

**Interaction of Abell Cluster 2063 and the Group of Galaxies MKW3s**

by

**J. K r e m p e ć - K r y g i e r**N. Copernicus Astronomical Center, Astrophysical Lab., ul. Rabiniańska 8, 87-100 Toruń  
Poland

e-mail: jkkart@ncac.torun.pl

and

**B. K r y g i e r**Toruń Centre for Astronomy, Department of Radioastronomy, ul. Gagarina 11,  
87-100 Toruń, Poland

e-mail: bk@astro.uni.torun.pl

*Received February 8, 1999*

## ABSTRACT

The changes of the dynamical properties of A2063 with the distance to the center of the cluster are discussed. The velocity dispersion increases with the distance from the central region of the cluster and decreases in its outer rings. Such an inverted profile of velocity dispersion might be the result of occurrence of dynamical subclusters and/or of circularization of galactic orbits. The existence of subclumps of galaxies in A2063 has been confirmed by the values of the Dressler-Shectman  $\delta$ -parameter and the spatial distribution of galaxies. Besides, the ratio of the number of ellipticals and the SO galaxies to that of spirals and irregulars decreases with distance from cluster center. The cD galaxy of A2063 has statistically significant peculiar velocity and does not lay at the minimum of gravitational potential of the cluster. The dynamical properties of A2063 and MKW3s may result from the encounter (merger) event.

**Key words:** *Galaxies: interactions – Galaxies: clusters: individual: A2063, MKW3s*

**1. Introduction**

Recently, there are many evidences of the interaction between the neighboring clusters or groups of galaxies from the measured redshifts of the large number of their members (Bird 1994, Escalera *et al.* 1994) and from the X-ray surface brightness distributions (Briel and Henry 1993, Bower *et al.* 1997). Such systems might merge in the time scale shorter or comparable with the Hubble time or the age of cluster (Roettiger *et al.* 1996). The interaction or merger will change the observed distribution of radial velocities of clusters leading to their deviations from the Gaussians (Roettiger *et al.* 1997). On the other hand, from the formation

theories for central dominant galaxies in clusters it is known that they should be located at the minimum of the cluster gravitational potential (Teague *et al.* 1990, Pinkney *et al.* 1996, Garijo *et al.* 1997). However, the radial velocities of the cD galaxies in clusters do often differ significantly from mean velocities of clusters of galaxies (*e.g.*, Pinkney *et al.* 1993). The presence of high peculiar velocities of cD galaxies gives evidences for existence of subclusters and for the occurrence of merger events.

It is the aim of present paper to discuss the dynamics of the Abell cluster of galaxies A2063 and of the group of galaxies MKW3s. The dynamical properties of the whole cluster A2063 and MKW3s are analyzed in Section 2. Section 3 deals with their changes with distance. In Section 4 the relation between these changes and the changes of the fractions of different morphological types of galaxies are discussed.

## 2. Dynamics of A2063 and MKW3s

A2063 ( $z = 0.0351$ ) is the Abell cluster of galaxies of richness class  $R = 1$ , distance class  $D = 3$  (Abell *et al.* 1989) and the Bautz-Morgan type II (BM II). MKW3s ( $z = 0.0443$ ) belongs to the group of galaxies defined by Morgan *et al.* (1975) and Albert *et al.* (1977). According to Bahcall (1980) the physical parameters of groups of galaxies are extension of those of rich clusters of galaxies. There is a dominant central galaxy at the center of MKW3s, namely NGC5920. NGC5920 resembles galaxies cD in rich clusters of galaxies in brightness but it is smaller. We have calculated the luminosity distances ( $DIS$ ) of A2063 and of MKW3s for the deceleration parameter  $q_0 = 0.5$  and  $H_0 = 50$  km/(s · Mpc) given in Table 1. Accordingly, 1 arcsec corresponds to 0.961 and 1.196 kpc at the distances of A2063 and of MKW3s respectively.

### 2.1. Dynamical Properties of Whole Cluster A2063 and MKW3s

To look for the evidences of interaction of A2063 and MKW3s their dynamical properties will be discussed in this Section. At first, we shall analyze if there are any deviations of their velocity distributions from the Gaussian ones. All published velocities (or redshifts) of galaxies in A2063 (Oegerle and Hill 1994, Bird 1994, Zabludoff *et al.* 1993) and in MKW3s (Hill and Oegerle 1993) have been used. We have found redshifts for 106 galaxies in A2063 ( $N$  in Table 1) and 34 galaxies in MKW3s. We have determined the relativistic radial velocities of members of the clusters  $v_r$ , the mean radial velocity of clusters  $v_{\text{rcl}}$  as well as the second (dispersion –  $\sigma_r$ ) and higher momenta of the Gaussian distributions, namely the skewness  $S$  and the kurtosis  $E$ . The calculated dynamical parameters and their  $1\sigma$  errors are given in Table 1.

The differences between the radial velocities derived from various published redshifts have never been larger than about  $\pm 100$  km/s. They are usually contained

within uncertainty  $\pm\sigma$  and seem to be random. For example, Wegner *et al.* (1996) have measured redshifts for ten galaxies in A2063 and derived the mean relativistic radial velocity equal to 10381 km/s which is consistent with that given in Table 1.

On the other hand, our cluster velocities and velocity dispersions given in Table 1 differ from those recently published by White *et al.* (1997). However, our determinations are based upon the observational data for much larger sample ( $N = 106$  for A2063) than those quoted by them. The low velocity dispersion of their subsample A2063SW, equal to 537 km/s, corresponds to our sample  $V$  in Table 3, laying on the border of A2063 and MKW3s. We have used  $\chi^2$ -test for the comparison of the observed and theoretical Gaussian distributions of radial velocities counted in bins of  $\Delta v = 400$  km/s (see Fig. 1). The probabilities  $P$ , that the distributions of radial velocities are Gaussians, have been estimated. We have found that the velocity distribution of galaxies in the whole cluster A2063 is Gaussian with the probability  $P$  of 99.9%, while that of MKW3s (probability 66%) is less peaky than Gaussian and is platykurtic.

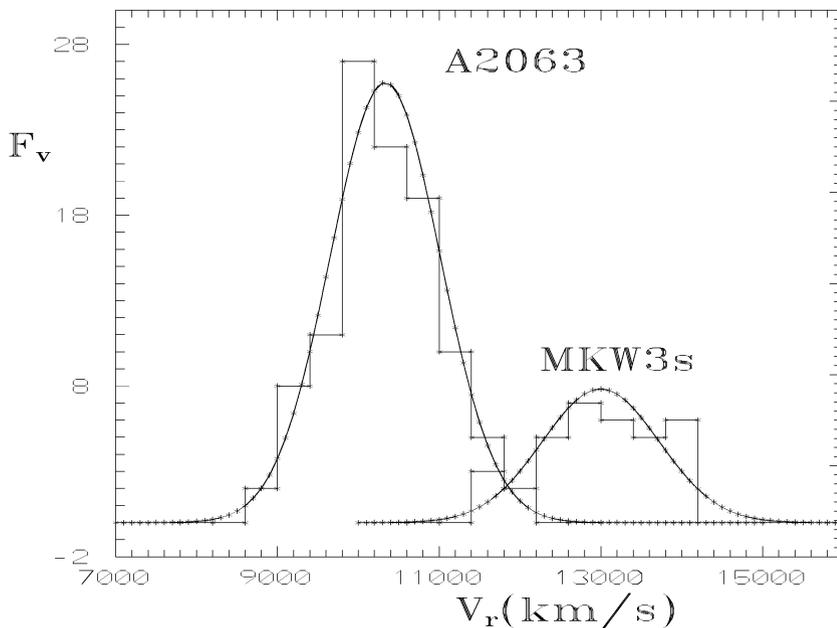


Fig. 1. Histogram of the observed radial velocities of galaxies in A2063 and MKW3s with the superimposed Gaussians derived with parameters given in Table 1. The bins of radial velocities are 400 km/s.

