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AntarctiCor: Solar Coronagraph in Antarctica for the ESCAPE Project

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Summary. — The Antarctica solar coronagraph –*AntarctiCor*– for the "Extreme Solar Coronagraphy Antarctic Program Experiment" –ESCAPE– comprises an internally-occulted coronagraph based on the externally-occulted ASPIICS coronagraph for the ESA formation-flying PROBA-3 mission. This paper describes the AntarctiCor design for ground-based observations from the DomeC Antarctica plateau of the polarized broad-band (591 nm $\pm$ 5 nm) K-corona and of the narrow-band (FWHM = 0.5 nm), polarized emission of the coronal green-line at 530.3 nm. The science goal of these observations is to map the topology and dynamics of the coronal magnetic field, addressing coronal heating and space weather questions.

1. – Introduction

The Antarctica plateau of Dome C (coord: 75 06S; 123 20E) offers a unique opportunity for ground-based observations of the solar corona, due to the high altitude of the site (3,233 m above sea level), the large amount of the daily hours of observations, and a level of sky-brightness background that is a factor 1.6, in the visible (530 nm), to a factor 4, in infrared (890 nm), lower than that in the best known coronagraphic site, that is, Haleakala, in Maui, Hawai'i. [1-3] In order to take advantage of this opportunity,

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the Italian *Piano Nazionale Ricerche Antartico* (PNRA) has selected our proposal for the "Extreme Solar Coronagraphy Antarctic Program Experiment" (ESCAPE) with the installation of an Antarctic coronagraph (*AntarctiCor*) at the Italian-French Concordia base on DomeC, during the austral summer 2018/2019. [4]

2. – ESCAPE Science Objectives

The primary science question to be addressed by ESCAPE is: *What is the relationship between the dynamics and magnetism of the solar corona and the evolution of solar activity and the solar cycle?*

2·1. *Specific Science questions.* – Comprehensive measurements of magnetic fields in the solar corona have a long history as an important scientific goal. Besides being crucial to understanding coronal structures and the Sun's generation of space weather, direct measurements of their strength and direction represent also crucial steps in understanding observed wave motions. ESCAPE aims at addressing the following questions:
How do coronal magnetic fields

- determine the topology of the corona?
- correlate to regions where slow and fast solar wind originate?
- drive the violent dynamics of the solar corona (e.g., coronal mass ejections)?
- interact through wave motions with the coronal plasma?

2·2. *Science Implementation.* – We propose to address these questions by developing a ground-based coronagraph capable of carrying out spectro-polarimetric imaging of the

- broad-band (591 nm ± 5 nm), linearly polarized K-corona brightness (pB);
- narrow-band (FWHM = 0.5 nm), linearly polarized emission of the coronal FeXVI line, 530.3 nm ("green-line").

The measurement of the polarized K-corona pB generated by Thomson scattering of photosperic light off coronal electrons will allow the determination of the coronal electron density. The measurement of the linearly polarized emission of the coronal FeXVI line will be interpreted in terms of the *saturated Hanle effect* to derive information on the direction of the coronal magnetic fields as projected on the plane-of-the-sky (e.g., [5, 6]). The spectro-polarimetric images are acquired with high temporal cadence (>15 Hz) in order to possibly detect wave motions in corona.

The magnetic field plays a pivotal role in the physics of the solar corona to understand the nature of the underlying physical processes that drive the violent dynamics of the solar corona that can also affect life on Earth. The Antarctic coronagraph for ESCAPE with its capability of measuring the polarization of coronal line-emission will be able to map the topology and dynamics of the magnetic field in corona.

3. – AntarctiCor Instrument

The Antarctica solar coronagraph AntarctiCor for the ESCAPE program is based on the optical design of the ASPIICS coronagraph of the PROBA-3 ESA mission. [7] The telescope design follows the classical Lyot scheme of an internally-occulted coronagraph. [8] Table I summarizes the AntarctiCor instrument characteristics.

TABLE I. – *AntarctiCor Instrument Parameters.*

AntarctiCor Instrument Parameters	
Telescope design	Classic internally-occulted Lyot coronagraph [8]
Aperture	50 mm
Eff. Focal Length	700 mm
Spectral Ranges	591 nm ± 5 nm K-corona; 530.3 nm ± 0.25 nm FeXIV "green line"
Camera type	Interline transfer CCD by PolarCam®, mod. U4 [10]
Camera format	1950 × 1950
Pixel size	$(7.4\ \mu m)^2$
Plate scale	4.3 arcsec/pixel (8.6 arcsec/polarization super-pixel)
Field-of-View	$\pm 0.6° = \pm 2.24 R_\odot$ ($\pm 0.84° = \pm 3.14 R_\odot$ along CCD diagonals)
Polarization analysis	spatial modulation by linear micropolarizer array on CCD sensor

3˙1. *Telescope.* – The telescope design is derived from the design of the ASPIICS coronagraph, [7] whose Demonstration Model lenses are available and are used to minimize the development of additional, new lenses. Some modification from the design of ASPIICS have been adopted due to the main difference between ASPIICS and AntarctiCor: the former is externally-occulted, the latter is internally occulted. The ASPIICS's objective doublet lens operates in the shadow of the external occulter, while the AntarctiCor objective is directly illuminated by the Sun-disk light. In order to minimize the internal reflection in the objective lens, this has been changed into an higly polished (i.e., 0.5 nm rms) singlet. The telescope is conceived according to a classic layout of an internally occulted coronagraph with a fore optics and a relay lens. [8] Each group sharing a common focal plane is diffraction limited at the wavelength of 530.3 nm (see Figure 1).

