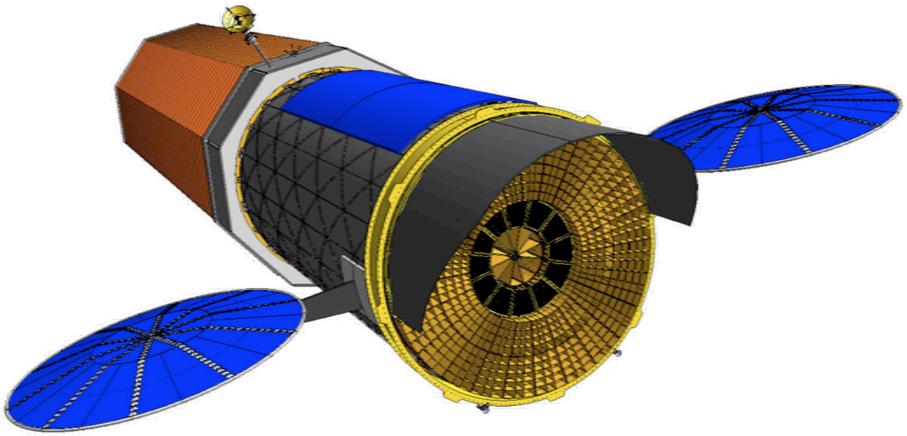
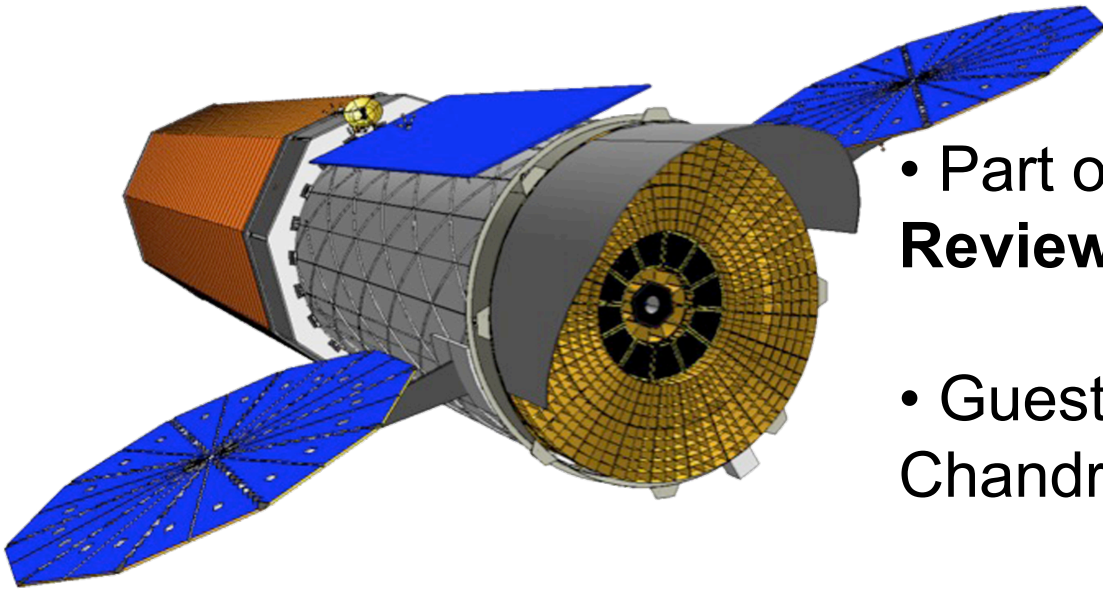


The International X-ray Observatory

Nicholas White, Arvind Parmar, Hideyo Kunieda

representing the IXO team

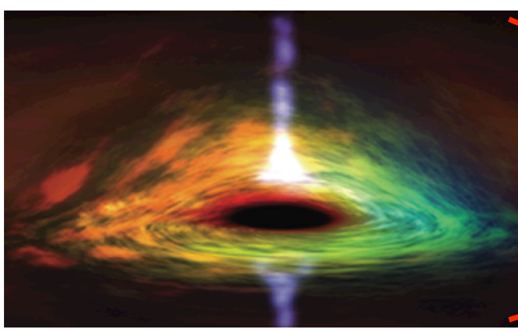
Basic Facts about IXO



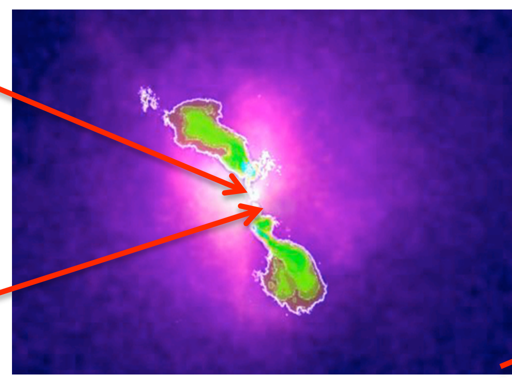
- Merger of ESA/JAXA XEUS and NASA's Constellation-X missions
- Part of US Astro2010 **Decadal Review** and ESA **Cosmic Visions**
- Guest Observatory, like Hubble, Chandra, Spitzer, Suzaku, Astro-H
- Launch: No Earlier Than ~2021

The International X-Ray Observatory (IXO) will address fundamental and timely questions in astrophysics:

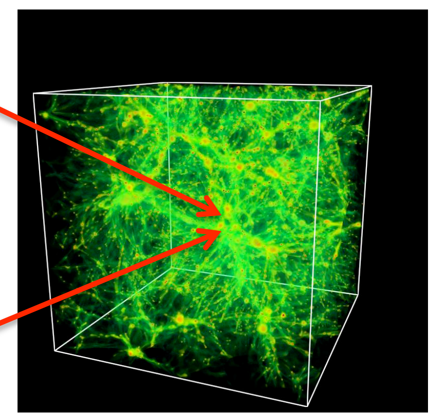
- What happens close to a black hole?
- When and how did super-massive black holes grow?
- How does large scale structure evolve?
- What is the connection between these processes?



Black Hole Accretion



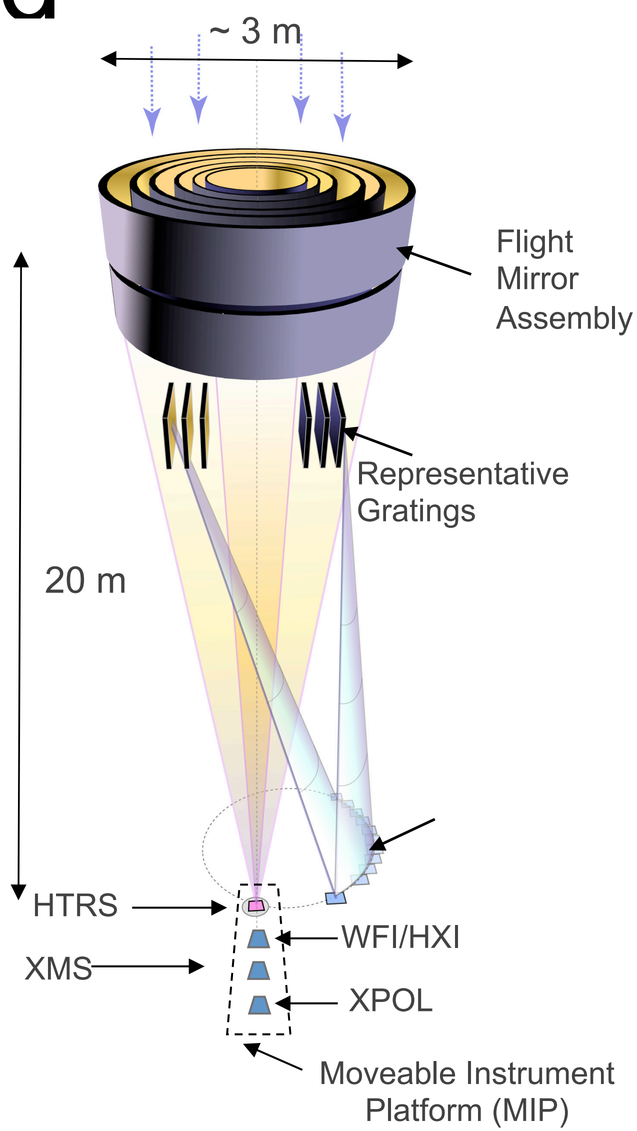
Hydra A Galaxy Cluster



Cosmic Web

IXO Payload

- Flight Mirror Assembly (FMA)
  - Highly nested grazing incidence optics
  - 3 sq m @ 1.25 keV with a 5'' PSF
- Instruments
  - X-ray Micro-calorimeter Spectrometer (XMS)
    - 2.5 eV with 5 arc min FOV
  - X-ray Grating Spectrometer (XGS)
    - R = 3000 with 1,000 sq cm
  - Wide Field Imager (WFI) and Hard X-ray Imager (HXI)
    - 18 arc min FOV with CCD-like resolution
    - 0.3 to 40 keV
  - X-ray Polarimeter (X-POL)
  - High Time Resolution Spectrometer (HTRS)

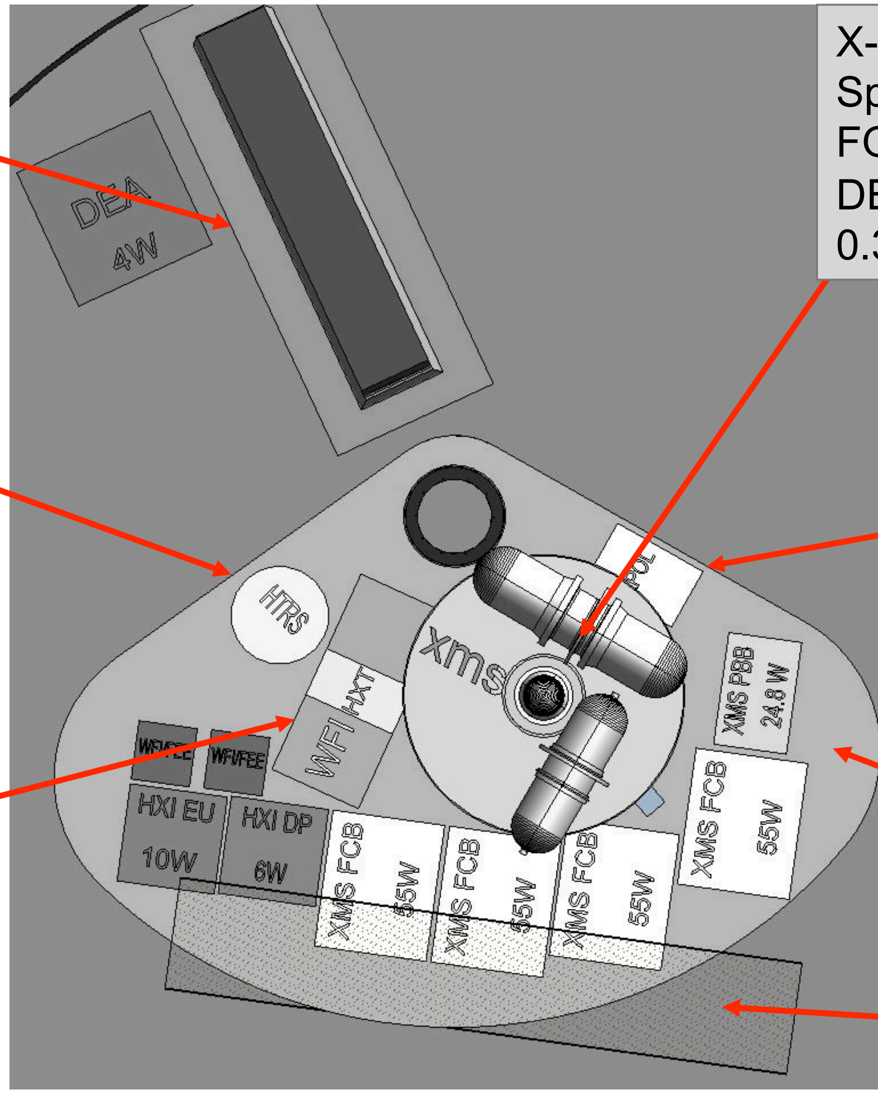


Focal Plane Layout

X-ray Grating Spectrometer Detector
0.3 to 1 keV
R = 3000
> 1000 cm^2

High Time Resolution Spectrometer
1 Crab > 90% livetime

Wide Field Imager
FOV 18 arc min
0.1-15 keV
DE < 150 eV
+
Hard X-ray Imager
FOV 8 arc min
> 150 cm^2@30 keV



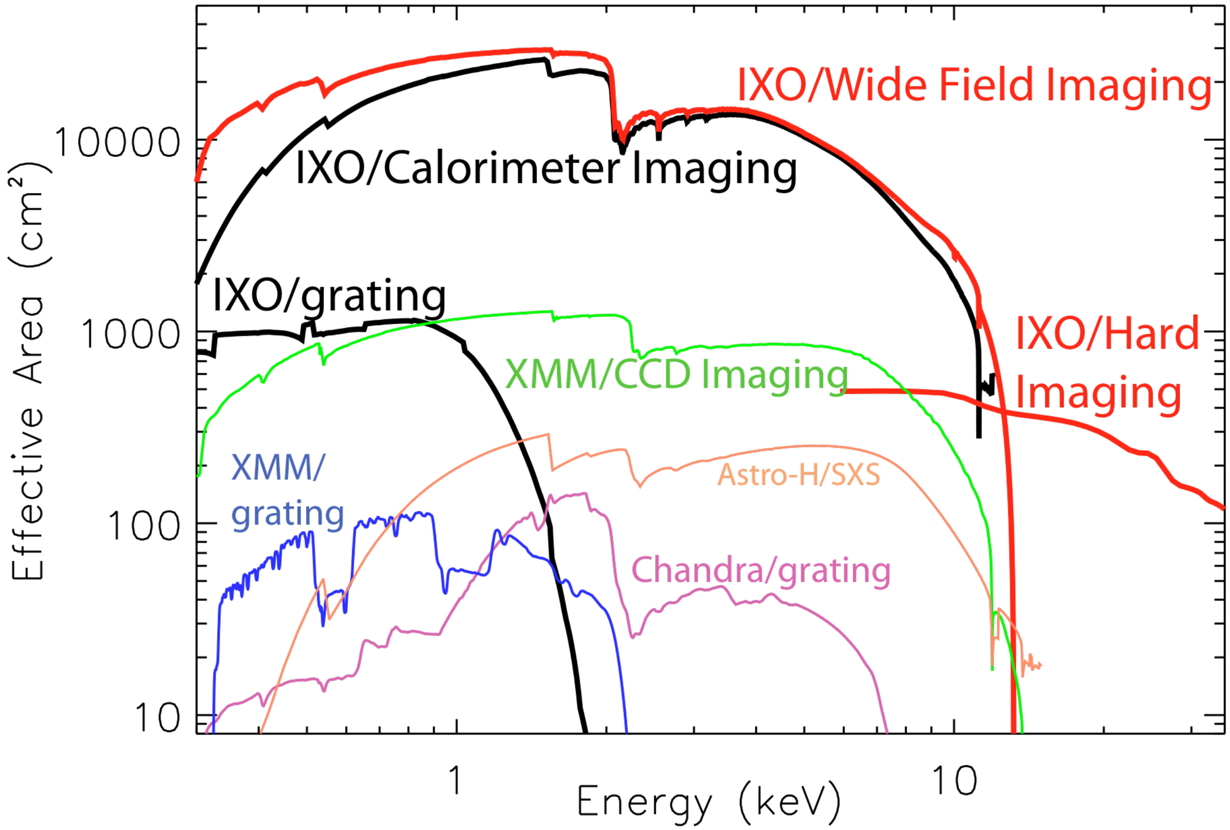
X-ray Micro-calorimeter Spectrometer
FOV 5 arc min
DE = 2.5 – 5.0 eV
0.3-7 keV

