A Diagnostic EVLA K-band Survey of 25 Massive Protostellar Objects (and beyond)

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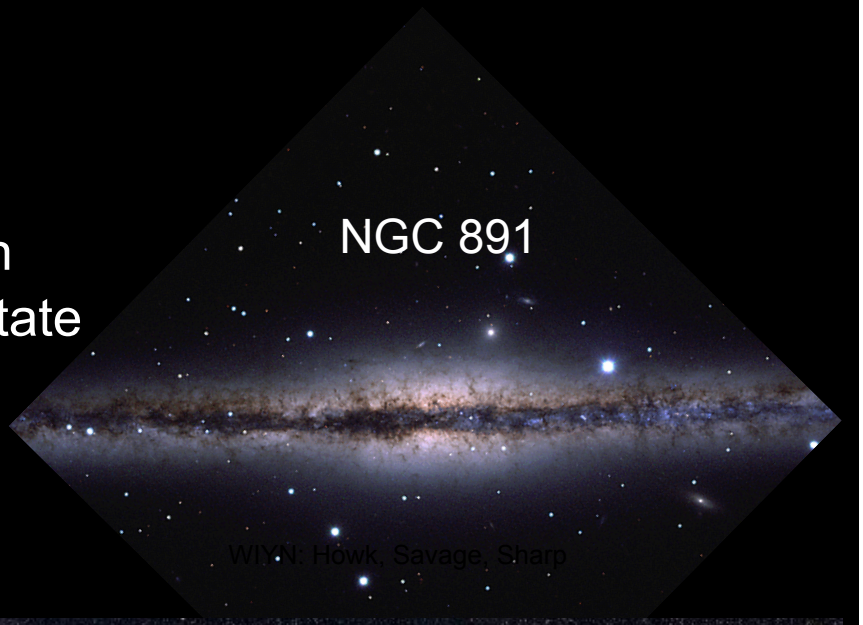
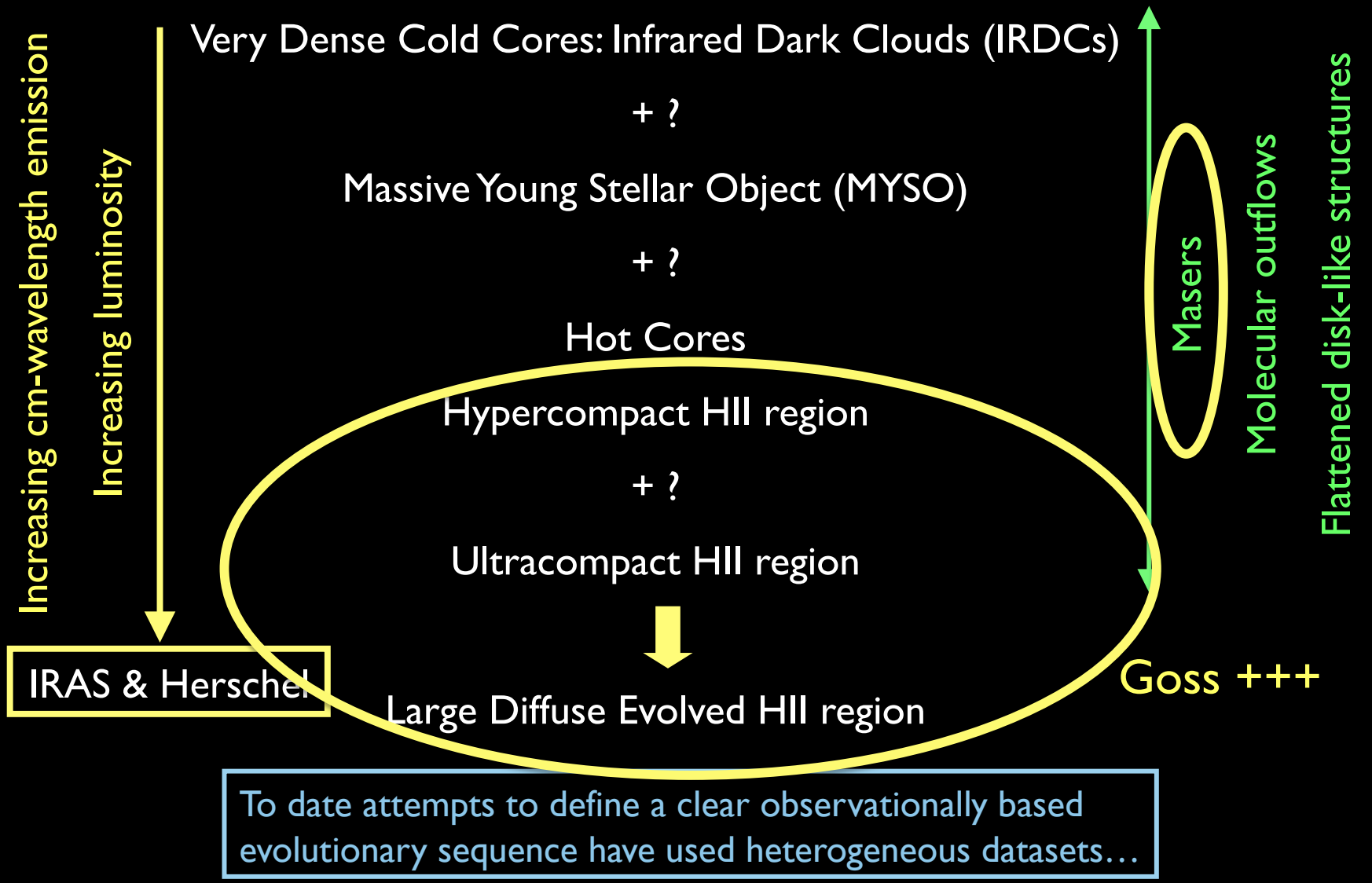
Why Is It So Challenging to Study MSF?

- Concentrated in the Galactic mid-plane towards the inner Galaxy
  - ➔ dust obscures all but longest wavelengths (> 4 μm)
- Located at large distances (> 1 kpc)
  - ➔ angular resolution a problem
- Forming in complex clustered environments
  - ➔ feedback and kinematic confusion
  - ➔ difficult to estimate evolutionary state



A Sort of Sequence with Many Caveats

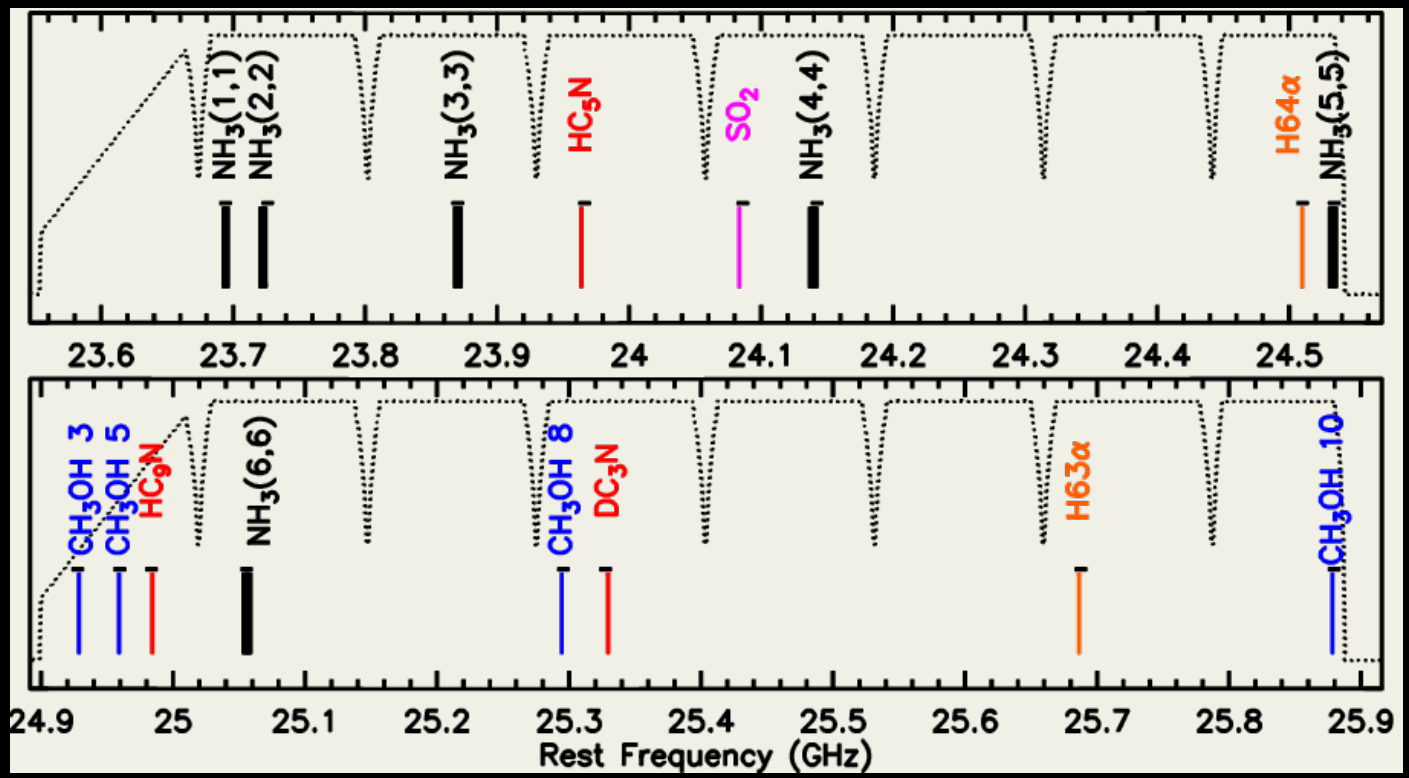


To date attempts to define a clear observationally based evolutionary sequence have used heterogeneous datasets…

