Constellation X

The Constellation X-ray Mission

The Constellation-X Mission

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The Constellation-X Mission

Science:

- Black Holes
- Dark Matter and Dark Energy
- Cycles of Matter and Energy

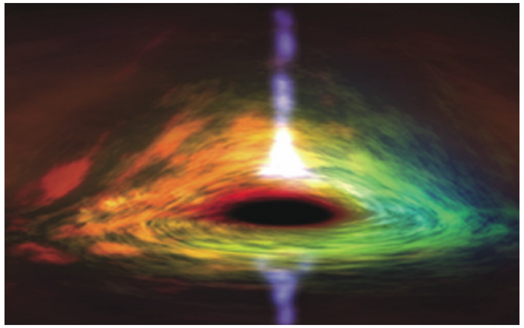
A Constellation of X-ray telescopes for high resolution spectroscopy:

- 25-100 times gain in throughput over current missions
- New facility that will open a new window for X-ray spectroscopy

The National Academy of Sciences Decadal survey ranked Constellation-X the next priority for a large space observatory to follow after JWST

Endorsed in the NAS Turner Committee Quarks to Cosmos Report

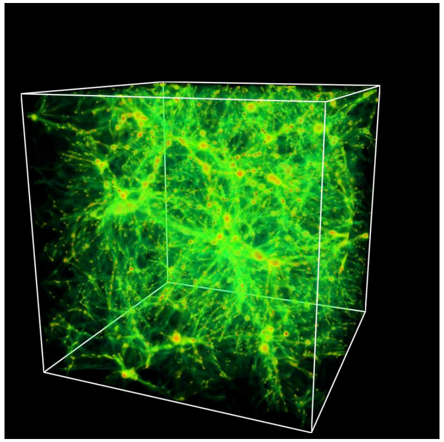
Constellation-X Science Objectives



Black Holes

Observe hot matter spiraling into **Black Holes** to test the effects of General Relativity

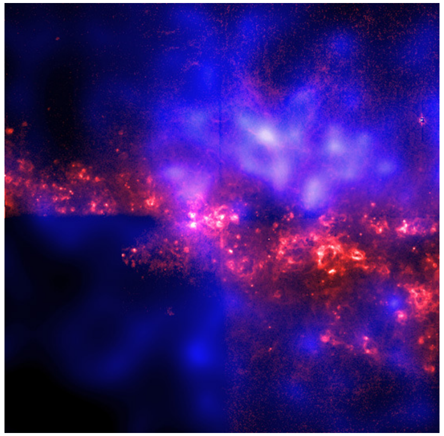
Trace their **evolution with cosmic time**, their contribution to the energy output of the Universe and their effect on galaxy formation



Dark Matter and Dark Energy

Use clusters of galaxies to trace the locations of **Dark Matter** and as independent probes to constrain the amount and evolution of **Dark Energy**

Search for the **missing baryonic matter** in the Cosmic Web



Cycles of Matter and Energy

Study dynamics of **Cosmic Feedback** (outflow of mechanical energy, radiation, and chemical elements from star formation and black holes to the interstellar and intergalactic medium)

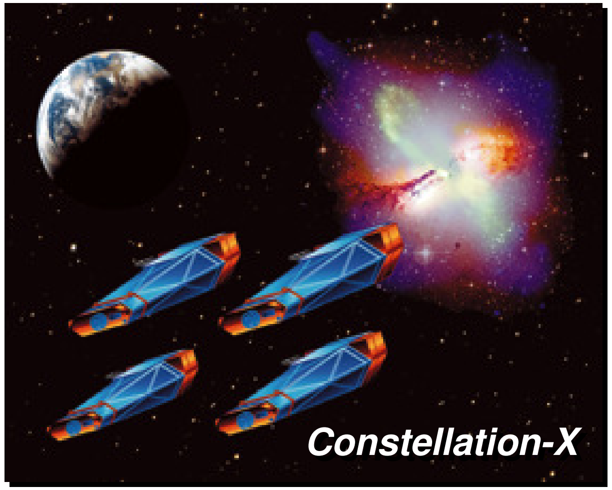
Creation of the elements in **supernovae**, The equation of state of **neutron stars, Stellar activity, proto-planetary systems** and X-rays from **solar system objects**

A new facility for high throughput X-ray spectroscopy

Constellation-X provides high throughput, high spectral resolution, & broad energy bandpass

Large sample sizes of key astrophysical objects

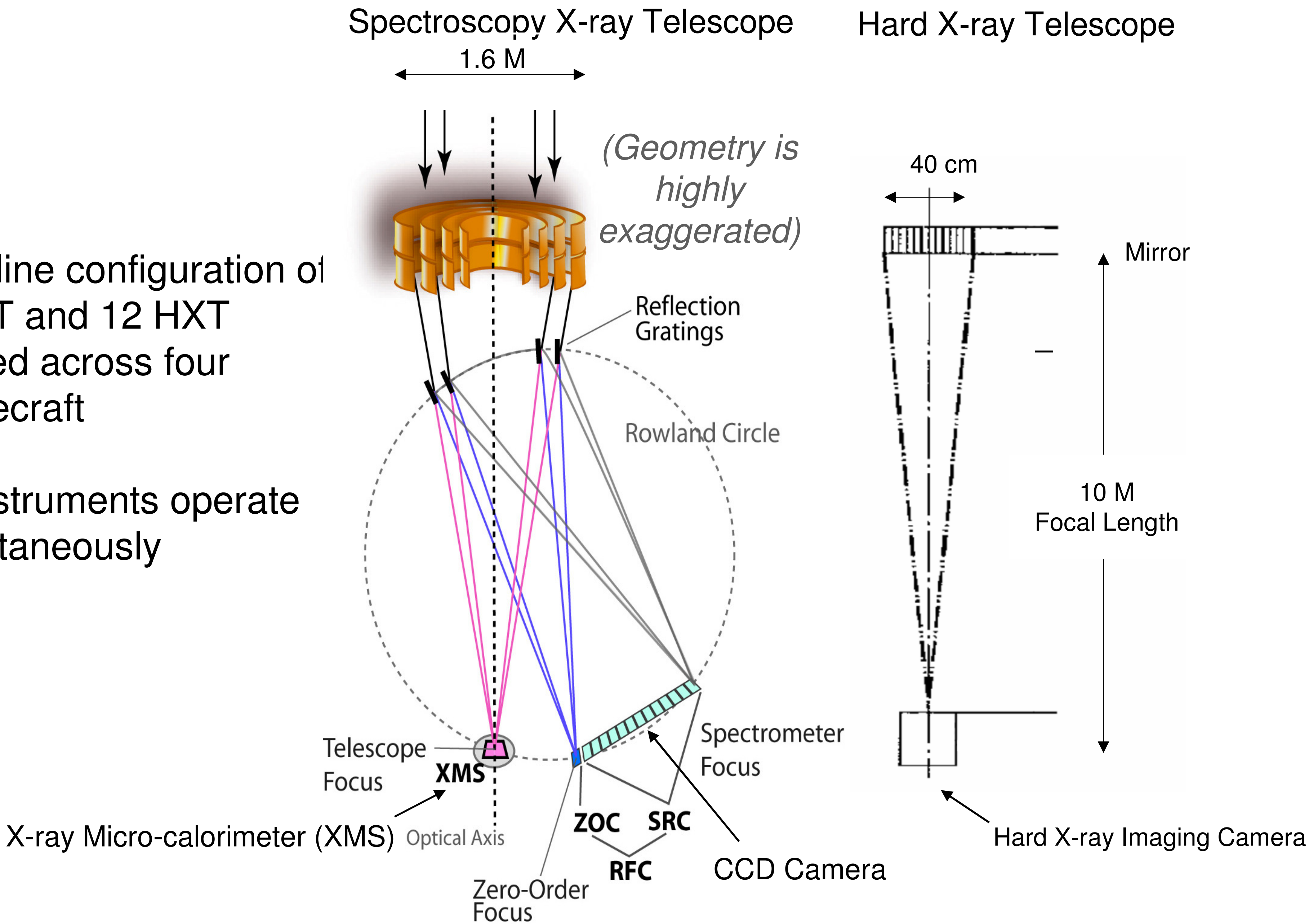
The spectroscopy of Constellation-X compliments the superb imaging of Chandra, in a manner similar to the way the Keck and Gemini compliment HST



