A broadband X-ray imaging spectroscopy with high-angular resolution: the FORCE mission

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Abstract

We present our concept of future Japan-lead medium-class mission, FORCE (Focusing On Relativistic universe and Cosmic Evolution), to be launched in the mid 2020s. FORCE is the direct successor to the broadband X-ray imaging spectroscopy aspect of Hitomi (ASTRO-H) with significantly higher angular resolution. The current design of FORCE defines energy band pass of 1–80 keV with angular resolution of $< 15''$ in half-power diameter, achieving a 10 times higher sensitivity above 10 keV compared to any previous missions with simultaneous soft X-ray coverage. Our primary scientific objective is to trace the cosmic formation history by searching for "missing black holes" in various mass-scales: "buried supermassive black holes (SMBHs)" residing in the center of galaxies in a cosmological distance, "intermediate-mass black holes" acting as the possible seeds from which SMBHs grow, and "orphan stellar-mass black holes" without companion in our Galaxy. In addition to these missing BHs, hunting for the nature of relativistic particles at various astrophysical shocks is also in our scope, utilizing the broadband X-ray coverage with high angular-resolution. FORCE are going to open a new era in these fields. The satellite is proposed to be launched with the Epsilon vehicle that is a Japanese current solid-fuel rocket. FORCE carries three identical pairs of Super-mirror and wide-band X-ray detector. The focal length is currently planned to be 10 m. The silicon mirror with multi-layer coating is our primary choice to achieve lightweight, good angular optics. The detector is a descendant of hard X-ray imager onboard Hitomi (ASTRO-H) replacing its silicon strip detector with SOI-CMOS silicon pixel detector, allowing an extension of the low energy threshold down to 1 keV or even less.

Key words: instrumentation: high angular resolution — X-rays: diffuse background — acceleration of particles

1. Scientific objectives and requirement

Our primary scientific objective is to trace the cosmic formation history by searching for "missing black holes" in various mass-scales. The missing black holes we define includes "buried supermassive black holes (SMBHs)" ($> 10^4\ M_\odot$) residing in the center of galaxies in a cosmological distance, "intermediate-mass black holes" (10^2–$10^4\ M_\odot$) acting as the possible seeds from which SMBHs grow, and "orphan stellar-mass black holes" ($< 10^2\ M_\odot$) without companion in our Galaxy. In addition to these missing BHs, hunting for the nature of relativistic particles at various astrophysical shocks is also in our scope.

In order to achieve these scientific objectives described here, a high sensitivity in the hard X-ray band with simultaneous broadband coverage is required. The sensitivity to point sources is generally limited by exposure time, background, and source confusion, and is getting better as exposure time increases, but at some point it saturates due to source confusion limit. Thus, higher angular resolution is strongly demanded to achieve a high sensitivity. Especially, in order to go down to 2–3 $\times 10^{-15}$ erg cm^{-2} s^{-1}, a requirement from the AGN survey (Mori et al. 2016), the angular resolution of $< 15''$ in HPD is necessary.

2. Mission design and scientific instruments

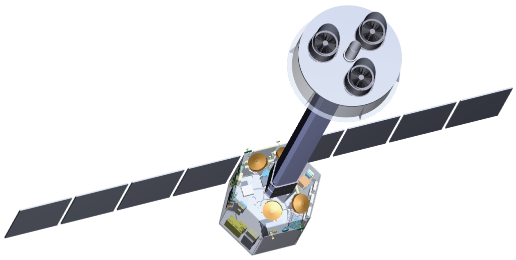

Fig. 1. A schematic view of the FORCE satellite.

FORCE has a weight of about 1 metric ton, and is planned to be launched with the Epsilon vehicle that is an ISAS/JAXA solid-fuel rocket. The satellite will be put into a circular orbit with altitude of 500–600 km and inclination angle of 31 degrees or less, which is similar to those of previous Japanese X-ray observatories. Figure 1 shows a schematic view of the satellite. FORCE carries co-aligned, three identical pairs of a supermirror with high angular resolution and a focal-plane detector with broadband response. The supermirror and the detector are separated by 10 m focal length. Such a long focal length is necessary to ensure sufficient effective area for hard X-ray focusing and requires an extendable optical bench (EOB) that can be stowed to fit in the launch fairing and deployed on-orbit. In the current design, the 10 m length is achieved by a combination of 2 m fixed optical bench (FOB) and 8 m EOB, and the mirror module is placed at the end of the EOB.

Table 1 summarizes key instrument parameters at this moment. High angular resolution of $< 15''$ in the broadband of 1–80 keV characterizes this mission. These parameters are defined by the design concepts of the mirror and detector, which are described in the following sections.

Table 1. Instrument parameters

Angular resolution	$<15''$ (HPD)
Multi-layer Coating	Pt/C
Field of view at 30 keV	$\sim 7' \times 7'$ (50% response)
Effective Area at 30 keV	370 cm^2
Energy range	1–80 keV
Energy resolution at 6 keV	<300 eV (FWHM)
Background	comparable to Hitomi/HXI
Timing resolution	several $\times$ 10 μs
Working temperature	-20 ± 1 °C

2.1. X-ray supermirror with high-angular resolution and Wideband hybrid X-ray detector

The mirror substrates of our X-ray supermirrors are made based on the single-crystal silicon mirror technology, which has a high potential of making light-weight, high-angular resolution X-ray optics (Zhang et al. 2016). In general, higher angular resolution is accompanied with larger mass and higher production cost. Considering our limited resource, we need to find out the best compromise among these factors. The silicon mirror can provide us with a solution for this issue. Although there are still a number of technical issues to be verified experimentally toward a flight-ready telescope, the silicon mirror with multi-layer coating is our primary choice to achieve light-weight, affordable, high angular optics.

The focal-plane detector of FORCE, wideband hybrid X-ray imager (WHXI), has the same concept as the hard X-ray imager (HXI) onboard Hitomi; Si and CdTe hybrid detector with active shield. Although HXI consists of four layers of double-sided Si strip detectors (DSSD) and a single layer of CdTe double-sided strip (DSD) detector (Nakazawa et al. 2016), WHXI replaces the four DSSD layers with a single SOI-CMOS pixel detector (SOIPIX) (Tsuru et al. 2014). Low readout noise achievable by SOIPIX could lower the energy threshold down to 1 keV and assure a broadband energy response required to the focal-plane detector of FORCE. CCD is an established Si detector with low readout noise, but its working temperature, typically < -60 °C, is too low to be placed closely together with the CdTe DSD, whose working temperature is about -20 °C, in a single camera. SOIPIX has a good time resolution, and what is more, self-trigger function so that anti-coincidence technique can be utilized, which is necessary to achieve low background.

References

Mori, K. et al. 2016, SPIE, id. 99051O
Zhang, W. et al. 2016, SPIE, id. 99051S
Nakazawa, K. et al. 2016, SPIE, id. 990511
Tsuru, T.G. et al. 2014, SPIE, id. 914412