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Submillimetre observations of a disc around the embedded source GL 490

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Summary. We present the results of mapping the 350μm emission around the bipolar outflow source GL 490. We also report *IRAS* observations of this source. The 350μm data show the source to be extended north–south. We interpret these results in terms of a disc of dust and gas surrounding the central embedded young star but show that it is incapable of channelling the bipolar molecular outflow. The outflow must therefore be collimated on scales smaller than 10^{17} cm.

1 Introduction

GL 490 is an obscured young stellar object which has been extensively studied at infrared and millimetre wavelengths. Harvey *et al.* (1979) found it to be compact at far- and mid-infrared wavelengths (<40 arcsec at 50μm and <10 arcsec at 10μm), Lada & Harvey (1981) found a high-velocity bipolar outflow in CO, while Kawabe *et al.* (1984) report a compact cloud seen in CS which is extended in a direction orthogonal to the CO outflow. MacGregor, Persson & Cohen (1984) have recently published the results of CCD spectrophotometry in the 0.6–1.0μm range of GL 490 and found several emission lines, indicating the presence of a circumstellar envelope similar to that found around Be stars. We have observed GL 490 as part of an ongoing programme of submillimetre photometry and mapping of compact young stellar and protostellar objects (Gee *et al.* 1985; Cunningham *et al.* 1984). We report the results of 350μm mapping and compare them with previous ground-based and airborne work as well as recent satellite measurements. We interpret these results in terms of a dense cloud of material surrounding the embedded star. However we show that this cloud is incapable of confining the bipolar outflow.

2 Observations

GL 490 was originally observed at 350μm during a daylight observing run on the United Kingdom Infrared Telescope (UKIRT) in 1984 July, when evidence that the source is extended was found. However due to poor weather these results were only suggestive. GL 490 was subsequently mapped on the night of 1985 January 8 under good observing conditions, using the QMC/Oregon submillimetre photometer (Ade *et al.* 1984) on UKIRT. The results of our photometry are given in Table 1; the uncertainties quoted are one sigma statistical uncertainties and we estimate the absolute uncertainties to be approximately 15 per cent. The observations were made with a narrow-band filter ($\bar{\nu}$=865 GHz, $\Delta\nu$=110 GHz) and calibrated with respect to Mars.

The map was centred on the position given by Harvey *et al.* (1979). Measurements were then made on a rectangular grid of spacing 30 arcsec with an approximately Gaussian beam of FWHM 55 arcsec. The chopping secondary mirror of the telescope was used in the three-position chopping mode (Duncan, Ade & Robson; in preparation), with a beam separation of 130 arcsec east–west at a chop frequency of 10 Hz. We estimate the absolute positions of the map to be good to ±15 arcsec with relative pointing accuracy ±1 arcsec.

GL 490 was also observed by the *Infrared Astronomical Satellite* (*IRAS*) and in Table 2 we present the fluxes from the *IRAS* Point Source Catalogue. In Fig. 1 we show the *IRAS* SKYFLUX map at 100μm along with our 350μm map and a schematic of the CO map of Lada & Harvey (1981). We identify the source to the south of GL 490 in the 100μm map as AFGL 5095 which has not previously been observed in the far-infrared (its fluxes from the *IRAS* Point Source Catalogue are 3.2, 70, 207 and 344 Jy at 12, 25, 60 and 100μm, respectively).

Table 1. 350μm observations of GL 490.

Wavelength (μm)	Flux (Jy)
12	82±8
25	278±28
60	716±72
100	783±78

Table 2. *IRAS* fluxes from the Point Source Catalogue.

Position (RA,Dec)	Flux Density (Jansky)
0,0	175.5±11.6
+30,0	70.0± 7.0
-30,0	130.4± 8.6
0,-30	228.6±10.1
0,+30	80.7± 8.1
0,-60	115.0±11.0
-30,-30	149.4±10.0
+30,-30	113.8±11.1
-60,0	3σ<29.6
-60,-30	3σ<29.6
-30,-60	82.4± 8.1
0,+60	3σ<28.9
0,-90	60.2±11.6
+30,-60	62.2±12.1
+60,-30	3σ<34.8
+60,0	3σ<35.4
+30,+30	48.3± 9.1
-30,+30	45.3±10.4

