Creating Dark Matter Mass Maps using Stratospheric Balloon Observations

Adam Aoua, YSP Student, *Belmont High School*
Karuna Tarafdar, YSP Student, *Newton South High School*
Sayan Saha, Physics, *Northeastern University*
Jaqueline McCleary, Physics, *Northeastern University*

NSF

YOUNG SCHOLARS PROGRAM

Northeastern University College of Science

Northeastern University Michael B. Silevitch and Claire J. Duggan Center for STEM Education

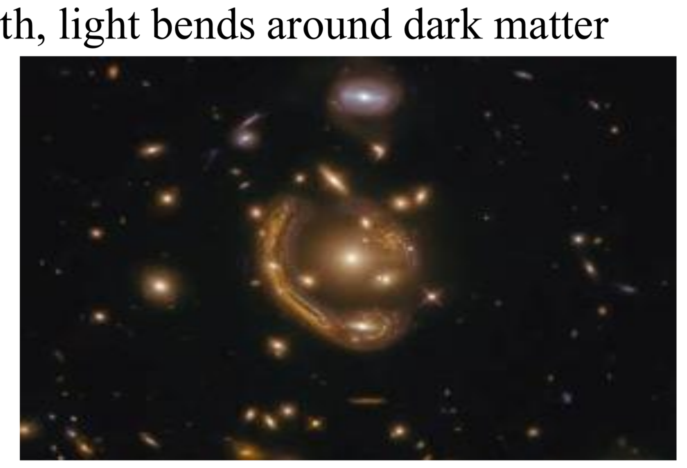
Abstract

The Super Pressure Balloon-borne Imaging Telescope (SuperBIT) completed its science flight in Spring 2023. Since then, extensive work has been carried out to process the imaging data and measure the shapes of thousands of galaxies. In this project, we used these measurements to construct weak-lensing mass maps of ~20 galaxy clusters. These maps trace the total mass distribution (both baryonic matter and dark matter) by measuring small distortions in the shapes of background galaxies. To further understand the distribution of dark matter, we created Signal to Noise (SNR) graphs which map the strength of gravitational lensing (a method of dark matter detections). Then, we created an algorithm to refine the graphs to maximize SNR peaks, which increases the certainty of dark matter presence. This tool can be used for future cosmological research.

SuperBIT preparing for test flight in 2017

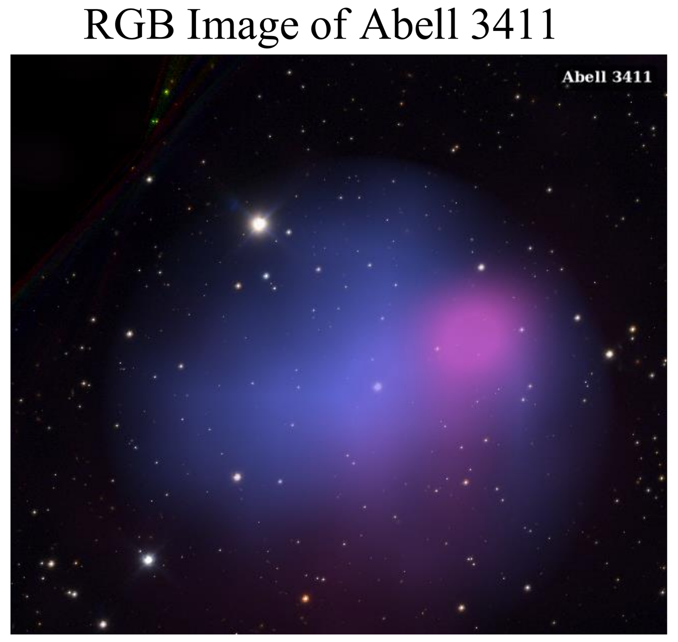
Background

Only 5% of the universe is composed of baryonic (ordinary) matter, while 27% is dark matter and 68% is dark energy. Dark matter, the focus of our project, does not emit, absorb, or reflect any electromagnetic waves, meaning it is invisible. Instead, dark matter can be detected through weak gravitational lensing. When distant galaxy clusters are observed from earth, light bends around dark matter and the distant galaxy will appear distorted. A major challenge during the measurement of gravitational lensing is differentiating between stars and galaxies as both appear as bright spots in the sky. Stars are located in the Milky Way and do not lens. Failing to remove them will result in a diluted signal. Our research accounts for this using Source Extractor. Once gravitational lensing is measured, it is shown in Signal to Noise Ratio (SNR) maps, which compare the amount of bending from gravitational lensing (Signal) to the random orientations of galaxies (Noise) at each position in a galaxy cluster. Ranging values of SNR represent the different levels of dark matter certainty. Our goal is to increase the certainty of dark matter. To do so, we created a tool to maximize the peak SNR in SNR graphs. Finally, to visualize the location of dark matter relative to stars, galaxies and baryonic matter in the galaxy cluster, the results from the refined SNR graph is overlayed onto the RGB images. RGB images are created by shifting galaxy cluster images from the SuperBIT up the electromagnetic spectrum.



