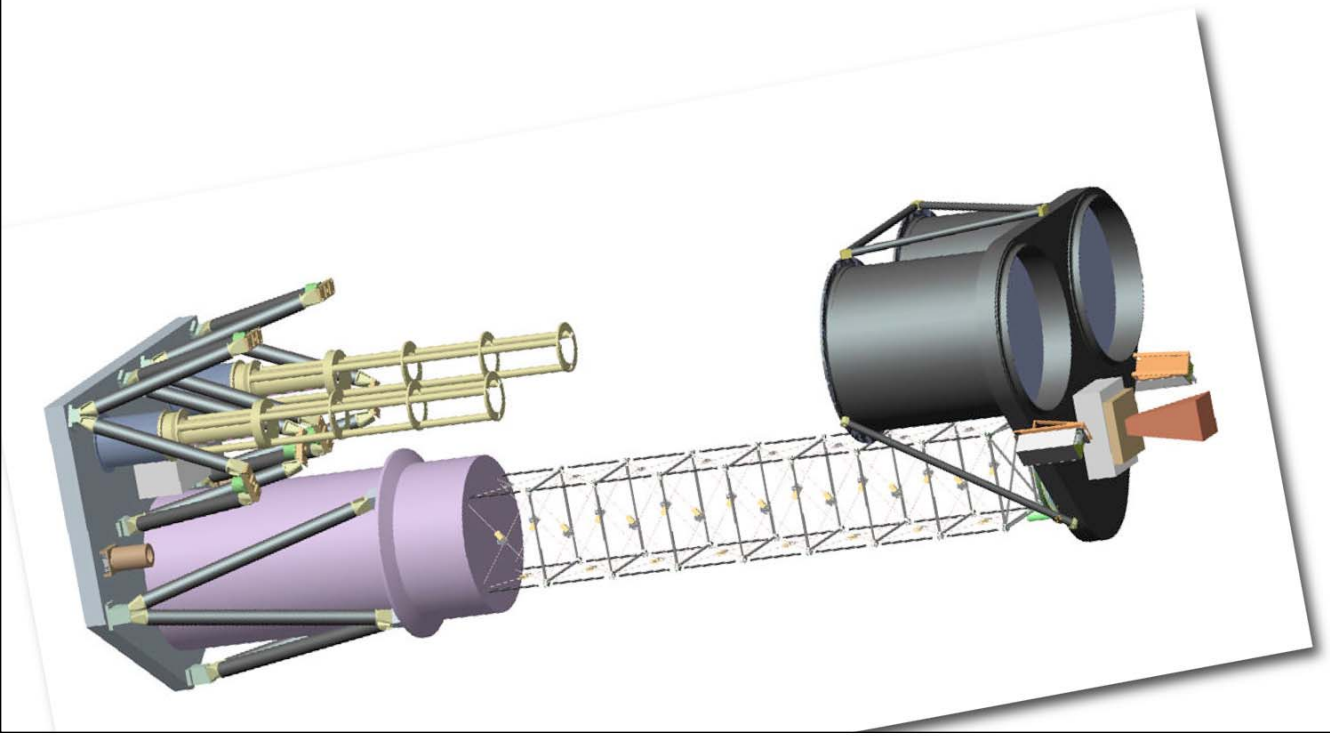
# NuSTAR

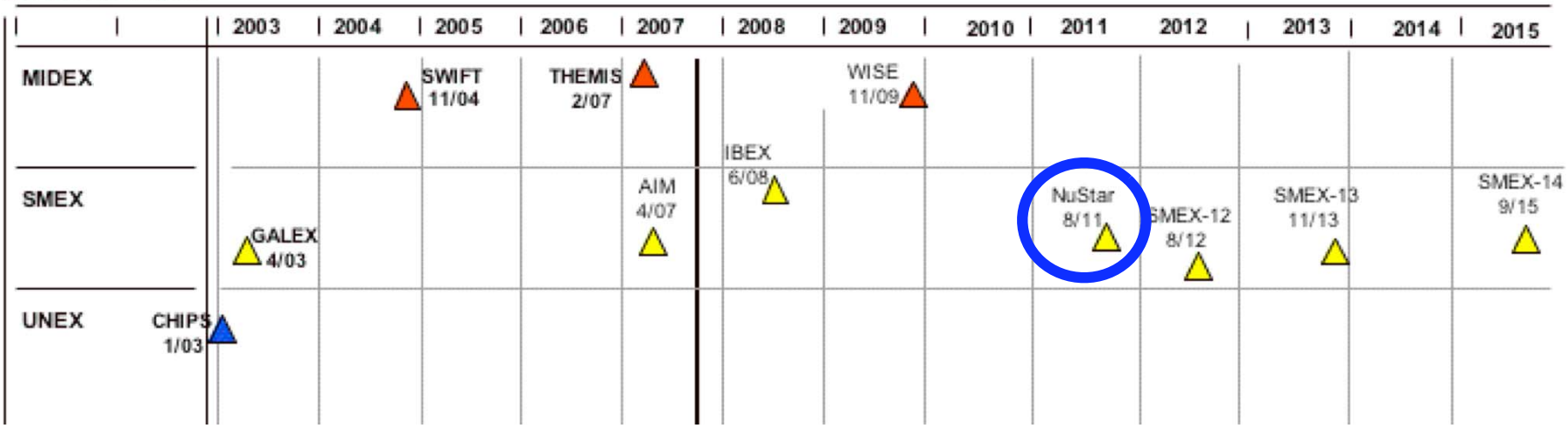
## the Nuclear Spectroscopic Telescope Array

**Daniel Stern, Project Scientist**
(Jet Propulsion Laboratory, California Institute of Technology)



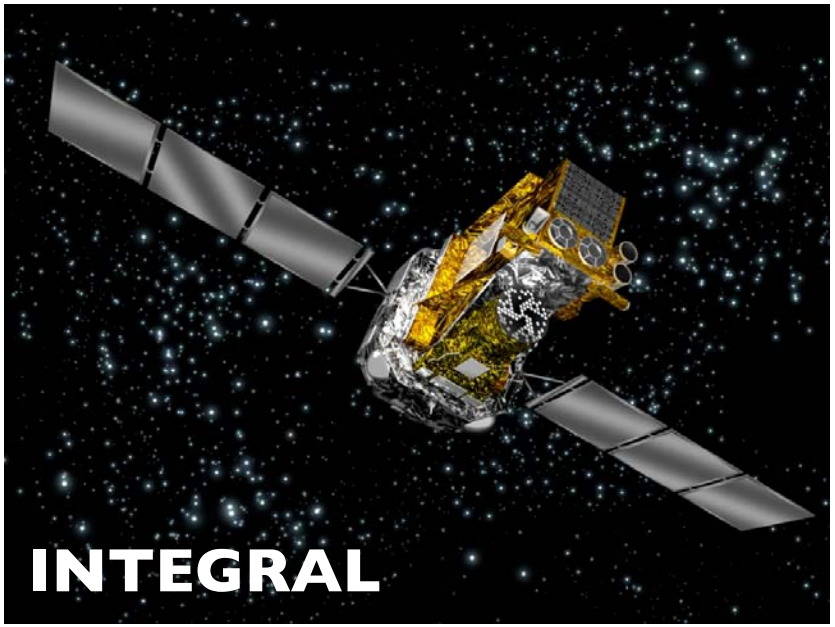
Chandra's 1st Decade of Discovery
Boston, 2009 September


