The Magnetic Field Structure at the Small Magellanic Cloud

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Abstract

- The Small Magellanic Cloud (SMC) is a gas rich dwarf irregular galaxy where the magnetic field can be strong enough to influence the interstellar medium dynamics.
- Together with the Large Magellanic Cloud (LMC), the SMC orbits the Milky Way and it is believed that the Magellanic Bridge, a structure linking the LMC and SMC, was formed due to a past collision between them.
- Hence, the aim of this project is to study the magnetic field structure in regions of the SMC supposedly affected by this past collision.
- For this purpose we have used optical polarimetric data obtained in Cerro Tololo Inter-American Observatory (CTIO) for 28 fields in the northeast and wing sections of the SMC.
- The polarization vectors trace the direction of the sky-projected magnetic field. Our data analysis shows that the main pattern of the magnetic fields is aligned with the Magellanic Bridge.
- In addition, it was possible to estimate the magnetic field intensity using the Chandrasekhar & Fermi method, which uses the spread of the polarization vectors. The weighted average for the uniform magnetic field component is $\mathbf{B} = \mathbf{(2.86 \pm 0.30)\mu G}$ and, for the random component, we find $\delta\mathbf{B} = \mathbf{(3.52 \pm 0.32)\mu G}$.

The Data

The data were obtained using CCD optical imaging polarimetry in a 1.5m telescope at Cerro Tololo Inter-American Observatory (CTIO).

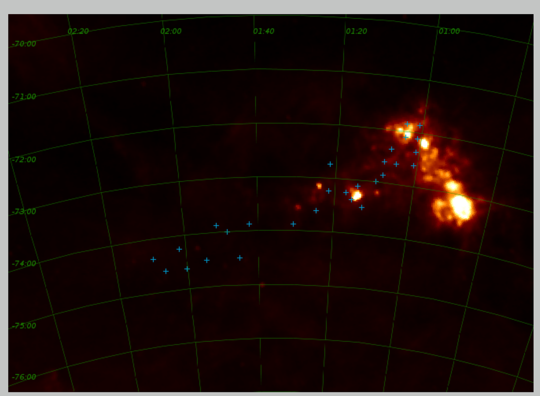

Figure: Positions of the CCD observed fields superimposed over an IRAS 100μm image.

- **Instrument:**
  - half-wave retarder plate + calcite + V filter.
- **Method:**
  - 4 plate positions to measure the Stokes parameters Q, U, -Q and -U.
  - 300s of exposure time per plate position.
- **Fields:**
  - 28 fields with 8x8 arcmin in the Northeast and Wing sections.

Data Reduction

The reduction was performed utilizing the software IRAF following the steps below:

- Instrumental noise elimination:
  - Overscan subtraction for eletronic noise.
  - Bias subtraction for read noise.
  - Flat-field correction for background noise.
- We did measurements of the non-polarimetric standard star HD9540 and concluded that there was no instrumental polarization.
- Calibration to the equatorial system was made using the polarimetric standard stars:
  - BD25727, HD23512 and HD298383.
- The photometry and polarimetric parameters were obtained utilizing the IRAF task quickpol (developed by the Polarimetric Group of USP).

Foreground Polarization

Due to the fact that SMC is an extragalactic object, we have to take into account the polarization caused by the dust present in our own Galaxy and subtract this from the observed polarization to get the instrisic one.

- Despite there are estimations for the foreground polarization from Schmidt (1976) and Rodrigues et al. (1997), neither of them have estimations for all the fields we have observed.
- So, we developed a method to estimate the foreground polarization from our own data, which is based on:
  - All fields have stars that have no polarization, but the values measured never reach P=0%.
  - When the polarization changes on a rate larger than 2, and the polarization angle from a diference larger than 20 deg, we assume that at this point the stars start to have intrinsic polarization rather than foreground.
  - To decide the values, for each field we plotted graphics for $\langle \mathbf{P} \rangle$ vs $\mathbf{P_{max}}$, $\langle \theta \rangle$ vs $\mathbf{P_{max}}$ and $\langle \theta \rangle$ vs $\mathbf{N_{stars}}$, and looked for the point where the conditions above are reached.
  - We have used just stars with $\frac{P}{\sigma_P} > 3$.

