XEUS: X-ray Evolving Universe Spectroscopy

1. Introduction
2. Cosmic Vision ESA's 2015-2025 long-term space plan
3. The current XEUS mission concept and capabilities
4. XEUS optics status
5. Spectroscopy with XEUS

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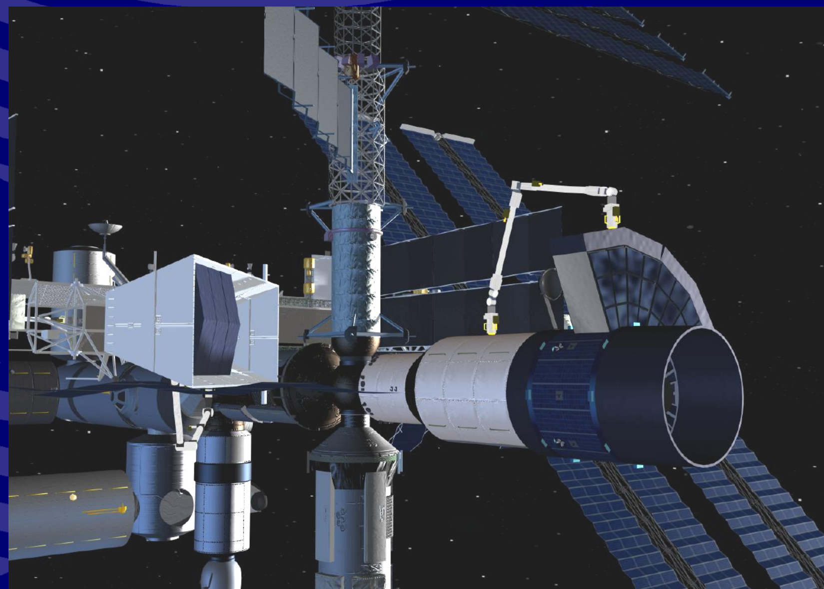
XEUS: X-ray Evolving Universe Spectroscopy

- Original XEUS concept was a 6 m^2 optic in LEO which was enlarged to 30 m^2 by robotic assembly at the ISS
- Two free flying spacecraft separated by 50 m focal length
- Optics based on XMM-Newton nickel technology
- Required Ariane V, Proton and STS launches and the ISS…..



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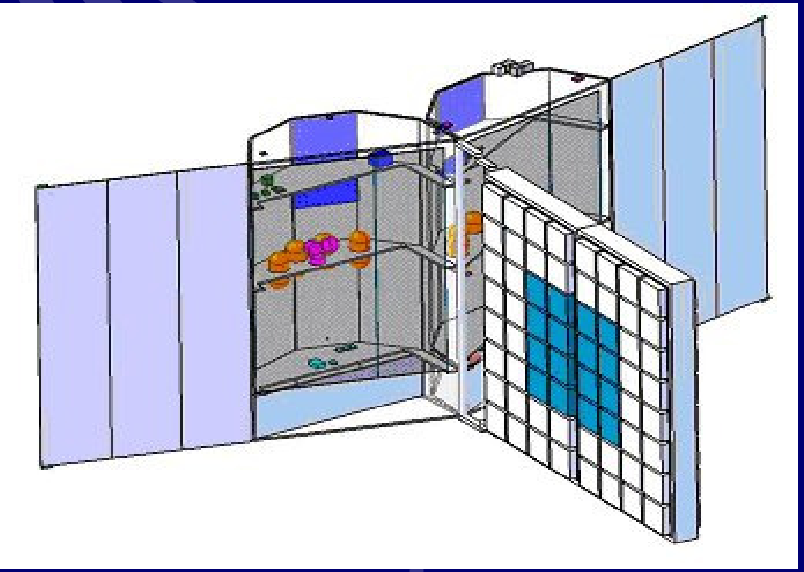
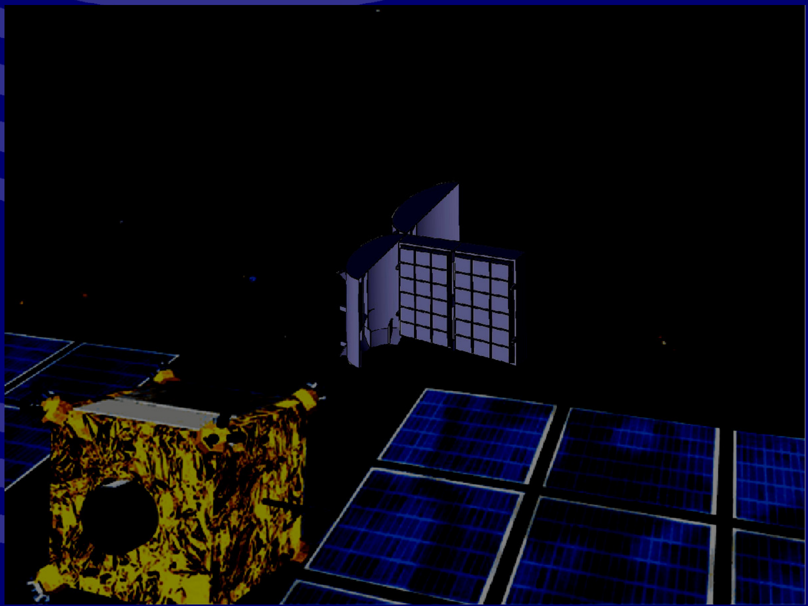
XEUS: X-ray Evolving Universe Spectroscopy

- In 2003 September, the XEUS Steering Committee recommended that ESA investigate non-ISS mission scenarios for XEUS.
- Timely recommendation due to emergence of a new ESA developed light-weight Si HPO mirror technology.
- Move away from ISS prompted US interest in a joint observatory class mission.
- Second XEUS concept was a joint ESA/NASA/JAXA mission with a 10 m^2 optic at L2 with a NASA provided Delta IV H launch (9.2 tonne to L2). Complete payload.





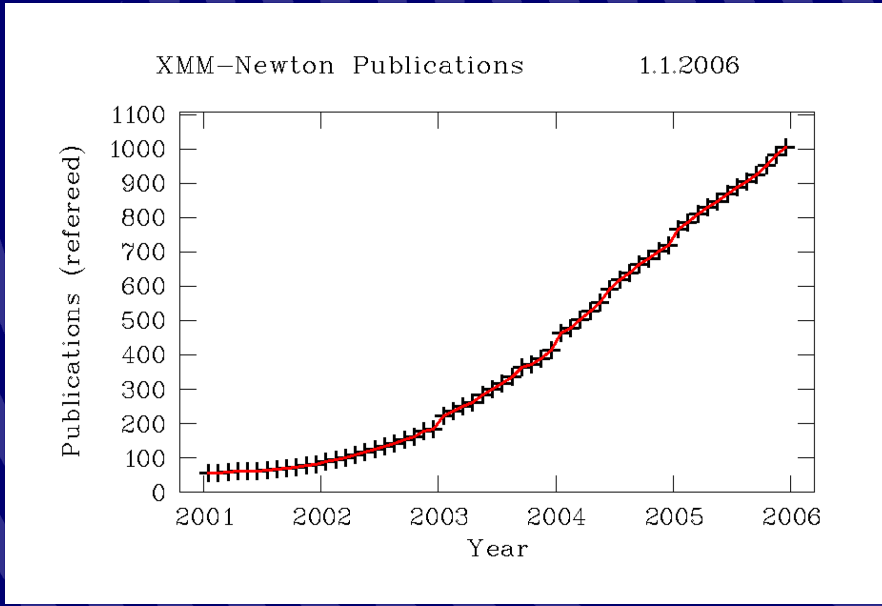
XEUS: X-ray Evolving Universe Spectroscopy

- XEUS is has always been a collaborative mission between ESA and ISAS-JAXA
- Unfortunately, the US decided to suspend collaboration, forcing a revision of the mission concept. This is necessary because Europe and Japan probably cannot afford the 10 m^2 mission studied jointly with NASA.
- This has resulted in a more cost-effective solution based around an Ariane V ECA launch (6.6 tonne to L2).
- Mission selection will be via ESA's Cosmic Vision 2015-2025 process.

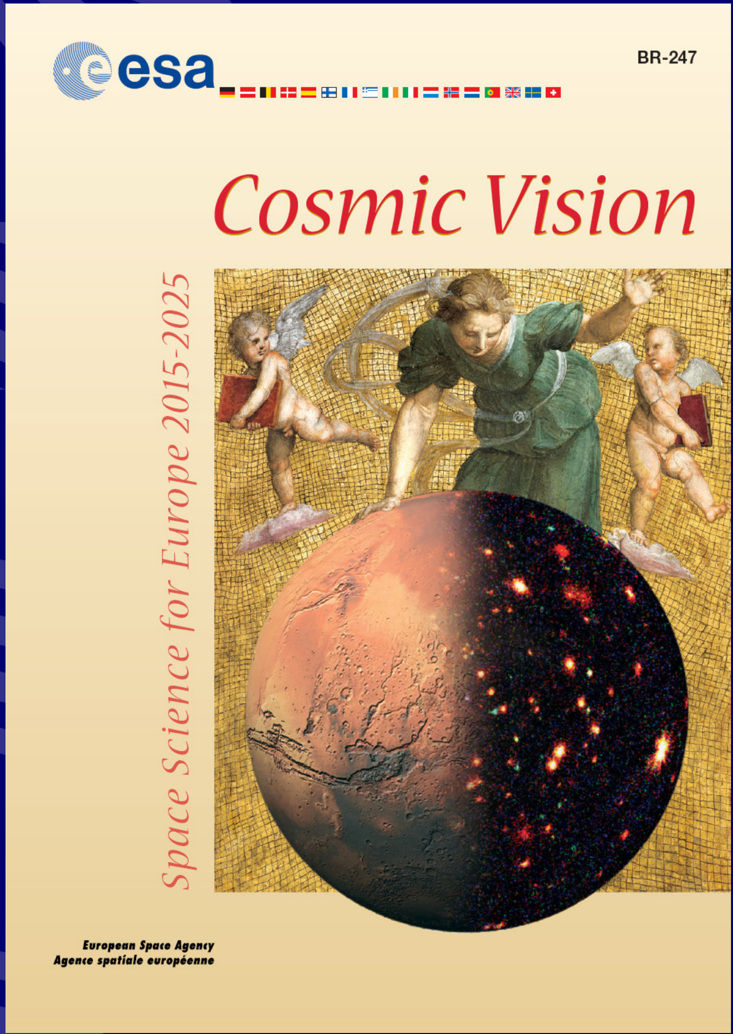
XEUS – Cosmic Vision

- Cosmic Vision is ESA's long-term science plan for 2015-2025 and follows previous Horizon 2000 (1984) and Horizon 2000+ plans (1994).
- 151 replies were received in response to ESA's call for themes issued in April 2004. Twice as many as with Horizon 2000.
- XEUS science features very prominently in the replies and has been very highly ranked by the ESA Science Advisory Structure.

