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CONSTELLATION-X TOP LEVEL REQUIREMENTS DOCUMENT (TLRD)

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1. SCOPE

The purpose of this document is to provide a self-contained set of top level requirements for Constellation-X in a form that can be used to develop and refine a reference mission, and that provides traceability to the fundamental science objectives for the mission.
This draft of the Top Level Requirements Document (TLRD) modifies the document to reflect Con-X/ASL, consistent with the single satellite, single launch mission configuration currently under study. In the future the TLRD will be supplemented by and updated to maintain consistency with a Science Requirements Document (SRD).

2. INTRODUCTION

The scientific objectives of the Constellation-X mission are briefly summarized in Section 2.1. More complete descriptions of the mission's scientific objectives can be found in the original mission proposals by GSFC (P.I. N. White), SAO (P.I. H. Tananbaum) and in the science book that is located at the Constellation-X website (http://constellation.gsfc.nasa.gov/). The requirements that must be met by the mission and spacecraft systems to achieve these objectives are defined in Section 3. The requirements defined in this document, unless otherwise noted, are applicable to the full constellation of mission telescopes, under normal mission operations. Some of the requirements need additional explanation for clarity. In these cases, the explanations are provided in italics following the statement of the requirement.

2.1 Constellation-X Science Objectives

The purpose of the Constellation-X mission is to study the structure and dynamics of cosmic X-ray sources by obtaining high resolution, high signal-to-noise X-ray spectra. Sources of interest include matter under extreme gravity (supermassive black holes and stellar endpoints), galaxies, clusters of galaxies and the intergalactic medium, stellar coronae and the interstellar medium (ISM), and Solar System objects. These objects emit strongly in the X-ray energy regime and vary in intensity on a broad range of timescales. The Constellation-X mission shall be designed to study these spectra and their variations on timescales from microseconds to years.

The fundamental Science Objectives are to:

I. Test General Relativity in the strong gravity limit by mapping the inner emission regions of black holes and determine the mass and spin of these black holes.

II. Trace visible matter throughout the universe to make an inventory of the baryon content, map the locations of Dark Matter and investigate the nature of Dark Energy.

III. Study the formation and evolution of black holes and determine their role in the evolution of structure in the universe. Do this with ≤100ks exposures which yield at least 1000 counts from the typical source in the ROSAT deep fields. The flux of these sources is such that a significant fraction of the below 10 keV background is resolved (~2×10^{-15} ergs/cm^2/s, 0.1—2.5 keV, for an AGN spectrum with α=1.7 and $N_H=3\text{x}10^{20}$).

IV. Study the interchange of matter, energy, and heavy elements between stars and the ISM, between the IGM and galaxies, between the ICM and clusters of galaxies, and its effect on their evolution.

Note: the above list is a severely shortened version of the mission's science objectives and is intended to be representative rather than comprehensive.

3. MISSION REQUIREMENTS

The mission requirements delineated below are intended to be consistent with achieving the science objectives as summarized in Section 2.1. These requirements, unless otherwise stated, apply to the entire mission from the beginning of normal mission science operations through end of life.

3.1 Bandpass and Effective Areas

The mission X-ray bandpass shall be from 0.3 keV to 40 keV. This bandpass may be implemented by using several instruments with narrower bandpasses.
The goal for the mission bandpass is 0.10 to 80 keV.

While the typical temperature of cosmic X-ray sources to be studied with Con-X is on the order of a keV, a broad bandpass is required to address Science Objectives I—IV. Many cosmic sources exhibit spectral features over a broad range of energies. These include Active Galactic Nuclei (AGN), in which Compton reflection off surrounding cold material produces a continuum spectrum at energies > 10 keV; stellar flares, in which a hard, non-thermal impulsive continuum above 10 keV can accompany the thermal emission produced during coronal heating events below 2 keV; and Supernova Remnants (SNRs), in which the synchrotron radiation generated by cosmic ray electrons accelerated at the shock front can produce a high energy tail in addition to the thermal component.

The mission effective area requirements are defined on-axis at a set of nominal bands and energies and are given in Table I below:

Table I
Minimum Effective Areas

Energy(keV)	Area(cm^2)
0.3 to 10	1,000
10 to 40	150
1.25	15,000
6.0	6,000

The mission effective area is defined as the sum of the effective areas of all Con-X telescopes and detector systems (which meet the energy specific spectral resolution requirements). It is the geometric area of the optics for on-axis operation times all loss factors (excluding dead time corrections for detectors) including, but not limited, to the following (all possibly functions of energy):

1. Structural obscurations
2. X-Ray reflectivity of mirror coatings
3. Factors for division of photon throughput between multiple detectors.
4. Filters in the detectors

5. Quantum efficiency of the detectors
6. Contamination of optical surfaces
7. Losses from mis-alignments

The minimum mission areas noted above are required to achieve Science Objectives I—IV. The nominal energies for the throughput requirements represent X-ray energy regimes of particular interest, for example, the iron K shell complex in the 6 keV regime and the broad iron L shell complex in the 0.7 to 1.2 keV regime. Observing these emission complexes is required for understanding the physics of AGN, black hole accretion disks, SNR, and stellar coronae.

