Helical Magnetic Fields in Molecular Clouds?

A new method to determine the line-of-sight magnetic field structure in molecular clouds

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1) Objective

Magnetic fields (B) are ubiquitous in the interstellar medium and are believed to be important in the process of star formation, yet probing magnetic fields in star forming regions is challenging. We propose a new method to use Faraday rotation measurements in Molecular Clouds (MC), to find the direction and magnitude of the component of B along the line-of-sight.

2) Faraday Rotation

When linearly polarized light passes through a magnetized region with free electrons, its plane of polarization rotates. The amount of rotation is given by:

$$\Psi = \lambda^2\left(0.812\int n_e \mathbf{B}\cdot\mathbf{dl}\right) = \lambda^2 \mathrm{RM}\ [\mathrm{rad}] \quad (1)$$

- Ψ: the amount of rotation [rad].
- λ: the wavelength of the electromagnetic wave [m].
- n_e: the volume electron density [cm^{-3}].
- B: the magnetic field in the region [μG].
- dl: the path length element [pc].
- The quantity in parenthesis: Rotation Measure (RM).
- B·dl is the line-of-sight component of magnetic field (B_{LOS}) multiplied by the path length along the line-of-sight.

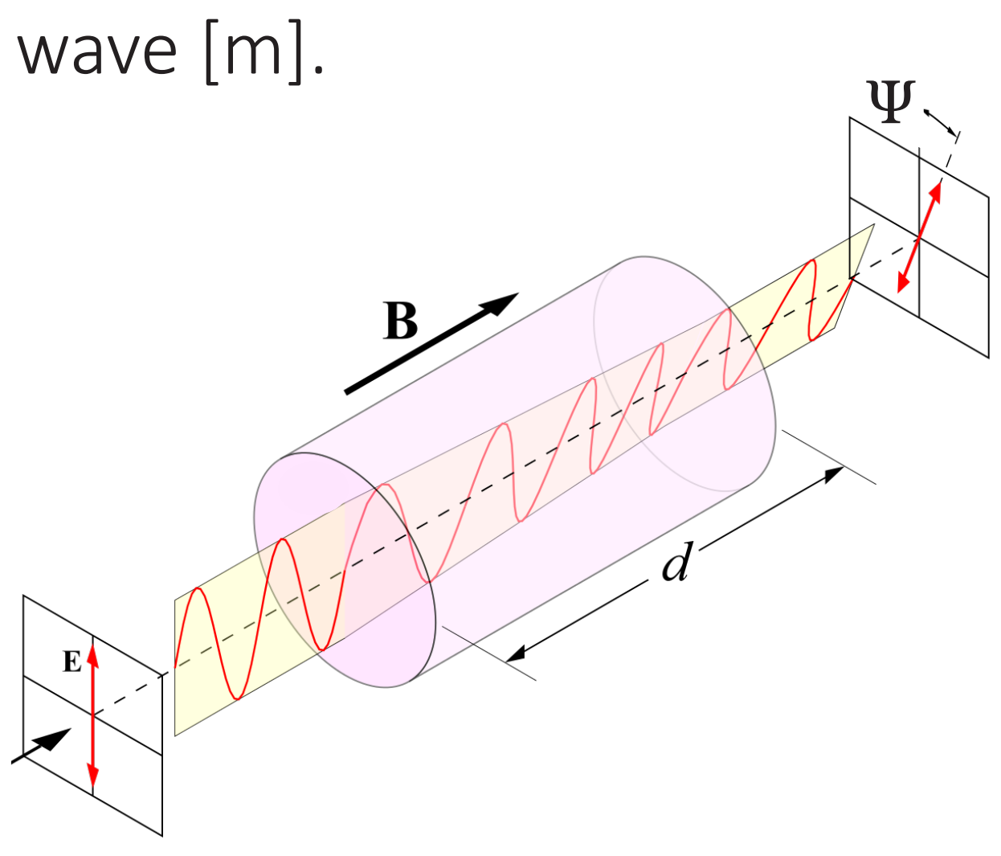

Fig. 1 Faraday Rotation Effect

3) Methodology

3a) Decoupling Galactic and MC Contributions

- We use the RM catalog from Taylor et al. 2009 [ApJ, 702, 1230].
- We visually identify OFF positions that are near the cloud and have $A_V < 1$ (see Kainulainen et al. 2009 [A&A, 508, L35]).
- We define ON positions that visually fall near or on the cloud and have $A_V > 1$.
- The RM of an OFF position is attributed to the Galaxy as a whole.
- The RM of an ON position is assumed to be a combination of the Galaxy and the MC.
- Since the ON and OFF positions are close to each other on the sky, subtraction of the two yields an estimate for the RM caused by the MC alone.

