Rotation of the cluster of galaxies A2107

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ABSTRACT

We present indications of rotation in the galaxy cluster A2107 by a method that searches for the maximum gradient in the velocity field in a flat disk-like model of a cluster. Galaxies from cumulative sub-samples containing more and more distant members from the cluster centre, are projected onto an axis passing through the centre and we apply a linear regression model on the projected distances \( z \) and the line-of-sight velocities \( V \). The axis with the maximum linear correlation coefficient \( r_{\text{max}} = \max |r(V, z)| \) defines the direction of the maximum velocity gradient, and consequently it presents the major axis of the apparently elliptical cluster. Because the effects of rotation are subtle, we put strong emphasis on the estimation of the uncertainties of the results by implementing different bootstrap techniques. We have found the rotational effects are more strongly expressed from distances \( 0.26 \pm 0.54 \, \text{Mpc} \) from the cluster centre. The total virial mass of the cluster is \( (3.2 \pm 0.6) \times 10^{14} \, \text{M}_\odot \), while the virial mass, corrected for the rotation, is \( (2.8 \pm 0.5) \times 10^{14} \, \text{M}_\odot \).

Key words: methods: statistical – galaxies: clusters: individual (A2107).

1 INTRODUCTION

Velocity gradients suggestive of galaxy cluster rotation were found in several studies (e.g. Kalinkov 1968, Gregory 1975, Gregory & Tiiff 1976, Gregory & Thompson 1977, Materne & Hopp 1983, Materne 1984, Williams 1986, Oegerle & Hill 1992, Sodré et al 1992, Biviano et al. 1996, Tovmassian 2002). It is commonly accepted opinion that there is no evidence of rotation of the galaxy clusters, however, if the galaxy clusters rotate their dynamics and dynamical evolution would be different. The velocity dispersion profiles must be corrected for the rotation and the corresponding virial mass estimation will be different. Many theoretical constructions are based on the assumption of no rotation e.g. the infall models and especially the theory of caustics (Regös & Geller 1989, Diaferio & Geller 1997, van Haarlem et al. 1993, Diaferio 1999, Rines et al. 2003).

Here we make an another attempt to reveal rotation in the galaxy cluster A2107. We have chosen this particular cluster to illustrate our method, because it is well studied and indications of rotations were already found (Oegerle & Hill 1992).

The structure of the paper is as follows: in Section 2 we present our method, the different bootstrap techniques that we use to estimate the uncertainties of the derived rotational parameters are presented in Section 3. In the next Section 4 we present the data for A2107 and in Section 5 our results. We finish with discussion and conclusions (Section 6). In order to compare our results with the previous studies we assume an Einstein-de Sitter cosmology and \( H_0 = 100 \, \text{km s}^{-1} \, \text{Mpc}^{-1} \). For this model at the cluster redshift \( z = 0.04100 < < 1 \), 10' correspond to 358 kpc.

2 METHOD

We consider a flat, disk-like galaxy cluster with regions with nearly solid body rotation. The main idea is to find the axis of the maximum velocity gradient which, in the disk-like model, defines the major axis of the cluster. The minor axis is the axis of rotation.

It is known the rotational effects are weak and their search would be successful if some cumulative technique is applied. Let us take sub-samples \( \{i\} \) of the cluster member galaxies, arranged by their projected distance from the cluster centre. Thus any sub-sample \( \{i\} \) contains the first \( i \) galaxies out to a given projected distance \( d_i \). The sub-samples \( \{i\} \) are not independent.

Let us introduce an axis passing through the cluster centre and rotating around it and we define the positional angle \( \varphi \) in the usual way (anticlockwise from N) as shown on
method. The symbols “+” and “−” are velocity deviations of the galaxies from the mean cluster velocity. Note the positional angle of rotation $\phi_b$ spans the whole range from 0 to 360 degrees.

Fig. 1. A schematic and idealistic representation of a disk-like cluster that indicates the axes and the angles used in the method. The symbols “+” and “−” are velocity deviations of the galaxies like cluster that indicates the axes and the angles used in the Figure 1.

A schematic and idealistic representation of a disk-axis with positional angle $\phi$. In linear approximation, this corresponds to the mean of $\langle x \rangle$ for the same sub-sample $\{i\}$.

Unfortunately the positional angles of the maximum elongation in the cluster cores are known to vary depending on the X-ray isophote level.