3.2 Spectral Resolution

The required mission spectral resolving powers across the mission bandpass are defined in the table below.

Table II: Mission Spectral Resolving Power (FWMH)

Energy (keV)	Resolving Power (E/DE)	Goals
0.3—1.0	>1250	>2500
1.0—1.25	>300*	>1250[#]
1.0—10.0	>300*	>3000*
6.0	>2400*	
10—40	>10	

*Applies to central 2.5x2.5 arc-min only
[#] This goal is based on the possibility of extending the high energy limit of a likely grating spectrograph.

Minimum spectral resolutions are required to achieve Science Objectives I and IV. The minimum spectral resolution anywhere over the line-rich 0.3—10 keV bandpass is set by the conditions that: 1) there be sufficient resolution to separate the important density-sensitive He-like triplets (resonance, forbidden and intercombination lines) arising from abundant metals (C through Zn) and 2) the majority of the individual spectral lines in this bandpass be resolved. The spectral resolving power in the 6.0—8.5 keV bandpass must be high enough to: 1) distinguish the lithium-like satellite lines from the overlapping helium-like transitions and 2) achieve a velocity resolution of at least 200 km/s in the Fe lines. We note that the likely instrumentation includes a dispersive spectrograph at low energies which has a resolving power of >1000, and a quantum calorimeter at higher energies with a fixed DE ~2.5 eV which corresponds to a resolving power of 400 at 1.0 keV, 1000 at 2.5 keV, and 2400 at 6.0 keV.

3.3 Spectral Accuracy

From 0.3 keV to 10 keV, the energy (wavelength) accuracy shall be <20% of the energy (wavelength) resolution, with a goal of <10%.

From 10 keV to 40 keV, the energy (wavelength) accuracy shall be <20% of the energy resolution.

Accurate energy (wavelength) scales (also known as registration) are required for line identifications, studies of radial velocity variations, and measurements of redshifts. These accuracies are driven by Science Objectives I and IV. For example, with stars and X-ray binaries, a 100 km/sec orbital velocity requires a relative error (during an observation or from observation to observation) of about 0.35 eV at 1 keV.

3.4 Photometric Accuracy

3.4.1 Absolute Fluxes

Errors in the absolute flux determination (end-to-end throughput over the mission bandpass) of an on-axis source at any given wavelength shall be <10% with a goal of <5%.

Absolute photometric accuracy conditions are set to allow for comparisons of observations at different epochs for variable sources, especially low-intensity, long-term variability. The photometric accuracies are necessary to achieve Science Objectives I—IV.

3.4.2 Relative Fluxes

Errors in the relative flux determinations of an on-axis source during a single observation shall be <5% between 0.3 and 10 keV and <20% between 10 and 40 keV. The goals shall be <2% and <10% respectively.

Relative photometric accuracy conditions are set to allow for plasma diagnostics using line and/or continuum ratios within a given spectrum. The relative photometric accuracies are necessary to achieve Science Objectives I—IV.

3.5 Angular Resolution

The angular resolution requirement for the imaging system (optics plus imaging detectors plus attitude determination system) is ≤15 arc-sec half-power diameter (HPD) from 0.3 keV to 7 keV and ≤30 arc-sec above 7 keV. The goal is to achieve a HPD of 5 arc-sec from 0.3 keV to 7 keV.

The PSFs shall be determined to TBD%.

The required spatial resolution is consistent with confusion-limited observations of the faintest source populations (~$2x10^{-15}$ ergs cm^{-2} s^{-1} below 10 keV) to be studied. This spatial resolution is necessary to achieve Science Objective II;, and allows for spatially resolved studies of extended objects in Science Objectives II and IV.

3.6 Field of View

The field of view (square) of the imaging system shall be at least 5 arc-minutes on a side. The goal is to achieve a field of view of 10 arc-min. Note that the spectral resolution requirement outside of the central 2.5 arc-min square region can be relaxed by a factor of ~four, re: Table II.

The minimum fields of view are set by the need to observe extended objects, such as SNRs and clusters of galaxies, and to achieve Science Objectives II, III and IV.

3.7 Off-Axis Area

The loss of effective area off-axis, relative to that on-axis, due to vignetting of the optics (mirror, collimators, baffles, etc) and similar effects, shall be less than 30% at energies less than and equal to7 keV at radial off axis angles of less than and equal to5 arc-min.

It is necessary to limit vignetting at off axis angles in order to efficiently study the extended sources in Science Objectives II and IV, and maximize the numbers of faint sources which can be studied in the deepest exposures (Science Objective III).

