Low polarization emission from the core of a CME

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LETTER TO THE EDITOR

Low polarised emission from the core of coronal mass ejections

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ABSTRACT

Aims. In white-light coronagraph images, cool prominence material is sometimes observed as bright patches in the core of coronal mass ejections (CMEs). If, as generally assumed, this emission is caused by Thomson-scattered light from the solar surface, it should be strongly polarised tangentially to the solar limb. However, the observations of a CME made with the SECCHI/STEREO coronagraphs on 31 August 2007 show that the emission from these bright core patches is exceptionally low polarised.
Methods. We used the polarisation ratio method of Moran & Davila (2004) to localise the barycentre of the CME cloud. By analysing the data from both STEREO spacecraft we could resolve the plane-of-the-sky ambiguity this method usually suffers from. Stereoscopic triangulation was used to independently localise the low-polarisation patch relative to the cloud.
Results. We demonstrated for the first time that the bright core material is located close to the centre of the CME cloud. We show that the major part of the CME core emission, more than 85% in our case, is Hα radiation and only a small fraction is Thomson-scattered light. Recent calculations also imply that the plasma density in the patch is 8×10^8 cm^{-3} or more compared to 2.6×10^6 cm^{-3} for the Thomson-scattering CME environment surrounding the core material.

Key words. Sun: coronal mass ejections (CMEs) – Sun: filaments, prominences – polarization – techniques: polarimetric

1. Introduction

The core of coronal mass ejection (CME) clouds occasionally exposes very bright concentrated patches in white-light coronagraphs. They are interpreted as cool plasma material from a prominence that was embedded inside the streamer environment

amount of polarisation even further. As a result, the linear polarisation of Hα radiation observed in prominences well above the limb ranges from a fraction of a percent (Gandorfer 2000; Wiehr & Bianda 2003) to a few percent (Leroy et al. 1984).

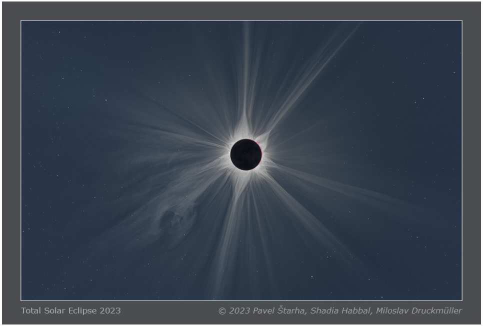
The white-light emission of the solar K-corona originates in Thomson scattering of photospheric light by free electrons.

Corona and Thomson scattering

The solar corona is composed of gas, dust, molecules, and magnetic fields that constantly stream from the Sun's surface.

Components of the solar corona:

- K-corona, scattering on electrons.
- F-corona, scattering on dust particles.
- E-corona, emission lines produced by ions in the corona.
- T-corona, thermal emission of dust particles.



Corona and Thomson scattering

- observation of the polarisation of the solar coronal brightness - among the earliest manifestations of Thomson scattering
- first successful observation - Francois Arago, eclipse 1842 (F. Arago gave the first report of the polarisation of coronal light.)
- 1879, These observations were interpreted by Schuster [1879] in terms of Sun light scattered at small particles in the solar corona.
- Schuster derived the ratio of the polarisation in directions tangential and radial to the Sun's centre

THE CORONA OF 8th July 1842 (ARAGO)

