High-resolution observations of Infared Dark Clouds

Sarah Ragan[1], Edwin Bergin[1], Lori Allen[2], David Wilner[2]

1 University of Michigan, Ann Arbor, MI, USA

2 Smithsonian Astrophysical Observatory, Cambridge, MA, USA

seragan@umich.edu

Abstract.

We present a detailed structural and kinematic study of a sample of infrared dark clouds, the likely precursors of massive stars and stellar clusters. With Spitzer IRAC images we have resolved absorbing structures at high angular resolution (~2''). Based on MIPS 24 micron data we have found that most dense absorbing condensations are starless. Our structural analysis finds that the the clump mass function (CMF) is dN/dM ~ M^{-1}. This is comparable to that estimated from CO emission studies in local clouds but flatter than estimated from dust emission studies in these same local clouds (e.g. Ophiuchus). We conclude that these objects are in early stages of cloud fragmentation and that the initial physics of this process leads to a flat CMF. To supplement these data, we have performed interferometric observations of high-density gas tracers to provide us with kinematical information at with high velocity resolution and comparable spatial resolution.

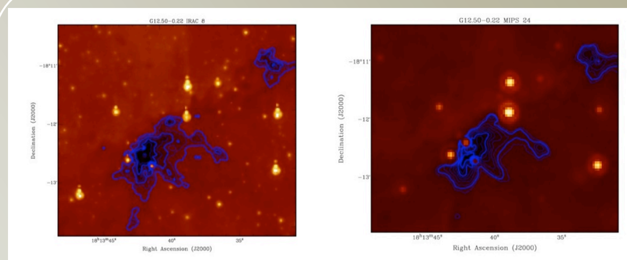

Figure 1: IRAC 8μm opacity map (left) and MIPS 24μm opacity map (right) exhibit corresponding structure in morphology.

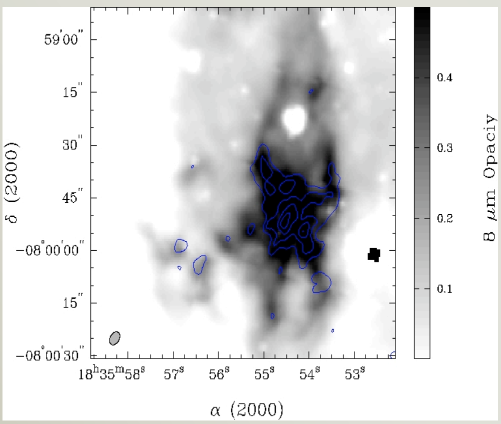

Figure 2: IRAC 8μm opacity map overlaid with NH_3 (1,1) integrated intensity contours from VLA observations.

Identification of Absorbing Structure and Fragmentation.

Given the non-uniform nature of radiation in the Galactic plane, care must be taken not to mistake fluctuations in the background for structure in the absorbing gas/dust. The predominant background source varies with wavelength in the Spitzer images: at 8μm, the dust absorbs the polycyclic aromatic hydrocarbons (PAHs), and at 24μm, the thermal radiation of the Galaxy provides the background. Despite this, upon comparison of the dark features present in both the 8 and 24μm images (see Fig. 1), we find striking morphological similarities between the two. This suggests that the structure seen in absorption is real and tracing the fragmentation in dense gas.

To further confirm this issue we use molecular tracers, specifically NH_3 and N_2H^+, that are known to trace extremely high-density gas (di Francesco et al., 2007). Previous studies (Ragan et al., 2006) have shown that these molecules correspond very well to dense absorbing material. Figure 2 shows that the high resolution molecular image is correlated with the 8μm opacity map. This is further illustrated in Figure 3, where we display the relationship between 8μm opacity and the integrated emission of N_2H^+ observed with BIMA. The excellent correlation led us to conclude that these objects are genuine massive dark clouds undergoing fragmentation, in many cases prior to the stage of stellar birth.

Mass Function.

In order to generate opacity maps, we model the smooth background variation using a spatial median filtering technique and assumed negligible foreground at both 8 and 24μm. We utilize the CLUMPFIND algorithm (Williams et al., 1994) to identify distinct structures within the cloud. Assuming a dust extinction cross section of $\sigma_{8\mu m} = 2.3 \times 10^{-23}$ cm^2, the column density follows as $N(H_2) = \tau_{8\mu m} / \sigma_{8\mu m}$. Using kinematic distance estimates to the IRDCs (Ragan et al., 2006), we compute the physical size and approximate the mass of each clump.

Using the IRAC images in this fashion provides a powerful counterpoint to studies of using dust emission in several ways. (a) The resolution is ~2", well below that offered by most millimeter and sub-millimeter facilities, (b) the column measurement is independent of dust temperature and (c) is sensitive to very small columns down to a few tenths of magnitude.

We calculate the differential clump mass function (DCMF) for each IRDC in our sample. The DCMF for our sample is shown in Figure 3. The characteristic slope is consistent with CO emission measurements of Williams et al. 2000, and in disagreement with studies of dust emission in local clouds (Ward-Thompson et al. 2007). This difference may be due to the different sensitivities between these techniques. Alternately, the IRDCs in our sample may be at an earlier evolutionary stage, and this DCMF may instead represent the initial conditions of cloud fragmentation rather than subsequent fragmentation to the stellar scale.

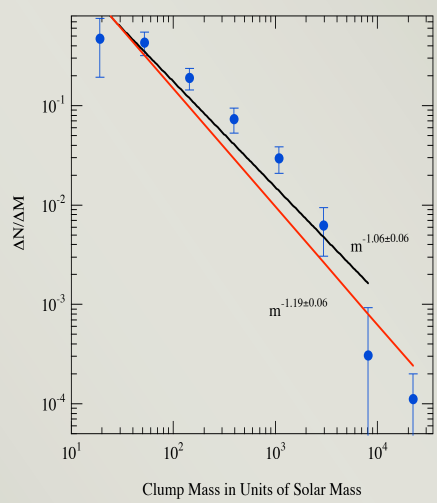

Figure 3 : Differential Clump Mass Function - The red line shows the fit including all data points. The black line is the fit using all but the last data bin.

References

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Work in Progress.

Full moment analysis yields useful velocity information across the clouds in our sample. Preliminary analysis suggests that the core-to-core velocities of individual clumps vary by ~1km/s across a cloud a few pc in size. Given the gas temperature of 15-20 K this implies supersonic relative motions and/or systematic gradients. We will also be able to examine the line widths in each field and explore whether the dense clumps have lower line widths when compared to the envelope as seen in low mass star forming regions.