The virial mass $M$ of a cluster is defined through the velocity dispersion $\sigma_V$. In fact,

$$\sigma_V = s_{r0}((i-2)/(i-1))^{1/2}$$

If the cluster rotates the velocity dispersion has to be corrected ($\sigma_V^\prime$), according to the formula above, but with $s_{r\text{max}}$ instead of $s_{r0}$. Then $M - M^\prime = \Delta M$ is a fictitious mass, due to rotation.

Supposing that some noticeable effects of rotation really exist, then, with our approach, we expect the following indications:

(i) The correlation coefficient $r_{\text{max}}$ will be significant for at least few consecutive sub-samples $\{i\}$.

(ii) The positional angles $\varphi_{\text{max}}$ for these consecutive sub-samples will not be randomly distributed along the entire range of $\varphi$, but in a relatively narrow interval.

(iii) The variation of $r$ and $s$ for $0^\circ \leq \varphi < 360^\circ$ would be close to sine waves and, for sub-samples $\{i\}$ with significant $r_{\text{max}}$, the phase shifts of both curves should be according to (ii), in a narrow range. The expressions for the sine waves of $r$ and $s$ are

$$r(\varphi) = r_{\text{max}} \sin(\varphi - \varphi_{\text{max}})$$

$$s(\varphi) = (s_{r0} + s_{\text{max}})/2 + [(s_{r0} - s_{\text{max}})/2] \sin(\varphi - \varphi_{r0})$$

(iv) The virial mass for some sub-samples $\{i\}$ will be significantly different as computed for $s_{r0}$ and $s_{\text{max}}$.

3 UNCERTAINTIES, BOOTSTRAP TECHNIQUES AND RANDOMISATION.

The question of uncertainties is a crucial one because the effects of rotation are weak. Where it is possible we rely on bootstrap uncertainties.

We apply two bootstrap techniques. The first one is the standard or the classical bootstrap (B) - (Efron 1982, Efron & Tibshirani 1986). Shortly, for each sub-sample we find the positional angle $\varphi_{\text{max}}$ and then resample the velocities $V$ and the projected distances $x$ on this axis in order to derive the bootstrap uncertainties of $\alpha$, $\beta$, $r$, $s$. This procedure however has the disadvantage that it is impossible to find the uncertainties of $\varphi_{\text{max}}$ and $\varphi_{r0}$.

That is why we apply simultaneously a modified bootstrap (MB) techniques: the positions and velocities of sub-sample $\{i\}$ are subject to bootstrap resampling after which the search for $r_{\text{max}}$ is carried out and the corresponding $\varphi_{\text{max}}$, $\alpha$, $\beta$, $r$, $s$, are derived. Note that each bootstrap sample leads to completely different $r_{\text{max}}$, $\varphi_{\text{max}}$, $\alpha$, $\beta$.

In all cases, we run $10^6$ bootstrap generations and calculate the corresponding quantities for $\varphi(0^\circ - 360^\circ)$ with a decrement of $0^\circ.1$. We use the resulting distribution of the quantity in question to derive the confidence interval.

Let us denote with $w_B$ whatever of the quantities we discuss. The first estimator of the uncertainty we use is the bias-corrected (bc) 68% confidence interval $w \in [w_B(0.16), w_B(0.84)]$ (Efron & Tibshirani 1986) with
\[ w_{bc}(t) = G^{-1} \left\{ \Phi^{-1}(t) + 2\Phi^{-1}(G(w_{obs})) \right\}, \quad (6) \]

where \( G \) is the cumulative distribution function (CDF) of the \( w_B, (w_{obs}) \) is the observed mean value, and \( \Phi \) is the CDF of the normal distribution (thus \( \Phi^{-1}(t) = -1, +1 \) for \( t = 0.16 \) and \( t = 0.84 \) respectively). This uncertainty is \( \Delta w_{ET} \). Efron & Tibshirani (1986) uncertainty is effectively used by Shepherd et al. (1997) and Kalinkov & Kuneva (1986a) for the space correlation functions of galaxies and clusters of galaxies.

The second estimator of the uncertainty we implement is the bootstrap standard deviation (Ling, Barrow & Frenk 1986)

\[ \Delta w_B = \sqrt{\sum_{n=1}^{10^4} \left( \frac{w_{B,m} - \langle w_B \rangle}{10^4} \right)^2 }^{1/2}, \quad (7) \]

where \( \langle w_B \rangle \) is the mean bootstrap value. This st.dev. is very effectively used by Kalinkov & Kuneva (1986).

