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STUDYING THE PATTERNS OF THE UNIVERSE

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Abstract. The SDSS galaxy catalog is one of the best databases for galaxy distribution studies. The SDSS DR8 data is used to construct the galaxy cluster catalog. We construct the clusters from the calculated luminosity density field and identify denser regions. Around these peak regions we construct galaxy clusters. Another interesting question in cosmology is how observable galaxy structures are connected to underlying dark matter distribution. To study this we compare the SDSS DR7 galaxy group catalog with galaxy groups obtained from the semi-analytical Millennium N-Body simulation. Specifically, we compare the group richness, virial radius, maximum separation and velocity dispersion distributions and find a relatively good agreement between the mock catalog and observations. This strongly supports the idea that the dark matter distribution and galaxies in the semi-analytical models and observations are very closely linked.

Key words: galaxies: groups, clusters – cosmology: dark matter, large-scale structure of the Universe

1. INTRODUCTION

The matter distribution of our Universe can be at large scales described with the cosmic web structure. The cosmic web consists of galaxy-rich areas that consist of superclusters and filaments. In addition, there are galaxy-poor regions like voids. Studying the inner structure of the cosmic web leads us to the hierarchical image of the Universe, where we can study structures within structures. Different properties of these substructures (galaxy groups and clusters) can lead us to better understanding of the evolution of observable matter and galaxies.

One motivation for creating a galaxy cluster catalog is the lack of cluster scale galaxy system catalogs. For groups there are several good catalogs for example Tago et al. (2010) and Yang et al. (2007). For superclusters probably one good catalog is provided by Liivamägi et al. (2010). The Tago et al. (2010) and the Liivamägi et al. (2010) catalogs are the most important for this work, since they are integrated into our cluster catalog.

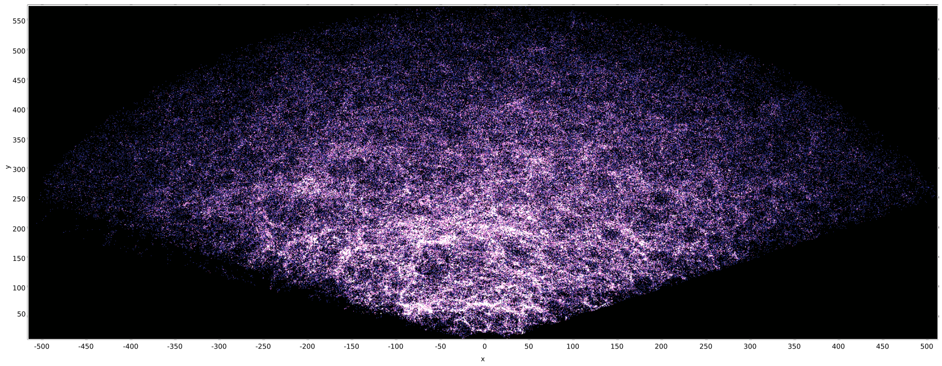

Fig. 1. Galaxy distribution in SDSS DR8 in cartesian coordinate system (where x is in the zenith direction). Standard transformation rules from spherical to cartesian coordinates were used).

Galaxy cluster catalogs map the largest gravitationally bound galaxy systems and they also enable us to study the inner structure of superclusters and cosmic web-structure. Due to observational limits there can be, mostly at greater redshifts, clusters that match one to one with Tago et al. (2010) groups or Liivamägi et al. (2010) superclusters, thus appearing as the same structures. Cluster catalogs can be used as a basis to describe and study large scale astronomical objects, they are also essential for further work – planning of observational projects, comparing theory (simulation) with observations.

One use of different catalogs is their comparison with dark matter models. There has been remarkable progress in the past decades in the study of the properties of dark matter, for example the measurement of CMB fluctuations by Wilkinson Microwave Anisotropy Probe (Bennett et al. 2003; Spergel et al. 2007). That, together with other studies, favours the ΛCDM model. The connection between the baryonic matter and dark matter and their physical evolution in large scales is best described with semi-analytical models (SAMs) like the Virgo consortium's Millennium simulation (Springel et al. 2005, hereafter MS) and the Bolshoi simulation (Klypin et al. 2010). In this respect, we are interested in the galaxy dark matter halo connection (Nurmi et al. in preparation).

We focus on the dark matter haloes and their sub-haloes (galaxies), study the properties of them both, and investigate how they are connected with observed galaxy groups. The comparison is quite straightforward, since observed galaxy groups can be considered as visible counterparts of dark matter haloes. The most suitable galaxies in Millennium SAMs for our analysis are the Font et al. (2008) and the Bertone et al. (2007) galaxy catalogs. They use galaxy formation theories, thus the data has dark matter halo and sub-halo information for simulated galaxies. This means that we can create mock galaxy groups from simulation data.

