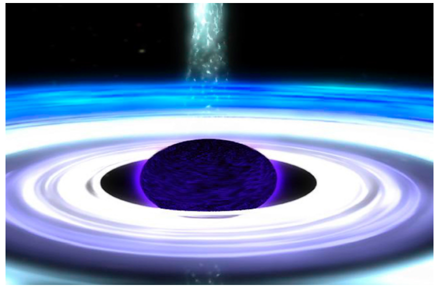
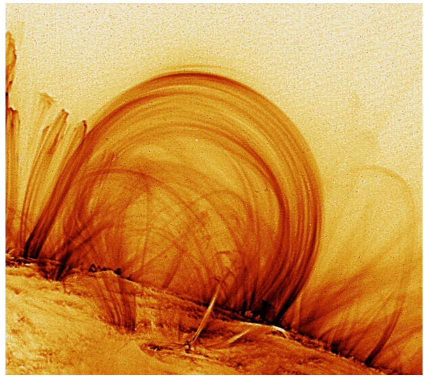
The International X-ray Observatory

A.N. Parmar, H. Kunieda & N.E. White on behalf of the ESA/JAXA/NASA IXO team

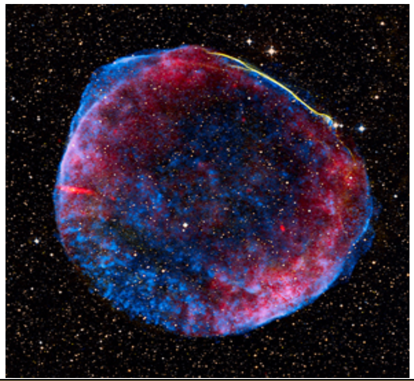
With thanks to R. Smith

IXO – Talk Outline

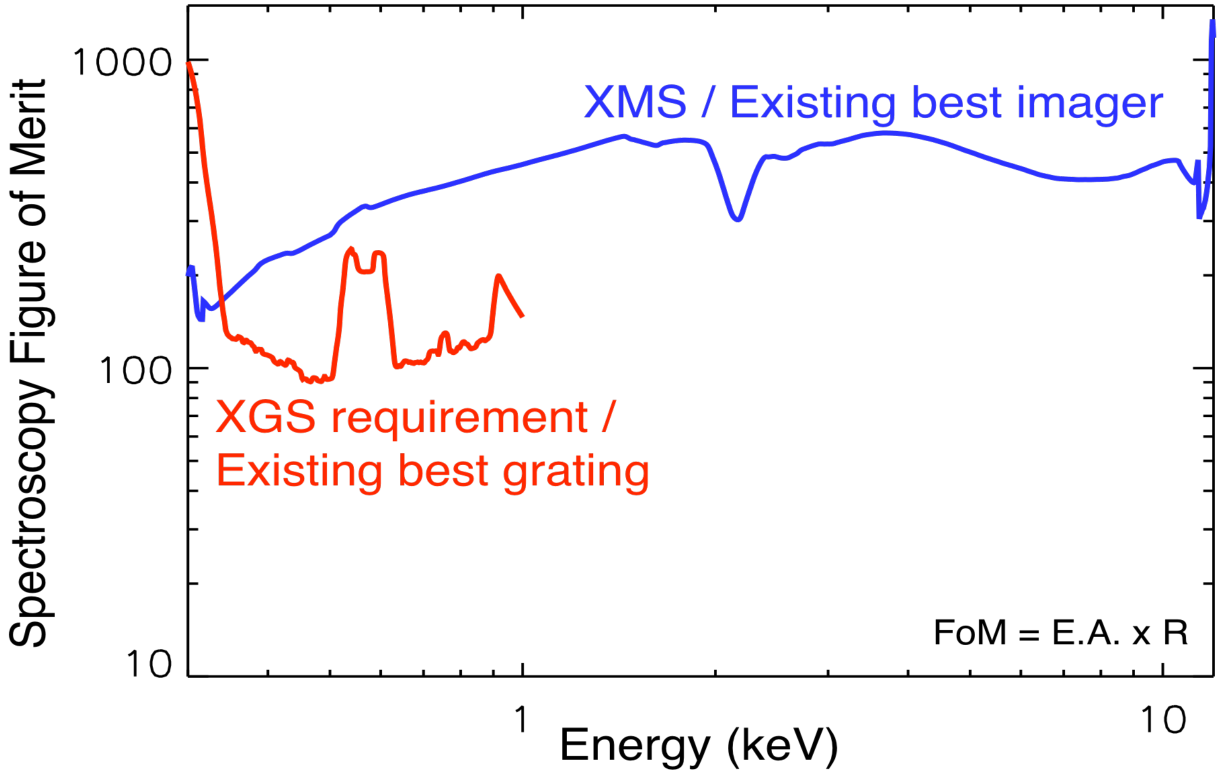




- IXO Overall Capabilities
- IXO High-Spectral Resolution Instruments
- High-resolution X-ray Spectroscopy with IXO
- Mission Concept
- Current Status and Future Plans

