The Evolving ISM in the Milky Way & Nearby Galaxies

Distributed Star Formation in the M17 Giant Molecular Cloud

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ABSTRACT

We have found 269 candidate young stellar objects (YSOs) within a 0.5-degree (14 pc at 1.6 kpc) radius of the M17 H II region by fitting model spectral energy distributions (SEDs) to point-source fluxes from the GLIMPSE Archive, combined with MIPSGAL 24 and 70 μm photometry and *MSX* point-source fluxes where available. Bright diffuse mid-IR background emission dramatically reduces the IRAC point source sensitivity in the M17 H II region, so all but a few of the detected YSOs lie outside the H II region. Of our sample, $\sim$160 YSOs in the earliest stages of formation are distributed throughout the extended outer regions of M17 giant molecular cloud. YSOs appear to be located beyond the previously measured extent of the molecular gas. Our YSO sample has a power-law IMF that is complete above $\sim 3\,M_{\odot}$. We estimate that at least 1250 stars are currently forming in the M17 molecular cloud. High-resolution imaging of M17 in X-rays with *Chandra* (Broos et al. 2007) has uncovered a population of 8,000–10,000 young stars within or near NGC 6618, the central ionizing cluster; our sample represents a complementary population. The M17 giant molecular cloud continues to form stars at $> 25\%$ of the star formation rate that produced the massive NGC 6618 cluster.

Subject headings: stars: formation — infrared: ISM — H II regions

1. Introduction

M17 is a well-studied nearby (1.4–1.9 kpc; Povich et al. 2007) massive star-formation region featuring a blister H II region erupting from the side of a giant molecular cloud. A

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recent study of the M17 H II region with the *Chandra X-ray Observatory* has revealed 886 X-ray point sources centrally concentrated in the $17' \times 17'$ ACIS field (Fig. 2 of Broos et al. 2007), implying a total population of 8,000–10,000 stars in NGC 6618, the M17 ionizing cluster. Wider-field near-IR imaging has provided evidence of ongoing star formation in the molecular cloud (Jiang et al. 2002). The GLIMPSE and MIPSGAL *Spitzer* Galactic plane surveys with the IRAC and MIPS instruments, respectively, provide the highest-resolution large-scale infrared views of M17 to date. These datasets allow us to probe the full extent of M17 as a star formation event. We can now develop a more complete picture of this region in the context of its larger environment in the Galactic plane.

2. Observations and Models

In this work we are interested primarily in the population of young stellar objects (YSOs) associated with M17. To identify YSO candidates, we first correlate (bandmerge) GLIMPSE Archive sources (including JHK_S photometry from *2MASS*) with MIPSGAL 24 μm point-source photometry. For sources resolved by IRAC or otherwise unextracted (due to steep background emission gradients, for example), we measure broadband fluxes using aperture photometry. For the brightest, unconfused sources, we further bandmerge with the *MSX* point source catalog, *IRAS* catalog, and/or MIPSGAL 70 μm fluxes, whenever possible. Sources with $\geq$4 flux datapoints in the resulting combined sourcelists are fit with model spectral energy distributions from a pre-computed grid of YSO models (Robitaille et al. 2006; hereafter RW06). We can robustly distinguish between YSOs and extincted photospheres of main-sequence and giant stars because YSOs require a thermal emission component from circumstellar dust to reproduce the shapes of their mid-IR excesses.

2.1. Overview

A GLIMPSE mosaic image of a 1-degree field centered on M17 is shown in Figure 1, with the locations of YSO candidates marked by colored circles (see §2.2). Active star formation is apparent out to the edge of our YSO search radius. The distributions of YSO candidates and diffuse 8.0 μm PAH emission (tracing dust and molecular gas exposed to UV radiation; Povich et al. 2007) indicate that the molecular cloud extends $15'$–$30'$ (7–14 pc) outward from its dense center (CO contours from Scoville et al. 1987). The cloud may be fragmenting; numerous small clusters of 5–10 detected YSOs are evident, many of them associated with IR dark clouds silhouetted against the 8.0 μm background emission.

