Tracing the Flow in Massive Molecular Clumps: New Results from CHaMP

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plus

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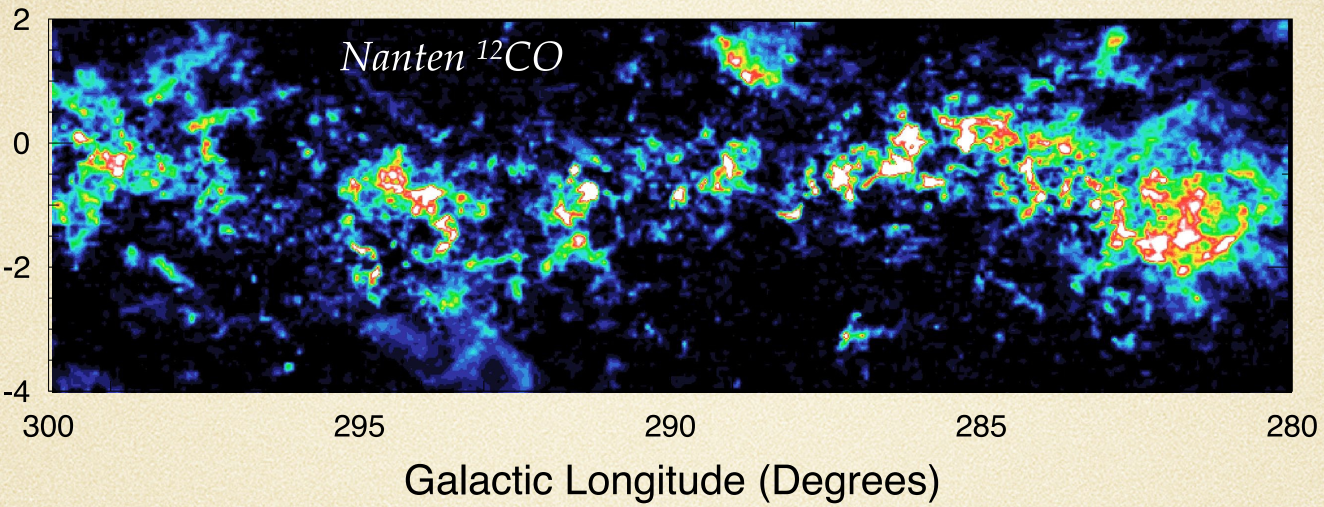
Billy Schap, Erik Muller, Frank Varosi, Dan Li, Sarik Jeram, Kyle Chamblee, many others

Tracing the Flow, Windermere, 3 July 2018

Overview of CHaMP (Census of High- and Medium-mass Protostars)



- Started in 2002 with Nanten maps, first **demographic** approach to massive SF
- Unbiased Mopra survey of all massive clumps in 120 deg^2, simultaneous imaging in 35 species: 86–93 GHz (data collection 2004–07) and 107–115 GHz (2009–2015)
- Resolution 37″ = high spatial dynamic range, and high sensitivity 0.3–0.4 K in 0.1 km/s channels
- Follow-up work with AAT, Gemini-S, SOFIA, archival data
- Published data available

Results to date

- Yonekura et al 2005: first Nanten mapping of η Carinae GMC and cores
- Barnes et al 2010: discovery of **massive global infall** in BYF 73
- Zhang et al 2010: origin of **radio-FIR correlation** in the Milky Way
- Barnes et al 2011: first Mopra maps & HCO^+ clump catalogue, a vast population of starless clumps, implied **long latency periods** for MSFR
- Barnes et al 2013: AAT NIR signposts of MSFR, strong **correlation between HCO^+, Brγ** ~~dense gas~~ → post-SF feedback indicator
- Ma et al 2013: first clump SED analysis
- Barnes et al 2016: ^{12}CO maps & clump catalogue, **pressure confinement** of clumps, supporting long latency periods, clumps as **base unit** (70-80% of mass) of GMCs
- Schap et al 2017: HCN analysis, **high column/subthermal** gas, confirming post-SF feedback status
- Andersen et al 2017: VLT NIR stellar content of BYF 73

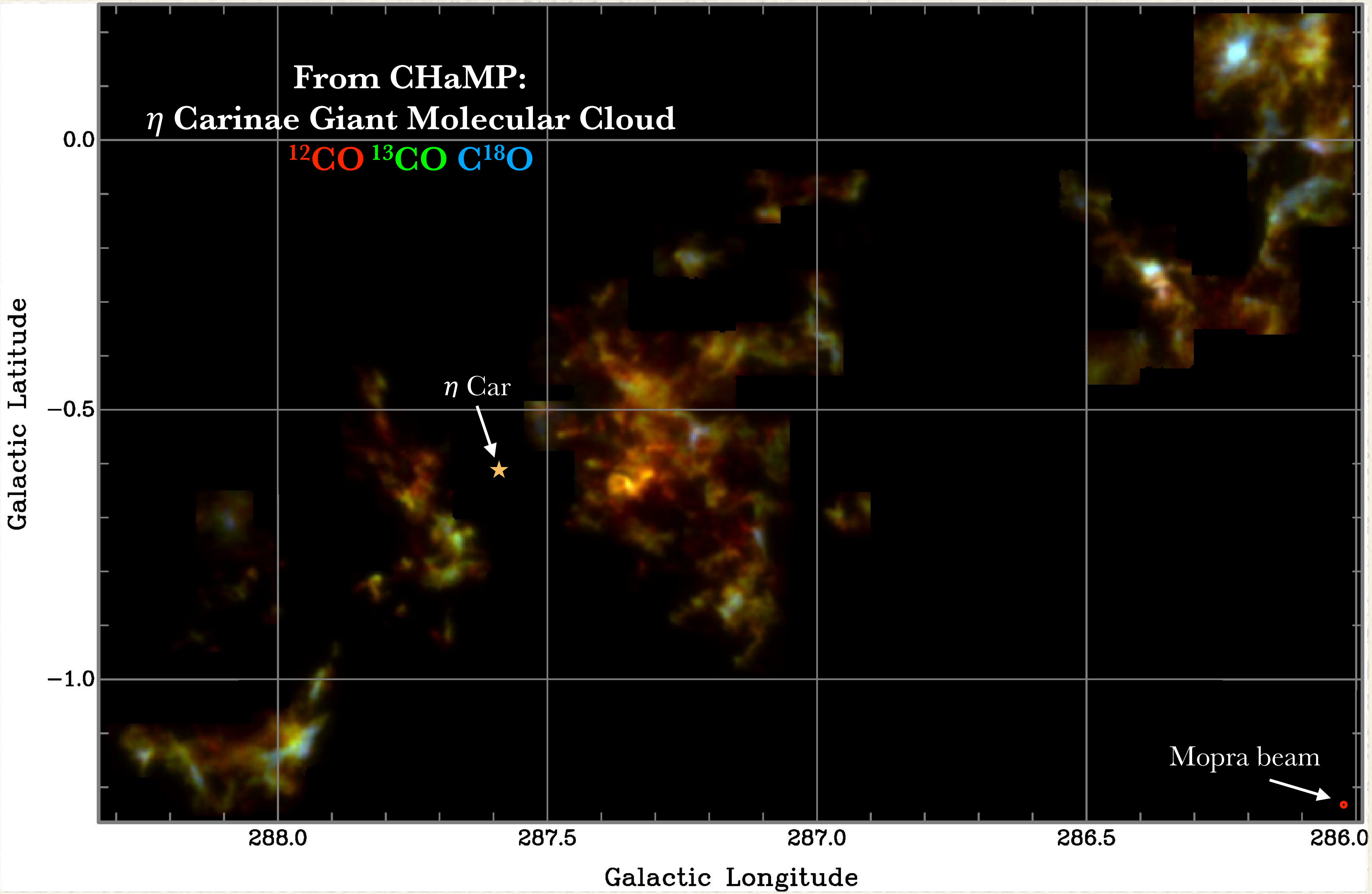
Highlights from recent papers

- Barnes, Hernandez, Muller, & Pitts 2018, ApJ, accepted:
  - full iso-CO radiative transfer solutions for 36 Regions
  - differential kinematics & dynamics
  - directly observer mass accretion/dispersal fluxes & timescales

