Protostars in the Molecular ISM: Probing their Structure with SCUBA at the JCMT

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Abstract.
We present submillimeter maps of two protostellar regions obtained during the commissioning of the SCUBA detector on the JCMT in 1997. The flux profiles at 450 and 850 μm are shown for RNO 43, and a first order calculation of its density distribution is made.

1. Introduction

The submillimeter regime is widely regarded as ideal for the study of protostellar candidates: sources which are actively accreting material through infall. Because these "class 0" sources remain deeply embedded in their parent molecular cloud cores, they are virtually undetectable in the infra-red regime. Thus, single dish techniques favour the submillimeter, where their intensity is high and resolution is favourable to their detection. However, until the commissioning of the Submillimeter Common User Bolometric Array (SCUBA) continuum detector at the James Clerk Maxwell Telescope (JCMT) in 1997, only the brightest protostellar sources at 850 μm ($>$ 5 Jy) were detectable due to limited receiver sensitivity.

SCUBA now permits us to observe sources 100 times fainter than previous receivers. Perhaps more importantly, we can now image the surrounding regions rather than just the central peaks and can thus hope to measure the flux profiles of these sources in the outer envelope where material has yet to collapse. This is essential since models of protostellar structure are differentiated by material which has not yet collapsed; Shu (1977) predicts $\rho \propto r^{-2}$ while McLaughlin & Pudritz (1996) predict $\rho \propto r^{-1}$. Flux profiles, combined with radiative transfer models, provide a measure of density distributions.

Here, we present 450 and 850 μm maps of the protostellar sources RNO 43, L1448 mm and L1448 N(B) made during SCUBA's commissioning phase. The resolution of the JCMT is $\sim 8''$ at 450 μm and $\sim 15''$ at 850 μm. The peak fluxes are summarized in Table 1. We also include the flux profile of RNO 43 which, as the only source which is not a member of a multiple system, is the most straight forward to interpret.

2. SCUBA maps

Figures 1 and 2 illustrate the regions of RNO43 and L1448 as imaged by SCUBA. RNO 43 is located at an estimated distance of 400 pc (Zhou et al. 1988) in a

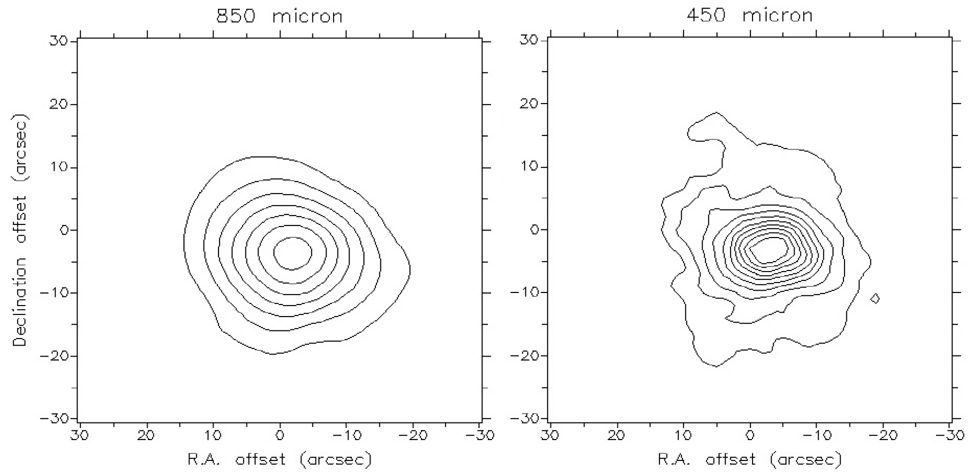

Figure 1. RNO 43. The central coordinates of both maps are $\alpha(2000) = 05\ 32\ 19.41$, $\delta(2000) = +12\ 49\ 41.8$. The contours of the 850 μm map range from 20 to 80σ in steps of 10σ, where σ is $\sigma = 0.01$ Jy beam^{-1}; at 450 μm, $\sigma = 0.03$ Jy beam^{-1} and contours from 20 to 110σ are shown. The larger beam size at 850 μm is evident in these images, as are some of the error lobe features at low contours in the 450 μm map.

northern fragment of the λ Orionis molecular ring. The protostar powers an extensive outflow region, which lies almost perpendicular to the line of sight and runs in a north-south direction on the sky, extending $\sim 12'$ on either side (Cabrit et al. 1988). Previous continuum measurements yielded a total flux of 0.97 Jy at 800 μm (Zinnecker et al. 1992). Our integrated flux at 850 μm in a $100''$ aperture is significantly higher at 2.4 Jy.