XEUS – Cosmic Vision

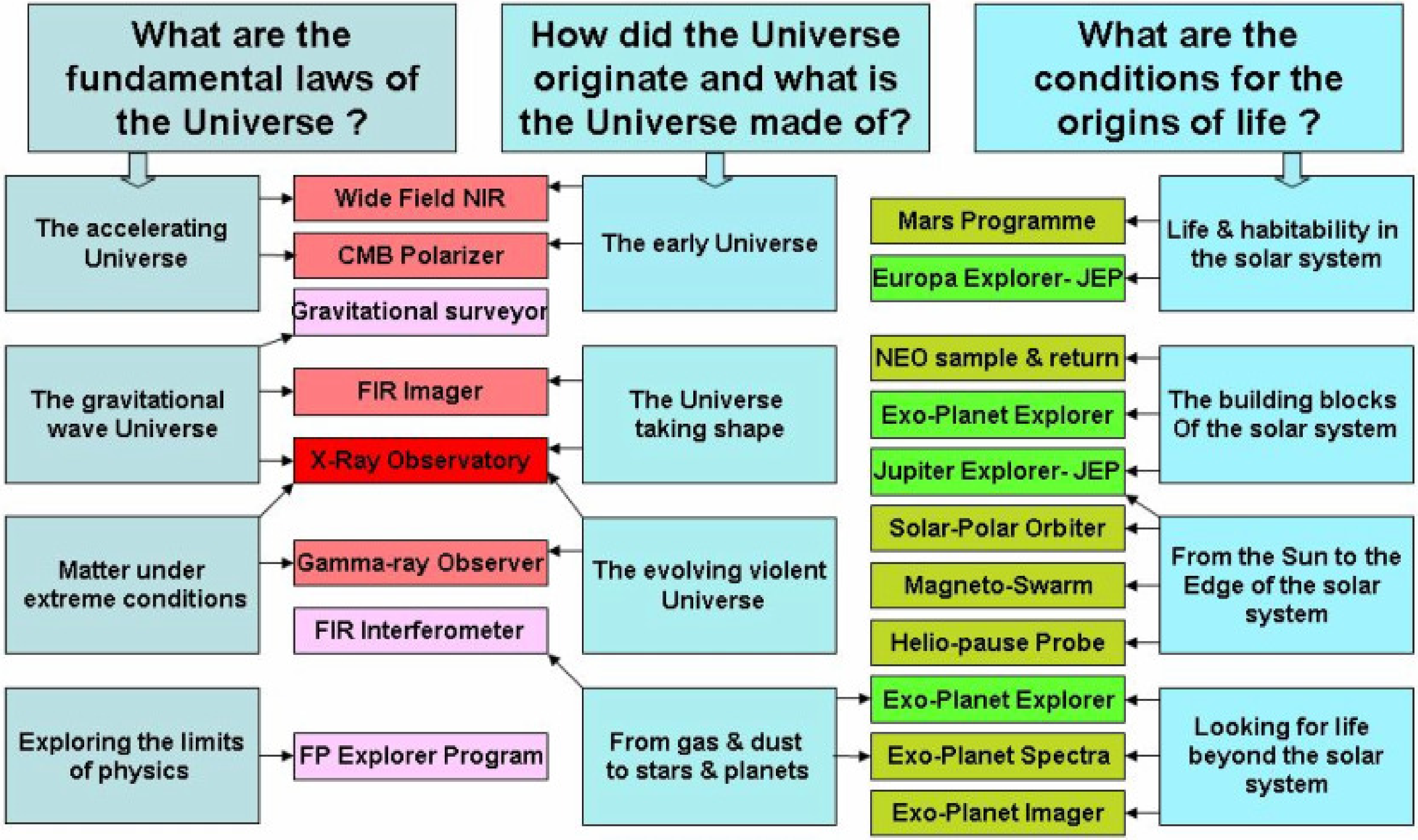


N. Schartel



- The ESA Science Advisory Structure has identified 3 overriding science questions with supporting themes and candidate mission areas.
- See ESA brochure BR-247

XEUS – Cosmic Vision



XEUS – Cosmic Vision

- The call for mission proposals is expected in May, (after the next SPC meeting) with responses due around the 3rd quarter of 2006.
- The AO will probably be for two missions of around 1 and 2 annual budgets (~400 or 800 M€). XEUS is clearly the latter!
- Selection of 4-5 missions for Assessment, followed by down selection to 2-3 missions for Definition (A/B1) with technology development funds made available for the second (larger mission).
- The challenge is to define a mission within this cost to that fullfils the science requirements defined by the community.

XEUS – Key Science Requirements (Goals)

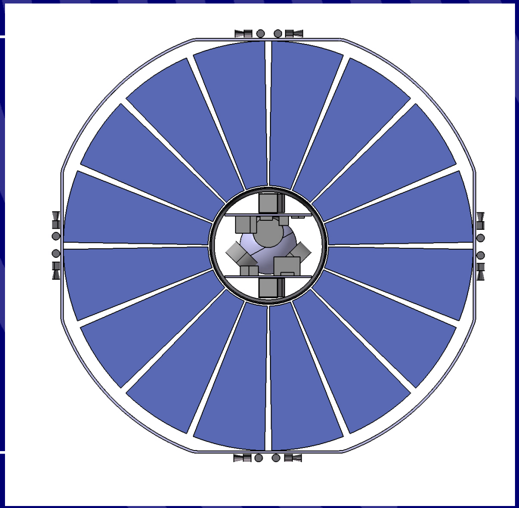
Effective area:	5 m^2 @ 1 keV
	2 m^2 @ 6 keV
	0.1 m^2 @ 40 keV (goal)
Sensitivity:	4×10^{-18} erg cm^{-2} s^{-1} (0.2-10 keV)
Fields of view:	7' x 7'
	30" x 30" (1.7' x 1.7' high-priority goal)
Angular resolution:	5'' (2" goal) HPD
Spectral resolution:	2 eV @ 0.5 keV (small FOV)
	6 eV @ 6 keV (small FOV)
	150 eV @ 6 keV (large FOV)
Energy range:	0.1 - 10 keV (40 keV, goal)
Time resolution:	10 μs (goal)

XEUS – Mission Concept

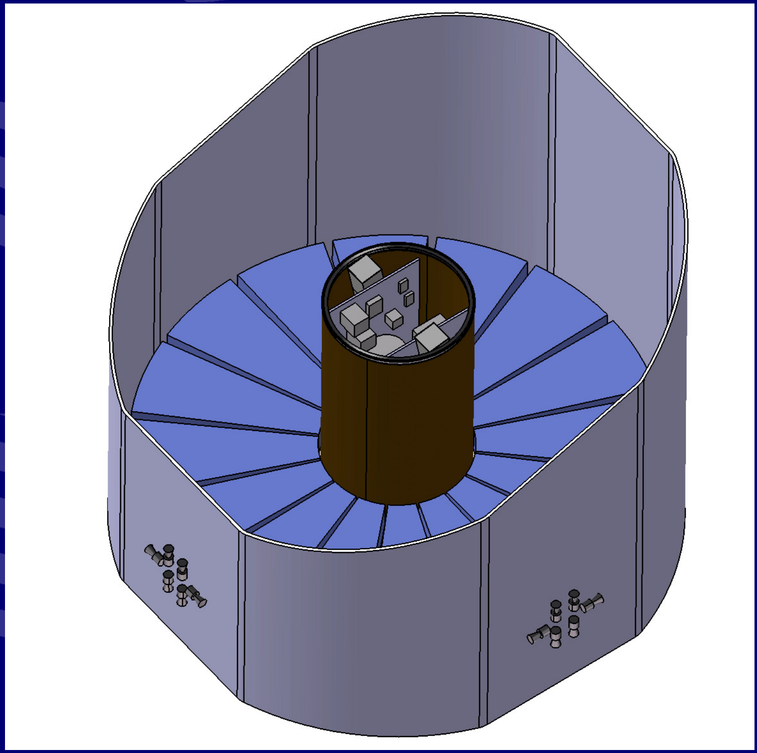
- Baseline launcher is now an Ariane V ECA – 6.6 tonne into an L2 transfer orbit.
- The deployable optical bench has been replaced by a fixed cylindrical optic. Allows simpler baffling and better thermal control as well as lower weight.
- Focal length reduced from 50 to 35 m.
- Baseline instruments are now wide- and narrow-field imagers. Accommodation of other high-priority instruments is being studied too.

