NEW INFRARED SOURCES ASSOCIATED WITH H II REGIONS

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Abstract. Photometry and mapping in the wavelength range 1.65–20 μ of the H II regions W3 and NGC 7538 have led to the discovery of a dozen new infrared emission sources. The sources have flux densities ranging up to 10^{-23} Wm^{-2} Hz^{-1} at 20 μ and diameters from < 3 to 40″. Some are associated with, and have similar brightness distributions to compact H II condensations observed at radio wavelengths; they have, however, 20-μ flux densities much greater than, and 2-μ flux densities much less than are predicted from the radio free-free spectra. It is concluded that in many cases there exist close spatial relationships between the hot dust and the ionized gas, and between infrared and OH/H_2O emission sources.

1. Introduction

We have been using the Mount Wilson 100-in. and Mount Palomar 200-in. telescopes to make broad-band observations of several galactic H II regions in the range 1.65 to 20 μ with as high as 5″ spatial resolution. The H II regions studied have generally been those which contain OH or H_2O maser sources and which have been shown by radio astronomers to contain compact condensations of ionized gas which may be connected with star formation processes. In this paper a brief account of two such sources, W3 and NGC 7538, is given. More detailed descriptions of these and other sources will shortly be published in the regular literature (Wynn-Williams *et al.*, 1972, 1973).

2. W3

W3 has several regions of interest at radio wavelengths. Most of the observations described here, however, relate to the W3 (continuum) source (G133.7 + 1.2), an area some 3′ in diameter, from which the bulk of the continuum radio emission originates at high frequencies.

Figure 1 shows the maps of the region at 2.2 and 20 μ compared with the 5-GHz map of the same area made with the Cambridge One Mile Radio Telescope (Wynn-Williams, 1971). The resolution of all these maps is in the range 5–10″. It can be seen that three of the compact H II condensations visible at 5 GHz have associated infrared sources.

The nature of the energy distribution of these sources (Figure 2) indicates that

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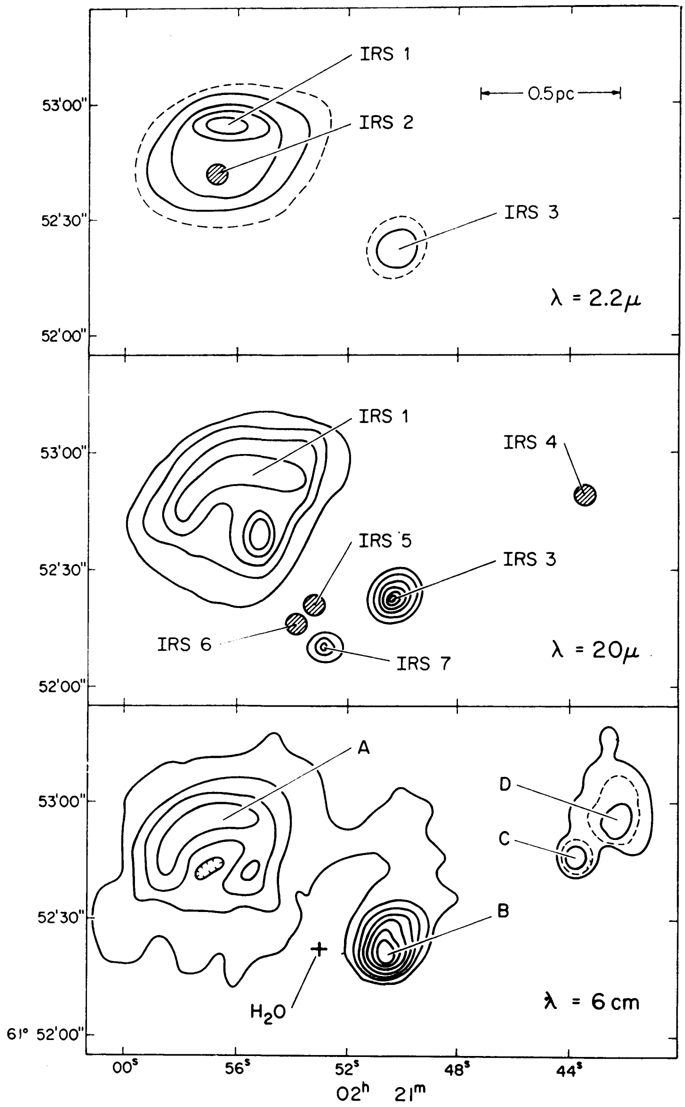

