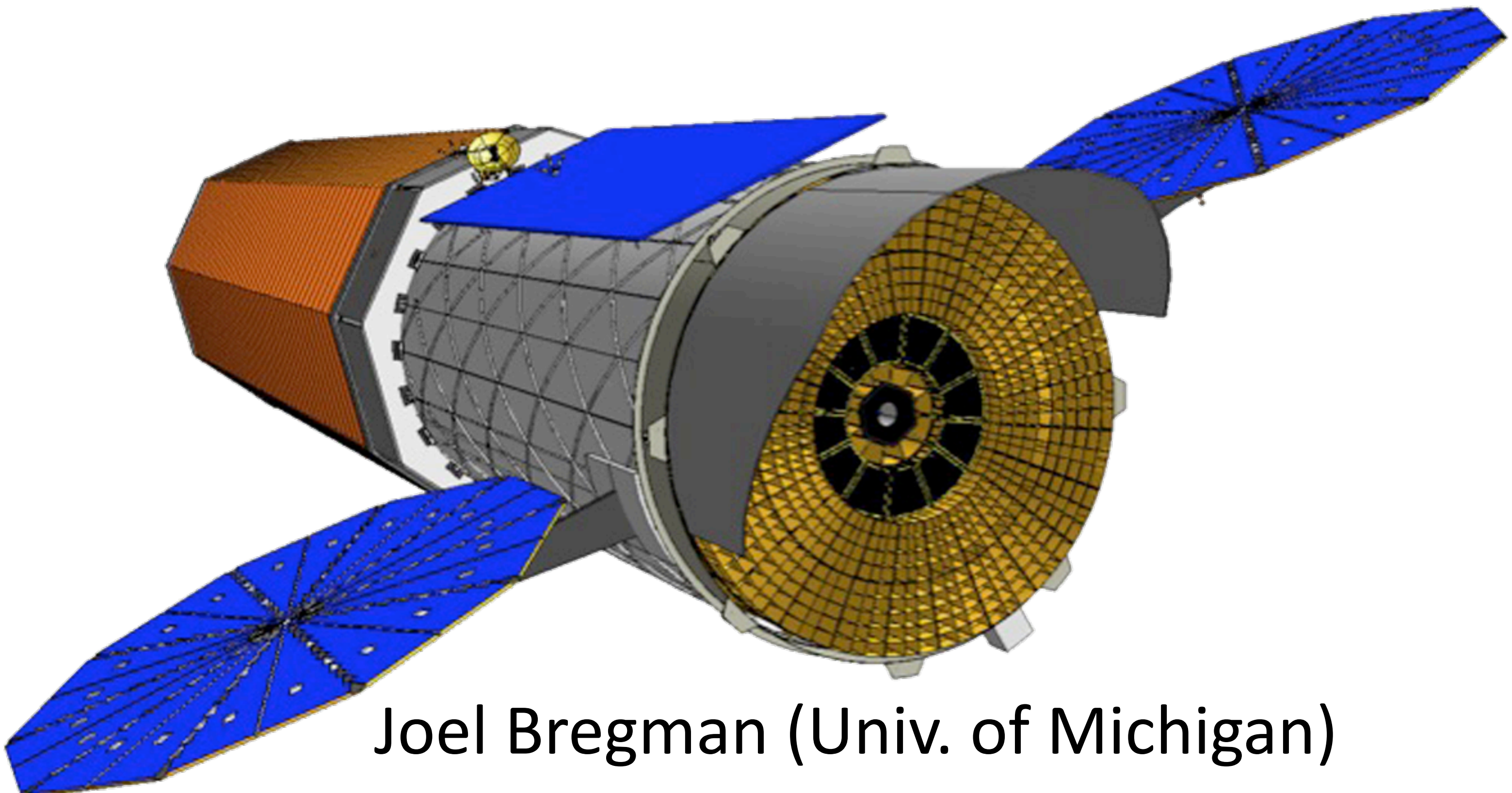
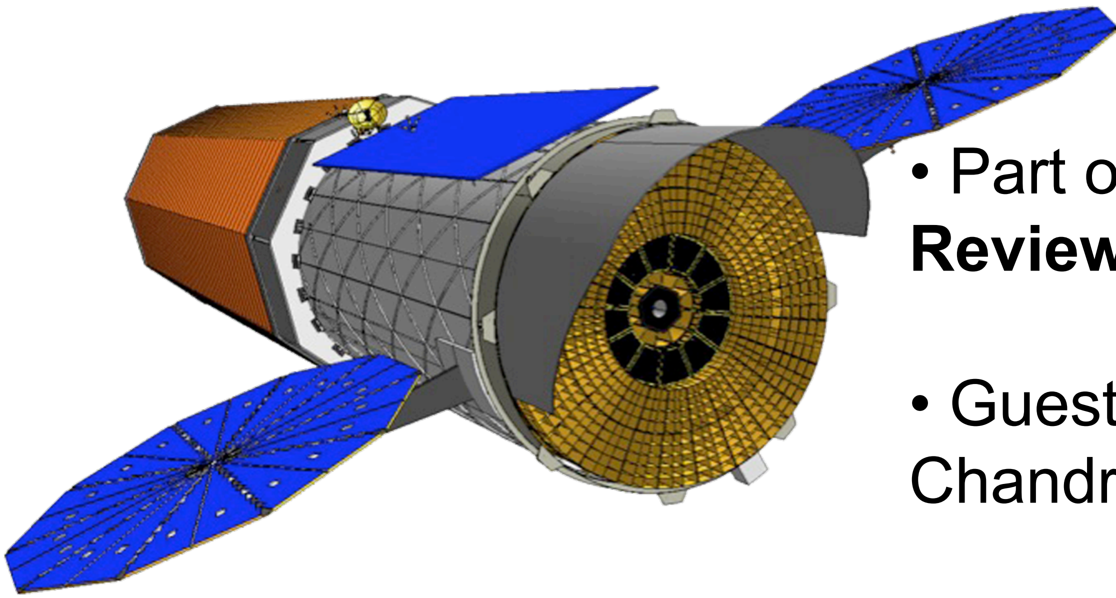
The International X-ray Observatory



Joel Bregman (Univ. of Michigan)

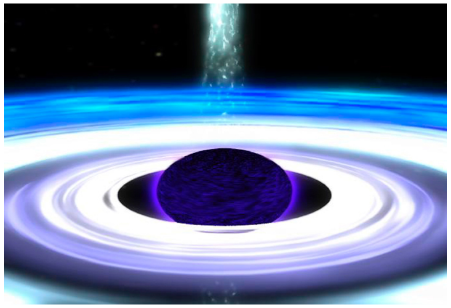
APS Meeting, Denver, 2009

Basic Facts about IXO

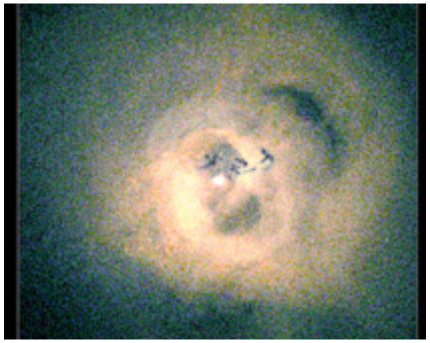


- Merger of ESA/JAXA XEUS and NASA's Constellation-X missions
- Part of US Astro2010 **Decadal Review** and ESA **Cosmic Visions**
- Guest Observatory, like Hubble, Chandra, Spitzer
- Launch ~2021

Main Science Topics



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

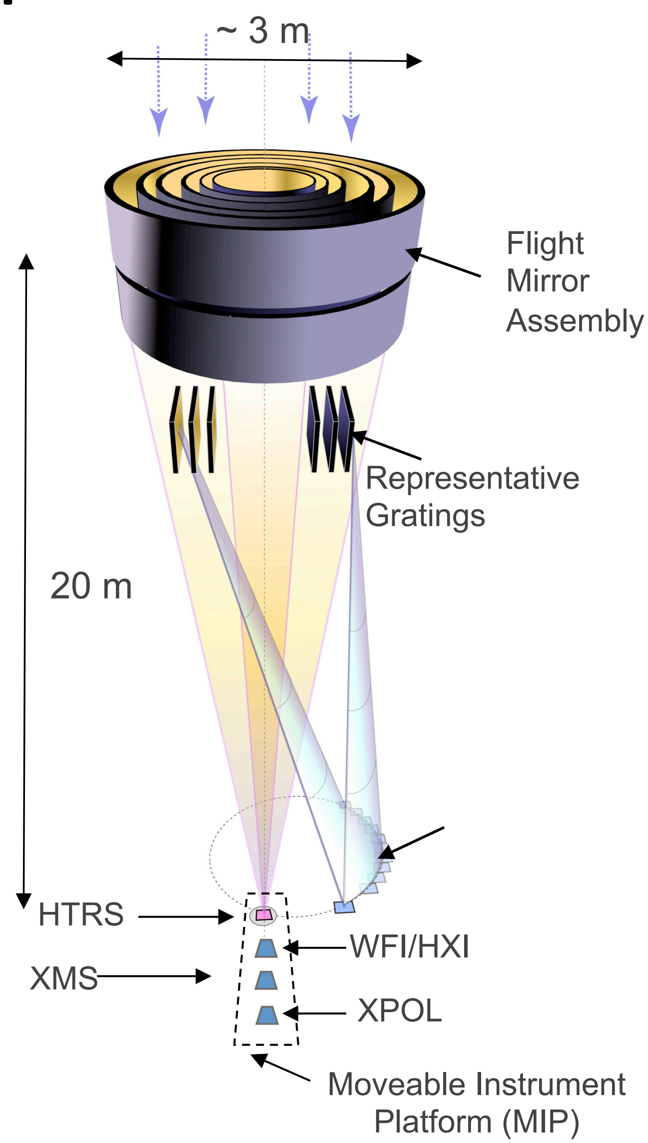


- **Black Hole Evolution and the Evolution of Galaxies, Clusters, and Large Scale Structure**

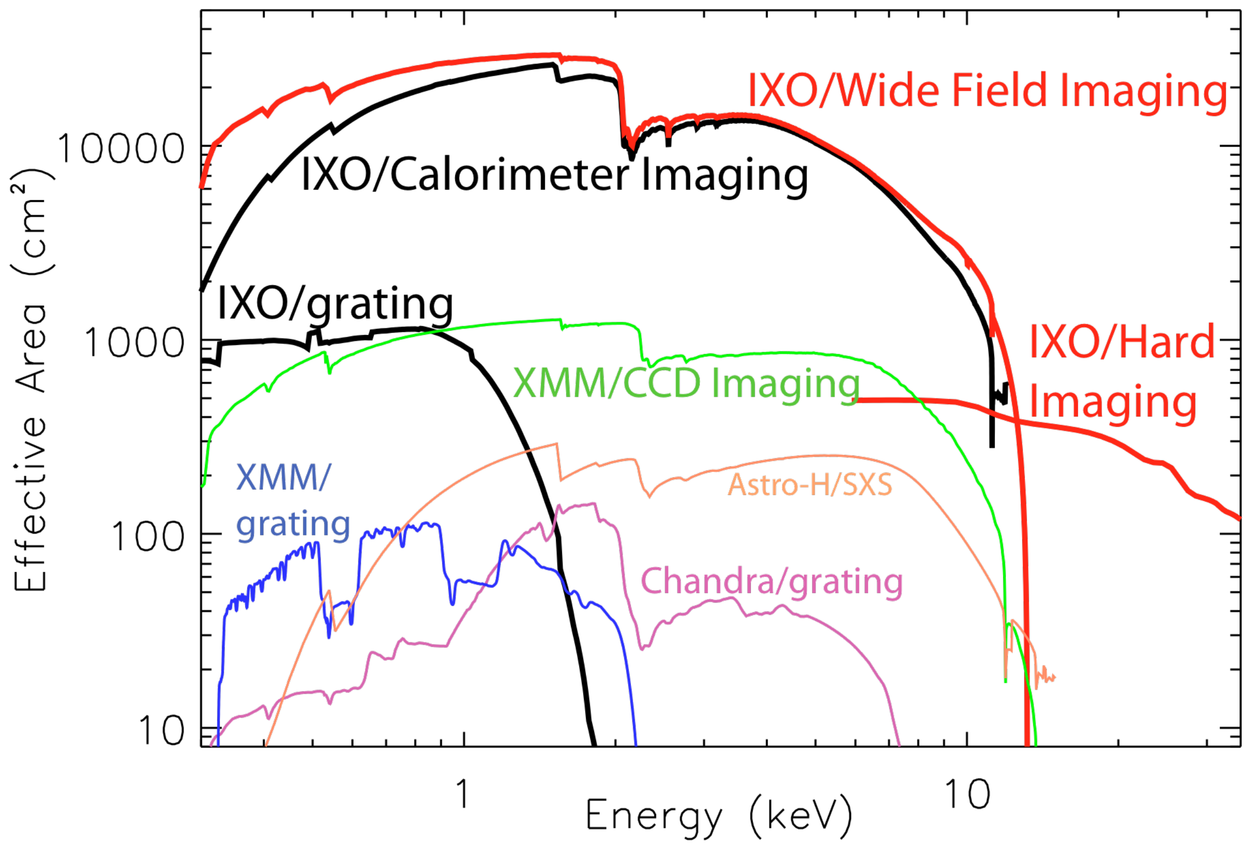
- **Life Cycles of Matter and Energy**
  - **Supernovae, stars**

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)