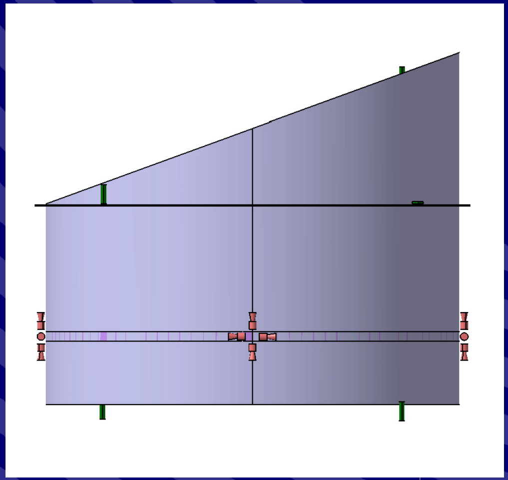
XEUS – Mission Concept

D = 4.20 m
(Rout = 2.10 m)



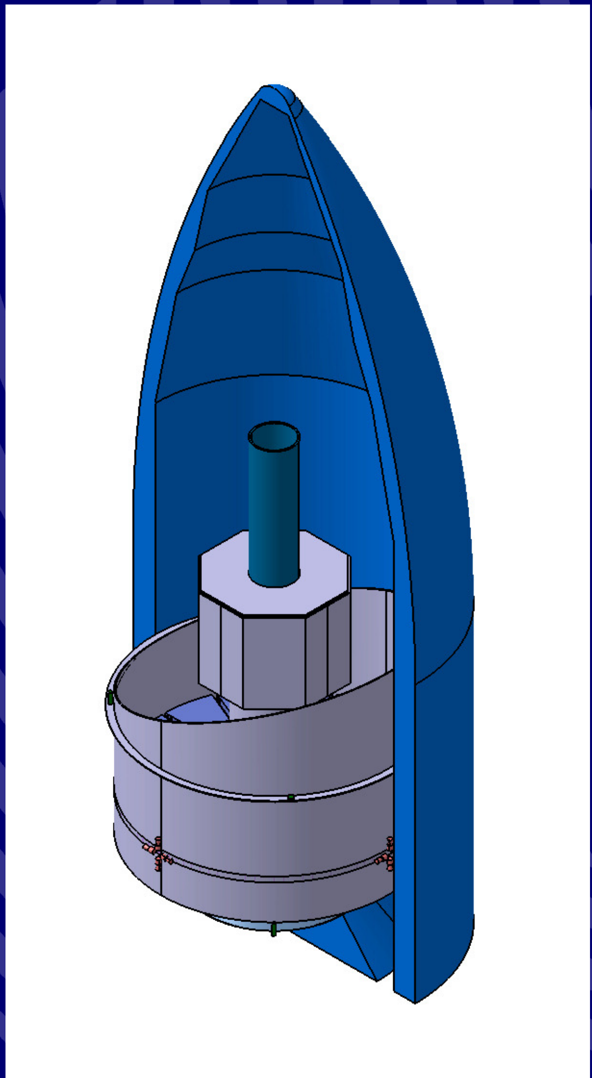
Skirt = 0.15 m
(cuts @ thrusters)



