

The ionized jet and molecular outflow from NGC 7538 IRS1

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The young heavily accreting ultra-compact HII region NGC 7538 IRS1 is known to drive a well collimated bipolar ionized jet approximately north-south. Yet most studies have reported that it drives a bipolar molecular outflow oriented from south-east (red-shifted) to north-west (blue-shifted). Precession has been suggested as an explanation of why the ionized and molecular outflows are mis-aligned. We have a large set of observations of NGC7538 IRS1 collected over several years using the single dish telescopes FCRAO, OSO, and JCMT and array observations with BIMA, CARMA, SMA and the VLA. We show that all the observed characteristics of NGC7538 IRS1 can be explained by a large (parsec scale) wide-angled outflow, which also shows some evidence for rotation.

NGC7538 IRS1

IRS1 lies in the boundary region between the large HII region NGC7538 and the dense molecular cloud south and southwest of it. The gas densities are low to the north and very high to the south.

IRS1 is very young, still heavily accreting (shows inverse P Cygni profiles in HCO+) and has the luminosity of an O7 star.

It is well established that IRS1 powers a North-South ionized jet, which dominates the radio emission up to ~ 300 GHz (Sandell et al. 2010) and the star almost certainly has an E-W accretion disk, although we have not managed to confirm it yet.

The molecular outflow, however, is believed to be south-east (red) - north-west (blue) (Scoville et al. 1986; Kameya et al 1989), or precessing (Krause et al. 2006). IRS1 is known to be surrounded by a cluster of young stars (especially to the south), which are seen as H₂O masers (Kameya et al. 1989) and/or mm-continuum sources (Qui et al. 2011) driving their own outflows. There are also several CH₃OH masers south of IRS1 confirming that there are multiple outflows in the area.

If we only look at the outflow in the vicinity of IRS1, it does look like a compact outflow from SE to NW, yet the ionized outflow is N-S. One really needs to look at the big picture! **Clue No. 1:** IRAC mid-IR images suggest a giant outflow.

