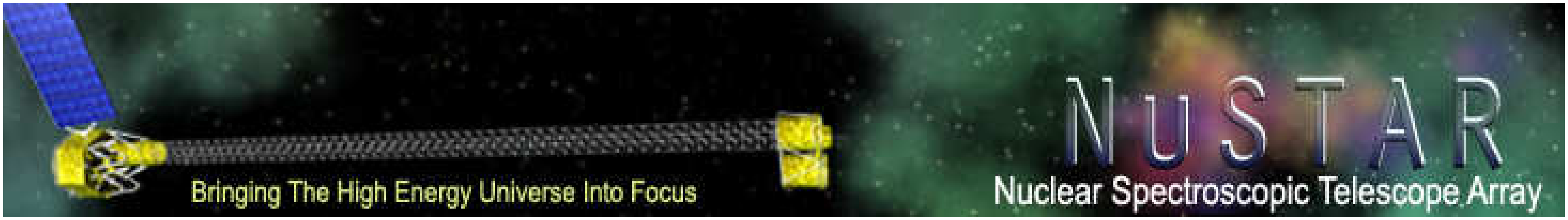
National Aeronautics and Space Administration



The Nuclear Spectroscopic Telescope Array (NuSTAR)

A New View of the High Energy Universe

Yunjin Kim

Jet Propulsion Laboratory

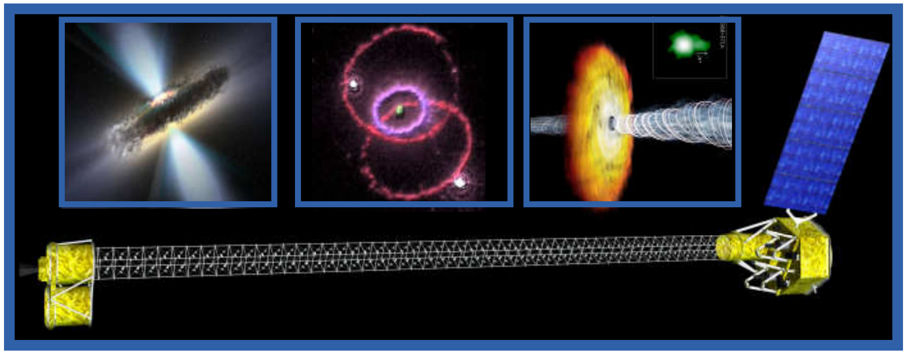
California Institute of Technology

and NuSTAR Team

Project Overview (1)

Salient Features

- PI-led (PI: Fiona Harrison, Caltech) SMEX mission
- *NuSTAR* will carry the first high-energy X-ray focusing telescope
- *NuSTAR* partners include Caltech, JPL, GSFC, Orbital, ATK, UCB, DNSC and Columbia University
- JPL managed project
- Launch readiness date: August 15, 2011
- Science operations: 2 years



Partners:
Caltech, JPL, Orbital Sciences Corporation, GSFC, ATK-Goleta, UC Berkeley, Danish Technical University, Columbia University

Science

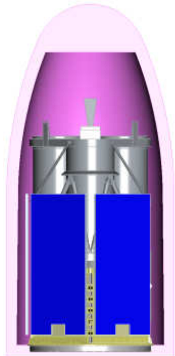
- ***NuSTAR will open a new window on the Universe by making maps of the high-energy X-ray sky (6 keV to 79 keV) that are more than 100 times deeper than from any previous mission***
- ***Objective 1****: Determine how massive black holes are distributed through the cosmos, and how they influence the formation of galaxies like our own*
- ***Objective 2****: Understand how stars explode and forge the elements that compose the Earth*
- ***Objective 3****: Determine what powers the most extreme active black holes*

Mission Overview (2)

<u>Orbital</u>

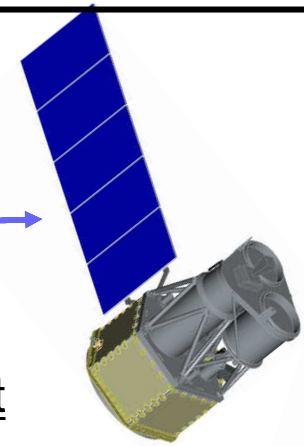
5° or 27° inclination

≥550 km circular



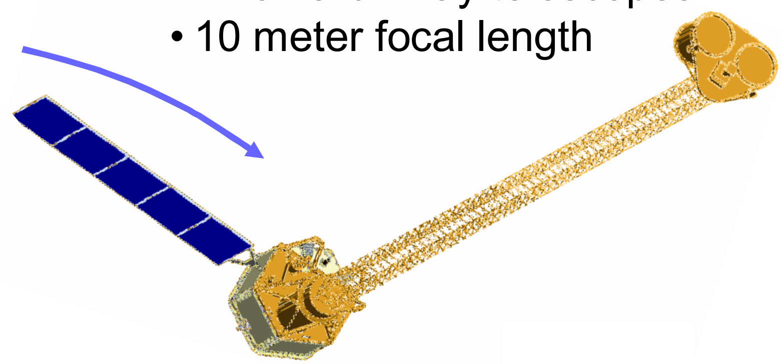
<u>Spacecraft</u>

- Three-axis attitude control



<u>Instrument</u>

- Two hard x-ray telescopes
- 10 meter focal length

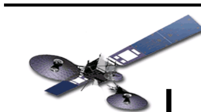


<u>Mission Profile</u>:

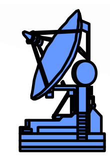
Long pointed observations of survey fields, specific science targets, ToOs.

Daily data downlinks, infrequent uplinks.

<u>Mission Operations</u>



TDRSS



UCB

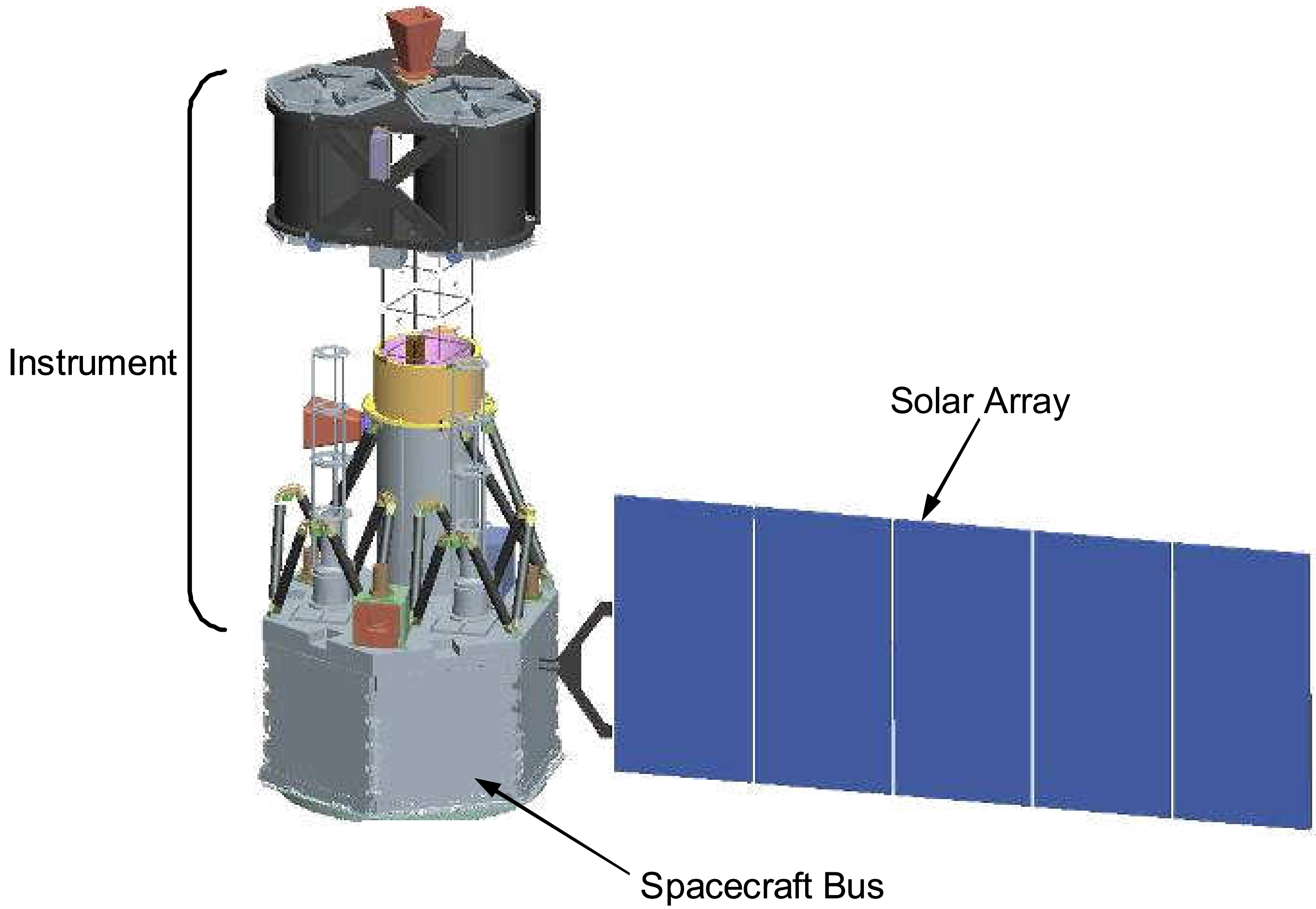
Mission operations center (UCB)

Science operations center (Caltech)

