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Space flight-model multichannel photometer for spectral detection of stratospheric transient luminous events in Taranis mission

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ABSTRACT

In 1990, scientists discovered and started studying the luminous events which occur above storms at altitudes of 20 to 100km. These Transient Luminous Events (TLE) are associated to high energy particle emissions like X rays, gamma rays… They cannot be easily observed from earth because of clouds and atmospheric absorption. Goal of Taranis satellite which will be launch in 2019 is to collect high resolution data on these TLE.

One of Taranis satellite instruments is a photometer which goals will be to measure emitted light in 4 different wavelength ranges and to distinguish TLE emission from lightning's emission. Bertin Technology has been assigned the task to design, develop, integrate and validate this optical sensor.

The photometer aims at measuring very low light levels with a high signal to noise ratio and with a good uniformity all over an important field of view. These requirements lead to use high sensitivity detectors, special filtering systems in UV channel (180-220nm) and specific optical system to limit the loss of energy and to flatten the optical response over the field of view.

The development of the photometer was submitted to important environmental constraints: mass, available space, vibration, shocks, temperatures… Bertin's challenge has been to take into account these strong environmental requirements which specific damping mechanical system working at low temperature. Final performances measured on the flying model are presented.

Keywords: Photometers, UV, TLE, Spectrometry, flight systems

1. INTRODUCTION

1.1 TARANIS Mission

Transient Luminous Event (TLE) is the name for phenomena occurring over thunderclouds from the top of troposphere to the lower thermosphere (20 to 100 km-altitude). The TLE hunt started in USA and it is now organized all around the world and even from space. First space images of sprites were extracted from thunderstorm movies taken from the space Shuttle in 1989-1991 [e.g. [1]]. Several years after, the Lightning and Sprite Observations (LSO) experiment has been designed by CEA and CNES [2] and operated by ESA astronauts from 2001 to 2004 on board the International Space Station (ISS). It was the first experiment observing sprites at nadir. In 2003, the MEIDEX experiment, on board the space Shuttle, measured numerous sprites and elves from oblique and limb directions [e.g. [3]]. The first experiment dedicated to TLE limb observations is ISUAL on board the low orbit satellite FORMOSAT-2. It was launched in 2004 and is still working.

TARANIS (Tool for the Analysis of RAdiations from lightNIng and Sprites) is a CNES satellite project belonging to Myriade series [4] and dedicated to the study of impulsive transfers of energy between the Earth's atmosphere and the space environment. Objectives [5] more precisely focus on the determination of the mechanisms at the origin of TLEs and on their effects on the Earth environment. To reach these objectives, the TARANIS scientific payload is composed of six scientific instrument. Among them, the MicroCameras and Photometers instruments (MCP), object of this paper, is in charge of the remote sensing of the sprites and the lightning in optical wavelengths [6]. The TARANIS originality is that observations are performed at the nadir above the thunderstorms for comparison of light emissions with corresponding X, gamma, radio emissions, instead at the horizon as previous observations from ground or even from space.

1.2 MCP Instrument

The scientific objectives of the MCP experiment are:

- To identify and characterize the TLEs, that is determining their duration, their brightness at different wavelengths, their size, relative location to their parent lightning…
- To locate the source regions of TLEs over the world,
- To identify and characterize the strongest lightning flashes,
- And to trigger other TARANIS instruments which may point out associated events.

To reach these objectives, it appears that an imager and a radiometer are required. MCP is then composed of two MicroCameras (MCP-MC) and four photometers (MCP-PH). MCP-MC, developed by Sodern, will be used to locate lightning flashes and TLEs and to classify TLEs in their different categories (column or carrot sprites, elves, jets …). MCP-PH, developed by Bertin Technologies, will be used to detect and discriminate on board TLEs and strong lightning flashes and to characterize them temporally and spectrally. MCP is expected to be used for the validation of the observations of the future Geostationary Lightning Mapper on board the next American meteorological satellite GOES-R [7]. In order to discriminate TLEs from lightings, MCP-PH is composed of 4 separated photometers, measuring the brightness in four different spectral bands : 160-260 nm for PH1, 337 +/- 5 nm for PH2, 762 +/- 5 nm for PH3 and 600-900 nm for PH4. Field of view is ranging from 46° (PH1 to PH3) to 80° (PH4).
This paper is dedicated to describe more in details, the engineering of the MCP-PH instrument. Focus on most critical performances like PH1 optical design in UV, environmental requirements (temperature, shocks and vibrations) and management of uniformity is made.

