SVOM : Catching high-energy transients on the fly!

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On behalf the SVOM collaboration
SVOM Consortium

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  - SECM Shanghai
  - NSSC Beijing
  - NAOC Beijing
  - IHEP Beijing
  - GuangXi University

- France (PI B. Cordier)
  - CNES Toulouse
  - APC Paris
  - CEA Saclay
  - CPPM Marseille
  - GEPI Meudon
  - IAP Paris
  - IJCLab Orsay
  - IRAP Toulouse
  - LAM Marseille
  - LUPM Montpellier
  - ObAS Strasbourg

- Mexico UNAM (Colibri)

- UK University of Leicester (MXT)

- Germany MPE Garching & IAAT Tübingen (MXT)
SVOM: Space-based multi-band astronomical
Variable Objects Monitor

Launch: 24/06/2024
Duration: 3+2 years

FRBs, FBOTs, TGFs, ...

SVOM white paper: arXiv:1610.06892
Gamma-Ray Bursts

- GRBs signal the violent formation of stellar-mass BHs and the launch of relativistic jets oriented more or less towards the Earth.
- HE prompt emission duration from a few ms to a few $10^2$ s
- Cosmological events – distance from 42 Mpc up to $z \sim 9.3$ (< 1 Gyr after Big-Bang)
- Extremely bright – Energetics $\sim 10^{46-55}$ erg (isotropy)

(credit: NASA) Veres+19, Nature
Kann+10
GRB/GW 170817 – Start of the multi-messenger era

- Coalescence of a binary NS followed \(\sim 2\) s later by a short off-axis GRB and a few hours later by the rise of a kilonova (r-process nucleosynthesis of heavy elements)

\[ \Rightarrow \text{Constraints on } H_0, \text{ the speed of gravity, NS EoS, structures of relativistic jets, ISM enrichment in heavy elements ...} \]
SVOM: Space-based multi-band astronomical Variable Objects Monitor

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Study of the local universe in synergy with GW / neutrino / EM facilities

- Demography of compact objects & tracing SF on cosmic times
- Studying accretion, relativistic jet physics
- Cosmological studies (e.g. re-ionization, formation of the first structures of the Universe, ...)
- Multi-messenger studies (e.g. speed of gravity, $H_0$ measurements)

Study of the early Universe ($z > 5$) and its contents

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SVOM: Space-based multi-band astronomical Variable Objects Monitor

Launch: 24/06/2024
Duration: 3+2 years

VT
“The Visible Telescope”
Narrow-field visible telescope
Ritchey Chretien \( \Phi=400\text{mm} \)
Localization accuracy < 1arcsec

ECLAIRs
“The trigger camera”
Wide-field X and Gamma rays telescope
Spectral range: 4 keV – 150 keV
Localization accuracy < 12arcmin

GRM
“The Gamma-Ray burst Monitor”
X-rays and Gamma-rays detectors
15 keV – 5 MeV
Localization accuracy < 5°

MXT
“The Micro-pore X-ray Telescope”
Narrow-field X-ray telescope
Spectral range: 0.2 keV – 10 keV
Localization accuracy < 1arcmin

GFT-1
“Ground-based Follow-up Telescope”
\( \Phi>1000\text{mm} \)

GWAC
“Ground Wide-Angle Cameras”
\( \Phi=180\text{mm} \)

GFT-2
“Ground-based Follow-up Telescope”
\( \Phi>1000\text{mm} \)

VHF Alert Network

Tracking antennas
Pointing Strategy

- Optimized for ground follow-up of detected transient events
  - Nearly anti-solar pointing (with Earth in instrument FOVs each orbit)
  - 65% duty cycle for ECLAIRs
  - 50% duty cycle for MXT & VT

- Avoidance of the Galactic plane + bright sources (e.g. Sco X-1)

- ECLAIRs annual exposure time
  - ~4000 ks on the Galactic poles
  - ~500 ks on the Galactic plane
ECLAIRS in a nutshell: 4–150 keV coded-mask camera

- Total FOV = 89 x 89 deg² (~2 sr)
- 80 x 80 Schottky-type CdTe detectors operated at –300 V & T = –20°C
- Geometrical area ~ 950 cm² – Total effective area ~360 cm² at peak – FWHM < 1.6 keV @ 60 keV
- On-board autonomous detection + on-board source catalogue & localisation (< 13’) – ~65 GRBs/yr
- Photon Counting Mode ⇒ All detected photons downloaded to the ground
ECLAIRs in a nutshell: 4–150 keV coded-mask camera

Shadowgram

Coded mask

Reconstructed sky image

source
GRM — Gamma-Ray Monitor

- Large FOV: The Gamma-ray Monitor
  - Onboard rate trigger ~ 90 GRBs/year

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IHEP

- 3 Gamma-Ray Detectors (GRDs)
- NaI(Tl) (16 cm Ø, 1.5 cm thick)
- Plastic scintillator (6 mm) to monitor particle flux and reject particle events
- FoV: 2.6 sr per GRD
- Energy range: 15 – 5000 keV
- Aeff = 190 cm² at peak
- Crude localization accuracy (5-10 deg² with 3 GRDs)
- Onboard rate trigger ~ 90 GRBs/year
  