- Pitts, Barnes, & Varosi 2018a, MNRAS, submitted:
  - FIR SED fitting and dust T/N maps for 5 Regions
  - CO abundance variations
  - L/M is a function of T alone
  - clumps have only 4 morphotypes in T/abundance

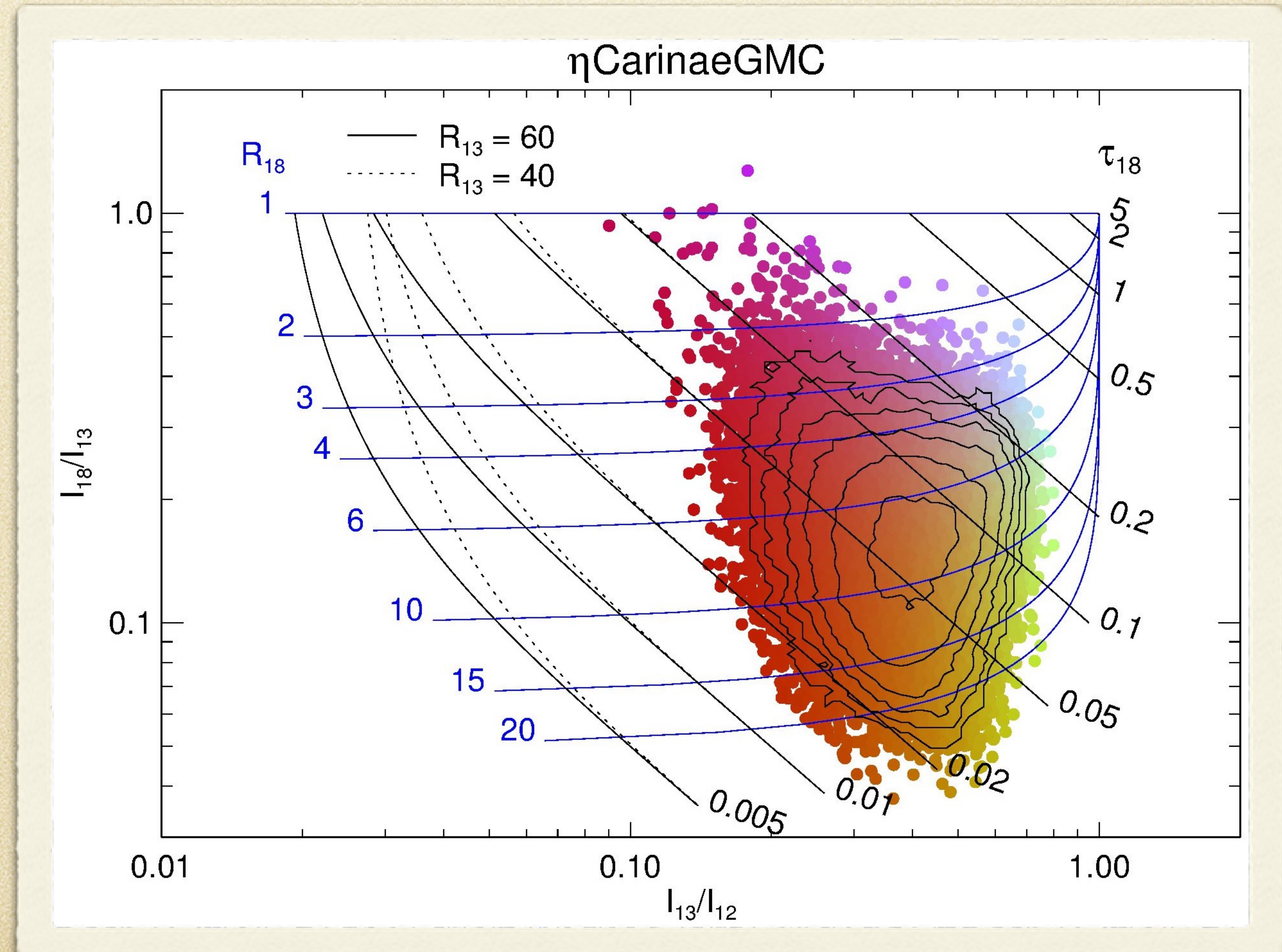
- Pitts, Barnes, Ryder, & Li 2018b, ApJL, submitted:
  - case study of one clump with SOFIA & Gemini-S

Insights from radiative transfer



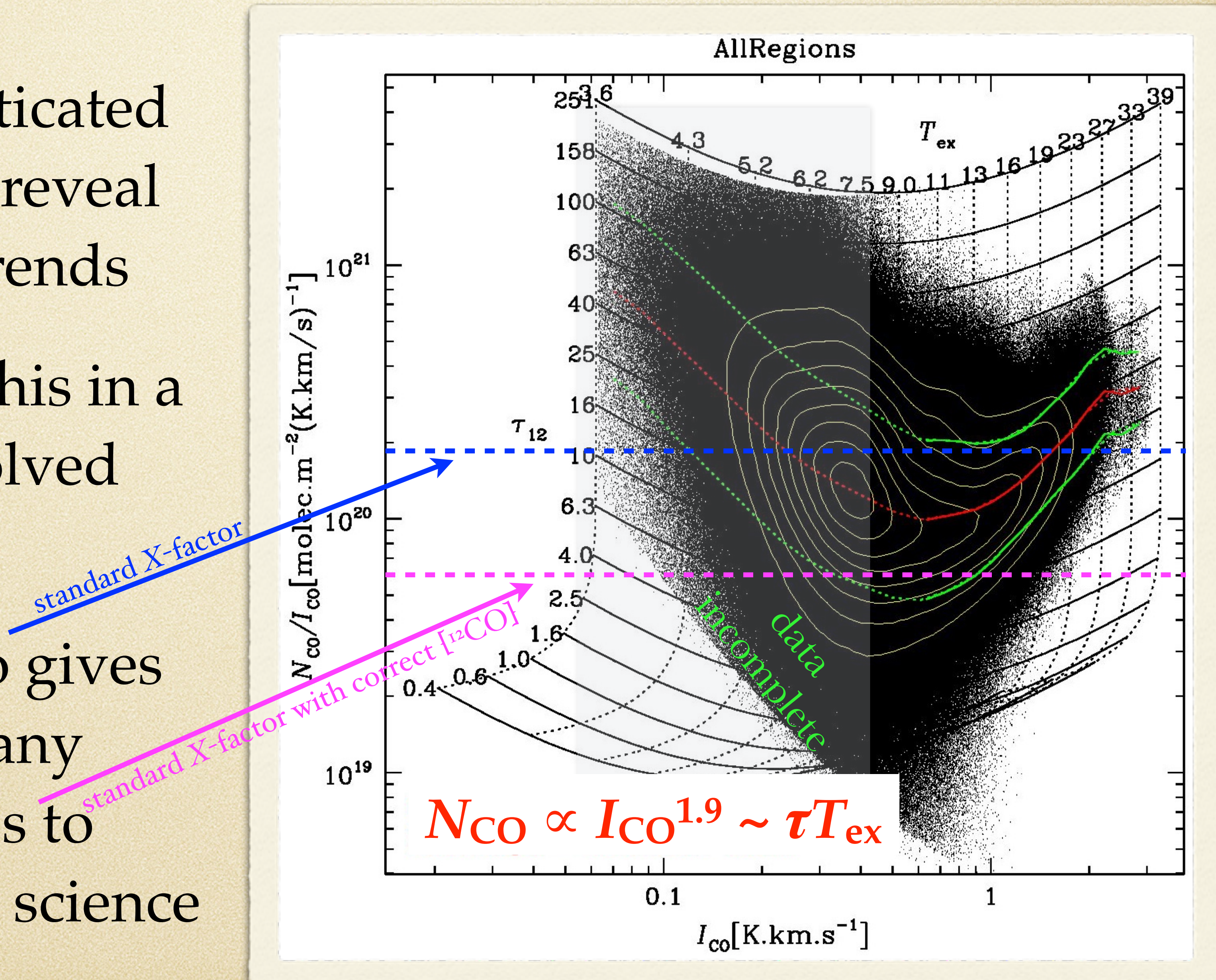
From line ratios to column densities

- Physical parameters spatially variable, so solve for τ and T_{ex} per voxel via plane-parallel radxfer
- Column density depends on **both** τ and T_{ex} , compute it directly



