Fragmenting Filaments and Evolving Cores - Insights from Dust Polarisation Study of a filament in Northern Orion B

Kshitiz K. Mallick[1], Doris Arzoumanian[2], Satoko Takahashi[1,3], Ray S. Furuya[1,4], Yoshiaki Misugi[1,5], Yoshito Shimajiri[6], Kate Pattle[7], Shu-ichiro Inutsuka[8]

[1]NAOJ; [2]Kyushu University; [3]SOKENDAI; [4]Tokushima University; [5]Kyushu Sangyo University; [6]Kyushu Kyoritsu University; [7]University College London; [8]Nagoya University

Abstract

We present analysis results of polarised dust emission at 850 μm for a parsec long filament in the northern part of the Orion B molecular cloud. The region was observed by the JCMT SCUBA-2/POL-2 polarimeter. The filament has a line mass ($\sim$80 $M_\odot$ pc^{-1}) larger than the critical (magnetic) line mass ($\sim$37 $M_\odot$ pc^{-1}); and hosts one starless, three prestellar, and four protostellar cores, with masses in the range 0.13 to 9.13 $M_\odot$. The mean (debiased) polarisation fraction of the filament and core pixels was calculated to be 5.3$\pm$0.3% and 3.2$\pm$0.3%, respectively, likely reflecting their distinct physical conditions. The polarisation fraction for the cores does not depend on the type of core, and was found to decrease with increasing column density, varying from 6-11% at the filament edges to $1^{+0.7}_{-0.1}$% in the denser parts ($N_{H2} \gtrsim 2\times10^{22}$cm^{-2}). Magnetic field orientation of the protostellar cores, in contrast to prestellar cores, appears to be relatively aligned with the magnetic field orientation of the local filament in this region. Using the Davis-Chandrasekhar-Fermi formalism, the plane-of-sky magnetic field strength for the protostellar cores ($\sim$39-110 μG) was found to be higher than that of the prestellar cores ($\sim$22-61 μG); and weakest for the starless core ($\sim$6 μG). The average value for the filament was found to be $\sim$31 μG. The magnetic field-volume density relation for the prestellar/starless cores and protostellar cores suggests a transition from weak field case to strong field case as the cores evolve from prestellar to protostellar phase.