  Will detect transients out of the ECLAIRs FOV
CNES, CEA, UL, MPE

- Micro-pores optics with square 40 μm pores ("Lobster Eye" optics, U.L.)
- pnCCD (MPE) based camera (CEA)
- FoV: 64x64 arcmin²
- Focal length: 1 m
- Energy range: 0.2 - 10 keV
- Aeff = 27 cm² @ 1 keV (central spot)
- Energy resolution: ~80 eV @ 1.5 keV
- Localization accuracy: <13 arcsec within 5 min from trigger

Innovative focusing « Lobster-Eye » X-ray optics
VT — THE VISIBLE TELESCOPE

XIOMP, NAOC

- Ritchey-Chretien telescope, 40 cm Ø, f=9
- FoV: 26x26 arcmin², covering ECLAIRs error box
- 2k * 2k CCD detector in 2 channels:
  - blue (400-650 nm)
  - red (650-1000 nm)
- Sensitivity: $M_V=22.5$ in 300 s
- Localization accuracy: <1 arcsec

Detection of the optical counterparts in two bands

Detection of ~ 80 % of ECLAIRs GRBs
SVOM from the ground

- Ground Follow-up Telescopes permit the fast identification and measure of early optical/NIR afterglows using the ECLAIRs positions, while the spacecraft is slewing to the source.
  - C-GFTs is located at Weihai observatory (Jilin province)
  - F-GFT will be located at San Pedro Martir (Mexico)

- Agreement to use the LCOGT network through NAOC guaranteed time (2000 h/yr)
- > 75% of ECLAIRs GRBs immediately visible by one of the ground telescopes
Response to a trigger

- Complete coverage of GRB emission over 7 decades in energy from trigger up to the late afterglow phase

<table>
<thead>
<tr>
<th></th>
<th>Swift</th>
<th>Fermi</th>
<th>SVOM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prompt</td>
<td>Poor</td>
<td>Excellent 8 kV -100 GeV</td>
<td>Very Good 4 keV - 5 MeV</td>
</tr>
<tr>
<td>Afterglow</td>
<td>Excellent</td>
<td>&gt; 100 MeV for LAT GRBs</td>
<td>Excellent</td>
</tr>
<tr>
<td>Redshift</td>
<td>~1/3</td>
<td>Low fraction</td>
<td>~2/3</td>
</tr>
</tbody>
</table>

> 90 % AG detection for MXT

> 80 % AG detection for VT
SVOM Reactions to MM event

- **Wide FOV HE instruments: ECLAIRs + GRM**
  - Slew if event is above ECLAIRs trigger threshold in less than 5 min
  - Sub-threshold events sent through VHF to SVOM ground segment
  - Otherwise, off-line detection on ground within ~6 – 12 h

- **Narrow FOV instruments: MXT + VT**
  - Require a decision to slew following the alert (ECLAIRs trigger or ToO)
  - Require a tilling strategy if error box > 1 deg²

- **Wide FOV ground-based instrument: GWAC**
  - Rapid automated response

- **Narrow FOV ground-based instruments: GFTs**
  - Rapid response (robotic telescopes)
  - Need an accurate localization

- **SVOM followed GW events from the O4 run (GWAC + C-GFT).**
SVOM Reactions to GRB/GW170817-like events

- If the GRB appeared in ECLAIRs/GRM FoV
  - ECLAIRs & GRM detection with high probability → slew request sent by ECLAIRs
  - MXT & VT follow-up observations → kilonova easily detectable by VT

- If not in ECLAIRs & GRM FoV
  - LV alerts received at the French science center
    → GWAC tilling of the GW error contour
    → GFT observations triggered, nearby galaxy targeting within the GW error contour
    → Upload ToO-MM to tile the GW error contour with MXT
Boosting transient search/follow-up

- **ECLAIRs offline trigger** designed to complement the onboard triggers with a more thorough search
  - Knowledge of the context (e.g. data before and after the detected transients)
  - More computing resources, less constraints on time and less conservative thresholds
  - Enable targeted searches on archival data from external facilities (VRO/LSST, GCN, LVK, IceCube, etc.)

- **ECLAIRs Quick Look Analysis** – Pipeline to detect serendipitous sources from each pass of data (several orbits) & to build science products enabling to track source long-term variability

- MXT pipeline will have similar features as the ECLAIRs QLA for detected serendipously sources from each pass of data.

