“The magnetic solar corona as revealed by polarimetry”
Toulouse Workshop, November 4-6 , 2014

Measuring the magnetic field in eruptive prominences using the PROBA-3 Coronagraph- Polarimeter

by

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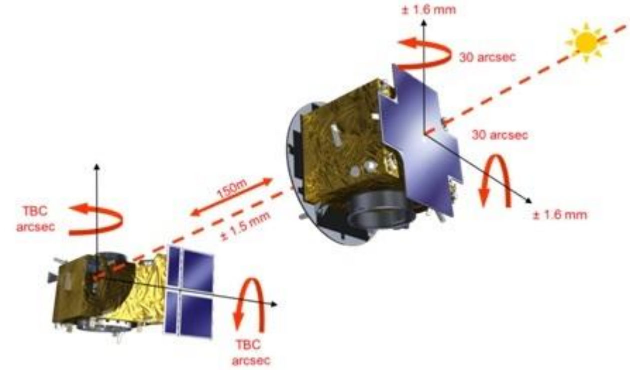
ASPIICS
Formation Flying Coronagraph



"Association of Spacecrafts for Polarimetric and Imaging Investigation of the Corona of the Sun"

- 2 Years formation flying ESA mission (2017-19) supported by a large consortium from EU (Proba-3 mission)

- Long time sequences of **Coronagraphic observations (W-L and line emissions)** above the solar limb bridging what has been done at ground- based using Total Eclipses and Lyot coronagraphs and what has been done in Space using externally-occulted coronagraphs

-ROB and CSL are now the main Labs concerned (Phase C started in 2014 under the PI-ship of A. Zhukov at ROB) following the original Phase B study (2012) from the LAS.

PROBA-3 Coronagraph System (ASPIICS) will be the first space coronagraph using

artificial eclipses

to cover the range of radial distances between 1.08 and 3 solar radii where the magnetic field plays a crucial role in the coronal dynamics, thus providing continuous observational conditions very close to those during a total solar eclipse, but without the effects of the Earth’s atmosphere and during several hours for each orbit. It is a “dream mission” for an eclipse observer!

Scientific Priority:

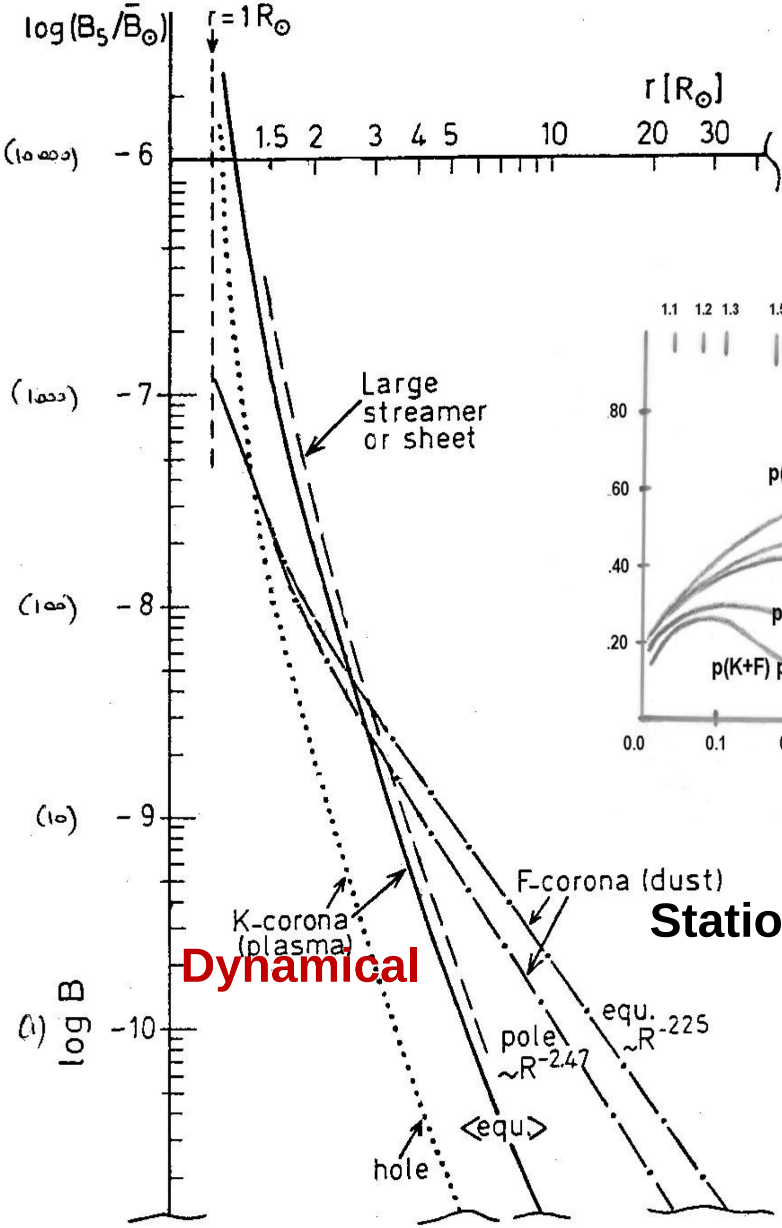
Role of W-L and Line Emission Structures in Dynamical Coronal Processes and Eruptions; Origin of CMEs

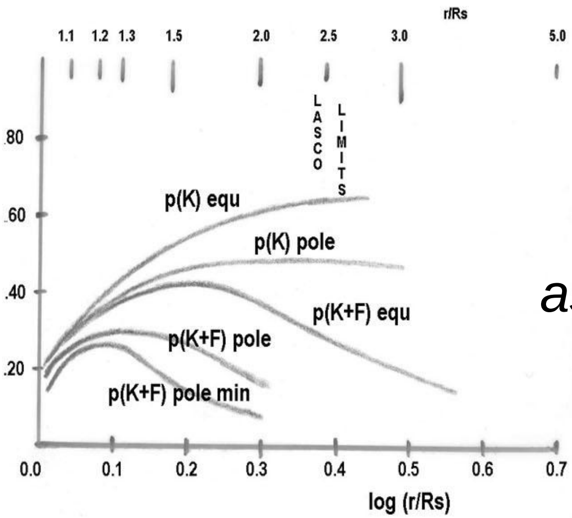
Magnetic field variations are central!

- **Advanced linear Polarimetry** of the W-L corona: Why ? How?

- Analysis of the « cool » corona magnetic fields and eruptive phenomena using **Hanle effect on the D3 line of HeI**

- The « new » **design** of the Imager/Polarimeter of Aspiics



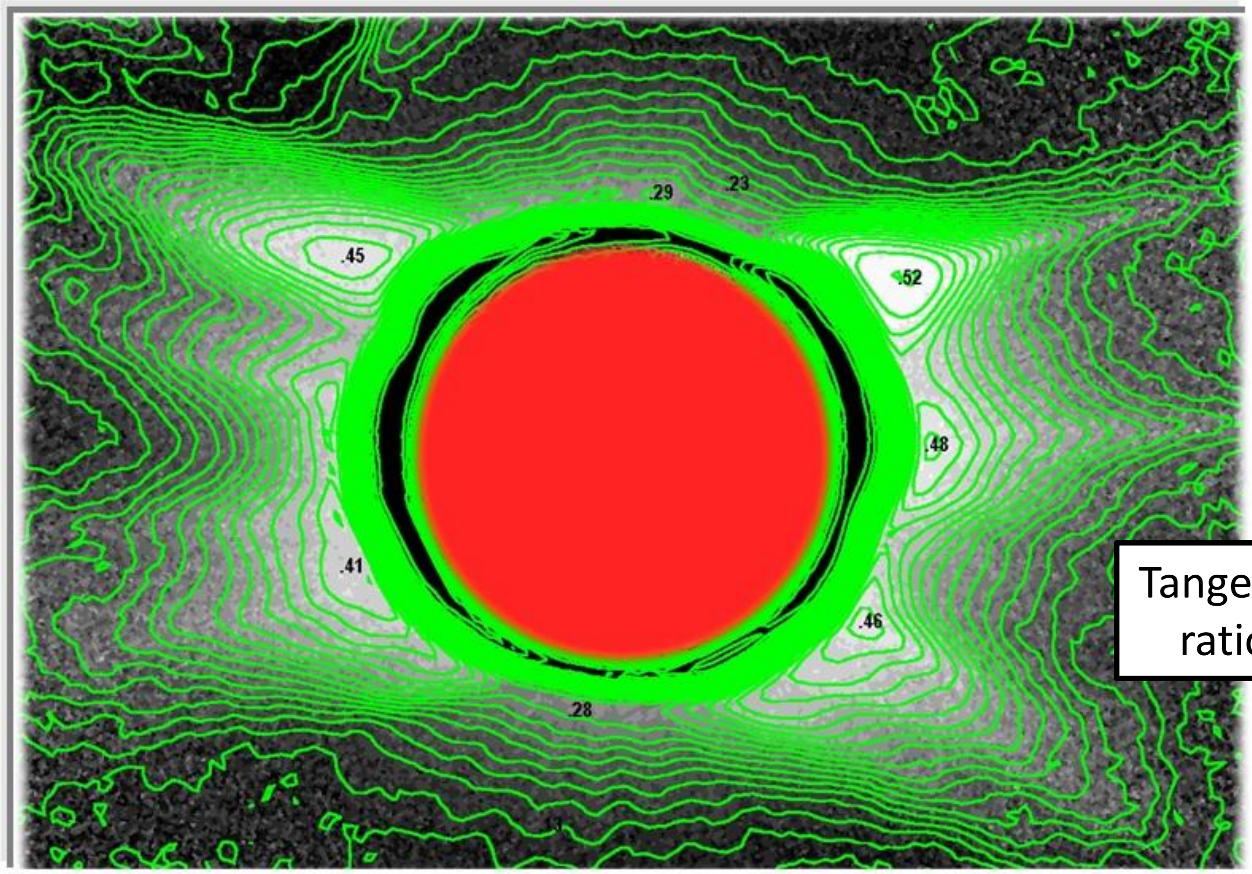


from Koutchmy (1995)

Interpretation of the axi-symmetric W-L linear polarization is rather easy (Baumbach; Allen; VdH; Saito etc.), providing ***no heterogeneity*** *exists and the* ***Thomson*** *scattering origin is assumed (electrons* ***at rest****) Polarization is strictly tangential*

