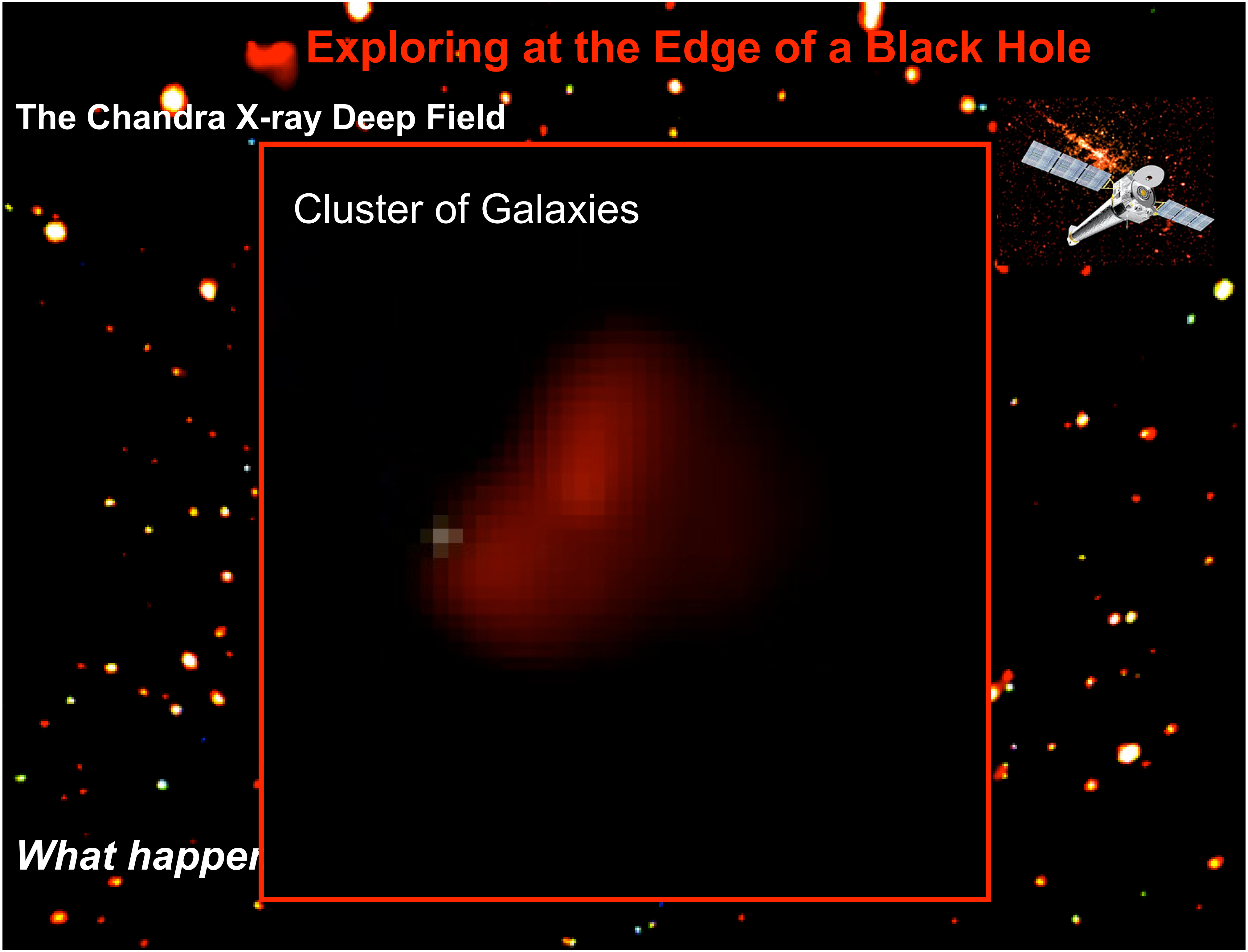
Constellation X

The Constellation X-ray Mission

The Constellation-X Mission Implementation Approach and Status

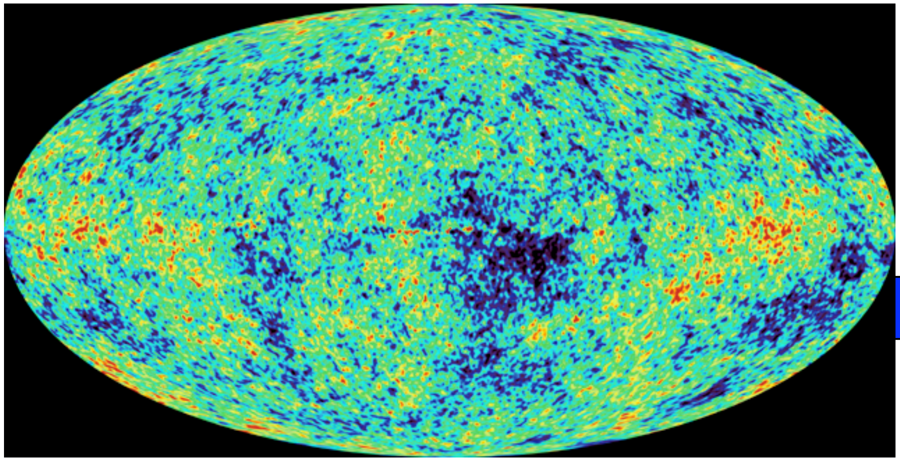
Nicholas White

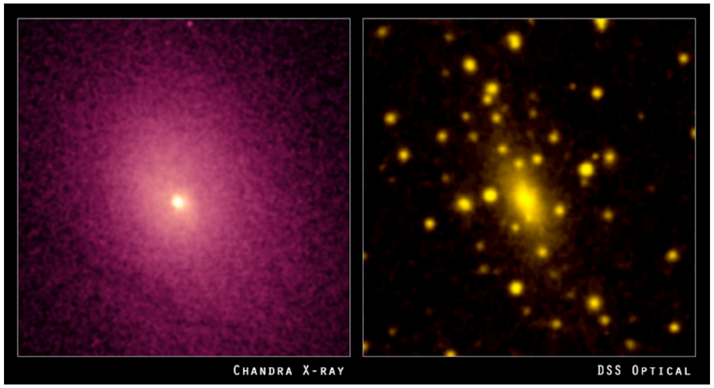
Project Scientist


Exploring at the Edge of a Black Hole
The Chandra X-ray Deep Field
Cluster of Galaxies
What happen

Clusters of Galaxies as Cosmological Probes

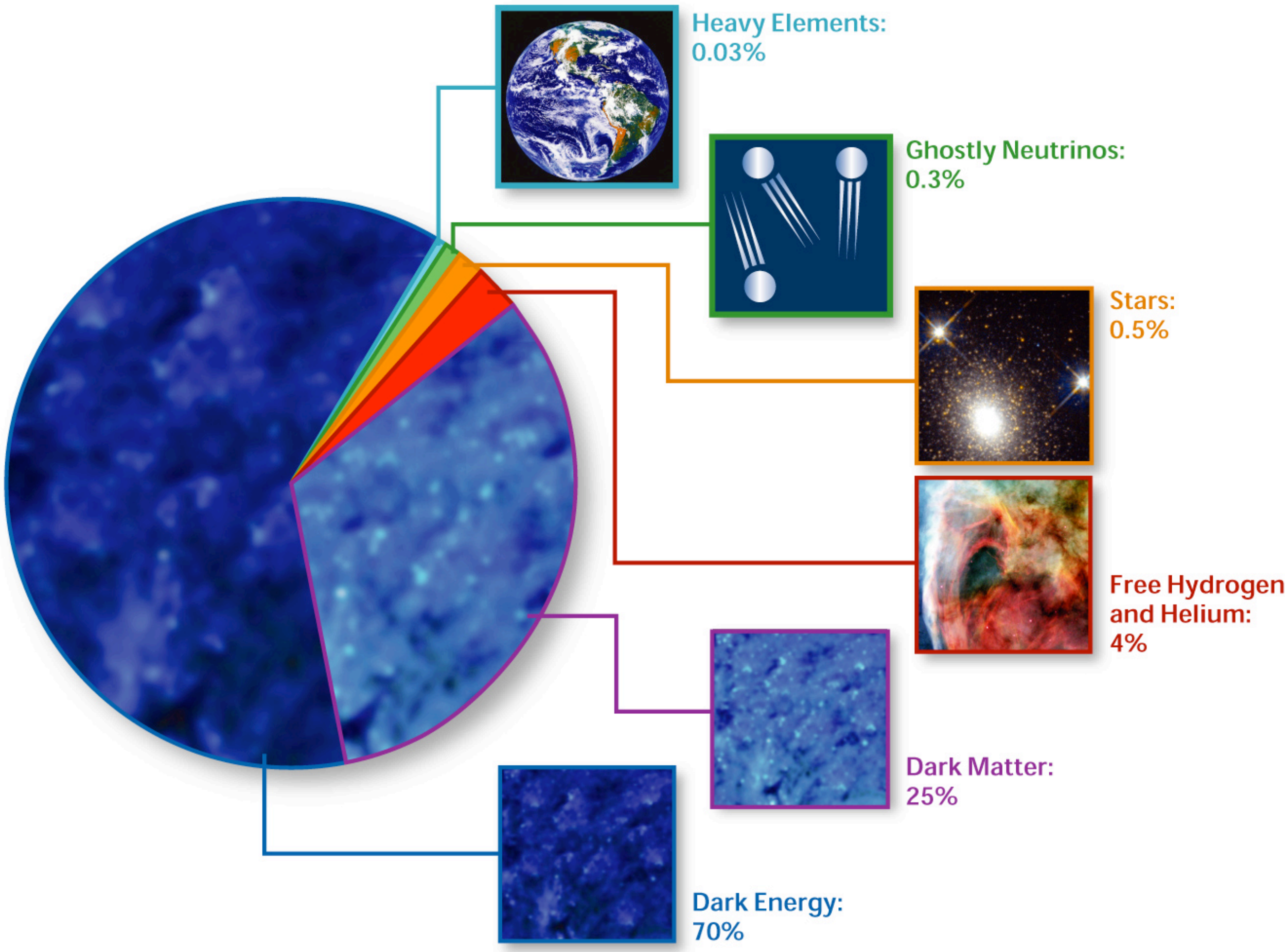
Clusters of galaxies are the largest objects in the Universe and grow from the initial fluctuations seen in the microwave background





Clusters of galaxies are the largest objects in the Universe and their properties and evolution are sensitive to the Cosmological parameters

The Dark Side of the Universe



We do not know what 95% of the universe is made of!

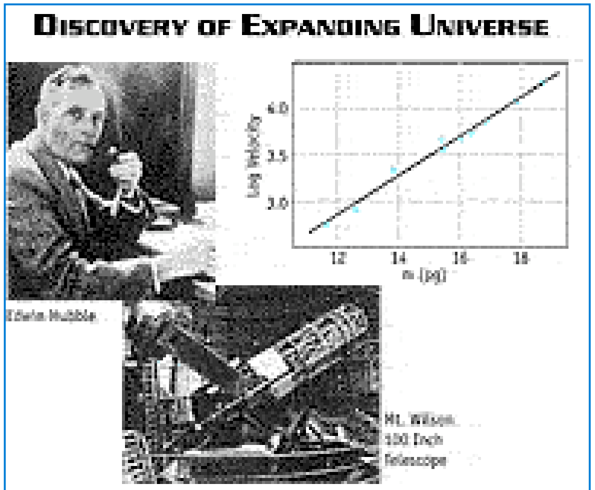
Solving this mystery may fundamentally change our view of the Universe and also may impact the standard model of particle physics!

Einstein’s Predictions

Three startling outcomes of Einstein’s general relativity:

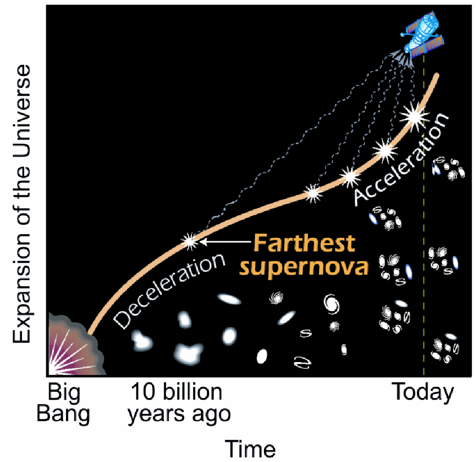
- ◊ The expansion of the Universe (from a Big Bang)
- ◊ Black holes
- ◊ A Cosmological Constant acting against the pull of gravity

Observations confirm these outcomes . . .



Hubble discovered the expanding Universe in 1929

Black holes found in our Galaxy and at the centers of most galaxies over the past three decades

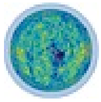


Evidence for an accelerating Universe was observed in 1998

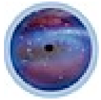
Completing Einstein's Legacy

- Einstein's legacy is incomplete, his theory fails to explain the underlying physics of the very phenomena his work predicted
  - → Unification of Quantum Mechanics and General Relativity
- We are on the threshold of a breakthrough comparable to Einstein's discoveries one century ago . . .