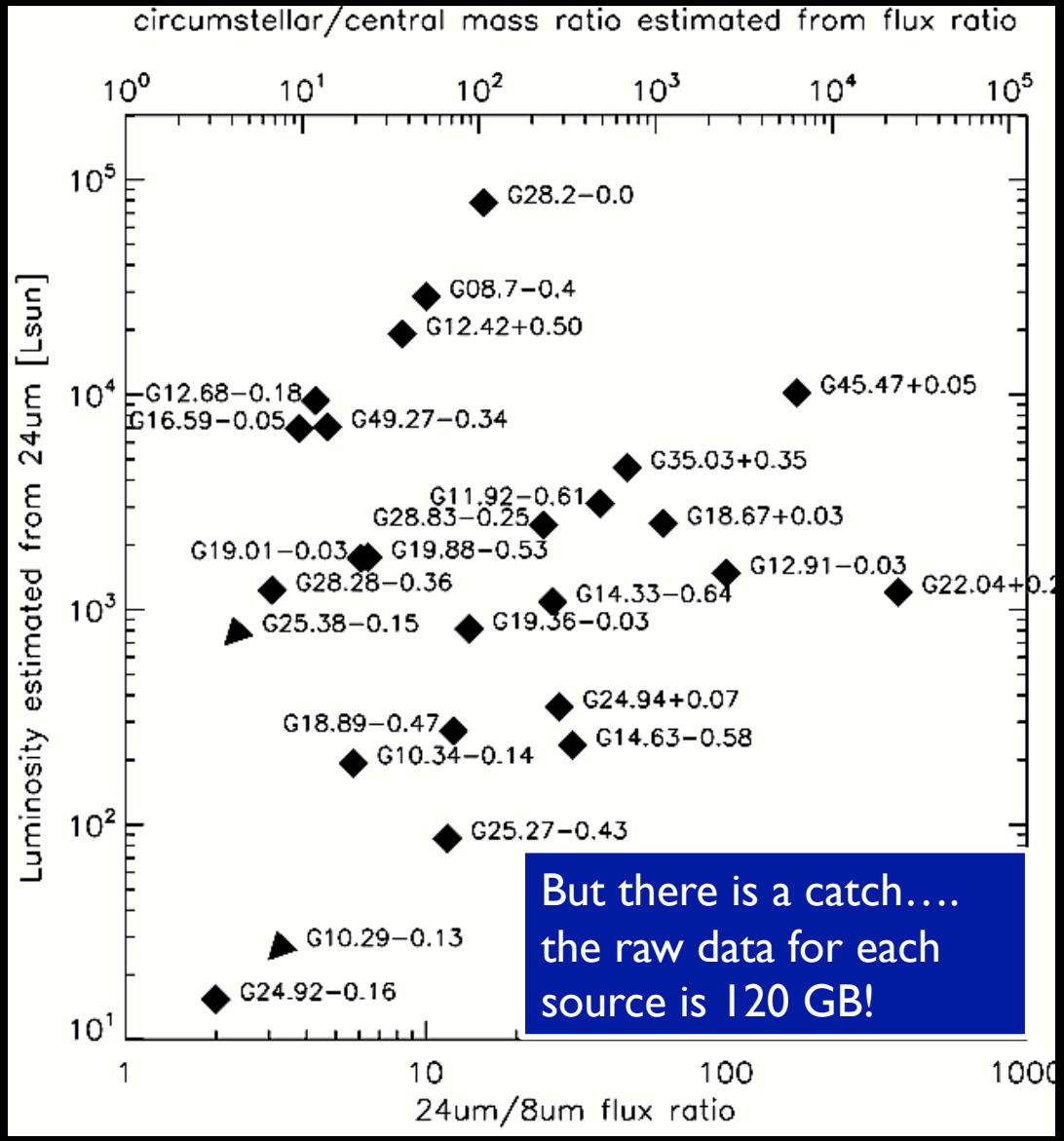
WIDAR Allows us to Observe Many Diagnostic Tracers Simultaneously!

16 x 8 MHz subbands with 0.4 km/s channels

- NH_3 1,1 to 6,6 (Temperature, density, and kinematics)
- CH_3OH, SO_2 (Masers and hot core tracer)
- HC_5N, DC_3N (Trace formation history of gas)
- 2 Radio Recombination Lines (Kinematics of ionized gas)
- Decent continuum bandwidth from line-free regions (Ionized gas)



The Sample & Data

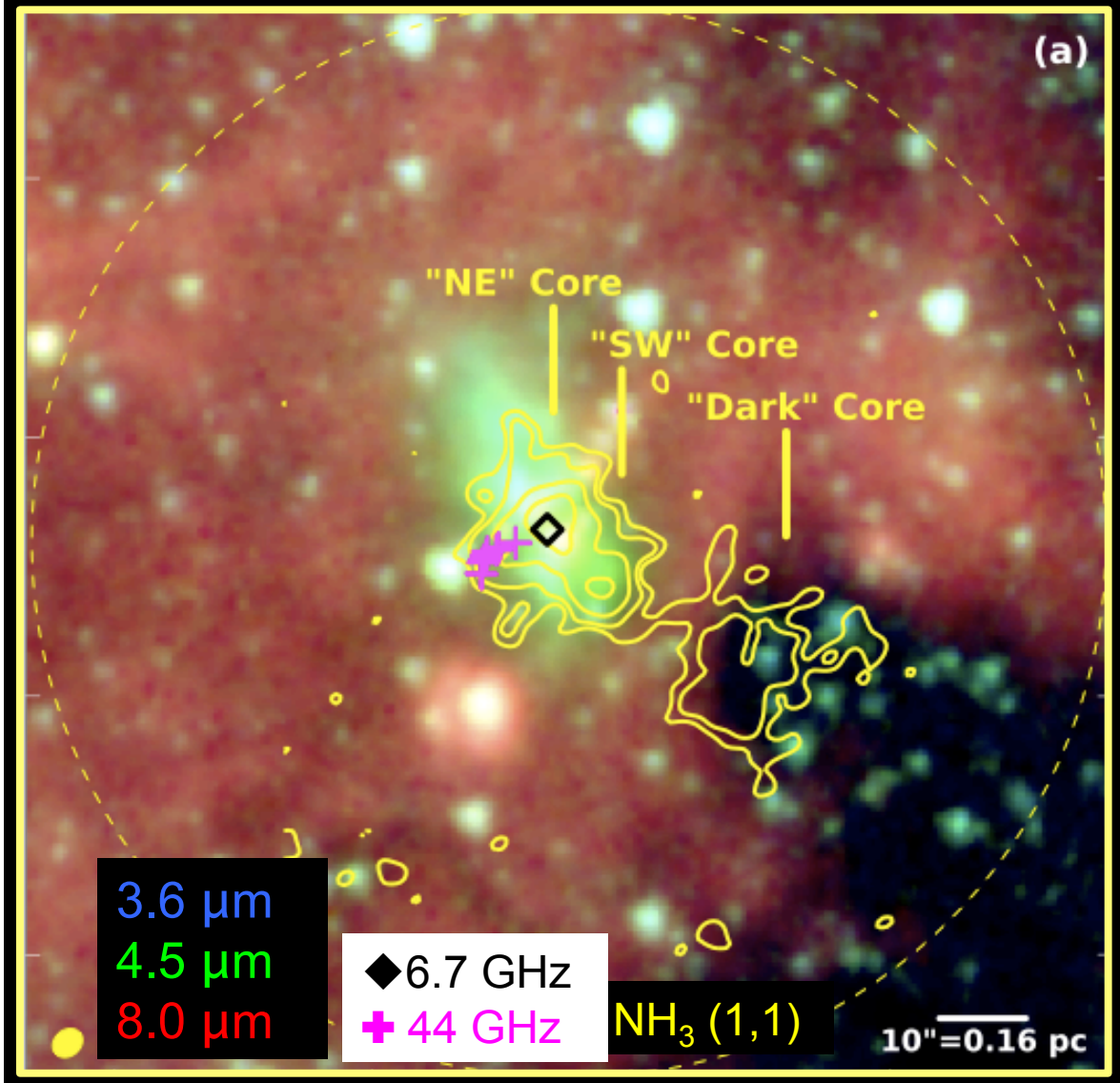


24 Targets

- Range in distance from 2-6 kpc
- Span wide range in luminosity and M_{core}/M_*
  - IRDCs (Infrared Dark Clouds)
  - EGOs (Extended Green Objects; Cyganowski et al. 2008); e.g. MYSO candidates
  - A few known HCHII, and UCHII regions

- 3.5 hour tracks
- 2' primary beam
- Resolution ~10,000 AU

G35.03+0.35 (D ~ 3.4 kpc)



"Extended Green Object" with strong 6.7 GHz (massive star formation) and 44 GHz (outflow tracer) methanol masers (Cyganowski et al. 2008; 2009)

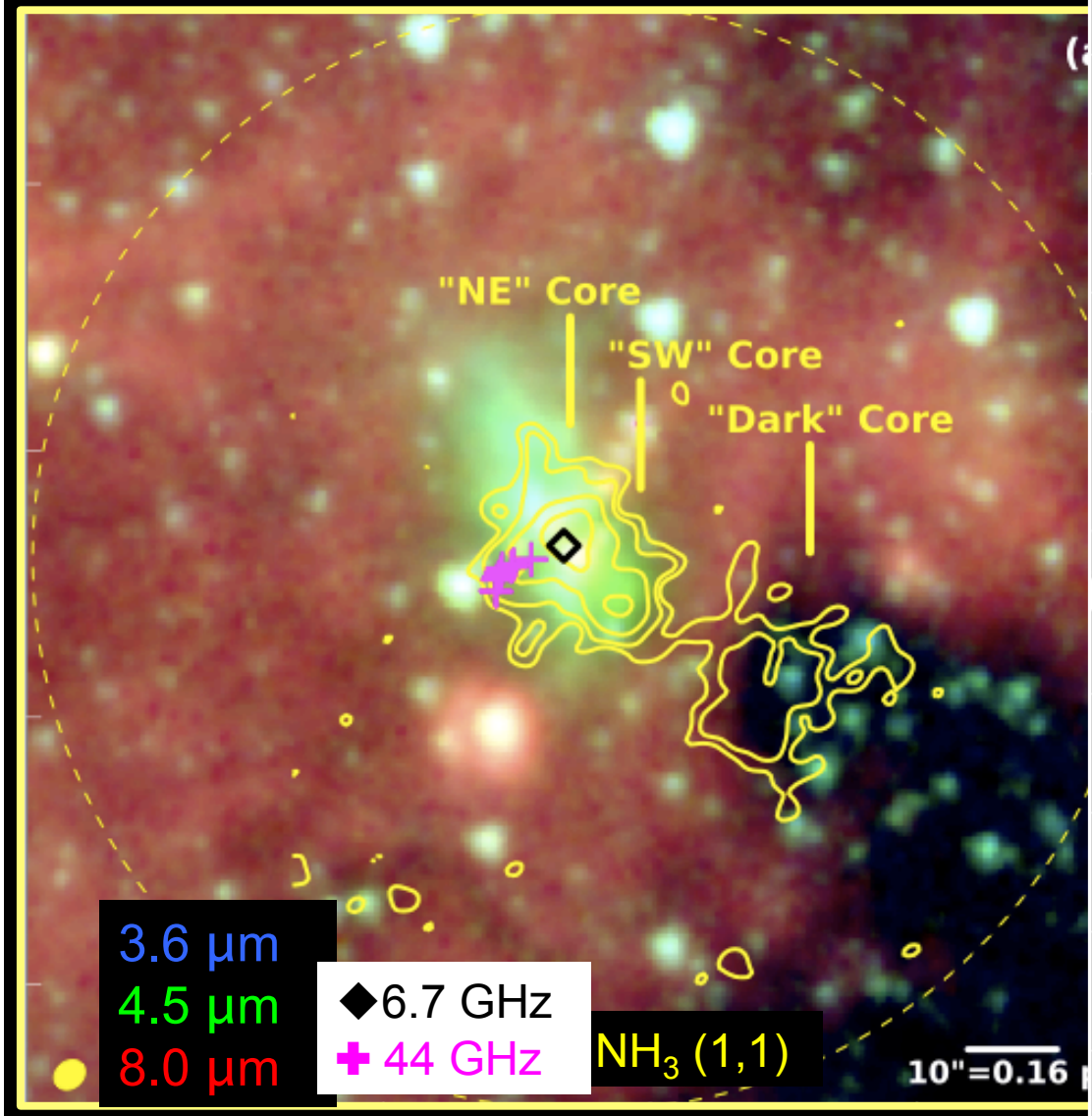
3 NH_3 (1,1) cores detected toward the EGO and nearby IRDC

