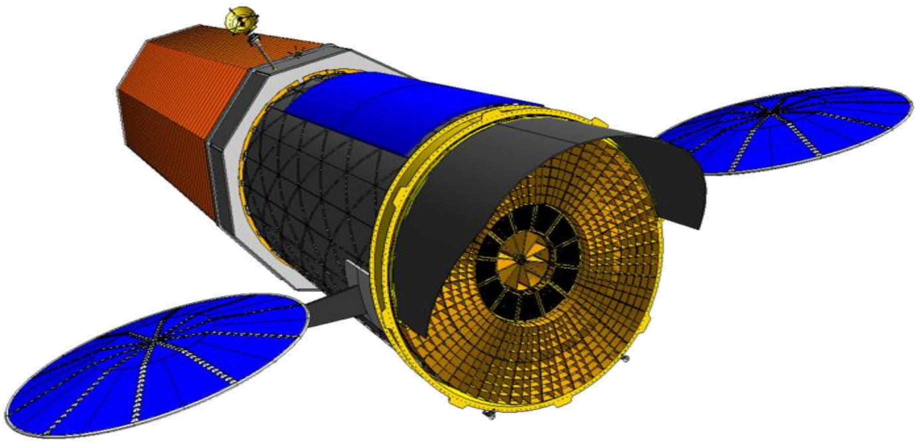
The International X-ray Observatory
IXO



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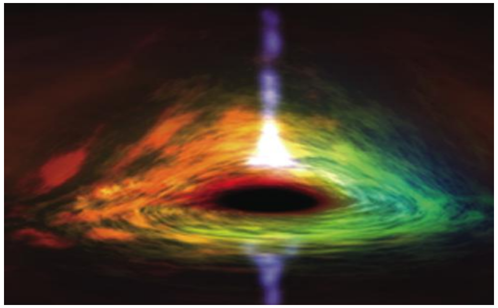
For the ESA-JAXA-NASA IXO Team

IXO Science Objectives



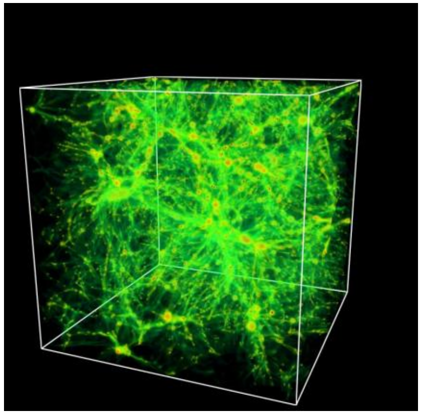
Black Hole growth and matter under extreme conditions

How do super-massive Black Holes grow and evolve?

What is the behavior of matter orbiting close to a Black Hole event horizons and does it follow the predictions of GR?

What is the equation of state of matter in Neutron Stars?

Galaxy Clusters, Galaxy Formation and Cosmic Feedback



What are the processes by which galaxy clusters evolve and how do clusters constrain the nature of Dark Matter and Dark Energy?

How does Cosmic Feedback work and influence galaxy formation?

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

The life cycles of matter and energy

How do supernovae explode and create the iron group elements?

How do high energy processes affect planetary formation and habitability?

How are particles accelerated to extreme energies producing shocks, jets and cosmic rays?

Key Performance Requirements

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

Mission Payload

Flight Mirror Assembly (FMA)

- Highly nested grazing incidence optics

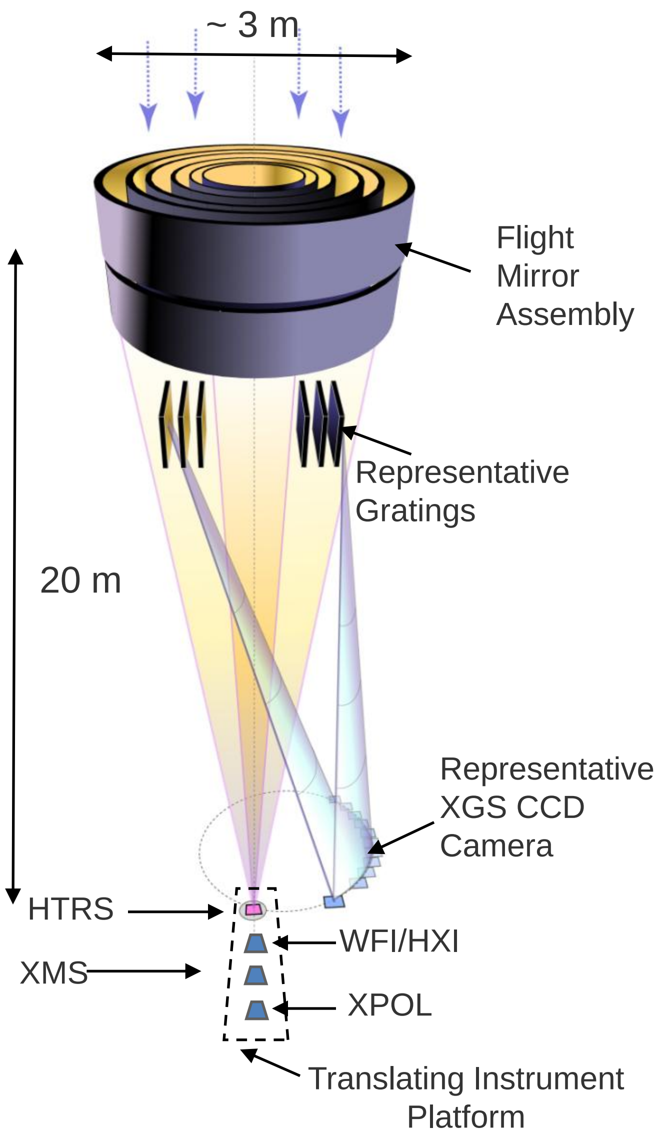
Spectroscopy Instruments

- X-ray Micro-calorimeter Spectrometer (XMS)
- X-ray Grating Spectrometer (XGS)

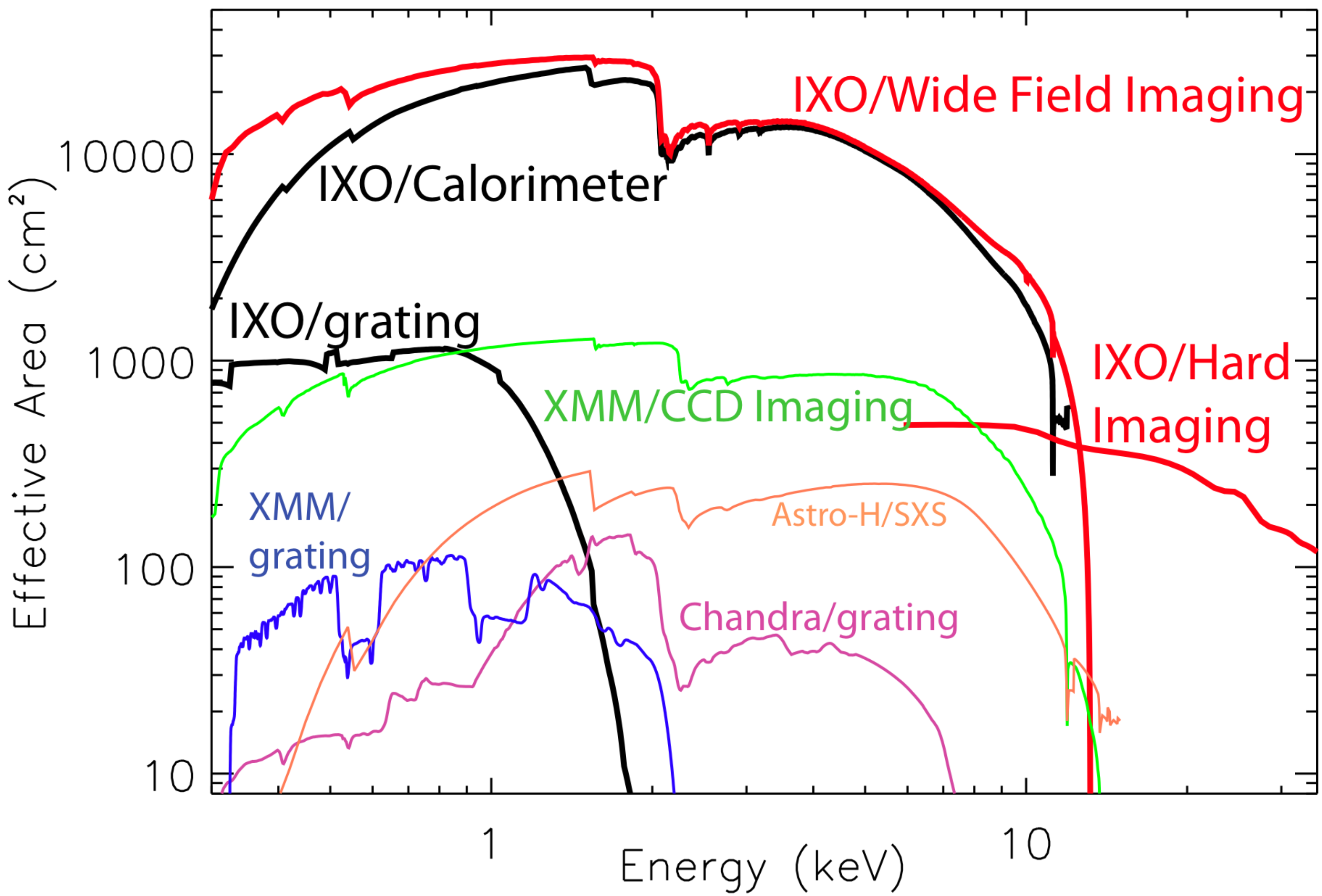
Imaging, Timing and Polarimetry Instruments