*Launch Schedule*



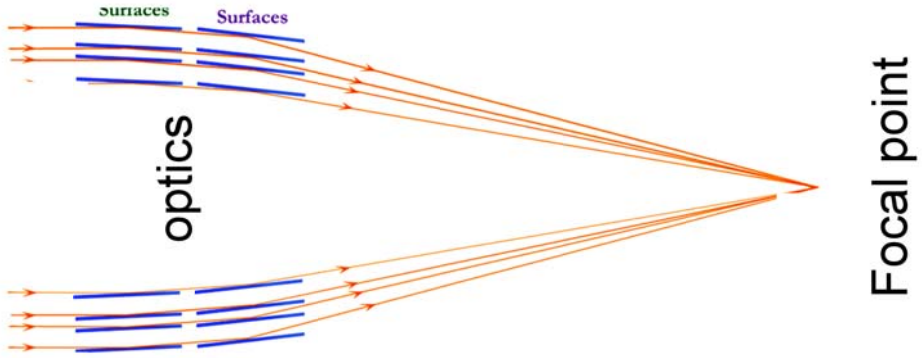

SMEX: Small Explorer
competitively selected in 2004
reinstated by NASA in November 2007
confirmed in August 2009

# NuSTAR will be the first focusing hard X-ray satellite



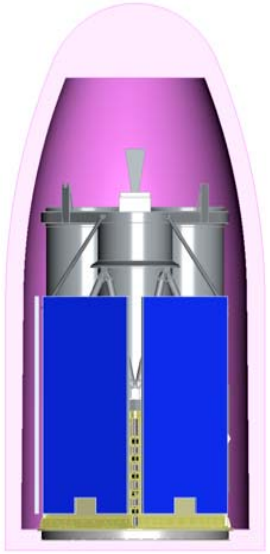


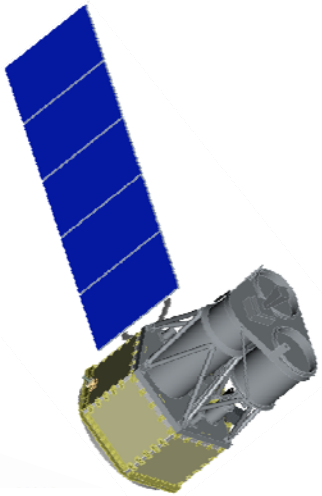
Coded Aperture Optics:
high background, large detector




