Science with the Constellation-X Observatory

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Abstract. The Constellation X-ray Mission is a high throughput X-ray facility emphasizing observations at high spectral resolution (E/\Delta E \sim 300–3000), and broad energy bandpass (0.25–40 keV). Constellation-X will provide a factor of nearly 100 increase in sensitivity over current high resolution X-ray spectroscopy missions. It is the X-ray astronomy equivalent of large ground-based optical telescopes such as the Keck Observatory and the ESO Very Large Telescope. When observations commence toward the end of next decade, Constellation-X will address many fundamental astrophysics questions such as: the formation and evolution of clusters of galaxies; constraining the baryon content of the Universe; determining the spin and mass of supermassive black holes in AGN; and probing strong gravity in the vicinity of black holes.

CONSTELLATION-X

The prime objective of Constellation-X mission is high resolution X-ray spectroscopy. It will cover the 0.25 – 40 keV X-ray bandpass by utilizing two types of high throughput telescope systems to simultaneously cover the low (0.25 to 10 keV) and high energy (6 to 40 keV) bands. The low-energy Spectroscopy X-ray Telescope (SXT) is optimized to maintain a spectral resolving power of at least 300 across the 0.25 to 10 keV band pass (E/\Delta E \sim 3000 at 6 keV) and has a minimum telescope angular resolution of 15'' HPD. The diameter of the field of view is 2.5' below 10 keV. The high energy system (HXT) with lower spectral resolving power (\Delta E \sim 1 keV) overlaps the SXT and primarily is used to measure the relatively line-less continuum from 10 to 40 keV. The diameter of the field of view is 8' for the HXT. The large collecting area is achieved with a design utilizing several mirror modules, each
with its own spectrometer/detector system. The spectral resolving power of the SXT and the effective area of SXT and HXT are shown in Figure 1.

The SXT uses two spectrometer systems that operate simultaneously to achieve the desired energy resolution: 1) a 2 eV resolution quantum microcalorimeter array, and 2) a set of reflection gratings for energies < 2 keV. The gratings deflect part of the telescope beam away from the calorimeter array in a design similar to XMM except that the direct beam falls on a quantum calorimeter instead of on a CCD. The two spectrometers are complementary, with the gratings optimal for high resolution spectroscopy at low energies and the calorimeter at high energies. The gratings also provide coverage in the 0.3-0.5 keV band where the calorimeter thermal and light-blocking filters cause a loss of response. This low-energy capability is particularly important for high-redshift objects, for which line-rich regions will be moved into this low energy band.

The HXT uses a multilayer coatings on individual mirror shells to provide the first focusing optics system to operate in the 6-40 keV band. Compared to other non-focusing methods such as those used for RXTE, Constellation-X has twice the area, 640 times the energy resolution, 240 times the spatial
resolution, and above 10 keV, 100 times the sensitivity. AXAF and XMM, designated as the workhorses of X-ray astronomy in the next decade, will detect photons with energies up to 10 keV.

The technology development program is now underway and is targeting a first launch in 2007-2008, around the time that AXAF will be reaching the end of its projected lifetime. An essential feature of the Constellation-X concept involves minimizing cost and risk by building several identical, modest satellites to achieve a large area. The current baseline is 6 satellites, although other multiple satellite configurations are also under consideration, with the final choice to be made based on a balance of overall cost and risk. The mission will be placed into a high earth or L2 orbit to facilitate high observing efficiency, provide an environment optimal for cryogenic cooling, and simplify the spacecraft design.

**SCIENCE GOALS**

Constellation-X is a key element in NASA’s Structure and Evolution of the Universe (SEU) theme aimed at understanding the extremes of gravity and the evolution of the Universe. We highlight here a few key science areas.

**How can we use observations of black holes to test General Relativity?** X-ray observations directly probe physical conditions close to the central engine of blackholes where the distortions of time and space predicted by general relativity are most pronounced. Constellation-X will use the spectral features of these objects (e.g. the broad iron Kα line discovered by ASCA [1]) to map out the geometry of the inner emission regions and determine the extent to which we can test general relativity.

