Measures of Galaxy Environment

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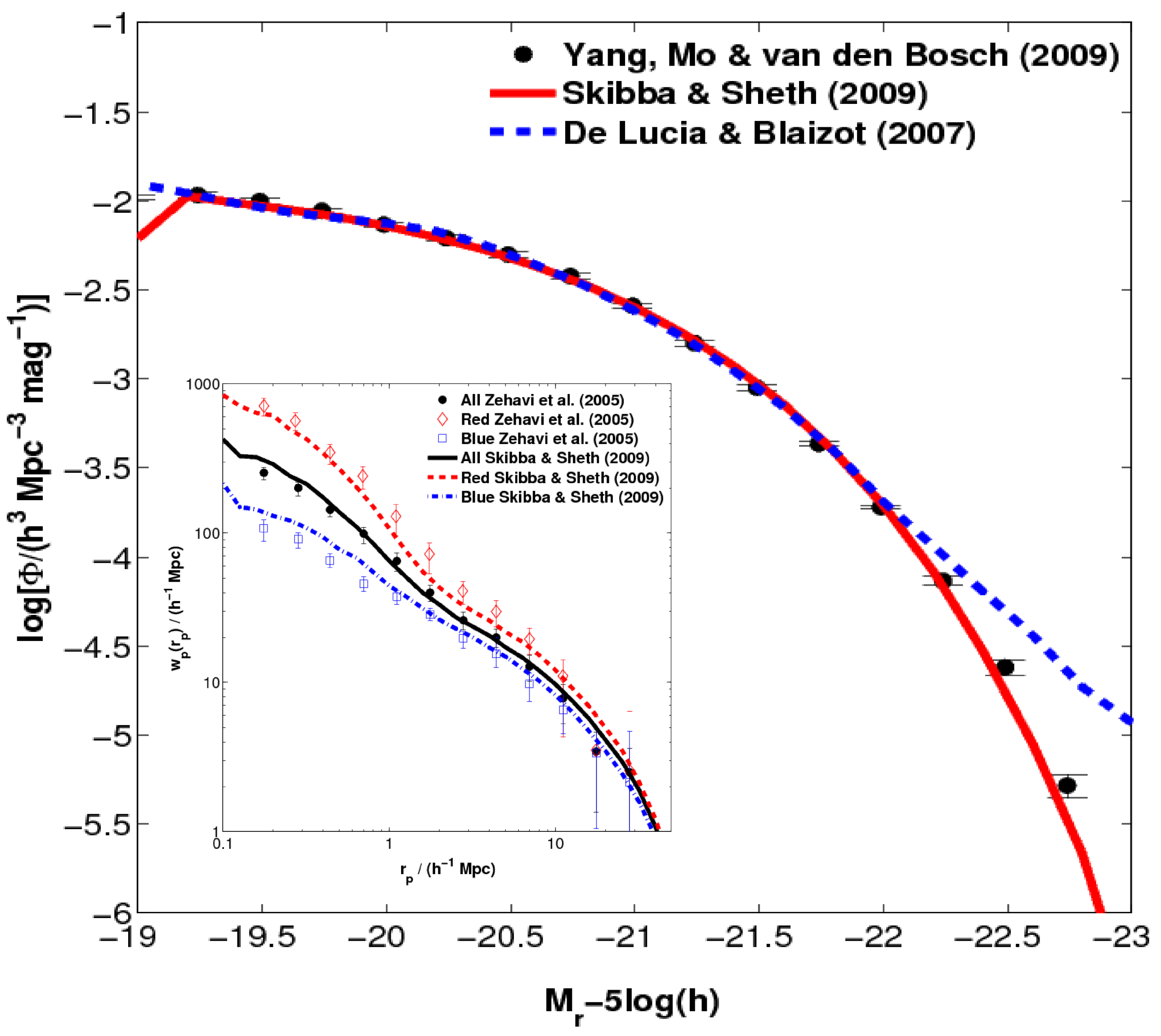
The role of a galaxy's environment in its evolution is studied extensively, but a variety of different methods are used to measure it. All these methods fall into two broad groups: those that use nearest neighbours and those that use fixed apertures. Using different techniques to measure environment opens up the possibility that different properties are being detected. To compare the galaxy environment measures used in the literature, we produce a mock galaxy catalogue by applying a halo occupancy distribution function to the z=0 output of the Millennium dark matter simulation. This model is constrained to reproduce the luminosity, colour and distribution of galaxies in the Sloan Digital Sky Survey. Twenty environment measures were then applied to this sample and the primary results are presented here.

