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POLLUX, A HIGH-RESOLUTION UV SPECTROPOLARIMETER FOR LUVOIR

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Abstract. POLLUX is a high-resolution, UV spectropolarimeter proposed for the 15-meter primary mirror option of LUVOIR. The instrument Phase 0 study is supported by the French Space Agency (CNES) and performed by a consortium of European scientists. POLLUX has been designed to deliver high-resolution spectroscopy (R $\geq$ 120,000) over a broad spectral range (90-400 nm). Its unique spectropolarimetric capabilities will open-up a vast new parameter space, in particular in the unexplored UV domain and in a regime where high-resolution observations with current facilities in the visible domain are severely photon starved. In this paper, we introduce the general context of LUVOIR, the design of POLLUX, and the required technology development needed to achieve the desired performances of the instrument.

Keywords: LUVOIR, high resolution spectroscopy, ultraviolet, polarimetry, magnetic fields, POLLUX

1 Introduction

The major challenge of contemporary astrophysics is to advance our understanding of the origin and evolution of galaxies, stars and planets that make up our Universe, and the life within it. The Large Ultraviolet/Optical/Infrared Surveyor (LUVOIR) is a multi-purpose observatory proposed as one of the four flagship mission concept studies led by NASA for the 2020 Decadal Survey, and is designed to address this challenge and the related science cases. For more details on the LUVOIR mission (see Ferrari, M. 2018, this proceeding). Under the leadership of LAM and LESIA (France), European institutes have come together to propose an instrument, POLLUX, that would be onboard the 15-meter primary mirror option of LUVOIR. POLLUX, is a high-resolution (R $\geq$ 120,000) spectropolarimeter, operating at UV wavelengths (90-400 nm), and is designed to address a range of questions at the core of the LUVOIR Science portfolio. The Phase 0 study for POLLUX funded by CNES, started in January 2017.

2 Science programs

POLLUX will operate over a broad spectral range (90 to 400 nm), at high spectral resolution (R $\geq$ 120,000). These capabilities will permit resolution of narrow UV emission and absorption lines, allowing scientists to follow the baryon cycle over cosmic time, from galaxies forming stars out of interstellar gas and grains, and stars forming planets, to the various forms of feedback into the interstellar and intergalactic medium (ISM and IGM), and active galactic nuclei (AGN).
The most innovative characteristic of POLLUX is its unique spectropolarimetric capability that will enable detection of the polarized light reflected from exoplanets or from their circumplanetary material and moons, and characterization of the magnetospheres of stars and planets and their interactions. The magnetospheric properties of planets in the solar system will be accessible at exquisite levels of detail, while the influence of magnetic fields on the Galactic scale and in the IGM will be measured. UV circular and linear polarization will provide a full picture of magnetic field properties and impact for a variety of media and objects, from AGN jets to all types of stars. POLLUX will probe the physics of accretion disks around young stars, white dwarfs, and supermassive black holes in AGNs, and constrain the properties, especially sphericity, of stellar ejecta and explosions. This list of science goals is not exhaustive, but it clearly shows the huge scientific impact that this instrument may have. The science cases just mentioned above are presented in more details in this volume.

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3 High-level requirements

The science goals summarized in the previous section drive the definition of the following essential high-level requirements for the instrument, presented in Table 1:

Table 1. High-level requirements to the spectropolarimeter

Parameter	Requirement
Wavelength range	90 - 400 nm
Spectral resolving power	120,000
Spectral length of the order	6nm
Polarization mode	Circular + linear (= IQUV)
Polarization precision	10^{-6}
Aperture size	0.03”
Observing modes	spectropolarimetry and pure spectroscopy
Radial velocity stability	Absolute = 1 km/s and relative = 0.1 pixel

4 Baseline optical architecture and specifications

The baseline configuration of POLLUX allows fulfilment of all the requirements for the instrument performance. To define it, we adopted the telescope parameters provided by the LUVOIR study, as of the end of year 2017. Most of the technologies required for a complete implementation present technology readiness levels (TRLs) compatible with a Phase 0 study. We did not find fundamental restrictions or physical limitations preventing its implementation. The major assumptions that we adopted are illustrated on Fig. 1 (left).