Beyond Einstein is a series of NASA missions linked by powerful new technologies, and interlinked science goals to address:



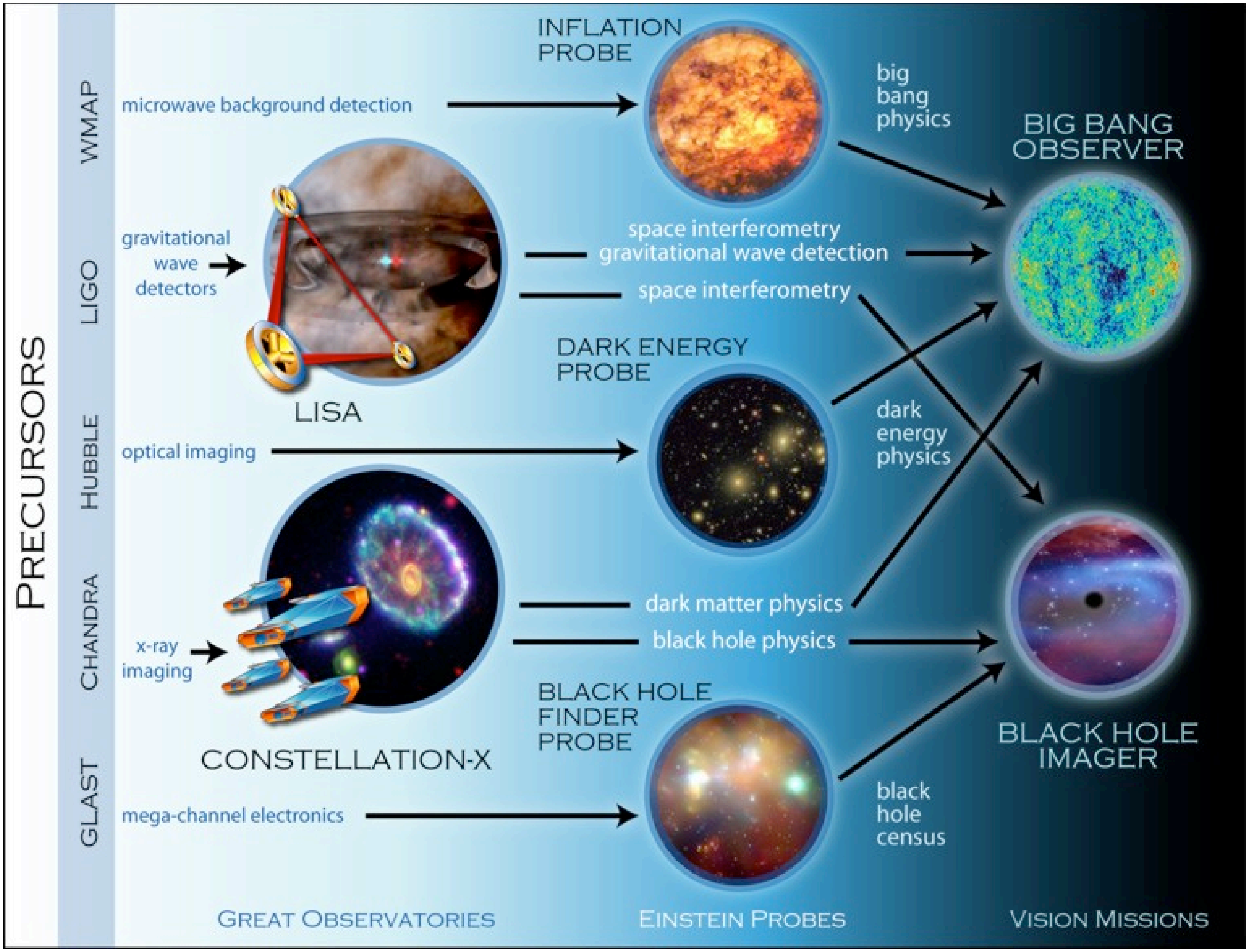
What powered the Big Bang?



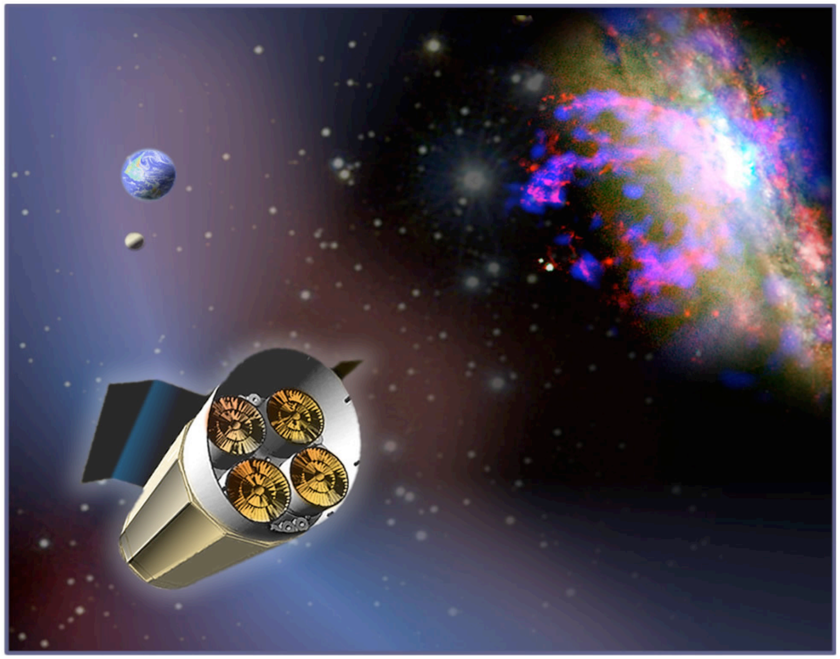
What happens at the edge of a Black Hole?

What is the mysterious Dark Energy pulling the Universe apart?

Beyond Einstein Program



The Constellation-X Mission



Constellation of X-ray telescopes

- X-ray observatories must be in space!
- Baseline design: four identical X-ray telescopes observing simultaneously
- Orbiting the Sun at the 2nd Lagrange point (very stable conditions)

- Allows X-ray imaging and high-resolution (R 300-3000) spectroscopy
- 25-100 more sensitive than current high-resolution X-ray instruments
- Major facility that will address:
  - Black Holes (evolution and tests of GR)
  - Dark Energy and Dark Matter
  - Open a new window of X-ray spectroscopy

Overall Mission Status

Constellation-X is an approved mission, currently pre-phase A

- Pre-phase A activities
  - **Documentation of science requirements and goals**, flow down to measurement requirements and mission implementation
  - **Technology development** in TRL3-6 range
  - **Mission architecture studies** that realize the science requirements, while minimizing the cost and technical risk

- End to end cost estimate for 2017/18 launch date:
  - $2.5B (Real Year dollars including inflation), or
  - $1.6B (Constant Year 2000 dollars)

- Launch date is currently driven by budget constraints and programmatic considerations, not technology or schedule
  - Decision pending whether Con-X, LISA or JDEM proceeds as next major Astrophysics observatory, and mission ordering there after…

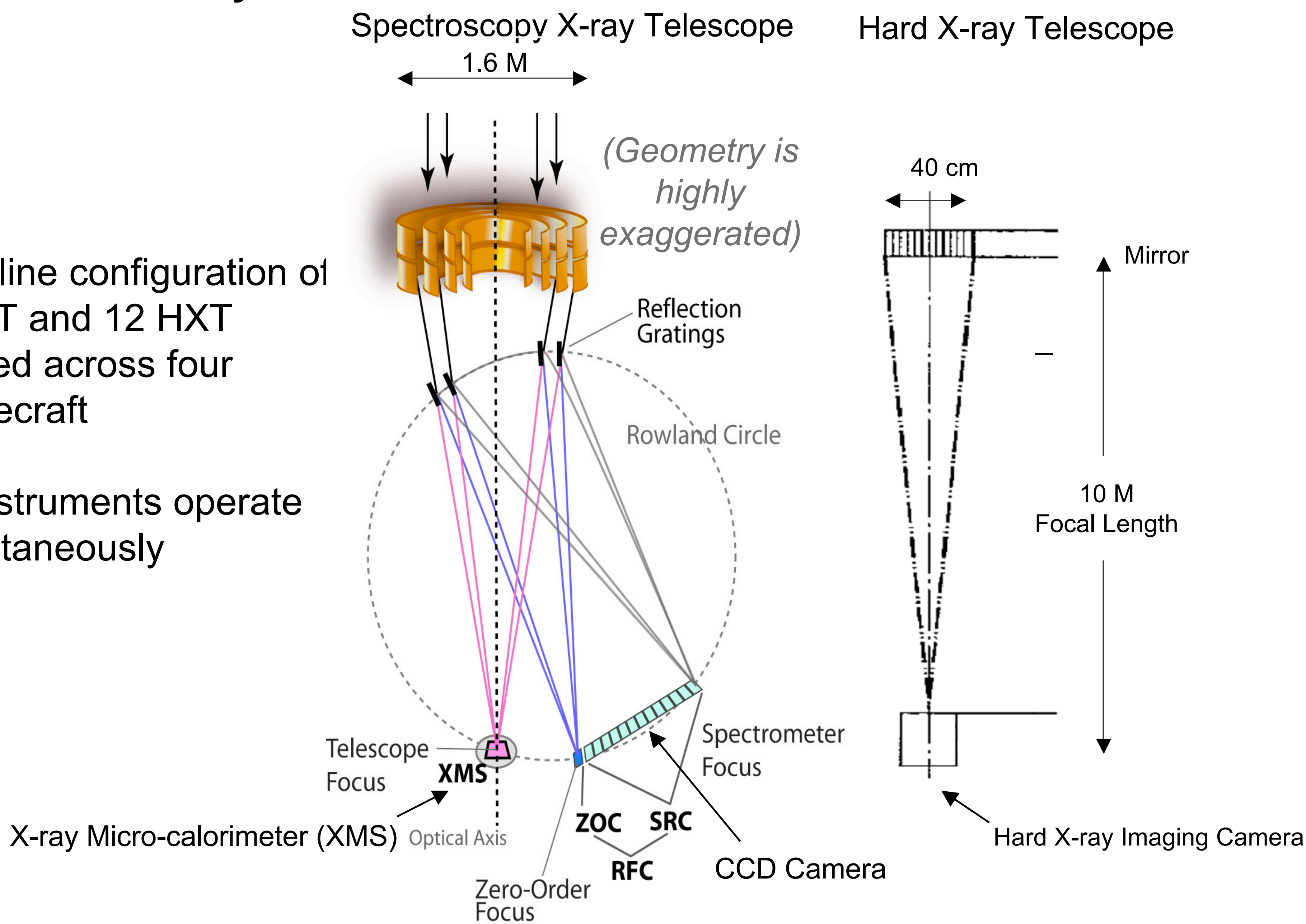
Constellation-X Capabilities

- A factor of 25-100 increased collecting area for R (E/ΔE) ~ 300 to 1500 spectroscopy
- Routine spectroscopy to a flux of 2 x 10^{-15} ergs cm^{-2} s^{-1} (0.1 to 2.0 keV), with 1000 counts in 100,000s, with a limiting sensitivity 10 times fainter
- Factor ~100 increased sensitivity in 10 to 40 keV band to determine continuum and search for non-thermal components
- Velocity diagnostics that with a ΔE of 4 eV at 6 keV, gives a bulk velocity of 200 km/s & line energy centroid capability equivalent to an absolute velocity of 20 km/s
- SXT angular resolution requirement of 15 arc sec HPD, with a 5 arc sec goal
- Field of View ≥ 2.5 × 2.5 arc min with at least 32 x 32 pixels
- Ability to handle 1,000 ct/sec/pixel

