Initial Conditions of Star Cluster & Solar System Formation

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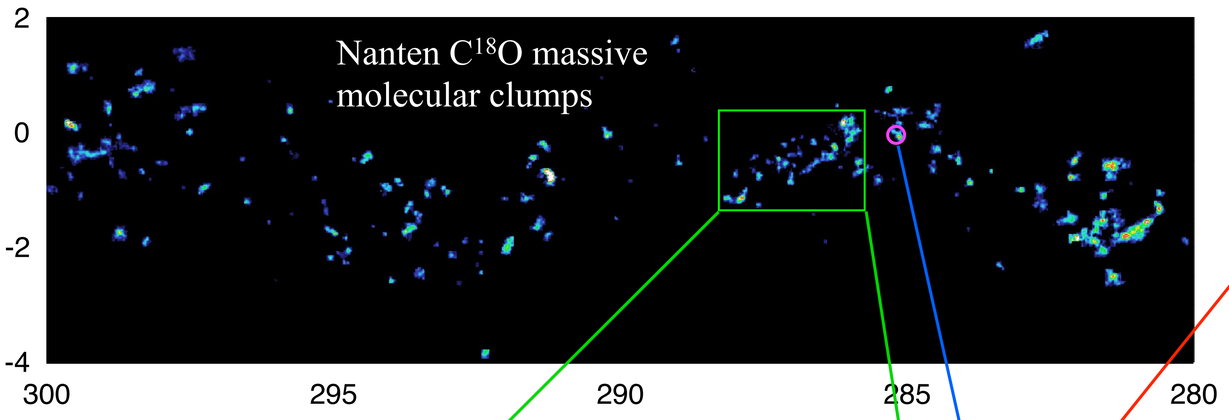
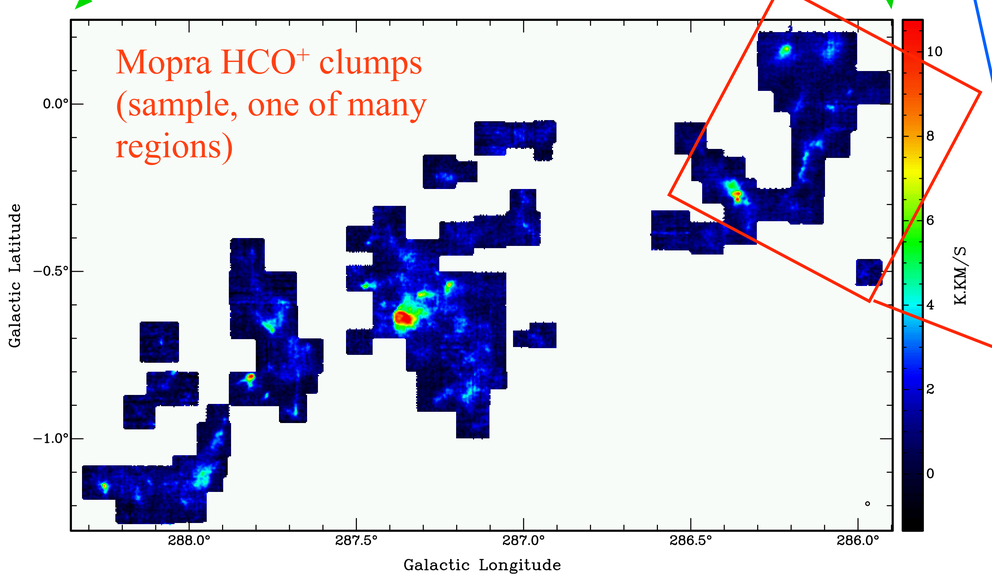