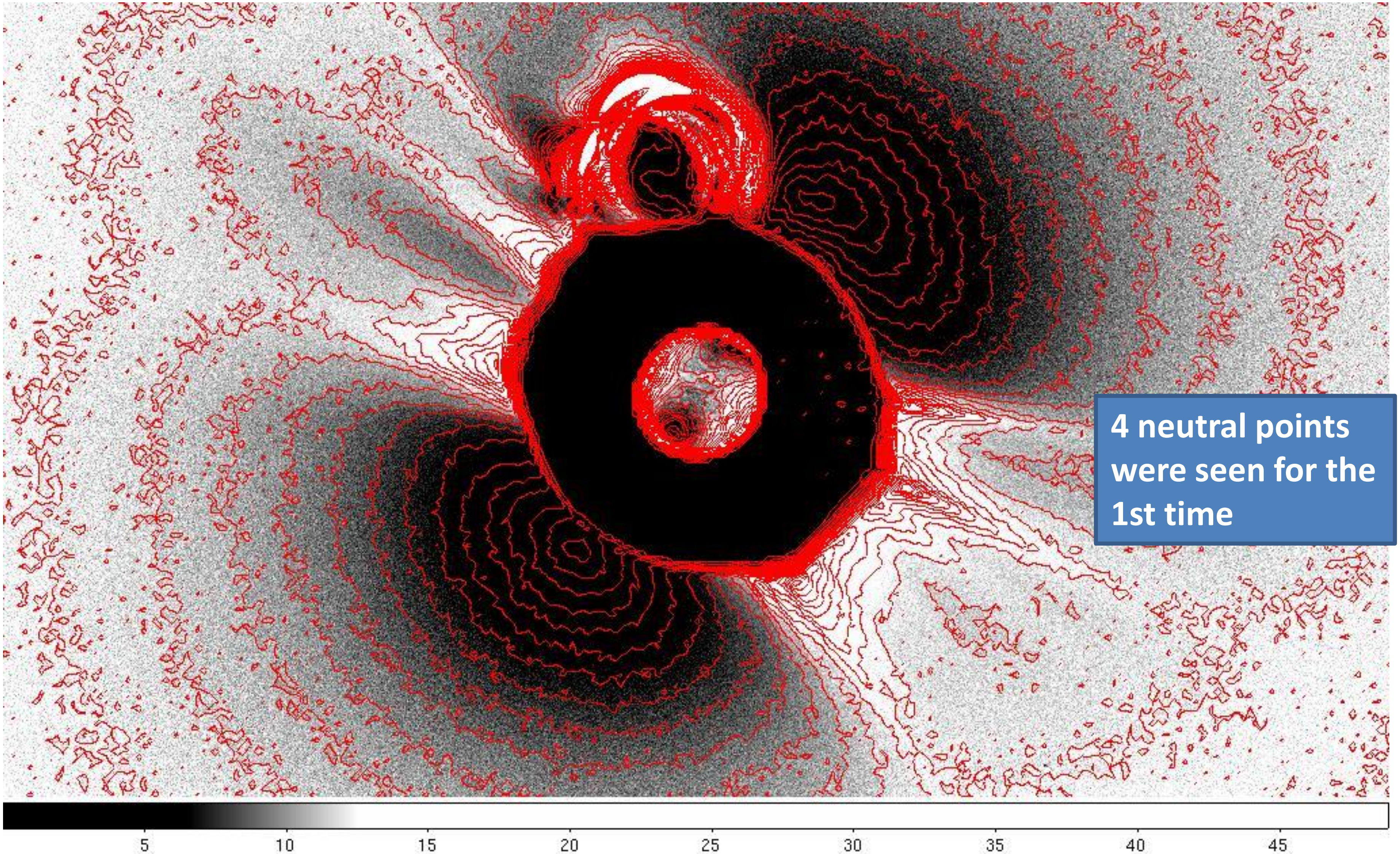
Thermal electron velocities are c/50 but sometimes much higher velocities exist at times of type IV Radio-bursts…

W-L polarization analysis confirms the assumption of Thomson scattering in the corona from total eclipses

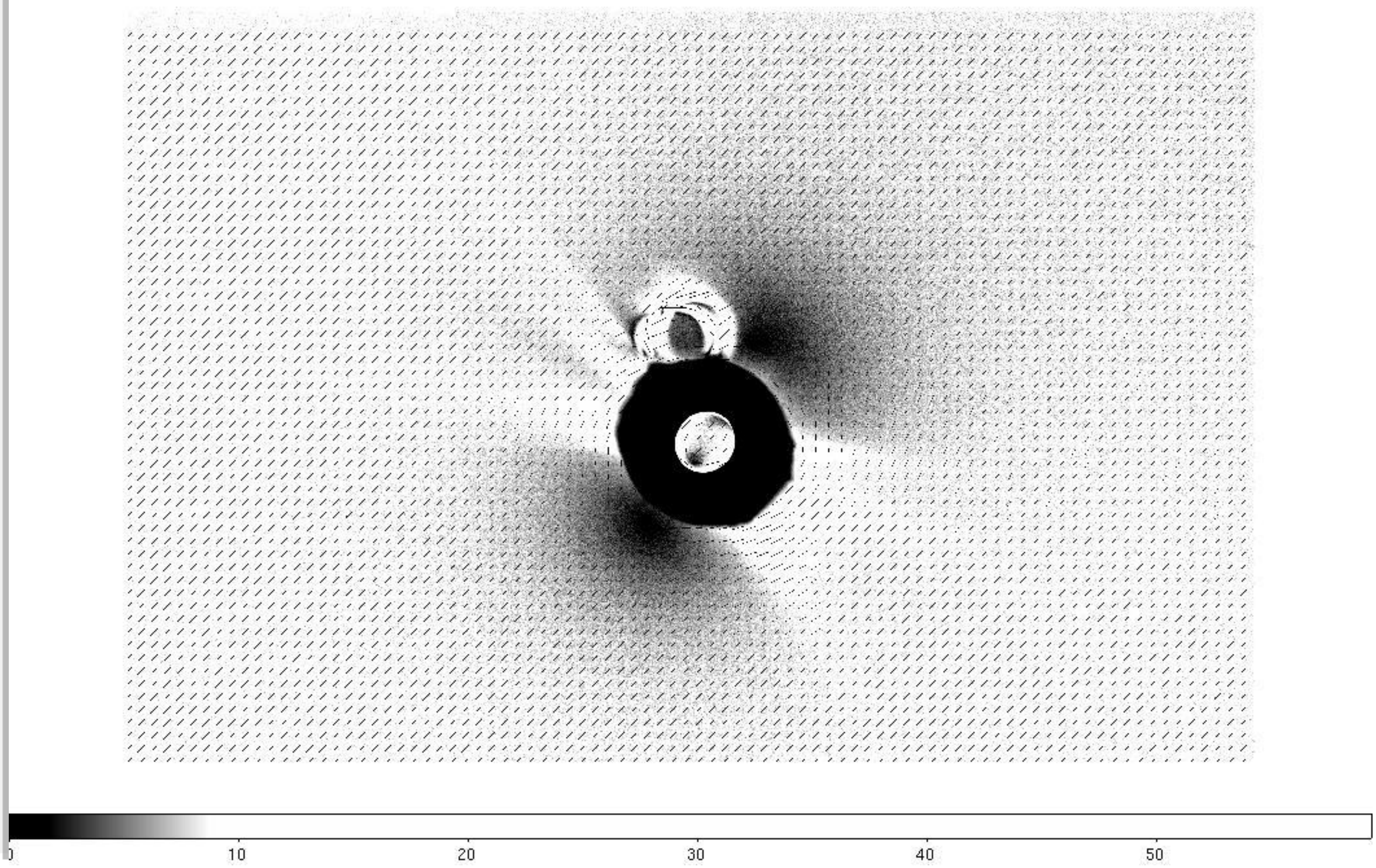


Tangential Polarization ratio with 2% steps

Isopleths of linear polarization ratio assuming it is radially symmetric Ecl. Corona of 2006/ IAP experiment with 4 LP at 45°

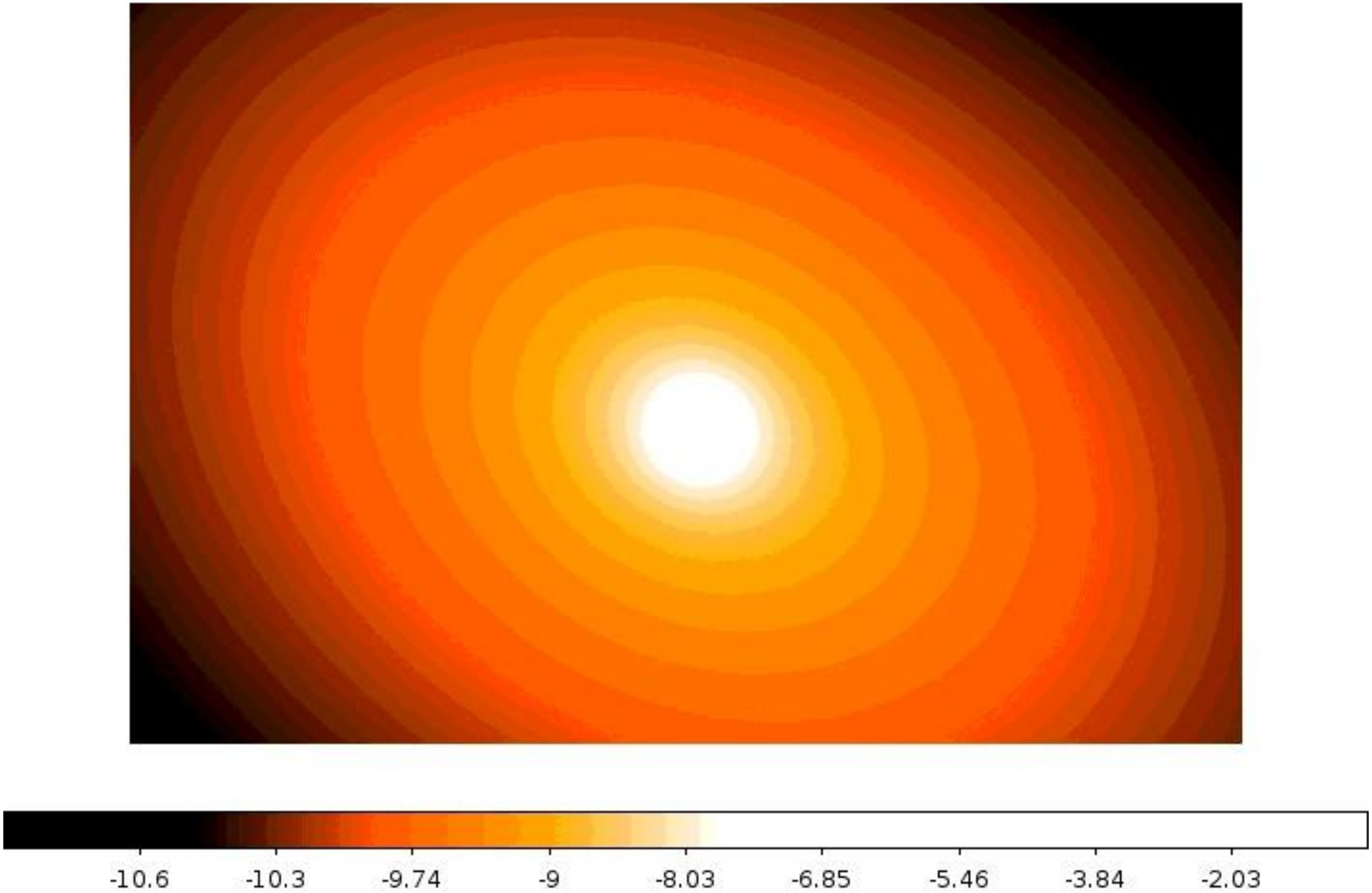


Results using the 5 sec exposures in positive; isopleths are separated by a 1% polarisation ratio