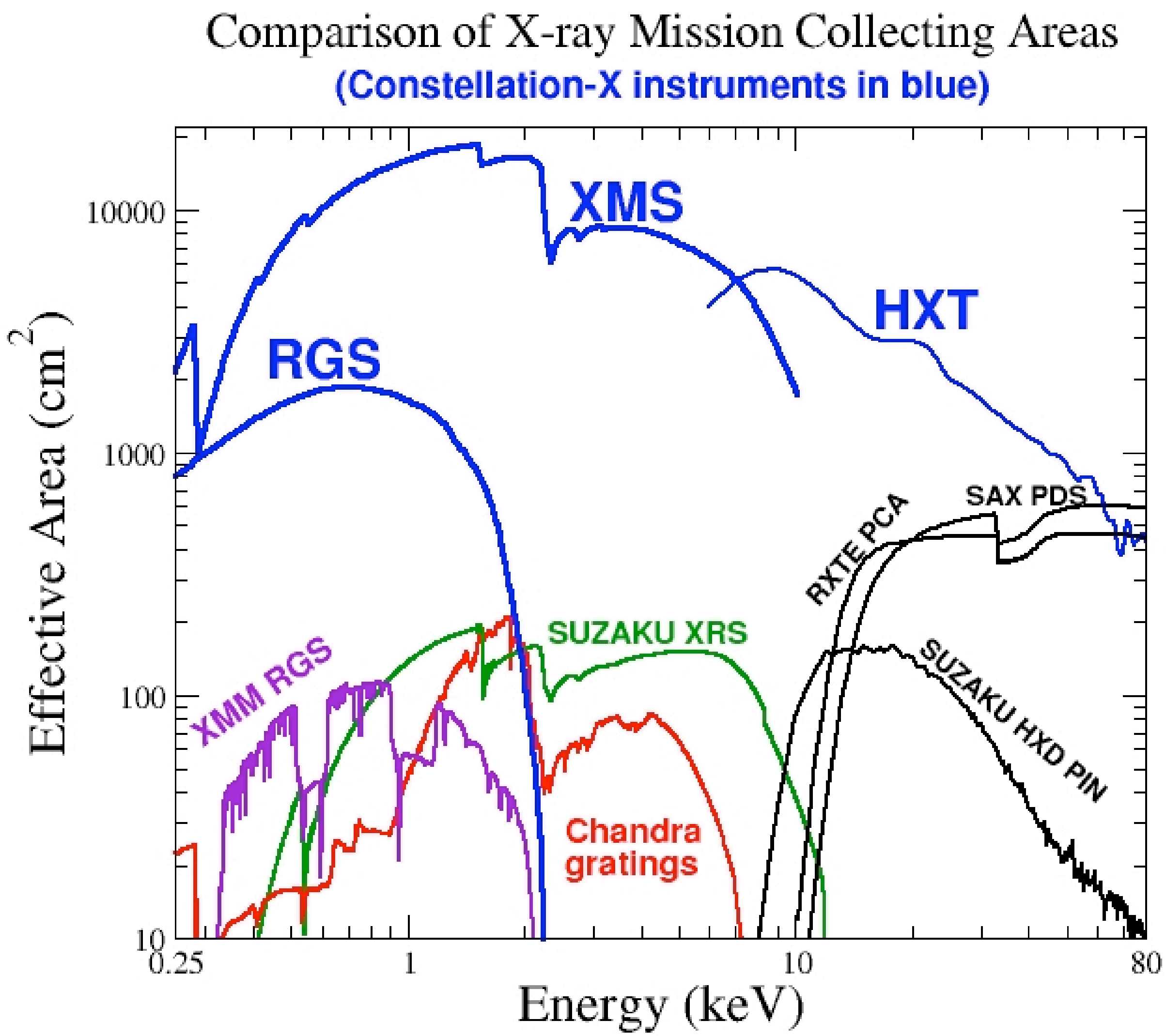
Constellation-X Payload

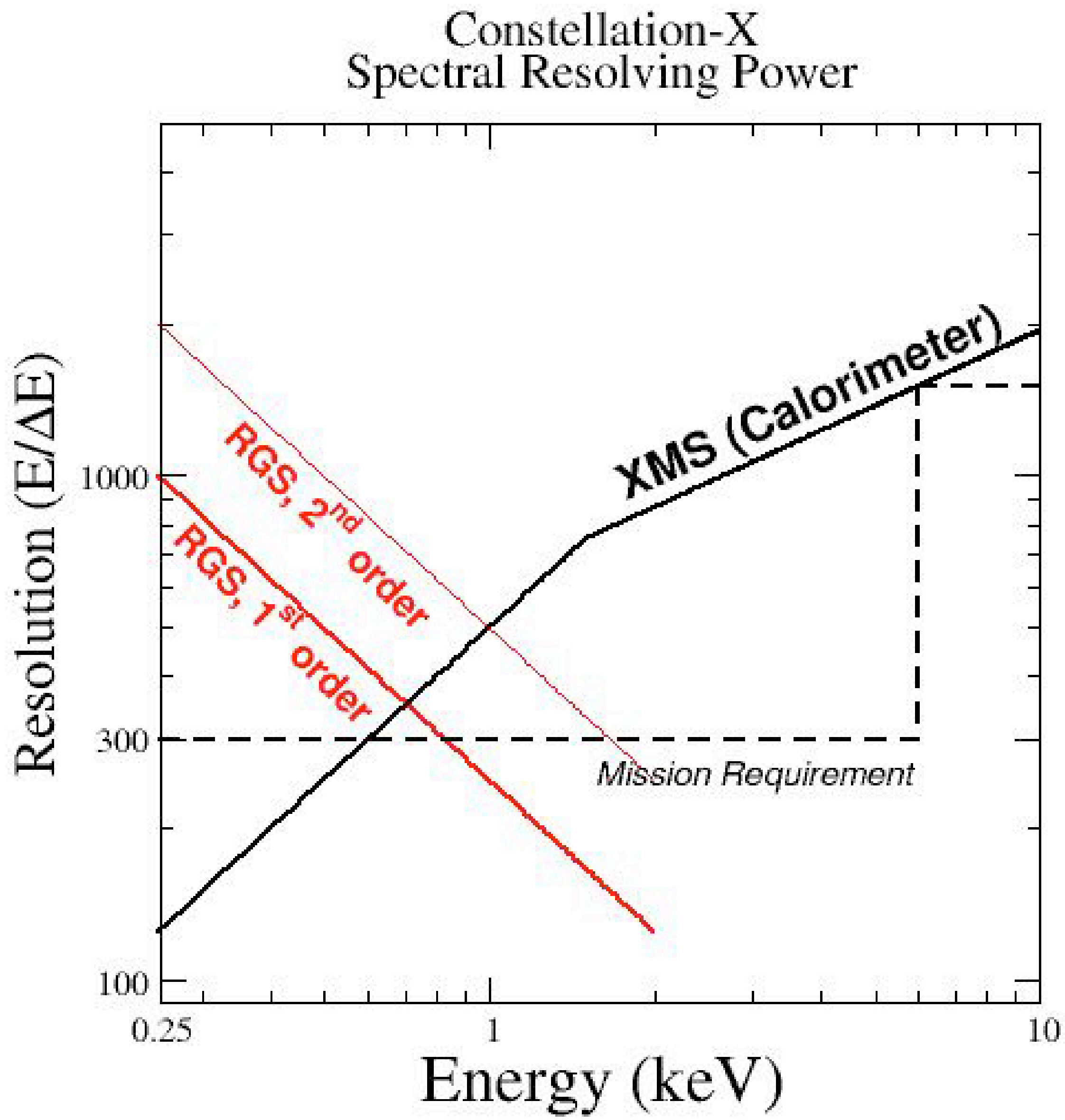
Baseline configuration of 4 SXT and 12 HXT divided across four spacecraft

