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 I XO

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 phase 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.

12/14/11
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### Comparing the Decadal to the IXO Science Case

<table>
<thead>
<tr>
<th>Topics</th>
<th>Typical Targets</th>
<th>Length</th>
<th># Obs</th>
<th>Total Time</th>
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<tr>
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<td>2 Tycho SNR</td>
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<tr>
<td><strong>Total</strong></td>
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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

If GR is correct, the measured spin and mass will be independent of the bright spot’s radius

GR incorrect

GR correct

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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)
“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.
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 $40 \times 40$ 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.

New Worlds

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

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.192)  
(p.196)  
(p.200)
2010 Decadal *Origin* Questions

- 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

- 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

• 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

<table>
<thead>
<tr>
<th>Science Topic</th>
<th>Target Information</th>
<th>Observation Requirement</th>
<th>Instrument</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Typical Target</td>
<td>S/N required</td>
<td>Instrum</td>
</tr>
<tr>
<td></td>
<td># of Pts</td>
<td>Src Size</td>
<td>Typical Flux</td>
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<tr>
<td><strong>Strong Gravity</strong></td>
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<td>10</td>
<td>8</td>
</tr>
<tr>
<td><strong>SMBH Spin Survey</strong></td>
<td>NGC 4051</td>
<td>10</td>
<td>5-10/bin</td>
</tr>
<tr>
<td></td>
<td>MCG-6-30-15</td>
<td>10</td>
<td>5×10⁻¹¹</td>
</tr>
<tr>
<td><strong>Neutron Star EoS</strong></td>
<td>4U1636-536</td>
<td>15</td>
<td>20/bin</td>
</tr>
<tr>
<td><strong>Growth of SMBH</strong></td>
<td>CDF-S</td>
<td>38</td>
<td>3×10⁻¹⁷</td>
</tr>
<tr>
<td><strong>Clusters / Feedback</strong></td>
<td>z=0.1-2 cluster</td>
<td>250</td>
<td>2-18</td>
</tr>
<tr>
<td><strong>Cosmology</strong></td>
<td>z=1-2 cluster</td>
<td>1000</td>
<td>3</td>
</tr>
<tr>
<td><strong>Cosmic Web of Baryons</strong></td>
<td>QSO B1426+428</td>
<td>30</td>
<td>10⁻¹¹</td>
</tr>
</tbody>
</table>

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