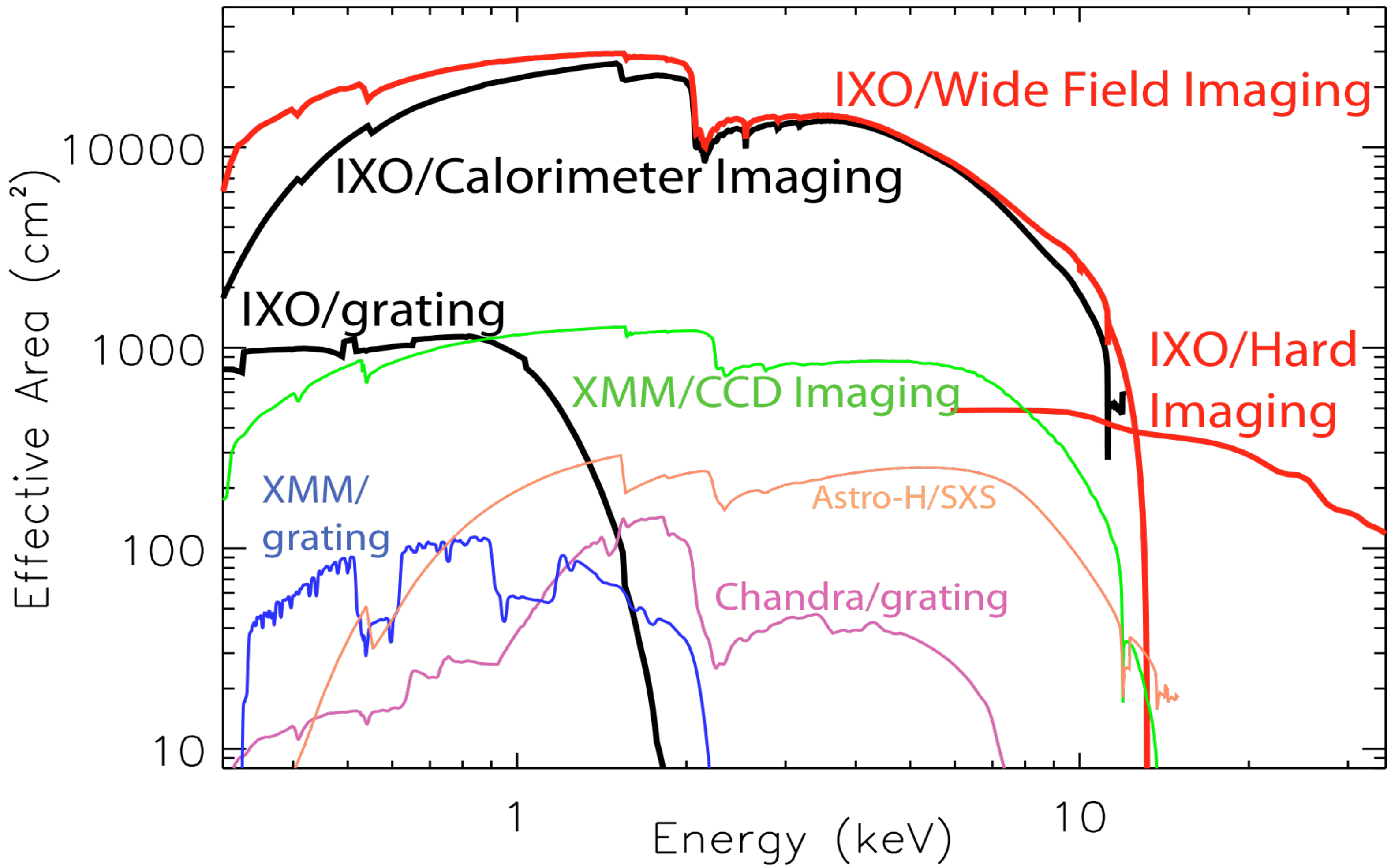


Summary



Spectroscopy capabilities 100x or more of current missions

IXO Effective Area Comparison



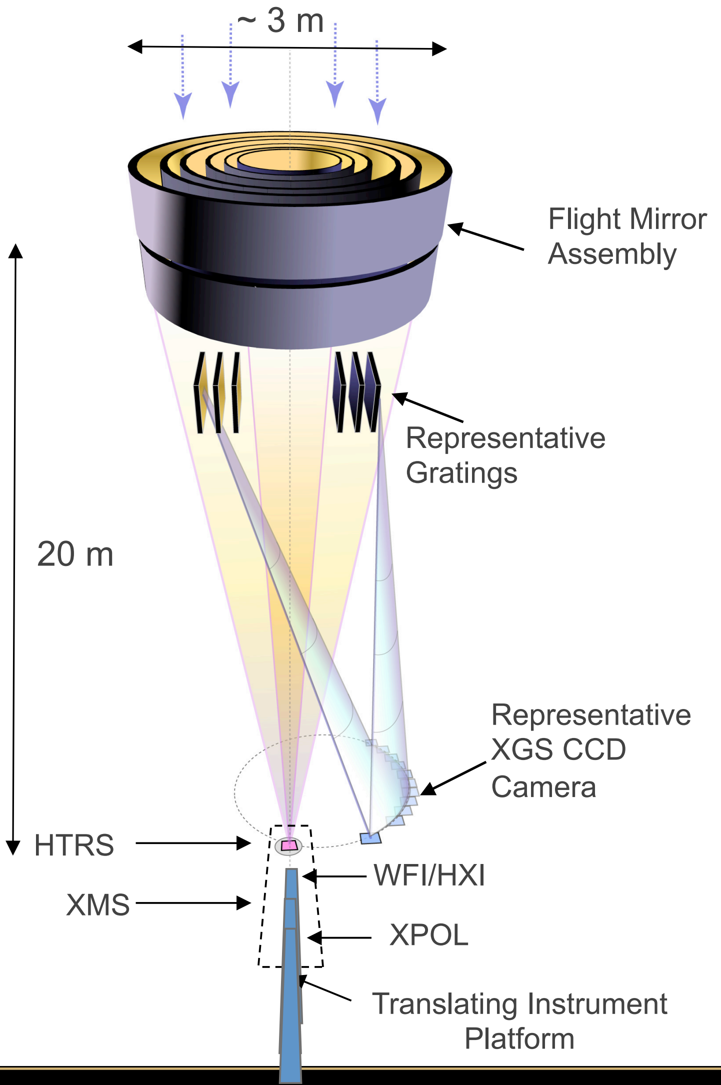
Strawman Payload

Optics

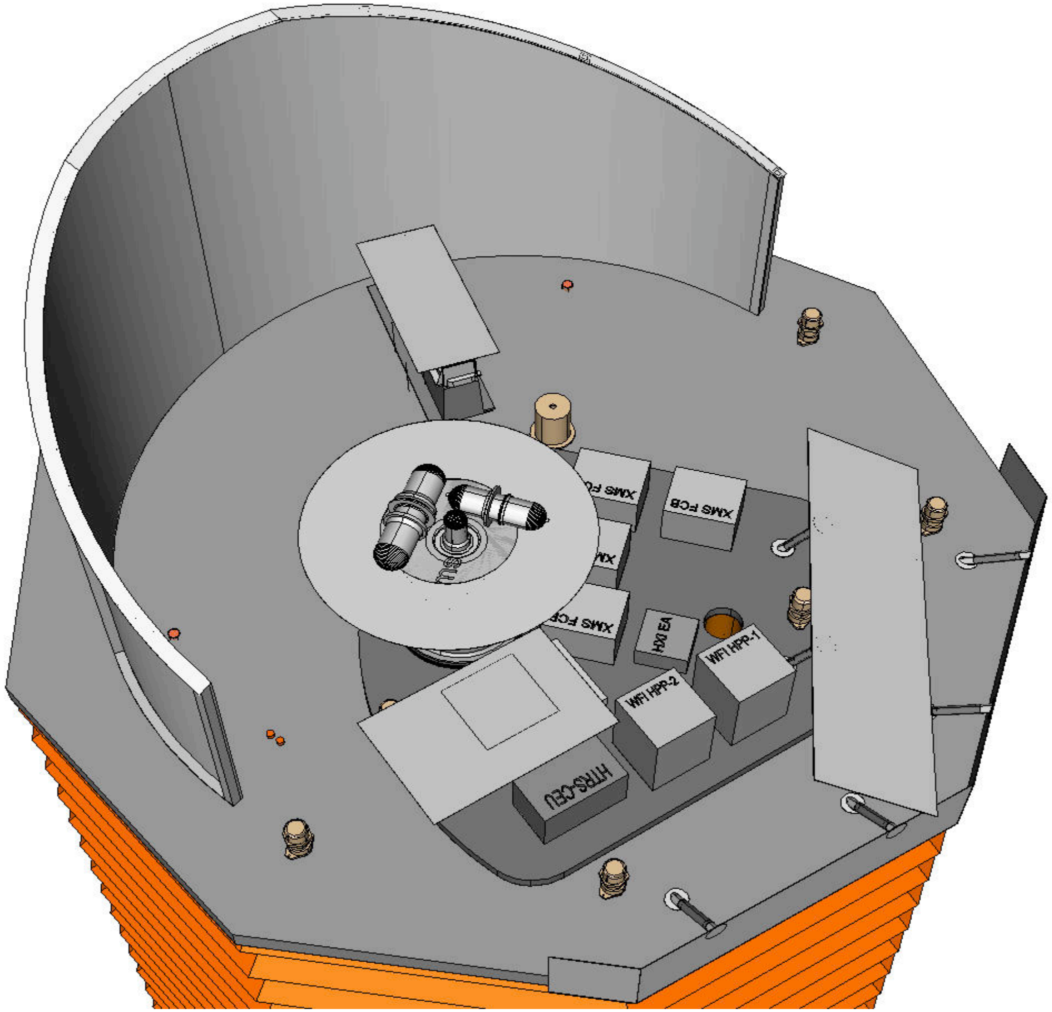
- Effective area 3 m^2 @ 1.25 keV, 0.65 m^2 at 6 keV with a goal of 1 m^2. 150 cm^2 (goal 350 cm^2) at 30 keV
- 5 arc sec HEW spatial resolution with a 20 m focal length

Instruments

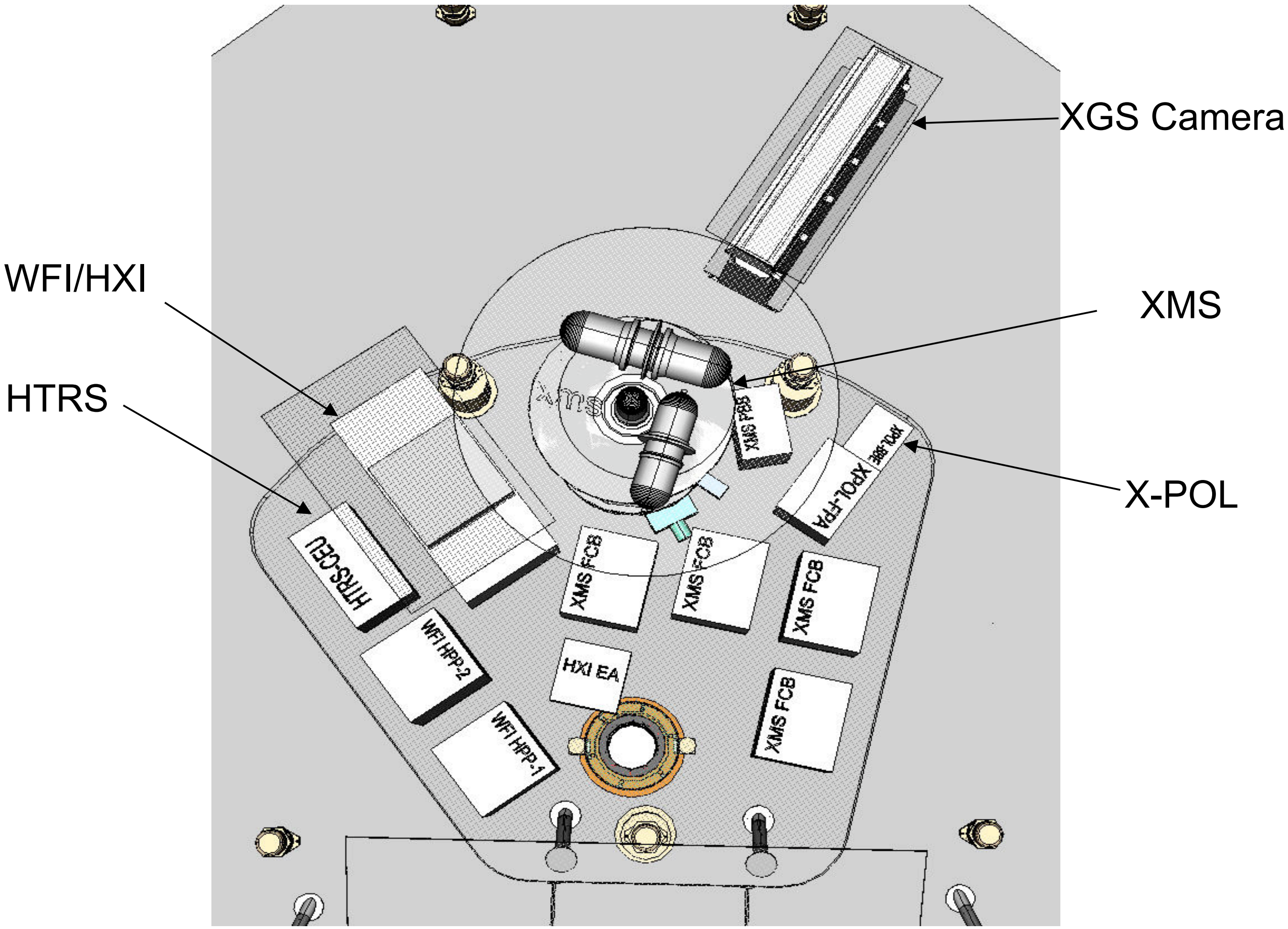
- X-ray Microcalorimeter Spectrometer (XMS)
  - 0.3 to 7 keV with 2.5 eV over 2 arc min and 10 eV over 5 arc min FOV
- Wide Field Imager (WFI)/Hard X-ray Imager (HXI)
  - 0.1 to 15 keV with <150 eV & 18 arc min FOV
  - HXI extends band pass to 40 keV
- X-ray Grating Spectrometer (XGS)
  - Dispersive from 0.3 to 1 keV with R ~ 3000, 1000 cm^2 area with a goal of 3000 cm^2
- X-ray Polarimeter (XPOL)
  - Gas Imaging Pixel Detector
- High Time Resolution Spectrometer (HTRS)
  - Bright source capability



Instrument Module

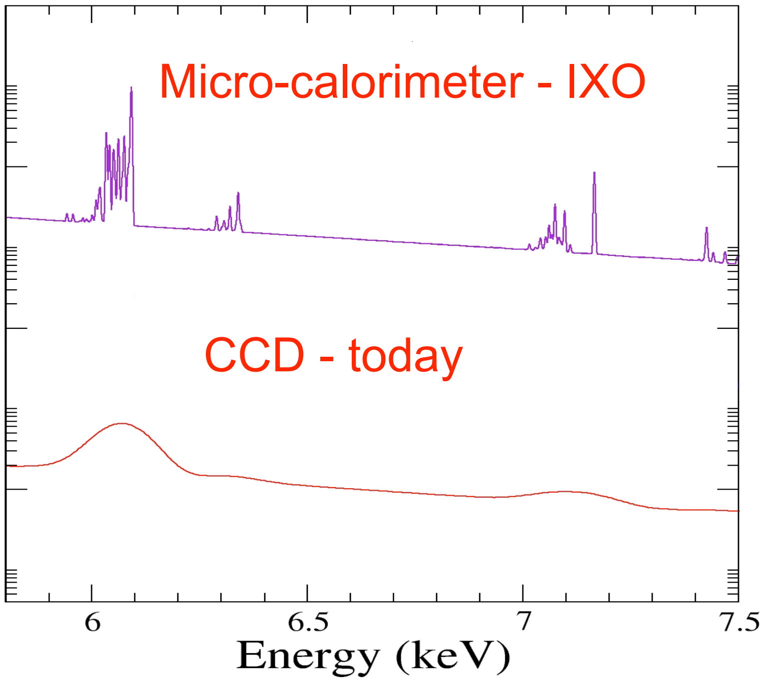


Instrument Layout

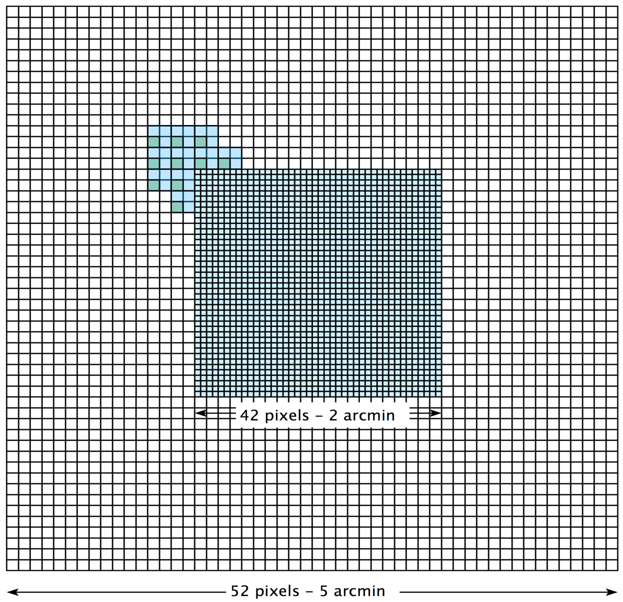


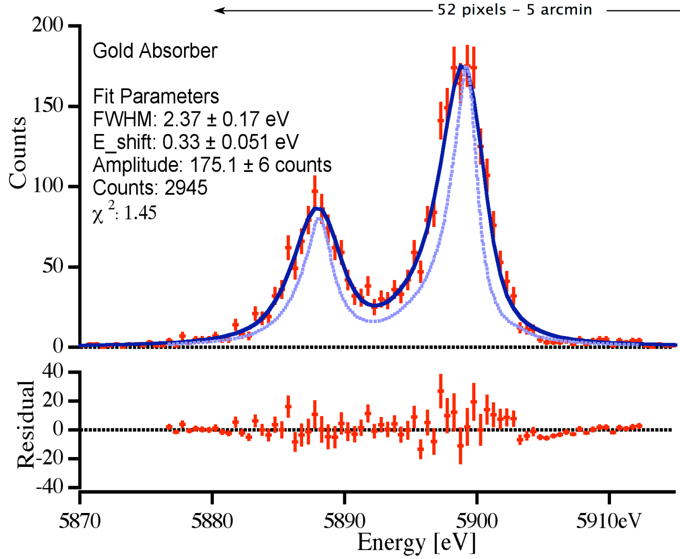
X-ray Micro-calorimeter Spectrometer (XMS)

- Thermal detection of individual X-ray photons
  - High spectral resolution
  - ΔE very nearly constant with E
  - High intrinsic quantum efficiency
  - Imaging detectors