Although Bird (1994) considered the third and the fourth momenta of the Gaussian distribution as better parameters than *e.g.*,  $a$ ,  $u$ ,  $B2$  or the biweight location, we have also derived those parameters. The parameters  $a$ ,  $u$  and  $B2$  have been introduced by Yahil and Vidal (1977) and Danese *et al.* (1980) as the tests of non-normality. The derived values of  $a$  for A2063 and MKW3s do not seem to indicate the deviation from the Gaussian distribution. We have found that the value of the  $u$  parameter is remarkably larger for A2063 than that for MKW3s.

Table 1  
Dynamical data for A2063 and MKW3s

	A2063	MKW3s
$N$	106	34
$z$	0.0351	0.0443
$R_A$ [arcmin]	52.01	41.80
$R_A$ [Mpc]	3.00	3.00
$DIS$ [Mpc]	205	257
$V_{\text{rel}}$ [km/s]	$10333 \pm 64$	$12998 \pm 119$
$\sigma_r$	$679.0 \pm 66$	$723.6 \pm 124$
$S$	$0.12 \pm 0.01$	$-0.43 \pm 0.07$
$E$	$-0.18 \pm 0.02$	$-0.51 \pm 0.09$
$\chi^2/dof$	4.02/18	8.54/11
P(%)	99.9	66
$a$	0.785	0.778
$u$	4.96	3.86
$MED$ [km/s]	$10327.8 \pm 64$	$13023.4 \pm 145$
$MAD$	$435.2 \pm 42$	$480.2 \pm 82$
$v_r(cD/D)$	$10142.5 \pm 48$	$12972.8 \pm 42$
$B2$	2.88	—
$\Delta v_{D-\text{rel}}$	$-191 \pm 80$	$-25.5 \pm 126$

Therefore, A2063 is more relaxed than MKW3s and the distribution of its radial velocities is closer to the Gaussian one. Finally we derived the biweight locations (Beers *et al.* 1990), *i.e.*, the sample median  $MED$  and an auxiliary estimate of scale – the median absolute deviation from the sample median  $MAD$ . One may notice from Table 1 that the median velocities  $MED$  do not differ considerably from the mean velocities  $V_{\text{rel}}$  for both clusters. We have also compared the radial velocities of the central galaxies ( $v_r(cD/D)$ ) in A2063 and MKW3s with the mean ones of A2063 and MKW3s. The central galaxy of MKW3s, *i.e.*, NGC5920 with its  $\Delta V_{D-\text{rel}} \approx 25 \pm 126$  km/s lies nearly at the bottom of gravitational well. On the other hand, the radial velocity of cD galaxy in A2063 is equal to  $10142 \pm 48$  km/s and differs from the mean velocity of the cluster by  $\Delta V_{D-\text{rel}} = -191 \pm 80$  km/s. Such a difference is statistically significant at the level of  $2\sigma$ . To confirm the motion of the cD galaxy in respect to the cluster we have applied the formalism given by Teague *et al.* (1990). The derived  $S_v$  – values are equal to 2.5, 2.6, 0.2, 12.0 and 3.1 for the whole cluster A2063, for sample I, for the Trevese *et al.*  $a$ ,  $b$  and  $c$  samples (see Table 2), respectively. Accordingly, on the basis of the  $\sigma$  criterion and the  $S_v$ -values the cD galaxy does not lay at the minimum of the gravitational potential of the cluster and exhibits significant peculiar motion at above 95% level. The galaxy cD of A2063 contains multiple nuclei having different velocities (Lauer 1988, Tonry 1985). Since the galaxy merger are very

important for the evolution of the brightest members of clusters of galaxies (Fisher *et al.* 1995), we calculated the change of velocity of this galaxy due to merger with smaller neighboring galaxies according to formulae given by Pinkney *et al.* (1993). We found that the statistically significant difference of velocity of the cD galaxy in respect to the cluster of galaxies is too large to be explained by the merger. It seems that two other galaxies superposed on the projected image of cD galaxy are not in tidal contact with cD galaxy.

## 2.2. Are A2063 and MKW3s Gravitationally Bound?

Since the velocity distributions of A2063 and of MKW3s superimpose at their wings, we have analyzed if they form the gravitationally bound system. The two cases have been considered, namely the motion of two mass points upon the radial orbits and upon the circular ones. In the former case the relative velocity  $V_{\text{rel}}$  depends on the total mass of the system  $M_{\text{tot}}$ , the separation of the components,  $R$ , and the inclination angle of the distance of A2063 and of MKW3s to the sky plane,  $\alpha$ , (Beers *et al.* 1991). Then, the relative velocity is given by:  $V_{\text{rel}} = \sqrt{\frac{G \cdot M_{\text{tot}}}{R_p}} \cdot \sin \alpha \cdot \sqrt{\cos \alpha}$ . Here the projected distance,  $R_p$ , ( $R_p = 1.8 \cdot h^{-1}$  Mpc) and the true separation,  $R$ , of A2063 and MKW3s are related by:  $R_p = R \cdot \cos \alpha$ . Using the velocity dispersions we obtained the virial masses of the system smaller than  $1.1 \cdot 10^{15} \cdot h^{-1} M_{\odot}$ . They agree with  $M = 5 \cdot 10^{14} M_{\odot}$  given by Oegerle and Hill (1994) and  $M = 1.0 \cdot 10^{15} M_{\odot}$  published by Bahcall and Cen (1993). The maximum relative velocity calculated for  $M_{\text{tot}} = 1.0 \cdot 10^{15} M_{\odot}$  and  $\alpha = 55^\circ$ , *i.e.*, 1348 km/s, is lower than the observed one equal to 2665 km/s. Therefore, if A2063 and MKW3s are moving upon radial orbits, they are not gravitationally bound.

In the latter case, A2063 and MKW3s are falling to the mass center with some angular momentum on a circular orbit. We have assumed that A2063 and MKW3s orbit each other at a separation  $R$  with relative velocity  $V_{\text{sys}} = \sqrt{\frac{G \cdot M_{\text{tot}}}{R}}$  (Fitchett *et al.* 1987). Then, their relative velocity and the projected separation are given by:

$$\lambda = \frac{R_p}{R} = \sqrt{1 - 2 \sin^2 \Theta \cdot \cos^2 \alpha};$$

$$\frac{V_{\text{rel}}}{V_{\text{sys}}} = \sqrt{\lambda} \cdot \sqrt{\lambda^2 - \cos^2 \Theta}.$$

Here  $\Theta$  is the angle between the normals to the orbital and sky planes. We also have a constrain  $|\lambda| \leq 1$ . We have calculated  $V_{\text{rel}} \leq 1087$  km/s for  $M_{\text{tot}} \leq 1.0 \cdot 10^{15} M_{\odot}$ ,  $\Theta = 90^\circ$  and  $\lambda \leq 1$ . Accordingly, A2063 and MKW3s do not form the bound system even if they move on circular orbit.

