A Diagnostic EVLA K-band Survey of 25 Massive Protostellar Objects

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How Do Massive Stars Form?

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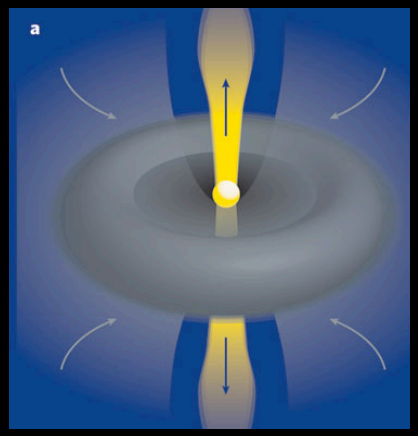
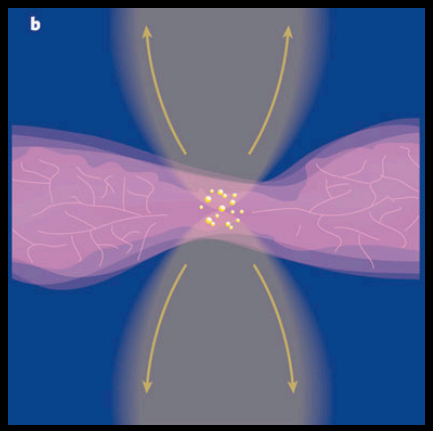
Its difficult to determine observationally because massive stars are:

- At large distances (> 1 kpc)
- Very deeply embedded during earliest phases (obscured shortward of mid-IR)
- Forming in clusters

0.1 pc ~20,000 AU



Low Mass



High Mass

- Catch them while they are young
- Develop observation-based evolutionary sequence
- Understand role of cluster feedback

A Sort of Sequence with Many Caveats

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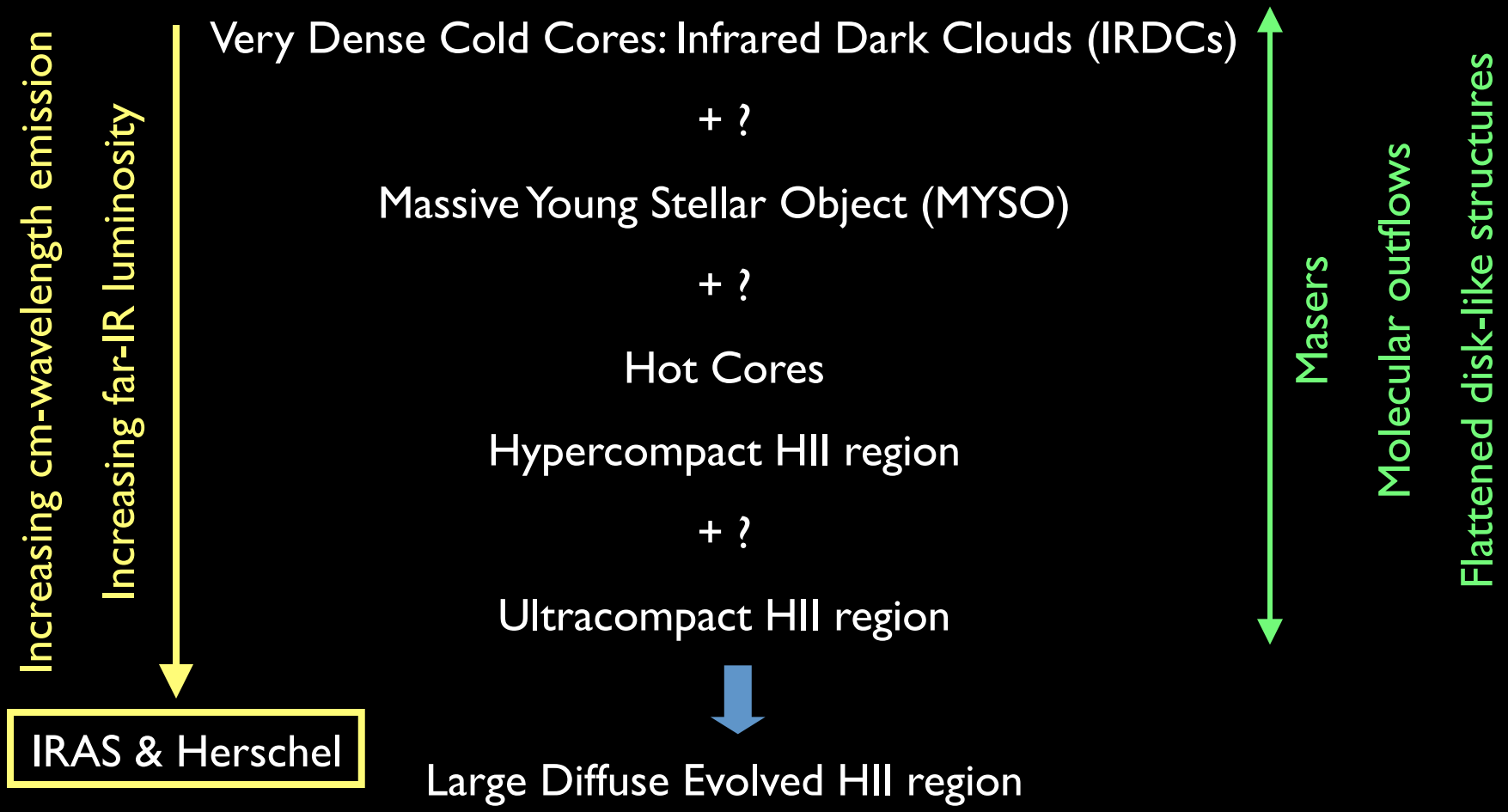


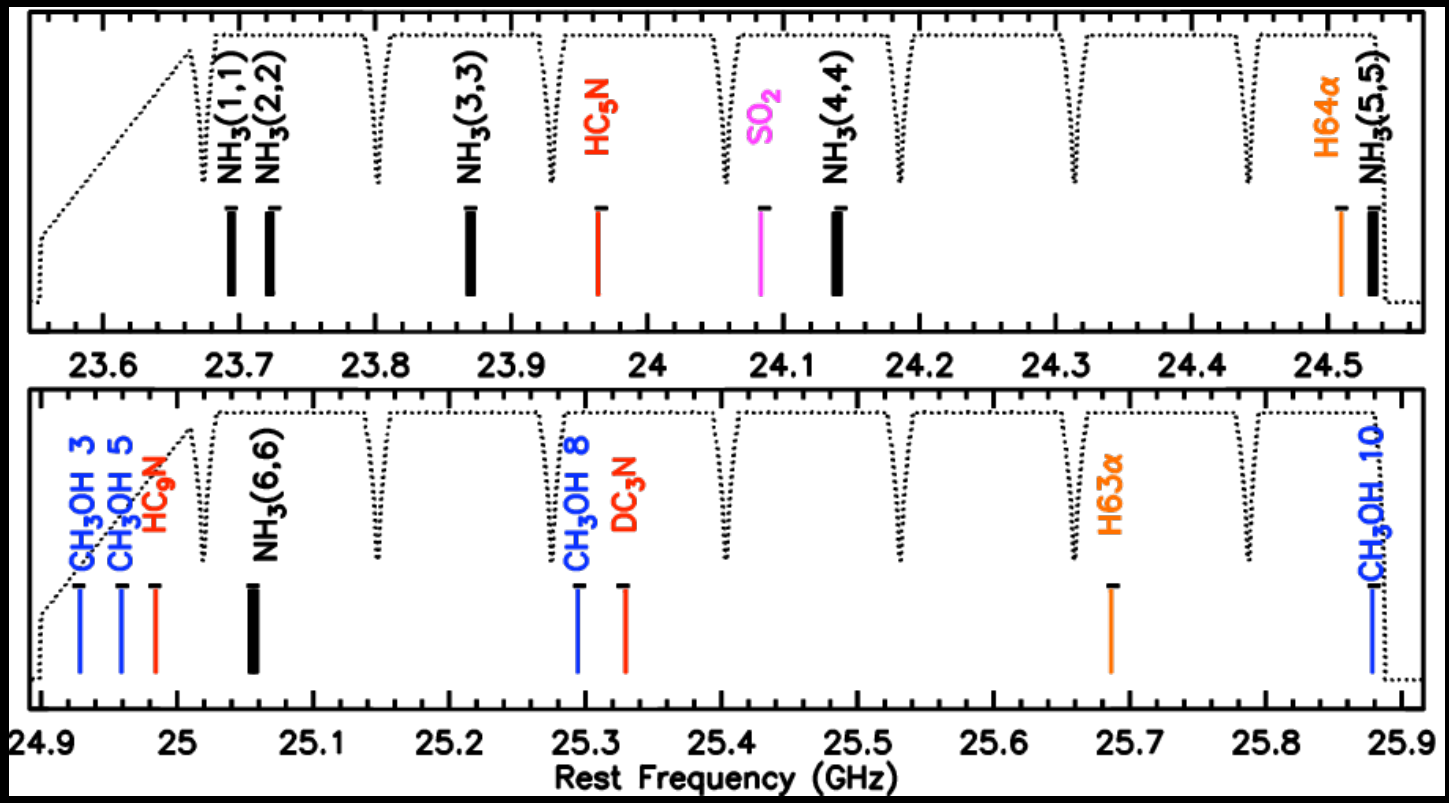
To date attempts to define a clear observationally based evolutionary sequence have used heterogeneous datasets…