The Model

To fully understand the properties of each environment measure a galaxy catalogue is required that has full three dimensional positions and is constrained to match the observable Universe. To achieve this we applied a halo occupancy distribution function (Skibba & Sheth 2009) to the z=0 output on the Millennium dark matter simulation (Springel et al. 2005). This created a model that accurately reproduced the number, luminosity, colour and position of galaxies as determined by SDSS. This is shown through the luminosity function and the two point correlation function below.



Environment Measures

The full list of twenty environment measures used in this work are given in the table. These break down into two broad groups; those that use neighbours and those that use apertures.

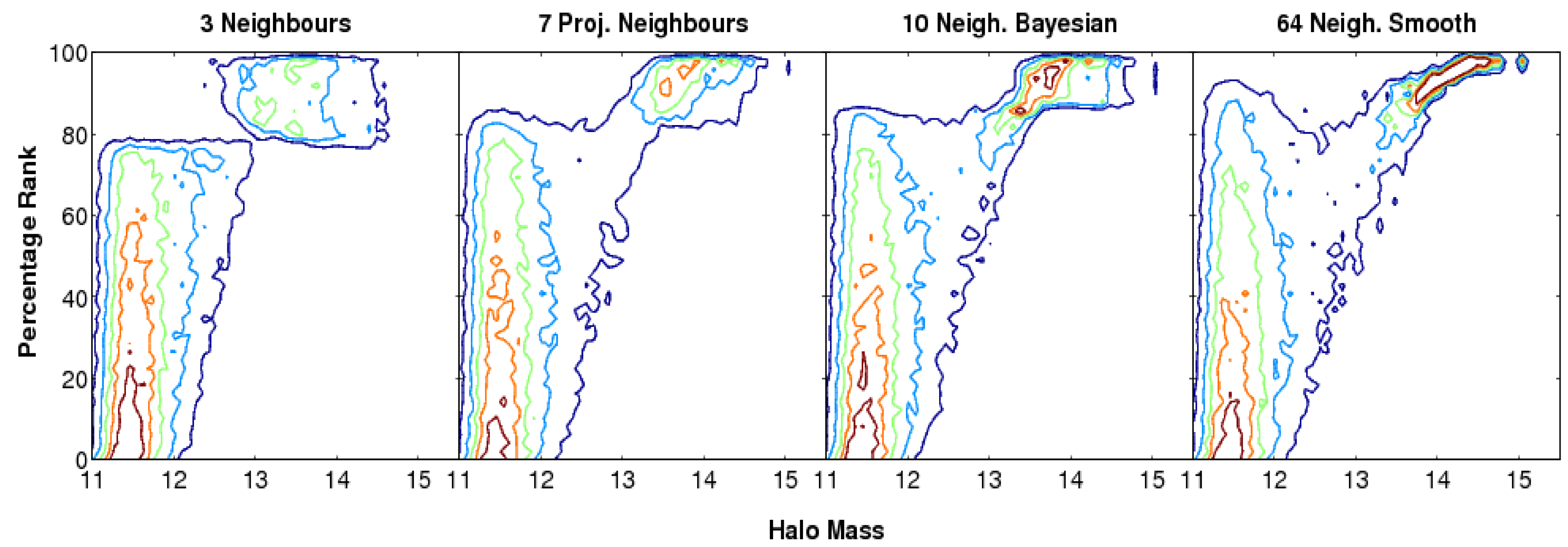
Neighbour: The distance to the *n*-th nearest neighbour is found in either real (3D) or projected (2D) space and this is used to calculate densities. Variations on this method include weighting the galaxies by distance so closer galaxies count more or using a Bayesian metric so that the sum of the distance to each galaxy is used. Voronoi diagrams can also be used to construct a volume that contains every point in space that is closest to a given galaxy.

Aperture: The aperture method counts the number of galaxies enclosed using a velocity cut in the third dimension to define the depth. Apertures can span a range is sizes with spherical ones being used on the largest scales. A variation on the aperture is to use an annulus, defining the inner and outer radii to enclose a region around a galaxy.

