Systematics Mitigation in SuperBIT Weak Lensing Data

Leila Ohashi, YSP Student, *Boston Latin School*
Marcus Michaud, YSP Student, *Boston Latin School*
Sayan Saha, Physics, *Northeastern University*
Jacqueline McCleary, Physics, *Northeastern University*

Northeastern University College of Science

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

Abstract

About 95% of the universe is composed of invisible components, roughly 69% dark energy and 26% dark matter, while only ~5% is ordinary (baryonic) matter, which we can observe through electromagnetic radiation. Despite being a small fraction, this visible matter can help us infer properties of the dark components. The Super Pressure Balloon-Borne Imaging Telescope (SuperBIT) targeted ~35 merging galaxy clusters, ideal sites to study the dark matter distribution in a non-equilibrium environment. Our goal was to improve the accuracy of results extracted from SuperBIT images through careful handling of systematics. In this project, we cleaned up noise and diffraction patterns that caused spurious detections near bright stars and image edges, and differentiated between background and cluster member galaxies. This all works towards the greater goal of more completely understanding the interplay between baryonic and dark matter.

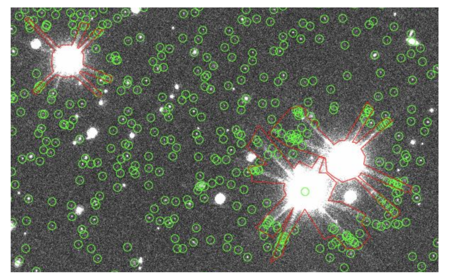
Background

Although dark matter makes up 26% of the universe, many of its properties still remain unknown, including its composition and non-gravitational interactions. One way to probe dark matter is a phenomenon called weak gravitational lensing. Gravitational lensing is the bending of light around large sources of mass, usually galaxy clusters, the largest gravitationally bound structures. That phenomenon results in distorted projections of objects that are behind the source of mass. By analyzing the magnification and shear of the lensed objects, the lens itself, which is mostly composed of dark matter, can be studied. Source Extractor, an analysis tool, catalogs objects in the images, but can misidentify image noise and star diffraction spikes as objects. These misidentifications must be manually corrected through masking. Then, the cluster member galaxies must be isolated from background galaxies in order to analyze background distortions. The membership of galaxies can be determined by several properties, including color, positions, and radii. All the cluster member galaxies have the same apparent redness, meaning that that color can be an identifier for cluster membership. Further analysis of position and size of the galaxy must be done to confirm the membership.

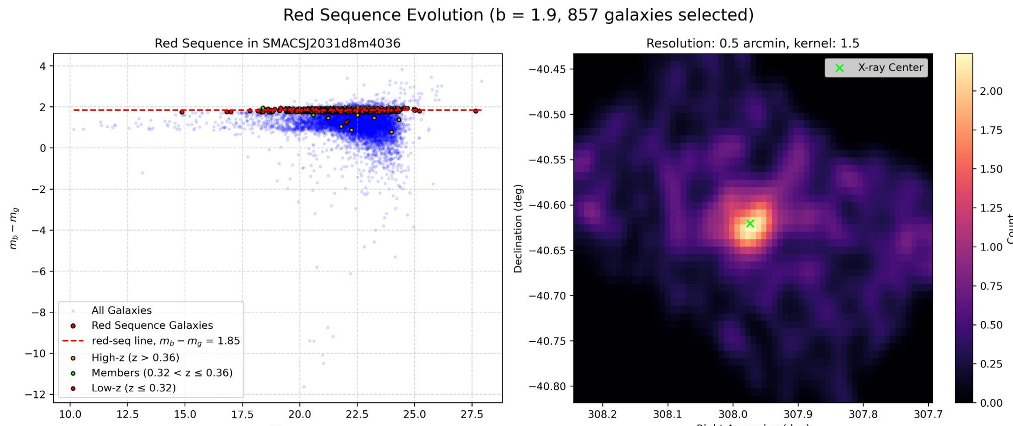
Strong gravitational lensing distortions in an image taken by JWST (from Webb Space Telescope)

