Off-Plane X-ray Grating Spectrometer for the International X-ray Observatory

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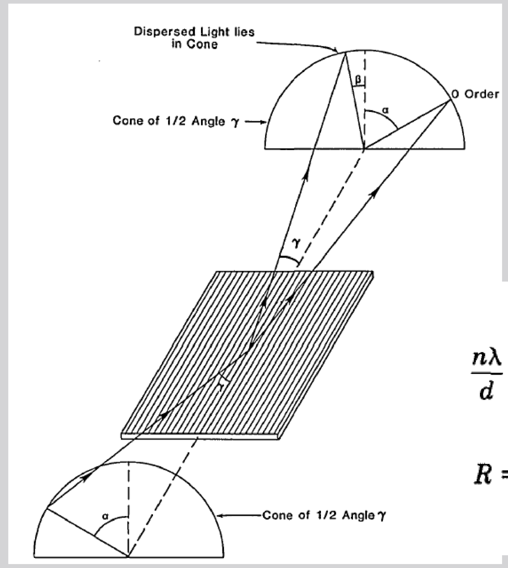
Abstract

The baseline configuration for the International X-ray Observatory (IXO) includes a soft x-ray grating spectrometer as part of its instrument complement to provide a spectral resolution of R >3000 over the 0.3 – 1 keV band with >1000 cm² effective collecting area. Using the current generation of reflection gratings flown on rocket experiments as a point of departure, an Off-Plane X-ray Grating Spectrometer (OP-XGS) is being proposed to the project to meet this need. These rocket experiments have demonstrated R of >100 with wire grid collimators and objective gratings that produce large point spread functions. Prototype gratings fabricated for the IXO project have achieved adequate throughput to obtain the IXO effective area requirement while resolution tests have demonstrated λ/Δλ > 200 when used with a 3 arc minute (angular resolution) telescope. When combined with the IXO telescope performance, the resulting spectral resolution is well over the IXO requirement. The OP-XGS will thus provide higher spectral resolution (over a slightly smaller energy range) than the Chandra LETGS instrument but with a larger effective collecting area providing improved sensitivity. The conceptual design and predicted performance of this system is presented here, along with the technology developments that will be needed to achieve the desired performance.

Mission Level Requirements	Requirement	Capability
Spectral resolution	3000	>3000
Effective area	1000 cm²	1000 cm² with option for 3000 cm²
Mass	100 kg	Estimate 81 kg
Power	100 W	Estimate 62 W (nominal)

Derived Requirements	Requirement	Capability
Grating to Grating angular alignment	1 / 2 / 5 arcsec in θx / θy / θz	Challenging, but Feasible
Grating to Grating Spatial alignment	0.1 mm in x, y 1 mm in z	Comply
Grating array to detector & FMA	1 / 2 / 5 arcmin 3 / 3 / 90 mm x / y / z	Dependent on S/C structure but believe these are not driving requirements

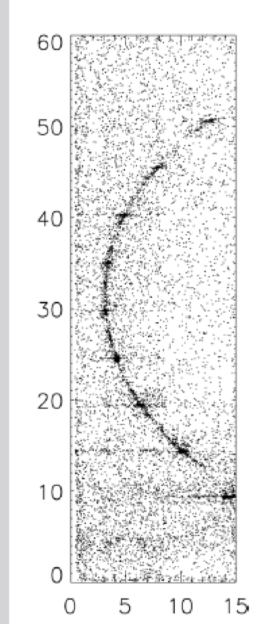
Off-Plane Grating Basic Principles:



