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Cyanopolyynes as a probe of infall in Serpens South

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Abstract: Cyanopolyynes are carbon-chain molecules of the form $HC_{2n+1}N$. At higher n, these molecules are among the longest and heaviest molecules found in the interstellar medium, and to date have been primarily seen toward several nearby, low-mass star forming regions, and in the atmospheres of AGB stars. We have detected bright HC_7N $J = 21-20$ emission toward multiple locations in the Serpens South cluster-forming region using the K-Band Focal Plane Array at the Robert C. Byrd Green Bank Telescope. HC_7N is seen primarily toward cold filamentary structures that have yet to form stars, largely avoiding the dense gas associated with small protostellar groups and the main central cluster of Serpens South.

Toward some HC_7N 'clumps', we find consistent variations in the line centroids relative to NH_3 (1,1) emission, as well as systematic increases in the HC_7N non-thermal line widths, which we argue reveal infall motions onto dense filaments within Serpens South with mass accretion rates of $\dot{M} \sim 2 - 5\ M_\odot\ Myr^{-1}$. This result extends the known star-forming regions containing significant HC_7N emission from typically quiescent regions, like the Taurus molecular cloud, to more complex, active environments.

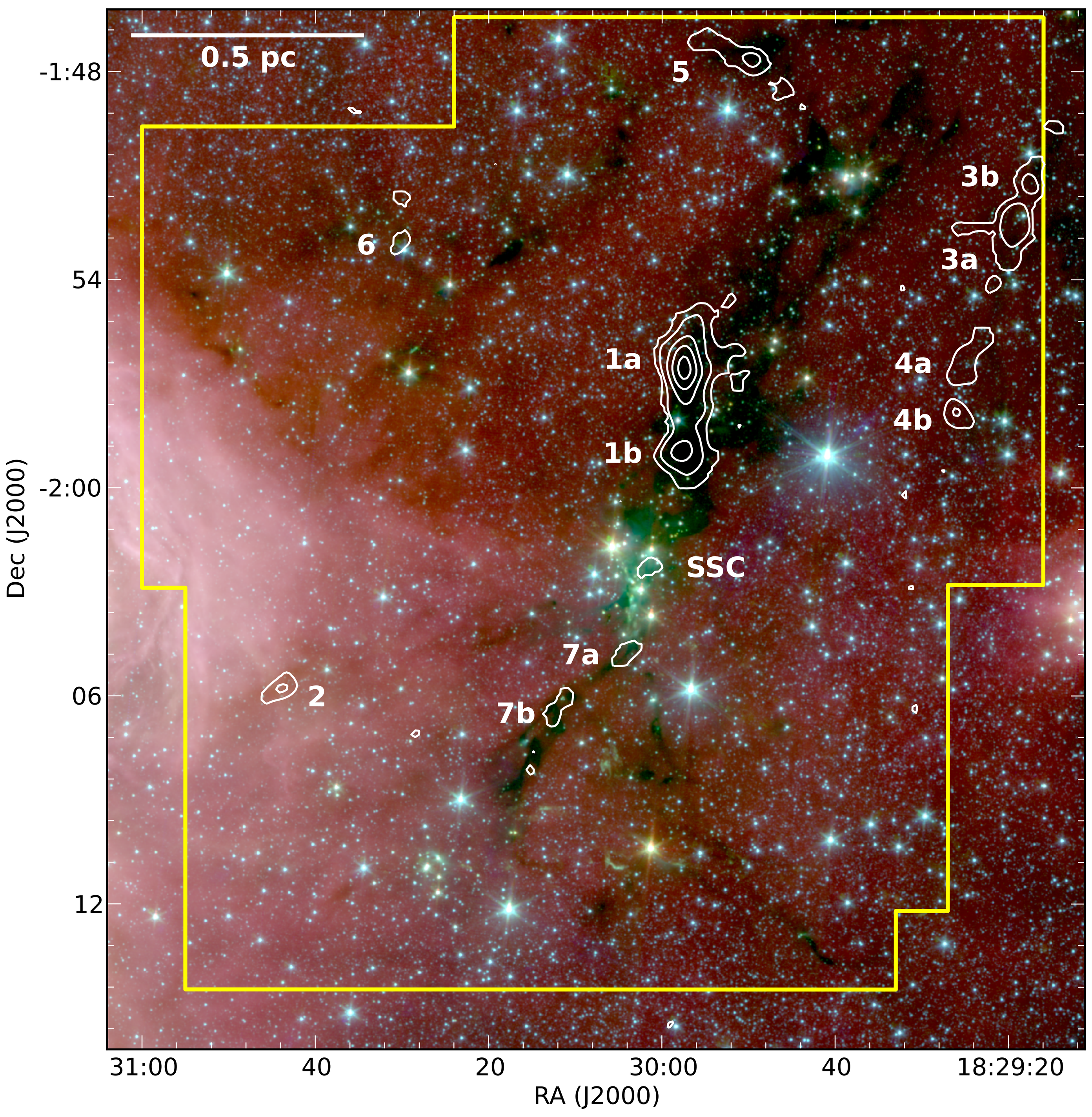
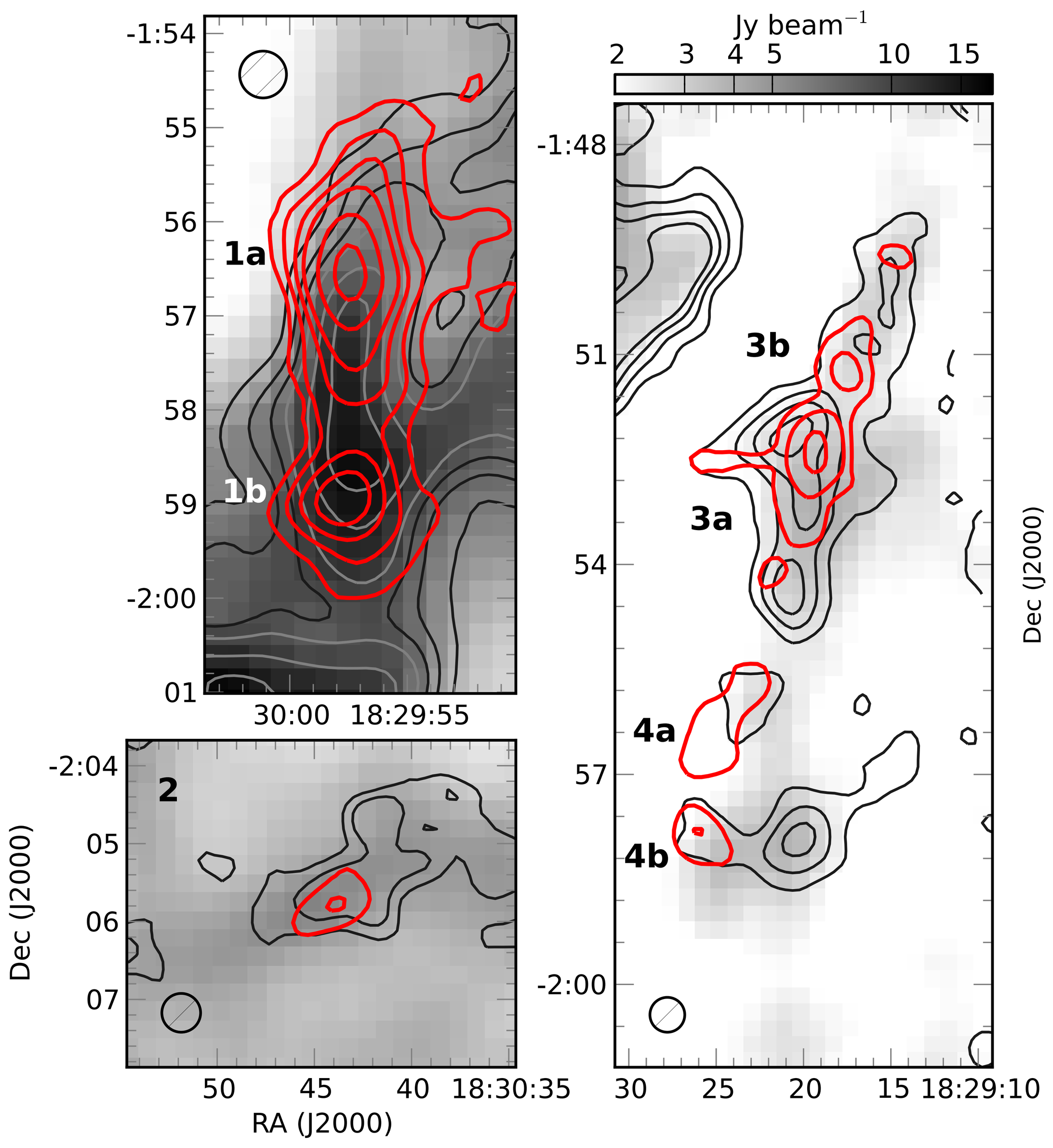


