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OBSERVATION OF EARLY PHOTONS FROM GAMMA-RAY BURSTS WITH THE *LOMONOSOV* / UFFO-PATHFINDER

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RESUMEN

UFFO-pathfinder es la misión pionera para observar la evolución temprana de los Estallidos de Rayos Gamma usando su estrategia de apuntado rápido. Está equipado con el Slewing Mirror Telescope para apuntado rápido en las longitudes de onda Ópticas y Ultravioleta, al mismo tiempo que tiene el telescopio de Estallidos y Alerta UFFO. Tiene un total de $\sim$ 20 kg de peso y será lanzado a bordo de un satélite ruso al final del 2014. Los detalles del instrumento y su desempeño son discutidos brevemente acá.

ABSTRACT

UFFO-pathfinder is a pioneering space mission to observe the early evolution of Gamma-ray Bursts using a fast slewing strategy. It consists of the Slewing Mirror Telescope, for rapid pointing at UV/optical wavelengths and the UFFO Burst Alert and Trigger Telescope. It has a total weight of $\sim$ 20 kg and will be launched on-board the Russian *Lomonosov* satellite at the end of 2015. The instrumental details of UFFO-pathfinder and its performance are discussed briefly here.

Key Words: gamma rays: general — space: instruments — telescopes — ultraviolet: general — X-rays: bursts

1. INTRODUCTION

Gamma-ray bursts (GRBs), first observed accidentally in 1967 by the U.S. Vela satellites (Klebesadel et al. 1973), are the most powerful explosions in the universe. They emit all types of electromagnetic radiation and happen on the cosmic distance scale. Noticeable progress has been made since the 1960s thanks to various detections from space missions such as CGRO (Gehrels et al. 1993), HETE-2 (Ricker et al. 2002), *Beppo*SAX (Boella et al. 1997), *Swift* (Gehrels et al. 2005), and also rapid follow-up by ground-based robotic telescopes like the BOOTES network (Castro-Tirado et al. 1999). However many enigmas still remained, especially the origin of GRBs. The GRB to afterglow transition is the least studied due to the lack of early observation in various wavelengths (Nakar & Piran 2004). With the purpose of this, the Ultra-Fast Flash Observatory (UFFO) was proposed in 2009 (Park et al. 2009, 2013). As the first step for the realisation and proof of the UFFO concept, i.e. fast slewing to GRB, fast localisation of GRB, and utilising small satellite, the payload of UFFO-pathfinder (see Table 1) has been built and is waiting for launch aboard the Russian *Lomonosov* satellite in 2015.

There are two instruments installed in UFFO-pathfinder. One is the Slewing Mirror Telescope (SMT) (Jeong et al. 2013; Kim et al. 2013), a key telescope of UFFO-pathfinder for UV/optical observations. The other is the UFFO Burst Alert and Trigger Telescope (UBAT) for GRB triggering and localisation in the energy range 5-100 keV. Once a GRB is triggered by the UBAT, the SMT is designed to point at the GRB less than 1 sec over its entire field of view, allowing nearly simultaneous observation in the X-ray and UV/optical regimes. The flight model of UFFO-pathfinder is shown in Fig. 2.

In this paper, we briefly review the design, construction and performance of UFFO-pathfinder. In the following section, sub-instrument details are pre-

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sented shortly in the following order: Slewing Mirror Telescope, UFFO Burst Alert and Trigger Telescope and UFFO-pathfinder Data Acquisition. The conclusion of this paper is discussed in Section 3. More details on the UFFO project, including UFFO-pathfinder, can be found in Park et al. (2013).

