

IXO: The International X-ray Observatory



On behalf of the IXO team

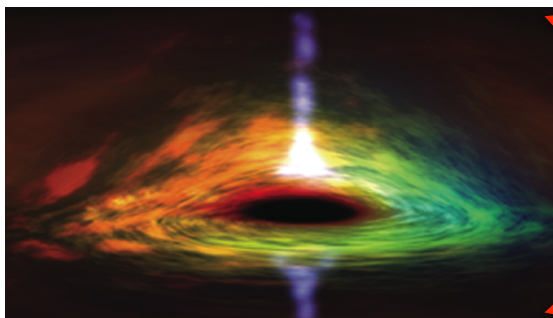


Assessment Study Presentation, Paris, 3 Feb 2011

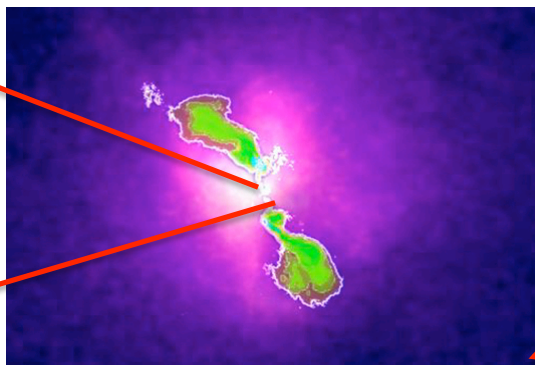


What is the connection between these processes?

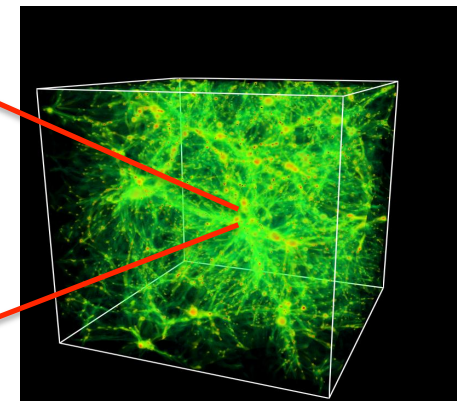
- **When did the first supermassive black holes form?**
 - *Cosmic Vision: The evolving, violent Universe*
- **How does large scale structure evolve?**
 - *Cosmic Vision: The Universe Taking Shape*
- **What happens close to a black hole?**
 - *Cosmic Vision: Matter Under Extreme Conditions*



Black Hole Accretion

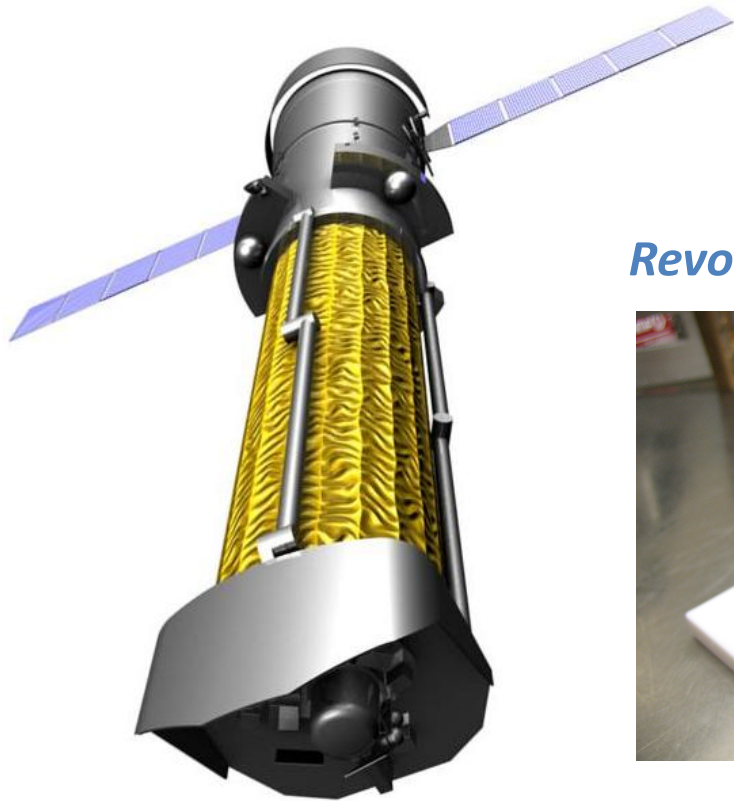


Feedback Processes



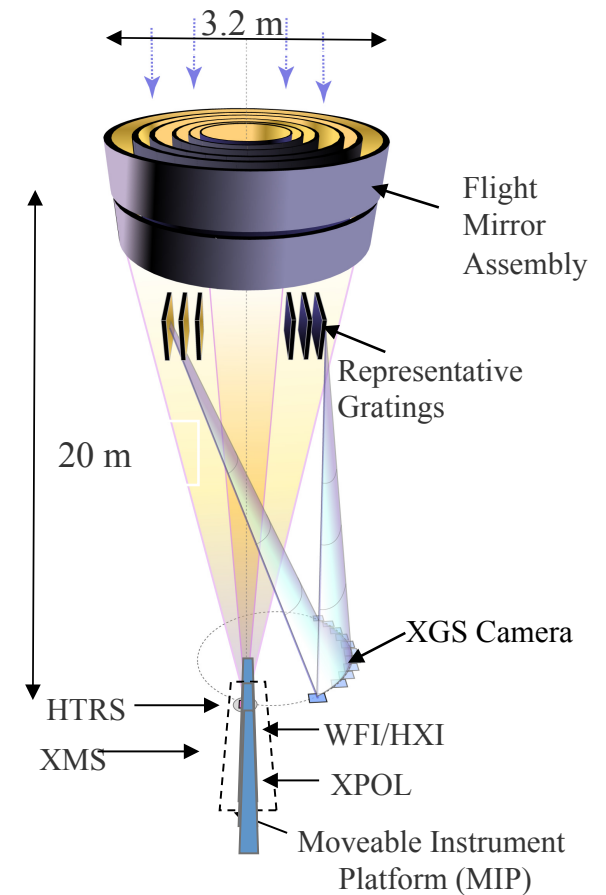
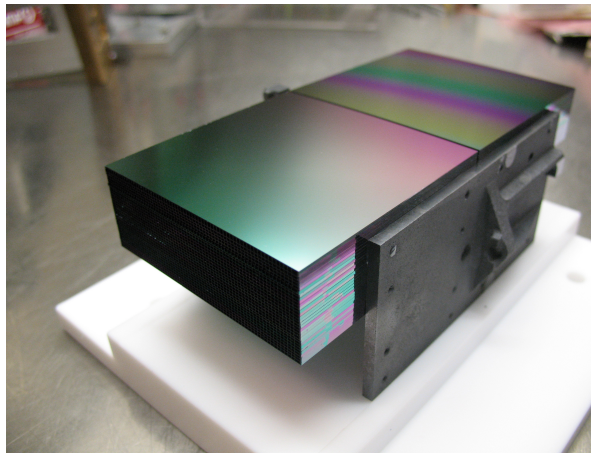
Cosmic Web

How will IXO do this?



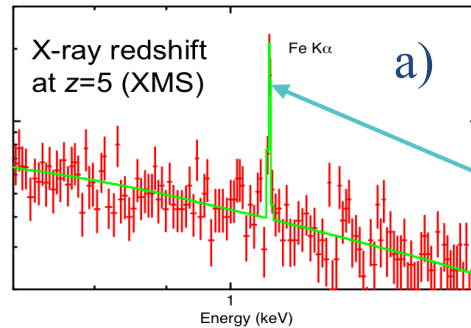
IXO spacecraft

Revolutionary optics technology

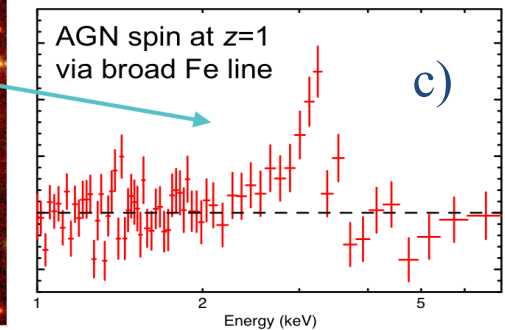
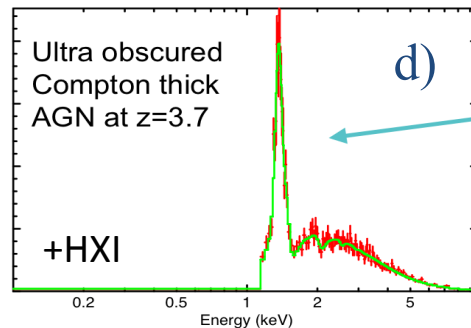
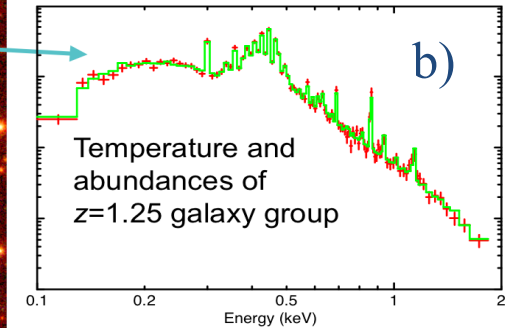
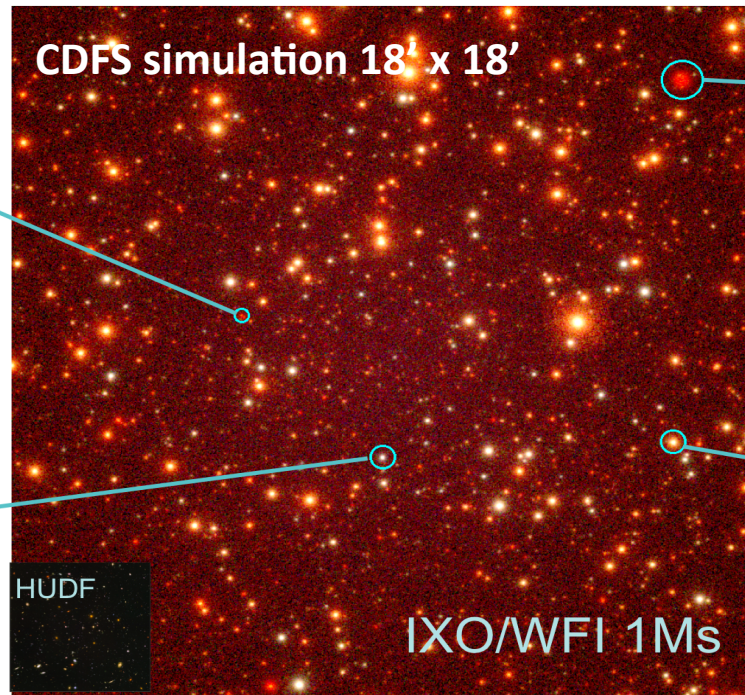


State-of-the-art payload

The Deep Universe



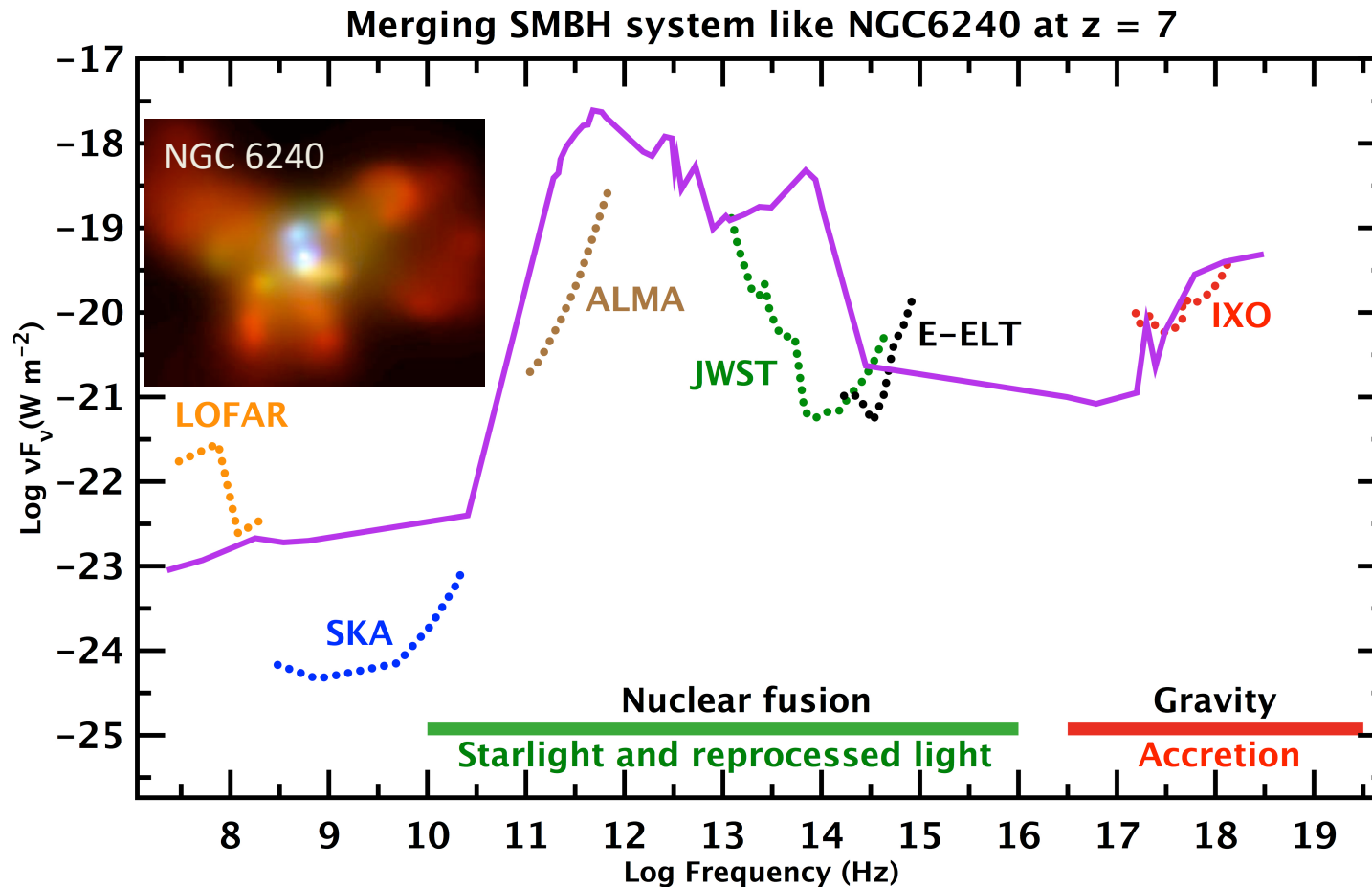
CDFS simulation $18' \times 18'$



- a) *Determine redshift autonomously in the X-ray band*
- b) *Determine temperatures and abundances even for low luminosity galaxy groups to $z>1$*
- c) *Make spin measurements of AGN to a similar redshift*
- d) *Uncover the most heavily obscured, Compton-thick AGN*

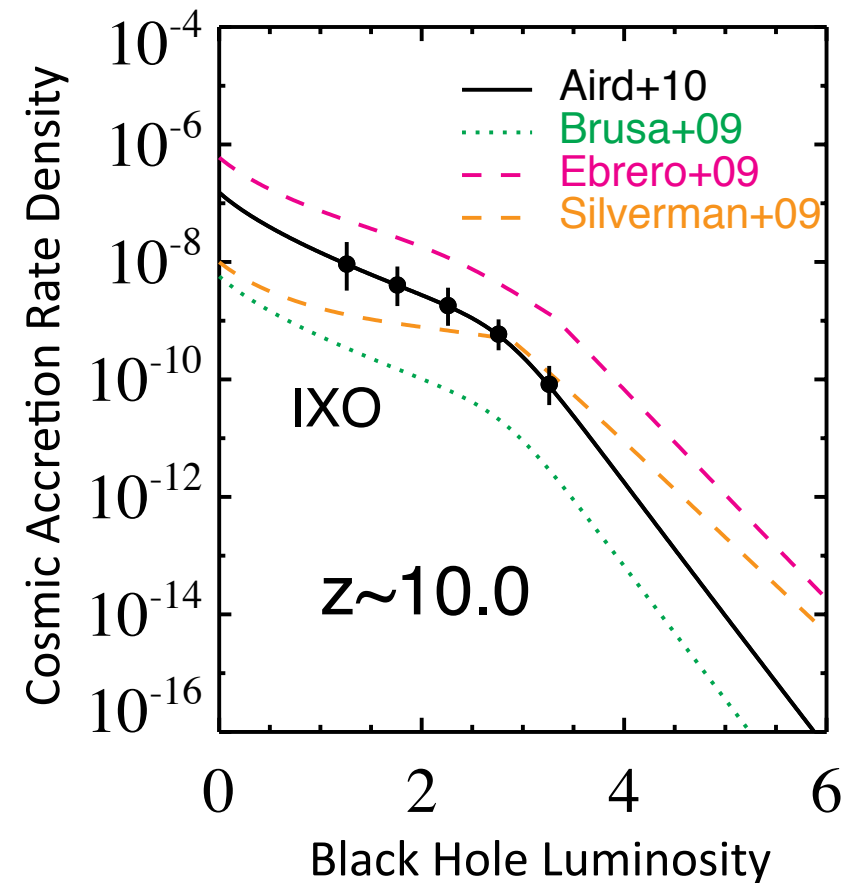
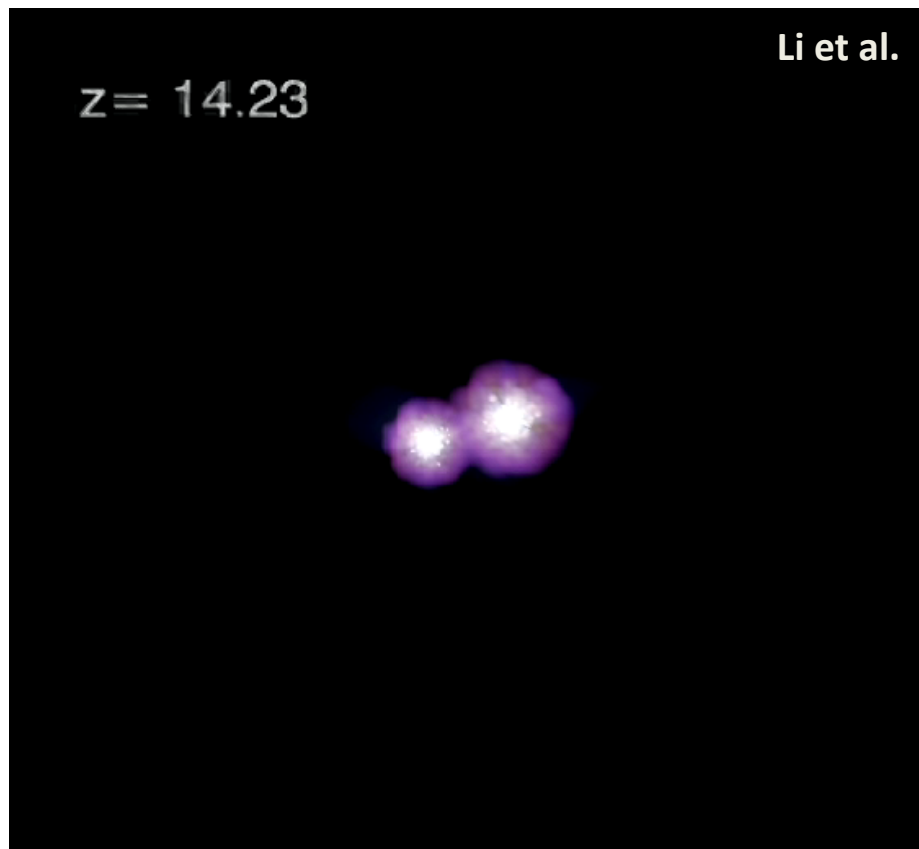
2.5 m² @ 1.25 keV
5 arc sec PSF

