The SVOM/ECLAIRs offline trigger pipeline for the detection of X-ray transients

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SVOM

Satellite launched on June 22, 2024!

Space-based multi-band astronomical Variable Objects Monitor (see talk on Wed, March 26 by B. Cordier)

Credit: SVOM collaboration

<u>Primary goal</u>: Monitor the sky & search for high-energy transients, focusing on Gamma-Ray Bursts (GRBs). Strong follow-up network. [1]
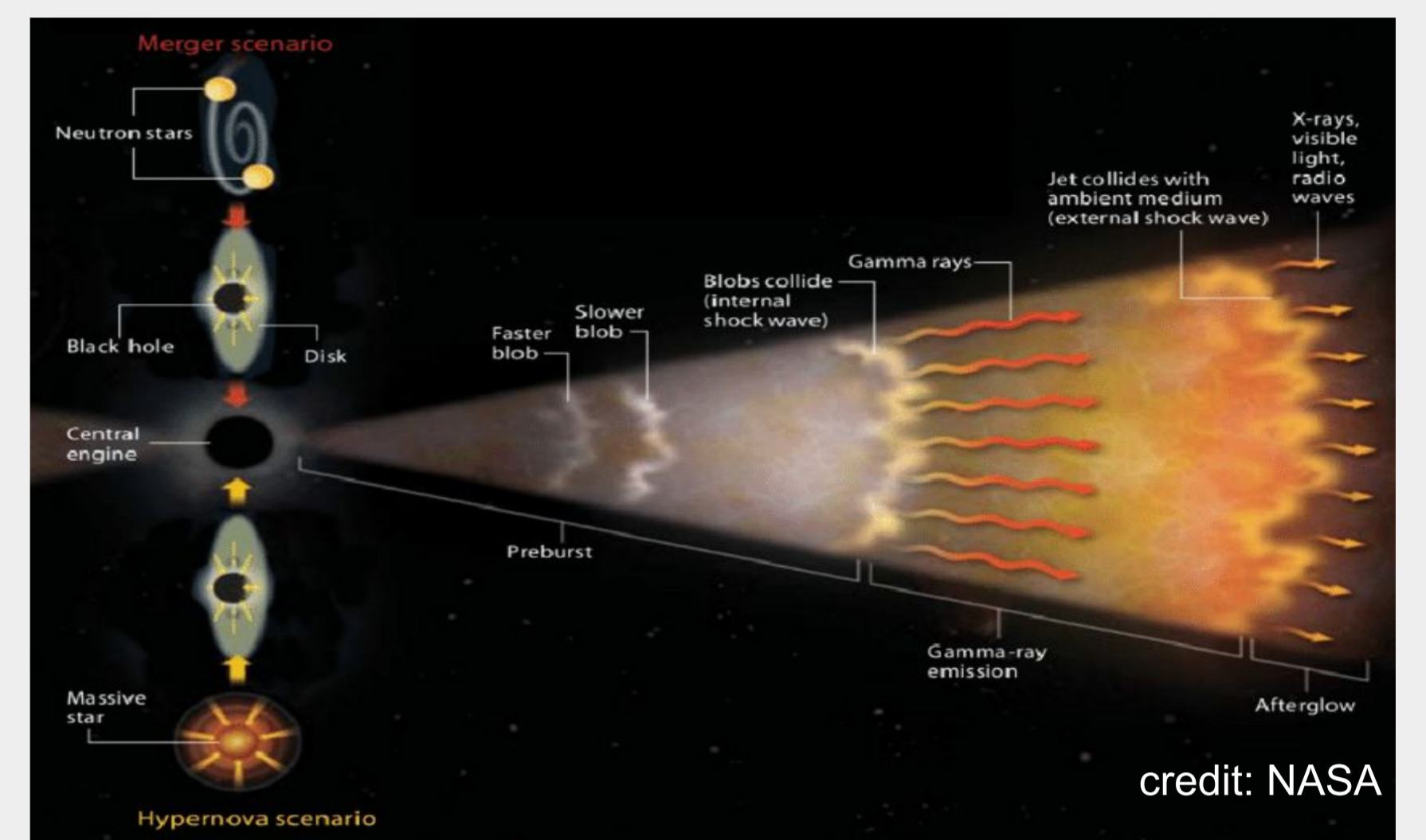
ECLAIRs [2]

photons

Credits: CNES/IRAP

Shield — Coded Mask — Front-end Electronics — Detection Plane — Data processing unit

