IXO's Science Objectives & the Decadal View of IXO Science

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and the IXO team

The Decadal on IXO

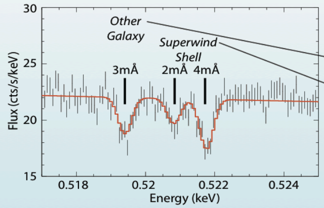
- "IXO is a versatile, large-area, high-spectral-resolution X-ray telescope that will make great advances on broad fronts ranging from the ***characterization of black holes*** to ***elucidation of cosmology*** and the ***life cycles of matter and energy in the cosmos***. Central to many of the science questions identified by this survey, IXO will revolutionize high-energy astrophysics with more than an order-of-magnitude improvement in capabilities." (p19, emphasis. added)

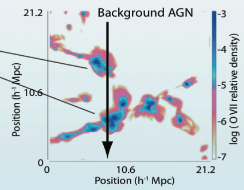
SCIENCE WITH IXO

LARGE-SCALE STRUCTURE & CREATION OF ELEMENTS

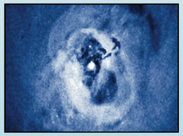
Missing baryons and the Intergalactic Medium

Find the missing baryons at low-*z* by characterizing hundreds of absorption systems seen against background targets .





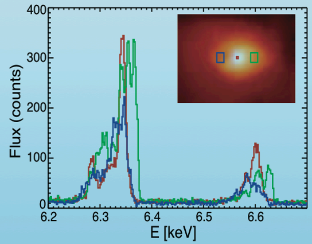
Cosmic Feedback and Cluster Evolution

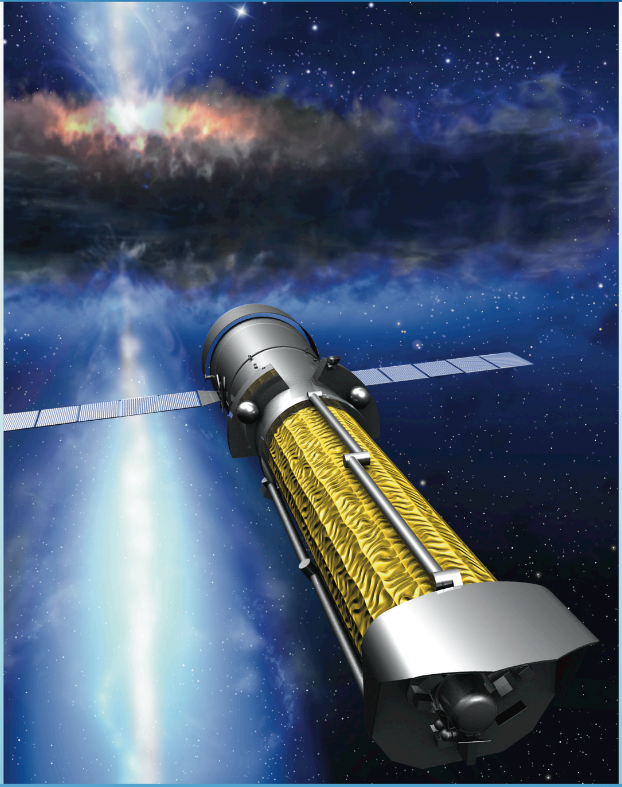


Measure feedback from SMBH in galaxies and clusters on the host environment. Establish the origin of excess entropy in clusters by studying their precursors at early epochs.

Precision Cosmology

Provide two independent measures of the Dark Energy equation of state via surveys of clusters at various epochs and measures of the gas fraction in massive clusters.



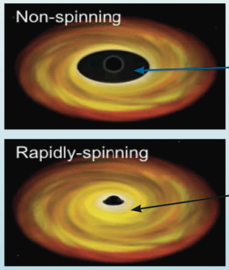


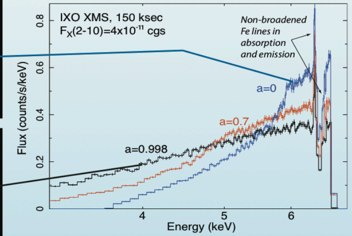
MATTER UNDER EXTREME CONDITIONS

Strong gravity and accretion physics

Survey spin of stellar and supermassive black holes via spectroscopy, timing and polarimetry to constrain their growth history and origin.

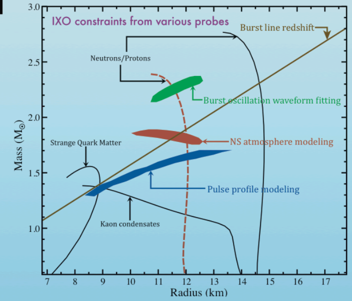
Probe strong-field General Relativity by Doppler mapping the innermost regions of accretion disks.



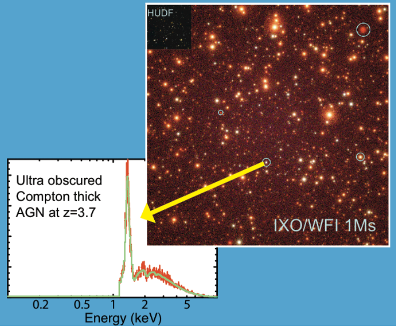


Neutron Star Equation of State

Measure mass and radius of a broad sample of neutron stars to constrain the equation of state of matter at supra-nuclear density.



