K-Corona Polarized Brightness Observations from METIS

INAF ISTITUTO NAZIONALE DI ASTROFISICA NATIONAL INSTITUTE FOR ASTROPHYSICS

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METIS VL Polarimetric channel requirements

Polarized Brightness observations and evaluation (the eclipse case)

The images alignment procedure

The application of the knowledge from the eclipse to the METIS data

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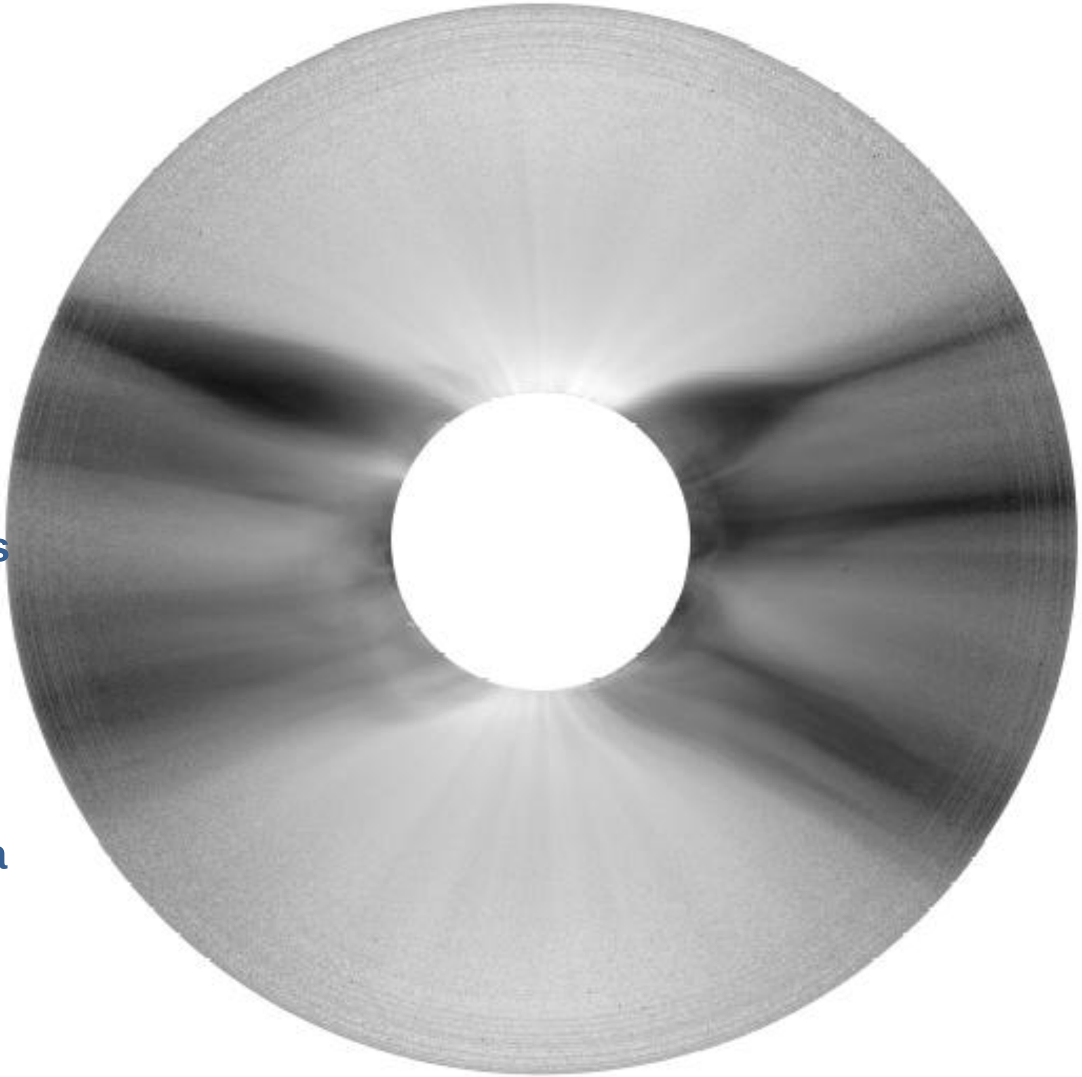