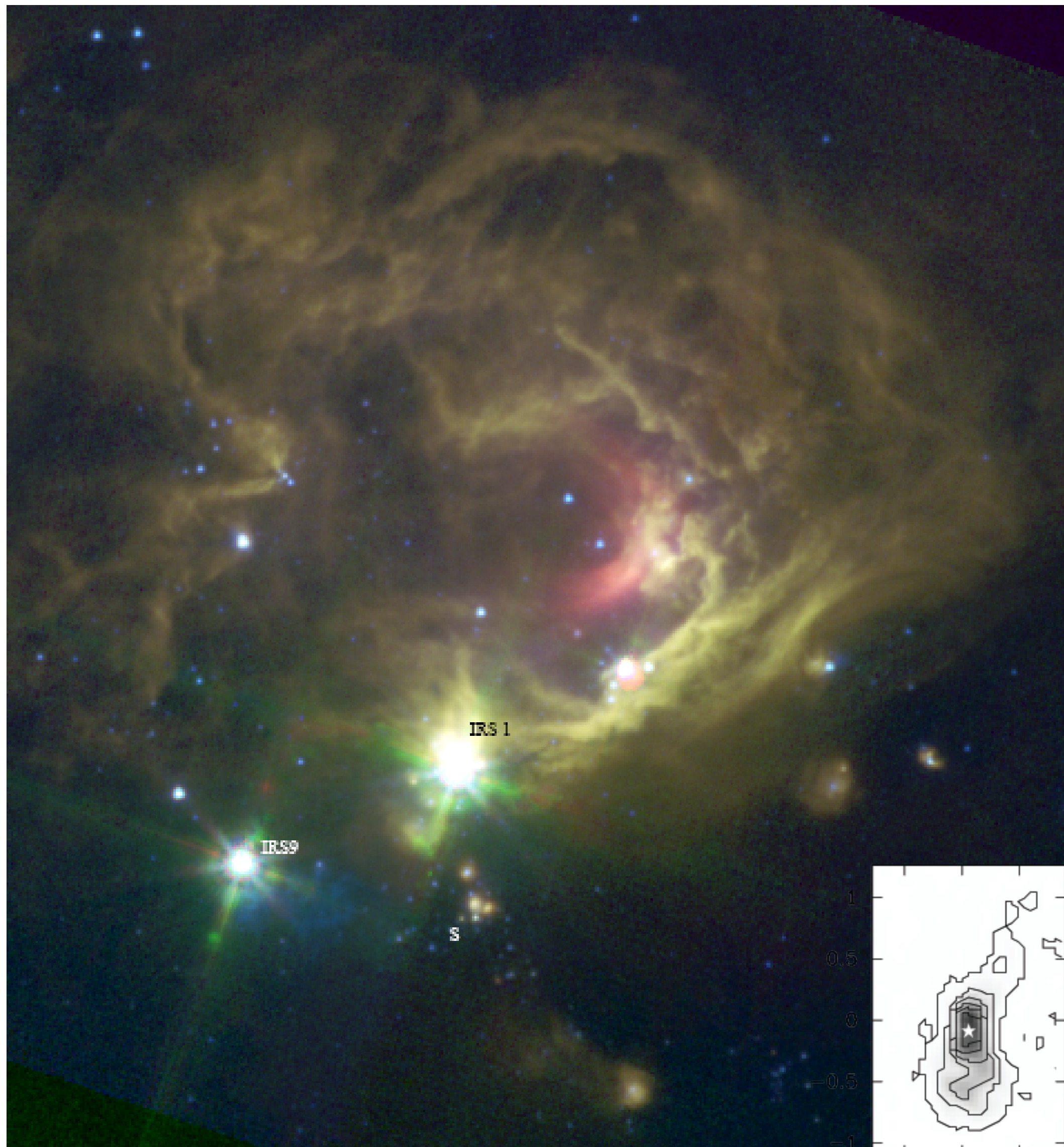


Fig 1. Spitzer color image (4.5/5.8/8 μ m) image of NGC7538. The strong PAH emission surrounding the HII region is very striking. IRS1 may power the large fan shaped outflow south of IRS1, which in the north is seen as a large cavity due to the low densities north of IRS1. The inset in the lower right shows the ionized jet from IRS1 as seen with the VLA at 14.9 GHz.

Clue No 2: Single dish JCMT CO 3-2 images (and older CO 2-1 data) show blueshifted high velocity gas extending up to ~1.5 arcmin north of IRS1, which at high velocities turns more N-S, and points back towards IRS1. There are no YSOs in that area which could drive the outflow. It has to come from IRS1.

