Observational Constraints on Massive Protoclusters

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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

Source I NIR cluster with density of ~1200 pc$^{-3}$ (Tapia et al. 1996)
The NGC6334 I Protocluster

SMA 1.3 mm Continuum

Resolution: 0.″8 x 0.″4
1400 x 700 AU

Peak Velocity (km/s)

CO(2-1)

1.3 mm
3.6 cm

HMPO density is ~10,000 pc⁻³

6″ = 10,000 AU

3.6 cm continuum (ionized gas)
The NGC6334 I(N) Protocluster

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Brogan et al. (2009)
Brogan et al. in prep.
The NGC6334 I(N) Protocluster

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Source I Line Emission: Tremendous Hot Core Emission!

Line-to-continuum ratio:

- 18% at 225 GHz
- 14% at 340 GHz

30% of lines in both bands are unidentified
Hot Core Line Emission
A total of 6 line sources in I(N) and 3 in source I.
Remarkable chemical variation between sources as little as 4000 AU apart.
The 1-d radial velocity dispersion is ~2 km s^{-1} for both protoclusters.

CH$_3$CN

Line excitation Tex
Morphology vs. line excitation temperature (Tex) suggests central heating, but optical depth is very high.

The gas temperatures are about 125 K.

SMA1 shows SE/NW velocity gradient and is perpendicular to the outflow.
Source I Continuum and Lines at 870 μm
(at our highest resolution)

In 870 μm data:
- No lines peak on SMA1 or SMA2 continuum peak \( \Rightarrow \) continuum opacity is simply too high

Resolution 0.5”x 0.3” (850 x 510 AU)

- Similar velocity gradients and high continuum opacity in Source I(N)
- See Hunter et al. poster #CP1 for H₂O and 44 GHz CH₃OH masers

For \( T_{\text{dust}} = 125 \text{ K} \), \( \tau_{\text{dust}} \sim 1 \) at 870 μm
I(N) CH$_3$CN

Temperatures

Some line profiles are complex, multiple temperature and velocity components necessary.
Comparison with Simulations

Resolution ~800 AU

Peters et al. (2010)
Summary

• ~800 AU resolution observations of protoclusters reveal:
  • HMPO density 5000 – 10000 pc\(^{-3}\)
  • Gradients suggestive of rotation, though not Keplerian
  • 1-d velocity dispersions of \(\sim 2\ \text{km s}^{-1}\); \(t_{\text{cross}}\sim(3-5)\times10^4\ \text{years}\)
  • \(T_{\text{gas}}\) 60 to 150 K and masses at this resolution are a few to few 10s of \(M_\odot\)
  • A range of evolutionary states within protoclusters from UCHII regions to optically thick line-free sources
  • High continuum opacity at \(\lambda < 1.3\text{mm}\) obscures line emission

Except for luminosity, and hot core emission sources I and I(N) are very similar... how to distinguish between YOUTH and Lower MASS star formation?

† ALMA will improve resolution and spectral sensitivity \(~25\times\)
† EVLA essential to probe optically thick inner disk regions
† Herschel & Sofia: far-IR \(\Rightarrow\) growth of luminosity