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Search for Binary Protostars

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Abstract. In an effort to shed more light on the formation process of binary stars, we have started a program to study multiplicity among nearby low- and intermediate-mass protostars using the OVRO Millimeter Array. Here, we describe the project and present the first results on the protostellar core in the Bok globule CB 230 (L 1177). At $10''$ resolution, the molecular core is resolved into two components separated by $\sim$5000 AU. The morphology and kinematics of the double core suggest that it formed from a single cloud core due to rotational fragmentation.

1. Introduction

A major gap in our understanding of low-mass star formation concerns the origins of binary stars. About 30 to 50% of low-mass main-sequence stars have companions, and the frequency of young T Tauri binary systems in nearby star-forming regions is nearly twice as high. Binary systems have been observed in all pre-main-sequence stages of evolution and there is growing evidence for proto-binary systems, although the numbers are still very small (e.g., Fuller et al. 1996; Looney et al. 1997). Both theory and observations support the hypothesis that binary systems form during the gravitational collapse of molecular cloud cores. Most scenarios propose bar formation and fragmentation in rotating and accreting protostellar cloud cores or circumstellar disks as a formation mechanism (e.g., Burkert & Bodenheimer 1996; Boss & Myhill 1995; Bonnell et al. 1991; Boss 1999). To understand the formation process of binary stars, high angular resolution studies of the earliest stages of star formation are required. We have, therefore, started a program to search for multiplicity among low- and intermediate-mass protostars (Class 0 and I) using the Owens Valley Radio Observatory (OVRO) Millimeter Array.

2. Observations

Our program aims at sub-arcsecond resolution corresponding to linear resolutions of 150 to 450 AU. Later, with ALMA, we aim for 0.1 arcsec resolution, or 15-45 AU, close to the peak of the pre-main sequence binary separation distribution. The mm continuum emission is used to trace the optically thin thermal dust emission. The molecular gas is traced by the $C^{18}O(1\rightarrow0)$ and $N_2H^+(1\rightarrow0)$ lines at 110 and at 93 GHz, respectively. $N_2H^+(1\rightarrow0)$ comprises seven hyperfine components and, compared to other molecules, depletes later and more slowly onto grains (Bergin & Langer 1997). It is, thus, a very reliable gas tracer of the the morphology of protostellar cores. Initial results presented here are based on observations conducted at OVRO in September and October 1999. The 1 mm and 3 mm continuum maps have 1 σ rms sensitivities of 4 mJy/beam for HPBW $2.0''\times1.5''$ and 0.7 mJy/beam for HPBW $5.2''\times4.2''$, respectively. The N_2H^+ images were obtained at low resolution only and have a velocity resolution of 0.2 km/s and a 1 σ sensitivity of 110 mJy/beam for HPBW $13''\times9.4''$.

The NIR, submm, and 1.2 mm continuum observations were performed at the 3.5 m Calar Alto telescope (MAGIC), the 15 m JCMT (SCUBA), and the IRAM 30 m telescope (19-channel bolometer array). We wish to thank Th. Henning, R. Zylka, R. Lenzen, D. Ward-Thompson, and J. Kirk who are involved in these programs.

3. CB 230 (L 1177)

CB 230 is a Bok globule located at a distance of ~450 pc. It contains a strong submm/mm continuum source (Launhardt & Henning 1997; Launhardt et al. 1998, 2000) and a dense CS core which shows spectroscopic signature of mass infall (Launhardt et al. 1997). The dense core is associated with two NIR reflection nebulae separated by $\sim10''$ (Yun 1996; Launhardt 1996). The western nebula is bipolar with a bright northern lobe perfectly aligned with the blue lobe of a well-collimated CO outflow (Yun & Clemens 1994). The much fainter southern (red) part of this bipolar nebula seems heavily obscured possibly by the infalling envelope. No star is visible and the NIR morphology can be interpreted as light emerging from a deeply embedded YSO and scattered outward through the outflow cone directed towards us. The eastern NIR nebula is much fainter and redder and displays no bipolar structure.

