ECLAIRs: THE GRB DETECTOR AND IMAGER FOR THE SVOM MISSION

J.-L. ATTEIA (IRAP, TOULOUSE)
ON BEHALF ON THE SVOM/ECLAIRs COLLABORATION
THE SVOM CONSORTIUM

- China (PI J. Wei)
  - SECM Shanghai
  - Beijing Normal University
  - Central China University Wuhan
  - Guangxi University Nanning
  - IHEP Beijing
  - KIAA Peking University
  - Nanjing University
  - NAOC Beijing
  - National Astronomical Observatories
  - Purple Mountain Observatory Nanjing
  - Shanghai Astronomical Observatory
  - Tsinghua University Beijing

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

- Mexico
  - UNAM Mexico

- UK
  - University of Leicester

- Germany
  - MPE Garching
  - IAAT Tübingen

Taking into account the feedback from Neil Gehrels Swift obs. & Fermi for space observations
TAROT for ground observations

KW25 - St Petersburg - Sep. 2019
ECLAIRs (CNES, IRAP, CEA, APC)
- 40% open fraction
- Detection area: 1000 cm²
- 6400 CdTe pixels (4x4x1 mm³)
- FoV: 2 sr (zero sensitivity)
- Energy range: 4 - 150 keV
- Localization accuracy <12 arcmin for 90% of sources at detection limit
- Onboard trigger and localization: ~65 GRBs/year

Well adapted for the detection of long GRBs with low E_{PEAK}

GRM Gamma-Ray Monitor (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
- A_{eff} = 190 cm² at peak
- Rough localization accuracy
- Expected rate: ~90 GRBs / year

Will provide E_{PEAK} measurements for most ECLAIRs GRBs
Will detect GRBs and transients out of the ECLAIRs FOV (with poor localization)
SVOM OVERVIEW

SPACE INSTRUMENTS with NARROW FIELD OF VIEW

MXT Micro-channel X-ray Telescope (CNES, CEA, UL, MPE)
- Micro-pores optics (Photonis) with square 40 µm pores in a “Lobster Eye” conf. (UL design)
- 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 for 50% of GRBs (statistical error)

Implements innovative focusing X-ray optics based on « Lobster-Eye » design
Will be able to promptly observe the X-ray afterglow

VT Visible Telescope (XIOMP, NAOC)
- Ritchey-Chretien telescope, 40 cm Ø, f=9
- FoV: 26x26 arcmin², covering ECLAIRs error box in most cases
- 2 channels: blue (400-650 nm) and red (650-1000 nm), with 2k * 2k CCD detector each
- Sensitivity M_V=23 in 300 s
- Will detect ~80% of ECLAIRs GRBs
- Localization accuracy <1 arcsec

Able to detect high-redshift GRBs up to z~6.5 (sensitivity cutoff around 950 nm)
Can quickly provide redshift indicators due to the presence of two channels

KW25 – St Petersburg – Sep. 2019
**GROUND BASED INSTRUMENTS**

- **Ground-based Wide Angle Camera (GWAC)**
  - **In China**: 40 cameras of 180 mm diameter at Ali Obs.
    - total FOV \(\sim 6000 \text{ deg}^2\); limiting magnitude 16 (V, 10s)
  - **In Chile**: 50 cameras of 250 mm diameter at CTIO
    - total FOV \(\sim 5000 \text{ deg}^2\); limiting magnitude 17 (V, 10s)
  - Operational since 2017, currently participating to O3.

- **Chinese Ground Follow-up Telescope (C-GFT)**
  - **Robotic 1.2m telescope**, Weihai Observatory
    - FoV = 21x21 arcmin\(^2\), 400-950 nm

- **French Ground Follow-up Telescope (F-GFT)**
  - **Robotic 1.3m telescope**, San Pedro Mártir (Mexico)
    - FoV = 26x26 arcmin\(^2\)
    - Multi-band photometry (400-1780 nm, 3 simultaneous channels)

- **Contribution to the LCOGT network (12x1m+2x2m tel.)**
  - >75% of ECLAIRs-detected GRBs will be immediately visible by one ground telescope (GFT or LCOGT)
ORBIT AND POINTING STRATEGY

Optimizing the ground follow-up of GRB candidates in order to increase the success of ground-based redshift measurements.