We have found that both uncertainties \( \Delta w_B \) and \( \Delta w_{ET} \) are consistent with each other, but we prefer \( \Delta w_{ET} \), since the estimator is valid even if the distribution of \( w \) is not Gaussian.

The uncertainty on the correlation coefficient can also be computed using the classical Fisher z-transformation (e.g. Press et al. 1992, Section 14.5). The uncertainties derived by this method are also consistent with the other two.

There is one problem—the bootstrap technique does not work when we determine the uncertainties of the virial mass estimates. In the resampling, some objects are duplicated and consequently the distance between them is zero and the cluster potential tends to infinity. In this case only we apply the jackknife estimate (see e.g. Efron 1982).

In order to assess the significance of the derived quantities we use randomised sub-samples for which the azimuthal angles (or \( \varphi \)) of the galaxies centres are made randomly distributed in the interval \([0^\circ, 360^\circ]\). This new sample is subject to the same procedure of parameter and confidence interval estimates. Here the uncertainties are only \( \Delta w_B \). It is worth to note that with this procedure the observed radial density and velocity distributions are not altered.

4 DATA

Coordinates and heliocentric velocities of galaxies in the direction of A2107 are taken predominantly from the most complete optical study of Oegerle & Hill (1992) – further on OH. Some corrections and additions are made according to NED (new redshifts and coordinates) and therefore new observational errors are defined. We use also data from other sources, e.g. Zabludoff et al. (1993). We reckon that galaxy Nr. 252 is the same as Nr. 273 (LEDA 94259) from the list of Oegerle & Hill (1992).

We adopt the X-ray centre of A2107 according to Ebeling et al. (1996) \( RA = 15^h 30^m 38^s \) and \( Dec = 21^\circ 47' 20'' \) for J2000. Our results however do not substantially differ neither if we adopt the original cluster centre of Abell (1958) and Abell, Corwin & Olowin (1989) nor if we take the cD galaxy (UGC 9958) as centre.

The member galaxies were selected using ROSTAT (Beers, Flynn & Gerhardt 1990) as well as the cone diagrams and the velocity distribution. There are 70 galaxies out to 37.0 arcmin from the X-ray centre within \( (V) \pm 2\sigma \). Zwicky galaxy 136-22 is the farthest member. For the non relativistic case (i.e. in the observed rest frame), the mean velocity is \( \langle V \rangle = 12291_{-41}^{+73} \text{ km s}^{-1} \), the standard deviation \( 627_{-56}^{+49} \text{ km s}^{-1} \), the bi-weighted estimate of location and scale \( V_{bw} = 12318 \text{ km s}^{-1} \) and \( s_b = 639 \text{ km s}^{-1} \), the median \( V_m = 12380 \text{ km s}^{-1} \) and the normalised absolute deviation \( s_m = 623 \text{ km s}^{-1} \), skewness -0.28, kurtosis -0.40.

Our results however do not substantially differ neither if we adopt the original cluster centre of Abell (1958) and Abell, Corwin & Olowin (1989) nor if we take the cD galaxy (UGC 9958) as centre.

All our results cited here are for this sample with size \( n = 70 \).

There are two galaxies at 1.2 arcmin from the cluster centre (Nrs. 242 and 289 from the list of OH) with velocities 14069 and 14028 km s\(^{-1}\). These galaxies could be taken as cluster members if we stand on the infall theory, since the velocity dispersion at the cluster centre should be the largest. Including these two galaxies we obtain for \( n = 72 \): \( \langle V \rangle = 12339_{-79}^{+70} \text{ km s}^{-1} \), \( s = 683_{-69}^{+64} \text{ km s}^{-1} \), \( V_{bw} = 12338, s_b = 685, V_m = 12386, s_m = 635 \text{ km s}^{-1} \), skewness 0.05, kurtosis -0.03.

All further conclusions are also referred to the sample with size \( n = 72 \).

5 RESULTS

In Fig. 2 we show \( r_{max} \) results for the sub-samples \( 6 \leq \{i\} \leq 70 \). For sample \{70\} the correlation coefficients are \( r_{max,70} = 0.358_{-0.111}^{+0.055} \). Assuming that correlation coefficients \( r_{max,70} \) and \( r_{max,rand} \) are almost normally distributed and are independent, the significance of their difference \( \langle r_{max} \rangle - \langle r_{rand} \rangle \) can be estimated from Student’s distribution. Consequently, the probability of the null hypothesis, that the correlation coefficients are drawn from one and the same population, is \( P < 1.0 \times 10^{-13} \).