- Wide Field Imager (WFI) and Hard X-ray Imager (HXI)
- X-ray Polarimeter (XPOL)
- High Time Resolution Spectrometer (HTRS)

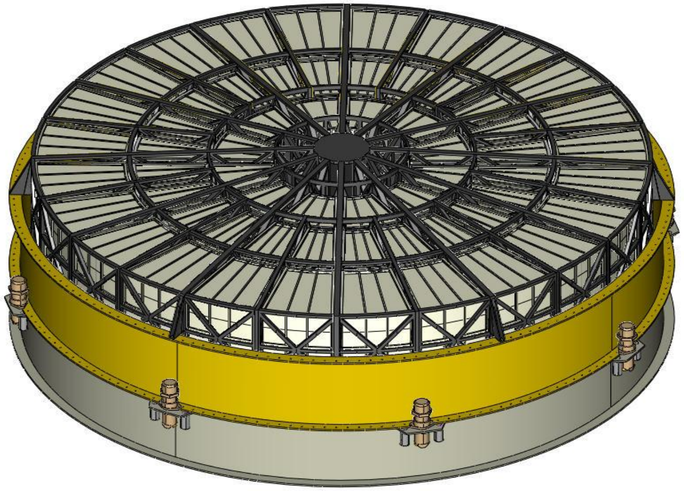
XMS, WFI/HXI, XPOL and HTRS observe one at a time by being inserted into focal plane via a Translating Instrument Platform



Effective area comparison

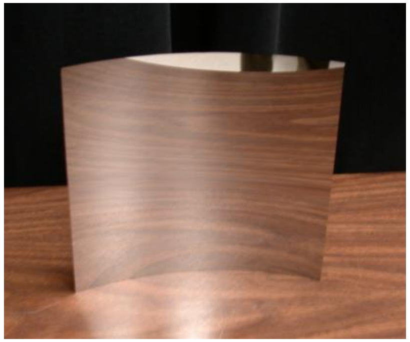


IXO X-ray Telescope

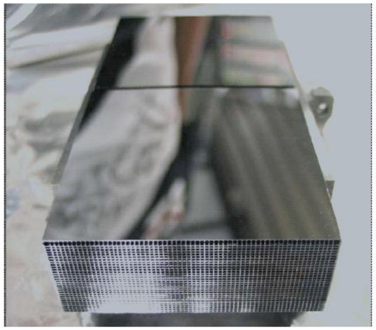


- Key requirements:
  - Effective area ~3 m^2 @ 1.25 keV
  - Angular Resolution <= 5 arc sec
- Single segmented optic with design optimized to minimize mass and maximize collecting area
  - Multilayers enhance hard X-ray response to 40 keV
- Two parallel technology approaches being pursued
  - ESA: Silicon micro-pore optics 3.8m diameter
  - NASA: Slumped glass 3.0m diameter
- Both making excellent progress
  - Already achieved 15 arc sec resolution, with further progress planned for this year
  - Slumped glass baselined for NuSTAR