Experimental Methods

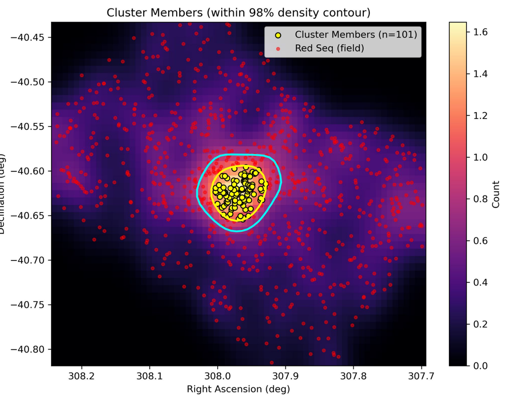
1. Image Masking with DS9 (astronomical imaging application)
   1.1. Create region files of polygons to mark diffraction spikes and noise
2. Red Sequence Galaxy Analysis
   2.1. Identify the common color of the galaxy members based on the colors of known cluster members
   2.2. Graph the positions of the galaxies to observe if they cluster
   2.3. Create contours to identify the cluster members
   2.4. Remove imposter members using radii data
   2.5. Check RGB image to confirm that background galaxies are not included as cluster members

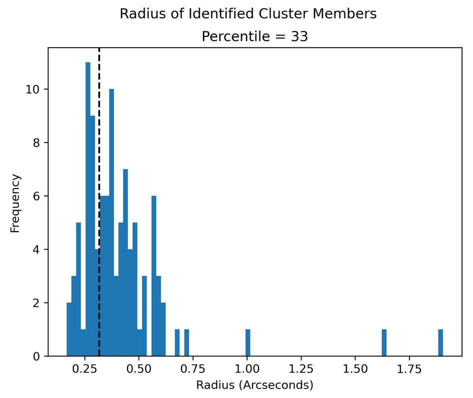


Polygon masking to create region files on DS9 for SMACSJ2031d8m4036



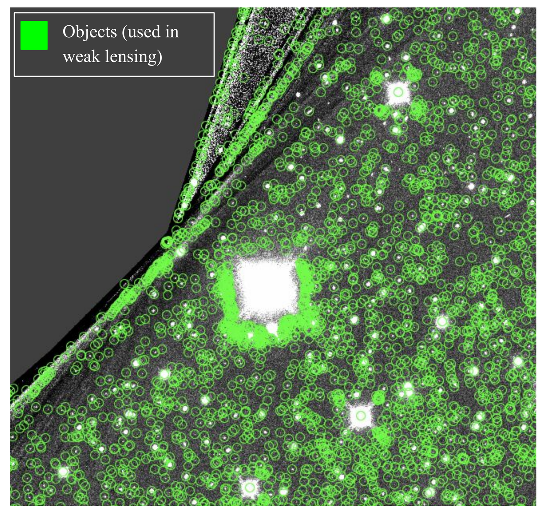
Color identification (left) and observation of clustering (right) for SMACSJ2031d8m4036



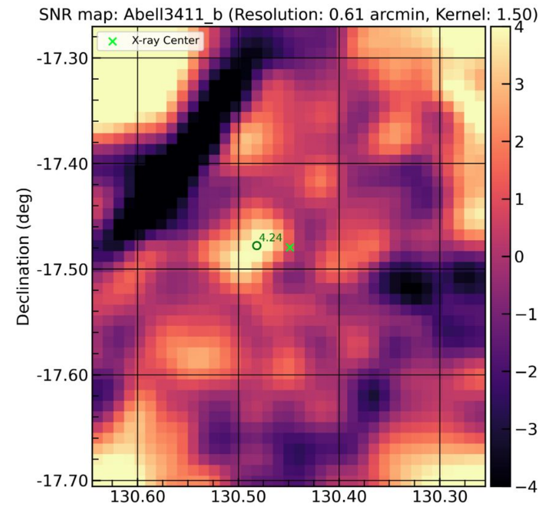


Contouring to identify cluster members (left) and removing imposters with radii (right) for SMACSJ2031d8m4036

