The *Fast!* Demographic Revolution from CHaMP and ThrUMMS: Physics of Molecular Clump Evolution

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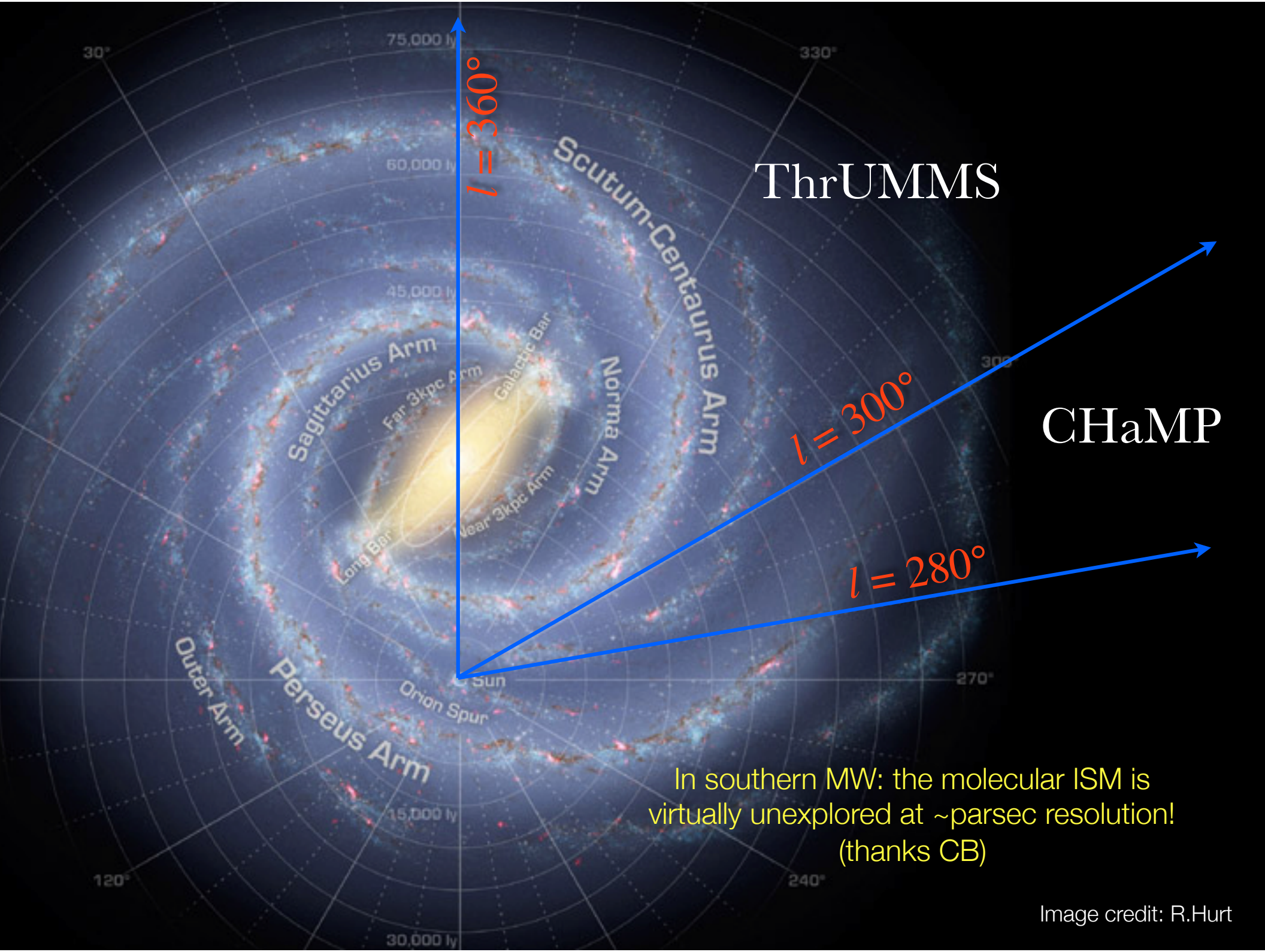
plus EVS VC RNR GG AG CB LF ADC FS RB

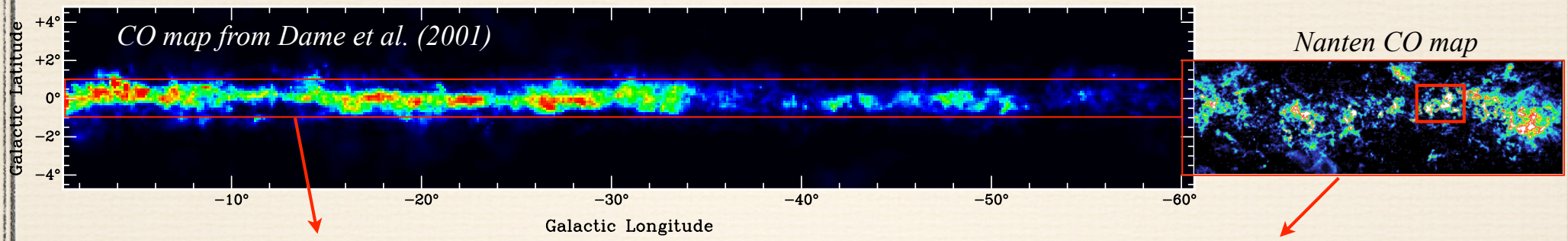
Multi-Scale Star Formation, Morelia, Mexico *3 April 2017*

Surveys

- Continuum surveys (GLIMPSE, Hi-GAL, ATLASGAL, BLAST, etc.) provide important SED information on clump masses & luminosities
- **Key point 0:** ***Kinematic information absent*** without spectroscopy. Need molecular lines
- **Key point 1:** **Resolution!** @ 3 kpc, 1′~ 1 pc ***resolves cloud evolution on the scale of cluster formation*** (at 8′, CfA-^{12}CO can't do this)
- **Key point 2:** ***Multi-species*** maps enable entirely new science (GRS-^{13}CO can't do this)
- A major motivator for CHaMP & ThrUMMS is **demographics** of clumps (including lifetimes) plus other physics


ThrUMMS
CHaMP
$l = 360°$
$l = 300°$
$l = 280°$
Scutum-Centaurus Arm
Sagittarius Arm
Norma Arm
Perseus Arm
Outer Arm
Orion Spur
Sun
Far 3kpc Arm
Near 3kpc Arm
Galactic Bar
Long Bar
75,000 ly
60,000 ly
45,000 ly
30,000 ly
15,000 ly
30°
330°
270°
240°
120°
In southern MW: the molecular ISM is virtually unexplored at ~parsec resolution! (thanks CB)
Image credit: R.Hurt

