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## DEVELOPMENT OF SLEWING MIRROR TELESCOPE OPTICAL SYSTEM FOR THE UFFO-PATHFINDER

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**Abstract.** The Slewing Mirror Telescope (SMT) is the UV/optical telescope of UFFO-pathfinder. The SMT optical system is a Ritchey-Chrétien (RC) telescope of 100 mm diameter pointed by means of a gimbal-mounted flat mirror in front of the telescope. The RC telescope has a  $17 \times 17$  arcmin<sup>2</sup> in Field of View and 4.3 arcsec resolution (full width half maximum of the point spread function) The beam-steering

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mirror enables the SMT to access a  $35 \times 35$  degree region and point and settle within 1 sec. All mirrors were fabricated to about 0.02 wavelengths RMS in wave front error (WFE) and 84.7% average reflectivity over 200 nm  $\sim$  650 nm. The RC telescope was aligned to 0.05 wavelengths RMS in WFE (test wavelength 632.8 nm). In this paper, the technical details of the RC telescope and slewing mirror system assembly, integration, and testing are given shortly, and performance tests of the full SMT optical system are reported.

## 1 Introduction

To measure the early photons from Gamma-Ray Bursts (GRBs), the Ultra-Fast Flash Observatory was proposed [1]. As the first step, the UFFO-pathfinder instrument has been developed and is scheduled to be launched 2013 as one of science payloads onboard the *Lomonosov* Russian satellite. The UFFO-pathfinder (Park *et al.* 2012) consists of two instruments, the UFFO Burst Alert and Trigger Telescope (UBAT) (Park *et al.* 2012; Jung *et al.* 2011; Nim *et al.* 2011; Na *et al.* 2011) for X-ray trigger and localization and Slewing Mirror Telescope (SMT; Jeong *et al.* 2013). When UBAT provides a trigger signal and approximate coordinates of a GRB to SMT, the SMT slewing mirror rotates quickly to the target coordinate and brings images of the UV/optical counter parts of GRB into the instrument FOV (Field of view) faster than the current GRB instruments in space and ground. The SMT optical system in UFFO-pathfinder is the first proof to realize such a measurement concept in GRB observation. In this paper, especially the technical details of SMT optical system, *i.e.* slewing mirror stage and RC telescope are presented shortly.

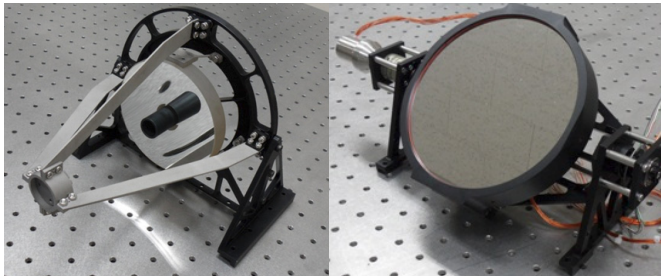
## 2 SMT RC telescope and slewing mirror assembly

The SMT optical system requirements are summarized in Table 1. The Ritchey-Chrétien (RC) telescope has a primary mirror (M1) of 100 mm in diameter and  $-1.01$  in conic coefficient and a secondary mirror (M2) of 20 mm in diameter and  $-1.83$  in conic coefficient. The telescope has 1.14 m effective focal length and fits within 200 mm SMT length budget in UFFO-pathfinder. It produces  $17 \times 17$  arcmin<sup>2</sup> in instantaneous FOV (IFOV) on the detector and almost diffraction limited performance, with a Modulation Transfer Function (MTF) of 0.77 at  $22.52 \text{ mm}^{-1}$  Nyquist frequency and an on-axis RMS spot radius of  $2.48 \mu\text{m}$ . Its spot diagrams over the SMT FOV are well within the Airy disk of 400 nm in diameter. The optics design satisfies all the RC telescope performance requirements as listed in Table 1. To minimize the stress on the M1 caused by a mismatch in thermal expansion coefficient (CTE) between the Invar flexure and the aluminum support structure, the M1 is mounted to the M1 support plate via 3 bi-pod flexures with 12 mm long, 2 mm wide, and 1.5 mm thick. The M2 cell is then mounted to the M1 support plate by 4 spider arms. The M2 cell has an invar spider core with 3 flexure blades. The final resulting RMS system WFE of the RC telescopes was found to be 22.3 nm for 633 nm in wavelength that is well within WFE requirement of  $<0.15$  waves.

