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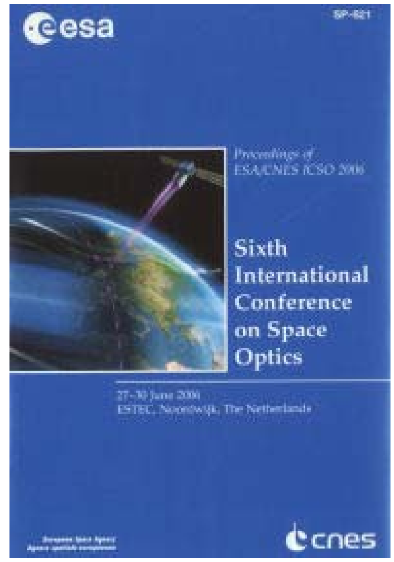

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LYRA, SOLAR UV RADIOMETER ON THE TECHNOLOGY DEMONSTRATION PLATFORM PROBA-2

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ABSTRACT

LYRA is a solar radiometer part of the PROBA 2 micro satellite payload. LYRA will monitor the solar irradiance in four soft X-Ray - VUV passbands. They have been chosen for their relevance to Solar Physics, Aeronomy and SpaceWeather: 1/ Lyman Alpha channel, 2/ Herzberg continuum range, 3/ Aluminium filter channel (including He II at 30.4 nm) and 4/ Zirconium filter channel. The radiometric calibration is traceable to synchrotron source standards. The stability will be monitored by on-board calibration sources (LEDs), which allow us to distinguish between potential degradations of the detectors and filters. Additionally, a redundancy strategy maximizes the accuracy and the stability of the measurements. LYRA will benefit from wide bandgap detectors based on diamond: it will be the first space assessment of revolutionary UV detectors. Diamond sensors make the instruments radiation-hard and solar-blind (insensitive to visible light) and therefore, make dispensable visible light blocking filters. To correlate the data of this new detector technology, well known technology, such as Si detectors are also embarked. The SWAP EUV imaging telescope will operate next to LYRA on PROBA-2. Together, they will provide a high performance solar monitor for operational space weather nowcasting and research.
LYRA demonstrates technologies important for future missions such as the ESA Solar Orbiter.

Key words: UV radiometer, diamond detectors.

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1. INTRODUCTION

The knowledge of the solar spectral irradiance is of large interest to Solar Physics, Aeronomy and to other fields of heliospheric and planetary research. The solar ultraviolet (UV) irradiance below 300 nm is the main source of the energy converted in the Earth's atmosphere, controlling its thermal structure [1].
Absolute measurements of the UV Sun irradiance are recognized to be difficult. They always require a space-born instrument. LYRA will be complementary to existing radiometers such as UARS, SEE/TIMED, SORCE, by monitoring the solar flux in four carefully selected UV passbands.

This paper describes LYRA (the LYman alpha RAdiometer), a solar EUV - VUV radiometer and the activities performed to deliver the Proto Flight Model (PFM). One purpose of the instrument is to demonstrate several technologies able to enhance vacuum ultraviolet measurements by increasing the UV detection efficiency and the ability to maintain calibration. LYRA benefits from diamond detectors: it will be the first space assessment of new UV detectors**.** Diamond is a wide bandgap material, that makes the sensors radiation-hard and "solar-blind". This latter property allows suppressing the usual filters, that block the unwanted visible, but attenuate seriously the desired UV radiation.

While spectral diagnostics are beyond its scope, LYRA has the advantage of quasi-continuous monitoring with very high cadence observations, up to 100 Hz, of interest for the study of solar flares and for the limb occultation technique. Continuous long-term time series of the EUV solar irradiance can bring insights into fundamental questions such as coronal heating, but here too, the higher the sampling rate, the lesser the bias of the statistics.

2. INSTRUMENT DESCRIPTION

LYRA is part of the scientific payload of Proba2 (project for on-board autonomy) micro-satellite, a space mission of the European Space Agency (ESA) that aims to:

- perform in-flight demonstration of a series of new spacecraft technologies
- support scientific mission of a set of selected instruments.

PROBA-2 is a technology evolution of the successful PROBA-1 in orbit since October 2001 [2]. The spacecraft has a size of less than a cubic metre with a weight of 100 kg.

