The Unseen: Clumping in the Outskirts of Galaxy Clusters

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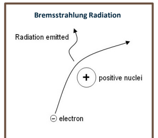
Introduction

- Galaxy clusters are the largest gravitationally bound structures in the universe.
- They contain 100s to 1000s of galaxies.
- The Intra-cluster-medium (ICM), which is a hot gas (~10^7 K) in between galaxies is detectable in the X-ray range via Bremsstrahlung radiation.
- ICM thermodynamical properties are extremely important for cosmology, i.e., how the universe formed and how it is evolving.
- Entropy in particular is essential to understand the dynamical properties of a cluster, including its evolution.
- Observations have shown unexpected results in derived entropy profiles for clusters.
- Gas clumping, a denser and cooler pocket of gas can affect how we measure entropy.
- Current telescopes cannot see these clumps.
- Star-X will be able to detect these clumps.
- This work simulates what STAR-X will see when looking at galaxy clusters.



The ICM is so hot that the gas is ionized. When electrons get deflected through interactions with ions, X-ray radiation is produced.

STAR-X

The Survey and Time-domain Astronomical Research eXplorer (STAR-X) will be proposed in the next Mid-Sized Explorer Class Mission (MIDEX) call by NASA at the end of 2021. It will have a low background due to its low altitude orbit and will be able to detect cluster outskirts. In a low Earth orbit, the Earth's magnetosphere will protect STAR-X from high energy charged particles. It also will be more efficient than previous missions (less exposure time, faster slewing).

Goals

- To investigate clump properties (size, temperature, density, number of clumps).
- To reproduce observed entropy profiles using simulated data and to determine what properties yield observed results.
- Determine if clumps would be detectable by STAR-X.

Methods

Simulation:

Building Data Grids:

- Two sets of 3D arrays are generated based on a given temperature and density profile.
- The datasets are loaded into yt, which processes information from computer simulations in order to produce mock observations.

Simulating Photons:

- The yt datasets are processed using pyXSIM.
- pyXSIM generates a 3D photon list, based on a thermal source model (apec).
- The output is a 3D array that describes how light would emanate from each cell of the grid based on the temperature and density at that point.

Projecting Photons to Simulate Images:

- The photon list can then be projected along an axis to generate a mock observation of a cluster at a given redshift.
- A 2D event file is then produced and using SOXS (an instrument simulator), a mock observation can be produced that simulates the response of a telescope.

Spectral Analysis:

- Spectra are extracted from concentric annuli centered at the X-ray emission peak.
- The data is fitted to find temperature (Eqn. 1) and surface brightness (Eqn. 2) values and then used to construct a radial profile for both temperature and density.
- An entropy profile can then be derived (Eqn. 3).

Eqn 1: $$T_{3D}(r) = T_0 \frac{(\frac{r}{r_t})^{-a}}{(1+(\frac{r}{r_t})^b)^{\frac{c}{b}}} \frac{(\frac{r}{r_{cool}})^{a_{cool}} + \frac{T_{min}}{T_0}}{(\frac{r}{r_{cool}})^{a_{cool}} + 1}$$

Eqn 2: $$n_p n_e = n_0^2 \frac{(r/r_c)^{-\alpha}}{(1+r^2/r_c^2)^{3\beta-\alpha/2}} \frac{1}{(1+r^\gamma/r_s{}^\gamma)^{\varepsilon/\gamma}} + \frac{n_{02}^2}{(1+r^2/r_{c2}^2)^{3\beta_2}}$$

Eqn 3: $$K = \frac{T}{n^{\frac{2}{3}}}$$

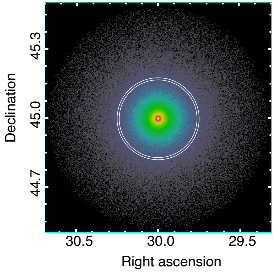


Figure 1: Reconstructed image of the Perseus Cluster based on Suzaku and Chandra archival data. Annulus 48 is shown in white.

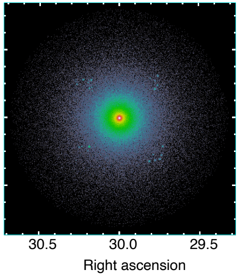
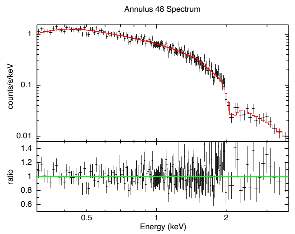


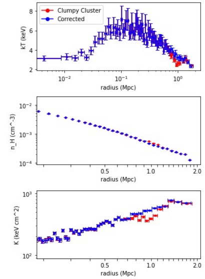
Figure 2: A recreation of the Perseus Cluster, with clumps injected.



Fit of the spectrum extracted from Annulus 48 as shown in Fig 1. Data is shown in the upper black curve, red curve represents the model, and the ratio demonstrates the goodness of the fit.

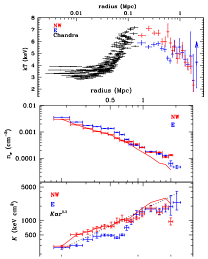
Results

Simulated Data



Results from the recreation of the Perseus Cluster, each profile is extracted from the same simulated image (Fig 2). Red signifies the cluster with clumps injected. Blue signifies clump-corrected data.

Observed Data



Observed results of the Perseus Cluster from Chandra (black) and Suzaku (blue and red). Red data points signify the NW arm of Suzaku observations. Blue points represent the E arm. Solid red line is clump-corrected.

Discussion

- The extracted temperature (top left), density (middle left), and entropy profiles (bottom left) from the simulated data follow the same trends as observed data (right). In particular, the entropy profile shows a similar drop due to clumping as seen in observations.
- Simulation produces realistic cluster data.
- Clumping code allows for precise control over clump parameters.
- Simulated clumping causes a realistic drop in the derived entropy profile.

Future Work

Make things more realistic:

- Add in instrumental and point source background.
- Add in galactic foreground.

Assess STAR-X's capability of detecting clumps

References

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