The highest \( r_{max,47} = 0.633_{-0.100}^{+0.061} \) (where st.dev. are according to the MB method) occurs for sub-sample 47, at \( d_i = 0.54 \text{ Mpc} \). For B the st.dev. are (+0.069,-0.084). For the randomised sub-sample 47 we have \( r_{max,rand} = 0.209 \pm 0.104 \). In this case \( P < 1.0 \times 10^{-17} \).

A crucial test for rotation is the diagram (\( \varphi_{max, d_i} \)) and (\( \varphi_{0, d_i} \)). If the points are randomly distributed in the interval \([0^\circ, 360^\circ]\) the hypothesis for rotation must be rejected. The results for both \( \varphi_{max} \) and \( \varphi_{0} \) are shown on Fig. 3, together with the corresponding results for azimuthally randomised sub-samples (denoted as stars). Note that if \( \varphi_{0,rand} \equiv \varphi_{max,rand} \). The st.dev. for the randomised sub-samples are \( \approx \{360^\circ\}/2^{1/2} \) which corresponds to the st.dev. of uniformly distributed positional angles. The differences between \( \varphi_{0} \) and \( \varphi_{max} \) are \( \approx 90^\circ \).

Next, for sub-samples with \( 0.54 < d_i < 0.76 \), for which \( r_{max} \) significantly differs from the azimuthally randomised correlation coefficients, (\( \varphi_{max} \)) = 173° ± 4°. We assume that this is the positional angle of the velocity gradient. The positional angle of the minor axis is (\( \varphi_{0} \)) = 271° ± 5°. The last value gives the positional angle of the rotational axis if our model is valid. The difference between both mean values is 98°.

In Fig. 4 we show the st.dev. of the regressions \( s_{r_{max}} \) and \( s_{r_{0}} \) for positional angles corresponding to \( r_{max} \) and \( r_{0} \) – there is significant distinction for those sub-samples where the maximum correlation coefficient is significant.
Figure 2. Observed $r_{\text{max}}$ (dots) and azimuthally randomised $(r_{\text{max,B}})$ (diamonds) for subsamples $\{i\} = 6 \div 70$ as a function of the distance from the cluster centre $d_i$. The st.dev. for $r_{\text{max}}$ are defined according to MB while for $(r_{\text{max,B}})$ are according to B. These types of errors are presented on all figures except Figs. 6-7.

Figure 3. The positional angles $\varphi_{\text{max}}$ (dots) and $\varphi_{\text{r0}}$ (diamonds). The stars show the results for azimuthally randomised sub-samples with the errors (dotted lines).

Figure 4. St.dev. of the regressions: $s_{\text{r0}}$ (dots) and $s_{\text{rmax}}$ (diamonds).

Figure 5. Variation of $r$ (solid line) and $s$ (dashed) as a function of the positional angle $\varphi$ for sub-sample $\{i\} = 47$.

Figure 6. The virial masses: $M^\circ$ (dots) and $M$ (diamonds). The error bars refer to the jackknife estimator. Fits with third order polynomials are also shown.

The variations of $r$ and $s$ as a function of $\varphi$ for sub-sample $\{i\} = 47$ are shown on Fig. 5. The curves are very close to sine waves. For the maximum correlation coefficient determined from azimuthally randomization of any sub-sample $\{i\}$, the $s$ curve is also sine-like but with much smaller amplitude and for various bootstrap resamples their phase angles are randomly distributed on $[0^\circ, 360^\circ]$.

For the sub-sample \{47\} we have $\varphi_{\text{rmax}} = 166^\circ$ and $\varphi_{\text{r0}} = 260^\circ$. And the virial mass estimate $M = (2.18 \pm 0.36) \cdot 10^{14} M_\odot$ and $M^\circ = (1.29 \pm 0.21) \cdot 10^{14} M_\odot$.