CO-EVOLUTION OF GALAXIES & THEIR SUPERMASSIVE BLACK HOLES



Cosmic growth of SMBH

Find young (z ~6-10) growing massive black holes by conducting multitiered surveys.

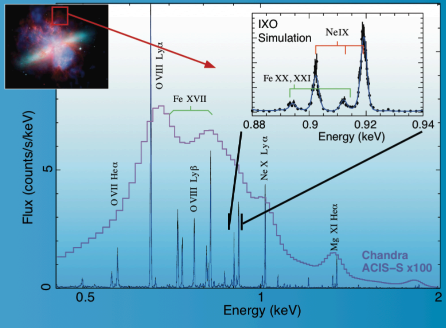
Characterize the energetics of the obscured growth phrase of SMBH between z~1-3.

Determine the growth mechanism of low-redshift SMBH by measuring their spin distribution.

Chemical evolution along cosmic time

Determine the epoch and mechanism of dispersion of chemical elements in the early intracluster medium.

Image outflows of metal-enriched plasma in starburst galaxies to assess the recent evolution of the intergalactic medium.



Comparing the Decadal to the IXO Science Case

Topics specifically listed for IXO in the 2010 Decadal Science Plan

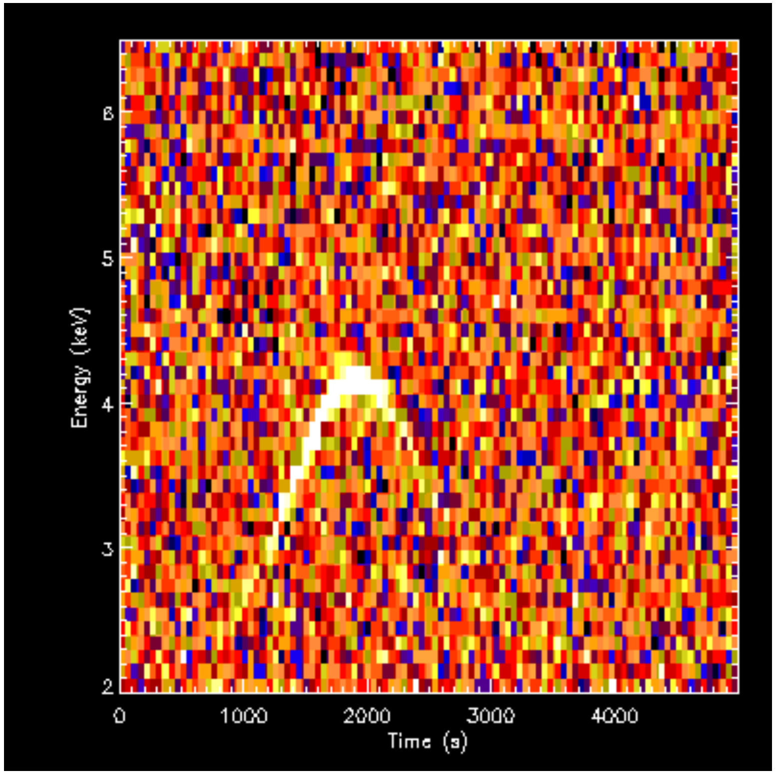
Topics called out in the Origin, Cosmic Order, or Frontiers of Knowledge Questions.

	Topics	Typical Targets	Length	# Obs	Total Time
			ksec		Msec
Galaxies and Black Hole Evolution					**30.6**
First SMBH	2	CDF-S	300	38	11.4
Obscured Growth of SMBH	1	NGC 4051	50	200	10.0
Cosmic Feedback	3	cluster	183	50	9.2
Large Scale Structure					**45.0**
Cosmic Web of Baryons	1	QSO B1426+428	600	25	15.0
Cluster Physics	2	z=0.1-2 cluster	160	94	15.0
Cosmology	2	z~0.5-2 cluster	15	1000	15.0
Matter Under Extreme Conditions					**22.4**
Stellar-Mass Spin	1	GRS1915+105	50	120	6.0
Strong Gravity Effects	8	MCG-6-30-15	200	40	8.0
Neutron Star Equation of State	1	EXO0748-676	32	170	5.4
QED Tests from Magnetars	1	SGR 1900+14	30	100	3.0
Life Cycles of Matter and Energy					**12.2**
SNR	2	Tycho SNR	100	80	8.0
Characterizing the Galactic ISM	1	MCG-6-30-15	seren.	100	0.0
Galactic Center	2	Sgr A*	250	4	1.0
Stars & Planets	5	Ophiucus	20	160	3.2
Total	**32**				**110.2**

