MODELING THE PRODUCTION OF INTERGALACTIC LIGHT IN THE PRE-COLLAPSE PHASE OF GALAXY GROUPS

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This paper reports one recent result from a set of pre-virialized galaxy group simulations that are being used in an investigation of measurement techniques for the quantity of intragroup light (IGL). We present evidence that the binding energy of the stellar material stripped from the galaxies is essentially uncorrelated with the local mass density. This suggests that IGL detection methods based on the distribution of luminosity perform poorly in detecting the unbound stars.

Keywords: galaxies: interactions, intergalactic medium, methods: N-body simulations

1. Introduction

The IDILICO project is an international collaboration that studies the assembly of galaxy aggregations from high-resolution, numerical simulations. We have recently finished the construction of an N-body model of a pre-virialized galaxy group specifically tailored for gaining understanding of the role of gravity on structure formation and galaxy evolution in the framework of the ΛCDM concordance cosmology. The properties of our group model are motivated by current theories of hierarchical galaxy formation and satisfy numerous observational constraints, providing a realistic caricature of these systems in which galaxies endure both continuous mass accretion from their surroundings and frequent interactions with neighbors in a changing environment.

Presently, our interest is focused on the galaxy mergers that occur within collapsing groups because of the hierarchical buildup of structure and, especially, on the accompanying production of diffuse, low surface brightness intergalactic light (IGL). Our method is to build and analyze a large statistical sample of such mergers. Here, we present one of the most important results we have obtained so far.

2. Simulations

Groups with $O(10^7)$ particles are created as uniform, spherical CDM perturbations at $z_i = 3$. The initial overdensities are such that the groups expand first linearly, then go through the turnaround, and finally experience a completely non-linear collapse at $z \sim 0$, as done in the pioneering work by Ref. 1. Each group contains 20 randomly distributed galactic halos with a Navarro-Frenk-White profile truncated at the virial radius. A 5% of the total galactic halo mass is placed at its center in the form of cold baryons (stellar particles). The gross structural and dynamical properties of this component are fixed by the virialized, extended CDM envelope following the analytical galaxy formation model by Ref. 3.
The total mass of the galactic halos is assigned according to a Monte Carlo realization of a flat ($\alpha = -1$) Schechter mass function down to $M/M^* = 0.05$. The smallest halos, $0.05 < M/M^* < 0.1$, are assumed to host only spheroidal stellar distributions. Above this latter mass threshold, morphologies are randomly drawn assuming a late-type galaxy fraction of 0.7. For early-type objects and bulges we adopt a Hernquist profile, while late-type galaxies have exponential stellar disks and isothermal vertical distributions. The adopted DM to stellar particle mass ratio is 28.50. The groups’ mass is set to $M_{\text{grp}} = 10^{13} h^{-1} M_\odot$.

The evolution of structure in our simulations is traced by a procedure that relies on an unbiased definition of the reference frame for unbinding which is unaffected by the recursive particle removal. Our halo finder algorithm also allows galactic halos to experience mass losses due to gravitational interaction with their neighbors, as well as mass growth due to the accretion and merger of surrounding matter and/or the re-capture of already stripped material.

3. Discussion and Results

The IGL consists of stars not bound to any galaxy. This physically appealing definition is, however, not observationally feasible. One of the handy alternatives to replace binding energy is local density. In its simplest form, density-based definitions adopt a limiting threshold below which stellar particles are considered IGL. This scheme is premised on the simple idea that stars are pulled from high to low density as they are stripped from their parent galaxies becoming thereafter unbound. Here we make quantitative measurements of the stellar component in our simulated mergers using both variables to test the validity of the hypothesis that gravitational stripping entails the production of low-density stellar material that is unbound.

Fig. 1 shows an example of the correlation diagrams that are inferred between the 3D local density and binding energy of the stellar component of a given galaxy.

![Fig. 1. Correlation between the (logarithm of the) 3D local density and binding energy of the stellar particles of a merging spiral galaxy. The two epochs depicted correspond to the beginning (left panel) and end (right) of the merger event. Note that binding energy grows to the right.](image-url)
during a merger event. In this specific case, we depict two time steps encompassing a merger between two large disks. In the plots, we use standardized values (z-scores) for the variables calculated from the mean and standard deviation of the data along the entire process. Color levels show the number of particles per pixel in logarithmic steps. In each frame, the black vertical line indicates the z-score value corresponding to a null binding energy (bound particles fall to the right of this line) for the selected galaxy. The black horizontal line, on the other hand, separates galactic (above) from IGL particles (below). The adopted density threshold, $\rho_{\text{IGL}} = 10^{-4} M_\odot \text{pc}^{-3}$, has been determined from observational arguments.

In the left panel of Fig. 1 we see that before the merger begins the binding state of the stellar particles and their local density are reasonably related. The data delineate a broad diagonal band in the bound-high-density quadrant (top-right), with particles in denser regions having the tendency of being more bound and vice versa. There is a very small fraction of luminous mass, $\sim 0.6\%$, that can be classified as diffuse according to the adopted density threshold, but that is nevertheless bound, and a yet smaller fraction, $\sim 0.07\%$, of unbound particles having $\rho > \rho_{\text{IGL}}$. The right panel shows the same correlation when the merger is virtually over. According to the starting premise, at this stage one would expect to see that a portion of the stellar particles has become underdense and unbound, spreading over the bottom-left quadrant of the plot. Nevertheless, this graph shows that among the $\sim 8\%$ of the particles detached from the galaxy, very few have local mass densities below $\rho_{\text{IGL}}$, while most of the light that would be termed diffuse (a mere $\sim 2.5\%$) is bound anyway. Therefore, we find that in a major merger the IGL particle candidates systematically avoid being both unbound and underdense to the extent that, in this example, the fraction of stellar light that at some point during the merger process is in the bottom-left quadrant of the log $\rho$ vs. $E$ plots never exceeds 2%.

In summary, while in our pre-collapse group simulations we measure amounts of diffuse, low-surface brightness IGL comparable to those predicted in previous works, we find that only a very small fraction of it is non-galactic light. We therefore warn that commonly used IGL detection methods based on the current position of the group luminosity, such as surface brightness or local density thresholds, may perform very poorly in detecting the truly unbound stellar material.

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