However, the above results are strongly affected by the projection. Then, we used the known condition, which has to be fulfilled if two bodies having masses  $M_1$  and  $M_2$  and core radii  $R_1$  and  $R_2$  will merge after the off-center collision

(Tremaine 1981), *i.e.*,

$$bV \leq \left[ \frac{8}{3} G^2 (M_1 R_2^2 + M_2 \cdot R_1^2) (M_1 + M_2) \right]^{\frac{1}{4}}.$$

Here  $b$  is the impact parameter and  $V$  – the circular velocity at  $R$ . We have considered two cases. First, we have put the virial masses and core radii obtained for A2063 and MKW3s, namely:

$$M_1 = M(\text{A2063}) = 5.2 \cdot 10^{14} h^{-1} M_{\odot}; \quad R_1 = 3'.5,$$

$$M_2 = M(\text{MKW3s}) = 2.5 \cdot 10^{14} h^{-1} M_{\odot}; \quad R_2 = 3'.4.$$

We derived the impact parameter  $b = (1.7 \pm 0.3) \cdot h^{-1}$  Mpc. For the average values of mass and core radii of the (A2063-MKW3s) system, we have calculated slightly smaller values of the impact parameter. In any case, the projected distance  $R_p = 1.8 h^{-1}$  Mpc agrees with the impact parameter at the confidence level of 68%. Therefore, A2063 and MKW3s might merge during the free-fall time  $t_{\text{eff}} \approx 3.2 \cdot 10^7$  yrs.

### 3. Changes of Dynamical Properties of A2063 with Distance

The deviation of the observed velocity distribution of galaxies in MKW3s from the Gaussian may result from its interaction with galaxies of A2063. Then, one should find the largest deviation for the galaxy samples, most distant from the cluster center. In this Section, we have looked for the changes of dynamics with distance from the center of A2063. Therefore, we have divided galaxies in A2063 into following non-overlapping, radially concentrated groups:

- sample I consists of galaxies laying closer than  $r/R_A = 0.2$ , what corresponds to radial distances  $r \leq 0.6$  Mpc;
- sample II containing galaxies in the ring  $0.2 < r/R_A \leq 0.4$ , *i.e.*,  $0.6 < r \leq 1.2$  Mpc;
- sample III forms galaxies in the ring  $0.4 < r/R_A \leq 0.6$ , namely  $1.2 < r \leq 1.8$  Mpc;
- sample IV consists of galaxies in the ring  $0.6 < r/R_A \leq 0.9$ , *i.e.*, between 1.8 and 2.7 Mpc;
- sample V containing galaxies laying out of  $r/R_A > 0.9$ , *i.e.*, farther than 2.7 Mpc.

We calculated for the above mentioned samples the same physical parameters as for all galaxies in A2063. They are given in Table 3. However, we derived two different velocity dispersions, namely  $\sigma_r^l$  in respect to the mean local velocity for each sample and  $\sigma_r$  relative to the mean cluster velocity. In Table 3, there are also given mean radial distances,  $r$ , from the center of A2063 and  $1\sigma$  errors. The observed distributions of radial velocities in bins of 400 km/s for different samples with the superimposed Gaussians are shown in Fig. 2.

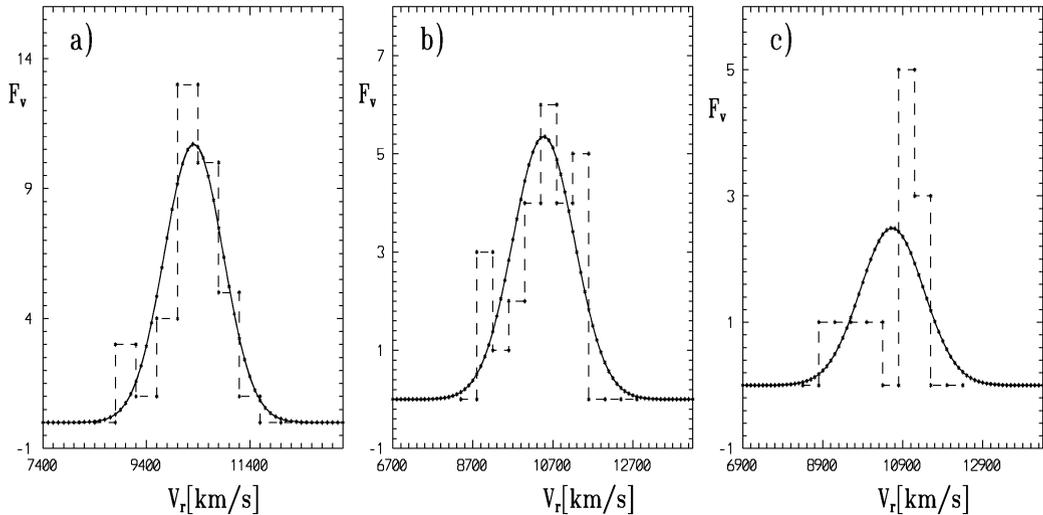


Fig. 2. Histograms of the observed radial velocities of different samples of galaxies in A2063 with the superimposed Gaussians derived with parameters given in Table 3. The bins of radial velocities are 400 km/s.

It is seen in Fig. 2 and Table 3 that deviations of observed distributions of radial velocities from the Gaussians increase with the distance from the cluster center. The largest differences (largest  $\chi^2$ ) occur for samples IV and V.

Table 2

Dynamical properties for the photometric samples

	Sample <i>a</i>	Sample <i>b</i>	Sample <i>c</i>
$N$	25	84	45
$z$	0.0347	0.0425	0.0358
$R_A$ [']	12.28	13.43	13.03
$r/R_A$	0.24	0.26	0.25
$DIS$ [Mpc]	203	237	202
$V_{rel}$ [km/s]	$10216 \pm 144$	$12452 \pm 245$	$10544 \pm 119$
$\sigma_r$	$719.2 \pm 147$	$2241.1 \pm 244$	$797.9 \pm 120$
$MED$ [km/s]	$10271.8 \pm 144$	$11694.5 \pm 173$	$10535.2 \pm 119$
$MAD$	$509.2 \pm 102$	$1581.4 \pm 173$	$532.7 \pm 80$
$\Delta v_{D-rel}$	$-71 \pm 152$	$-2218.5 \pm 250$	$-388.3 \pm 128$

Recently, Trevese *et al.* (1997) have discussed the  $F$ -band photometry of 84 galaxies brighter than  $m_3 + 3^m$  in A2063. They have also given the ellipticity of cluster members, *i.e.*,  $\epsilon = 1 - \frac{b}{a}$ , where  $\frac{b}{a}$  is the ratio of the lengths of minor to major axis. For 25 galaxies Hill and Oegerle (1993) have already determined the radial velocities. We have considered them as sample *a*. The redshifts and radial velocities for the remaining galaxies have been estimated from the relation between the measured redshifts and magnitudes  $m_a$ . All 84 galaxies have been

designated as sample *b*. We have found that sample *b* contains a lot of galaxies, which should not be considered as cluster members on the basis of  $3\sigma$  criterion. Since the redshifts measured by Hill and Oegerle (1993) agree well with those estimated from  $m_a$ , we have distinguished as a sample *c* all galaxies satisfying  $3\sigma$  criterion. The dynamical data calculated for these samples are given in Table 2.

The comparison of the dynamical properties of discussed samples with the data derived for A2063 given in Table 1 indicates that they agree within the error limits for samples *a* and *c*. On the other hand, sample *b* contains bright distant galaxies having luminosity distances from 182 up to 351 Mpc. Such galaxies do not satisfy the  $3\sigma$  criterion for cluster membership and have very high velocity dispersion. Accordingly, the  $m_3 + 3^m$  criterion for cluster membership includes into the cluster faint close and distant bright galaxies.

