

Understanding low and high velocity dispersion compact groups

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Abstract.

A galaxy system must have a minimum velocity dispersion for its mass to be greater than the sum of the masses of its galaxies. Nearly half of the nearby Hickson compact groups (HCGs) have too low a velocity dispersion in comparison with the rotational velocities of their spiral galaxies and internal velocity dispersions of their early types.

A detailed study of the low velocity dispersion group, HCG 16 — the only known group of late-type galaxies with diffuse intergalactic X-ray emitting hot gas — reveals that half of the diffuse X rays are associated with foreground/background sources and the remaining gas is clumpy and mostly associated with the bright galaxies of the group. The large-scale environment of the group suggests that HCG 16 lies where a cosmological filament falls perpendicularly onto a large-scale sheet.

The observed frequency of compact groups is lower than predicted from the extended Press-Schechter formalism, which also predicts that most $10^{13} M_{\odot}$ objects in the Universe must be fairly old and hence have already coalesced into single objects, reminiscent of elliptical galaxies over-luminous in X-rays that are now being discovered.

Thus, the low survival time of dense groups against the merging instability is no longer a worry for compact groups, as they form in large enough numbers. I show why other arguments against the reality of HCGs no longer hold, partly because of the biases of Hickson's sample.

1. Introduction

Compact groups (hereafter CGs) have been puzzling astronomers for a number of years. How can a few bright galaxies coexist within less than 100 kpc? CGs may have formed early, and have managed to survive the merging instability (Governato et al., 1991; Athanassoula, in these proceedings) or else formed just recently (Hickson, 1982). Alternatively, CGs may not be truly dense in 3D, but caused instead by chance alignments of galaxies along the line of sight within larger loose groups (Mamon, 1986), clusters (Walke & Mamon, 1989) and cosmological filaments (Hernquist et al., 1995, hereafter HKW).

In this contribution, we provide new light on this debate by studying the group velocity dispersions, X-ray, optical and continuum radio emission, and by predicting the frequency of dense groups as compact as Hickson's (1982,

hereafter HCGs) appear to be, using the (Press & Schechter, 1974) cosmological formalism. We conclude on the nature of HCGs.

2. Low velocity dispersion compact groups

For near spherical virialized systems, mass increases with some power (near 3, as is easily shown by combining the virial theorem with a critical mean density for virialization) of the velocity dispersion of virialized systems. One therefore expects that *there must be a minimum velocity dispersion for a virialized galaxy system to be more massive than the sum of the masses of its member galaxies.* Systems near full collapse should have even larger velocity dispersions.

For a tighter constraint, within a given radius R , the sum of the masses of the galaxies *before they got close to one another* must be smaller or equal to the mass within the same radius that the group would have *once it virializes*: $M(R) \geq \sum_j m_j(R)$. Assuming Navarro, Frenk, & White (1995) profiles for groups and halos of galaxies, one can show (Mamon, 1999) that the velocity dispersion σ_v of a given dense group must satisfy:

$$\sigma_v^2 \geq 0.16 \sum_{\text{spirals}} v_{\text{rot}}^2 + 1.0 \sum_{\text{ellipticals}} \sigma_{v,E}^2, \quad (1)$$

where the sums are over the deprojected maximum rotation velocities of spirals and the internal velocity dispersions of ellipticals.

Table 1. Hickson compact group minimum velocity dispersions

| Group | N_S | σ_S^S | N_E | σ_v^E | σ_v^{min} | N | σ_v |
|--------|-------|--------------|-------|--------------|-------------------------|-----|------------|
| HCG 16 | 4 | 151/166 | 0 | — | 151/166 | 4 | 99 |
| HCG 23 | 2 | 123 | 0 | — | 123 | 4 | 180 |
| HCG 33 | 1 | 93 | 0 | — | 93 | 4 | 172 |
| HCG 34 | 1 | 83 | 0 | — | 83 | 4 | 365 |
| HCG 37 | 1 | 93 | 2 | 266 | 282 | 5 | 445 |
| HCG 40 | 3 | 124 | 1 | 199 | 234 | 5 | 160 |
| HCG 44 | 2 | 98 | 1 | 158 | 186 | 4 | 145 |
| HCG 57 | 3 | 166 | 2 | 195 | 256 | 7 | 275 |
| HCG 79 | 1 | 42 | 0 | — | 42 | 4 | 150 |
| HCG 88 | 2 | 118 | 0 | — | 118 | 4 | 24 |
| HCG 89 | 2 | 79 | 0 | — | 79 | 4 | 35 |
| HCG 90 | 3 | 106 | 0 | — | 106 | 4 | 108 |

