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SVOM: a new mission for Gamma-Ray Bursts studies

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Abstract. The French Space Agency (CNES) in collaboration with the Chinese National Space Administration (CNSA) and the Chinese Academy of Sciences (CAS) are developing a new mission aiming at studying Gamma-Ray Bursts (GRBs) called SVOM (Space-based multi-band astronomical Variable Objects Monitor).

The mission will consist of a set of space borne instruments and a set of ground based ones. The space borne instruments include two wide field of view gamma-ray instruments, and two narrow field ones operating in the X-ray and visible domains. The two gamma-ray instruments are a coded mask soft-gamma ray imager (4–250 keV), ECLAIRs, with a 2 sr field of view, which detects and localizes in real time GRB candidates, and a gamma-ray spectrometer (50 keV–5 MeV), GRM, with the same field of view as ECLAIRs, but without imaging capabilities. The narrow field instruments, used after an autonomous satellite slew for fine localization and afterglow studies, are MXT (0.2–10 keV) and VT (400–950 nm).

The space borne instruments are complemented on ground by two dedicated robotic telescopes (GFTs), designed for position refinement and early afterglow studies, and a set of ground wide angle cameras (GWACs) that aim at monitoring the field of view of ECLAIRs with the goal of detecting the prompt optical emission of GRBs.

Key words. Gamma-rays: bursts – Galaxy: abundances – Cosmology: observations – Instrumentation: detectors – Instrumentation: miscellaneous

1. Introduction

Gamma-Ray Bursts (GRBs) have been one of the most fascinating mysteries in modern astrophysics (see Gehrels et al. 2009, for a recent review). These elusive flashes of gamma-ray radiation, discovered in 1969, lasting from a fraction of to hundreds of seconds have turned out to be followed with longer lasting emission (hours to months) at X-ray, optical, and radio wavelengths, and are thought to be generated either by the coalescence of two compact object (for the short ones, lasting less then 2 s), or by the final stages of a very massive star (for those lasting longer). The efficient quest for GRB counterparts, which started with the Beppo*SAX* mission and is continuing today thanks to the *Swift* satellite has proved that GRBs are cosmological objects – in the sense that their progenitors are located at an average redshift of $\sim$2.5 and are even hosted

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in the most distant galaxies known today (e.g. GRB 090423 at z=8.3, Tanvir et al. 2009 and GRB 090429B at z=9.4, Cucchiara et al. 2011) – making them potential tracers of the star formation history of the Universe, it's chemical enrichment, and it's re-ionisation history. Besides the cosmological aspects of GRBs, of course, the study of the phenomenon itself is of great importance for the investigation of the acceleration and radiative processes in relativistic flows, for the nature of the GRB progenitors and their association to Supernovae of type Ib/c, as well as for fundamental physics problems like the origin of cosmic rays, the emission of gravitational waves, and Lorentz Invariance tests (e.g. Laurent et al. 2011).

In order to contribute to study in more detail all the aspects mentioned above, the French Space Agency (CNES), the Chinese National Space Administration (CNSA) and the Chinese Academy of Sciences (CAS) are developing a new mission aiming at studying GRBs called *SVOM* (Space-based multi-band astronomical Variable Objects Monitor). The *SVOM* mission will consist of a set of co-aligned space borne instruments (two wide field gamma-ray instruments and two narrow field telescopes working in the X-ray and in the visible domain) and a ground segment including two dedicated robotic telescopes and a set of wide angle cameras. *SVOM* will be launched in a low Earth orbit (~600 km) with an inclination of 30°. The *SVOM* pointing strategy derives from a combination of two main constraints: the avoidance of bright X-ray galactic sources and an anti-solar pointing, to have the GRBs always detected on the night side of the Earth. Even if the latter choice induces some dead time at mission level, due to the Earth passages occulting ECLAIRs field of view once per orbit, it will enhance the possibility of successful follow-up with large ground based facilities, with a goal of 75% of *SVOM* GRBs easily observable during their early afterglow phase.