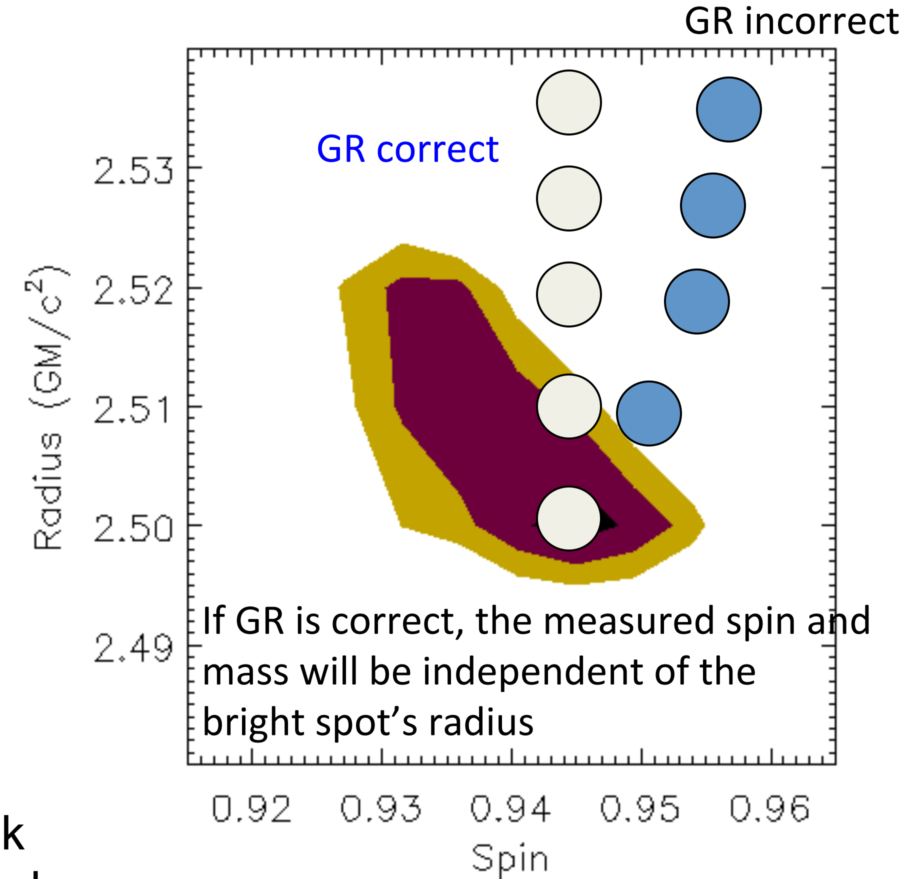
Based on both IXO Yellow Book science plan and SDT observation plan developed for Astro2010 RFI#1.

What happens close to a black hole?

"Scientists have an exact theoretical description of space-time around black holes but do not know if this description is correct. One way to find out is to observe X-ray-emitting gas and stars as they spiral toward a black hole's event horizon beyond which nothing, not even light, can escape." (p.13)