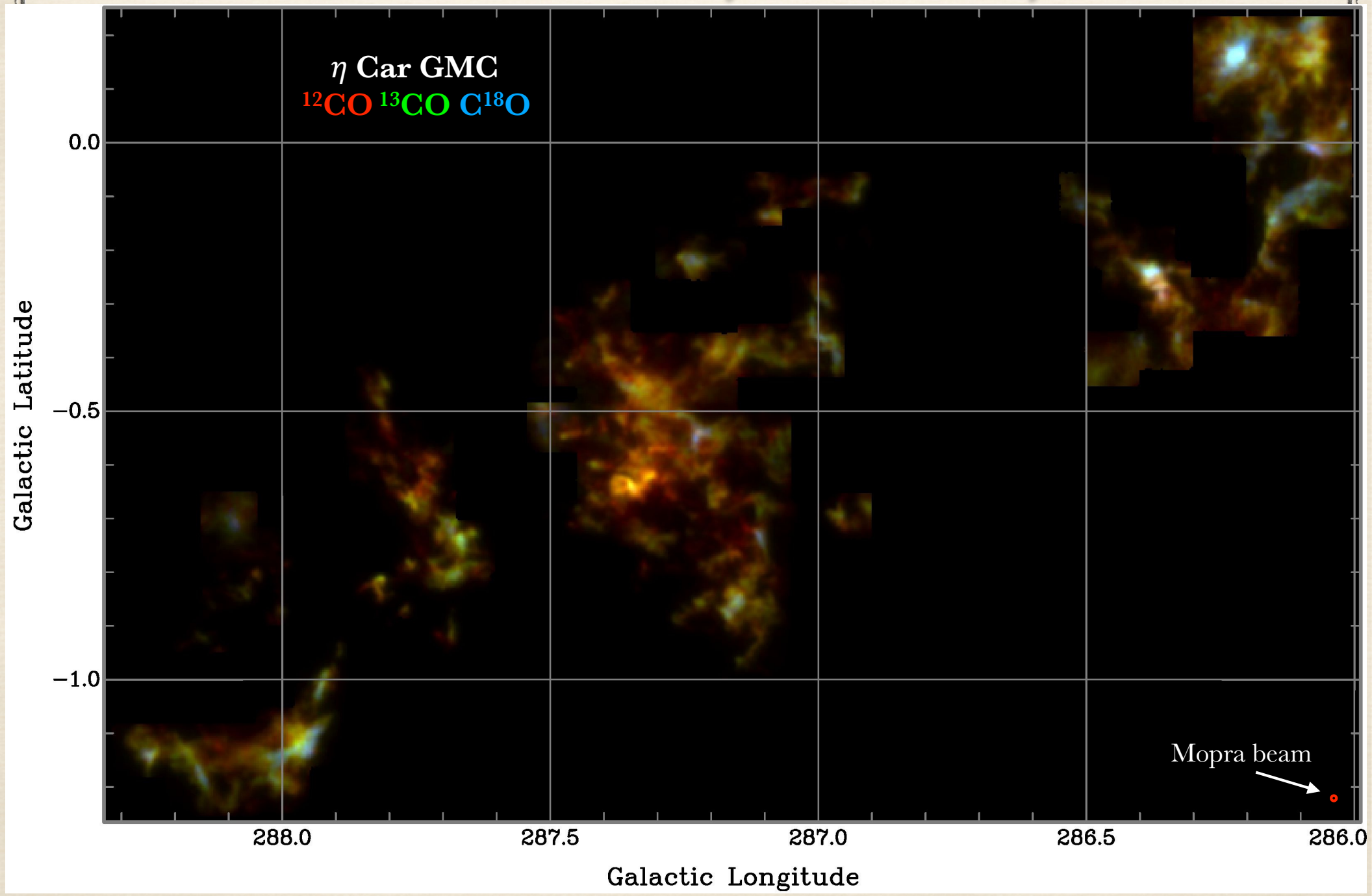
ThrUMMS+CHaMP @Mopra



- Started in 2010
- Complete, unbiased coverage of 60°×2°
- Simultaneous maps of ^{12}CO, ^{13}CO, C^{18}O, CN (all $\mathcal{J}$=1–0)
- 72″ resolution, rms ~1K in 0.34 km/s channels: very high spatial × spectral dynamic range = 300,000 × 3000
- OPEN PROJECT (data available ahead of publ.); collaborations welcome

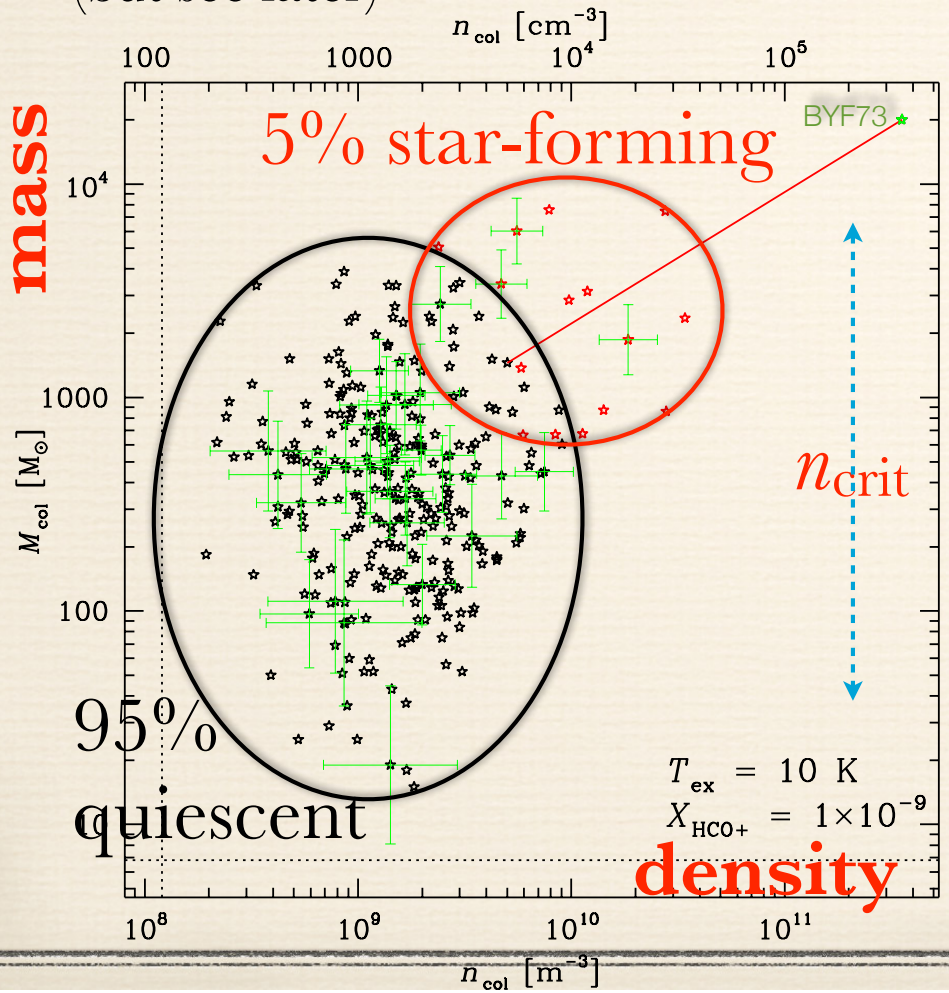
- Started in 2002 with Nanten maps
- Unbiased survey of complete population of massive clumps in 20°×6°, re-mapped with Mopra
- Simultaneous maps of 16 species ~ 90 GHz **PLUS** 16 more ~ 110 GHz (e.g., CN, iso-CO, HCO^+, N_2H^+, HCN)
- 40″ resolution, rms 0.3–0.7 K in 0.1 km/s channels: high SDR and sensitivity
- Published data available, other access by collaboration