Figure 1 (left): *Spitzer RGB (8 μm, 4.5 μm, 3.6 μm) image of the Serpens South protocluster (Gutermuth et al. 2008). White contours show integrated HC_7N $J = 21-20$ emission at 0.15 K km s^{-1} (4 σ), 0.3 K km s^{-1}, 0.6 K km s^{-1}, 0.9 K km s^{-1}, and 1.2 K km s^{-1}. Individual HC_7N emission peaks are labeled. The physical scale assumes d = 260 pc. Yellow contours show the map extent where the rms noise per velocity channel of width 0.15 km s^{-1} is σ < 0.1 K.*



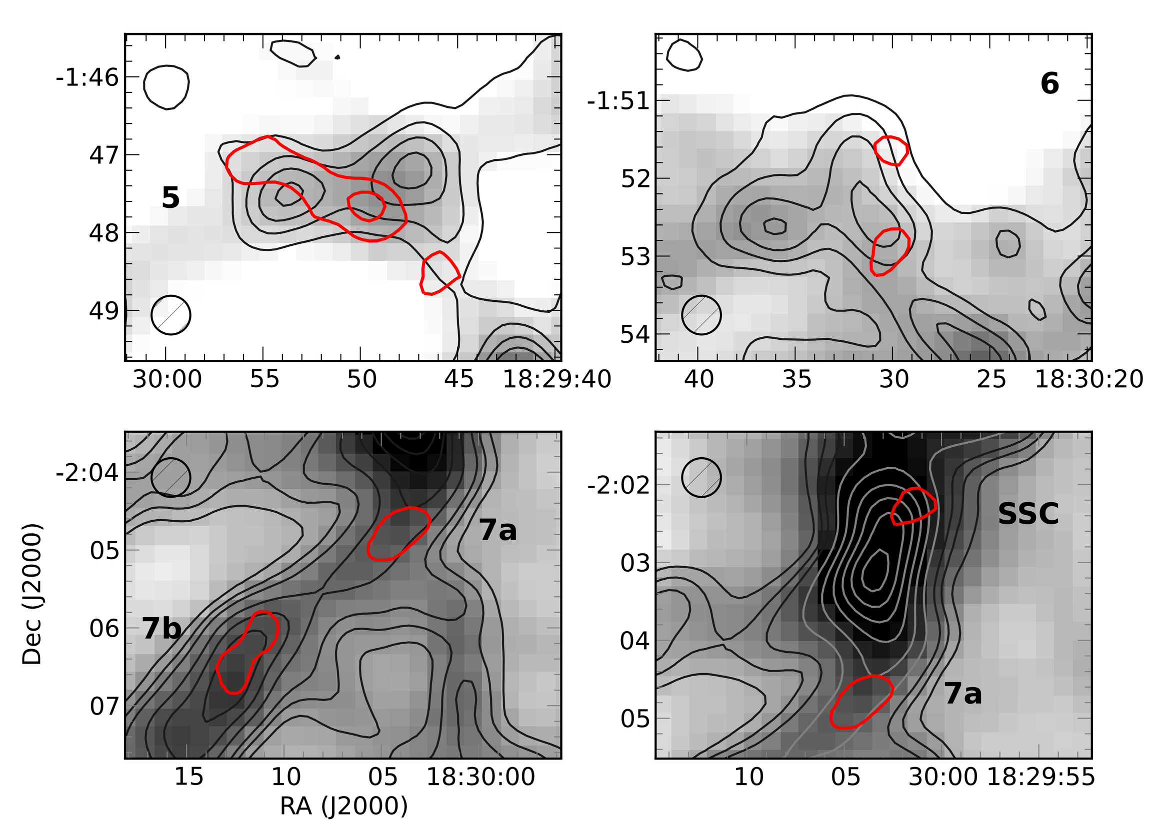


Figure 2: *Herschel SPIRE 500 μm dust continuum emission (greyscale; André et al. 2010) toward HC_7N clumps identified in Figure 1. Overlaid are NH_3 (1,1) integrated intensity contours (grey contours) and HC_7N $J = 21-20$ integrated intensity contours (red, at intervals of 0.15 K km s^{-1}, or 4-σ). The 32" FWHM GBT beam at 23 GHz is shown by the hashed circle in each subplot. The Herschel beam at 500 μm is 36".*

Chemistry: HC_7N emission peaks are rarely co-located with those of either NH_3 or continuum, although the required line excitation conditions are similar. The distribution of HC_7N and NH_3 can be explained through simple chemical models of cold, dense gas: NH_3 has a long formation timescale at a given gas density. Long carbon-chain molecules like HC_7N are produced rapidly in cold, dark clouds, but high abundances are only found well before the models reach a steady-state chemical equilibrium (Herbst & Leung 1989). The relative abundance of NH_3 to HC_7N suggests that the HC_7N is tracing gas that has been at densities $n \sim 10^4\ cm^{-3}$ for timescales $t \sim 1 - 2\times10^5$ yr (Fig. 3).

