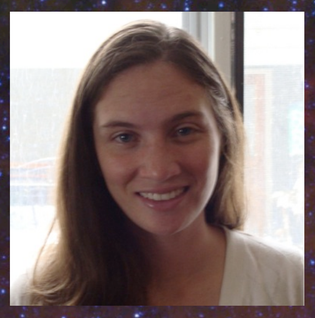
The Dynamic Role of Large-Scale Gas Flows in High-Mass Star-Forming Filaments



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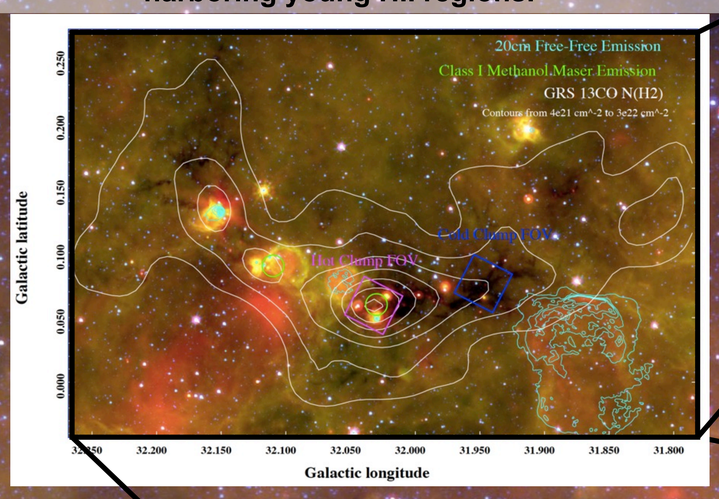
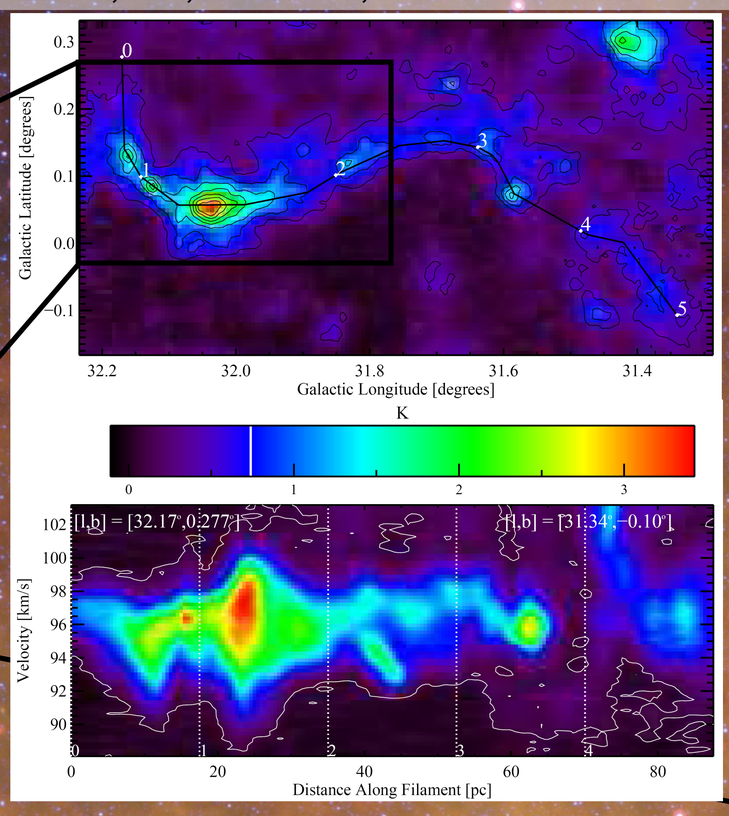
We investigate the large-scale gas flows in a Massive Molecular Filament (MMF: M(H_2) > 10^4 $M_\odot$, l > 10 pc, and Δv < 5 km/s) aligned with the Galactic Plane and forming high-mass stars. We find a coherent velocity structure along the length of the 80 pc filament and hypothesize that it was formed at the intersection of star-forming bubbles. Along the line-of-sight, the filament shows strong radial infall signatures, particularly toward the dark, quiescent regions. Finally, we compare the physical properties of two high-mass star-forming clumps within the filament at different evolutionary stages, from quiescent, cold, mid-IR-dark, to warm and active with an embedded UCHII region.

