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Taranis MCP: a joint instrument for accurate monitoring of transient luminous event in the upper atmosphere

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Abstract— The TARANIS microsatellite – CNES, Myriade family - is dedicated to the study of the impulsive transfers of energy between the Earth atmosphere and the space environment, including transient phenomena such as Transient Luminous Events (TLEs) and Terrestrial Gamma-ray Flashes (TGFs). It observes from above thunderstorm areas. Part of the payload, the “MicroCameras and Photometers” (MCP) instrument is in charge of the remote sensing of TLEs in terms of optical imaging and waveforms. Its objectives are to identify and characterize lightning flashes and TLEs in optical wavelengths, to determine spectral properties and to provide an alert to all TARANIS instruments for common TLE observations at high resolution. The purpose of this paper is to describe the methodology to observe TLEs from the nadir and to detail the specifications and performances of the MCP instrumentation.

Keywords-component: *Lightning, TLE, sprite, elve, space, imager, radiometer, optical, TARANIS, MCP*

I. INTRODUCTION

TARANIS (Tool for the Analysis of RAdiations from lightNIing and Sprites) is a CNES satellite project belonging to CNES Myriade series [1] and dedicated to the study of impulsive transfers of energy between the Earth's atmosphere and the space environment. Objectives more precisely focus on the determination of the mechanisms at the origin of Transient Luminous Events (TLEs), Terrestrial Gamma-ray Flashes (TGFs) and on their effects on the Earth environment. TLEs are large light emissions generally observed obliquely in the upper atmosphere above thunderstorms at altitudes from 20 to 100 km. The scientific objectives of the TARANIS mission fall into three broad categories [2]:

- Advance physical understanding of the links between TLEs, TGFs and environmental conditions (lightning activity, geomagnetic activity, atmosphere/ionosphere coupling, occurrence of Extensive Atmospheric Showers, etc.).
- Identify other potential signatures of impulsive transfers of energy (electron beams, associated electromagnetic or/and electrostatic fields) and provide inputs to test generation mechanisms.
- Provide inputs for the modeling of the effects of TLEs, TGFs and bursts of precipitated and accelerated electrons (lightning induced electron precipitation, runaway electron beams) on the Earth's atmosphere.

To reach these objectives, the TARANIS scientific payload is composed of six scientific instruments: MCP (Micro-Cameras and Photometers), XGRE (X-ray, Gamma-ray and Relativistic electron experiment), IDEE (Instrument Detecteur d'Electrons Energetiques), IME-BF (Instrument de Mesure du champ Electrique - Basse Frequence), IME-HF (Instrument de Mesure du champ Electrique - Haute Frequence), IMM (Instrument de Mesure du Champ Magnétique), associated to the Multi Experiment Interface Controller (MEXIC). XGRE is composed of three X and gamma detectors (20 keV–10 MeV) with measurement of the relativistic electrons (1 MeV– 10 MeV). IDEE has two energetic electrons detectors (70 keV–4 MeV). IME-BF and IME-HF measure the electric field from DC to 30 MHz. IME-BF records the three component of the magnetic field from few Hertz to 20 kHz and up to 1 MHz for one component. At last, MCP is the optical sensor of the payload. Its 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.

The scientific payload is operated as a single instrument. The objective is: first, to make a low time resolution survey of the optical and field/particle events at medium and low latitudes, then, under alert, to record well synchronized high resolution data. Alerts may be triggered by the detection of a priority event (TLEs, TGFs, electron beams, or burst of electromagnetic or electrostatic wave) by one of the instrument. They are controlled by the MEXIC before being transmitted to all the instruments. The scientific payload weighs 65 kg, its power consumption is 40 W daytime and 70W nighttime. Data of “event” and “survey” modes will be stored on a mass memory of 16 Gbits and transmitted by X link, to the CNES control station.

The scientific payload is systematically switched on from -60° to $+60^\circ$ geographical latitudes with two exceptions: (a) the optical instruments are switched off during the daytime, (b) the X and gamma rays instrument and the photometers are switched off over the South Atlantic Anomaly (SAA).

TARANIS is presently in construction and foreseen for a launch in 2015. It is expected to be a two-year mission. It will fly in a 98° sun-synchronous orbit at altitudes of about 700 km. According to the present launcher opportunities, there is a high probability for operations around 13:30 LT.

This paper is dedicated to describe the MCP scientific objectives, the nadir measurement methodology, the TLE-lightning identification processing, and the instrument.

II. TRANSIENT LUMINOUS EVENTS AND THEIR OBSERVATION FROM SPACE

Transient Luminous Event (TLE) is the generic name for phenomena occurring over thunderclouds from the top of troposphere to the lower thermosphere (20 to 100 km-altitude). They are called sprites, halos, elves, blue jets, or gigantic jets (Figure 1. **Erreur ! Source du renvoi introuvable.**). Their temporal and spatial characteristics are very different, as the physical mechanisms at their origin.