WIDAR Allows us to Observe Many Diagnostic Tracers Simultaneously!

EVLA

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, HC_9N, DC_3N (Trace formation history of gas)
- 2 Radio Recombination Lines (Kinematics of ionized gas)
- Decent continuum bandwidth from line-free regions (Ionized gas)



Early Test Result: NGC6334I

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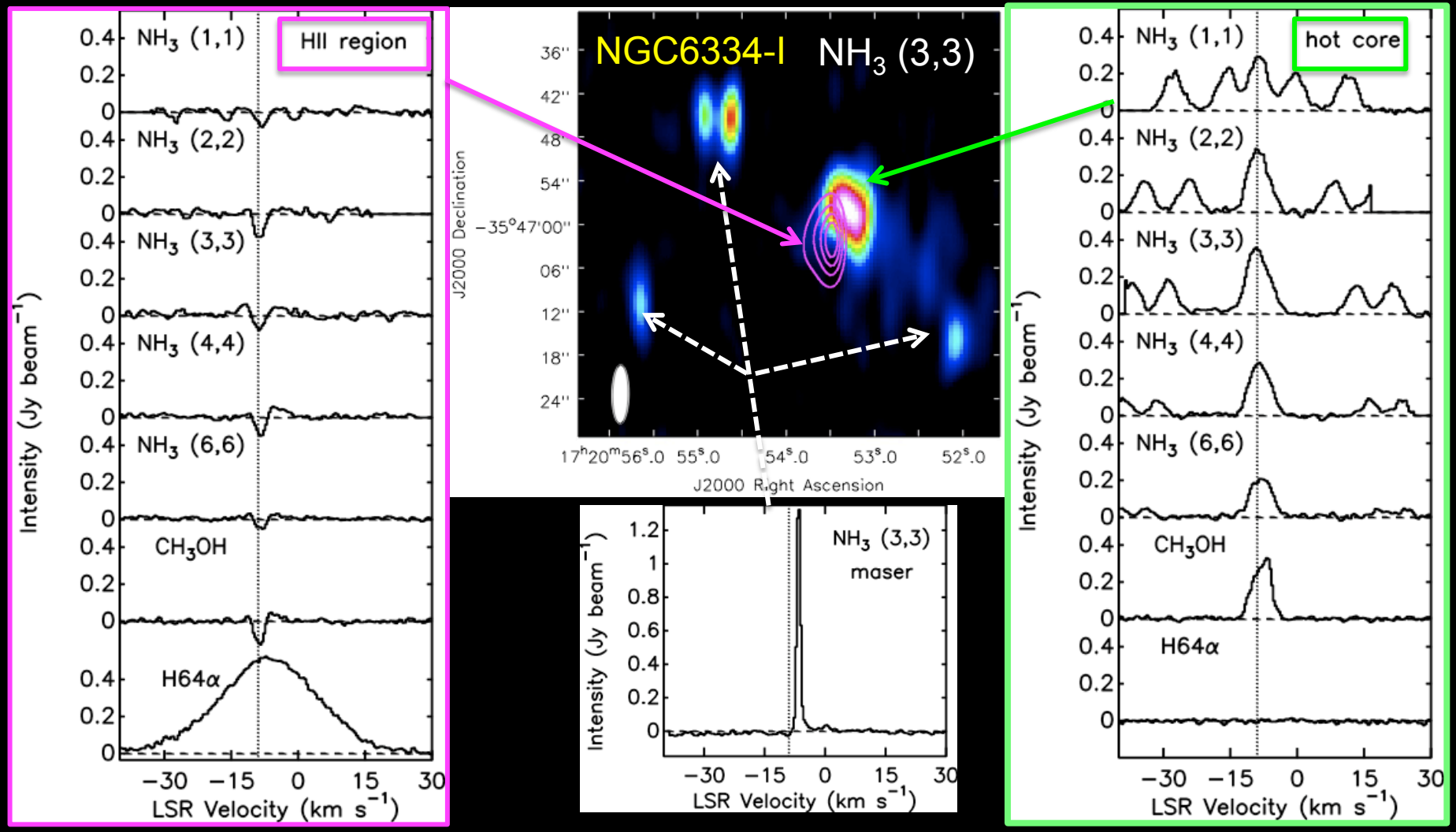
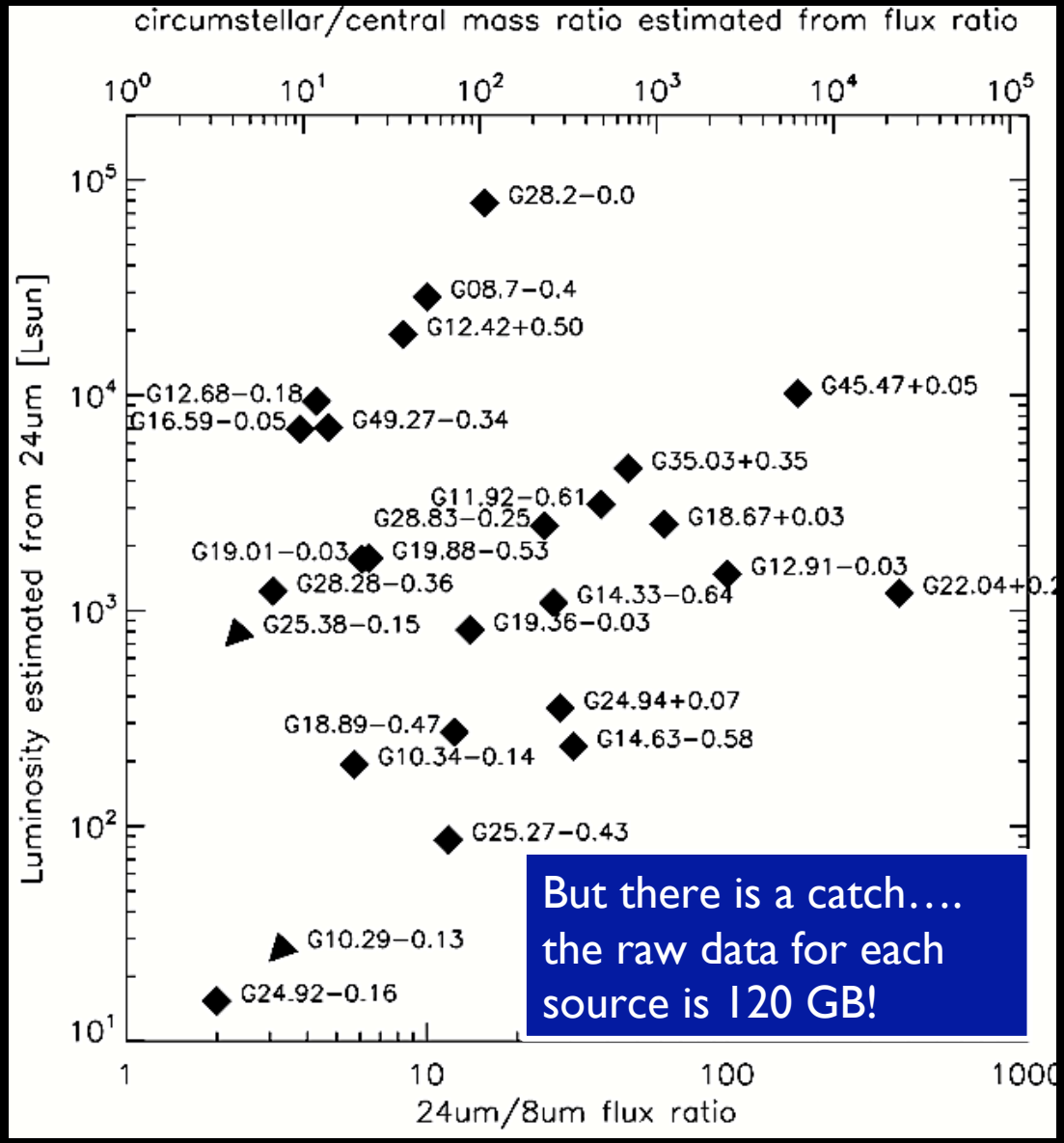
- Protocluster with 2 hot cores and an ultracompact HII region at D~1.6 kpc
- 10-minutes on-source
- Used 8 narrow (8 MHz) sub-bands



