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UV POLARIMETERS FOR POLLUX ONBOARD LUVOIR

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Abstract. Pollux, the European high-resolution spectropolarimeter designed for LUVOIR, will work from 90 to 400 nm. In order to optimize its efficiency, the range is divided in 3 channels: far ultra-violet (FUV) from 90 to 124.5 nm, mid-UV (MUV) from 118.5 to 195 nm and near-UV (NUV) from 190 to 400 nm. Optical materials' properties being different between channels, each one will benefit from its own polarimeter adapted to its wavelength range. All polarimeters will use temporal modulation and will be composed by a modulator and an analyzer. The NUV polarimeter is similar to the one often used in in visible range: it uses waveplates and a polarizer and works thus in transmission. The FUV polarimeter has to be innovative because no birefringent material transmits light at these wavelengths. It will use mirrors and work by reflexion. The MUV polarimeter will benefit from the design of the two others so that it will be the most efficient possible. This proceeding presents these three polarimeters designed for Pollux.

Keywords: Ultra-violet, polarimeter, Pollux, LUVOIR, temporal modulation, transmission, reflection

1 Introduction

The Large Ultra-Violet Optical InfraRed surveyor (LUVOIR) is a project of a 15-m diameter telescope for the 2020 NASA decadal survey. It has four instruments including Pollux. Pollux is the European instrument of this project, led by France. It is a high resolution spectropolarimeter working in the ultra-violet (UV) domain from 90 to 400 nm. Its wavelength range has been divided in three channels to optimize its performances: FUV, MUV and NUV. Each channel has its own polarimeter working with temporal modulation. Each polarimeter has a modulator and an analyzer as shown in Figure 1. The modulator rotates around the optical axis and rotates the polarization while the analyzer filters the light polarized in a particular direction. At the output of the polarimeter, we then have a linear equation of the input Stokes vector. By taking several measurements for each angular position of the modulator - at least four to get the four Stokes parameters - we can retrieve the input Stokes vector.

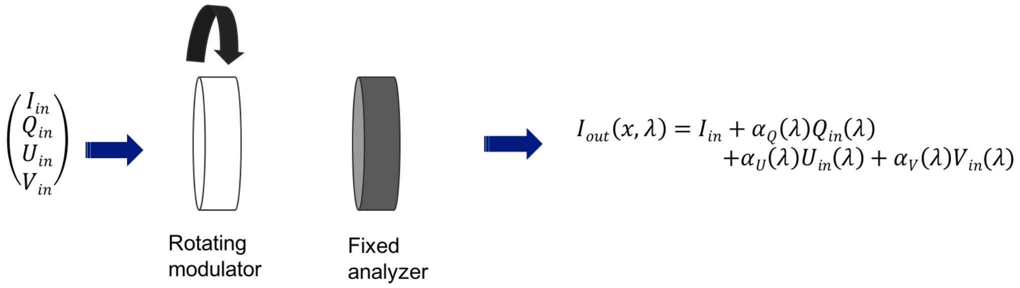

Fig. 1. Principle of a polarimeter working with temporal modulation.

We describe below the design and performances of each polarimeter.

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2 NUV polarimeter

2.1 Principle and optical design

The NUV polarimeter works from 190 to 400 nm. It has a design similar to the optical polarimeters used on the ground as showed in Figure 2. The modulator is made of a stack of two MgF_2 plates and the analyzer is a MgF_2 Wollaston prism. The modulator takes 6 angular positions: 2.3°, 36.0°, 50.4°, 69.9°, 112.6°, and 147.7°. The MgF_2 plates have the following characteristics:

- Plate 1: angle of fast axis α_1 =32.6° and thickness e_1 =12.8 µm
- Plate 2: angle of fast axis α_2 =147.3° and thickness e_2 =3.7 µm.

