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THE MULTIPLE INFRARED SOURCE GL 437

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Received 1980 September 19; accepted 1980 November 20

ABSTRACT

Infrared and radio continuum observations of the multiple infrared source GL 437 show that it consists of a compact H II region plus two objects which are probably early B stars undergoing rapid mass loss. The group of sources appears to be a multiple system of young stars that have recently emerged from the near side of a molecular cloud. Emission in the unidentified 3.3 \( \mu \)m feature is associated with, but more extended than, the emission from the compact H II region; it probably arises from hot dust grains at the interface between the H II region and the molecular cloud.

Subject headings: infrared: sources — nebulae: individual — stars: early-type

I. INTRODUCTION

GL 437 is a compact (~15" diameter) cluster of infrared sources (Kleinmann et al. 1977) associated with a rotating molecular cloud (Schneps et al. 1978). Two of the infrared sources correspond to faint nebulous visible objects which have emission line spectra (M. Cohen and Kuh 1977). Image tube photography at 0.94 \( \mu \)m by J. Cohen and Frogel (1980) shows all three sources plus a fourth, fainter object not seen at 3 \( \mu \)m (Fig. 1a). As an infrared source, GL 437 is interesting in that it shows strong 2.2 \( \mu \)m polarization (Dyck and Lonsdale 1979), is associated with visible nebulosity, and shows very strong emission in the 3.3 \( \mu \)m and in other unidentified infrared bands (Kleinmann et al. 1977).

In this paper we describe radio continuum and infrared photometric observations aimed at elucidating the nature of the individual objects, together with a study of the spatial variation of the 3.3 \( \mu \)m feature. We adopt a distance of 3 kpc to the source, although this value is uncertain (Schneps et al. 1978).

II. OBSERVATIONS AND RESULTS

a) Radio Observations

GL 437 was observed in 1978 March and October with the Cambridge 5 km telescope at 2.7 and 5 GHz, with half-power beamwidths of approximately 4" and 2". The 2.7 GHz map is presented in Figure 1b and shows a single source associated with the western infrared source (GL 437W in the nomenclature of this paper) with a suggestion of an extension about 4" to the south. The integrated flux density of the source is 20±4 mJy at 2.7 GHz, although the visibility function indicates that there may be an additional 7 mJy of extended low brightness emission near the source. The position of the peak 2.7 GHz emission is given in Table 1. The diameter of the source, as estimated from the visibility function, is 2"±1".

The 5 GHz Cambridge data agree with the 2.7 GHz data but are of lower signal-to-noise ratios. In particular, they show that at 5 GHz the flux density of GL 437W is not significantly different from that at 2.7 GHz, suggesting a spectral index corresponding to optically thin free-free emission.

The region was also observed at 5 GHz on the VLA of the National Radio Astronomy Observatory4 in 1979 January, with the observing parameters described by Beichman, Becklin, and Wynn-Williams (1979). The \( u-v \) plane coverage at that time was insufficient to map details of the structure of GL 437 reliably, except to confirm a diameter of 2"–3" and a total 5 GHz flux density of about 20 mJy. Upper limits of 1.2 mJy (3 \( \sigma \) limit) were derived from the VLA observations for point sources of emission at the positions of GL 437N, GL 437S, and GL 437E.

b) Photometry of the Sources

Photometry and accurate position determinations were made of the three infrared sources GL 437W, GL 437N,