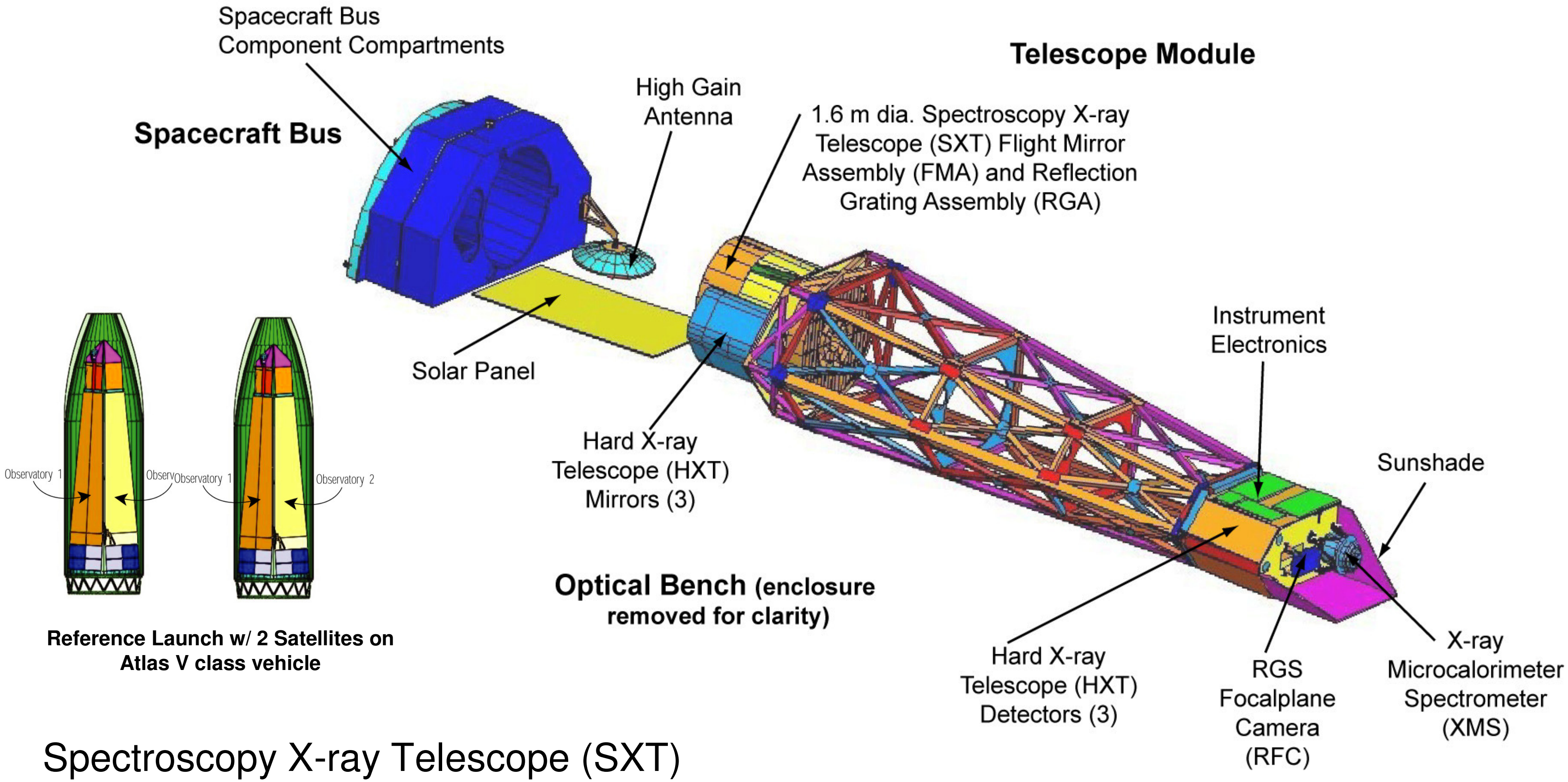
Constellation-X Payload

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

All instruments operate simultaneously

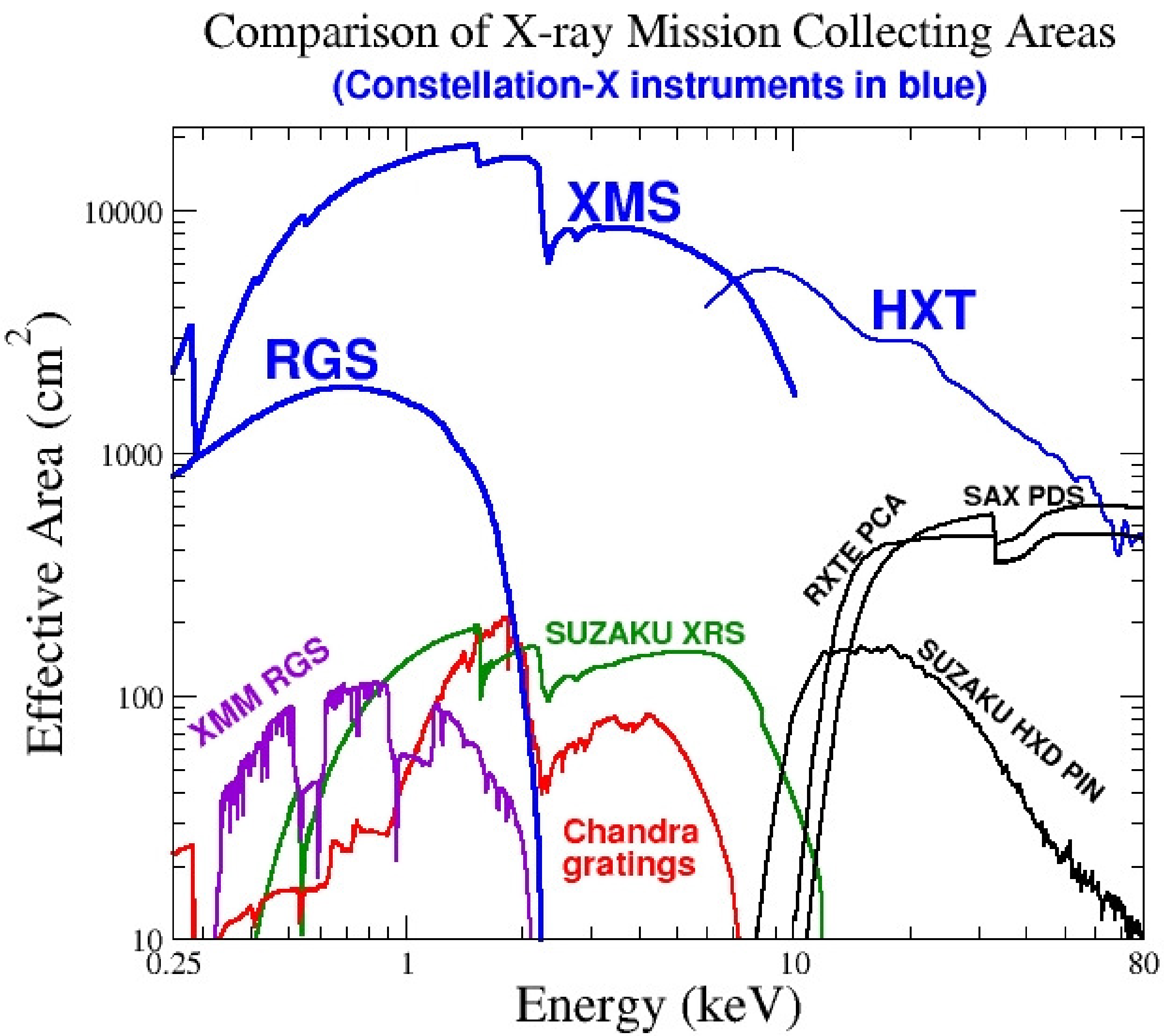


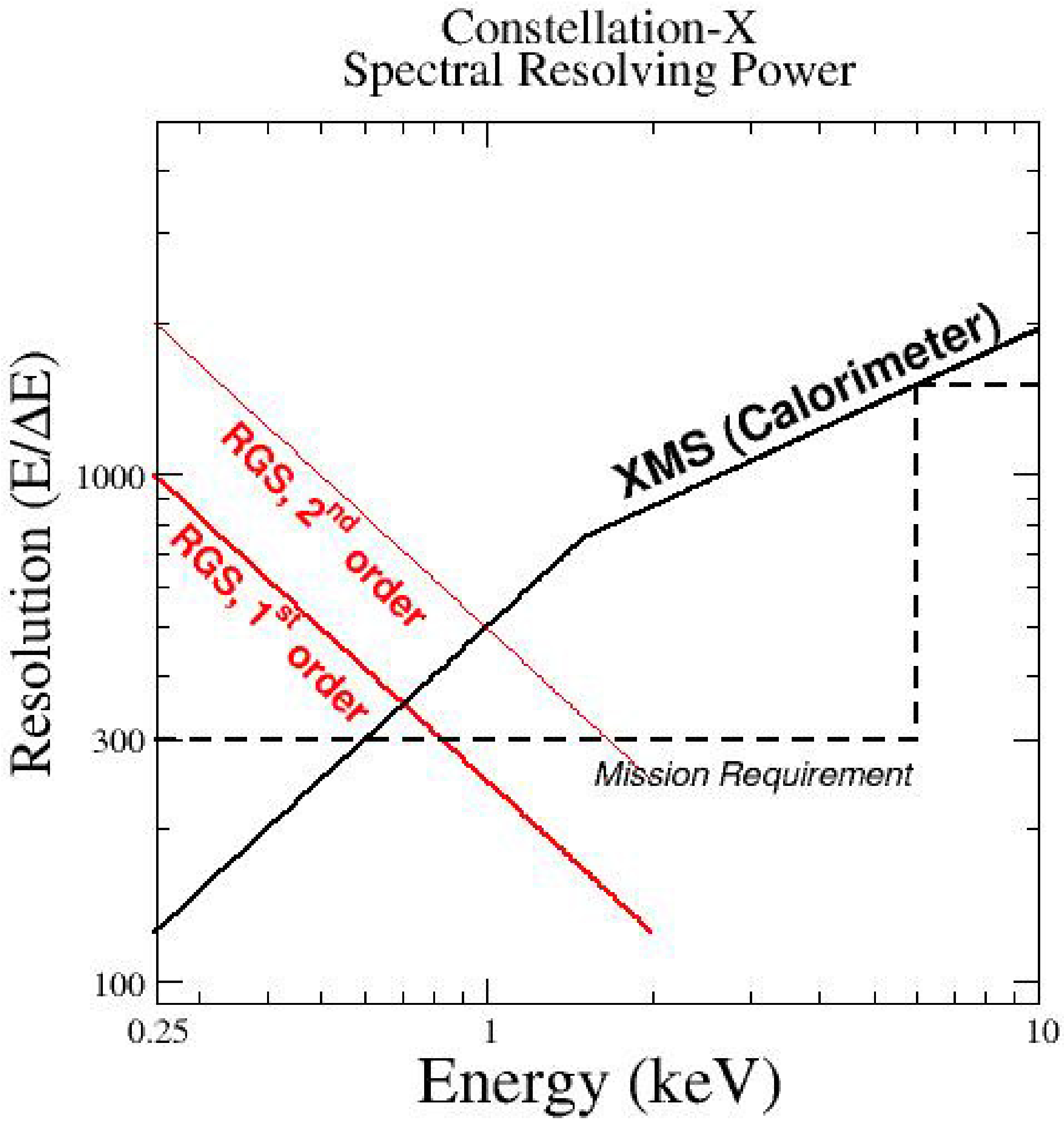
View of Observatory



- 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

Comparison of collecting area





In-plane grating configuration

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

Overall Mission Status

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

- Currently pre-phase A
  - **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 and goals, 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)

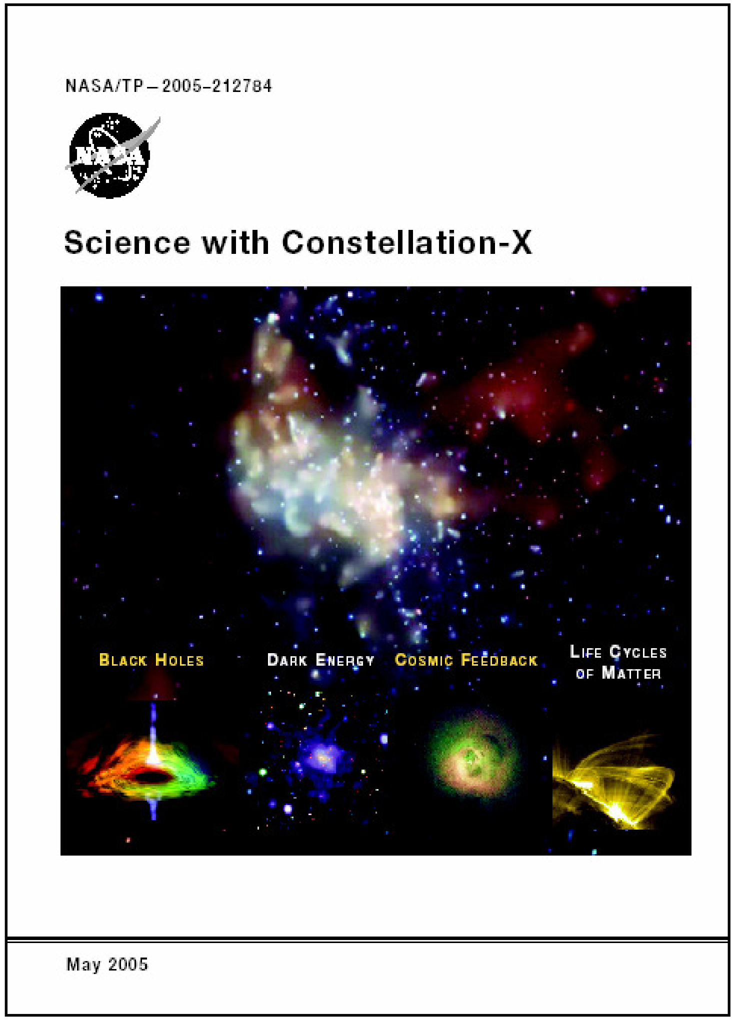
- Launch date is currently driven by budget constraints and programmatic considerations, not technology or schedule
  - Decision pending whether Con-X, LISA or JDEM proceeds as next major Astrophysics observatory, and mission ordering there after…

The Constellation-X Science Case Update

- **October 2004 through January 2005,**
  >60 scientists met in small groups and produced
  13 white papers (100 pages of text)
- **Goal: Update the Constellation-X science case given progress by Chandra and XMM-Newton over past 5 years**
  - **Team leaders in this effort:**
    - **David Alexander (IoA)**
    - **Jean Cottam (GSFC)**
    - **Jeremy Drake (CfA)**
    - **Jack Hughes (Rutgers)**
    - **Casey Lisse (U Md)**
    - **Jon Miller (U Mich)**
    - **Michael Muno (UCLA)**
    - **Richard Mushotzky (GSFC)**
    - **Frits Paerels (Columbia)**
    - **Chris Reynolds (U Md)**
    - **Gordon Richards (JHU)**
    - **Michael Shull (Colorado)**
    - **Randall Smith (JHU/GSFC)**
    - **David Strickland (JHU)**
    - **Tod Strohmayer (GSFC)**

Down load from http://constellation.gsfc.nasa.gov

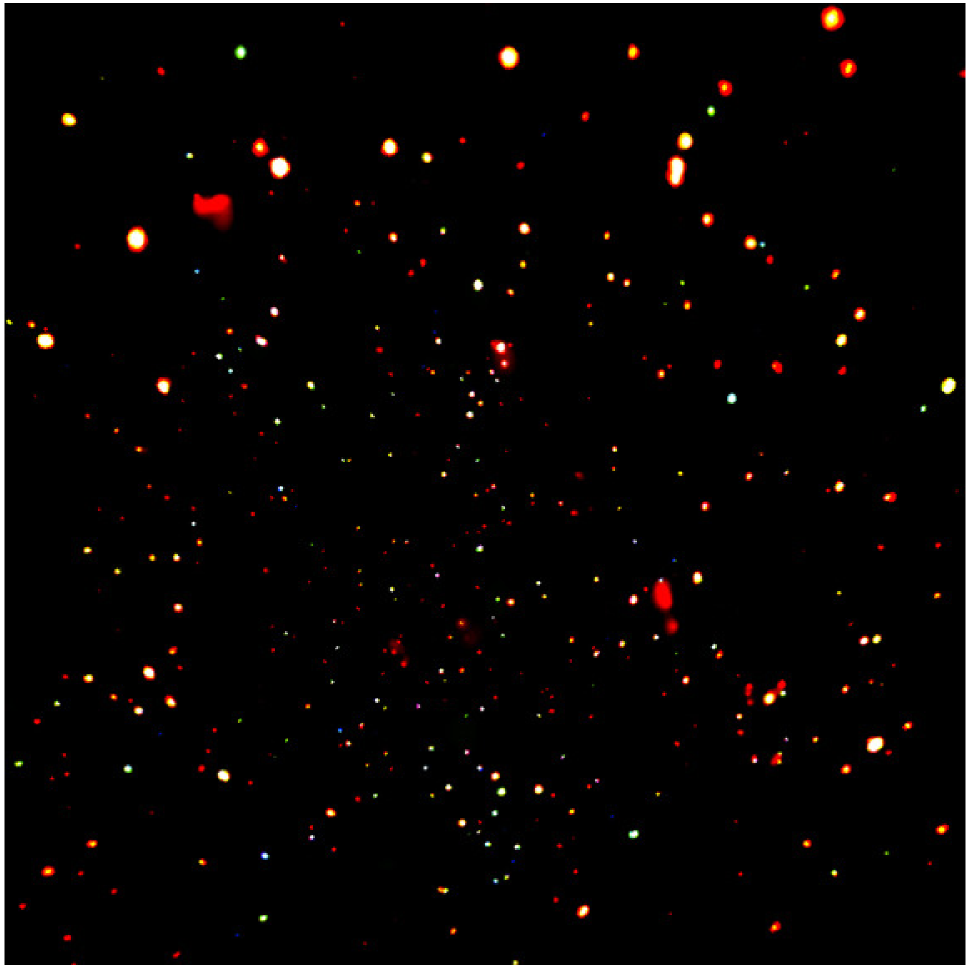
Result of the Process:
"Science with Constellation-X" booklet