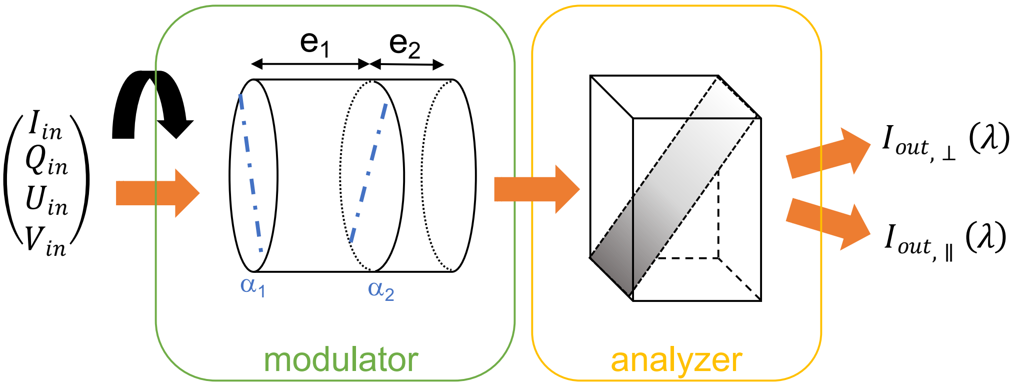

Fig. 2. Optical design of the NUV polarimeter using temporal modulation working from 190 to 390nm.

2.2 Theoretical efficiency

The design takes into account the measurements of both ordinary and extraordinary beams at the output of the analyzer. We then have 2 measurements for each angular positions of the modulator, which make a total of 12 measurements. The NUV polarimeter modulation matrix then have 12 lines and 4 columns (one for each stokes vector). The modulation matrix is shown in Figure 3. This matrix allows us to go from the input Stokes vector to the output measurements. The pseudo inverse of this matrix, the demodulation matrix, allows us to go from the measurements to the input Stokes vector. It is displayed in Figure 4.

The demodulation matrix coefficients are used to calculate the polarimetric efficiencies. The efficiencies are shown in Figure 5. The efficiencies have also been computed for the case where only the ordinary beam can be recovered. In both case, the results are very satisfying, oscillating around the optimal efficiency 57.7%.

The transmission of the polarimeter is an important matter, especially in the UV as the flux is often low. For the modulator, the transmission depends on the number of plates. Indeed, most of the loss is due to the Fresnel coefficient at the diopters. The ideal solution is to put all the plates in optical contact so the Fresnel coefficient are involved only at the input and output of the modulator. Unfortunately, due to the thermal expansion, this solution risks to break the plates. A thermal study has to be made before assuming optical contact can be used. If not, air gaps should be considered between plates. The issue with this solution is that it creates fringes like an interferometer. If optical contact cannot be used, an optical study should be done to see how the fringes will affect the measurement of the polarimetry. In Figure 6, the transmission of both case is displayed as a function of wavelength. Using optical contact makes an improvement around 15% on the transmission.

2.3 Test bench

To test this polarimeter, a bench has been set up to make spectropolarimetric measurements. A scheme of this bench is shown in Figure 7. First, the UV source sends a flux into a module made with a Rochon prism and a quarter wave-plate, which can create any polarization. Then the light enters the polarimeter before finally going into the spectrometer. This bench will allow us to create a polarization and then measure it in order to see the precision and accuracy of our prototype. Tests are expected to provide results in 2019.

