Searching for Warm Dark Matter in Merging X-ray Clusters

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1 Abstract

A project is being carried out to look for a potential Warm Dark Matter (WDM) candidate particle in the merging Bullet Cluster system. Using a sterile neutrino model of WDM proposed by Abazajian *et al.* [1] and data from the XCS Survey, the project aims to use X-ray spectroscopy to further constrain the WDM particle mass.

2 What is Warm Dark Matter?

Historically, evidence for dark matter in the Universe has been mounting, both from observations of the velocity dispersion in clusters and from the presence of galaxy rotation curves that do not match those predicted by the inverse-square law. Additionally, the suggested mass from strong lensing and the necessary theoretical component in simulations of large-scale structure formation have led to the standard "Cold" dark matter, being both collisionless and interacting by gravity alone. Having a short free-streaming scale, (till recently) CDM produced a large excess of dwarf galaxies in simulations. The proposal for "Hot" dark matter, with a long free streaming length, would lead to the wiping out of small structure in these simulations. The proposal for an intermediate candidate, a so-called Warm Dark Matter (WDM) particle, is warranted.

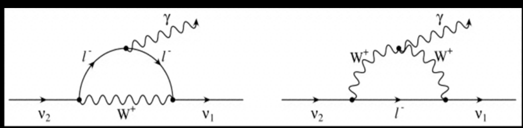

FIGURE 1: Principal radiative decay modes for massive singlet neutrinos. [1]

Abazajian *et al.* [1] point to the potential of indirectly observing a potential WDM particle - the singlet ("sterile") neutrino - using X-ray telescopes. Their model presents the sterile neutrino as spontaneously decaying into an X-ray photon (as in Figure 1), with an energy somewhere in the 1-10 keV range and most likely ≤ 5 keV. Although the predicted flux is unlikely to be measurable with current generation telescopes, some reasonable analysis can be made to help constrain this model further.

3 The Bullet Cluster, 1E 0657-56

FIGURE 2: Bullet Cluster, 1E0657-56: X-ray emitting gas in pink, weak lensing map (i.e. the majority of the mass) in blue [2]

Figure 2 shows the merging Bullet Cluster system. The bright pink, as imaged by Chandra, indicates X-ray emission from hot, IGM plasma, where the two merging sub-clusters have been excited by collision. The blue, representing the weak lensing map, indicates where the mass is distributed. As this is dislocated from the hot gas, it must be comprised of the non-collisional elements that have sailed right-through, i.e. galaxies and any hypothetical, non-interacting dark matter. This observation has had major ramifications for alternative theories of gravity, such as MOND; as while it does not preclude them, it shows that there is necessarily some physical component that can be called dark matter.

Investigations into the Bullet Cluster [3], [4], [5] and a similar system [6], [7] have better constrained the interaction cross-section of these dark matter particles and in the latter case, applied the sterile neutrino model described above to Chandra measurements, shrinking the mass of the sterile neutrino to < 6.3 keV. This project attempts a similar analysis, using XMM Newton observations from the XCS Survey.

The very rare orientation of these systems - perpendicular to the line of sight - is what enables the discrimination of the dark and luminous matter components, making them perfect for observation of dark matter properties. This, coupled with the scarcity of research (especially that constraining candidate particle mass/cross-section) motivates this project.

2 The Project

The aim of the project is to apply this sterile neutrino model to an analysis of XMM Newton observations from the XCS Survey. To do this, I have modified a code that was developed by E. Lloyd-Davies to reduce X-ray data from the XCS pipeline. My modification allows spectra to be extracted from specifically chosen regions. An example of the method is shown in Figure 3, where the regions of interest, i.e. those containing the WDM, have been obtained by overlaying a weak lensing map of the Bullet Cluster (made available by Clowe *et al.* [4], [8]) then extracting the spectra from these regions. In this way the WDM signal is enhanced over that coming from the hot cluster plasma or from point sources. A background region is also selected for later correction.

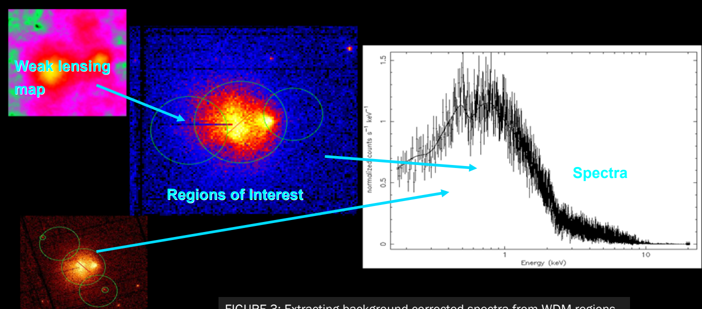

FIGURE 3: Extracting background corrected spectra from WDM regions.

The XSPEC software is then employed to perform a statistical fit based on the Planckian "mekal" model with absorption modelled by "wabs". Further code by Lloyd-Davies that instructs XSPEC to perform repeated fittings was then altered to allow for the addition of a narrow Gaussian line to the model, imitating the sterile neutrino annihilation line. This is incrementally "stepped" through the model spectra at different energies, then fitted at each step, with allowance for changes in the decay line width at different energies. This corrects for XMM's non-linear variation of energy resolution across the energy range. Limits were added to prevent the Gaussian line from becoming confused with the main spectra "hump".

The majority of the project work involved testing this code with simulated spectra (containing "fake" WDM signals) to provide a selection function as a measure of the efficacy of the code. When used on the Bullet Cluster data, a graph of the cash-statistic was derived. The minima represent a good fit between the model and the data, hence showing that there are several emission lines - see figure 4.

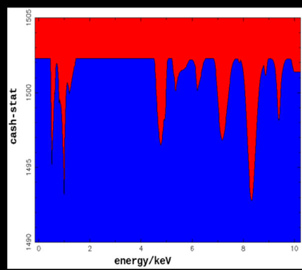

FIGURE 4: Minima of cash-stat indicate emission lines.

Finally, I wrote a piece of automated code to cross-check emission lines found with this method against with those already catalogued (and hence known not to be from WDM). Through a process of elimination, a WDM annihilation line may this be uncovered.

5 Future Work

As yet, nothing conclusive has been found. It is hoped that, due to the lower noise at higher energy, an upper constraint for the sterile neutrino mass may be found to compliment or contradict that found by Boyarsky *et al.* [7]. The limiting factor for both Chandra and XMM observations is the energy resolution at lower energies. It is hoped that this project will assist in a future investigation utilizing later generation telescopes with superior energy resolution.

To extend this project, the modelling in the code will need to take better account of the temperature of the cluster; whilst a cooler cluster will give a stronger DM signal, hotter clusters have less lines to confuse detection. Repeated testing with simulated spectra across a range of temperatures to derive comparative selection functions should find the optimum case.

Further work could include: use of different models and fit statistics, applying other fitting techniques, such as genetic algorithms or annealing, or stacking data from similar mergers to improve SNR.

References

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[8] The Bullet Cluster 1E0657: Official Project Page, <http://flamingos.astro.ufl.edu/1e0657/>.

Special thanks to D. Clowe for making the Bullet Cluster weak lensing maps publicly available [8] and also to my supervisors for their invaluable assistance.