NGC7538-IRS1: Polarized Dust & Molecular Outflow

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Introduction

The protostellar cores created from fragmentation of the initial cloud gravitational collapse can form massive stars; and the outflows provide an efficient mean to tranport out the angular momenta during the core collapse. The feedback via outflow from massive star forming regions appears to play a crucial role in redistribution of gas, dust metals in the ISM, affecting its subsequent fragmentation and consequently the initial mass function in its star formation complex.

We present dust polarization and CO molecular line images of NGC 7538 IRS 1. We combined data from the SMA, CARMA and JCMT telescopes to make images with ~ 2.5″ resolution at 230 and 345 GHz. The images show a remarkable spiral pattern in the dust polarization and molecular outflow. These data dramatically illustrate the interplay between a high infall rate onto IRS1 and a powerful outflow disrupting the dense, clumpy medium surrounding the star.

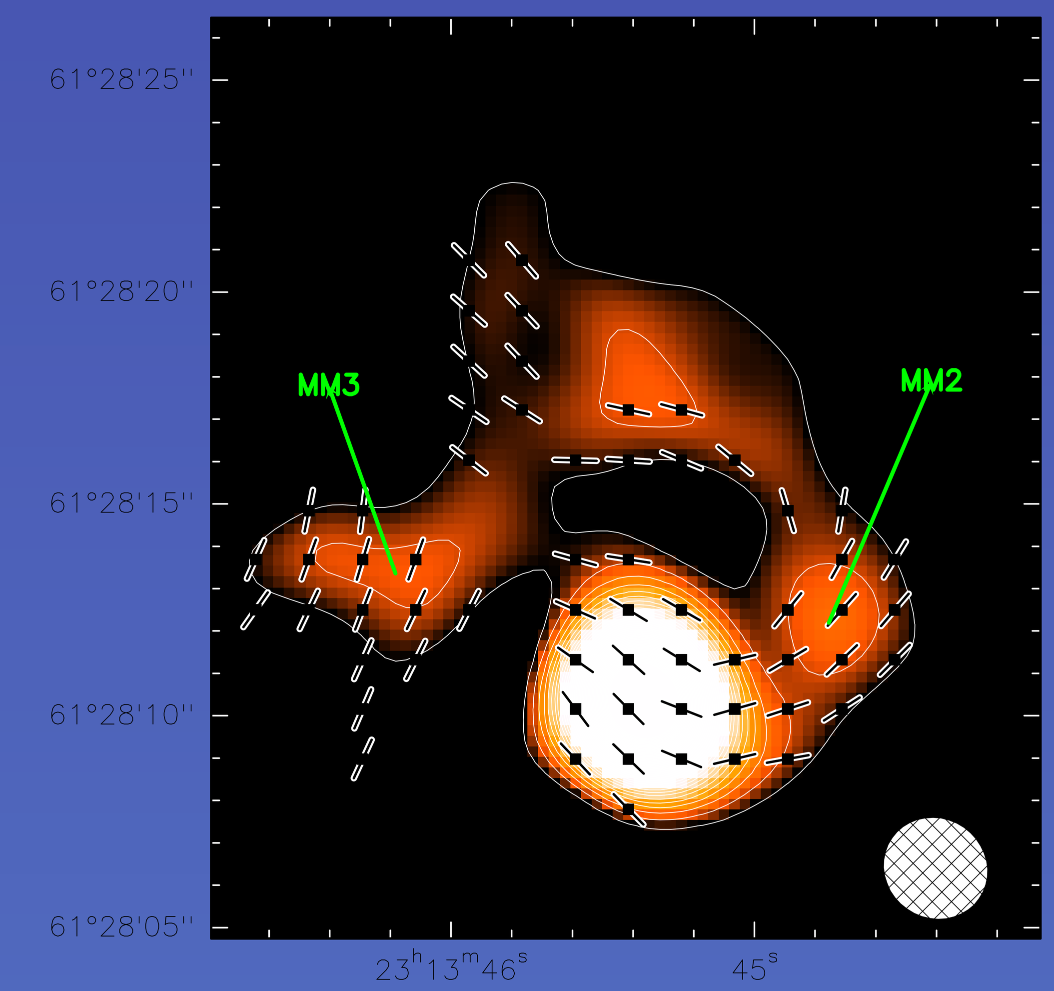


Fig.1 - CARMA 1 mm polarization vectors overlaid on CARMA 1 mm dust continuum(color-scale and contours). The polarization vectors have been rotated by 90◦ to show the p.o.s magnetic field orientation. The length of each vector is arbitrarily set to 0.5%.

