A new look at G353.2+0.9: cloud cores and star formation

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Abstract

We present a multi-wavelength study with new mm- and NIR-observations of the star forming region G353.2+0.9, in the NGC6357 complex. From the mm-data we identify multiple cores in different molecules and transitions, and infer their masses and physical conditions, through an LTE analysis of each molecular clump in the region. We also use an LVG model to have a better description of the physical properties typical of the cores. We find that the open cluster Pis-24 is the main source of ionizing photons for the HII region, in contrast with what was proposed before [1]. The elephant-trunk structure pointing toward the open cluster Pis-24 is worth noting. We identify a molecular clump probably associated with this feature, that appears to be very dense and to host a young stellar object, located at its apex and associated with an UCHII region. From the deep JHK photometry we identify and classify the embedded sources. We find highly reddened sources, up to $A_v \sim 30$ mag, several of which show a NIR excess, proving the existence of embedded young stellar objects. These are often found in small clusters, and are possibly the result of triggered star formation by the nearby cluster Pis-24. From a comparison with X-ray data from the literature we establish the presence of evolutionary gradients.

Introduction

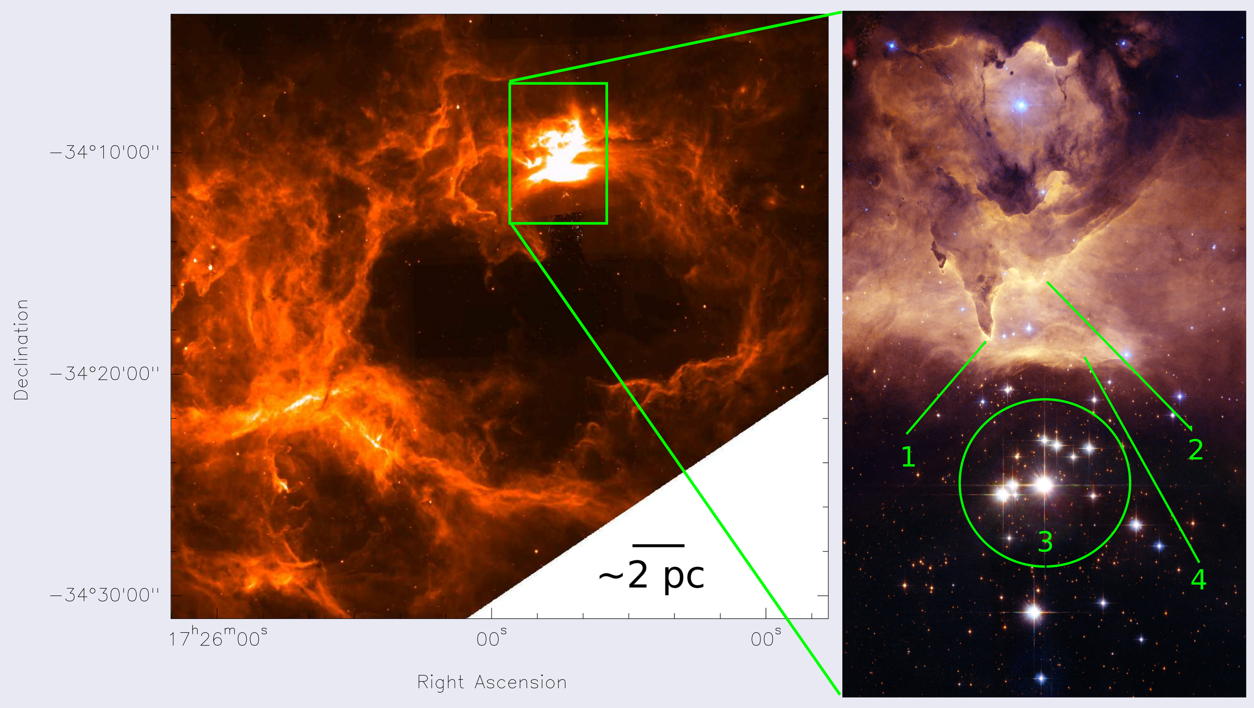

Figure: On the left is an image at 8 μm of NGC6357, taken from the Spitzer-GLIMPSE survey. At the center of the region there is a large cavity, or a collection of smaller ones. On the right, G353.2+0.9 is shown in detail in an HST image. Here, the pillar (or elephant-trunk) (1), the ionization front (2) and the center of Pis-24 (3) are indicated. The "bar" (4) was previously thought to be an ionization front [1].

