

# High Resolution Submm Observations of Massive Protostars

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## Open Questions

- Stellar density?
- Role of jets and disks?
- Evolutionary sequence?

ERA of ALMA, Madrid, Spain, Nov. 13, 2006

# The Submillimeter Array Observations:

## CepA-East, NGC 7538 IRS1, G5.89-0.39

- ❖ Eight 6-m antennas
- ❖ 2 Sidebands each 2 GHz wide separated by 10 GHz
- ❖ 345 GHz tuning centered at 336 / 346 GHz
- ❖ Resolution  $\sim 2''$  in compact configuration,  $< 1''$  extended
- ❖ Continuum rms noise  $\sim 10$  mJy/beam
  - Only line free channels used
- ❖ Line rms noise  $\sim 300$  mJy/beam

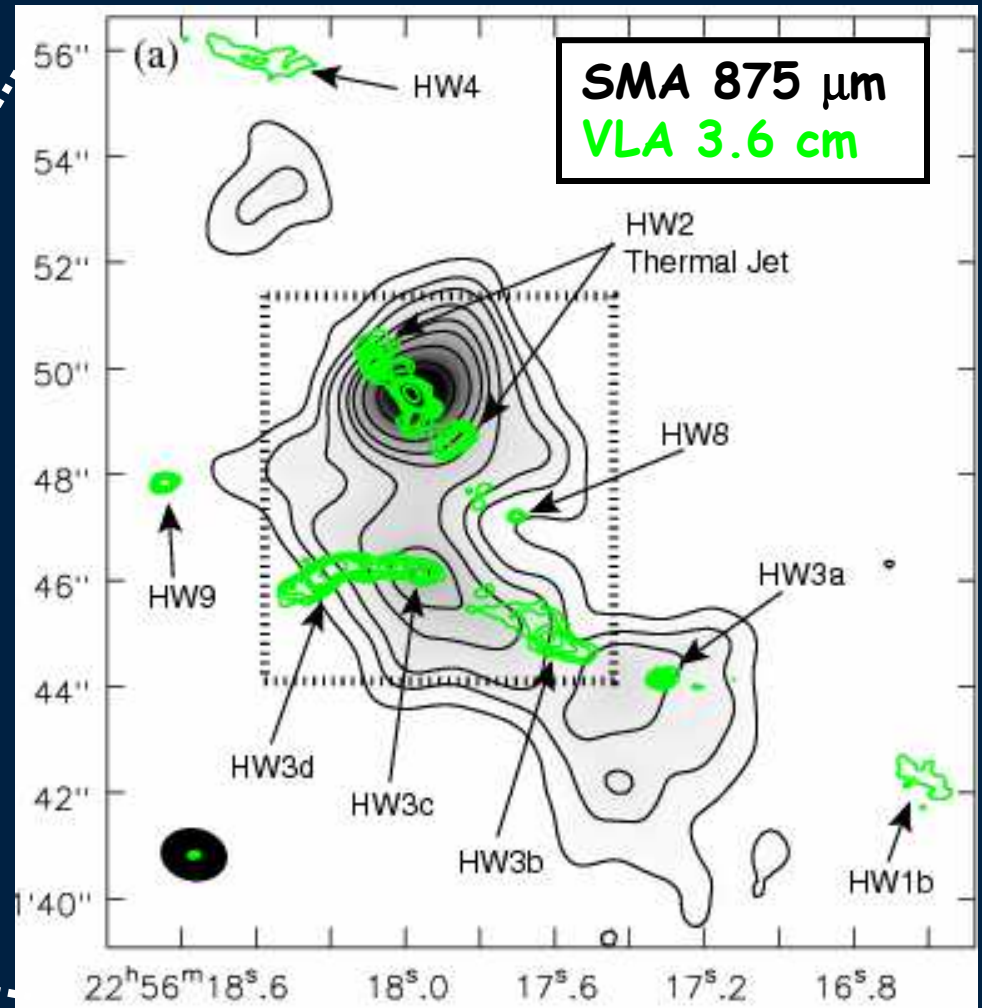
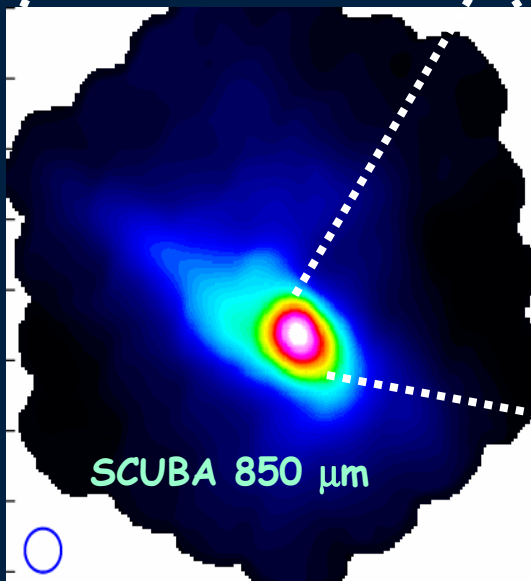
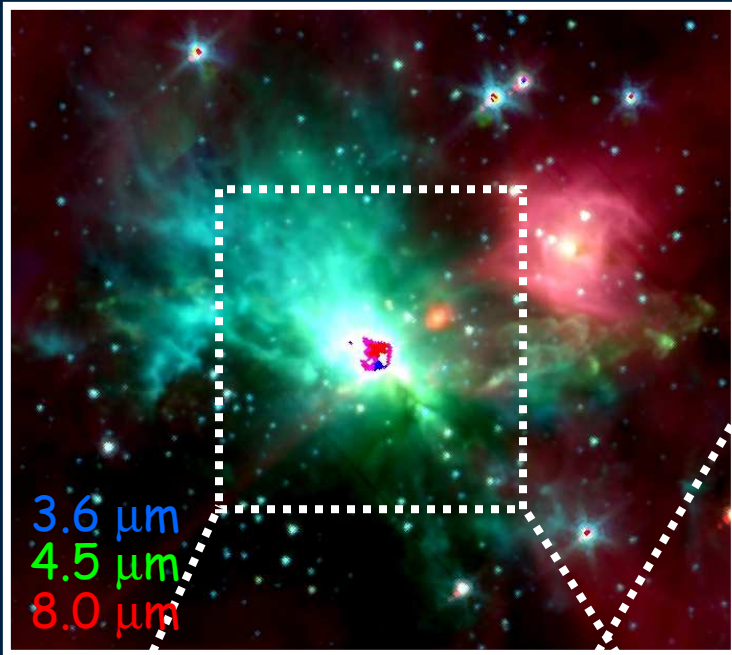


ALMA will improve resolution and spectral sensitivity by more than factor of 25!

# The Many Protostars of CepA-East

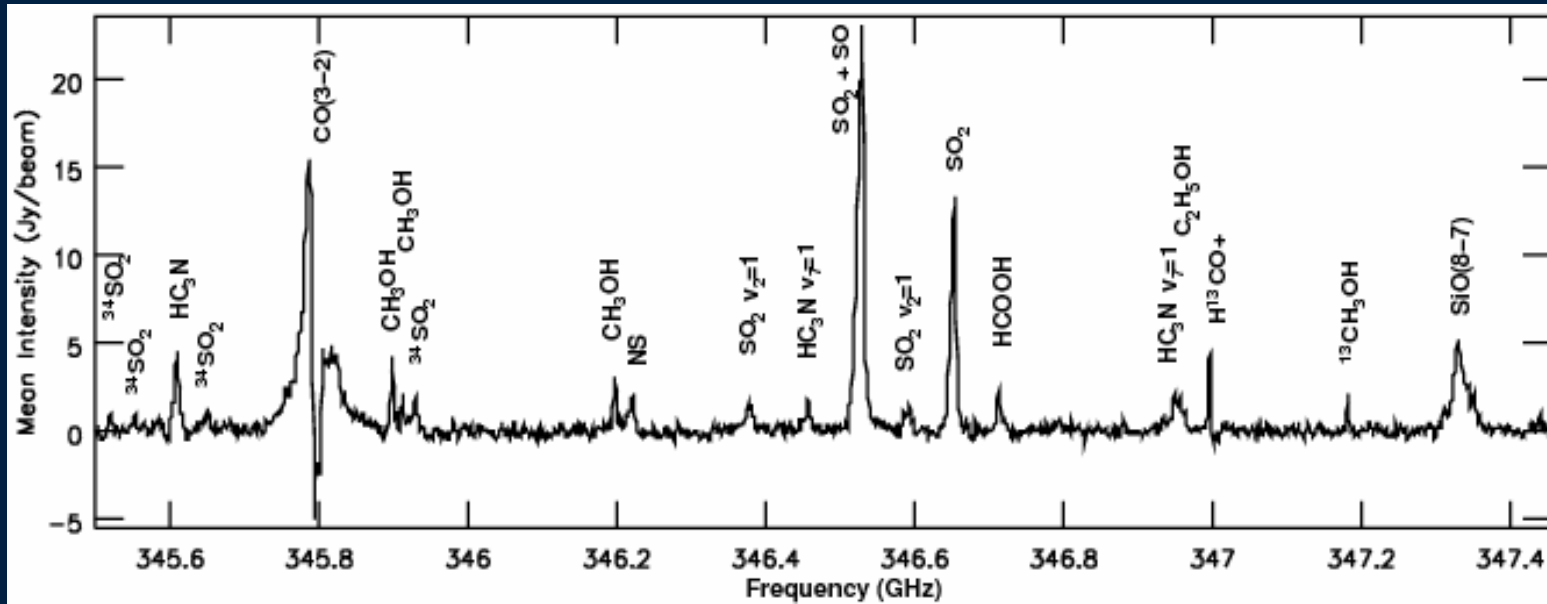
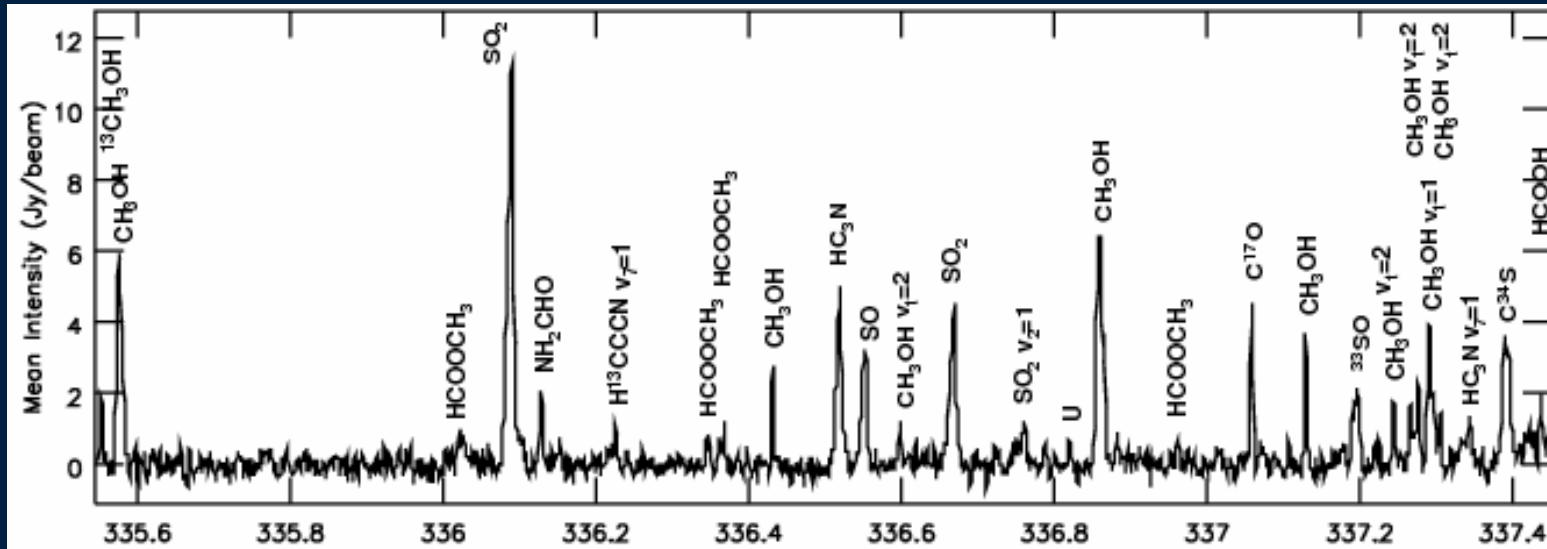
$d=0.73$  kpc