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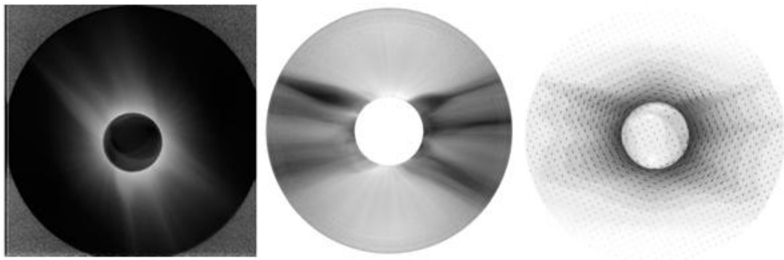
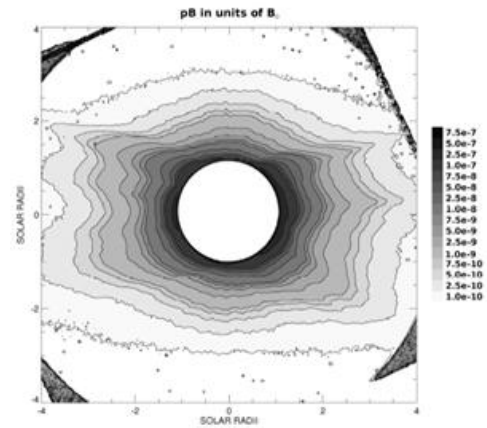
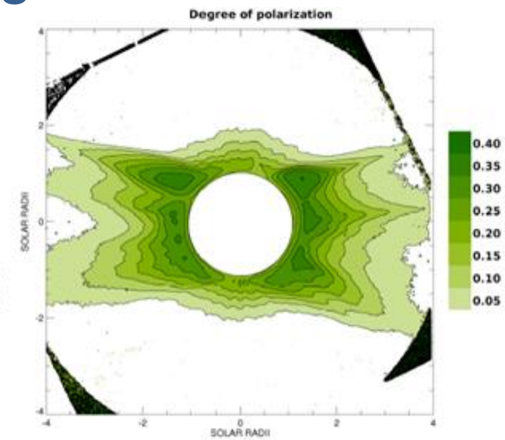
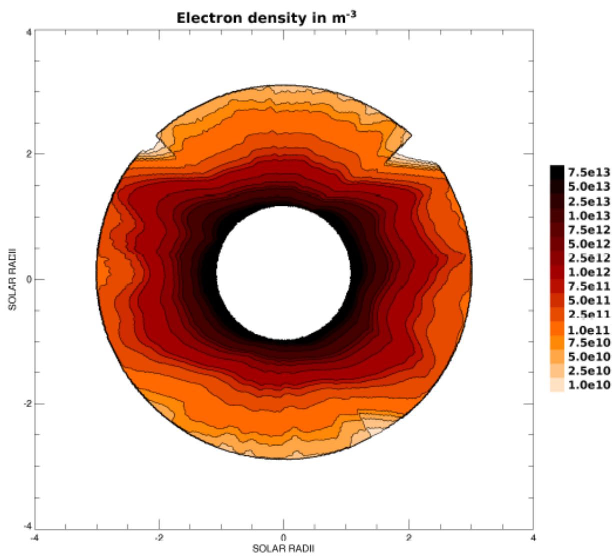
Why detect the solar K-corona polarized brightness?







Electron density (spherical symmetry approx.) →



Electron effective temperature (assuming the corona in hydostatical equilibrium) →

Upper limit of the Helium abundance in corona (assuming the hydrostatical equilibrium in corona) →

Separation of the K and F corona

K-Corona Polarized Brightness Observations from METIS

METIS Visible Light Polarimetric Channel (requirements/1)

The driver for the METIS polarimeter performances is given by the accuracy in the estimation of the electron density

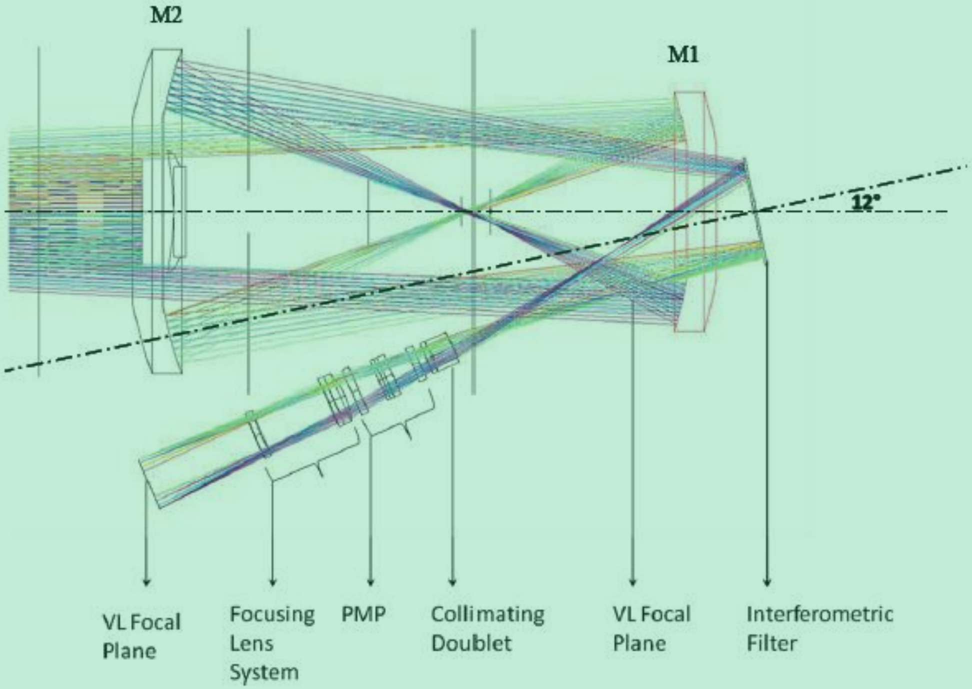
R [Ro]	Ne Equator (cm^{-3})	Error Ne Equator %	Ne Pole (cm^{-3})	Error Ne Pole %
1.5	7.13e6	0.1	1.70e6	7.0
2.0	1.17e6	0.8	3.19e5	9.2
2.5	3.72e5	1.5	9.64e4	13.3
3.0	1.69e5	2.4	3.95e4	19.7
3.5	9.33e4	3.2	2.03e4	26.3