NGC6357 is a complex of molecular clouds and HII regions in the southern sky, at a distance of 2.5 kpc, nearly in direction of the Galactic center. It is a very active star-forming complex. The Figure shows a large cavity, or a collection of smaller blended ones, at the center of this region. G353.2+0.9 coincides with the maximum of the emission at various wavelengths, from the radio to the optical. South of this region lies Pismis 24, an open cluster containing many early type stars, two of which are amongst the brightest and bluest known (O3.5 If and III(f*), [2]). This cluster constitutes the main source of ionizing photons for G353.2+0.9, and it is responsible for the creation of the pillar, visible at the center of the HII region.

Identification of individual clumps

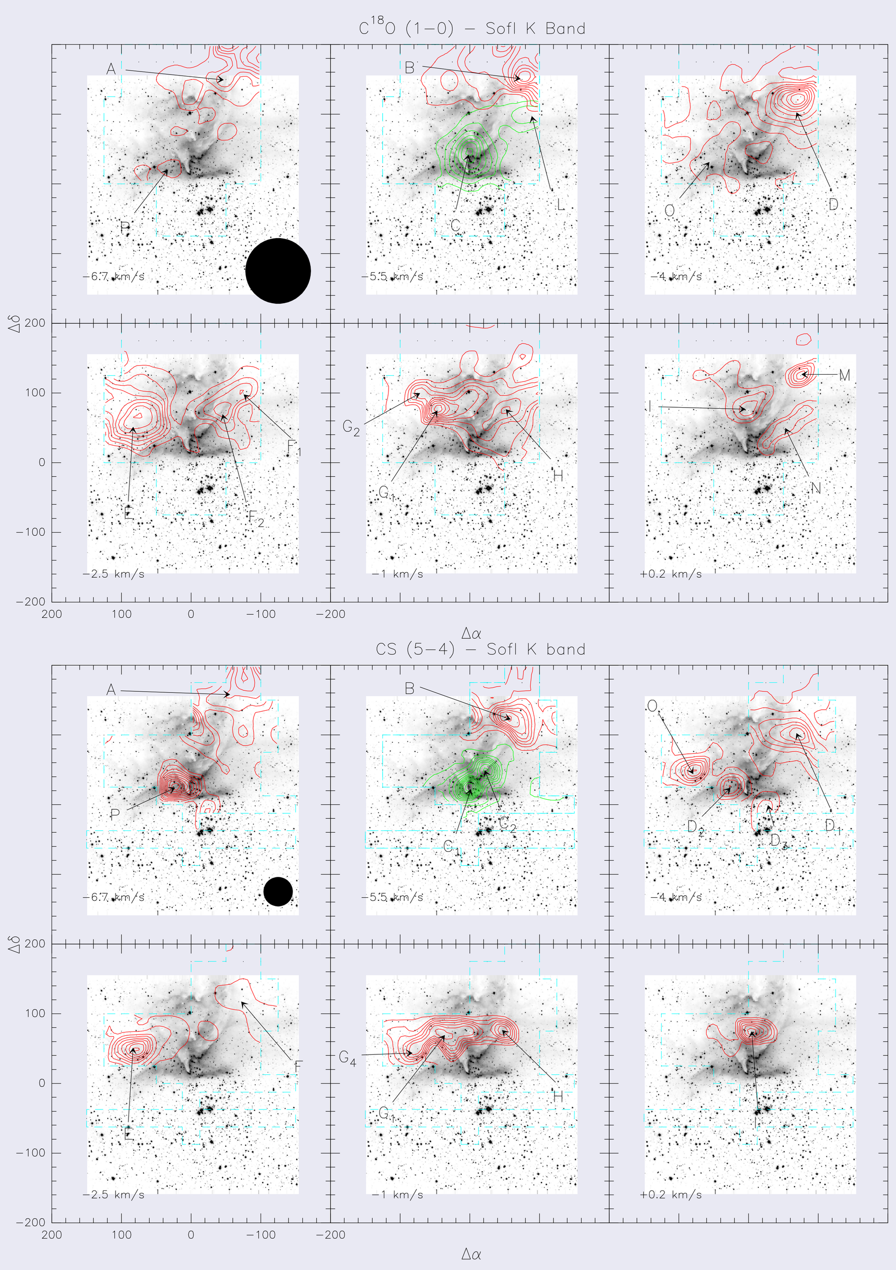

Figure: Identification of individual clumps in the region. The molecular emission (contours) is superimposed on the K-band image (ESO NTT-Sofl). At increasing resolution, the number of resolved structures increases. The number of clumps identified increases also if one uses the high-density tracers, suggesting fragmentation. It is also interesting to note that the projected center of the clumps do not coincide in every transition, which may be caused by resolution, chemistry, or by peculiar excitation requirements. There is no gas associated with the bar.