5'



resolution 1."3 x 1."0

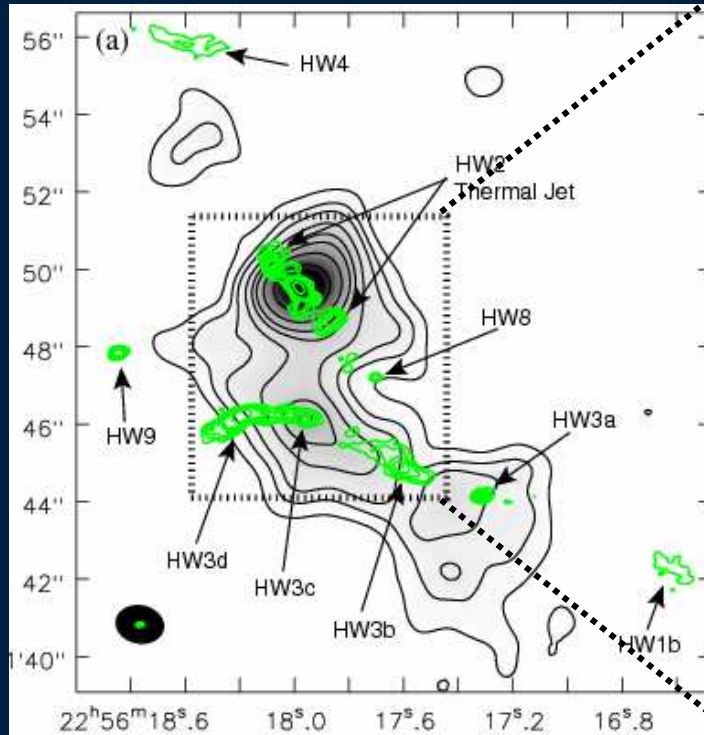
# CephA-East Line Forest



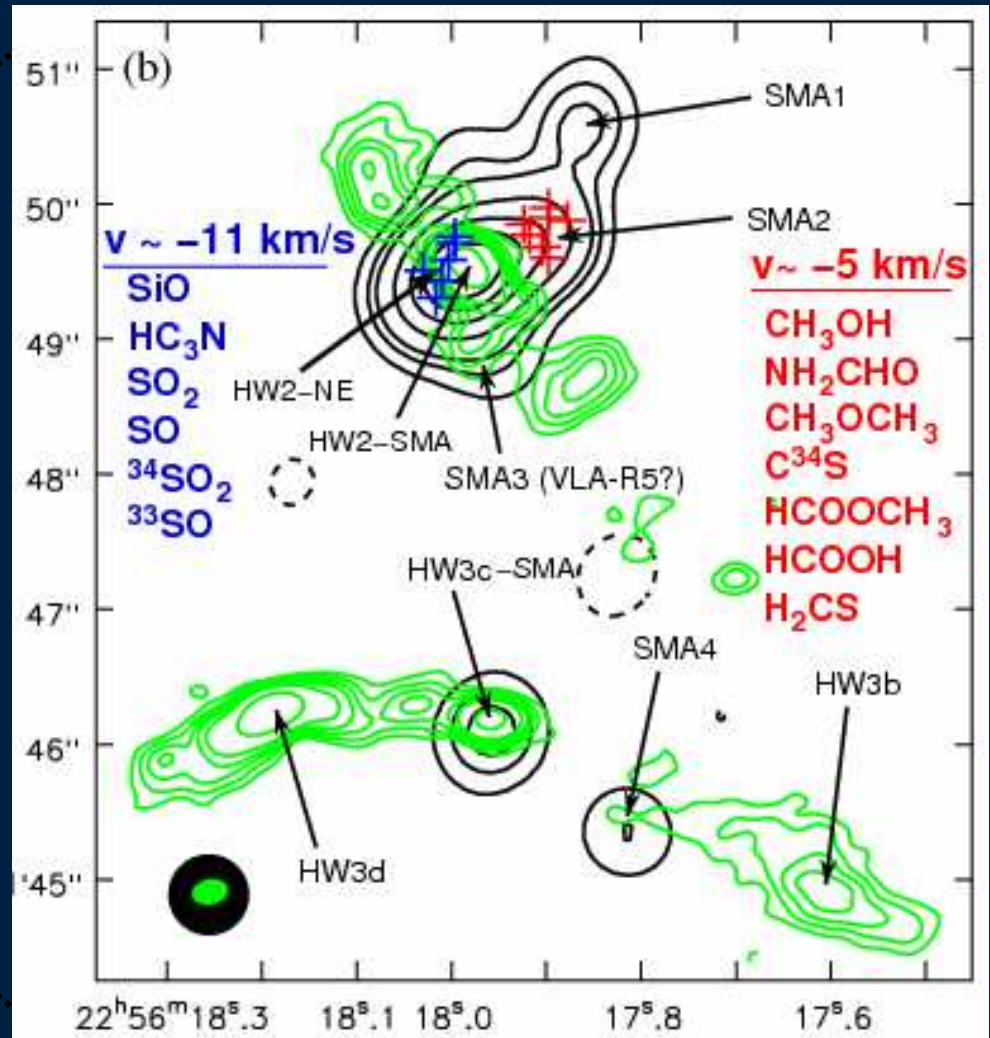
Spectra are similar to that of OrionA single dish data (Schilke et al. 1997)



# Chemical Differentiation



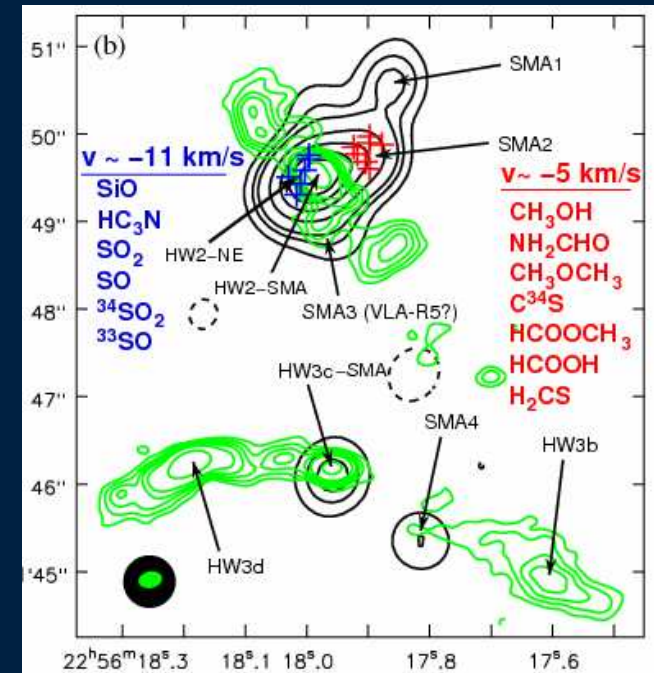
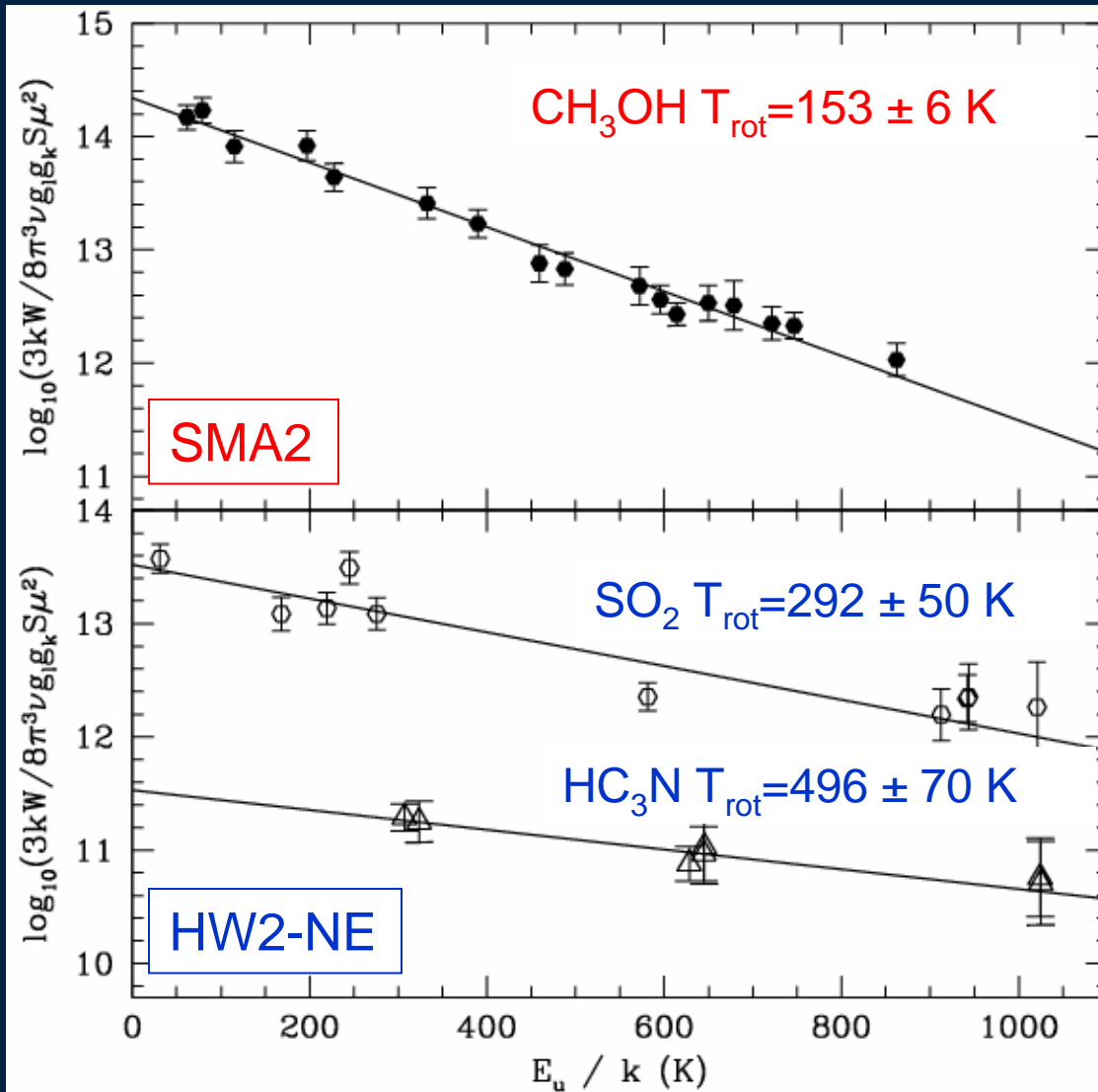
SMA 875  $\mu\text{m}$   
VLA 3.6 cm



resolution 0."6

$$n_{\text{protostars}} = 8 \times 10^5 \text{ pc}^{-3}$$

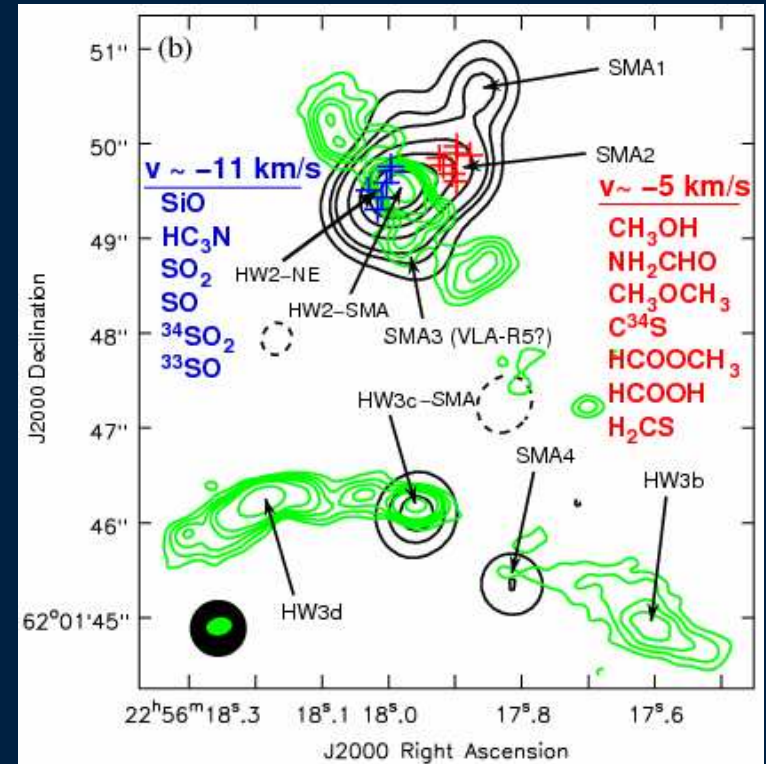
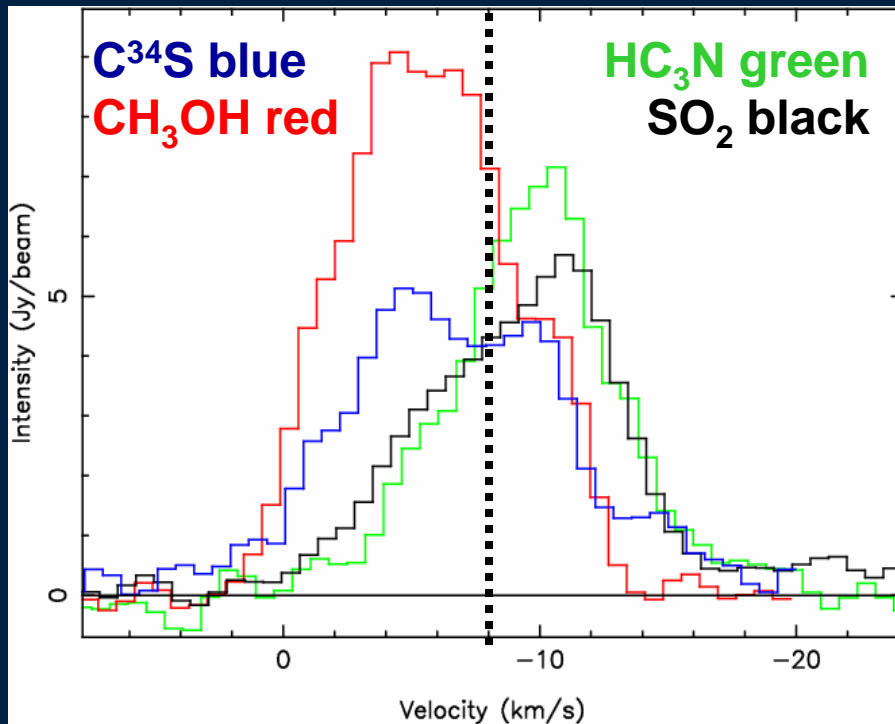
# CepA-East Temperatures



$\text{CH}_3\text{OH}$  and  $\text{SO}_2$  corrected for optical depth effects. For  $\text{CH}_3\text{OH}$ , max  $\tau \sim 30!$

$T_{\text{rot}}$  2x higher than reported by Martin-Pintado et al. (2005) based on 30m data - probably a beam dilution effect

