International X-ray Observatory (IXO)

Hot Baryons in Deep Potential Wells: IXO Studies of Hot Gas in Galaxies, Groups and Clusters

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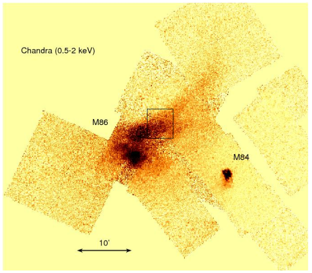
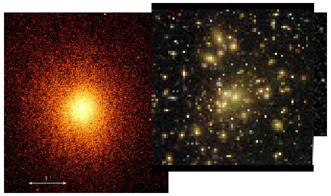
Clusters of galaxies are the largest collapsed, virialized systems in the Universe with total masses up to 10^{15} $M_{\odot}$. While most of the mass in clusters is dark matter, most of the baryonic mass is in the form of a hot ($T=10^{7-8}$ K), optically thin plasma that is only visible through its X-ray emission. Clusters of galaxies represent one of the few places in the Universe where the intergalactic medium "lights up" and is bright enough to study in detail. The X-rays emitted by the hot, diffuse gas provide a unique view of not only the structure of clusters and the distribution of dark matter in the cluster potential wells, but also of how gravity and other physical processes act on matter to create the galaxies. IXO studies are crucially important for understanding the physics of clusters, including the interactions between galaxies and the ICM. The growth of clusters through mergers, and the distribution of metals. Through the measurement of line broadening, line shifts, and the distribution of the heavy elements in the cluster gas, IXO opens a new window on the physical processes occurring in cluster gas: turbulence, bulk motions, enrichment, and magnetic fields. IXO's high spectral resolution and large throughput will allow us to measure bulk motions and turbulence an order of magnitude better than previous observatories including XMM, Astro-H and SRG, for the first time, at or even below the levels expected from simulations of structure formation.

Measuring ICM Velocities and Understanding Cluster Evolution

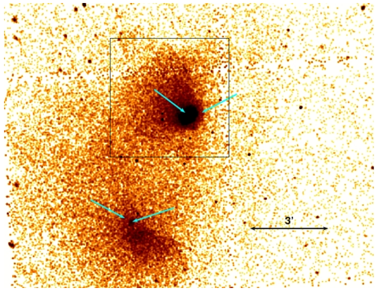


Chandra x-ray image of the Virgo cluster around the elliptical galaxy M86. The long (> 380 kpc) gas tail has been ram pressure stripped from M86 as it moves through the Virgo intracluster medium.

IXO will measure the velocity, temperature and abundance of M86's core gas and tail and the mixing of the enriched cool galaxy gas with the hot ICM. Small box shows the FOV of the IXO calorimeter.

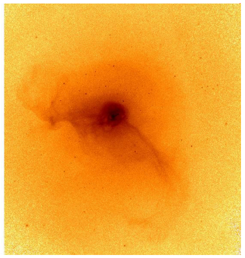


A1689: (left) Chandra (right) HST Lensing suggests a superposition of three clusters (Natarajan 2009). IXO will measure the Fe-line velocity and mass for each superposed cluster.



A115: Chandra image of merging subclusters. IXO will measure the gas velocity,temperature and abundance. Arrows mark cD galaxy cores and leading edges. (box shows calorimeter FOV).

Cool Core Diagnostics and Gas Turbulence in M87's halo



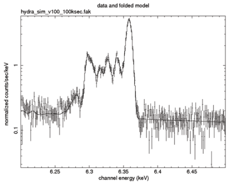
Chandra image of M87

Multi-temperature and abundance diagnostics in the M87 gas (IXO 50ks observation for a 1'X1' region with F_x (0.5-2 keV = 4.3 10^{-12} ergs s^{-1} cm^{-2} 10% cool 1 keV plasma + hot 2.3 keV)

T_1 = 0.99 +/- 0.002 T_2 = 2.27 +/- 0.01

- Fe, Si, S (cool) = 2.3 +/- 0.14 solar
- O, Mg (cool) = 0.9 +/- 0.24
- Fe, Si, S (hot) = 0.7 +/- 0.01
- O, Mg (hot) = 0.3 +/- 0.05

AGN outbursts from the SMBH may cause the gas in the core to be turbulent which can contribute to the pressure support. The AGN outbursts may also disperse the heavy elements from the core. IXO will measure gas turbulence by determining line widths in the x-ray spectra and will map the distribution of heavy elements.

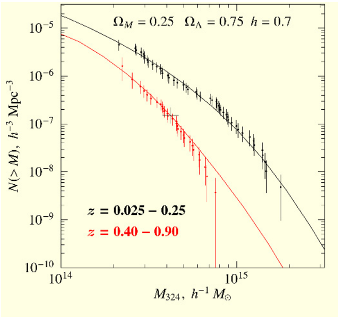


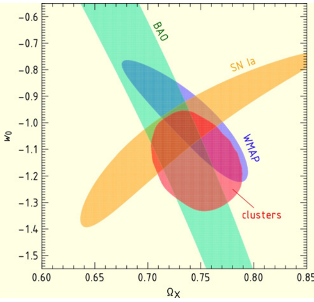
Simulated x-ray spectrum

Cluster Evolution and Determining Cosmological Parameters

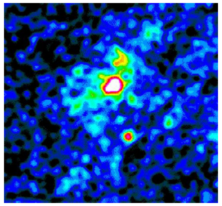
Clusters evolve significantly over relatively modest redshifts. The cluster mass function shows fewer massive clusters in a sample of clusters at 0.4<z<0.9, compared with a low redshift 0.025<z<0.25 sample (Vikhlinin et al 2008, left panel below). The growth of structure provide a sensitive measure of cosmological parameters that differs from the "distance" methods used in SN1a and cluster baryon fraction studies.

IXO observations of clusters detected in wide field surveys (e.g. SRG/eROSITA or SPT/ACT S-Z) will reduce the uncertainties on W_0 compared to the current constraints shown below (Vikhlinin et al. 2008, right panel below).





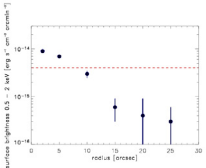
Simulated IXO Galaxy Group at z = 2



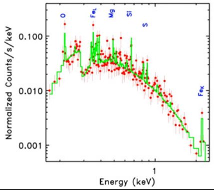
High z Group at z = 2

- F_x = 5 10^{-16} erg s^{-1} cm^{-2}
- L_x = 7 10^{43} erg s^{-1} [0.5 -2 keV]
- central surface brightness. ~ 2 x background
- core radius 40 kpc = 5"

At redshifts ~2, few, if any, massive clusters are expected to have formed. In this quasar epoch, galaxy groups will be the largest collapsed systems. IXO will measure the temperatures and elemental abundances of the gas.



Surface brightness of group gas is determined to about 3.5 core radii (140 kpc)



Spectroscopy of group gas:

- Temperature +- 3%
- [Fe] +- 11%
- [Si] +- 18%
- [O], [Mg] +- 30%

Cluster Physics with the WFI and the calorimeter:

Clusters are not only the most massive virialized systems, they are also the largest. With an 18' x 18' WFI field of view, cluster mergers, like the bullet cluster and A3667 will be fully imaged.

IXO will observe distant clusters and groups and, by opening this discovery space, address key questions ranging from the evolution of AGN feedback in clusters to whether the dark energy equation of state changes with redshift.

The bullet cluster: hot gas from two merging clusters is shown in pink. Blue regions show the dark matter as traced through lensing. Cluster mergers are the most energetic events in the Universe since the Big Bang. IXO will determine shock parameters and study cluster energetics.