BEYOND EINSTEIN: From the Big Bang to Black Holes

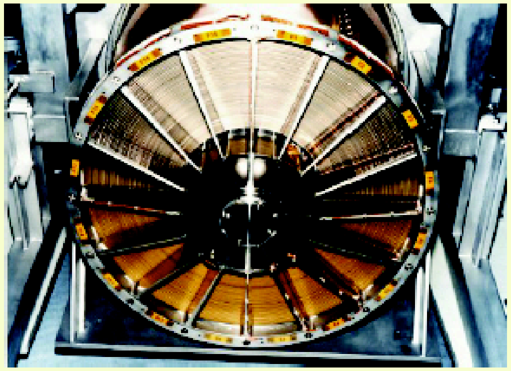
Future X-ray Observatories

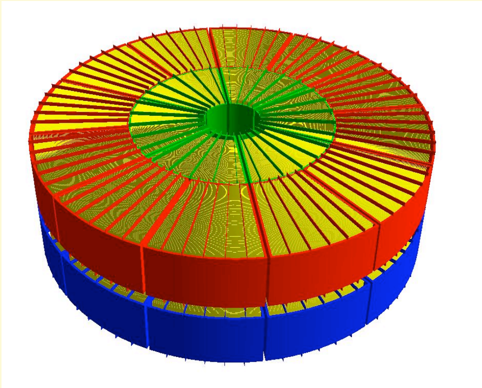
Presented by
Ann Hornschemeier

Deputy Project Scientist, Constellation-X (GSFC)

Making the Most of the Great Observatories
May 22-24, Pasadena, CA

A Quick Primer on X-ray Optics: *They are extremely heavy.*



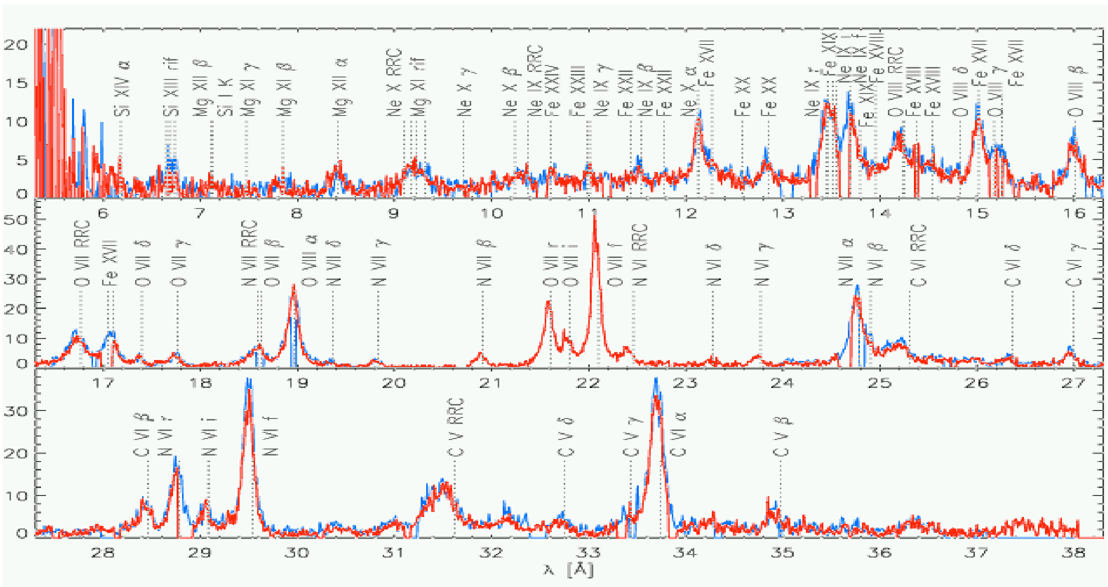


CHANDRA	XMM-NEWTON	CON-X
0.5"	14"	5-15"
18500 kg/m^2	2300 kg/m^2	250 kg/m^2
A_{eff} @ 1 keV	A_{eff} @ 1 keV	A_{eff} @ 1 keV

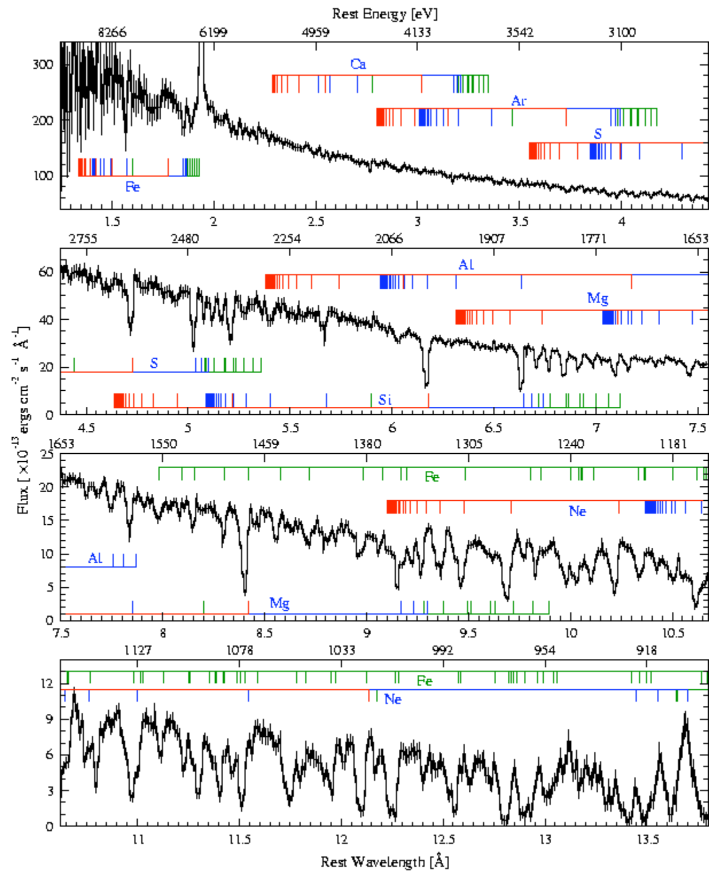
credit: Marcos Bavdaz, ESA-XEUS team

A Glimpse of the future

Heroic Grating observations from Chandra and XMM-Newton are providing the first glimpse of the power of X-ray Spectroscopy



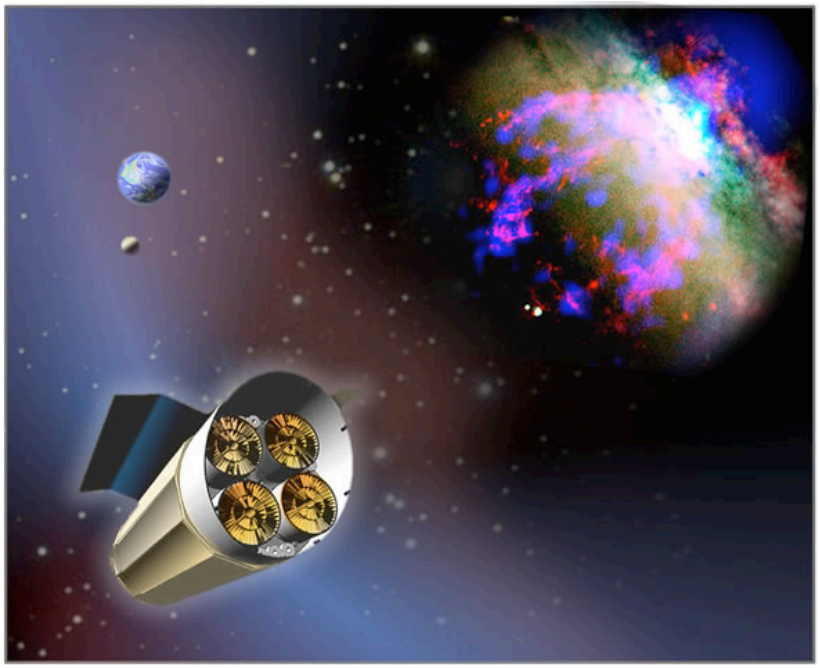
110 ks XMM RGS Spectrum of NGC1068
Kinkhabwala et al 2002



Chandra HETGS Spectrum of NGC3783 from Kaspi et al (2002) 900 ks!