Overview of the Filamentary Region

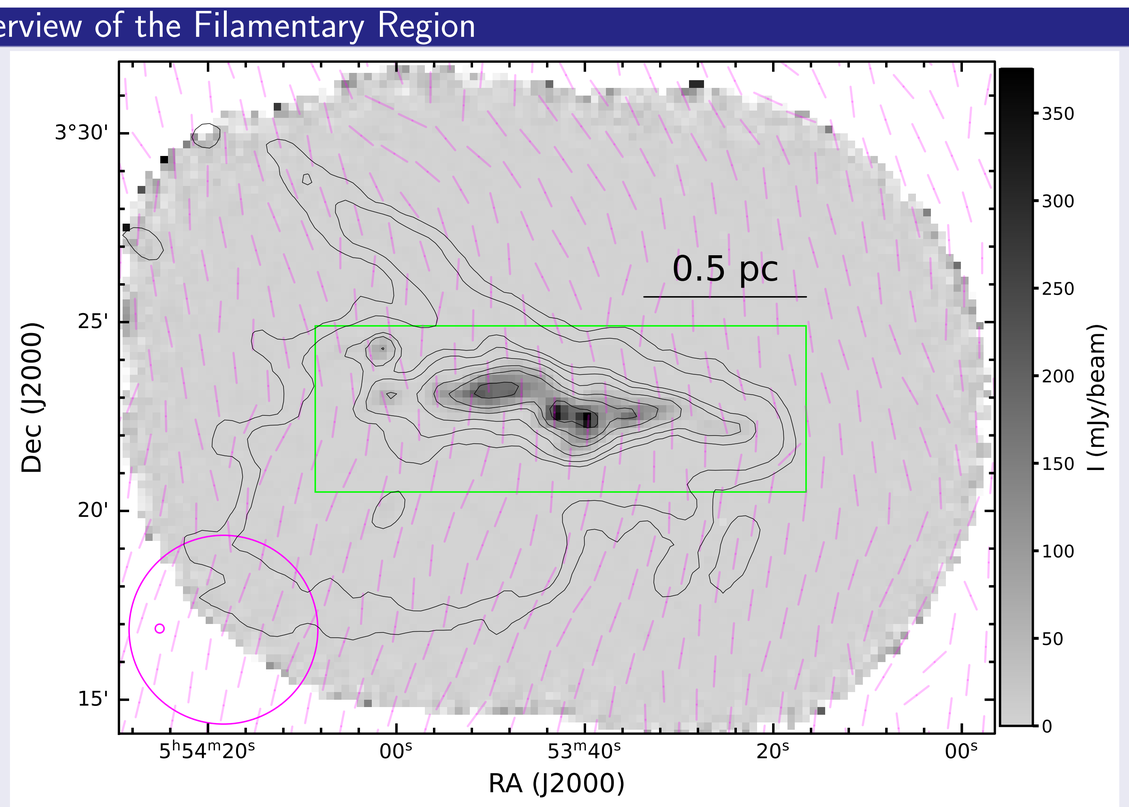


Figure 1: JCMT stokes I map of the observed region. Contours from the HGBS (*Herschel* Gould Belt Survey) column density map (resolution$\sim$18.2") are drawn at 0.2, 0.25, 0.55, 0.7, 1, 1.5, 2, and 3×10^{22} cm^{-2}. *Planck* magnetic field half-vectors are shown by magenta line segments. It should be noted that the *Planck* data is oversampled here. Magenta circles on bottom left show the *Planck* beam ($\sim$5') and the JCMT beam ($\sim$14"). Green box is the filamentary region analysed in this work.

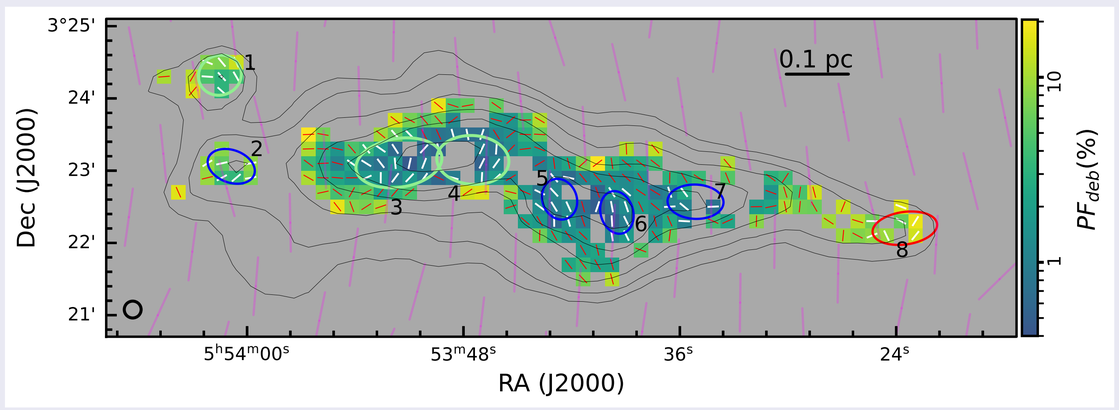


Figure 2: PF_{deb} (debiased polarisation fraction) image overlaid with HGBS sources. Red, Green, and Blue ellipses are the starless, prestellar, protostellar extended-core regions, respectively. Contours mark the N_{H2} thresholds of 0.55, 0.7, 1, 1.5, 2, and 3×10^{22} cm^{-2}. Red and white line segments denote the orientation of the POL-2 B_{pos} half-vectors (θ, measured east of north) for the filament and the cores, respectively. Magenta line segments show the magnetic field half-vectors from *Planck*. Black circle on bottom left shows the JCMT beam ($\sim$14").