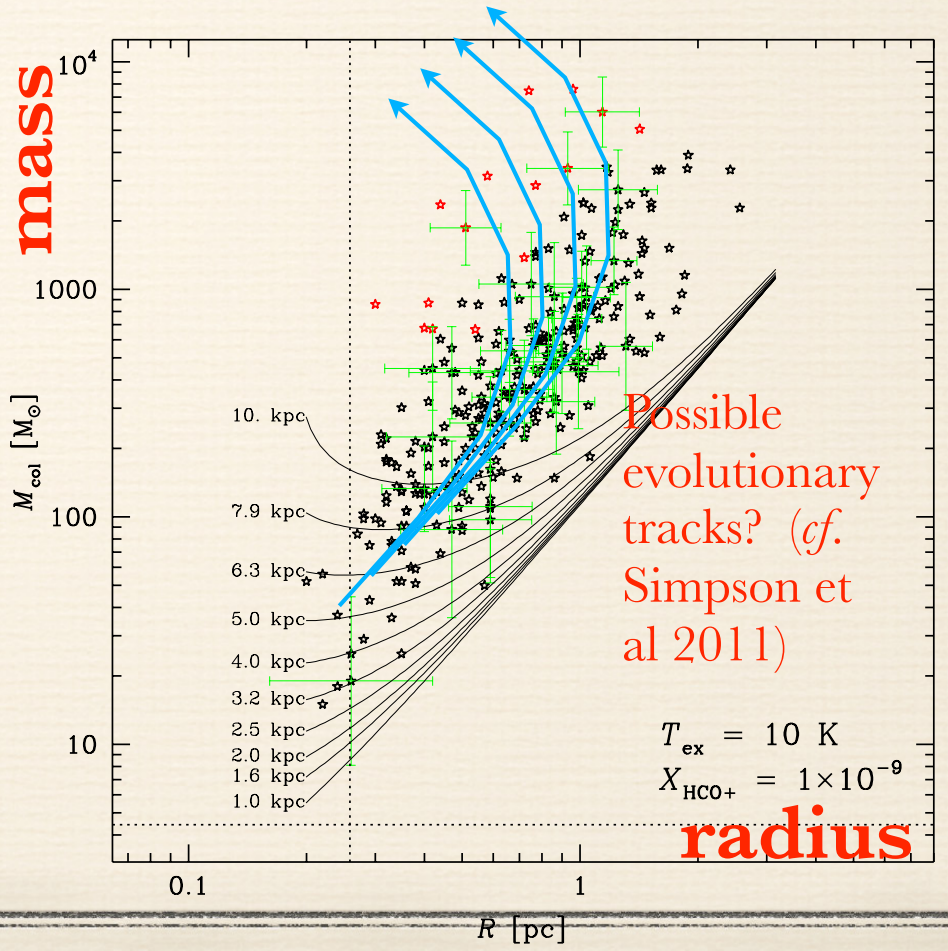
CHaMP eye candy



First demographics: a vast population

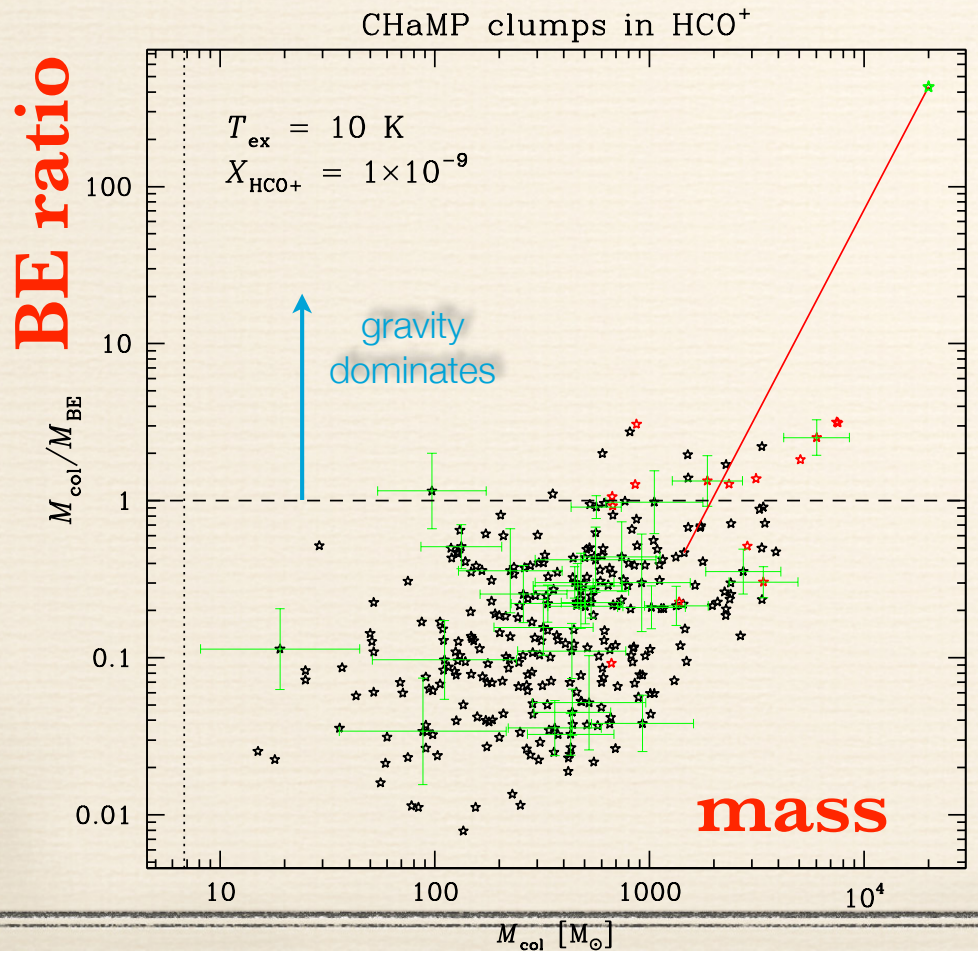
- A population-based study gives us first clues to the molecular cloud life cycle (Barnes,Yonekura,Fukui+2011): BYF catalogue in HCO^+
- Confirmed Krumholz+Thompson (2007), Narayanan+(2008) prediction of "a vast population of ***subthermally***-excited clouds"; most also seem ***sub-critical*** (but see later)