2. MCP-PH SPECTRAL PERFORMANCES

2.1 PH1 Photometer optical design

PH1 system is constituted of 3 main parts : a spectral filter detailed in next part, collecting system, and a detector.

In order to optimize the volume-efficiency of collection, a compound parabolic concentrator (CPC) has been selected as the collection system and its main parameters have been calculated to maximize collection efficiency (Fig 1). CPC is constituted by a metallic alloy substrate, a thick nickel deposition on internal surface; these two elements have been chosen for its dilatation characteristics and for its ability to be aluminum coated with a good adhesion to substrate avoiding possible “delamination” under temperature variation in space. This assembly is finally coated with protected aluminum as UV enhanced coating. In order any additional losses by scattering likely to happen in UV, it was important to optimize the roughness. As a cost-roughness tradeoff, a high performance diamond turning machining was finally selected. A highly reduces roughness down to 5 nm rms was achieved which was in line with specified performances.

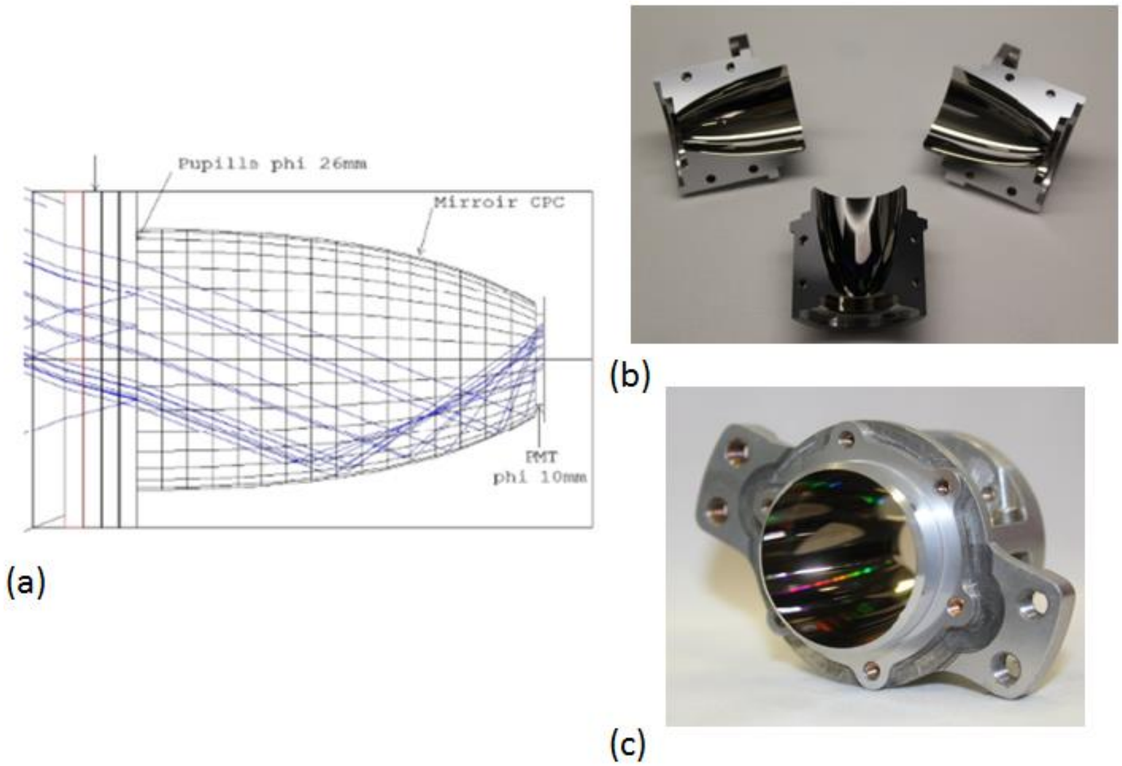

Figure 1. (a) Zemax ray trace view inside CPC, (b) CPC prepared for coating operations, (c) CPC after coating ready to be implemented in the system.

Because of very low input radiance level in UV, to maximize SNR, several Hamamatsu photomultipliers with reference R4443Q-CsTe was chosen for PH1 photometer were purchased, their quantum efficiency @170-230 nm measured and the best one was finally implemented in Flight Model (FM).

