X-ray Astronomy and Observational Cosmology

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Galaxy clusters...

Chandra Ripple Image of Perseus
The Chandra data show the ripples in the hot gas that fills the Perseus cluster. The features were discovered by using a special image-processing technique to bring out subtle changes in brightness. These ripples are sound waves thought to have been generated by cavities blown out by jets from a supermassive black hole (bright white spot) at the center of the Perseus cluster.
(Credit: NASA/CXC/IoA/A.Fabian et al.)

An artist’s illustration depicts the sound waves (ripples) in the hot gas that fills the Perseus cluster. Key elements of the system are labeled.
(Illustration: NASA/NASA/CXC/M.Weiss)

3-color X-ray Image of Perseus
The Chandra image shows the supermassive black hole at the center of Perseus A, seen as a white point. This image is 350 thousand light years across at the distance of the Perseus cluster. The hot cluster gas is seen as diffuse emission. Low-energy X-rays (0.3-1.5 keV) are shown in red, medium-energy X-rays are shown in green (1.5-3.5 keV), and high-energy X-rays are shown in blue (3.5-7.0 keV).
(Credit: NASA/CXC/IoA/A.Fabian et al.)

Galaxy Cluster Mass Function
Galaxy clusters are the largest gravitationally bound structures in existence. Their formation and growth over the history of the universe is sensitive to the underlying cosmology, especially the power spectrum of initial density fluctuations. This branch of cosmology will benefit greatly from large all-sky surveys designed to identify clusters, as well as from an improved understanding of the physics of galaxy clusters. The images above are from simulations of the formation of large scale structure in the universe.

Cluster Observations
The primary observables of X-ray spectroscopy are the density, temperature and metallicity of the emitting gas. Many other thermodynamic quantities can be derived from these. The gas temperature can be related to the total gravitating mass (including dark matter) of the cluster. This allows us to find the ratio of gas mass to total mass, which is a powerful cosmological probe (see below).

X-ray Distance Measurement
This set of illustrations (left) shows the technique used to make distance measurements to galaxy clusters. Chandra’s observations are used to determine the ratio of the mass of the hot gas and the mass of the dark matter in different galaxy clusters. This “gas fraction” depends on the assumed distances to the clusters, which in turn depends on the amount of matter and dark energy in the Universe. Because galaxy clusters are extremely large, the gas fraction should be the same for every cluster, and so the distances to the clusters are adjusted to satisfy this requirement.

Each of these 3 illustration shows Chandra in the top left, observing a galaxy cluster, shown in the top right (in red). The relative amounts of hot gas (in red) and dark matter (in blue) are shown at the bottom, with the green marker giving the expected, correct amount. The first illustration shows a gas fraction that is too small, implying that the distance to the cluster is too small, the second shows the correct gas fraction and distance, and the third illustration shows a gas fraction and distance that are too large.
(Credit: NASA/CXC/M.Weiss)