Constellation-X will be able to observe sources 100 times fainter to exploit these diagnostics on typical X-ray sources.

The Constellation-X Mission



NGC 3079

Science Goals:

- **Black Holes**
  - Probing strong gravity
  - Evolution & effects on galaxy formation
- **Dark Matter and Dark Energy**
  - Cosmology using clusters of galaxies
- **Cycles of Matter and Energy**
  - Cosmic feedback, extreme states of matter, stellar coronae, supernovae, planets, etc..

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

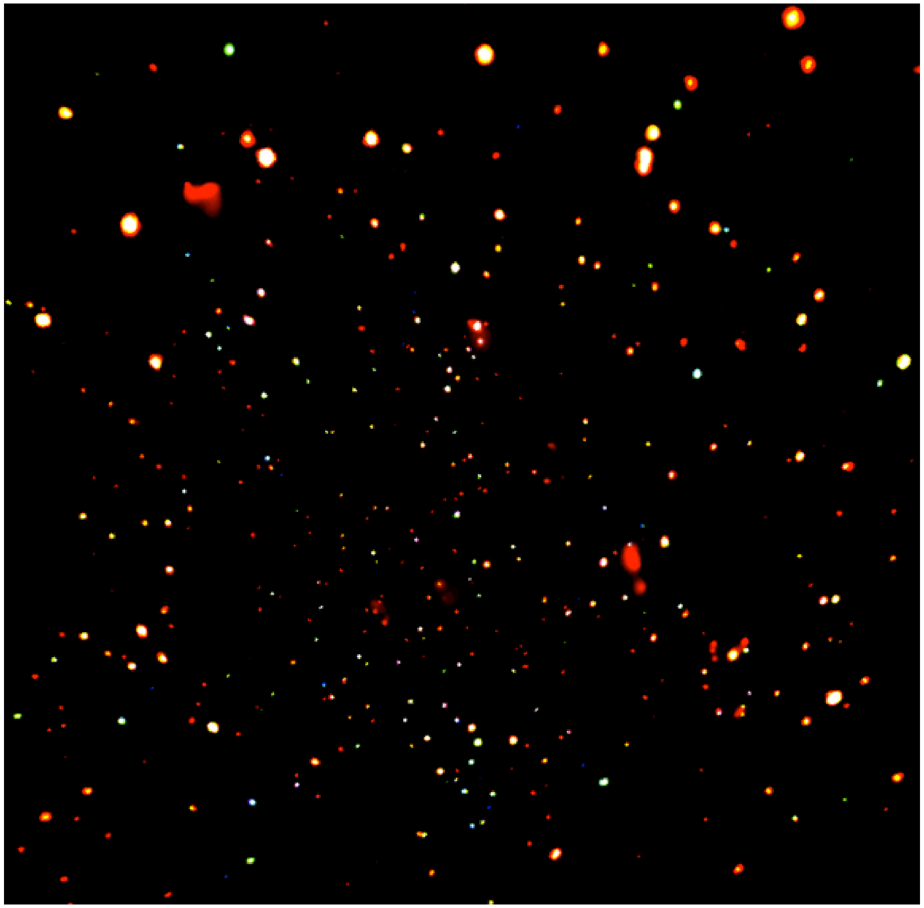
- 25-100 times gain in throughput over current missions
- Four soft X-ray (0.25-10 keV) telescopes and 12 hard X-ray (10-40 keV) telescopes, in a single spacecraft, at L2, pointing at the same target with the data combined on the ground

The Chandra Deep Fields

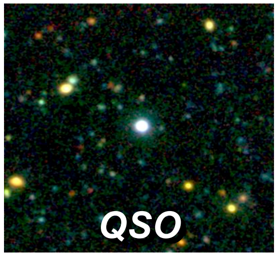
Chandra has resolved the X-ray background into active galactic nuclei (AGN) with a space density of a few thousand per sq deg

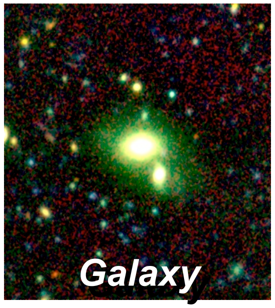
- Constellation-X will gather high-resolution X-ray spectra of the elusive optically faint X-ray sources

- Chandra deep surveys have the sensitivity to detect AGN up to z~8



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



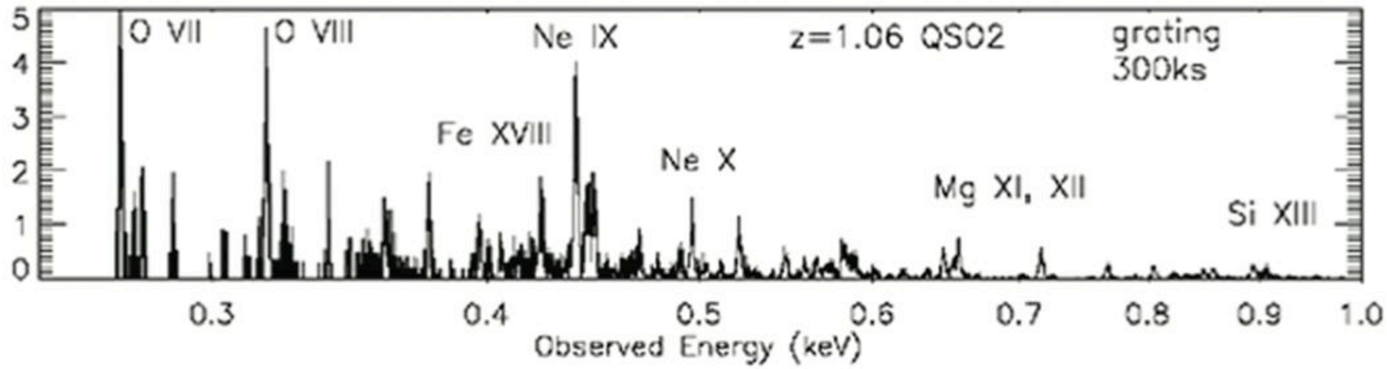


Chandra sources identified with mix of active galaxies and normal galaxies, many are optically faint and unidentified

