# Signatures of flow precession discovered around the high-mass protostar NGC 7538 IRS1 using bispectrum speckle interferometry

S. Kraus[1], Y. Balega[2], M. Elitzur[3], K.-H. Hofmann[1]
M. Meyer[4], Th. Preibisch[1], A. Rosen[1], D. Schertl[1], G. Weigelt[1] E. T. Young[4]

MPIfR

(1) Max-Planck-Institut für Radioastronomie, Bonn, Germany
(2) Special Astrophysical Observatory, Karachai-Cherkesia, Russia
(3) Dept. of Physics & Astronomy, Univ. of Kentucky, Lexington, USA
(4) Steward Observatory, Univ. of Arizona, Tucson, USA

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 6m telescope 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 discerned in our $K'$-band images, into account, we obtain a rough estimation of 280 years for the precession period, implying non-coplanar tidal interaction of a close companion with a circumbinary protostellar disk as possible triggering mechanism.

## Observations

The observations were performed using the 6m *Special Astrophysical Observatory* (SAO) telescope located on Mt. Pastukhov in Russia and the 6.5m *Multiple Mirror Telescope* (MMT) on Mt. Hopkins, Arizona. Images were reconstructed from the obtained speckle interferograms using the bispectrum speckle interferometry method (Weigelt 1977; Lohman et al. 1983).

## Detected NIR IRS1 Elongation & Outflow Structures

The IRS1 Airy disk appears asymmetric in our images, extending along P.A. ∼–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 ∼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 $\mu$m 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.