**Table 1.** Requirements for SMT optics.

SMT optics	Slewing mirror and RC telescope
Aperture size	10 cm
Slewing coverage	$70 \times 70$ arcdeg <sup>2</sup>
Slewing speed	>30 deg / sec
Detector FOV	$17 \times 17$ arcmin <sup>2</sup>
Angular resolution	4 arcsec
Advanced resolution	0.5 arcsec (after centroiding)
Modulation Transfer Function	>0.4 at 22.52 mm <sup>1</sup>
Sensitive wavelength	200 – 650 nm
Mass	3 kg
Volume	600 (l) $\times$ 320 (w) $\times$ 200 (h) mm <sup>3</sup>

The slewing mirror stage has an aluminum support ring and RTV566 pads are inserted between the ring and mirror around its peripheral, front and back surfaces. A two axes gimbal stage is constructed with stepper motors and rotary encoders. Using the harmonic drive gear, its step size is controlled with  $\sim 4$  arcsec precision and the rotation angle can be controlled precisely to 2 arcmin in accuracy. The 2 axis stage can be rotated from  $+22.25^\circ$  to  $-21.47^\circ$  in inner axis and from  $+66.26^\circ$  to  $-2.25^\circ$  in outer axis on average. It allows for the full  $\pm 35^\circ$  in sky coverage. The total mass of slewing mirror assembly is measured to about 1.85 kg, satisfying the mass requirement of  $< 2$  kg. All mirrors are made of *Zerodur* substrates, coated with  $\text{SiO}_2 + \text{Al}$  for a reflexivity  $R_{\text{avg}} > 85\%$ . The slewing mirror *Zerodur* blank is light weighted 482 g to satisfy the mass budget  $< 0.6$  kg. The developed SMT optical system is presented in Figure 1.



**Fig. 1.** Manufactured SMT optics system, RC telescope (*left*) and slewing mirror stage (*right*).

### 3 System validation test of SMT optics

The flight model SMT performance was validated in Russia. The pre-flight model of RC telescope was used as a collimator. A He-Ne laser beam with 635 nm

was focused on the PFM RC telescope focus point. It was then diverged before being collimated to a parallel beam to feed the slewing mirror that redirected it to the M1. The beam was subsequently reflected by M2, and then focused onto the focal plane. The resulting focal images of the 4.3 arcsec ( $Y$ -slice, Gaussian fit  $1\sigma$ ) PSF is presented in Figure 2.

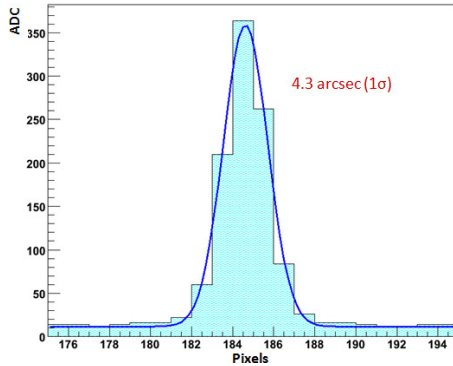


Fig. 2. Point spread function of flight model SMT [2].

## 4 Conclusion

The UFFO project has proposed for the first time the systematic exploration of UV/optical GRB light curves far earlier than 60 seconds after the localization of GRBs by X-ray observations. It is based on a novel concept of Slewing Mirror Telescope (SMT) that utilizes a fast slewing or tracking mirror, instead of controlling the attitude of a whole satellite or telescope body, to point and track the target GRB. It has 10 cm aperture and provides a  $\sim 4.3$  arcsec ( $1\sigma$  width) PSF over  $17 \times 17$  arcmin<sup>2</sup> in IFOV. And the angular resolution will be recovered up to 0.5 arcsec after the centroiding algorithm. This IFOV can be expanded to cover  $\pm 35$  degrees in operational FOV within about 1 s after the trigger using slewing mirror. The SMT optical system has been designed, constructed at first time and its SMT flight instrument is now integrated in the *Lomonosov* satellite pending launch in 2013.

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