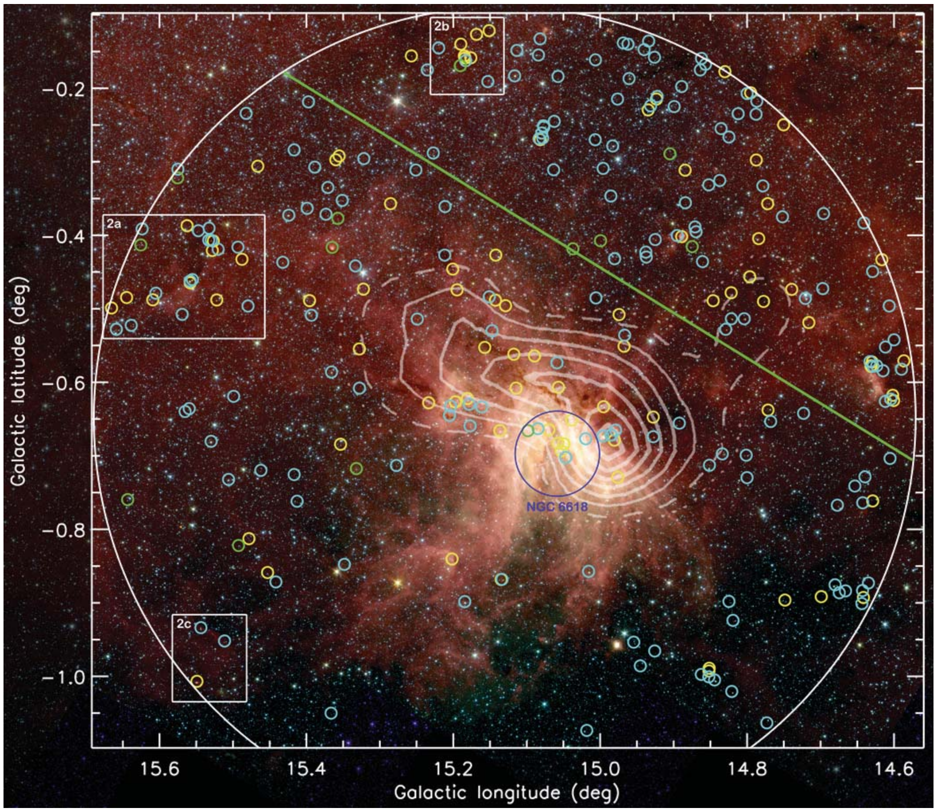

Fig. 1.— GLIMPSE full-color (*red*: 8.0 μm, *orange*: 5.8 μm, *green*: 4.5 μm, *blue*: 3.6 μm) image of the M17 H II region. Positions of YSO candidates are marked by colored circles (see §2.2). White contours are taken from Scoville et al. (1987) and delineate the dense molecular cloud in CO emission. The *white* circle is our YSO search radius. YSO candidates lying below the *green* line are likely to be associated with M17. The numbered boxes show regions enlarged in Fig. 2.

The CO maps presented by Sanders et al. (1986) reveal that M17 is not the only dense molecular cloud in this field. Based upon the CO distributions in (l, b, v) and the distribution of our YSO candidates, we can draw a rough boundary through our sample that divides YSO candidates that probably associated with the M17 molecular cloud from those that are more likely to be associated with neighboring clouds (*green* line in Figure 1). This cut selects 160 candidate YSOs that could be associated with M17.

Our YSO sample may be contaminated by unassociated sources. Potential contaminants include mass-losing asymptotic giant branch stars that produce dust and YSOs along the line of sight that are not associated with a prominent molecular cloud. Background galaxies may also be a source of contamination, but they are not a major concern, because GLIMPSE is a shallow survey. In order to estimate the fraction of contaminants in our sample, we performed a YSO search using identical methods in a control field 0.5 degrees square centered at $(l, b) = (15.1, 0.6)$. The control field is symmetric with M17 about the Galactic plane but happens to lie in a region with low diffuse 8.0 μm emission and no CO emission detected in the Sanders et al. (1986) maps. Based upon the density of YSO candidates detected in the control field, we can place an upper limit of 30% on the fraction of contaminants in our sample. The actual fraction of contaminants will be less because the faint IR backgrounds and lower extinction gives a longer observational line-of-sight through the control field than through the M17 field.

2.2. YSO evolutionary stages

Following the criteria of RW06, we use the model parameters of envelope accretion rate $\dot{M}_{\rm env}$ and circumstellar disk mass $M_{\rm disk}$, normalized by the mass of the central star $M_\star$, to separate the models fit to our detected YSOs into evolutionary Stages:

$$\begin{array}{lll}
\text{Stage 0/I:} & \dot{M}_{\rm env}/M_\star > 10^{-}6~{\rm yr}^{-1} & \\
\text{Stage II:} & \dot{M}_{\rm env}/M_\star < 10^{-}6~{\rm yr}^{-1}; & M_{\rm disk}/M_\star > 10^{-6} \\
\text{Stage III:} & \dot{M}_{\rm env}/M_\star < 10^{-}6~{\rm yr}^{-1}; & M_{\rm disk}/M_\star < 10^{-6}.
\end{array}$$

The color-coding of the circles marking sources in Figures 1 & 2 corresponds to the most probable Stage of the source. The Stage taxonomy parallels the T Tauri Class taxonomy: 0/I, heavily embedded in an infalling, dusty envelope (*yellow*, 32% of our sample); II, optically thick circumstellar disk (*cyan*, 64%); and III, optically thin debris disk (*green* 4%). The SEDs of Stage III YSOs are the most difficult to separate from stellar photospheres because their IR excesses are small. Because ours is a conservative sample, with a goal of reliability over completeness, we probably under-count Stage III YSOs.

