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LUMINOUS RADIO-QUIET SOURCES IN THE W3(MAIN) CLOUD CORE

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ABSTRACT We have resolved 450μm and 800μm emission from the W3(Main) star forming region into three major peaks, using $8'' - 14''$ beams with the James Clerk Maxwell Telescope on the summit of Mauna Kea. One of the submillimeter sources is identified with W3 – IRS5, a well-known candidate protostar. However, to our suprise, we find that none of the submillimeter peaks coincides with any of the prominent compact HII regions in the area. We estimate that the three submillimeter sources together contribute 30 – 50% of the total bolometric luminosity of the region, and speculate that the contribution of luminous radio-quiet sources to the total luminosity of HII region/molecular cloud complexes may be larger than is often assumed.

INTRODUCTION

The spectral energy distributions of HII region/molecular cloud complexes indicate that the bulk of their luminosity is emitted in the far infrared and that this far infrared and submillimeter emission is generated by cool (T = 30–60 K) dust (see e.g. Wynn-Williams & Becklin 1974; Chini, Krugel, & Wargau 1987). Because of the large beam sizes typically used for far-infrared and submillimeter continuum observations, it has been difficult to determine whether the OB stars ionizing the HII regions are the sources of the luminosity, or whether this luminosity is generated independently within the nearby molecular material. We present new submillimeter continuum observations of the W3(Main) region with high spatial resolution (< 0.1 pc). These new observations show that the distribution of submillimeter flux is not similar to the distribution of radio continuum emission, and suggest that the total luminosity generated by HII region/molecular cloud complexes is not dominated by the O and B stars which generate the observed HII regions.

OBSERVATIONS

Submillimeter observations of the W3(Main) region were made with the 15 m JCMT in 1992 November. The continuum maps were obtained using the facility UKT-14 bolometer system with passbands centered at approximately 450 μm and 800 μm. Our results are shown in Figure 1, along with maps of 20 μm

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(Wynn-Williams et al. 1972) and a 5 GHz radio continuum emission (Harris & Wynn-Williams 1976). The submillimeter continuum emission breaks up into three main emission centers—one in the east, and two in the west. We designate the sources SMS 1, 2, and 3 from E to W in order of decreasing right ascension.

DISCUSSION

SMS 1 is resolved and nearly circular at half power, with low flux level extensions to the east in the direction of IRS 3/W3B and north in the direction of IRS 1/W3A (see Figure 2a). The 450 μm and 800 μm centroid positions are consistent with the 20 μm position of IRS 5 (Wynn-Williams et al. 1972), several H_2O maser groupings (Genzel et al. 1987), and the radio continuum source W3(M) (Colley 1980).

SMS 2 lies close to the 20 μm source IRS 4 (Wynn-Williams et al. 1972), and near to the compact HII region W3(C) (Wynn-Williams 1971; see Figure 2b). We find that the position of SMS 2 lies 7.5″ from the center of W3(C). The size of the positional discrepancy is sufficiently large that we are confident that SMS 2 is not associated with W3(C). IRS 4 lies 4″ from the centers of both W3(C) and SMS 2, nearly on a line between these two sources. Therefore we conclude that there are are least two distinct major sources of emission in this area (W3(C) and SMS 2), and quite likely an additional unrelated infrared source (IRS 4).

SMS 3 is more extended than the other two submillimeter sources, with FWHM size of $30'' \times 16''$ ($\alpha \times \delta$). No 20 μm emission was detected in this region to a point source detection threshold of 150 Jy (Wynn-Williams et al. 1972), nor was radio continuum emission detected greater than 6 mJy/2″ beam (Harris & Wynn-Williams 1976).

Combining our data with infrared results (Wynn-Williams et al. 1972; Werner et al. 1980), we have estimated the 20–800 μm luminosities for these three sources, as well as for IRS 1 (which was not detected as a distinct source in our submillimeter maps) and the entire region. The total luminosity for the region is estimated to be 5.2×10^5 $L_\odot$. IRS 1 and IRS 5 each account for about 30% of the total. SMS 1 and SMS 2 account for an additional 6% each. However, it should be noted that the luminosity of SMS 2 may contain some additional contribution from either IRS 4 or the source associated with W3(C), and therefore this luminosity should be regarded as an upper limit to the luminosity of SMS 2.