$$\frac{n\lambda}{d} = \sin\gamma(\sin\alpha + \sin\beta),$$

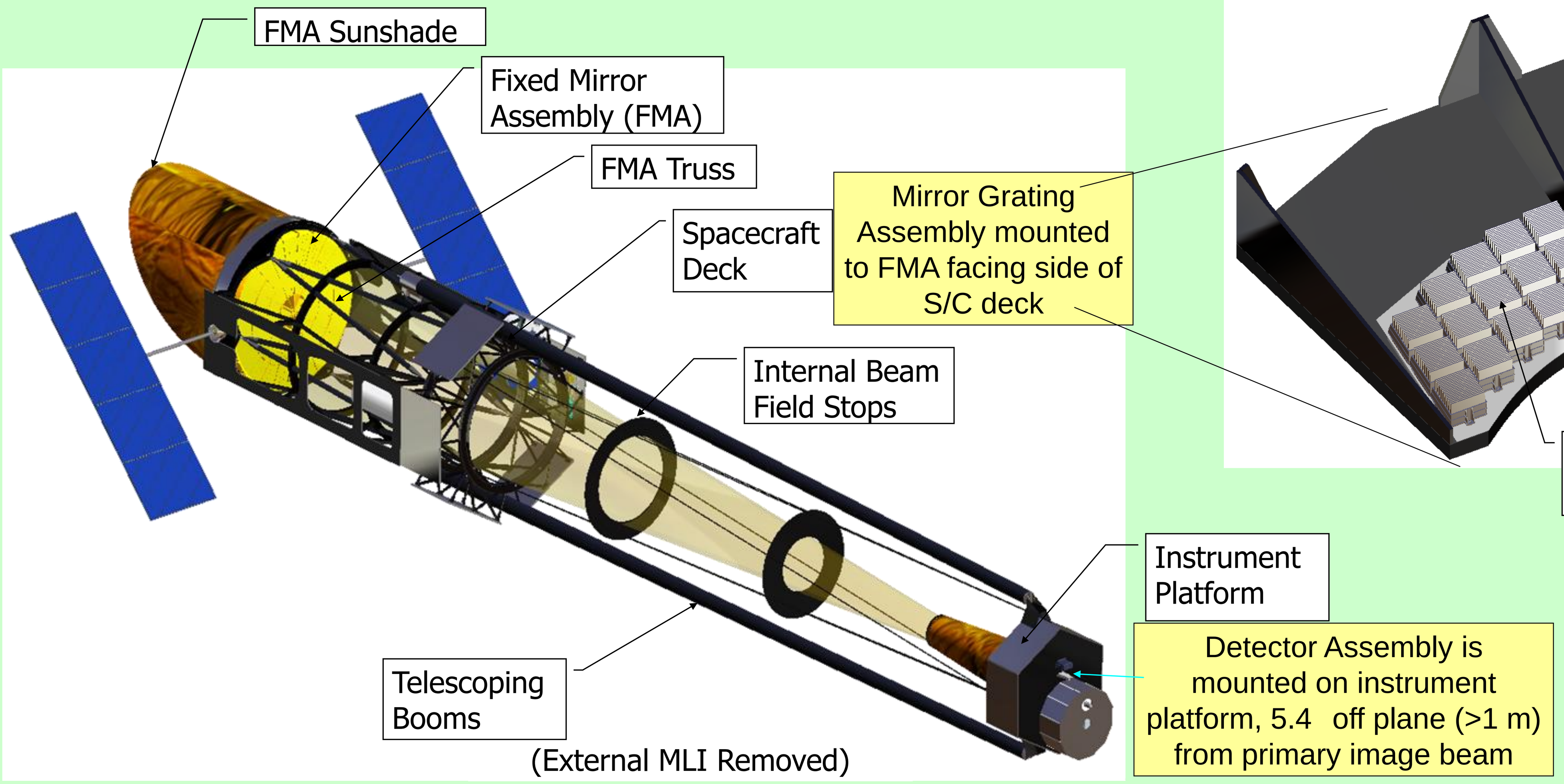
$$R = \frac{(\sin\alpha + \sin\beta)\sin\gamma}{B\cos\beta},$$

