STATISTICAL ANALYSIS OF THE RELATIVE ORIENTATIONS BETWEEN FILAMENTS AND MAGNETIC FIELDS IN STAR FORMING REGIONS

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Abstract. Filamentary structures are ubiquitous in the interstellar medium (ISM). This is particularly true in molecular clouds, with most clumps and cores forming inside the densest regions of filaments. Both simulations and observations suggest that magnetic fields play a key role in the formation and evolution of filaments and in the process of star formation. In this context, the study of the relative orientations between filaments and magnetic fields has become a go-to method to obtain new insight. Here, we use a dedicated method, FilDReaMS, to detect and extract filaments at multiple scales in the 116 fields of the *Herschel* 'Galactic Cold Cores' (GCC) key-project (18"−36" resolution), which measures dust emission in star-forming regions located in various Galactic environments. We then compare the filament orientations to the orientation of the plane-of-sky magnetic field ($\boldsymbol{B}_{\perp}$), inferred from *Planck* observations of the dust polarized emission (7' resolution). We present the results of our statistical analysis of these relative orientations as functions of filament spatial scale, gas column density (N_{H_2}) and Galactic environment. In most *Herschel* fields, we find that small, low-N_{H_2} filaments tend to be roughly parallel to the magnetic field, while large, high-N_{H_2} filaments tend to be roughly perpendicular. Although this trend is not systematically observed, it is still prevalent, which confirms the existence of a coupling between magnetic fields at cloud scales and filaments at smaller scales.

Keywords: ISM: clouds - ISM: structures - ISM: magnetic fields - dust - infrared - ISM: submillimiter - ISM: techniques - image processing

1 Introduction

In star-forming regions, prestellar and protostellar cores are mostly located in dense filaments (André et al. 2014). Hence, the early stages of star formation are linked to the formation and evolution of filaments. The main physical actors involved are gravity, turbulence and magnetic fields. However, their actual roles and interplay are still poorly understood (McKee & Ostriker 2007). To make progress in our physical understanding, different scales must be probed, from molecular clouds to filaments, clumps and cores. Statistical analyses based on the *Planck* survey show that filaments in the diffuse ISM are mostly parallel to the plane-of-sky magnetic field ($\boldsymbol{B}_{\perp}$), while in molecular clouds, there appears to be a transition from parallel to perpendicular relative orientations at a column density $N_{\mathrm{H}} \sim 5.0 \times 10^{21}\,\mathrm{cm}^{-2}$ (Planck Collaboration et al. 2016a,b). In a combined *Herschel*-*Planck* analysis of a high-latitude star-forming cloud, Malinen et al. (2016) found evidence for a similar transition at $N_{\mathrm{H}} \sim 1.6 \times 10^{21}\,\mathrm{cm}^{-2}$; they would have found a value consistent with *Planck*'s had they used the same convention for dust opacity.

Our purpose is to study the statistics of the relative orientations between filaments and $\boldsymbol{B}_{\perp}$ as functions of the physical properties of the local gas and Galactic environment.

2 Method: FilDReaMS

We use our new filament detection method FilDReaMS, for Fil*ament* D*etection and* Re*construction* a*t* M*ultiple* S*cales*, presented in Carrière et al. (2022a,b). We apply FilDReaMS to the 116 fields of the *Herschel* GCC program (18"−36" resolution; Juvela et al. 2010). In short, FilDReaMS uses a rectangular template (a bar of width W_{b}) to search for filamentary structures in an image, then repeats this process over a whole range of

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bar widths. Thus, FilDReaMS provides information on the widths of filaments, their column densities, their orientations and the robustness of the detection.

In a second step, we study the filaments' orientations relative to the orientation of $\boldsymbol{B}_\perp$ inferred from *Planck* observations of the dust polarized emission (7 ' resolution), and we do so at multiple scales.

