International X-ray Observatory (IXO)

Science with the International X-ray Observatory

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Exploring The Hot Universe with IXO

The International X-Ray Observatory, a joint NASA-ESA-JAXA effort, is a next generation X-ray telescope that will answer many fundamental questions in contemporary astrophysics under three main science themes:

1) Black Holes and Matter Under Extreme Conditions

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

3) Life Cycles of Matter and Energy

IXO is a guest observer, general-use observatory for the entire astronomical community. The scientific problems that IXO will ultimately address will be driven by community proposals.

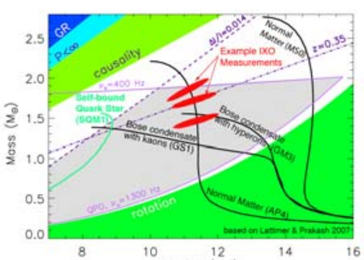
To address these questions, IXO will employ optics with 20 times more collecting area at 1 keV than any previous X-ray telescope. The focal plane instruments will deliver up to **100-fold increase in effective area for high resolution spectroscopy** from 0.3-10 keV, deep spectral imaging from 0.1-40 keV over a wide field of view, unprecedented polarimetric sensitivity, and microsecond spectroscopic timing with high count rate capability.

The Hot Universe

The X-ray sky is dominated by two kinds of sources: accreting supermassive black holes (SMBH) in galactic nuclei, comparable in size to the Solar System, and clusters of galaxies, more than a million lightyears across. What is perhaps most remarkable is the discovery that these two are inextricably linked. The energy liberated by growing black holes influences the infall of gas in galaxies and clusters, while some analogous process, still poorly understood, ties the growth of black hole mass to a fixed fraction of its host galaxy's bulge – a two-way connection called "feedback." On the smallest scales, **X-rays provide unique electromagnetic spectral signatures from the regions of strong gravity near black holes and neutron stars.**

The principal aims of IXO are to study the extreme environment and evolution of black holes, the energetics and dynamics of the hot gas in large cosmic structures and the connection between the two phenomena. IXO will also constrain the equation of state of neutron stars and track the dynamical and compositional evolution of interstellar and intergalactic matter throughout the epoch of galaxy growth. IXO will also enable revolutionary studies of virtually every class of astronomical object and is sure to make serendipitous discoveries, characteristic of all major advances in astronomical capabilities.

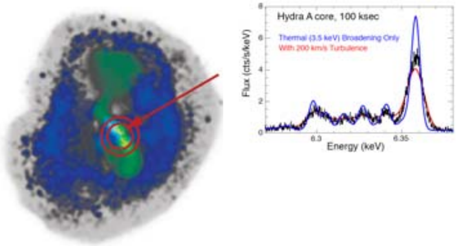
Matter under Extreme Conditions



What is the equation of state of matter at the supra-nuclear densities in neutron stars? This is a regime in which theory has significant uncertainties, and beyond testing on Earth. The high resolution spectroscopy and energy-resolved fast timing allowed by IXO will measure the mass and radius for a few dozen neutron stars in Low-Mass X-ray Binaries (The Behavior of Matter Under Extreme Conditions, Paerels et al. 2009). The figure shows three such possible IXO measurements (red) of neutron star masses and radii that would distinguish between models in the allowed (gray) region.

Black Holes and Feedback

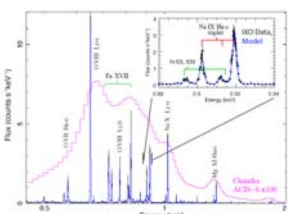
There are two primary feedback mechanisms: 1) The radiative output of the black hole can heat the surrounding gas and dust, and drive it via radiation pressure; and 2) If significant AGN power emerges in winds or jets, mechanical heating and pressure can provide the link between the SMBH and the surrounding material (Fundamental Accretion and Ejection Astrophysics, Miller et al. 2009). The high spectral resolution and imaging capability of IXO will provide the necessary spectral diagnostics for studying and distinguishing between both forms of feedback (Cosmic Feedback from Massive Black Holes, Fabian et al. 2009).



IXO will study this feedback, such a the strong jets found in cluster AGN shown in this Chandra/VLA image of Hydra A. AGN have a profound effect on the growth of structure in the Universe and IXO's non-dispersive spectral/spatial measurements with 2.5 eV spectral resolution (inset spectrum) will determine the temperature, ionization state, and velocities in the intra-cluster medium, catching "feedback" processes in action. The overlaid circles show show 100-150 kpc extraction regions. (Image adapted from Wise et al. 2007).

Life Cycles of Matter and Energy

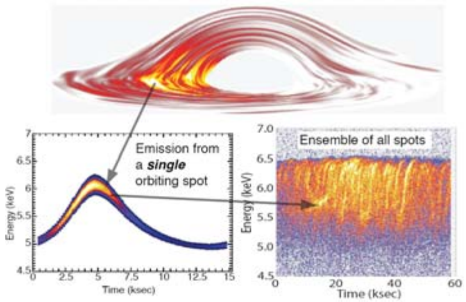
The leap in effective area and high-resolution spectroscopic capabilities of IXO will enable major advances in every field of astrophysics. The dispersal of metals from galaxies can occur as starbursts drive out hot gas that is both heated and enriched by supernovae. This hot gas has been detected with current X-ray missions, but IXO is needed to measure the actual hot gas flow velocity using high-throughput spectroscopic imaging to determine the galactic wind properties and their effects (Starburst Galaxies: Outflows of Metals and Energy into the IGM, Strickland et al. 2009).