Corona and Thomson scattering

- 1930, Minnaert extended them by taking the solar limb darkening into account, D(r), D(r)-B(r)
- the most known and used eq are the one used and popularised by Billings, 1966

$$I_t = I_0 \frac{N_e \pi \sigma}{2}[(1-u)C + uD]$$

$$I_t - I_r = I_0 \frac{N_e \pi \sigma}{2} sin^2 \chi[(1-u)A + uB]$$

σ - Thomson scattering cross section,

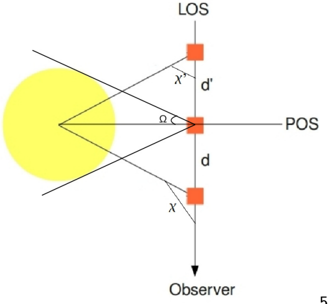
u - limb darkening coefficient

$$A = \cos\Omega \sin^2\Omega$$

$$B = -\frac{1}{8}\left[1 - 3\sin^2\Omega - \frac{\cos^2\Omega}{\sin\Omega}(1 + 3\sin^2\Omega)\ln\frac{1+\sin\Omega}{\cos\Omega}\right]$$

$$C = \frac{4}{3} - \cos\Omega - \frac{\cos^3\Omega}{3}$$

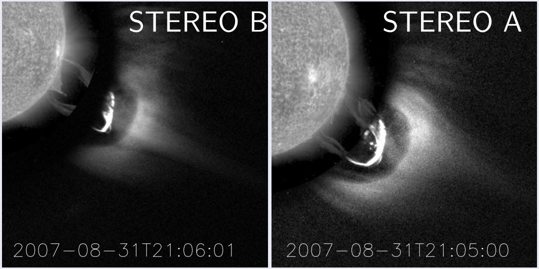
$$D = \frac{1}{8}\left[5 + \sin^2\Omega - \frac{\cos^2\Omega}{\sin\Omega}(5 - \sin^2\Omega)\ln\frac{1+\sin\Omega}{\cos\Omega}\right].$$

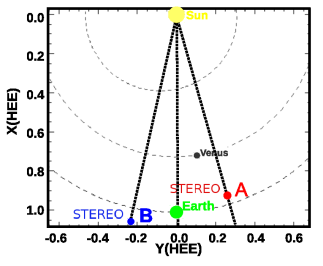


Observations

The CME event

- Date: 31 August 2007
- Instrument: COR1/STEREO
- COR1 FOV $[1.4\text{-}4]R_\odot$
- separation angle (STA,STB) $= 28^\circ$
- Source: an eruptive prominence





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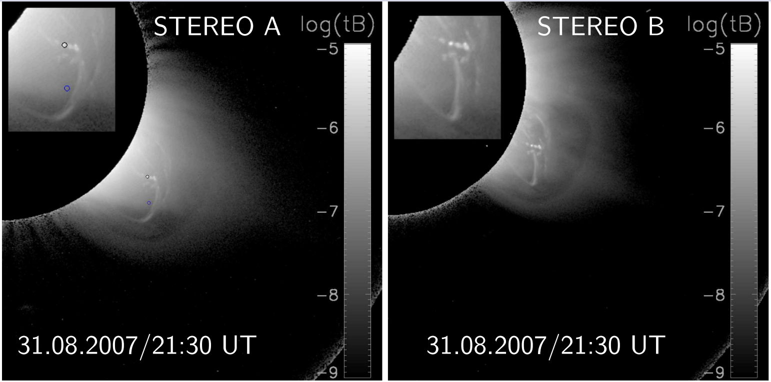
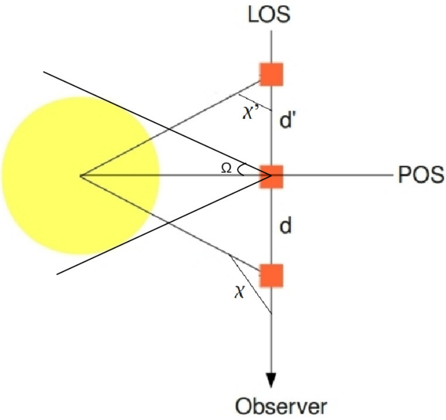


- obs $\Delta\lambda = 22$ nm, H_α (656 nm) centered
- COR1 linear polarizer @ 0,120,240 deg
- $p_B = \frac{4}{3}\sqrt{[(I_0 + I_{120} + I_{240})^2 - 3(I_0 I_{120} + I_0 I_{240} + I_{120} I_{240})]}$
- $t_B = \frac{2}{3}(I_0 + I_{120} + I_{240})$
- $u_B = t_B - p_B$

