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Design of a FUV polarimeter for Pollux aboard HWO

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Scientific context

Pollux is proposed as the European instrument aboard HWO, a future NASA flagship mission.

HWO

- 3 designs under study
- 6 to 8 m diameter
- Planned launch \approx 2040

Pollux

- Resolution up to $R=120\,000$
- Waveband: 100 – 1 200 nm
- FUV band: 100 – 120 nm

Concept

As there are no birefringent or transparent materials in the 100 – 120 nm waveband, we chose a different way to perform spectropolarimetry using mirrors [1].

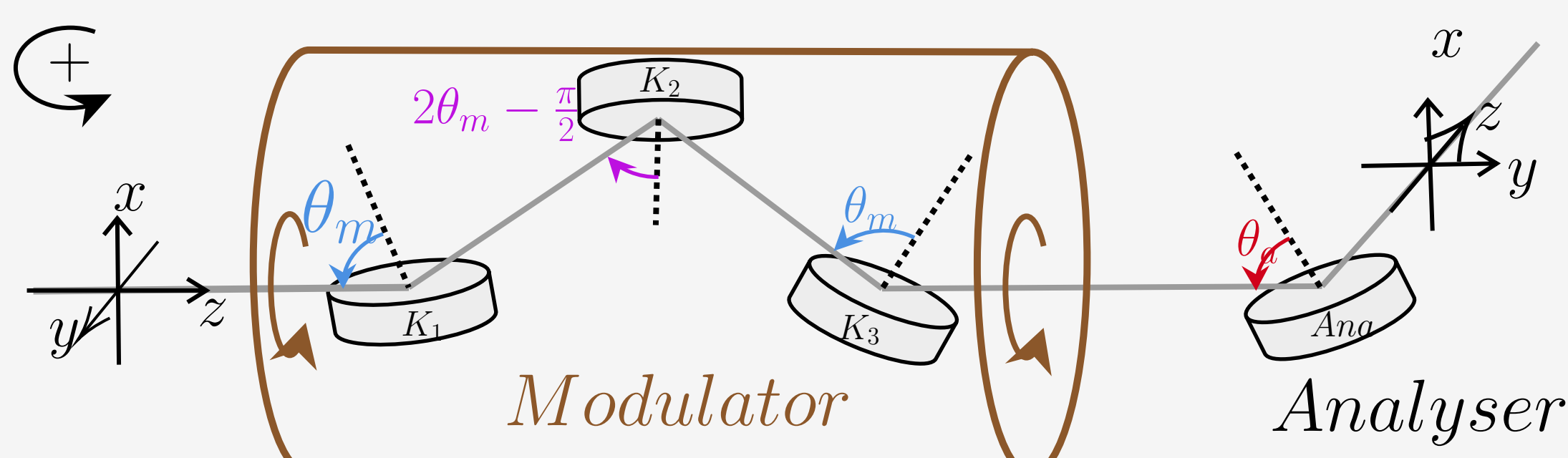


Figure 1: Concept of the reflective polarimeter

Design

We considered different materials for mirrors and coatings such as SiC, B₄C [2], TaC, MgF₂ [3], Mo, Al, and Si.

Analyser

- Goal: maximise the S reflectivity and minimise the P reflectivity
- SiO₂ substrate + 50 nm B₄C deposition + 29 nm MgF₂ layer on top

