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MULTI-MESSENGER ASTRONOMY WITH SVOM

J.-L. Atteia[1] and the SVOM collaboration.

Abstract. The Sino-French space mission *SVOM* (Space-based multi-band astronomical Variable Objects Monitor) is mainly designed to detect, localize and follow-up Gamma-Ray Bursts. The satellite, to be launched late 2021, embarks two wide-field gamma-ray instruments and two narrow-field telescopes for X-ray and optical imaging. It is complemented by a dedicated ground segment encompassing a set of wide-field optical cameras and two 1-meter class follow-up telescopes.

With the advent of multi-messenger astronomy, which detects and exploits the information transported by gravitational waves and particles in addition to photons, there is a renewed interest for cosmic explosions and compact objects, which are the main targets of *SVOM*. We describe here the main characteristics of the mission and its expected contribution to multi-messenger astronomy.

Keywords: gamma-ray bursts, gravitational waves, space instrumentation.

1 The SVOM mission

The *SVOM* mission* is the result of a bilateral collaboration between France (CNES) and China (CAS, CNSA), involving many research institutes from these two countries and contributions from the University of Leicester, the Max Planck Institut für Extraterrestische Physik and the Universidad Nacional Autónoma de México. *SVOM* is lead by J.Y. Wei in China and B. Cordier in France. The mission encompasses a space segment, with four instruments embarked on-board a low earth orbit satellite, and a ground segment with two sets of wide-field optical cameras, two 1-meter class ground follow-up telescopes, and a network of $\sim$ 45 VHF receiving stations distributed along the footprint of the orbit (Fig. 1). The launch of *SVOM* is scheduled late 2021 with three years of nominal operations and a possible extension of two years.

The main science driver of *SVOM* is gamma-ray burst (GRB) physics. This is the core program, which includes the GRB-Supernova connection, the nature of the central engine, the identification of the progenitors of short GRBs and the physics of GRB jets. Between GRBs, *SVOM* will carry out other programs driven by the narrow-field instruments: a general program and a target of opportunity program mostly focused on non-GRB science. A detailed description of *SVOM* science objectives can be found in Wei et al. (2016).

2 SVOM instrumentation and system

SVOM is designed as a multi-wavelength observatory. The satellite embarks four instruments whose main characteristics are presented in Fig. 4. They work in synergy: while the two narrow-field telescopes, the Micropore X-ray Telescope (MXT – Götz et al. (2014); Mercier et al. (2018)) and the Visible Telescope (VT – Wu et al. (2012)) observe pre-planned sources, ECLAIRs† (Godet et al. 2014; Schanne et al. 2014) and the Gamma-Ray Monitor (GRM – Dong et al. (2010)) monitor the hard X-ray sky to detect and characterize high-energy transients over a broad energy range (4 keV – 5 MeV). When a transient is detected, its position is immediately sent to the ground and to the satellite, which may repoint its narrow field telescopes in minutes. The soft response of the ECLAIRs wide-field camera and a fast link to ground-based infrared telescopes should facilitate the identification of high redshift events.

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* http://www.svom.fr/
† ECLAIRs means "lightning flash" in French

