The Nuclear Spectroscopic Telescope Array (NuSTAR)

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Mission Overview:

The Nuclear Spectroscopic Telescope Array experiment (NuSTAR) is a NASA Small Explorer (SMEX) mission. It is scheduled for launch in late 2011. The mission life is 2 years, although 5+ years operation is feasible since there are no expendables. NuSTAR will operate in the 6-78 keV energy band. It will be the first mission to employ true focusing optics at energies significantly above 8 keV. Previous missions have utilized pseudo-imaging techniques such as coded aperture masks. Focusing will enable higher angular resolution and sensitivity than previous hard X-ray missions. An overview of the experiment is shown in fig. 1. Of note is the adjustable mast that will deploy two optics 10.15 meters from the focal plane arrays. This will be the first use of a deployable mast in a high energy astrophysics mission. The optical bench, which supports the optics modules, contains three metrology lasers, which provide real time information on relative shifts in the optics-focal plane due to mast motion. The optics bench also contains a star tracker, an electronics box and 3 Phaeton accelerometers. The focal plane bench supports the mast and its canister, 2 focal plane assemblies, 3 metrology detectors, the central electronics box, 2 star trackers and a magnetometer.

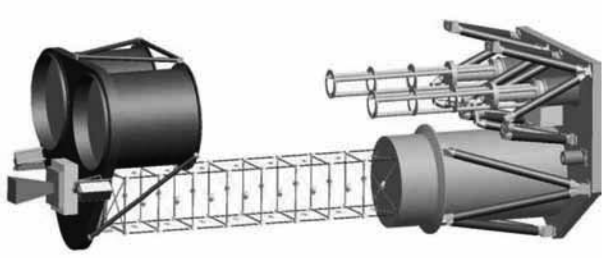

Fig. 1. NuSTAR telescopes in deployed configuration

NuSTAR will be launched by a Pegasus XL in a 550×600 km orbit of 6 degree inclination. The spacecraft (ATK Space Systems) is single string with 3-axis attitude control. There will be daily downlinks via TDRSS, and uplinks will not be routinely required. The pointing strategy will emphasize long observations of survey fields, specific pointed observations and targets of opportunity. The mission operations center will be at Berkeley and the science operations center at Caltech. Processed data will be delivered to both science users and the NASA science archive (HEASARC).

NuSTAR achieves extremely large effective area in a compact geometry in the energy band beyond Newton and Chandra ($\gtrsim$ 10 keV). It achieves this through a combination of large geometric area, long focal length and multilayer coatings on the optics (see below). This is illustrated in fig. 2, where NuSTAR is seen to provide effective area comparable to the high throughput Newton mission, but extending out to much higher energies. The combination of high angular resolution (current estimated on-orbit performance 50") and large effective area lead to unprecedented sensitivity over previous

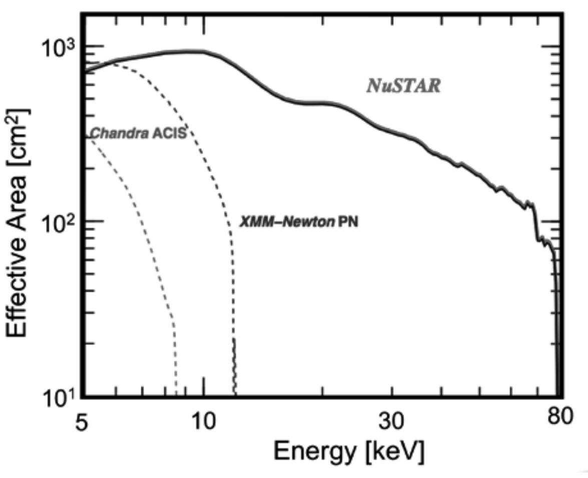

Fig. 2. NuSTAR effective area

non-imaging missions in the hard X-ray band. This is indicated in fig. 3; NuSTAR will achieve $\sim$ 100 times better sensitivity than previous major missions such as RXTE and Integral.