The Sample & Data

EVLA

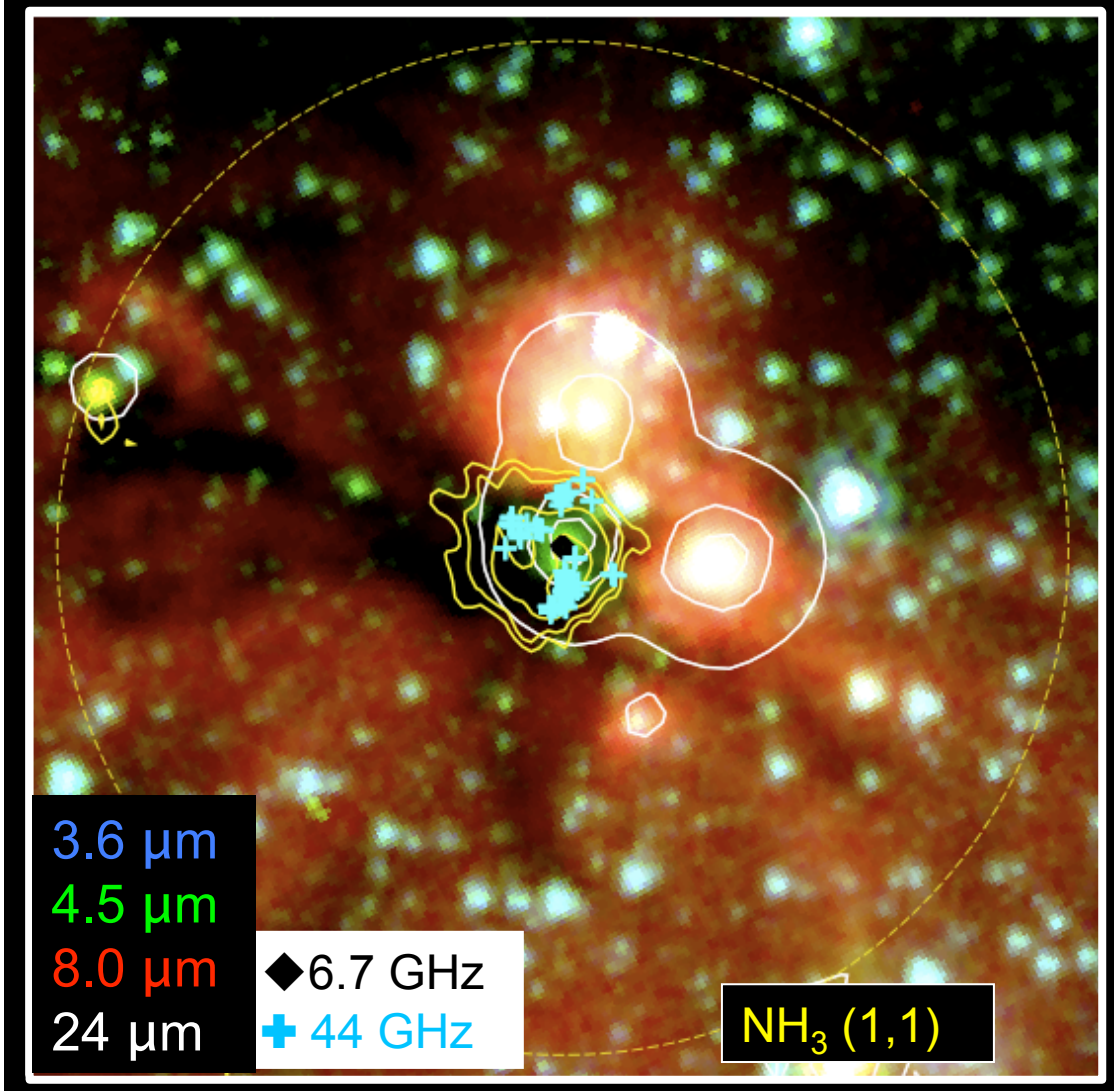


- Targets span wide range in luminosity and M_{core}/M_*
  - IRDCs (Infrared Dark Clouds)
  - EGOs (Extended Green Objects; Cyganowski et al. 2008); e.g. MYSO candidates
  - A few known HCHII, and UCHII regions

- 3.5 hour tracks
- 2' primary beam
- Resolution ~10,000 AU
  - 2-4 kpc D-config
  - 4-6 kpc C-config
- Line sensitivity (0.4 km/s channels):
  - 3 mJy/channel/beam
- Continuum sensitivity:
  - ~ 0.2 mJy/beam

G22.04+0.22 (D=3.6 kpc)

EVLA



Resolution: 3.6" x 2.4" (~10,000 AU)

