ON THE X-RAY EMISSION OF THE LOW-MASS GALAXY GROUPS

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ABSTRACT

It is shown that low-mass groups obey the $L_X \propto \sigma^4$ law deduced for galaxy clusters. The impression of the more shallow slope of the $L_X-\sigma$ correlation for groups is created not by enhanced X-ray emission, but by the underestimation of the radial velocity dispersion of some groups.

Subject headings: galaxies: clusters: general — X-rays: galaxies

1. INTRODUCTION

Solinger & Tucker (1972) showed that if the source of X-ray radiation is hot gas bound in clusters, then the X-ray luminosity, $L_X$, should be correlated with the radial velocity dispersion, $\sigma$. Thermal emission from the intracluster gas yields an X-ray luminosity, $L_X$, proportional to the square of the gas density. In the case of a constant mass-to-light ratio, the $L_X$ is proportional to the square of the mass of the cluster. If the cluster is a relaxed system, $\sigma$ is roughly proportional to the square root of the mass. Thus, $L_X \propto \sigma^4$. Quintana & Melnick (1982) showed that the $L_X$ of galaxy clusters, indeed, obeys the expected correlation. Dell’Antonio, Geller, & Fabrikant (1994) showed that rich groups follow the $L_X \propto \sigma^4$ relation, but groups with smaller $\sigma$ do have a more shallow slope, $L_X \propto \sigma^{2.7}$. All recent observations (Mahdavi et al. 1997; Zabludoff & Mulchaey 1998; Helsdon & Ponman 2000; Mahdavi et al. 2000; Xue & Wu 2000; Mahdavi et al. 1997) proved that the dependence of the X-ray emission for low-mass groups (which includes compact groups) on the $\sigma$ is much weaker than for galaxy clusters. Zimer, Mulchaey, & Zabludoff (2001), analyzing the results of different investigators, mentioned some discrepancies and concluded that they were due to poorly determined $\sigma$ and $L_X$-values. All data show, however, that some number of low-mass groups of galaxies are located on the left side of the line $L_X \propto \sigma$. It has been generally assumed that the reason for such location of groups on the $L_X-\sigma$ graph is the enhanced (by 1–2 orders of magnitude) X-ray emission of groups. It is widely assumed that the excess X-ray luminosity of the low-mass groups is explained by the “mixed emission” scenario (Dell’Antonio et al. 1994), in which the emission from the intragroup plasma may be contaminated by a superposition of diffuse X-ray sources corresponding to the hot interstellar medium of the member galaxies. However, the shift of groups to the left of the $L_X \propto \sigma^4$ line may have another reason: the underestimation of $\sigma$.

This has been shown that Hickson compact groups (HCGs) and Shakhbazian compact groups have triaxial spheroid “cigar-like” shapes (Malykh & Orlov 1986; Hickson et al. 1984; Oleak et al. 1998). In a series of papers, Tovmassian and collaborators (Tovmassian, Martinez, & Tiersch 1999; Tovmassian & Chavushyan 2000; Tovmassian, Yam, & Tiersch 2001) showed that $\sigma$-values of compact groups (CGs) and of loose groups (LGs) associated with them, which are also elongated and have the same orientation as the corresponding CGs, are correlated with the elongation of groups determined by the $b/a$ ratio. This means that members of CGs and LGs move along the elongation of the corresponding group. It has been shown by Tovmassian (2001a, 2001b) and Tovmassian & Tiersch (2001) that out of three possibilities of such movement (flying out of the galaxies from the center of the group in opposite directions, infalling from opposite directions, and regular rotation of member galaxies in elongated orbits around the gravitational center of each system), the latter possibility is the more realistic one. The rotation time is less than $\sim 3 \times 10^9$ yr, so CG + LG systems may well be virialized. The measured $\sigma$ of such elongated groups depend on the orientation of the group. The highest $\sigma$-values are observed in those groups whose orientation of elongation is close to the line of sight. Such groups generally have the highest $b/a$ ratio, though the chainlike groups oriented at small angles $\theta$ to the line of sight would also have relatively high $\sigma$-values. The measured $\sigma$ of the majority of groups oriented at intermediate angles to the line of sight are smaller. The groups oriented close to the orthogonal to the line of sight have the smallest measured $\sigma$; i.e., their $\sigma$-values are highly underestimated. The latter groups are the most elongated and have the smallest $b/a$ ratio. Hence, they would be located on the left part of the $L_X-\sigma$ graph. We show in this Letter that underestimation of the $\sigma$-values of the seen edge-on elongated groups, indeed, creates the more shallow slope of the $L_X-\sigma$ correlation.

2. ANALYSIS OF DATA

For this analysis we used the data set of Mahdavi et al. (2000), which is the largest sample of the low-mass galaxy groups with detected X-ray emission, and the X-ray—selected sample of HCGs (Ponman et al. 1996). We compared $b/a$ ratios of the groups most remote to the left of the line $L_X \propto \sigma^4$ on the $L_X-\sigma$ graph with those of the most remote to the right or with those of all other groups. The $b/a$ ratios for RASSCALS (ROSAT All-Sky Survey—Center for Astrophysics Loose Systems) were determined on the corresponding maps presented in Mahdavi et al. (2000), and those of HCGs were taken from Tovmassian et al. (1999). In the latter paper it is shown that

1 Here $a$ 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).
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Fig. 1.—$L_X$-$\sigma_v$ relation of groups. Data are taken from Mahdavi et al. (2000). Only the groups located at the utmost left and the utmost right from the line \( L_X \propto \sigma_v \) are drawn. The ratios are shown.

