Coronal Magnetograph (CorMag): A Spectro-polarimeter for the study of the coronal magnetic fields

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OUTLINE

- Scientific Objectives
- Tunable Spectro-Polarimeter
- Development of the spectro-polarimeter/CorMag
- Joint observations
- Conclusions

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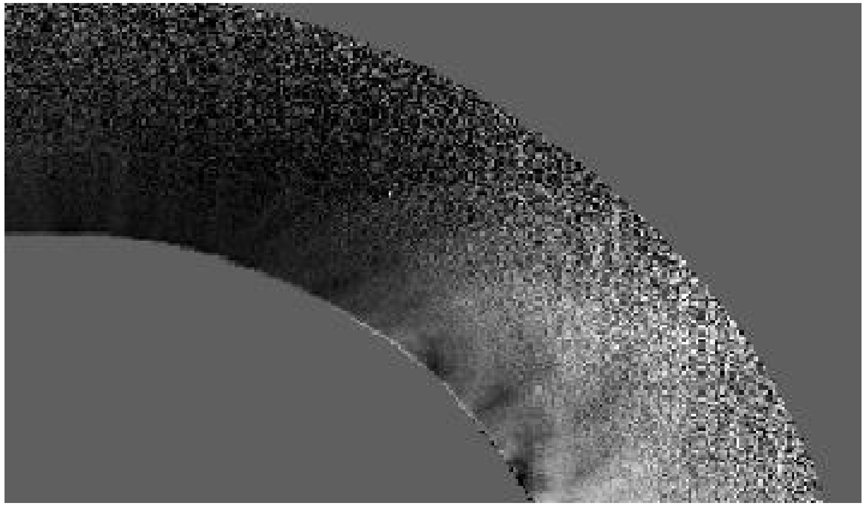
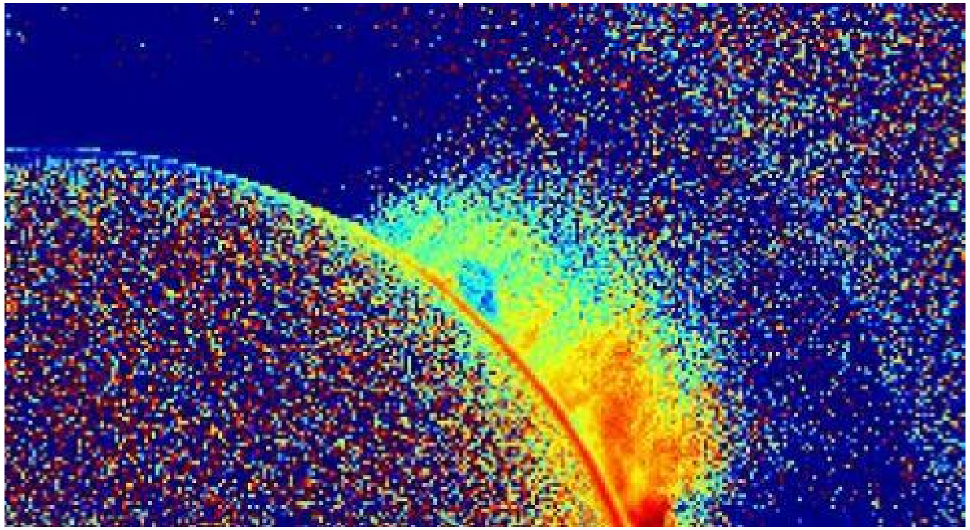
SCIENTIFIC OBJECTIVES (1)

Magnetic Field Topology Diagnostics





SCIENTIFIC OBJECTIVES (2)

From the study of the emission profile of the forbidden transition line of Fe XIV (green line)

- Doppler width:

$$\Delta\lambda = \sigma\sqrt{2} = \mathrm{FWHM}/(2\sqrt{\ln 2})$$

- Kinetic ions temperature T_i

$$\Delta\lambda = (\lambda_0/c_0)\sqrt{2kT_\mathrm{i}/m_\mathrm{i}} = (\lambda_0/c_0)v_{1/e}$$

- Effect of turbulence and/or heating processes comparing the kinetic temperature and the line formation temperature

- Coronal magnetic field through the Hanle effect on the polarization of the line

SCIENTIFIC OBJECTIVES (3)

Evaluation of physical parameters of the inner solar corona (<1.4 R_{SUN})

From polarization of K-corona (and assumption on distribution simmetry)

- Electron density n_e

$$pB = K \int_{\rho}^{\infty} N_e \frac{\rho^2}{r^2}[(1-u)A(r) + uB(r)] \frac{r\,dr}{\sqrt{r^2-\rho^2}}$$

- Effective electron temperature T (assuming corona in hydrostatic equilibrium)

$$N_e\left(\frac{r}{R_\odot}\right) = N_e\left(\frac{r_0}{R_\odot}\right) e^{-\frac{\mu m_H G M_\odot}{k R_\odot T}\left(\frac{R_\odot}{r_0} - \frac{R_\odot}{r}\right)}$$

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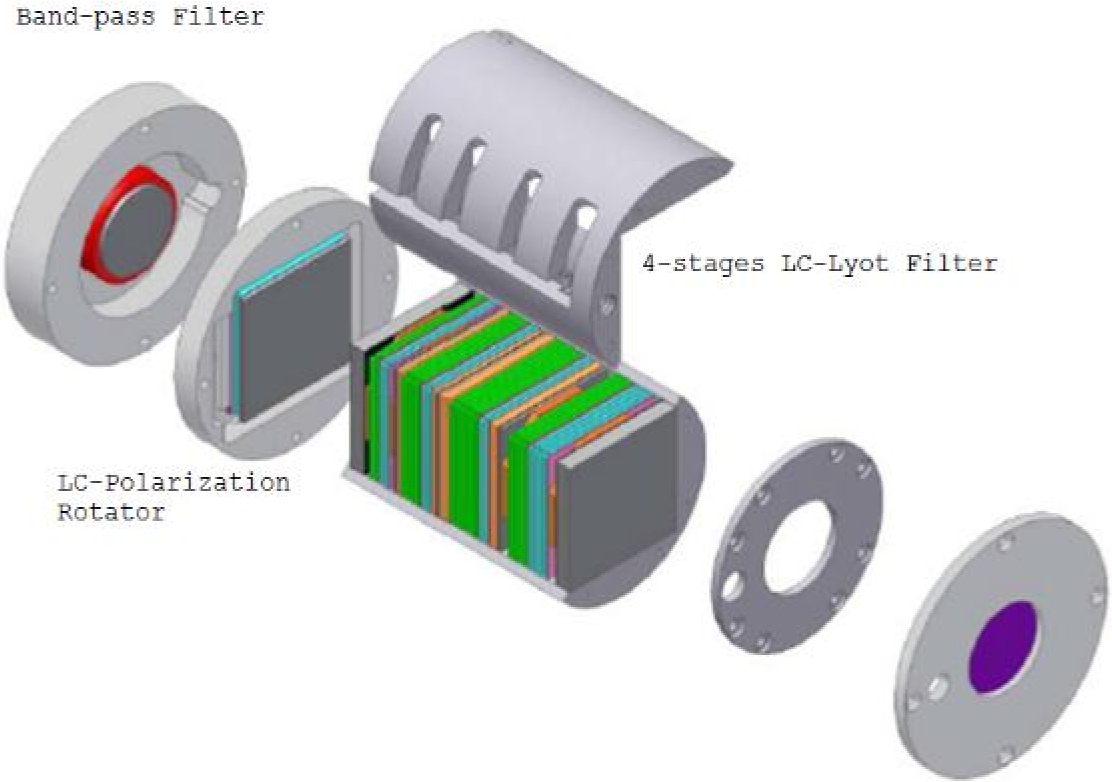
Instrument description (1)

The LC-based spectro-polarimeter is composed by a **4-stages LC-Lyot filter**, tunable in wavelength changing the voltage applied to the LCs, a **polarization rotator** for the polarimetric capabilities, changing the rotation of the polarization applying a voltage to the LCPR and **a band-pass prefilter,** cutting-off the secondary peaks of the LC-Lyot filter.



