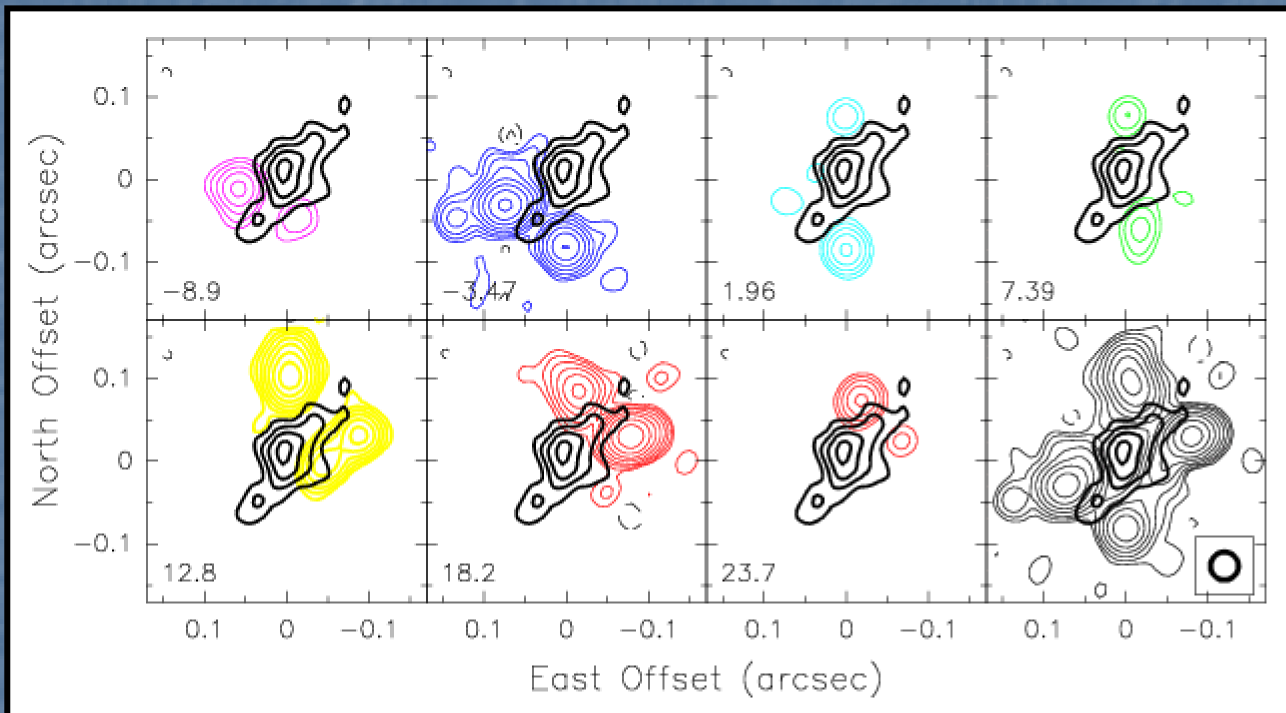
Models for the Source I disk/outflow



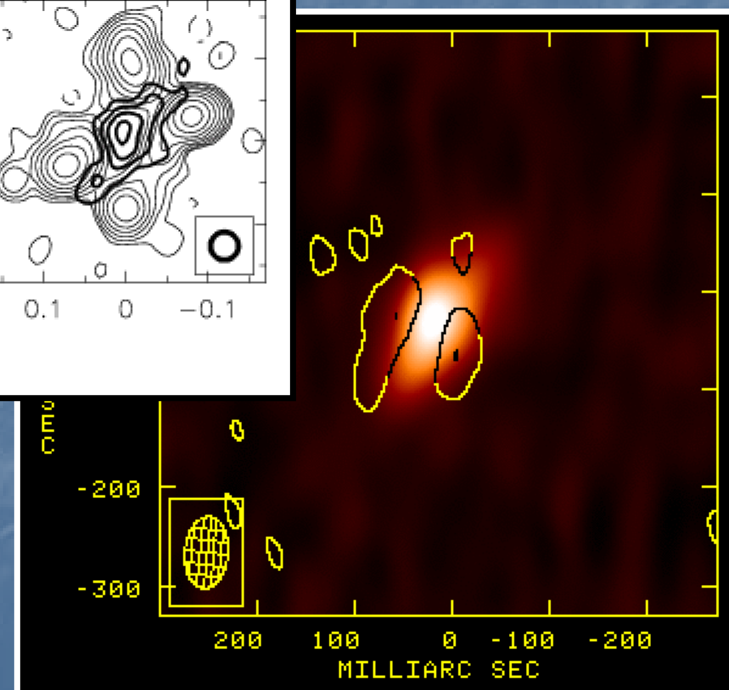


Ionized gas moving off disk surface

- Reid, Menten, Greenhill, Chandler (2007)