We have computed the cumulative virial mass of A2107 for sub-samples \{20\} to \{70\}, following the prescriptions of Heisler, Tremaine \& Bahcall (1985). We have used the velocity dispersion $\sigma_V$ to derive the usual virial mass $M$ as well as the corrected virial mass $M^\circ$. The results are given on Fig. 6. The error bars were calculated implementing the jackknife method. There is a slight difference between $M$ and $M^\circ$. The distinction begins at $\{i\} = 20$, at $d_{20} = 0.22$ Mpc. In order to compare both estimates we fit the masses with third order polynomials, as shown on Fig. 6. On Fig. 7 we show $M - M^\circ$ together with the difference between both polynomials. If our finding that the cluster A2107 rotates
is true, then Fig. 6 would reflect a fictitious mass, due to rotation. Our estimates for the total masses are \( M = (3.21 \pm 0.62) \cdot 10^{14} M_\odot \) and \( M^c = (2.80 \pm 0.54) \cdot 10^{14} M_\odot \).

The parameter \( \beta \) of the examined regression, which represents the maximum velocity gradient expressed in km s\(^{-1}\) Mpc\(^{-1}\) is shown on Fig. 8. Actually it is \( \beta_{r_{\text{max}}} \) and also \( \langle \beta_{r_{\text{max}}, M_B} \rangle \) as functions of \( d_i \).

Our method gives an opportunity to estimate an upper limit for the rotational period. In Fig. 9 we show the upper limits for \( P_{r_{\text{max}}} \) compared with the results from azimuthally randomised samples. The estimate is simplistic – we have not included any correction for the inclination of the galaxy cluster. Any inclination of our flat model will inevitably decrease the period.

The analysis up to now was based on cumulative distributions. It is possible however to obtain an additional information by considering the differential case. Let us denote the differential sub-samples by \( \{p, p + q - 1\} \), where \( p = 1, 2, \ldots, 70 \) and \( q = 3, 4, \ldots, 70 \). Repeating our procedure for the differential sub-samples, which are in fact galaxies in different annuli, we find that \( r_{\text{max}} \) is very noisy for small \( p \) and \( q \) and at its maximum \( r_{\text{max}} = 0.814^{+0.040}_{-0.102} \) for \( \{25, 47\} \) (i.e. \( p = 25 \) and \( q = 23 \) or for distances 0.26 \pm 0.54 Mpc from the cluster centre). For the same sub-sample the azimuthally randomised bootstrap resampling gives \( r_{\text{max}} = 0.271 \pm 0.133 \). The corresponding probability is \( P < 1.0 \cdot 10^{-11} \) and it is larger than that for sub-sample \( \{47\} \) since there are fewer degrees of freedom.

The standard deviations of the estimates for the \( r_{\text{max}} \) and \( r_0 \) are \( s_{r_{\text{max}}} = 446^{+118}_{-42} \) km s\(^{-1}\) and \( s_{r_0} = 767^{+92}_{-56} \) km s\(^{-1}\) correspondingly. For the differential sub-sample \( \varphi_{r_{\text{max}}} = 167^\circ \) and \( \varphi_{r_0} = 261^\circ \). For these 23 galaxies the derived period is \( P = (2.43^{+0.30}_{-0.21}) \cdot 10^9 \) years. The corresponding differential virial masses are \( M = (3.51 \pm 0.60) \cdot 10^{14} M_\odot \) and \( M^c = (1.19 \pm 0.20) \cdot 10^{14} M_\odot \).

The results from the differential treatment are in agreement and support the cumulative ones.

### 6 DISCUSSION AND CONCLUSIONS

A2107 is a nearby cluster of richness class 1, classified as BMI (Abell 1958, Abell, Corwin & Olowin 1989). The Abell’s count of galaxies is \( N_A = 51 \), the cluster radius is 45 arcmin (22.4 arcmin from Struble & Rood 1987, \( H_0 = 50 \)) and the RS classification type is cD (Struble & Rood 1987). The cluster is isolated and is also identified (Kalikov, Valtchanov & Kuneva 1998b) as Zwicky cluster ZC 7573 (Zwicky & Herzog, 1963) as distance group Near, type \( mc \), population of galaxies 293 and equivalent radius \( r_{eZ} = 69.4 \) arcmin. At 26.5° and positional angle of 204° is located another Zwicky cluster ZC 7578 (distance group VD, population 110, type \( mc \), \( r_{eZ} = 7.8 \) arcmin).

There is no detailed description of A2107. Girardi et al. (1997) comment on A2107 – “Remarkably regular cluster”.

