Testing the Polarization-Intensity Gradient Method for Magnetic Field Strength Estimation in Dense Core Simulations

Jo-Shui Kao (NTHU/ASIAA), Shih-Ping Lai (NTHU), Hsi-Wei Yen (ASIAA), Patrick M. Koch (ASIAA)

Science Goal

Magnetic fields play an important role in the star formation process and collapsing dense cores. However, it is difficult to directly measure the magnetic field strength in observation. The polarization–intensity gradient method is a new approach to estimate the magnetic field strength using polarization angle and intensity gradient, which can provide the map of position-dependent magnetic field strength estimates. In this project, we evaluate the applicability of this method to observational data and to determine whether it can provide robust magnetic field strength estimates in realistic star-forming environments.

Polarization–Intensity Gradient Method

Assumption: intensity gradient is a measure for the resulting direction of motion in the MHD force equation (Koch+2012)

$$\sin\alpha \times F_B = \sin\psi \times (F_P + F_G)$$

$$F_B \rightarrow \frac{B^2}{4\pi R}$$

$$B = \sqrt{4\pi R \times \frac{\sin\psi}{\sin\alpha} \times \rho\nabla\phi}$$

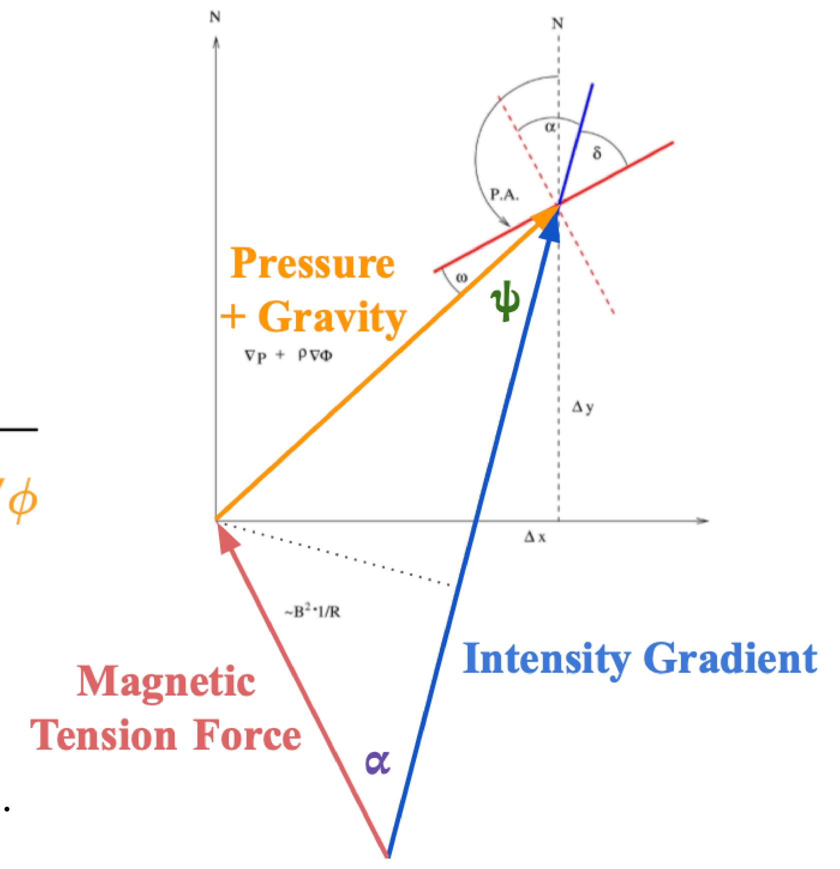

Figure 1: Relative angles of B field (red), gravity (orange), and intensity gradient (blue).

Simulation with RAMSES

1. Isolated collapsing dense cores
   a. mass-to-flux ratio λ: 2, 5, 10 (B ~ 0.27, 0.11, 0.05 mG)
   b. non-rotating, rotating
   c. misaligned (initial B field, rotation axis)
   d. inclination angle: 15°, 30°, 45°, 60°, 75°, 90°(edge-on)
2. Dense cores in molecular cloud (Ntormousi and Hennebelle 2019)
   a. initial turbulence

- POLARIS: radiative transfer modelings
- CASA-simobserve: synthetic observations
  - beam size ~ 1.1"
  - Pixel size ~ 0.265" (= 265 AU)