We observed the following molecular transitions with the SEST: $C^{18}O$(1-0), $C^{18}O$(2-1), CN(1-0), CN(2-1), CS(2-1), $C^{34}S$(2-1), CS(3-2), CS(5-4), $H_2CO(2_{1,2}\text{-}1_{1,1})$, SiO(5-4), and CH_3CCH(6-5). To identify individual clumps in the region, we decomposed the emission profiles of optically thin transitions in Gaussian components. Then, we used these as a template for the other transitions. The Gaussian components were then associated around central velocities determined with the aid of channel maps. In the Figure we show the results of this procedure for a low-density tracer ($C^{18}O$) and for a high-density tracer (CS). We determined the typical T, N_{H_2}, n_{H_2}, and mass of the clumps in the region from the different transitions. These results are summarized in the following Table.

Molecule	T_{ex} [K]	T_K [K]	N_{H_2} [10^{22} cm^{-2}]	Max visual extinction [mag]	n_{H_2} [10^3 cm^{-3}]	Total Mass [$M_\odot$]
$C^{18}O$	$15-20$		$0.1-1$	20	$0.1-1$	2000
CS	$10-25$	$20-65$	$0.5-10$	100	$10-200$	5000
CN	$10-35$		$0.2-5$	40	$0.5-5$	4500
H_2CO			$1-7$	40	$10-100$	2500
CH_3CCH	$20-50$	$20-50$				

Column densities and masses agree well between different molecules and transitions, except for CN, where the differences between parameters derived from (2-1) and (1-0) reach an order of magnitude. This is due to sub-thermal excitation, that causes the upper levels to be underpopulated with respect to the LTE case.

870 μm continuum

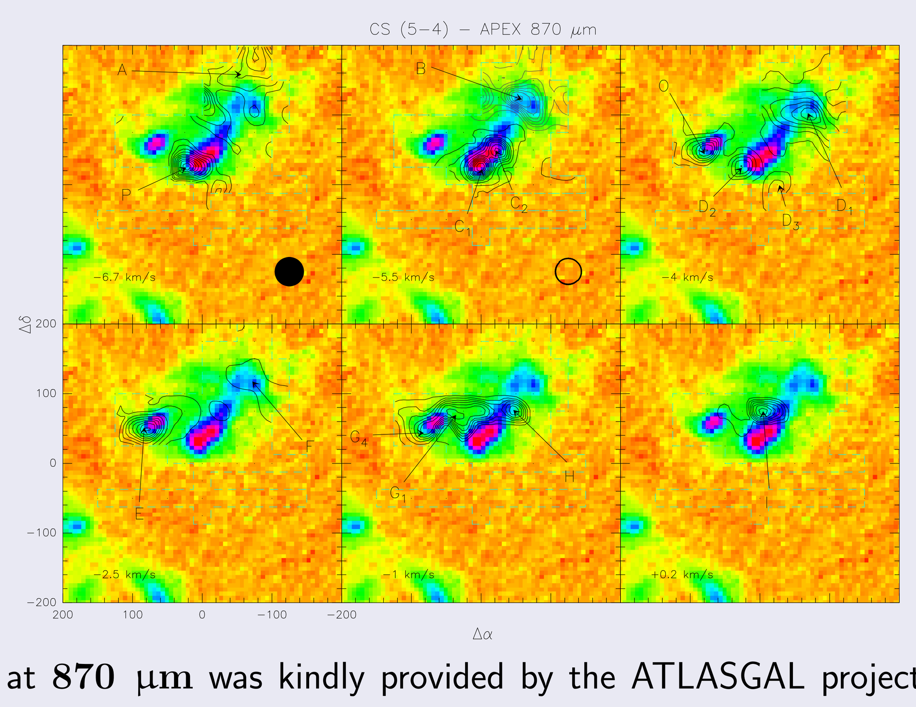

Figure: CS(5-4) emission superimposed on the image at 870 μm, (ATLASGAL). This allows us to establish a possible association between the components at 870 μm and the molecular clumps.

