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The SVOM ECLAIRs gamma-ray burst trigger

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Abstract. SVOM, the Space-based multi-band astronomical Variable Objects Monitor, is a Chinese-French satellite mission devoted to Gamma-Ray Bursts (GRBs), which will be observed by the large field-of-view coded-mask soft-gamma-ray telescope ECLAIRs onboard. Its Scientific Trigger will detect and localize the events on the sky, to repoint the spacecraft for follow-up observations and to alert the community in near-realtime. This paper summarizes advancements on the ECLAIRs Scientific Trigger.

Key words. Objects: Gamma-Ray Bursts – Mission: SVOM – Instrument: ECLAIRs

1. Introduction

SVOM is a French-Chinese mission devoted to study Gamma-Ray Bursts (GRBs) (Wei 2016), under development in Phase C, to be launched after 2021. SVOM will study GRBs in a wide temporal and spectral range, thanks to its 4 onboard instruments:

(i) ECLAIRs, the soft gamma-ray coded-mask telescope and GRB trigger,
(ii) GRM, the gamma-ray monitor, a NaI spectrometer detecting in the 15-5000 keV energy range,
(iii) MXT, the multi-pore optics X-ray Telescope (0.2-10 keV),
(iv) VT, the Visible Telescope observing in the 400-950 nm band, with a limiting magnitude Mv=22.5.

In addition, the SVOM mission employs two sets of ground-based instruments:

(i) GWACs, ground-based wide-angle cameras (500-800 nm, Mv=16) with a total field of view (FoV) > 5000 deg^2,
(ii) GFTs, ground-based follow-up telescopes (400-1800 nm).

The ECLAIRs instrument (Godet 2014; Schanne 2015) is very compact, within an allocation of less than 90 kg and 90 W, and offers a 2 sr-large FoV ($89^o \times 89^o$), with a detection plane made of 80×80 CdTe pixels (4×4×1 mm^3) spanning an active area of 1000 cm^2 and detecting in 4-150 keV (imaging 4-120 keV), placed under a coded mask made of Ta (thickness 0.6 mm, size 54×54 cm^2, 40% open fraction), with a localization accuracy better than 13 arcmin at detection limit, and a photon by photon data acquisition (ph. timing 20 μs). The ECLAIRs onboard Scientific Processing and Control Unit (UGTS, Unité de Gestion et de Traitement Scientifique) (Schanne 2013; Le Provost 2013) analyzes the real-time data in order to detect and localize the GRBs, request the spacecraft slew for GRB-afterglow follow-up observations by the onboard narrow-FoV instruments (MXT & VT) and alert the GFTs and ground observers.

2. The UGTS unit onboard ECLAIRs

The functions of the UGTS are:

(i) the control of the ECLAIRs instrument (including configuration, housekeeping, thermal control, noisy pixel management, and power supply management),
(ii) the ECLAIRs-detector data acquisition and transfer to the SVOM mass-memory for delayed X-band download,
(iii) the Scientific Trigger on transient sources, including the onboard data analysis for source detection and localization,
(iv) the generation of near-realtime alert messages, sent to the ground via a VHF transmitter, and
(v) the request for autonomous satellite slews to the trigger target within 3 to 5 min.

The hardware of the UGTS is radiation tolerant, based on ITAR-free components, and includes 10 modules packed side by side:

(i) the ECLAIRs power supply, with 4 modules for the detection plane and 2 modules for the UGTS,
(ii) 2 UGTS I/O boards equipped with FPGA for detector management, and
(iii) 2 UGTS CPU boards for the data acquisition and trigger functions.

The duplicated UGTS modules are used in cold redundancy.

The UGTS CPU boards are composed of an FPGA for data acquisition and preprocessing and a Leon3 dual-core CPU (clocked at 80 MHz, 256 MB RAM, 8 MB MRAM). A time partitioning hypervisor provides predefined processing time-slots for the command-control and trigger functions, with most of the CPU power allocated to trigger.

The hardware of the UGTS is procured by the French Space Agency CNES, the software and firmware is developed by CEA.

