Performance of The Nuclear Spectroscopic Telescope Array (NuSTAR) Mission

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Abstract

The Nuclear Spectroscopic Telescope Array (NuSTAR) will be the first focusing hard X-ray (6 - 79 keV) mission in orbit. NuSTAR will fly two co-aligned telescopes consisting of multilayer coated grazing incidence optics and shielded focal planes with CdZnTe pixel detectors. The NuSTAR instrument incorporates a deployable mast to achieve a 10-m focal length. This Small Explorer Mission is currently under development, and is scheduled for launch in mid 2011.

Key words: X-ray telescope: X-ray optics: X-ray detectors

1. Introduction

The Nuclear Spectroscopic Telescope Array (NuSTAR) will be the first focusing telescope on orbit to operate in the high energy X-ray band (6 - 79 keV). The NuSTAR instrument contains two co-aligned telescopes that consist of multilayer coated grazing incidence optics and solid state CdZnTe detectors that together extend focusing to the hard X-ray band above 10 keV. NuSTAR achieves a 10-meter focal length by employing an extendible mast that deploys on-orbit. The mission will launch on a Pegasus XL rocket into a low-inclination (6-degree) 600 km low-Earth orbit. This orbit largely avoids the SAA, resulting in low background. We describe here the expected performance of the instrument. Further information about NuSTAR can be found at http://www.nustar.caltech.edu.

2. Optics

The NuSTAR optics are based on multilayer coated, thermally formed glass segments mounted into a conical approximation Wolter I geometry. Each optic consists of 130 shells, with each shell segmented both in azimuth and along the optical axis. The segments are made of borosilicate glass formed into cylindrical sections using a thermal forming technique developed for the *Constellation-X* mission by the Goddard Space Flight Center. Depth graded multilayer coatings are applied to the substrates at DTU Space, and the segments are mounted into conical shells at Columbia University.

The projected angular resolution of the optics is 45" Half Power Diameter (HPD). The substrate figure is dictated by the quality of the forming mandrels, which for NuSTAR is 20 – 50 arcseconds depending on the mirror shell. The multilayer recipes are optimized for a smooth response as a function of energy, and good off-axis response. There are 10 mirror groups, and groups one to seven (the inner, small radius shells) are coated with depth graded Pt/SiC multilayers to extend the energy range up to 78.3 keV, while mirror groups eight to ten are coated with W/SiC multilayers to improve mid-energy response.

3. Focal Plane

The NuSTAR focal plane contains actively shielded CdZnTe pixel detectors, which provide excellent spectral resolution and high quantum efficiency without requiring cryogenic operation. The focal plane will consist of 4 hybrid detectors arranged in a 2 × 2 array. The hybrids consist of a 2 mm thick CdZnTe sensor coupled to a custom low-noise ASIC developed at Caltech. Each hybrid detector has 32 by 32 pixels with a pixel pitch of 604.8μm. The optical axis will be offset from the center of the array so that it intersects the active area of one hybrid. The focal planes are actively shielded in a CsI crystal well that is 1.5 cm thick at the base. In addition, a passive aperture stop which passively deploys from the shield simultaneous with the mast deployment limits the diffuse X-ray background with an opening angle of 1.3

