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Projection Effects of Galaxy Clusters

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Introduction

Galaxy clusters, which are contained in dark matter halos, are used as cosmological probes by counting the number of galaxies (richness) in it. The model from M. Costanzi et al. 2019 gives richness as a function of mass:

$$\langle \lambda^{\mathrm{cent}} | M \rangle = 1 \text{ for } M \geq M_{\mathrm{min}}$$
$$\langle \lambda^{\mathrm{cent}} | M \rangle = 0 \text{ otherwise}$$
$$\langle \lambda^{\mathrm{sat}} | M \rangle = \left(\frac{M - M_{\mathrm{min}}}{M_1 - M_{\mathrm{min}}} \right)^{\alpha}$$

λ^{cent} is the number of center galaxy and λ^{sat} is the number of satellite galaxies. In figures, this is labeled as 'Costanzi'.

In observation, uncertainty about the line-of-sight distance and radius make it difficult to count galaxies. Distant galaxies are receding from us due to the expansion of the universe, so the light emitted from those galaxies are redshifted. Once we know the redshift, we can calculate the distance using the Friedmann-Robertson-Walker metric. Galaxies can also have velocity not due to expansion which will contribute to the redshift and change the distance calculated. High accuracy redshift data also requires extensive telescope time and is expensive.

In the idealized situation, the richness is counted with spheres, but this is not possible because the only line of sight is from earth. Instead, galaxies inside a cylinder are counted in observation.

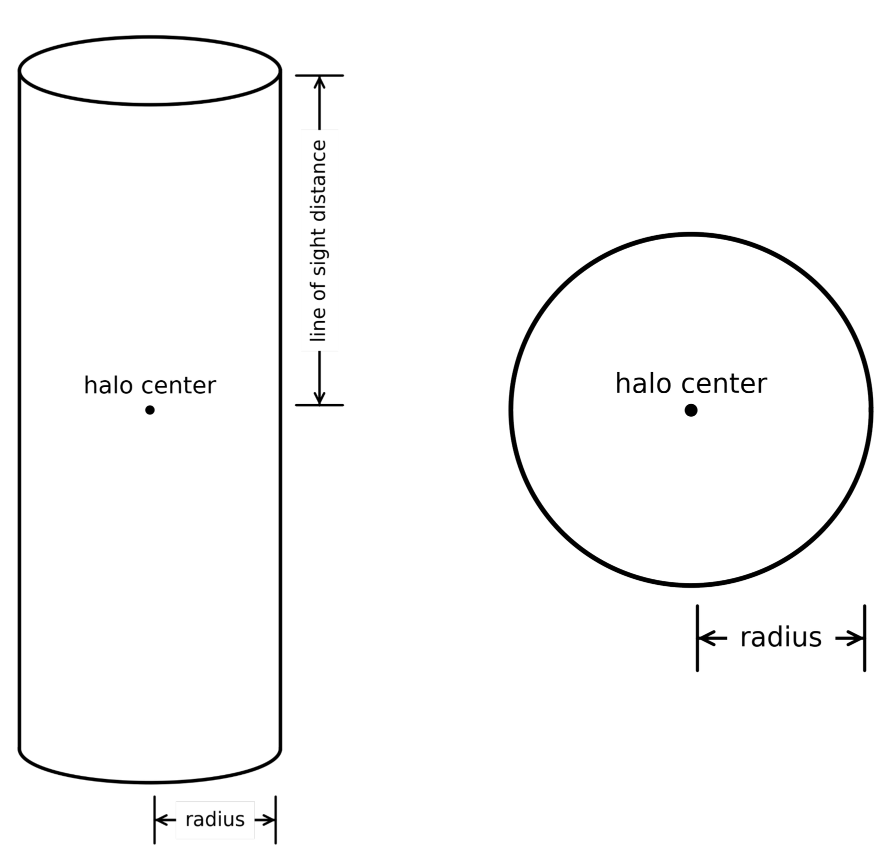

Figure 1: The left is the cylinder used in observation. The right is idealized situation of spherical counts.

Methodology

With simulation data, so we knew the exact locations of all galaxies and radii of dark matter halos. We used the Abacus N-body simulation from Garrison et al. 2017 at redshift z = 0.3 and counted with ideal spheres. In figures, this is labeled as 'Abacus'. With the ideal counts known, different methods of counting from observers could be compared.