PROBA-2 includes major Belgian contributions. It is developed under an ESA General Support Technology Program (GSTP) contract by a consortium led by Verhaert Design & Development (Belgium). It will be launched in 2007 as a piggy back payload, to reach a helio-synchronous polar dawn-dusk orbit for a nominal 2-year mission.

Near LYRA, SWAP, the Sun Watcher using Active Pixel Sensor and on-board image processing will provide an image of the solar corona at 17.4 nm [3]. The LYRA and SWAP solar payloads both developed under the management of the Centre Spatial de Liège (CSL, Belgium) will provide an overall survey of the solar corona during the PROBA-2 mission.

2.1 Radiometer design

LYRA is a compact solar VUV radiometer [3], designed, manufactured and calibrated by a Belgian - Swiss - German consortium with additional international collaborations. It has a set of three redundant units (see Fig. 1), each including four spectral channels: 1- 20 nm (zirconium filter), 17-70 nm (aluminum filter), 115-125 nm (Lyman *alpha*) and 200-220 nm (Herzberg). Each channel includes a pinhole collimator and a head with a precision aperture, a spectral filter, a detector and two LED light sources (See Fig. 2).

The design of the head takes into account opening angle, cleanliness, thermal and mechanical issues.

The Physikalisch Meteorologisches Observatorium Davos (PMOD, Switzerland) provides the optical, electronical and mechanical design which is similar to the VIRGO photometer on board of SOHO and the SOVIM radiometer. The solar-blind diamond detectors have been designed and fabricated at IMOMEC, Belgium, in collaboration with the National Institute for Materials Science (NIMS), Tsukuba, Japan. The LYRA development takes into account cleanliness and thermal issues usually necessary for the EUV spectral range.

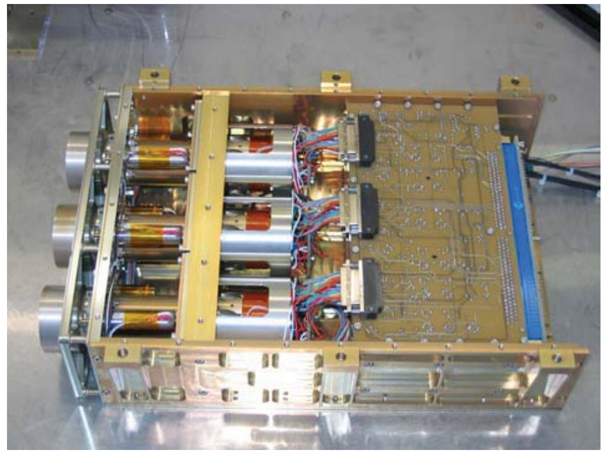

Fig. 1: View of the 3 heads in the FM, each with 4 channels are aligned behind an aperture door

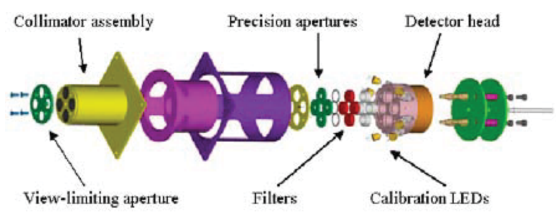

Fig. 2: Exploded view of one of the three identical LYRA units. Each unit contains 4 spectral channels. The collimator, the filters, the LEDs and the head can be seen. The detectors are hidden by the head. The incoming radiation is coming from the left side

2.2 LYRA Structure and electronics design

The dimensions of LYRA are 315 mm * 92 mm * 222 mm with a mass of 3.533 kg. Given the geometry of the collimator, view-limiting apertures of 8 mm diameter, precision apertures of 3 mm diameter and detector sensitive area of 4 mm, the FOV is 2.09° and the unobstructed FOV is 7°. An alignment cube on the top of the box is coaligned with the collimator axes. This alignment cube allows the co alignment between SWAP and LYRA on the platform.

Great care is taken on the electronics part since signals in the range of 100 pA are expected. The electronics is composed of 5 subsystems, a first PCB pre-amplifier fixed to the detector, an amplifier, a MUX/VCF board, to convert the signal current to frequency, a digital board with the ASIC and the data interface, and finally a power converter board.

