# CHaMP and ThrUMMS: Demographics of Molecular Cloud Evolution in the Milky Way

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New multi-line mapping surveys of molecular clouds (CHaMP, ThrUMMS, etc.) are enabling an unprecedented demographic analysis of the physics of entire cloud populations. Key insights from such surveys include (but are not limited to): (1) The existence of a vast population of subthermally excited, massive dense clumps, the majority of which are not engaged in vigorous star formation; (2) The pressure-stabilisation of these clumps against dispersal by their overlying envelopes, implying long (10s of Myr) cloud lifetimes; (3) A new CO → $H_2$ conversion law accounting for these numerous pc-scale, low-excitation, high-opacity and high column density clumps, suggesting the total molecular mass of clouds from pc to kpc scales may be underestimated by a factor of ~2, and increasing the gas depletion timescale by the same factor; and (4) A revision to the concept of large molecular clouds, including GMCs, to be structures composed of pc-scale clumps (75% by mass) connected by a more diffuse, large-scale cloud (25% by mass).

## The Survey Projects

CHaMP @ Mopra: 300° > *l* > 280°, *J*=1→0 lines of $HCO^+$, HCN, $N_2H^+$, iso-CO, CN, ~25 others (Barnes et al 2011 *ApJS* **196** 12 and 2016 *ApJS* in press; Schap et al 2016 *MNRAS* subm.)

ThrUMMS @ Mopra: 360° > *l* > 300°, *J*=1→0 lines of CN, iso-CO (Barnes et al 2015 *ApJ* **812** 6)