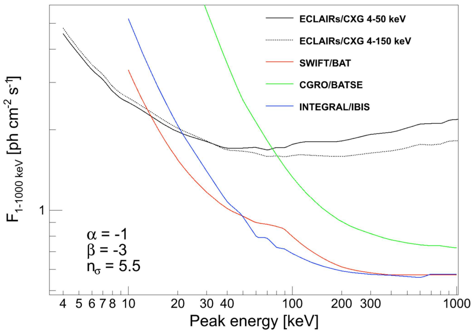
In this paper I will focus on the design and the expected scientific performances of the SVOM instruments.

2. ECLAIRs

ECLAIRs will be provided by a consortium of French laboratories (CEA, IRAP, APC, IAP), and it is a coded mask telescope, based on the heritage of the IBIS/ISGRI camera on board the ESA *INTEGRAL* satellite (Lebrun et al. 2003). The ECLAIRs detector (CXG) is composed of 80×80 CdTe crystals (0.4×0.4×0.1 cm) coupled to a low-noise electronic read-out systems (IDeF-X), which allows the CXG to measure the energy deposited by photons down to 4 keV. This low energy threshold detector, coupled to a random coded mask with an open fraction of 40%, will be particularly suited to detect GRBs with low peak energies (see Fig. 1), and hence potentially the most distant ones, but also X-ray Flashes (XRFs), and the very low redshift GRBs. Current simulations indicate that the fraction of GRBs detected by ECLAIRs above redshift 6 are expected to be of the order of 10–20%.

The data generated by the CXG will be analysed in real time by the ECLAIRs on-board electronics system (UTS), which will accomplish the task to look for new sources and to localize them. This will be done mainly through two search algorithms, one based on the monitoring of the count rates of the camera, which uses the imaging as a confirmation of the detected excess and for localization purposes, and a second one, which cyclically analyses the images accumulated on a time scale of 20 s and longer, in order to detect and localize new sources that could have been missed by the former algorithm.

Once a GRB is detected by the UTS, it issues an alert which is immediately transmitted to the ground through a VHF emitter to a network of dedicated VHF receivers, covering the *SVOM* orbit on ground, that sends the information to the French Science Centre (FSC, see § 6), which in turn dispatches it to the ground based observatories for follow-up observations. At the same time a slew request is issued to the platform, which autonomously re-points the narrow field instruments towards the ECLAIRs error region for afterglow studies and fine localisation.



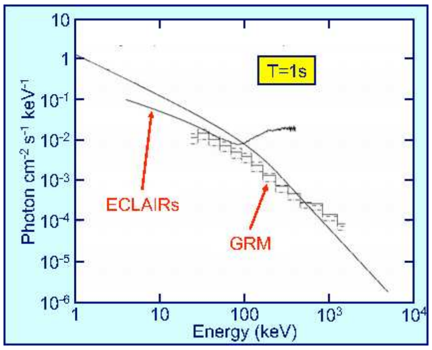


Fig. 1. Left: Expected ECLAIRs 5.5 σ sensitivity as a function of the peak energy of the GRB (the α and β parameters of the Band function (Band et al. 1993) are also given), compared to currently flying and past experiments. Right: Combined ECLAIRs-GRM 1 s sensitivity curves compared to an average BATSE GRB spectrum with a 50–300 keV flux of 1 photon cm^{-2} s^{-1}.

3. GRM

The Gamma-Ray Burst Monitor (GRM) will be provided by the IHEP-Beijing, and its aim is to extend the spectral coverage of the GRBs detected by ECLAIRs to the MeV domain (see Fig. 1), by observing simultaneously the same portion of the sky. This will allow the *SVOM* GRBs to be studied in more detail with respect to previous experiments, since they will have at the same time good spectral coverage over a wide energy range (4 keV to 5 MeV), and a good localization, two properties that are not available at once with the current instrumentation, unless a same GRB is observed by two different satellites at the same time (e.g. *Swift* and *Fermi*/GBM, which is a quite rare event).