Glass

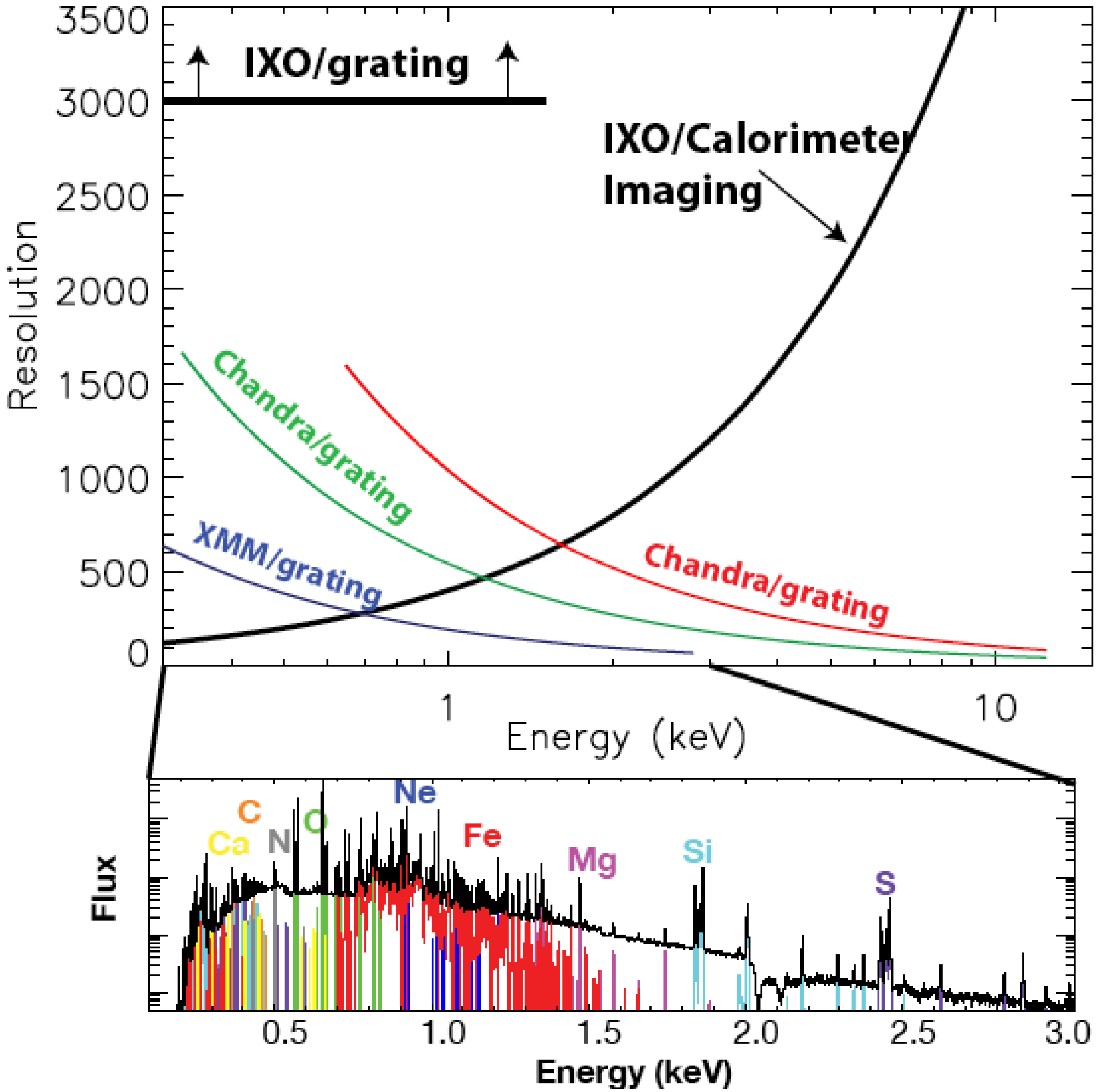


Silicon



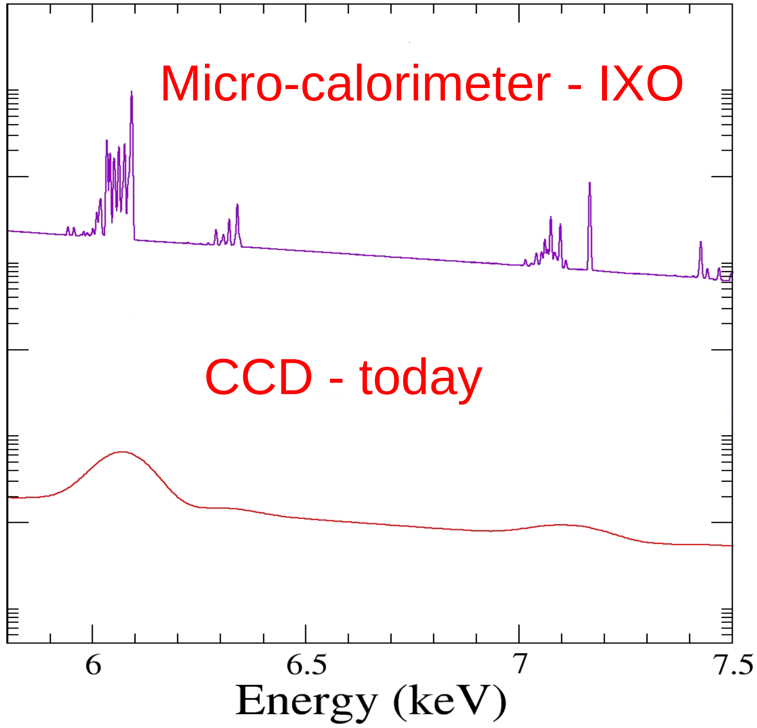
Spectral Capability

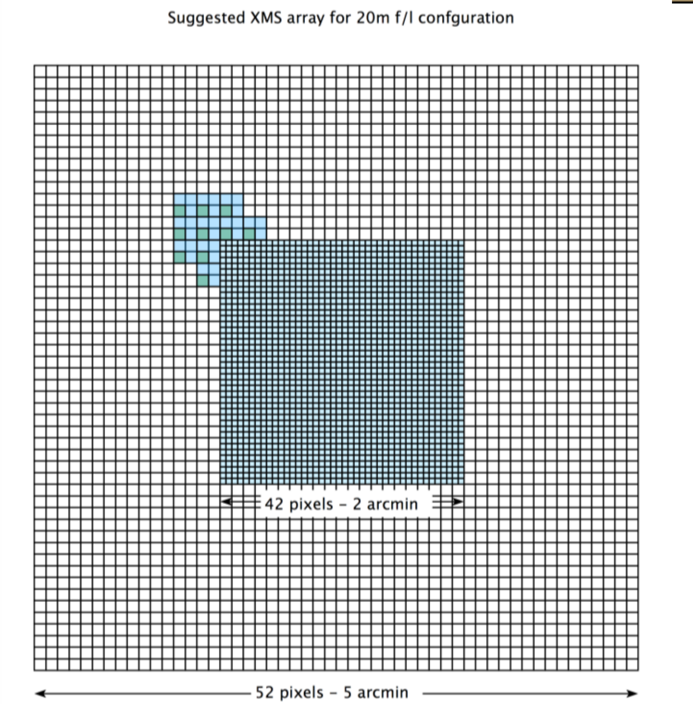
The IXO energy band contains the K-line transitions of 25 elements Carbon through Zinc allowing simultaneous direct abundance determinations using line-to-continuum ratios, plasma diagnostics and at iron K bulk velocities of 200 km/s

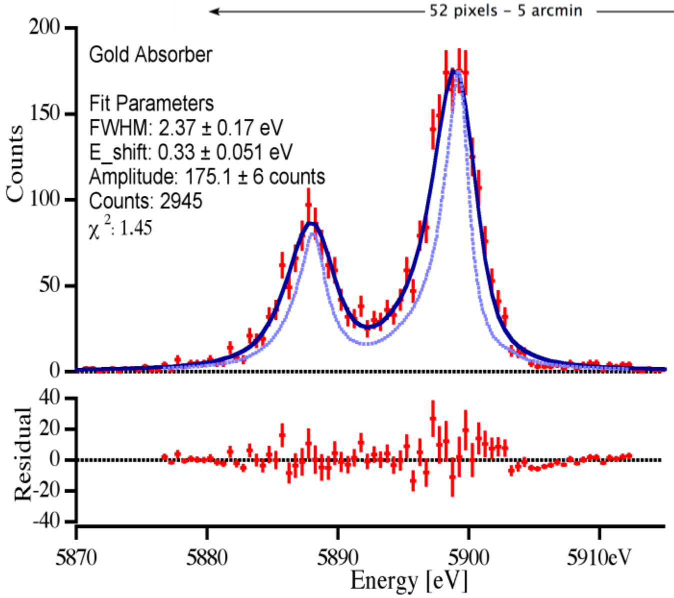


Example of Next Generation Instrument Capability X-ray Micro-calorimeter Spectrometer (XMS)

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

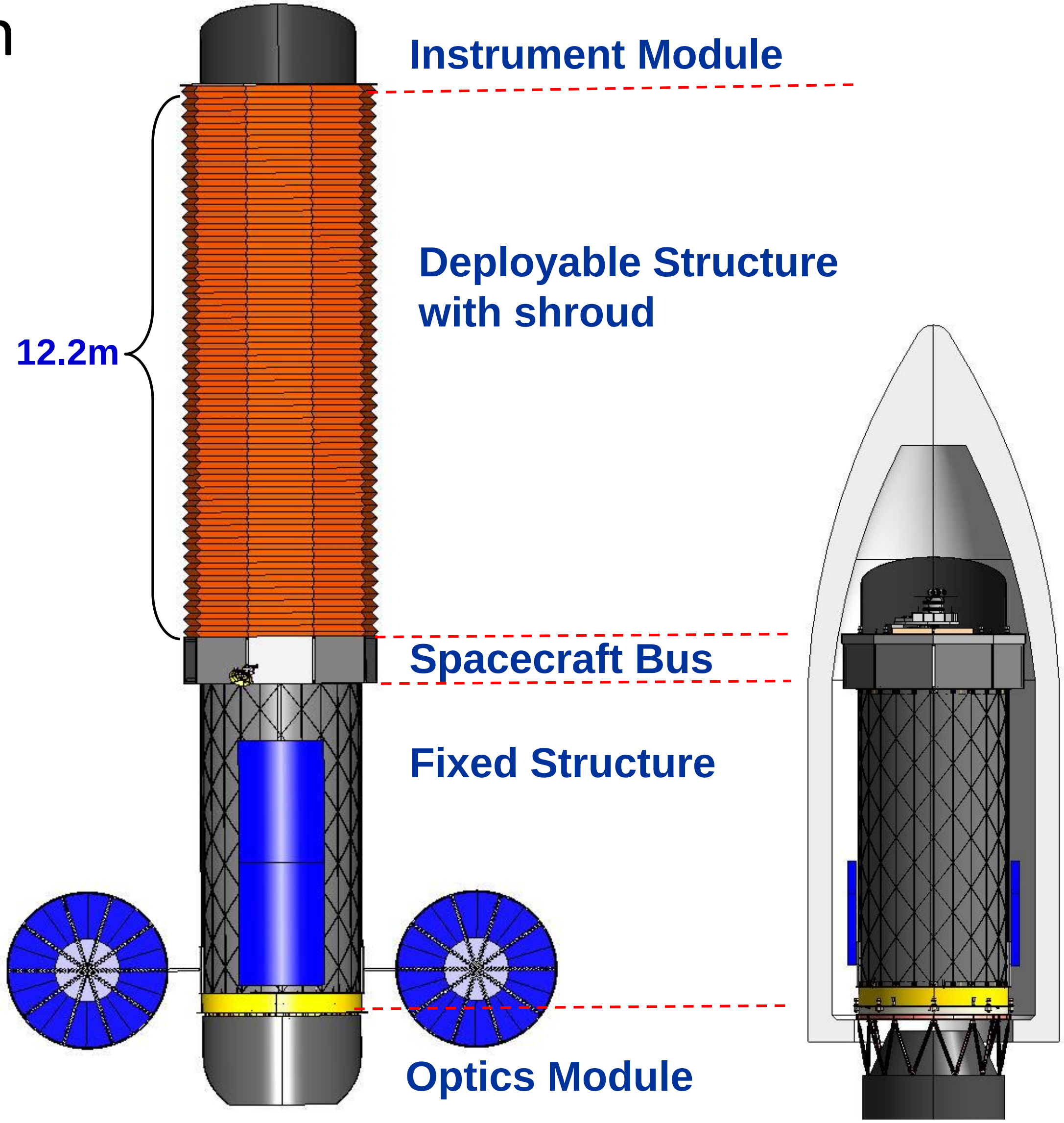






NASA Mission Design

- 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
- 5 year required lifetime, with expendables for 10 year goal