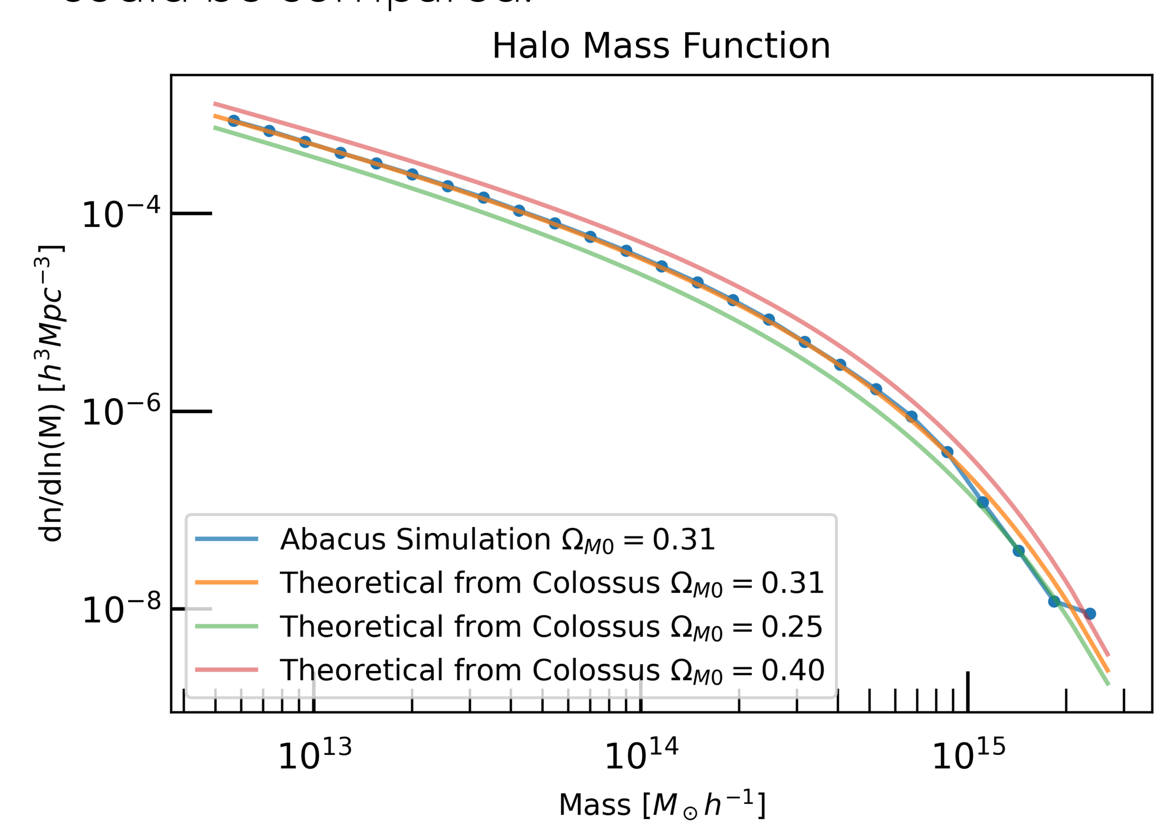

Figure 2: The number density per logarithmic mass interval of halos.

The radius of a halo can be fixed (1 Mpc/h) or iteratively calculated in observation. Iteratively determining the radius is guessing the richness, converting to radius, and repeating until the radius does not change. Dark matter halos overlap, so to prevent small halos from blowing up galaxies are counted towards the more massive halo. This is called percolation.