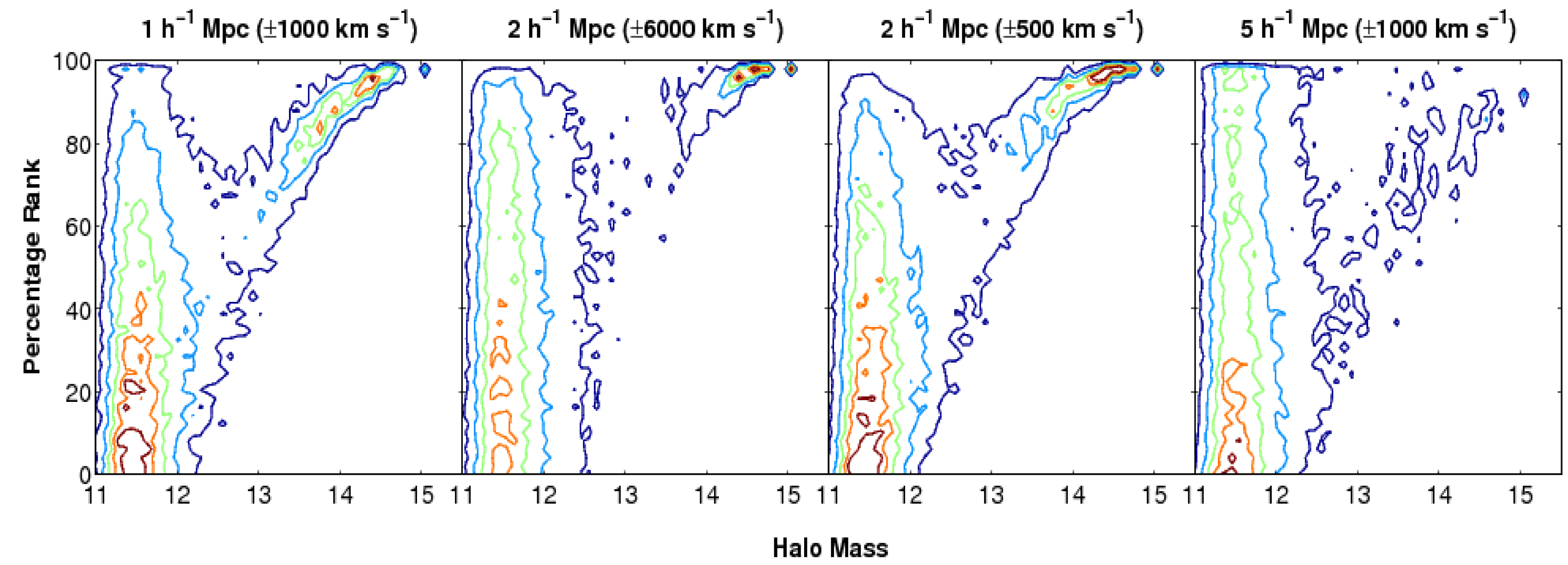
Number	Method
	Neighbours
1	3rd Nearest Neighbour
2	Voronoi
3	Mean 4th & 5th Nearest Neighbour
4	5 Neighbour Cylinder
5	7th Projected Nearest Neighbour
6	10 Neighbour Bayesian Metric
7	20 Neighbour Smooth Density
8	64 Neighbour Smooth Density
	Aperture
9	1 h^{-1} Mpc (±1000 km s^{-1})
10	2 h^{-1} Mpc (±500 km s^{-1})
11	2 h^{-1} Mpc (±1000 km s^{-1})
12	2 h^{-1} Mpc (±6000 km s^{-1})
13	5 h^{-1} Mpc (±1000 km s^{-1})
14	8 h^{-1} Mpc Spherical
	Annulus
15	0.5-1 h^{-1} Mpc (±1000 km s^{-1})
16	0.5-2 h^{-1} Mpc (±1000 km s^{-1})
17	0.5-3 h^{-1} Mpc (±1000 km s^{-1})
18	1-2 h^{-1} Mpc (±1000 km s^{-1})
19	1-3 h^{-1} Mpc (±1000 km s^{-1})
20	2-3 h^{-1} Mpc (±1000 km s^{-1})