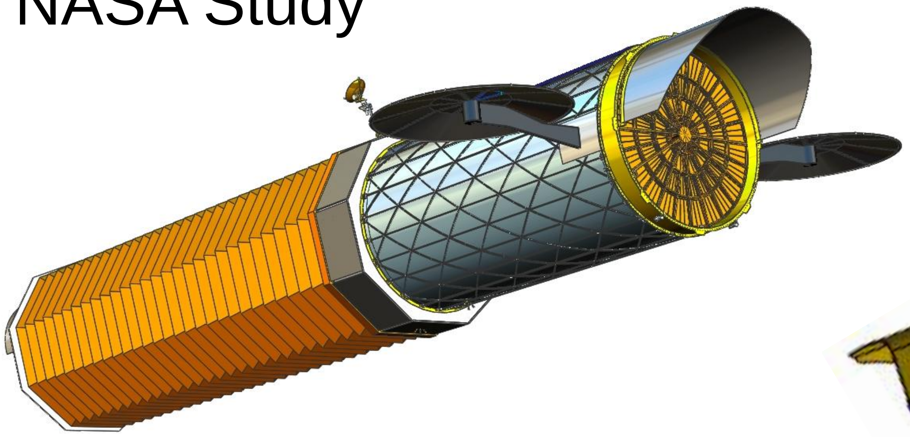


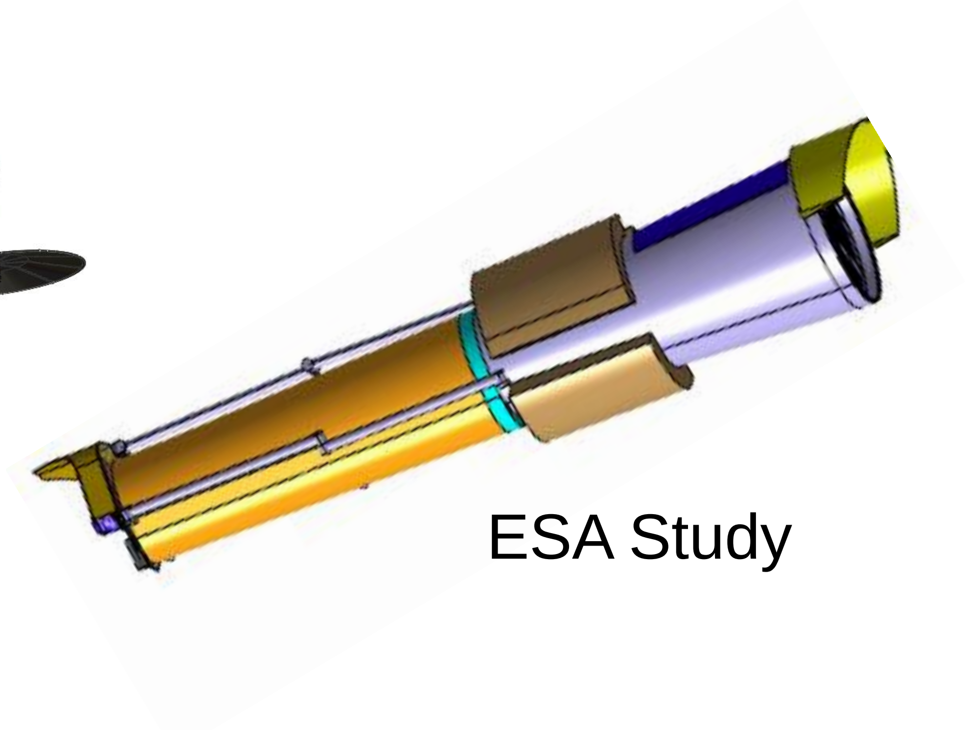
Deployed IXO Configuration

Stowed IXO Configuration

IXO Mission Studies

NASA Study

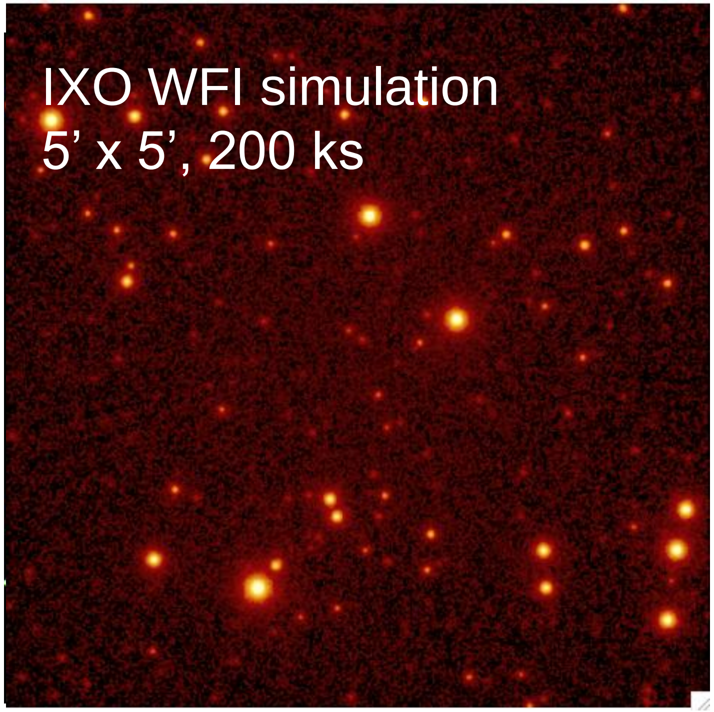




ESA Study

Separate ESA and NASA mission studies demonstrate overall mission feasibility, with no show stoppers

How do Supermassive Black Holes Grow and Evolve?



20 day exposure with Chandra will be a routine observation for IXO

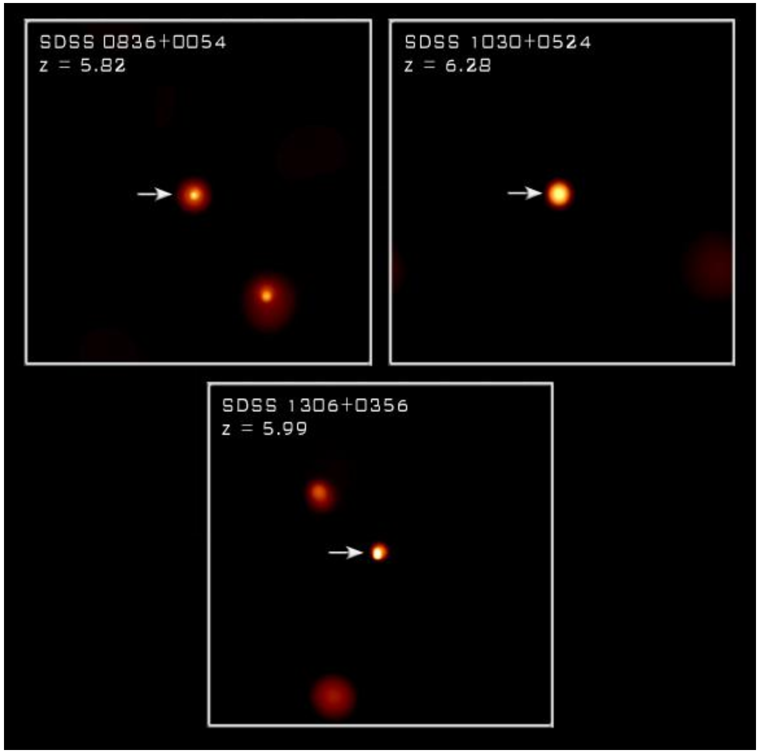
Chandra and XMM-Newton deep fields reveal that super-massive Black Holes are common throughout the Universe and that X-ray observations are a powerful tracer of their evolution

Most of these sources have <30 detected X-ray counts even in 20-day ultradeep X-ray surveys

IXO will greatly expand our view of the accretion light of the high-redshift Universe

IXO will bring a factor of 10 gain in telescope aperture combined with next generation instrument technology to realize a quantum leap in capability