The Chandra Deep Fields

Chandra has resolved the X-ray background into active galactic nuclei (AGN) with a space density of a few thousand per sq deg

- Constellation-X will gather high-resolution X-ray spectra of the elusive optically faint X-ray sources
- Chandra deep surveys have the sensitivity to detect AGN up to z~8



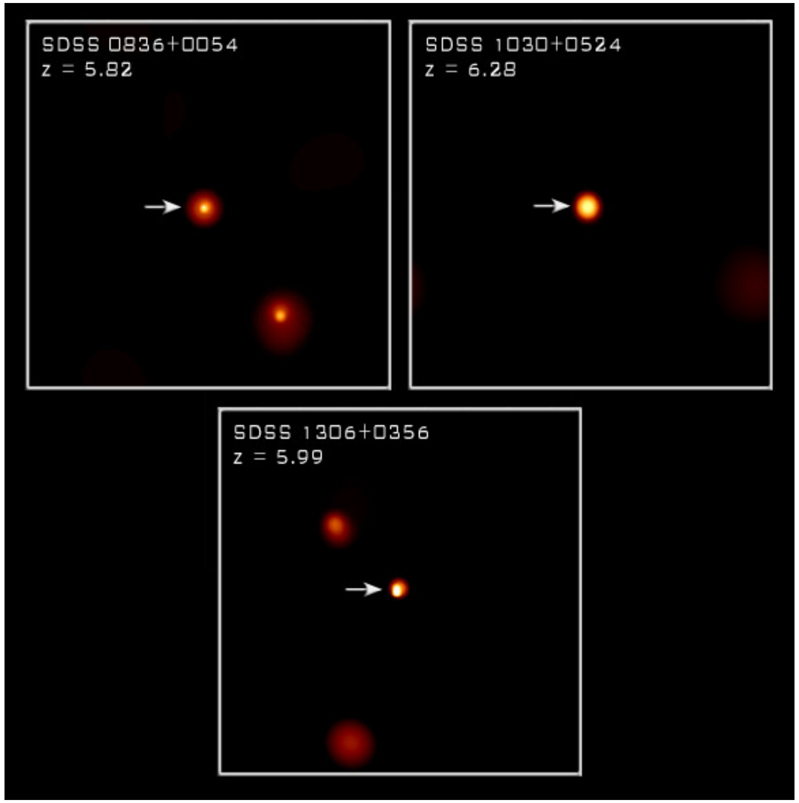
2 Megasecond Observation of the CDF-N (Alexander et al. 2003)

Chandra sources identified with mix of active galaxies and normal galaxies, many are optically faint and unidentified

X-ray Detections of High Redshift QSOs

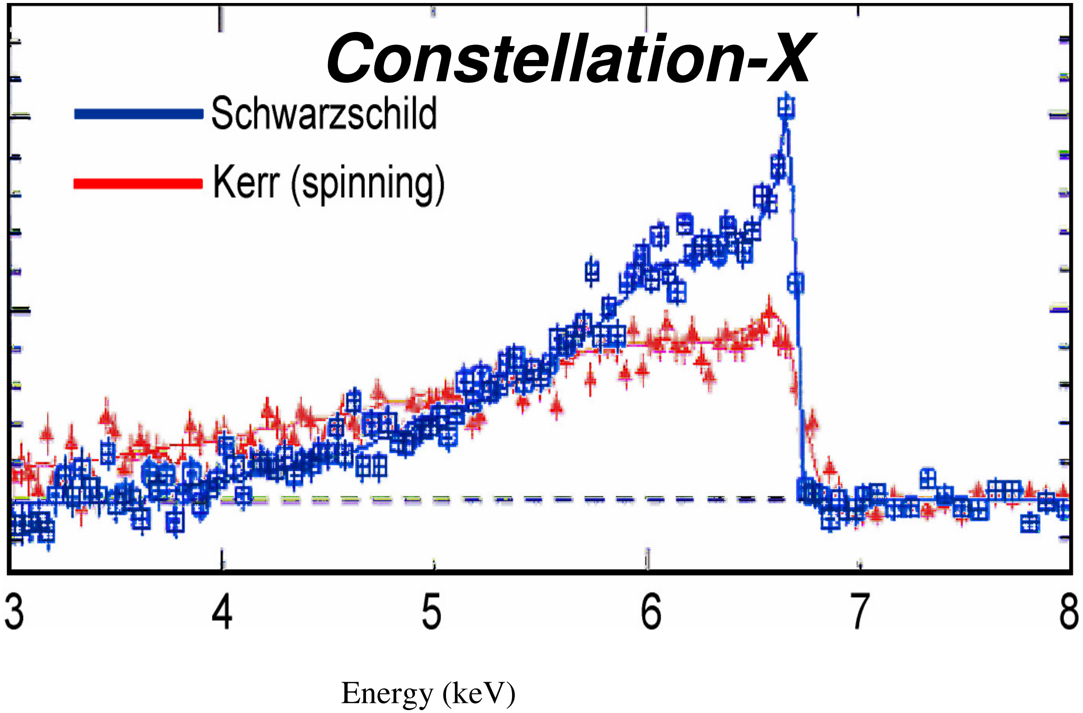
Chandra has detected X-ray emission from three high redshift quasars at z ~ 6 found in the Sloan Digital Sky survey

Flux of 2-10 x 10^{-15} erg cm^{-2} s^{-1} beyond grasp of XMM-Newton, Chandra or Astro-E2 high resolution spectrometers, but within the capabilities of Constellation-X to obtain high quality spectra



High resolution spectroscopy enables study of the evolution of black holes with redshift and probe the intergalactic medium of the early universe

Constellation-X, Black Holes and Strong Gravity

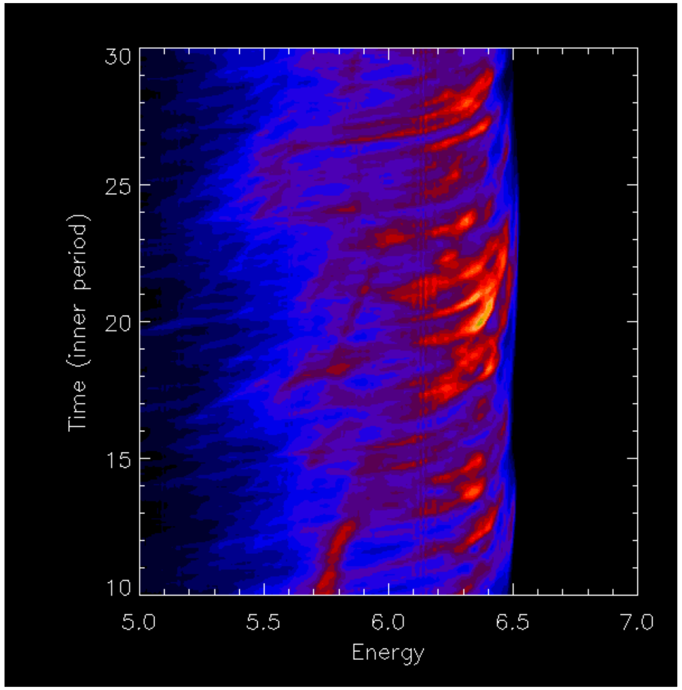


Constellation-X will probe close to the event horizon with 100 times better sensitivity to:

- ✓ Observe iron profile from the vicinity of the event horizon where strong gravity effects of General Relativity can be observed
- ✓ Use Line profile to determine black hole spin
- ✓ Reverberation analysis to determine black hole mass
- ✓ Investigate evolution of black hole properties (spin and mass) over a wide range of luminosity and redshift

The next step in studying Iron K lines

QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.



Analysis of iron line variability (from orbital motion of disk & reverberation effects) allows to to separate effects of

- Accretion disk physics
- Spacetime geometry

Requires superior collecting area of Constellation-X

Constellation-X constraints on Cosmology from observations of Clusters

Constellation-X will derive cosmological parameters using (at least) three different techniques:

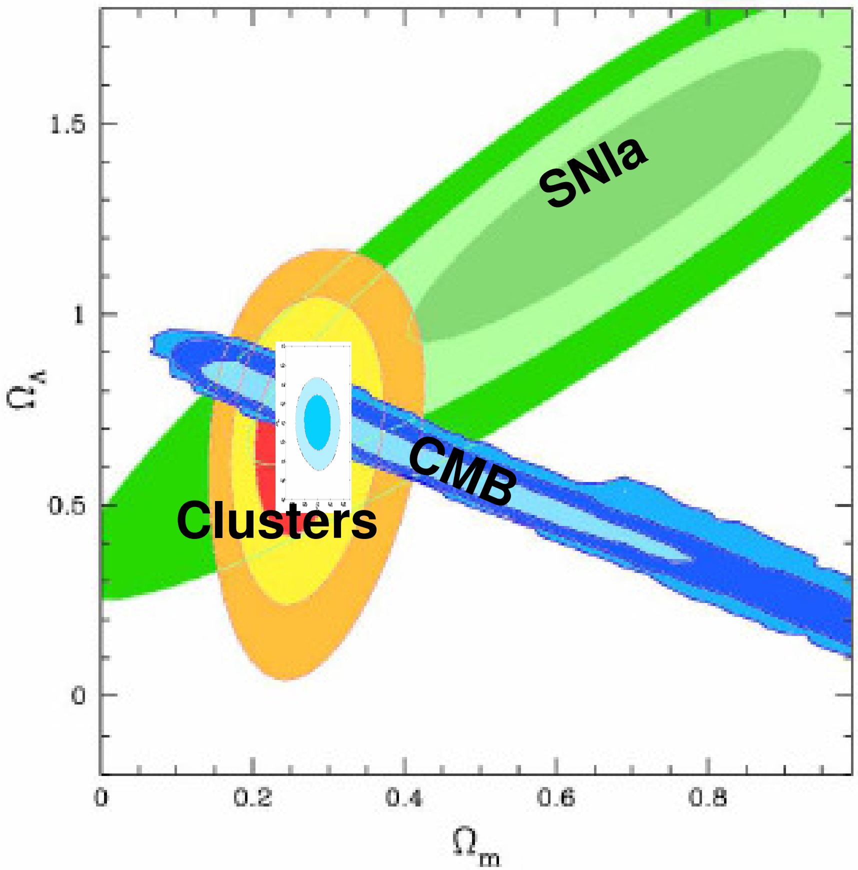
1. In combination with microwave background measurements the Sunyaev-Zeldovich technique to measure absolute distances

2. Using the gas mass fraction in clusters as a “standard candle”

3. Measuring the evolution of the cluster parameters and mass function with redshift

Cosmological Parameters with Constellation-X

(Allen et al. 2005)



Rapetti and Vikhlinin

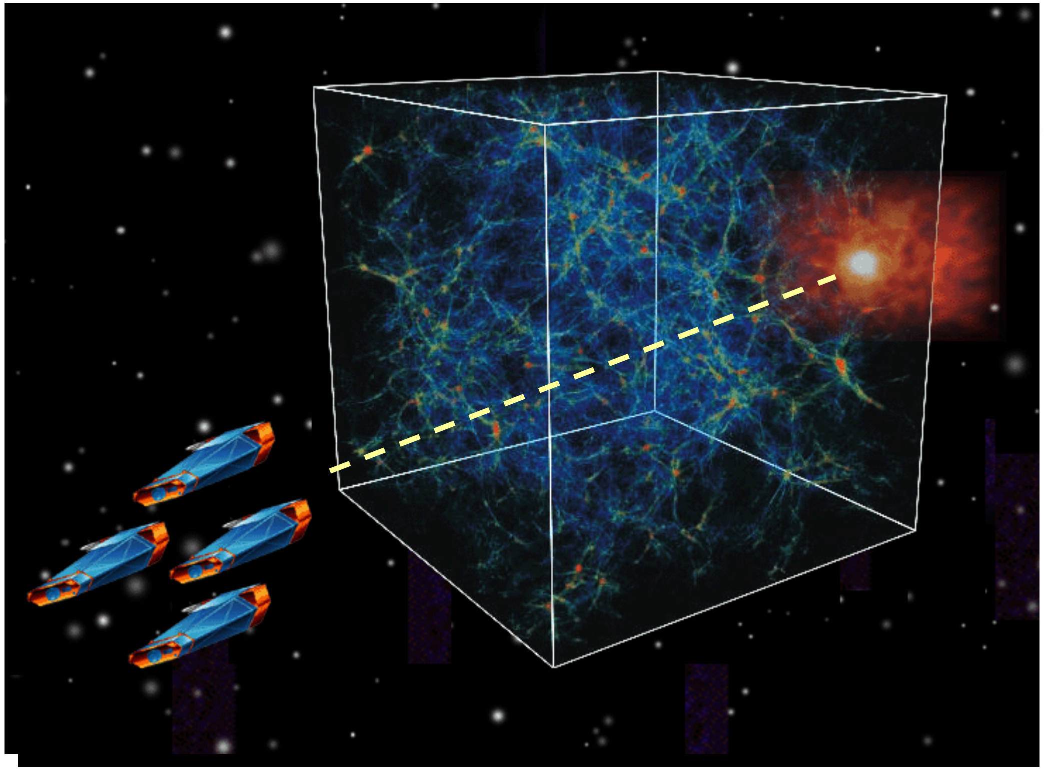
- Constellation-X effective area critical to study large sample of clusters
- A large snapshot survey followed by deeper spectroscopic observations of relaxed clusters will achieve f_{gas} measurements to better than 5% for individual clusters:
  - Corresponds to Ω_M=0.300±0.007, Ω_Λ=0.700±0.047
  - For flat evolving DE model,