An EGO in an IRDC with significant 24 μm emission

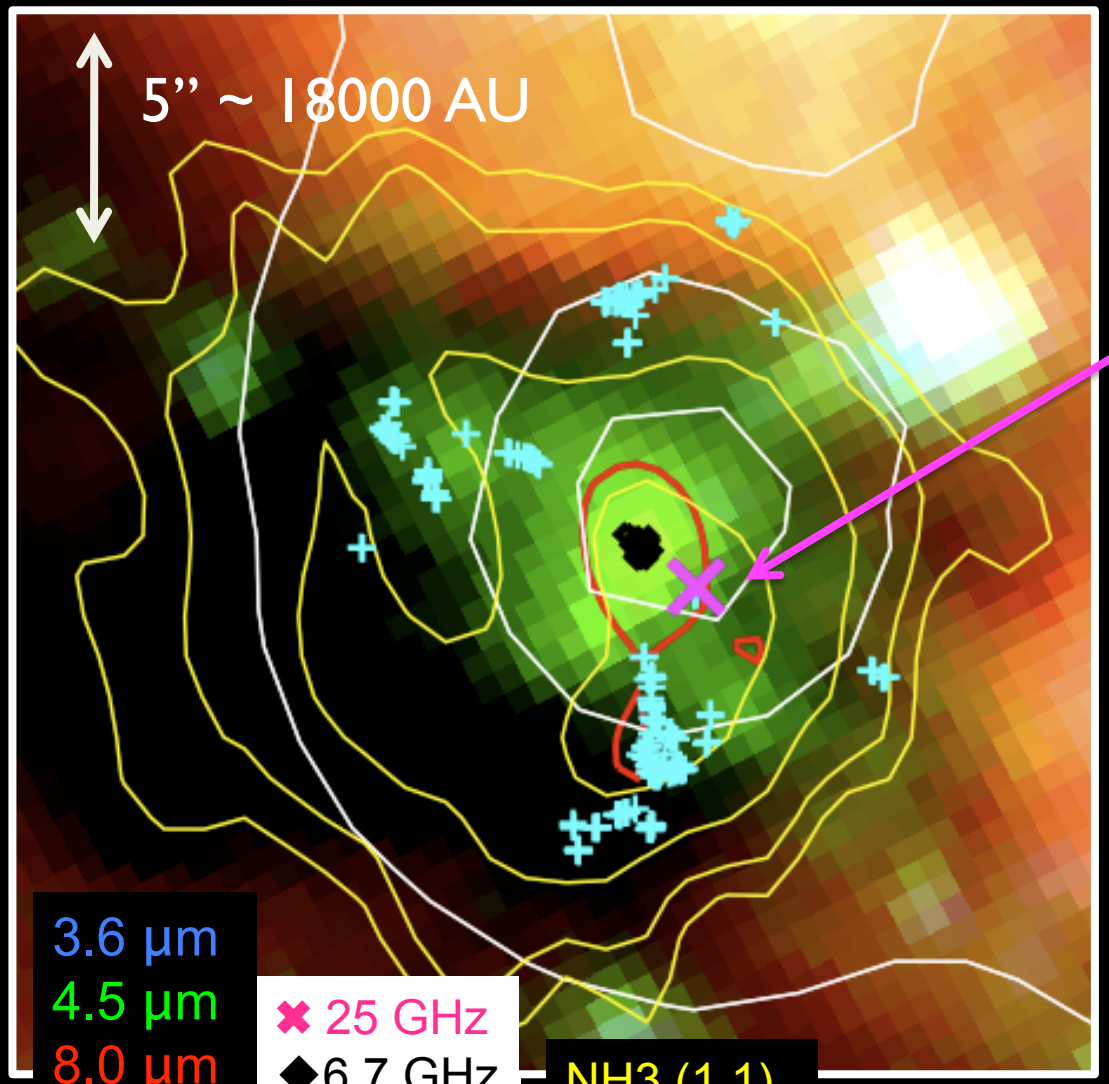
@25K; M_{gas}~ 270 $M_{\odot}$ (BGPS)

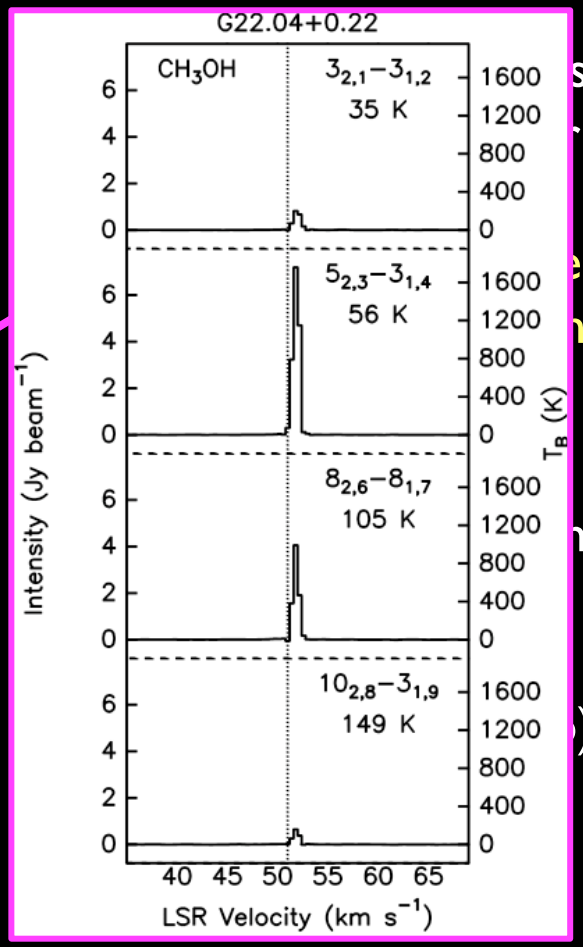
Strong 6.7 GHz (massive star formation) and 44 GHz (outflow tracer) methanol masers (Cyganowski et al. 2009)

NH_3 (1,1) core detected toward the EGO and nearby protostar

Zoom: G22.04+0.22 (D=3.6 kpc)