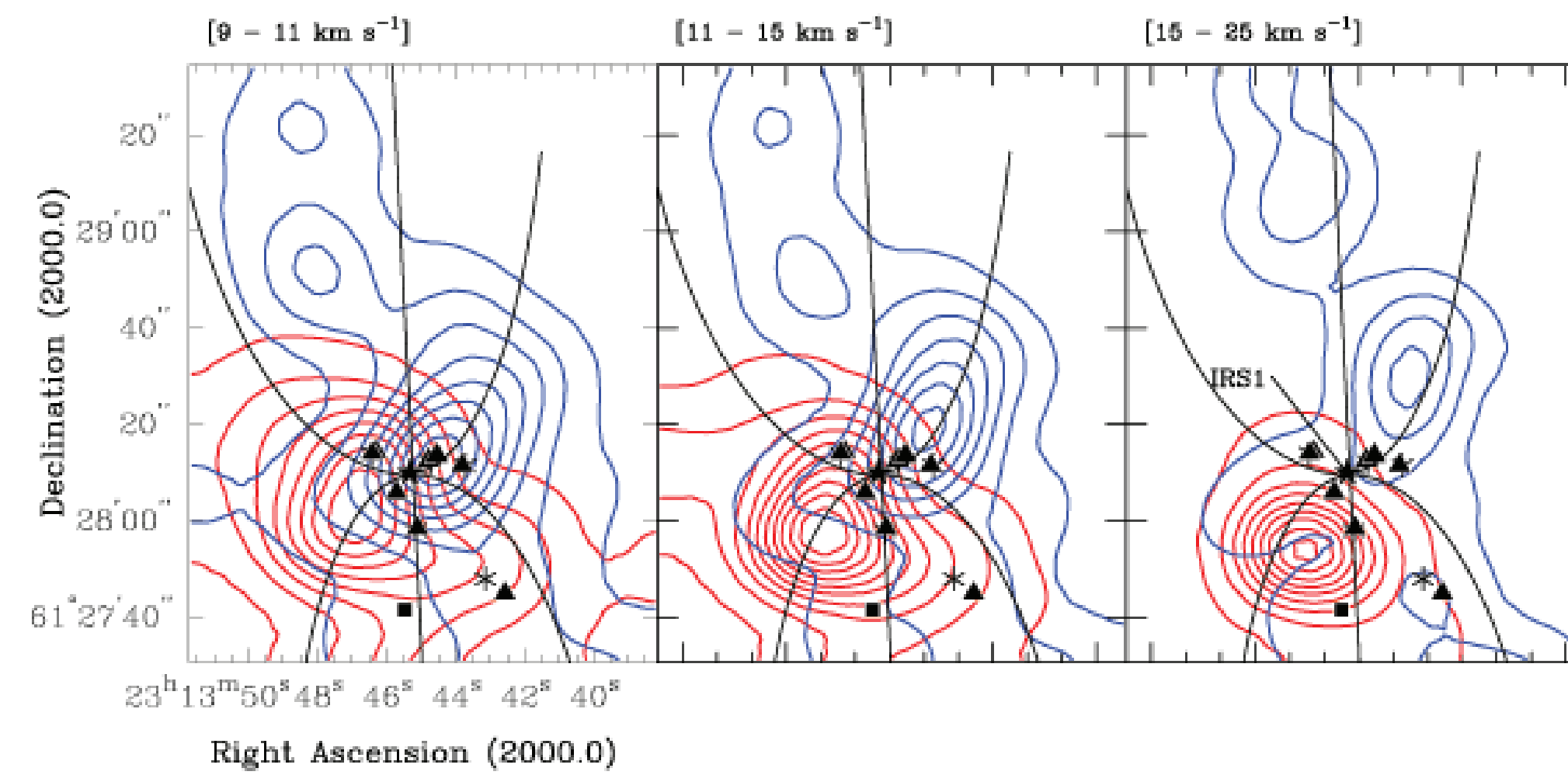


Fig 2. JCMT CO 3-2 map showing blue- and redshifted high velocity emission in three velocity intervals, low, intermediate and high. On the figure we show the perceived symmetry axis of the IRS1 flow. We also outline the approximate extent of the outflow based on CO, ¹³CO and HCO⁺ CARMA and SMA images. Triangles mark positions of H₂O masers, squares CH₃OH Class I masers, and stars mm-sources from Qui et al. (2011).

Results from CARMA and SMA imaging

HCO⁺ 1 - 0 CARMA+FCRAO image (4.5'' res) shows the IRS1 blueshifted outflow, which appears wide-angled. Part of the outflow, here assigned to sma4, could equally well be due to IRS1. How the outflow goes to the south is not clear, but from the HCO⁺ it appears blueshifted to the west of IRS1.