2.3 Detector, filters and radiometric model

The detector technologies developed for LYRA are a photo-resistive device (metal-semiconductor-metal, MSM) under 5V bias and a n-i-p photodiode (PiN). Note that the PIN photodiode is operated in a photovoltaic mode (unbiased). Classical Si diode detectors are used for comparison with a well known technology. A radiometric model based on the solar spectral irradiance, transmittance of the LYRA filters and detector responsivity (PiN, MSM and Si) is used to determine the anticipated photocurrents and their spectral purity. The anticipated photocurrent was also required to define the feedback resistor of the amplifiers. A generic detector was used until all flight model devices were calibrated across the full necessary range. Updating the radiometric model with the most reliable data was and is a permanent process within the LYRA project. For most of the channels, the radiometric model fits well with the calibration data of the overall instrument. Only one channel indicates a large discrepancy with respect to the radiometric model computed value. If the accuracy of the current calculations are well determined, the observed discrepancy is linked to this problematic channel configuration. Indeed, this channel has two Lyman alpha filters (one N and one XN) to get enough spectral purity, because it is using a Si detector. Each filter transmission / rejection was measured separately, but it was not possible to measure the rejection once the filters are put together. The rejection is about 10^{-8}, well below the limits of the measurement setup. As an example, the results of one filter transmittance measurement are given in Fig. 3.

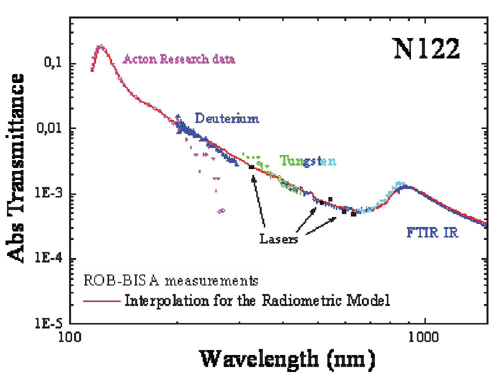

Fig. 3: Measured transmission and radiometric extrapolation for the N122 filter

There is no special difficulty with the Herzberg channel thanks to the large expected signal (>nA) and the used of PiN detectors. However this must be moderated by its small variability (<2%) and hence, by the need for high precision. For Lyman alpha, Al and Zr channels, the results display the same signal as for AXUV detectors (from IRD) with two filters. The superiority of diamond detectors over Si detectors is clear from this channel, where despite the two filters the spectral purity and S/N ratio is worse.
Additionally, as a wide bandgap material, diamond makes the sensors radiation-hard and “solar blind”.

3. *CALIBRATIONS*

3.1 *Traceability to radiometric standards*

It is a scientific goal of LYRA to improve the absolute accuracy of the measurement (goal 5%). This implies the need for sub-systems and system calibrations, on-ground and in-flight. The radiometric responsivity of each LYRA channel has to be determined over a wavelength range that is extremely large: from the soft X-Rays (1 nm) to the near infrared. First, subsystems (filters, MSM detectors, PIN detectors) are characterized for their UV responsivity, visible light blocking, background noise, dark current, linearity, temporal stability within different wavelength ranges. Secondly, the LYRA instrument was calibrated, each channel separately. The measurements were carried out by several teams at radiometric calibration facilities: CSL, PTB/BESSY, NIST, and IMOMEC. To cover such a large spectral range, synchrotron beamline facilities are required. They also provide the traceability to a primary source standard. The calibration results obtained with the different detector types and filters are reported in dedicated publications.
A first global calibration of the LYRA instrument was performed in July 2005 with two monochromatic beamlines (Normal Incidence (NI) and Grazing Incidence (GI) of the Physikalisch-Technische Bundesanstalt (PTB) at the electron storage ring BESSY II in Berlin.
Started in November 2003, the pre-delivery tests and calibration activities were finished in 2005. The LYRA calibration plan consists of the following calibration programs:
(1) *First detector campaign at IMOMEC and PTB/BESSY*. This campaign was used to characterize and compare the spectral responsivity of MSM and PiN structures over the spectral range from 1 nm to 1000 nm [4] (Fig. 4). Based on the various data sets gathered during the calibration campaigns (Fig. 5), the PiN diodes show good response in the Herzberg channel but are insensitive at the Lyman alpha wavelength.

