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Dynamics of Hickson Compact Groups of Galaxies

H. M. Tovmassian, V. H. Chavushyan, O. Martinez and O. Yam

Instituto Nacional de Astrofísica Óptica y Electrónica, AP 51 y 216, 72000, Puebla, Pue, México

H. Tiersch

Sternwarte Königsleiten, 81477, München, Leimbachstr. 1a Germany

Abstract. It is shown that the radial velocity dispersion of Hickson compact groups of galaxies (HCGs) is correlated with the elongation of groups, b/a. It means that galaxies in a group move preferentially along its elongation. Inspection of radial velocities of member galaxies in chain-like and in round HCGs shows that galaxies in HCGs most probably rotate around the gravitational center of the corresponding group. Other two possible mechanisms: flying apart of galaxies from the group in opposite directions, and infall of field galaxies upon the group are excluded. It follows that HCGs are more stable formations than it has been previously assumed, and that the known inconsistencies between the results of N-body simulations and the observational facts are not relevant.

1. Introduction

Hickson compact groups have been extensively studied during the last decades. Much of the interest raised is because N-body simulations have shown that members of HCGs should merge and form a single galaxy in a few crossing times (Barnes 1985, Barnes 1989, Ishizawa 1986, Mamon 1987, Zheng, Valtonen & Chernin 1993). More recent N-body simulations of poor groups (Bode et al. 1994, Athanassoula, Makino & Bosma 1997) have indicated that the hypothesized formation of a central massive galaxy is a sufficiently rapid process. Meanwhile, observations do not prove the expected high rate of merging (Zepf 1993). Moreover, a strange absence of strong radio sources, and absence of strong signs of interaction, such as blue colors or FIR-emission, the fact that the elliptical members (best candidates for ongoing mergers) are not more frequently first-ranked than spirals, etc., have been mentioned (Menon 1995, Leon, Combes & Menon 1998, Zepf 1993, Moles et al. 1994, Fasano & Bettoni 1994, Pildis, Bregman & Schombert 1995, Sulentic 1997). To overcome the contradictions with observations, Mamon (1986, 1995) suggested that HCGs do not exist as physical entities, and are rather the result of a projection of galaxies in loose groups (LGs). On the other hand, Hernquist, Katz & Weinberg (1995), Ostriker, Lubin & Hernquist (1995) suggested that HCGs are filaments seen end-on. Contrary to this, many evidences in favor of the physical reality of HCGs (Hickson

1997 and references therein) have been presented. To conciliate the results of N-body simulations with the facts on the physical reality of HCGs, Governato, Bhatia & Chincarini (1991), Diaferio, Geller & Ramella (1994, 1995) suggested that HCGs are being formed continually in collapsing LGs. This mechanism, however, does not eliminate the mentioned contradictions.

2. Regularity of Movement of Member Galaxies in HCGs

A clue to the solution of the problem was given by Tovmassian, Martinez & Tiersch (1998). They showed that the radial velocity dispersion, σ_v, of HCGs correlates with the elongation b/a[1]. It was already known that HCGs have a triaxial spheroidal configuration with the true mean sphericity $\epsilon = 0.26$ (Malykh & Orlov 1986). Elongated groups with small b/a have, on average, smaller σ_vs, while more round groups with high b/a ratio have higher σ_vs. This finding showed that HCGs are real physical formations, and that member galaxies in each HCG are moving along its elongation.

If member galaxies are indeed moving along the elongation of a group, then σ_vs of chain-like groups with small 2D galaxy-galaxy median projected separation R (supposed to be oriented at relatively small angle to the line-of-sight) should, on average, be higher than that of groups with higher R (supposed to be oriented almost orthogonal to the line-of-sight). There are 29 chain-like HCGs with $b/a \leq 0.20$. The mean R of 16 of them with $R < 40$ kpc is 26.3 ± 7.0 kpc, and the mean σ_v is 245.5 ± 106.4 km s^{-1}. The mean R for 13 other groups with $R > 40$ kpc is 68.4 ± 26.0 kpc, and the mean σ_v is, as it was expected, smaller, 137.5 ± 134.3 km s^{-1}. The Kolmogorov-Smirnov (K-S) test showed that the hypothesis that both distributions are of the same parent distribution is rejected with sufficiently high significance level $\alpha = 0.0065$. The groups of the two samples considered contain, on average, practically the same number of member galaxies, 3.6 and 3.7. Thus, the found correlation is not due to differences of the group masses. Hence, member galaxies in HCGs are, indeed, moving preferentially along the elongation of the corresponding group.

