



A Future Generation Ultra High Throughput X-ray Telescope Concept

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Thesis statements:

- ▲ X-ray astronomy will within 15 years require a very large ($A \sim 3 \times 10^6 \text{ cm}^2$) spaceborne soft X-ray telescope.
 - Fine-scale measurements of cosmic hot gas distribution.
 - Spectroscopy of most distant X-ray sources with measurements of elemental abundances from first generation star formation.
- ▲ We propose a mission architecture with formation flying.
 - Separate spacecraft for telescope and detectors.
 - No optical bench.
- ▲ Lighter weight optics are needed for cost feasibility.

ABSTRACT*

X-ray astronomy will play an increasingly important role in studies of the early universe and of large scale structure. However, these studies are ultimately limited by sparse photon numbers. Therefore, there is a need to develop generations of telescopes with progressively larger collecting area under mass constraints that are increasingly severe. The challenge is actually much greater in the X-ray band than the optical. X-ray telescopes place the reflectors at angles of a degree with respect to the source direction and the telescope reflects the X-ray twice. Consequently, the physical area of the X-ray reflectors is two orders of magnitude larger than the effective aperture. Large mass is currently a problem for the Constellation-X Mission. As we look forward beyond Constellation for Astronomy's Decadal Survey we realize that a radically different approach is required based upon super light weight reflectors and perhaps in situ assembly of the telescope.

*This work is supported by NASA under a grant from the Institute for Advanced Concepts.

OUTLINE

- I. Introduction
- II. Mission Architecture
- III. X-ray optical design
- IV. Technology development
- V. Summary

I. X-ray astronomy expects many new discoveries in the next 15 years.

- ▲ Most baryonic matter in Universe is probably hot gas.
 - Exists as a network of filaments connecting clusters of galaxies
 - Appears as absorption lines in spectra of distant quasars
- ▲ X-rays (and IR) penetrate through dust from earliest phases of star formation.
- ▲ Chandra and XMM will identify many new distant sources, with flux too low for spectroscopy on those missions.
- ▲ Fine-scale structures cannot be mapped by current or planned missions.
- ▲ Detector technology usually advances more rapidly than the missions which use them.
- ▶ We will need an ultra high throughput x-ray telescope.

II. Existing and planned mission models are not suitable for an UHT X-ray telescope.

- ▲ Launch cost of massive integral observatory based upon Chandra X-ray Observatory, XMM model is excessive.
 - Everything aboard one spacecraft, high risk, strict vehicle constraints.
 - Payload probably too large for any launch vehicle.
- ▲ Launch costs of many moderate spacecraft (Constellation-X model) are excessive.
- ▲ In either case, failed or obsolete detectors cannot be replaced.
 - e.g., third detector failure of ROSAT ended its life with telescope in excellent condition.

A benchless mission architecture with station keeping has many advantages.

- ▲ Separate spacecraft for telescope and each detector.
- ▲ System positioned at sun-earth L_2 point.
- ▲ Station-keeping, attitude control required for each vehicle.
- ▲ Advantages:
 - Mass and volume of the telescope vehicle are reduced.
 - Complexity of the observatory is lower, reliability is higher.
 - Integration costs are much lower.
 - Replaceable and interchangeable detectors.
 - Other space agencies may participate in the mission, dividing costs.
 - No stringent time and weight constraints on individual detectors.
 - Costs more evenly distributed in time with phased launches of detectors.
 - Adaptation to improved detector designs possible.

The grazing incidence telescope is the largest component of the observatory.

- ▲ $\sim 3 \times 10^6 \text{ cm}^2$ collecting area.
- ▲ 30 m diameter grazing incidence mirror assembly.
- ▲ 250 m focal length.
- ▲ Situated on its own spacecraft.
 - Passive roll in station-keeping.
 - Displays fiducial markers, transmits ranging signals to detector.