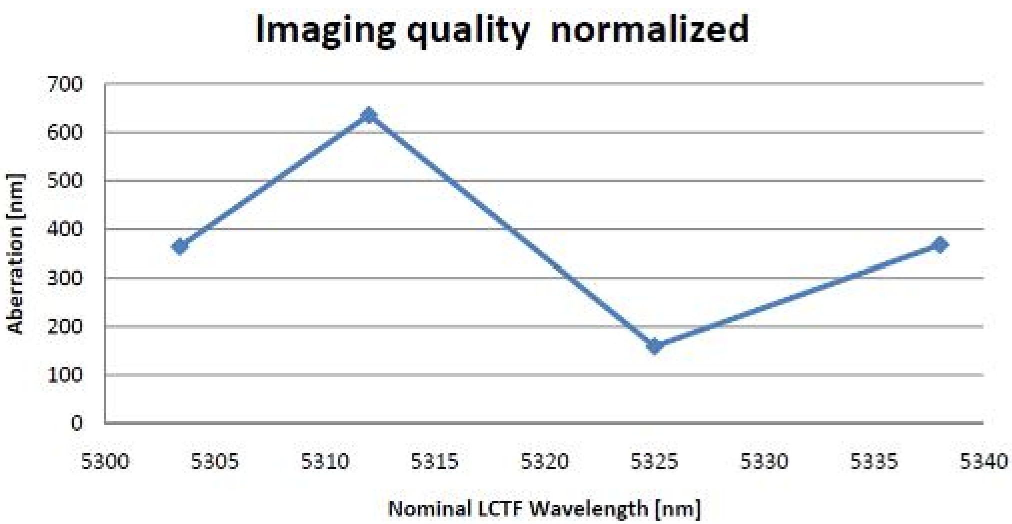
Instrument description (2)

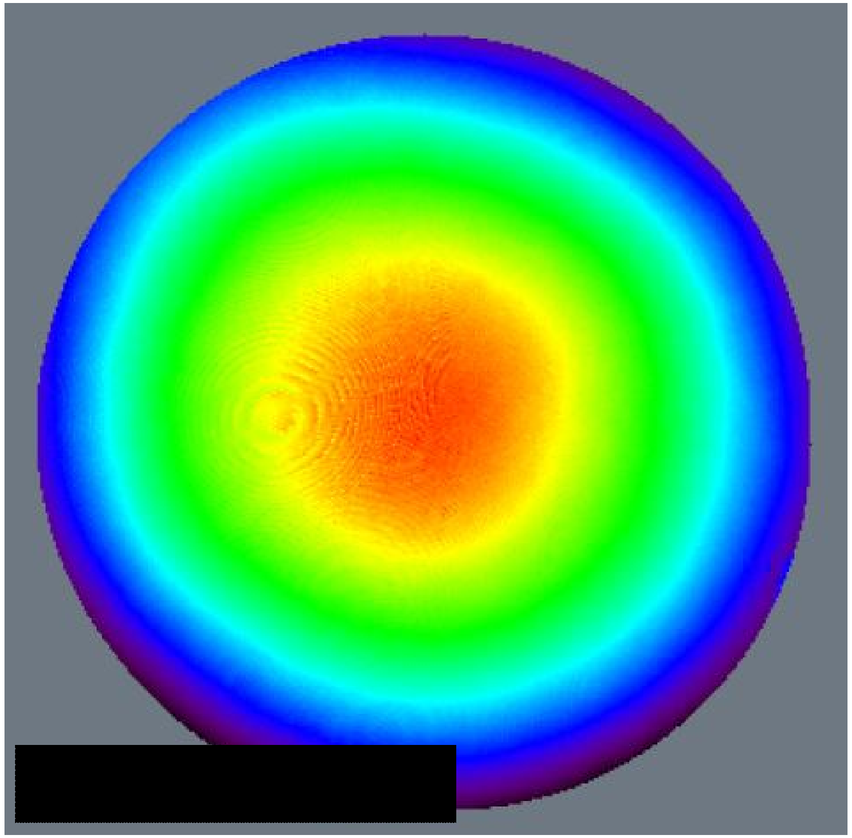
- Compact design
- Low power consumption (thermal stabilization)
- No moving parts
- Low mass

LCTF General	Length [mm]: 90 Diameter [mm]: 60 Aperture [mm]: 20 Number of stages: 4 FSR [nm]: 2.7 FWHM [nm]: 0.15 Center wavelength [nm]: 528.64 – 533.38 Tuning step [nm]: 0.01
Pre-filter	Manufacturer: Andover Corp. Center wavelength [nm]: 530.69 FWHM [nm]: 1.89
LCPR	Manufacturer: MLO Rotation angles [deg]: 0 - 180

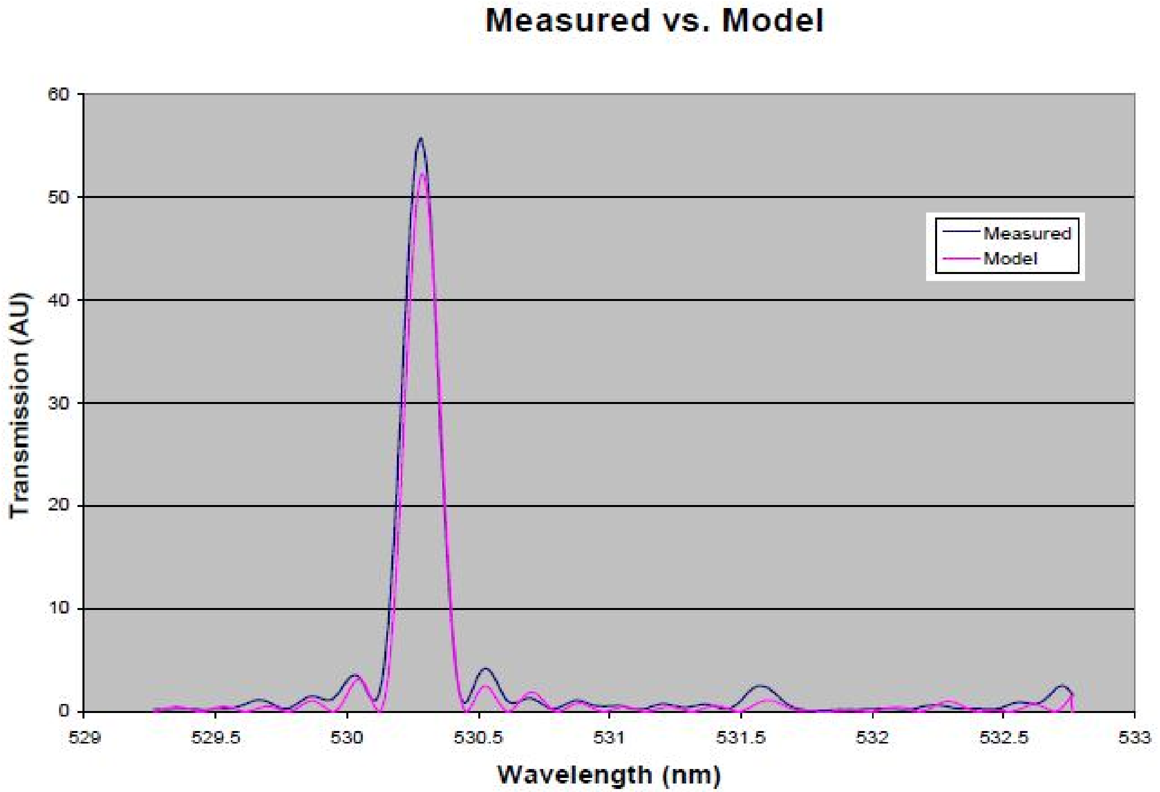
Optical Performances

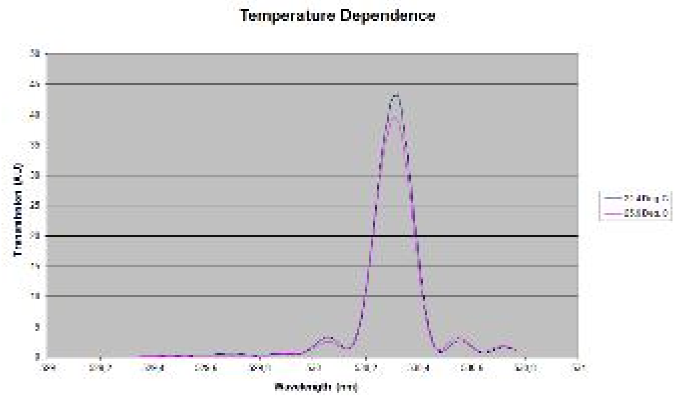
Image quality between ½ λ and ¾ λ

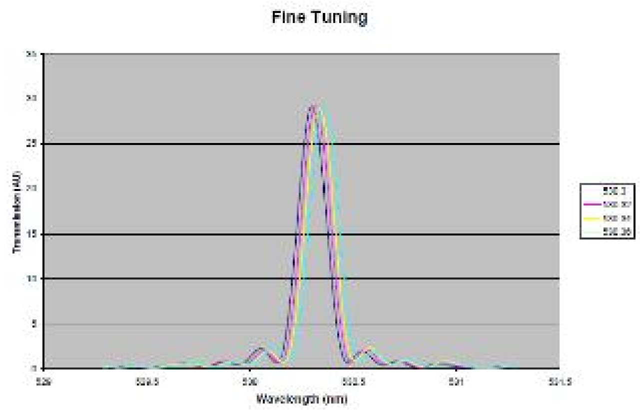



[redacted]