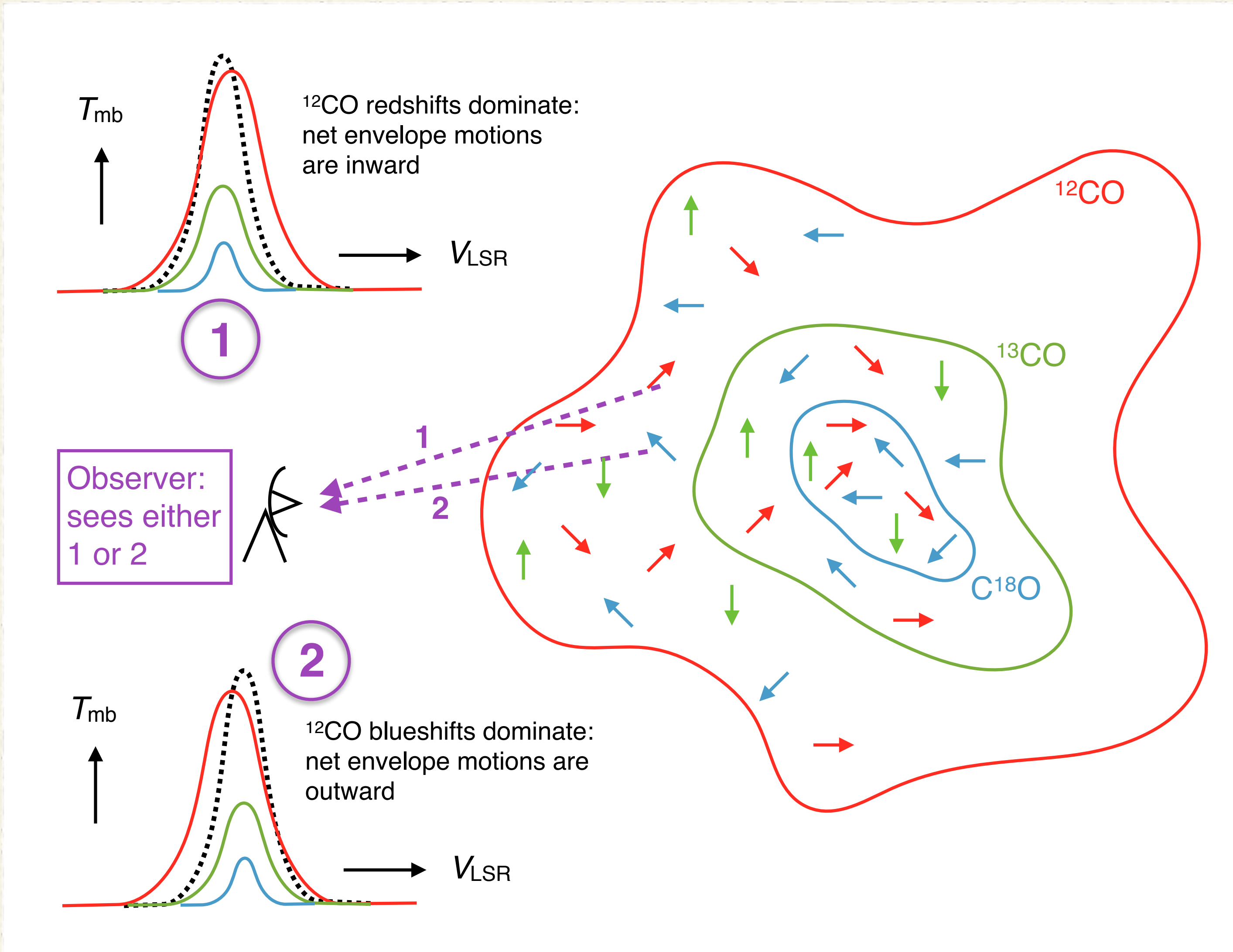
Surprise! Conversion laws transformed, and resolution in 3D Matters

* More sophisticated analysis can reveal interesting trends
* Need to do this in a velocity-resolved manner
* Not doing so gives wrong N: many consequences to downstream science