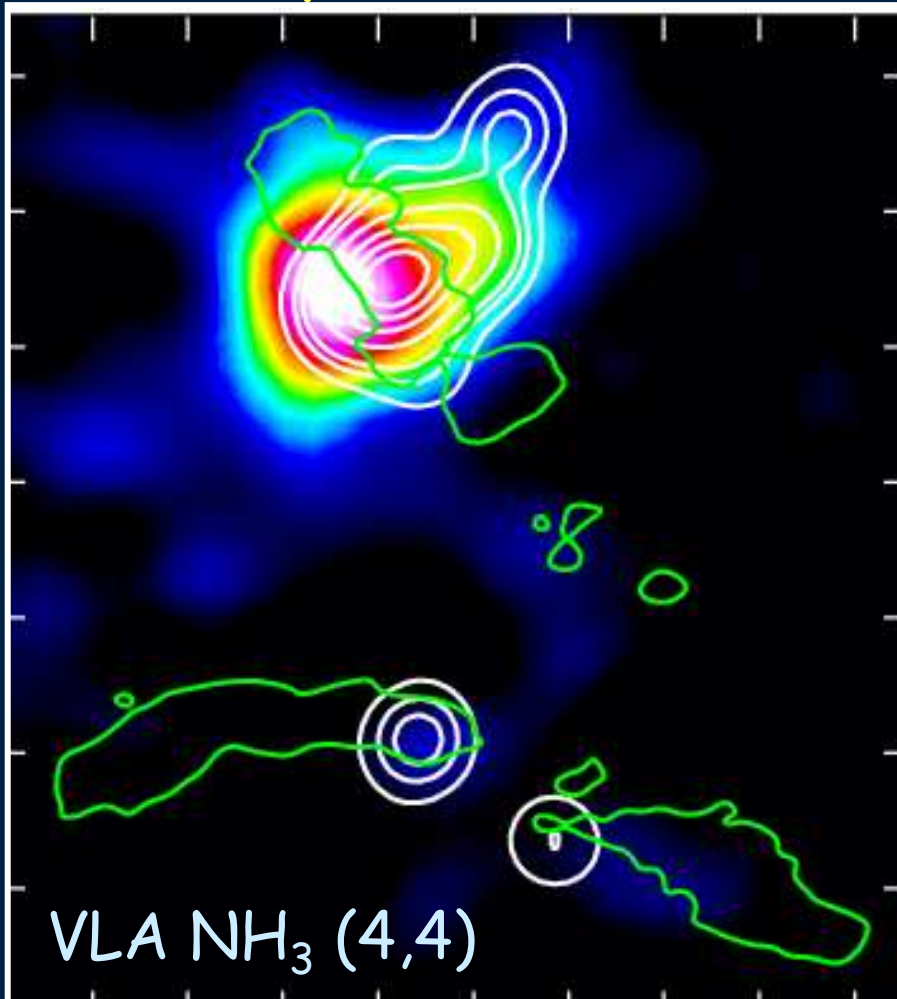
# Velocity Gradients Don't Always Equal Rotation...



Insufficient spatial resolution  
causes apparent  
velocity/position gradient

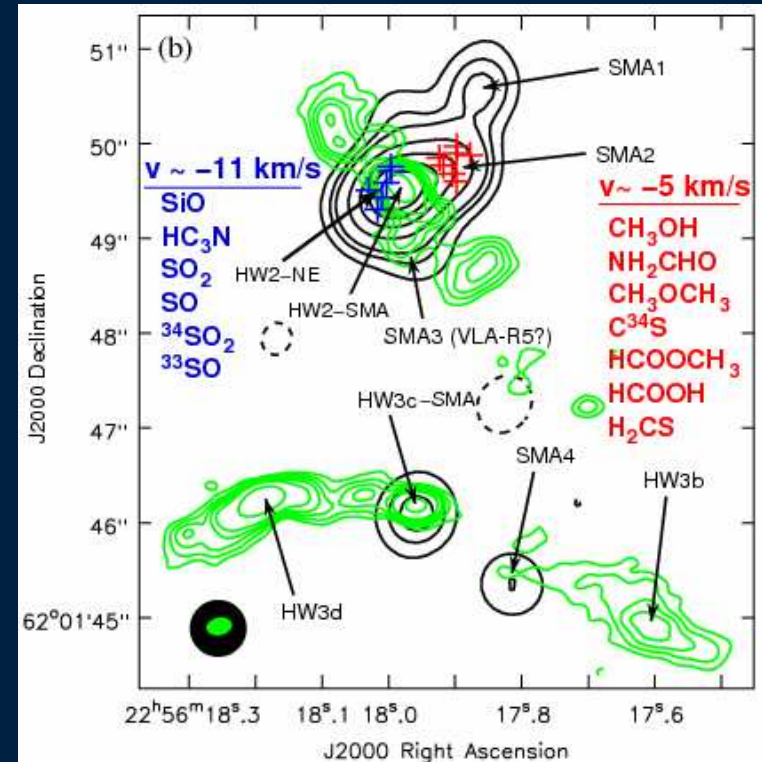
No evidence for a disk as  
reported by Patel et al. (2005)

# Velocity Gradients Don't Always Equal Rotation...



No evidence for a disk as reported by Patel et al. (2005)

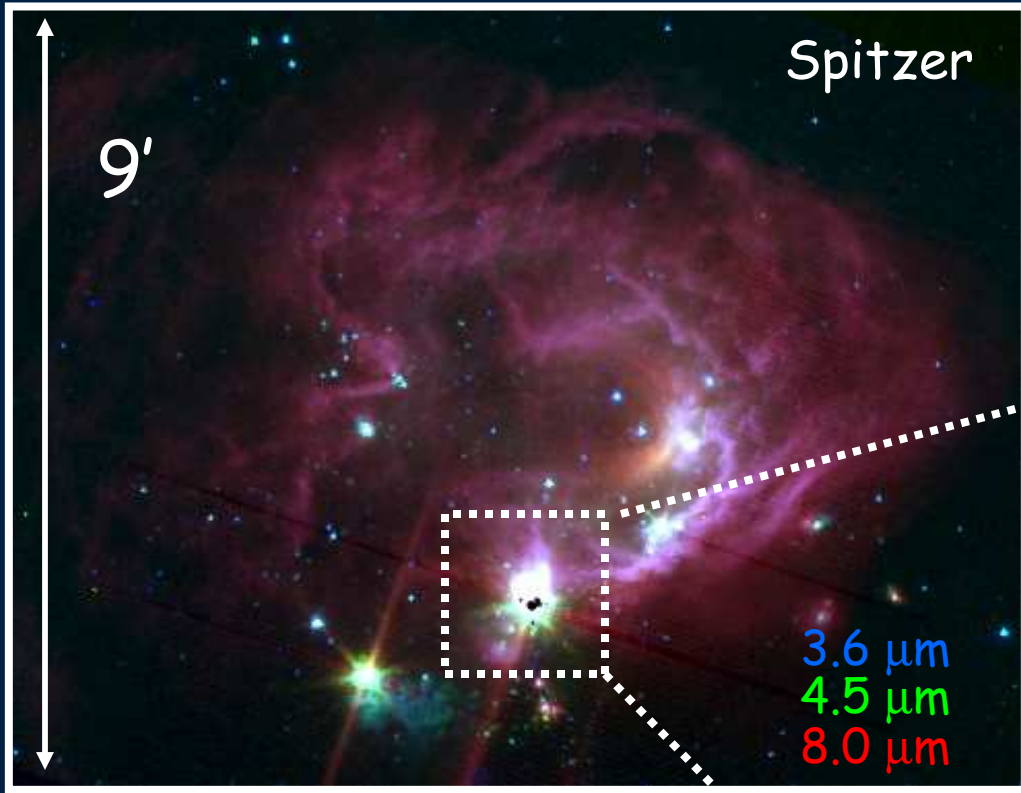
Also see Comito et al. (in prep.)



- Detection of  $\text{NH}_3$  (4,4) confirms high temperatures, and positions of HW2-NE, and SMA2.

- HW2-NE shock interaction at base of jet rather than protostar as suggested by Martin-Pintado et al. (2005)?

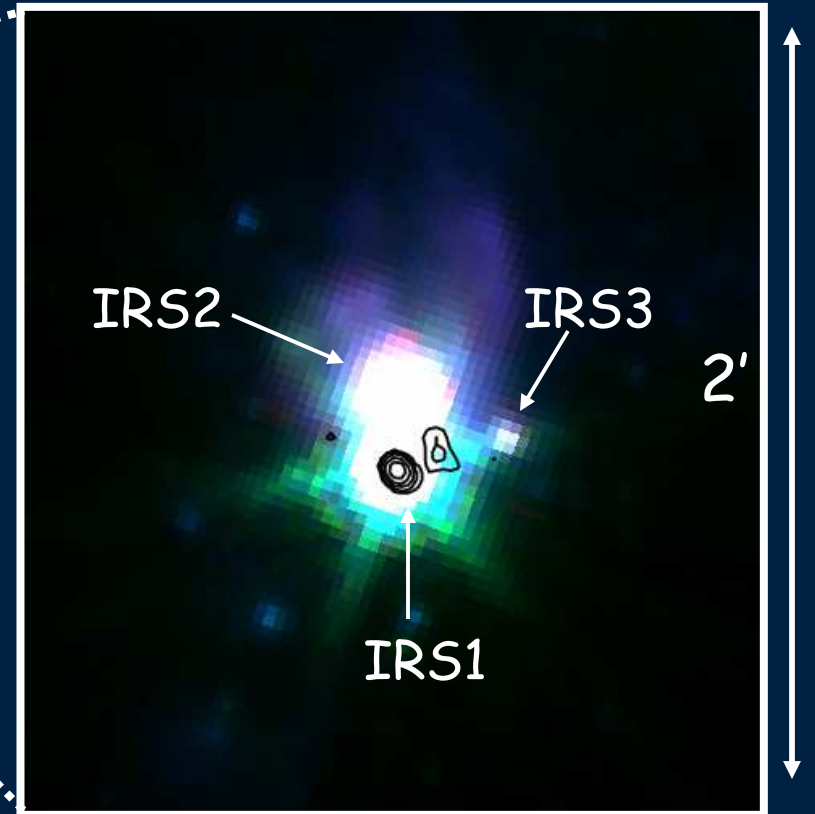




# NGC7538 IRS1

$d=2.8$  kpc

$2''=5600$  AU



Spitzer

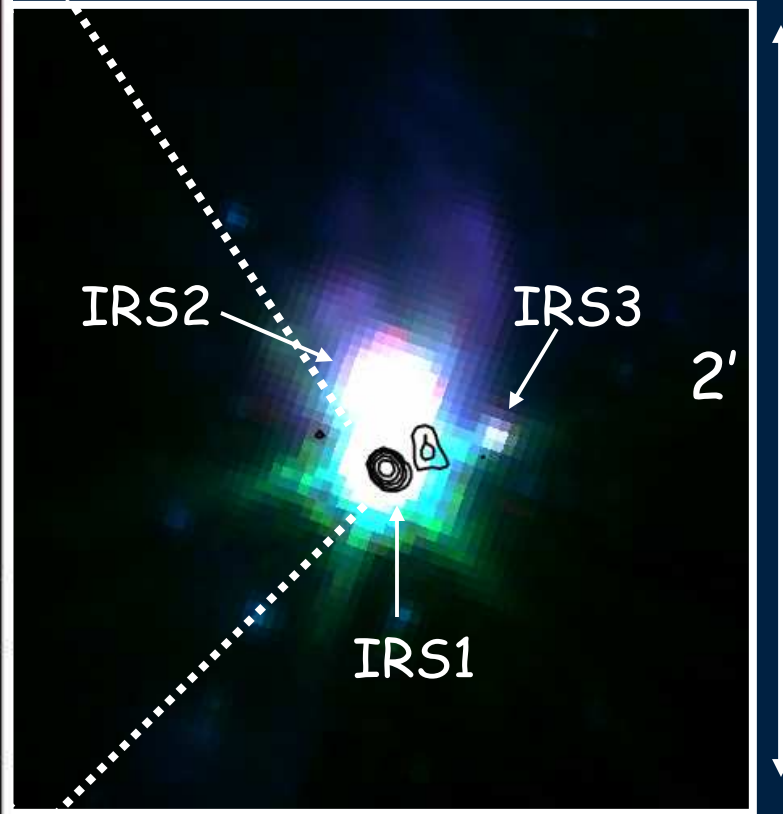
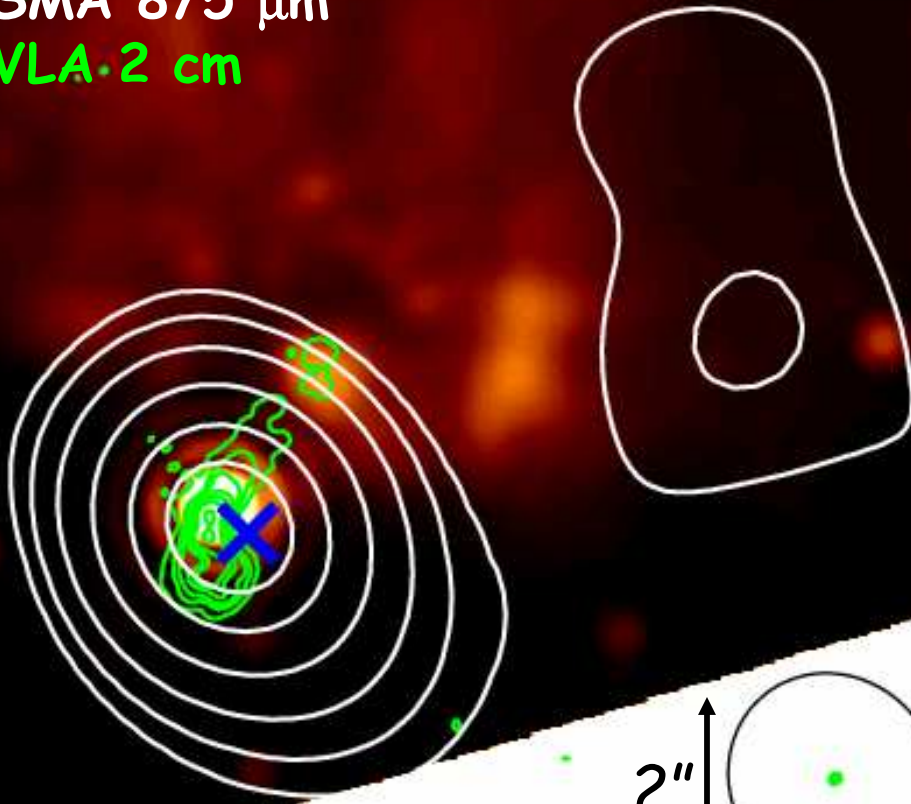
9'