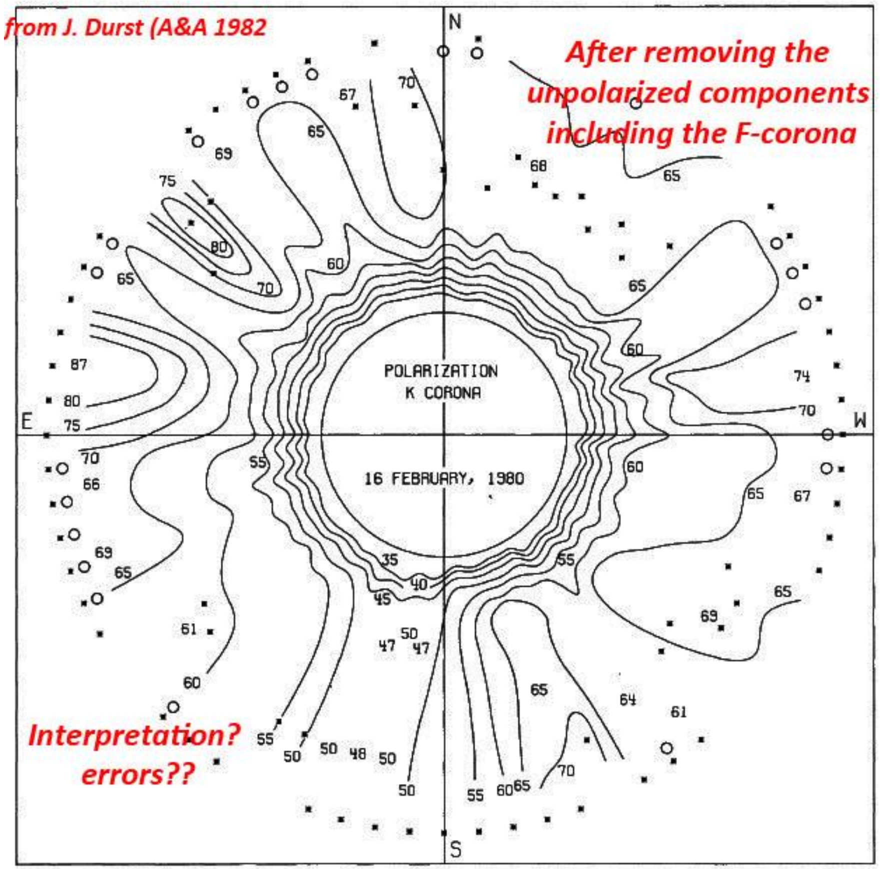
Direction of polarization and the sky background (long exposure- blue channel)

The F- corona- Constant in time, unpolarized and homogeneous



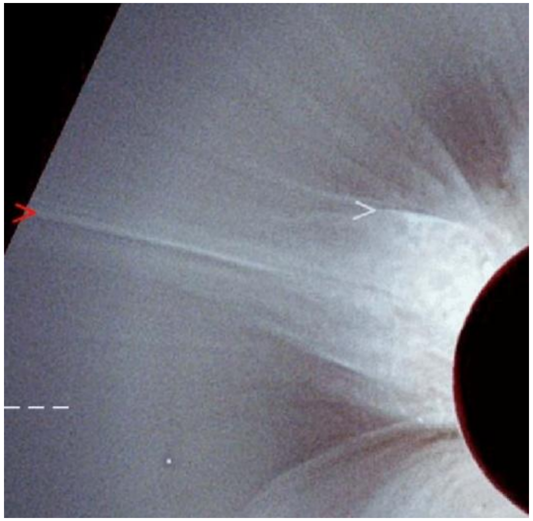
Koutchmy and Lamy 1985 IUA Coll.

Everything much more complicated after removing the unpolarized F- corona taking into account the overlaps of structures

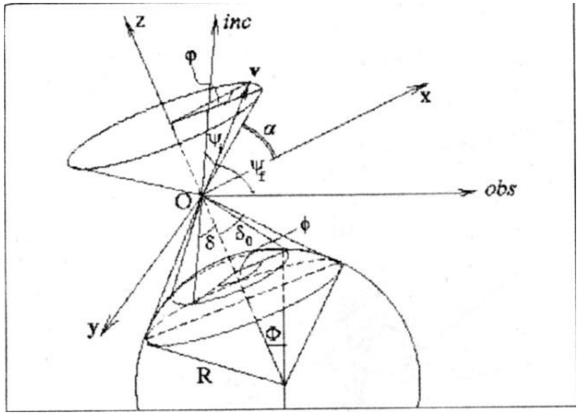


Isopleths of K corona polarization p_K (polarization in %). As predicted by model calcula

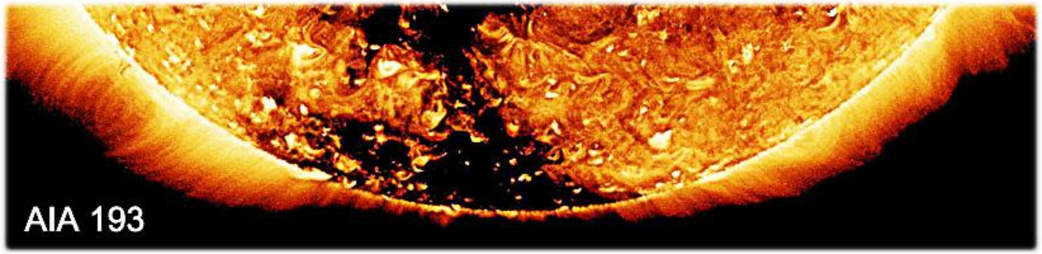
Also: Abnormal Polarization was theoretically considered by M. M. Molodensky in SP 73 (seminal paper)



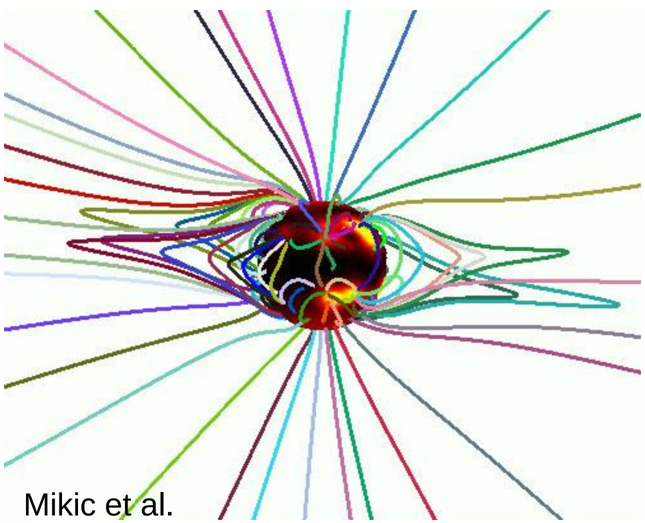
Quasi-linear transient structure: polarization? What is the 3D structure?



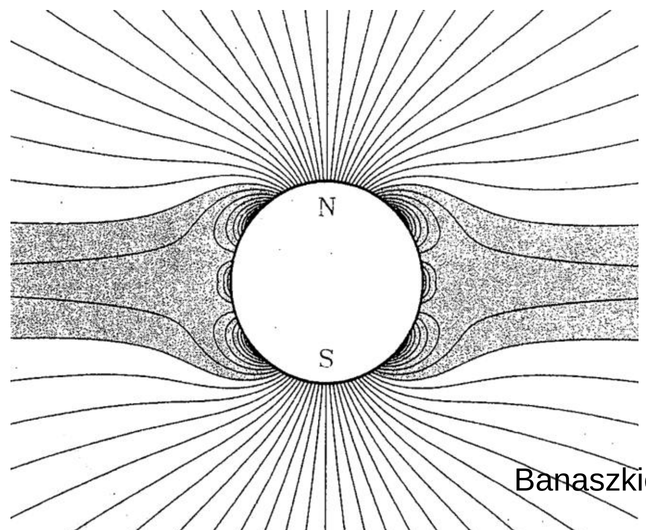
Inverse Compton effect in the solar corona from Koutchmy & Nikoghossian 2002



ASPIICS will observe
during the Years of the
next Solar Minimum
Polar regions will be covered
by CH with Polar Plumes
rising over: Polar Magnetic Field?
Source(s) of the Fast Wind?