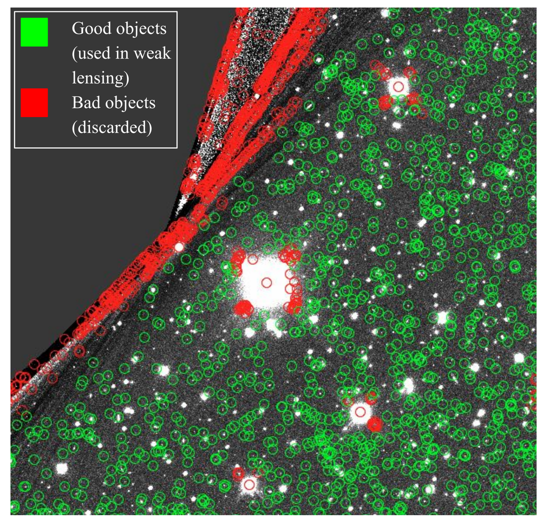
Results



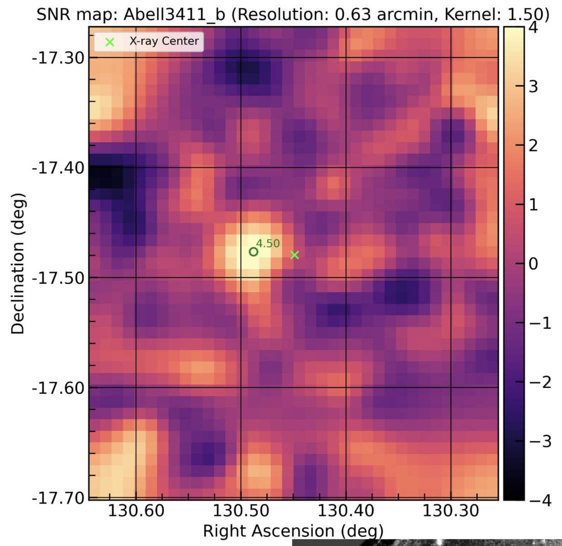
Visual of cataloged objects with bad detections for Abell 3411



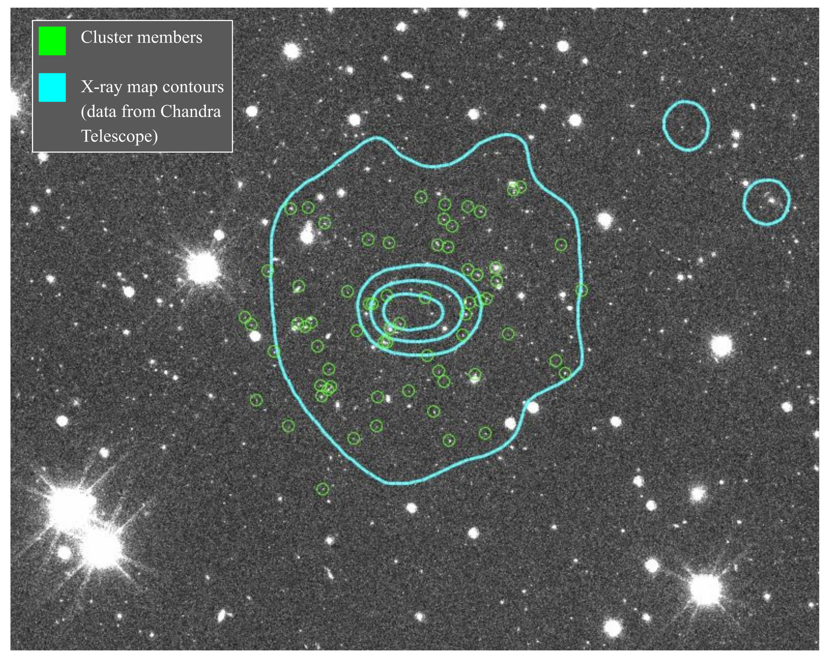
Gravitational lensing signal with bad detections for Abell 3411