Presumably rotation of clusters of galaxies is difficult to be established with certainty. Matern & Hopp (1983) have shown that it is extremely hard (if generally possible) to distinguish the case of a single cluster in rotation from the case of two overlapping clusters, which are merging or departing from each other. That is why OH, investigating the same cluster A2107, have examined both possibilities. They employed the \( \delta \)-test of Dressler & Shectman (1988) and they have found that there is significant sub-structuring in A2107. Supposing that \( \sum_{\delta} = n \) when there is no spatial-velocity correlation, OH performed 1000 Monte Carlo (MC) simulations and found \( \langle \sum_{\delta} \rangle_{MC} = 111 \)
(see also Oegerle & Hill 2001). Because their sample contains $n = 68$ cluster members, they concluded that A2107 contains substructures. All $\sum \delta_{MC}$ are smaller than 111 and hence the probability for existence of substructures in A2107 is $> 0.999$. We have carried out exactly the same experiment but with $10^5$ Monte Carlo simulations and found that $\sum \delta_{MC}$ are almost normally distributed with mean $\langle \sum \delta_{MC} \rangle = 70.00 \pm 10.82$ against $\sum \delta_{obs} = 102.3$. Our result supports the conclusion of OH that A2107 indeed contains substructures with probability $> 0.994$.

Concerning the velocity distribution, relying on the large peculiar velocity of the central cD galaxy (UGC 9958, $V_{pec} = 270$ km s$^{-1}$; see also Oegerle & Hill, 2001), OH decomposed the velocity histogram into two sub-clusters. They have chosen one decomposition amongst infinite number of possibilities. Indeed, there are no reasonable arguments that constrain us to assume two sub-cluster centres or that the velocity histogram is superposition of two (or may be more?) distributions.

We have verified the hypothesis for sub-clustering – one against two centres. We have used another powerful test especially for two sub-structures (Lee 1979), introduced in the cluster sub-structure studies by Fitchett (1988) and successfully applied by Fitchett & Webster (1987), Rhee, van Haarlem & Katgert (1991b), Pinkney et al. (1996). Our result, on the base of 10 000 simulations of azimuthally randomised samples, leads to Lee function $L_{el} = 1.42 \pm 0.21$ while $L_{obs} = 2.11^{+0.31}_{-0.31}$. The alternative hypothesis, that the cluster has two sub-structures, is accepted at significance of at least 95%. The corresponding positional angle of the two sub-cluster centres is $145^\circ$.

But the sub-clustering does not rule out the hypothesis of rotation. It is plausible that the cause of sub-clustering in the Dressler-Sheetman diagram (Fig. 5 of OH) is just due to the rotation, since the most prominent clumpiness is along the maximum gradient in the velocity field of A2107, indicated by our $\varphi_{rmax}$. Indeed, from galaxy studies we know that the velocity field of disk-like rotating galaxies without any massive halo has two extremes, $V_{max}$ and $V_{min}$. This would cause apparent sub-clustering. But if there are two overlapping clusters, then it will be unlikely they will generate a mimicry of rotation – first of all, the velocity histogram will have two peaks or quite broad velocity distribution with rather unrealistically high velocity dispersion. None of this is observed in A2107. Secondly, we have investigated the behaviour of correlation coefficients, positional angles etc. From our point of view, if there are two sub-clusters that are located at positional angle close to $\varphi_{rmax}$, this would be regarded as evidence for rotation. Nevertheless some authors disregard this possibility as the cause of the velocity gradient (den Hartog & Katgert 1996).

Our strongest evidence for rotation is the consistent measure of the positional angle of the velocity gradient $\varphi_{rmax}$ for consecutive cumulative sub-samples. One way of validating the inferred positional angle is to compare it with the positional angle of the elongation of the cluster $\varphi_{el}$. For our flat disk-like model $\varphi_{el} = \varphi_{rmax} = \varphi_{el}$. Debating the Binggeli’s effect (Binggeli 1982) many authors have measured $\varphi_{el}$, as well as ellipticities, of various samples of Abell clusters (e.g. Struble & Peebles 1985, Struble & Rood 1987, Lambas et al. 1990). While Struble & Peebles (1985) have found $\varphi_{el} = 137^\circ$ for A2107, Rhee & Katgert (1987) quote $160^\circ$ and $93^\circ$ for the 50 and 100 brightest galaxies respectively, within a radius of 1 Mpc. According to Binggeli (1982) $\varphi_{el} = 62^\circ$. In a detailed investigation Rhee, van Haarlem & Katgert (1991a, 1992) apply three different methods and determine for the same cluster, using about 300 galaxies out to 0.75 Mpc, that $\varphi_{el} = 75.68$ and $90^\circ$ with ellipticities 0.13, 0.00 and 1.00 respectively. But according to their Fig. 5 (Rhee, van Haarlem & Katgert 1991a) $\varphi_{el} \approx 143^\circ$ for the first 20 brightest galaxies while for the first 70 is about $3^\circ$.