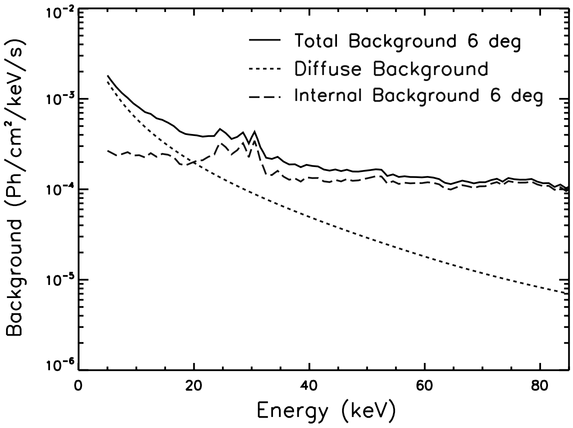

Fig. 1. Simulated background at 6 degree equatorial orbit

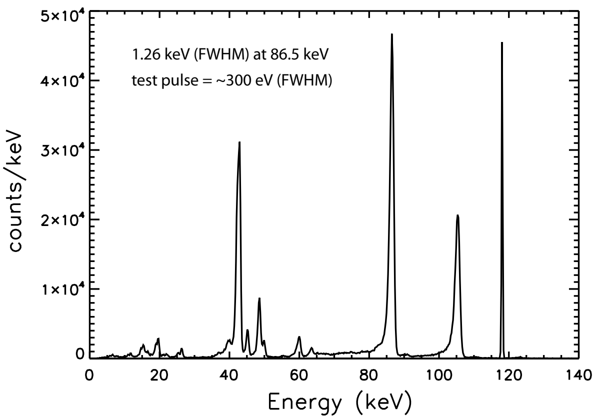

Fig. 2. Eu-155 source spectrum observed with NuSTAR prototype detector at 0°C

millisteradians.

The internal and diffuse background for the 6 degree equatorial orbit is shown in Figure 1. The low inclination orbit largely avoids the SAA (<3% of time is spend in SAA), for a stable and low background. The background estimates are the result of extensive Monte Carlo modeling using MGGPOD and GEANT.

The maximum data rate is 400 events/sec for two telescopes, however the livetime since the last event is recorded with each event, so that sources with countrates up to 10,000/s will have accurate flux measurements. Figure 2 shows a spectrum from an ^{155}Eu gamma-ray source taken with Caltech ASIC coupled to a 2 mm thick CdZnTe detector at 0 °C. The hybrid achieves energy resolution of 1.26 keV (FWHM) at 86.5 keV and $\sim$300 eV (FWHM) for the test pulse. For X-ray energies below 20 keV, the energy resolution approaches the readout noise limit of 300 eV.

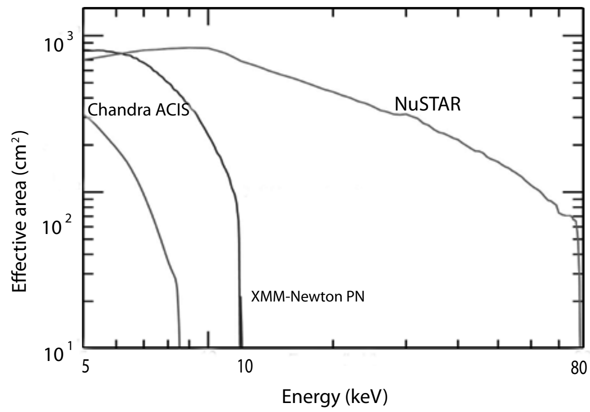

Fig. 3. Observatory effective area

4. Observatory Performance

The observatory effective area of NuSTAR as well as Chandra ACIS and XMM-Newton PN are shown in the Figure 3. As the figure shows, NuSTAR has an extended sensitivity compared to previous missions up to 78.3 keV, after which the area is cutoff due to the Pt K-edge.

Targets of opportunity can be observed within a few hours, with worst case turn around 12 hours.

5. Data Analysis - Archiving

Data will be sent down via the Tracking and Data Relay Satellite System and ground stations to the University of California, Berkeley. The data will be passed on to the Science Operations center at the California Institute of Technology, where it will be prepared for the science community and the HEASARC science archive. Data will be available for the science community after validation by the Science Operatons Center.

6. Summary

The observatory will provide a combination of sensitivity, spatial, and spectral resolution factors of 10 to 100 improved over previous missions that have operated at these X-ray energies. A NASA Small Explorer (SMEX) mission, NuSTAR is currently in Phase B development and is scheduled to launch into low-Earth equatorial orbit in August 2011.

References

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