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4The National Radio Astronomy Observatory is operated by Associated Universities, Inc., under contract with the National Science Foundation.
Fig. 1.—(a) An 0.94 μm image tube photograph of GL 437 taken by J. G. Cohen and J. A. Frogel at the KPNO 0.9 m telescope. (b) 2.7 GHz radio continuum map made with the Cambridge 5 km radio telescope. The contour is 36 K (3 mJy per beam area) and the half-power beamwidth (shown shaded) is 4″ in R.A.×4″ in decl. (c) and (d) Maps of GL 437 made with a 6″ beam on the IRTF. The contours, which are based on 2.2 μm, 3.3 μm, and 3.8 μm observations at the positions marked with dots, are the calculated 3.3 μm continuum and feature flux densities, as described in the text. One contour level equals 20 mJy per beam on the 3.3 μm continuum map and 10 mJy per beam on 3.3 μm feature map. The crosses on the 2.7 GHz map show the positions of the infrared sources as given in Table 1.
and GL 437S using the 2.2 μm telescope on Mauna Kea in 1978 August–September, with some preliminary work in 1977 October.

The absolute positions were determined at 2.2 μm by using an offset guider to measure the displacements of the three infrared peaks from two nearby stars whose positions had earlier been measured off the Palomar Observatory Sky Survey prints. The position of GL 437W was also measured with respect to the stars at 20 μm and with respect to the other two sources GL 437N and GL 437S at 10 μm; at this latter wavelength, but not at 20 μm, it was possible to peak up on each source separately. The peaking up was done with a 5'/5 diaphragm at 2.2 μm, and a 6'/7 diaphragm at 10 and 20 μm. There were no significant position changes with wavelength for any source, so the positions given in Table 1 represent the mean determination of the positions at all infrared wavelengths. The positions agree within error with the 3.5 μm positions of the sources in the map of Kleinmann et al. (1977) and the 0.94 μm sources as determined by Cohen and Frogel (1980); the 0.94 μm picture in Figure 1a has therefore been positioned to correspond most closely with Figure 1c. The western source coincides with the radio source seen in Figure 1b, while the northern source lies closest to the H$_2$O maser source independently discovered by Sargent (1978) at Haystack and by Jaffe (1980) at Bonn. The northern source stands out as being the most strongly polarized of all the 2 μm sources studied by Dyck and Lonsdale (1979).

Photometry of the three infrared sources between 1.2 and 25 μm was carried out on the 2.2 μm telescope, using the same wavelengths and filters as described by Dyck and Simon (1977), with the substitution of a 3.8 μm (Δλ = 0.4 μm) filter for the 3.4 μm filter and the addition of 1.2, 1.65, and 2.2 μm filters with widths of 0.3 μm, 0.3 μm, and 0.4 μm, respectively. The 1.2–3.8 μm observations were made with a 5'/5 diaphragm and an indium antimonide photovoltaic detector; those at 5–25 μm were made with a germanium bolometer and a 6'/7 diaphragm. The InSb measurements were made by first peaking up the signal at 2.2 μm at each of the three positions, while the bolometer measurements were made by peaking up with a broad-band 10 μm filter. For most measurements, a 30” N-S chopper spacing was used; no corrections for flux in the reference beam were made. The photometric results are shown in Figure 2; the visible and near-infrared points for GL 437W and GL 437S are as given by Cohen and Kuhi (1977); they were taken with a smaller diaphragm (4′′×2′′) than the data presented in this paper.

No studies of GL 437E, the fourth object in Cohen and Frogel’s picture, were carried out, since we did not know of its existence when making the observations. Measurements at 3.8 and 2.2 μm on the IRTF as part of the experiment described in § IIc gave flux densities near GL 437E of 5 and 8 mJy, respectively, but this emission is as likely to be part of the extended emission around the region as from the compact object seen at 0.94 μm.

c) Mapping of the 3.3 μm Emission Feature

The spatial distribution of the strong 3.3 μm unidentified feature was studied using the 3 m IRTF telescope on 1979 November 12. The flux density through a 6′′ diaphragm was measured at 15 locations around GL 437 (marked with dots in Figure 1) using three filters, namely the 2.2 μm and 3.8 μm broad-band filters plus a special filter with a central wavelength of 3.3 μm and a bandwidth of 0.2 μm. The chopper throw was 32′′ in a N-S direction. The 3.3 μm continuum map shown in Figure 1c was obtained by interpolation with a power law between the 2.2 and 3.8 μm observations. The 3.3 μm feature map (Fig. 1d) is the result of subtraction of the 3.3 μm continuum flux density from that measured in the 3.3 μm filter. The intrinsic width of the 3.3 μm feature in some other celestial objects is about 0.06 μm (Tokunaga and Young 1980), so that the peak flux density of the 3.3 μm feature is underestimated by a factor of ~3 in Figure 1d.