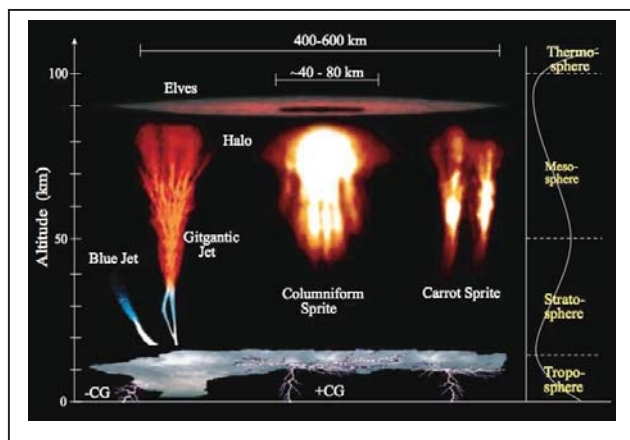


Figure 1. Schematic illustration showing the occurrence morphology of TLEs. Courtesy from Sato et al. [32].

Blue jets and gigantic jets are upward discharges [3] which propagate from the top of the thundercloud up to 40 km altitude (blue jets) [4] or up to the ionosphere (gigantic jets) [5,6]. They last several hundreds of milliseconds. Elves occur just after intense lightning flashes (whatever their polarity) when the electromagnetic pulse generated by the discharge reaches the lower ionosphere (elves occur around 90 km altitude) [7, 8, 9, 10]. They last less than 1 ms and spread over hundreds of kilometers [11]. Sprites appear at the altitude of the upper stratosphere and mesosphere. They are triggered by lightning discharges (positive polarity). Their morphological properties were described using numerous images of these phenomena taken all around the world. Sprites are usually composed of a cluster of vertical columns, sometimes accompanied by downward and upward branching structures which form carrot-like features at 50–90 km altitudes [e.g., 12, 13]. Sprite small structures are typically characterized by diameters ranging from a few tens to a few hundreds of meters [14, 15]. They are considered to be streamer type air discharges [16, 17]. Halos appear above the limit between the lower-structured region and the upper-diffuse region at about 75 km [18], when the quasi-electrostatic field generated by the parent lightning exceeds the local conventional breakdown electric field threshold. Their vertical and horizontal extents are 75 to 85 km and 60 to 90 km respectively [19, 20, 21]. Recent works about TLEs are reviewed by Pasko et al. [22].

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. 23]. Several years after, the Lightning and Sprite Observations experiment has been designed by CEA and CNES [e.g. 24] and operated by ESA astronauts from 2001 to 2004 on board the International Space Station (ISS). It was the first, and up to now, the only 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. 25]. 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 in 2012. This instrument gives a lot of information about the TLE spatial distribution [26] and radiometry in a very broad spectral range [e.g. 27]. New space-borne instruments are in development as MCP, on board TARANIS [2, 28, 29], MMIA, part of ASIM on board the ISS [30], or even recently launched as LSI and PH, part of GLIMS on board the ISS [31, 32, 33].

III. MCP SCIENTIFIC OBJECTIVES AND TLE DETECTION PRINCIPLES

A. MCP scientific objectives

The scientific objectives of the MCP experiment are:

- To identify and characterize the TLEs (sprites, halos, elves, etc.), 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 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 will be used to detect on board TLEs and strong lightning flashes and to characterize them temporally and spectrally.

The next section describes the need requirements for MCP-MC and MCP-PH in order to detect and unambiguously identify TLEs. Observing TLEs from nadir implies to know how to differentiate them from lightning flashes while they can be superimposed. The TLE detection principles will also be described in the next section.

B. MCP need requirements and TLE detection principles

1) MCP-MC

The concept of discriminating TLEs from images taken at the nadir has been validated by the LSO experiment on-board the ISS [28, 34, 35]. Blanc et al. [28] suggested distinguishing TLEs from lightning by their spectral content. The concept is to observe simultaneously the same scene with two cameras. One of them, the "Lightning camera", measures the lightning flashes in a spectral broad band. The other camera, the "Sprite camera", is especially designed to maximize the contrast between the TLE and lightning lights. In the LSO experiment, both cameras are identical (same CCD and optics); a narrowband filter centered on 763 nm is added in front of the optics of the "Sprite camera". The bandwidth of the filter includes mainly the N2 1P (3-1) emission band which is the most intense of the N2 1P sprite emission band [e.g. 36]). The O2 (0-0) band, near 761.9 nm, is a strong absorption band which damps the lightning emissions without perturbing the TLE emissions because the damping depends on the O2 concentration which is much stronger in the troposphere than in the upper atmosphere. A part of the lightning emission between 757 and 768 nm could nevertheless be transmitted through the filter. LSO experiment gives first statistics on the lightning flash radiation inside the "sprite filter" [37].