Previous single-dish mm continuum and molecular line observations did not resolve the central part of the dense core. But they demonstrated that the mm emission has a core-envelope structure and peaks at the origin the western bipolar NIR nebula (Fig. 1, top row). The slight extension of the continuum emission to the south east suggests that the faint eastern NIR source is also associated with circumstellar material.

The new OVRO continuum maps at 1 mm and 3 mm (Fig. 1, bottom row) show only one unresolved component clearly associated with the origin of the western bipolar nebula. The compactness and location of the 1 mm continuum source observed (<400 AU E-W extent), together with the bipolar structure of the NIR nebula, suggest the presence of a circumstellar disk. The compact source contains ~10% of the total 1 mm continuum flux in the IRAM map. A significant contribution by free-free emission can be ruled out since the bolometric luminosity of the entire cloud core of 11 $L_\odot$ points to a low-mass protostar with no capability to ionize its environment (Launhardt et al. 1997). The eastern source may be too faint to detect (<2 mJy at 3 mm and <10 mJy at 1 mm) or no compact disk is associated with it.

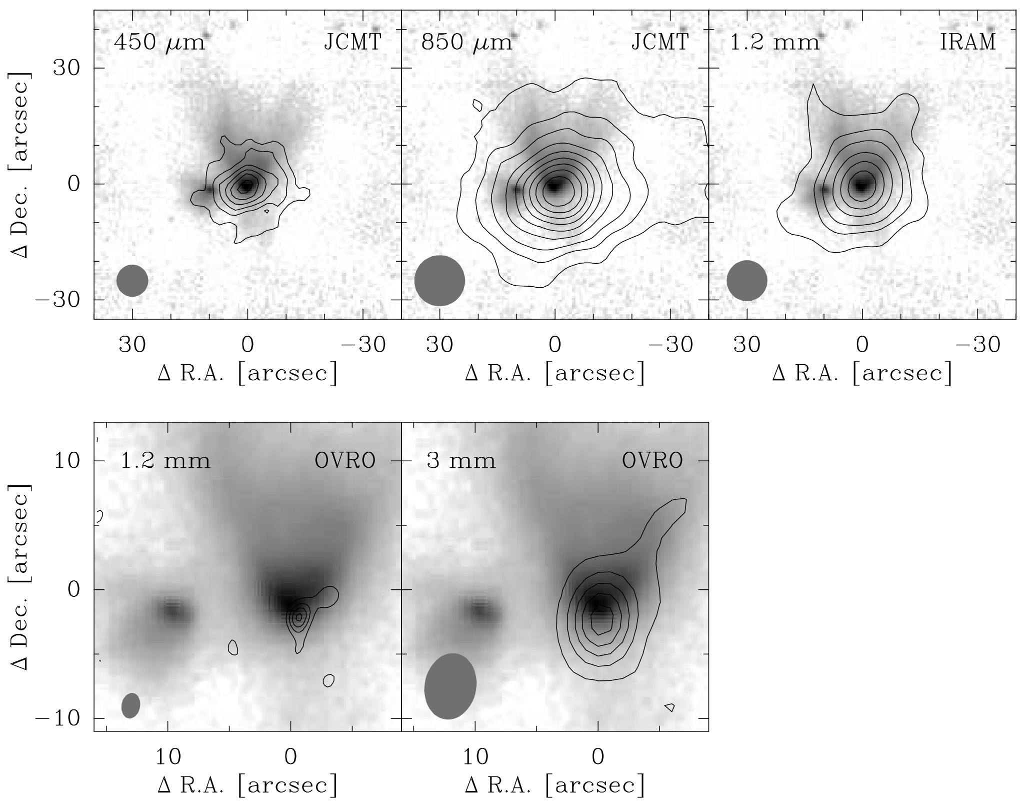

Figure 1. K-band image of the NIR reflection nebula in CB 230 (grey-scale, Calar Alto 3.5 m telescope, MAGIC) overlayed with contour maps of the dust continuum emission at 450 and 850 μm (JCMT), 1.2 mm (IRAM; OVRO), and at 3 mm (OVRO). Contour levels start at $3\,\sigma$.