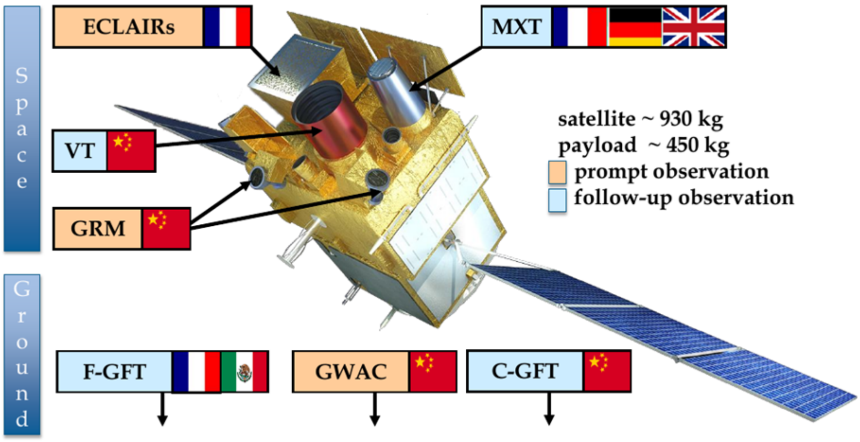

Fig. 1. Schematic view of the "*SVOM* system", including the satellite and its four instruments (GRM, ECLAIRs, MXT and VT), and the ground segment with two sets of wide-field optical cameras and two robotic follow-up telescopes.

In addition to the space instruments, *SVOM* encompasses a ground segment with two sets of Ground Wide Angle Cameras, located in China and Chile, which observe several thousands square degrees down to $M_V = 16 - 17$ (GWACs – Fu et al. (2017)), and two 1-meter class Ground Follow-up Telescopes located in China and Mexico (with a NIR imaging camera for the second one) (GFTs – see e.g. Floriot et al. 2018; Corre et al. 2018). Fig. 3 shows a set of GWACs at the Xinglong Observatory (China) and the Colibrí telescope under construction. Several GWACs are already operational and used to follow-up GW alerts from LIGO and Virgo (Turpin et al. 2019). Overall, *SVOM* is similar to the very successful Neil Gehrels Swift Observatory with some important differences: a smaller satellite with smaller instruments (at the notable exception of VT), the addition of gamma-ray spectrometers comparable to the NaI modules of *Fermi*/GBM, and a set of unique ground-based instruments dedicated to the photometric follow-up of HE transients detected by the satellite.

In order to promote the follow-up and spectroscopy of *SVOM* GRBs with large facilities on Earth, the space borne instruments are pointed close to the anti-solar direction ("à la HETE"). One consequence of this choice is that the instruments will see the Earth crossing their field of view every orbit. In normal operations, the narrow-field instruments look at pre-planned targets (this is the General Program, GP) and wide-field instruments stare the sky for high-energy transient sources (this is the Core Program, CP). When a new transient source is detected, its position is sent to the ground and a pointing request is sent to the satellite, which will execute it, depending on its feasibility. *SVOM* can also perform target of opportunity (ToO) observations within minutes of request with one GFT and within hours of request with MXT and VT. The time sharing between the three observing programs CP, GP, ToO is shown in (Fig. 2).

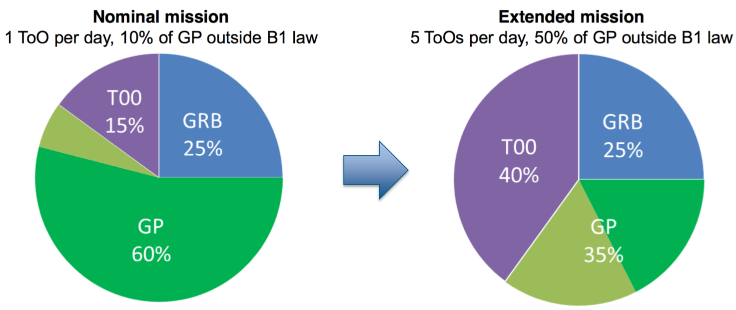

Fig. 2. Time sharing between the three observing programs of SVOM. The light green zone shows the GP time spent outside the nominal pointing law, called the "B1 law" (a nearly anti-solar pointing law, which avoids the galactic plane). The GRB time is an estimate based on a predicted trigger rate of ~ 65 GRB/yr.

3 SVOM in the multi-messenger era

The recent discovery of multi-wavelength electromagnetic radiation (GRB + afterglow + kilonova) associated with the merger of two neutron stars that produced a burst of gravitational waves (Abbott et al. 2017a,b, and ref. therein) opened the window of multi-messenger astronomy, which is the joint observation of photonic and non-photonic signals from astronomical sources.