Black Holes and the Cosmic X-ray Background

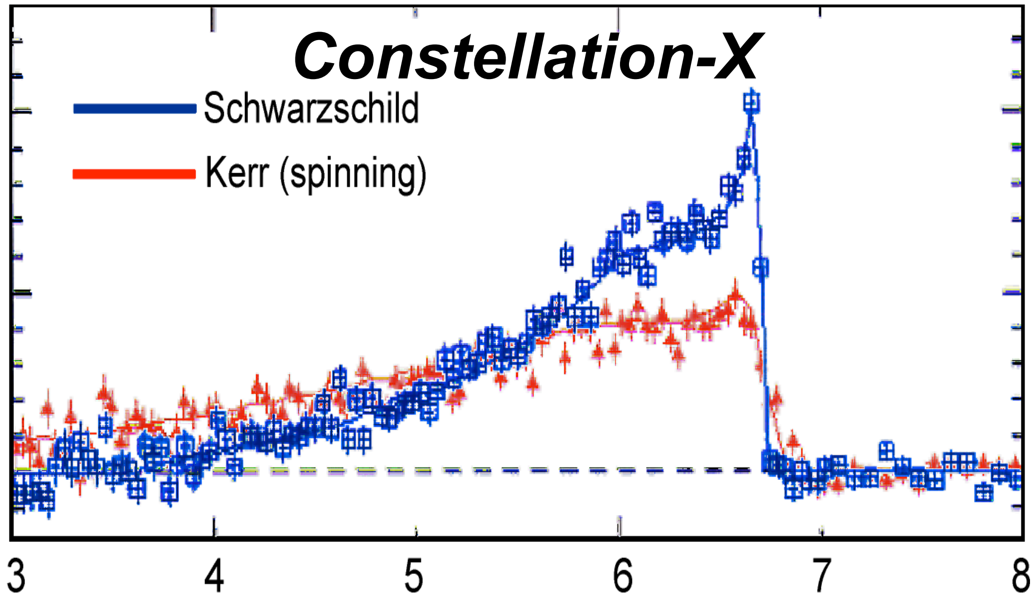
- Constellation-X will provide detailed spectroscopic IDs

Con-X simulation of faint z=1.06 "Type II QSO"



- Near the background peak energy (20-50 keV) only 3% is resolved (Krivonos et al. 2005)
- Constellation-X will have unprecedented imaging capability at 10-40 keV will resolve a significant fraction of the hard X-ray background

Constellation-X, Black Holes and Strong Gravity



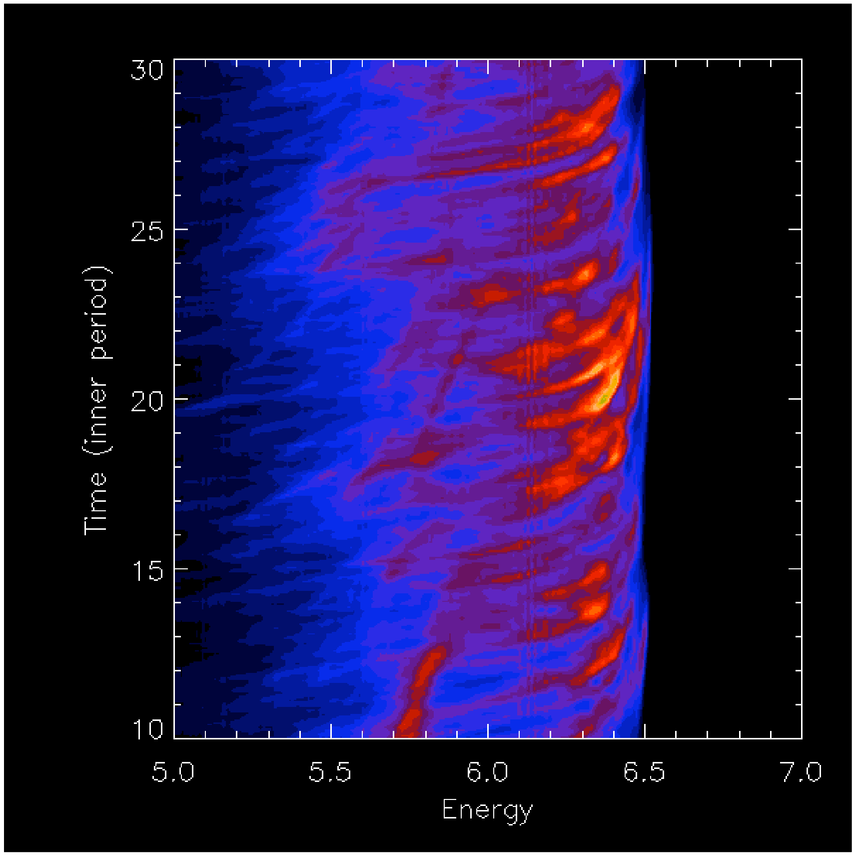
Energy (keV)

Time resolved X-ray spectroscopy near the last stable orbit:

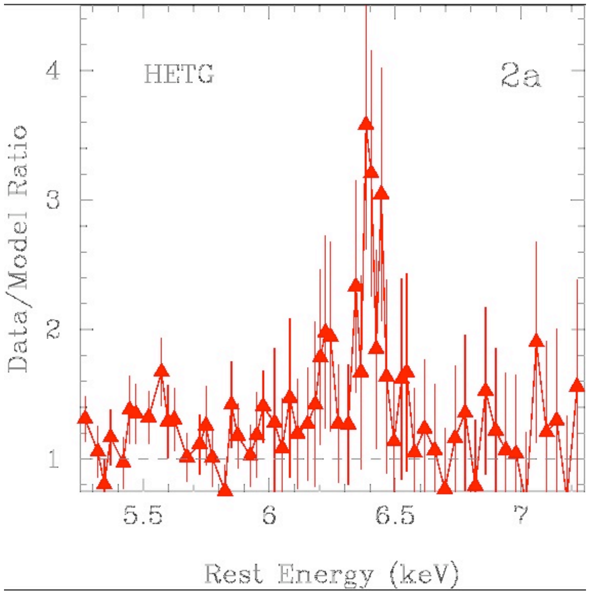
- ✓ iron profile from the vicinity of the event horizon where strong gravity effects of General Relativity can be observed
- ✓ Use Line profile to determine black hole spin
- ✓ Reverberation analysis to determine black hole mass
- ✓ Investigate evolution of black hole properties (spin and mass) over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

Iron Line Variability

- Constellation-X will allow detailed study of line variability
- See effects of non-axisymmetric structure orbiting in disk
  - ✓ Follow dynamics of individual "blobs" in disk
  - ✓ Quantitative test of orbital dynamics in strong gravity regime



Armitage & Reynolds (2003)



Chandra-HETG data on NGC3516 (Turner et al. 2002)

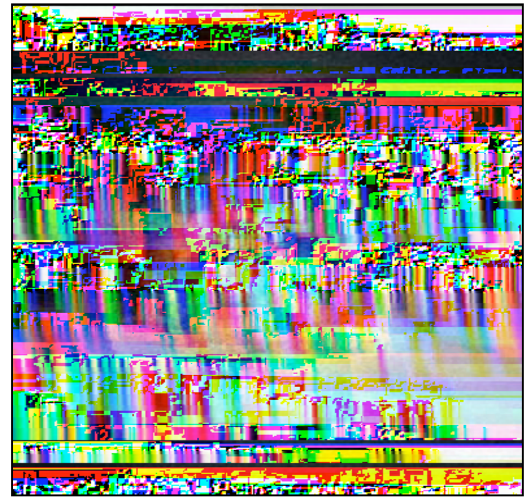
Evidence for non-axisymmetric structure may already have been seen by Chandra and XMM-Newton… Constellation-X area needed to confirm and utilize as GR probes

