DYNAMICS OF GROUPS AROUND INTERACTING DOUBLE ELLIPTICALS: MEASURING DARK MATTER HALOES

H. Quintana
Astrophysics Group, P. Universidad Católica de Chile

INTRODUCTION

Binary galaxies, as binary stars, are important to measure masses, as suggested by Page (1952). Because three orbit parameters are measurable for galaxies at one instant of time, severe uncertainties remain in the orbit and mass determinations. These uncertainties can partly be overcome by statistical studies of selected samples and/or n-body simulations. Close double galaxies (and isolated galaxies) could also be useful to estimate dynamical masses if we can find test particles around them.

Interacting elliptical pairs or dumb-bell galaxies are found with a large range, between 0-1200 km s^{-1}, of relative radial velocities. Standard 2-body orbit calculations, highly uncertain due to projection factors, suggest for the largest velocity differences very large galaxy masses, if the systems are bound and stationary. However, recent n-body simulations model these binaries as galaxies captured from hyperbolic orbits, requiring masses of order a few times $10^{11} M_\odot$ (Borne $et~al.$ 1988), but producing systems that are short lived.

A different picture appears when we study observationally the dynamical mass of interacting double ellipticals using faint satellite galaxies. These satellites contribute little luminosity and, presumably, little mass to the system. We present results of two such groups, basically forming systems of test particles, around the dumb-bells NGC 4782/3 and IC5049. We also briefly discuss the satellite group around the central dumb-bell in the cluster Sersic 40/6. Apparently we detect large quantities of dark matter in the vicinity of these dumb-bell galaxies, because the system masses of $\sim 4.5 \times 10^{13} M_\odot$ and $8 \times 10^{13} M_\odot$ for NGC 4782/3 and IC 5049, respectively, are quite high. Likewise, the mass of the Sersic 40/6 inner core is $7 \times 10^{13} M_\odot$. The possibility that a common massive dark matter halo increases the merging times of these types of galaxies is suggested. In this paper we assume $H_0' = 100$ km s $^{-1}$ Mpc^{-1}.

RESULTS AND DISCUSSION

We briefly discuss below the three cases mentioned.
a)] IC 5049 $\equiv$ ESO 341-IG15.

Lauberts (1982) classifies it as a $m_B = 14.69$ E+E system with a common envelope, apparently belonging to the NGC 6958 galaxy group (v=2,757 km s^{-1}). However, spectra taken at the 100" Du Pont telescope at Las Campanas Observatory with the 2D-Frutti detector, showed that the mean E+E velocity is 11,700 km s^{-1}, with relative velocity between the E components of 890 km s^{-1}. Inspection of the field reveals a concentration of very faint galaxies in the area. The spectra of 15 galaxies showed that 11 faint satellite galaxies form a group centered at 11,871 km s^{-1}, with 31% chance of a gaussian distribution centered at the mean db velocity. Velocity dispersion of this group is an outstanding 580 ($\pm$160, -90) km s^{-1} and its velocity histogram is consistent with a gaussian distribution.

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No faint galaxies were found in front of the group and 2 were background galaxies at v$\simeq$ 27,000 km s^{-1}. Literature velocities in the neighbourhood list NGC 6958 at 2,757 km s^{-1}, 341-IG6 at 6,969 km s^{-1} and 341-IG16 at v = 12,689 km s^{-1}. A number density map of 260 galaxies in a 2° × 2° area down to m = 18, approximately, shows a sharp symmetrical enhancement that peaks at the position of IC 5049, due mostly to faint galaxies. This density distribution strongly suggests the group effectively cluster around IC 5049, with a scale of order 300 kpc. From inspection of the plates the combined luminosity of the faint galaxies can be estimated to be of order 20-25% of the group luminosity.

Application of a mass estimator for test particles around a single massive object (Bahcall and Tremaine 1981) gives M$_s$ = 4.3×10^{13} M$_\odot$. Likewise, use of the virial theorem, median mass, average mass and projected mass estimators following Heisler *et al.* (1985) discussion for equal mass self-gravitating systems, gives masses of similar order, as shown in Table 1.

If mass is concentrated following luminous matter, then each db component has an associated mass roughly 40% of these values. Even if the masses of the db galaxies themselves correspond to traditional M/L $\sim$ 30 for E galaxies, then they, or the group, have a large amount of dark matter concentrated in a small volume beyond the optical galaxies and with a scale out to about 300 kpc.

These measurements should be confirmed by a wider dynamical analysis of the neighbourhood of IC 5049, to ascertain we are not measuring the effects of superposed groups unrelated to IC 5049 or the projection of a galaxy filament or wall around IC 5049. Anyway, the density maps do not suggest outlying structures.

b)] The group around NGC 4782/3.

This system has been studied by de Souza and Quintana (1990), who give observational details. Summarizing, this system formed by a m_B = 12.1 EO+EO pair of interacting elliptical galaxies is at v = 4,544 km s^{-1} with 650 km s^{-1} velocity difference between components. Borne *et al.* (1988) proposed a model in which these galaxies are located at the closest point of an hyperbolic encounter with small impact parameter, producing a bound system as orbital momentum is transferred to internal stellar motions. In fact, internal dispersions are rather high, $\sim$400 km s^{-1} and $\sim$300 km s^{-1}, for each member. The resulting timescale of the merger is of order 10^8 years. Using OPTOPUS at the ESO 3.6m telescope, de Souza and Quintana observed the surrounding group of fainter galaxies. They found 13 members (plus 17 galaxies at v = 17,000 km s^{-1} or higher) with a group velocity dispersion of 450 km s^{-1}. Assuming a single point mass surrounded by test particles a mass of 3.6 × 10^{13} M$_\odot$ is obtained as indicated in Table 1. A similar discussion as in the previous system leads us to assign corresponding masses of $1-2 \times 10^{13}$ M$_\odot$ to each of the db components, either associated to the outskirts of the luminous mass or to the group, which has typical dimensions of order 300 kpc. In any case, most of this large amount of mass is in dark form as again the resulting global M/L is of the order $\sim$1000 (M/L)$_\odot$, while the M/L of the luminous galaxies is typically $\sim$10-30, as assumed by Borne *et al.* (1988).

c)] The E+E interacting system at the center of the Sersic 40/6 cluster.