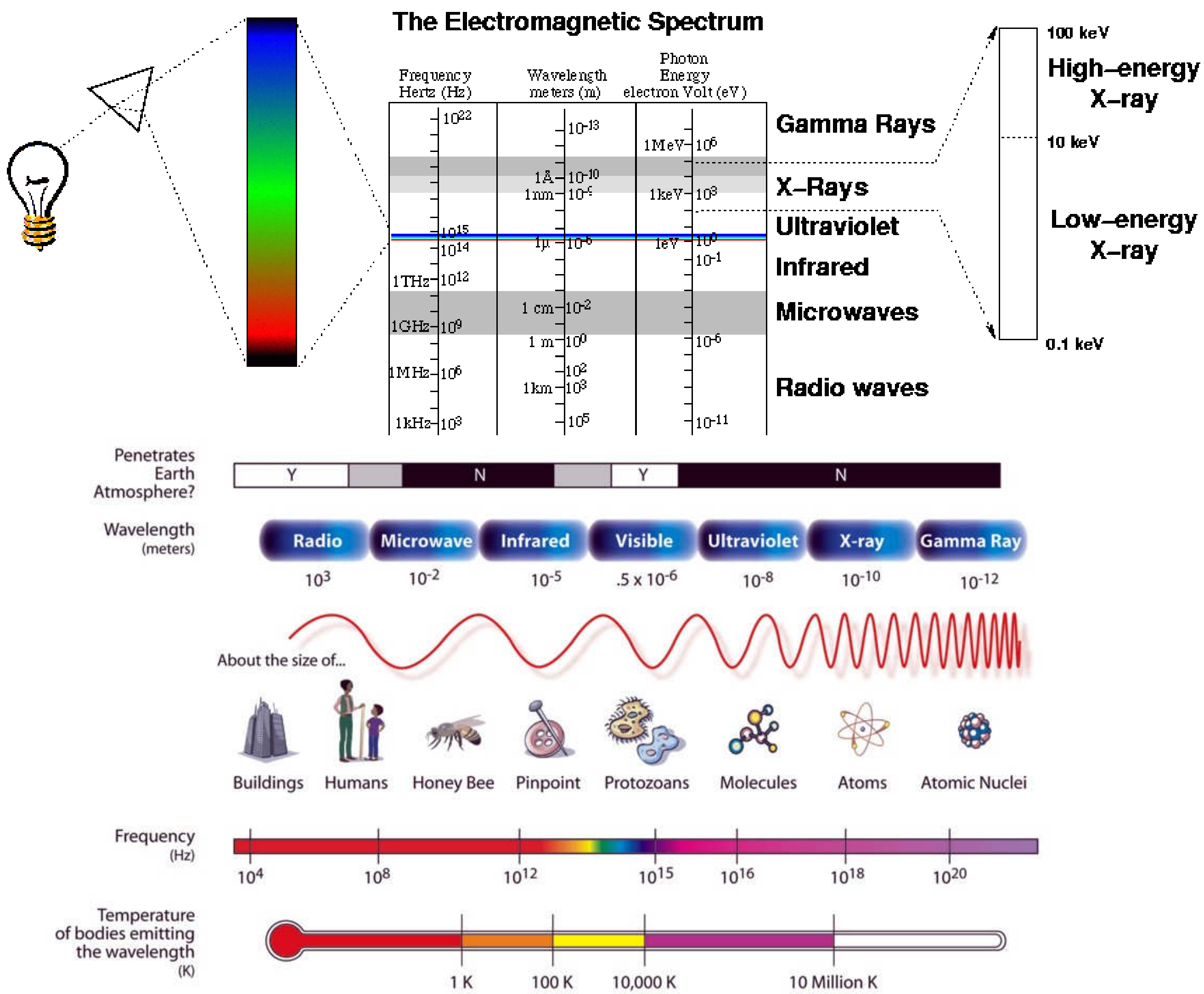
Science team

Science Archive (HEASARC)

NuSTAR Observatory



X-ray Observation



The High Energy Focusing Telescope (HEFT)

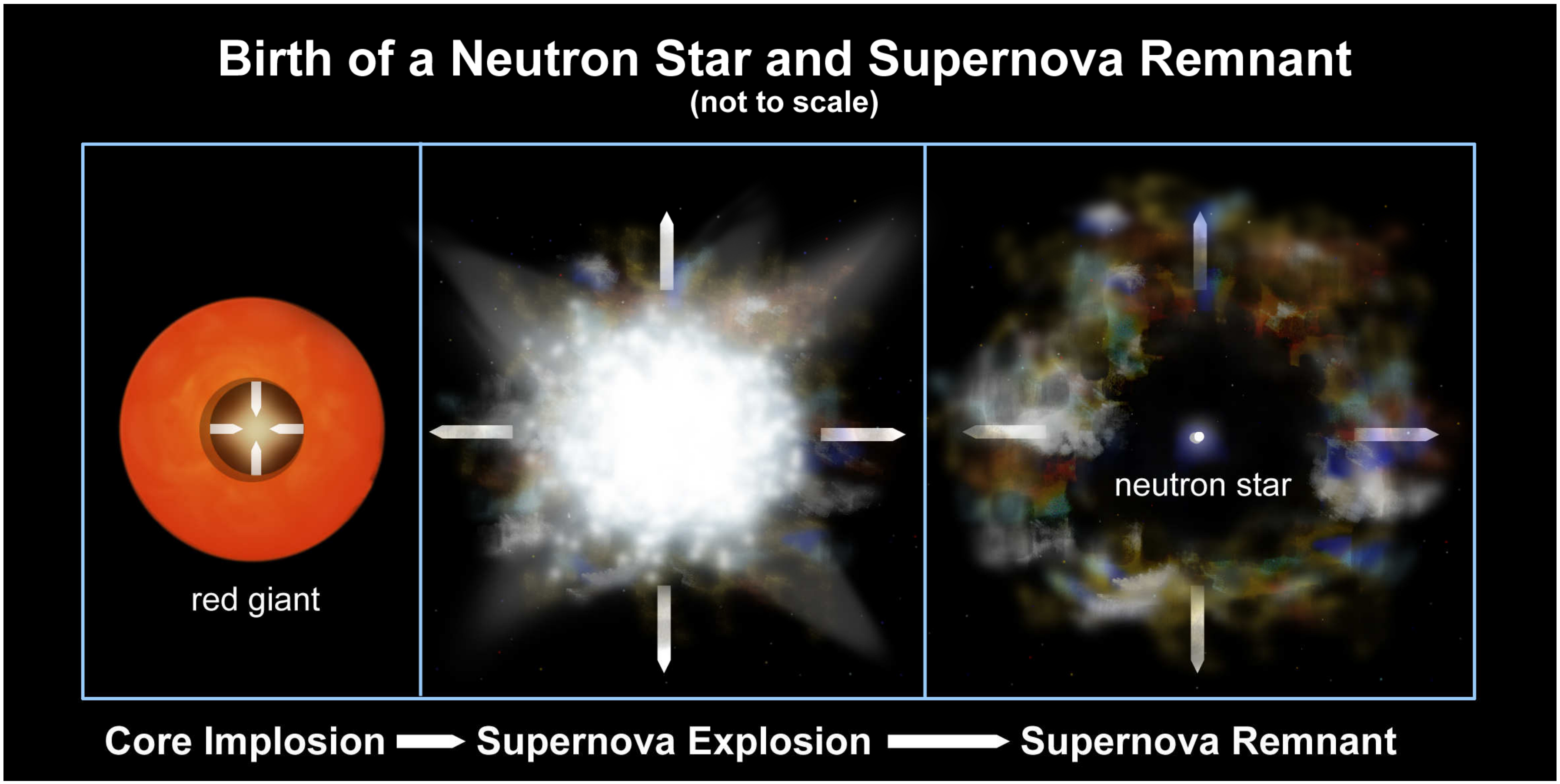
CALIFORNIA INSTITUTE OF TECHNOLOGY 1891

COLUMBIA UNIVERSITY

DANISH NATIONAL SPACE CENTER

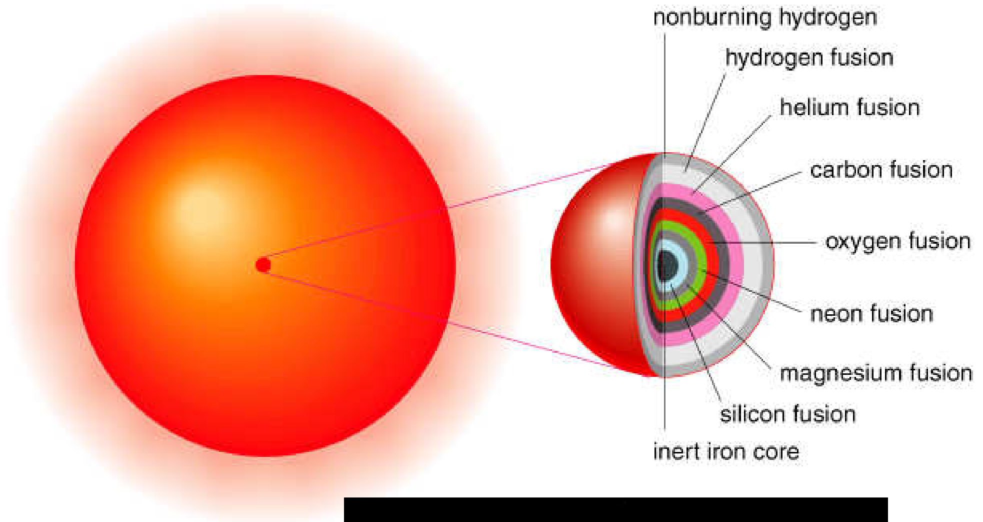
Cal

Birth of a Neutron Star & Supernova Remnant

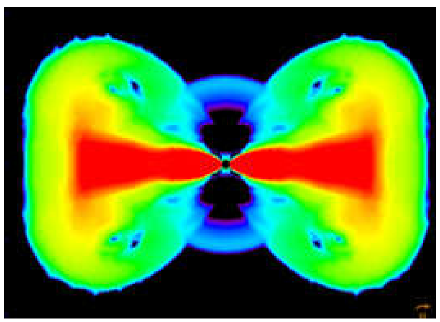


To map young remnants to understand how stars explode and distribute the elements

NuSTAR will be a new tool for looking inside of a supernova; probing down to the very core.