IXO is a Vast Improvement over Existing Missions



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

Spectral Capability

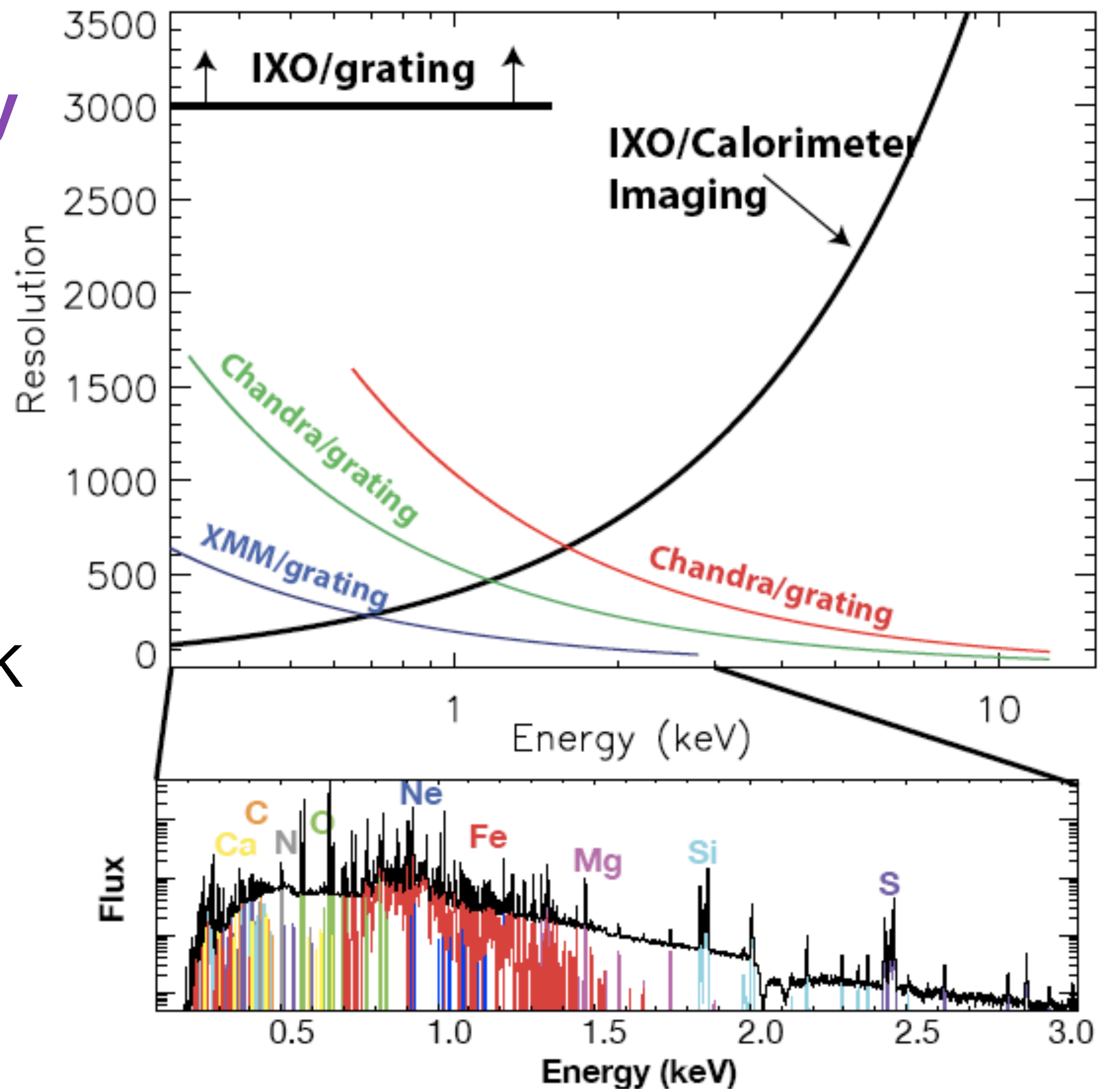
K-line transitions of 25 elements

Carbon through Zinc

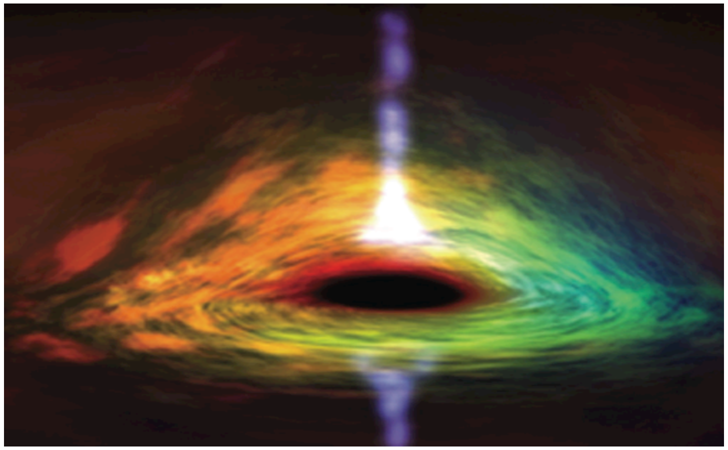
Abundances

Temperatures: 10^6-10^8 K

Velocities

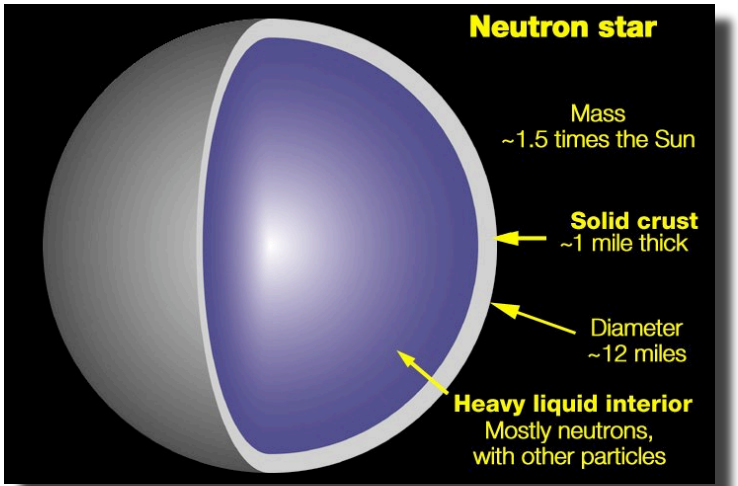


Black Holes and Matter under Extreme Conditions



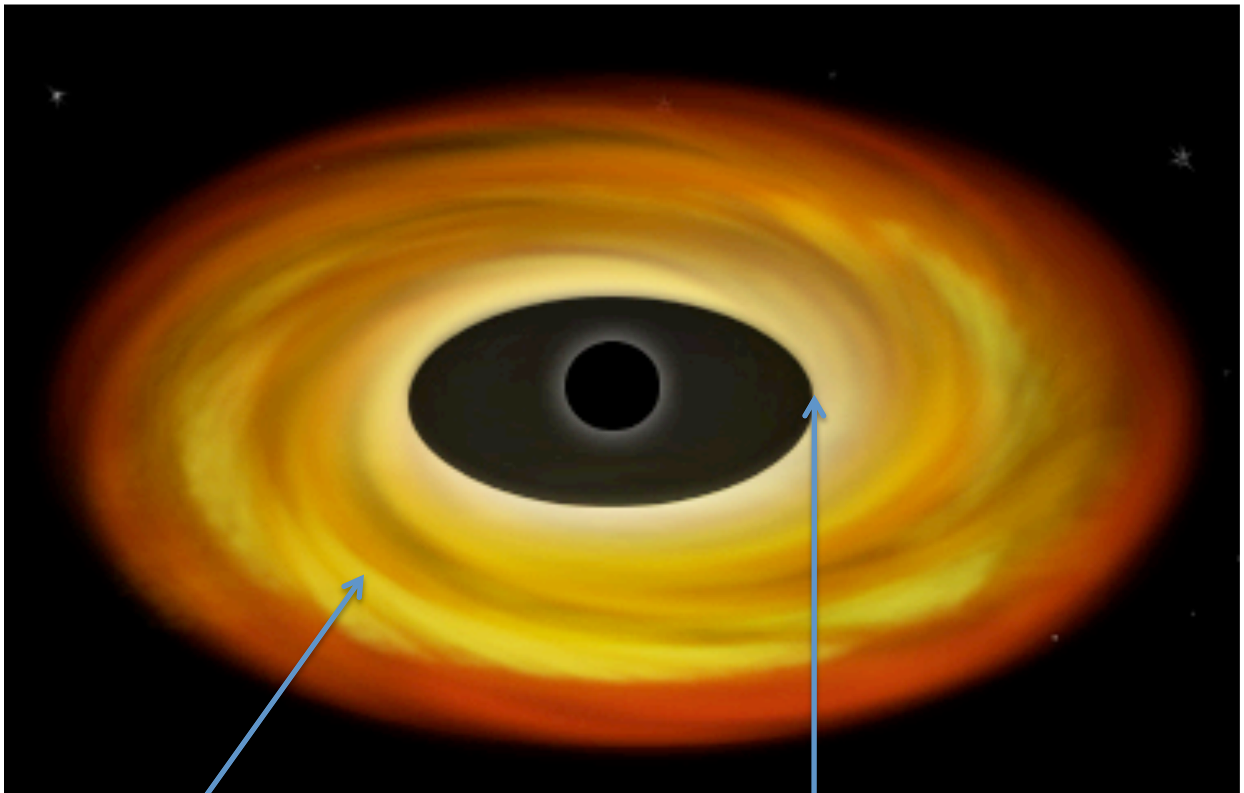
Does matter orbiting close to a Black Hole event horizon follow the predictions of General Relativity?

How do super-massive Black Holes grow? Does this change over cosmic time?



What is the Equation of State of matter in Neutron Stars?

Black Holes and Accretion Disks

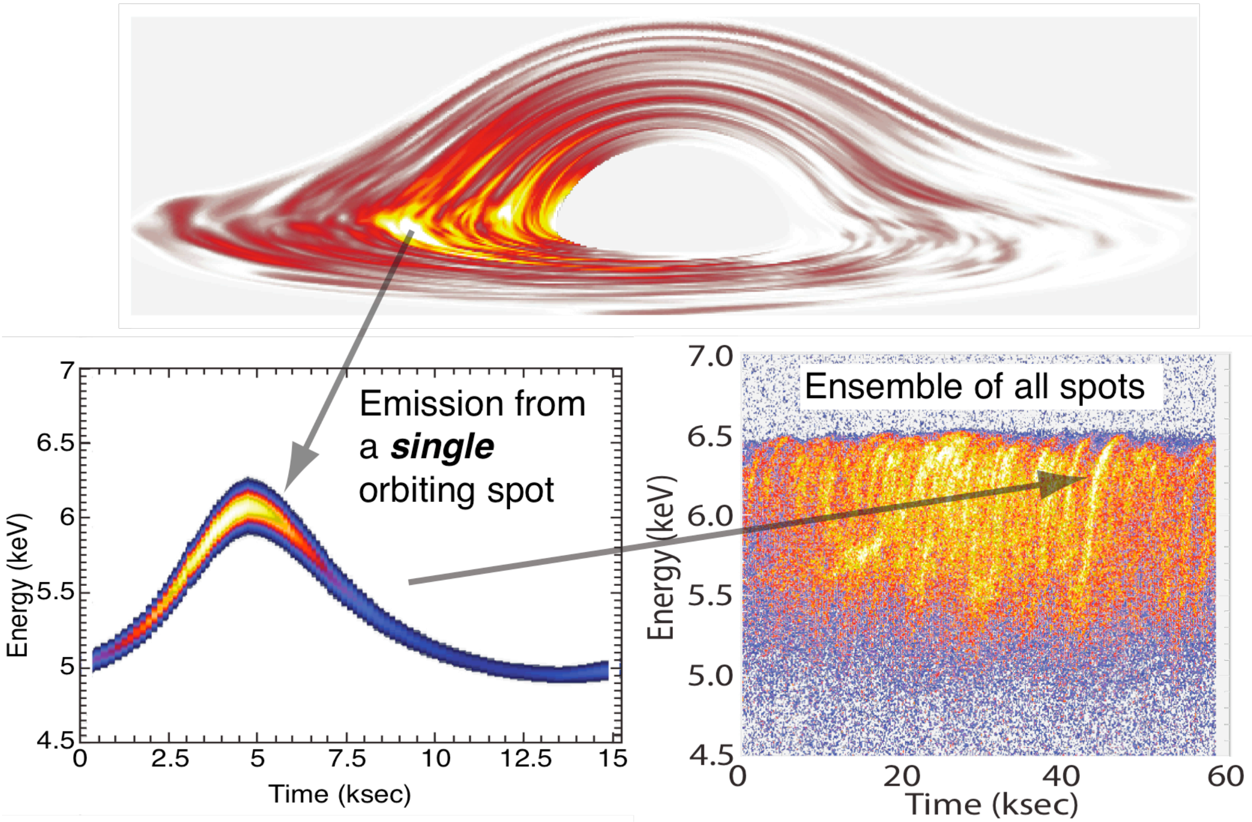


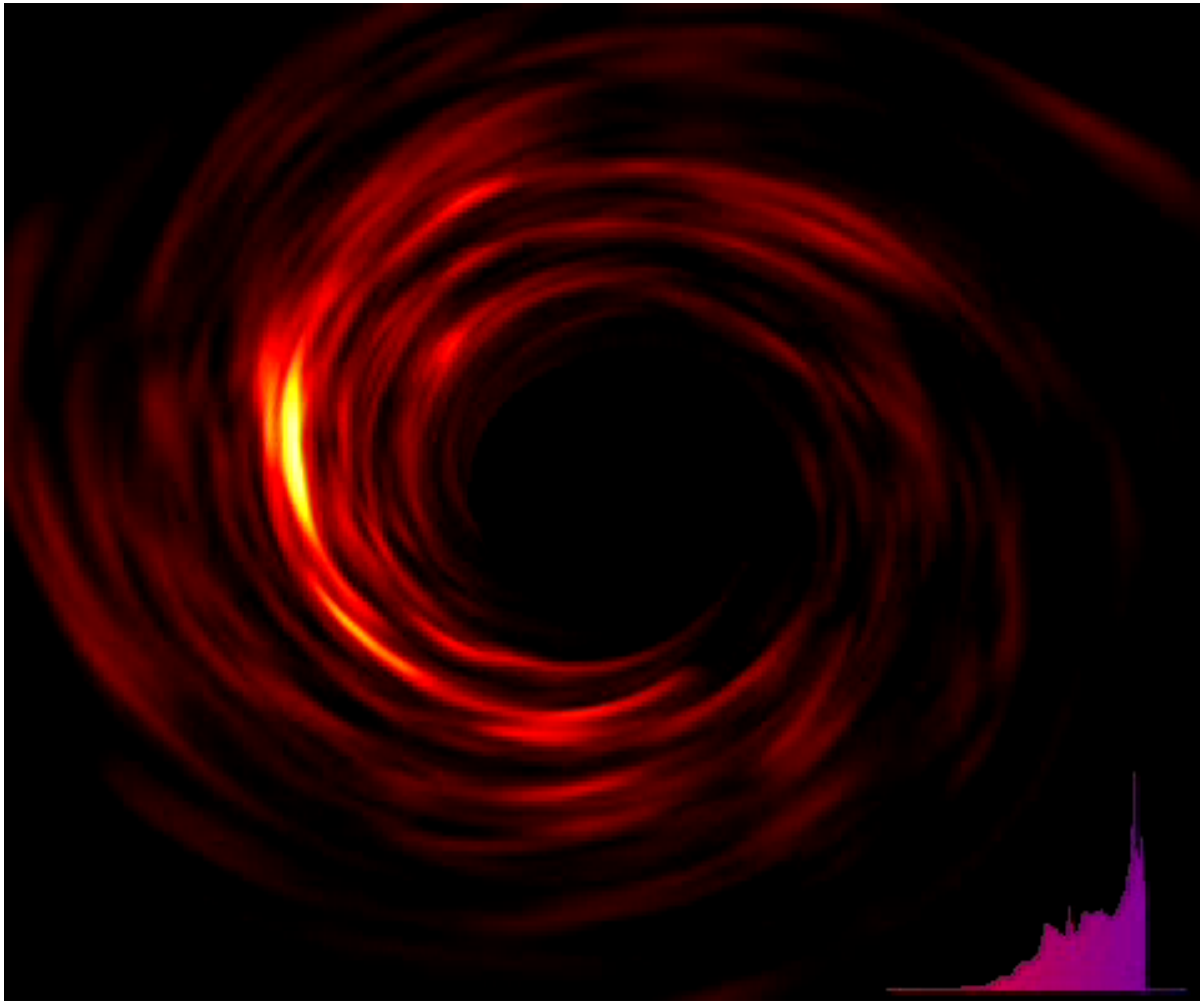
Accretion disk
(irregular emission)

Inner stable orbit
(depends on spin)

Emission from a hot spot emitting a single line

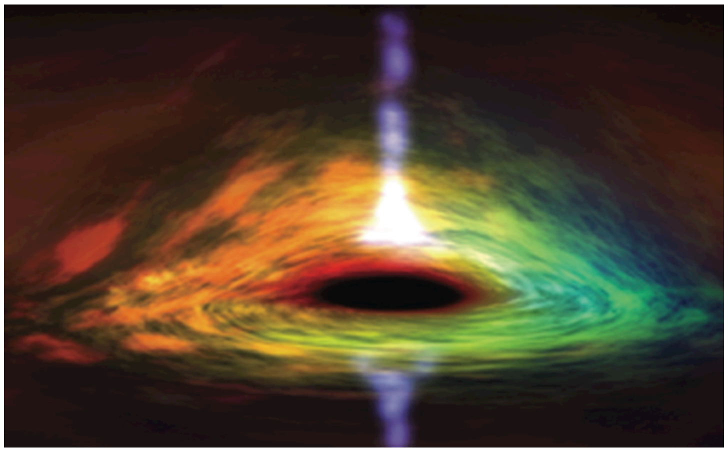
Time variation of line energy (and intensity) depend on GR properties of Kerr Metric (spin)





Magneto-hydro-dynamic simulations of accretion disk surrounding a Black Hole (Armitage & Reynolds 2003)

Black Holes and Matter under Extreme Conditions



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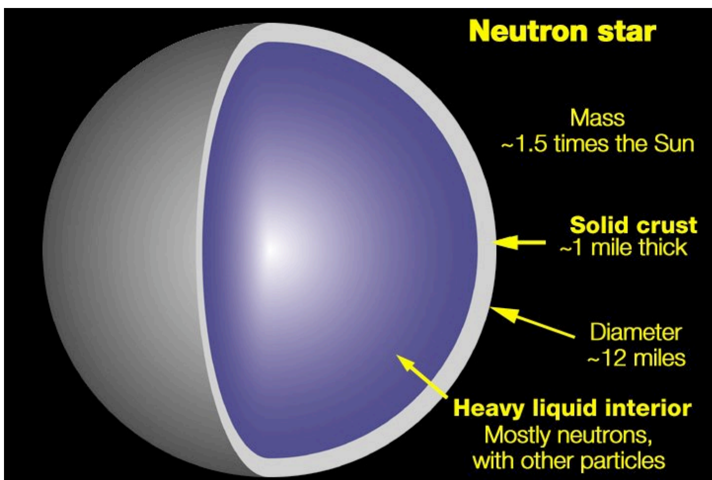

