14. HIGH-VELOCITY CLOUDS: THE MISSING LINK?¹

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Abstract. Hierarchical structure formation models predict the existence of large numbers of low velocity dispersion dark halos. Galaxy surveys find far fewer galaxies than predicted by analytical estimates and numerical simulations. In this paper, we suggest that these dark halos are not missing, but have been merely misplaced in the galactic astronomy section of the journals: they are the high-velocity clouds (HVCs). We review the predictions of our model for the Local Group origin of the HVCs and its implications for the formation and the evolution of our Galaxy. We describe recent observations that confirm many earlier predictions and discuss future tests of the model.

1. The missing galaxy problem

A generic prediction of hierarchical structure formation models is the existence of large numbers of low-mass halos. The Press-Schechter formalism (Press & Schechter 1974) predicts that the galaxy mass function,

\[ n(M) \propto M^\alpha \exp(-M/M_*) \]

This chapter has remained essentially unchanged since its submission (January 1999).

H. van Woerden et al. (eds.), High-Velocity Clouds, 297–312  
has a steep faint-end slope, $\alpha \approx -2$. Numerical simulations (Efstathiou et al. 1988; Gelb & Bertschinger 1994) are consistent with the Press-Schechter approach: they also predict copious low-mass halos.

Most galaxy surveys, however, do not seem to find large numbers of low-luminosity, low-velocity-dispersion galaxies. Loveday et al. (1999) summarize a number of recent field surveys that find a faint-end slope in the range $-1.2 \lesssim \alpha \lesssim -0.7$. Groups have similar “flat” galaxy luminosity functions with slopes typically $\sim -1$ (Muriel et al. 1998). While surveys that reach lower surface-brightness limits find more dwarf galaxies (Bothun et al. 1997, Dalcanton et al. 1997), even the inclusion of these systems does not appear to increase the faint-end slope enough to reconcile theory and observation.

In our own Local Group, where the galaxy inventory is thought to be essentially complete, the discrepancy is even more severe. Simulations at the appropriate scale suggest that the Local Group should contain roughly 1000 objects with velocity dispersions larger than 10 km s$^{-1}$ (Klypin et al. 1999). Observers however have only been able to find $\sim 30$ galaxies in the Local Group (Mateo 1998).

Where are the missing dark halos? There is either something wrong with hierarchical structure formation, the numerical simulations, or there are a host of unidentified bound systems in the Local Group.

What are the likely properties of these low-velocity-dispersion halos? Star formation is likely to be inefficient in these low-luminosity systems, because the cosmological ultraviolet background can prevent or at least delay the formation of atomic and molecular hydrogen (Babul & Rees 1992; Kepner et al. 1997; Barkana & Loeb 1999). If these missing galaxies have not formed stars, they likely persist as small bound objects containing mostly ionized hydrogen and possibly a handful of stars. These dark halos may be the high-velocity clouds (HVCs).

The HVCs are clouds of atomic hydrogen, detected primarily by means of their 21-cm emission, that cannot be in circular rotation about the Galactic Center. Because they are largely found at high galactic latitude, and because the H$\text{I}$ layer of the Milky Way is so thin, the characteristic distance to the HVCs can, in principle, be anywhere between several hundred parsecs and 1 Mpc. In this paper, we will argue that the evidence points to a Local Group origin for the HVCs. Oort’s (1964) original idea that the clouds represent infall onto the Milky Way was abandoned long ago, because of the discovery of HVCs with positive galactocentric velocities. Nevertheless, we will argue that his insight that the HVCs represent the unaccreted remnants of galaxy formation is largely correct. We will also offer some speculations on the implications of the Local Group origin. A fuller, more detailed account of the arguments presented in this paper may