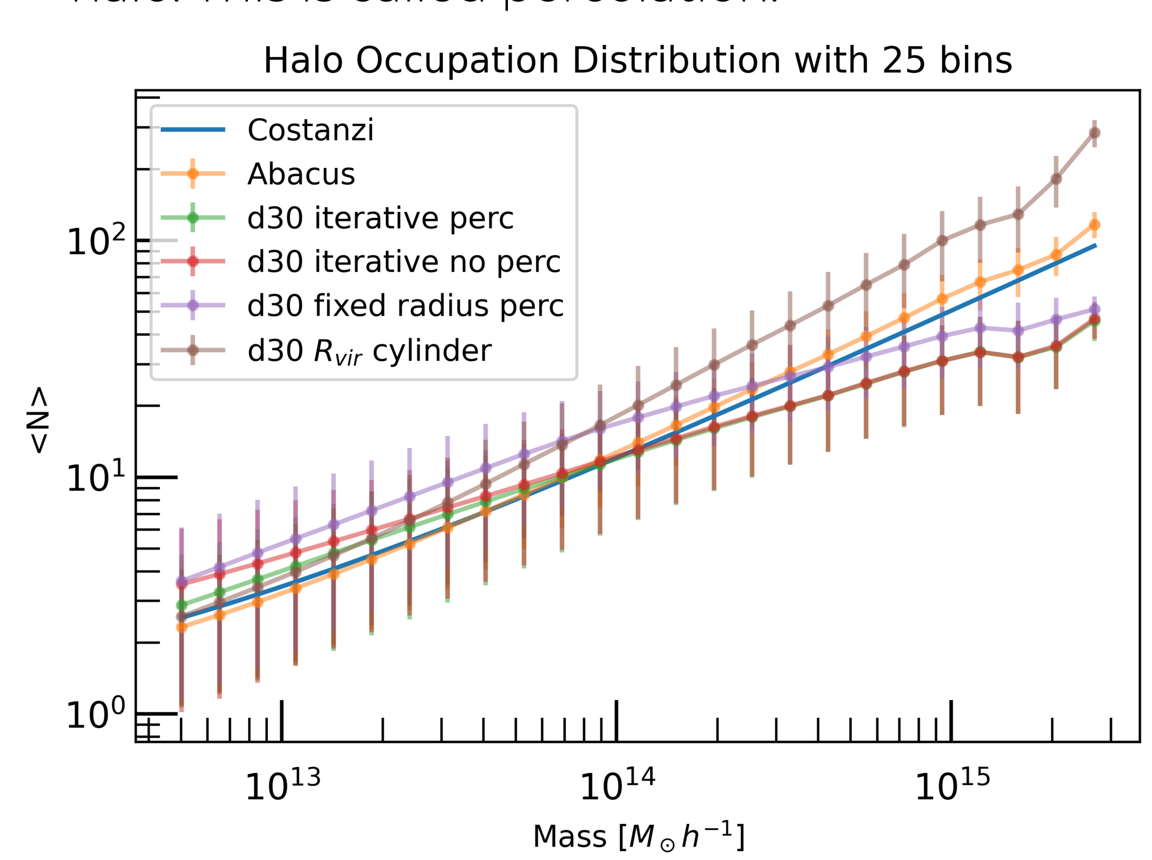

Figure 3: Comparison of iterative and fixed radius, cylindrical counting with and without percolation with a line-of-sight distance of 30 Mpc/h. Included is counting with a cylinder of radius R_{vir}.

In Figure 3, counting without percolation results in a higher count. This affects halos of lower masses and has little effect at $10^{14}\ \mathrm{M_{\odot}h^{-1}}$ and higher. The richness from a fixed radius results in overcounting. As a sanity check, the mass that corresponds to a radius of 1 Mpc/h is $7.3 * 10^{13}\ \mathrm{M_{\odot}h^{-1}}$ and the cylindrical counting with radius R_{vir} matches there.

The uncertainty in line-of-sight distance affects the richness because galaxies can be within the halo, but the distance calculated from redshift may be out of the halo. Different line-of-sight distances are used when counting to study the effect.