The Telescope Optics

The most familiar type of X-ray optics in astronomy is the double conical telescope, especially the Wolter Type 1 telescope. This optic has been employed in every X-ray telescope mission to date and in all those awaiting launch. A Wolter telescope can be segmented and this is, in fact, being considered for the European XEUS telescope.

Kirkpatrick-Baez Mirror

Segmentation can also be applied, perhaps more effectively to the “Kirkpatrick-Baez” (K-B) array of stacked orthogonal parabolic reflectors (Figure A). As shown in Figure B, a large K-B mirror can be segmented into rectangular modules of equal size and shape.

A segmented K-B telescope has the advantage of being highly modular on several levels. All segments are rectangular boxes with the same outer dimensions. Along a column, the segments are nearly identical and many are interchangeable with each other. All reflectors deviate from flatness only slightly after the figures are imparted. On the other hand the Wolter reflectors are highly curved in the azimuthal direction and the curvature varies over a wide range. Furthermore, within a segment, the K-B reflectors themselves can be segmented along the direction of the optical axis. As shown in Figure C, a K-B mirror system can be folded more easily than the Wolter mirror into a compact volume for launch and deployment in space.

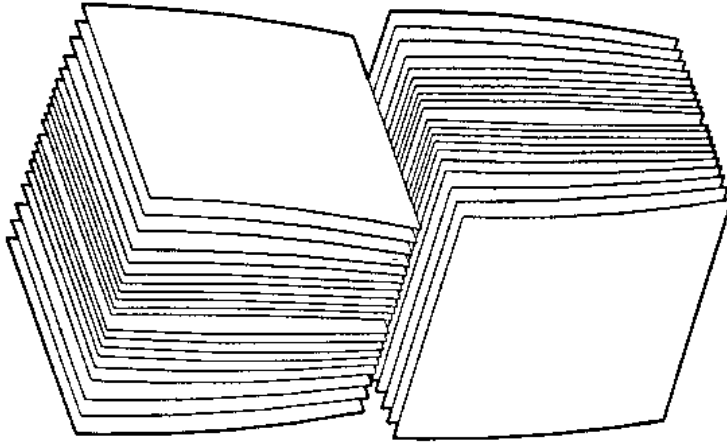


Figure A. Kirkpatrick-Baez mirror consisting of orthogonal stacks of reflectors. Each reflector is a parabola in one dimension.

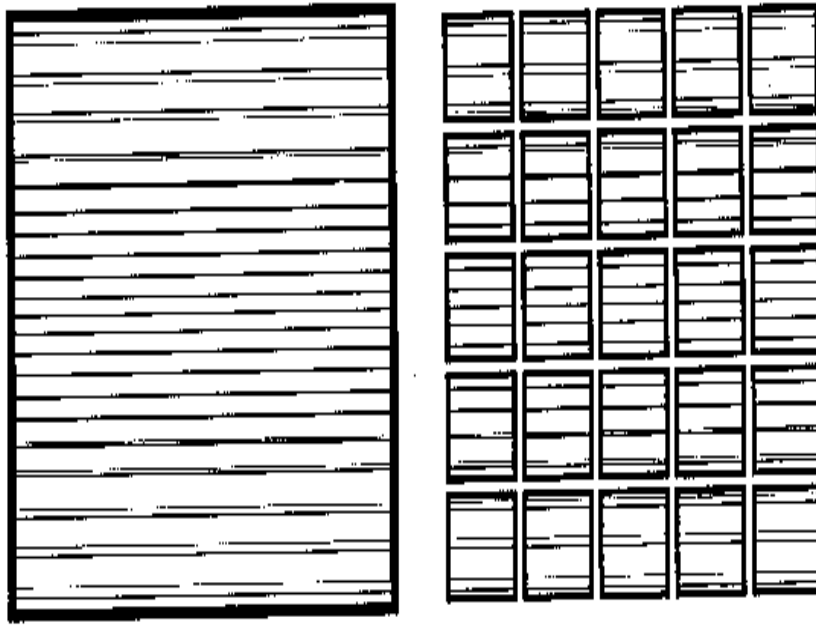


Figure B. A large K-B mirror can be segmented into rectangular modules of equal size and shape.

