An empirical microphysical determination of cosmic ray transport in the Gould's Belt

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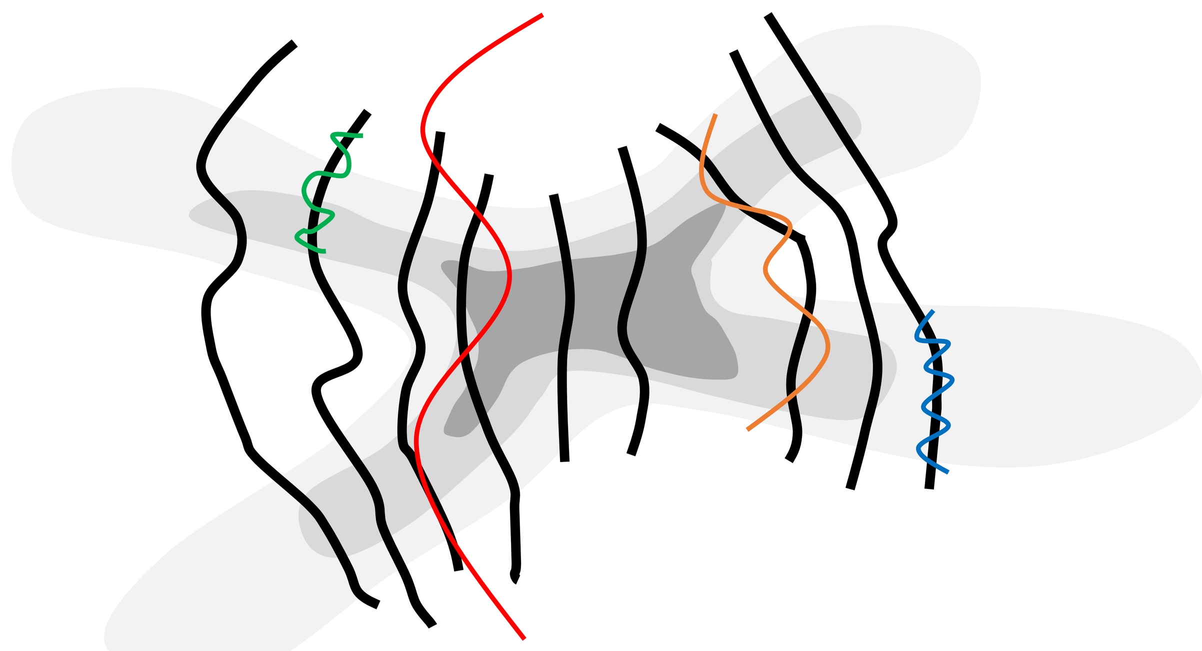
Abstract

Cosmic rays (CRs) are key drivers of ionization, heating, and chemistry in molecular clouds, but their propagation through complex, magnetized environments remains uncertain. Traditional estimates of the CR diffusion coefficient rely on large-scale observations and lack direct connection to the microphysics of CR transport. We present a new empirical method to estimate the CR diffusion coefficient based on small-scale magnetic field properties. Using 850 μm dust polarization data, we derive magnetic field strengths via the angular dispersion function and extract the magnetic power spectrum through Fourier analysis. These measurements allow us to characterize CR propagation grounded in gyro-scale physics. Applying our method to JCMT observations of clouds in the Gould's Belt, we estimate the diffusion coefficient at TeV energies. This work provides a first validation of the method and opens the door to future applications at lower CR energies using high-resolution ALMA data.

Method

We assume that the background magnetic field varies over scales much larger than both the magnetic fluctuations and the gyroradii of cosmic rays (CRs). Under this approximation, the diffusion coefficient can be estimated as follows:

1. **Angular Dispersion Function** - Characterizes the field fluctuations over scale ℓ :
   $S_2(\ell) = \frac{1}{N_{pair}} \sum_{i=1}^{N_{pair}} [\varphi_i(s+\ell) - \varphi_i(s)]^2$
2. **Power Spectrum** - Obtained via the Wiener–Khinchin theorem:
   $\hat{P}(k) = \frac{1}{2} \mathcal{F}[S_2(\ell)]$
3. **Magnetic Field Fluctuations Along Field Lines**
   $\mathcal{J}(\lambda_1) \equiv \int_0^{\lambda_1} d\lambda \frac{\lambda}{\lambda_1} \hat{P}_{\parallel}(k_c\lambda) + \int_{\lambda_1}^{\infty} d\lambda \frac{\lambda_1}{\lambda} \hat{P}_{\parallel}(k_c\lambda)$
4. **Spatial Diffusion Coefficient**
   $D \approx \frac{2c^2}{15 P_{\mu\mu}}\ , \ P_{\mu\mu} \approx \frac{\mathcal{J}(\lambda_1)}{v_A \lambda_1} \left(\frac{\omega_L B_0}{B}\right)^2 \mathcal{I}_{\perp}$



Cosmic ray propagation in the molecular cloud. The black lines represent magnetic field lines; the red line corresponds to a higher-energy CR, and the blue line to a lower-energy CR.

Diffusion Coefficient