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# The Status of the Ultra Fast Flash Observatory - Pathfinder

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**Abstract**

The Ultra Fast Flash Observatory (UFFO) is a project to study early optical emissions from Gamma Ray Bursts (GRBs). The primary scientific goal of UFFO is to see if GRBs can be calibrated with their rising times, so that they could be used as new standard candles. In order to minimize delay in optical follow-up measurements, which is now about 100 sec after trigger from the *Swift* experiment, we rotate a mirror to redirect light path so that optical measurement can be performed within a second after the trigger. We have developed a pathfinder mission, UFFO-pathfinder to launch on board the *Lomonosov* satellite in 2012. In this talk, I will present scientific motivations and descriptions of the design and development of UFFO-pathfinder.

*Keywords:* Gamma Ray Bursts, Early Light Emissions, Ultra Fast Flash Observatory

## 1. Introduction

Now we are savoring the renaissance of the GRB science by virtue of wonderful data obtained by various experiments such as *Swift* [1] and *Fermi* [2]. However, a regime of early time in UV-optical wavelengths still remains an unexplored region in parameter space. Although a great improvement of early photon measurement from GRB was carried out by *Swift* using the fast in-site follow-up capability, only a handful of optical light curves have been observed in sub-minute domain due to an intrinsic limitation on its response time. *Swift* first determines a GRB position using the Burst Alert Telescope (BAT) which has a large field of view. After that, the space craft slews to point its UV-Optical Telescope (UVOT) to the position of the GRB. The minimum response time of *Swift* is about 60 seconds arising from computational latency in determination of the location, and slewing method of rotating the entire space

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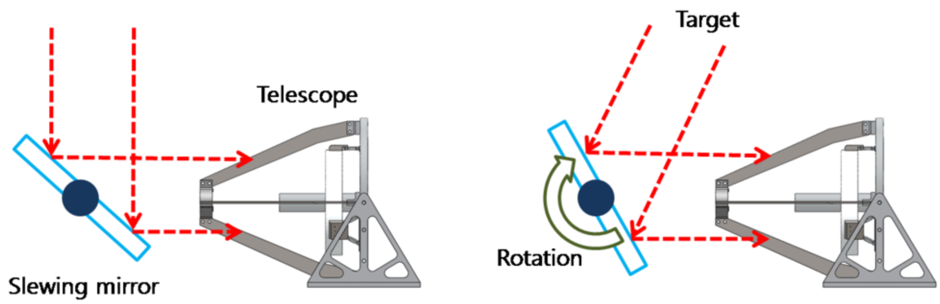


Figure 1: Fast Slewing Concept of UFFO

craft.

UFFO approach is to reduce the response time by 1) employing a fast localization and 2) a new slewing method which rotates only a small mirror to redirect the optical path of the incoming GRB beam instead of the entire spacecraft (see Figure 1) [3]. We have successfully developed a rapid response space observatory with a fast localization capability based on the Field-Programmable Gate Array (FPGA) technology which can calculate localization within 1 sec after the trigger, and a gimbal mirror system moving a target in our entire field of view to the focal point within 1 sec. An advanced slewing mirror system has been proposed to achieve sub-millisecond slewing time using Electro Mechanical System (MEMS) Micro Mirror Array [4]. But the implementation of a large area mirror array and a precise angle control to obtain uniform distribution of micro mirror surfaces are still technically challenging.

As the first step, we have developed a pathfinder mission, to be named the UFFO-pathfinder [5], with a mass of 20 kg and launched in 2013. Even though it has a limited size, UFFO-pathfinder will demonstrate its concept and may bring great scientific results from successful detection of early optical emissions from GRBs. In parallel with the pathfinder mission, we plan a bigger scale mission with 100 kg mass (UFFO-100) [3] and 600 kg mass (UFFO-600) to obtain competitive sensitivity and statistics with *Swift* for future observations.

There are many scientific topics with great interests in the sub-minute regime where we could find great hints to understand intrinsic properties of GRBs. For instance, examinations of prompt optical emission from short-hard GRBs and dark bursts are unique scientific subjects of UFFO project. Measurements of peak emission times in early light curves can lead to determine the bulk Lorentz factor [6]. Furthermore, rising times of light curves are possibly correlated with optical luminosity so that it could be calibrated [7]. Once the intrinsic properties of GRBs are fully understood, GRBs would serve as a reliable cosmological standard candle which extends the Hubble diagram up to much larger redshift than SN-Ia supernovae [8]. Fast transient emissions such as primordial black holes [9] are also exciting topics for UFFO with the fast response [3].

## 2. The UFFO-Pathfinder Instrument

The payload of the UFFO-pathfinder consists of two telescopes; one is the UFFO Burst Alert Telescope (UBAT) [10] for event trigger and its localization in a wide Field of View (FOV) of $90 \times 90$ arcdeg$^2$, and the other is the Slewing Mirror Telescope (SMT) [11, 12] for UV-optical follow-up measurement in a narrow FOV of $17 \times 17$ armin$^2$. Figure 2 shows schematic views as well as the manufactured flight model of the UFFO-pathfinder.

