IN-FLIGHT PERFORMANCE OF THE SOLAR UV RADIOMETER LYRA / PROBA-2

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I. INTRODUCTION

LYRA is a solar radiometer, part of the PROBA-2 micro-satellite payload (Fig. 1). The PROBA-2 [1] mission has been launched on 02 November 2009 with a Rockot launcher to a Sun-synchronous orbit at an altitude of 725 km. Its nominal operation duration is two years with possible extension of 2 years. PROBA-2 is a small satellite developed under an ESA General Support Technology Program (GSTP) contract to perform an in-flight demonstration of new space technologies and support a scientific mission for a set of selected instruments [2]. PROBA-2 host 17 technological demonstrators and 4 scientific instruments. The mission is tracked by the ESA Redu Mission Operation Center.

One of the four scientific instruments is LYRA that monitors the solar irradiance at a high cadence (> 20 Hz) in four soft X-Ray to VUV large passbands: the “Lyman-Alpha” channel, the “Herzberg” continuum range, the “Aluminium” and “Zirconium” filter channels. The radiometric calibration is traceable to synchrotron source standards [3]. LYRA benefits from wide bandgap detectors based on diamond. It is the first space assessment of these revolutionary UV detectors for astrophysics. Diamond sensors make the instruments radiation-hard and solar-blind (insensitive to the strong solar visible light) and, therefore, visible light blocking filters become superfluous. To correlate the data of this new detector technology, silicon detectors with well known characteristics are also embarked. Due to the strict allocated mass and power budget (5 kg, 5W), and poor priority to the payload needs on such platform, an optimization and a robustness of the instrument was necessary. The first switch-on occured on 16 November 2009. Since then the instrument performances have been monitored and analyzed during the commissioning period. This paper presents the first-light and preliminary performance analysis.

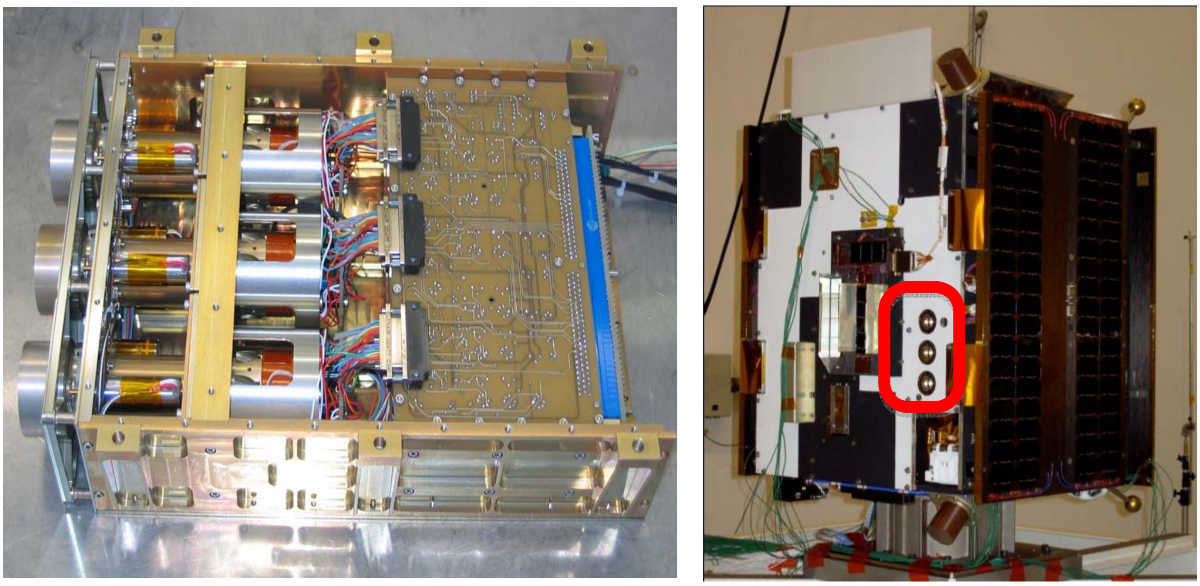


Fig. 1. LYRA instrument (left) and LYRA on the PROBA-2 spacecraft (right)

II. LYRA CHARACTERISTICS

LYRA monitors the solar integrated flux in 4 X-Ray and VUV passbands at a high sampling frequency. The 4 passbands have been chosen for their relevance to solar physics, space weather, and Earth aeronomy:

- Channel 1: 115-125 nm (Lyman-Alpha passband)
- Channel 2: 200-220 nm (Herzberg passband continuous range)
- Channel 3: 17-70 nm (Aluminium filter, EUV passband, including 30.4 nm He II line)
- Channel 4: 1-20 nm (Zirconium filter, soft X-Ray passband) .