3. The UGTS scientific algorithms

Since onboard sky-image reconstruction takes about 2 s, while GRBs can be as short as a few 10 ms, two simultaneous trigger algorithms are implemented in the UGTS:

(i) the so-called ‘Count-rate Trigger’ runs in cycles of 2.5 s. During each cycle, in a first processing step, detector counts are analyzed in 4 overlapping energy strips (e.g. 4-120, 4-25, 15-50, 25-120 keV, to be sensitive to soft- and hard-spectrum GRBs) and 9 detector zones (full detector, 4 halves, 4 quadrants, to detect off-axis bursts) by fitting background models on past data, extrapolating them to each considered time-slice (10 ms to 20 s range), computing the significance of the count-rate increase over background, and storing significant ones into a buffer. In a second processing step, for the most significant not yet processed excess in the buffer, the sky image is reconstructed, in which a new source is searched.
(ii) the so-called ‘Image Trigger’ runs in cycles of 20 s, systematically producing sky images in 4 energy strips. They are subsequently added into a history of the most recent sky images of time-scales from 20 s to 20 min. Each of the sky images produced by summation is searched for a transient source.

The sky-image reconstruction, performed by both triggers, consists in the mask-pattern deconvolution of the detector-plane image. A new source is detected as a sky-image excess in signal-to-noise ratio (SNR) above a threshold (SNRalert), excluding positions where the Earth is present in the FoV. Known source positions are also excluded, unless they are very bright (above a source acceptance threshold). Alerts are produced either for new sources (not present in the known-source catalog) or for very bright known sources. Their positions are determined precisely by a fit in the sky images. As time goes on, the detection SNR of a source may increase, and the trigger produces subsequent alert messages, until the SNR exceeds the slew threshold (SNRslew), in which case a spacecraft slew is requested (or until timeout). An alert sequence comprises also light-curve messages and supplementary information for the burst advocate on ground to determine the quality of the alert before communication to the community. During the trigger process, low significance excesses are also logged in recurrent VHF messages and sent to the GWACs to search for prompt optical emission.

4. The UGTS scientific software

The UGTS Scientific Software is coded in C++, managed by a build system using version control on gitlab. The code can be compiled on the flight-Leon CPU, as well as on a ground-Linux system for development. Additional tools permit to use the C++ libraries in python for code prototyping, trigger-output analysis and display. During flight operations, at the SVOM Science Center or Instrument Center, the ground-Linux machines will also be used for scientific performance tests, replay of the flight data and for trigger-parameters tuning and optimization.

A prototype of the Trigger has been used to determine the overall ECLAIRs detection and trigger efficiency for various types of GRBs. Input GRB catalogs including light curves have been constructed from existing missions such as CGRO/BATSE, Swift/BAT and Fermi/GBM, by extrapolation into the ECLAIRs energy band. Those bursts and the overlaid Cosmic X-ray Background modulated by Earth passages through the FoV are projected photon by photon through an ECLAIRs instrument model, to produce hits on the detector, which are fed into the UGTS Trigger prototype to determine it overall efficiency. By normalizing the rate of GRBs/yr for the BATSE catalog, a number between 40 and 54 GRBs/yr of BATSE type are expected to be detected by ECLAIRs (at SNRalert=8.5 σ). An additional benefit of 4 to 10 GRBs/yr are expected thanks to the low-energy threshold of 4 keV. BATSE used a count-rate trigger only, hence 2 to 3 long duration GRBs/yr are expected to be added by the Image Trigger. In total 46±8 to 67±10 GRBs/yr are expected (Antier 2016) to be detect onboard ECLAIRs.

Beyond this prototype Trigger, the onboard catalog of known sources in the ECLAIRs energy band, detectable by ECLAIRs on the longest time-scale of the Trigger (20 min) has been determined (Dagoneau 2019) using the database of RXTE/ASM (5-12 keV) and Swift/BAT (14-195 keV). After each slew, the onboard Trigger computes the detector illuminations of strong known sources present in the FoV. Every 20 s, those are fit together with the background model and subtracted from the detector-plane images, prior to mask-deconvolution. Reconstructed sky images, free of strong sources and their coding noise, are summed into the 20 min-sky history. Alternatively, a promising method using a wavelet transform of the detector-plane image to remove large-scale background, followed by a fit of strong-source contributions only, is under study (Dagoneau 2019).

In addition to standard GRBs, a study (Dagoneau 2018) shows that ECLAIRs will open a discovery space for Ultra-Long duration GRBs (ULGRBs, a new class of GRBs, including possibly highly redshifted events), thanks the long pointing durations foreseen for SVOM (from 1 up to 14 consecutive orbits) and thanks to the long time-scales offered by the image trigger (up to 20 min and beyond if needed, much longer than for previous missions).

The flight software of the UGTS is currently under development and test, expected to be delivered in 2020.

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