Focusing Optics:
low background, compact detector

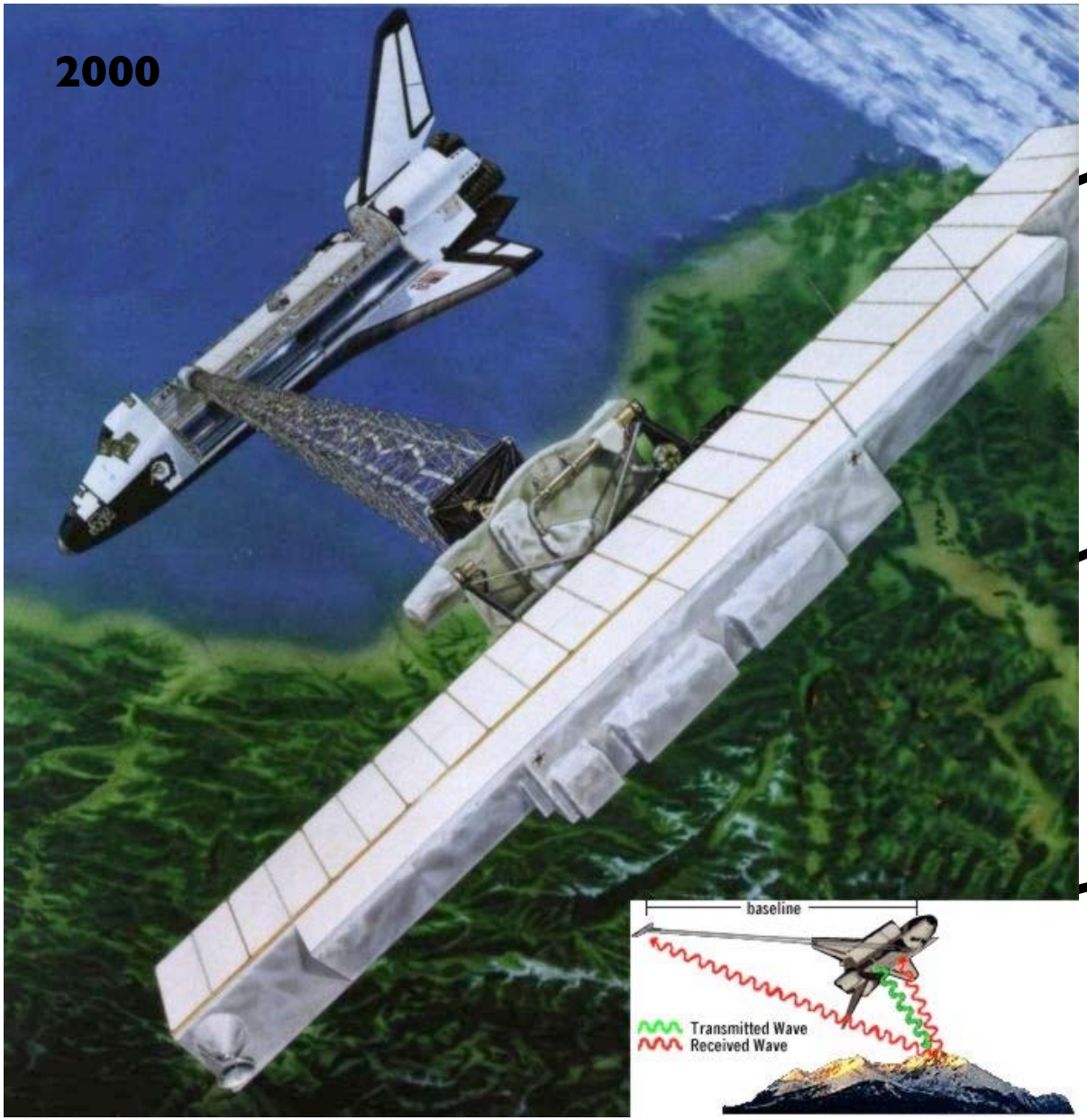
# NuSTAR launch & orbit

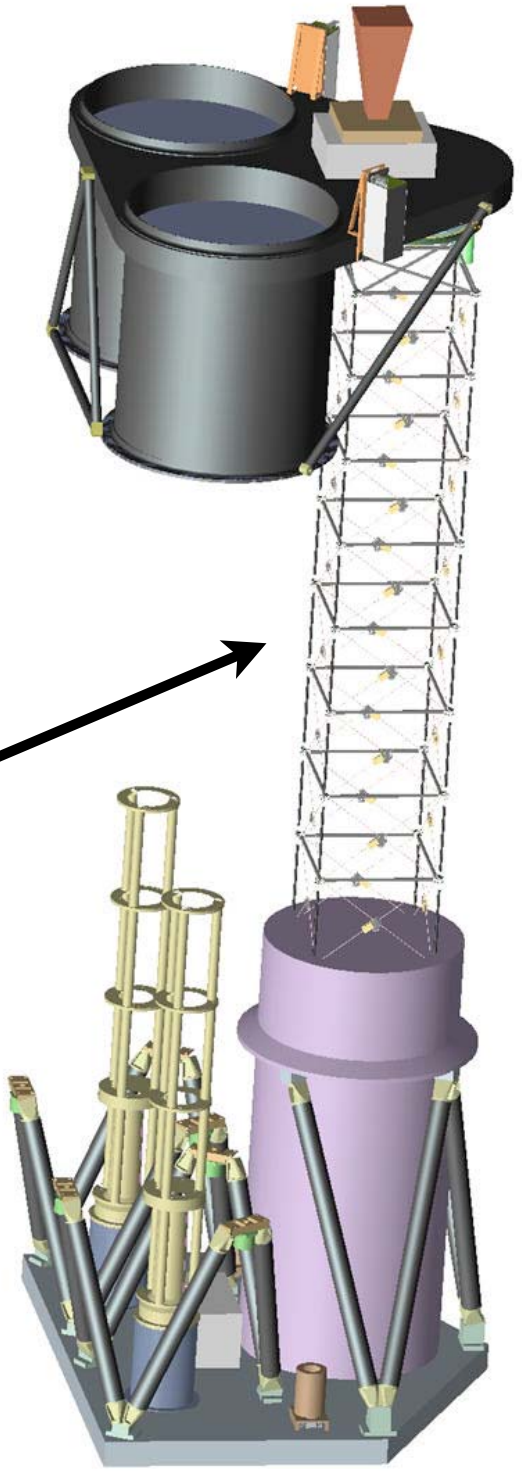





Pegasus launch from Kwajelein:
low earth orbit, 550x600 km
low inclination, 6°

# Three Key Technologies



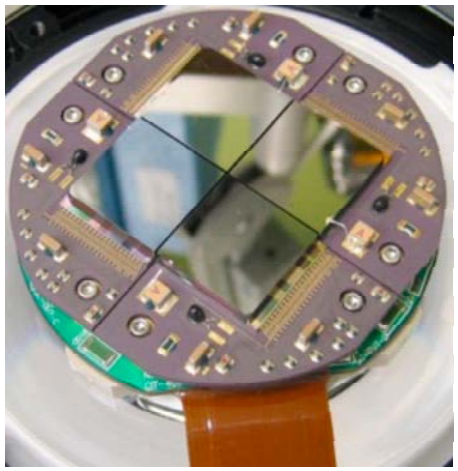



# NuSTAR Hardware

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

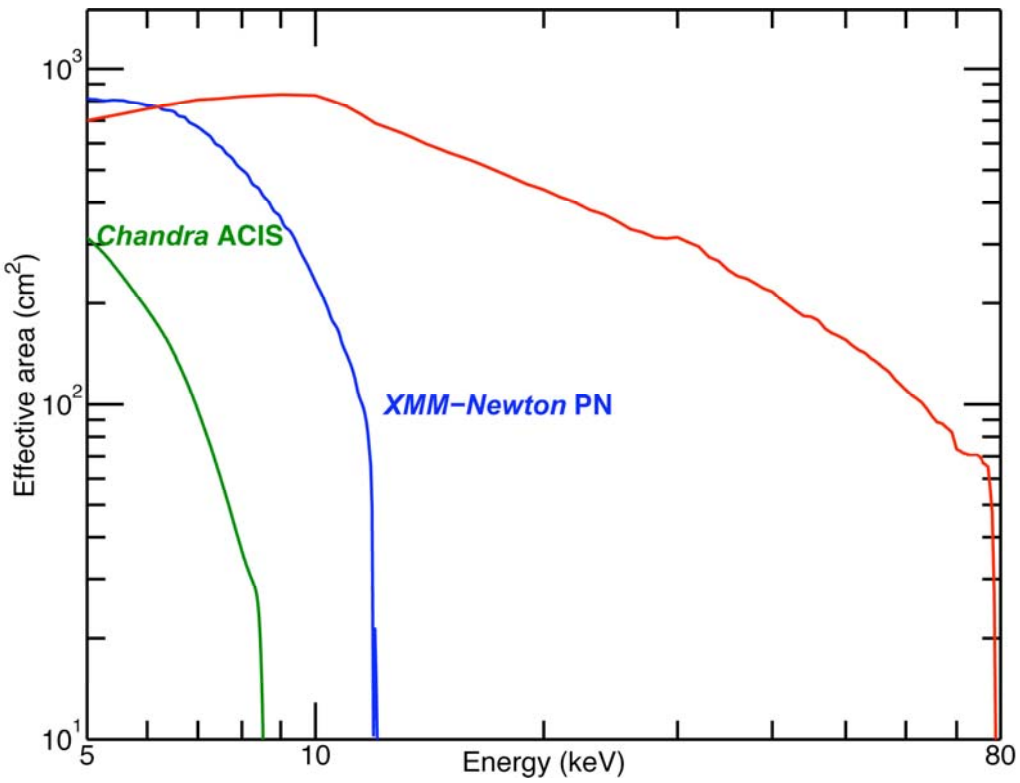
**Copenhagen (DTU-Space): optics coating**
depth graded Pt/SiC and W/Si coatings

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



**Caltech: focal plane**
CdZnTe detectors

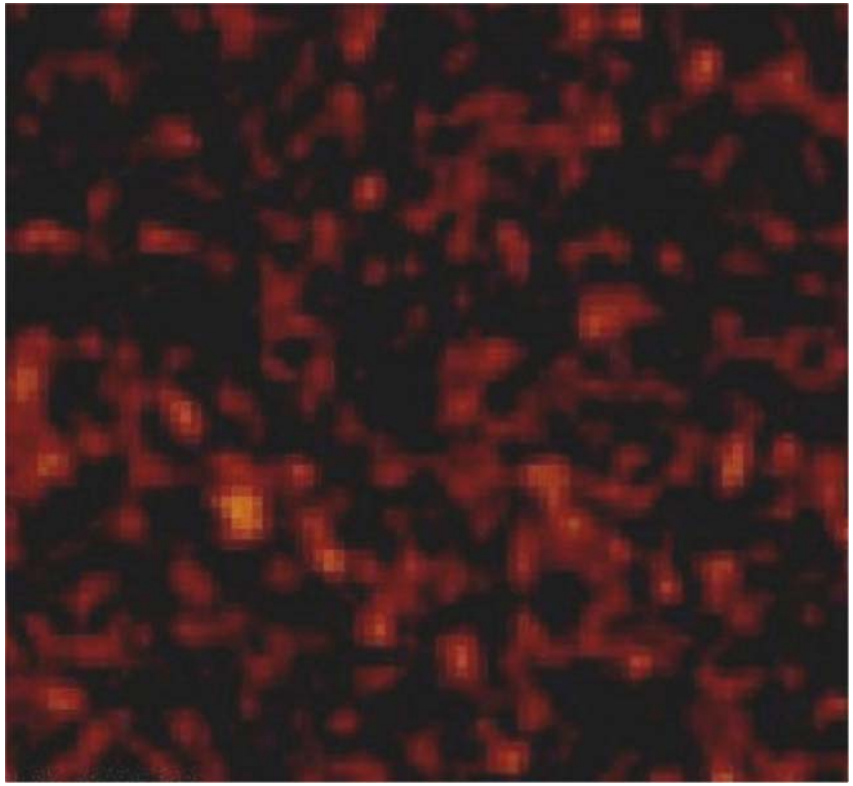
**Columbia: optics assembly**
expected performance ~45 arcsec




| | |
|---|---|
| **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<br>600 eV at 6 keV |
| **Sensitivity (3σ, 1 Ms):** | 2 x $10^{-15}$ erg/cm²/s (6-10 keV)<br>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<br>550 km x 600 km |
| **Mission Lifetime:**<br>**Orbit Lifetime:** | 2 years baseline<br>>7 years orbit lifetime |

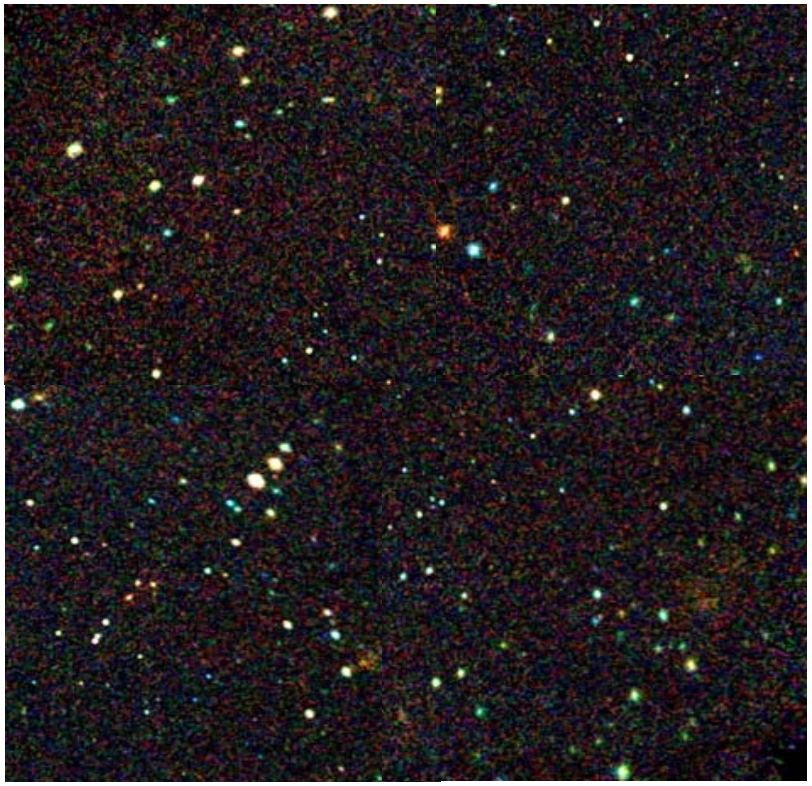
current best estimates (CBEs),
as of September 2009

