The Structure of Magnetic Fields in Molecular Clouds

Determining the 3D structure of the magnetic fields in molecular clouds using polarized dust observations

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Motivation

Star formation is inefficient in molecular clouds; the Galactic star formation rate is shown to be significantly lower than if stars formed primarily due collapse under gravity.

Magnetic fields and turbulence have been proposed as means that inhibits gravitational collapse, and the focus of this study is on determining the 3D structure of the magnetic fields in molecular clouds, to better understand star formation.

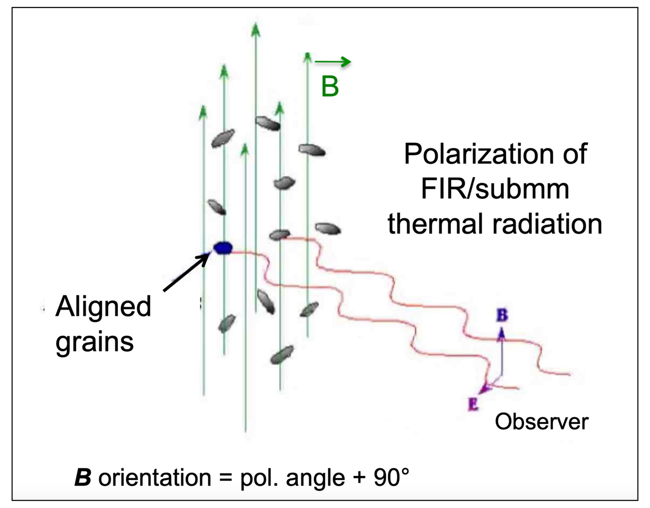
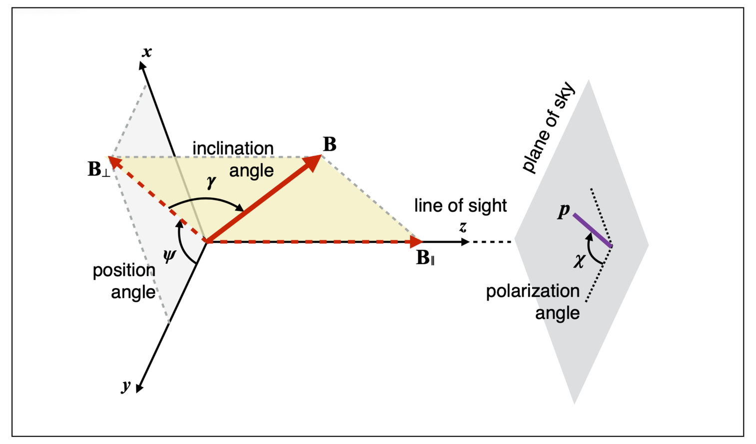


Figure 1. Grains align with their short axis parallel to the magnetic field in a molecular cloud. Light is polarized as a result. The degree of polarization depends on the cross sectional area of the grains, which is influenced by the inclination angle.

Figure 2. The inclination angle with respect to the plane-of-sky(POS), given by **γ**. The magnetic field is shown projected onto the POS with respect to **γ**.



Dust polarization

Non-spherical dust grains in molecular clouds align with their minor axis parallel to the magnetic field (Figure 1). This causes the light from the cloud to be polarized, and we can estimate the magnetic field inclination angle, **γ**, from this polarization (Figure 2). It is expected that there is a higher inclination angle for lower polarization fraction, and vice versa.