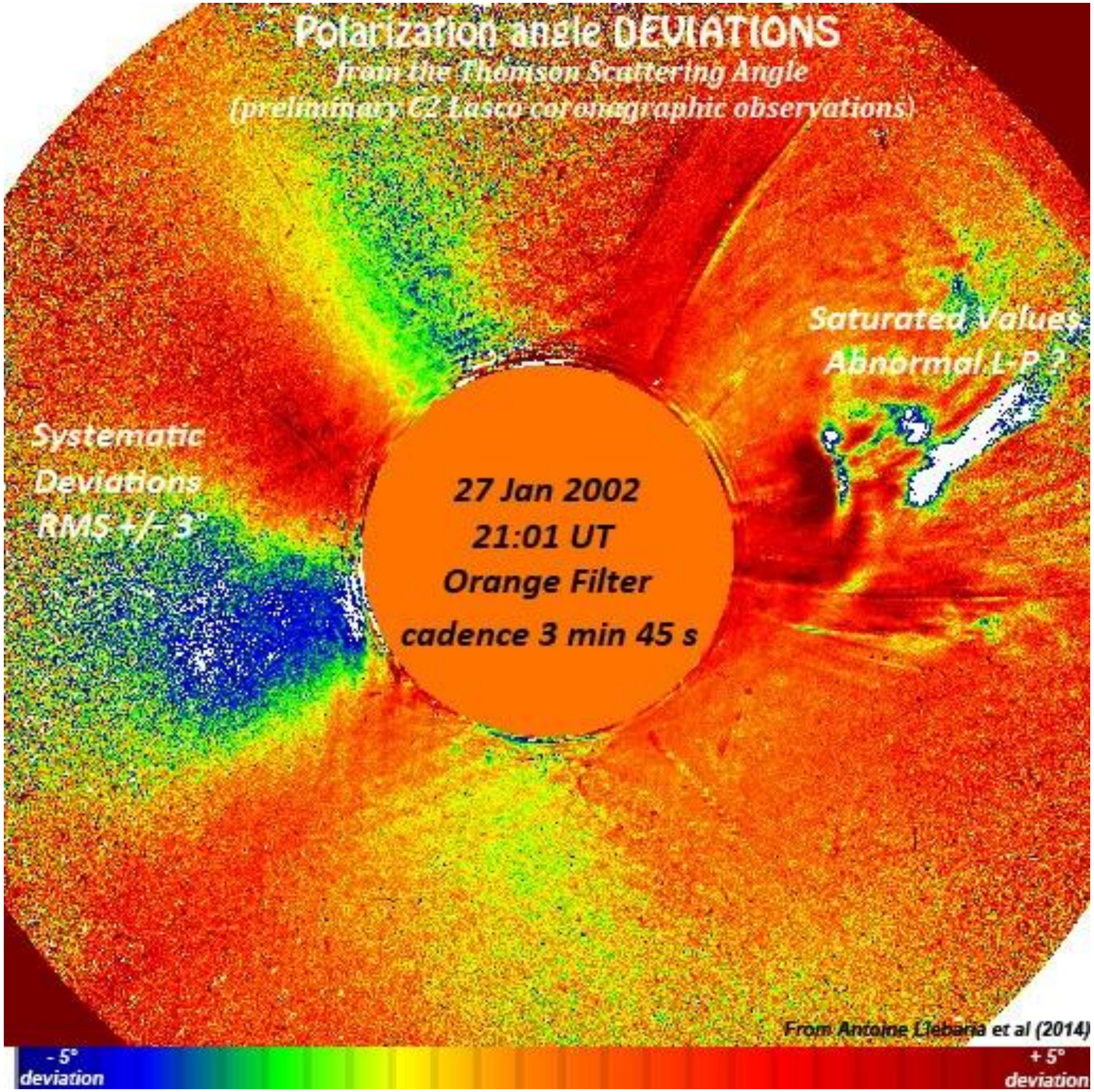


Mikic et al.



Banaszkiewicz,. Axford & McKenzie

Attempt to measure the angular deviations using the method of 3 L-P at 60°

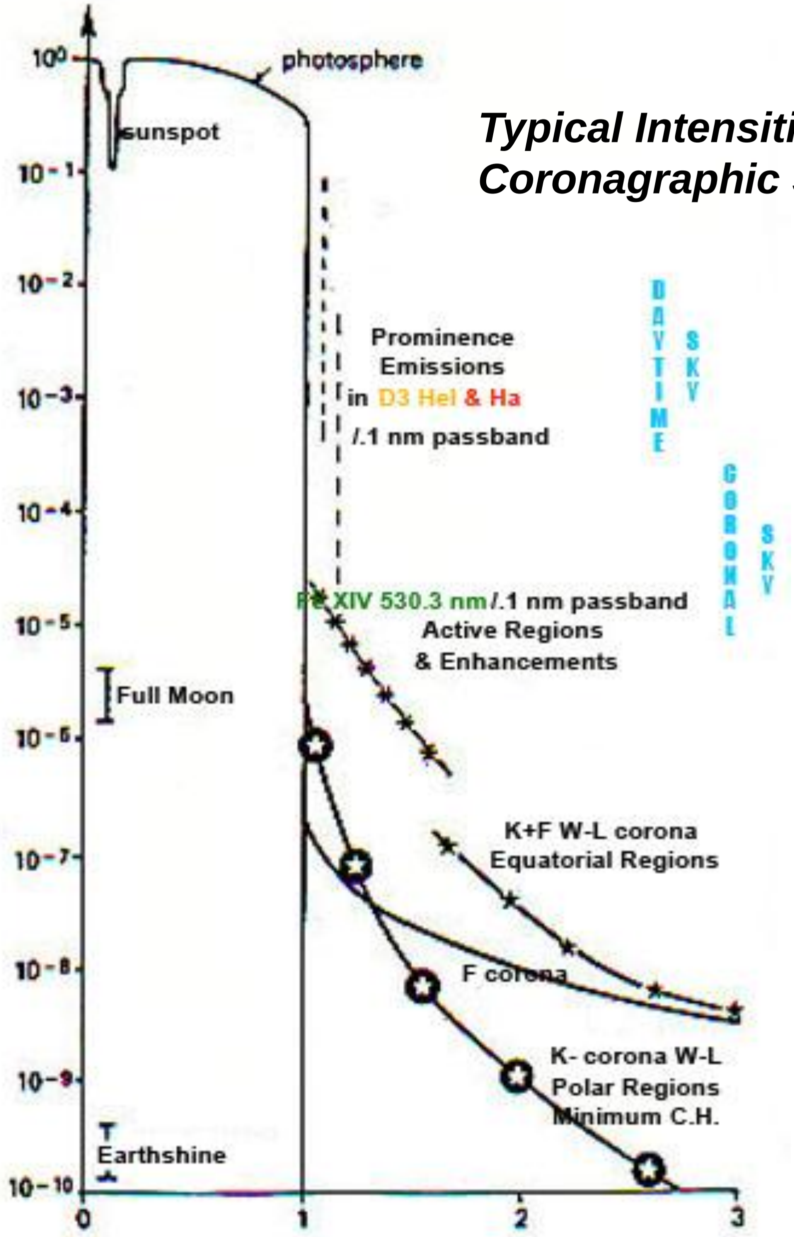


*Most recent CCD Polarization Analysis (here from Lasco C2 SoHO observations- A. Llebaria et al 2014) convincingly shows the precision obtained using 3 Linear Polarizers at 60° is largely **insufficient** (dispersion typically +/- 3%) for considering **structures and details.***

The precision should be greatly improved

An **imaging polarimeter** is needed as it was proposed for ASPIICS.

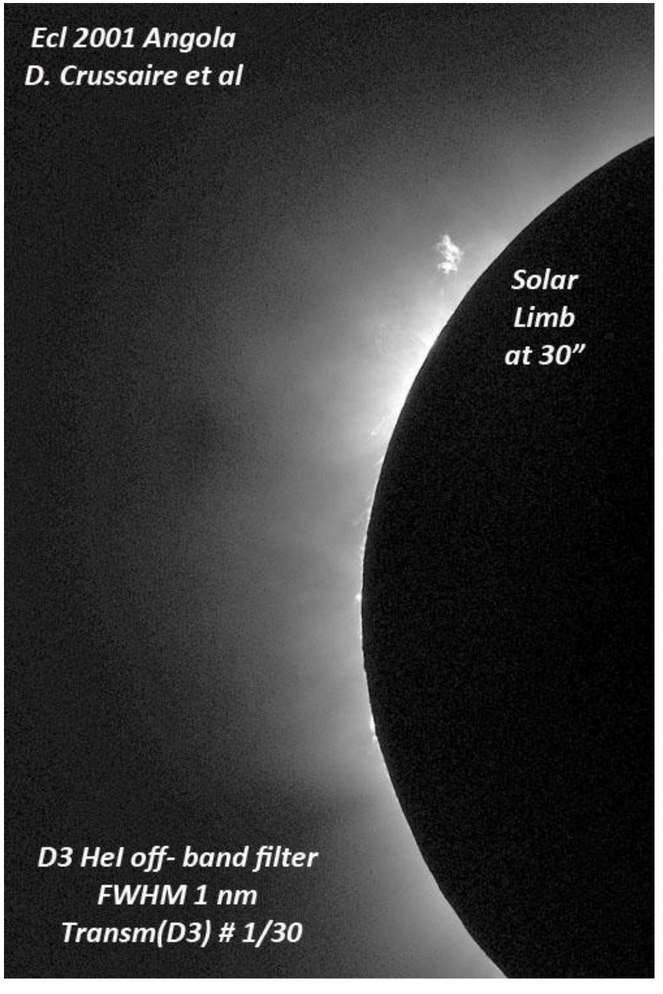
Targets for the polarimeter

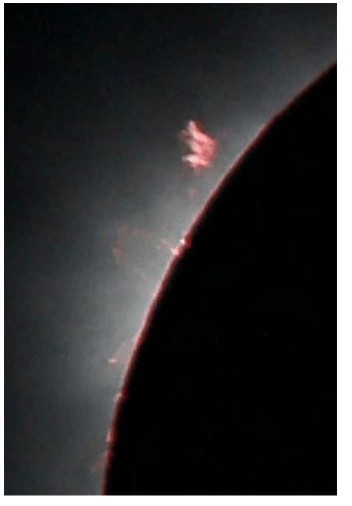


The "cool" Corona (low excitation emission lines)

The "hot" Corona: monochromatic emission lines & W-L scattering by e−

Illustrated example of simultaneous observation of the cool and the less cool corona (ecl 2001)





Partial eclipse
Color CCD
Image
Hα and D3 HeI
emission
dominates in
prominences

HeI D3 line (587.6 nm)
eclipse filtergram (from a sequence of 24)
Off band filter of 1 nm FWHM
Note the W-L corona of intensity
close to the D3 cool emission

Use of the HeI D3 “broad” filter in Aspiics:

- **no line brightening effect in the D3 line (**like Hα shows);

