# Initial Conditions of Star Cluster & Solar System Formation

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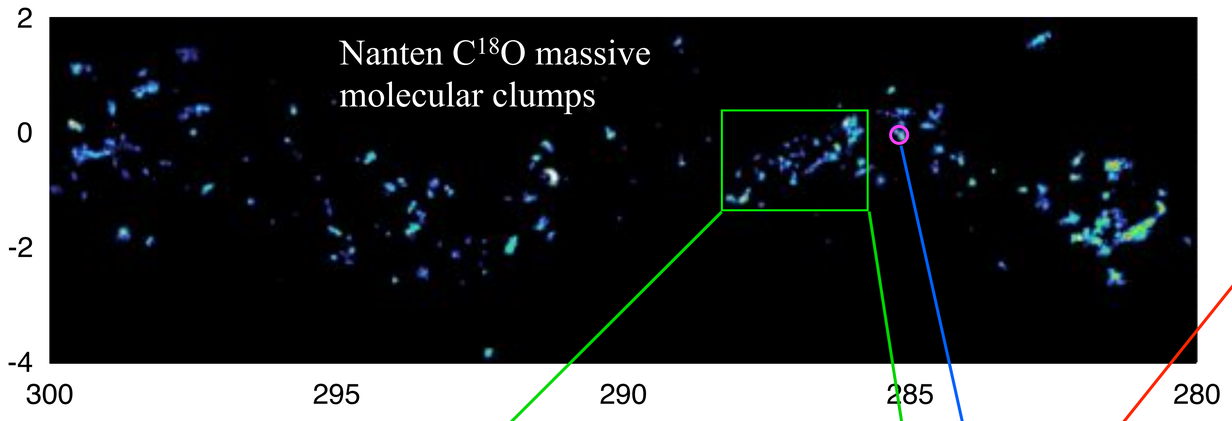
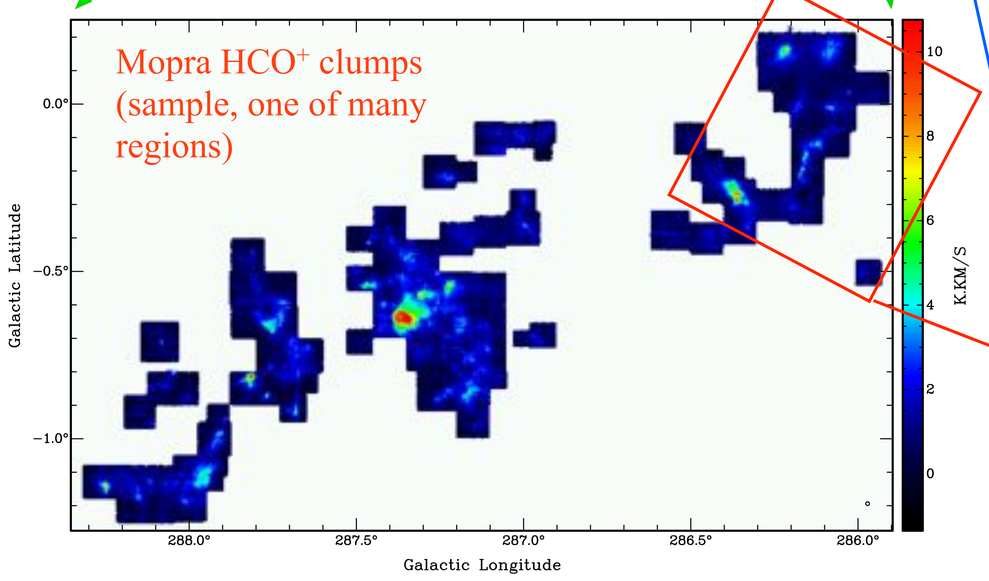