2.3. Three regions of interest

Many YSO candidates stand out prominently in the MIPS 24 μm images. Enlargements of the three boxed areas in Figure 1 are shown in combined GLIMPSE and MIPSGAL color images in Figure 2:

(a) This prominent, star-forming IR dark cloud appears to be connected to M17 by an arc of diffuse 8.0 μm emission. The set of well-fit models to the example Stage III YSO (top) give mass, luminosity ranges of 2–4 $M_\odot$, 5–100 $L_\odot$. The Stage 0/I YSO (bottom), bright at 24 μm, is modeled at 6–10 $M_\odot$, 200–1500 $L_\odot$, the luminosity including a contribution from accretion. This source exhibits excess emission at 4.5 μm, a signature of outflow activity.

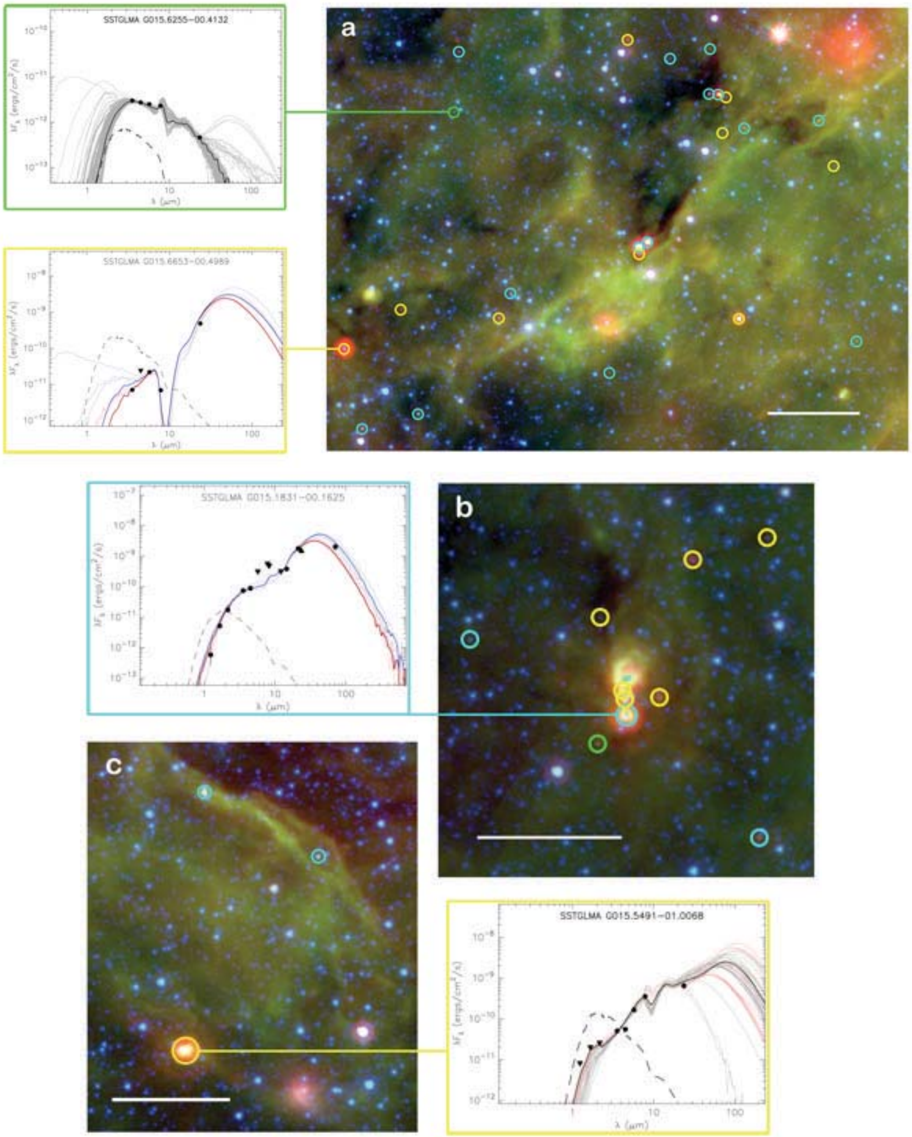

Fig. 2.— Combined GLIMPSE/MIPSGAL (*red*: 24 μm, *green*: 8.0 μm, *blue*: 4.5 μm) images of the boxed regions in Fig. 1. Scalebars are 2 arcmin (0.9 pc). Plots show model SEDs fit to the broadband fluxes of selected individual YSO candidates. The colored curves show the models in different apertures, and the dashed curves are the stellar photospheres in the absence of circumstellar dust. Fluxes used as upper or lower limits for model fitting are plotted as triangles.

