DOES IRAS 16293–2422 CONTAIN A HOT CORE? NEW INTERFEROMETRIC RESULTS

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Abstract

High angular resolution H2CO line observations have been carried out for the low mass proto-binary star IRAS 16293–2422 using the OVRO millimeter array. Simultaneous continuum observations reveal that the source most probably contains two accretion disks, less than ∼250 AU in size, through which matter is fed onto the stars. The observations suggest that the binary has cleared most of the material in the inner part of the envelope, out to the binary separation. The H2CO interferometer observations indicate the presence of large scale rotation roughly perpendicular to the large scale CO outflow associated with this source. The H2CO emission is dominated by the compact dense and hot (T > 100 K) gas close to the positions of the continuum peaks.

Key words: ISM: molecules – ISM: abundances – stars: formation – astrochemistry

1. Introduction

Recent studies (Jørgensen et al. 2002; Schöier et al. 2002; Shirley et al. 2002) have suggested that the inner envelopes of low-mass protostars are dense (> 10⁶ cm⁻³) and warm (> 80 K), as would be expected from scaling of high-mass protostars (Ceccarelli et al. 1996; Ivezić & Elitzur 1997). Detailed modelling of multi-transition single-dish observations towards the deeply embedded low mass protostellar object IRAS 16293–2422 (Ceccarelli et al. 2000; Schöier et al. 2002) shows that the abundances of some molecules, e.g. H2CO and CH₃OH, are drastically increased in the warm and dense inner region of the circumstellar envelope. The location where this increase occurs is consistent with the radius at which ices are expected to thermally evaporate off the grains (∼90 K). However, the small spatial scale of the region of hot gas (< 100 AU) and the infalling nature of the envelope lead to very different chemical time scales between low mass and high mass hot cores, which may prevent production of second-generation complex molecules in low mass protostars. Also, shocks are thought to be relatively more important in low mass protostars. High angular resolution observations are needed to pinpoint the origin of the abundance enhancements and possibly distinguish these two scenarios. We present here observations of H2CO at 1 mm using the Owens Valley Radio Observatory (OVRO) millimeter array at ∼3″ resolution. The line ratio of the two H2CO lines observed is a measure of the gas temperature.

2. Observations and data reduction

IRAS 16293–2422 was observed using the OVRO millimeter array between September 2000 and March 2002. The continuum emission at 1.37 mm was obtained simultaneously with the H2CO 322 → 221 and 303 → 202 line emission at 218.222 and 218.475 GHz, respectively. IRAS 16293–2422 was observed in the L and E configurations. The natural weighted continuum observations has a 1σ noise of about 20 mJy beam⁻¹ with a beam size of 3′′9 × 1′′9.

3. Results and discussion

3.1. Continuum emission

In Fig. the 221.7 GHz (1.37 mm) continuum emission observed toward IRAS 16293–2422 is presented. As expected for this proto-binary star, two continuum sources are detected, separated by approximately 5″ with faint extended emission also present. The total observed continuum flux density at 1.37 mm is about 3.5 Jy. This is roughly 50% of the flux obtained by Walker et al. (1990) from mapping with a single dish telescope, indicating that the interferometer resolves out some of the emission. The positions of the continuum sources are consistent with the two 3 mm sources MM1 (southeast) and MM2 (northwest) found by Mundy et al. (1992). At the distance of IRAS 16293–2422 (160 pc) the projected separation of the
Figure 1. OVRO interferometer maps of $^{12}$CO emission (contours) overlayed on the 1.37 mm continuum emission (greyscale) from IRAS 16293–2422. The $^{12}$CO emission has been separated into a blue (4-7 km s$^{-1}$; solid lines) and a red (1-4 km s$^{-1}$; dashed lines) part. Contours start at the 2$\sigma$-level (1.0 Jy beam$^{-1}$ km s$^{-1}$) with contours spaced by 2$\sigma$. Also indicated is the direction of the large scale CO outflow. The southeast continuum source is MM1 whereas MM2 is to the northwest.

Figure 2. Visibility amplitudes of the OVRO 1.37 mm continuum emission towards IRAS 16293–2422 as function of the projected baseline length. The central position is taken to be midway between MM1 and MM2. The observations are plotted as filled symbols with $1\sigma$ error bars. Also shown are the predictions from the continuum model (Schöier et al. 2002), with the same $uv$ sampling as the observations (dash-dotted magenta line) with unresolved compact emission (dashed blue line) added to the model. A model envelope with a cavity (solid red line) is shown to best reproduce the observations.

Figure 3. Comparison between the $^{12}$CO ($3_{03} \rightarrow 2_{02}$) line emission towards IRAS 16293–2422 at the source position from JCMT single-dish observations (lower spectrum) and OVRO interferometric observations (upper spectrum) restored with the JCMT beam (22$''$). The OVRO spectrum has been scaled by a factor of 22 in order to account for all the flux seen in the JCMT spectrum.

