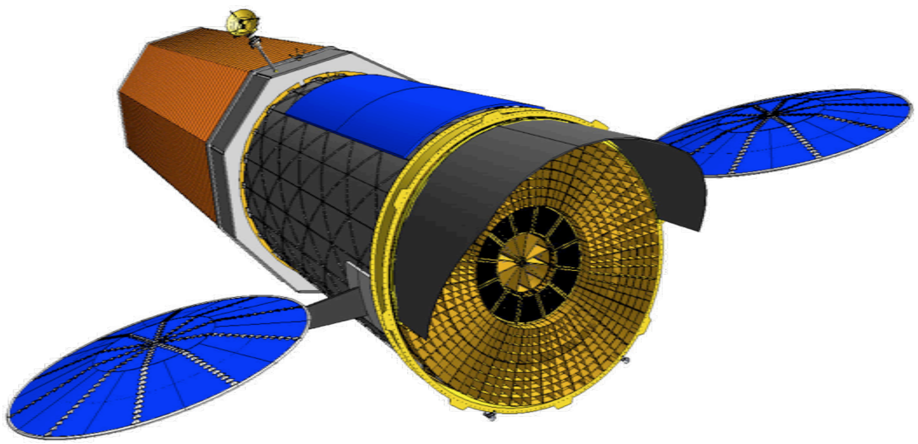
The International X-ray Observatory IXO



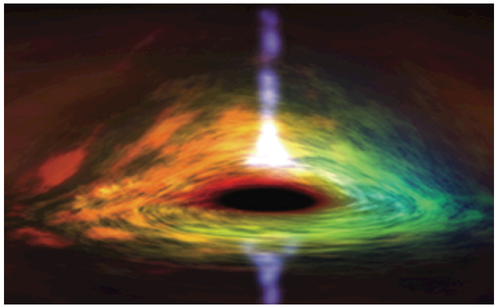
Nicholas White

Arvind Parmar

Hideyo Kunieda

For the ESA-JAXA-NASA IXO Team

IXO Science Objectives



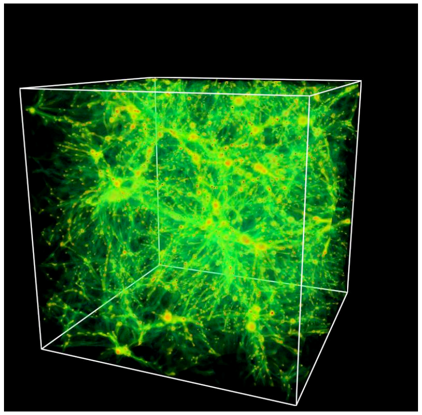
Black Hole growth and matter under extreme conditions

How do super-massive Black Holes grow and evolve?

What is the behavior of matter orbiting close to a Black Hole event horizons and does it follow the predictions of GR?

What is the equation of state of matter in Neutron Stars?

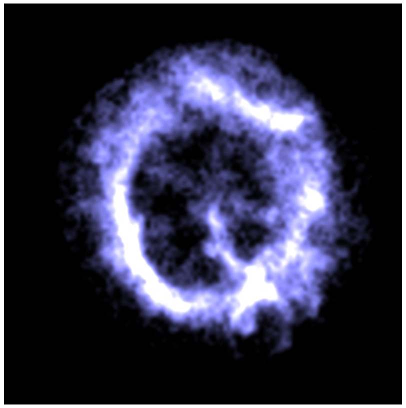
Galaxy Clusters, Galaxy Formation and Cosmic Feedback



What are the processes by which galaxy clusters evolve and how do clusters constrain the nature of Dark Matter and Dark Energy?

How does Cosmic Feedback work and influence galaxy formation?

Are the missing baryons in the local Universe in the Cosmic Web and if so, how were they heated and infused with metals?



The life cycles of matter and energy

How do supernovae explode and create the iron group elements?

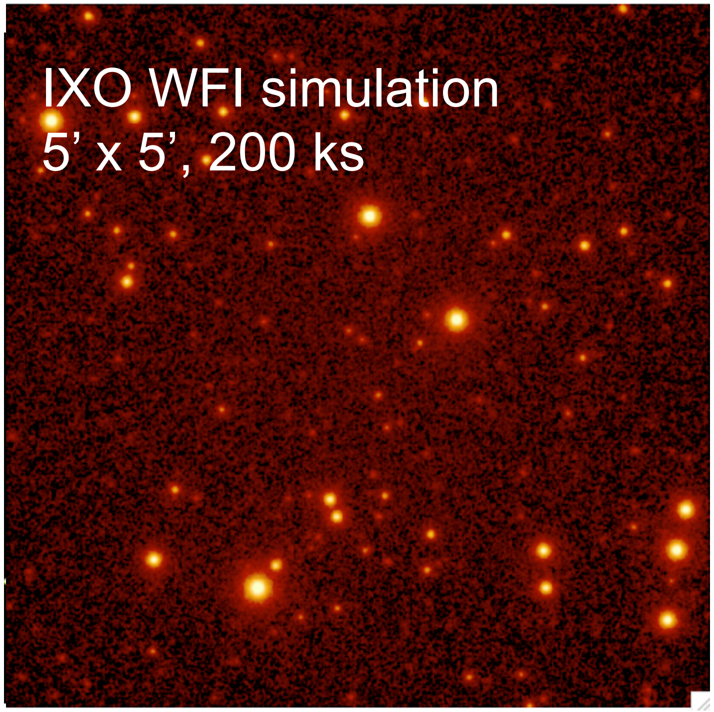
How do high energy processes affect planetary formation and habitability?

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

Key Performance Requirements

Mirror Effective Area	3 m^2 @1.25 keV 0.65 m^2 @ 6 keV 150 cm^2 @ 30 keV	Black hole evolution, large scale structure, cosmic feedback, EOS Strong gravity, EOS Cosmic acceleration, strong gravity
Spectral Resolution/FOV E = 0.3 – 7 keV E = 0.3 –1 keV	ΔE = 2.5 eV within 2 arc min 10 eV within 5 arc min < 150 eV within 18 arc min E/ΔE = 3000 from with an area of 1,000 cm^2	Black Hole evolution, Large scale structure Missing baryons using tens of AGN
Mirror Angular Resolution	≤5 arc sec HPD <7 keV ≤30 arc sec HPD > 7 keV	Large scale structure, cosmic feedback, black hole evolution, missing baryons Black hole evolution
Count Rate	1 Crab with >90% throughput	Strong gravity, EOS
Polarimetry	1% MDP on 1 mCrab in 100 ksec (2 - 6 keV)	AGN geometry, strong gravity
Astrometry	1 arcsec at 3σ confidence	Black hole evolution
Absolute Timing	50 μsec	Neutron star studies

How do Supermassive Black Holes Grow and Evolve?

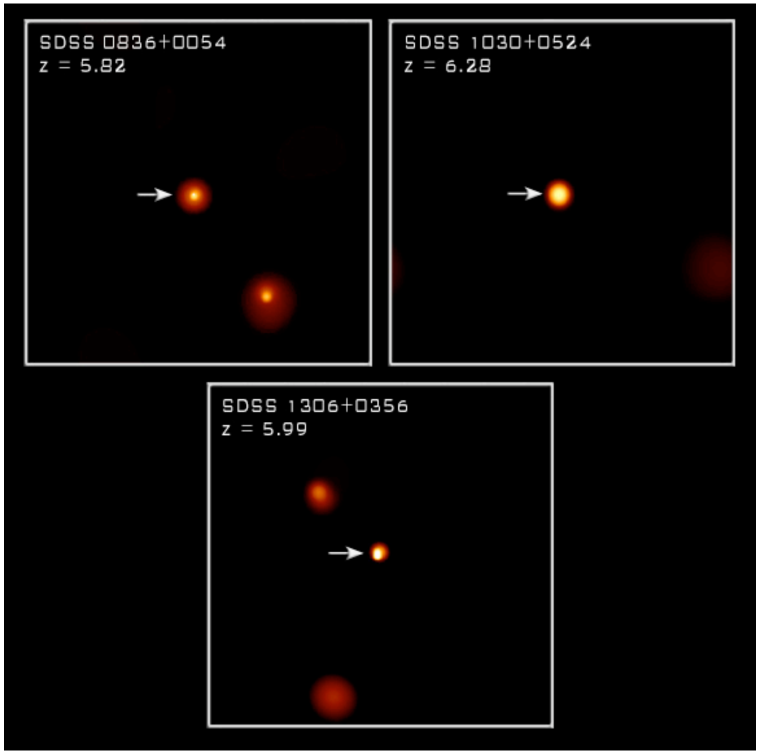


20 day exposure with Chandra will be a routine observation for IXO

- Chandra and XMM-Newton deep fields reveal that super-massive Black Holes are common throughout the Universe and that X-ray observations are a powerful tracer of their evolution
- Most of these sources have <30 detected X-ray counts even in 20-day ultradeep X-ray surveys
- IXO will greatly expand our view of the accretion light of the high-redshift Universe