a Positions are given as an offset from α (1950) 03 23 41.4 δ (1950) +58 36 52

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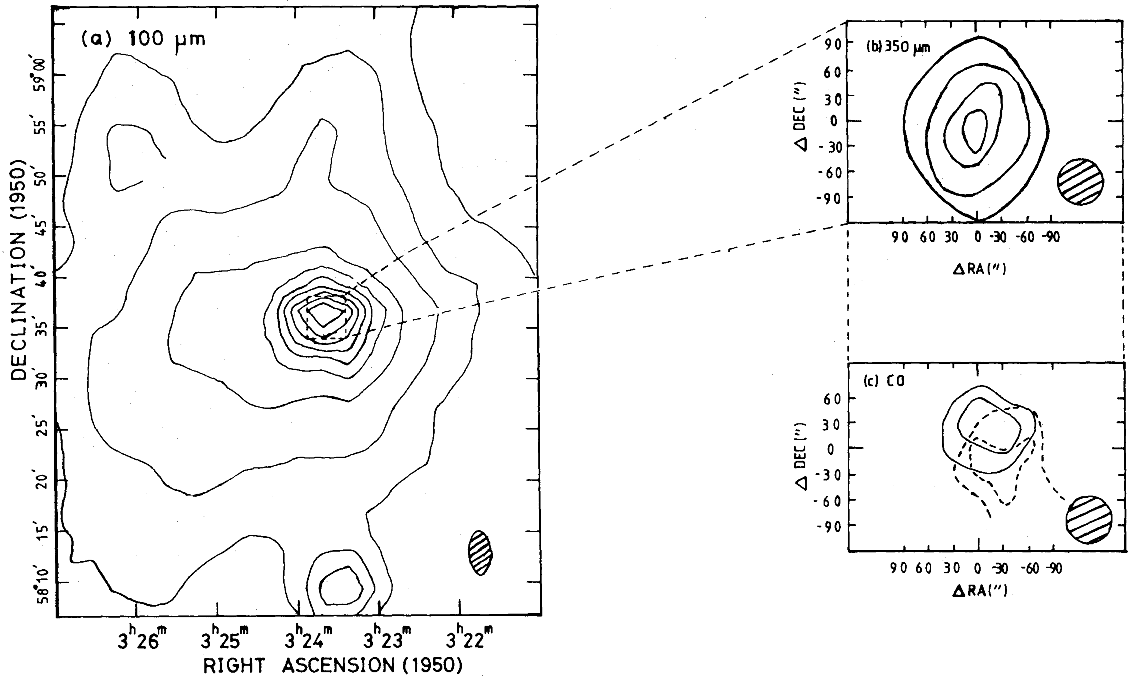

Figure 1. (a) The *IRAS* SKYFLUX map of the region around GL 490. The contours are equally spaced, the outermost contour being 80×10^6 Jy/sr and the innermost contour 440×10^6 Jy/sr with intervals of 40×10^6 Jy/sr. The hatched ellipse represents the *IRAS* beam. (b) The ground-based 350 μm map of GL 490, contours at 25, 75, 135 and 185 Jy per 55 arcsec beam. The hatched circle represents the beam. (c) A schematic of the CO map of Lada & Harvey (1981) showing the distribution of intensities in the blue-shifted (dashed line) and red-shifted (solid line) wings. The hatched circle represents the beam.

3 Discussion

Our 350 μm map [Fig. 1(b)] shows that GL 490 is extended at this wavelength. Fitting Gaussian profiles and deconvolving the beam we estimate a source FWHM 70 arcsec (NS) × 30 arcsec (EW) (see Fig. 2), with a peak flux of 230 Jy and an integrated flux of 430 Jy over the map. The 100-μm map shows that there is also weak extended emission on a scale of several arcmin. The presence of this emission explains the difference between the 100 μm flux as measured in the large beam of *IRAS* (~4 arcmin) and the result of Harvey *et al.* (1979) with a 40 arcsec beam. Similarly, the fact that Harvey *et al.* found no suggestion of extended emission is not surprising since they would