Polarimeter
<1% for 1 mCrab in 100ks

Translation Platform

Radiator

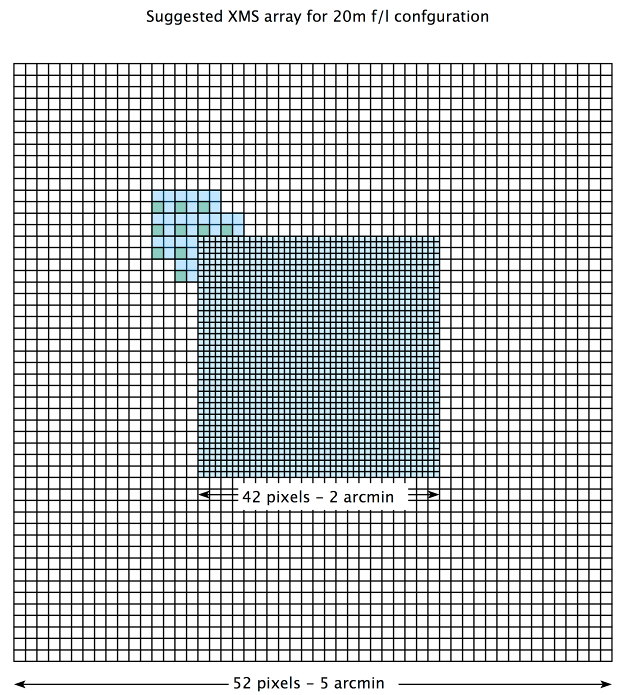
IXO is a Vast Improvement over Existing Missions

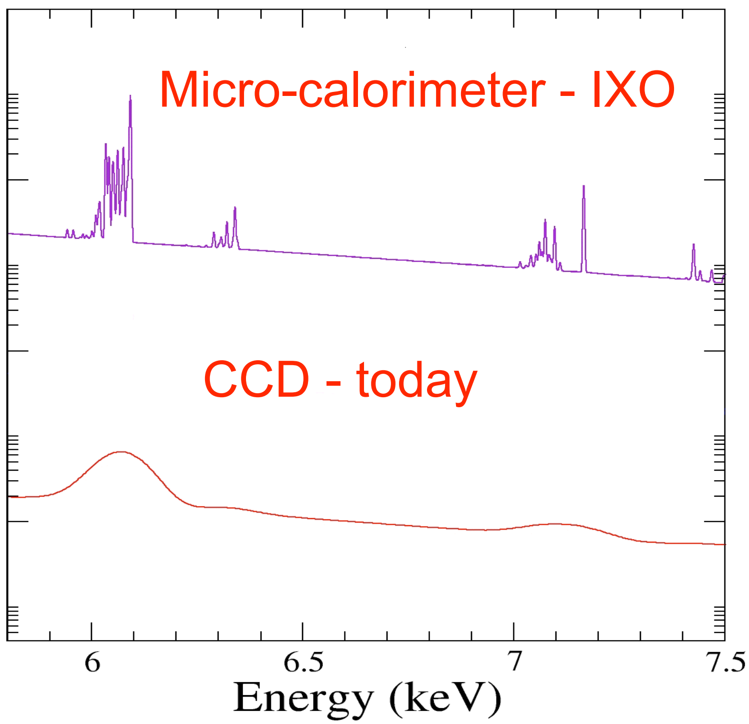


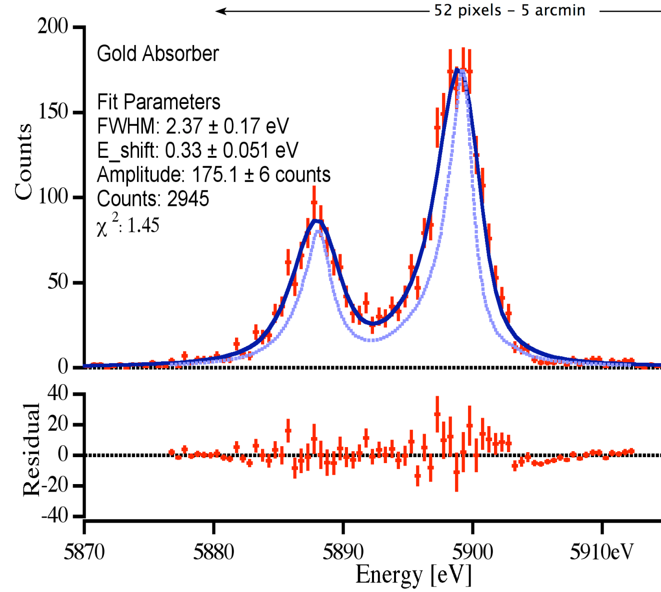
Effective area a factor of >10x of current missions
Spectroscopy capabilities >100x of current missions

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







Spectral Capability

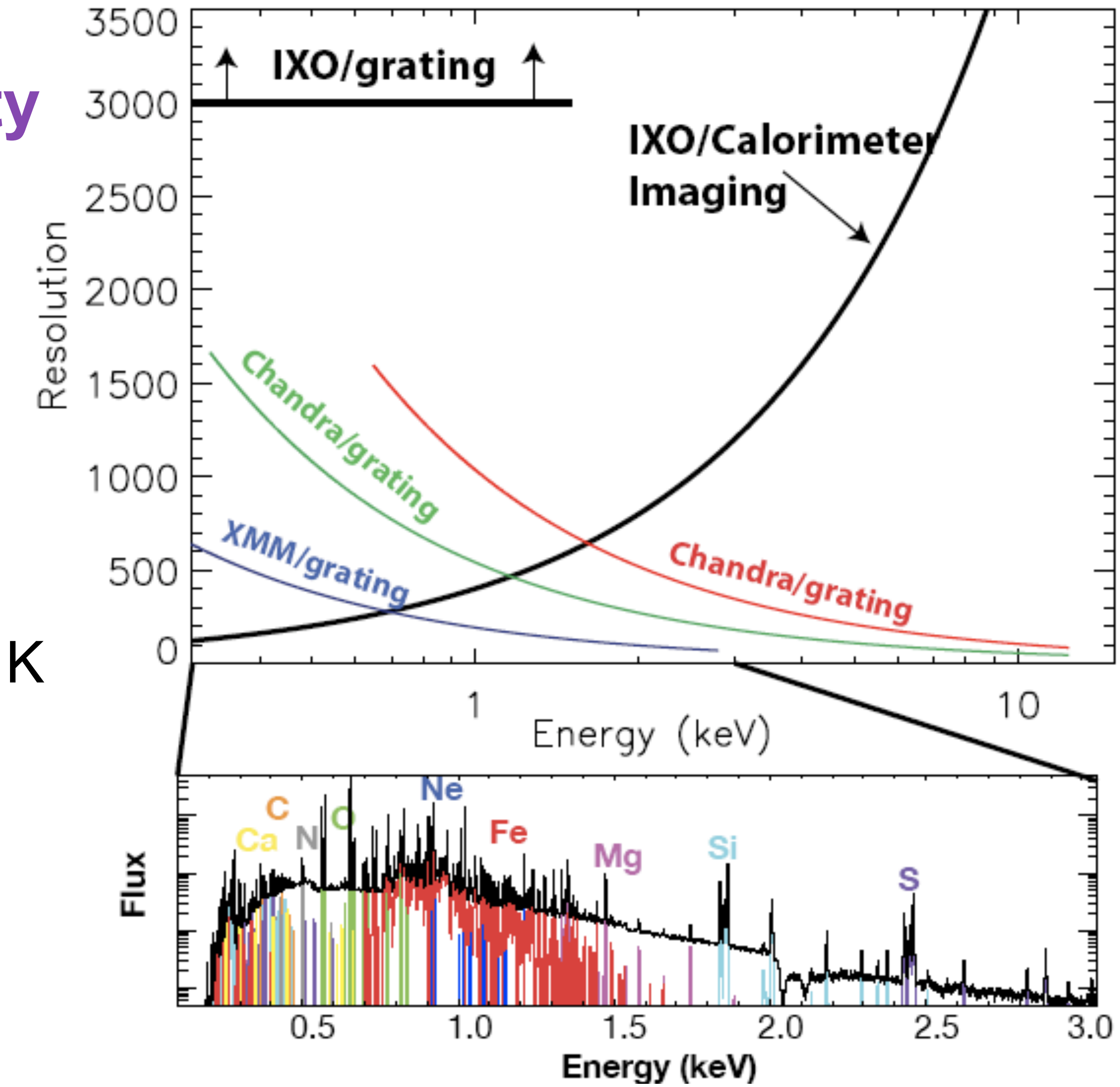
K-line transitions of 25 elements

Carbon through Zinc

Abundances

Temperatures: 10^6-10^8 K

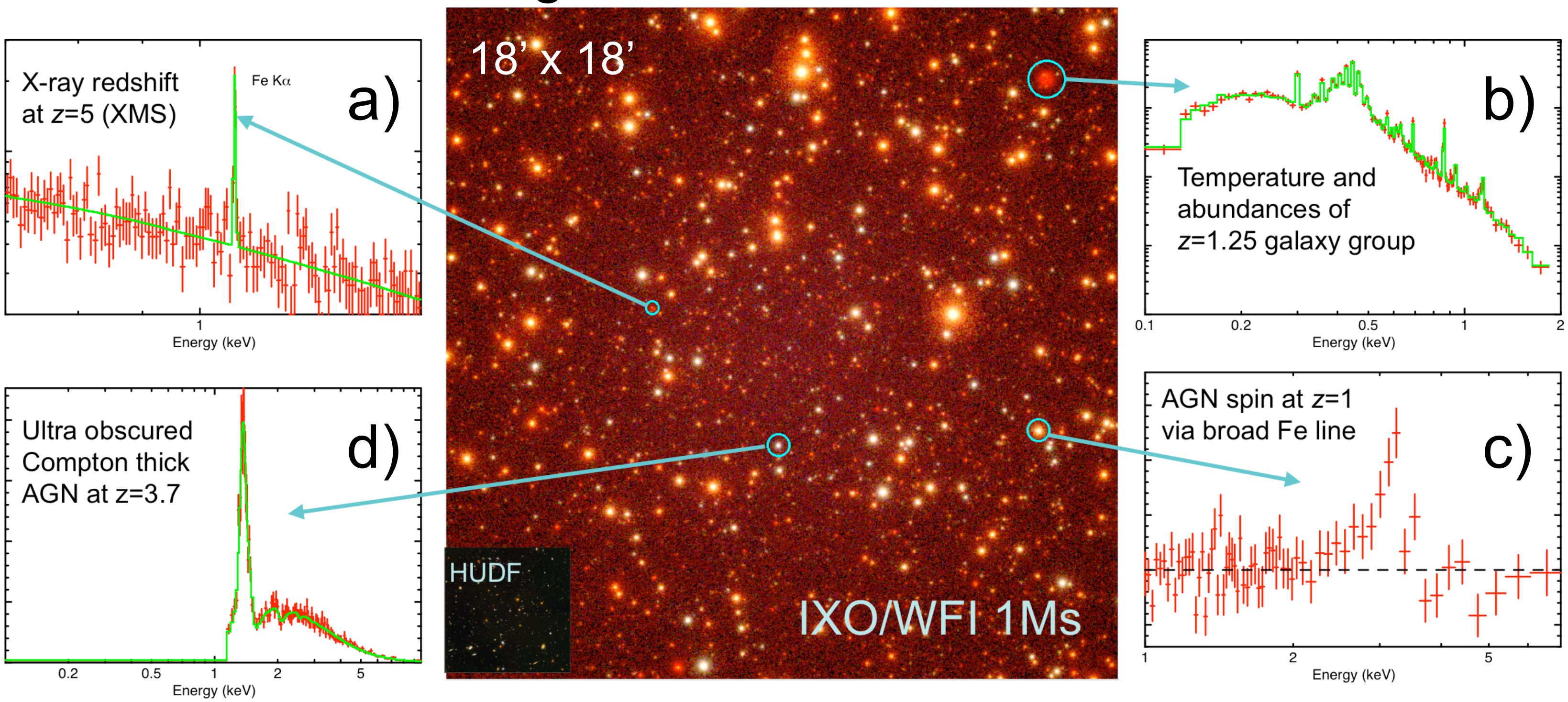
Velocities ~ 100 km/s



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, EOS Strong gravity, EOS Cosmic acceleration, strong gravity
Spectral Resolution	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 @ 6 keV within 18 arc min diameter (0.1 - 15 keV) E/ΔE = 3000 from 0.3–1 keV with an area of 1,000 cm^2 with a goal of 3,000 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
Mirror Angular Resolution	≤5 arc sec HPD (0.1 – 7 keV) ≤30 arc sec HPD (7 - 40 keV) with a goal of 5 arc sec	Large scale structure, cosmic feedback, black hole evolution, missing baryons Black hole evolution
Count Rate	1 Crab with >90% throughput. ΔE < 200 eV (0.1 – 15 keV)	Strong gravity, EOS
Polarimetry	1% MDP (3 sigma) 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

Black Hole and Large Scale Structure Evolution with IXO

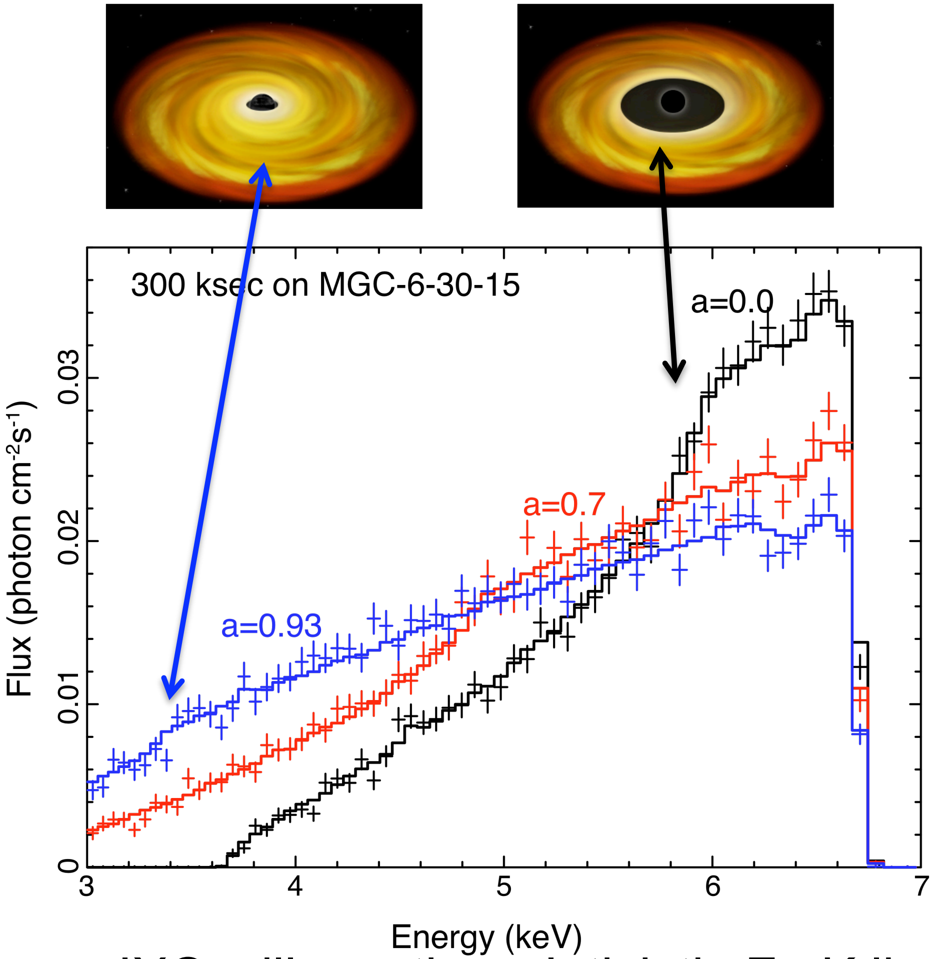


IXO will be 20 times faster than Chandra to make wide and deep surveys:

a)determine redshift autonomously in the X-ray band
b)determine temperatures and abundances even for low luminosity galaxy groups
c)make spin measurements of AGN to a similar redshift
d)uncover the most heavily obscured, Compton-thick AGN