1. When did the First SMBH Form?



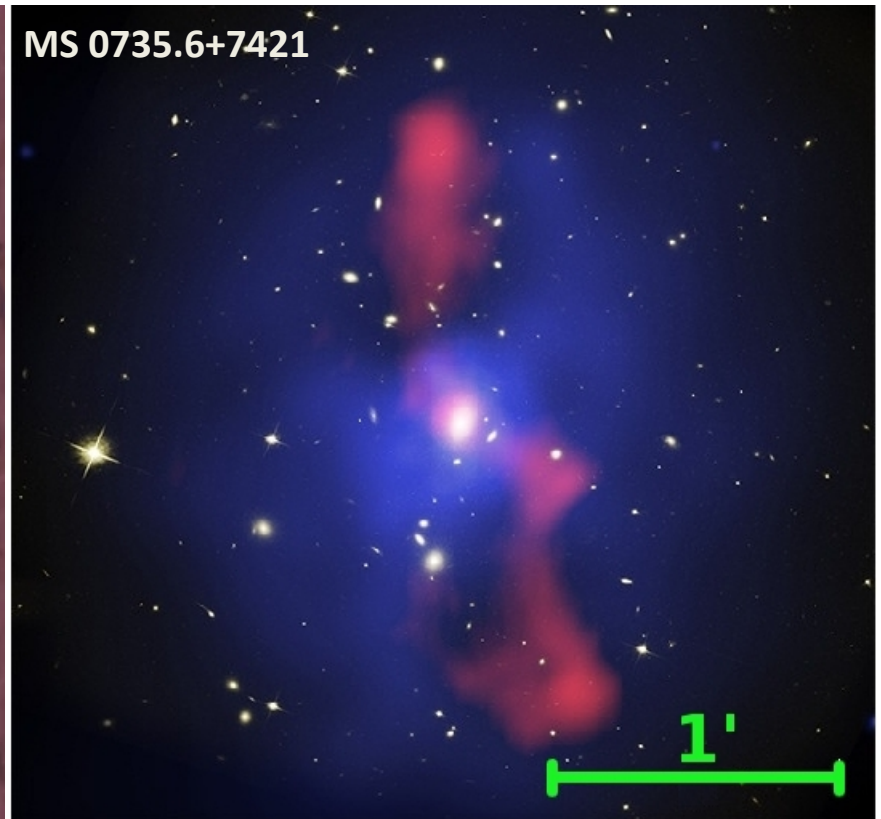
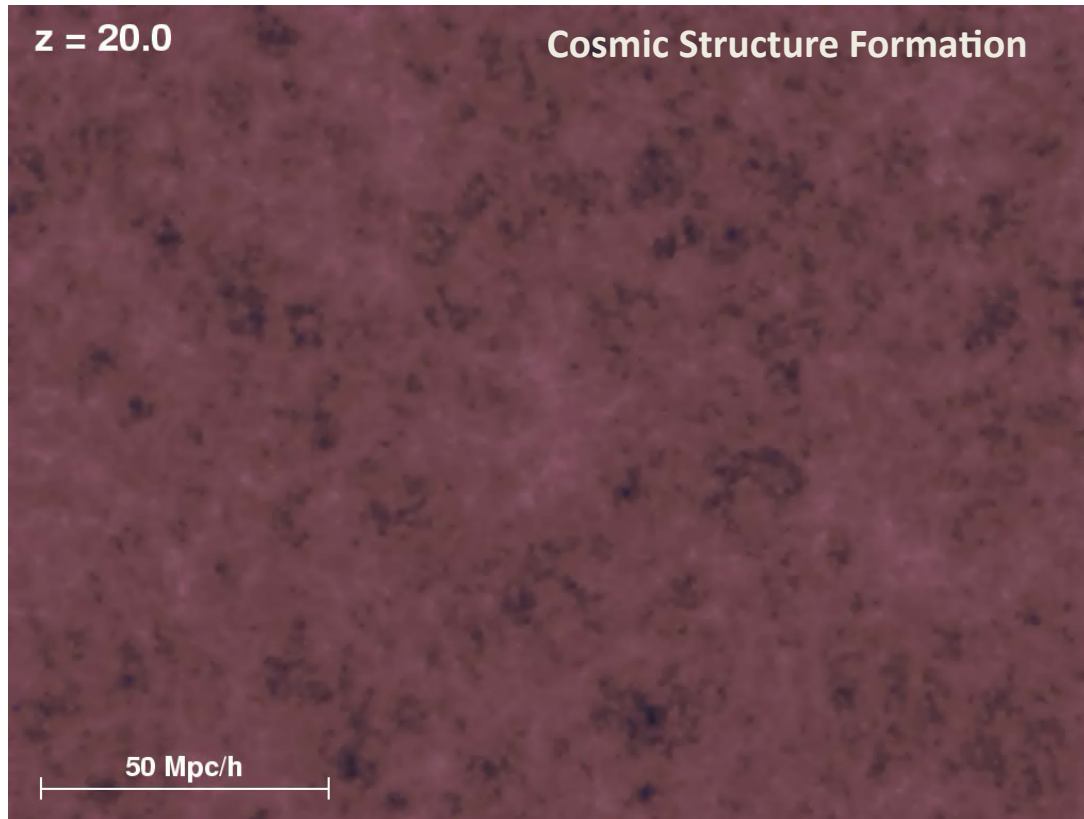
2.5 m^2 @ 1.25 keV
5 arc sec PSF

Tracing Accretion into the Early Universe

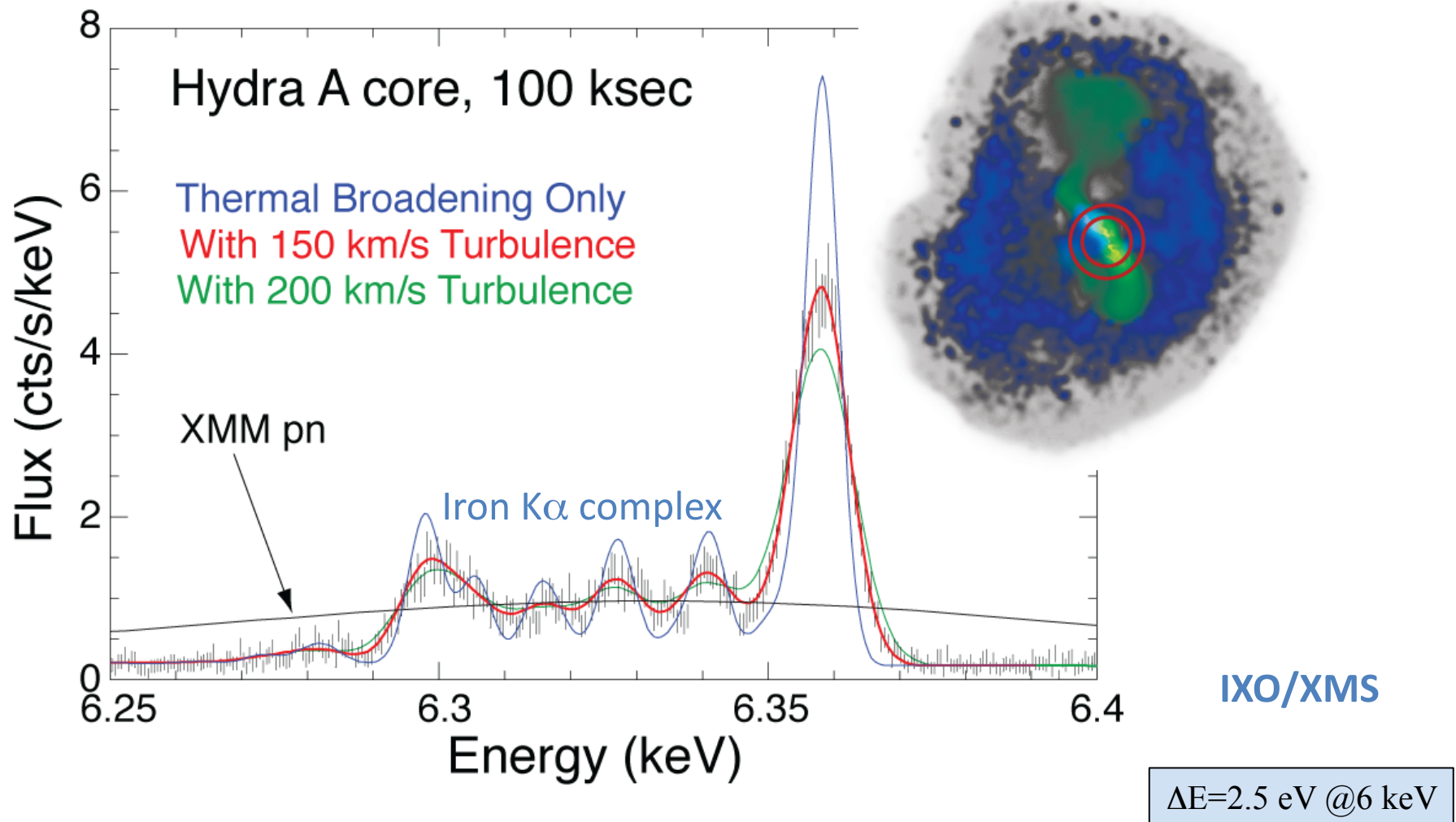


2.5 m² @ 1.25 keV
5 arc sec PSF

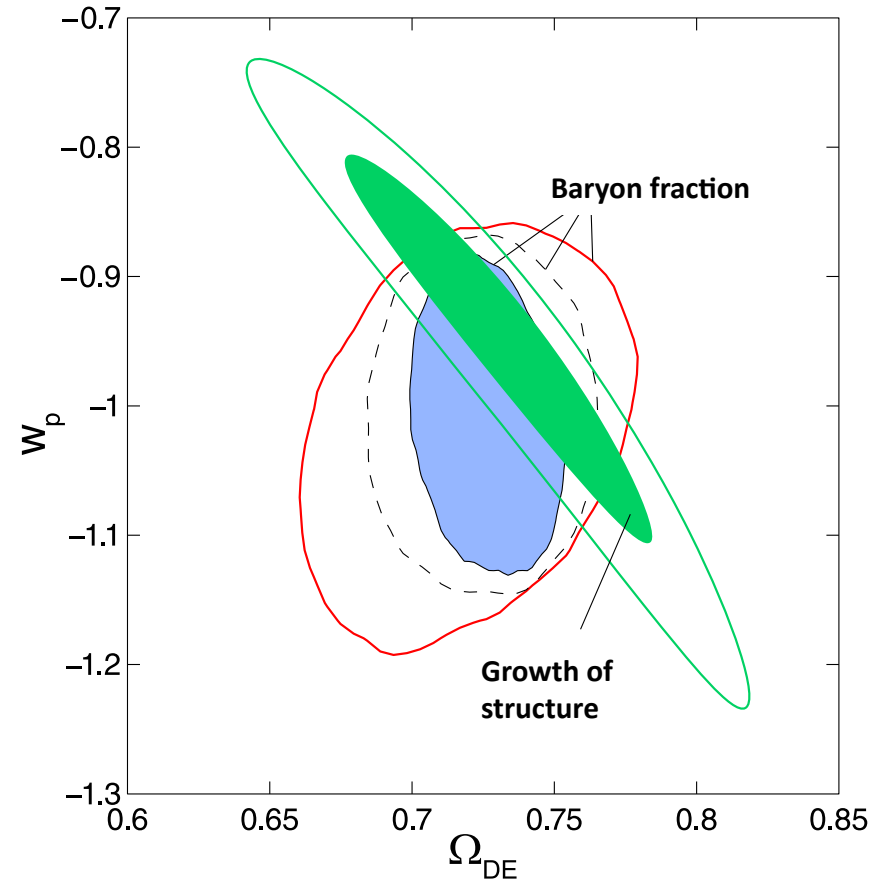
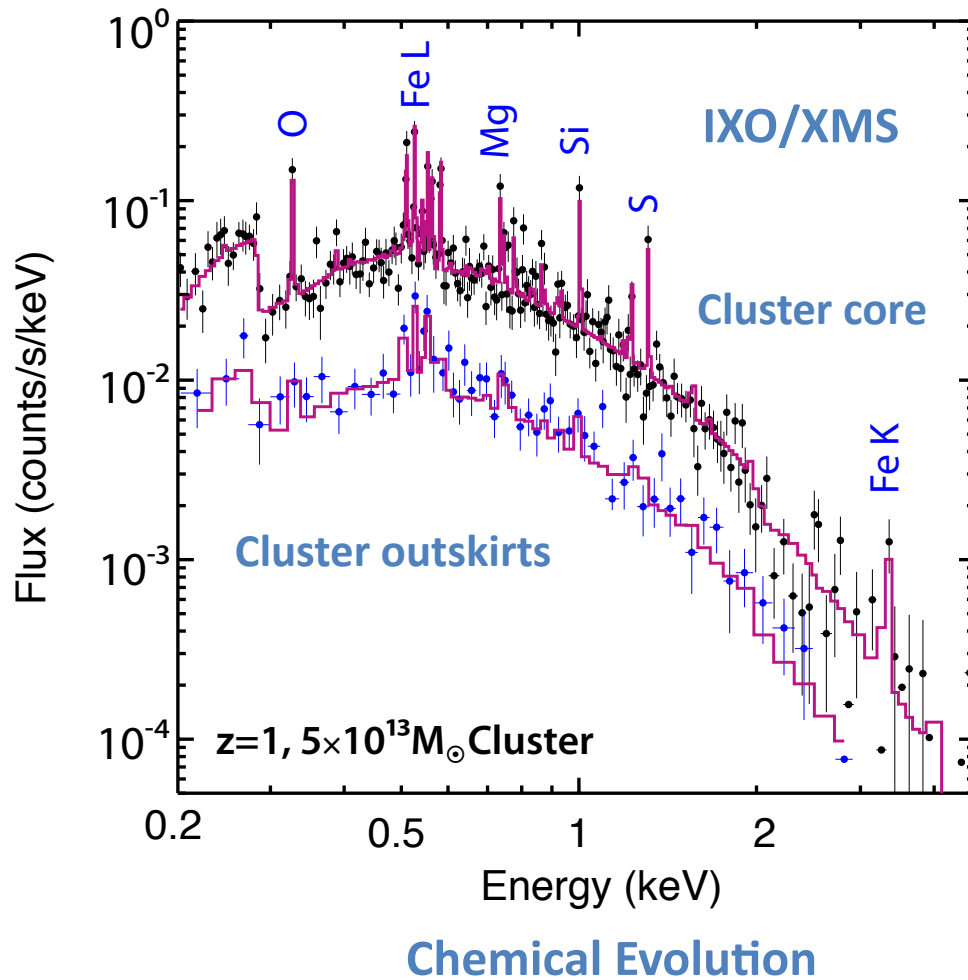
2. How did Cosmic Structure Evolve?



How did Cosmic Structure Evolve?