$$\mathrm{RM_{ON}} - \mathrm{RM_{OFF}} = \mathrm{RM_{MC}} = 0.812\left(\int n_e \mathrm{B_{LOS}dl}\right)_{\mathrm{MC}}$$

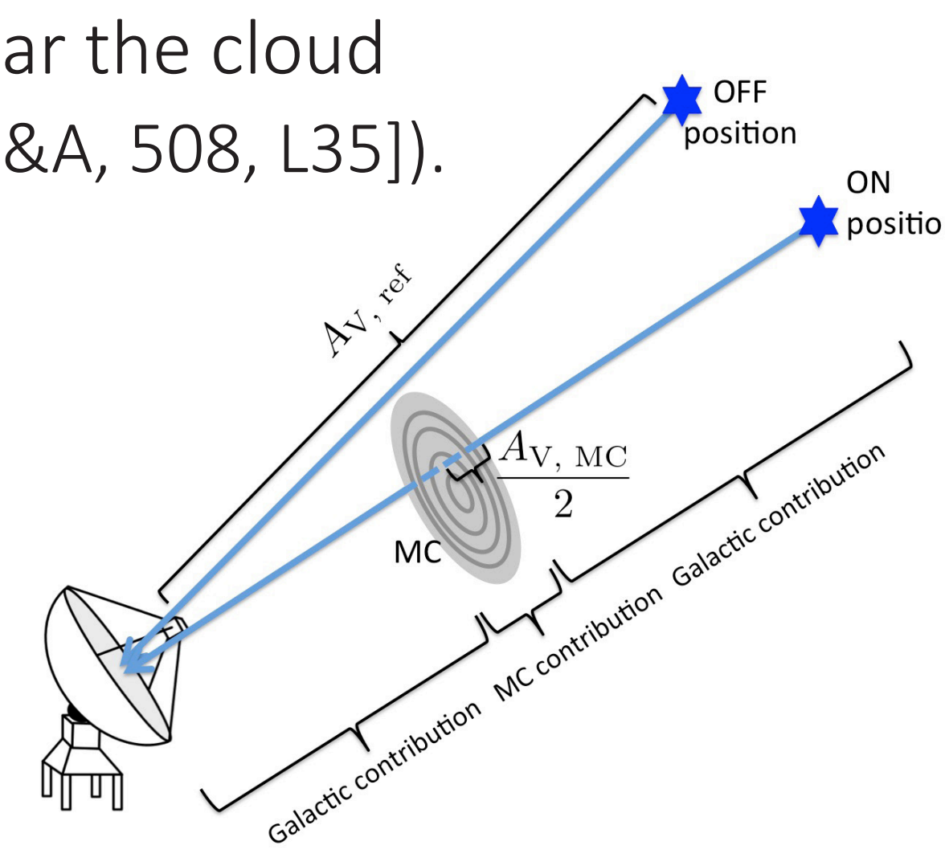

Fig. 2 ON and OFF illustration

3b) Finding electron densities inside MCs

- We find the visual extinction (A_V) at each RM point using the extinction maps of Kainulainen et al. 2009. A_V serves as a proxy for H_2 column density ($N(H_2)$).
- We solve the coupled chemical rate equations for a small network of ~250 reactions to obtain the electron abundance (X_e) as a function of A_V.
- For every RM point we obtain N_e from $N_e = X_e \times N(H_2)$.
- N_e replaces n_e dl in the RM equation.