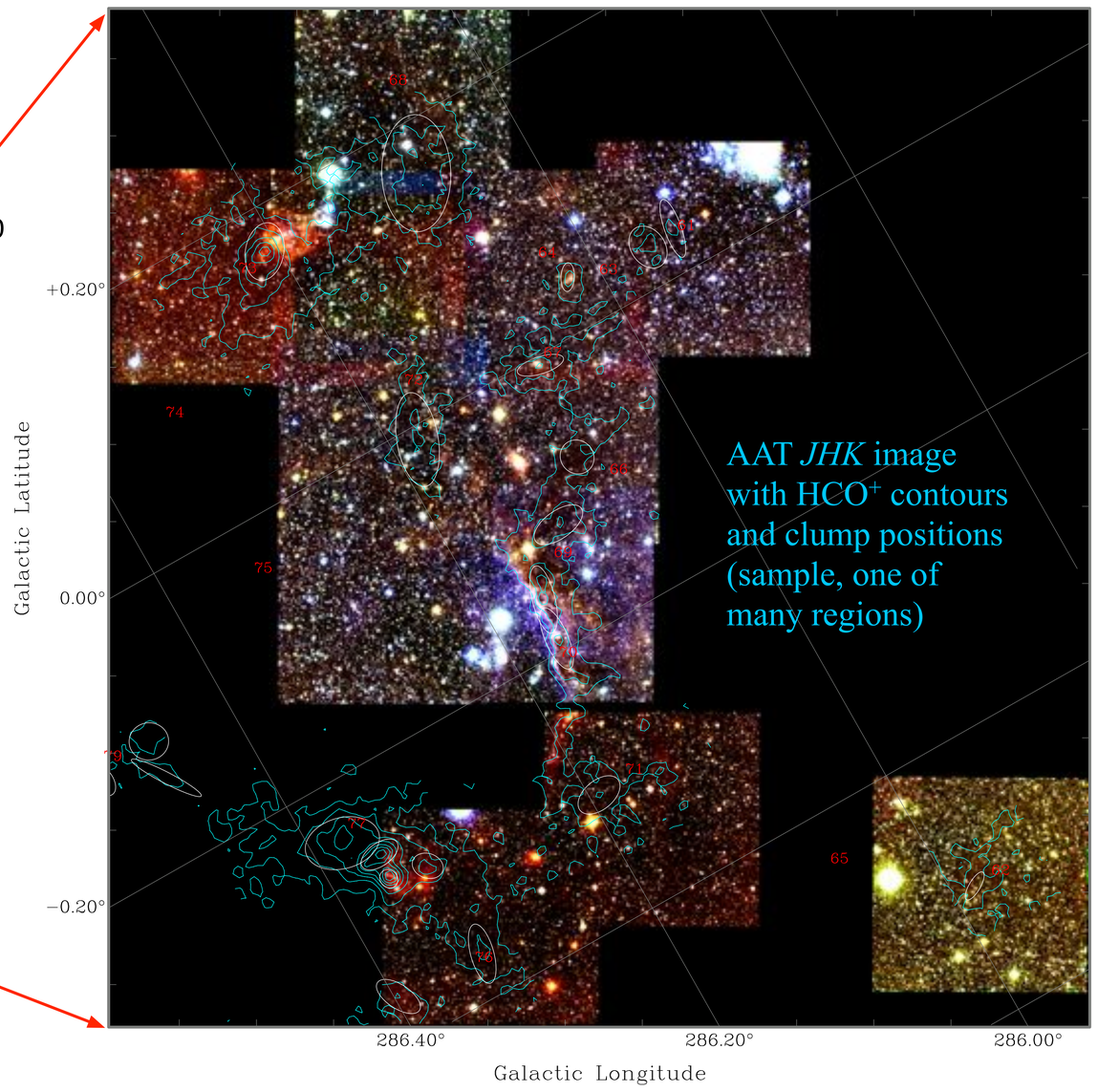

## 1. CHaMP: The Galactic Census of High- and Medium-mass Protostars

***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.



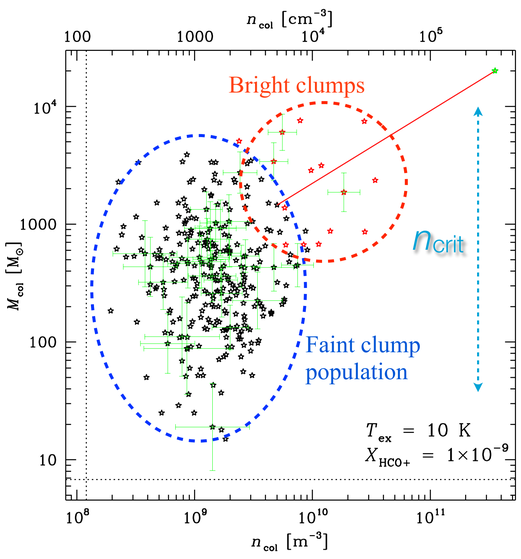

***Detailed multi-wavelength follow-up 2:*** AAT near-IR images of all 300 BYF clumps in *JHK* broadband (below, closeup of portion of η Carinae GMC as *JHK* colour-composite overlaid by $HCO^+$ contours), **PLUS** 3 narrowband filters (Brackett-γ, $H_2$ $S(1)$ $v$=1→0, and $v$=2→1) for all clumps. In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