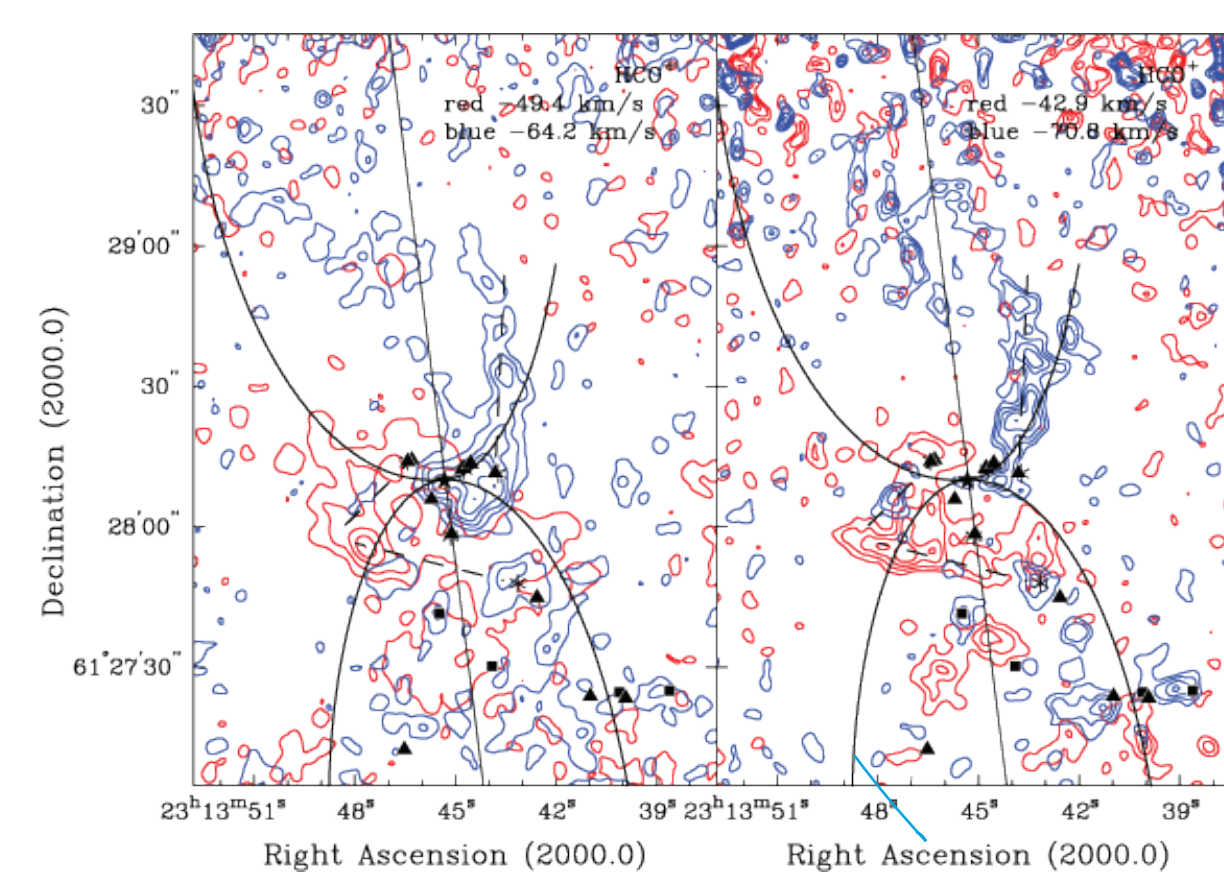


Fig 3. CARMA HCO⁺ 1-0 mosaic (5 km/s wide intervals) combined with FCRAO single dish image. The symbols are the same as in Fig. 2. Possible orientation of additional outflows is indicated.

¹³CO 1 - 0 CARMA + OSO 20 m images outline the outflow cavity walls at low velocities.

