DWARF SPHS/FIRST-GALAXIES CONNECTION

Massimo Ricotti
CASA, University of Colorado, Boulder CO 80309 and
IoA, University of Cambridge, UK, CB3 0HA
ricotti@ast.cam.ac.uk

Abstract I analyze the properties of the first galaxies in cosmological simulations with radiative feedback. Preliminary results indicate similarities with the observed properties of the bulk of dwarf spheroidal galaxies (dSphs) in the Local Group and Andromeda. I briefly discuss observational tests that could help in understanding the impact of a population of small primordial objects on the cosmic evolution.

1. Introduction

Ricotti, Gnedin and Shull 2002a,b have studied radiative feedback processes that regulate the formation of the first galaxies. Contrary to normal galaxies, the global star formation in these objects is self-regulated on cosmological scales. This happens because internal and external radiative feedback processes are important in triggering or suppressing their ability for form stars. Typically star formation in the first galaxies is bursting and the emitted ionizing photons remain confined in the denser filaments of the intergalactic medium (IGM), preventing a complete IGM reionization. The main parameter that regulates the star formation is \( \langle f_{\text{esc}} \rangle \): the escape fraction of ionizing photons. In this talk I present preliminary results on the properties of the first galaxies in our simulations. I try to understand the differences and similarities with observed dSphs and discuss the observational consequences of the existence of such a population of small primordial galaxies \(^1\). DSphs

\(^1\)By definition these “microgalaxies” form in dark matter (DM) “minihalos” with masses \( M_{DM} \leq 10^8 \, M_\odot \). If the gas is of primordial composition (metal free), molecular hydrogen is the only coolant available to form dense gas clouds and the first stars (Population III). There is not consent on a unique name for this population of primordial objects, sometimes also called PopIII objects or “small-halo” galaxies.
have masses comparable to those of the first galaxies, but this does not necessarily imply that they are relics of primordial objects. It is possible that part or all of the observed dSphs are galaxies formed later from larger Dark Matter (DM) halos, subsequently stripped of part of their DM content. Our goal is to distinguish between these two formation scenarios comparing observed properties with simulated properties.

2. First galaxies versus Dwarf Spheroidals

Perhaps the most remarkable characteristic of dSphs is the large velocity dispersion of their stars compared to their total visible mass. This observation is often interpreted as the presence of a dark halo that dominates dynamical motions down to the very center of the galaxy. DShps are either gas poor or do not contain gas at all (NGC147), with a few exceptions (e.g., Sculptor perhaps has a gas cloud in the other halo). The stars in dSphs are usually fitted with exponential luminosity profiles or low concentration King profiles. Most of the dSphs have experienced one or more bursts of star formation about 15Gyr ago and do not present recent star formation episodes. Exceptions to this rule are Carina, LeoI and LeoII. Well known properties of dSphs are the luminosity-metallicity relationship and the luminosity-mass to light ratio relationship. When spectroscopic metallicities of single stars are available, the spread in metallicity of the stars is often very large (e.g., Draco $-3 < [Fe/H] < -1.5$). Figs. 1-2 compare some of the aforementioned relationships with the results of one of our simulations (labeled “p3” in Table 1) at redshift $z=10$. The left panels show the simulated galaxies with $M_\ast > 10^4 M_\odot$. Only few normal galaxies with $M_{DM} > 10^8 M_\odot$ are present in the simulation at $z=10$, but they appear to have different properties. The right panels show both dSphs and dwarf Irregulars in the Local Group and Andromeda. The symbols have the following meaning: very old dSphs (filled circles); old dSphs (asterisks); dSphs with a young stellar population (open circle); dwarf Irregulars (open squares); dwarf Ellipticals (filled squares). The mass to light ratio of old dSphs should be $M_\ast/L_V \approx 1.2$ (typical for globular clusters). Smaller values are expected for dwarf Irregulars and dSphs with more recent star formation episodes. Here we adopt $M_\ast/L_V = 0.6$, because gives a maximum baryon fraction similar the cosmic value (but the scatter is large).