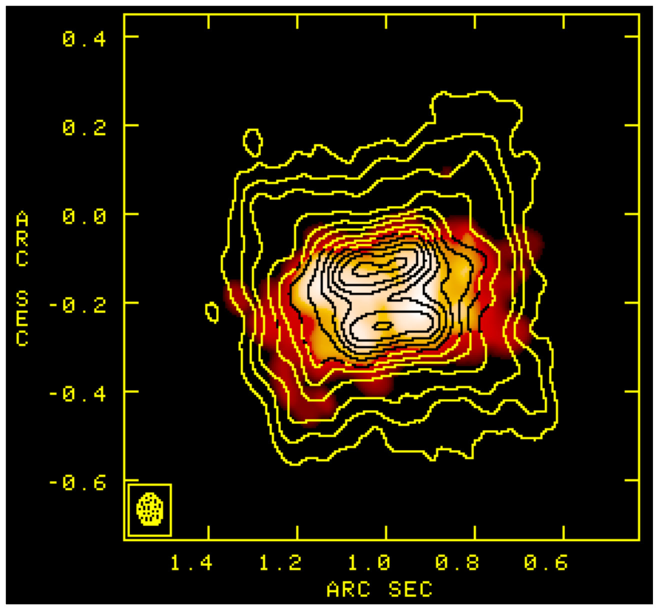
- Difference of 5.4 years:



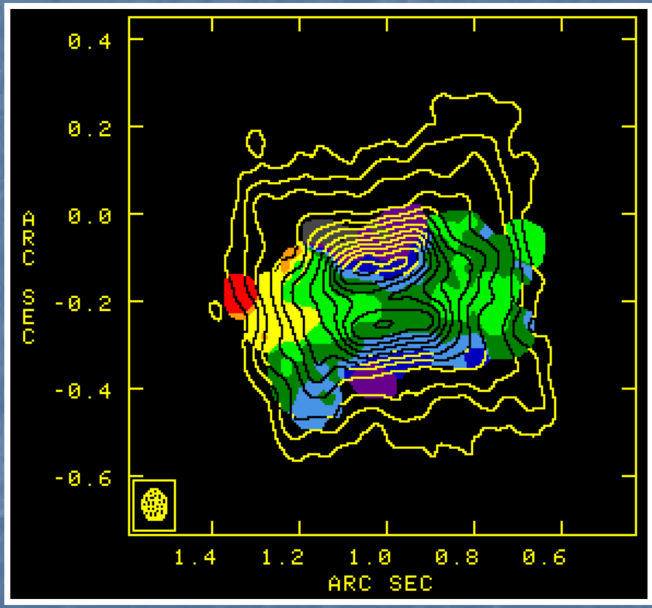
MWC349: RRL masers

- Close to edge-on disk
- H66α emission amplifies free-free emission in ionized wind
- Rotation in the disk, plus blueshifted outflow

Continuum + integrated H66α emission



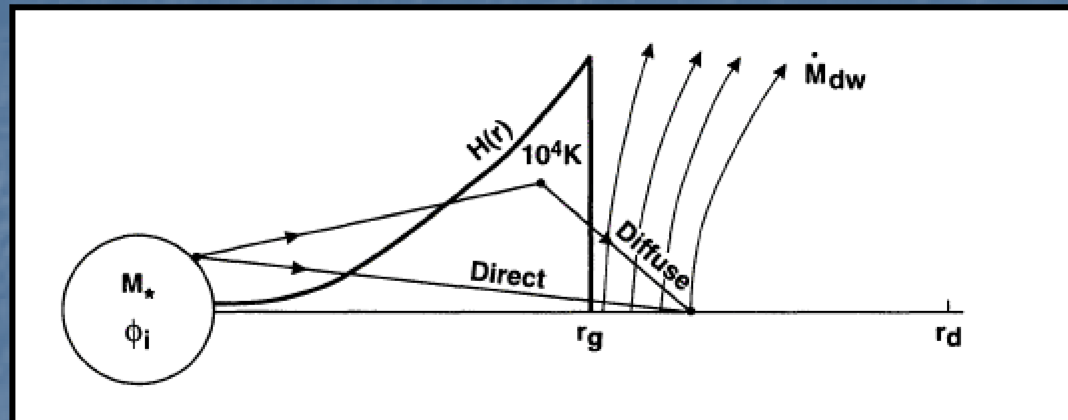
Radial velocity



Martin-Pintado, Chandler, Thum, Jimenez-Serra

Photo-evaporating disk model

Hollenbach et al. (1994)



$Ne = A r^{-\gamma} e^{-(\theta/\theta_o)}$:

$A = 5.4 \times 10^9 cm^{-3}$

para $r = 10^{14}$ cm

$\gamma = 2.11$

$\theta = 10°$

$Te = 6.000$ K

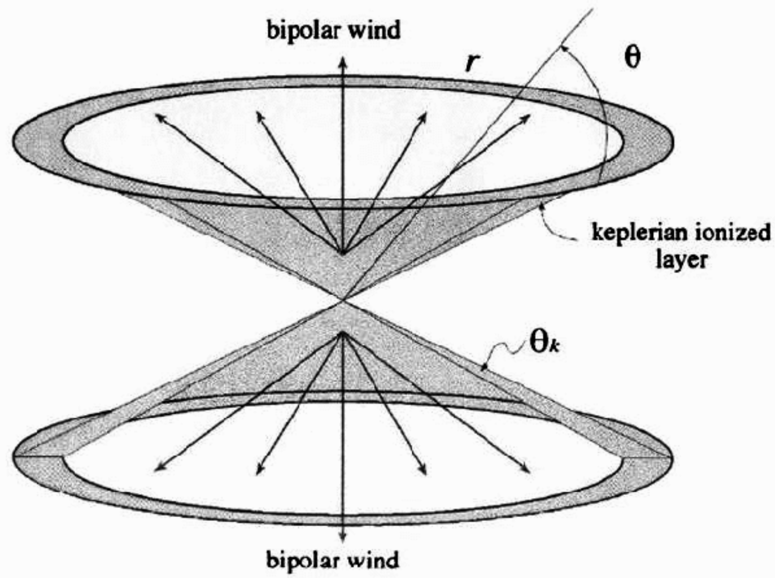
Keplerian disk:

$M_* = 30$ Mo

$\theta_k = 3.5°$

Bipolar wind:

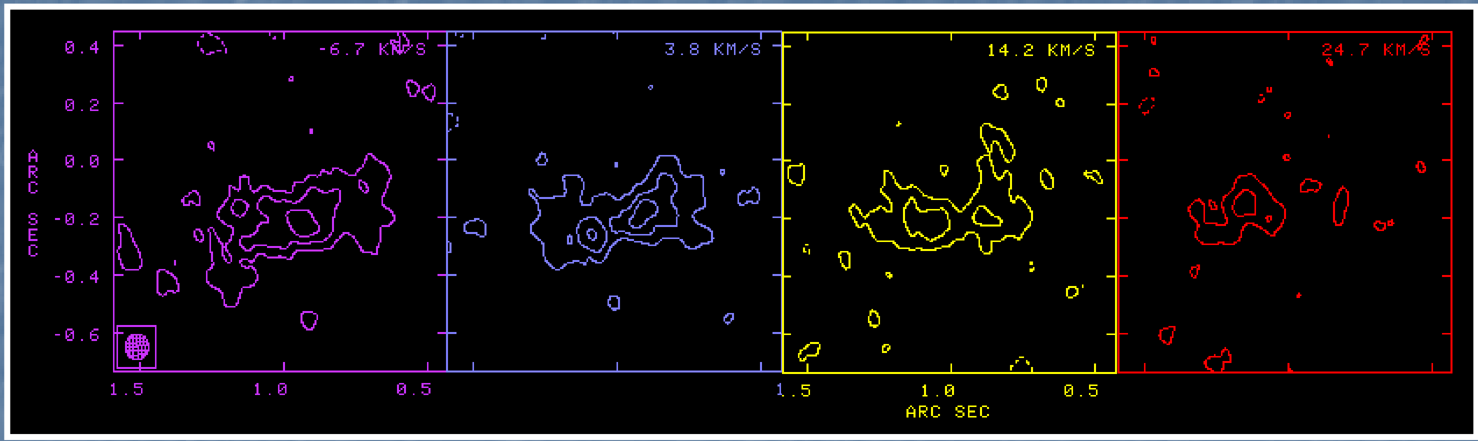
$V_{exp} = 58$ km s^{-1}



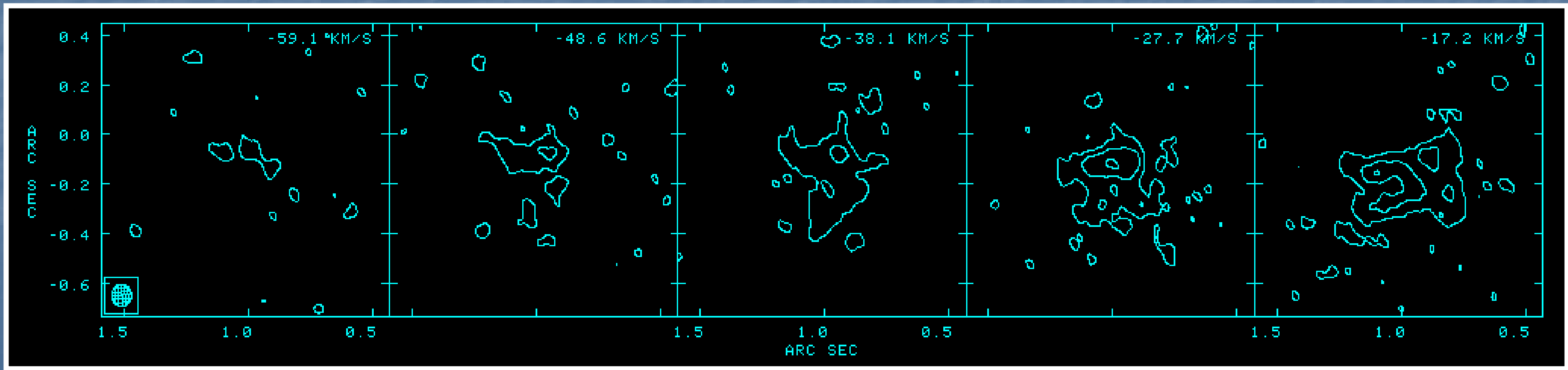
Martin-Pintado

Rotation and photo-evaporation

- Rotation centered on systemic velocity



- Blueshifted bipolar outflow from near side of disk surface



Capabilities of the EVLA

- The EVLA will multiply ten-fold the VLA's capabilities
- Full frequency coverage from 1 to 50 GHz
  - 8 frequency bands with cryogenic receivers
  - Two separately-tunable polarization pairs, with no restrictions on their tuning (unlike current VLA)
- 1 μJy point-source continuum sensitivity (most bands)
- New correlator with 8 GHz/polarization capability
  - 16384 minimum channels/baseline with full polarization
  - Full recirculation capability for increased flexibility: 4,194,304 channels at maximum spectral resolution
  - 128 independently tunable frequency slots
- Completion by 2012