The MSM structures show higher responses with a solar blindness of typically 4 decades in magnitude between 200 and 400 nm. Their time response is of the order of several ms.
The MSM are selected for the Lyman alpha and Soft X-rays channel, where a signal of 100 pA is expected

and is manageable by the LYRA electronic. Alternative detectors are considered to provide a spare or a calibration backup in this channel.

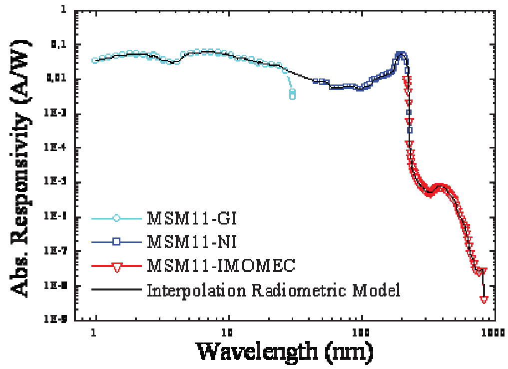

Fig. 4: MSM11 detector responsivity combining PTB (Gi and NI) and IMOMEC measurements.

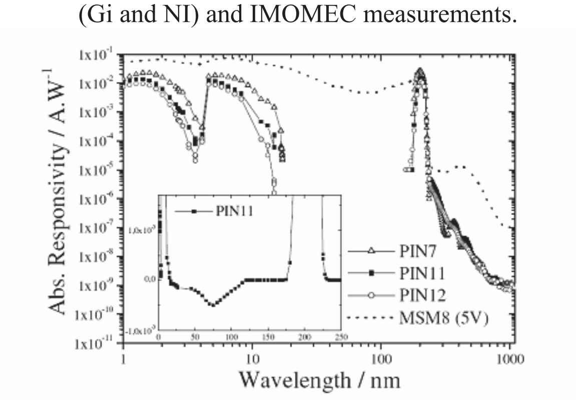

Fig. 5: Typical absolute spectral responsivities (A/W) measured for PiN and MSM diamond detectors.

(2) *Precision aperture area measurements at PMOD*. Only the precision apertures are critical and therefore calibrated. The open aperture diameter is 3.0 mm. The manufacturing tolerance of the precision apertures is H7 or +10/-0 µm in diameter. After manufacturing, the apertures were sent to the Swiss Federal Office of Metrology and Accreditation (METAS) for calibration. The inspection of roundness allows area calibration by diameter. The overall accuracy must be considered as not better than 1.2 μm in diameter, that is $8x10^{-4}$ in relative terms.

(3) *LEDs calibration campaign at IMOMEC*. The following tests were carried out:
- Operational point stability and drift,
- Measurement and comparison of the operational point of different photodiodes (Fig. 6),
- Switching behavior after prolonged stress,
- Temperature dependence of the emission and the emission stability at various temperatures,
- Calibration with respect to diamond detector.

This latter calibration indicates that it is necessary to add pinholes in front of the LED to avoid saturation of the electronics.
The LED temperatures are monitored during flight so that a stability of a few percents is expected.

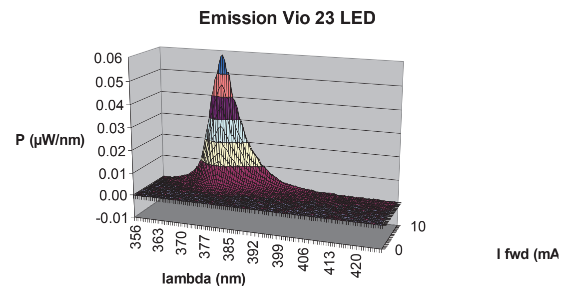

Fig. 6: 380 nm LED emission spectra versus forward current

(4) *Filters calibration campaign at CSL, MPS, ROB and PTB/BESSY*. Measurements of the light transmission are performed. The flight filters are documented with a complete package of certifications. After these tests, correlation with the manufacturer data is carried out. Example of comparison between the manufacturer data ARC (Acton Research Corp. USA) and the measured one for the Herzberg filters is presented in Fig. 7. Same as been completed with the Aluminum and Zirconium filters measured data with the LUXEL data.
Finally, the filters were mounted on the Flight Model (FM) instrument for vibration, thermal and solar blind tests.

