DISCOVERY OF TWO DUST PILLARS NEAR THE GALACTIC PLANE

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ABSTRACT

We report the discovery of two dust pillars using GLIMPSE archival images obtained with the Infrared Array Camera on board the Spitzer Space Telescope. They are located close to the Galactic molecular cloud GRSMC45.453+0.060 and they appear to be aligned with the ionizing region associated with GRSMC45.478+0.131. Our three colour mosaics show that these stellar incubators present different morphologies as seen from planet Earth. One of them shows the unquestionable existence of young stellar objects in its head, whose influence on the original cocoon is evident, while the other presents a well defined bright-rimmed ionizing front. We argue that second-generation star formation has been triggered in these protuberances by the action of massive stars present in the nearby H II regions.

Subject headings: stars:formation — infrared: stars, ISM — H II regions — Galaxy: structure

1. INTRODUCTION

The Milky Way presents a region at approximately 5 kpc from the Sun that dominates its star-forming structure. This region is called the Galactic Ring and it is an enormous reservoir of material for the formation of new stars and stellar clusters. Most of the Galactic Giant H II regions, far-infrared (far-IR) luminosity, diffuse ionized gas, and supernovae remnants are associated with the ring according to Clemens et al. (1988).

The Galactic Ring remains largely unexplored. Jackson et al. (2006) have conducted a molecular line survey of the inner Galaxy called the Boston University-Five College Radio Astronomy Observatory Galactic Ring Survey (GRS)1. This survey uses the molecular transition $^{13}$CO $J = 1 \rightarrow 0$ which peers more deeply into the interiors of molecular clouds than the more common $^{12}$CO. This data set has provided the tools to discover infrared dark clouds which represent the densest clumps within giant molecular clouds where massive stars may eventually form. We are using this information to select several regions that present high intensity in the molecular transition in order to perform a detailed mid- and near-IR follow-up research.

We are interested in performing a thorough description of the stellar populations in those regions, with emphasis on the massive stellar components. Massive stars are born in giant molecular clouds and form most likely in stellar clusters (Lada & Lada 2003). They physically and chemically interact with their environment by the ionization due to ultraviolet (UV) light, by stellar winds, and by supernova explosions. Massive stars spend their youth embedded in the molecular cloud in which they form; therefore, young massive stars must be studied at infrared or longer wavelengths.

It has been found that massive young clusters ($M > 10^4 M_\odot$ and age < 20 Myr) usually trigger a second-generation of star formation, and frequently the most luminous second-generation sources are located inside the heads of dust pillars oriented towards the central cluster. Giant dust pillars are often found at the edges of H II regions. The dust pillars in M16 (the Eagle Nebula, Hester et al. 1996) are a well known example. Walborn (2002) provides a review of the some interesting dust pillars in our Galaxy including the Horsehead, the Cone, the Eagle, the Carina Finger, and one in NGC 3603. Dust pillars have also been found in starburst regions in the Magellanic Clouds (30 Doradus and N11).

In this Letter, we present the discovery of two dust pillars located close to the conspicuous molecular cloud GRSMC45.453+0.060 (using the notation of Simon et al. 2001 to name the Galactic Ring Survey Molecular Clouds.) We briefly discuss their morphology from the observation of three-colour mosaics constructed using Spitzer Space Telescope images.

2. OBSERVATIONS

2.1. Galactic Ring Survey

Jackson et al. (2006) have conducted a molecular line survey of the inner Galaxy using the SEQUOIA multipixel array on the Five College Radio Astronomy Observatory 14-m telescope. This Galactic Ring Survey (GRS) uses the molecular transition $^{13}$CO $J = 1 \rightarrow 0$, and covers a Galactic longitude range of $l = 18^0 - 55^0$ and a latitude range of $|b| < 1^\circ$, a total of 75.4 deg$^2$.

We have used the GRS to identify interesting regions where we would perform mid- and near-IR studies, with particular interest in the massive star populations. The 5 kpc ring dominates both the molecular interstellar medium and the star-formation activity in the Milky Way. Therefore, it plays a crucial role in the dynam-
ics, structure, and evolution of our Galaxy.

We retrieved the FITS cubes in the range \( l = 43^\circ 0 - 47^\circ 0, b = 0^\circ 0 \) from their survey and we built a colour contour plot shown in Figure 1. The image shows the GRS \(^{13}\CO\) intensity integrated over all velocities \((V_{\text{LSR}} = -5 \text{ to } 85 \text{ km s}^{-1})\). The color scale ranges from 0 to 30 K km s\(^{-1}\). Jackson et al. (2006) gives the details of these observations. Four molecular clouds are clearly seen and we labeled them in the bottom image. These clouds have been studied by Simon et al. (2001) and Kraemer et al. (2003) using the GRS and the Midcourse Space Experiment data.