EVLA performance goals

- The EVLA will be vastly more powerful than the VLA:

Parameter	VLA	EVLA	Factor
Point Source Sensitivity (1-σ, 12 hours)	10 μJy	1 μJy	10
Maximum BW in each polarization	0.1 GHz	8 GHz	80
# of frequency channels at max. bandwidth	16	16,384	1024
Maximum number of frequency channels	512	4,194,304	8192
Finest frequency resolution	381 Hz	0.12 Hz	3180
(Log) Frequency Coverage (1 – 50 GHz)	22%	100%	5

- EVLA is funded by NSF, $58M + $17M NRAO contributed effort
- Canada is providing the correlator, $18M equivalent
- Mexico has contributed $1.8M for electronics and receivers

EVLA sensitivity in 12 hours

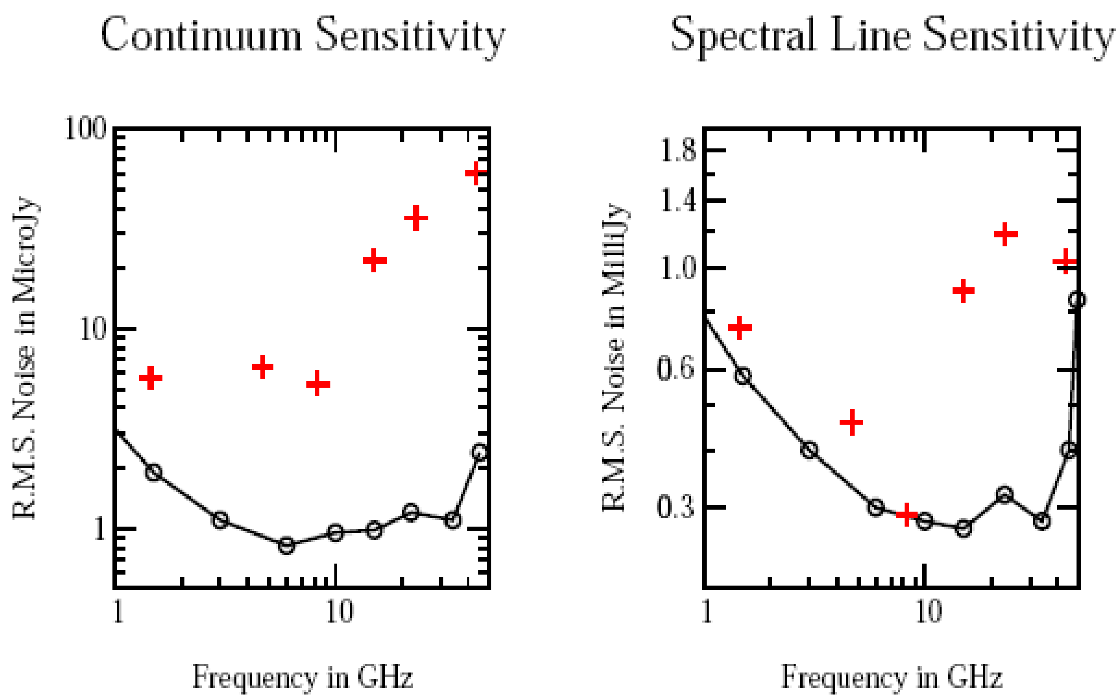
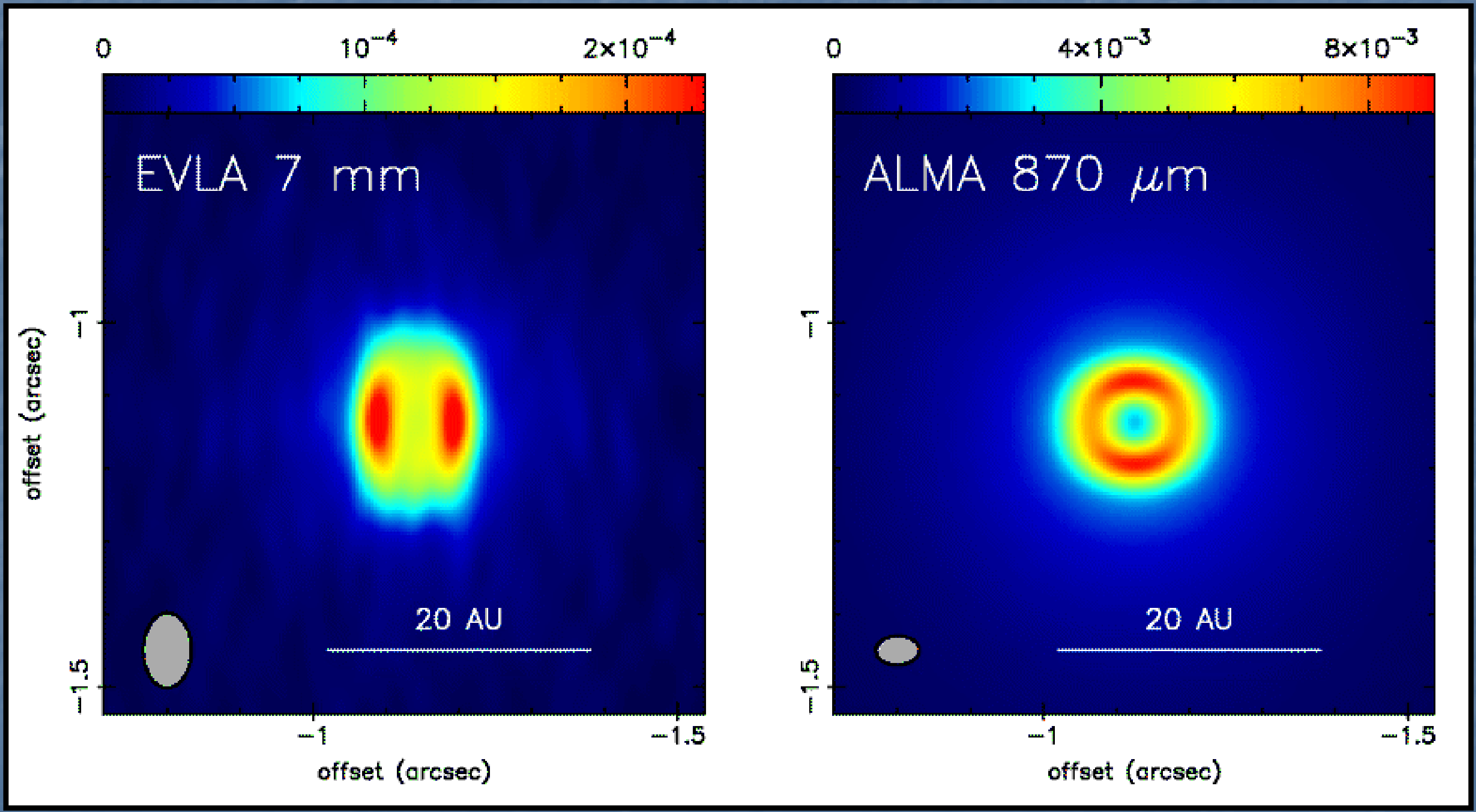