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)

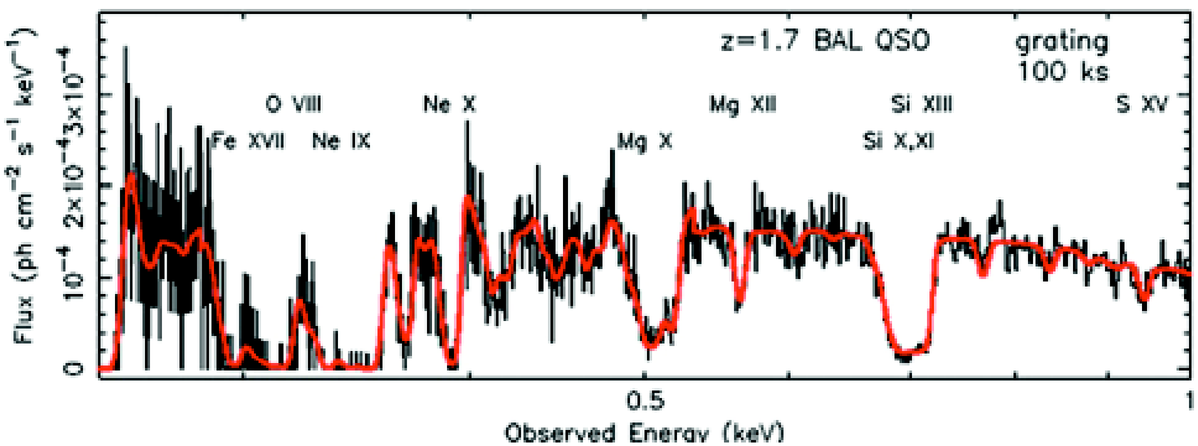
- Con-X's non-dispersive X-ray spectroscopy required to probe hot plasma in cluster cores (Begelman et al. 2003, 2005)

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)



Enabling the Future

What can be done with the current Great Observatories?

X-ray Astronomy Roadmap

Chandra

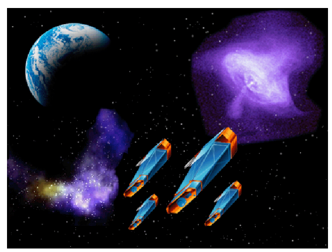
XMM-Newton

Astro-E2

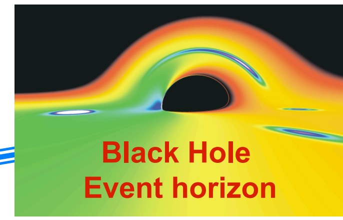
0.1-0.35 m^2
0.5-90 arc sec

Constellation-X

20-100 times increased sensitivity for spectroscopy



3 m^2
5-15 arc sec



BHI: MAXIM

10 Million times finer imaging

0.1-1.0 m^2
0.1 micro arc sec

Generation-X

1000 times deeper X-ray imaging

50-150 m^2
0.1-1 arc sec

Constellation-X endorsed by US National Academy of Sciences McKee-Taylor Survey as a high priority mission for this decade

Project #1:

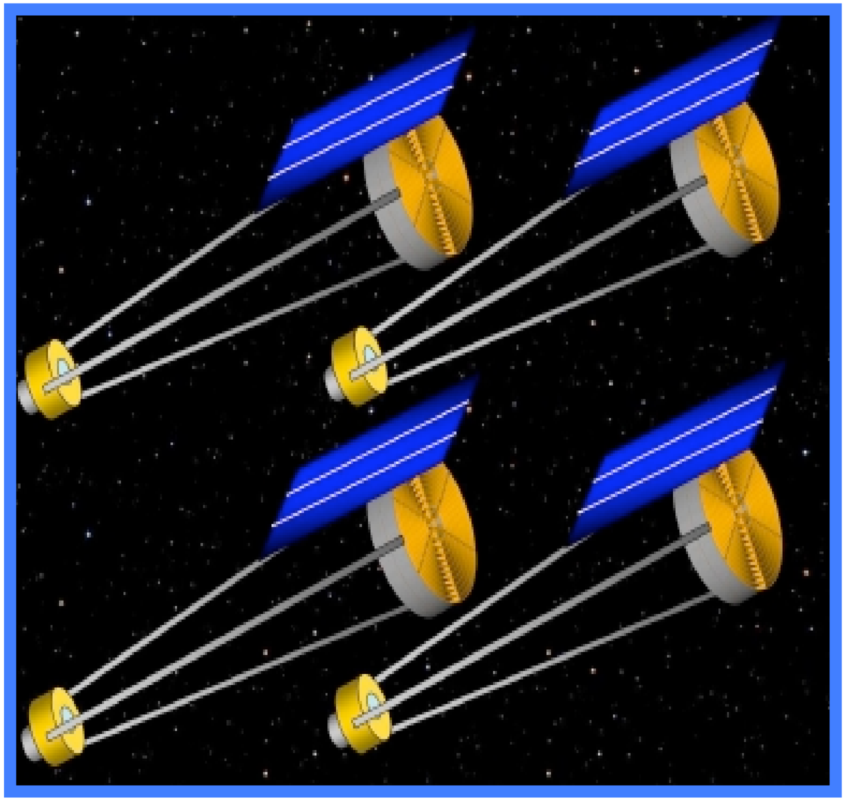
Pinpointing the X-ray Confusion Limit with an Ultradeep Chandra Survey

Advertisement: X-ray Surveys meeting November 5-7, 2006, Cambridge, MA

X-ray Astronomy in 2025/2030: The next time we'll have sub-arcsecond X-ray imaging capability??

- Gen-X is a NASA "Vision" Mission: 2-year study just completed
- Will have 0.1" optics and 100 m^2 collecting area
- detailed AGN studies to z=10, X-ray evolution of star-forming galaxies directly to *z*=4
- NOTE: ESA will fly XEUS around 2020 (?) with 2" angular resolution