All instruments operate simultaneously



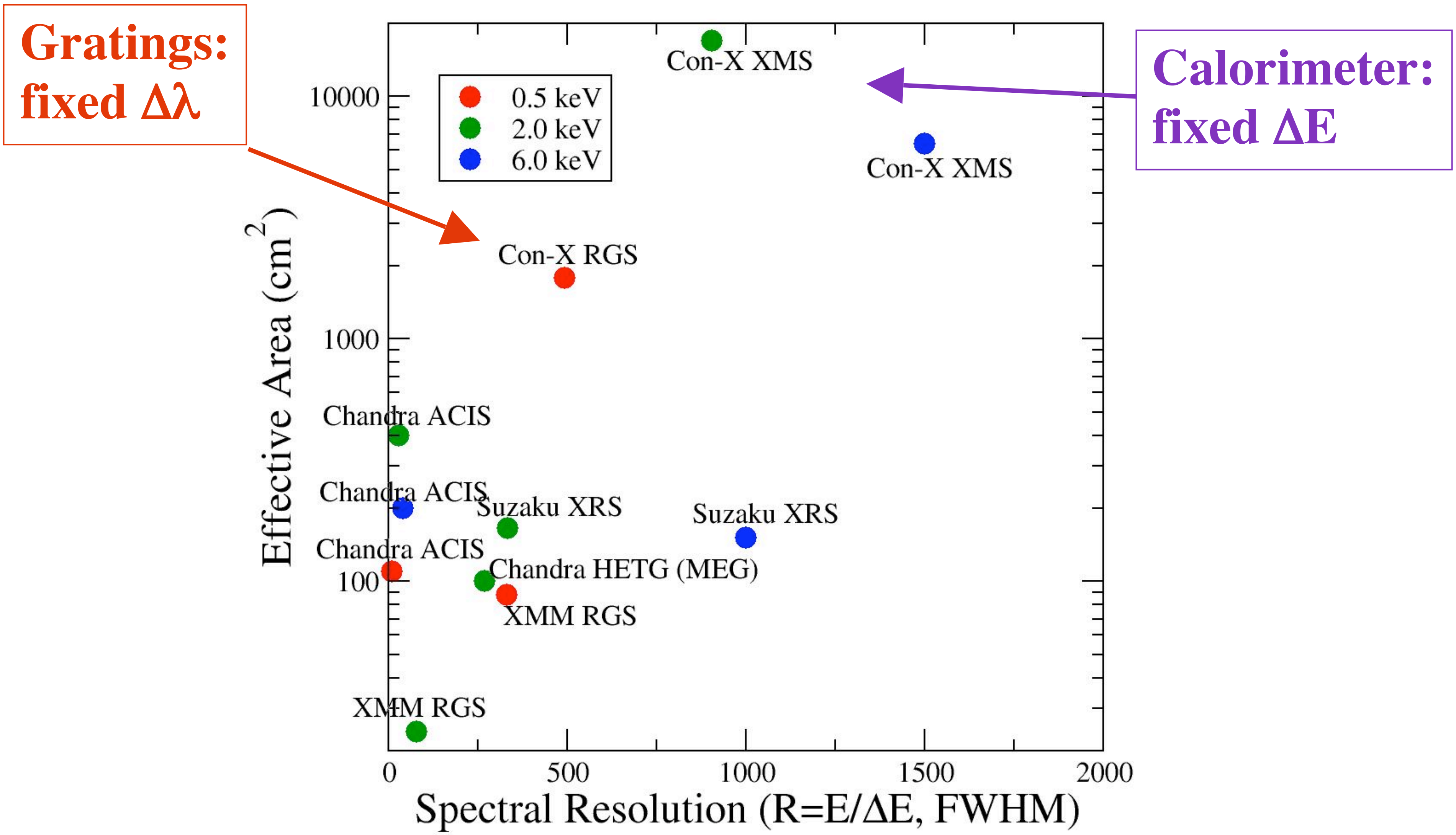
Comparison of collecting area



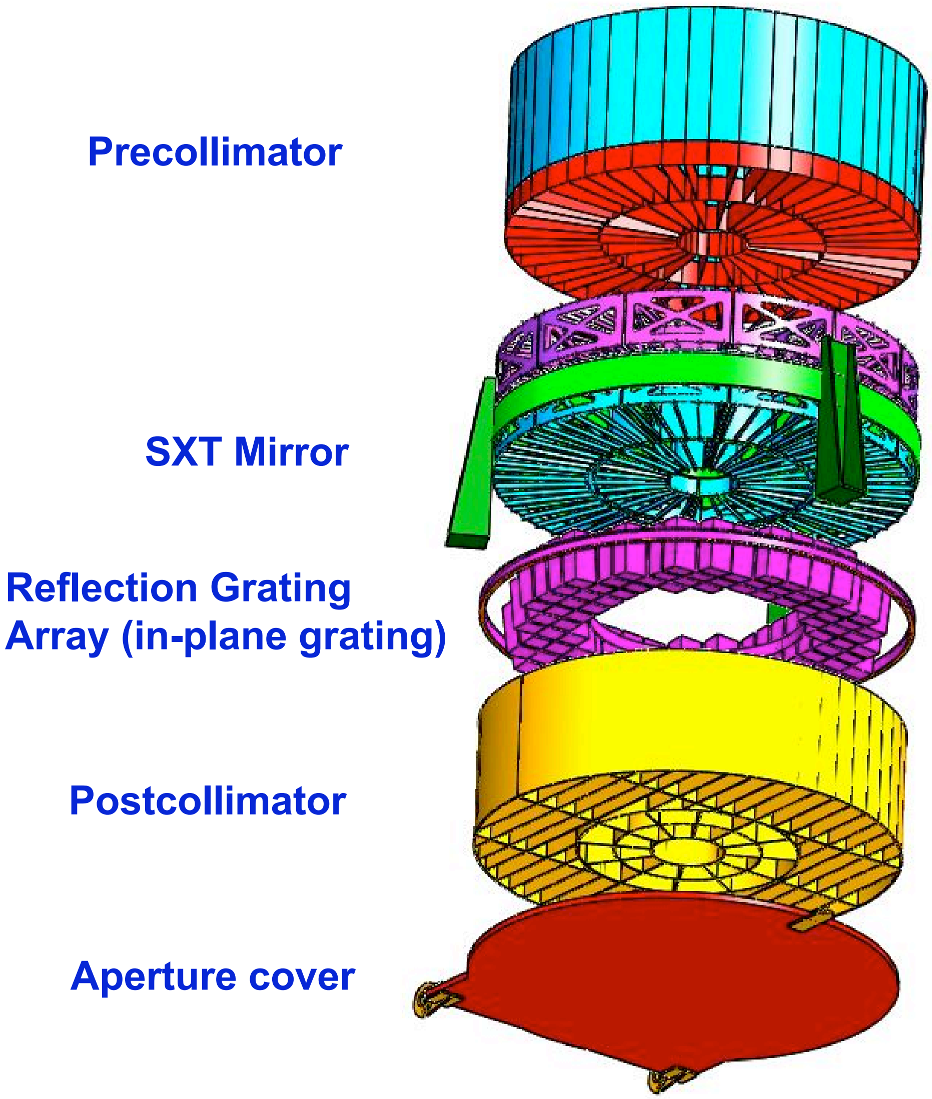


In-plane grating configuration

Collecting area vs. Spectral resolution



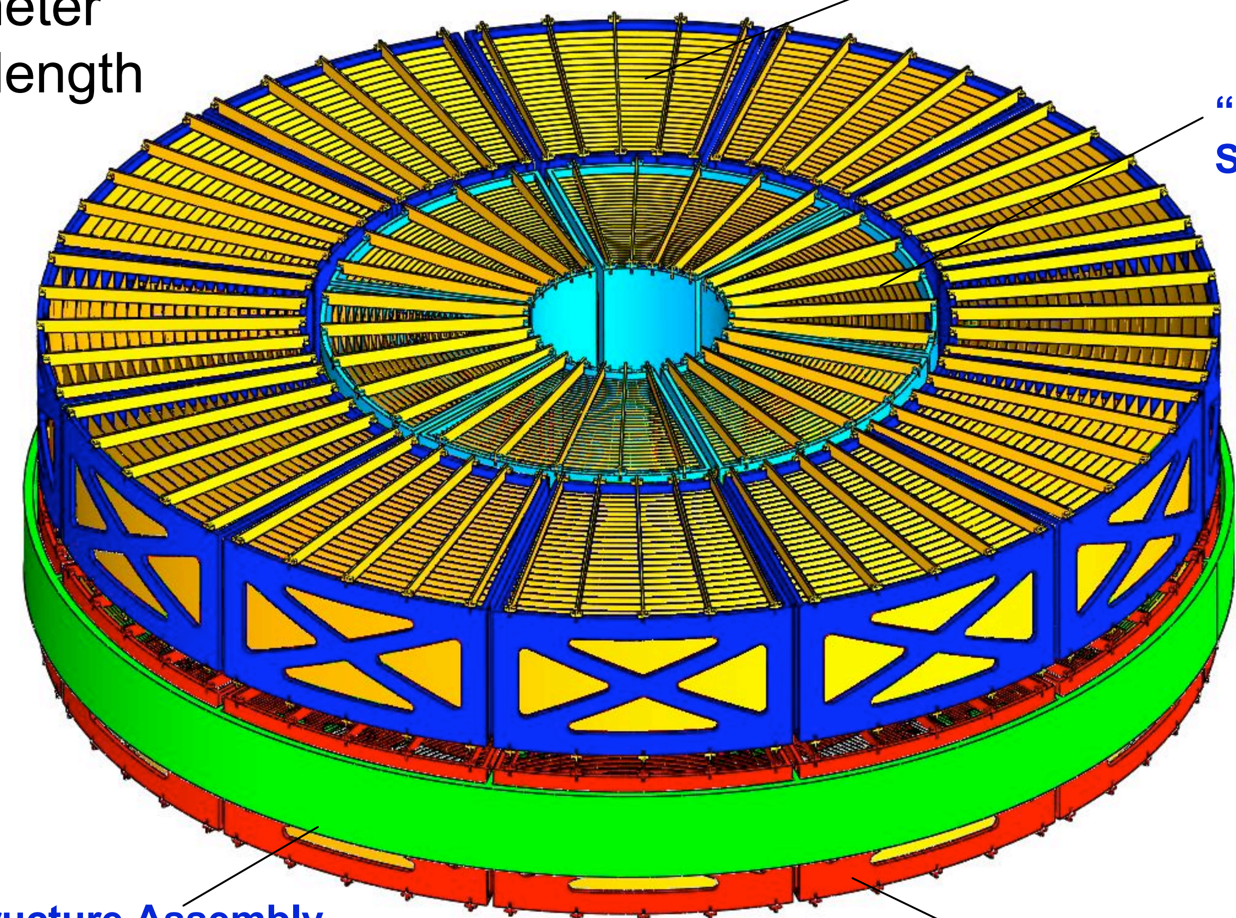
SXT Flight Mirror Assembly (FMA)



SXT Mirror Reference Concept

- General Overview of Design

1.6m Diameter
10m focal length
640 kg

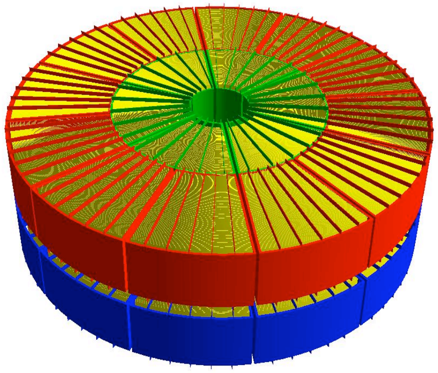


~200 reflector pairs, 3600 mirror segments

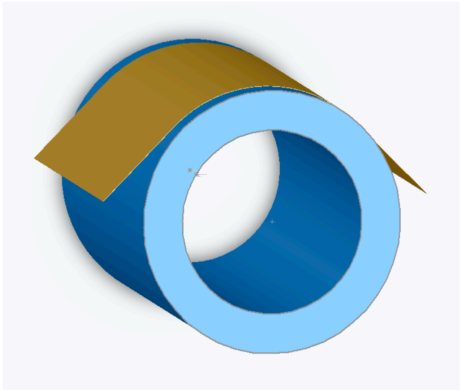
Spectroscopy X-ray Telescope

- Mirror Design
  - Wolter-1, true P/H pairs
  - Segments: 60°, 30°
- Highly Nested, Low Mass, < 12.5'' HPD
  - Segmented technology (Suzaku), thin glass, meets mass requirement
  - Requires 10x improvement in HPD and 4x increase in diameter
- Mirror segment fabrication process
  - Thin, thermally formed glass substrates on P/H forming mandrels
  - Thin gold reflectors on replication mandrels
  - Gold reflector epoxied to glass P/H

SXT Mirror

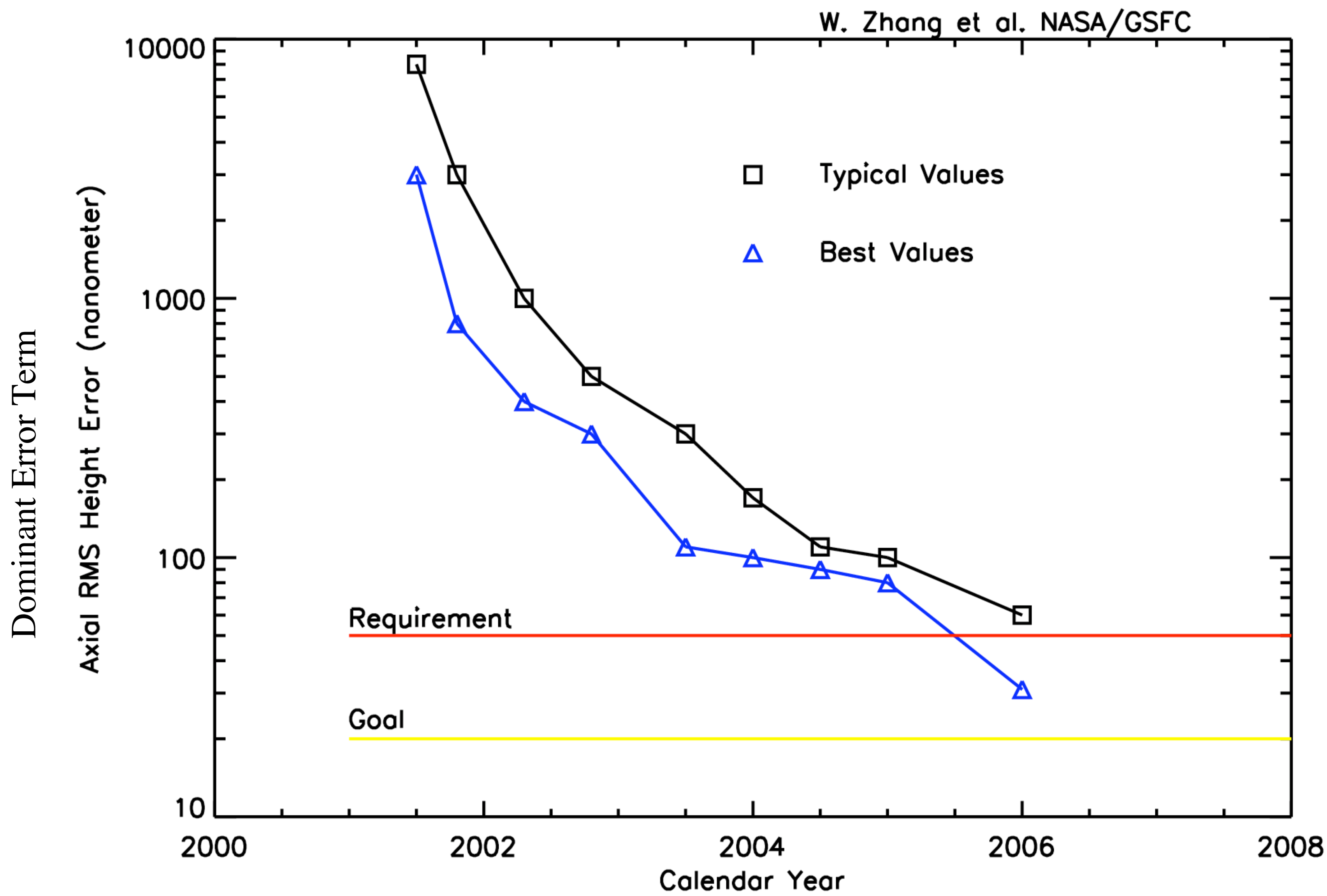


Glass Substrate Fabrication



Gold Reflector

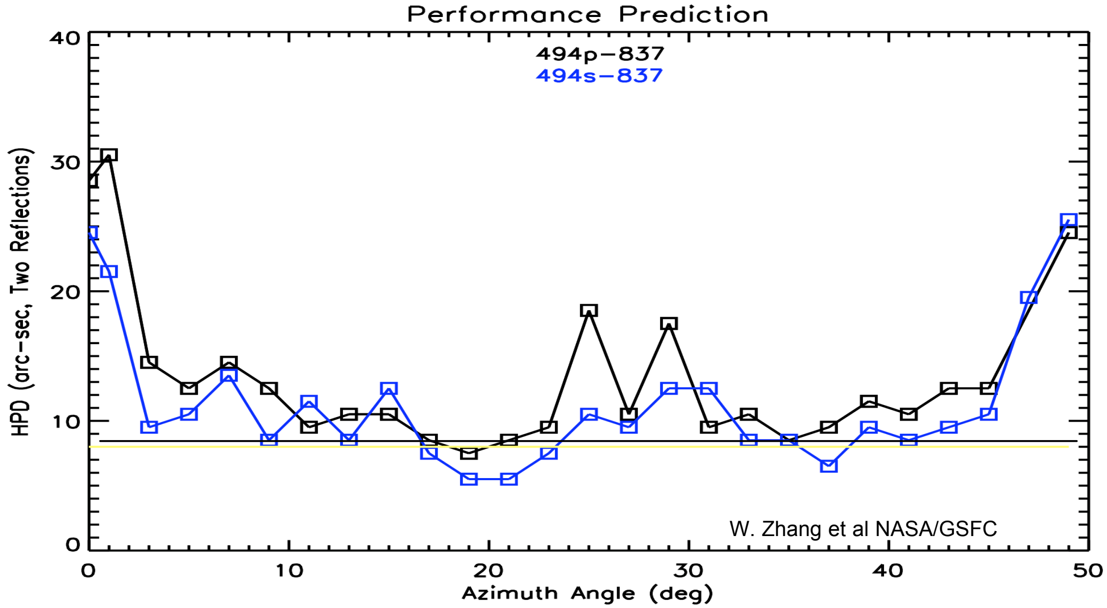
Spectroscopy X-ray Telescope Reflector Progress



Spectroscopy X-ray Telescope Reflector Progress Cont'd

- MANY reflectors within factor of 2 of requirement, improvements continuing
- BEST pair of glass substrates near requirement *w/o epoxy replication*

BEST glass substrates
Prediction @ 1.24keV
Axial rms only:
8'' allocated
(12.5'' total HPD PSF)

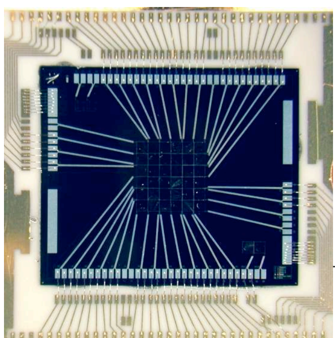


- Some evidence mandrel quality limits substrate performance, but still under investigation
- Improved substrate mandrels may eliminate epoxy replication process: no replication mandrels, process simplification, faster schedule
- Zhang et al