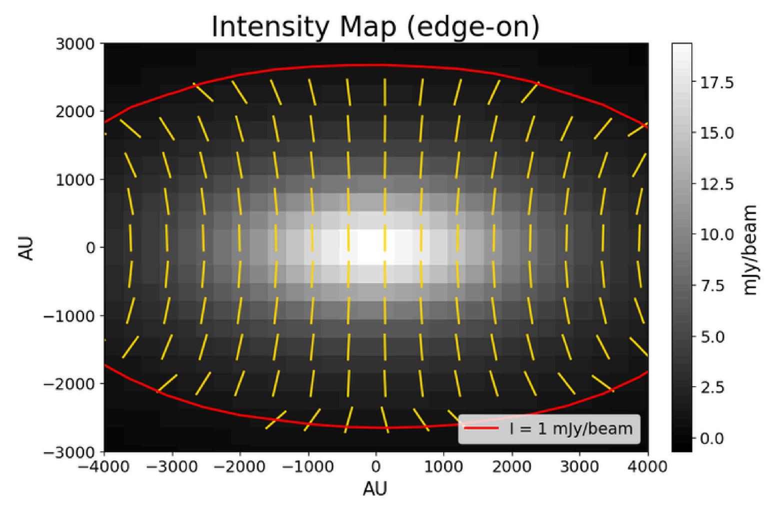

Figure 2: Intensity and B field direction map from simobserve (model: λ=2, non-rotated).

Results: B Field Strength in Collapsing Dense Core

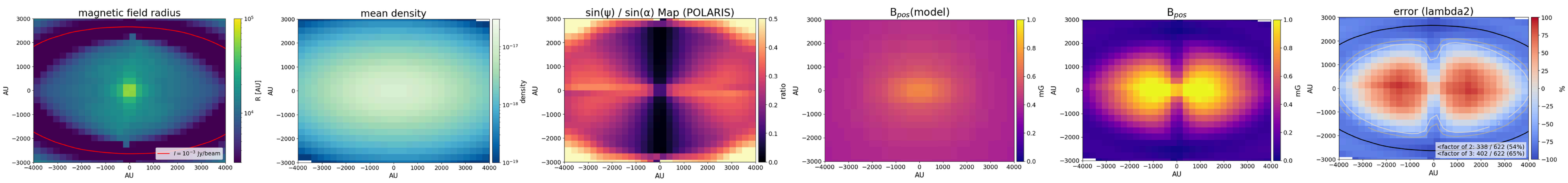

Figure 3: Estimate magnetic field strength with the polarization-intensity gradient method (model: λ=2, non-rotated, edge-on).

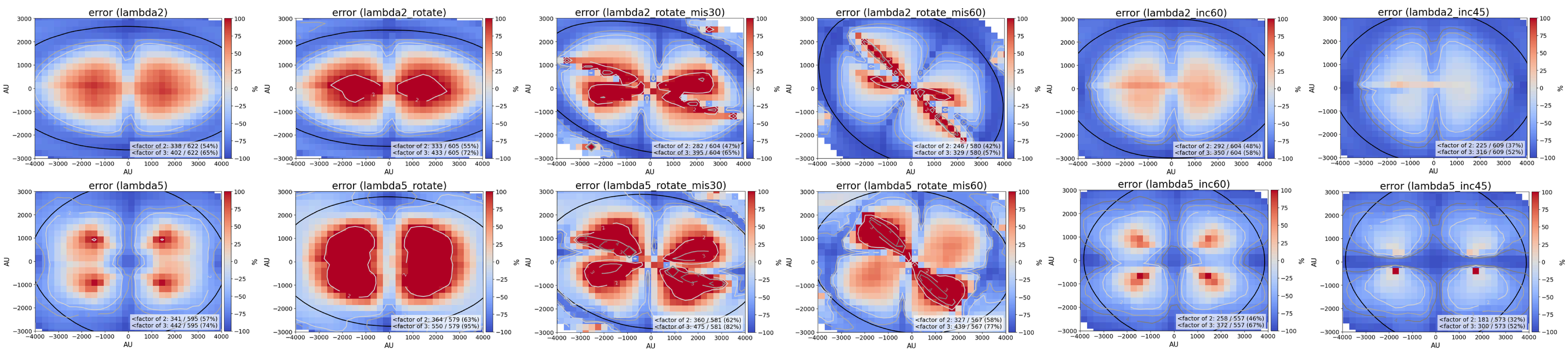

Figure 4: Error map for different models.

The polarization-intensity gradient method can estimate the magnetic field strength with error smaller than a factor of 3 (Fig. 4), except:

- For regions where the magnetic field lines appear nearly straight, the method tends to overestimate the magnetic field strength due to the large magnetic field curvature radius (Fig. 5).
- For hourglass-shaped magnetic field structures, the magnetic field strength is underestimated when the inclination angle is < 45° (Fig. 6) because the underestimate of the magnetic field curvature radius.