EVLA



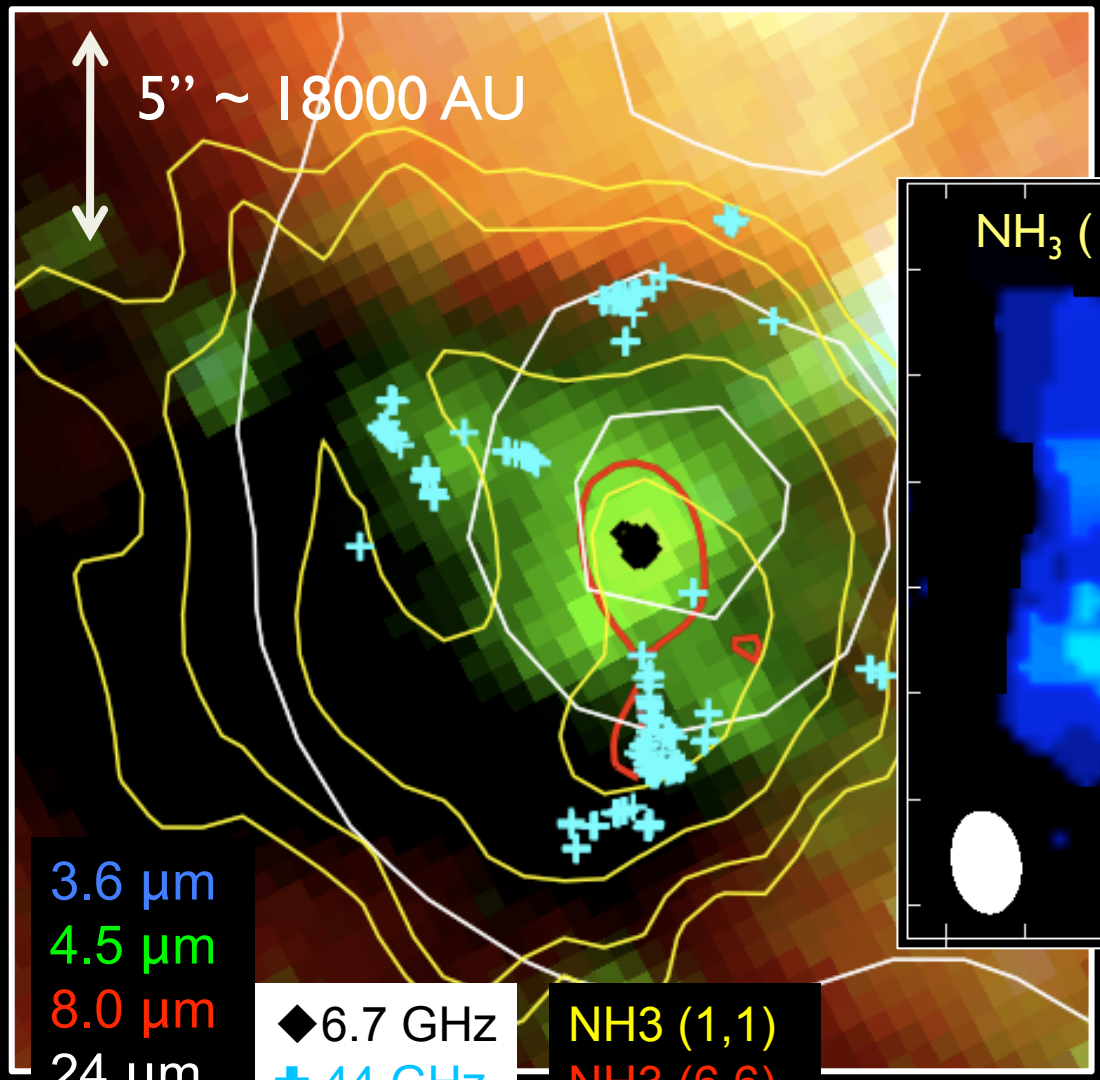


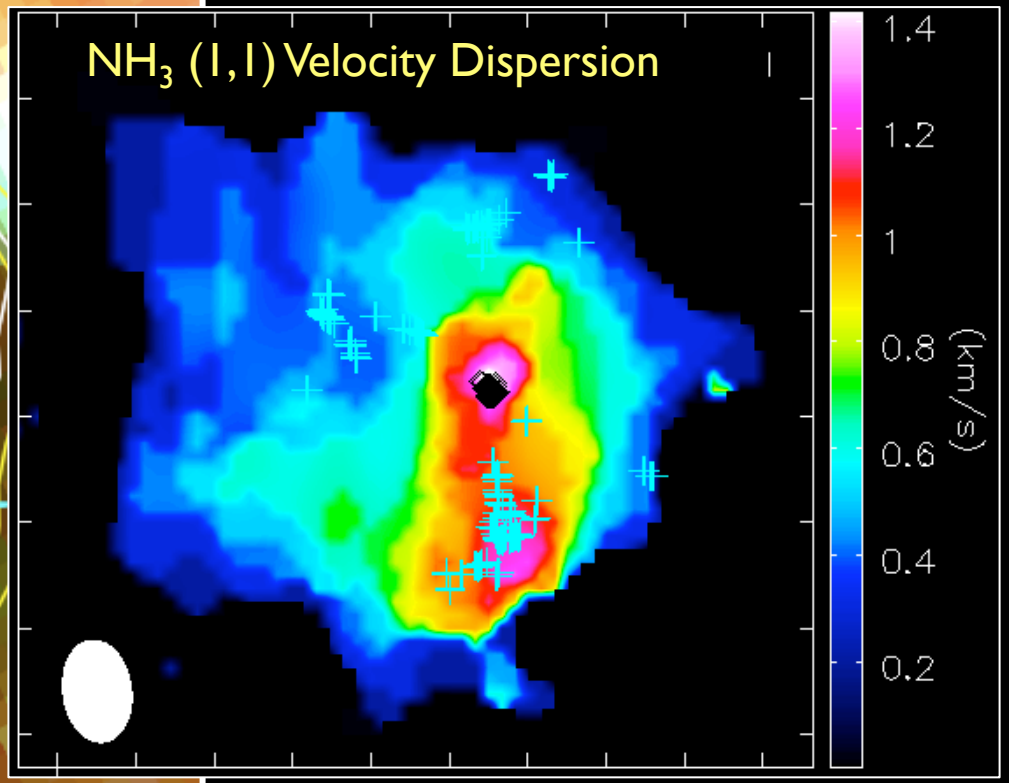
25 GHz methanol maser emission toward peak 44 GHz maser location

Resolution: 3.6" x 2.4" (~10,000 AU)

Zoom: G22.04+0.22 (D=3.6 kpc)

EVLA

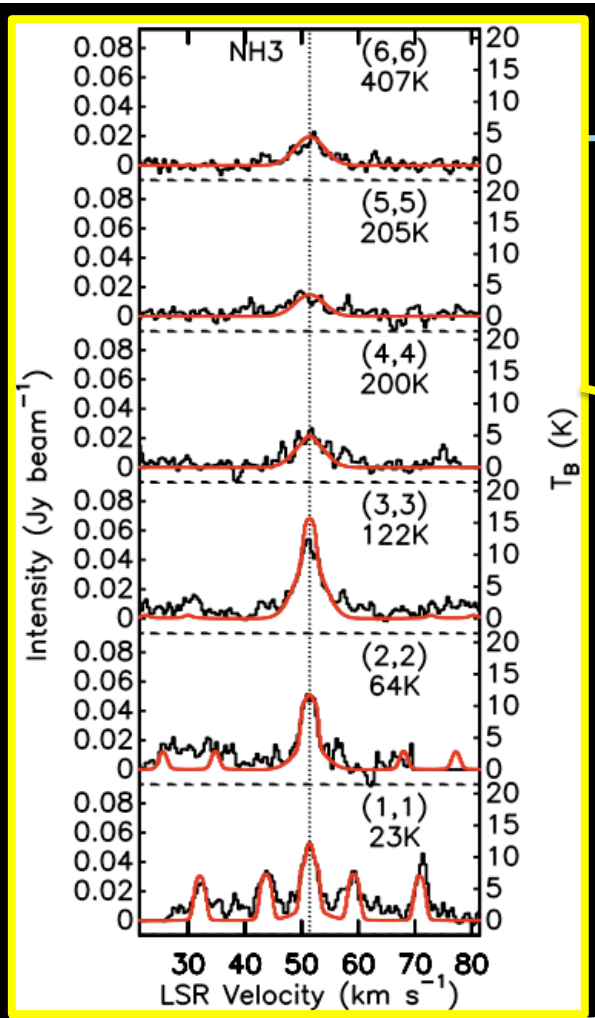


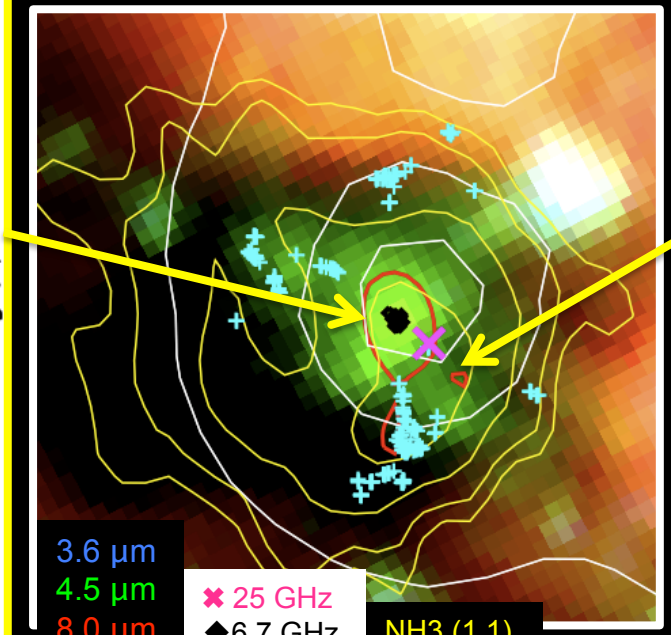


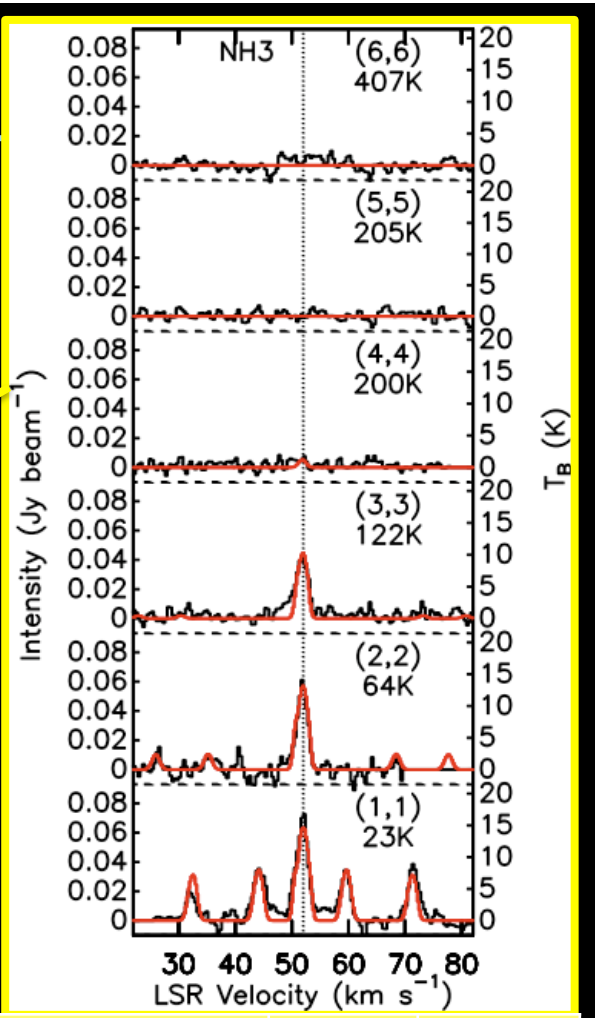
Velocity field relatively featureless except toward 6.7 GHz maser, where its blue-shifted