3. Possible Mechanisms of Regular Movements of Member Galaxies

Regular movements of member galaxies preferentially along the main axis in HCGs may be explained in the three following ways:

1. HCGs *disintegrate*, and their members *depart from each other* in opposite directions.

2. Environmental galaxies *fall upon the group from opposite directions* (Governato, Bhatia & Chincarini 1991, Diaferio, Geller & Ramella 1994, 1995).

3. HCGs are *gravitationally bound systems*, the members of which *rotate* around the gravitational center of the group in elongated orbits.

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[1] a is the angular distance between the most widely separated galaxies in the group, and b is the sum of the angular distances b_1 and b_2 of the most distant galaxies on either side of the line a joining the most separated galaxies (Rood 1979).

Disintegration of a compact group (CG) may be explained by two possible mechanisms:

a. *Ejection* of galaxies in opposite directions from the central galaxy according to Ambartsumian's (1961) or Arp's (1999, and references therein) ideas. However, no mechanism generating such processes is known, and so we will not consider this option.

b. *Disintegration* due to the outer gravitational force. A group would disintegrate if it is located between large clusters. However, the distribution of orientation of the major axes of HCGs is isotropic in relation to the large cluster-cluster alignment (Palumbo et al. 1993). Hence, this option is not sustainable. The gravitational influence of other CGs may be another possibility. However, the velocity of galaxies in a group initiated by the gravity force of another group with relatively small mass would be much less than the observed values. Hence, there is no outside acceptable force for stretching the groups.

Occasional infall of environmental galaxies upon CGs may certainly take place. Tovmassian, Yam & Tiersch (2001) and Tovmassian (2001) showed that almost each HCG is associated with an LG member distributed along the elongation of the corresponding group. It was found that σ_v of members of an LG is correlated with the elongation of the whole HCG+LG system (Tovmassian & Chavushyan 2000). Hence, members of LGs also move preferentially along the elongation of the corresponding system. This fact seems to be in favor of the infall mechanism. However, as cosmological N-body simulations have shown, the filaments exist over a wide range of scales (West 1994, Eisenstain, Loeb & Turner 1997), meanwhile the width of HCG+LG systems are less than 125 kpc (Tovmassian 2001). It means that infall should generally be *isotropic*. It is not easy to explain then why CGs are found only in very narrow filaments, along which infall may take place from opposite directions. Moreover, according to Palumbo et al. (1993) groups of galaxies are not generally aligned with either their nearest neighbors or with Abell clusters. On the other hand, it is widely assumed that filaments are connecting large clusters. It means then, that galaxies in CGs move not along the filaments. It is, therefore, apparent, that occasional infall may not account for a systematic regular movement of member galaxies.

We are left, then, with the third option, rotation. If member galaxies rotate around the gravitational center of the group, then in groups observed end-on, the galaxies which move towards the observer should be located on one side of the cross-section of the group, while the galaxies which are moving in opposite direction, should be located on the other side. In the case of infall of galaxies upon the group there should be no regularity in the location of group members. In six out of nine HCGs with $b/a \geq 0.60$ (the elongation of which is oriented close to the line-of-sight) the galaxies which are moving towards or away from us are well separated from the cross-section spread of groups (Figure 1). In only two groups, HCG 20 and HCG 99, are the galaxies with positive and negative residual radial velocities (RVs) mixed over the cross-section of the corresponding groups.

Another test relates to chain-like groups seen side-on. If galaxies from filaments fall upon the group, then the residual RVs of members of an LG located on one side of the center of the CG+LG system, at relatively large distances from it, and the residual of those located on the other side should