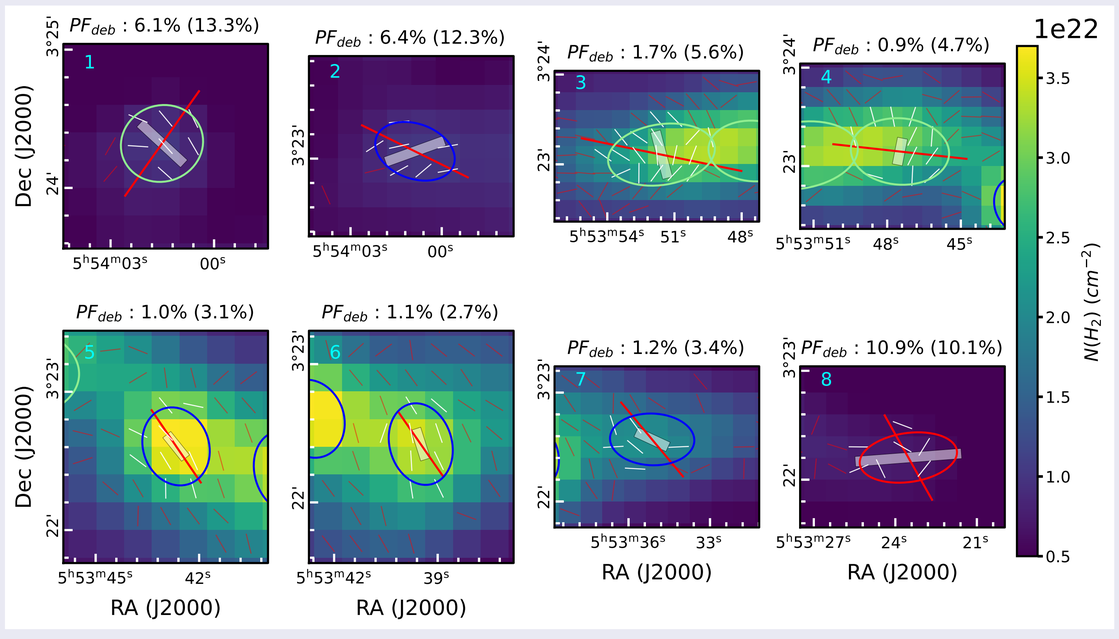


Figure 3: Zoomed-in image of the cores (and their respective neighbourhoods) overlaid on the column density map. Thicker red and cyan segments (in each subfigure) denote the mean θ of the neighbourhood (θ_{ngbr}) and the core ($\theta_{extCore}$), respectively. These two segments have been scaled by PF_{deb}; but for cores 1, 2, and 8, the lengths have been further scaled down by a factor of 3. At the top of each subfigure, mean PF_{deb} values for the core and the neighbourhood (in brackets) are given.

Transition from Weak to Strong field with Core Evolution ?

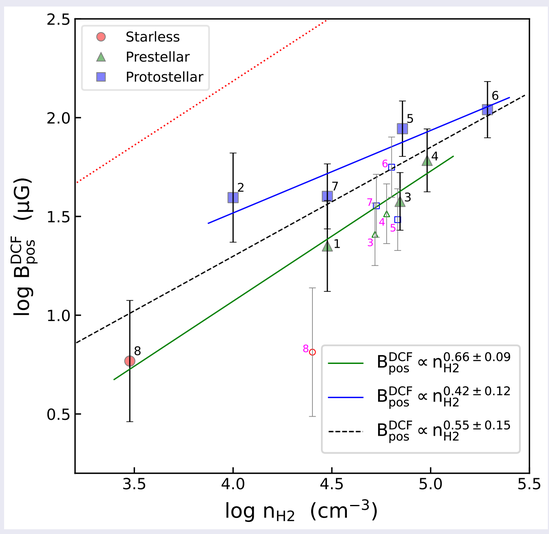


Figure 4: Log-log relation between B_{pos} and n_{H2} for the *Herschel* cores. The red dotted line is the relation from Crutcher et al. 2010 (slope$\approx$0.65 derived from Zeeman measurements). The filled symbols denote the core values and unfilled symbols the respective neighbourhood values. Both are labelled. The green line, blue line, and the black dashed line show the best straight line fit between log B_{pos}^{DCF} and log n_{H2} for the prestellar/starless cores (1, 3, 4, and 8), protostellar cores (2, 5, 6, and 7) and all the cores together, respectively.

The index for the prestellar/starless cores ($\kappa \sim 0.66\pm0.09$) indicates a weak field case. On the other hand, the more evolved protostellar cores ($\kappa \sim 0.42\pm0.12$) appear to be consistent with the strong field case. The overall value ($\kappa \sim 0.55\pm0.15$) lies between the two limits.

This analysis indicates a possible scenario wherein the prestellar/starless core stage could be dominated by weak field case, and there is a transition to strong field domain as the core moves along its evolutionary path to protostellar stage.