R [Ro]	PB Equator Units B_{Sun}	PB Equator Counts (3 ex)	Δ PB % Equator		PB Pole Units B_{Sun}	PB Pole Counts (3 ex)	Δ PB % Pole	
			Kpol budget	Shot noise			Kpol budget	Shot noise
1.5	3.99E-8	37322	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1.6	2.70E-8	39066	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1.7	1.81E-8	36436	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1.8	1.22E-8	32199	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1.9	8.60E-9	27952	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2.0	6.29E-9	24571	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2.1	4.78E-9	21799	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2.2	3.71E-9	19447	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2.3	2.89E-9	17096	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2.4	2.27E-9	14937	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2.5	1.80E-9	13121	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2.6	1.46E-9	11607	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2.7	1.20E-9	10386	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2.8	1.01E-9	9385	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2.9	8.56E-10	8529	1.0	6.9	1.97E-10	1965	1.0	27.6
3.0	7.34E-10	7779	0.9	7.6	1.71E-10	1813	0.9	31.8
3.1	6.33E-10	7113	1.0	8.6	1.49E-10	1673	1.0	35.5
3.2	5.50E-10	6471	0.9	9.3	1.30E-10	1533	0.9	39.0
3.3	4.81E-10	5797	0.8	10.6	1.14E-10	1379	0.8	43.3
3.4	4.23E-10	5182	1.0	11.1	1.01E-10	1236	1.0	46.1
3.5	3.73E-10	4613	0.9	11.6	8.89E-11	1099	0.9	47.6

Fineschi et al. Proc. of SPIE 5901 1I (2005)

METIS Visible Light Polarimetric Channel (requirements/2)

The requirement for the polarimetric channel is to measure the polarized brightness with an accuracy better than 1%.



Crescenzio et al. Proc. of SPIE 84433J (2012)

Polarized Brightness observations and evaluation (the eclipse case/1)

Using a polarimeter as the METIS one, a single frame can be write as:

$$m_i = g\left(I \quad Q\cos\delta_i \quad U\sin\delta_i\right) + b$$

Where *g* is the efficiency of the system (containing the transmission of the polarimeter and the quantum efficiency of the detector), *I*, *Q* and *U* are the Stokes parameters, δ_i are the LCVR retardances and *b* is the detector bias and dark current. From the linear combination of 4 frames (m_i) acquired at different values of δ is possible to evaluate *I*,*Q*, *U* and the *pB:*

$$pB = \sqrt{Q^2 + U^2}$$

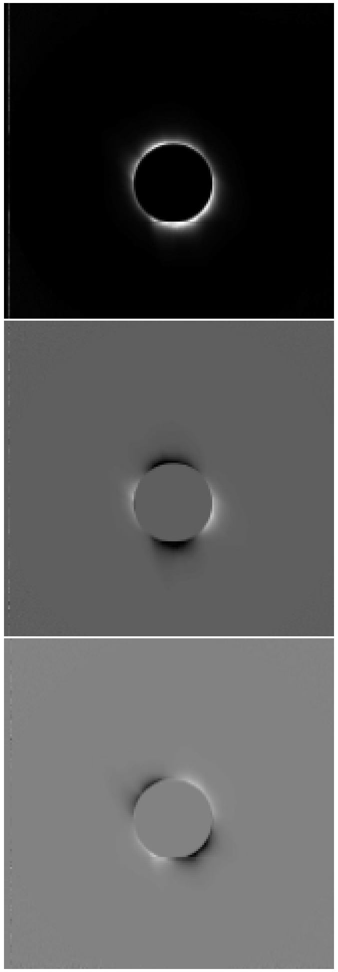
Polarized Brightness observations and evaluation (the eclipse case/2)

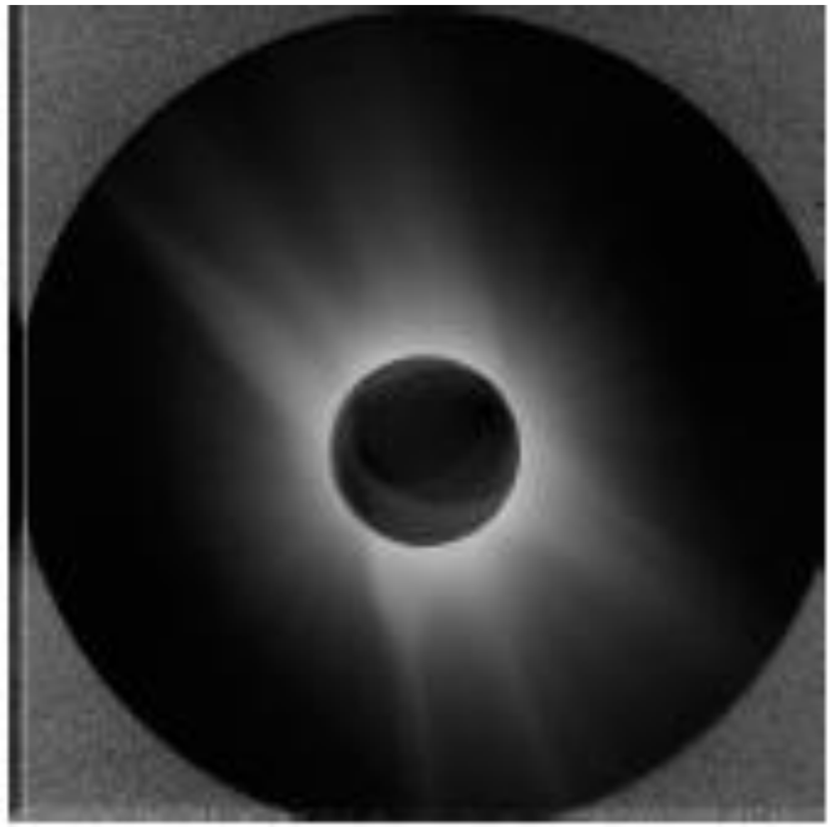
2006 March 29 total solar eclipse (observed with E-Kpol)