Apparently the estimates of $\varphi_{el}$ for A2107 are not very reliable. Perhaps the reason is objective – it seems that $\varphi_{el}$ depends on the brightness of the galaxies and the distance to the cluster centre. There are examples of drastic variations of $\varphi_{el}$ in some clusters in the most elaborate paper on this subject (Burgett et al. 2004).

As stated above there are two possibilities to explain the velocity gradient in a galaxy cluster - two-body model or rotation. An anonymous referee however turned our attention on a third possibility: according to simulations of galactic tides in dwarf spheroidal galaxies Piatek & Pryor (1995) have shown that tides produce large ordered motions which induce apparent rotation. Biviano et al. (1996) assume that the velocity gradient in the central part of Coma cluster maybe due to tidal effects caused by falling groups of galaxies and not by rotation. But in the case of A2107 it is not quite the same, because we did not find any groups of galaxies in this regular cluster.

The parameters $\beta$ and $\varphi_{rmax}$ derived with our method may be compared with those of other authors. The positional angle of the rotational axis of OH, namely $70^\circ$, is close to our determination $271^\circ - 180^\circ = 91^\circ$. From $\delta V/\delta X, \delta V/\delta Y$ for A2107 in Table 3 of den Hartog & Katgert (1996) we infer $\varphi_{rmax} \approx 330^\circ$. The last value is close to our estimate of $\varphi_{rmax} = 173^\circ$ with $180^\circ$ difference depending on the convention used.

The parameter $\beta$ after den Hartog & Katgert (1996) is $842$ km s$^{-1}$ Mpc$^{-1}$ (for $H_0 = 50$ km s$^{-1}$ Mpc$^{-1}$). Our value $\beta$ for the entire cluster A2107 is 718 while for the sub-samples $\{47\}$ and $\{25,47\}$ the values are 2232 and 2527 km s$^{-1}$ Mpc$^{-1}$ correspondingly. OH give $\approx 1800$ km s$^{-1}$ Mpc$^{-1}$ for the whole cluster, which is close to our value for the sub-samples but not for sample $\{70\}$.

Our estimate of the rotational period is $P = (2.4^{+0.3}_{-0.2}) \cdot 10^8$ years, while the azimuthally randomised bootstrap generations give $P = (1.3 \pm 2.3) \cdot 10^8$ years. We have to note that our method of searching the maximum correlation in random samples leads to artificially decreasing the period of rotation. The period quoted by OH is $7 \cdot 10^8$ years. These periods are not corrected for the inclination of the cluster. Our estimate of $P$ could be compared with the corresponding value of Gregory & Tiffit (1976) for the outer regions in Coma cluster (A1656), which is about $2 \cdot 10^8$ years. We presume the real period is $< 2 \cdot 10^8$ years and therefore A2107 has made already few rotations during the Hubble time.

There are several virial mass estimates for A2107. All estimates are not substantially different because they are based on one and the same radial velocity data. According to OH the total virial mass of A2107 is $M \approx 4 \cdot 10^{14} M_\odot$ and in the frame of their two-body model, the masses of both sub-structures are $\sim 1.3 : 1$. Girardi et al. (1998) give a virial mass $M = (3.0_{-0.9}^{+0.94}) \cdot 10^{14} M_\odot$ and a corrected
\( M^c = (2.62^{+0.83}_{-0.77}) \cdot 10^{14} M_\odot \) (according to their Eqn. 8).

Girardi et al. (2002) use the corrected mass only. But the correction of Girardi et al. (1998, 2002) has quite a different nature – it is due not to rotation but to a modification of the virial theorem in order to compensate the incompleteness of the sample out to the virial radius.

Our estimated total mass of A2107 is \( M = (3.21 \pm 0.62) \cdot 10^{14} M_\odot \) (without any correction). Most importantly, reducing the effect of rotation we infer virial mass \( M^c = (2.80 \pm 0.54) \cdot 10^{14} M_\odot \). The simplest way to get this virial mass is to estimate the velocity dispersion from the linear regression at positional angle \( \phi_{r0} \).

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