High-Energy Sky Observation by Two Small Satellites Using Formation Flight *(FFAST)*

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Abstract

We are planning to have a *Formation Flying Astronomical Survey Telescope (FFAST)* that will make a hard X-ray ($\leq 80\,\mathrm{keV}$) imaging survey. Two small satellites($\sim 1\,\mathrm{m}^3$), a telescope satellite and a detector satellite, will be placed into a circular 550 km orbit and in formation flying that will be controlled the separation of $20\,\mathrm{m}\pm10\,\mathrm{cm}$. With a relative-circular orbit, we can select the scanning sky region arbitrarily; in the case of covering $\Omega \sim 1000\,\mathrm{deg}^2$ areas of sky, the detection limit of 0.1 mCrab will be achieved in two years. Hence, the *FFAST* will be able to fill the sensitivity gap of AGN surveys performed by ongoing and future hard X-ray missions.

Key words: workshop: proceedings — Hard X-ray — Formation Flying — AGN survey

1. Introduction

The recent technological advances of multilayer coating enable us to develop focusing hard X-ray system using Brag reflection. In the last ten years, several research groups have conducted hard X-ray observations by a balloon-borne experiment, *InFOCus*, *HERO*, *HEFT*, and *SUMIT*. And, X-ray astronomical satellites that carry a hard X-ray telescope are being planned in the 2010s (e.g. *NuSTAR*, *ASTRO-H*). Due to the grazing angle of the X-ray reflection, on the other hand, the X-ray telescope increase in length so that we can have enough effective area. However, the longer focal length will have a difficulty to be equipped with a single satellite. Hence, it is quite reasonable to separate the mirror and the detector into two spacecrafts maintained a certain distance using formation flying.

Therefore, we propose a *Formation Flying Astronomical Survey Telescope (FFAST)* mission that will cover a large sky area in hard X-ray band.

2. Design and Performance

The telescope satellite and the detector satellite of *FFAST* are put into the circular 550 km orbit and kept the distance of $20\,\mathrm{m} \pm 10\,\mathrm{cm}$ by a formation-flying guidance system. Fig.1 shows the configuration of *FFAST* in the orbit. The size of each satellite except the solar panels is about $1\,\mathrm{m}^3$.

The telescope satellite has a hard X-ray super-mirror that is an assembly of depth-graded Pt/C multilayer coated mirrors in a conical approximation to the Wolter I geometry (Ogasaka et al. 2008). The *FFAST* X-ray telescope (FFAST/XRT) that covers the energy range up to 80 keV is identical that of $ASTRO-H$ with the exception of the focal length. We have improved multiple thin-foil optics and now achieved 90 arcsec (HPD) with good rotation asymmetry PSF. We show the effective area of FFAST/XRT in the middle left panel of Fig.1.

The detector satellite carries an SD-CCD that functions as a hard X-ray imaging spectrometer up to 100 keV (Miyata and Tamura 2003). The SD-CCD is a CCD with a scintillator plate that is directly attached to the back-side of the CCD. X-rays enter into the CCD from the front (electrode) side. High energy X-rays that penetrate the CCD will be absorbed in the scintillator and converted into visible light, which is detected by the CCD. Note that the scintillator events, X-ray events directly detected in the depletion layer, and a cosmic-ray events are easily distinguished by the charge spread and the pulse height. The CCD chip is fully depleted which can be a back-illuminated CCD identical to that em-

