HOW DOES CHAOTIC TURBULENCE AFFECT THE VIRIALIZATION OF GALAXY CLUSTERS POST COLLISION?

1. Abstract

An in depth understanding of turbulent motions within the intracluster medium would shed further light on how complex structures form within the universe. We propose to observe the Eris Cluster, a galaxy cluster that is composed of majority active galactic nuclei, whose outflows supply kinetic energy to the intracluster medium. The Eris Cluster is currently undergoing a collision with another galaxy cluster. We wish to determine if the chaotic nature present in the ICM of the Eris Cluster will affect the way that both structures will re-virialize after the collision, as well as determine how energy and mass will be distributed in the new structure.

2. Scientific Justification

We have long since known that galaxy clusters are the largest structures in the universe that are virialized, having been first used by Fritz Zwicky in 1933 on the Coma Cluster, where he also first postulated the existence of dark matter (Zwicky, 1933). We also have observed galaxy cluster collisions. These collisions disrupt the energy of each cluster, but over time the resulting structures will end up re-virializing.

During the collision, there will be lots of turbulence present within the intracluster medium (hereafter ICM). Galaxy clusters contain galaxies, hot gas, and dark matter. The hot gas behaves like a fluid and thus allows us to use some properties of fluids, mainly the Reynolds Number. The Reynolds Number is a dimensionless quantity that helps to predict the flow of the fluid. A high Reynolds Number indicated turbulent flow while a low Reynolds Number indicated laminar flow. The Reynolds Number is inversely proportional to the viscosity of the fluid. While still an open question, it is believed that the viscosity of the ICM is extremely low, or at the very least not significant to affect the ratio of density and velocity fluctuations (Marin-Gilabert et al., 2024). Thus from the Reynolds Number, it is expected that the flow of hot gas will result in turbulent flow naturally. Turbulence is also increased by the motion of galaxies, active galactic nuclei (AGN) outflows, and from cluster collisions, as these all add kinetic energy to the hot gas (Sparke and Gallagher, 2007).

The Eris Cluster is a galaxy cluster that happens to be filled with a momentous amount of AGN, and is also colliding with another cluster. The outflow from the AGN present within the cluster supplies the ICM with kinetic energy, thus increasing the turbulent flow within the cluster. Turbulence is important within galaxy clusters as they help describe the mass and energy distribution within the cluster, and the Eris Cluster happens to be a distinct example for observation. The way that we measure turbulence within galaxy clusters is by looking at the x-ray emission of the hot gas, which is a combination of a bremsstrahlung and power law emission spectrum (Kolodzig et al., 2017). The kinetic Sunyaev-Zel'dovich effect also applies to the ICM, having a close correlation to the dynamical state of the cluster (Monllor-Berbegal et al., 2024). We can also infer turbulence through fluctuations present within the thermal spectrum.

The question that needs answering is the following: does the chaotic turbulence present in the Eris Cluster affect how the structures will re-virialize post collision?

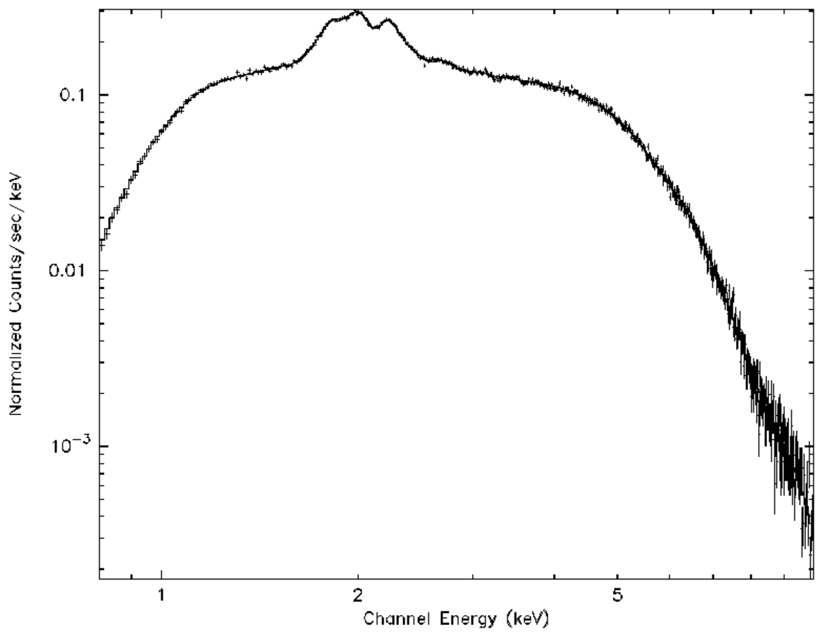

Figure 1: a bremsstrahlung emission simulation from Chandra's HEG grating, made by WepSpec at 1000 ks, column density of $1 \times 10^{22}\ cm^{-2}$, and a temperature of 2 keV, the estimated temperature of the intracluster medium in the Eris Cluster.

3. Observing Plan

We are requesting the use of Chandra's High-Energy Transmission Grating for our observations. Chandra has been used for observations of galaxy cluster collisions before in order to track the distribution of dark matter (Harvey et al., 2015). As can be seen in Figure 2, in combination with Hubble, they managed to plot out the post-collision distribution of stars, as well as infer the distribution of dark matter from the gravitational lensing effect it had on the background light. Chandra observations allowed them to trace out the distribution of the gas.