Spectroscopic Performances

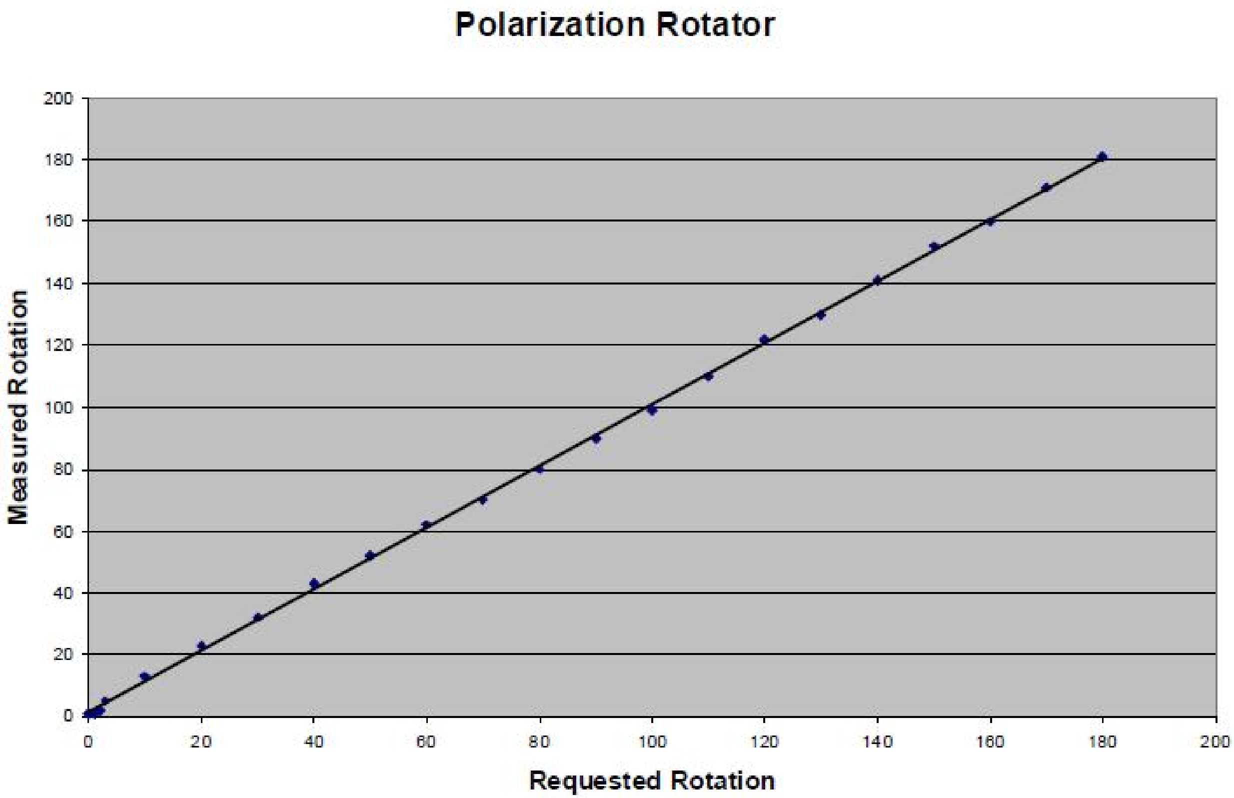




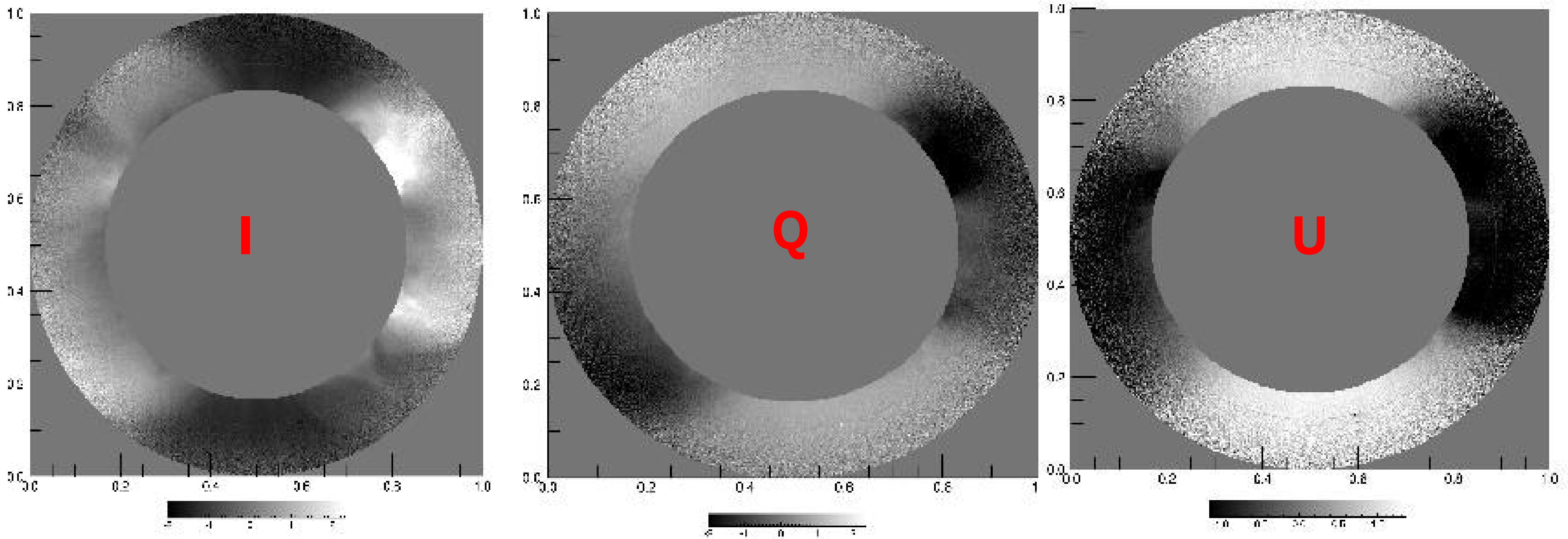


Polarimetric Performances (1)

Laboratory calibration of the polarimetric capabilities of the spectro-polarimeter.

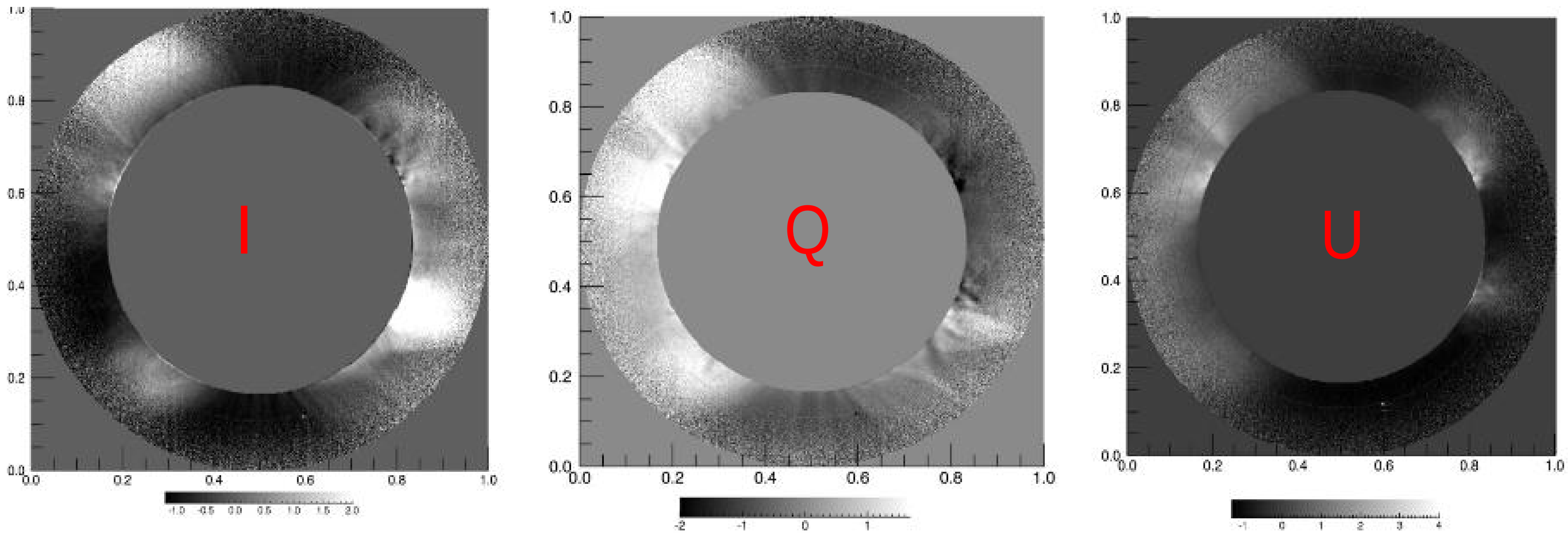


Polarimetric Performances (2)