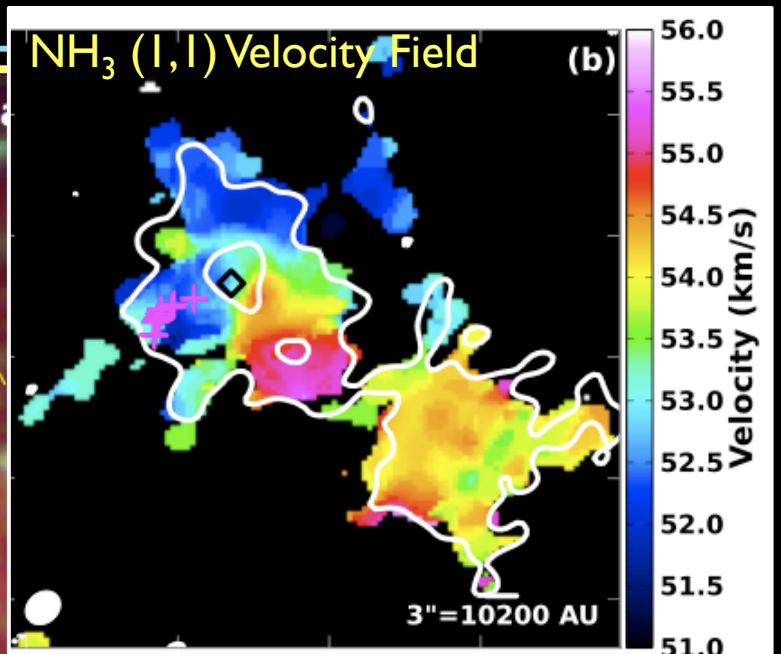
@25K; $Mass_{gas}$ ~ 350 $M_\odot$ (BGPS)

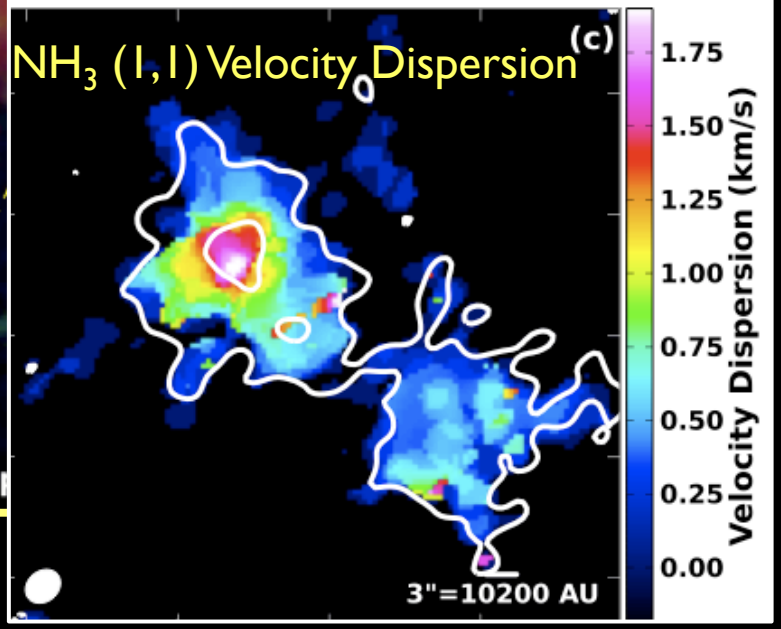
Resolution: 3.7" x 3.0" (~11,000 AU)

Brogan et al. (2011; ApJL Special issue)

G35.03+0.35 Kinematics

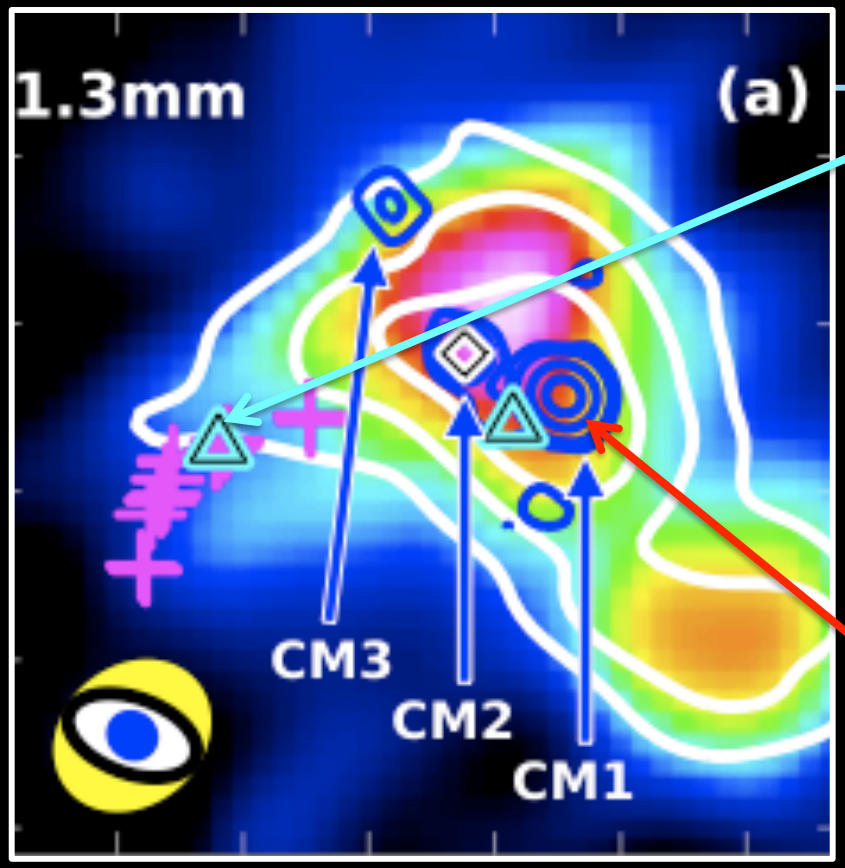


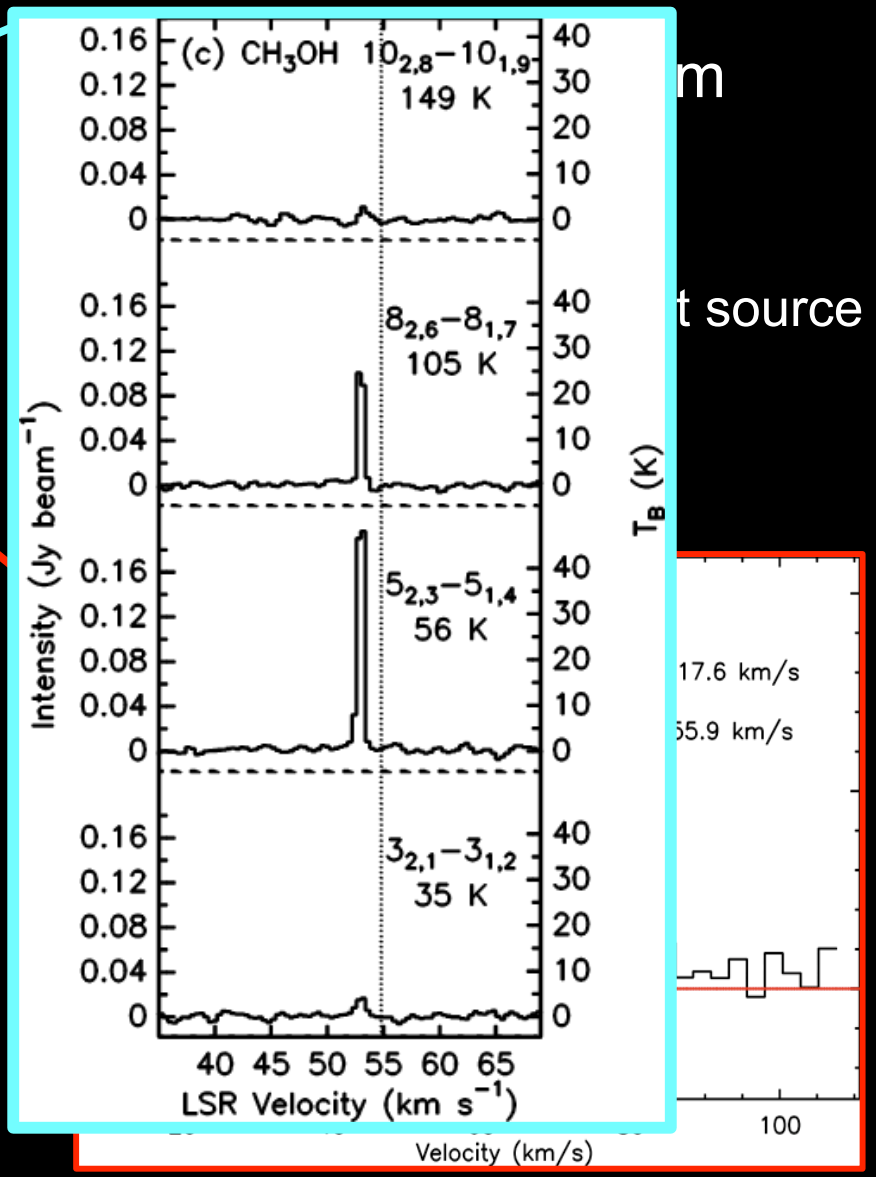




Resolution: 3.7" x 3.0" (~11, 000 AU)