**What is the total energy output of the Universe?** Models of cosmic X-ray background predict that the emission at hard X-rays is due to many absorbed AGN [2], with their central engines primarily visible via hard X-rays (and perhaps infrared). If most of the accretion in the Universe is highly obscured, then the emitted power per galaxy based on currently available optical, UV, or soft X-ray quasar luminosity functions may be substantially underestimated. By using hard X-ray spectra to advance our knowledge of the total luminosity of AGN, Constellation-X will bring us closer to knowing the total energy output of the Universe.

**What roles do supermassive black holes play in galaxy evolution?** Constellation-X measurements of black hole mass and spin for the high z quasar sample will allow understanding of the relative evolution rates of black holes and their host galaxies, and will shed light on when massive black holes formed compared to the galaxy formation epoch.

**How does gas flow in accretion disks and how do cosmic jets form?** Accretion disks play a fundamental role in many astrophysical settings, ranging from the formation of planetary systems to accretion onto supermassive
black holes in AGN. There are, however, many controversies about the nature of viscosity which drives the accretion process, about the stability of the disk at various accretion rates, and about the relevance of advection and mass outflows, and the mechanisms by which jets are formed. Constellation-X will probe the physics of accretion disks to a level not currently possible, by resolving line features from the accretion disk photosphere and by measuring the continuum shape over a broad energy band.

**When were clusters of galaxies formed and how do they evolve?**
To date, cluster abundances have been measured in the X-ray band out to a redshift of about 0.4 but no discernible evolution with \( z \) has been seen. Constellation-X spectra of clusters over a range of redshifts will provide crucial information about the presence of primordial gas, including any input from possible pre-galactic generations of stars as well as the contribution from stellar nucleosynthesis as a function of time. The high sensitivity of Constellation-X is essential for extending such studies to the “poorer cousins” of clusters, groups of galaxies. Moreover, by mapping the velocity distribution of hot cluster gas via Doppler shifts in the emission lines, Constellation-X will allow us to examine the effects of collisions and mergers between member galaxies and between separate subclusters and clusters.

**Where are the “missing baryons” in the local Universe?**
Recent observations of the Lyman-\( \alpha \) forest show that at large redshifts most of the predicted baryon content of the Universe is in the IGM, while at low redshifts, the baryon content of stars, neutral hydrogen, and X-ray emitting cluster gas is roughly one order of magnitude smaller than that expected from nucleosynthesis arguments. Therefore, a large fraction of baryonic content of the local Universe is considered “missing”. Numerical simulations [3] predict that the missing matter may reside in the IGM with a temperature range of \( 10^5 − 10^7 \) K. Such gas in the IGM can be detected with the high sensitivity, high resolution instruments aboard Constellation-X through the absorption lines of metals against the X-ray spectra of background quasars (e.g. OVII and OVIII).

**How are matter and energy exchanged between stars and the Interstellar Medium and how is the Intergalactic Medium enriched?**
The chemical enrichment of the Universe is dominated by star formation and the release of the processed material into the ISM via stellar winds and supernova explosions. Moreover, supernova explosions and enhanced star forming activities can drive hot gas out of the galaxy and enrich the ICM/IGM on megaparsec scales. Detailed, spatially-resolved X-ray spectra reveal the stellar/supernova abundances, the composition of the surrounding ISM, and the interaction of the expanding blast wave with the surrounding material. High throughput instruments such as those aboard Constellation-X are needed to measure the K-lines of less abundant elements such as F, Na, Al, P, Cl, K, Sc, Ti, V, Cr, Mn, Co, Ni, Cu, and Zn. The increased sensitivity of Constellation-X will allow us to extend these studies to external galaxies, beyond the Magellanic Clouds to M1 and M33, for example. This will allow us to further
our understanding of the history of star formation and exchange of matter between the ISM and stars.

REFERENCES