The GRM is composed by two identical units, each of which consists of a phoswich scintillator detector, made of 15 mm of NaI in front of 35 mm of CsI, enveloped by a 6 mm plastic scintillator used for reducing the particle induced background. Each module has an on-axis effective area of 280 cm^2, and a nominal energy range of 50 keV–5 MeV. A particle monitor unit (PM) completes the GRM.

4. MXT

The Micro-channel X-ray Telescope (MXT, 0.2–10 keV) will be provided by a France-led European consortium (CNES, CEA, IRAP, and LAM in France, University of Leicester in the UK, and IAAT and MPE in Germany). It is a focussing X-ray telescope with a field of view of about 1 degree diameter, based on a copy of the optic of the MIXS-T telescope that is being built for the future ESA mission to Mercury *BepiColombo* (Fraser et al. 2009). The MIXS-T optic is based on the approximation of a Wolter-I classical X-ray mirror through the use of glass square pore micro-channel plates. The micro-channels are 20 μm wide, with a pitch of 26 μm, and can be coated with Ir or Pt in order to enhance the reflectivity and the high-energy response. The micro-channel plates (MCPs) are assembled in couples (front and rear) in a way to have one reflection in each plate and finally to focus the X-ray 1 m below the optic, see Fig. 2. The MCPs are assembled in sextants and finally arranged into a circular optic of 21 cm of diameter enabling to image a X-ray source at infinity to a PSF width currently measured with pre-production MCPs to 3.7 arc min FWHM. The goal is to reach a 2 arc min PSF, and the achievement of this goal depends critically on the ability of correctly align the MCPs with respect to each other.

The detector plane of MXT will be based on a pn CCD developed for the DUO mission (Meidinger et al. 2006), and is a smaller version of the CCD currently used for the eROSITA telescope to be launched on the german-russian *Spectrum-Röntgen-gamma* mission. It is a frame transfer back-illuminated

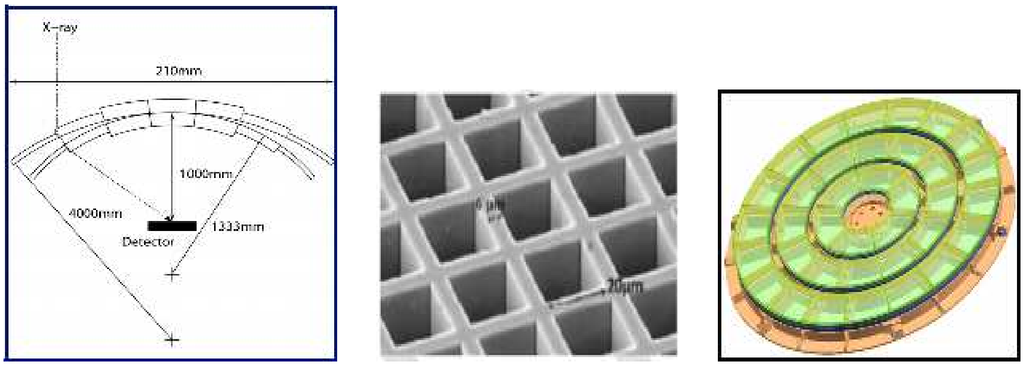


Fig. 2. Left: Optical scheme of the MIXS-T/MXT optic. Centre: A close view of the micro-channel plates. Right: assembled MCPs into a complete optic (from Fraser et al. 2009).

CCD with an image area of 256×256 pixels of 75 μm side. The frame-store area has reduced height pixels of 50 μm, and it is read out parallely by two CAMEX chips. This radiation hard CCD has an excellent low-energy energy resolution (50 eV at 277 eV), and its 450 μm thickness of depleted Si implies an enhanced sensitivity at the high end of the energy range.

Simulations show that despite the smaller effective area provided by the MCPs with respect to XRT mirrors on board *Swift* (~50 cm^2 vs ~150 cm^2), most of the GRB afterglows detected by the MXT will be studied in pretty the same detail as it is done now by XRT, at least for the first day after the GRB, see Fig. 3.