G35.03+0.35 Zoom





NH_3 (1,1) (colorscale)
SMA 1.3 mm Continuum
VLA 3.6 cm continuum

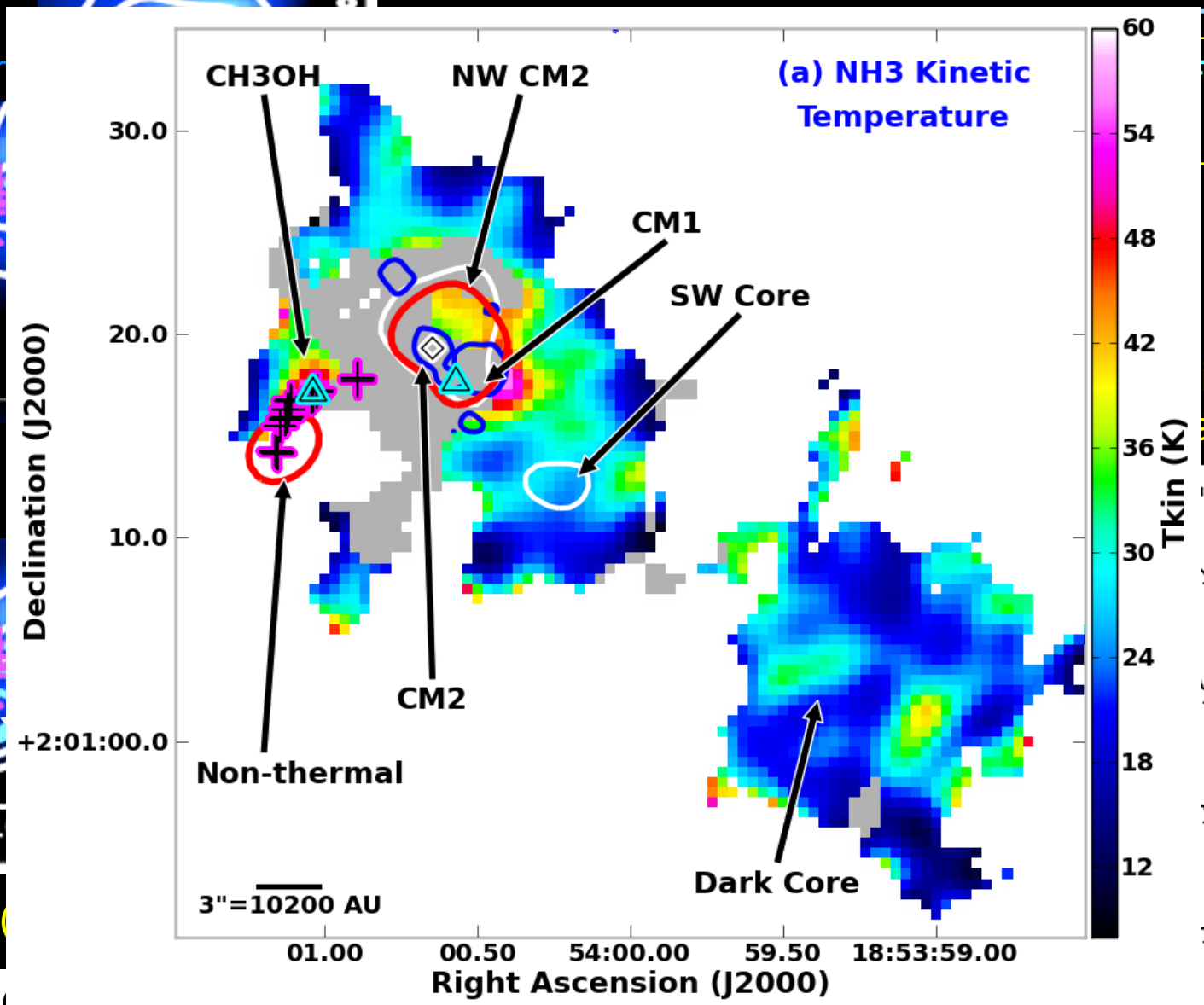
Methanol masers
◆6.7 GHz
✚ 44 GHz
Δ 25 GHz

G35.03+0.35 Temperatures

NH_3 (2,2)
3.6 cm
continuum

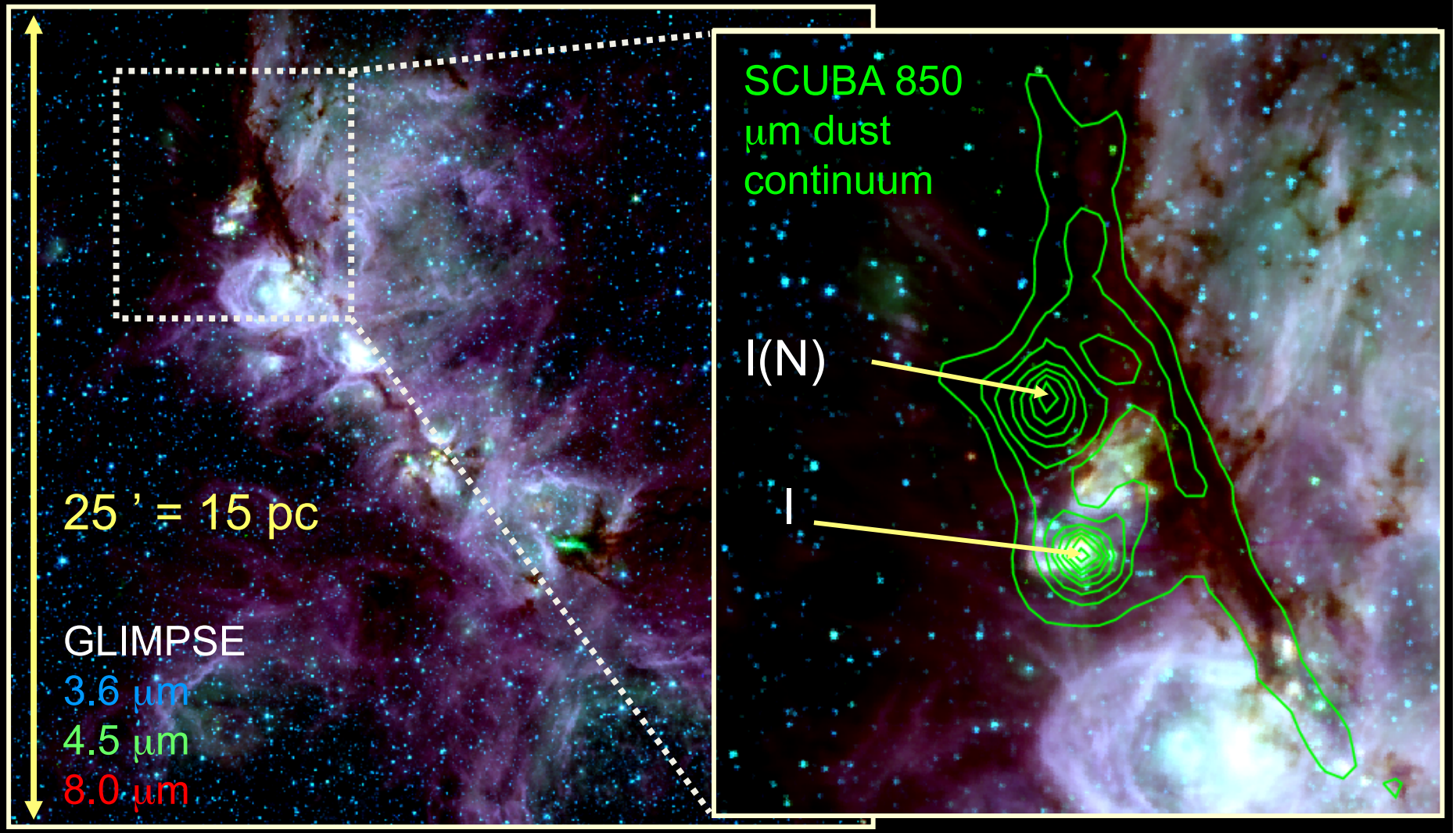
NH_3 (3,3)
NH_3 (6,6)

NH_3 (



◆6.7 GHz
✚ 44 GHz

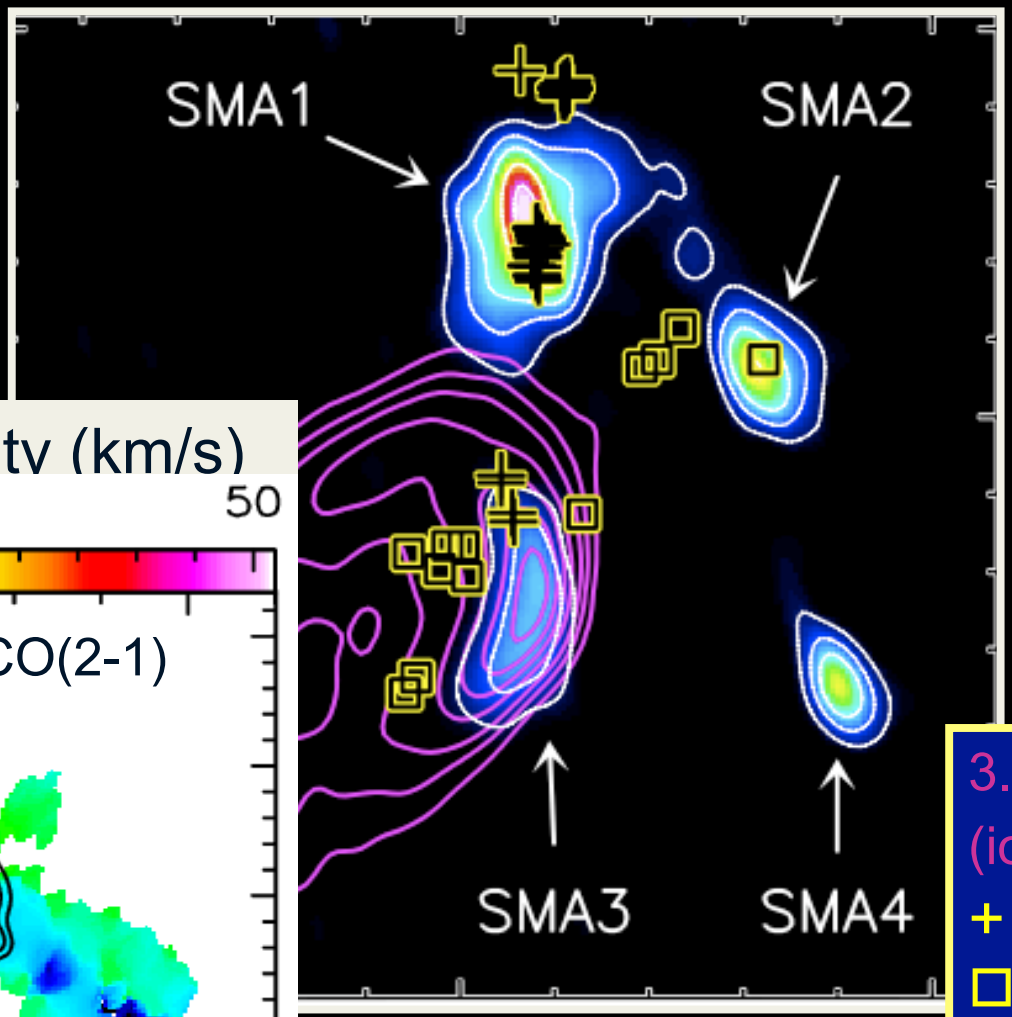
The NGC6334 Star Forming Complex

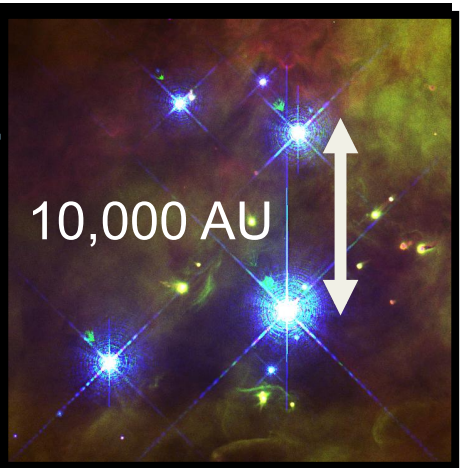


- Distance ~ 1.7 kpc
- NGC 6334 I luminosity $3 \times 10^5 L_\odot$, I(N) two orders of magnitude less
- Based on infrared, I(N) is probably less evolved than I