X-ray Micro-calorimeters

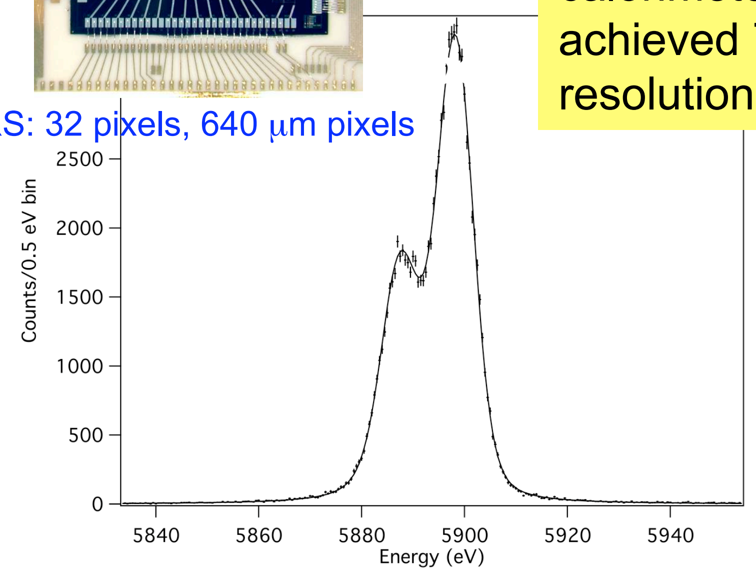
Thermal detection of individual X-ray photons gives a 20-40 increased spectral resolution over the Chandra CCDs

Arrays have been successfully demonstrated on sounding rockets and now *Suzaku* (Astro-E2)

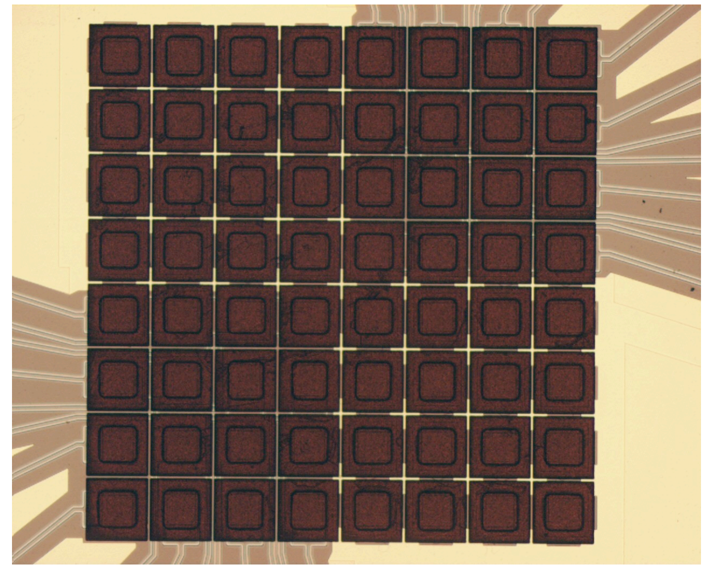


Suzaku X-ray calorimeter array achieved 7 eV resolution on orbit

XRS: 32 pixels, 640 μm pixels

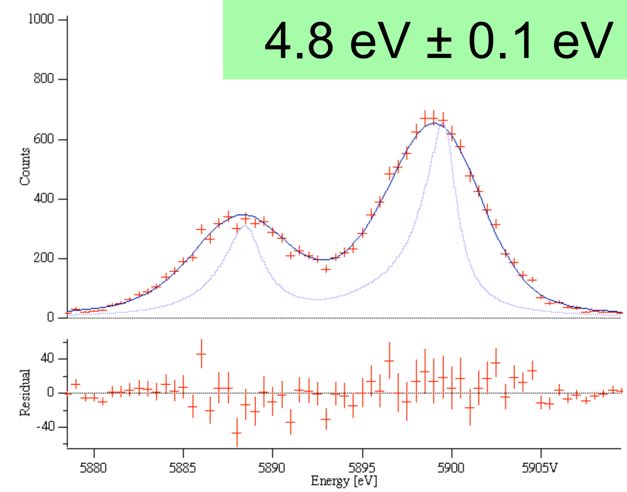


Next generation arrays being developed for Constellation-X now approaching mission goals of 2-4 eV

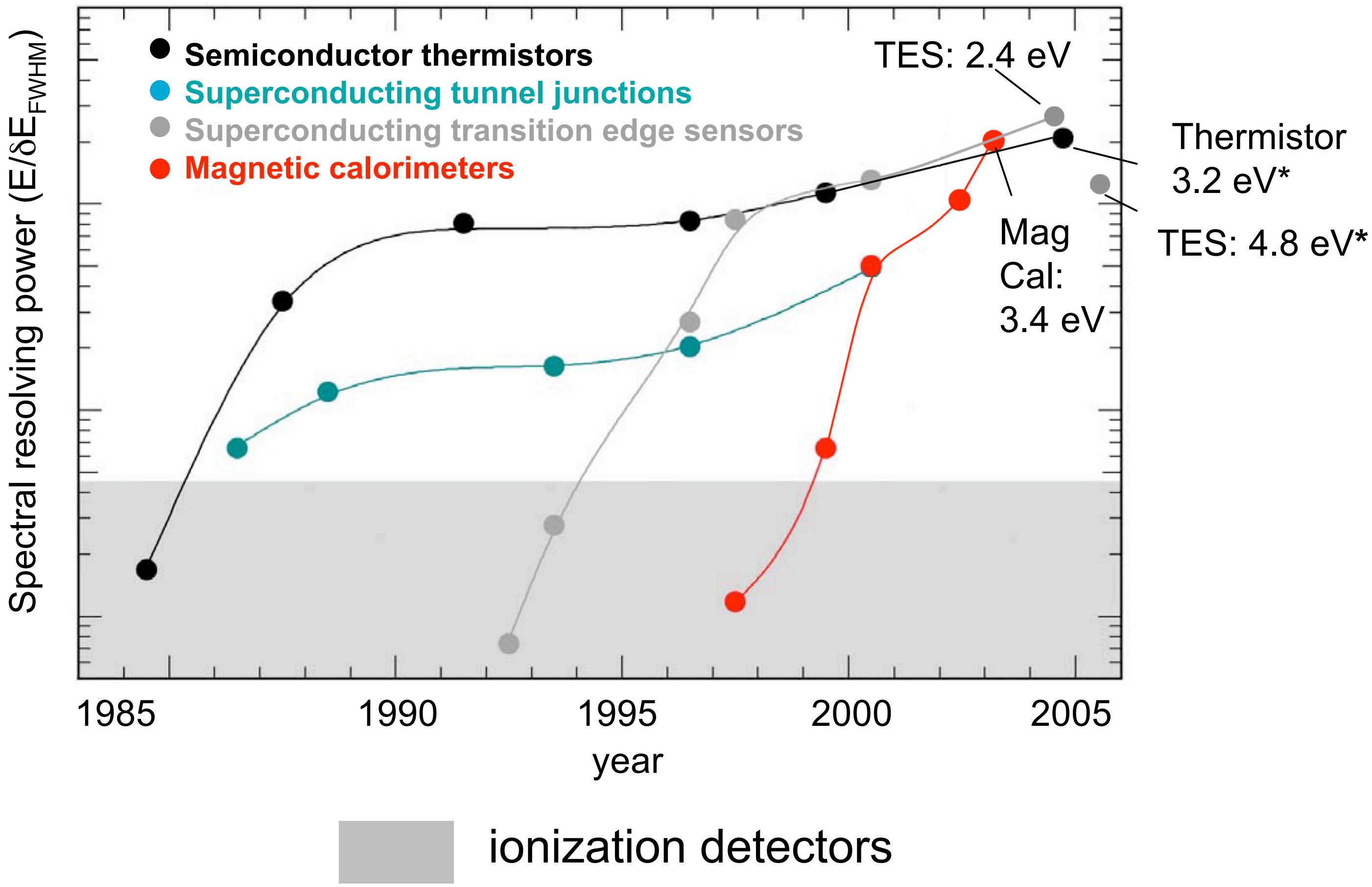


8x8 development TES array for Con-X with 250 μm pixels

4.8 eV ± 0.1 eV FWHM



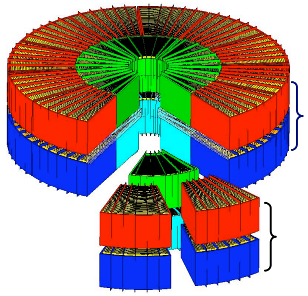
Micro-calorimeter Progress: ΔE@6 keV



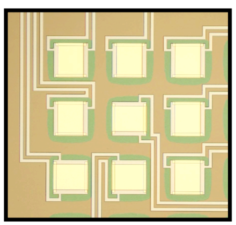
* These devices meet Con-X requirements for quantum efficiency

Kelley et al, Irwin et al, **Silver et al,** Kilbourne et al,
Porter et al, Eguchi et al

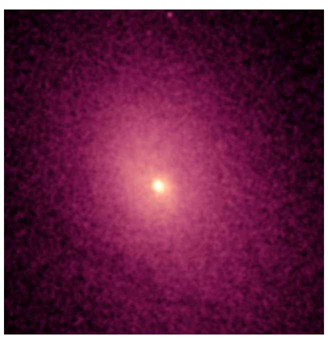
Precision Cosmology with Constellation-X



Constellation-X provides the required capabilities with large telescope area and 2-4 eV micro-calorimeter spectrometers



This combination is ideal to observe clusters of galaxies!



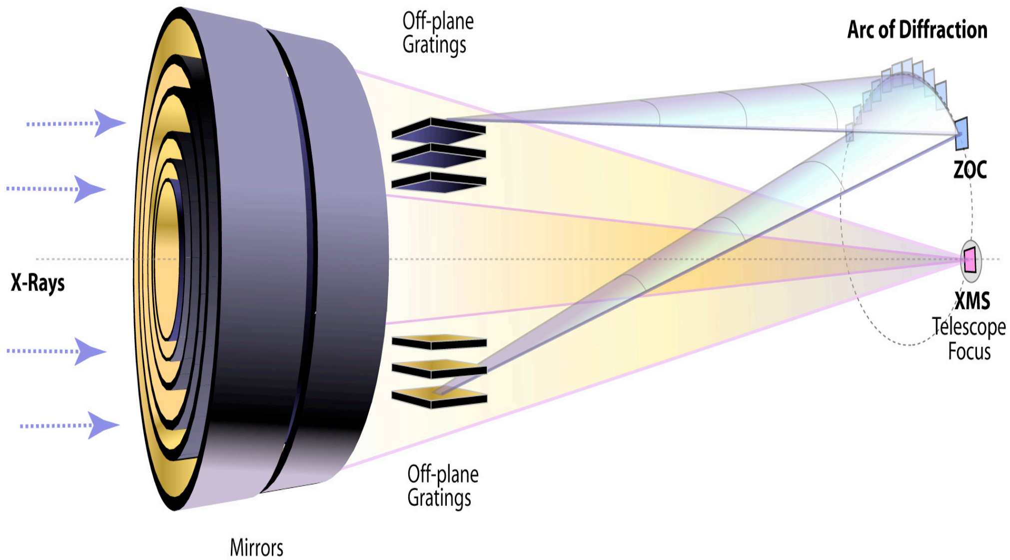
X-ray observables are:

- **X-ray temperature and luminosity to give cluster mass**
- **Gas mass fraction (ratio of baryons to total cluster mass)**
- **Velocity structure of the cluster**

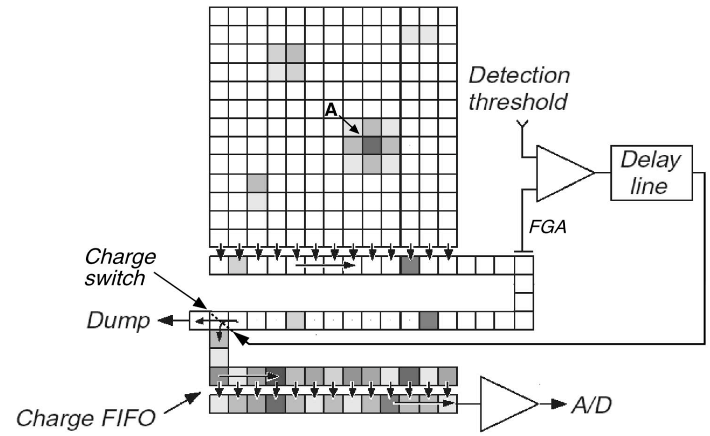
Constellation-X will be able to measure the mass of <u>any</u> cluster of galaxies in the Universe $>10^{14}$ solar masses - resulting in a sample of ~500 clusters

Reflection Grating Spectrometer

0.25-2.0 keV, E/dE>300 <1keV



(Geometry is highly exaggerated)



Event-Driven CCD

Pixels are non-destructively sensed, and only those with signal charge are saved and digitized

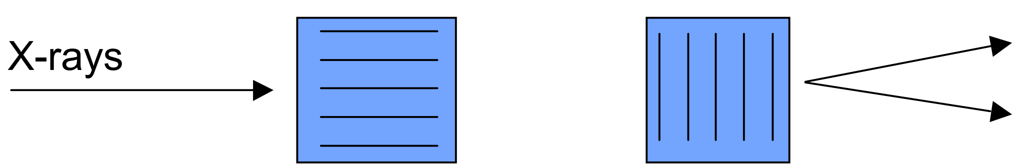
High speed: 100 x Chandra/ACIS (reduced pileup, thinner OBF, higher low E QE)