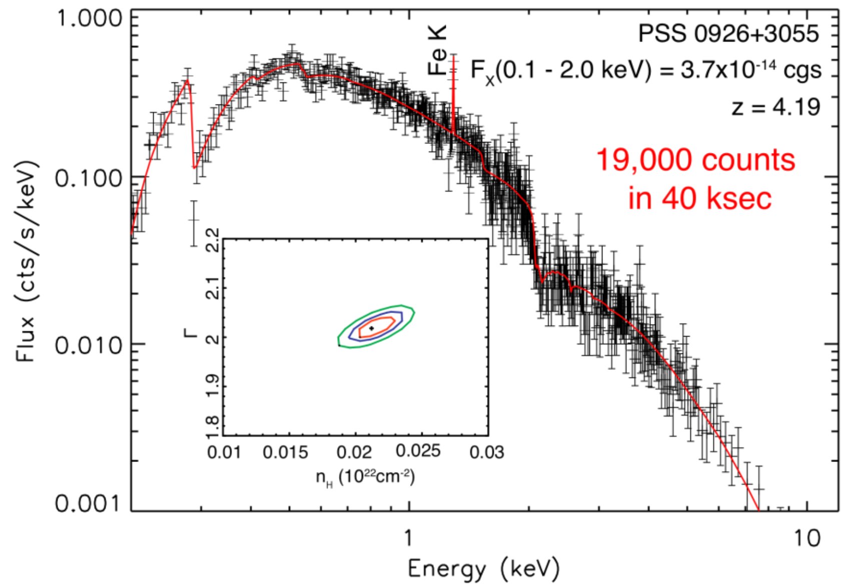
How do AGN evolve at high redshift?



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

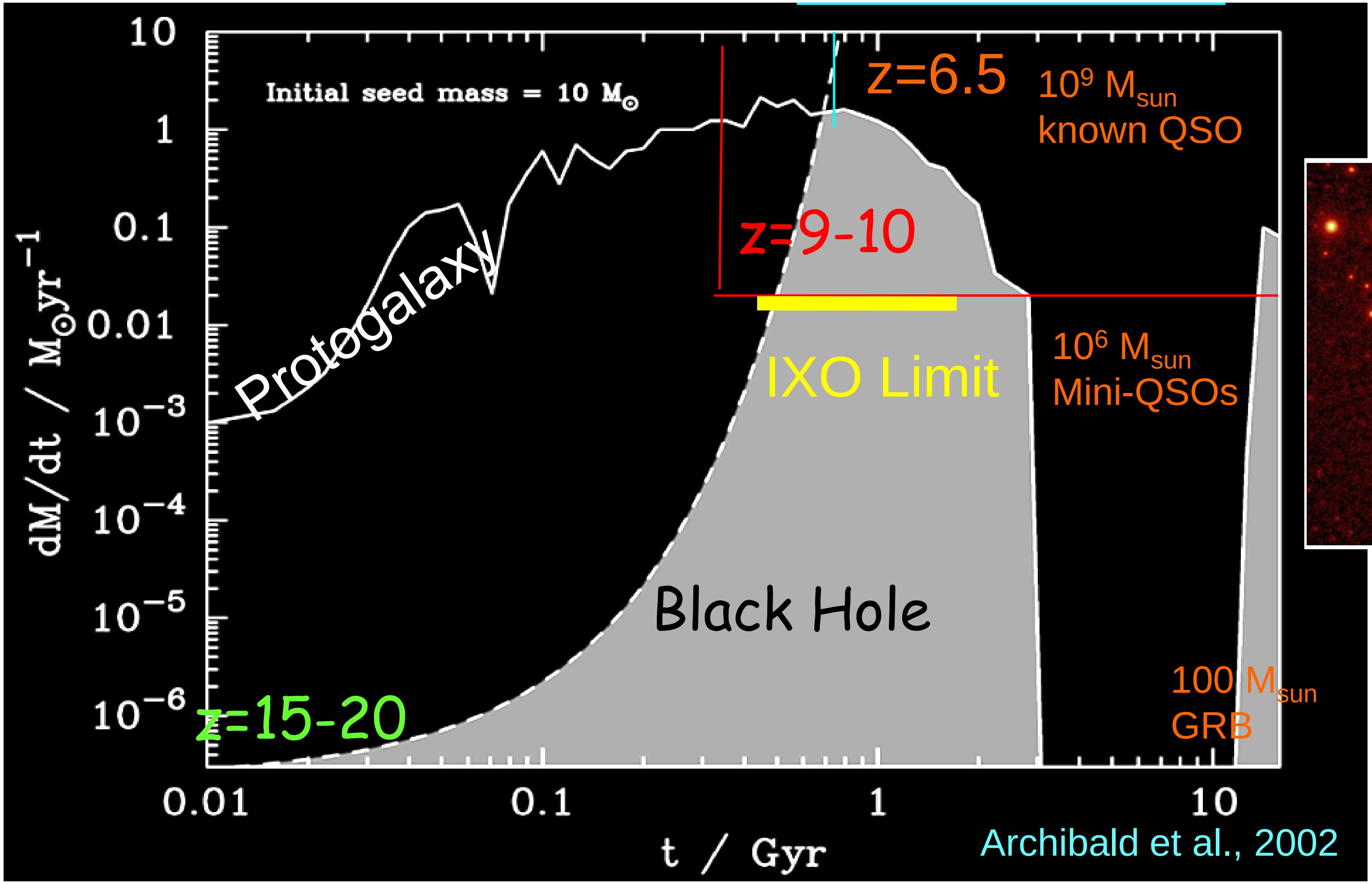
IXO Simulation (40 ks)

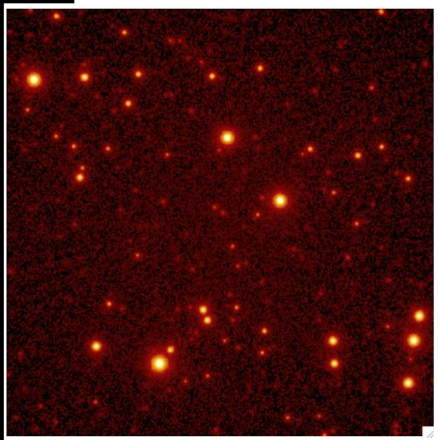


X-ray spectra can give:

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

How do super-massive Black Holes grow and evolve?





IXO WFI simulated deep field

10^6 M_o Mini-QSO @ redshift of 10 is detectable by IXO

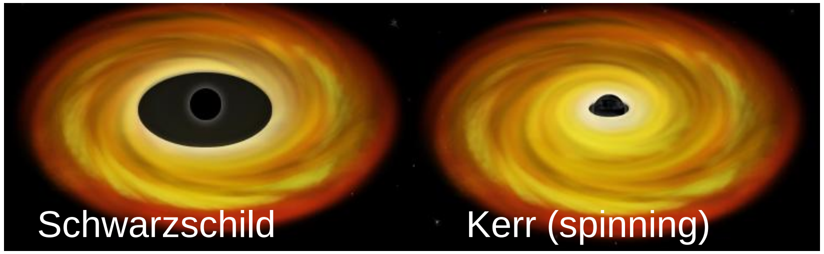
How do super-massive Black Holes grow and evolve?

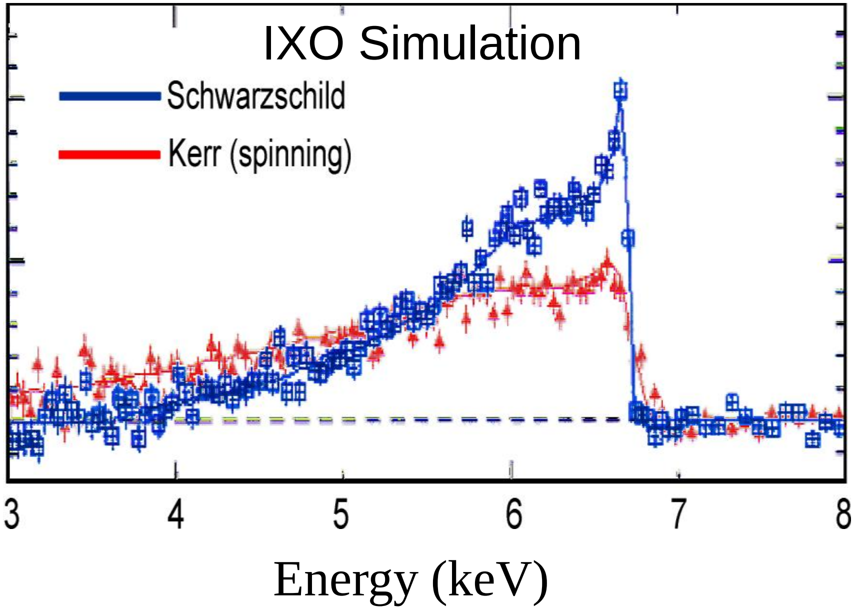
Relativistically broadened iron K lines have been detected from within 6 gravitational radii of Black Hole by ASCA, XMM-Newton, Chandra and Suzaku