Figure 3.1: The current (+), and projected (o) continuum (left) and spectral line (right) point source sensitivity (1σ in 12 hours) of the VLA after the Ultrasensitive Array is completed. For the continuum plot, the bandwidths of Table 3.1 are assumed. For the spectral line plot, the assumed bandwidth corresponds to a velocity width of 1 km/sec. The width of the '+' symbols demonstrates the approximate range of tuning with the current VLA. The EVLA will be continuously tunable over the entire band.

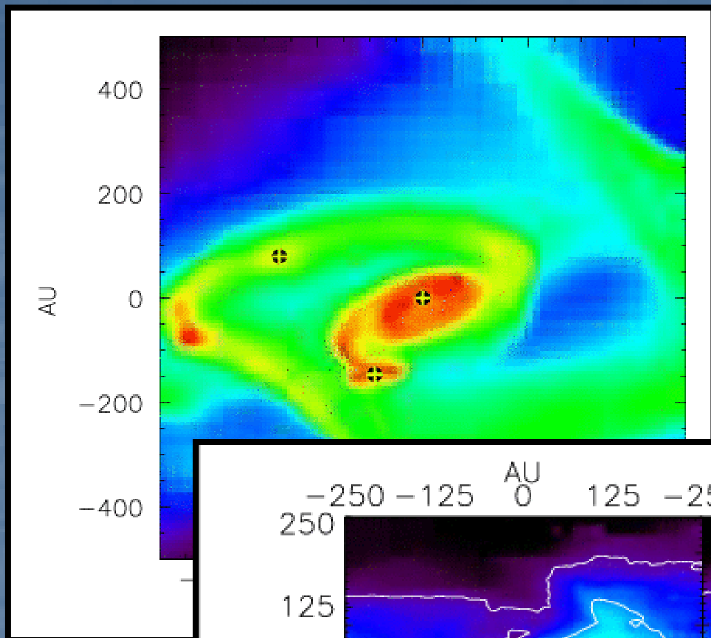
TW Hya with the EVLA and ALMA

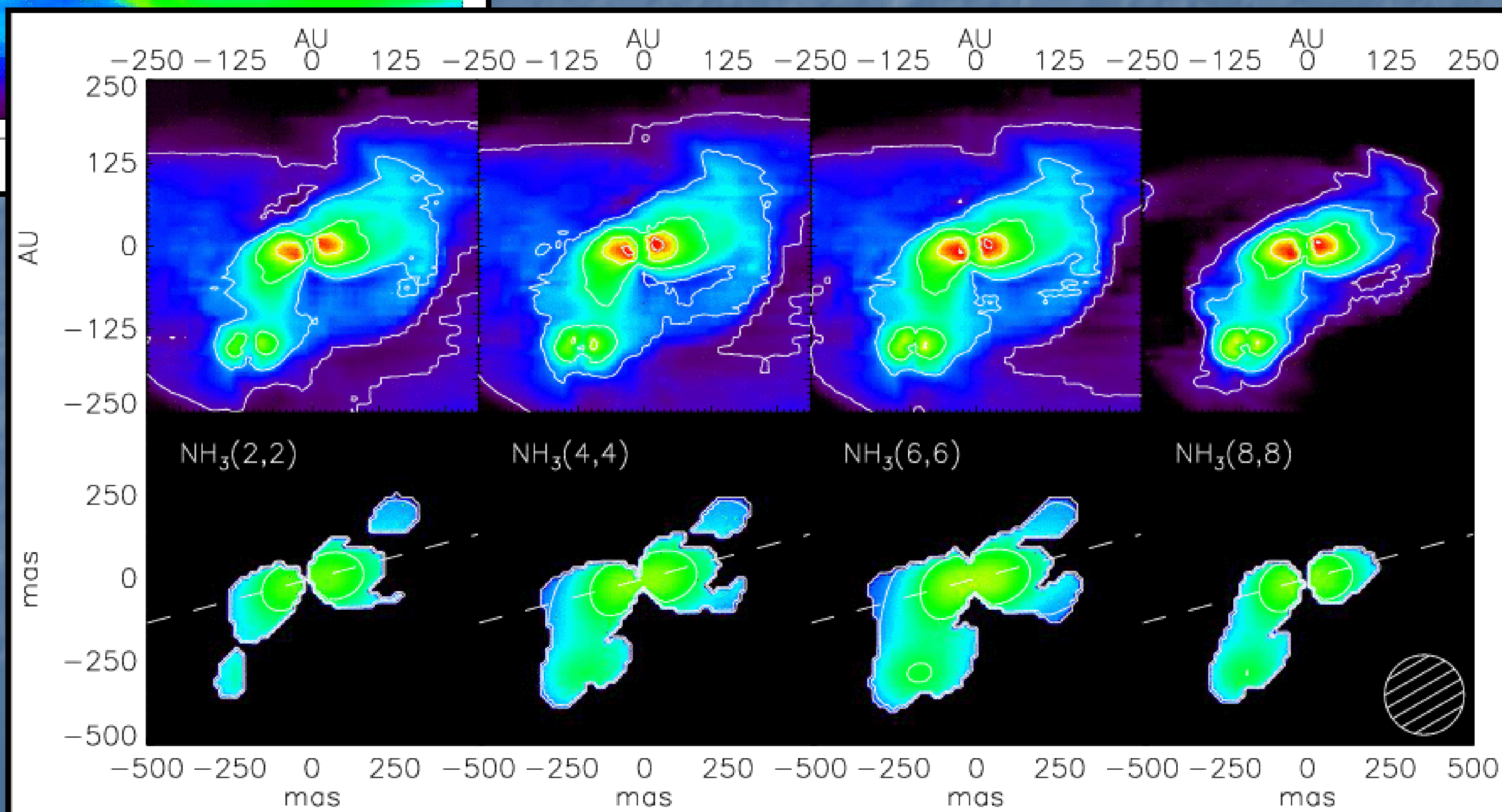
- Simulations of Calvet et al. (2002) model, courtesy David Wilner