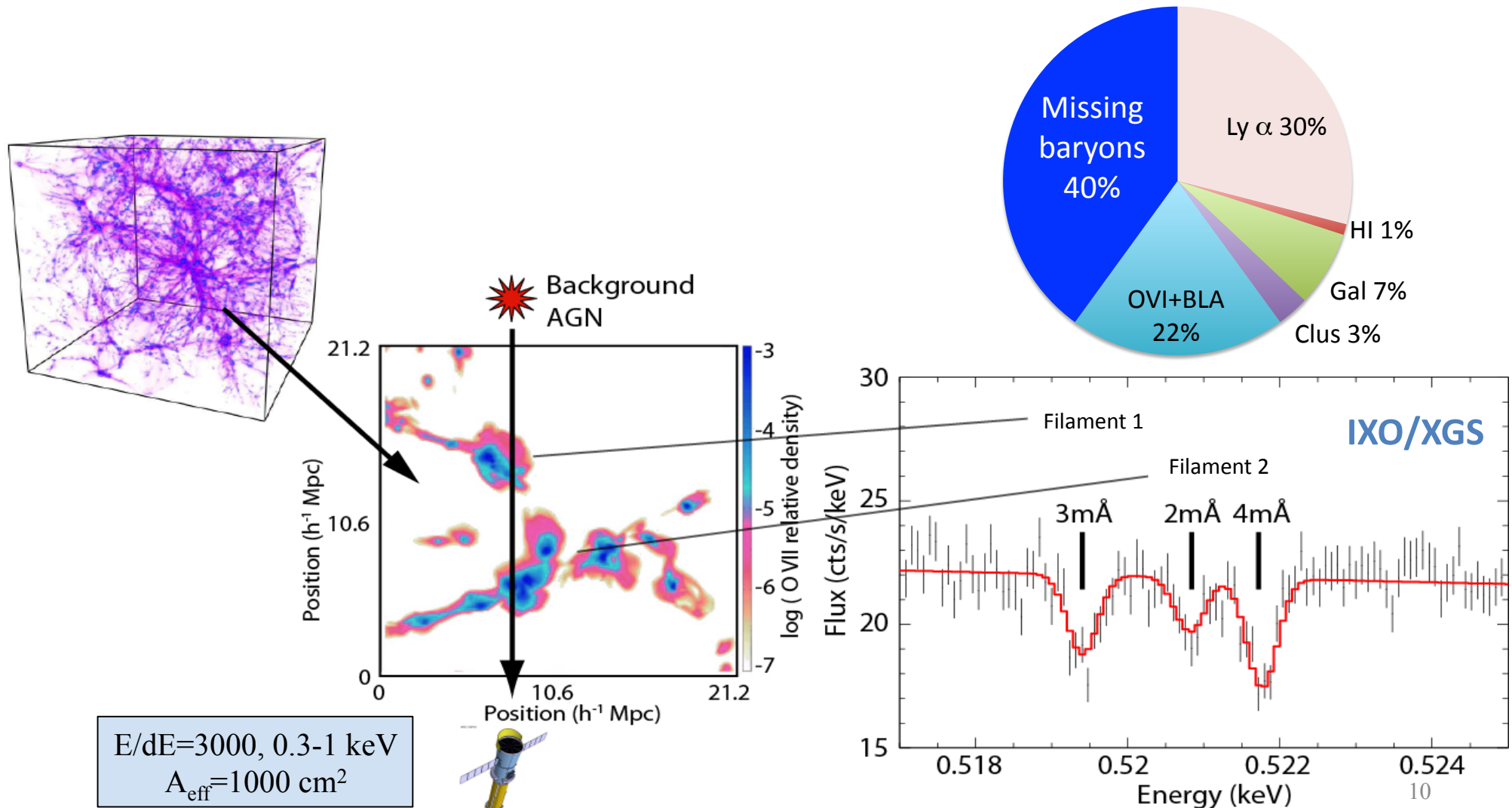
From Physics to Cosmology with Clusters



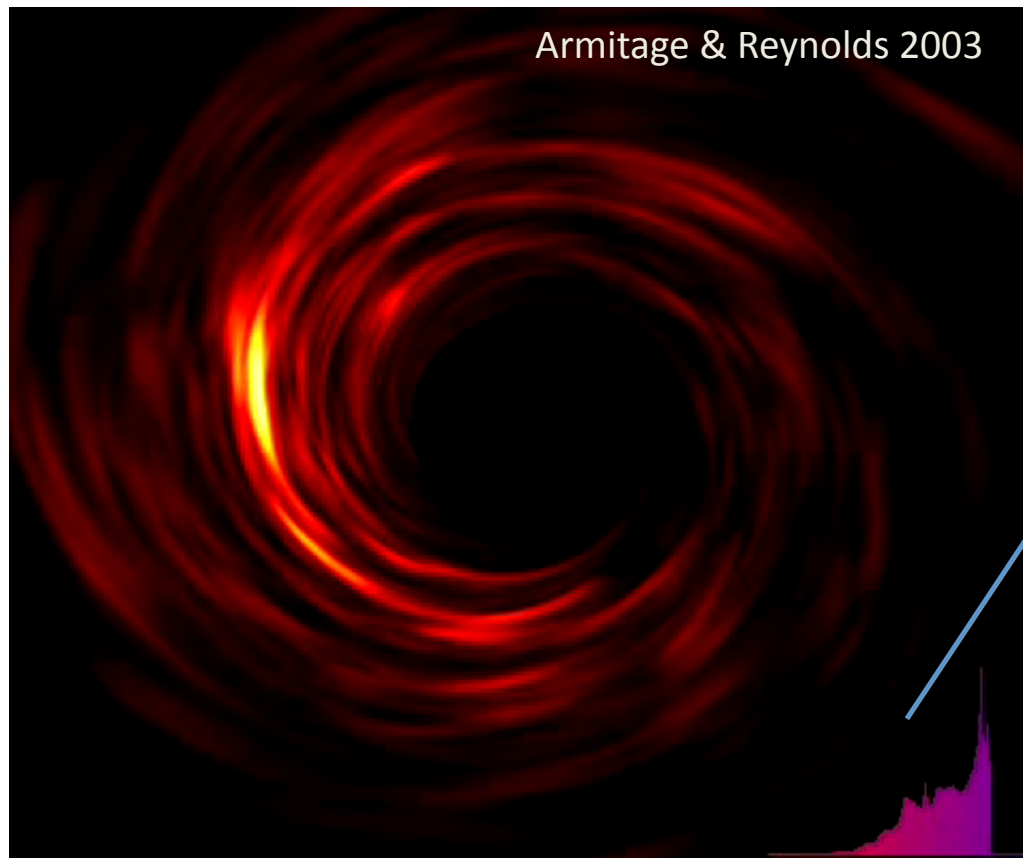
Dark Energy

2.5 m² @ 1.25 keV
5 arc sec

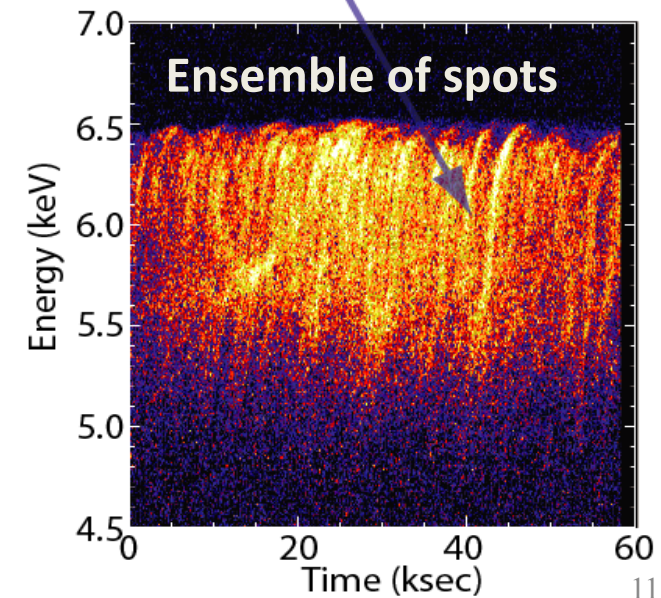
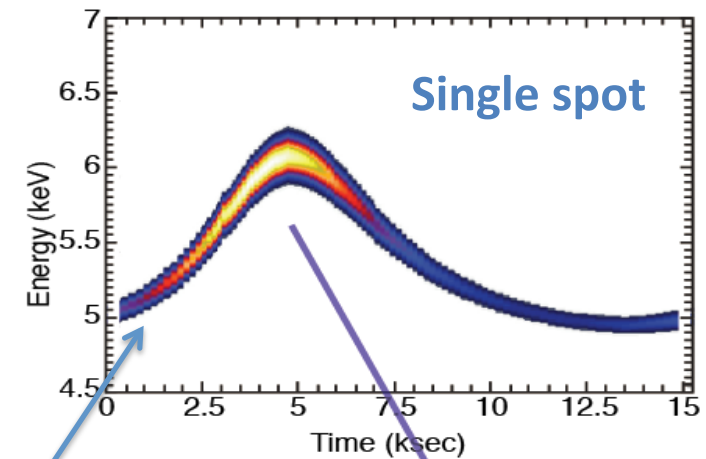
The Missing Baryons



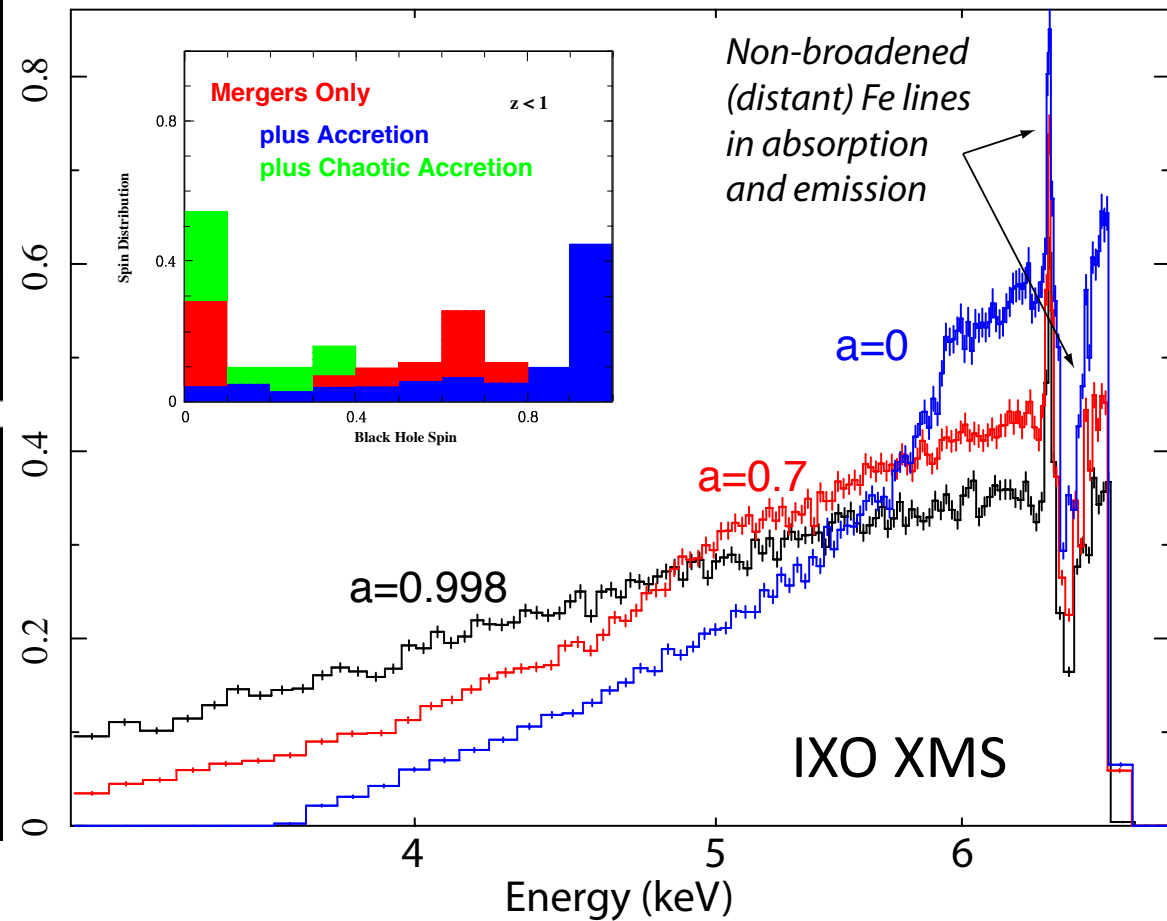
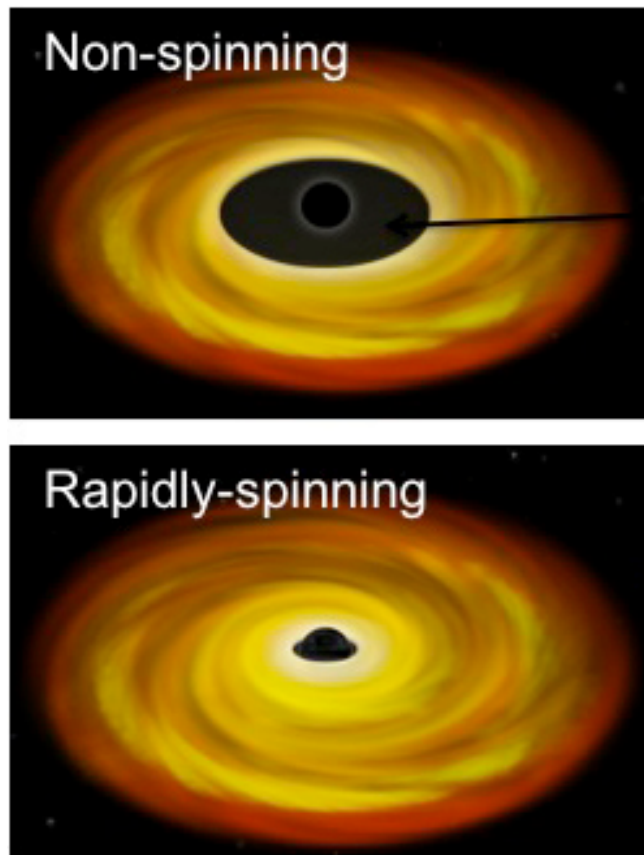
3. What Happens Close to a Black Hole?



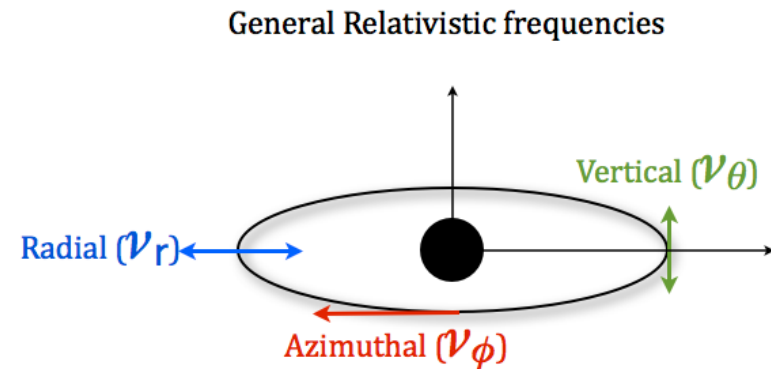
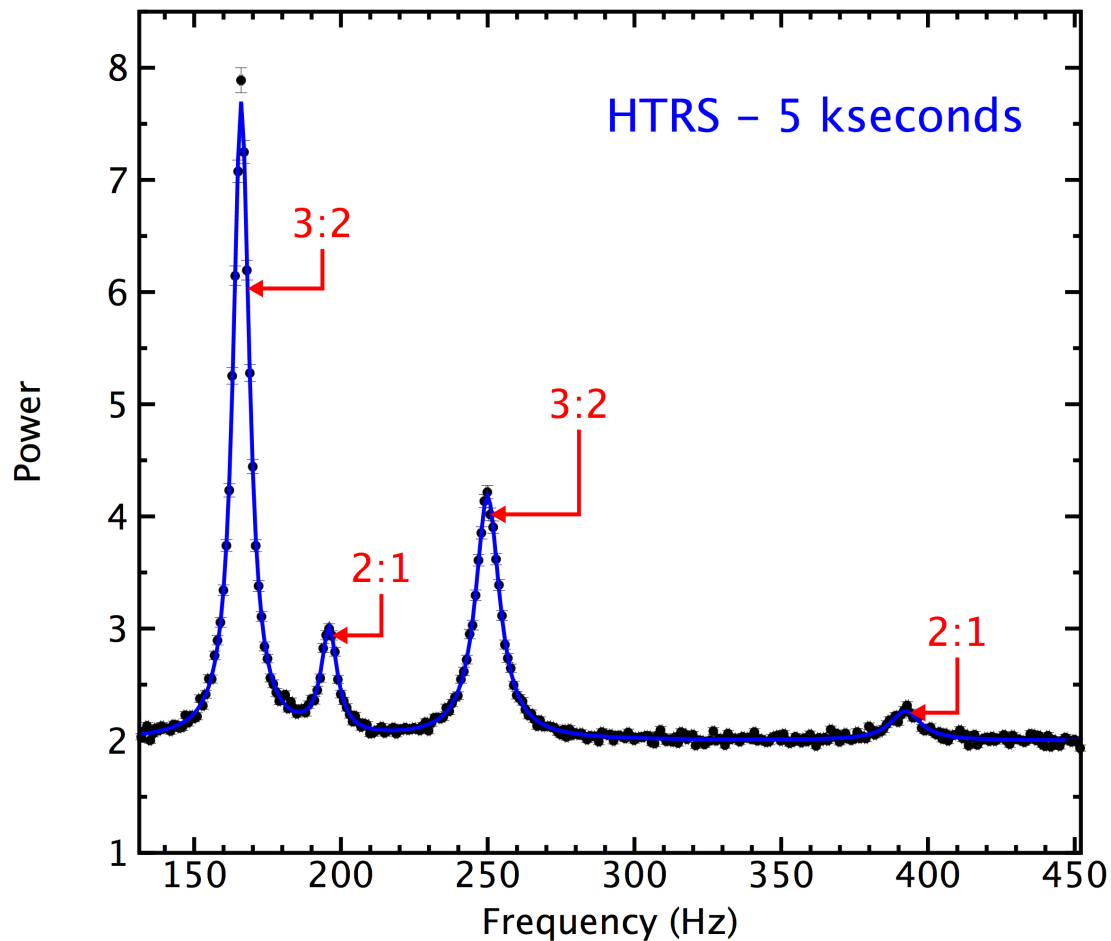
0.65 m² @ 6 keV