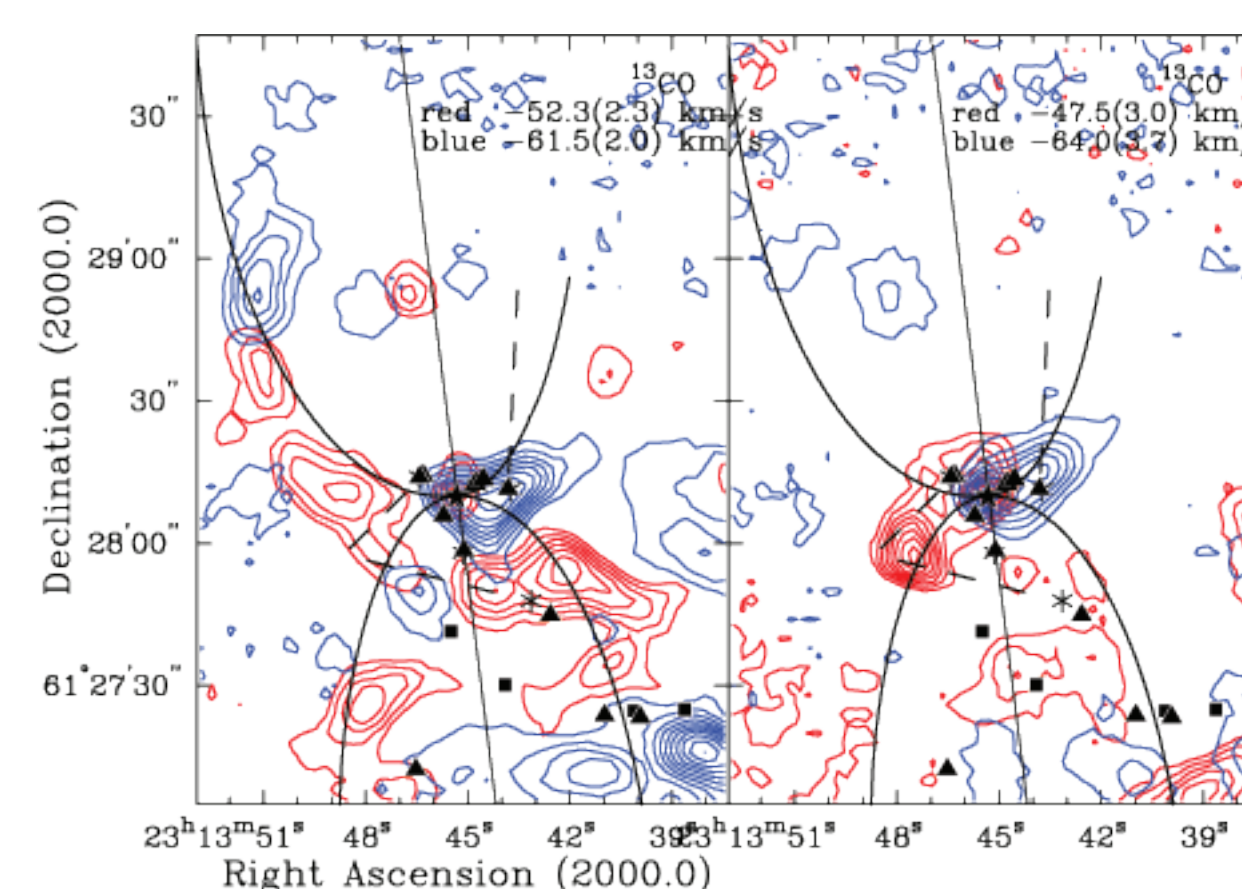


Fig 4. CARMA ¹³CO 1-0 mosaic combined with OSO 20m single dish image. Like HCO⁺, ¹³CO suggests a wide-angled outflow to the north. Low velocities suggest the outflow might be rotating.

CO 3 - 2 single pointing SMA + JCMT image shows the outflow activity near IRS 1, but does not have enough spatial coverage to show the large blueshifted outflow north of IRS 1.

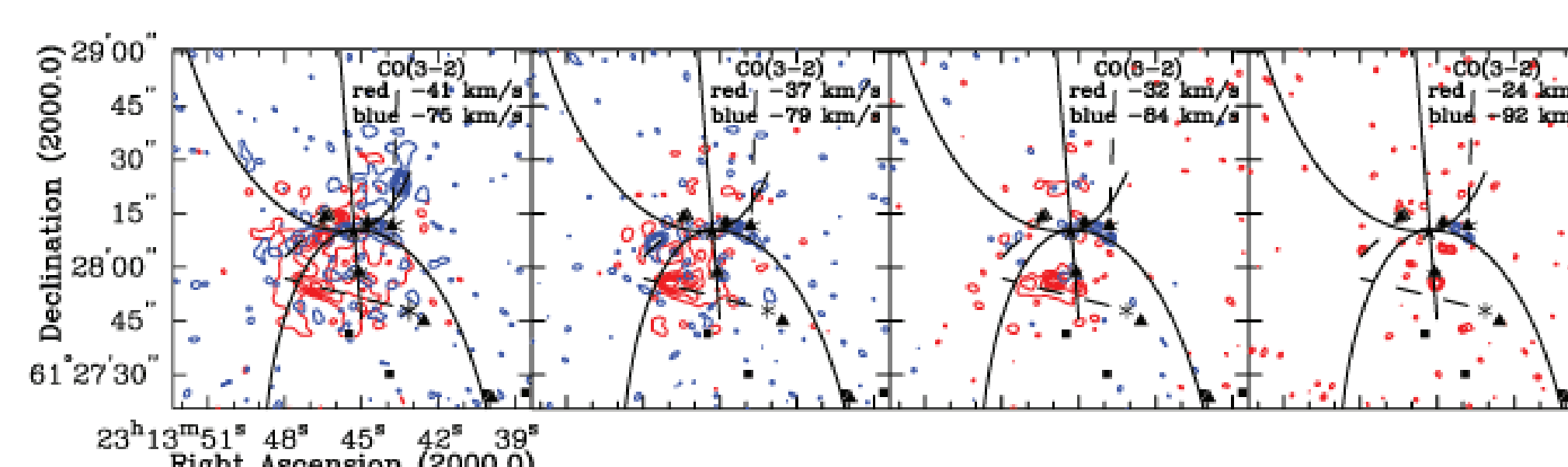


Fig 5. SMA single pointing combined with JCMT data showing the outflows at very high velocities.

A deep **CO 3 - 2** CARMA mosaic (4.5'' res.) is sensitive enough to pick up the IRS 1 outflow in the north and shows that the high velocity CO is close to the symmetry axis at high velocities; even near IRS 1.

