Outflows from the young high-mass star NGC 7538 IRS1 revealed by near-infrared Bispectrum Speckle Interferometry

S. Kraus[(1)], K.-H. Hofmann[(1)], Th. Preibisch[(1)], D. Schertl[(1)], G. Weigelt[(1)]
M. Elitzur[(2)], M. R. Pestalozzi[(3)], M. Meyer[(4)], E. T. Young[(4)]

(1) Max-Planck-Institut für Radioastronomie, Bonn, Germany
(2) Dept. of Physics & Astronomy, Univ. of Kentucky, Lexington, USA
(3) School of Physics, Univ. of Herfordshire, Hatfield, UK
(4) Steward Observatory, Univ. of Arizona, Tucson, USA

MPIfR

MAX-PLANCK-GESELLSCHAFT

Abstract

Bispectrum speckle interferometry of the massive protostellar object NGC 7538 IRS1 is presented. Our observations were carried out in the near-infrared K'-band using two 6-meter-class telescopes, namely the SAO and the MMT. The recorded speckle interferograms were used to reconstruct high-dynamic range images showing a fan-shaped structure in which several stars and blobs of diffuse emission are embedded.

IRS1 is a massive (30 $M_\odot$) protostar which is associated with an ultracompact (UC) H II region and a CO outflow. Remarkably, at the position of IRS1, a group of linear-aligned methanol masers has been detected, which most likely trace a Keplerian-rotating circumstellar disk (Pestalozzi et al., 2004). We find a misalignment between the outflow direction expected by the orientation of the methanol maser disk and the other outflow tracers, which we interpret in the context of a disk precession model. Taking the S-shaped morphology, that can be conceived in our K'-band images, into account, we obtain a rough estimation of 230 years for the precession period, implying non-coplanar tidal interaction of a close companion with a circumbinary protostellar disk as possible triggering mechanism.

Observations

Initial observations were performed on 2002-09-24 using the 6.0m *Special Astrophysical Observatory* (SAO) telescope located on Mt. Pastukhov in Russia. Additional data was gathered on 2004-12-20 with the 6.5m *Multiple Mirror Telescope* (MMT) on Mt. Hopkins, Arizona. Images with a resolution of 334 mas (MMT), respectively 146 mas (SAO), were reconstructed using the bispectrum speckle interferometry method (Weigelt 1977; Lohman et al. 1983).

Detected IRS1 Elongation & Outflow Structures

The IRS1 Airy disk appears asymmetric in our images, extending along P.A. $\sim$-60° beyond the first two diffraction rings (see Figure 1). We can rule out binarity of IRS1 down to the diffraction limit. Extending from IRS1, we detect a diffuse fan-shaped structure with an $\sim$90° opening angle, which we interpret as scattered light from an outflow cavity excavated by strong outflow activity from IRS1. Contributions from the H_2 2.112 μm line are also likely. Within this fan-shaped structure, 18 fainter stars and several blobs are embedded. The arrangement of the diffuse blobs might be interpreted as systematical, suggesting an S-shaped morphology.

