A bipolar nebula in Orion identified with the IRAS source 05329−0505

R. D. Wolstencroft*, S. M. Scarrott†, R. F. Warren-Smith‡, H. J. Walker‡, B. Reipurth§ and A. Savage*

*Royal Observatory, Blackford Hill, Edinburgh, EH9 3HJ
†Department of Physics, University of Durham, South Road, Durham, DH1 3LE
‡University of Leiden, Wassenaarseweg 78, Leiden, Netherlands
§University Observatory, Oster Voldgade 3, DK-1350 Copenhagen K, Denmark

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Summary. The IRAS source 05329−0505 is found to be the central illuminating star of a bipolar nebula. A circumstellar dust torus completely obscures the star from direct view at optical wavelengths but light escapes along the axis of the torus to produce a visible reflection nebula with two lobes. The pattern of polarization orientations differs in the two lobes (centrosymmetric versus plane parallel), and can be understood in terms of a tilted dust torus, containing aligned dust grains, which partially attenuates the light from the E lobe. Based on IRAS and near-infrared photometry the central source is very red and has a luminosity of about 50 L⊙ which is radiated mostly longward of 10 μm by cool grains (150 K) heated by the star. If the star has not yet reached the main sequence it is likely to be a Herbig Ae star. If it is a ZAMS star it is most probably a very highly reddened A0V star (A_V=22); the near-infrared excess at K and L' is consistent with warm grains (700 K) close to the star.

1 Introduction

The optical counterparts of sources in the IRAS Point Source Catalogue have been identified in a field in Orion (5.6 degree^2 centred on RA=05h 31m, Dec=−05° 35′) by Wolstencroft, Walker & Savage (1985, in preparation), using SERC UK Schmidt Telescope 1/SR plates of the region. A number of extended objects have been found on the plates which correspond in position with IRAS sources but are for the most part unlisted in the 31 IRAS Association Catalogues used to identify IRAS sources. One of these, IRAS 05329−0505, was found to be located within a visible bipolar nebula and the relationship between this source and the structure and illumination of the nebula is the subject of this Short Communication.

This nebula, which is object 19 in a recent list of small nebulae in Orion (Reipurth 1985), is illustrated in Plate 1. It comprises two faint lobes of nebulosity located on either side of the
indicated position of the IRAS source. The appearance of bipolar nebulae is varied and is dependent on the angle between the line-of-sight and the axis of symmetry of the nebula, as Neckel & Staude (1984) have noted in their recent search for such nebulae on the Palomar Observatory Sky Survey prints. Using Neckel & Staude's selection criteria, IRAS 05329−0505 can fairly be described as a classical example. Frequently a disc or torus of gas and dust surrounds the central star and this collimates the illumination of the lobes and partially or totally obscures the starlight for a distant observer in or near the plane of the disc. The lobes of bipolar nebulae normally show appreciable levels of linear polarization arising from the scattering of light from the central star by dust grains in the lobes. In the case of the present object the major axis of the system is oriented approximately E−W and a lane of obscuration, which is tentatively identified with the circumstellar torus, appears to delineate the lobes with the IRAS source located in what seems to be the densest part of the obscuration. The two lobes differ in size and shape, and this is illustrated both in the CCD image (Plate 1) and in the isophotal map (Fig. 1). The fainter isophotes are elongated in the E−W direction in both lobes, with the W lobe being much more extended. The E lobe is more compact with the brightness peak exhibiting circular contours suggesting that the region might contain a point source; this is not the case for the W lobe for which the brightest contours are not circular. The brightness gradients are very pronounced on the S and E edge of the W lobe, and on the N edge of the E lobe. Assuming that the bipolar nebula is in the Orion complex then its linear size is 0.17 pc which is typical of other similar objects such as those studied by Neckel & Staude (1984).

2 Infrared photometry

The central source was detected by IRAS at 12 and 25 μm, but only upper limits were determined at 60 and 100 μm (Table 1). The 12 to 25 μm flux density ratio yields an effective

\[ \text{Figure 1. An intensity contour and linear polarization map in the } I \text{ waveband (800 nm) of the nebulosity near the IRAS source 05329−0505. The position of the source is marked at the coordinate origin with a filled circle; it coincides with the illuminating star as defined by the polarization vectors in the W lobe of reflection nebulosity. The integration bins of the polarization data are } 7.2 \times 7.2 \text{ arcsec}^2 \text{ at 7.2-arcsec intervals. The contour levels at the W end of the map show the presence of a foreground star just beyond the edge of the CCD frame. The observations were obtained with the Durham University imaging CCD polarimeter at the 1-m telescope of the Wise Observatory.} \]
Plate 1. Image of the bipolar nebula centred on the *IRAS* source 05329−0505 obtained with the CCD camera at the Danish 1.5-m telescope at La Silla. The effective passband is 850 to 1100 nm. N is up and E to the left.
### Table 1. Properties of IRAS 05329–0505.

