Mass Loss from Stars and the Evolution of Stellar Clusters
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Newly Born O Stars in Clusters

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Abstract. We present 4.5μm, 8μm, and 24μm images of four UCHII regions that we have obtained using the *Spitzer* IRAC and MIPS instruments. We show that the exciting stars of one of our objects appears double and the other three are multiple, e.g., small clusters. These latter sources also have other nearby (within 5 pc) star forming regions. The birth of relatively isolated massive stars seems typically to be in small clusters and connects to multiple nearby sites of star formation. We resolve the dust cocoons surrounding the exciting sources of spatial dimension $\approx$ 1pc, as predicted by the models. Three of the cocoons are asymmetric.

1. Introduction and Motivation

Ultra Compact H II regions (UCHII) regions were first extensively characterized by Wood & Churchwell (1989) as surrounding a newly born O star, or stars, in which a gas and dust cocoon left over from the birth process still surrounds the exciting object(s). Because of the high gas density, the ionized hydrogen region is typically smaller than 0.1 pc, whereas the dust cocoon is typically ten times larger. Given the nature of the initial surveys, most radio selected UCHII regions are considered to be "single star excited" and are located along the Galactic plane. That is, they are not associated with Giant H II (GHII) regions where most O stars are born in large clusters. UCHII regions are found in GHII regions when they are specifically searched (e.g., in W49). Our radio sample is, however, relatively isolated in location. There is some evidence (e.g. Sewilo et al. (2004) that multiplicity may be a common characteristic of UCHII regions.

The exciting stars are typically of type O, although early B types also produce these ionized regions. The exciting stars are not visible in the optical due to dust extinction both along the line of sight and locally, but near IR photometry and spectroscopy (Hanson et al. 2002) have revealed a few of them as O type from the presence of absorption features. Most exciting stars are featureless in the K band, as would be the case if dust from a closeby natal disc is emitting at this wavelength and diluting the photospheric features. A few are invisible even in K due to the heavy extinction from the surrounding dust cocoons.

We are ultimately interested in the nature of the exciting stars but the thrust of this paper will be to look at their possible multiplicity within the UCHII region and detection of the cocoon. We used the *Spitzer* Infra-red Array Camera (IRAC) and Multiband Imaging Photometer for Spitzer (MIPS) instruments, which provide a major spatial improvement over the all sky *IRAS* 12–25 μm and Galactic plane *MSX* 8–21 μm imaging surveys. The 4.5μm emission is primarily produced by the disc and/or envelope of the exciting star, the 8μm band samples a Polycyclic Aromatic Hydrocarbon (PAH) feature, and the 24μm wavelength measures the cooler cocoon dust emission (80-100 K). This is illustrated by the models of Whitney et al. (2005). At a few microns the star itself contributes only negligible radiation, especially compared to the presence of a disc or an envelope (hot dust).

In our *Spitzer* GO2 program we have observed 41 UCHII regions, taken from the larger compilation of Crowther & Conti (2003). In this paper we give preliminary results for four sources which are illustrative of the commonalities and distinctions among the entire sample.

2. Spitzer Observations

We obtained *Spitzer* MIPS 24μm and 70μm observations of 41 ultracompact H II regions, and IRAC observations of 10 ultracompact H II regions which were not covered by the Galactic Legacy Infrared Mid-Plane Survey Extraordinaire (GLIMPSE) (Benjamin et al. 2003). We present *Spitzer* observations of four representative UCHII regions, G05.885-0.392, G28.200-0.049, G29.956-0.016, and G45.456+0.060. Furness et al. (these proceedings) present 70μm imaging taken either with wide or fine scale photometry mode depending on the predicted peak brightness.

IRAC observations of G05.885-0.392 were obtained in our program, while the other three are from the GLIMPSE archive. The MIPS 24μm and IRAC data are processed with the *Spitzer* Science Center (SSC) pipeline[1]. The full-width-half-maximum (FWHM) of the point-spread-function (PSF) is $\sim 6''$ in the 24μm image and $1.7''$ in the IRAC images. The uncertainty of the calibration is less than 5% for all IRAC wavelengths (Reach et al. 2005) and less than 10% for the MIPS 24μm band. High order Airy ring artifacts are apparent in some MIPS images. These are caused by sampling the PSF at very high signal-to-noise.