I

Q

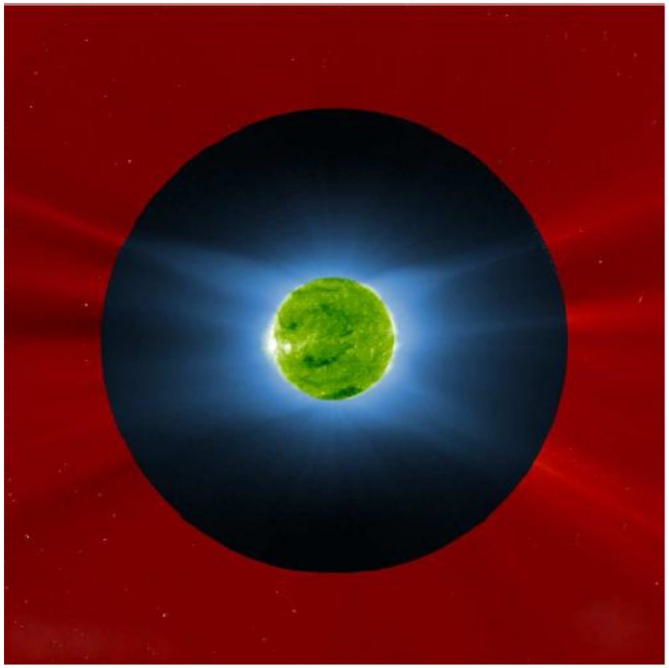
U

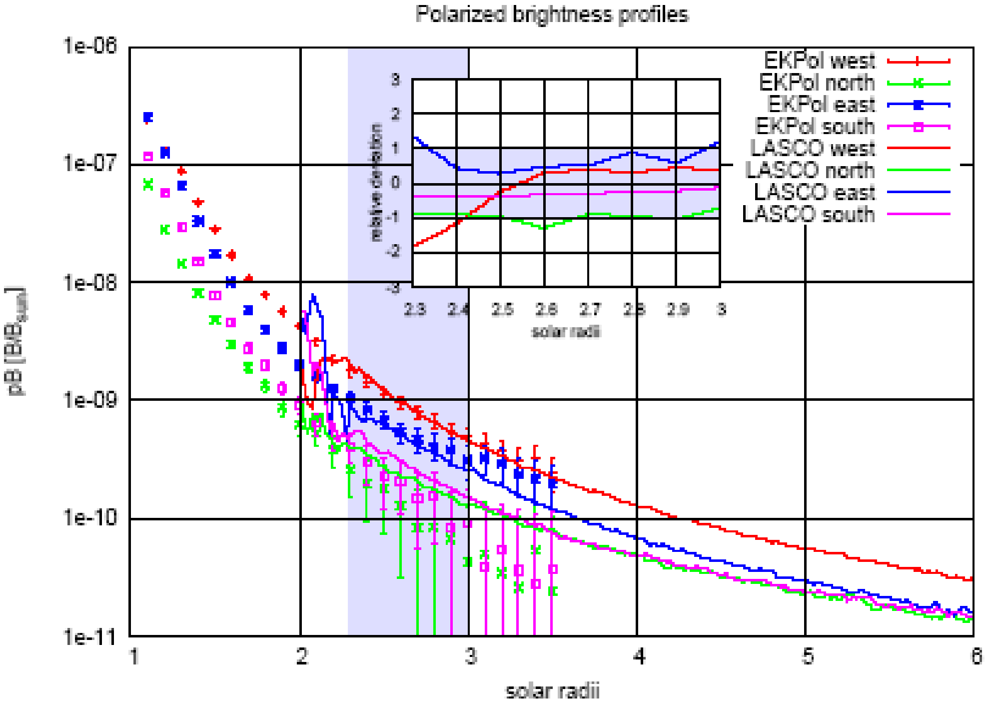




Polarized Brightness observations and evaluation (the eclipse case/3)