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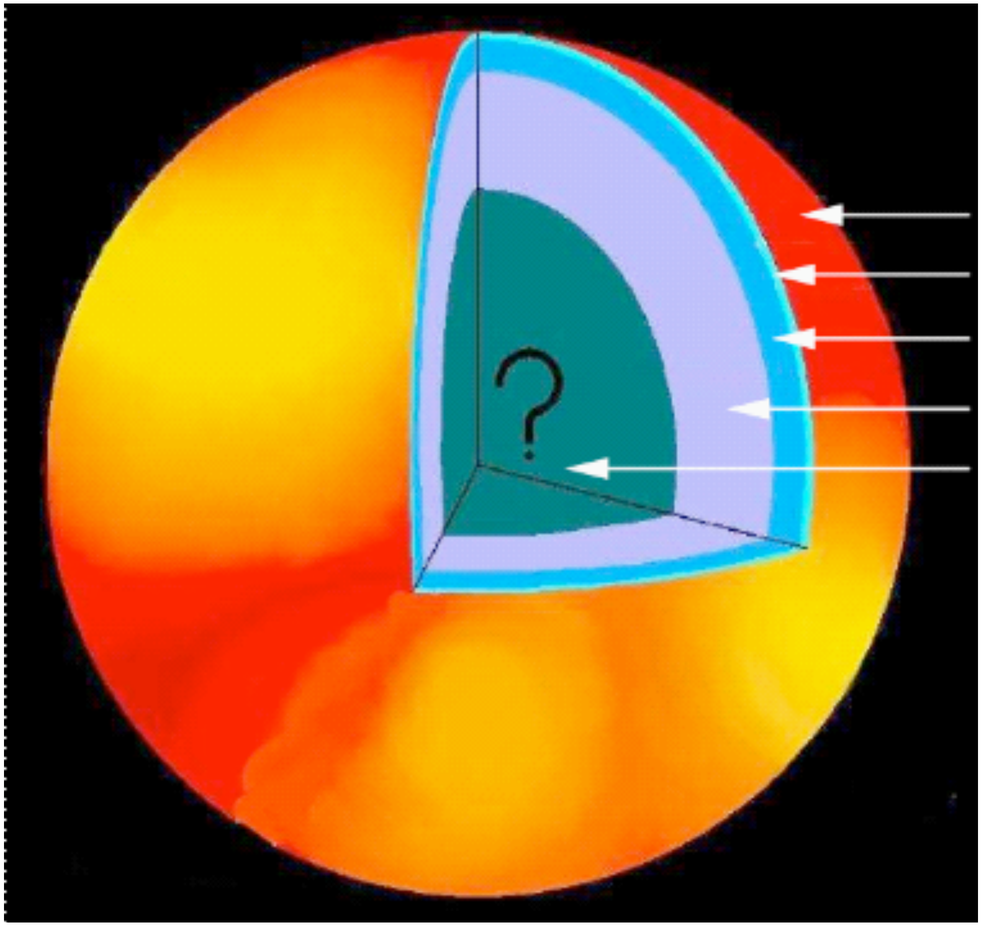
Neutron Star Equation of State (EOS)



How does QCD work at high density and low temperature?

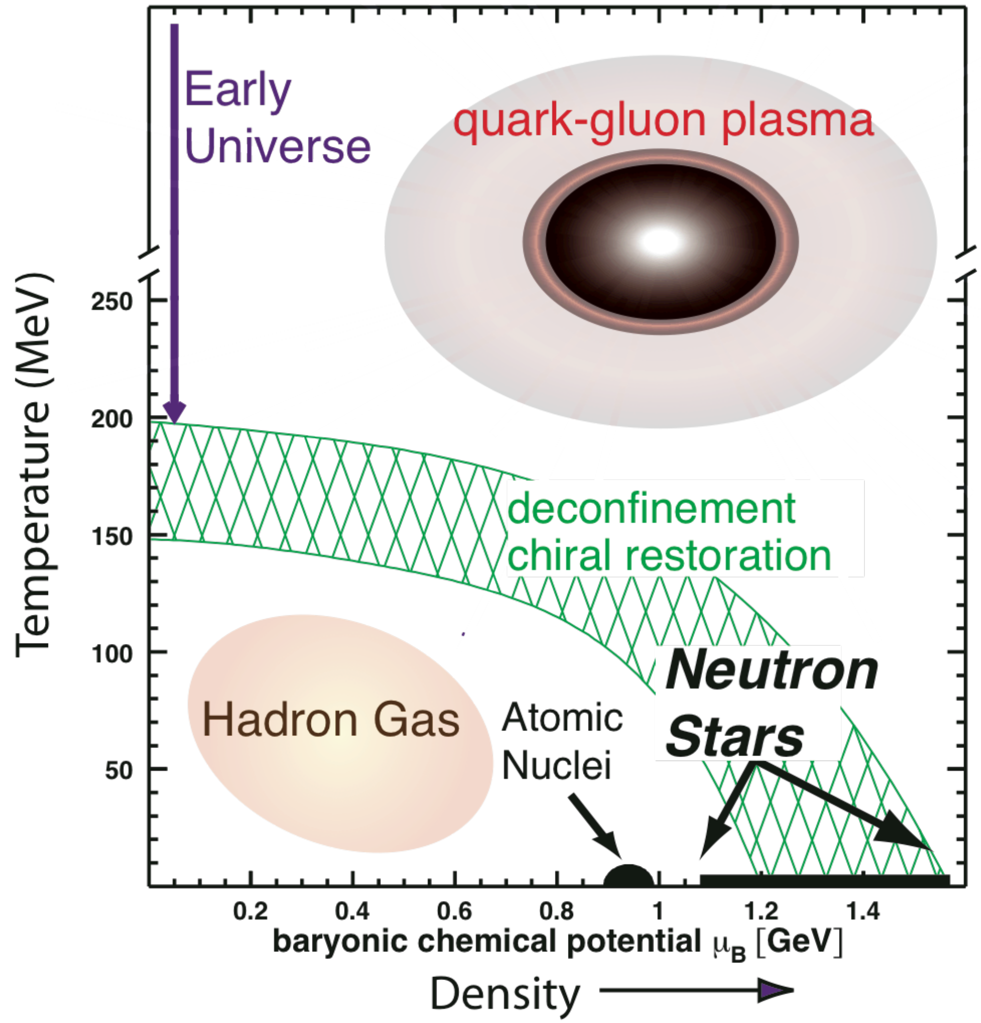
- Outer crust normal
- Phases of matter in Core uncertain: hadrons, Bose-Einstein condensates, quark matter
- **Mass – Radius relationship is the best constraint on the EOS**

Neutron Star Equation of State

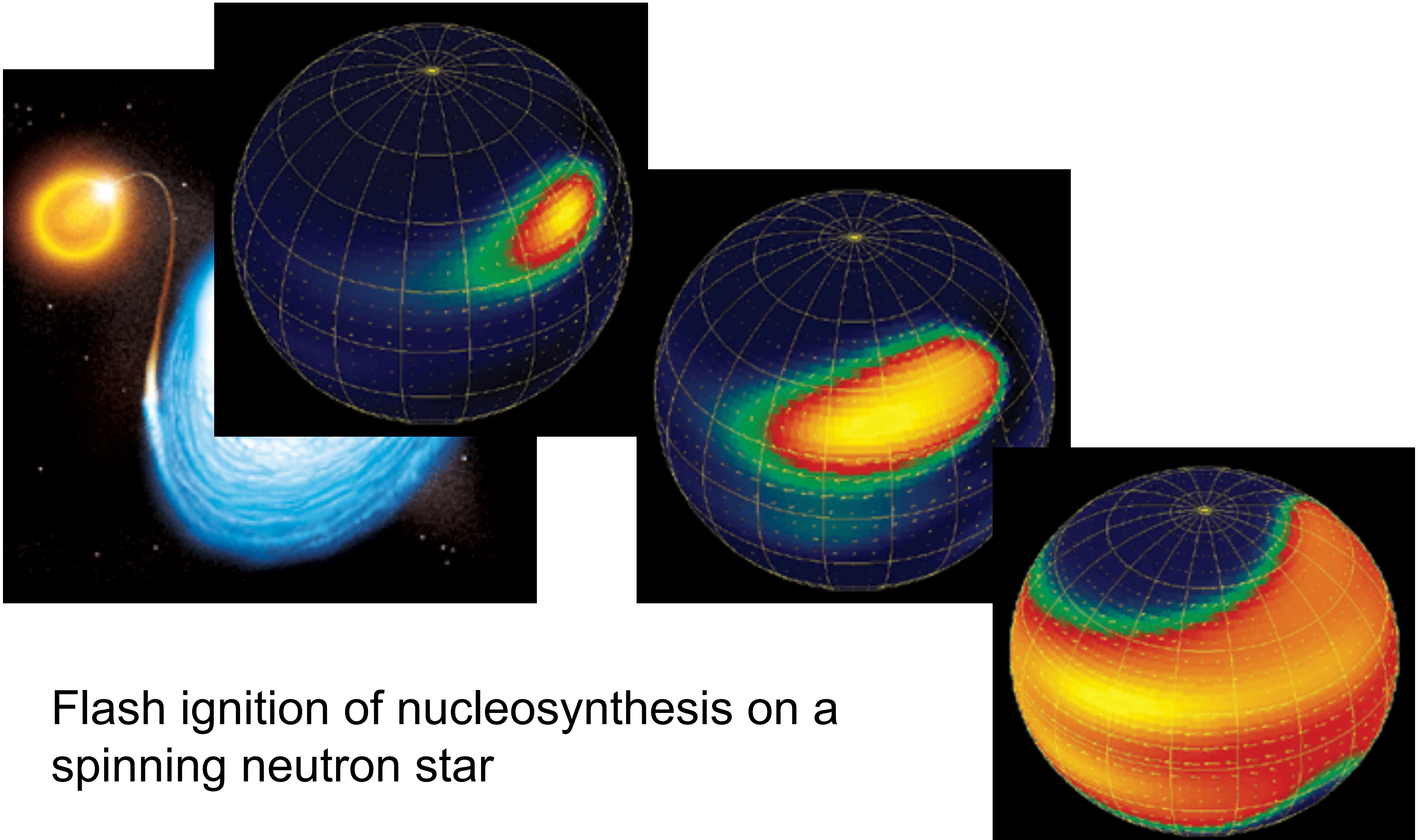
Extremes of density **not found anywhere else in the Universe**

Entirely new states of matter may be present.

Neutron star mass & radius
→ **Equation of State**
→ **QCD Theory**



Outburst on a Neutron Star: Nucleosynthesis



Flash ignition of nucleosynthesis on a spinning neutron star

Determining M,R separately

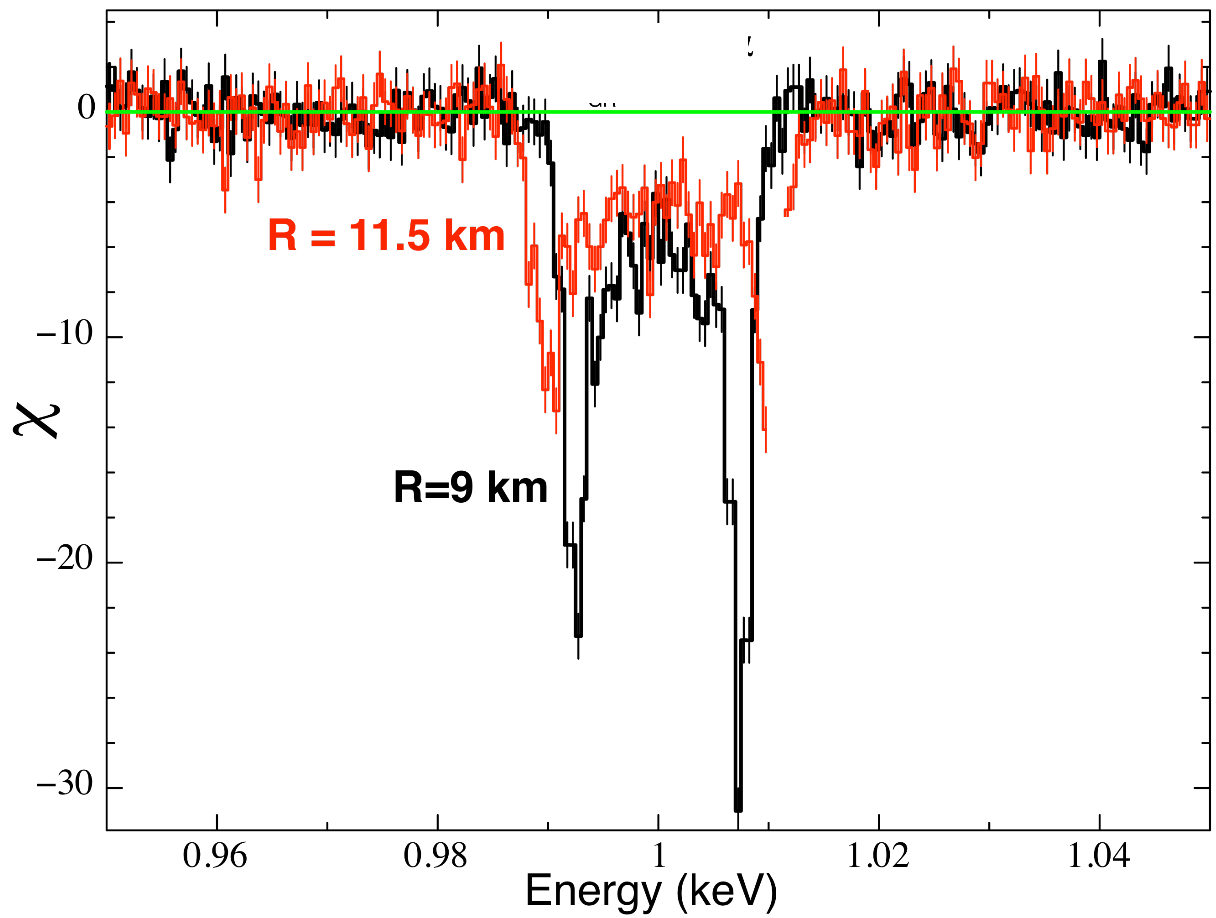
IXO XMS spectrum of x-ray burst

Slowly rotating (45 Hz), 1.4 $M_\odot$ neutron star

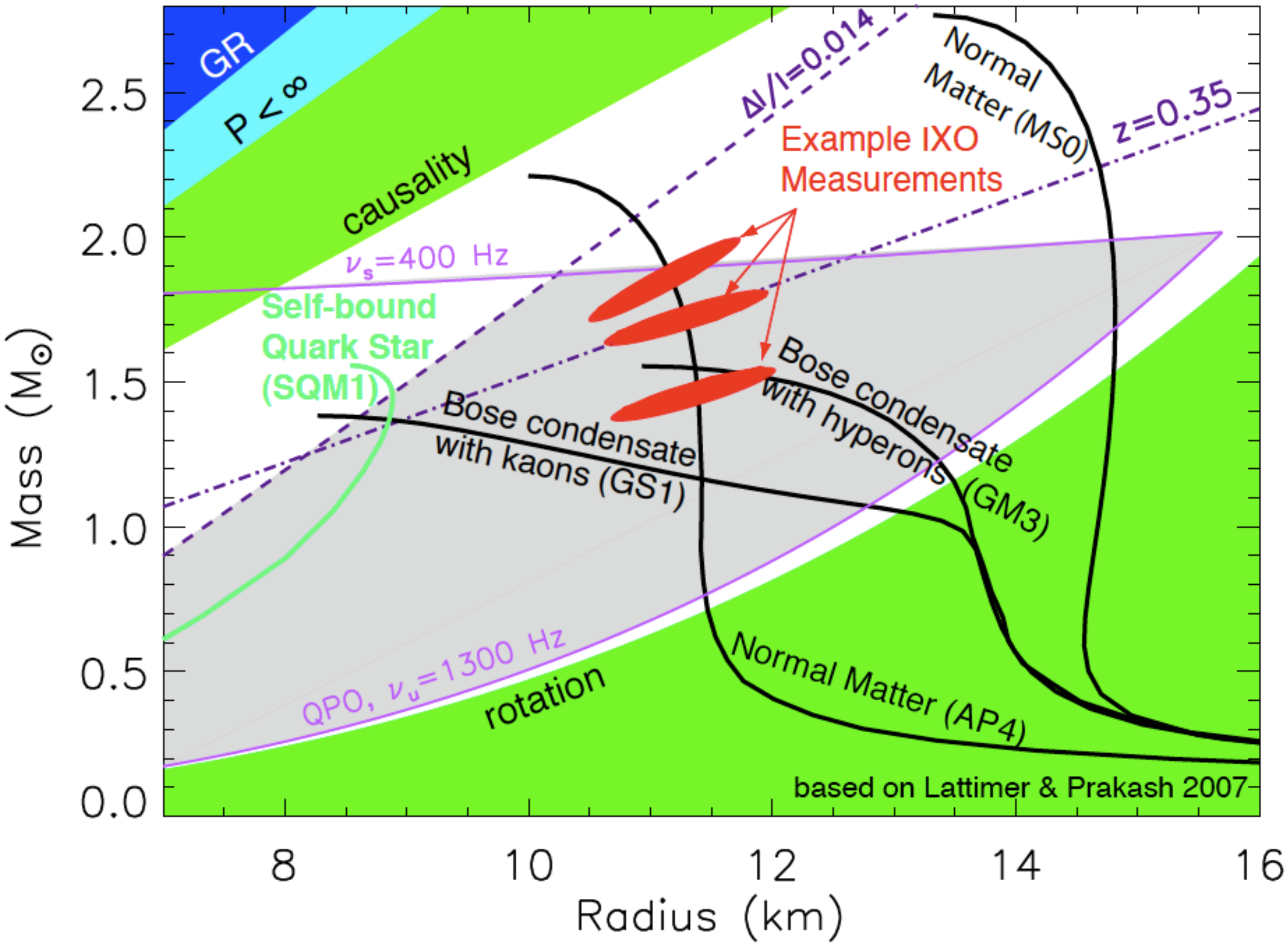
Fe XXVI Hα for z_{GR} = 0.35 – determines **M**/**R**