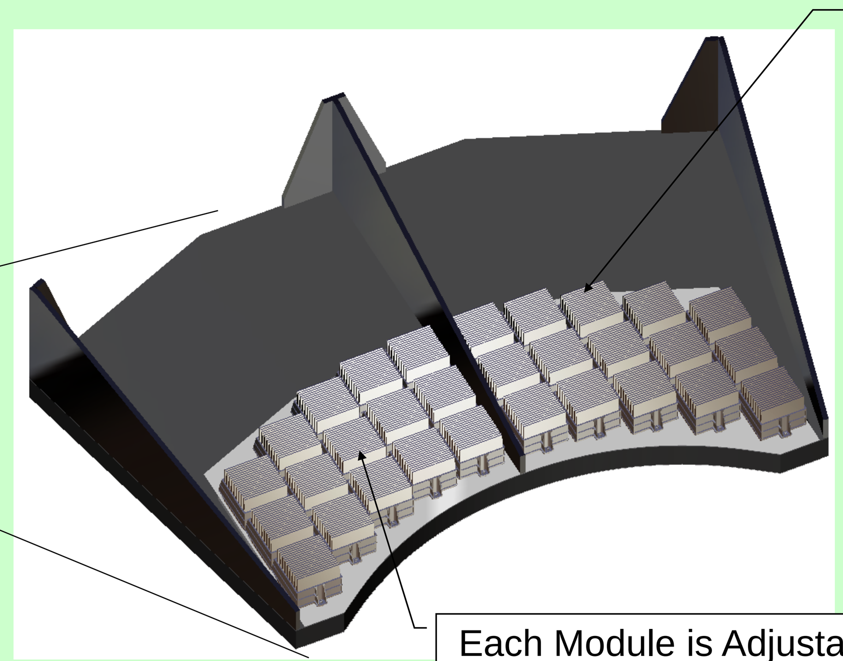
The behavior of an off-plane grating is fundamentally described by the conical diffraction equation. [2]



Approximate imaging focus (equivalent)

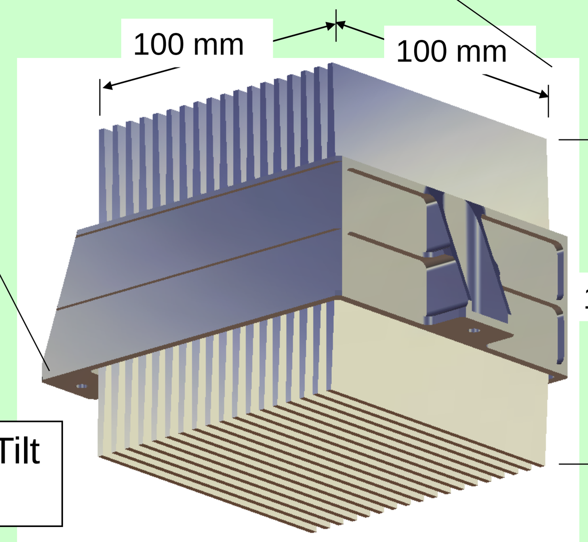
Example detector plot. Grating orders from Cu-L line. R can be calculated using spot width and distance between orders. [1]