IXO will bring a factor of 10 gain in telescope aperture combined with next generation instrument technology to realize a quantum leap in capability

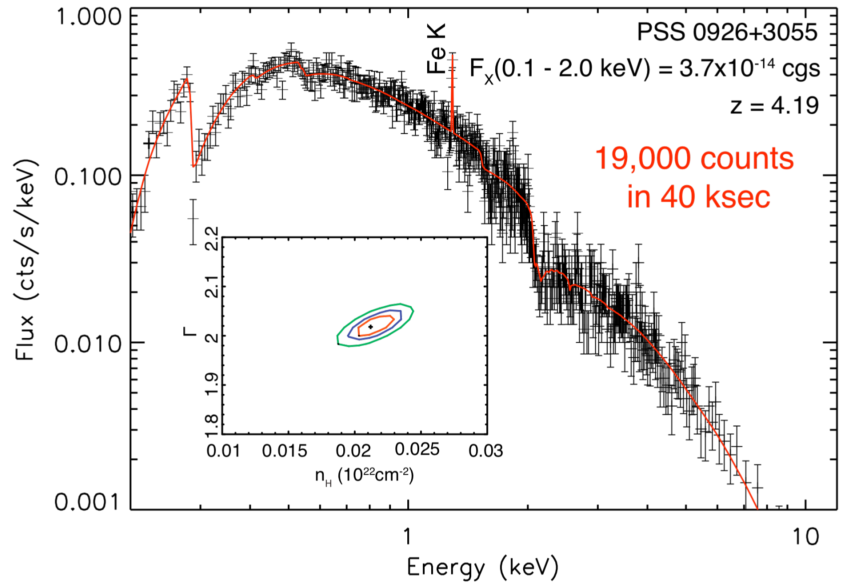
How do AGN evolve at high redshift?



Chandra has detected X-ray emission from ~100 quasars at z > 4

Flux is beyond grasp of XMM-Newton and Chandra high resolution spectrometers, but well within the capabilities of IXO

IXO Simulation (40 ks)

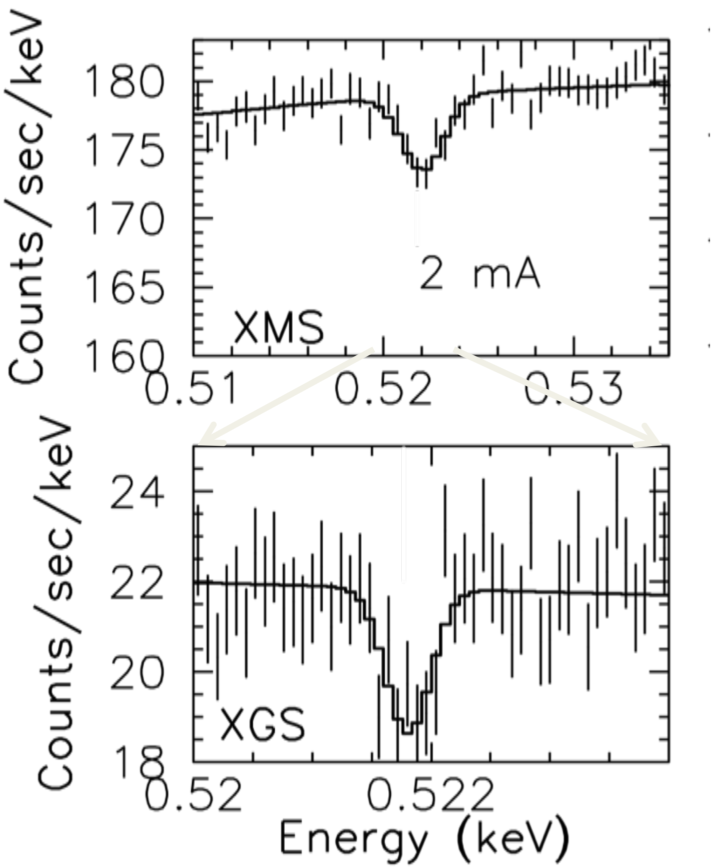


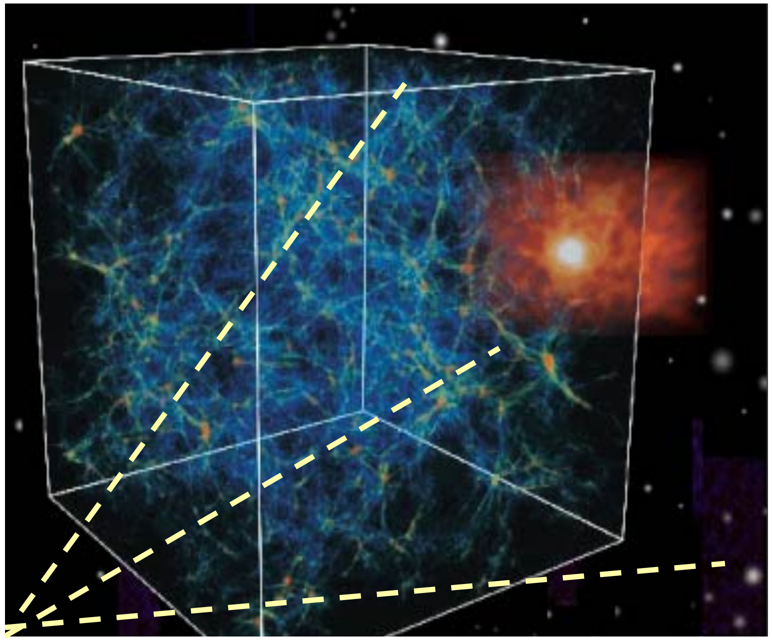
X-ray spectra can give:

- redshifts!
- disk ionization
- constraint of L/L_{Edd}

Are the missing baryons in the local Universe in the Cosmic Web and if so, how were they heated and infused with metals?

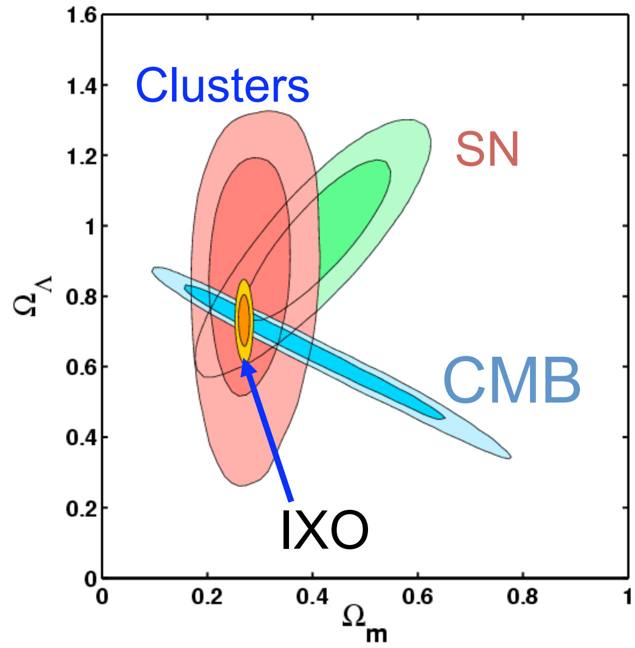
40% of the Baryons in the local Universe are predicted to be caught in a hot plasma trapped in the warm-hot intergalactic medium (WHIM)





IXO will detect ionized gas in the hot IGM medium via OVII absorption lines in spectra of many background AGN to detect the missing Baryons and characterize them

How do relaxed clusters constrain Dark Energy?



