NuSTAR
the Nuclear Spectroscopic Telescope Array

Daniel Stern, Project Scientist
(Jet Propulsion Laboratory, California Institute of Technology)
SMEX: Small Explorer
competitively selected in 2004
reinstated by NASA in November 2007
confirmed in August 2009
NuSTAR will be the first focusing hard X-ray satellite

Coded Aperture Optics:
high background, large detector

Focusing Optics:
low background, compact detector
NuSTAR launch & orbit

Pegasus launch from Kwajelein: low earth orbit, 550x600 km, low inclination, 6°
Three Key Technologies

- Hard X-ray optics (HEFT/Con-X/IXO)
- Deployable mast (SRTM: Shuttle Radar Topography Mission)
- CdZnTe detector (HEFT)
NuSTAR Hardware

**GSFC: optics slumping**
>50% of flight substrates produced similar to Con-X/IXO process measured figure 20-30 arcsec

**Copenhagen (DTU-Space): optics coating**
depth graded Pt/SiC and W/Si coatings

**ATK/Goleta: extendable mast**
fully deployed flight mast

**Caltech: focal plane**
CdZnTe detectors

**Columbia: optics assembly**
expected performance ~45 arcsec
### Energy Range:
- 6-80 keV

### Angular Resolution:
- 45 arcsec (HPD)

### Field of View:
- 12 x 12 arcmin

### Spectral Resolution:
- 1.2 keV at 68 keV
- 600 eV at 6 keV

### Sensitivity (3σ, 1 Ms):
- 2 x 10^{-15} erg/cm²/s (6-10 keV)
- 1 x 10^{-14} erg/cm²/s (10-30 keV)

### Timing Resolution:
- 1 msec

### ToO Response:
- ≤24 hr

### Launch Date:
- August 2011

### Orbit:
- 5 degree inclination
- 550 km x 600 km

### Mission Lifetime:
- 2 years baseline
- >7 years orbit lifetime

**current best estimates (CBEs), as of September 2009**
INTEGRAL

2x2 degrees, 20-40 keV
1.5 month w/ IBIS

NuSTAR

2x2 degrees
simulated NuSTAR image
NuSTAR Baseline Science Plan (2 yr)

**Objective #1:** How are black holes distributed through the cosmos, and how do they affect the formation of galaxies?

**Objective #2:** How are stellar remnants distributed within the Galaxy and near the Galactic center?

**Objective #3:** How do stars explode and forge the elements that compose the Earth?

**Objective #4:** What powers the most extreme active galactic nuclei?

~6 months of unallocated science observing time in first 2 years: for ToO’s, additional programs, and/or to respond to primary program
Objective #1: Extragalactic Surveys

- peaks at ~30 keV
- constrains the accretion history of the universe, e.g., the formation history of supermassive black holes
- requires a population of heavily obscured AGN

Objective #1: Extragalactic Surveys


pluses = Chandra Deep Fields/GOODS
diamond = XMM Lockman Hole

INTEGRAL/Swift

1-2 %

30 keV
Objective #1: Extragalactic Surveys

XBoötes Field
8.5 deg²

COSMOS Field
1-2 deg²

GOODS Fields
300 arcmin²

~400 src’s 20-40 keV

~50 src’s 20-40 keV

~50% of CXB
Objective #2: Galactic Surveys

Galactic surveys: locate remnants of collapsed stars (white dwarfs, neutron stars, black holes) to study the endpoints of stellar evolution.

NuSTAR simulation of the Galactic center
$2^\circ \times 0.8^\circ$
(M. Muno)
Objective #3: Supernova Survey

NuSTAR will map historic SNe

$^{44}\text{Ti}$ lines at 68 and 78 keV provides important, new diagnostics

$<24\text{ hr ToO}$ capability to observe Galactic core collapse SNe and SNe Ia out to Virgo, should they occur during the lifetime of the mission
Massive star uses up its fuel.

Explosion: A supernova.

Expanding shell slams into surrounding medium at supersonic speed. Heats up and glows.
Objective #4: Blazar Monitoring

NuSTAR will conduct coordinated surveys with the Fermi Gamma-Ray Telescope and ground-based TeV telescopes to provide temporal tomography of nature’s most powerful particle accelerators.
Other Potential Programs

- Particle acceleration in the solar corona
- Axion decay in the Sun
- Hard X-ray emission from protostars and stellar flares
- Galactic TeV sources
- Pulsar wind nebulae
- Galactic black holes in quiescence
- X-ray bursters
- Cyclotron lines in X-ray pulsars
- Magnetars
- Ultraluminous X-ray sources
- Non-thermal emission from galaxy clusters
- Dark matter annihilation signatures
- INTEGRAL sources
- etc.....
NuSTAR will bring the high energy universe into focus.

Summary

<table>
<thead>
<tr>
<th>Energy Range:</th>
<th>6-80 keV</th>
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<tbody>
<tr>
<td>Angular Resolution:</td>
<td>45 arcsec (HPD)</td>
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<tr>
<td>Field of View</td>
<td></td>
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<tr>
<td>(50% response):</td>
<td></td>
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<tr>
<td>Strong Source</td>
<td></td>
</tr>
<tr>
<td>Positioning (&gt;$10^7$):</td>
<td>1.5 arcsec (1° radius)</td>
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<tr>
<td>Spectral Resolution:</td>
<td>1.2 keV at 68 keV (FWHM)</td>
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<tr>
<td>Sensitivity (3σ, 1 Ms):</td>
<td>2x10^{-15} erg/cm²/s (6-10 keV)</td>
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<td>Timing Resolution:</td>
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<tr>
<td>ToO Response:</td>
<td>&lt;24 hr</td>
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<tr>
<td>Launch Date:</td>
<td>August 2011</td>
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<tr>
<td>Orbit:</td>
<td>6 degrees</td>
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<tr>
<td>Saturating Count Rate:</td>
<td>250 cts/sec in HPD</td>
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<td>Orbit Lifetime:</td>
<td>2 years baseline</td>
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<tr>
<td>Mission Lifetime:</td>
<td>&gt;7 years orbit lifetime</td>
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http://www.nustar.caltech.edu/

current best estimates (CBEs), as of September 2009
Flight mast deployment test