The histograms of observed radial velocities of galaxies belonging to sample *b* with the superimposed Gaussian distributions for sample *c* (solid line) and sample *b* (dashed line) are shown in Fig. 3.

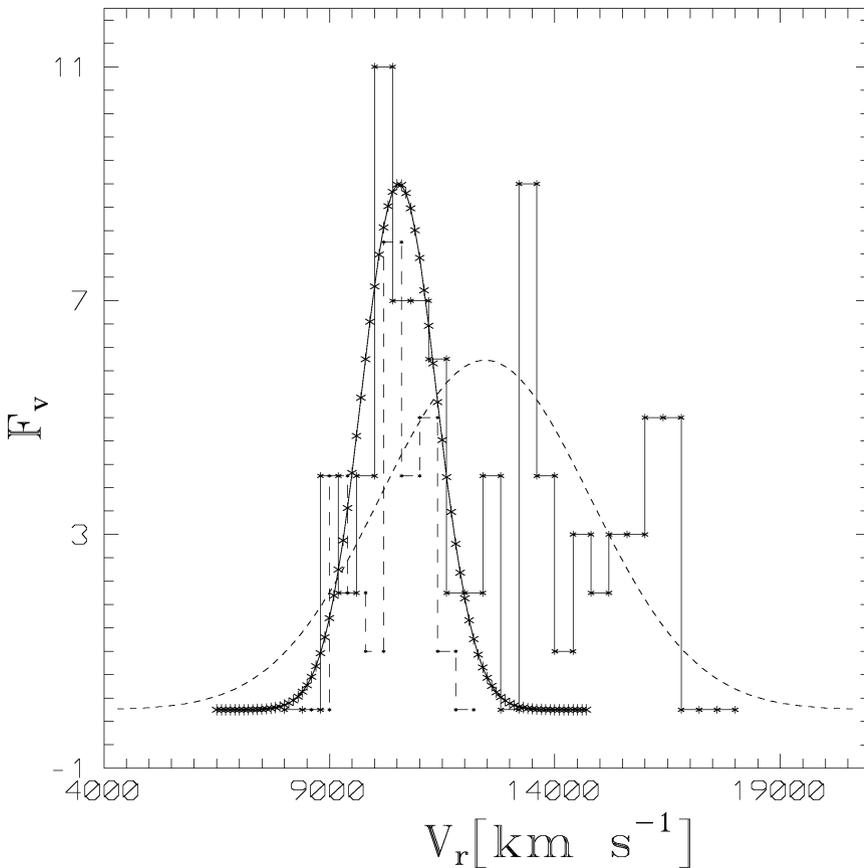


Fig. 3. Histograms of the observed radial velocities of sample *b* with the superimposed Gaussian distributions for sample *c* (solid line) and sample *b* (dashed line).

It is seen in Fig. 3 that the distribution of radial velocities for sample *b* consists of two or three subsamples including sample *c*, for which the velocity distribution

is Gaussian with probability of 57%. Comparison of the distributions of radial velocities in Fig. 1 and Fig. 3 indicates that only galaxies of sample *c* belong dynamically to A2063. Therefore, the cluster membership criterion based upon the magnitudes  $m_3 + 3^m$  might artificially increase the number of cluster members.

Table 3  
Changes of dynamical data of A2063 with distance

Sample	I	II	III	IV	V
<i>N</i>	37	25	12	8	24
<i>z</i>	0.0350	0.0356	0.0361	0.0346	0.0343
<i>DIS</i> [Mpc]	212	215	218	209	271
$V_{\text{rel}}$ [km/s]	10317 ± 91	10470 ± 149	10631 ± 222	10371 ± 305	10115 ± 109
$\sigma_r^l$	570	771	796	892	554
$\sigma_r$	570 ± 66	784 ± 109	855 ± 162	904 ± 223	597 ± 109
<i>r</i> [Mpc]	0.280 ± 0.15	0.893 ± 0.24	1.4067 ± 0.14	2.2115 ± 0.32	6.0854 ± 2.52
<i>S</i>	-0.61 ± 0.1	-0.48 ± 0.1	-0.66 ± 0.3	1.17 ± 0.4	1.54 ± 0.3
<i>E</i>	0.25 ± 0.04	-0.84 ± 0.17	-1.13 ± 0.5	0.13 ± 0.05	3.82 ± 0.8
$\chi^2/dof$	11.0/15	11.2/15	11.1/15	12.0/15	169.8/15
P(%)	75	73	74	67	0
<i>a</i>	0.739	0.797	0.808	0.683	0.651
<i>u</i>	4.45	3.40	3.08	3.34	5.08
<i>MED</i> [km/s]	10361 ± 52	10585 ± 185	10856 ± 275	9943 ± 378	10136 ± 109
<i>MAD</i>	317 ± 52	475 ± 95	520 ± 150	244 ± 86	313 ± 65
$\Delta v_{\text{D-rel}}$	-175 ± 103				

It is seen from Table 3 that the dispersion of radial velocities increases with the distance from the cluster center. It is only 570 km/s within the region of  $r/R_A \leq 0.2$  and increases up to 892 km/s for galaxies laying in the ring  $0.6 < r/R_A \leq 0.9$ . In the most distant region, *i.e.*, at  $r/R_A > 0.9$  the dispersion of radial velocity decreases again below the value observed at the central region of A2063. Since this sample may contain galaxies of the neighboring group we divided it into two subsamples, *i.e.*,

*Va*:  $N = 11$ ,  $\sigma_r = 734 \pm 155$  km/s and  $r = 3.5519 \pm 0.56$  Mpc;

*Vb*:  $N = 13$ ,  $\sigma_r = 484 \pm 69$  km/s and  $r = 8.2292 \pm 1.19$  Mpc.

It is seen that the velocity dispersion of the last subsample is very low, which confirms our suggestion. The increase of velocity dispersion with distance from the center of A2063 is faster for  $\sigma_r$  and it is shown in Fig. 4 as dashed line.

We consider the difference in velocity dispersion between the successive bins as statistically significant if it is larger than the sum of their  $1\sigma$  errors. Accordingly, we notice that this criterion is only fulfilled for radial distances smaller than  $1.2 \cdot h^{-1}$  Mpc (samples I–II) and larger than  $2.7 \cdot h^{-1}$  Mpc (samples IV–V). In any case, the velocity dispersion increases uniformly over the first four bins in spite