Stokes parameters of the K-Corona acquired during 2010 Total Solar Eclipse
(J. Girella – Master degree Thesis - 2014)

Polarimetric Performances (3)



Stokes parameters of the E-Corona acquired during 2010 Total Solar Eclipse
(J. Girella – Master degree Thesis - 2014)

Comparison with classic Fabry-Perot etalon

Filter	F-P Etalon	LCTP
Spectral Resolution (nm)	0.02	0.15
Spectr. Tuning step (nm)	0.02	0.01
Free Spectr. Range (nm)	0.5	2.5
Finesse	25	17
No. of fringes at AOI = 20°	40	900 (Effective)
Spatial Res. (arcsec)	120	5
Transmissivity	70%	30%
SNR/SNR$_{F\text{-}P}$	1	2

Instrument	Fabry-Perot interferometer		Lyot filter	
N. of data	5	7	5	7
Δ(CW) (%)	~ 0.001	~ 0.0005	~ 0.001	~ 0.0005
Δ(FWHM) (%)	9-10	4-6	10-15	4-6
S/N range	~ 10-50		~ 8-40	
Countrate (s^{-1})	1.2 e+2		1. e+2	
Dwell time (s)	~ 40-50		~ 50-60	

NB: uncertainties are 2-σ errors (95.4% confidence level)

This comparison just take into account the spectroscopic performances. Fabry-Perot etalons don't have polarimetric capabilities.

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Development of the Spectro-polarimeter - Milestones

2009
- Development of the spectro-polarimeter during ESA/StarTiger activities

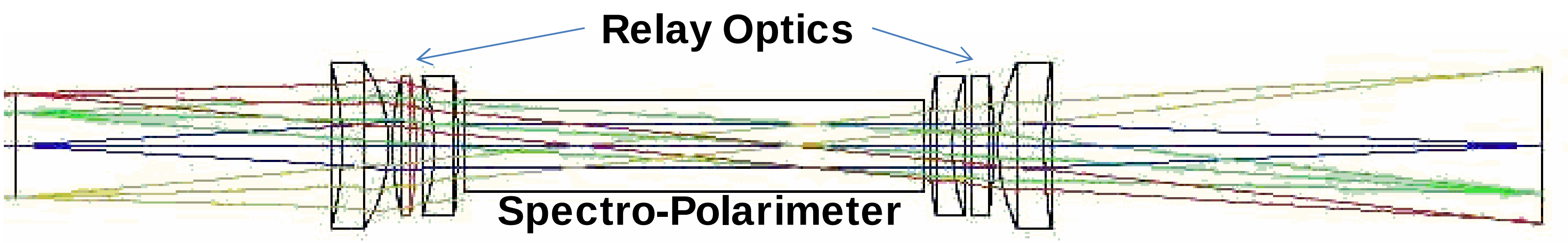
2010
- Complete the development and full calibration of the device. Comparison with a classic high performances Fabry-Perot etalon
- Data acquisition campaign during Total Solar Eclipse

2013
- Installation of the device at LSO and first tests

2014
- Ugrade of the installation and first coronal data

2009 – First development

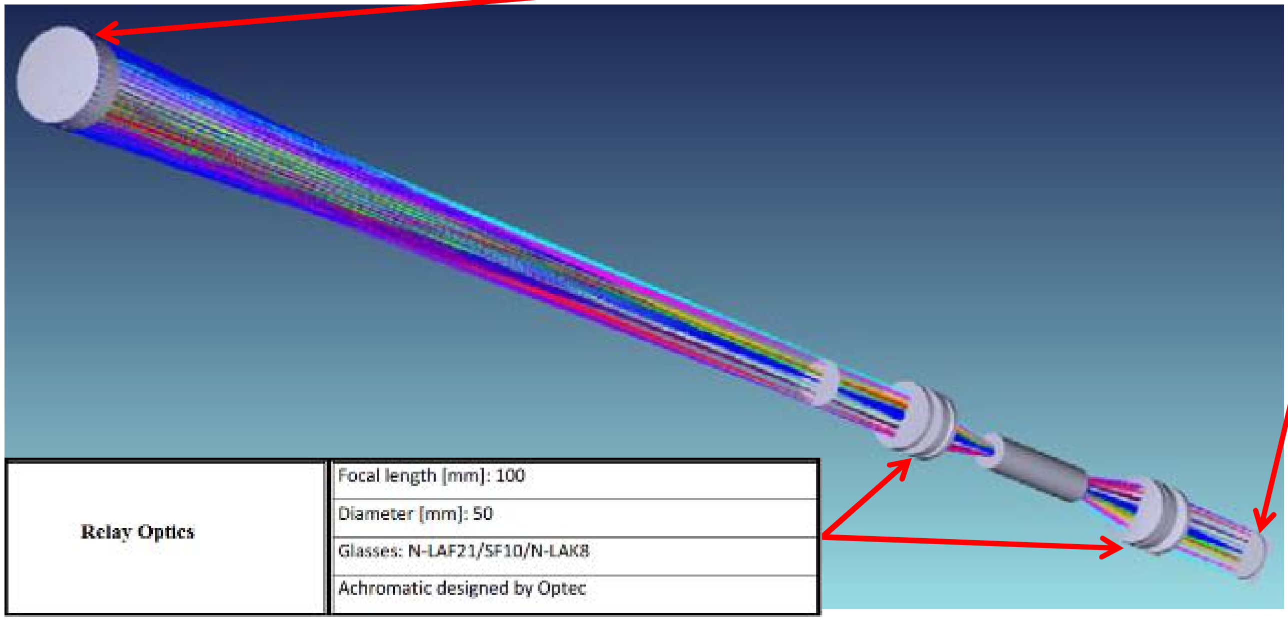
The tunable specto-polarimeter has been developed as an alternative to the F-P etalon for the ESA/PROBA 3/ASPIICS instrument. The full development has been performed during the ESA/StarTiger activities, as the calibration and the comparison with the Fabry-Perot etalon shown in the previous slides.



[Ray-trace of the tunable spectro-polarimeter accomodation for ASPIICS/PROBA3 satellite as presented at the middle of ESA/StarTiger activities]

2010 – Total Solar Eclipse/CorMag instrument

Objective lens [O]	Focal length[mm]: 800 Diameter [mm]: 60 F/#: 13.3	Detector [D]	Type: CCD Camera FLI Proline 1001E Sensor: Kodak KAF-1001E Frame size [pixels]: 1024x1024 Pixel size [μm]: 24 A/D Conversion [bit]: 16