Resolution: 3.6" x 2.4" (~10,000 AU)

G22.04 NH_3 Fits







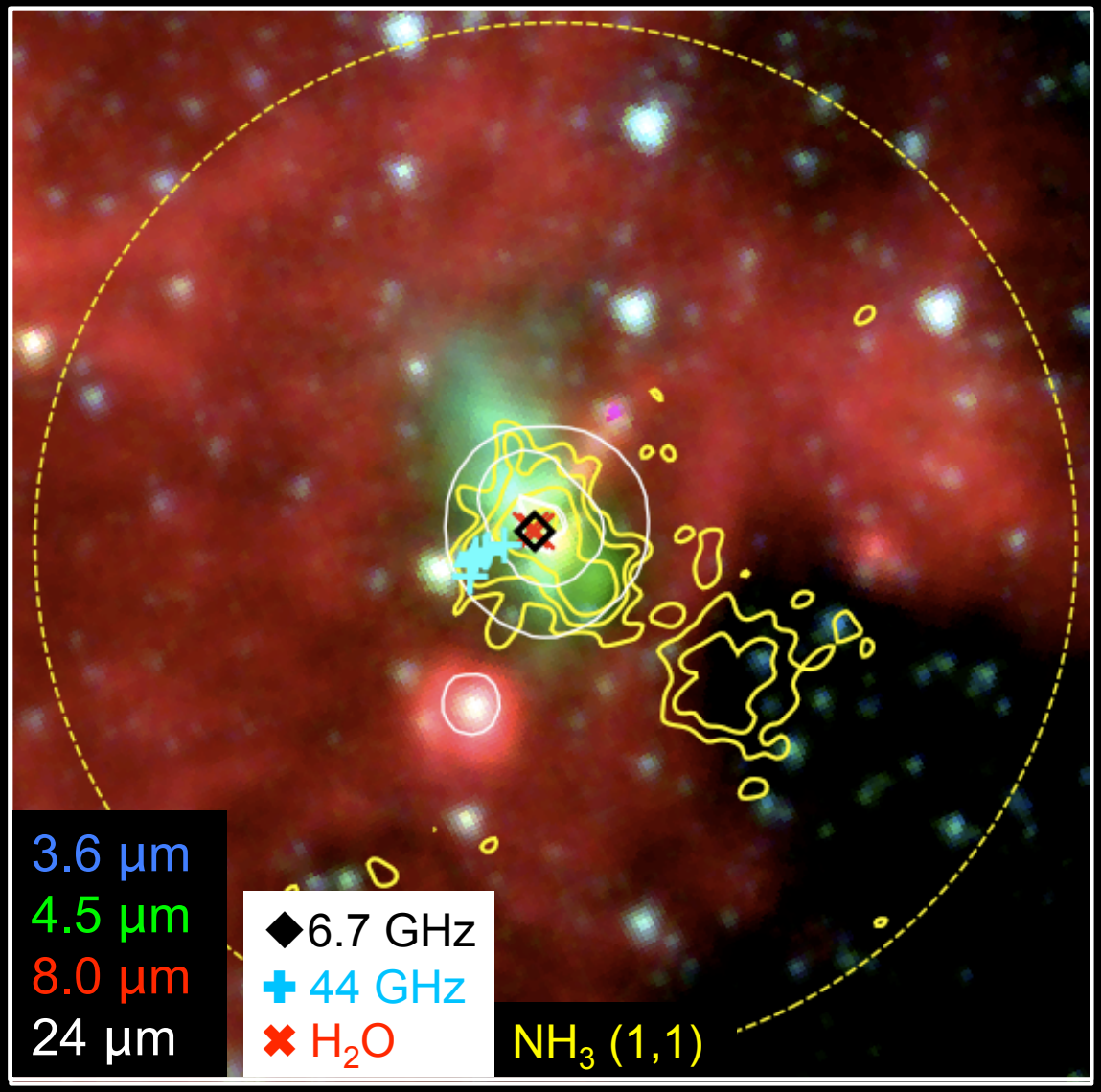
Fit	Line 1	Line 2	Line 3
Size (")	2.7	2.7	2.2
T_{rot} (K)	15	22	170
Log(N) (cm^{-2})	15.0	16.7	16.0
Vlsr (km/s)	51.4	51.4	51.4
ΔV (km/s)	1.1	1.5	6.0

Fits with custom scripting of xclass

Fit	Line 1	Line 2
Size (")	2.7	2.7
T_{rot} (K)	26	26
Log(N) (cm^{-2})	15.3	16.5
Vlsr (km/s)	52	51.8
ΔV (km/s)	1.1	1.6

G35.03+0.35 (D ~ 3.4 kpc)

EVLA



Resolution: 3.6" x 3.0" (~11,000 AU)

An EGO with significant 24 μm emission

@25K; M_{gas} ~ 330 $M_{\odot}$ (BGPS)

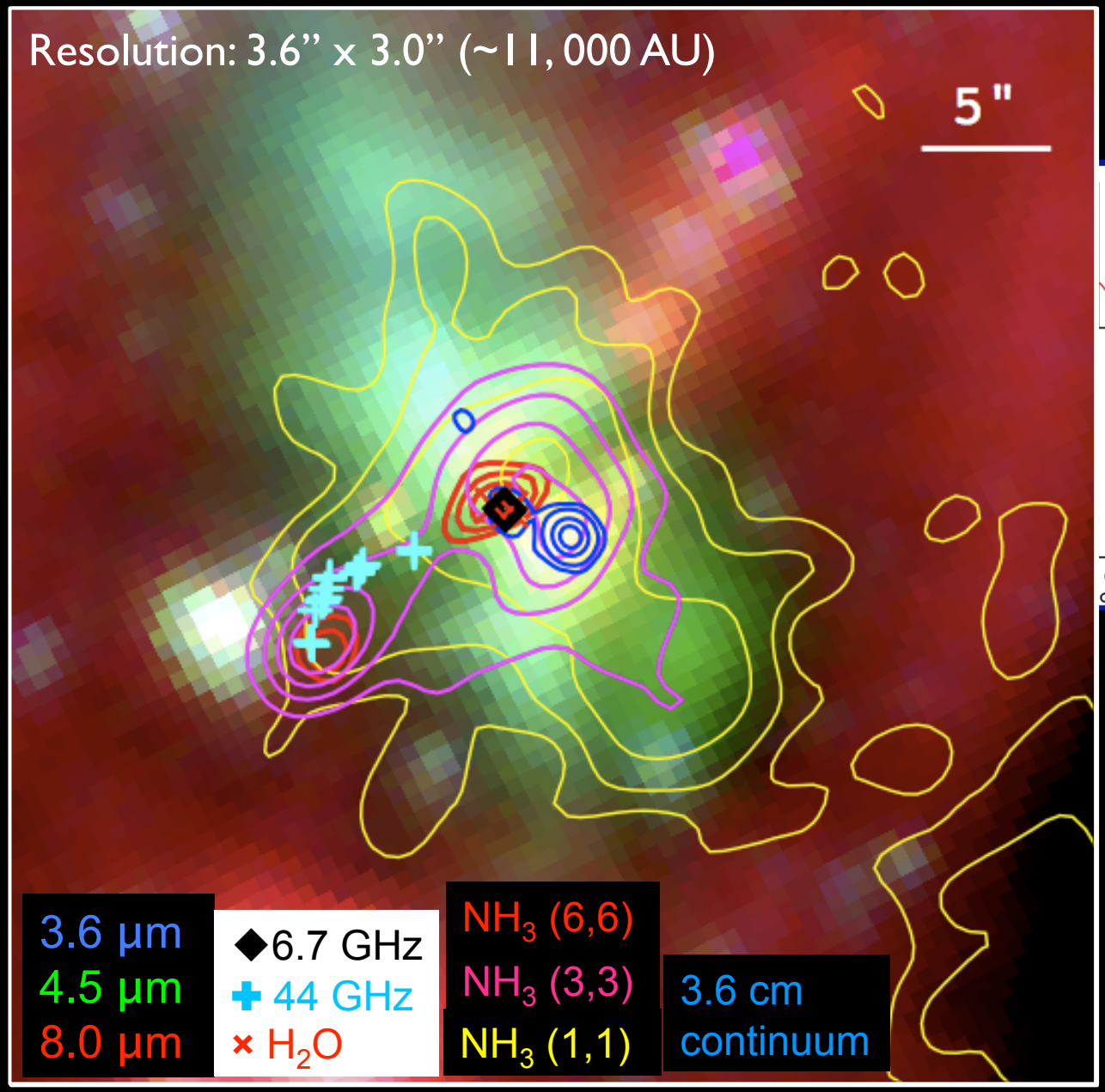
Strong 6.7 GHz (massive star formation) and 44 GHz (outflow tracer) methanol masers (Cyganowski et al. 2009)