The scientific goals as well as a complete description of the LYRA payload are detailed in [4]. In Figure 1 (left panel) we show the LYRA instrument with its three identical units and (right panel) the instrument mounted on the PROBA-2 spacecraft. The introduction of 3 times the same set of channels is required to fulfil a special redundancy strategy. One set of channels is used continuously, the second 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 evolution of radiometric sensitivity of the sensors and filters can be assessed. Furthermore, the use of LEDs, located behind the filters, will help disentangle filter and detector aging. In addition, the redundancy concept is enhanced by using three types of detectors, the PIN-type and MSM-type diodes that are radiation hard and solar blind diamond UV sensors, and AXUV silicon photodiodes.

III. FIRST LIGHT

Two weeks after launch, on 16 November, 2009, the LYRA electronic system was switched on for the first time and the reception of the first housekeeping values was confirmed and found to be nominal. The LYRA temperatures vary between 27.4 and 33°C all along the orbit. These variations are due to the presence of eclipses every orbit. During the following weeks, all the functions of LYRA were tested, such as bake-out, decontamination procedure, dark current, calibration procedure, determination of the nominal integration time, and characterization of the LED stability signal.

After the winter hibernation period of the spacecraft, the first lights were observed on 05 January 2010. The doors were unlocked without any problem despite the criticality of the operation and were opened one by one. The first data acquired with covers opened did not correspond to Sun signal because the spacecraft was pointed away from the Sun. Then, real first light measurements were acquired after the spacecraft has been pointed back to Sun-center (Fig. 2 and Fig.3). Amongst other observations, first light acquisitions show a very strange noise in some channels, appearing consecutively to an ASIC reload, and which in most cases disappears when the signal drops under a certain level (during eclipses or when closing covers). Several tests not originally foreseen in the commissioning plan were performed to understand this behaviour without affecting the success of commissioning. The noise problem was mostly solved by closing the cover after each ASIC reload, but it is not possible to accurately foreseen the time when the ASIC will be reloaded. Nevertheless, since so far we have never encountered problems due to SEU (which was the main reason for reloading the ASIC). Therefore, it has been decided to cancel, for the time being, all ASIC reloads.

To complete these first light operations, reference acquisitions at all possible integration times were carried out. Continuous LED signal with an integration time of 500 ms were also acquired. Those data will be used in the long term to determine whether the level of signal for each channel is stable or decreases (and hence whether the detectors are degrading).

During the commissioning phase, it was also demonstrated that there was no problem in combining LYRA activities with the EUV imager SWAP. This is important to allow comparison and completion between the two instruments on the same observation periods. It was also assessed that LYRA and SWAP are well co aligned.

IV. IN-FLIGHT PERFORMANCES

The analysis of the first light provides already a lot of information about the operation and the science of LYRA. What is clearly observed is:

- the presence of eclipses (by the Earth) in each orbit
- the crossing of South Atlantic Anomaly (SAA)
- the slow stabilization of MSM diamond detectors (channels 1 and 3 of unit 1, and channels 1, 3 and 4 of unit 2 (Fig.2)), already know from the on- ground characterization
- the signal affected by the satellite's large angle rotations (4 times per orbit)
- occasional appearance of "noisy data"