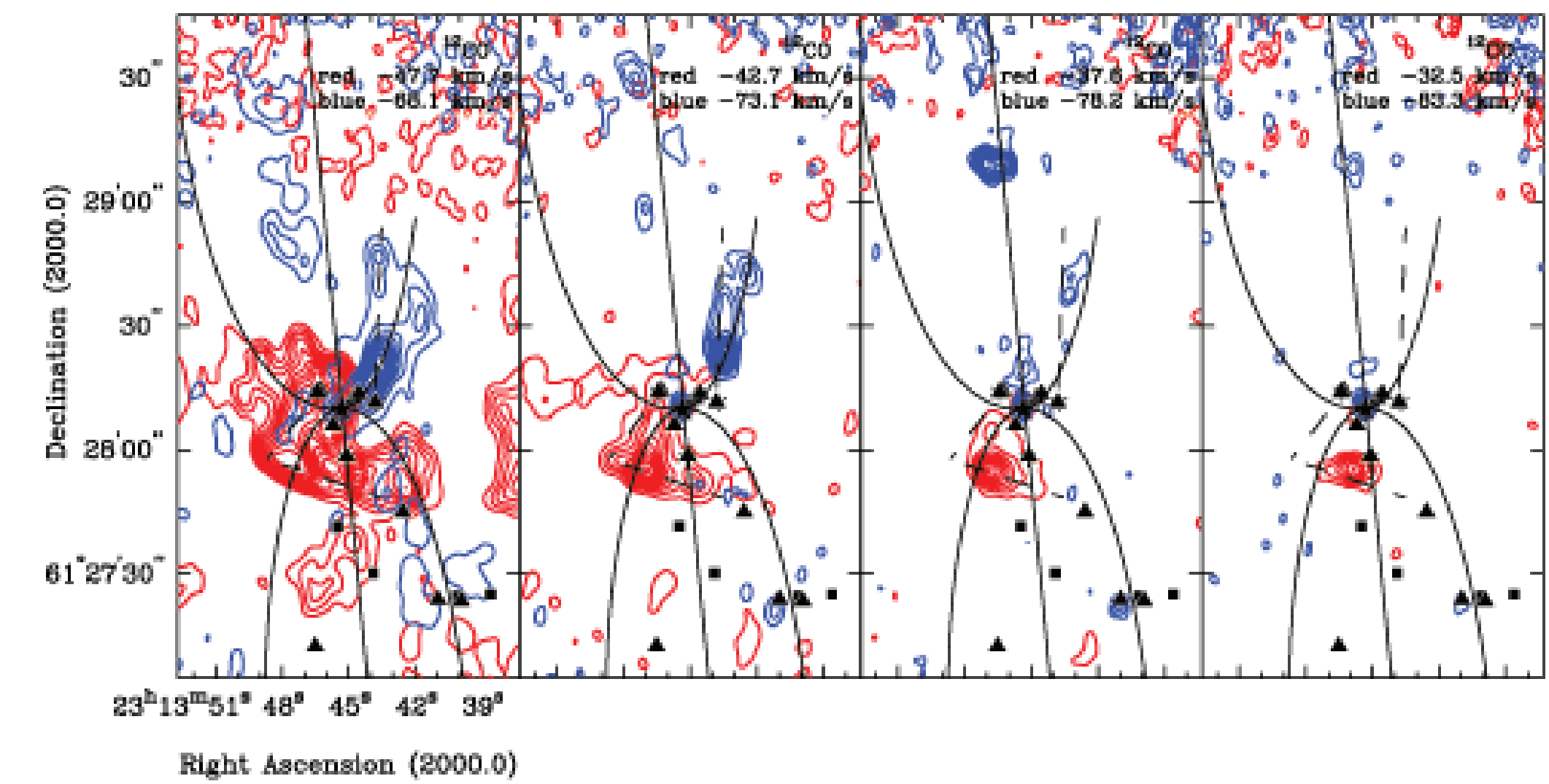


Fig 6. CARMA CO 1 - 0 mosaic with 4.5'' spatial resolution showing the IRS1 outflow at high velocities.

Conclusions

Below (Fig. 7) we have overlaid some of the CARMA images on the IRAC color image to show that the interferometry images support the idea that IRS1 has created the cavity extending to ~4' north of IRS1. The greyscale overlay is HCO⁺ showing the distribution of dense molecular gas. In the north it tracks the PDR ridge, in the south it shows that the outflow has excavated the dense gas allowing the outflow (and background stars) to shine through the cloud.