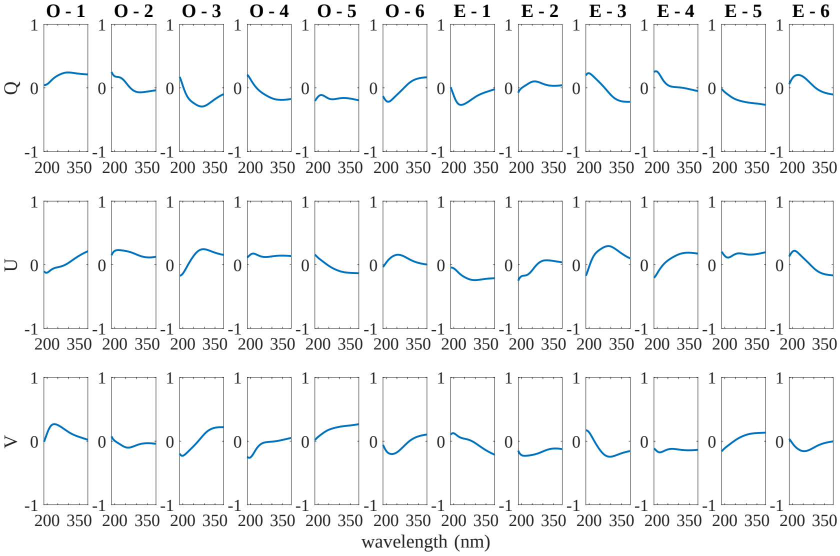

Fig. 3. Modulation of the NUV polarimeter. The first column is not showed as it is equal to 1.

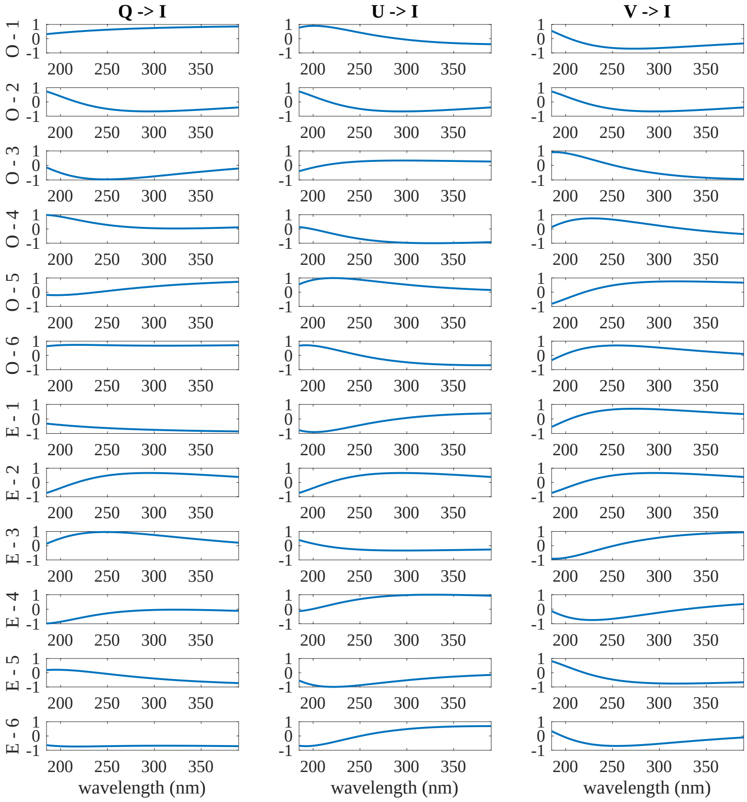

Fig. 4. Demodulation of the NUV polarimeter. The first line is not showed as it is equal to 1.