- The instrument entrance is a pinhole, rather than a slit, for simpler aberration correction.
- The spectral range is split into 3 channels: Far-UV (90-124.5 nm), Medium-UV (118.5-200 nm) and Near-UV (200-400 nm). This allows to achieve high spectral resolving power with feasible values of the detector length, the camera optics field of view and the overall size of the instrument. It also allows to use dedicated optical elements, coatings and detectors and polarimeter for each band, hence obtain a gain in efficiency.
- The FUV and MUV boundaries are set relative to the Lyman α line, such that this line is always present on both channels
- The MUV and NUV channel are separated by means of a dichroic splitter
- Currently there are no dichroic splitters operating in the FUV below the Ly α line, and there is no evidence that such an element will become possible in the future. We have decided to use a flip mirror to feed the FUV channel. The flip mirror is located immediately before the dichroic splitter.
- MUV+NUV channels are recorded simultaneously, while the FUV is recorded separately (temporal separation).
- The spectra are recorded on δ-doped EMCCD detectors (Nikzad, S. at al. 2016). These combine the linearity of CCDs with the photon-counting ability, which is a key capability enabling detection of faint UV signals. Furthermore, these detectors now deliver high quantum efficiency thus offering the possibility to reach very high signal-to-noise ratios.
- Detectors with 13μm pixels will be used for POLLUX. They may be passively cooled to $\sim$120K (to reduce dark current level etc.). In the FUV channel, the detector active area is 203mm $\times$19mm, while for MUV and NUV, the active areas are 131mm $\times$ 19mm and 131mm $\times$ 24mm, respectively.
- In each channel the beam is collimated by an ordinary off-axis parabolic (OAP) mirror. The off-axis shift and the corresponding ray deviation angle are chosen in such a way that the distance between the entrance pinhole and the echelle grating is large enough to place the polarimeter and corresponding mechanical parts. The MUV and NUV mirrors have identical geometry, though they may have different coatings and have slightly different operation mode due to the difference in each polarimeters design.

- The cross-disperser in each channel operates also as a camera mirror, so it is a concave reflection grating. This approach allows minimisation of the number of optical components and increases the throughput. In order to correct the aberrations, the cross-dispersers surface is a freeform and has a complex pattern of grooves formed by holographic recording.
- Adopted coatings on the optical elements of POLLUX are optimized for each element of each channel.
- Polarimeters are located immediately after the splitters in each channel to avoid instrumental polarization by the spectrograph elements. The polarimeters are retractable in the MUV and NUV to allow the pure spectroscopic mode. In the FUV only the modulator is retractable. The analyzer is kept in the optical path to direct the beam towards the collimator.
- Change of the optical path caused by removing the polarimeter from the beam is compensated by translating the OAP mirror for the three channels.
- The polarimeter design was optimized for each channel accounting for the technological feasibility (see Le Gal, M. 2018, this proceeding).

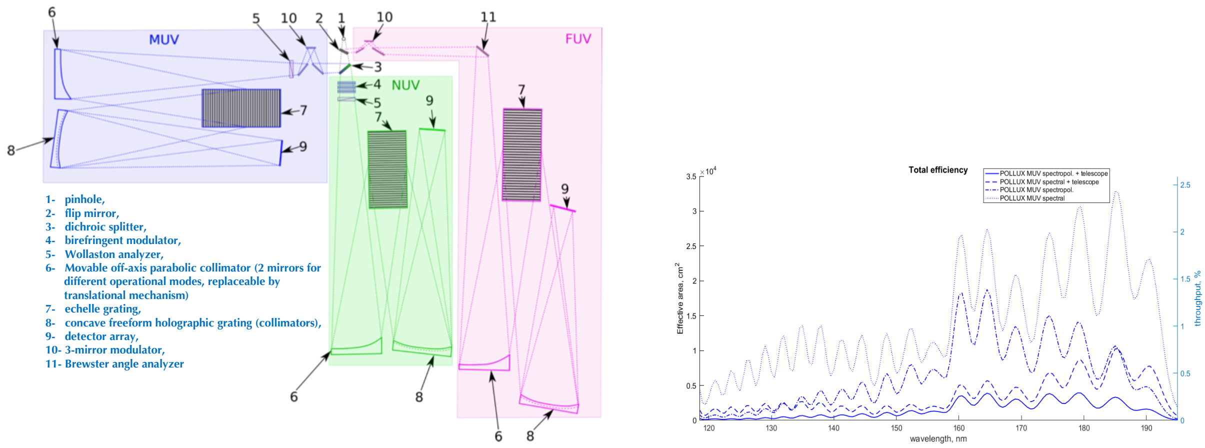

Fig. 1. Left: POLLUX baseline architecture schematic diagram. **Right:** Overall efficiency and the corresponding effective area for the POLLUX MUV channel (scale factor is 135 000 cm^2)