Generation-X



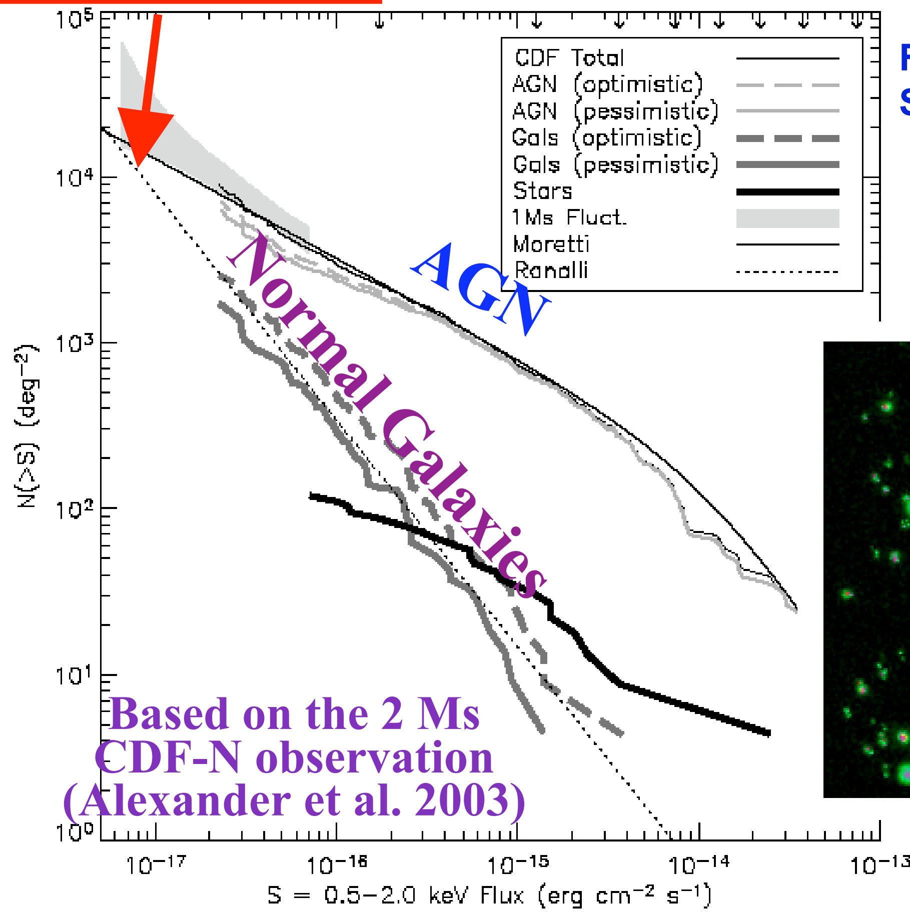
Galaxies become dominant below 1×10^{-17} erg cm^{-2} s^{-1} (0.5 –2 keV)

r counts will have an "upturn" below cm^{-2} s^{-1} due to normal/star-forming galaxies

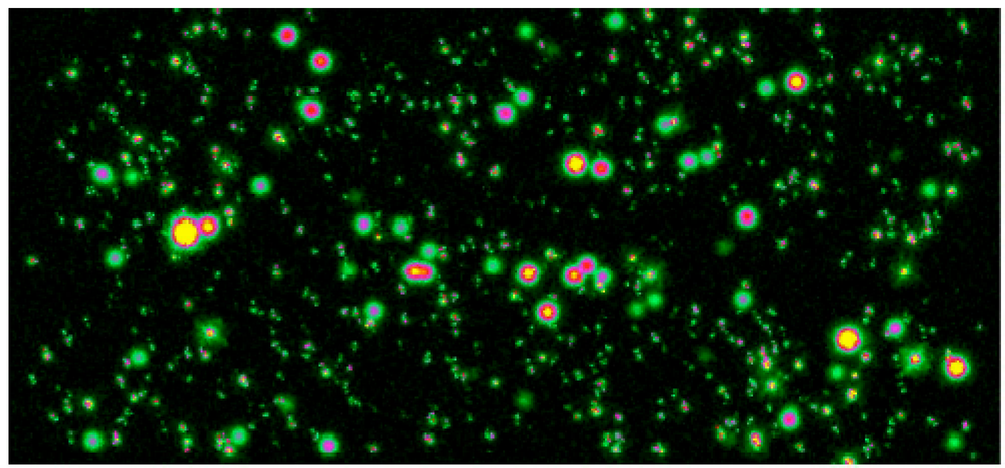
et al. (2004)

CRITICAL: ULTRA-DEEP CHANDRA SURVEY OF THE DISTANT UNIVERSE (5-10 Ms) to reach below 1×10^{-17} erg cm^{-2} s^{-1}

Focus on deep survey fields with good Spitzer + HST coverage for host galaxy ID



Hubble Deep Field-North, Gen-X 1 Ms simulation



Project #2:

Enhancing future dark energy cluster surveys with a large Chandra cluster survey program

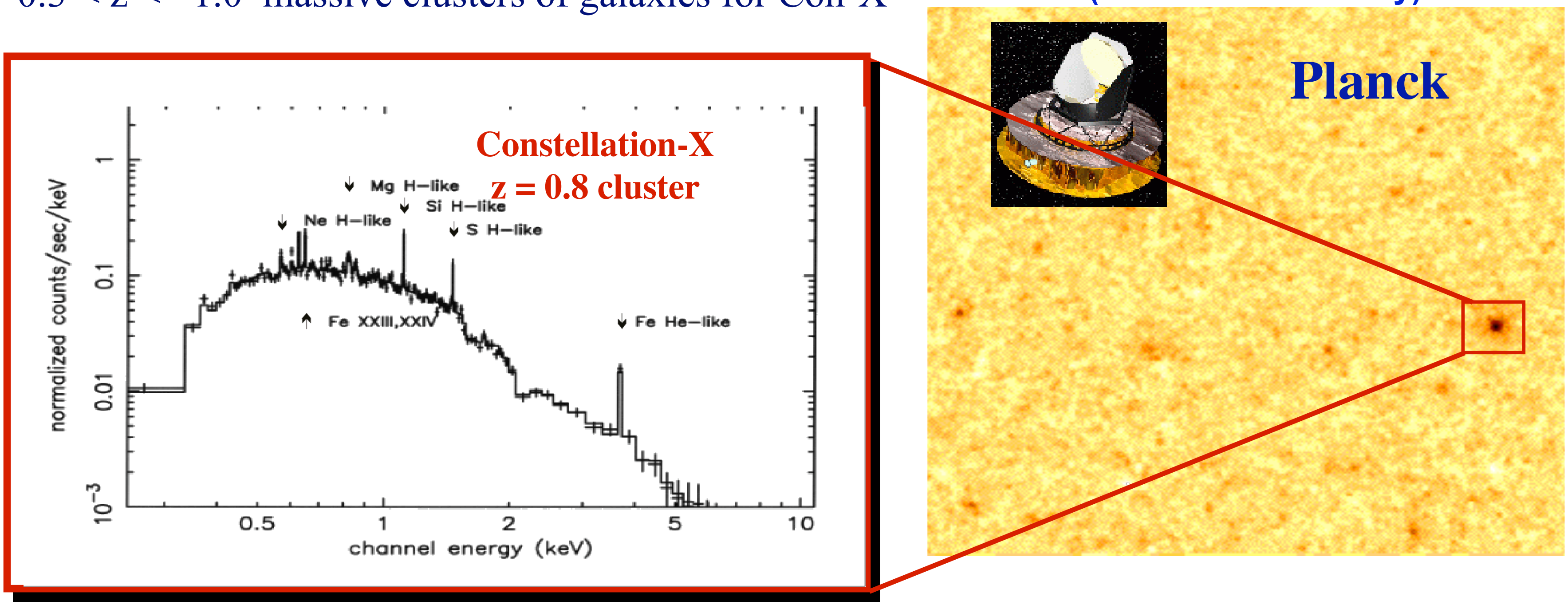
note: Con-X field of view is 2.5’ x 2.5’

Cosmology with Clusters of Galaxies

Con-X will measure mass and temperature profiles (+ dynamics!) in clusters to high precision using spectroscopy

Issue: must have a large sample (hundreds) of $0.3 < z <\sim 1.0$ massive clusters of galaxies for Con-X