Observations

ORION A

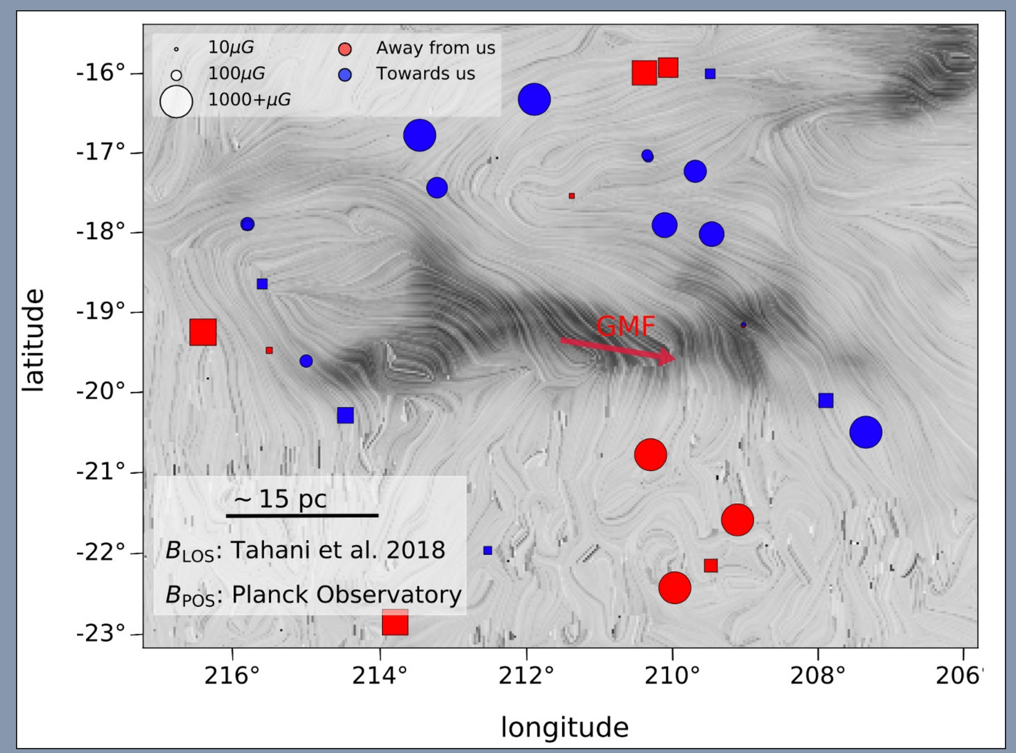


Figure 3. The structure of the magnetic field of the Orion A molecular cloud, as shown Tahani (2022). The filamentary structure illustrates the hydrogen column density of the cloud. The blue and red markers represent the measurements of the line-of-sight field component from Faraday rotation observations, pointing towards and away from us, respectively. The squares represent points with high uncertainties. The size of the markers represent the strength of the field. The drapery lines represent the B_{POS} observed by the Planck Space Observatory. The red 'GMF' vector shows the Galactic Magnetic Field (GMF) projected on the plane-of-sky Tahani (2022).

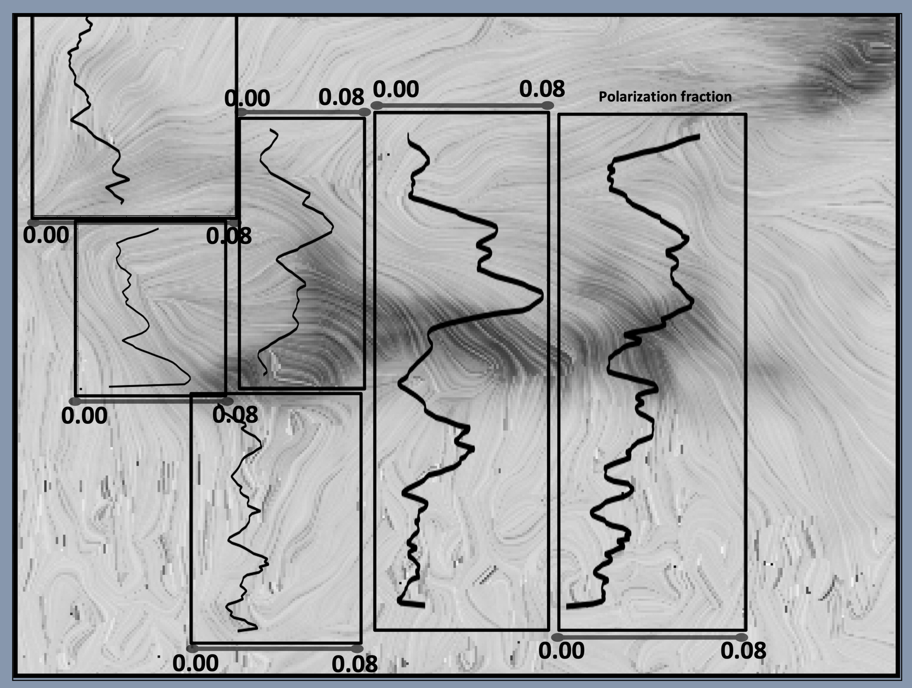


Figure 4. The change in the polarization fraction throughout the cloud, illustrated on the same map as in Figure 2. The polarization fraction range on the x-axis for each insert panel is 0.00 to 0.08. The filament can be seen by the dark region in the center, where a decrease in the polarization fraction is observed. From the Faraday rotation observations in Figure 3, we expect a reversal in the magnetic field direction across the cloud. The change in polarization fraction from the center of the cloud to the regions around the cloud can be attributed to this reversal.