2.2 PH1 Spectral filter performances

To be able to have an efficient discrimination between lightning and TLE wavelength in visible range should not be detected by channel #1. The filter should have an important transmission factor for wavelength from 180 nm to 240 nm and a good rejection ratio for wavelength higher than 280nm. These specifications means that a specific filter had to be developed; Reosc was selected to make to studies, the manufacturing and the qualification of a set of these filters. The function was implemented through 4 diopters of 2 substrates. To limit the adherence risk and to benefit manufacturer experiences, the chosen substrate is CaF2. To enhance transmission in UV, the same strategy than for the detector was used: several filters were manufactured, measured and the best one has been integrated in the FM. The final measured transmission through the best filter measured is presented on Fig 2, the filter system was compliant with all requirements.

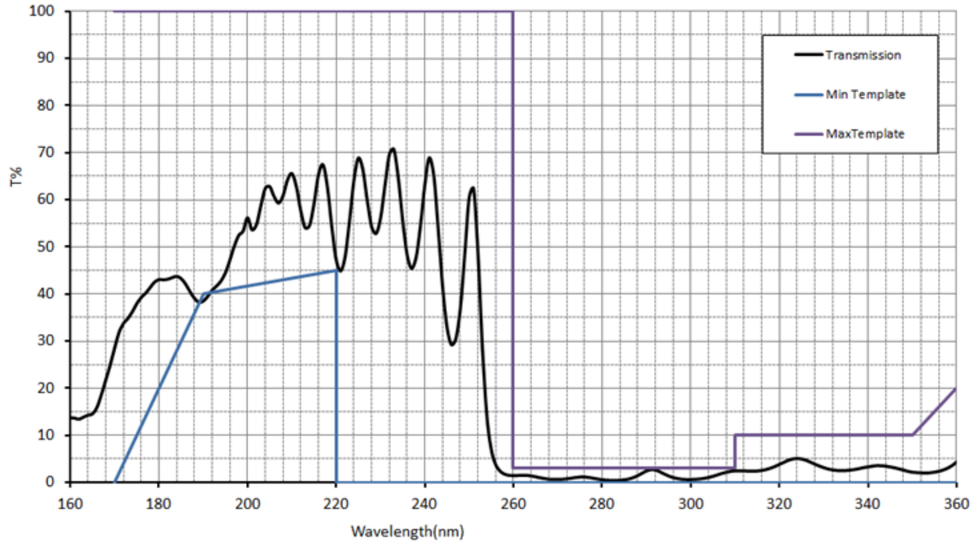

Figure 2. Spectral transmission curve measured on PH1 spectral filter assembly with specified template.

2.3 Environment

A specific attention has been paid to cleanliness during manufacturing process of the filters and some measurements have been done at supplier facilities to evaluate impact of molecular contamination. In environmental condition of its cleanroom, the molecular contamination had a very fast effect on transmission. To study this impact on filter transmission, filters have been exposed at cleanroom atmosphere at the supplier facilities. After a few days, the transmission decreases of about 10% around 200nm. These results led to the design of a specific integration process and a decontamination systems on critical optics.

A cleaning step has been specifically added in integration procedure. The cleaning is done with a UV ozone oven which has demonstrated is efficiency during contamination analysis at Reosc. Bertin procured necessary equipment and made some efficiency verification before FM component cleaning.

To add the capability to clean optics in case of molecular contamination in flight, a de-contamination system imagined by CNES has been implemented (Fig 3). The objective of this de-contamination system is to heat critical optics over 50°C. A CNES study shows that in this case, part of molecular contamination is removed. This heating is done with a heating patch positioned on the mechanical support.

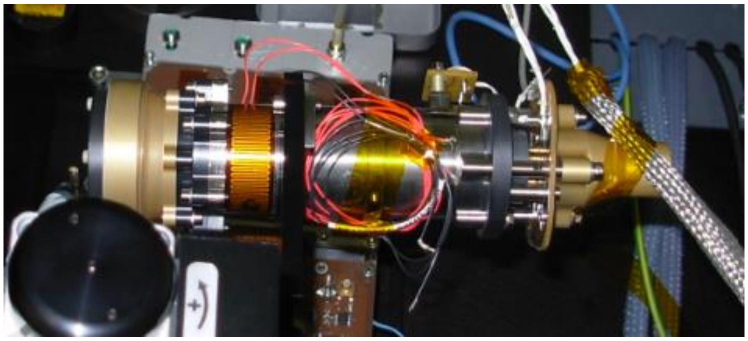

Figure 3. On-board decontamination system based on heating device.