2006 March 29 total solar eclipse pB compared with LASCO C2 results





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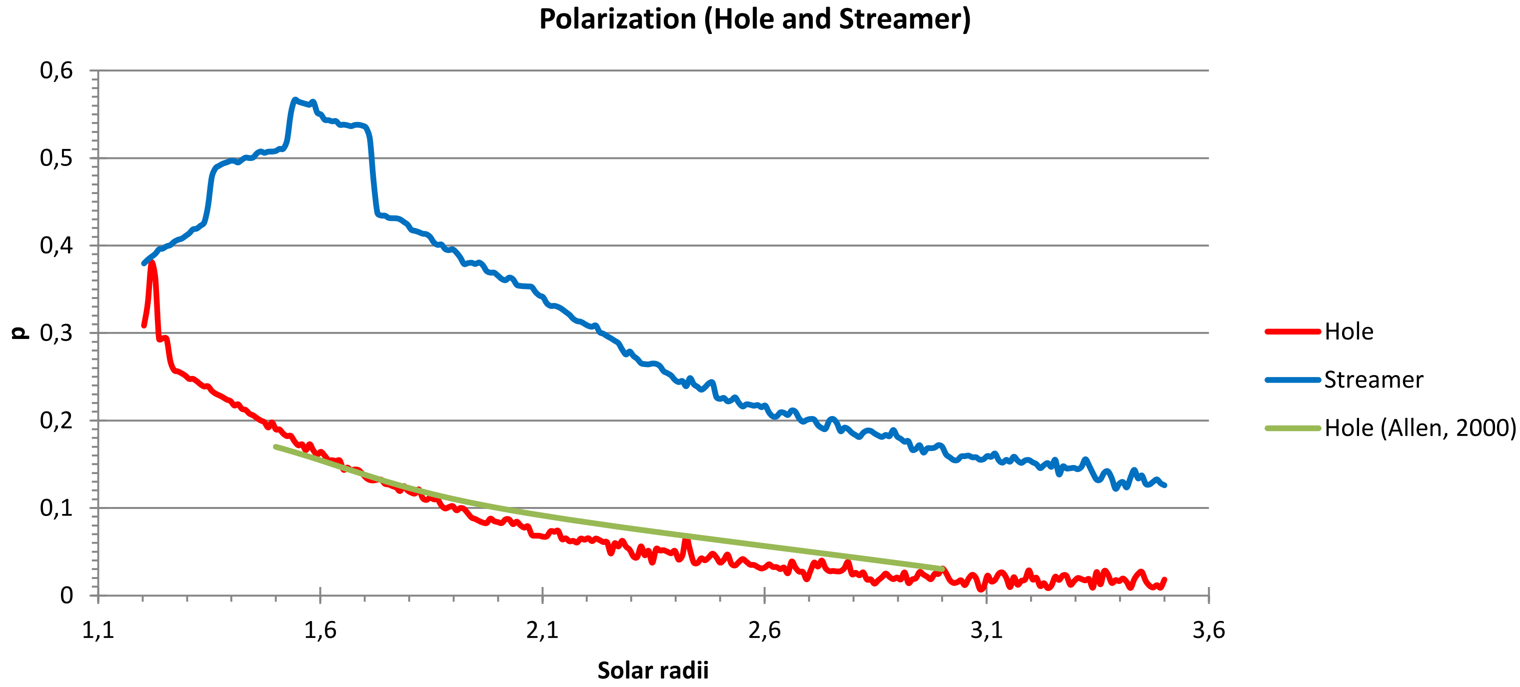
Polarized Brightness observations and evaluation (the eclipse case/4)

2006 March 29 total solar eclipse polarization



Polarized Brightness observations and evaluation (the eclipse case/5)

How to evaluate electron density

Starting from the *pB* and interpolating this data for each direction using a function:

$$pB\left(\frac{\rho}{R_\odot}\right) = c_0\left(\frac{\rho}{R_\odot}\right)^{-d_0} + c_1\left(\frac{\rho}{R_\odot}\right)^{-d_1}$$

is possible to evaluate (in the approximation of spherical symmetry) the profile of electronic density (N_e) (*Minnaert, 1930; Van de Hulst, 1950; Billings, 1966*):

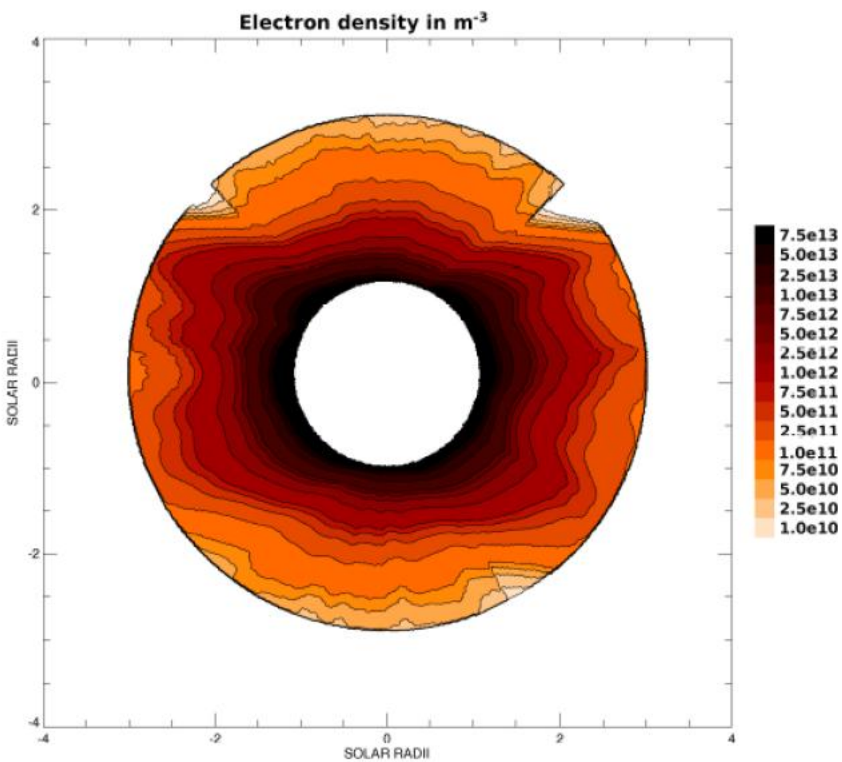
$$N_e\left(\frac{r}{R_\odot}\right) = \frac{a_0\left(\frac{r}{R_\odot}\right)^{-b_0} + a_1\left(\frac{r}{R_\odot}\right)^{-b_1}}{[(1-u)A(r)+uB(r)]}$$

