Magnetic Field Structure of the NGC1333 IRAS 4A Protostellar Outflows

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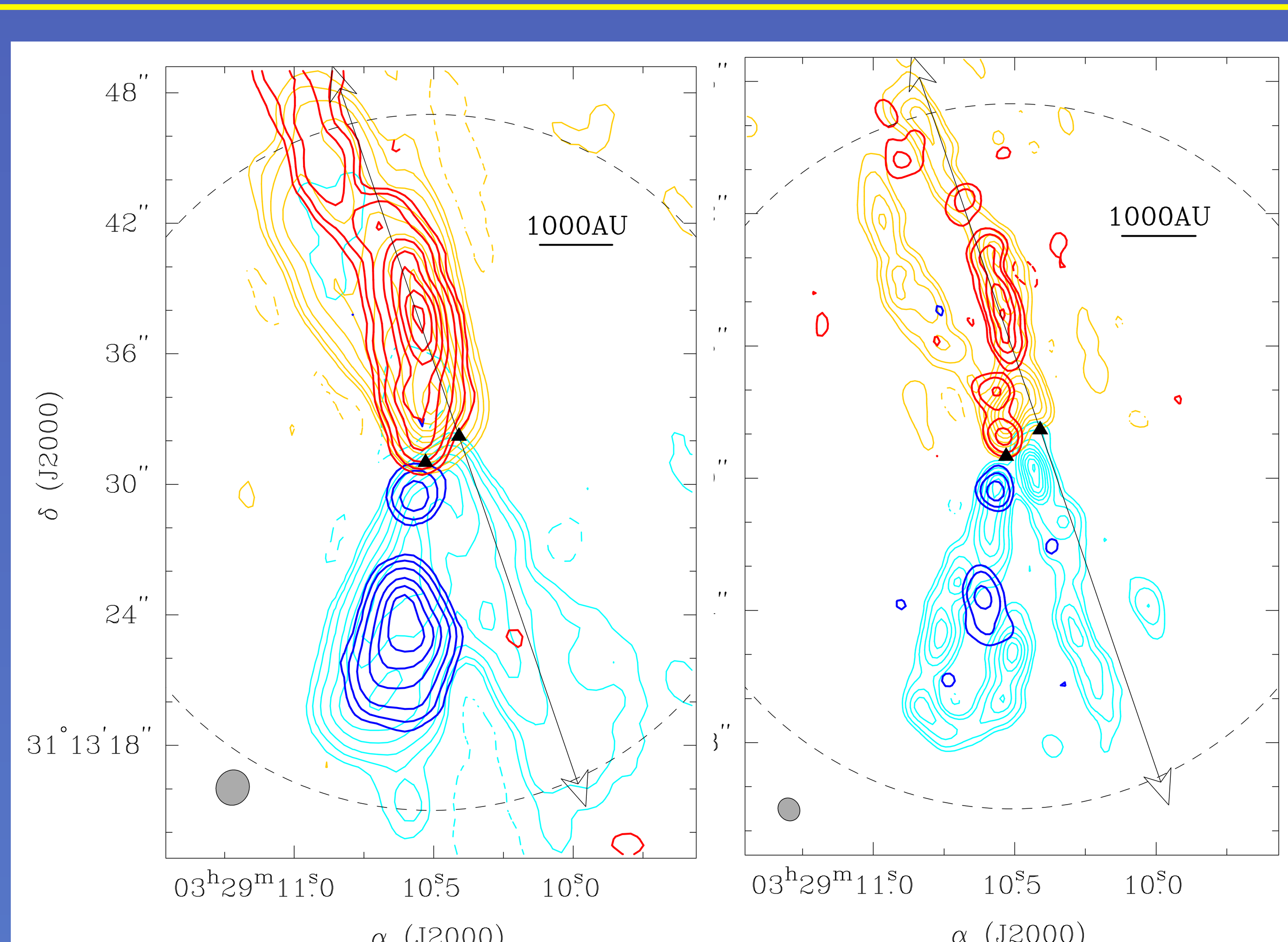
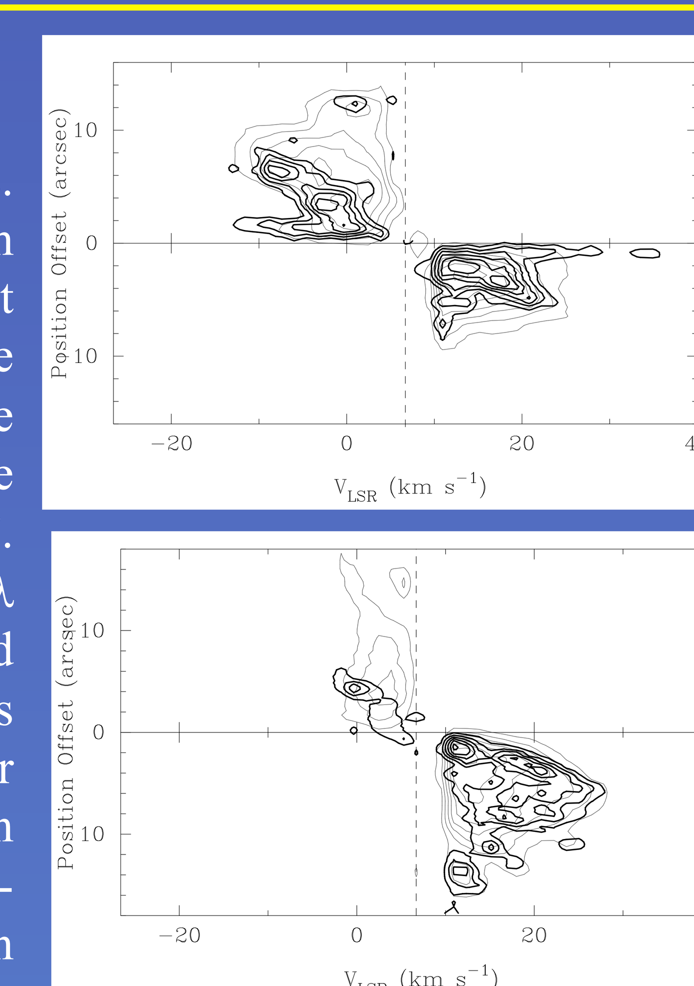
Abstract