# INTEGRAL



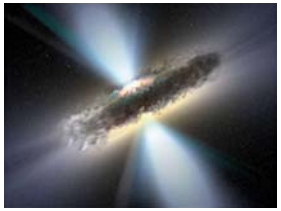
2x2 degrees, 20-40 keV
1.5 month w/ IBIS

# NuSTAR



2x2 degrees
simulated NuSTAR image

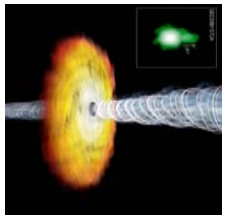
# NuSTAR Baseline Science Plan (2 yr)



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

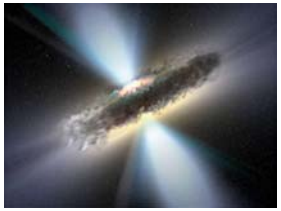
**Objective #2:** How are stellar remnants distributed within the Galaxy and near the Galactic center?

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

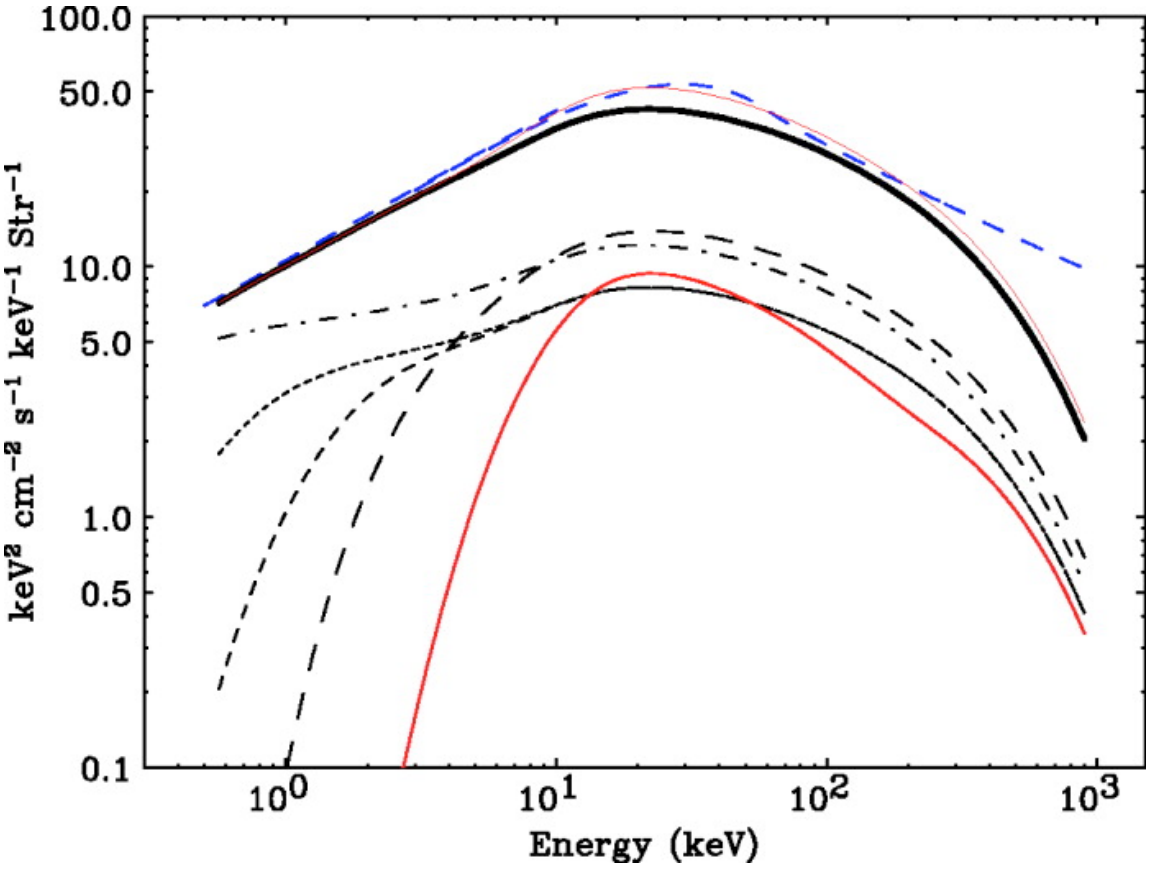


**Objective #4:** What powers the most extreme active galactic nuclei?

*~6 months of unallocated science observing time in first 2 years: for ToO's, additional programs, and/or to respond to primary program*