- Calibration
- Median filter
- background removal for pB and tB

Polarization Ratio (PR) method



LOS = line-of-sight
POS = plane-of-sky

- Based on the polarization properties of the Thomson scattering
- Developed by Moran and Davila, 2004
- suitable for 3D reconstruction of CME cloud
- COR takes polarized images at 0,$\pm$ 60 deg. $\Rightarrow$ polarized, unpolarized and total brightness image
- The degree of polarization is a function of the scattering angle χ
- χ depends on the distance d from POS
- $\pm$ d

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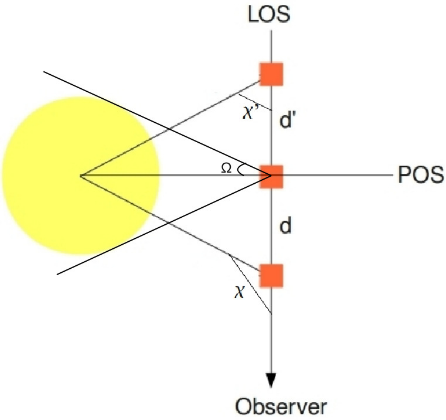

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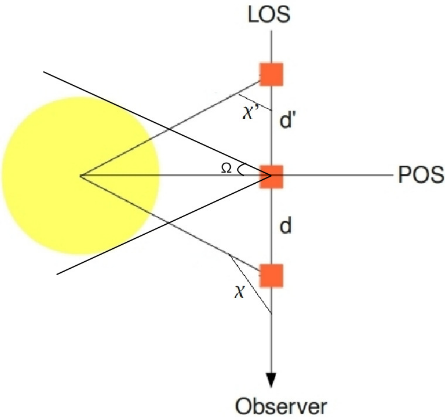

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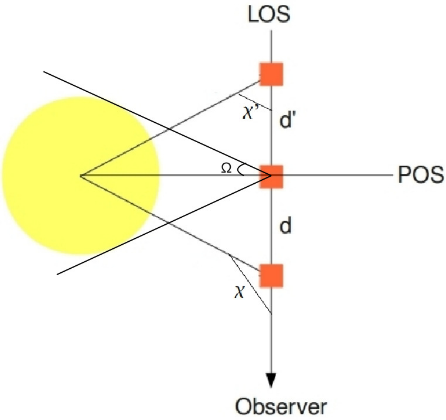

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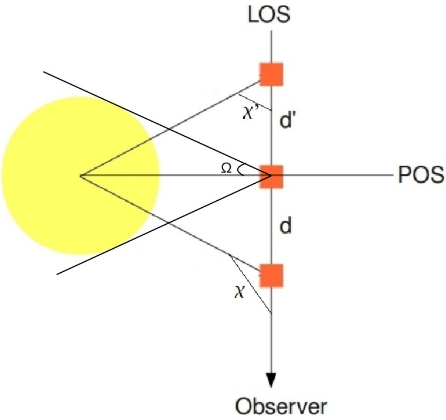

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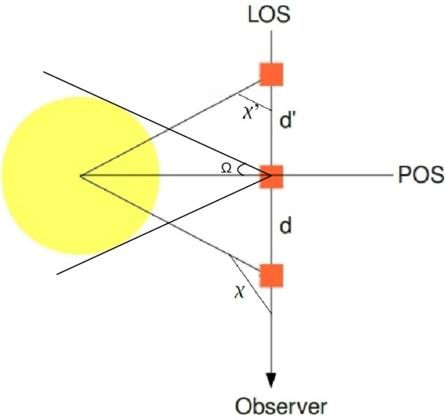