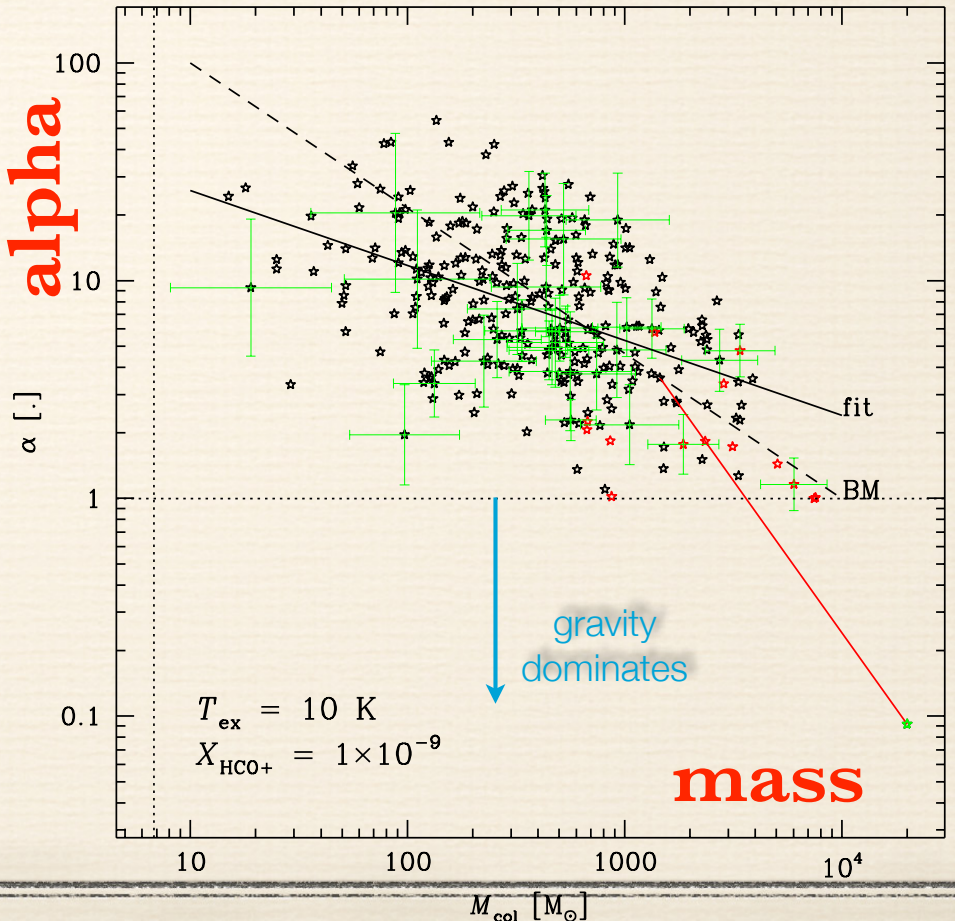




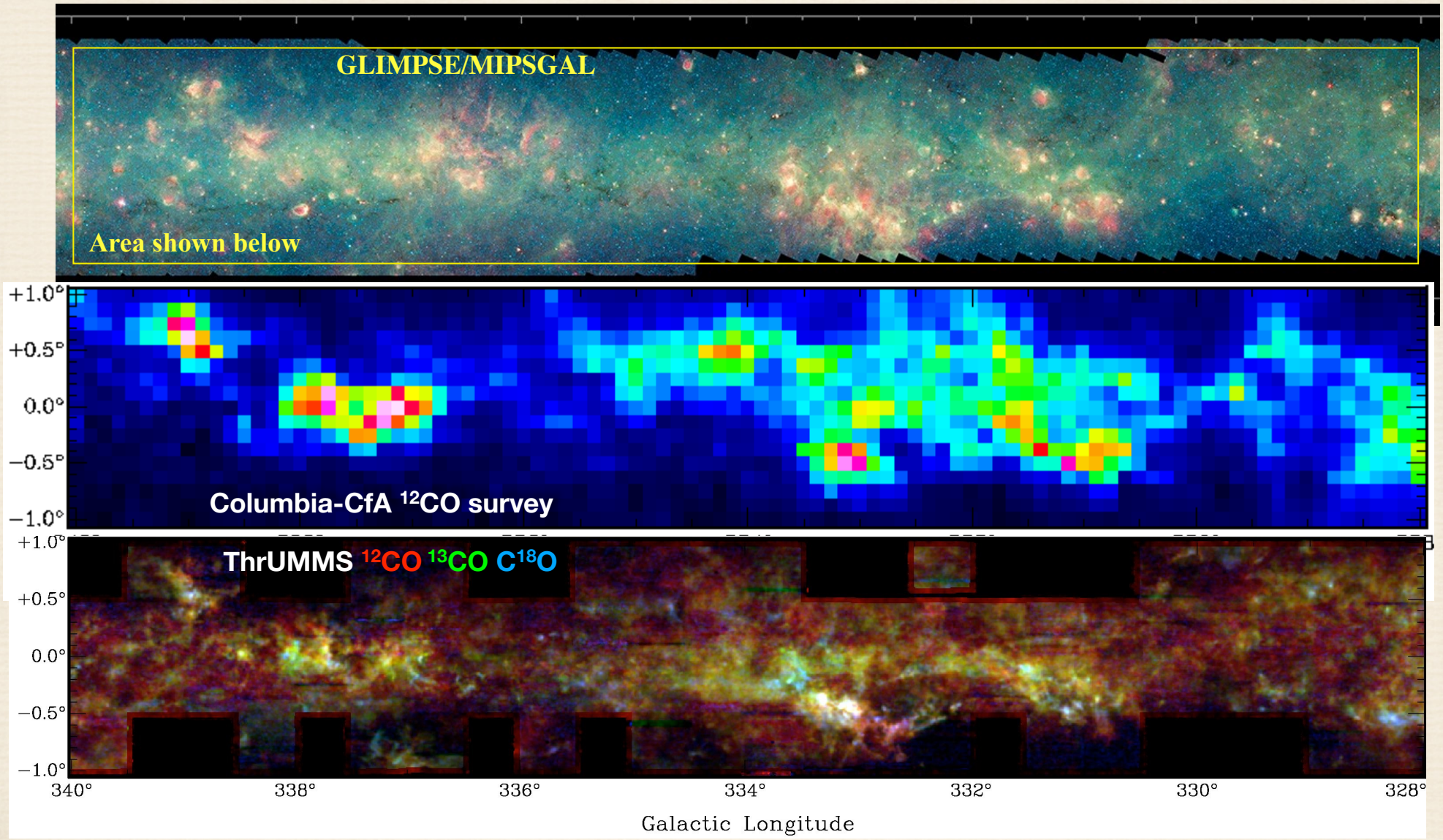
Sub-thermal and sub-critical(?)