Line profile gives a direct measure of the Black Hole spin (see Brenneman poster)

By surveying the spins of supermassive black holes, IXO will show how they grow

Merger-only growth of SMBHs results in a broad distribution of spins whereas growth via the standard accretion model results in mostly maximally-spinning black holes (e.g., Berti & Volonteri 2008)



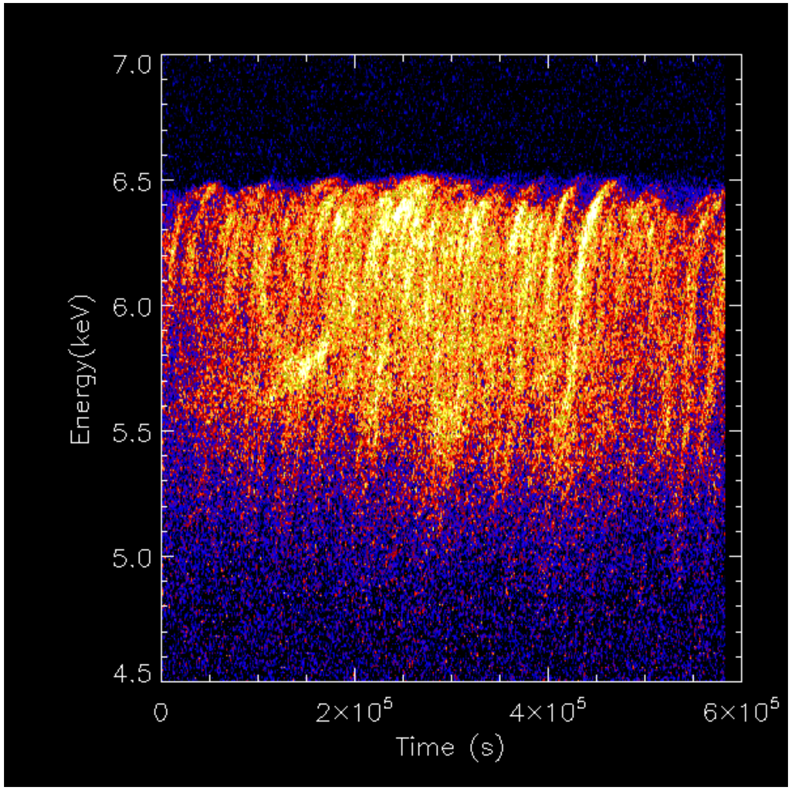


Very Broad Line = Spinning BH

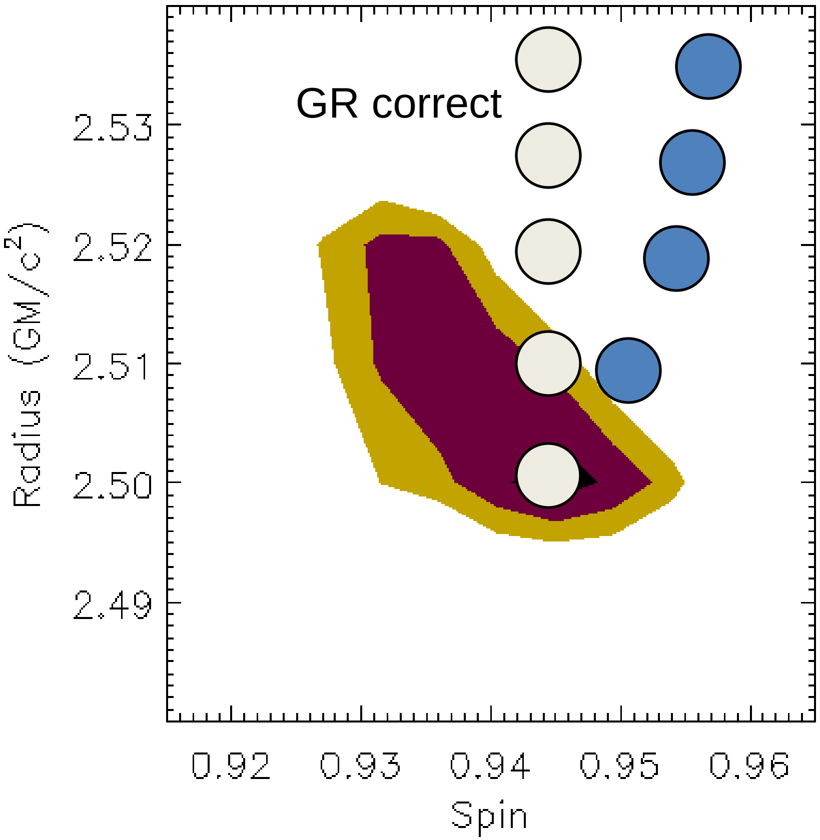
What is the behavior of matter orbiting close to a Black Hole event horizons and does it follow the predictions of GR?

X-ray iron K line bright spots in accretion disk surrounding Black Hole trace orbits that can be mapped with IXO

If GR is correct, IXO measured spin and mass should be independent of radius of bright spot



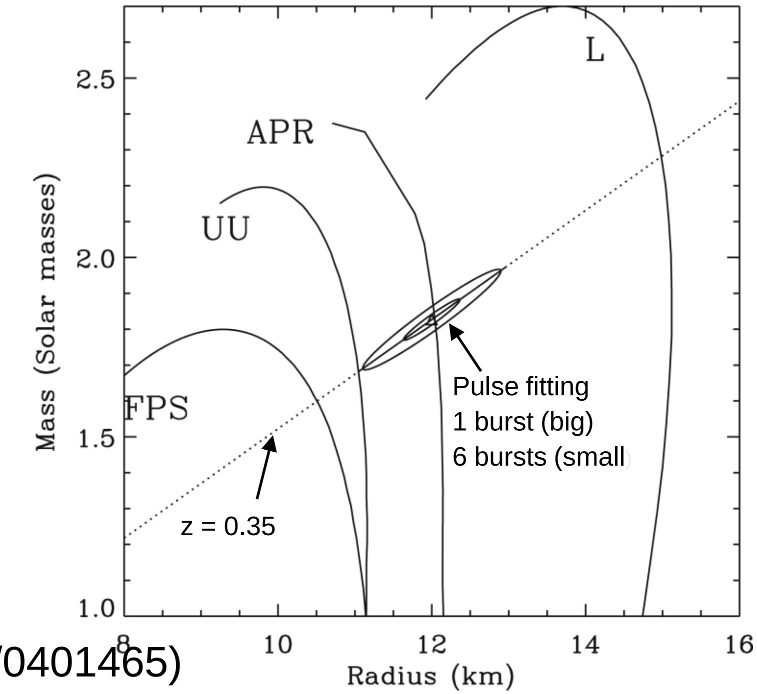
IXO Simulated observation of hot spots orbiting Black Hole



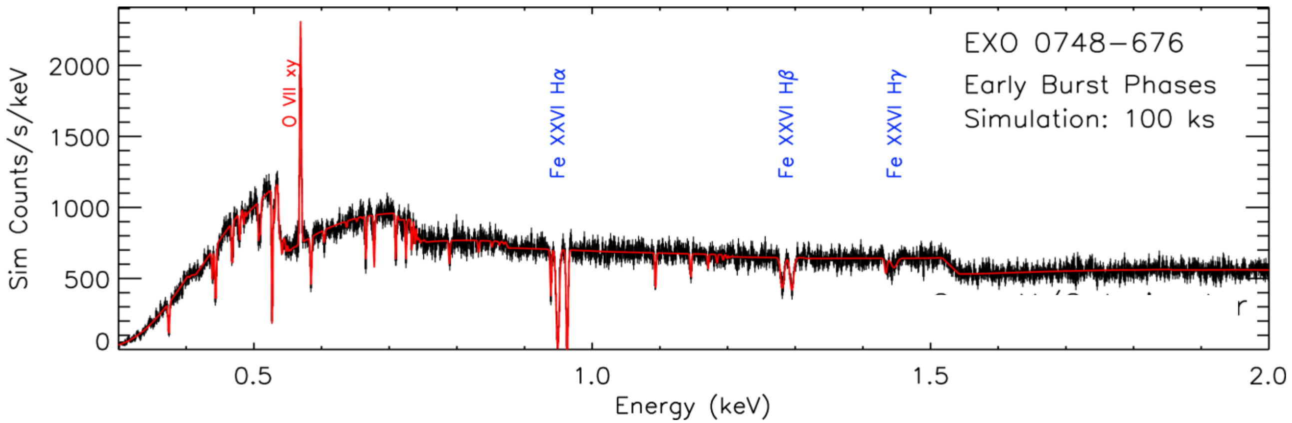
What is the Neutron Star Equation of State?