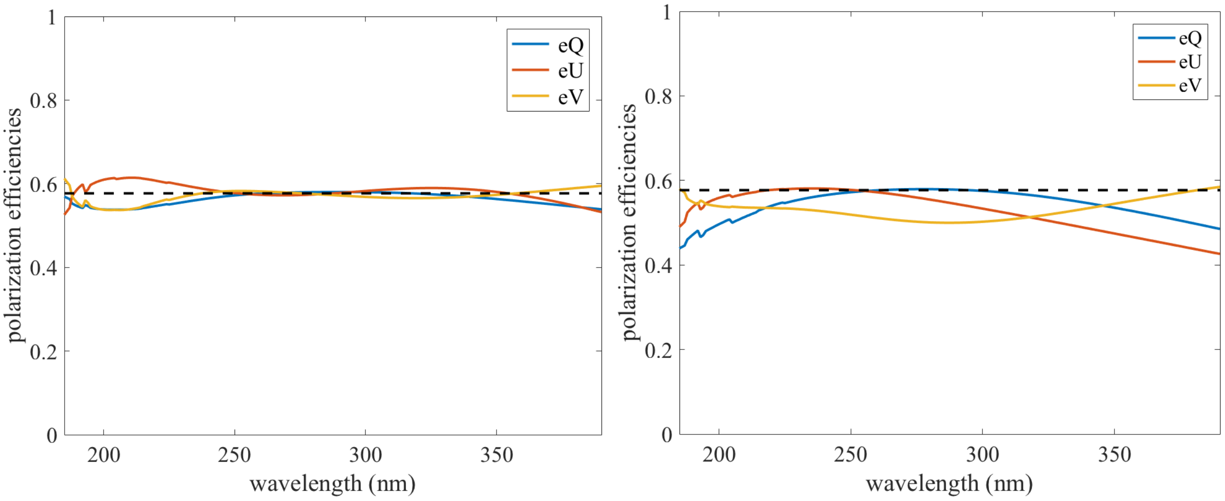

Fig. 5. Left: Polarimetric efficiencies for 12 measurements (both ordinary and extraordinary beams at the output of the Wollaston). **Right:** Polarimetric efficiencies for 6 measurements in case only the ordinary beam can be measured.

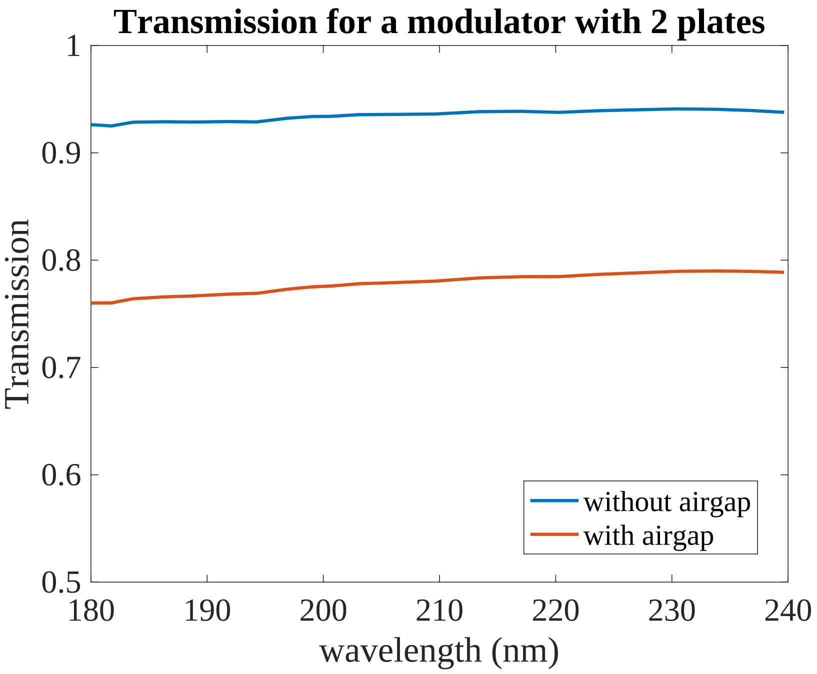

Fig. 6. Transmission of the modulator with air gaps (red line) or with optical contact (blue line).

3 FUV polarimeter

3.1 Principle and optical design

The FUV polarimeter works from 90 to 124.5 nm. Contrary to the NUV one, the FUV polarimeter cannot work with transmission materials as there is no birefringent material transmitting light under 110 nm. This polarimeter has to use reflection. The optical design is showed in Figure 8. The modulator is made with three mirrors fixed one to another but rotating as a block around the optical axis. At each reflection, the light is phase shifted. This K-mirror creates a modulation of the light. The analyzer is a Brewster angle reflecting only the s-polarized light. The issue with using Brewster angle is that it is monochromatic. A quasi Brewster angle has to be studied in order to work for the full range between 90 to 124.5 nm. A problematic point to simulate

