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

CHANDRA

0.5”
18500 kg/m²
A_{eff} @ 1 keV

XMM-NEWTON

14”
2300 kg/m²
A_{eff} @ 1 keV

CON-X

5-15”
250 kg/m²
A_{eff} @ 1 keV

credit: Marcos Bavadaz, 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

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

The Constellation-X Mission

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**

**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

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)

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

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

Perseus Cluster of Galaxies (Chandra image)
X-ray Astronomy Roadmap

- **Chandra**
  - 0.1-0.35 m²
  - 0.5-90 arc sec

- **XMM-Newton**

- **Astro-E2**
  - 0.1-0.35 m²
  - 0.5-90 arc sec

**Constellation-X**
- 20-100 times increased sensitivity for spectroscopy
- 3 m²
- 5-15 arc sec

**BHI: MAXIM**
- 10 Million times finer imaging
- 0.1-1.0 m²
- 0.1 micro arc sec

**Generation-X**
- 1000 times deeper X-ray imaging
- 50-150 m²
- 0.1-1 arc sec

**First Black Holes & Galaxies**

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

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**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 m² 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

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Galaxies become dominant below $1 \times 10^{-17}$ erg cm$^{-2}$ s$^{-1}$ (0.5 – 2 keV) due to normal/star-forming galaxies. Based on the 2 Ms CDF-N observation (Alexander et al. 2003).

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Counts will have an “upturn” below $1 \times 10^{-17}$ erg cm$^{-2}$ s$^{-1}$ due to normal/star-forming galaxies. Critical: Ultra-Deep Chandra Survey of the Distant Universe (5-10 Ms) to reach below $1 \times 10^{-17}$ erg cm$^{-2}$ s$^{-1}$.

Focus on deep survey fields with good Spitzer + HST coverage for host galaxy ID.
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 $0.3 < z < 1.0$ 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
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:
  - dielectronic transitions
  - weak blending from unidentified lines (mostly Fe L)

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)
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
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 $2 \times 10^{-15}$ 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.