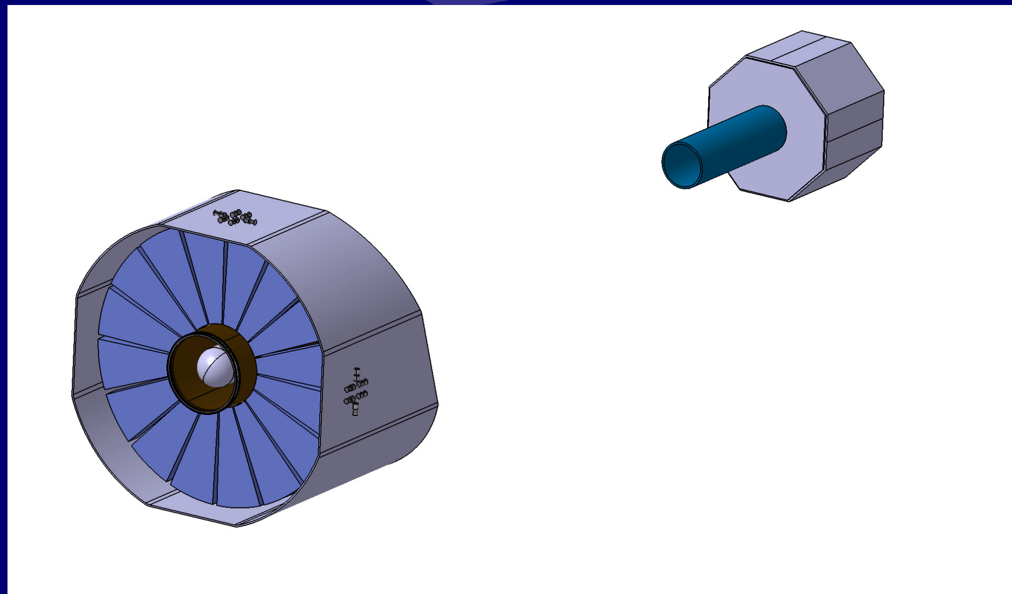


16 petals
0 to + 20 deg

XEUS – Mission Concept



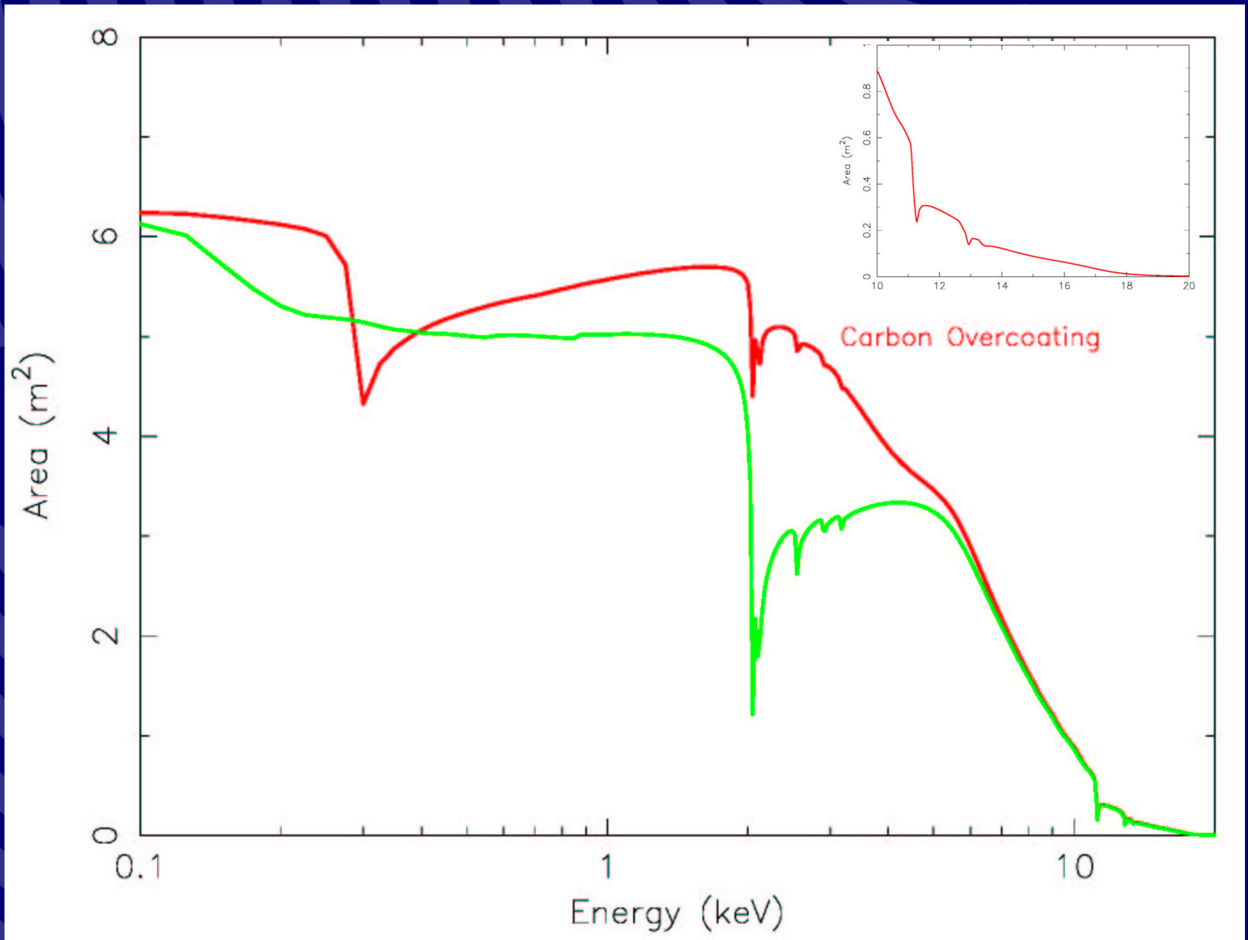
Composite in the A5 fairing



FF during operations

XEUS – Mirror Performance

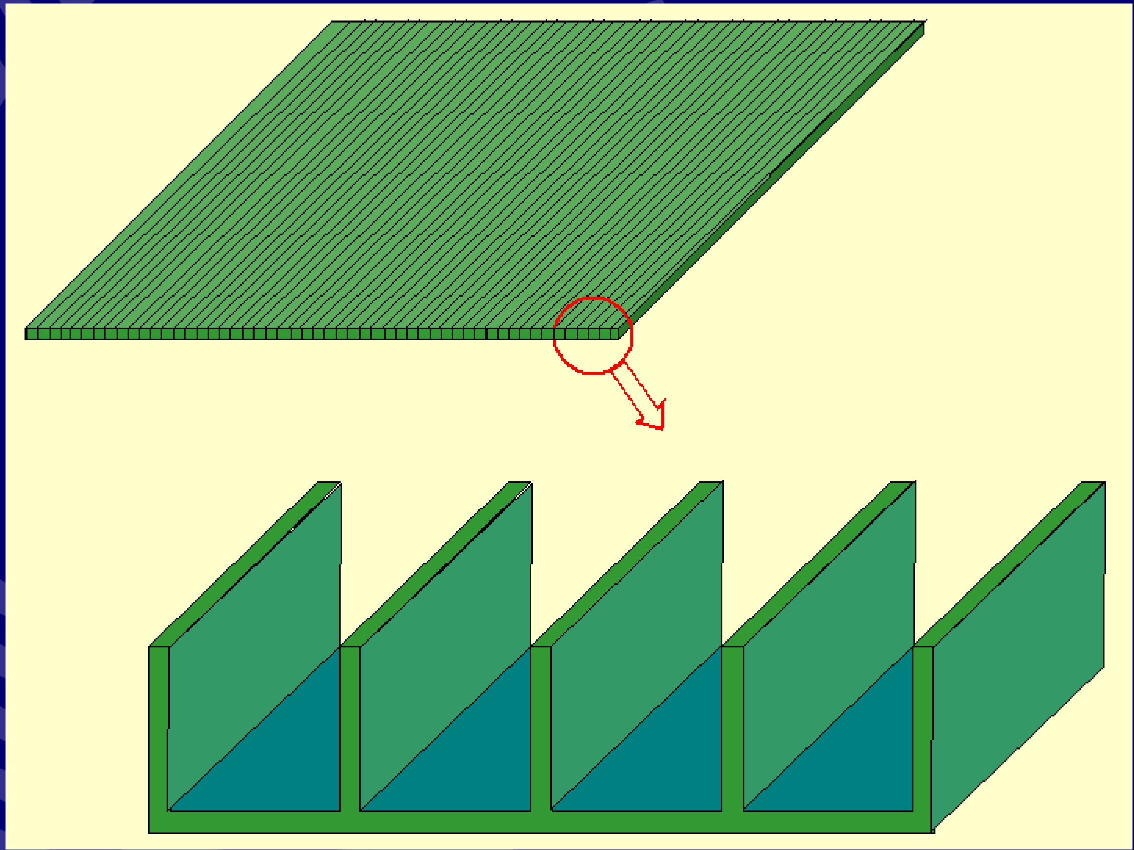
Iridium with 100 Ang carbon overcoat



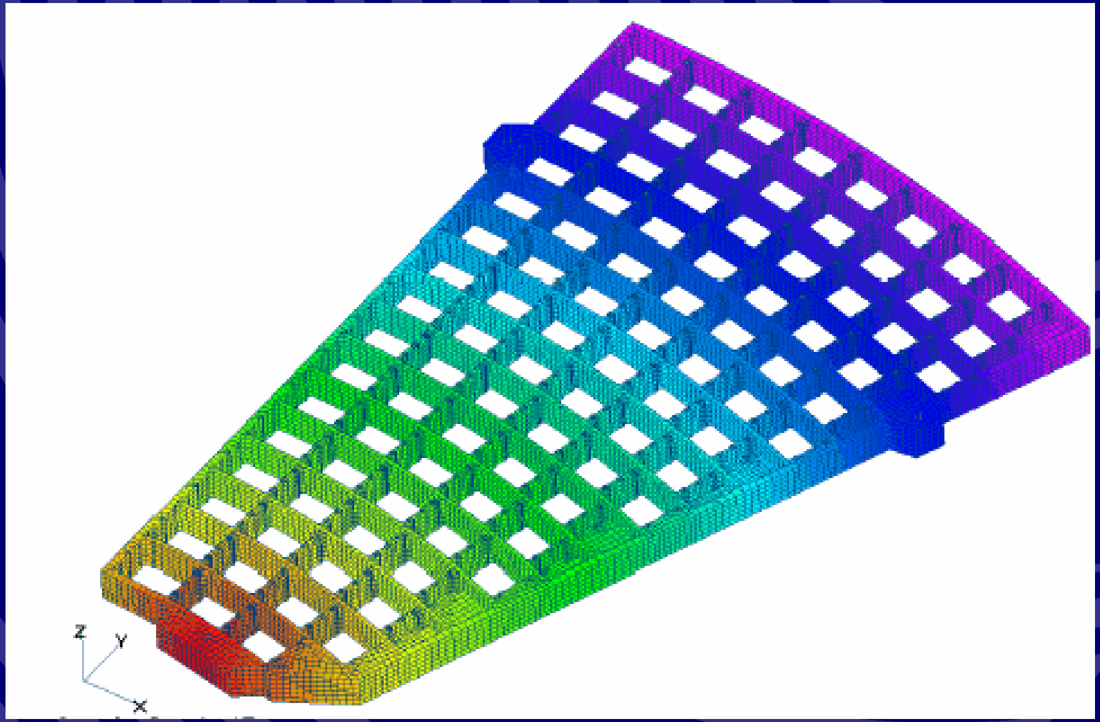
XEUS – Optics Development

High performance and low mass (~ 1 tonne) made possible by a breakthrough in high resolution, light-weight, X-ray optics

- High-precision pore optics (ESA/Patent/499)
- Utilizes latest generation of silicon wafers from the chip industry. <1 micron flatness.
- Coated on reflector side
- Rib-structured to provide strength and maintain alignment
- Slumped into a conical approximation to Wolter I geometry and then stacked and assembled into a petal structure.



XEUS – Mirror Petal Design



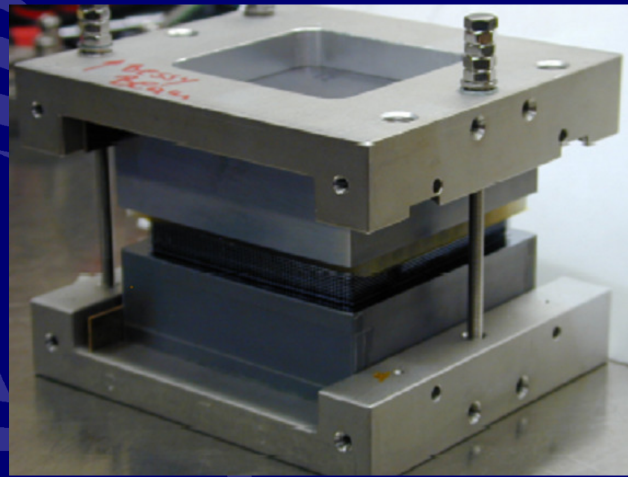
Finite Element Analysis by Keyser-Trede. Color shows temperature distribution across the petal. 3 attachment points/petal. 16 petals in total. Fixed alignment.

XEUS – Optics Development

Current Optics Activities:

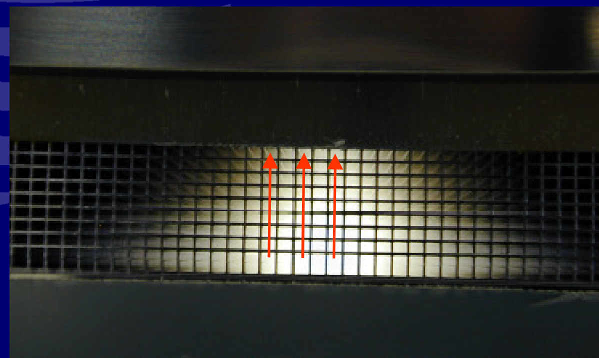
- Improving robotic stacking with better placement accuracy as well as minimizing dust contamination – cleanliness a key issue.
- Next biggest effect is figure errors on the forming mandrel. New higher-quality mandrels have been recently delivered
- Investigating how many plates can be assembled before figure is significantly degraded.
- Investigating different coating materials to enhance reflectivity.
- Nest steps are to assemble 2 stacks into a (Wolter I) pair and measure properties.

XEUS – Optics Development



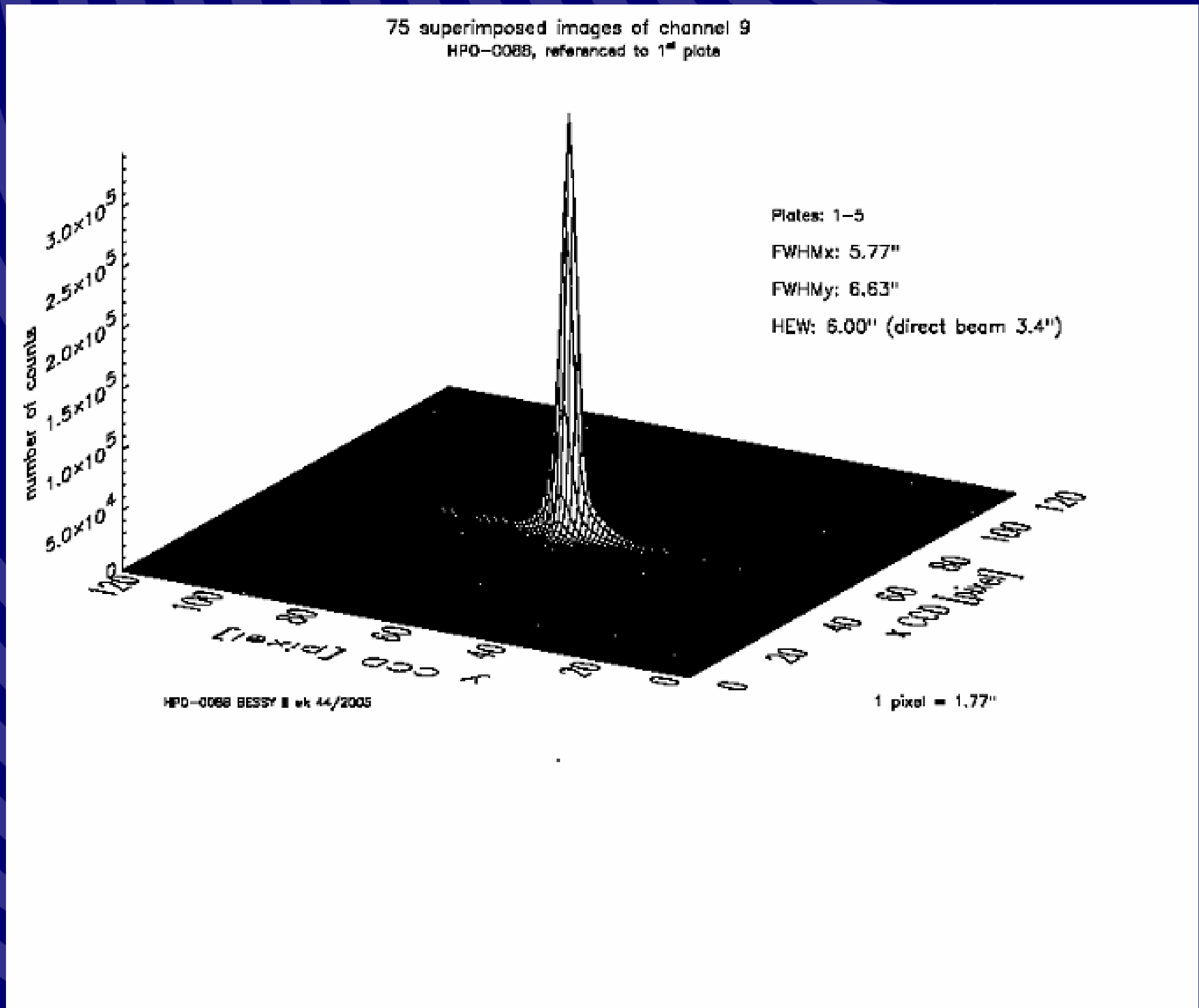
Current Optics Results:

- Most of the test results obtained so far, are “engineering” without directly demonstrating the imaging performance – due to step-by-step approach and lack of 50 m facility.
- Measurements at Bessy use 3 keV monochromatic pencil beam. Latest results show 2 arcsec HWE in best regions, 5 arcsec in extended regions.
- Recently placed a number of stacks in the Panter facility (mainly as an interface check).