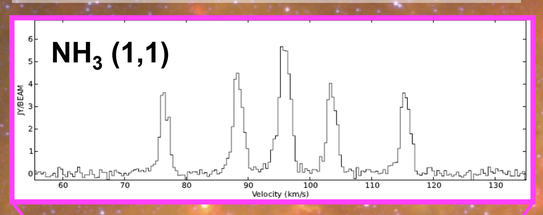
The cloud shows a range of star-forming activity from cold, mid-IR-dark, and quiescent to evidence of Class II methanol maser emission, to warm, mid-IR-bright, and harboring young HII regions.

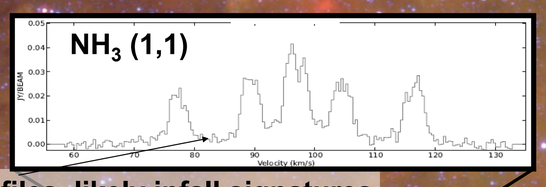




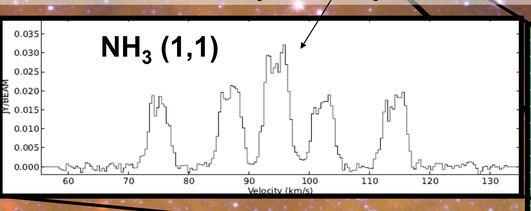
Massive Molecular Filament: G32.02+0.06: M(H_2) > 10^5 $M_\odot$, l > 80 pc, and Δv < 5 km/s. The ^{13}CO shows a coherent velocity structure (Δv < 5 km/s) over the 70 pc length of the molecular filament, with a wider dispersion (~8 km/s) near the star forming activity. The molecular gas traces out the edges of two converging bubble walls.

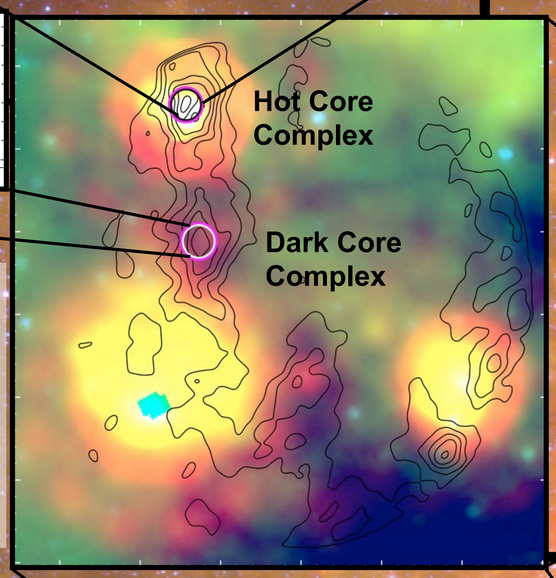
Cold Core: T ~ 13 K, r ~ 0.4 pc
Σ(H_2) ~ 0.5 g cm^{-2}, Mass ~ 65 $M_\odot$