Measuring Black Hole Spins



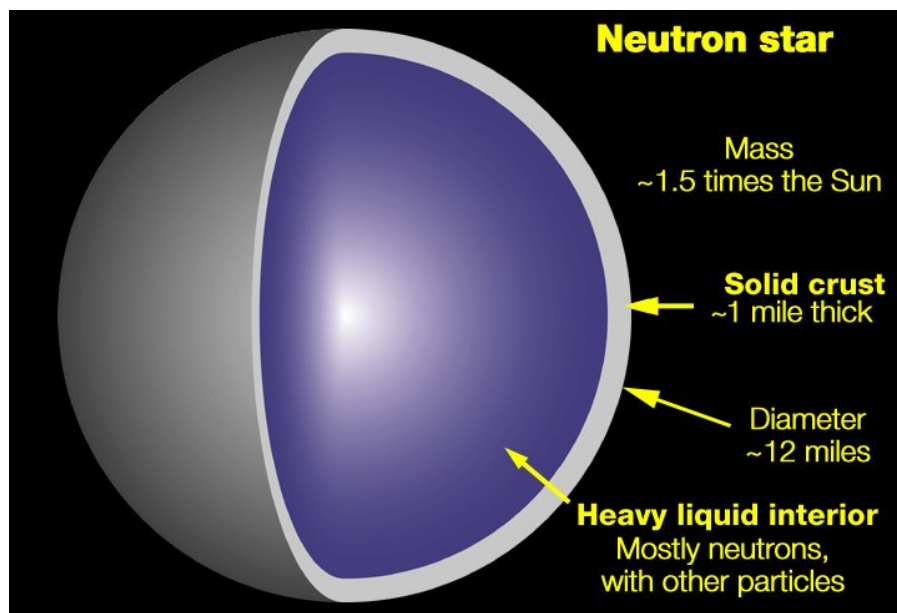
General Relativistic Astrophysics



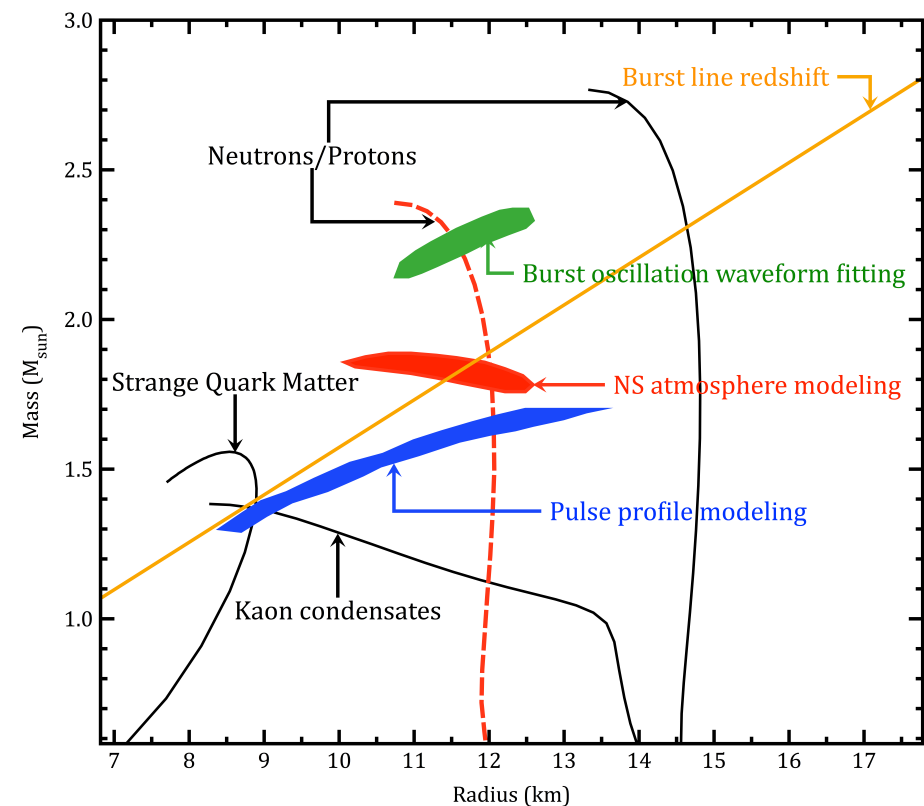
10 μ s time resolution

Fundamental Physics:

The Equation of state of dense matter

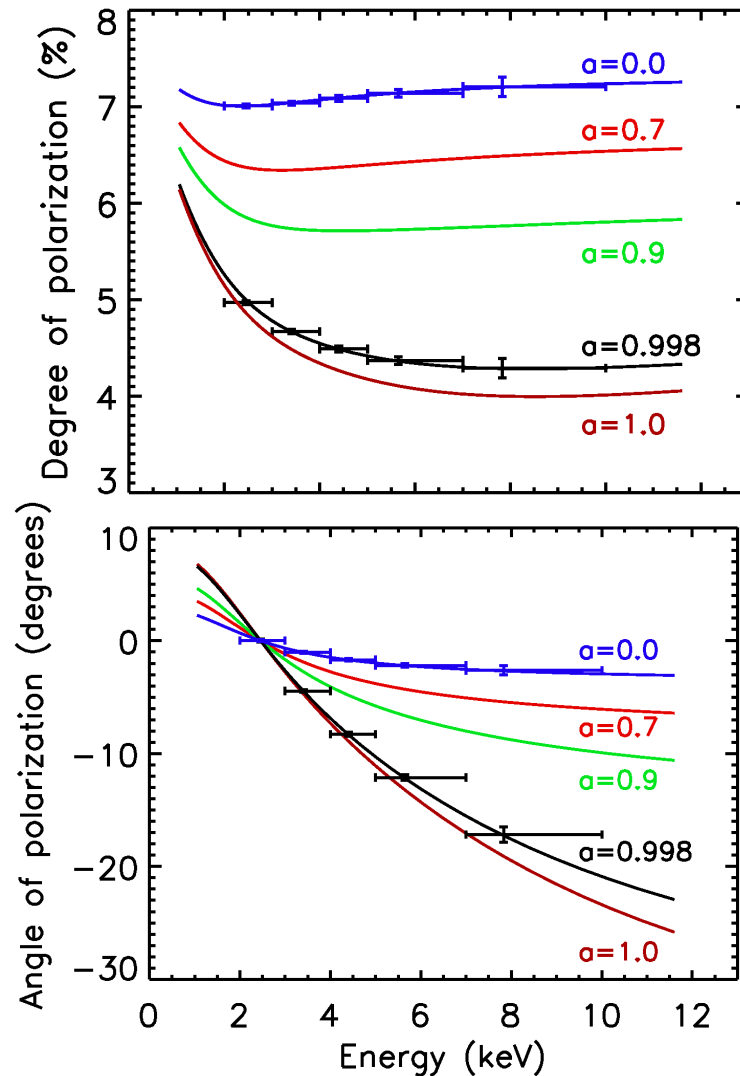


Neutron star structure



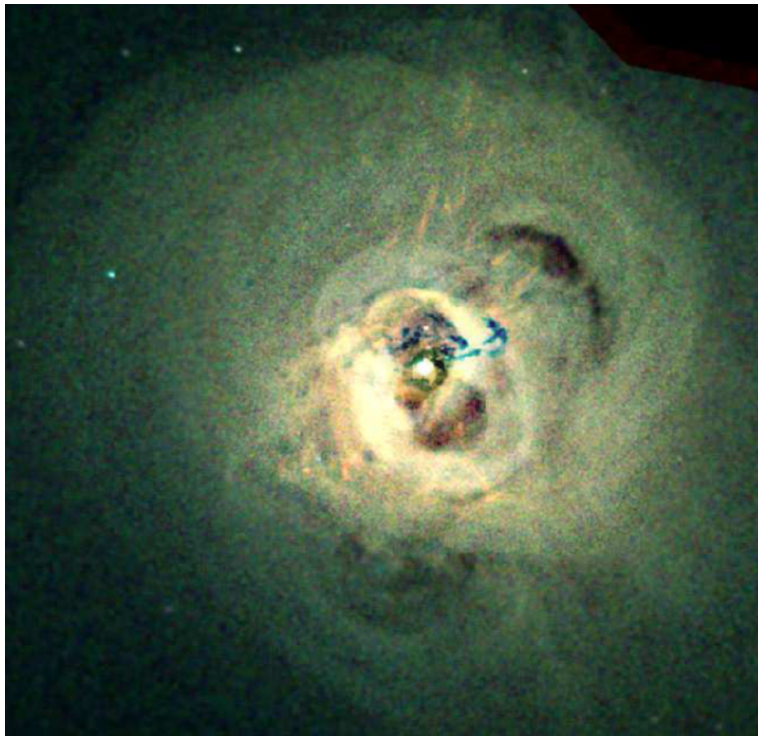
Mass-radius relation

X-ray Polarization: A New Probe of GR

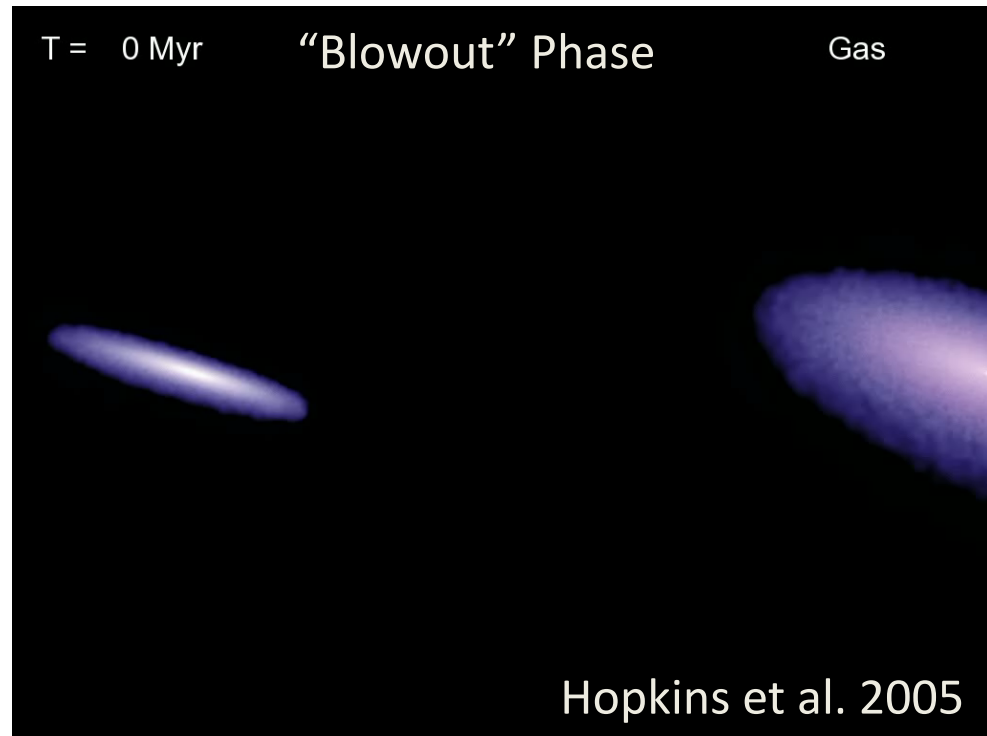


1% MDP, 1 mCrab,
in 100ks

4. Cosmic Feedback: Connecting Black Holes and Large Scale Structure

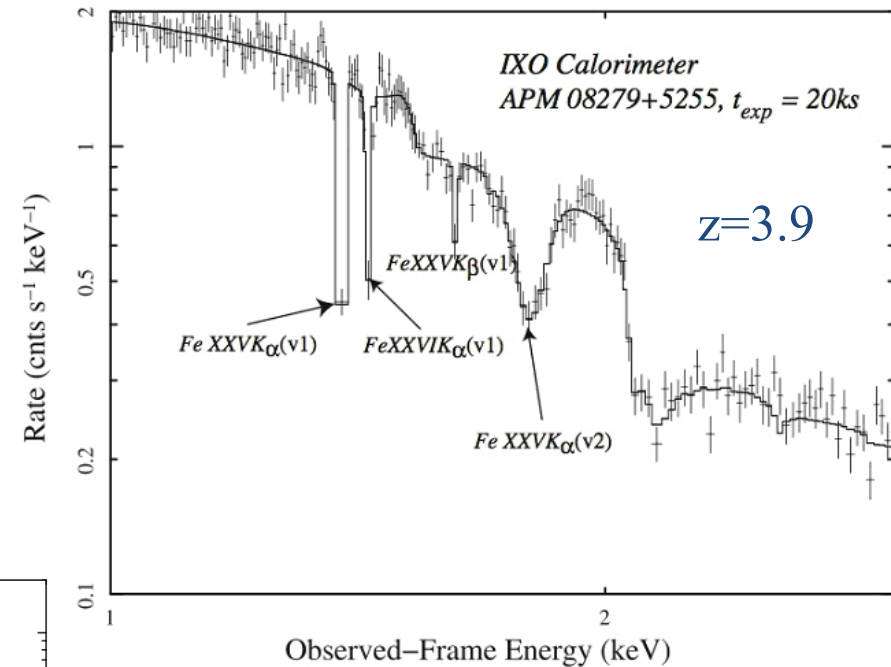
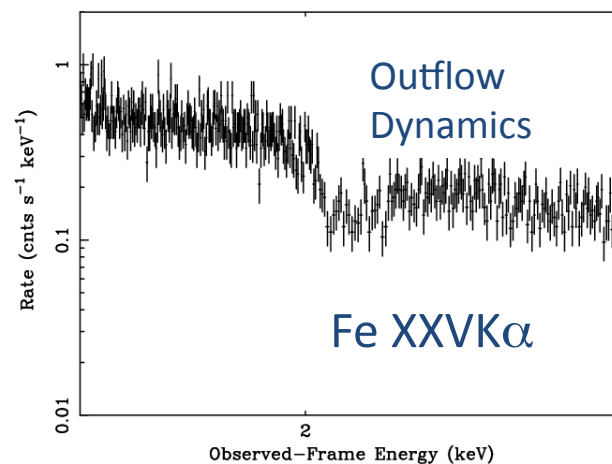
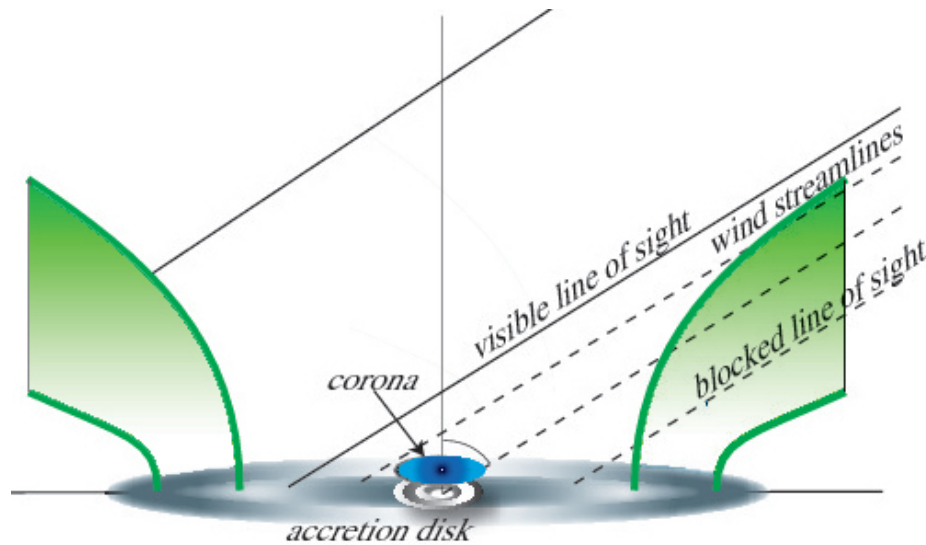