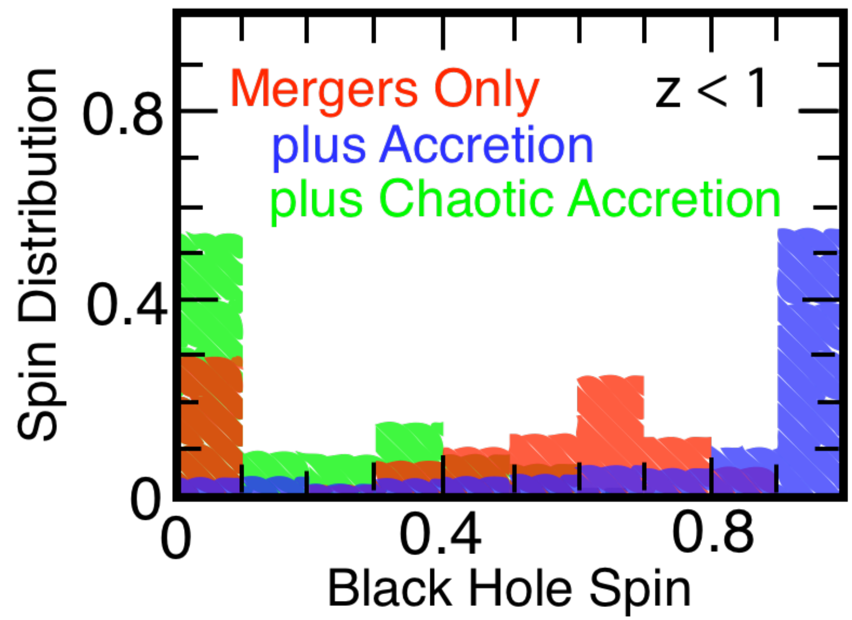
3 sq m @ 1.25 keV
5 arc sec

Super-massive Black Hole Spin & Growth



Fe K Line

Berti & Volonteri (2008)

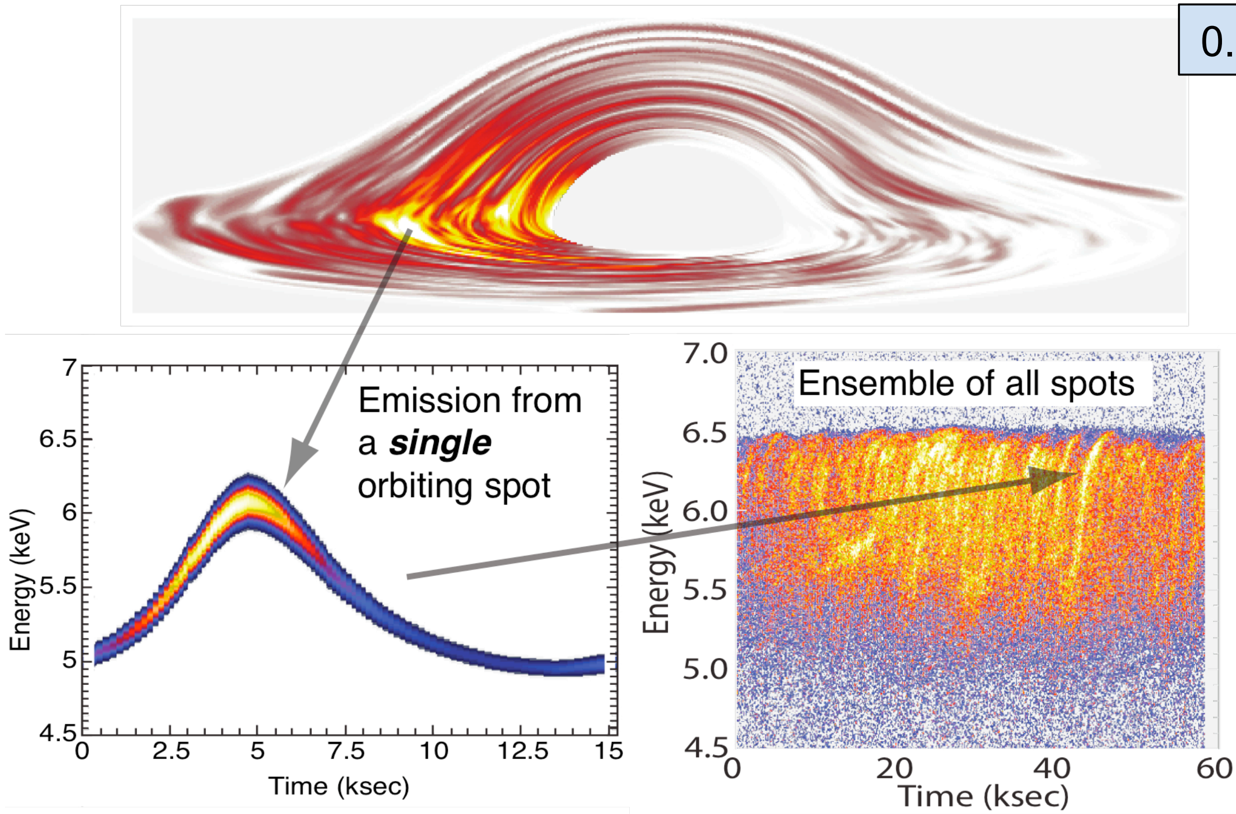


IXO will use the relativistic Fe K line to determine the black hole spin for 300 AGN within z < 0.2 to constrain the SMBH merger history

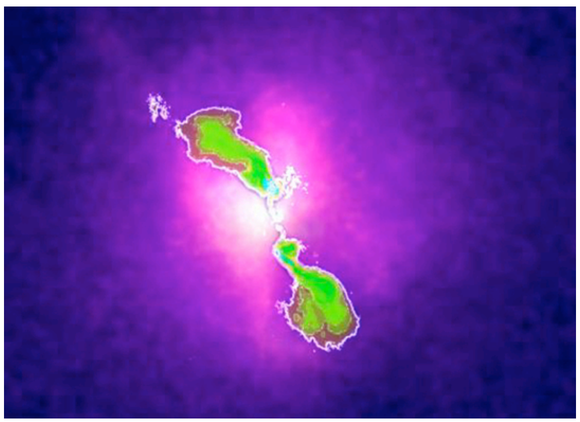
Emission from a hot spot emitting a single line

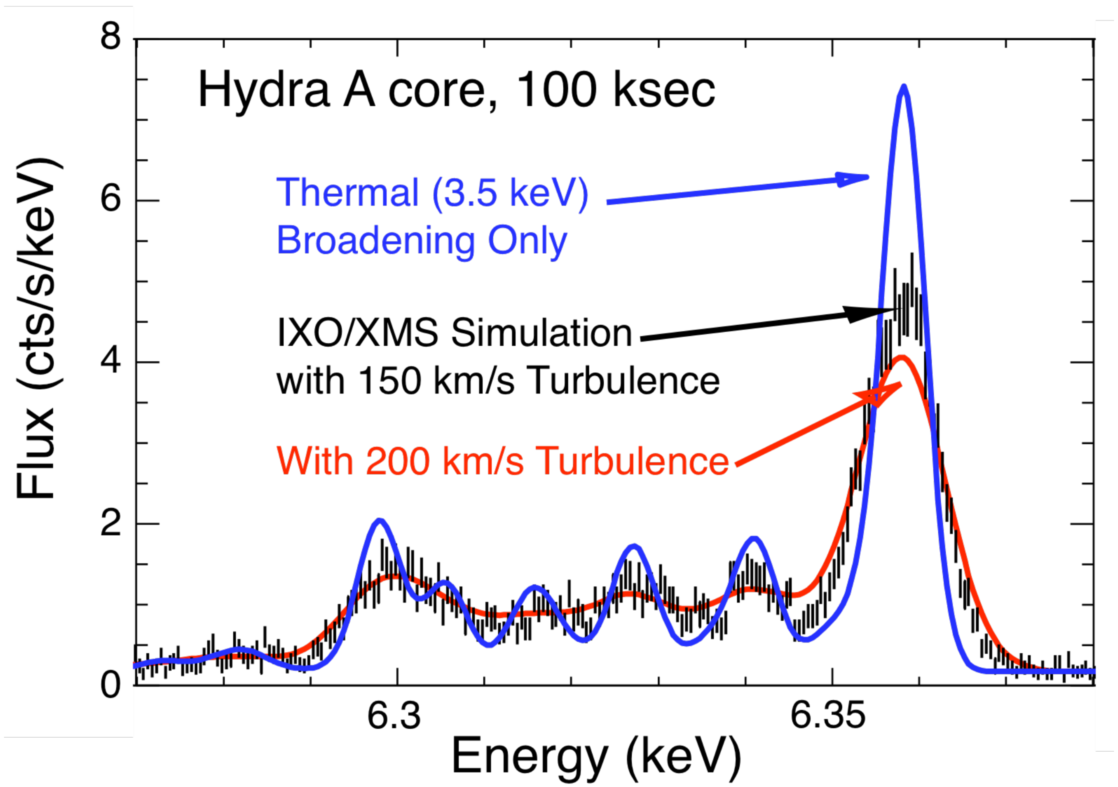
Time variation of line energy (and intensity) depend on GR properties of Kerr Metric (spin)

0.65 sq m @ 6 keV



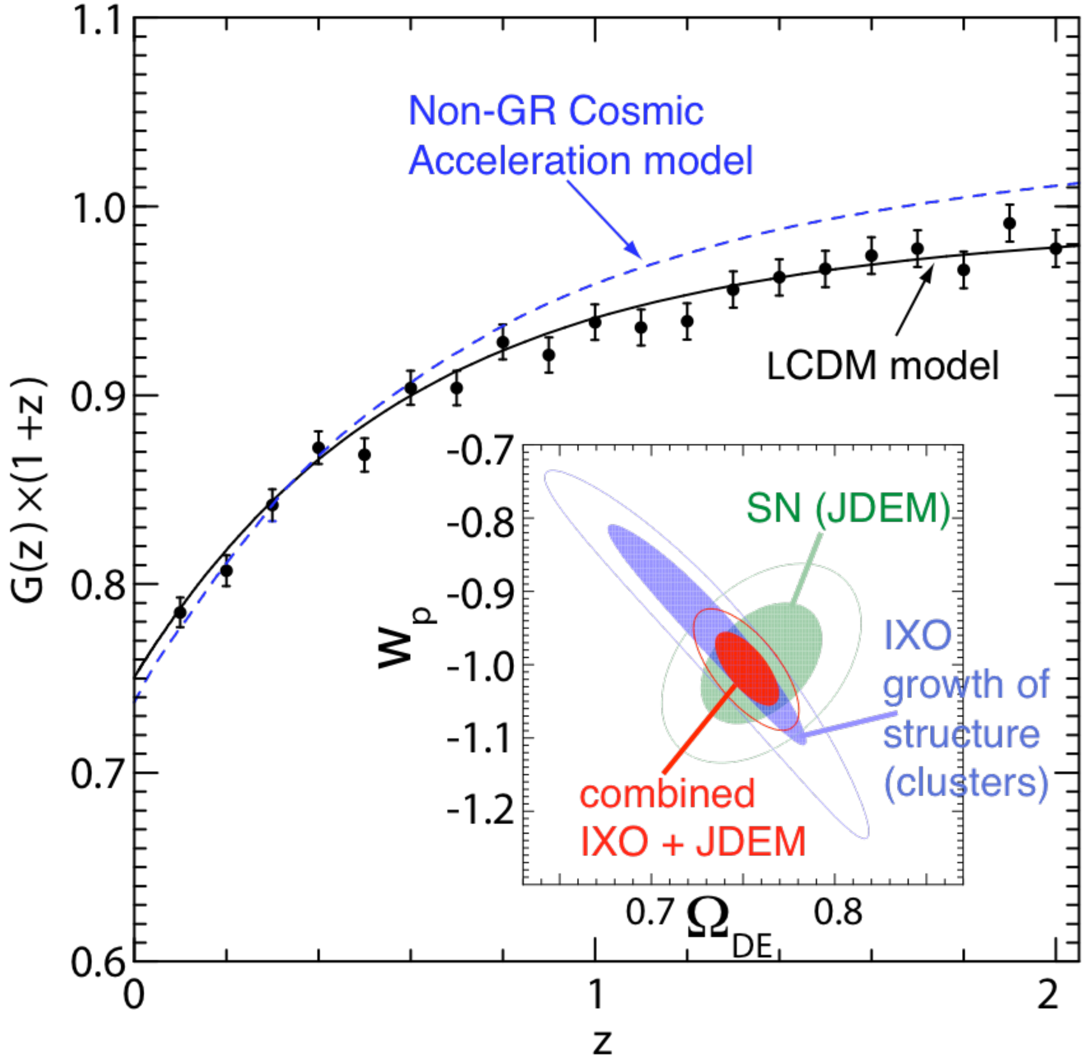
IXO Measurements of Turbulence in Cluster Gas





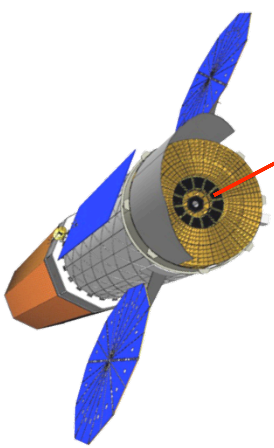
2.5 – 5 eV @ 6.4 keV
5 arc sec
5 arc min FOV

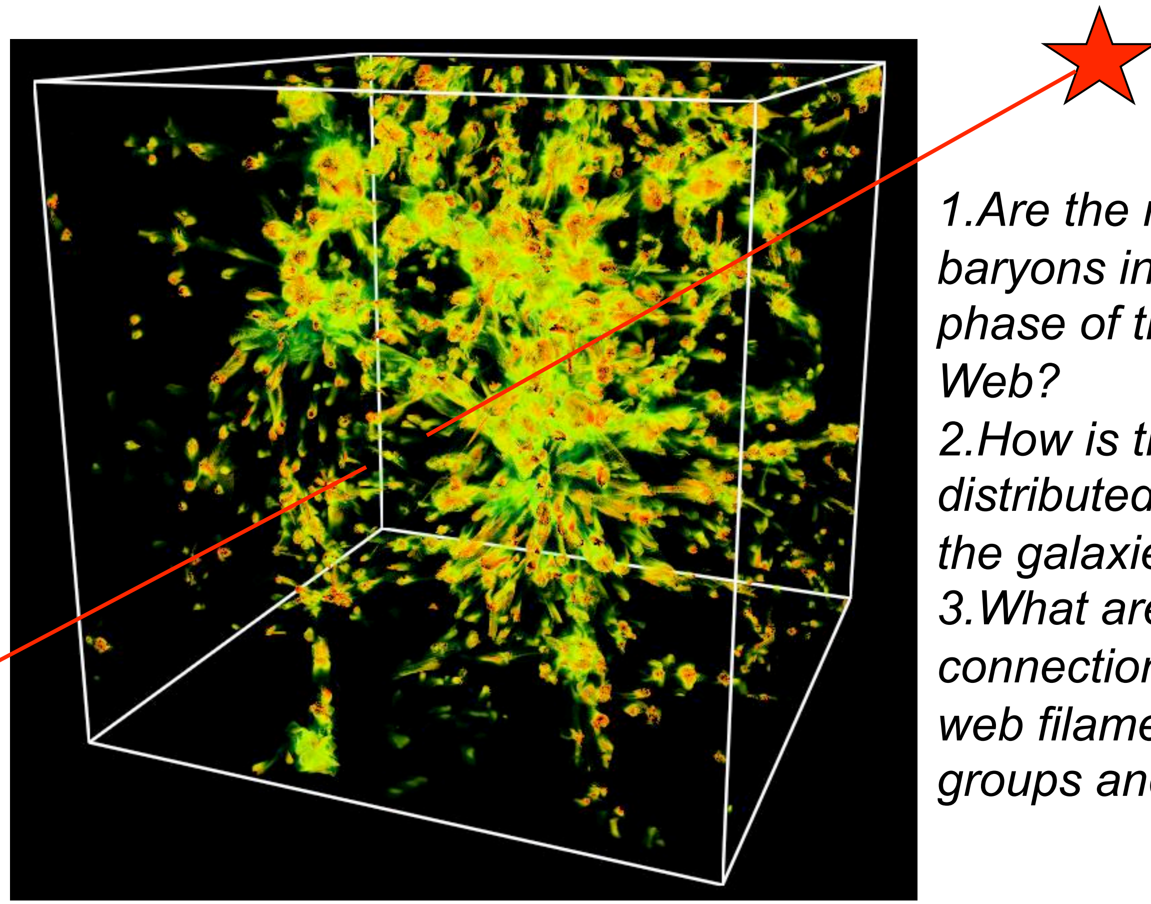
IXO Measurements of Cluster Mass Function