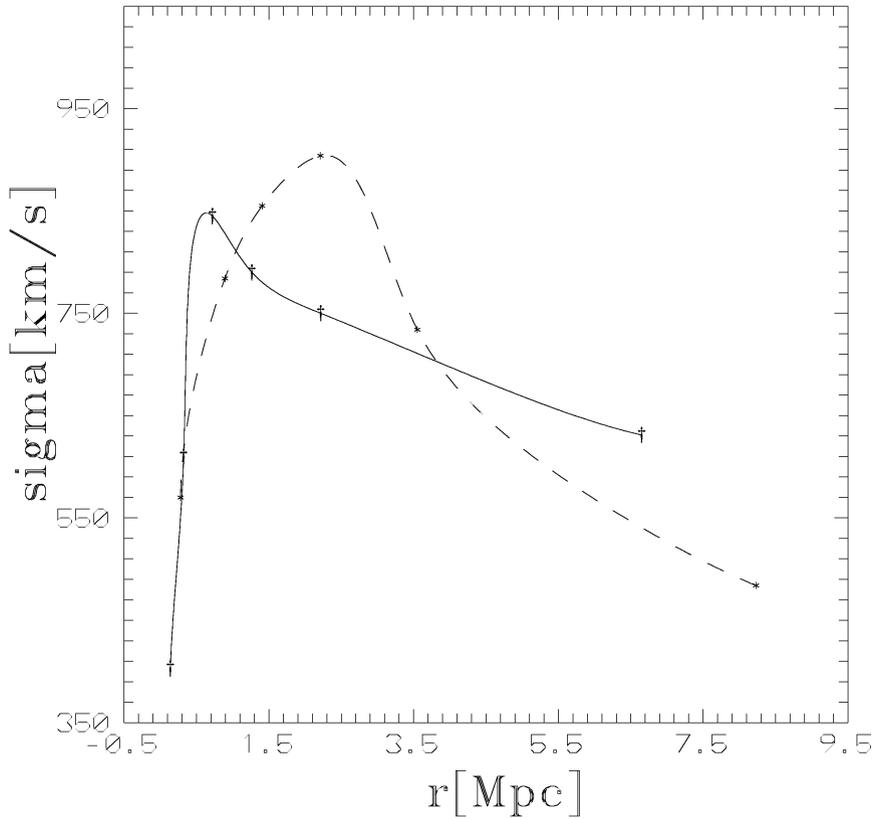


Fig. 4. Velocity dispersion profile of A2063 calculated for samples given in Table 3 (dashed line) and for narrower central bins (solid line). The  $1\sigma$  errors are shown as bars.

of large  $1\sigma$  errors. In different published papers we found the velocity dispersion changing from 521 (Freudling *et al.* 1991) up to  $718^{+80}_{-60}$  km/s (Hill and Oegerle 1993). Accordingly, the quoted values of velocity dispersion may refer to different populations of galaxies, namely galaxies laying at different distances from the cluster center.

To check, to which distance from the cluster center the velocity dispersion increases, we calculated all the discussed physical parameters for the smaller bins, namely for:

- 1)  $r/R_A \leq 0.07$ , *i.e.*,  $r \leq 0.2$  Mpc; 2)  $0.07 < r/R_A \leq 0.17$ , what corresponds to  $0.2 < r \leq 0.5$  Mpc; 3)  $0.17 < r/R_A \leq 0.33$ , *i.e.*,  $0.5 < r \leq 1$  Mpc; 4)  $0.33 < r/R_A \leq 0.5$ , namely for  $1 < r \leq 1.5$  Mpc; 5)  $0.5 < r/R_A \leq 1$ , *i.e.*,  $1.5 < r \leq 3$  Mpc; 6)  $r/R_A > 1.0$  ( $r > 3$  Mpc).

The changes of the velocity dispersion with distance derived for these bins are shown in Fig. 4 as solid line with  $1\sigma$  error bars. It is seen in Fig. 4, that the statistically significant rise of velocity dispersion has been restricted to the central region of 1 Mpc. Therefore, A2063 has inverted profile of velocity dispersion.

Such profile might be a result of orbital circularization (den Hartog and Katgert 1996). Orbital circularization occurs due to dynamical friction, when the orbital

decay time in radial direction is shorter than in traverse one. The frictional force is proportional to the local density, which decreases with distance from the cluster center. Accordingly, the orbital circularization will be most remarkable for orbits that come near the cluster center. We shall discuss the galactic orbits in the next paper.

However, the apparent substructure in the velocity-radius diagram might artificially transform a peaked profile (profile with maximum  $\sigma_r$  in center) into the inverted one.

To check if such substructure exists in A2063 we used the Dressler-Shectman  $\delta$  parameter. The majority of subclumps in A2063 are characterized by small values of  $\delta$  with  $\bar{\delta} = 1.26 \pm 0.80$  (see solid line in Fig. 5). However, there is a long tail of subsamples with remarkable deviation of local velocity ( $\delta \geq 2.0$ ) and especially a group of 11 galaxies having  $\delta = 3.10$ . The latter group is too distant from the cluster center ( $DIS \approx (2.34 \div 2.50)$  Mpc) to be responsible for the inverted profile of velocity dispersion. The maximum of  $\delta$ -distribution in MKW3s occurs at smaller  $\delta$ -values (dashed line in Fig. 5) than in A2063.

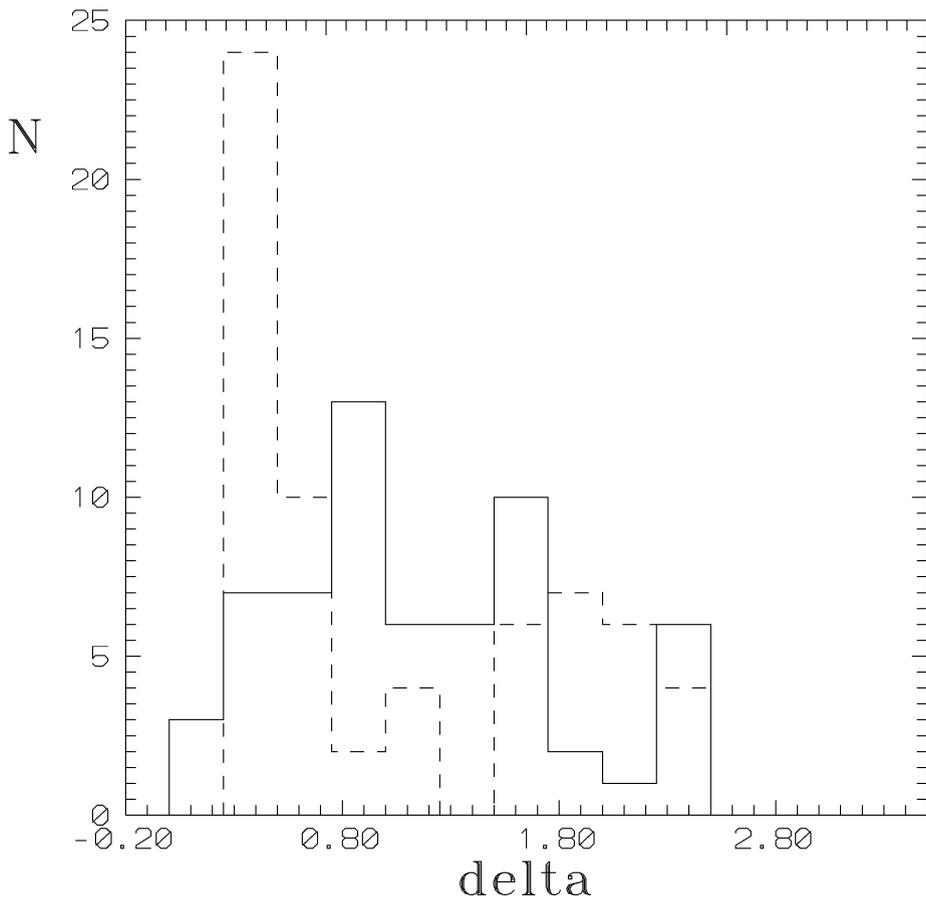


Fig. 5. Distributions of  $\delta$ -parameter values for A2063 (solid line) and MKW3s (dashed line)

We have transformed the equatorial coordinates of all discussed galaxies in A2063 to the Cartesian ones and reduced them to the cluster center. The derived space distribution is shown in Fig. 6. It is seen in Fig. 6 that in addition to high maximum corresponding to the central part of A2063, there are a few smaller ones connected with small distant subclumps of galaxies mentioned above based on the values of  $\delta$ -parameter. Space distribution of galaxies observed by Trevese *et al.* (1997) ( $\frac{r}{R_A} \leq 0.26$ ) is more extended in space (in luminosity distance) with the slight maximum only at the most central region.