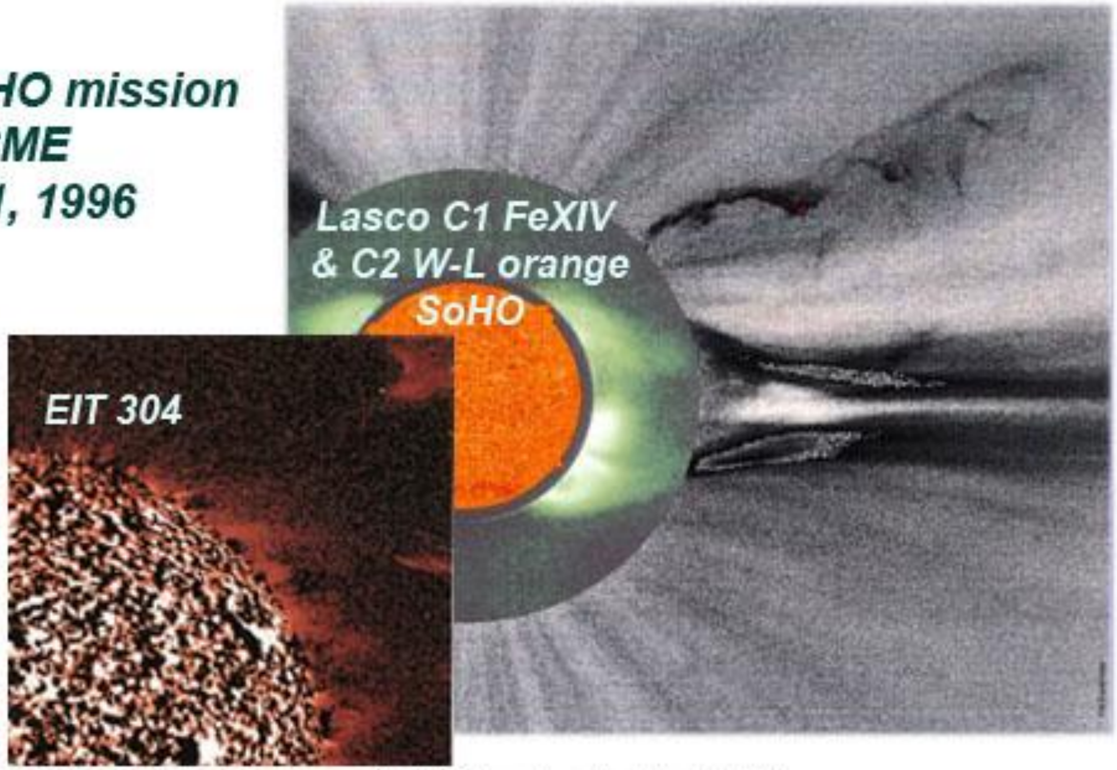
- « **less cool**» (24 eV) than Hα (> CH revealed > TR);

- Ideally sensitive to the magnetic **Hanle effect in the inner corona** (maximum sensitivity is 7 G instead of 70 G for Lyα)

- **W-L corona** simultaneously observed using a 0.5 or a 1nm passband filter

Example taken from C2- Lasco (SoHO) observations in the “orange” channel

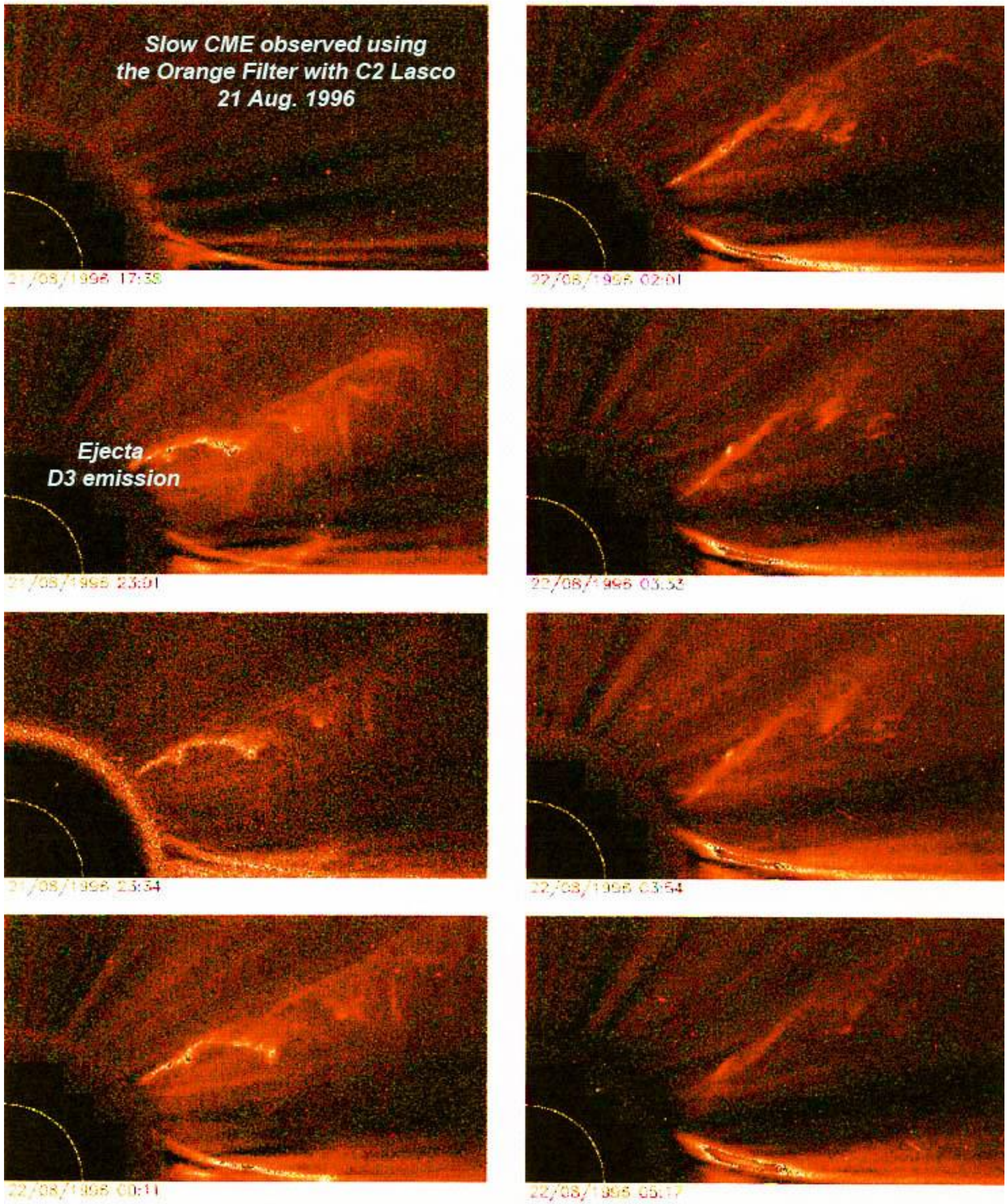
The “first” SoHO mission slow CME of Aug. 21, 1996



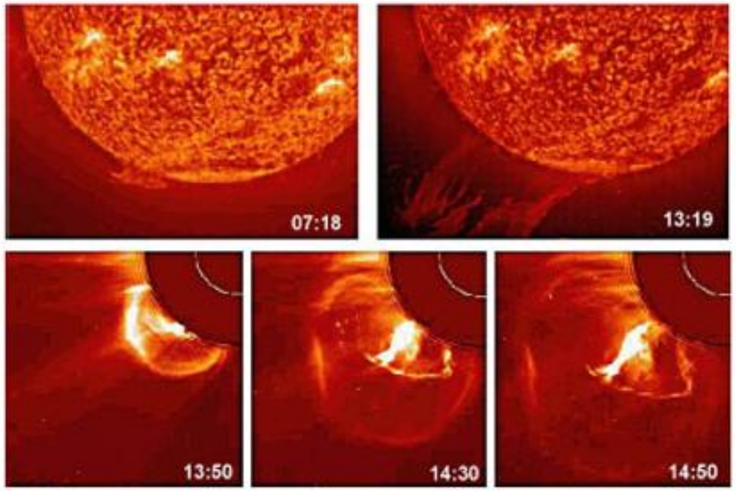
“Cool” coronal HeI D3 emissions revealed in ejecta during a slow CME event: helical structure

Table 2. Parameters of the ejecta, measured using the time sequence of C2-LASCO observations and using the single EIT (304 Å) image.

	$r(R_\odot)$	$Lat_\odot(°)$	$< \frac{\Delta I}{I_0} >$ (%) (preliminary)	$< \frac{\Delta I}{I_{local}} >$ (%) (preliminary)	$< V >$ ($km.s^{-1}$)
EIT : a_1	1.76	43.4	0.83		
EIT : a_2	1.81	44.9	0.80		
EIT : b	1.44	27.8	1.30		
C2 : E_2	[2.36;2.65]	[39;28]		8.5	0 ± 40
C2 : E_3	[2.6;3.0]	[37;31]		8	15 ± 35
C2 : E_4	[3.1;4.5]	[34;26]		5.5	50 ± 20
C2 : E_5	[3.2;4.15]	[32;27]		4	85 ± 5
C2 : E_6	[3.3;5]	[28;22]		7	55 ± 15
C2 : E_7	[4.1;4.8]	26.5		5.5	105 ± 5

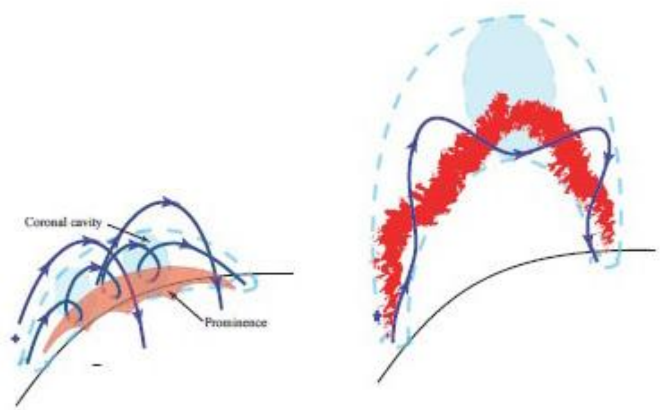


From Boulade et al. 1997

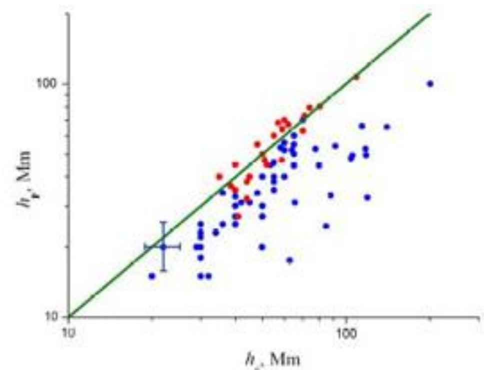


Polar crown filament eruption on 14 June 1999 visible in SOHO/EIT He II 304 Å line (top row) and the following CME observed with LASCO C2 (bottom row).

The eruptive prominence is an important part of the **CME** event



A sketch of the 3-D geometry of a magnetic flux rope with a coronal cavity and a prominence inside in equilibrium (left) and during eruption (right).