The Perseus Cluster



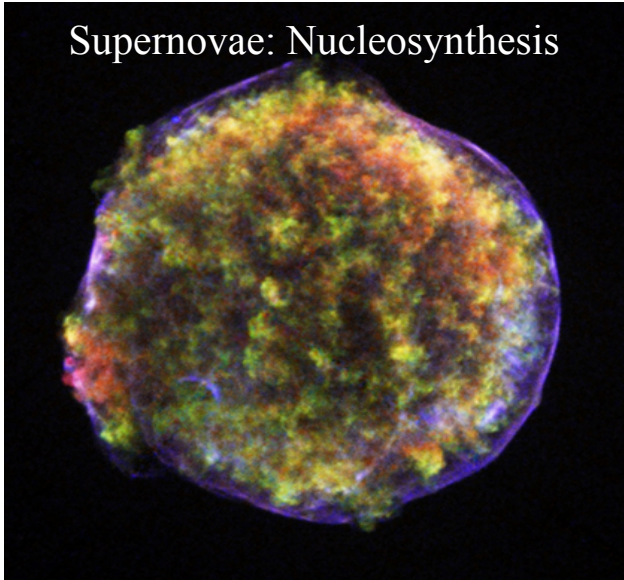
Galaxy Evolution

The Physics of Feedback

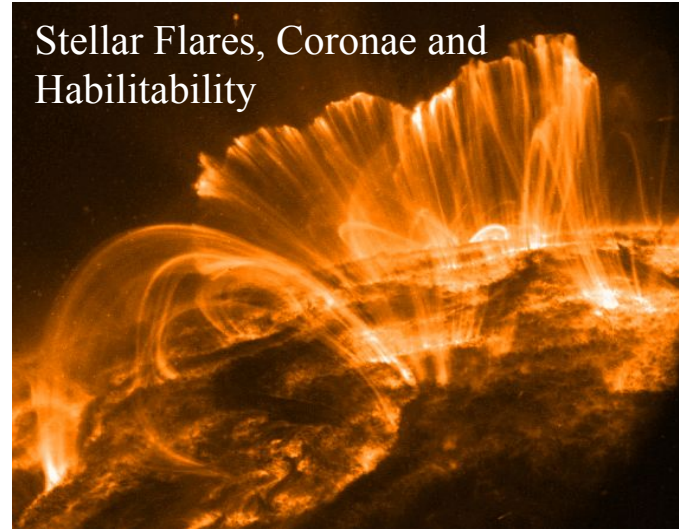


Life Cycles of Matter and Energy

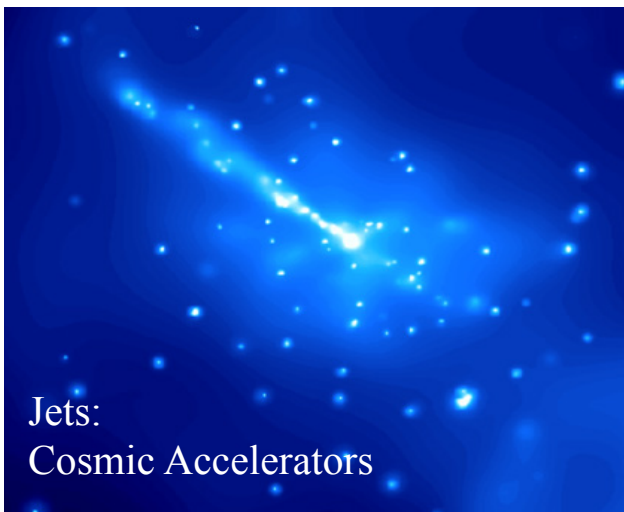
Supernovae: Nucleosynthesis



Stellar Flares, Coronae and Habitability



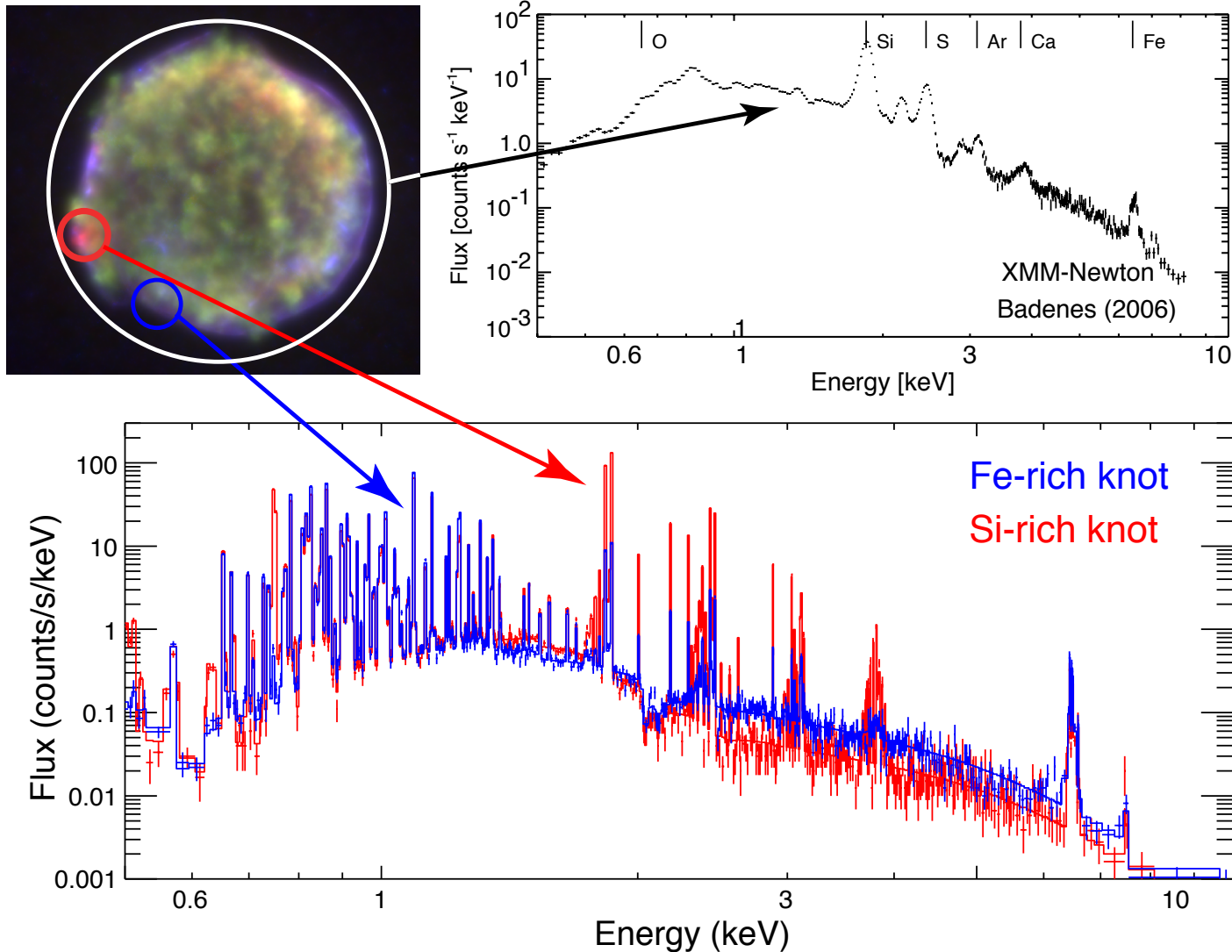
Jets:
Cosmic Accelerators



Charge Exchange: Comets



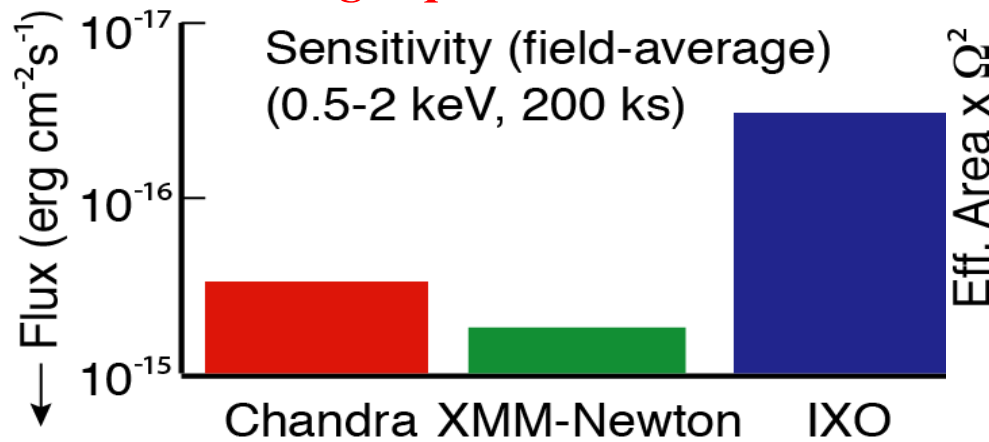
Life Cycles of Matter and Energy



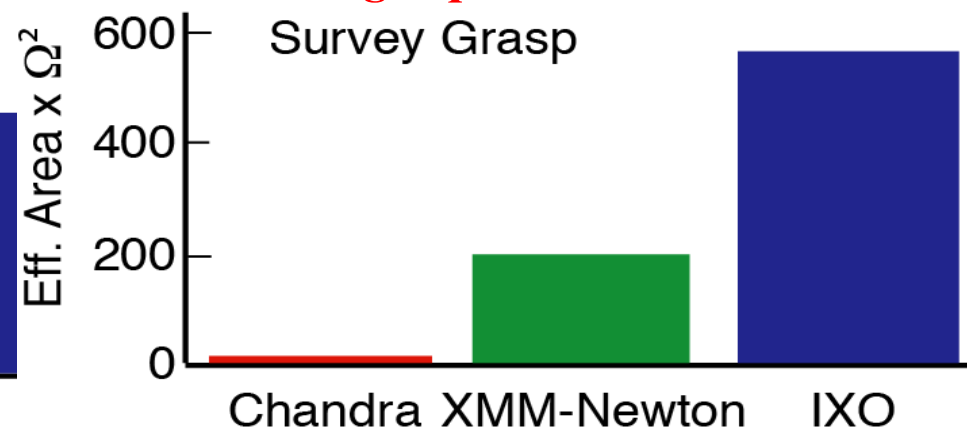
PARAMETER	REQUIREMENTS	SCIENCE
Effective Area	2.5 m^2 @ 1.25 keV 0.65 m^2 @ 6 keV with a goal of 1 m^2 150 cm^2 @ 30 keV with a goal of 350 cm^2	Black hole evolution, large scale structure, cosmic feedback Strong gravity, Equation of State Cosmic acceleration, strong gravity
Spectral Resolution (FWHM)	$\Delta E = 2.5 \text{ eV}$ (@ 6 keV) within 2×2 arcmin $\Delta E = 10 \text{ eV}$ (@ 6 keV) within 5×5 arcmin (bandpass 0.3-12 keV) $\Delta E = 150 \text{ eV}$ @ 6 keV within 18 arcmin diameter (0.1-15 keV) $E/\Delta E = 3000$ (0.3-1 keV) with an area of $1,000 \text{ cm}^2$ and a goal of $3,000 \text{ cm}^2$ for point sources $\Delta E = 1 \text{ keV}$ within 8×8 arcmin (10-40 keV)	Black hole evolution & cosmic feedback Large scale structure Missing baryons using tens of background AGN
Angular Resolution	5 arcsec HPD (0.1-7 keV) 30 arcsec HPD (7-40 keV); goal of 5 arcsec	Large scale structure, cosmic feedback, black hole evolution, missing baryons
Count Rate	1 Crab with > 90% throughput $\Delta E < 200 \text{ eV}$ @ 6 keV (0.3-15 keV)	Strong gravity Equation of State
Polarimetry	1% MDP on 1mCrab, 100 ksec, 3σ (2-6 keV)	AGN geometry Strong gravity
Astrometry	1.5 arcsec at 3σ confidence	Black hole evolution
Absolute Timing	100 μsec	Neutron star studies