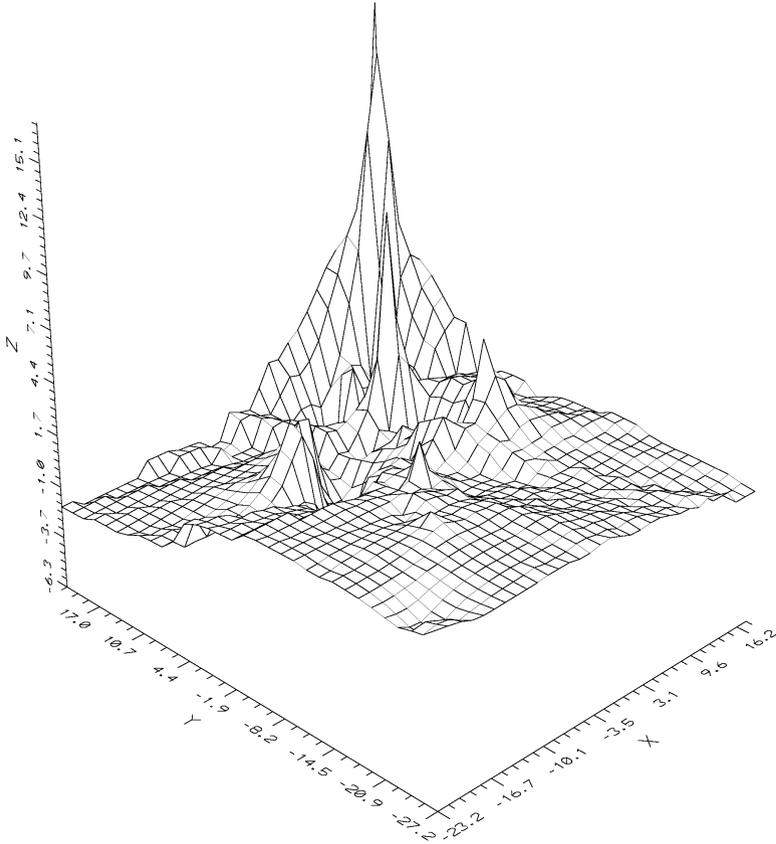


Fig. 6. Spatial distribution of galaxies in A2063.

The skewness  $S$  and kurtosis  $E$  indices given in Table 3 indicate that the observed velocity distributions of distant samples deviate at the significance level  $2\sigma$  from the Gaussian ones. Then, we have described their velocity distributions by the formula:

$$f(V, \mu) = g(V) + \sum_{n=0}^l a_n(V) \cdot P_n(\mu).$$

Here  $g(V)$  is the Gaussian distribution of sample velocities and  $P_n(\mu)$  – the Legendre polynomials of order  $n$ . We limit our considerations to the first two orders of Legendre polynomials. Then, one has:  $P_0(\mu) = 1$ ;  $P_1(\mu) = \mu = \cos\theta$  and  $P_2(\mu) = \frac{1}{4} \cdot (3\cos 2\theta + 1)$ . The angle  $\theta$  is contained between the average velocity vector of each group of galaxies and the line of sight.

The average square of velocity dispersion of sample galaxies is described by:

$$b = \frac{\sigma_r^2 + 2\sigma_t^2}{3}.$$

Here  $\sigma_r$  and  $\sigma_t$  are the radial and tangential components of velocity dispersion. Based on the observational data, we have assumed the changes of the ratio of  $\frac{\sigma_t^2}{\sigma_r^2}$  with clustercentric distance  $r$  according to the law:

$$\frac{\sigma_t^2}{\sigma_r^2} = 1 - \frac{k \cdot r}{1 + a \cdot r}.$$

One might constrain the values of  $(a - k)$  by the condition  $\frac{\sigma_t^2}{\sigma_r^2} \geq 0$ . Accordingly, one has  $(a - k) \geq (r_1)^{-1}$ , where  $r_1$  is given as  $\frac{r}{250}$ . We considered:  $k = 0.5$  and  $0.9$ ;  $a = 0.2$ ;  $0.5$  and  $0.7$  and made the calculations up to  $1.2 \cdot R_A$ , *i.e.*,  $1.8$  Mpc. The first ranged coefficients, derived from the condition that the  $f$  and  $g$  distributions give the same kinetic energy, are given by the expressions:

$$\begin{aligned} a_0 &= g(V) c_0 \left[ 1 - \frac{2}{3b} (V_{\text{rcl}} - V_{\text{tot}})^2 + \frac{1}{15 \cdot b^2} (V_{\text{rcl}} - V_{\text{tot}})^4 \right], \\ a_1 &= g(V) \cdot c_1 \cdot \frac{(V_{\text{rcl}} - V_{\text{tot}})}{\sqrt{b}} \cdot \left[ -1 + \frac{1}{5 \cdot b} \cdot (V_{\text{rcl}} - V_{\text{tot}})^2 \right], \\ a_2 &= g(V) \cdot c_2 \cdot \frac{(V_{\text{rcl}} - V_{\text{tot}})^2}{b}. \end{aligned}$$

Here  $V_{\text{rcl}}$  is the average velocity of the group of galaxies and  $V_{\text{tot}}$  – the average velocity of a cluster.

The coefficient  $c_0$ ,  $c_1$  and  $c_2$  depend upon the skewness  $S$ , kurtosis  $E$ ,  $\sigma_t$  and  $\sigma_r$ , as follows:

$$\begin{aligned} c_0 &= \frac{5 E \cdot \sigma_r^4 + \frac{4}{3} (\sigma_r^2 - \sigma_t^2)^2}{8 b^2}, \\ c_1 &= \frac{5 S \cdot \sigma_r^3}{6 b^{3/2}}, \\ c_2 &= \frac{\sigma_r^2 - \sigma_t^2}{3 \cdot b}. \end{aligned}$$

For each group of galaxies we have calculated  $a_0$ ,  $a_1$ ,  $a_2$  and the distribution functions for different inclination angles of the velocity vector to the line of sight.

The calculated values of  $f(V, \mu)$  change only slightly with the angle  $\Theta$ . The ratios  $\frac{f(V, \mu)}{g(V)}$  are largest for the most distant samples of galaxies, *i.e.*, samples IV and V. For the central group I, the distributions of galaxies are nearly Gaussian for all discussed values of  $k$  and  $a$  with the exception of  $k = 0.9$  and  $a = 0.2$ , while for sample V  $\frac{f(V, \mu)}{g(V)}$  is equal to 1.5 and 155 for  $k = 0.5$ ,  $a = 0.7$  and  $a = 0.2$ ,

respectively. Therefore, one might explain the changes of the dynamical parameters of A2063 with clustercentric distance by the change of asymmetry of tangential components of velocity and by variation of galactic orbits.