- "Dense gas" which is ***not so dense***, but …
- … Sub-thermal excitation also implies ***larger opacities and masses*** (see also later)
- Implies either (a) *long, quiescent lifetimes* (50–100 Myr) for clouds *before* they form stars, if they are stable entities: requires ***pressure-stabilisation***, or (b) *high creation/destruction rate*: clouds are ***ephemeral*** (BYF+11)





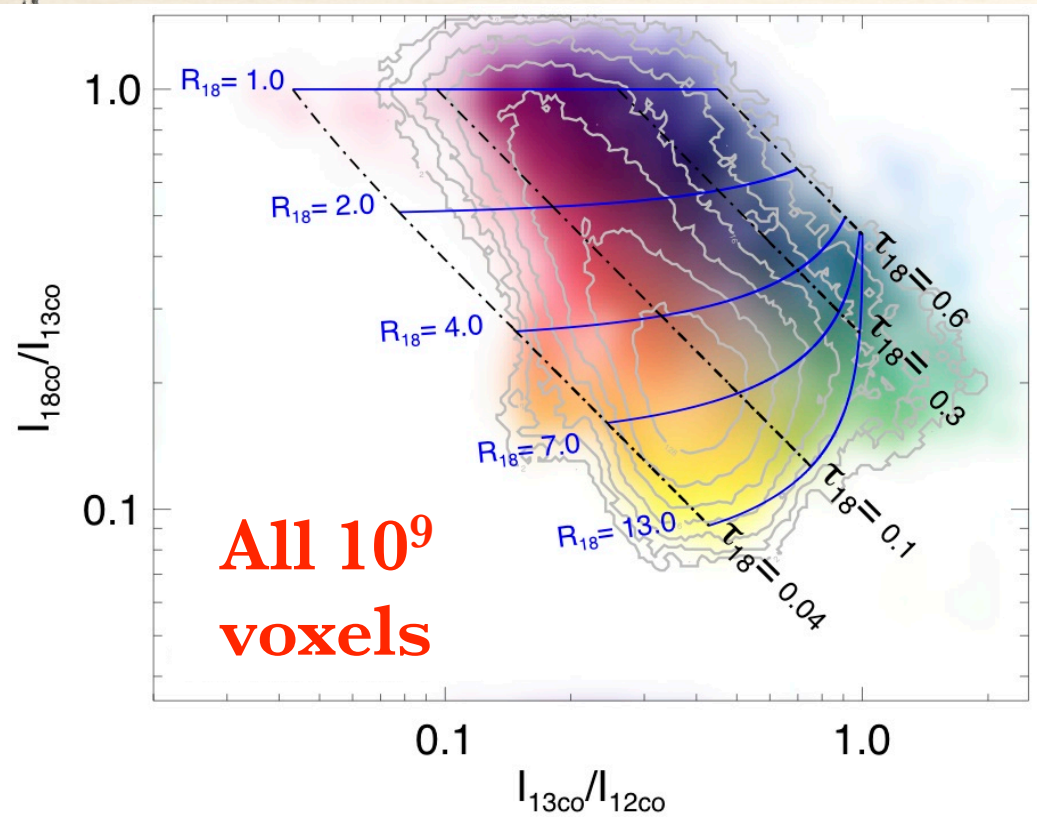
ThrUMMS eye candy

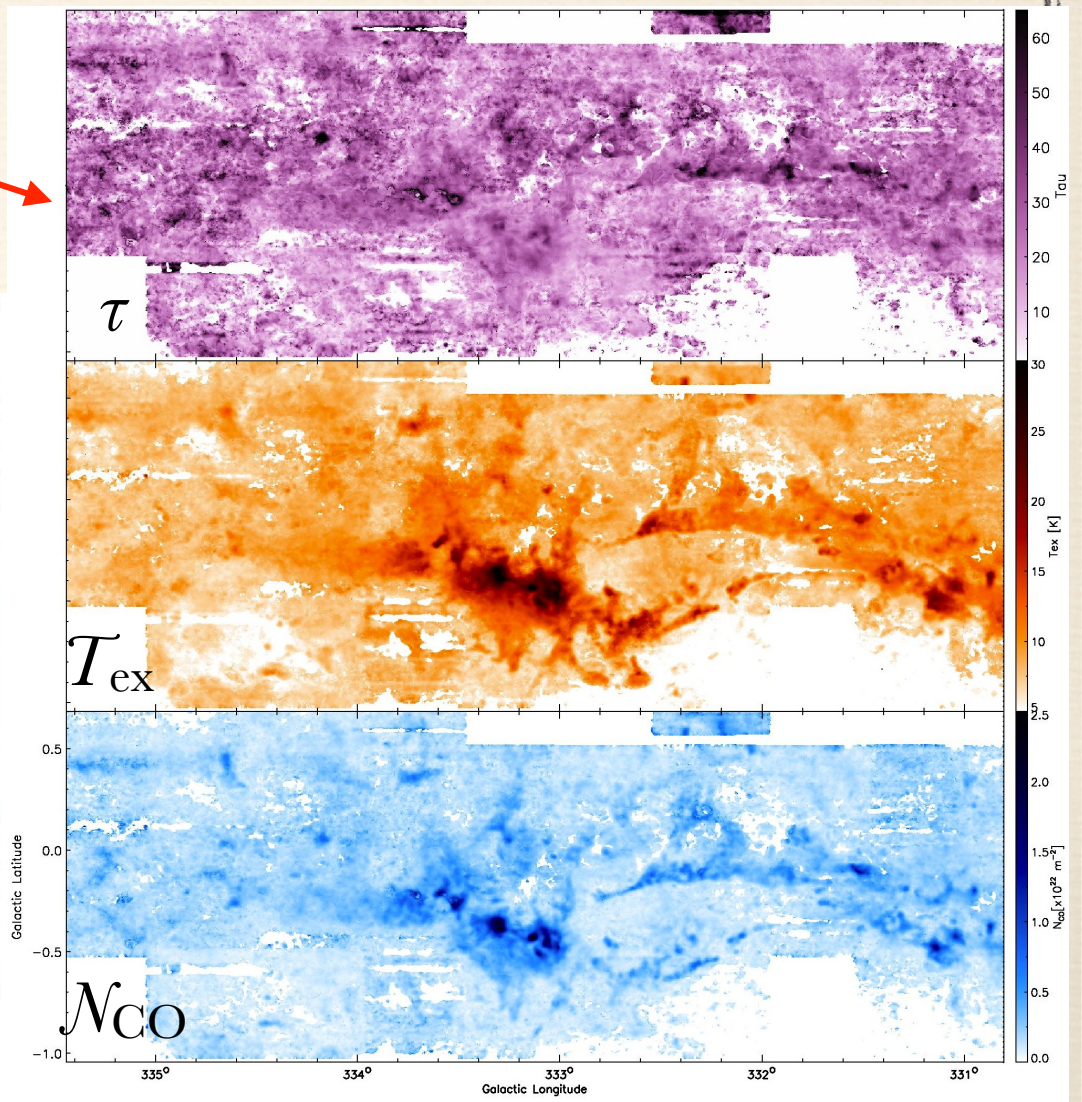


- 3D resolution = physics, and "colour" = more physics!

ThrUMMS line ratios (BM+2015)

