Molecular Filamentary Clouds, Structures and Polarization

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Abstract. We are concerned with the formation and physics of interstellar molecular filaments with wavy, sinusoidal shapes. We present NOT images of small-scale, helical structures in an elephant trunk in the Rosette nebula suggesting the presence of helical magnetic fields. These imply the presence of electric currents in the trunk. We also present the results of an extensive and deep mapping of the linear polarization of stars in three regions with molecular filaments. The observations were made with the CCD polarimeter at NOT, and show that the dark filaments add very little to the background polarization of stars in the areas. We have modeled the filamentary clouds observed and calculated the polarization.

1. Introduction

Molecular filaments with wavy, sinusoidal shapes are apparent on the very large scales, as seen on sky maps of H I (Hartmann & Burton 1997; Verschuur 1991), as main building blocks in giant molecular clouds such as the Orion GMC (see e.g. Bally 1989), and in clouds of intermediate and small sizes. The architecture of individual clouds is affected by changes in the environment but also by internal forces produced, for instance, by star formation in the clouds. It has become increasingly clear that magnetic fields are of vital importance for the structure and dynamics of the clouds. Knowledge of the magnetic field structure is therefore important for the interpretations.

Magnetic field strengths of some ten μG have been measured by means of methods relying on Zeeman splitting (e.g. Crutcher et al. 1993). The direction of the field can in principle be obtained by measuring the direction of linear polarization of light from background stars on the assumption of an alignment of elongated dust grains in the field (Davis & Greenstein 1951). It was long thought that such polarization outlined the magnetic field structure inside the clouds. Two new aspects of this picture have become apparent. The first is that in certain cloud regions there is a large spread in position angle, and in some cases even a bimodal distribution (Goodman et al. 1990; Myers & Goodman 1991). The second is that when overviewing degree and direction of polarization in larger areas around the clouds, it is not directly evident that dark clouds add much of intrinsic polarization over that of the general field (Goodman et al. 1995; see also Gerakines et al. 1995).

For most theories on the formation of dark filaments, magnetic fields play a dominant role (see e.g. Shibata & Matsumoto 1991; Hanawa et al. 1993; Lazarian 1993; Nakamura et al. 1995; Gehman et al. 1996; Nakajima & Hanawa 1996; Padoan et al. 1998). The possibility that sinusoidal and helical structures develop as a consequence of helical magnetic fields along the filaments accompanied by electric currents was considered by Carlqvist & Gahm (1992), and applied to large-scale H I filaments by Verschuur (1995). A consequence of the helical geometry of the magnetic field is that bimodal distributions, "flips" of 90°, in the position angles can arise (Carlqvist & Kristen 1997). However, the degree of polarization is expected to be very small due to frequent collisions between particles. Other possibilities have been listed by Goodman et al. (1995).

In the present paper we present NOT observations of filamentary clouds, including direct imaging of an elephant trunk in the Rosette nebula showing evidence for helical magnetic field structures, and CCD polarimetry of three filamentary cloud regions. Theoretical models of filamentary structures and their polarizing capabilities are considered.

2. Observations

Direct imaging in the B-band of a Rosette elephant trunk was made with the TEK1024 CCD at NOT. Polarization observations in a total of 11 CCD-fields in three filamentary cloud regions, the L1400 complex, L204 and MBM25 were carried out with a Tex512 CCD at NOT in 1993 and 1994. Images were obtained through a linear polarizer (7500 - 22000 Å), and a broad band filter (cut-on at 6750 Å) giving an effective band approximately corresponding to the Johnson I filter. The total field of view is 170" with a pixel size of 33". For each position in the sky the polarizer was rotated through at least 2 cycles of 0°, 45°, 90°, and 135° in rotation angle. The reductions relied on careful aperture photometry. Near-infrared H and K band imaging of an area in the L1400 complex was performed with the ARcetri Near Infrared CAmera at NOT (Arnica, a 256×256 NICMOS3 detector).

3. Results and Discussion

The clouds were selected because they are composed of thread-like, wispy filaments, which may indicate special arrangements of the magnetic field substructure in the clouds, and because these cloud regions appear to be relatively undisturbed by star formation. In particular, the Rosette trunk is a magnificient example of long, twisted dark filaments, apparent also in other regions like the Lagoon nebula (Caulet 1997). From extinction maps derived from the B-image presented in Fig. 1 (left) we conclude that the trunk is composed of helical subfilaments, like a coaxial cable of dark ropes, some of which are not resolved at the limit of resolution corresponding to 1600 au at the distance of the trunk. We propose that this structure most likely results from a helical magnetic field along the trunk axis, which in turn *implies* the presence of electric currents along the trunk (see Carlqvist et al. 1998).