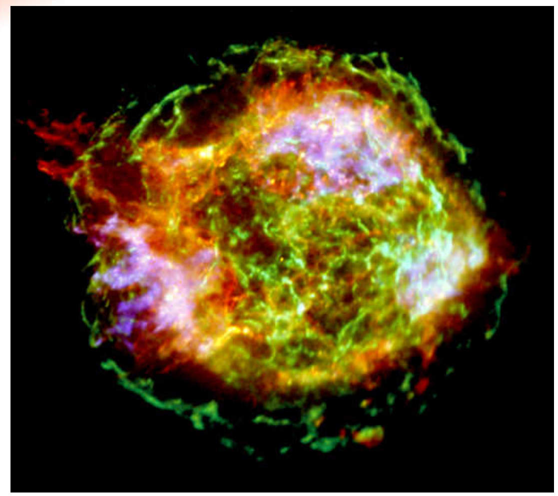
© Addison-Wesley Longman



The explosion (theory)

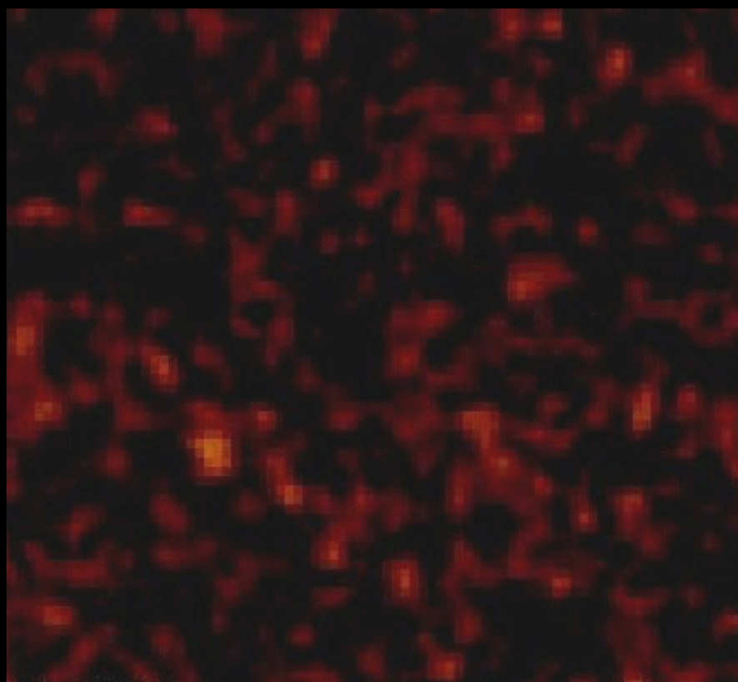
?

The remnant



Steve Boggs, UC Berkeley, for the *NuSTAR* Science Team

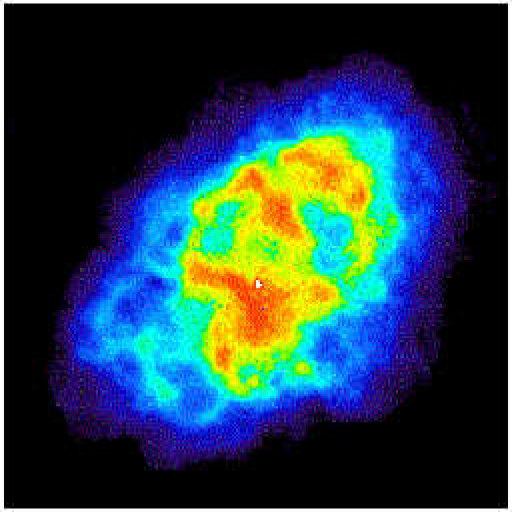
NuSTAR's map of the hard X-ray sky



INTEGRAL/IBIS - 2 x 2 degrees.

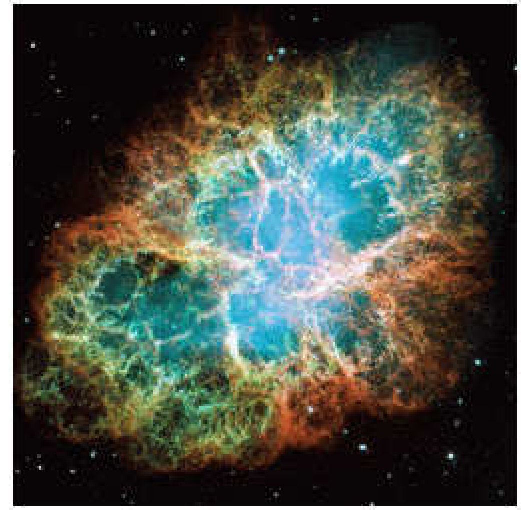
NuSTAR simulated image - 2 x 2 degrees.

Crab Nebula: Remnant of an Exploded Star (Supernova)

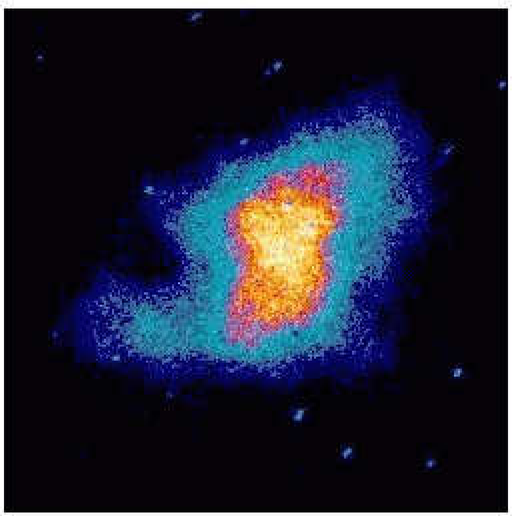


Radio wave (VLA)

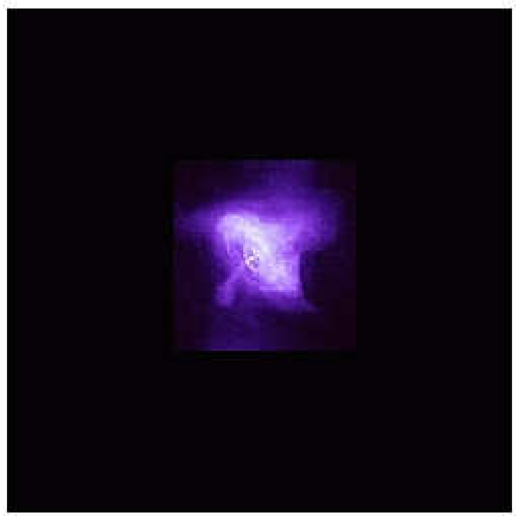
Infrared radiation (Spitzer)



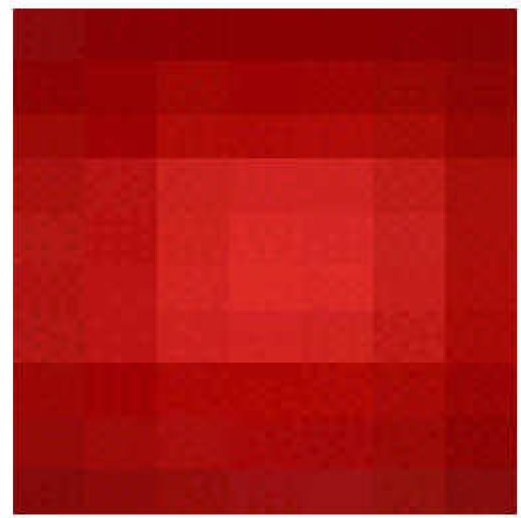
Visible light (Hubble)



Ultraviolet radiation (Astro-1)

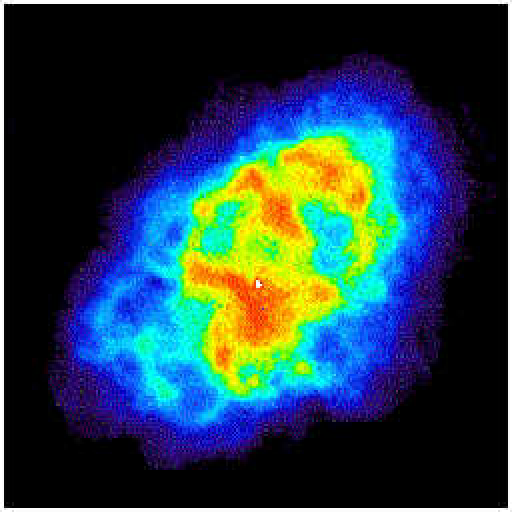


Low-energy X-ray (Chandra)



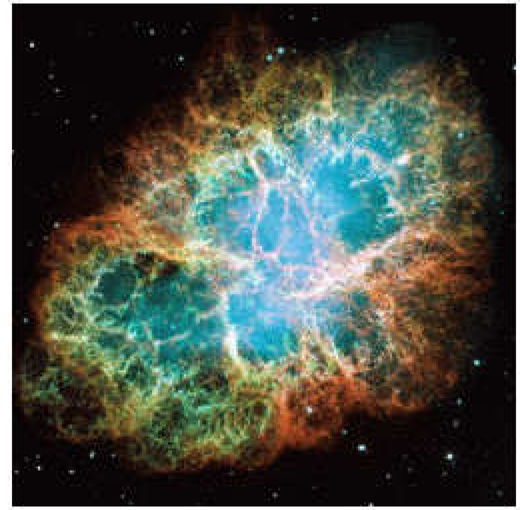
High-energy X-ray (Integral)

Crab Nebula: Remnant of an Exploded Star (Supernova)

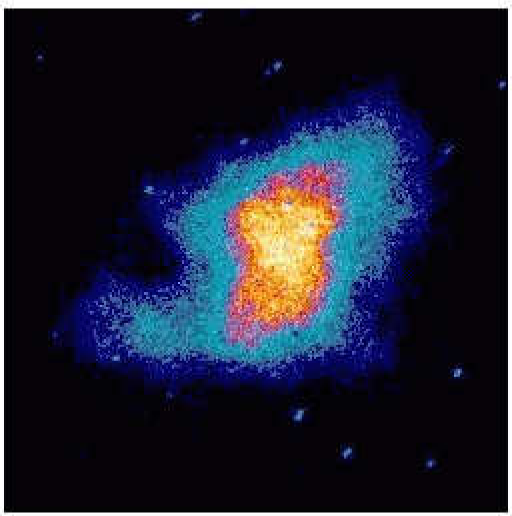


Radio wave (VLA)

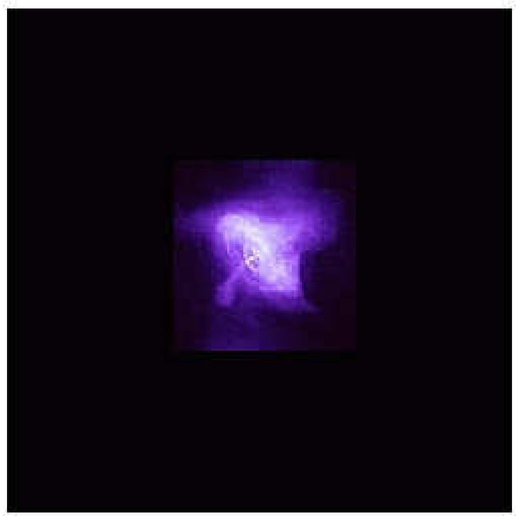
Infrared radiation (Spitzer)



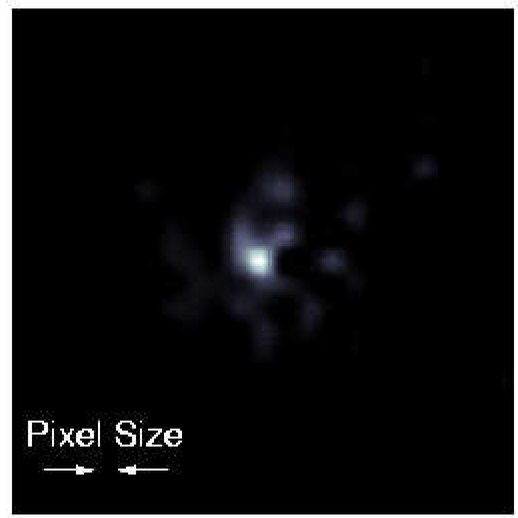
Visible light (Hubble)