Table 1. Submillimeter Source Sizes and Peak Fluxes. The FWHM and 850 μm peak flux of L1448 NW are no doubt affected by the close proximity of L1448 N(B).

Source	850 μm FWHM [$''$]	850 μm Peak Flux [Jy beam^{-1}]	450 μm Peak Flux [Jy beam^{-1}]
RNO 43	15.9	0.86	3.66
L1448 mm	14.5	2.0	10.6
L1448 N(A+B)	15.1	4.9	39.0
L1448 NW	11.1	1.6	2.0
Uranus	14.3	71.5	179.7

The L1448 cloud is located in the Perseus complex at a distance typically estimated to be 300 pc (Bachiller et al. 1990). The 850 μm map of Figure 2 reveals the bright northern source L1448 which is elongated to the NW, as well as L1448 mm (a.k.a. L1448 C, Curiel et al. 1990), a fainter source $\sim 90''$ (0.13 pc) to the SE which drives the powerful outflow seen in this region. The outflow is aligned in the direction of L1448 N and the L1448 mm source appears slightly extended along the direction of its outflow in our 450 μm map.

L1448 N is comprised of three sources: N(A) and N(B), a binary of separation 6-8$''$seen with the VLA (Curiel et al. 1990); and NW 20$''$to the northwest, discovered at 3 mm with the OVRO interferometer (Terebey & Padgett 1997). Figure 2 clearly shows N(B) and N(A) as a single bright peak, with the extension revealing L1448 NW. The positions of the 450 μm peaks are less clear, but these

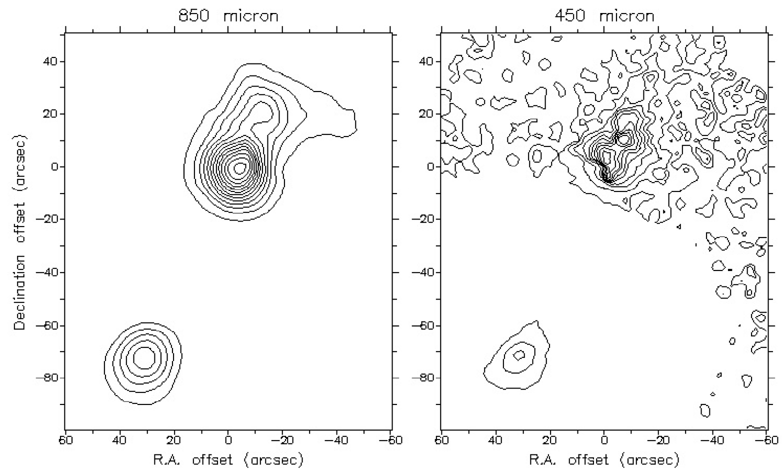

Figure 2. L1448. The central coordinates of both maps are $\alpha(2000) =$ 03 25 38.92, $\delta(2000) = +30$ 44 5.3. The contours of the 850 μm image range from 20 to 140σ in steps of 10σ ($\sigma = 0.03$ Jy beam^{-1}), while those of the 450 μm image range from 5 to 50σ in steps of 5σ ($\sigma = 0.7$ Jy beam^{-1}). The difference noise level across the 450 μm map is obvious. The integration time of maps centered on L1448 mm exceeded that on L1448 N by a factor of five. Mutiple protostellar candidates can be identified in both maps.

are most likely associated with N(B) and NW. Barsony et al. (1998) present a multi-wavelength analysis of the sources and outflows of this interesting region.

