Science With The International X-ray Observatory

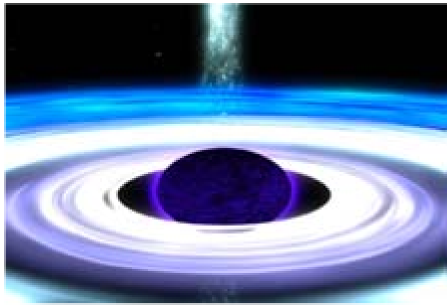
Randall K Smith

For the IXO Team

Main Science Topics

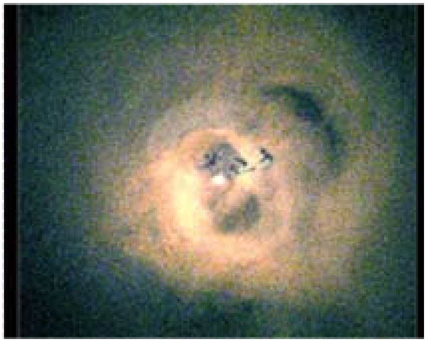
IXO

1. Black Holes and Matter under Extreme Conditions



2. Galaxy Formation, Galaxy Clusters and Cosmic Feedback

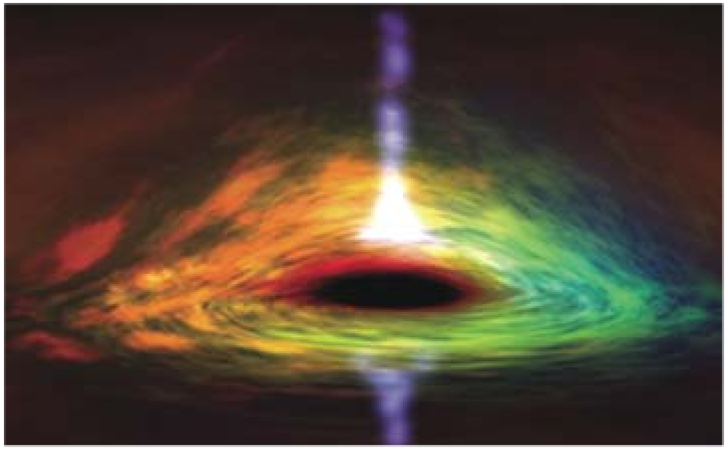
   (Dark Matter, Dark Energy, Black Hole energetics)

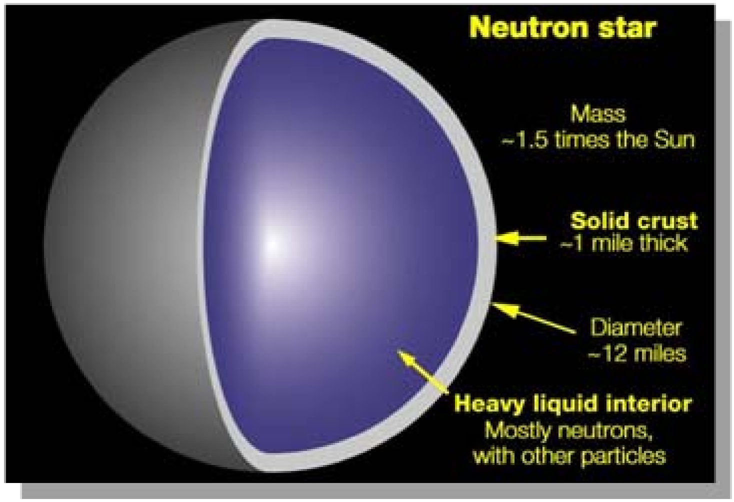


3. Life Cycles of Matter and Energy

Black Holes and Matter under Extreme Conditions

IXO





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?

Galaxy Formation, Galaxy Clusters and Cosmic Feedback

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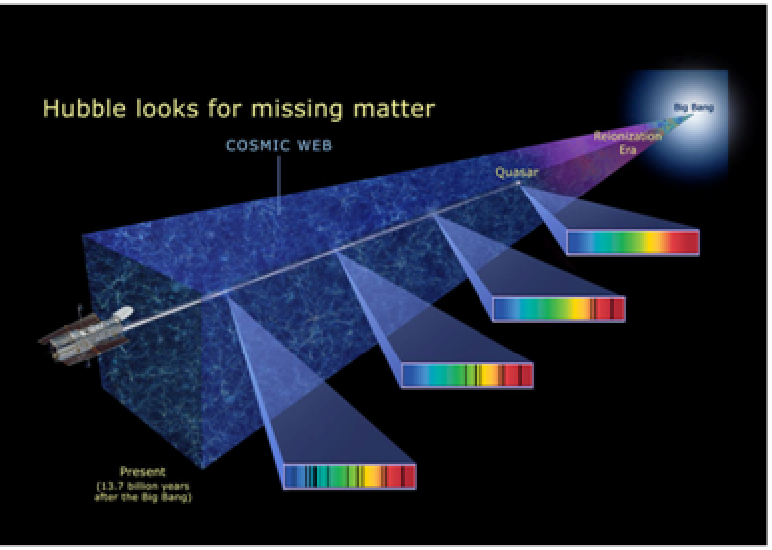
How does Cosmic Feedback work and influence galaxy formation?

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

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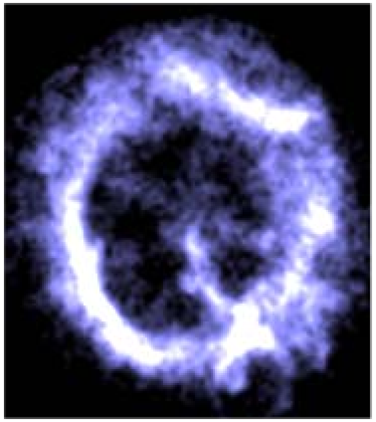
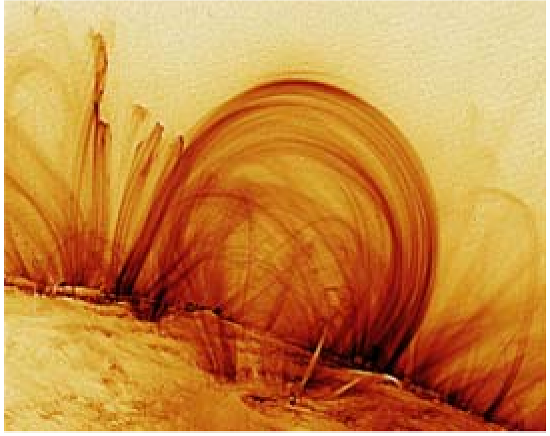




When and how were the elements created and dispersed?

How do high energy processes affect planetary formation and habitability?

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

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

Opening a new window

IXO

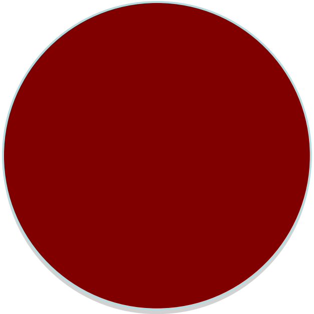
High-resolution effective area of Chandra or XMM-Newton (shown actual size)

With this effective area, and a resolution of 300-1000, Chandra and/or XMM-Newton have been able to discover the effects of cosmic feedback heating cooling-flow clusters, find winds ejected from black hole accretion disks, determine the characteristics of winds around AGN (**will fill in with good graphics, point is that great astrophysics has been and is being done now with high-resolution X-ray spectra**).

Opening a new window

High-resolution effective area of Chandra or XMM-Newton (shown actual size)

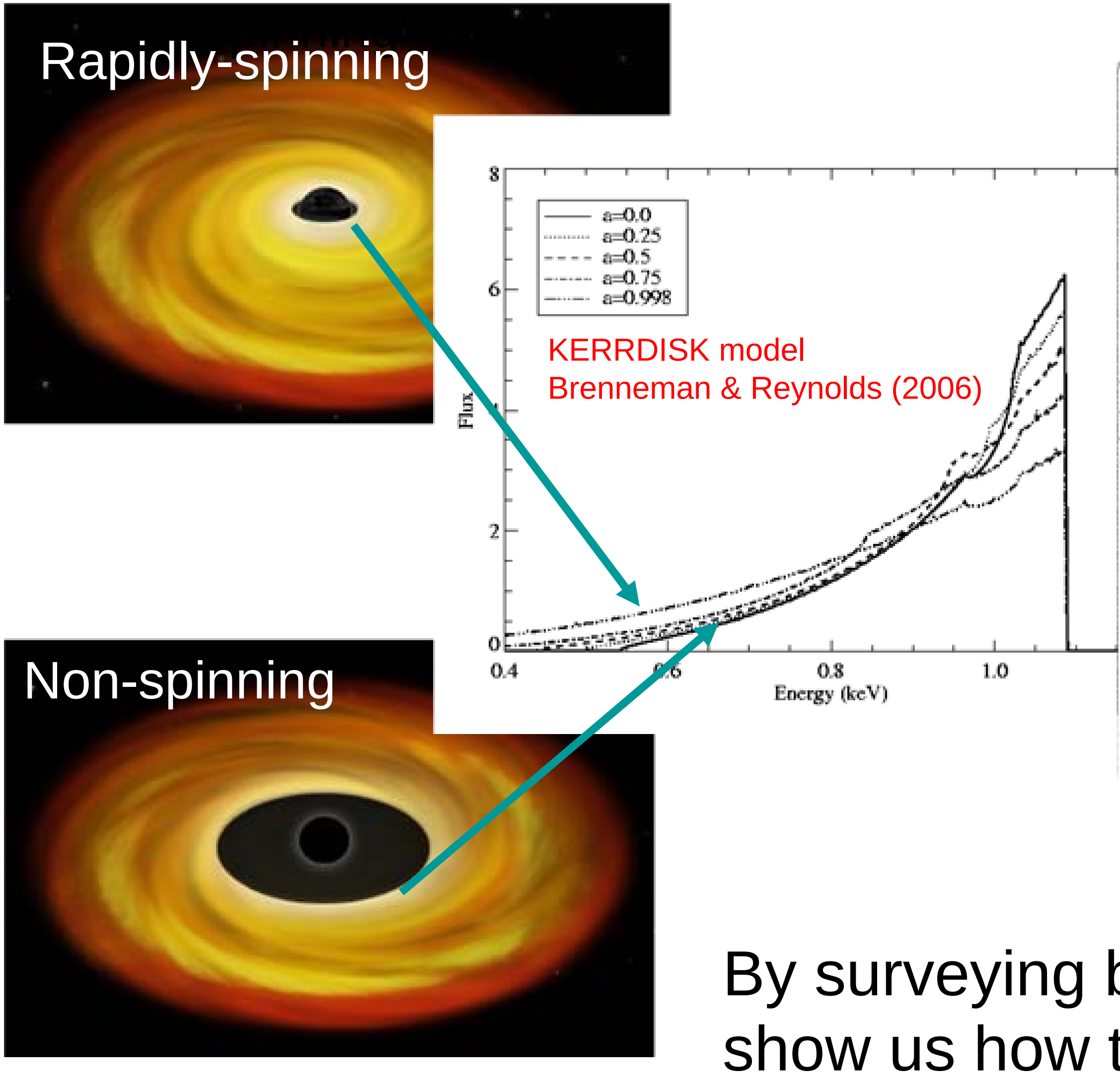
High-resolution effective area of IXO (shown actual size)



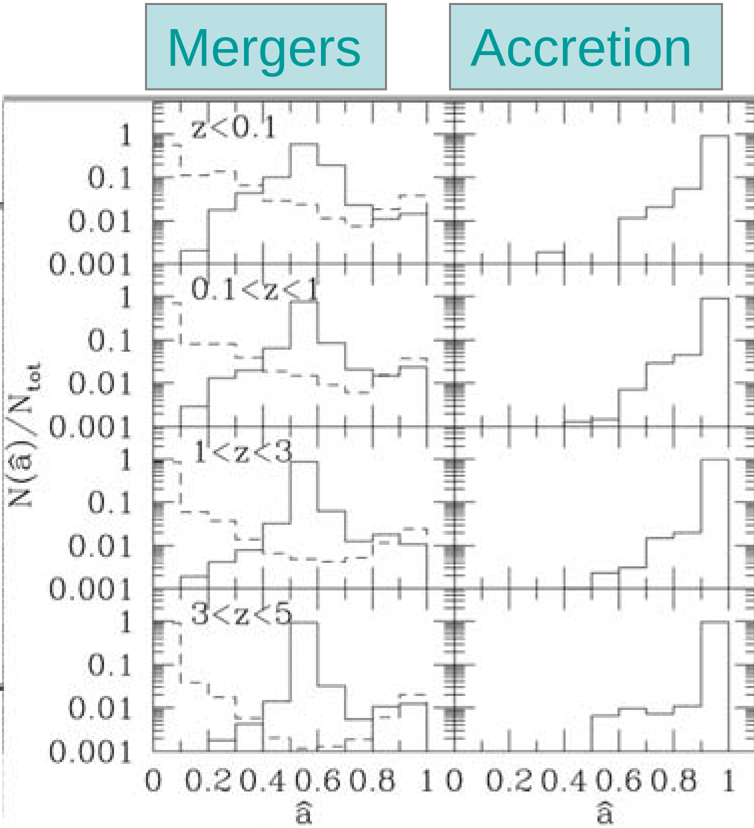
To meet the IXO science objectives requires a factor of 10-100 increase in effective area with high spectral resolution:

- Telescope area: ~ 3 m^2 @ 1 keV, ~ 1 m^2 @ 6 keV, ~ 0.07 m^2 @ 40 keV
- Angular resolution of ~ 5 arc sec or better
- Spectral resolution ($E/\Delta E$) of ~ 1250-2400 (over 0.3 to 7 keV)
- FOV of ~ 5 arc min or better

Black Hole Spin & Growth



KERRDISK model
Brenneman & Reynolds (2006)



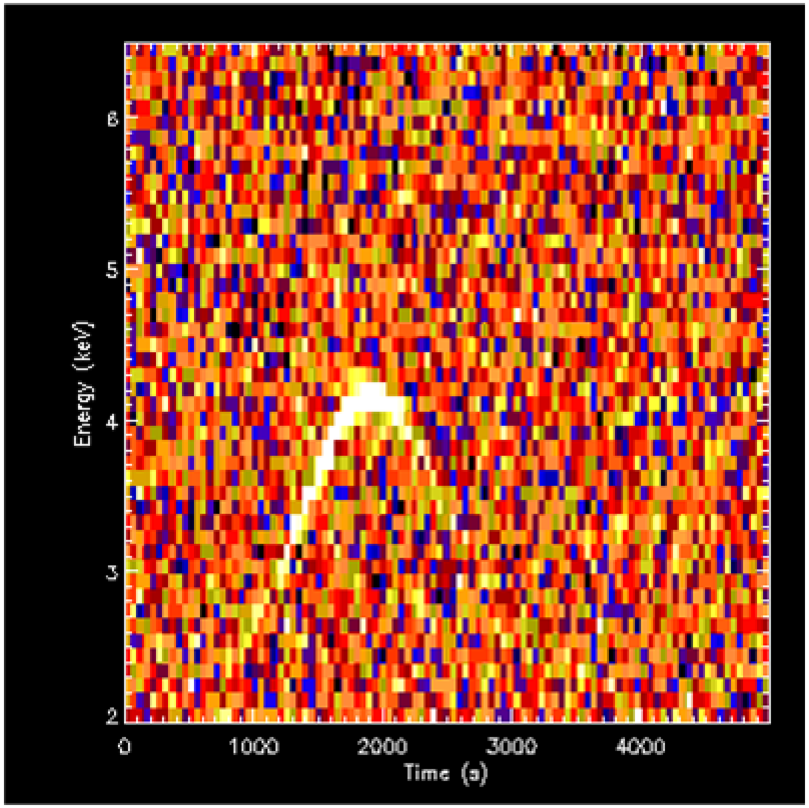
Volonteri et al. (2005)

By surveying black hole spin, IXO will show us how they grow.

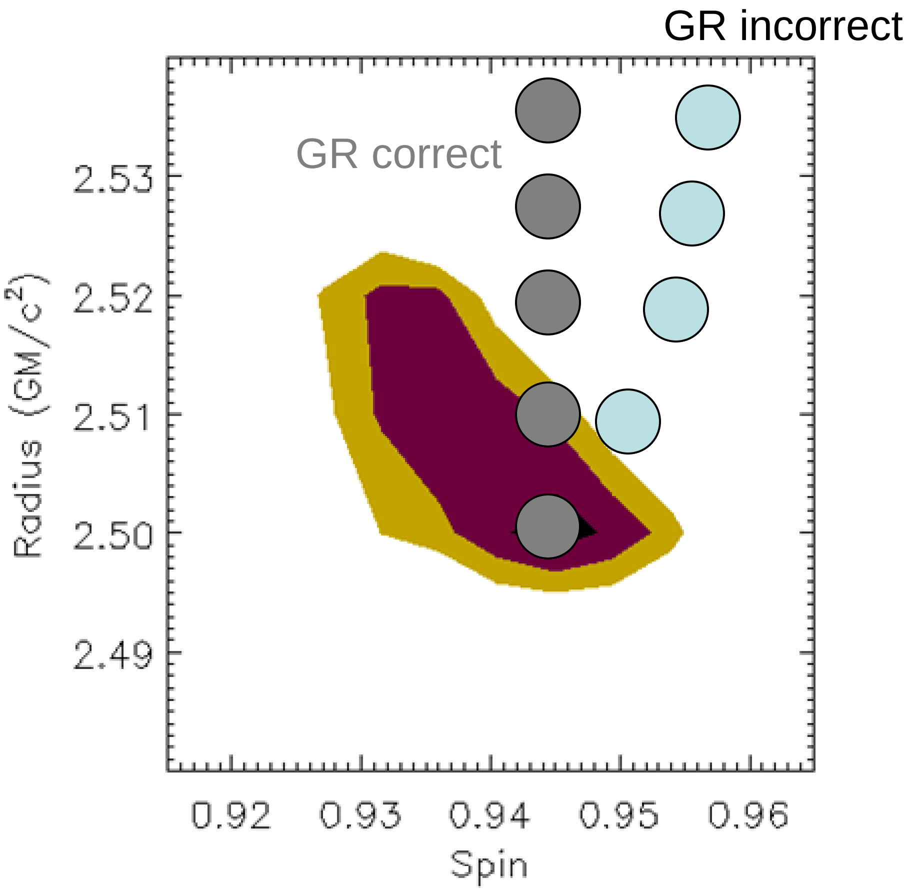
Testing General Relativity

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



$F=5\times10^{-11}$ erg/s/cm2; EW=20eV; $M=6\times10^{7}$
r=2.5 ; a=0.95 ; i=30 degrees



Quantum Chromodynamics

IXO

Quantum Chromodynamics

IXO

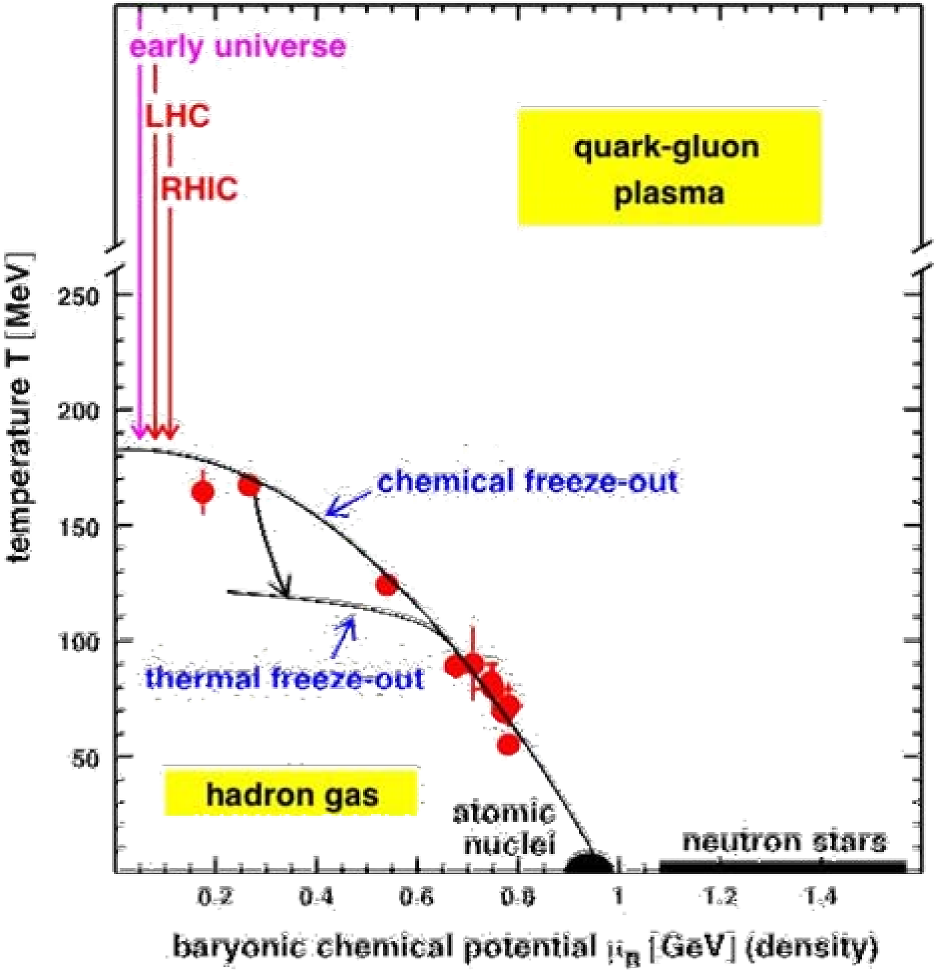
What is the equation of state of matter at supranuclear densities?

Interiors of neutron stars present extremes of density **not found anywhere else in the Universe**

Nature of matter in these conditions a deep mystery – entirely new states may be present

Neutron star mass+radius measurements will test current models of QCD

40-year old problem that *IXO* may finally resolve



Quantum Chromodynamics

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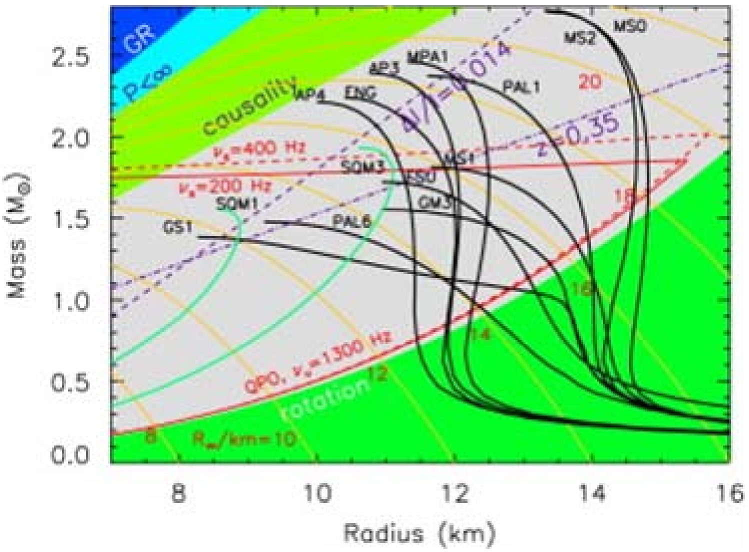
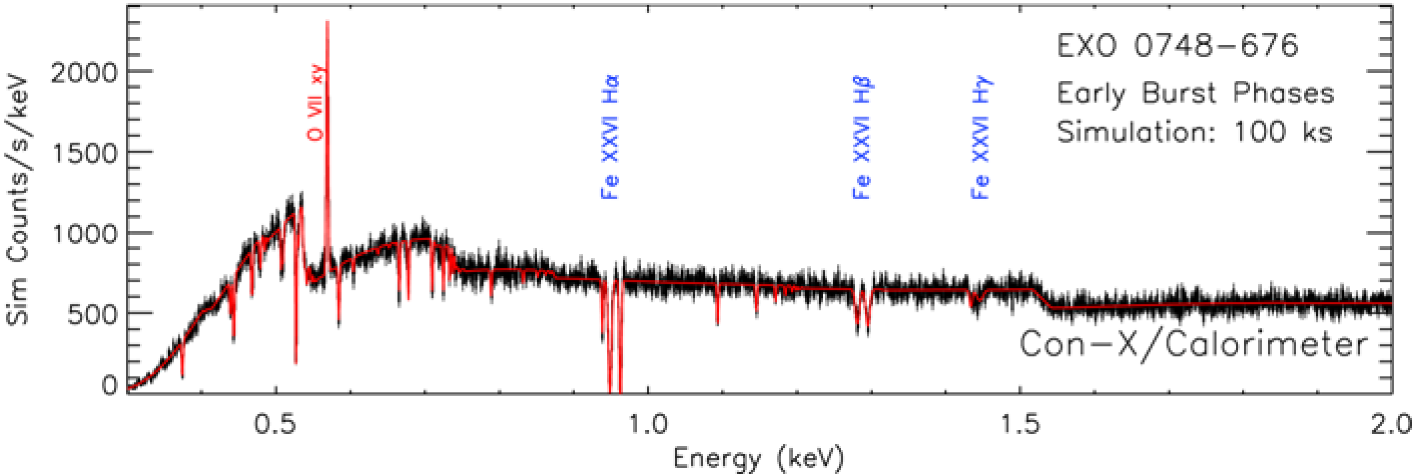
What is the equation of state of matter at supranuclear densities?

With measurements of EXO 0748-676 and a dozen other suitable sources, IXO will define the EOS for neutron star matter and answer long-standing questions about QCD.