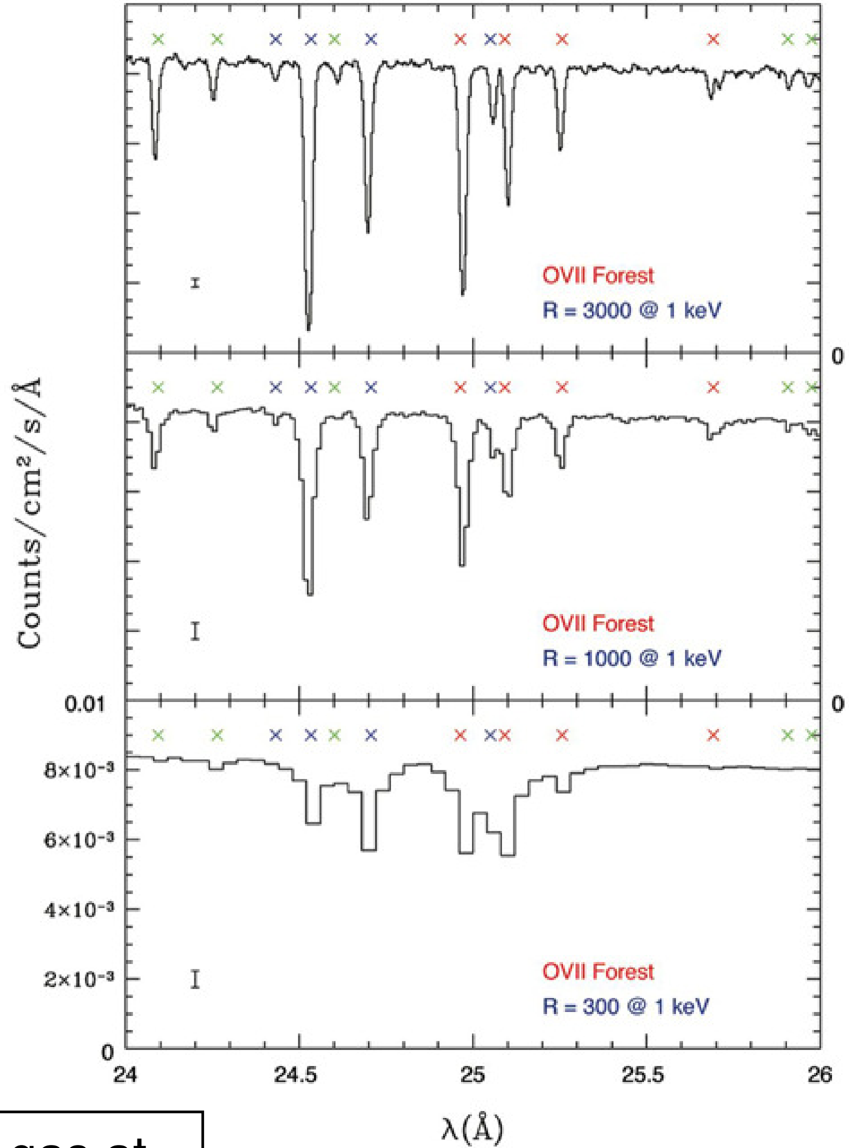
    w_0 = -1.00±0.15, w' = 0.00±0.27

Constraints are similar & complementary to SN Ia studies

Constellation-X will search for the missing baryons trapped in the Cosmic Web

- Detect ionized gas in the hot inter galactic medium via absorption lines in spectra of hundreds of background quasars



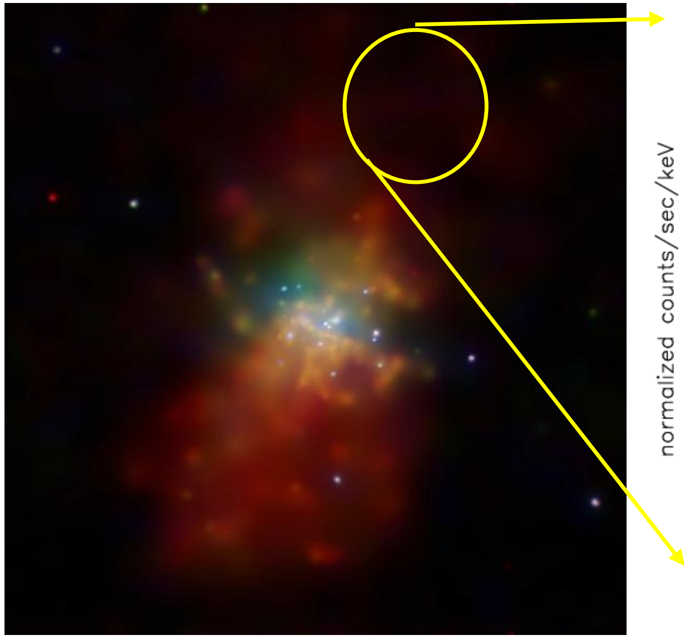


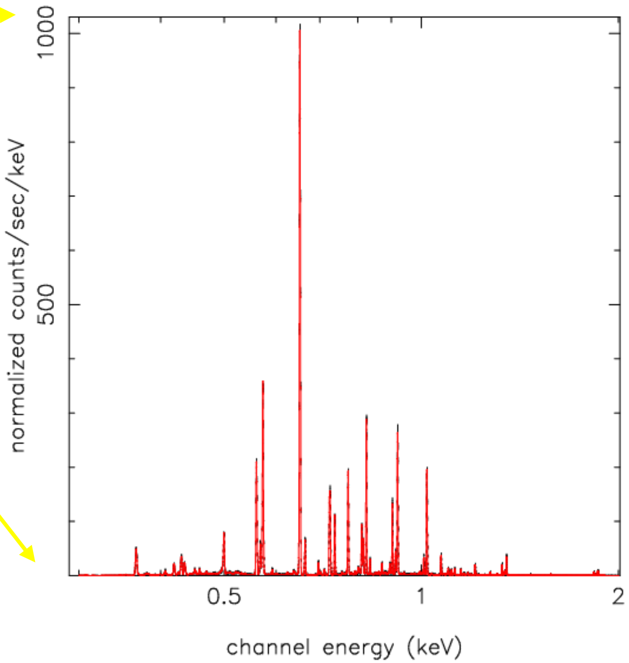
Constellation-X will probe up to 70% of the hot gas at low redshifts through OVII & VIII resonant absorption

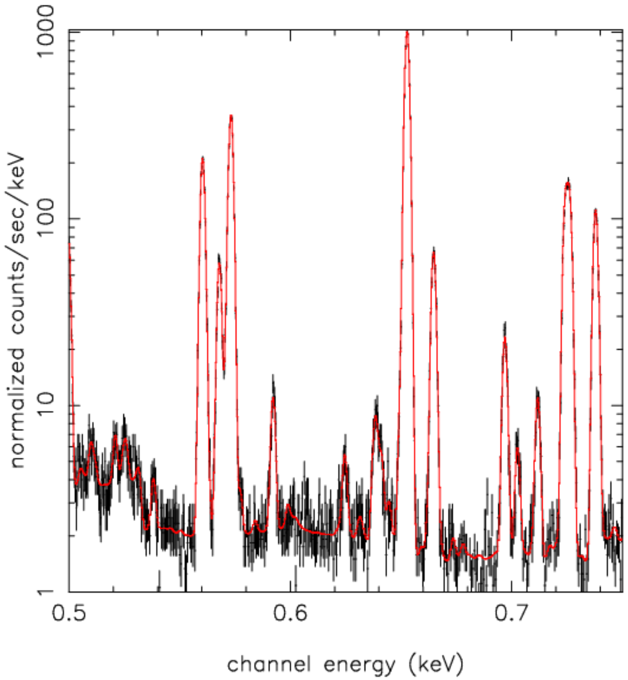
Credit: Nicastro

Supernova (Stellar) feedback Wind plasma diagnostics (D. Strickland, JHU)

Poster 16.06 (Strickland)







M82 Chandra central 5x5 kpc
0.3-1.1 keV
1.1-2.8 keV
2.8-9.0 keV

Simulated 20 ks Constellation-X northern halo observation, 0.3-2.0 keV

O VII and O VIII region. Well resolved triplet, high S/N in continuum.

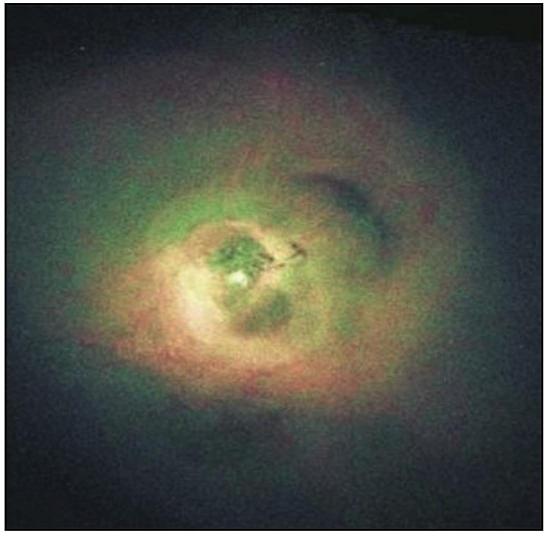
With calorimeter ~2-eV resolution at 1keV we can determine temperatures, densities, and metallicities accurately in many extended winds (not just M82)

Black Holes and Cosmic Feedback

Large scale-structure simulations require AGN feedback to regulate the growth of massive galaxies (e.g., Di Matteo et al. 2005, Croton et al. 2005)

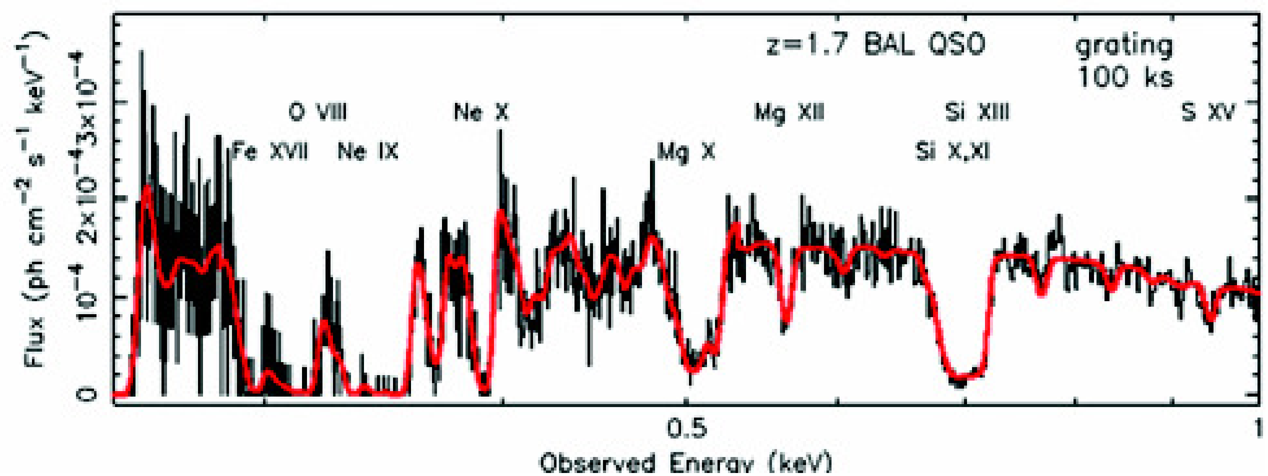
- **Con-X's non-dispersive X-ray spectroscopy required to probe hot plasma in cluster cores (Begelman et al. 2003, 2005)**

Perseus Cluster of Galaxies (Chandra image)



- **Con-X will reach the powerful AGN outflows in the quasar epoch (1<z<4)**

Con-X simulation of BAL QSO (S.Gallagher, UCLA)



SXT Flight Mirror Assembly (FMA)

