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TWO EXAMPLES OF CLUSTER DYNAMICAL CUSPS: A496 AND SERSIC40/6

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RESUMEN. Se presentan las dispersiones de velocidad y las masas viriales para los cúmulos Sersic40/6 y A496, basándose en datos previamente publicados y recientemente obtenidos. Se discute la presencia en ambos cúmulos de un estrecho grupo de miembros débiles que rodean las galaxias centrales, formando cúspides de densidad. Sin embargo, en contraste con otros ejemplos de cúmulos, como en A2029, las galaxias del núcleo tienen dispersiones mucho más pequeñas que el resto de las galaxias, con valores similares a la dispersión del halo cD. De este modo, se puede suponer que estos núcleos están atados a las galaxias centrales y que podemos por lo tanto estimar las masas dinámicas en los núcleos, lo cual incluirá cualquier material obscuro en la vecindad inmediata de las cD's.

ABSTRACT. Velocity dispersions and virial masses are presented for the clusters Sersic40/6 and A496, based on previously published and recently obtained data. We discuss the presence in both clusters of a tight group of faint members surrounding the central galaxies, forming density cusps. However, in contrast to other examples of clusters, as in A2029, the core galaxies have much smaller dispersions than the overall clusters, with values similar to the cD halo dispersion. Thus, it can be assumed these cores are bound to the central galaxies and we can then derive an estimate of the dynamical masses in the cores, which will include any dark matter in the immediate vicinity of the cD's.

Key words: **CLUSTERS-GALAXIES – GALAXIES-DYNAMICS**

I. INTRODUCTION

The cluster A496 has the second strongest detected cooling flow in its center (Nulsen *et al.* 1982). Previous optical studies of the velocity field of A496 were carried out by Quintana *et al.* (1985) (32 galaxy velocities); Proust *et al.* (1987) (15 velocities, 2 new members); and Hu *et al.* (1985) (velocities of the central galaxy and 3 other very close companions). Moreover, Tonry (1985) measured the velocities and internal dispersions of the cD and of a close satellite and Green *et al.* (1988) obtained a further 3 velocities. A total of 40 velocities were reported in the literature.

The cluster Sersic 40/6 was first dynamically studied by Melnick and Quintana (1981a and 1981b) (29 galaxy velocities). Later Materne *et al.* (1982) and Green *et al.* (1988) increased the total number of measured galaxy velocities to 33. Furthermore, Carter *et al.* (1985) obtained spectra along the line passing through both nuclei of the dumb-bell in Sersic 40/6. Our results confirm the high velocity dispersion and virial mass of this cluster.

II. OBSERVATIONS AND RESULTS

The spectroscopic observations were made at the 100" du Pont telescope of the Las Campanas Observatory with the Boller & Chivens spectrograph and the Shectograph detector. Reductions and redshifts measurements were carried out with the IRAF image processing system (typical rms error of the mean radial velocity:

30-40 kms^{-1}). Details of the observations are reported elsewhere (Quintana and Ramírez, 1989). A total of 72 and 84 galaxy velocities were used for A496 and Sersic 40/6, respectively. The cluster velocity dispersions, with corresponding 68% confidence limits, were calculated following the precepts of Danese *et al.* (1980). Dynamical masses of the clusters were calculated using mass estimators for self-gravitating systems of equal mass bodies following Heisler *et al.* (1985).

The estimators are MV: virial mass, MP:projected mass, MA: average mass and MM: median mass (assuming isotropic orbits), given by the formulas:

$$MV = \frac{3\pi N}{2G} \cdot \frac{\sum_i v_{zi}^2}{\sum_{i<j} \frac{1}{R_{ij}}}$$

$$MP = \frac{f_{MP}}{G(N-1.5)} \cdot \sum_i v_{zi}^2 R_i$$

$$MA = \frac{2 f_{MA}}{GN(N-1)} \cdot \sum_{i<j} (v_{zi} - v_{zj})^2 R_{ij}$$

$$MM = \frac{f_{MM}}{G} \cdot med_{ij}[(v_{zi} - v_{zj})^2 R_{ij}]$$

where v and R are relative to galaxy centroid and $f_{MP} = 32/\pi$, $f_{MA} = 2.8$ and $f_{MM} = 6.5$.

An extensive analysis was done using all estimators in simulated galaxy clusters. The conclusions show that all estimators are very stables and have excelent correlation between them, as shown when applied to groups by Heisler *et al.* Simulations of more than 10,000 clusters of 20, 80 and 320 galaxies, fitted by a King (1966) model, allowed us to evaluate the expected errors of each estimator.

In the core region the virial mass was estimated assuming that the faint galaxies form a system of test particles orbiting around the massive object (Bachall and Tremaine, 1981), calculating virial mass:

$$MV = \frac{3\pi}{2G} \cdot \frac{\sum_i v_{zi}^2}{\sum_i \frac{1}{R_i}}$$

and projected mass

$$MP = \frac{16}{\pi G N} \cdot \sum_i v_{zi}^2 R_i$$

where v and R are relative to the central galaxy. Results are shown in Table I, assuming $H_o = 50$ kms^{-1}Mpc^{-1}.