3. The Flux Profile of RNO 43

RNO 43 is more extended at 850 μm than the calibrator Uranus, as indicated by the FWHM sizes in Table 1. Thus, RNO 43 has been resolved by the JCMT, and a flux profile can be generated.

Analysis of the flux profile is typically undertaken as follows: if the temperature and density both behave according to power laws with $T(r) \propto r^{-q}$ and $\rho(r) \propto r^{-p}$ and the flux density obeys $S_\nu(\theta) \propto \theta^{-m}$, the indices are related by $m = q + p - 1$ (Adams 1991). This follows from the assumed infinite nature of the profiles. Figure 3 shows the flux profiles of RNO 43 and the calibrator Uranus at 450 and 850 μm respectively. The straight line reflects a flux index of unity, i.e. $S_\nu(\theta) \propto \theta^{-1}$, which corresponds to $\rho(r) \propto r^{-2}$ if the source is isothermal ($q = 0$) or $\rho(r) \propto r^{-1.6}$ under the common assumption of a centrally heated source ($q = 0.4$: Wolfire & Cassinelli 1986; Adams & Shu 1986).

Although RNO 43 is categorized as a class 0 source, it has detectable emission at 60 and 100 μm (Zinnecker et al. 1992), indicating that it could be approaching the older class I phase. In this phase, most of the circumstellar envelope has already accreted onto the central star, and theoretical models of inside-out collapse (Shu 1977; McLaughlin & Pudritz 1997) predict a density distribution characterized by $r^{-1.5}$, very close to the value indicated by the power law in Figure 3 in the case of a centrally heated source. A crude analysis of these data deconvolved from the beam implies a size of 4.5$''$ based on the 450 μm data and 5$''$ from the 850 μm data, much smaller than the 10$''$ measured by Zinnecker et al. (1992). Thus, RNO 43 may be smaller in extent than was originally believed.

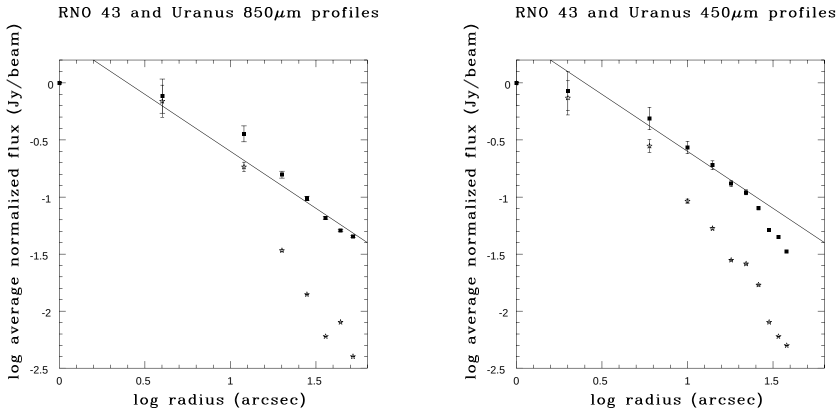

Figure 3. Flux Profiles of RNO 43. These log-log plots were produced by measuring the average flux per pixel in annuli of equal width from the central peak pixel. The values have been normalized to the value of the central pixel. The width of the annuli roughly correspond to the HPHW, i.e. $4''$ at 450 μm and $8''$ at 850 μm. The points are plotted at the mid-radius of each annulus. Error bars correspond to 20% of the normalized, averaged flux. At both wavelengths, flux profiles of Uranus (stars) and RNO 43 (squares) are plotted. The power-law shown corresponds to $S_\nu \propto \theta^{-1}$ as discussed in the body of the text.

4. Conclusions

Our profiles of RNO 43 do not show evidence of the flattening which characterize the flux profiles of starless cores (Ward-Thompson et al. 1994). The flattening of the profiles in Figure 3 is certainly an instrumental effect. Thus, if the profile does flatten, it must do so inward of 3500 AU ($10''$ at the distance of RNO 43). We have obtained SCUBA data of the prototypical class 0 source VLA 1623, which will allow us to look more closely at the central region of its flux profile, since its distance of 160 pc means $10''$ corresponds to only 1600 AU.

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