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# Mapping the Hercules supercluster to understand large scale structure formation and environmental effect on galaxies

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**Abstract.** Using spectroscopic and photometric data from SDSS, we aim to map the distribution of matter on the Hercules supercluster ($z \approx 0.038$). Its diversity of environments include from filaments and relaxed clusters to structures on several dynamical stages, like pre-interacting, on collision and post-collision clusters, making Hercules an excelent laboratory to the study of galaxies in different scales. We are going to evaluate if two clusters (A2153 and A2159) are gravitationally bound to the main structure. The results will allow us to know the spatial limits of Hercules and make a comparative study between populations of galaxies along the supercluster and neighbouring filaments.

**Resumo.** A partir dos dados espectroscópicos e fotométricos do SDSS, nosso objetivo é mapear a distribuição de matéria no superaglomerado de Hércules ($z \approx 0.038$). Sua diversidade de ambientes inclui desde filamentos e aglomerados relaxados até estruturas nos mais diversos estágios dinâmicos, como aglomerados em pré-interação, em colisão e pós-colisão, tornando Hércules um excelente laboratório para estudos de galáxias em diferentes escalas. Nesta primeira etapa iremos avaliar se dois aglomerados (A2153 e A2159) estão gravitacionalmente ligados à estrutura principal. Os resultados nos permitirão conhecer os limites espaciais do superaglomerado de Hércules e fazer um estudo comparativo entre as populações de galáxias ao longo do superaglomerado e dos filamentos vizinhos.

**Keywords.** galaxies: clusters: general – galaxies: clusters: individual: A2153 – galaxies: clusters: individual: A2159 – large-scale structure of Universe

## 1. Introduction

The definition of a supercluster of galaxies is not well established, apart from the fact that they are vast overdense regions observed along the cosmic web. In this study we follow the definition of supercluster as a set of gravitationally bound structures that will collapse in the future, and use this to delimit the Hercules supercluster (SCL160) physical boundaries. Afterwards, we wish to be able to study the properties of its member galaxies as a function of the large scale environment in which they are embedded.

Hercules is composed of the clusters A2147, A2151, A2152 and two other structures identified by Monteiro-Oliveira et. al (2022), A and B (Figure 1). Other two clusters from the Abell catalogue, A2153 and A2159, can be seen in the nearby density field (Figure 2). At first we don't know if these two are real physical structures, it could be that their detection was caused by a projection effect, so our initial goal is to determine whether these structures exist, check if they are bound to Hercules, and finally obtain the complete picture of the supercluster.

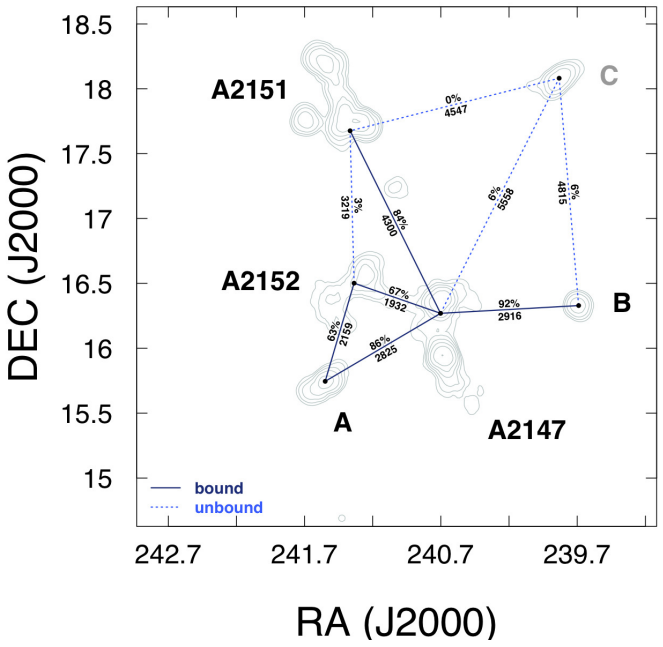


**Figure 1.** A schematic skeleton of the Hercules supercluster. Three structures, labeled as A, B and C were identified by Monteiro-Oliveira et. al (2022). The numbers above the lines represent the probability that adjacent structures are gravitationally bound. Under the lines are the distances in kpc.

## 2. Methods

We traced the distribution of matter using spectroscopy data from SDSS-DR17 in a circular region with 4.5 degrees of radius centered in $\alpha, \delta$ = (240.57792, +16.020), as shown in Figure 2. We also used photometric data to determine the red sequence in Hercules' redshift by selecting galaxies in the central region of the supercluster (A2152+A2147) and finding the most dense region in the color-color diagram (i-z) x (g-r), as seen in Figure 4. This contour was then applied to all photometric galaxies within Hercules' radius, resulting in Fig. 3.

Finite gaussian mixture modelling from the R package *Mclust* (Scrucca et. al 2016) was employed to check if the candidate clusters A2153 and A2159 could be separated into multiple components (Figure 5). Kolmogorov-Smirnov (K-S) test was then applied to check compatibility between redshift distributions from neighbouring structures.