Columns (2) and (4): number of spirals and ellipticals used; columns (3) and (5): minimum group velocity dispersion (in km s^{-1}) from spirals and from ellipticals; column (6): global minimum group velocity dispersion (km s^{-1}), *i.e.*, $(\sigma_v^{\text{min}})^2 = (\sigma_v^S)^2 + (\sigma_v^E)^2$; column (7): number of accordant redshift galaxies in a group; column (8): measured group velocity dispersion (km s^{-1}).

Although there is still little data on the internal kinematics of HCG galaxies, Table 1 above shows that 5 HCGs out of 12 (HCGs 16, 40, 44, 88 and 89) have abnormally low velocity dispersions, and two others (HCGs 57 and 90) have just marginal velocity dispersions. We expect to measure by chance low velocity dispersions in roughly 20% of dense groups (those with chance tangential velocity vectors). Still, most of the 5 HCGs mentioned above have too low velocity

dispersions to be dense systems near virialization. The simplest alternative is that they are chance alignments within loose groups near turnaround, since at turnaround the velocity dispersion of galaxy systems is expected to be small. Another possibility is that *tidal friction* has been effective in slowing down the galaxies, although this is only expected in much more compact groups near full coalescence (Weinberger et al., 1999; Temporin, in these proceedings).

The two groups with $\sigma_v \simeq \sigma_v^{\min}$ may simply have little intergalactic matter. Given that the internal kinematics data on HCG galaxies is very incomplete (only one group has data for all its members, *i.e.*, $N = N_S + N_E$), some of the groups with high velocity dispersions may turn out to have only marginal velocity dispersions and thus possess little intergalactic matter, while some of the marginal ones may in fact be non-real. In any event, *there seems to be 3 classes of compact groups, following decreasing velocity dispersion: groups with substantial intergalactic matter, groups with little intergalactic matter and chance alignments within loose groups (or clusters or cosmological filaments).*

Finally one may be tempted to secure more precise velocity dispersions by including the galaxies from the environment of HCGs with the data of de Carvalho et al. (1994) and Zabludoff & Mulchaey (1998), but these spectroscopic surveys show that the velocity dispersion usually increases with inclusion of the environment galaxies, and it is not clear that one is not increasingly affected by interlopers.

3. HCG 16

We now focus on HCG 16, the prime example of a low velocity dispersion spiral-rich compact group.

3.1. X-ray emission

The X-ray properties of HCG 16 are controversial and possibly extreme.

In the ROSAT/PSPC X-ray survey of HCGs, by Ponman et al. (1996, hereafter PBEB), HCG 16 was the coldest detected group ($T = 0.30 \pm 0.05$ keV), and there are no other spiral-only compact groups with diffuse X-ray emission (Mulchaey in these proceedings; see also PBEB). Moreover, whereas diffuse X-rays were clearly detected by PBEB, Saracco & Ciliegi (1995) failed to detect such diffuse emission at an upper limit 16 times lower,¹ whereas only a factor 2.3 is attributable to the wider (“bolometric”) energy range in which PBEB compute their luminosities. Given the low temperature that PBEB derive for HCG 16, their derived X-ray luminosity places it two orders of magnitude above their compact group luminosity-temperature relation and roughly a factor of two above the extrapolation of the cluster trend. It thus seems difficult to reconcile HCG 16 with a low temperature extrapolation of regular X-ray emitting compact groups.

¹Given the fluxes measured by Saracco & Ciliegi (1995) for HCG 16 and their adopted value for H_0 , their quoted upper limit for their luminosities were underestimated by a factor 2 for all undetected groups in their Table 4 except HCG 3.

Dos Santos & Mamon (1999) have re-analyzed the ROSAT/PSPC observations of HCG 16 with the hopes of resolving the discrepancy between Saracco & Ciliegi and PEBB and establishing if an irregular morphology is caused by clumpiness or fluctuations in signal-to-noise ratios. Figure 1a below shows the X-ray emission of HCG 16 as contours overlaid on a greyscale map of the group. The emission beyond the galaxies is indeed significant in a few compact regions: around the galaxies a&b, c and d, as well as a few clumpy regions outside the galaxies denoted C1 (comprised of 4 sub-clumps), C4 and C5.