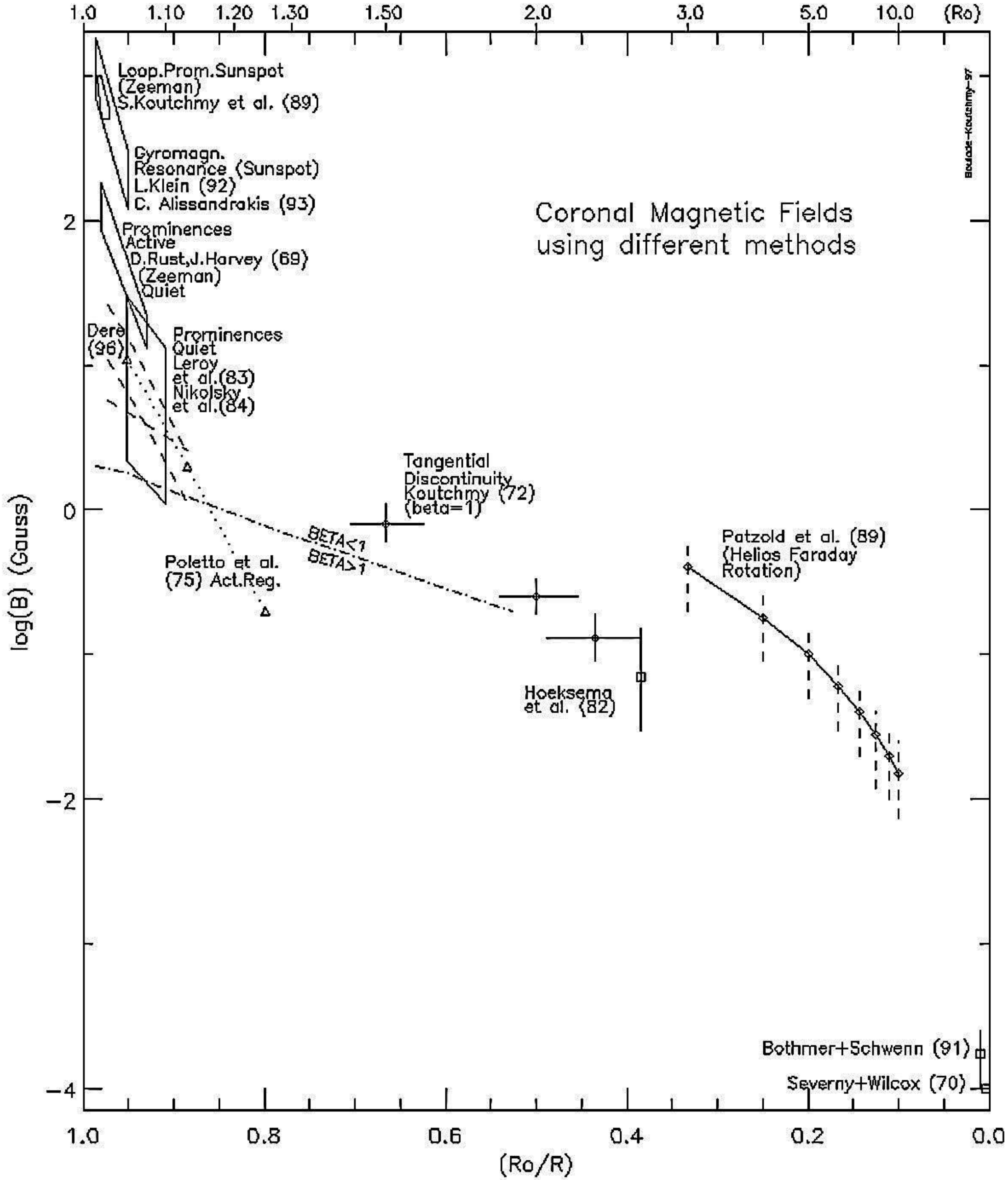


The observed filament height above the chromosphere h_p versus the critical height of stable filament equilibrium h_c. The blue circles correspond to the filaments which safely passed the west limb. The red circles correspond to the filaments which disappeared from the disk. The straight green line corresponding to an equality of these quantities is the stability boundary.

The magnetic context dynamics is at the origin of the eruption

Both the **magnitude** and the **direction** of the field are needed parameters

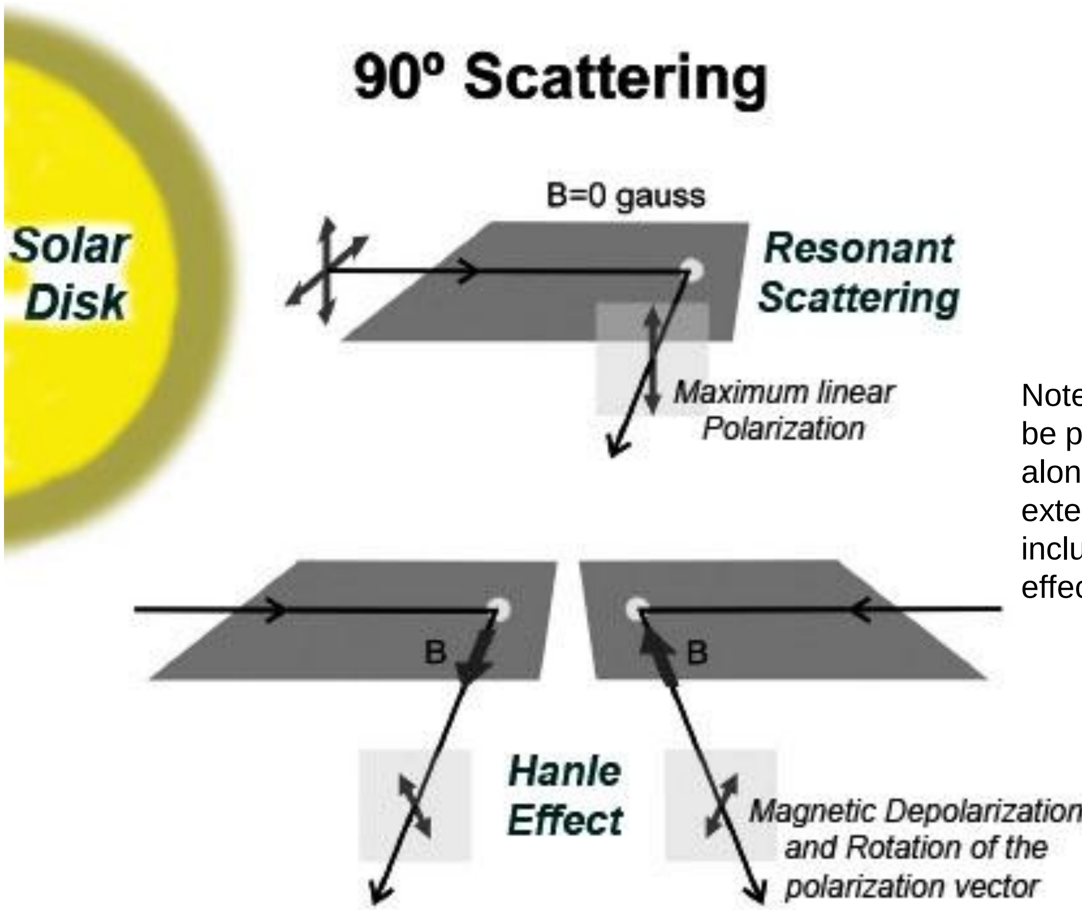
from: Filippov and Koutchmy (2008) Ann. Geophys.



Magnetic Fields
of **0.5 to 10 Gauss strength**
should be
Measured in the
inner corona:

it is the range
of fields ideally
covered by the
Hanle effect
on the D3 HeI line

Hanle effect will permit measuring the weak magnetic field in “high” prominences <u>of low intensity</u> imbedded inside the corona using the D3 HeI emission line of coronal level.

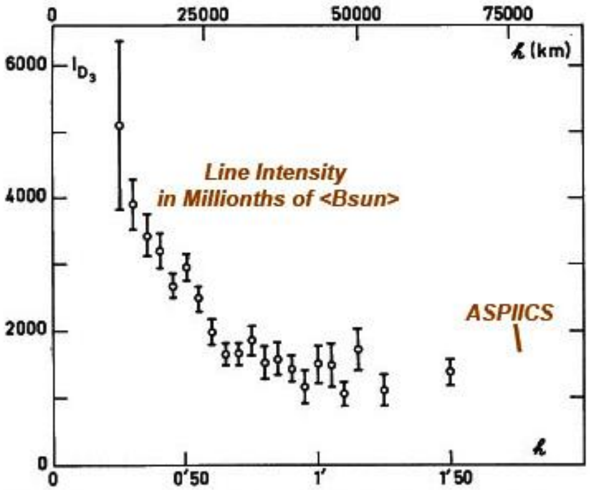


The 90° scattering case in the absence (top panel) and in the presence (bottom panels) of a deterministic magnetic field.

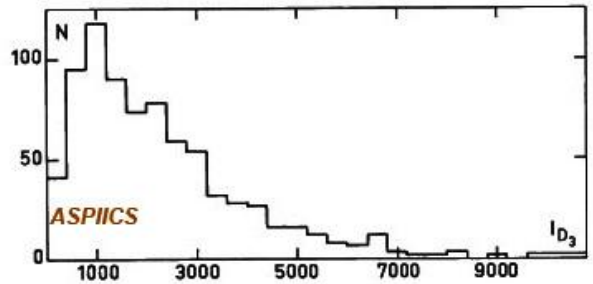
adapted from Trujillo Bueno et al 2005

Note: some depolarization will be produced when integrating along the LOS and over the extension of the Solar disk, including the limb- darkening effect

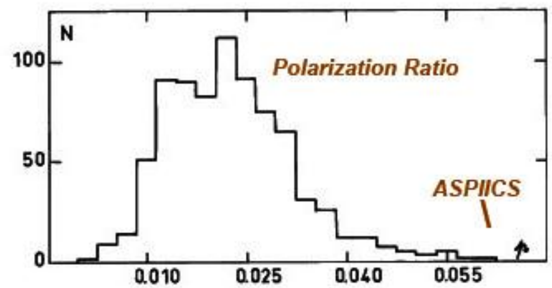
D3 HeI line Coronagraphic Observations of the Hanlé Effect at Pic du Midi Observatory



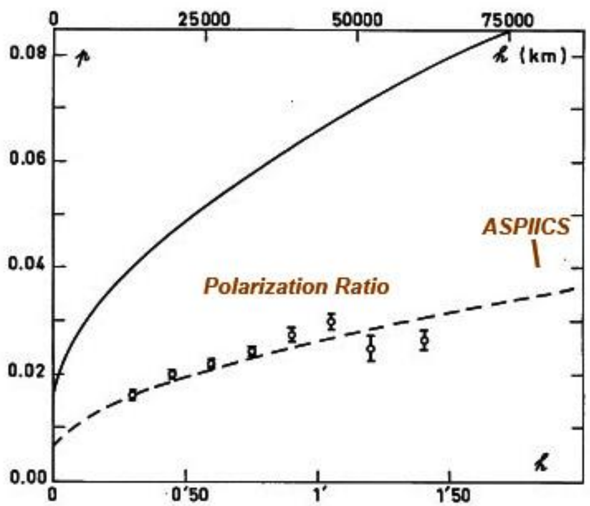
Average height variation of D 3 line intensity I_{D3} in different points of various prominences