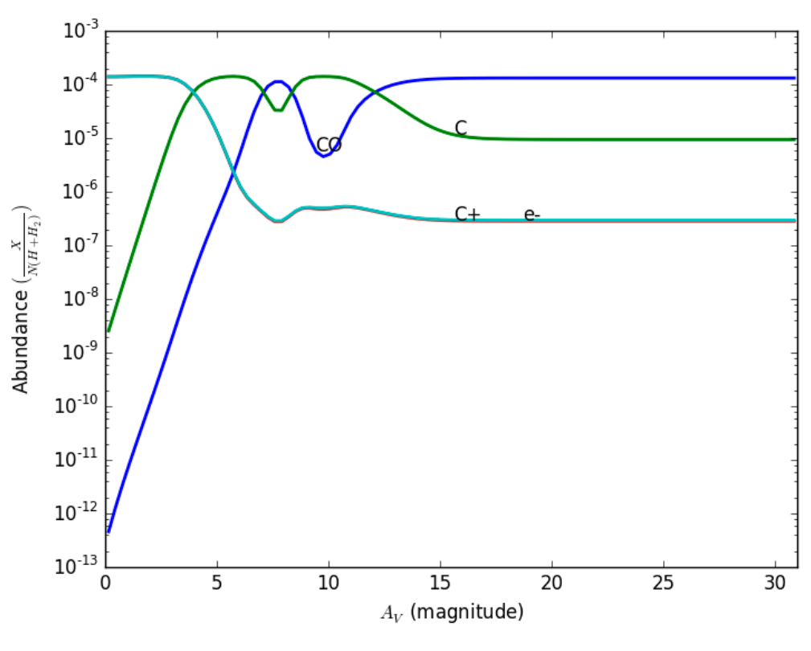

Fig. 3 Chemical Abundance Result

4) Published Results (Tahani et al. 2018 - Accepted in A&A, arxiv.org/abs/1802.07831)

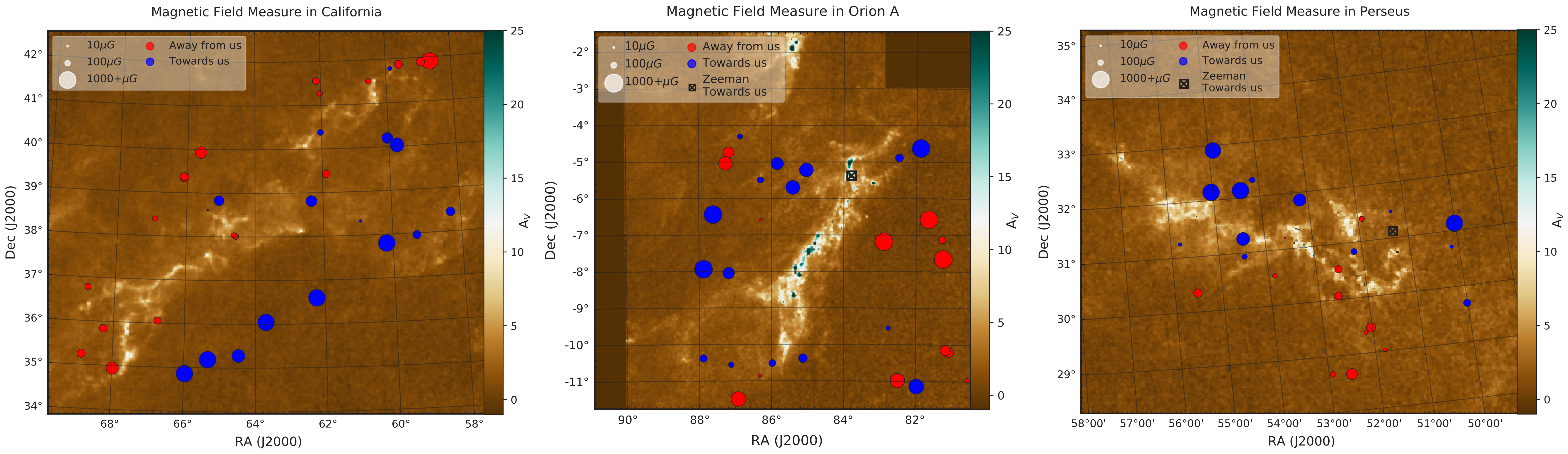

Fig. 4 Magnetic field maps for three of our four clouds.

4a) Zeeman Comparison

We apply our method to four clouds: the Orion A & B cloud complexes, the California molecular cloud, and the Perseus molecular cloud and find good agreement for B_{LOS} (both in magnitude and direction) with estimates from a limited number of Zeeman measurements in the same regions. Above we show three of these clouds.

4b) Helical Magnetic Fields?

In Orion A and California MCs we see an evidence for magnetic field reversal from one side of these filamentary structures to the other. In the Perseus MC at first glance the magnetic fields seem to suggest the same morphology, but there are too few data points to make a strong conclusion. These reversals could be an indication of a helical magnetic field threading these filamentary structures.

