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# UV SPECTROPOLARIMETRY WITH CASSTOR, POLSTAR, AND POLLUX

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**Abstract.** Ultraviolet (UV) spectropolarimetry emerges as a crucial tool for understanding the life cycle of matter in the Milky Way. It allows us to characterise the interstellar medium by measuring the magnetic field and the size and nature of interstellar grains. It also offers a unique window for studying very young or massive stars, as well as the final stages of stellar evolution. In addition, UV spectropolarimetry can help to better understand the interactions between stars and planets, which is crucial to understand the conditions in which life emerges. This includes studying the impact of stellar winds, magnetic interactions, and tidal forces. Finally, for the most ambitious missions such as HWO, UV spectropolarimetry will also be used to study cosmology, for example by measuring the D/H ratio and the temperature of the cosmic microwave background, or to study the intergalactic medium. To achieve these objectives, we are developing three instrument projects with different timelines: CASSTOR, Polstar, and Pollux.

Keywords: Spectropolarimetry, UV, FUV, HWO, Pollux, CASSTOR, Polstar

## 1 Introduction

Ultraviolet (UV) spectropolarimetry offers a unique approach to studying a wide range of astrophysical phenomena, from the interstellar medium to stellar and planetary interactions. By measuring both the spectrum and the polarisation of UV light, this technique enables the characterisation of magnetic fields and the properties of interstellar dust grains. In addition, it provides insights into the life cycles of stars, particularly the early and late stages of stellar evolution. UV spectropolarimetry is also critical for understanding the environments around young and massive stars, as well as star-planet systems. In this paper, we present three instrumental projects that aim to expand the capabilities of UV spectropolarimetry: CASSTOR, Polstar, and Pollux. These projects span different wavelengths and scientific objectives, promising new discoveries about our galaxy and beyond.

## 2 CASSTOR

CASSTOR is a pioneering nanosatellite mission designed to demonstrate UV spectropolarimetry science and technology, focussing on the observation of various types of hot stars.

### *2.1 Scientific Cases*

CASSTOR observational capabilities are focused on hot stars, including magnetic hot stars, magnetic chemically peculiar stars (notably $\alpha^2$ CVn stars), OB stars, classical Be stars, Wolf-Rayet stars, blue supergiants, and magnetic supergiants. The mission plans to observe approximately 40 stars from these categories, providing the first UV spectropolarimetric measurements of stars.

### *2.2 Design*

CASSTOR is proposed to CNES for a 2028 launch. The nanosatellite will feature a 12 cm primary mirror and have a total size of 16 U. Its spectropolarimeter will operate in the 135-291 nm waveband, achieving a spectral resolution of R=12,500. This project is a collaborative effort between LESIA, CNES, and LAM.

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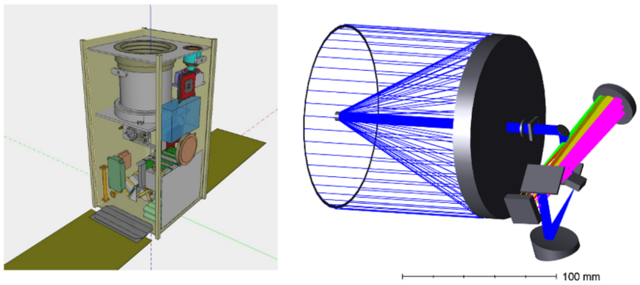


**Fig. 1.** Optical payload and optical design of CASSTOR. ©CNES

## 3 Polstar

### 3.1 Scientific cases

Like CASSTOR, Polstar will study hot stars but with the capability to observe fainter stars and achieve higher precision. A key focus will be on understanding the rotation of hot stars and its role in their evolution and properties (Ignace & Scowen 2024).

### 3.2 Design

Polstar will be proposed as a SMEX mission to NASA for a 2031 launch. It will feature a 40 cm primary mirror and its spectropolarimeter will operate in the 113-278 nm waveband with a spectral resolution of R=20,000. The mission is led by PI P. Scowen at NASA/Goddard, with LESIA contributing to the polarimeter. The design drivers of this instrument are presented in a 2022 paper (Woodruff et al. 2022).