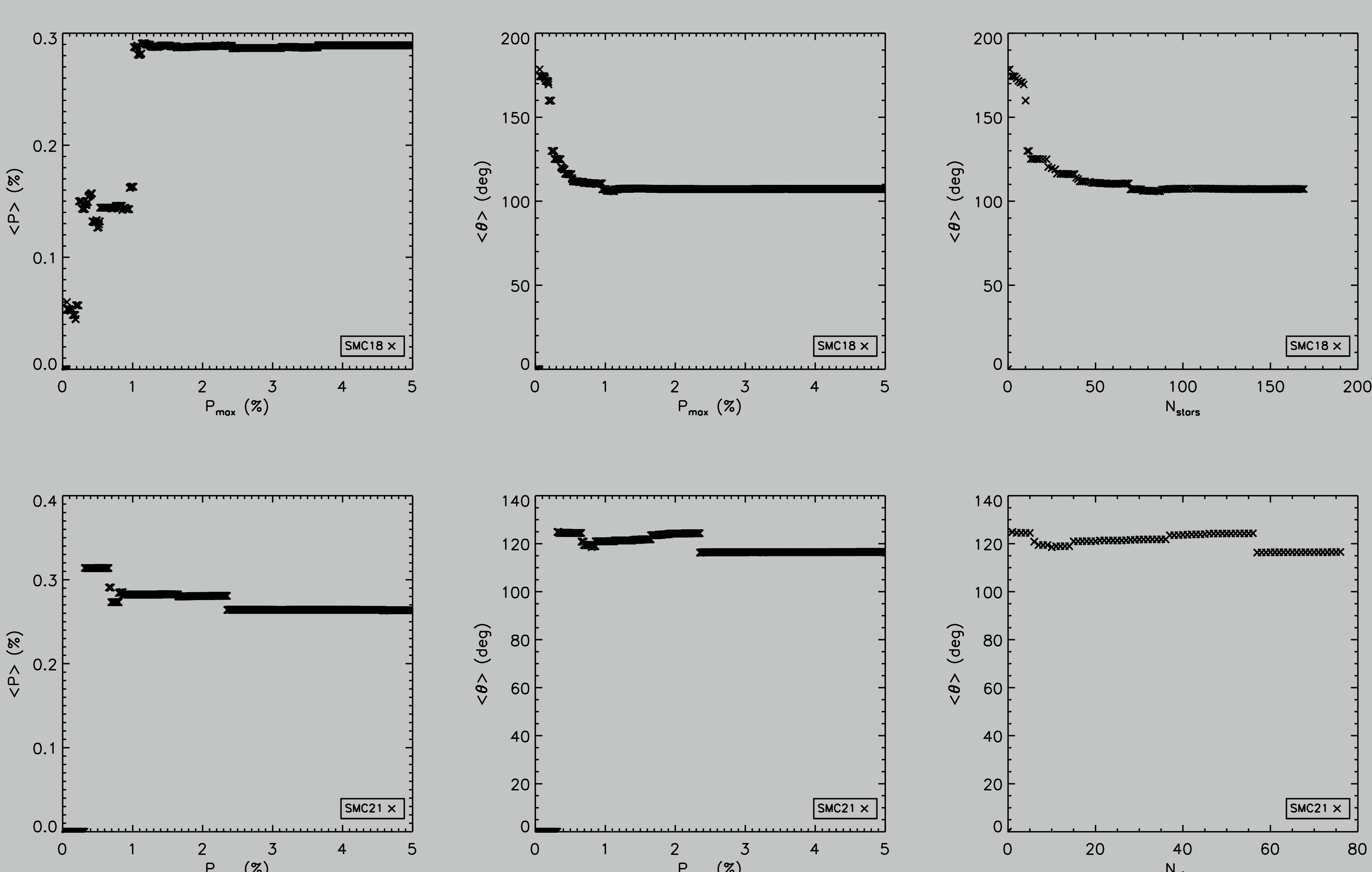

Figure: Example of graphics for two fields. In the first one it was clear when the stars have just foreground polarization (smc18), while in the other one (smc21) it is not so easy to determine this point.