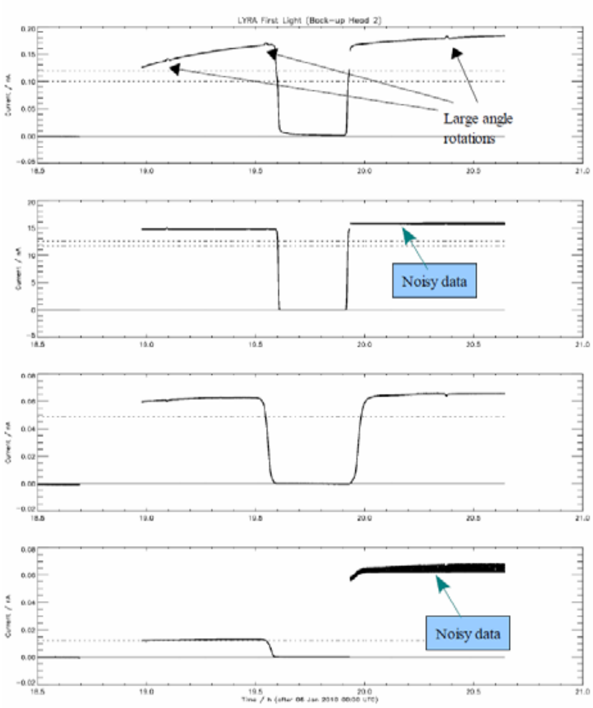


Fig. 2. First light sun pointing on head 2. The noisy data are observed on channel 2 and 4 of head 2. The small bumps are linked to spacecraft rotation. The spacecraft makes a 90° spin rotation 4 times per orbit

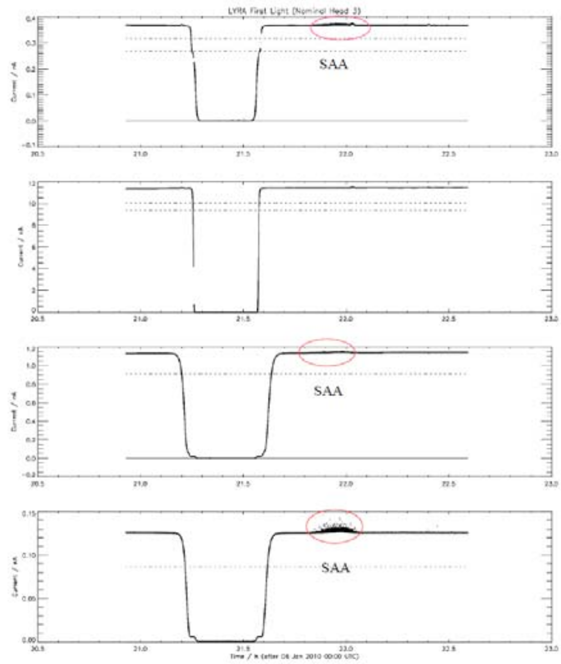


Fig. 3. First light sun pointing on head 3. The noise on the channel 1, 3 and 4 is coming from the South Atlantic Anomaly (SAA)

IV.1 *Occultation*

From the launch till end of February, on every orbit, the spacecraft crossed an "eclipse" zone, in which the Sun was occulted by the shadow of the Earth. Before entering and when exiting the shadow of the Earth, the instrument observed through the Earth atmosphere, which absorbed part of the solar signal. The curve of such an "occultation" is presented below (Fig. 4) for unit 2. As expected, shorter wavelengths are absorbed sooner than the longer ones. However, the small bump in the Lyman-Alpha curve (Channel 2-1) was unexpected. It appears on all three units curves and might be caused by a contamination of the Lyman-Alpha channel by longer wavelengths. The problem is still under investigation. These data are very useful for the study of atmospheric absorption and will give inputs to atmospheric models.