## ThrUMMS' 26,000 Molecular Clouds: Star Formation & Evolution of the ISM in Action

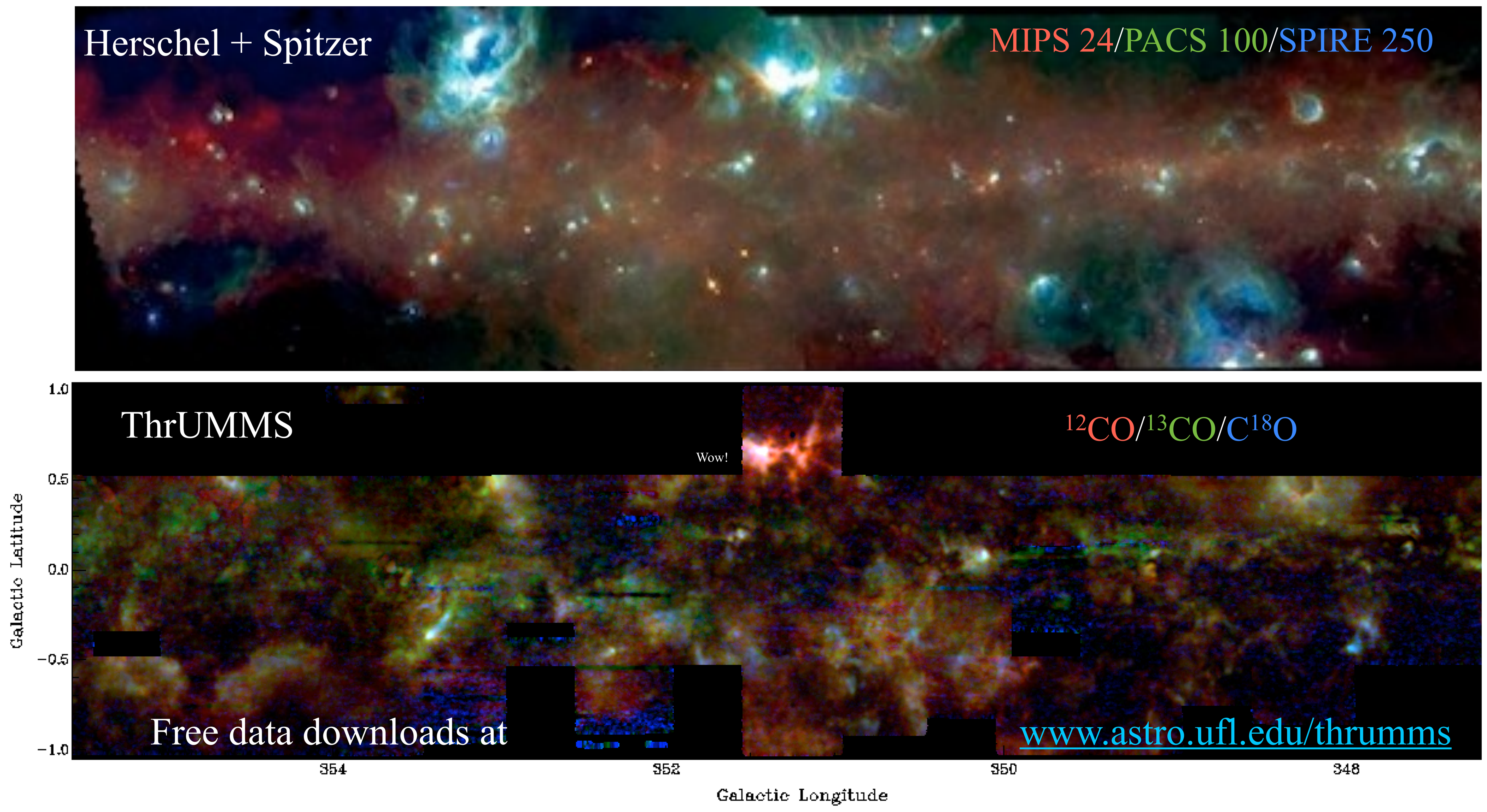


***Figure 1 (Barnes et al 2015 ApJ 812 6):*** Sample 8°×2° map as a colour composite of integrated intensity images from the data cubes (ThrUMMS covers 360° > *l* > 300° at 1′ resolution: see project specs, left). Note the strong colour variations, indicative of different line ratio, opacity, and excitation environments in the molecular material of the Milky Way. We have used a radiative transfer analysis of these data to derive a **new CO → $H_2$ conversion law**. We have also generated a **26,000-cloud catalogue** to derive statistics on the physics of the entire MW molecular cloud population (see A. Hernandez poster), and are examining the **3D structure of the molecular ISM** (see R. Benjamin talk). CHaMP provides similar but much more sensitive and higher-resolution data over its area.

## CHaMP: Detailed Demographics of Massive Molecular Clumps

### 1. A Vast Population

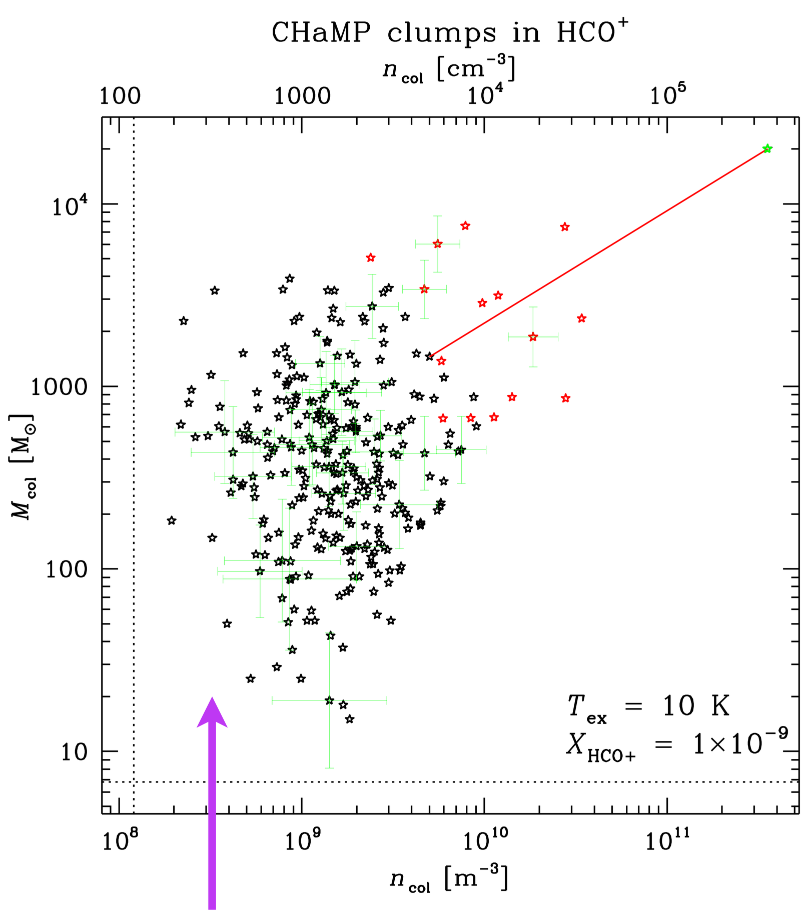


***Figure 2 (Barnes et al 2011 ApJS 196 12):*** Physical conditions of massive clumps' dense interiors, as traced by $HCO^+$. Only ~5% of these are engaged in massive star/cluster formation (red points), the rest are starless or have very low levels of SF activity (black points). This suggests **very long clump lifetimes**, several 10s of Myr.