IXO gives a factor of ten improvement

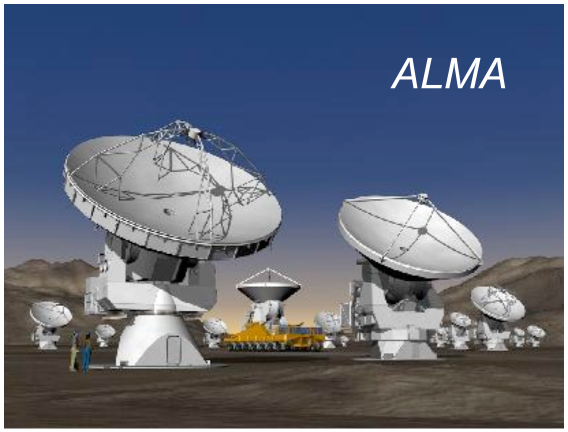
In the terms of the Dark Energy Task Force Figure of Merit this is a Stage IV result

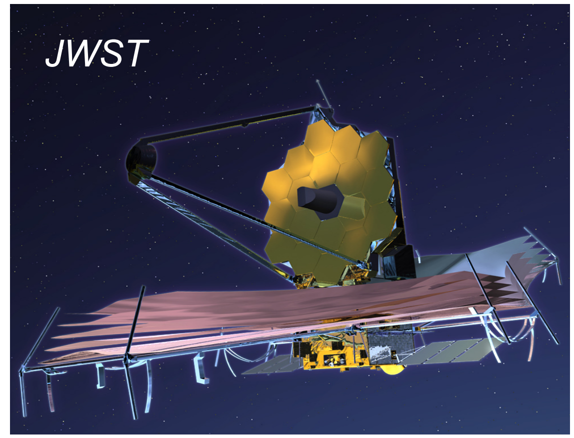
Rapetti, Allen et al 2006 (Astro-ph/0608009)

- Using the gas mass fraction as a standard ruler measures f_{gas} to 5% (or better) for each of 500 galaxy clusters to give Ω_M=0.300±0.007, Ω_Λ=0.700±0.047
- 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

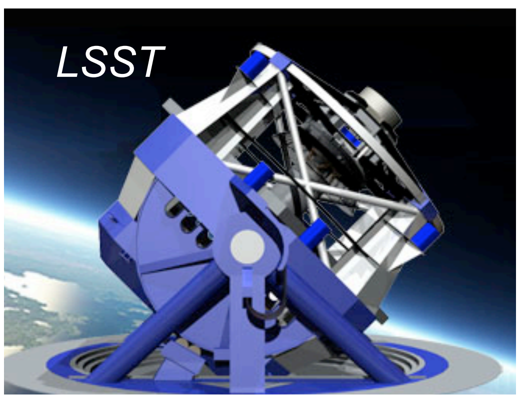
IXO: A future astrophysics great observatory

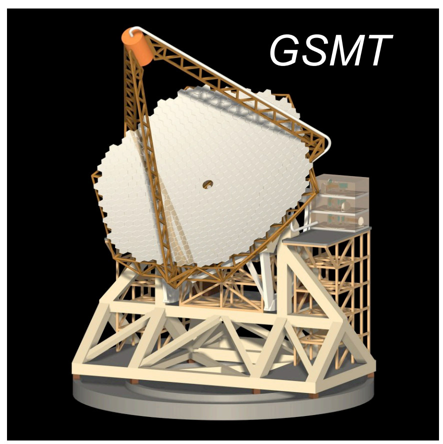
Sub-mm

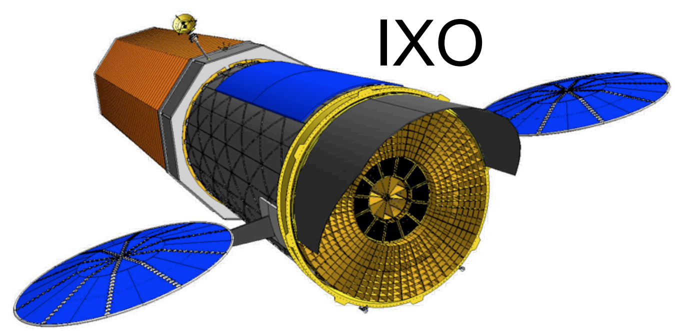




IR







Optical

X-ray

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

Mission Payload

Flight Mirror Assembly (FMA)

- Highly nested grazing incidence optics

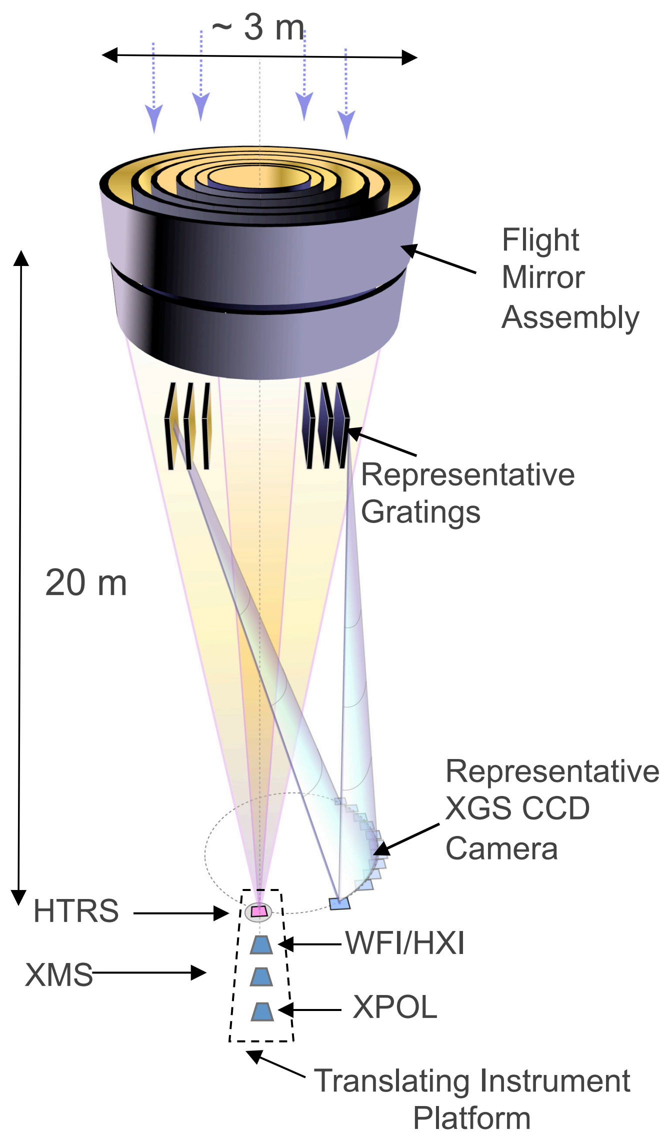
Spectroscopy Instruments

- X-ray Micro-calorimeter Spectrometer (XMS)
- X-ray Grating Spectrometer (XGS)

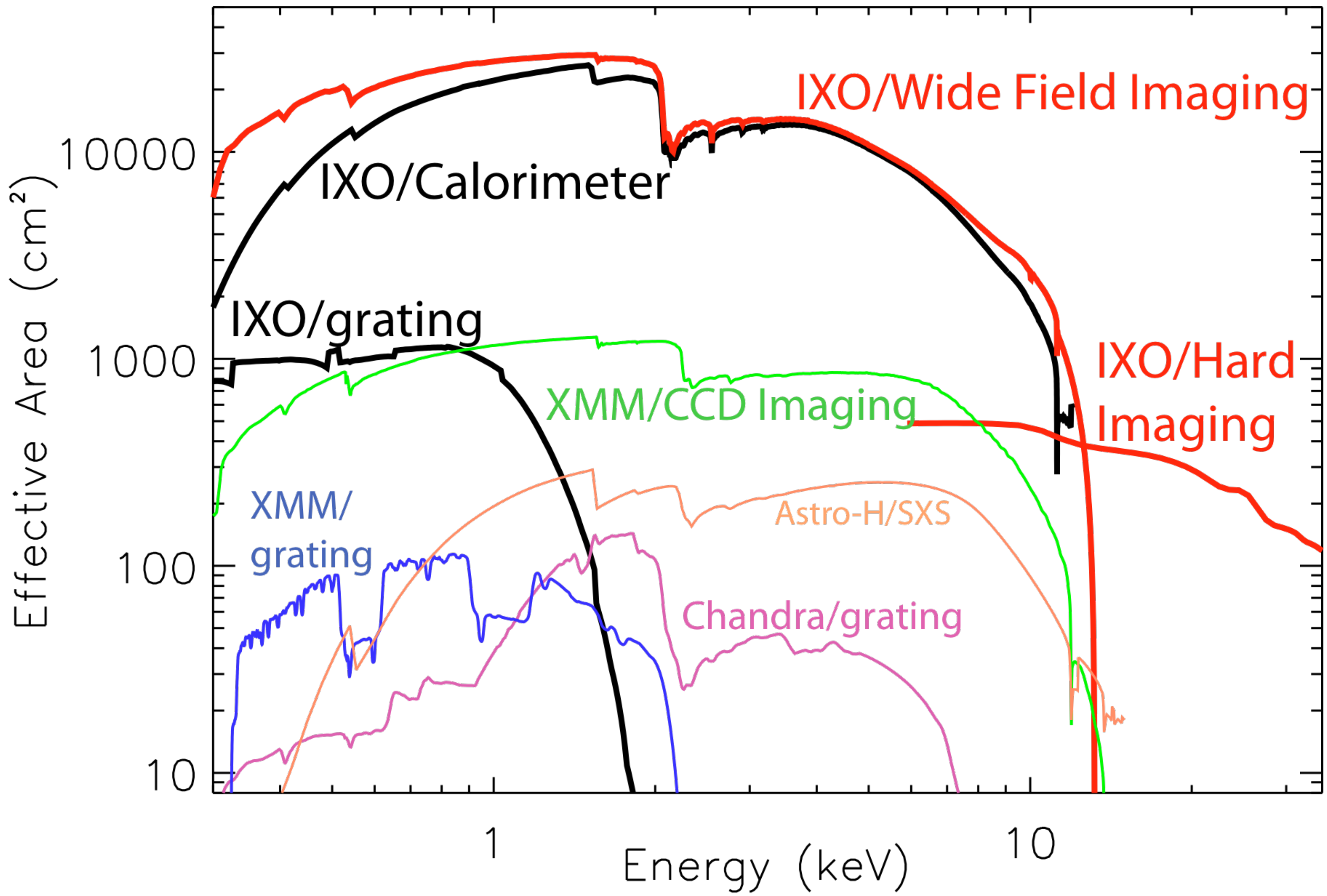
Imaging, Timing and Polarimetry Instruments