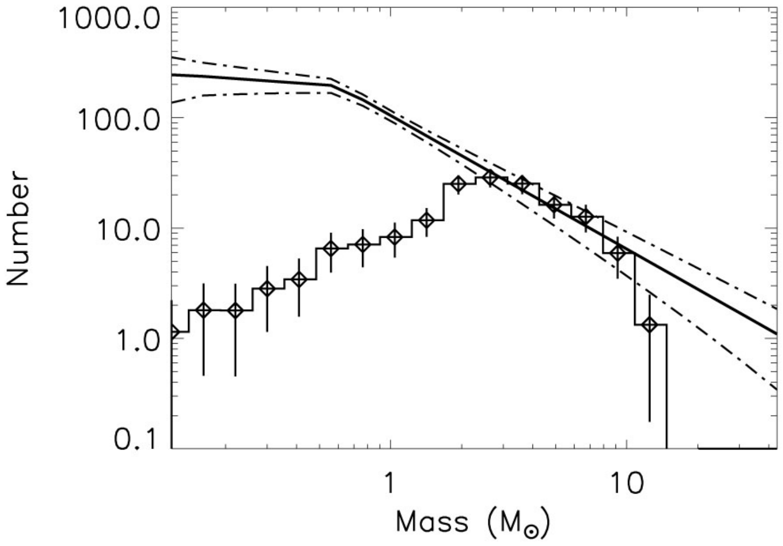

Fig. 3.— IMF of the 160 candidate YSOs associated with the M17 molecular cloud. The IMF of Muench et al. (2002), plotted as a solid curve (dash-dotted curves give the error envelope) has been fit to the portion of the observed IMF that appears to be complete (∼3–9 $M_\odot$).

(b) A cluster of YSOs produces a peanut-shaped IR diffuse emission structure. The lower half of the peanut can be well-fit by YSOs of 6–8 $M_\odot$, 1000–2000 $L_\odot$, if the fluxes in the bands most strongly contaminated by PAH emission are used as upper limits only.

(c) Two candidate YSOs appear to lie on a dust filament seen in emission. The bright Stage 0/I YSO (3–10 $M_\odot$, 100–1000 $L_\odot$) below the filament appears to be relatively isolated. It has been previously catalogued as an *IRAS* point source.

2.4. Initial mass function (IMF)

Using the RW06 models to constrain the masses of the 160 YSO candidates located below the *green* line in Figure 1, we construct an IMF of the stars forming in the M17 molecular cloud (Figure 3). The observed IMF turns over below a stellar mass $M \approx 3\,M_\odot$, our completeness limit. We fit the Orion Trapezium IMF (Muench et al. 2002) to the part of the observed IMF where we are complete. After correcting for a maximum of 30% contaminants in our sample, we place a lower limit of 1250 on the total YSO population in the extended regions of the M17 molecular cloud. The corresponding total stellar mass of the YSOs is $\gtrsim 1000\,M_\odot$.

3. Results

The M17 giant molecular cloud harbors a distributed YSO population that represents a significant level of ongoing star formation in this region. Broos et al. (2007) infer a population of 8,000–10,000 young stars and YSOs for the M17 H II region by scaling the X-ray luminosity function of their sources to that of Orion. This corresponds to a total mass in stars of 6300–8000 $M_{\odot}$. Because NGC 6618 is younger than 1 Myr, and star formation is ongoing in the H II region (Jiang et al. 2002), we assume an average age of 5×10^5 yr for the stellar population, yielding a star formation rate of 0.013–0.016 $M_{\odot}$ yr^{-1}. The IR-detected YSOs are more embedded and hence younger than the stars in the NGC 6618 cluster. Based upon their evolutionary stages and clustering properties, we estimate an average age of $\lesssim 2.5 \times 10^5$ yr. We thus obtain a minimum total star formation rate of 0.004 $M_{\odot}$ yr^{-1} for the YSOs currently forming in the molecular cloud. This represents 25–30% of the star formation rate that produced the massive ionizing cluster in the H II region, but distributed through a volume ∼15 times larger.

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