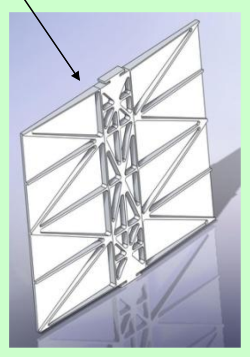


The assembly is comprised of 30 Mirror Modules

Each Module is Adjustable for Tip/Tilt & Piston at the mounting points

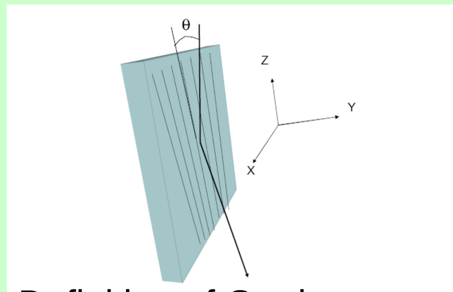


Each Module contains 15 to 18 individual lightweighted gratings

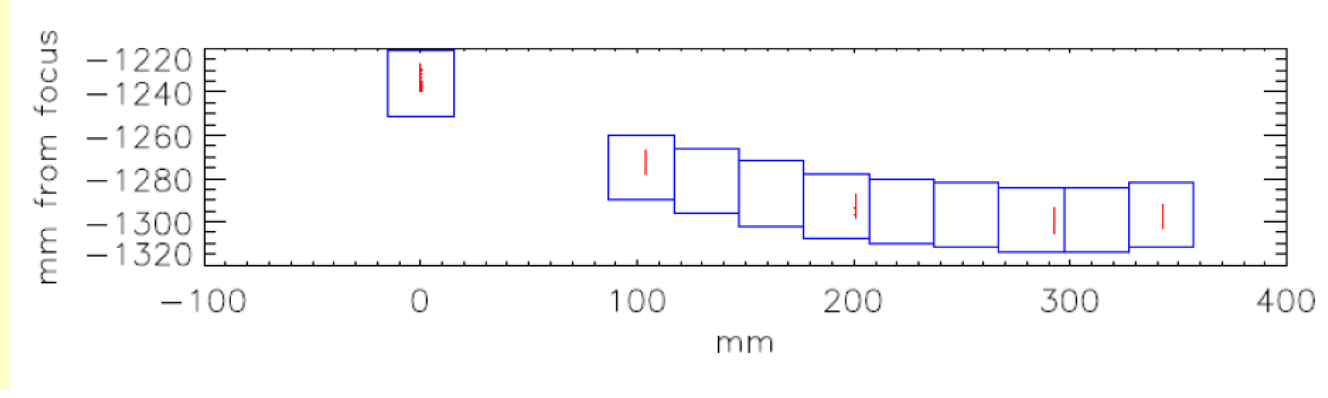


(notional)

Concept provides a straight-forward engineering challenge, minimizing required technology "invention"

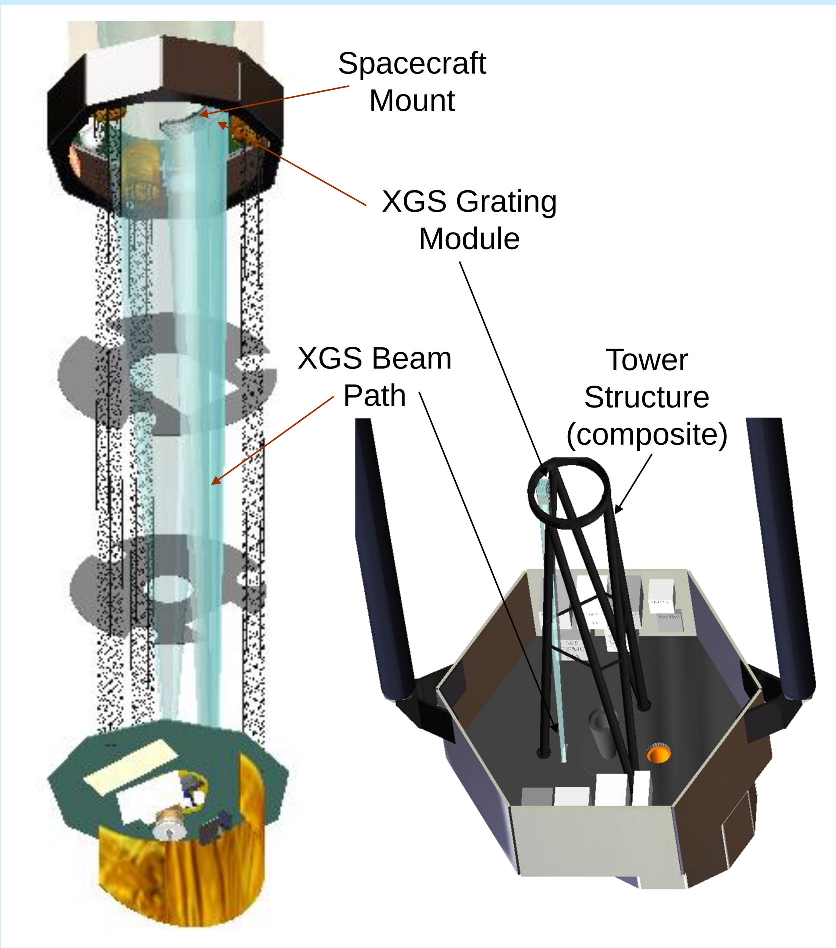


Definition of Grating Coordinate System (x,y,z)



Raytrace of the 13.1 m configuration. Spectral lines are red and blue boxes are 30 mm CCDs.