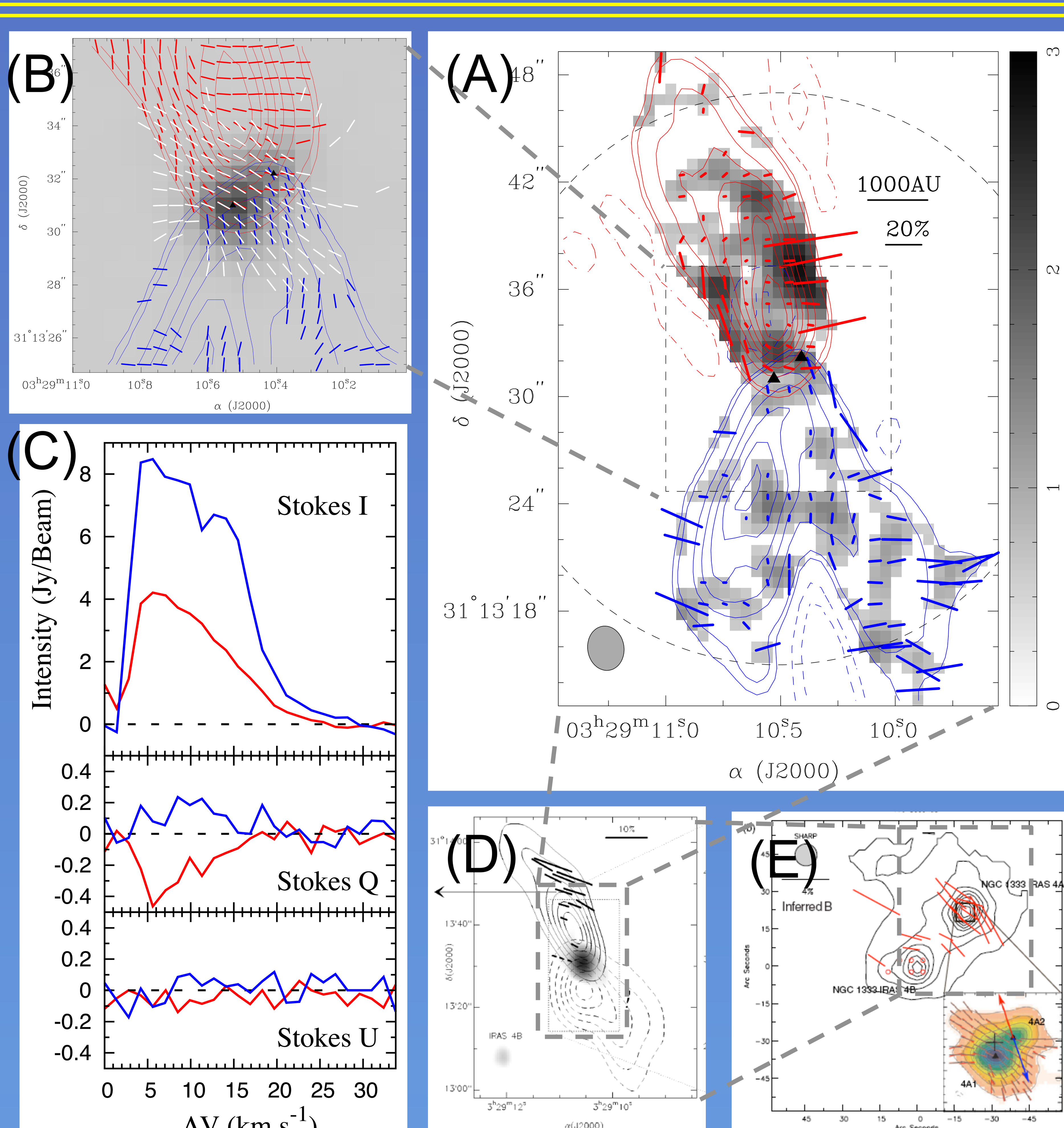
We present the polarization map of CO J = 3-2 line in the molecular outflows launched from NGC1333 IRAS 4A protostellar core. The spectral line polarization arises from the Goldreich-Kylafis effect, which predicts that the polarization could be either parallel or perpendicular to the magnetic field direction. To resolve the orientation of CO polarization to magnetic field direction, comparisons between CO polarization and dust polarization are made with the knowledge that the dust polarization is perpendicular to the magnetic field. We found that within the IRAS 4A dusty envelope, the CO J = 3-2 polarization directions are mostly perpendicular to the dust polarization, suggesting that the CO polarization is parallel to the magnetic field. The directions of the CO polarization appear to vary smoothly from the dust continuum to the red-shifted lobe of the outflows without any abrupt changes, implying that the CO polarization remains parallel to the magnetic field direction in the outflows. We speculate that a helical field may be wrapping around the outflows, which is consistent with the theoretical expectations for outflows associated with a rotating disk. Considering that the CO J = 3-2 polarized emission is mainly contributed from low velocity component of the outflow, the magnetic fields revealed by CO J = 3-2 polarization may be resulted from the interaction between envelope and outflows.