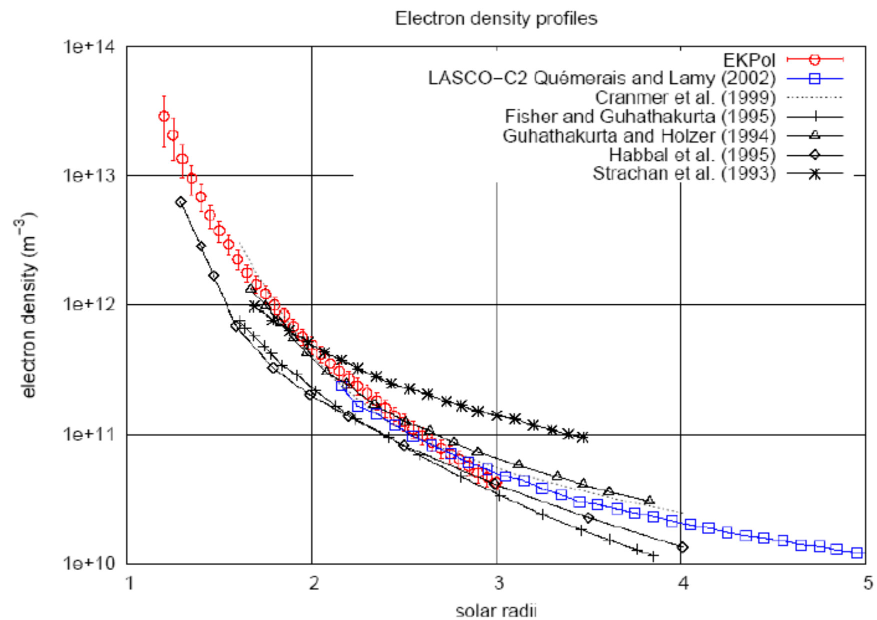
Where u is the linear coefficient of limb-darkening, $A(r)$ and $B(r)$ are geometrical factors, $b_i=d_i+1$ and

$$a_i = \frac{c_i}{KR_\odot\sqrt{\pi}}\frac{\Gamma\left(\frac{b_i+3}{2}\right)}{\Gamma\left(\frac{b_i+2}{2}\right)}.$$

Polarized Brightness observations and evaluation (the eclipse case/6)

2006 March 29 total solar eclipse electron density compared with LASCO C2 results

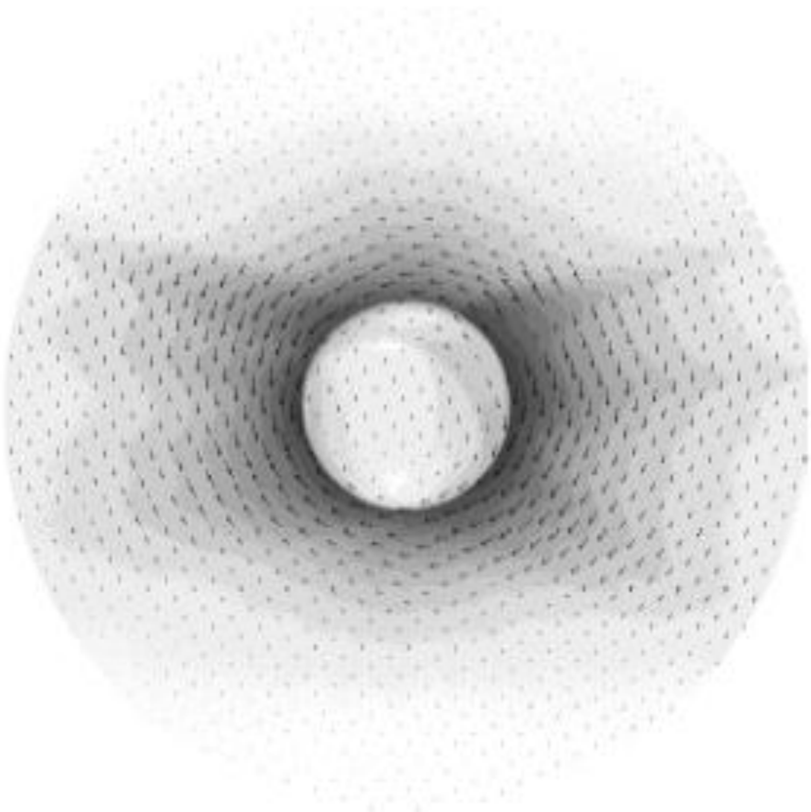


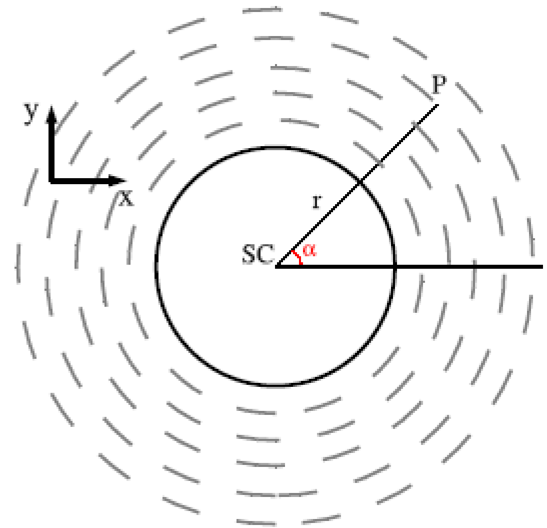


Capobianco et al. Proc. of SPIE 845040(2012)

The images alignment procedure (1)

