

# The 3-D structure of the galactic magnetic field

## A case study of the high-latitude cloud LDN 134

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**Abstract.** This study presents an investigation into the 3D structure of the Galactic Magnetic Field (GMF) centered on High-Latitude Clouds, specifically LDN 134. We used optical polarization data from the Interstellar Polarization Survey (IPS), obtained with the IAGPOL instrument at the Pico dos Dias Observatory. The observational data was cross-matched with GAIA DR3 and StarHorse2 catalogs to incorporate distance and reddening. We applied a polarization model that integrates the radiative transfer of Stokes parameters ( $I, Q, U$ ) along the line of sight, incorporating a 3D distribution of regular and turbulent magnetic field components and an interstellar dust model. Preliminary results indicate that while initial parameters provided good agreement for visual extinction ( $A_V$ ), they failed to satisfactorily fit the polarization for LDN 134. However, incorporating a random magnetic field component resulted in a notable improvement, providing the closest fit to the observations. Future work will focus on investigating the model's parameter space and separating stars into foreground, embedded, and background populations.

**Resumo.** Este trabalho apresenta uma investigação sobre a estrutura 3D do Campo Magnético Galáctico (GMF) centrada em Nuvens de Alta Latitude, especificamente a LDN 134. Utilizamos dados de polarização óptica do Interstellar Polarization Survey (IPS), obtidos com o instrumento IAGPOL no Observatório do Pico dos Dias. Os dados observacionais foram cruzados com os catálogos GAIA DR3 e StarHorse2 para incorporar distância e avermelhamento. Aplicamos um modelo de polarização que integra a transferência radiativa dos parâmetros de Stokes ( $I, Q, U$ ) ao longo da linha de visada, incorporando uma distribuição 3D de componentes regulares e turbulentas do campo magnético e um modelo de poeira interestelar. Resultados preliminares indicam que, embora os parâmetros iniciais tenham fornecido boa concordância para a extinção visual ( $A_V$ ), não ajustaram satisfatoriamente a polarização para a LDN 134. Contudo, a incorporação de uma componente aleatória do campo magnético resultou em uma melhoria notável, fornecendo o ajuste mais próximo às observações. Trabalhos futuros focarão na investigação do espaço de parâmetros do modelo e na separação das estrelas em populações de primeiro plano, imersas e de fundo.

**Keywords.** dust – clouds – magnetic fields – polarization

### 1. Introduction

This study presents an investigation into the 3D structure of the Galactic Magnetic Field (GMF), centered on ten High-Latitude Clouds.

We used optical polarization data from the Interstellar Polarization Survey (IPS) (Magalhães et al. 2000), carried out by our group.

Starlight polarization is caused by the preferential absorption of radiation by dust grains aligned with the magnetic field, as illustrated in Fig. 1.

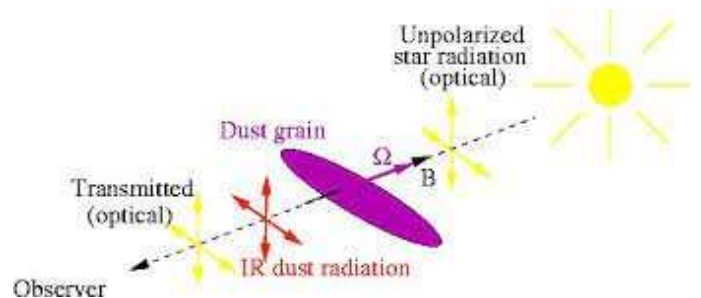
Motivations for Studying the GMF at High Latitudes Understanding Cosmic Microwave Background (CMB) Polarization:

- Star and Cloud Formation
- Cosmic Ray Propagation
- Interstellar Turbulence

In this work, we investigate the dark cloud LDN 134, Fig. 2, through the application of a polarization model.

This model incorporates a 3D distribution of both the regular and turbulent components of the Galactic magnetic field, as well as an interstellar dust model.

The investigation is based on polarimetric data from approximately 300 stars located in the field of view containing the Hipparcos stars: HIP 77332, HIP 77410, HIP 77542, and HIP 78116.