IRS 5 has long been recognized as a candidate high-mass protostar, based on its high luminosity, infrared energy distribution, and relatively weak radio continuum emission (see e.g. Wynn-Williams et al. 1972; Hackwell et al. 1978; Werner et al. 1980; Wynn-Williams 1982). We have found two more sources in the W3(Main) cloud that exhibit behavior similar to that of IRS 5. While both have luminosities about a factor of 5 lower than that of IRS 5, they are not associated with detected radio continuum emission. These radio-quiet sources account for at least 35% (SMS 1/IRS 5 + SMS 3) and up to 50% (SMS 1/IRS 5 + SMS 2 + SMS 3) of the total luminosity generated in the W3(Main) core. With the addition of extended emission probably generated by lower-luminosity, non-ionizing sources, the luminosity from W3(Main) could be roughly equally

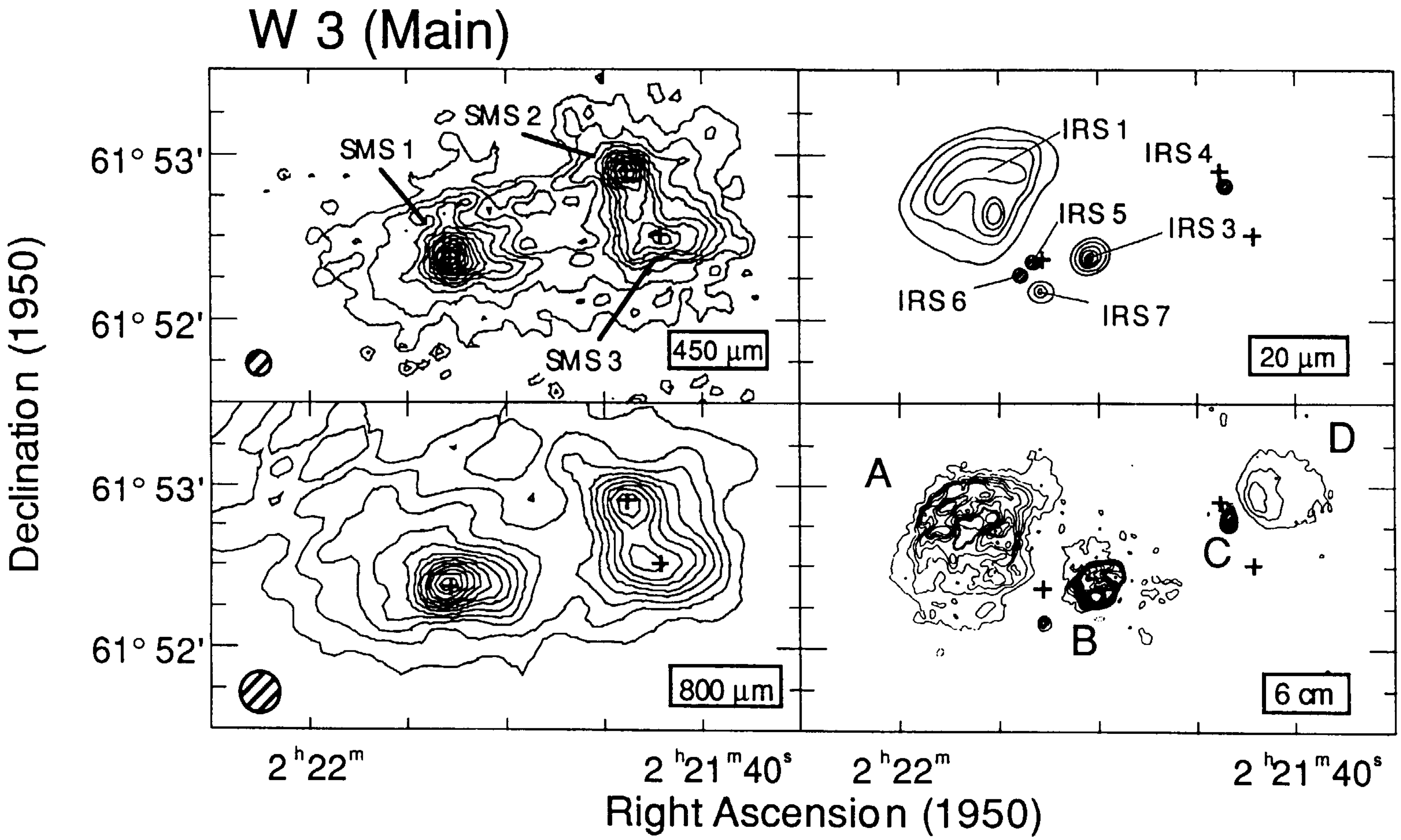

Fig. 1 Submillimeter images of the W3 (Main) region at 450 µm (**top left**) and 800 µm (**bottom left**) compared with the 20 µm map from Wynn-Williams et al. (1972; **top right**) and the 5 GHz contours from Harris & Wynn-Williams (1976; **bottom right**). The submillimeter beam sizes are shown in the lower left of each relevant panel. Contours for the 450 µm map begin at 15 Jy / 8" beam and increment by 15 Jy / 8" beam. Contours for the 800 µm map begin at 1 Jy / 14" beam and increment by 1 Jy / 14" beam.