- On-going internal discussion to see if on the long run possibility to build a live SVOM catalog

- Development of science modules for FINK (e.g. orphan GRB afterglows, kilonovae, TDE)

- Possibility to obtain SVOM prompt reaction to follow up one source in the ECLAIRs catalogue
SVOM Scientific Programs

- **Core Program (CP):** GRB science (25 % of time, highest priority)

- **General Program (GP)** – guest observing program: Observations will be awarded by a TAC (a SVOM member needs to co-sign the proposal)
  - 10 % of time on low Galactic latitude sources during the mission nominal phase
  - Up to 50 % during the mission extended phase

- **Targets of Opportunity (ToO) program:** Alerts sent from the ground to the satellite
  - Initially, 1 ToO per day focused on transient and MM follow-ups
  - Devoted time will increase during the mission extended phase

Urgent ToOs uploaded onboard in < 12 h
## SVOM Data Policy

### Core Program (GRB)

- **Real-time VHF scientific products** (under the supervision of the Burst Advocates) will be public as soon as they are available => similar to Swift or Fermi-GBM.

- All the **scientific products are public six months** after the data production.

### General Program (GP)

- **Semester Call for proposal** (in association with a SVOM Co-I), it can include ToO.

- All the SVOM data will be distributed to the Responsible Co-I.

- **One year of proprietary period** before all the scientific products become public.

### ToO Program (still under discussion)

- **ToOs triggered by the SVOM CO-Is** => we will make **publicly available as soon as possible** any scientific product that is relevant to perform follow-up observations. The number of products to be publicly released will be addressed case by case.

- **ToOs triggered by non SVOM CO-Is** => **all the scientific products will be public** as soon as they are available.

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- Raw data and data reduction pipelines not released outside the collaboration

- **Possibility for external people to contribute to science WGs**

  Affiliated members if agree to provide any useful pieces of information (data, models) in a regular basis

- **Proprietary time on request to the SVOM PIs**
Take away

- All instruments integrated on the satellites
- Satellite TVAC and environmental tests performed with success!
- **The Flight Acceptance Review in January 2024 gave the go for the launch at the end of June 2024.**
- Preparing the commissioning phase actively and finishing developments of the ground segment

- SVOM will be a powerful HE transient machine working in synergy with MM facilities!
- SVOM will be also an observatory open to the community (through Guest Observer and ToO programs).
- If you are interested in using SVOM data for your research or to contribute to the SVOM science activities, please get in touch with us.
BACK-UP SLIDES
Synergy with HE & VHE instruments

Grb 190114c (110-180 s)
Adapted from Acciari+19 (Nature)
ECLAIRs in a nutshell *(Godet+14, Godet+22)*

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
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<tbody>
<tr>
<td>Energy range</td>
<td>4 – 150 keV</td>
</tr>
<tr>
<td>Detecting area</td>
<td>~950 cm²</td>
</tr>
<tr>
<td>Detectors</td>
<td>6400 CdTe detectors</td>
</tr>
<tr>
<td>Total effective area in 10-70 keV</td>
<td>≥340 cm²</td>
</tr>
<tr>
<td>Photopake effective area @ 6 keV</td>
<td>≥200 cm²</td>
</tr>
<tr>
<td>Field of view</td>
<td>2.05 sr total</td>
</tr>
<tr>
<td>Sensitivity to 1 second long GRB</td>
<td>2.5 × 10⁻⁸ erg cm⁻² s⁻¹ in [5–50] keV</td>
</tr>
<tr>
<td>Source Localization Error</td>
<td>11.5 arcmin for sees with SNR=8</td>
</tr>
<tr>
<td>Energy resolution at 60 keV</td>
<td>&lt; 1.6 keV</td>
</tr>
<tr>
<td>Time resolution – dead time</td>
<td>20 ns, &lt;5% for 5 × 10⁴ c/s</td>
</tr>
<tr>
<td>Data acquisition mode</td>
<td>Photon mode</td>
</tr>
<tr>
<td>Data rate</td>
<td>≤18 Gb/day</td>
</tr>
</tbody>
</table>

- **4 keV energy threshold** to increase sensitivity to XRFs & high-z GRBs

- **3 MLI covers** to make sure the camera cavity to prevent optical loading

- **Photon counting mode**
  - All photons transmitted to the ground
  - Readout electronics able to discard particles showers, fluorescence and Compton events as multiple events

- **Automatic software to disable noisy pixels**

- **On-board autonomous detection** [count-rate + image triggers] & localisation
  - Time scales from 10 ms to 20 min
  - 4 energy bands, 9 detector zones
  - Rate ~ 65 GRBs /year

- **Detection plane** segmented in 8 sectors with an independent electronics each

- **Shield made of Pt (0.8 mm) / Cu (0.1 mm)**
  - Opacity > 80 % below 150 keV
  - Use for in-flight monitoring of energy scale

- **Opacity > 80 % below 150 keV**

- **Use for in-flight monitoring of energy scale**
GRB Outputs

- ECLAIRs sensitive to all classes of GRBs
- Rate ~ 65 GRBs/yr including a few GRBs with $z > 5$
- GRM FOV wider than ECLAIRs one
- Rate ~ 90 GRBs/yr – poorer localization (5-10 deg with 3 GRD)
- ECLAIRs sensitivity to short GRBs can be improved when combined with GRM.