Using geometrical properties of the K-corona polarized radiation (pB vector direction tangential to the occulter edge)





$$S = \begin{pmatrix} I \\ -pB\cos 2\alpha \\ -pB\sin 2\alpha \\ 0 \end{pmatrix}$$

$$m_i^{bg} = I - pB\cos(2\alpha - \delta_i)$$

$$\frac{m_i^{bg} - I}{pB} = -\cos(2\alpha - \delta_i)$$

The images alignment procedure (2)

$$m_i^{bg} = I - pB\cos(2\alpha - \delta_i)$$

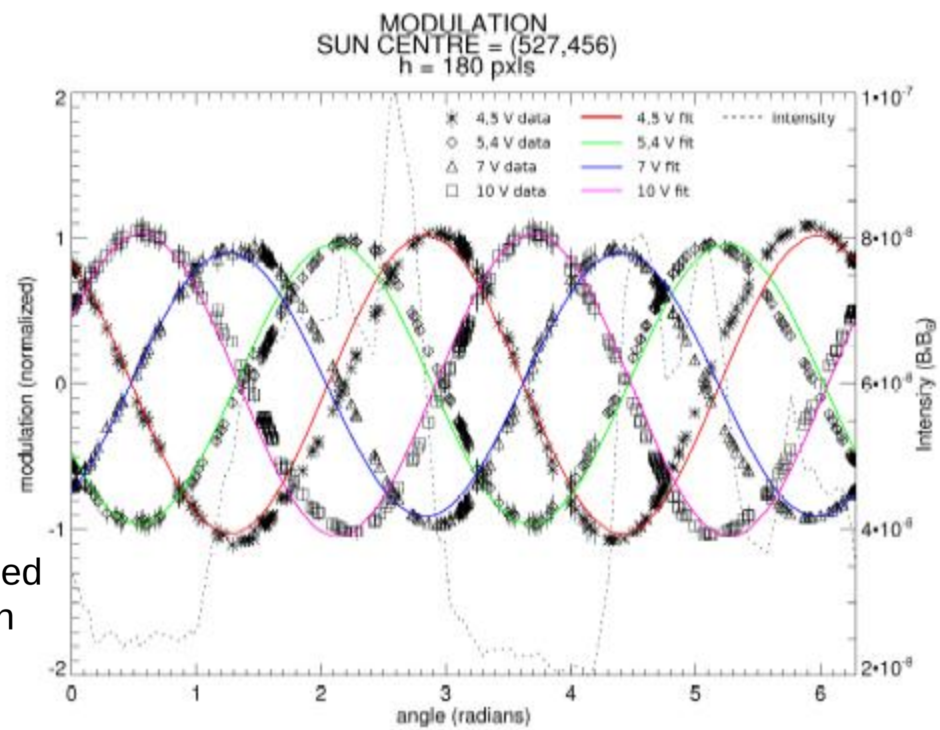
$$\frac{m_i^{bg} - I}{pB} = -\cos(2\alpha - \delta_i)$$

Fitting with the function (3 param.)

$$y = P_0 - P_1\cos(2x - P_2)$$

FIT IS NOT GOOD

The center of the sun has been supposed corresponding to the center of the moon (occulter)

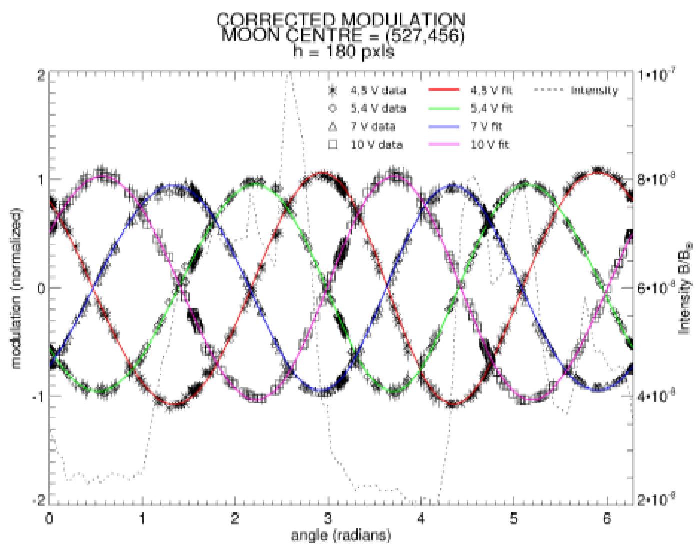


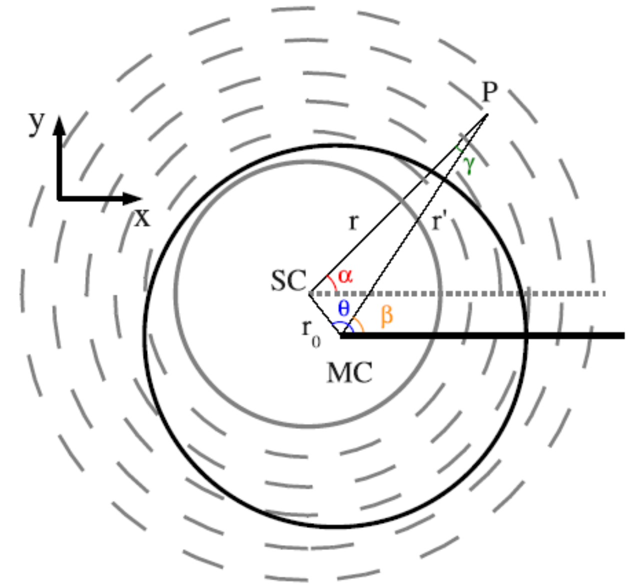
The images alignment procedure (3)

$$\frac{m_i^{bg} - I}{pB} = -\cos\left\{2\beta - 2\arcsin\left[\frac{r_0 \sin(\theta-\beta)}{\sqrt{r_0^2 + r'^2 - 2 r_0 r' \cos(\theta-\beta)}}\right] - \delta_i\right\}$$