Considering the science goals of the *SVOM* mission, the great diversity of its instruments, and the possibility to organize multi-wavelength observing campaigns quickly, we expect a strong involvement in multi-messenger astronomy. First, it will be possible to search for non-photonic signals (neutrino or GW) coincident in space and time with *SVOM* HE transients. *SVOM* presents two interesting features for this task: the low energy threshold of ECLAIRs, which permits the detection of faint and soft X-Ray Flashes (XRFs) and the wide-field of view of GRM with a good sensitivity to short GRBs (sGRBs). Since XRFs and sGRBs are fainter and more numerous than classical GRBs, they can be detected at smaller distances. The increased sensitivity of GW interferometers and neutrino detectors at the beginning of the next decade will offer a unique opportunity to find the non-photonic counterparts of nearby XRFs or sGRBs detected by *SVOM*, if they exist. Second, *SVOM* will participate to the searches for multi-wavelength afterglows of GW or neutrinos events: the wide field of view of the MXT and the possibility to schedule tiled observations with MXT, VT and the GFTs, will allow to quickly explore regions of several square degrees in X-rays, visible and NIR with a good sensitivity, in order to detect and characterize the photonic counterparts of GW or neutrino bursts. We are working hard to ensure that *SVOM* will fully contribute to the development of multi-messenger astronomy in the next decade.

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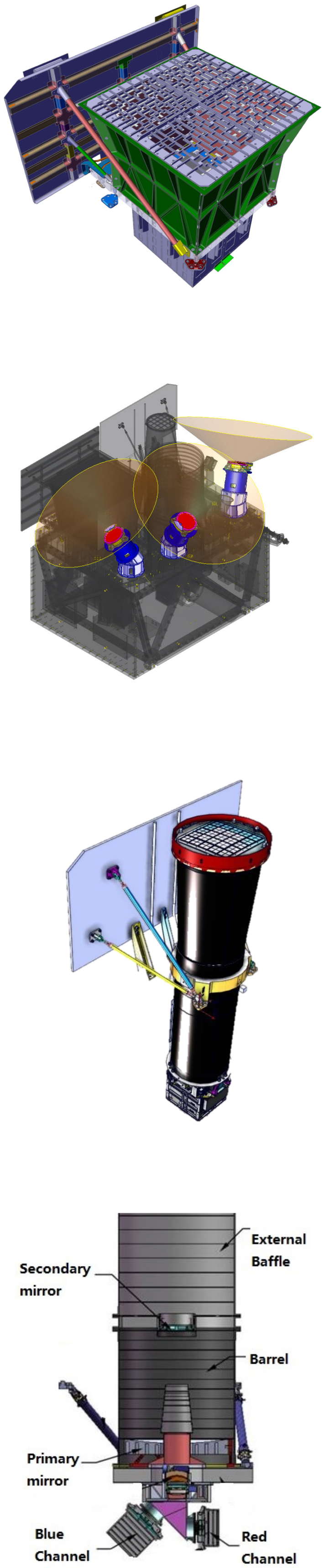
Fig. 3. Left: A set of GWAC, at the Xinglong Observatory in China. **Right:** The Colibrí GFT at the 'Observatoire de Haute-Provence' (France) before its installation at the 'Observatorio Astrónomico Nacional' (Baja California, México).



ECLAIRs (CNES, IRAP, CEA, APC)

- 40% open fraction
- Detection area: **1000 cm²**
- **6400 CdTe pixels** (4x4x1 mm^3)
- **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 EPEAK

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**
- Aeff = 190 cm² at peak
- Rough localization accuracy
- Expected rate: **~90 GRBs / year**

Will provide EPEAK measurements for most ECLAIRs GRBs
Will detect GRBs and transients out of the ECLAIRs FOV (with poor localization)

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)

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
Can provide redshift indicators due to the presence of two channels

Fig. 4. The four space borne instruments of SVOM. **Left:** schematic drawings. **Right:** main characteristics.