For TARANIS, the "sprite camera", named MCS, will also use a narrowband filter of 10 nm Full Width at Half maximum (FWHM) centered at 762 nm while the "lightning camera", named MCE, will use a narrowband filter at 777 nm of 10nm FWHM instead of the broadband used by LSO. This narrowband includes one of the strongest emission bands of lightning flash due to atomic oxygen excitation [38]. It was used in three last space-borne instruments dedicated to lightning detection and location (OTD, LIS [39] and FORTE [40]). Lightning brightness through this band is thus well documented. The TLE-producing thunderstorm size is hundreds of kilometers. A disk of ~500 km diameter

is then a good compromise to detect TLEs. A sampling of about 1 km at nadir is convenient for space sprite observations.

The distance between TLEs and parent lightning flashes ranges from a few km to ~50 km [41]. This 1km resolution will allow having on the same or on successive images both TLEs and their parent lightning flashes. Measurements of the structures inside TLEs as sprite tendrils are performed from ground. Recent ground based observations use very rapid camera (more than 10,000 frames per second) to describe the streamer physics inside sprites. Differently, space observations are adapted to the measurement of different emissions (including gamma emissions) and statistics more difficult to be performed from ground. Such studies do not need high space and time resolutions. Standard video cameras (30 frames per second) are used by most of the observers all around the world. A frame rate of 10 per second is acceptable to detect sprite from space and to separate the different strokes which make up a lightning flash.

The sources and the cameras have been modeled in order to evaluate the performances of MCP-MC. The sources are lightning flashes and TLEs. Lightning flashes are modeled as radiating surface located at the height of the cloud top (i.e. from 10 to 20 km altitude) [e.g. 42]. Realistic shapes of lightning flashes are given by LSO observations [37]. The radiance range for MCE is given by LIS measurements [39]. The MCS lightning radiance range is deduced from the calculated ratio between wideband and narrowband measurement performed by LSO [37]. For TLEs, a 3D finite element model of sprite has been developed. Column sprites are represented by 3 km diameter columns from 55 to 85 km altitude. Carrot sprites are modeled as truncated cones with a diameter of 3 km at the cone base (45 km altitude) and 15 km at its top (85 km altitude). A sprite volume radiance of 1.1×10^{12} photons/s/m³/sr at 762 nm ($\sim 9 \times 10^{-7}$ W/m² on the entrance pupil) has been calculated from ISUAL observations [27]. Elves are modeled as radiating surface located at 90 km altitude. Their shape is like a ring centered on the lightning flash. Their radiance is deduced from ISUAL observation [43, 44].

The cameras are also modeled taking into account optic design (distortion, PSF, focal length, aperture, transmission...), relative misalignment between cameras, CCD characteristics (quantum efficiency, dark current and its specific noises ...). They are supposed to be on board TARANIS that is at 700 km altitude. The photon number arriving at the pupil level is calculated taking into account the source radiance and its duration, the characteristics of the optics and the filter and the distance from the source to the satellite. This number of photons is then converted in photo-electrons measured by each pixel of the CCD using its quantum efficiency.

Figure 2. shows the MCE and MCS images resulting from a simulation including two lightning flashes (at the left of the image and in its top right corner) and TLEs which occur over the lightning flash located in the top right corner of the image.

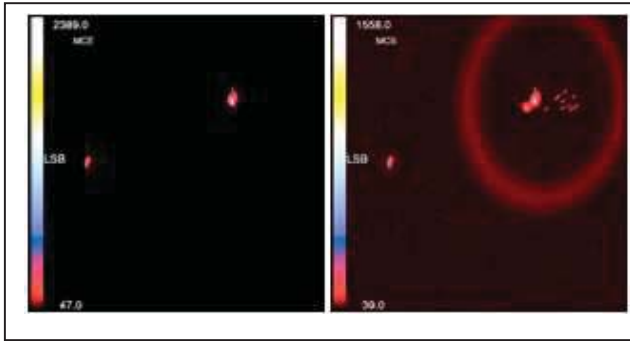


Figure 2. Simulation results of TLEs and lightning observation by the "lightning camera", MCE and the "Sprite camera", MCS. The simulated field of view is 500 km $\times$ 500 km.

One carrot sprite and several column sprites have been assumed to be located in the distance limit of 50 km around the lightning flash center. A strong elve, centered on the lightning flash, has been also added. The simulated field of view is 500 km $\times$ 500 km at ground level. MCE and MCS images are expressed in Least Significant Bit (LSB). One can see on MCS image that the most intense objects are lightning flashes. But the TLEs appear clearly thanks to a well-adapted color scale. These images show clearly the interest of having 2 cameras filtered at different wavelengths. With only MCS image, one cannot differentiate what is due to TLEs and what is due to lightning flash. The comparison with the MCE image removes all doubt because MCE is sensitive only to lightning flash.

