Small Galaxy Groups
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The connection between dark matter, internal motions and configurational properties of triple galaxies

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Abstract. Numerical simulations of the dynamics of triplets of galaxies show that virial estimations of the individual masses of triplets are unreliable because of strong nonsteadiness of these groups and projection effects. However, the mass of a typical small galaxy group can be estimated statistically, from data on a whole homogeneous ensemble of groups such as, for example, Karachentsev's Catalogue of compact galaxy triplets. The characteristic total mass of a triplet from this catalogue is 4 - 7 times greater than the visible mass when the standard mass-to-light ratio is assumed. This suggests the presence of some considerable amount of dark matter even in these compact triplets. In wide triplets of galaxies the amount of dark matter may be significantly larger. The presence of distributed dark matter makes motions of galaxies in triplets more stochastic. In this case the existence of long-lived hierarchical configurations (temporary binaries) in triple systems becomes much less probable than without dark matter. The analysis of internal motions of galaxies in triplets and their configurations may be interpreted as additional non-dynamical evidence of the presence of dark matter in galaxy triplets.

1. Introduction: mass estimation for small groups.

Small groups of galaxies may be the most common type of systems of galaxies. Groups may contain nearly half of all galaxies in the universe (de Vaucouleurs 1975, Tully 1987). The mass estimation for small groups with $3 < N < 30$ presents a much more difficult problem than such estimation for individual giant galaxies with halos or rich clusters of galaxies. For small groups the kinetic to potential energy ratio T/U is not fixed and varies significantly from one moment to another during the dynamical evolution of the system (i.e. these systems are non-stationary), and also because of projection effects (only radial velocities of the galaxies and their projected positions on the sky can be used for a dynamical mass estimation). Therefore, an application of any virial type mass estimator to an individual observed group (e.g. a triple galaxy from the Karachentseva et al. 1979 list) gives an uncertainty up to 4 orders of magnitude (Kiseleva and Chernin 1988, Anosova et al. 1991, Chernin and Mikkola 1991). However, a reliable statistical estimation of a typical mass of a small group is possible for a homogeneous ensemble of groups (the same multiplicity and selection criterion

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applied) using the 'computer physics' approach developed initially in Leningrad (St. Petersburg) in the late 1980s (see reviews by Kiseleva and Orlov 1993, Karachentsev et al. 2000 and references therein). This approach was applied to the sample of 46 of Karachentsev's compact galaxy triplets selected as probable physical systems out the whole list of 83 triplets (we used the selection criterion by Anosova 1987). The results showed that the typical mass of a triplet is 4 to 7 times larger than the luminous mass determined from the standard mass-to-light ratio (Kiseleva and Chernin 1988, Chernin and Mikkola 1991, Anosova et al. 1992). Dolgachev and Chernin (1996, 1997) estimated the typical total mass of 108 wide galaxy triplets (Trofimov and Chernin 1992) which they treated as dynamically young systems in the stage of initial free-fall. They found that the amount of dark matter in these systems has the same order of magnitude as in compact triplets.

2. Dark matter, configurations and internal motions of triple galaxies

Numerical simulations of the dynamical evolution of three-body systems show that these systems without dark matter have hierarchical configurations with a close binary during most of their lifetimes. Many of the temporary binaries exist for a very long time while the third body is in a stage of distant ejection (but not escape). The situation completely changes if even a modest amount of dark matter is distributed within the volume occupied by the triple system. Fig.1 shows the trajectories of galaxies within triple systems without dark matter (left hand vertical panel) and with a distributed amount of dark matter 3 times larger than the total mass of galaxies (right hand vertical panel). All three galaxies have equal masses and zero initial velocities. Both cases start from the same initial configuration chosen in the region of all possible configurations (see e.g. Agekian and Anosova 1967, Kiseleva and Orlov 1993). In this region the configuration of a triplet is uniquely defined by a pair of numbers x and y, where $x \geq 0,\ y \geq 0,\ (x+0.5)^2 + y^2 \leq 1$. Each horizontal panel a, b and c of Fig. 1 shows trajectories of bodies during one crossing time τ starting from time $T = 0$. In the system without dark matter the temporary binary begins to form when $T \approx 2\tau$ and the left panel of Fig. 1(c) does not show the third body which is at the stage of distant ejection. The right hand panel show that the presence of dark matter makes the whole dynamics of the triplet much more stochastic with no bounded binaries being formed (despite the increasing number of close approaches of two galaxies).