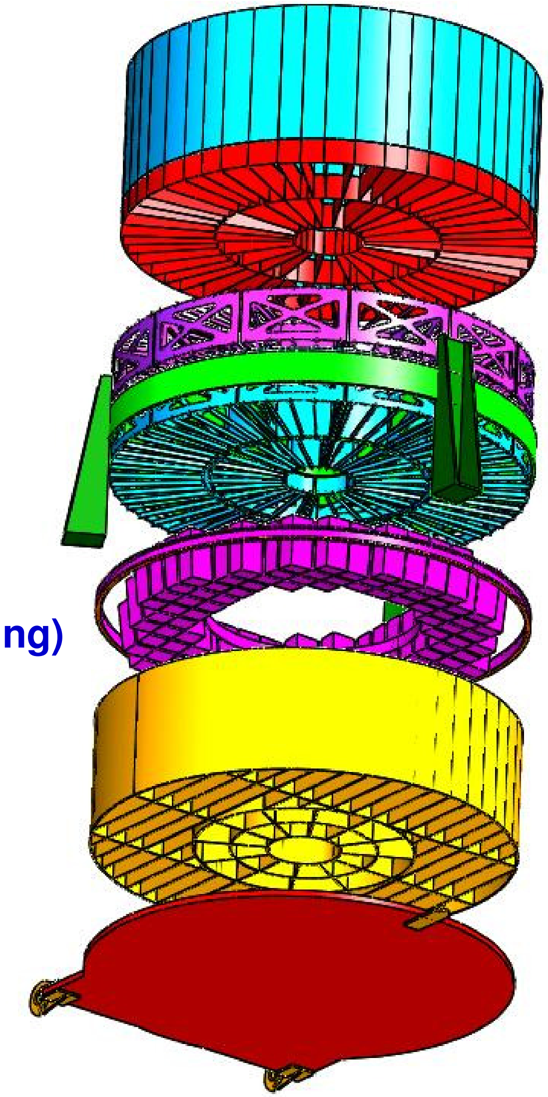
Precollimator

SXT Mirror

Reflection Grating
Array (in-plane grating)

Postcollimator

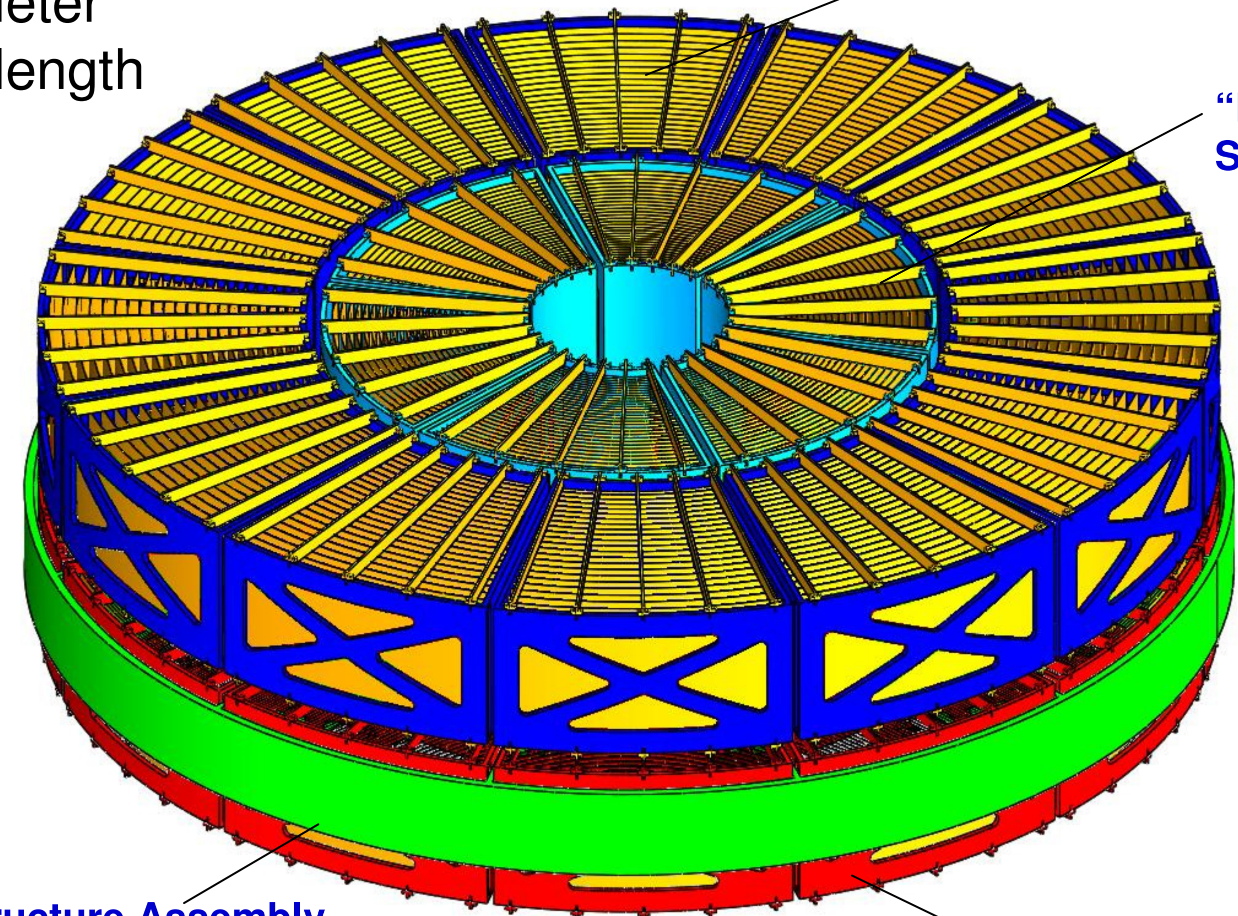
Aperture cover



SXT Mirror Reference Concept

- **General Overview of Design**

1.6m Diameter
10m focal length
640 kg

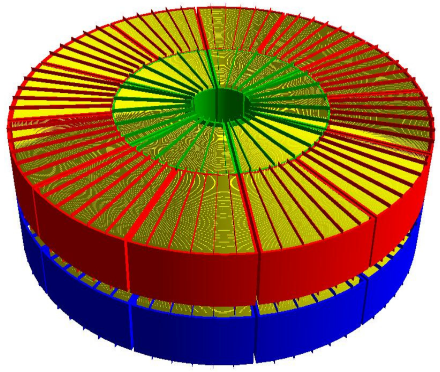


~200 reflector pairs, 3600 mirror segments

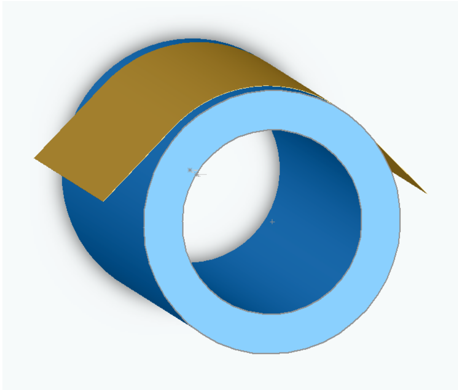
Spectroscopy X-ray Telescope

- Mirror Design
  - Wolter-1, true P/H pairs
  - Segments: 60^{o}, 30^{o}
- 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

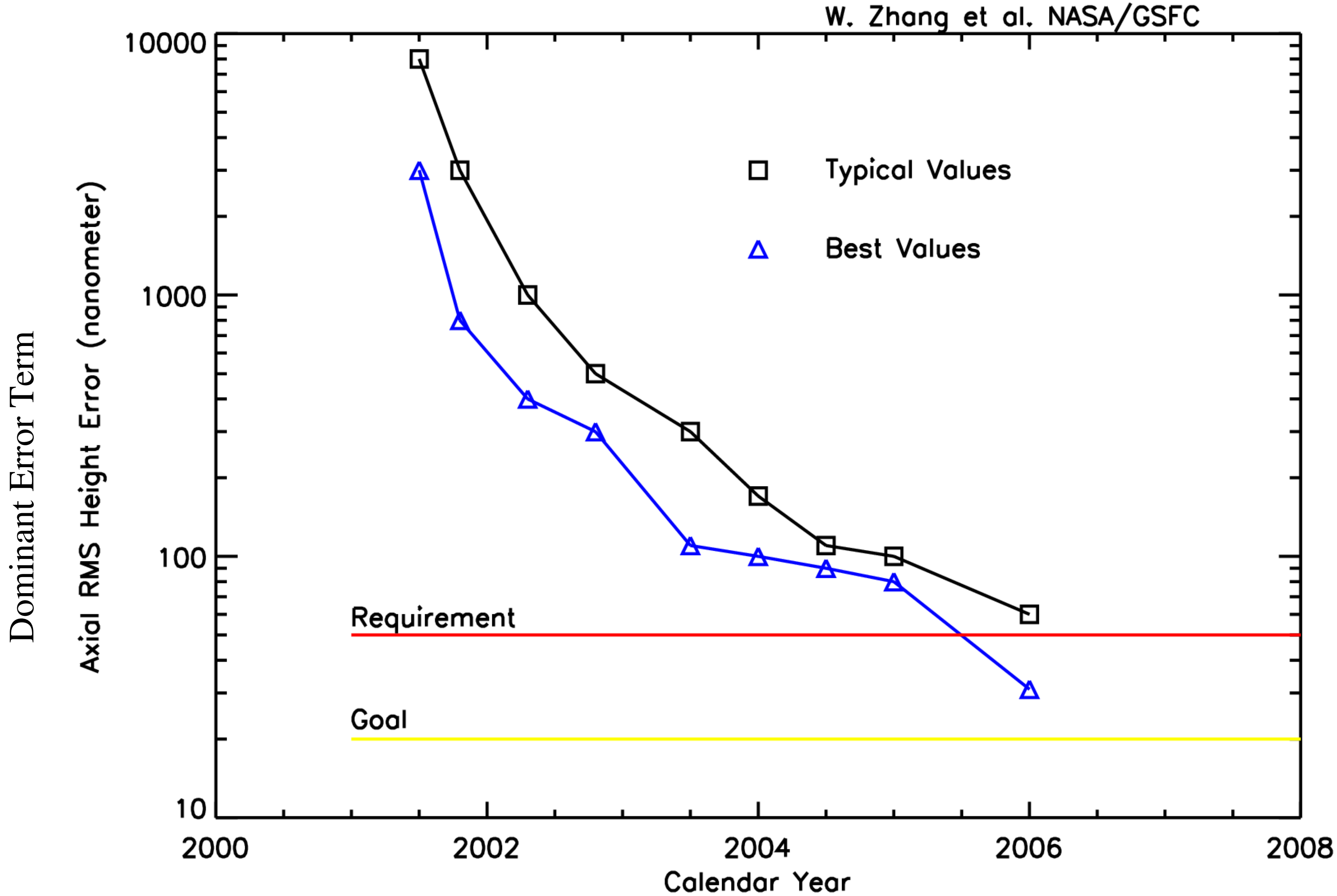


Glass Substrate Fabrication



Gold Reflector

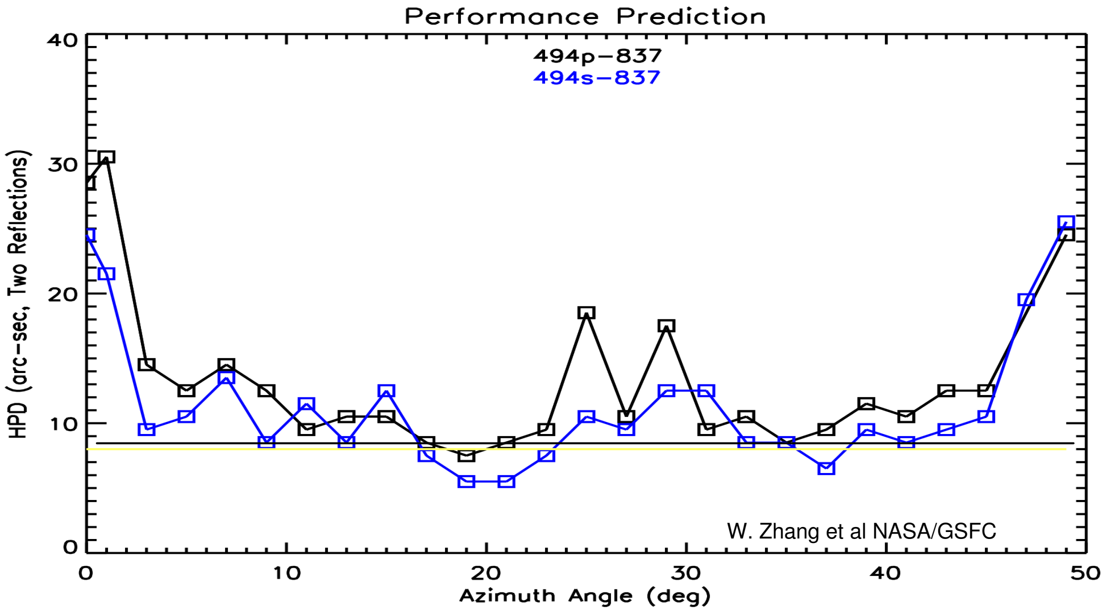
Spectroscopy X-ray Telescope Reflector Progress



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)