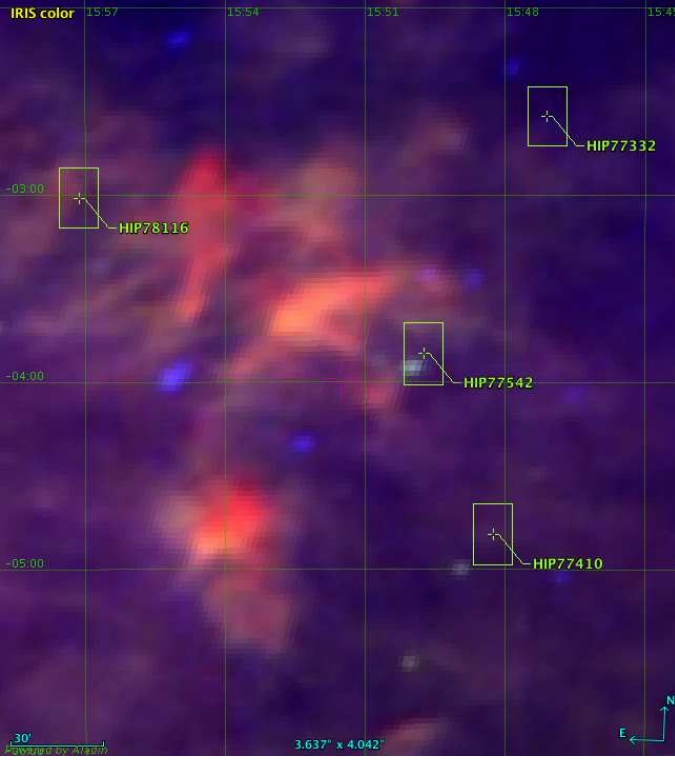
**FIGURE 1.** The origin of interstellar polarization. Dust grains aligned by the magnetic field polarize starlight via absorption (parallel to the B-field) and also emit polarized thermal radiation (perpendicular to the B-field). by Ponthieu & Lagache at [www.planck.fr/article263.html](http://www.planck.fr/article263.html)

### 2. Data and Methods

We performed V-band polarimetry using the IAGPOL instrument on the 60 cm B&C telescope at the Pico dos Dias Observatory (LNA) to determine the degree of polarization (P) and polarization angle for stars within the line of sight.

The observational data was cross-matched with the GAIA DR3 and StarHorse2 catalogs to incorporate distance, reddening, and other parameters.

To correct for the statistical bias inherent to low signal-to-noise ratio polarization measurements, the method described in



**FIGURE 2.** Cloud LDN134 in infrared from IRAS-IRIS colored.

Versteeg et al. (2023) was applied. The debiased polarization ( $P_d$ ) was calculated from the measured polarization ( $P$ ) and its uncertainty ( $\sigma_P$ ), according to Eq. 1.

$$P_d = P - \sigma_P^2 \frac{1 - e^{-\frac{P^2}{\sigma_P^2}}}{2P}. \quad (1)$$

The polarization model integrates equations that describe the variation of the Stokes parameters of the starlight along the line-of-sight, using:

- Uniform 3-D magnetic field from Jansson & Farrar (2012) and Jaffe et al. (2013);
- A random component of the field, of chosen scale length, was added to the uniform field;
- Dust model of Rodrigues et al. (1997);
- The 3-D dust distribution built from GAIA and StarHorse (Anders et al. 2022).

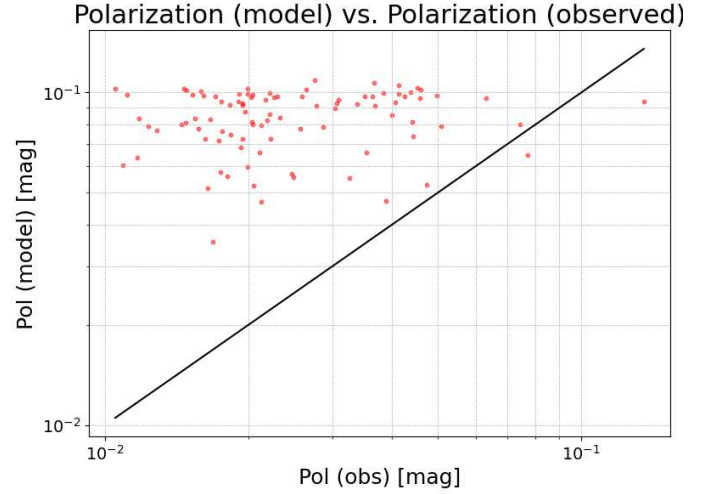
A turbulence scale length of 10 pc was applied in all models, a value chosen to encompass the full line of sight depth of our data.