The spatial distribution of the continuum and feature differ markedly from one another, in that the emission in the continuum has three peaks, whereas that in the
feature appears to be a single source centered on the radio source GL 437W but appears to be significantly more extended than either the continuum or the radio source.

III. DISCUSSION

a) Nature of Objects

The western source, GL 437W, is apparently the most luminous of the three objects with a luminosity of about $3 \times 10^3 L_\odot$ in the range 1–20 $\mu$m. Its energy distribution is of an unusual shape and could well be produced by the superposition in the observing beam of two types of dust, one at a temperature of around $10^3$ K producing the emission shortward of 5 $\mu$m, and another at a temperature of around 250 K producing the emission longward of 5 $\mu$m. A plausible explanation for this variation could be that the hot dust resides within the ionized region and is heated by L$\alpha$, while the cooler dust lies outside of or close to the ionization front and is heated by stellar and nebular radiation escaping the H II region (Wynn-Williams and Becklin 1974; Wright 1973). Alternatively, there could be more than one type of dust grain present, as in the Orion Nebula (Becklin et al. 1976).

From the free-free flux density of GL 437W and its measured angular size, it may be deduced that in the core its electron density is of the order of $10^4$ cm$^{-3}$. The emission measure of such an object would be low enough ($3 \times 10^6$ pc cm$^{-6}$) that self-absorption is not significant at 2.7 or 5 GHz. The rate of ionization as deduced from the radio flux density is $1.4 \times 10^{46}$ s$^{-1}$, a value which corresponds to a ZAMS B0.5 star (Panagia 1973). Such a star would have a bolometric luminosity of $10^4 L_\odot$, a value not greatly different from that of $3 \times 10^4 L_\odot$ measured for the whole GL 437 cluster by Telesco et al. (1981).
The infrared energy distributions of GL 437N and GL 437S are best explained by emission from dust grains heated to temperatures of a few hundred Kelvins. This result can be most easily explained if each component contains a source of luminosity closely associated with the dust grains. Such a model is in contrast to Cohen and Kuhl's (1977) conclusion that GL 437 is primarily a reflection nebula illuminated by a single star. The emission lines seen in Cohen and Kuhl's spectrum of GL 437S indicate that it contains a source of ionizing radiation at its center. The measured Hα flux density from GL 437S through a 2′′7×4′′ diaphragm is 4.1×10⁻¹⁵ W m⁻² (M. Cohen, private communication); when corrected for 6.6 mag of visual extinction, this flux corresponds to a 5 GHz free-free flux density of 5 mJy, significantly larger than the upper limit determined on the VLA. We may, therefore, conclude that GL 437S is self-absorbed at 5 GHz and, therefore, has a large emission measure and electron density. Further evidence for large electron density in GL 437S comes from the weakness of forbidden lines in its spectrum (Cohen and Kuhl 1977). Models of accreting protostars (e.g., Yorke and Krügel 1977) in general predict such large column densities of dust that they are totally obscured at visible wavelengths. We, therefore, believe that the most satisfactory model for GL 437S involves an early-type star undergoing rapid mass loss. Such an object could have a very compact H II region with an r⁻² density distribution surrounded by, or contiguous with, a region containing newly formed dust grains that absorbs part of the light emitted by the star and reradiates it in the 1–20 μm range, as in a nova (Ney and Hatfield 1978). In this picture, the infrared emission from GL 437S (and probably GL 437N) is not attributable to dust in the molecular cloud. The idea that luminous stars undergo a period of rapid mass loss at a very early stage in their evolution is supported by observations such as those of the BN source and IRC2 in Orion (Hall et al. 1978; Downes et al. 1981). The discovery of H₂O emission from GL 437 provides some additional support for this view, since Genzel et al. (1978) argue that the velocity structure of most H₂O masers is best explained in terms of mass-loss processes.