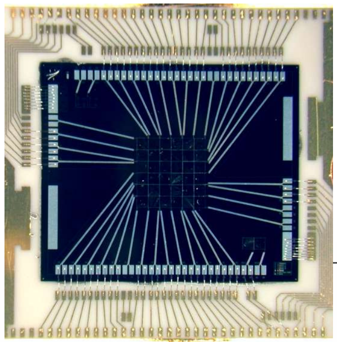


- Some evidence mandrel quality limits substrate performance, but still under investigation
- Improved substrate mandrels may eliminate epoxy replication process: no replication mandrels, process simplification, faster schedule
- Zhang et al

X-ray Micro-calorimeters

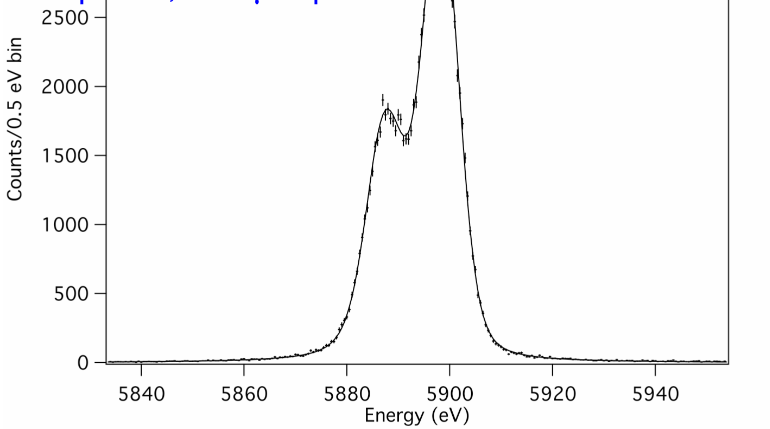
Thermal detection of individual X-ray photons gives a 20-40 increased spectral resolution over the Chandra CCDs

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

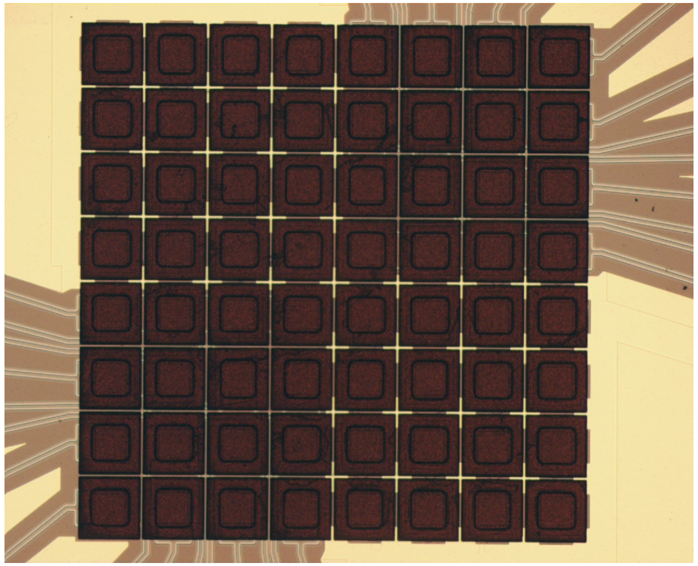


Suzaku X-ray calorimeter array achieved 7 eV resolution on orbit

XRS: 32 pixels, 640 μm pixels

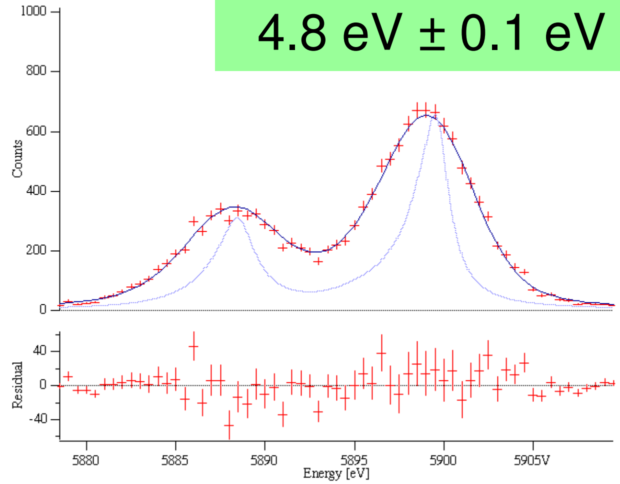


Next generation arrays being developed for Constellation-X now approaching mission goals of 2-4 eV

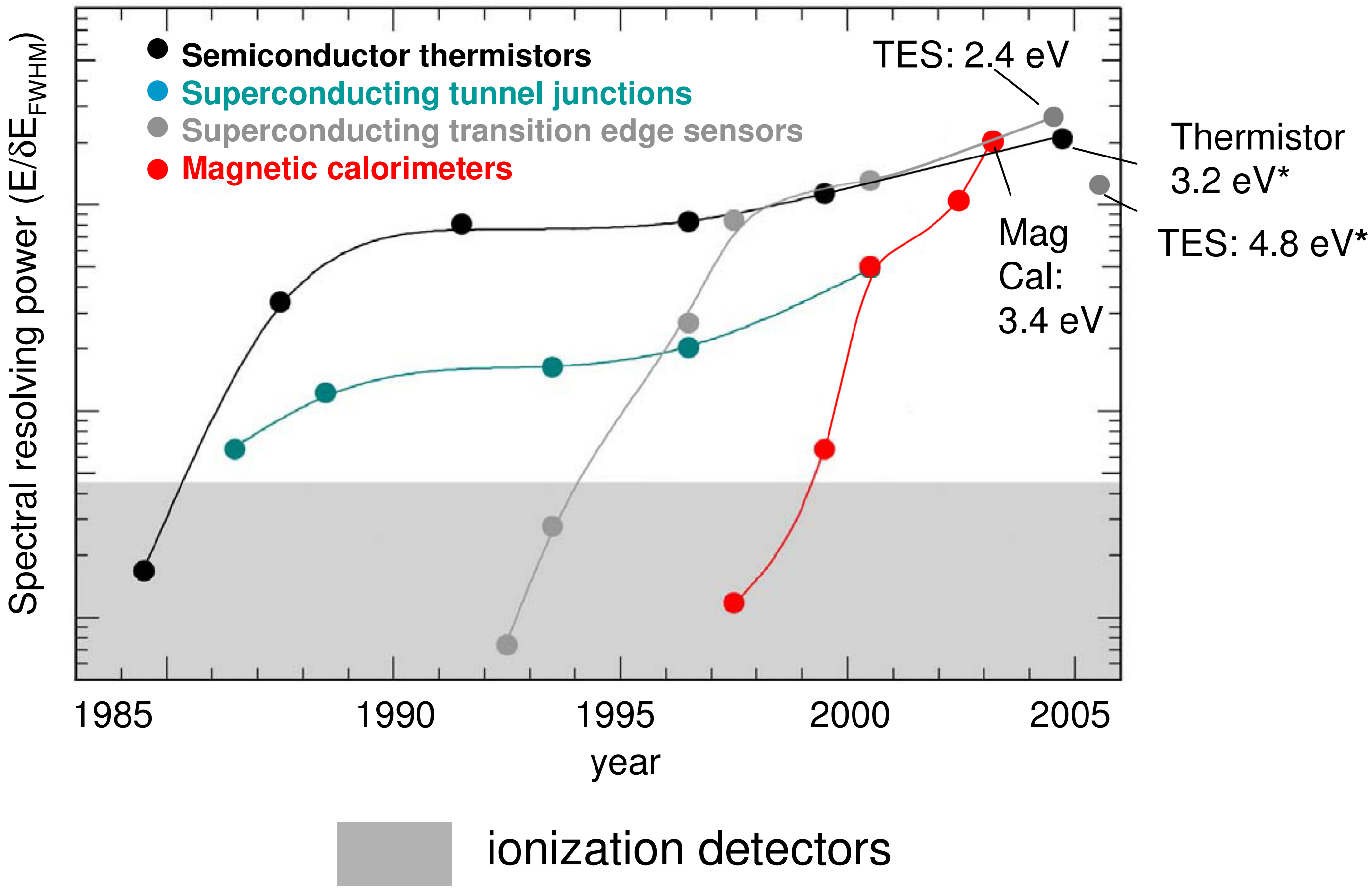


8x8 development TES array for Con-X with 250 μm pixels

4.8 eV ± 0.1 eV FWHM



Micro-calorimeter Progress: ΔE@6 keV

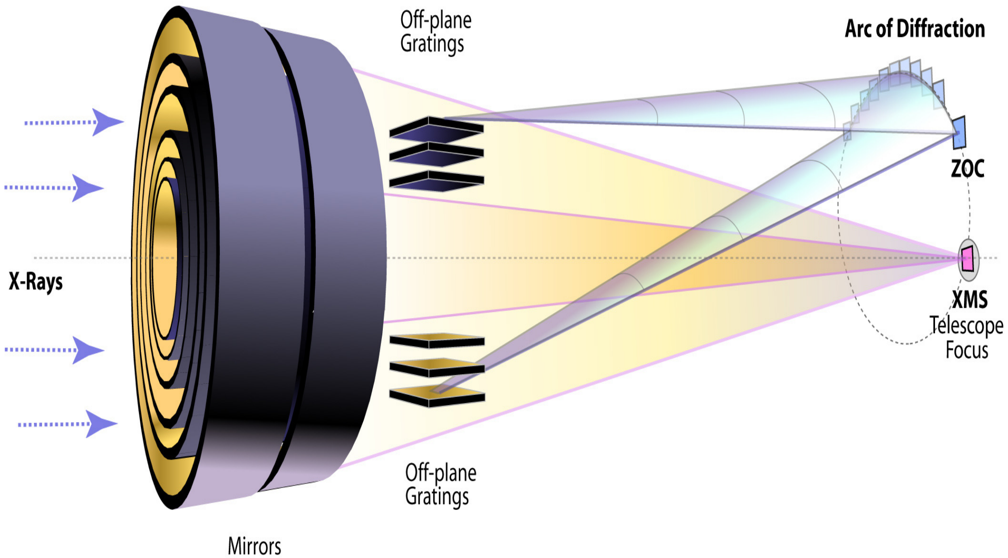


* These devices meet Con-X requirements for quantum efficiency

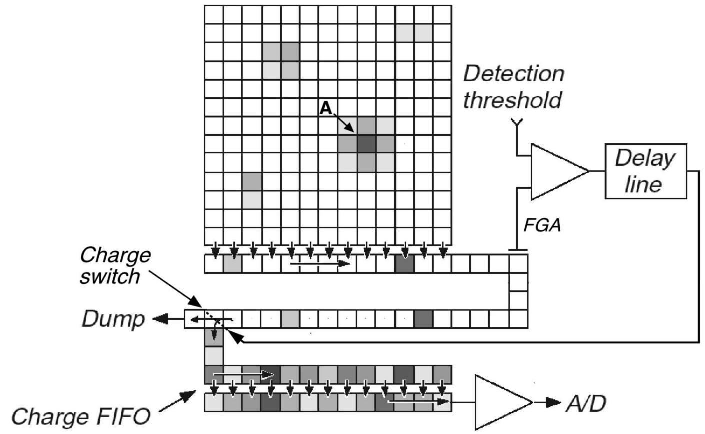
Kelley et al, Irwin et al, Silver et al, Kilbourne et al,
Porter et al, Eguchi et al

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:

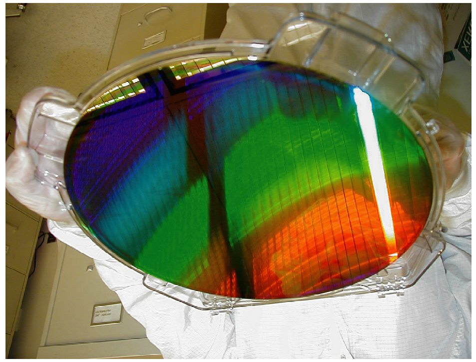
TECHNOLOGY STATUS: Gratings and CCD's

Grating

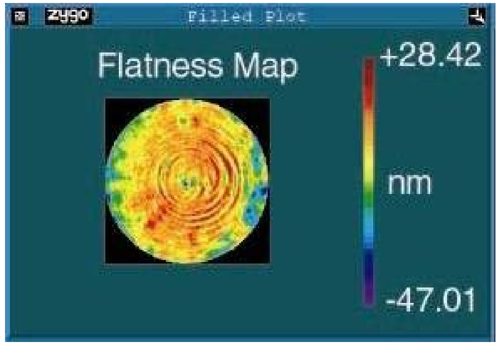
- Grating Patterning – Scanning Beam Interference Lithograph – SBIL (MIT)
  - Patterned gratings in required size
  - Demonstrated required blaze and smoothness; required line density
  - Currently upgrading SBIL to accommodate radial (fan-shaped) grooves (to be complete '06)
- Grating Patterning – Holographic (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)