VELA C

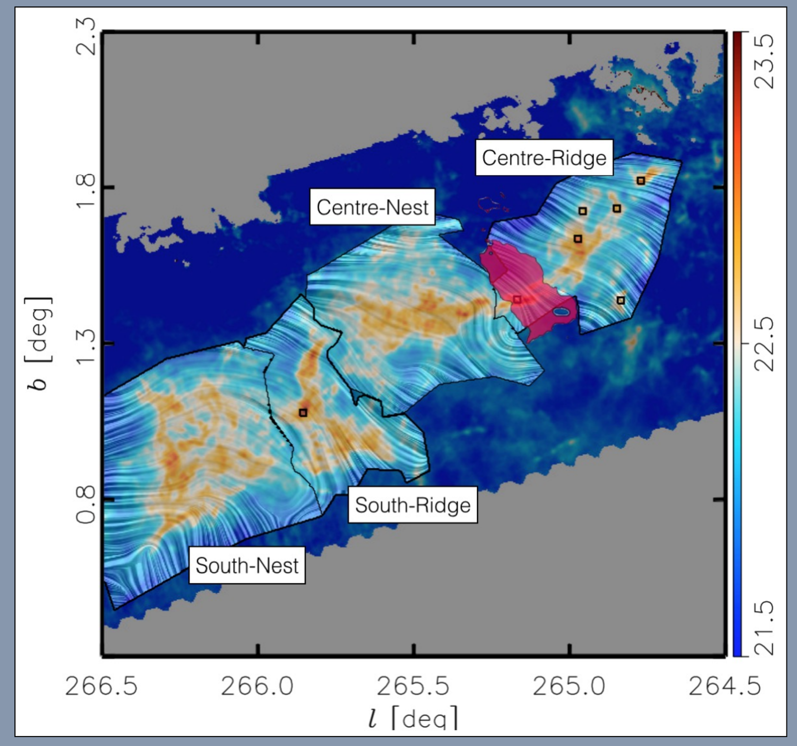


Figure 5. Sub-regions and magnetic field lines of the Vela C molecular cloud, as measured by BLASTPoL (Soler(2017)). The field lines indicated by the "drapery" pattern show the field lines projected onto the plane-of-sky. The hydrogen column density filaments can be seen in the center of the cloud, where the colors are given by log(N_H). The squares indicate high mass cores and the region in magenta has a higher temperature due to a massive cluster of stars.