Polarization Map

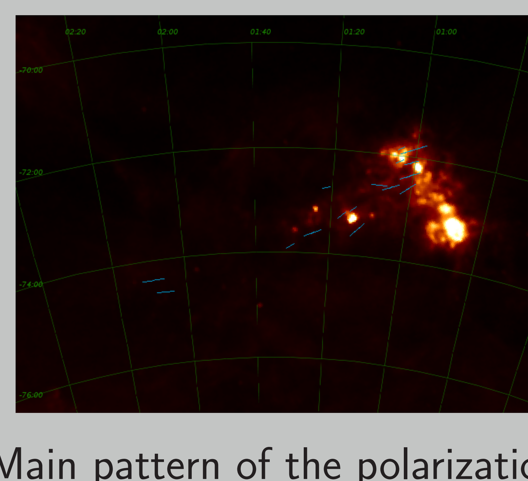

Figure: Main pattern of the polarization superimposed over an IRAS 100μm image.

- The vectors represent the main pattern of the polarization for each field.
- The fields that do not appear did not have a main pattern or a foreground polarization estimated for Schmidt (1976) and Rodrigues et al. (1997).
- It is noticeable that these vectors are aligned with the magellanic bridge.

The Catalogue

After finishing the reduction process we have obtained a catalogue with more than 10,000 stars with $\frac{P}{\sigma_P} > 3$.

- **Calibrations:**
  - Magnitudes:
    - The mag calibration was made using the catalogue *"UBVR CCD Survey of the Magellanic Clouds (Massey +, 2002)"*.
    - The precision is $\sigma_{mag} \simeq \mathbf{0.11}$ **mag**.
  - Positions:
    - The positions were calibrated using images from *"Digital Sky Survey"*.
    - The precisions are $\sigma_{AR} \simeq \mathbf{0.19}$ **s** and $\sigma_{DEC} \simeq \mathbf{1.0}''$.

Magnetic Field Estimation

To estimate the magnetic field intensity we have used the Chandrasekhar & Fermi (1953) method modified by Falceta-Goncalves et al. (2008).

$$\begin{cases} \frac{1}{2}\rho\delta V_{LOS}^2 \simeq \frac{1}{8\pi}\delta B^2 \\ B_{sky} + \delta B \simeq \sqrt{4\pi\rho}\frac{\delta V_{LOS}}{tg\delta\theta} \end{cases}$$

ρ : density
δV_{LOS} : velocity dispersion in the line-of-sight
$\delta\theta$: spread of the polarization vectors
δB : magnetic field random component
B_{sky} : sky-projected magnetic field component

Field	B (μG)	Field	B (μG)
smc01	$(13,9 \pm 2,0)$	smc12	$(4,3 \pm 1,1)$
smc02	$(3,08 \pm 0,88)$	smc13	$(-2,3 \pm 1,1)$
smc03	$(5,1 \pm 1,2)$	smc15	$(6,0 \pm 1,3)$
smc04	$(-1,87 \pm 0,73)$	smc16	$(11,2 \pm 2,7)$
smc05	$(8,7 \pm 1,6)$	smc18	$(1,4 \pm 1,2)$
smc06	$(7,0 \pm 1,6)$	smc26	$(9,2 \pm 2,1)$
smc07	$(0,91 \pm 0,84)$	smc27	$(12,1 \pm 2,3)$
smc09	$(3,58 \pm 0,84)$	—	—

Table: The main component of the sky-projected magnetic field intensity.

- We used the average values from the hidrogen component of the gas:
  - $\rho = \mathbf{2.04 \times 10^{-25}}$ $\mathbf{g/cm^3}$ (Mao et al. 2008)
  - $\delta V_{LOS} = \mathbf{(22 \pm 2)}$ **km/s** (Stanimirovic et al. 2004)
- $\delta\theta$ was obtained from our data reduction and varies for each field.
- The negative values of $\mathbf{B_{sky}}$ probably represent areas where the magnetic field has only the random component.
  - It is important to estimate ρ and δV_{LOS} locally to obtain more accurate values for $\delta\mathbf{B}$ and also $\mathbf{B_{sky}}$.

Future Goals

- Re-estimate the magnetic field intensity using local values for ρ and δV_{LOS}.
- Correlate the following:
  - The gas and the magnetic field.
  - The polarimetric map and structures found with the satelite Spitzer.
  - The polarimetric catalogue and that one's of stars with envelope.
- Study the role of the magnetic field in the magellanic bridge formation.

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