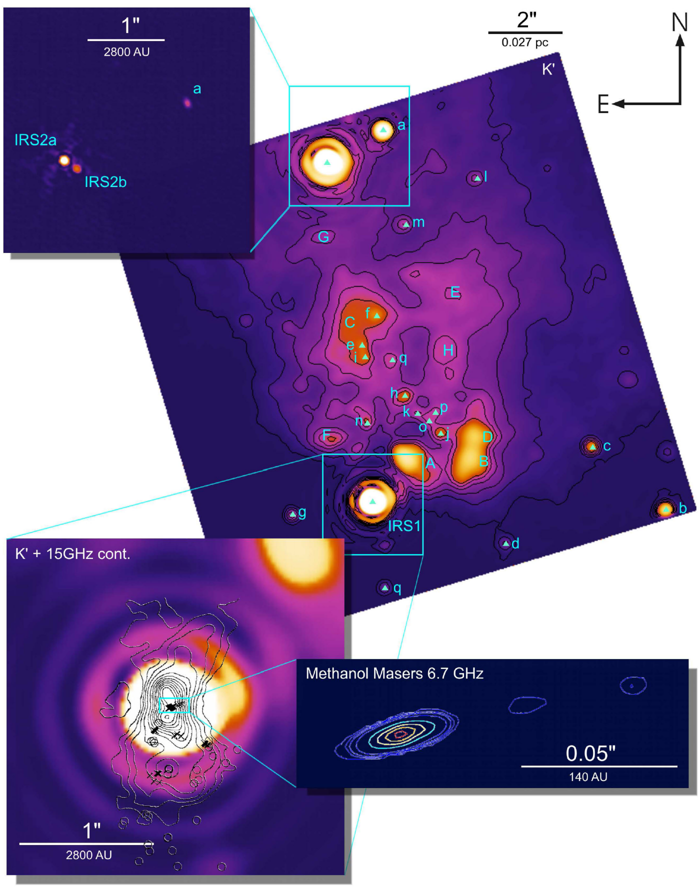

Figure 1: Speckle image reconstructed from MMT data. The inset in the upper left corner shows a diffraction-limited image (73 mas, SAO-data) of IRS2, around which we discovered a companion (separation 195 mas). In the lower left, IRS1 is shown, emphasing the elongation of the IRS1 Airy disk overplotted with the 15-GHz radio continuum and the position of the OH (circles) and methanol (crosses) masers (from Hutawarakorn, 2003). In the lower right, we show the integrated brightness of the methanol masers in order to stress the misalignment of the suspected maser disk with the outflow direction.

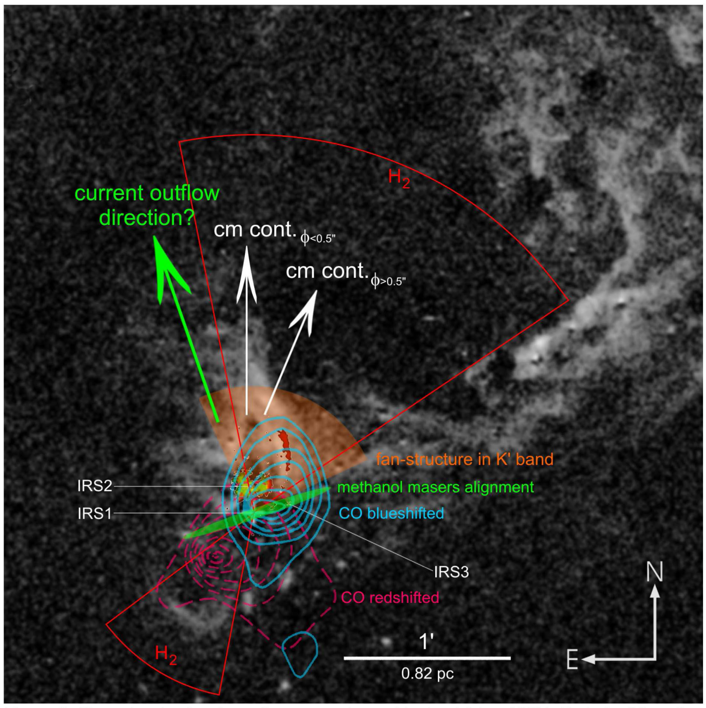

Figure 2: Illustration showing the outflow tracers detected in the vicinity of IRS1: Both the CO outflow (red/blue lobe; Kameya et al., 1989) and the H_2 emission (greyscale, Davis et al., 1998) indicate a bipolar outflow, oriented along P.A. $\sim$-50°. Close to the outflow driving source, the IRS1 UCH II region shows some bending, oriented $\sim$–20° at scales $\gtrsim$0.″5 and $\sim$0° at $\lesssim$0.″5 (white arrows). The outflow direction suggested by the orientation of maser feature A is pointing even further to the east (P.A. $\sim$+20°, green).