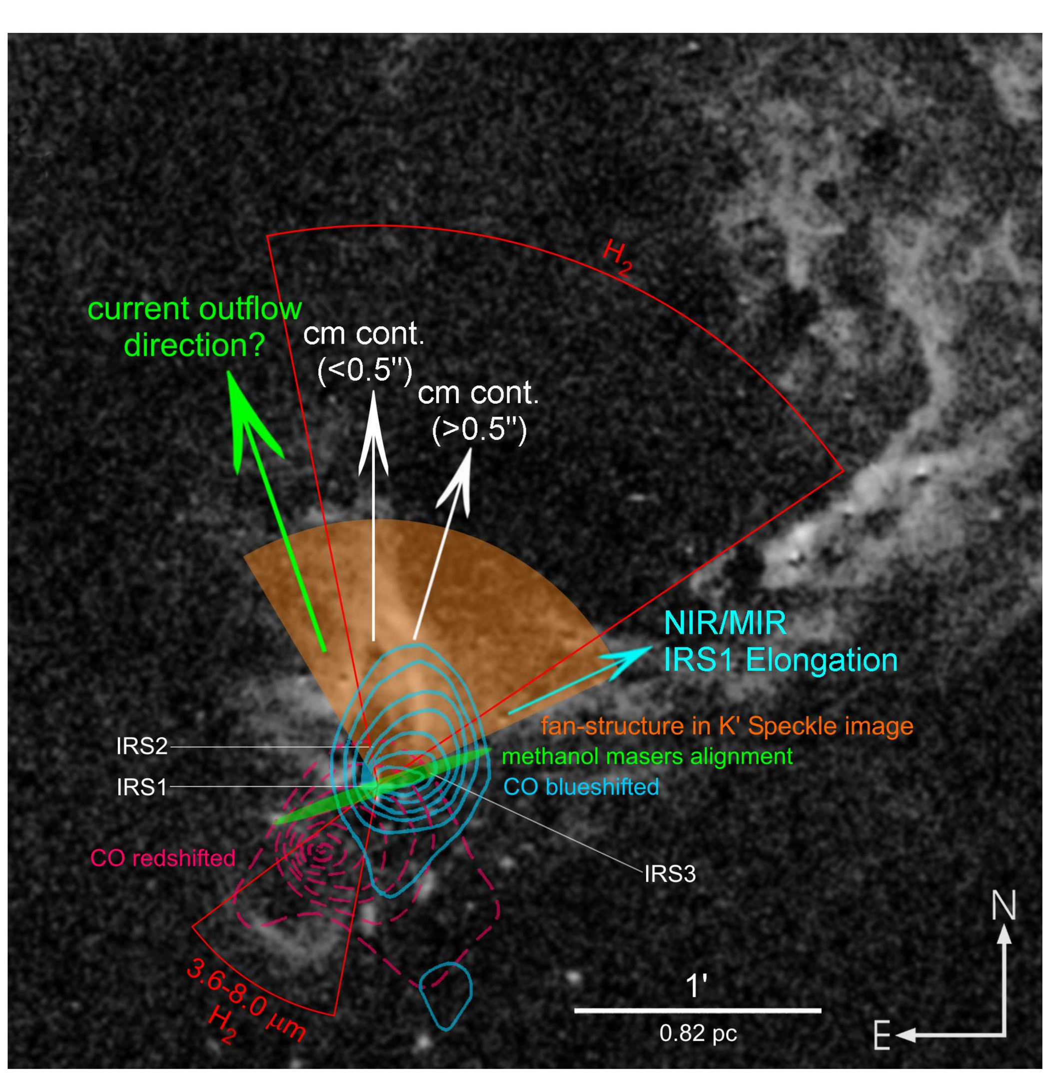


**Figure 1:** Illustration showing the outflow tracers detected in the vicinity of IRS1: Both the CO outflow (red/blue lobe; Kameya et al. 1989) and the $H_2$ emission (greyscale, Davis et al. 1998) indicate a bipolar outflow, oriented along P.A. ∼–50°. Close to the outflow driving source, the IRS1 UC H II region shows some bending, oriented ∼–20° at scales ≳0.″5 and ∼0° at ≲0.″5 (white arrows). The outflow direction suggested by the orientation of maser feature A is pointing even further to the east (P.A. ∼+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 UC H 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). Therefore 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.