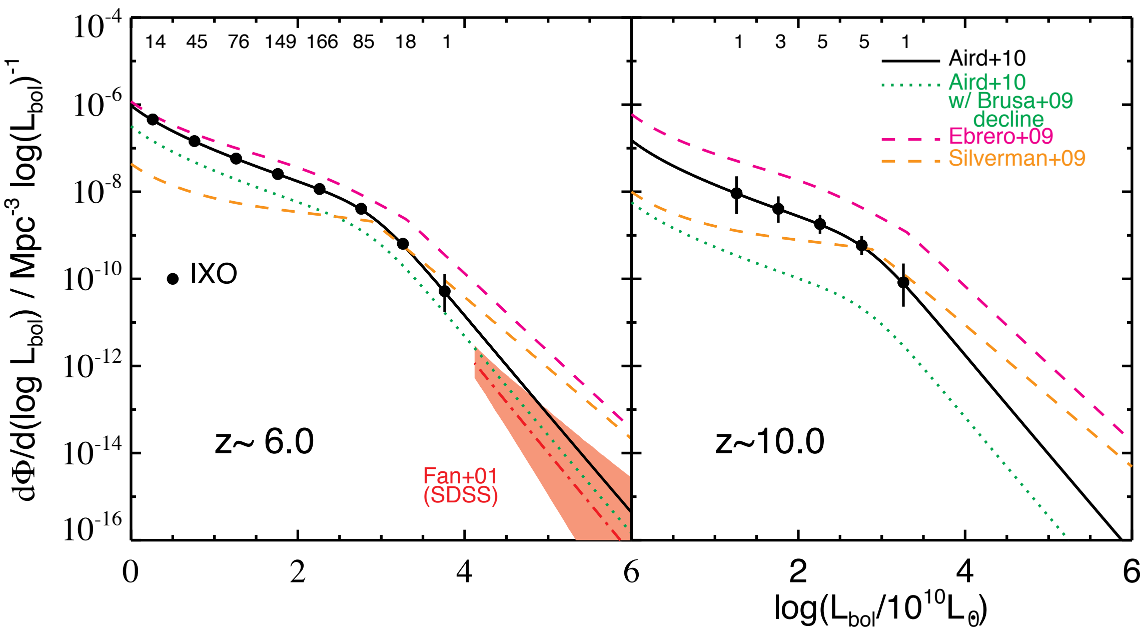


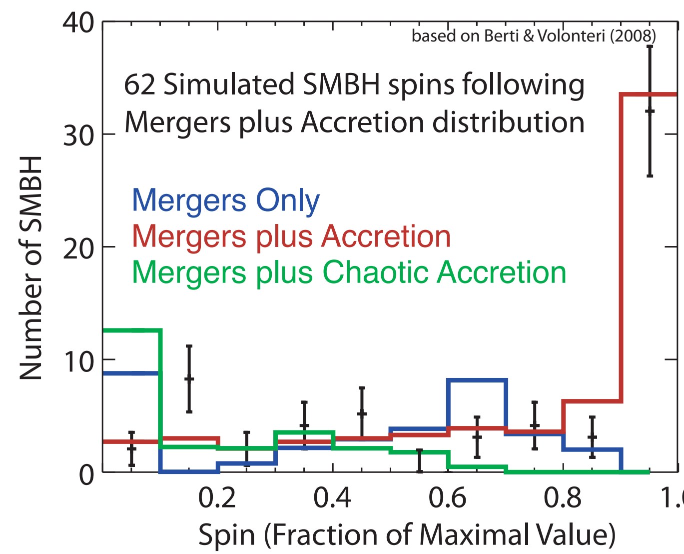
X-ray Fe-K line bright spots in accretion disk surrounding Black Hole trace orbits that can be mapped with IXO



When and how did super-massive black holes grow?

"It is already known from observations that these black holes can grow very soon after the galaxies form. However, the manner in which this happens is still a mystery. These accreting black holes can be seen back to the earliest times using the proposed space-based Wide-Field Infrared Survey Telescope (WFIRST) and the International X-ray Observatory (IXO) …" (pp.190-191)



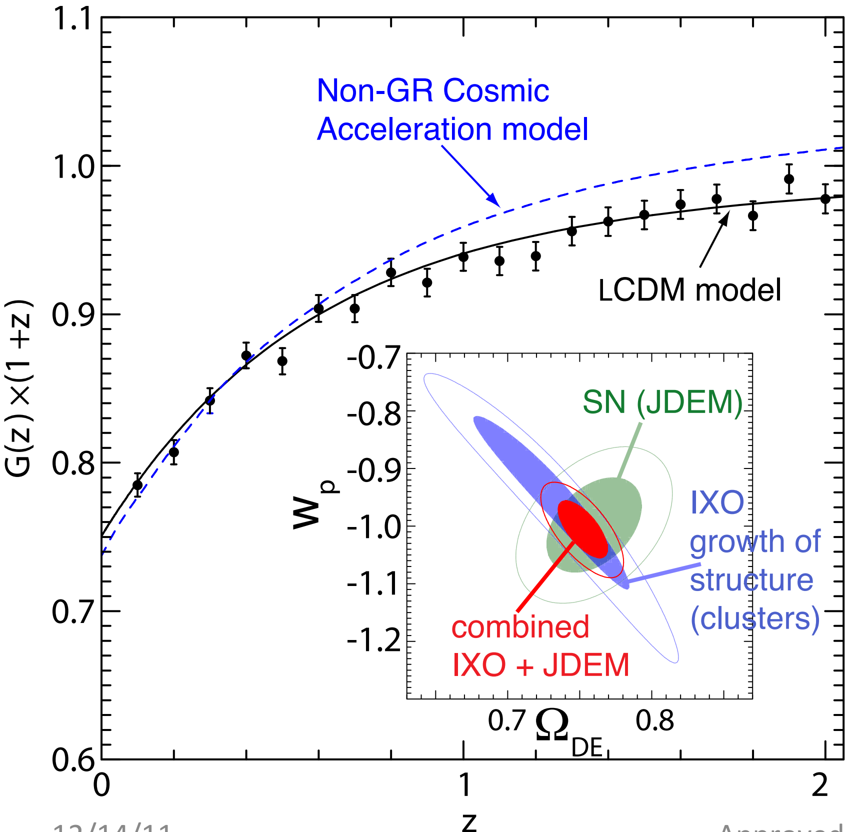


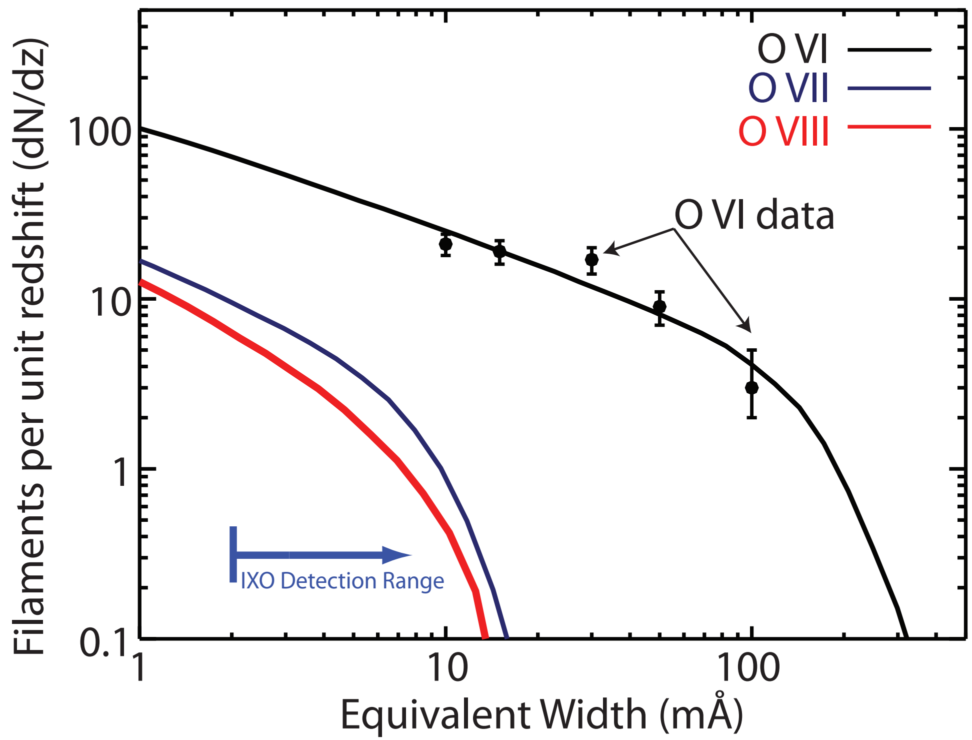
Predicted bolometric luminosity functions at z~6 and z~10 will discriminate between the different evolutionary models, revealing the crucial role of SMBH accretion in the very early Universe.