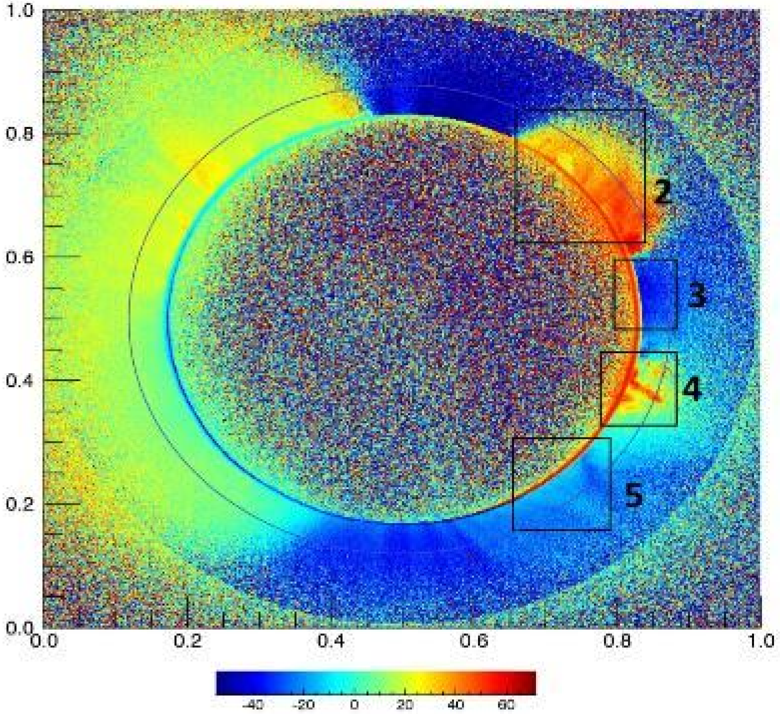


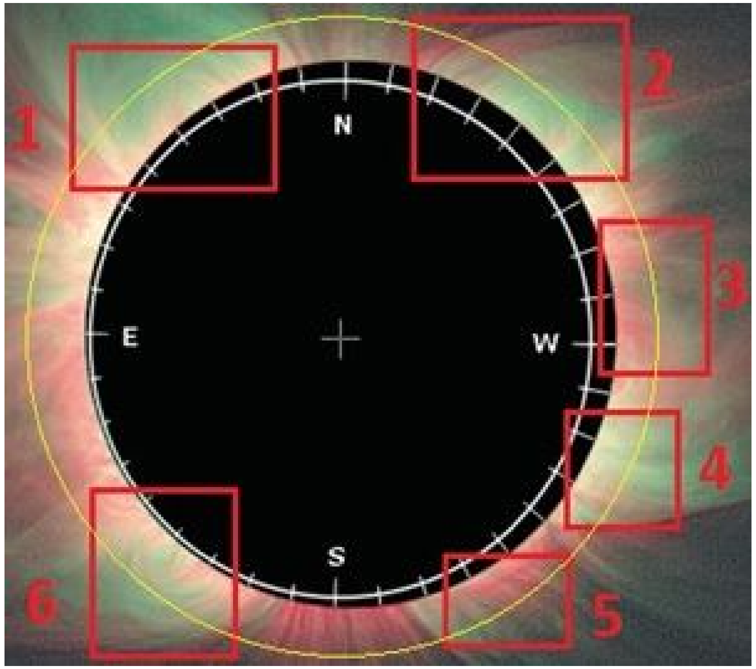
Relay Optics	Focal length [mm]: 100 Diameter [mm]: 50 Glasses: N-LAF21/SF10/N-LAK8 Achromatic designed by Optec

2010 – Total Solar Eclipse/Results

Polarization angle of FeXIV line as detected by CorMag

[J. Girella – Master degree Thesis – 2014]





High-resolution FeX and FeXIV image by Druckmuller

2010 – Total Solar Eclipse/Results

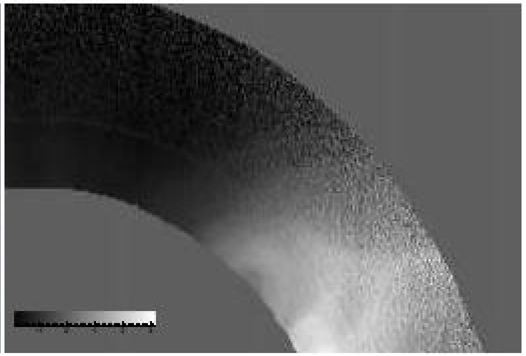
Cavity close to the N-W limb

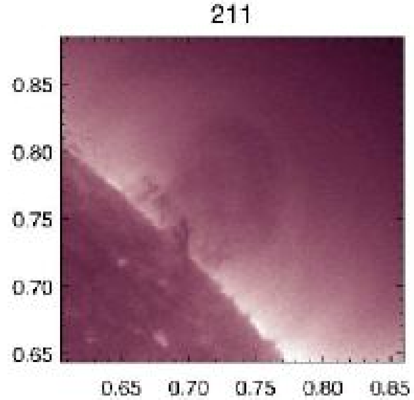
[J. Girella – Master degree Thesis – 2014]

Druckmuller [spatial resolution: 1 arcsec/px]

CorMag [spatial resolution: 12.4 arcsec/px]

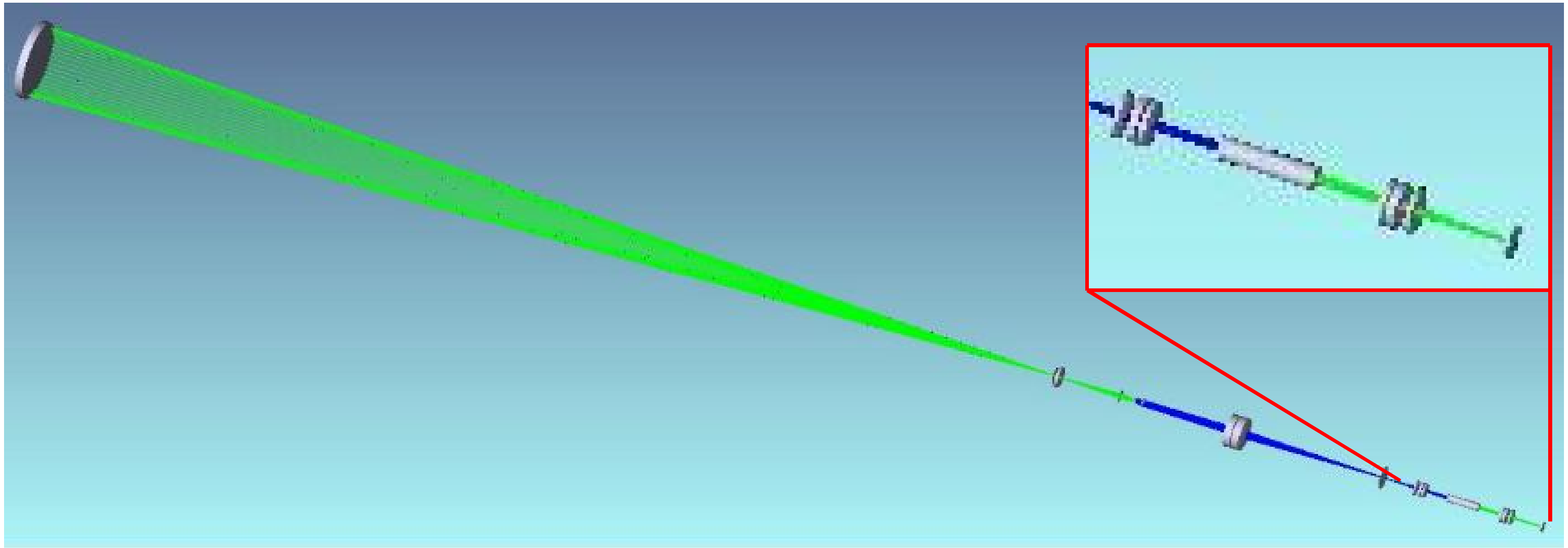
SDO/AIA [spatial resolution: 1.5 arcsec/px]



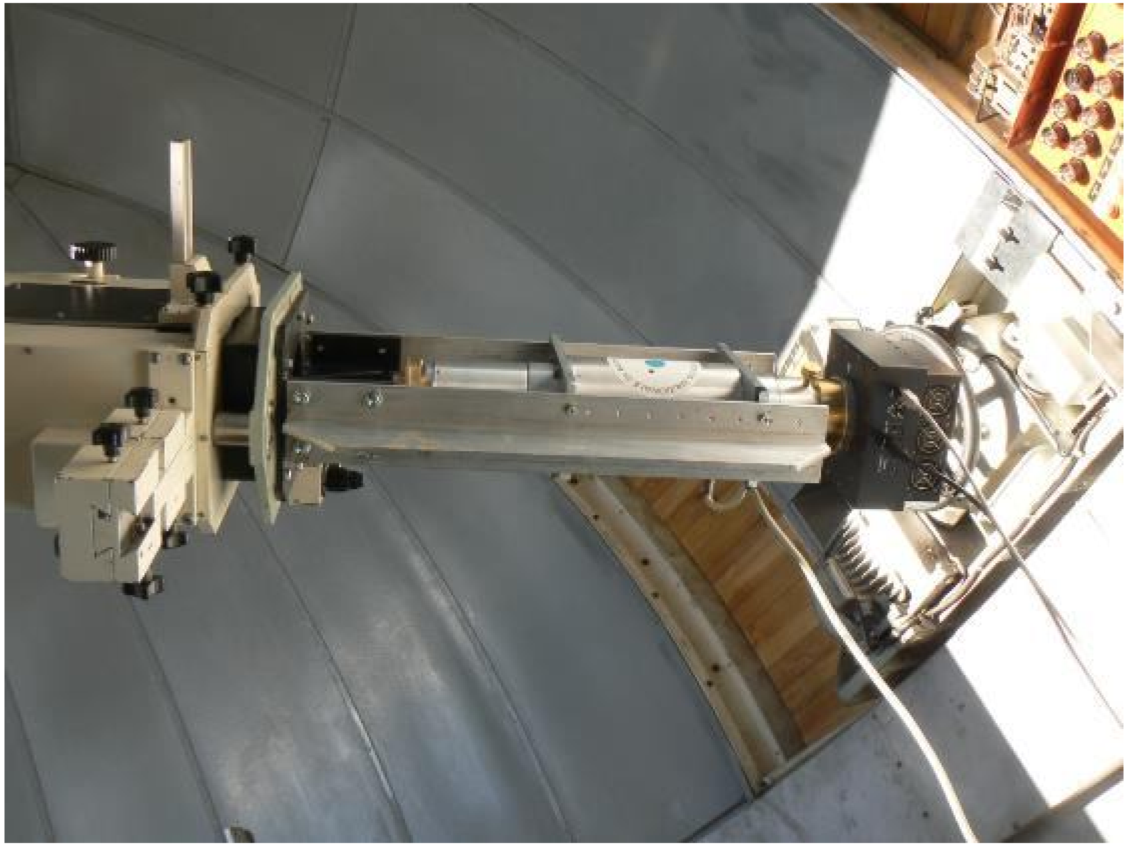


2013 – First installation at Lomnicky Stit Observatory (1)

