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# Peculiar motions of galaxy clusters in the regions of superclusters of galaxies

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We present results of the study of peculiar motions of 57 clusters and groups of galaxies in the regions of the Corona Borealis (CrB), Bootes (Boo), Z 5029/A 1424, A 1190, A 1750/A 1809 superclusters of galaxies and 20 galaxy clusters located beyond massive structures ($0.05 < z < 0.10$). Using the SDSS Data Release 8 data, a sample of early-type galaxies was compiled in the systems under study, their Fundamental Planes (FP) were built, and relative distances and peculiar velocities were determined. Within the galaxy superclusters, significant peculiar motions along the line of sight are observed with rms deviations of $652 \pm 50$ km s$^{-1}$ in CrB and $757 \pm 70$ km s$^{-1}$ in Boo. In the Z 5029/A 1424 supercluster near the rich Z 5029 cluster, the most considerable peculiar motions with an rms deviation of $1366 \pm 170$ km s$^{-1}$ are observed. The rms deviation of peculiar velocities of 20 clusters that do not belong to large-scale structures is equal to $0 \pm 20$ km s$^{-1}$. The whole sample of the clusters under study has the mean peculiar velocity equal to $83 \pm 130$ km s$^{-1}$ relative to the cosmic microwave background.

*Keywords*: Galaxies: clusters: individual: Corona Borealis, Bootes, Z 5029/A 1424, A 1190, A 1750/A 1809, A 2142 – large scale structure of the Universe

## 1 Introduction

In the large-scale structure of the Universe, the largest systems of galaxies, the superclusters are interconnected by filaments from galaxies and located along the boundaries of voids. Such large systems (or parts thereof) of galaxies can be gravitationally bound, if within their limits the desired contrast of the average density of galaxies is achieved (see, e.g. Dunner et al. 2006). If galaxy clusters in superclusters are quite densely located in the sky, one can expect the presence of large peculiar velocities in them which can be measured by determining distances to galaxy clusters. Such compact superclusters within $0.05 < z < 0.1$ are superclusters Corona Borealis (CrB), Ursa Major (UMa) and Bootes (Boo). Among the superclusters, the most studied are

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the CrB supercluster (Postman et al. 1988; Small et al. 1998; Kopylova and Kopylov 1998; Batiste and Batuski 2013; Baiesi Pillastrini 2016) and UMa supercluster (Kopylova and Kopylov 2007), and the least studied is the Boo supercluster.

Model calculations of peculiar motions of galaxy clusters (taking errors into account) for the CDM model with $\Omega = 0.3$ have shown that the distribution of one-dimensional peculiar velocities of the clusters has a peak at 400 km s$^{-1}$ and stretches to 1500 km s$^{-1}$. Their rms deviations are $\langle V_{1D}^2 \rangle^{1/2} = 544$ km s$^{-1}$ and in observations it is $725 \pm 50$ km s$^{-1}$ (Bahcall et al. 1994).

The aim of the present work is the study of peculiar motions of groups and clusters of galaxies located in the regions of the massive superclusters of galaxies Corona Borealis and A 2142, Bootes, in the regions of smaller superclusters of the galaxies such as SCl 24, SCl 38, SCl 61 (Einasto et al. 2011), and pairs of galaxy clusters. Moreover, there are 20 clusters of galaxies in our sample that do not practically belong to such large superclusters at the redshifts $0.05 < z < 0.10$.

The paper is arranged in the following way. In Section 2, we describe the selection of early-type galaxies, build the FP, and determine relative distances of groups and clusters of galaxies. In Section 3, we calculate peculiar velocities and determine their rms deviations in the superclusters. In the Conclusion, we give the results obtained. In this paper, we used the following cosmological parameters: $\Omega_m = 0.3$, $\Omega_\Lambda = 0.7$, $H_0 = 70$ km s$^{-1}$ Mpc$^{-1}$.

## 2 Building the fundamental plane of early-type galaxies

Our sample is composed of 57 clusters of galaxies with redshifts $0.05 < z < 0.1$. The dynamical characteristics of galaxy systems are based on the measurement of one-dimensional radial velocities dispersion by which the virial mass is calculated within the empirical radius $R_{200}$ on the assumption of $M(r) \propto r$. The radius $R_{200}$ is close (but smaller) to the virial, and within the density of the system 200 times exceeds the critical density of the Universe. $R_{200}$ can be estimated with the formula $R_{200} = \sqrt{3}\sigma/10H(z)$ Mpc (Carlberg et al. 1997). First, we estimated the average radial velocity of the cluster $cz$ and its dispersion $\sigma$, then from the dispersion we found the radius $R_{200}$. Galaxies with the velocities greater than $2.7\sigma$ were considered as background (described in more detail in Kopylova and Kopylov 2017).

