International X-ray Observatory (IXO)

Kinematic Measurements of AGN Feedback in the Era of the International X-ray Observatory IXO

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Abstract

The International X-ray Observatory (IXO) will open a new window into the study of AGN feedback in galaxy clusters. Its high spectral resolution and throughput will allow us, for the first time, to directly detect the large scale motions induced by expanding radio lobes/X-ray cavities of powerful AGN (like Cygnus A), thereby calibrating their power without the need for additional hydrodynamic assumptions. Such a measurement will allow us to calibrate the AGN feedback efficiency in clusters. We present detailed numerical simulations of AGN feedback in clusters that verify IXO's ability to deliver on this promise. In order to accurately predict IXO's performance, we developed a simulator, called XIM, that is publicly available. XIM has two parts: It self-consistently calculates the thermal X-ray emission from a gas-dynamical simulation (taking data cubes of velocity, temperature, and density as input from any cosmological simulation). It then convolves the output spectro-image with the response functions for an X-ray telescope of choice, with an emphasis on IXO and Chandra. Its main purpose is for numerical simulators to easily and accurately predict the X-ray signal of a simulated cluster detected by different telescopes.

Feedback on cluster scales

- Cluster centers cool radiatively in a cooling time much shorter than a Hubble time.
- Chandra & XMM: Cluster cooling flow problem requires heating
- Jets from central black holes: prime candidate for energy source
- Heat transfer mechanism unclear.
- Feedback switch mechanism (regulation of cluster temperature) unclear.
- IXO will be able to make accurate measurements of many important physical parameters of black hole feedback (energetics, direct detection of plasma heating)

Radio galaxy dynamics: Shocks

- Radio galaxies drive shocks into the IGM
- Some shocks soften into sound waves (Perseus), but strong shocks persist (even though bubbles expand sub-sonically)
- Chandra has detected a number of shocks around radio glaxies: M87, Hydra A, MS 0635+74, Cygnus A, and others
- Unline buoyant bubbles, shocks can be timed accurately and give exact estimate of power and intermittency
- Shocks can also heat IGM

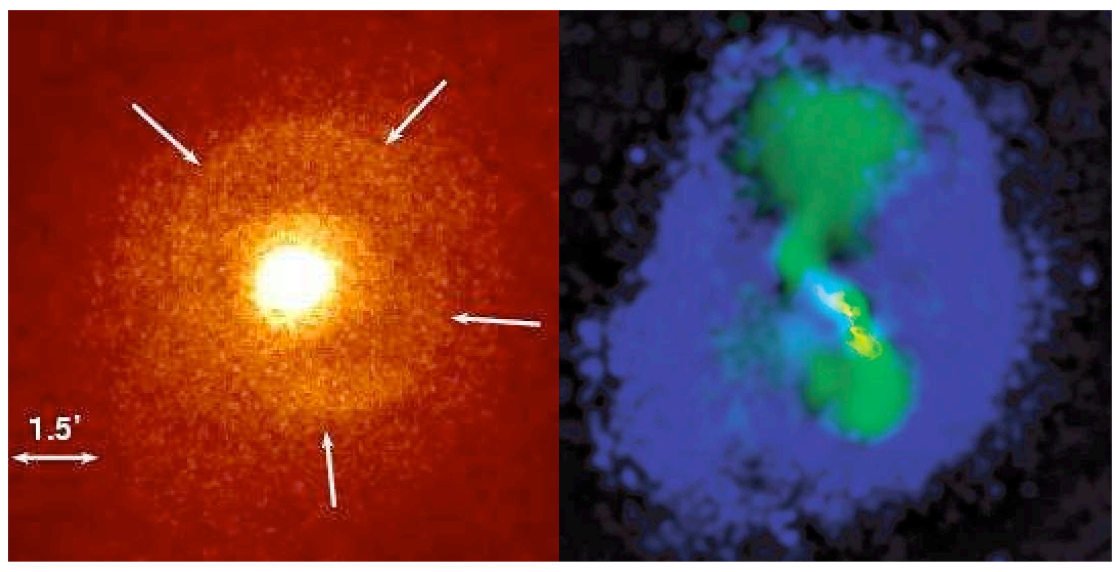

Figure 1: Images of shocks in M87 (Forman et al. 2007) and Hydra A (Wise et al. 2007)