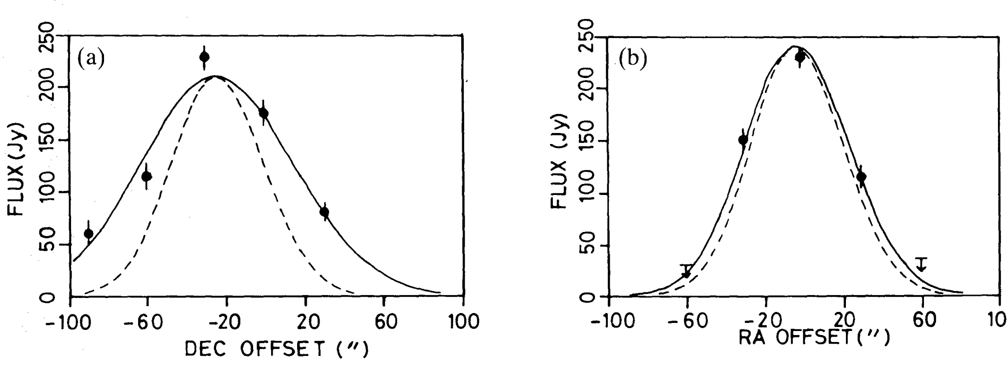

Figure 2. (a) The north–south 350 μm flux distribution through the centre of GL 490. The beam profile is shown by the dashed line, while the solid line shows the beam convolved with a Gaussian source with the best-fit FWHM of 70 arcsec. The error bars indicate the 1σ statistical uncertainties. (b) As for (a) but showing the east–west flux distribution with the solid line being a convolution of the beam with a Gaussian of FWHM 30 arcsec.

have been chopping on to the extended cloud. [We note however that Lada & Harvey (1981) found a narrow CO component extending over 1°. This low-velocity CO is presumably associated with the large-scale extended 100μm emission apparent in the SKYFLUX map.] The source is also extended (but to a lesser extent) at 60μm, while the *IRAS* 12μm flux is in excellent agreement with the small beam measurement of Merrill, Russell & Soifer (1976) and with the original AFGL fluxes (Price & Walker 1976) indicating that the source is very compact (<10 arcsec) at these wavelengths.

Fig. 3 shows the emission from GL 490 in various beam sizes at several different wavelengths. The overall spectrum, both in small and large beams, is unusually broad compared to other far-infrared compact sources (e.g. Wynn-Williams 1982). This indicates a very wide range of temperature in the emitting dust grains. Together with the observed variation of angular size with wavelength this suggests that at the shorter wavelengths we are seeing emission from nearer the centre of a centrally-heated cloud.

The total luminosity of GL 490, assuming a distance of 900 pc (Harvey *et al.* 1979) and integrating over the *IRAS* and 350μm total flux data and the data of Merrill *et al.* (1976) is $2.7\times10^3 L_\odot$, corresponding to a B2 ZAMS star (Panagia 1973). From their measurement of the Bγ flux from GL 490, Thompson & Tokunaga (1979) conclude that the number of Lyman continuum photons is consistent with a B0.5 star. However, Krolik & Smith (1981) and Simon *et al.* (1981, 1983) deduce that the Brackett lines are optically thick and arise in a mass outflow of $10^{-7} M_\odot \mathrm{yr}^{-1}$ from the central star. Krolik & Smith (1981) treat the excitation mechanism as purely thermal while Simon *et al.* (1983) show that photoionization from the $n=2$ level by Balmer continuum photons may be an important process in this and similar objects.

The broad spectrum of thermal emission from GL 490 clearly indicates a wide range of dust temperatures. However, fitting the two longest wavelength *IRAS* bands and our total 350μm flux we obtain a best-fit of 40 K and emissivity $\propto \nu^{1.5}$. The temperature derived is clearly an average,

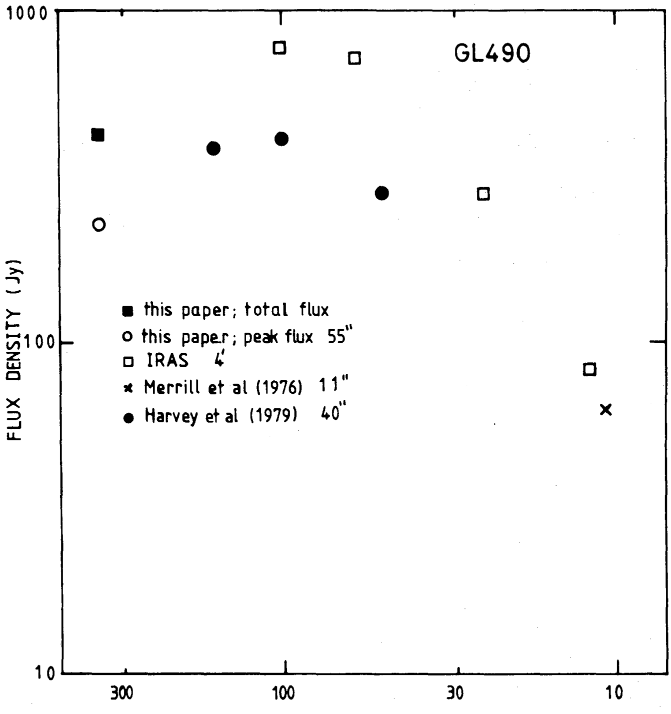

Figure 3. Infrared to submillimetre photometry of GL 490 in various beam sizes showing the unusually broad spectral energy distribution.