- Wide Field Imager (WFI) and Hard X-ray Imager (HXI)
- X-ray Polarimeter (XPOL)
- High Time Resolution Spectrometer (HTRS)

XMS, WFI/HXI, XPOL and HTRS observe one at a time by being inserted into focal plane via a Translating Instrument Platform

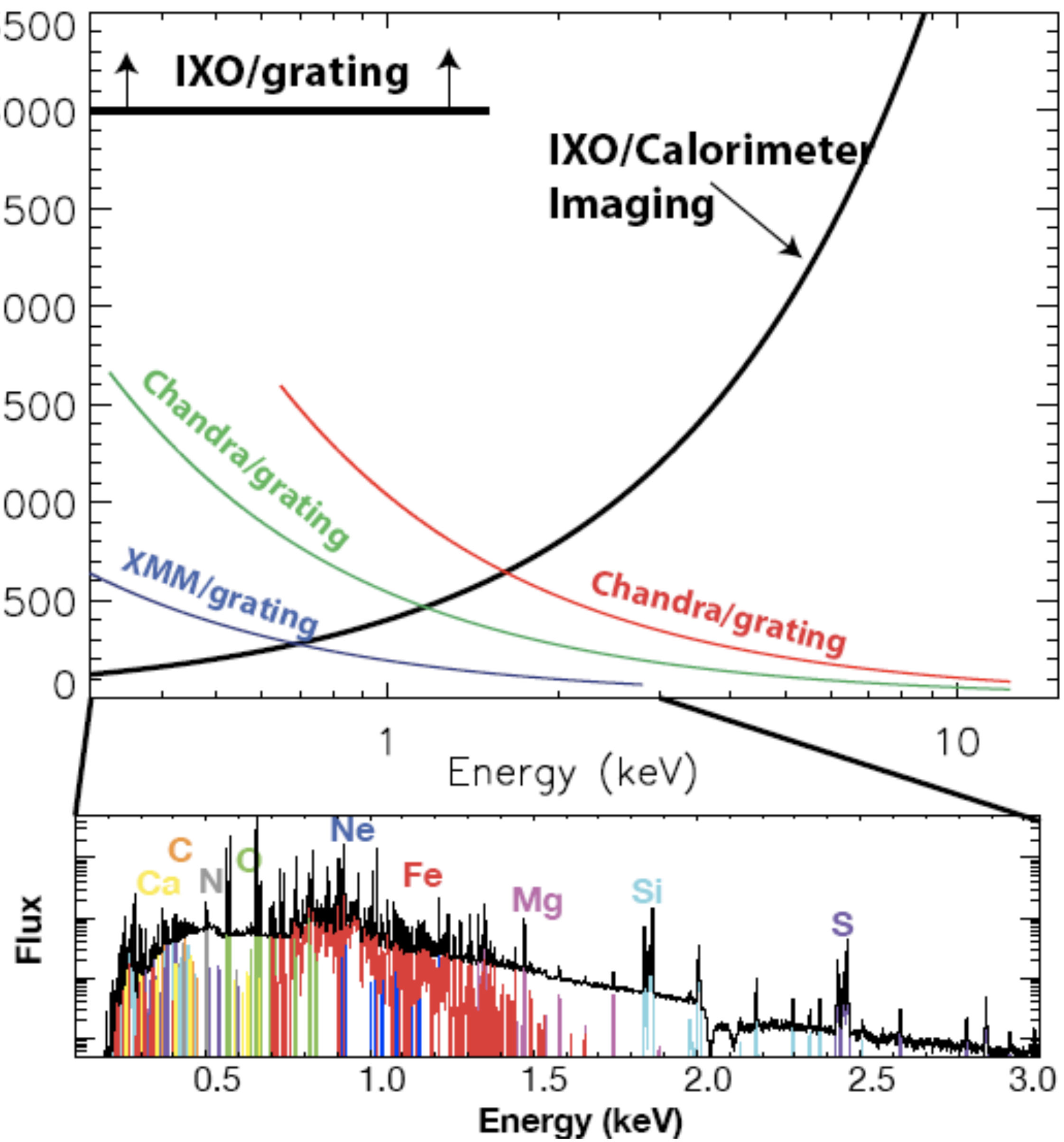


Effective area comparison



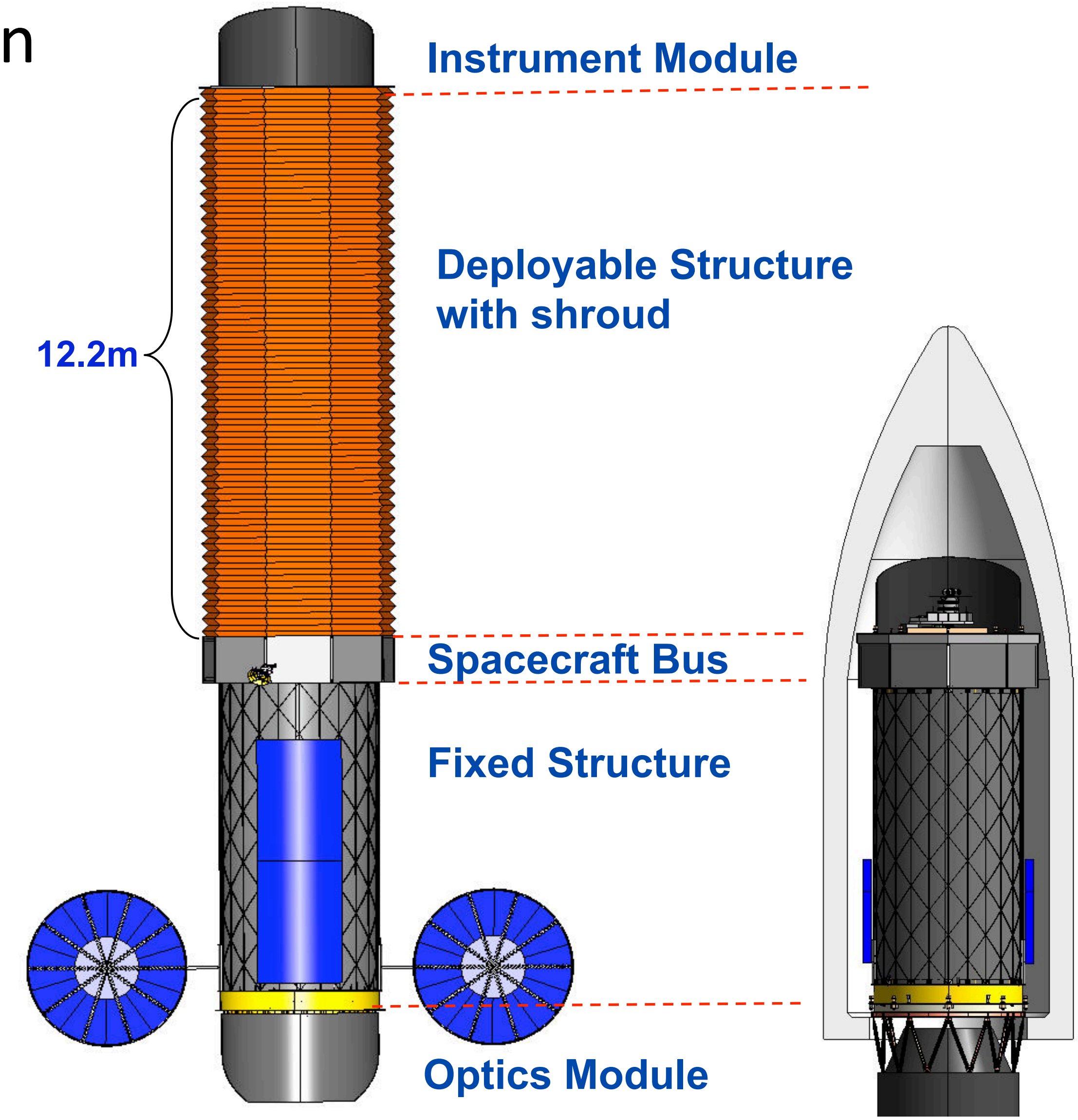
Spectral Capability

The IXO energy band contains the K-line transitions of 25 elements Carbon through Zinc allowing simultaneous direct abundance determinations using line-to-continuum ratios, plasma diagnostics and at iron K bulk velocities of 200 km/s