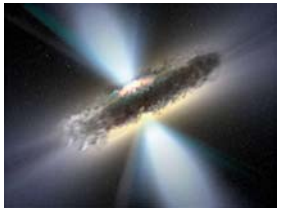


# Objective #1: Extragalactic Surveys

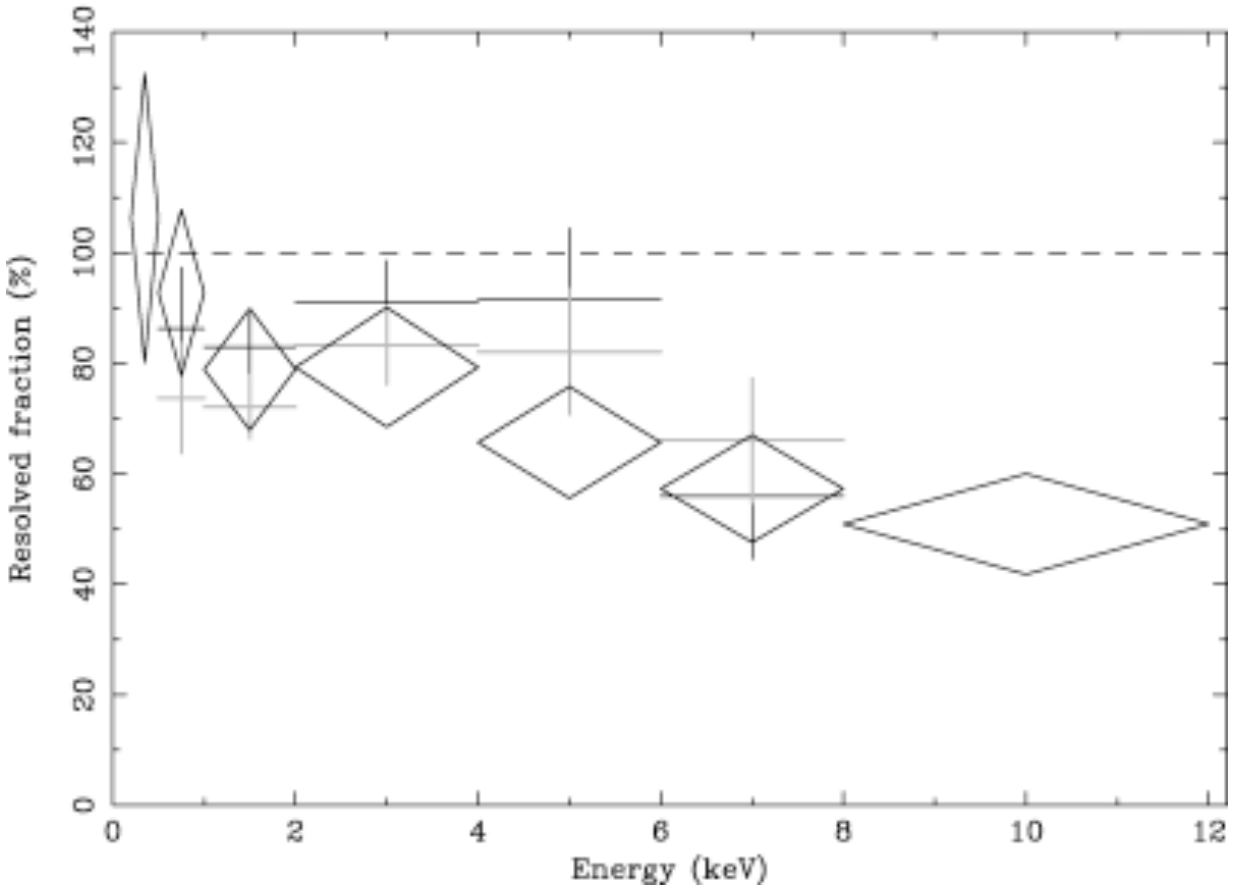



- peaks at ~30 keV
- constrains the accretion history of the universe, e.g., the formation history of supermassive black holes
- requires a population of heavily obscured AGN