Study the Absorption by Hot Baryons with IXO

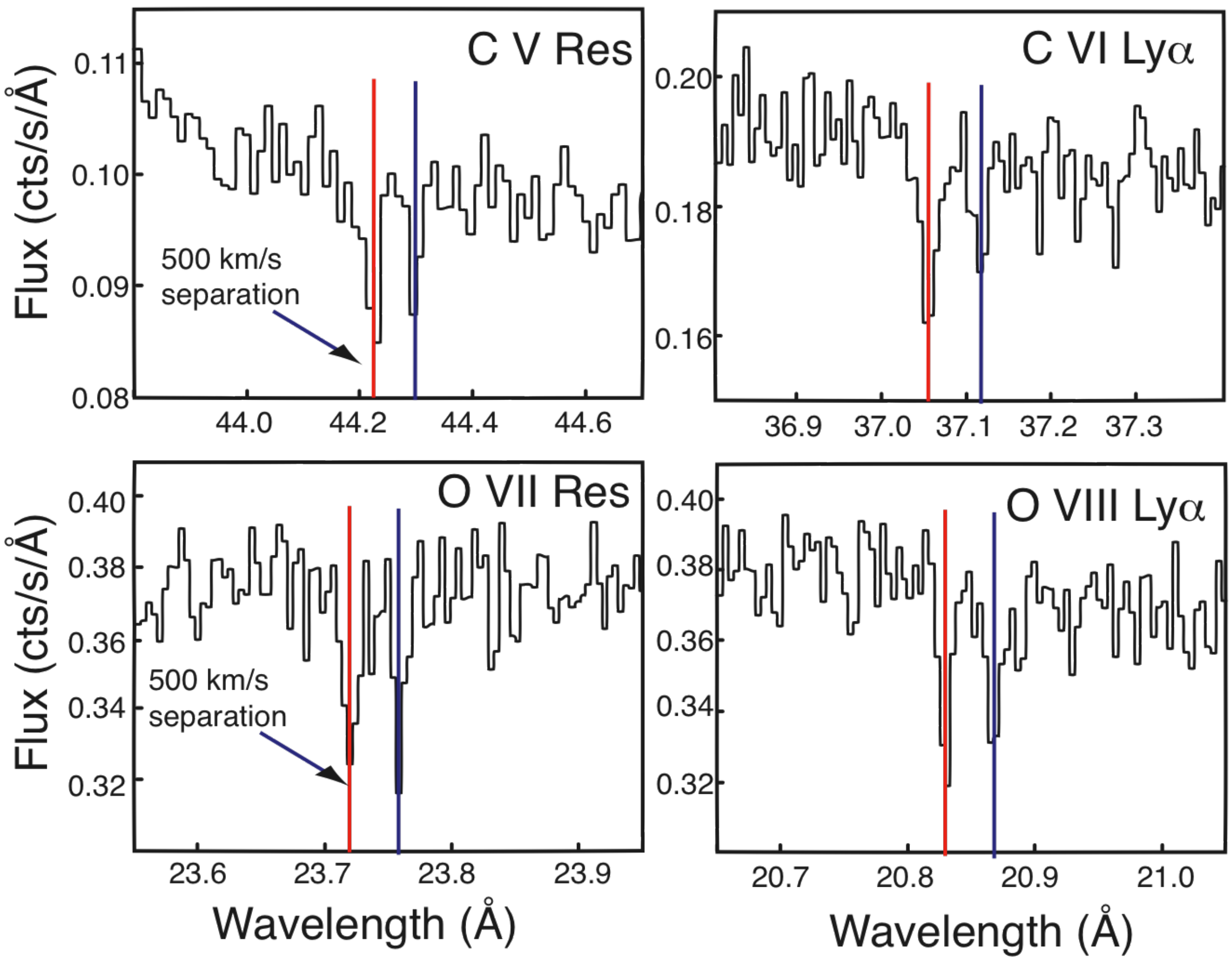
Key features are *OVII and OVIII* *(1s-2p transition at 574 eV, Lya line at 654 eV)*





1. *Are the missing baryons in the hot phase of the Cosmic Web?*
2. *How is the hot gas distributed relative to the galaxies?*
3. *What are the connections of the web filaments to groups and clusters?*

The Missing Baryons

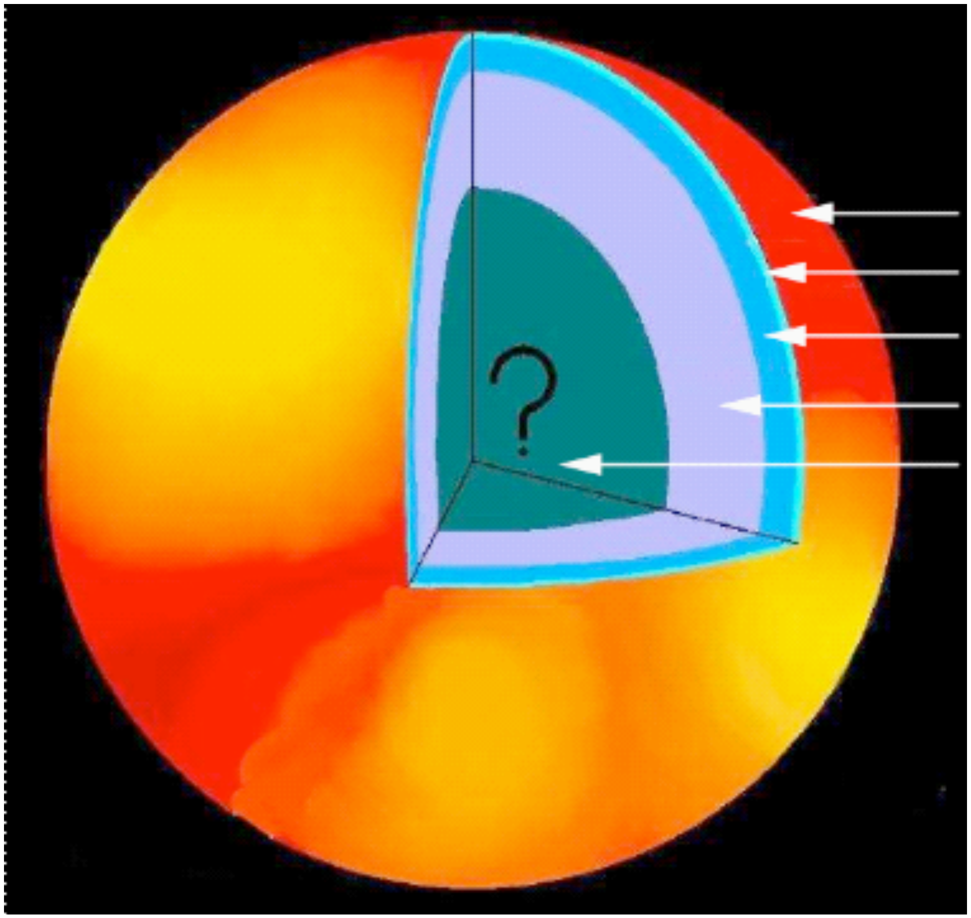


Using existing surveys, 30+ suitable sources.

Expect ~ 3-10 Metal Systems per line of sight in 200-300 ks with IXO Gratings

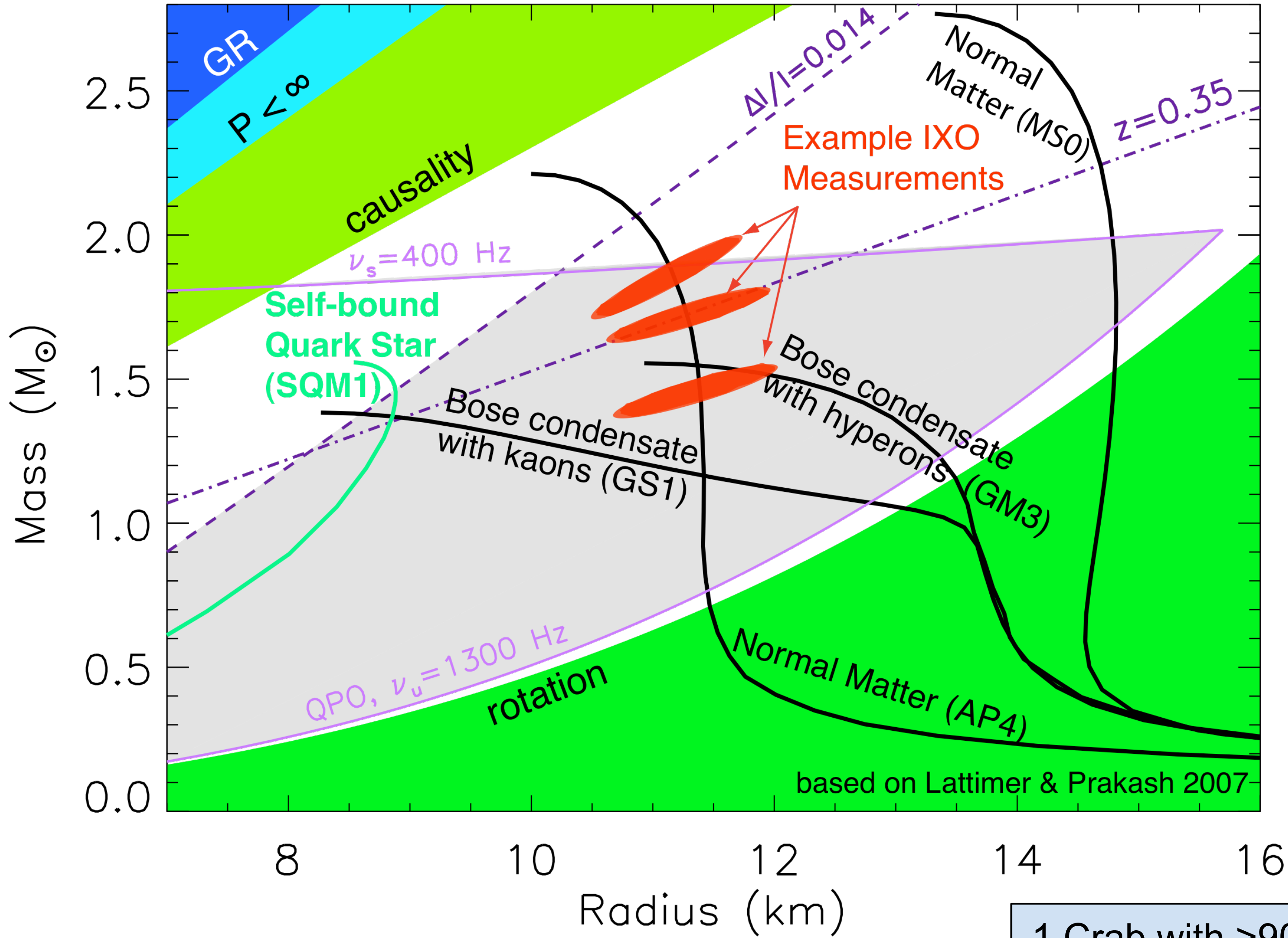
R ~ 3000 from 0.3-1 keV
Area ~ 1,000 sq cm

Neutron Star Equation of State



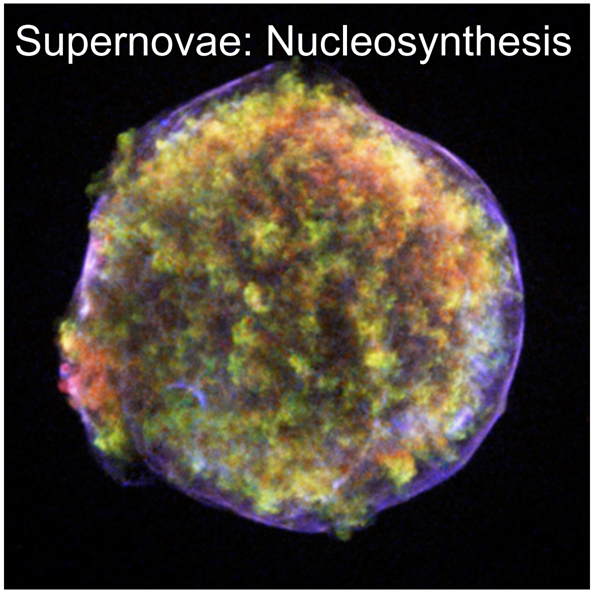
- Outer crust 'normal', but core uncertain.
- Hard to extrapolate from normal nuclei (~50% protons) to the high-density regime of nearly 0% proton fraction.
- EOS models depend upon assumptions made about the phase of matter in the core: (e.g., hadrons, Bose-Einstein condensates, quark matter).
- Each new phase increases the compressibility of the star, allowing for a smaller NS.