UBAT is a coded mask aperture camera which is conceptually similar to the *Swift* BAT system. By analyzing the shadow image of the coded mask on the imagine sensor, directions of the x-ray source can be determined. The UBAT system consists of three major components: a coded mask, detectors and electronics. The coded mask made of Tungsten Alloy has randomized rectangular hole patterns with 50% open fraction. The detector is formed by $48 \times 48$ pixels YSO crystal array which is attached on 36 Multi Anode Photo Multipliers (MAPMT) with $8 \times 8$ pixels. The MAPMT is highly sensitive while having low thermal noise, so that energy threshold can lower down to 10 eV. Since the coded mask loses opacity for high energy x-rays, energy range for UBAT is limited to the 200 eV. All electronics including the analog readout board, the digital processing boards, the trigger board, and the high voltage board are located under MAPMT array, forming a compact structure of the UBAT detector module located at the bottom of the UBAT. We implemented all digital processes

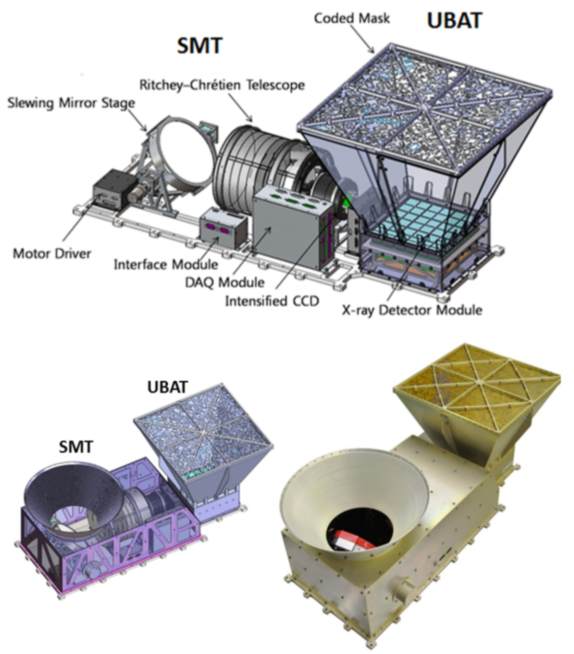


Figure 2: A Schematic view of UFFO-pafthfinder without the enclousure of SMT to display internal components(top), an exterial view (bottom left), and photograph of the manufactured flight model (bottom right).

only using FPGA which provides great advantages in terms of processing time and timing control. The trigger processing and the imaging processing run simultaneously in independent logic units to minimize latency in the imaging process for the localization. This is an advanced aspect over the $Swift$ BAT. However, the limited memory resource in UBAT FPGA allows only once task per second. Therefore, practical latency for the GRB localization is to be in the order of 1 sec.

Once a trigger occurs, the GRB coordinate information is transferred to SMT for the follow-up observation in the UV-optical band. SMT is the key concept of UFFO-pathfinder consisting of three instruments: the slewing mirror stage, a focusing optics, and high sensitive photo detector. The slewing mirror stage is a motorized two-axis gimbal for beam steering with a D=15 cm plane mirror placed in front of a Ritchey-Chrétien Telescope (RCT). The mirror rotation angle is ±15° off axis, resulting in an accessible FOV of $60 \times 60$ arcdeg$^2$ without the aberration inherent in wide-field optical systems. Using geared stepping motors, the gimbal can rotate faster than 15 deg/sec so that GRB events in the sky coverage of UBAT can be targeted within 1 sec. A precise motion control using the micro-stepping technique of stepping motor and a close-loop control using high resolution rotary encoders, obtained targeting resolution is better than 2 arcmin. For the focusing optics, we employ a Ritchey-Chrétien type of telescope in order to obtain a long effective focal length (1,140 cm) for the aperture size D=10 cm in the limited dimension of the UFFO-pathfinder payload [11]. The slewing mirror stage and the RCT were designed to be light weight and small sizes while having high endurances to shocks/vibrations which occur during the launch phase and a low degradation in the optical performance by thermal stress in the orbit. The integrated system wave front error is better than $1/20\ \lambda$ at 632.8 nm. We use an Intensified Charged Coupled Device (ICCD) for a photo detector on the focal plane. The ICCD consists of $256 \times 256$ monochromic pixels, which corresponds to 4 arcsec of the pixel FOV. The photocathode of the ICCD has 20% of quantum efficiency. The gain of the intensifier can be adjusted from $10^3$ to $10^6$ by the control program [13].