Suggest we ALSO continue to follow up the lower-z known X-ray selected clusters with Chandra GO program over the next 5+ years (Chandra FOV is key)



A Chandra imaging "pre-survey" would reduce the cost and risk of Constellation-X dark matter/dark energy studies

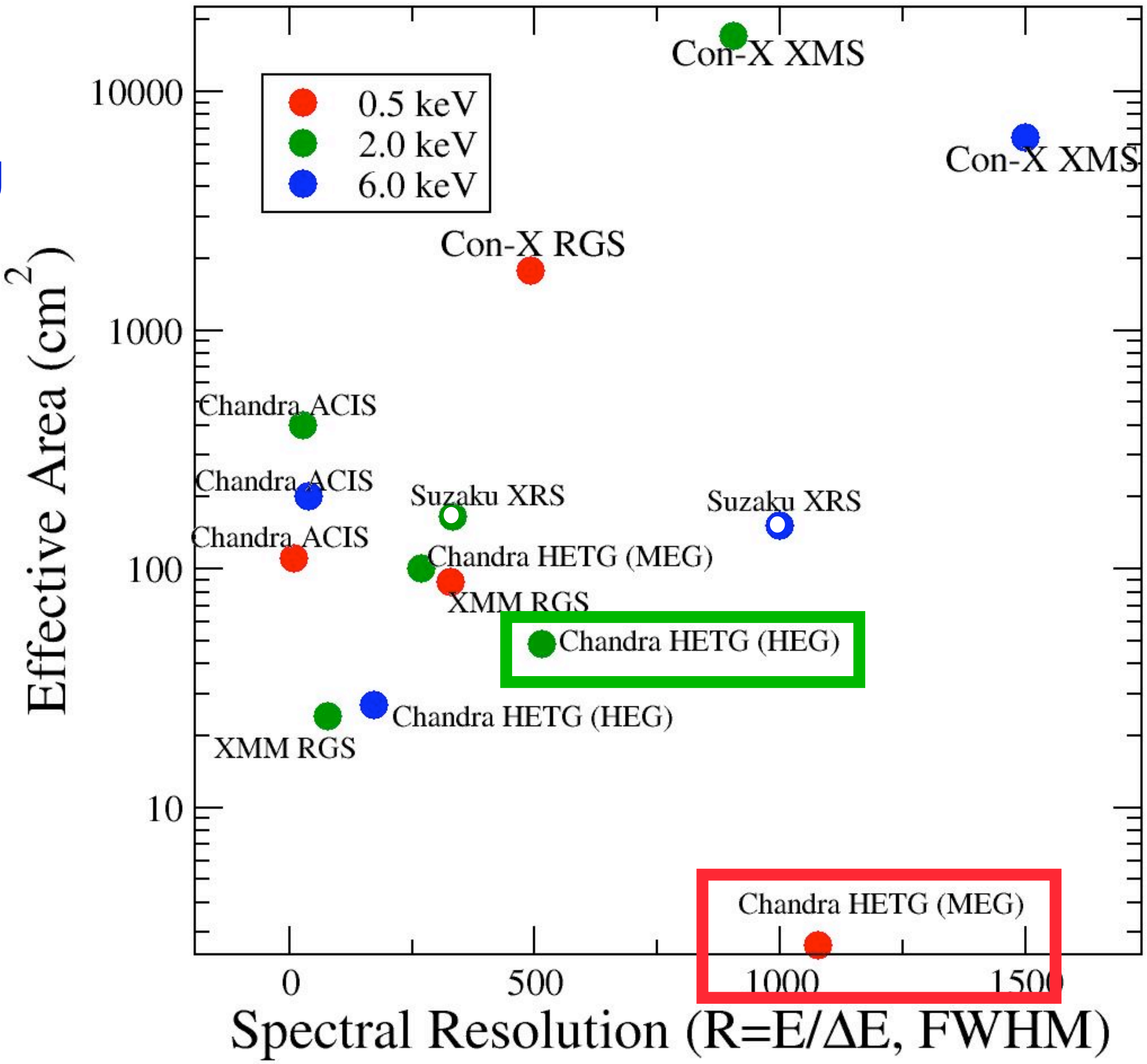
SZE derived cosmological parameters using 500 clusters Molnar et al (2002)

Project #3:

Pathfinder atomic astrophysics with 500+ ks Chandra HETG observations

Current X-ray Spectrometers vs Con-X

- **Chandra HETG has much smaller collecting area than Con-X**
- **particularly important in the 0.6-1.2keV "Fe L" portion of the spectrum**



Deep Chandra HETG Observations as Atomic Astrophysics Pathfinder for Constellation-X

- **Example of faint lines: Capella HETG spectrum ($\Delta\lambda \sim 0.014$ angstroms)**

- **Lyman series line ratios useful for diagnosing optical depths & temperature**

- **Other topics include:**
  - **dilectronic transitions**
  - **weak blending from unidentified lines (mostly Fe L)**

