Abstract

We present a mid-infrared study of the source NGC 3576. The high-resolution images were taken at the Gemini South Observatory Through narrow and broad bands at 10 and 18 μm. The nearly diffraction limited images show IRS 1 resolved into 4 sources for the first time at mid-infrared wavelengths. The positions of the sources are coincident with massive young stellar objects detected at near infrared. The properties of each source, such as spectral energy distribution, the silicate absorption feature, color temperature and luminosities were obtained and are discussed. We found that the sources are so embedded in their birth cocoons that it precludes any strong contribution to the ionization of the HII region. A possible location of the ionizing source of the HII region is discussed. We also report observations of other YSOs candidates and the detection of a new diffuse mid infrared source without a near infrared counterpart.
Introduction

A very interesting YSOs have been identified in the Galactic giant HII (GHII) regions M17 Hanson, Howarth & Conti (1997); W42, W31 (Blum, Conti & Damineli (2000), Blum, Damineli & Conti (2001)) and NGC 3576 (Figuerêdo et al. (2002), hereafter FBDC). These are luminous YSOs with excess emission in the K-band and have color indexes $H - K > 2$. $J$ and $H$ spectra of these objects typically show a featureless continuum. In some cases the CO bandhead at 2.3 $\mu$m is seen in absorption or emission.

In the case of NGC 3576, FBDC have identified 2 luminous objects with $K$-band excess coincident with the position of IRS 1 Frogel & Persson (1974). Their NIR spectra have the CO bandhead in emission, possibly indicating a circumstellar disk, but do not show any photospheric feature, indicating that they are still embedded in their dust cocoons.

We have performed MIR observations at Gemini-S in December 2001 in order to investigate the nature of these and other similar objects in NGC 3576. The high resolution images were taken with the MIR camera OSCIR, through the wide $N$-band and the narrow filters at 7.9, 9.7, 12.5 and 18.3 $\mu$m.

1. The Images

The comparison between the images taken at the $K$ and the $N$ band at the position of IRS 1 is shown in Figure 1a and Figure 1b respectively. This figure shows IRS 1 resolved into 4 sources for the first time at 10.5 $\mu$m. The double nature of source #60 (all sources named with “#” follows the nomenclature suggested by FBDC02) is also revealed and due to the high spatial resolution of the image we speculate that sources #60b(K) and #60b(N) are associated.

Besides the position of IRS 1, we have imaged the position of #95, shown in Figure 2. In this image we identified the sources #83 and #85 and we identified the diffuse source IRS1:SE. This source does not have any NIR counterpart and was observed for the first time. We speculate the possibility of an YSO in a earlier stage of formation, such as a hot molecular core, but more data are needed to give any firm conclusion.

2. The Data

2.1 Fluxes

Fluxes measured at NIR wavelengths by FBDC ($JHK$) and Moneti (1991) ($L$) were plotted in the Figure 3 along the MIR fluxes from this work.
MIR observations of massive YSOs

Figure 1a. K-band image of IRS 1 taken with the PHOENIX Acquisition Camera Blum (2003).

Figure 1b. OSCIR N-band image of IRS 1. North is up and east is to the left in both images.

Figure 2. Mosaic of IRS 1 and source #95 taken in the 12.5 µm band. The image is 16”×11”. The contour flux levels are in arbitrary units and the orientation is the same of Figure 1.

2.2 Color Temperature, Luminosity and Spectral Types

From the fluxes of each source measured through the narrow-band filters we derived the color temperature of each source. The MIR lu-
Figure 3. NIR to MIR broad-band spectral energy distribution of IRS 1. Squares correspond to source #48, circles correspond to source #50 and diamonds to source #60. Error bars are smaller than the symbols.

minosity was obtained by integrating the fluxes and an estimate of the bolometric luminosity was derived based on the assumption that MIR luminosity represents 10% of the total luminosity (Wood & Churchwell (1989)). The results are in the Table 1 and the spectral types were obtained from the evolutionary grids of Schaller et al. (1992).

<table>
<thead>
<tr>
<th>Source</th>
<th>(T_c) (K)</th>
<th>(L_{\text{MIR}}) (erg s(^{-1}))</th>
<th>(\log L/L_{\odot})</th>
<th>Sp Type (ZAMS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#48</td>
<td>215 (±10)</td>
<td>2.7\times10^{36}</td>
<td>3.8</td>
<td>B1</td>
</tr>
<tr>
<td>#50</td>
<td>280 (±10)</td>
<td>2.4\times10^{37}</td>
<td>4.8</td>
<td>O8</td>
</tr>
<tr>
<td>#60b</td>
<td>&gt; 100(^a)</td>
<td>3.5\times10^{35}</td>
<td>2.9</td>
<td>B3</td>
</tr>
<tr>
<td>#95</td>
<td>270 (±15)</td>
<td>1.5\times10^{35b}</td>
<td>2.5</td>
<td>B5</td>
</tr>
</tbody>
</table>

\(^a\) Lower limit for the temperature due to the unresolved nature of source at 18.2 \(\mu\)m.
\(^b\) MIR luminosity is an upper limit based on the upper limit to the flux in the 18 \(\mu\)m band.

3. Where is the Ionization Source of NGC 3576?

The MIR source IRS 1 was believed to be the ionizing source of NGC 3576 or at least, to be the origin of the bulk of the emitted Lyman

\(\text{J H K L N IHW18}\)
Continuum photons ($\sim10^{50}$ s$^{-1}$ De Pree, Nysewander & Goss(1999)). Comparing the radio continuum map (kindly provided by Chris DePree) with the $K$-band image we note that IRS 1 nor any NIR source in particular can be associated with the ionization of the gas. Pictured in Figure 4 is the $K$-band inverted image, overplotted by the radio continuum level curves and the positions of the MIR sources from Frogel & Persson (1974). This figure indicates that the ionizing source of this region is behind the dark clouds southwestern of IRS 1 and cannot be detected even at 2.2 $\mu$m.

We plan to map the entire GHII region at MIR wavelengths in order to investigate the environment where the radio emission is flowing.
4. Conclusions

We have presented MIR images of NGC 3576 IRS 1 where it was resolved in 4 sources for the first time at these wavelengths. We derived the spectral types of some sources detected in this region confirming the hypothesis of massive YSOs still embedded in their dust cocoons.

Source #50 is the brightest source at MIR, but it is not detected at J and H bands also it is barely seen at the K band. For these reasons we believe that source #50 is the youngest object among the sources detected in this study.

Comparing the origin of the radio flux with the NIR image, we have found that no source can associated with the ionizing source of NGC 3576. Moreover the origin of this radiation appears to be blocked by dense dark clouds in the line of sight.

The complete results and a full discussion of this study can be found in Barbosa et al. (2003)

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References

Private communication