3.8 Extended Source Capability

The mission shall be capable of obtaining spectra; with the stated spatial and spectral resolutions, over the energy range of 1keV to 40 keV for sources larger than the HPD defined above.

The extended source capability is necessary to achieve Science Objectives II and IV. This is in effect a requirement for an imaging spectrometer over this energy range.

3.9 Bright Source Capability

Sources with fluxes up to ¼ Crab (equivalent to $9x10^{-9}$ ergs/cm^2/s over 2keV-11keV) for the mission effective area shall be observable without degradation of spectral resolution or timing precision, relative to fainter sources.

Loss of otherwise detectable photons due to instrumental dead time and telemetry saturation shall be limited to 10% for fluxes up to ¼ Crab.

For fluxes above ¼ Crab, timing precision shall not be degraded but some spectral resolution degradation will be permitted.

3.10 Radiation

The mission and its instruments shall be designed to operate for the mission life within the expected radiation environment. The science instruments shall also be capable of calibrating the effects of the radiation on their performance and performance degradation.

3.11 Timing Requirements

3.11.1 Timing Accuracy

Over the mission bandpass individual photon arrival times shall be measured to an accuracy of +/-100 microseconds relative to UTC. The goal is +/- 50 microseconds.

The timing accuracy is driven by the need to compare times of events as measured at different observatories, both space- and ground-based, and to allow for accurate measurements of time variable phenomena.

3.11.2 Timing Resolution

The photon counting instruments shall have a time resolution for photon arrival times of +/-10 microseconds with a goal of +/-1 microsecond.

The timing resolution is driven by the need to study highly variable phenomena in black hole and neutron star accretion disks, pulsar spin rate changes, and burst sources.

3.12 Celestial Coordinate Accuracy

The mission shall provide a celestial location accuracy (post-facto reconstruction) of 5 arc-seconds (3 sigma).

A precise celestial location is required to enable comparison of source positions (and hence source identification) between Constellation-X and other space- and ground-based observatories. This accuracy is necessary to achieve Science Objective III.

3.13 Observation Duration

Individual, uninterrupted, observations, utilizing the full mission collecting area, shall be between 1ks and 200ks in duration.

Observations that require more than 200ks can be accommodated by multiple individual observations. Such observations may be for faint objects, or for objects with variability on timescales of several days.

3.14 Re-pointing

The mission must be capable of a 60 degree slew and settle time of less than 1 hour.

3.15 Solar System Objects

The mission shall be capable of observing solar system objects.

3.16 Sky Coverage

The mission orbit and attitude constraints must be such that 90% of the sky is accessible at least twice per year, with viewing windows no shorter than 2 weeks in duration, and 100% of the sky is available at least once a year with a minimum viewing window of one week.

3.17 Real Time Observing

There is no requirement for real time observing during normal science operations.

3.18 Targets of Opportunity

Targets of Opportunity (TOOs) shall be observable within 24 hours notice with a goal of 12 hours. TOOs shall be limited to no more than 2 per month.

The limitation on the number of TOOs per month is per the FST (meeting date June 00) to avoid large impacts on the mission support staff, and on the mission observing plan.

3.19 Data Latency

Data shall be available to the investigator within 2 weeks of completion of an observation. The goal shall be 72 hours. Bright source observations (i.e., where the data rate significantly exceeds the average rate) shall be made available to the investigator within 4 weeks of completion of the observation.

3.20 Viewing Efficiency

An overall viewing efficiency of 85% is required.

3.21 Mission Lifetime

Constellation-X shall be designed for a minimum normal mission operations life of five years. Consumables shall be sized for 10 years of normal missions operations.

The number of sources that need to be observed extensively with Constellation-X is in the hundreds, and it would not be possible to cover statistically adequate numbers of the variety of classes of sources in less time. The straw man observing program to carry out the four science objectives requires ~4 years of observing time, which will extend over ~5 years at 85% observing efficiency. Many galactic sources have important timescales of months to years, for example binary periods, precession periods of accretion disks, significant precession of eccentric orbits, decay of short period orbits, etc. Fluctuations in pulse periods of accreting pulsars have timescales of months and galactic X-ray novae have decay times of up to a year.

3.22 Redundancy

The Constellation-X mission shall be configured such that no single failure will result in the loss of more than 25% of the mission science, exclusive of launch vehicle failure.

4. LIST OF ACRONYMS

AGN	Active Galactic Nuclei
ASL	Atlas Single Launch
FST	Facility Science Team
GSFC	Goddard Space Flight Center
HPD	Half-Power Diameter
ICM	Intra-Cluster Medium
IGM	InterGalactic Medium
ISM	InterStellar Medium
kbps	kilobits per second
keV	kilo-electron Volt
PSF	Point Spread Function
SNR	SuperNova Remnant
UTC	Coordinated Universal Time
SAO	Smithsonian Astrophysical Observatory
SRD	Science Requirements Document
TLRD	Top Level Requirements Document
TOO	Target Of Opportunity
TBD	To Be Determined