CorMag in the same configuration of the eclipse (except for the objective lens) has been installed in the focal plane of one of the two coronagraphs installed at Lomnicky Stit Observatory. [see J. Rybak presentation]



2013 – First installation at Lomnicky Stit Observatory (2)

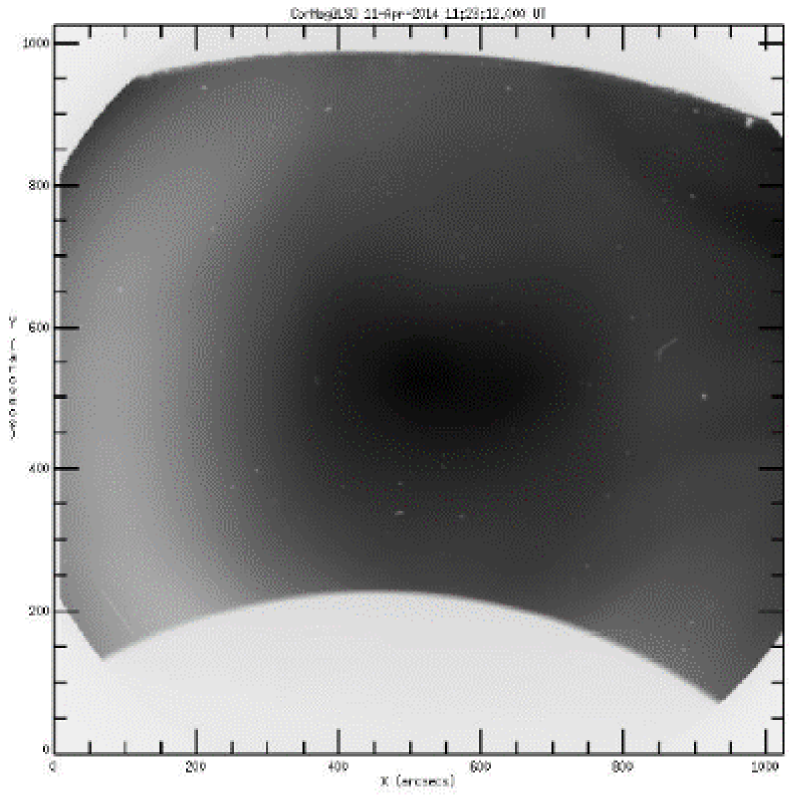


2013 – First installation at Lomnicky Stit Observatory (3)

<u>The first light was acquired</u>.

Problems identified:

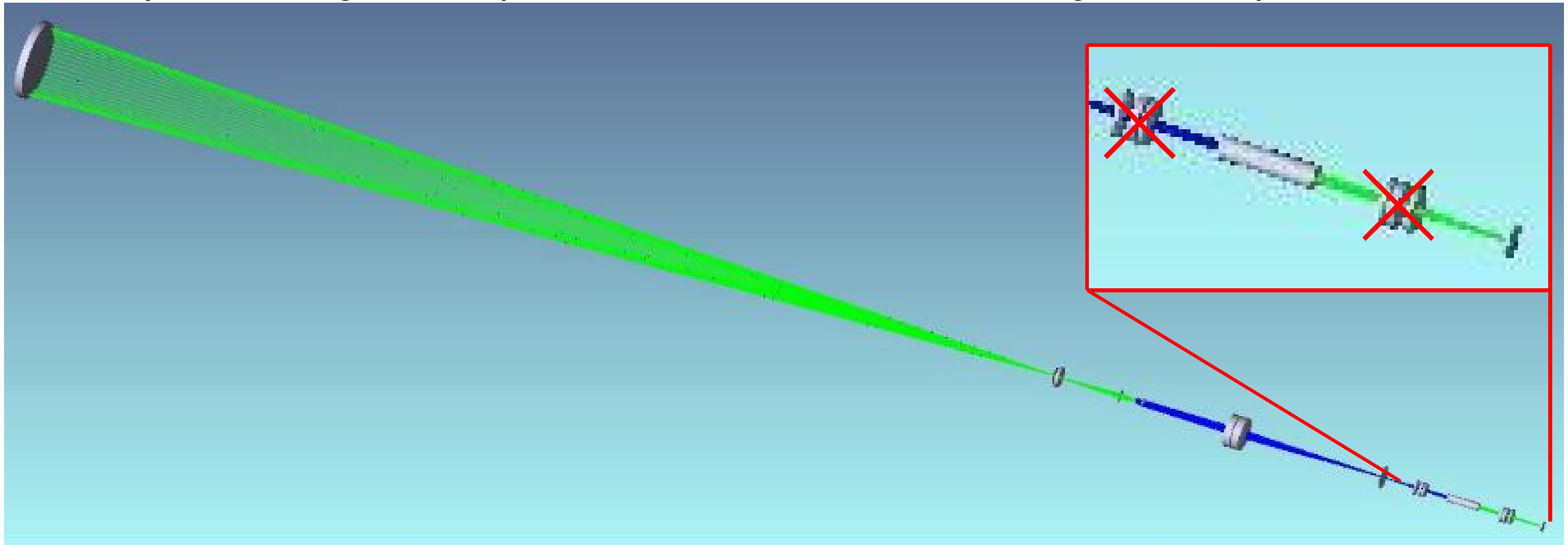
- Ghosts
- IR leak
- VL leak
- Thermal stabilization (see J. Rybak presentation)
- Pointing (see J. Rybak presentation)



2014 – Upgrade/Ghosts removal (1)

In order to remove ghosts, the following actions was performed:

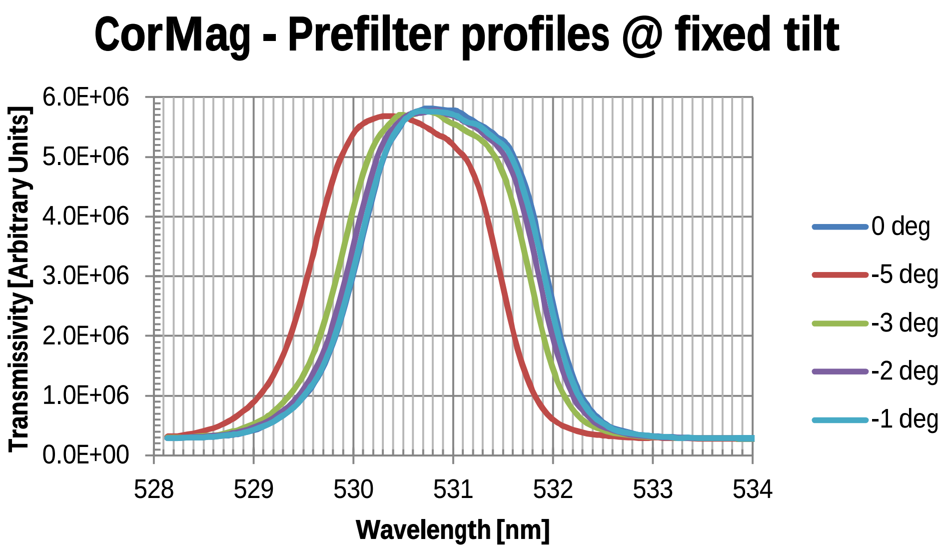
1. New optical configuration (from collimated beam to convergent beam)

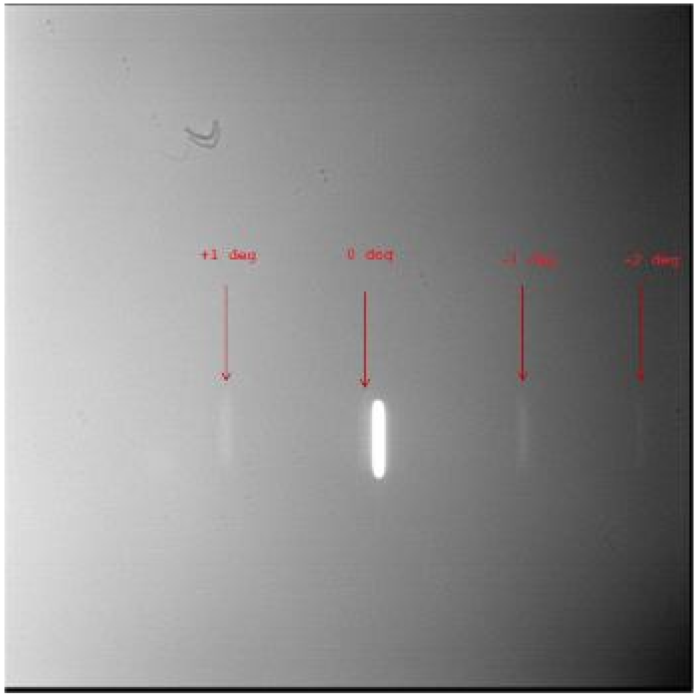


2014 – Upgrade/Ghosts removal (2)

