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ORIGIN AND EVOLUTION OF STRUCTURE FOR GALAXIES IN THE LOCAL GROUP

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ABSTRACT

The Milky Way did not form in isolation, but is the product of a complex evolution of generations of mergers, collapses, star formation, supernovae and collisional heating, radiative and collisional cooling, and ejected nucleosynthesis. Moreover, all of this occurs in the context of the cosmic expansion, the formation of cosmic filaments, dark-matter haloes, spiral density waves, and emerging dark energy. This paper summarizes a review of recent attempts to reconstruct this complex evolution. We compare simulated properties with various observed properties of the Local Group. Among the generic features of simulated systems is the tendency for galactic halos to form within the dark matter filaments that define a super-galactic plane. Gravitational interaction along this structure leads to a streaming flow toward the two dominant galaxies in the cluster. We analyze this alignment and streaming flow and compare with the observed properties of Local-Group galaxies. Our comparison with Local Group properties suggests that some dwarf galaxies in the Local Group are part of a local streaming flow. These simulations also suggest that a significant fraction of the Galactic halo formed at large distances and arrived later along these streaming flows.

Key words: galaxies: evolution; galaxies: formation; galaxies: the Local Group

1. INTRODUCTION

It has been known for some time [e.g. (White & Rees, 1978)] that the Milky-Way Galaxy did not form in isolation as the collapse of a single cloud (Eggen et al., 1962). Rather, it is the result of the development of a much more extended structure and the chaotic merging of smaller structures (Searle, 1978). This structure begins within the initial dark-matter potentials formed during the radiation-dominated epoch and then evolves into the filament/void morphology characteristic of the standard cosmological constant plus cold-dark-matter (ΛCDM) cosmology. Within this structure there has been a complex sequence of heating by mergers, star formation and supernovae, along with collisional and radiative cooling and the collapse of star forming cold molecular clouds. One must analyze all of these processes within the entire extended early Local Group (LG) in order to understand the properties of the Milky Way and its satellite systems.

Indeed, it is these satellite systems that give the best glimpse into the early evolution of the LG, as these systems are remnants of the initial merging protogalactic structures that were to form the present-day dominant large galaxies of the LG. Here we summarize a recent review (Mathews et al., 2014) of some of the current understanding and challenges regarding the formation and evolution of the galaxies and nucleosynthesis in the LG. A great deal of evidence has been compiled recently toward this understanding, while at the same time, large scale simulations are approaching sufficient resolution to present a plausible history of how the local galactic environment came into being.

It is straightforward [e.g. (Mathews et al., 2012; Zhao, 2011a,b)] to do large scale structure simulations with random initial conditions in a standard ΛCDM cosmology. One begins by specifying the content, e.g. $\Omega_\Lambda = 0.726$ and $\Omega_M = 0.274$ and a baryon content of $\Omega_B = 0.0456$ as deduced from the Wilkinson Microwave Anisotropy Probe *WMAP* (Hinshaw et al., 2013) or Planck Surveyor (PLANCK Collaboration, 2013). One problem (Gómez et al., 2012) with trying to reconstruct a model for the LG is that the determination of "best-fit" parameters is not unique. Indeed, very different halo merger histories can reproduce the same observational data set. Thus, attempts to uniquely characterize the formation history of the LG using numerical simulations must be done statistically by analyzing large samples of high-resolution N-body simulations.

The code that was used in Mathews et al. (2014) and by many others for numerical simulations is the n-body smoothed-particle hydrodynamics (SPH) code GADGET, originally developed by Springel et al. (2001). The current public version GADGET-2 (Springel et al., 2005a) is used by most, although a newer GADGET-3

Version now exists and is used by some researchers in the field.

Perhaps the most ambitious recent applications of this code have been in the Aquarius project (Springel et al., 2008). This consists of cosmological simulations of the formation of six dark matter haloes with a mass and merging history similar to that believed for the halo of the Milky Way. For the highest resolution in the simulations, the main halo contains $\sim 1.5 \times 10^9$ particles with nearly $3{\times}10^5$ sub-halos. The high resolution simulation utilized a particle mass of $10^3 M_\odot$ allowing for study of the ultra faint satellite galaxies. The simulations assumed a ΛCDM cosmology, with a matter density parameter of $\Omega_M = 0.25$; and cosmological constant of $\Omega_\Lambda = 0.75$. A matter power spectrum normalization of $\sigma_8 = 0.9$ with spectral slope of $n_s = 1$, and a Hubble parameter of $h = 0.73$ were adopted.

Two large collaborations have also been established to study the effects of different modeling techniques (Kim et al., 2014) and feedback prescriptions (Spannapieco et al., 2012) on Milky Way sized galaxy simulations in a Local-Group-like environment. The AGORA Project (Kim et al., 2014) used common astrophysics packages and initial conditions in order to study the effects of adopting alternative codes such as the smoothed particle hydrodynamics code GASOLINE (Wadsley et al., 2004; Stinson et al., 2006), or adaptive mesh refinement codes such as ART (Kravtsov et al., 1997), ENZO (Bryan et al., 1995), and RAMSES (Teyssier, 2003) on the resulting evolution of dwarf galaxies in cosmological simulations and in particular on a model of a Milky Way sized galaxy and satellites in a Local Group-like environment. The Aquila Comparison Project (Spannapieco et al., 2012) contrasts thirteen gas-dynamical simulations of a Milky Way galaxy embedded in a Local Universe and, in particular, finds that the effect of the adopted feedback on the prominence of the stellar disk overwhelms the variations due to the modeling techniques. The statistics of satellite galaxies around Milky-Way like hosts have been studied in the Millennium simulation (Springel et al., 2005b; Wang et al., 2012) where the brightest satellites were determined to be more massive than those found in observations. In addition, the Bolshoi simulation (Busha et al., 2011) found agreement with SDSS observations on the probability of a Milky-Way-like halo having none, one, or two Magellanic Cloud-like satellites.

The good news is that these different simulation codes essentially all agree in terms of the dark matter dynamics and non-radiative gas physics (as long as the resolution is sufficient). On the other hand, the bulk properties of simulated galaxies depend almost entirely on the details of star formation and feedback from the heating from stars and supernovae. Prescriptions for this vary considerably from code to code [e.g. Stinson et al. (2006)]. Moreover, most simulations either lack or have problems with: black hole feedback; detailed chemical evolution of various elements; effects of dust; magnetic fields; radiation transport (ionization balance); and the detailed mixing of ejected elements. Ultimately all simulations invoke some level of approximation and only by detailed comparison with observations can the validity of the approximations be tested.

Although simulations of Local-Group like systems have been attempted for decades, a few persistent challenges have remained. There are three problems that are so prevalent in the simulations that they have acquired names. These are the *core-cusp problem*, the *missing-satellites problem*, and the *too-big-to-fail problem*. There is also the problem of the delicate balance between stellar/SN feedback and cooling/star formation, and the problem of poor resolution for dwarf galaxies, and the lack of a galactic bulge in the Local Group. These problems are summarized in detail in (Mathews et al., 2014).

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