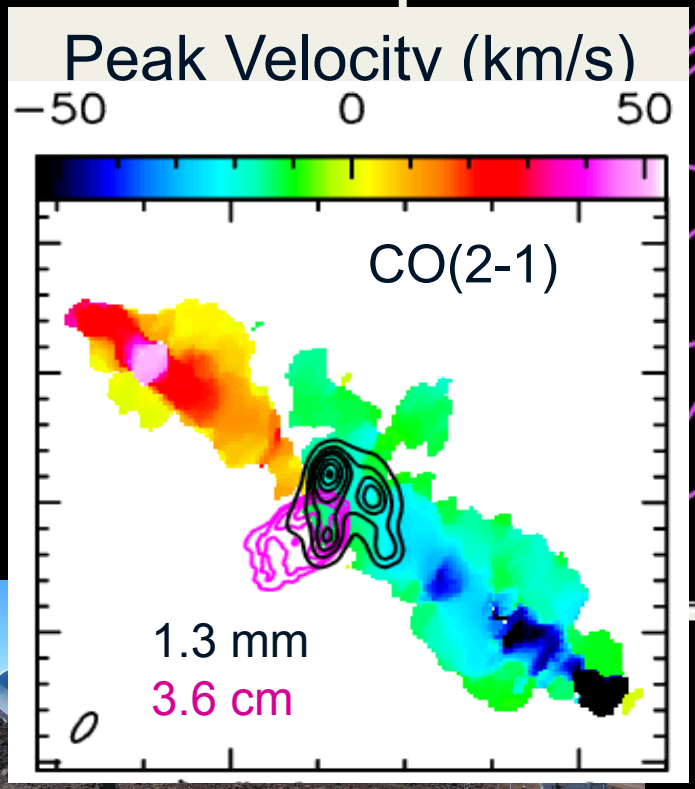
NGC6334I Protocluster: Warm Dust Around 4 Massive Protostars

SMA 1.3 mm Continuum
Resolution:
0.”8 x 0.”4
1400 x 700 AU





6”= 10,000 AU

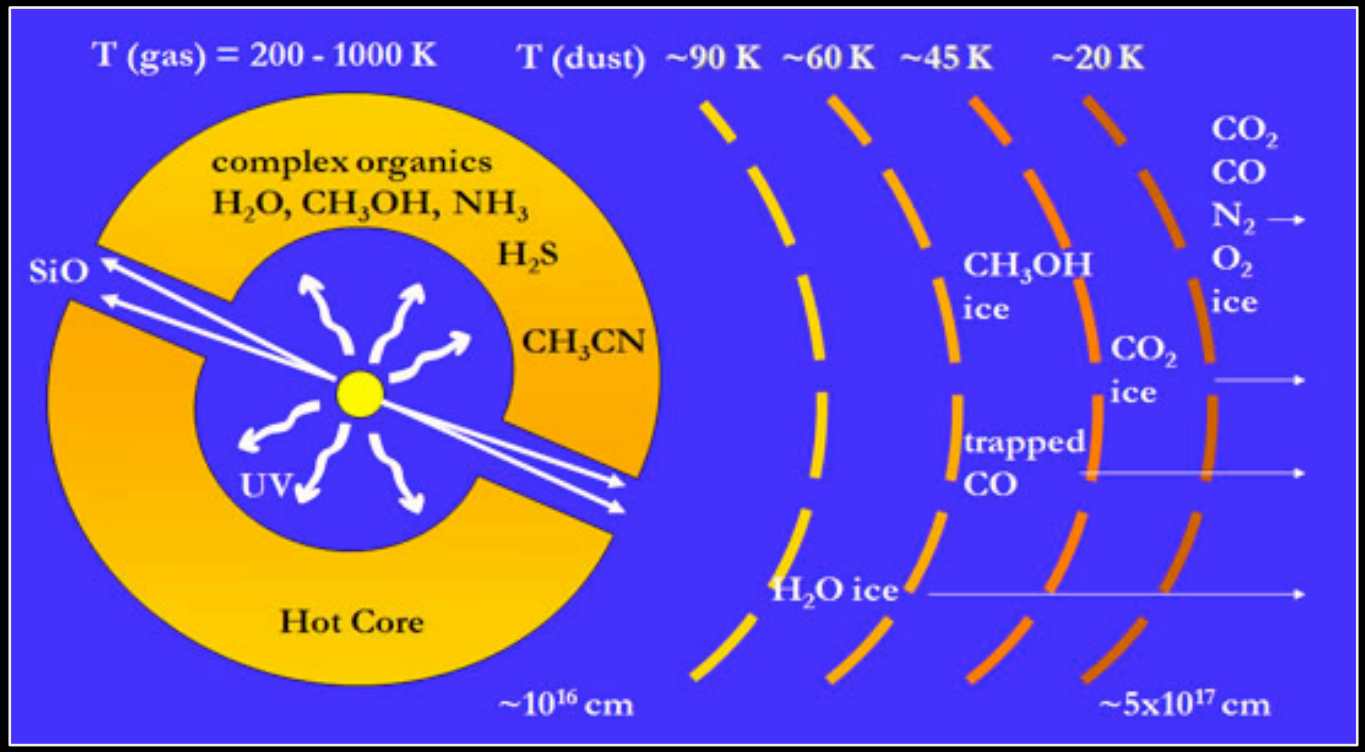


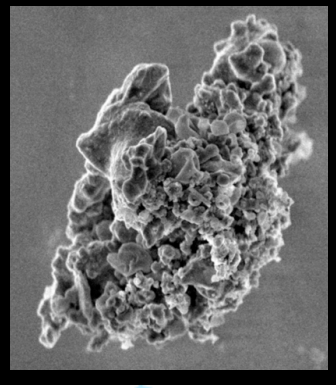
3.6 cm continuum (ionized gas)
+ H_2O masers
□ 6.7 GHz methanol masers (Norris et al. 1993)

Hunter et al. (2006)
Brogan & Hunter in prep.

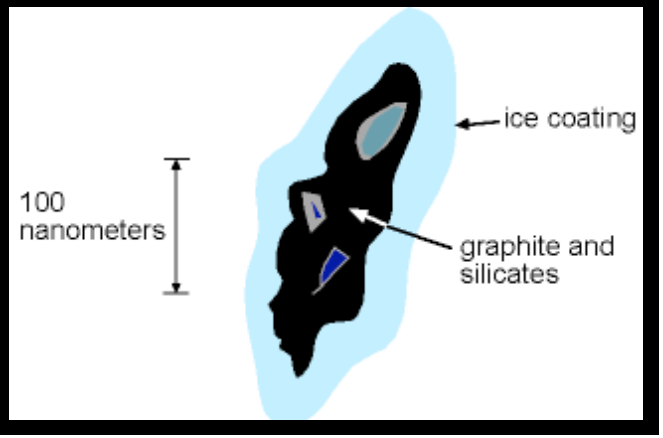
"Hot Cores" around Massive Protostars

Van Dishoeck & Blake (1998)