The same simulations also show that the majority of the afterglows detected by MXT will be localized to a precision better than 1 arc min. In particular for half of them an error box smaller than 30 arc sec will be available already 10 minutes after the start of the observation.

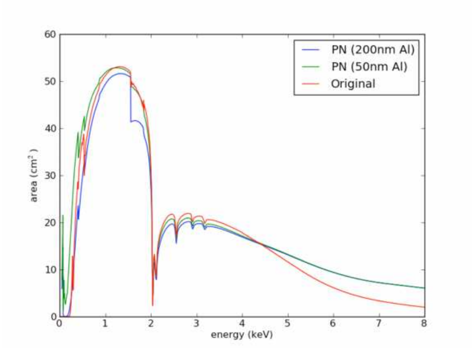
5. VT

The space-borne Visible Telescope (provided by NAOC and XIOPM) will be able to improve the GRB localizations obtained by ECLAIRs and MXT to sub-arc second precision through the observation of the optical afterglow. In addition it will provide a deep and uniform light-curve sample of the detected optical afterglows, and allow to do an early selection of optically dark GRBs and high-redshift GRB candidates (z>4). The field of view of the telescope will be 21×21 arc min, sufficient to cover the error box of the CXG. The detecting area of the CCD has 2048 × 2048 pixels to ensure the sub-arc second localization of detected sources. It has a modified Ritchey-Chrétien optical design with a primary mirror diameter of 45 cm. The aperture of the telescope will guarantee a limiting magnitude of $M_V = 23$ (5σ) for a 300 s exposure time. Such a sensitivity is a significant improvement over the UVOT on board the *Swift* satellite and over existing ground-based robotic GRB follow-up telescopes. The VT is expected to detect nearly 80% of SVOM GRBs for which a slew is performed, see Fig.4. The telescope will have at least two bands in order to select high-redshift GRB candidates. They are separated at 650 nm, which corresponds to a redshift of z~4-4.5 using Lyα absorption as the redshift indicator.

6. Ground segment

The performances of the *SVOM* space borne instruments are summarized in Table 1 in terms of localization capabilities, multi-wavelength coverage, and GRB rate per year. But in order to fully exploit this information and to better investigate the *SVOM* GRBs, the contribution of the ground based instrument is very important.

The link between the space and the ground is done by the *SVOM* ground segment, composed by S- and X-band receivers for telemetry



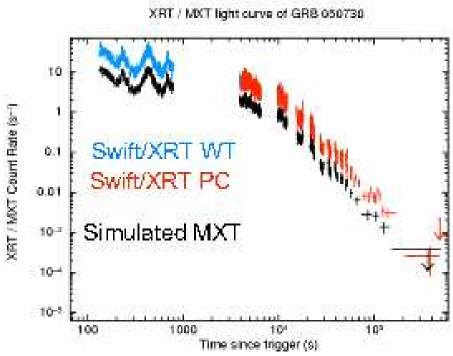
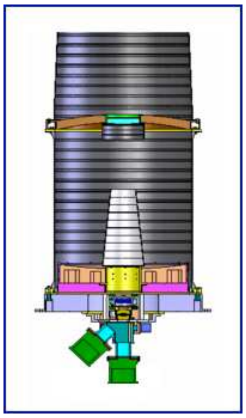


Fig. 3. Left: Expected MXT effective area using the pn CCD with different optical filters (blue and green) and using a thinner CCD (red) Right: Simulated MXT light curve of GRB 050730 compared to the XRT data.