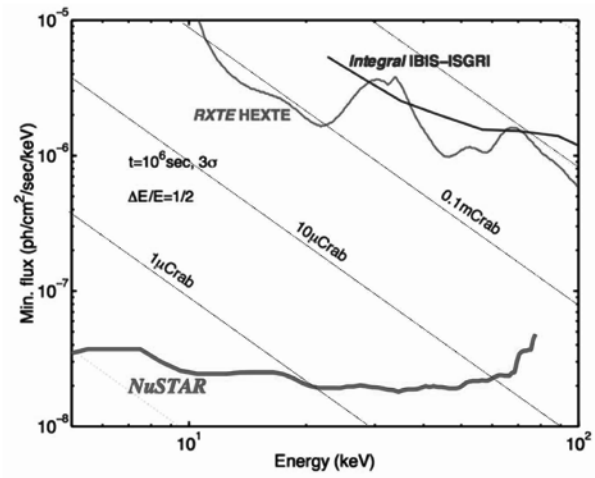

Fig. 3. NuSTAR continuum sensitivity

Science Objectives:

While the observing plan details continue to be worked out, the broad science objectives of NuSTAR are clearly defined. A supermassive black holes survey will be performed through a combination of deep pointings in the GOODS field ($>$ 200 arcmin^2), along with a wide survey ($>$ 4 deg^2). Hard X-rays are particularly appropriate for such a survey due to their ability to penetrate dust and gas obscured objects such as shrouded AGN. The second objective is to study collapsed stellar remnants through a survey of the Galactic center (GC). With 100 times the sensitivity of Integral in the 20-40 keV energy band, and more than an order of magnitude better angular resolution, NuSTAR will, for instance, identify more than $\sim$ 100 high mass X-ray binaries in the GC. A broad survey of the GC will not only detect Sgr A*, but also a large number of low mass X-ray binaries, and targets of timely interest, such as magnetars. A third goal of NuSTAR is to study supernova explosion physics and stellar nucleosynthesis through observations of young supernova remnants (SNR). Deep pointings will be obtained of both Cas A and SN 1987A. The Cas A pointing will be used to obtain a spatial map of the ^{44}Ti line emission at 68 and 78 kev. NuSTAR carries high energy resolution ($\sim$ 1 keV at the Ti lines) Cadmium Zinc Telluride (CdZnTe) detectors, and thus NuSTAR can perform Doppler-resolved spectroscopy of the Ti lines as well. This combination of diagnostics will provide an unprecedented ability to study supernova explosion physics. The fourth goal of NuSTAR is to study the TeV gamma ray sources detected by telescopes such as HEGRA, HESS and MAGIC. The nature of these sources is diverse, including pulsar wind nebulae, supernova remnants and star clusters. At least 4 of these sources will be observed, and contemporaneous observations with gamma ray and optical telescopes will be undertaken. Finally, in the lucky event of a SN Ia closer than Virgo or a core collape SN in the Local Group, NuSTAR will respond within 48 hours.

Instrument Overview (Optics):

The optics design is a conical approximation to the Wolter type-I geometry (Serlemitsos et al. 1995), with each mirror shell consisting of an upper and lower section. There are 130 mirror shells per optic. The inner shells are segmented into sextants and the outer shells into twelftants. The 2 telescopes thus have 4752 segments. The glass segments start out as flat sheets, and are thermally-slumped into the proper shape using a process first introduced to X-ray astronomy some 10 years ago (Hailey et al. 1997), and with improvements developed for the Constellation-X and IXO missions (Zhang et al. 2002). After slumping, the individual glass segments are coated with a multilayer, an artificial crys-