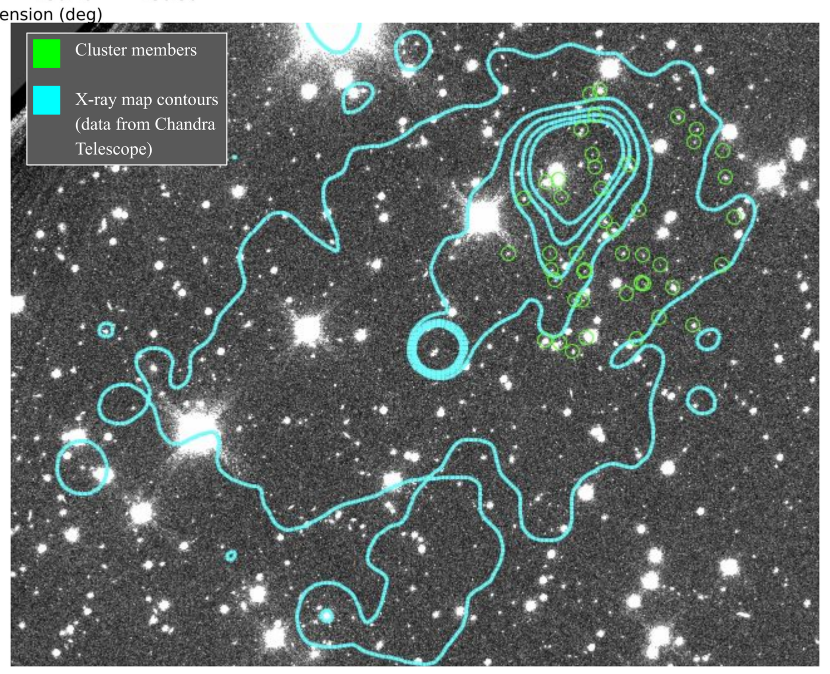


Visual of cataloged objects with corrected detections for Abell 3411



Gravitational lensing signal with corrected detections for Abell 3411





Identified galaxies in galaxy cluster overlaid with X-ray map for SMACSJ2031d8m4036 (left) and Abell 3411 (right)

Conclusion and Future Steps

Conclusion: The original objective to mitigate the systematics in the lensing data was accomplished. Misidentified objects were removed from the object catalog of SuperBIT images, and background galaxies were isolated from the cluster members through analysis of color, position and radii.

Future Work: To understand the distribution of dark matter, the weak lensing signals need to be analyzed via the distortions in the background galaxies. The cluster members that we identified also serve as an independent probe. Dark matter can be studied further by looking at the interplay between different probes, such as X-ray data.

References

Abell Catalog of Galaxy Clusters. (n.d.). Go Astronomy. Retrieved July 21, 2025, from https://go-astronomy.com/abell-cluster.php?Abell=3144

Astronomical coordinate systems. (2025, July 6). Wikipedia. Retrieved July 21, 2025, from https://en.wikipedia.org/wiki/Astronomical_coordinate_systems

The Bullet Cluster. (2006, August 21). Harvard Chandra X-Ray Observatory. Retrieved July 21, 2025, from https://chandra.harvard.edu/graphics/resources/handouts/lithos/bullet_lithos.pdf

Equatorial coordinate system. (2025, March 20). Wikipedia. Retrieved July 21, 2025, from https://en.wikipedia.org/wiki/Equatorial_coordinate_system

Fraknoi, A., Morrison, D., & Wolff, S. C. (2022). *Astronomy 2e* (2nd ed.). OpenStax CNX.

Gravitational Lensing. (n.d.). Center for Astrophysics. Retrieved July 21, 2025, from https://www.cfa.harvard.edu/research/topic/gravitational-lensing

Nancy Grace Roman Space Telescope. (n.d.). NASA. Retrieved July 21, 2025, from https://roman.gsfc.nasa.gov

Parallax in astronomy. (2025, June 22). Wikipedia. Retrieved July 21, 2025, from https://en.wikipedia.org/wiki/Parallax_in_astronomy

Photometric system. (2025, February 27). Wikipedia. Retrieved July 21, 2025, from https://en.wikipedia.org/wiki/Photometric_system

Sutter, P. (2022, August 22). *Dark matter could finally reveal itself through self-interactions*. Space.com. Retrieved July 21, 2025, from https://www.space.com/dark-matter-theory-self-interacting

Weak Gravitational Lensing. (2025, February 12). Wikipedia. Retrieved July 21, 2025, from https://en.wikipedia.org/wiki/Weak_gravitational_lensing#:~:text=Gravitational%20lensing%20acts%20as%20a,down%20this%20%22shape%20noise%22.

Webb's First Deep Field (NIRCam Image) [Photograph]. (2022, July 12). Webb Space Telescope. https://webbtelescope.org/contents/media/images/2022/035/01G7DCWB7137MYJ05CSH1Q5Z1Z?Tag=Gravitational%20Lensing

Acknowledgements

Northeastern Cosmology Group

Jacqueline McCleary, Assistant Professor of Physics

Sayan Saha, Postdoctoral Research Associate

Center for STEM Education

Claire Duggan, Executive Director

Jennifer Love, Associate Director

Victoria Berry, D'mitra Mukasa & Ahmed Othman, YSP Coordinators

Nicolas Fuchs, Program Manager

Mary Howley, Administrative Officer

This work was supported by the National Science Foundation