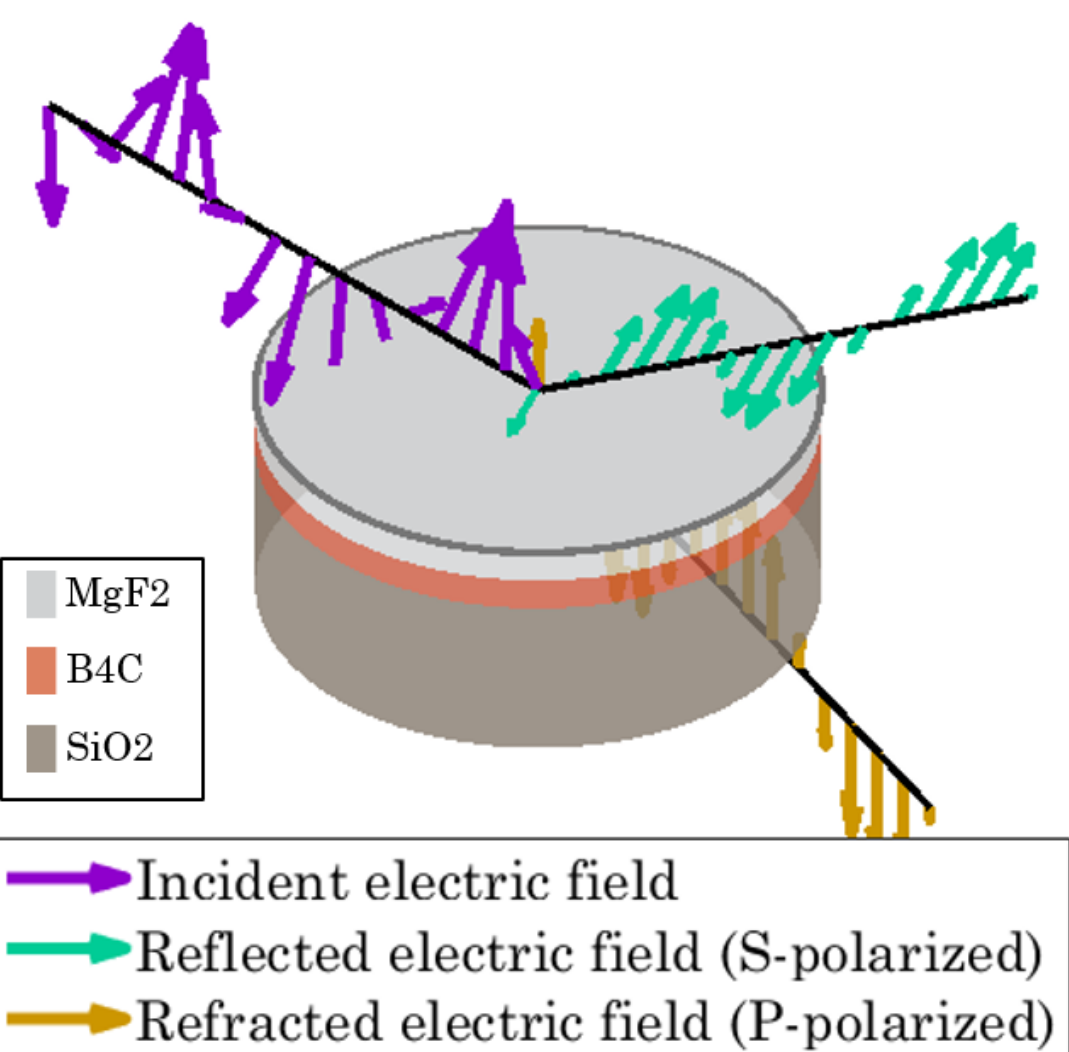


Figure 2: Mirror at Brewster's angle

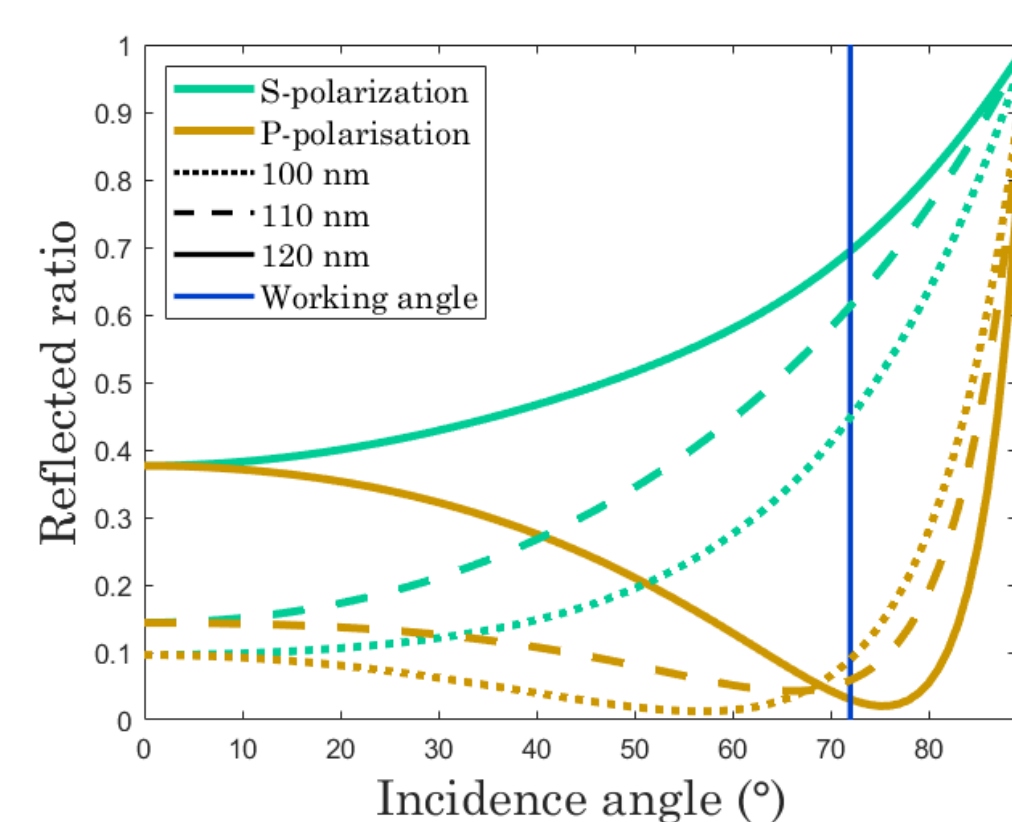


Figure 3: Reflection at Brewster's angle

Modulator

- Goal: Modulate the polarization
- 3 plane mirrors in SiC coated by CVD deposition, mounted as a K-mirror