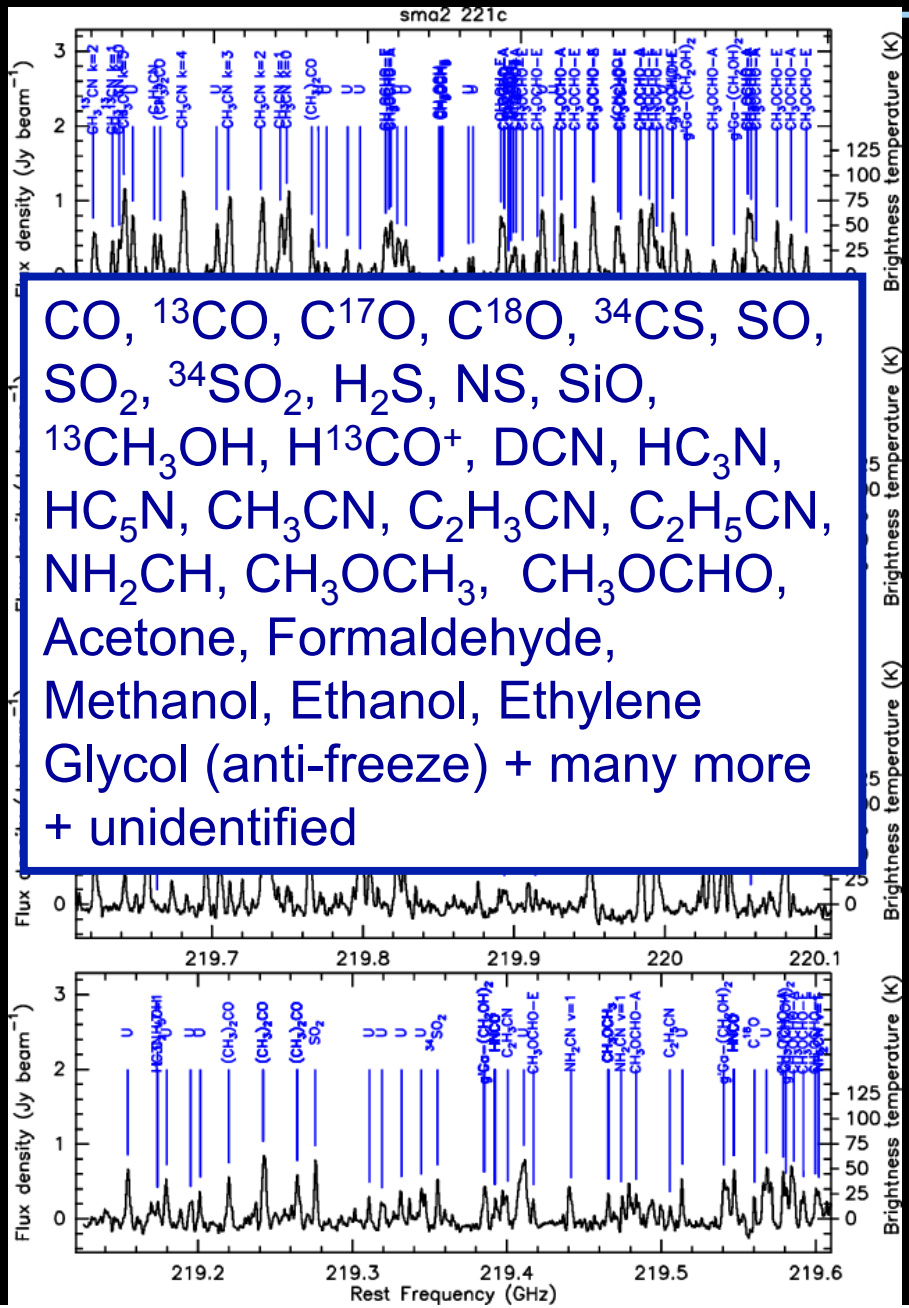




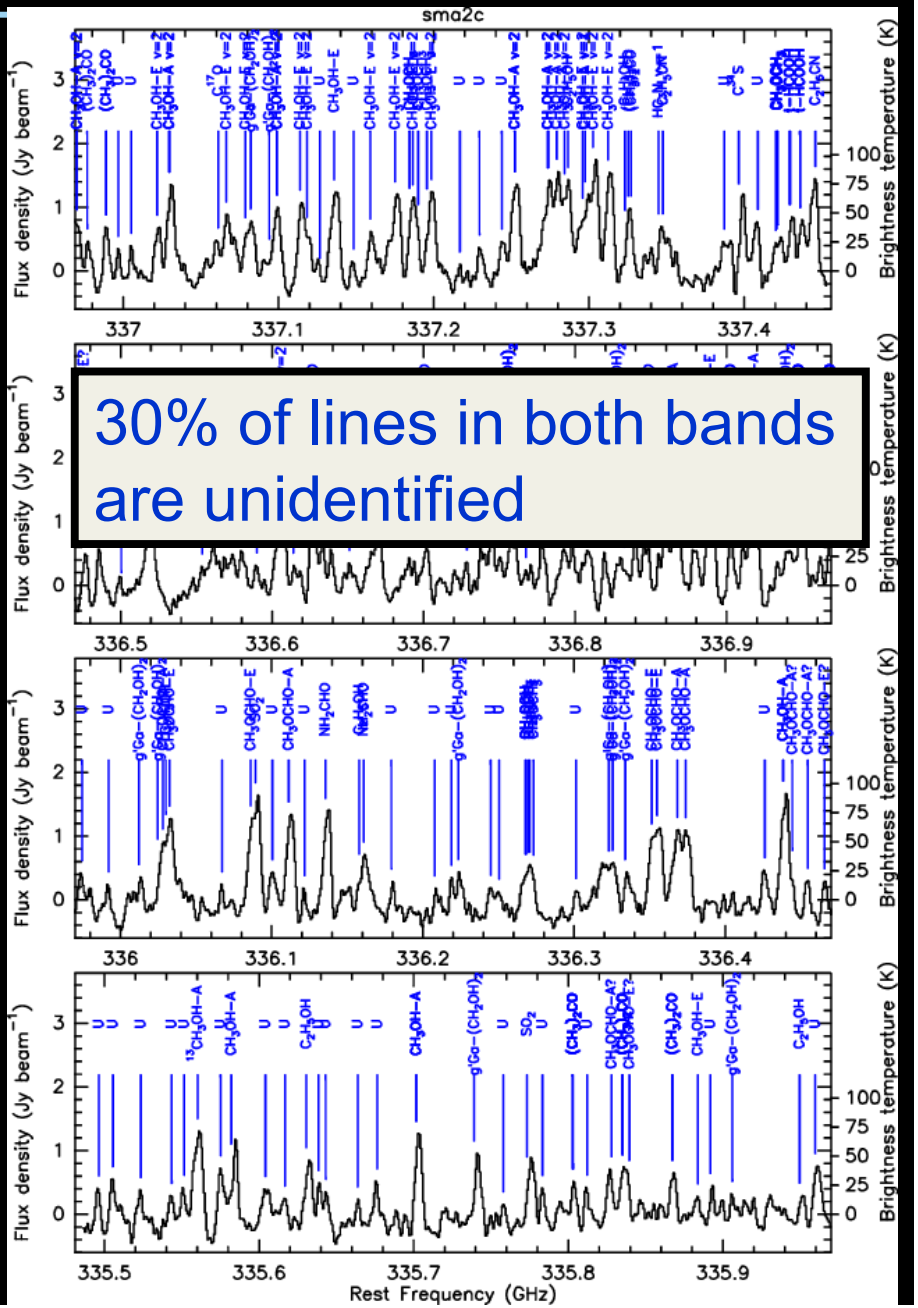
- Dust grain ice mantles melt
- High temperature combined with newly liberated material drive copious organic chemistry
- Can only be observed at small spatial scales (beam dilution)



Now That's a Hot Core! (SMA 1.3 and 0.87 mm)

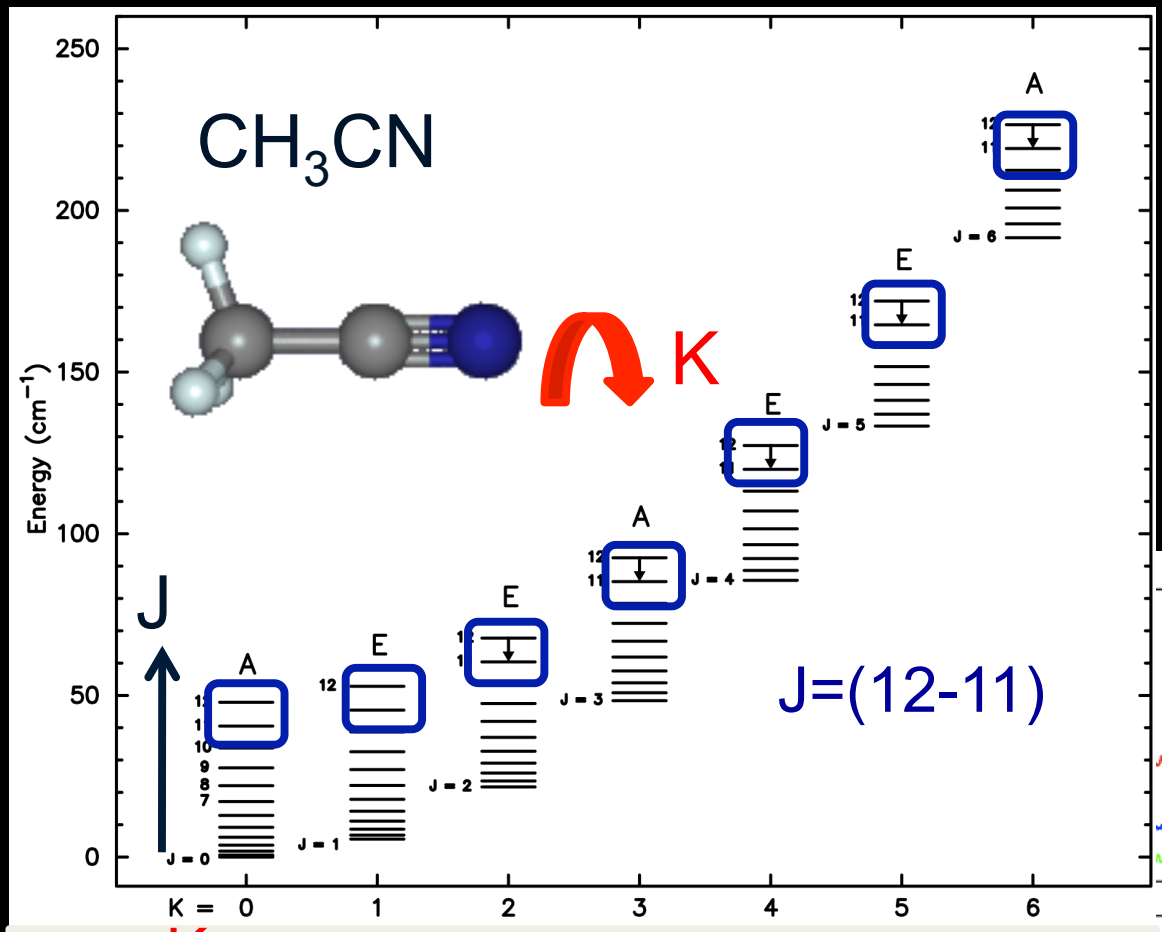


CO, ^{13}CO, C^{17}O, C^{18}O, ^{34}CS, SO, SO_2, $^{34}SO_2$, H_2S, NS, SiO, $^{13}CH_3OH$, $H^{13}CO^+$, DCN, HC_3N, HC_5N, CH_3CN, C_2H_3CN, C_2H_5CN, NH_2CH, CH_3OCH_3, CH_3OCHO, Acetone, Formaldehyde, Methanol, Ethanol, Ethylene Glycol (anti-freeze) + many more + unidentified

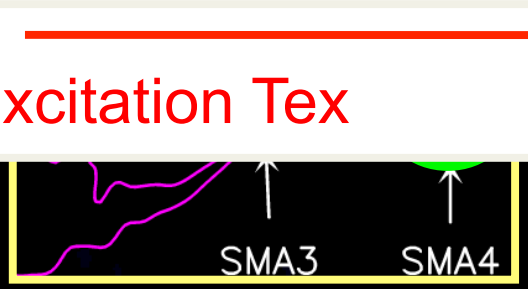


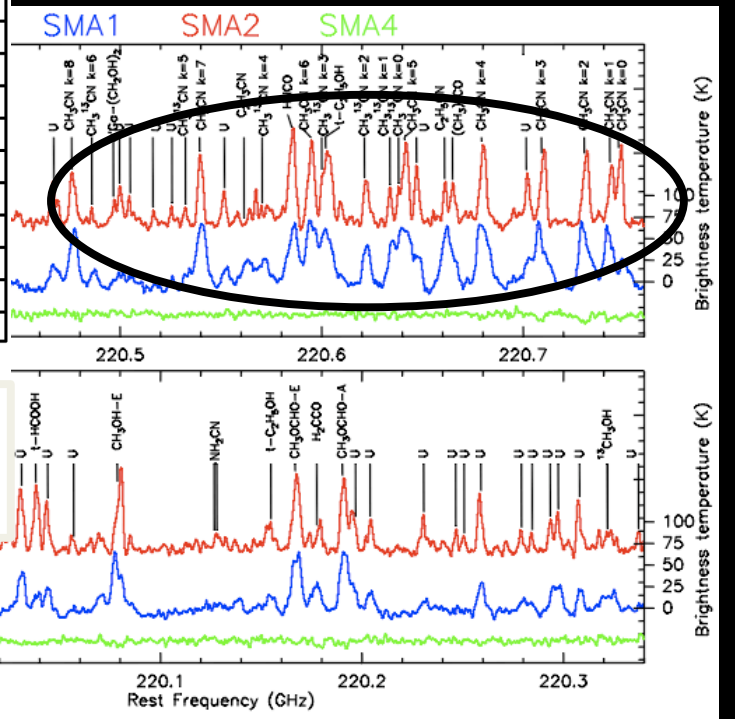
30% of lines in both bands are unidentified