### 2.1. Stokes parameters

The radiative transfer of the Stokes parameters ( $I, Q, U$ ) was calculated along the line of sight, incorporating a model of absorption layers and a magnetic field with both large-scale regular and small-scale random components. We applied linear interpolation to the grid properties along the optical path, as described by the Eqs. 2, 3 and 4.

$$\frac{dI}{ds} = -I\alpha_T, \quad (2)$$

$$\frac{d}{ds} \left( \frac{Q}{I} \right) = \Delta\alpha \cos(2\Psi), \quad (3)$$



**FIGURE 3.** Comparison between modeled and observed polarization for the star HIP 77332. Model configuration by Jansson (2012) with  $ma=0$ .

$$\frac{d}{ds} \left( \frac{U}{I} \right) = \Delta\alpha \sin(2\Psi). \quad (4)$$

The total absorption coefficient,  $\alpha_T$ , is derived from the dust distribution model. The differential absorption coefficient  $\Delta_c = 0.5(\alpha_{\parallel} - \alpha_{\perp})$ , associated with polarization-inducing cylindrical grains, is parameterized by Eq. 5.

$$\Delta\alpha_C(s, \gamma) = \alpha_T \left\{ 1.086 \left( \frac{P}{A_V} \right)_{\gamma_0} \right\} \left( \frac{\alpha_{T,0}}{\alpha_{C,0}} \right) \times \frac{h(\gamma)}{\left\{ \left( \frac{\alpha_{T,0}}{\alpha_{C,0}} \right) \right\} - 1 + g(\gamma)}, \quad (5)$$

Finally, the functions  $h(\gamma, \gamma_0)$  and  $g(\gamma, \gamma_0)$  provide, respectively, the dependence of the differential cross-sections,  $Q_{\parallel}$  and  $Q_{\perp}$ , for cylindrical grains, according to Rodrigues et al. (1997) (equations 6 and 7).

$$g(\gamma, \gamma_0) = \frac{Q_{\parallel}(\gamma) + Q_{\perp}(\gamma)}{Q_{\parallel}(\gamma_0) + Q_{\perp}(\gamma_0)}, \quad (6)$$

$$h(\gamma, \gamma_0) = \frac{Q_{\parallel}(\gamma) - Q_{\perp}(\gamma)}{Q_{\parallel}(\gamma_0) - Q_{\perp}(\gamma_0)}. \quad (7)$$

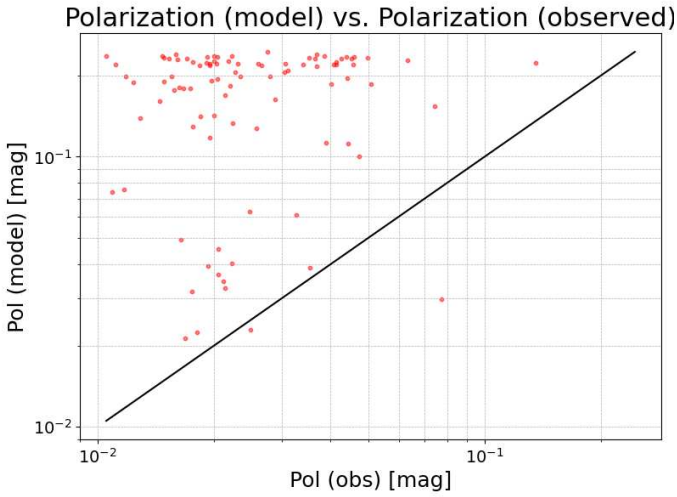
### 3. Preliminary Results and Discussion

While the initial simulation parameters were calibrated based on the BICEP2 field, they failed to produce a satisfactory fit when applied to the LDN134 field (Figs. 3, 4 and 6), although they did provide a good initial agreement for visual extinction (Fig. 5).

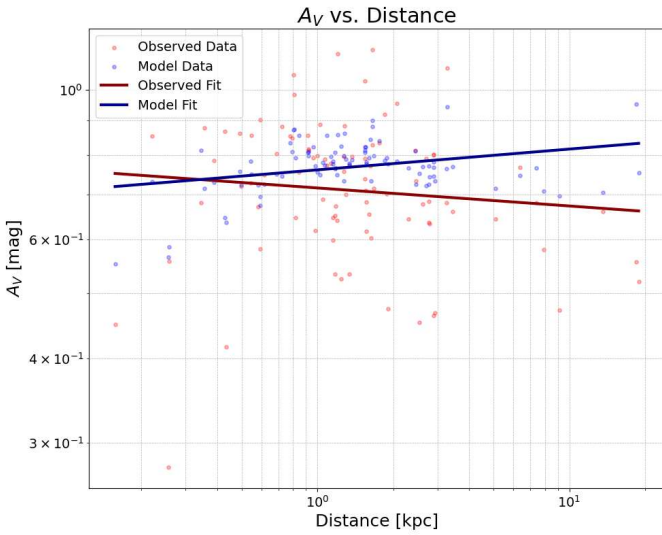
Incorporating a random magnetic field component into the model (panels with  $ma=2$ ) shows a notable improvement. However, the agreement with the data is still not fully satisfactory. Among the tested configurations, the Jansson (2012) model provides the closest fit to the observed polarization.

