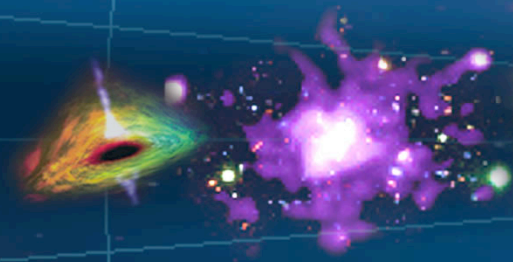
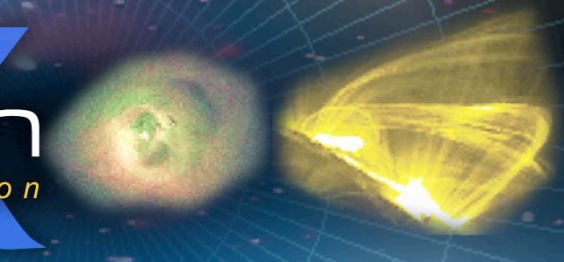
BEYOND EINSTEIN: From the Big Bang to Black Holes



Constellation-X

The Constellation X-Ray Mission



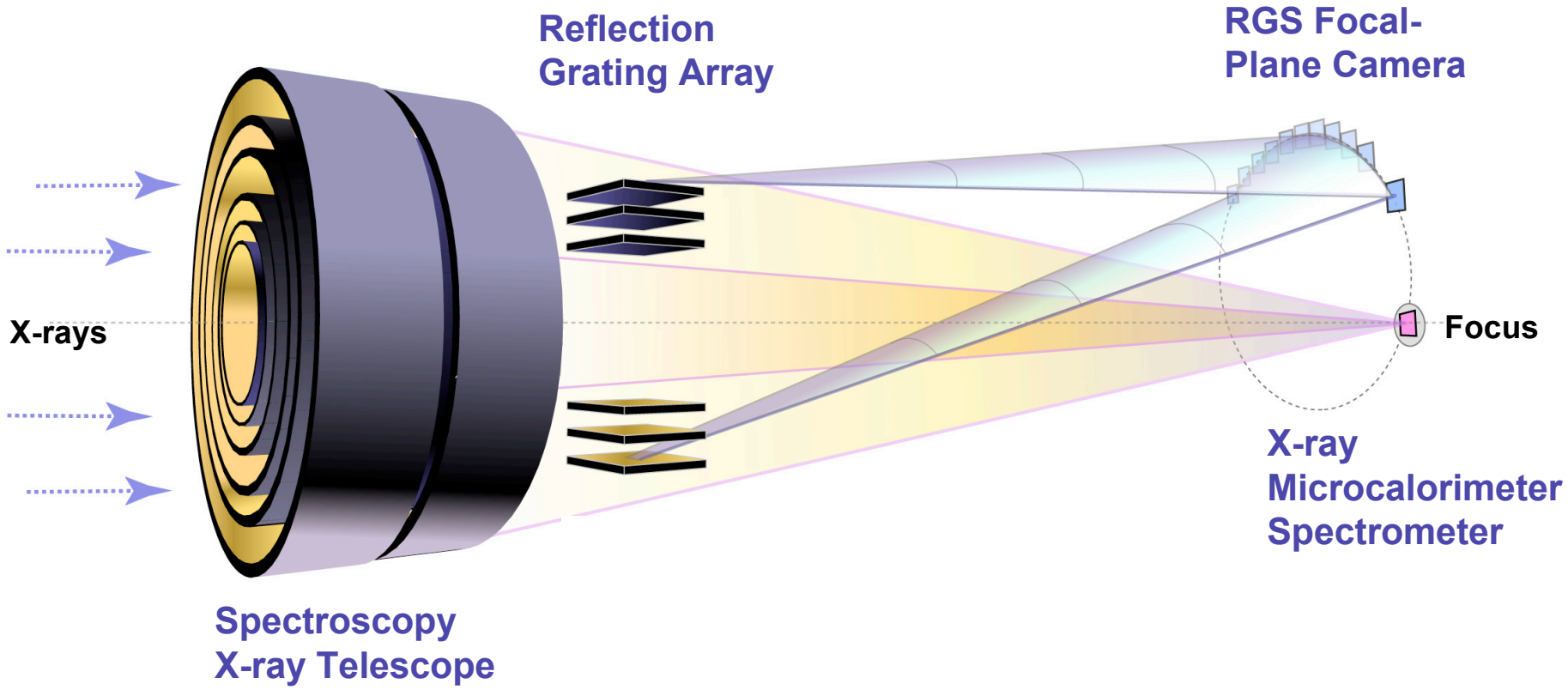
The Constellation-X Reflection Grating Spectrometer

