

SVOM/ECLAIRS and the study of Gamma-Ray Bursts

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Abstract: My PhD thesis deals with the instrument ECLAIRS, the X- γ -ray coded-mask camera of the SVOM mission. I have developed a method that simulates astrophysical scenarios as they would be seen by ECLAIRS. This method has several scientific and instrumental applications, some of them presented in this poster. For example, it allows to predict and foster the ECLAIRS instrument detection performances or to validate the on-ground tests performed on the flight model currently.

The SVOM mission



Space-based multi-band astronomical Variable Objects Monitor

The purpose of SVOM is the detection and follow-up of the most powerful explosions in the Universe, the γ -ray bursts (GRBs). These explosions are generated while a massive star core or the product of a compact objects merger collapses into a black-hole. The SVOM GRB detection alerts will be sent to the whole scientific community, enabling follow-up observations and contributing to astrophysics domains such as cosmology, high-z galactic evolution, ... (Wei et al. 2016).

SVOM instruments and observations

ECLAIRS PFM after shielding and coded mask integration



- Characteristics:**
- 4 – 120 keV
 - 90 × 90 deg² FoV
 - 6400 CdTe detectors
 - 400 cm² @ 20 keV
 - 1.6 keV energy resolution

Detection

ECLAIRS X- γ -ray coded-mask camera
GRM Gamma-Ray bursts Monitor

Slew of the satellite within 10 minutes

Follow-up

MXT Microchannel X-Ray Telescope
VT Visible Telescope

Ground Telescopes:
Colibri, C-GFT, GWAC

- Prompt γ -ray emission detection & Spectroscopy
- (ECLAIRS) Source localization 90% conf. within 13 arcmin radius

- Afterglow observation (X-Ray, Visible and NIR)
- (MXT) Source localization 90% conf. within 1 arcmin radius
- (VT) Source localization 90% conf. within 1 arcsec radius
- Host galaxy observation
- Supernova, Kilonova observation

METHOD

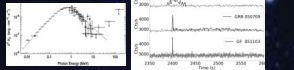
End-to-end simulation of ECLAIRS Astrophysical background and high-energy transients

Photons from Background

Origin: CXB, Albedo, Reflection and Particles taken from database generated with GEANT4

Photons from HE transients

created from Lightcurves & Spectrums



ECLAIRS Simulations

Galactic X-ray sources
Real Attitude Files from CNES

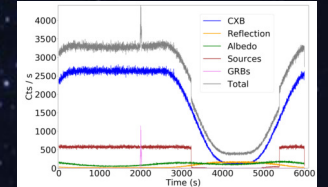
Monte-Carlo based simulations coupled with ray-tracing algorithms to generate the events created by incoming photons (Mate et al. 2019), allowing to get context-based estimation of the on-board events,

Simulated Events

with their associated time, energy, position

Count/Image trigger: Detection of the transients?

Count based detection algorithm (Schanne et al. 2019) : comparison between the expected events number for a given timescale, energy range, ... with the actual recorded number. When the count exceeds a threshold, a sky image is created: if a new source is found inside, an alert is sent to the SVOM satellite.

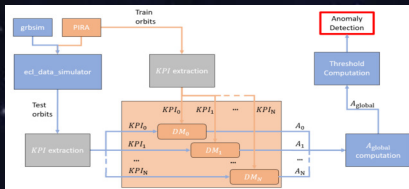


Example of a lightcurve from a simulated orbit. Long-term variations are created by the Earth transiting in ECLAIRS FoV.

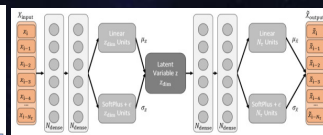
SCIENTIFIC APPLICATION

γ -Ray Bursts detection with Machine Learning algorithms for the SVOM/ECLAIRS offline trigger, Arcier et al. 2021, in prep

Context: SVOM/ECLAIRS will be able to transmit the integrity of on-board raw events to the ground via X-band telemetry to re-treat them, for example via Machine-Learning algorithms.