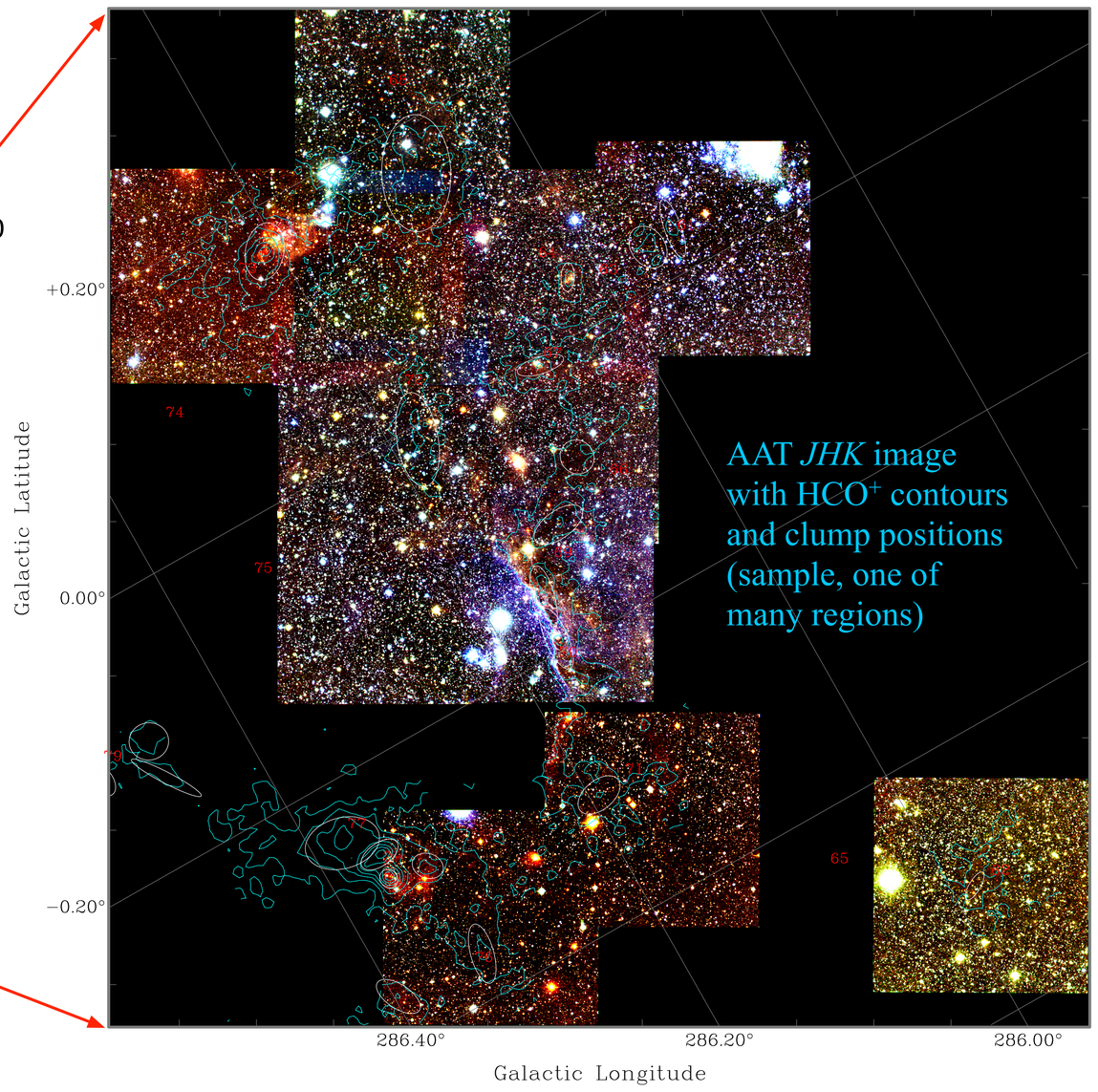
1. CHaMP: The Galactic Census of High- and Medium-mass Protostars

Starting point: Nanten maps of 20°×6° area in J=1–0 lines of $C^{18}O$ (shown above), plus ^{12}CO, ^{13}CO, HCO^+, at 4′ resolution: 209 massive molecular clumps from $C^{18}O$ and HCO^+ maps — the Nanten Master Catalogue (NMC).