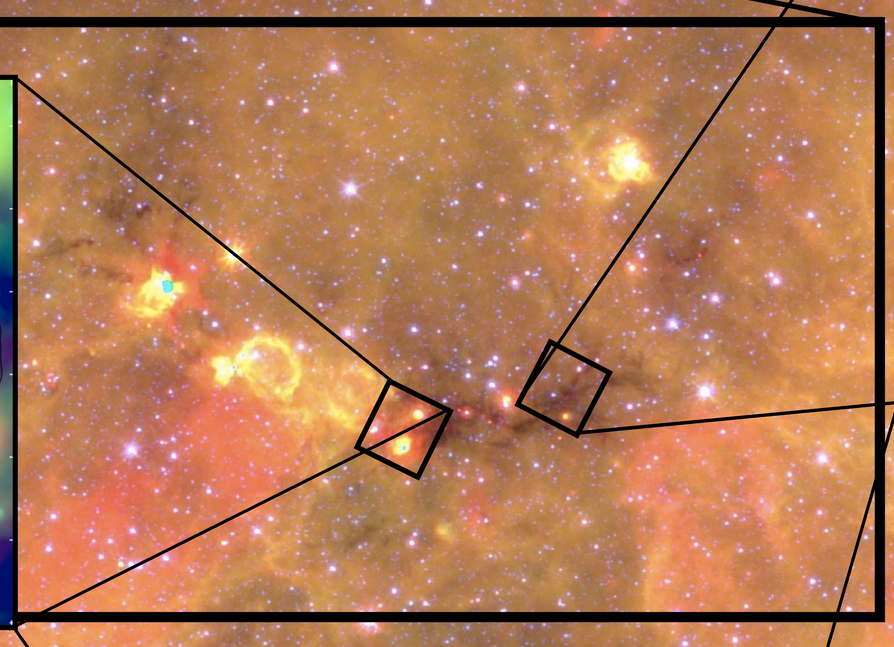


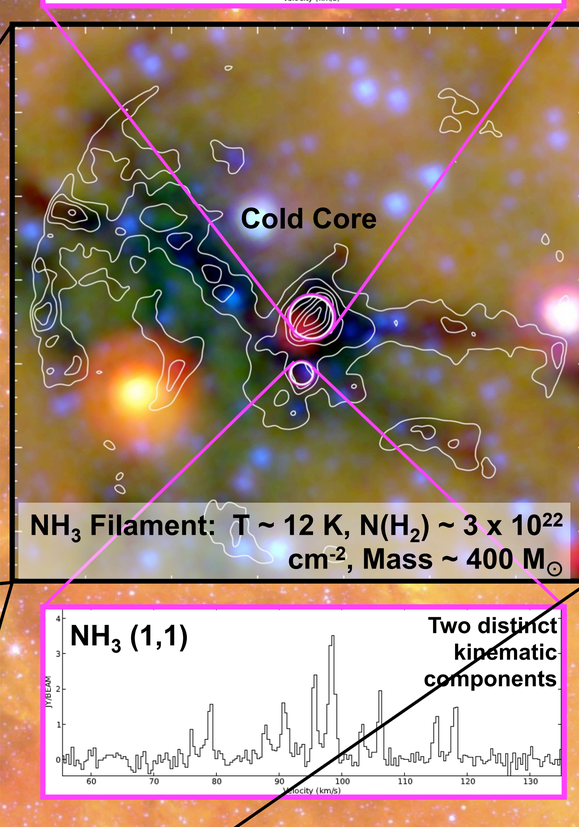


Both show complicated profiles, likely infall signatures



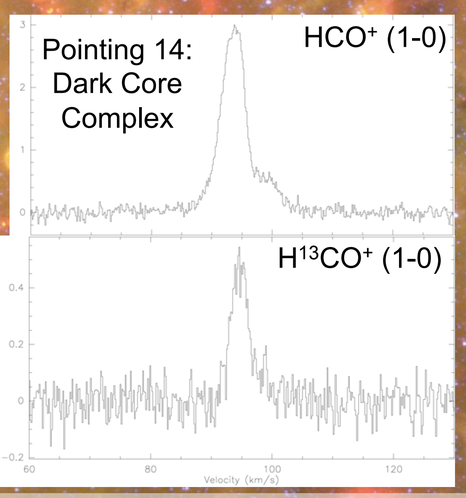