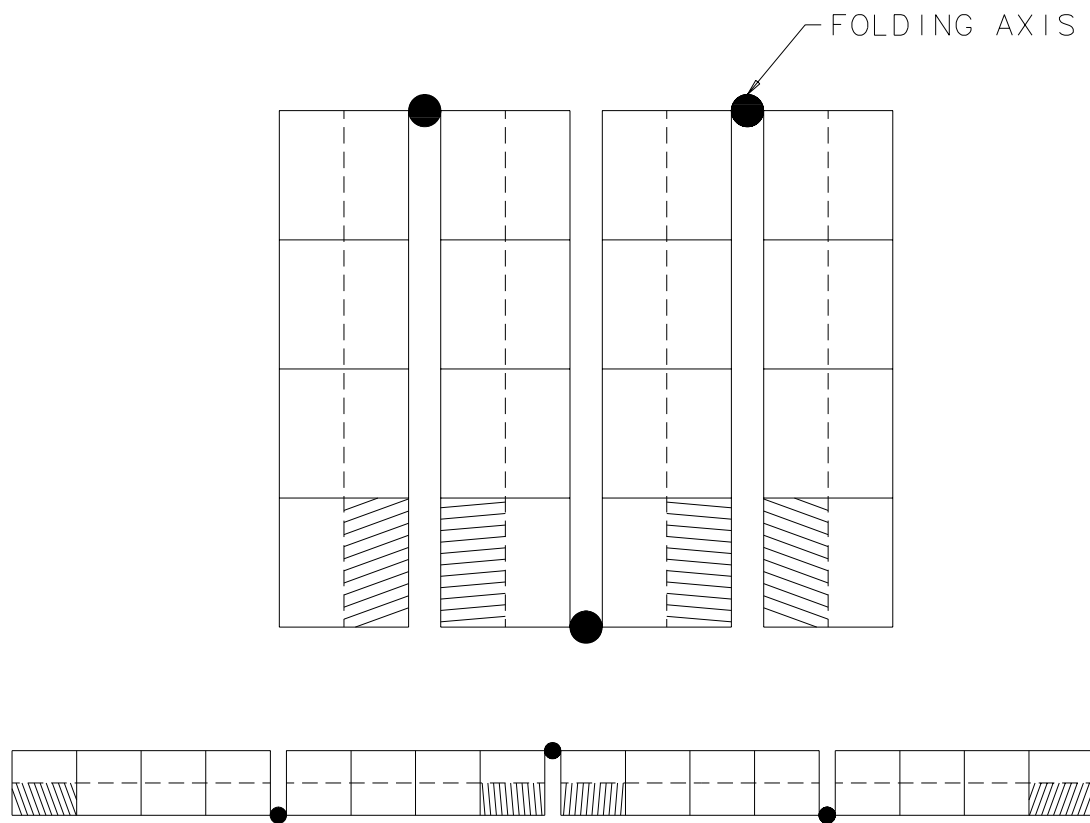


Figure C. Mirror folded for launch (upper) and unfolded in situ (lower).