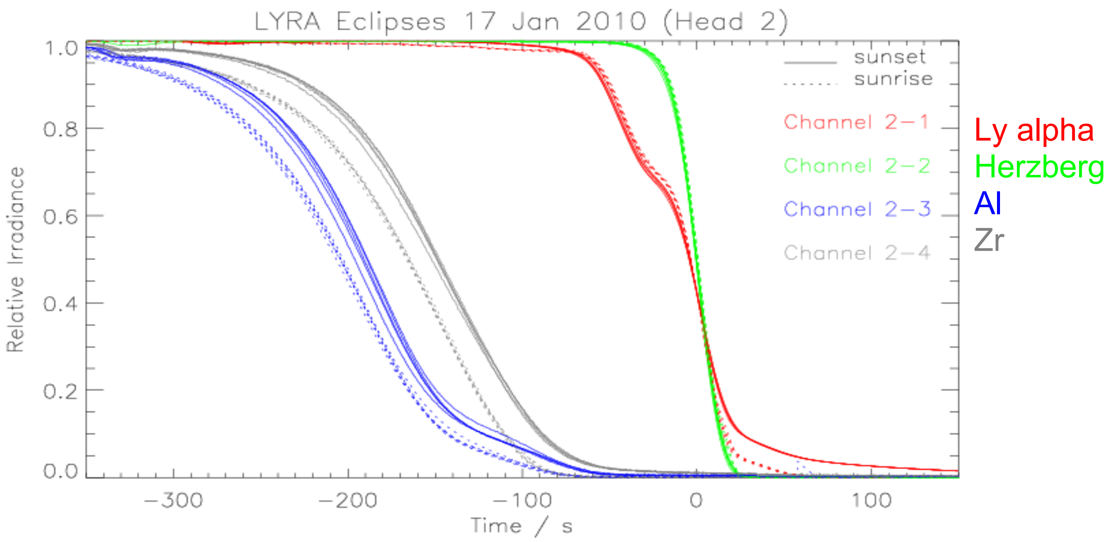


Fig. 4. Overplot of the successive sunsets and sunrises in one day for all four channels

IV.2 Flares

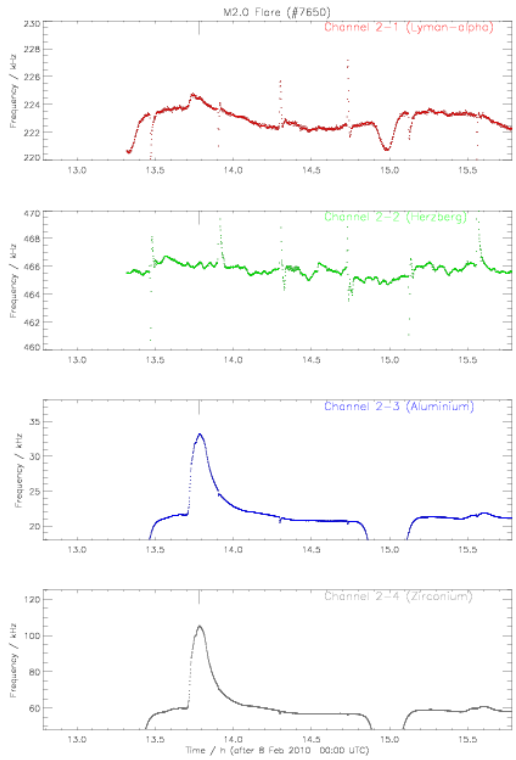
Flares up to M level have been already observed with LYRA (Fig. 5). A comparison with GOES 14 has shown that LYRA was able to detect all the events listed by GOES (unless it was not observing Sun at the time of the flare) down to level B1.5. LYRA provides a good correlation to GOES flares but with a better temporal resolution. Most of the time, flares are detected in Al and Zr channels. But a few exceptionally strong and impulsive flares also show variations in Lyman-Alpha.

IV.3 Degradation

From the time the covers have been opened, LYRA unit 2 (which is the one used nominally) has degraded (see Fig. 6), especially in Lyman-Alpha and Herzberg channels. So far, Lyman-Alpha is the channel having the most degraded, down to 40% of its initial signal level. This degradation tends to stop since February for Lyman-Alpha and since May for the Herzberg channel. Units 1 and 3 are being used much less frequently than unit2. With the help of the LEDs, it is observed that the detector signals remain the same. This indicates that there is no degradation of the detectors, but that the degradation comes from the filters. To compensate this problem, the degradation is calculated and introduced in the acquired data to produce correct and reliable monitoring data of the solar irradiation.

IV.4 Bake out / decontamination

A long bake out has been scheduled to see whether it was possible to decontaminate the instrument and recover part of the signal loss mentioned in the previous section. But no increase of the amount of signal was observed after the bake-out.



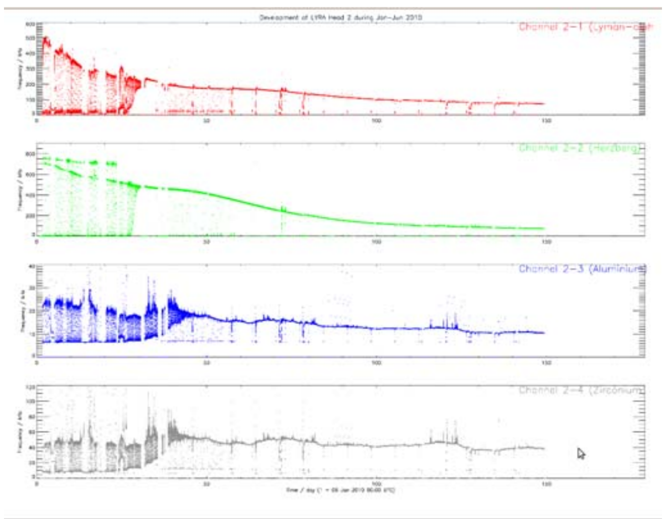


Fig. 6. Evolution of the LYRA degradation between January and -June 2010 of the most used Head 2