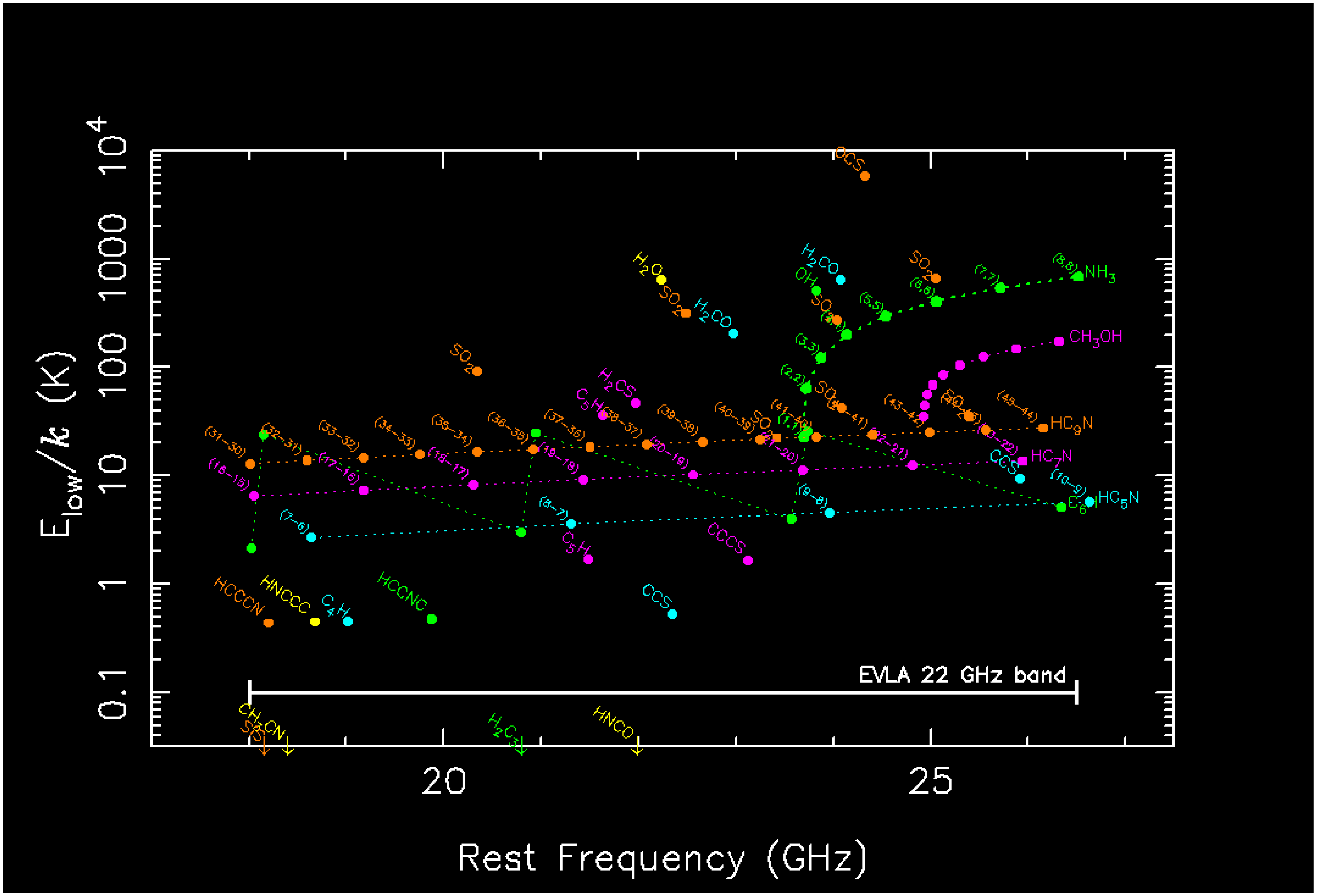
Massive protostellar disks

- All NH_3 inversion transitions available in one go
- Simulation by Krumholz et al. (2007)