Fitting with the function (5 param.) $\quad r' \equiv P_3 = cost$

$$y = P_0 - P_1 \cos\left\{2x - 2\arcsin\left[\frac{P_2 \sin(P_4 - x)}{\sqrt{P_2^2 + P_3^2 - 2P_2P_3\cos(P_4 - x)}}\right] - P_5\right\}$$





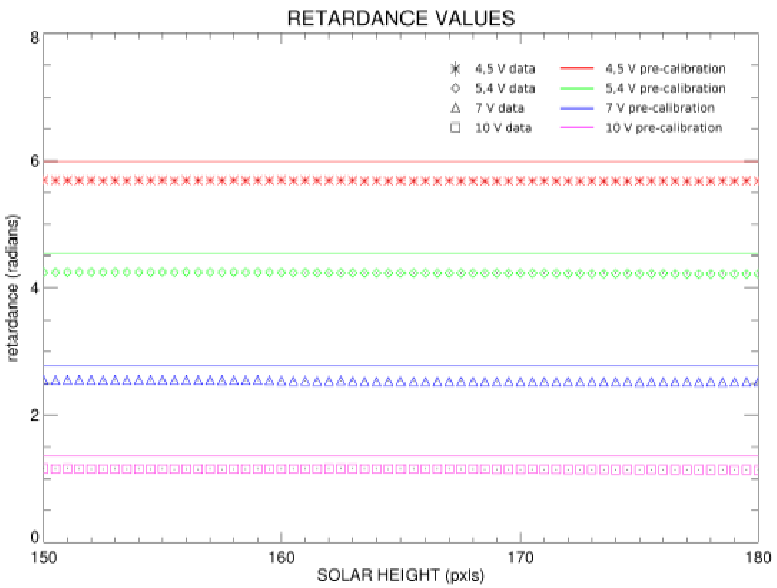
K-Corona Polarized Brightness Observations from METIS

The images alignment procedure (4)

$$\frac{m_i^{bg} - I}{pB} = -\cos\left\{2\beta - 2\arcsin\left[\frac{r_0\sin(\theta-\beta)}{\sqrt{r_0^2 + r'^2 - 2r_0 r'\cos(\theta-\beta)}}\right] - \delta_i\right\}$$

$$y = P_0 - P_1\cos\left\{2x - 2\arcsin\left[\frac{P_2\sin(P_4 - x)}{\sqrt{P_2^2 + P_3^2 - 2P_2P_3\cos(P_4 - x)}}\right] - P_5\right\}$$

This procedure allow us also to check the applied retardances



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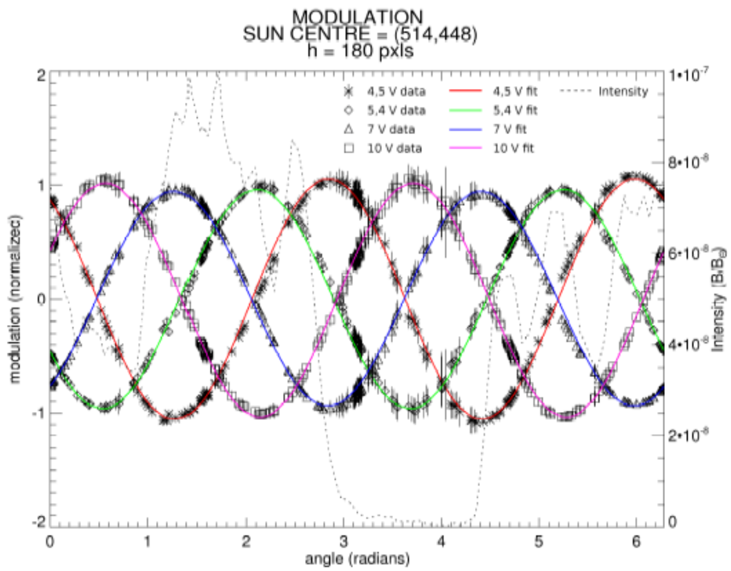
The images alignment procedure (5)

Summarizing the alignment procedure include:

- A raw estimation of the moon center and pB
- The evaluation of the sun center (using 5 parameters fit)
- The check of the applied retardances using the 3 parameters fit using the sun center coordinates



A 2006 eclipse frame fit a METIS frame?

	EKPol		METIS
Frame size	1024x1024 px	Rebinning -------->	2048x2048 px
Frame depth	16 bit		16 bit
Plate scale	8.6 arcsec/px		10.3 arcsec/px
Field of view	+/- 4 Rsun	Rescaling -------->	+/- 3 Rsun (@ 0.3 AU)

The two instruments have a compatible plate scale and the same frame depth. A rebinning and a rescaling operations are required!!!

Conclusions

The eclipse images are scientifically relevant and give out a good confidence in the data acquisition and data analysis procedures;

The eclipse images (after rebinning and rescaling operations) are representative of the METIS polarized brightness images and can be used as Lena image for test (i.e. tests of the image compression algorithms);

The eclipse images allow us to check and verify the full data analysis pipeline (VL);

The heritage of the alignment procedure of the eclipse images should be usefull if METIS sun sensor is descoped