NGC 7538 IRS1 Maser Feature A

The massive protostar IRS1, located at a distance of $\sim$ 2.8 kpc, is associated with an UCH II region and is also the suspected driving source of a bipolar CO outflow. In 1998, Minier et al. reported the discovery of linear-aligned methanol masers at the position of IRS1 and interpreted them as an edge-on circumstellar disk. The accuracy of the alignment and the stunning precision with which the position-velocity diagram of these masers could be modelled makes the maser feature NGC 7538 IRS1-A one of the most intriguing candidates for Keplerian-rotating protostellar disks (see Pestalozzi et al., 2004 and PPV-poster). Therefore, for the following interpretation we assume that maser feature A resembles a circumstellar disk, mentioning that an alternative scenario was presented by De Buizer and Minier (2005) which suggests that the methanol masers might trace an outflow cavity.

Indications for Disk and Jet Precession

It is most remarkable that the maser disk is not orientated perpendicular to the large-scale outflow tracers (CO, outflow cavity) but misaligned by $\sim$ 60° (see Figure 2). We suggest jet precession as one possible explanation. This scenario would also explain the S-shaped morphology in our K'-band images and the bending of the UCH II region observed in the 15 GHz radio-continuum (Campbell 1984).

Possible Precession Mechanisms

Assuming an outflow velocity of 250 km s^{-1} (as reported from line profile measurements by Gaume et al., 1995), we derive a precession period of $\sim$230 years and a precession angle of $\sim$45°. These values put strict constraints on possible precession mechanisms. After considering several mechanisms, we identify tidal interaction with a companion as most plausible. The short precession period implies a non-coplanar orbit which is causing the circumbinary disk to precess and maybe to warp (Larwood et al., 1997). The orbital period of the hypothetical binary would be significantly shorter than the precession period (Bate et al., 2000), maybe of the order of tens of years, corresponding to a semimajor axis of some tens of AU for a Keplerian orbit.

Implications

Identifying the appropriate formation mechanism of massive stars, either accretion via a circumstellar disk or stellar coalescence, remains one of the major open questions in star formation. The detection of precessing outflows from massive stars might contribute a unique insight, as precessing outflows carry not only information about the accretion properties of the outflow driving source, but also about the kinematics (stellar multiplity) within its closest vicinity.

Until now, clear indications for flow precession were reported for just one massive young stellar object, namely IRAS 20126+4104 (Shepherd et al., 2000). A companion, which might cause this precession, was detected just recently at a separation of $\sim$0.″5 (850 AU, Sridharan et al., 2005). Comparing the precession properties for IRAS 20126+4104 and NGC 7538 IRS1 reveals that the precession angles are very wide in both cases ($\sim$45°) and that the period seems to be signficiantly shorter in the case of NGC 7538 IRS1 ($\sim$10^2 vs. $\sim$10^5 years).

References

Bate M.R., Bonnell I.A., Clarke C.J., et al., 2000, MNRAS 317, 773
Gaume R.A., Goss W.M., Dickel H.R., et al., 1995, ApJ 438, 776
Lohmann A.W., Weigelt G., Wirnitzer B., 1983, Appl. Opt. 22, 4028
Shepherd D.S., Yu K.C., Bally J., et al., 2000, ApJ 535, 833
De Buizer J.M., Minier V., 2005, ApJ 628, L151
Larwood J.D., Papaloizou J.C.B., 1997, MNRAS 285, 288
Sridharan T.K., Williams S.J., Fuller G.A., 2005, ApJ 631, L73
Davis C.J., Moriarty-Schieven G., Eislöffel J., et al., 1998, AJ 115, 1118
Kameya O., Hasegawa T.I., Hirano N., et al., 1989, ApJ 339, 222
Pestalozzi M.R., Elitzur M., Conway J.E., et al., 2004, ApJ 603, L113
Campbell B., 1984, ApJ 282, L27
Hutawarakorn B., Cohen R.J., 2003, MNRAS 345, 175
Minier V., Booth R.S., Conway J.E., 1998, A&A 336, L5
Weigelt G., 1977, Opt. Commun. 21, 55

Poster presented at the Protostars & Planets V conference, October 24–28, 2005
contact e-mail: skraus@mpifr-bonn.mpg.de