Modulation positions

- Optimised number of positions
- Optimised position angles
- 6 positions: 0° | 70° | 134° | 218° | 269° | 325°

Performances

A perfect reflective polarimeter should have:

- An extraction efficiency at 0.577 on the whole waveband
- A total reflectivity at 0.5

Our polarimeter has the following performances:

- Good extraction efficiency on the waveband, and especially above 115 nm.
- Reflection at 0.8 ± 0.1 on the SiC mirror.
- Reflection at 0.4 ± 0.1 on the analyser.
- Total reflectivity at 0.125

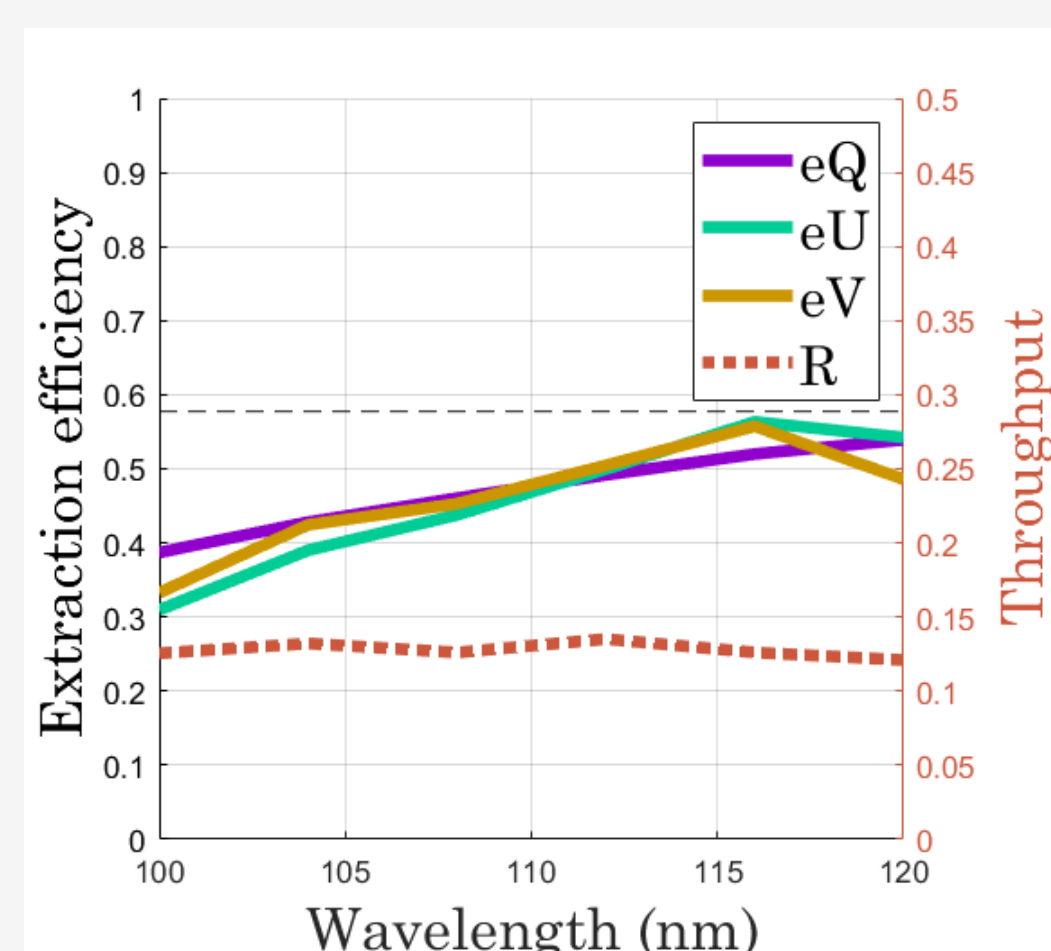


Figure 4: Extraction efficiency

Mathematical formalism

To design the polarimeter, we use the Stokes and Mueller formalism.