# NGC7538 IRS1

d=2.8 kpc

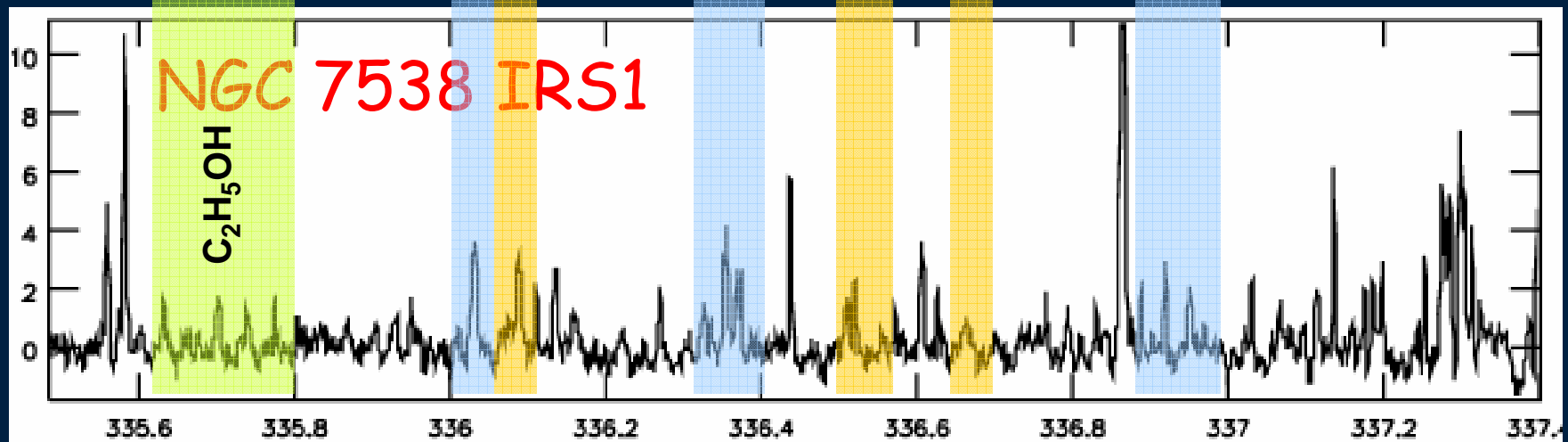
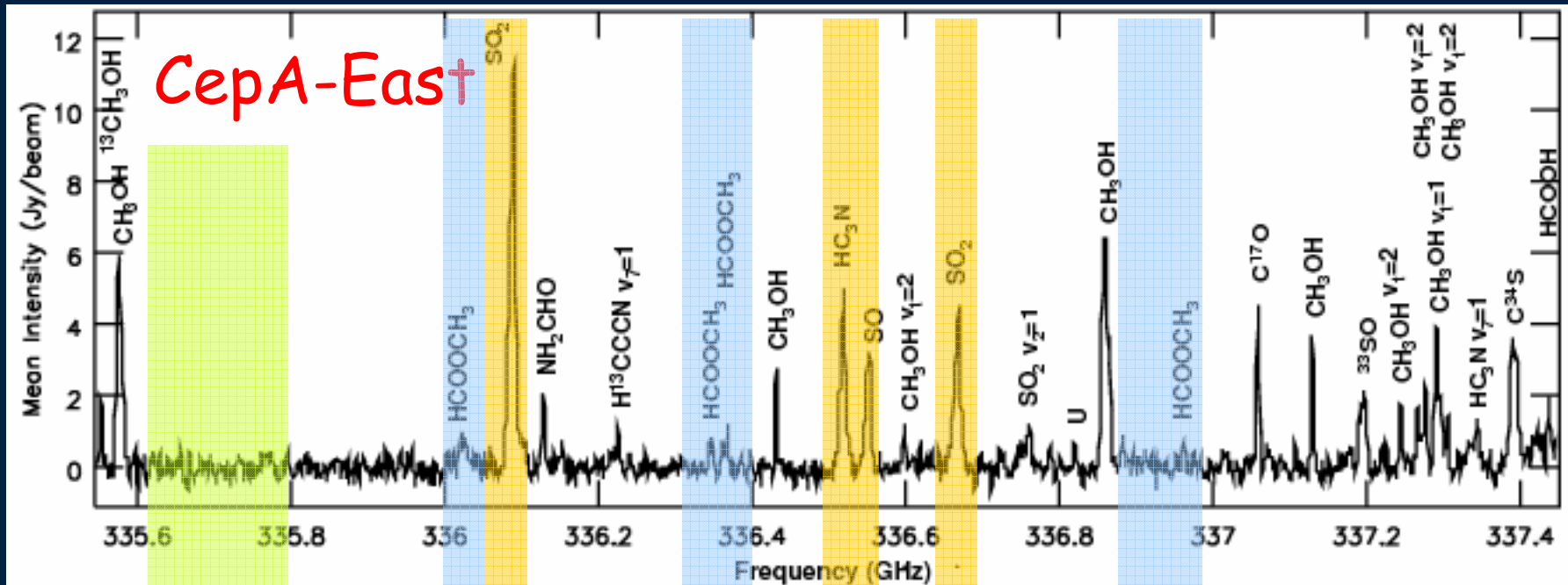
2"=5600 AU

SMA 875  $\mu\text{m}$   
VLA 2 cm

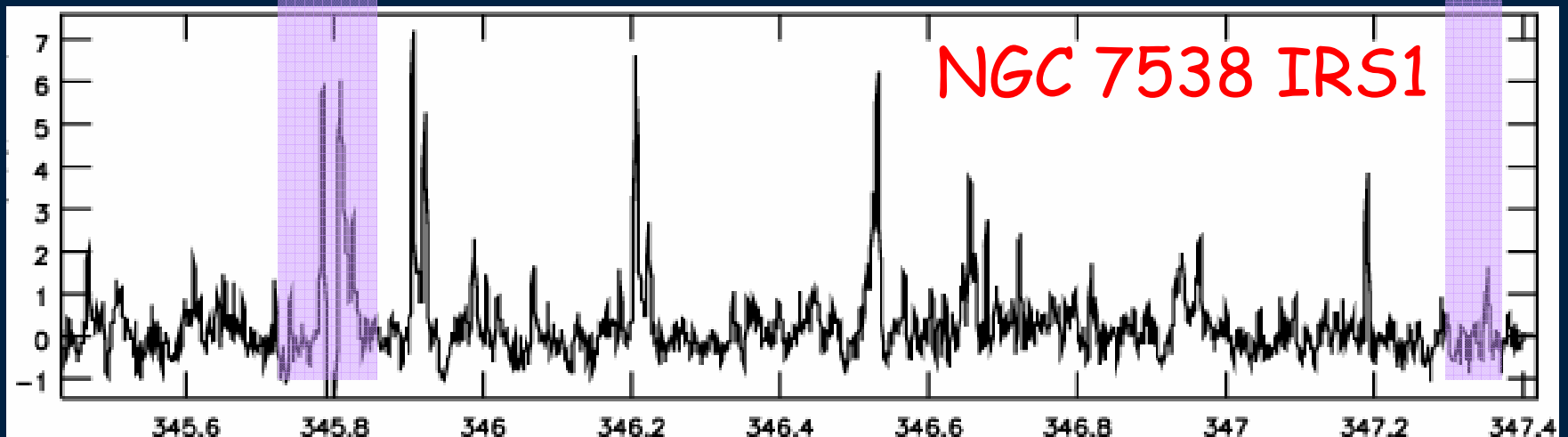
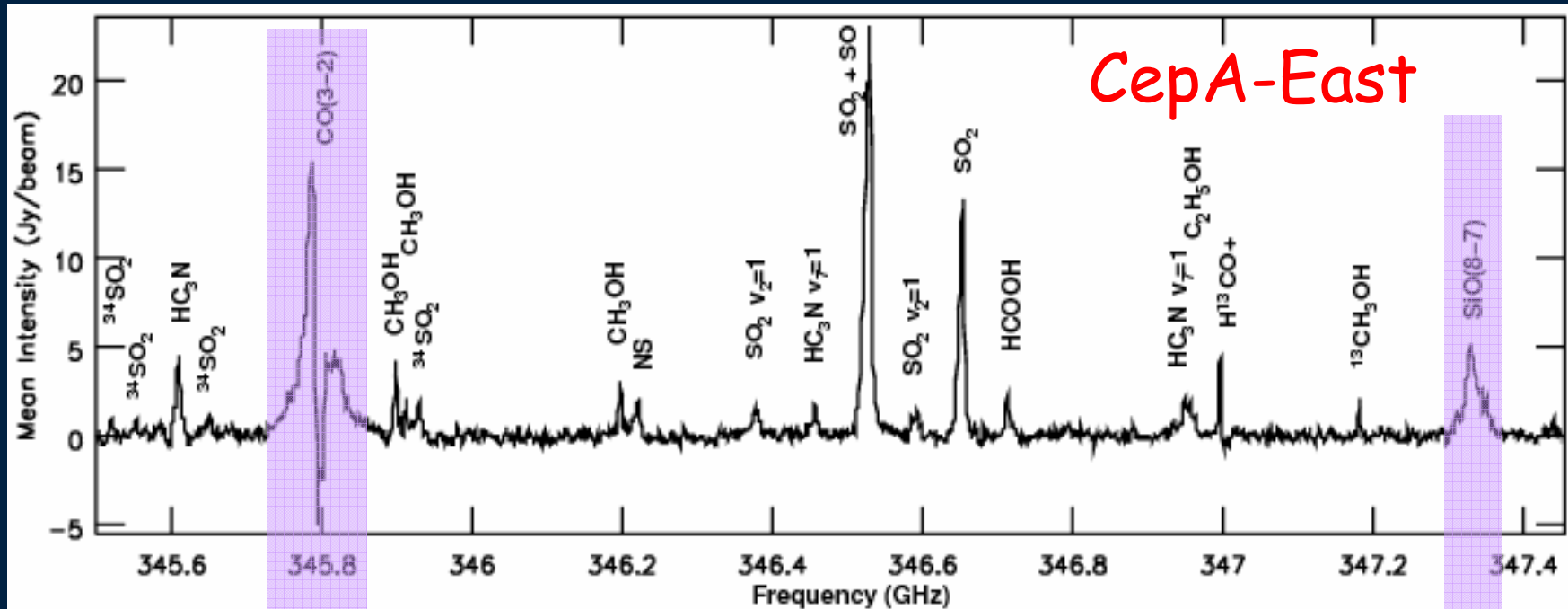


K' image from Kraus et al. (2006)

# NGC 7538 Line Forest Comparison-I

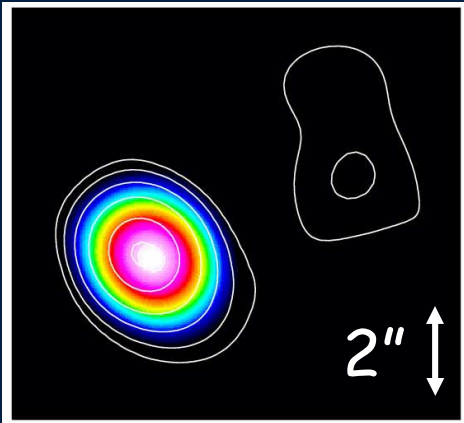


# NGC 7538 Line Forest Comparison-II

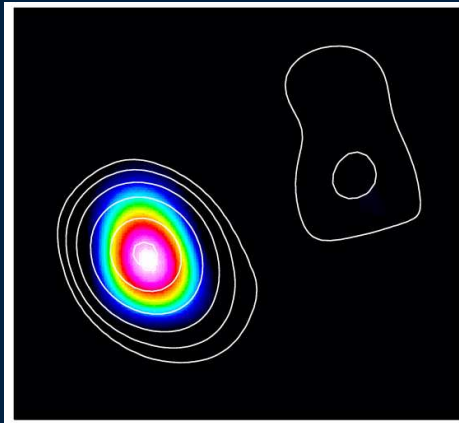




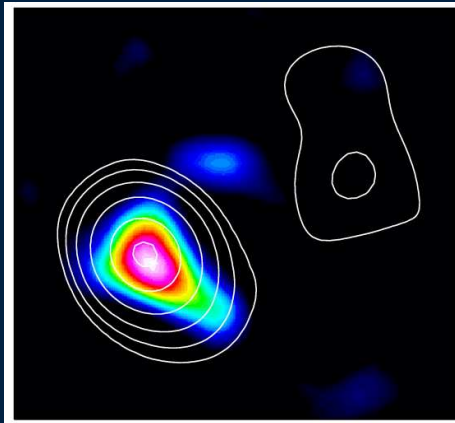
# Distribution of Molecules in NGC7538 IRS1