Ueda et al. 2003, ApJ, 598, 886



# Objective #1: Extragalactic Surveys




INTEGRAL/Swift

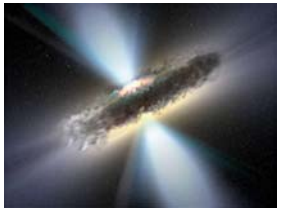
**1-2 %**

30 keV

pluses = Chandra Deep Fields/GOODS

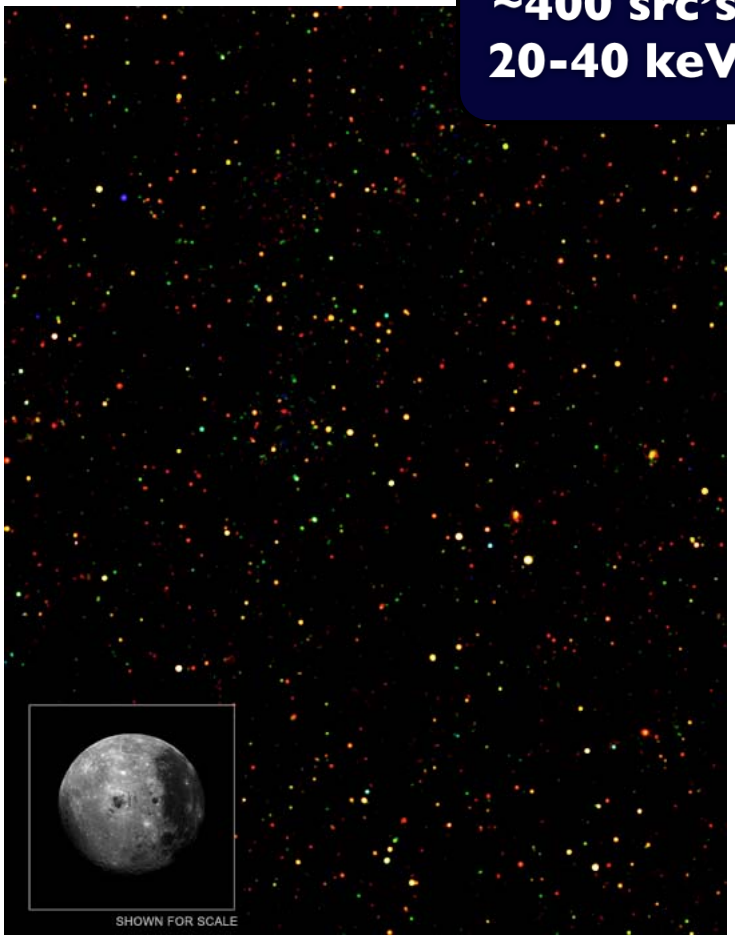
diamond = XMM Lockman Hole

Worsley et al. 2005, MNRAS, 357, 1281

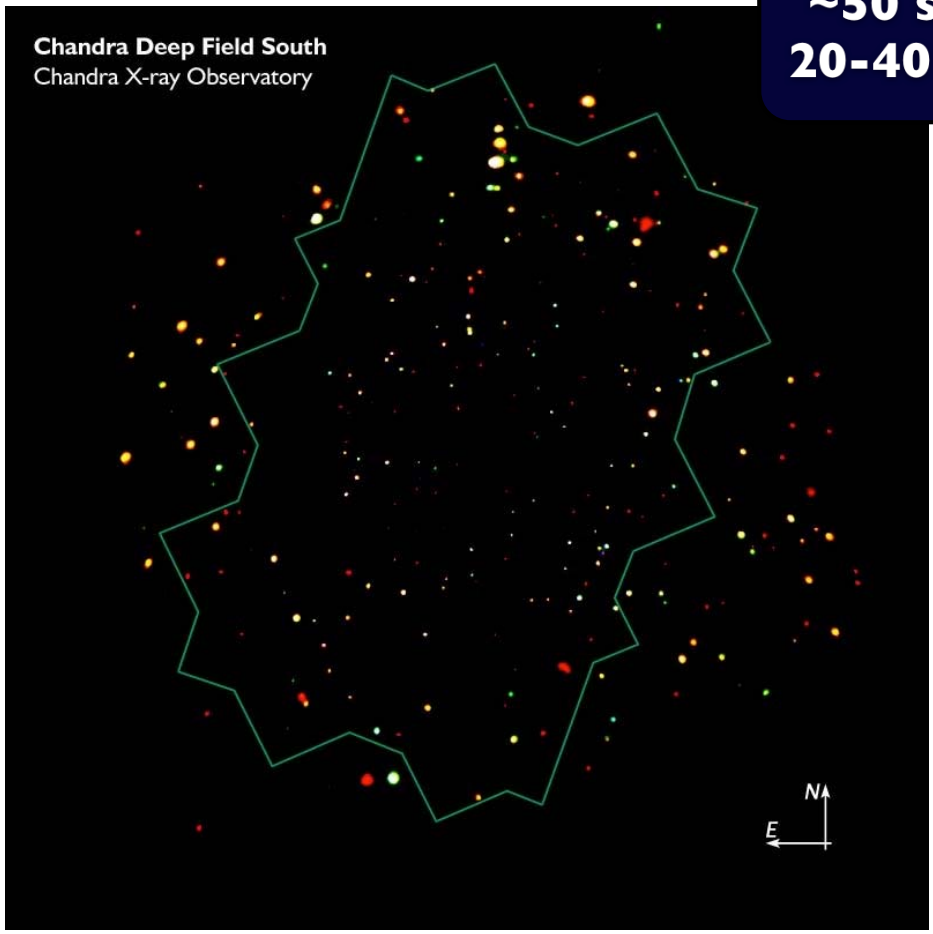


# Objective #1: Extragalactic Surveys

~400 src's
20-40 keV




~50 src's
20-40 keV



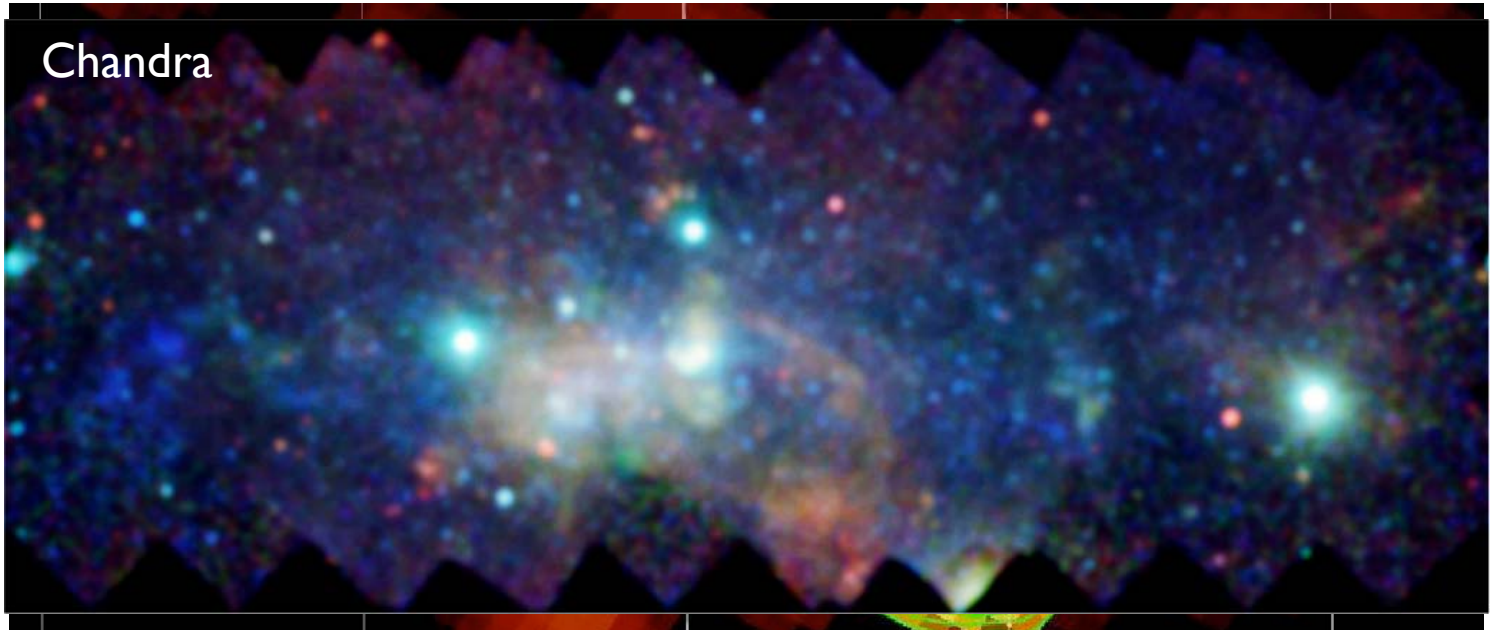

XBoötes Field
8.5 deg$^2$

COSMOS Field
1-2 deg$^2$

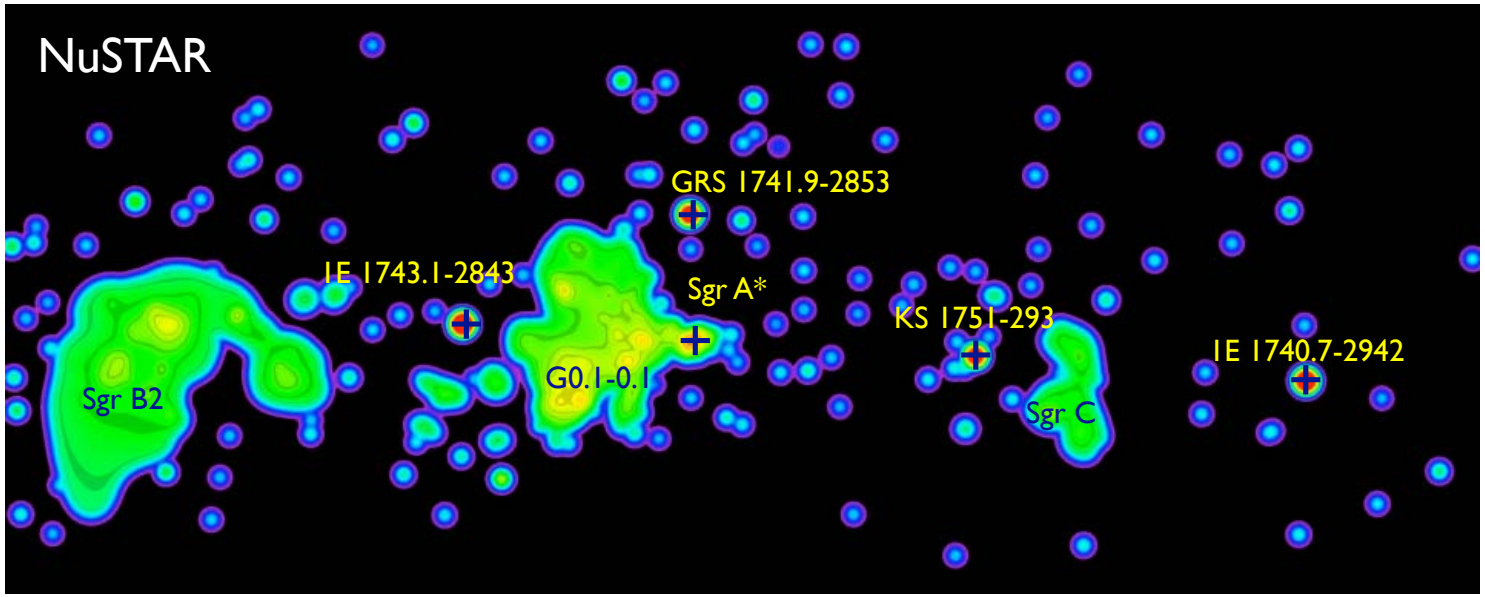
GOODS Fields
300 arcmin$^2$

~50% of CXB

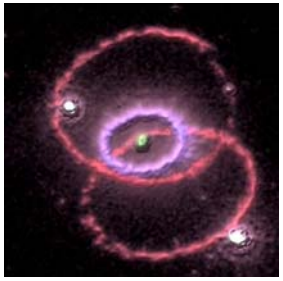
# Objective #2: Galactic Surveys



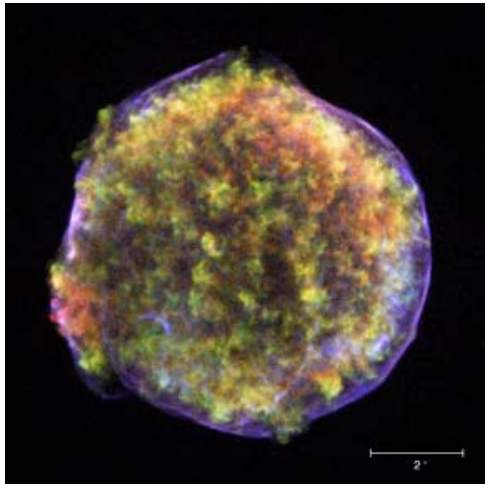

Galactic surveys:
*locate remnants of collapsed stars (white dwarfs, neutron stars, black holes) to study the endpoints of stellar evolution*



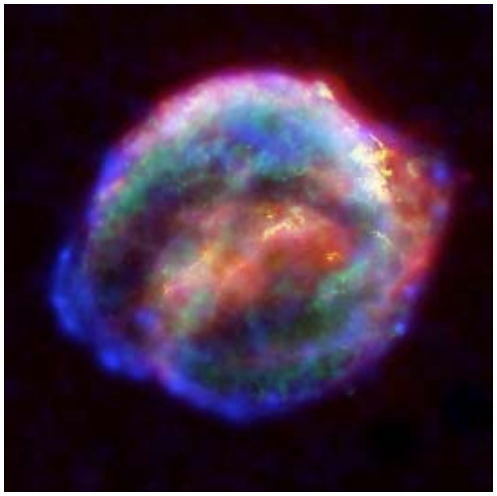

NuSTAR simulation
of the Galactic center
2° x 0.8°
(M. Muno)