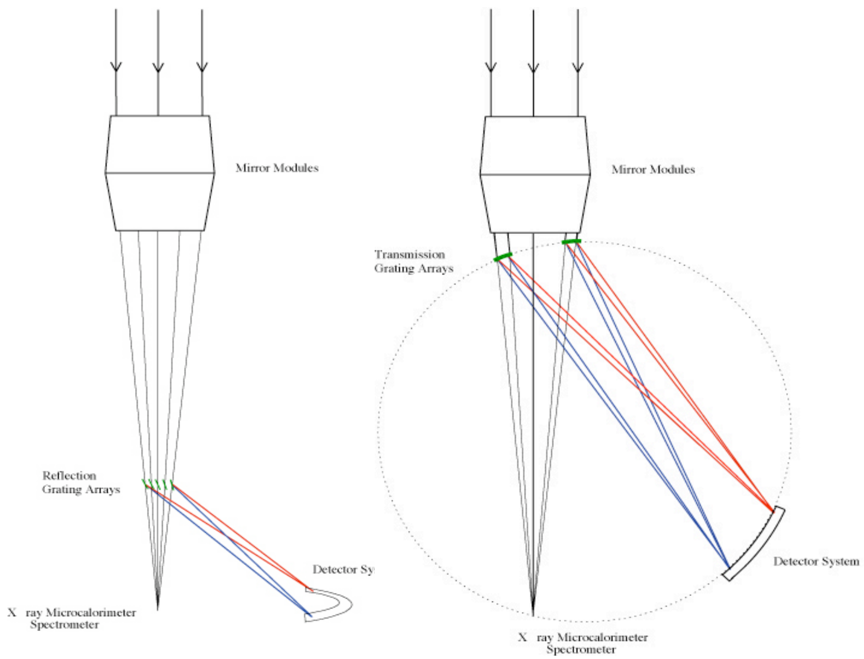
Suggested XMS array for 20m f/l confguration



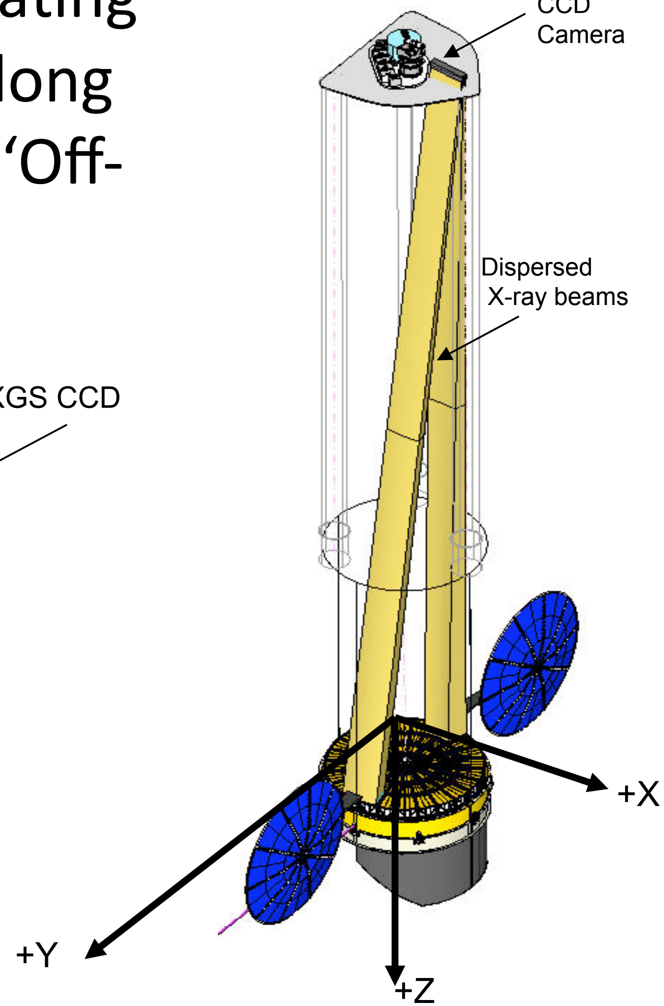


XGS Gratings

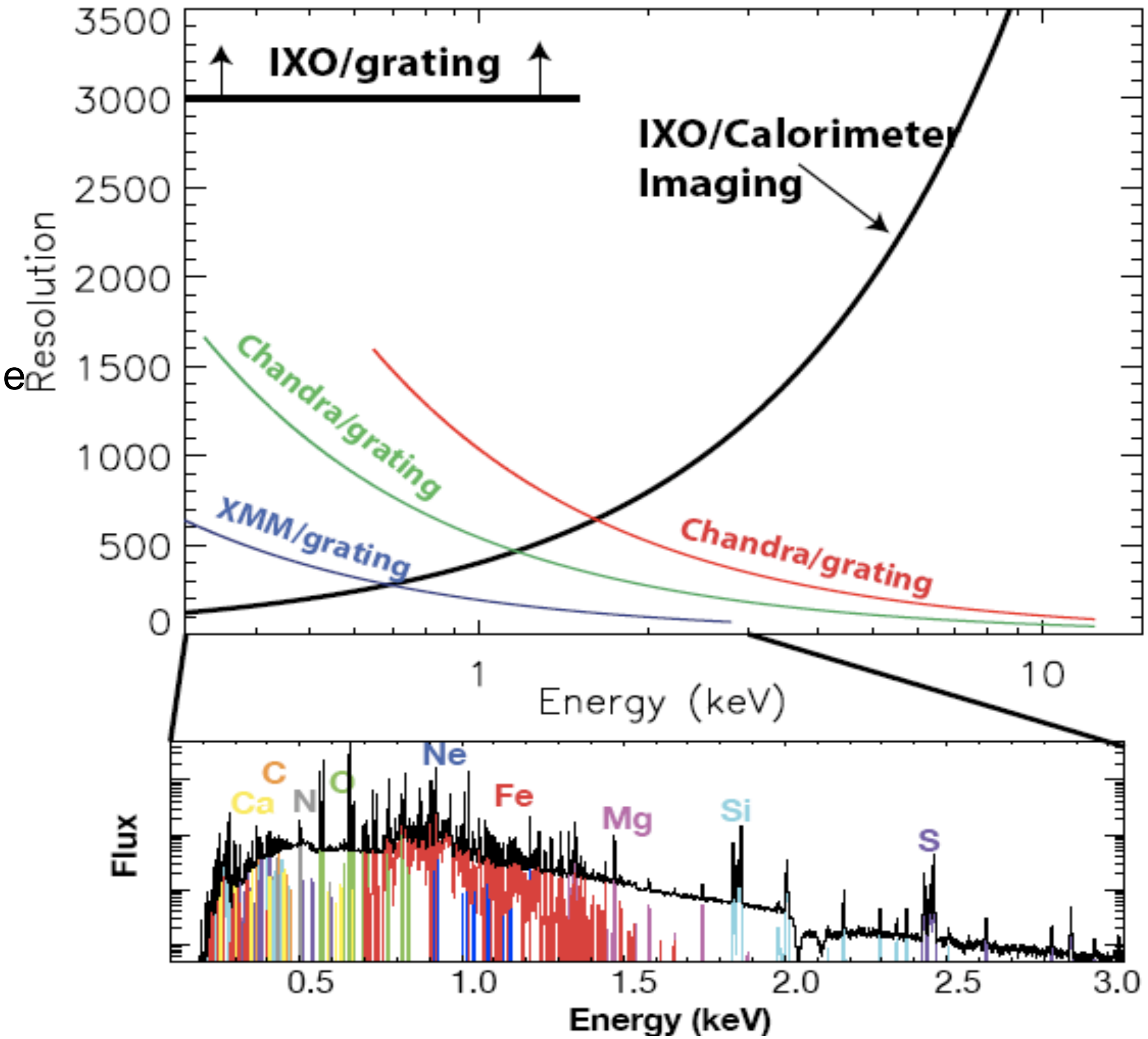
- The accommodation of 2 (deployable?) grating arrays mounted beneath the mirrors, or along the tube 'Critical Angle Transmission' and 'Off-plane reflection gratings' is being studied



XGS CCD



Spectral Capability



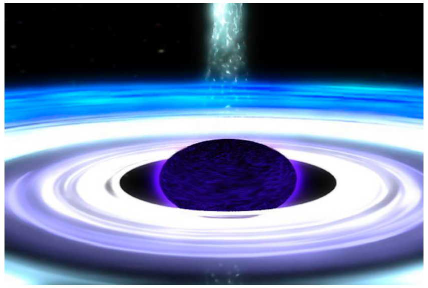
The IXO energy band contains the K-line transitions of 25 elements Carbon through Zinc allowing simultaneous direct abundance determinations using line-to-continuum ratios, plasma diagnostics and at iron K bulk velocities of 200 km/s

Key Performance Requirements

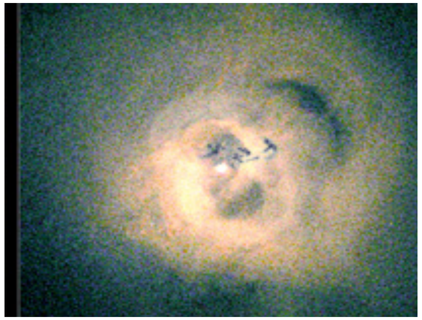
Mirror Effective Area	3 m^2 @1.25 keV 0.65 m^2 @ 6 keV with a goal of 1 m^2 150 cm^2 @ 30 keV with a goal of 350 cm^2	Black hole evolution, large scale structure, cosmic feedback, Strong gravity, EOS Cosmic acceleration, strong gravity
Spectral Resolution (FWHM)	ΔE = 2.5 eV within 2 x 2 arc min (0.3 – 7 keV) . ΔE = 10 eV within 5 x 5 arc min (0.3 - 7 keV) ΔE =150 eV at 6 keV within 18 arc min diameter (0.1 - 15 keV) $E/\Delta E$ = 3000 (0.3–1 keV) with an area of 1,000 cm^2 and a goal of 3000 cm^2 for point sources ΔE = 1 keV within 8 x 8 arc min (10 – 40 keV)	Black Hole evolution, Large scale structure Missing baryons using tens of background AGN
Angular Resolution	≤5 arc sec HPD (0.1 – 7 keV) 30 arc sec HPD (7 - 40 keV); goal of 5 arc sec	Large scale structure, cosmic feedback, black hole evolution, missing baryons
Count Rate	1 Crab with >90% throughput. ΔE < 150 eV @ 6 keV (0.1 – 15 keV)	Strong gravity, EOS
Polarimetry	1% MDP on 1 mCrab,100 ksec, 3σ, 2 - 6 keV	AGN geometry, strong gravity
Astrometry	1 arcsec at 3σ confidence	Black hole evolution
Absolute Timing	50 μsec	Neutron star studies

Main Science Topics

- Black Holes and Matter under Extreme Conditions

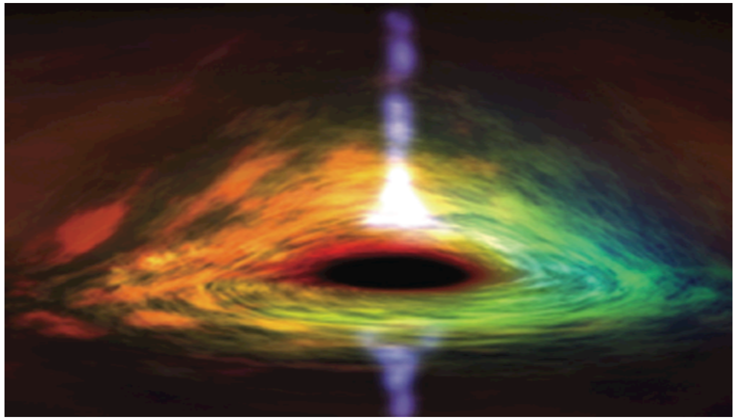


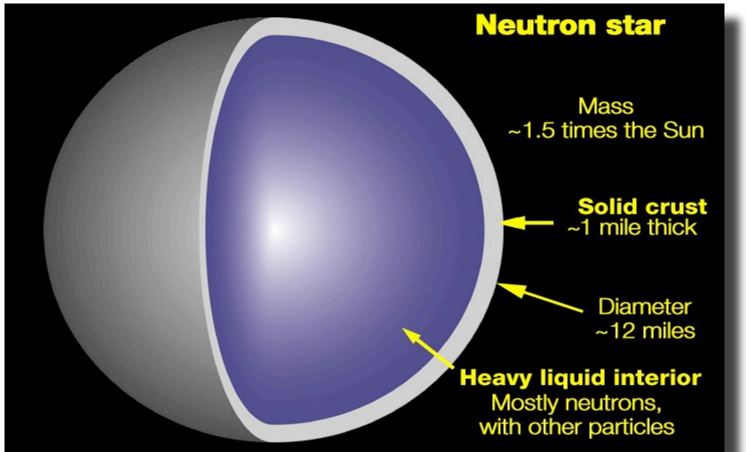
- Formation and Evolution of Galaxies, Clusters, and Large Scale Structure



- Life Cycles of Matter and Energy

Black Holes and Matter under Extreme Conditions



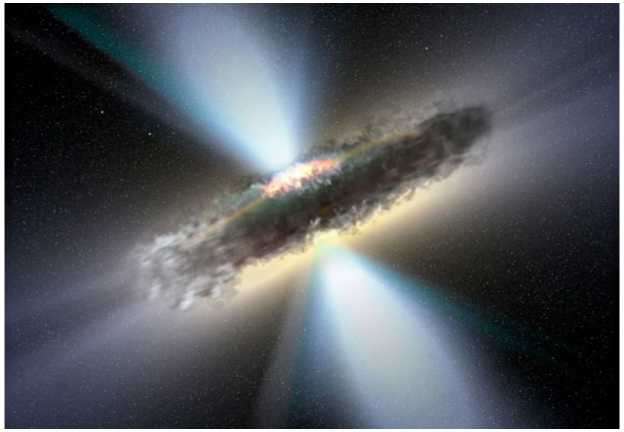


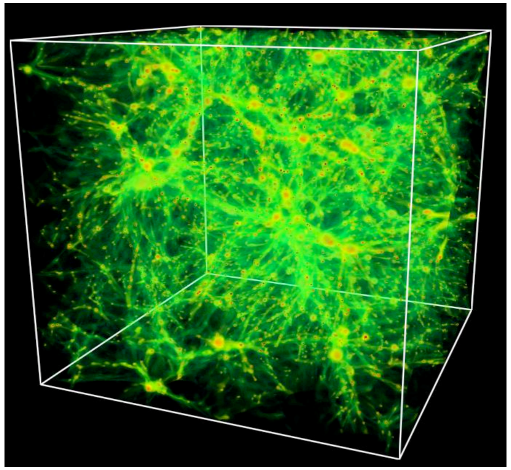
How do super-massive Black Holes grow? Does this change over cosmic time?