This system has been studied by Quintana and Ramírez (1990), where details are presented. The db components have a velocity difference of $\sim$ 300 km s^{-1}, with internal

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dispersions of 250 km s^{-1} at the nuclei and $\sim$650 km s^{-1} at the outer optical halo (Carter *et al.* , 1985). This value is close to the 710 km s^{-1} dispersion of the faint group of closest 10 galaxies to the db, thus significantly lower than the cluster global dispersion of 1440 km s^{-1}, obtained from 80 galaxies. A mass of $\sim 7 \times 10^{13} M \odot$ is derived for this inner core, if assumed bound. This mass is basically associated to the central db. If we take typical values for the ellipticals M/L ratio, then this large amount of mass must be in the form of dark matter. We note that similar methods applied to the central core of the cluster A 496 give a mass $\sim 2.5 \times 10^{12} M_{\odot}$ associated to the cD galaxy in that cluster, in fair agreement with usual dominant E galaxy masses.

From the evidence of these three db systems, we can tentatively conclude the following:

The motion of faint galaxies (approximately test particles) around some pairs of interacting E galaxies seems to measure very large system masses, which for the most part must consist of dark matter. If dark matter follows luminous matter, most of this dark matter is associated to the bright E galaxies themselves as dark haloes, with values of the order of 10^{13} M$_{\odot}$ per galaxy. Otherwise, a large common halo of dark matter is present around some systems of galaxies. This could be a characteristic of some dumb-bell systems. In both hypotheses it seems that the ratio of luminous to dark matter can vary widely in different galaxy systems.

The tidal distortions shown by db galaxies could be interpreted as due to short, transient collisions, with estimated lifetimes of $\sim$1.5 dynamical times, as recently done in the literature. In this case, these systems should be rather rare. However, we see many examples of db's, isolated, in groups or in clusters (some classified as multiple nuclei cD's). The large amounts of dark matter associated to the db galaxies in these examples (to individual or to common extended haloes) could alter the conditions of those encounters in such a way that merging times become extended. The possibility of seeing massive dark halo effects in other systems remain open and the results of Dressler *et al.* (1986) for NGC 720 are a hint in this direction.

References

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Table 1: Masses of Group Systems Centered on db Galaxies

$$(H_0 = 100 \text{ km s}^{-1} \text{ Mpc}^{-1})$$

System	M_V $10^{13} M_\odot$	M_M $10^{13} M_\odot$	M_A $10^{13} M_\odot$	M_P $10^{13} M_\odot$		MS_V $10^{13} M_\odot$	MS_P $10^{13} M_\odot$
IC 5049	8.2	6.8	7.8	10.2	*	4.3	6.9
				20.4	**		13.8
N4782/3	4.5	4.9	4.2	5.3	*	3.6	5.7
				10.6	**		11.4
Sersic 40/6	7.1	8.2	7.5	11.4	*	3.6	6.2
(db inner core)				22.8	**		12.4

Notes:
a) * : isotropic orbits; ** : radial orbits.
b) M denotes total mass of equal-mass self-gravitating system; MS denotes total mass of system of test particles around a massive particle. M_V and MS_V = Virial Mass; M_M = Median Mass; M_A = Average Mass; M_P and MS_P = Projected Mass.

DISCUSSION

Schneider: Could you comment on the degree of bimodality in the velocity distribution within the groups and whether it might be indicative of an unbound collision between two groups?

Quintana: The histogram for the velocities for both groups shows no evidence for bimodality. However, one has 13 members in each and more data could perhaps show such an effect. So far, we have just one group in each case.

Miller: Most of your galaxies in the field of these double systems seem to be dwarfs. Is that typical of most galaxies, or is it an unusual feature of the dumbbells? Is this telling you something about the dynamics of these systems?

Quintana: It is believed that most groups are deficient at the faint end of the luminosity function. In this sense these two groups are atypical. However, with just two examples it is hard to ascertain special properties of the faint galaxies found. In fact, many dumbbells are in groups, and velocity data is needed to decide on membership of individual faint galaxies.

Borne: The simulations only indicate the mass on the scale of the luminous matter, and cannot tell anything about the mass of possible dark matter on larger scales. Even so, the observed distortions are not consistent with a circular orbit for the dumbbell in NGC 7482/83, but with an unbound trajectory. The high velocity dispersion of the surrounding group may simply result from the superposition of two groups following each of the galaxies. This unbound group would not be virialized, and your mass estimates would be invalid.

Quintana: Certainly the mass estimators measure the mass on the scale size of the group, which is of order 200-300 kpc in radius in these examples. The velocity histograms show no sign of being two distributions. If the E galaxies are followed by accompanying groups, the resulting group should be highly anisotropic as the satellite galaxies will not have the same type of collision as the central pair. In fact, it is unlikely that the resulting system will remain bound, given the initial conditions for velocity and mass assumed in the hyperbolic orbit simulations. This should be borne out by analysis of additional groups. It is surprising that the examples observed turned out so similar. If E galaxies have groups of faint galaxies normally associated with them, then the hypothesis of group superposition could be tenable. As far as I know the simulations have not considered dark matter halos. These factors should be investigated with models before we can reject other alternatives.

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