The image at 870 μm was kindly provided by the ATLASGAL project [3]; it shows the emission from the cold dust component. We used this image to associate the molecular clumps with the components visible at this wavelength. We fitted bidimensional Gaussians to the 870 μm emission, in order to find the flux density of individual components. From the integrated flux density, assuming a temperature, we determined the mass of the dust for each clump, that can be related to the total mass by means of the gas-to-dust ratio. These agree quite well with the values derived form the molecular emission (reported in the Table above).

Colour-colour and colour-magnitude diagrams

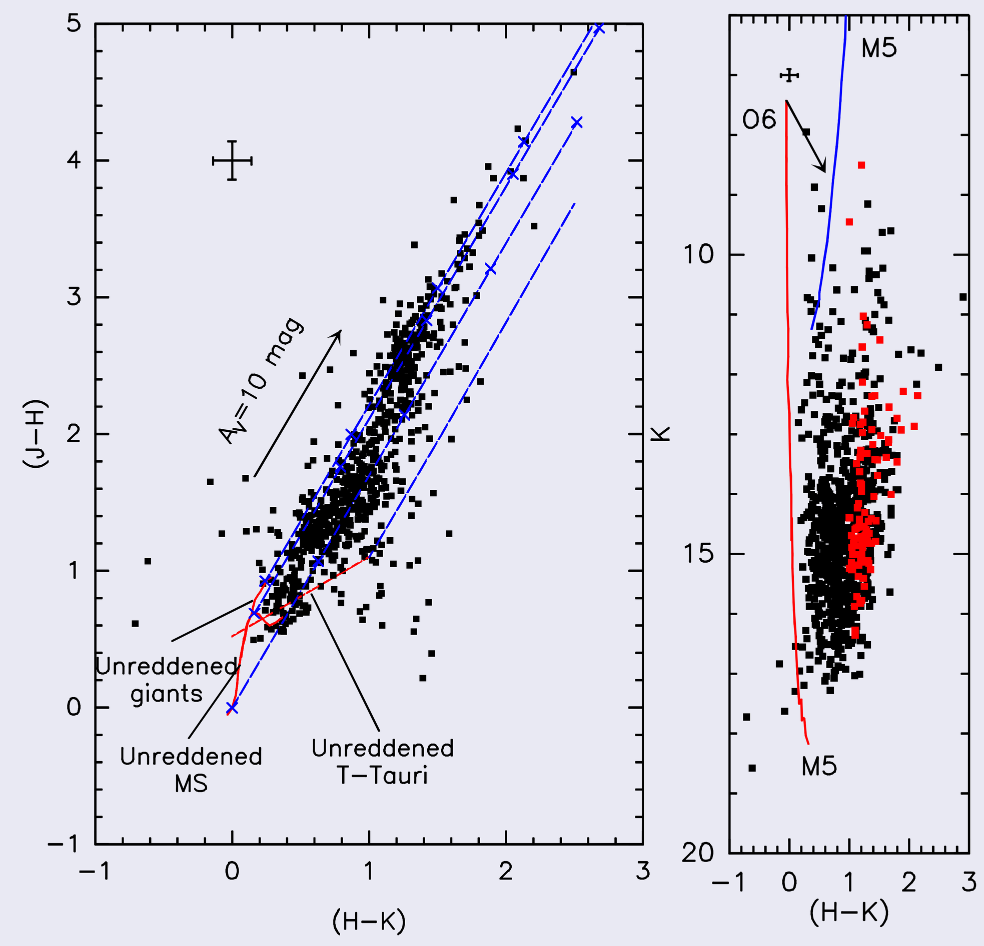

Figure: Colour-colour and colour-magnitude diagrams of the sources north of $\delta = -34°11'20"$ (J2000). The unreddened loci of MS, giants and T-Tauri stars are indicated in the colour-colour diagram, while those of MS (red) and giants (blue), drawn for a distance of 2.5 kpc, are shown in the colour-magnitude diagram. The arrows in both panels mark the direction of interstellar extinction. The identified background red giants (in red in the colour-magnitude diagram) were removed from the sample. About 35% of the sources in the field have a NIR excess.