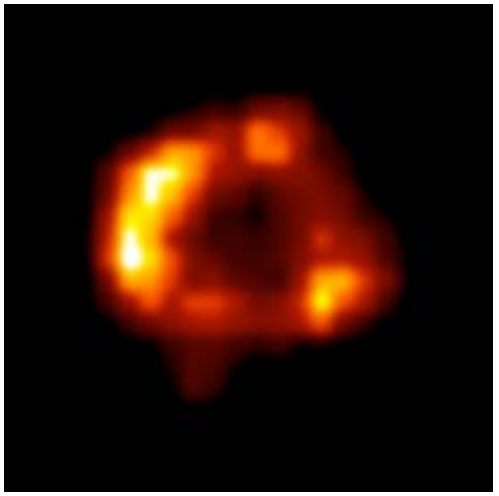
# Objective #3: Supernova Survey



*Tycho*



*Kepler*

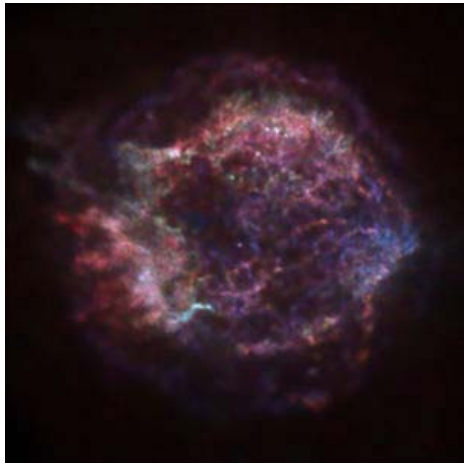


*SN 1987A*

NuSTAR will map historic SNe

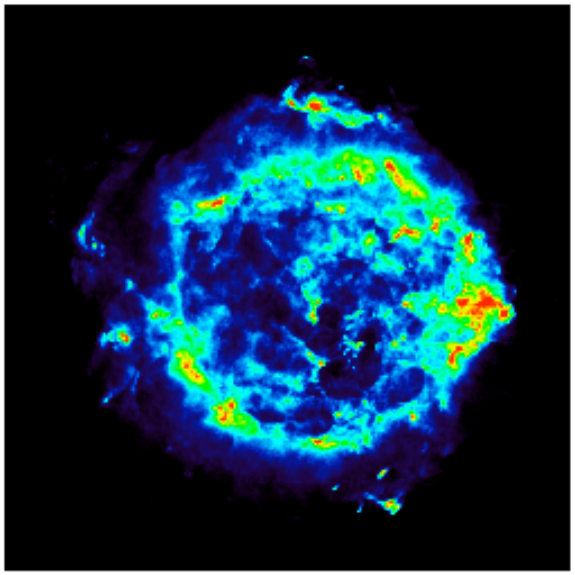
$^{44}$Ti lines at 68 and 78 keV
provides important, new diagnostics

<24 hr ToO capability to observe Galactic core collape SNe and SNe Ia out to Virgo, should they occur during the lifetime of the mission



*Cassiopeia A*

# *Cassiopeia A*



Radio wave (VLBI)

Infrared radiation (Spitzer)

Visible light (Hubble)

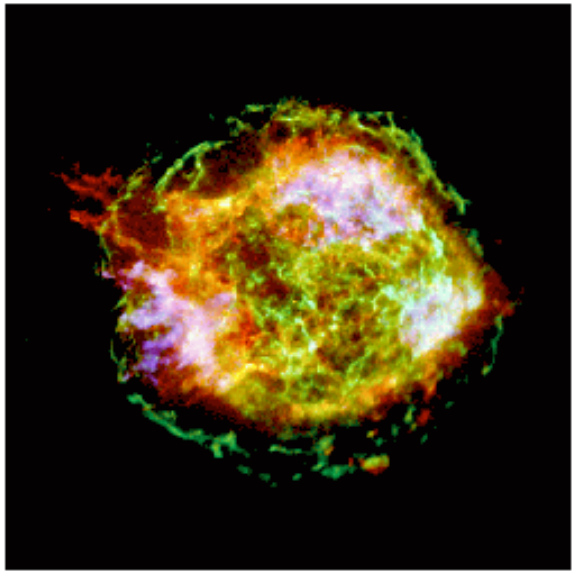
***Massive star uses up its fuel.***

↓

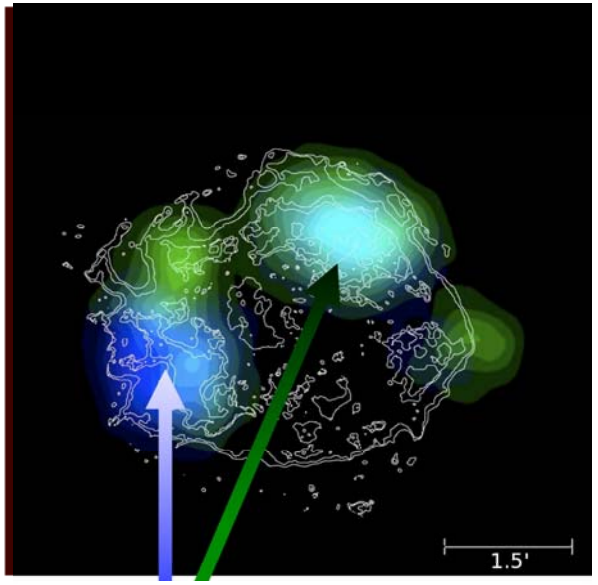
***Explosion: A supernova.***

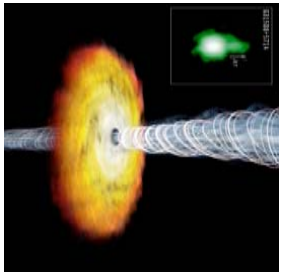
↓

***Expanding shell slams into surrounding medium at supersonic speed. Heats up and glows.***



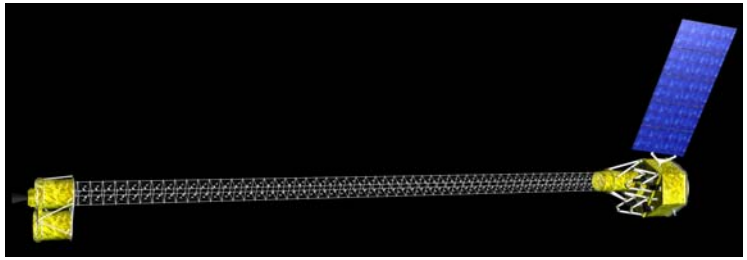
Low–energy X–ray (Chandra)





# 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



NuSTAR
X-ray (keV)

Fermi
γ-ray (MeV-GeV)

HESS, Veritas
γ-ray (TeV)

# Other Potential Programs

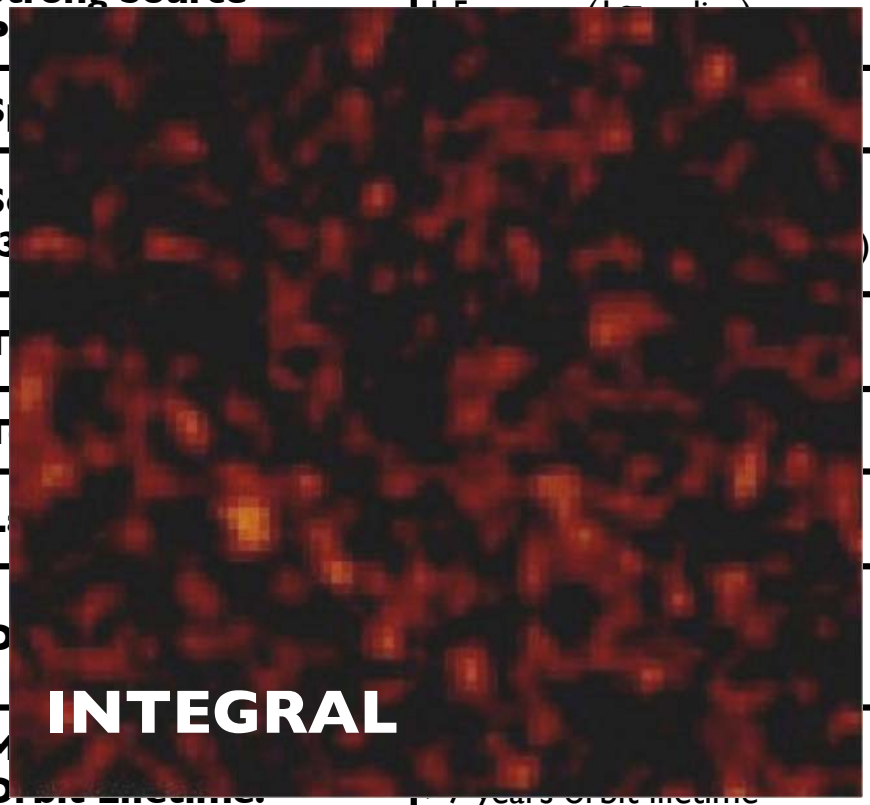
- *Particle acceleration in the solar corona*
- *Axion decay in the Sun*
- *Hard X-ray emission from protostars and stellar flares*
- *Galactic TeV sources*
- *Pulsar wind nebulae*
- *Galactic black holes in quiescence*
- *X-ray bursters*
- *Cyclotron lines in X-ray pulsars*
- *Magnetars*
- *Ultraluminous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