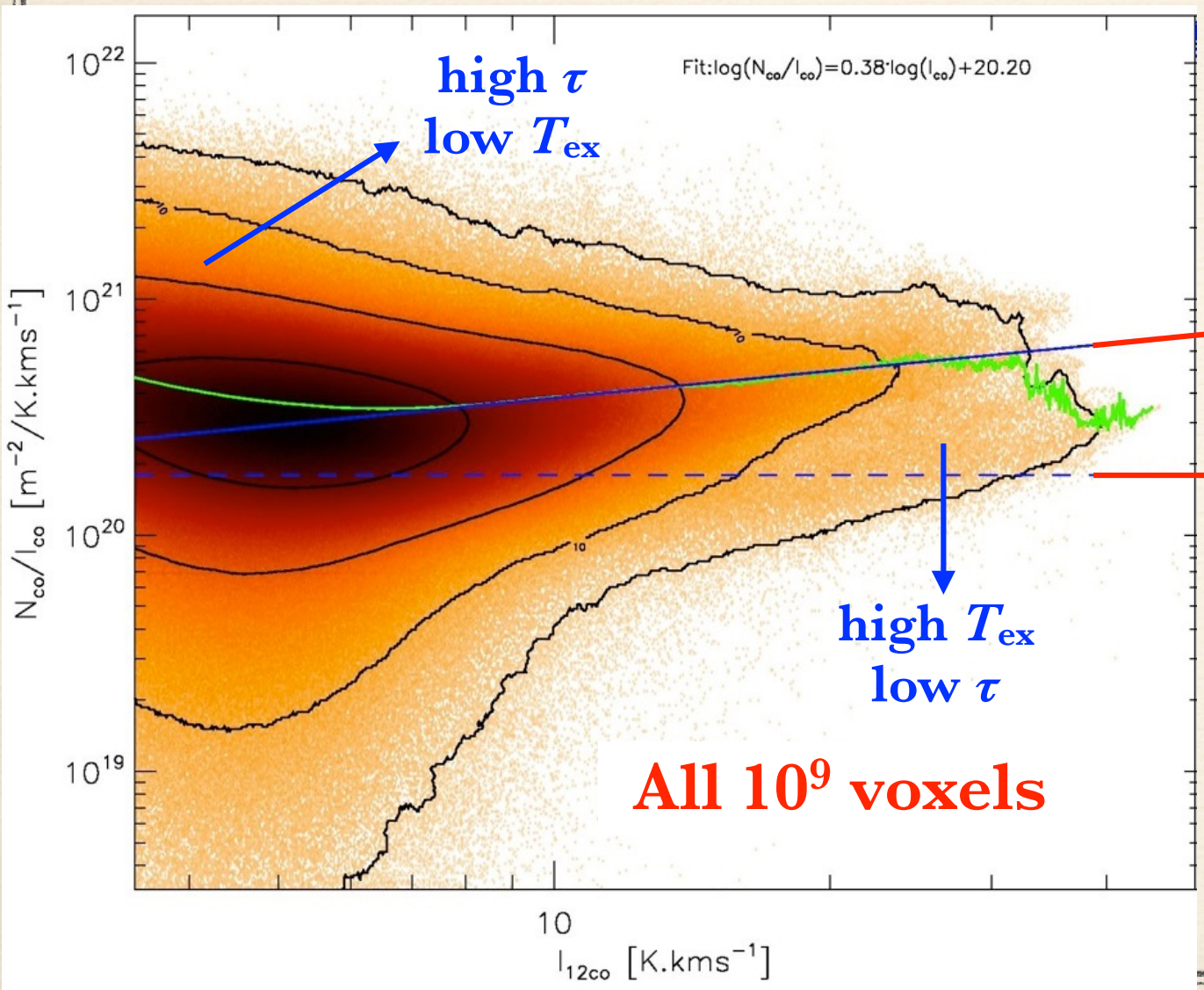
- Plane-parallel radiative transfer
- iso-CO ratio-ratio plane
  - PPV cubes of physical parameters
- Now compare N_{CO}/I_{CO} (should = the X factor) to I_{CO}…





A new conversion law

- Averaged across 4Q, ThrUMMS conversion law $N \propto I^{1.4}$ => **~2× as much molecular mass** as standard X factor



- **Gas depletion timescales** in MW-analogue disks also ~2× longer
- Schmidt-Kennicutt laws may need recalibration

power law

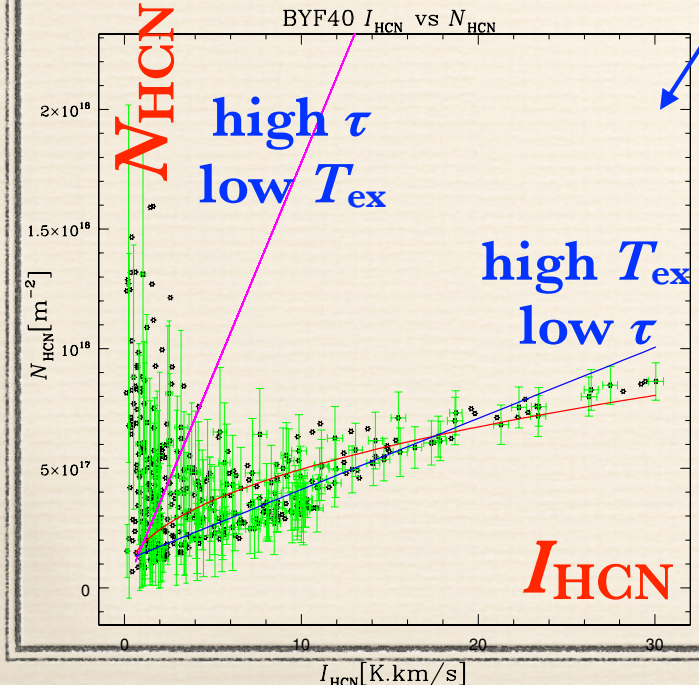
constant X factor: no good!