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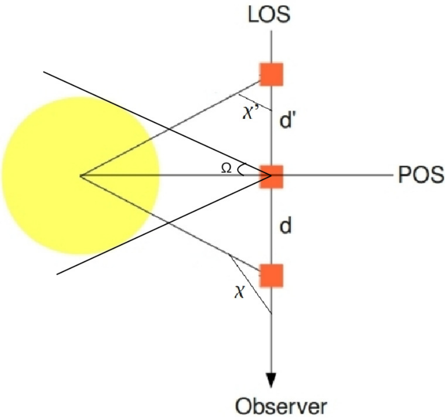

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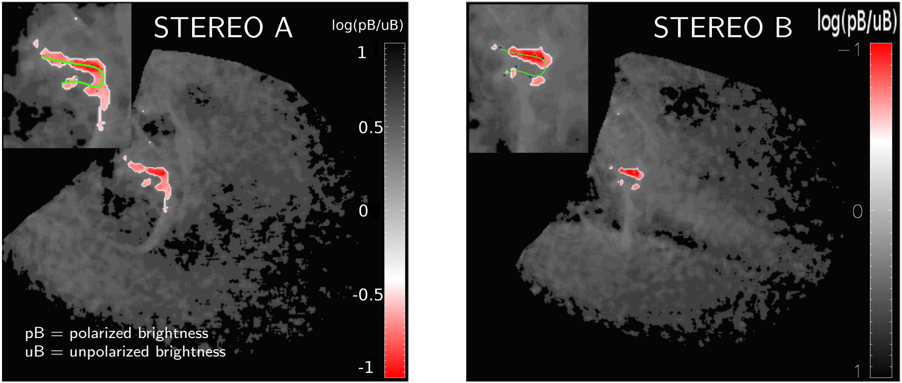

- Polarization ratio pB/uB
- Red patch – low polarized values

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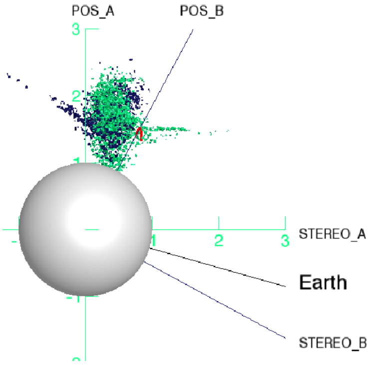

POS_A = plane-of-sky of STEREO A sc.
PR = Polarization Ratio
COR = coronagraph telescope

- Applying the PR method on images from COR1 A and B $\rightarrow$ 3D position for each pixel
- Green dots: scatterer location derived from COR1 A
- Blue dots: scatterer location derived from COR1 B
- Using two spacecraft $\Rightarrow$ forward/backward symmetry of Thomson scattering
- The mysterious location of the CME core: "Horns"- low polarization patches $\Rightarrow$ Thomson scattering does not apply
- What is the real location of the CME core?

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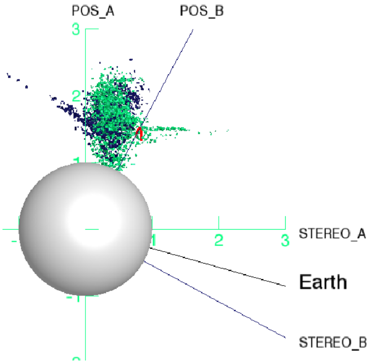

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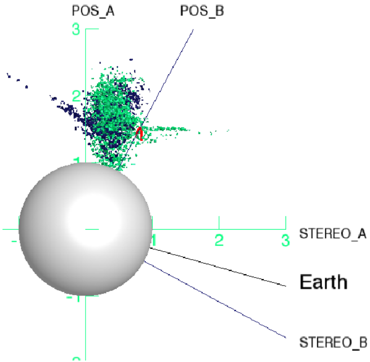

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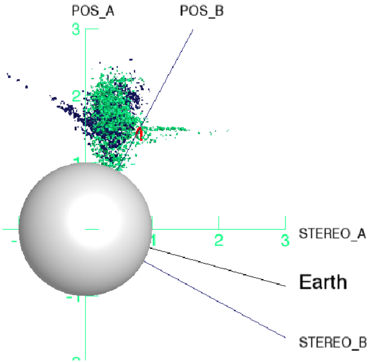