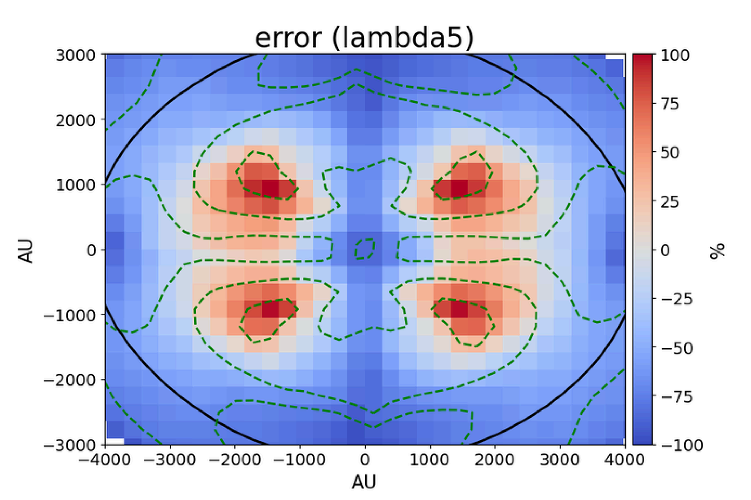

Figure 5: Error map overlap with the contour of magnetic field curvature radius (model: λ=5, non-rotated).

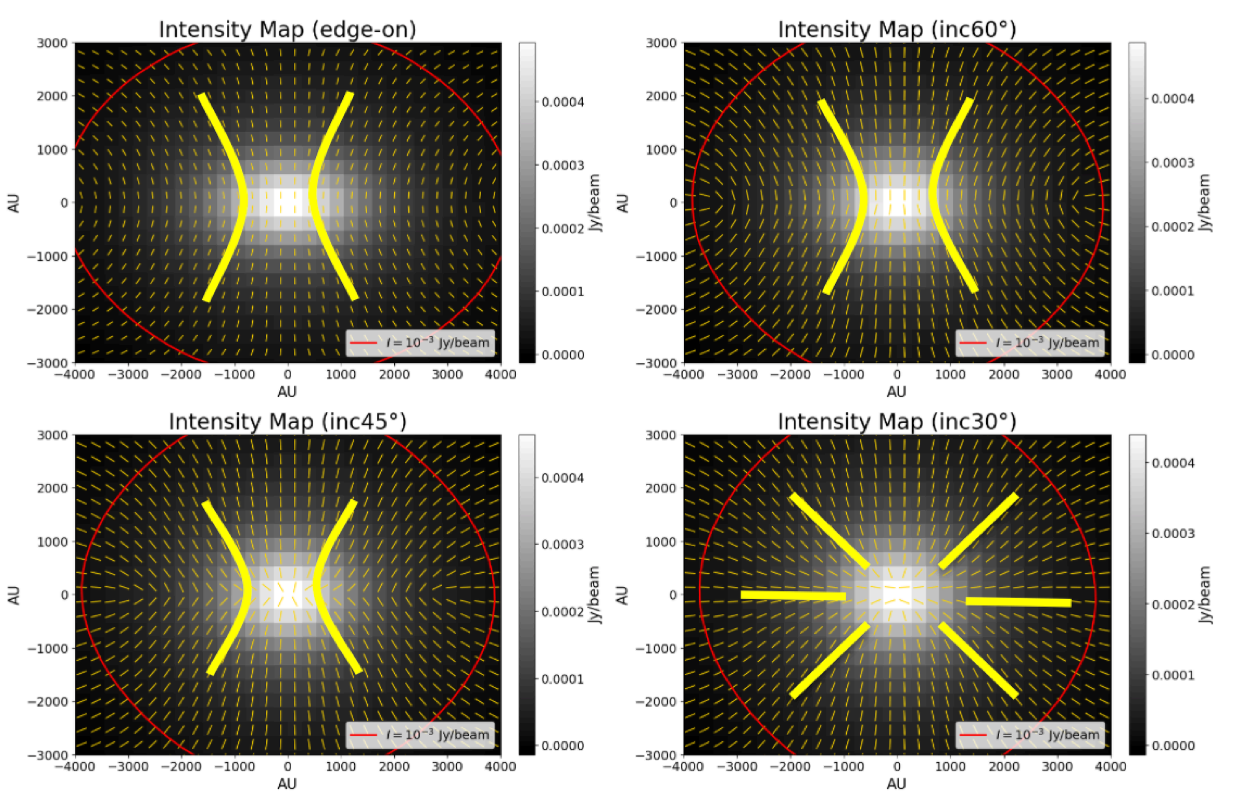

Figure 6: Intensity and polarization map for different inclination angle (model: λ=5, non-rotated).

Future Works

1. In what kind of physical conditions can we apply the polarization–intensity gradient method?
2. In the polarization–intensity gradient method, which parameters contribute the largest uncertainty?
3. Does the intensity gradient represent the plane-of-sky gas motion?
4. Compare with the DCF method
5. Test the polarization–intensity gradient method on envelope scale

References

Polarization-intensity gradient method:
Koch et al. 2012a, b
RAMSES:
Teyssier 2002, Fromang et al. 2006
Ntormousi and Hennebelle 2019

jskao@asiaa.sinica.edu.tw