Dust Polarization

The image presented in Figure 1 summarizes the results of the CARMA polarization observation at 230 GHz (Hull et al 2013). The dust continuum emission is shown in color-scale with the plane of the sky (POS) component of B-field (B_{pos}) overlaid as vectors. The B-field vectors are aligned along a spiral centered on IRS 1. Similar results were obtained from the SMA observations at 345 GHz (Frau et al 2014). High percentage polarization (~ 6%) with remarkable alignment of the vectors along the spiral is seen through out the field-of-view (FOV). A deviation of polarization vectors near the dust clump MM5 is noted. The presence of H2CO masers suggest that a star may have already formed with an outflow disrupting the spiral polarization pattern. However, there is a marked decrease in the polarized intensity towards the center of IRS1 (~ 1%) as observed towards most star forming regions where depolarization creates a "hole" due to the star formation process itself.
We can thus determine the plane-of-sky B-field B_{pos} towards MM2/MM3 as given by $B_{pos} = f\sqrt{4\pi\rho}\ \delta V/\delta\varphi$, where ρ is the gas density, δV is the velocity dispersion and δφ is the dispersion in the polarization angle and f is a factor ~ 0.5 correcting for any smoothing effect due to B-field averaging along the l.o.s provided the field is strong (δφ < 25) (Ostriker et al. 2001). We infer B_{pos} for MM2 and MM3 to be ~ 3.5 and 7.5 mG respectively.