Hot Core Line Emission

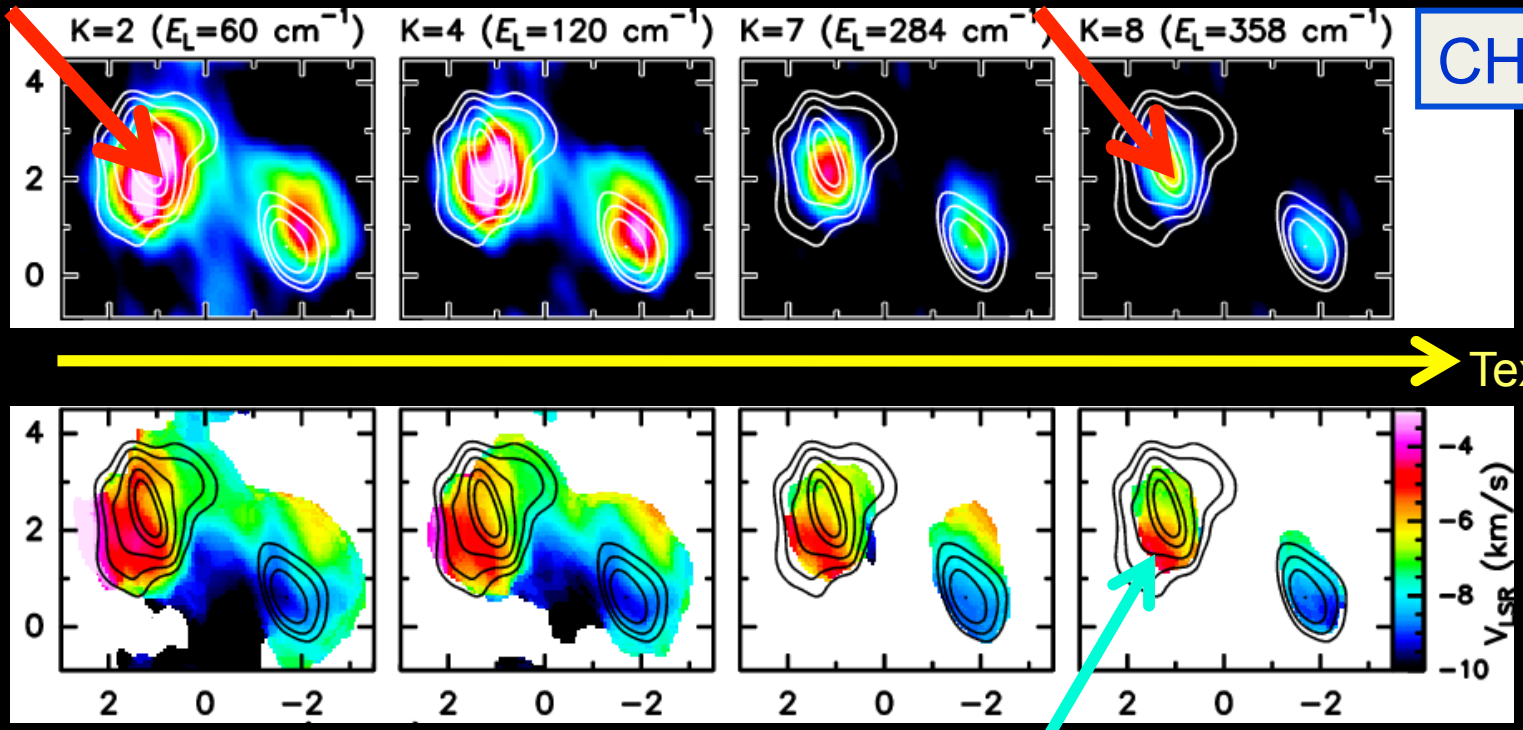


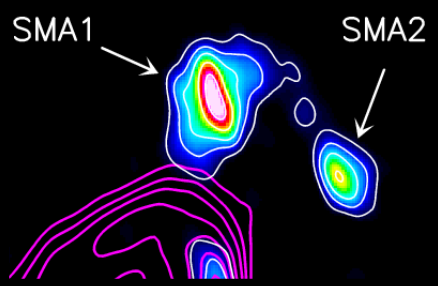
- SMA4 Strangely devoid of line emission
- Chemical diversity only 4000 AU apart





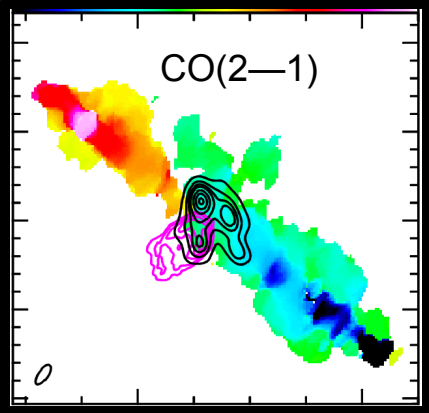
Zooming in on SMA1 and SMA2 in Methyl Cyanide



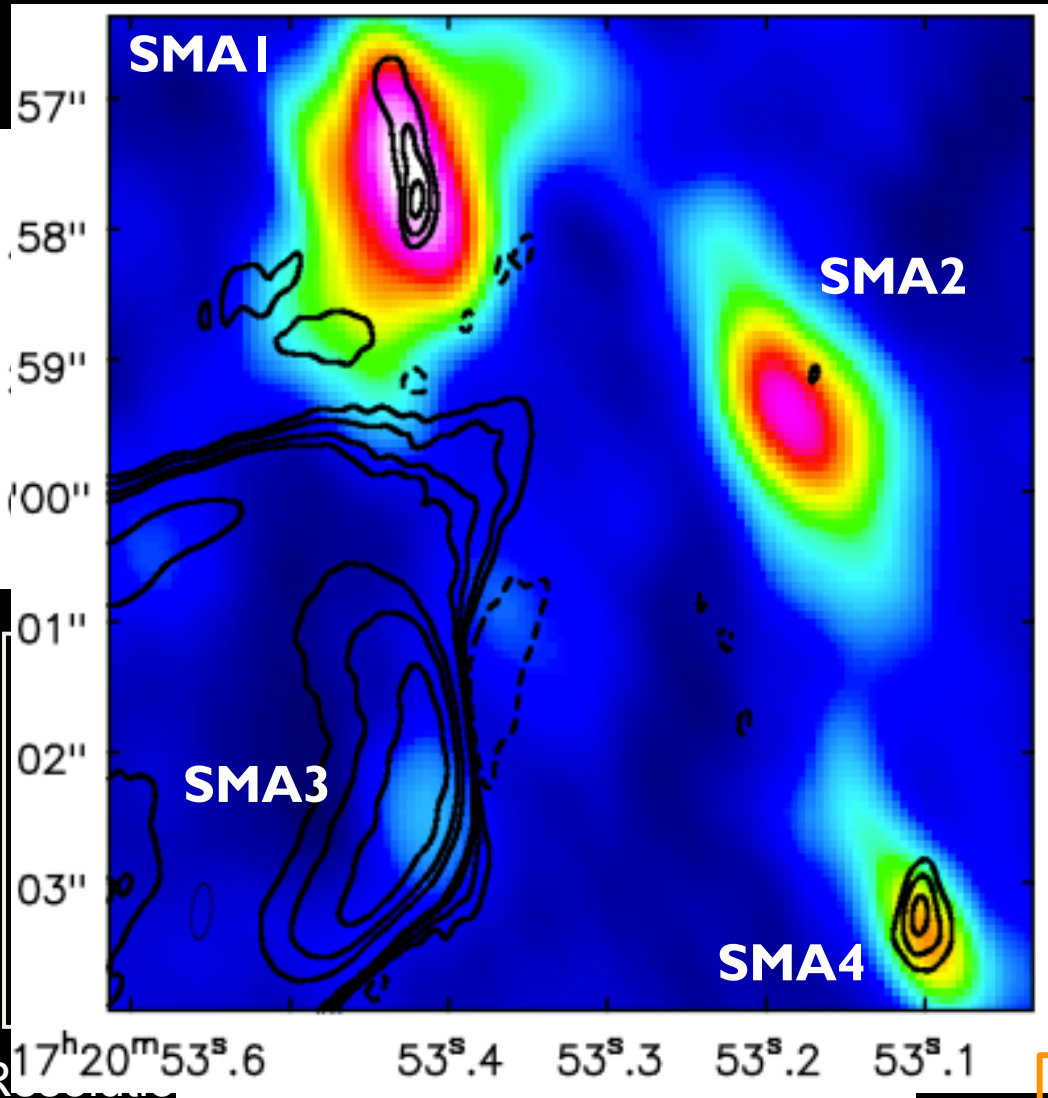


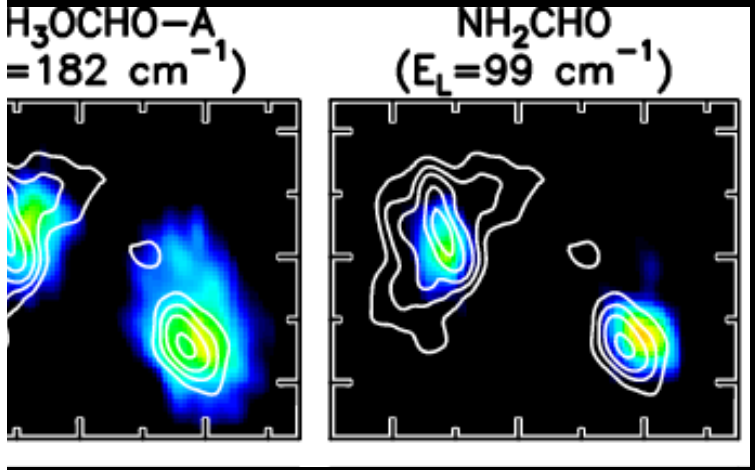
1.3 mm continuum

- Morphology vs. line excitation temperature (Tex) suggests central heating
- The gas temperatures are about 125 K
- SMA1 shows SE/NW velocity gradient and is perpendicular to the outflow