- Devices Fabricated

- Readout Electronics testing underway

Grating Ruling Geometry:

Off-plane **In-plane**



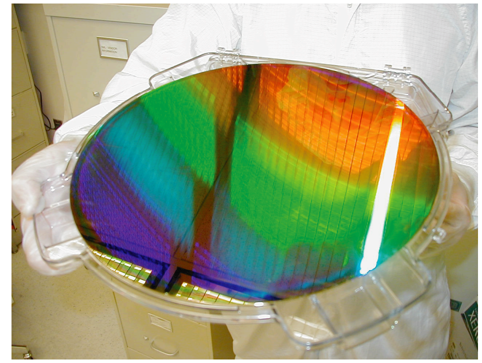
TECHNOLOGY STATUS: Gratings and CCD's

Grating

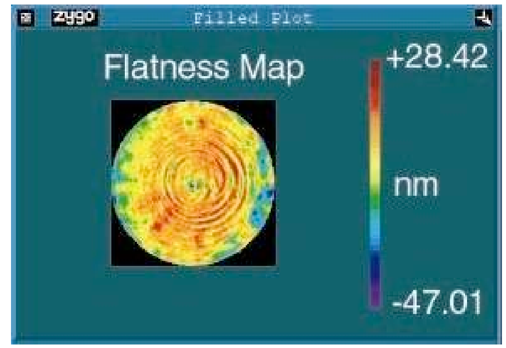
- **Grating Patterning – Scanning Beam Interference Lithograph – SBIL (MIT)**
  - Patterned gratings in required size
  - Demonstrated required blaze and smoothness; required line density
  - Currently upgrading SBIL to accommodate radial (fan-shaped) grooves (to be complete ‘06)
- **Grating Patterning – Holographic (Jobin Yvon, U of Colorado)**
  - Ruled high line density radial grating
- **Demonstrated substrate flatness better than required (MIT)**
- **Prototype masters and replicas show record-level efficiencies in X-ray test (MIT)**

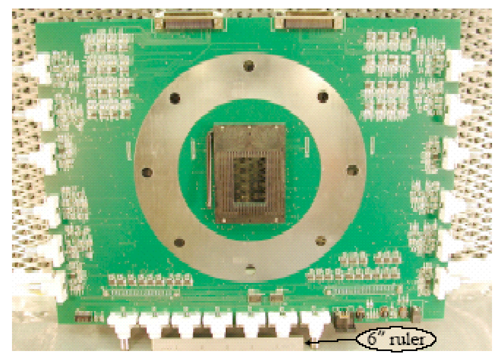
CCD (MIT/LL)

- **High-speed readout Event Driven CCD**
  - Successfully completed two lot's of Event Driven CCD's
- **High quantum efficiency, high production yield**
  - Demonstrated high yield "chemisorption" backside processing (U of Arizona on LL devices)
  - Recent progress on LL Molecular Beam Epitaxy backside processing also looks promising



SBIL patterned grating (MIT)





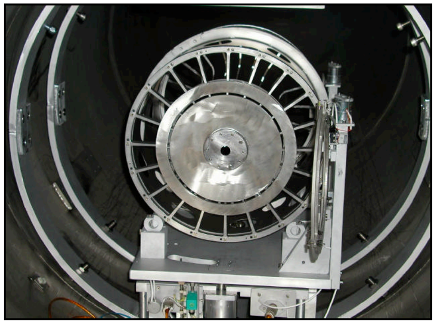
EDCCD: Large motherboard and camera plate (MIT)

Hard X-ray Telescope (HXT)

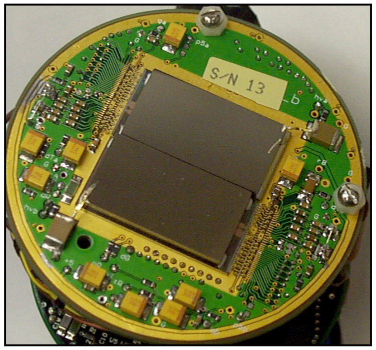
- Glass Mirrors (Columbia, CalTech, DSRI)
  - HEFT (balloon) mirror meeting Con-X mass and performance requirements has successfully flown
  - Prototype mirrors have performances better than required; have been successfully acoustic and vibration tested
- Nickel Mirrors (SAO, MSFC, Brera)
  - Single shell mounted prototype has demonstrated angular resolution better than required in X-ray test
  - Fully lightweighted shells have been produced
- Detectors (CalTech)
  - CdZnTe hybrid pixel detectors have been demonstrated on HEFT
    - Meets required performance
    - Vibration tested

HEFT 72-shell glass mirror optic

Prototype mirror acoustics tested at JPL facility



Single shell nickel mirror in X-ray test



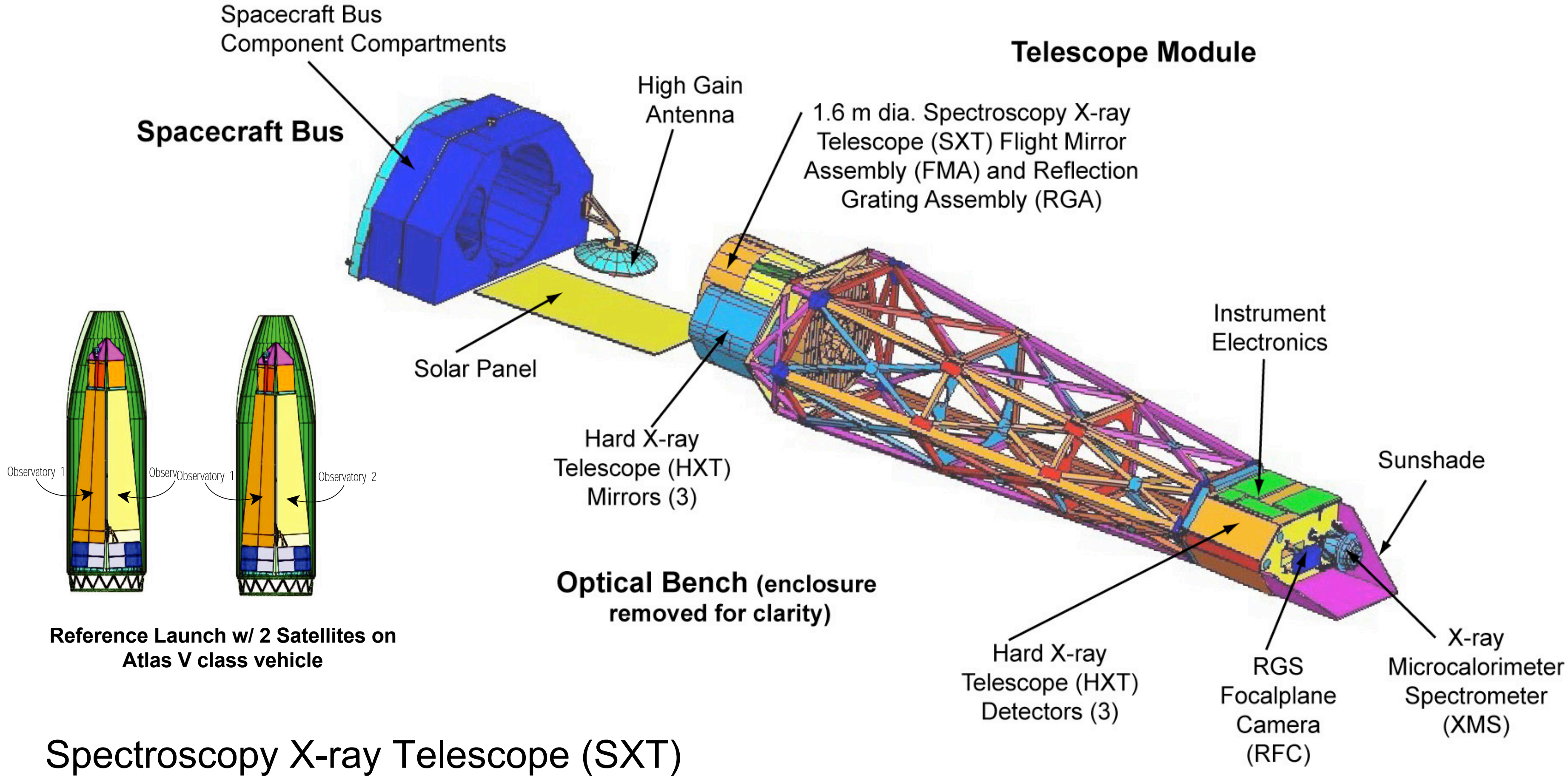
CdZnTe hybrid pixel detector

CdZnTe vibration test

TECHNOLOGY UPDATE SUMMARY

- **Spectroscopy X-ray Telescope:**
  - Epoxy replicas consistently within factor 2 of meeting requirements, improvements continue
  - Best substrates meet (partial) requirements, possible process simplification
- **X-ray Microcalorimeter Spectrometer**
  - 4eV requirement met for non flight like arrays
  - Flight like arrays close to requirement and improving
- **Reflection Grating Spectrometer**
  - Off-Plane Grating technology looks promising
  - Event Driven CCDs for readout
- **Hard X-ray Telescope**
  - Telescope(s) meeting requirements, goals being approached
  - Detectors meet requirements, optimization for L2 being pursued

Reference Mission Design (2002-2006)



Spectroscopy X-ray Telescope (SXT)
Hard X-ray Telescope (HXT)
SXT consists of a single mirror assembly (SXT FMA) shared by two instruments
- Reflection Grating Spectrometer (RGS)
- X-ray Microcalorimeter Spectrometer (XMS)

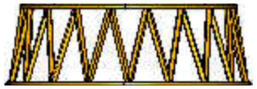
HXT consists of 3 mirror assemblies, each with a detector at its focus

New Launch Vehicle: Delta IV H

Most capable US LV, throw mass: 9380 kg to L2 (C3 = -0.5)

Fairing internal diameter: 4.5 m

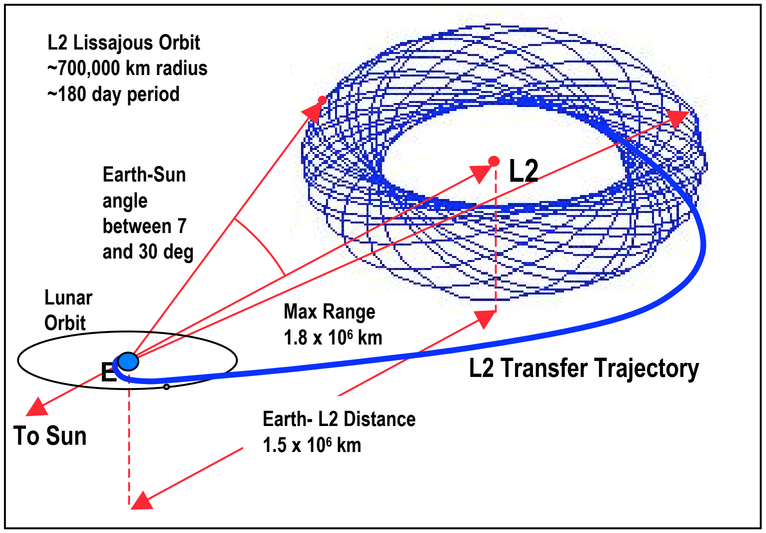
4394-5 Payload Adapter ("Elephant Stand")



- **Allows for no CG height limitation**
- **386 kg PAF weight factored in published throw mass**