Detector image with GRB 241018A

Characteristics:
- FOV=89 x 89 deg² (~2 sr)
- 4 – 150 keV / Photon counting
- Localization (90% c.l) ≤13'

Gamma-Ray Bursts (GRBs) [3]

- **Prompt emission:** X-ray emission of duration ~ $10^{-3} - 10^2$ s → Detected by **ECLAIRs**
- **Afterglow:** Multiwavelength emission lasting from a few hours to a few days, in some cases up to a few years (radio)
- Produced within **relativistic jets** coming from :
  - core-collapse of massive stars ("long GRBs"),
  - merger of binary NS/NS-BH ("short GRBs") ⇒ strong GW emitters ⇒ multi-messenger astro.

credit: NASA

ECLAIRs Triggers

<u>On-board</u> Real-time Triggers:
- Image trigger: Search for new sources by building images over different timescales and energy bands
- Count-rate trigger: Search for excesses in the count-rate, then localized through imaging process

<u>On-ground</u> (offline trigger):
- **All data** is sent to the ground for **resource-intensive** analysis which is not possible on-board
- Better knowledge of the **context**
- More relaxing constraints on thresholds → useful for fine-tuning of the onboard trigger
- Enables further synergy with other multi-messenger instruments → targeted searches

Complicated context

- Dynamic/complex background (SAA passages, Earth occultation, satellite slews, variable X-ray sources, particles, etc.)
- Solar flares due to high Solar activity at the moment

Soft X-ray transient first detected by EP — Noisy pixels — Gap of data due to the SAA crossing

ECLAIRs count-rate, around 4pm the 8th december 2024, with an X-ray transient (EP241208A)

Offline Trigger Pipeline (OFTG) [4]

Blind Search

Inputs
- ECLAIRs Events
- SVOM Attitude and Orbital data
- Stability (GTI)[I]

Pre-processing
- Data selection
- +
- Modelling of background & X-ray sources contributions

Detection Algorithms

Count Rate based algorithms[a] :
- ➔ Polynomial background estimation based method
- ➔ Wavelet based method [4]
- ➔ Fourier sum based method [4]

Image based algorithms[a]

Machine learning based algorithms[b] (eg : anomaly detection)

Post-processing
- Merge detections
- Compute detections characteristics
- Search for counterparts

Human Check

Notify the World 🌍

[I] GTI = Good time Interval : indicate the slot of time for good quality data, the stability of the satellite attitude, the satellite passage through the South Atlantic Anomaly (SAA), the data acquisition interruption, the presence of the Earth in the field of view