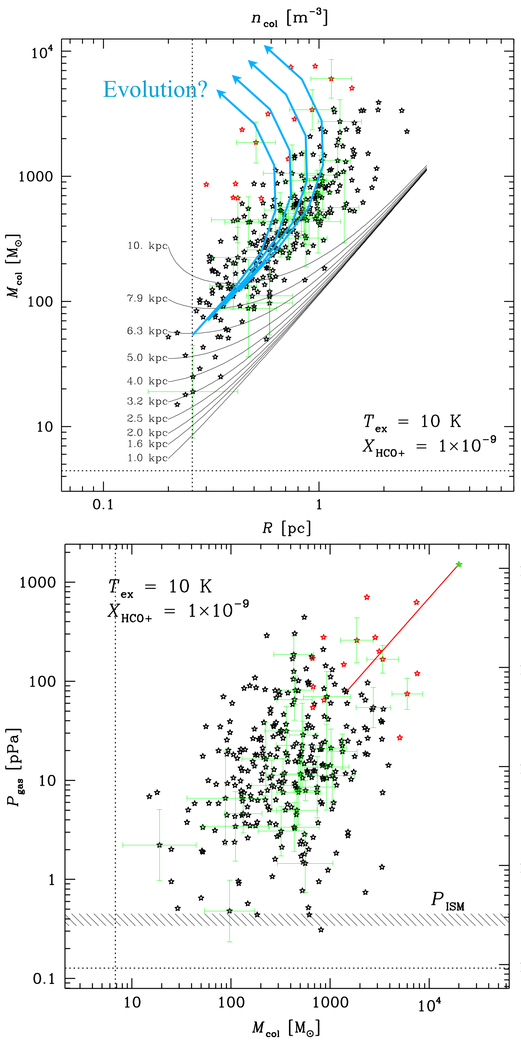



## 2. Millimetre-Wave Results

**$HCO^+$**

- 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





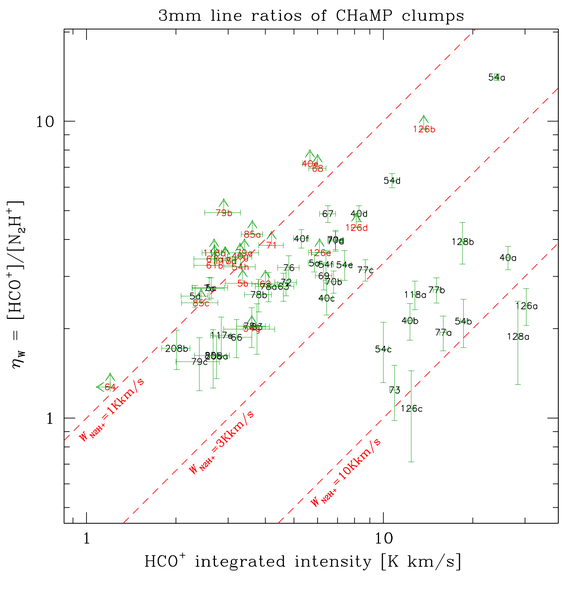


**Summary**

- 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. $HCO^+$**

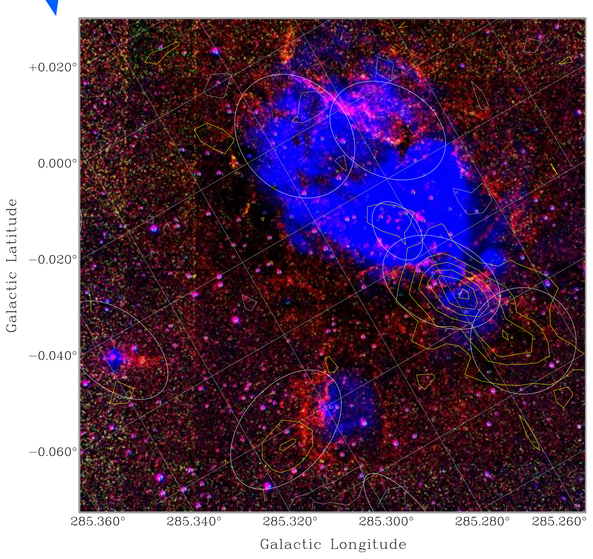