3. Mid-IR imaging

We will present the mid-IR data in four figures, in which we have adjusted representative UCHII regions to the same physical scales, at both 1 pc and 5 pc. The order of presentation is from the less to the more complex. The images are arranged vertically in order of increasing wavelength. In some cases, one or more wavelengths did not cover the entire square frame but the placement of

[1]http://ssc.spitzer.caltech.edu/irac[mips]/documents

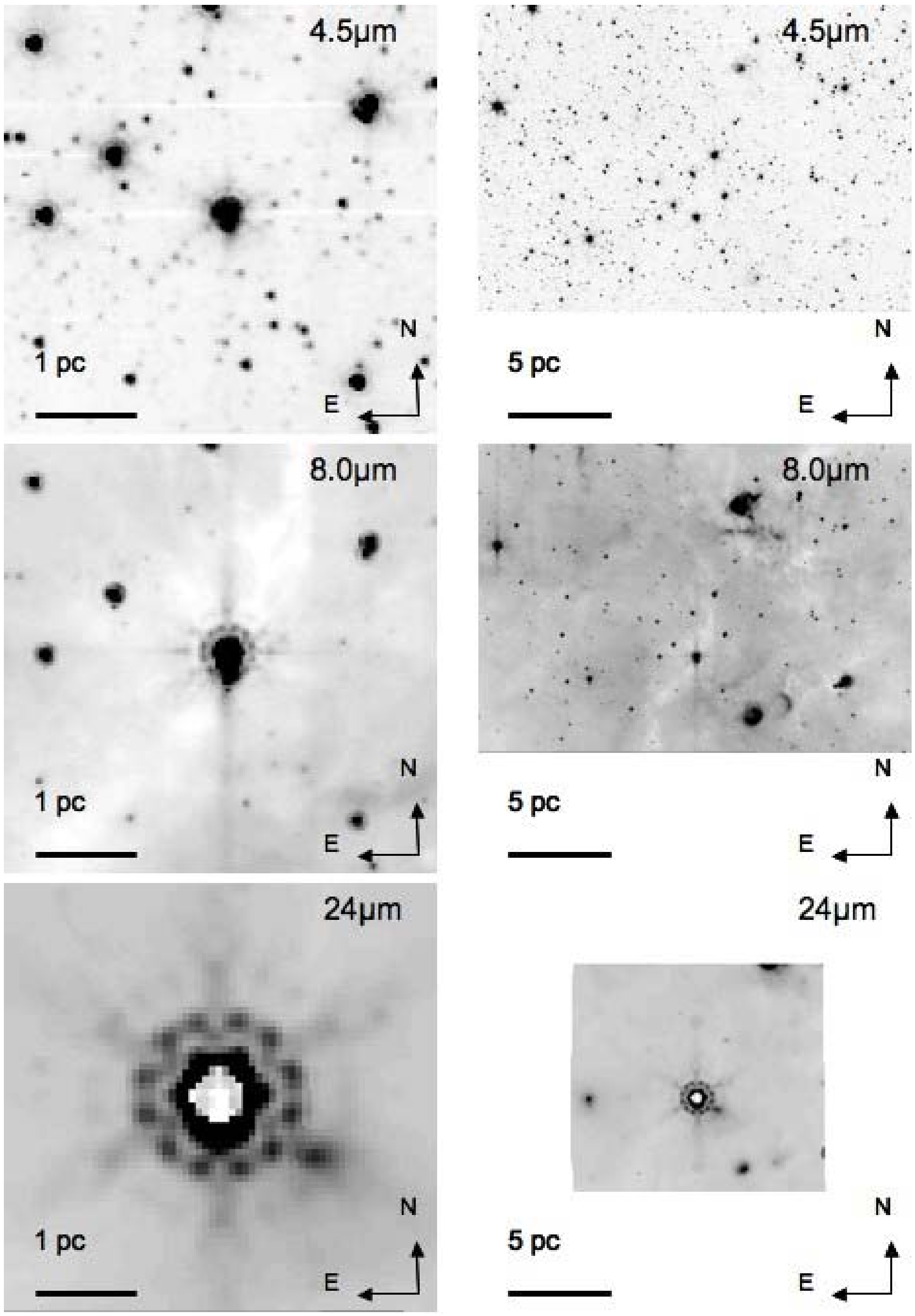

Figure 1. G28.200-0.049 shown at 4.5, 8 and 24μm, with two different scales in the left and right column. The same physical scale has been used to show the sizes of the respective features of the UC HII region. The 4.5 micron image shows the stellar content, the 8 micron the PAH emission and the 24 microns shows cool dust emission, which is exceedingly bright at this wavelength. The images are centered at the same position. Figs. 2-4 have the same format as Fig. 1.

each image is such that the center of the UCHII region has the same placement on the page and lines up both horizontally, and also vertically.