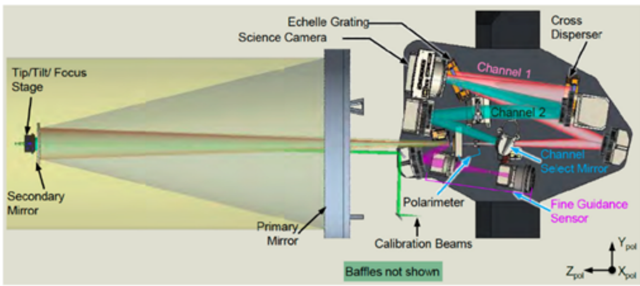


**Fig. 2.** Optical design of Polstar. ©Scowen et al. (2022)

## 4 Pollux onboard HWO

### 4.1 Scientific cases

Pollux is designed to address a wide range of scientific cases as Bouret et al. (2018) explained. For example, it will provide a detailed characterisation of the interstellar medium by measuring the interstellar magnetic field and determining the size and nature of interstellar grains. The mission will also focus on the study of young or massive stars, as well as the final stages of stellar evolution. Additionally, Pollux aims to enhance our understanding of star-planet interactions by analysing the effects of stellar winds, magnetic interactions, and tidal forces. In the realm of cosmology, it will measure the D/H ratio, study the temperature of the cosmic microwave background, and investigate the intergalactic medium.

### 4.2 Design

Pollux is proposed as an instrument for the Habitable Worlds Observatory (HWO). The HWO mission will feature a 6-8 metre telescope, with Pollux operating across a broad wavelength range of 100-1200 nm. Muslimov et al. (2024)

presented the design of the instrument. The design is composed of four channels: a visible and near-infrared channel, a near-ultraviolet (NUV) (230-470 nm) channel, a mid-ultraviolet (MUV) (118-230 nm) channel, and a far-ultraviolet (FUV) channel (100-120 nm). Each channel will have it's own polarimeter which will be optimised for the considered waveband.

It will achieve a spectral resolution of R=60,000 in the visible (VIS) range and R = 120,000 in the far ultraviolet (FUV) range.

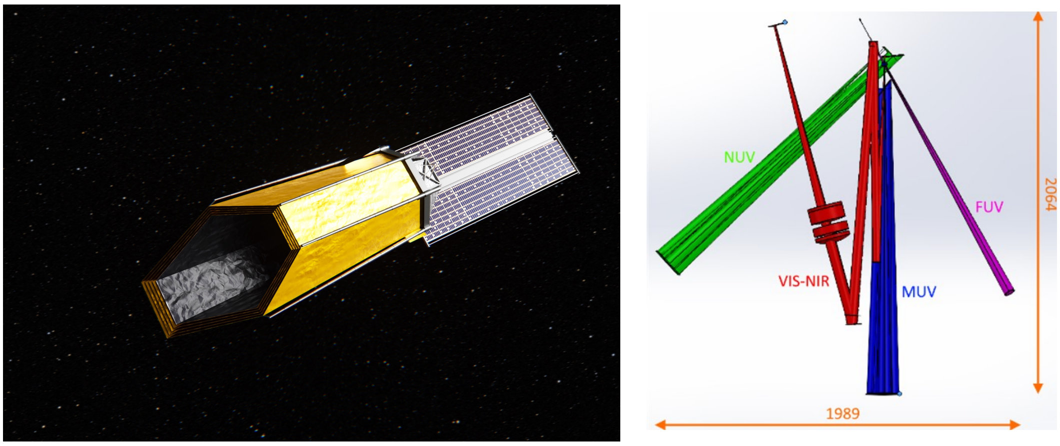


**Fig. 3. Left:**Artist view of HWO (`https://svs.gsfc.nasa.gov/14594`). **Right:** Pollux optical design. ©E.Muslimov

## 5 Polarimeter concept

### 5.1 Polarimetry above 120 nm

For CASSTOR, Polstar and the NUV, MUV and visible channels of Pollux, the polarimeter will conform to a standard architecture with birefringent plates that rotate about the optical axis, along with a polariser. However, the UV waveband presents significant challenges in terms of transmission properties, material selection, plate thickness, and alignment precision. To address these issues, numerous investigative studies and experimental test benches have been performed (Le Gal 2021) and are currently under development.