### 2. Pressure Stabilisation by Envelopes

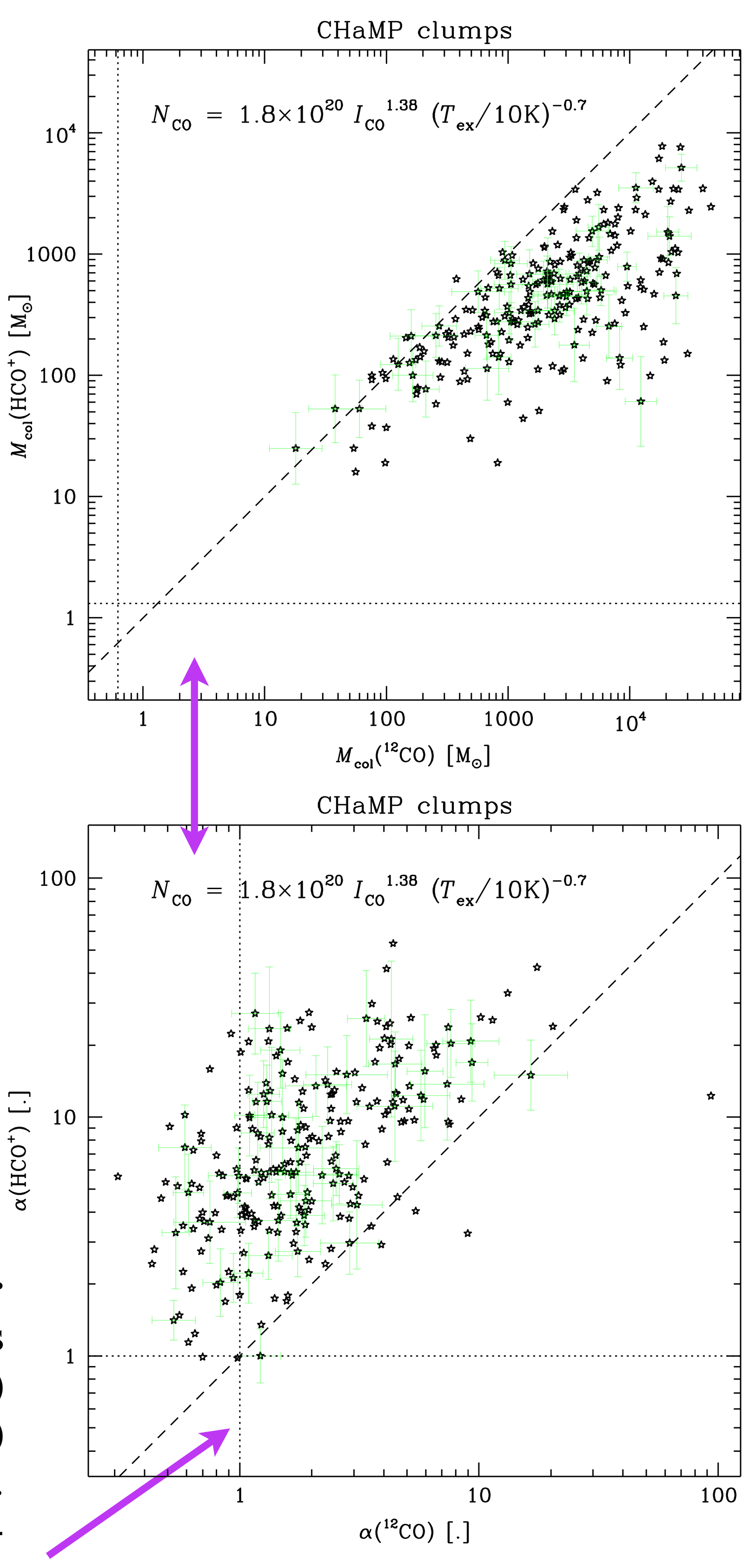


***Figure 3 (Barnes et al 2016 ApJS in press):*** Comparison of masses (top) and virial alphas (bottom) for clump interiors (traced by $HCO^+$) and interiors+envelopes (traced by $^{12}CO$) based on an alternative CO conversion law. These show that the massive clump population is **closer to virial equilibrium** than when just considering their denser interiors.