Detailed multi-wavelength follow-up 1: Mopra maps of 121/209 brightest NMC clumps in ~40 molecular lines near 90 and 110 GHz, simultaneously including HCO^+, HCN, N_2H^+, $C^{18}O$, ^{13}CO, ^{12}CO, etc, at 40″ resolution (eg, HCO^+ map of η Carinae GMC shown below). In HCO^+, NMC clumps break up into 303 Mopra clumps — the BYF catalogue: a flux-limited, uniform, complete, unbiased sample of massive, dense clumps.



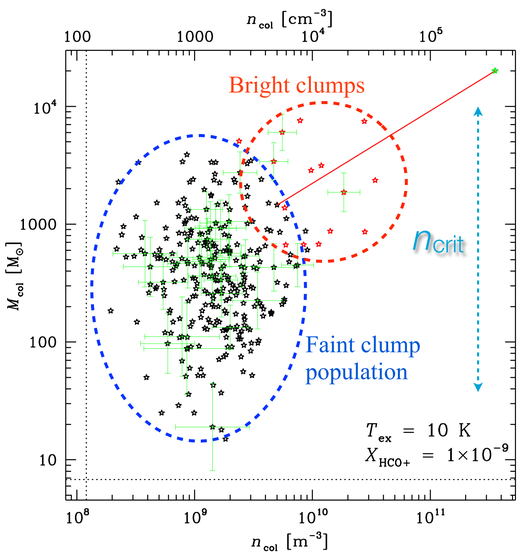
Detailed multi-wavelength follow-up 2: AAT near-IR images of all 300 BYF clumps in *JHK* broadband (below, closeup of portion of η Carinae GMC as *JHK* colour-composite overlaid by HCO^+ contours), **PLUS** 3 narrowband filters (Brackett-γ, H_2 $S(1)$ v=1→0, and v=2→1) for all clumps. In these bands we see the evidence of cloud disruption and heating by the embedded YSO content.