Sersic 40/6

For Sersic 40/6 we found a total mass of order (3 ± 1) x 10^{15} $M_\odot$. The high cluster dispersion is confirmed, as we found 1440 kms^{-1} for 84 member galaxies. If we consider the central galaxies: the dumb-bell and its ten closest neighbors, we find that the velocity dispersion of this group is significantly lower than the overall cluster value. The dumb-bell mean velocity of 17,853 kms^{-1} has a 99% of probability to be coincident with the core mean velocity (Quintana and Lawrie, 1982). Materne *et al.* (1982) analysed the number density profile and fitted the radial distribution with a two-component model because the isothermal model was not good inside 4 arcmin from the cluster center (the same region containing the galaxies with low velocity dispersion value). This density cusp plus its low dispersion strongly suggest the presence at the center of this cluster of a dynamically bound subsystem, a dynamical cusp.

All mass determinations indicate that the db mass (including its halo) is at the very top of cD galaxy masses. The key question is whether the dumb-bell galaxy and its surrounding group really forms a relaxed bound system, as the evidence presented suggests. Further velocities need to be obtained in the core and cluster to ascertain the detailed velocity field.

TABLE I. Mean velocities, velocity dispersions and dynamical masses (H_o = 50 kms^{-1}Mpc^{-1}).

	Sersic 40/6			A496		
Parameter	cluster	core	db	cluster	core	cD
N	84	12	2	70	11	1
<v> (kms^{-1})	17359±167	17432±219	17321±90	9649±78	9647±65	9648±20
σ_v (kms^{-1})	1440(126,-110)	684(208,-109)		619(61,-47)	188(63,-34)	
σ_{int} (kms^{-1})			halo nucleus 562±77 236±56 (W) 616±98 327±34 (E)			275±12
MV^a (10^{14}M$_\odot$)	34.8±5.2	1.4±0.8		5.6±1.0	0.06±0.05	
MP^a (10^{14}M$_\odot$)	48.0±7.2	2.3±1.4		7.8±1.2	0.14±0.09	
MA^a (10^{14}M$_\odot$)	38.3±5.7	1.5±0.8		6.2±1.1	0.09±0.05	
MM^a (10^{14}M$_\odot$)	30.8±6.8	1.6±1.1		5.3±1.1	0.05±0.03	
MV^b (10^{14}M$_\odot$)			0.7±0.1			0.011±0.002
MP^b (10^{14}M$_\odot$)			1.2±0.5			0.021±0.010

N: number of galaxies.
<v>: mean velocity.
σ_v: velocity dispersion calculated with N particles.
σ_{int}: internal velocity dispersion of each db or cD. References - Sersic 40/6: Carter *et al* (1985), A496: Tonry (1985).
MV: virial mass.
MP: projected mass.
MA: average mass.
MM: median mass.
[a] Based on equal mass bodies calculations, assumes isotropic orbits (Heisler *et al.* 1985).
[b] Based on test particles orbiting a massive object (db or cD), assumes isotropic orbits (Bahcall and Tremaine, 1981). Measures the inner part of the core, with 10 galaxies in both cases.

; will be interesting to investigate with numerical models the influence that the tidal effects of the group ave in heating up the dumb-bell halo. Analysis considering the dumb-bell system rotation or the merging arameters of the group are necesary to clarify these matters, as the halo shows typical distortions seen in ther double elliptical dumb-bell systems.

'he cluster total mass is of order (5.5 ± 1) x 10^{14} M$_\odot$, corresponding to the global velocity dispersion of 620 ms^{-1}. In the central regions this dispersion decreases continuously as closer galaxies to the cD are considered. Vithin the internal 5 arcmin lie the 10 closest galaxies forming the inner core with a velocity dispersion of nly 188 kms^{-1}; the dispersion of 14 galaxies is 303 (+85,-50) kms^{-1} and increases to 671 (+112,-75) kms^{-1} or galaxies within 10 arcmin. The inner core has a 99% of probability that the cD's velocity coincides with he center of the histogram gaussian fit. The same probability is found when all cluster galaxy velocities are onsidered, showing the cD is at the dynamical center. The dynamical mass of the cluster and core, using he estimators listed, and the later calculated under the assumptions that is bound to the cD, are given in 'able I.

n both cD dominated clusters, we have continuity in the range of dispersions between the cD halo and core alaxies and we can argue that core galaxies are bound to the cD. The continuity of velocity dispersion values n the stellar component and satellite galaxies of the cD can be taken as direct evidence in support of the annibalism theory of formation of cD galaxies. This is sharp contrast to the situation found in A2029 by Bower *et al.* (1988) and A2271 and A2634 (Bothun and Schombert, 1988), where no cores were identified round that cluster cD, but in agreement to A2589 (Bothun and Schombert, 1988) which shows a similar ore.

The cD in A496 could have been partly formed by cooling flow mass deposition as we obtained an upper limit for the cD mass of only 1.5 x 10^{12} $M_\odot$. However, the high 7 x 10^{13} $M_\odot$ mass of the dumb-bell in Sersic 40/6 would have required an extremely high cooling flow rate of mass inflow. The presence of large cD haloes and cluster cores, having similar velocity dispersions and dynamically dominating the regions that control the cooling flow, could have strong influence on the magnitude and evolution of these flows. Models of cooling flows (Thomas *et al.* 1987) would need to take into account the formation of such subsystems of galaxies bound to cD's.

A more detailed analysis, including photometric data for both clusters, will be reported in a future work.

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