The elve amplitude is close to the MCS noise level. Column sprites appear as dashes due to the incidence angle ($\sim 15^\circ$) point of view. The carrot sprite is close to the lightning. One part of it is superimposed to it and it is difficult to differentiate them. Weaker TLEs or TLEs superimposed on lightning flashes are more difficult to be observed and differentiated from lightning without suppression of the lightning flash counterpart from the MCS image. This is performed by subtracting the MCE image after multiplying it by a factor depending on the instrument optics. This factor is calculated by a linear regression of the amplitude of pixels inside lightning flash spot in the both images. Physically, this takes into account the ratio of the lightning intensity measured in the both narrow bands and the ratio of the conversion of photoelectrons in LSB for both cameras. As a misalignment exists between the cameras, the MCE image has to be firstly co-registered. The simulation of the co-registration and image subtraction is shown in Figure 3. The lightning flash residue is very low and the TLEs appear then alone. Carrot sprite has a comet shape due to the viewing angle. During the TARANIS mission, this processing will systematically be realized on ground in the mission center.

This simulation and other calculations, not presented here, show that a signal to noise ratio (SNR) higher than 4 in the raw image is necessary to detect sprites. Elve can be even detected with lower SNR thanks to their size and shape.

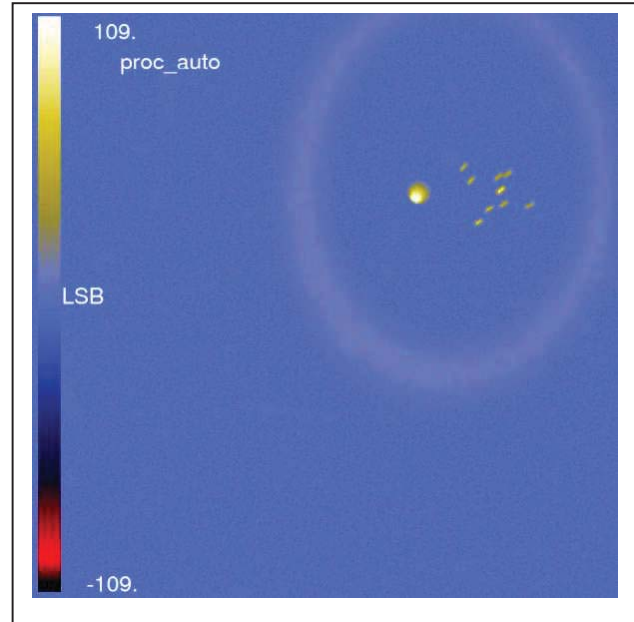


Figure 3. TLE identification processing result.

Some additional requirements can be deduced from these calculations: a very good mutual covering of camera field of view is necessary, the camera misalignment must be known with a very high precision (few arc seconds) and the observation start time has to be very well synchronized between both cameras.

To be able to detect faint TLEs it is important not to truncate images. This means that if images are compressed for memory saving, the compression algorithm must be lossless. In the survey mode, the requirement is to measure most of the lightning observable all along the night-time orbit and to locate them. This is needed to analyze the lightning activity in the thunderstorm when a TLE occurs. Sprite identification will only be possible in the event mode.

2) MCP-PH

Most of TLEs are triggered by a lightning flash. The delay between the lightning flash and the TLE varies from 0.5 ms to several tens of milliseconds. This delay depends on the physical mechanism at the origin of the different TLEs. Elves ever occur ~ 0.5 ms after the lightning flash. This time is a bit larger from 0.5 to 1 ms for halos and varies from 0.5 ms to few milliseconds for sprite columns. Carrot sprites can be delayed of several tens of milliseconds. The duration of an optical lightning flash observed from space is several hundreds of microseconds while elves and sprites last few milliseconds. Jets are the longest events with duration exceeding hundreds of milliseconds. Photometers thus need a better time resolution than cameras for observing these time differences. MCP has to alert the TARANIS payload of a TLE occurrence. Triggering with cameras is more difficult than with photometers because the resolution in time is lower and the whole image processing, previously discussed, is only possible on ground.

At last, TLEs are mainly due to the excitation of vibrational levels of molecular nitrogen [e.g. 36]. These different levels require different electron energies. Photometric measurements at different wavelengths can then give important information on the physical mechanisms which produce TLEs.

MCP-PH will measure the irradiance in four different spectral bands:

- PH1: inside the N2 Lyman-Birge-Hopfield (LBH) UV band system from 160 to 260 nm,
- PH2: the most intense line of the N2 second positive band at 337 ± 5 nm for TLEs,
- PH3: the most intense line of the N2 first positive band at 762 ± 5 nm for TLEs,
- And PH4: from 600 to 900 nm. This last spectral band will be dedicated to lightning flash measurements. This band has been used by FORTE satellite to detect lightning from similar orbit [39].