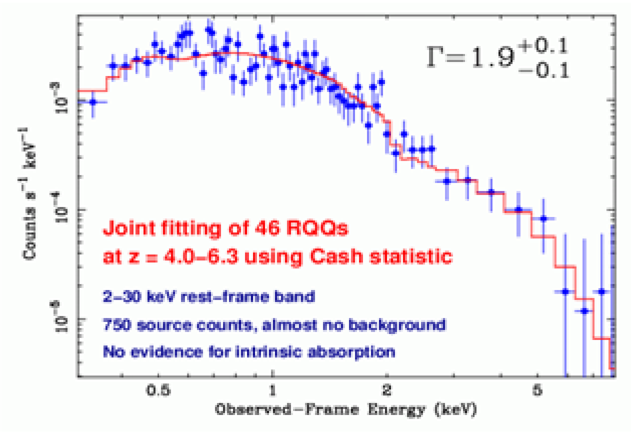
Lattimer & Prakash 2007



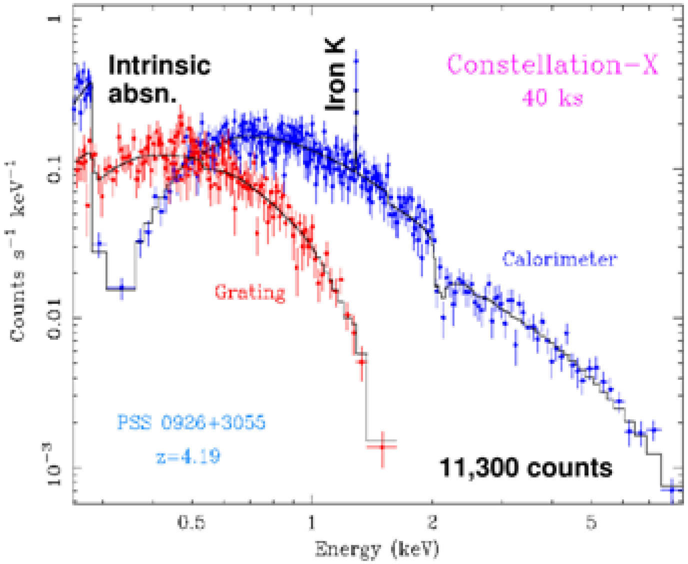
High Redshift (z>4) AGN

IXO

Basic Chandra Joint Fitting - Vignali et al. (2005)



High-Quality IXO Spectra – 1000-80000 counts



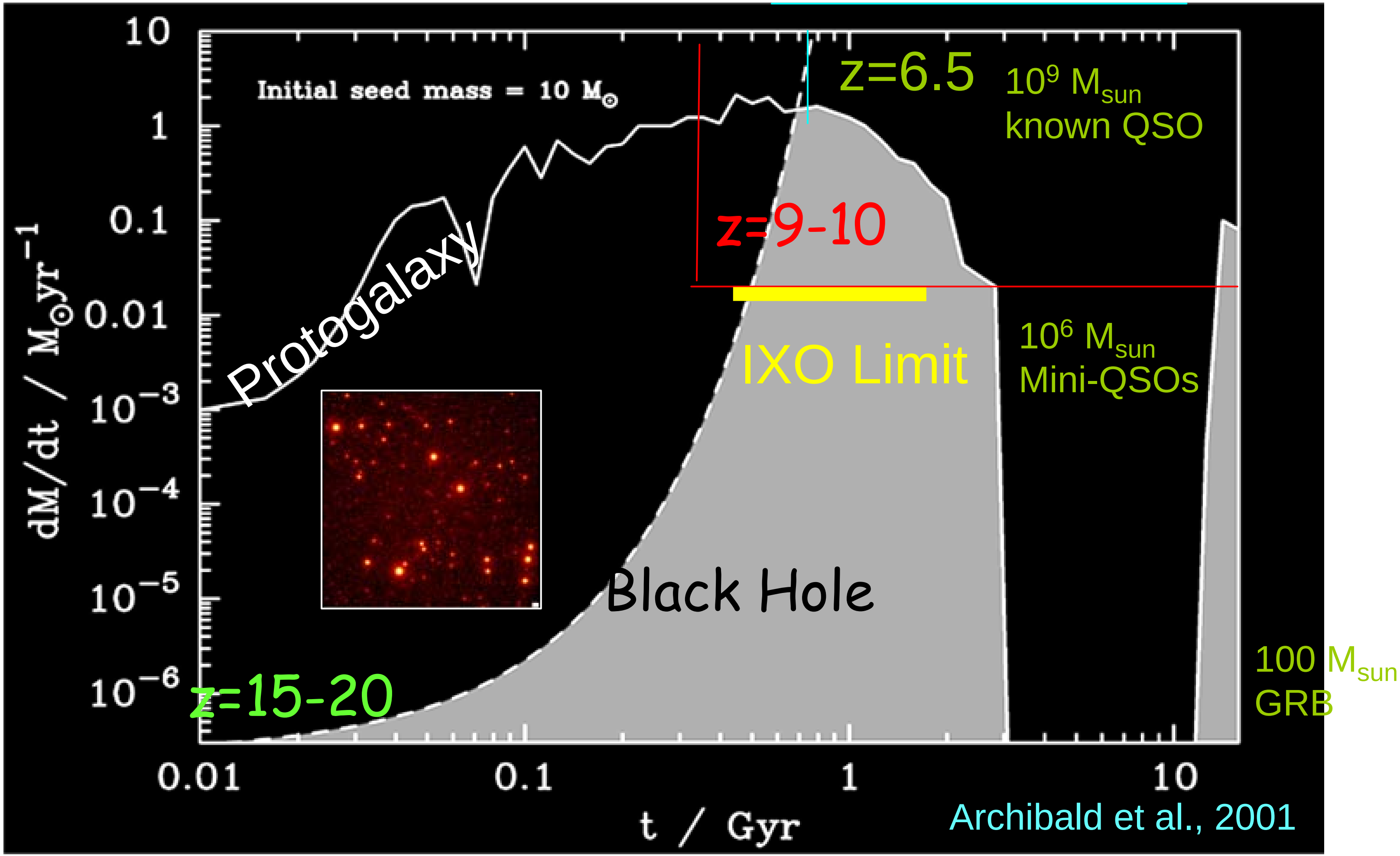
X-ray continuum shape – L / L_{Edd} indicator

Iron K lines – Disk ionization, rotation, Baldwin effect, multiple SMBHs

Compton-reflection continuum – Disk ionization

Variability – Relations to SMBH mass and L / L_{Edd}

First Black Holes

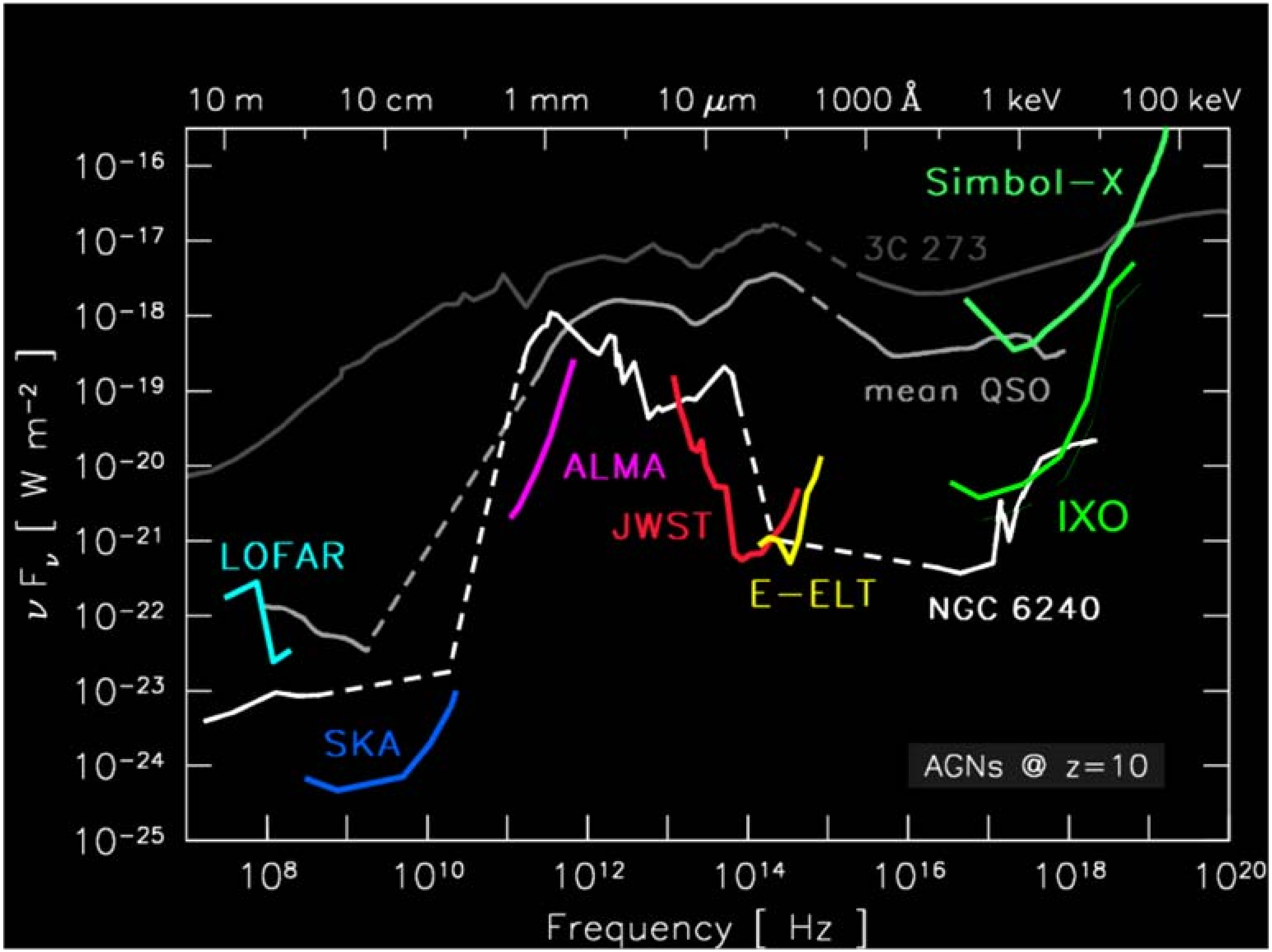


Archibald et al., 2001

10^6 M_o @ redshift of 10 is detectable by IXO

Multi-λ Power of future facilities @ z=10

IXO



Future Observations of First Galaxies

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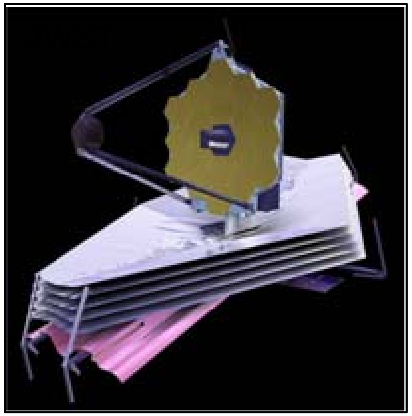
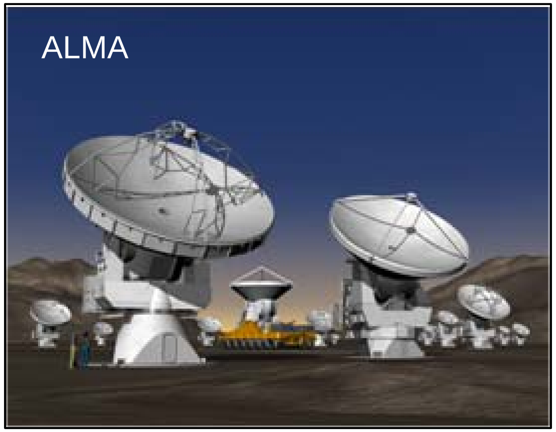
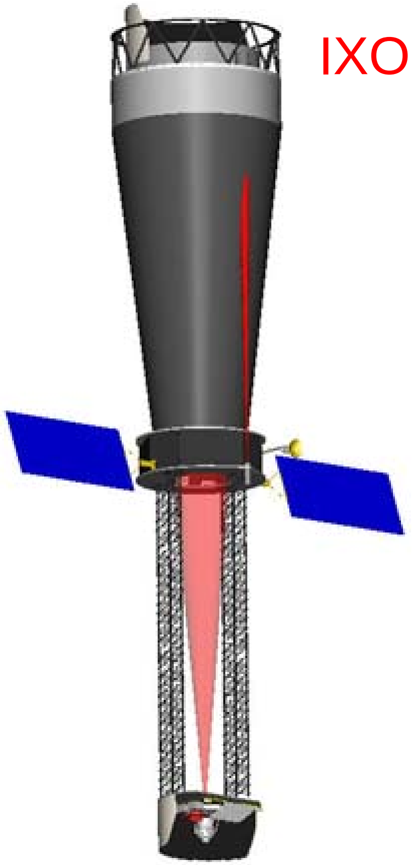
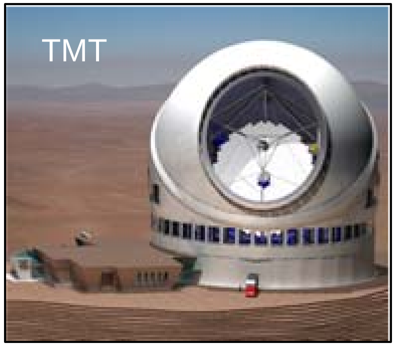
Starlight from First Galaxies