Ultraviolet radiation (Astro-1)

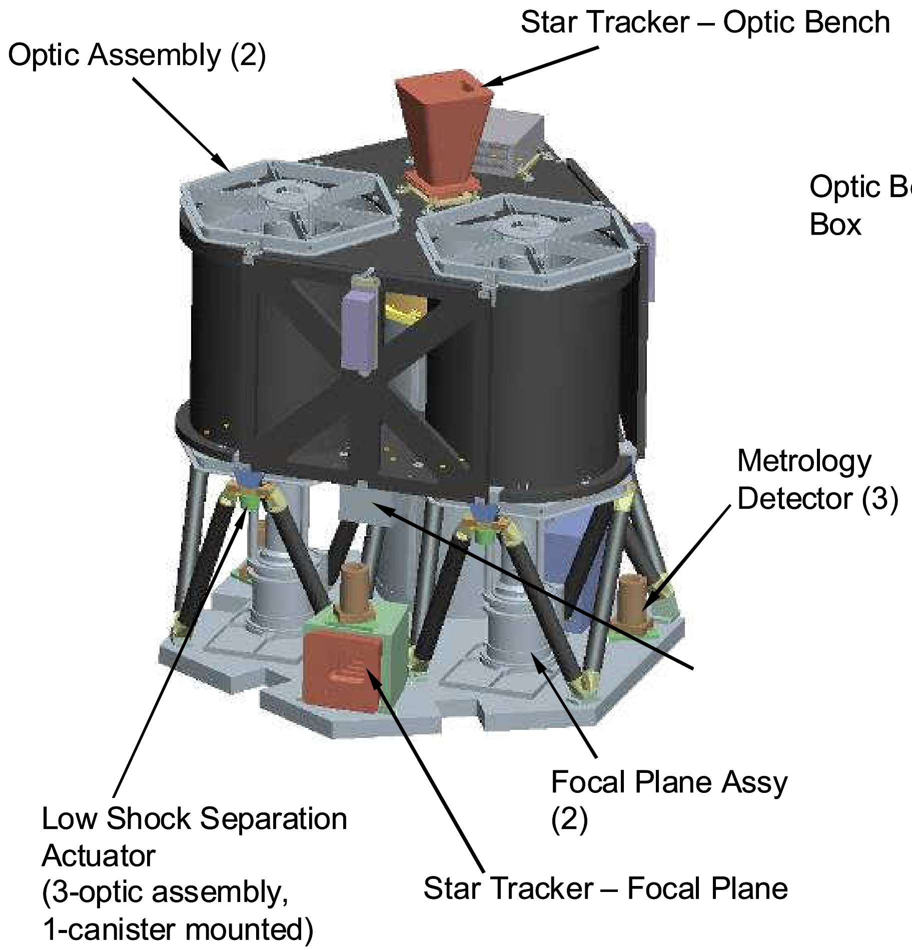


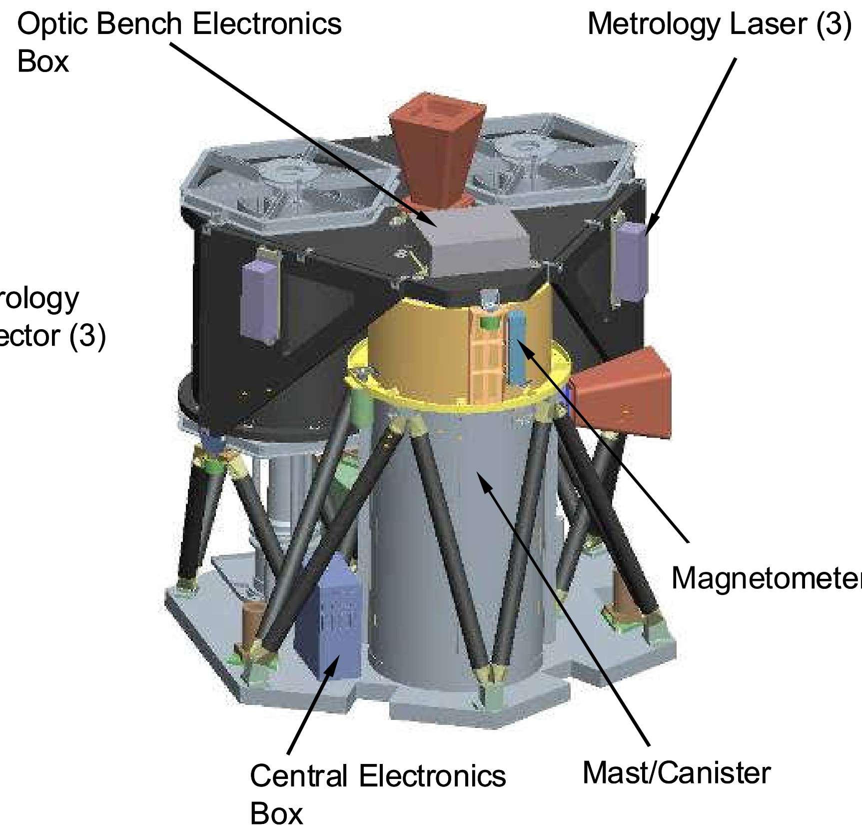
Low-energy X-ray (Chandra)



High-energy X-ray (HEFT)
*** 15 min exposure ***

Instrument

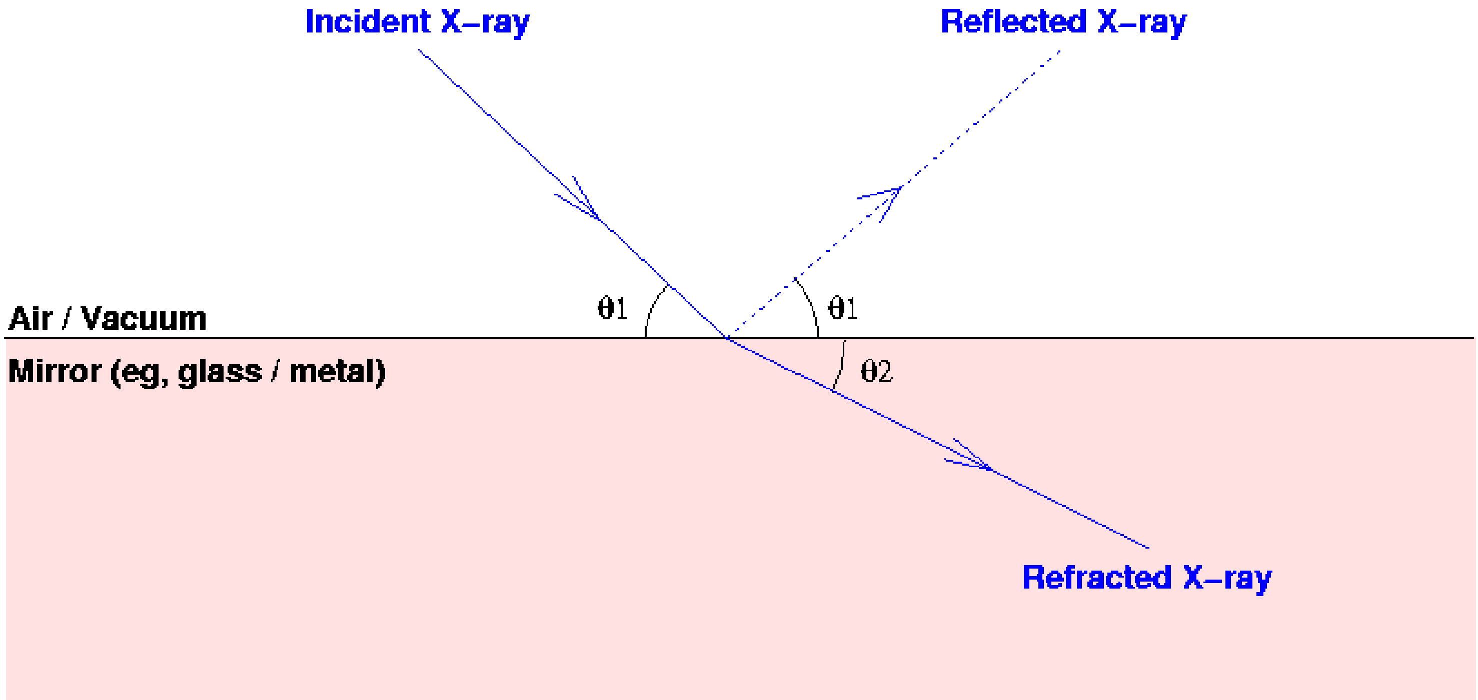

Star Tracker – Optic Bench
Optic Assembly (2)
Metrology Detector (3)
Focal Plane Assy (2)
Low Shock Separation Actuator (3-optic assembly, 1-canister mounted)
Star Tracker – Focal Plane


Optic Bench Electronics Box
Metrology Laser (3)
Magnetometer
Central Electronics Box
Mast/Canister

Optics: X-ray Reflection

X-rays bend slightly toward the surface (opposite from visible light)