In contrast to the dust continuum emission, all seven hyperfine structure components of the N_2H^+(1–0) line are detected at both NIR positions. The N_2H^+ data resolve the molecular cloud core into two separate components each of which is spatially coincident with one of the two NIR nebulae (Fig. 2). The projected separation of the two sources is ∼5000 AU. The double core seems to rotate around an axis perpendicular to the connecting line and approximately parallel (in projection) to the outflow of the western source. A comparison of the kinetic, gravitational, and rotational energy of the double core system shows that the two cores are gravitationally bound. This is consistent with the assumption that the double core formed due to rotational fragmentation from a single cloud core and with the orientation of the assumed circumstellar accretion disk around the western protostar. The angular resolution is not yet high enough to derive the rotation curves of the individual cores, but planned observations should improve the resolution considerably. The projected separation of ∼5000 AU is at the upper end of the pre-main-sequence binary separation distribution, Nevertheless, these preliminary results suggest that the Bok globule CB 230 contains a “true” wide binary protostar system.

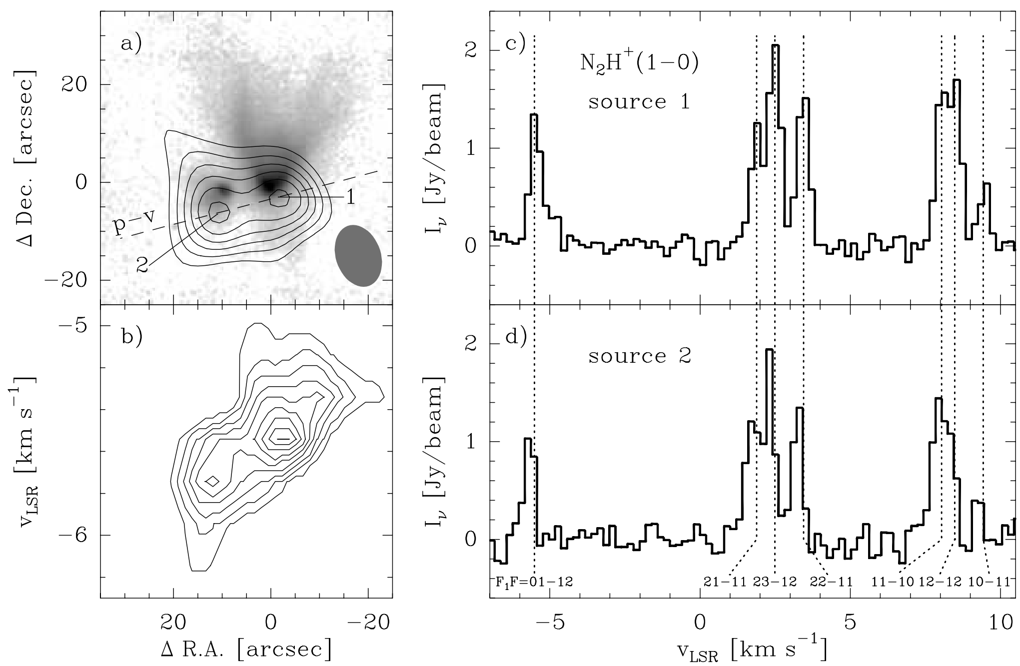

Figure 2. CB 230, N_2H^+(1–0) OVRO results. a) Contour map of the integrated intensity of the (J F_1 F = 101–012) hyperfine structure line of N_2H^+ together with K-band image of the NIR reflection nebula (grey-scale). b) Position-velocity diagram of this line component along the dashed line marked in box a). c) and d) Full spectra of the N_2H^+(J=1–0) line at the two source positions marked in map a).

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