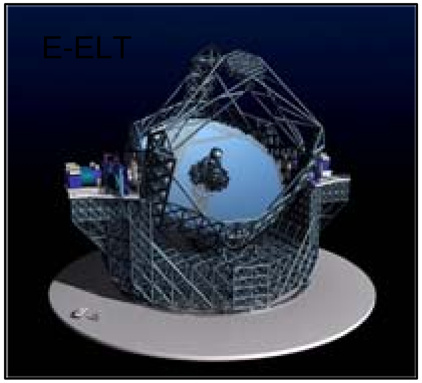
Accretion Light from First Galaxies











Accretion Processes

- Disk accretion onto super-massive black holes supplies 10-20% of the total ionizing flux in the universe. *What physical processes make that possible?*
- The majority of super-massive black holes are quiescent, and not fed by standard disks. *What is the nature of low-level accretion?*

Accretion Processes

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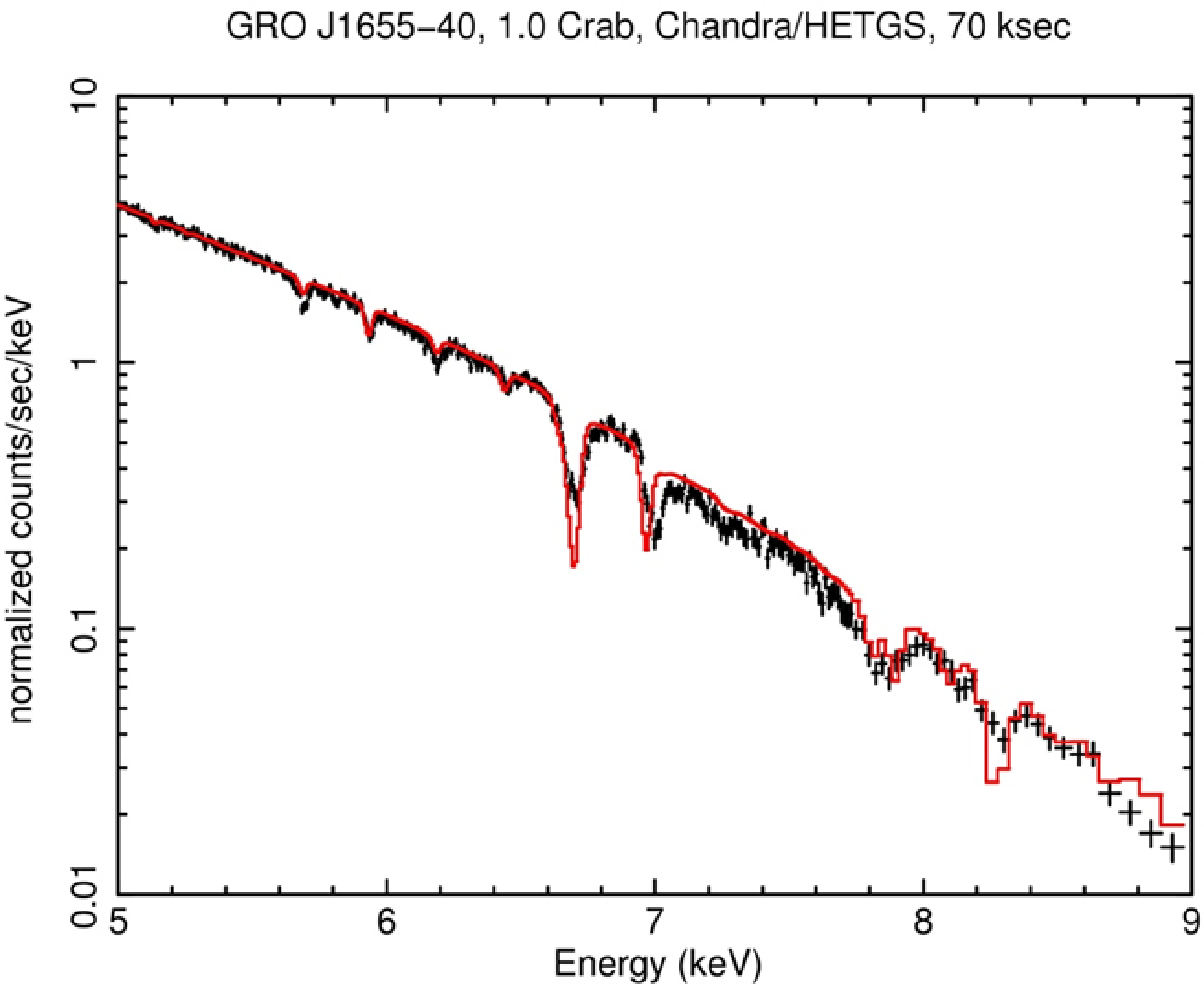
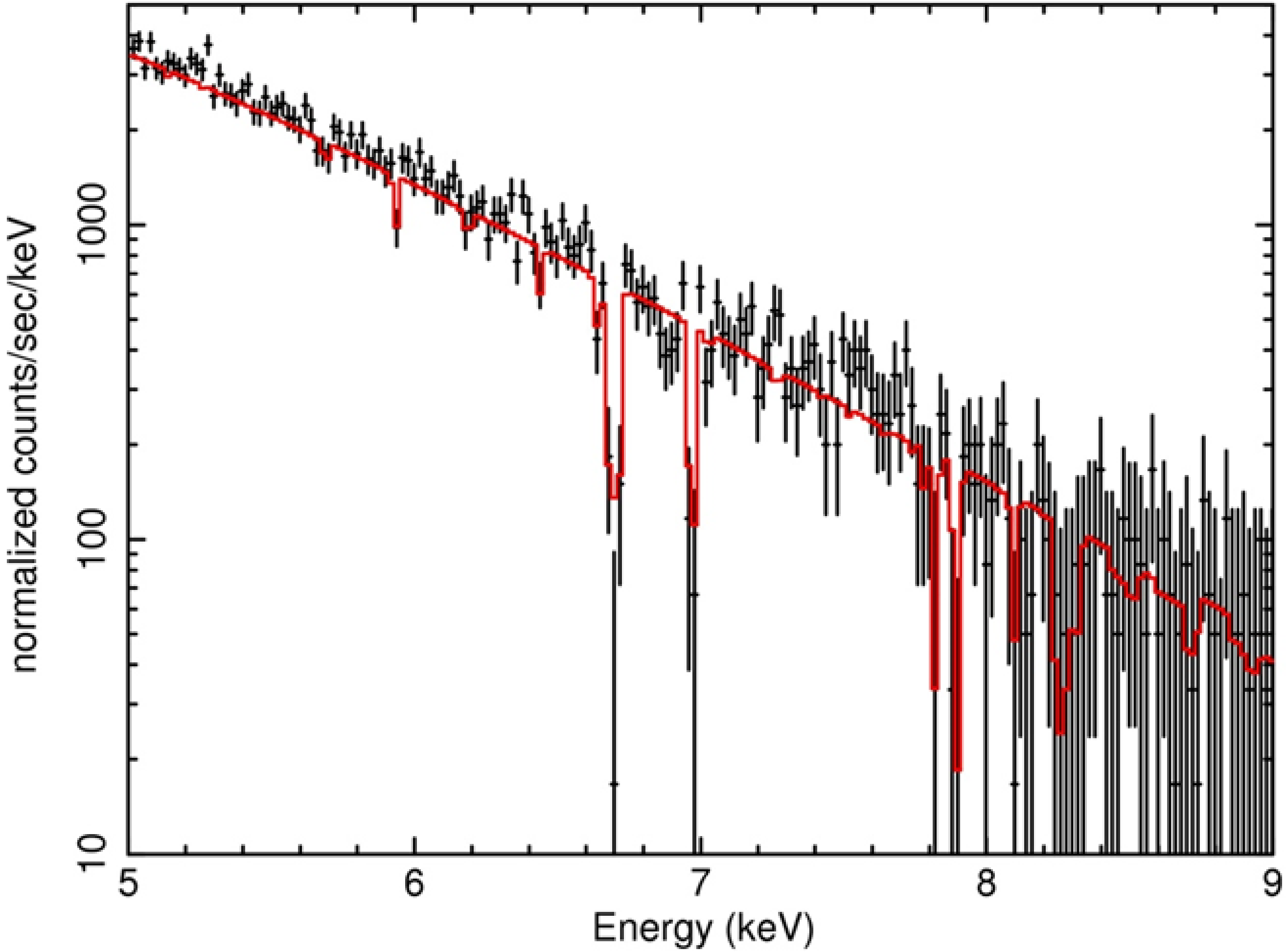