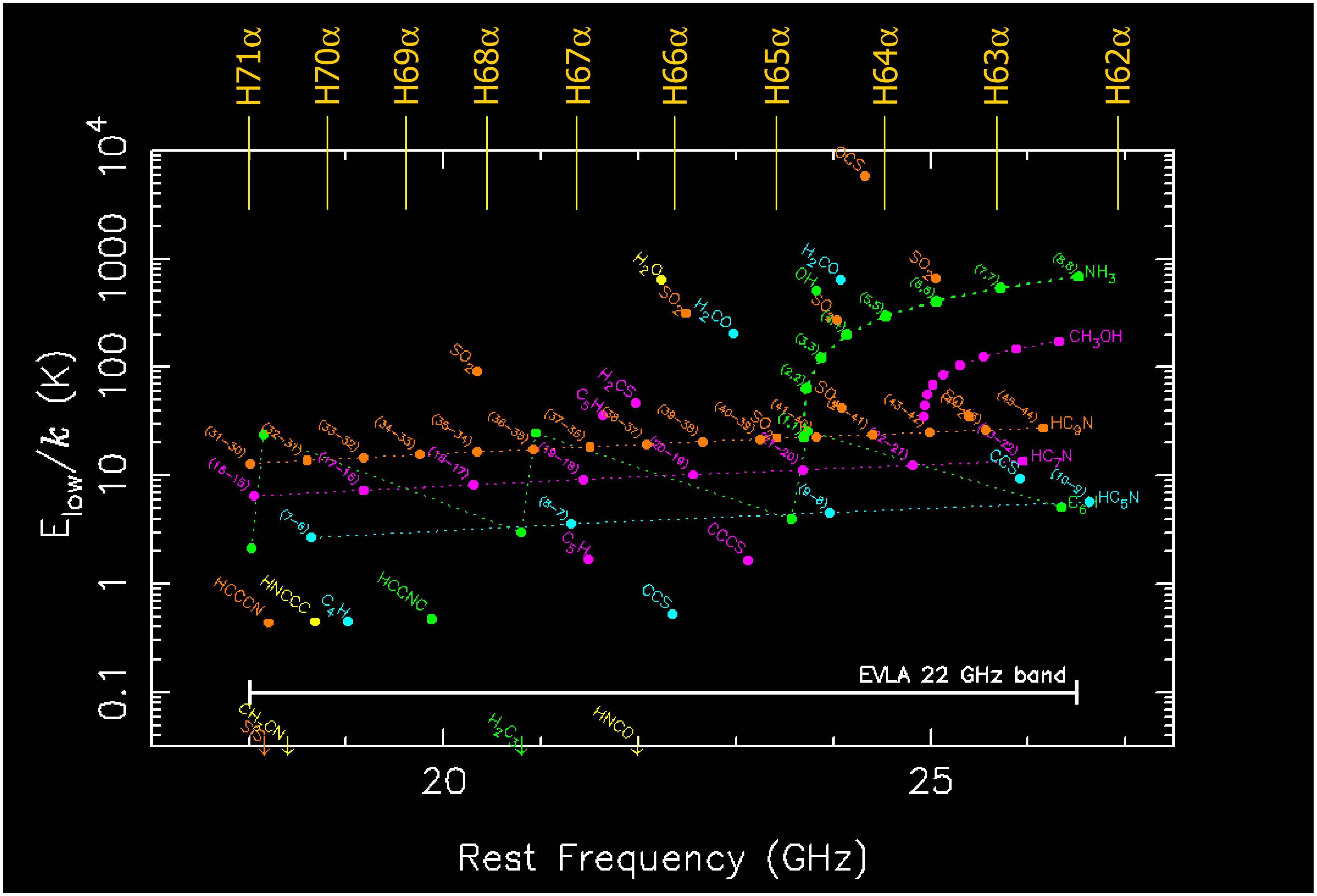




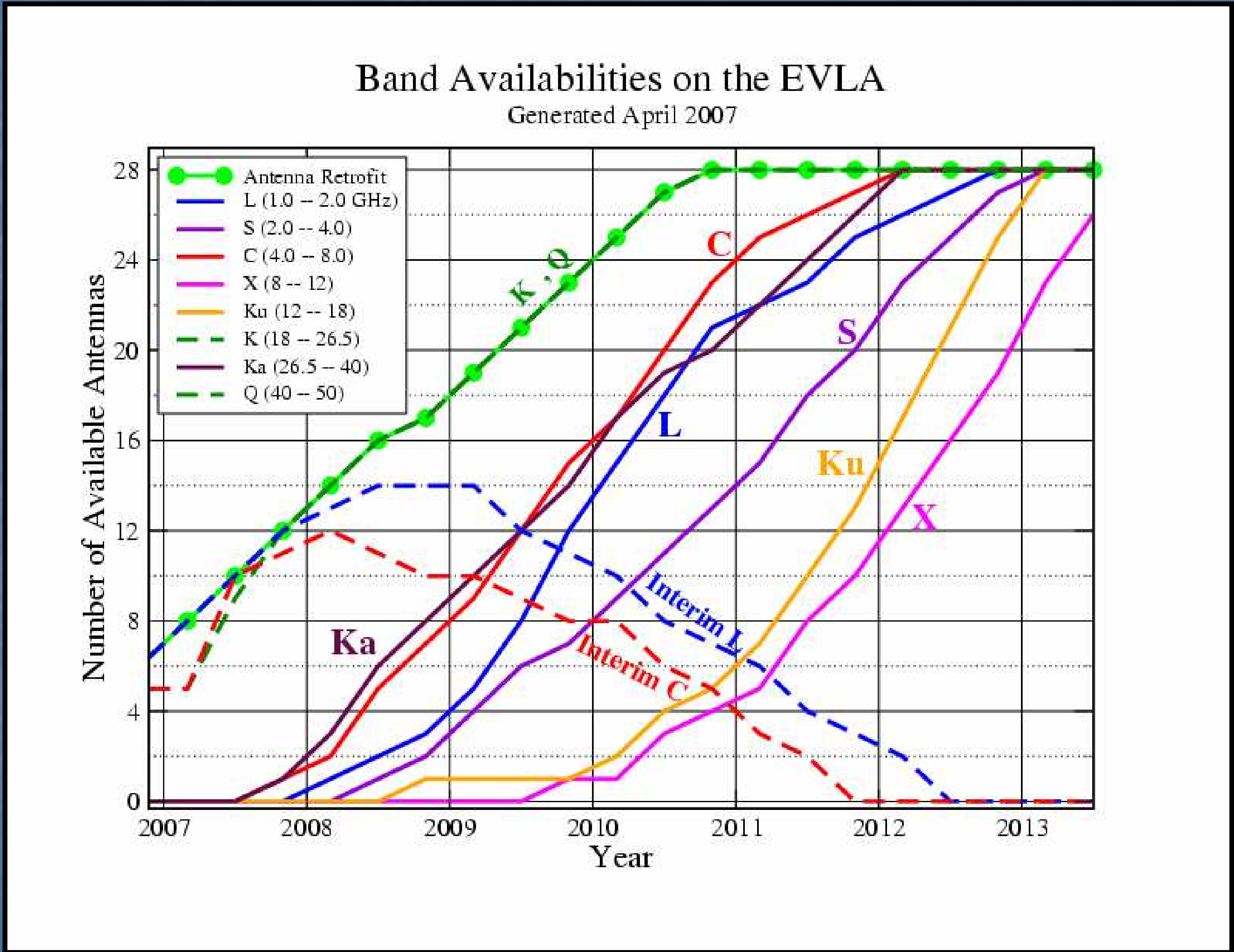
Molecular transitions at K-band (22 GHz)



Hydrogen recombination lines



EVLA antenna/band availability



Status of the EVLA

- Currently have 10 EVLA antennas included in regular observations
- Full instantaneous bandwidths not available until the correlator is commissioned, 2010
- New science capabilities currently come from new frequency access
  - L-band (1.2–2.0 GHz): new space from 1.74–2.0 GHz is RFI free
  - C-band (4.0–8.0 GHz): good sensitivity, but good polarization purity only within 'old' VLA frequency range of 4.5–5.0 GHz (will be corrected by new wideband OMTs)
  - K-band (18–26.5 GHz): full tuning range now available
  - Ka-band (26.5–40 GHz): by end 2008 ~9 receivers will be available
  - Q-band (40–50 GHz): the old limitation on tuning separation of ~400 MHz between IF pairs has gone
  - S-band (2.0–4.0 GHz): coming in 2010
  - Ku-band (12–18 GHz) and X-band (8–12 GHz): coming in 2011

Conclusions

- EVLA will be needed for disk studies where dust emission is optically-thick to ALMA
  - determining grain size distributions
  - kinematics of disks in dense regions (massive protostars and disks around Class 0 low-mass protostars)
- Disk/jet interactions
  - assess contributions from free-free emission
  - imaging of ionized gas with resolution comparable to ALMA
- New capabilities already available with 10 EVLA antennas, currently in expanded tuning ranges
- 8 GHz instantaneous bandwidth and up to 4 million channels available with new correlator, expected to be available for science in 2010