NASA Mission Design

- The observatory is deployed to achieve 20 m focal length
- Observatory Mass ~6100 kg (including 30% contingency)
- Launch on an Atlas V 551 or Ariane V
- Direct launch into an 800,000 km semi-major axis L2 orbit
- 5 year required lifetime, with expendables for 10 year goal

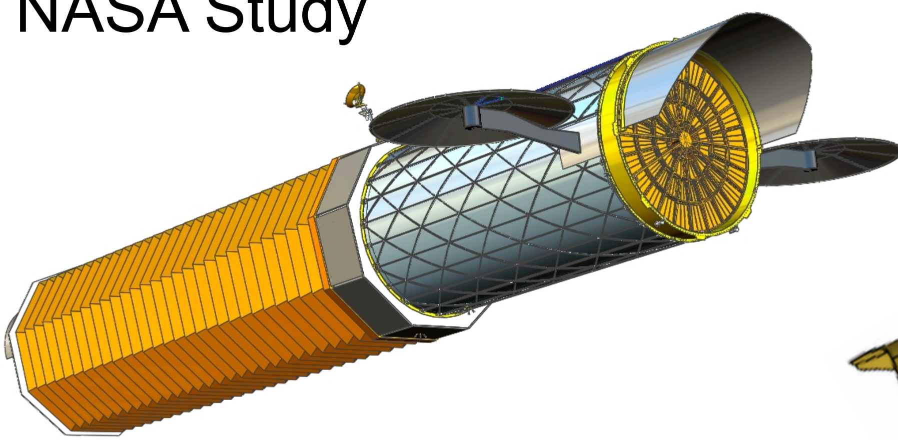


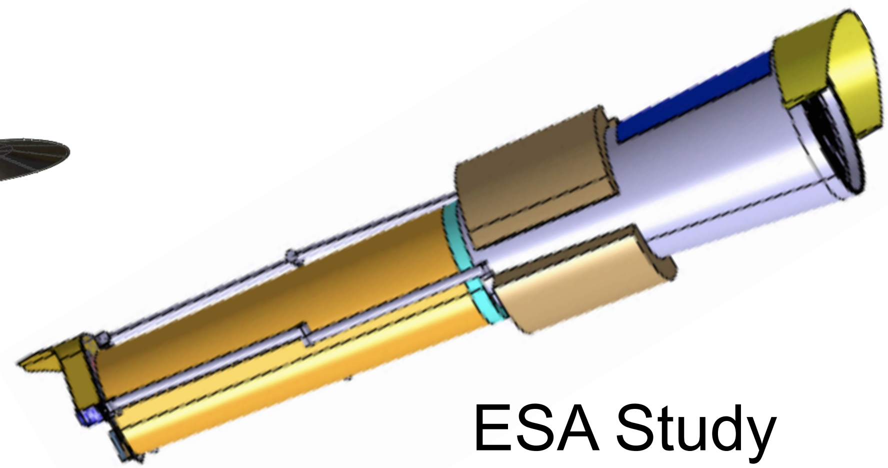
Deployed IXO Configuration

Stowed IXO Configuration

IXO Mission Studies

NASA Study

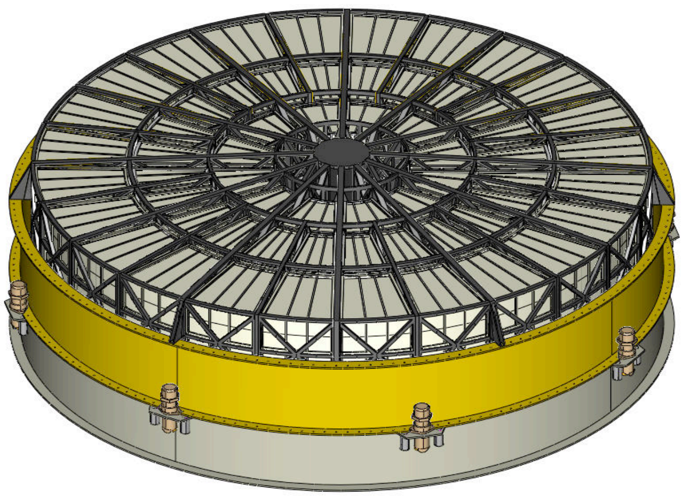




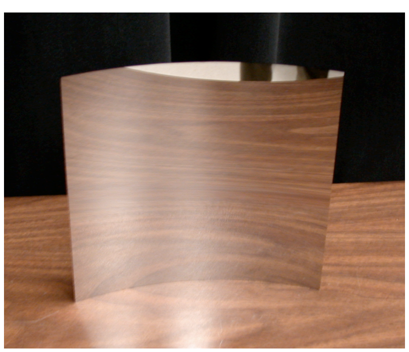
ESA Study

Separate ESA and NASA mission studies demonstrate overall mission feasibility, with no show stoppers

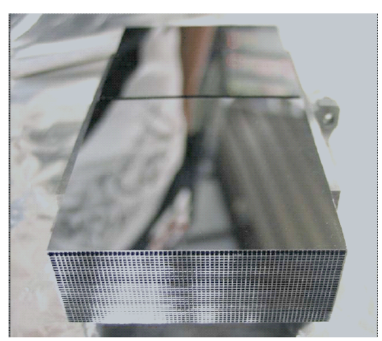
IXO X-ray Telescope



Glass



Silicon



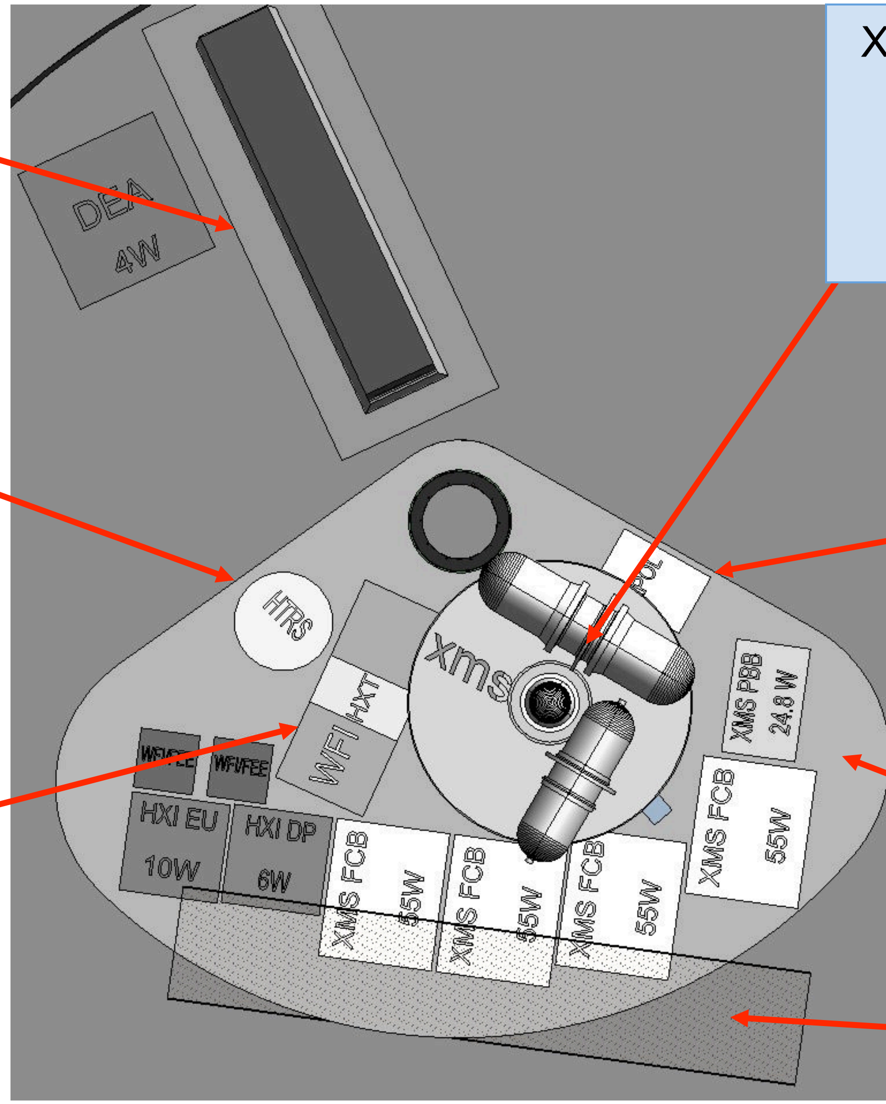
- Key requirements:
  - Effective area ~3 m^2 @ 1.25 keV
  - Angular Resolution <= 5 arc sec
- Single segmented optic with design optimized to minimize mass and maximize collecting area
  - Multilayers enhance hard X-ray response to 40 keV
- Two parallel technology approaches being pursued
  - ESA: Silicon micro-pore optics 3.8m diameter
  - NASA: Slumped glass 3.0m diameter
- Both making excellent progress
  - Already achieved 15 arc sec resolution, with further progress planned for this year
  - Slumped glass baselined for NuSTAR