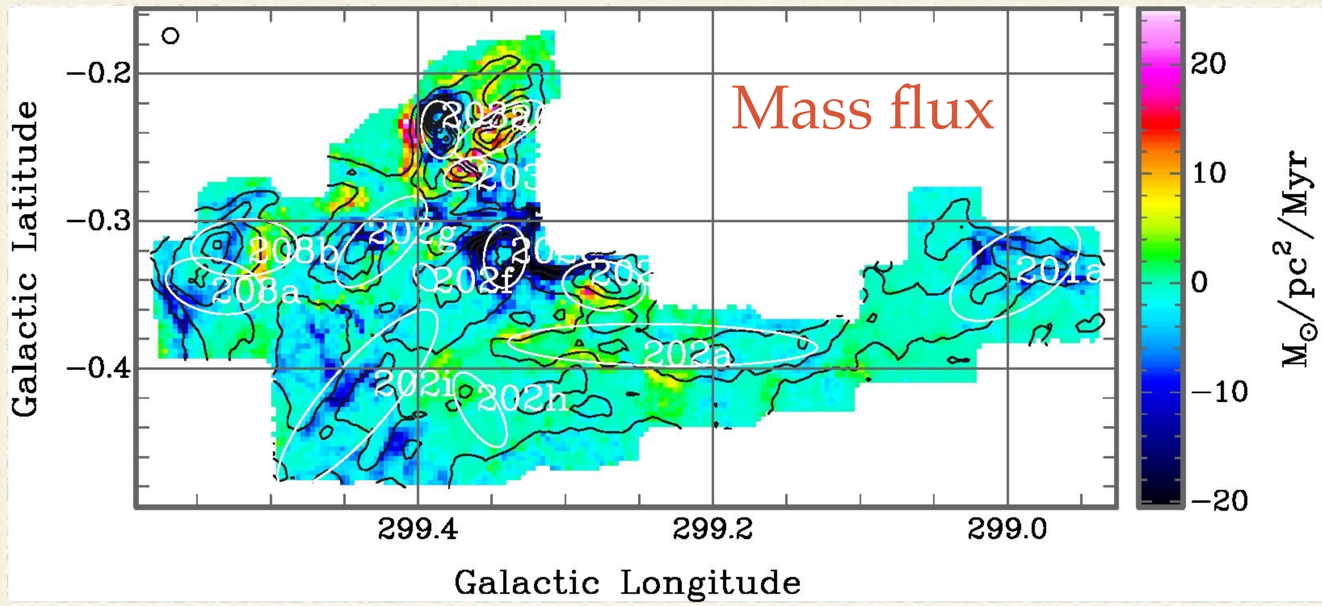
Apply to envelopes vs. interiors

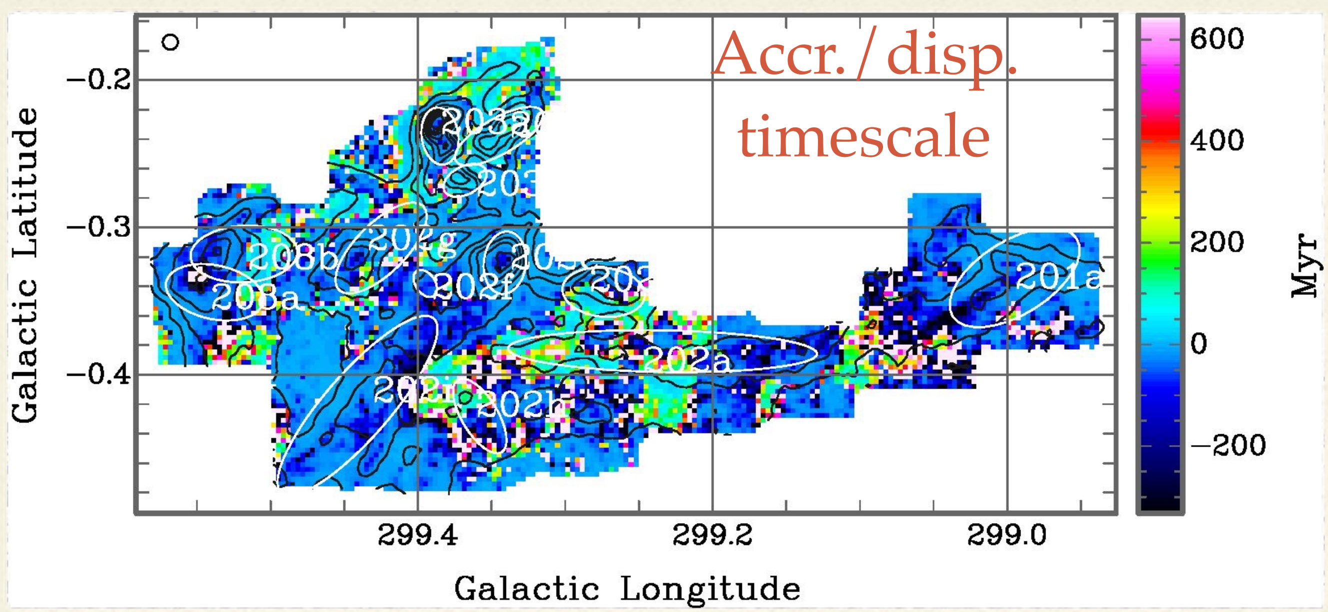
- Compare ^{12}CO envelope material with interior N
- Evaluate mass/momentum distributions separately



Differential dynamics

- Although this is just a snapshot, we see direct evidence of cloud ***mass assembly and dispersal***
- All this points to a larger gas reservoir, longer depletion/SF timescales, other consequences



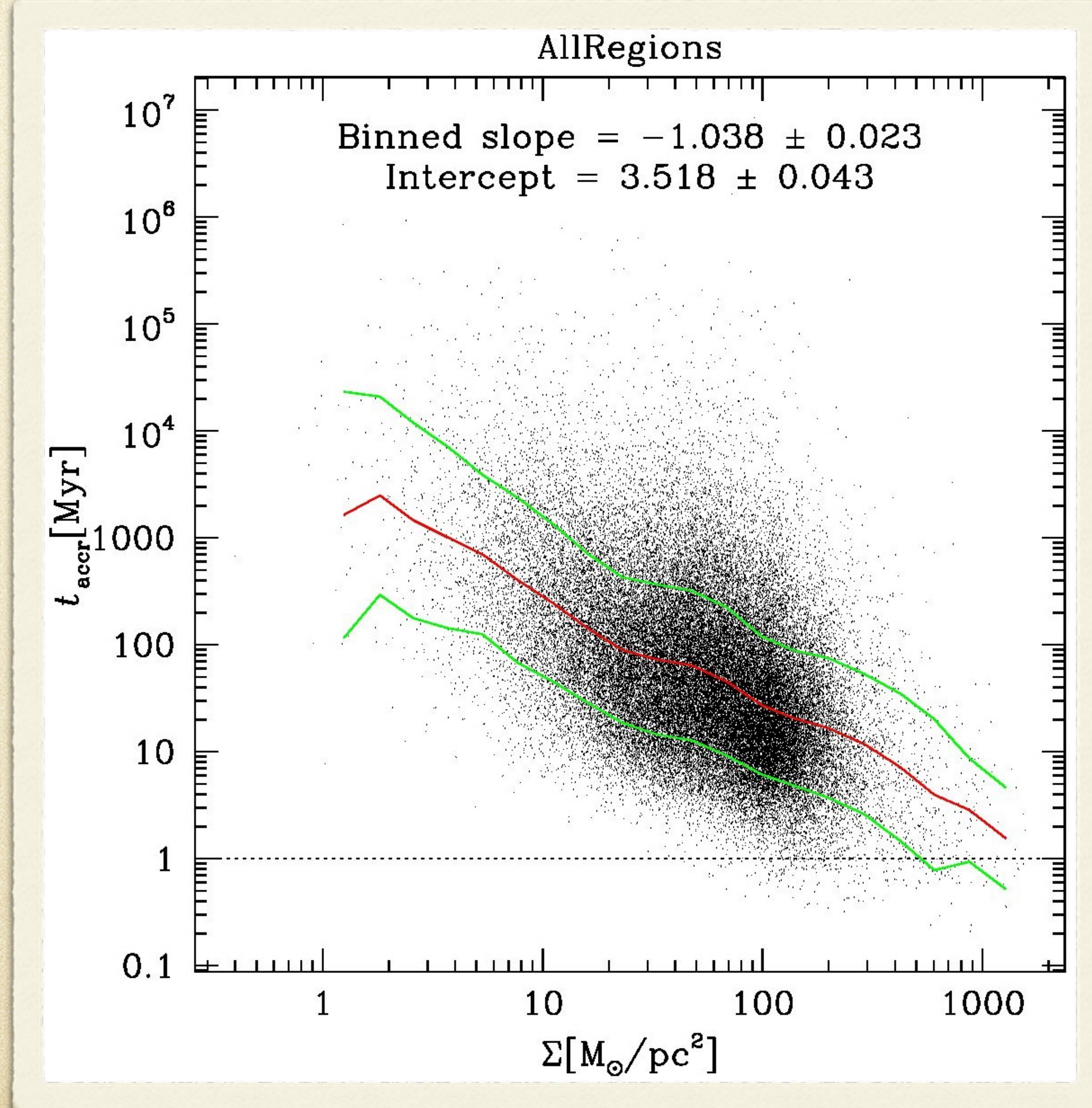


Another surprise

* Molecular clouds are both accreting and losing mass in a locally random way
* Global average timescale for accretion, across many clumps, depends on Σ :

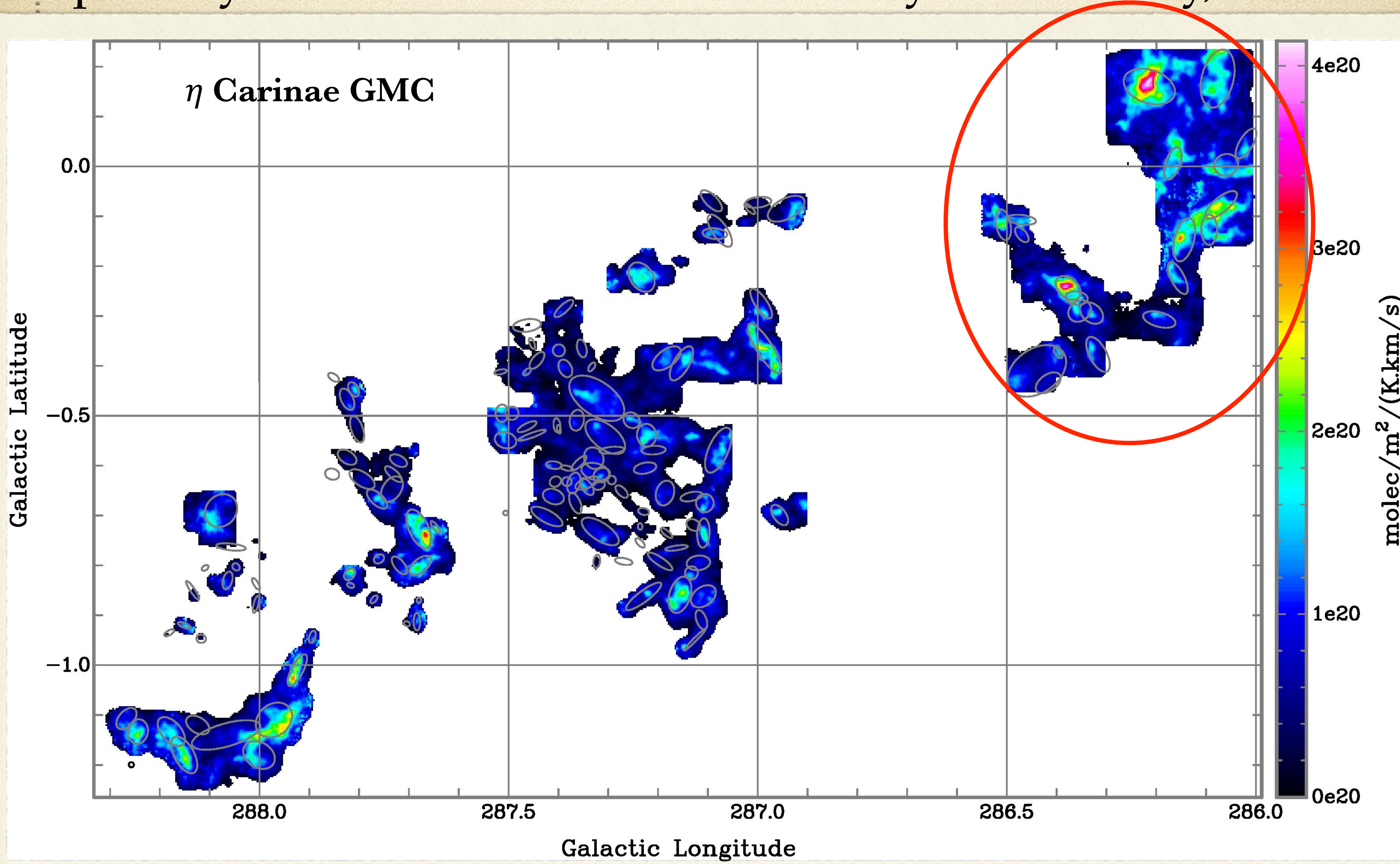
$$\Sigma(t) = \Sigma_{\mathrm{mol}}\, e^{t/16\mathrm{Myr}}$$