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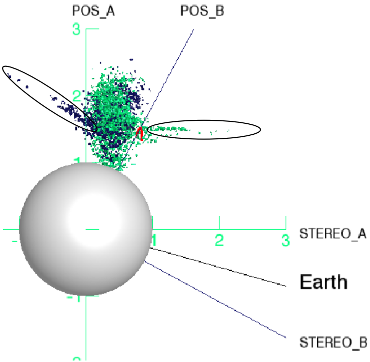

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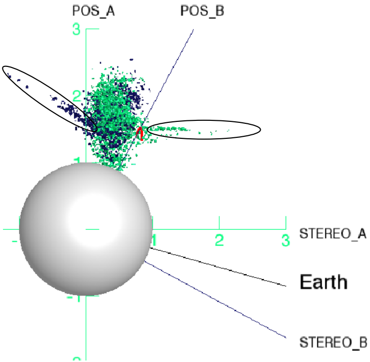

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- retrieves the 3D information of curve-like objects
- two and three view directions
- based on the stereoscopic reconstruction technique
- B-spline functions are used in order to obtain smooth curves

1. **The epipolar geometry**
   - stereo base line, angle, plane
   - epipolar plane/line
2. **Identification and matching**
   - automatic
   - by visual inspection

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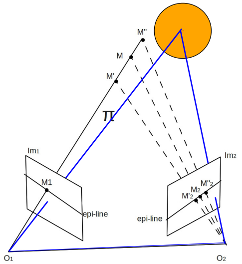

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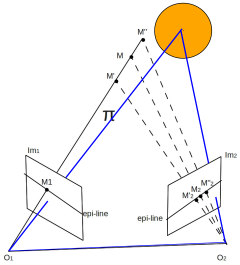
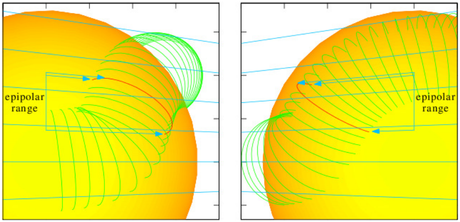
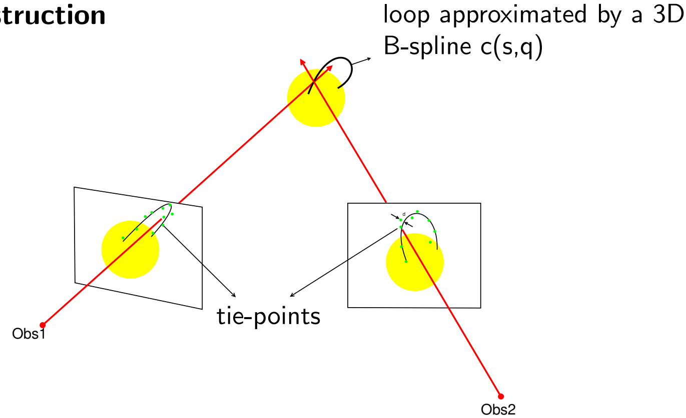




Multi-view B-spline Stereoscopic Reconstruction (MBSR)