SMA NGC6334 I Continuum and Lines at 870 μm





peak on SMA1 or SMA2
m peak ⇨ continuum opacity
too high

T_{dust}=125 K, τ_{dust} ~ 1 at 870 μm

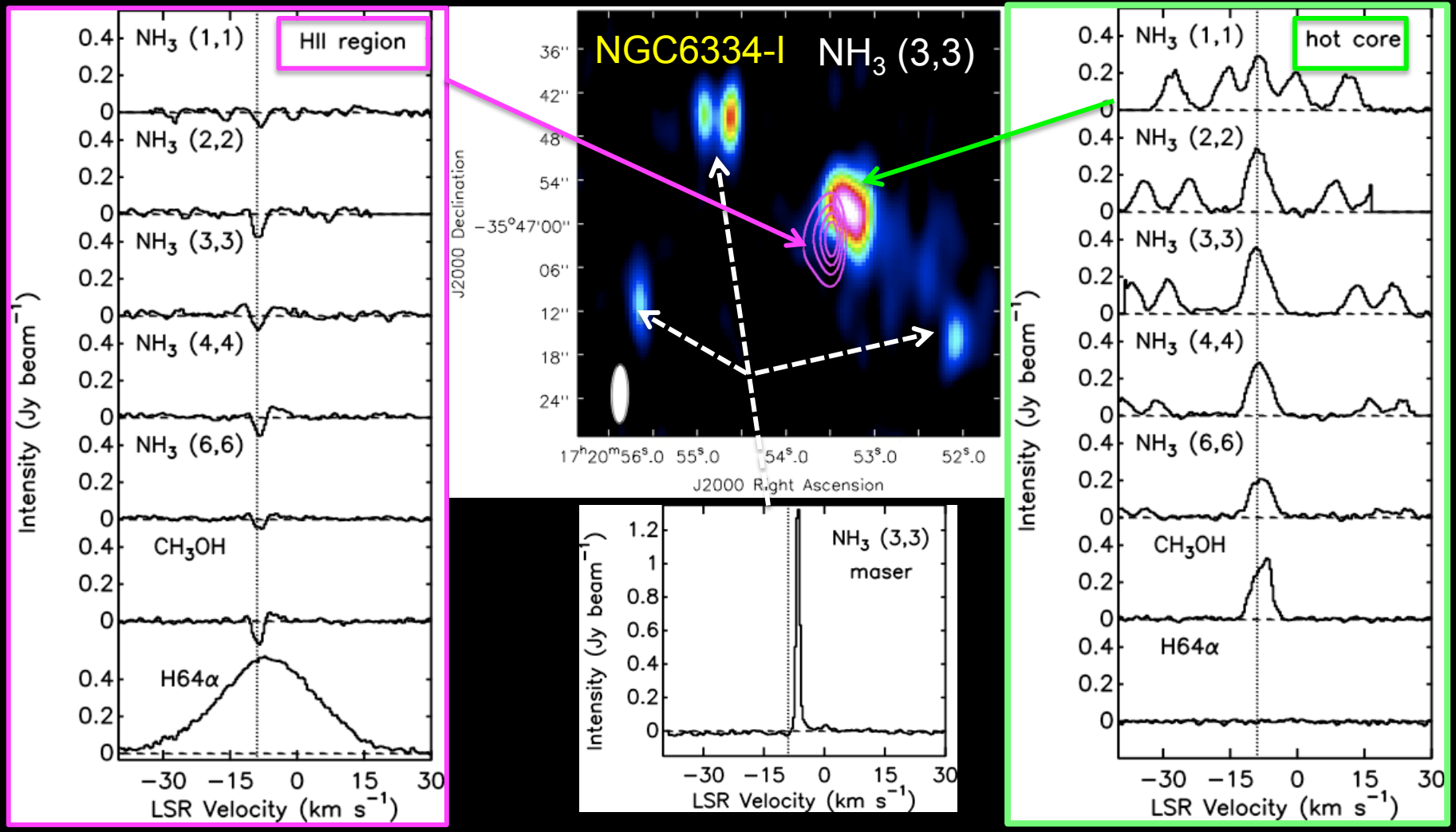
SMA 870 μm (0.8" x 0.4")

EVLA 7 mm (0.4" x 0.15")

Coming soon…. NH_3 emission with this angular resolution

Early Test Result: NGC6334I

- Protocluster with 2 hot cores and an ultracompact HII region at D~1.6 kpc
- 10-minutes on-source
- Used 8 narrow (8 MHz) sub-bands



Cheers Miller, and Happy Birthday

THANK YOU for all the help, friendship, collaborations, yummy dinners, and laughs. I promise (really) to finish that W51B paper soon …☺

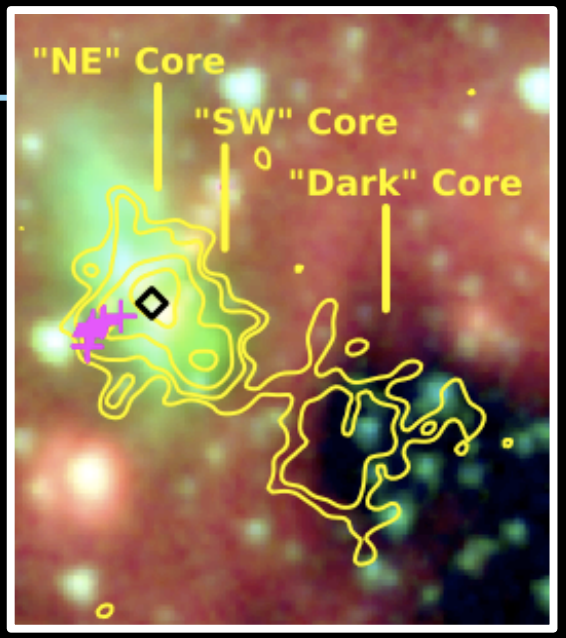
Summary

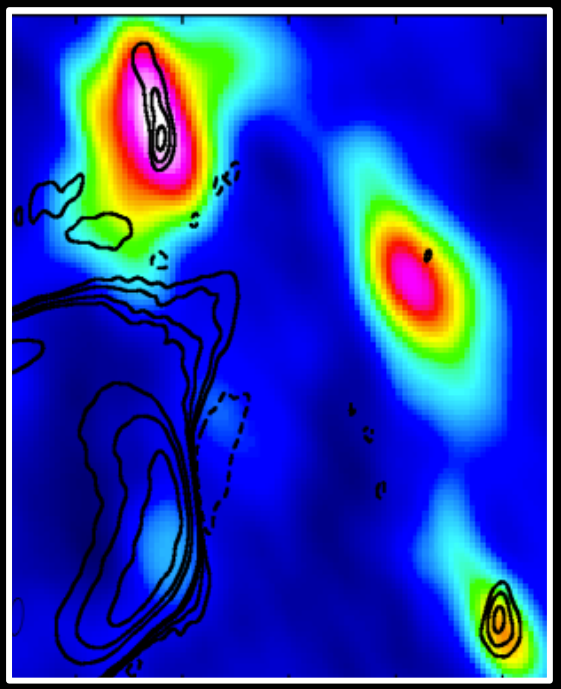
- WIDAR provides powerful new capability for simultaneous diagnostic spectroscopic observations of massive protostars/protoclusters

- Early results are showing incredible complexity:
  - Temperatures
  - Kinematics
  - Shocks
  - Continuum properties
  - Masers

- ALMA will provide amazing new views of molecular gas around MYSOs, but EVLA critical to reveal optically thick interiors

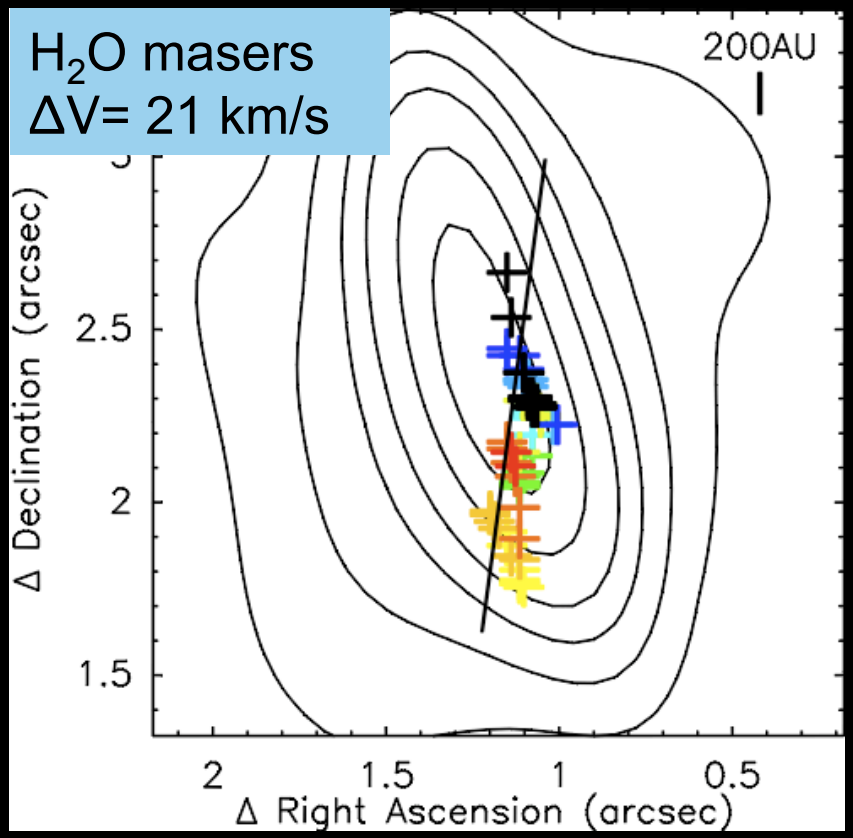
- ALMA Cycle 0 proposal deadline June 30!



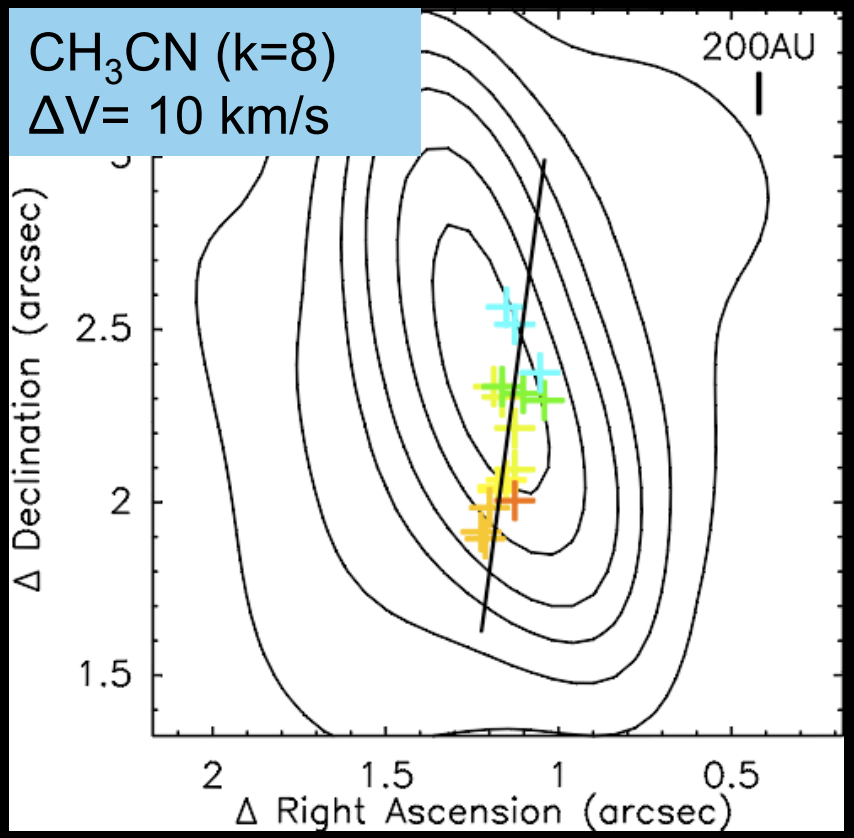


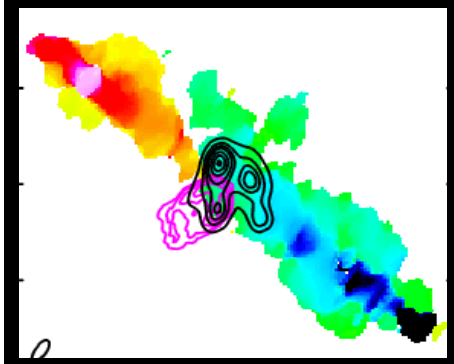
SMA1 Velocity Gradient = Disk(ish) Rotation?

H_2O masers
ΔV= 21 km/s



CH_3CN (k=8)
ΔV= 10 km/s





IF we assume Keplerian rotation and the full velocity width, the enclosed mass is ~ 20 - 40 $M_\odot$

	T_{dust}(K)	$M_{gas}(M_\odot)$
SMA1	85-150	45-13

Gas reservoir on small sizescales