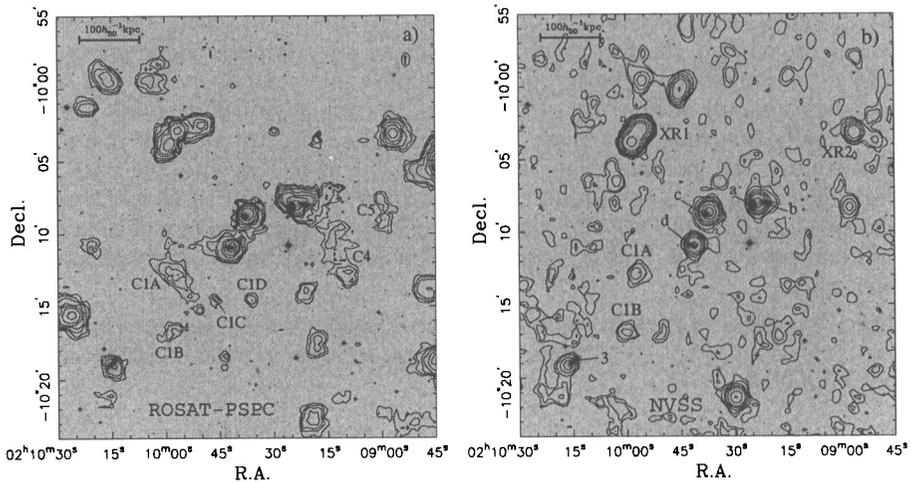


Figure 1. Contour maps of (a): the adaptively smoothed (50 counts per smoothing circle) ROSAT/PSPC X-ray emission, b): the NVSS 20 cm radio emission of HCG 16, both superimposed on an optical DSS image. The five polygonal regions (C1–C5) dividing the emission region in HCG 16 are also shown, as well as the different components of region C1 (C1A, C1B, C1C and C1D, see text).

Figure 1b shows the 20 cm continuum radio contours, measured with the NVSS survey, and illustrates the similarity between the X-ray and 20 cm continuum radio morphologies of HCG 16. A closer look (Dos Santos & Mamon, 1999) reveals that C1A is connected with a radio-galaxy, which turns out to have a redshift (Ribeiro et al., 1996) that clearly places it in the background, C1B is connected with a radio-source, C1C is related to a foreground star, and C5 is connected to a radio-source and to a background group or cluster. This reduces the X-ray luminosity of the diffuse hot gas connected with HCG 16 by 50% to $L_X^{\text{bol}} = 2.3 \times 10^{41} h_{50}^{-2} \text{ erg s}^{-1}$. In the regions without significant X-ray emission, the upper limits to the counts correspond to at most one quarter of the space density of hot gas in the detected regions. Hence, the hot gas in HCG 16 is clumpy.

3.2. Large-scale environment

If HCG 16 is part a cosmological filament viewed nearly end-on (HKW), one should see this filament in its large-scale environment. We have searched with NED a roughly cubical region around HCG 16 of $40 h_{50}^{-1}$ Mpc size. HCG 16 is close enough ($cz = 3899 \text{ km s}^{-1}$) that NED should be fairly complete around it.