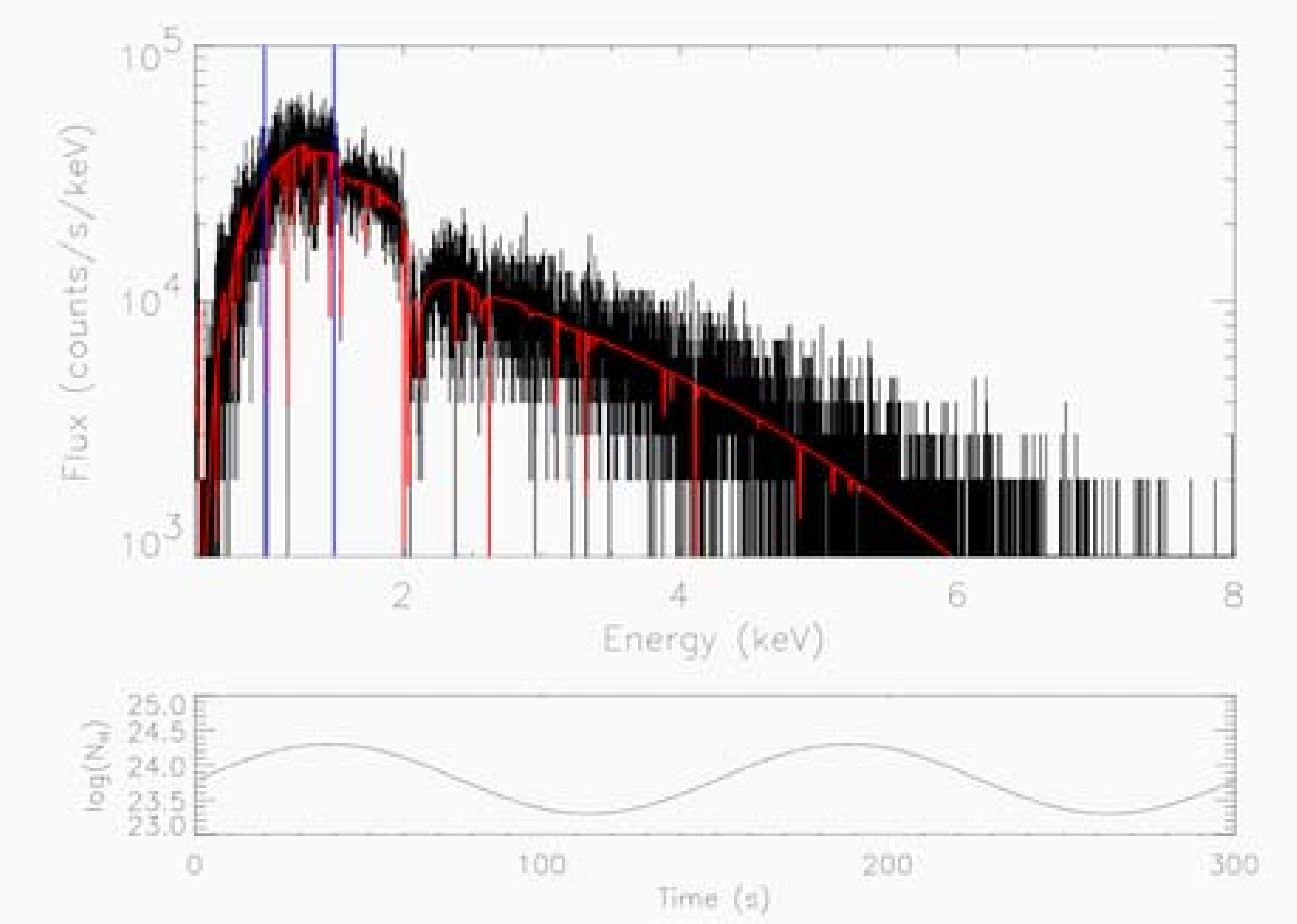
Accretion Processes

IXO

3 seconds = 30,000 R_Schw = P_orb @ 200 R_Schw



Accretion Processes



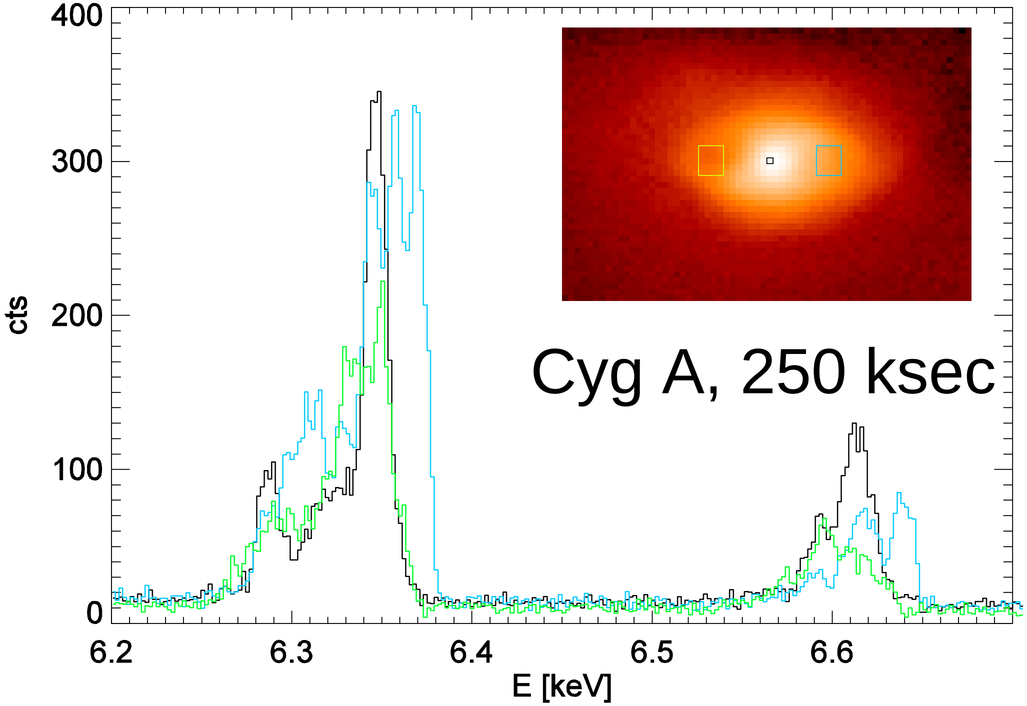
Cosmic Feedback

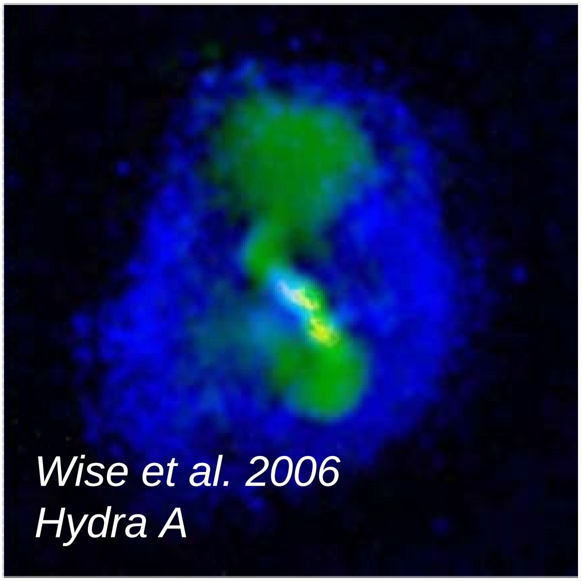
IXO

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

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

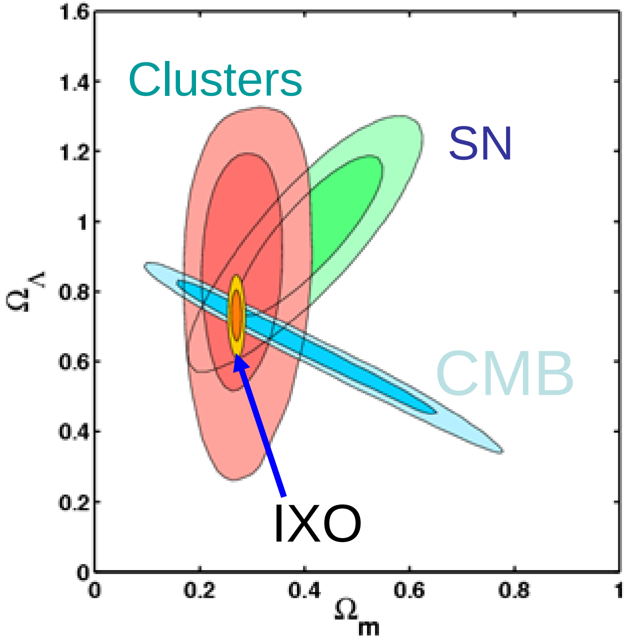


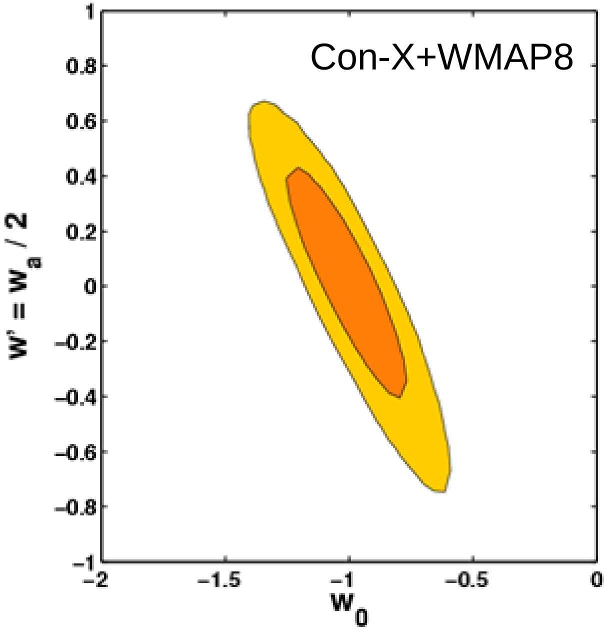


Wise et al. 2006
Hydra A

Dark Energy

IXO





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)

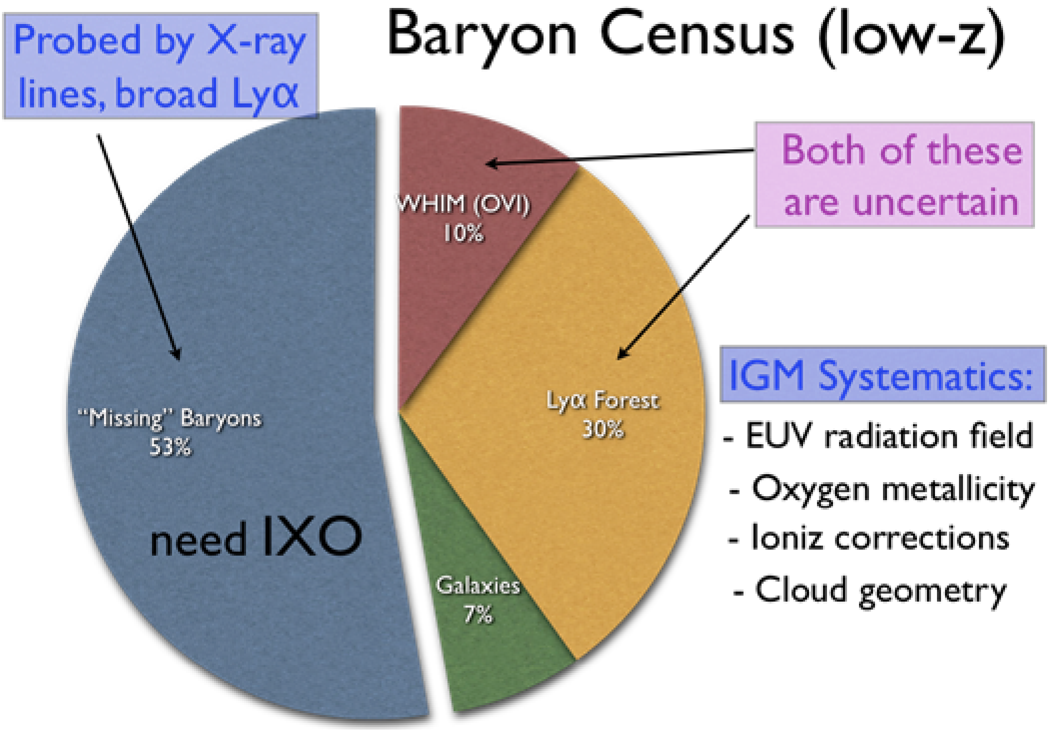
- Using the gas mass fraction as a standard ruler measures f_{gas} to 5% (or better) for each of 500 galaxy clusters to give $\Omega_M=0.300\pm0.007$, $\Omega_\Lambda=0.700\pm0.047$

- 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

Finding the “Missing Baryons”

Will also show a spectrum here, but the exciting results from the gratings teams yesterday mean that this could get quite a bit better!



Baryon Census (low-z)

Probed by X-ray lines, broad Lyα

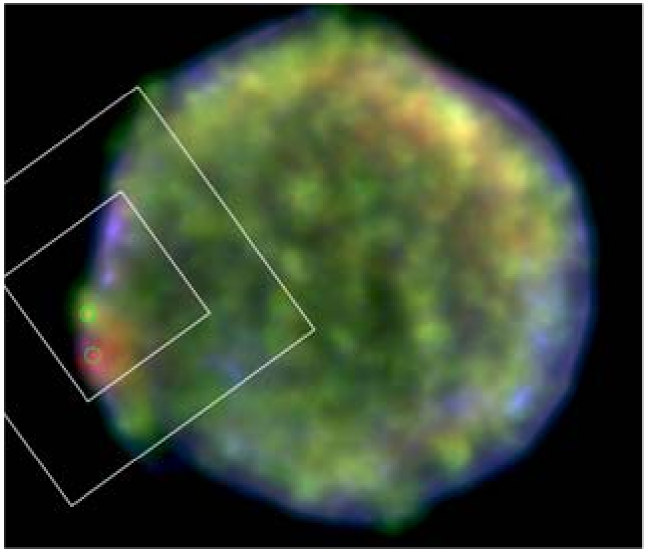
Both of these are uncertain

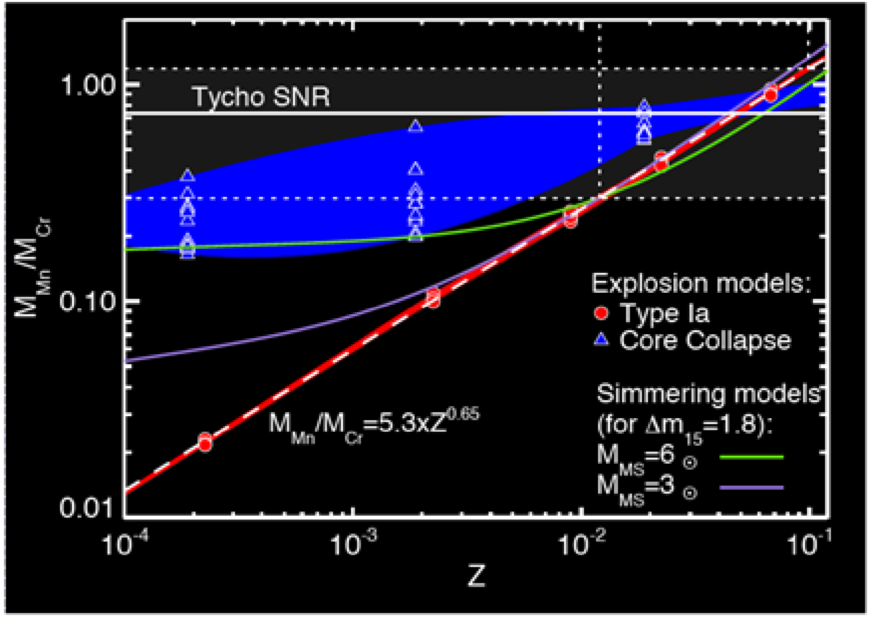
need IXO

IGM Systematics:

- EUV radiation field
- Oxygen metallicity
- Ioniz corrections
- Cloud geometry

Supernova: Type 1a Remnants





Badenes, Bravo, & JPH 2008, ApJL, 680, L33

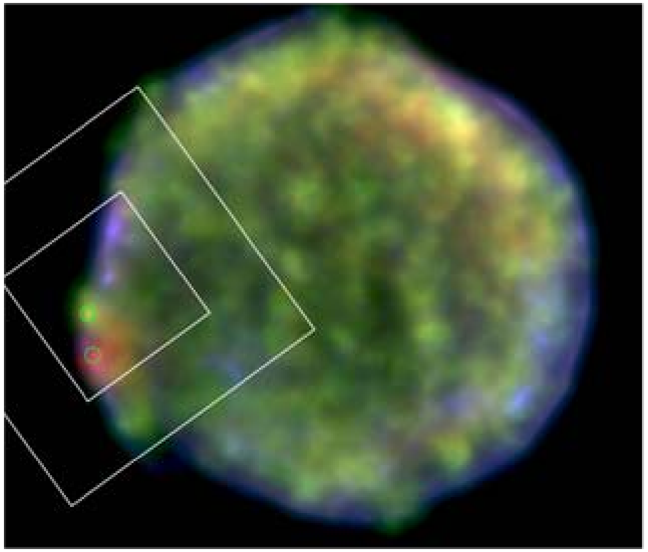
Model SNIa explosions using different neutron excesses and various classes of explosions

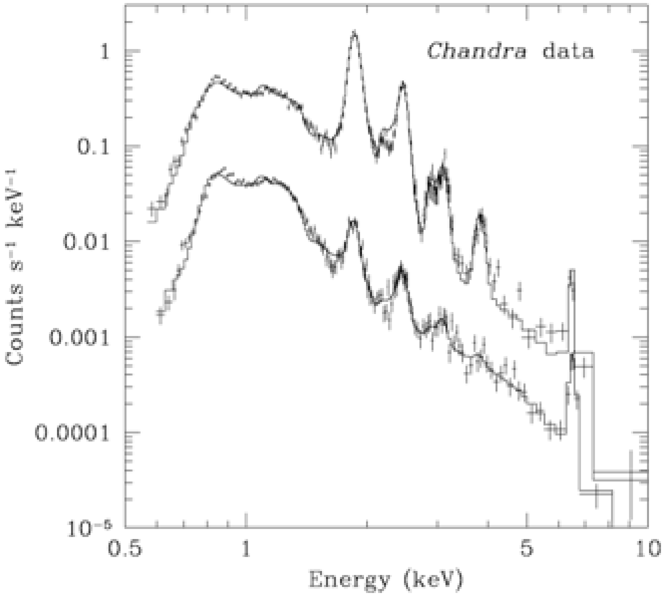
For the progenitor of Tycho's SN, this yields a supersolar metallicity