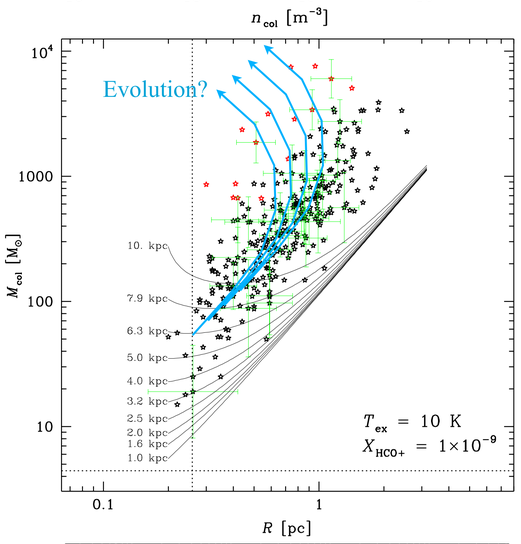


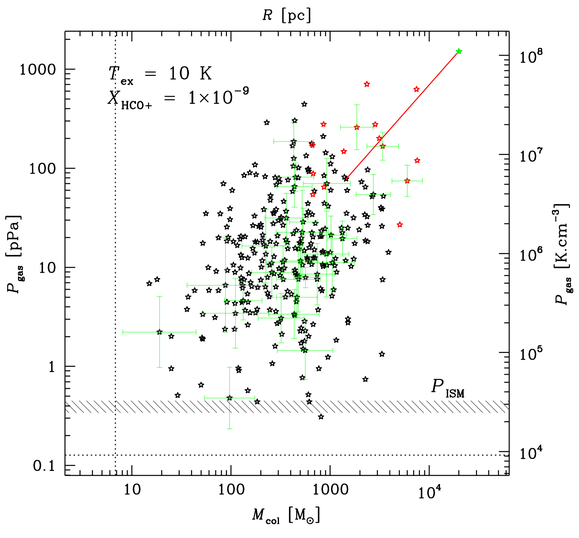
2. Millimetre-Wave Results

HCO^+

- integrated line intensity 1–30 K km/s
- peak line brightness 1–7 K
- linewidth 1–10 km/s
- integrated line luminosity 0.5–200 K km/s pc²
- FWHM size 0.2–2.5 pc
- mean projected axial ratio 2 : **similar to clusters**
- optical depth 0.08–2 : **low**
- total surface density 30–3000 $M_\odot$/pc²
- number density (0.2–30) × 10⁹/m³ : **much less than n_{cr}!**
- mass 15–8000 $M_\odot$: **massive**
- virial parameter 1–55 } **pressure confined?**
- total gas pressure 0.3–700 pPa }
- no Larson-type size–linewidth relation
- clumps are long-lived, probably > 50 Myr





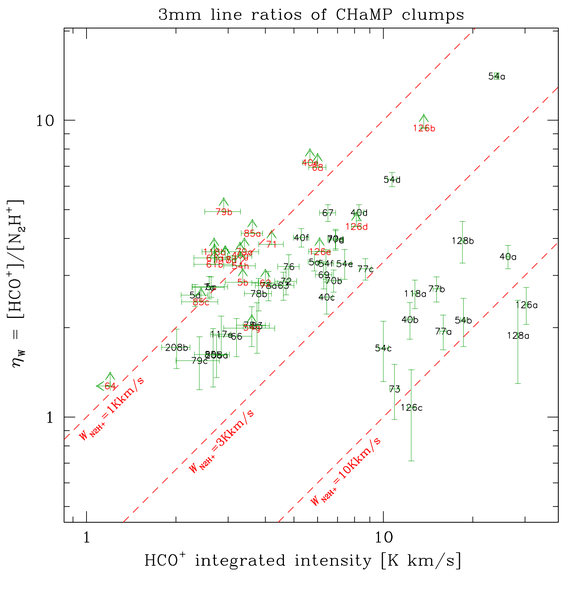


Summary

- 95% are subthermally excited, massive, & dense, unlike typically studied bright star-forming regions
- the fainter clumps may represent a long-lived stage of pressure-confined, gravitationally stable massive clump evolution, and clumps may not engage in vigorous massive star formation until the last 5% of their lifetimes

N_2H^+ vs. HCO^+

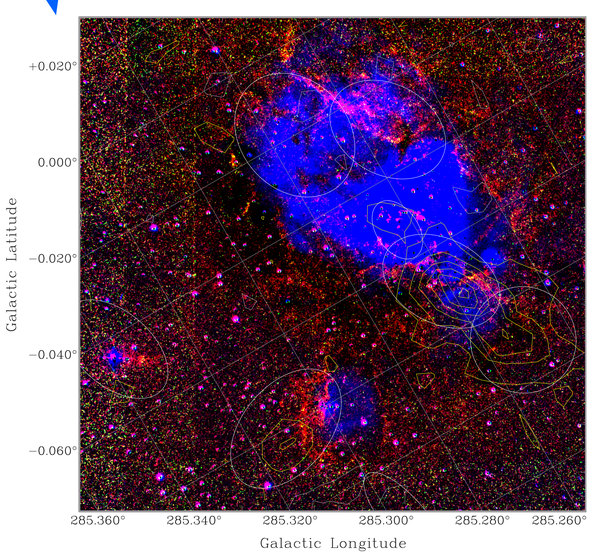
- morphology similar, but line ratio varies strongly between clumps: WHY??? The IR is the key....