Spin survey reveals final results of SMBH growth mechanisms

How does large scale structure evolve?

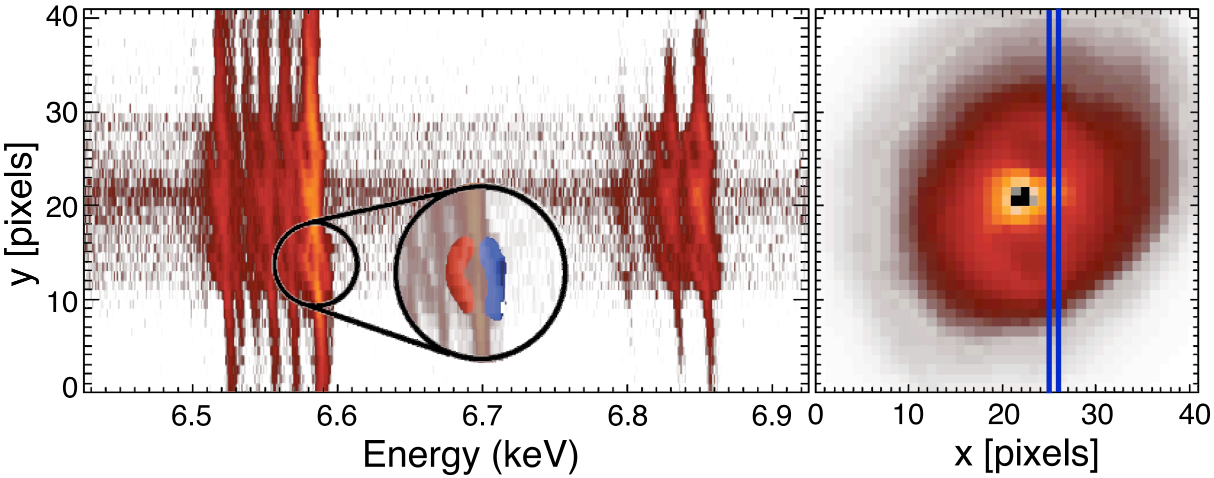
“Over the next decade it will be a high priority to extend such precision mapping over cosmic time: to have, in effect, a 13-billion-year-long movie that traces the buildup of structure since the universe first became transparent to light. This can be done by using … X-ray surveys that reveal the distribution of the hot gas found in groups and clusters of galaxies.” (p.52)





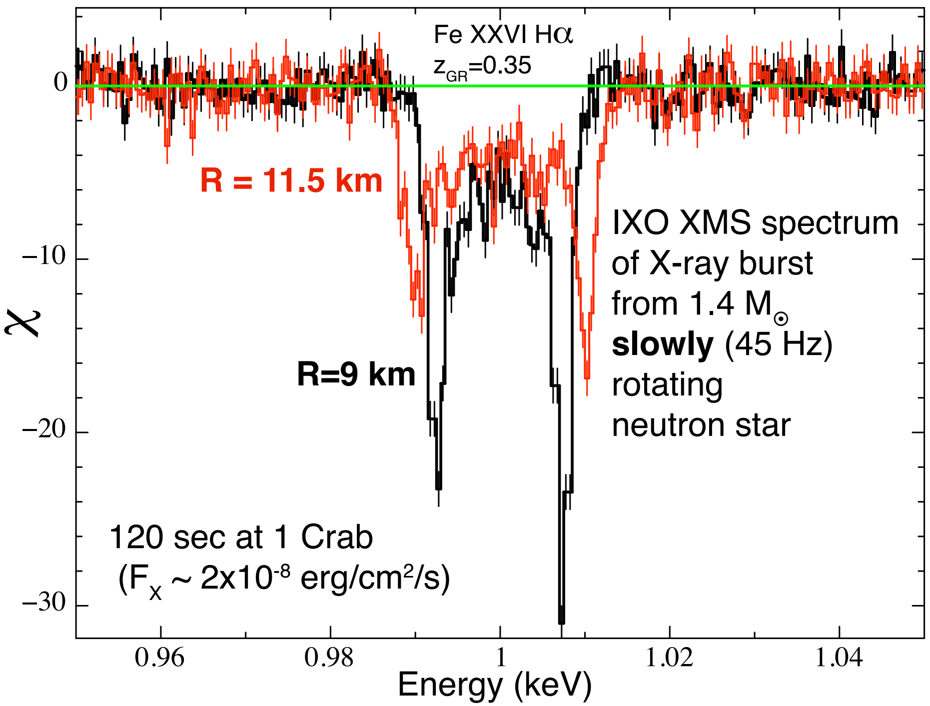
What is the connection between supermassive black hole formation and evolution of large scale structure (i.e., cosmic feedback)?