### 4. Future Work

Our next steps will focus on:



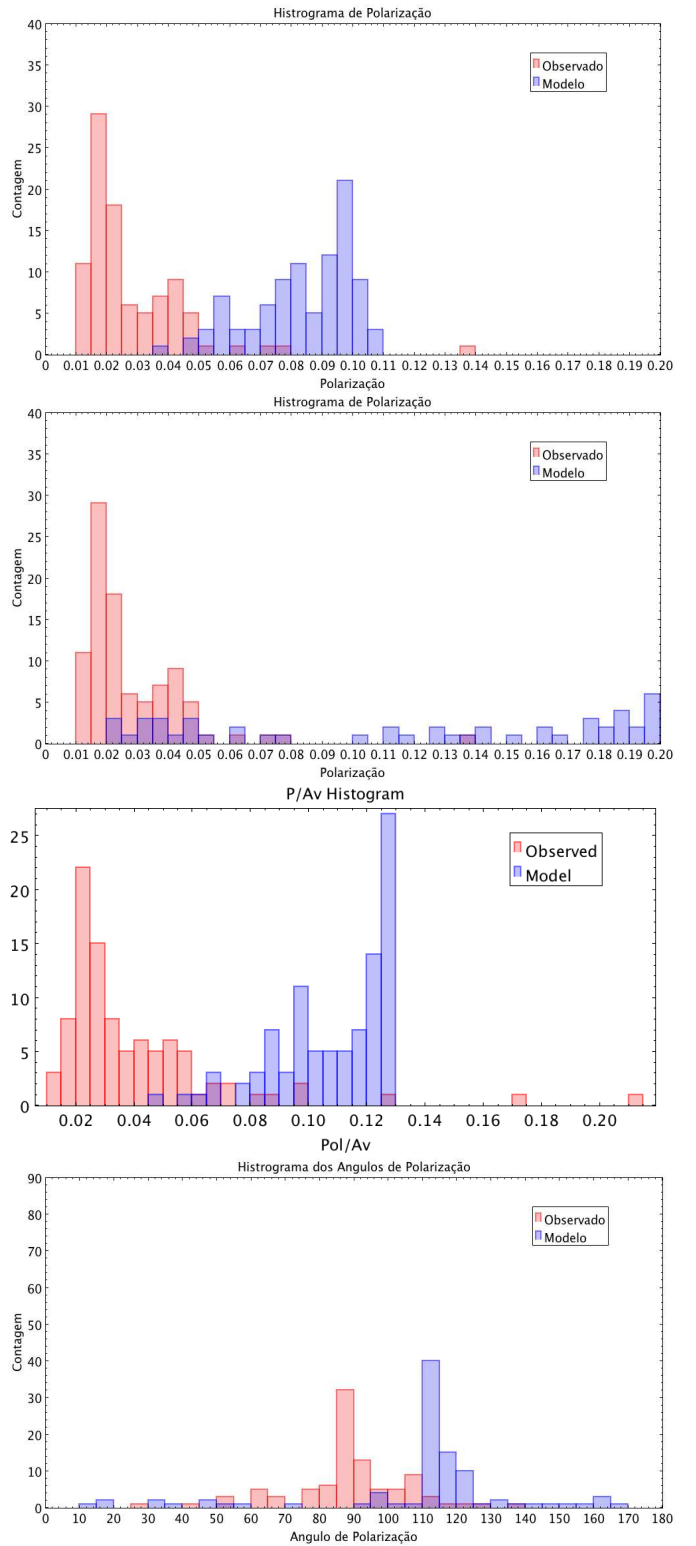
**FIGURE 4.** Comparison between modeled and observed polarization for the star HIP 77332. Model configuration by Jansson (2012) with  $ma=2$ .



**FIGURE 5.** A plot of visual extinction ( $A_V$ ) as a function of distance. The observed data are shown as red points, and the model predictions are represented by blue points. Jansson (2012) model with  $ma=2$

- Performing a detailed comparison between the model and observations by separating the stars into distinct populations: foreground (in front of the cloud), embedded (within the cloud), and background (behind the cloud);
- Further investigating the model’s parameter space to better suit the physical conditions of the target clouds;
- Cross-matching our catalog with the HI4PI survey (2016) for HI column density;
- Cross-matching our catalog with the Bailer-Jones et al. (2021) catalog for stellar distances not found in other surveys;
- Applying the Davis-Chandrasekhar-Fermi method to estimate the magnetic field strength and model its structure using the combined dataset.

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**FIGURE 6.** From the Stars HIP77332 From the top (1) Polarization Histogram: Jansson (2012) model with  $ma=0$ . (2) Polarization Histogram model: Jansson (2012) model with  $ma=2$ . (3)  $P/A_V$  Histogram Jansson (2012) model. (4) Position Angle Histogram Jansson (2012) model.

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