THE UFFO SLEWING MIRROR TELESCOPE FOR
EARLY OPTICAL OBSERVATION FROM GAMMA RAY BURSTS

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While some space born observatories, such as SWIFT and FERMI, have been operat-
ing, early observation of optical after grow of GRBs is still remained as an unexplored
region. The Ultra-Fast Flash Observatory (UFFO) project is a space observatory for
optical follow-ups of GRBs, aiming to explore the first 60 seconds of GRBs optical emis-
sion. Using fast moving mirrors to redirect our optical path rather than slewing the
entire spacecraft, UFFO is utilized to catch early optical emissions from GRB within
1 sec. We have developed the UFFO Pathfinder Telescope which is going to be on board
of the Lomonosov satellite and launched in middle of 2012. We will discuss about scien-
scientific potentials of the UFFO project and present the payload development status, especially for Slewing Mirror Telescope which is the key instrument of the UFFO-pathfinder mission.

Keywords: Gamma Ray Bursts; after glow; fast slewing.

1. The Ultra Fast Flash Observatory

The discovery of afterglow of the Gamma Ray Burst (GRB) was carried out by a follow-up observation of the William Herschel Telescope in 1997.\(^1\) It was 20 hours after the GRB 970228 detected by BeppoSAX with a fast localization capability.\(^2\)

Scientists’ dream to capture early optical emissions from GRBs was realized by Swift which was launched in 2004. It has the unique capability of in-site flow-up measurement in the Space\(^3\) rather than just sending the localization information to the ground telescope for flow-up observations. As soon as the Burst Alert Telescope determines the localization of the GRB event, the space craft rotates toward the GRB direction to allow flow up measurements of UV/Optical and X-ray telescopes in narrow field of views (FOV). However, this method takes time longer than 60 seconds, which is limited by the rotation speed of the space craft and computing process for localization.

The Ultra Fast Flash Observatory (UFFO)\(^4\) is a new concept of GRB telescope with a fast slewing capability exploring first 60 seconds of optical emissions from GRBs. Instead of rotating entire space craft, a slewing mirror in front of an optical telescope rotates to redirect beam path (see Figure 1). The smaller moment of inertia of the slewing mirror than the space craft, the faster slewing (within 1 second) is achievable with a limited power budget in the space mission. An advanced slewing method based on Micro Electro Mechanical System (MEMS) Micro Mirror Array\(^4,5\) has been proposed for a sub millisecond slewing time. However, a technical challenge still remains especially in precise angle control of individual micro-mirrors. For the first step, we have developed the UFFO-Pathfinder on board of the Lomonosov mission (See Figure 2) which is going to be launched in the middle of 2012. Since the UFFO joined the mission late as a piggy back payload on the TUS telescope,\(^6\) only limited mass (20 kg) and power (20 W) were allowed. Despite of its small size, UFFO-pathfinder will prove the concept and possibly bring interesting results.

![Fig. 1. UFFO concept.](image-url)
There are several interesting science potentials with the fast slewing capability of UFFO. As Panaitescu and Vestrand suggest, the optical luminosity of GRBs would be calibrated by rising times of light curves. However, their claim still needs to be confirmed with a larger number of events containing early parts of light curves. If we are able to calibrate GRBs, we will have another cosmological standard candle extending the Hubble diagram up to the highest red shifts. As a matter of fact, Swift was not utilized to observe optical emissions in a short time scale less than 60 sec. On the other hand, tests of prompt optical emissions from short-hard GRBs and furthermore any optical emissions from dark burst are outstanding topics with the fast response of UFFO. Optical emission is widely believed to come from the external shock while X-rays from internal shocks. Comparing these two light curves in early time scale, UFFO would provide important keys to understand optical emission mechanisms.

Figure 3 shows the overall structure of UFFO-Pathfinder. It consists of two instruments, one is UFFO Burst Alert Telescope (UBAT) and the other is Slewing Mirror Telescope (SMT). UBAT is a $90 \times 90$ wide FOV coded mask X-ray camera to trigger GRB events, as well as to determine their localization information. The coded-aperture mask made of Tungsten has randomized rectangular hole patterns with 50% open fraction. We used $48 \times 48$ YSO crystal array attached onto 36 units of $8 \times 8$ Multi Anode Photo Multipliers. The localization resolution of UBAT is better than 10 arcmin with an energy range of X-rays 10–100 keV. A fast imaging process runs on a Field-programmable gate array (FPGA) chip checking significance of signal in the x-ray image to issue trigger and localization information in every second. We describe SMT in next section.

2. Slewing Mirror Telescope

SMT is the key concept of the UFFO aiming to explore the sub-minute regime of optical emissions from GRBs. SMT consists of three main instruments; Slewing
Mirror Stage (SMS), Ritchey-Chrétien Telescope (RCT), and a photo detector. Important parameters of SMT are listed in Table 1.