Waiting for GRB detection...

Avoidance of the galactic plane (most of the time) and intense sources such as Sco X-1

ECLAIRs exposure map (65 GRBs/year, 1 ToO per day)
- 4 Ms in the direction of the galactic poles
- 500 ks on the galactic plane

65% of duty cycle for ECLAIRs about 50% for MXT and VT
Alerts are transmitted to a network of >40 VHF receivers on Earth.

Goal: 65% of the alerts received within 30 s at the French Science Center.

ECLAIRs + post-slew X-ray and Visible information is also sent through the VHF link.
ECLAIRs INSTRUMENT

- ECLAIRs is a coded mask hard X-ray imager made of 4 sub-systems:
  - The detection unit DPIX (IRAP)
  - The mask (APC)
  - The structure & shield (CNES)
  - The on-board calculator UGTS (CEA)
## ECLAIReS general description

### EXPECTED PERFORMANCE

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy range</td>
<td>4 – 150 keV</td>
</tr>
<tr>
<td>Detecting area</td>
<td>≈1000 cm²</td>
</tr>
<tr>
<td>Detectors</td>
<td>6400 CdTe detectors (mounted as 200 modules)</td>
</tr>
<tr>
<td>Effective area in 10–70 keV</td>
<td>≥340 cm²</td>
</tr>
<tr>
<td>Effective area @ 6 keV</td>
<td>≥200 cm²</td>
</tr>
<tr>
<td>Field of view</td>
<td>2.06 sr total</td>
</tr>
<tr>
<td>Sensitivity to 1 sec long GRB</td>
<td>2.5 $10^{-8}$ erg cm$^{-2}$ s$^{-1}$ in [5–50] keV</td>
</tr>
<tr>
<td>Intrinsic Source Localization Error</td>
<td>11.5 arcminutes for sources with SNR=8</td>
</tr>
<tr>
<td>Energy resolution at 60 keV</td>
<td>&lt; 1.6 keV</td>
</tr>
<tr>
<td>Time resolution</td>
<td>10 microsecond</td>
</tr>
<tr>
<td>Dead time</td>
<td>&lt;5% for $10^5$ cts/s</td>
</tr>
<tr>
<td>Data rate</td>
<td>≤18 Gb/day</td>
</tr>
</tbody>
</table>
ECLAIRs ROLE

- Being the wide-field imager and trigger of SVOM, ECLAIRs fulfills various tasks:
  
  - **Monitoring the hard X-ray sky**: ECLAIRs records the time, position, and energy of all detected photons -- you can make your own trigger on the ground.

  - **On-board trigger and imaging**: ECLAIRs detects, localizes and characterizes HE transients. It generates alerts and slew requests:
    - 2 types of trigger: **count trigger** (10 ms - 20 s) & **image trigger** (20 s - 20 min)
    - Count triggers must be validated with an image showing a significant excess
    - Triggers are vetted against a list of known transient sources
ECLAIRs OPERATIONS AND IN-FLIGHT CALIBRATION

- ECLAIRs is always working, except inside the SAA

- When it is in operation, ECLAIRs...
  - Records the properties of all detected photons: time, position, energy, multiplicity
  - Look for count and image triggers
  - Manages its internal status

- In-flight calibration relies on internally produced fluorescence lines of Cu (8 keV) and Ta/Pb (≈70 keV) produced in the graded shield and in the mask.