Dark Matter Halo Mass

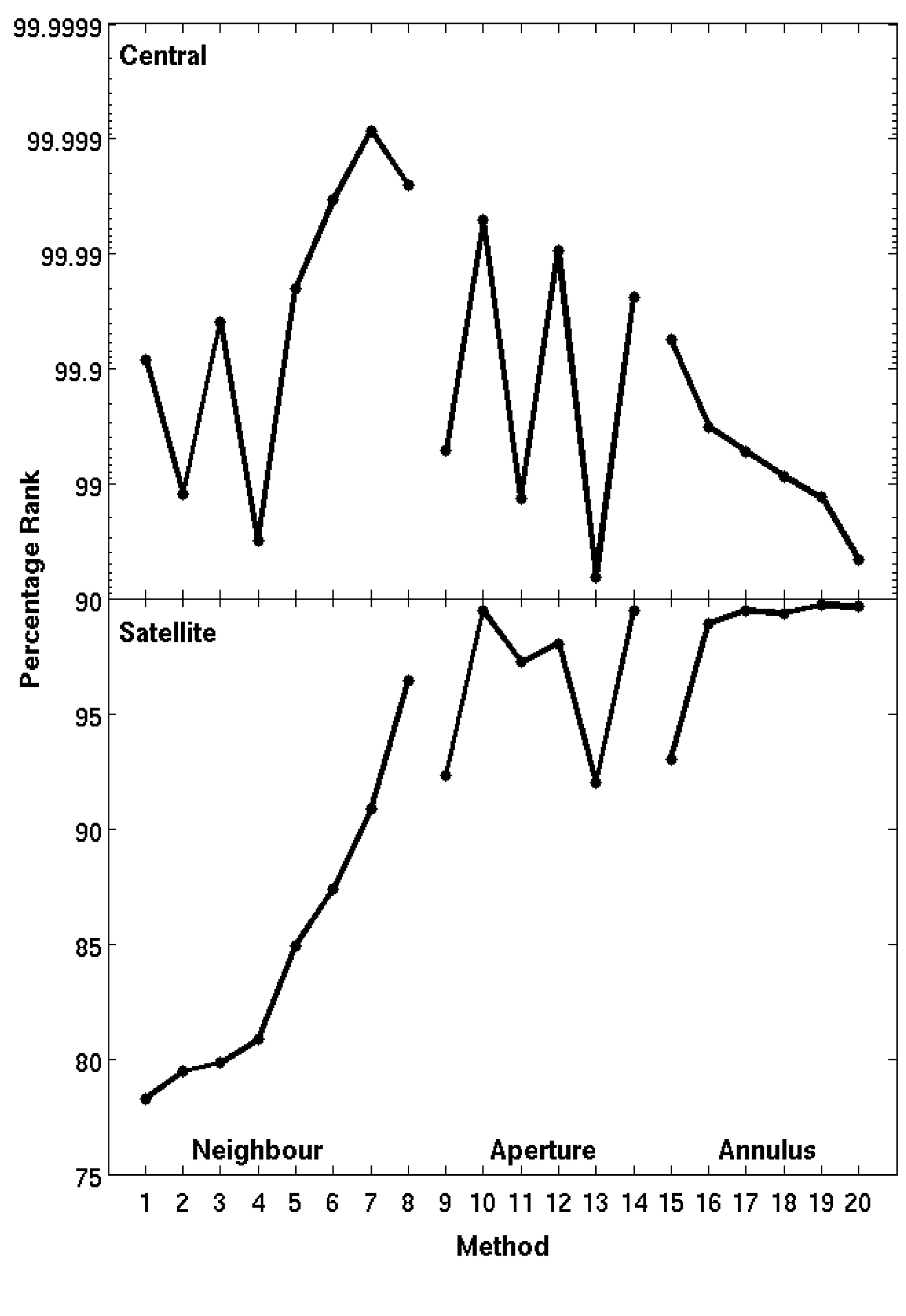
The galaxy properties of the model are all calculated using the dark matter halo mass. This should lead to the environment measure showing a relation with this property. Plots of the halo mass against density (converted to a percentage rank where 100% is most dense and 0% is least) are shown below. The methods have been separated by neighbour and aperture with a range in the methods being shown.



The distribution for nearest neighbour produces two regions. At the high mass end the neighbour search has stayed within the halo and so records higher densities. At the low mass end the neighbour search has left the halo and so the inter-halo separation causes a lower density to be measured. The high mass end also shows that the density of galaxies within a halo is independent of halo mass. While the density decreases radially in a halo the cores of intermediate mass haloes are as dense as high mass ones.



For aperture based methods the recovered densities are dependant on halo mass. Larger haloes are recovered as denser. This is reflective of the methods measuring the 'large-scale environment.'



Individual Galaxies

The figure on the left shows the density measured for the central and furthest satellite galaxies of one of the largest haloes in the sample. For the central galaxy all methods measure a high density as it is at the centre of a large halo. For the satellite galaxy the neighbour based methods record lower densities reflecting the fact that the galaxy is near the edge of the halo. The aperture based methods record higher densities showing the galaxy is in a high mass halo.

Conclusions

- Neighbour based methods measure 'local environment' internal to a halo.
- Aperture based methods measure 'large-scale environment' external to a halo.
- The galaxy density of haloes is independent of dark matter halo mass.
- The Millennium Simulation was carried out by the Virgo Supercomputing Consortium which includes the HPC facilities at the University of Nottingham.

References: De Lucia G., Blaizot J., 2007, MNRAS, 375, 2; Muldrew S.I. et al., 2011, in prep; Skibba R.A., Sheth R.K., 2009, MNRAS, 392, 1080; Springel V. et al., 2005, Nat, 435, 629; Yang X., Mo H.J., van den Bosch F.C., 2009, ApJ, 695, 900; Zehavi I. et al., 2005, ApJ, 630, 1