* See B+18, arXiv: 1806.00492



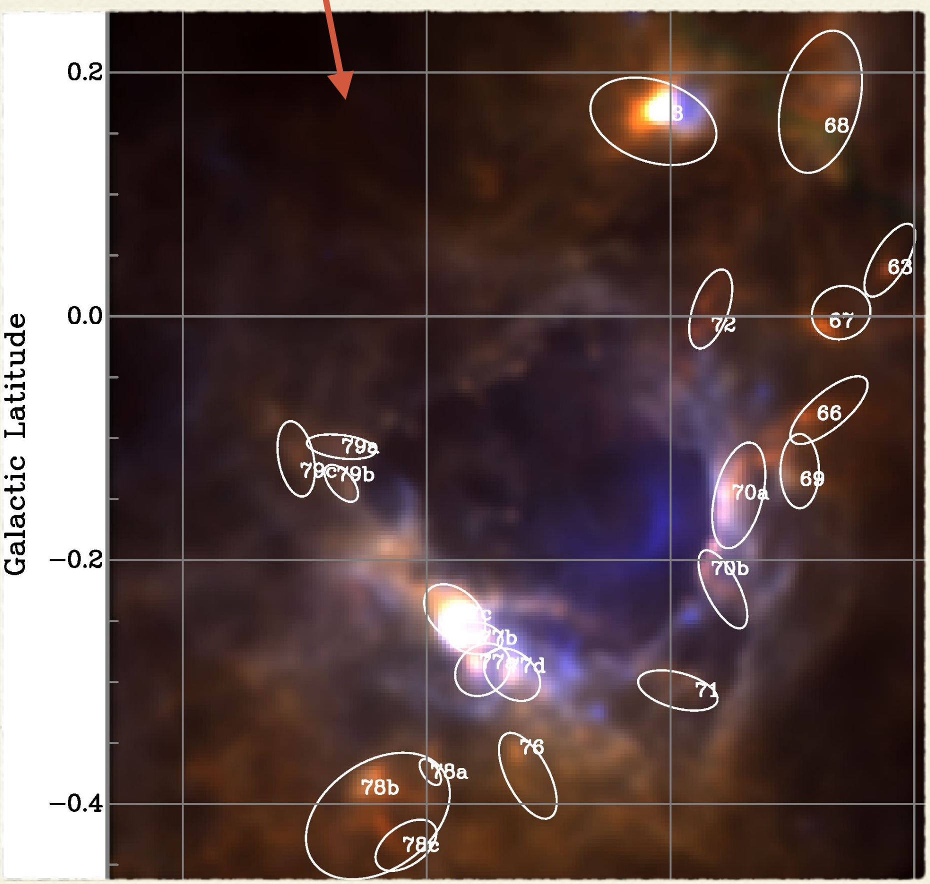
Consequences

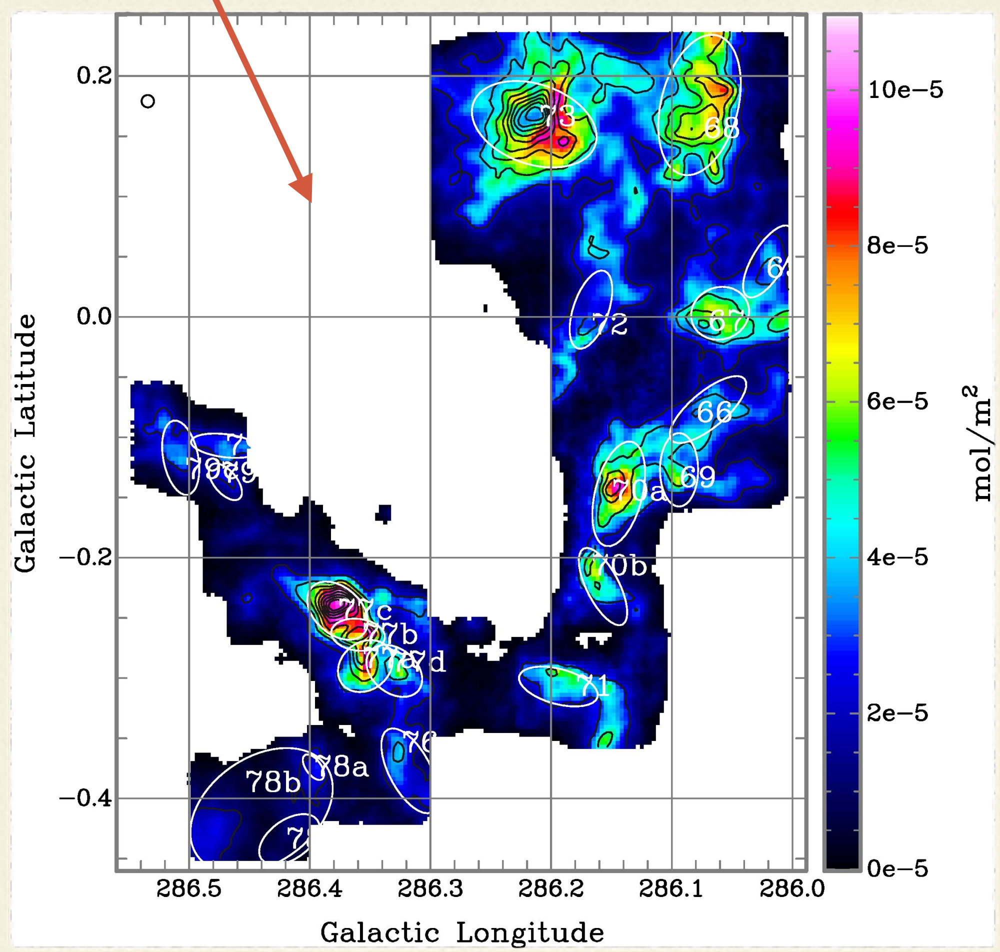
* Spatially-resolved X-factor: it varies systematically, **a lot!**