Fig. 1. The W3 (continuum) region at 2.2-μ, 20-μ, and 6-cm wavelength. The radio continuum data are taken from Wynn-Williams (1971) and have a resolution of 6.5″ × 7.4″; the position of the H_2O maser source is as given by Hills *et al.* (1972). Hatched circles indicate unresolved sources and dashed contours are half intervals. Sources to the west of $02^h21^m48^s$ are not shown at 2.2 μ because of the presence of confusing field stars.

heated dust must be responsible for the emission in the 3- to 20-μ range. The close correspondence between the 20-μ and 5-GHz maps indicates that the heated dust and the ionized gas occupy the same regions of space. Observations at 10 and 20 μ indicate a dust temperature of the order of 150 K, and that the infrared emission from the sources can be caused by a collection of small particles with a total mass of only 10^{-2}

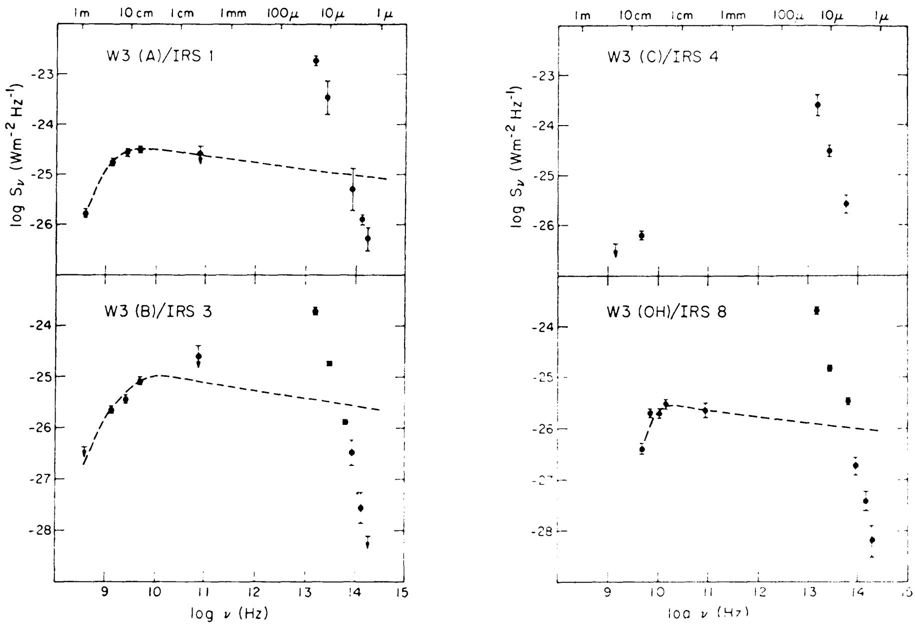

Fig. 2. The energy distributions of the four sources W3(A)/IRS1, W3(B)/IRS(3), W3(C)/IRS4, and W3(OH)/IRS8 at radio and infrared wavelengths. The dashed lines indicate the expected infrared thermal emission from the ionized hydrogen as predicted from the radio emission. References for the radio data are given in Wynn-Williams *et al.* (1972).

of the ionized gas. It is thus unnecessary to make any special assumptions about the nature or concentration of the dust mixed with the gas.

It can also be seen in Figure 2 that the 2-μ emission from the sources is well below that predicted from free-free and free-bound transitions in the ionized hydrogen plasma. There must therefore be large amounts of obscuring material associated with and in front of the ionized gas/hot dust region. These amounts vary, but reach 50 visual magnitudes in front of W3 (B).

There are several other infrared sources in Figure 1 as well as those already mentioned, which do not correspond to H II condensations. The magnitude and infrared color of one of these, IRS2, show that it is almost certainly a highly obscured O5 star, and the main source of excitation and energy in W3 (A)/IRS1. One of the others, IRS5, has a flux density of 500×10^{-26} Wm^{-2} Hz^{-1} at 20 μ, but a diameter of less than 3″ (10^4 AU). Its luminosity (3×10^4 $L_\odot$) and temperature (300–400 K) lead to speculation that it may be a massive protostar. Its position agrees within 3″ with that of the H_2O maser source as determined by Hills *et al.* (1972).