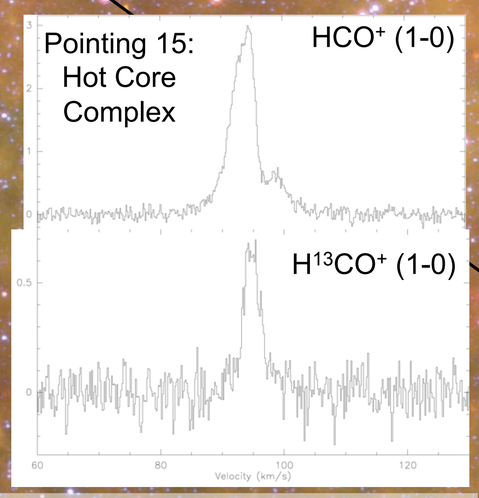


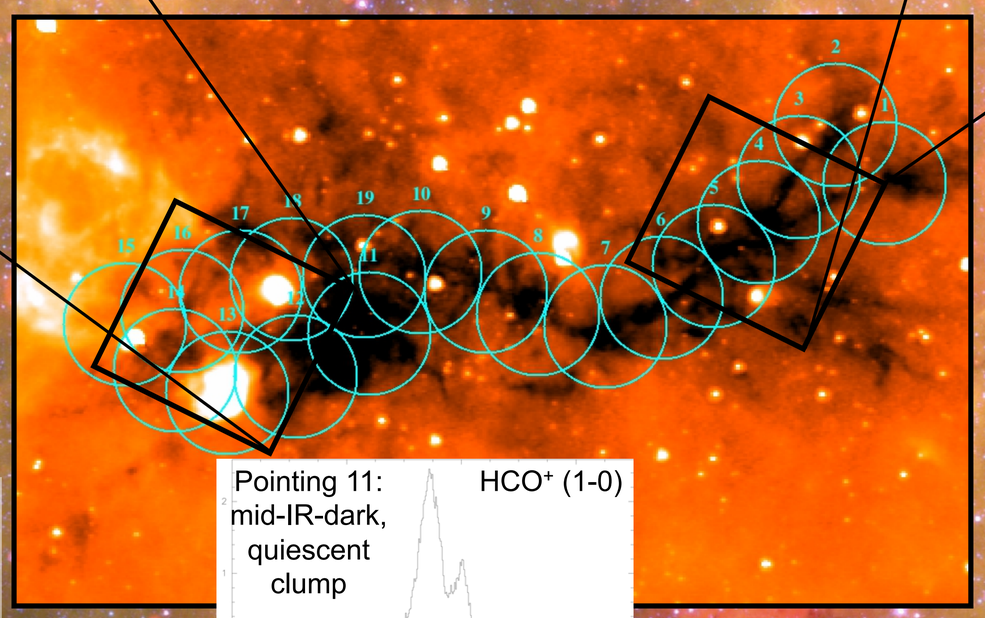


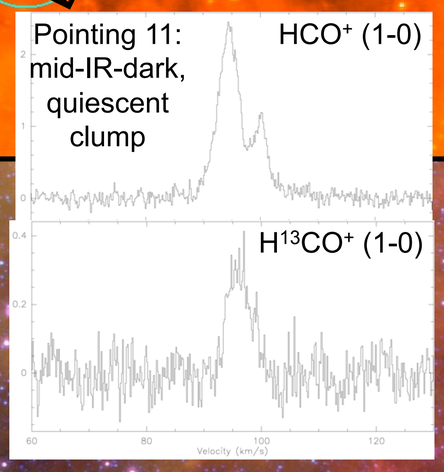
NH$_3$ Filament: T ~ 12 K, N(H_2) ~ 3 x 10^{22} cm^{-2}, Mass ~ 400 $M_\odot$