Z = 0.048 (-0.036, + 0.051)

Large uncertainty, but definitely not subsolar

Supernova: Type 1a Remnants





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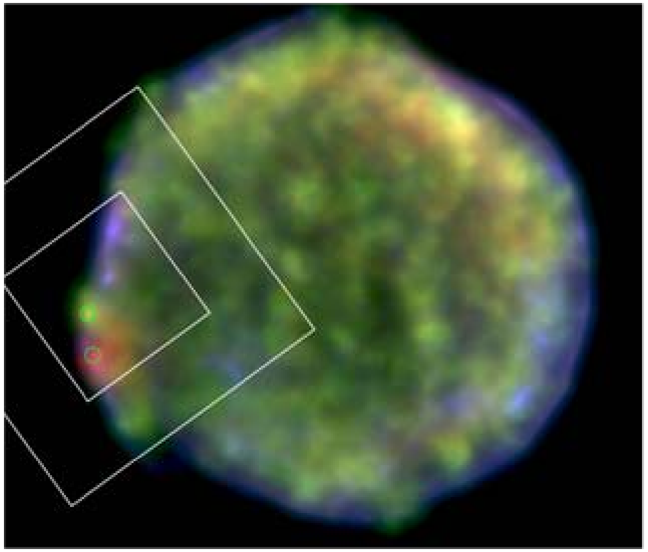
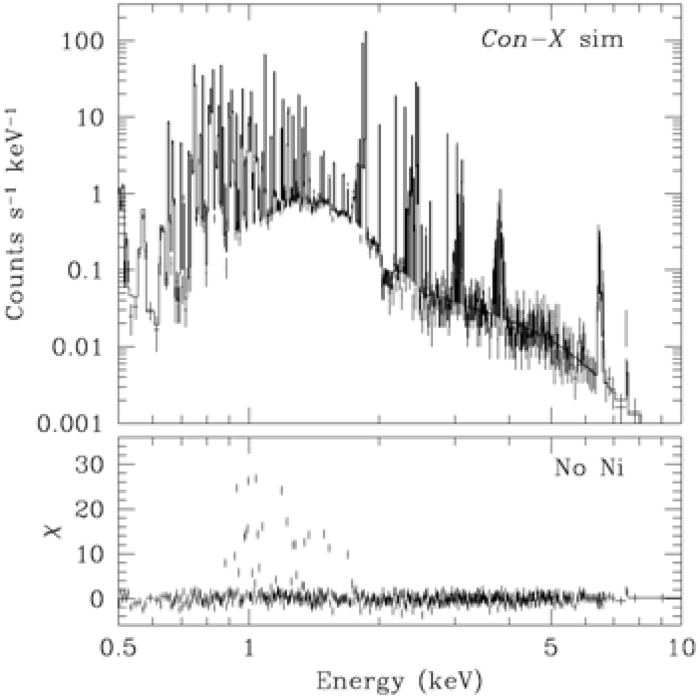




Simulated IXOspectrum derived from Chandra fits.

Detection (3σ) of Cr Kα takes 70 ks, Mn Kα takes 220 ks

Can make map of Mn/Cr on 15” arcsec scales

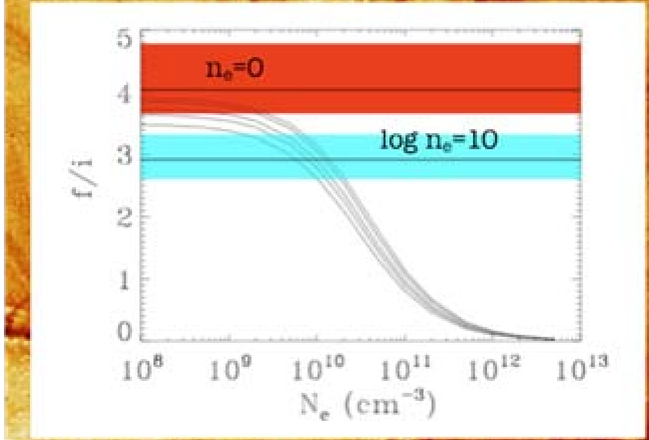
L lines easier to detect (Ni residuals)

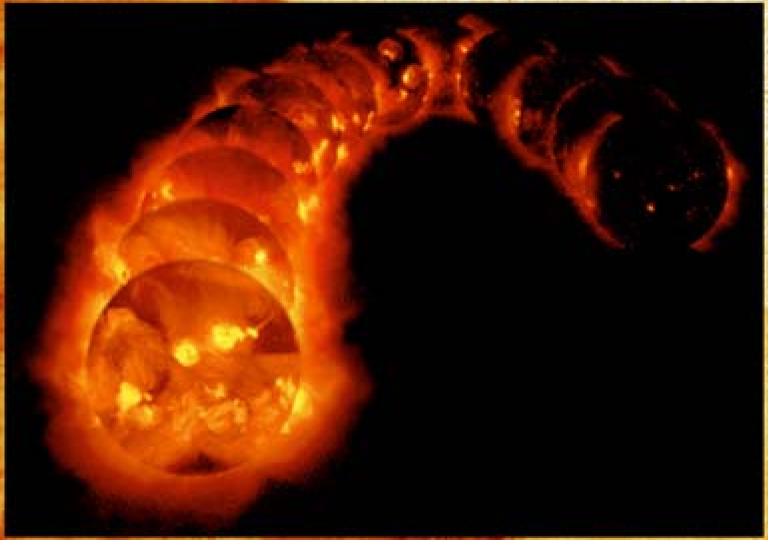
Is the Sun a Solar-type star?

IXO

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

Observing Strategy





using XMS, constrain n_e from O VII f/i for a solar minimum star ($L_x=2\times10^{26}$ erg s^{-1}) at 5 pc in 50 ks; 20 stars in 1 Ms to span L_x, T_x, fB

X-rays and Planetary Disks

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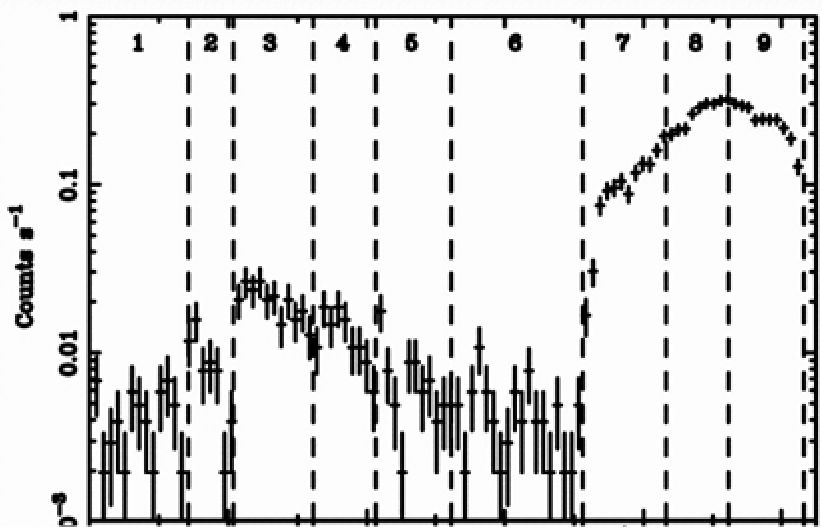
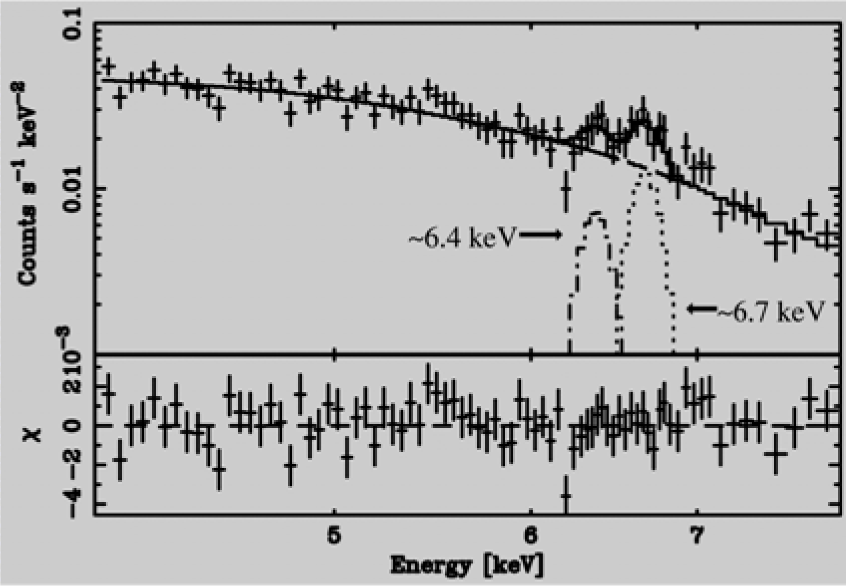
How do X-rays influence planet formation in protoplanetary disks?

YLW 16A: protostar in Oph



Chandra YLW 16A superflare, 1.2 days
Imanishi et al. 2001



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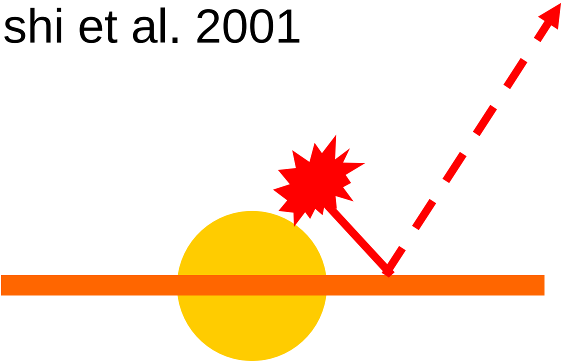
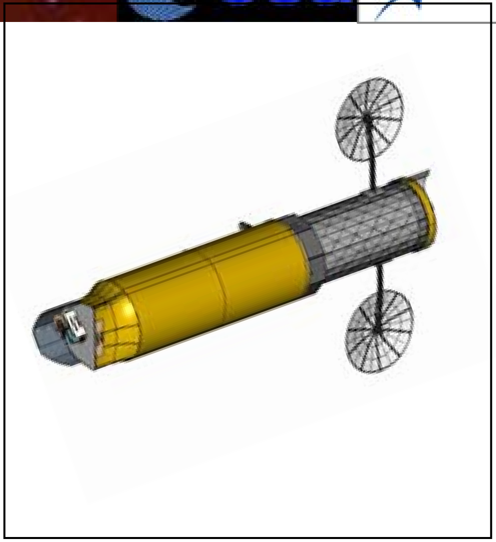
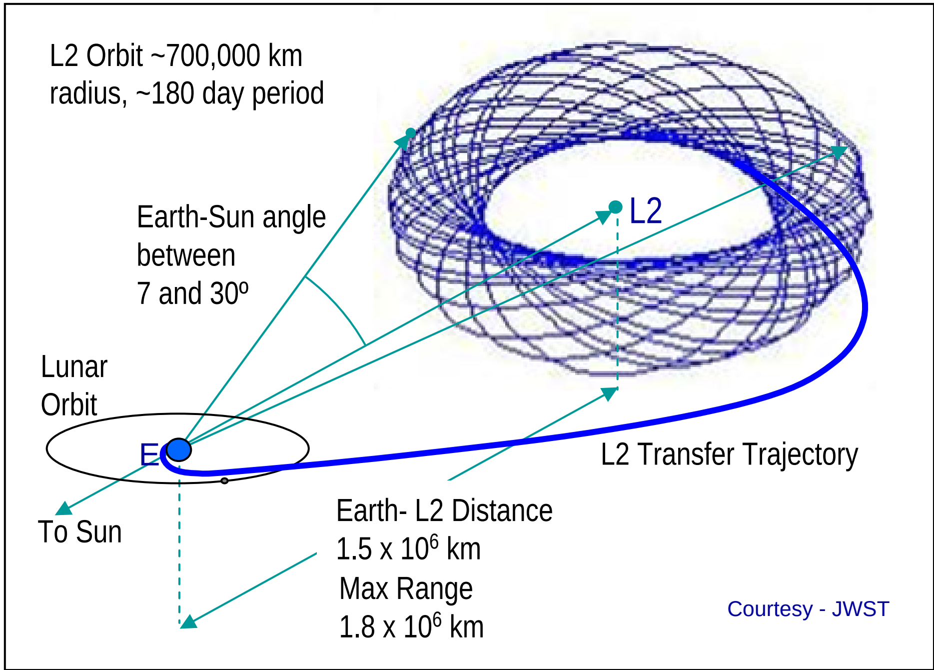