2. UFFO-PATHFINDER

2.1. *Slewing Mirror Telescope*

As the main system of UFFO-pathfinder, the SMT was developed for simultaneous GRB detection with the X-ray trigger telescope utilising a gimbal mirror system in front of the focusing telescope. It provides a 1 sec response time over the UBAT half-coded FOV, 70 × 70 arcdeg^2. The SMT optics use a Ritchey-Chrétien design with a 100 mm effective aperture. Its instantaneous FOV is 17 × 17 arcmin^2 to cover UBAT localisation and f-number is 11.4. The primary and secondary mirrors were fabricated with a precision of RMS ∼ 0.02 waves in wave front error (WFE) and 84.7 % in average reflectivity over the wavelength range 200-650 nm. The entire SMT optics were aligned to an accuracy of RMS ∼ 0.05 waves in WFE at 632.8 nm, having almost diffraction limited performance (Jeong et al. 2013). An Intensified Charge-Coupled Device (ICCD) is used as a detector having a pixel size of 4 × 4 arcsec^2. The ICCD can operate the gain of 10^3 to 10^6 el/el, depending on GRB flux and observes faint objects down to ∼ 19 magnitude (8 σ) in white light per 100 seconds (Kim et al. 2013). It has a total mass of 11.5 kg, dimensions of 650 (l) × 320 (w) × 200 (h) and average power consumption of 10W. The instrumental specification are summarised in Table 1. The full field of 256 × 256 is readout in 20 msec and changeable exposure time depending on the session. The SMT includes the main UFFO-pathfinder Data Acquisition (UDAQ) and UFFO Bus Interface (UBI) inside of its enclosure.

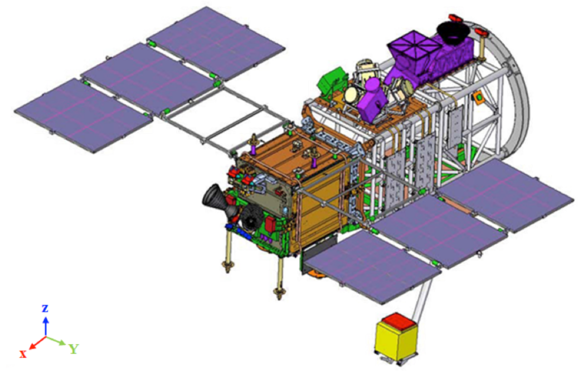

Fig. 1. *Lomonosov* satellite deployed view in space. UFFO-pathfinder is in purple colour.

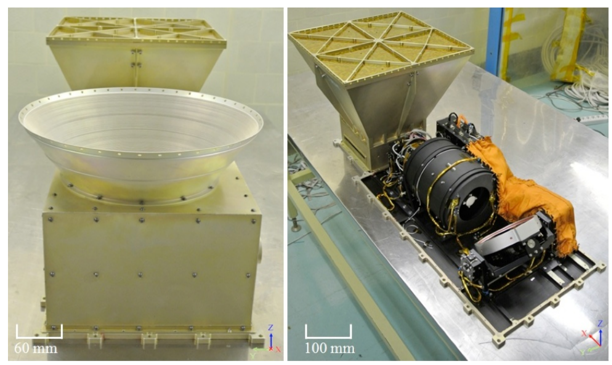

Fig. 2. Flight model of UFFO-pathfinder.

2.2. *UFFO Burst Alert and Trigger Telescope*

The UFFO Burst Alert and Trigger Telescope (UBAT) is for GRBs triggering and localisation. The UBAT is a coded-mask aperture X-ray camera with a wide FOV of 1.8 sr. The detector module consists of the YSO (Yttrium Oxyorthosilicate) scintillator crystal array, a grid of 36 multi-anode photomultipliers (MAPMTs), the detector area is 191 cm^2. Analog to digital readout electronics are included. When the gamma/X-ray photons hit the YSO scintillator crystal array, it produces UV photons by scintillation in proportion to the energy of the incident gamma/X-ray photons. The UBAT detects X-ray source of GRBs in the 5-100 keV energy range, localises the GRB within 10 arcmin (7 σ) accuracy. The entire trigger calculations with the data from UBAT, including rate trigger and imaging trigger, are also performed in a way of pipelining in another FPGA, which reduces the latency significantly. It sends this position to the SMT as well as drift correction in real time. All process is controlled by a field programmable gates arrays (FPGA) to reduce the processing time.