Focal Plane Layout

X-ray Grating Spectrometer Detector
0.3 to 1 keV
R = 3000
> 1000 cm^2

High Time Resolution Spectrometer
1 Crab > 90% livetime

Wide Field Imager
FOV 18 arc min
0.1-15 keV
DE < 150 eV
+
Hard X-ray Imager
FOV 8 arc min
> 150 cm^2@30 keV



X-ray Micro-calorimeter Spectrometer
FOV 5 arc min
DE = 2.5 eV
0.3-7 keV

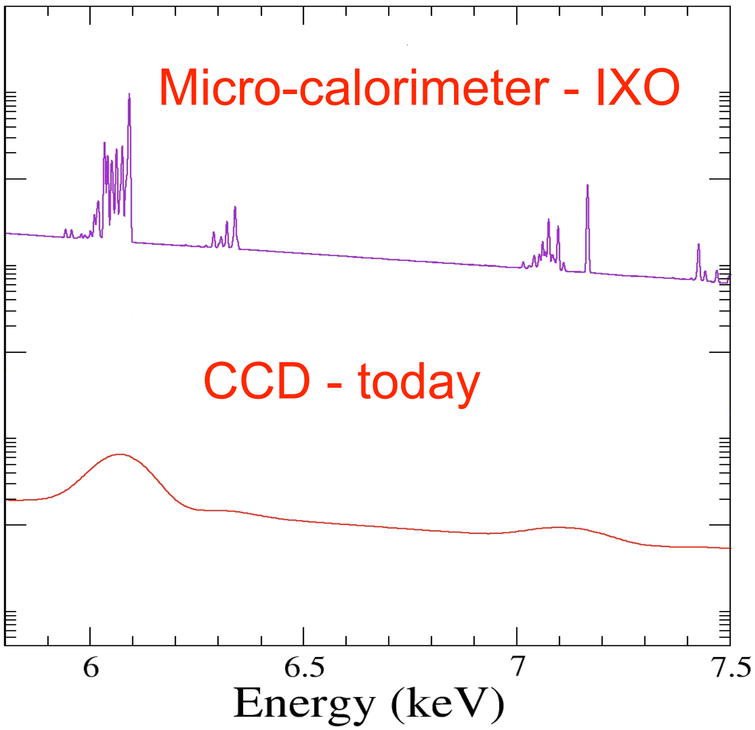
Polarimeter
<1% for 1 mCrab in 100ks

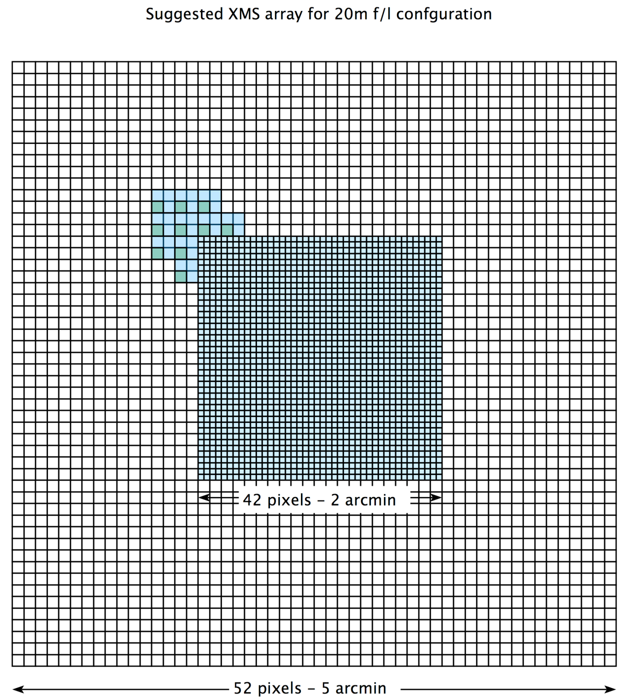
Translation Platform

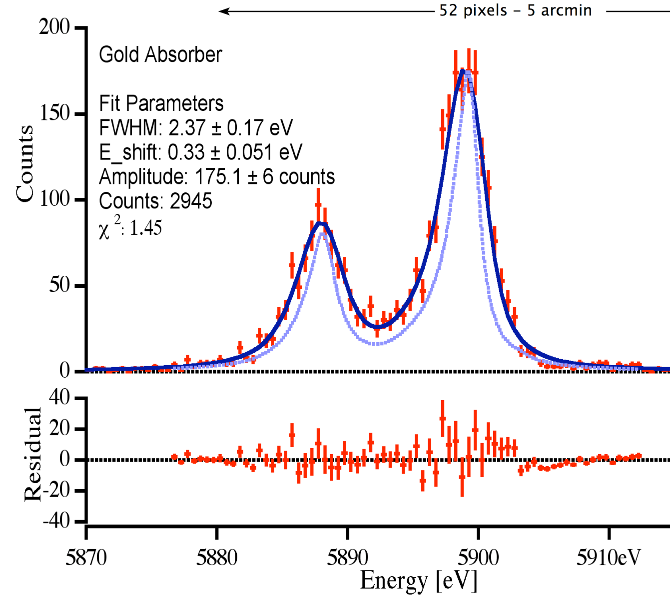
Radiator

Example of Next Generation Instrument Capability X-ray Micro-calorimeter Spectrometer (XMS)

- Thermal detection of individual X-ray photons
  - High spectral resolution
  - ΔE very nearly constant with E
  - High intrinsic quantum efficiency
  - Imaging detectors







IXO Study Team

IXO Study Coordination Group
ESA Chair: A.N Parmar
NASA Chair: N.E. White
JAXA Chair: H. Kunieda

IXO Science Definition Team
ESA Chair: X. Barcons (ES)
NASA Chair: J. Bregman
JAXA Chair: T. Ohashi

IXO Instrument Working Group
ESA Chair: P. de Korte (NL)
NASA Chair: J. Nousek
JAXA Chair: H. Tsunemi

IXO Telescope Working Group
ESA Chair: R. Willingale (UK)
NASA Chair: R. Petre
JAXA Chair: H. Kunieda

IXO Science Associates

IXO Study Coordination Group

Members	Europe	Japan	US
Study Scientists	Arvind Parmar (co-chair)	Hideyo Kunieda (co-chair)	Nick White (co-chair)
Study Managers	Philippe Gondoin	Tadayasu Dotani	Jean Grady
HQ Representatives	Fabio Favata	Tadayuki Takahashi	Michael Salamon
Agency appointed Community Scientists	Didier Barret (F)	Takeshi Tsuru	Mark Bautz
	Paul Nandra (UK)	Kazuhisa Mitsuda	Mitch Begelman
	Luigi Piro (I)	Takaya Ohashi	Jay Bookbinder
	Lothar Strüder (D)		Kathy Flanagan