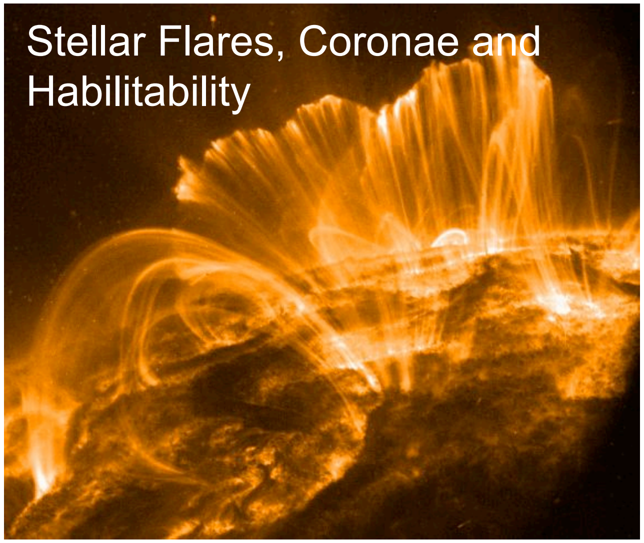
Neutron Star Equation of State



1 Crab with >90% throughput.
ΔE < 200 eV (0.1 – 15 keV)

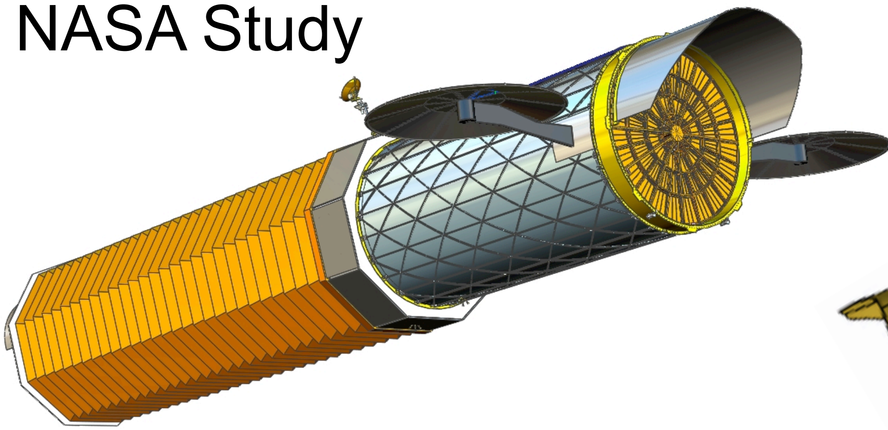
Life Cycles of Matter and Energy

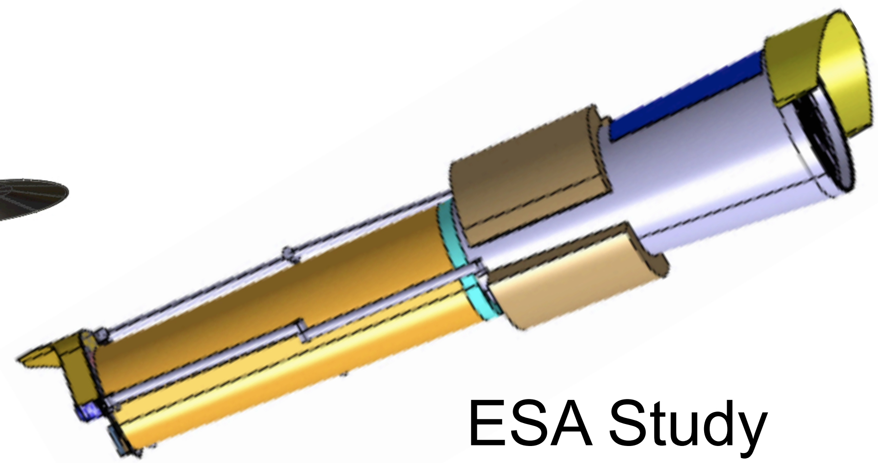




IXO Mission Studies

NASA Study





ESA Study

Mission Life

- 5 years required, 10 years goal

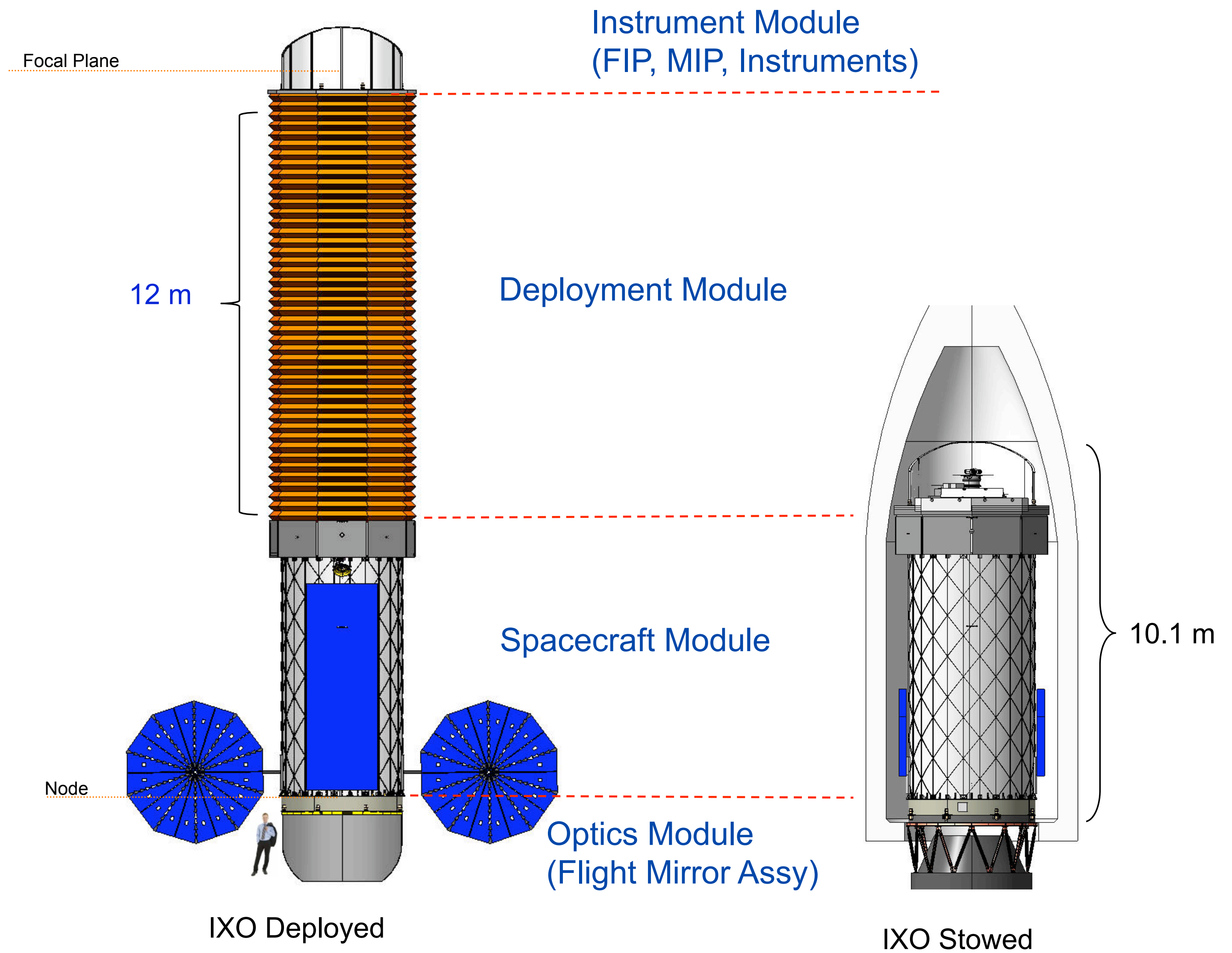
Launch

- December 2021
- Atlas V 551 or Ariane 5
- Max Liftoff Mass: 6425 kg

Orbit

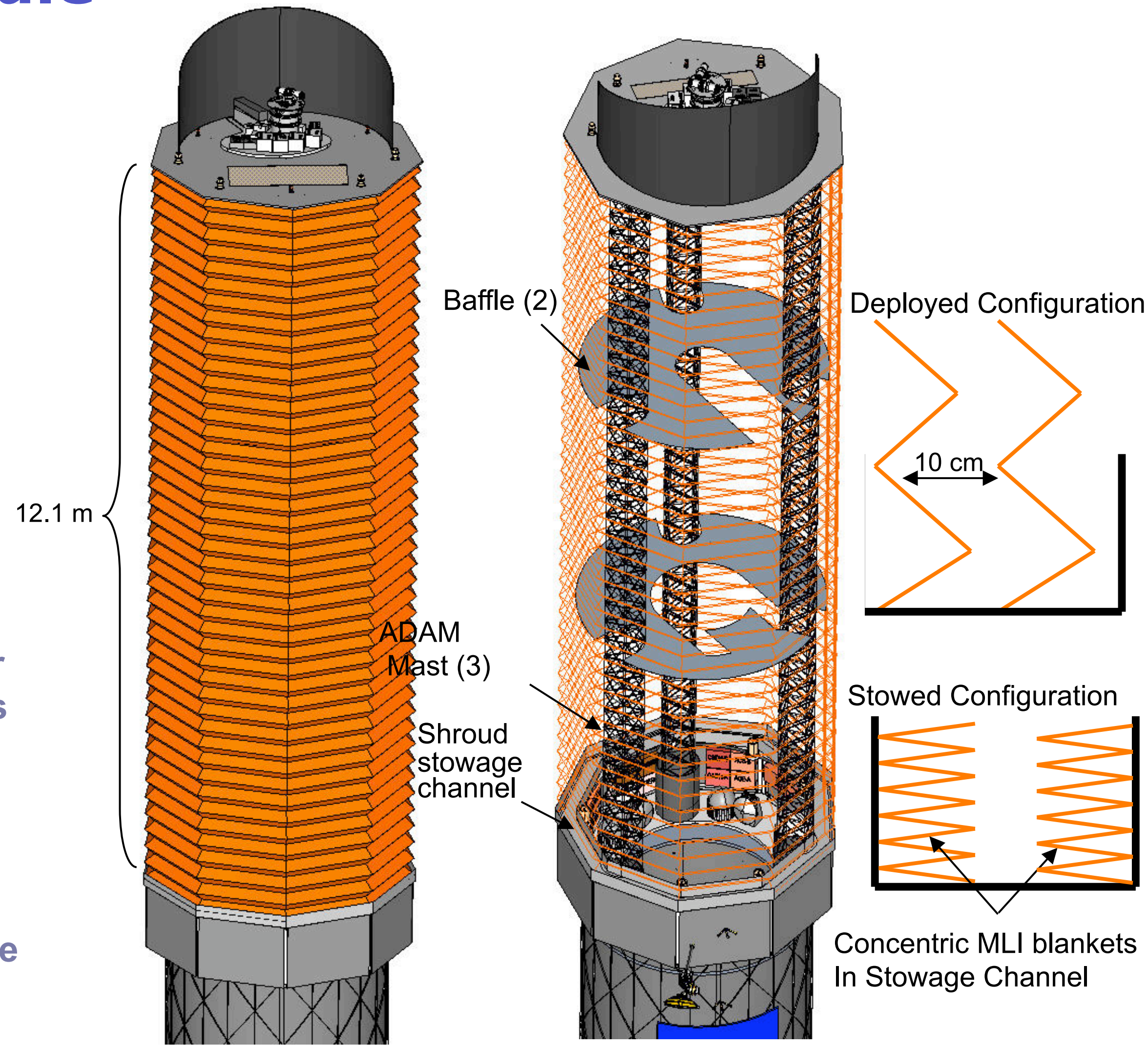
- L2 800,000 km semi-major axis halo orbit

IXO Observatory

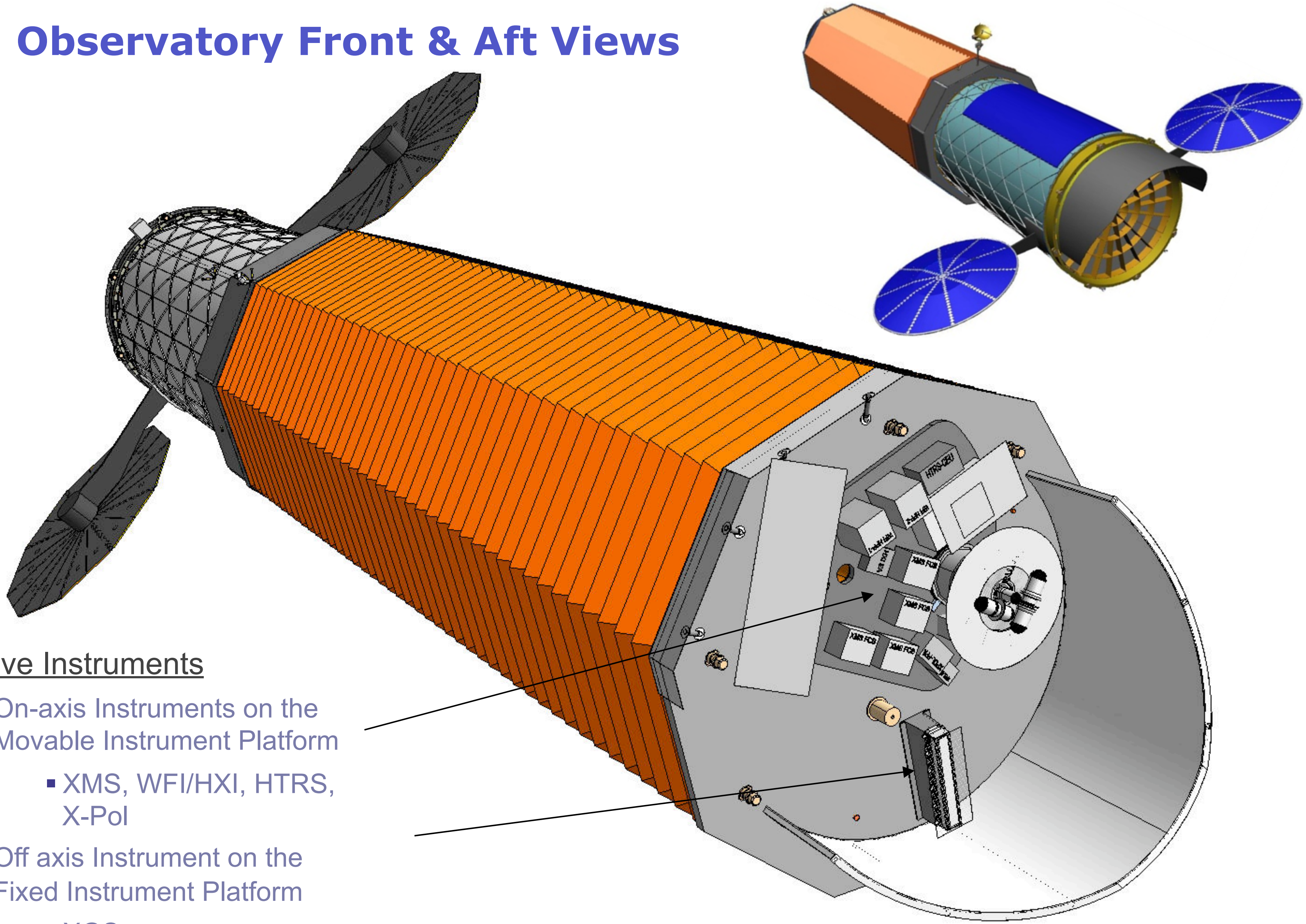


Deployment Module

- **3 ADAM masts deploy the IM, shroud, baffles and harness**
  - **Provides on-orbit alignment stability between optics and detectors**
  - **1.0 torsion and 1.5 bending**
  - **Proven technology**
  - **Mast and harness stows into canister**
- **Shroud blocks light and supports baffles**
  - **Accordion-pleated multi-layer insulation blanket assemblies**
  - **Two concentric blanket assemblies form a "Whipple shield" to minimize micrometeorite penetrations**
  - **Stows in channel on top of the spacecraft bus**



Observatory Front & Aft Views

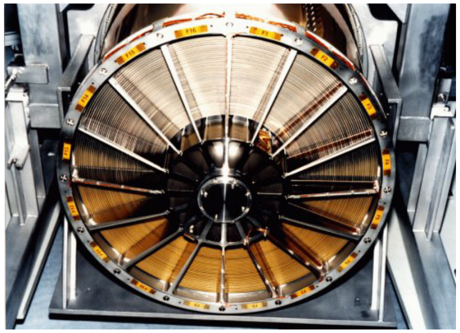


Five Instruments

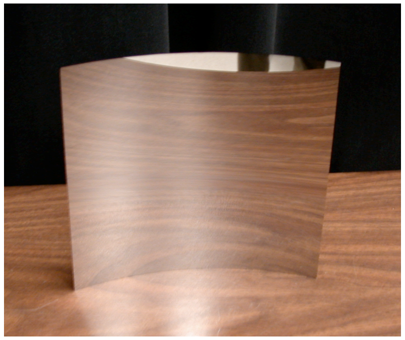
- On-axis Instruments on the Movable Instrument Platform
    - XMS, WFI/HXI, HTRS, X-Pol
- Off axis Instrument on the Fixed Instrument Platform
    - XGS

