GALAXY SUPERCLUSTERS DETECTED IN THE MODIFIED PF-CATALOG USING THE FOF METHOD

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Abstract. The Modified Catalog of Galaxy Clusters and Groups (Panko & Flin 2006, PF), covering an area of 5000 square degrees in the southern sky, was used as the input for the search of galaxy superclusters. Only the estimated redshifts could be used, since the PF catalog is a 2D catalog, with the calibration correlating the redshift of galaxy clusters with the magnitude of the tenth brightest cluster galaxy. Only galaxy clusters containing more than 50 galaxies were considered, and the FoF method was applied. The nearest neighbour distances for 1711 input clusters were calculated and analyzed, and 20 isolated clusters were found with the nearest neighbour at a distance greater than $68h^{-1}$Mpc. A distance of $24h^{-1}$ Mpc between clusters was selected for the supercluster search, and 49 superclusters containing from 4 to 9 galaxy clusters were detected. Calculations for each supercluster include: its inferred center, RA, Dec, $z_{est}$, the maximum distance between supercluster members and the estimated supercluster shapes. A typical size of superclusters identified here is about $55h^{-1}$Mpc, and they appear mainly as elongated pancakes, with a weak correlation between the axes $c/a$ and $b/a$, without a strong dependence on multiplicity.

Key words: galaxies: clusters, superclusters: general

1. INTRODUCTION

In the current ΛCDM cosmological paradigm, the distribution of galaxies on large scales, reflects primordial density fluctuations in the early Universe. Very large structures, such as galaxy superclusters, are not virialized, and constitute filamentary or planar structures, supercluster characteristics that were established mainly from 3D galaxy surveys (e.g., Huchra et al. 1983; Efstathiou, Sutherland & Maddox 1990). An independent dataset was used here to study observational properties of galaxy superclusters. Only rough estimates were possible for the shapes of structures of low multiplicity; exact shapes were not analyzed.

2. OBSERVATIONAL DATA

The Catalog of Galaxy Clusters and Groups (Panko & Flin 2006, hereafter PF) was used as the input for this investigation. The resulting 6188 galaxy clusters and groups were found using the data from the Muenster Red Sky Survey (Ungruhe et al. 2003, hereafter MRSS), a large-scale galaxy catalog covering an area of about
5000 square degrees in the southern hemisphere, complete to a magnitude limit of $r_F = 18.3$. The same magnitude limit defines the completeness limit for galaxies in the PF catalog. Since the Muenster Red Sky Survey does not contain galaxy redshifts, the distances to galaxy clusters were estimated using the $(\log z) \text{ vs. } m_{10}$ relation (Biernacka et al. 2009), following Dalton et al. (1997).

Subsequent investigations of individual clusters revealed some rich regions in which galaxy clusters were not completely separated. The catalog was therefore revised, although most results, such as the distribution of cluster richness or ellipticity and the redshift calibration, remained essentially unchanged.

A value of $N \geq 50$ was assigned as the number of galaxies in a structure field separating clusters and groups of galaxies (Biernacka et al. 2007). The modified PF catalog has 1711 such structures with $z_{\text{est}} < 0.15$. The distribution of the input clusters on the celestial sphere and their estimated redshift distribution is shown in Figure 1.

2. SUPERCLUSTERS SEARCH

For the search of superclusters the Friends-of-Friends method (FoF) was applied. An object belongs to a friends-of-friends group if it is located within some critical interval (linking length) of any other object in the group. After all such groups are identified, those with less than a specified minimum number of group members are rejected. This method, introduced by Huchra & Geller (1982), accepts that the linking length to the nearest neighbour depends on the distance from the observer to object. We have used the Zeldovich et al. (1982) form of the FoF method, i.e. the linking length to the nearest neighbour was accepted to be the same for all input data.