- morphology similar, but line ratio varies strongly between clumps: WHY??? The IR is the key....



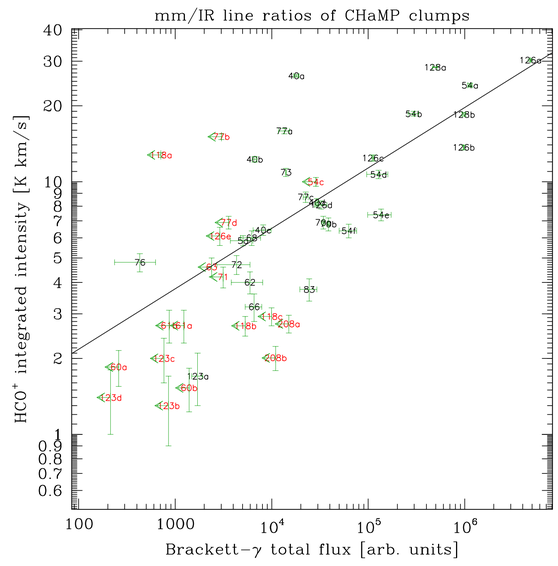

## 3. Near-IR Results

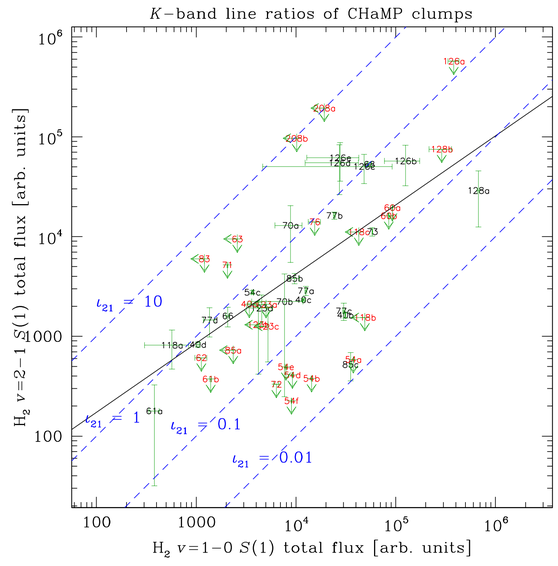
(for first 20% of BYF catalogue)

- $HCO^+$ 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