In this work, to determine the relative distances of galaxy clusters we used galaxy parameters presented in the SDSS Data Release 8 (Aihara et al. 2011). According to this release, which takes into account image processing errors of large galaxies allowed in previous releases, the FP in the r-band of 93 000 early-type galaxies ($z < 0.2$) was built (Saulder et al. 2013): $\log R_e\,[\mathrm{kpc}] = 1.034 \log \sigma + 0.301 \langle \mu \rangle_e + \gamma$. In this equation, $R_e$ is the effective radius of a galaxy in kpc, $\langle \mu_e \rangle$ is the average surface brightness within this radius, and $\sigma$ is the central dispersion of stellar radial velocities. We used the form of obtained FP, specifying at the same time the zero-point $\gamma$ for our sample ($\gamma = -7.775$). The rms deviation of the FP zero-point is equal to $0.068 \pm 0.003$ which is equivalent to the 16% error of the distance determination for a single galaxy. The formal error of the cluster distance determination depends on the number of the used galaxies and varies from 2% to 12%.

## 3 Determination of distances and peculiar velocities of galaxy clusters

Figure 1 shows the individual observed distances (zero-points $\gamma$ calculated at $\log R_e$ in arcseconds) of the galaxies in the A 2065 (solid circles) and in the more distant cluster A 2142 (open circles) depending on their radial velocities relative the CMB. A bold line shows the expected Hubble dependence between radial velocity and distance calculated for a model we accepted and the zero point equal to $-7.775$. In this case, the comoving radial distance $D = (cz/H_o)\,(1 - 0.225z)/(1 + z)$ is calculated with $q_o = -0.055$, and the correction for stellar evolution in the galaxy $Q = 1.07z$ is introduced in the zero point of the FP (Saulder et al. 2013). Solid vertical lines near each cluster show their radial velocities relative to the CMB. Dashed (horizontal) lines show average distances of the galaxy clusters determined from the FP and radial velocities corresponding to them (vertical lines). The difference of radial velocities is characterized as a peculiar velocity of a group or a galaxy cluster along the line of sight. In other words, $V_{\rm pec} = c\,(z_{\rm CMB} - z_{\rm FP})/(1 + z_{\rm FP})$, where $c$ is the light velocity, $c\,z_{\rm CMB}$ is the radial velocity of a cluster relative to the CMB, and $c\,z_{\rm FP}$ is the radial velocity of a cluster corresponding to a distance determined with the FP.