### 3.1 A New Conversion Law

Both CHaMP & ThrUMMS show dramatic variations in the CO line ratios, indicating a very wide range of optical depth and excitation conditions, from warm and translucent to cold and opaque. The population of cold clouds in particular have optical depths for $^{12}CO$ easily exceeding 100 in some locations. Together with a metallicity-dependent term from Narayanan et al (2012 *MNRAS* **421** 3127) which applies to disk galaxies in general, we find the following conversion law provides the best consistency in physical properties of massive clumps (Barnes et al 2016, *ApJS*, in press), based on both surveys' large-scale CO data:

$$N_{H2} = \frac{X_{CO}\,(I_{CO}/\mathrm{K\ km\ s^{-1}})^{1.38}}{(T_{ex}/10\ \mathrm{K})^{0.7}\,(Z/Z_{\odot})^{0.65}}$$

### 3.2 Kennicutt-Schmidt

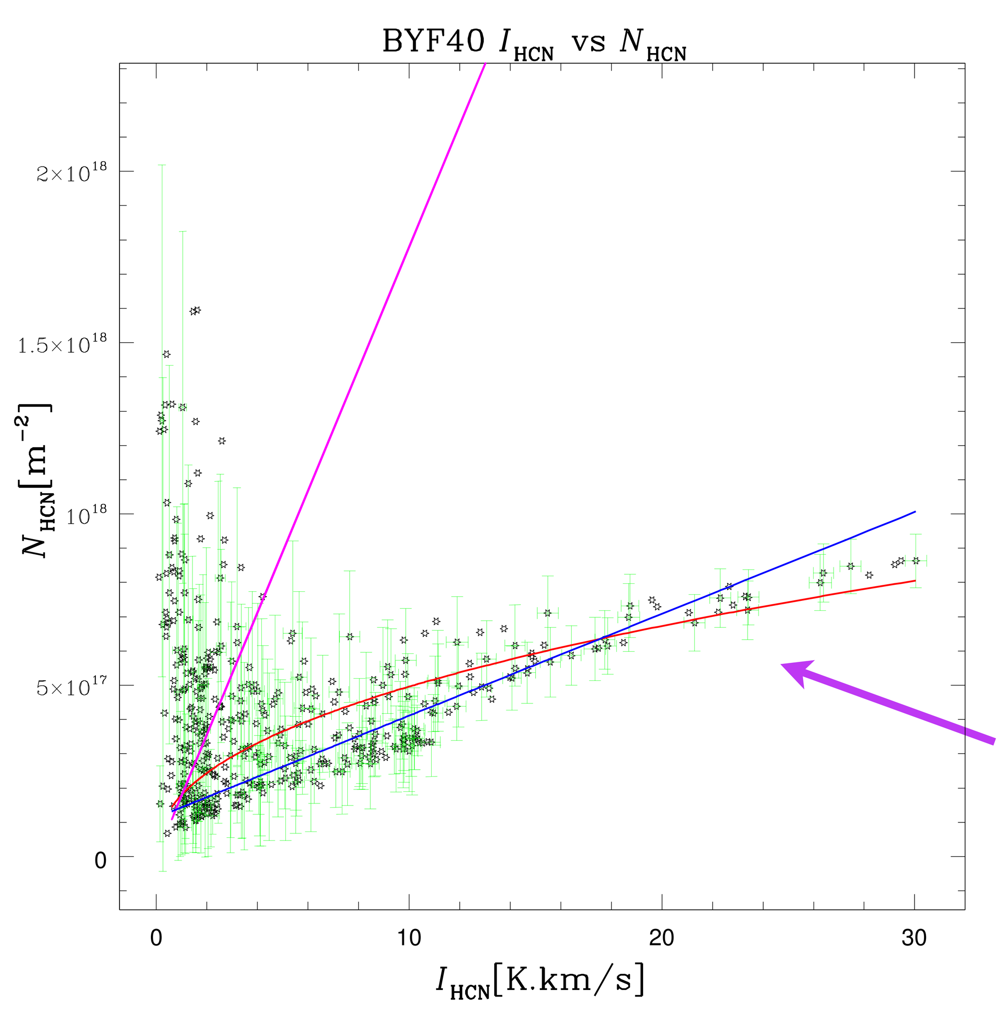


***Figure 4 (Schap et al 2016 MNRAS subm.):*** Column density vs intensity from hyperfine ratio analysis of HCN emission in a subset of CHaMP clumps. The coloured lines show that neither linear nor power laws fit the data. The wide occurrence of high-*N*, low-*I* points suggests that the **molecular mass of the Milky Way, and the gas depletion timescale, may have been substantially underestimated**.