Portion of the 300 ks Capella spectrum

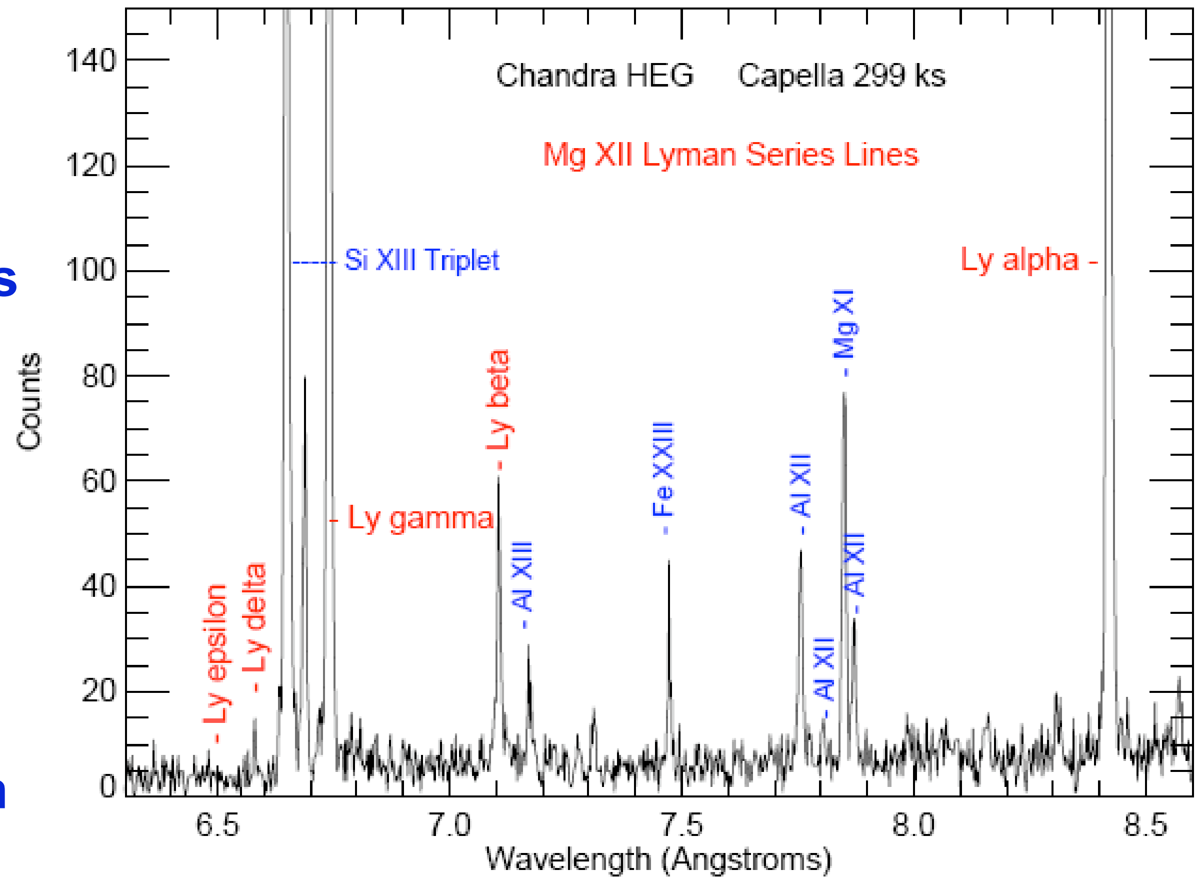


Figure courtesy of Nancy Brickhouse (SAO)

Mission Status:

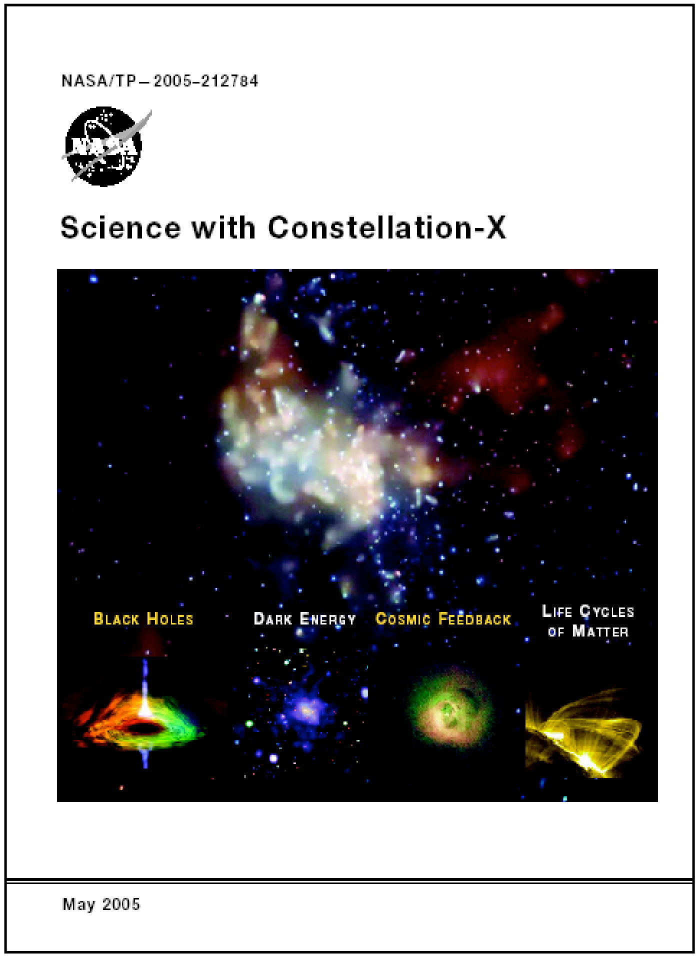
- Launch date : 2018
- Mirrors fabricated at <15” angular resolution
- Flight-like calorimeters have achieved 3.2 eV spectral resolution (goal is 2 eV)
- Off-plane gratings show great promise for even better throughput and higher resolution
- Hard X-ray Telescope technology mostly at TRL6
- Basic single spacecraft design in hand

Project Scientist:
Nicholas White (GSFC)

Chair of the Facility Science Team:
Harvey Tananbaum (SAO)

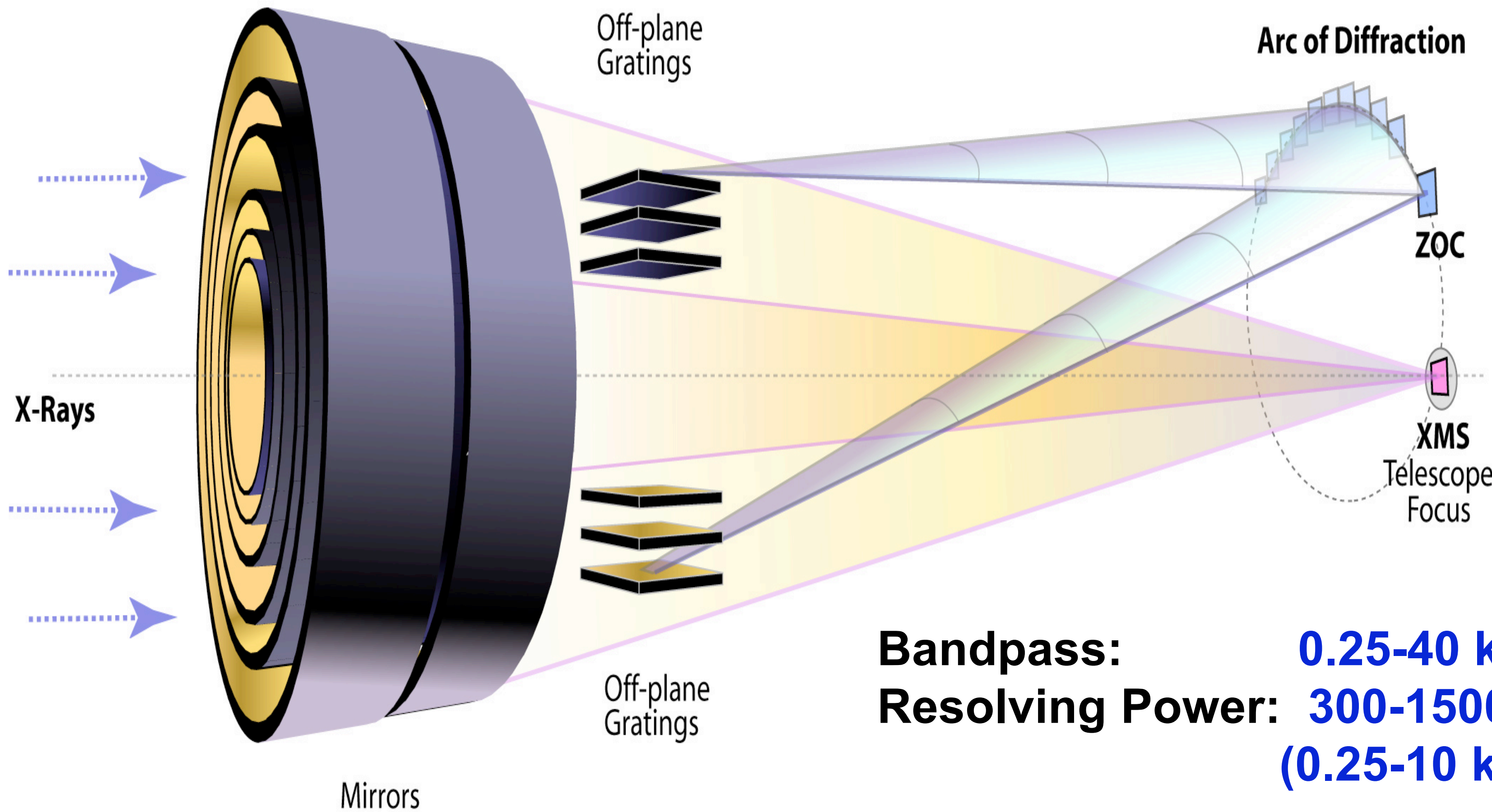
Recent 40-page update to Constellation-X Science Case:
“Science with Constellation-X” booklet

http://constellation.gsfc.nasa.gov



The heart of Constellation-X: A very large X-ray mirror

Areal density: 250 kg/m^2
Total collecting area: 1.5 m^2
(@ 1.25 keV)