IXO is a Vast Improvement over Existing Missions

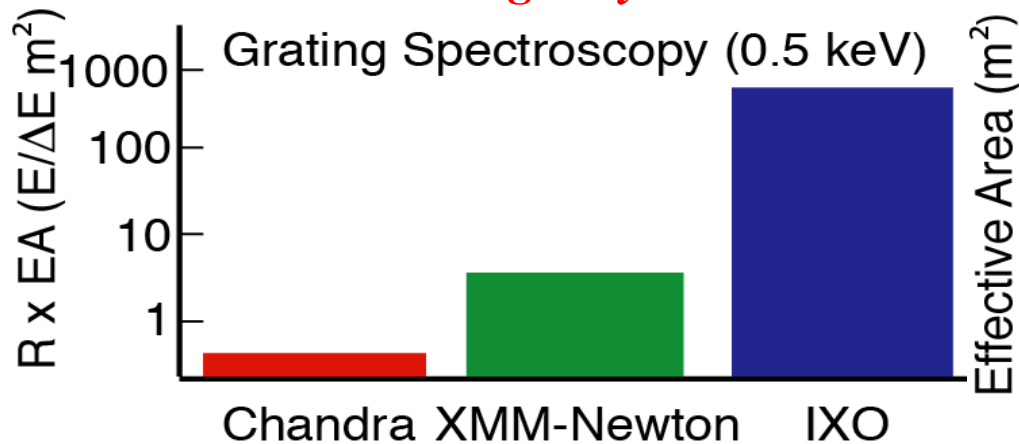
Growing supermassive black holes



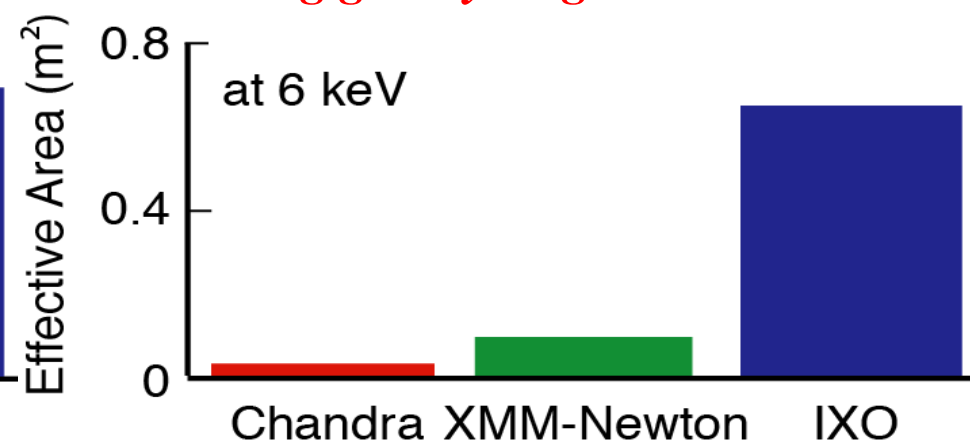
Growing supermassive black holes



Missing baryons



Strong gravity/large scale structure

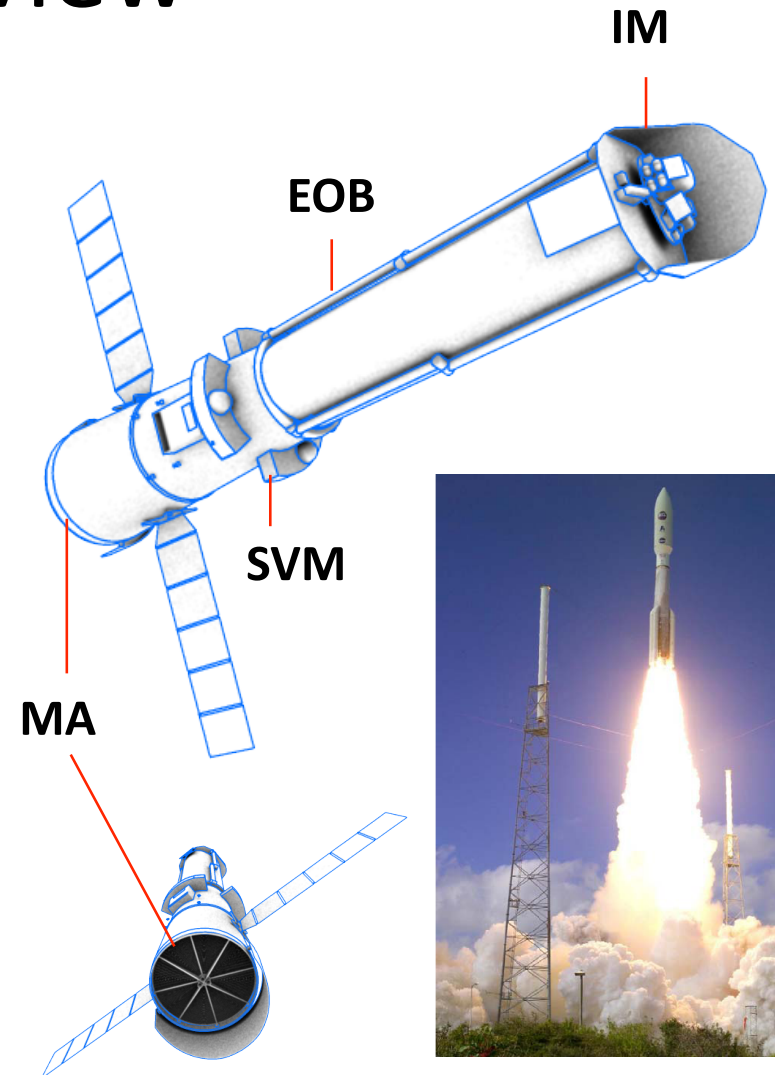


The IXO Mission

Paris, 3 Feb 2011

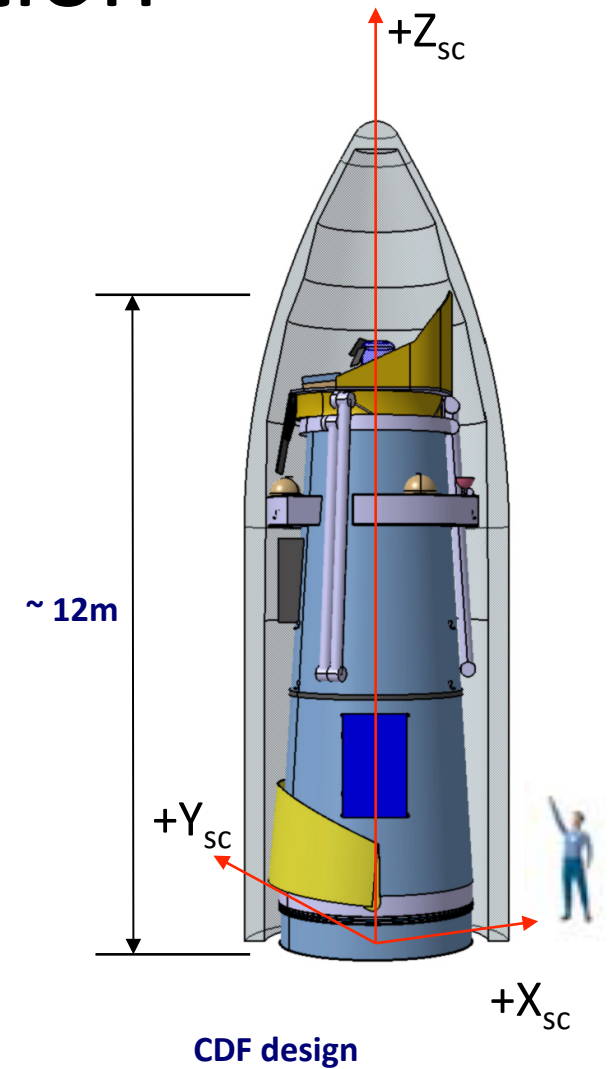
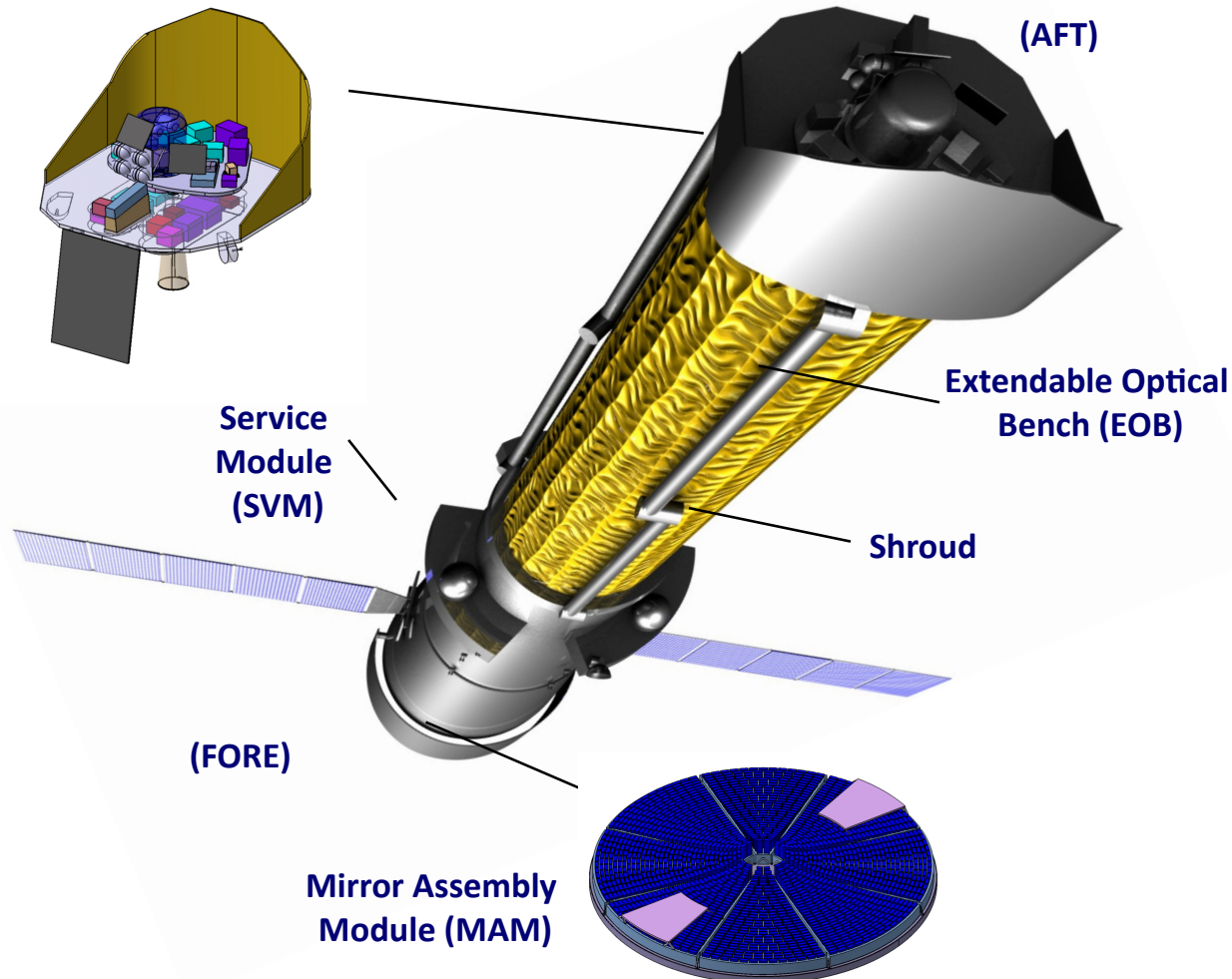
Mission Overview

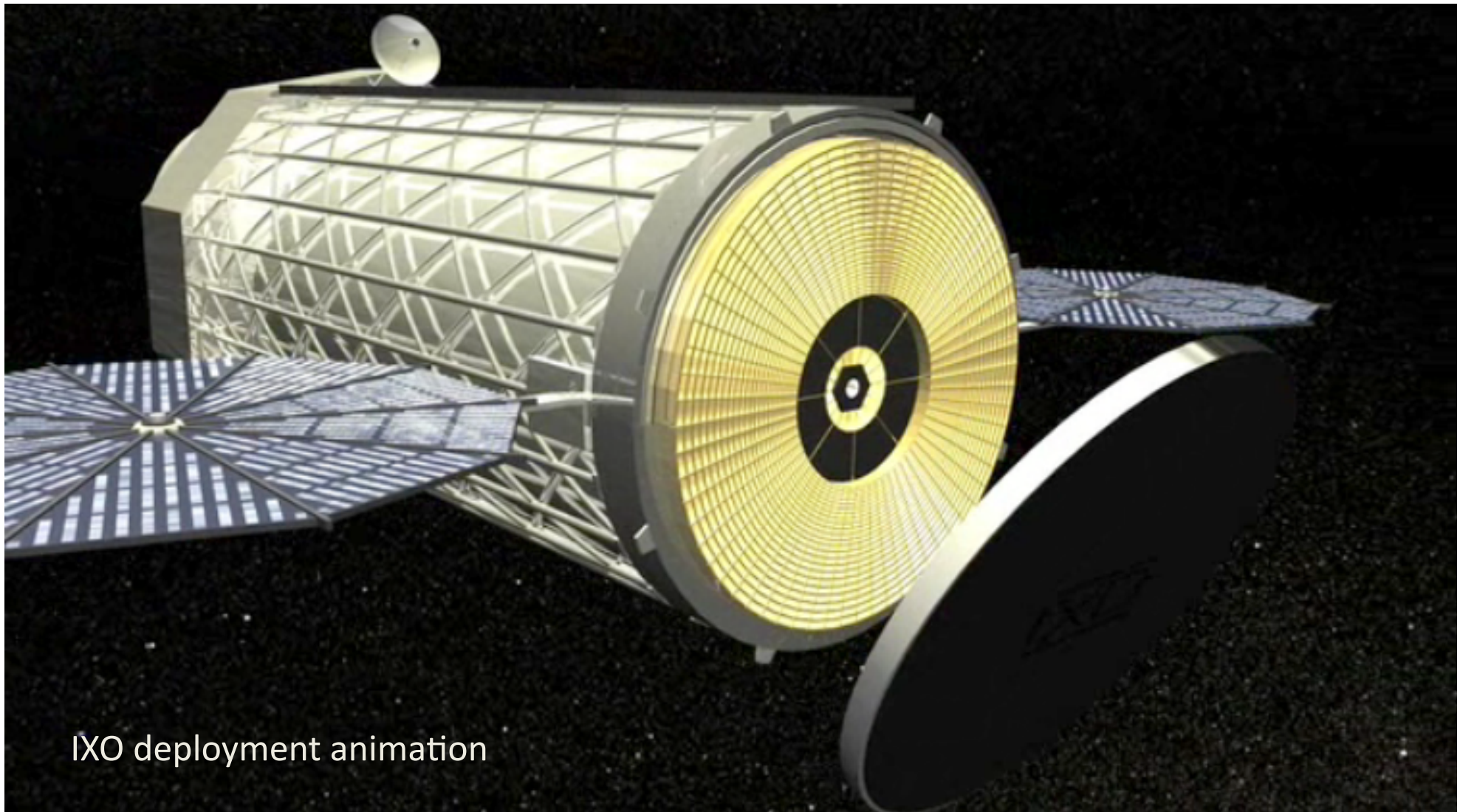
- Large X-ray observatory (facility class mission, follow up to XMM-Newton & Chandra).
- Merger of XEUS (candidate to CV15-25) and Constellation X.
- Single, large aperture telescope, 0.1 to 40 keV.
- Large class S/C (10m, 6.5 t), with extendable optical bench to reach a 20m focal length.
- LV = Atlas V/551 (or Ariane 5/ECA), large halo orbit at L2.
- Nominal lifetime 5 yr, consumables for 10 yr.
- Four key elements:
Mirror Assembly (MA), Service Module (SVM), Extendable Optical Bench (EOB) and Instrument Module (IM).



Spacecraft configuration

Instrument Module (IM)



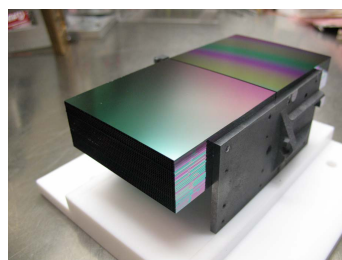


IXO deployment animation

IXO optics

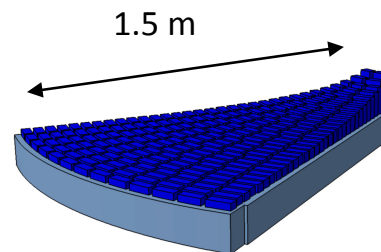
- X-ray telescope, 3.2m dia with a total effective area $> 2.5 \text{ m}^2$ (at 1.25 keV).
- Angular resolution 5" (at energy $< 7 \text{ keV}$).
- $F = 20\text{m}$ dictated by energy range and effective area. Wolter I (XMM).
- Two optics technologies are available (system design compatible):
 - Baseline is Silicon Pore Optics (SPO, Europe).
 - SPO under development and now at TRL=4. TRL=5 expected by 2011.
 - Optics mass $\sim 650 \text{ kg}$ (SPO), located in Mirror Assembly Module.
 - Back-up is Segmented Glass Optics (SGO, USA & Europe).
 - Confirmation of optics technology expected by end of 2012.

Modular / hierarchical approach: Module to Assembly

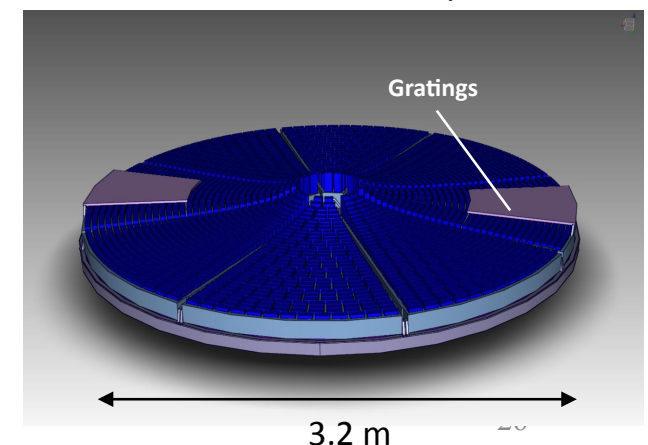


Mirror Module

10 cm

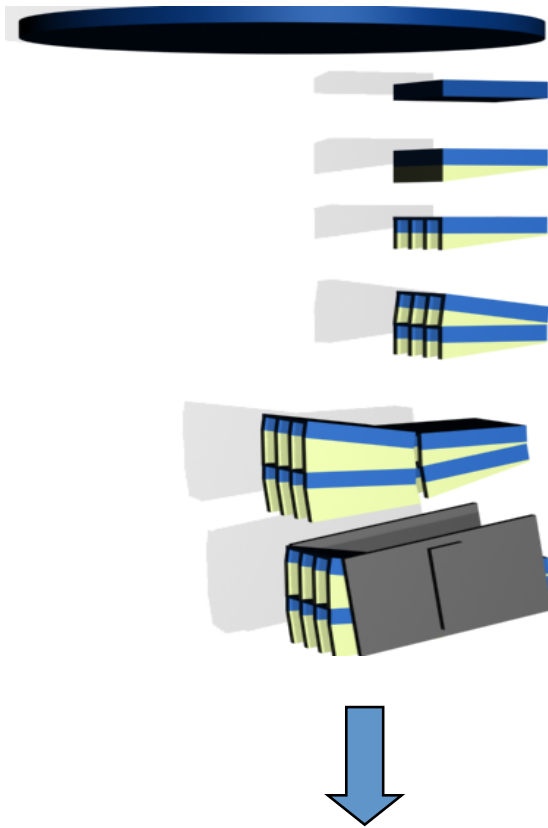


Petal



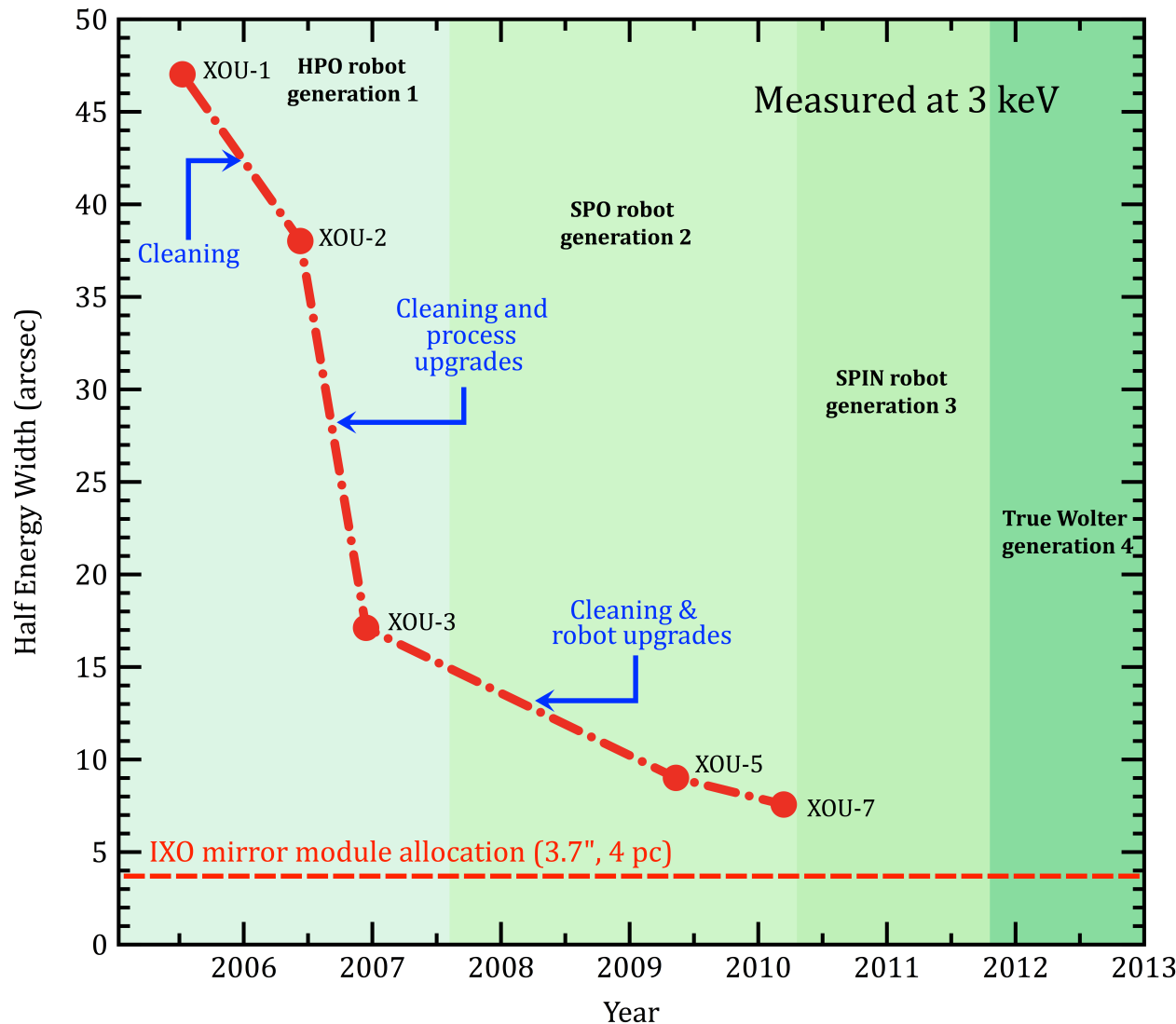
Mirror Assembly

IXO optics

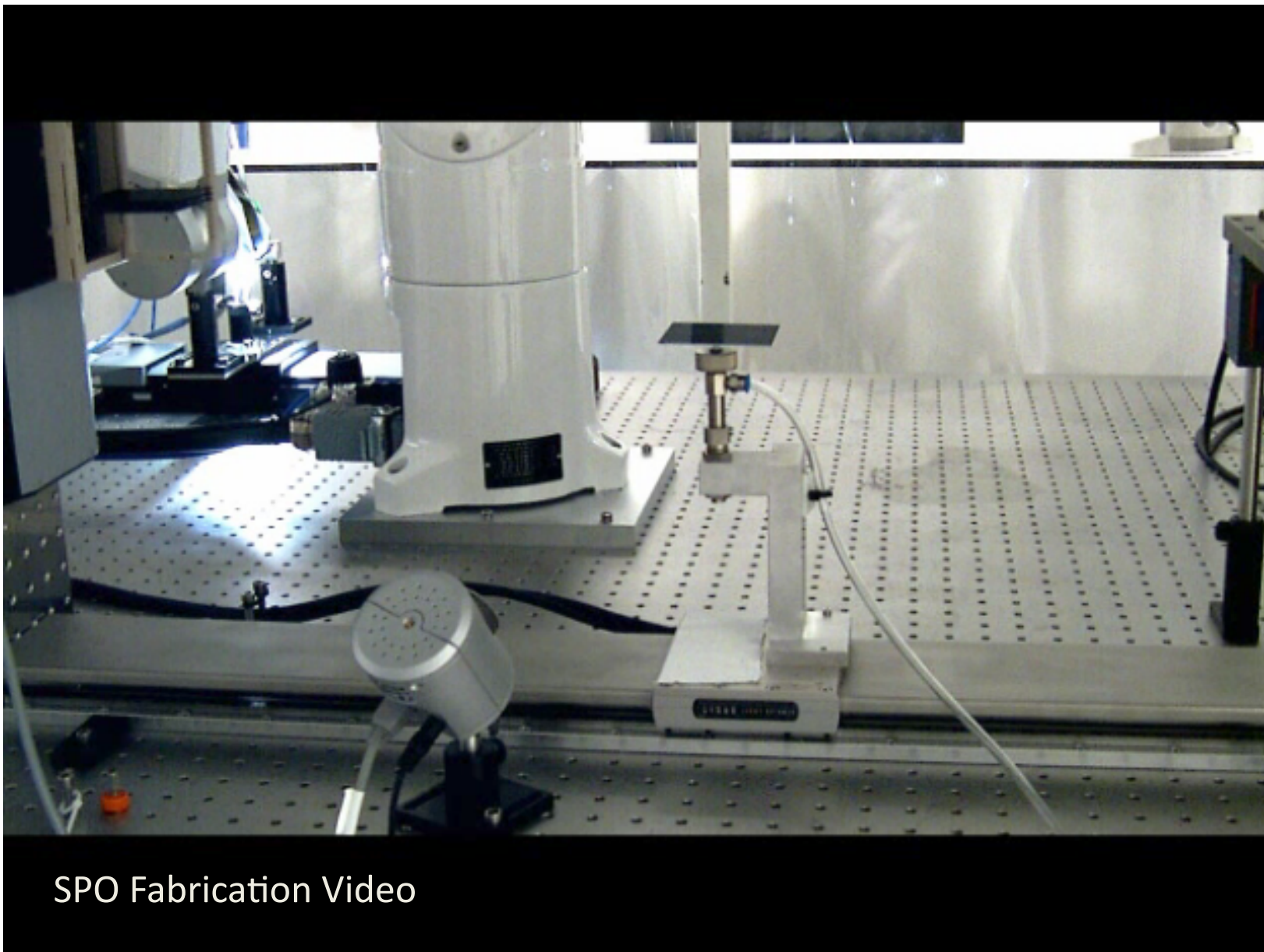


- SPO based on super-polished, commercial quality Si wafer.
- Micro-electronics fabrication processes to produce individual modules.
- Robotic assembly facility in clean room.
- Detailed thermo-mechanical analysis & test.
- Development plan in place. Activities are ongoing to:
 - Pre-qualify MM in relevant environment.
 - Consolidate mass production process.
 - Continue to improve angular resolution.