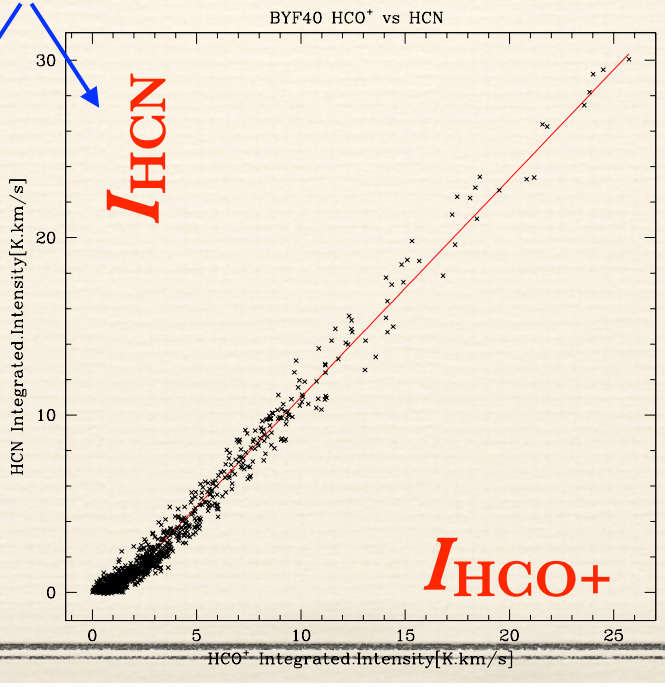
- Comes from large amounts of **high-τ, low T_{ex}** gas
- Old X factor prescription underestimates τ, mass
- Could independently check this with CHaMP (see later)

Dense gas tracers? Or…?

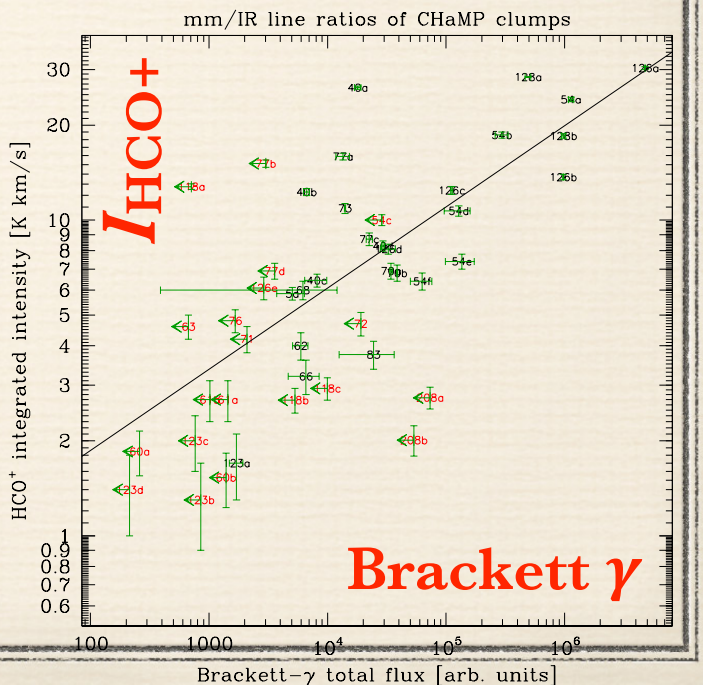
- I_{HCN} is a standard "dense gas tracer," but …
- … in CHaMP clouds, I_{HCN} **doesn't trace dense gas!**
- Also, HCO^+ scales with Brγ, and with HCN
- Calls into question entire basis of dense-gas/extragalactic SK relation
- So these species look like **"*post-SF feedback indicators*"**? (thanks AG)
- Suggests a lot more (~2×) molecular mass is "hidden" in unremarkable, fainter (but detectable) non-star-forming gas; the "bathtub" is larger