The study of probably physical Karachentsev's compact triplets does not show any excess of hierarchical configurations which one would expect if there was no dark matter in these systems. Of course, one should not forget that we only see two-dimensional projections of real triplets and try to reconstruct the real configurations. Methods of inverse-matrix and of random coincidences (Trofimov 1990, Anosova et al. 1993) were suggested and applied to Karachentsev's triplets. It was shown that the 'real' triplets as well as their projections do not show any excess of hierarchical systems. Indeed, computer simulations showed that statistically projection effects produce more visible hierarchical configurations than the number of such configurations in real three-dimentional sys-

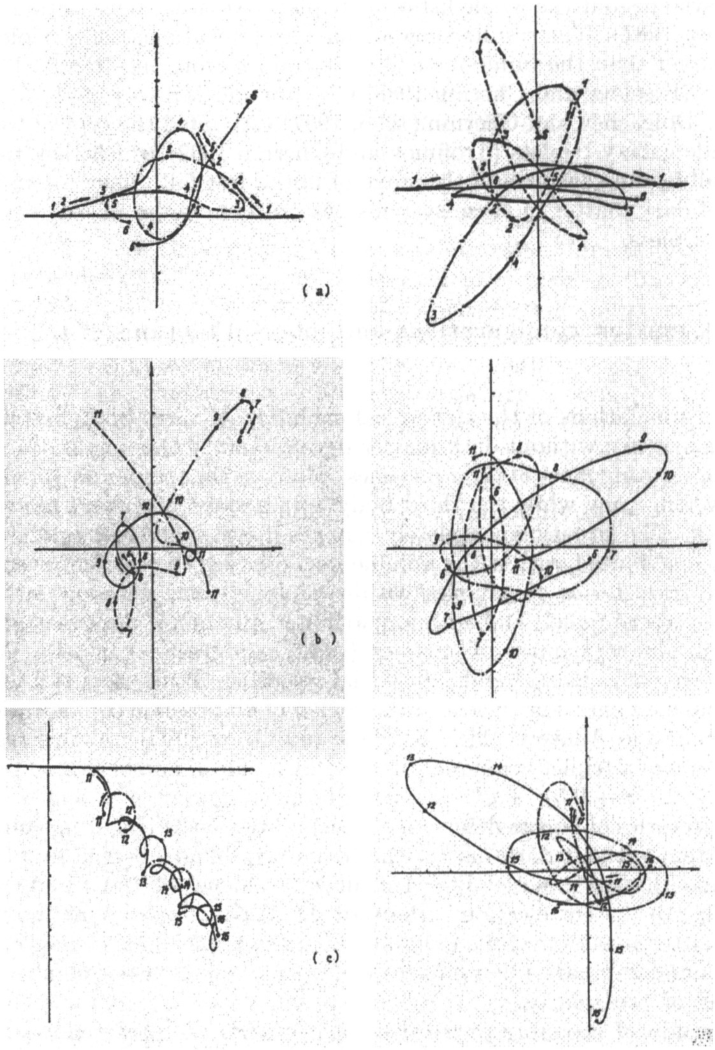

Figure 1: The trajectories of bodies in the same triple system without dark matter (left hand vertical panel) and with dark matter equal to three times the total mass of the galaxies (right hand panel) over the first 3 crossing times.

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tems (Chernin et al. 1994). The method of configurational parameters (Kiseleva and Orlov 1989, Anosova et al. 1993) that is not sensitive to projecton effects was applied to compact triplets and also did not show any preference for hierarchical structure in these groups. This result may be treated as additional non-dynamical evidence of the presence dark matter in compact triplets.

One more indirect piece of evidence may be obtained from the analysis of internal motions of galaxies in triplets. Kiseleva and Orlov (1993a) studied statistically the character of these motions in compact and wide triplets. They found that in the probably physical Karachentsev compact triplets galaxies move isotropically with probability $P = 0.93$. At the same time the hypothesis of rotational and radial (collapse or expansion) motions must be rejected. The isotropy of space velocity distributions is evidence that compact triplets are well evolved dynamical systems, and dark matter may play an important role in this evolution. Note that wide triplets from the Huchra and Geller (1982) group catalog are likely to be dynamically young systems still at the stage of initial collapse (probability $P = 0.51$). These results are in good agreement with the results of Dolgachev and Chernin (1996, 1997). Thus, the amount of dark matter (comparable to the amount in compact groups) within the volume of wide groups (which is much larger) is not big enough to decrease significantly the time of initial free-fall and to provide fast stochastisation in wide triplets. However, at later evolutionary stages still fewer binaries will be formed and the overall dynamical evolution of these groups will be more active than if they had no dark matter at all.

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