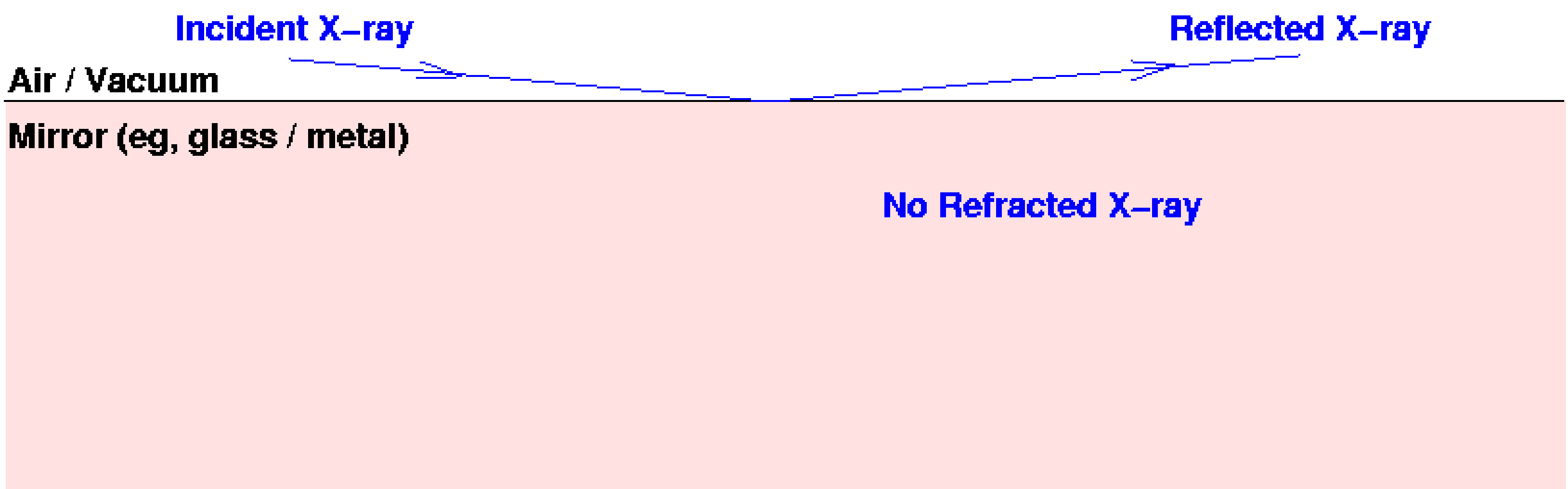
n= 1 - δ - iβ $\delta \sim 10^{-3}$



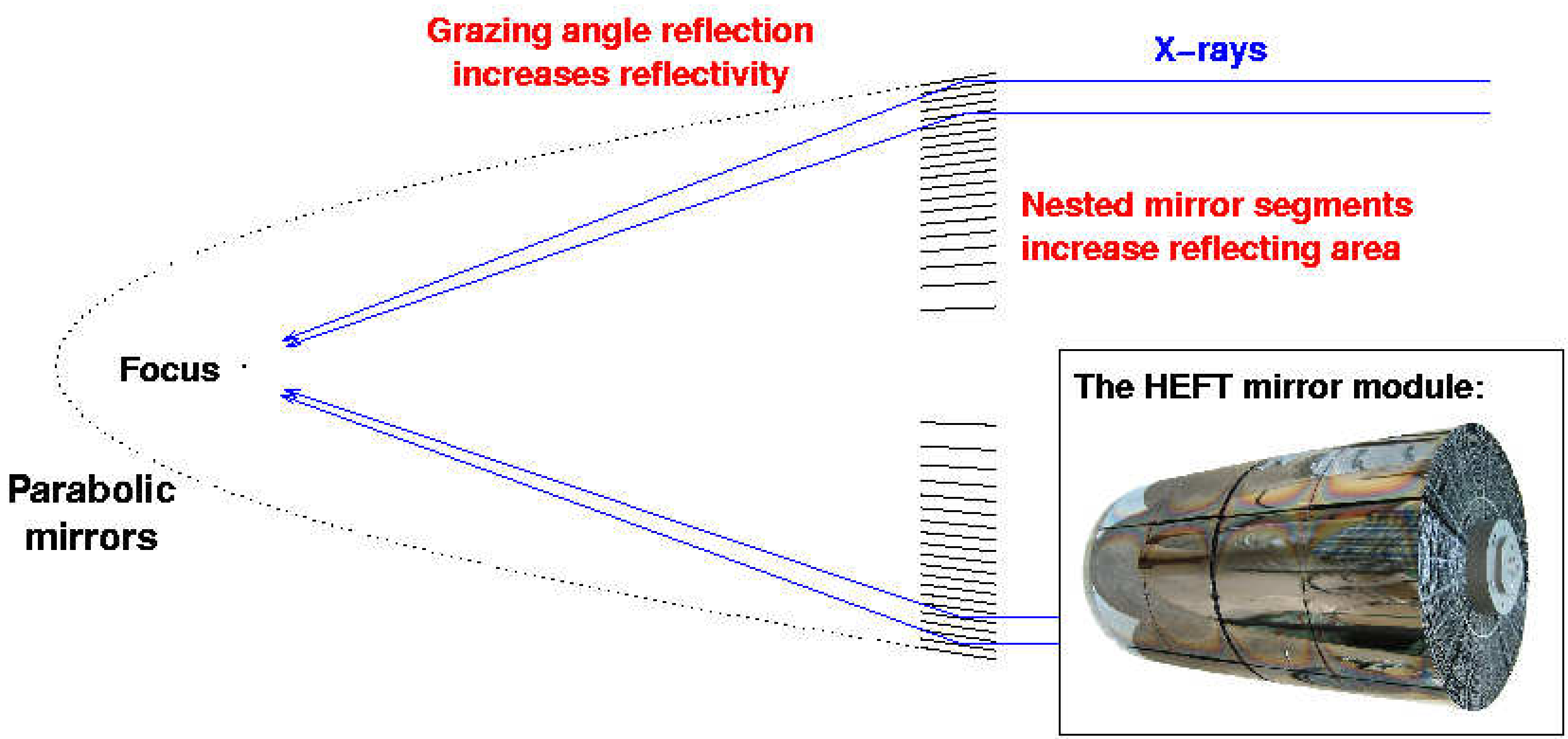
Optics: X-ray Total External Reflection

Critical condition for total external reflection

Critical angles are very small (< 1 degree)

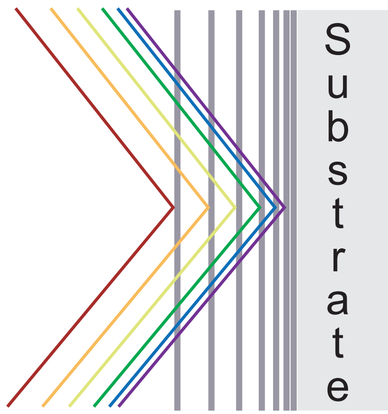


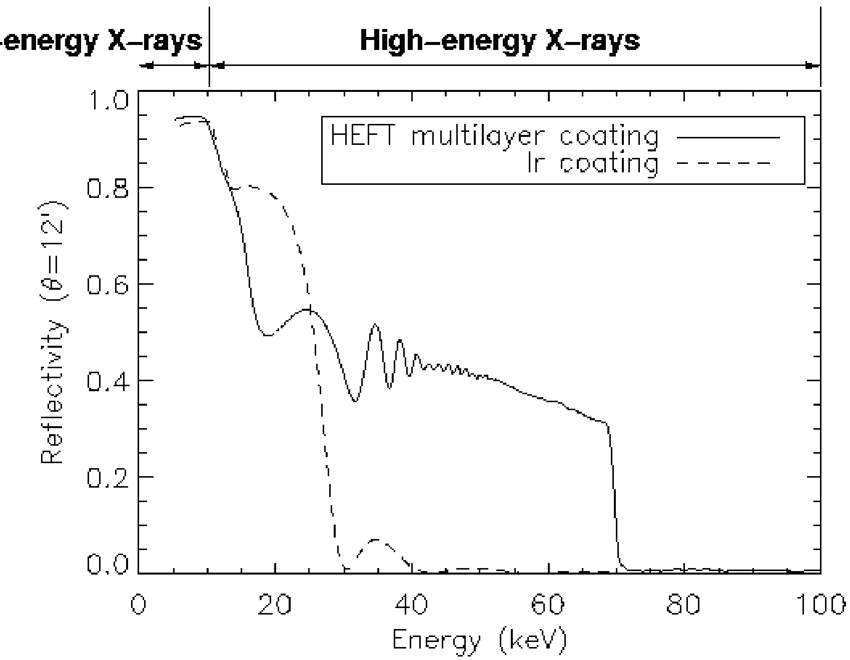
Optics: Nested Mirror Segments



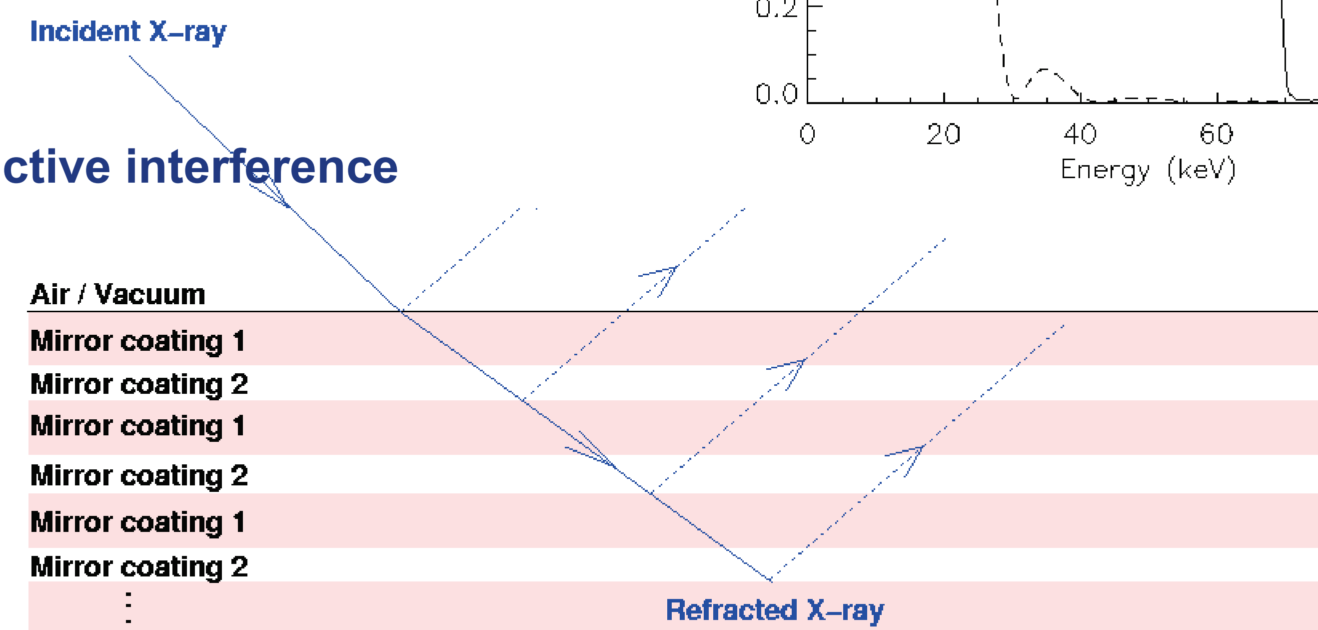
Need two conic sections to eliminate aberrations