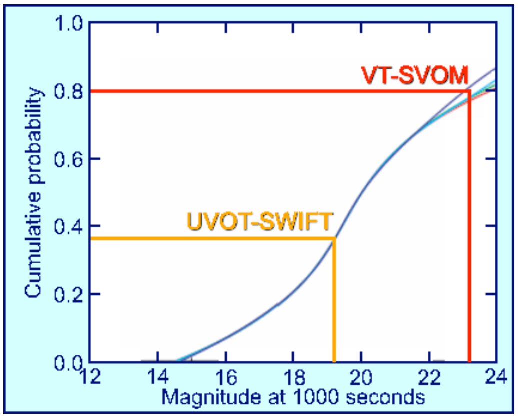


Fig. 4. Left: Current VT design. Right: Intrinsic cumulative optical afterglow distribution following Akerlof & Swan (2007) compared to the UVOT and VT sensitivities.

downlink and tele-commands uplink, the VHF network for the reception of the alerts, the mission control centre, based in China, and the French and the Chinese Science Centres (CSC and FSC). The science centres are responsible for the scientific and technological survey of the respective instruments, and for elaborating and distributing the alerts of *SVOM* to the scientific community. In particular the FSC is responsible of receiving, filtering and dispatching the alerts coming from the VHF network.

Part of the *SVOM* ground segment are also the two dedicated Ground Follow-up Telescopes (GFTs) and the Ground Wide Angle Cameras (GWACs) described below.

6.1. GFTs

Two *SVOM* robotic telescopes will automatically position their 20-30 arc min field of view to the position of GRB alerts and, in case of a detection, they will determine the position of the source with 0.5 arc sec accuracy. Both telescopes will be provided with multi-band optical cameras and the French GFT will also have a near infra-red CCD. Since one telescope can only observe those candidates occurring above the horizon and during night at the telescope site, these sites will be located in tropical zones and at longitudes separated by 120° at least, in order to fulfil the requirement of a 40% efficiency. These telescopes could also be used

Table 1. Summary of the performances of the space borne SVOM instruments

	Spectral domain	Field of view	Localization accuracy	Number of GRBsyear
ECLAIRs	4–250 keV	2 sr	< 10 arc min	~ 80
GRM	50 keV–5 MeV	2 sr	N.A.	~ 80
MXT	0.2–10 keV	64×64 arc min	< 1 arc min	~ 60
VT	400–950 nm	21×21 arc min	<1 arc sec	~ 50

to follow the so-called *sub-threshold alerts*, namely alerts which are not considered to be reliable enough to be distributed to the whole community. This procedure allows increasing the chance of detecting low S/N events, while not wasting the observing time of instruments which are outside the *SVOM* collaboration.

The scientific objectives of the GFTs include the quick identification and characterization of interesting GRBs (e.g. highly red-shifted GRBs, whose visible emission is absorbed by the Lyman alpha cut-off and the Lyman alpha forest, dark bursts, nearby GRBs), and multi-wavelength follow-up of 40% of *SVOM* GRBs (at optical and X-ray wavelengths) from 30 to 10^4 seconds after the trigger. This will be done with the GFT and the VT at optical wavelengths and CXG and the MXT at X-ray wavelengths, allowing scientists to measure the spectral energy distribution of the burst during the critical transition between the GRB and the afterglow.

6.2. GWACs

The Ground-based Wide-Angle Camera array is designed to observe the visible emission of more than 20% of *SVOM* GRBs from 5 minutes before to 15 minutes after the GRB onset. The array is expected to have an assembled field of view of about 8000 deg^2 and a 5σ limiting magnitude $M_V = 15$ for a 15 s exposure time for full moon nights. To comply with both the science requirements and technical feasibility, each camera unit will have an aperture size of 15 cm, a 2048 x 2048 CCD and a field of view of 60 deg^2. In total about 128 camera units are required to cover the 8000 deg^2.

7. Concluding Remarks

Even if the future sino-french mission *SVOM* mission will be mainly dedicated to GRB studies, it will provide a great opporunity, thanks to its multi wavelength capabilities, to study other astrophysical objects in detail. In particular the combined use of the narrow-field instruments with a balanced sensitivity in the X-ray and optical domains will permit for the first time long un-interrupted observations without the necessity of complicated coordination between the space and ground observatories.

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