5) In progress theoretical and observational work

5a) 3D Magnetic Fields in Orion A

(M. Tahani, R. Plume, J. Brown, and J. Soler, 2018, in prep)

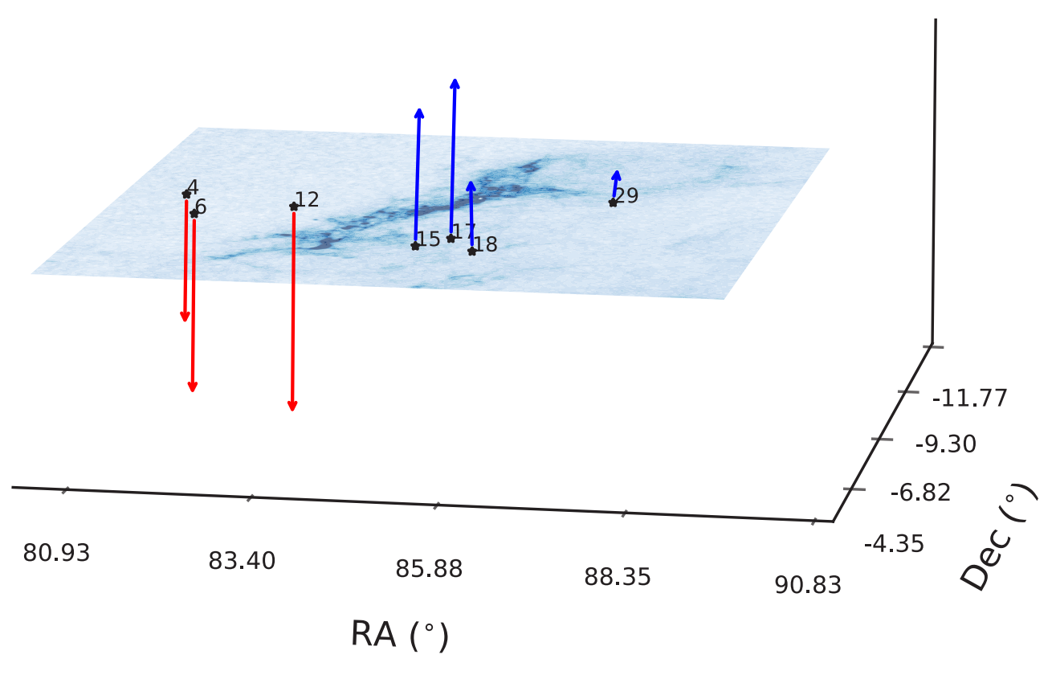

Fig. 5 A 3D visualization of magnetic field in Orion A

We combine the Planck magnetic field results (perpendicular to the line-of-sight) with our B_{LOS} values to investigate the 3D magnetic field morphology in Orion A. Initial results suggest that the 3D field can be consistent with a helical magnetic field as well as the magnetic field bending as the result of shocks, a scenario suggested by Heilies 1997 [ApJS, 111, 245].

5b) Magnetohydrodynamics Simulations

(In collaboration with R. Pudritz & D. Seifried)

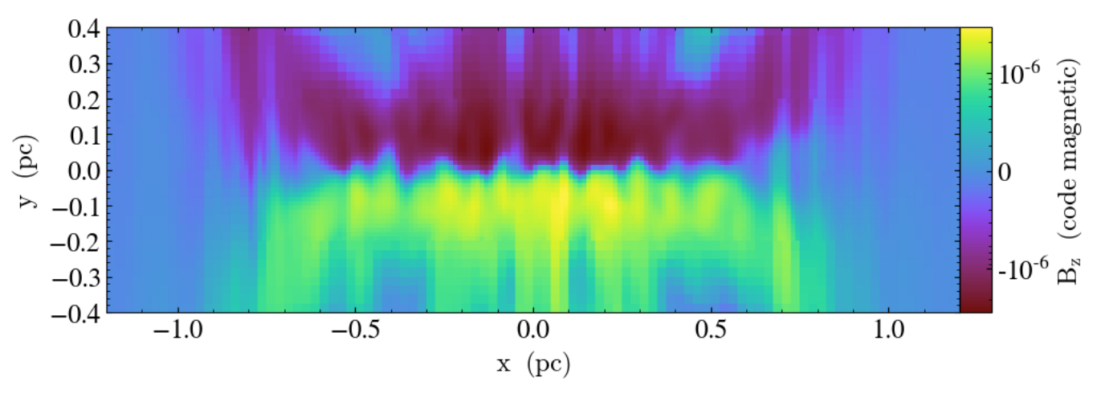

Fig. 6 Signature of magnetic field reversals seen in a small filament. Helicity has not yet been detected in these simulations.

We are simulating magnetic field evolution in cylindrical filaments to determine if we can match our observations of magnetic field reversals. So far, while we can simulate magnetic field reversals in different sections of a filament (see Fig. 6), these are not produced by helical fields in the simulations but are the result of magnetic field bending due to self-gravity.