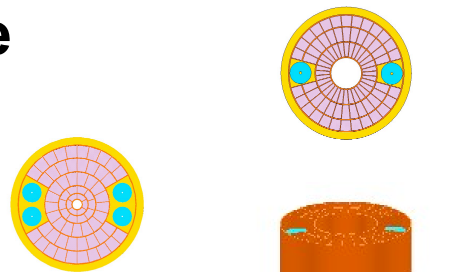
Direct insertion to L2

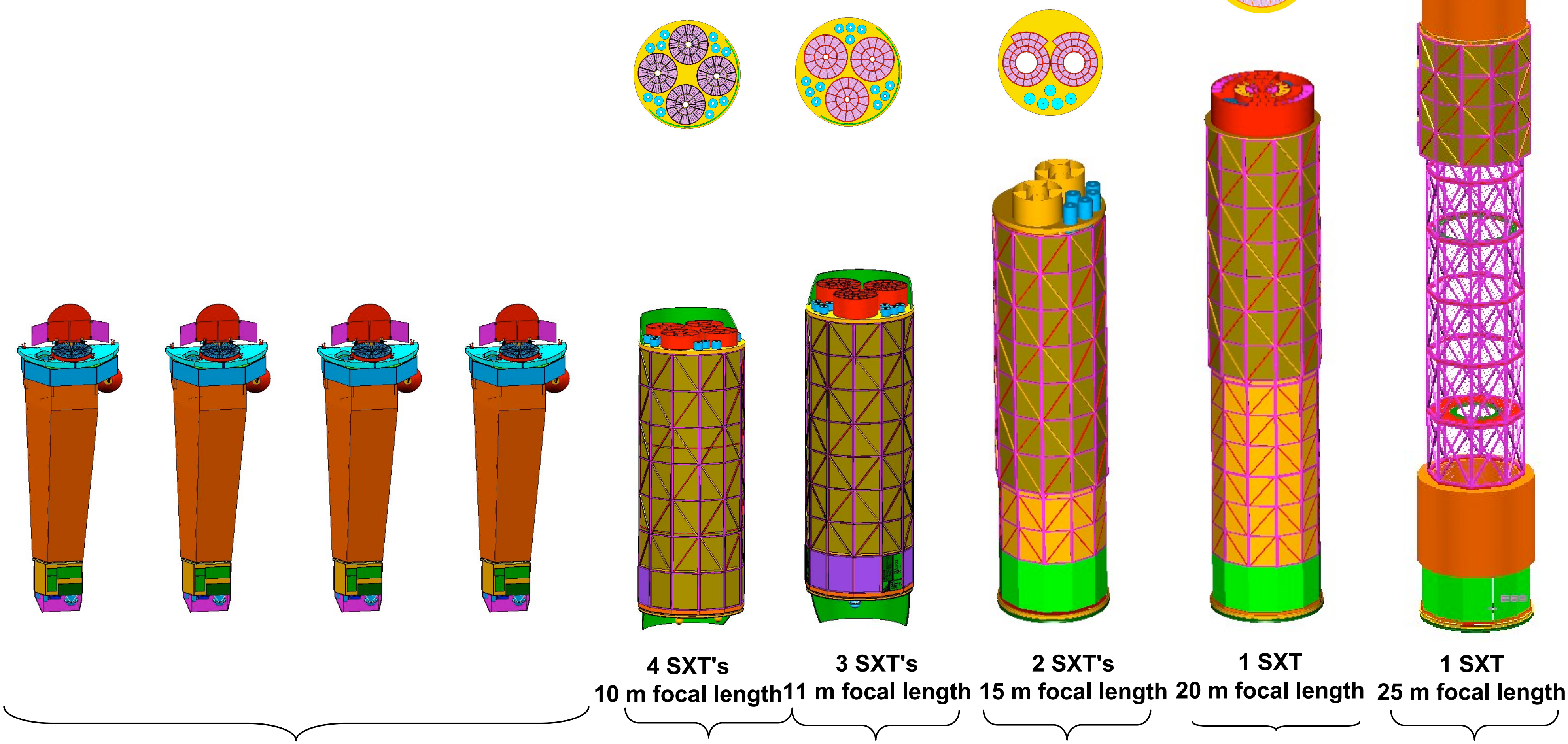
- **Several launch opportunities available almost every day**
  - **Except 3-4 days when Moon is "in the way"**
- **No lunar phasing loops**



Single Launch Single Satellite Configuration Trade

Use a single Delta IVH, maintaining science requirements





Reference: 2 Atlas V-class launches

Optic configurations traded for single Delta IVH launch

4 Telescope, 10m focal length selected as very promising alternate

Optics Module (OM)

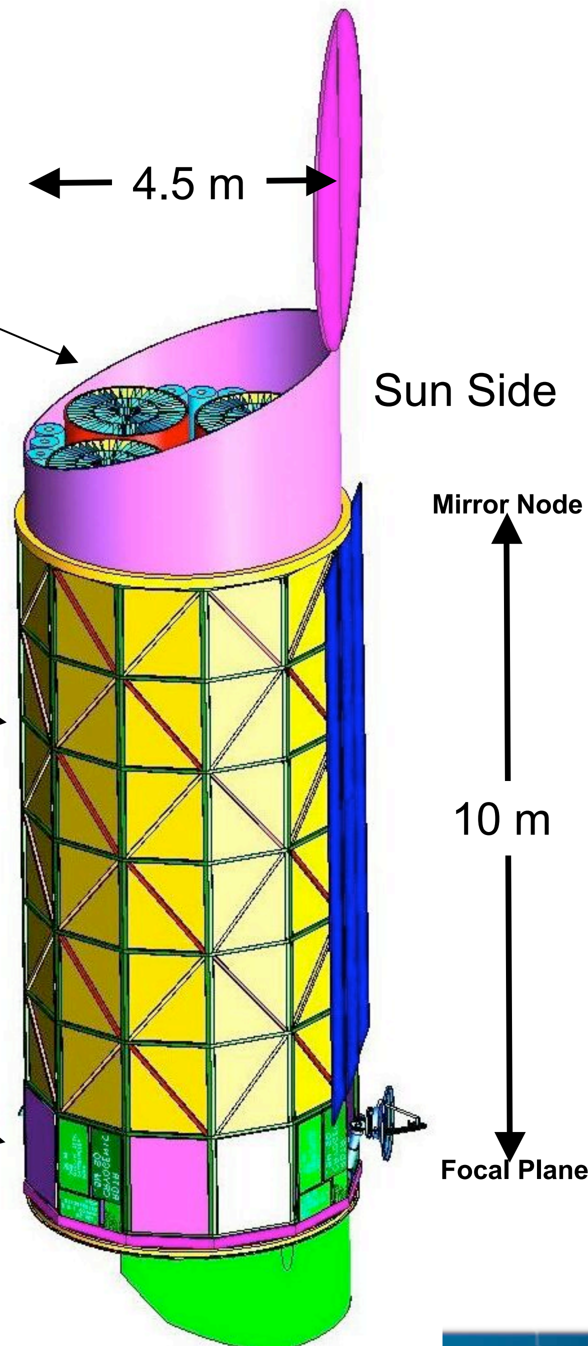
- SXT and HXT mirror assemblies
- FMA Thermal System and control electronics
- Door/sunshade and internal cover/door
- Star Tracker

Metering Structure Module (MSM)

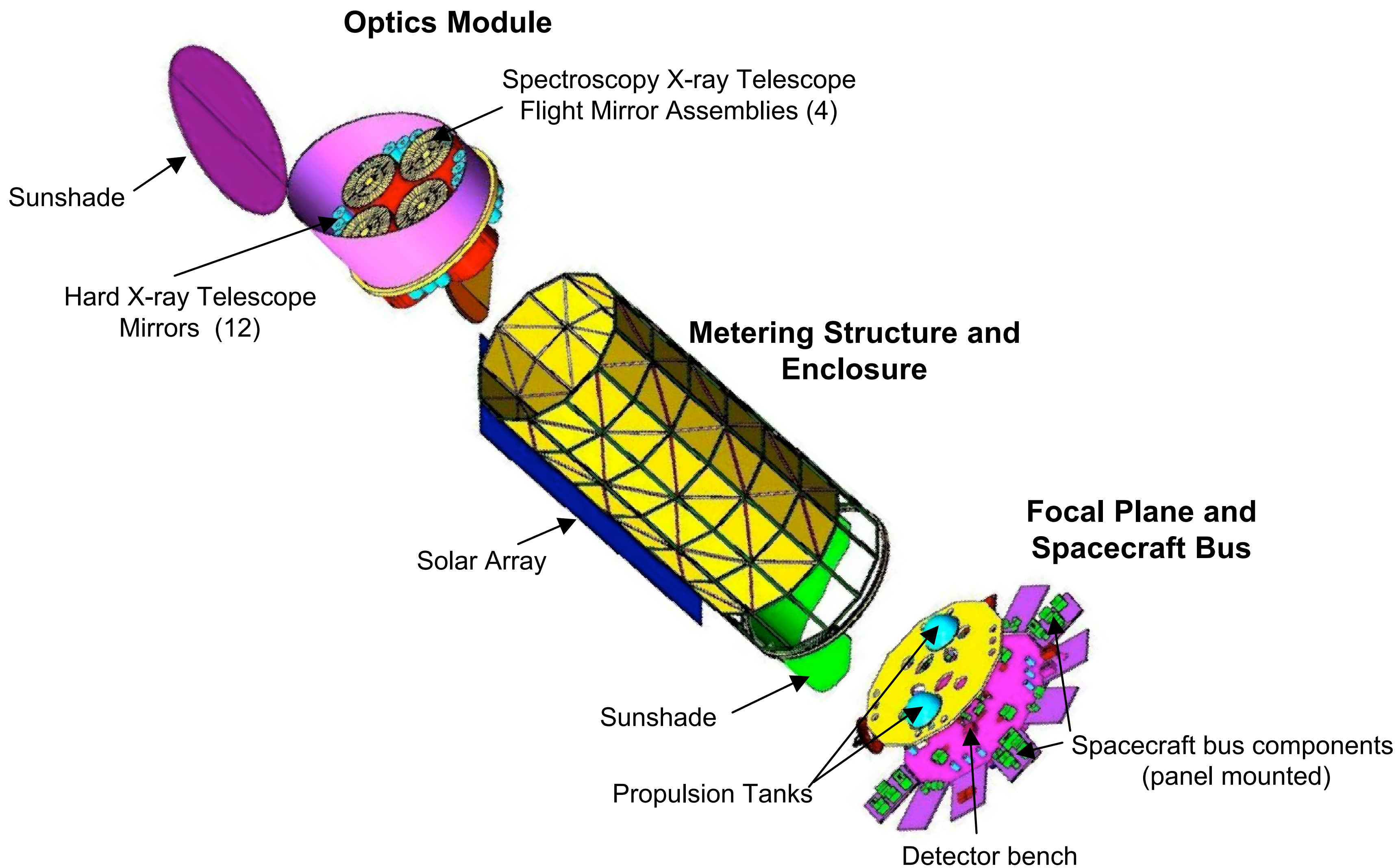
- Fixed metering structure
- Light and Micrometeoroid shield
- Internal Baffles
- Solar Arrays

Focal Plane Module (FPM) and S/C Bus

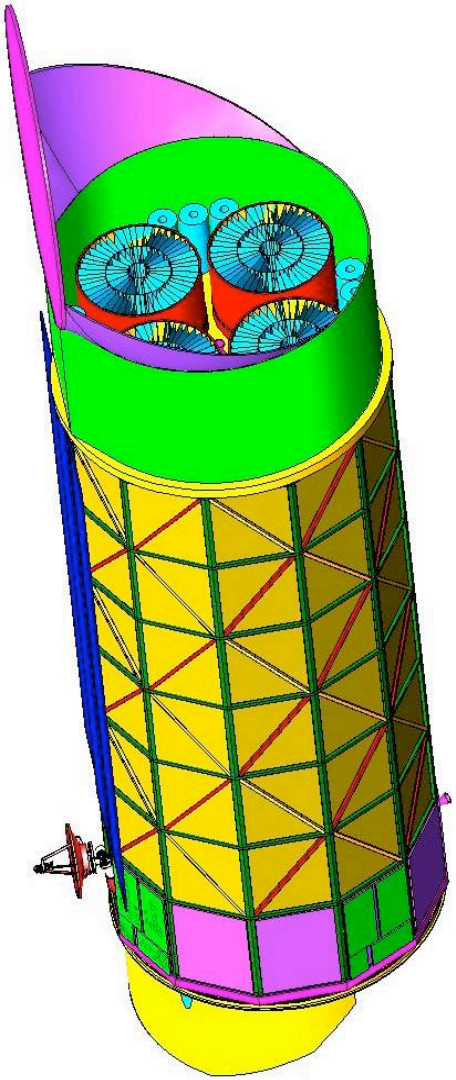
- All instrument detector systems on aft-most deck, baffles
- Propulsion Tanks
- Electronics for instruments on panels and Benches
- Spacecraft bus subsystem components on panels and deck



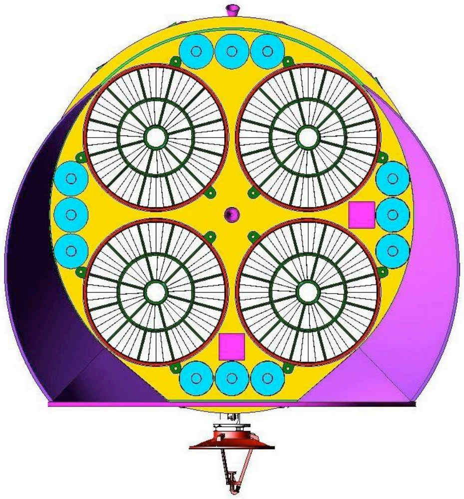
Single Launch Mission Configuration (“Expanded” view shown for clarity)