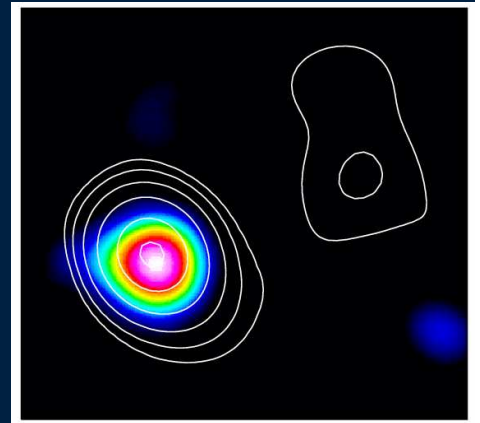
$\text{CH}_3\text{OH}$



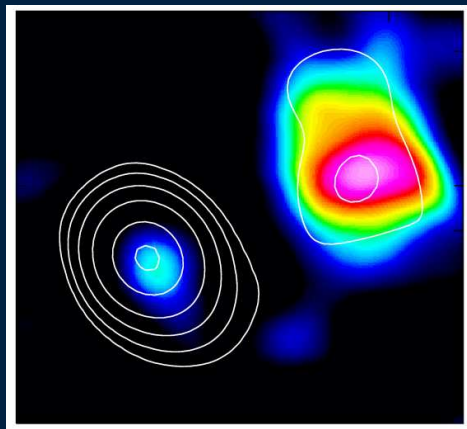
$\text{C}_2\text{H}_5\text{OH}$



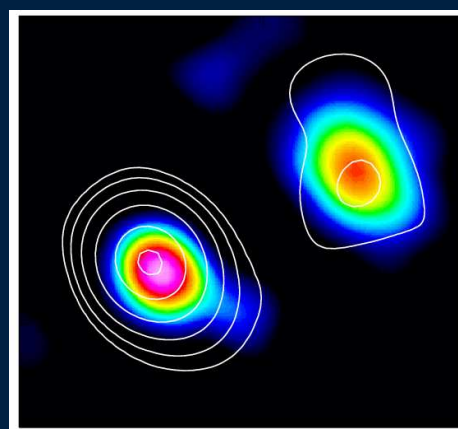
$\text{HC}_3\text{N}$



$\text{SO}_2$

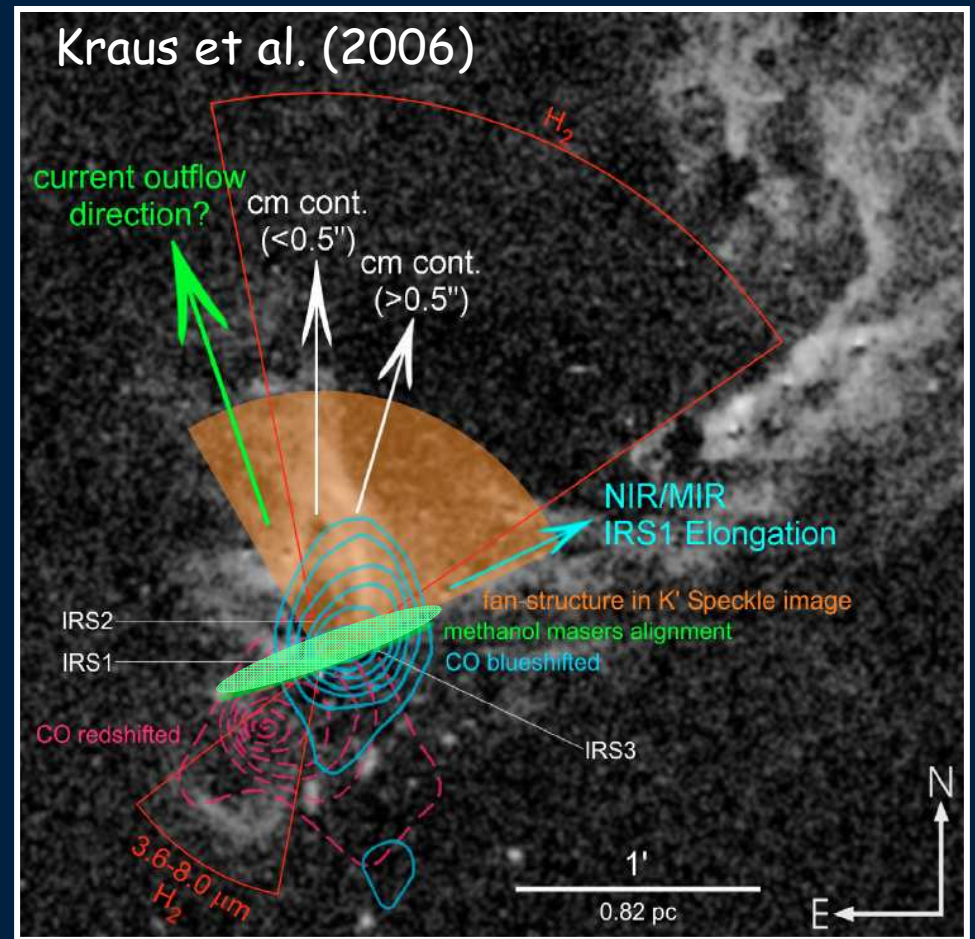


$\text{C}^{17}\text{O}$



$\text{C}^{34}\text{S}$

# Methanol in IRS1: Outflow and Disk?



CH<sub>3</sub>OH maser disk at P.A.=-70°

Pestalozzi et al. (2004); Minier et al. (2000, 2001)

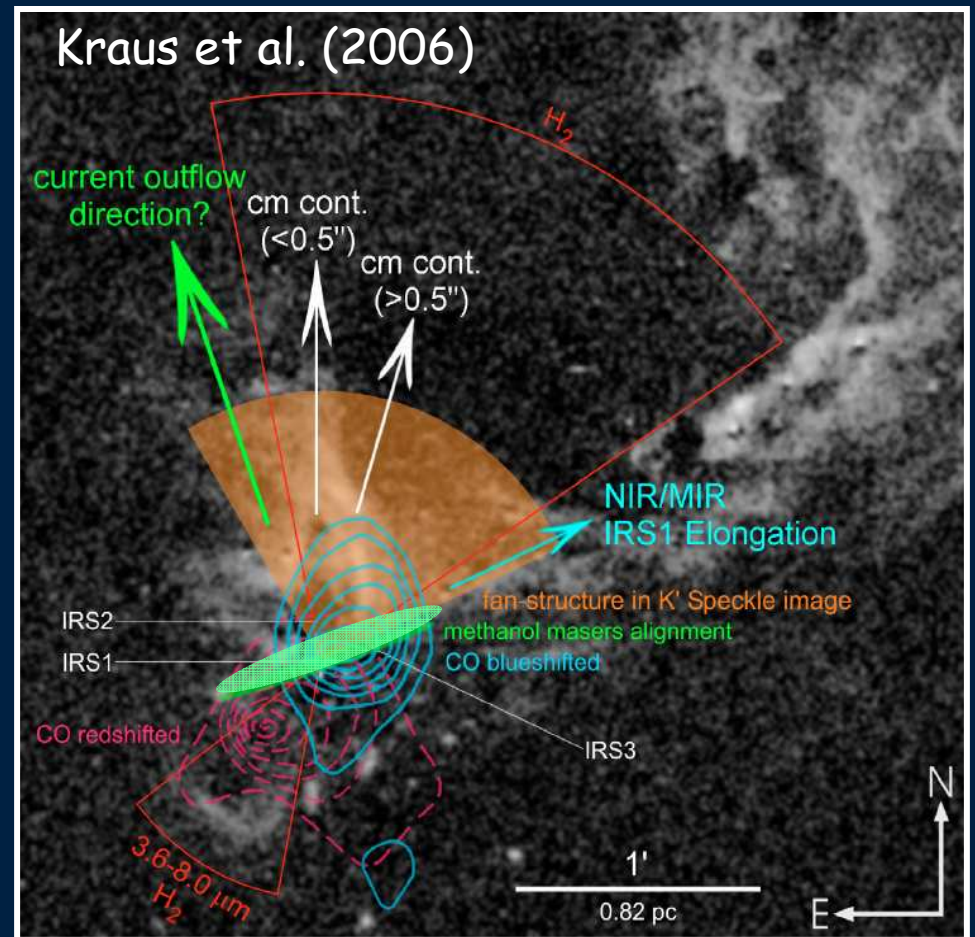
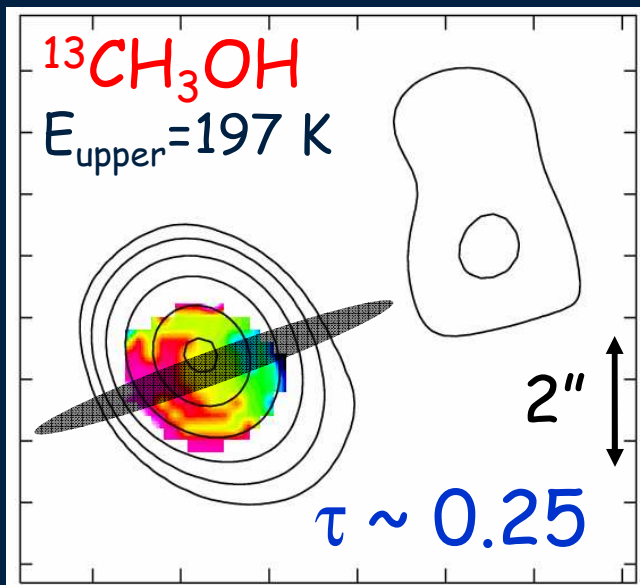
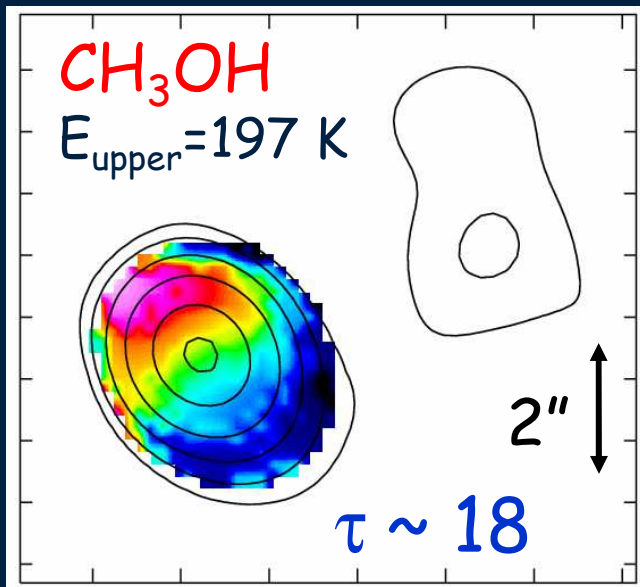
Mid-IR dust has similar elongated morphology

Kraus et al. (2006); De Buizer & Minier (2005)

Evidence for Jet Precession, P=280 years

Kraus et al. (2006)

# Methanol in IRS1: Outflow and Disk?



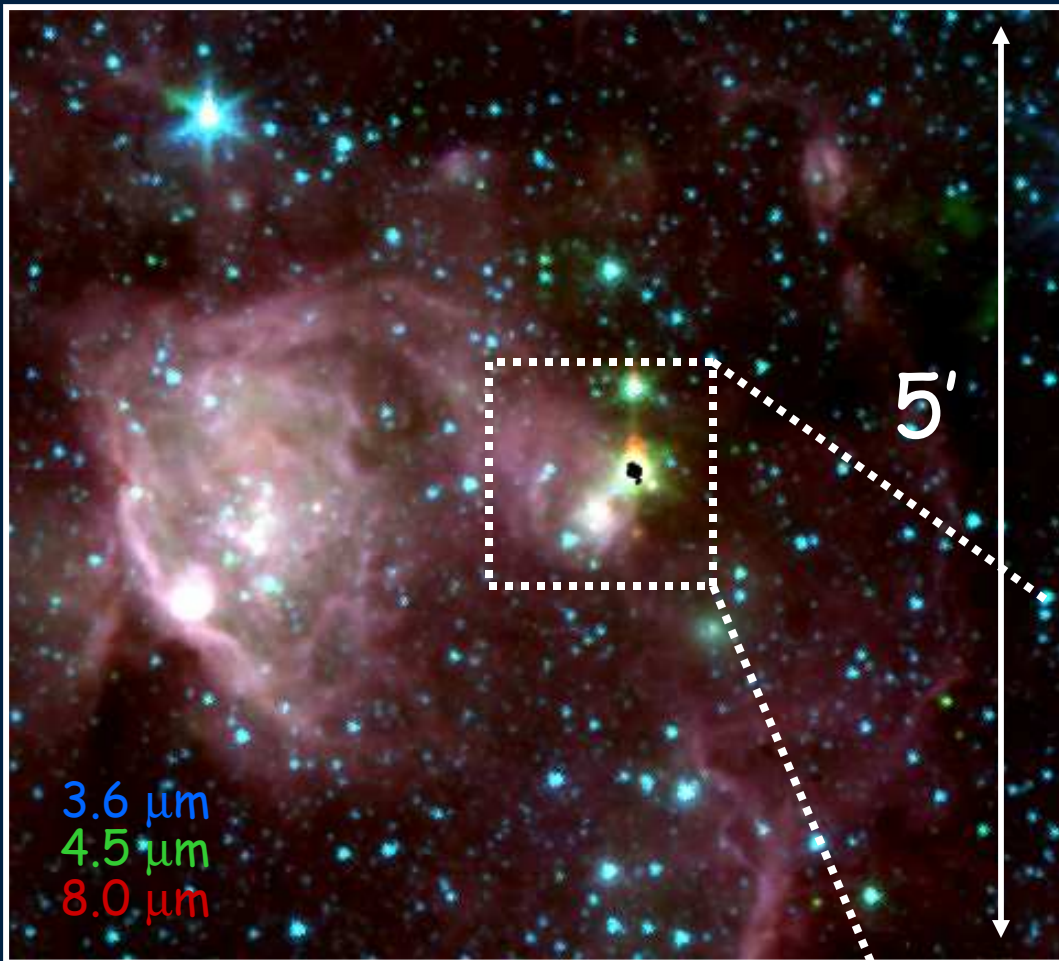
IF interpreted as Keplerian disk with radius < 0.7'' (r=2000 AU) and  $\Delta v=4$  km/s,  $M < 32 M_{\odot}$  consistent with maser and spectral type estimates

BUT better resolution is needed...