The Large Collecting Area Secret: Lightweight Optics

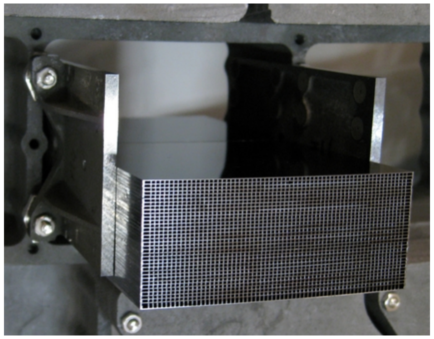
CHANDRA
0.5" HEW
18500 kg/m²



XMM-NEWTON
14" HEW
2300 kg/m²



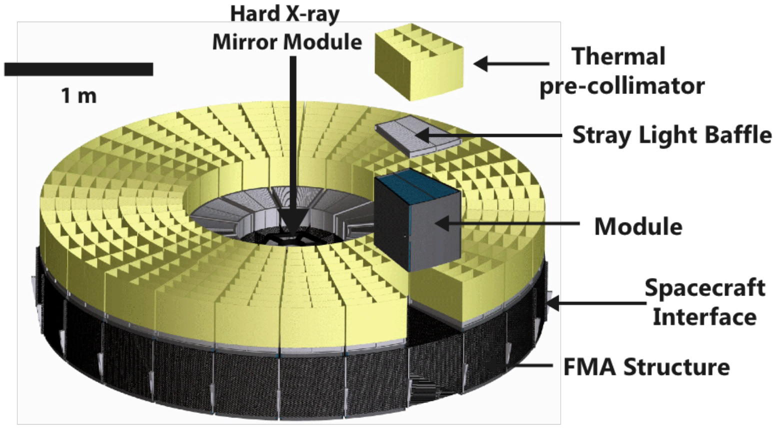
Slumped Glass
5" HEW
~270 kg/m²

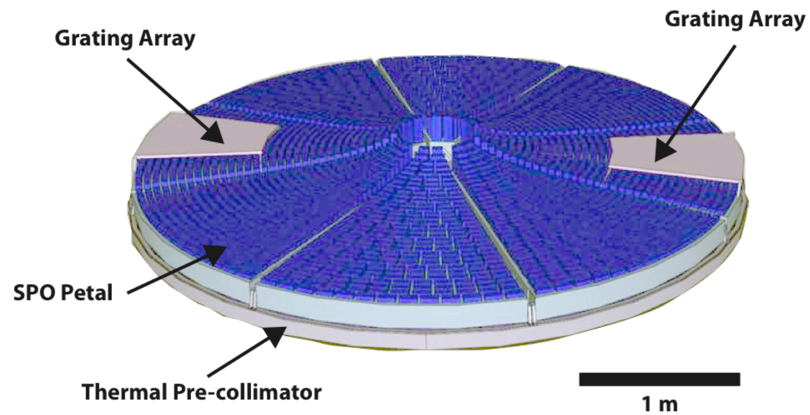


Si-HPO
5" HEW
~200 kg/m²

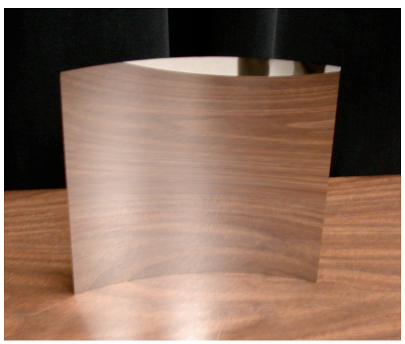
IXO Options

IXO X-ray Telescope



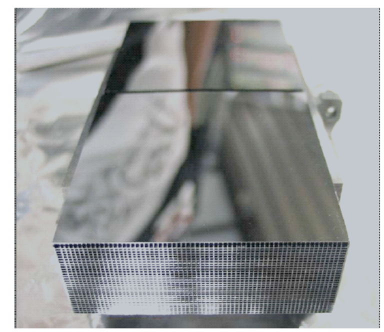


Glass



- **Key requirements:**
  - **Effective area ~3 m^2 @ 1.25 keV**
  - **Angular Resolution <= 5 arc sec**
- **Two technology approaches being pursued**
  - **ESA: Silicon micro-pore optics 3.8m diameter**
  - **NASA: Slumped glass 3.0m diameter**

Silicon



- **Both making excellent progress**
  - **Already achieved 10 to 15 arc sec resolution, with path to 5 arc sec by 2012**
  - **Slumped glass baselined for NuSTAR, demonstrates production approach**

Summary

IXO addresses key and timely questions confronting Astronomy and Astrophysics

IXO will bring a factor of 10 gain in telescope aperture and a factor of 100 increased spectral capability

Studies by ESA, JAXA and NASA demonstrate that the mission implementation for a ~2021 launch is feasible with no major show stoppers

X-ray Grating Spectrometer

Two grating technologies are under study:

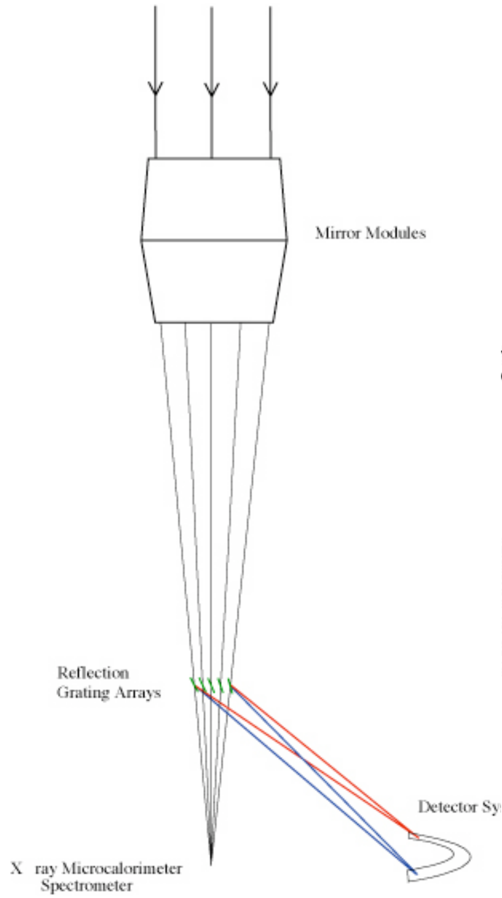
- Critical Angle Transmission (CAT) grating
- Off-plane reflection grating

CCD detectors:

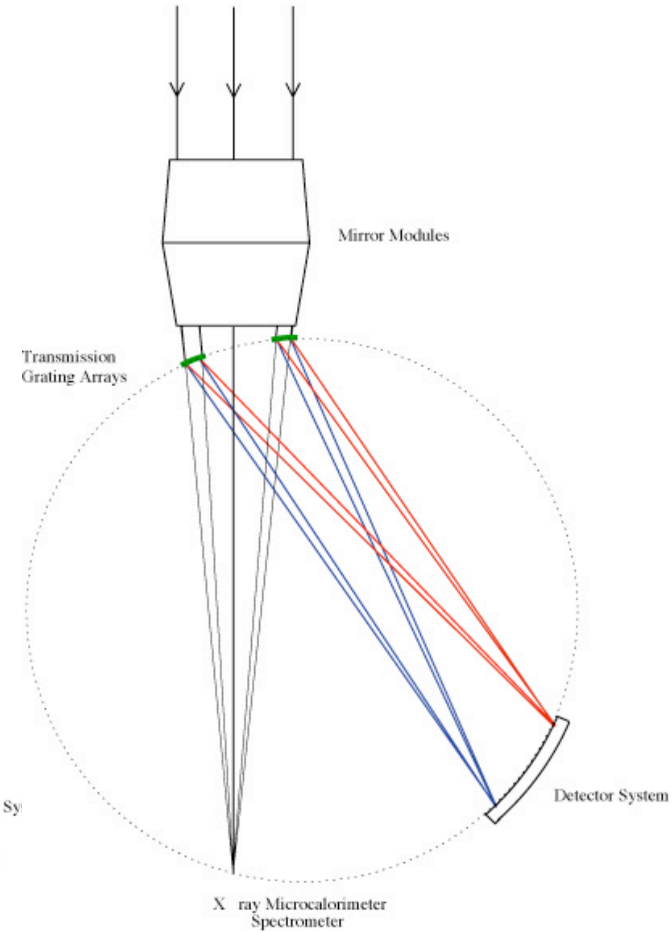
Back-illuminated (high QE below 1 keV),

Fast readout with thin optical blocking filters

Heritage from Chandra, XMM, Suzaku



Off-plane



Critical Angle Transmission

Wide Field and Hard X-ray Imagers

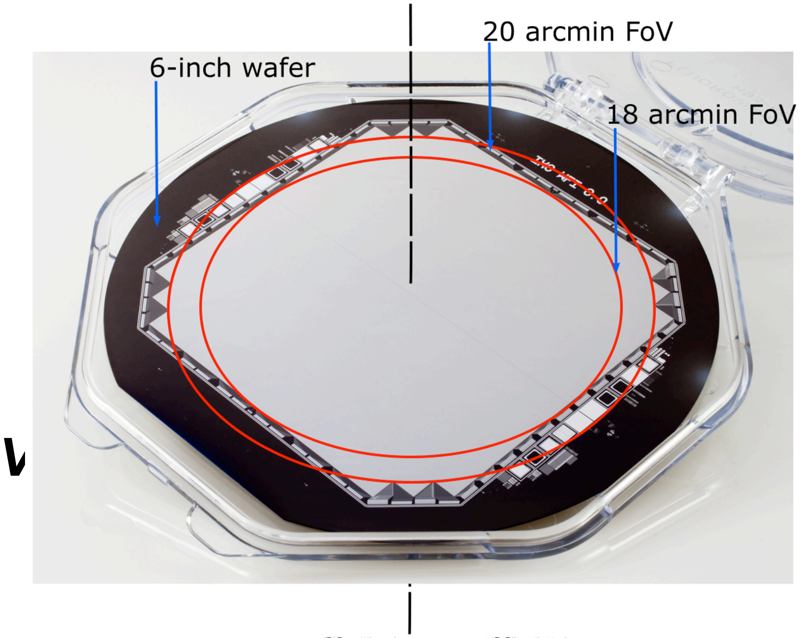
Wide field imager (WFI):

Silicon active pixel sensor

- field of view: 18 arcmin

- energy range: 0.1 to 15 keV

energy resolution: < 150 eV @ 6 keV

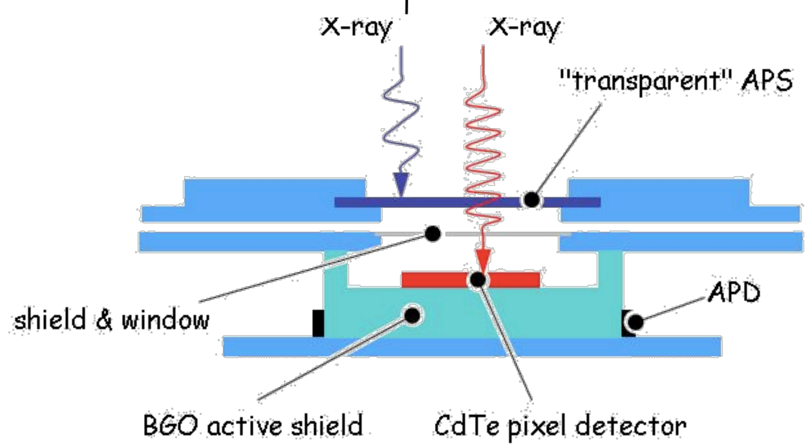


Hard X-ray imager (HXI):

Cd(Zn)Te pixel array located behind

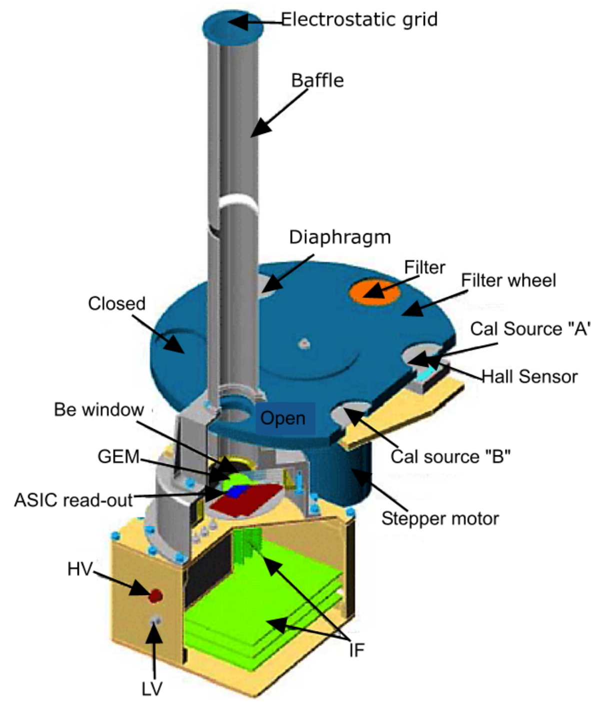
- energy range extension to 40 ke

- field of view: 8 arcmin

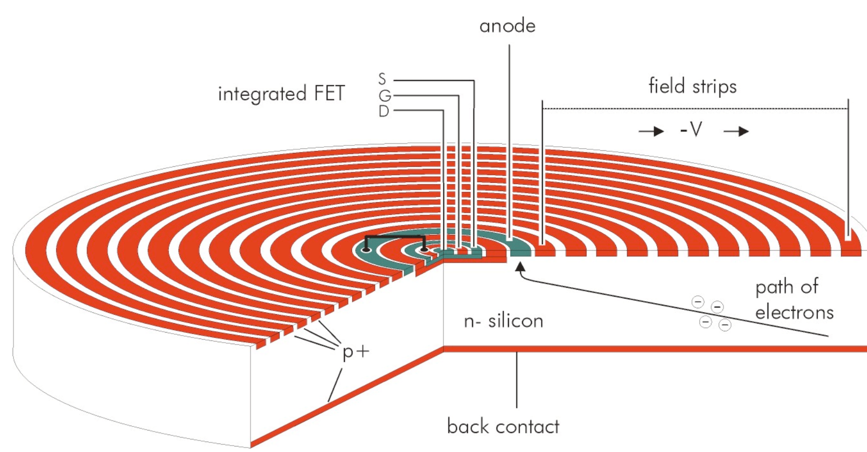


X-POL and HTRS

X-ray Polarimeter
Micropattern Gas Chamber
Imaging Detector
1% polarization



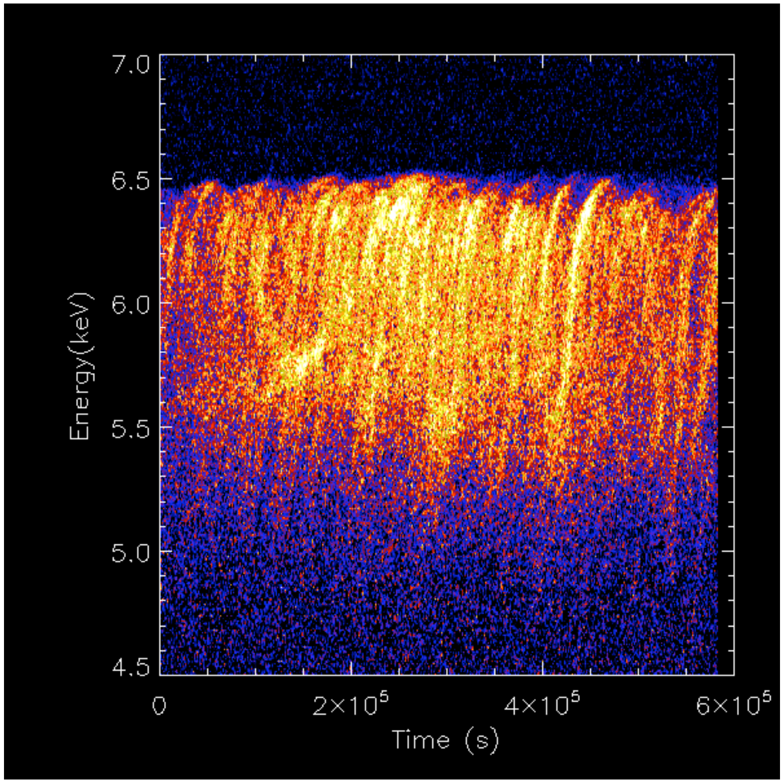
High Time Resolution Spectrometer
37 hexagonal low-capacitance
silicon drift diodes (SDD)
up to 2 M counts/sec, about 6 Crab