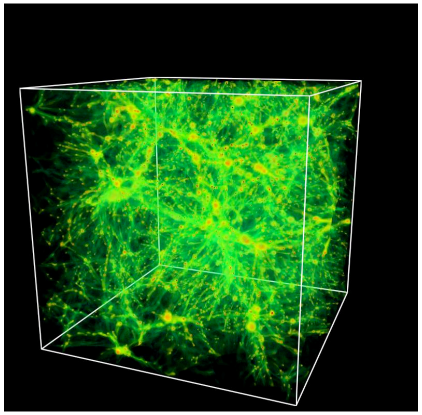
Bandpass: 0.25-40 keV
Resolving Power: 300-1500
(0.25-10 keV)

Constellation-X Science Objectives

Black Holes

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

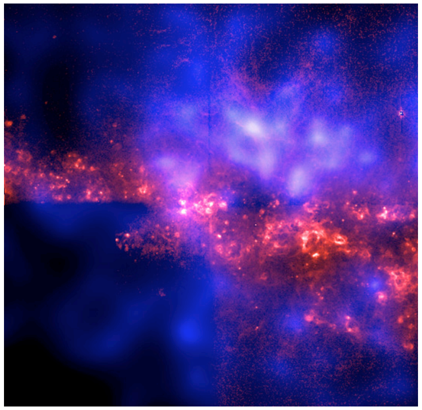
Trace their **evolution with cosmic time**, their contribution to the energy output of the Universe and their effect on galaxy formation



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

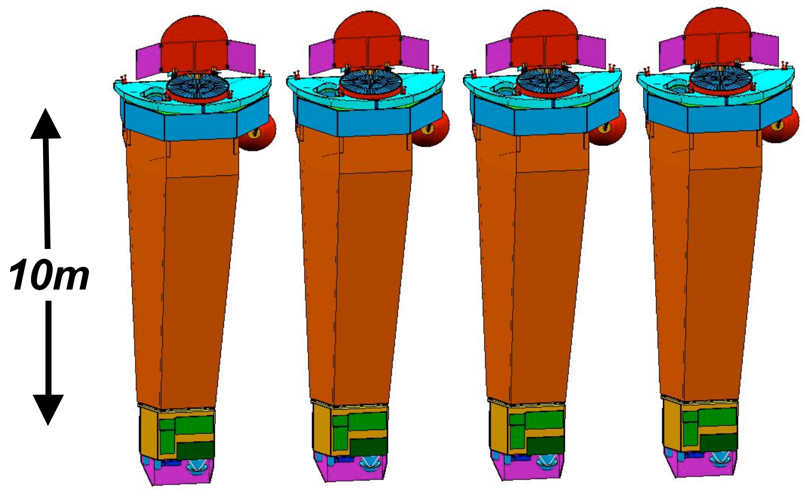


Cycles of Matter and Energy

Study dynamics of **Cosmic Feedback**

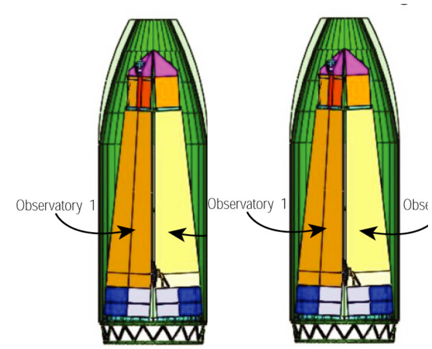
Creation of the elements in **supernovae**, The equation of state of **neutron stars, Stellar activity, proto-planetary systems** and X-rays from **solar system objects**

Mission Configuration Trade Study



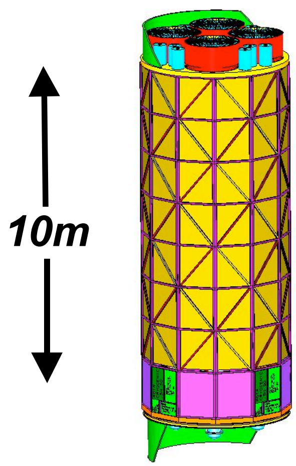
Past Reference Design

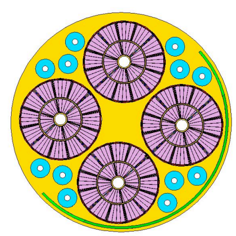
Launched in pairs on 2 Atlas V class launchers

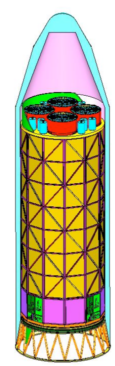


Current Reference Design

Single launch on the new Delta IVH launcher





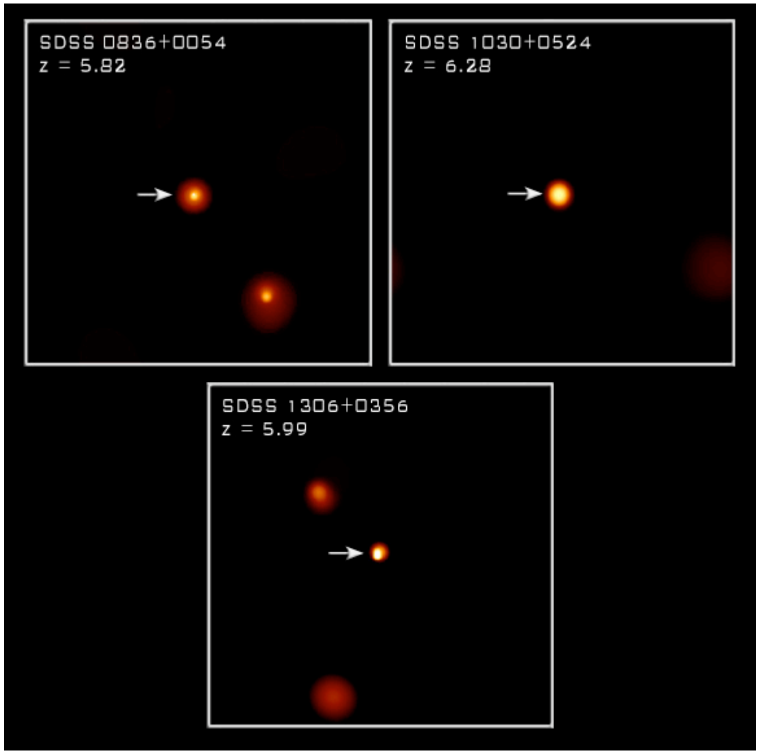


Launch cost saving of ~$120M ***with no loss in science capability***

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