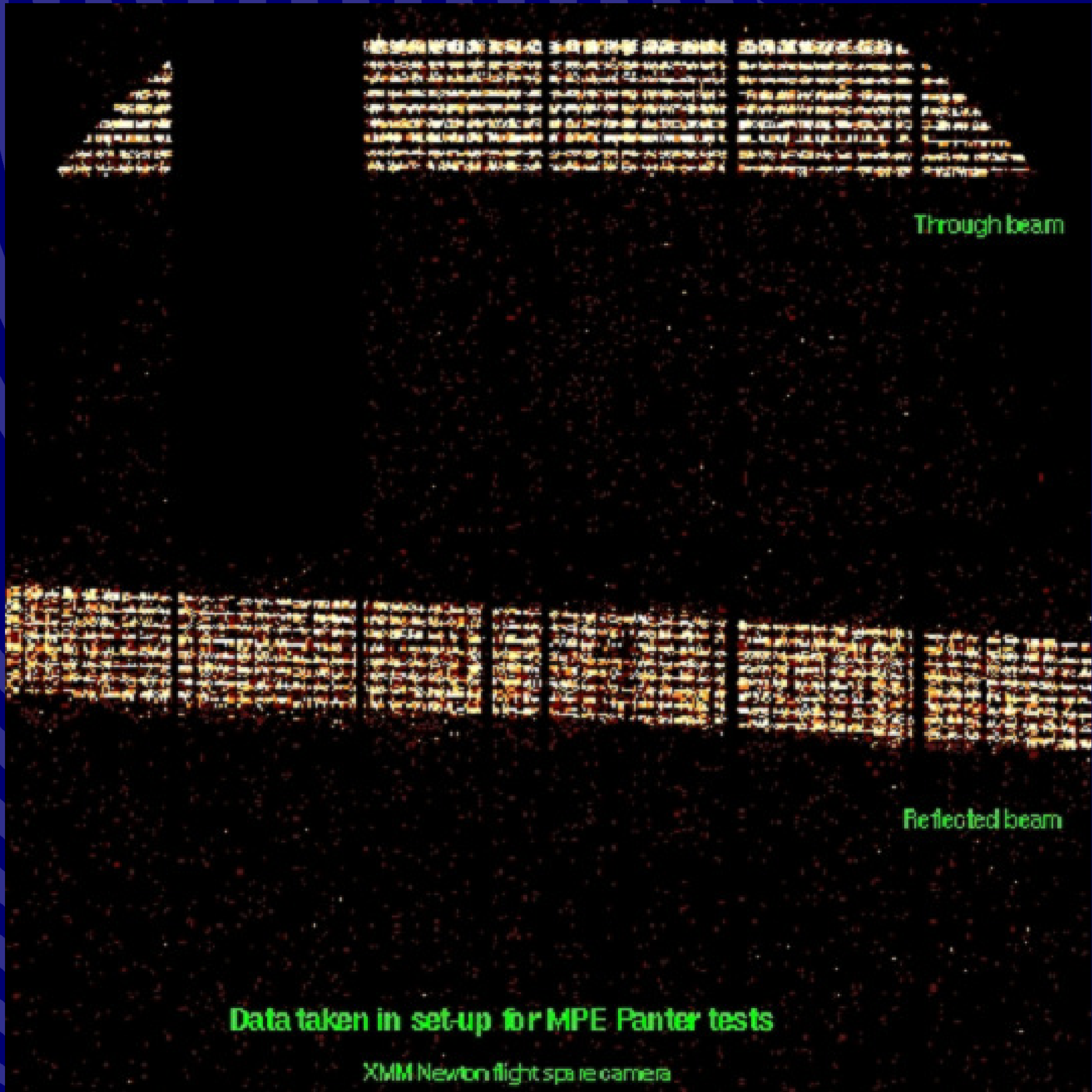
XEUS – Optics Development

Current Bessy Performance:



XEUS – Optics Development

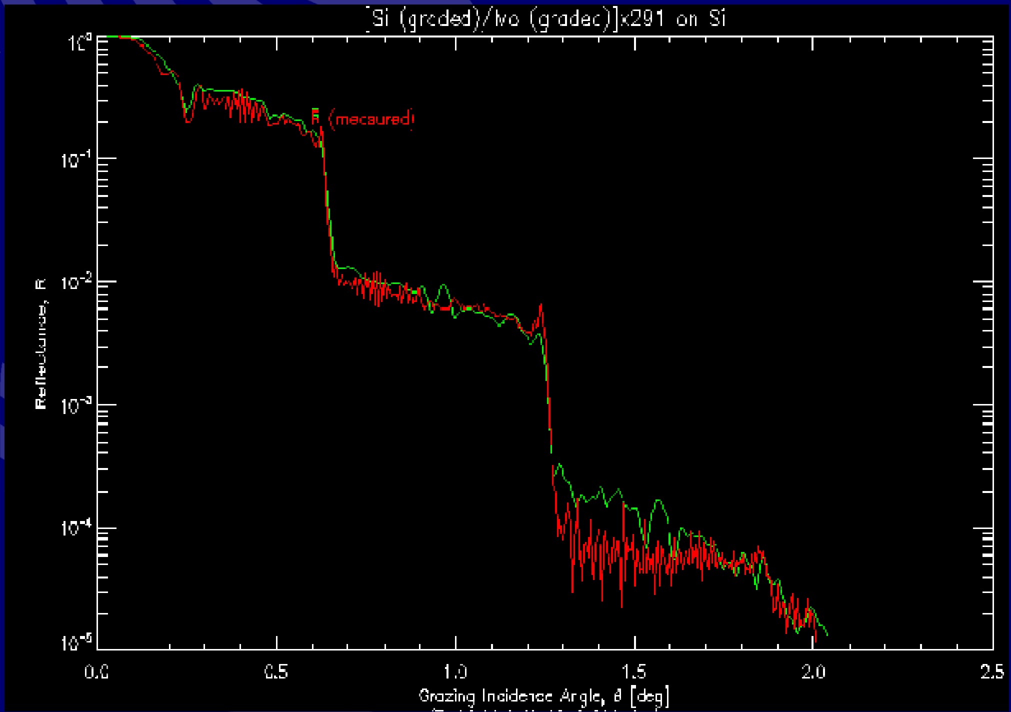
Panter Measurement:



XEUS – Optics Development

Multilayer Development:

- Figure shows comparison between measurement and theory at 28 keV when 290 Mo/Si layers were added to Si.
- Surface roughness of best Si wafers is 0.15 nm.
- However, test sample had 0.25 nm roughness. After application of multilayers roughness only increased slightly to 0.3 nm.
- Therefore good indications that application of multilayers on inner shells can be used to boost high-energy response without significantly degrading the spatial resolution.



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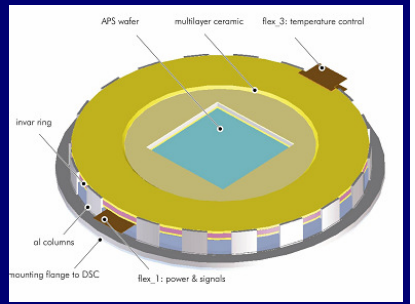
XEUS – Model Payload For Study

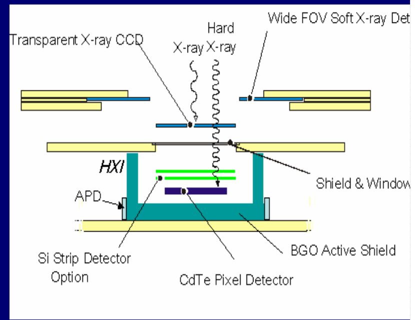
Baseline Instruments:

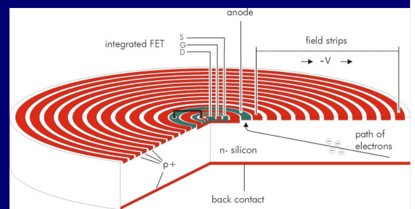
- *Wide Field Imager* – silicon active pixel sensor – 7' FOV, broad band spectra with CCD-like energy resolution.
- *Narrow Field Imager* – cryogenic imaging spectrometer with 30” FOV. One of two instruments, either optimized to low energies (<2 keV), or higher energies. 2 eV at 0.5 keV and 6 eV at 6 keV FWHM energy resolutions.

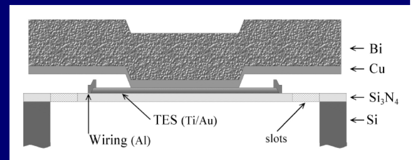
Additional Instruments:

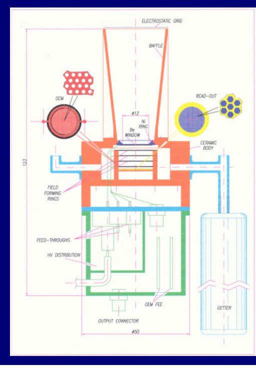
- *Narrow Field Imager* – second device
- *Hard X-ray Camera* – to extend the response to 40 keV. 5' FOV.
- *High time Resolution Spectrometer* – providing 10 μs timing, a 2 10^6 event s^{-1} capability with 200 eV energy resolution.
- *X-ray Polarimeter* – providing 2% MDP at 3σ confidence for 10 mCrab source in 10 ks.