Finally, two further infrared sources were discovered close to the W3(OH) source, some 12′ away from the region mapped in Figure 1. One of these, IRS8, whose spectrum is shown in Figure 2, is coincident with the OH, H_2O, and radio continuum positions, while the other, with a rather flatter energy distribution than that of IRS8, is not coincident with any known optical or radio feature.

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3. NGC 7538

The radio properties of the small nebula NGC 7538 have recently been discussed by Habing *et al.* (1972). Continuum, presumably thermal, emission is evident from the optically bright parts of the nebula, and also from a small optically faint condensation. This latter source, which has a diameter of less than 15″ and a flux density of about 10^{-26} Wm^{-2} Hz^{-1} at 21 cm is coincident within experimental error with the position of OH emission as determined by Hardebeck (1971). Martin (1972) has mapped the same region at 5 GHz with 6.5″ resolution. He finds that most of the flux comes from a component 8″ in diameter, the position of which is shown in Figure 3, but that there is a weak extension southwards towards 61°11′50″.

In view of this close association between a radio and an OH source, it was decided to search for infrared emission from the vicinity of the radio condensation. A very powerful source was indeed discovered and Figure 3 shows a 20-μ map of the source with 5″ resolution. It can be seen that the infrared emission has its origin in a cluster of at least three small sources, spread over a region about 15″ diameter. Individual energy distribution for these objects are not yet available, but the cluster as a whole has a flux density of about 700×10^{-26} Wm^{-2} Hz^{-1} at 20 μ falling smoothly to 0.2×10^{-26} Wm^{-2} Hz^{-1} at 1.65 μ in a manner fairly similar to the W3 objects shown in Figure 2.

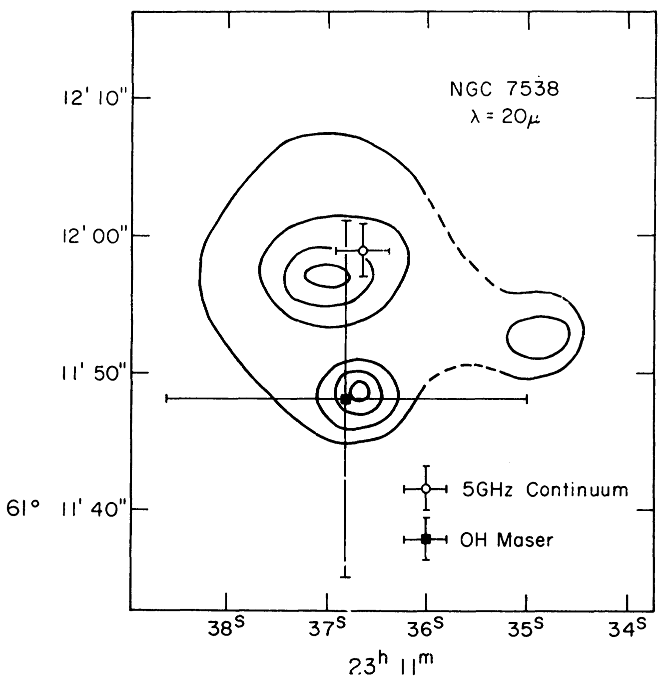

Fig. 3. The 20-μ emission from the vicinity of the OH source in NGC 7538. The crosses show the peaks of the 1720-MHz OH emission (Hardebeck, 1971) and of the 5-GHz thermal radio continuum emission (Martin, 1972).

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Comparison with Martin's results would therefore indicate that, as in W3, some, but not all, of the infrared sources in NGC 7538 are coincident with H II condensations or microwave maser sources.

4. Conclusions

On the basis of the observations of W3, NGC 7538, and some other H II regions which are still being analyzed, it may be concluded that:

(1) In general H II condensations are infrared sources in the range 3–20 μ. The data are consistent with the emission having its origin in heated dust mixed with the ionized gas.

(2) The condensations are hidden optically by large quantities of obscuring matter, up to 50 visual magnitudes thick in one case.

(3) There exist additional infrared sources in the vicinity of the H II condensations. One of these may be a protostar with a luminosity of $3 \times 10^4 L_{\odot}$.

(4) There is a close connection between infrared sources and OH maser sources in H II regions.

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