Mission Overview

IXO

- Single Mirror Configuration
  - 3.3 m dia mirror with a 20-25 m focal length
  - Part of the metering structure is extensible (12.2m)
- Mission Life and Sizing
  - Class B Mission, no performance degradation w/ single point failure
  - Mission Life: 5 years required, 10 years goal, consumables sized for 10 years
- Launch & Orbit
  - Launch on an Atlas V or Ariane
  - Direct launch into an L2 800,000 km semi-major axis “zero Insertion delta-v” halo orbit
  - 100 day cruise to L2





Courtesy - JWST

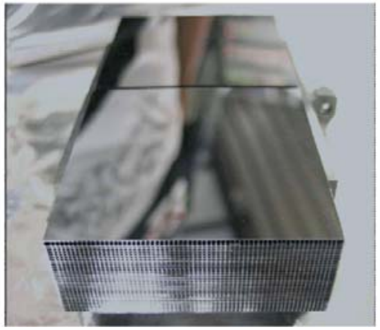
X-ray Mirror Baseline

IXO

- Key requirements:
  - Effective area ~3 m^2 @ 1.25 keV ; ~1 m^2 @ 6 keV
  - Angular Resolution <= 5 arc sec
- Single optic with design optimized to minimize mass and maximize the collecting area ~3.4m diameter
- Two parallel technology approaches being pursued
  - Silicon micro-pore optics – ESA
  - Slumped glass – NASA
- Both making good progress

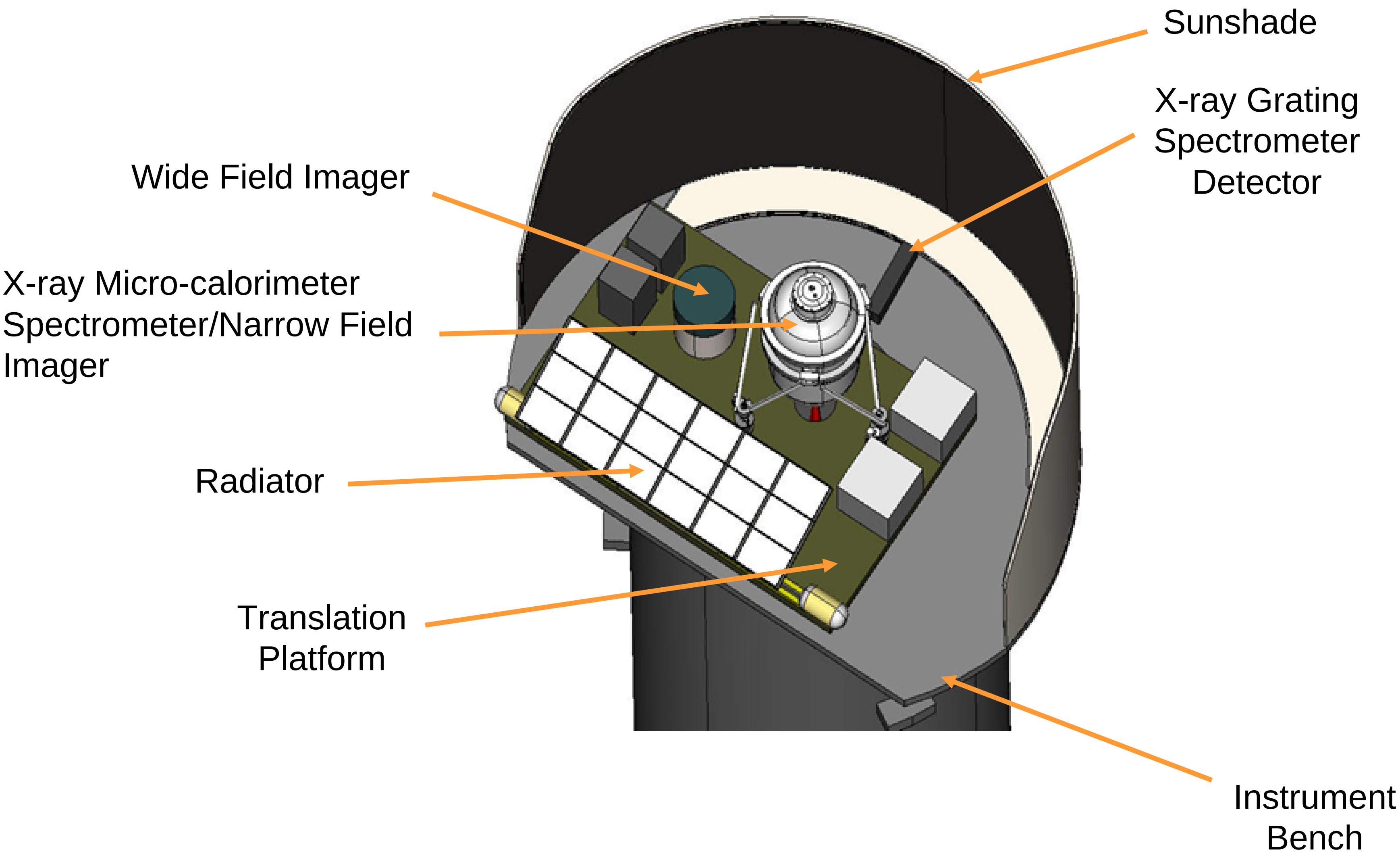
Glass

Silicon



Focal Plane - Preliminary Layout

IXO



Summary

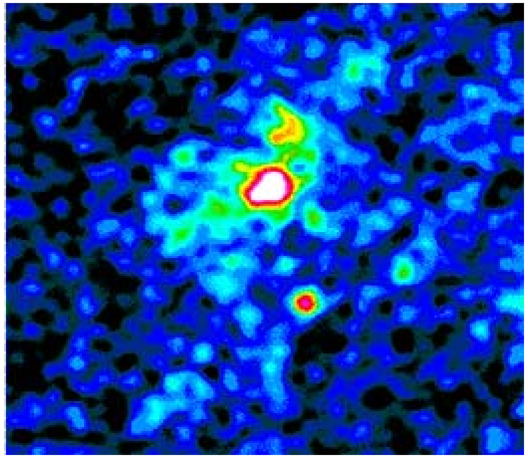
IXO

- Agreement to proceed with a single large International X-ray Observatory, 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 and know by 2010 the outcome

Backup

First Groups of Galaxies

IXO

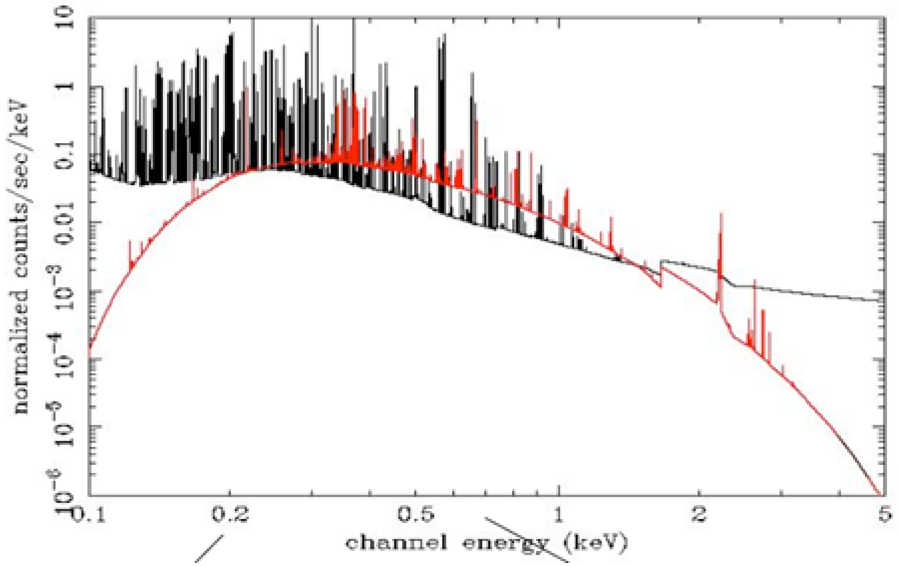


2 keV

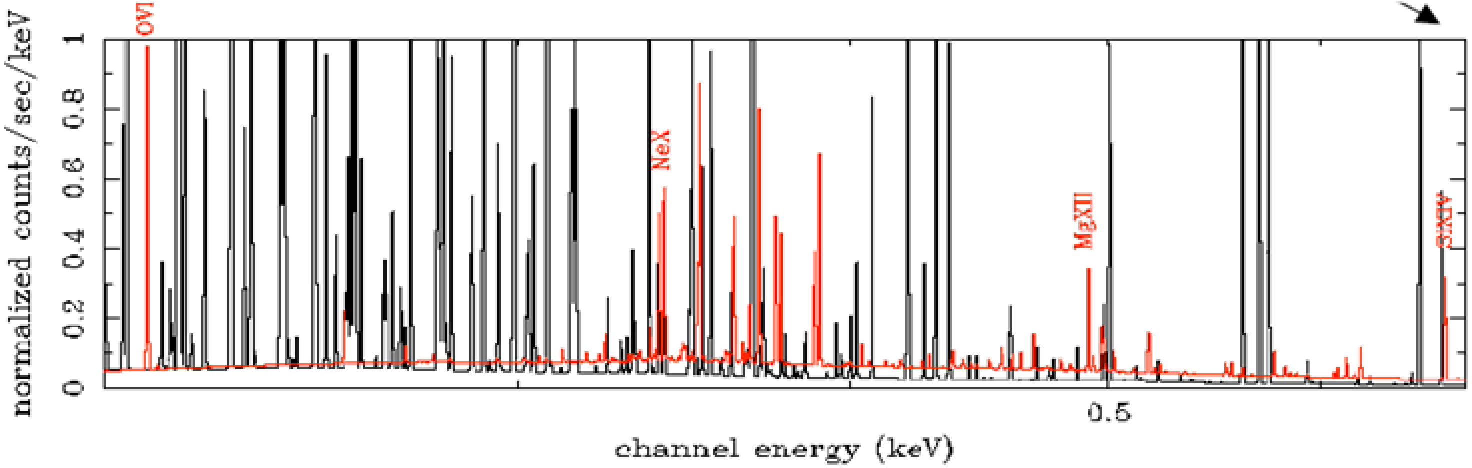
log L_{bol}=43.7

z=2

300 ksec



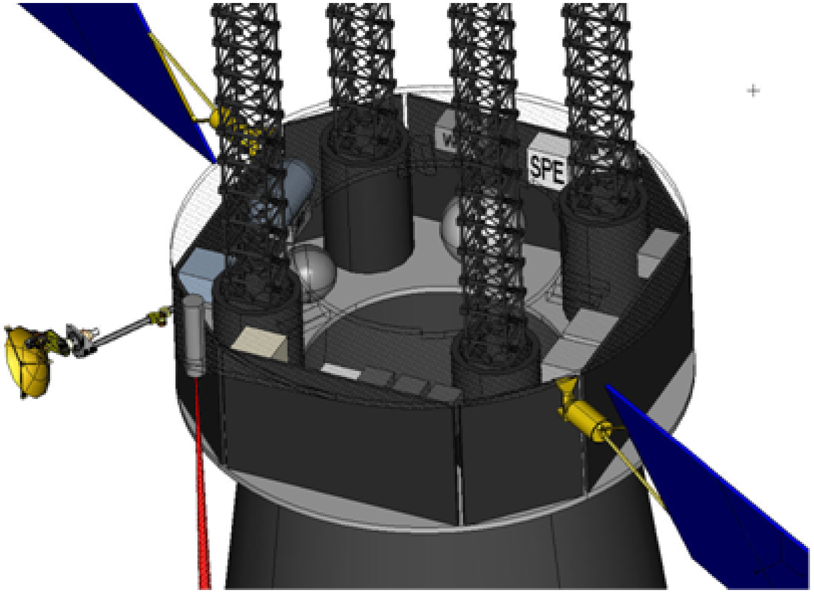
Credit: H. Bohringer + M. Arnaud

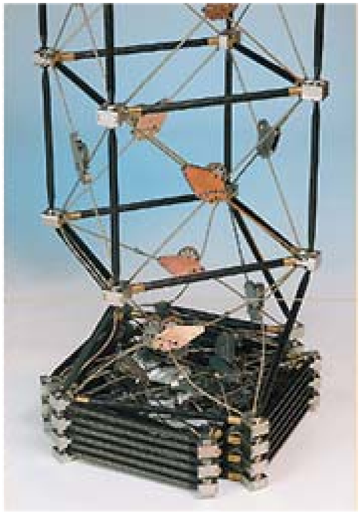


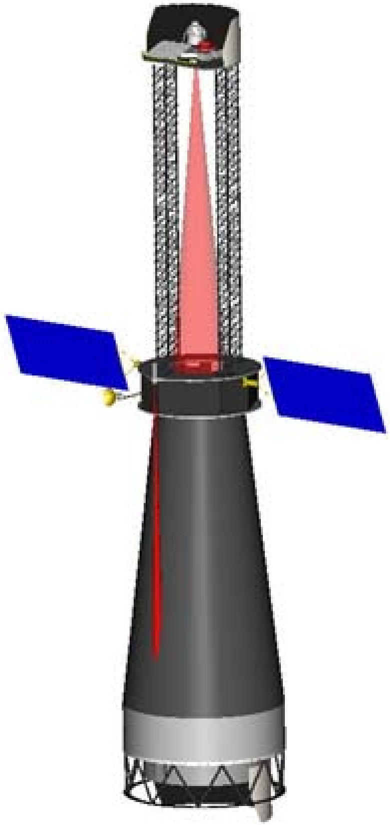
Baseline Agreed Concept

- Focal length of 20-25m with extendible optical bench
- Concept must accommodate both glass (NASA) and silicon (ESA) optics technology (with final selection at appropriate time)
- Core instruments to include:
  - Wide Field Imager
  - X-ray Micro-calorimeter/Narrow Field Imager
  - X-ray Grating Spectrometer
  - Allocation for further modest payload elements
- Concept compatible with Ariane V and Atlas V 551