The determination of the gas distribution in the Eris Cluster will be important. We can use the information regarding the distribution of gas currently present in the Eris Cluster, alongside the other cluster it is colliding with, to try and predict what the subsequent structure would like after the collision ends. Simulations of cluster collisions have been performed before (see Ricker, 1998, and Willis, 2025). If we are allowed to use Chandra for our observations, we can then perform simulations with the data from the Eris Cluster to predict how the resulting post-collision structure and re-virialization will occur.

Figure 2: Credit to : NASA/ESA/STScI/CXC, D. Harvey (Ecole Polytechnique Federale de Lausanne, Switzerland; University of Edinburgh, UK), R. Massey (Durham University, UK), T. Kitching (University College London, UK), and A. Taylor and E. Tittley (University of Edinburgh, UK. The images presented here are 6 different galaxy clusters observed by Harvey et al. The blue represents the distribution of dark matter post-collision, while the pink represents the gas post-collision.

4. **Technical Feasibility**

We are requesting 1000 ks with Chandra's HETG viewed through a Galactic column density of around $2 \times 10^{20} cm^{-2}$. Chandra's sensitivity with the HETG is 0.8 keV - 10 keV covers the expected temperature of the Eris Cluster (also refer to Figure 3). Chandra's higher angular resolution will also assist in distinguishing the finer details of the x-ray spectrum that we hope to use to understand the turbulence. The visibility of the Eris Cluster was checked with ObsVis, the Chandra Observation Visualizer to determine the visibility periods, where it was determined that the Eris Cluster will be visible for 1000 ks throughout Cycle 27.

5. **Conclusion**

By observing the Eris Cluster's highly turbulent ICM with Chandra's HETG, we can use the obtained data to perform simulations to determine the effects on re-virialization of the post-collision structures and to further our understanding of how turbulence affects the intracluster medium.

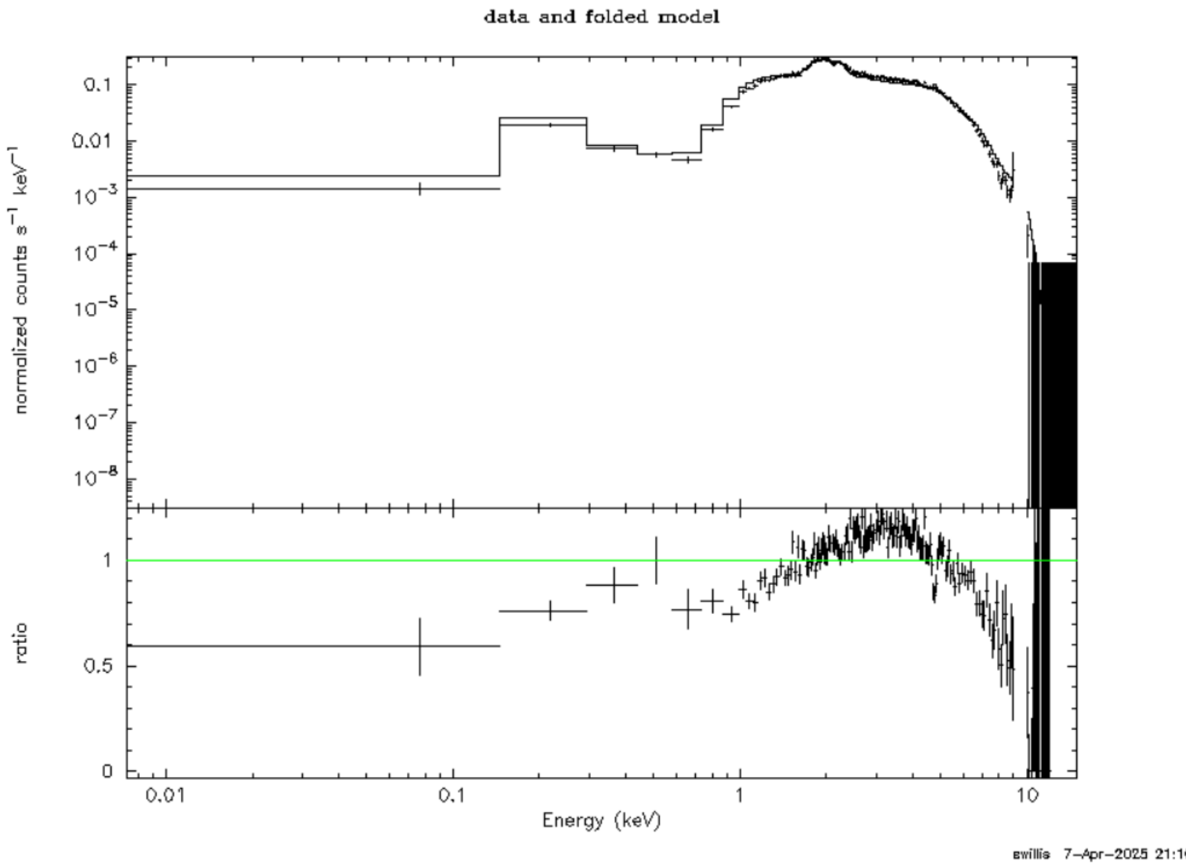

Figure 3: The residuals that remain from fitting a power law and a bremsstrahlung component to the simulated data from WebSpec. This plot has a reduced chi-squared of 1.93672. The ratio line fits rather well with the simulated data between energies of 1.4 keV and 5 keV.

6. References

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Notices of the Royal Astronomical Society, Volume 473, Issue 4, February 2018, Pages 4653–4671, https://doi.org/10.1093/mnras/stx2581;