XIM: virtual X-ray observations from hydrodynamic simulations

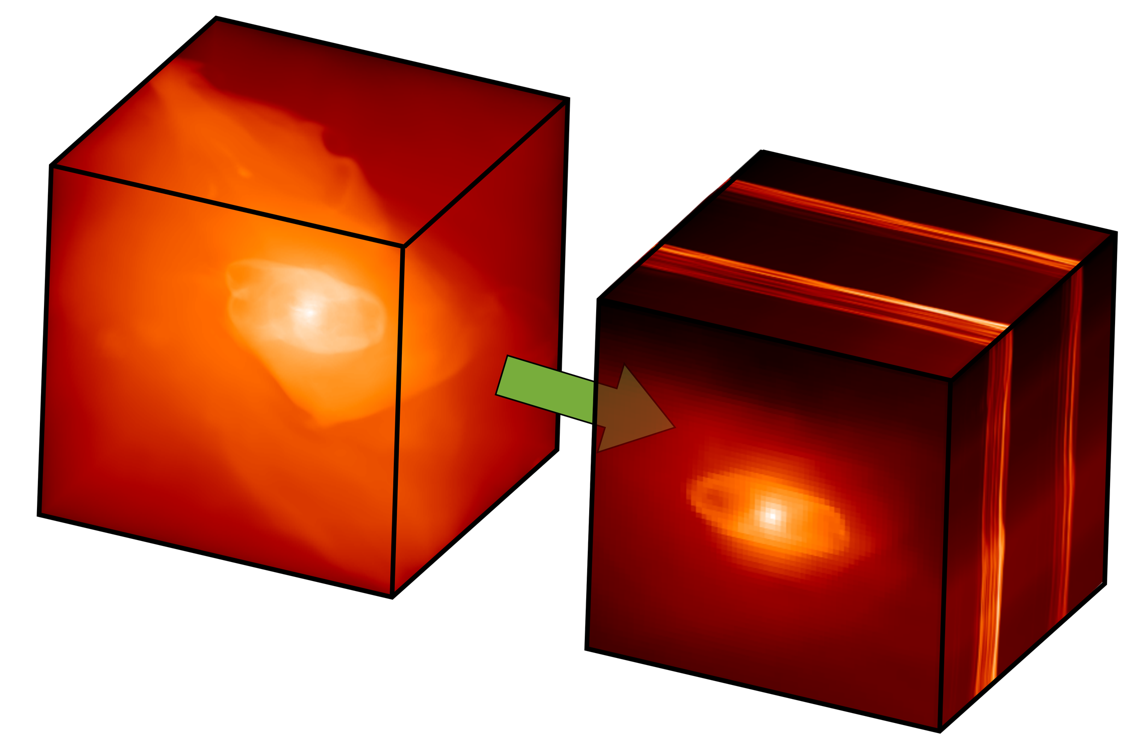

Figure 2: Left: 3D rendering of density from cluster simulation. Right: Spectral projection of the same cube along one axis, convolved with IXO's spectral response. Shown is the energy range 6.2 - 6.8 keV at IXO's 2.5 eV spectral and 5" spatial resolution.

Features of XIM:

XIM calculates the X-ray thermal spectrum from the output of hydro simulations of clusters and other thermal gases.

Input from hydro simulation: 3D-grid of density, temperature, line-of-sight velocity, filling factor, metallicity

Parameters: cosmology, distance, Galactic absorption column, exposure time, output energy grid

Output: X-ray spectral cube at simulation resolution, spectral cube at telescope resolution, folded through telescope response, simulated observation, series of

Physics / algorithms:

- Spectral projection along line of sight
- Non-relativistic Doppler shift
- Thermal plasma emission using APEC (Smith et al. 2001)
- Flux conservative regridding, logarithmic bilinear interpolation in energy and temperature
- Sub-grid turbulent broadening
- Real instrument response matrices for IXO, Con-X, Chandra, XEUS, reads FITS response files in OGIP CAL/GEN/92-002 format.
- PSF idealized as energy independent Gaussian (version 1.0)
- Simple parallelization included for large grids

Simulated Chandra observations via MARX:

- XIM interfaces with MARX to create events files of virtual Chandra observations.
- MARX preforms a realistic ray-tracing through the telescope, including realistic PSF and response modeling.
- Blank sky background files added optionally (in preparation)

Availability: XIM is written in IDL and it is freely available at http://www.astro.wisc.edu/~heinzs/XIM Please reference Heinz & Brüggen 2009 or Brueggen et al. 2009 if you use the code.