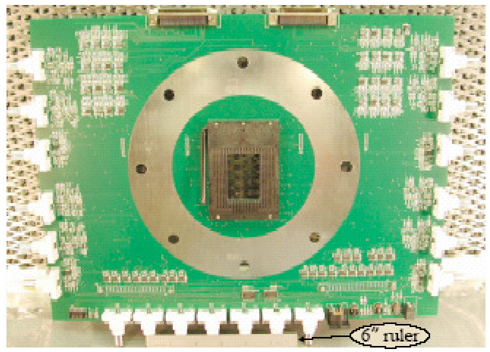
CCD (MIT/LL)

- 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)





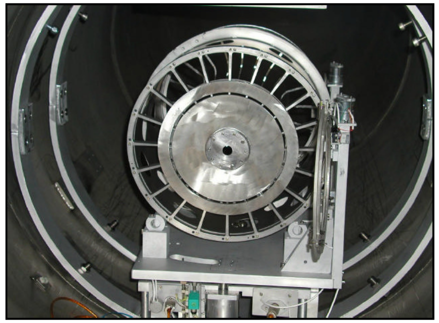
EDCCD: Large motherboard and camera plate (MIT)

Hard X-ray Telescope (HXT)

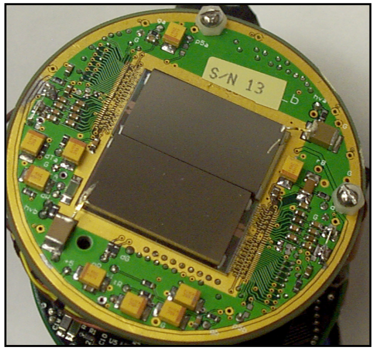
- **Glass Mirrors (Columbia, CalTech, DSRI)**
  - **HEFT (balloon) mirror meeting Con-X mass and performance requirements has successfully flown**
  - **Prototype mirrors have performances <u>better than</u> required; have been successfully acoustic and vibration tested**
- **Nickel Mirrors (SAO, MSFC, Brera)**
  - **Single shell mounted prototype has demonstrated angular resolution <u>better than</u> 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

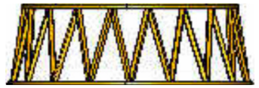
New Launch Vehicle: Delta IV H

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

Fairing internal diameter: 4.5 m

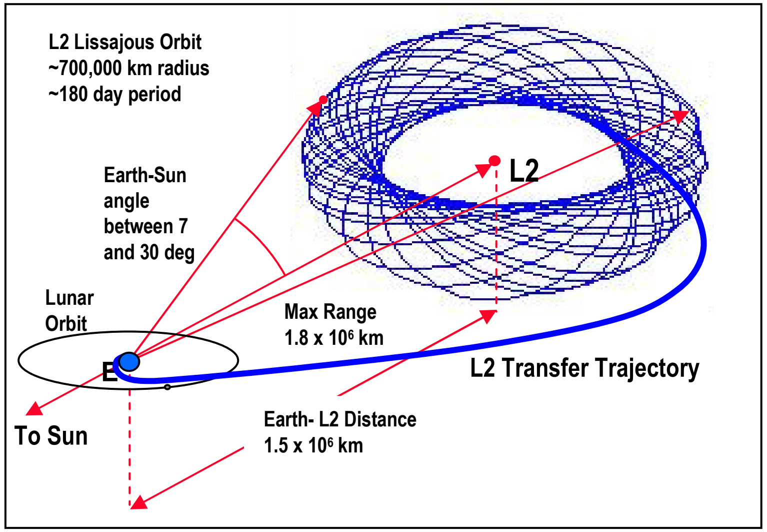
4394-5 Payload Adapter ("Elephant Stand")

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



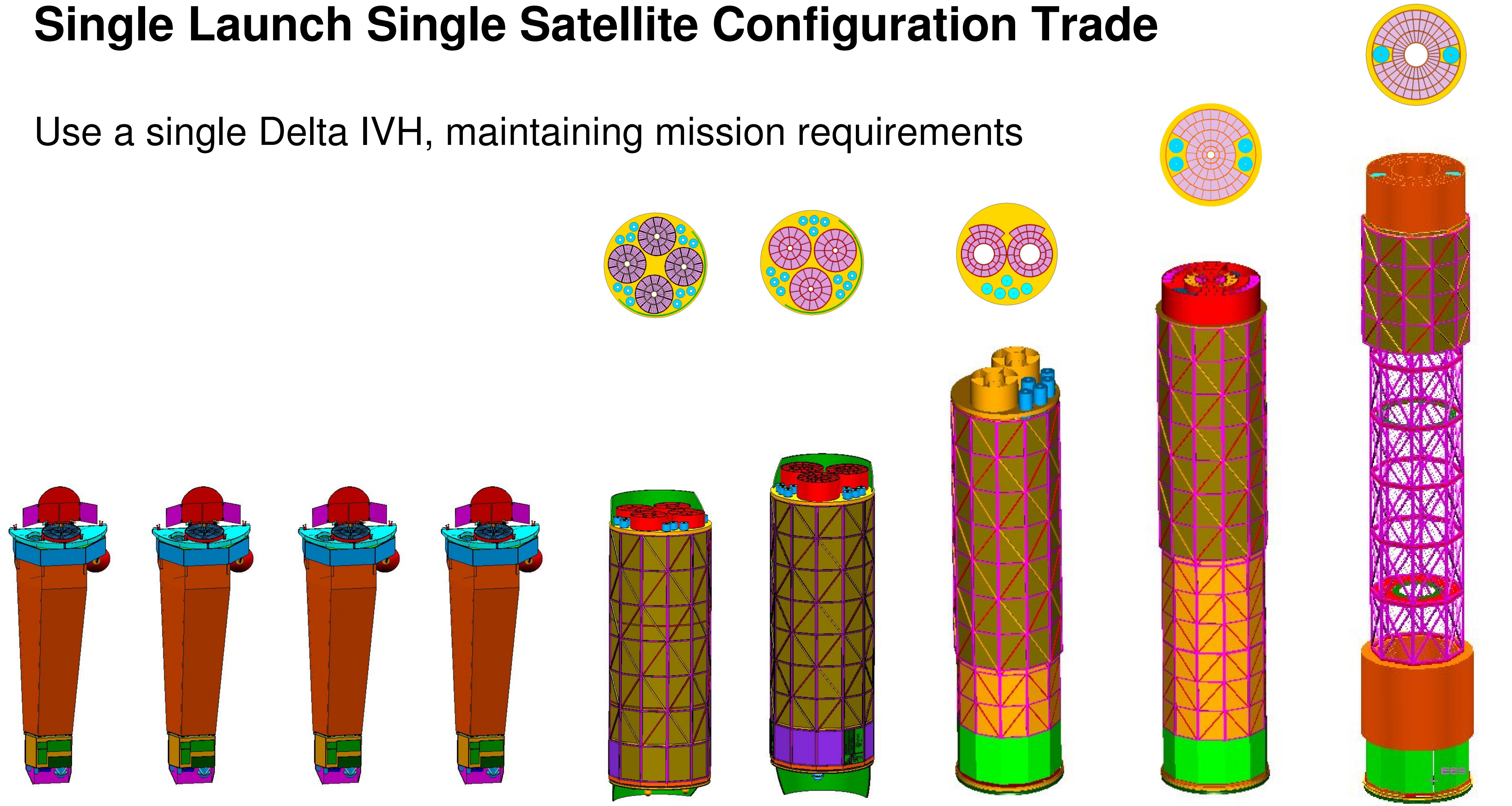
Direct insertion to L2

- **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 mission requirements



4 SXT's
10 m focal length

3 SXT's
11 m focal length

2 SXT's
15 m focal length

1 SXT
20 m focal length

1 SXT
25 m focal length

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)

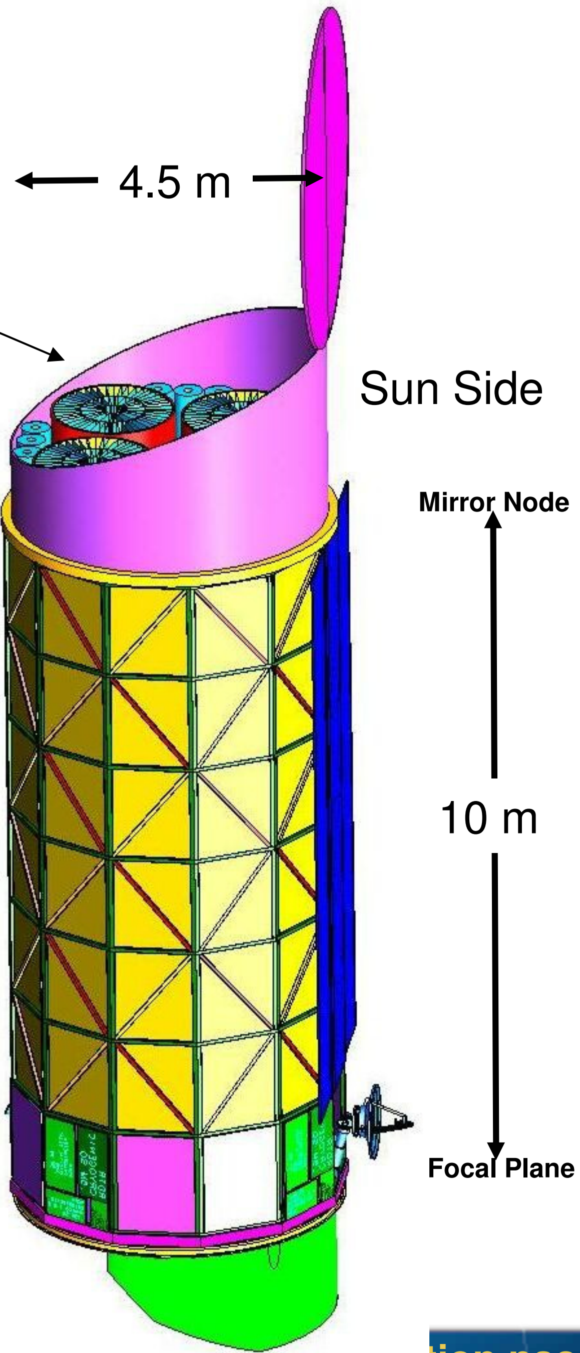
- SXT and HXT mirror assemblies
- FMA Thermal System and control electronics
- Door/sunshade and internal cover/door
- Star Tracker

Metering Structure Module (MSM)

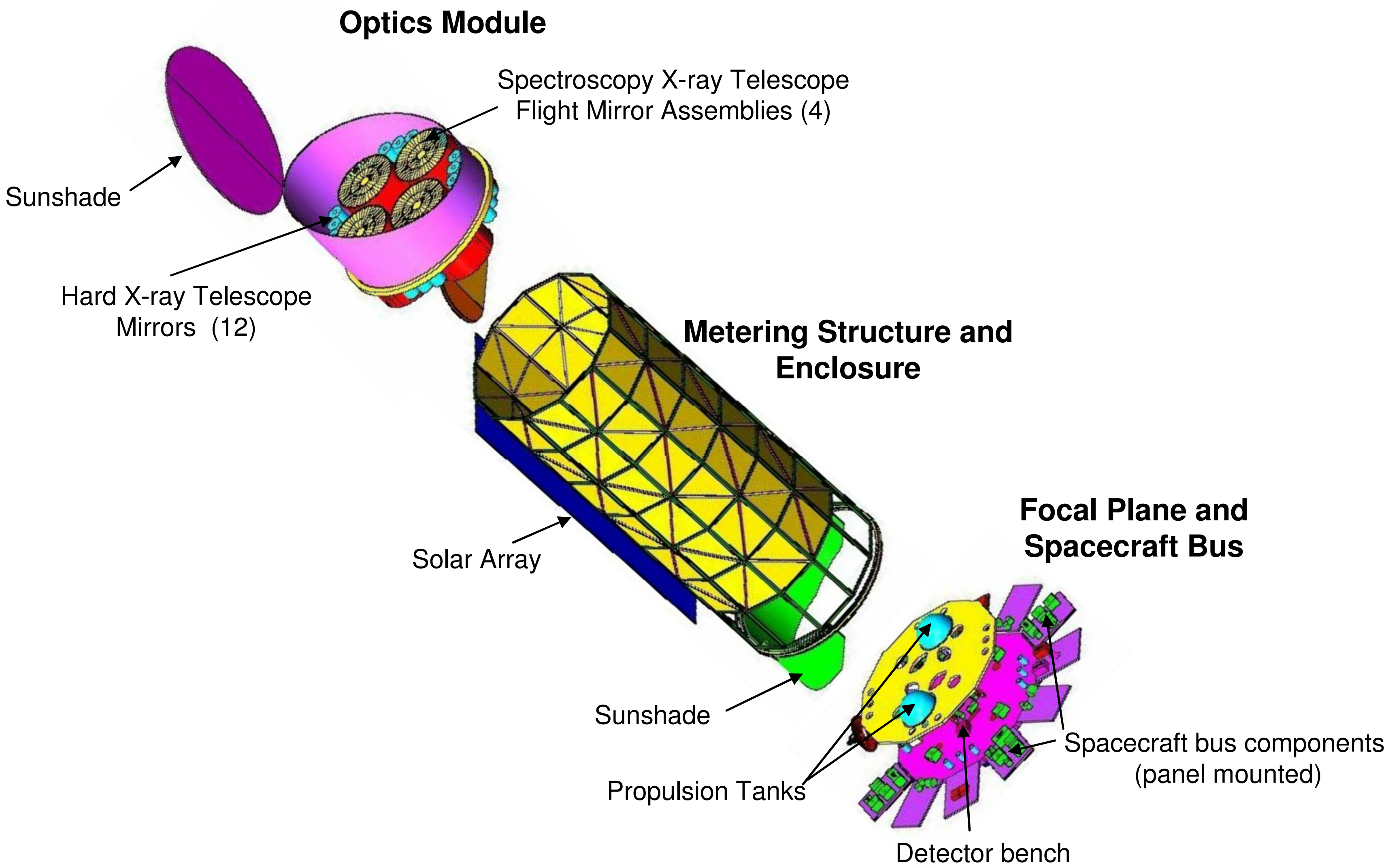
- Fixed metering structure
- Light and Micrometeoroid shield
- Internal Baffles
- Solar Arrays