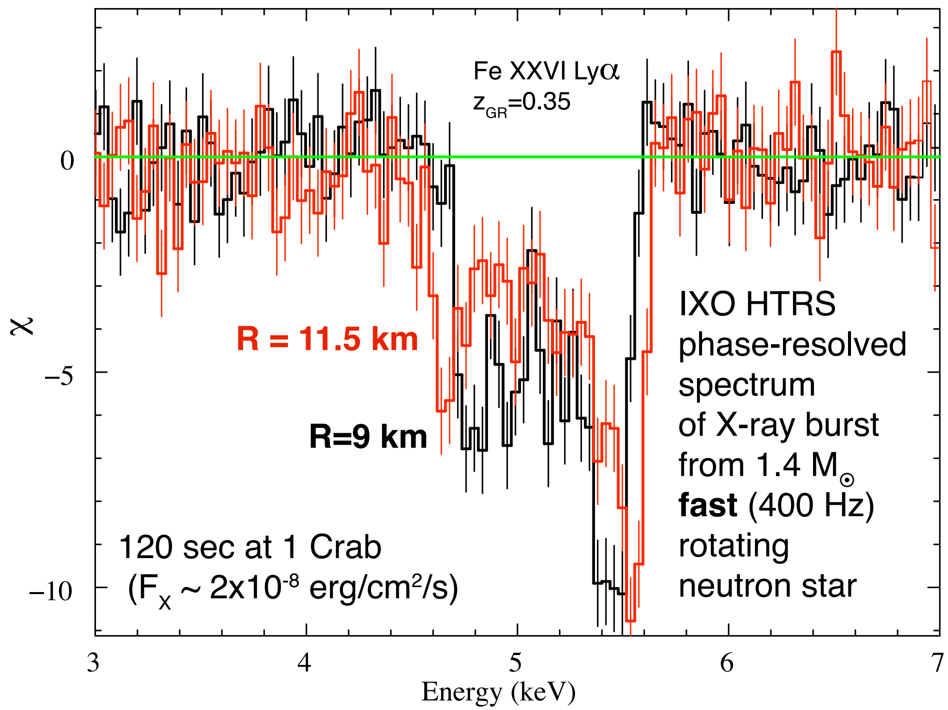
"The Chandra and XMM-Newton X-ray observatories are being used to measure the environmental impact of energy injection from the black hole and also to give us a glimpse of matter as it swirls inexorably inward toward the event horizon at the very edge of the black hole. Future more powerful X-ray observatories will provide detailed maps of these processes, so that we can directly witness the accretion of matter (by which black holes grow) and can also understand the impact they have on the lives of their "host" galaxy." (p.59)



How does matter behave at very high density?

"Neutron stars can be thought of as giant atomic nuclei, and understanding how their radii change with the mass is of fundamental importance for nuclear physics and complements what is being learned from collisions of heavy ions. These astronomical measurements are becoming possible using radio and X-ray telescopes." (p.204)