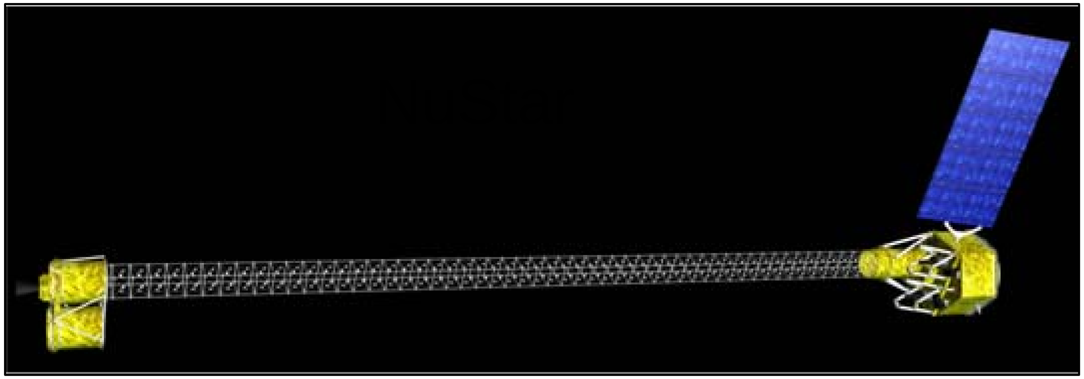
ADAM Mast Deployable Concept **IXO**







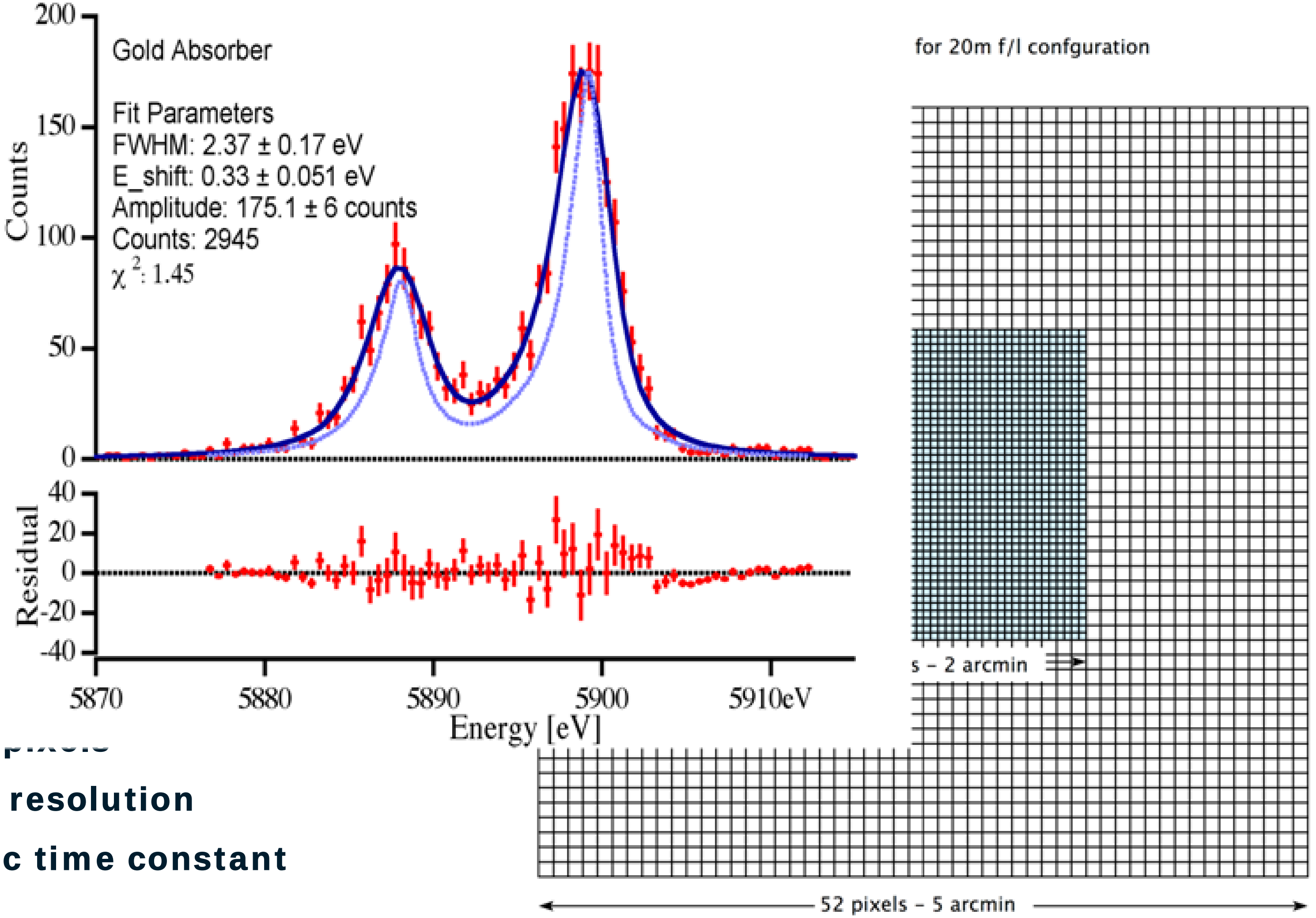
- ADAM masts, same as for NuStar
- Separate light-tight “shower curtain” shroud



X-ray Micro-Calorimeter Spectrometer

IXO

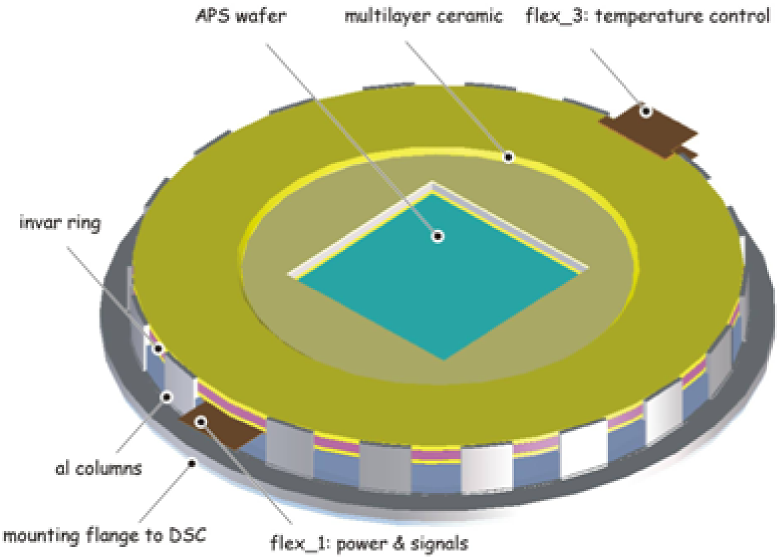
- **Central,**
  - **Indivi**
  - **42 x 4 sec pi**
  - **2.0 ar**
  - **2.5 eV**
  - **~ 300**
- **Outer, e**
  - **4 abso**
  - **Extend FOV**
  - **52 X 5 arcmin pixels**
  - **<10 eV resolution**
  - **<2 msec time constant**



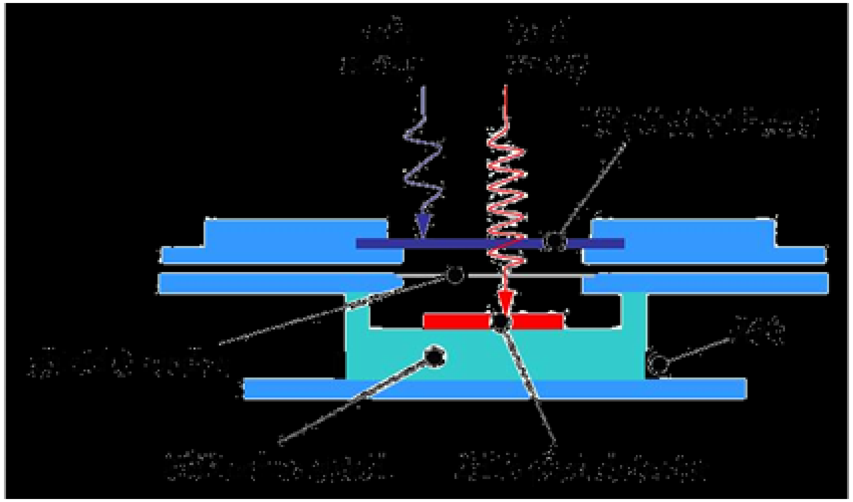
Wide Field and Hard X-ray Imagers

IXO

Wide field imager (WFI):
Silicon active pixel sensor
- field of view: 12 arcmin
- energy range: 0.1 to 15 keV
- energy resolution: < 150 eV @ 6 keV
- count rate capability: 8 kcps (< 1% pileup)

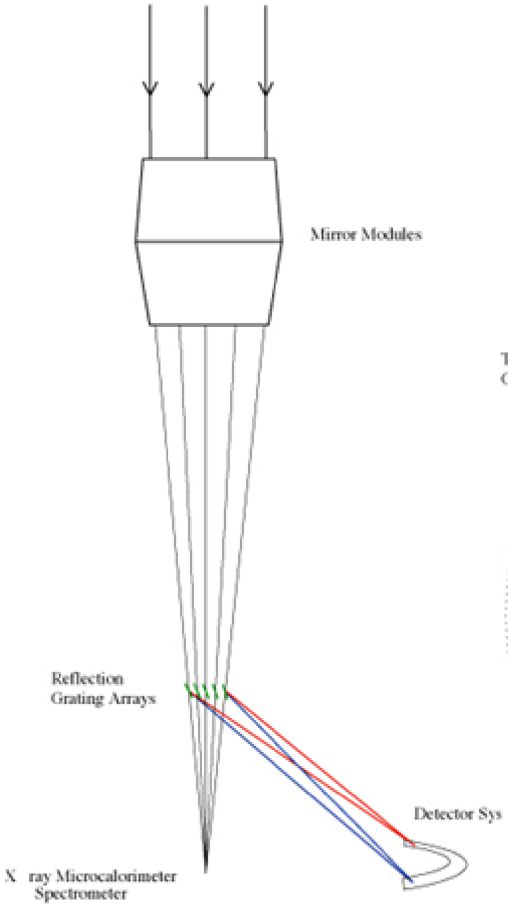


Hard X-ray imager (HXI):
Cd(Zn)Te pixel array located behind WFI
- energy range extension to 40 keV
- field of view: 8 arcmin

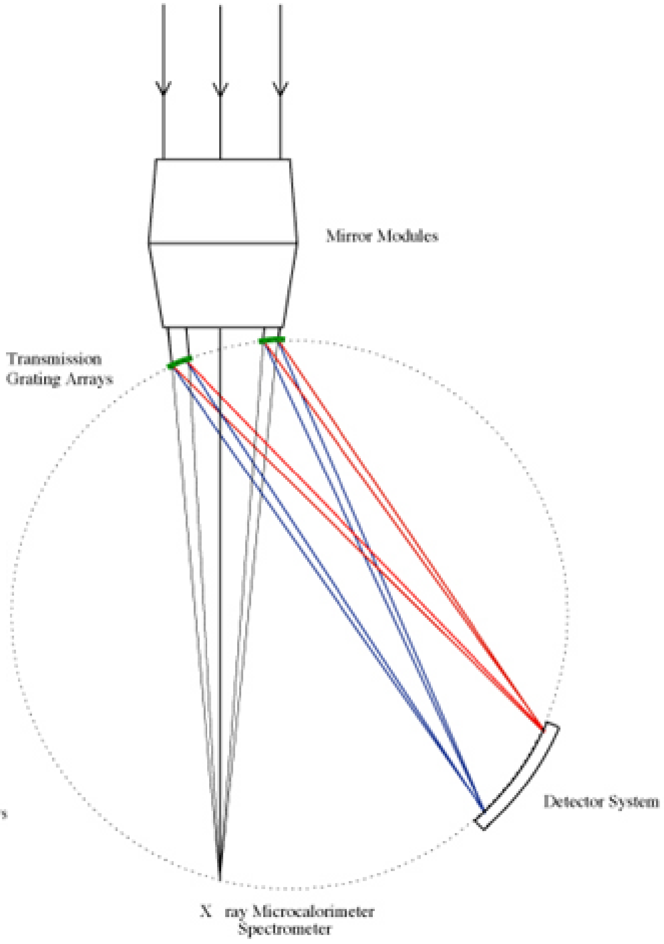


X-ray Grating Spectrometer

- 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

Further Payload Elements

Possible modest payload elements include:

1. X-ray polarimeter
2. High time resolution, bright source capability

These capabilities may be part of the core instruments and/or an additional instrument