### 4. Clumps as Building Blocks of the Molecular ISM

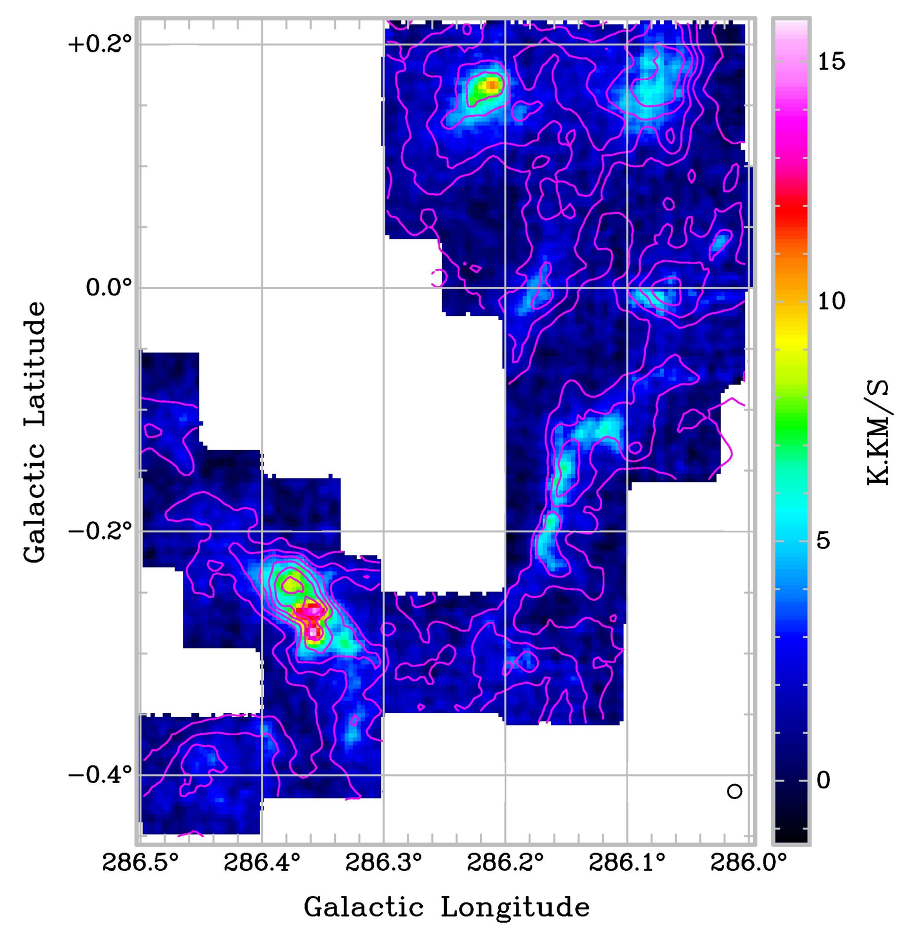


***Figure 5 (Barnes et al 2016 ApJS in press):*** Overlay of $^{12}CO$ contours (magenta) on an $HCO^+$ image of part of Region 9. Note the **close correspondence** between the emission morphology in the two species; This similarity exists in clump sizes and linewidths (80% of the clump populations have the same distribution), orientation (60%), and brightness (100%, after scaling by a factor of 10).

## Pending Applications for CHaMP and ThrUMMS Data

- Fully 3D gas temperature, opacity, column density, abundance, structural, and kinematic cubes of GMCs, & comparison with Hi-GAL based SED fits/dust temperatures
- Kinematic distances & detailed dynamics of all major ISM & Galactic-scale structures on large & small scales, including a comparison with GASKAP (HI)
- Dependence of astrochemistry, cloud structure, internal physics, kinematics, arm-interarm differences, and the radio-FIR correlation, on Galactocentric distance and other environmental factors