NGC 7538 S - a High-Mass Protostar with a Rotating Disk.

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We present new 1.4 mm imaging with the BIMA[3] array of the high mass protostar NGC 7538 S in continuum and several molecular transitions. We resolve the continuum emission at 1.4 mm into an elliptical source with a size of $\sim 8'' \times 3''$ centered on the OH/H_2O maser position. Both DCN and the dust continuum show the elliptical dust disk as well as fainter, more extended emission from the surrounding cloud core. The DCN J = 3 → 2 maps confirm the velocity gradient seen in $H^{13}CN$ J = 1 → 0 and show an even larger velocity gradient than seen $H^{13}CN$, although near the center of the accretion disk some of the emission appears to originate from the outflow. ^{13}CO J = 2 → 1 is heavily self absorbed at the cloud velocity, but the line wings show the outflow with a similar extent to that seen in HCO^+ J = 1 → 0. CH_3CN J = 11 → 10 shows a more centrally condensed ($\leq 5''$) and hotter source coinciding with the center of the accretion disk. The emitting region for CH_3CN gets progressively smaller for higher K transitions, which shows that the temperature increases towards the center of the accretion disk. The mass of the continuum "disk" is $\sim 85\ M_\odot$ and the luminosity is $\sim 10^4\ L_\odot$ at an assumed distance of 2.8 kpc, while the enclosed mass estimated from DCN gives $\sim 80\ M_\odot$.

1 Introduction

We still know very little about high–mass protostars. It is assumed that high–mass protostars are surrounded by accretion disks and that they drive molecular outflows, similarly to those seen in low mass protostars. However, since high-mass stars evolve much more rapidly than low–mass stars, there are hardly any examples of true high-mass protostars. Many high–mass stars power outflows [1], but whether they also have accretion disks is less clear. High-mass star forming regions are more distant and high-mass stars generally form in clusters or small groups making it difficult to isolate and map disks around high–mass protostars, because of confusion and poor spatial

[3] The BIMA array is operated by the Universities of California (Berkeley), Illinois, and Maryland with support from the National Science Foundation.

resolution. Although there are now more than 30 low-mass Class 0 sources (i.e. true protostars), there are only a few high-mass protostellar candidates that appear to share the same characteristics as their low mass counterparts. Molinari et al. [2] identified IRAS 23385 + 6053 as a high–mass Class 0 object driving a molecular outflow, but this protostar is at a distance of 4.9 kpc. They did not have enough resolution to confirm a rotating disk. IRAS 20126 + 4104 [3] has been the best example of a young high-mass (proto)star driving an outflow and being surrounded by a rotating disk. Recently, however, Sandell and Sievers [4] identified NGC 7538 S as a high–mass protostar. Follow up observations by Sandell et al. [5] showed that it drives a compact bipolar outflow and that it has a rotating massive disk orthogonal to the outflow. In this paper we present new BIMA observations on this massive protostellar disk and the dense cloud that surrounds it.

2 Background

The molecular cloud southwest of the H II region NGC 7538 is a well known site of high-mass star formation [6]. However, the OH and H_2O maser source 80″ south of IRS 1, NGC 7538 S, is even younger and more extreme than any of the other known high–mass (proto)stars in this region. It is very deeply embedded in a cold massive cloud core and is undetected in the NIR and MIR. It has only weak free-free emission, which appears to originate in an ionized jet. Sandell et al. [5] observed NGC 7538 S with the BIMA array at 3 mm and show that this source is a high mass protostar, which powers a luminous young ($\leq$ 2,000 yr) bipolar outflow. Imaging in the optically thin $H^{13}CN$ J $= 1 \rightarrow 0$ line shows that the maser source is surrounded by a rotating disk seen nearly edge on and perpendicular to the outflow. The symmetry axis of the outflow is centered on the OH/H_2O maser and the dynamical center of the disk. The rotation curve derived from the $H^{13}CN$ map gives an enclosed mass for the disk of $\sim 40\ M_\odot$, while line and continuum observations predict a mass of $\geq 80\ M_\odot$. The surrounding cloud core has a mass of $\sim 1000\ M_\odot$ within a radius of 0.15 pc.

3 New Results

During the 2002/2003 winter season we observed NGC 7538 S at 1 mm with two frequency settings. One targeting H_2CO $3_{2,2} \rightarrow 2_{2,1}$ and $3_{0,3} \rightarrow 2_{0,2}$ and including SO $5_5 \rightarrow 4_4$; the other one primarily DCN J $= 3 \rightarrow 2$ and CH_3CN J $= 12 \rightarrow 11$ (K = 0 to 5), but also including ^{13}CO J $= 3 \rightarrow 2$. Both frequency settings had line–free bands for getting a good continuum map of the protostellar disk. Fig. 1 shows selected spectra towards the center of the protostar. Most, if not all of the observed molecules show some high velocity blue–shifted emission towards the center and in the vicinity of the ionized jet. Emission in H_2CO $3_{0,3} \rightarrow 2_{0,2}$ and DCN are dominated by the disk and both molecules show that the disk is rotating with a Keplerian–like rotation curve. The deep DCN image shows an even larger velocity gradient than Sandell et al. [5] measured in $H^{13}CN$ J = 1 → 0. If one assumes that the gas is still gravitationally bound, the rotation curve measured from DCN gives an enclosed mass of ~ 80 $M_\odot$, which is in good agreement with the mass derived from optically thin molecules assuming standard abundances. CH_3CN J = 11 → 10 shows a more centrally condensed ($\leq 5''$) and hotter source ($T_k > 100$ K) coinciding with the center of the accretion disk. The emitting region for CH_3CN gets progressively smaller for higher K transitions, which shows that the temperature increases towards the center of the accretion disk. CH_3CN also shows a striking blue wing (see e.g. Fig 1), which becomes more dominant at high K transitions, suggesting that the high velocity gas is very hot near the center of the accretion disk.