[a] Methods implemented in the pipeline
[b] Methods in development

Targeted Search

Inputs : External alerts
- GCN notices & circulars
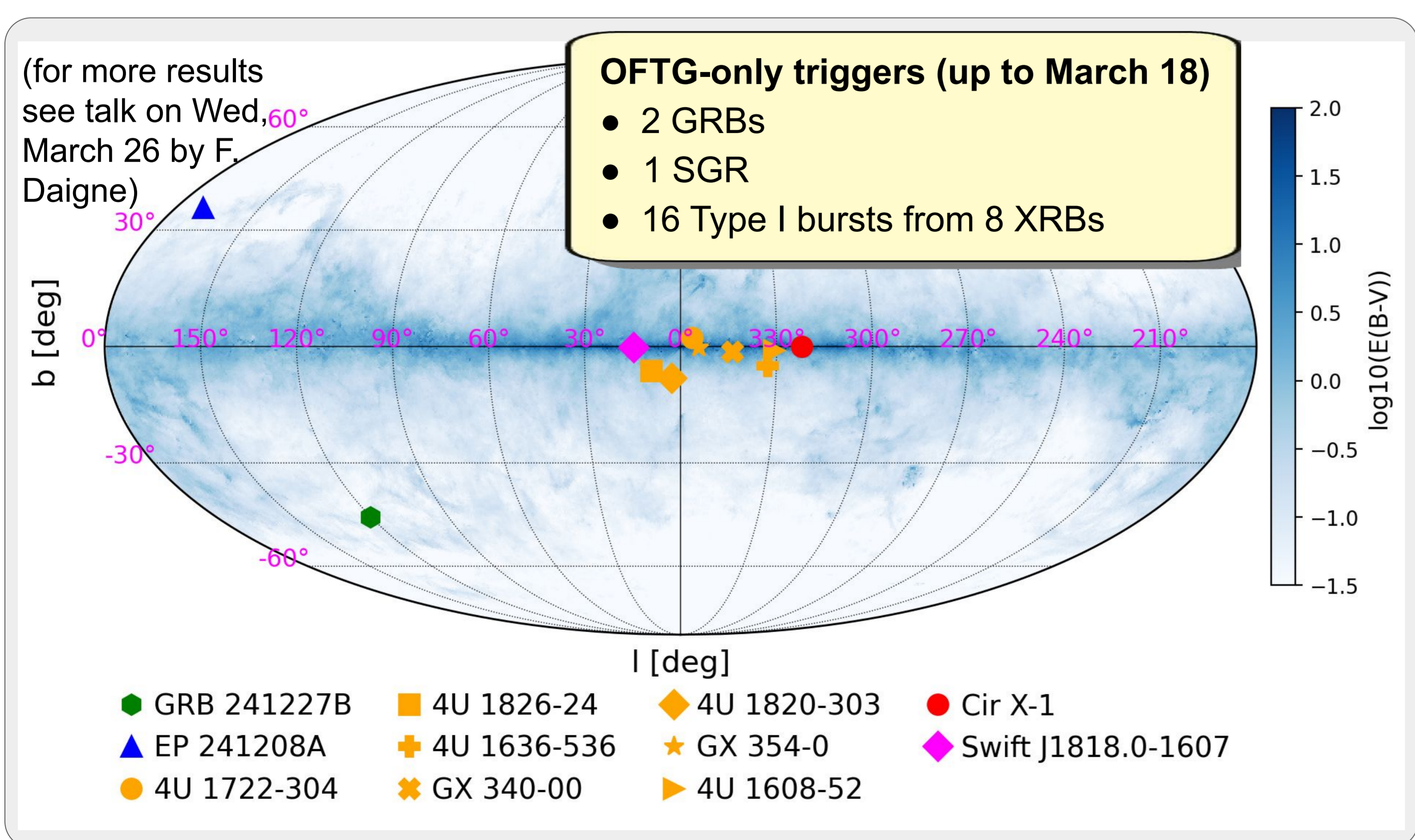- Astro-COLIBRI
- VRO/LSST FINK Broker
- FRB CHIME
- etc.

Types of events
- GRBs
- GW events
- Super-/kilo-novae
- FRBs
- TDEs, etc.

Search for counterparts in ECLAIRs data based on position and/or time

Searching space (area vs. time) for different types of sources

full sky — 1 week

GW position X, time ✓
GRBs position ✓ time ✓
SNe, KNe position ✓, time X

(for more results see talk on Wed, March 26 by F. Daigne)

OFTG-only triggers (up to March 18)
- 2 GRBs
- 1 SGR
- 16 Type I bursts from 8 XRBs

b [deg] — l [deg] — log10(E(B-V))

- ● GRB 241227B
- ▲ EP 241208A
- ● 4U 1722-304
- ■ 4U 1826-24
- ✚ 4U 1636-536
- ✖ GX 340-00
- ◆ 4U 1820-303
- ★ GX 354-0
- ▶ 4U 1608-52
- ● Cir X-1
- ◆ Swift J1818.0-1607

Summary

- We have developed an offline trigger pipeline (OFTG) to complement the on-board triggers and to enhance the detection capabilities of SVOM.
- OFTG includes both blind and targeted searches with several detection (incl. machine learning-based) algorithms.
- The pipeline retrieves all the on-board triggers.
- The pipeline has been running continuously on flight data for 3 months and has discovered new X-ray transients un-detected on-board.

References: [1] SVOM white paper, J-Y Wei et al. 2016, [2] O. Godet et al. 2014, SPIE, [3] T. Piran, 2014, RMP, [4] M. LLAMAS LANZA, 2014, PhD thesis