The images are provided as negatives. Several images, e.g., the 24μm image of G28.200, have artifacts near the bright stars. They are due to the bright star latents which are reinforced at the mirror positions at ± 2 arcmin because of repeated dither patterns in the photometry mode. The objects around the bright 24μm sources are due to an Airy ring. The artifacts such as Airy rings and latents should be ignored.

In looking at the images the reader should keep in mind that the 4.5μm wavelength images are dominated by the stars, the 8μm by the PAH emission, and the 24μm, by the heated dust emission.

3.1. G28.200-0.049 (IRAS 18353-0628)

The distance of 5.7 kpc is taken from Fish et al (2003). This source is double but with no evidence of other stellar companions. There is a dust emission source at 8 pc to the NNW, plus another another at 4 pc to the SW, which has a dusty crescent to its NW which appears to be affected by another dust source to its WNW. The central exciting object of the UCHII region has a dust emission core just under 1 pc in diameter. Dark clouds appear from the northwest to southeast crossing the central emission of G28.200-0.049, and a few small dark clouds of filaments and clumps appear in the northwest at 10 pc away.

3.2. G29.956-0.016 (IRAS 18434-0242)

The distance of 7.4 kpc is from Crowther & Conti (2003). There is a central exciting star which has been classified as O5 by Hanson et al. (2005) from K band spectra and this is one of the few stars found with absorption spectral features. The central object is clearly multiple with additional bright stars to the N, the W, and NW. The 5pc images show considerable nebulosity towards the S which is the well known GHII region G29.944-0.042, which also contains several distinct dust clouds. Its kinematic distance is 6.2 kpc (Conti & Crowther 2004), so it may be in the foreground of the UCHII region. The dust cocoon of the UCHII region appears elongated to the SW with a long diameter of about 2 pc.

3.3. G45.456+0.060 (IRAS 19120+1103)

We adopt a distance of 6.6 kpc for this UCHII region (Crowther & Conti 2003). This is a very complex object with multiple stars within 1 pc. The PAH images show considerable structure. The dust cocoon is asymmetric, aligned NS with longer dimension 2 pc. There are other fainter dust clouds within a few pc. Indeed, there are two other UCHII regions in the vicinity (Wood & Churchwell 1989), namely G45.478+0.130 (IRAS 19117+1107) about 8 pc to the NW, plus G45.466+0.046, which can only be seen 2 pc to the east in the 24μm image. Multiple protostars are in the G45.466+0.046 region, and the central source is a bright 24μm point source and shows elongated 4.5μm excess emission indicating the presence of outflows. The field shows similar morphology to an H II region, showing a circular, incomplete filament (7pc) shaped by PAH emission and 24μm bright, heated dust emission inside the circular filament.