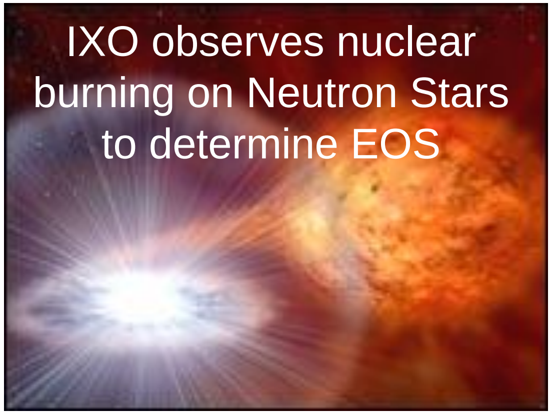
IXO will provide many high S/N measurements of X-ray burst absorption spectra:

- 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



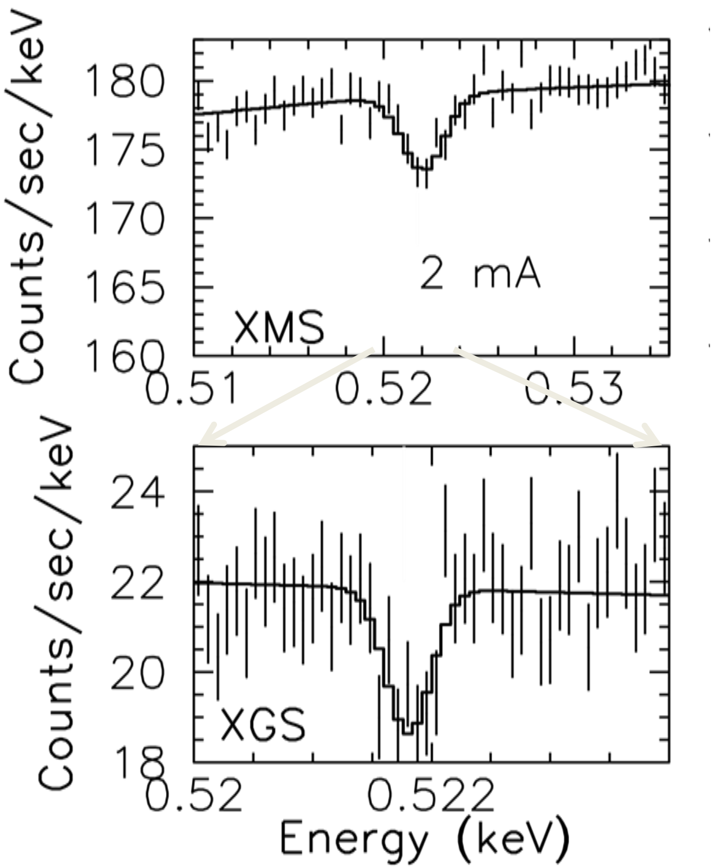
Cottam et al (astro-ph/0211126), Strohmayer (astro-ph/0401465)

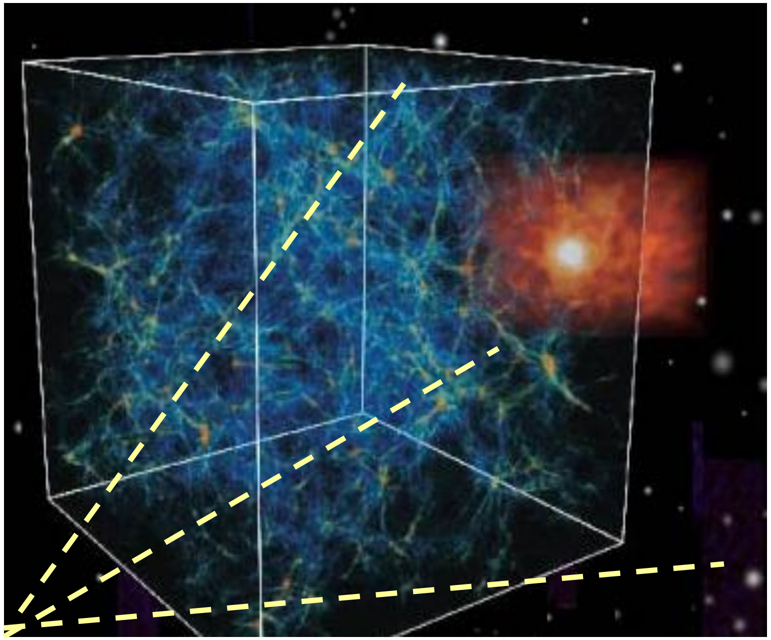




Are the missing baryons in the local Universe in the Cosmic Web and if so, how were they heated and infused with metals?

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?

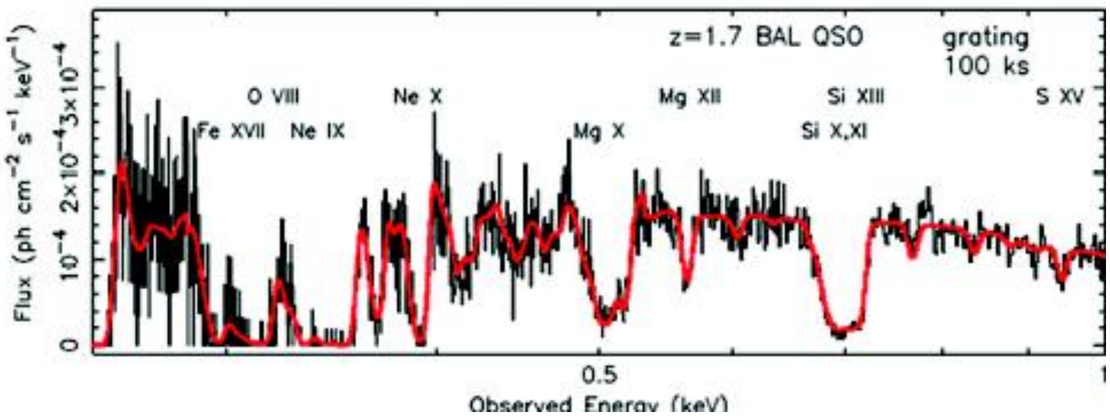
NOTE: HEINEMAN PRIZE LECTURE TOMORROW AM

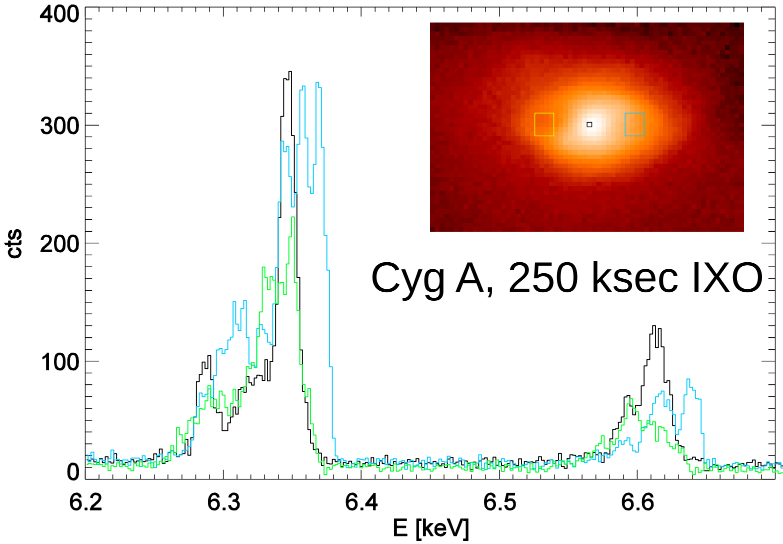
Large scale-structure simulations require AGN feedback to regulate the growth of galaxies and galaxy clusters

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

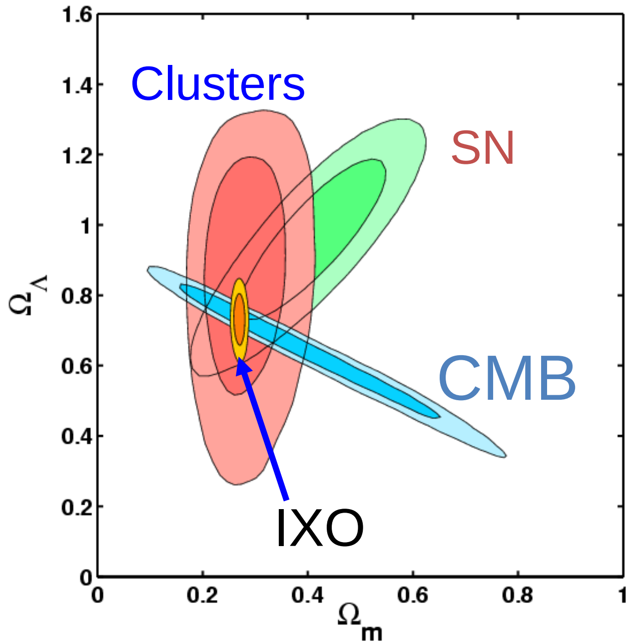
IXO will probe the hot ICM/IGM through velocity measurements to the required ~100 km/s and determine mass outflows in quasars with winds

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





How do relaxed clusters constrain Dark Energy?