Focal Plane Module (FPM) and S/C Bus

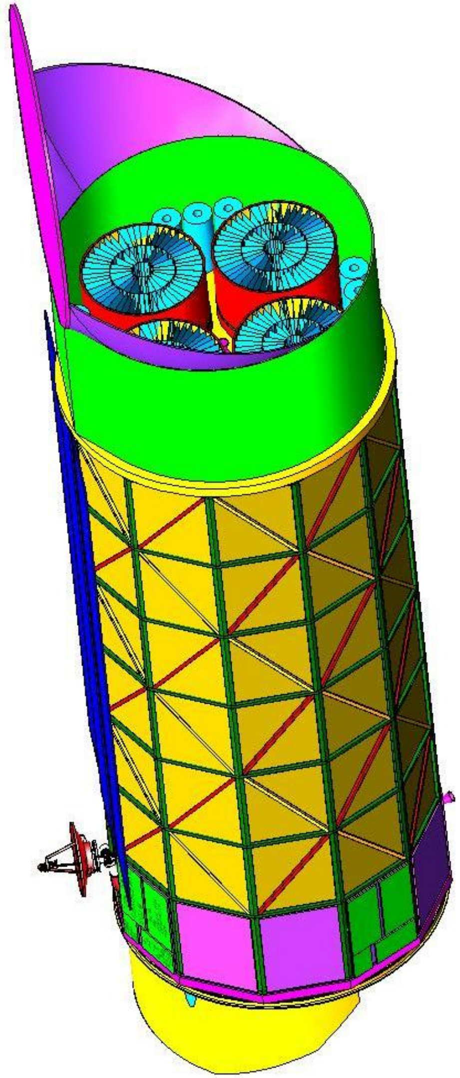
- All instrument detector systems on aft-most deck, baffles
- Propulsion Tanks
- Electronics for instruments on panels and Benches
- Spacecraft bus subsystem components on panels and deck



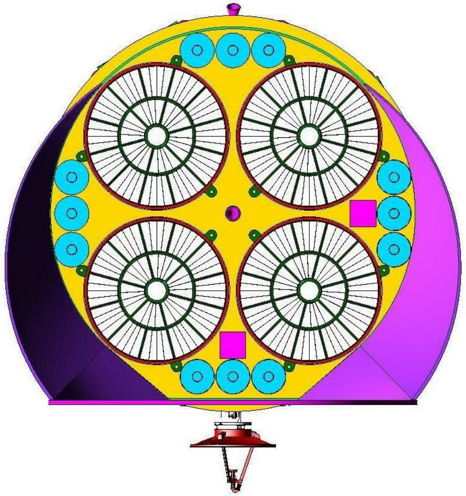
Single Launch Mission Configuration (“Expanded” view shown for clarity)

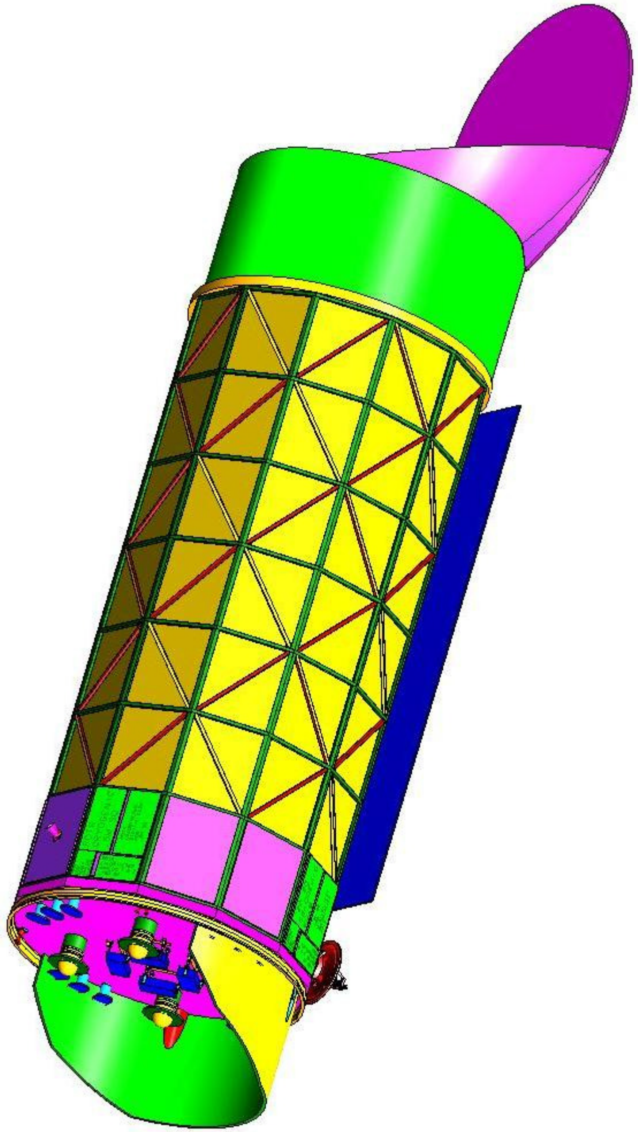


Observatory - Front and Aft Views

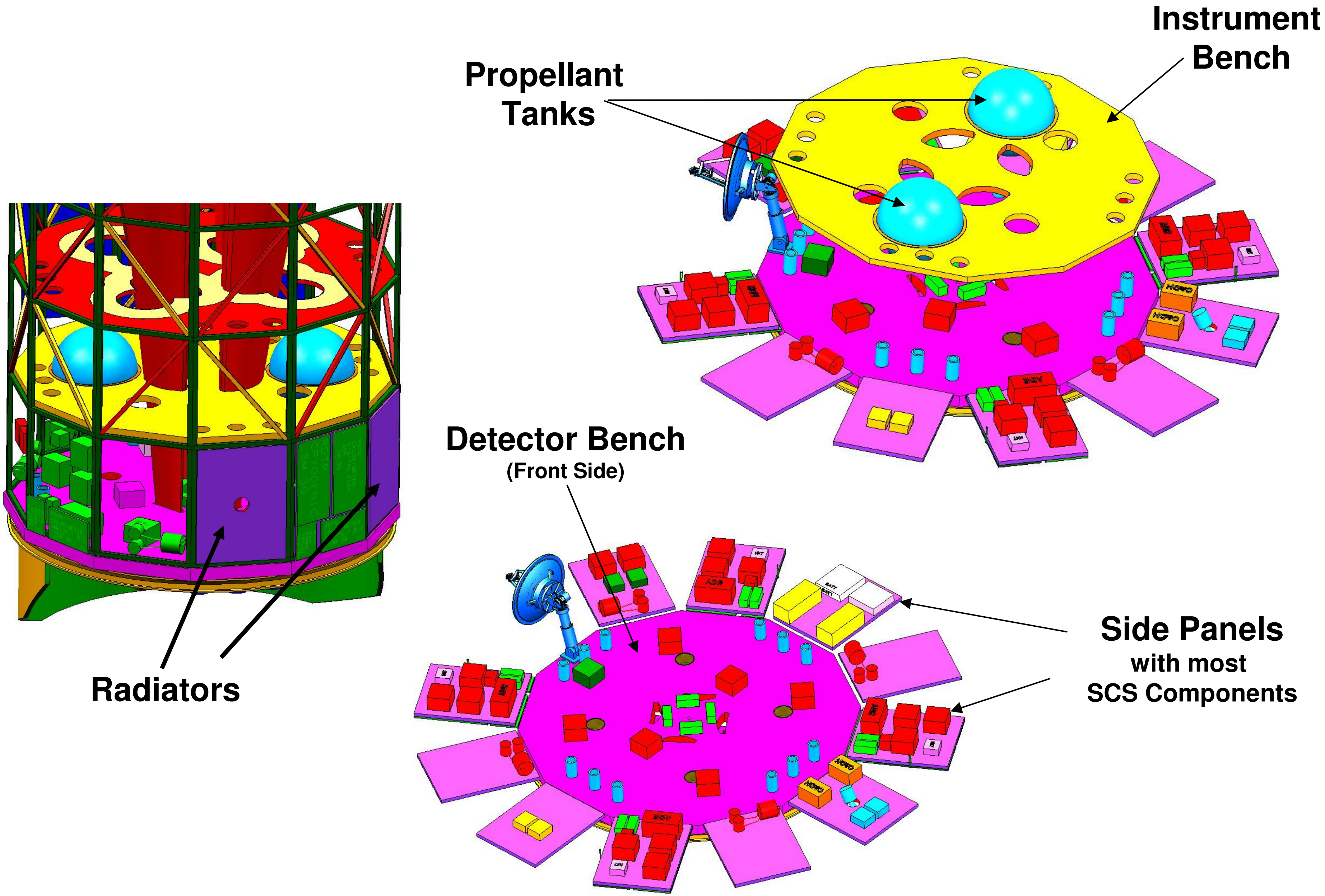


Front View



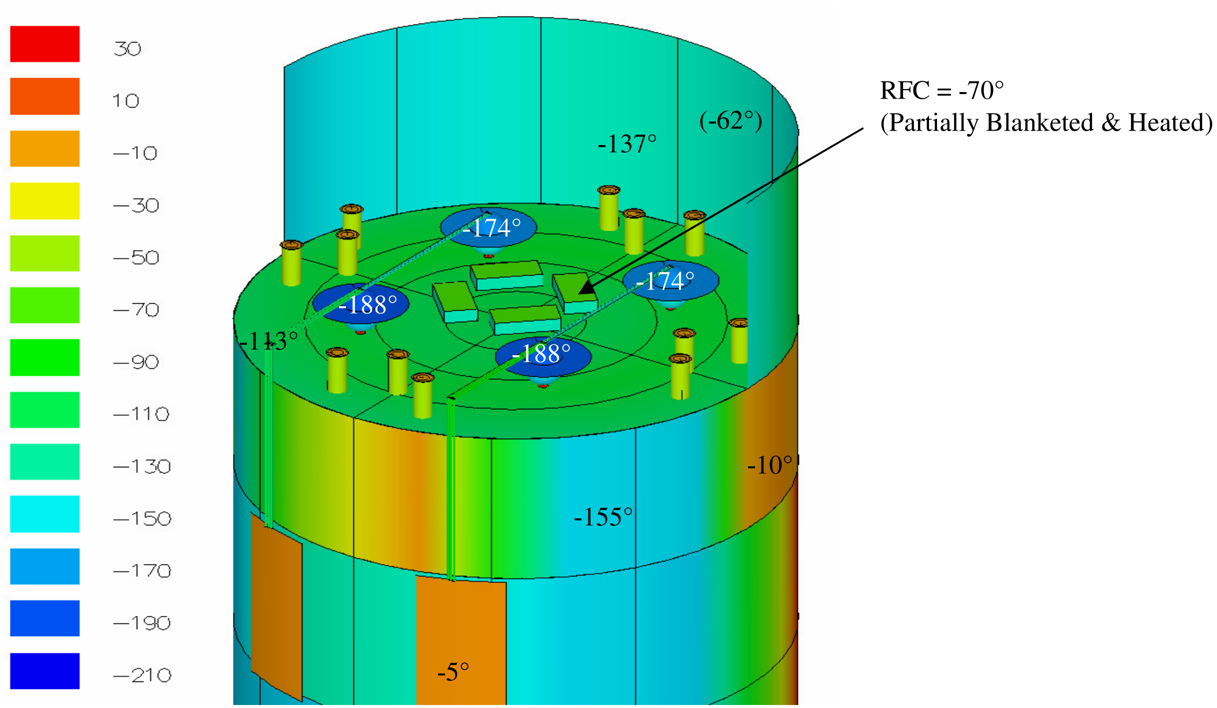


FPM and SCS - Detailed Views



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



Summary

The Beyond Einstein mission Constellation-X addresses compelling and high priority science questions, recently revalidated by a community led update to the science case

The technology development continues to make substantial progress, with mission launch date primarily driven by budget and programmatic constraints

Project study of single launch, single satellite approach using a Delta IV H launcher looks very promising - final selection of configuration will be made during phase A

Visit the Constellation-X Website

http://constellation.gsfc.nasa.gov