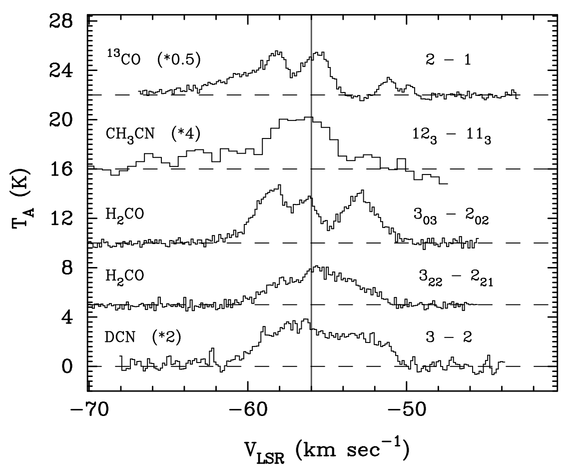

Fig. 1. Selected 1.4 mm spectra towards the center of the protostellar disk. Note the strong self-absorption in H_2CO $3_{03} \rightarrow 2_{02}$ and ^{13}CO J = 1 → 0, suggesting infall. Most lines show some blue–shifted high velocity gas. All spectra except H_2CO have been scaled; the scaling factor is given in parenthesis.

Continuum observations at 220 GHz (Fig 2) with $\sim 3.5''$ resolution show not only the disk, but also the cold surrounding cloud core and looks almost identical to the integrated DCN map. A two component Gaussian fit gives a size of $7.6'' \times 2.8''$ at a position angle (p.a.) of 57° and a total flux density of 0.8 Jy.

Assuming Hildebrand [7] dust opacity, a dust emissivity of 1.5, a gas–to–dust ratio of 100 and a dust temperature of 35 K gives a total disk mass of ~ 85 $M_\odot$, in good agreement with the mass derived from molecular lines and with the dynamical mass. A Gaussian fit to the integrated DCN emission

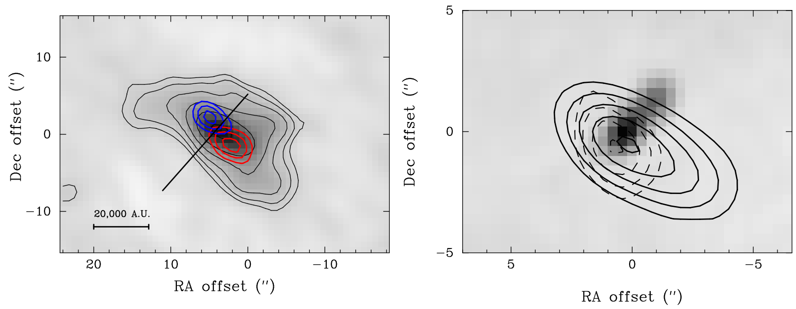

Fig. 2. left: Greyscale image of the 1.4 mm continuum map overlaid with contours; the position of the protostar is at +3.7″, +0.5″. The overlaid grey contours show the blue– (northeast) and red–shifted (southwest) emission of DCN ±2 km s^{-1} from the systemic velocity of the disk and integrated over 1 km s^{-1}. The symmetry axis and extent of the outflow is indicated by the solid line. **right:** A close up view of the continuum disk centered at 0″, 0″, with the emission from the surrounding cloud suppressed. The continuum disk is plotted with linear contours and overlaid on a 6 cm VLA grey scale map showing an ionized jet emerging from the protostar. The dotted contours show the extent of the CH_3CN K=3 emission.

gives a nearly identical size (8.5″ × 3.4″ at a p.a. of 51°). Although the disk does not appear perfectly symmetric around the dynamical center of the disk (Fig 2), we have not found any evidence for more than one active star formation center in the NGC 7538 S cloud core. The DCN map shows a secondary peak 6″ to the northwest of the protostar (at $V_{lsr} \sim -59$ km s^{-1}), which is also evident in the continuum map. However, whether this is a separate protostellar condensation or due to interaction with the blue–shifted outflow is still unclear.

All our observations show that this is an extremely massive young rotating disk, which is in the process of forming one or several high–mass stars. Such a disk cannot be stable, but is probably supported by the high pressure from the dense cloud core surrounding it.

References

1. H. Beuther, P. Schilke, T. K. Sridharan et al: Astron. Astrophys. **383**, 892 (2002)
2. S. Molinari, L. Testi, J. Brand et al: Astrophys. J. **505**, L39 (1998)
3. Q. Zhang, T. R. Hunter, T. K. Shridharan: Astrophys. J. **505**, L151 (1998)
4. G. Sandell, A. Sievers: Astrophys. J., in press (2004)
5. G. Sandell, M. Wright, J. R. Forster: Astrophys. J. **590**, L45 (2003)
6. M. Werner, et al: Mon. Not. R. Astron. Soc. **50**, 101, (1978)
7. R. Hildebrand: J. Roy. Astron. Soc. **24**, 267 (1983)