(5) *Second detector campaign at IMOMEC, CSL, MPS, NIST and PTB/BESSY*. This calibration program of FM detectors is designed to know their XUV-to-VIS response and the stability of their performance with time [5]. Part of this campaign addresses other characterizations (linearity, flat field).

(6) *Global instrument calibration campaign at PTB/BESSY*. This program has assessed the radiometric performance of the whole LYRA in order to provide the most accurate knowledge of its spectral response with the flight electronics configuration (Fig. 8), time response (Fig. 9), flat field (raster scan) and linearity.

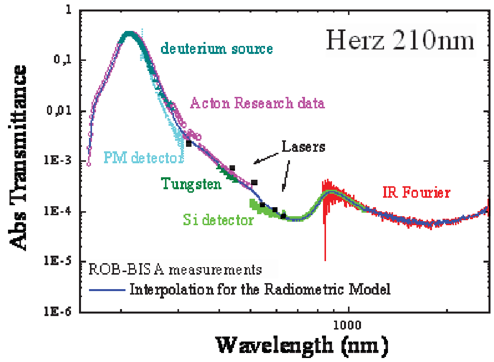

Fig. 7: Herzberg filter transmission combining CSL, BISA-ROB measurements and compared to ARC data and extrapolated radiometric model.

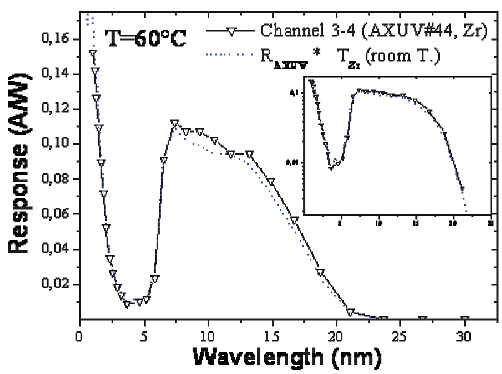

Fig. 8: Absolute spectral responsivity (in A/W) of the Zirconium filter channel between 1 nm and 30 nm. For comparison, the dotted line represents the model used in the LYRA radiometric model (detector R x Filter T).

(7) Second *instrument calibration campaign at PTB/BESSY.* This campaign had the same goals as the previous one, but was needed since some channels have been modified with respect to the first calibration campaign. Additional tests were performed to

- verify the ageing effect after 6 months storage and the complete set of environmental campaign,
- verify the temperature environment impact,
- evaluate long drift effects (Fig. 9),
- calibrate at temperatures close to the expected orbit one,
- measure LED signal after EUV illumination.

(8) Heliostat tests. These tests were performed to verify the correct rejection of the channels. From ground looking to the Sun, no signal should be recorded by LYRA. This test was very useful to detect a defect filter that occurred during integration in the double filter holder.

After delivery and during flight operations, further ground calibrations will be performed on the spare unit of the detector head.

3.2 In-flight calibration monitoring

The redundancy strategy requires that all three units are made comparable, although they are not identical. One is used continuously, the second (probably the one with the IRD-AXUV silicon detectors) on a weekly basis, while the last remains closed most of the time and is only used a few times during the mission. In this way, the radiometric evolution of the sensors and filters will be assessed. Furthermore, the LEDs will help to disentangle filter and detector ageing. In-flight flat field campaigns will look for possible burn-in effects.