IXO optics



- X-ray tests on Mirror Modules (3 keV).
- Stack with 4 pairs as 'standard candle' (total of 8 plates).
- Fully representative of flight mounting & assembly scheme.
- XOU-7 started pre-qualification (used for models validation).



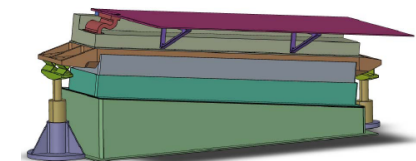
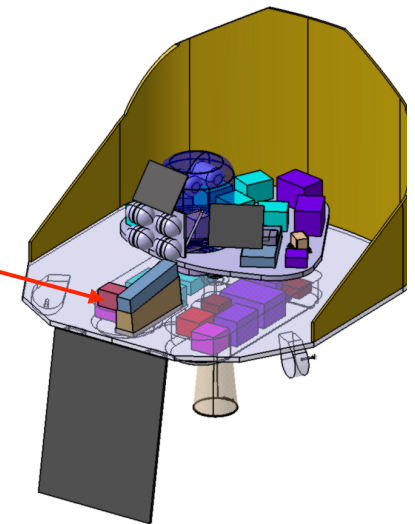
SPO Fabrication Video

The IXO instruments

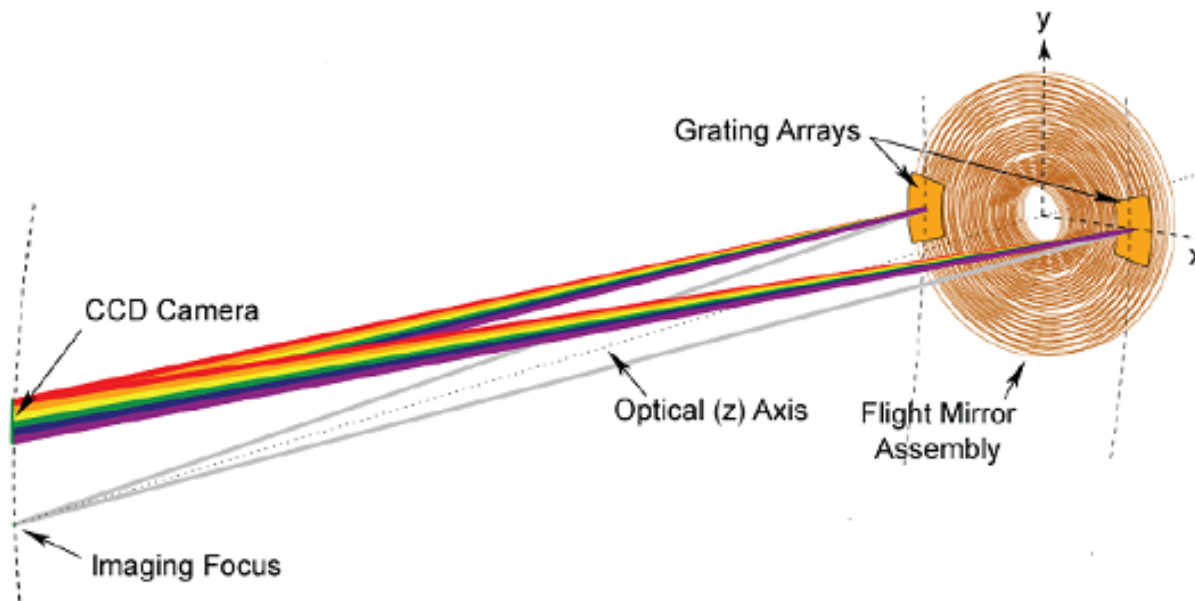
IXO Model Payload (~ 700 kg, 90 Gbit/day – parallel study):

- **X-ray Grating Spectrometer (XGS-CAT/OP), CCD focal plane (continuously illuminated via own gratings, at fixed location).**

Fixed platform



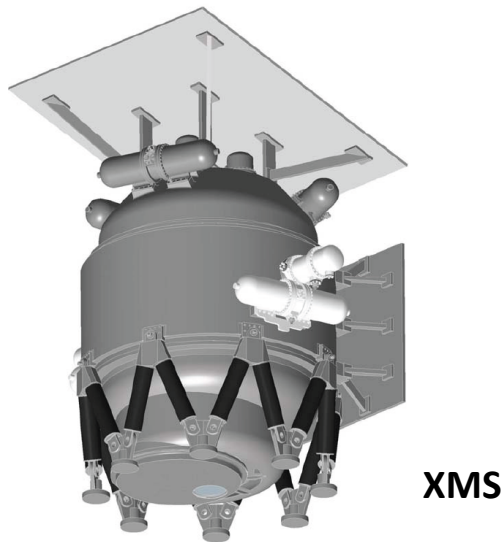
XGS/CAT



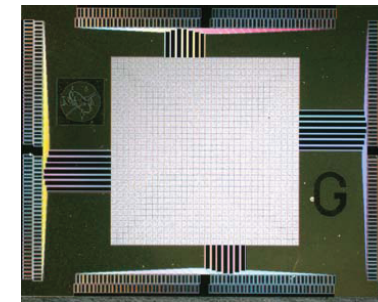
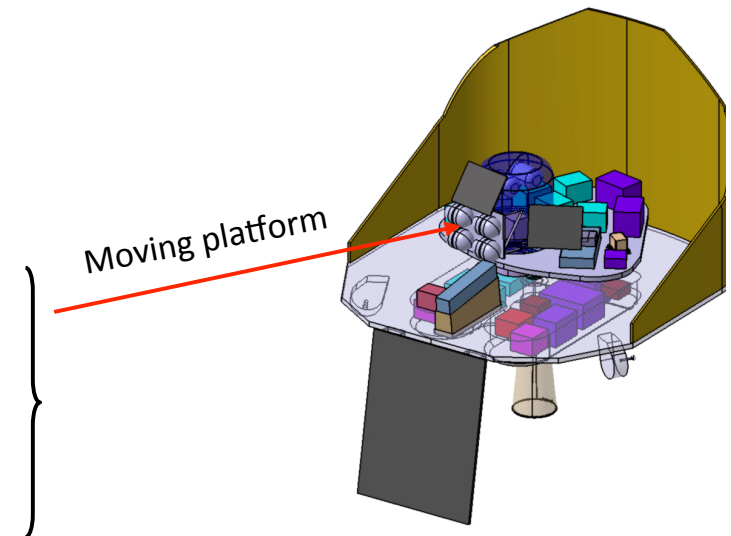
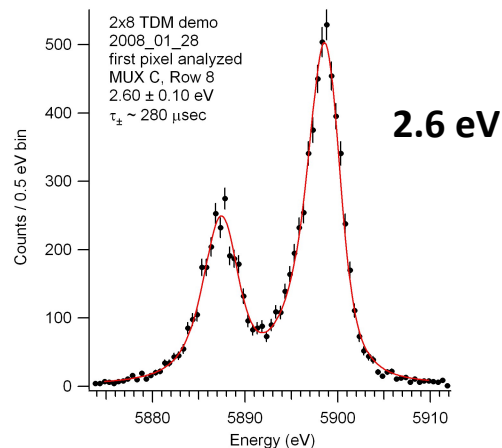
The IXO instruments

IXO Model Payload (~ 700 kg, 90 Gbit/day – parallel study):

- X-ray Grating Spectrometer (XGS-CAT/OP), CCD focal plane (continuously illuminated via own gratings, at fixed location).
- **Micro-calorimeter Spectrometer (XMS), TES focal plane**



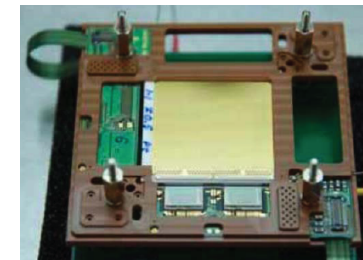
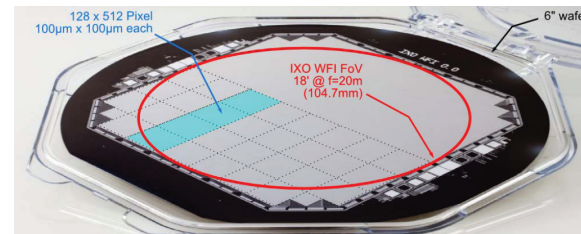
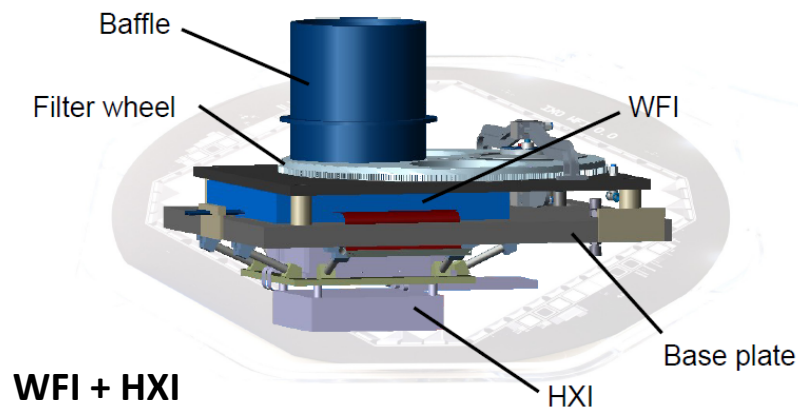
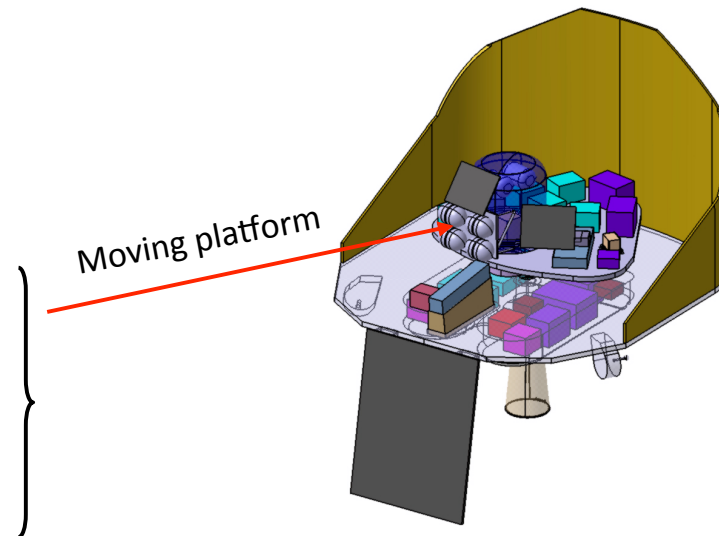
XMS



The IXO instruments

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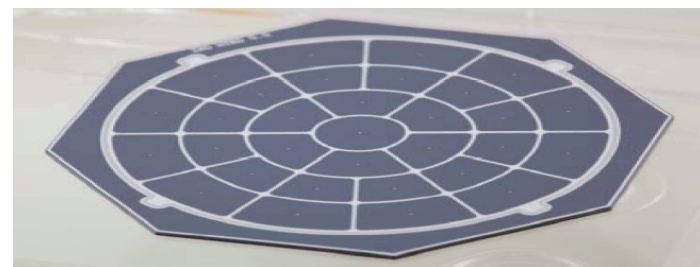
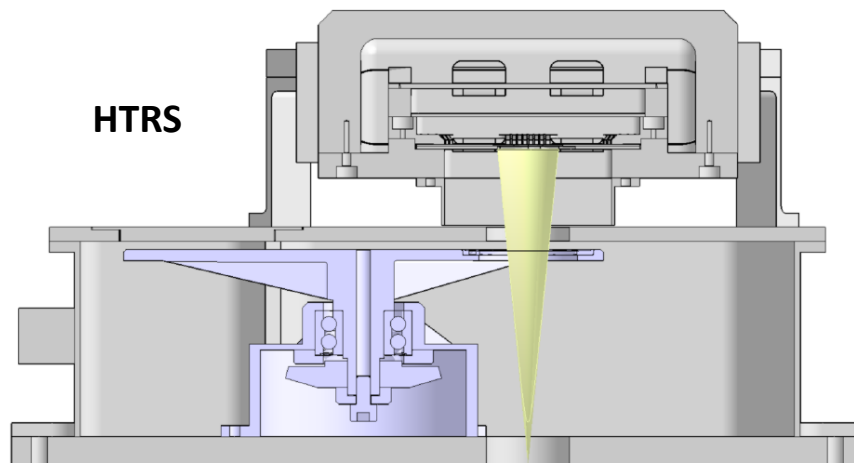
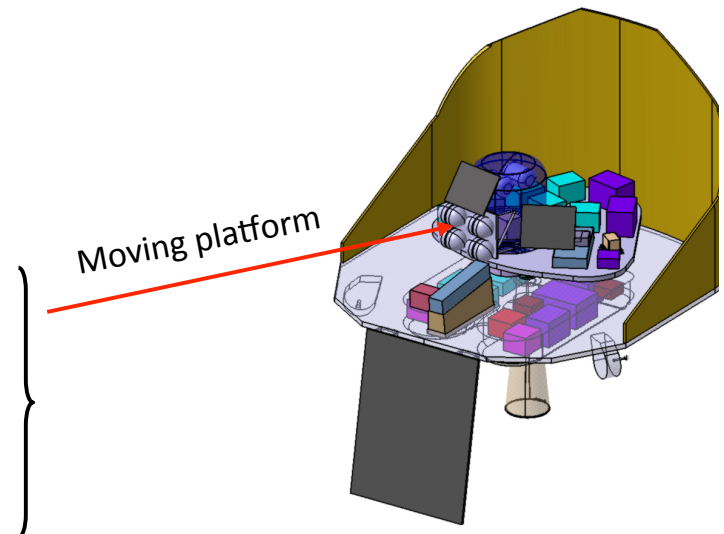
- X-ray Grating Spectrometer (XGS-CAT/OP), CCD focal plane (continuously illuminated via own gratings, at fixed location).
- Micro-calorimeter Spectrometer (XMS), TES focal plane
- **Wide Field Imager (WFI), Si APS focal plane with coaxial**
Hard X-ray Imager (HXI), Si/CdTe detectors



The IXO instruments

IXO Model Payload (~ 700 kg, 90 Gbit/day – parallel study):

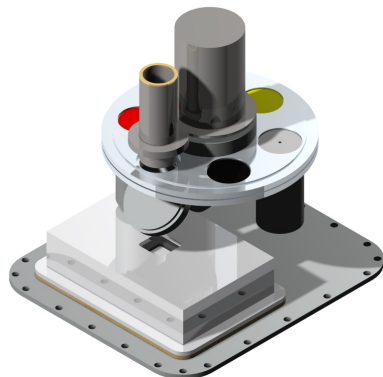
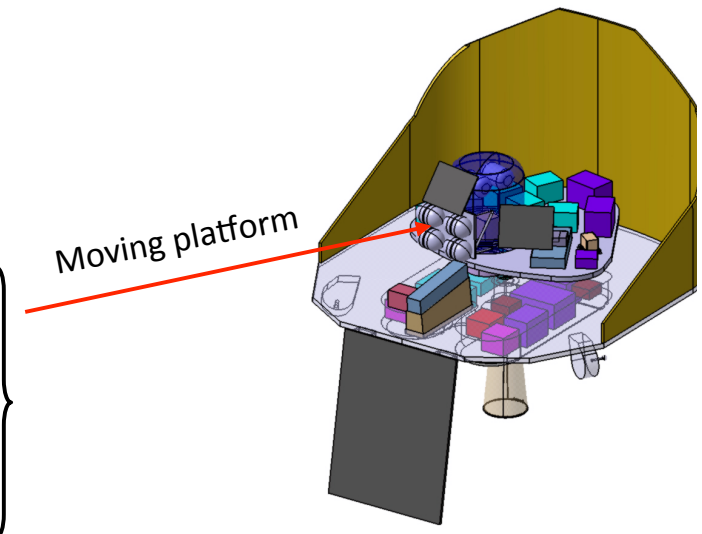
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- Wide Field Imager (WFI), Si APS focal plane with coaxial
- Hard X-ray Imager (HXI), Si/CdTe detectors
- **High Time Resolution Spectrometer (HTRS), SiDD focal plane**