Stokes Vector

We need to describe partially polarised light, so the Stokes formalism is preferred.

$$S = \begin{pmatrix} I \\ Q \\ U \\ V \end{pmatrix} = \begin{pmatrix} P_H + P_V \\ P_H - P_V \\ P_{45} - P_{135} \\ P_R - P_L \end{pmatrix}$$

Mueller matrix

For a reflection:

$$M_R(\theta_m, \lambda) = \begin{pmatrix} \mathcal{R}_s + \mathcal{R}_p & \mathcal{R}_s - \mathcal{R}_p & 0 & 0 \\ \mathcal{R}_s - \mathcal{R}_p & \mathcal{R}_s + \mathcal{R}_p & 0 & 0 \\ 0 & 0 & -Q\cos(\delta) & -Q\sin(\delta) \\ 0 & 0 & Q\sin(\delta) & -Q\cos(\delta) \end{pmatrix}$$

with $Q = 2\sqrt{\mathcal{R}_s\mathcal{R}_p}$.

\mathcal{R}_s , \mathcal{R}_p and δ are calculated using the Fresnel formula on bulk or coated material [4][5].

Rotation matrix

A reflective component rotated is:

$$M'(\alpha) = R_R(\alpha) \times M \times R_R(\alpha)$$

with $R_R(\alpha)$ a rotation matrix:

$$R_R(\alpha) = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos(\alpha) & -\sin(\alpha) & 0 \\ 0 & \sin(\alpha) & \cos(\alpha) & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Here, the change in coordinate system due to reflection is considered.

Merit function

The merit function considers:

- The extraction efficiency:

$$\epsilon(k) = \sqrt{6 \times \sum_{i=1}^6 D_{k,i}^2}^{-1}$$

with $D_{k,i}$ the coefficient of the demodulation matrix.

- Reflectivity: $R = (\mathcal{R}_s + \mathcal{R}_p)2$

Pollux test bench

In parallel, we are working on CASSTOR, a bench that will serve as a proof-of-concept for a nanosat of the same name. It will also be useful for Pollux's NUV and MUV channels.

Then, this test bench will be adapted to test the FUV polarimeter (purple part in Fig. 5). This bench will be the first demonstrator of FUV spectropolarimetry on a large waveband.

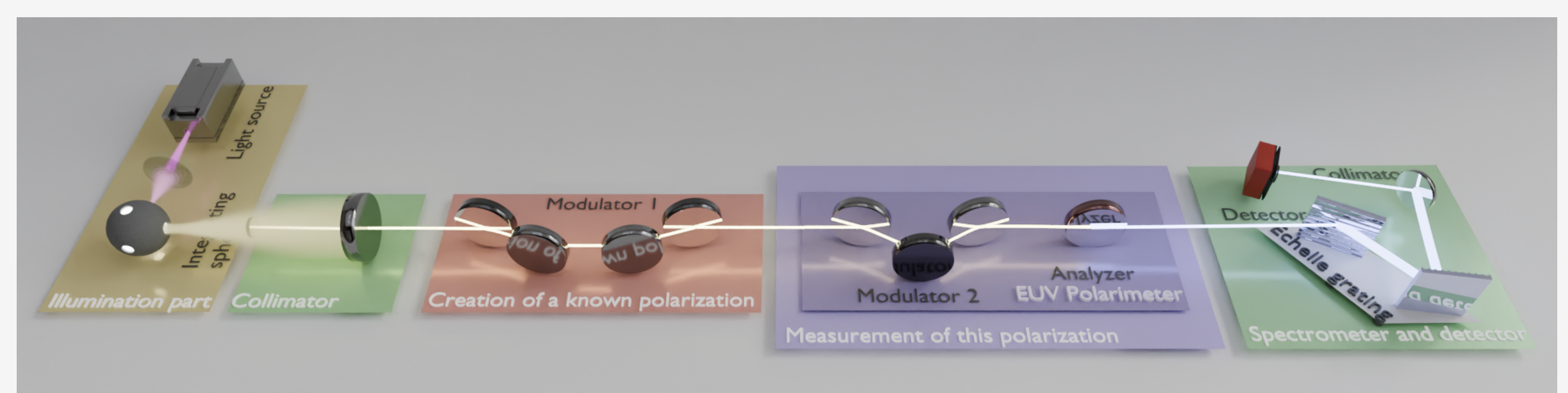


Figure 5: Scheme of Pollux test bench

This bench will be mounted in a vacuum tank in a clean room at the Paris Observatory. Firstly, we will test the polarimeter from 115 to 120 nm (where the extraction efficiency is maximal). Then, we will test it above 115 nm with a different lamp and polariser.

Conclusion

We designed a polarimeter that works under 120 nm, using only reflective optics. We need to build the test bench to prove that this can be effectively used on the Pollux FUV channel aboard HWO.

References

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