The field of view of PH1, PH2 and PH3 has to be the same as the camera one. The mutual covering of photometer and camera field of view must be very high (more than 95%). PH4 will have a much larger field of view (disk of 700 km radius) than other photometers to be similar to the field of view of other TARANIS instruments. The irradiance range requirement for PH1, PH2 and PH3 is derived from ISUAL measurements. This instrument is the first one to provide calibrated photometric observation in a wide spectral range [44]. For PH4, the statistics of FORTE measurements have been used [45]. The phenomena dynamics requires a sampling frequency of at least 20 kHz. The four photometers must be synchronized to be able to compare the recorded waveforms.

To detect on board TLEs, a special attention has been paid to find a way to discriminate efficiently TLEs from lightning flashes. One important ISUAL feedback is the confirmation that TLEs radiate in LBH band system [43]. At these wavelengths, the atmosphere fully absorbs radiation coming from altitude lower than 20 km where lightning occur. The upper part of the PH1 filter bandwidth (260 nm) is then chosen to remove by atmospheric filtering all lightning radiation which could reach TARANIS. With such a filter, PH1 will then measure only TLEs. The triggering strategy is to search the occurrence of a sharp peak inside each photometer waveform. A peak is detected when the signal level exceeds a fixed threshold over a determined time window. Threshold and time window will be adjustable during the flight. To send an alert, TLE detection must be confirmed simultaneously by two or more photometers including PH1. These precautions are taken to avoid any false alert due to high energy particle interaction with photometers.

IV. MICROCAMERAS INSTRUMENT DESCRIPTION

MicroCameras are the imager instrument of the experience. The ranges of radiances that the cameras have to observe are presented in TABLE I. in the scientific unit $\text{ph/cm}^2/\text{sr/s}$ (calculated from references). The equivalent spectral radiance in the instrumental unit $\text{W.m}^2.\text{sr}^{-1}.\mu\text{m}^{-1}$ is only estimated from the reference value, averaging the radiance in the 10 nm bandwidth.

To meet its scientific objectives, MicroCameras instrument is constituted of the following subparts:

An optical module MC-U containing:

- Two optical heads, each one dedicated to a specific wavelength (762nm for sprite and 777nm, for lightning with 10nm FWHM)
- Two detection sub-assemblies, based on a cooled CCD
- A CCD proximity electronic board, used for binarisation of the signals
- A mechanical structure

An electronic module, deported away 1m from the optical one, containing:

- An electronic board for data compression and data formatting
- A mechanical structure allowing racking with other electronic modules of the payload

We will describe these two modules of the instrument consecutively.

A. The sensor module MicroCameras Unit (MC-U)

1) The main interfaces for small cameras

As a microsatellite, TARANIS offers around 1m^2 to its payload, and this surface is shared between 8 instruments and telecommunication and attitude equipment. MC-U volume is about 125 mm wide by 180mm long and 165 mm high. Its weight is estimated around 2kg and its power consumption is less than 4.5W. Taking into account these constraints, we will expose in the subparts allowing to reach the expected performances to image the TLEs.

2) The detection subassembly

The detection subassembly is based on a qualified technology, used on many EADS SODERN star-trackers of the SED_6 and HYDRA family.

TABLE I. RANGES OF VALUES OF RADIANCES TO OBSERVE IN THE TWO WAVELENGTHS OF THE MICROCAMERAS

	@ 762 nm		@ 777 nm	
	Radiances ($\times 10^{12}$ $\text{ph/cm}^2/\text{sr/s}$)	Equivalent radiances ($\text{W.m}^2.\text{sr}^{-1}.\mu\text{m}^{-1}$)	Radiances ($\times 10^{12}$ $\text{ph/cm}^2/\text{sr/s}$)	Equivalent radiances ($\text{W.m}^2.\text{sr}^{-1}.\mu\text{m}^{-1}$)
Sprites	0.5 to 5	0.13 to 1.3	0.5 to 5	0.128 to 1.28
Lightning	0.003 to 1.23	7.8×10^{-4} to 0.3	0.056 to 22.6	1.4×10^{-2} to 5.8

SODERN is the manufacturer of MC-U and has a good knowledge of the performances, from the beginning to the end of life of the detection subassembly. It is based on a CCD 4720 from E2V, front illuminated, Non Inverted Mode Operation (NIMO). It's a frame transfer CCD, with a circular mask on the image zone, which produces circular pictures of the observed scenes. The detector is cooled by a two-stage thermo-electric cooler (TEC).