"Molten Ring" taken in 2020 by the Hubble Space Telescope, showing gravitational lensing

RGB Image of Abell 3411



X-ray (hot gas, baryonic matter)

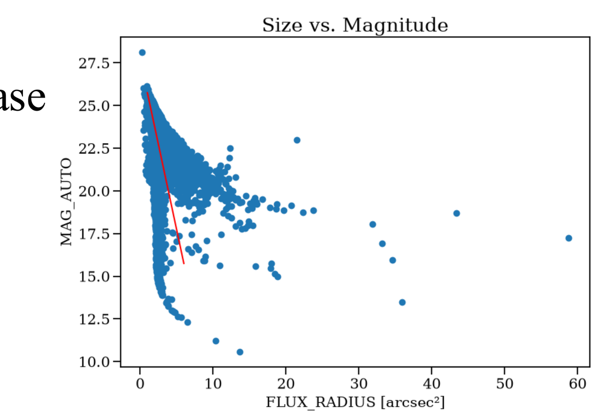
Dark matter

Experimental Methods

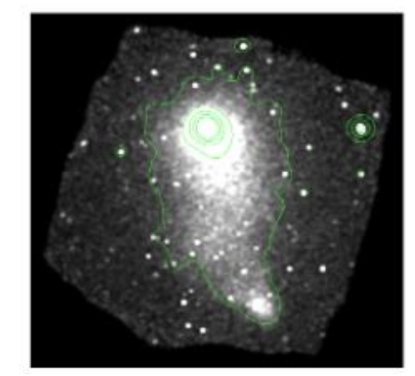
Software Applications:

- VS Code, through the Explorer HPC cluster database
- SAO Image DS9, astronomical imaging and data visualization

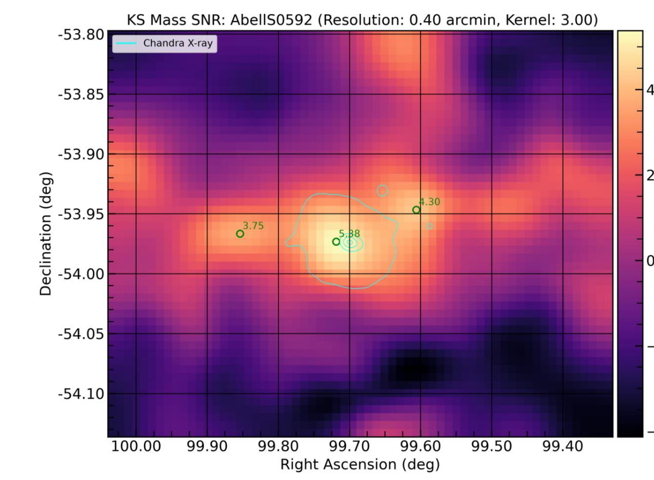
- Used source extractor to detect sources on raw imaging data and measure photometric quantities
- Created a classifier using source extractor to differentiate between galaxies and stars
- Created Signal to Noise Ratio (SNR) maps
- Created x-ray contours used in the SNR images
- Manually tuned SNR maps to maximize SNR
- Automated the tuning process with a python code
- Refined our code by:
  - Preventing over smoothing
  - Only looking at the central galaxy cluster
  - Minimizing B mode
- SNR images provide location about the position and certainty of dark matter
- Overlayed dark matter and baryonic matter on RGB images



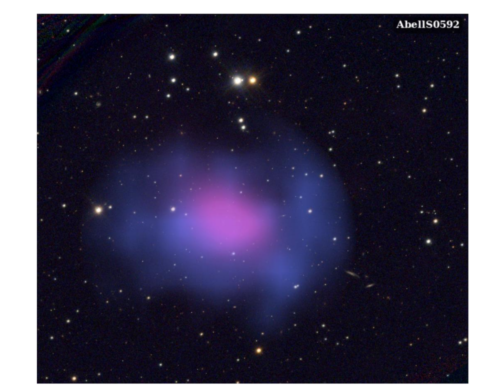
Graph of objects detected from Source Extractor of the 1E0657 Bullet Cluster, inverse magnitude of brightness is on the y-axis & the size of the object is on the x-axis



X-ray contour of Abell 2384a, created in DS9



SNR image of Abell S0592



RGB image of Abell S0952 with baryonic matter (pink) and dark matter (purple) overlayed

Conclusion and Future Steps

Our optimization function for SNR maps will be used by other researchers in the SuperBIT collaboration (UToronto, Princeton, NASA JPL, and Durham University, etc.) to continue mapping dark matter across the universe.