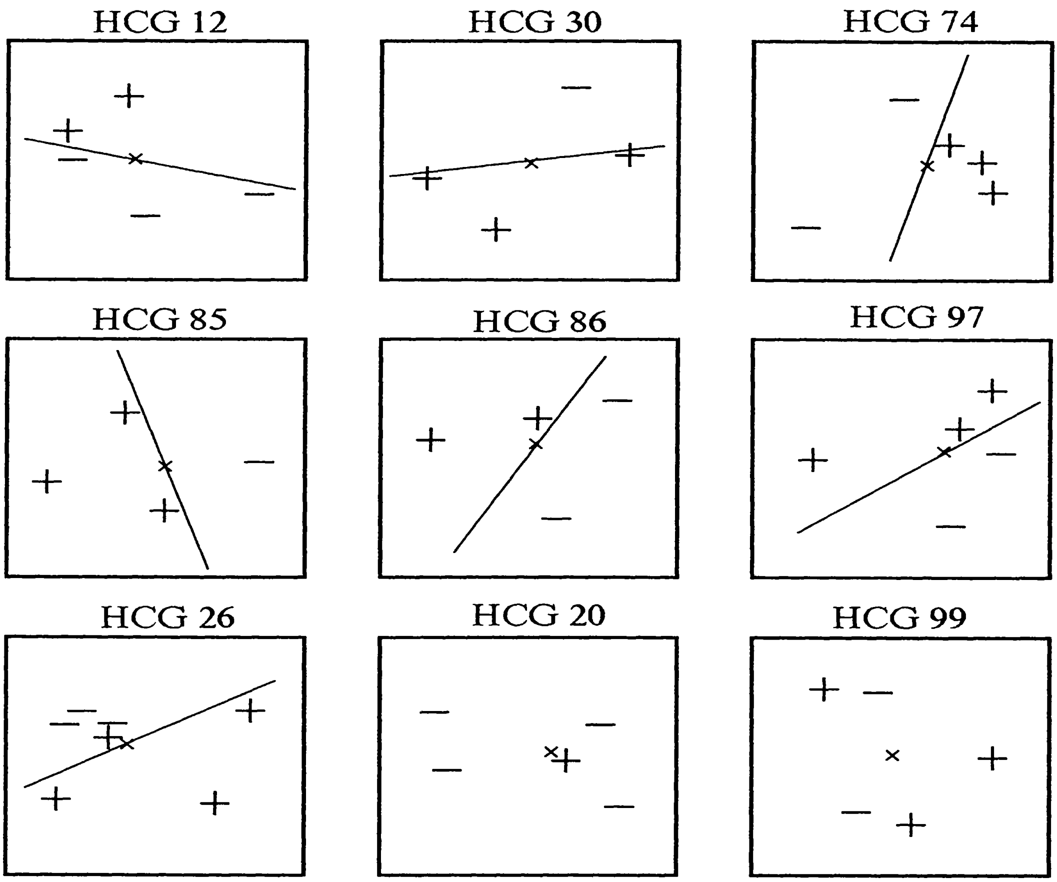

Figure 1. The distribution of galaxies moving away from us (+) and towards us (–) over the cross-sections of round HCGs with $b/a > 0.6$. Galaxies with discordant redshifts are not shown.

have opposite signs. Inspection of RVs of compact and poor groups studied by Carvalho et al. (1997) and Zabludoff & Mulchaey (1998) shows that there is no regularity in the distribution of signs of residual RVs in relation to the center of the group.

Thus, the relative widths of cross-sections of CGs and filaments, and the radial velocity data on HCGs and LGs associated with them *contradict* the suggestion of an inward motion of member galaxies. Observational data are *in favor of systematic rotation* of member galaxies around the gravitational center of the group.

Using the mean value of the crossing-time for HCGs, $\tau_c = 4/\pi\ R/V$, where R is the mean value of the two-dimensional galaxy-galaxy separation, and V is the intrinsic three-dimensional velocity dispersion, we may roughly estimate the rotation time. R may be determined more correctly in chain-like groups, and V - in round groups. For 29 HCGs with $b/a \leq 0.2$, the mean $R = 45$ kpc, and for 24 round groups with $b/a > 0.5$, the mean V is $\sim$ 460 km s^{-1} (R and V values are taken from Hickson et al. 1992). The mean τ_c is $\sim 10^8$ yrs. If a HCG member makes one revolution during $2\tau_c$ time, then according to Kepler's third law, an LG galaxy at a mean distance of 250 kpc from the center of the CG (Tovmassian 2001) makes one revolution in $\sim 3 \times 10^9$ yrs, which is less than the Hubble time. It follows that the faint members may be gravitationally bound to the corresponding group, and that the HCG+LG systems may be virialized.

Hence, the third option, i.e., rotation of member galaxies around the gravitational center of corresponding HCG, is *the most realistic mechanism.* HCGs are, thus, more stable systems than it has been predicted by N-body simulations in which regular movements of member galaxies were not taken into account.