2.1 Missing Galactic satellites?

A powerful method to constrain models on the formation of the first galaxies is to count the number density of simulated relic primordial
Dwarf Sphs/First-galaxies connection

galaxies at z=0 and compare it with observations. Unfortunately there are two main difficulties in doing this exercise correctly. (i) Simulations of the formation of the first galaxies that include realistic physics are computationally expensive and require a small box size to achieve the mass resolution needed. This implies that we can not evolve the simulation down to z=0. Therefore in order to compare the simulation results (in this case at z=9) with observations we need to extrapolate the results from z=9 to z=0 using other methods (analytical or numerical). After reionization, “small-halo” galaxies should stop forming and the ones already formed are expected to lose their diffuse interstellar medium (ISM) due to photoevaporation. This should stop their star formation. Depending on the environment (cosmic overdensity), a fraction of “small-halo” galaxies will merge to form larger objects. Some larger objects will be stripped of part of their mass due to tidal forces or shocks. Therefore some dSphs could be “large-halo” galaxies observed during the phase of their disruption. (ii) Observations could be missing a large fraction of the low-surface luminosity density dwarfs. Another caveat that should be mentioned is on the determination of the virial masses of dSphs, that could be biased because of tidal interactions.

Fig. 3 shows the mass function of simulated galaxies at about z = 9 (shaded histograms) compared with observations at z=0 in the Local Group. I show the result of two high resolution simulations with $\langle f_{esc}\rangle = 0.01$, labeled “p2-2” and $\langle f_{esc}\rangle = 0.1$, labeled “p3” (see Table 1).

| RUN  | $N_{\text{box}}$ | DM Mass Res. $h^{-1} M_\odot$ | SED | $\epsilon_{UV}$ $(10^{-5})$ | $\epsilon_*$ | $\langle f_{esc}\rangle$ |
|------|-----------------|-----------------|-----|-----------------|-----------|-----------------|
| p2-2 | 128             | $3.94 \times 10^4$ | Pop. II | 1.1 | 0.05 | 1% |
| p3   | 256             | $4.93 \times 10^3$ | Pop. III | 2.5 | 0.1 | 10% |

Note. — Parameter description: $N_{\text{box}}^3$ is the number of grid cells (the box size is 1 $h^{-1}$ Mpc). $\epsilon_*$ is the star formation efficiency, $\epsilon_{UV}$ is the ratio of energy density of the ionizing radiation field to the gas rest-mass energy density converted into stars (depends on the IMF), and $\langle f_{esc}\rangle$ is the escape fraction of ionizing photons from the resolution element.
3. Conclusions and Future Directions

I have shown preliminary results, part of a larger work currently in progress (Ricotti, Gnedin and Shull 2003, Ricotti and Gnedin 2003, in preparation), to constrain and understand the theory for the formation of the first galaxies in the universe. I have shown how observations of dwarf galaxies in the Local Group can be used to constrain theoretical results of cosmological simulations with radiative feedback. If we establish a connection between dSphs and relics of the first galaxies we can hope to
learn in some detail the physics that regulates the formation of the first stars in the universe, and the importance of Population III stars. The answer to currently popular quests on the stellar initial mass function, stellar nucleosynthesis, star formation efficiency of Population III stars at $z \sim 30$, could be found studying the most numerous and closest galaxies to the Milky Way.

Studies of thermal and chemical evolution of the intergalactic medium as a function of redshift and overdensity can further constrain the model.
Figure 3 Mass function histogram of DM halos at $z \approx 10$ for two simulations. The shaded histograms show the mass function of luminous galaxies (with $M_* \geq 10^4 M_\odot$). The points with error-bars show the observed number density of galactic satellites at $z=0$. The thick dotted and dashed lines are shown to illustrate the evolution of the mass function from $z=10$ to $z=0$ according to the Press-Schechter formalism.

once a realistic treatment of supernova feedback is included in the simulation (Ricotti, Gnedin and Shull 2003, in preparation).

References

Ricotti, M., Gnedin, N. Y., & Shull, J. M. 2002a, ApJ, 575, 33
Ricotti, M., Gnedin, N. Y., & Shull, J. M. 2002b, ApJ, 575, 49