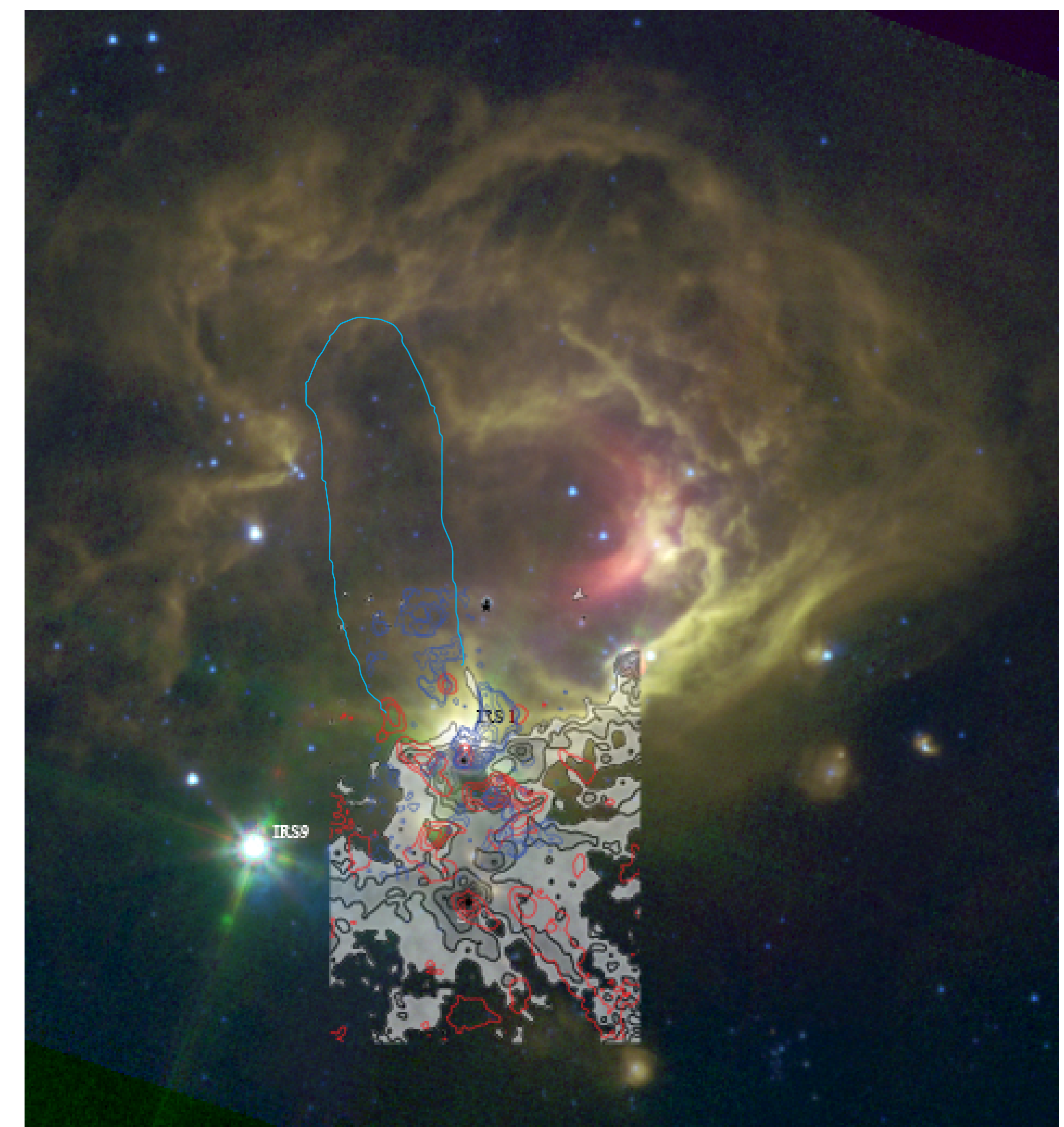


Fig 7. IRAC three color image from Fig 1. Here we overlaid the HCO⁺ emission in gray scale integrated over 6.5 km/s centered on the cloud velocity. The red contours are low velocity ¹³CO (CARMA + OSO, Fig 3). and the blue contours high velocity CO 1 - 0 emission (CARMA, Fig 6). Finally we outlined the cavity in the north with a blue line to show the cavity which has been cleared by IRS1.

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