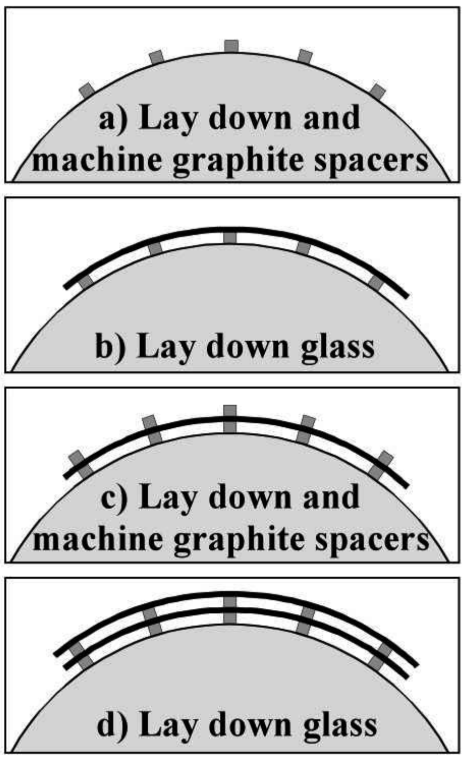

Fig. 4. Fabrication of glass-graphite-epoxy composite optics

tal consisting of a bi-material layer of constantly varying d-spacing, and atomic interfacial smoothness. This approach (Christensen et al. 2000) greatly enhances reflectivity through coherent reflection of hard X-rays over a broad energy band. The optics are a graphite-glass-epoxy composite structure built using the error-correcting monolithic assembly and alignment process – EMAAL (Hailey et al. 2003). In this process graphite spacers are epoxied to a Titanium mandrel, and the spacers are machined to the precise surface at which the glass segments must sit. The glass segments are epoxied in place, and another layer of spacers epoxied to the glass and machined to the proper surface. More glass is added and the process repeated, as illustrated in fig. 4. In this fashion tedious optical alignment of each shell of glass is replaced with precision machining of spacers. This approach to building hard X-ray optics was verified in the flight of the HEFT balloon experiment (Harrison et al. 2005). A recent NuSTAR prototype optic is shown in fig. 5, where the Titanium mandrel, spacers and glass segments are visible. This prototype gave 45" (HPD), close to the 43" requirement for as-built performance.

Fig. 5. NuSTAR prototype telescope. The segmented glass and spacers are visible on the Titanium mandrel

Instrument Overview (Focal Plane):

The focal plane detectors are 2mm thick pixel-hybrid CdZnTe read out by a 32×32 arrayed ASIC with amplifier, discriminator, sample and hold and on-chip ADC (Harrison et al. 2005). The anode is segmented with 0.6 mm (12 arcsecond) pixels. Four 2cm×2cm detectors form a single focal plane, providing a field of view 12.7' on a side. The energy resolution of the CdZnTe is 600 eV and 1 keV (FWHM) at 6 keV and 60 keV respectively. The time tag is 10 microsec. The focal plane detectors are collimated by CsI active veto shields read out by Hamamatsu R2248 photomultiplier tubes. Two 100 micron beryllium windows combine to form both a micrometeorite shield and entrance window. A prototype CdZnTe unit attached to the focal plane motherboard, which accommodates the 4 detectors of an individual focal plane assembly, is shown in fig. 6. The engineering model has demonstrated all the necessary performance requirements.

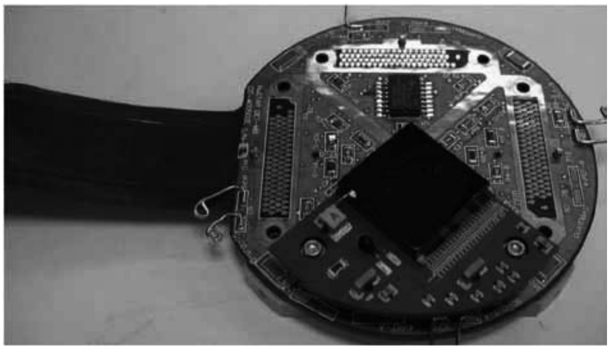

Fig. 6. One of four CdZnTe pixel hybrids on the focal plane motherboard

Summary:

Currently all the instrument subsystems have completed their critical design reviews. The mission critical design review is scheduled for February 2010. Fabrication of flight optics begins in the fall of 2009.

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