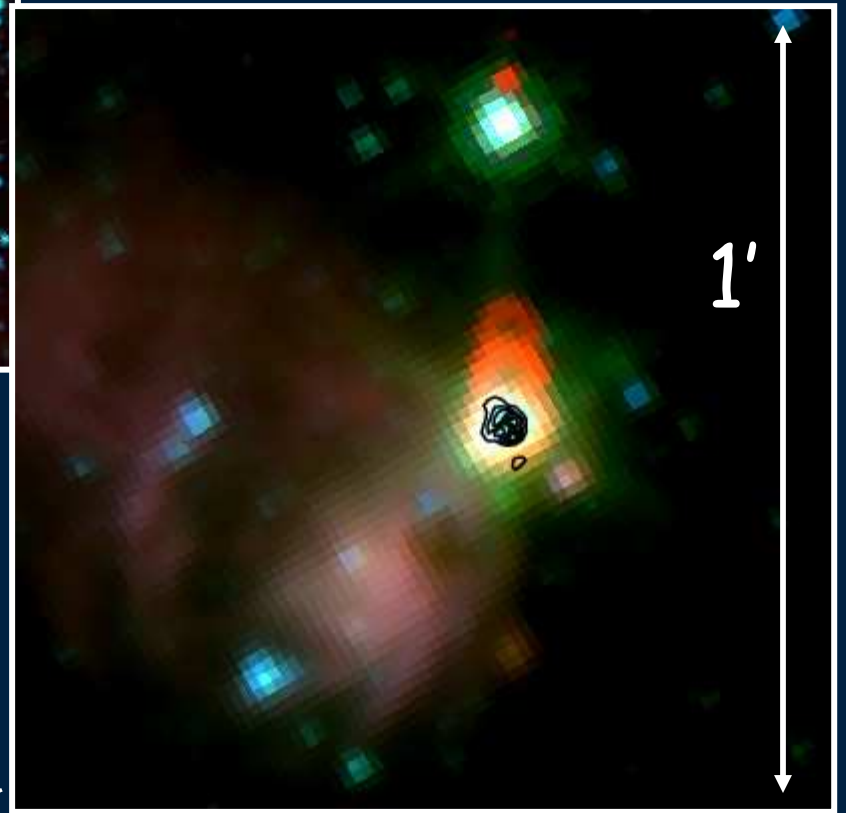
# The Enigmatic G5.89-0.39

d=2.0 kpc



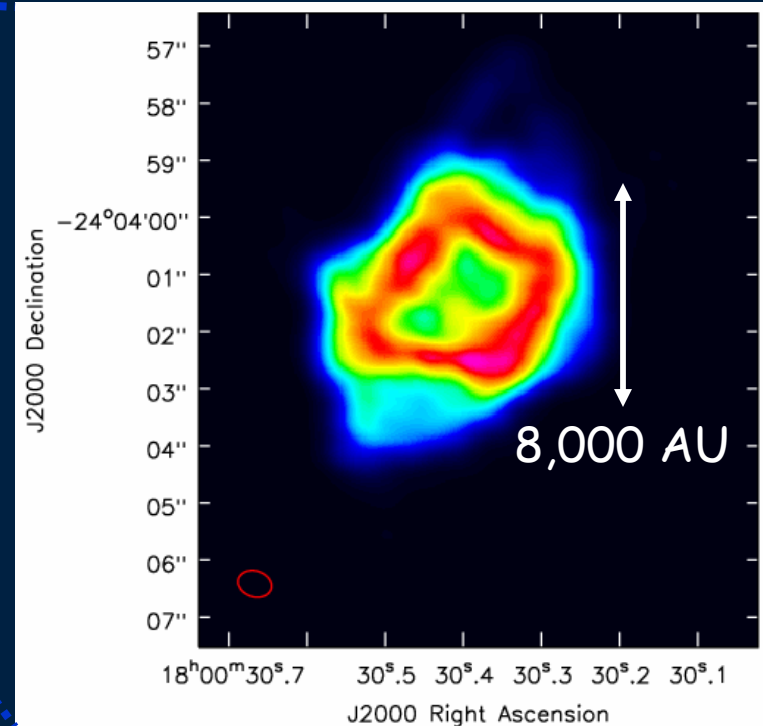
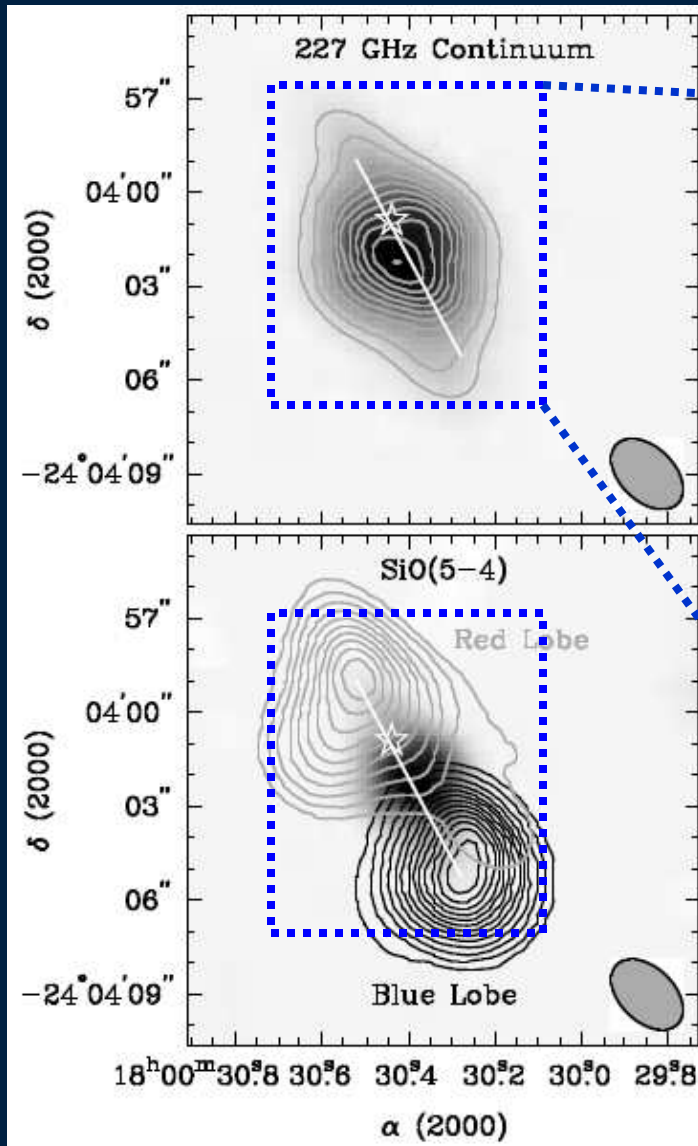
3.6 μm  
4.5 μm  
8.0 μm

Spitzer GLIMPSE





# Previous High Res. Radio Data

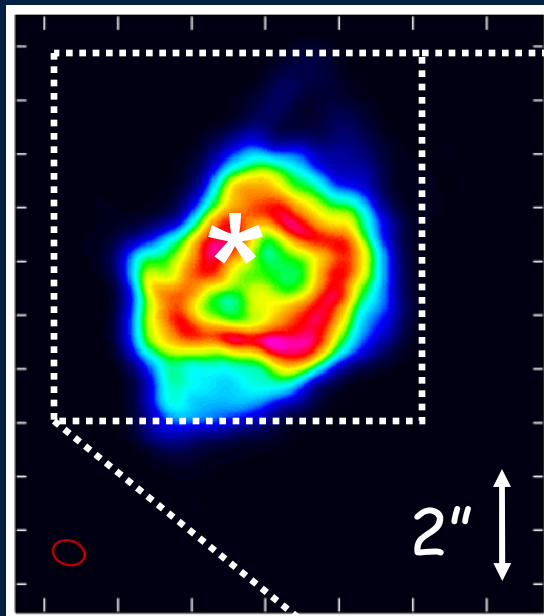


Archival VLA 3.6cm [0."6 x 0."45]

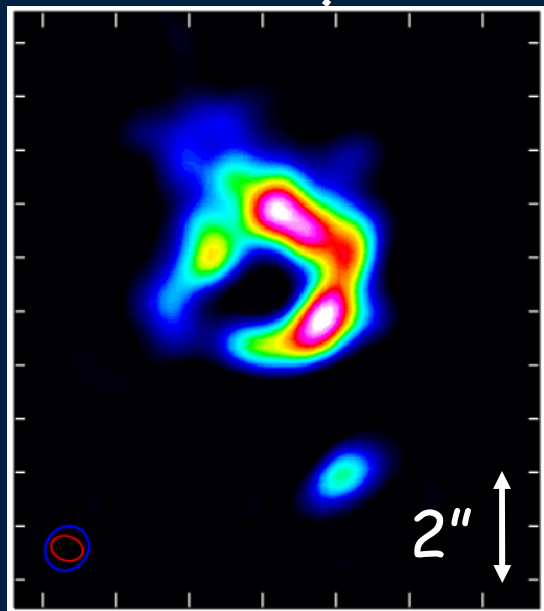
SMA 1.3mm: Sollins et al. (2004) [2."8 x 1."8]

# So Where's the Star in G5.89-0.39?

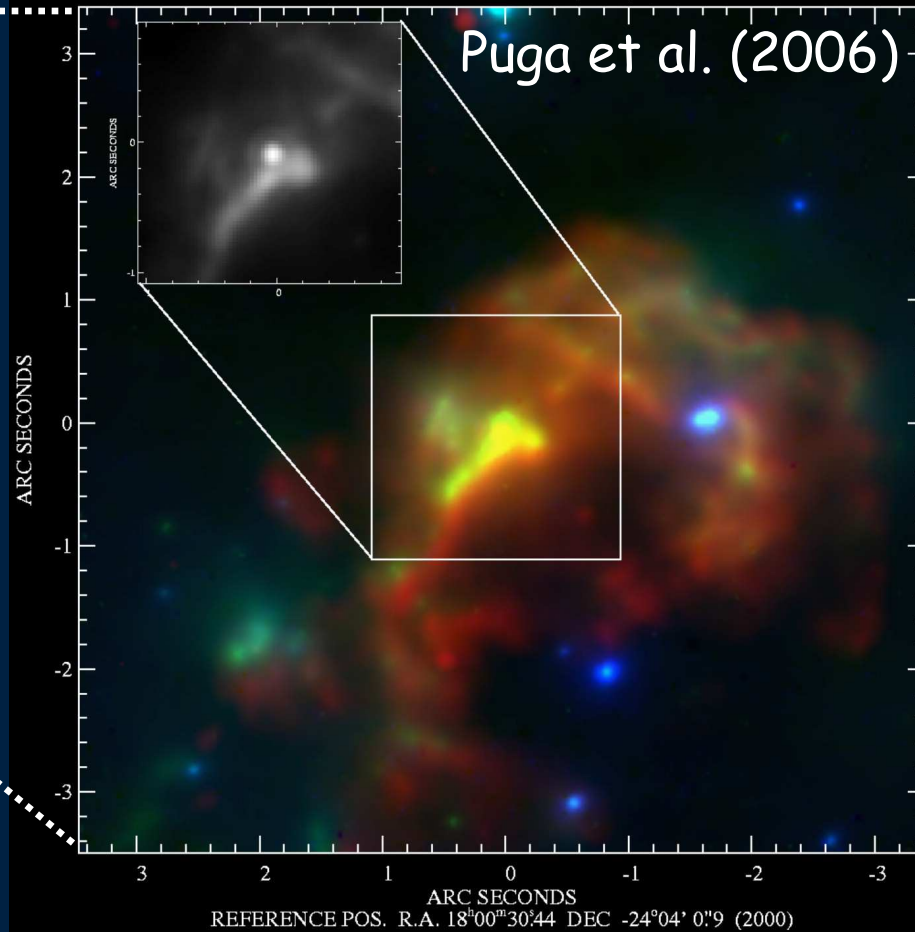
VLA  
3.6 cm



SMA  
875  $\mu\text{m}$



G5.89-0.39 NACO H/Ks/L'



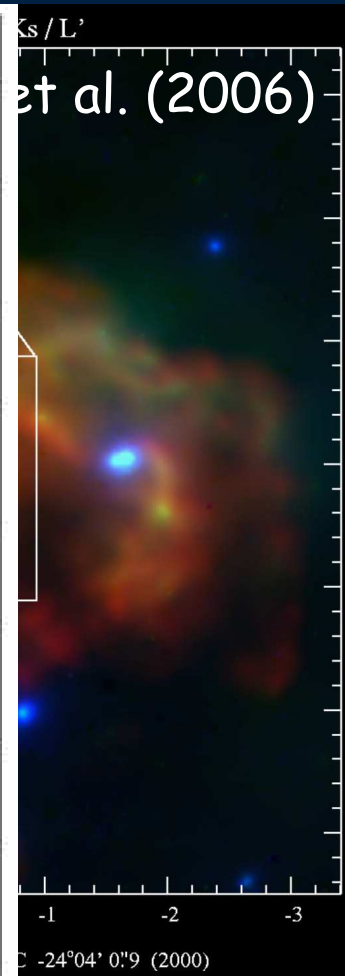
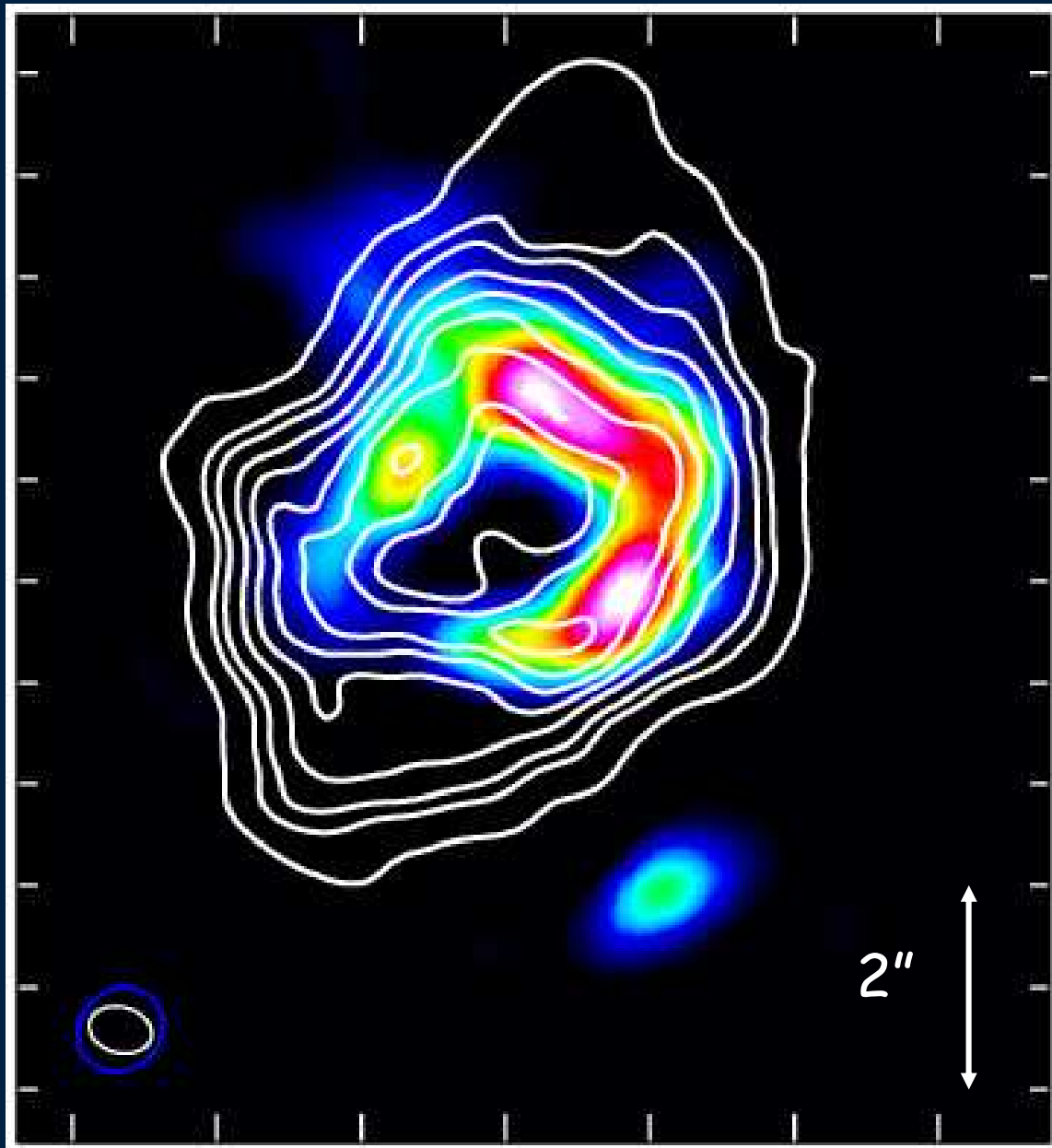
Extended config.