Mailing List: ixo-scg@imperial.ac.uk

IXO Science Definition Team

ESA Appointed Members	NASA Appointed Members	JAXA Appointed Members
Monique Arnaud (F)	Steve Allen	Shunji Kitamoto
Xavier Barcons (ES, co-chair)	Neil Brandt	Kyoko Matsushita
Hans Bōhringer (D)	Joel Bregman (co-chair)	Takaya Ohashi (co-chair)
Massimo Cappi (I)	Jack Hughes	Yuichi Terashima
Andrea Comastri (I)	Christine Jones	Yoshihiro Ueda
Andy Fabian (UK)	Jon Miller	Noriko Yamasaki
Mariano Mendez (NL)	Rachel Osten	
Salvatore Sciortino (I)	Frits Paerels	
Jacco Vink (NL)	Chris Reynolds	
Mike Watson (UK)	Mike Shull	
Paul Nandra (UK, ex-offico)	Mitch Begelman (ex-officio)	

Secretaries: Mike Garcia, Ann Hornschemeier & Randall Smith

Mailing List: ixo-sdt@imperial.ac.uk

IXO Instrument Working Group

European Members	U.S. Members	Japanese Members
Didier Barret (F)	Mark Bautz (ex-officio)	Ryuichi Fujimoto
Ronaldo Bellazzini (I)	Tom Buckler (ex-officio)	Motohide Kokubun
Piet de Korte (NL, ESA co-chair)	Dave Burrows	Kiyoshi Hayashida
Jan-Willem den Herder (NL)	Webster Cash	Kazuhisa Mitsuda
Lionel Duband (F)	Tali Figueroa	Kazuhiro Nakazawa
George Fraser (UK)	Ralf Heilmann	Tadayuki Takahashi
Ian Hepburn (UK)	Kent Irwin	Hiroshi Tsunemi (co-chair)
Andrew Holland (UK)	Ali Kashani	
Peter Lechner (D)	Rich Kelley	
Olivier Limousin (F)	Caroline Kilbourne	
Didier Martin (ESA, ex-officio)	Randy McEntaffer	
Luigi Piro (I)	John Nousek (co-chair)	
Claude Pigot (F)	Brian Ramsey	
Lothar Strüder (D, ex-efficio)	Rick Rothschild	

Mailing List: ixo-iwg@imperial.ac.uk

IXO Telescope Working Group

European Members	U.S. Members	Japanese Members
Ladislav Andricek (D)	Steve Odell	Hisamitsu Awaki
Marcos Bavdaz (ESA)	Rob Petre (co-chair)	Manabu Ishida
Finn Christensen (DK)	Paul Reid	Hideyo Kunieda (co-chair)
Peter Friedrich (D)	Suzanne Romaine	Yoshimoto Maeda
Rene Hudec (CZ)	Mark Schattenburg	
Giovanni Pareschi (I)	Will Zhang	
Dick Willingale (UK, ESA appointed co-chair)	Jay Bookbinder (ex-officio)	

Mailing List: ixo-twg@imperial.ac.uk

IXO Science Associates

Around 300 IXO Science Associates worldwide who are:

- Considered part of the IXO science team and encouraged to work with the SDT to further refine the science case – contact one of the SDT chairs if you want to get involved!
- Regularly informed about developments in the project
- Invited to the science meetings
- To become a science associate contact one of the project scientists

Mailing List: ixo-sa@imperial.ac.uk

IXO Science Team Meeting

GSFC 20-22 August 2008

IXO Science Team Meeting

MPE 17-19 September 2008

Astro2010 Charge

- The Astro2010 committee will survey the field of space- and ground-based astronomy and astrophysics, recommending priorities for the most important **scientific and technical** activities of the decade 2010-2020.
- The principal goals of the study will be to carry out an assessment of activities in astronomy and astrophysics, including both new and previously identified concepts, and to prepare a **concise report** that will be addressed to the agencies supporting the field, the Congressional committees with jurisdiction over those agencies, and the scientific community.

[http://www.nationalacademies.org/astro2010]

THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

11

Astro 2010

Astro2010 Survey Committee (ASC)

Roger Blandford, Chair, Stanford University
Lynne Hillenbrand, Executive Officer, California Institute of Technology

Subcommittee on Science
Martha P. Haynes, Vice Chair – Science Frontiers, Cornell University
Lars Bildsten, University of California, Santa Barbara
John E. Carlstrom, The University of Chicago
Fiona A. Harrison, California Institute of Technology
Timothy M. Heckman, Johns Hopkins University
Jonathan I. Lunine, University of Arizona
Juri Toomre, University of Colorado at Boulder
Scott D. Tremaine, Institute for Advanced Study

Subcommittee on State of the Profession
John P. Huchra, Vice Chair – State of the Profession, Harvard-University
Debra M. Elmegreen, Vassar College
Joshua Frieman, Fermi National Accelerator Laboratory
Robert C. Kennicutt, Jr., University of Cambridge
Dan McCammon, University of Wisconsin-Madison
Neil de Grasse Tyson, American Museum of Natural History

Subcommittee on Programs
Marcia J. Rieke, Vice Chair – Program Prioritization, University of Arizona
Steven J. Battel, Battel Engineering
Claire E. Max, University of California, Santa Cruz
Steven M. Ritz, NASA Goddard Space Flight Center
Michael S. Turner, The University of Chicago
Paul Adrian Vanden Bout, National Radio Astronomy Observatory
A. Thomas Young, Lockheed Martin Corporation [Retired]

THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

12

Astro 2010

Subcommittee on Science

- **Chair: Haynes**
  - **Bildsten, Carlstrom, Harrison, Heckman, Lunine, Toomre, Tremaine**
- **Five Science Frontiers Panels (SFP)**
  - **NRC Committees**
  - **Write Panel Reports**
  - **Four central questions**
  - **One area of unusual discovery potential**
- **Recommend:**
  - **An integrated scientific observational and theoretical research program using panel reports**
- **Draft Science portion of report**

THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

13

Astro 2010

Science Frontier Panels

Planetary Systems and Star Formation (PSF), Lee Hartmann

- **Solar system bodies (other than the Sun) and extrasolar planets, debris disks, exobiology, formation of individual stars, protostellar and protoplanetary disks, molecular clouds and the cold ISM, dust, and astrochemistry.**

Stars and Stellar Evolution (SSE), Roger Chevalier

- **The Sun as a star, stellar astrophysics, structure and evolution of single and multiple stars, compact objects, supernovae, gamma-ray bursts and solar neutrinos. Extreme physics on stellar scales.**

The Galactic Neighborhood (GAN), Mike Shull

- **Structure and properties of nearby galaxies including the Milky Way and their stellar populations, interstellar media, star clusters. Evolution of stellar populations.**

Galaxies across Cosmic Time (GCT), Meg Urry

- **Formation and evolution of galaxies and galaxy clusters, active galactic nuclei and QSOs, mergers, star formation rate, gas accretion, global properties of galaxies and galaxy clusters, supermassive black holes.**

Cosmology and Fundamental Physics (CFP), David Spergel

- **Early universe, microwave background, reionization and galaxy formation up to virialization of protogalaxies. Large scale structure, intergalactic medium, determination of cosmological parameters, dark matter, dark energy. High energy physics using astronomical messengers, tests of gravity, physical constants as determined astronomically.**

THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

14

Astro 2010

Subcommittee on Programs

- **Chair: Rieke**
  - **Battel, Max, Ritz, Turner, Vanden Bout, Young**
- **Four Programmatic Prioritization Panels (PPP)**
  - **NRC committees**
  - **Write panel reports**
- **Recommend:**
  - **Synthesize panel reports into a prioritized, cost-constrained and balanced program for next decade**
    - Independent contractors evaluate construction and full running cost, schedule, risk for major contenders.
  - **Research technology development program to enhance existing capabilities and enable missions starting in the following decade**
- **Draft program part of report**

THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

17

Astro 2010

Programmatic Prioritization Panels

Radio, Millimeter and Submillimeter from the Ground (RMS)

- **Observatories and telescopes that observe primarily in these wavebands**

Optical and Infrared Astronomy from the Ground (OIR)

- **Observatories and telescopes that observe primarily in these wavebands**

Electromagnetic Observations from Space (EOS).