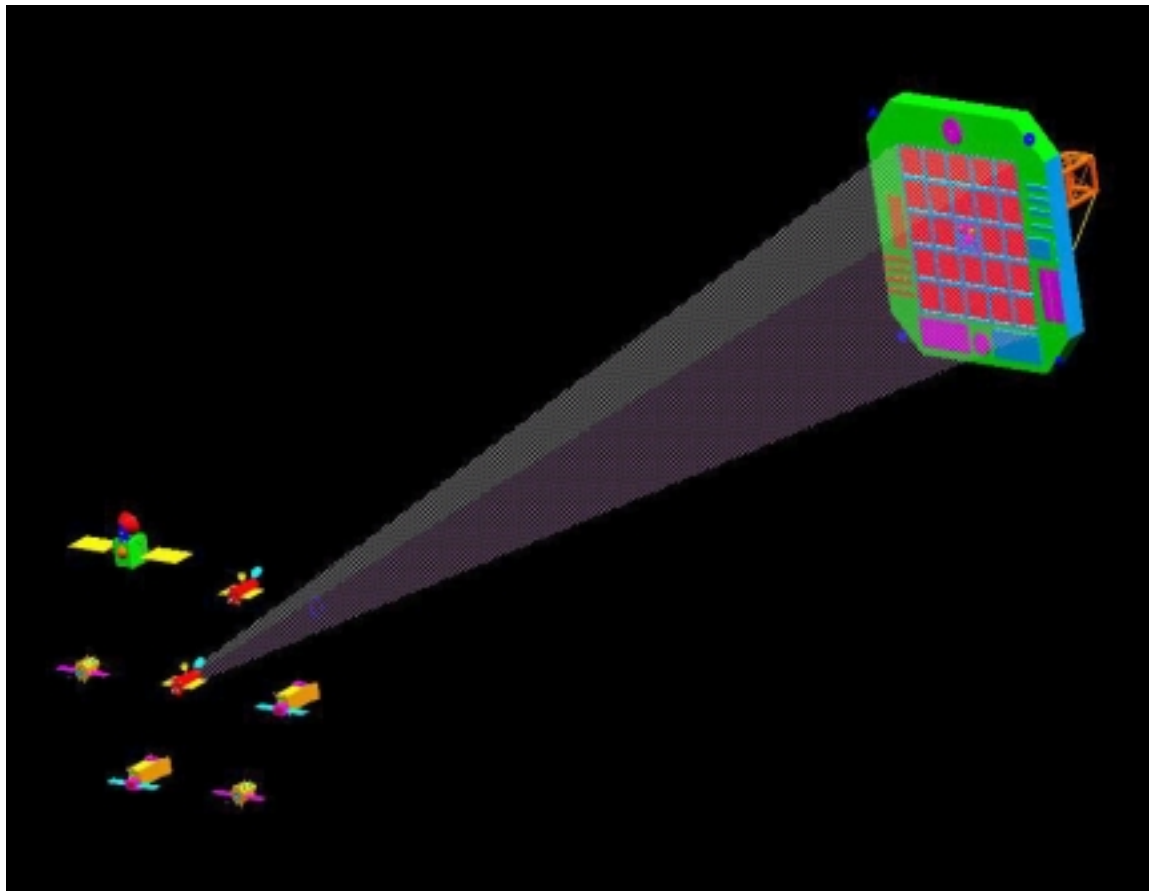
The X-ray Observatory

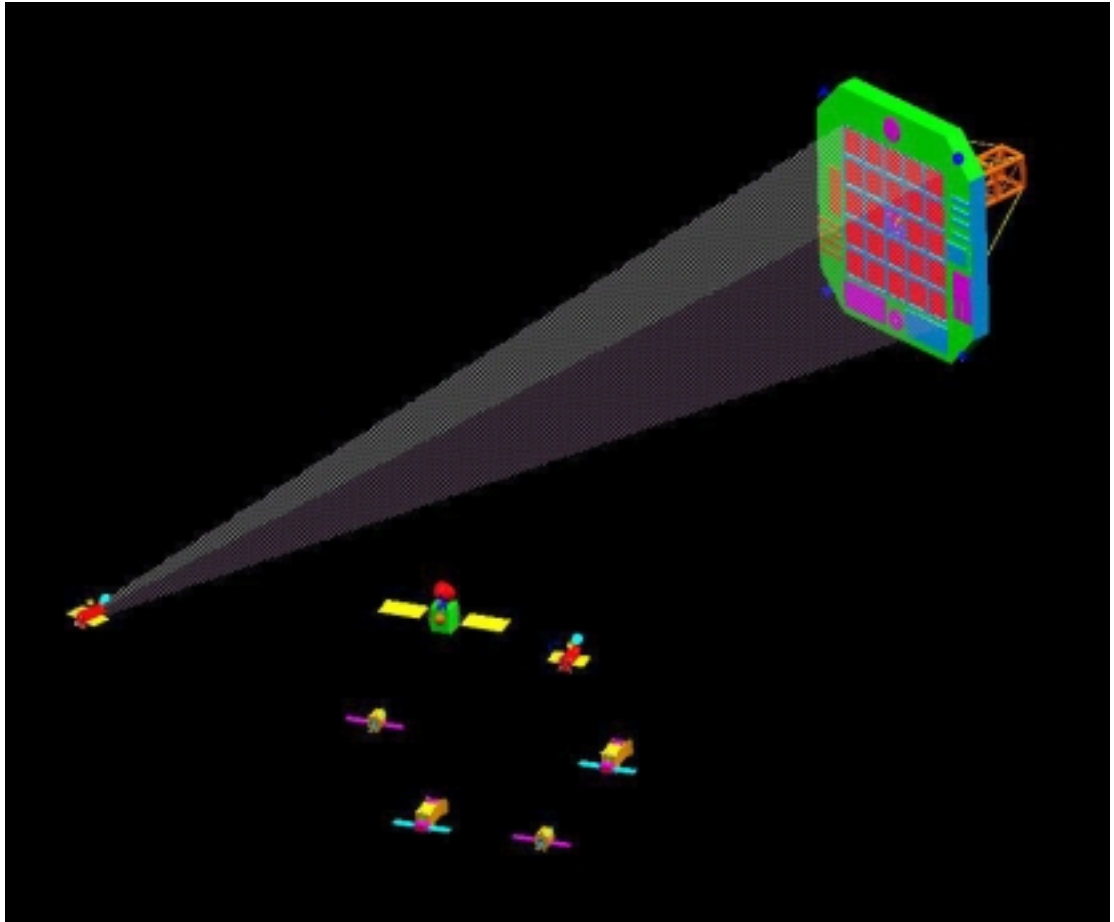
The following series of color figures illustrates the operations of the Ultra High Throughput Observatory.