<table>
<thead>
<tr>
<th>1. Coordinates (1950)</th>
<th>05h32m58s.65</th>
<th>05h32m58s.95 (±0′.05)</th>
</tr>
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<tbody>
<tr>
<td>(IRAS)</td>
<td>-05°05′46″</td>
<td>-05°05′49″ (±3′)</td>
</tr>
<tr>
<td>(K measurements in 12.4 and 15.0 arcsec apertures)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. IRAS flux density</td>
<td>μm</td>
<td>12</td>
</tr>
<tr>
<td>(±6 per cent)</td>
<td>Jy</td>
<td>4.43</td>
</tr>
<tr>
<td>3. Near-infrared magnitudes</td>
<td>Aperture</td>
<td>J</td>
</tr>
<tr>
<td>(±0.1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.0</td>
<td>7.8</td>
<td>15.1</td>
</tr>
<tr>
<td>12.4</td>
<td>14.0</td>
<td>11.9</td>
</tr>
<tr>
<td>15.0</td>
<td>12.3</td>
<td>9.5</td>
</tr>
<tr>
<td></td>
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<tr>
<td>C=Colour corrected</td>
<td></td>
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</tbody>
</table>

blackbody temperature of 150 K for the dust in the obscuring lane that is heated by the central star: this is typical of the blackbody temperatures indicated from IRAS measurements (100 to 200 K) for the central sources of the Neckel & Staude sample of bipolar nebulae (White & Gee 1985). The central star is not seen on the deep CCD images but a very red near-infrared source is apparent 5 arcsec from the position of the IRAS point source which is almost certainly the near-infrared counterpart of the IRAS source. (Note that in the IRAS Point Source Catalogue IRAS 05329–0505 is erroneously associated with a 13 mag star about 4.9E and 25 arcsec S which is object 02344 in the New Catalogue of Suspected Variable Stars, Kukarkin et al. 1982).

JHKLL' measurements of the near-infrared source were obtained with both the UKIRT 3.8-m and ESO 1-m telescope (Table 1). The energy distribution between 1.25 and 25 μm is shown in Fig. 2: the IRAS points are for a field of view of 0.75×4.6 arcmin² and the near-infrared points for an aperture of 7.8 arcsec diameter. Although the multi-aperture photometry at 2.2 μm indicates that the central source may be slightly extended, after allowance for the aperture effect, it is clear that the majority of the luminosity is radiated at λ≈10 μm: assuming that the source is a 150 K blackbody at the distance of the Orion Molecular Cloud (500 pc) we deduce \(L=50 L_\odot\). It is not clear whether the central star (i) has recently reached the main sequence, or (ii) is still a pre-main-sequence object. Consider first case (i). For the central stars of the bipolar nebulae studied by Neckel & Staude (1984) and White & Gee (1985) it was assumed by them that the stars had reached the main sequence. If this assumption is adopted for IRAS 05329–0505 we infer a spectral type of about A0V from the observed luminosity. An unreddened A0V star at 500 pc would have \(V=J=H=\ldots=9.2\): using the standard extinction \((A_V:A_J:A_H:A_K:A_L)=1:0.265:0.155:0.090:0.045\) (see Koornneef 1983) the measured values of \(A_J\) and \(A_H\) both yield \(A_V=22\). Beyond \(H\) the observed magnitudes (Table 1) are considerably brighter than expected for \(A_V=22\) (\(K=11.2\), \(L=10.2\)). We attribute this excess (see Fig. 2) to the thermal emission from grains at a temperature of 695 K which lie close to the star. Infrared excesses corresponding to blackbody temperatures of 500 to 1300 K were deduced by Neckel & Staude for their sample of central stars.

Now consider case (ii). If the central star has not yet reached the main sequence it is likely to be either a T Tauri or Herbig Ae/Be star. There seems to be general agreement that the late-type T Tauri stars have low-mass and the early-type Herbig Ae/Be stars have intermediate mass, with the dividing line at about 2.0 to 2.5 \(M_\odot\). The higher mass pre-main-sequence stars are also more luminous. In the comprehensive catalogue of Herbig Ae/Be stars compiled by Finkenzeller & Mundt (1984) \(\langle L\rangle=170 L_\odot\) with all but one having \(L>20 L_\odot\). In the sample of T Tauri stars discussed by Cohen & Kuhi (1979) and by Lada & Wilking (1984) very few stars have \(L>10 L_\odot\).
Figure 2. The energy distribution of IRAS 05329−0505. The flux density $F_\nu$ is in Jy. Open circles are IRAS data which can be fitted to a 150 K blackbody. Near-infrared photometry (see Table 1) with an aperture of 7.8 arcsec diameter is shown by crosses: the broken line is the best fit to a reddened A0V star and the full line shows a blackbody fit to the excess at $K$ and $L$.