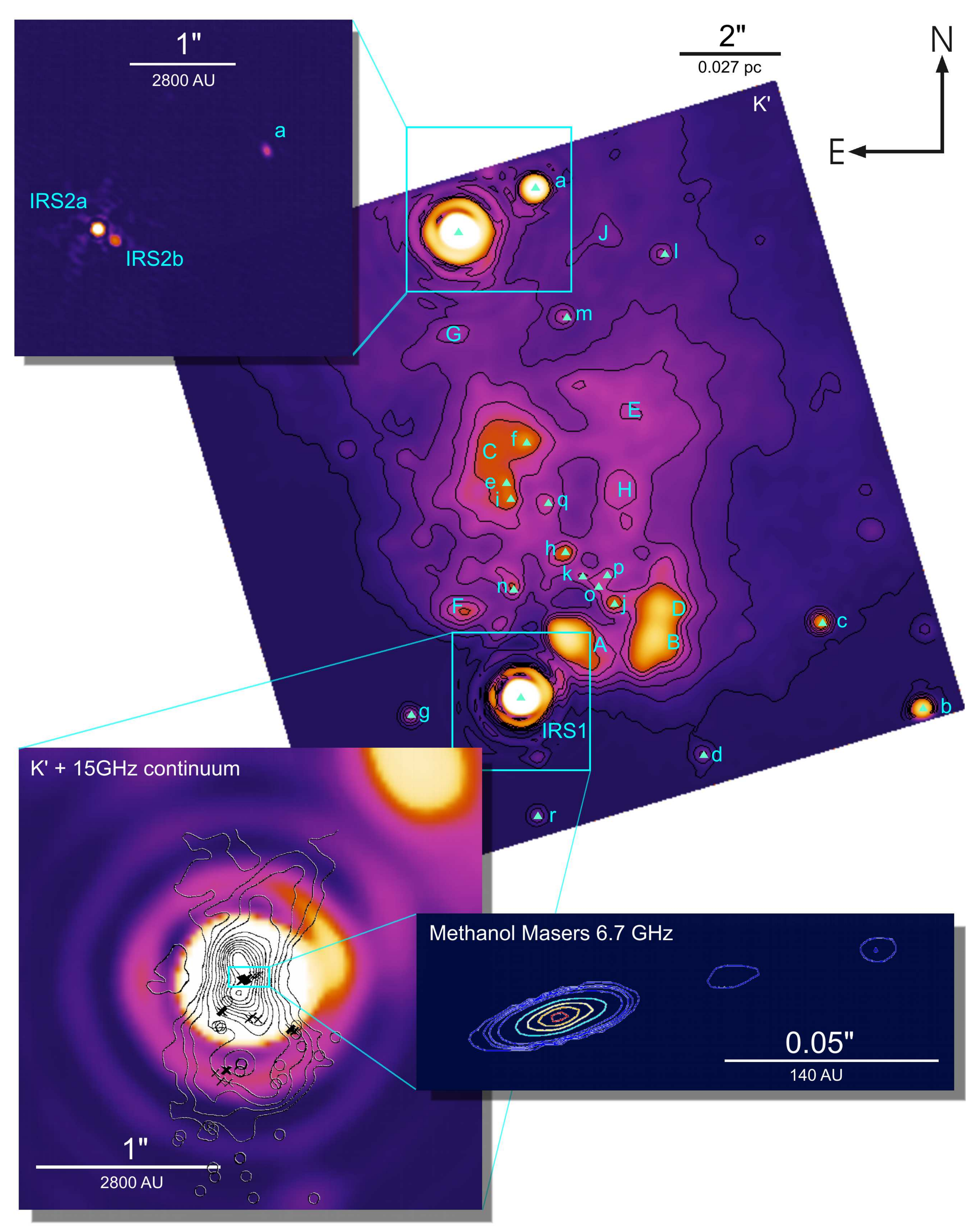


**Figure 2:** Speckle image reconstructed from MMT data with a resolution of 334 mas. The inset in the upper left corner shows a diffraction-limited image (73 mas, SAO-data) of IRS2, around which we discovered a companion (separation 195 mas). In the lower left, IRS1 is shown, emphasizing the elongation 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.

## 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, $H_2$, fan-shaped outflow cavity) but misaligned by $\sim$ 60° (see Figure 2). On scales $\lesssim 1''$, a bending ($\sim$ 25°) of the UC H II region can be conceived (Campbell 1984), which seems to continue in the S-shaped morphology in our $K'$-band images. Based on these indications for a systematic change in the outflow direction, we suggest jet precession as one possible explanation.

## Molecular Hydrodynamic Simulations

We use the version of the ZEUS-3D code as modified by Smith & Rosen (2003), which includes some molecular cooling and chemistry, as well as the ability to follow the molecular ($H_2$) fraction. The large precession envisioned for the flow associated with NGC 7538 IRS1 requires that the simulation be performed on a very wide computational grid. For the flow we have chosen a nominal speed of 150 km s$^{-1}$ and a 30° precession angle. The precession has a period of 120 years. The flow is also pulsed, with a 30% amplitude and a 30 year period. This short period assists in the reproduction of the multiple knots of $K'$-band emission near NGC 7538 IRS1. The jet flow also is sheared at the inlet, with the velocity at the jet radius 0.7 that of the jet center. We have chosen a jet number density of $10^5$ hydrogenic nuclei cm$^{-3}$, while the ambient density is $10^4$.