3) The optical heads

The optical heads of the two cameras are nearly identical: it's the same combination of spherical lenses, optimized between 750 and 800 nm for a circular field of view. The angular total field of view is around 46°. Since we have at the same time a high requirement in spectral filtering (10 nm wide) and we need to collect a maximum of photons from the faint TLEs, the chosen aperture number is 1.6. It's a telecentric combination to avoid a shift of the central filtered wavelength and the spectral filter is placed near the sensor. Each camera is only distinguished by its spectral filter: the camera dedicated to sprites (MCS) is filtered at 762nm and the one dedicated to lightning (MCE) is filtered at 777nm. The radiance is not equal between the two bands and the signal range is balanced by a neutral filter, an absorbing glass. This combination is around 50 mm long for a diameter of 25 mm.

The optical heads main characteristics are:

- A really good uniformity of irradiance with a loss of only 1 %, optimized to the detriment of distortion
- A focal length of 17mm
- A resolution of 1.1 km at the center and 1.4 km at the edge of the field of view (due to distortion)
- A quite high distortion around 10%, that will be corrected on ground
- A Modulation Transfer Function (MTF) lowly constrained and an image quality with a low sensitivity to temperature and defocusing.

The spectral filters are both highly constrained by the optical aperture of 1.6. This results in a shift of the central wavelength (CWL) toward the short wavelengths and weakening of the edges. The first phenomenon can be compensated by design but the second one implies to obtain really sharp edges in collimated light. In addition, as the two CWLs are close and lightning have a higher radiance, both filters need a good rejection to really differentiate TLEs from lightning. Consequently, we have to deal with internal straylight, due to multiple reflections of the lightning residual spectrum in MCS (despite the 762nm filtering), and that can be seen in the Sprite camera at the same time as the TLE. Lenses curvature, location of filters and antireflective coating are optimized to reduce it. We also have to care about external straylight, coming from the sun. As the observation is done at night and we want to observe between -60 and +60° in latitude, sun is often seen at the beginning and the end of the observation phase (entrance in eclipse). Each optical head is equipped with a sun baffle, conic shaped with

vanes, angularly well optimized and with a good dark surface treatment.

4) The electronic part of MC-U

The electronic part of MC-U aims at controlling the detector and binary coding of the detected signals. It is composed of 4 small connected Printed Circuit Boards (PCBs), folded up to below and next to the detection subassembly. The complementary functions are deported on the electronic module MC-A that will be presented in a further part.

5) Mechanical architecture of MC-U

The two cameras are interdependent in a same mechanical structure to obtain the stability we need. The following figure (Figure 4.) presents MC-U mechanical structure and the main part that can be seen.

6) Performances of MC-U

For the lowest signal of the range of radiance of the TLEs and lightning we calculated the performances in signal to noise ratio (SNR) in MC-U raw images, at the beginning and end of life (BOL & EOL) conditions. The results are shown in TABLE II.

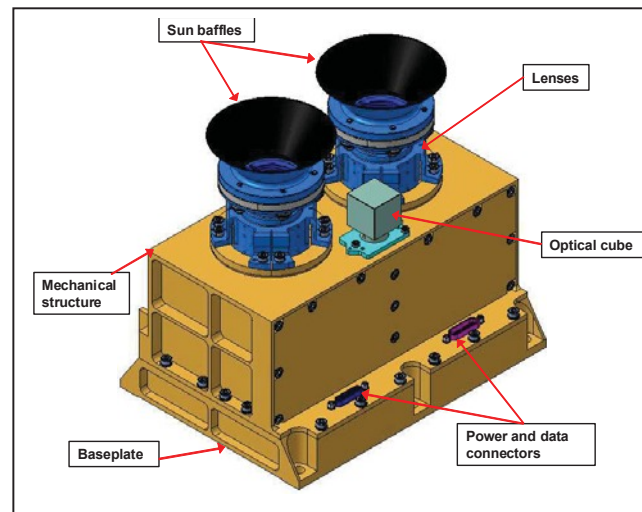


Figure 4. General architecture of MicroCameras Unit

TABLE II. CALCULATED PERFORMANCES OF MICROCAMERAS MC-U ON THE WEAKEST RADIANCE OF SPRITE FOR THE SPRITE CAMERA MCS AND ON THE WEAKEST RADIANCE OF LIGHTNING FOR THE LIGHTNING CAMERA MCE

	BOL		EOL	
	MCS	MCE	MCS	MCE
SNR requirement	4	5	4	5
Expected SNR	5.4	7.1	5.3	5

B. The electronic module of MicroCameras instrument (MC-A)

The electronic module of the instrument is deported one meter away from MC-U. Its main functions are:

- To produce the specific voltages for MC-U and mainly the detector, from the secondary power lines
- To control the TEC loop to cool the CCDs (-7°C)
- To manage the different modes and to compress data in Survey (high loss) or Event mode (lossless)
- To produce formatted data in packets with a specific TARANIS header

Its main interfaces are 7W of power consumption, a size of 115mm by 190 mm in surface, with a mechanical frame of 22 mm high, for a weight estimated to 400g. The mechanical frame is similar to the one presented for photometers in the Figure 7.