### 2.2. Spitzer observations

The Galactic Legacy Infrared Mid-Plane Survey Extraordinary (GLIMPSE: PI: Ed Churchwell, see Benjamin et al. 2003 for a description of the project), was conducted using the Infrared Array Camera (IRAC; Fazio et al. 2004) onboard the Spitzer Space Telescope (Werner et al. 2004). This survey covered approximately 220 deg\(^2\) of the Galactic plane, covering a latitude range of \( b = \pm 1^\circ \), and a longitude range of \(|l| = 10^\circ 0 - 65^\circ 0\). IRAC has four bands, centered at approximately 3.6, 4.5, 5.8 and 8.0 \(\mu\)m (hereafter [3.6], [4.5], [5.8], and [8.0], respectively), each of which has a field of view of \( \sim 52^\prime \times 52^\prime \). All four bands are observed simultaneously. The calibrated data from the Spitzer Science Center (SSC pipeline ver. S10.5.0) were processed through the GLIMPSE pipeline reduction system. Image processing includes masking hot, dead, and missing data pixels. Several image artifacts (described in Hora et al. 2004 and the IRAC Data Handbook) are corrected for in the GLIMPSE pipeline: they remove artifacts such as stray light in all bands, they correct for muxbleed (in [3.6] and [4.5] bands), and for banding (in [5.8] and [8.0] bands). Cosmic rays are also removed.

The individual frames were mosaicked using MONTAGE\(^2\), to produce an image of the entire field at each band. The mosaic images conserve surface brightness of the original images. The angular size of each resulting tile is \(1.1 \times 0.8^\circ\) or 6640 \(\times\) 4840 pixels\(^2\). The pixel size of the final data product is 0\(\prime\).06. For this work, we used the archival images from the GLIMPSE survey which are centered around \( l = 45^\circ 50, b = 0^\circ 0 \) and which are provided by the Spitzer Science Center in their data release of April 2007.

### 2.3. 2MASS images

The Two Micron All Sky Survey (2MASS; Skrutskie et al. 2006) has uniformly scanned the entire sky in three near-infrared bands to detect and characterize point sources brighter than about 1 mJy in each band, with signal-to-noise ratio greater than 10, using a pixel size of 2\(\prime\).0. This project used two 1.3-m telescopes (one in each hemisphere) equipped with a three-channel camera, each channel consisting of a 256 \(\times\) 256 pixels\(^2\) array of HgCdTe detectors, capable of observing the sky simultaneously in bands \( J\) (1.25 \(\mu\)m), \(H\) (1.65 \(\mu\)m), and \(K_S\) (2.17 \(\mu\)m). We retrieved \( J\), \(H\), and \(K_S\) archival 2MASS images that cover a 30 arcminute region around \( l = 45^\circ 50, b = 0^\circ 0 \). We also downloaded the catalogue of stars from the Point Source Catalog (PSC) that contains a total of 79528 objects found in the same region.

### 3. Mid-infrared mosaics

The individual FITS frames from GLIMPSE were mosaicked using MONTAGE and our own IDL codes to produce a three-colour image of the entire field around GRS\(^{13}\CO\) 45.453+0.060. We combined the images obtained in filters [3.6], [5.8], and [8.0] by assigning blue to the shortest wavelength band, green to the intermediate band, and red to the longest wavelength band. This particular color combination was chosen to highlight particular properties of the images. Figure 1 [Bottom] shows the three-colour mosaic where we have labeled four spectacular molecular clouds: GRS\(^{13}\CO\) 45.073+0.129, GRS\(^{13}\CO\) 45.122+0.132, GRS\(^{13}\CO\) 45.453+0.060, and GRS\(^{13}\CO\) 47.8+0.131. Each of them is associated with an Infrared Astronomical Satellite (IRAS) point source and with thermal radio continuum emission which is indicative of H\(\alpha\) regions (Kraemer et al. 2003). A comparison with the GRS \(^{13}\CO\) \( J = 1 \rightarrow 0 \) map shows that all four molecular cores present bright \(^{13}\CO\) emission as well as extended mid-IR emission. Note the bridge of \(^{13}\CO\) emission connecting the two groups of molecular clouds.

A closer inspection of the structure close to GRS\(^{13}\CO\) 45.453+0.060 reveals the existence of two striking dust pillars. Figure 2 shows a magnified version of this region in the Galaxy.

The IRAC bands show bright, diffuse, and very highly structured emission, which is produced primarily by polycyclic aromatic hydrocarbon (PAH) features and 

### 4. Morphology of the Dust Pillars

Our three-colour mosaic, built using mid-IR GLIMPSE images in IRAC [3.6], [5.8], and [8.0] bands shows the existence of a couple of dust pillars located to the northeast of GRS\(^{13}\CO\) 45.453+0.060. Using the approximate Galactic coordinates of their heads, we name them DP45.542-0.006 and DP45.543-0.029. Table 1 provides their Galactic coordinates.