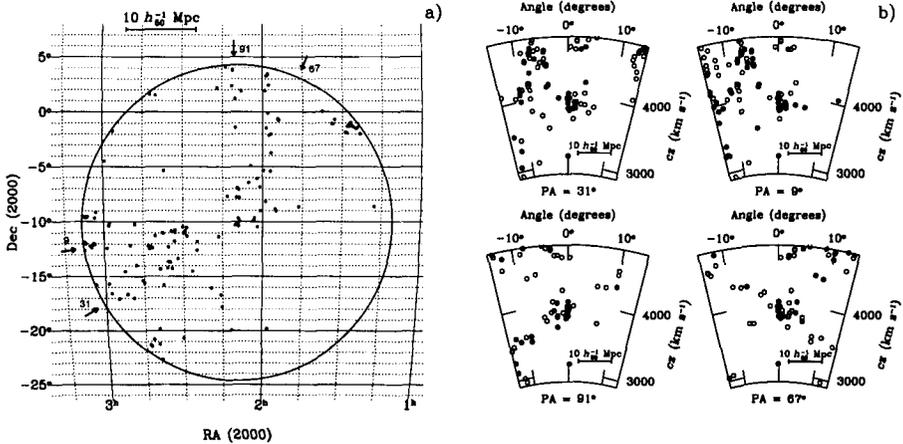


Figure 2. Environment of HCG 16, limited to $cz = 3899 \pm 1000 \text{ km s}^{-1}$. a) Projected environment (HCG 16 in center). b) Line-of-sight environments from wedge diagrams at 4 position angles. *Filled* and *open* symbols refer to galaxies within projected distances of respectively 1 and $5 h_{50}^{-1}$ Mpc from the major axis of the projected wedge. HCG 16 and its 3 neighboring galaxies appear as the *finger of God* of filled symbols at the center of each diagram.

The projected environment of HCG 16 within $\pm 1000 \text{ km s}^{-1}$ from the group distance (Fig. 2a) suggests concentration of galaxies along 4 projection angles. Figure 2b shows the wedge diagrams in each of these position angles, and one can guess a filament at $PA = 31^\circ$, stopping at HCG 16 and a wide sheet visible at $PA = 91^\circ$ and 67° . *There are no filaments closely aligned to the line-of-sight* as would have been favored by HKW.

4. Cosmological predictions on the mass functions of groups

Although loose groups have generally not yet collapsed, one can apply the Press & Schechter (1974, hereafter, PS) formalism to these systems, assuming that when they will collapse, their mass is what we infer today ($t = t_0$). We then obtain

$$N_{LG}(M, t_0) = \int_{t_0}^{2t_0} dt R_{\text{form}}(M, t) , \tag{2}$$

where R_{form} is the rate of formation of structures derived by Kitayama & Suto (1996) from the PS formalism.

N -body simulations suggest that compact groups cannot survive (with at least 4 members) for over $\Delta t = (0.05 - 0.10) t_0$ (Bode et al., 1993; Athanassoula et al., 1997; Athanassoula in these proceedings), the fraction increasing with mass. Assume therefore that compact groups must have undergone their cosmological collapse within that time. One then obtains

$$N_{\text{DG}}(M, t_0) = \int_{t_0 - \Delta t}^{t_0} dt \int_{M/2}^M dM' R_{\text{form}}(M', t) P(M, t_0 | M', t), \quad (3)$$

where P is the probability that a dense group of mass M exists today given that it collapsed with a mass $M' < M$ at time $t < t_0$ (given by Lacey & Cole, 1993).

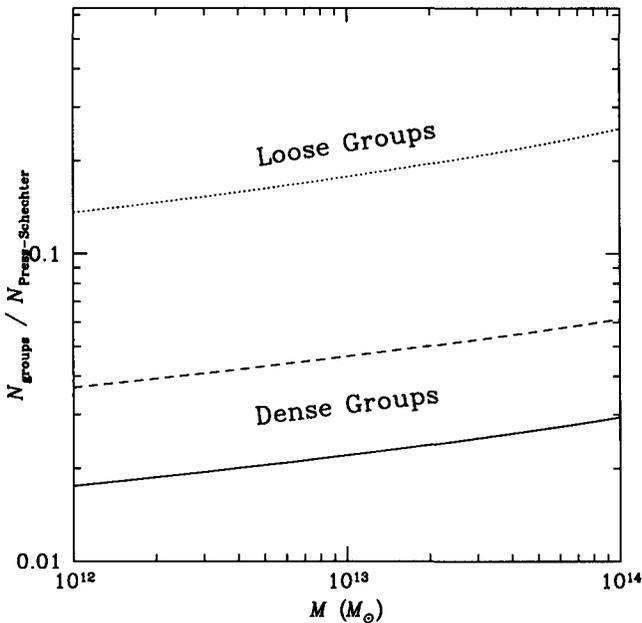


Figure 3. Loose (*thin dotted curve*) and dense (*dashed and solid thick curves*) group mass functions scaled to the Press-Schechter cosmic mass function, derived from extended Press-Schechter theory (eqs.[2] and [3]), assuming a Λ CDM cosmology with $\sigma_8 = 0.9$. *Dashed and solid curves* refer to dense groups collapsing later than 0.9 and $0.95 t_0$, respectively.

