1. INTRODUCTION

Origin of Molecular Outflow is open question.

(a) Entrainment Model \( \Rightarrow \) Linear momentum of a jet is transferred to ambient molecular material

(b) Magnetically Driven Model \( \Rightarrow \) Molecular gas is directly driven by the magnetic Lorentz force

Magnetic drive model has an advantage to solve “the angular momentum problem of new born stars.”

Angular momentum of the parent cloud core \((-1M_\odot)\) is much larger than that of the protostar / star.

If we look for observational evidence of magnetic drive of molecular outflow, \( \Rightarrow B_z \) Toroidal B-Field

Because the torque is induced by \( F_r \times J_{pol} \times \nabla B \times B_{pol} \)

If we find the toroidal magnetic field \( B_z \), this indicates magnetic drive.

Polarization observation of dust thermal emissions can explore the existence of toroidal magnetic field \( B_z \).

2. METHOD

Oblate/prolate dust is aligned in the B-field direction, this emits polarized light. EM wave’s E vector // B field.

Stokes parameter \( I, Q, \) and \( U \)

\[
\begin{align*}
Q &= C \cdot R \cdot F \cdot c - B_z \cdot \cos 2\gamma \cos^2 \gamma \sin \theta ds \\
U &= C \cdot R \cdot F \cdot c - B_z \cdot \sin 2\gamma \cos^2 \gamma \sin \theta ds \\
\end{align*}
\]

\( C \): difference of cross sections perp and parallel to \( B \)
\( R \): reduction factor due to imperfect grain alignment
\( F \): flux factor due to turbulent B-field

\( \gamma \): angle b/w \( B \) and plane of the sky,
\( \psi \): angle b/w projection of \( B \) and \( \eta \)-axis

Calculate following \( q, u, \Sigma, \) and \( \Sigma_2 \), using simulation data.

Relative Stokes parameter

\[
\begin{align*}
q &= \int \rho \cos 2\gamma \cos^2 \gamma \sin \theta ds \\
u &= \int \rho \sin 2\gamma \cos^2 \gamma \sin \theta ds \\
\Sigma &= \int \rho ds \\
\Sigma_2 &= \int \rho \left( \frac{\cos^2 \gamma}{2} \frac{1}{3} \right) ds \\
\end{align*}
\]

Observe quantities

Polarization direction

\[
\begin{align*}
\cos 2\chi &= \frac{q}{(q^2 + u^2)^{1/2}} \\
\sin 2\chi &= \frac{u}{(q^2 + u^2)^{1/2}} \\
\end{align*}
\]

Polarization degree

\[
p = \alpha \sqrt{q^2 + u^2} \\
\Sigma - \alpha \Sigma_2
\]

3. RESULT

Prestellar \( \Rightarrow \) Protostar 7000yr after FC form.

Simulation data

Starless phase [left]

1. Intensity indicates a disk (this strong field model) or a spherical shape (weak field model not shown)
2. Direction of a disk ~ low polarization region whose distribution is asymmetry with respect to \( y \)-axis: weakly polarized from upper-right to lower-left at \( \theta = 30^\circ - 60^\circ \)

Protostar phase [right]

1. Outflow traces a low polarization region.
2. This contains a strongly polarized region near the center (acceleration region) viewing from \( \theta = 30^\circ - 60^\circ \), which contains a horizontally polarized region surrounding the \( \eta \)-axis.
3. Viewing from the pole direction, azimuthal polarization pattern is emphasized.

4. CONCLUSION

Existence of \( B_z \) can be found from polarization observation.