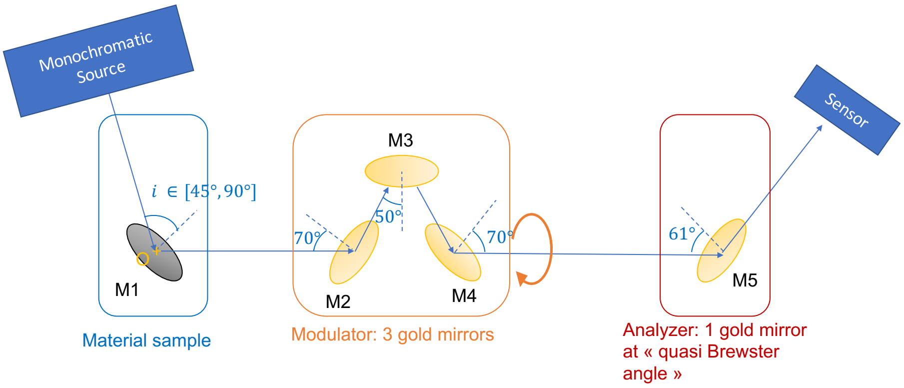

Fig. 7. Optical design of the test bench. This test has been designed to measure the performances of the NUV polarimeter. The light from the UV source enters first into a prism and a quarter waveplate in order to create any polarization then it goes into the polarimeter and finally into the spectrometer. The goal is to make spectropolarimetric measurements on the polarized light we've created.

this polarimeter is the optical indices of materials. Few can be found in the literature, and the ones found are different from one paper to another, suggesting than the indices are very sensitive to contamination and manufacture process at these wavelengths. Therefore, it has been decided to set up an experiment to measure some material samples to guarantee the reliability of the indices of the materials we will use.

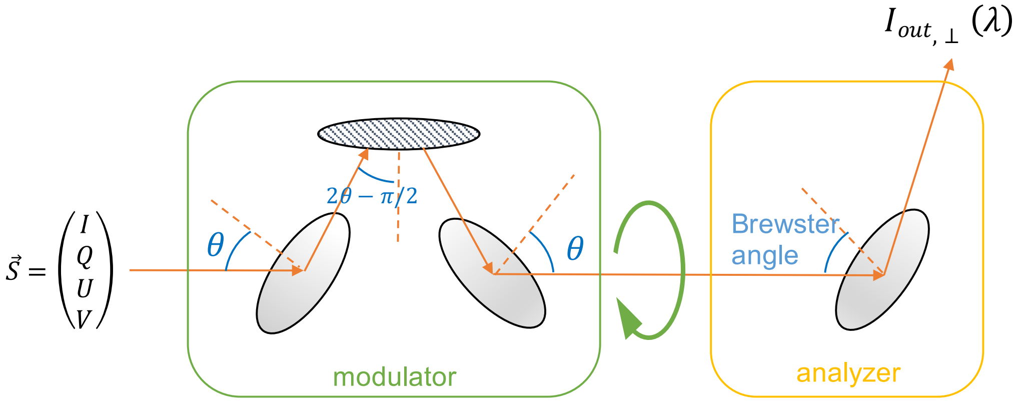

Fig. 8. Optical design of the reflective FUV polarimeter using temporal modulation working from 90 to 124.5 nm.

3.2 *Experiment to measure polarimetric properties on different material samples*

To measure polarimetric properties, we need a polarimeter working at the wavelength of interest, which means we need to find a material that we know very well theoretically. This material is gold. Gold does not have specific polarimetric properties and is not a first choice to build a polarimeter but it is very well known even at 90 nm, very pure and very constant with the manufacture process. The experiment we have set up thus measures the Stokes vector at its input and at the output of a sample using a gold polarimeter. A sketch of the experiment is shown in Figure 9. We will measure various promising materials in particular SiC, B_4C and ta-C. Results of this experiment should be available soon.