The colour-colour and colour-magnitude diagrams allows one to determine the properties of the observed stellar population. The colour-colour diagram shows that in the field there are several giants, which is not unexpected, since we are looking nearly in direction of the Galactic center. The vast majority of these sources in the northern field ($\delta \geq -34°11'20"$, J2000), have extinctions in excess of $10-15$ mag, suggesting they are mainly background sources. This is also consistent with the location of these sources (in red) in the colour-magnitude diagram, and with the fact that their position is anti-correlated to the molecular gas distribution. In the field, $\sim 35\%$ of the sources show a NIR excess, which may include contamination from background and/or foreground sources.

Comparison of X-ray sources and sources with a NIR excess

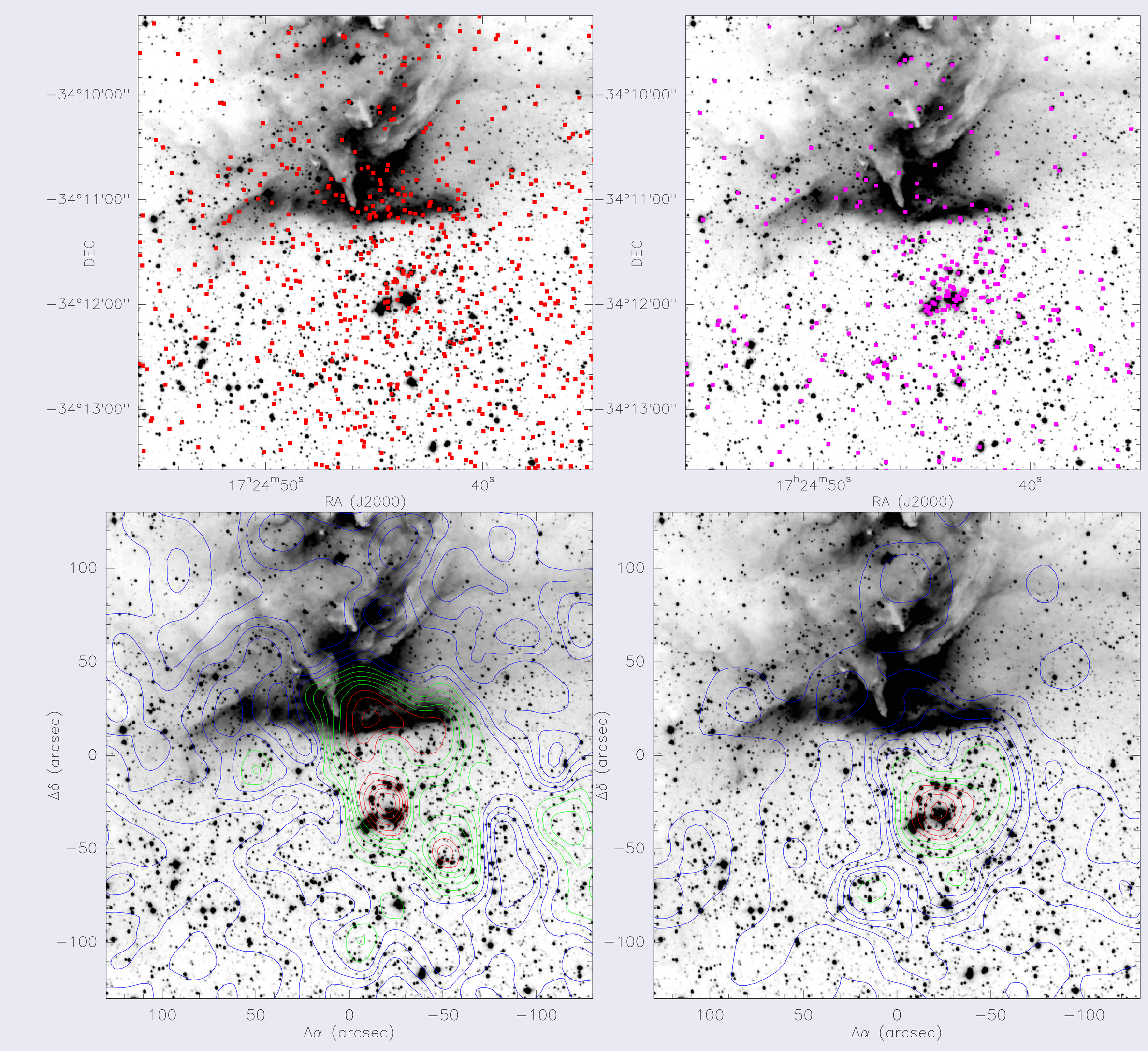

Figure: Comparison of positions and surface density of sources with a NIR excess and sources detected in X-rays. The concentration of sources with a NIR excess in the HII region, where X-ray sources do not show a comparable increase in source counts, suggests that these sources are on average younger than those in Pis-24.