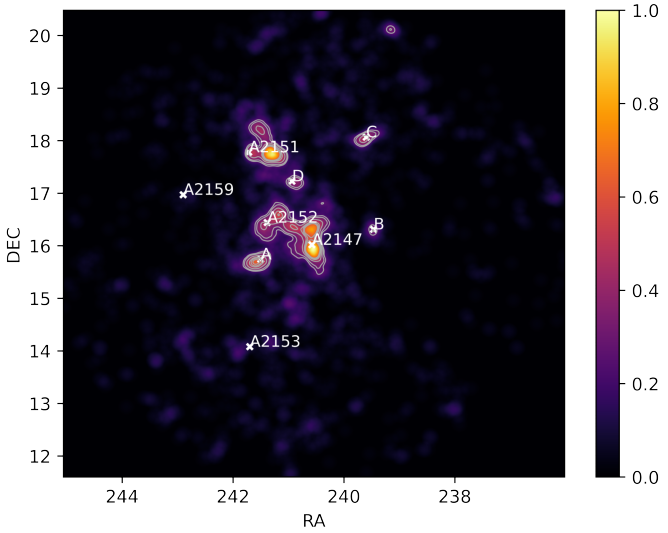


**Figure 2.** Smoothed number density map for SDSS's SpecObj galaxies in the Hercules supercluster region (radius of ~12 Mpc), showing its main components and candidate members A2153 and A2159.

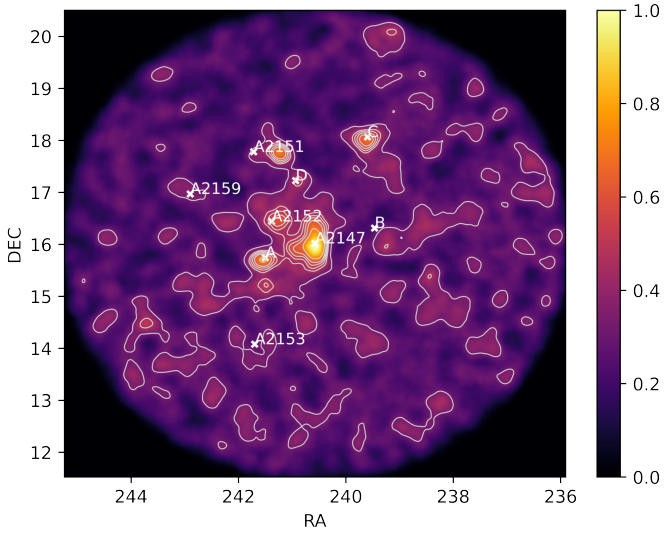


**Figure 3.** Same as Figure 2, but using only photometrically selected galaxies from Hercules' red sequence. Both maps share similar features, especially in the central regions.

## 3. Results

Some evidence suggests that A2153 is a smaller cluster located at redshift compatible with that of the Hercules supercluster. First, A2153 has a reasonable number of observed galaxies, N = 128. Its redshift distribution (Figure 5) shows two gaussian-like shapes that would be expected from a galaxy cluster.

A K-S test between the right-most redshift distribution component of A2153 (Figure 5) and its nearest structure, the southern component of A2147 (see Figure 2), results in a p-value of p = 0.35, so that we don't reject the null hypothesis that both distributions come from the same sample. This A2153 component has a velocity dispersion of 493 km $s^{-1}$, which makes sense physically because it is similar to the values found in low density structures, such as A2151's southern structure (D), which has a velocity dispersion of 471 km $s^{-1}$. Hence we conclude that A2153 might be an existing structure with the same redshift of A2147.

As for A2159, there was no clear evidence favoring its existence.

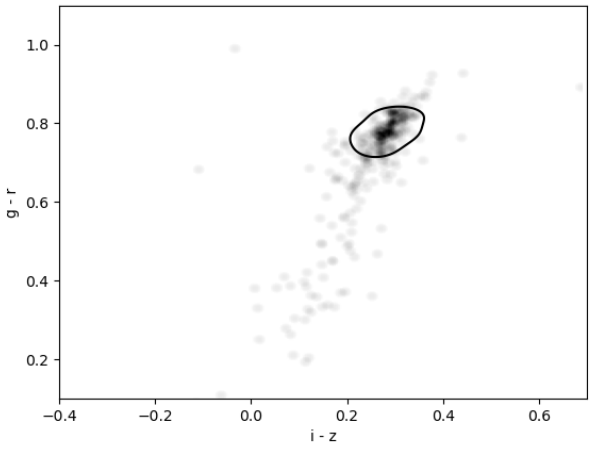


**Figure 4.** Color-color diagram for A2152's and A2147's galaxies. The red sequence is detected within a contour on the most dense region.

## 4. Conclusion

Using spectroscopic and photometric data from SDSS, we tried to find out if the clusters A2153 and A2159 are members of the Hercules supercluster. We found a decent number of galaxies in A2153 and properties compatible with Hercules' clusters, such as velocity dispersion, colours and redshift distribution.

This is not enough to ensure that this cluster exists, so the next immediate step is to use the RPM code (Reliable Photometric Membership), by Lopes & Ribeiro (2020), which detects cluster members using only photometric information, and obtain a definite answer.

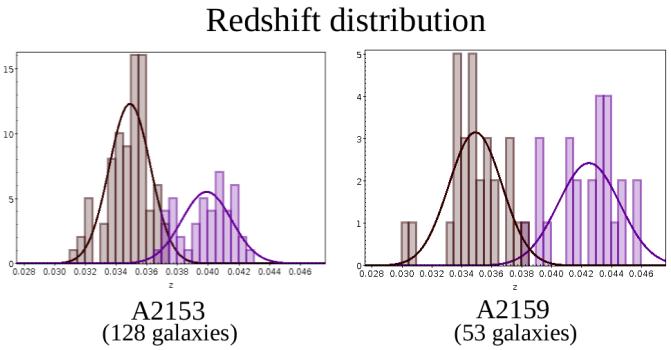


**Figure 5.** The redshift histogram for A2153 (left side) and its two components detected by *Mclust*. The same is shown for A2159 on the right side.

## References

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