In order to remove ghosts, the following actions was performed:

2. Tilt the bandpass filter of 5 deg





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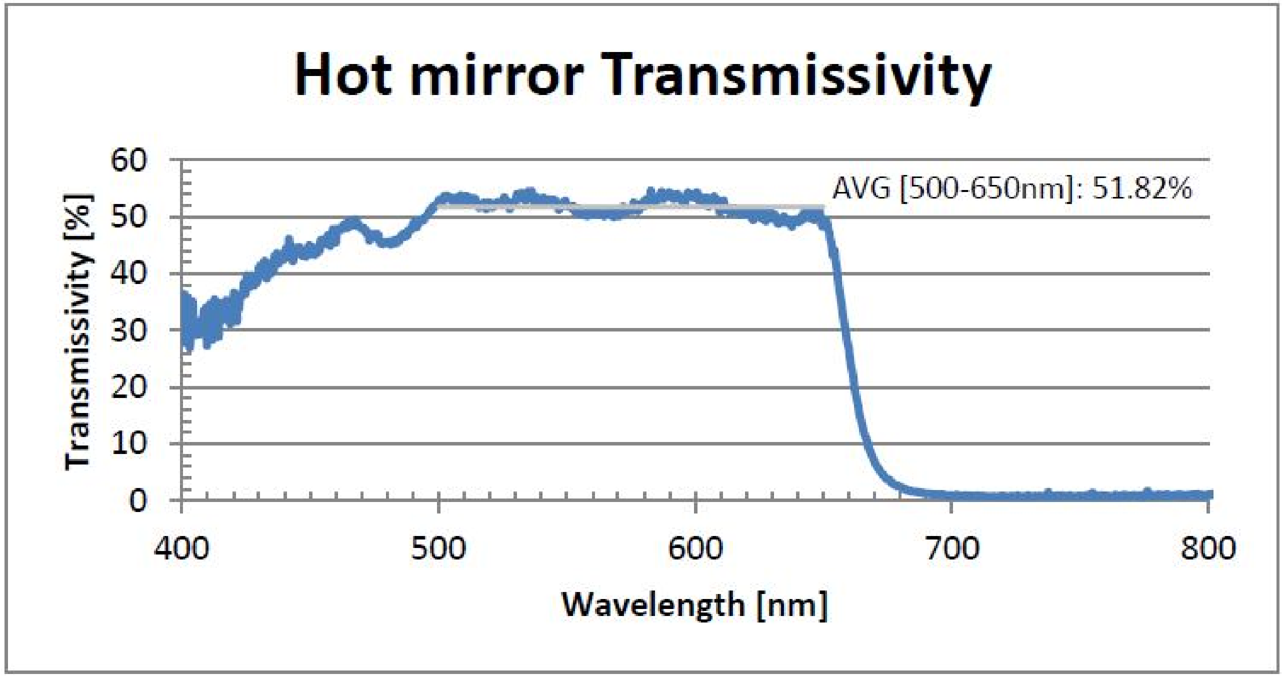
“The magnetic solar corona as revealed by polarimetry” meeting
Toulouse, Nov . 06, 2014

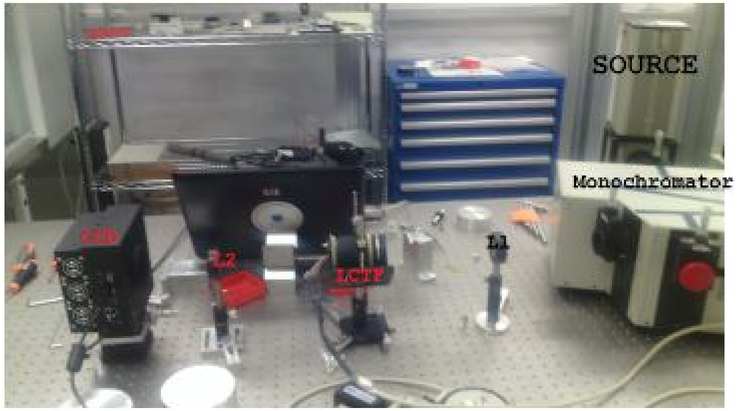
2014 – Upgrade/IR leak removal

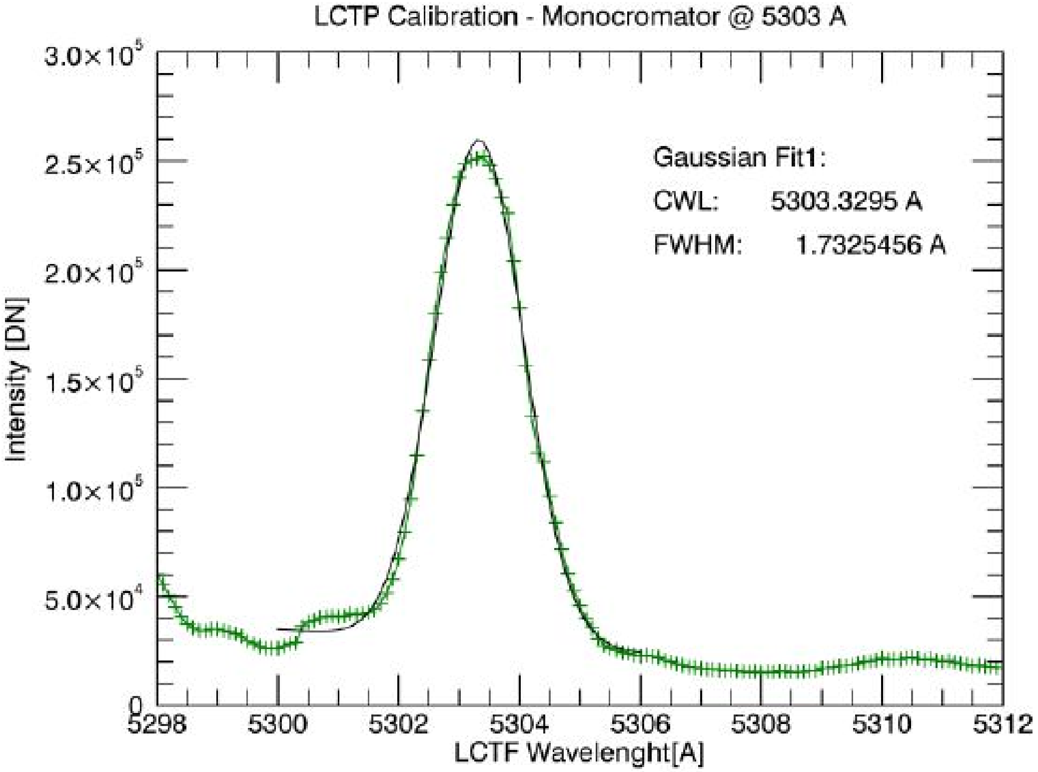
In order to remove the IR leak, an hot mirror has been inserted in front of the CorMag



2014 – Upgrade/Calibration

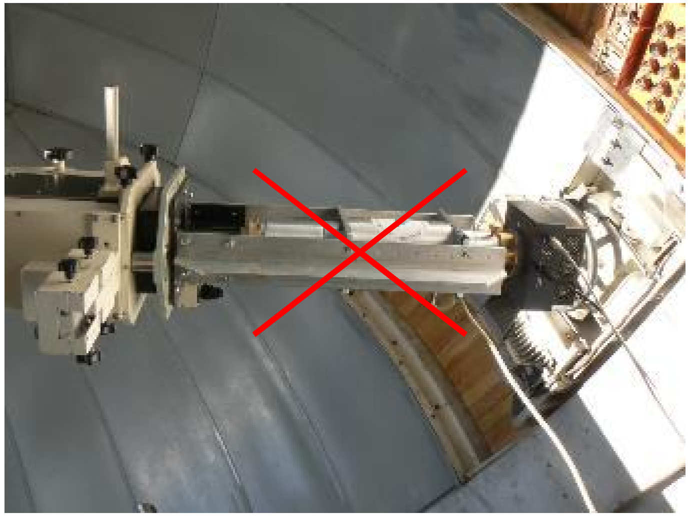
The CorMag in the new configuration has been recalibrated before the installation at the coronagraph