The comparison of the surface density of sources with a NIR excess with that of X-ray sources (Chandra) shows that the sources with NIR excess concentrate in the HII region, while X-ray sources do not. Considering that X-rays efficiently select slightly more evolved sources (Class III), this suggests that the sources in the HII region are, on average, younger than the stars outside it. This is consistent with the idea that the formation of some sources here could have been triggered by the effects of the ionizing photons and/or winds from the cluster stars.

K sources

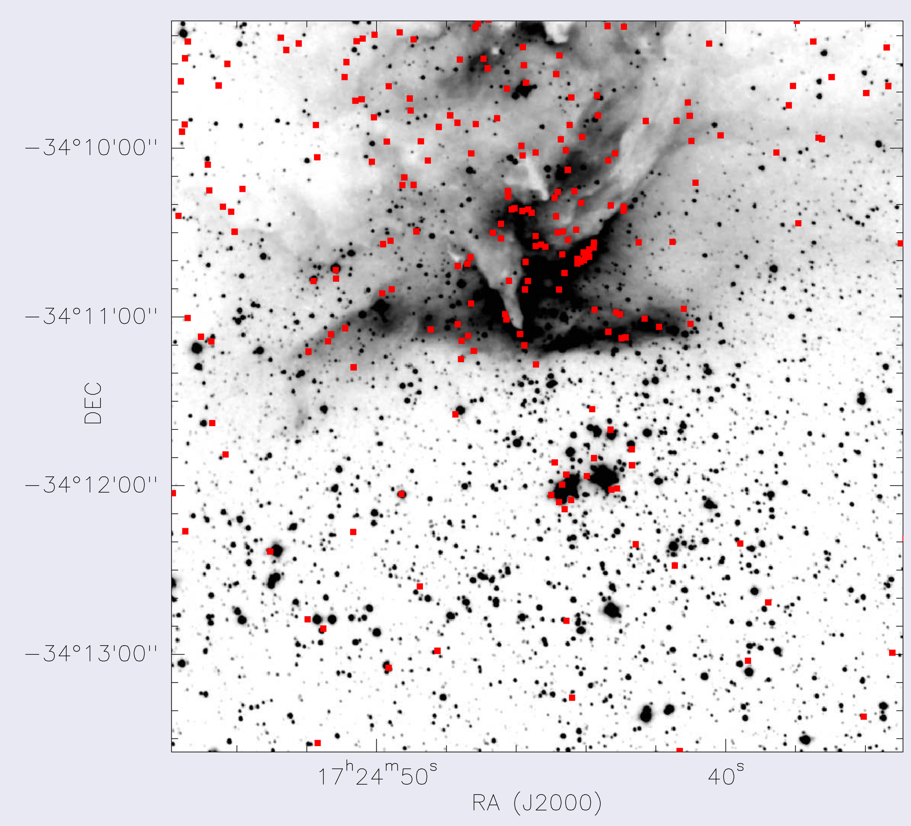

Figure: Position of sources detected only in the K band. These sources concentrate in the HII region and along the obscuration features. Note the significant clustering of sources along the ionization front. The position of these sources indicate that Pis-24 induced star formation in G353.2+0.9.

The sources detected only in the K band are those that are most affected by extinction, and these are concentrated in the direction of the molecular clumps, south of the obscuration lanes, i.e. on the side facing Pis-24. In particular, a significant cluster is visible along the ionization front. This agrees with the idea that at least some of the star formation occurring in G353.2+0.9 was triggered by the massive stars in Pis-24. In this region also high-mass stars are being formed: one is at the tip of the pillar, with an estimated spectral type B0-B2 [4], and possibly two more coincide with the two other ultra-compact HII regions, found by [1], between the pillar and the ionization front.

References

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