Molecular Clouds and Star Formation: A Multiwavelength Study of Perseus, Serpens, and Ophiuchus

Thesis by

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Abstract

In this thesis I utilize large-scale millimeter and mid- to far-infrared surveys to address a number of outstanding questions regarding the formation of low mass stars in molecular clouds. Continuum $\lambda = 1.1$ mm maps completed with Bolocam at a resolution of $31''$ cover the largest areas observed to date at millimeter or submillimeter wavelengths in three molecular clouds: 7.5 deg^2 in Perseus (140 pc^2 at the adopted distance of $d = 250$ pc), 10.8 deg^2 (50 pc^2 at $d = 125$ pc) in Ophiuchus, and 1.5 deg^2 (30 pc^2 at $d = 125$ pc) in Serpens. These surveys are sensitive to dense substructures with mean density $n \gtrsim 2 - 3 \times 10^4$ cm^{-3}. A total of 122 cores are detected in Perseus, 44 in Ophiuchus, and 35 in Serpens above mass detection limits of $0.1 - 0.2$ $M_\odot$. Combining with *Spitzer* mid- and far-infrared maps from the c2d Legacy program provides wavelength coverage from $\lambda = 1.25 - 1100$ μm, and enables the assembly of an unbiased, complete sample of the youngest star forming objects in three environments. This sample includes 108 prestellar cores, 43 Class 0 sources and 94 Class I sources.

The approximately equal number of starless cores and embedded protostars in each cloud implies a starless core lifetime of $2 - 4 \times 10^5$ yr, only a few free-fall timescales. This timescale, considerably shorter than the timescale predicted by the classic scenario of magnetic field support in which core evolution is moderated by ambipolar diffusion, suggests that turbulence is the dominant process controlling the formation and evolution of dense cores. However, dense cores in all three clouds are found only at high cloud column densities, where $A_V \gtrsim 7$ mag, and the fraction of cloud mass in these cores is less than 10%, indicating that magnetic fields must play some role as well. Measured angular deconvolved sizes of the majority of starless cores are consistent with radial density profiles substantially flatter than $\rho \propto r^{-2}$, or with Bonnor-Ebert spheres. The prestellar core mass distribution (CMD) has a slope of $\alpha = -2.5 \pm 0.2$ for $M > 0.8$ $\mathrm{M}_\odot$, remarkably similar to recent measurements of the slope of the stellar initial mass function: $\alpha = -2.3$ to -2.8. While this result does not rule out the importance of feedback or competitive accretion, it provides support for the hypothesis that stellar masses are determined during the core formation process.

The lifetime of the Class 0 phase is estimated to be $1 - 2 \times 10^5$ yr in Perseus and Serpens, or approximately half that of the Class I phase, arguing against a very rapid early accretion phase. In Ophiuchus the fraction of Class 0 sources is much smaller, consistent with previous measurements of a short ($\sim 10^4$ yr) Class 0 phase in that cloud. A large population of low luminosity Class I sources that cannot be explained by constant or monotonically decreasing accretion rates is observed in each cloud. This result strongly suggest that accretion during the Class I phase is episodic, with sources spending approximately 25% of the Class I lifetime in a quiescent state.

Finally, I investigate the environmental dependence of star formation by comparing the dense core populations of the three clouds. Cores are found at considerably higher cloud column densities in Ophiuchus than in Perseus or Serpens; more than 75% of cores occur at visual extinctions of $A_V \gtrsim 8$ mag in Perseus, $A_V \gtrsim 15$ mag in Serpens, and $A_V \gtrsim 20 - 23$ mag in Ophiuchus. Cloud CMDs are well characterized by power-law fits ($dN/dM \propto M^\alpha$) above their empirically derived 50% completeness limits, resulting in slopes of $\alpha = -2.1 \pm 0.1$ in Perseus, $\alpha = -2.1 \pm 0.3$ in Ophiuchus, and $\alpha = -1.6 \pm 0.2$ in Serpens. Measured slopes for Perseus and Ophiuchus broadly agree with turbulent fragmentation, but the relative shapes of the observed cloud CMDs are inconsistent with detailed simulations of the dependence of CMD shape on Mach number.

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