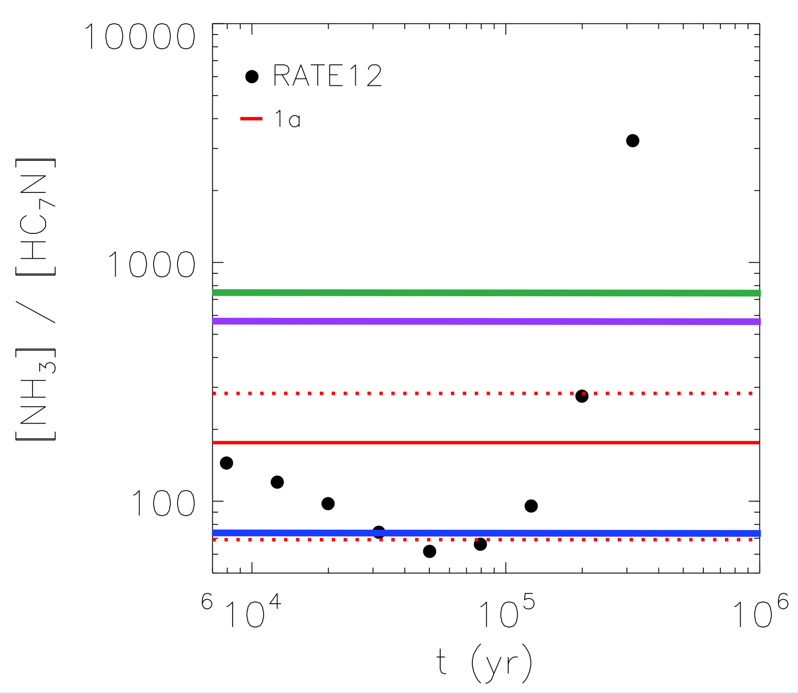


Figure 3: *Black points show predictions from the 'dark cloud' chemical model ($n = 10^4\ cm^{-3}$, T = 10 K, A_V = 10) by McElroy et al. (2013) for the $[NH_3]/[HC_7N]$ ratio as a function of time. Red lines show the mean value (solid) and standard deviation (dashed) for HC_7N clump 1a. Clumps 2, 3a, 3b, 4a, and 4b have mean abundance ratios ~ 70 (blue), while the SSC and 7b show $[NH_3]/[HC_7N]$ ~ 500 - 700 (purple & green lines).*

Is HC_7N tracing infalling material?

Toward the HC_7N clumps 1a and 1b, we find:

- supercritical *M/L* relative to equilibrium, isothermal cylinder
- plane-of-the-sky velocity gradients, pointing to increased $[HC_7N] / [NH_3]$ abundance ratios (Fig. 4a,b)
- coherent variations in v_{LSR} between HC_7N and NH_3 consistent in direction with infall onto a filament (Fig. 4c)
- increased non-thermal line widths relative to NH_3 emission by ~ 0.07 km s^{-1} (Fig. 4d)

Mass accretion rate along filament (from velocity gradients and line widths) ~ 14 $M_\odot\ Myr^{-1}$, comparable to the filament mass of ~ 30 $M_\odot$.

Toward the other HC_7N clumps, we find similar variations in v_{LSR} between HC_7N and NH_3, as well as smooth velocity gradients in the HC_7N emission.