Even more surprises

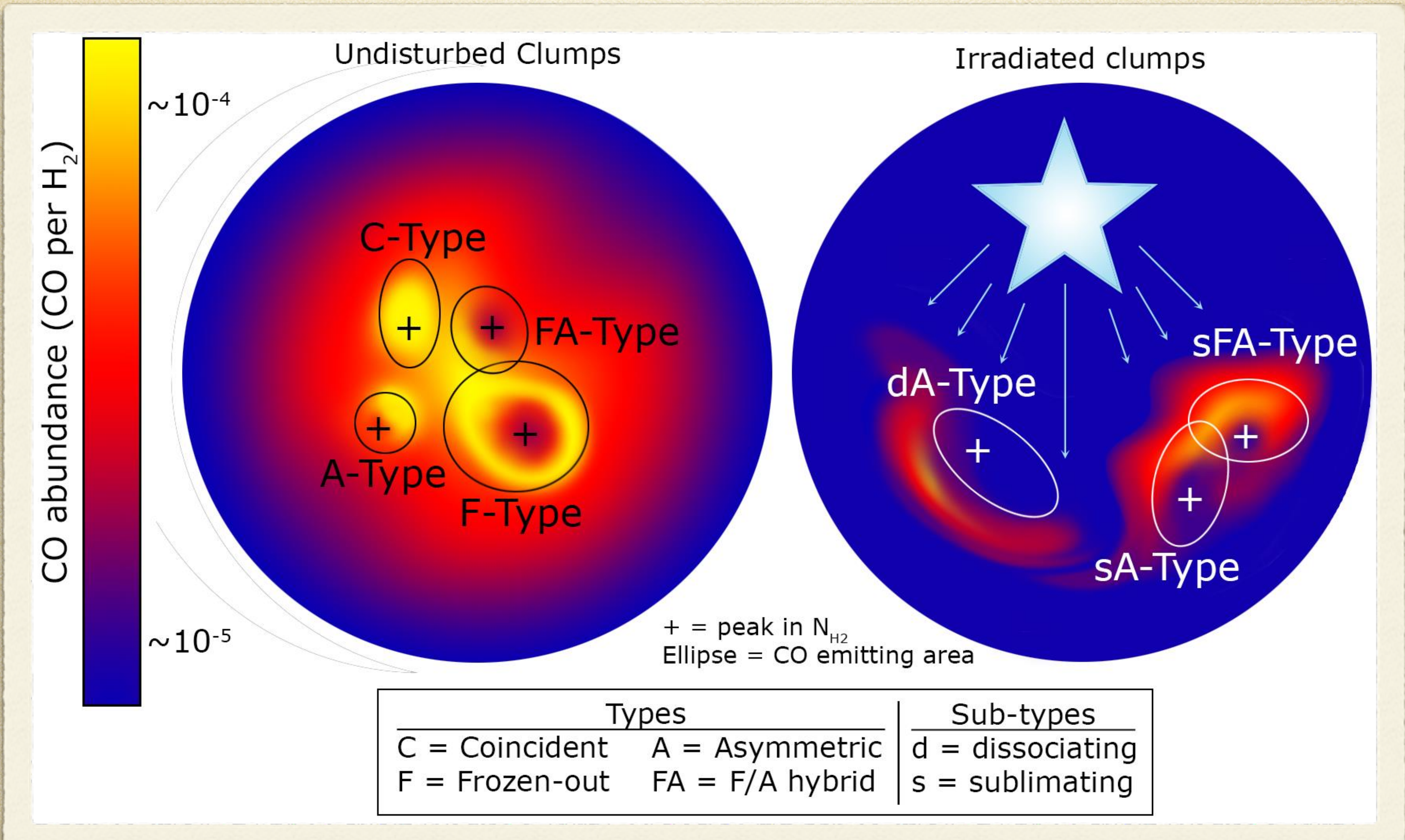
- Use *Herschel* data to compute dust-based N_{H_2} map
- Derive $[^{12}CO]/[H_2]$ abundance map: it's mostly ***much lower*** than expected, and varies ***a lot*** too!





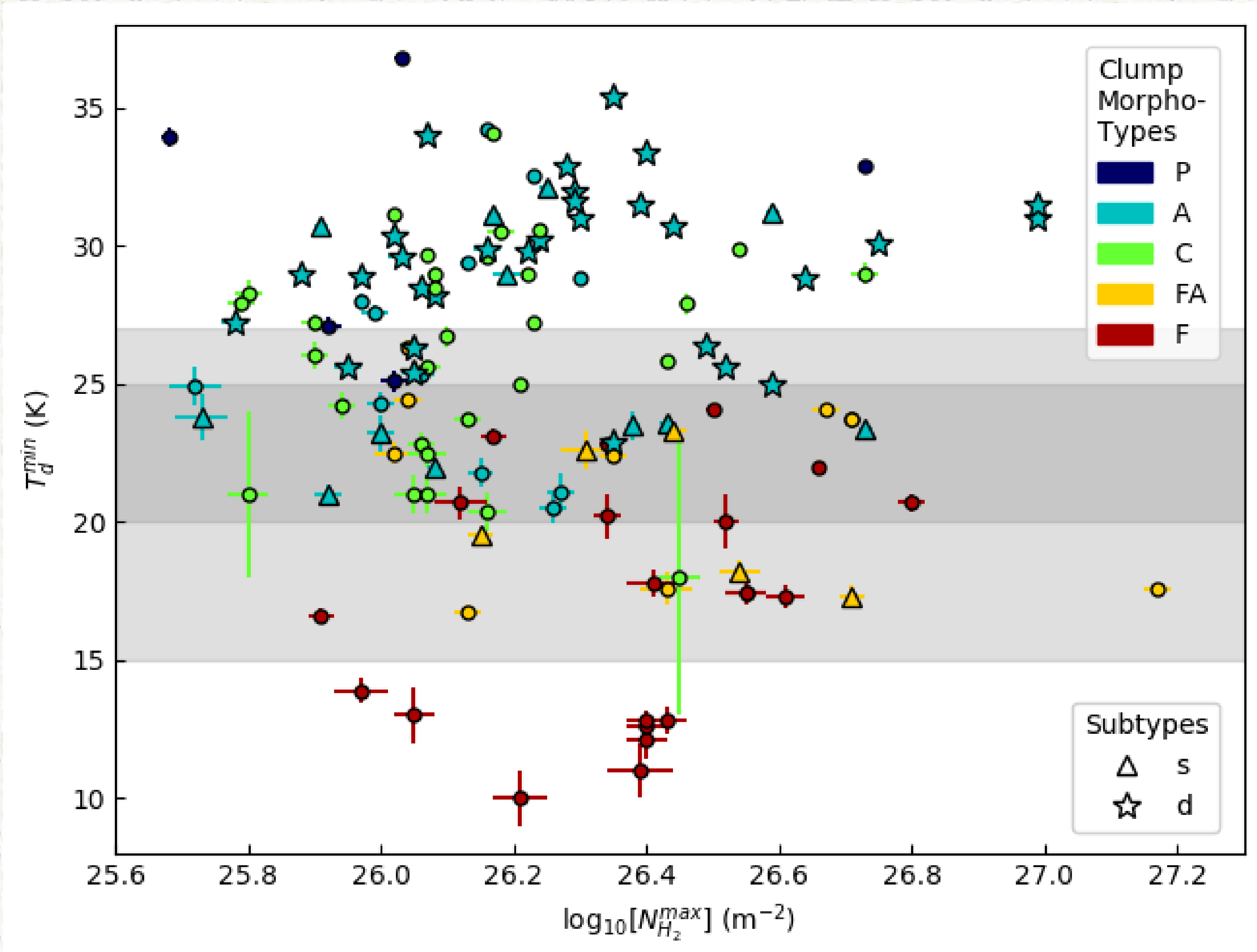
Temp/abundance morphotypes

- Abundance patterns reduce to only 4 morphotypes, which depend mainly on *T*/radiation environment