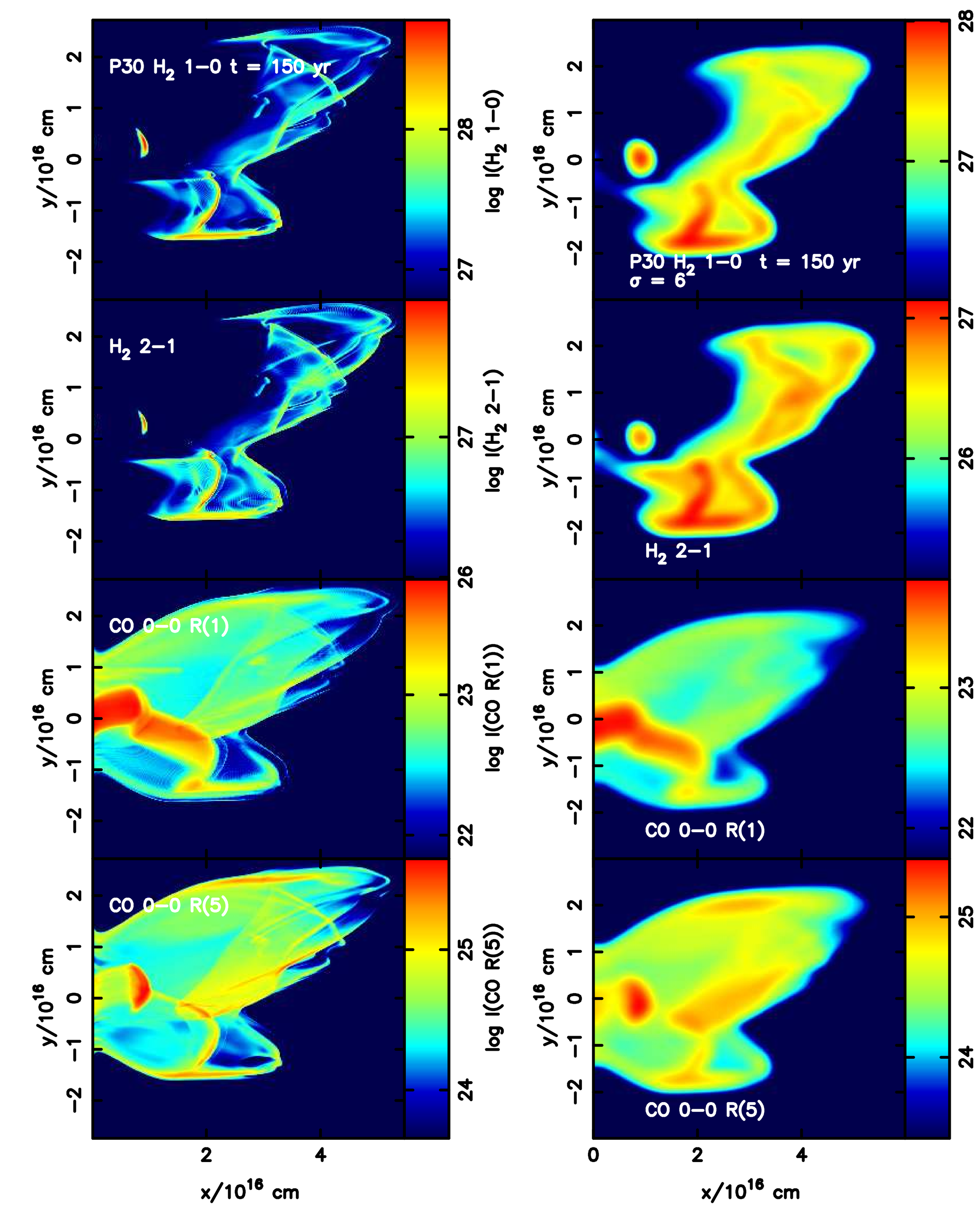


**Figure 3:** Integrated molecular emission line maps from the simulation. The images on the right are convolved with a Gaussian beam with $\sigma$=6 zones.

The time-averaged mass flux is $2.6 \times 10^{-6}$ $M_\odot$ yr$^{-1}$. Similar calculations of the momentum flux and kinetic energy flux, or mechanical luminosity, yield values of $3.8 \times 10^{-4}$ km s$^{-1}$ $M_\odot$ yr$^{-1}$ and 4.7 $L_\odot$, respectively.

## 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 ∼280 years and a precession angle of ∼40°. 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 multiplicity) 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 ∼0.″5 (850 AU, Sridharan et al. 2005). Comparing the precession properties for NGC 7538 IRS1 and IRAS 20126+4104 reveals that the precession angles are very wide in both cases (∼40°) and that the period seems to be considerably shorter in the case of NGC 7538 IRS1 (∼$10^2$ vs. ∼$10^5$ years).

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