The sources is about $\sim 800$ AU. The sources are unresolved and the fitted sizes in the $uv$-plane of MM1 and MM2 provide upper limits to the sizes of these disks of $\sim 250$ AU in diameter. The total fluxes estimated for the compact components MM1 and MM2 are 0.7 Jy and 1.1 Jy, respectively. The remaining 1.7 Jy of emission is attributed to the contribution from an extended circumbinary envelope. Assuming the emission to be optically thin and adopting a dust temperature of 40 K sets lower limits to the masses of 0.25 and 0.4 M$_\odot$, respectively.

Schöier et al. (2002) determined the circumstellar structure of IRAS 16293–2422 from detailed modelling of the observed continuum emission. In addition to the SED, resolved images at 450 and 850 $\mu$m obtained with the SCUBA bolometer array at the JCMT were used to constrain the large scale envelope structure. In order to investigate if the brightness distribution at 1.37 mm from the envelope model is consistent with the flux picked up by the interferometer, the same $uv$ sampling was applied to the model output. Furthermore, the interferometer data constrain the envelope structure at smaller scales ($\sim 1''$) than the JCMT single-dish data ($\sim 10''$). In Fig. 2 the visibility amplitudes of the observed emission are compared to the model predictions. Fitting just two compact sources underestimates the flux at small baselines, indicating additional large scale emission. Addition of
the best fit envelope model of Schöier et al. (2002) produces the correct amount of flux at the smaller baselines but provides too much emission at intermediate baselines (∼ 5′′), i.e., at scales of the binary separation. It is found that an envelope model that is void of material on scales smaller than the binary separation best reproduces the observed visibilities. The emission from the two unresolved components, possibly accretion disks, is estimated to contribute ∼ 25% to the total flux at 1.37 mm.

3.2. Molecular line emission

The observed H$_2$CO (3$_{22}$ → 2$_{21}$ and 3$_{03}$ → 2$_{02}$) line emission obtained at OVRO is shown in Fig. 1. The emission is clearly resolved and shows a ∼ 6′′ separation between the red (4−7 km s$^{-1}$) and blue (1−4 km s$^{-1}$) emission peaks. The direction of the red-blue asymmetry is roughly perpendicular to the large scale CO outflow associated with MM1 (Walker et al. 1988) and is indicative of an overall rotation of the material encompassing both MM1 and MM2. The emission from both lines peaks close to the positions of MM1 and MM2. The (3$_{22}$ → 2$_{21}$)/(3$_{03}$ → 2$_{02}$) line ratio is sensitive to the temperature of the emitting gas (e.g., van Dishoeck et al. 1995), and is > 0.4 close to the positions of MM1 and MM2 indicating hot (> 100 K) gas. Single-dish observations (van Dishoeck et al. 1995; Schöier et al. 2003, in prep.) show that the H$_2$CO line emission is extended to scales of ∼ 30′′. Also, the large scale (3$_{22}$ → 2$_{21}$)/(3$_{03}$ → 2$_{02}$) line ratio is ∼ 0.25, much lower than for the interferometer data, suggesting that a cold (< 50 K) component dominates the single-dish flux.

Care has to be taken when interpreting the interferometer maps due to the low sensitivity to weak large scale emission. A direct comparison between the single-dish flux, suggesting that the extended cold material is resolved out by the interferometer and that a hotter compact component is predominantly picked up. This is to be expected from the ‘jump models’ introduced by Schöier et al. (2002) where a steep gradient in abundance needed to be introduced, for a number of molecular species including H$_2$CO, in order to model emission lines probing a wide range of excitation conditions. Simulations where the $uv$ sampling from the observations has been applied to the best fit H$_2$CO models from Schöier et al. (2002) with and without a jump in the abundance show that the ‘hot core’ component dominates the flux as seen by the interferometer (> 50%).

4. Summary and outlook

Interferometric continuum observations suggest that the inner parts of the circumbinary envelope around IRAS 16293–2422 is relatively void of material on scales smaller than the binary separation (∼ 5′′). The simultaneous H$_2$CO line observations indicate presence of hot and dense gas close to the peak positions of the continuum emission consistent with thermal evaporation of ices in ‘hot core’ regions close to the protostars. Based on the morphology and line widths little of the observed interferometric emission is thought to be associated with the known outflow(s) associated with this source.

Additional interferometric data have been obtained for IRAS 16293–2422 in a wide range of lines including C$^{18}$O, CH$_3$OH, HCN, N$_2$H$^+$ and SiO, that will provide additional constraints on the physical and chemical structure in the circumstellar envelope. Whatever their precise origin, the molecules located in the inner envelope of IRAS 16293–2422 can be incorporated into the growing circumstellar disk(s) and become part of the material from which planetary bodies are formed.

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