It could be that as a (prestellar) core permeated by a weak magnetic field collapses with flux-conservation (Mestel et al. 1966, MNRAS), then at some stage during the collapse, the (cross-sectional) area will become small but the total flux being the same, the field strength associated will now be higher. At this stage, the prestellar core is probably dense enough to transition to a protostellar stage, and the field strong enough to be called strong field case. Another possible reason could be a difference of condition of the respective local regions. The eastern part of the filament (see Figure 1) appears to to be joined by a secondary filament from its north. The flow of material along the secondary filament to the eastern part of the main filament could be affecting the physical conditions there. The western part with protostellar cores 5, 6, and 7 is devoid of such an effect.

Comparison of Core Properties with Filament

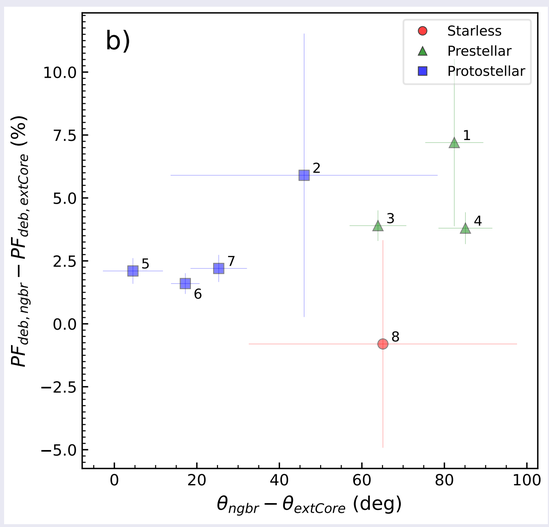


Figure 5: Difference of core values from their respective neighbourhood values. The x-axis is the difference in orientations of the magnetic field, and the y-axis is the difference in debiased polarisation fractions.

The neighbourhood shows a higher polarisation fraction than the core for all except core 8. Considering only core regions 3-7 in the dense part of the filament for our analysis, we find that prestellar cores appear to have a larger deviation, both in PF_{deb} and θ, than the protostellar cores. Thus overall, there is a clear separation here between the prestellar and protostellar cores in how they relate to the values of their respective neighbourhoods.

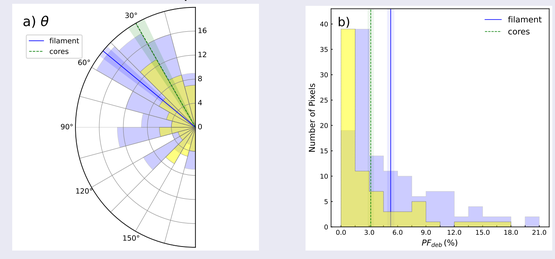


Figure 6: *(a)* Polar histogram of θ (orientation angle of B_{pos}). *(b)* Histogram of PF_{deb}. The distributions for the filament and extended-core regions are shown in blue and yellow, respectively; and the mean values as blue lines (50$\pm$3 degrees and 5.3$\pm$0.3%) and green-dashed lines (30$\pm$4 degrees and 3.2$\pm$0.3%), respectively. The color spans on either side of the mean vertical lines show the error on the mean.

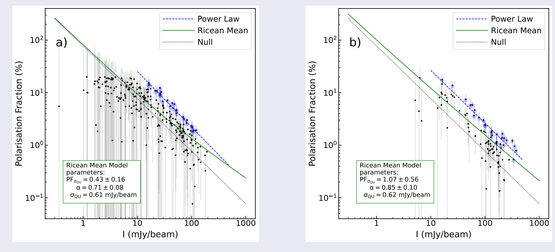


Figure 7: *(a)* Polarisation Fraction vs. stokes I relation for all the filament/non-core pixels. In both panels, black dots denote the observed polarisation fractions (PF) of all the pixels, i.e. no selection of pixels has been carried out using any (SNR) criteria, except PF $\leq$20%. They are used for the Ricean Mean Model fit shown by the green curve. Blue circles, on both panels, mark the debiased polarisation fractions (PF_{deb}) of pixels satisfying the high SNR criteria used for single-power law fitting (dashed-blue curve). Black dashed curve shows the null hypothesis. The fitted parameters for the Ricean Mean Model are also given.

Examination of polarisation parameters for the filament and the core regions shows a smaller polarisation fraction for the cores. The polarisation fraction as a function of intensity is given by $PF \propto I^{-\alpha}$, wherein we calculated the value of α for the filament (0.71$\pm$0.08) and the cores (0.85$\pm$0.10) separately by applying the Ricean Mean Model. The α values, along with the smaller polarisation fraction of the cores, suggest a combination of loss of grain alignment and change in structure of the field between the filament and the cores.