IXO will be able to measure shock velocity in Cygnus A

Taylored 3D hydro simuation of Cygnus A (Heinz et al. 2006):

- Correct density and temperature of host clusters
- 10^{46} ergs/s jet supplied by central black hole
- "Observed" at correct red-shift to match observed size, yielding an age of 20 Myrs.
- *Simulated* Chandra image agrees to within a few percent in surface brightness with *real* Chandra observation
- Morphology of simulated X-ray and radio images in very good agreement with observations

Simulated 250 ksec IXO observation of Cygnus A:

- Cygnus A fits perfectly within IXO's 32 pixel high density array
- Simulated IXO observation *clearly resolves* the approaching and receding walls of the shocked cavity
- "XIM/IXO" velocity = 650 km s^{-1}, simulated velocity = 680 km s^{-1}

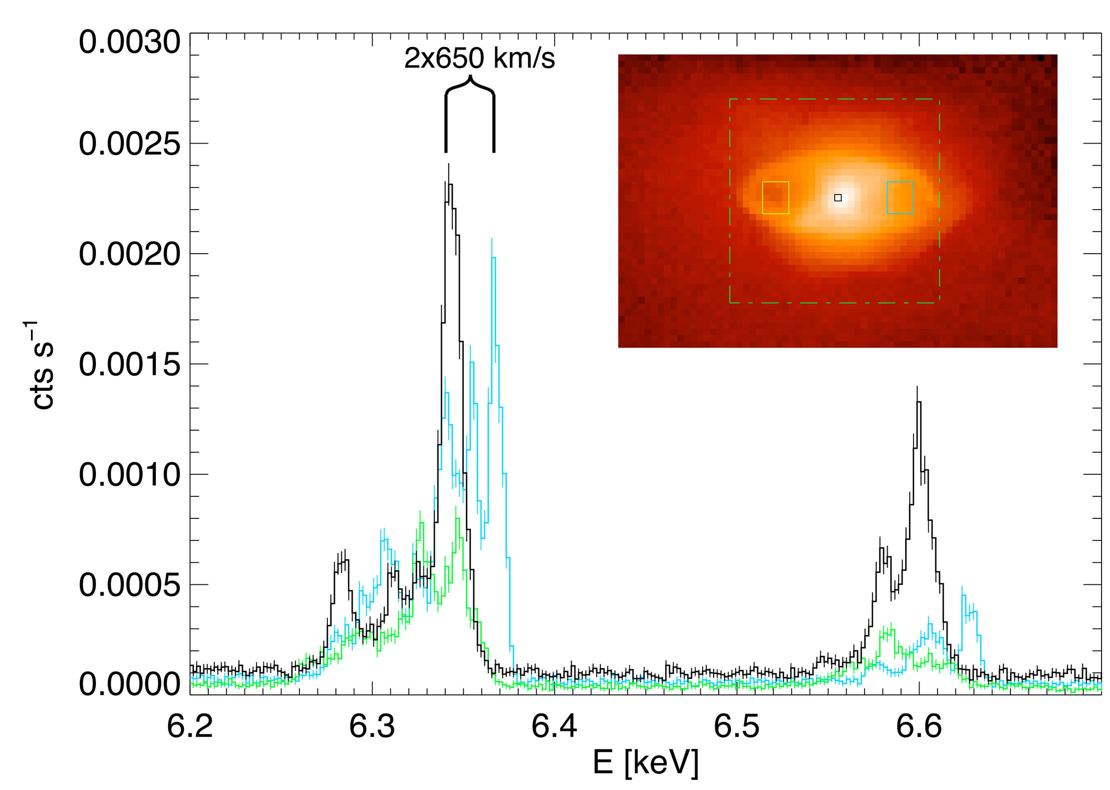

Figure 3: Simulated 250 ksec IXO exposure of Cygnus A. Shown is the X-ray spectrum around the Fe K-alpha line. Lhe emission lines come from from He and H-like iron (red-shifted to Cyg A rest frame) for three different lines of sight through the source. The two spectra through the lobes (green and blue) clearly show the expanding shell at about 650 km s^{-1}. Inset shows the X-ray image of Cyg A in the 6-7 keV band as seen by IXO (dashed contour: field of view of IXO high density array)