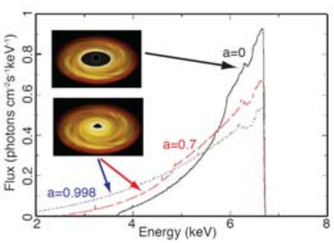
IXO high resolution X-ray spectra (blue) show the metal-enriched hot gas outflowing from a starburst galaxy, a part of the feedback process unresolvable with current X-ray CCD data (magenta).

Extreme Conditions: Black Holes

• What is the structure of space-time near the event horizon? The strongest gravitational fields in the Universe occur around black holes, where the extreme effects of General Relativity (GR) are evident in the form of gravitational redshift, light bending, and frame dragging. The spectral signatures needed to determine the physics of the accretion flow into the black hole themselves are only found in X-rays.



The image at top shows the disk around a black hole as seen in the FeKα line. Hot spots in the disk trace nearly 'test particle' orbits. The two panels at the bottom show the arcs traced by these hot spots in the time/energy plane, the left panel showing the model of emission from a single hot spot, and the right panel showing simulated IXO data of the ensemble. GR makes specific predictions for the form of these arcs, and the ensemble of arcs determines the mass and spin of the black hole and the inclination of the accretion disk. IXO will be the first observatory with sufficient area at FeKα to allow these time-resolved measurements.



Are black holes in the centers of galaxies spinning? General relativitstic effects created by rotating black holes broaden and redshift Fe Ka lines, allowing measurements of the intrinsic spin of the black hole. At low spin (a=0) the inner edge of the disk is truncated at larger radius and the profile is less broadened than with high spin (a=0.998)

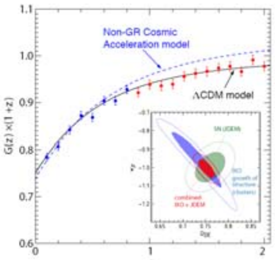
Key Performance Requirements

Parameter	Value	Science Driver	Instruments
Mirror Effective Area	3 m^2 @ 1.25 keV 0.65 m^2 @ 6 keV 150 cm^2 @ 30 keV	Black hole evolution Strong gravity Strong gravity	
Spectral Resolution (FWHM), over FOV, over band	ΔE = 2.5 eV, 2 × 2′, 10 eV, 5 × 5′, (0.3–7 keV) ΔE = 150 eV, 18′, (0.1–15 keV) $E/\Delta E$ = 3000, (0.3–1 keV)	Black hole evolution; Cluster structure Early black holes/BH evolution Missing baryons	XMS WFI XGS
Angular Resolution	≤ 5 arc sec HPD (0.1–7 keV) 30 arc sec HPD (7–40 keV)	Cosmic feedback Strong gravity	XMS, WFI WXI
Count Rate	10^6 cps with > 90% throughput.	Strong gravity, EOS	HTRS
Polarimetry	1% MDP on 1mCrab, 100 ksec, 2–6 keV	Strong gravity	XPOL

Large Scale Structure

X-ray observations reveal the largest bound structures in the Universe and their evolution on cosmological timescales.The dominant form of baryons in these clusters of galaxies is hot (T > 10^7 K) gas, which can be probed only in X-rays. IXO's unprecedented capabilities will enable us to confront the question of: **How did large scale structure evolve?**

The mystery of dark energy can be studied by observing either the expansion history of the universe or the growth of matter density perturbations. X-ray observations of galaxy clusters with IXO will provide both tests Cosmological Studies with a Large-Area X-ray Telescope, Vikhlinin et al. 2009) and, thus, will be a important contribution to other planned cosmological experiments. The combination of geometric and structure growth approaches dramatically improves parameter constraints and also tests whether the cosmic acceleration is caused by modifications to GR on large scales. X-ray observations are already unrivaled in terms of providing the mass information for individual clusters. IXO will make the further advance required using its high-resolution spectroscopic imaging capabilities.

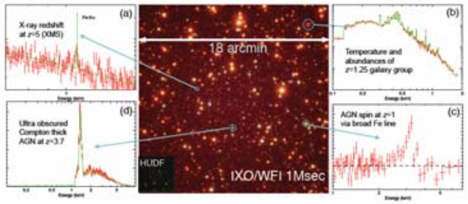


The growth of structure as a function of z for simulated observations with IXO of 2000 clusters at z=0-2. The dashed line shows the growth expected in one of the non-GR models of cosmic acceleration. The inset illustrates improvements in the dark energy equation of state constraints from combination of distance-redshift and structure growth methods.

Galaxy and Black Hole Evolution

Extragalactic astronomy explores the dawn of the modern Universe when the first galaxies formed. Future observatories, including JWST, ALMA and 30m-class ground-based telescopes will intensively observe the starlight from the first galaxies. IXO will play a crucial role in this broad investigation by using the accretion light from the first SMBHs (10^7-10^9 M). SMBHs are now known to be an integral part of typical massive galaxies. X-rays can reveal the conditions in the immediate vicinity of the first SMBHs, and they can also probe the broader environment via absorption studies.

A key design goal of IXO is to chart "The Growth of Supermassive Black Holes Over Cosmic Time" (Nandra et al. 2009). This requires a combination of large effective area (3 sq. m at 1 keV), good angular resolution (5 arc sec) and wide field of view (18 arc min) in the X-ray band, allowing IXO to reach Chandra's limiting sensitivity 20× faster. This will enable the first full characterization of the population of typical accreting SMBHs at z~7, and push the discovery space out to z~10.



The above WFI simulation of the Chandra Deep Field South with Hubble Ultra Deep Field (HUDF) in inset. Simulated spectra of various sources are shown, illustrating IXO's ability (clockwise from top left) to: a) determine redshift autonomously in the X-ray band, b) determine temperatures and abundances even for low luminosity groups to z>1, c) make spin measurements of AGN to a similar redshift, and d) uncover the most heavily obscured, Compton-thick AGN.