while the emissivity fit probably arises from a smoothly varying emissivity $\propto \nu$ at short wavelengths and $\propto \nu^2$ at long wavelengths (Hildebrand 1983). Using this temperature we derive a 350 μm optical depth in the central 55 arcsec beam of 0.008, however as Hildebrand (1983) has pointed out the submillimetre optical depth is relatively insensitive to the temperature. Keene, Hildebrand & Whitcomb (1982) derive a relationship between the 400 μm optical depth and visual extinction based on the submillimetre measurements by Whitcomb *et al.* (1981) of the reflection nebula NGC 7023, calibrated against optical and ultraviolet extinction measurements. We extrapolate their result to 350 μm assuming a long-wavelength grain emissivity $\propto \nu^2$ (Hildebrand 1983) to obtain $A_V/\tau_{350}=4700$. This implies an optical extinction of 38 mag through the cloud, in reasonable agreement with the value of 51±6 mag obtained from the depth of the 9.7 μm absorption feature (Willner *et al.* 1982; Roche & Aitken 1984). MacGregor *et al.* (1984), however, derive a visual extinction of 11.5 mag to the embedded star, suggesting that our line-of-sight to the star is relatively empty of material, such as is possible if the cloud has a disc-like structure.

Using the relations between τ_{350} and $N(H_2)$ derived by Hildebrand (1983) from the results of Whitcomb *et al.* (1981) we find a *peak* molecular-hydrogen column density $N(H_2)=3.6\times10^{22}\,\mathrm{cm}^{-2}$, in excellent agreement with the value of $3\times10^{22}\,\mathrm{cm}^{-2}$ obtained by Lada & Harvey (1981) for the central 1 arcsec on the basis of their CO measurements. Taking a geometric mean size of 46 arcsec (=0.2 pc) and assuming a Gaussian density distribution for the source we also derive a peak density $n(H_2)=1.5\times10^5\,\mathrm{cm}^{-3}$ and a total cloud mass $\sim 90\,M_\odot$.

The CO observations indicate that the molecular outflow is oriented almost directly towards us with the blue-shifted lobe pointing slightly SW and the red-shifted lobe slightly NE. Our submillimetre observations indicate that the emitting region is extended NS. This fact, combined with our previous discussion, leads us to suggest that the compact source in GL 490 is embedded in a disc of dust and gas, as also implied by the CS observations of Kawabe *et al.* (1984). We now wish to examine the question of whether this cloud is capable of collimating the bipolar outflow. A similar analysis has been presented by Davidson & Jaffe (1984) for the sources L 1455 and L 1551, however, they did not resolve the submillimetre-emitting cloud surrounding those objects.

In order for a static core to channel an initially isotropic stellar wind, the gravitational force F binding the core must exceed the integrated momentum flux in the wind. From Newton's second law the force due to momentum deposited by the wind is $M_L V_L^2/r_L$, where M_L, V_L and r_L are the mass, velocity and linear extent of the outflow lobe, respectively. For a star of mass M_*, surrounded by a core of total mass M_c with a Gaussian density distribution of radius to half-maximum r_c, the binding force on the core is

$$F=GM_c(8\ln 2M_*+M_c)/r_c^2, \tag{1}$$

where G is the gravitational constant. Hence we can derive a simple condition for confinement, namely

$$\frac{GM_c r_L}{M_L V_L^2 r_c^2}(8\ln 2M_*+M_c)\gg 1. \tag{2}$$

Taking the parameters derived here for the core, and those for the flow from Lada & Harvey (1981), and assuming the central star to be a B2 ($\sim 20\,M_\odot$) we find the LHS of equation (2) to be 0.12. [We also note that the kinetic energy of the outflow (2×10^{47} erg; Lada & Harvey 1981) is very much greater than the gravitational binding energy of the core (7×10^{45} erg).]

We therefore conclude that the observed core material is incapable of confining the outflow; collimation of the flow must be occurring on a scale less than 10^{17} cm. This must cast doubt on previous suggestions (e.g. Snell, Loren & Plambeck 1980; Bally 1982) that observed discs of molecular gas and dust around embedded sources do in fact collimate bipolar outflows.

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