### 5.2 Polarimetry below 120 nm

Below 120 nm, there are no birefringent and transparent materials. Instead, we used the change of polarisation induced by a reflection (in particular, at Brewster's angle). LeGal et al. (2019) and Batkis et al. (2023) developed the idea of a K-mirror assembly to modulate the polarisation of light. Later, Girardot et al. (2024) proposed a design for the FUV band of Pollux based on this idea. As presented on Fig. 4, the fist three mirrors rotates around the optical axis. This creates a variation of the polarisation at the exit of the modulator. Then, a last mirros has the role of an analyser and select the P polarised light. Thus, there is a variation of intensity of the output beam, depending on the position of the modulator. Finally we can calculate the polarisation of the input beam by knowing this variation of intensity using the Mueller formalism.

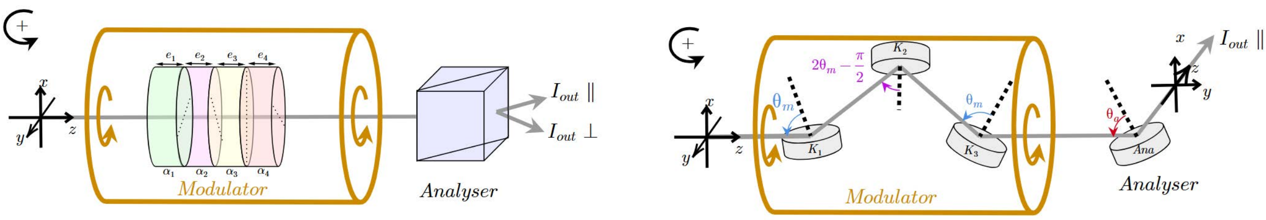


**Fig. 4. Left:**NUV-MUV polarimeter design based on a stack of 4 birefringent plates followed by a Wollaston prism. **Right:**FUV polarimeter design

## 6 Conclusions

The development of ultraviolet (UV) spectropolarimetry instruments such as those of CASSTOR, Polstar, and Pollux for HWO represents a significant advancement in our ability to explore and understand various astrophysical phenomena. CASSTOR will demonstrate the capabilities of UV spectropolarimetry with its focus on hot stars, while Polstar aims to extend these capabilities to fainter stars and higher-precision measurements. Pollux promises to provide comprehensive insights into almost all fields of astrophysics. Together, these missions will enhance our understanding of the Milky Way and the broader universe, opening new avenues for discovery and scientific advancement.

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## References

Batkis, M. F., Quijada, M. A., Scowen, P. A., et al. 2023, SPIE

Bouret, J.-C., Neiner, C., De Castro, A. I. G., et al. 2018, Space Telescopes and Instrumentation 2018: Ultraviolet to Gamma Ray

Girardot, A., Neiner, C., & Réess, J.-M. 2024, Proceeding of SPIE

Ignace, R. & Scowen, P. 2024, The Polstar UV Spectropolarimetry Mission

Le Gal, M. 2021, Theses, Université Paris sciences et lettres

LeGal, M. L., Ariste, A. L., & Neiner, C. 2019, International Conference on Space Optics — ICSO 2018

Muslimov, E., Neiner, C., & Bouret, J.-C. 2024, in Space Telescopes and Instrumentation 2024: Ultraviolet to Gamma Ray, ed. J.-W. A. den Herder, S. Nikzad, & K. Nakazawa, Vol. 13093, International Society for Optics and Photonics (SPIE), 130933D

Scowen, P. A., Gayley, K., Ignace, R., et al. 2022, Astrophysics and Space Science, 367, 121

Woodruff, R., Neiner, C., Casini, R., et al. 2022, Space Telescopes and Instrumentation 2022: Ultraviolet to Gamma Ray