The distance to the nearest neighbour for all 1711 clusters lies within 4.6 and 173.7 $h^{-1}\text{Mpc}$, and only for 20 structures the nearest neighbour is more than 68.5 $h^{-1}\text{Mpc}$ distant. Such clusters are characterized as isolated, and they are mainly clusters with $z > 0.12$. A value of $24 h^{-1}\text{Mpc}$ corresponds to a random distribution in the input data and comprises only 20% of the objects; it was used as an estimate of clusterization. Some 62 superclusters were found with a multiplicity...
of 3, and 49 with a multiplicity between 4 and 9. The distribution by multiplicity is summarized in Table 1. The lists were compiled for galaxies associated with superclusters and for isolated clusters, for future statistical investigation.

For each supercluster, calculations were made for the position of its center, RA, Dec, $z_{est}$, the maximum projected distance between its components, and its shape using a triaxial ellipsoid approximation. For the last calculation the data for supercluster members were transformed into rectangular coordinates, a matrix was formed for each supercluster from the positions of member components relative to the supercluster centroid, and its eigenvector was derived. The eigenvector components are proportional to the best-fit ellipsoid semi-axes (e.g., Jang-Condell & Hernquist 2001; Plionis et al. 1991; Kolokotronis et al. 2001). The maximum dimensional value considered was taken as $a$, the second and third as $b$ and $c$, respectively. That is valid for rich structures, and is correct for poor structures as well. For example, the semi-axes relation for a regular tetrahedron is $1:1:1$, and such a structure can be described as rounded.

3. RESULTS AND DISCUSSION

According to this study, 49 of the delineated superclusters are not spherical structures. The positions in the $c/a - b/a$ plane for superclusters from this study with noted multiplicities are shown in Figure 2. It appears that 20 of the superclusters are flat, elongated structures; they have values for the ratio $c/a \leq 0.1$. Some 10 others have ratios $b/a < 0.5$; their multiplicity is 4 or 5, with only one 6-member supercluster out of six also in this group. In the list of all superclusters, only 2 (with $N = 4$ and $N = 8$) can be interpreted as non-flat (noted in Figure 2 by arrows). They have semi-axes $c/a > 0.5$ and $b/a > 0.75$. Other superclusters have maximum values of $c/a = 0.38$, with mean values of $c/a = 0.17$ for all data and 0.15 for 4-member superclusters, with a s.e. of about ±0.03. In similar fashion, the mean value of $b/a$ is about 0.48 for all data as well as for

<table>
<thead>
<tr>
<th>Multiplicity</th>
<th>Number</th>
<th>$D_{max}, h^{-1}$ Mpc</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>30</td>
<td>58</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
<td>55</td>
</tr>
<tr>
<td>6</td>
<td>5</td>
<td>73 (62)</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>55</td>
</tr>
<tr>
<td>8</td>
<td>2</td>
<td>83 (53)</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>48</td>
</tr>
</tbody>
</table>
4-member groups, with a s.e. of about ±0.04. The correlation between \( c/a \) and \( b/a \) was found to be significant at the level \( r = 0.60 \), a value providing evidence only for a tendency in the data, since \( c < b \) by definition.

The typical maximum projected separation between supercluster members is about \( 55 h^{-1} \) Mpc, excluding two superclusters with multiplicities of 6 and 8. The richest superclusters cannot be used for statistical analysis, however the maximum distances between other supercluster members are listed in column 3 (\( D_{\text{max}} \)) of Table 1, while values for second ranked clusters are given in brackets. If the maximum distance is considered to be representative of the size of superclusters, then the values found here are smaller than the value of \( 100 h^{-1} \) Mpc obtained by Bahcall & Soneira (1984).

4. SUMMARY AND CONCLUSIONS

A large compilation of galaxy positions comprising a field of about 5000 square degrees was used as input in a search for galaxy superclusters. Some 49 superclusters were found having a multiplicity ranging from 4 to 9, with estimated redshifts lying within the limits 0.068–0.117. The typical size of the identified superclusters is about \( 55 h^{-1} \) Mpc, and they appear like elongated pancakes, with a weak correlation between semi-axes values \( c/a \) and \( b/a \), and without a strong dependence on multiplicity.

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