We may argue that these pillars appear to be aligned with the ionizing region GRS\(^{13}\CO\) 45.478+0.131. We can also speculate that DP45.543-0.029 is located in front of DP45.542-0.006, and is more heavily obscured. The
northern rim of DP45.542-0.006 is very well defined and we can trace the silhouette of DP45.543-0.029 on the structure of DP45.542-0.006. These protrusions obviously began as pre-existing density enhancements in the original surrounding molecular cloud, and they evolved into the forms seen under the combined effect of photoionization and flows coming from the nearby H II regions. These pillars are the result of the interaction of massive stars with their environment, and they are most likely places of star formation.

For our research we assume a distance to the molecular cloud GRSMC45.453+0.060 of 6.0 kpc. This distance was determined kinematically by Simon et al. (2001). A simple measurement of the length and width of the pillars is given in Table 1. The definition of these measurements is of course subjective because the base of the pillars merges into larger dust structures. We want to emphasize that we measure projected quantities, since the inclination angles are unknown. Our estimated values are in agreement with those that Walborn (2002) calculated for other dust pillars in the Galaxy.

The heads of the two pillars that we discovered are dramatically different as seen from our point of view. Both of them show the presence of young stellar objects, but while the stars in the head of DP45.543-0.029 appear to remain enclosed in the dusty cocoon, those of DP45.542-0.006 have already started to disrupt the interstellar medium. This is a perfect indicator of ongoing stellar evolution, and it may suggest that the stars in the latter pillar are older. However, it is possible that due to the geometry of the region, the dust may be concealing the disruption of the ISM produced by the new born stars in DP45.543-0.029. From the 2MASS point source catalogue of this region, and at a resolution of 2″0 per pixel we find three objects at the tip of DP45.542-0.006, and two in DP45.543-0.029.

We may speculate that the stars in these pillars represent a second generation of star formation in this region. Studies of bright-rimmed clouds containing infrared sources have been taken as evidence of star formation induced by radiatively driven implosion (Walborn 2002; Hester et al. 1996; Sugitani & Ogura 1994). Triggered second-generation star formation in the vicinity of O-type stars and clusters is ubiquitous, and often the second generation is associated with dust pillars. These processes may play an important role in the self propagation of star formation in the Galaxy.

5. RESULTS AND FUTURE WORK

Recent Galactic surveys in radio and the infrared are providing us with exciting new tools to study nearby star formation and the interaction of massive stars with their environment. In this research we have used the Galactic Legacy Infrared Mid-Plane Survey Extraordinaire (GLIMPSE) conducted using the Spitzer Space Telescope and the Galactic Ring Survey (GRS) performed at the Five College Radio Astronomy Observatory. GRS has the ability to identify and probe active star-forming gas, and GLIMPSE delineates the structure of molecular clouds and their dust composition.

We discovered two remarkable dust pillars near the molecular cloud GRSMC45.453+0.060. Even though they seem close to each other (in projection), one of them shows a more evolved structure that the other, from our point of view.

We intend to continue our research of this whole star forming region of the Galaxy. We will perform near infrared studies to gather information on their stellar populations by means of photometry and spectroscopy. A future paper will investigate the truth of the speculations proposed in this Letter in more detail, but new spectroscopic and photometric observations of this region are strongly encouraged in order to characterize the nature of these clouds and the stellar population associated with them. The space-mass-age distributions of the objects in these regions will tell us great deal about the relationships between higher- and lower-mass star formation. In particular we are interested in the distribution of stellar ages in order to corroborate our hypothesis of the two-stage star formation process.

The early results of our research indicate the importance of large field-of-view IR observations like the ones provided by the GLIMPSE survey. We are confident that our detailed studies of star forming regions near the Galactic plane will play a crucial role in the overall understanding of the Milky Way.

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### Table 1

| Pillar          | $l$  | $b$    | Length [pc] | Width [pc] | L/W  |
|-----------------|------|--------|-------------|------------|------|
| DP45.542-0.006  | 45º 32' + | 00º 21' + | 2.3         | 1.1        | 2.1  |
| DP45.543-0.029  | 45º 34' + | 01º 45' + | 1.7         | 0.9        | 1.9  |

**Fig. 1.** — **[Top]** Color-scale representation of the integrated intensity of the $^{13}$CO $J = 1 \rightarrow 0$ emission from the Galactic Ring Survey, integrated from $V_{LSR} = -5$ to 85 km s$^{-1}$. The colour scheme ranges from 0 to 30 K km s$^{-1}$. The orientation is given in the Galactic coordinate system. **[Bottom]** Three colour mosaic built with IRAC images. We combined images obtained with filters 3.6 $\mu$m (blue channel), 5.8 $\mu$m (green channel), and 8.0 $\mu$m (red channel). We have labeled four prominent molecular clouds, and the rectangle shows the enlarged area depicted in Figure 2.
Fig. 2.— [Top] This three colour mosaic shows the region in Figure 1 marked with the rectangle. We have rotated this image so that
North is up and East is left. [Bottom] A zoomed version of the mosaic showing in detail the structure of the two dust pillars. Note the
different morphology of the two heads as we see them from planet Earth.