Optics: Multilayer Coating

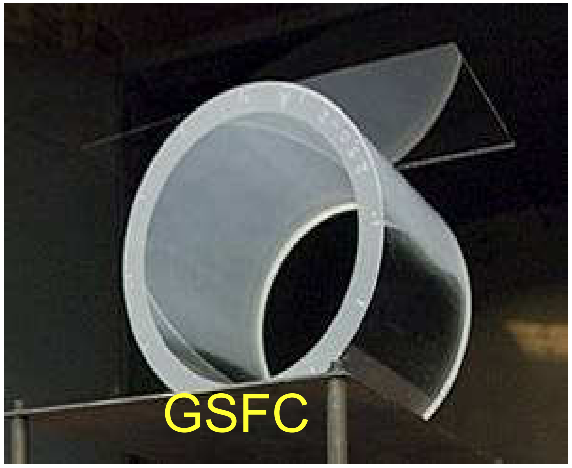


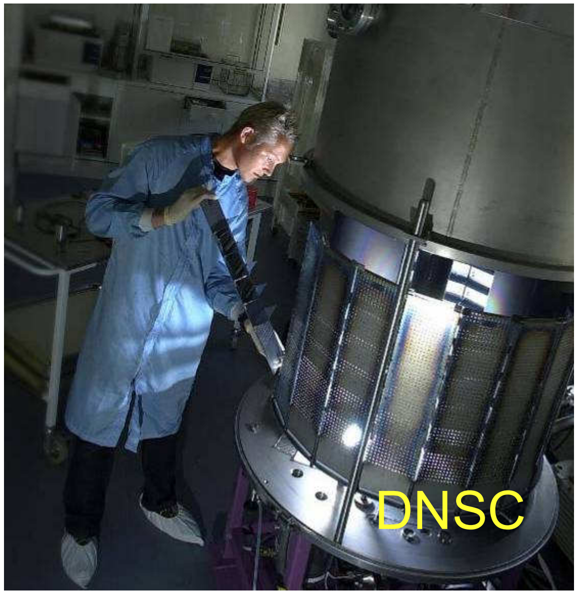


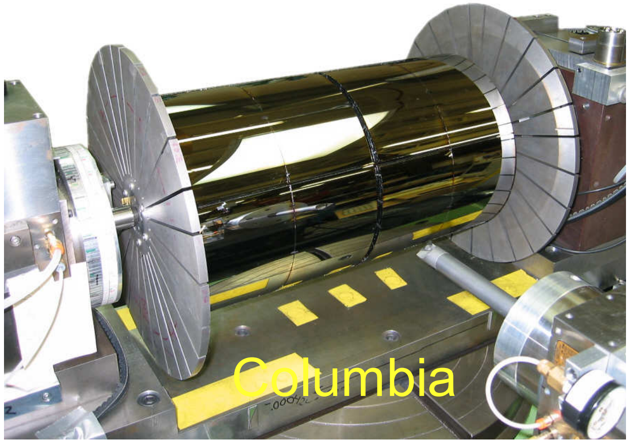
Constructive interference



Optics Construction



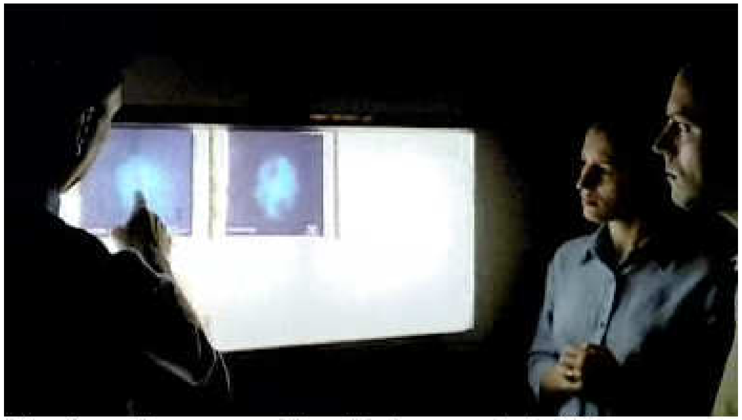




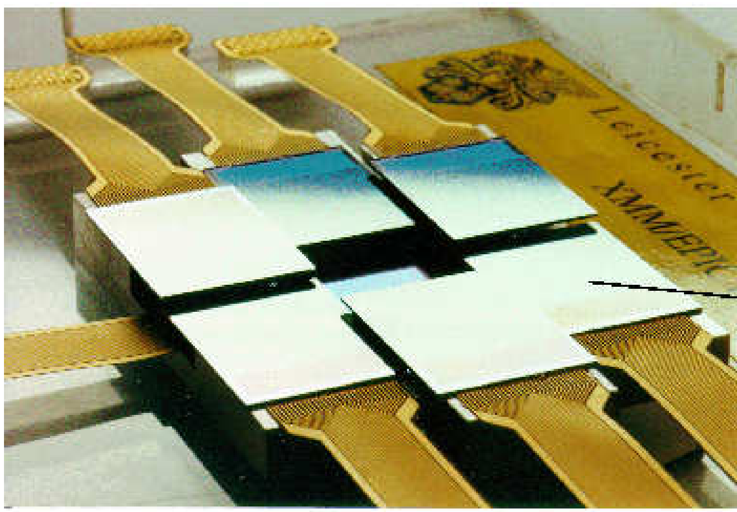
Combine small angles with multiayer coatings

- many nested shells (72 HEFT, 130 NuSTAR)
- coatings with up to 700 layer pairs
- thinnest pairs: 25 angstroms!

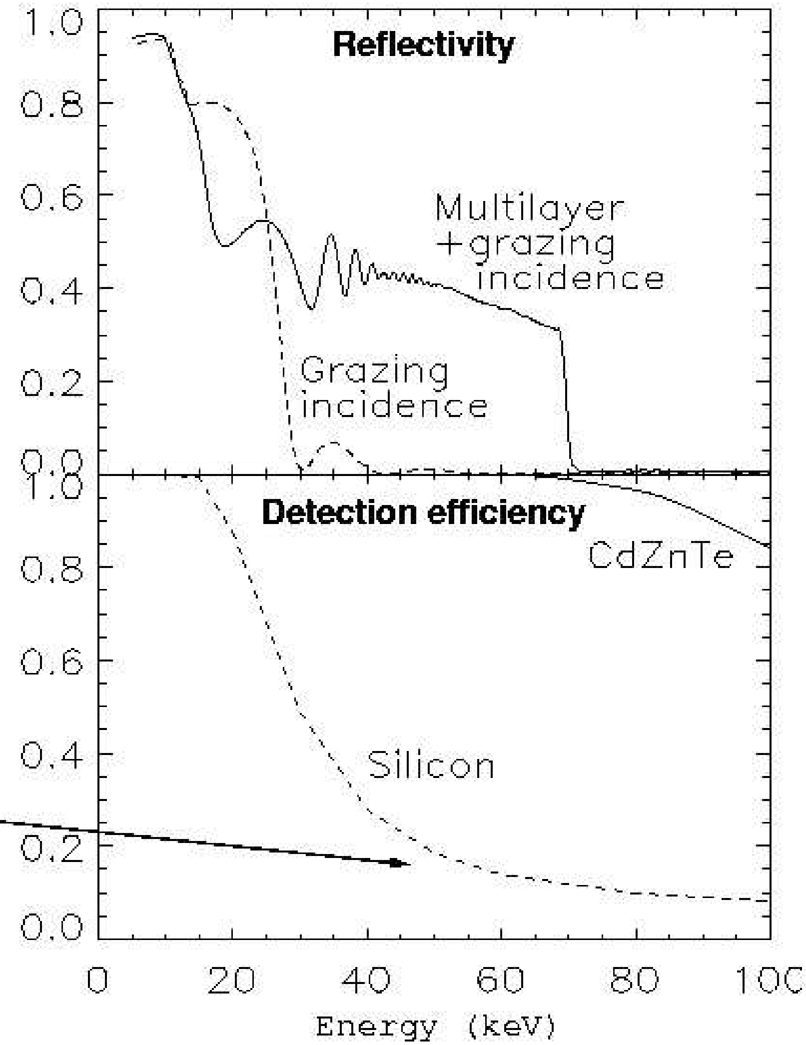
Detector: CdZnTe



Doctors' approach: photographic film
Efficiency: 2%

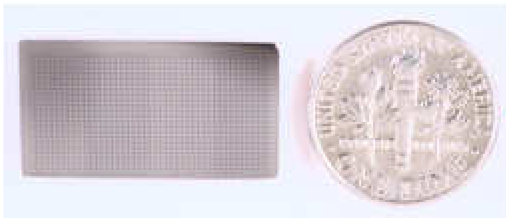


Low–energy X–ray astronomy: silicon CCDs
Efficiency for high–energy X–rays: 10%

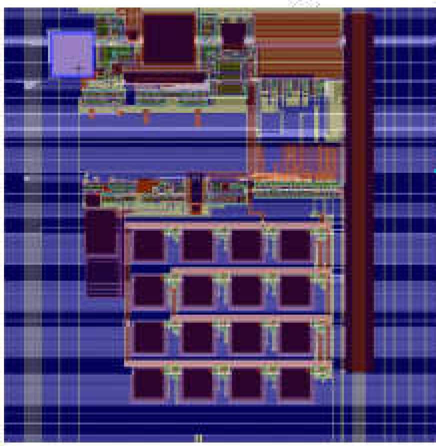


Conventional detectors are too inefficient.

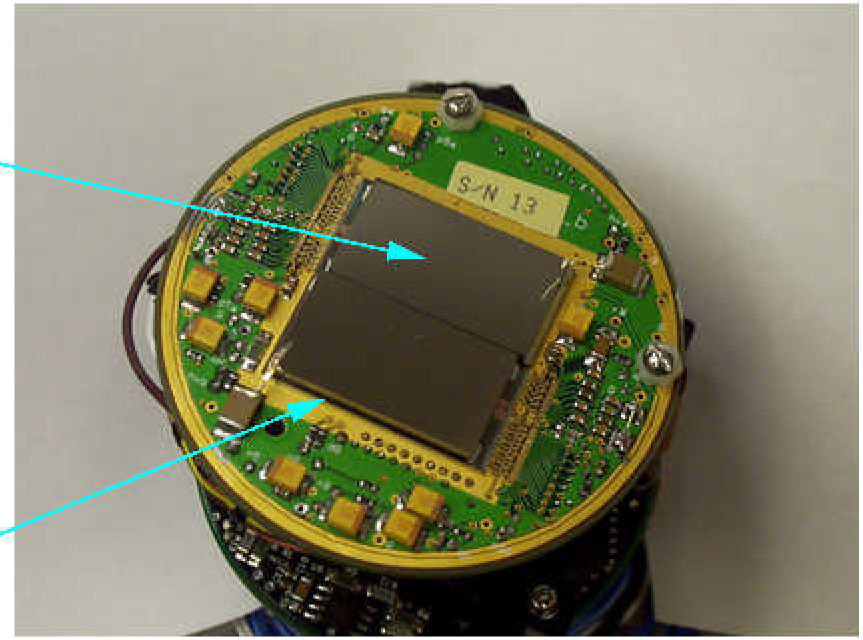
Focal Plane Detector



Cadmium zinc telluride (CdZnTe):
High atomic numbers (Z=48,30,52)
=> High electron binding energy
=> Over 99% efficiency in trapping high–energy X–rays.