For this reason their measured radial velocity dispersions are smaller than the real values. Location of such groups on the left side of the \( L_X \propto \sigma_v \) line creates an impression of a more shallow slope of the \( L_X-\sigma_v \) correlation. Possible errors in \( \sigma_v \) ratios caused by missed members or chance interlopers would apparently increase the dispersion of the mean values, but they would not introduce systematic errors in either direction.

The following 10 RASSCALS are the most remote to the left (Fig. 1): SRGb063 (0.35), SRGb075 (0.60), SRGb119 (0.44), SSb085 (0.43), NRGb045 (0.61), SSb153 (0.52), NRGs317 (0.43), SRGb009 (0.42), SS2b293 (0.41), and SS2b313 (0.37). The following 10 groups are the most remote to the right: SS2b056 (0.87), NRGb004 (0.77), NRGs027 (0.62), NRGb0032 (0.56), NRGs110 (0.50), NRGs117 (0.75), NRGb155 (0.96), NRGs388 (0.45), SS2b261 (0.46), and NRGs040 (0.87). The corresponding \( \sigma_v \) ratios are listed in parentheses. The other 49 groups with measured X-ray emission are located along the line within a stripe with the width \( L_X \propto \sigma_v \).

Fig. 2.—$L_X$-$\sigma_v$ relation for HCGs (from Ponman et al. 1996). The line \( L_X \propto \sigma_v \) is drawn as in Fig. 1. The \( \sigma_v \) ratios are shown.

The correlation between \( \sigma_v \) and \( \sigma_v \) ratios does not depend on the number of group members.

The same trend is observed in the case of HCGs. The mean value of the \( \sigma_v \) ratios of the four groups located most remote to the left of the line \( L_X \propto \sigma_v \) (Fig. 2) is equal to \( 0.20 \pm 0.05 \), while that of the remaining 18 groups is equal to \( 0.44 \pm 0.18 \). The Kolmogorov-Smirnov test rejected the hypothesis that the compared distributions are of the same parent distribution in both considered cases. The significance level of rejection for the RASSCALS is \( \alpha = 0.0069 \) and for HCGs is \( \alpha = 0.0082 \).

Hence, the groups located to the left of the \( L_X \propto \sigma_v \) line on the \( L_X-\sigma_v \) graph have the smallest \( \sigma_v \) ratios. This indicates that they are oriented close to the orthogonal to the line of sight.

The highest \( \sigma_v \) values of HCGs are \( \sim 600 \) km s\(^{-1}\). The highest \( \sigma_v \) values of the groups studied by Mahdavi et al. (2000) are of the same order. Apparently, these are the groups observed end-on. Their measured \( \sigma_v \) values generally correspond to the real values. Such groups would be located at the utmost right of the \( L_X \propto \sigma_v \) graph. With the increase of the angle \( \theta \), the \( \sigma_v \) ratio and the corresponding \( \sigma_v \) of the group would decrease. At angles \( \theta \) of about 75° the measured \( \sigma_v \) values would be about 400 km s\(^{-1}\) smaller in comparison to the real values, and \( \log \sigma_v \) would be about 2.2, which corresponds to that of the groups located at the utmost left on the \( L_X-\sigma_v \) graph.

Thus, it is not that the X-ray luminosities of the low-mass groups are higher than expected by the \( L_X \propto \sigma_v \) law but that their \( \sigma_v \) values are underestimated. Rich clusters have a much more symmetric round shape, and orientation may have negligible effect on the measured \( \sigma_v \) value. The spread of clusters around the \( L_X \propto \sigma_v \) line is due to the natural dispersion of parameters.

3. CONCLUSIONS

Consideration of the \( \sigma_v \) ratios of the low-mass groups shows that groups located at the utmost left of the \( L_X \propto \sigma_v \) line on the \( L_X-\sigma_v \) graph have, on average, smaller \( \sigma_v \) ratios than those located at the utmost right. The elongation of groups with small
ratios are oriented close to the orthogonal to the line of sight. The measured $\sigma_v$-values of these groups are, thus, underestimated and are smaller than the real values. Therefore, such groups are artificially shifted to the left on the $L_X-\sigma_v$ graph. This creates an impression of an enhanced X-ray luminosity. If one takes into account the reasonable amount of underestimation of $\sigma_v$ (of the order of 200–300 km s$^{-1}$/H$_{100}$), which corresponds to angle $\theta$ of about 40$^\circ$–50$^\circ$, then the corresponding groups will be moved to the right, toward the line $L_X \propto \sigma_v^4$. Hence, the low-mass groups obey the $L_X \propto \sigma_v^4$ law for clusters of galaxies (Solinger & Tucker 1972; Quintana & Melnick 1982). This means that there is no need to apply any mechanism of enhancement on the X-ray luminosity of the low-mass groups since, in reality, there is no enhancement.

CGs are stable systems with members probably rotating around the gravitational center of the corresponding group (Tovmassian 2001a, 2001b). Because of regular movement in elongated orbits, the velocities of member galaxies in the central region of a CG are sufficiently high. Therefore, the efficiency of interaction in such groups would be smaller than in the numerical simulations in which such regular movement has been neglected (Barnes 1985, 1989; Ishizawa 1986; Mamon 1986, 1990; Zheng, Valtonen, & Chernin 1993). The formation of the hot interstellar medium in member galaxies, widely assumed as an explanation of the excess X-ray emission, may be very rare and may not dominate the global X-ray emission. In fact, what is claimed by many to be excess X-ray luminosity in the low-mass groups is due to a projection effect and, thus, is a result of the misinterpretation of the observational data. The finding of Mahdavi & Geller (2001) that clusters of galaxies and single elliptical galaxies form a continuous relation $L_X-\sigma_v^4$ are consistent with the result presented in this Letter. Low-mass groups are not exotic objects and obey the same law.

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