Doppler shifts cause line splitting – width depends on **R**

120s exposure for 1 Crab burst

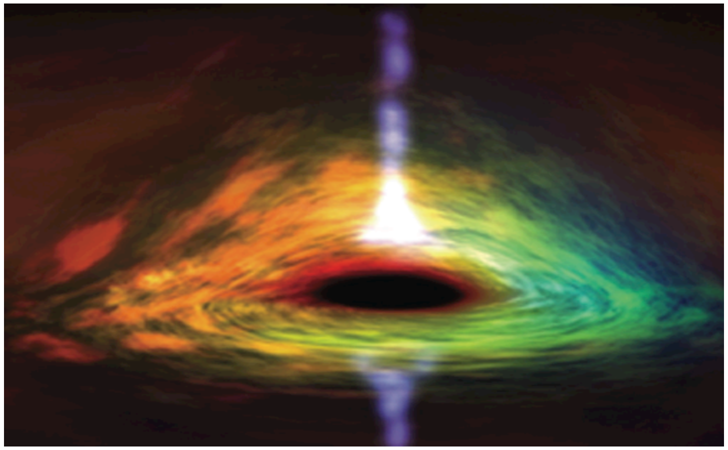


Neutron Star Equation of State



Lattimer & Prakash 2007

Black Holes and Matter under Extreme Conditions



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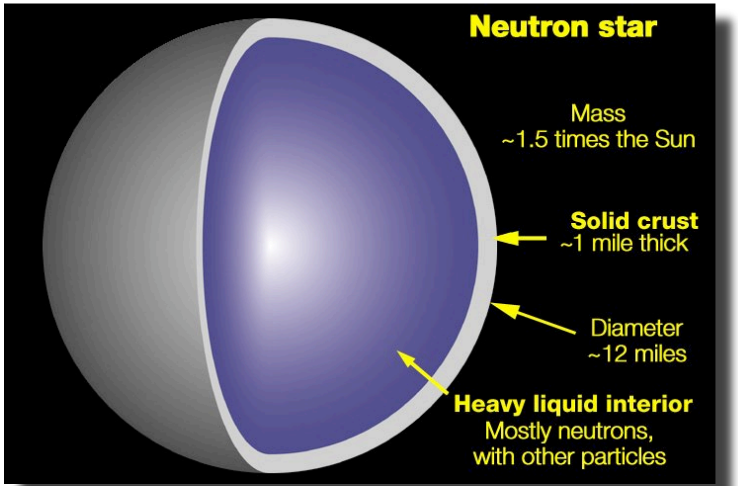
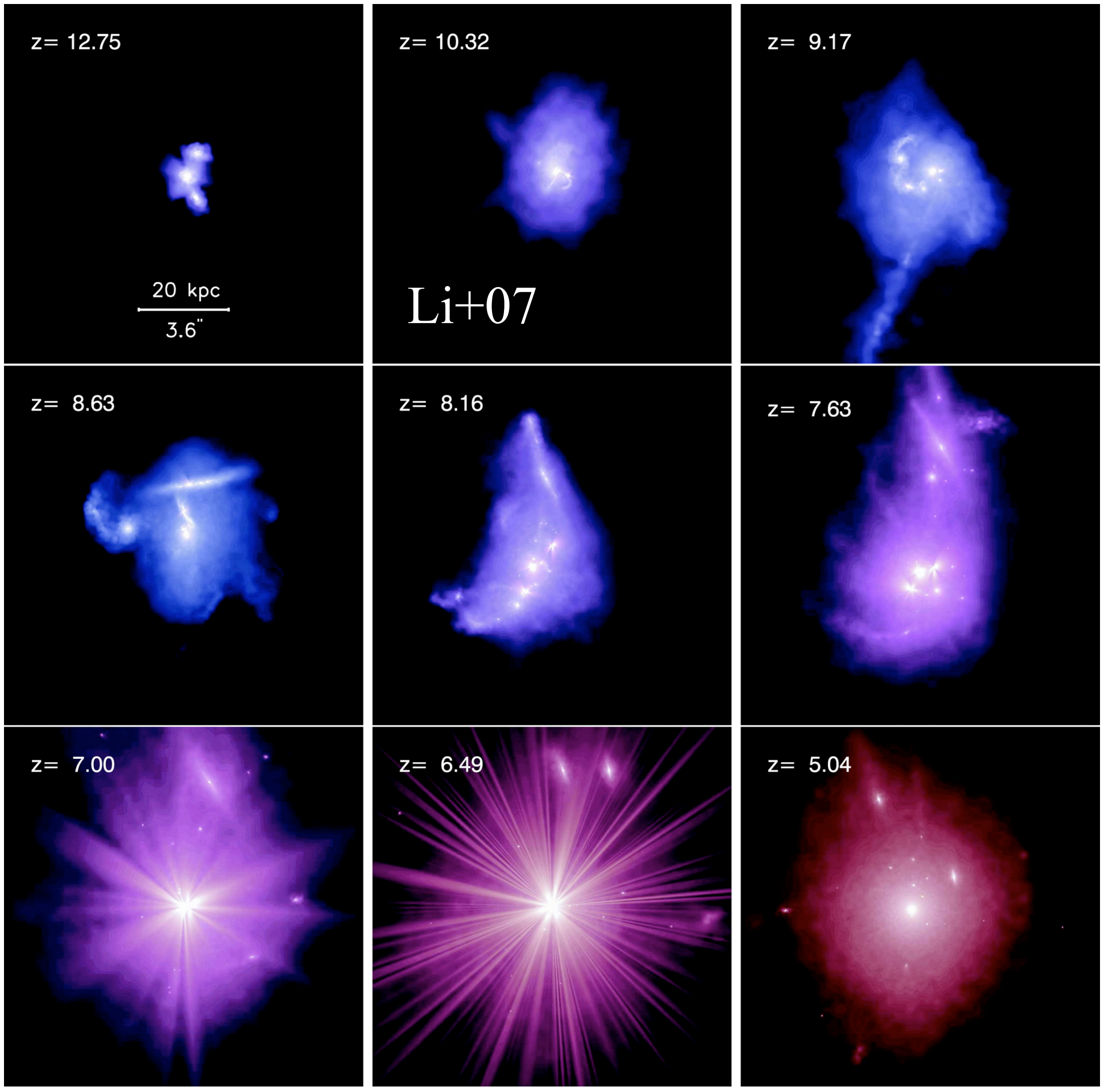


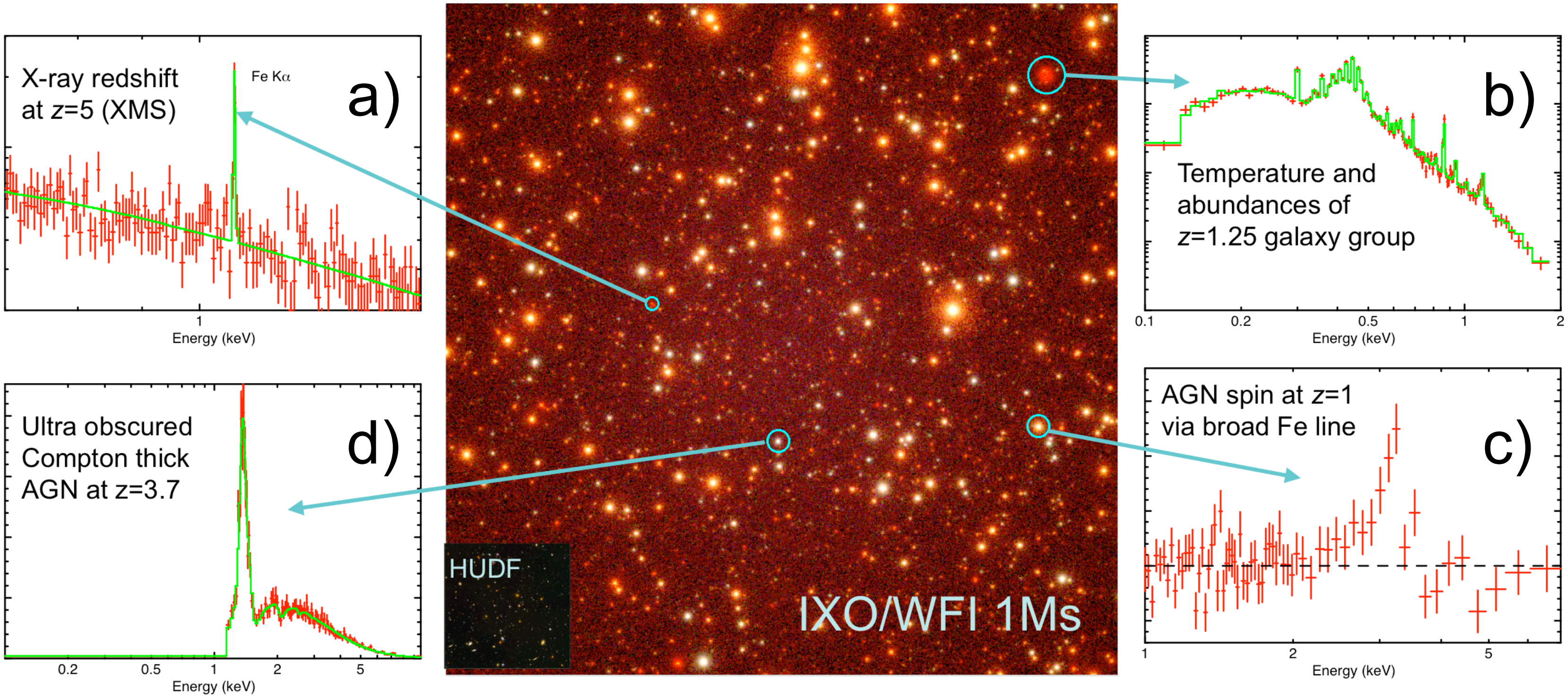
How do super-massive Black Holes grow? Does this change over cosmic time?

Building a ~10^9 M_{sun} BH at z=6.4



1. Gas rich major merger
   From Li et al. 2007,
   Hopkins et al. 2005
2. Inflows trigger BH accretion & starbursts
3. Dust/gas clouds obscure AGN
4. Luminous quasar forms with strong wind/outflow
5. AGN wind sweeps away gas, quenching SF and BH accretion

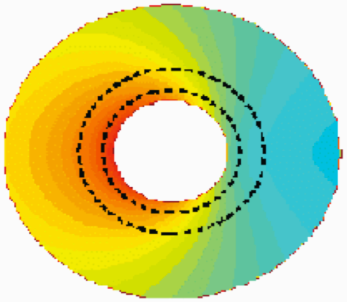
Black Hole and Large Scale Structure Evolution with IXO



IXO has the ability to characterize the extragalactic Universe:

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

SMBH **Spin**: Fe Kα

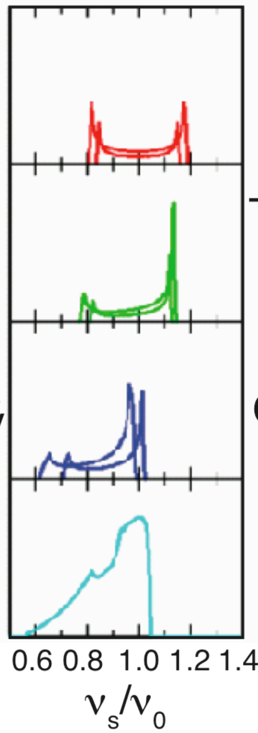


Newtonian

Special Relativity

General Relativity

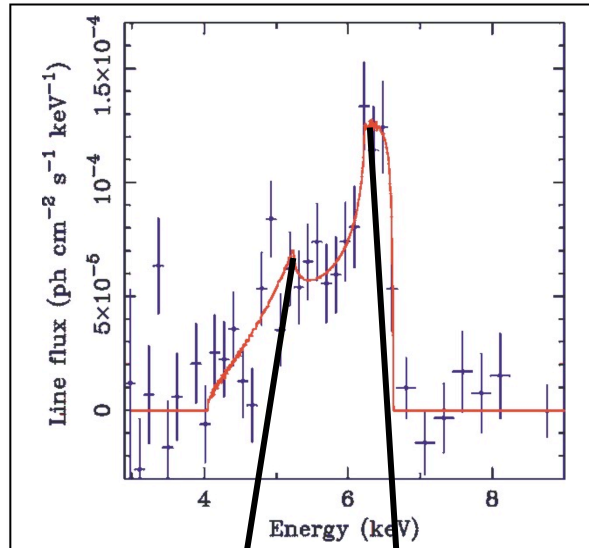
Line Profile



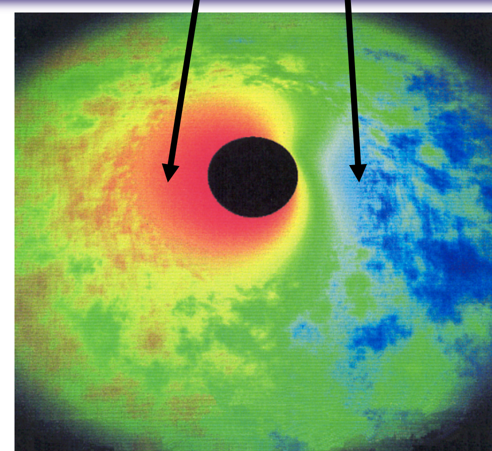
Transverse Doppler Shift, Beaming

Gravitational Redshift

Fabian 1991

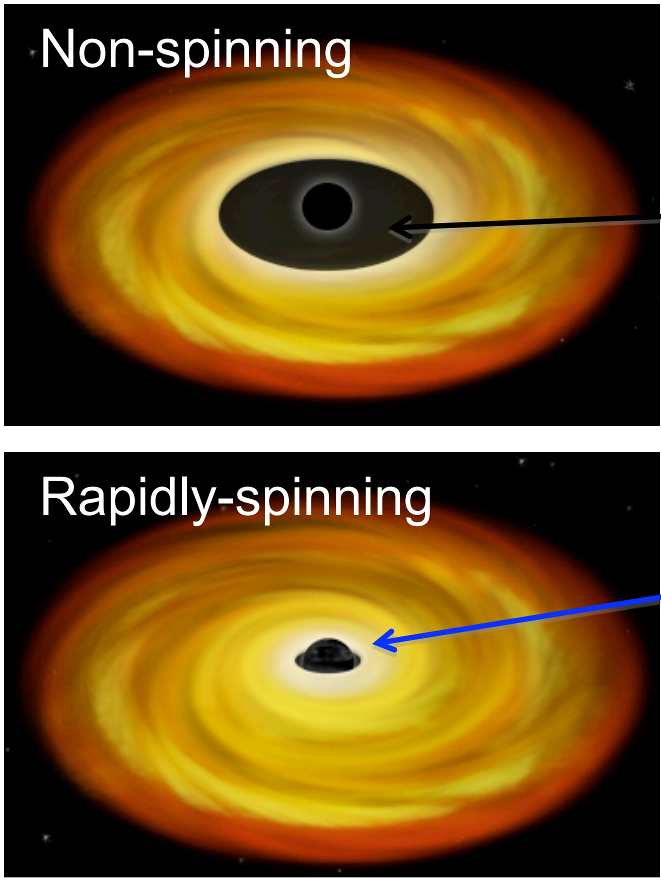


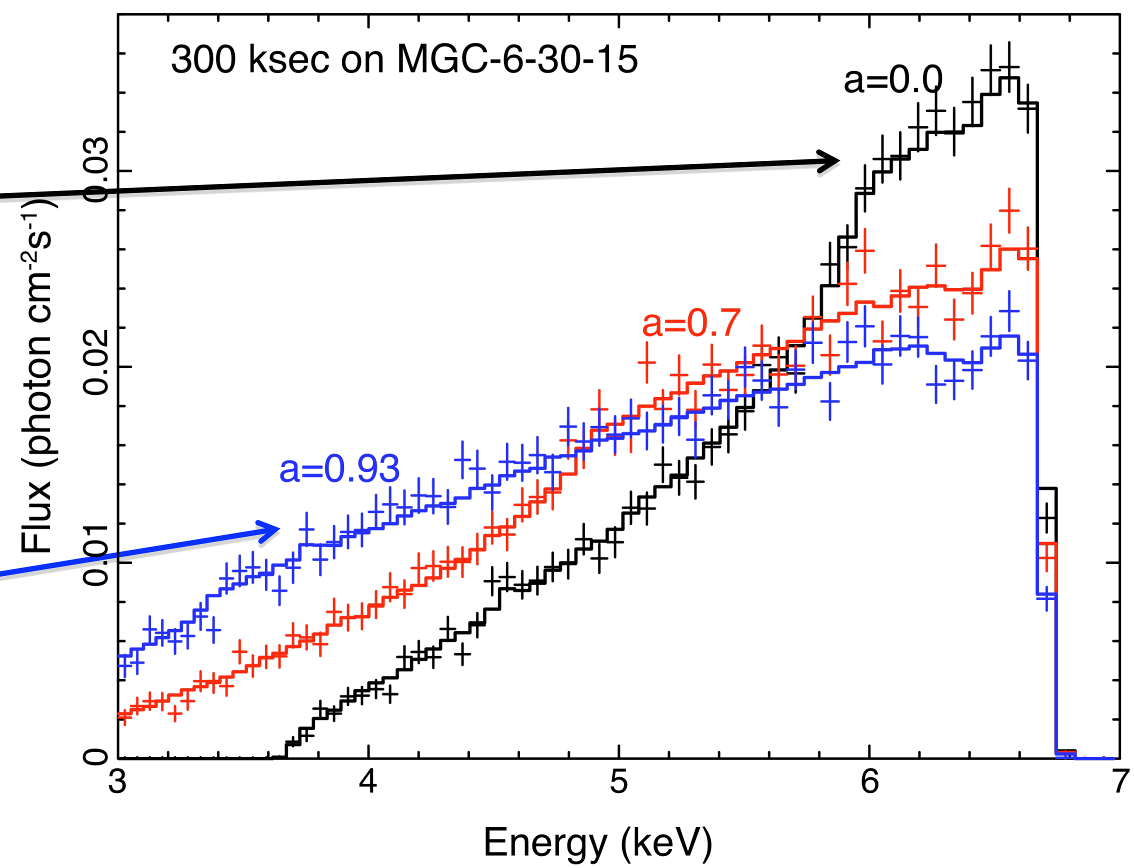
First observation Relativistic Fe line in SMBH - 1995



Theoretical 'image' of an accretion disk.

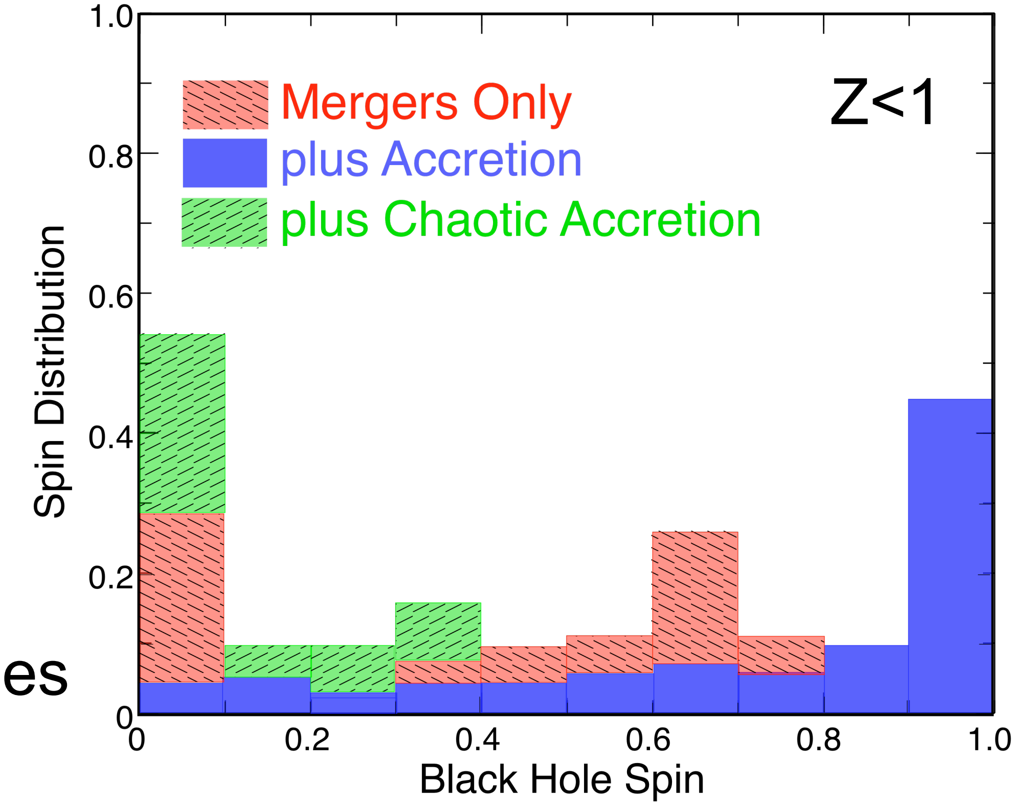
Black Hole Spin & Growth





IXO will measure relativistically-broadened iron line emission, measuring the black hole's spin.

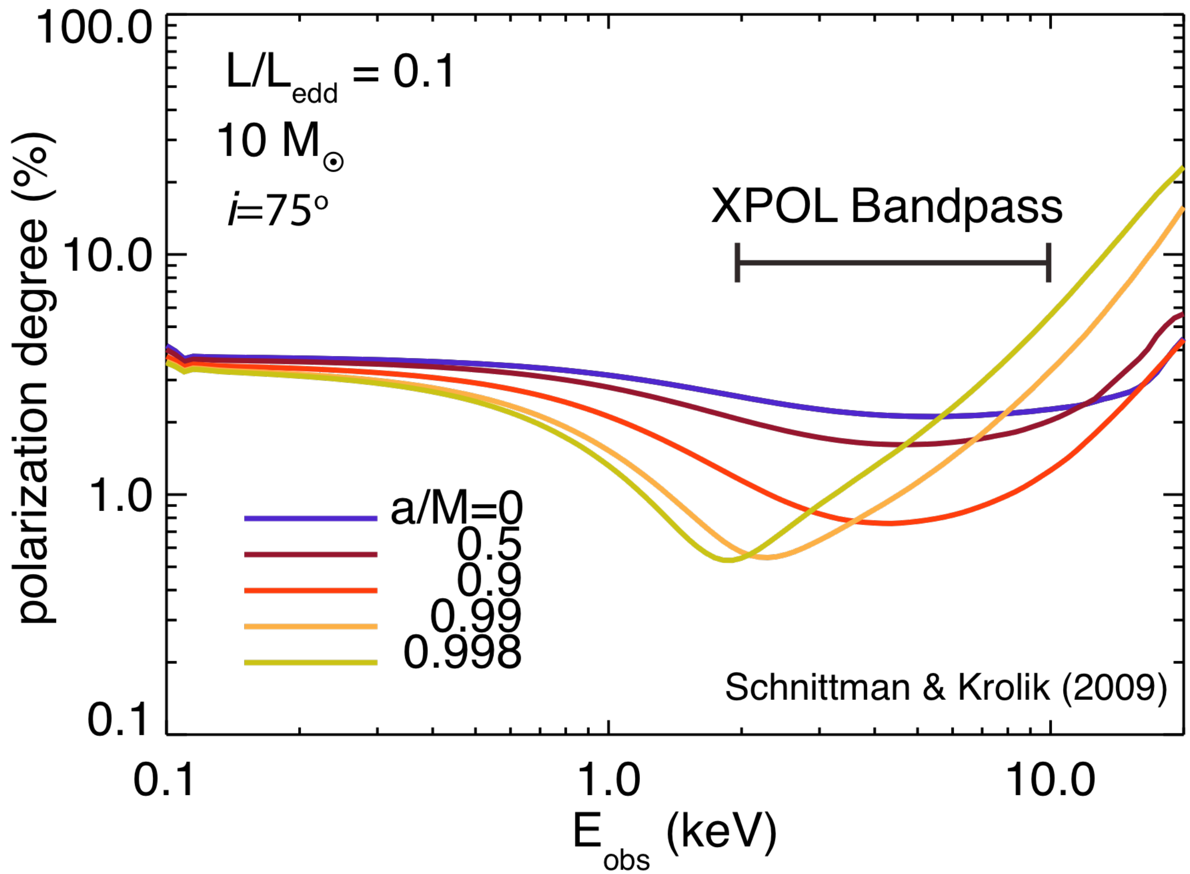
Supermassive Black Hole Spin & Growth



- **Merger-only growth:** broad distribution of spins
- **Mergers with standard accretion:** mostly maximally-spinning black holes
- **Mergers plus chaotic accretion** (growth from absorbing smaller (0.1%) SMBHs, no accretion disk) leads to slow rotation.

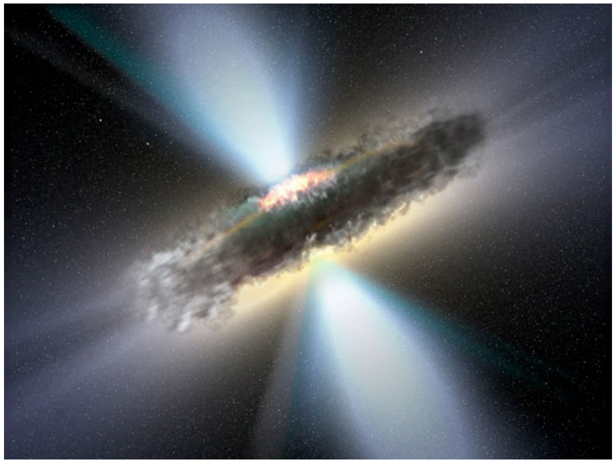
based on Berti & Volonteri (2008)

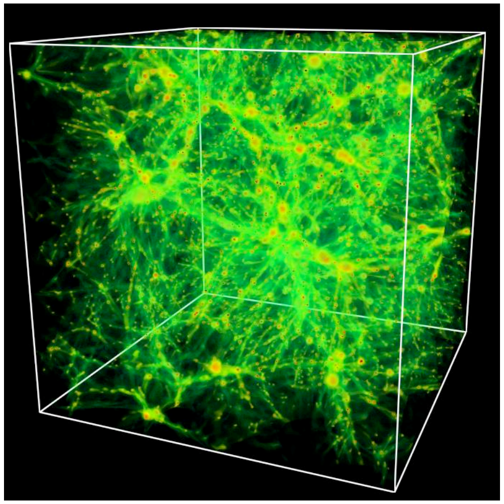
Polarization



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.

Formation and Evolution of Galaxies, Clusters, and Large Scale Structure





How does Cosmic Feedback work and influence galaxy formation?

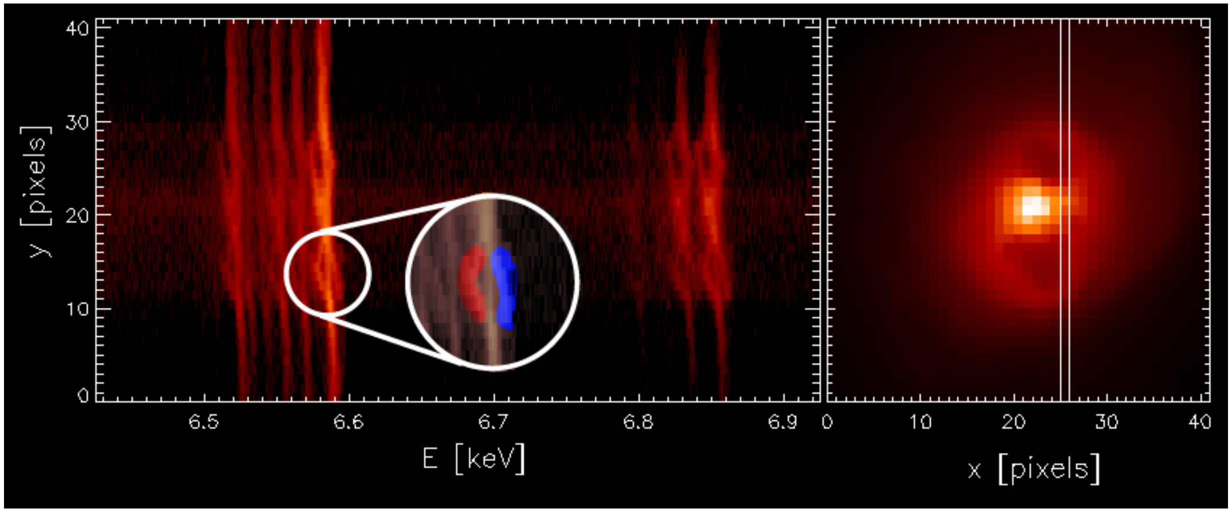
How does galaxy cluster evolution constrain the nature of Dark Matter and Dark Energy?

Where are the missing baryons in the nearby Universe?