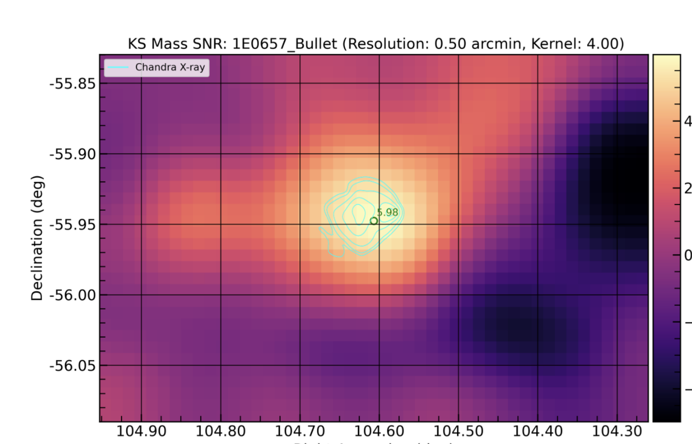
Future steps include continuing to fine tune our optimization function to make it as accurate and efficient as possible. Additionally, while we were creating SNR graphs for the galaxy clusters we noticed that for some of them the positions of the dark matter (bright spots) were completely off to the side. In the future, we could look into why this is and fix these images. Finally, we would run the optimization function on all 20 galaxy clusters to map dark matter and improve our certainty and accuracy in these maps.

Results

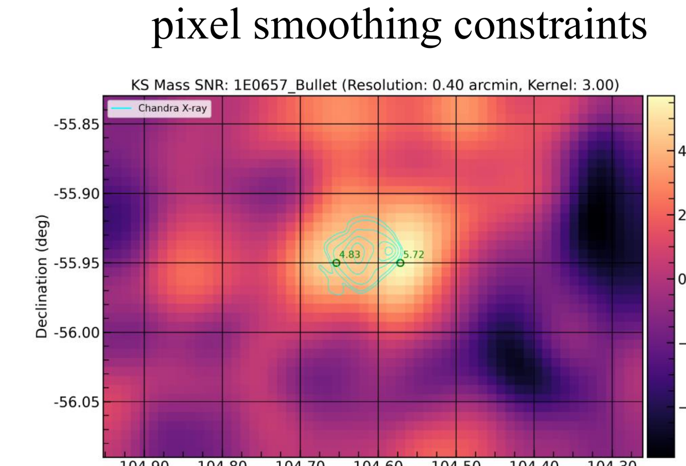
We used the new SNR images, which were tuned through the optimization function, to create new kappa files. Then, we overlayed the kappa files onto our original RGB galaxy cluster images.

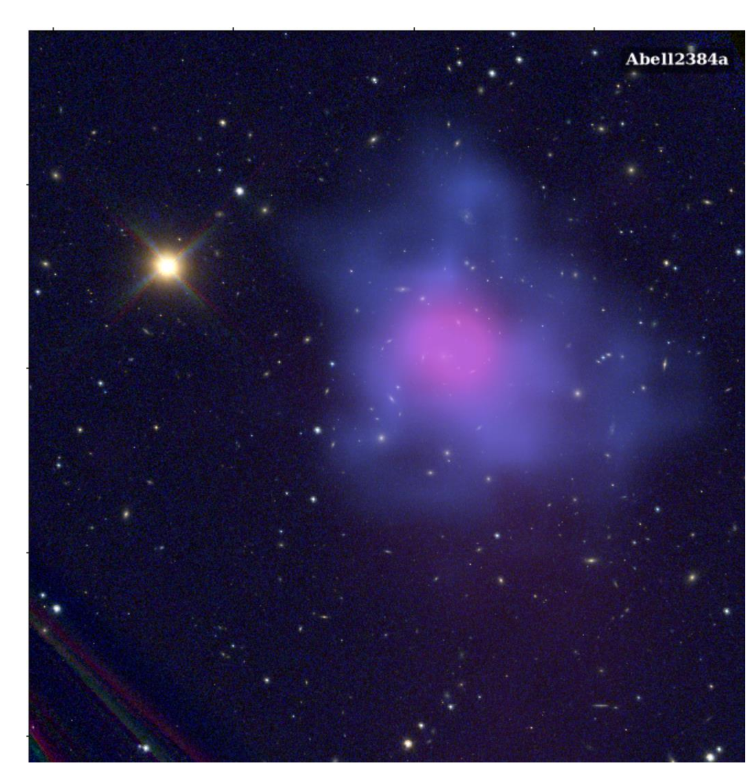
Before running the optimization function the SNR images had significantly lower peaks. Increasing the highest peaks on SNR images is important as a higher peak corresponds to a greater certainty of dark matter. Overall, this helps create a more accurate map of dark matter, allowing researchers to get a better understanding of dark matter's function in our universe.