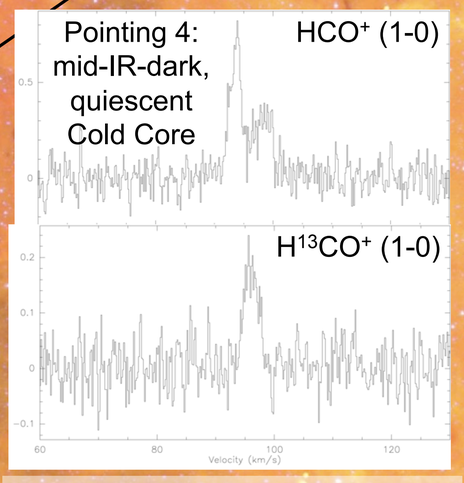
Filament: Smooth temperature distribution, 10-20 K
Hot Core Complex: Compact (<0.1 pc), warm (~35-40 K), Dense (Σ_{max} ~1.5 g/cm^2) cores, ~100 $M_\odot$
Dark Core Complexes: Compact (<0.1 pc), cold (~12-15 K), Dense (Σ_{max} ~1.5 g/cm^2) cores, ~50-150 $M_\odot$





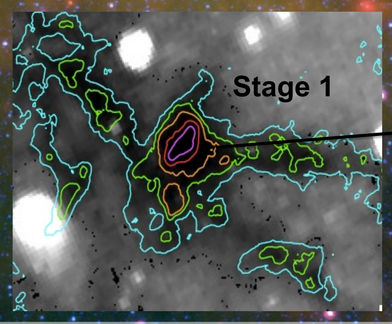


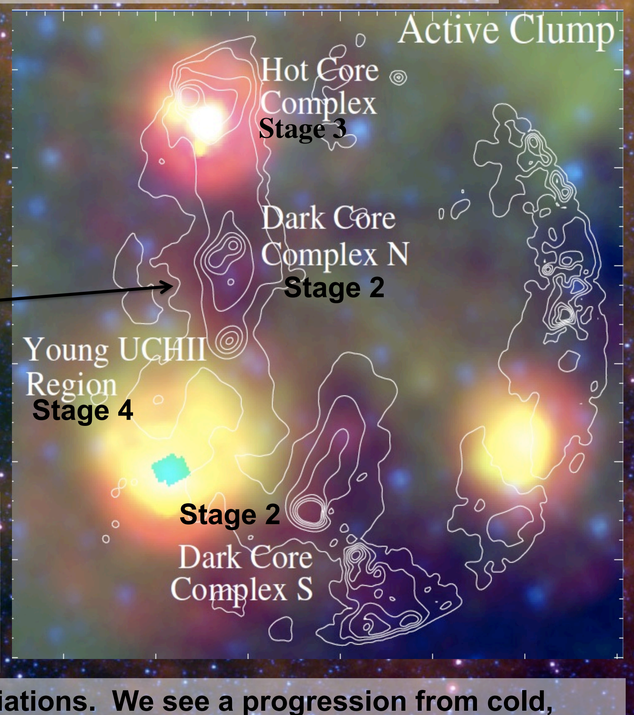




The high-mass star-forming clumps embedded within the MMF show signatures of large-scale radial infall as evidenced by the blue-shifted optically thick HCO$^+$ (1-0) self-absorption at the velocity of the optically thin H^{13}CO$^+$ (1-0) emission. The blue-shifted absorption troughs are strongest in the quiescent, high-density, mid-IR-dark portions of the cloud. This indicates that large scale infall plays a role early in the evolution of clumps forming high-mass stars.

The quiescent clump shows blue-shifted self-absorption on 70" (about 1.8 pc at 5.5 kpc) scales, indicating large-scale collapse / gas flows.