The SMS is a two-axis Gimbal mirror located in front of RCT (Figure 4). The FOV of RCT is 17 arcmin × 17 arcmin. The slewing capability extends the SMT sky coverage up to 70 arcdeg × 70 arcdeg. Because of the space limitation, the

![Diagram of UFFO-Pathfinder payload.](image)
The UFFO Slewing Mirror Telescope for Early Optical Observation

Fig. 4. Two-axis Motorized slewing mirror stage. Motor of inner axis of the gimbal is located under the mirror.

motor and the support structure of the inner axis are located below the mirror. A 6 inch Zerodur substrate of the mirror was light-weighted to be 482 g. Silicone pads are used for mirror mounting in the support ring. Average reflectivity is about 85% in a range of 200–700 nm wave length. We use stepping motors with 200 steps/rev and 100:1 Harmonic Drive reducers. The minimum step of the mirror rotation is about 4 arcsec using the 1/16 micro-stepping control technique. The speed of motor rotation is faster than 15 deg/sec so that objects in the sky coverage can be targeted within 1 sec. High precision rotary encoders are employed for the close loop control. Obtained targeting resolution is better than 2 arcmin. The power consumption of SMS is less than 3 Watt.

The RCT is designed to be light weight (∼1 kg) and small size (180 × 180 × 250) with a $D = 10$ cm aperture and F number 11.4. Figure 5 shows the opto-mechanical structure of RCT. The rear part is the main support plate of RCT holding three bi-pod flexures of the primary mirror (M1) and four spiders of the secondary mirror (M2). The obscuration ratio is 12.5%. With two triangular side brackets, only the main support plate is fixed at the SMT base plate to minimize optical miss-alignments due to non-uniform mechanical- and thermal-stress on the base plate. Reflectivity of mirrors is the same as the slewing mirror. Integrated system has 1/20 $\lambda$ Wave Front Error (WFE) at 632.8 nm wavelength.

We use an Intensified Charged Coupled Device (ICCD) for the photo detector. The ICCD consists of 256 × 256 monochromic pixels corresponding 4 arcsec of pixel FOV. Quantum efficiency of the ICCD is about 20%. The gain of the intensifier is adjustable in a range of $10^3$–$10^6$. All SMT functions such as motor control, ICCD control/readout and data transfer are controlled in FPGA logic.

The overall shape of the SMT is a box with a truncated cone shade. The box cover consists of duralumin skin and polycarbonate support frame. Multi Layer Insulator covers the entire SMT box. The inside of the SMT cover is black-painted...
to reduced scattered light background. The surface of the shade is precisely lathed to be saw tooth grating patterns to increase reflectivity of undesired lights such as the moon lights. There are three electronics sub-units inside the SMT enclosure; the DAQ/Power, the SMT control-readout, and the Motor control. The base plate is the mechanical support structure of all sub-components of SMT as well as UBAT, and also plays an important role of thermal conduction to the platform.

3. Tests & Readiness

A Series of Thermal-Vacuum (TV) and Shock-Vibration (SV) tests were performed at the National Space Organization (NSPO), Taiwan, in July 2011. The main goal was to verify the UFFO system functionalities under the TV and SV conditions mimicking experimental environment of the space mission. In a TV chamber (See Figure 6), UFFO was exposed to several thermal cycles the temperature range of $-30 \sim 40^\circ$C for about 30 hours under the vacuum pressure of $\sim 10^{-7}$ mbar. The SV tests followed one week after the TV test. UFFO experienced shocks of 45 g for 3 msec, as well as vibration 1–9.5 g in the frequency range of 5–2000 HZ in three axes. All records of temperature- and acceleration-profiles on critical points such as electronics, SMS, and opto-mechanical structures were found to be healthy during tests. No mechanical/electrical failure was found in the tests, neither no out-gassing vestige. The WFE of RCT measured right after the SV test was satisfactory.

The UFFO was finally integrated at Istra, Russia in April 2012. Before the delivery, a full system validation tests were performed a full system validation test (See Figure 7). With commands sent through the interface module, SMT showed successful performances of slewing toward known directions and image taking.
The UFFO Slewing Mirror Telescope for Early Optical Observation

Fig. 6. SMT thermal-vacuum test in NSPO.

Fig. 7. System Verification during the final integration in Istra, Russia. The UFFO is vertically oriented. The other RCT in the right side is used to produce a parallel beam.

Optics collimation and the ICCD performance were tested with a parallel beam located in the target direction. Preliminary data analysis of obtained images shows the system Point Spread Function (PSF) to be 3.4 arcsec which is consistent with the PSF of ICCD.
4. Summary

To explore the first 60 seconds of optical emissions from GRBs, we proposed the new approach of GRB space telescope with a rapid slewing capability. We have completed the development of the UFFO-pathfinder payload during the past two and half years. The SMT has been delivered to Russia, and the UBAT will be delivered before June 2012. With the small size of payload, about 40 events per year are expected to be triggered by UBAT. Among these events, only several events with accurate localization information could be captured by SMT. Although the number is not great, even just handful number of events would be enough to prove the UFFO concept, and possibly bring key messages from cosmological distances. The design of the full UFFO mission is already in progress. The full UFFO requires more than 100 kg of mass with a \( D = 20–30 \) cm aperture of optical telescope. Several additional new instruments are proposed such as such as IR camera, spectrometer, and polarimeter. The full UFFO mission is targeted to be launched around 2015. Our accomplishment with the UFFO-pathfinder will be a crucial milestone for the Full UFFO.

References

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