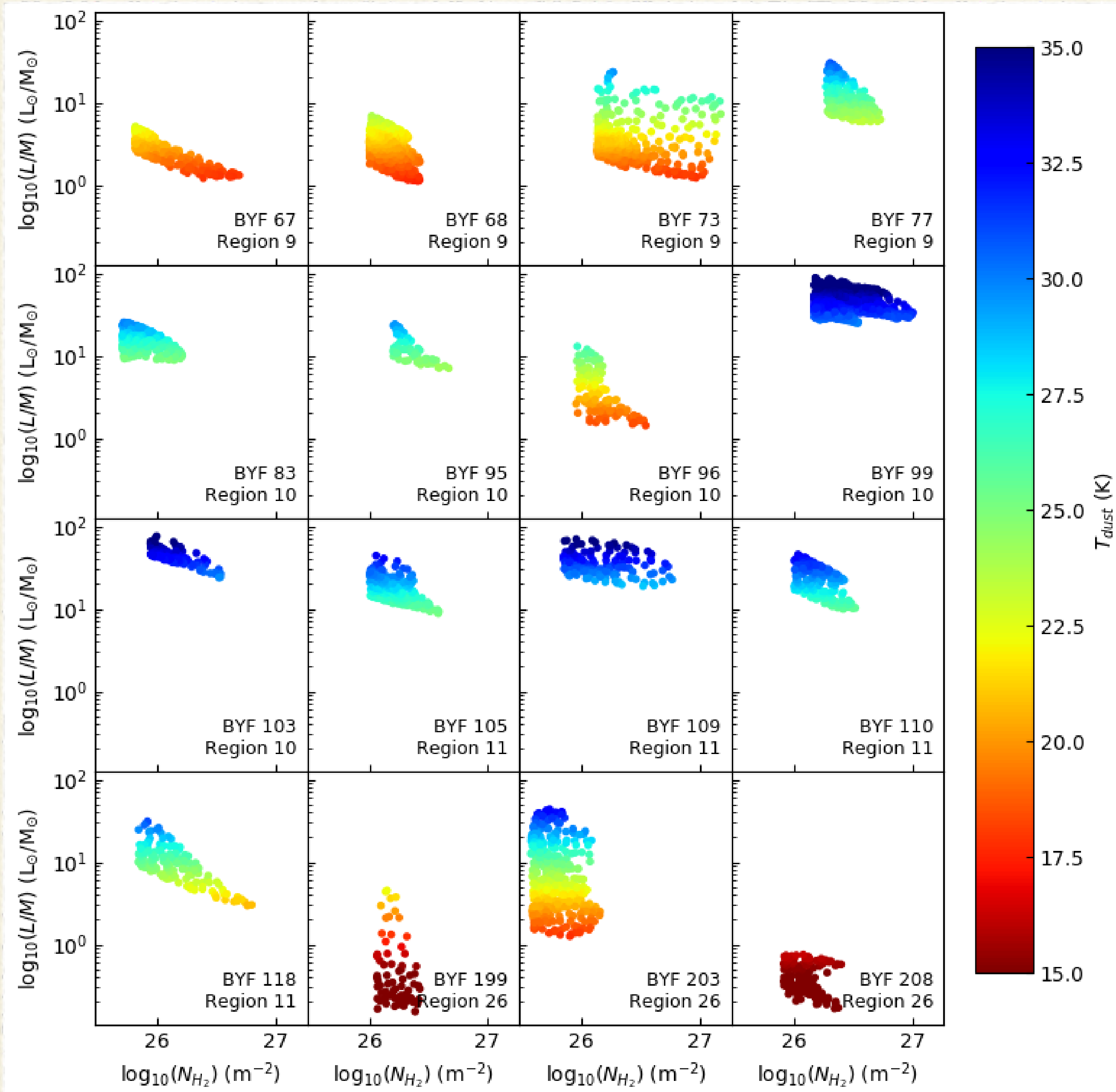
Yet more surprises

- These types don't seem to depend on column density, but they do depend on $T_{\rm dust}$



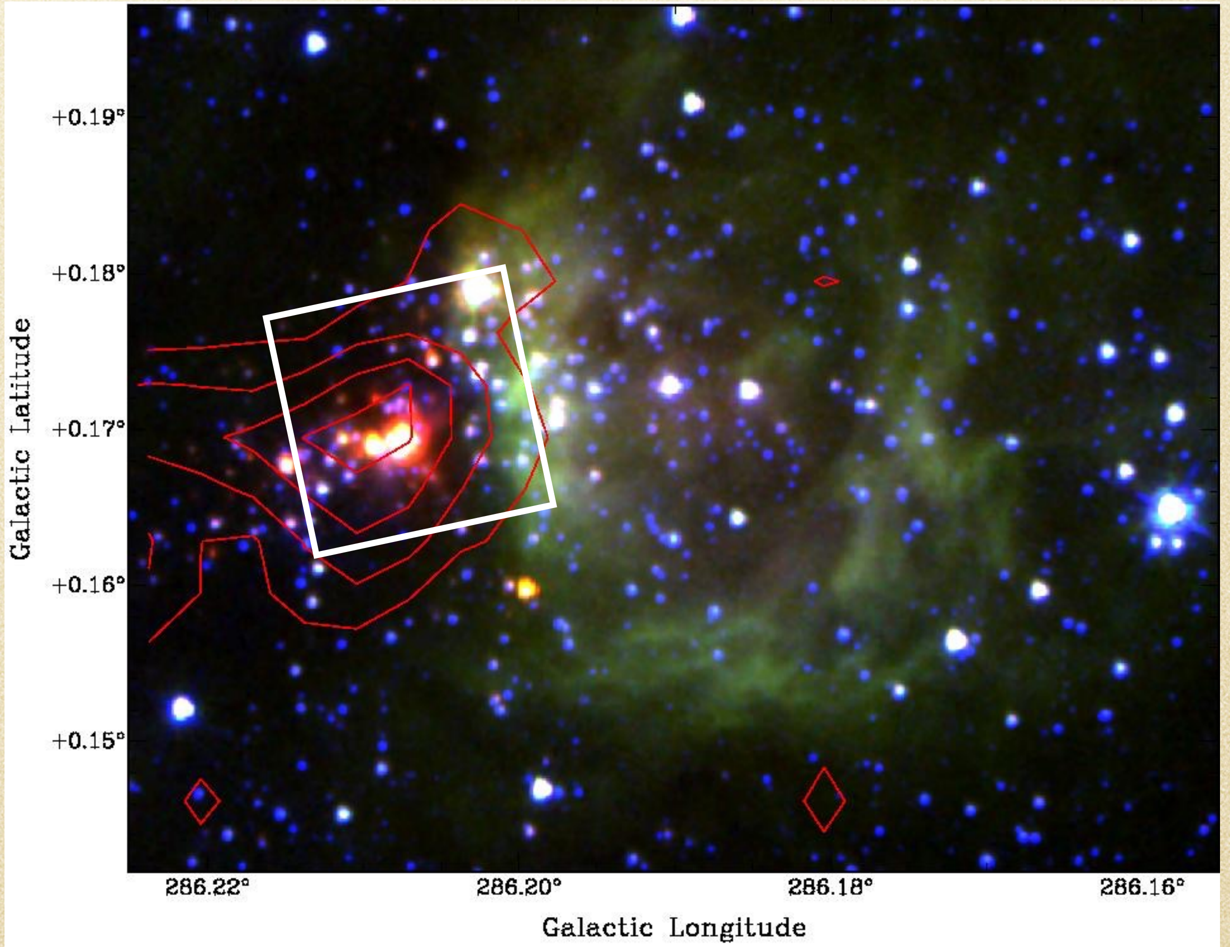
L/M traces T, not evolution

- For SED fits, $L/M \propto T^{\beta+4}$
- $T_{\rm dust}$ falls towards the centers of most clumps
- See R. Pitts poster 21 / back wall, and P+18a MNRAS subm.