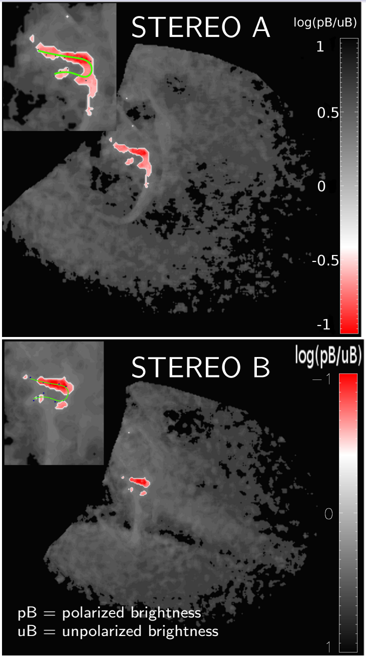
3. Reconstruction

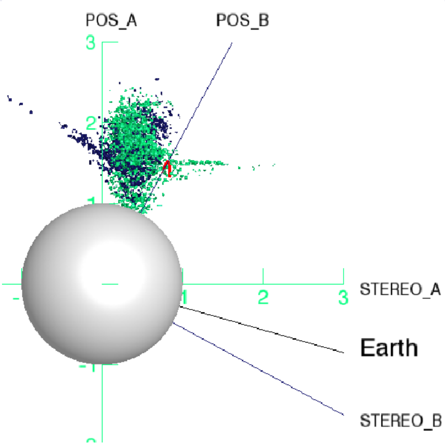


The least– square code minimizes

$$\sum_{\text{images } j} \sum_{\text{tie-points } i} |P_j \cdot \mathbf{c}(s_{i,j};\mathbf{q}) - \mathbf{x}_{i,j}|^2 + \mu \int |\frac{d^2}{ds^2} \cdot \mathbf{c}(s;\mathbf{q})|^2 ds$$

PR and MBSR





⇒ Red patch – low polarized values

⇒ The green curve – the projection of the 3D reconstructed curve

What is the cause of the horns?

- scattering on the dust particles (Morgan & Habbal, 2007)
- Thomson-scattering from enhanced plasma far away from the POS (Billings, 1966)
- The resonant scattering on Hα atoms (Poland & Munro, 1976)

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From observations:

$$\Rightarrow \quad r = \frac{pB}{tB} = \frac{\frac{pB}{uB}}{1+\frac{pB}{uB}} \simeq \begin{cases} 0.5 & \text{for } r_{\mathrm{Th}} \\ 0.1 & \text{for } r_{\mathrm{patch}} \end{cases}$$

$$\Rightarrow \quad tB_{\mathrm{patch}} \simeq 10\ tB_{Th}$$

What is the cause of the horns?

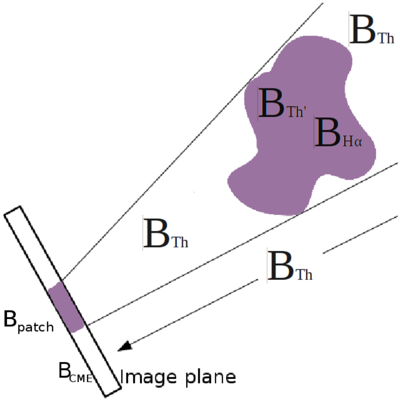
We consider:

$$tB_{\mathrm{patch}} = tB_{\mathrm{H}\alpha} + tB_{\mathrm{Th}'} + tB_{\mathrm{Th}}$$
$$pB_{\mathrm{patch}} = pB_{\mathrm{H}\alpha} + pB_{\mathrm{Th}'} + pB_{\mathrm{Th}}$$

We assume:

$$r_{\mathrm{Th}} \simeq r_{\mathrm{Th}'}$$

$$\frac{tB_{\mathrm{H}\alpha}}{tB_{\mathrm{Th}'}} = \frac{8}{1-18\, r_{\mathrm{H}\alpha}} < 8$$



$r_{\mathrm{H}\alpha} < \frac{1}{18}$ – agrees with values obtain from chromospheric measurements (Gandorfer, 2000)

Summary and Conclusions

- We applied the polarization ratio method to a CME on 31.08.2007
- From the 3D reconstruction of the CME cloud, we identify unusual locations of the CME core
- We applied stereoscopy to identify the 3D real location of the CME core
- Based on the analysis, the conclusion is that the major part of the CME core emission is H_α radiation (85%) and only a small fraction is Thomson-scattered light

Thank you!