Schap et al 2016 – HCN hyperfine line ratio analysis



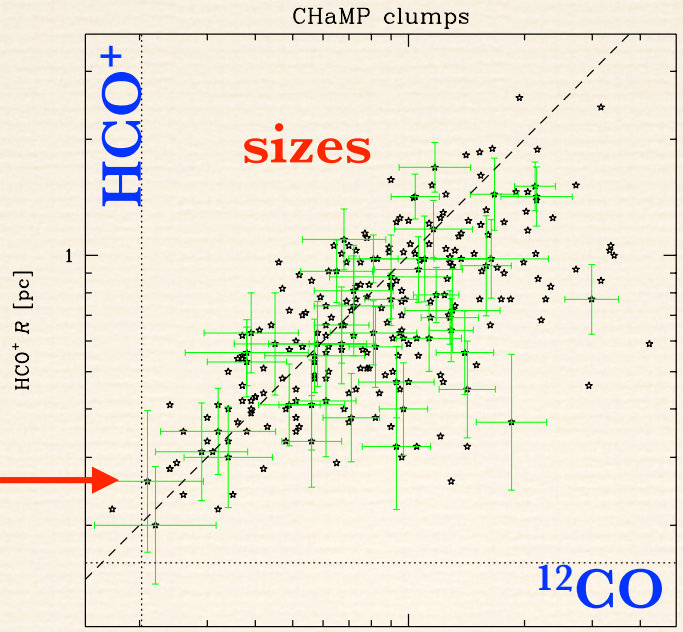


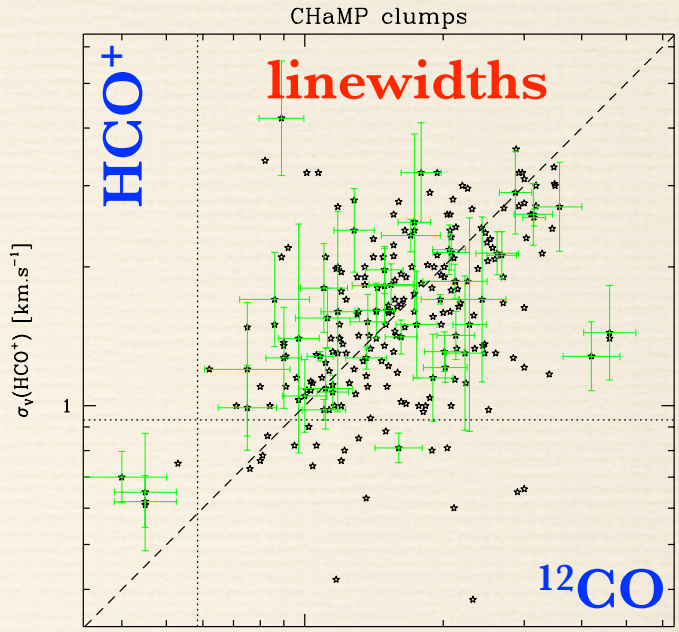
PB et al 2013

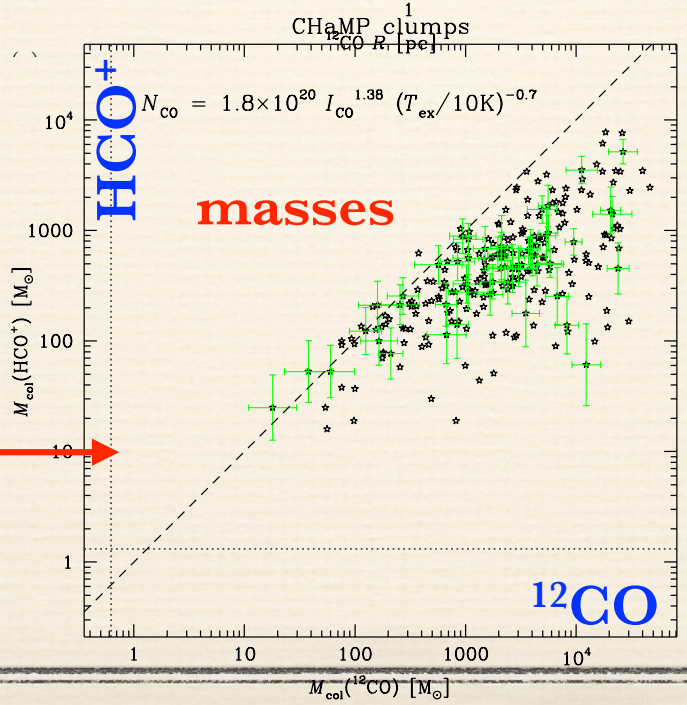


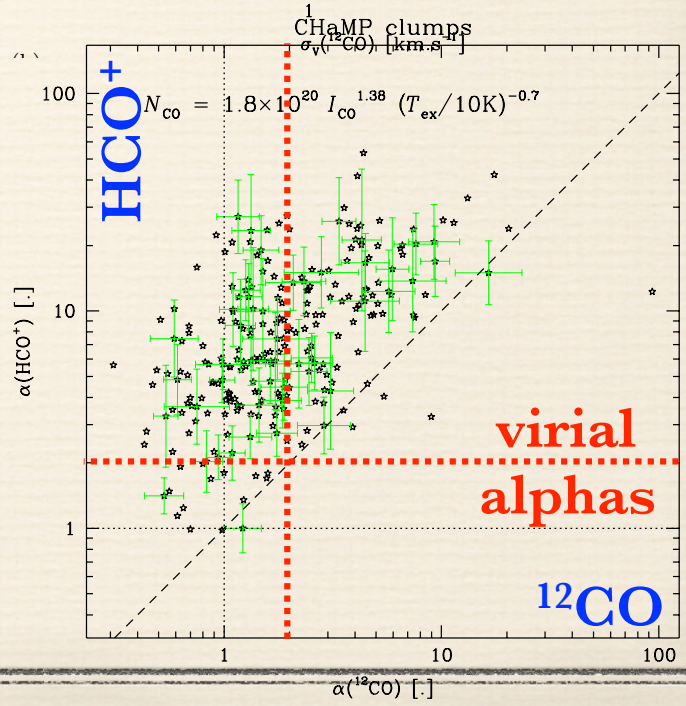
Pressure-stabilisation, building blocks

- (PB+2016) If HCO^+ traces clumps' interiors, then ^{12}CO must trace less-dense envelopes. How do properties compare?
- Clumps look **~the same**! And contain **75%** of the larger cloud's mass => **building blocks** of the molecular ISM
- But including their ^{12}CO envelopes, they are more massive and **closer to VE** than their dense interiors (old X factor wrong)

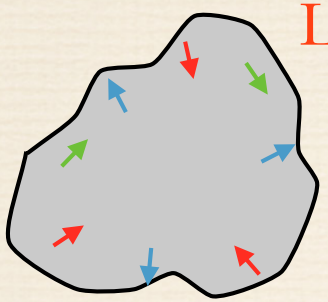






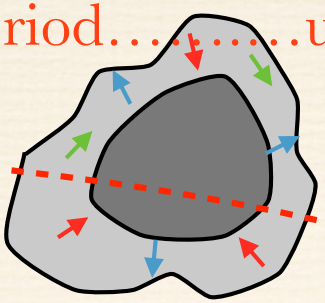


A revised paradigm

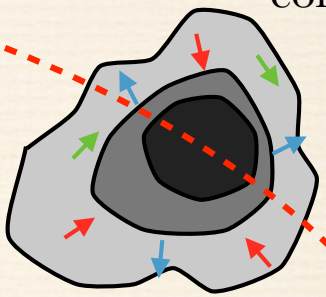


Marginally bound molecular clump forms, **stochastically** accumulates/disperses mass from larger flows, becomes **base unit** of SF

Long latency period……up to 100 Myr

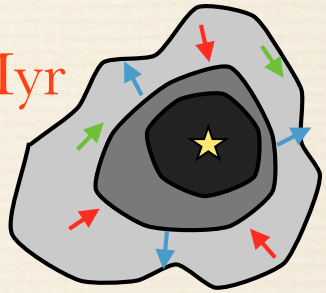


"Denser" clump forms, **pressure-stabilised** by overlying massive envelope; gas mostly **sub-thermal & opaque**, slow accumulation/ dispersal continues



Lower mass protostellar cores form, help maintain turbulence; cloud remains cold, "quiescent"

Low- & medium-mass SF **accelerates** during last few Myr

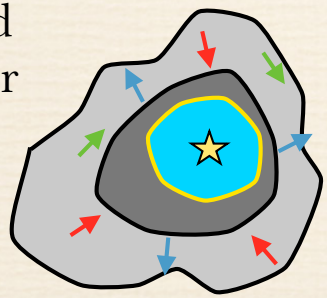


~0.3 Myr

Final, rapid mass inflow, massive protostar(s) & protocluster form

Hot core phase, "**dense gas**" tracers become bright, gas **warms, opacity drops**

~1 Myr



Classic HII region, molecular cloud disperses, cluster revealed

~5 Myr