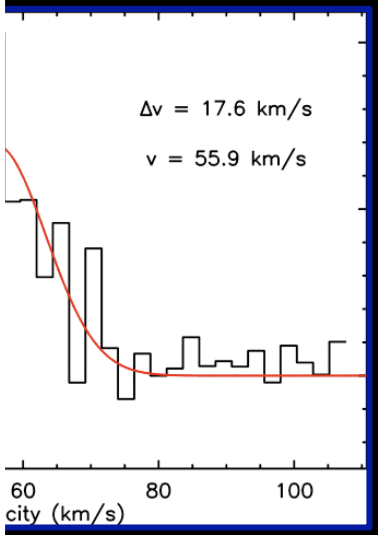
H_2O Masers (Forster & Caswell 1989)

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

Zoom: G35.03+0.35 (D~3.4 kpc)

EVLA

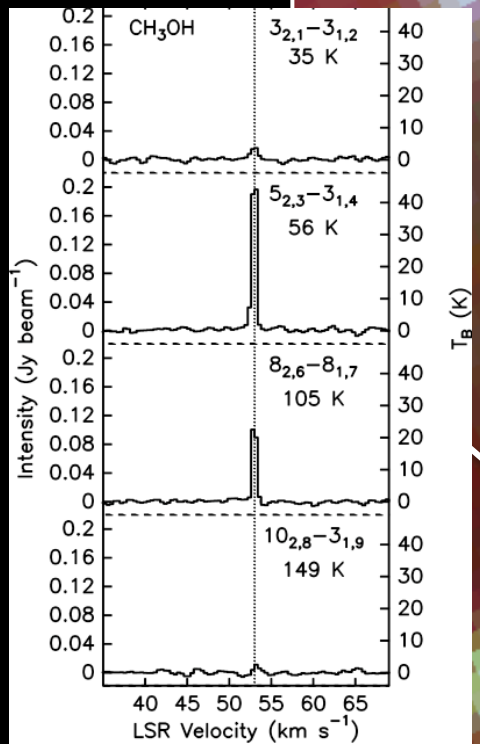




VLA 3.6 cm continuum showing 3 compact sources; one coincident with 6.7 GHz methanol masers (Cyganowski et al. in prep.)

Zoom: G35.03+0.35 (D~3.4 kpc)

EVLA



25 GHz CH_3OH Class I maser

Resolution: 3.6" x 3.0" (~11,000 AU)

5"

✚ 25 GHz

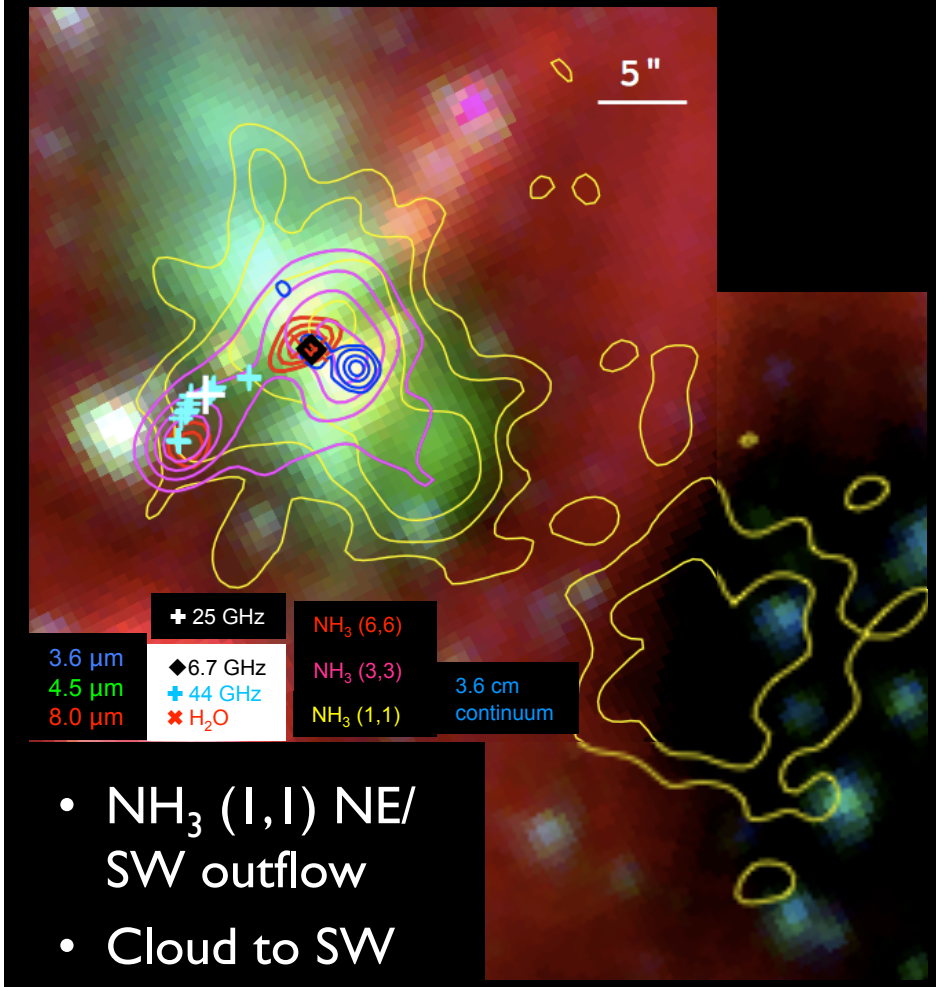
3.6 μm
4.5 μm
8.0 μm

◆6.7 GHz
✚ 44 GHz
✖ H_2O

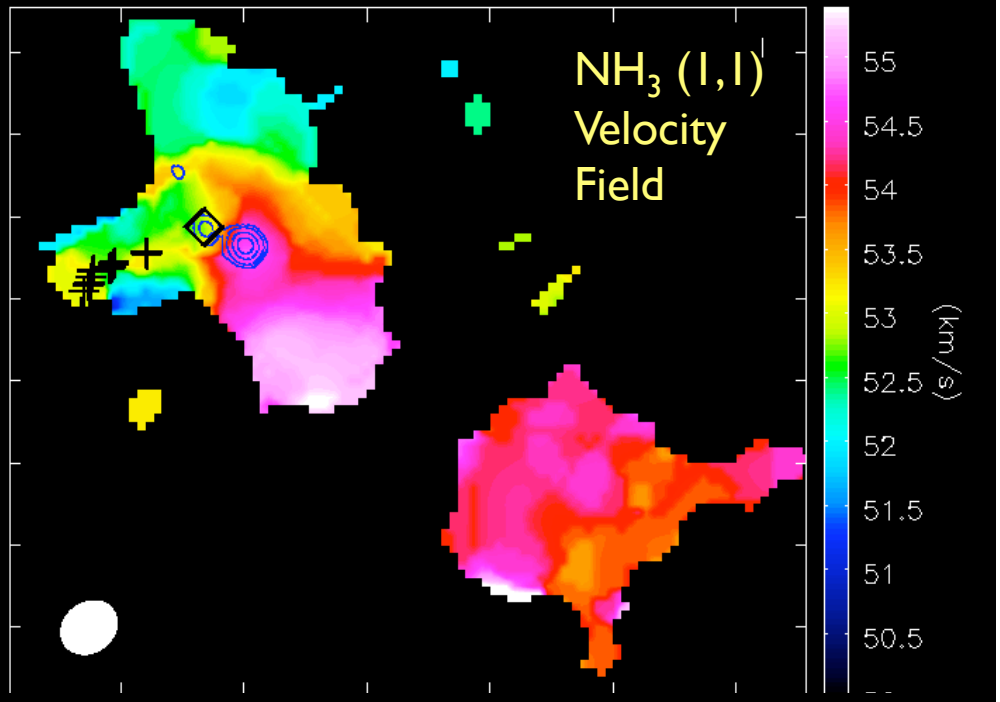
NH_3 (6,6)
NH_3 (3,3)
NH_3 (1,1)