Does matter orbiting close to a Black Hole event horizon follow the predictions of General Relativity?

What is the Equation of State of matter in Neutron Stars?

Formation and Evolution of Galaxies, Clusters, and Large Scale Structure



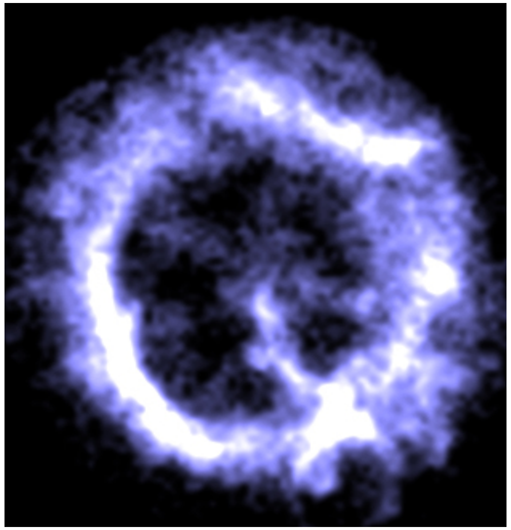


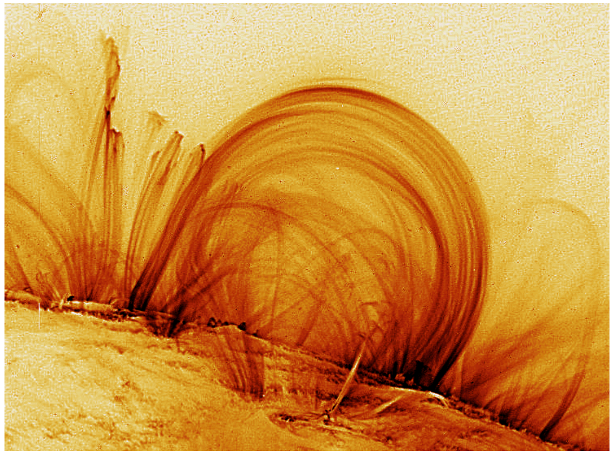
How does Cosmic Feedback work and influence galaxy formation?

How does galaxy cluster evolution constrain the nature of Dark Matter and Dark Energy?

Where are the missing baryons in the nearby Universe?

Life Cycles of Matter and Energy





When and how were the elements created and dispersed?

How do high energy processes affect planetary formation and habitability?

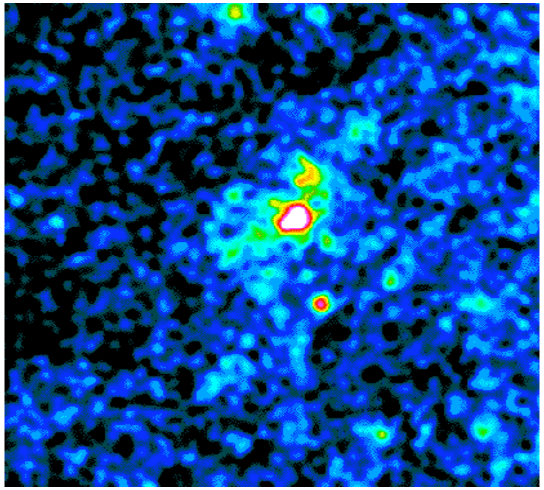
How do magnetic fields shape stellar exteriors and the surrounding environment?

Science Drivers for IXO Spectroscopy

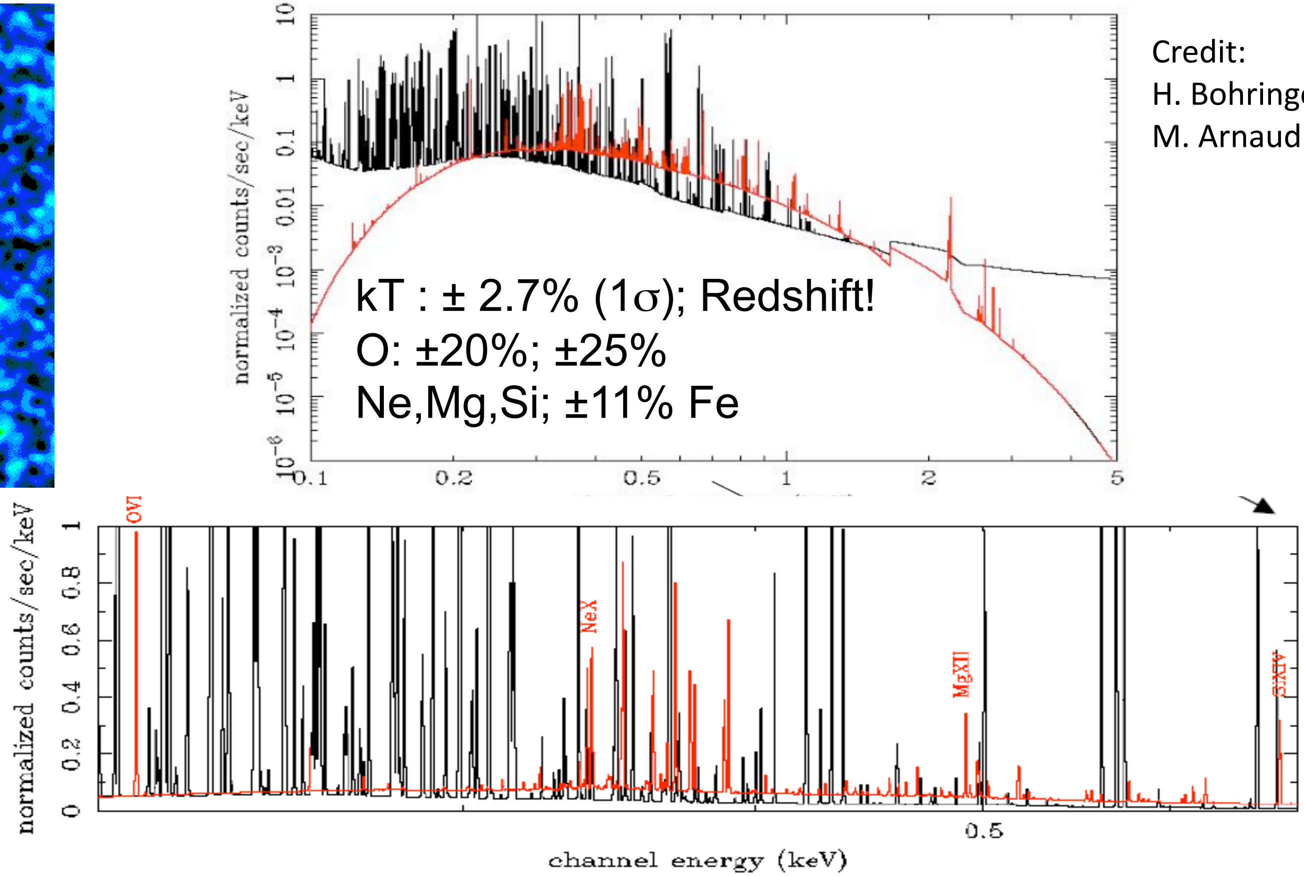
Astrophysical research in many wavebands emphasizes the value of spectroscopy at, or near, the line resolution – the Doppler width of O VIII at 1-2 x10^6 K is 40-80 km/s (FWHM). R=3000 gives 100 km/s – approaching the ideal situation.

- The Intergalactic Medium (WHIM)
- Galactic Halos and Local Group galaxies
- Neutron Stars and Black Holes & AGNs
- Interstellar Medium (hot-phase, winds)
- Stars (coronae and atmospheres)
- Extragalactic halos (feedback)
- Solar system and Interplanetary Medium

The First Clusters and Groups



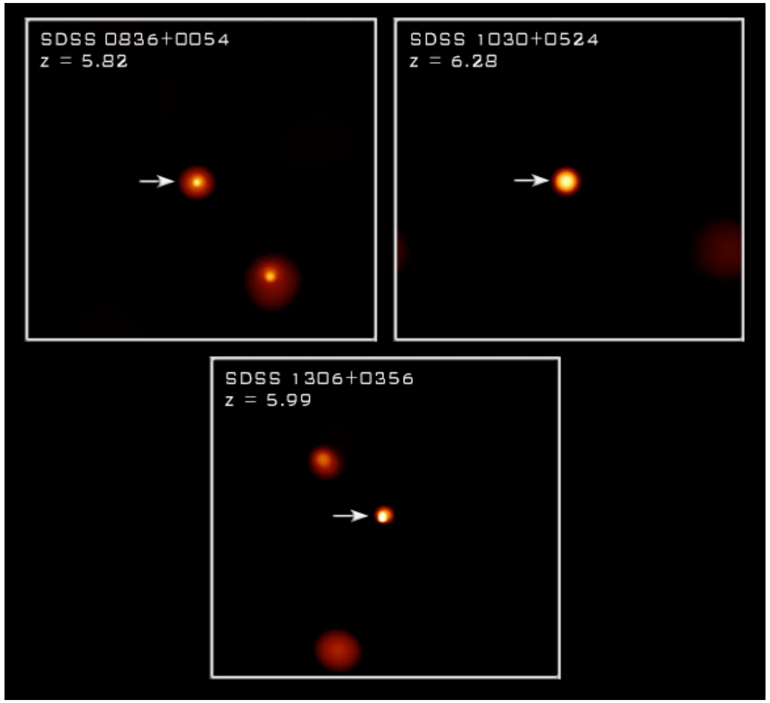
2 keV, log L_{bol}=43.7
z=2, 300 ksec



Credit:
H. Bohringer +
M. Arnaud

IXO will detect and study the first and most distant groups of galaxies formed in the Universe, precursors of today's massive clusters.

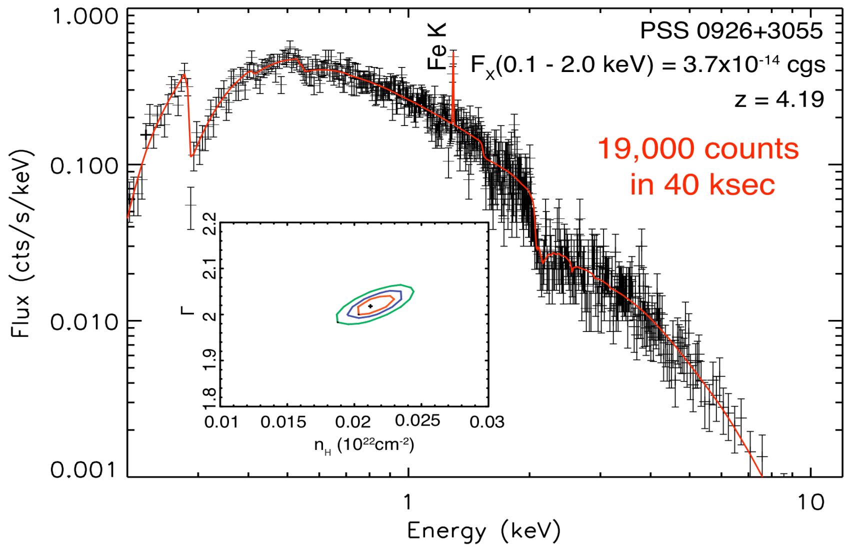
How do AGN evolve at high redshift?