Rossi Prize lecture tomorrow!

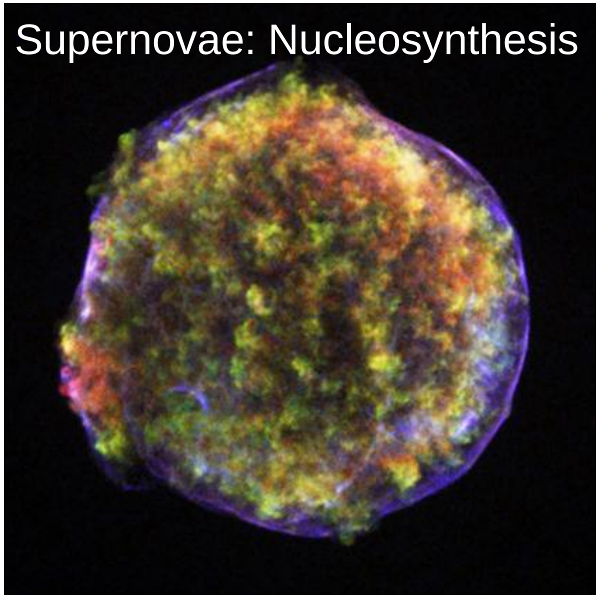
IXO gives a factor of ten improvement

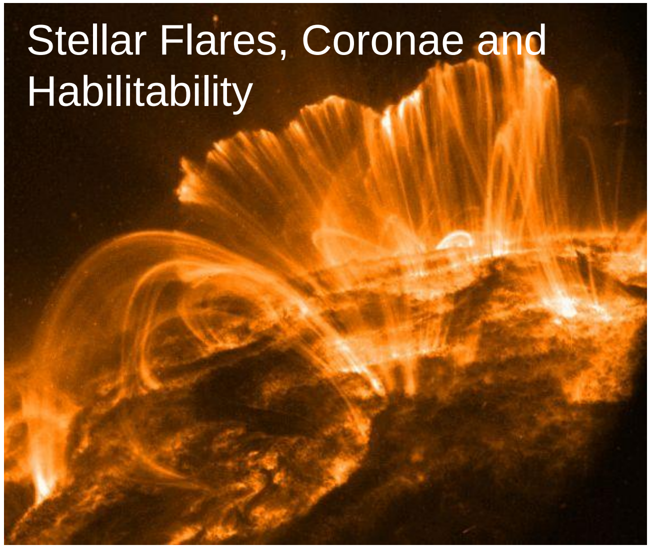
In the terms of the Dark Energy Task Force Figure of Merit this is a Stage IV result

Rapetti, Allen et al 2006 (Astro-ph/0608009)

- Using the gas mass fraction as a standard ruler measures f_{gas} to 5% (or better) for each of 500 galaxy clusters to give Ω_M=0.300±0.007, Ω_Λ=0.700±0.047
- Cluster X-ray properties combined with sub-mm data measure absolute cluster distances via the S-Z effect and cross-check f_{gas} results with similar accuracy
- Determining the evolution of the cluster mass function with redshift reveals the growth of structure and provides a powerful independent check

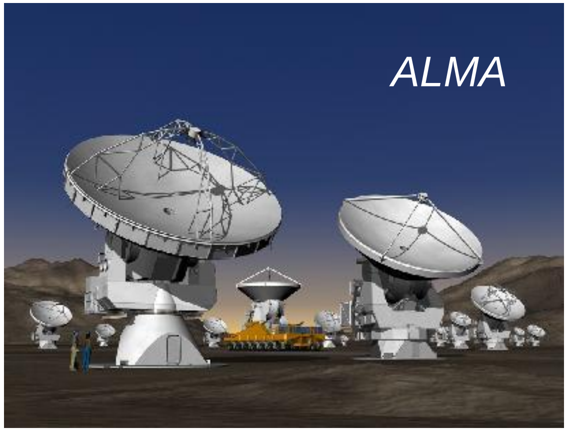
Life Cycles of Matter and Energy

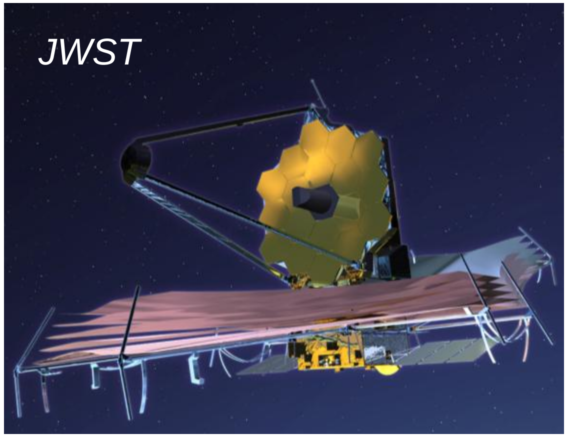




IXO: A future astrophysics great observatory

Sub-mm





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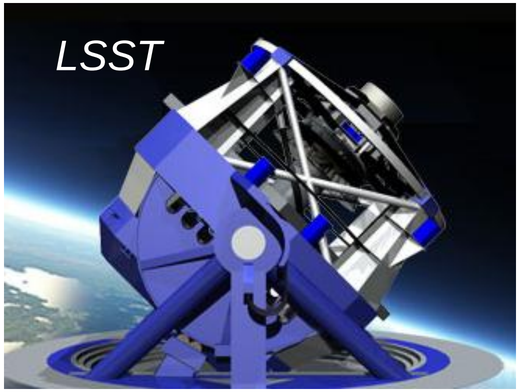

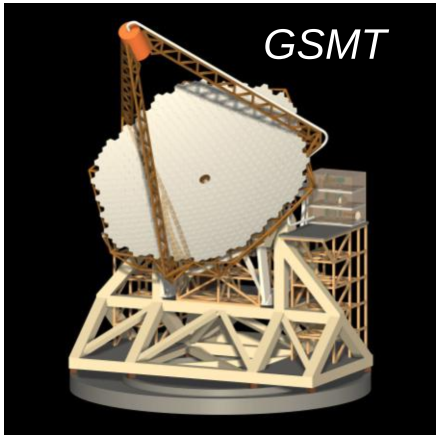

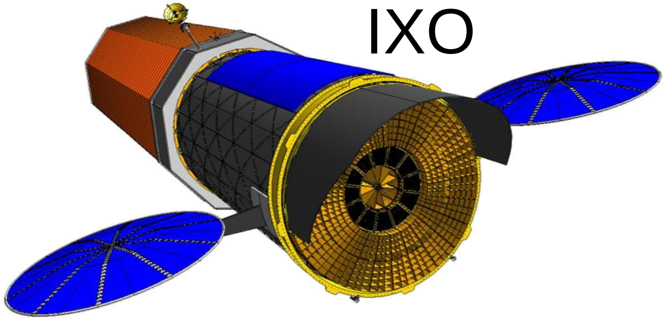

IXO

Optical

X-ray

The two order of magnitude increase in capability of IXO is well matched to that of other large facilities planned for the next decade

Summary

IXO addresses key and timely questions confronting Astronomy and Astrophysics

IXO will bring a factor of ten gain in telescope aperture combined with next generation instrument technology to realize a quantum leap in capability

Separate studies by ESA and NASA demonstrate that the mission implementation for a 2020 launch is feasible with no major show stoppers