Fig. 5. LYRA signal of flares M2 of 28 February 2010, 13:47 UTC

IV.5 *South Atlantic Anomaly (SAA)*

The SAA is visible in the silicon-detector channels and, much less, in the diamond MSM channels either with an electronic gain 10 times higher. This effect is illustrated in the Figure 7, representing dark current curves for unit 1, where

- channel 1 (Lyman-Alpha) is an MSM diamond detector with gain 10
- channel 2 (Herzberg) is a PIN diamond detector (very stable)
- channel 3 (Aluminium) is a MSM diamond detector with gain 1
- channel 4 (Zirconium) is a Si detector

The locations where those perturbations are detected were transferred on a world map. The result clearly matches the SAA Observation tuning. These observations were already carried out before the LYRA first light. It demonstrated that the diamond technology is nearly not sensitive to the SAA.

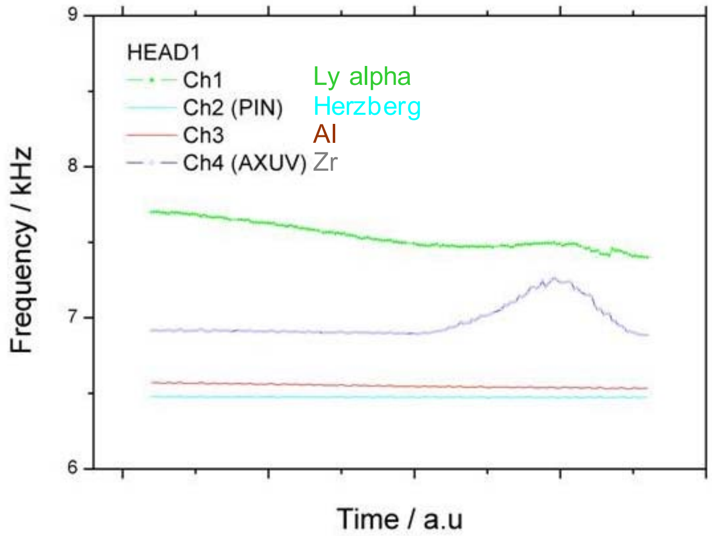


Fig. 7. Dark current curve of head 1 indicating the influence of the SAA

IV.6 Solar eclipse by the moon

On 15 January 2010, an annular solar eclipse happened above Asia. Seen from PROBA-2 the eclipse was partial. This allows to observe different homogeneity of irradiance distributions on the solar surface of EUV channels (Fig. 8) as compared to the chromospheric channels.

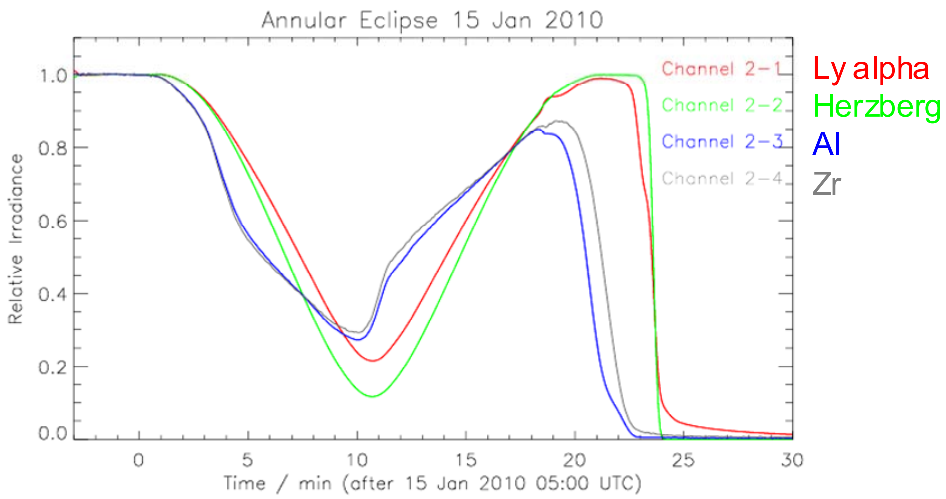


Fig. 8. Relative irradiance data of all 4 channels during the solar eclipse of 15 January 2010