The luminosity of IRAS 05239−0505 is $L = 50 L_\odot$ and on this basis it is very probably a Herbig Ae star. Canto et al. (1984) suggest that a correlation exists between abundant circumstellar material and detectable molecular outflows from Herbig Ae and Be stars. High velocity CO emission has been detected from stars with $r$, the ratio of integrated flux longward of 0.9 $\mu$m to the integrated flux shortward of 0.9 $\mu$m, in the range $\sim 30 - 100$ ($r$ is a measure of the amount of circumstellar material according to Cohen & Schwartz 1976). On this basis high-velocity CO emission might also be detected from IRAS 05329−0505, for which $r > 100$.

3 Imaging polarimetry

In December 1984 we obtained brightness and polarization maps of the nebula in the $I$ waveband (800 nm) using the Durham imaging CCD polarimeter (Scarrott et al. 1983) at the Cassegrain focus of the 1-m telescope of the Wise Observatory, Israel. Fig. 1 shows the polarization measurements superimposed on a brightness contour map. The polarization and brightness data have been corrected for the faint reflection nebulosity that covers the whole field surrounding the bipolar nebula. The W lobe shows relatively high levels of linear polarization (up
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to 35 per cent). For distances beyond about 50 arcsec from the IRAS source the polarization pattern is centrosymmetric indicating that it is a reflection nebulosity illuminated by a source which, within measurement error, is coincident with the position of the IRAS source in the dust lane: to be specific, the IRAS source lies within the 95 per cent confidence ellipse (defined by the polarization pattern) whose major (minor) axis is 20(3) arcsec. In regions of the W lobe closer to the IRAS source the pattern deviates progressively from circularity merging into a parallel pattern which extends throughout the central dust lane. This central polarization is not perpendicular to the major axis of the nebula but more nearly perpendicular to a line joining the brightness peaks of the two lobes. Some additional polarizing mechanism must be operating to change the otherwise circular pattern of vectors. While a source of illumination extended along the dust lane might account for the pattern close to the central source the same source is inconsistent with the more circular pattern seen further out.

The polarization in the E lobe is still quite significant (up to 20 per cent) but reduced relative to that in the other lobe. The polarization orientations are not centrosymmetric and tend to lie N-S especially in the brighter regions with the stellar-like knot showing the highest level of polarization in the area. If the polarizations in this lobe arise solely from scattering then the source of illumination would need to be at least 1 arcmin W of the IRAS source. However there is no evidence for such a source and the brightness structure of the nebula strongly suggests a physical association between the lobes. We therefore expect the E lobe to be illuminated by the same source as the W lobe. If the non-circular pattern in the E lobe arose from an extended source, then the size of the source would need to be much greater than is required for the W lobe. We therefore discount the possibility of an extended source and propose instead that the non-circular polarization pattern arises from extinction by aligned grains in a circumstellar disc or torus surrounding the central star. If the torus is tilted to the plane of the sky such that the nearside overlies the E lobe then the scattered light from this lobe will have to pass through, and be attenuated by, the aligned grains in the torus, and a further component of polarization will be induced in the light reaching us. The combination of polarizing mechanisms could therefore produce the polarization observed in the E lobe even if the IRAS source provides the initial illumination. This interpretation has also been applied to explain non-centrosymmetric polarizations in several objects e.g. NGC 2261 (Gething et al. 1982), NGC 6729 (Ward-Thompson et al. 1985) and Parsamyan 21 (Draper, Warren-Smith & Scarrott 1985). Since some small effect is also seen in the W lobe we conclude that the disc has considerable thickness and also obscures the inner portion of the W lobe to some extent. Although the shape of the polarization pattern in the E lobe suggests that this lobe suffers the higher extinction a quantitative assessment of the extinction is not possible without knowing the initial polarization and brightness within each lobe. Because of its higher extinction we would expect the E lobe to appear fainter and less extended. However the two lobes have comparable surface brightness and we therefore conclude that the two lobes are intrinsically different, both in surface brightness (the E lobe has the greatest intrinsic surface brightness) and extent. The presence of a circumstellar torus also accounts for the elongated structure of the overall nebula since it would serve to collimate the mass flow which (we presume) is or has been taking place in the axial E-W direction. The more compact structure of the E lobe might result from an impediment to the flow, e.g. a higher cloud density which may also have produced a higher level of brightness.

Acknowledgments

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References