3 Results

In Fig. 1, we present an example of the analysis performed for one of the GCC fields. We show the N_{H_2} map of the *Herschel* G132 field as well as all the filaments obtained with FilDReaMS, together with their bar widths W_b. In Fig. 2, we show 2D histograms of the relative orientation angles between filaments and $\boldsymbol{B}_\perp$ ($\psi_f^* - \psi_B$) as functions of N_{H_2}, for all the detected filaments. The filaments are split into 3 ranges of W_b defined by the smallest (S), largest (L) and all intermediate (M) values of W_b.

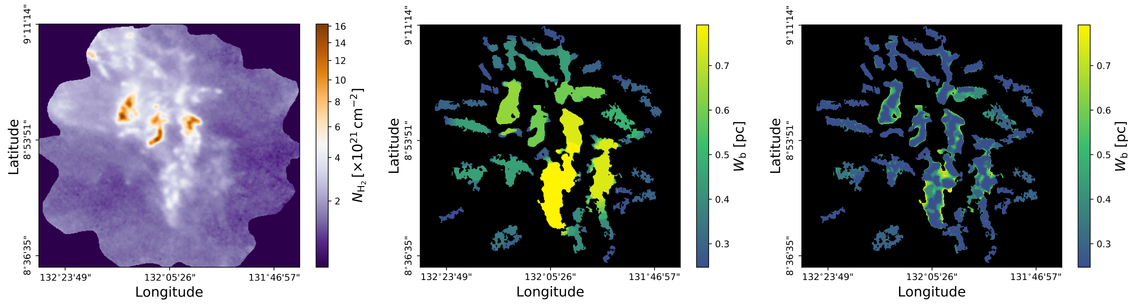

Fig. 1. G132 - **Left:** N_{H_2} map. Detected filaments, with the larger (**Middle**) and the smaller **Right** in the foreground.

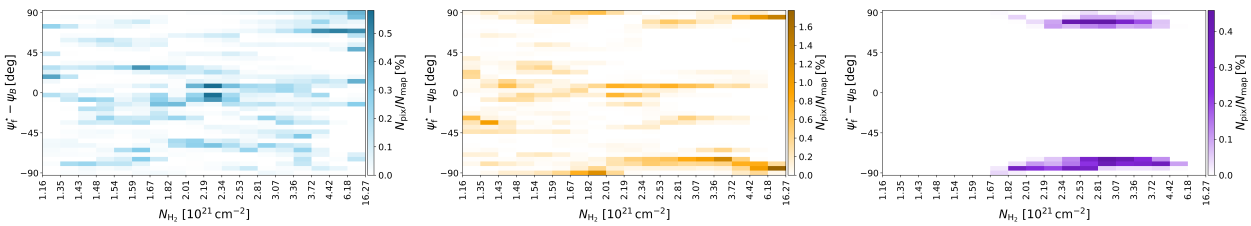

Fig. 2. 2D histograms for G132 - **Left:** S filaments. **Middle:** M filaments. **Right:** L filaments.

We combine the analyses of all 116 fields in order to identify statistical trends in the relative orientations between filaments and $\boldsymbol{B}_\perp$. The general trends we find agree with previous studies: smaller filaments at lower N_{H_2} are mostly parallel to $\boldsymbol{B}_\perp$, while filaments at higher N_{H_2} are mostly perpendicular to $\boldsymbol{B}_\perp$, with a transition from parallel to perpendicular to $\boldsymbol{B}_\perp$ occurring at $N_{\mathrm{H}_2} \in [0.8, 2] \times 10^{21}\,\mathrm{cm}^{-2}$. However, over 30% of the GCC maps show different results, with either filaments mostly parallel to $\boldsymbol{B}_\perp$ at all scales and N_{H_2}, or opposite transitions from perpendicular to parallel to $\boldsymbol{B}_\perp$ at higher N_{H_2}, or absence of clear preferred orientations.

This is work in progress. What we would like to do is identify the actors responsible for the different trends, such as dust polarisation fraction, large-scale magnetic field orientation, evolutionary stage of cores, etc.

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