Presented by

Jean Cottam (RGS Instrument Scientist)

SPIE, May 29 2006

Reflection Grating Spectrometer



(Geometry is highly exaggerated)

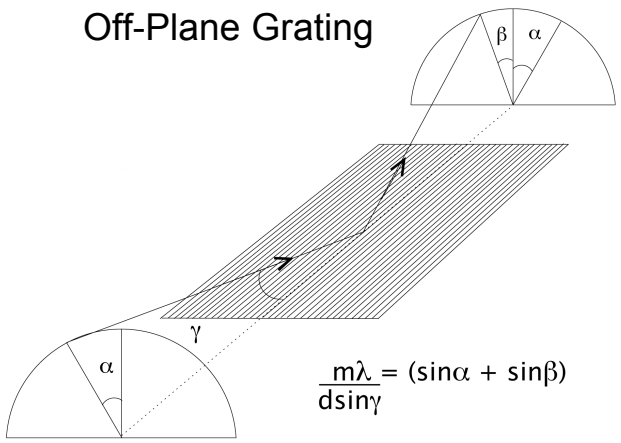
Reflection Grating Spectrometer

- The RGS and XMS are complementary. A grating spectrometer is needed to satisfy the Con-X spectral resolution requirements at low energies.
  RGS: $\Delta\lambda$ is roughly constant $\Rightarrow$ R = $\Delta\lambda/\lambda$ increases with Wavelength.
  XMS: ΔE is roughly constant $\Rightarrow$ R = $\Delta E/E$ increases with Energy.

- The Reflection Grating Spectrometer (RGS) consists of an array of co-aligned reflection gratings, the Reflection Grating Array (RGA), that disperses x-rays to the RGS Focal-Plane Camera (RFC). There are 4 RGS instruments on the Constellation-X mission.

  – The current design employs off-plane gratings. Each RGA consists of ~650 identical gratings assembled into ~50 grating modules.

  – The RFC consists of ~13 CCDs in two systems: the Spectroscopy Readout Camera (SRC), which images the dispersed spectrum, and a zero-order camera (ZOC).



RGS Requirements & Technology Challenges

Parameter	Requirement	Goal
Bandpass	0.25-2.0 keV	0.1 - 2.0 keV
Resolving Power (E < 0.6 keV)	$\lambda/\Delta\lambda \geq 300$	$\lambda/\Delta\lambda \geq 3000$
Throughput (E < 0.6 keV)	> 1000 cm^2	--

Reflection Grating Array (RGA)

- High Reflection Efficiency → Off-Plane Gratings, Anisotropic Etching
- Low-Mass, Close-Packing → Thin Substrates
- Mass Production → Replication, Modular Assembly

RGS Focal Plane Camera (RFC)

- Thin Optical Filters → Fast-Readout "Event-Driven" CCDS
- High Quantum Efficiency → New MBE Back-Side Process
- High-Yield Production

Technology Development Teams

RGA Grating Development

- **Massachusettes Institute of Technology / Stanford University**

  Grating Fabrication & Assembly: Mark Schattenburg, Ralf Heilmann

  RGS Design & Modelling: Kathy Flanagan, Andy Rasmussen

- **University of Colorado**

  Off-Plane Grating Development & Demonstration: Webster Cash, Ann Shipley

RFC Detector Development

- **Massachusettes Institute of Technology**

  CCD Development & Fabrication: George Ricker, Gregory Prigozhin

Grating Development at MIT

Specialized Grating Fabrication:

- Silicon wafers patterned with Scanning Beam Interference Lithography (SBIL) "Nanoruler". Anisotropic etching used to form grooves.
  - → Excellent groove control ($\Delta p/p \sim 10^{-5}$)
  - → Smooth, high efficiency gratings
- **Key parameters (size, blaze, line density, flatness) and replication processes have been demonstrated**:
- SBIL undergoing upgrades to VP-SBIL needed for radial-grooved Con-X gratings.

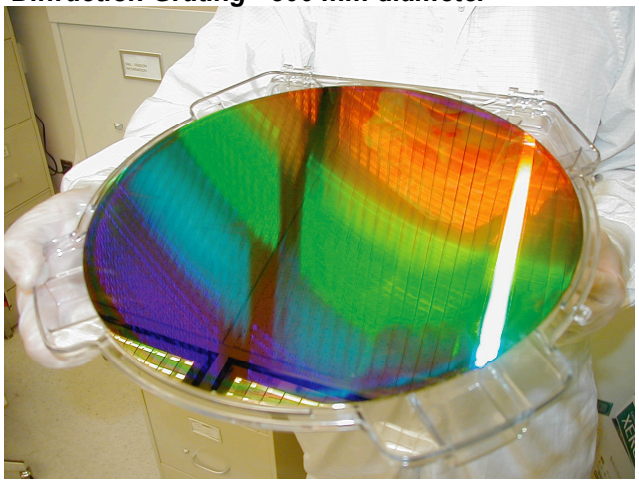
Grating Module Assembly:

- Testing technique that constrains and significantly flattens the grating.
  See Akilian et al. 6266-134 (Tuesday).

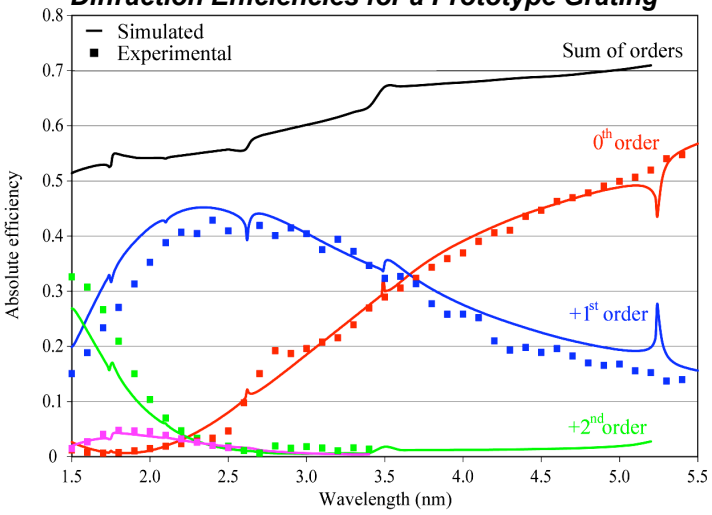
X-ray Testing & Modeling:

- Record efficiencies have been measured. Modelling of efficiency and resolution continue.

Diffraction Grating - 300 mm diameter



Diffraction Efficiencies for a Prototype Grating



Grating Development at UC

X-ray Performance Testing:

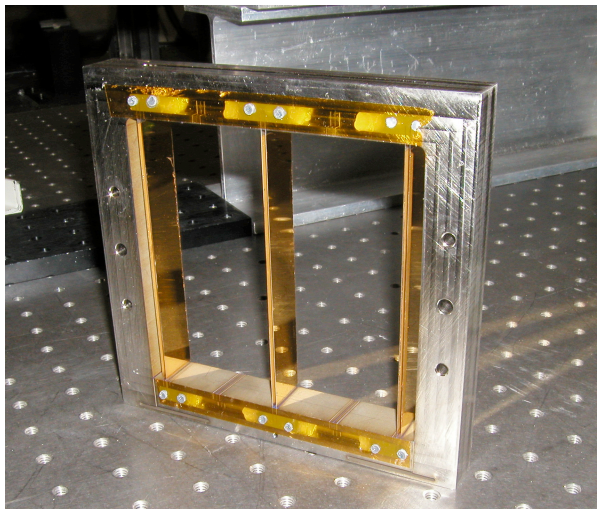
- Efficiency is routinely measured in local facility.
- Preparing for resolution test at MPE/Panter. The 120m beamline and spare XMM mirror approximate flight illumination. **Test planned for late 2006**.
- Working with commercial vendor, Horiba Jobin-Yvon to fabricate test grating for Panter test.

Testing Thin Substrates:

- Close-packing of thin off-plane gratings provides maximum throughput with minimal structural blockage, and satisfies mass requirements.
- Investigating distortions introduced when replicating gratings onto thin substrates.
  See *Shipley et al. 6273-138 (Tuesday)*
- X-ray sounding rocket provides excellent test bed for technology development.
  See *McEntaffer et al. 6266-154 (Tuesday)*

Testing Facility with Monochromator Feeds

Mounted Off-Plane Gratings -- 0.125mm Thick



CCD Development at MIT

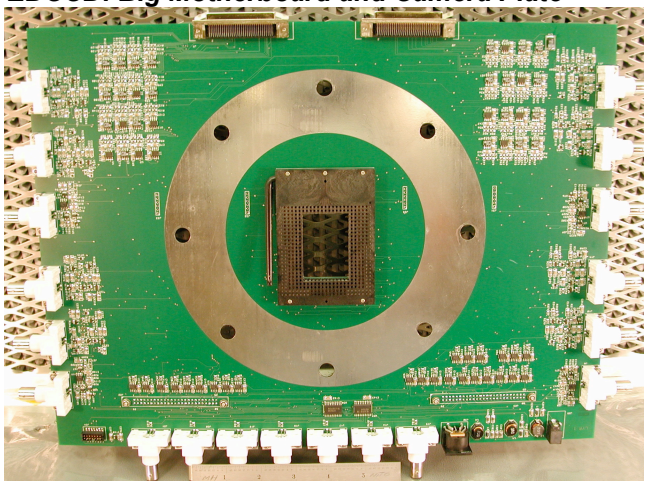
Event-Driven CCDs:

- Novel device recognizes and digitizes only pixels with photon-induced charge. These can be operated at 10x faster readout rates than conventional CCDs:
  - → Much less sensitive to optical light so thinner blocking filters can be used.
  - → Significant power reduction.
- Gen 1.5 device has been **successfully readout at 1Mpix/s** in normal operating mode!

MBE Back-Side Processing:

- Newly improved back-side thinning techniques are showing excellent spectral resolution with **FWHM of 50 eV at 0.25 keV**.
- Energy resolution and symmetry in the line profile strongly suggest excellent quantum efficiency.

EDCCD: Big Motherboard and Camera Plate



Summary

The RGS technology teams are making excellent progress:

- Demonstrated fabrication of critical grating parameters.
- Expect to fabricate flight-prototype grating within the next year.
- Efficiency testing underway. Initial resolution test will be completed in the next year.
- Fabricated CCDs with required readout speeds and energy resolution.

RGS-Related Presentations at SPIE

- **Assembly of thin gratings for soft x-ray telescopes**, M. Akilian, R. K. Heilmann, & M. L. Schattenburg, 6266-135.
- **High-resolution x-ray spectroscopy with the reflection grating spectrometer of Constellation-X**, E. R. Schindhelm & W. C. Cash, 6266-13
- **Studies in thin diffraction gratings for flight applications**, A. Shipley, R. McEntaffer, & W. Cash, 6273-138.
- **A Sounding rocket payload for x-ray observations of the Cygnus Loop**, R. McEntaffer, E. Schindhelm, W. Cash, & A. Shipley, 6266-154.