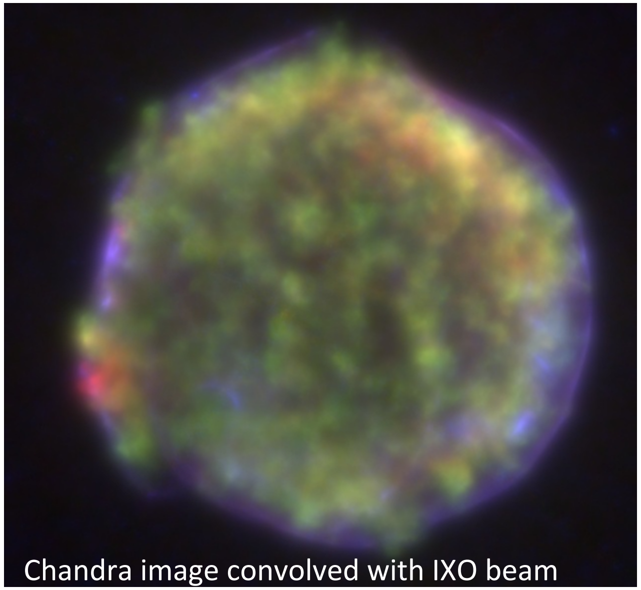


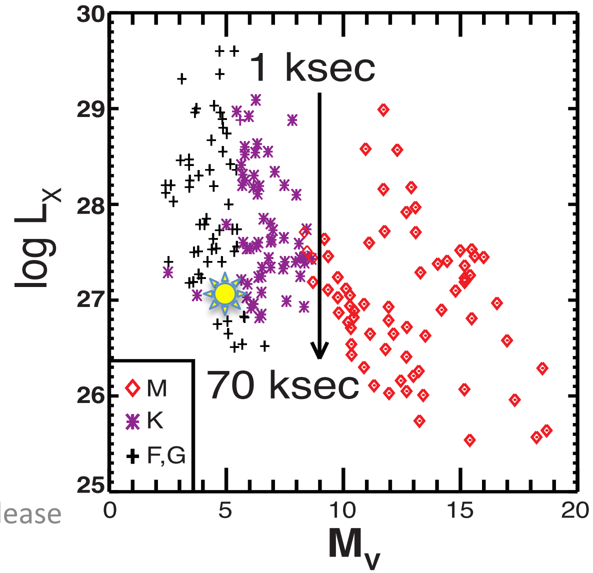


Multiple techniques available, including (left) direct measurement of M/R from gravitational redshift for slow rotators, and (right) determining R by resolving the Doppler line profile for fast rotators.

Other Topics

- "…X-ray observations of clusters of galaxies will allow us to measure the neutrino mass or push its upper limit downward by an order of magnitude…" (p.74)
- "…X-ray, gamma-ray, and radio observations of these stellar remnants will … reveal the accelerator dynamics of the stellar ghosts." (p.66)
- "…[S]tudy the structure and strength of magnetic fields on the surfaces of nearby stars, and changes in the magnetic fields can be diagnosed with X-rays." (p.64)


Chandra image convolved with IXO beam



Descopes

“The panel therefore evaluated the impact on some key science programs of a 30 percent reduction in mirror area—a substantial mass reduction—and a spatial resolution of only 10 arcseconds, the state of the art. It concluded that the ability of the mission to meet its primary science goals would not be heavily compromised; degradation would be mostly quantitative rather than qualitative.” (p287)

The IXO-team evaluation of a 30% mirror reduction and/or removal of outer portion of XMS. Although some science would be lost, none of the losses to the core science with the lost effective area were deemed to be of “major” significance since they could be recovered with more observing time.

	Downscope Options	
	Mirror Area	XMS FOV
Matter Under Extreme Conditions (nominally 12% of mission)		
Strong Gravity	Yellow	Green
Neutron Star Equation of State	Yellow	Green
QED Tests from Magnetars	Green	Green
Black Hole Evolution (nominally 20%)		
Deep Survey	Yellow	Green
SMBH Spin Survey	Blue	Green
Stellar-Mass Spin	Yellow	Green
Large Scale Structure (nominally 37%)		
Cosmic Feedback from SMBHs	Blue	Yellow
Galaxy Cluster Evolution	Yellow	Red
Cosmology	Yellow	Red
Cosmic Web of Baryons	Green	Blue
Life Cycles of Matter (nominally 14%)		
Starburst Galaxies	Blue	Blue
Local Group & ISM Mapping	Blue	Blue
ISM Gas & Dust - Composition	Green	Green
Formation of the Elements	Blue	Red
Stellar flares	Yellow	Green
Stellar atmospheres	Blue	Green
Protoplanetary Disks	Yellow	Blue
Observatory Science (nominally 17%)	Red	Red

Legend

- Green: Minimal or no impact
- Blue: Linear impact with time
- Yellow: Worse than linear / some science loss inevitable
- Red: Major impact / significant science losses inevitable

Conclusions: The Decadal View of IXO

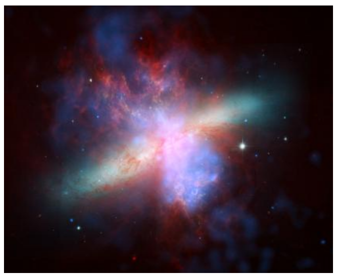
- "Large-aperture, time-resolved, high-resolution X-ray spectroscopy is required for future progress on all of these fronts, and this is what IXO can deliver." (p. 214)

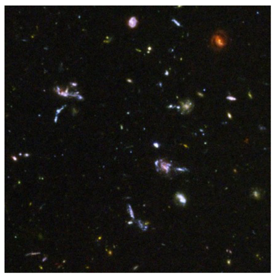
- "The key component of the IXO focal plane is an X-ray microcalorimeter spectrometer—a 40 × 40 array of transition-edge sensors covering several arcminutes of sky that measure X-ray energy with an accuracy of roughly 1 part per 1,000 (depending on energy)." (p. 214)

Backup

2010 Decadal Science Plan (for X-rays)

Cosmic Dawn

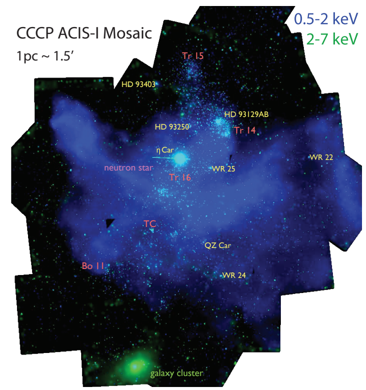




- Use GSMT and IXO to monitor the exchange of gas between the galaxies and the surrounding IGM.
- Study the rate of formation and growth of black holes in the nuclei of young galaxies using IXO and WFIRST.