IV.7. Routine activity

After the commissioning phase and a correct understanding of the instruments, LYRA enters in its operational phase with the following iterative activities:

The nominal acquisition is run with unit 2 with an integration time of 50 ms. Every week a calibration is carried out by measuring the dark signal and the LED signal. On a monthly basis back up acquisitions are performed with unit 1 and 3, as well as quasi-flat field which can be achieved by off- pointing of the spacecraft. Finally, every six months a bake out – decontamination is planned. These routine activities give a daily monitoring of the solar EUV and FUV irradiance with high temporal resolution. The data are reported on http://sidc.be/index.php.

V. CONCLUSIONS AND ACKNOWLEDGEMENTS

The operational temperature of LYRA is close to 40°C instead of 25°C as intended. Degradation of filter transmission on a spacecraft is unavoidable and the rate of sensitivity loss is a measure of the cleanliness of the satellite which in the case of LYRA is rather adverse. Despite the unfavourable thermal and cleanliness environment at spacecraft level, the instrument works correctly and provides relevant scientific results [5].

LYRA is a successful technological demonstration instrument. It is the first use of diamond detectors (of two types, PIN and MSM) for space scientific research. In-flight performance analyses have been started during the commissioning phase and are continued to improve knowledge of the instrument performance and capabilities. LYRA is thus a preparatory instrument for other similar radiometer, from which lessons will be derived and expertise gained on diamond detectors in space applications.

LYRA is also used in the frame of space weather and solar science, providing high temporal cadence data up to 20 Hz. Data are available in near-real time (9 passes/24 hours).

The LYRA instrument was developed by the PMOD/WRC (Ch), Project Management, PA/QA, spacecraft interfaces, payload integration and commissioning was under the responsability of Centre Spatial de Liège (University of Liège, B) with the PI ship of the Royal Observatory of Belgium (B). The diamond detectors were developed by IMOMEC (University of Limburg, B) and support for calibration was provided by the Max Planck Institute for Solar System Research (D). Belgian activities are funded by the Belgian Federal Science Policy Office (BELSPO), through the ESA/PRODEX program. The Swiss PRODEX programme supported the development and construction of the LYRA hardware.

REFERENCES

[1] Teston F., Creasey R., Bermyn J., Mellab K., "PROBA: ESA's Autonomy and Technology Demonstration Mission", Proceedings of the 13th Annual AIAA/USU Conference on Small Satellites (1999).

[2] Rochus P., Defise J.M, et al., "PROBA II Payload: A Belgian mini space Weather Observatory", 55th International Astronautical Congress (2004).

[3] A. BenMoussa, I.E. Dammash, M. Dominique, B. Giordanengo, J.F. Hochedez, U. Schühle, A. Theissen, S. Koller, W. Schmutz, Gillotay, Y. Stockman, J-M Defise and M. Kretzschmar. "Pre-Flight Calibration of LYRA, the Solar VUV radiometer on board PROBA2". A&A 508 (2009) 1085-1094.

[4] J.-F. Hochedez, W. Schmutz , M. Nesladek, Y. Stockman, U. Schuehle, A. BenMoussa, S. Koller, K. Haenen; D. Berghmans, J.-M. Defise, J.-P Halain, A. Theissen, V. Delouille, V. Slemzin, D. Gillotay , D. Fussen ,M. Dominique, F. Vanhellemont, D. McMullin,M. Kretzschma, A. Mitrofanov, B. Nicula, L. Wauters, H. Roth, E. Rozanov, I. Ruedi, C. Wehrli, H. Amano, R. Van der Linden, A. Zhukov, F. Clette, S. Koizumi,V. Mortet, Z. Remes, R. Petersen, M. D'Olieslaeger, J. Roggen, P. Rochus, "LYRA: the Solar UV radiometer onboard the ESA PROBA-2", Advances in Space Research Vol 37, Iss 2, pp 303-312 (2006).

[5] J-F Hochedez., I. Dammasch, W. Schmutz, , "FIRST RESULTS FROM THE LYRA SOLAR UV RADIOMETER" 38th COSPAR Scientific Assembly 2010.