4 MUV polarimeter

The MUV polarimeter works from 118 to 195 nm. It will benefit from both the NUV and the FUV designs, based on performances. For now, as the experiment on reflective materials is not finished, the design is based

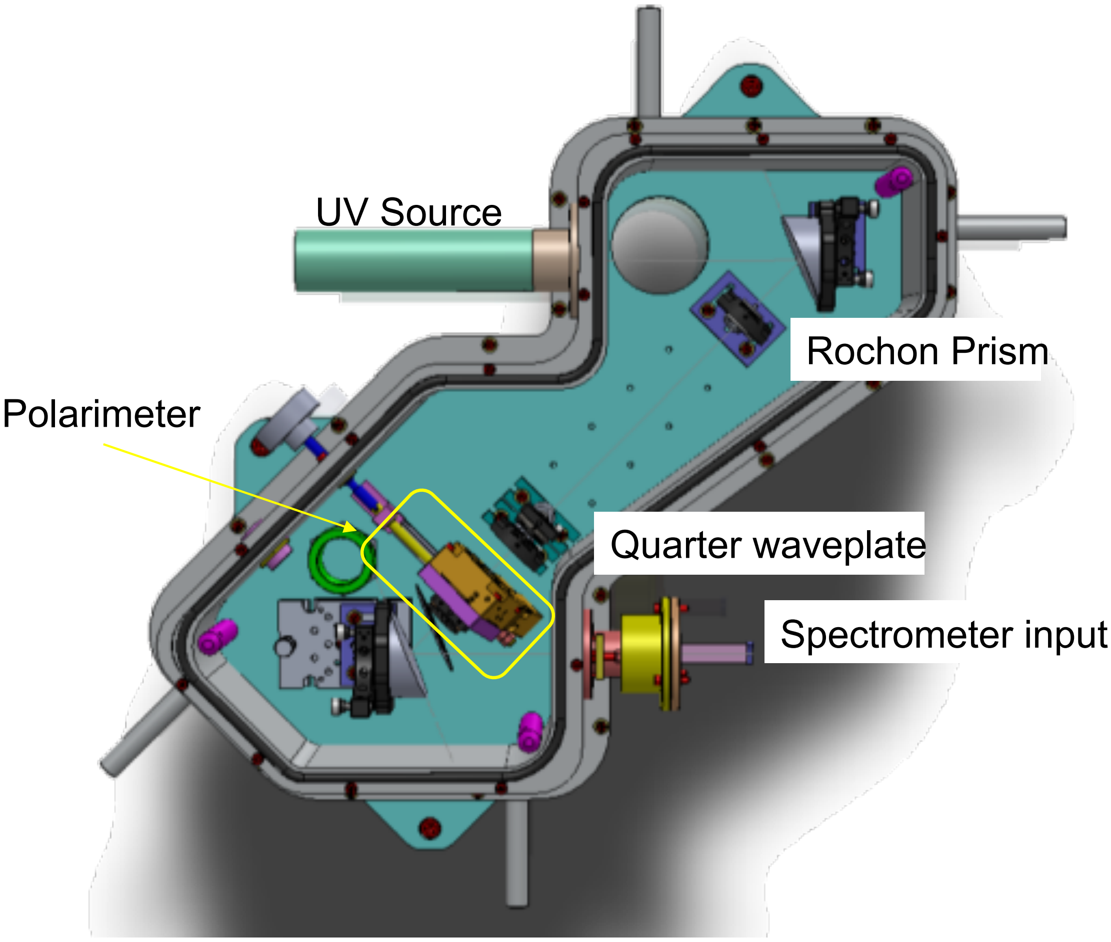

Fig. 9. Optical design of the experiment using a gold reflective FUV polarimeter using temporal modulation. This experiment is designed to measure polarimetric properties .

on the NUV polarimeter. The modulator is made of a stack of two MgF_2 plates and the analyzer is a MgF_2 Wollaston prism.

5 Conclusion

Three polarimeters are being studied for Pollux, one for each channel. Each polarimeter is optimized for its wavelength range. Although the NUV and the MUV use quite usual polarimeter designs, the FUV polarimeter is an innovative reflective polarimeter. Each polarimeter is or will be tested in vacuum condition. An experiment to measure some polarimetric properties in the FUV on some material samples has also been set up.

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