Mate et al. 2019
ECLAIRs general description

**INSTRUMENTAL CHALLENGES**

- **The low energy threshold** poses several challenges to the instrument:
  - Mask structure (next slide)
  - Opacity to visible light
  - Leakage current of the detectors and ASIC readout noise →
  - Management of transient hard X-ray sources by the on-board computer

- **Mass/volume allocation** is very limited: ECLAIRs is 2.5 times lighter than Swift/BAT

- Get reliable GRB triggers with highly variable background: Earth transits, SAA, noisy pixels…

Lacombe et al. 2018

KW25 - St Petersburg - Sep. 2019
SOME PICTURES

Column 1:
On-board computer

Column 2 (top to bottom):
Detection plane (partly filled) and detection module (inset)
Detection plane electronics

Column 3 (top to bottom):
Mask
Structure & shield
Structure with the mask
INSTRUMENT CHARACTERIZATION

- Detection plane:
  - Response of individual pixels: effective area $A(E, \theta)$, energy threshold, resolution, linearity,
  - Response of the entire plane: uniformity, cross-talk, dead time, temporal stability.

→ Measured with radioactive sources (next slide)

- On-board computer:
  - Estimation of the sensitivity to various GRBs and transients
  - Injection of realistic simulated data, including background, GRBs & SAA

- Instrument:
  - Light opacity
  - RX transparency (down to low energies)
  - DPIX $\leftrightarrow$ UGTS communication
  - Imaging and source reconstruction
The prototype detection plane involves \( \approx 1000 \) detectors (32 modules of 32 detectors).

Its characterization involves many complex measurements, and detailed simulations.

Performance is measured with radioactive sources in a large vacuum chamber.
FEW EXAMPLES

‣ The left plot shows a map of the counts recorded by 725 detectors (2 modules and 11 detectors are switched off)

‣ The right plot shows a typical spectrum

‣ The prototype shows excellent performance!
ECLAIRs delivered to China by the end of 2020
SVOM to be launched at the end of 2021

SVOM white paper: http://arXiv:1610.06892
First Tests of the VHF Ground Station Prototype: Excellent Results!

The first 10 Ground Stations to be deployed in 2019
### Core Program: a complete GRB sample

<table>
<thead>
<tr>
<th></th>
<th>Swift</th>
<th>Fermi</th>
<th>SVOM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prompt</td>
<td>Limited</td>
<td>Excellent 8 keV -100 GeV</td>
<td>Very Good 4 keV - 5 MeV</td>
</tr>
<tr>
<td>Afterglow</td>
<td>Excellent</td>
<td>/</td>
<td>Excellent</td>
</tr>
<tr>
<td>Redshift</td>
<td>~1/3</td>
<td>/</td>
<td>~2/3</td>
</tr>
</tbody>
</table>

### Physical mechanisms at work in GRBs
- nature of GRB progenitors and central engines
- acceleration & composition of the relativistic ejecta

### Diversity of GRBs: event continuum following the collapse of a massive star
- X-ray rich GRBs/X-ray Flashes and their afterglow
- GRB/SN connection

### Short GRBs and the merger model
- GW emission from the final stages of orbital decay and merger
SVOM OVERVIEW

besides GRBs ...svom as an open observatory

The general program (GP)

- Observation proposals being awarded by a TAC (a SVOM co-I needs to be part of your proposal) for astrophysical targets of interest mostly compliant with the satellite attitude law
- Only 10% of the time can be spent on low Galactic latitude sources during the nominal mission, up to 50% during the extended mission

Target of Opportunity (ToO) programs

- **ToO-NOM** is the nominal ToO which covers the basic needs for efficient transient follow-up alerts sent from the ground to the satellite (GRB revisit, known source flaring, new transient)
- **ToO-EX** is the exceptional ToO which covers the needs for a fast ToO-NOM in case of an exceptional astrophysical event we want to observe rapidly.
- **ToO-MM** is the ToO-EX dedicated to EM counterpart search in response to a multi-messenger alert. What differs from the ToO-NOM and ToO-EX is the unknown position of the source within a large error box...

- Initially 1 ToO/day focussed on time domain astrophysics including multi-messengers, will increase during the extended mission