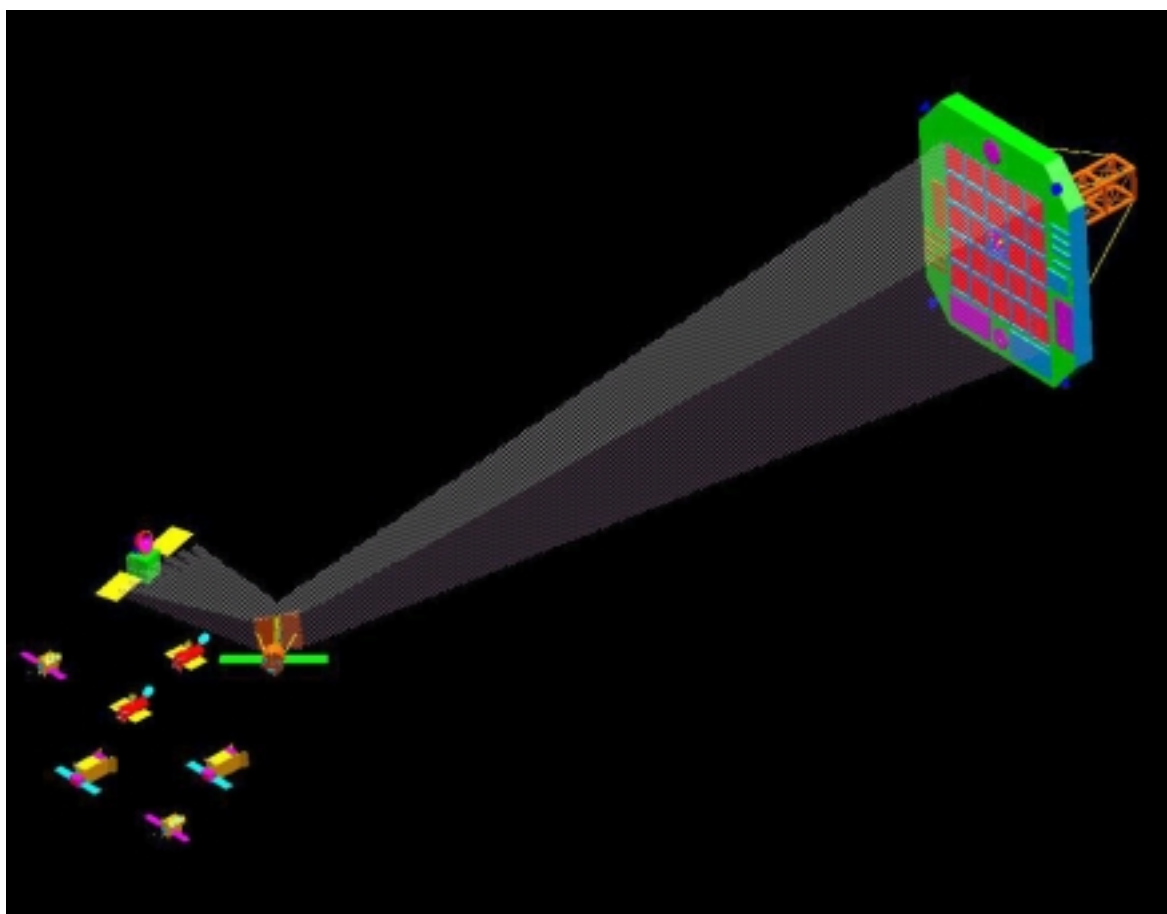
The first shows a segmented telescope (as a Kirkpatrick-Baez type mirror assembly) situated on its own spacecraft. At a distance equal to the focal length (about 300 m) are a group of spacecrafts containing detectors of various different types, i.e. high resolution, wide field, spectroscopy, etc. Usually only one detector is active and precisely stationed at the focus. With the aid of its own sensors and signals sent from the telescope that spacecraft performs station keeping to maintain that distance equal to the focal length with a few millimeters.

In the second figure the target is changed. Only the active detector which may not be the same one of the previous figure has changed position to take up the focal plane station. The others can stay put until they go into service.

The third figure shows an alignment of three satellites which may be needed for certain very high resolution dispersive spectroscopy measurements.







IV. Improved lightweight optics needed!

- ▲ Segmented, ultra-light weight optics must be developed.
 - Monolithic mirror elements, whether Wolter Type I or Kirkpatrick-Baez, are impractical.
 - Curvature may be achieved with quasi-flat elements.
- ▲ We estimate a **30 ton** mirror assembly with existing technology.
 - Assuming 125 μm Al foil reflectors
 - 50% overhead for support structure.
 - Does not include vehicle assembly and control systems.
- ▲ The cost feasibility of the mission will be greatly aided if we can reduce this by a factor of two or three.

Implementation will require significant technological advances.

- ▲ Constellation-X mission will result in improved replication technology for light weight reflectors.
- ▲ Advancement in light composite materials for substrates is expected within the next 15 years.
- ▲ A telescope with more modest requirements may help with satellite rendezvous and station-keeping system development:
 - High-energy telescope
 - 2 meter diameter, 200 meter focal length
 - Better sensitivity at 20-100 keV for pointed studies of point sources than any other instrument.

V. Summary

- ▲ X-ray astronomy will in 15 years require an ultra high throughput spaceborne soft X-ray telescope.
- ▲ We propose a benchless mission architecture with station keeping as the most cost effective.
- ▲ Modular segmented optics will be required, regardless of mirror design.
- ▲ Improved ultra light weight optics are necessary to minimize telescope assembly weight.
- ▲ A smaller mission would allow system development in advance of a full-scale mission.