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

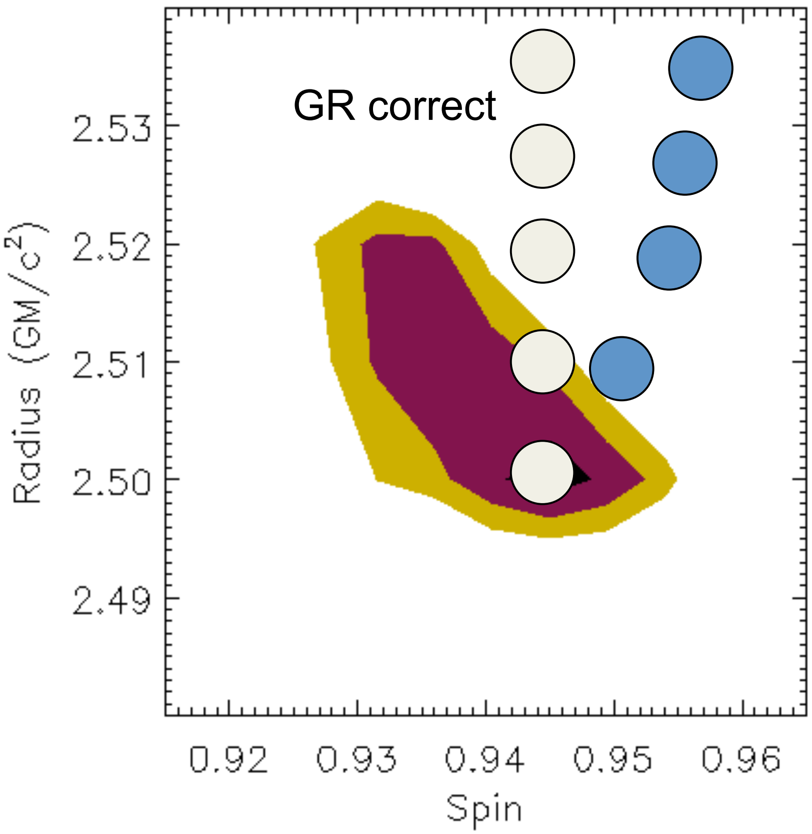
X-ray iron K line bright spots in accretion disk surrounding Black Hole trace orbits that can be mapped with IXO

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

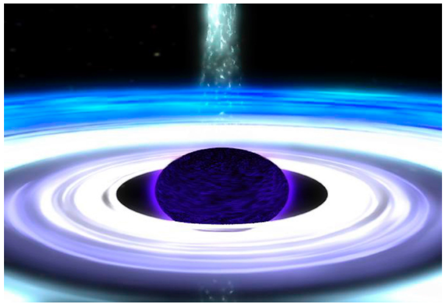


IXO Simulated observation of hot spots orbiting Black Hole

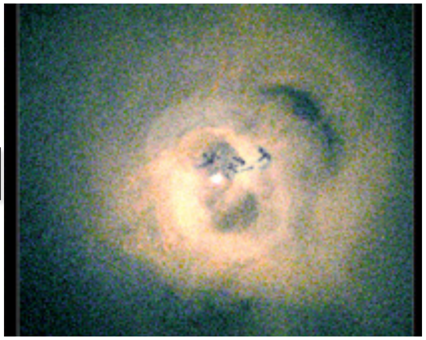
GR incorrect



Main Science Topics

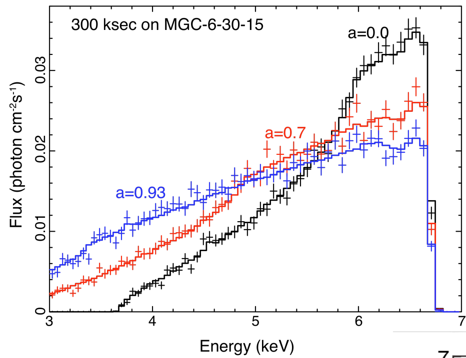


- **Matter under Extreme Conditions**
  - **Neutron stars; General Relativity**

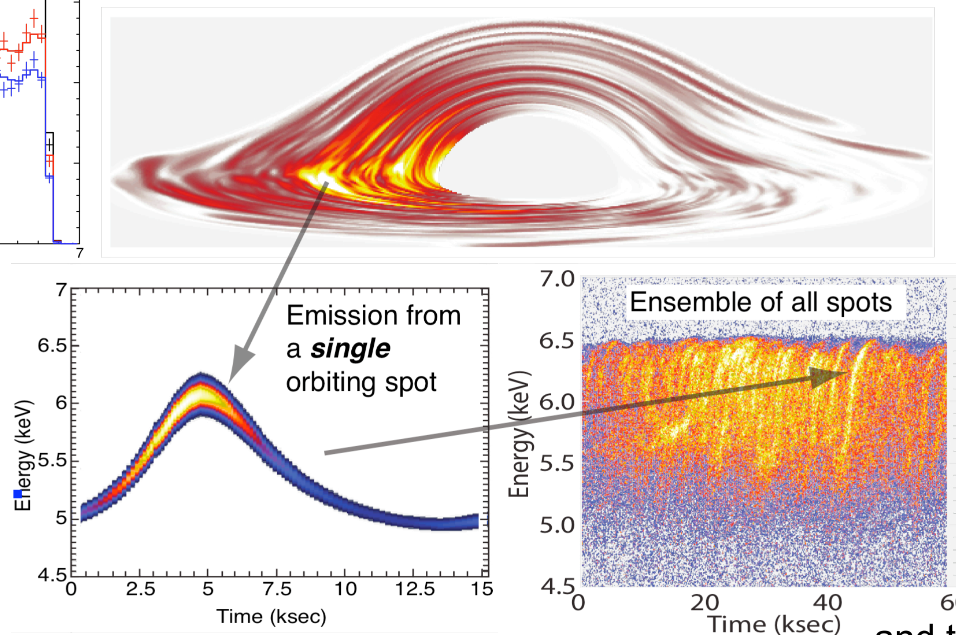


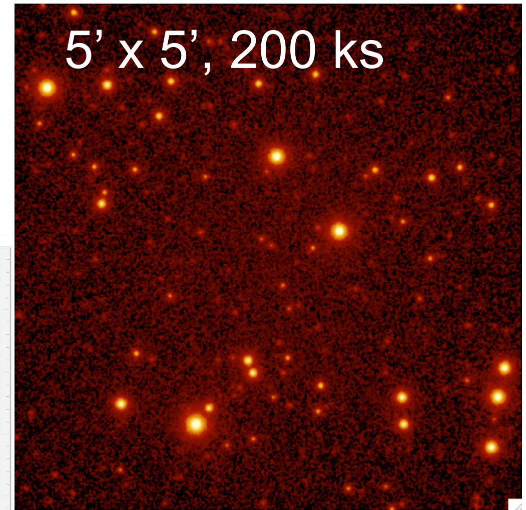
- **Black Hole Evolution and the Evolution of Galaxies, Clusters, and Large Scale Structure**

- **Life Cycles of Matter and Energy**
  - **Supernovae, stars**



Individual Black Holes…and Black Hole Surveys

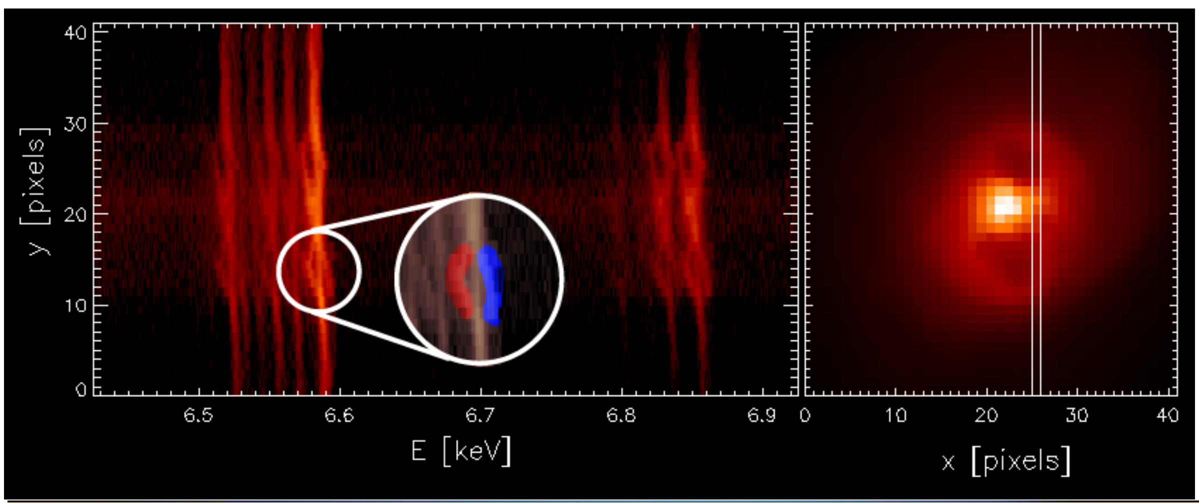


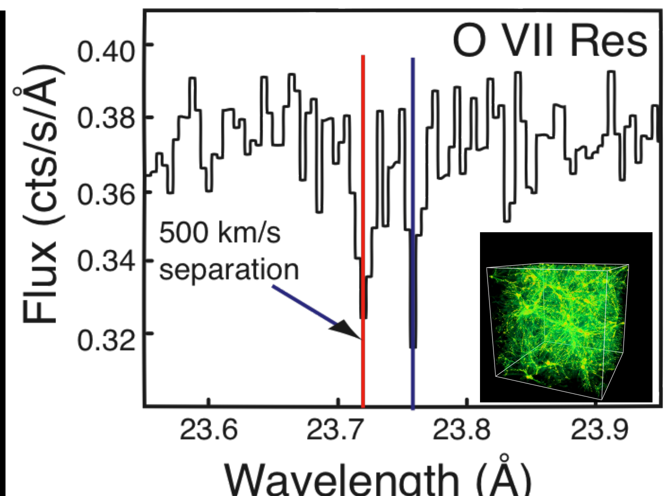


IXO will measure…

…and the Cosmic Web

Cluster Gas Motion and Feedback

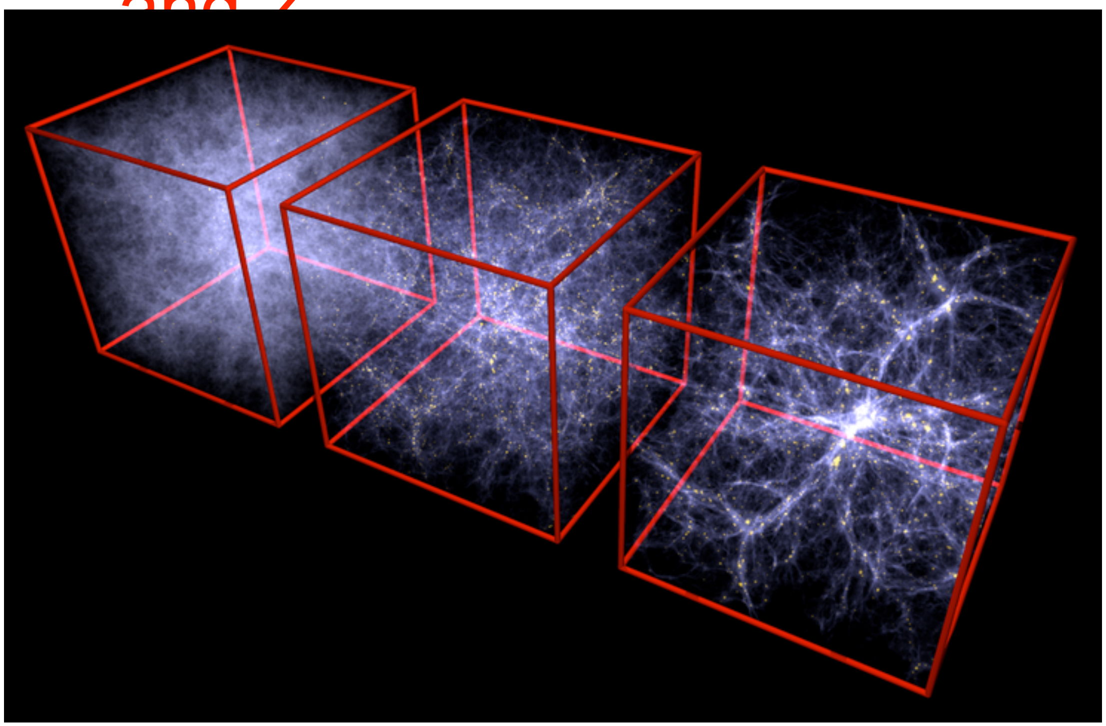


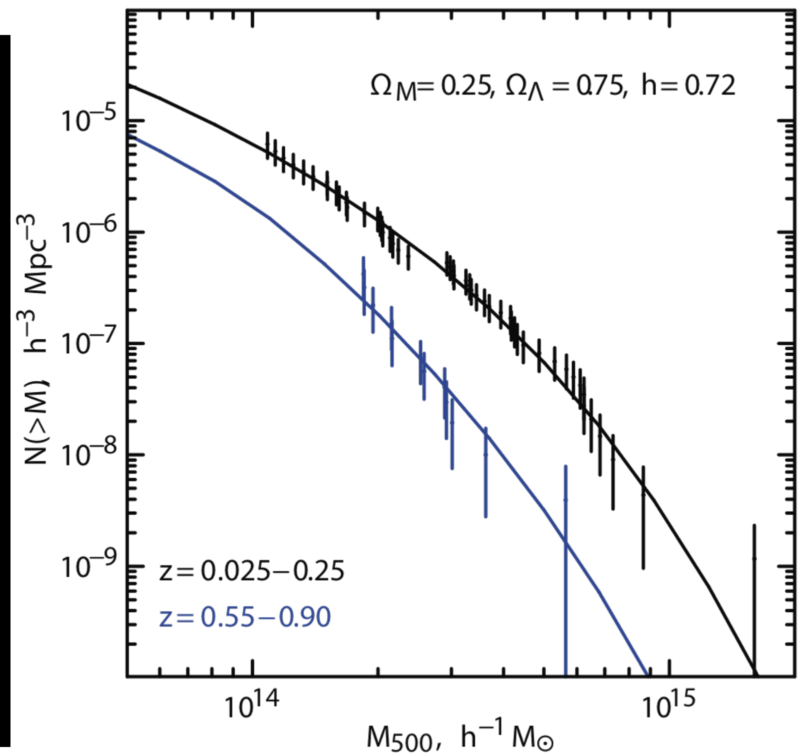


Cosmology with IXO

The growth of cosmic structure:

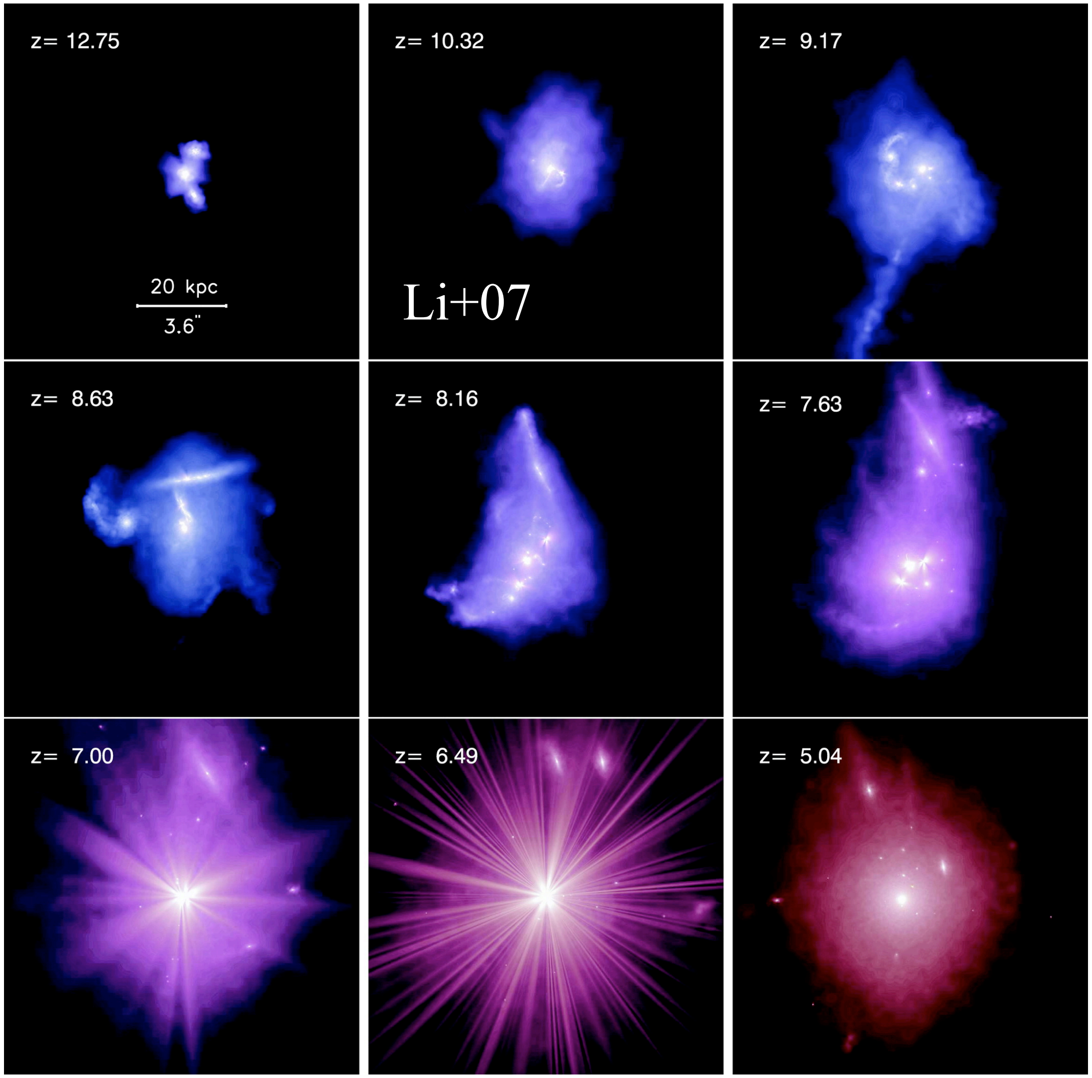
Measure the space density of clusters with mass and z