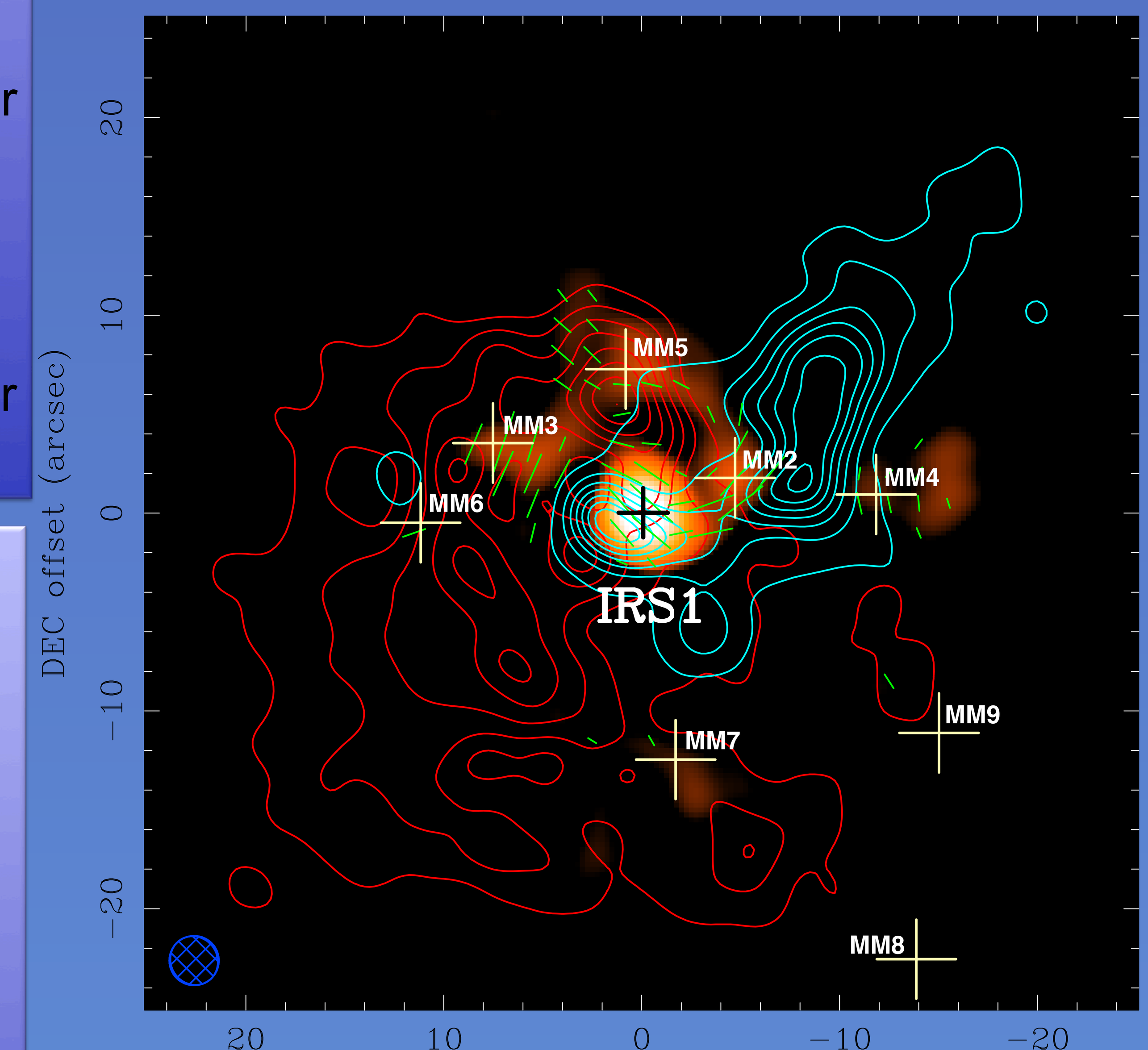


Fig. 1 Red and Blue shifted CO(3-2) emission (SMA+JCMT) overlaid on the dust polarization image (CARMA) at 230 GHz. The positions are offsets from IRS1 at R.A. (J2000) = 23h 13m 45.s 37, Dec. (J2000) = ◦ 61 28 10. 43.

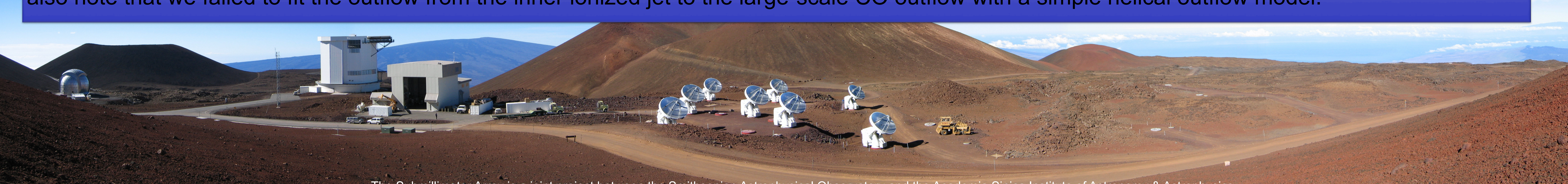
CO Outflow:

Figure 2 presents the red- and blue-shifted CO(3-2) outflow constructed from the image cube combining SMA and JCMT data. We also compared CARMA CO(2-1) and SMA CO(3-2) channel images in a comparable angular resolution. The CO(2-1) structure observed with CARMA is in good agreement with the CO(3-2) structure observed with the SMA.

We note that within the inner 2" scale, the VLA observation shows a bipolar ionized outflow in nearly N-S from the HC HII region at IRS 1. The red-shifted CO emission shows a curved outflow structure, initially starting from north, at MM 5 turning to east and continues to change direction by up to 180 degree. The blue-shifted CO emission also shows the outflow gas distributed SE around IRS 1 in a few arcsec scale and then stretching to west and passing through a dust emission gap between MM2 and MM4 and moving to NW; eventually the blue-shifted CO extends to north over an angular scale of 100" as observed in CO(1-0).

Implications in Astrophysics:

The IRS 1 in NGC 7538 is a vigorous star formation region. With 3-10 x 10^{-2} M_o yr^{-2} accretion rate (Zhu etal 2013), the materials from the surrounding molecular gas reservoir continues to fuel the region right after an early type O star formed within the hyper-compact (HC) HII region in the center. The energy source in the HC appears to be responsible to the energetic outflow (>5x10^{46} ergs), currently collimated in the N-S direction. The apparent rotation of the bipolar outflow and the highly magnetized, spiral pattern in the dust emission imply an substantial interaction between accretion materials, outflow and energy feedbacks from the high mass stars recently formed in this region. As a consequence of fragmentation due to gravitational instability, the dust clumps along the spiral pattern have formed protostars distributed around the IRS 1. Frau et al 2014 modeled the velocity pattern observed in the spiral as expansion at 9 km/s. They note that the outflow energy is comparable to the spiral arm kinetic energy. They detected 14 dust cores with masses 3.5 to 37 M_o, and a total mass 160 M_o, in which star formation may be enhanced by ram pressure form the outflow. The molecular gas in the outflow mass is a fraction (20-30%) of the infall. The ultimate source of the mass in the spiral is part of the infall. The spiral pattern may result from a rotating outflow, and/or could be an infalling, clumpy filament compressed and ablated by the outflow from IRS1. We also note that we failed to fit the outflow from the inner ionized jet to the large-scale CO outflow with a simple helical outflow model.



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