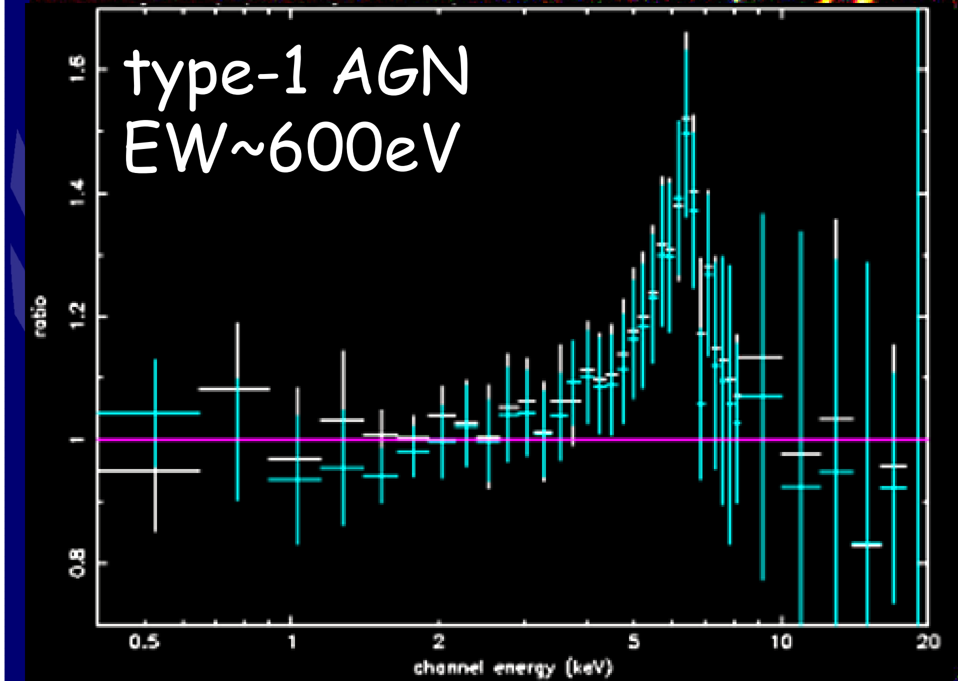


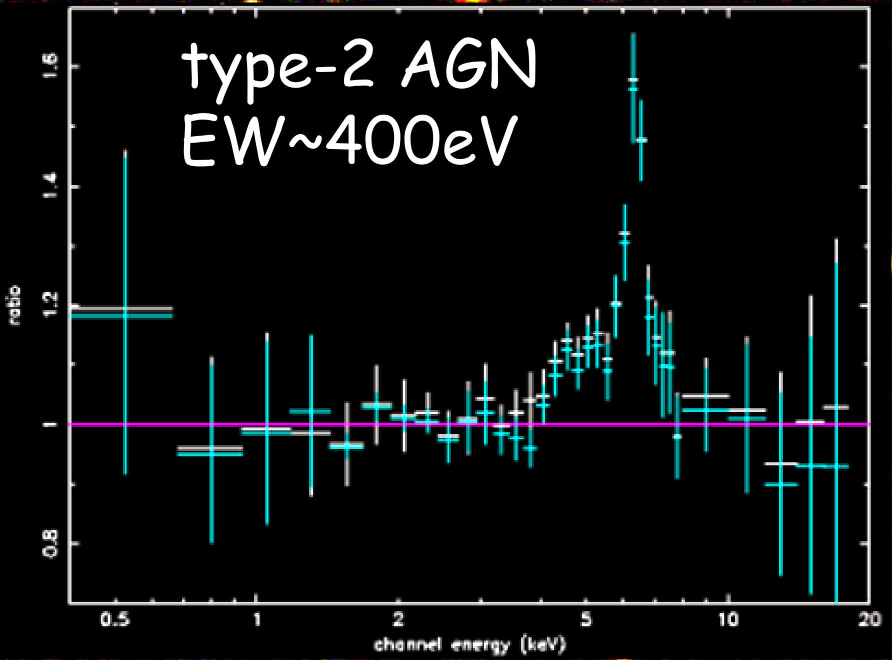




XEUS – The Deep X-ray Universe

Average rest-frame spectra show relativistic Fe-lines

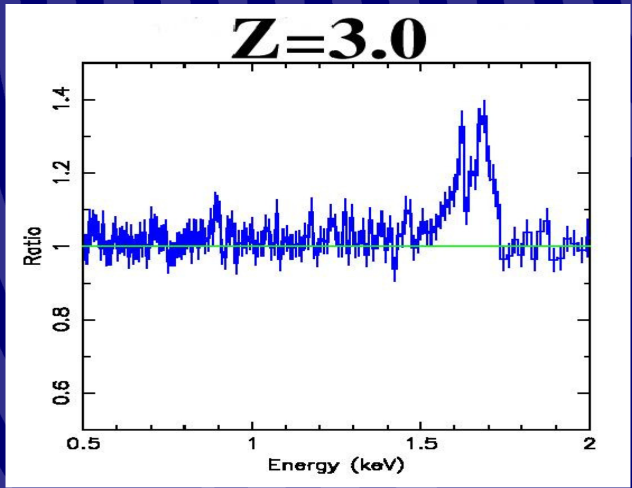


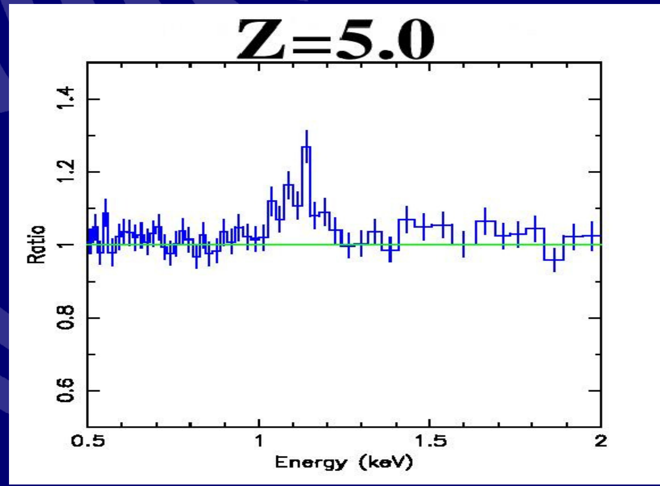


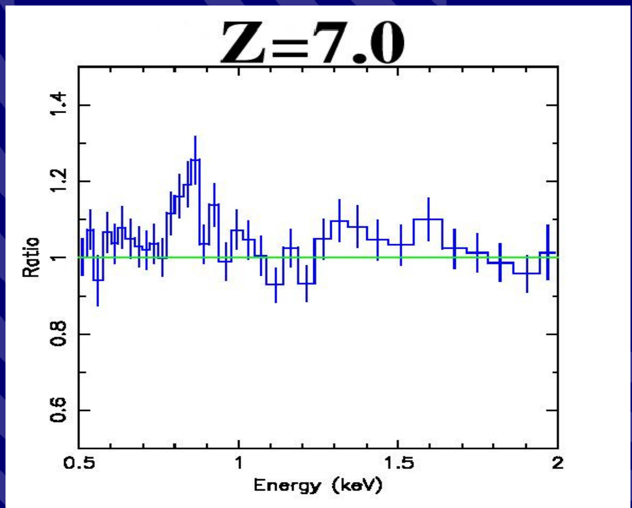
Streblyanskaya et al., 2004

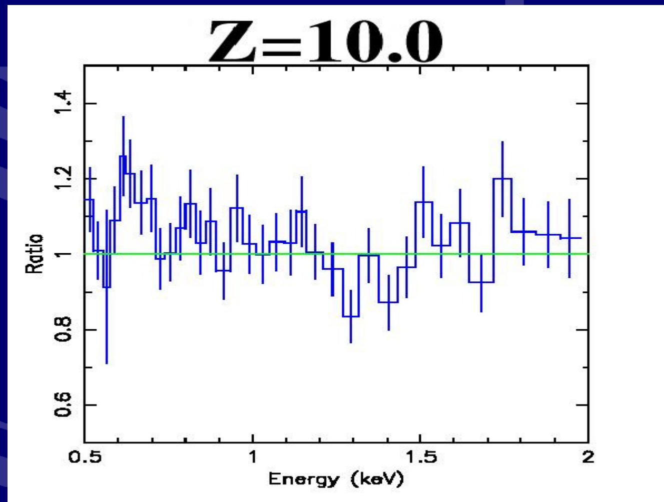
800 ks XMM-Newton observation

XEUS – Simulated Deep Field 10^{44} erg s^{-1} AGN Spectra

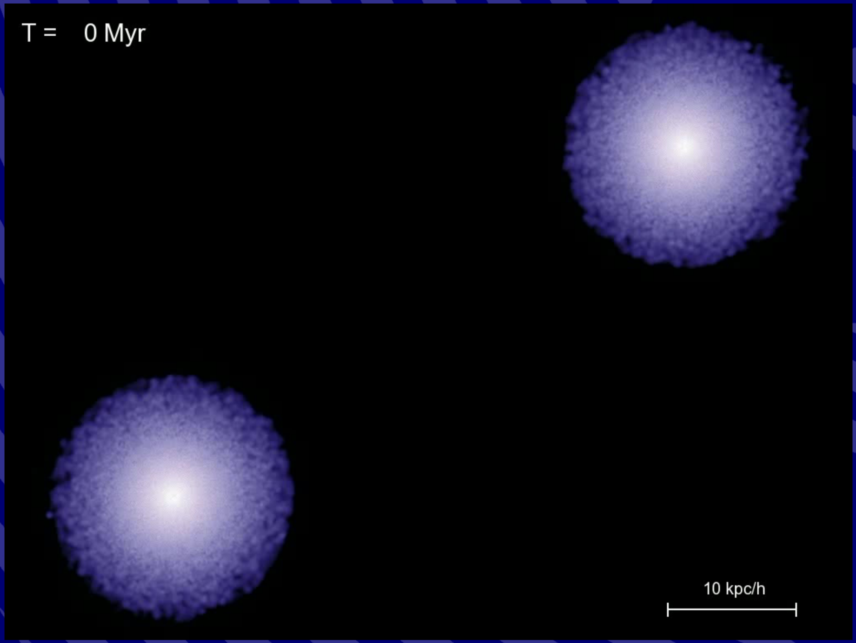


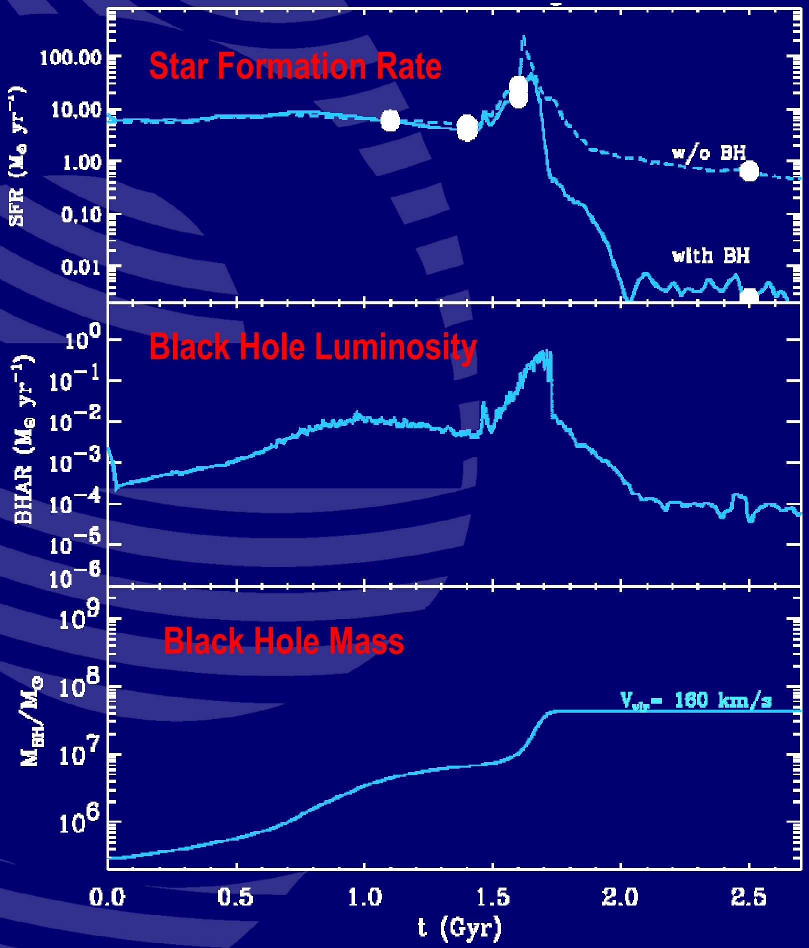






XEUS – Co Evolution of Galaxies and BHs

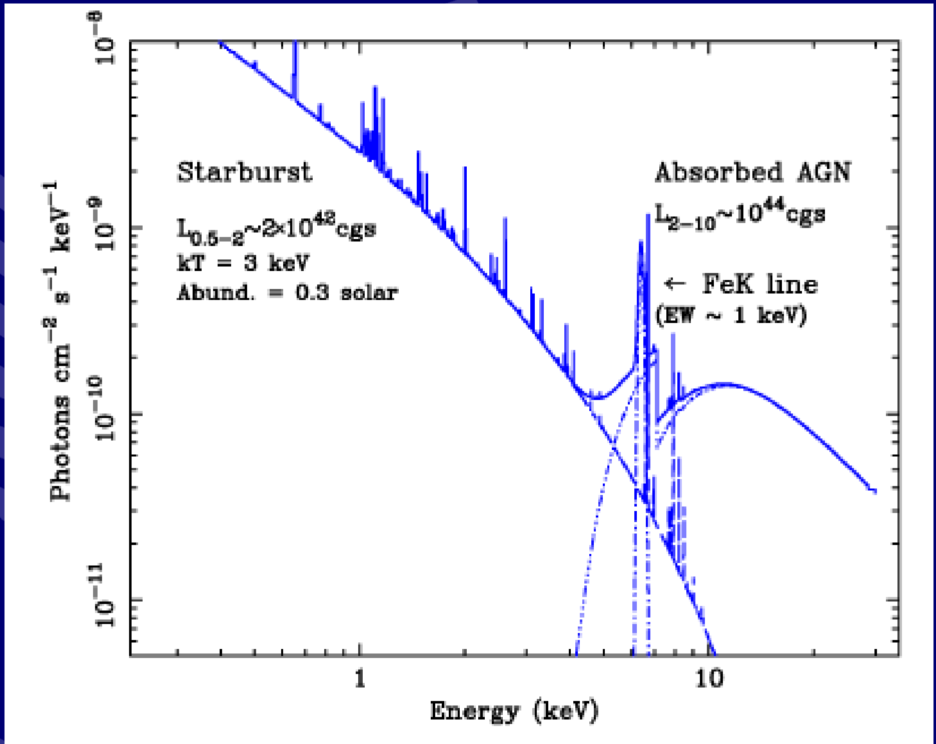




Simulation by T. de Matteo, V. Springel & L. Hernquist

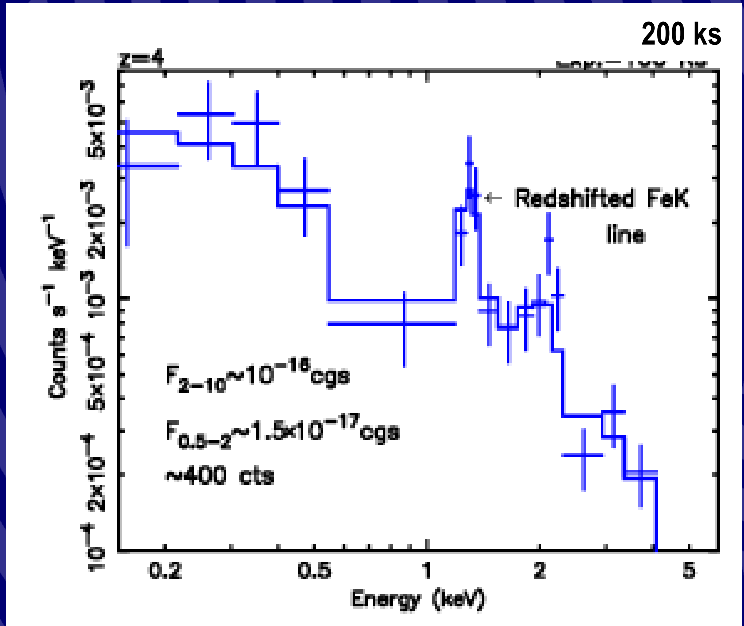
XEUS – Simulated Composite Spectra

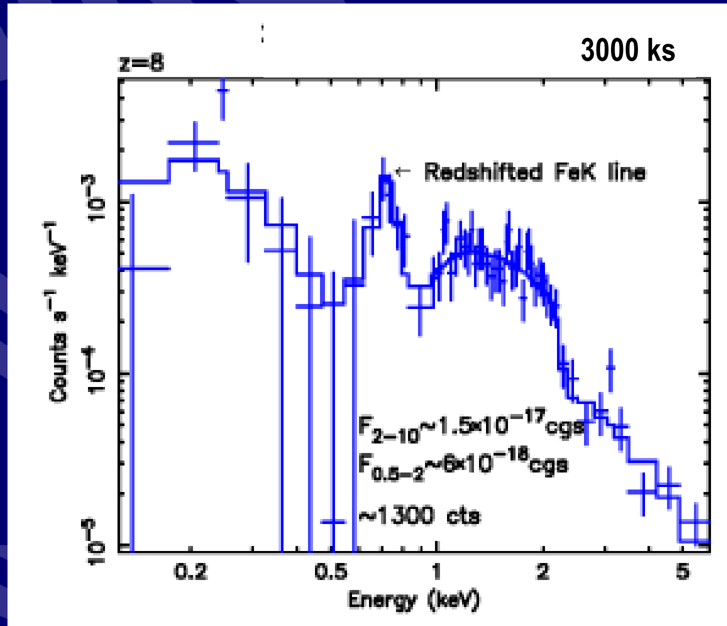
- XEUS can study dust enshrouded AGN at high redshifts and separate the contributions from starbursts and AGN.
- The figure shows a composite spectrum consisting of a kT= 3 keV 0.3 solar metallicity thermal gas and an absorbed AGN with a strong (EW=1 keV) Fe line primarily due to reflection.
