Formation, evolution, and survival of massive star clusters
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CHaMP: From Molecular Clouds to Massive Young Clusters

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Abstract. I review the major science outcomes to date of the Galactic Census of High- and Medium-mass Protostars (CHaMP), and also report the latest observational results on this unbiased, uniform sample of massive, cluster-forming molecular clumps, based on new mm-wave and IR data. These clouds represent the vast, subthermally-excited population of clumps predicted by Narayanan *et al.* (2008) to dominate the molecular mass of disk galaxies. Besides confirming their existence, we have presented evidence that these massive clumps probably spend a large fraction (90–95%) of their long lives (possibly up to 100 Myr) in a mostly quiescent, low star formation rate (SFR) state. This is likely ended when a density or internal pressure threshold is crossed, after which vigorous, massive cluster formation consumes the densest gas with a high SFR, dispersing the embedding envelope. New results presented in two other posters at this Symposium include (1) the first analysis of HCN emission from the dense gas (Schap *et al.* 2015), and (2) the first deep photometry of clusters in this sample based on NIR AAT & CTIO data, and on MIR Warm Spitzer IRAC data (Dallilar *et al.* 2015).

Keywords. Star formation, molecular clouds, cluster formation

1. Survey Description

The $20^\circ \times 6^\circ$ Nanten survey of the Carina Arm of the Milky Way, in the $J{=}1{\rightarrow}0$ lines of ^{12}CO, ^{13}CO, C^{18}O, and HCO$^+$, was used as the starting point for CHaMP (Barnes *et al.* 2011). We identified 202 massive, dense clouds in the Nanten data, and made more sensitive molecular line maps of the brightest 120 Nanten clouds with the Mopra radio telescope. The Mopra observations resolved these 120 clouds into 303 parsec-scale clumps in the $5\times$ higher-resolution maps, and are in multiple 3mm tracers, including the 4 lines listed above, plus HCN, CN, N_2H^+, and many others, obtained simultaneously with Mopra's powerful spectrometer.

2. First Molecular Line Results

The first molecular line data that were analysed and published were for the HCO$^+$ line at 89 GHz (Barnes *et al.* 2011). From measurements of basic observed properties of the 303 clumps (such as peak integrated intensity, velocity dispersion, clump size, etc.), we derived a number of physical properties for the entire clump population, such as optical depth, column/surface density, mass, total internal pressure, and virial parameter (among others). From this analysis, a number of unexpected implications have emerged.

For example, the distribution of CHaMP clumps in the mass-density plane shows that virtually all clumps have central densities well below that required to thermalise the HCO$^+$ line, and that only a small fraction of clumps ($\sim$5%) are engaged in vigorous massive star and cluster formation. This confirms that a vast population of subthermally excited massive clumps must dominate the cloud population in the Milky Way's cold ISM, as predicted by Narayanan *et al.*(2008). These mostly quiescent clumps must therefore also survive a very long time (possibly as long as 100 Myr), since the sample is an unbiased population and the actively star-forming clumps are dispersed in a few Myr.

3. First Narrowband NIR Results

CHaMP was designed to be a comprehensive, multi-wavelength survey of massive star formation. Therefore, in addition to the molecular line emission from pre- and protostellar gas, we also obtained complete NIR data on the CHaMP clumps in both broad- and narrowband filters, using the AAT and CTIO Blanco 4m telescopes. The narrowband AAT images of 2μm line emission from CHaMP clumps include Brackett-γ and the $S(1)$ v=1→0 and 2→1 lines of H_2. These data, and the companion broadband images (see below), confirm that most clumps, while massive, are relatively quiescent in their star formation activity (Barnes *et al.* 2013).

Moreover, among the 3mm and NIR lines, only the following pair shows a correlation. HCO^+ is traditionally thought of as a tracer of cold, dense gas, yet it is strongly correlated with Brackett-γ, a tracer of massive young stars. Therefore, not all 'dense gas tracers' trace dense gas! Rather, careful column density calculations show that species such as HCO^+ and HCN trace a combination of column density and excitation.

4. New Molecular Line Results

The HCN line at 88 GHz has hyperfine components which provide a stand-alone opportunity for LTE radiative transfer analysis. The ratios show that simple conversions of integrated intensity to column density are not reliable, and could mask large amounts of quiescent, subthermally-excited, high column density gas, underscoring the conclusions of the mm-wave/NIR comparison (Barnes *et al.* 2013). See the companion paper by Schap *et al.* (2015) for more details.

5. New broadband NIR and deep Warm *Spitzer* photometry

In a companion poster by Dallilar *et al.* (2015), we show preliminary results from an analysis of broadband NIR and deep Warm *Spitzer* photometry, including extinction measures and protostellar content for each of the CHaMP clumps. Again, these show that most clumps have only a small number of embedded protostar candidates, despite being typically quite massive ($\sim$700 $M_\odot$).

6. Implications

ChaMP forces us to revise the prestellar history of molecular clouds, which are much more numerous and have far longer lifetimes than previously realised. This allows ample time, for example, for slow processes like ambipolar diffusion to let the cold gas slip through any magnetic field, which might otherwise provide cloud support against gravity.

References

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