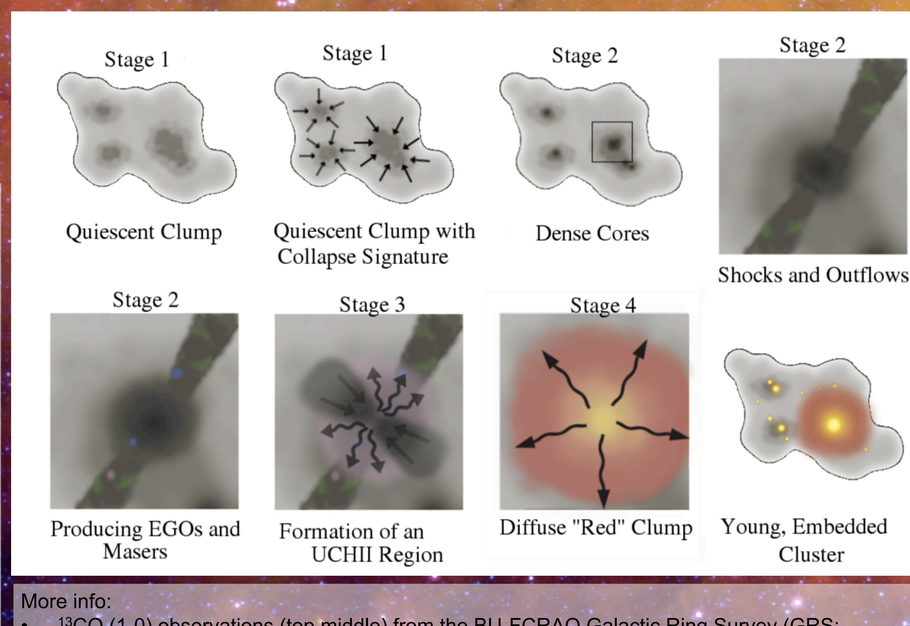




Since we are observing two clumps within a single MMF, we can single out the effects of evolution from those of distance, resolution, large-scale environment, and abundance variations. We see a progression from cold, extended, quiescent cores (Stage 1, T ~10 K, r ~ 0.5 pc, Σ_{max} ~0.5 g/cm^2) to fragmented complexes of compact, dense cores (r < 0.1 pc, Σ_{max} ~1.5 g/cm^2). These fragmented dense cores range from cold and quiescent (Stage 2, Dark Core Complexes, T~12-15 K) to warm and active (Stage 3, Hot Core Complex, T~35-40 K).

***[Right]* A possible observational evolutionary sequence for high-mass star-forming clumps (from Battersby et al. 2010). An example of each of these is shown in the figure on the left.**

Recent statistical analysis of dense dust clumps using Herschel and various star-formation tracers indicates a relative lifetime of the quiescent phase (of dense, dust clumps - Stage 1) of about 70% or 0.6 - 1.2 Myr, 2-4% or 35,000 years for the methanol maser phase (Stage 2), and a relative lifetime of 30% or 0.3-0.5 Myr for the active phase (Stage 3 and Stage 4). For more details see upcoming paper, Battersby & Bally, submitted … or just ask me!



More info:
- ^{13}CO (1-0) observations (top middle) from the BU-FCRAO Galactic Ring Survey (GRS; Jackson et al. 2006)
- High-resolution NH_3 (1,1), (2,2), and (4,4) observations from the Karl G. Jansky Very Large Array (VLA), Battersby et al., submitted
- HCO$^+$ and H^{13}CO$^+$ observations recently conducted on the 12m telescope operated by Arizona Radio Observatory (ARO). Battersby, Myers, Kirk, & Shirley, in prep.
- mid-IR images from Spitzer -- Red: 24 μm, Green: 8 μm, Blue: 4.5 μm (GLIMPSE; Benjamin et al. 2003, MIPSGAL; Carey et al. 2009
- Class II methanol masers (top left) from Pestalozzi et al. 2005 (and survey references within that paper) and 20cm free-free emission (top left) from MAGPIS (White et al. 2005)