Our polarimetric survey of the three filamentary regions mentioned above yields magnitudes, in the I band, and both the degree and direction of linear polarization with satisfactory accuracies for a 387 stars down to magnitude I = 19.5. Since the majority of these stars are background objects this opens the possibility to study possible small-scale irregularities in the polarization patterns on angular scales down

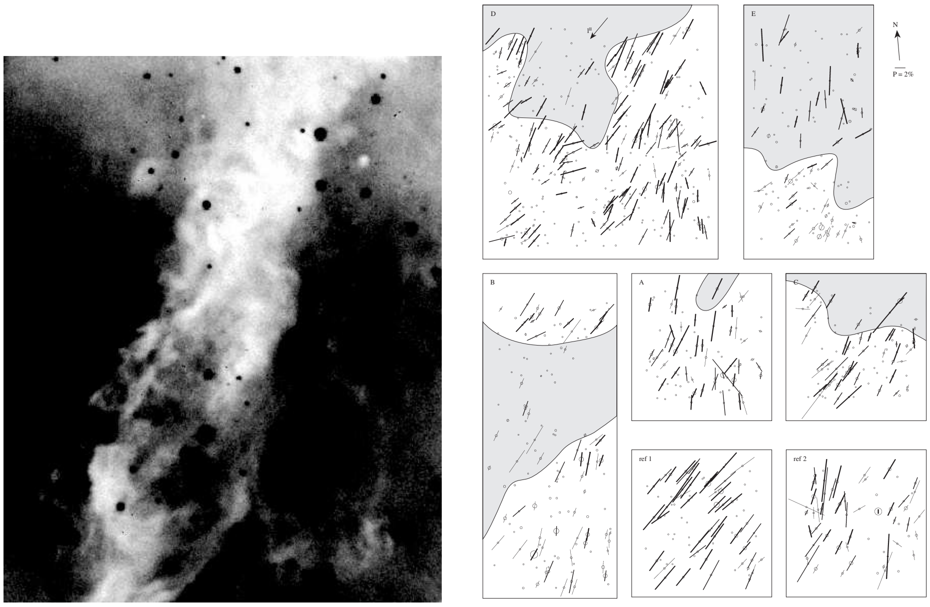

Figure 1. *Left: NOT B-image (144"x180") showing the system of helix-like, interwoven dark filaments in reversed intensity. Right: Results of the polarimetry in the direction of the L1400 complex for stars brighter than I=19.5 mag. The regions A to D cluster around α = 4h 30m, δ = +55°. Each reference field (ref 1 and 2) covers one CCD field. The north direction is indicated by an N arrow. The length of the polarization vector correlates linearly with the degree of polarization, and the scale is indicated by the key, corresponding to P = 2%. The galactic longitude direction is indicated by the arrow in the upper left panel. Notice that the pattern of polarization is very smooth and homogeneous over this complex with no apparent difference between obscured (grey) and non obscured (white) regions.*

to a few arc seconds. This high sensitivity and spatial resolution obtained with the NOT is superior to what has been achieved before. Typical uncertainties in polarization angle is only 10°, and for the polarization degree ΔP/P $\sim$ 0.3. In addition, we derived extinctions from star counts and H-K colour excesses.

The main result of this investigation is that the patterns of polarization are remarkably smooth over the fields, particularly in the L1400 complex as seen in Fig. 1 (right), and there is no indication of any statistically significant difference in polarization degree and angle between obscured and non-obscured regions. Hence, the interstellar filaments produce a negligible contribution to the total interstellar polarization. This is in line with and emphasizes recent results obtained for other cloud regions by e.g. Arce et al. (1998).

We have also calculated the expected degree of polarization in the three clouds studied, based on the Davis-Greenstein mechanism and simplified geometries of the clouds. We derive intrinsic polarizations that are considerably smaller than the typical background polarization, a result in agreement with the polarimetric results.

Finally, we like to point out that dark filaments can contain molecular clumps, as found e.g. for the extended, serpentine-like, dark filaments in Chameleon III by Gahm et al. (1998).

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