It is highly probable that galaxies, during their rotation around the gravitational center of a HCG which has a prolate spheroid configuration with relatively small cross-section, would pass close to each other in its central region. There interactions between them could certainly occur. However, since the velocities of galaxies near the pericenter of the orbit are sufficiently high, the interaction time is short, the efficiency of interactions would be small, and the merging processes would be rare. This explains the lack of mergers and the lack of strong radio and FIR sources in HCGs. However, the process of sweeping out the gas from member galaxies may be very effective, and spirals would be converted to elliptical or lenticular galaxies. Indeed, the fraction of spiral galaxies in HCGs, $f_s = 0.49$, is significantly less than in the field (Hickson, Kindle & Huchra 1988).

4. The X-rays Emission of the Compact Groups

It is known that in clusters of galaxies $L_x \propto \sigma_v^4$ (Solinger & Tucker 1972, Quintana & Melnick 1982), but groups do have more shallow slope. It has been generally assumed that the reason is the enhanced (by one-two orders of magnitude) X-rays emission of groups. The excess X-rays luminosity of the low-mass groups is explained by the "mixed emission" scenario (Dell'Antonio et al. 1994) when the emission from the intragroup plasma is contaminated by a superposition of diffuse X-rays sources corresponding to the hot interstellar medium of the member galaxies.

Tovmassian, Yam & Tiersch (2002) showed that the shallow slope of $L_x \propto \sigma_v$ line for groups is due to underestimation of σ_vs. The mean b/a of ten RASSCALS (Mahdavi et al. 2000) at the utmost left of the $L_x - \sigma_v$ graph is equal to 0.44 ± 0.11, and that of the groups at the utmost right is 0.68 ± 0.19. The mean value of b/a of four HCGs (Ponman et al. 1996) located farthest to the left of the line $L_x - \sigma_v^4$ is equal to 0.20 ± 0.05, while that of the remaining 18 groups is equal to 0.44 ± 0.18. The K-S test rejected with the significance levels $\alpha = 0.0069$ and $\alpha = 0.0082$ the hypothesis that in both cases the compared distributions are of the same parent distribution. Hence, the groups located to the left of the $L_x \propto \sigma_v^4$ line on the $L_x - \sigma_v$ graph have the smallest b/a ratios. They are oriented close to been orthogonal to the line-of-sight. For this reason their measured σ_v are smaller than the corresponding real value. Location of such groups on the left side of a $L_x \propto \sigma_v^4$ line creates the impression of the more shallow slope of the $L_x - \sigma_v$ correlation. Hence, *not* that the X-rays luminosities of the CGs are higher than it is expected by the corresponding law for clusters of galaxies, but their σ_vs are *underestimated* instead. Thus, consideration of geometrical effects solves the longstanding problem of the X-rays emission of groups of galaxies.

5. Conclusions

It is shown that σ_vs of HCGs are correlated with their elongation (Tovmassian, Martinez & Tiersch 1999). It means that member galaxies in a group move preferentially along its elongation. It is concluded that members of a HCG most probably rotate in elongated orbits around its gravitational center. Other two possible explanations: the departure of member galaxies in opposite directions, and infall of LG galaxies upon the CG from opposite directions are ruled out (Tovmassian 2001, 2002).

The finding that HCGs contain other members distributed along the elongation of the corresponding groups (Tovmassian 2001, 2002, Tovmassian, Yam & Tiersch 2001), and that their σ_v, as well as that of the proper members of HCGs, correlates with the ellipticity of the whole system (Tovmassian & Chavushyan 2000) shows that HCGs are the cores of gravitationally bound poor galaxy groups.

Hence, HCGs are more stable systems than it has been previously assumed. They possess an elongated space configuration and contain more members located at relatively large distances from them. The member galaxies most probably rotate around the gravitational center of the corresponding group. Elongated space configuration of HCGs, and regular rotation of their members around the corresponding gravitational center, are in agreement with the observed presence of galaxies showing signs of interaction, and a smaller relative content of spirals. The lack of apparently merged galaxies is also explained.

It is shown that the X-rays luminosity of CGs is not enhanced and obeys the $L_x \propto \sigma_v^4$ found for clusters of galaxies. The discrepancy is due to geometrical effects.

All members of elongated groups whose orientation is close to the line-of-sight are seen near each other on sky, though the distances between them in space may be quite high. Such systems may often be recognized as poor groups or even poor clusters. If the orientation of an elongated group is nearly orthogonal to the line-of-sight, the group would be detected as a CG if its bright members happen to be close to each other on the sky during regular rotation around the gravitational center of the group.

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