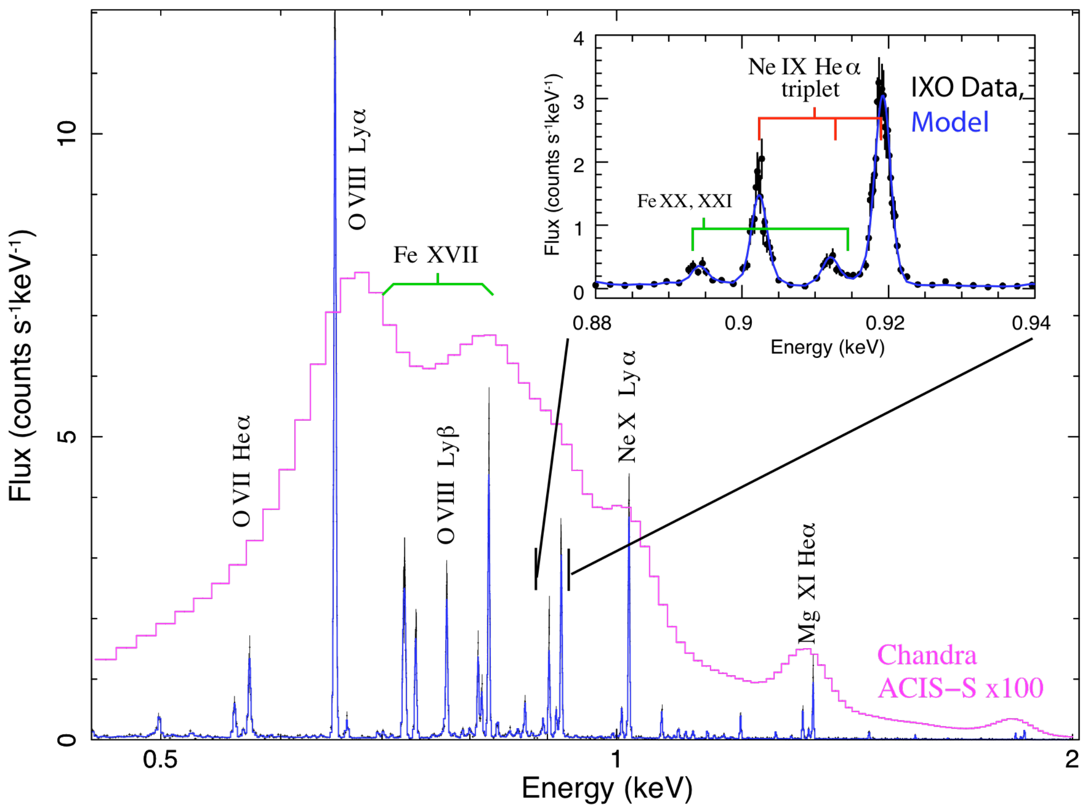
Cosmic Feedback

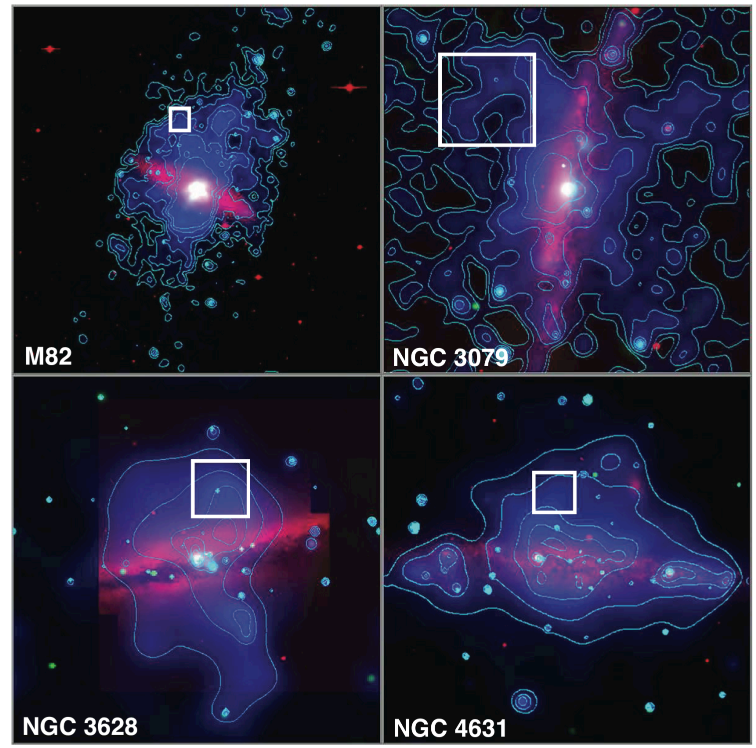
AGN feedback: regulates the growth of galaxies and clusters of galaxies

IXO: Velocity measurements → bubble expansion and energy transfer



Starburst Superwinds



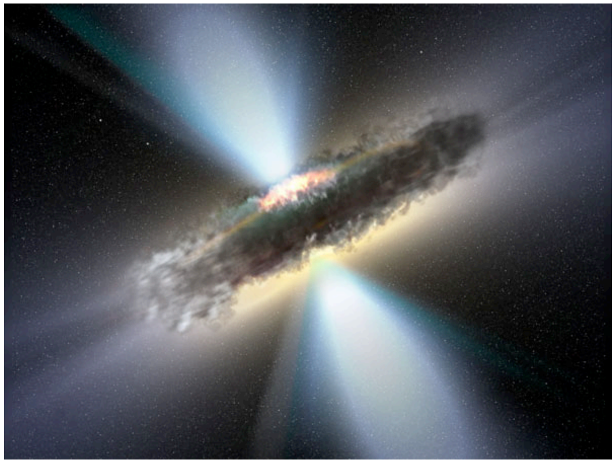


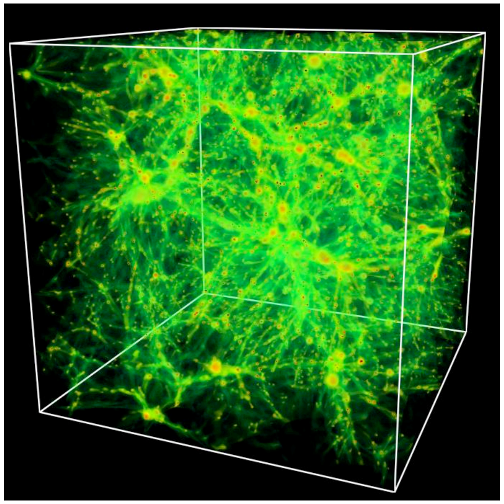
Outflows from Starburst galaxies now known

IXO: flow velocities, mass and energy outflow rate

abundances and pollution of environment

Formation and Evolution of Galaxies, Clusters, and Large Scale Structure





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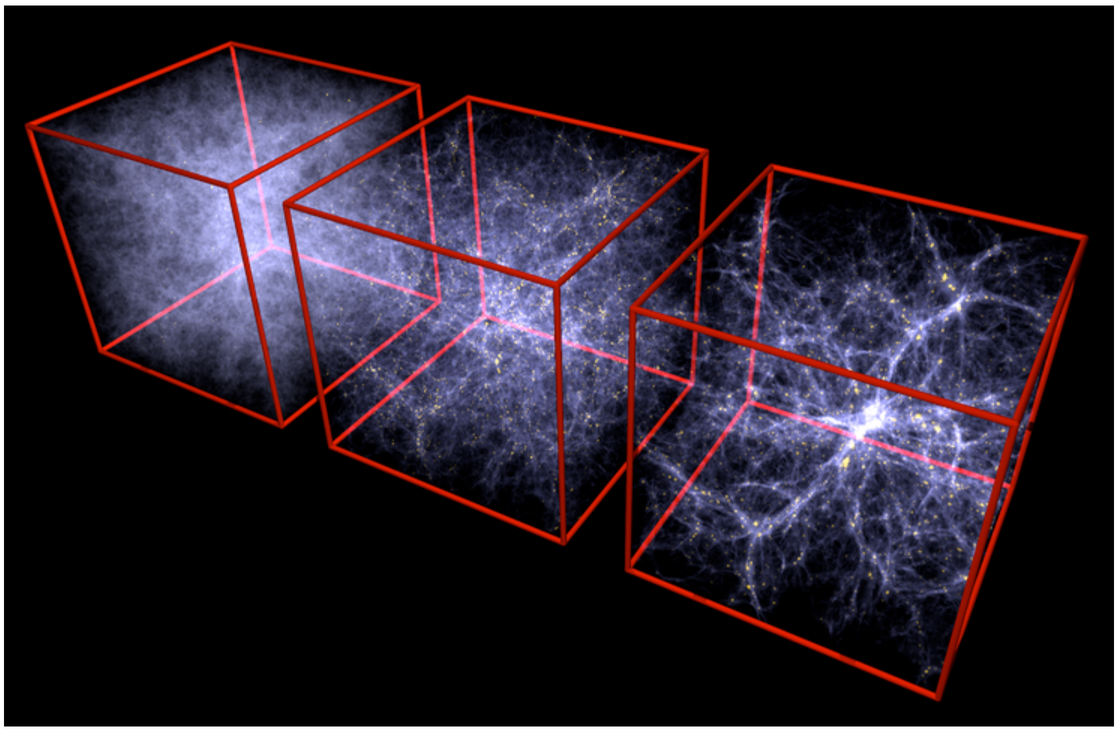
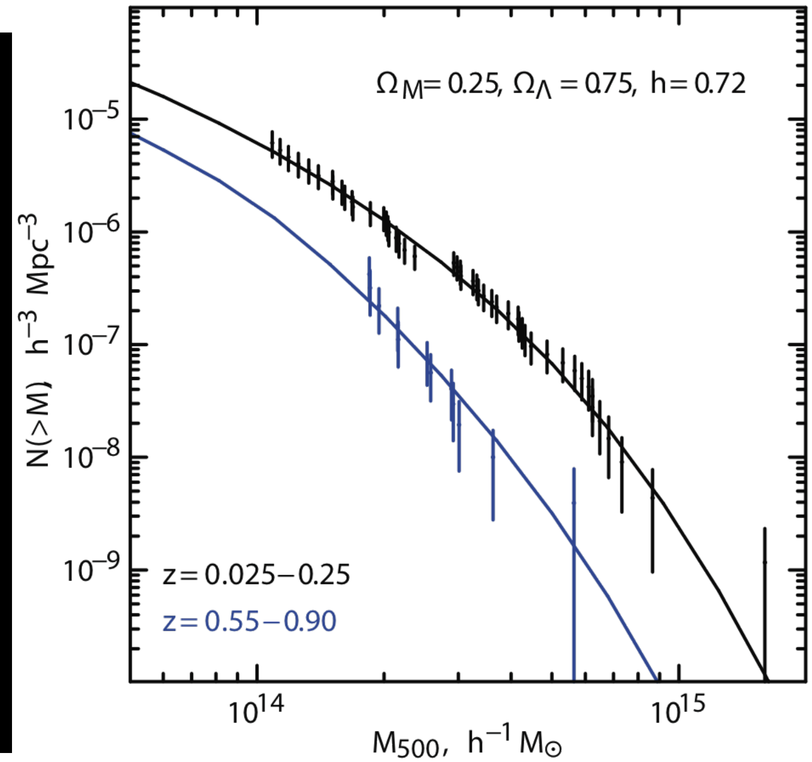
Cosmology with IXO

The growth of cosmic structure:

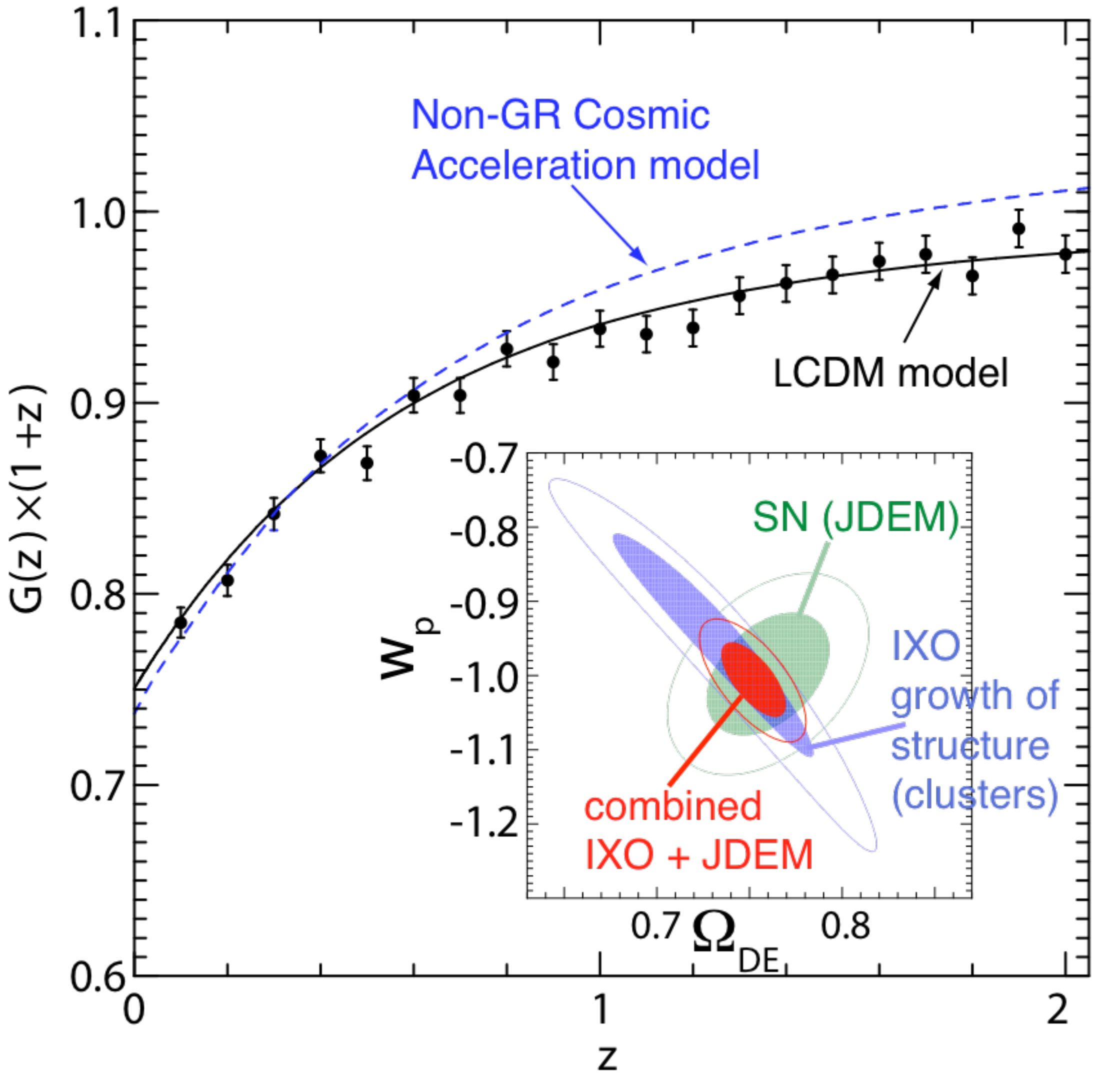
Measure the space density of clusters with mass and z



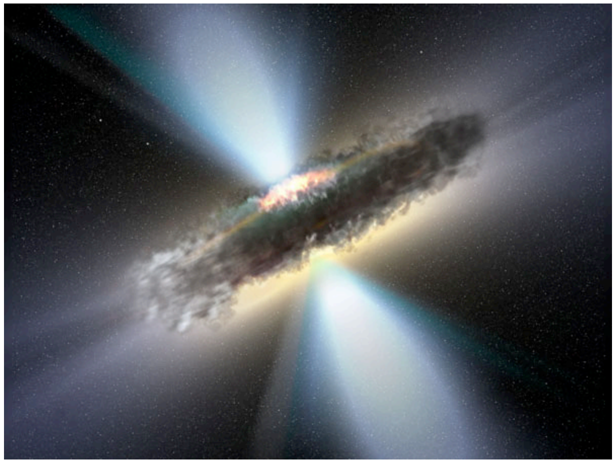


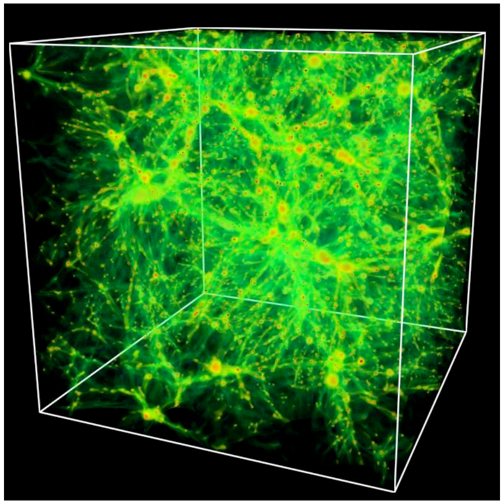
Vikhlinin+09

IXO Measurements of Cluster Mass Function



Formation and Evolution of Galaxies, Clusters, and Large Scale Structure





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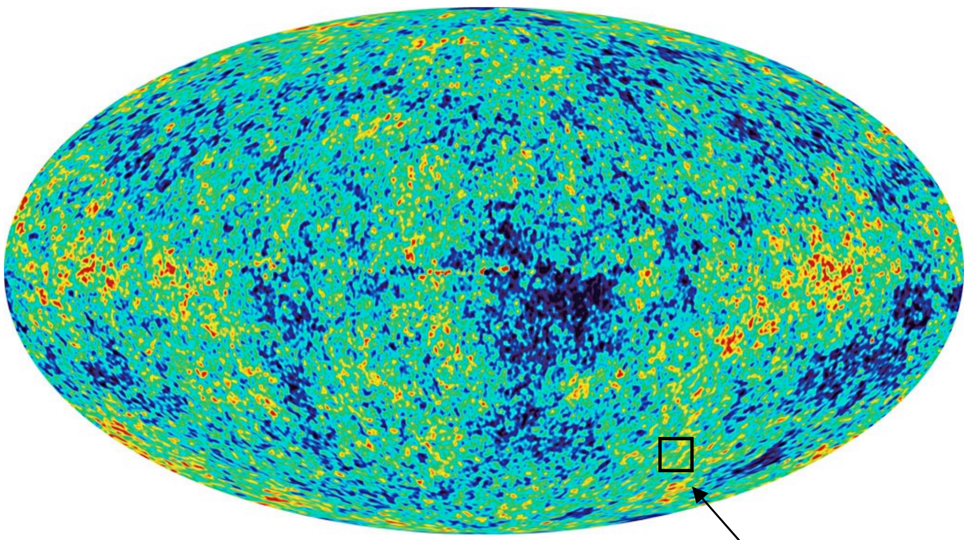
Missing Baryons