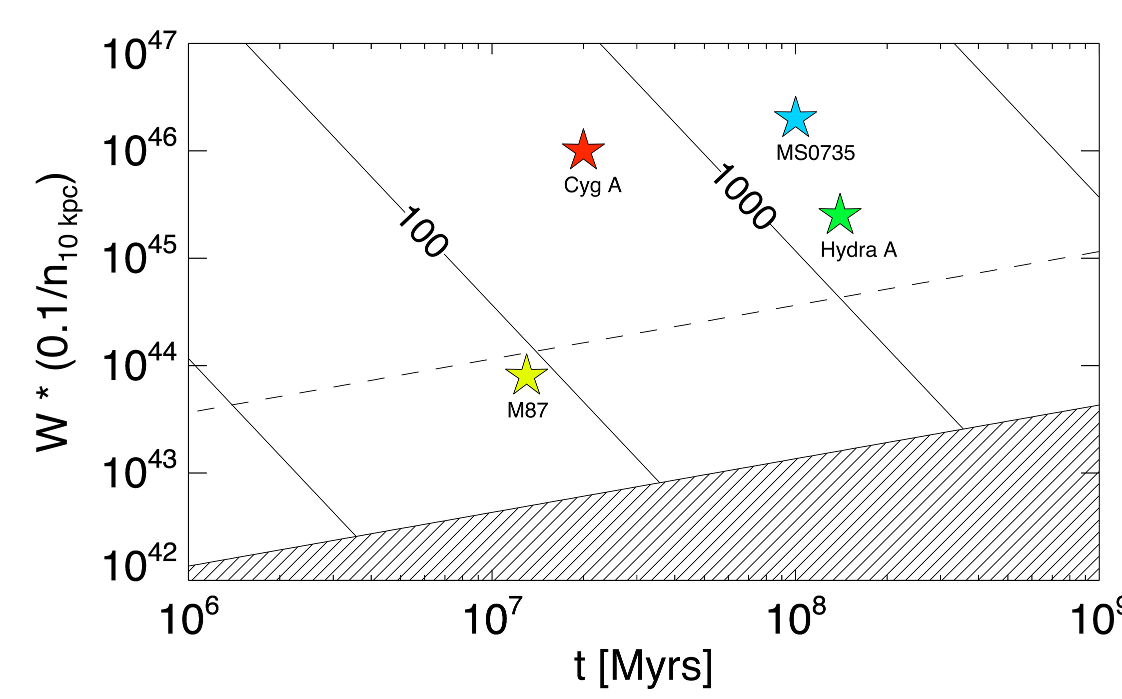

Figure 4: Detectability constraints for radio galaxy dynamics with IXO as a function of radio galaxy age and power for typical cluster parameters (beta profile with beta=0.5). Hatched area: Energy resolution limit (2.5 eV) for expansion velocity - below this line, even under the most optimistic circumstances, expansion cannot be measured. Dashed line: Expansion velocity of 300 km/s, comparable with the expected level turbulent broadening in clusters. Below this line, it will be difficult to measure expansion velocities. Solid lines: Distance in Mpc out to which IXO will be able to spatially resolve the radio galaxy.

References:

Forman et al. 2007, ApJ 665, 1057
Wise et al. 2007, ApJ 659, 1153
Brüggen, Scannapieco, & Heinz 2009, submitted to MNRAS
Heinz et al. 2006, MNRAS 373, L65
Heinz & Brüggen, 2009, in preparation
Smith et al. 2001, ApJ 556, L91

Download scripts and responses @ http://www.astro.wisc.edu/~heinzs/XIM

Attend "The Monster's Fiery Breath" conference in Madison, June 1-5 2009