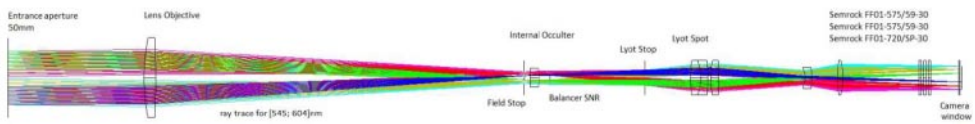

Fig. 1. – Optical scheme of the internally-occulted coronagraph *AntarctiCor*.

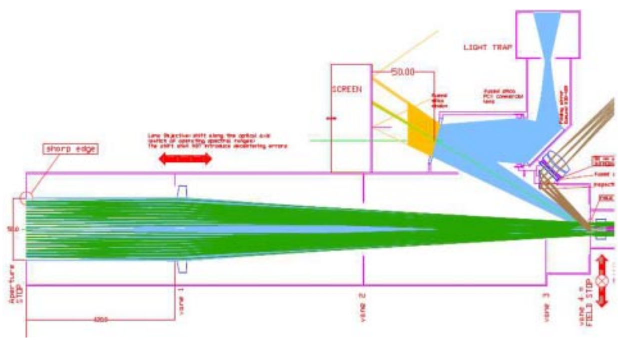

Fig. 2. – Optical scheme of *AntarctiCor* showing the Sun-disk rejection by the internal occulter.

Fig. 3. – *AntarctiCor* in the INAF *Optical Payload Systems* facility, Turin, for tests and calibrations.

The objective lens makes a real image of the Sun-disk on the internal occulter. This is a reflecting prism rejecting the sunlight into a light trap. A microscope allows the view of the Sun-disk image on the internal occulter to check their relative centering (see Figure 2). The stray-light analysis, performed by following the same approach in Ref. [9], indicates an expected stray-light level $< 10^{-9}$ of the Sun-disk brightness.

Figure 3 shows the telescope's optomechanical housing. This is "winterized", that is, it is themally stabilized so that it can operate in environments with temperatures down to -40 °C.

3˙2. *Filters and Detector with Micropolarizing array.* – The focal plane instrumentation of AntarctiCor comprises a mechanically-tunable (i.e., by tilting) narrow-bandpass (FWHM = 0.5 nm) filter, centered on the green line (530.3 nm). The measurement consists in acquiring polarized images, on and off the narrow spectral band. A pattern of polarizers with four discrete polarizations, a "super-pixel", is repeated over the entire micro-polarizers array. The size of the micro-polarizers matches the size and pitch of the PolarCam® sensor. [10] The four polarizer orientations enable the on- and off-band linear Stokes parameters of the FeXIV emission-line and K-corona emission to be determined.

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REFERENCES

[1] Arnaud J., Faurobert M. and E. Fossat, *Dome C: An exceptional site for solar observations. Mem. S.A.It.*, **78** (2007) 105
[2] Damé L., *Solar Astrophysics Program at Dome C to Benefit the Exceptional Solar Observing Conditions of the Site* in *SCAR Astronomy and Astrophysics from Antarctica (AAA) International Workshop*, Sydney Australia 29 June–1st July 2011
[3] Faurobert M., Arnaud J., and Y. Vernisse, *Extinction and sky brightness at Dome C EAS Publ. Series*, **55** (2012) 365-367
[4] cfr. www.italiantartide.it

[5] House L.L., Querfeld C.W, and Rees D.E., *Coronal emission-line polarization from the statistical equilibrium of magnetic sublevels. II. FeXIV 5303 Å. ApJ*, **255** (1982) 733-736

[6] Judge P., *Spectral lines for polarization measurements of the corona magetic field. V. Information content of magnetic dipole lines. ApJ*, **622** (2007) 677-690

[7] Galy C., Fineschi S., *et al.*, *Design and Modelisation of ASPIICS Optics. SPIE*, **9604** (2015) 9604-7

[8] Lyot B., *Étude de la couronne solaire en dehors des éclipses. Zeitschrift für Astrophisik*, **Bd. 5** (1932) 73-95

[9] Fineschi S.., *et al.*, *Stray-light analyses of the METIS Coronagraph on Solar Orbiter. SPIE*, **9604** (2015) 96040K-1

[10] cfr. www.4DTechnology.com