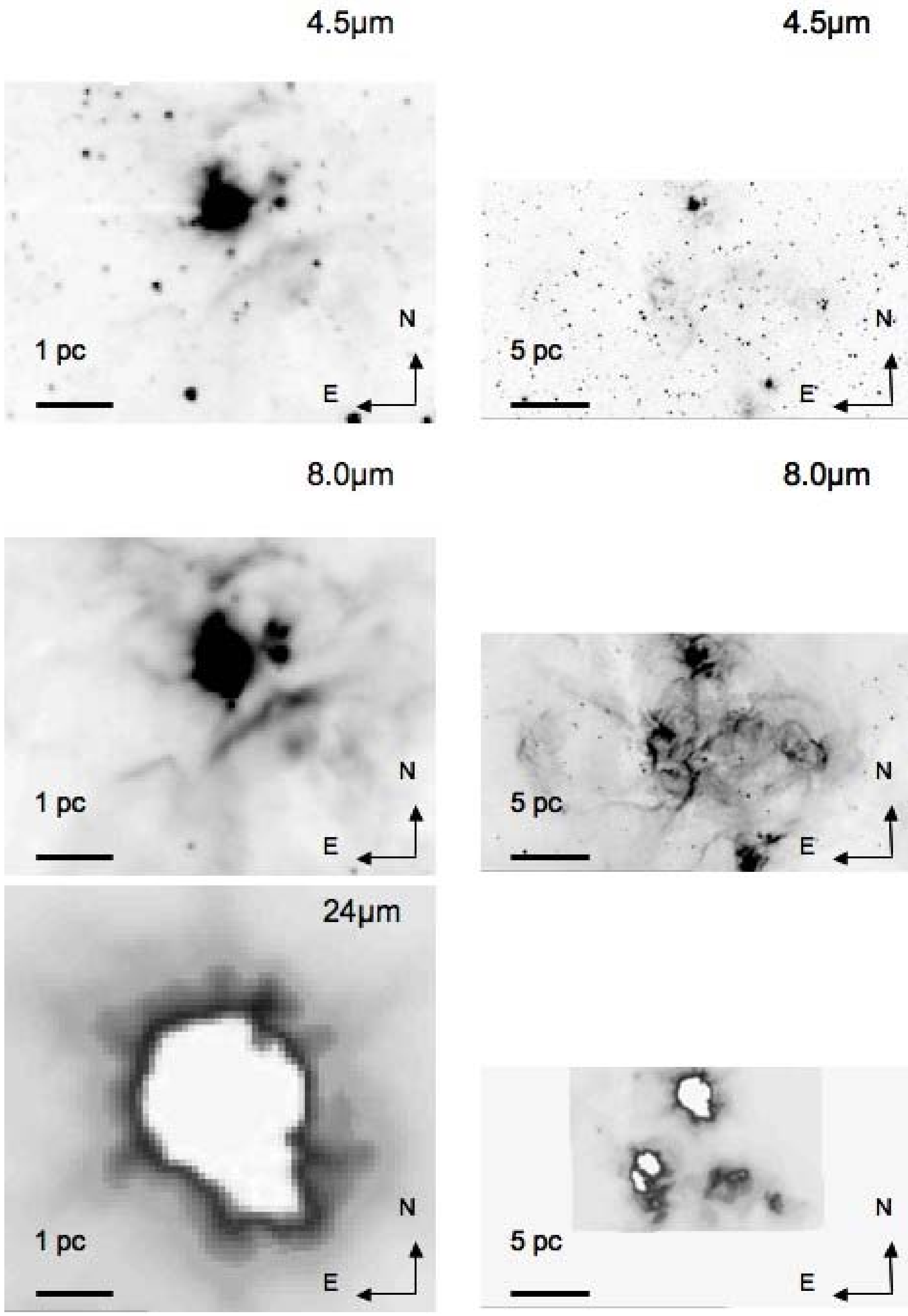

Figure 2. G29.956-0.016 images shown at 4.5, 8 and 24μm. Saturated pixels appear in white in the 24μm image (also in Figs. 3 and 4). The dust cocoon of the UCHII region appears elongated to the SW with a long diameter of about 2 pc based on MIPS 24μm and MSX images. The images show that the central object is clearly multiple with additional bright stars to the N, the W, and NW.