Chandra has detected X-ray emission from ~100 quasars at z > 4

Flux is beyond grasp of XMM-Newton and Chandra high resolution spectrometers, but well within the capabilities of IXO

IXO Simulation (40 ks)

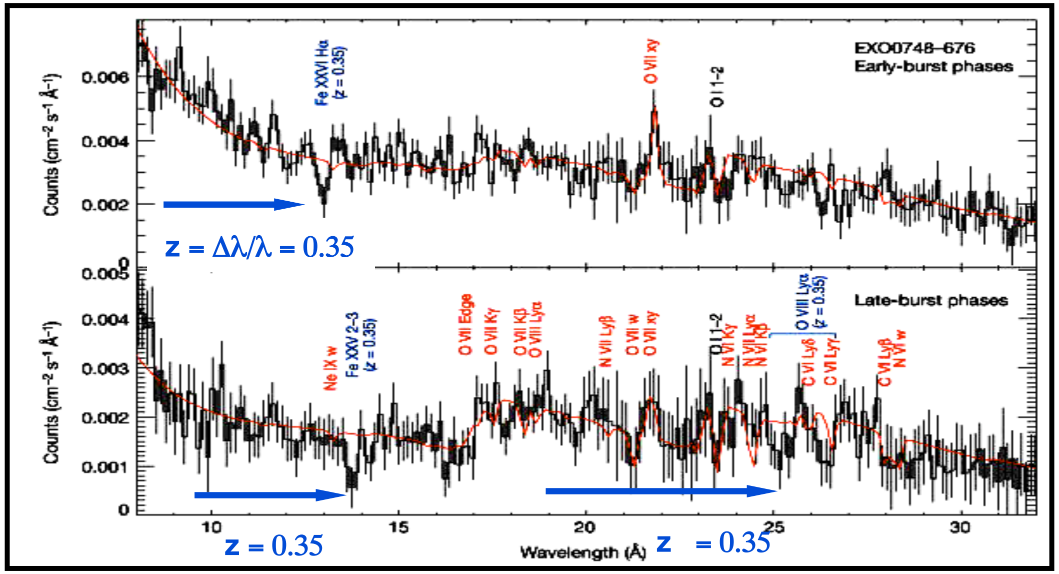


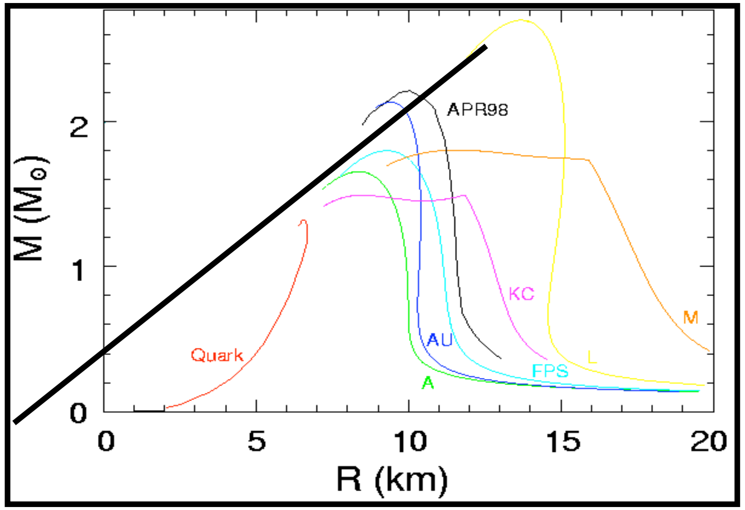
X-ray spectra can give:

- redshifts!
- disk ionization
- constraint of L/L_{Edd}

Neutron Star Equation of State

XMM-Newton has detected the gravitational redshift in the surface of a neutron star (Cottam et al. 2002)

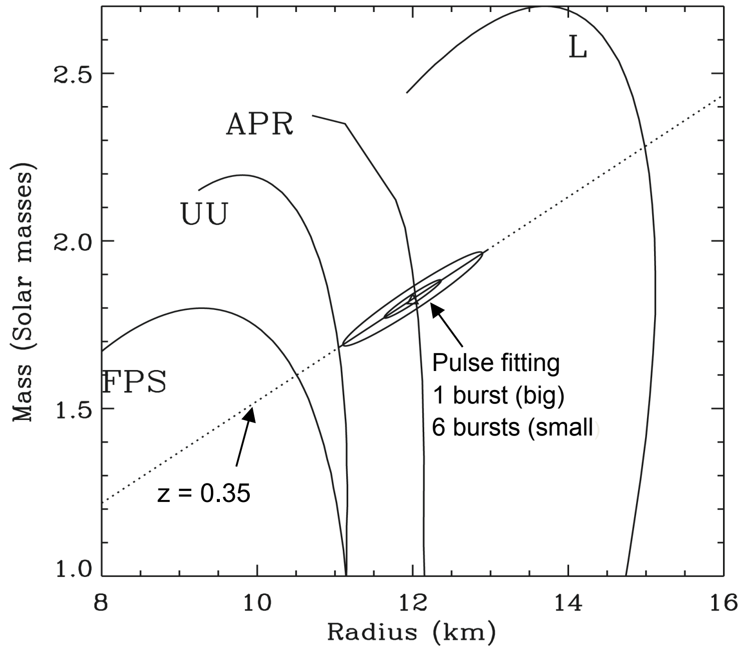




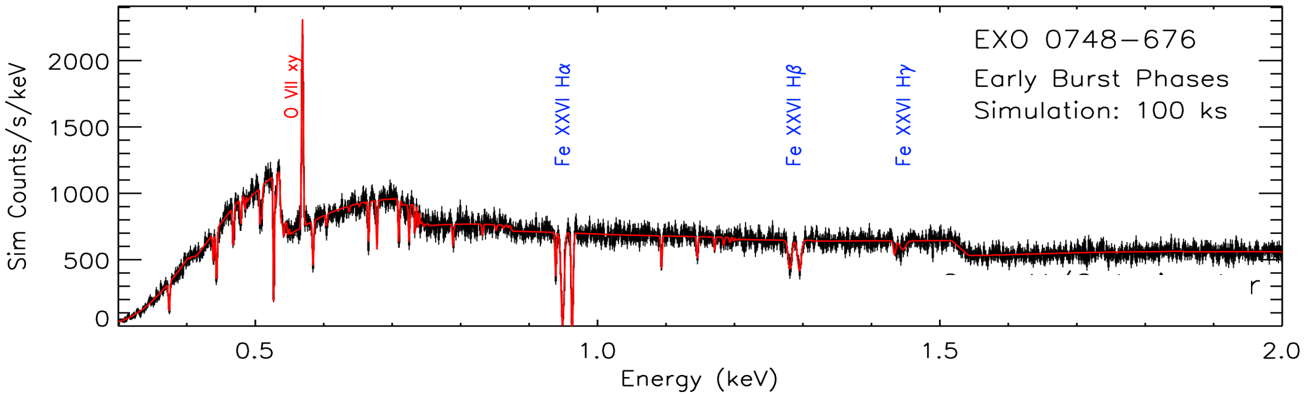
What is the Neutron Star Equation of State?

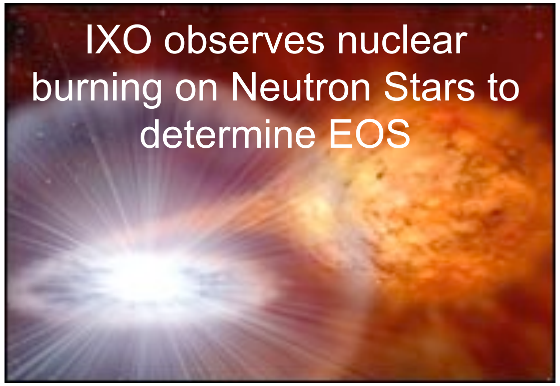
IXO will provide many high S/N measurements of X-ray burst absorption spectra:

- Measure of gravitational red-shift at the surface of the star for multiple sources, constrains M/R
- Absorption line widths constrain R to 5-10%.
- Pulse shapes of coherent oscillations on the rise of the burst can provide an independent measure of mass and radius to a few percent

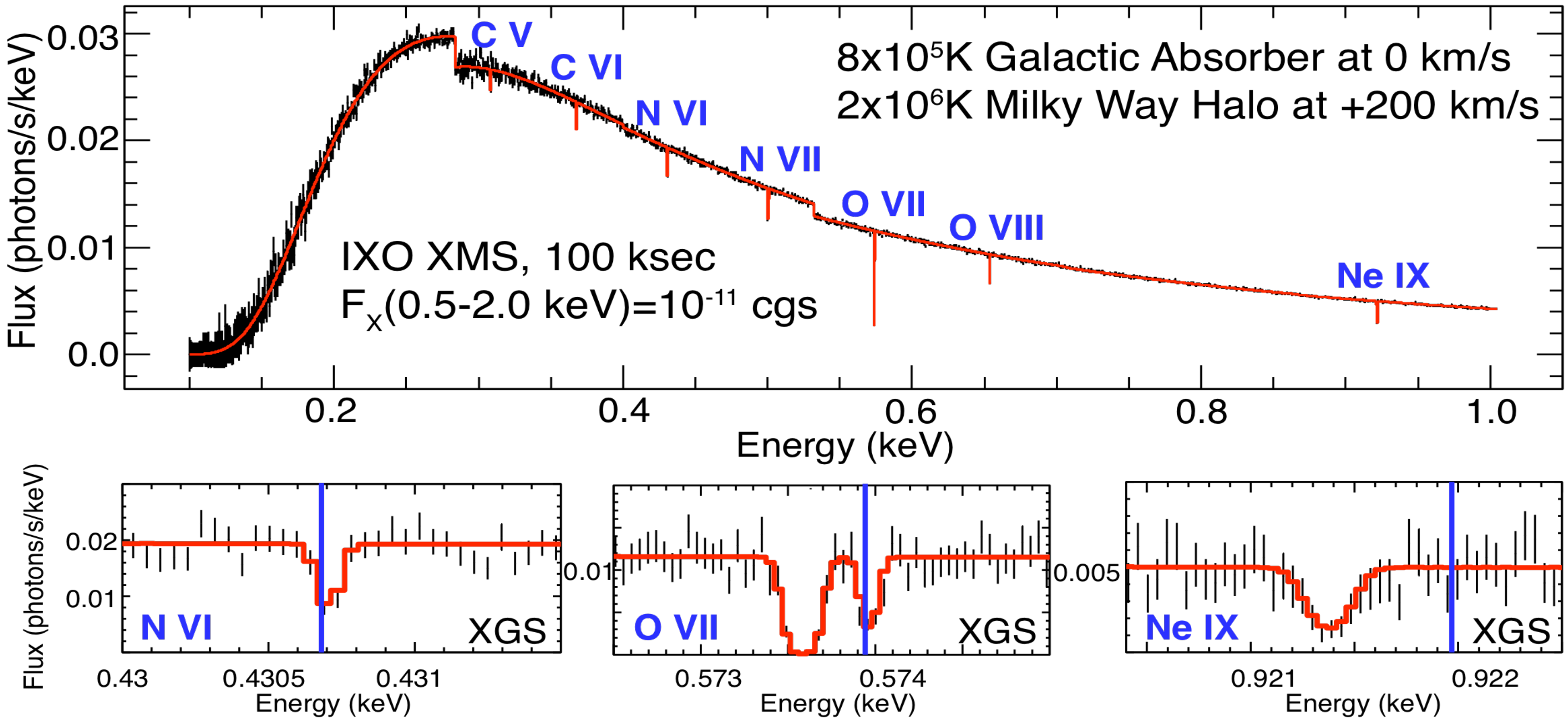


Cottam et al (astro-ph/0211126), Strohmayer (astro-ph/0401465)