- **This will include all space-based astronomical projects observing the electromagnetic spectrum.**

Particle Astrophysics and Gravitation (PAG)

- **This will include all ground- and space-based projects exploring non-electromagnetic particles and gravitational radiation.**

THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

18

Astro 2010

Astro2010 Timeline (provisional)

- December 5 2008 — 1st meeting ASC
- January 6, 2009 — AAS town meeting, sessions
- January 9, 2009 — 2nd meeting ASC
- January 14 2009 — Submission Deadline for Notices of Interest
- January 2009 — 1st meetings SFP, ISG; start town halls
- February 15 2009 — Submission of Science White Papers
- May 4 2009 — APS Town meeting, sessions
- May 11 2009 — 3rd meeting ASC; 1st meeting PPP
- June 8 2009 — AAS meeting, PPP workshops
- September 2009 — 4th meeting ASC; SFP drafts, ISG data
- October 2009 — Cost-schedule-risk analysis, SFP review
- December 2009 — PPP drafts, ASC recommendations
- January 2010 — ASC draft; PPP review
- April 2010 — ASC review
- July 2010 — Report release and communication of content

THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

24

Astro 2010

Decadal Key Dates

Science white papers due Feb 14, 2009

Mission implementation due April 2009

Mission presentations at June 8, close to AAS meeting in Pasadena

Activity Notices of Intent

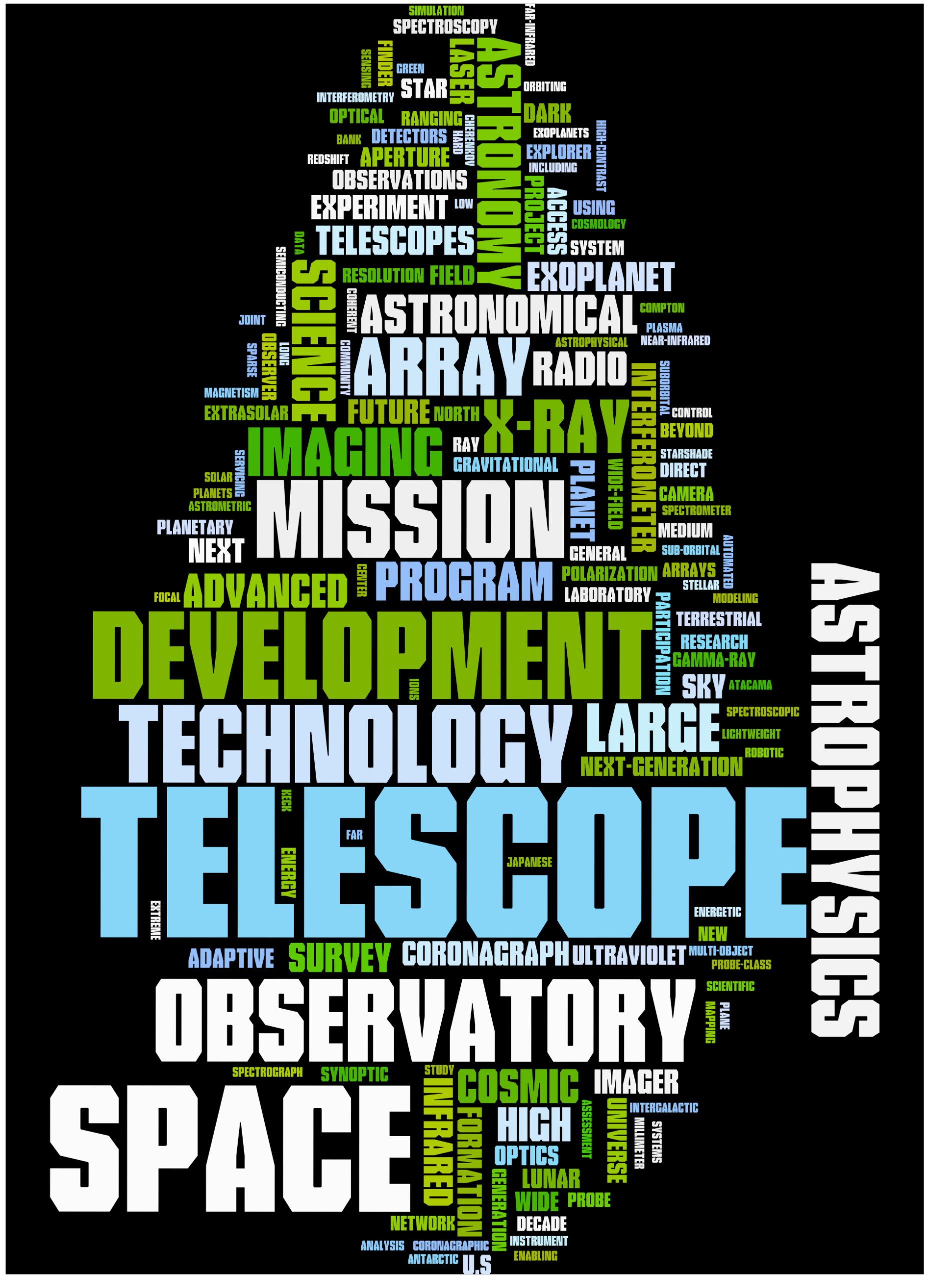
- "Activity" – projects, missions, telescopes, laboratories etc
- Program Subcommittee will decide which activities will be invited to make presentations
- ATST and other ground-based solar telescopes, JDEM, LISA, cosmic ray projects >1GeV, neutrinos from cosmic sources... are currently expected to be prioritized
- Space-based solar, underground DM, planetary science, gravitational and neutrino physics experiments, JWST, AMS, LIGO, SOFIA... will not be prioritized
- Submit by Jan 14 2009

THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

23

Astro 2010

171 NOIs


SIMULATION
SPECTROSCOPY
FAR-INFRARED
FINDER
SENSING
LASER
ASTRONOMY
GREEN
STAR
ORBITING
INTERFEROMETRY
OPTICAL
RANGING
DARK
DETECTORS
HARD
CHERENKOV
EXOPLANETS
HIGH-CONTRAST
EXPLORER
REDSHIFT
APERTURE
INCLUDING
OBSERVATIONS
EXPERIMENT
LOW
PROJECT
ACCESS
USING
COSMOLOGY
TELESCOPES
SYSTEM
DATA
SEMICONDUCTING
SCIENCE
RESOLUTION
FIELD
EXOPLANET
COHERENT
ASTRONOMICAL
COMPTON
JOINT
LONG
PLASMA
ASTROPHYSICAL
NEAR-INFRARED
SPARSE
OBSERVER
COMMUNITY
ARRAY
RADIO
SUBORBITAL
MAGNETISM
INTERFEROMETER
CONTROL
EXTRASOLAR
FUTURE
NORTH
X-RAY
BEYOND
RAY
STARSHADE
IMAGING
GRAVITATIONAL
SERVICING
SOLAR
PLANET
WIDE-FIELD
DIRECT
PLANETS
CAMERA
ASTROMETRIC
SPECTROMETER
PLANETARY
MISSION
MEDIUM
NEXT
GENERAL
SUB-ORBITAL
AUTOMATED
CENTER
POLARIZATION
ARRAYS
STELLAR
FOCAL
ADVANCED
PROGRAM
LABORATORY
MODELING
PARTICIPATION
TERRESTRIAL
DEVELOPMENT
RESEARCH
GAMMA-RAY
IONS
SKY
ATACAMA
ASTROPHYSICS
SPECTROSCOPIC
TECHNOLOGY
LARGE
LIGHTWEIGHT
ROBOTIC
NEXT-GENERATION
KECK
FAR
TELESCOPE
JAPANESE
ENERGY
EXTREME
ENERGETIC
NEW
ADAPTIVE
SURVEY
CORONAGRAPH
ULTRAVIOLET
MULTI-OBJECT
PROBE-CLASS
SCIENTIFIC
OBSERVATORY
PLANE
MAPPING
SPECTROGRAPH
SYNOPTIC
STUDY
COSMIC
IMAGER
INFRARED
FORMATION
ASSESSMENT
UNIVERSE
INTERGALACTIC
SYSTEMS
MILLIMETER
SPACE
HIGH
OPTICS
GENERATION
LUNAR
WIDE
PROBE
NETWORK
DECADE
ANALYSIS
CORONAGRAPHIC
INSTRUMENT
ANTARCTIC
U.S
ENABLING

Science White Papers

- Address how understanding of astronomical frontiers may be advanced
- Should be addressed to one or more panels
- Multiple submissions allowed
- Identify critical questions and specific opportunities
- Theory, experiment and observation
- Scope of science panels is inclusive, connections to other areas of science are important
- Expecting submissions involving missions that are started or operating as these provide a context for future programs
- AAS Bulletin Boards a great way to organize collaborations on white papers
- 7pp; submit 9-15 Feb; public documents

THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

22

Astro 2010

Summary

IXO addresses key and timely questions confronting Astronomy and Astrophysics

IXO will bring a factor of ten gain in telescope aperture combined with next generation instrument technology to realize a quantum leap in capability

Separate studies by ESA and NASA demonstrate that the mission implementation for a 2020 launch is feasible with no major show stoppers