The bullet cluster consists of two merging clusters, but only one is present here because the function oversmoothed the clusters into one cluster



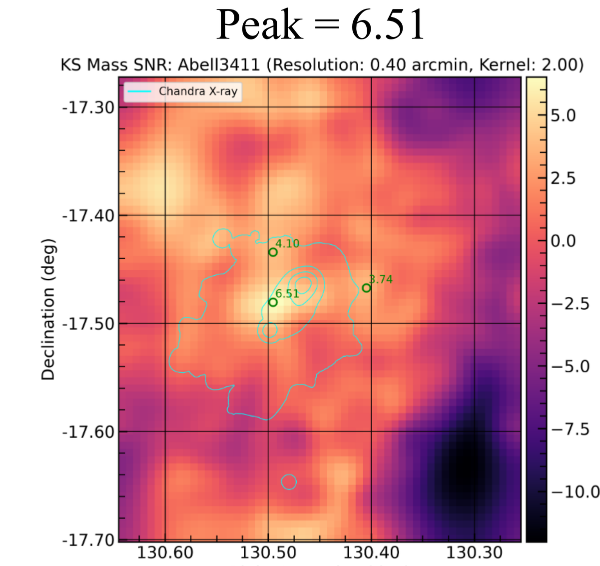
After tuning 1E0657_Bullet, with pixel smoothing constraints



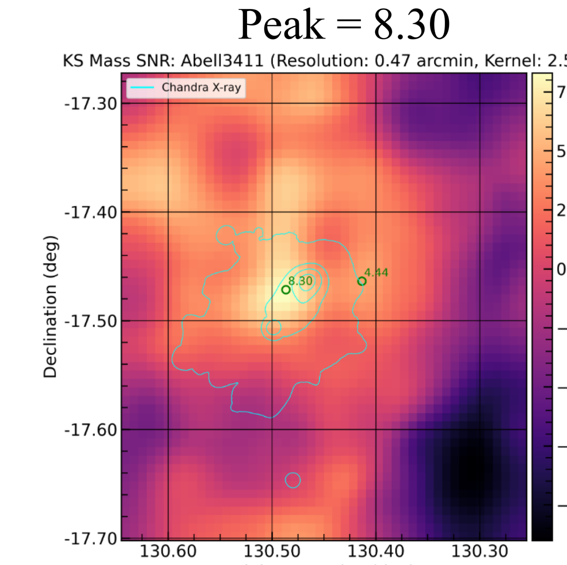


RGB image of Abell 2384a with baryonic matter (pink) and dark matter (purple) overlayed

Before tuning Abell3411, Peak = 6.51



After tuning Abell3411, Peak = 8.30



References

Balzer, A. (2026, April 16). Weak Lensing. NASA. Retrieved July 23, 2026, from https://science.nasa.gov/mission/roman-space-telescope/weak-lensing/

Díaz-Sánchez, A. (2025, Aug 17). "Molten Ring" Galaxy. NASA. Retrieved July 23, 2026, from https://science.nasa.gov/asset/hubble/molten-ring-galaxy/

Stoltz, J. (2026, Jul 15). Dark Matter. NASA. Retrieved July 23, 2026, from https://science.nasa.gov/dark-matter/

University of Toronto. (2017, May 10). Welcome to SuperBIT. UToronto. Retrieved July 23, 2026, from https://sites.physics.utoronto.ca/bit

Acknowledgements

Cosmology and Astrophysics Lab
Prof. Jacqueline McCleary, Assistant Professor of Physics
Sayan Saha, Postdoctoral Research Associate
Center for STEM Education
Claire Duggan, Executive Director
Jennifer Love, Associate Director
Ahmed Othman, Kenneth Carbajal, & Francis Corcell, YSP Coordinators
Nicolas Fuchs, Program Manager
Mary Howley. Administrative Officer

This work was supported by the National Science Foundation