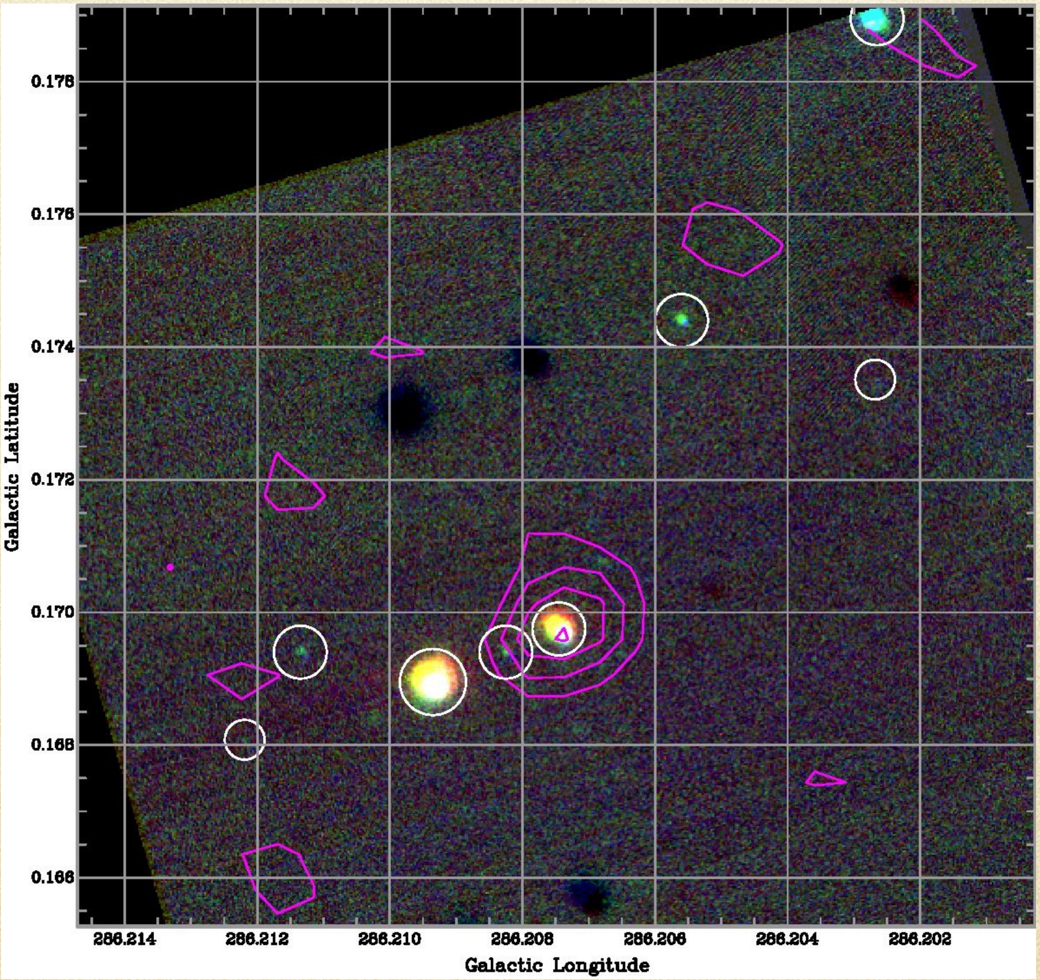
A case study: BYF 73 (The exception that proves the rule)

- The only CHaMP clump out of 300 that is rapidly collapsing
- Most massive @ 20,000 $M_\odot$, α_{vir} ~ 0.1, $dM/dt = 0.03\ M_\odot/yr$ (B+2010)
- Spitzer/AAT:



Gemini-S / T-ReCS data

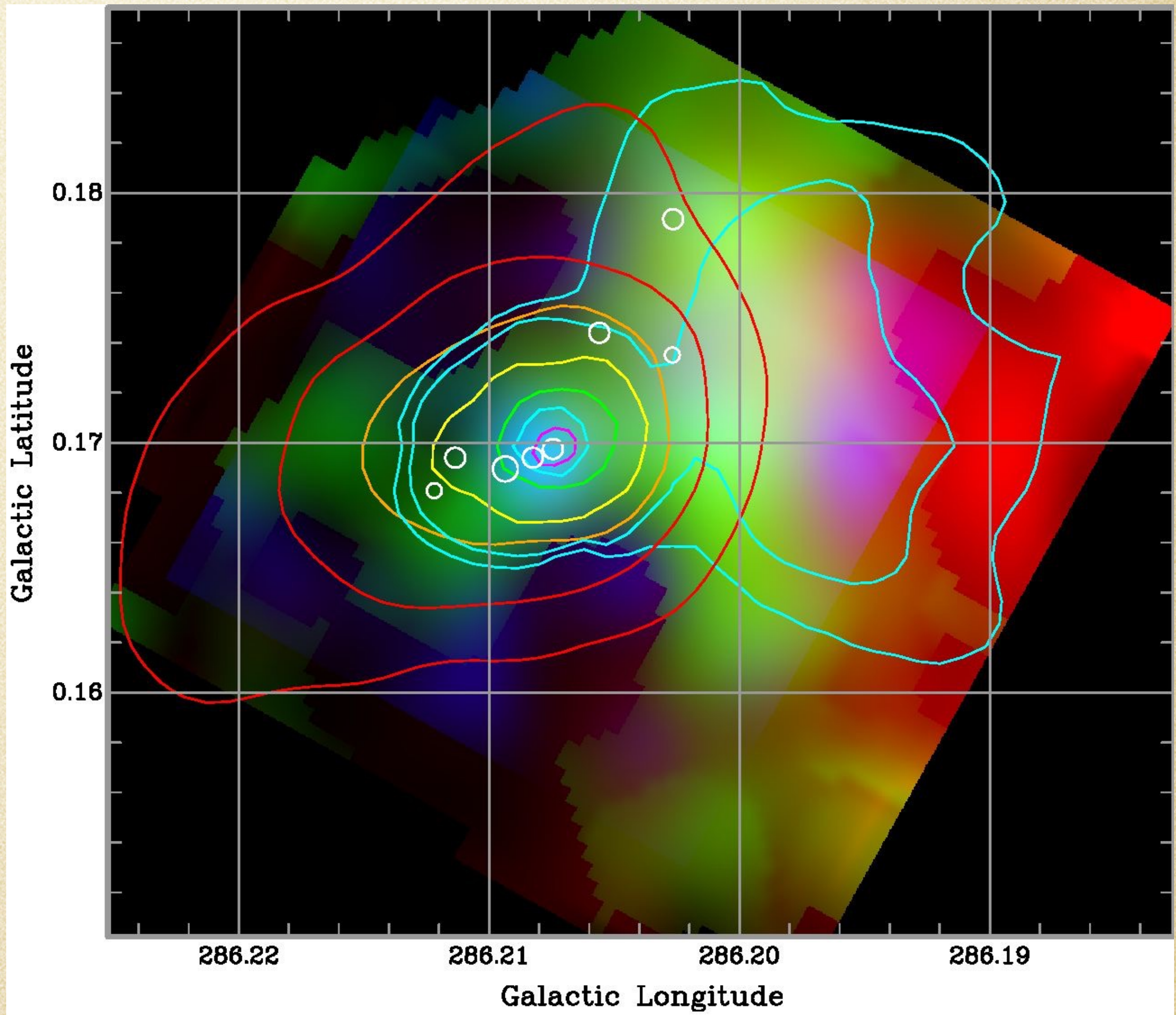
- Only 8 point sources, only 6 of which are likely protostars, only 3 of which are massive, only 1 of which is detectable with ATCA



- Clump is gas-dominated, but most of this gas is focused around 1 core

SOFIA/FIFI-LS data

- MIR 2 is most massive @ 200–400 $M_{\odot}$, but only 1-2% of clump's mass
- Has 60% of clump's luminosity, some of which may be coming from gravitational PE release
- CII and OI lines mostly trace SF, not so much the mass
- See R. Pitts poster 21/back wall, and P+18b ApJL subm.



Summary

- *Barnes et al 2018:* single X-factor is illusory, mass conversion follows power laws $N_{CO} \propto I_{CO}^2 \sim \tau T_{ex}$ at full velocity resolution, averaging down to $N_{CO} \propto I_{CO}^{1.3}$ when velocity-integrated; overall cloud masses ~2–3x higher
- Long mass assembly times, and **long clump lifetimes** (~50+ Myr), now directly confirmed as gas "**sedimentation**" from pressure-confining envelopes, with a gradually rising star formation rate as ∑ rises and ending with a **terminating crescendo** of MSF
- *Pitts et al 2018a:* N_{H2} and T_d maps from FIR-SED fitting show **CO abundance varies strongly** across Regions and clumps, but has 4 distinct **morphological types** which depend strongly on T_d and G_0 due to **depletion/desorption/dissociation** of CO
- *Pitts et al 2018b:* BYF 73's C^+/O^0 ratio & MIR/FIR continuum confirm dense, high mass cloud with its **massive central protostellar core** as focus of infall, smooth-gas-dominated, early evolutionary state

Final thoughts

- **Takeaways:** long latency periods, dense gas tracers don't trace dense gas, emissivity ≠ column density