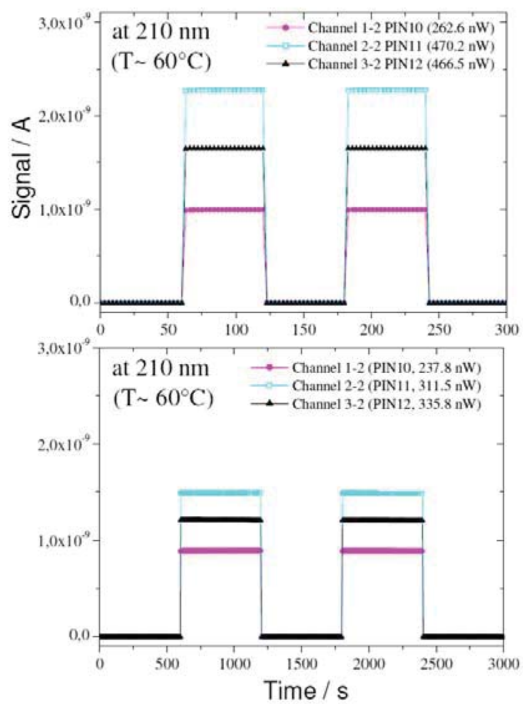

Fig. 9: Absolute signal (in A) of the Herzberg channels as a function of time at 210 nm for a short period (top) and for a long period (bottom).

4. LYRA DEVELOPMENT

LYRA development is based on a PFM approach. An EM was build mainly to characterise and check the electronic behaviour of the instrument. When a good understanding of the electronic and check of the interface with the S/C was performed, the PFM has been manufactured. The major issue during the

instrument preparation was the availability of good diamond detectors. An additional year in the development was entirely dedicated to the detector optimisation.
Once, it was decided to go ahead with the existing detectors, LYRA underwent a classical ECSS PFM (European Cooperation for Space Standardization Proto Flight Model) approach. The functional tests show good operation of the instrument and comply with the strict requirements for the power consumption from the platform.
The nominal power consumption is 2.85 W in nominal mode, to compare to the 5 W requirements. A thermal balance test was used to correlate the thermal model. Vibration test indicates that the eigen frequencies are far well above the 140 Hz required. The first measured eigen frequencies are 555 Hz along X, 410 Hz along Y and 522 Hz along Z. These values are somehow far from the predicted one, but the discrepancies are well understood.
Finally, thermal vacuum test was performed and demonstrated good operation at the maximum and minimum operating temperatures (+ 60 to – 40 °C) and the survival (none operational) temperature (+70 to – 40°C). Additionally to these classical tests, some additional tests were carried out, as a test robustness of the foil filters. Indeed, as mentioned previously, these are only 150 nm thick for Al (300 nm for Zr), and during some preliminary calibration activities one of them broke. Some modifications were performed on the initial design to add some venting paths between the two cavities of the filters. Then, the instrument successfully underwent an equivalent depressurisation as the one going through during launch.

5. CONCLUSION

The design, the scientific objectives and the development of the LYRA instrument have been reviewed. Presently, LYRA is ready to be integrated on the PROBA-2 spacecraft and is stored its nitrogen purged container. LYRA will provide valuable inputs for space weather forecasting, data for new scientific research and also a continuation to the solar survey of the ageing SOHO mission.

6. Acknowledgements

LYRA is a project of the Centre Spatial de Liège, the Physikalisch-Meteorologisches Observatorium Davos and the Royal Observatory of Belgium funded by the Belgian Federal Science Policy Office (BELSPO) and by the Swiss Bundesamt für Bildung und Wissenschaft. LYRA receives development support from MPS.

7. REFERENCES

1. J.-F. Hochedez et al., LYRA, a solar UV radiometer on PROBA-2, *Advances in Space Research*, Volume 37, Issue 2, p. 303-312.
2. Teston, F., Creasey, R., Bermyn, J., K., M., Aug. 1999. PROBA: ESAs Autonomy and Technology demonstration Mission. *Proceedings of the 13th Annual AIAA/USU, Conference on Small Satellites*.
3. J.-M. Defise, et al., Feb. 2004, SWAP: Sun watcher using APS detector on-board PROBA-2, a new EUV off-axis telescope on a technology demonstration platform. *Telescopes and Instrumentation for Solar Astrophysics*. Edited by S. Fineschi, M. A. Gummin, Proceedings of the SPIE, Volume 5171, pp. 143-154.
4. BenMoussa, et al., Dec. 2003. Solar-Blind Diamond Detectors for Lyra, the Solar VUV Radiometer on Board Proba II. Experimental Astronomy 16, 141-148.
5. BenMoussa, et al., Mar. 2006, Radiometric characteristics of new diamond PIN photodiodes. Measurement Science and Technology 17, 913-917.