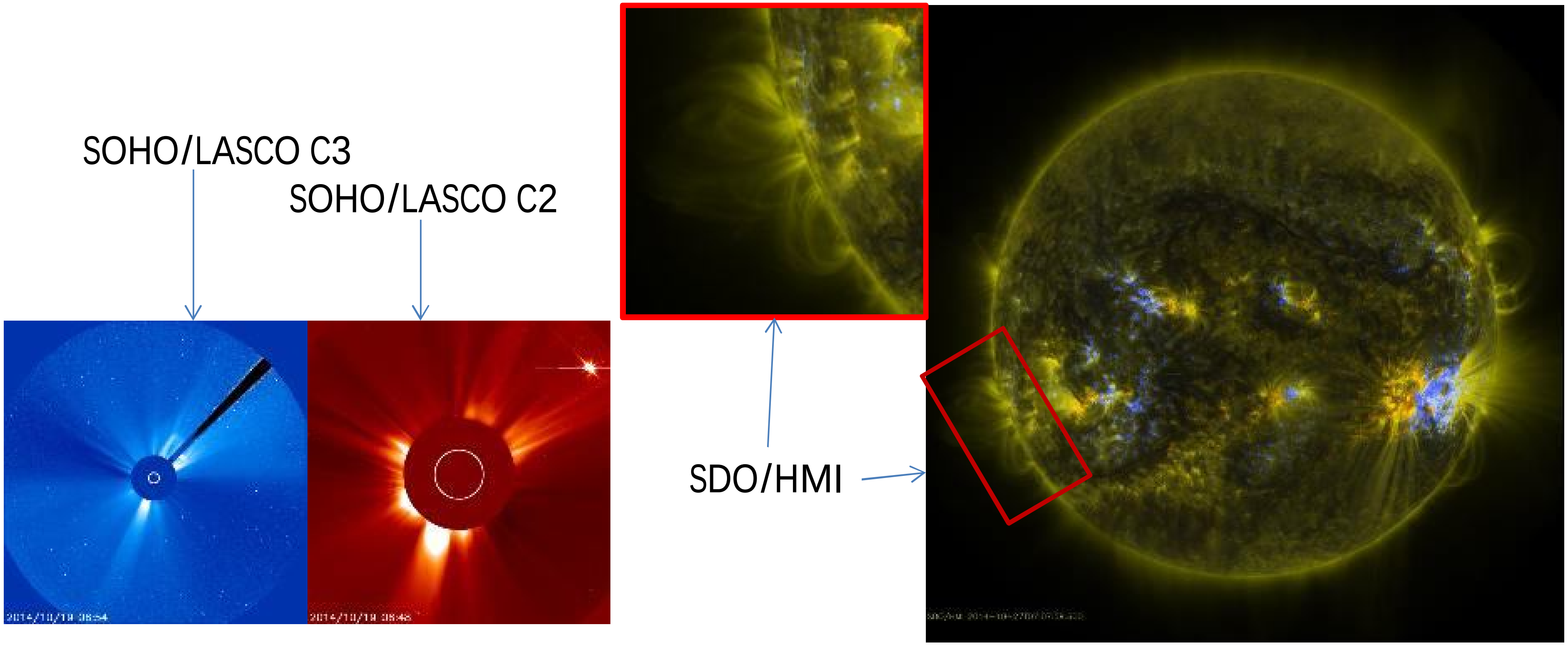
2014 – Upgrade/New installation

The new configuration in convergent beam of the CorMag at the Zeiss coronagraph at LSO



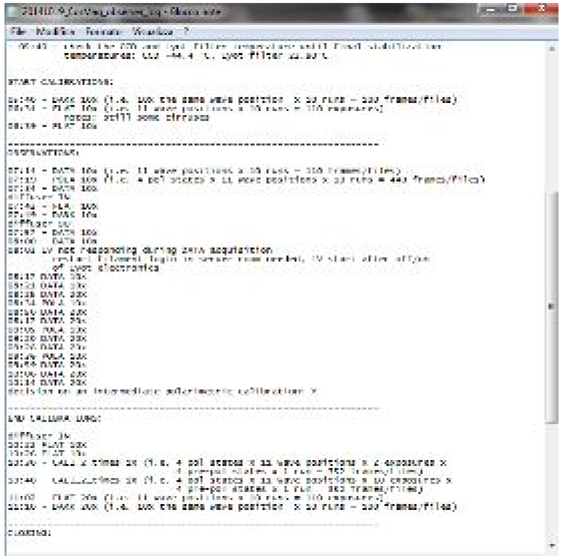
2014 – First data/ancillary

Data Observations with "good" sky conditions: 2014, Oct, 19



2014 – First data

Data Observations with “good” sky conditions: 2014, Oct, 19



<u>During ~6 hours:</u>
- 2314 Data frames;
- 1760 Polarimetric frames;
- 400 Dark;
- 770 flat field (with diffuser);
- 704 Calibration frames (with diffuser and prepolarizer)

TOTAL: 5948 frames (~12 GB of raw data)

Data analysis is still in progress. Evidence of the FeXIV in the inner corona (~1.1 - 1.2 R_{sun})? To be compared to other data (SDO images)

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Joint observations CorMag/COMP-S

A unique opportuny for the study of the coronal magnetic fields analyzing the kinetic temperatures of different ions (i.e. Fe^{13+} and Fe^{9+})

Advances in Space Research

The Dynamic Heliosphere

Using LASCO-C1 spectroscopy for coronal diagnostics

M. Mierla, R. Schwenn, L. Teriaca, G. Stenborg, B. Podlipnik

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DOI: 10.1016/j.asr.2005.04.081

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Abstract

The LASCO-C1 telescope was designed to perform spectral analysis of coronal structures by means of a tunable Fabry–Pérot interferometer acquiring images at different wavelengths. Results from spectral scans of the Fe XIV 5303 Å green coronal emission line are presented. Physical quantities like the ion temperature (line width), and the flow velocity along the line of sight (Doppler shifts) are obtained over the entire corona.

Keywords

Sun: corona; Sun: Fe XIV; Sun: dynamics of corona; Sun: line width

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Conclusions

The Earth-based observations of solar corona still represents a huge opportunity for the development and test of new instrumentation and for scientific observations. The limits due to the atmosphere (limited FoV and few hours per year observations) are, for some study, compensated by the no limits in data volume and easy access/development/replace of the instrumentation.

Bibliography (1)

Some plots/images are extracted from the following references:

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PROCEEDINGS PAPER

Liquid crystals Lyot filter for solar coronagraphy

Author(s): S. Fineschi; G. Capobianco; G. Massone; T. Baur; A. Bemporad; L. Abbo; L. Zangrilli; V. Dadeppo

FORMAT	MEMBER PRICE	NON-MEMBER PRICE	
PDF	$15.00	$18.00	ADD TO CART

Paper Abstract

The "Association de Satellites Pour l'Imagerie et l'Interférométrie de la Couronne Solaire", ASPIICS, is a solar coronagraph to be flown on the PROBA-3 Technology mission of the European Space Agency. ASPIICS heralds the next generation of coronagraphs for solar research, exploiting formation flying to gain access to the inner corona under eclipse-like conditions in space. The science goal is high spatial resolution imaging and two-dimensional spectrophotometry of the Fe XIV 530.3 nm emission line. This work describes a liquid crystal Lyot tunable-filter and polarimeter (LCTP) that can implement this goal. The LCTP is a bandpass filter with a full width at half maximum of 0.15 nm at a wavelength of 530.3 nm. The center wavelength of the bandpass is tunable in 0.01 nm steps from 528.64 nm to 533.38 nm. It is a four stage Lyot filter with all four stages wide-fielded. The free spectral range between neighboring transmission bands of the filter is 2.7 nm. The wavelength tuning is non-mechanical using nematic liquid crystal variable retarders (LCVRs). A separate LCVR of the Senarmont design in tandem with the filter, is used for the polarimetric measurements. A prototype of the LCTP has been built and its measured performances are presented here.

Paper Details

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Published in SPIE Proceedings Vol. 8148
Solar Physics and Space Weather Instrumentation IV
Silvano Fineschi; Judy Fennelly, Editor(s)

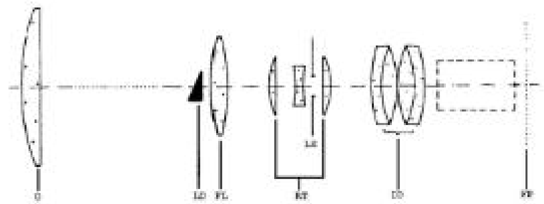
SPIE Newsroom

10.1117/2.1201407.005531

Measuring the sun's coronal green line from Earth

Gerardo Capobianco, Silvano Fineschi, Jan Rybak, Giuseppe Massone, Jaroslav Ambroz, Matus Kozak, and Ales Kucera

Combining a robust, classically designed coronagraph with liquid-crystal-based focal plane instrumentation enables effective Earth-based observations of the sun's corona.



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Girella, Master Degree Thesis, Università degli studi di Torino (2014)

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THANKS FOR YOUR ATTENTION!!!

QUESTIONS??

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