2.3. *The UFFO-pathfinder Data Acquisition*

The UFFO-pathfinder Data Acquisition (UDAQ) controls the two telescopes and communicates with the spacecraft. The UDAQ stores the UBAT and SMT data in several flash memories and transfers the data to the BI via UBI. It is also responsible for monitoring of all housekeeping, calculation of the orbit, recognition of day and night with its photo-sensors, calculation priority of triggers from UBAT and BDRG (another gamma-ray detector on *Lomonosov* satellite) and power management. All of these functions are implemented in a FPGA for the low power consumption and real-time processing.

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TABLE 1

SPECIFICATION OF UFFO-PATHFINDER

Mass (kg)	21.5	
Power (W_{avg})	25	
Volume (mm^3)	958.5(l) × 400(w) × 382.5 (h)	
Data size (mb / day)	300	
Volume (mm_3)	622(l) × 374(w) × 200 (h)	409(l) × 409(w) × 372 (h)
Mass (kg)	11.5	10
Power (W_{avg})	12	13
Slewing coverage	70 × 70 arcdeg^2	...
FOV	17 × 17 arcmin^2	90.2 × 90.2 arcdeg^2
Pixel FOV	4 arcsec	10 arcmin
Energy range	0.2 - 0.65 μm	5 - 100 keV
Data size (MB / day)	200	100

[a]The original of this table comes from (Park et al. 2013)

UDAQ operates the system automatically as following the pre-defined scheduler consists of so called, "states and transitions".

3. PERFORMANCE

Fig. 3 shows the X-ray imaging by UBAT. The detector response begins at 5 keV and it gives a trigger with 7 σ accuracy after 5 sec. it is confirmed in laboratory tests using different kinds of radioactive source and an X-ray source tube. Depending on the source flux and energy, a triggering is possible on the timescales of 1-8 sec. With an improvement of the trigger algorithm before launch, the trigger latency will be reduced further.

4. SUMMARY

We expect that ~ 20-30 GRBs / year will be measured by UFFO-pathfinder. Even if it is a rather small number of events, each event will be unique to understand for GRB mechanism using rapid optical response of SMT within 1 sec. And thanks to low energy response of UBAT, the number of events will be increased for soft X-ray repeater and high redshift GRBs. For the realisation of the UFFO concept, i.e. rapid response SMT, compact payload, affordable small satellite and fast calculation of GRB position using FPGAs, UFFO-pathfinder has been built successfully during the last 4 years. The flight model of UFFO-pathfinder has now entered the final stage of full integration to the *Lomonosov* satellite. The launch is foreseen at the end of 2015.

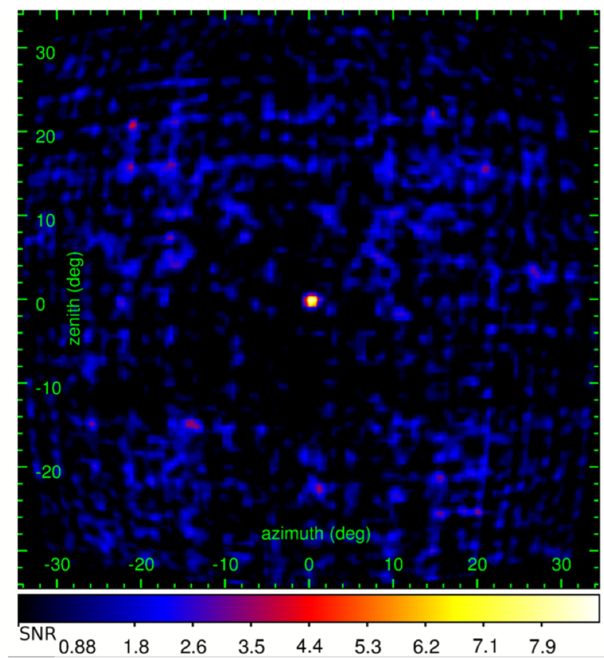

Fig. 3. Imaging capability of UBAT.

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