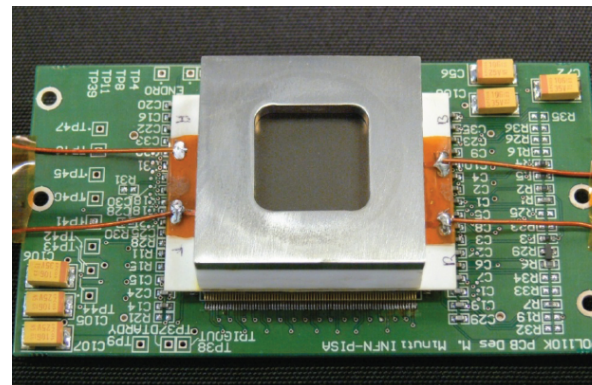
The IXO instruments

IXO Model Payload (~ 700 kg, 90 Gbit/day – parallel study):

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- Micro-calorimeter Spectrometer (XMS), TES focal plane
- Wide Field Imager (WFI), Si APS focal plane with coaxial
- Hard X-ray Imager (HXI), Si/CdTe detectors
- High Time Resolution Spectrometer (HTRS), SiDD focal plane
- **X-ray Polarimeter (XPOL), with gas pixel detector.**



XPOL

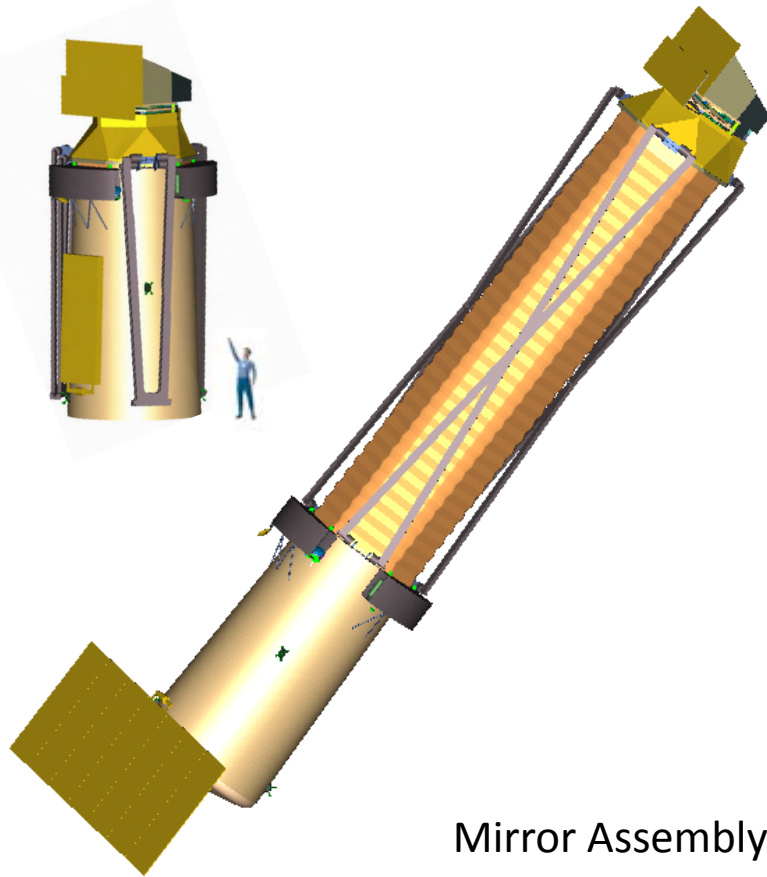
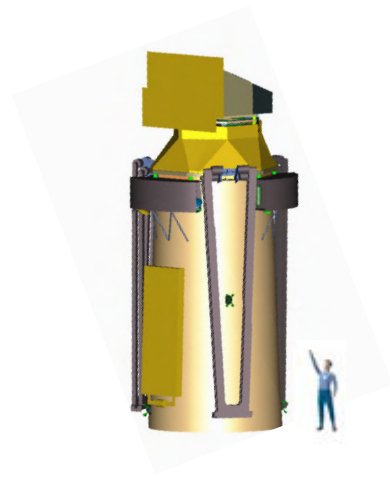


International cooperation

- IXO is an international cooperation program (ESA, JAXA and NASA).
- Different scenarios were examined during the assessment study.
- Reference scenario put forward to ESA review reflects partnership capabilities and heritage.
- Since Astro2010, SPO technology has been baselined (with SGO as back-up).
- Optional scenario with ESA maintaining system level responsibility.

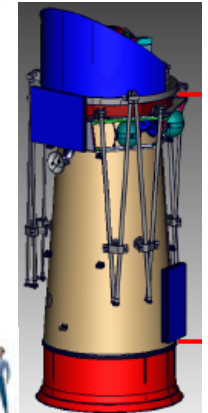
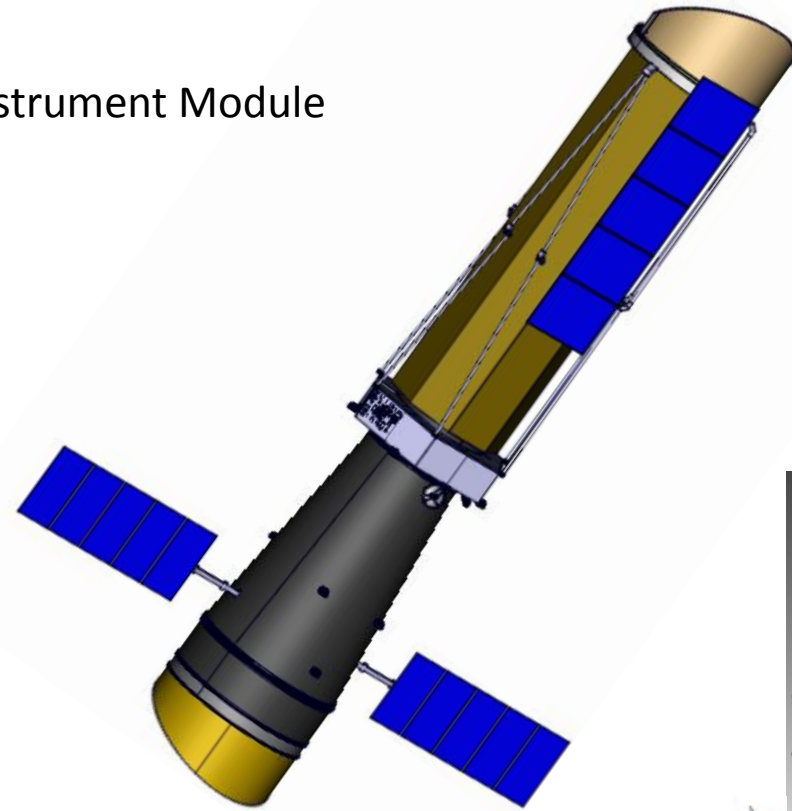
	ESA	Europe MS	NASA	JAXA
System/AIV-T			X	
SVM			X	
EOB + Shroud				X
FMA (w/ optics)	X			
IM	X			
LV + LVA			X	
MOC			X	
SOC	(X)		X	(X)
XMS cryo-chain				X
XMS		(X)	X	(X)
XGS		(X)	X	
WFI		X		
HXI				X
HTRS		X		
XPOL		X		

Industrial assessment



Mirror Assembly Module

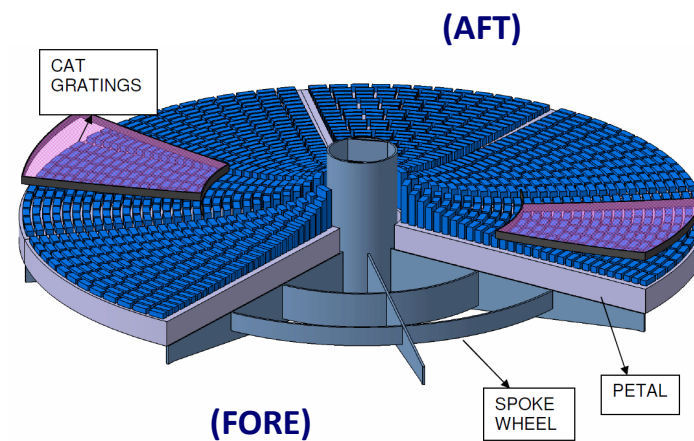
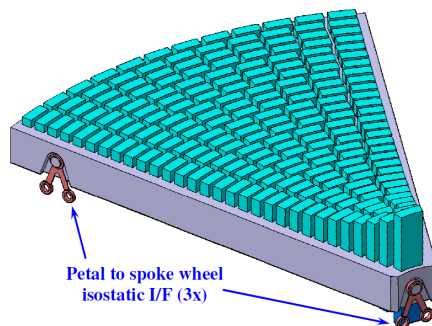
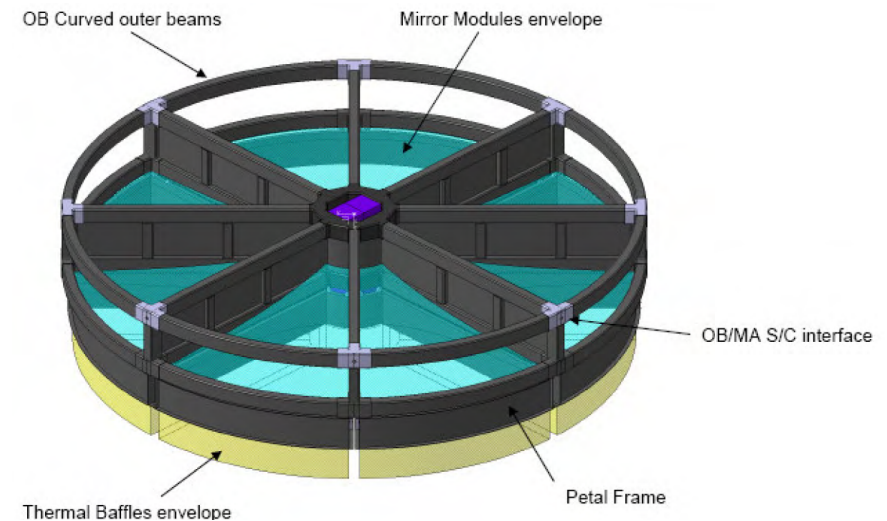
Instrument Module



Mirror Assembly Module

ESA contribution.

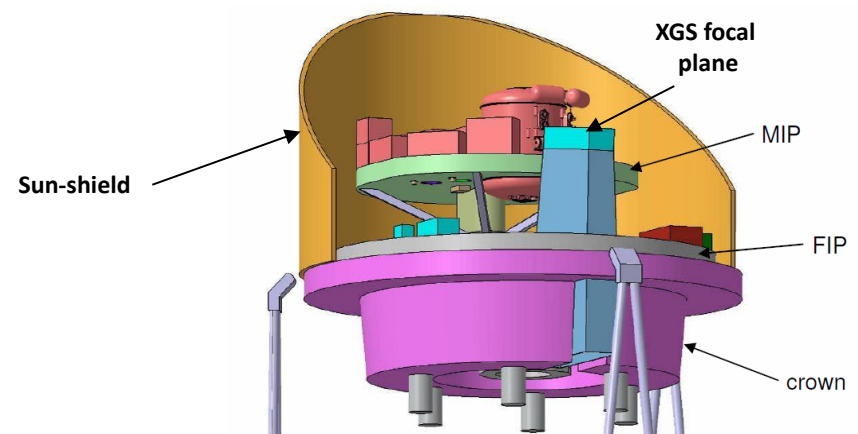
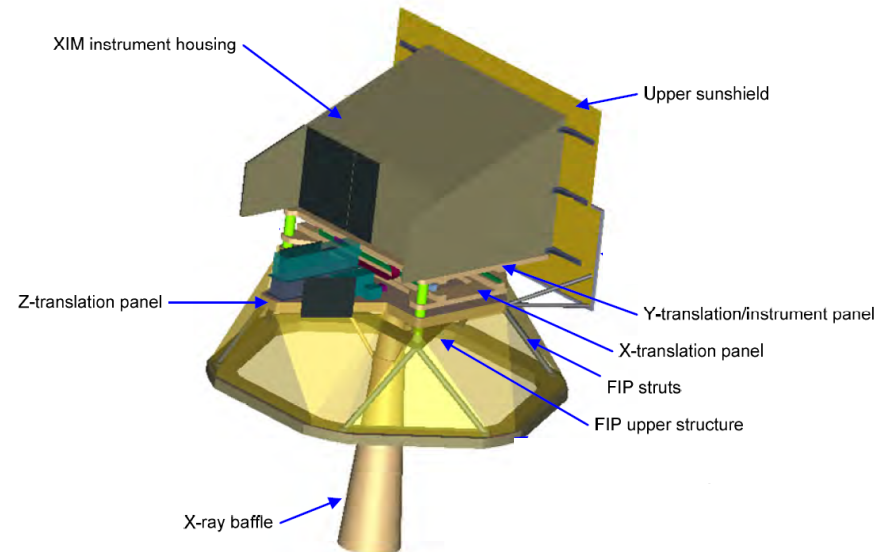
- Main elements:
 - X-ray optics (Mirror Modules)
 - Supporting structure & covers.
 - Thermal control elements.
- Total Mirror Module mass ~ 1700 kg.
- Both designs meet the science requirements.



Instrument Module

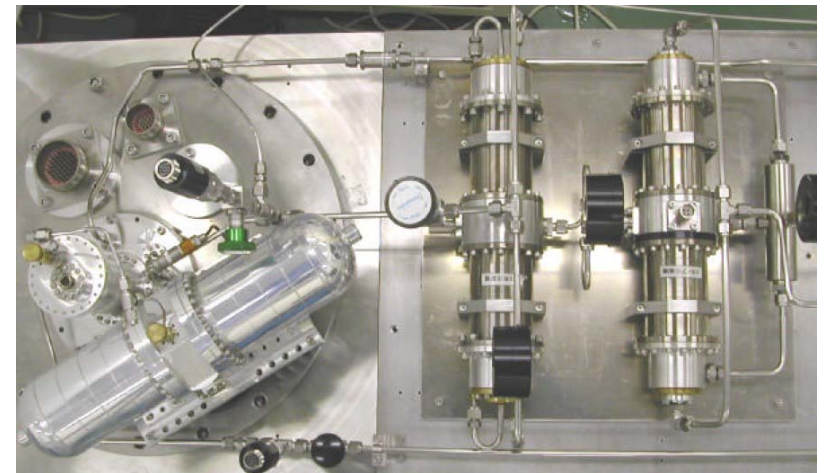
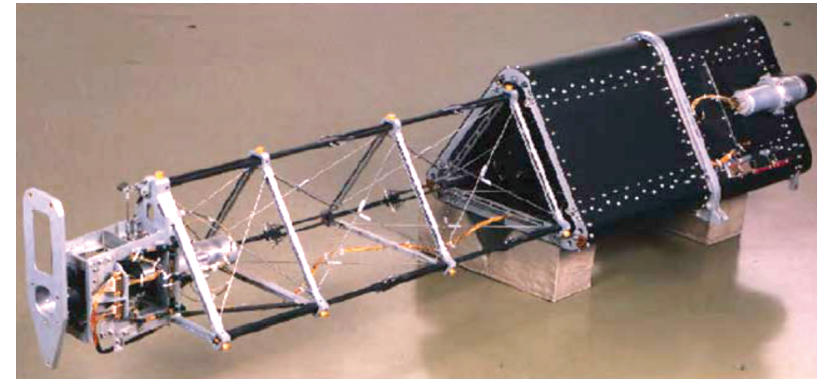
ESA contribution.

- Main elements:
 - Fixed Platform (FIP),
 - Moving Platform (MIP),
 - Mechanisms and thermal control HW.
- Total module mass ~ 1300 kg (including instruments).
- Both designs (rotating/translation mechanism) meet the requirements with comparable resources.



Study summary

- A feasible design identified by both Industrial Studies.
- System configuration consistent with NASA design.
- Resource budgets with margins exceeding the required level (SLM ~22%).
- Reference scenario takes into account heritage & expertise from previous developments (Astro-H, SPO, XMS).
- Flight heritage on payload elements (e.g. WFI APS Vs. BepiColombo MIXS).
- No significant developments required at S/C level.



ESA review

System level and Spacecraft:

- Reduce complexity of the Instrument Module, simplifying the mechanism design.

Optics:

- The review board considered that an angular resolution $< 10''$ is achievable with SPO and compatible with TRL=5 by the end of the Defin. Ph. ($5''$ angular resolution remains a goal).

Instruments:

- High level of design maturity of the IXO model payload was noticed by the board.
- Reduce complexity of the cryogenic spectrometer (XMS now 60% of total P/L mass).

Programmatic aspects:

- Reference scenario has clear technical I/F, reflecting partnership capabilities and heritage.
- Project schedule: launch by the end of 2022 considered as realistic.
- Production of flight optics (on critical path) requires adequate preparation in the Def. Ph.
- Instruments AO to be moved forward as much as possible (XMS on critical path).
- If compatible with CaC, ESA to consider taking lead on SOC (to be negotiated).

Conclusions

- System level studies have showed that IXO is feasible and converged on similar configuration and technical solutions.
- Steady progress is recorded on the optics developments, on track to achieve TRL=5 before the completion of the Definition Phase.
- The IXO model payload is mature and can take benefits of prior studies and expertise from recent science missions.
- The X-ray optics, Mirror Assembly and Instrument Module are well within the capabilities of the European space industry.

Both European industry and the scientific community have the opportunity to play a key role in building the next generation X-ray observatory, enabling 'orders of magnitude' gain in science performance.