- Source luminosity assumed the same as the nearby galaxy NGC 6240.



Credit: A. Comastri & M. Cappi

XEUS – Simulated Composite Spectra





Simulated XEUS spectra of the composite starburst-AGN. These show that with a deep field exposure, the spectra of sources at z=8 could be obtained and their Fe-K lines detected and studied.

Credit: A. Comastri & M. Cappi

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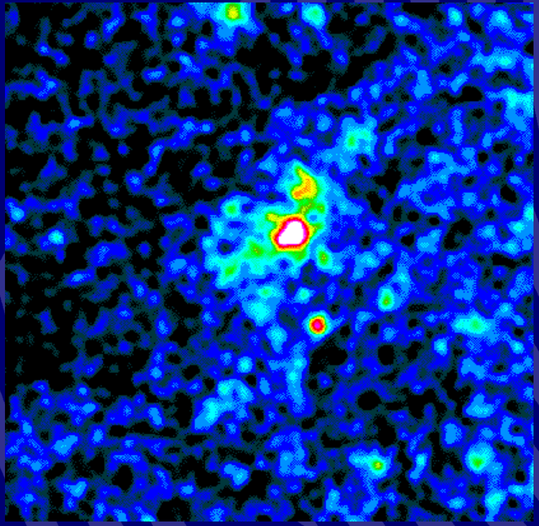
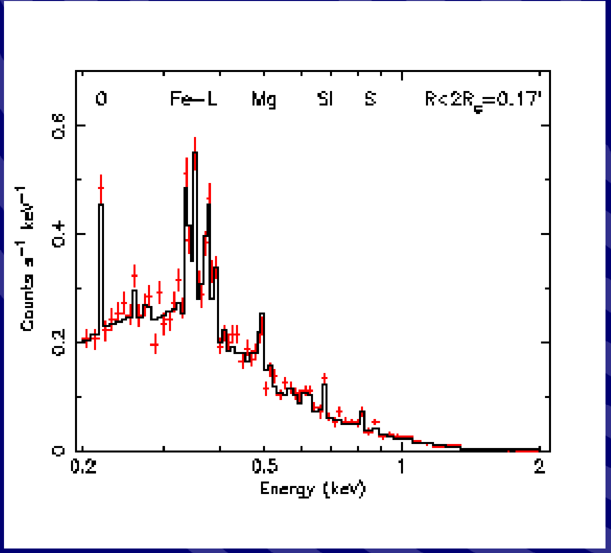
Formation and Evolution of Galaxy Clusters



Credit: H. Böhringer



- XEUS will be a powerful tool for observing the formation of large-scale structure in the Universe.
- Simulated XEUS image of a 10^{43} erg s^{-1} Hickson-type group at z=2 with 5” HEW angular resolution.

- Simulated spectrum of a 10^{43} erg s^{-1} group at a redshift of 2 with 0.3 cosmic abundance. 600 ks exposure with XEUS.
- Emission lines of Fe and the major α-elements are visible.
- The temperature can be measured to ± 3%.
- The Fe and O abundances can be measured to ± 10% and 20%.