Cosmic Microwave Background (z = 1000)

The general belief was that this

Became this

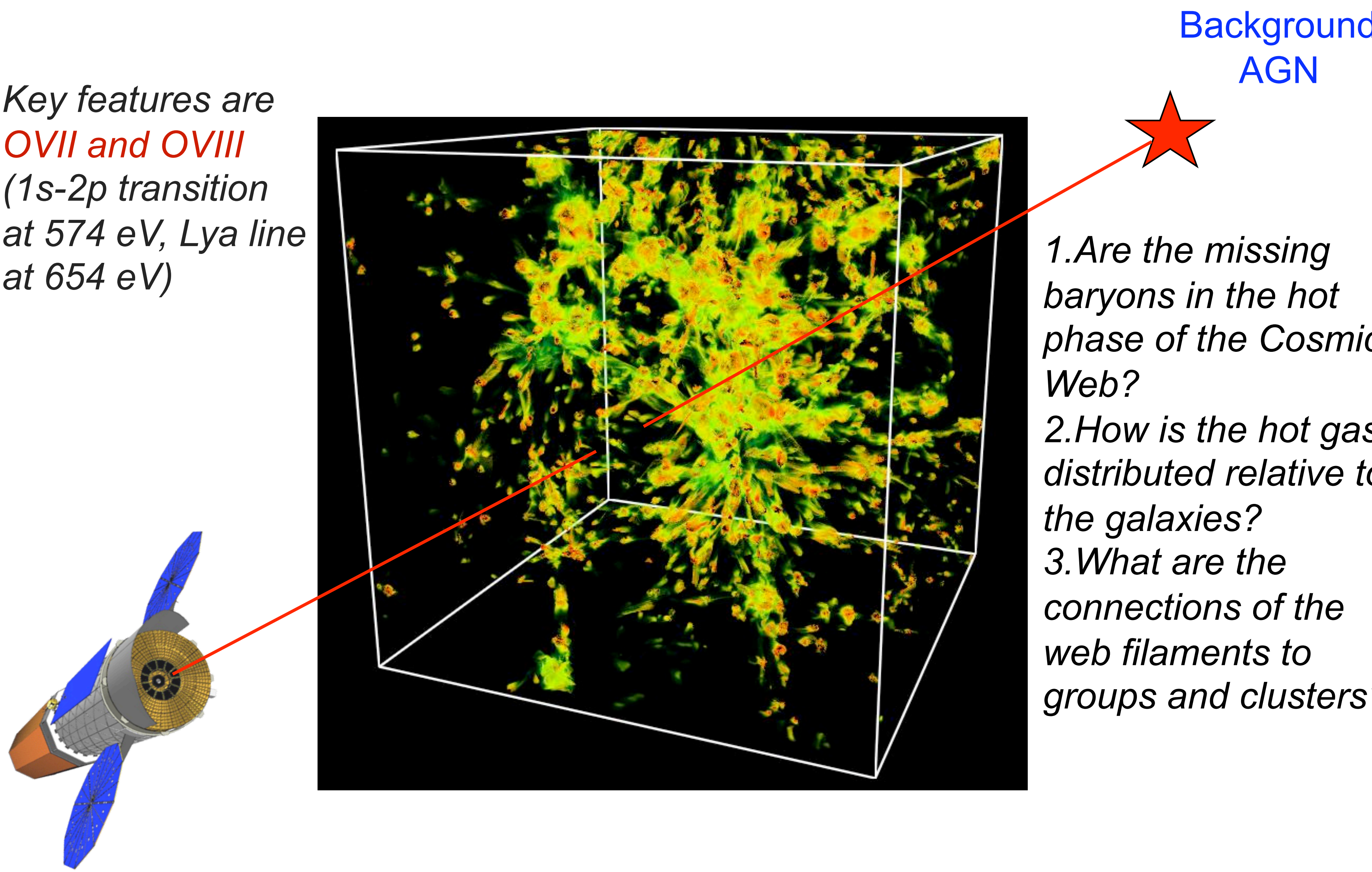
But then someone counted the baryons and found otherwise….

Missing Baryons at Low Z

- Only 5% of the baryons formed galaxies
- The rest is gaseous
  - 30% in gaseous form with T < 10^5 K
- Models Predict…
  - The rest is hot ($10^{5.5}$ – 10^7 K)
  - Heated by collapse of dark matter filaments plus galactic superwinds
- **The Cosmic Web of Baryons**

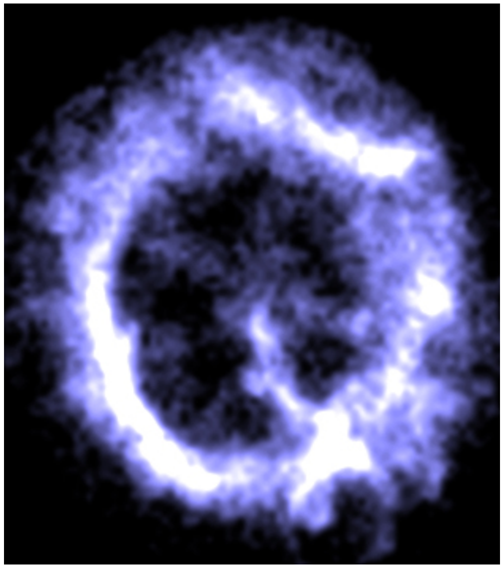
Study the Absorption by Hot Baryons with IXO

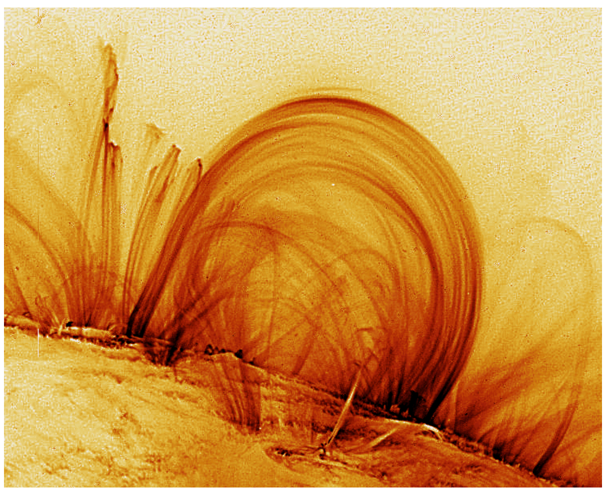
Key features are *OVII and OVIII* *(1s-2p transition at 574 eV, Lya line at 654 eV)*



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?

Life Cycles of Matter and Energy





When and how were the elements created and dispersed?

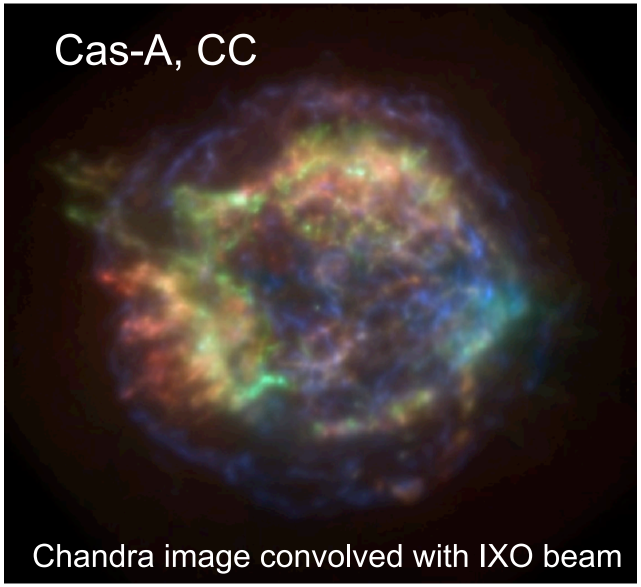
How do high energy processes affect planetary formation and habitability?

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

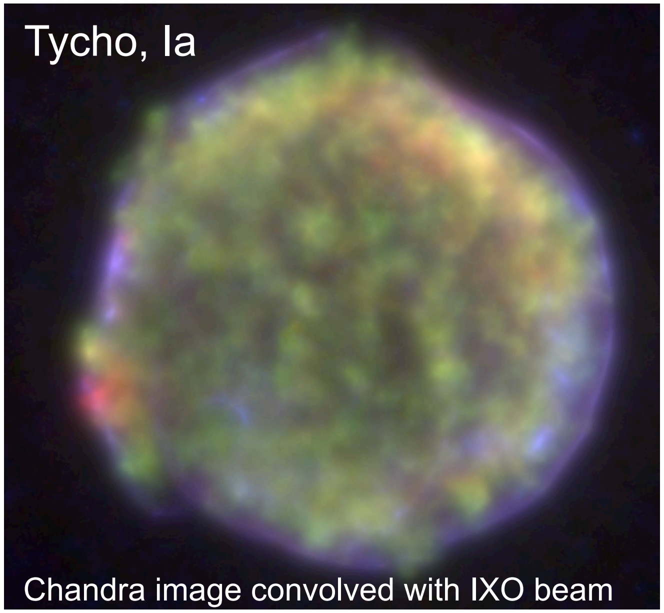
Forming the Elements

X-rays:

- **Uniquely** illuminate the composition and dynamics of the shocked ejecta and ambient medium
- IXO images plus spectra provide 3-D view of remnants



Chandra image convolved with IXO beam

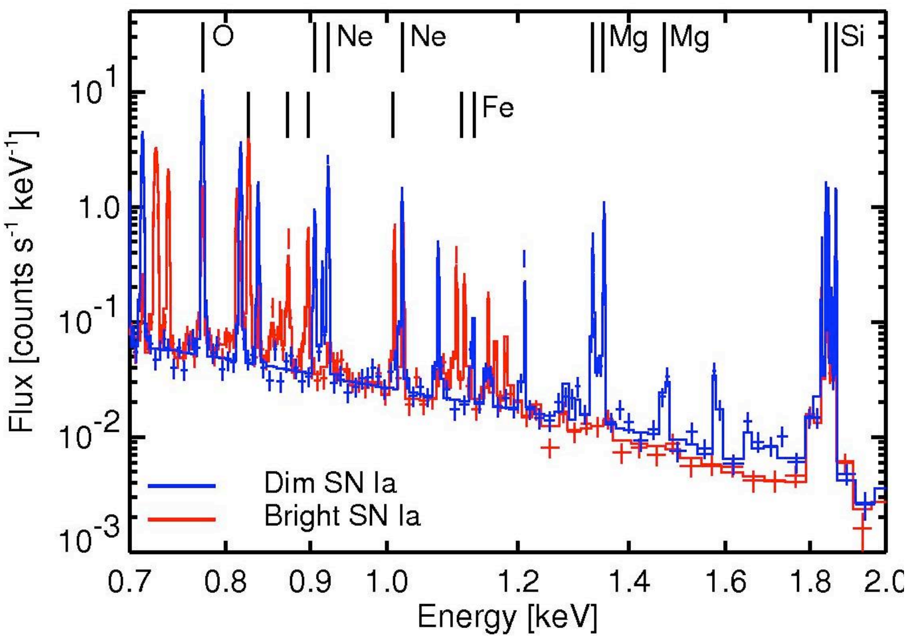


Chandra image convolved with IXO beam

Fe-group synthesis

- CC SNe – Fe comes from the innermost region, near jet/neutrino driven convection that drives the explosion
- In SN Ia, nucleosynthesis **is** the explosion (provides the energy to unbind the star); amount of Fe is key to optical light curve

Remnants of SN Ia in M33



IXO simulations

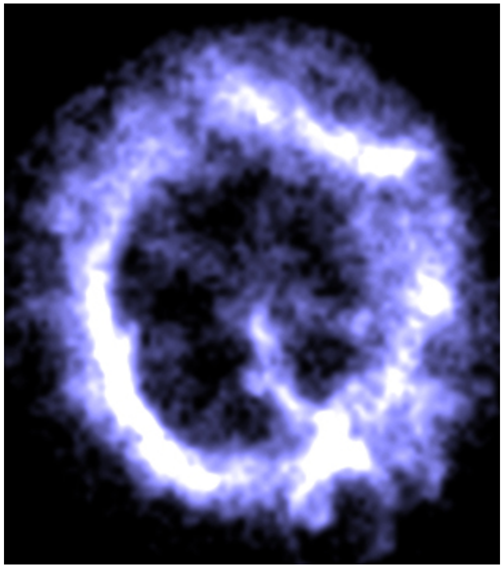
bright Ia's—Fe-rich (red) &

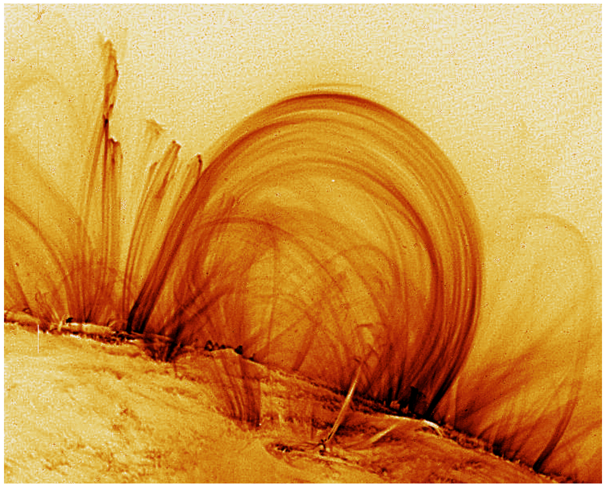
dim Ia's—Fe poor (blue)

- Bright and dim Type Ia SNe have different progenitors (Scannapieco & Bildsten 2005)

- Mn/Cr ratios constrain metallicity of progenitor and ages: different Ia subtypes (Badenes at al. 2006, 2008)

Life Cycles of Matter and Energy





When and how were the elements created and dispersed?

How do high energy processes affect planetary formation and habitability?

Heating of the protostellar disk

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

More information is available…

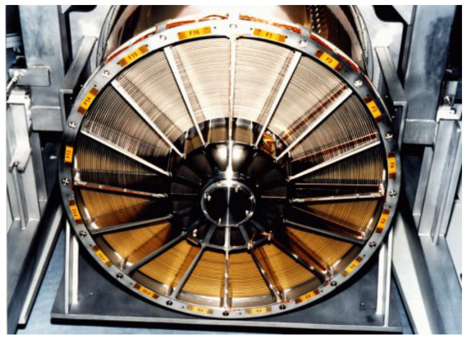
- Measuring the Gas and Dust Composition of the Galactic ISM and beyond
- Mass-Loss and Magnetic Fields as Revealed Through Stellar X-ray Spectroscopy
- Starburst Galaxies: Outflows of Metals and Energy into the IGM
- The Evolution of Galaxy Clusters Across Cosmic Time
- The Missing Baryons in the Milky Way and Local Group
- The Growth of Supermassive Black Holes Over Cosmic Time
- Stellar-Mass Black Holes and Their Progenitors
- Fundamental Accretion and Ejection Astrophysics
- X-ray Cluster Cosmology
- X-ray Studies of Planetary Systems
- The Cosmic Web of Baryons
- Spin and other relativistic phenomena around black holes
- The Behavior of Matter Under Extreme Conditions
- Cosmic Feedback from Massive Black Holes
- Formation of the Elements