0."87 x 0."76

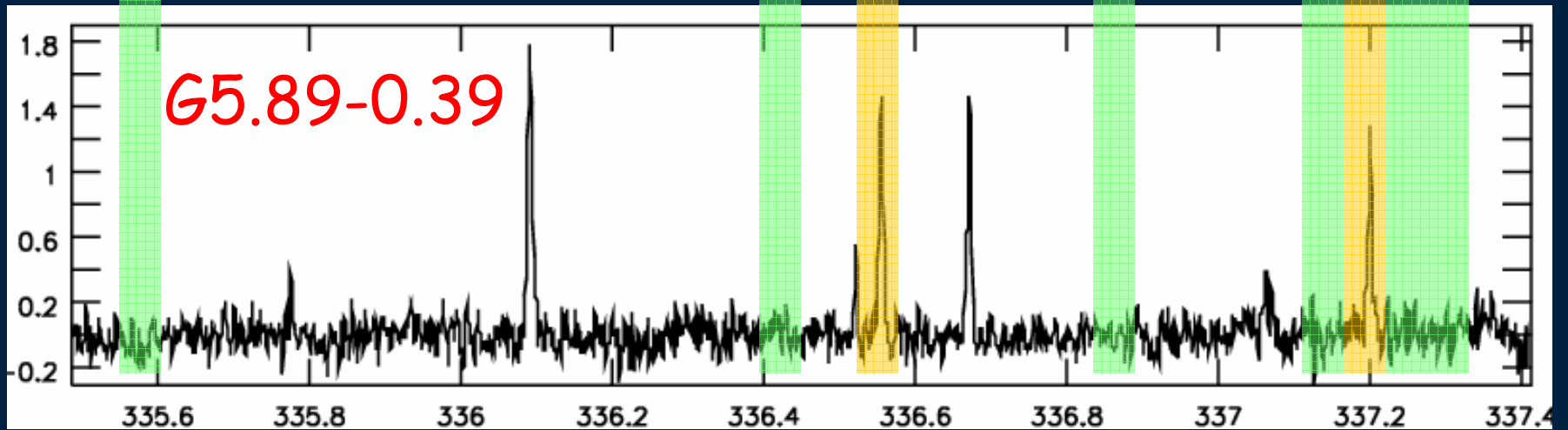
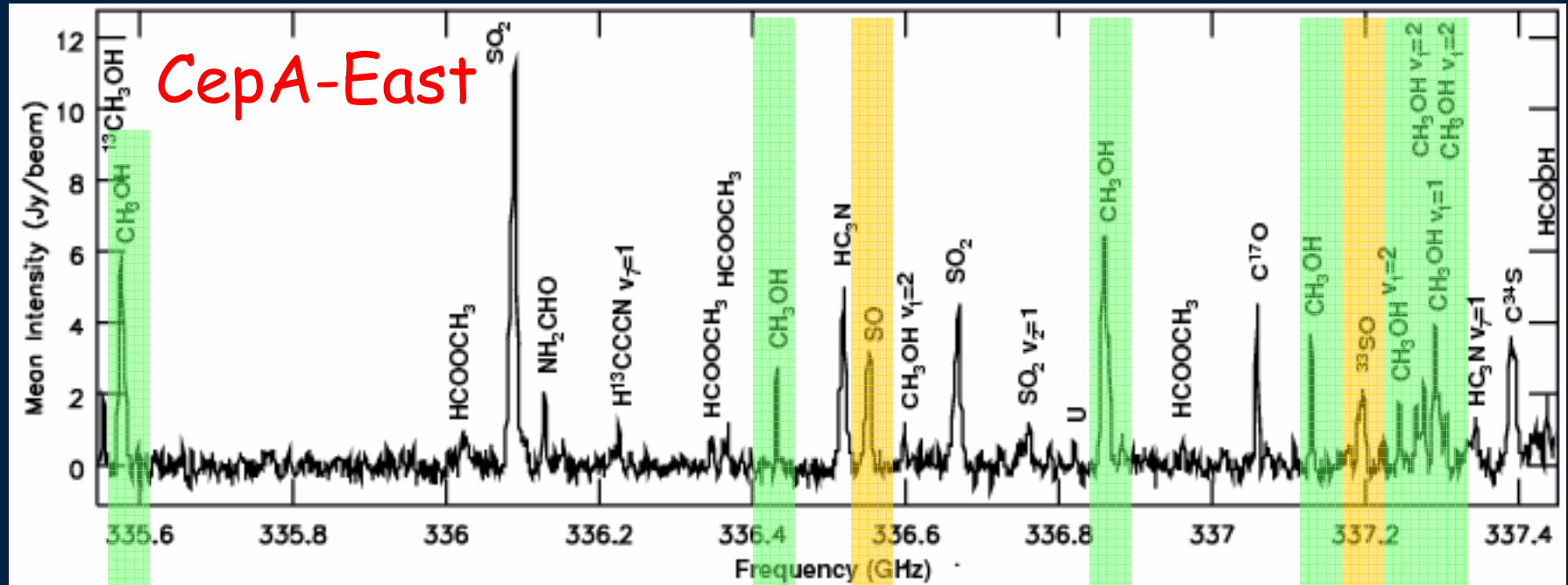
# So Where's the Star in G5.89-0.39?

VLA  
3.6 cm

SMA  
875  $\mu\text{m}$

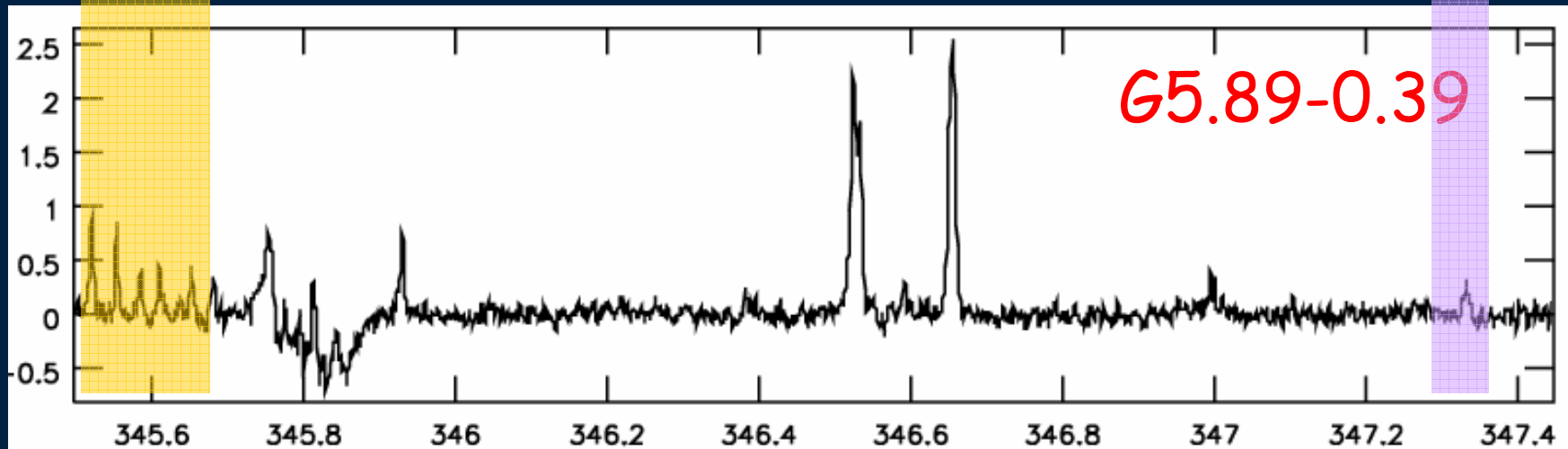
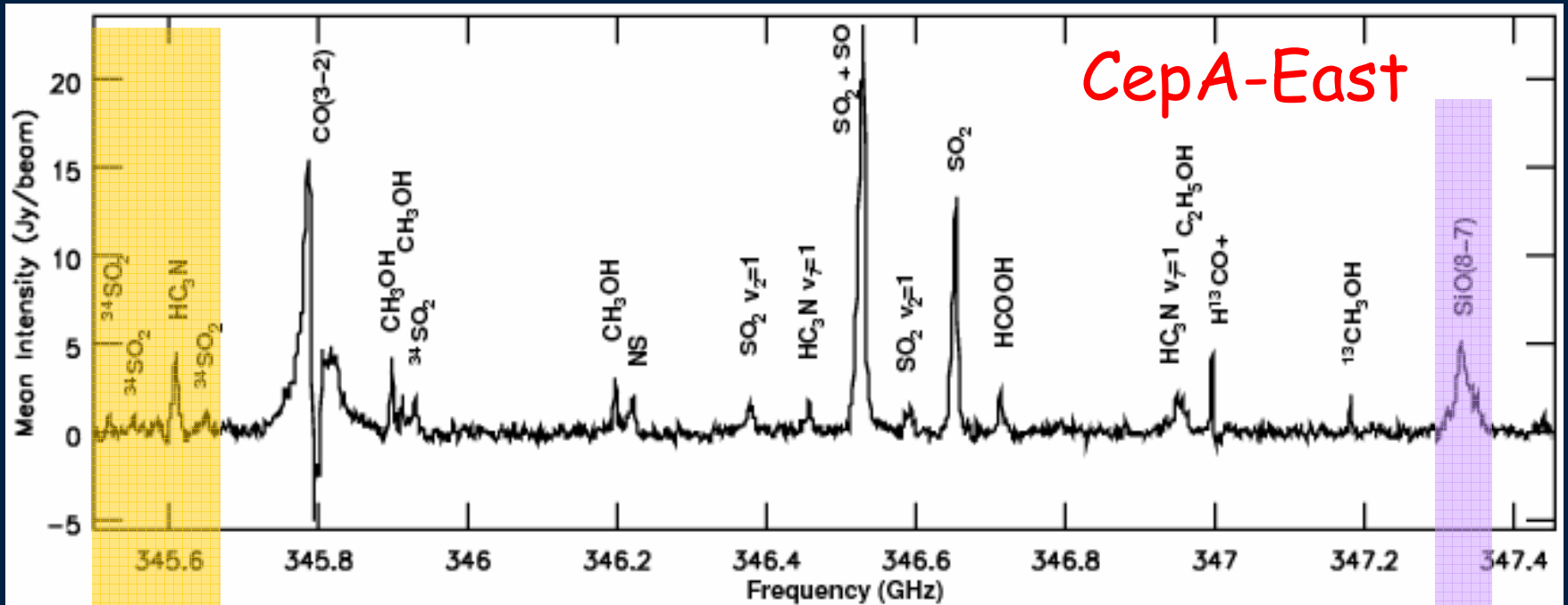