3. PHOTOMETERS UNIFORMITY

Photometer field of view is 21,4° for channel #1,# 2 and #3 and is 43.4° for channel #4. These fields of view correspond to observed surfaces on earth which are 2 discs with a radius of 276km and 700km respectively. One of the critical requirement concerns the uniformity of angular response : for each point of the field of view, the measurement variation has to be lower than +/- 4%. Some characteristics of the optical system (lenses and filter treatment, the cosine effect and pupil aberration, sensor sensibility) induces an important non uniformity on the angular response.

In order to obtain a flat photometers response, all optical system have been assembled and the angular response measured within the useful spectral range of each photometer; resulting curve for PH2 is presented on Fig 4b. A specific neutral metallic pattern has then be design by Bertin to correct the non-uniformity. This deposit has been made directly on a lens surface with 3 main constraints: not being in a pupil plane (to be able to act on field distribution), not being the first surface to degradation by atomic oxygen and to be compatible with surface curvature. Neutral filters deposits has been realize by Optimask company (Fig 4a) using chrome with geometrical accuracies down to few microns. Final uniformity of the system was measured by Bertin. Fig 4c is showing final angular response of PH2 photometer as an example; flatness lower than 4% was obtained which is in line with mission requirements.

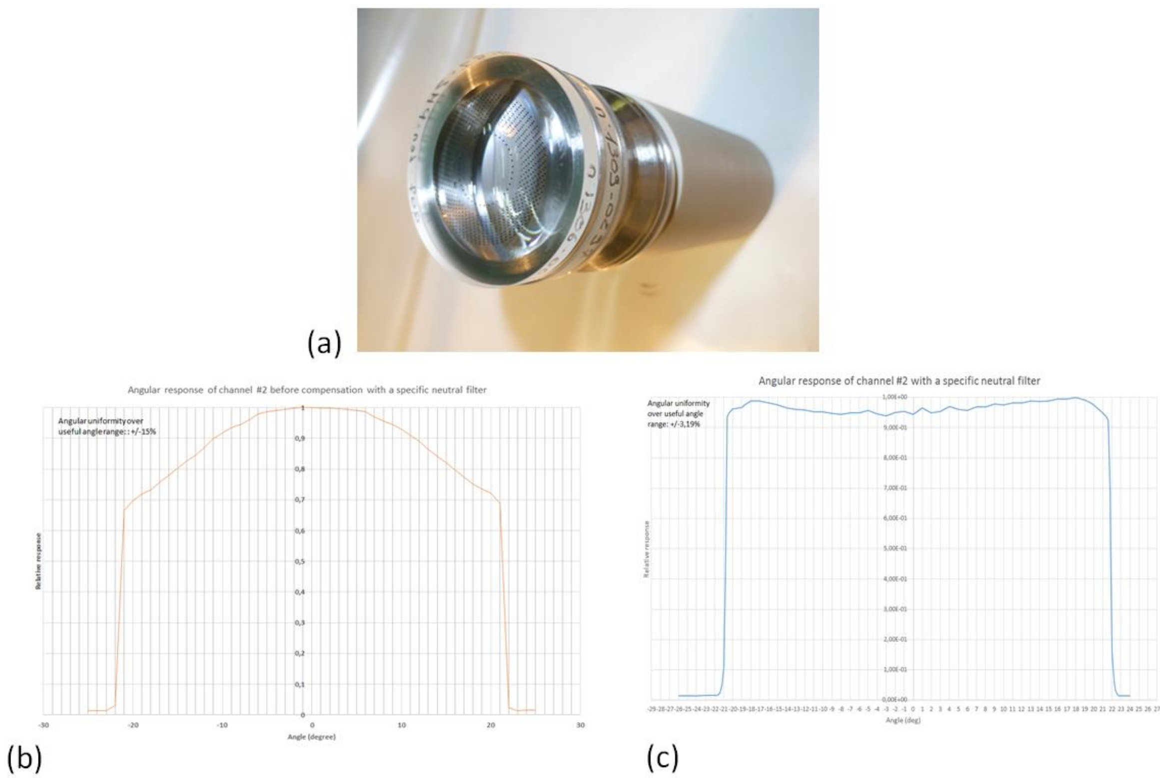

Figure 4. (a) Picture of the PH2 photometer lens where neutral homogenizing filter pattern was applied. The angular uniformity has been measured respectively (b) before and (c) after deposit of the pattern on the lens. Uniformity > 96% has been successfully achieved.