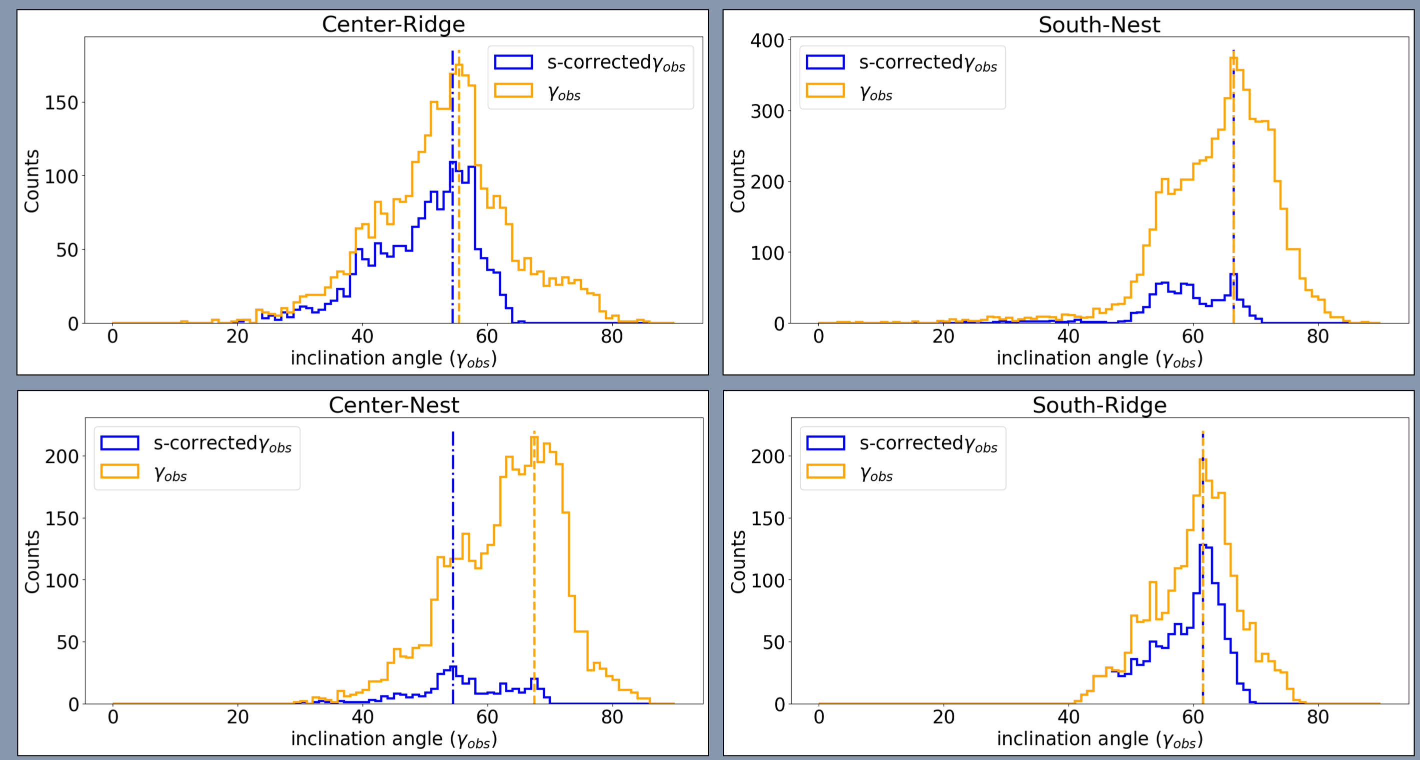


Figure 6. These figures show the *p* derived inclination angles in comparison with the *S*-corrected inclination angles for each of the subregions in Vela C. The dispersion of the polarization angles, *S,* can be used to identify regions of the cloud where the magnetic field is well ordered. Chen et al. (2019) concluded that more accurate measurements of the inclination angle are made when only the regions with lower *S* are analyzed. The vertical lines show the mode of the inclination angles corresponding to the most probable value of the inclination angle in the given region of the cloud.

Analysis

In Vela C, the inclination angle was found from the polarization fraction (Figure 6, yellow). We also estimated the inclination angle by excluding regions of high dispersion in polarization angle were eliminated, as shown in the s-corrected **γ** in Figure 6 (blue). The inclination angle from the polarization fraction was found using $p = \frac{p_0 cos^2\gamma}{1 - p_0(cos^2\gamma - \frac{2}{3})}$. In Orion A, the polarization fraction was compared to the reversal in the magnetic field seen in Faraday rotation measurements from Tahani (2022)(Figure 3 and 4).

Acknowledgements

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Results

Vela C

Region	S-corrected inclination angle (γ)
Center-Ridge	54.5°
Center-Nest	54.5°
South-Ridge	61.5°
South-Nest	66.5°

Orion A

The polametric observations of Orion A, seen in Figure 4, show an increase in the polarization around the filament and a decrease at the filament. This is consistent with magnetic field reversal from Tahani (2022). The decrease in the polarization fraction at the filament can be attributed to the increase in column density, as this negative correlation is often observed (Sullivan(2017)).

Summary

Using polarimetric observations, we got insight into the 3D magnetic field structure of the Vela C molecular cloud, where we saw that it's magnetic field inclination angle increased towards the south of the cloud. In Orion A, results from the polarization fraction method suggest that the inclination angle would increase towards the filament in the cloud, in contrast to previous observations. Thus, a more thorough analysis of the cloud's structure and column density is required to confidently determine the inclination angle of it's field.

Literature cited

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Sullivan C. H., Fissel L. M., King P. K., Chen C.-Y., Li Z.-Y., Soler J. D., 2021, Monthly Notices of the Royal Astronomical Society, 503, 5006