Disks are common around high-mass protostars

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Abstract

We present high-resolution K-band polarimetric images of several massive young stellar objects, whose masses exceed 10 solar masses. The polarization vectors around these sources are nearly centro-symmetric, indicating they are dominating the illumination of each field. Three out of the four sources show elongated low-polarization structures passing through the centers, suggesting the presence of polarization disks. The structures and the reflection nebulae make up bipolar outflow/disk systems, supporting the scenario that massive stars are also formed via initial gravitational collapse and subsequent mass accretion from their circumstellar disks. In particular, S140 IRS1 show well defined outflow cavity walls and, a polarization disk which matches the previously observed disk wind, thus confirming the polarization disk is actually the circumstellar disk. Taking previously found polarization disk into consideration, we find disk occurrence around massive protostars is quite frequent. The high detection rate of the disks strongly suggests that disks are common features around massive protostellar objects, and the mass accretion scenario may be valid at least to most of the massive stars in the Galaxy.

1. Introduction

With the wide availability of high resolution observations, the presence of disks around massive young stellar objects (MYSOs) has become a hot topic recently. The reason for this, is the dispute about the way massive stars are formed. That massive stars are formed in a scaled-up version of low-mass stars (Shu, Adams, & Lizano 1987) would be a natural thought. However, theoretical considerations suggest that, if the mass of the central star exceeds 8 $M_\odot$, the mass inflowing to the star will be halted due to the tremendous radiation pressure from the central star. This will finally reverse the mass inflow and keep the central star from growing (Kahn 1974). Such a consideration leads to an entirely different mechanism, i.e., massive stars are formed through mergers of lower-mass protostars (Bonnell, Bate & Zinnecker 1998). Recent studies show that a circumstellar disk and outflow may play a role more important than previously thought. In addition to transferring excessive angular momentum outward, a disk/outflow system can also redirect the tremendous radiation from the central protostar to escape via the outflow cavity, thus greatly minimizing effects of the radiation pressure (e.g., Krumholz, McKee, & Klein 2005).

Disks around MYSOs have been detected over a wide range of wavelengths with different tracers (Patel et al. 2005; Jiang et al. 2005; Cesaroni et al. 2006; Beltran et al. 2006). These results suggest that up to early B type stars **can** be formed through a similar route as solar type stars. It is still unclear whether all stars in this mass range are actually formed in this way. Here we report several circumstellar disks or toroid structures around massive protostars by high-resolution near-infrared polarimetric imaging observations, strongly suggesting that disks are a common feature associated with early B-type stars, and they may share a common formation process with their low-mass counterparts.

2. Results and discussions

The main results are presented in Fig. 1. A common feature is immediately noticed from inspection of the polarization vectors (left panels) for each field. In most of the fields, the polarization vectors are facing towards the center, forming centro-symmetric patterns, suggesting the MYSOs being studied are dominating the illumination of some or all of the fields. However, details of the polarization morphology are different from region to region, and are described below.

S140 IRS1: The polarization vectors are nearly perfectly centro-symmetric (Fig. 1a, left panel), suggesting that IRS1 is dominating its surrounding area; no other sources affect the polarization. There are two low-polarization lanes passing through the central source. One is in the SW-NE direction at a position angle (p.a.) ~45 ° . In the pseudocolor image composed from intensity image and polarized flux image (Fig. 1a, right panel), two blue, parabolically curved features, separated by this lane, presumably representing reflection nebulosities, are seen opening towards the SE and NW, respectively. These two reflection nebulosities should be the outflow cavity walls. The wall profile to the NW is more clearly observable. The morphologies of the walls indicate that the opening angle is rather large (~150 °), consistent with the poor outflow collimation ratio observed previously (Hayashi et al. 1987). The low-polarization lane in the southwest-northeast direction, therefore, represents a circumstellar disk. Hoare (2006) observed S140 IRS1 at high resolution in the centimeter continuum band, and found an elongated structure, which is interpreted as an ionized equatorial disk wind. An over-plot of the ionized disk wind on the pseudocolor image shows that it matches the polarization disk very well (Fig. 1a, right panel). This strongly suggests that the polarization disk is actually a circumstellar disk. The linear size of the polarization disk is rather large (2700 AU), implying the dusty disk is more extended than the ionized disk wind.

S255 IRS1: A bipolar nebula is located around S255 IRS1 (Fig. 1b, right panel) at p.a. ~35 ° . High degrees of polarization (up to ~30%) in the nebula indicate that it should be a reflection nebula illuminated by the central source, IRS1, as illustrated by the polarization vectors (Fig. 1b, left panel). In the SW part of the nebula there could be some contaminations the outflow from IRS3 (seen in the eastern edge of the field) may overlap (Tamura et al. 1991). In spite of this, the morphology of the bipolar nebula suggests a collimated outflow from IRS1 with a small opening angle (~50 °). Once more, a biconical low-polarization lane runs through IRS1, roughly perpendicular to the axis of the reflection nebula at p.a. ~110 ° , with a linear size of ~5700 AU. The polarization vectors in the lane are roughly parallel to the lane. Again, this lane should be the circumstellar disk of IRS1.