There are some studies that are similar to ours, for example Berlind et al. (2006), where they use N-body simulations to find the best linking length for their friend of friends (FoF) groups from SDSS. The main difference is that in this work several volume-limited observational samples are analysed and the different group properties are studied. In Nurmi et al. (in prep.) we compare the Millennium based mock galaxy groups with observational groups and study how the physically bound halo sub-halo groups fit together with SDSS groups.

Table 1. Properties of the cluster catalog.

Property	Value
Number of clusters	58138
Percentage of clusters in superclusters	12
Clusters with more than 3 member galaxies	18507
Properties of clusters with 3+ member galaxies	
Average number of galaxies in cluster	8.6
Average number of groups in cluster	1.9

This work is a short introduction to the Sepp et al. (in prep.) catalog and to the group properties study where we compare different group construction methods in observations and simulations (Nurmi et al. in preparation).

2. DATA AND METHODS

We use data from the 8th data release of the Sloan Digital Sky Survey[1], see Figure 1. For galaxy cluster study this release is practically the same as the 7th release (Abazajian et al. 2009). The clusters are defined using the luminosity (it represents mass distribution with acceptable accuracy) density field of the sample. Our sample contains 583 362 galaxies. The Hubble constant $H_0 = 100\,h\,\mathrm{km\,s^{-1}Mpc^{-1}}$, the dark matter density parameter is $\Omega_\mathrm{m} = 0.27$, the dark energy density parameter is $\Omega_\Lambda = 0.73$ and the magnitudes correspond to the rest-frame magnitudes at z = 0. The first steps of creation the cluster catalog are nearly the same as in Liivamägi et al. (2010), where additional information about data preparation and references can be found. The main difference is that we used narrower B_3 spline kernel $B_3(x/a)$ with the scale of $a = 1$ Mpc h^{-1}, because we are interested in more compact structures. The clusters are constructed from the density field with simple rules. First we find denser regions of the field, that we call peaks, these regions are the cornerstones of clusters. Galaxies and Tago et al. (2010) galaxy groups are assigned to peaks (clusters). Group galaxies are always assigned to a single cluster, since there are groups that have some members closer to one peak and some to another peak. For this selection we assign all the group member galaxies to the peak that is closer to the groups centre point. A detailed description of the clusters will be given in Sepp et al. (in prep.).

For Nurmi et al. (in prep.) we use SDSS DR7 data and the Tago et al. (2010) galaxy group catalog in particular. Additionally we use also MS and the SAMs. MS is a cosmological N-body simulation of the ΛCDM model performed by the Virgo Consortium and it was carried out with a customized version of the GADGET2 code. The MS follows the evolution of 2150^3 particles from redshift z=127 in a box with the side length of 500 Mpc h^{-1}. The cosmological parameters of the MS are: $\Omega_\mathrm{m} = \Omega_\mathrm{dm} + \Omega_\mathrm{b} = 0.25, \Omega_\mathrm{b} = 0.045, h = 0.73, \Omega_\Lambda = 0.75$. The simulated galaxies in the MS data are based on merger trees and their properties are obtained by using SAMs, where the star formation and its regulation by feedback processes are parametrised in terms of analytical physical models. In particular we use the Font et al. (2008) and Bertone et al. (2007) models. We use three different methods to construct simulated galaxy groups. Firstly we use FoF haloes identified in the MS and sub-haloes identified with subfind algorithm (Springel et al. 2005). The substructures of the first Millennium groups are used to define

[1] `http://www.sdss3.org/dr8/`

our second SAM groups. These groups consist of a main galaxy (main halo) and satellite galaxies (sub-haloes). So in the second method galaxy groups are collections of haloes inside one large dark matter halo. The third method is the most similar to the observational galaxy groups. Groups from the simulation data are created using the same method and limits as in Tago et al. (2010). We compared the following galaxy group properties against each other: luminosity function of galaxies, richness, virial radius, maximum projected size, velocity dispersion. We found that there is a rather good agreement between the SAMs and observational data. Details will be given in Nurmi et al. (in prep.).

3. CONCLUSIONS

In this work the Sepp et al. (in prep.) cluster catalog is introduced. A short description of the methods and results, see Table 1 for details, are given. We also provide some preliminary results of the comparison between observational groups and different Millennium simulation based galaxy groups. This work will be presented in full detail by Nurmi et al. in the near future.

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