BISTRO: NGC 2071IR

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NGC 2071IR

- **Massive dense core** with 8 near-infrared objects in the central region (Walther et al. 1993)
- **Bipolar outflow** (Bally 1982; Snell et al. 1984)
- \( d = 417 \pm 5 \text{ pc} \) (adopt the distance of NGC 2068 derived by Kounkel et al. 2018)

Observation (13.3 hrs)
- JCMT SCUBA 2 POL-2 polarimeter at 450\(\mu\)m and 850\(\mu\)m at Band-2 weather
- DAISY observing mode covering 12’ area

- Spatial resolutions: 9.6”, corresponding to 4000 AU (\(~0.02\text{pc}\)) at 450\(\mu\)m
  14.1”, corresponding to 5800 AU (\(~0.03\text{pc}\)) at 850\(\mu\)m
- Sensitivity: 20 mJy/beam at 450\(\mu\)m, 1.5 mJy/beam at 850\(\mu\)m

\* Note: \(^{12}\text{CO}(3-2)\) emission (using the HARP archive data) has been subtracted in the 850\(\mu\)m continuum map & 225 GHz continuum from SMA archive data
Previous polarization studies

Matthew et al. 2002, 2009 using JCMT SCUPOL
  - pinched B-field structure at the center
  - B-field strength of 56 µG using the Chandrasekhar and Fermi method

Cortes et al. (2006) using BIMA with the spatial resolution of about 4 arcsec
  - B-fields in the outflow are parallel to outflow direction based on $^{12}$CO(2-1) line polarization observation
NGC 2071 IR

POL-2 (this study)

SCUPOL (Matthews et al. 2009)

Polarization Vector
1. Observational results

Polarization vector map at 850µm

SCUBA POL-2 850µm polarization vectors map of the NGC 2071IR.
Polarization vectors at (P/δP)≥3
1. Observational results

Inferred B-field vector map at 850µm
pinched morphology at the center
1. Observational results

**Polarization vector map at 450/850µm**

Good polarization angle agreement in the center region at both 450/850 µm data
2. Polarization properties: depolarization

- **Grain growth**: slow decline (-0.33) at 850 µm at the center region
  ※ radiative torque alignment (Lazarian & Hoang 2007)
  : larger and cooler grains are more efficient in the grain alignment
- **geometrical effect**: $<P>_{450\mu m, 9.6''} = 1.47\%$, $<P>_{850\mu m, 14.1''} = 0.89\%$, at the center

![Graphs showing polarization properties and depolarization](image)
2. Polarization properties: depolarization

- **Grain growth**: higher polarized intensity at the stronger intensity of $I$ at 850 $\mu$m
2. Polarization properties: depolarization

- **Grain growth**: lower $\beta$ (optical spectral index) value toward the center region

\[
\frac{I_{\nu_{450\mu m}}}{I_{\nu_{850\mu m}}} = e^{\frac{h\nu_{850\mu m}}{kT}} - 1 \left( \frac{\nu_{450\mu m}}{\nu_{850\mu m}} \right)^{\beta+3}
\]
Summary of the Polarization properties

(1) Pinched B-field structure at the center dense core region
   : No evidence of hourglass B-field morphology, since there’s no flattened structure

(2) Good polarization angle agreement in the center region at both 450/850 µm data
   : supporting the validity of 450 µm polarization data

(3) Depolarization at both 450/850 µm with a slope of about -1
   - grain growth at the center region ?
     - slow decline at the center of 850 µm polarization data of slope = -0.33,
       while no trend at 450 µm data
     - higher polarized intensity at the stronger intensity
     - lower optical spectral index ($\beta$) at the center
   - geometrical effect ?
     : average polarization fraction at the center region: 1.47% (450 µm), 0.89%(850 µm)
3. B-field properties: B-field strength < gravity

\[ B_{\text{pos}} = 0.52 \, \text{mG} \]

(plane-of-sky B-field strength derived by Chandrasekhar-Fermi method Crutcher et al. 2004)

- Angular dispersion = 14.5° (using the unsharp masking method Pattle et al. 2017)
- FWHM velocity dispersion from \(^{18}\text{O} (3-2)\) after subtracting the thermal motion (0.2 km/s) = 0.75 km/s
- Hydrogen volume density = 0.98 \times 10^6 /\text{cm}^3

\[ B_{\text{pos}} = Q \sqrt{4\pi \rho} \frac{\delta V}{\delta \phi} \approx 9.3 \frac{\sqrt{n(\text{H}_2) \Delta V}}{\delta \phi} \, \mu\text{G} \]

\[ \lambda \equiv \frac{(M/\Phi)_{\text{obs}}}{(M/\Phi)_{\text{crit}}} \sim 1.2 \]

(slight gravitational collapse)
3. B-field properties: B-field strength < outflow

B-fields are well-aligned with the bipolar outflow

- \( E_B \sim 5.1 \times 10^{37} \) J
- \( E_K \sim 2.2 \times 10^{38} \) J
  (based on the \(^{13}\text{CO}(3-2)\) emission)
- Outflow is shaping the B-field morphology
Summary of the B-field properties

Strong B-field $B_{\text{pos}} = 0.52 \text{ mG}$ (10 times stronger than the result of Matthews et al. 2002)

B-field are well-aligned with the bipolar outflow, following the cavity walls.

However,

1. $\lambda \equiv (M/\Phi)_{\text{obs}} / (M/\Phi)_{\text{crit}} \sim 1.2$
   
   : gravity overcomes the resistance of the magnetic field

2. $E_K > E_B$ : outflow shapes the magnetic field morphology