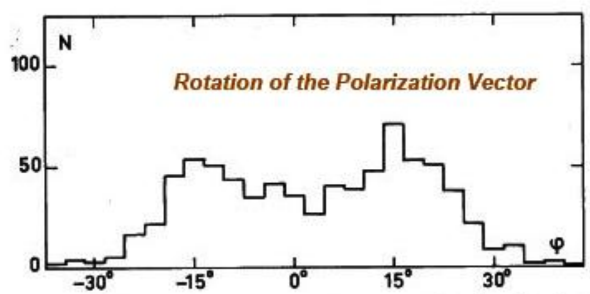
Histogram of the D 3 line intensity I_{D3} as observed in various points of quiescent prominences. Intensity unit is 10^{-6} Å of the continuous photospheric spectrum



Histogram of the degree of polarization, *p*, for quiescent prominences



Average height variation of the degree of polarization; the solid curve corresponds to the maximum theoretical polarization (pure resonance scattering); the dotted curve is the same with all ordinates divided by 2.5



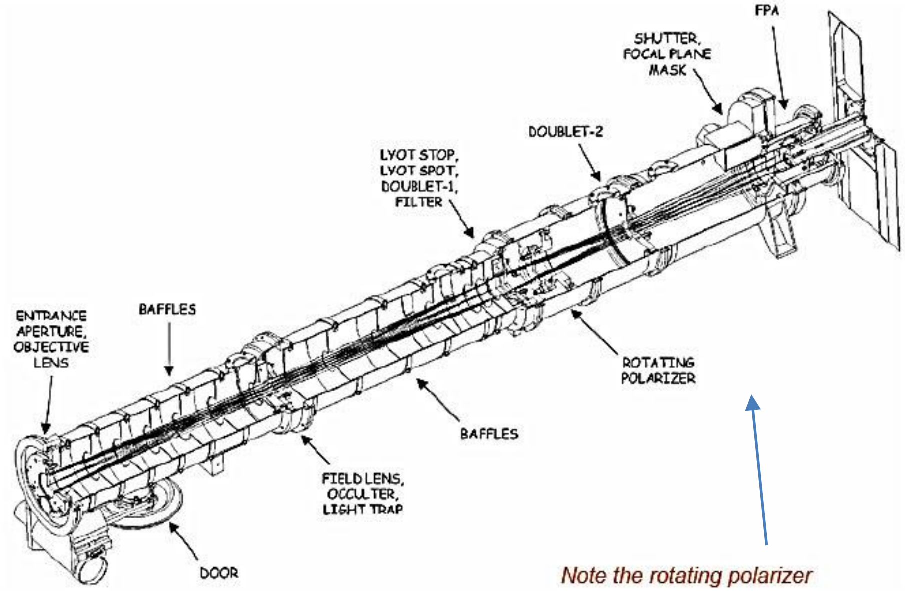
Histogram of the deviation φ of the polarization direction in quiescent prominences; φ is measured counter-clockwise starting from the tangent to the solar limb

Using the spaceborne **Aspiics Imaging Polarimeter** it is possible to go much further out **towards higher altitude and towards lower-emission prominences and "ejecta"** (cool coronal emissions) and *measure their* **Magnetic field**

From Leroy, Ratier and Bommier, A&A (1978)

SECCHI (Stereo mission) C1 coronagraph
Howard et al. 2007

Examples of existing Imaging Polarimeters

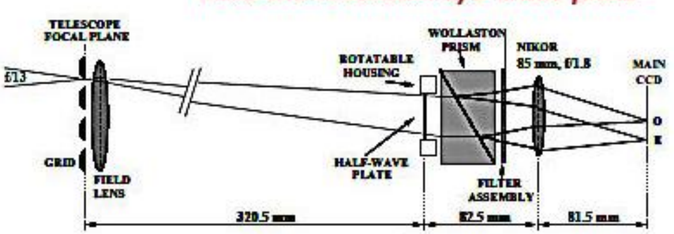


An Imaging Polarimeter(IMPOL) for multi-wavelength observations

A. N. Ramaprakash[1], Ranjan Gupta[1], A. K. Sen[2], and S. N. Tandon[1]

[1] Inter-University Centre for Astronomy and Astrophysics, Post Bag 4, Ganeshkhind, Pune - 411 007, INDIA
[2] Center for Plasma Physics, Sapta Shwahid Marg, Dispur, Guwahati - 781 006, INDIA

Focal plan Assembly;
note the rotatable 1/2 wave plate



Schematic of the IMPOL optical layout

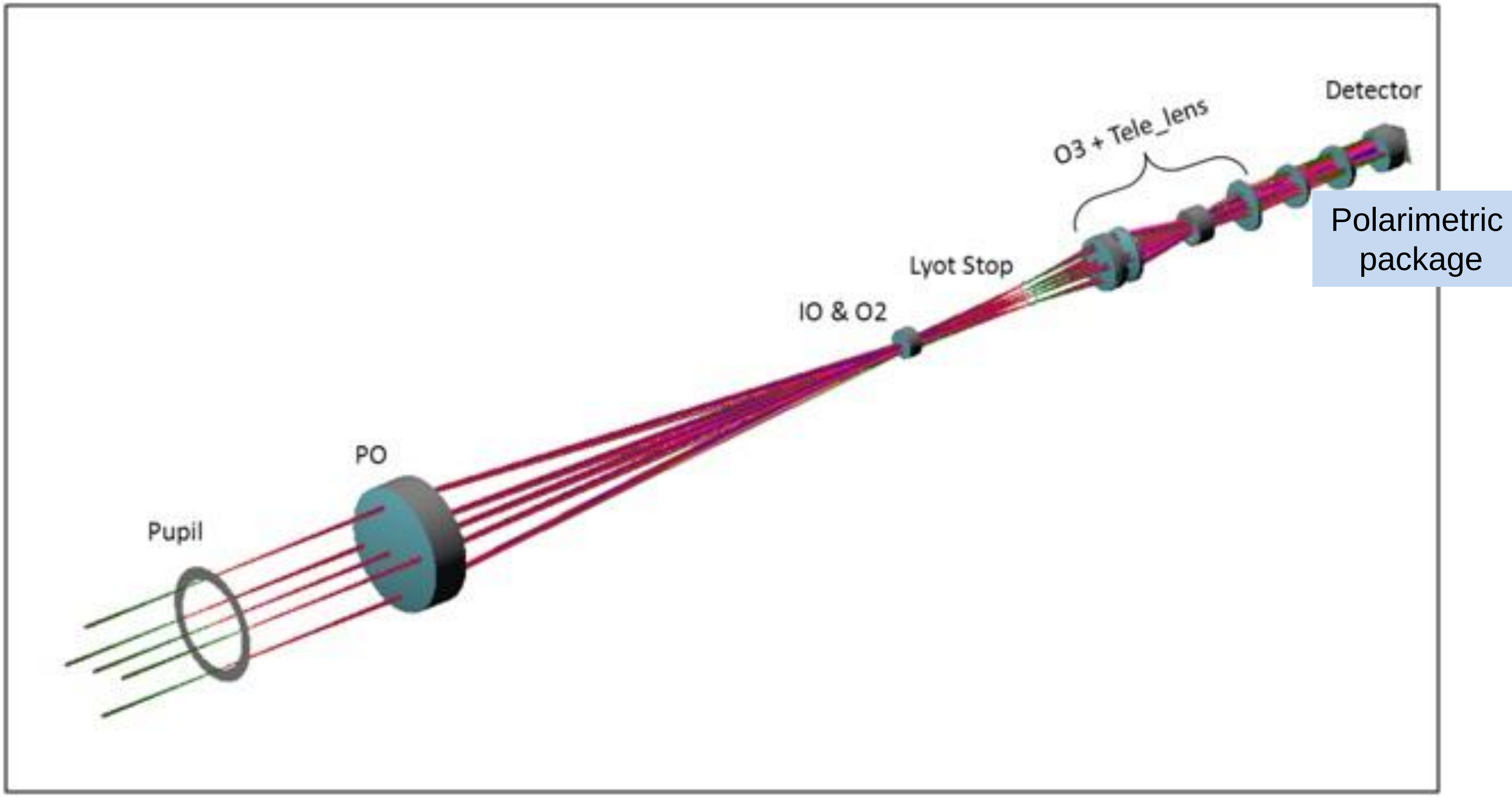
$$I_e(\alpha) = \frac{I_{up}}{2} + I_p \cos^2(\theta - 2\alpha)$$

$$I_o(\alpha) = \frac{I_{up}}{2} + I_p \sin^2(\theta - 2\alpha)$$

I_{up} & I_p are the intensities in unpolarized and polarized condition respectively in the incoming beam; θ & α are the position angles of the polarization vector and the half-wave plate fast-axis respectively with reference to the axis of the Wollaston prism.