# G5.89 Line Forest Comparison-I

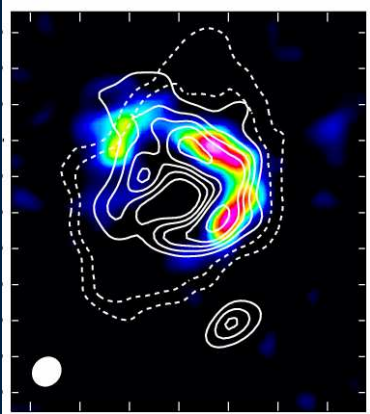




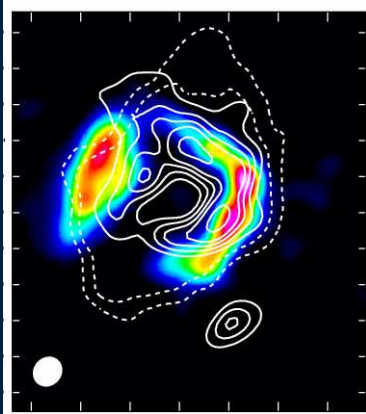
# G5.89 Line Forest Comparison-II



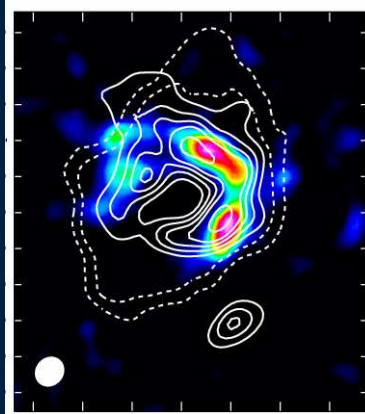
# The Complex Chemistry of G5.89



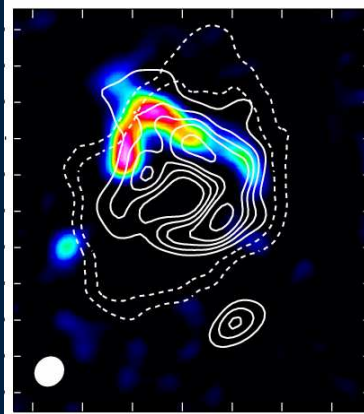
SO



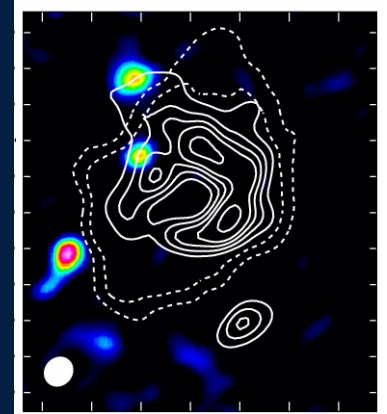
SO<sub>2</sub>



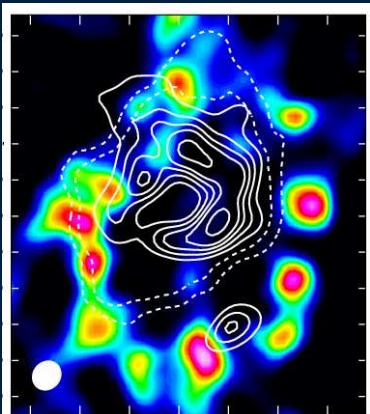
<sup>34</sup>SO<sub>2</sub>



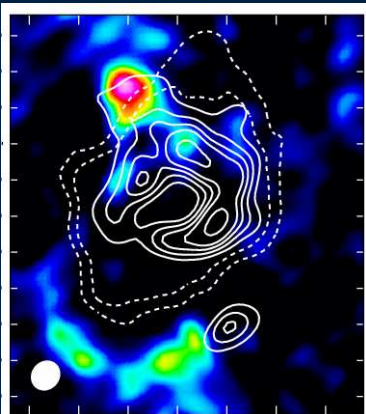
HC<sub>3</sub>N



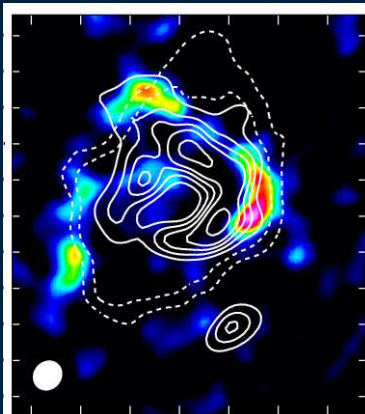
CH<sub>3</sub>OH



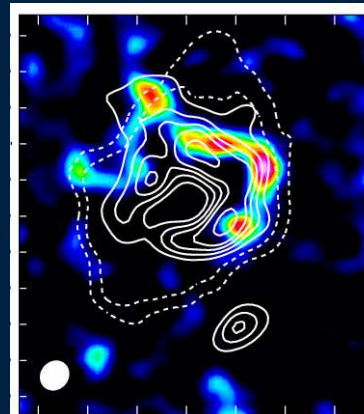
CO



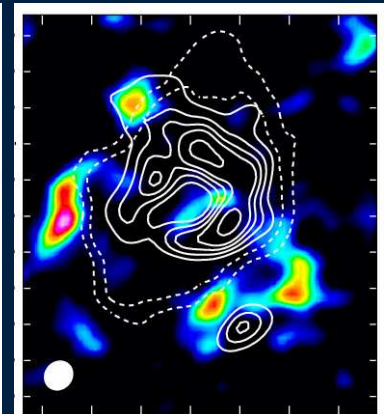
C<sup>34</sup>S



H<sup>13</sup>CO<sup>+</sup>

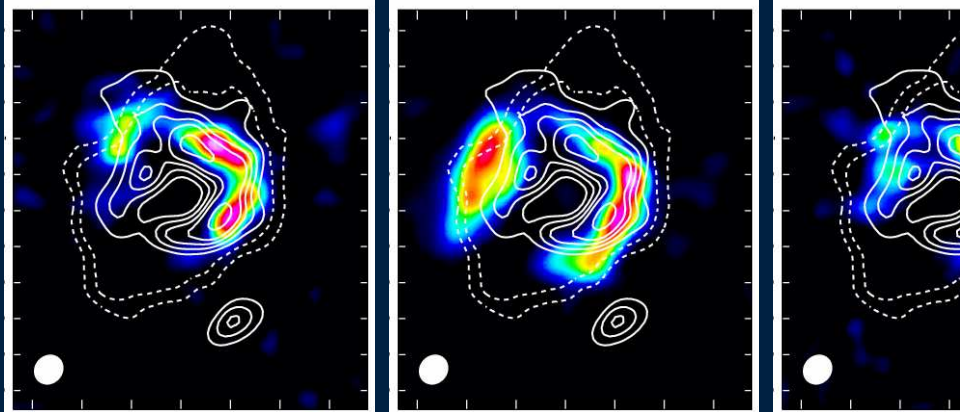


C<sup>17</sup>O



SiO

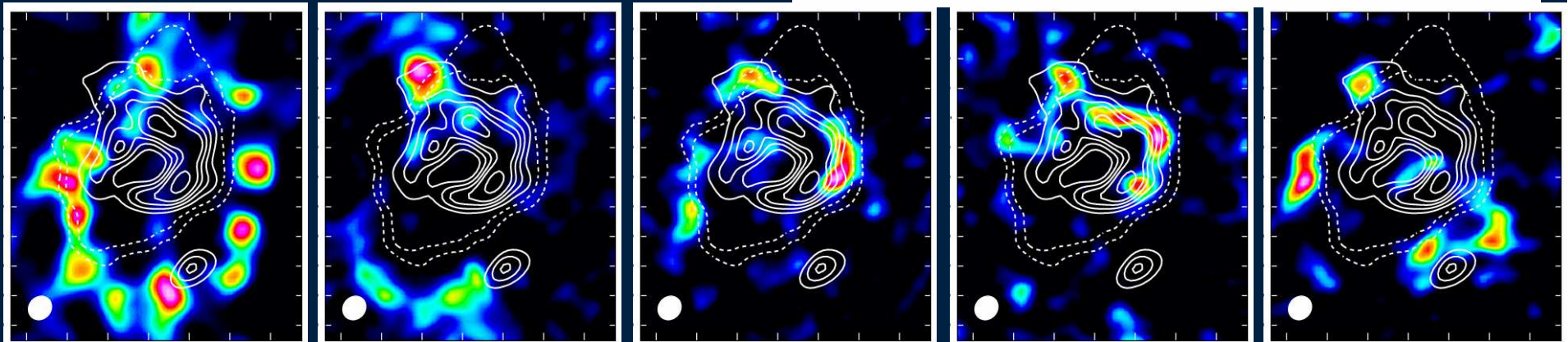
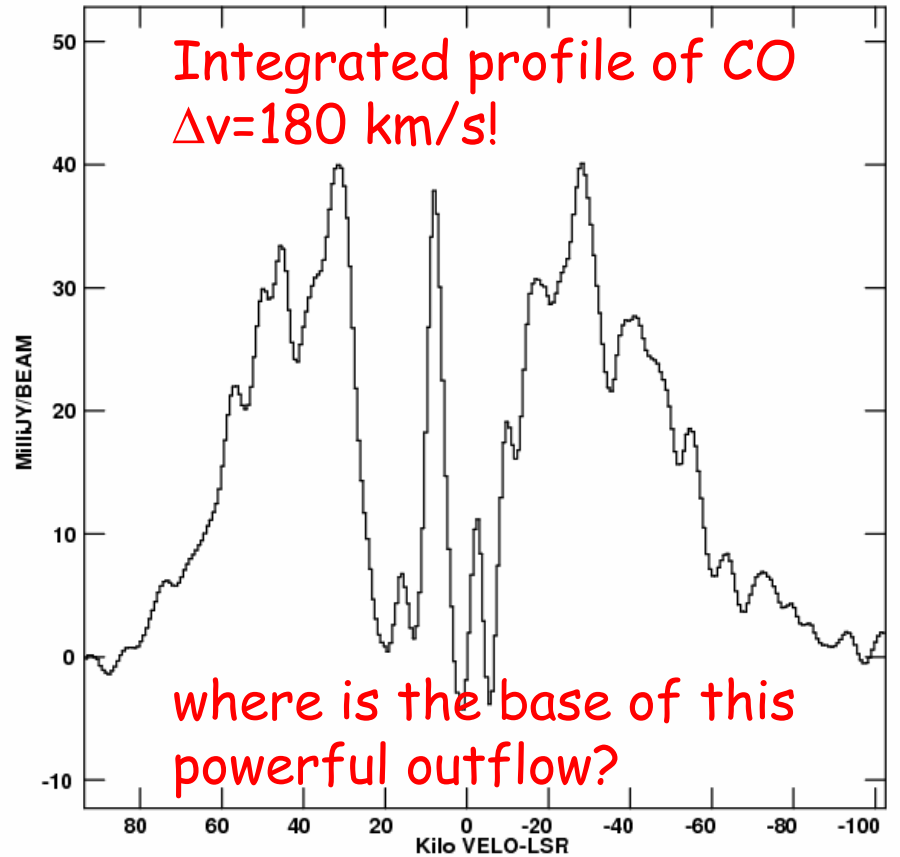
# The Complex Chem



SO

SO<sub>2</sub>

<sup>34</sup>S



CO

C<sup>34</sup>S

H<sup>13</sup>CO<sup>+</sup>

C<sup>17</sup>O

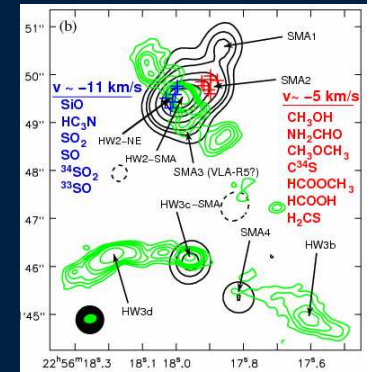
SiO



# Summary and Conclusions

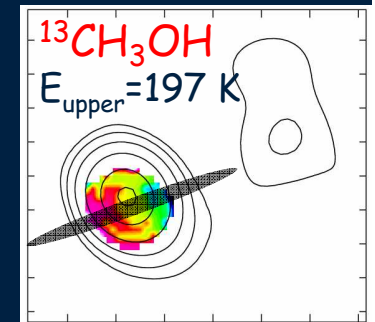
## • CephA-East

- No molecular line evidence for a disk (yet!). There are at least two hot cores and four dust cores in the vicinity of HW2.
- Analysis of many species is crucial for a complete understanding.
- Morphology of shock-tracing molecules suggest interaction at base of HW2 jet. VLA  $\text{NH}_3$  data in excellent agreement with SMA.



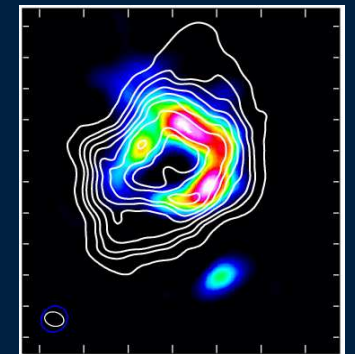
## • NGC 7538 IRS1

- Methanol kinematics confirm outflow orientation and possible disk
- Very little sulfur bearing species ( $\text{SO}_2$ ) compared to CephA



## • G5.89-0.39 - Where is the powering source?

- $875 \mu\text{m}$  continuum is mostly free-free. No point source or bipolar jet. Very little organic molecules. Not a prototypical hot core.



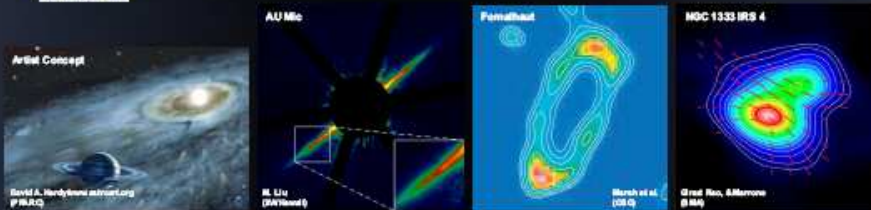
The sensitivity and resolution of ALMA will be essential to understand these chemical and evolutionary differences.



# Transformational Science with ALMA: Through Disks to Stars and Planets



June 22-24, 2007 at the North American ALMA Science  
Center of the National Radio Astronomy Observatory  
in Charlottesville, VA



## How ALMA Will Impact our Perspectives On:

- Cores, Fragmentation and the Earliest Observable Stages of Protostellar Disks
- The Disk-Envelope-Outflow Connection
- Low and High Mass Disk Structure
- Flaring, Spiral Density Waves, Turbulence, and Magnetic Fields in Protostellar Disks
- Disk Chemistry, Kinematics, Isotopic Anomalies, Grain Growth, and Sedimentation
- Debris Disks
- Planet Formation: Fragmentation and Gaps
- Synergy between ALMA and Upcoming Optical, Infrared, and Radio Facilities

### SOC:

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C. Brogan (NRAO)  
M. Hayashi (NAOJ)  
M. Hogerheijde (Leiden)  
D. Johnstone (HIA)  
Z. Li (UVa)  
L. Mundy (U. Maryland)  
J. Williams (U. Hawaii)  
A. Wootten (NRAO)

### LOC:

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J. Neighbours (NRAO)  
A. Remijan (NRAO)



<http://www.cv.nrao.edu/naasc/disk07.html>

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Web:

<http://www.cv.nrao.edu/naasc/disk07.html>

Pre-registration is now available