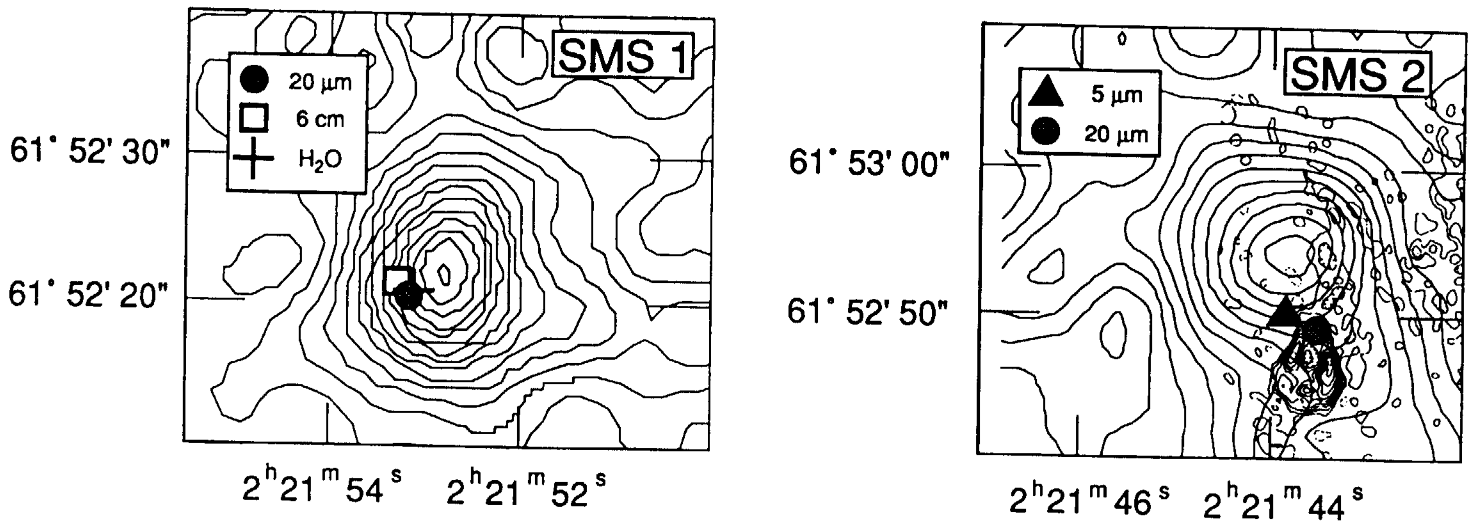

Fig. 2 a) Contours of the 450 μm emission near IRS 5. The 450 μm contours begin at 5 Jy / 8" beam and increment by 5 Jy / 8" beam. The positions of the 20 μm source, the radio continuum source W3 (M) and the H_2O maser centers are indicated by a circle, box and cross respectively. **b)** Comparison of our 450 μm contours with the 15 GHz emission from Colley (1980) toward the SMS 2 / IRS 4 / W3 (C) region. The 450 μm contours begin at 5 Jy / 8" beam and increment by 5 Jy / 8" beam. The position of the 20 μm and 5 μm sources are indicated by a circle and a triangle respectively.

divided between sources associated with HII regions and sources which have little or no ionized environs.

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15. Supplementary Notes

16. Abstract Data at far-infrared wavelengths are difficult to obtain and usually have much lower spatial resolution than data which are routinely obtained at other wavelengths. However, the many astrophysical problems that can only be well addressed in the far-infrared have inspired efforts to extract high spatial resolution information from instruments including the Infrared Astronomical Satellite (IRAS) and the Kuiper Airborne Observatory (KAO). The IRAS data also provide a fundamental archive since IRAS produced a nearly complete survey of the infrared sky. Although the IRAS survey strategy was not designed with the specific purpose of constructing images of the sky, the ingenuity of software developers has recently resulted in innovative techniques which are allowing astronomers to push the limits of these and other far-infrared data.

The goal of this workshop was to discuss new science and techniques relevant to high spatial resolution processing of far-infrared data, with particular focus on high resolution processing of IRAS data. Users of the maximum correlation method, maximum entropy, and other resolution enhancement algorithms applicable to far-infrared data gathered at the Infrared Processing and Analysis Center (IPAC) on the Caltech campus in Pasadena for two days in June 1993 to compare techniques and discuss new results. During a special session on the third day, interested astronomers were introduced to IRAS HIRES processing, which is IPAC's implementation of the maximum correlation method to the IRAS data. Individuals who desire further information about IRAS or HIRES processing are encouraged to contact IPAC.

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