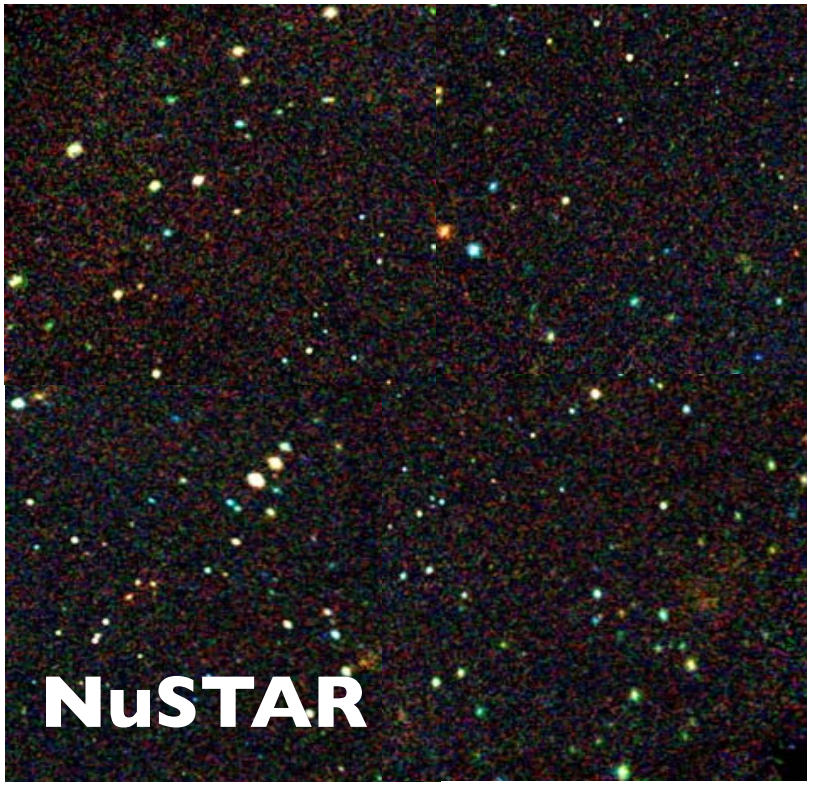
# Summary

| | |
|---|---|
| **Energy Range:** | 6-80 keV |
| **Angular Resolution:** | 45 arcsec (HPD) |
| **Field of View (50% response):** | 10 arcmin (10 keV)<br>8 arcmin (40 keV)<br>6 arcmin (68 keV) |
| **Strong Source P** | |
| **S** | |
| **S (3** | ) |
| **T** | |
| **T** | |
| **L** | |
| **O** | |
| **M O** | 7 years orbit lifetime |
| **Saturating Count Rate:** | 250 cts/sec in HPD |

current best estimates (CBE),
as of September 2009

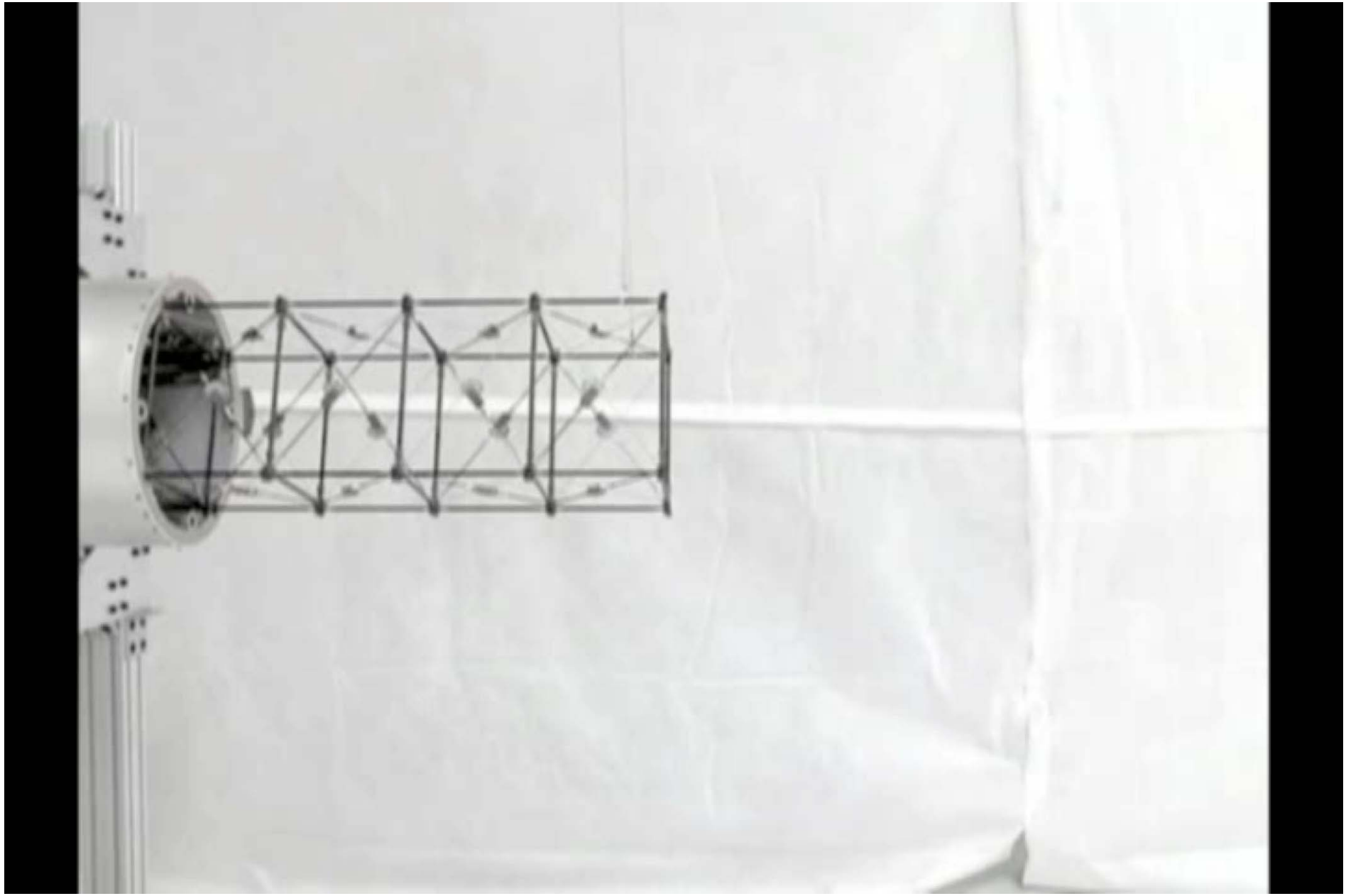
**NuSTAR will bring the high energy universe into focus**




two orders of magnitude improvement in sensitivity over any previous hard X-ray mission

http://www.nustar.caltech.edu/



Flight mast deployment test