NGC7538 IRS1: Reflection nebulosities are seen to the northwest and northeast of IRS1, but rather faint to the southeast (Fig. 1c, right panel). The polarization pattern of these nebulosities is generally centro-symmetric with respect to IRS1 (Fig. 1c, left panel), indicating that they are illuminated by the IRS1. There is no significant polarization disk detected. From radio observations Gaume et al. (1995) suggest a south-north outflow from IRS1. The reflection nebulosities to the northwest and northeast are therefore likely to be the cavity walls of the blue-shifted outflow. Previous observations show the redshifted lobe is spatially coincident with the blue-shifted one which extends to the northwest. This would explain why we do not clearly see the southern counterpart of the reflection nebulosity. From the methanol maser observation,

IRAS 23033+5951: This is the most complicated region of the four. In the color image (Fig. 1d, right panel), a conical nebulosity is seen, opening to the east. Several peaks are detected in the K-band. However, only the one that is marked by a plus (S1) is point-like. To the east of S1, two other major peaks are detected. That they are not point-like and they have high polarizations suggests they are infrared reflection nebulosities (IRN). The polarization vectors indicate these nebulae are illuminated by S1. Again, we see a low-polarization lane, which is more clearly seen in the polarization degree image (Fig 1d, left panel), running roughly south-north (p.a. ~160 °) and passing through the center of S1; the polarization vectors are generally aligned with the direction of the lane. As discussed above, this lane indicates the presence of a disk or a toroid. The size of this structure is about 6700 AU.

Of the four sources, three (S140 IRS1, S255 IRS1 and I23033) show strong evidence for the presence of a disk or toroid. All of the sources are deeply embedded in their natal clouds (A_V > 15 for IRAS23033+5951, >20 for S255 IRS1 and >30 for S140 and NGC7538). Taking the BN object (Jiang et al. 2005) into consideration, at least 4/5 of our targets have circumstellar disks/toroids. Such a high detection rate suggests that circumstellar disks are frequently, if not ubiquitously, associated with MYSOs. It is interesting to note that the sizes of the disks tend to increase with the masses of their host star. We conclude that a majority of massive stars, at least those at the lower-mass part of massive stars (10-30 $M_\odot$), are formed through a similar way to low-mass stars, rather than by the merging of a cluster of low-mass young stellar objects.

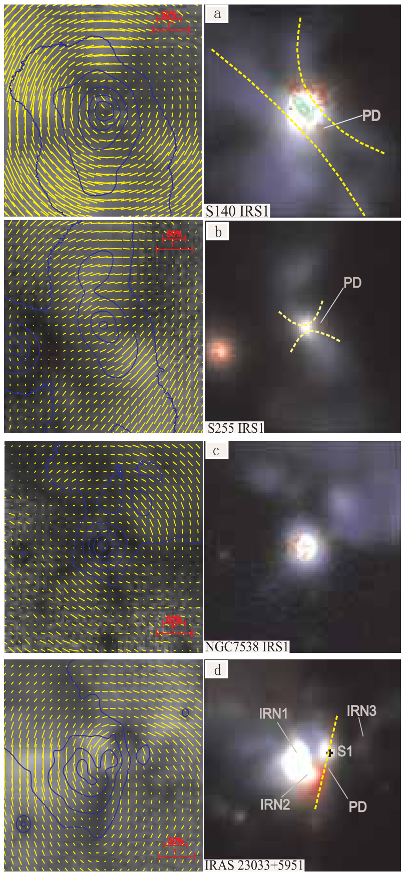

Fig. 1.| (left panels) Polarization degree images of the targets, S140 IRS1, S255 IRS1, NGC7538 IRS1, and IRAS 23033+5951, overlaid by polarization vectors (yellow dashes) and brightness contour (blue curves). The angular and polarization scales are shown in the corners. The contours start from 19.32, 22.95, 19.73, and 20.81 mag pixel^{-1}, respectively, and decrease every 1.25 mag pixel^{-1}. (right panels) Pseudo-color images of these fields, composed of pure brightness images (red) and polarized brightness images (blue). A blue feature indicates the highly polarized nebulosity, which should be reflective. Red features are low polarization areas. The polarization disk (PD) is indicated with double lines to delineate the edge of the disks (S140 IRS1 and S255 IRS2), or a single line to indicate the position (IRAS23033+5951). For S140 IRS1, The contours of 5 GHz continuum emission are superimposed (Hoare 2006) on the color image to illustrate the coincidence between the polarization disk (red lane) and the ionized disk wind. North is up and east is to the left for all panels.

3. Conclusion

We present K-band polarimetric images of four MYSOs. Of the four targets, three show evidence of polarization disks. The high detection rate suggest the occurence of the disks / toriods around MYSOs is rather frequent, which further suggests the massive stars, at least those in the lower part of the massive regime, are formed in a similar process as their lower-mass brothers.

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