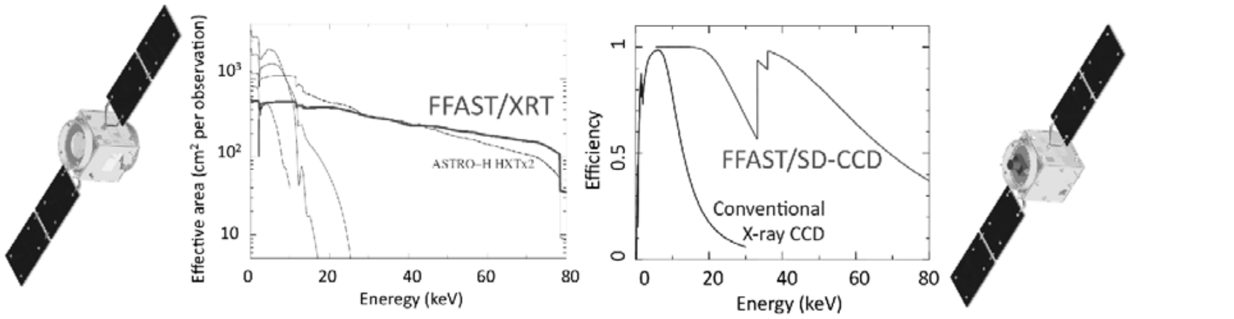

Fig. 1. *FFAST* configuration in orbit. (left : the telescope satellite, right : the detector satellite). The effective area of the FFAST/XRT (middle left). The detection efficiency of the SD-CCD (middle right).

ployed on *ASTRO-H*. The middle right panel of Fig.1 shows the detection efficiciency of the SD-CCD; the depletion depth of the CCD is $\sim 200\mu$m, and the thickness of the CsI scintillator plate is $\sim 300\mu$m. Three 3-side-buttable SD-CCD chips on the *FFAST* focal plane cover the FOV of 10'×15'. And they are working at $-90\,^{\circ}$C with a mechanical cooler that is almost identical to that developed for the *ASTRO-H* CCD and that employed in the *Suzaku* satellite (Mitsuda et al. 2007).

We have already demonstrated the hard X-ray telescope with the super-mirror and the SD-CCD by *SUMIT* balloon-borne experiment in 2006.

In the attitude control, the telescope satellite aligns the optical axis on the center of SD-CCD array, and the the detector satellite tracks the telescope to focus on the SD-CCD surface. Moreover, the roll angle of the detector satellite is controlled so that star images move in the same as vertical charge-transfer direction of the CCD, which is operated in TDI mode. We note that the detector satellite has a reaction control system (RCS) that can control the satellite orbit. The RCS is used to compensate the non-gravity perturbation except for contingency. Because the two satellites in a tandem construction fit inside shroud of a solid rocket now being developed, they will be launched by means of a single rocket.

3. *FFAST* Orbital Design

As has been mentioned, two satellites will be placed into Keplerian orbit and maintained a constant distance. According to the C-W solution of Hill's equation that describes the relative motion of these two spacecrafts, one can derive only two possible orbits for the formation flying, an along-track orbit and a relative-circular-orbit. Using a guiding-formation-flying with a small amount of thruster gas in the relative-circular orbit (relative-circular FF), we can arbitrarily choose and confine sky survey region. Thus, from the perspective of scientific objectives, we are considering employing the relative-cicular FF.

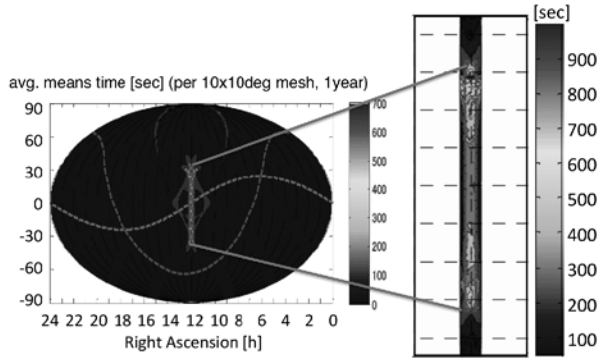

Fig. 2. Exposure map of *FFAST* 3×66 square degree scanning observation in a year.

And, we have designed the orbit for 3×66 square degree scanning observation. The expected exposure map in a year is shown in Fig.2. From our calculation, the survey flux limit of 0.1 mCrab intensity will be achieved for 46% of the region. In two years, 0.1 mCrab flux limit over ∼1000 square degree of the sky. Hence, *FFAST* has a possibility to perform a unique AGN survey to fill the sensitivity gap of AGN surveys done by on-going and future missions in hard X-ray regime.

4. Summary

We described here the *FFAST* project that will be the first focusing hard X-ray mission using a formation flying. The *FFAST* survey in two years ($\Omega \sim 1000\,\mathrm{deg}^2$, $S_{\rm lim} \sim 0.1\,$mCrab) is expected to fill a sensitivity gap between shallow all-sky and deep pencil-beem AGN surveys.

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