On the other hand, if the hydrostatic equilibrium between the kinetic energy of galactic components and thermal energy of the ICM gas exist there is the relation between the velocity dispersion,  $\sigma_r$ , and the intracluster gas temperature,  $T_g$ . We used the average statistical relation ( $\sigma_r - T_g$ ) derived by Lubin and Bahcall (1993), *i.e.*,  $\sigma_r = (332 \pm 52) \cdot [kT(\text{keV})]^{0.6 \pm 0.1}$  km/s. Then, the changes of the velocity dispersion with distance might be transformed to the rise of the temperature of intracluster gas from 2.5 keV in the central region up to 5.31 keV in the outer ring (from 1.8 to 2.7 Mpc). The estimated mean temperature of the ICM gas in A2063 is 4.1 keV (David *et al.* 1993) and it might change from 3.5 keV up to 5.3 keV in the confidence level of 90%. It is worth noting that the cooling flow occurs in A2063. Generally, in cooling flow the changes of the temperature of ICM gas and of the deposition mass rate with distance are described by  $\frac{T}{T_0} = \left(\frac{r}{r_0}\right)^{\left(\frac{3}{3-\alpha}\right)}$  and  $\dot{M} \propto r^{\frac{3 \cdot (2-\alpha)}{5-2 \cdot \alpha}}$ , respectively. We estimated the changes of  $T_g$  with distance  $r$  as  $\frac{T}{T_0} = \left(\frac{r}{r_0}\right)^{0.4}$  and  $\dot{M} \propto r^{1.4}$ . Generally, for clusters one has  $T_g \propto r^{1.2}$  and  $\dot{M} \propto r$ . Therefore, for A2063 the changes of  $T_g$  are shallower. Such relations are consistent with the mass deposition rate which reaches the value of about  $50M_\odot/\text{yr}$  at the distance of 200 kpc from the cluster center (Thomas *et al.* 1987).

#### 4. Morphological Fractions in A2063

It is known that there is the segregation of different morphological types of galaxies in some clusters. Recently, two different relations are considered to explain it, namely the morphology-density (T- $\Sigma$ ) and the morphology-clustercentric distance (T-R) relations. According to Dressler (1980) and Dressler *et al.* (1997) the former one occurs in both types of nearby clusters of galaxies, *i.e.*, the centrally concentrated relaxed clusters and irregular less concentrated ones, but only in the distant ( $z \approx 0.5$ ) concentrated ones. On the other hand, Whitmore *et al.* (1993) and Adami *et al.* (1998) have considered the (T-R) relation as fundamental.

We have taken the morphological types of galaxies belonging to A2063 from the catalog published by Dressler (1980) to look for morphological segregation and its relation with any global property of A2063. The center of A2063 has been put at the position of the cD galaxy designated as 60 by Dressler. We have made a field correction taking for E/SO/(S+I) the percentages 18/33/59 following Whitmore *et al.* (1993).

After Kriessler and Beers (1997) we have assumed the spherical distribution of galaxies in A2063, although Trevese *et al.* (1997) observed the asymmetric one.

Then, we have calculated the relative distances of galaxies, *i.e.*,  $r/r_{\text{max}}$ . For  $r_{\text{max}}$  we adopted the maximum distance quoted in the catalog. The changes of

distributions of the morphological types of galaxies with the relative clustercentric distance are shown in Fig. 7.

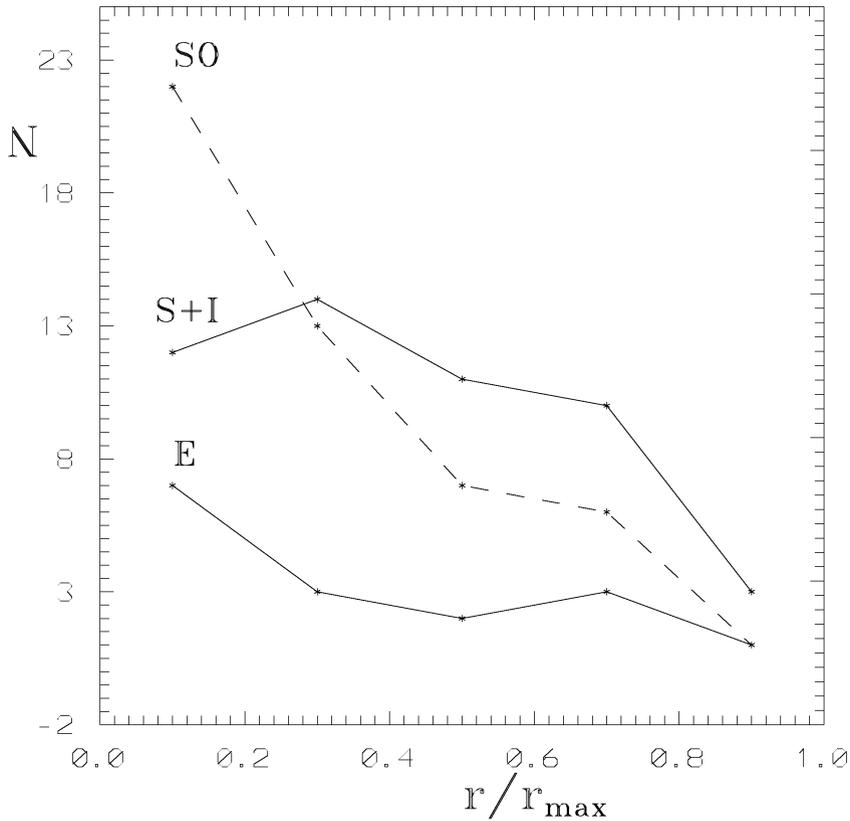


Fig. 7. Distributions of morphological types of galaxies in A2063. Ellipticals and the D galaxies are designated as E. (S–I) group contains spirals and irregulars.

It is seen in Fig. 7 that the SO galaxies dominate in the central region of A2063 (about 54%) while spirals and irregulars are more frequent in the outer layers of the cluster (about 55%). Their number declines rapidly with the clustercentric distance (from 54% to 29%). The distribution of E galaxies decreases rapidly (from 17% to 10%) close to the center ( $r/r_{\max} \leq 0.4$ ) and then remains relatively constant (see Fig. 7).

We have checked if there is also the  $(T-\Sigma)$  correlation. The distributions of the surface densities of galaxies, described by the King law for core radius  $r_c = (3.4 \pm 0.1)$  and central density of galaxies  $N_0 = (1000 \pm 150)$  galaxies  $\cdot \text{arcmin}^{-2}$  as well as for general gravitational potential calculated by Krygier and Krempeć-Krygier (1998), have been used. We have not found any significant  $(T-\Sigma)$  relation except for the rapid rise or decline of the fraction of the (S+I) or of the (E+SO) galaxies, respectively, in the most distant layer. There is a correlation between the fraction of  $(E+SO)/(S+I)$  and the velocity dispersion which suggests that a deep potential well is needed to increase the elliptical fraction. Accordingly, in A2063 the morphology-clustercentric distance and/or the morphology-velocity dispersion relations are the fundamental ones.

For the Trevese *et al.* (1997) sample, we have found that in the central part of A2063 there are more galaxies having  $\epsilon \leq 0.3$ , *i.e.*, nearly spherical ones ( $b/a \geq 0.7$ ).

In the inner parts of A2063 the density profile for spirals is much flatter than the profile for SO and elliptical galaxies. It might be a result of luminosity segregation, which is a manifestation of the physical processes of mass segregation. Heavy galaxies move slower and their distribution is more centrally concentrated than that of light galaxies.

Using the distribution of different morphological types of galaxies and their radial velocities we have derived the observed changes of relative radial velocities  $\Delta V_r = V_{\text{gal}} - V_{\text{rcl}}$  with relative clustercentric distance  $\frac{r}{R_A}$  according to formulae:

- i) for the (SO+E) galaxies concentrated mainly at the central parts of A2063:  

$$\Delta V_r = 132.73 \cdot \exp\left[1.77 \cdot \left(\frac{r}{R_A}\right)\right].$$

In general, their radial velocities relative to the cluster increase with clustercentric distance. However, they seem to become constant for distances larger than distance where the maximal velocity dispersion occurs.

- ii) for the (S+I) galaxies which number density decreases with clustercentric distance but which form the most populated sample at outer parts of the cluster:  $\Delta V_r = 1218.5 \cdot \exp\left[-1.35 \cdot \left(\frac{r}{R_A}\right)\right].$

This is an average behavior. In fact, their velocities might also increase with clustercentric distance up to the inversion point of velocity dispersion.