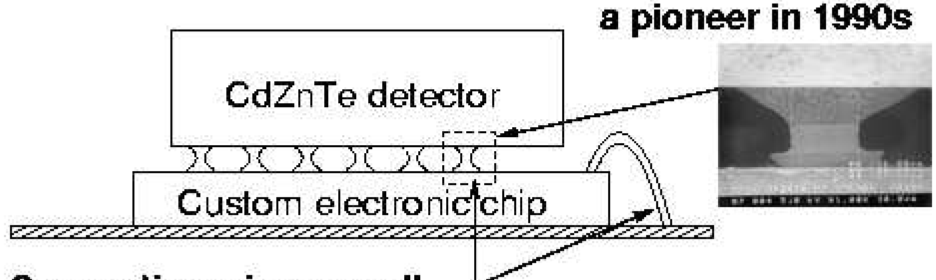


Underneath: Custom electronics for X–ray detection and amplification; built as integrated circuit (ASIC); compact, low–power, low–noise.



Side view schematics:

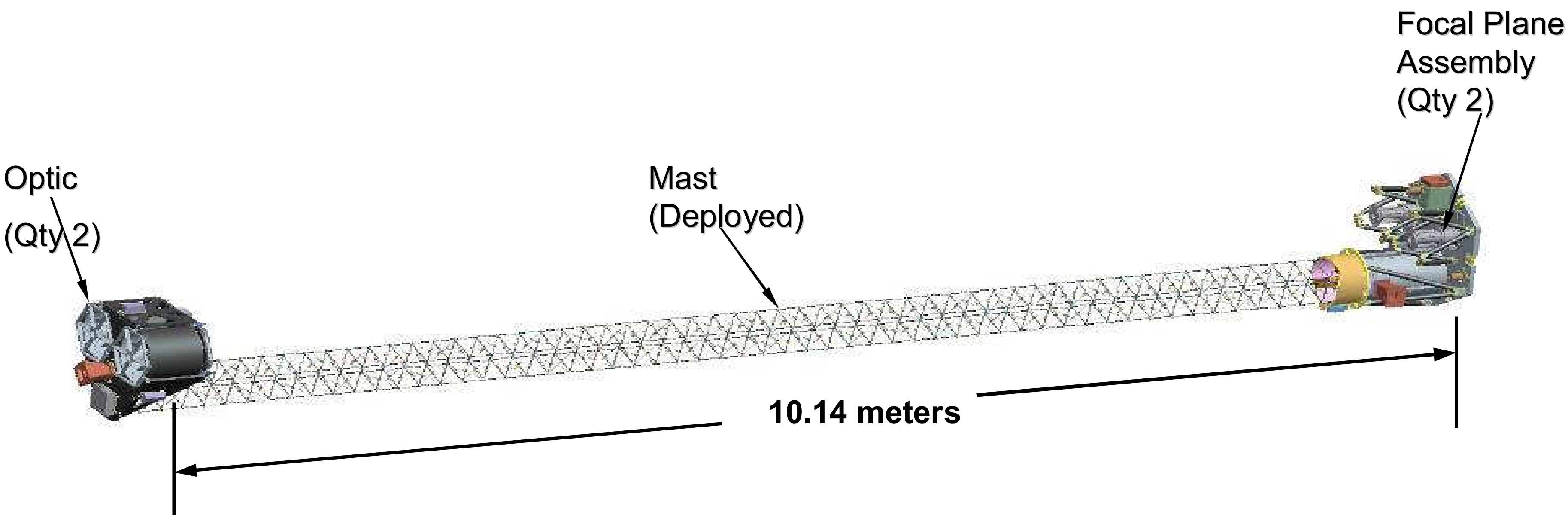
Flip–chip bonding: a pioneer in 1990s



Connecting wires are all narrower than human hair

Mast: Focal Length

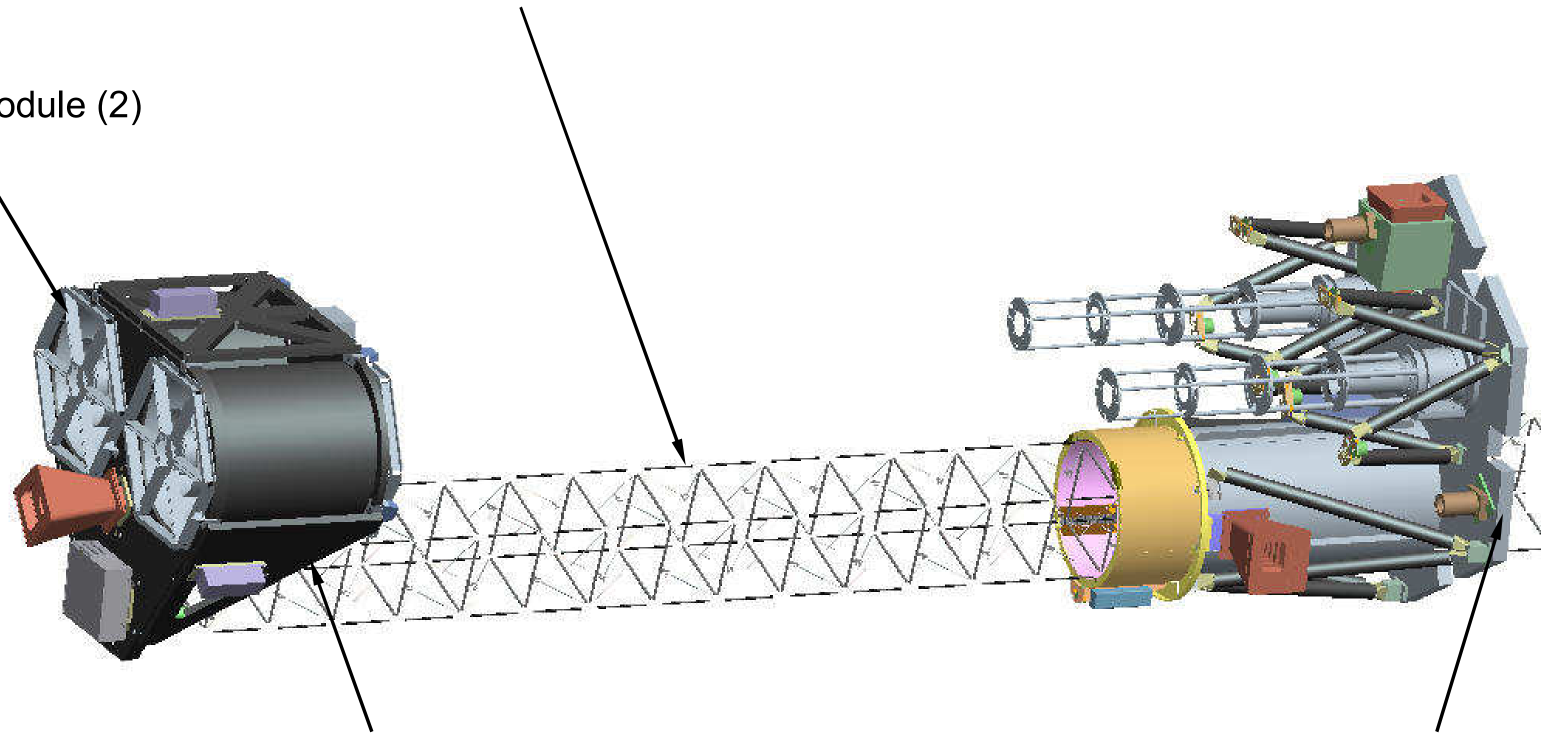
- The thermally stable deployable mast provides a 10.14 meter focal length between the tip-mounted optic assemblies and their corresponding base-mounted focal plane assemblies



Mast: Deployment

Mast and Adjustment Mechanism - The mast and adjustment mechanism are responsible for providing a stable, 10.14 meter separation between the focal plane assemblies and the tip mounted optic modules

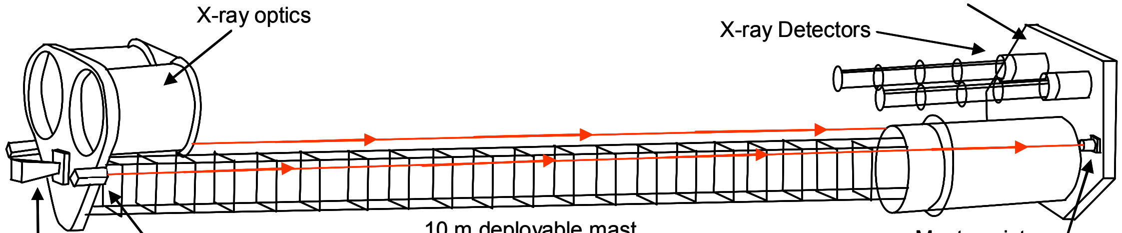
Optic Module (2)



Optical Bench – The optical bench is responsible for structurally supporting the two optics modules, three metrology lasers, an optic bench electronics box, a star tracker, and a rear-facing camera.

