AMR Simulations of the Cosmological Light Cone: SZE Surveys of the Synthetic Universe

Eric J. Hallman¹, Brian W. O’Shea², Michael L. Norman³, Rick Wagner³, Jack O. Burns¹

¹ Center for Astrophysics and Space Astronomy, Department of Astrophysical & Planetary Science, University of Colorado, Boulder, CO 80309
² Los Alamos National Laboratory, Los Alamos, NM 87501
³ Center for Astrophysics and Space Sciences, University of California-San Diego, 9500 Gilman Drive, La Jolla, CA 92093

1 Abstract

We present preliminary results from simulated large sky coverage (∼100 square degrees) Sunyaev-Zeldovich effect (SZE) cluster surveys using the cosmological adaptive mesh refinement N-body/hydro code Enzo. We have generated simulated light cones to match the resolution and sensitivity of current and future SZE instruments. These simulations are the most advanced calculations of their kind. The simulated sky surveys allow a direct comparison of large N-body/hydro cosmological simulations to current and pending sky surveys. Our synthetic surveys provide an indispensable guide for observers in the interpretation of large area sky surveys, and will develop the tools necessary to discriminate between models for cluster baryonic physics, and to accurately determine cosmological parameters.

2 Background and Method

Clusters of galaxies form from the highest peaks in the primordial spectrum of density perturbations generated by inflation in the early universe. They are the most massive virialized structures in the universe, and as such are rare objects. The number density of galaxy clusters as a function of mass and redshift is strongly dependent on a number of cosmological parameters [1, 2]. Cluster survey yields depend on the value of the minimum flux probed as a function of redshift, the growth function of structure, and the redshift evolution of the comoving volume element [3].

The simulation used to generate the light cones described in this poster is of a 512 Mpc/h comoving volume of the universe, with the following cosmological parameters: \((\Omega_b, \Omega_{CDM}, \Omega_{\Lambda}, h, n, \sigma_8) = (0.04, 0.26, 0.7, 0.7, 1.0, 0.9)\).
The simulation was initialized on a $512^3$ root grid with $512^3$ dark matter particles, corresponding to a dark matter (baryon) mass resolution of $7.2 \times 10^{10}$ ($1.1 \times 10^{10}$) $M_{\odot}/h$ and an initial comoving spatial resolution of 1 Mpc/h. The simulation was then evolved to $z=0$ using a maximum of 4 levels of adaptive mesh refinement. This simulation results in a higher dynamic range than achieved by any previous AMR cosmological simulation representing such a large physical volume.

These light cone simulations are run with both dark matter and baryons, unlike most previous similar studies. It has been shown in recent studies using both simulations [e.g., 1] and high resolution X-ray observations of galaxy clusters [e.g., 2, 3] that many clusters show strong departures from both equilibrium and isothermality. These deviations can have a strong impact on both the observable and derived properties of clusters. We have previously shown that deviations of factors of 10 or more are common in SZE and X-ray observables during even low mass ratio mergers. Thus, in order to properly simulate sky surveys, it is critically important to self-consistently include baryons in numerical simulations.

The light cone discussed here was generated from the above simulation using a stacking method similar to that used by [4], but with 100 times the angular coverage of the best previous N-body+hydro light cone of [5]. We simulate an SZE observation of a 100 square degree region of the sky, looking at the corresponding comoving volume of the universe from $z=0.1$ to $z=2.75$. We use 26 discrete volumes of $\delta z \approx 0.1$. We have generated SZE Compton $y$ parameter images that are 2048 pixels on a side and cover 10 degrees x 10 degrees at a resolution of approximately 17.5 arcseconds/pixel. The images are then degraded using Gaussian smoothing to the resolution of several experiments which will be providing SZE data in the very near future, including APEX-SZ, the South Pole Telescope, the Planck Surveyor and the Atacama Cosmology Telescope.

This work was supported in part by a grant from the U.S. National Science Foundation (AST-0407368).

References

[1] L. Wang and P. J. Steinhardt. Cluster Abundance Constraints for Cosmological Models with a Time-varying, Spatially Inhomogeneous Energy Component with Negative Pressure. ApJ, 508:483–490, December 1998.
[2] Z. Haiman, J. J. Mohr, and G. P. Holder. Constraints on Cosmological Parameters from Future Galaxy Cluster Surveys. ApJ, 553:545–561, June 2001.
[3] P. Rosati, S. Borgani, and C. Norman. The Evolution of X-ray Clusters of Galaxies. ARA&A, 40:539–577, 2002.
Fig. 1. 10 × 10 degree synthetic SZE Compton y survey image from Enzo AMR simulation of comoving 512 Mpc/h volume. The simulation contains $512^3$ root grid zones and $512^3$ dark matter particles with up to 4 levels of dynamic refinement. The image contains $2048^2$ pixels for an angular resolution of $\sim 0.3$ arcmin/pixel. Image contains structures from $z=2.75$ to $z=0.1$.

[4] E. Rasia, S. Ettori, L. Moscardini, P. Mazzotta, S. Borgani, K. Dolag, G. Tormen, L. M. Cheng, and A. Diaferio. Systematics in the X-ray cluster mass estimators. *MNRAS*, 369:2013–2024, July 2006.

[5] A. Vikhlinin, M. Markevitch, S. S. Murray, C. Jones, W. Forman, and L. Van Speybroeck. Chandra Temperature Profiles for a Sample of Nearby Relaxed Galaxy Clusters. *ApJ*, 628:655–672, August 2005.

[6] M. Markevitch, A. H. Gonzalez, L. David, A. Vikhlinin, S. Murray, W. Forman, C. Jones, and W. Tucker. A Textbook Example of a Bow Shock in the Merging Galaxy Cluster 1E 0657-56. *ApJL*, 567:L27–L31, March 2002.

[7] A. C. da Silva, D. Barbosa, A. R. Liddle, and P. A. Thomas. Hydrodynamical simulations of the Sunyaev-Zel’dovich effect. *MNRAS*, 317:37–44, September 2000.
[8] V. Springel, M. White, and L. Hernquist. Hydrodynamic Simulations of the Sunyaev-Zeldovich Effect(s). *ApJ*, 549:681–687, March 2001.