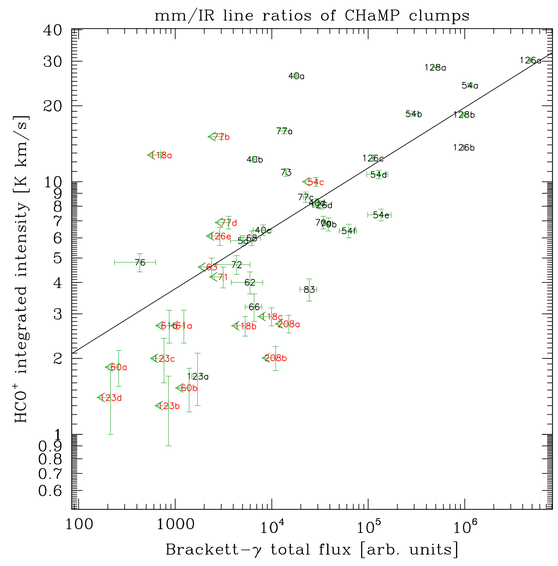
3. Near-IR Results

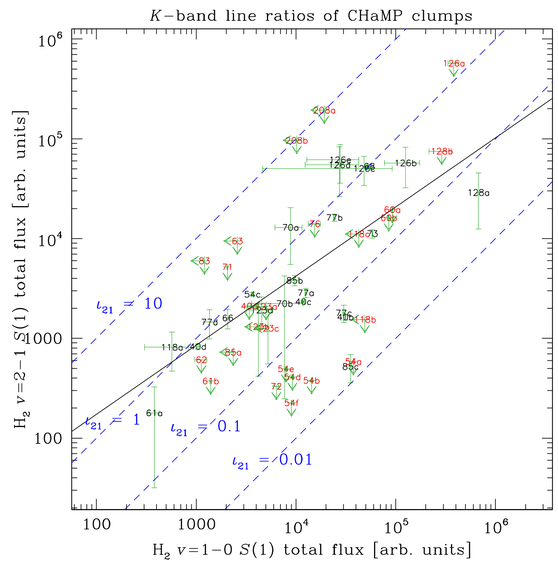
(for first 20% of BYF catalogue)

- HCO^+ strongly correlated with Br-γ emission, but not with H_2 emission: "dense gas tracers" do not trace dense gas, but a combination of column density and excitation
- N_2H^+ not correlated with Br-γ or H_2; actually avoids Br-γ emission
- line ratios show most H_2 emission is fluorescent
- HCO^+/N_2H^+ line ratio is correlated with Br-γ: ionisation also destroys N_2H^+ while enhancing HCO^+



Sample composite image of *K*-narrowband filters H_2 $S(1)$ v=1→0 (red), v=2→1 (green), and Br-γ (blue), overlaid by Mopra N_2H^+ emission (yellow contours) and HCO+ clump positions (white ellipses). Note how the N_2H^+ tends to avoid the strong Br-γ, as if hiding behind the ionisation fronts (between the Br-γ and H_2 emission).





4. Implications

Massive clumps live long, quiescent lives before massive star formation starts, slowly accumulating mass and increasing their density. During this period they have time to form low-mass stars at a low rate, and see their N_2H^+ abundance rise as the cloud condenses and cools. Once a density threshold is crossed, a cluster forms with massive star(s), which then chemically alters, heats, ionises, and drives off the gas.

Therefore, if most stars (including low-mass stars) form in clusters, many solar systems around low-mass stars could show evidence of their natal cluster's final birth pangs, in the presence of a strong UV field.

Papers

Yonekura et al (2005) *ApJ* **634** 476 — η Carinae GMC clumps
Barnes et al (2010) *MNRAS* **402** 73 — Massive protostellar cluster
Barnes et al (2011) *ApJS* **196** 12 — BYF clump catalogue
Barnes et al (2013) *MNRAS* accepted — mm and IR signposts of evolution
Ma et al (2013) *ApJ* submitted (arXiv:1211.6492) — SEDs of clumps

More background information, maps, images, and all data files (including all derived physical parameters) are available at the CHaMP website, www.astro.ufl.edu/champ