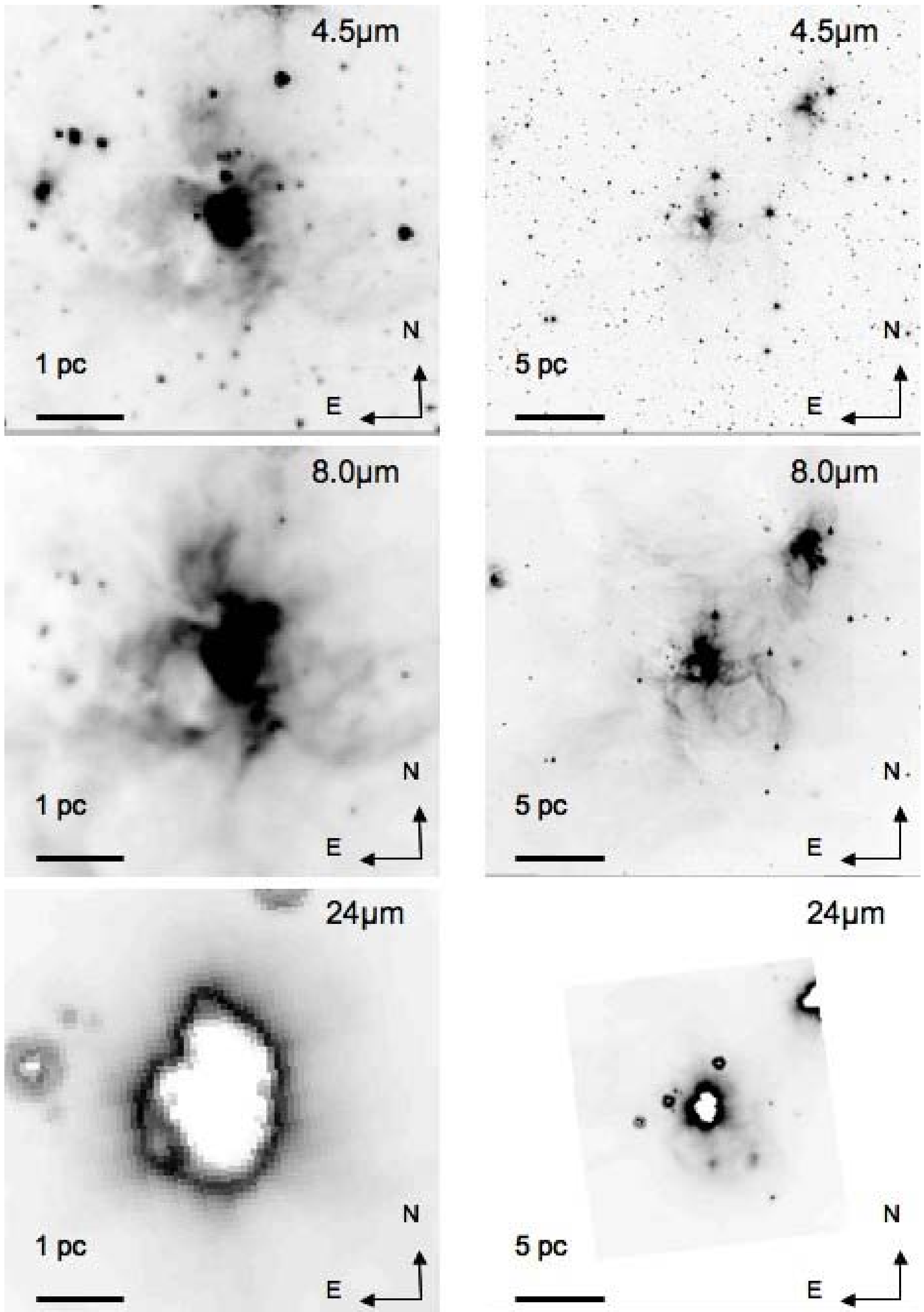

Figure 3. G45.456+0.060 shown at 4.5, 8 and 24μm. The images show very complex structures with multiple stars within 1 pc. The PAH images show considerable structure.