Therefore, in central parts of A2063, *i.e.*, at distances smaller than  $\frac{r}{R_A} = 0.4$  (closer than  $1.2 \cdot h^{-1}$  Mpc from the cluster center), where the (SO+E) galaxies form the main population, the average relative radial velocities will increase with distance. It is seen as inverted dispersion profile. However, the above relations are based on a small number of galaxies. Nevertheless, the (S+I) galaxies seem to move on the radial orbits which circularize near the cluster center. Unfortunately, we cannot discuss in details the relations between kinematical and morphological properties of galaxies in A2063 because we do not have the morphological types for a majority of galaxies with measured radial velocities. However, for another sample of galaxies we know the change of the fraction of the (E+S0) to the (S+I) galaxies with clustercentric distance and for some of them the changes of the velocities, as discussed above. It is worth to notice that the variation of galaxy velocities refers mainly to central parts of A2063 for the (E+S0) galaxies while in the case of the (S+I) galaxies to the outer parts.

On the other hand, it is well known that the rates of change of galactic orbital parameters, *i.e.*, energy and angular momentum, determine the evolution of the galaxy phase-space distribution functions. Hence, the changes of the fractions of different morphological types of galaxies with distance from the cluster center are closely related to the types of the galactic orbits. Since A2063 has the inverse

profile of velocity dispersion and a central inversion of the kinetic temperature its core could be relatively cool remnants of the violent relaxation process. A hotter envelope was accreted by secondary infall on the core. Therefore, the isotropic orbits will dominate in the core while in the outer regions of the cluster the orbits are radial.

## 5. Conclusions

The distribution of radial velocities of A2063 is almost Gaussian, while that of MKW3s slightly deviates from the normal one. However, we found that the changes of dynamical properties of A2063 with distance are correlated with the changes of the fractions of morphological types of galaxies. The central region of A2063 consists mainly of ellipticals and the SO galaxies and it is characterized by lower dispersion of radial velocities. The outer layers of A2063 contain more spirals and irregulars and have higher dispersion of radial velocities. The most distant region, which does not satisfy these relations, might contain some galaxies belonging to MKW3s since the distribution of radial velocities of A2063 and of MKW3s are superimposed at the edge.

However, the profile of velocity dispersion depends remarkably upon the widths of the distance bins. The inverted profile of velocity dispersion was confirmed and enhanced for narrower bins of distance. It might be a result of circularization of the galactic orbits especially in central region of A2063.

Besides, the cD galaxy of A2063 does not lay at the minimum of the gravitational potential of the cluster but its radial velocity significantly differs from the mean velocity of the cluster as well as from the mean velocity of its most central region. Such dynamical properties of A2063 and cD galaxy may be a result of recent merger event.

**Acknowledgements.** We would like to thank Prof. A. Kus and Dr. A. Marecki for critical reading of the manuscript. This work was partly supported by the Nicolaus Copernicus University grant No 310-A.

## REFERENCES

- Abell, G.O., Corwin, H.G., and Olowin, R.P. 1989, *Astrophys. J. Suppl. Ser.*, **70**, 1.  
 Adami, C., Biviano, A., and Mazure A. 1998, *Astron. Astrophys.*, **331**, 439.  
 Albert, C.E., *et al.* 1977, *Astrophys. J.*, **211**, 309.  
 Bahcall, N.A. 1980, *Astrophys. J. Letters*, **238**, L117.  
 Bahcall, N.A., and Cen, R. 1983, *Astrophys. J. Letters*, **427**, L49.  
 Beers, T.C., *et al.* 1990, *Astron. J.*, **100**, 32.  
 Beers, T.C., *et al.* 1991, *Astrophys. J.*, **257**, 17.  
 Bird, C.M. 1994, *Astron. J.*, **107**, 1637.  
 Bower, R.G., *et al.* 1997, *MNRAS*, **291**, 353.  
 Briel, U.G., and Henry, J.P. 1993, *Astron. Astrophys.*, **278**, 379.

- Danese, L., *et al.* 1980, *Astron. Astrophys.*, **82**, 322.
- David, L.P., *et al.* 1993, *Astrophys. J.*, **412**, 479.
- Dressler, A. 1980, *Astrophys. J. Suppl. Ser.*, **42**, 565.
- Dressler, A., *et al.* 1997, *Astrophys. J.*, **490**, 577.
- Escalera, E., *et al.* 1994, *Astrophys. J.*, **423**, 531.
- Fisher, D., Illingworth, G., and Franx, M. 1995, *Astrophys. J.*, **438**, 539.
- Fitchett, M., and Webster R. 1987, *Astrophys. J.*, **317**, 653.
- Freudling, W., *et al.* 1991, *Astrophys. J.*, **377**, 349.
- Garijo A., Athanassoula, E., and Garcia-Gomez C. 1997, *Astron. Astrophys.*, **327**, 930.
- Hartog, den R., and Katgert, P. 1996, *MNRAS*, **279**, 349.
- Hill, J.M., and Oegerle, W.R. 1993, *Astron. J.*, **106**, 831.
- Kriessler, J.R., and Beers, T.C. 1997, *Astron. J.*, **113**, 80.
- Krygier, B., and Krempeć-Krygier, J. 1998, *Astron. Astrophys.*, in press.
- Lauer, R.T. 1988, *Astrophys. J.*, **325**, 49.
- Lubin, L.M., and Bahcall, N.A. 1993, *Astrophys. J.*, **415**, L17.
- Morgan W.W., *et al.* 1975, *Astrophys. J.*, **199**, 545.
- Oegerle, R.W., and Hill, J.M. 1994, *Astron. J.*, **107**, 857.
- Pinkney, J., *et al.* 1993, *Astrophys. J.*, **416**, 36.
- Pinkney, J., Roettiger, K., and Burns J.O. 1996, *Astrophys. J. Suppl. Ser.*, **104**, 1.
- Roettiger, K., Burns, J.O., and Pinkney, J. 1996, *Astrophys. J.*, **473**, 651.
- Roettiger, K., Loken, Ch., and Burns, J.O. 1997, *Astrophys. J. Suppl. Ser.*, **109**, 307.
- Teague, P.F., Carter, D., and Gray, P.M. 1990, *Astrophys. J. Suppl. Ser.*, **72**, 715.
- Thomas, P.A., Fabian, A.C., and Nulsen, P.E.J. 1987, *MNRAS*, **228**, 973.
- Tonry, J.L. 1985, *Astron. J.*, **90**, 2431.
- Tremaine, S.D. 1981, in: "The Structure and Evolution of Normal Galaxies", Ed. Fall and Lyndel-Bell, Cambridge University Press, p. 67–87.
- Trevese, D., *et al.* 1997, *Astron. Astrophys. Suppl. Ser.*, **125**, 459.
- Wegner, G., *et al.* 1996, *Astrophys. J. Suppl. Ser.*, **106**, 1.
- Whitmore, B.C., and Gilmore, D.M. 1991, *Astrophys. J.*, **367**, 64.
- Whitmore, B.C., Gilmore, D.M., and Jones, C. 1993, *Astrophys. J.*, **407**, 489.
- White, D.A., Jones, C., and Forman, W. 1997, *MNRAS*, **292**, 419.
- Yahil, J.L., and Vidal, N.V. 1977, *Astrophys. J.*, **214**, 347.
- Zabludoff, A.I., *et al.* 1993, *Astron. J.*, **106**, 1273.