ASPIICS with the improved polarimetric channel inserted

(See the Technical Note PROBA-3/ASPIICS Polarization Analysis,1July 2014)



Options: ***the ½ wave rotating plate could be replaced by a combination of a fixed ¼ wave plate with an Achr.LCVR (option studied by S. Fineschi et al. to be space qualified for an orbital mission) permitting as well the analysis the 530.3nm line of FeXIV (and of Hα of HI ?)***

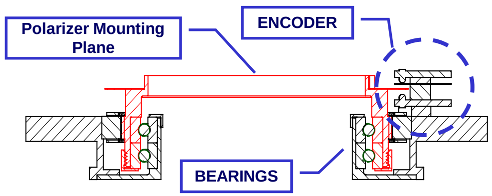
Hollow-Core Motor (1 of 2)

Requirement	Hollow-Core Motor 2S00085 – 101
Position Repeatability	± 30 arc-sec
Time for 180° Move	0.6 sec
Operating Temperature	0 to 40° C
Survival Temperature	-20 to 55° C
Expected Operations	557,440

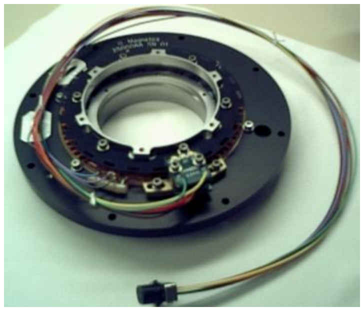
The rotating device used in several Space experiments like Stereo A and B (in COR- 1) ; HMI of SDO etc. to be adapted for rotating the ½ wave plate

Heritage

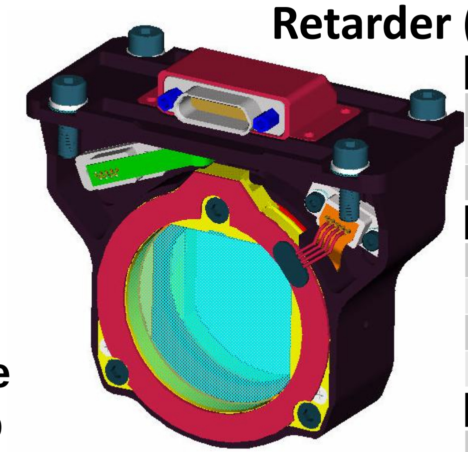
- Motor/Encoder Based on SXI Filterwheel
- Bearing Arrangement from MDI, Solar B



Hollow Core Motor Section



Achromatic Liquid Crystals Variable Retarder (ALCVR)



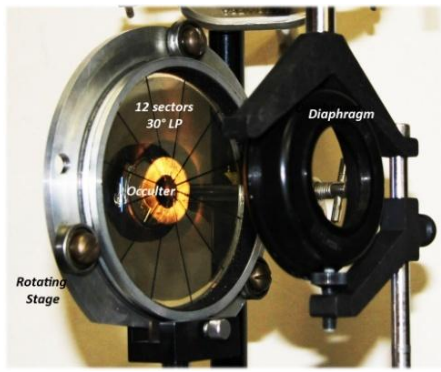
Opto-mechanical	
Dimensions (mm)	61(l)*40(w)*78(h)
Mass (g)	191
Clear Aperture (mm)	25
Liquid Crystals control	
Wave	Square
Frequency (kHz)	2.0
Voltage (V)	+15/ – 15V (p-p)
Power Cons. (mW)	0
Heater	
Power (mW)	< 100

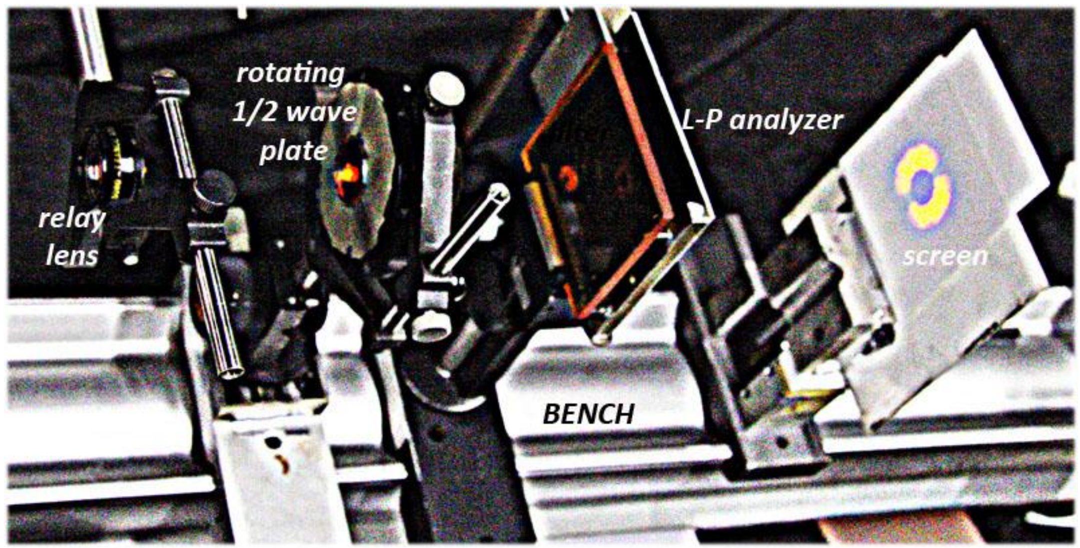
Features:
- No rotating/moving parts;
- Low DC Voltage;
- Resp. time 200 ms

Calibration aspects:
- Temperature stabilized to operational temp. +/- 1°C or in alternative a temperature calibration of the device can be used.

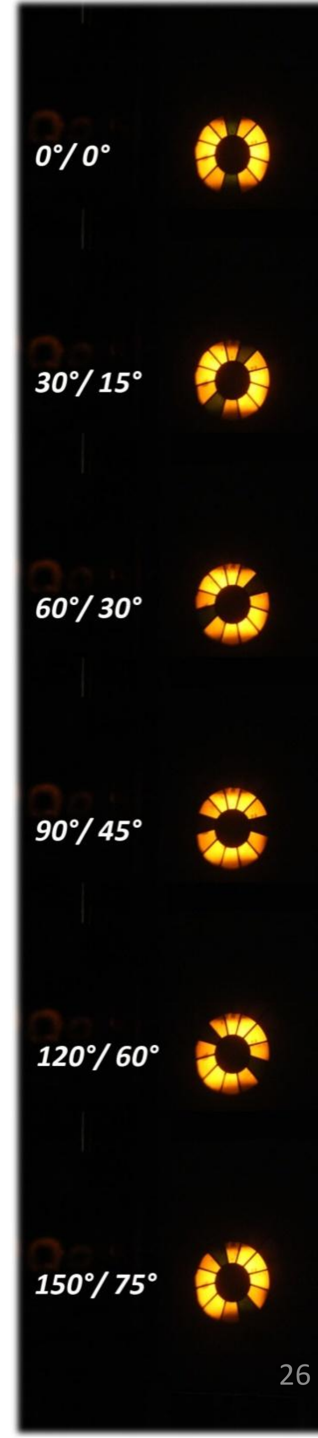
The new generation modulator Rotating the l- polarization plane Developped by the Italian group (S. Fineshi el al)

A demonstration Mock-up tested at IAP with example of Linear Polarization Analysis in 6 directions, using a rotating ½ wave plate





Un message issue de l'expérience de LASCO:
« toute redondance est bonne à prendre et parfois indispensable.»
from A. Llebaria, pers. comm.. 2 July 2014



Conclusions

-Improving the polarimetry capability of Aspiics will result in reaching the basic scientific requirement regarding the physics of CMEs;

- The use of a rotating ½ wave optical quality plate or a LCVR on axis will permit:

i/ an excellent precision in linear polarization analysis (W-L)

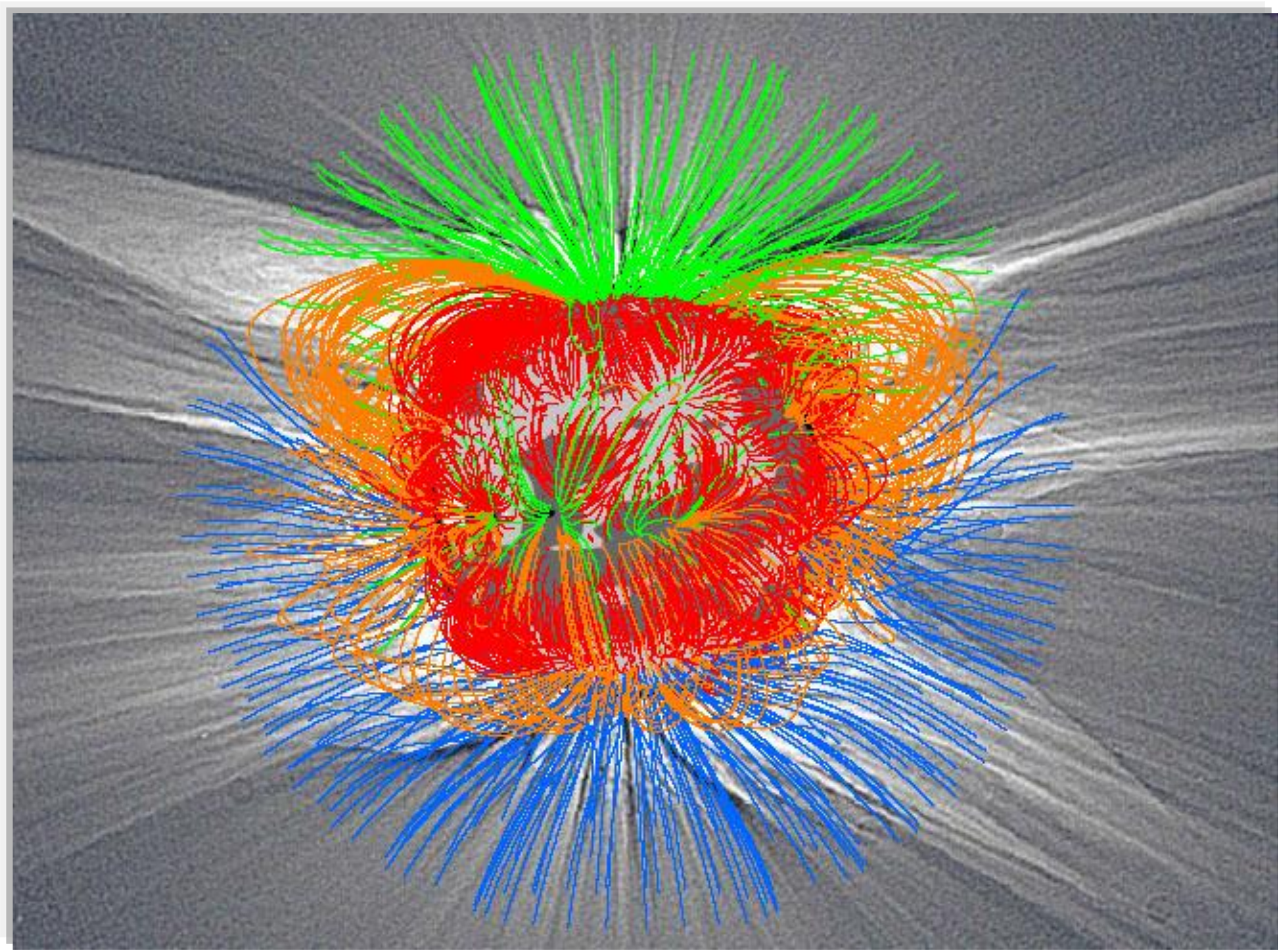
ii/ important new diagnostics of the coronal plasma, including the **strength and the direction of the magnetic field at coronal heights**.

iii/ a greatly improved overall capability of the mission, including the use of several channels and filters.

What about the ground-based support?

ASPIICS
Formation Flying Coronagraph

Thank You !



 Match using the PFSS model (but: no free magnetic energy…)

From Wang et al. 2007