b) The 3.3 μm Emission Feature

The 3.3 μm emission feature has now been detected in more than a dozen galactic infrared sources besides GL 437. An attractive explanation for the origin of this feature has been put forward by Dwek et al. (1980). They propose that this feature, together with others at various longer wavelengths, arise in some unnamed organic coating on the surface of very small, possibly graphite, grains. These grains comprise but a small fraction of the total mass or total extinction of the interstellar dust and, in the presence of visible or near-infrared radiation, make little contribution to the infrared emission. When heated by u−ν radiation, however, their small size results in their achieving a much higher temperature than their larger counterparts, with the result that the 3.3 μm feature, and others, become prominent in emission. This mechanism, discussed quantitatively by Dwek et al., provides a natural explanation for the well-established close association between the 3.3 μm feature and sources of ultraviolet emission as recognized by the presence of an H II region.

Based mainly on the observations of the Orion Nebula by Selligren (1980), Dwek et al. (1980) proposed that most of the 3.3 μm emission comes not from within the H II region where the feature-emitting grain coating is perhaps destroyed, but at the boundary with the dense region.

GL 437 is one of the few regions where the spatial distribution of the 3.3 μm emission has been determined, so it provides an interesting test of the Dwek et al. proposals. The results described in § II c indicate that the emission feature is definitely associated with the compact H II region, rather than GL 437S or GL 437N, and that the half-power width of the 3.3 μm emitting region, about 10′′, is significantly larger than the diameter of the H II region.

The difference in angular size between the H II region and the 3.3 μm emitting region presents, at first sight, a problem for the Dwek et al. model, since the ultraviolet radiation field outside of the H II region is considerably attenuated by absorption of ionizing photons. If, however, the H II region lies at the edge of a molecular cloud, then this problem may be circumvented. Figure 3 shows a possible geometrical configuration for GL 437W, based on the blister model of H II regions of Icke, Gatley, and Israel (1980). Most of the radio emission comes from the apex of the blister, accounting for the compact appearance of Figure 1b, while the 3.3 μm emission comes from a more extended region along the interface between the ionized gas and the molecular cloud. Calculations based on the geometry of Figure 3

![Figure 3](https://example.com/figure3.png)

Fig. 3.—Possible geometry for GL 437. The compact H II region GL 437W appears as the densest part of an H II blister eating into a molecular cloud. The sources GL 437N and GL 437S lie in front of the molecular cloud.
suggest a temperature in the range of 200–250 K for the grains emitting the 3.3 μm feature.

IV. CONCLUSIONS

Although GL 437 is projected against a dense molecular cloud, two pieces of evidence, namely the presence of visible emission and the spatial extent of the 3.3 μm feature, suggest that the infrared sources have recently emerged from the near side of the cloud. One of the three infrared sources is a compact H II region, while the other two are probably young stars which are most likely undergoing mass loss. The group as a whole provides another example of the tendency noted by Beichman, Becklin, and Wynn-Williams (1979) for infrared sources associated with star formation in molecular clouds to exist in small clusters rather than singly.

We thank Martin Cohen, Judy Cohen, Dan Jaffe, and Charlie Telescope for supplying us with unpublished data, David O'Dell for assistance with the radio observations, and the staff of the 2.2 m and IRTF telescopes for help with the infrared observations. We also thank Kris Sellgren for discussions and Susan Kleinmann for her collaboration at all stages in this work. This research was supported by NASA grant NASW 3159 and NSF grant AST 78-26028.

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