Stokes I Maps

Left: Maps of the CO J = 3-2 emission averaged over 5.7 km s^{-1} intervals. The velocity ranges with respect to the systemic velocity of V_{LSR} = 6.7 km s^{-1}. The red and blue contours represent the high velocity component ranging 14.8 – 20.5 km s^{-1}, and the orange and cyan contours represent the low velocity component ranging 3.5 – 9.2 km s^{-1}. The triangles mark the positions of protostellar binary IRAS 4A1 and 4A2. The dashed circle shows the 32" diameter of SMA primary beam at 345 GHz. Maps with 1". 65 x 1".52 and 1".07 x 0".96 resolution using all *uv* data and data > 50 kλ are shown. *Right:* PV diagrams along the outflow axes from 4A1 (*top*) and 4A2 (*bottom*). The maps reveal that the NGC1333 IRAS 4A CO outflows are composed by a faster outflow launched from 4A1 and a slower outflow launched from 4A2. The CO outflow from 4A2 is consistent with the SiO outflow in Choi et al. (2005, arrows in the *left* panel) The red-shifted outflows from 4A1 and 4A2 are merged together in the northern part while the 4A1 outflow be bent to the direction of the 4A2 outflow.

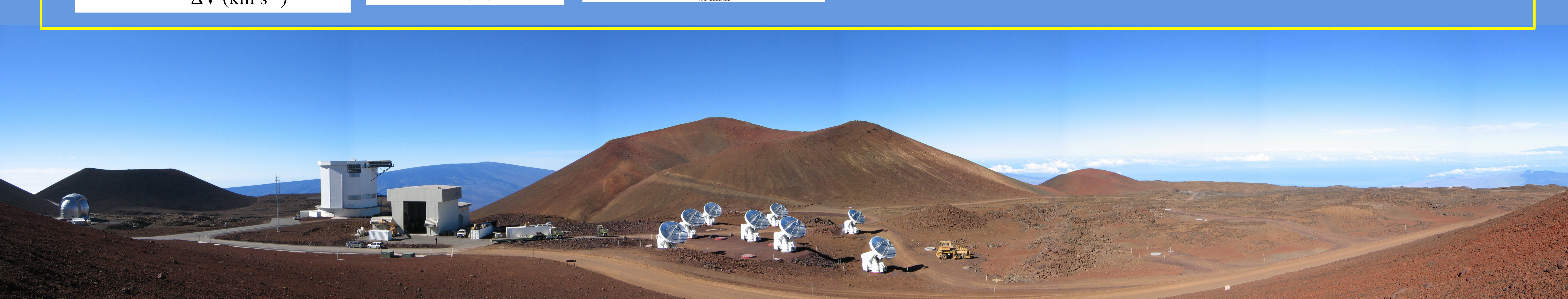




Polarization Maps

Panel A: Polarization map of the CO J = 3-2 outflow with 2".49 x 2".03 resolution using data < 70 kλ. The Stokes I, Q, and U maps are integrated over ΔV = 3.5 – 12.0 km s^{-1} in the red-shifted and blue-shifted emission. The gray scale shows the polarized intensity. The line segments show the polarization directions with their lengths proportional to the polarization percentage. *Panel B:* A zoom-in map of the central region. The white segments show the dust polarization detections. The position angles of dust polarization are flipped by 90 degree to indicate the magnetic field direction. The gray scale represents the dust continuum emission. *Panel C:* Spectra of the Stokes I, U and U emission. The red and blue profiles present the spectra in the red-shifted and blue-shifted outflows, respectively. *Panel D:* BIMA observations of CO J = 2-1 polarization with 9".0 x 6".0 resolution (Girart et al. 1999) *Panel E:* SCUBA 350 µm dust polarization map wth 15' resolution (Attard et al. 2009)

The CO J = 3-2 polarization directions are perpendicular to the dust polarization at the core center, suggesting that the CO J = 3-2 polarization is parallel to the magnetic field. The directions of the CO J = 3-2 polarization appear to vary smoothly from the core center to the red-shifted lobe of the outflows without any abrupt changes, implying that the CO J =3-2 polarization remains parallel to the magnetic field direction in the red-shifted outflow. The morphology of CO J = 3-2 polarization can be explained with a helical magnetic field wrapping the red-shifted outflow. The helical field might be the sources that bends the 4A1 outflow into the 4A2 outflow. The position angles of CO J = 3-2 and 2-1 polarizations are consistent at core center but differ by 60 degree in the northern part of outflow. Since the CO J = 3-2 and 2-1 lines might trace different layers of the outflow, the different position angles in the CO J = 3-2 and 2-1 polarizations might suggest different helical structures in different layers of the outflow. Considering the CO polarization is contributed from short baselines, low velocity range, and shows position angles differ from the ambient field, the magnetic fields traced by CO J = 3-2 could be resulted from the interaction of the outflow and ambient field.



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