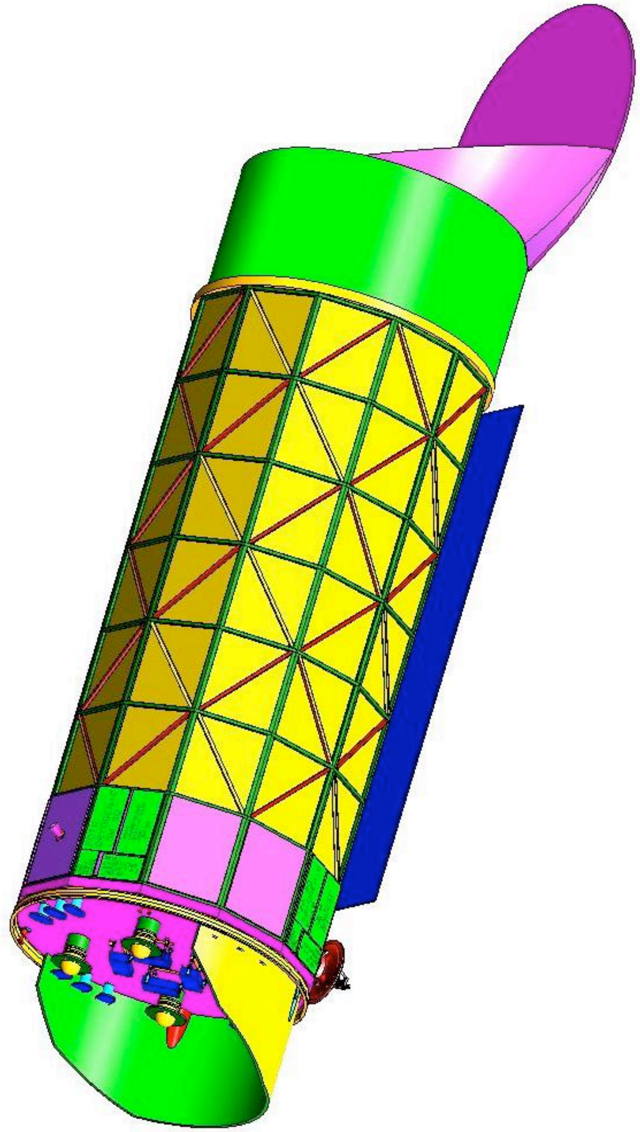


Observatory - Front and Aft Views

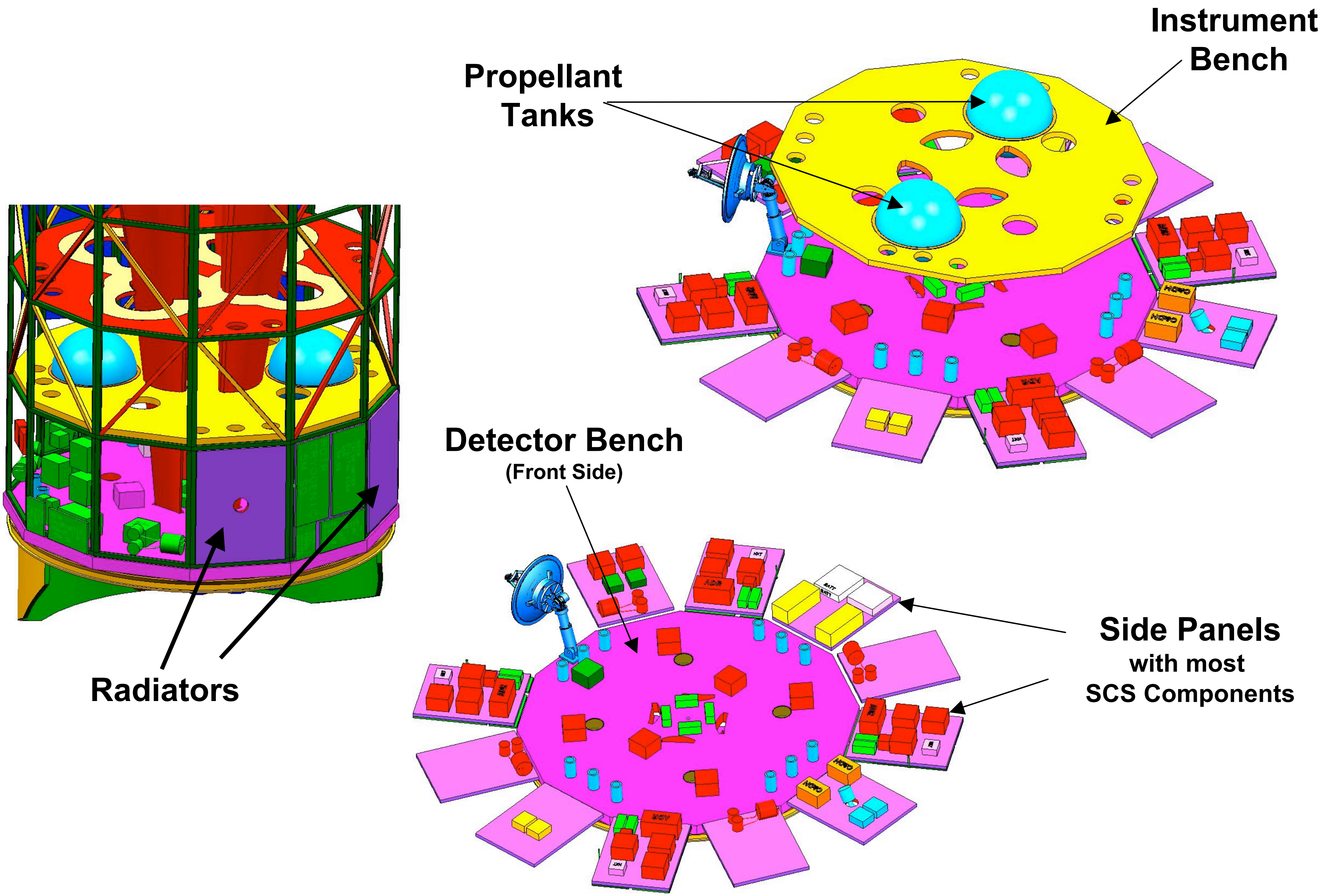


Front View



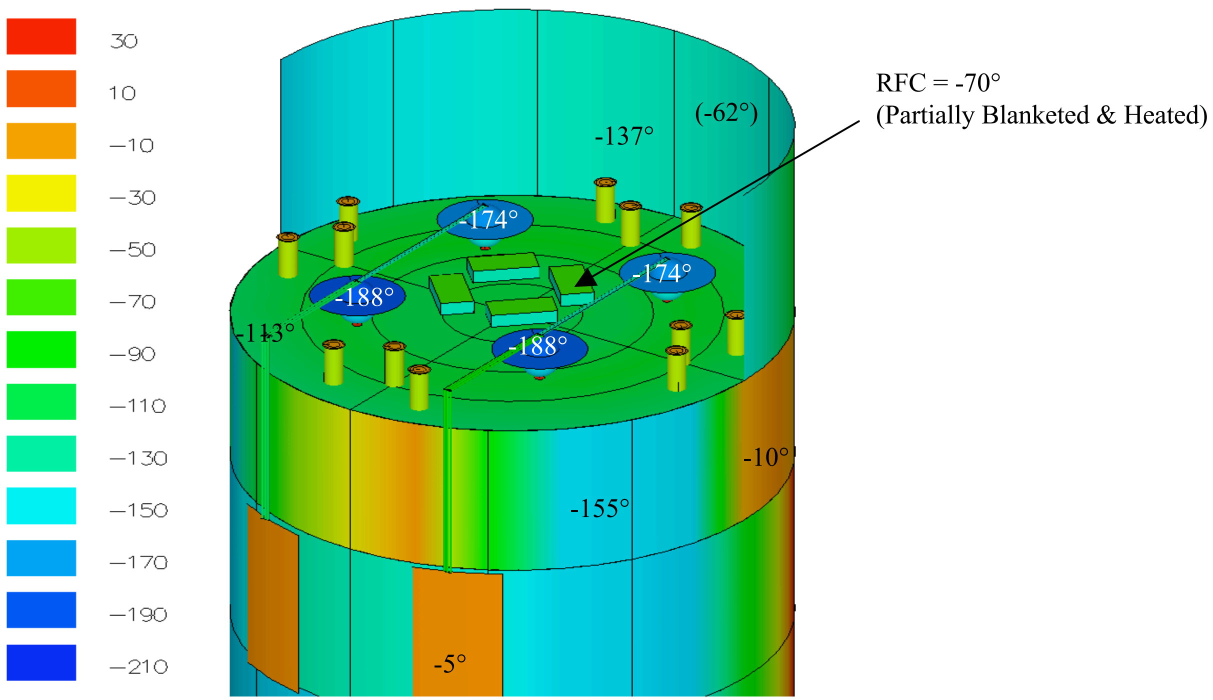


FPM and SCS - Detailed Views

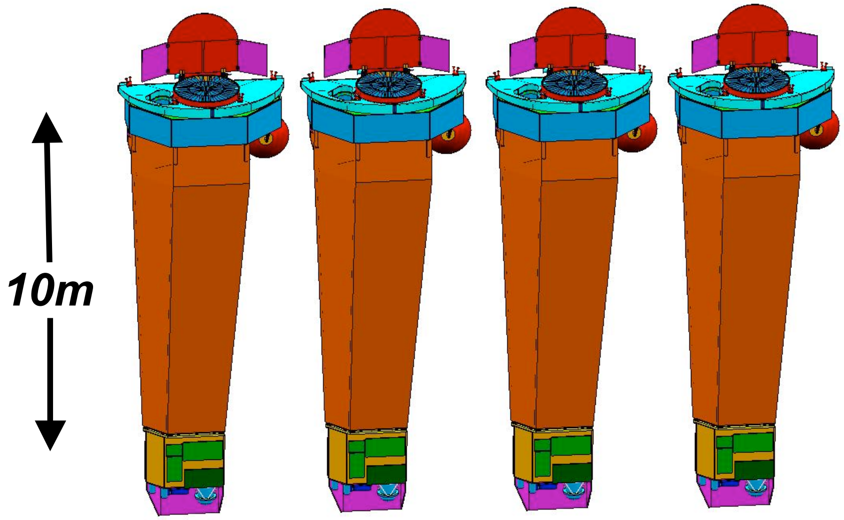


Subsystems Highlights

- **Thermal**
  - All requirements met (per ~100 node thermal model analysis)
  - FMA: Electrically heated Pre- and Post-Collimators maintain mirrors at 20ºC at all times
  - MSM: Conventional design w/ radiators; circumferential gradient 8 ºC
  - FPM: Embedded heat pipes to lower gradients
  - Cryocoolers: Sunshade and passive radiators maintain < 150 ºK
  - Cold Head: Heat pipes carry heat load to radiators

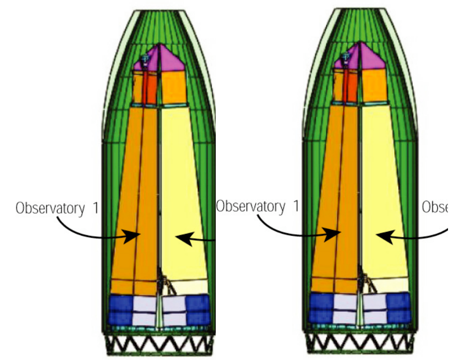


Constellation-X Updated Configuration



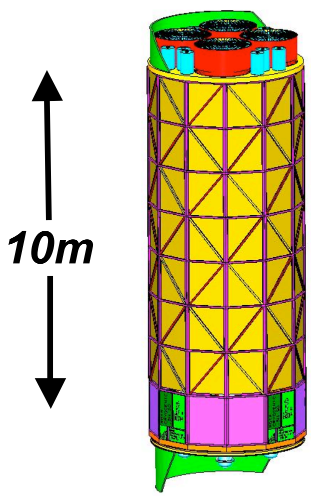
Old Design

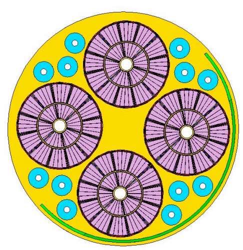
Launched in pairs on 2 Atlas V class launchers

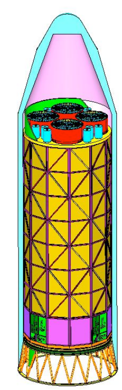


New Design

Single launch on the new Delta IVH launcher

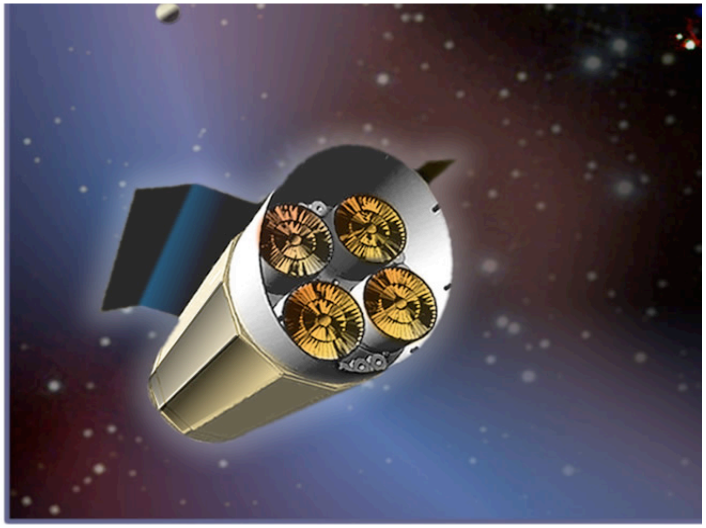






Launch cost saving of ~$100M ***with no loss in science capability***

Summary



Constellation-X opens the window of X-ray spectroscopy to address compelling and high priority Beyond Einstein science questions on Black Holes and Dark Energy

The technology development continues to make substantial progress

A single launch, single satellite approach is now the mission baseline

http://constellation.gsfc.nasa.gov