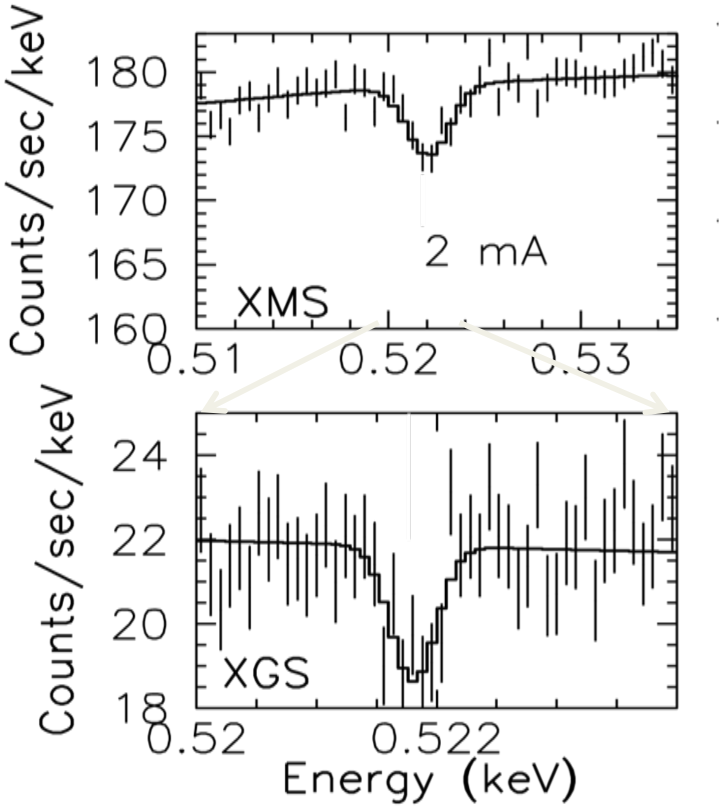
The Missing Baryons – Local Group

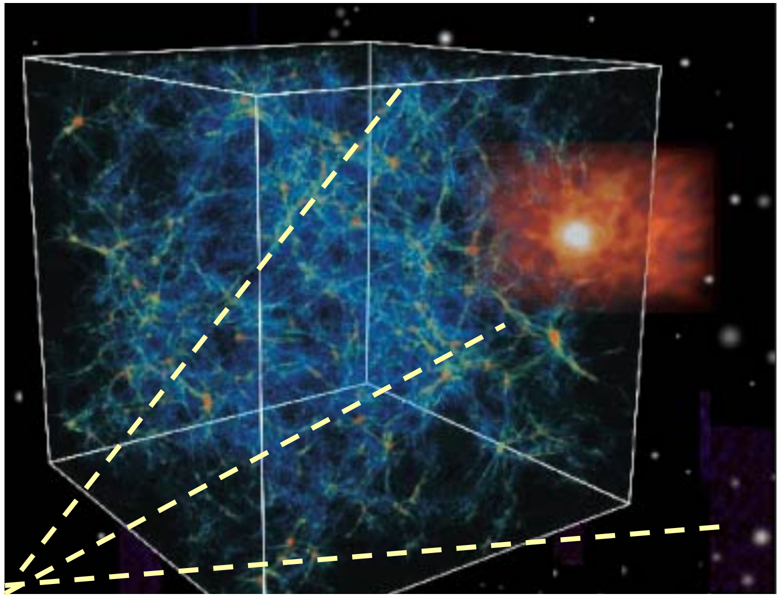


Absorption detected in 9 sightlines at >3σ with XMM-Newton/Chandra - proof of concept (mean EW 20 Å). Need 100 sightlines with 100 km/s for dynamics

Are the missing baryons in the local Universe in the Cosmic Web and if so, how were they heated and infused with metals?

40% of the Baryons in the local Universe are predicted to be caught in a hot plasma trapped in the warm-hot intergalactic medium (WHIM)





IXO will detect ionized gas in the hot IGM medium via OVII absorption lines in spectra of many background AGN to detect the missing Baryons and characterize them

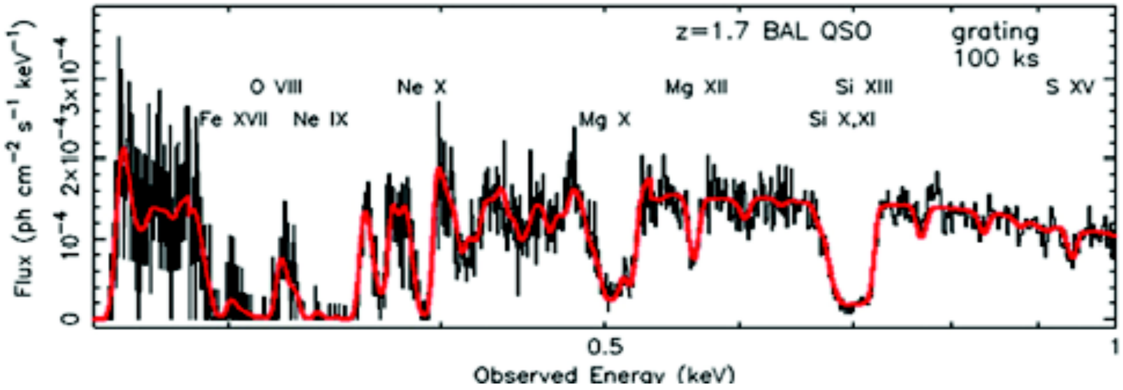
How does Cosmic Feedback work and influence galaxy formation?

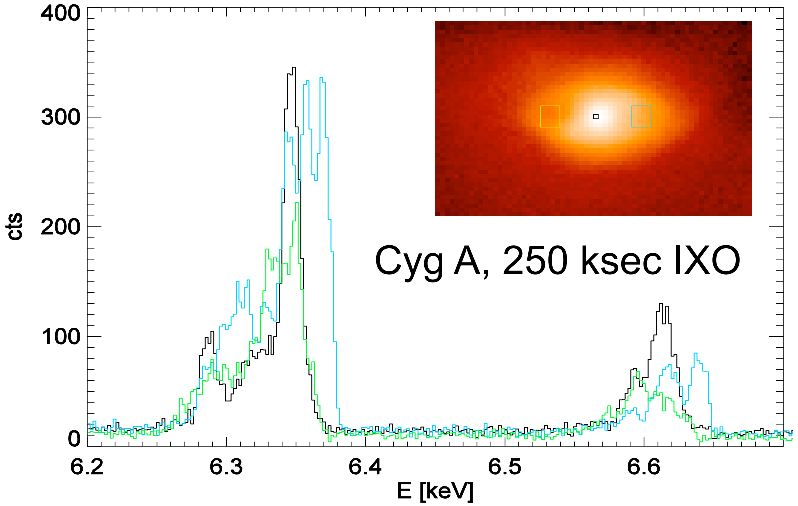
Large scale-structure simulations require AGN feedback to regulate the growth of galaxies and galaxy clusters

Velocity measurements crucial to determine heating and state of Intra-cluster medium

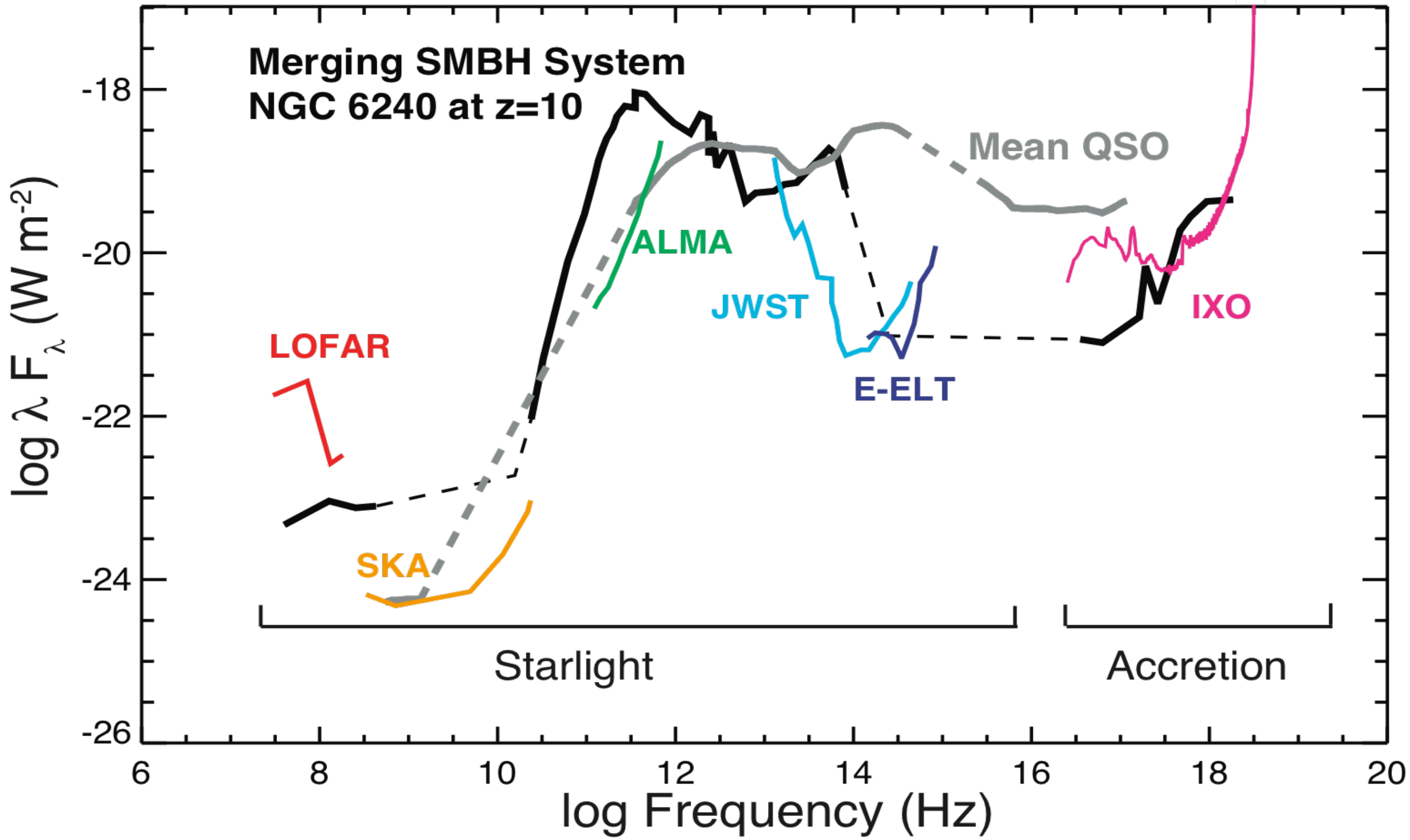
IXO will probe the hot ICM/IGM through velocity measurements to the required ~100 km/s and determine mass outflows in quasars with winds

IXO simulation of BAL QSO (S.Gallagher, UWO)





SMBH's at high redshift with IXO



In order for IXO to happen, we need the support of the **whole** astronomical community – IXO science has to appeal across many wavebands.