## 3. Space Qualification and Integration

Space qualification tests of UFFO-pathfinder were performed at the National Space Organization (NSPO), Hsinchu, Taiwan during summer 2011. Tests were mainly focused on verification of the UFFO-pathfinder system in thermal-vacuum and shock-vibration environments. For the thermal vacuum test, the UFFO-pathfinder instruments were placed in a chamber under the vacuum pressure of $10^{-7}$mbar. A temperature cycle test was performed in a range of $-30 \sim 40$ °C for 30 hours. Temperature profiles measured on several sub-instruments and vital monitoring data found no electrical failure during the test. In addition, UFFO-pathfinder demonstrated a successful cold start at −30 °C, proving its outstanding ability to withstand these temperature extremes. Visual inspection after the test found neither mechanical failure nor out-gassing vestige. The shock-vibration tests were carried out a week after the thermal-vacuum tests. We applied to UFFO-pathfinder 45 g of shocks for 3 msec, and vibrations with amplitude 1-9.9 g in a range of 5-2000 HZ in three axes. All recorded acceleration-profiles were within the designed value, except an unexpected resonance found in gimbal stage during the vibration test. A reinforced design modification resolved this issue later on. The impact on the RTC was evaluated by measuring a wave-front-error after the shock-vibration tests, resulting no visualized degradation of optical performance.

The UFFO-pathfinder moved to Istra, Russia for final integration into *Lomonosov* satellite in April 2012.

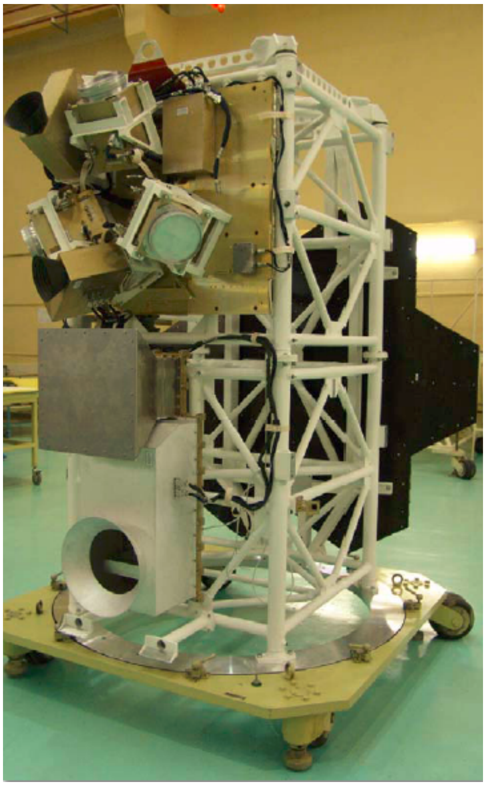

Figure 3: A photograph of the *Lomonosov* payload.

Figure 3 shows the integrated *Lomonosov* payload. A full system validation tests were accomplished in site. System control and data taking were established via the interface module. Successful tests of slewing mirror toward known direction, where a parallel beam source is located in, as well as taking target image supplied evidence that proved that the system to be ready. The obtained image shows the Point Spread Function (PSF) of final system to be 4.8 arcsec which mainly comes from the smearing effect on ICCD. UBAT detector response also has been examined using X-ray bombarded from known directions. Figure 4 shows a successful X-ray image obtained by off-line analysis of data taken by UBAT, which sufficiently testifies healthiness of the system.

The FPGA logic for the imaging process has not been perfectly implemented yet. However, the logic development will be continued to completion by the middle of 2013. While the hardware is being ready, software development for system optimization and system calibration, such as the collimation of two optical axes for UBAT and SMT, optimization of motor control for fast settling, and an advanced hit finding algorithm to reduce

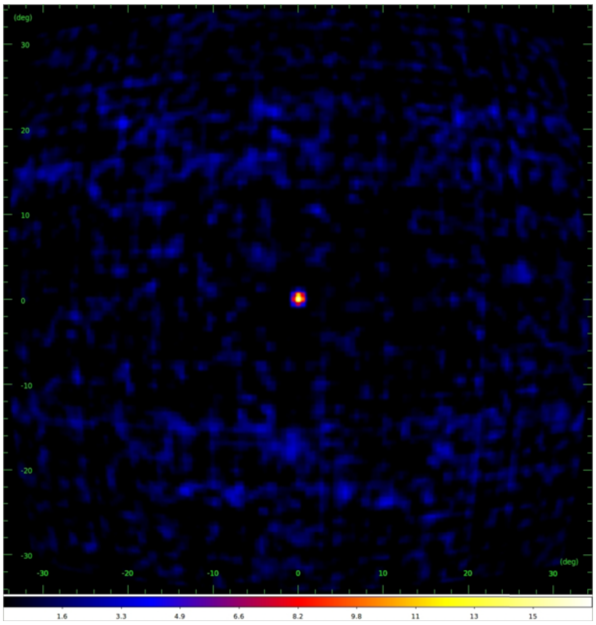


Figure 4: Reconstructed X-ray source image obtained by UBAT. the source point is clearly seen in the center. The nearfield effect due to a geomatric contraint in the laboratory has been corrected by the reconstruction software.

cross-talk in UBAT detector etc, are steadily continued in 2013.

## 4. Summary

UFFO is utilized to observe early light emissions from GRBs using a fast localization and slewing system. We successfully developed UFFO-pathfinder which now has been integrated onto the *Lomonosov* satellite for launch in the end of 2013. Upon a success of this pathfinder mission, the full scale of UFFO mission is going to follow. The UFFO teams scientific endeavor will be continued to realize great scientific potential of early photon emissions, which will advance understanding of the nature of GRBs.

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