Correlation between velocity and abundance gradients

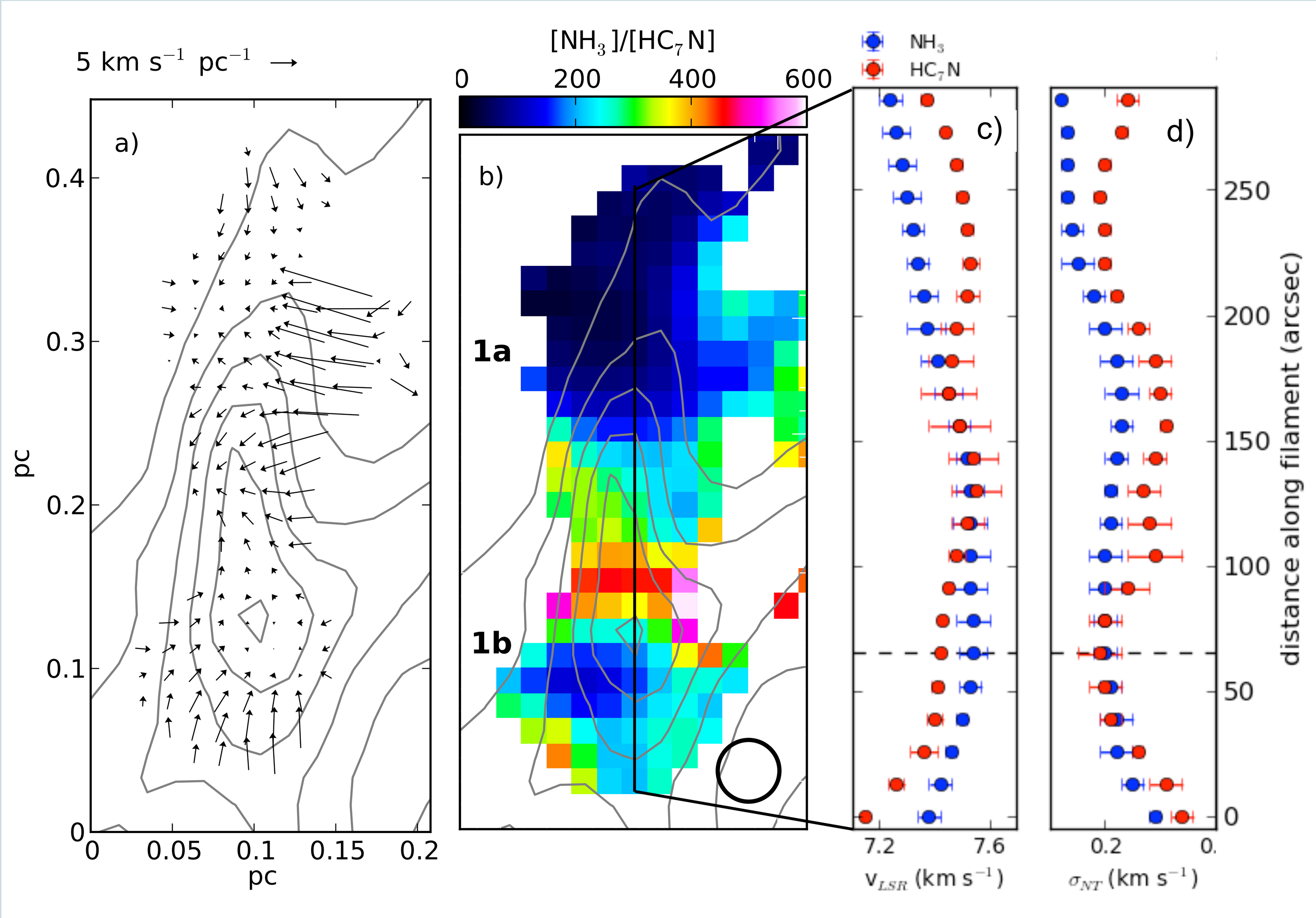


Figure 4: ***a)*** *Gradient in line-of-sight velocity (v_{LSR}) of HC_7N emission toward HC_7N clumps 1a and 1b. In both figures, grey contours show the 1.1 mm continuum emission.* ***b)*** *Map of the $[NH_3] / [HC_7N]$ abundance ratio toward the same region. The circle shows the 32" FWHM beam.* ***c)*** *v_{LSR} derived from fits of NH_3 (blue symbols) and HC_7N (red symbols) averaged in increments of 13" in declination along a line of constant R.A. that follows the filament axis (shown in black). Error bars show the 1−σ spread in values along the perpendicular (R.A.) axis.* ***d)*** *The non-thermal line width, σ_{NT}, for NH_3 (blue symbols) and HC_7N (red symbols) along the filamentary axis.*

The simultaneous mapping of HC_7N with NH_3 has allowed us to detect HC_7N at low abundances in regions where it otherwise may not have been looked for. HC_7N reveals newly dense material in the cluster, either through recent accretion onto existing dense cores or newly-formed cores, and facilitates further analysis of how filaments form and accumulate mass. Serpens South is also an ideal target to study long carbon chain and molecular ion chemistry.

References:

André et al. 2010, A&A 518, 102 • Friesen et al. 2013, MNRAS, submitted • Gutermuth et al. 2008, ApJ, 673, 151 • Herbst & Leung. 1989, ApJS, 69, 271 • McElroy et al. 2013, A&A, 550, 36