Dectector array is mounted in an "annulus" from the center of the image plane. The CCD at "0 mm" is to detect the zero order light from the grating to allow alignment of the spectra. This version is 1.22 – 1.32 m radially displaced from the central focus of the FMA. The spectral resolution and coverage depends on the CCD placement & pixel size and the image quality at the detector plane.

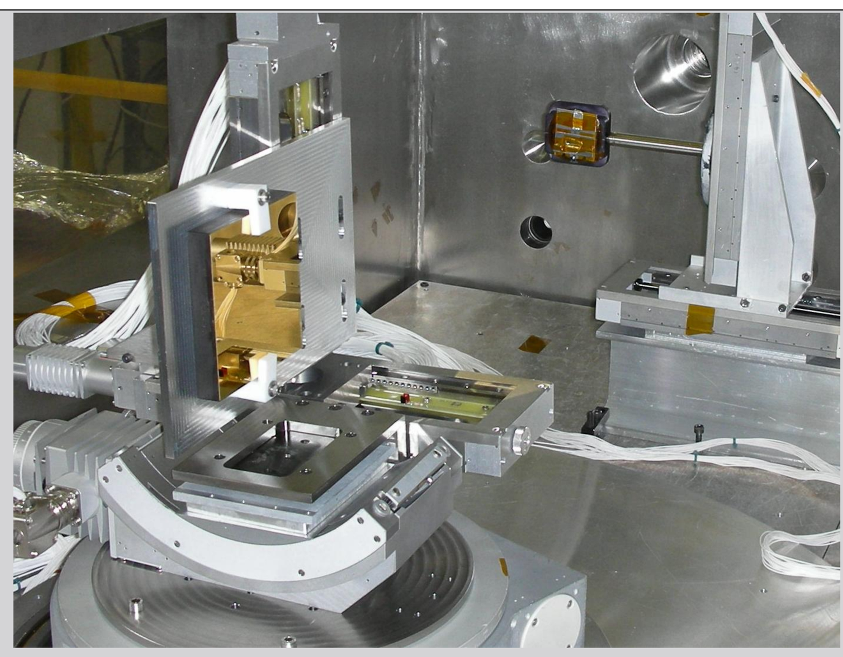


Location of Grating Module is an Open Trade:

Left is the original OP-XGS concept (shown above)

Right is an alternative "tower" concept

- Much smaller grating module with many fewer individual gratings
- Reduced detector area required at the image plane
- Rigid structure connects the grating array and the detector plane
- More difficult to meet the resolution requirements with the shorter dispersion distance
- Requires higher image quality from the x-ray telescope



A prototype grating (shown here) with 4245 grooves per millimeter was tested at the University of Colorado. R~200 was demonstrated with a 180 arcsecond telescope beam. Theoretically the same grating should obtain R~3000 with a 15 arcsec telescope beam and greater than that with the 5 arcsec beam IXO is designed to provide. The grating design will be optimized for IXO requirements and a demonstration program is in development to validate the scaling relationship.

CONCLUSIONS:

- The OP-XGS approach relies on technology that has been demonstrated in lab experiments and similar (but smaller) gratings have been used in rocket experiments
  - Technology drivers are flatness in fabrication, alignment, and lightweight substrate design to meet mass requirements
  - Primarily an engineering problem, not a technology problem
- Approach is SCALABLE to meet area coverage and spectral resolution requirements (within mass and power allocations)
- Spectral resolution and coverage a function of detector, distance between gratings and detectors, and grating properties
  - Increased spectral resolution or spectral coverage can be obtained by optimizing parameters

References:
[1] *Off-plane grating performance for Constellation-X* by Steve Osterman, Randall L. McEntaffer, Webster Cash, Ann Shipley. Proc. of SPIE Vol. 5488, 2004
[2] *X-ray optics 2: A technique for high resolution* by Webster Cash. APPLIED OPTICS Vol. 30, No. 13, 1 May 1991