Focal Plane Bench Assembly – The focal plane bench assembly is responsible for structurally supporting the mast/canister, two focal plane assemblies, three metrology detectors, the central electronics box, two star trackers, and a magnetometer

Metrology



NuSTAR metrology System measures orientation that individual X-ray photons arrives from

All data processing is post processing

All measurements are relative to initial in-flight calibration

Metrology System consists of
- **Optical Bench Mounted Star Tracker**
- **2 laser beams and corresponding position sensitive detectors**

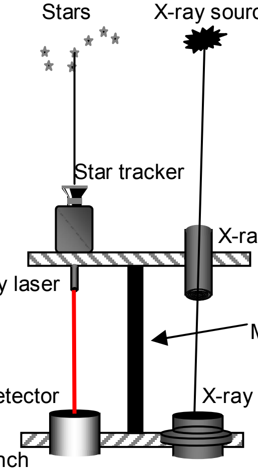
Metrology system measures:
- **Inertial orientation of optical bench**
- **Lateral displacement of focal bench relative to optical bench**

Metrology system does NOT measure:
- **Distance between optical bench and focal plane bench**
- **Inertial orientation of focal bench**

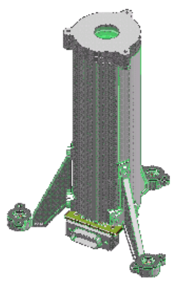
Update rate: ~100 Hz

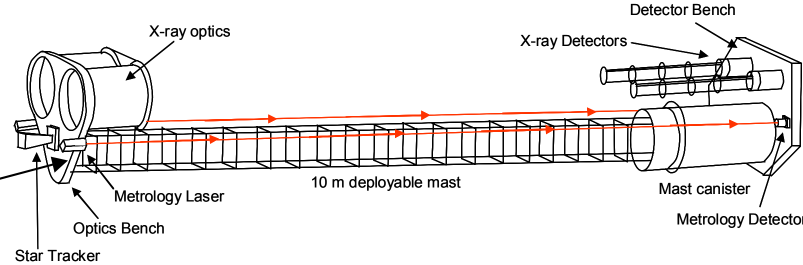
Accuracy: 150 microns

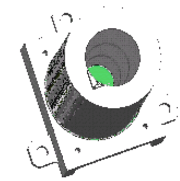
NuSTAR simplified instrument model

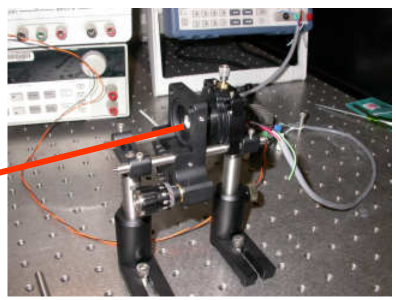


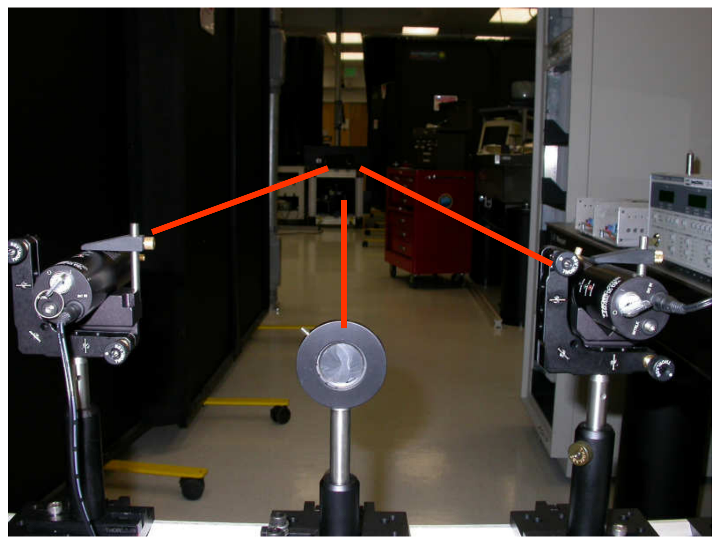
Metrology: Testbed

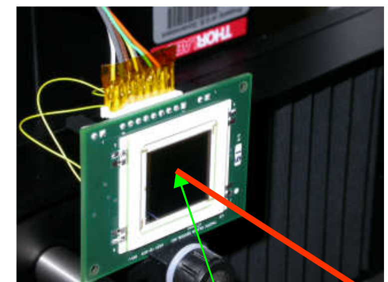


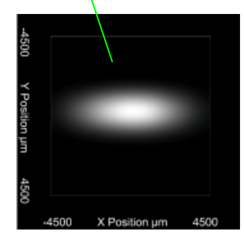


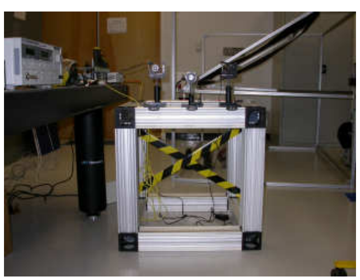




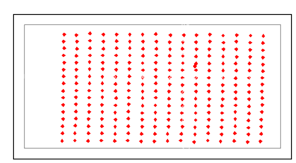


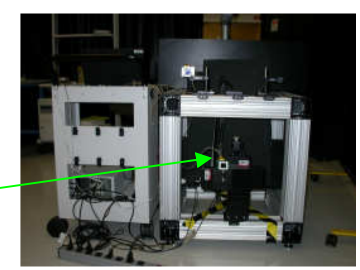




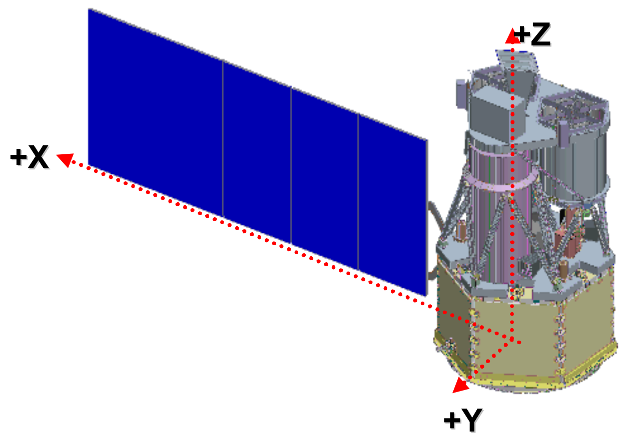


10 meters





Spacecraft



Orbital Sciences Corporation heritage LEOStar spacecraft

Mechanical
- Aluminum Facesheet Over Aluminum Honeycomb Bus
- Carbon Fiber Over Aluminum Honeycomb Arrays

Attitude Control
- 3-axis Stabilized Zero Momentum System
- Star Tracker Provides Attitude Data
- Gyro Provides Rate Data
- Sun Sensors Provide Attitude Data in Safe Hold
- TAM & Torquers for Momentum Control

Command & Data Handling
- Standard MIL-STD-1553 and RS-422 Interfaces
- Standard CEU + Mission Unique Card (MUC) Accommodates Payload Needs

Electrical Power
- Single Wing Deployed Single Axis GaAs Solar Arrays
- 16 A-Hr Battery
- Heritage Power Regulation Electronics
- Power Converter Box

Software and Fault Protection
- Execution of Stored and Real-Time Command Sequences
- Safe Hold Mode Protects Spacecraft During Faults

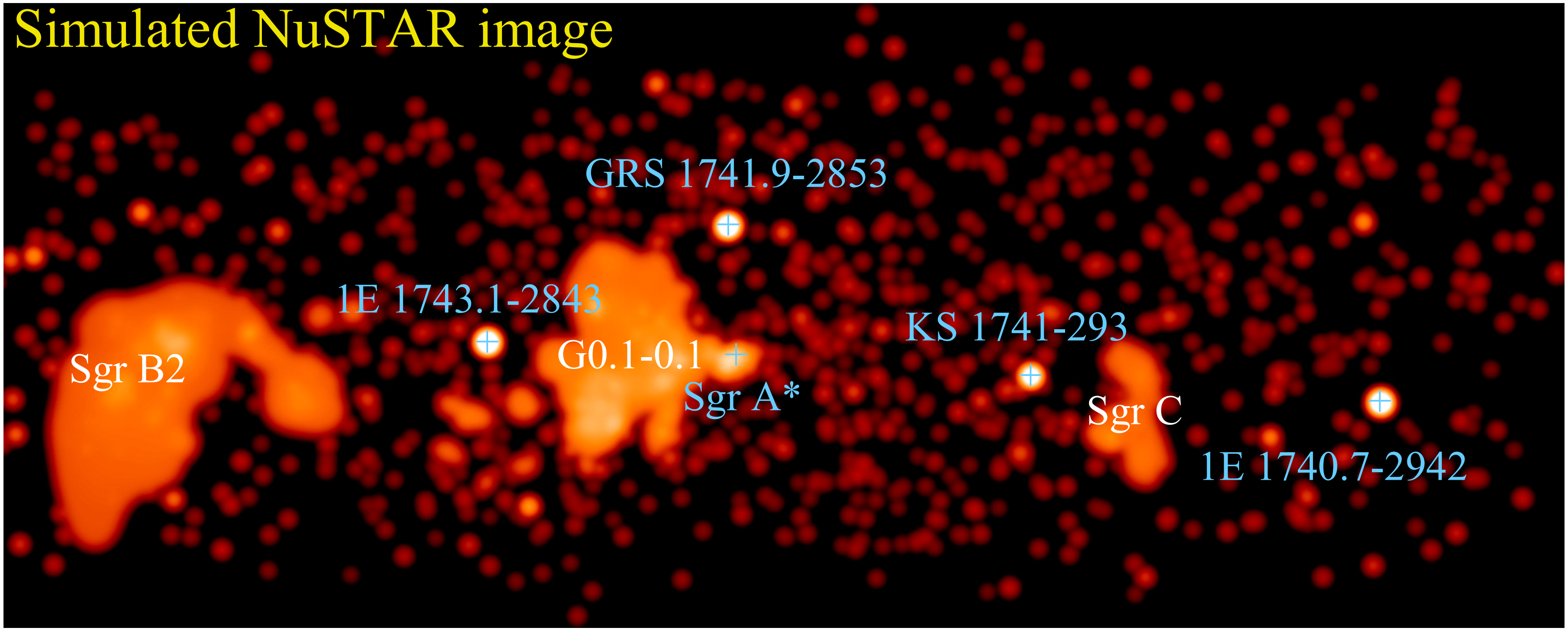
Thermal Control
- MLI & Silver Teflon for Passive Thermal Control
- Thermistors and Heaters for Component Thermal Control

RF Communication
- 32 kbps S-band Uplink, 2 Mbps S-band Downlink
- 2 Omni Antennas Provide Near Spherical Coverage

Mission Schedule

- System Requirements Review
  - **July 9 , 2008**
- Project Preliminary Design Review
  - **June 9, 2009**
- Project Critical Design Review
  - **February 2, 2010**
- Instrument Delivery to Observatory I&T
  - **November 12, 2010**
- Observatory I&T
  - **November 13, 2010 - June 24, 2011**
- Launch
  - **August 15, 2011**
- Science Operations
  - **September 15, 2011 – October 1, 2013**

The Future: *NuSTAR*



- 40" angular resolution
- Sensitivity ~10^{-15} erg cm^{-2} s^{-1} (20-40 keV; 10^6 s).

Michael Muno (Caltech) for the *NuSTAR* team