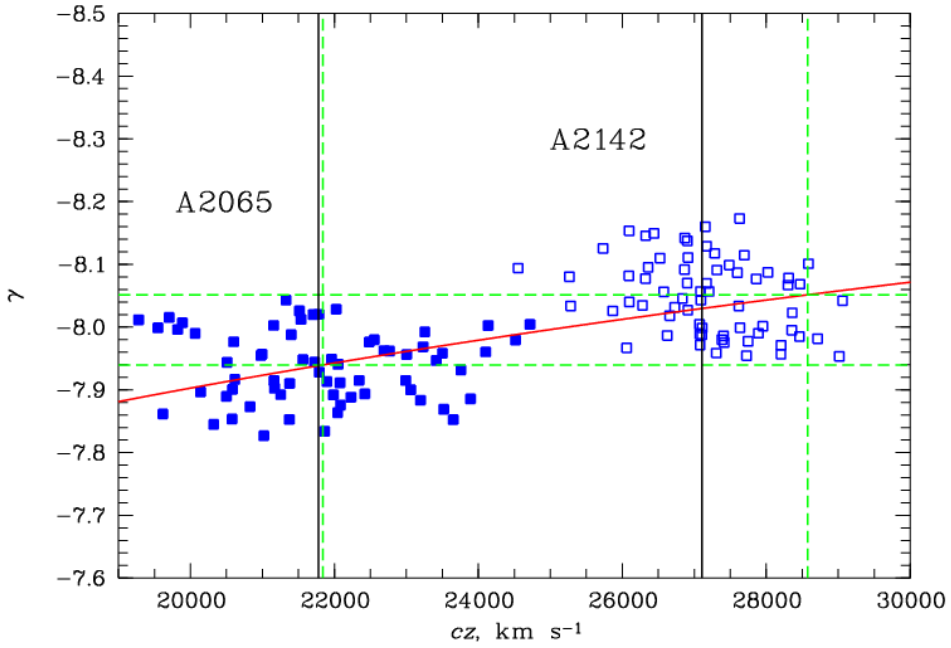



**Figure 1** Dependence of the individual distances, zero points of the FP $\gamma$ on the radial velocities of the galaxies located within the radius $R_{200}$ in the clusters A 2065 (solid circles) and A 2142 (open circles). A bold line corresponds to the Hubble relation between radial velocity and distance. Solid vertical lines show average radial velocities of clusters $cz_{\rm CMB}$ that give corresponding distances at the inter-crossing with the Hubble curve; dashed lines show average distances of the clusters found with the FP and radial velocities corresponding to them, $cz_{\rm FP}$.

**Table 1** Peculiar velocities and rms deviations of peculiar velocities in samples of galaxies.

| Sample | $N$ | $V_{\rm pec}$ | $< V^2_{\rm pec} >^{1/2}$ |
|---|---|---|---|
| SCl CrB | 9 | $428 \pm 210$ | $652 \pm 50$ |
| SCl Boo | 11 | $-168 \pm 280$ | $757 \pm 70$ |
| SCl Z 5029/A 1424 | 4 | $535 \pm 360$ | $1366 \pm 170$ |
| SCl A 1190 | 3 | $-640 \pm 450$ | $496 \pm 130$ |
| SCl A 1750/A 1809 | 4 | $877 \pm 420$ | $630 \pm 170$ |
| A 2244+A 2245 | 2 | | $1473 \pm 540$ |
| A 2029+A 2033 | 2 | $-445 \pm 700$ | $0 \pm 170$ |
| field | 20 | $-59 \pm 140$ | $0 \pm 20$ |
| total | 57 | $83 \pm 130$ | $646 \pm 10$ |

Table 1 presents average peculiar velocities of the galaxy cluster systems and their rms deviations along the line of sight with squared error check.

The greatest rms deviations $\langle V^2_{\rm pec}\rangle^{1/2}$ of one-dimensional peculiar velocities are observed in the supercluster Z 5029/A 1424 and in the pair of rich galaxy clusters A 2244 and A 2245. The A 2244 cluster is the main one in this pair, since it has an X-ray luminosity an order of magnitude greater than A 2245 (Ebeling et al. 1998), and does not have a peculiar velocity. A 2244 cluster is moving toward it with a great positive peculiar velocity. In the pair of the A 2029 and A 2033 galaxy clusters, $\langle V^2_{\rm pec}\rangle^{1/2}$ is equal to zero. In this pair, the main system is A 2029 (with a very high X-ray luminosity (Ebeling et al. 1998), and A 2033 is a smaller system gravitationally bound with it. Both clusters are on the same distance $\gamma$ and their small peculiar velocities have same sign; they are moving away from us. The whole sample of galaxy clusters has an inconsiderable peculiar velocity relative to the CMB $83 \pm 130$ km s$^{-1}$. The rms deviation $\langle V^2_{\rm pec}\rangle^{1/2}$ of peculiar velocities of 20 galaxy clusters beyond the massive structures with $\sigma > 500$ km s$^{-1}$ is equal to $0 \pm 20$ km s$^{-1}$.

## 4 Conclusions

Model calculations show that high peculiar velocities, $V_{\rm pec} > 10^3$ km s$^{-1}$, appear in dense galaxy superclusters (Bahcall et al. 1994). In the present paper, we analyze the dynamics of galaxy clusters in the rich superclusters Corona Borealis and Bootes and in poorer superclusters Z 5029/A 1424, A 1190, A 1750/A 1809, in pairs and galaxy clusters which do not belong to any large structures and do not have neighbors of comparable sizes within 4 Mpc in the sky plane and within the radial velocity range of $\pm$ 3000 km s$^{-1}$.

The main result of our study is that the rms deviation of the peculiar velocities of galaxy clusters in superclusters is larger than 500 km s$^{-1}$ (Table **??**) and is much higher than the rms deviation of the peculiar velocities of galaxy systems that do not belong to massive structures. The mean peculiar velocity of the whole sample of the galaxy clusters relative to the CMB is $83 \pm 130$ km s$^{-1}$.

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