Vikhlinin+09

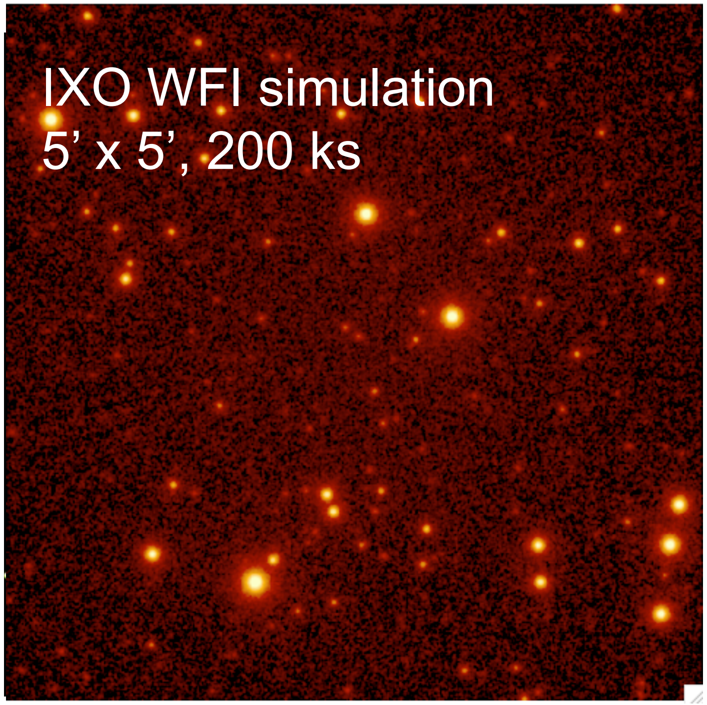
Building a ~10^9 M_{sun} BH at z ~ 6



- Gas rich major merger
- Inflows trigger BH accretion & starbursts
- Dust/gas clouds obscure AGN
- AGN wind sweeps away gas, quenching SF and BH accretion
- IXO well tuned to follow and confirm/constrain this process

Hernquist (1989)
Springel et al. (2005)
Hopkins et al. (2006)

When and How do Super-massive Black Holes Grow?

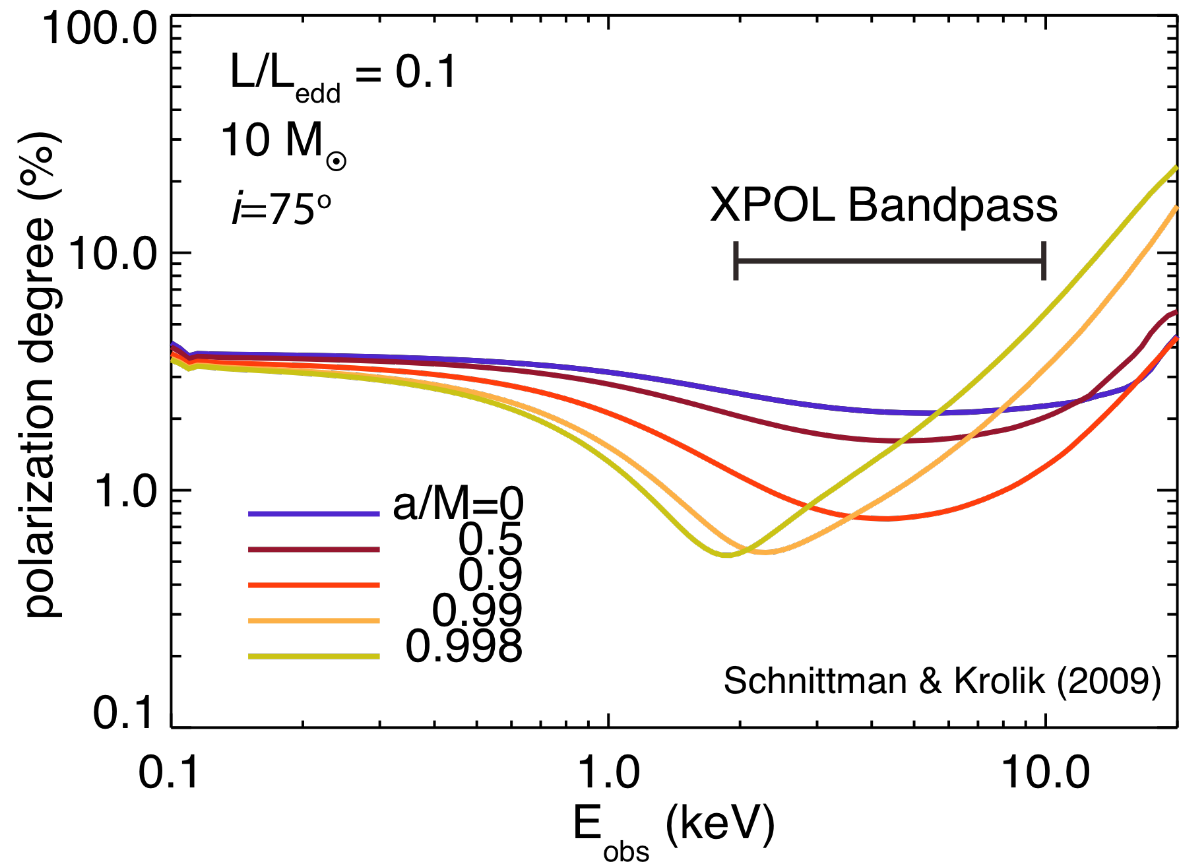


20 day exposure with Chandra will be a routine observation for IXO

- Chandra and XMM-Newton deep fields reveal that super-massive Black Holes (SMBH) are common
- X-ray observations are a powerful tracer of their growth and penetrate obscuring material
- Most of Chandra sources only have <30 counts even in 20-day deep surveys
- Spectra can measure: redshift, detect multiple SMBH, estimate Eddington luminosity, black hole spin, outflows, absorption, etc..

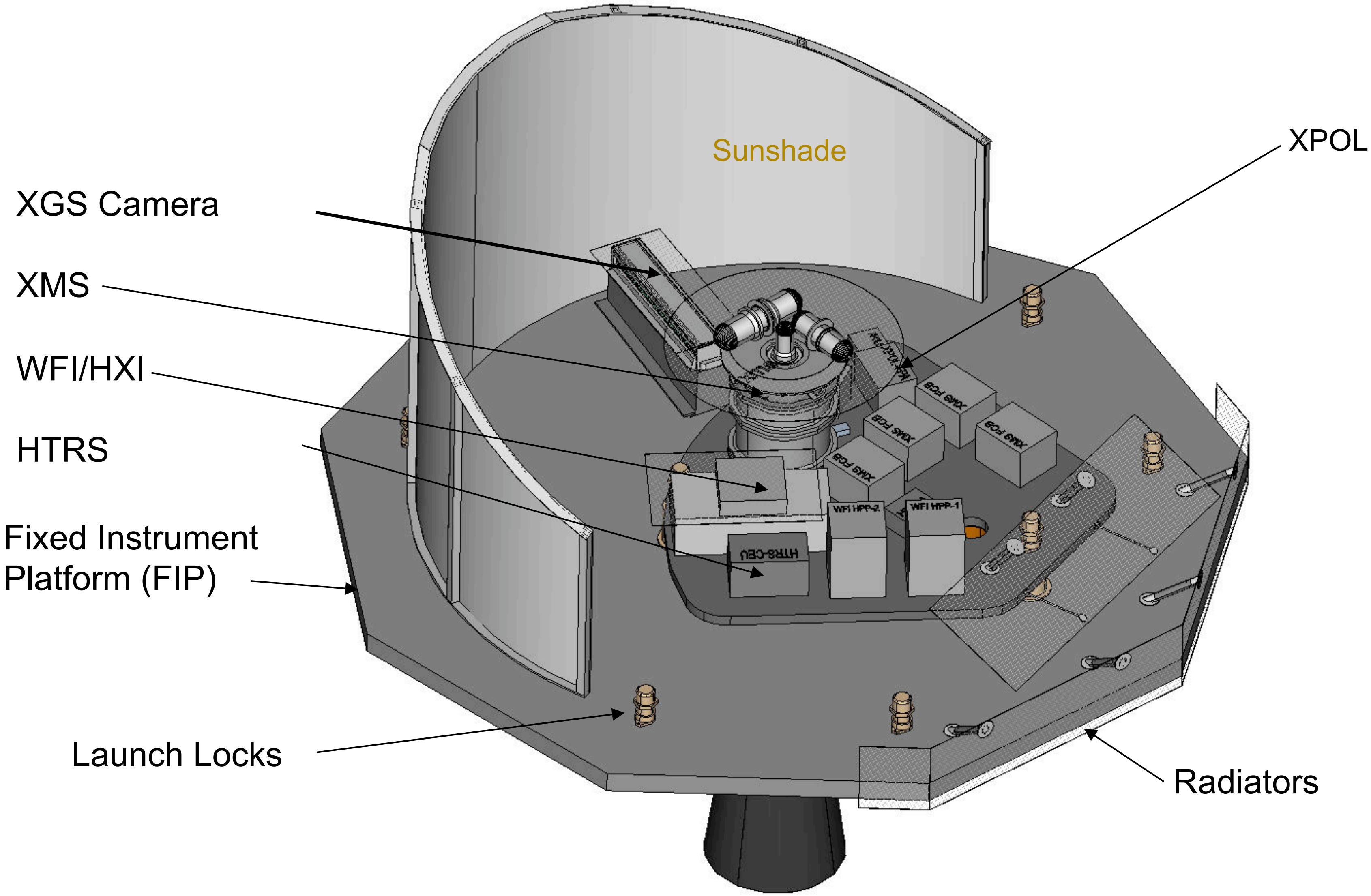
IXO will reach the deepest Chandra fields 20 times faster, and provide spectral surveys on a square degree scale with high spectral resolution

Polarization



Polarization observations can accurately determine the spin/mass (a/M) ratio for a typical Galactic BH binary. A 100 ksec XPOL observation will make energy-resolved measurements each sensitive to ~0.5% (3σ), easily separating these models.

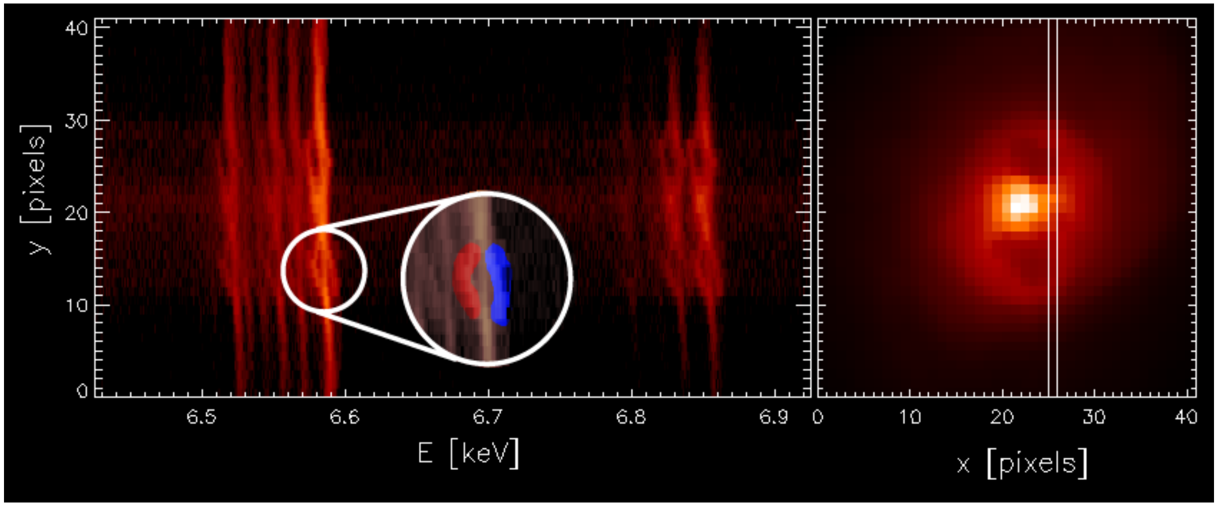
Instrument Module



Cosmic Feedback

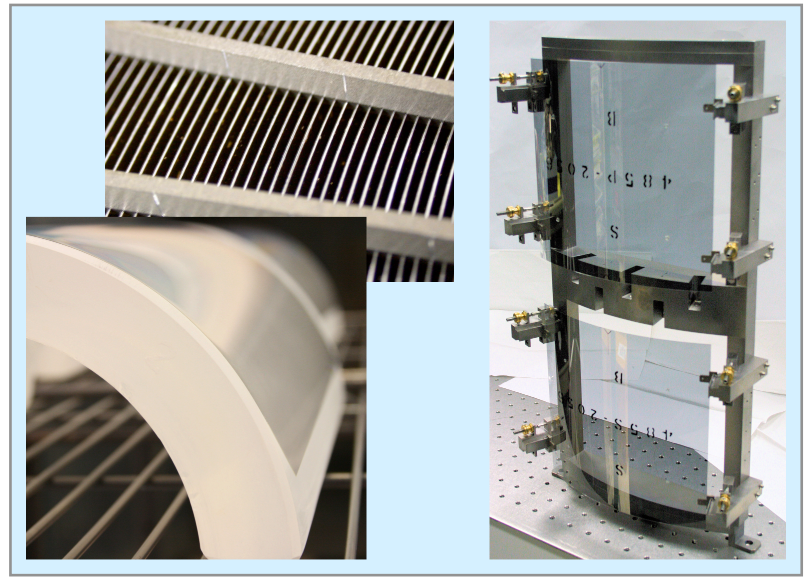
AGN feedback: regulates the growth of galaxies and clusters of galaxies

IXO: Velocity measurements → bubble expansion and energy transfer



Mirror Technology Approach

- Two fully independent mirror technology paths to TRL **6**
  - Segmented slumped glass
  - Si pore optics
- TRL 6 achieved for both by January 2012
  - 5 months prior to Technology Review
- Technology development roadmaps provided as appendices to written responses
  - Defined milestones for TRL 4 & 5
  - TRL 6 at module/petal level



Segmented Slumped Glass

Silicon Pore Optic Petal