Schematic representation of the algorithm



Donut Model architecture, based on a Variational Auto-Encoder adapted for univariate time series anomaly detection (Xu et al. 2018)

Method:

- Simulate training orbits (background) and test orbits (bkg + GRB) with method in blue above
- Extract time series (KPIs) of statistical parameters from the on-board raw events characteristics (time, energy, position)
- Train Donut Models with training orbits KPIs
- Get individual anomaly scores from test orbits KPIs with trained DMs, combine them
- Compare global anomaly score with threshold

Results:

- Semi-supervised learning architecture \rightarrow versatility of the algorithm
- 10% improvement compared to on-board count trigger algorithm

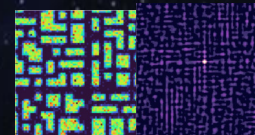
Perspectives:

- Hyperparameters tuning during flight
- Better KPIs (zone segmentation, ...)

INSTRUMENTAL APPLICATIONS

Validation support of on-board algorithms with simulations

Context: The SVOM/ECLAIRS instrument is in its last development phase: the Proto-Flight Model (PFM) is entirely built and will soon be delivered to the CNSA. The on-board computer (UGTS) and its GRB detection algorithm are particularly scrutinized, mainly its communication with the SVOM computer and the management of the events generated on the detection plane (DPIX).



PFM test: Am-241, projecting the mask pattern on the DPIX (left) Sky image reconstructed via deconvolution (right)

Instrumental Effects

Using output data and real configurations from PEQM/PFM tests.

ELSimulatorD

Simulate ECLAIRS FPGAs and communicate output frames to the UGTS.

Simulated Events

from end-to-end simulations of orbits, tests, ...

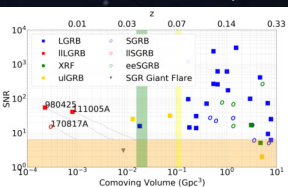
Validation Results:

- Dead Time
- Noisy pixel algorithm
- Detection plane efficiency
- UGTS algorithms

SCIENTIFIC APPLICATION

Detection of short high-energy transients in the local Universe with SVOM/ECLAIRS, Arcier et al. 2020, *Astroph. & Space Science*

Context: Starting from a carefully selected sample of high-energy transients from the local Universe ($z < 0.3$), we have simulated the detection performances of the ECLAIRS instrument and discussed the possible implications from a scientific perspective.



Expected on-axis SNR for the objects in our sample compared to their distance

Results:

35/41 high-energy transients detected & localized

Implications:

- Nature of Long GRBs without supernovae
- SGR Giant Flares in the Virgo cluster
- Multi-messenger astronomy LIGO/Virgo gravitational-waves interferometers
- Sub-luminous high-energy transients

BONUS: ASTROPHYSICS

Are BBH mergers and GRBs drawn from the same BH population? Arcier & Atteia 2021, *Astronomy & Astrophysics*, under review

Context: The birth of stellar black-holes (BHs) is correlated to long GRB detections. On the other hand, Binary BH (BBH) mergers are also observed thanks to the gravitational waves interferometers (reported in catalogs GWTC-1 and -2). Here we study in which extent the BH population traced by long GRBs is similar to the BBH population observed during mergers.

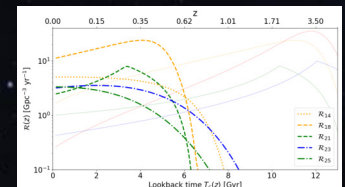
Method: N/N_{max} test

For the 47 BBH mergers in GWTC-1/2:

- Calculation of horizon redshift z_h
- Computation of N and N_{max}

Using obtained N/N_{max} distribution:

- KS-test of N/N_{max} vs $U(0,1)$
- Model accepted if p-value > 1%



Density rate of accepted GRB models

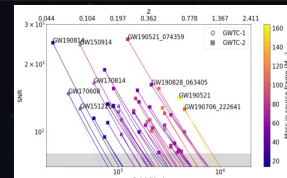


Illustration for BBH mergers of the SNR dependency on redshift for the z_h calculation

Results:

- Few long GRBs population models accepted
- Requiring a delay between the BH formation and the merger event > 6 Gyr
- Prediction of mergers death after $z = 1$
- OR only a sub-category of BBH mergers are associated with BHs created with long GRBs, i.e. isolated binaries systems.