(p.192)

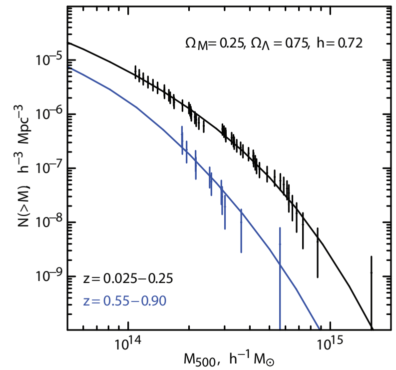
New Worlds

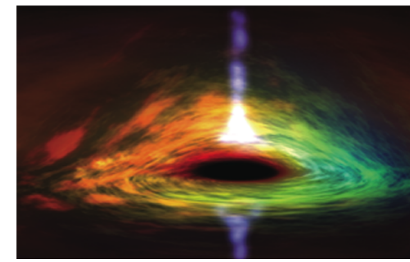


- Assess habitability by using IXO to characterize the frequency and intensity of flares on host stars.

(p.196)

Physics of the Universe





- Find and study distant clusters of galaxies to measure the rate of growth of structure in the universe using IXO and microwave background observations.
- Observe x-rays from gas orbiting close to the event horizon of black holes using IXO and relativistic jets produced by black holes using ACTA.

(p.200)

2010 Decadal *Origin* Questions

(p. 46)

- How did the universe begin?
- What were the first objects to light up the universe and when did they do it?
- **How do cosmic structures form and evolve?**
- **What are the connections between dark and luminous matter?**
- What is the fossil record of galaxy assembly and evolution from the first stars to the present?
- **How do stars form?**
- **How do circumstellar disks evolve** and form planetary systems?

2010 Decadal *Cosmic Order* Questions

(p. 57)

- **How do baryons cycle in and out of galaxies, and what do they do while they are there?**
- **What are the flows of matter and energy in the circumgalactic medium?**
- **What controls the mass-energy-chemical cycles within galaxies?**
- **How do black holes grow, radiate, and influence their surroundings?**
- **How do rotation and magnetic fields affect stars?**
- **How do the lives of massive stars end?**
- How diverse are planetary systems?
- **What are the progenitors of Type Ia Sne and how do they explode?**
- Do habitable worlds exist around other stars, and can we identify the telltale signs of life on an exoplanet?

2010 Decadal *Frontiers of Knowledge* Questions

(p. 68)

- **Why is the Universe accelerating?**
- **What is dark matter?**
- **What are the properties of neutrinos?**
- **What controls the mass, radius, and spin of compact stellar remnants?**

IXO’s Observing Plan

Table 1-1. Science Flowdown Matrix

	Target Information				Observation Requirement													Instrum
Science Topic	Typical Target	# of Ptgs	Src Size	Typical Flux	Analysis	S/N required	Obs Time	Abs Ast	FOV	Band-pass	PSF HPD	Mirror Effective Area Rqmt (sq m)			Energy Res Rqmt		Rel Timing	Primary (Second)
			arcmin	erg/cm²/s			Msec	arc-sec	arc-min	keV	arcsec	1.25 keV	6 keV	30 keV	FWHM(eV)	@ E (keV)	μsec	
Strong Gravity	MCG-6-30-15	20	point	5×10^{-11}	spectra	10	8	N/A	N/A	1-40	N/A	1.5	***0.65***	0.015	2.5	6	N/A	XMS (WFI/HXI)
SMBH Spin Survey	NGC 4051	200	point	10^{-12}	spectra	5-10/bin	10	N/A	N/A	***1-40***	N/A	1	0.65	***0.015***	***1000***	***30***	N/A	WFI/HXI (XMS)
	MCG-6-30-15	10	point	5×10^{-11}	polari-zation	***1% MDP***		N/A	N/A	2-10	N/A	2.5	0.5	N/A	1200	6	N/A	XPOL
Neutron Star EoS	4U1636-536	15	point	10^{-8}	spectra	20/bin	5.5	N/A	N/A	0.3-10	N/A	3	0.6	N/A	***150***	***0.3-6***	***10***	HTRS
Growth of SMBH	CDF-S	38	point	3×10^{-17}	imaging spectra	5 at flux limit	10	***1***	***18 dia***	0.3-2	***5***	***3***	0.65	0.015	150	1	N/A	WFI/HXI (XMS)
Clusters / Feedback	z=0.1-2 cluster	250	2-18	10^{-13}	imaging spectra	50 at flux limit	14	N/A	***2 × 2***	0.3-40	***5***	***3***	0.65	0.015	***2.5***	***6***	N/A	XMS (WFI/HXI)
Cosm-ology	z=1-2 cluster	1000	3	5×10^{-14}	image, spectra	2000 cts/obj	15	10	***5 × 5***	0.3-7	10	1	0.1	N/A	***10***	***6***	N/A	XMS (WFI/HXI)
Cosmic Web of Baryons	QSO B1426 +428	30	point	10^{-11}	spectra	12/bin	15	N/A	N/A	***0.3-1***	5	N/A	N/A	N/A	***0.1***	***0.3***	N/A	XGS (XMS)

Total time: 77.5 Msec. With 85% efficiency, achievable in 3 year mission or ~60% of a 5 year mission.