C. Calibration

The onboard calibration for MicroCameras mainly aims at correcting the dark signal shift. There is no onboard dedicated source to monitor the radiance performance shift. We plan to choose orbits when we will mainly fly above dark oceans without moonlight. At the moment, no more in-flight calibration is defined.

D. Current development

The MicroCameras instrument is currently in Phase C. An electronic breadboard has been produced for MC-U and is currently under tests and an engineering model is in manufacturing for MC-A. This electronic board will undergo coupled tests with the payload interfaces boards, the engineering models of MEXIC equipment. By the end of the year 2012, we plan to lead the Critical design Review and then to produce the flight model of the instrument.

V. PHOTOMETERS INSTRUMENT DESCRIPTION

As for the MicroCameras, the photometers instrument is composed of a sensor module PH-U and an “analyzer” module, i.e. an electronic board that is plugged into the MEXIC module. This chapter describes the preliminary design of both of them, as defined during a phase B study. Some modifications may occur in the next phases, but the main architecture principles should remain.

A. The sensor module (PH-U)

The main choice was to dedicate one optical path per spectral band. Indeed sharing optics between several bands would have saved space, but it would have lead to more complex focal planes and optical coatings, at the limit of feasibility. Thus the sensor is composed of four optical and electronic chains as depicted by Figure 5.

The optics is composed of two stages, front and back to the spectral filter.

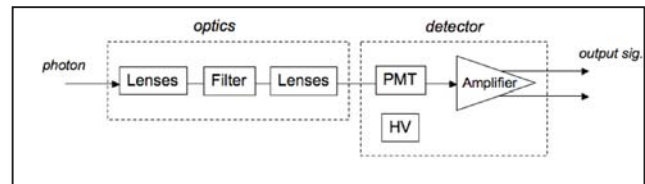


Figure 5. Optical & electrical chain for one channel (PH4 uses no PMT and HV module)

The filter of each band defines the narrow spectral band, and has to be placed in a telecentric configuration so that each point of the field of view sees the same spectral band. The filters are one technical difficulty due to their narrowness. Moreover for PH1, the wavelengths are in the UV, and a low rejection ratio in the visible is mandatory.

Given the very low irradiance produced by the optical phenomena to be observed (down to few tenths of $\mu\text{W} / \text{m}^2$), the detection module will be a photomultiplier, except for PH4 where the signal is 100 times higher. For that reason the focal planes include High Voltage modules to drive the cathodes of the photomultipliers. This HV modules provide a voltage up to several hundreds volts from the 5 V power supply. The high voltage is defined on ground for each orbit in order to adapt the detection gain to the radiance of the TLEs and lightning. Furthermore, the amplifier module will have four possible gain factors that will be chosen, for each orbit, to fit to the dynamic range of the ADC in the analyzer. The detailed definition of the photomultiplier (material of the window and the photocathode) will be chosen with respect to the spectral performances.

But another issue has to be taken into account: the vibration levels that the module has to stand for. Its most fragile components are the photomultipliers. Special care will have to be paid in the choice of the model, or in its accommodation. A dumping mechanical system is currently under consideration.

Besides these functional constraints, the module will have to respect the volume (205 mm long, 125 mm large, 200 mm high), the mass (2.5 kg) and the power (less than 3.5 W). Figure 6. shows the general architecture of the module.

B. The analyzer module (PH-A)

The analyzer is an electronic Printed Circuit Board to be inserted into the MEXIC module. It is dedicated to the photometer instrument. It is in charge of the following main functions. In interface with the sensor:

- Driving the High Voltages of the photomultipliers
- Driving the power supply of the calibration sources (see next paragraph)
- Providing the necessary power lines (+5V, ± 12 V) and switching them ON and OFF
- Acquiring (including digitalizing) signals from the sensor.

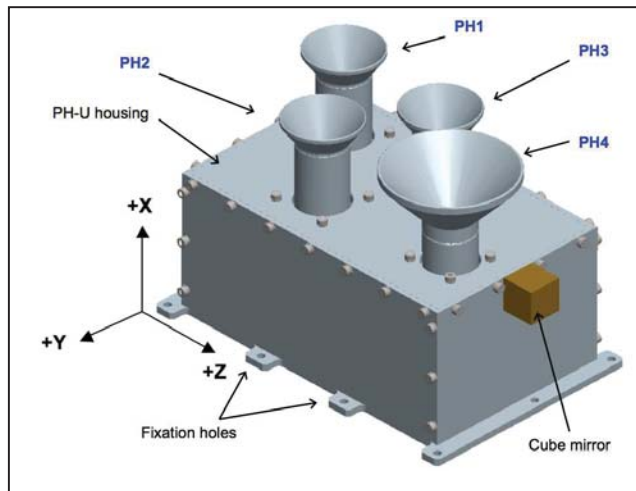


Figure 6. General aspect of the photometer sensor module (preliminary). In green is the electronic mother board. One can see the for optical cubes and their sun shield. The focal planes are mounted on small PCBs.