See the Astro 2010 Decadal Web site

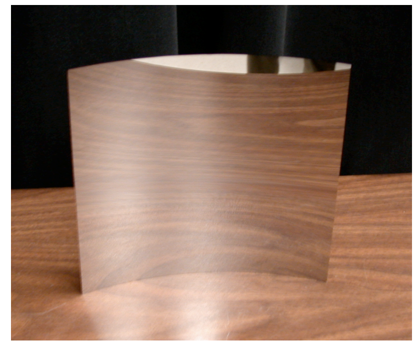
Or our site, http://ixo.gsfc.nasa.gov

The Large Collecting Area Secret: Lightweight Optics

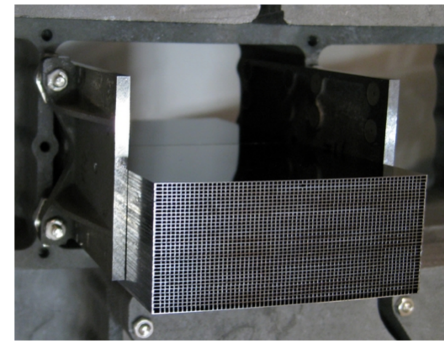
CHANDRA
0.5″ HEW
18500 kg/m^2



XMM-NEWTON
14″ HEW
2300 kg/m^2



Slumped Glass
5″ HEW
~270 kg/m^2

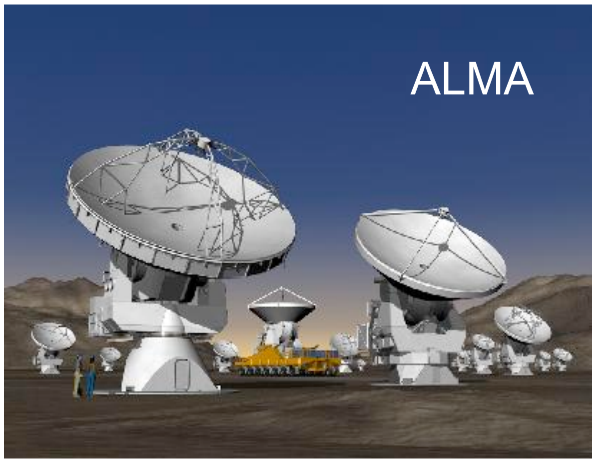


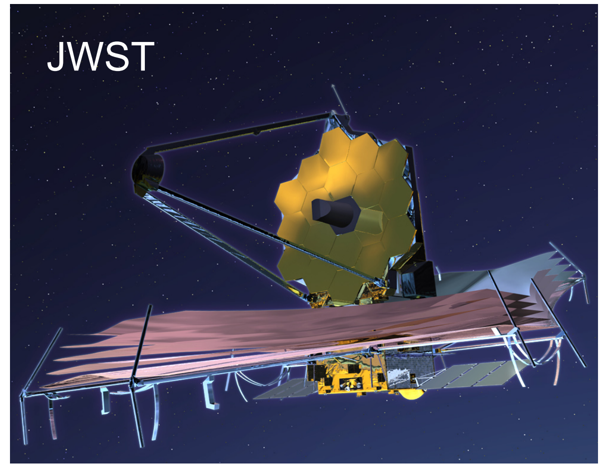
Si-HPO
5″ HEW
~200 kg/m^2

IXO Options

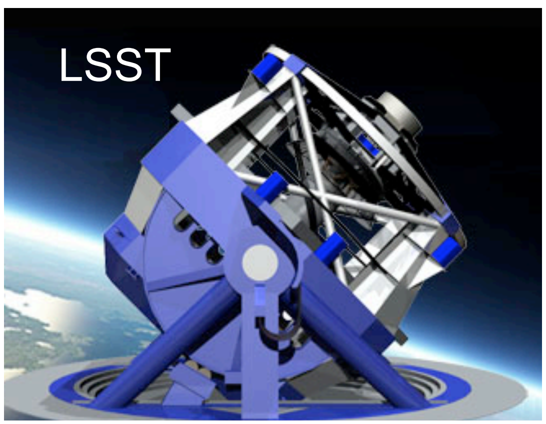
IXO: A Future Great Observatory

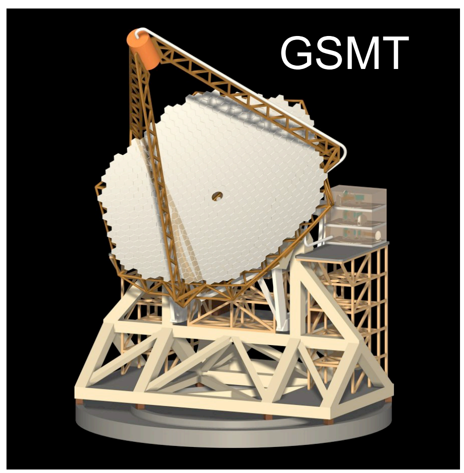
Sub-mm

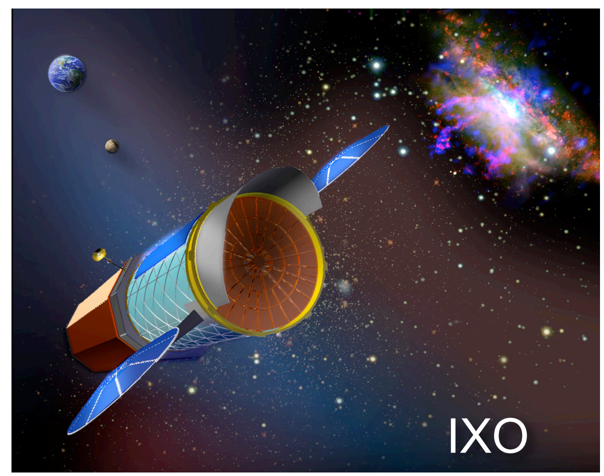




IR







X-ray

Optical

The two order of magnitude increase in capability of IXO is well matched to that of other large facilities planned for the 2010-2020 decade

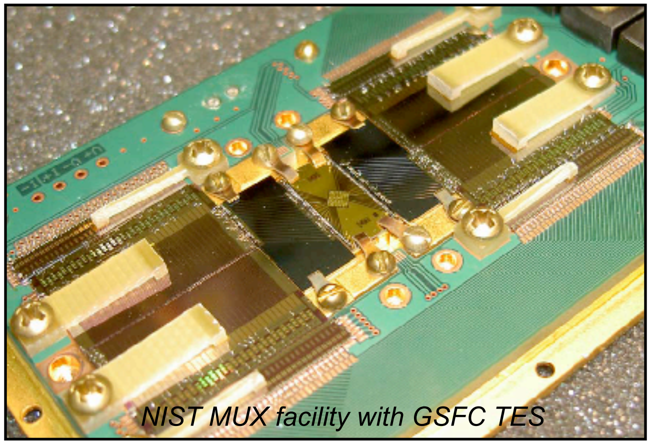
Micro-calorimeter Progress

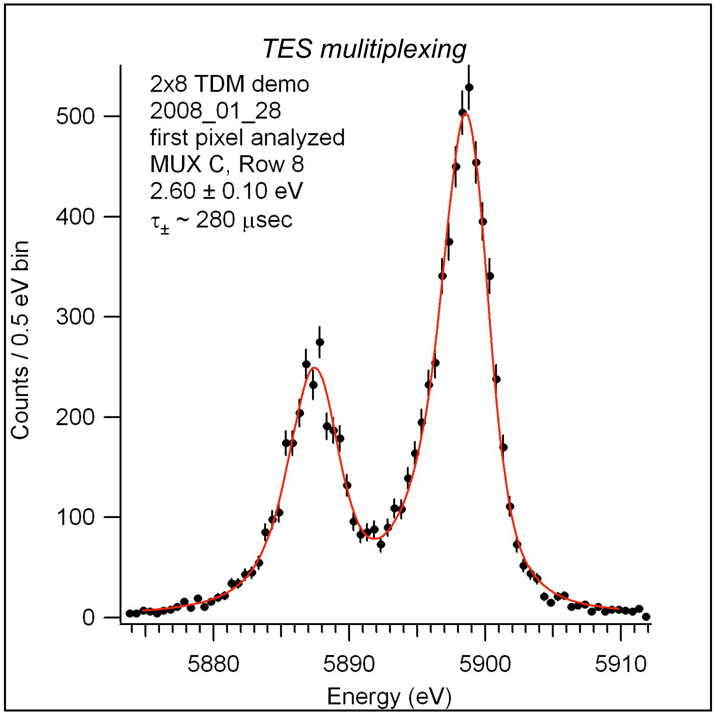
Multiplexed Readouts are essential to reduce the number of amplifiers

- Demonstrated a 2 x 8 time division readout with a spectral resolution of ~3 eV average (~2.6 eV best pixel)

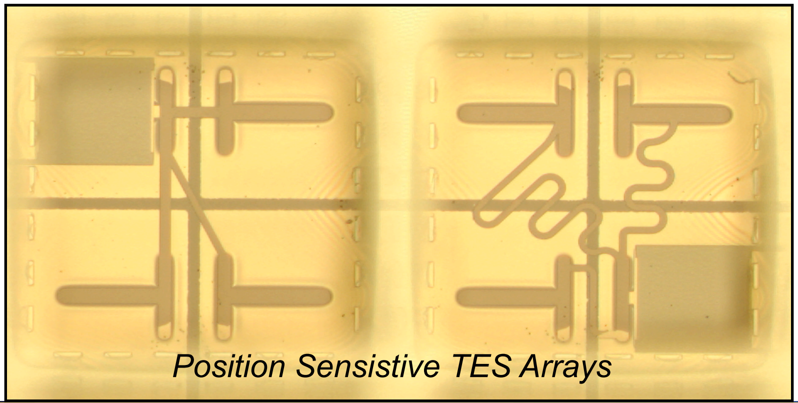
For outer part of array require position sensitive arrays

- fabricated and tested the first Position Sensitive TES's with spectral resolution 5 eV (meets requirement of <10 eV)


NIST MUX facility with GSFC TES

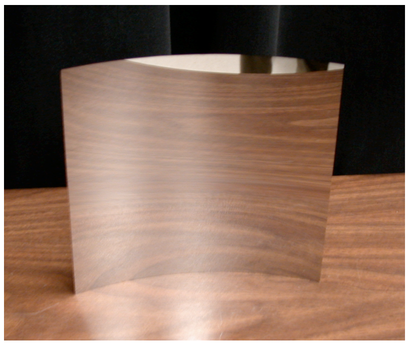


Energy resolution of 2.6 eV

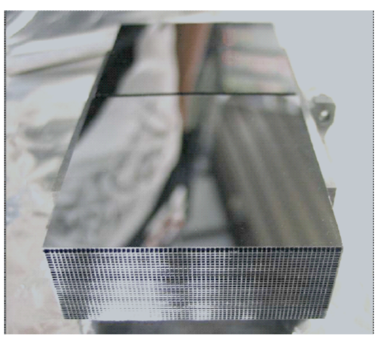

Position Sensistive TES Arrays

X-ray Mirror Baseline

Slumped Glass

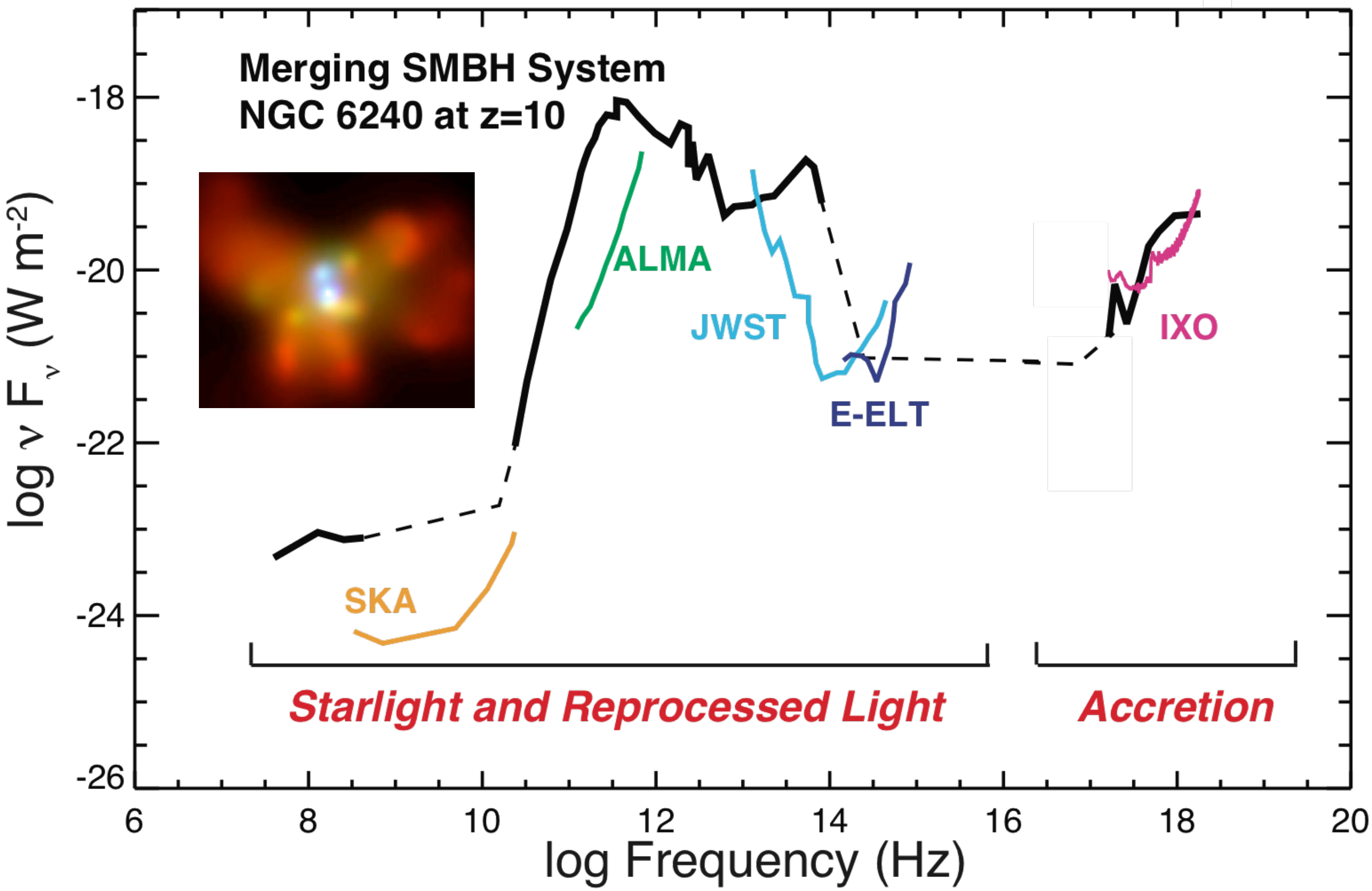


Silicon Pore Optics

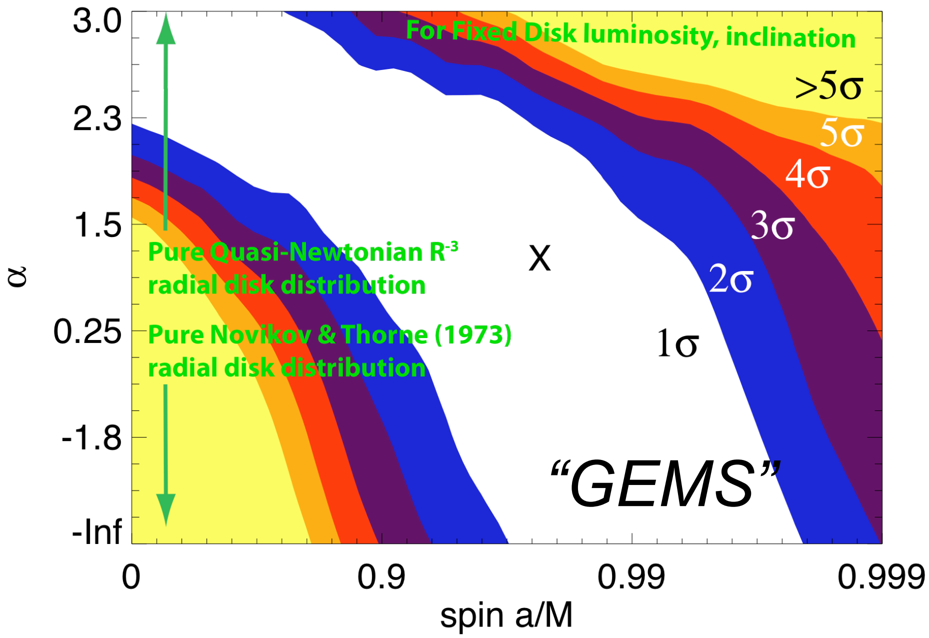


- Key requirements:
  - Effective areas:
  - ~3 m^2 @ 1 keV
  - ~1 m^2 @ 6 keV
  - Angular Resolution <= 5 arc sec
- Single segmented optic with design optimized to minimize mass and maximize the collecting area ~3.2m diameter
- Two parallel technology approaches being pursued
  - Silicon micro-pore optics – ESA
  - Slumped glass – NASA

SMBH's at high redshift with IXO



Polarization



Schnittman & Krolik (2009)

To estimate the ability of polarization observations to accurately determine a/M and α for a typical Galactic BH binary. The value of α represents the range from a pure Novikov & Thorne (1973) disk model if α=-Inf, and a Newtonian-type disk if α=3, giving a steep rise in emissivity all the way down to the BH horizon. Recent simulations suggest a mix of the two, with significant dissipation in the plunging region, increasing the emissivity interior to the ISCO.