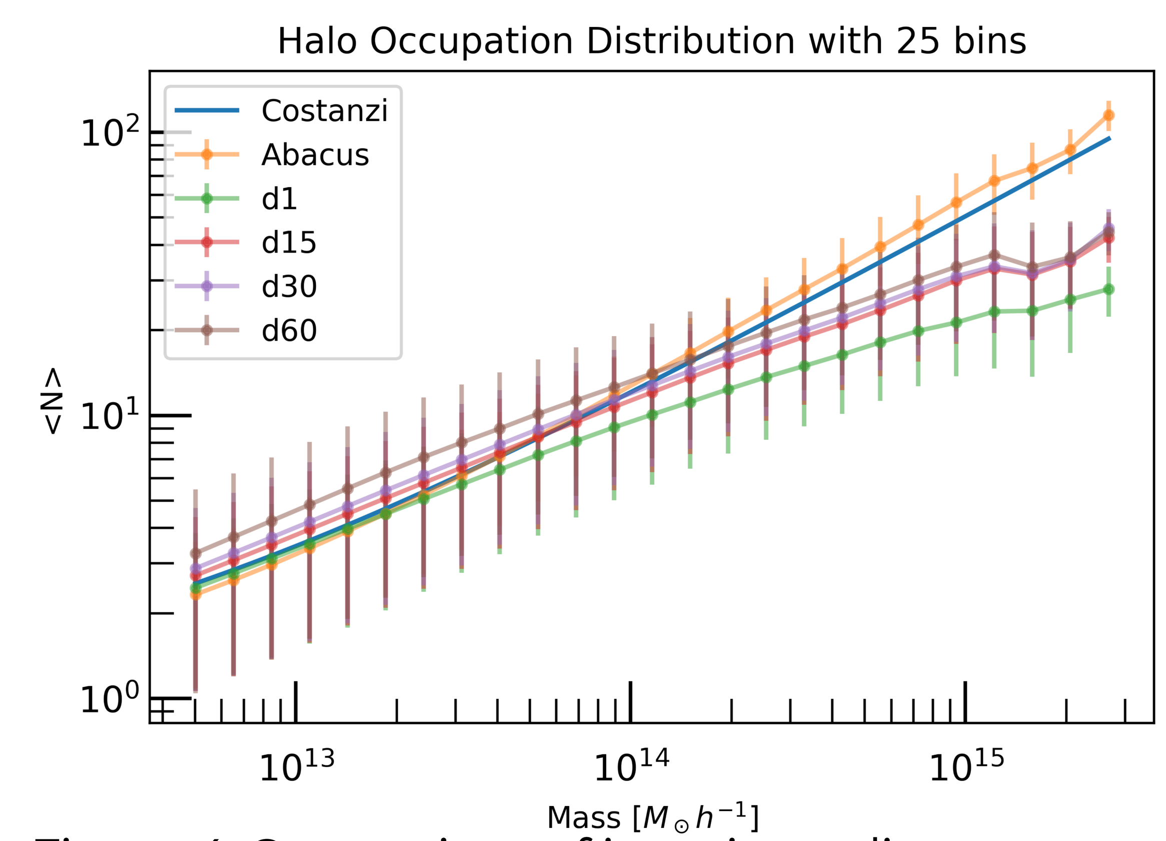

Figure 4: Comparison of iterative radius, cylindrical counting with varying line-of-sight distances. The number after 'd' is the line-of-sight distance in Mpc/h.

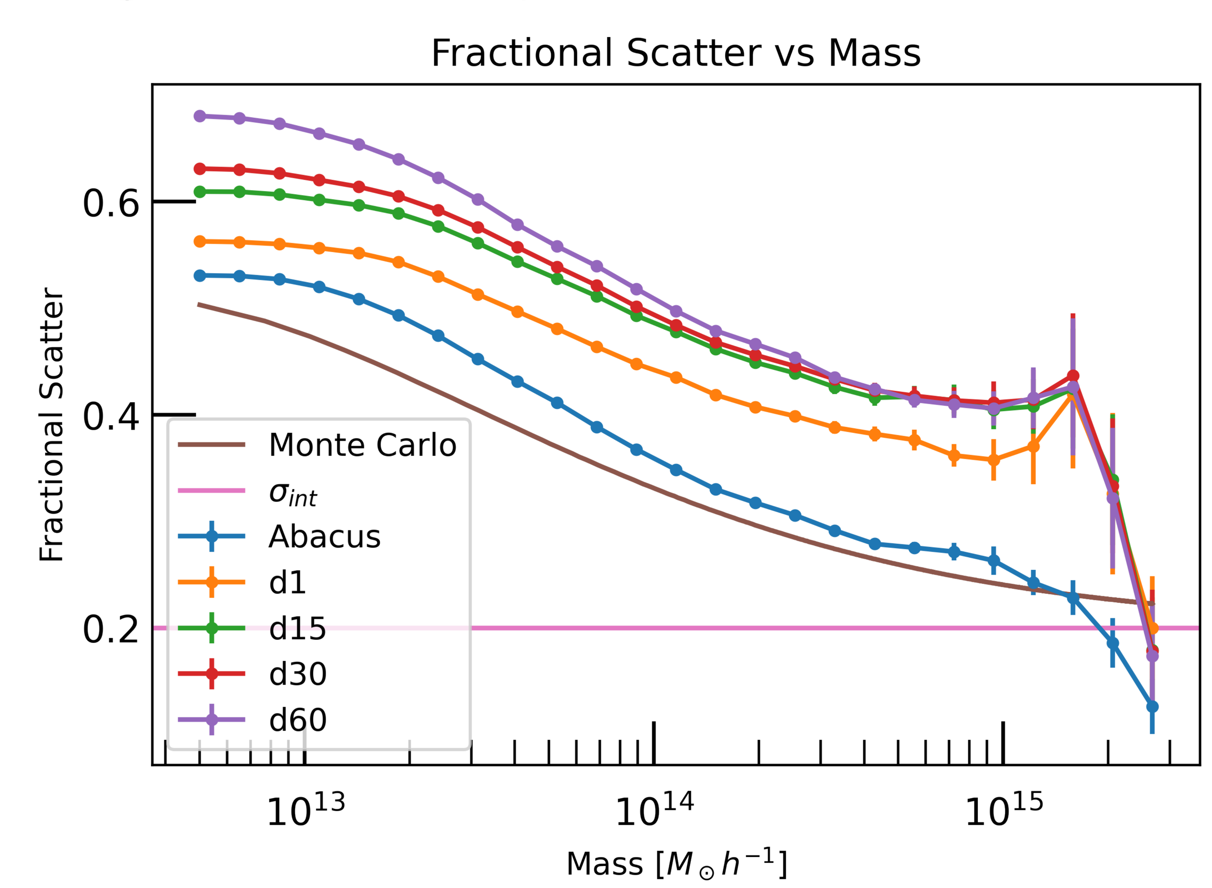

Figure 5: The fractional scatter at each mass interval from figure 3. $\boldsymbol{\sigma}_{\mathbf{int}}$ is the input scatter of the simulation.