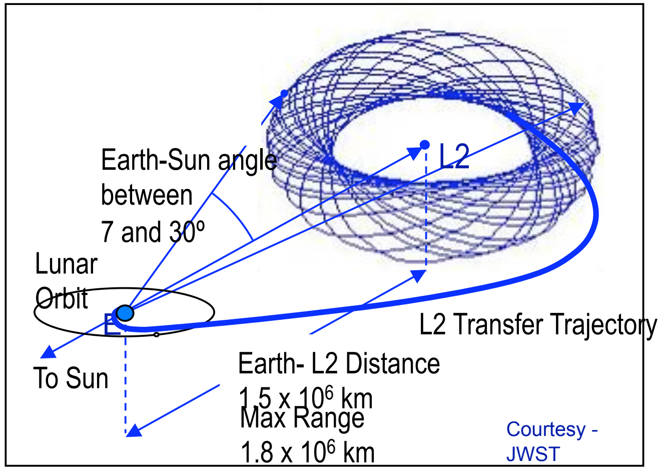
Mission Concept

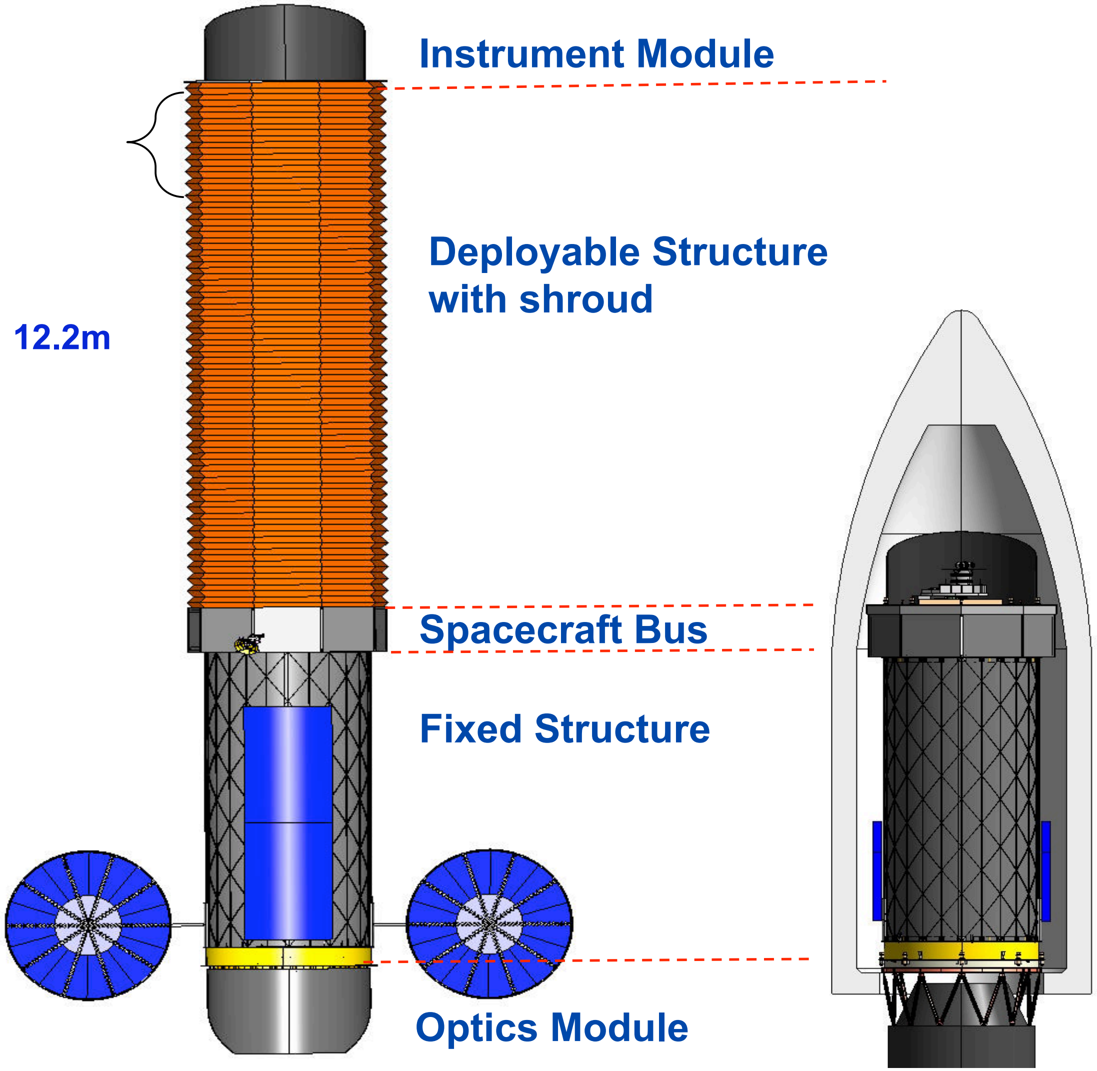
Key Attributes:

- Atlas 551 or Ariane V launch to L2 halo orbit. 5 year lifetime, with consumables for 10 years. ±20 deg Sun angle range. On-target ToO response within 24 hours.
- 1.5 hours down-link per day during routine operations.
- Mission concept has been elaborated in the NASA MDL and ESA CDF facilities
- Both studies came to the same conclusion: **the mission is feasible** and mass limited (for either launcher) with the strawman payload and a mirror area of 3 m^2 at 1 keV.
- Optics technology is the key – hence the two parallel tracks with slumped glass and Silicon. ESA is investing significant funds in demonstrating the 5” performance requirement in the next 2 years.

NASA Mission Design

- The observatory is deployed to achieve 20 m focal length
- Observatory Mass 6100 kg (including 30% contingency)
- Launch on an Atlas V 551 or Ariane V
- Direct launch into an 800,000 km semi-major axis L2 orbit

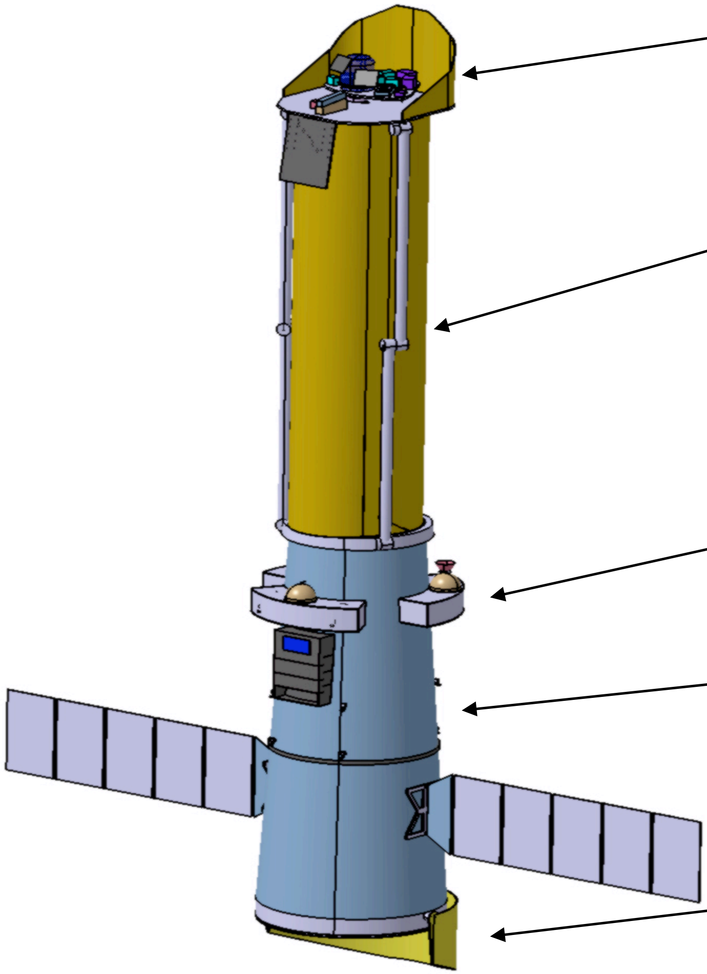




Deployed IXO Configuration

Stowed IXO Configuration

ESA Mission Design



Instrument module

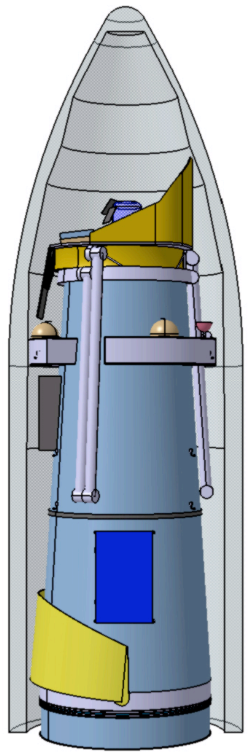
Optical bench deployment
mechanism

(+ deployable shroud)

Service module

Fixed conical optical bench

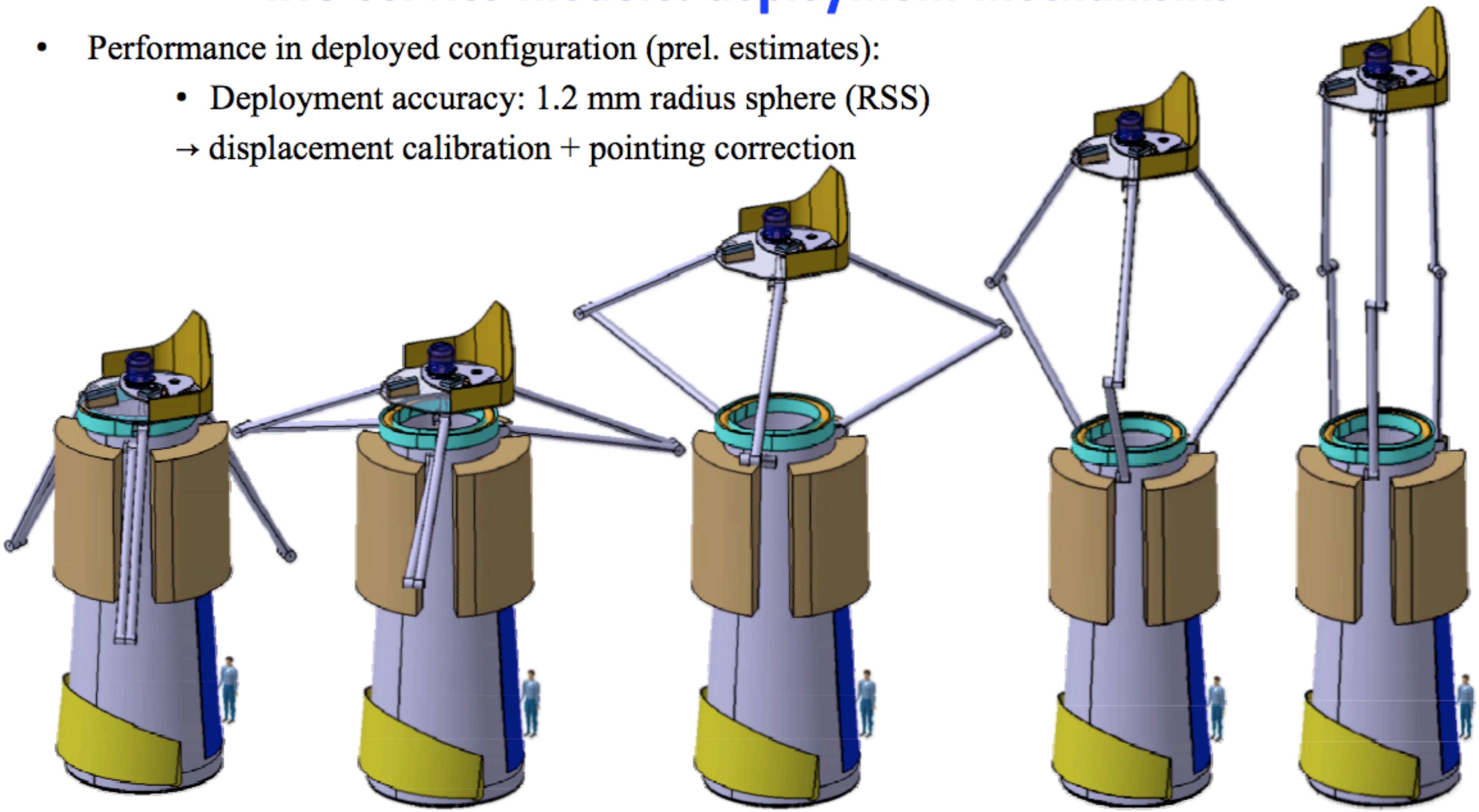
Deployable Sun shield



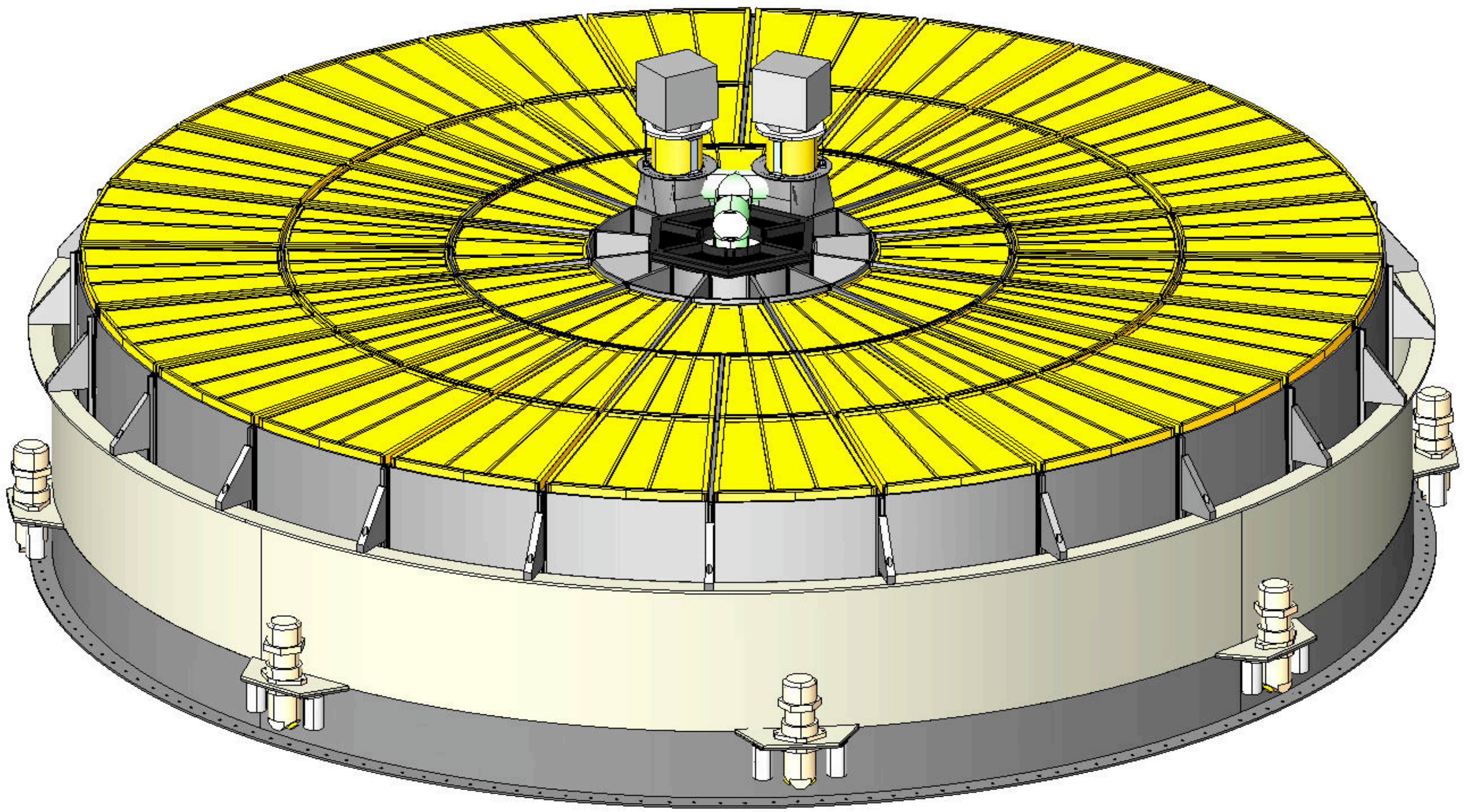
IXO service module: deployment mechanisms