Figure 3 shows the resulting loose and dense group mass functions, both normalized to the PS cosmic mass function, for a Λ CDM cosmology (SCDM and OCDM with reasonable values for σ_8 yield roughly similar curves). Massive

dense groups survive longer simply because they have more galaxies, so the figure should be interpreted by adopting the recent collapse (*solid curve*) for the lower mass end and the earlier collapse for the high mass end. The ratio of dense to loose groups then varies with increasing group mass from 12 to 20%. If compact groups are replenished by infalling galaxies (Governato et al., 1996), they collapse even earlier and we would predict even more compact groups today.

In contrast, the estimates of the ratio of HCGs to loose groups range from 0.5–8% (Walke & Mamon, 1989; see also Mamon, 1986, 1992). Comparison of the HCG sample with a similar compact group sample automatically selected from COSMOS/EDSGC galaxies (Prandoni et al., 1994; Iovino in these proceedings) shows that the HCG sample is severely incomplete: inspection of Prandoni et al.'s Fig. 7 suggests that the incompleteness of the HCG sample is a factor of 3 at the bright-end and increasingly worse at fainter magnitudes.

Now if dense groups represent only a few percent of the cosmic mass function, where are the remaining virialized cosmic structures with masses near $10^{13} M_{\odot}$? The answer is simple: *the remaining structures collapsed too early to be visible as compact groups today, and must then be in different stages of the final coalescence of groups.* This includes quartets with massive dominant members (thus failing Hickson's 1982 magnitude concordance criterion: $m - m_1 < 3$), as well as triplets, and binaries. But since the cosmic multiplicity function decreases with increasing galaxy number, one is led to conclude that most of the missing structures are fully coalesced, single galaxies, which harbor large X-ray halos, as discovered by Mulchaey & Zabludoff (1999, see Mulchaey, in these proceedings) and Vikhlinin et al. (1999). Therefore, we predict that *X-ray over-luminous ellipticals should be more common than compact groups.*

5. Why Hickson's compact groups are dense in 3D after all

It is very difficult to decide whether the numerous signatures of galaxy interactions in CGs are proofs of their reality or alternatively simply binary interactions within binary-rich chance alignments of galaxies within the line of sight (Mamon, 1992; Hernquist et al., 1995). The high fraction of HCGs with diffuse X-ray emission (PBEB) should be reduced when one only considers groups with *regular* diffuse X-rays (§ 3.1). However, the combination of HI (Verdes-Montenegro, in these proceedings) and optical (Mendes de Oliveira, in these proceedings) data on HCGs suggests that most of these are real interacting systems. In view of this beautiful data, the arguments spelled out by Mamon (1986) against the reality of HCGs must be reappraised.

The large predicted cosmic rate of production of dense groups (§ 4 above) implies that the low survival time of dense groups is no longer a good argument against the reality of most compact groups. Moreover, the end products of dense groups — isolated bright elliptical galaxies with huge X-ray halos — are now being seen (Mulchaey & Zabludoff, 1999; Vikhlinin et al., 1999).

Whereas mergers tend to increase rapidly the difference in first and second ranked magnitudes, the low $\langle m_2 - m_1 \rangle$ of HCGs (Mamon, 1986, 1987) is simply caused by Hickson's strong bias (Prandoni et al., 1994) against groups with dominant members still satisfying the magnitude concordance criterion. This

bias probably also causes the absence of significant luminosity segregation in comparison with simulated groups (Mamon, 1986, 1987).

The morphology-density relation of HCGs is offset (Mamon, 1986) relative to the cluster / loose group / field morphology-density relation (measured by Postman & Geller, 1984): at a given galaxy number density, HCGs have too many spirals. However, HCGs have too *few* spirals given their velocity dispersions in comparison with the cluster morphology-velocity dispersion trend (PBEB).

There happens to be virtually no low velocity dispersion HCGs beyond $10,000 \text{ km s}^{-1}$, therefore the number of HCGs whose low velocity dispersion (§ 2) suggests they are non-real is limited to roughly 10 out of 69 accordant redshift HCGs with at least 4 members.

Therefore, *there are few arguments left against the reality of HCGs*. However, the samples of automatically defined compact groups (Iovino, in these proceedings) will be much looser on average (given the same compactness criterion as originally used by Hickson), since the HCG sample is severely incomplete for marginally compact groups (Walke & Mamon, 1989; Prandoni et al., 1994), hence one would expect that *automatically selected compact groups will be more prone to chance alignments* (see Walke & Mamon, 1989).

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