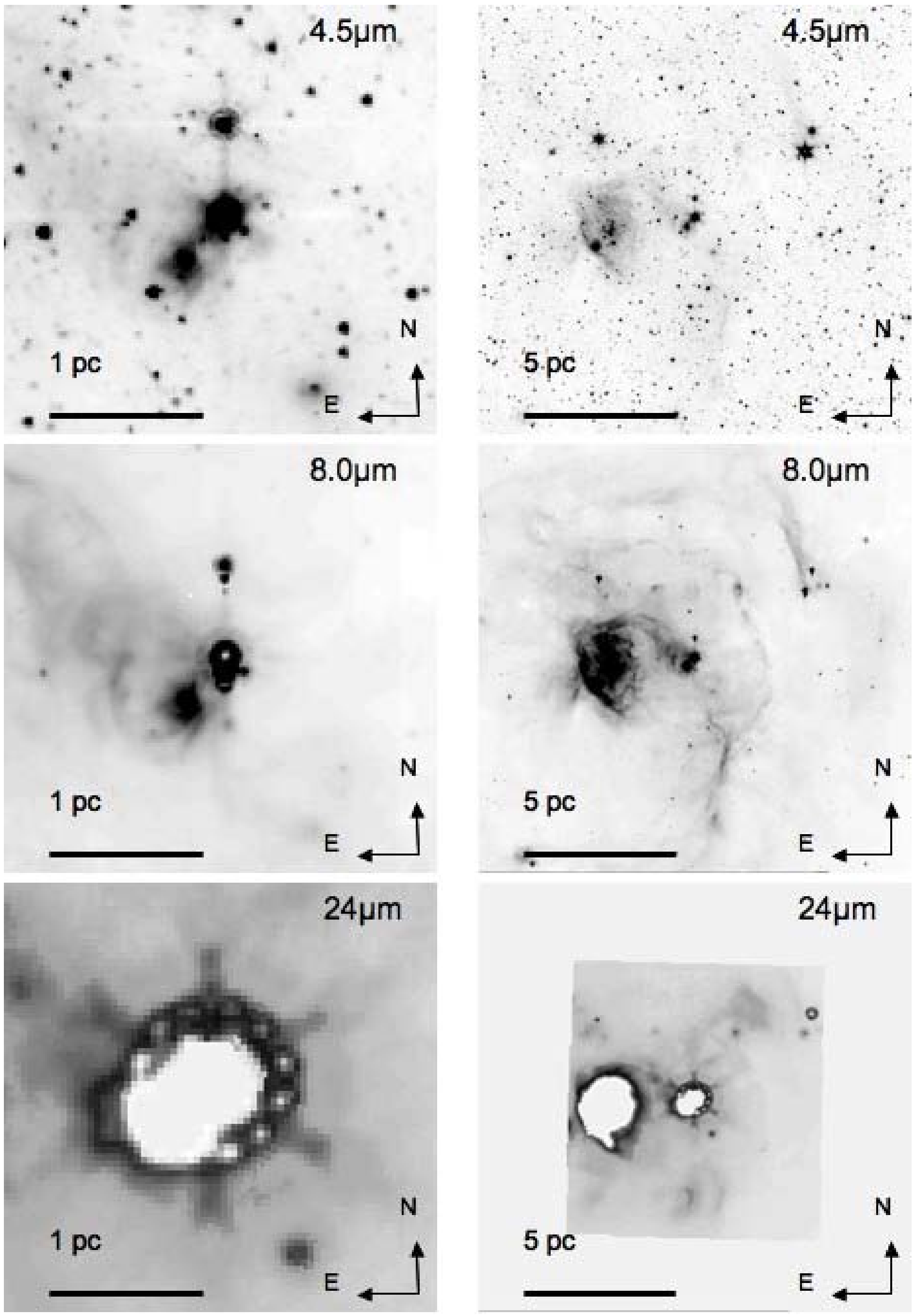

Figure 4. G5.885-0.392 shown at 4.5, 8 and 24μm. Several stars are found within 1 pc, indicating a small cluster of stars in this UCHII region.

3.4. G05.885-0.392 (IRAS 17574–2403)

The distance of 3.8 kpc is taken from Fish et al. (2003). In this source several other stars are found within 1 pc, indicating a small cluster of stars in this UCHII region. Another H II region, G05.899-0.427 (Lockman 1989), is seen 3 pc to the E, with a more extensive dust shell. This H II region appears to be physically connected to the UCHII region, as indicated by the PAH image. The dust cocoon is asymmetric, oriented SE, with long dimension about 1 pc. This corresponds to the position of a close neighbor star to the one at the centre of the UCHII region. An interesting circular PAH filament appears in the N and W along with small scale, clumpy and thin dark clouds, where a few protostars are present.

4. Conclusions

We have found that multiplicity seems to be a common denominator of the central stars of Galactic plane UCHII regions, which might better be described as small O star clusters. We have examined altogether 35 sources, and only two (one of which we illustrated here), appear to be only single or double. The birth of massive stars outside of GHII regions appears to result in small clusters and is typically connected to several adjacent sites of star formation.

We have spatially resolved the predicted dust cocoons surrounding UCHII regions at the expected size ∼1 pc. They are for the most part not spherical in appearance but elongated so as to include one or more neighboring stars/sources.

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