As seen in Figure 4 and 5, counting with a line-of-sight above 15 Mpc/h has little effect. The fractional scatter is the standard deviation in richness divided by the average richness in a mass interval. The noise in the data at high masses is due to fewer halos of that mass to sample from as seen in Figure 1.

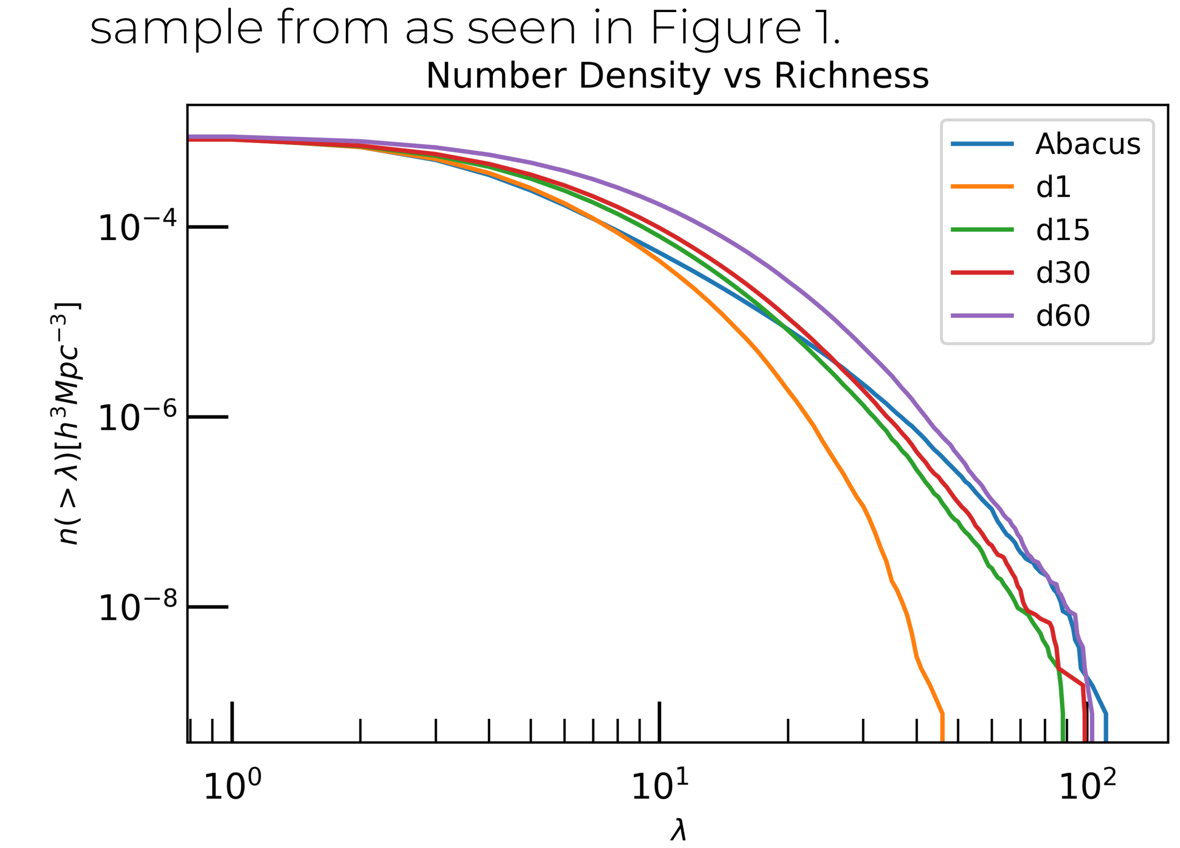

Figure 6: The number density of halos of greater richness for different line-of-sight distances.

Conclusion

The richness-mass relation and its scatter is dominated by galaxies within a projection depth of 15 Mpc/h. Galaxies beyond 15 Mpc/h have negligible impacts. Percolation and the uncertainty in radius has relatively weak impact on the richness-mass relation and scatter.

References

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