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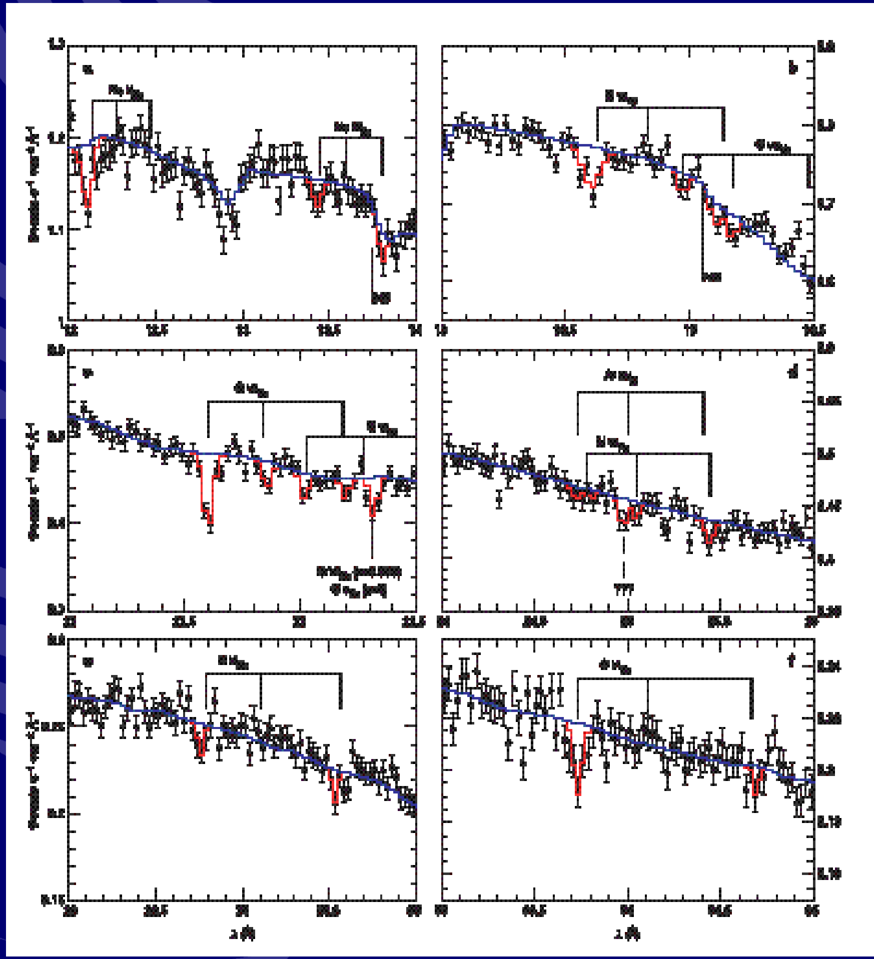
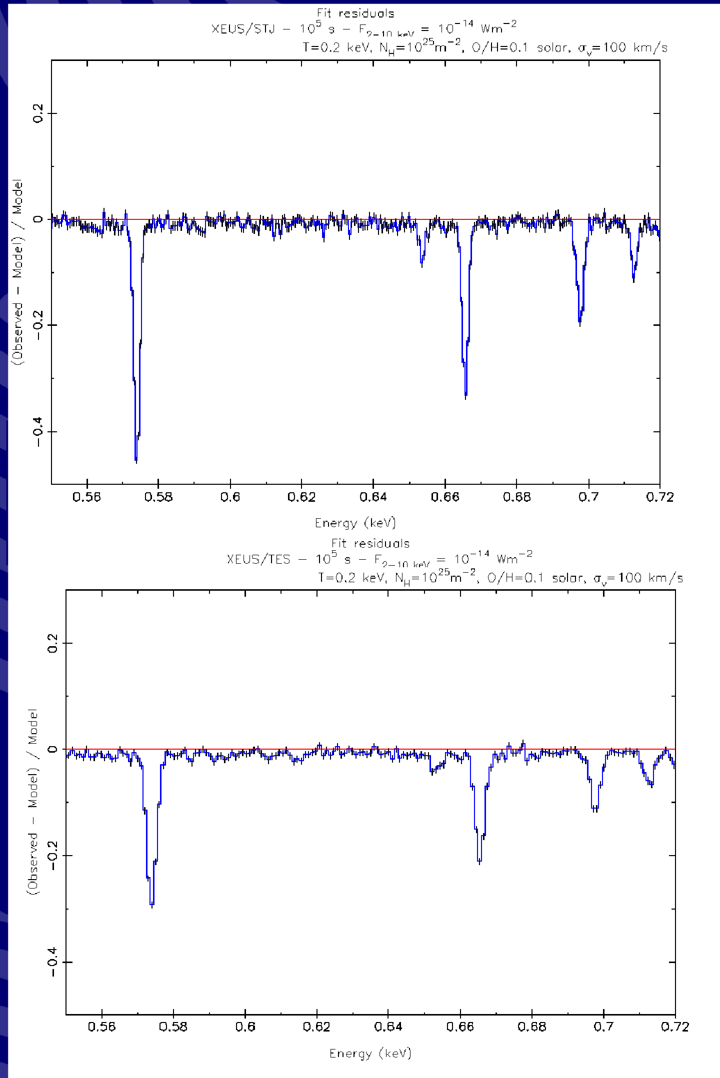
Studying the WHIM in Absorption

- Studying the WHIM provides some of the hardest challenges
- Need a combination of good spectral resolution and large area
- Seen in absorption towards a few of the brightest AGN (e.g., Nicastro et al. 2005)
- Traces of O VII and N VII at z= 0, 0.011 and 0.027



Studying the WHIM in Absorption

- Simulations by J. Kaastra for a background source with 2-10 keV flux of 10^{-11} erg cm^{-2} s^{-1}
- $N_H = 10^{21}$ cm^{-2}, O/H = 0.1 solar, kT = 0.2 keV, σ_v = 100 km s^{-1}
- Importance of spectral resolution!

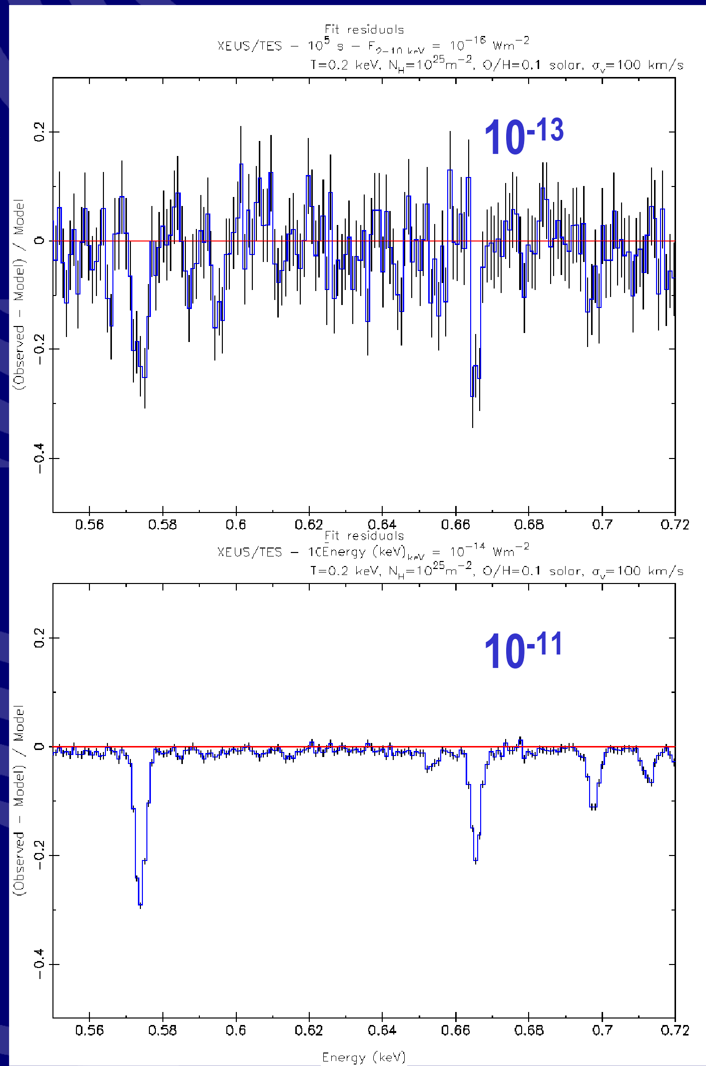


STJ : 1.2 eV FWHM

TES : 3.0 eV FWHM

Studying the WHIM in Absorption

- 100 ks simulations for sources with 2-10 keV fluxes of 10^{-13} and 10^{-11} erg cm^{-2} s^{-1}
- There are 10 sources per square deg $>10^{-13}$ erg cm^{-2} s^{-1} so can be used to map the WHIM
- Need both large area and high spectral resolution
- Note that to determine relative abundances reliably need to determine T, σ_v simultaneously with abundance



XEUS: On-going Activities

- Two parallel sets of XEUS activities underway in ESA:
  - Mission selection via the Cosmic Vision process. Proposal will be prepared following the call to be issued soon.
  - Further industrial studies to better define mission critical elements (formation flying, mirror technology, mirrors & focal plane accommodation (EADS Astrium) etc.)
- Both sets of activities come together at the end of 2007 when XEUS should be ready to enter its definition phase (A/B1).
- Technology development (mirrors, detectors, formation flying) funded by ESA with significant contributions from the member states.

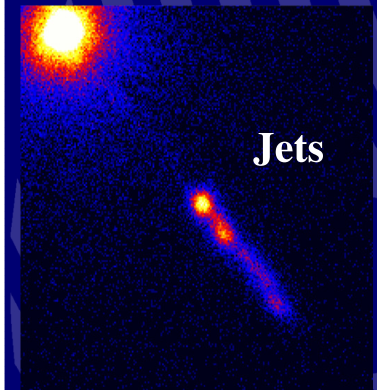
XEUS – Overall Schedule

Mission

- Definition phase (A/B1, competitive): 2008-2009
- Design phase (B2, prime selected): 2009-2010
- Phase C/D: 2011 – mid 2016
- Launch campaign: 2017
- Launch: 2017
- Operation (nominal): 2017 to 2022

Optics

- HPO module optical model: mid 2005 - end 2006
- Petal engineering model: 2008-2009
- Infrastructure development: 2009- 2011
- FM production: 2011 to 2015
- Mirror MSC AIT: 2016



Conclusions

- The breakthrough in X-ray optics has placed the high-energy community in a strong position in Cosmic Vision. We need to capitalize on this success to maintain the leading role of high-energy astronomy in the ESA Science Programme.
- The continued strong support of the wide scientific community and the endorsement by the ESA Science Advisory Structure are vital for this is to happen.
- The XEUS community will need to respond to the Cosmic Vision AO expected soon with a proposal for a global mission led by Europe with substantial international involvement.