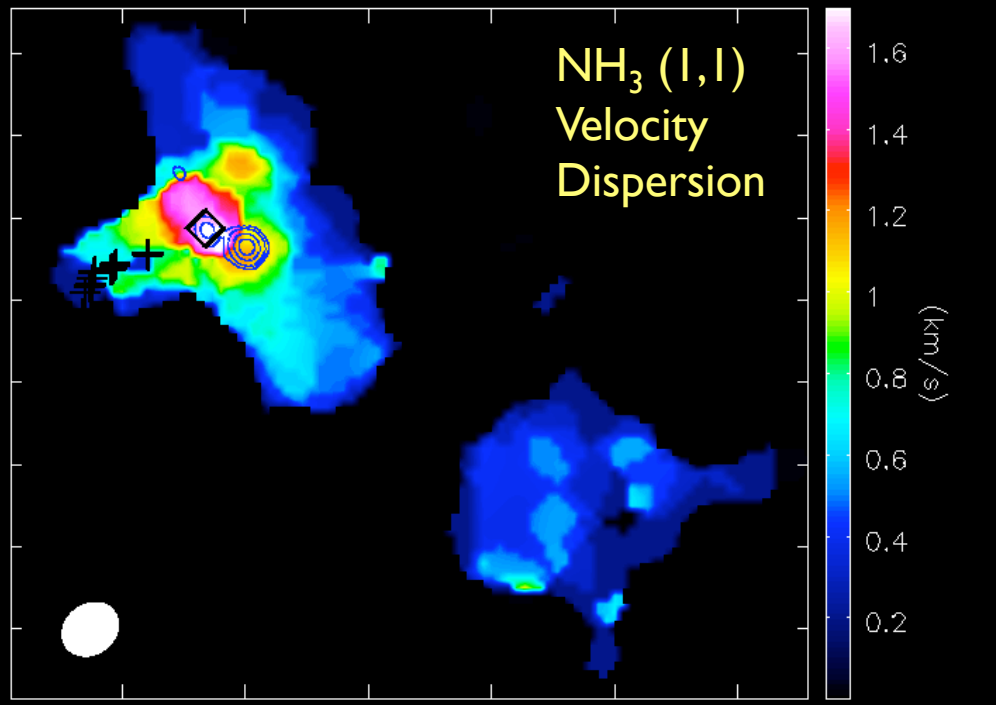
3.6 cm continuum

G35.03+0.35: Kinematics

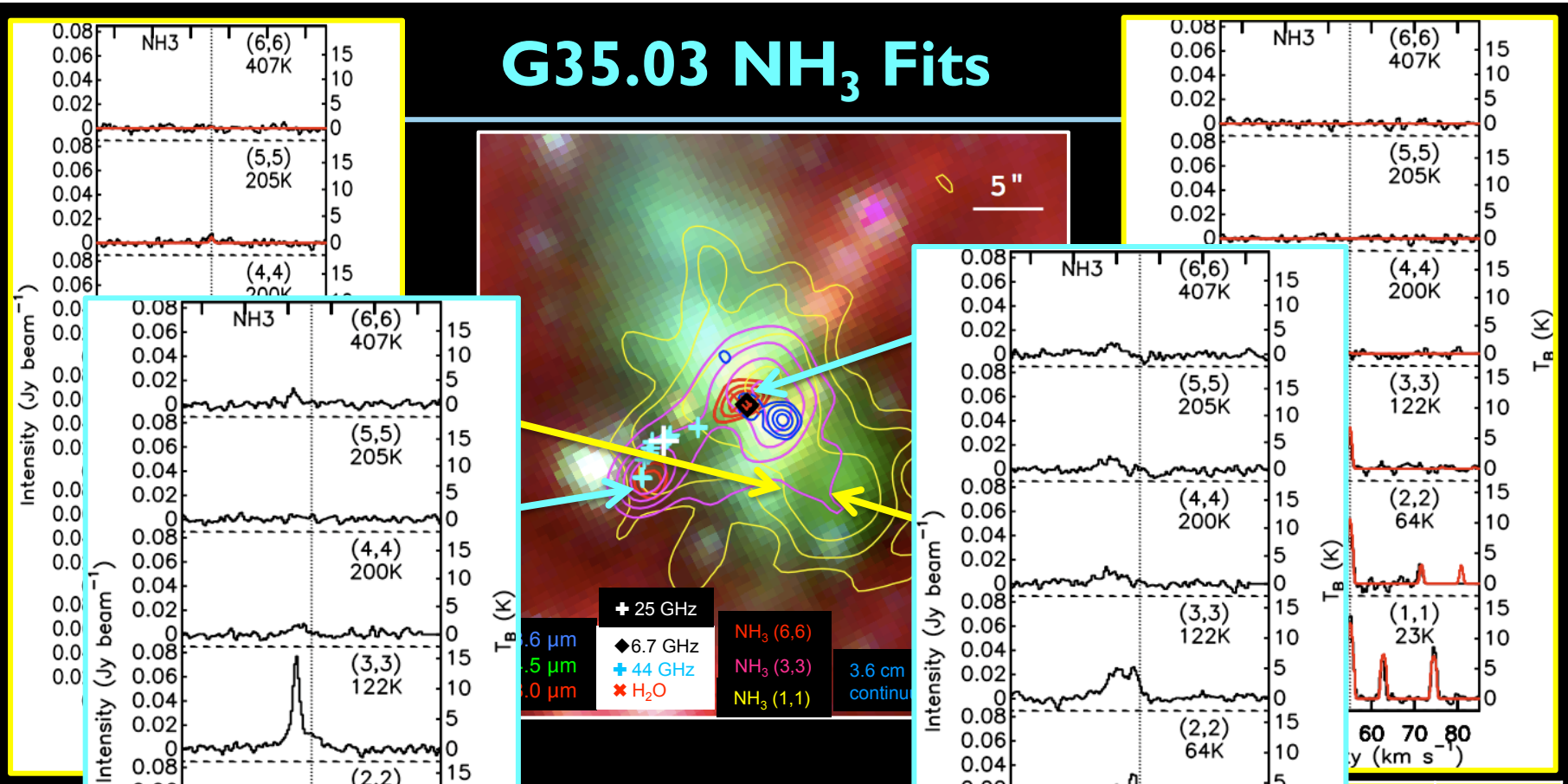


- NH_3 (1,1) NE/ SW outflow
- Cloud to SW appears distinct
- Increased line widths toward 6.7 GHz maser source





G35.03 NH_3 Fits



Fit		Line 1	Line 2
Size (")		3.2	3.2
T_{rot} (K)		17	21
Log(N)		16.7	15.2
Vlsr (k		55	55
ΔV (km		0.8	0.8

NH_3 maser emission?

Fits with custom scripting of xclass

Hot core? Strong blue-shifted emission

Summary

EVLA

- WIDAR provides powerful new capability for simultaneous diagnostic spectroscopic observations of massive protostars/protoclusters
- Potential to reveal critical observational signposts of evolutionary state and massive star formation
- Early results are showing incredible complexity:
  - Temperatures
  - Kinematics
  - Shocks
  - Continuum properties
  - Masers
- Complementary observations from SMA and CARMA and soon ALMA ongoing (see Claudia Cyganowski's poster)