5 Performance evaluation

The overall efficiency of POLLUX was computed under a set of assumptions. The pick-off mirror is assumed to be covered with the same broadband coating as the telescope mirrors (Al+MgF2+SiC). The dichroic is taken to be identical to that used in GALEX (see `http://www.galex.caltech.edu/researcher/techdoc-ch1.html`), but its efficiency curves are shifted by 17.1 nm to the red.
The coatings of the flip mirror is single-layer SiC. The coating of the collimators and the cross-dispersers are single layer SiC in the FUV, and Al+LiF+AlF3 in the MUV and NUV.
The 3-mirror modulator and analyzer of the polarimeter in the FUV are in SiC. For the MUV, the 3-mirror modulator is coated with Al+LiF, while the analyzer is in MgF2. For the NUV, both the plates and analyzers are in MgF2. For each channel, the echelle gratings work under pure Littrow mounting. They are etched into Si substrate, and their profiles are not fully optimized at this stage of the proposal. The echelle coating is taken to be Al+LiF for all the channels.
Efficiency of the cross-disperser grooves is that for an ideal blazed profile in Al multiplied by the coating reflectivity. The detector quantum efficiency assumes an uncoated δ-doped EMCCD. In the future it will be optimized for each of the channels separately.
Reflection losses inside the telescope are accounted for. It is assumed that the telescope mirrors are coated by the Al+LiF+AlF3 coating and the working beam experiences 4 bounces with a small angle of incidence.

The total efficiency (Fig. 1, right) is the product of efficiencies of all the elements. The result was also converted into the effective area (adopting a geometrical coefficient A_{geom}=135 $\times 10^4$ cm^2 for LUVOIR). In the final design of POLLUX, we expect that using specifically tailored coatings for each channel will improve its throughput. One can note that the FUV throughput drops to zero below 103 nm. This is explained by the telescopes cut-off and represents a point of ongoing discussion with the LUVOIR team and future improvement. However, the current baseline already shows that POLLUX is feasible and its science goals reachable.

6 Conclusions and future work

POLLUX is a high-resolution UV spectropolarimeter for the LUVOIR space telescope project. The preliminary design concept of POLLUX as presented here shows that, thanks to the recent developments in optical components and detectors technologies, this instrument will be able to reach the target performance and cover a variety of groundbreaking science cases.

During this preliminary study a number of technological risks and critical points, which define the future work, were found. Below we provide a short overview of them:

1. the characteristics of the baseline design will be update according to the new telescope parameters, coatings, thermal properties etc... as provided by the LUVOIR team, following their final assement
2. The properties of some of the reflective coatings, especially the ones used in the FUV channel should be examined under different conditions, including incidence angles and polarization states and be space-qualified. Also, the deposition technique and alternative materials should be considered in details.
3. For the final design, an optimized dichroic must be designed. Its reflectivity and transmission for the working angles of the POLLUX must be measured. Moreover, the FUV channel will be placed in the direct propagation after the flip mirror, while the MUV/NUV will be placed in reflection in order to increase the FUV throughput.
4. The size of the FUV echelle grating exceeds the maximum size of a grating ever produced with the chosen technology. So this is a technological risk and a subject for future studies.
5. The possibility to fabricate a holographic freeform grating with triangular grooves must be demonstrated in practice. Scaling of such an element represents a separate technological challenge. We should note that the backup solution for this element is a variable line spacing ruled freeform grating.
6. The detector parameters are also subject to a further investigation. Use of CMOS instead of CCD is an option. Because the detectors have large dimensions, we should study options of tiling. Furthermore, in the future one may consider the detectors anti-reflective coating properties.
7. Finally, a number of necessary analyses have not been performed yet including tolerance analysis and ghost analysis.

Throughout 2018, we will continue to improve the optical and mechanical design. We will also study the thermal architecture, the thermo-mechanical stability, the main electronic hardware and software, the data telemetry, the power and mass budget, the AIT/AIV model philosophy, the contamination and cleanliness issues, and the radiation impact. The complete study will be included as a dedicated POLLUX chapter in the document presenting the final study of LUVOIR to the NASA decadal 2020 committee.

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