Such solution has been implemented on PH3 and PH4 with same success. However it was not possible to do the same with PH1 because of the absence of suitable optical surface and the need to maximize SNR.

4. MCP-PH SPECIFIC MECHANICAL DESIGN

The photometers has to tolerate important environmental constraints such as vibration, temperature variation, vacuum, shocks. Mechanical design has been studied to maintain optics, spectral filters and detectors in this complex environment. Specific attention has been paid to maintain lenses within its mechanical structure and also for mechanical support of photomultipliers (Fig 5).

Lenses (PH2, PH3 and PH4) of each optical system are maintained with a spring ring which absorbs vibration and shocks and which compensates dilatations due to temperature variations (Fig 5a). Photomultipliers of channels #1, #2, #3 are also very fragile. Their mechanical support have to guaranty that low constraints will be applied and that their pins will not experience too much effort.

Filters material and coatings are also sensitive to shocks. Mechanical design of filters supports has been optimize to protect optics from vibrations and temperature variations, taking into account dilatation characteristics within the temperature range. The conception has been validated by modelization and with vibration tests on an Engineering Model (EM). The first shock tests induced damage to filters. Because the source of the shock on the satellite could not be reduced and because of fragility of filters, the most valuable solution was to protect channel #1 optics with a damping system. The damping system adapted to flying conditions and to the shock level applied to the photometer is an elastomer system. The design had to take into account damping system behavior under vibration stresses. First hypothesis was to use qualified material but modelizations show that qualified elastomers do not have required mechanical characteristics mostly because of temperature conditions down to -20°C during shock. This condition indeed induces a modification of elastomer behavior; specific elastomer has then been created and qualified by SMAC company for TARANIS application (Fig 5b and 5c).

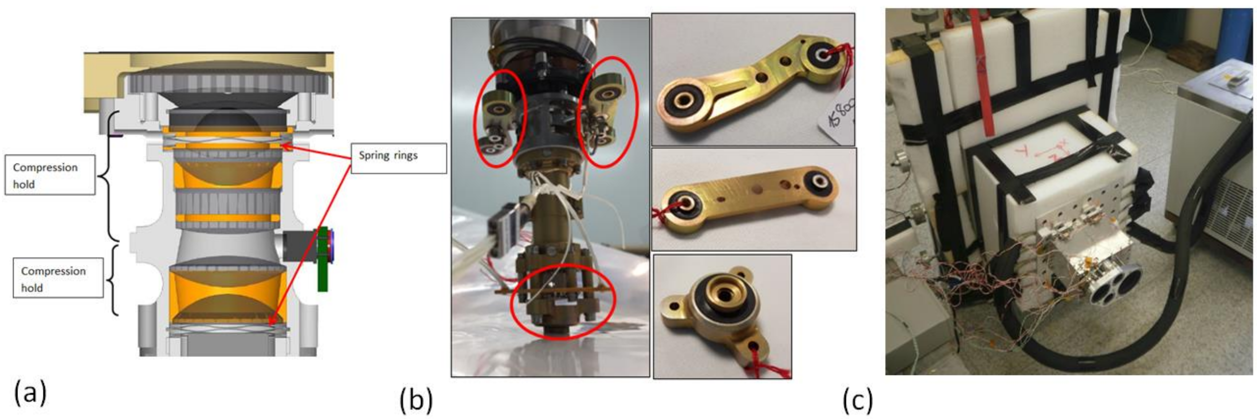

Figure 5. (a) CAD view of mechanical damping system of PH4 Photometer. (b) Damping system implemented on Taranis PH1 photometer. (c) Picture of vibration testing setup at low temperature (-20°C) performed on EM at CNES facilities.

Damping system efficiency has been validated with shocks at low temperature on EM which has been fixed on a cooled plate and shock has been applied at a temperature of -20°C (Fig 5c). A visual inspection validated the integrity of filters and acceleration sensors analyzed the behavior of the system. These tests have been completed with shocks test at ambient temperature and vibration tests to validate the impact of damping system integrated to channel #1 on channel #1 photomultipliers and on the entire system.

5. CONCLUSION

The technical solutions for most demanding performances of MCP-PH instruments of TARANIS mission have been presented. Thanks to innovant and cutting edge technologies designed, implemented and qualified by Bertin Technologies and its main suppliers, it has been possible to meet all main mission requirements.

Concerning TARANIS schedule, qualification tests on the whole payload as well as integration on platform are planned to be achieved during summer 2018. TARANIS satellite will normally be ready for launch in August 2019 with a window in October 2019.

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