Constraints on Dark Matter and Cosmic Ray Populations in Galaxy Clusters

Galaxy clusters are the largest gravitationally-bound objects in the universe, and have been detected in many wavelengths of light, including optical, x-ray, and radio. The presence of radio emission indicates that non-thermal processes are taking place within clusters. It is expected that clusters also produce gamma (γ) rays, given the detection of non-thermal emission. However, clusters have not yet been observed in this energy band, including by the Large Area Telescope (LAT), the principal instrument aboard the Fermi Gamma-ray Space Telescope. The Fermi-LAT team has used this non-detection to put upper limits on the flux of γ-ray emission from a number of galaxy clusters [1] and place constraints on dark matter annihilation within clusters [2].

Various astrophysical processes within clusters could result in the production of γ-rays, including cosmic ray collisions and dark matter decay and annihilation. Cosmic ray (CR) protons and electrons are thought to be accelerated and injected into the intra-cluster medium (ICM) in a number of ways, including by shock waves caused by structure formation and cluster mergers, active galactic nuclei (AGN) and supernovae within the cluster [3]. Relativistic CR electrons can upscatter cosmic microwave background photons via IC scattering to produce γ-rays, and collisions between CR protons and ICM gas molecules can also produce γ-rays. These inelastic collisions produce neutral pions which decay directly into γ-rays, and charged pions which decay into electrons that can then IC scatter to produce more γ-rays.

The annihilation or decay of dark matter candidate particles known as weakly-interacting massive particles (WIMPs) results in γ-ray emission either directly or indirectly through subsequent decay the annihilation or decay products, which are model-dependent. Decay prodcuts of certain WIMPs include pions, which decay into γ-rays. Leptons are another possible annihilation product, and can produce γ-rays via bremsstrahlung and IC scattering [2]. The shape of the γ-ray spectra resulting from CRs and dark matter are predicted to be different, but also difficult to distinguish from one another without adequate statistics [4]. The shape of the γ-ray spectrum resulting from CR protons is predicted in [3] to be essentially universal across a large sample of clusters. Predicted γ-ray spectra from both CRs and dark matter annihilation for a selection of clusters are presented in [4].

A way to further constrain dark matter annihilation and analyze CR populations within clusters is to stack the data from a well-selected sample. I propose to join the cluster stacking team within the Fermi Collaboration and begin a project to determine the best clusters to stack in order to constrain dark matter, specifically the annihilation cross section and decay lifetime. I will work primarily with Tesla Jeltema and Stefano Profumo on this project; we will also collaborate closely with Jan Conrad and Stephan Zimmer at the University of Stockholm. In addition, we plan to select a sample of clusters for analysis of the γ-ray spectrum due to CRs, also with Olaf Reimer and Keith Bechtol at KIPAC, and Anders Pinzke at University of Stockholm.

A list of clusters with the highest predicted γ-ray fluxes, selected for study from a catalog of clusters with large x-ray fluxes and presence of radio emission, is presented in [1]. Starting with that list of clusters, we will choose candidates based primarily on the predicted γ-ray flux, proximity to the galactic plane (the closer to the plane, the more background from our galaxy), and whether the cluster contains a bright point source previously detected in γ-rays, such as a central AGN, which would be a difficult-to-model large source of background. I have already collected Fermi-LAT data for each of the clusters listed in [1] for regions of interest varying in size ($1°$, $5°$, $10°$) around the coordinates of the center of the cluster. We will treat these data as background, since clusters have not yet been detected by Fermi-LAT. We will add a modeled γ-ray signal, resulting from dark matter annihilation or decay, to each cluster and determine which clusters have the best signal-to-noise ratios. We can then select a sample of clusters for stacking and test how the addition or subtraction of particular clusters from our sample affects constraints. Preliminary work in calculating dark matter annihilation cross sections from clusters has been done by collaborators in Stockholm. There are only a handful of clusters that have very large γ-ray fluxes and low background, but we may be able to provide significantly better constraints if a larger sample of clusters with lower fluxes are included in the analysis.

We will also select a sample of clusters for CR analysis using a similar method as for dark matter. However, selecting clusters for CR analysis will be more difficult than for dark matter. While simulations have shown that the CR proton spectrum and distribution within clusters is uniform [3], choosing the most appropriate method for adding signal to the clusters will require careful consideration of all of the possible CR channels for γ-ray production within clusters.

I am currently funded by the UCSC Graduate Division through the Cota-Robles fellowship, and am an affiliated student member of the Fermi-LAT team. I am using the Fermi Science Tools, a free, publicly available suite of analysis tools developed by the Fermi Collaboration for my analysis. While clusters may be detected in γ-rays by Fermi-LAT in the future, we can extract interesting constraints on dark matter and analyze the CR population within clusters with currently available data, using a stacking analysis. We hope to have presentable results, at least for dark matter, by May, in time for the Fermi Symposium, and also plan to present our results in a paper.

References

[1] M Ackermann et al. Gev gamma-ray flux upper limits from clusters of galaxies. *The Astrophysical Journal Letters*, 717(1):L71, 2010.

[2] M Ackermann et al. Constraints on dark matter annihilation in clusters of galaxies with the Fermi large area telescope. *Journal of Cosmology and Astroparticle Physics*, (05):025, 2010.

[3] Anders Pinzke and Christoph Pfrommer. Simulating the gamma-ray emission from galaxy clusters: a universal cosmic ray spectrum and spatial distribution. *Mon. Not. Astron. Soc.*, 409(2):449, 2010.

[4] Tesla Jeltema, John Kehayias, and Stefano Profumo. Gamma rays from clusters and groups of galaxies: Cosmic rays versus dark matter. *Physical Review D*, 80(2):1, 2009.