In case of anomaly in the house keeping data (over consumption for instance), the analyzer has to switch the sensor OFF.

In interface with the On Board Computer:

- Processing in real time the 4 channel data to rise an "event" alert
- Packaging, formatting, storing and sending the data (with compression for the survey mode)
- Monitoring of house keeping data and sending alarm to the payload manager (MIU-1)

The board is composed of power drivers, DAC and ADC in interface with the sensor, a FPGA to process all the data (it has about 130 IN/OUT ports and its clock frequency is 20 MHz), a second FPGA for the interface with MEXIC, and a rolling memory. This 32 Mbits memory stores the high definition data in a rolling stack. In case of an "event" alert, the data are formatted and sent to MEXIC, with a time range starting before the event. If no event occurs, the high definition data are erased, only survey compressed data are sent.

The size of the board is 115 x 190 mm². It is mounted in a frame shown by Figure 7.

C. Calibration

A coarse calibration, or good health test, can be played onboard thanks to calibration sources inserted in the sensor module. Its architecture is as simple as possible: in each optical tube, a LED is mounted beside the detector. It is directed towards the outside that is under the optical filter. So its light, when powered ON, will be reflected by the filter to the detector. The uniformity of this beam is not an issue, the only goal is the check that the signal delivered by the detectors are similar to those measured on ground before launch. The four LEDs will be driven by the same power supply in parallel.

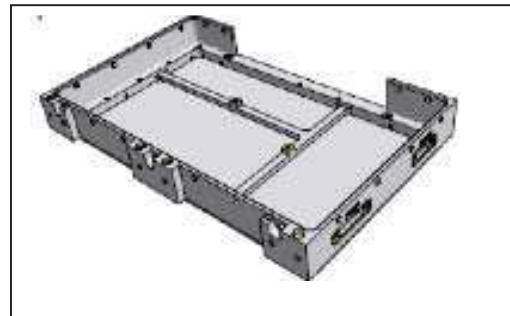


Figure 7. Frame of the analyzer electronic board.

Fine calibrations will use vicarious targets, as dark oceans to get the dark level, and well known desert areas under Moonlight to get the gain of each channel. Several orbits will be dedicated to the calibration of each instrument during the life of Taranis, including MCP.

D. Current development

PH-U is in design and PH-A engineering model is in development. This model should be produced before the end of the year 2012. It will be under isolated tests and then will be coupled to MEXIC engineering model to validate its design. The flight model manufacturing is planned for 2013.

VI. CONCLUSION

We presented the recent known phenomena which appear above the troposphere called Transient Luminous Events. They occur over thunderclouds, are large and intense but really brief. TLEs are difficult to study precisely from ground over the whole electromagnetic spectrum and we want to continue their first space observations to improve their knowledge.

The optical set of the TARANIS payload, the experiment MCP, aim at characterizing more precisely TLEs duration, brightness and relative location to their parent lightning. It is composed of two compact instruments: the radiometer Photometers MCP-PH and the imager MicroCameras MCP-MC. Both uses N2 emission band near 762 nm to identify TLEs, combined with two other bands for PH-U. The lightning flashes are identified thanks to a broadband on PH-U and a narrow band at 777nm for MC-U. The analysis of faint TLEs in MCP-MC is based on a subtraction of the two cameras' images that requires an accurate co-registration. Photometers have a high time resolution to process data onboard in order to trigger the entire payload on a TLE occurrence.

To meet these objectives, we described the MicroCameras and Photometers instruments: both are constituted of an optical module and an electronic module. For MCP-MC, the detection is based on two cooled CCD, a high aperture and a good spectral filtering. The electronic part mainly realizes data compression and formatting. For MCP-PH, photomultipliers are the basis of detection. They imply high voltage converters on PH-U. The main function of the electronic module is the real-time processing of PH-U

data to detect TLE on board and send an alert to the whole payload.

We are now manufacturing engineering models for the two electronic boards MC-A and PH-A. We plan to lead autonomous tests, and then coupled tests with the MEXIC equipment of the payload by the end of the year 2012. The Critical Design review for MicroCameras is also planned at that term in order to manufacture MCP-MC flight model in 2013. We will precise in the following months the details of calibrations, in flight and on ground. We have to go on with the specification and development of the ground processing. We also plan to improve our simulator taking into account calibration with more precision and ground processing.

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