- Performance in deployed configuration (prel. estimates):
  - Deployment accuracy: 1.2 mm radius sphere (RSS)

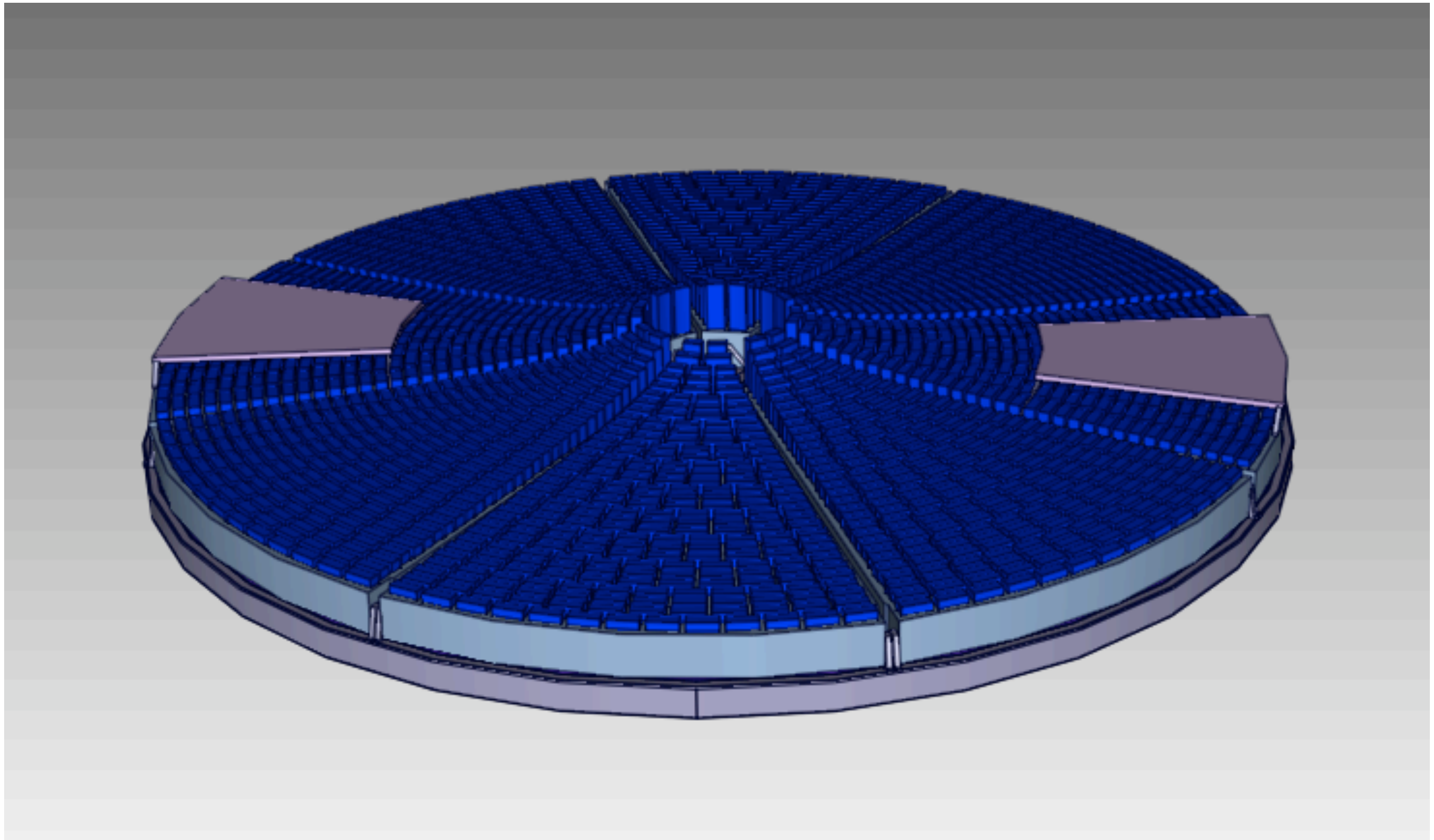
  → displacement calibration + pointing correction



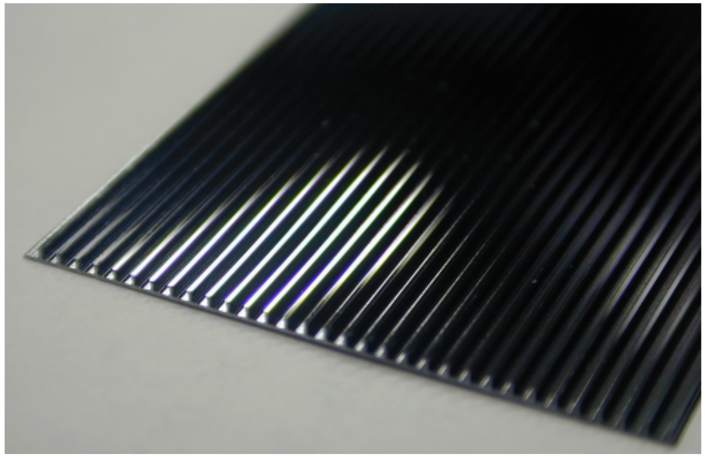
Optics Module – NASA Design

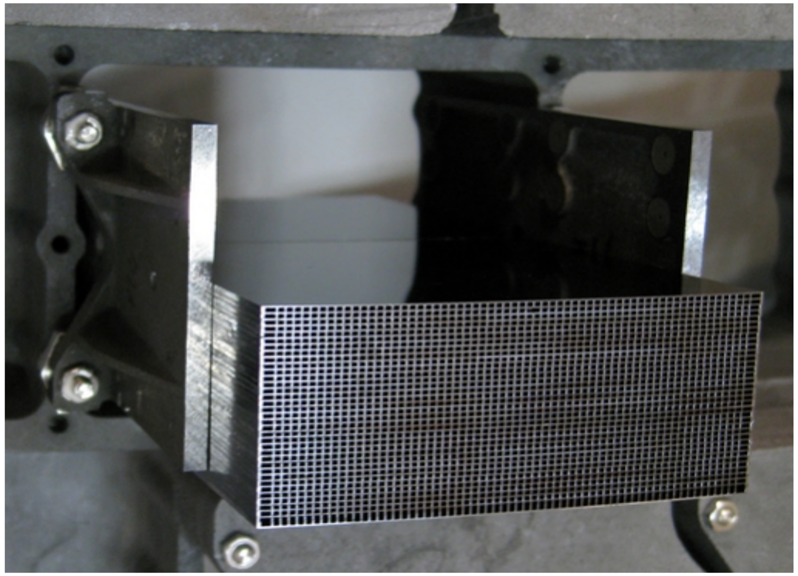


Optics Module – ESA Design



Silicon Pore Optics





- Uses commercial high-quality 12” silicon wafers
  - plane-parallel <0.6 μm over 300 mm
  - large-scale production so cheap
  - Wafers are diced, wedged, ribbed, coated, Si bonded (stacked) and then integrated to produce basic Wolter I approximation optics element
- Current Performance
  - Previous generation stacks have been tested in Panter and Bessy facilities. Best result was 17” on bottom 4 plates.
- Next Steps
  - Awaiting results of testing first stacks produced by the new stacking robot. Steps to reach 5” have been identified and technology plan put into place

Current Status

- XEUS was selected by ESA's Cosmic Vision Process as one of three L class missions to compete for one potential launch slot in 2020. L class budget is 650 M€ (+ national contributions)
- Joint IXO Steering Committee and Science, Instrument and Telescope WGs established. Membership posted on the ESA and NASA IXO websites.
- Which agency will eventually lead the mission has not been discussed – will be decided at HQ level.
- The IXO mission concept and science case has been submitted to the US Astro2010 Decadal Review. 15 White Papers on the science. Currently working on the next step – the production of a 20 page mission summary.

The Next Steps

- In the ESA system, IXO is competing for the first Large Cosmic Vision slot (L1) together with LISA and a mission to Jupiter.
- (Parallel) industrial system studies are expected to start in mid-2009. The next (3 => 2) ESA down-selection will start after completion (Q4 of 2010).
- US Decadal results are also expected mid-2010. IXO must do well as this will set the scene for the ESA selection.
- Two selected missions will undergo Definition Studies before final selection in 2012. Instrument AO release expected at the end of 2011.
- International partnerships decisions/agreements in late 2012.
- Selection of mirror technology and placing of industrial contract for the optics (critical path) by end 2013.

IXO Study Team

IXO Study Coordination Group
ESA Chair: A.N Parmar
NASA Chair: N.E. White
JAXA Chair: H. Kunieda

IXO Science Definition Team
ESA Chair: X. Barcons (ES)
NASA Chair: J. Bregman
JAXA Chair: T. Ohashi

IXO Instrument Working Group
ESA Chair: P. de Korte (NL)
NASA Chair: J. Nousek
JAXA Chair: H. Tsunemi

IXO Telescope Working Group
ESA Chair: R. Willingale (UK)
NASA Chair: R. Petre
JAXA Chair: H. Kunieda

IXO Science Associates (~300)

IXO Study Coordination Group

Members	Europe	Japan	US
Study Scientists	Arvind Parmar (co-chair)	Hideyo Kunieda (co-chair)	Nick White (co-chair)
Study Managers	Philippe Gondoin	Tadayasu Dotani	Jean Grady
HQ Representatives	Fabio Favata	Tadayuki Takahashi	Michael Salamon
Agency appointed Community Scientists	Didier Barret (F)	Takeshi Tsuru	Mark Bautz
	Paul Nandra (UK)	Kazuhisa Mitsuda	Joel Bregman
	Luigi Piro (I)	Takaya Ohashi	Jay Bookbinder
	Lothar Strüder (D)		Kathy Flanagan

Mailing List: ixo-scg@imperial.ac.uk

How Can I Get Involved?

Find out more by going to one of the IXO websites such as:
http://ixo.gsfc.nasa.gov/

Response matrices and background files are available.

See what IXO can do in your area of science. And then get involved by becoming an IXO Science Associate: contact aparmar@rssd.esa.int in Europe

Around 130 European Science Associates who get informed about latest IXO developments and work with the Science Definition Team on promoting and refining the science case for IXO.

Summary

- IXO has replaced the previous Constellation-X and XEUS studies following an inter-agency agreement to proceed with a single large International X-ray Observatory which will provide a factor 10-100 increase in capability
- The science case is very powerful and addresses key and topical questions
- The technology development is proceeding well
- We are on track to submit a very strong proposal to the US Decadal Survey and ESA Cosmic Visions process.
- However, the competition is strong and we will need the broad support of the astronomical community if we are to be the large Cosmic Vision mission in 2020.