HYPERGALAXIES

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"Galaxies are like people: they depend on both genetics and environment" (van den Bergh 1975)

1. INTRODUCTION

Studies of the dynamics of small aggregates of galaxies have shown that these systems possess extensive and massive coronas (Einasto 1972, Ostriker and Peebles 1973, Einasto, Kaasik and Saar 1974, Ostriker, Peebles and Yahil 1974). The dimensions of massive coronas are so large that all close companion galaxies as well as high-velocity hydrogen clouds are situated in their interiors. In other words if massive coronas were considered extensions of galaxies then giant galaxies with their coronas would form in fact compact groups of galaxies. It is evident that it is not suitable to identify a galaxy with a group of galaxies. For this reason following the suggestion of Chernin we consider galaxies with their massive coronas and all objects moving in the coronas as distinct building blocks of the Universe as hypergalaxies (Einasto et al. 1974a). Hypergalaxies form compact subgroups in groups of galaxies. Examples of hypergalaxies are subcondensations of galaxies and extragalactic matter around the Galaxy and the Andromeda galaxy in the Local Group.

In the following we use the term galaxy for the galaxy proper, i.e. its visible populations without the massive corona. The term group of galaxies is used in the conventional sense to designate a density enhancement in the Universe smaller than clusters of galaxies. In the case of isolated hypergalaxies, there is no real difference between hypergalaxies and groups. Many hypergalaxies form multiple systems - these aggregates of hypergalaxies are conventional groups of galaxies.

Studies of the spatial distribution of nearby galaxies indicate that most galaxies form aggregates of varying richness from poor groups to rich clusters of galaxies (de Vaucouleurs 1971). This result has

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been confirmed by a statistical study conducted by Soneira and Peebles (1977). They conclude that if a true field component of galaxies does exist, it amounts to substantially less than 18% in a catalogue selected to a limiting apparent magnitude. The majority of known groups of galaxies are located in the disks of superclusters. The mean distance between the centres of the groups is 3-10 Mpc, and their mean outer radius $\sim$ 1 Mpc. Thus groups are well separated from each other.

2. SPATIAL STRUCTURE OF HYPERGALAXIES

The distribution of galaxies in hypergalaxies is not random. Bright companion galaxies together with the main galaxy usually form a multiplet in the centre of the aggregate. Examples are our Galaxy and the Magellanic Clouds, the Andromeda galaxy and its two elliptical companions M 32 and NGC 205, M 81 and NGC 3077. Dwarf galaxies of very low luminosity form a cloud of much larger radius around the main galaxy (Einasto et al. 1974a).

The structure of a hypergalaxy can be studied in detail in the case of our Hypergalaxy. As demonstrated by Lynden-Bell (1976), Kunkel and Demers (1976), Einasto et al. (1976a) and Haud and Einasto (1977), both optical companions of our Galaxy as well as the high-velocity hydrogen streams are all strongly concentrated towards a great circle. In space all these companions form a flat disk with the Galaxy in its centre. It is remarkable that the disk of the Hypergalaxy forms almost a right angle, 70°, with the main plane of the Galaxy. This is a clear indication that the disk of the hypergalaxy is not a simple continuation of the disk of the main galaxy.

3. DYNAMICS OF HYPERGALAXIES

One of the most remarkable properties of hypergalaxies as well as of clusters of galaxies is a very close dynamical link between the main galaxy and the surrounding aggregate of galaxies. In studying the mass distribution in hypergalaxies Einasto et al. (1974a, 1975) noted that the cumulative mass distribution, calculated from the motion of companion galaxies, forms a smooth extrapolation of the mass distribution of the main galaxies, calculated from the inner motions in these galaxies. Since $M(R) \alpha \sigma_r^2(R) R \alpha R$, this relationship means that the velocity dispersion of stars in the main galaxies is approximately equal to the dispersion of relative velocities of companion galaxies. A more detailed study (Einasto et al. 1976b) indicated that this equality is valid over the whole observed range of velocity dispersions from 80 km s^{-1}in dwarf hypergalaxies to 1000 km s^{-1} in rich clusters of galaxies (Figure 1). This equality concerns only the main galaxies of aggregates. All companion galaxies have a smaller internal velocity dispersion.

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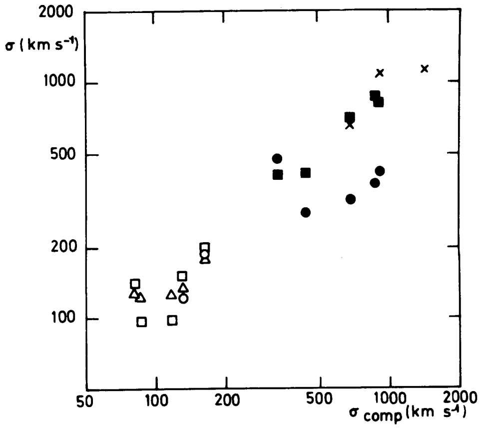

Figure 1. Internal velocity dispersion σ, in galaxies versus external velocity dispersion σ_{comp}, of galaxies for individual hypergalaxies and clusters. Internal velocity dispersions are given for the nuclei of galaxies (circles) for the periphery of galaxies (squares) or are calculated from the maximum rotational velocities of spiral galaxies (triangles) or from X-ray temperatures (crosses). Aggregates with spiral main galaxies are designated by open symbols, aggregates with elliptical main galaxies by filled symbols. Data from Faber and Jackson (1976) and a compilation by Einasto et al. (1976b).

4. MORPHOLOGY AND LUMINOSITY OF GALAXIES IN HYPERGALAXIES

The principal properties of hypergalaxies depend on the luminosity and morphological type of the main galaxy. All aggregates of galaxies with an elliptical main galaxy have a velocity dispersion exceeding 200 km s^{-1}; all aggregates with a spiral main galaxy have a smaller velocity dispersion (Figure 1). The velocity dispersion is proportional to the mean density of the galaxy. Thus this relationship indicates that the density is the principal factor determining both the morphological type of the main galaxy and the properties of the whole aggregate.

In a given hypergalaxy companion galaxies of different morphological types and luminosities are segregated from each other (Einasto et al. 1974b). All elliptical companions of a given luminosity are located inside a sphere of a certain radius, all spiral and irregular companions of a given luminosity are located outside this sphere (Figure 2). The radius of the segregation sphere is smaller the higher is the luminosity of the companions.

5. LUMINOSITY FUNCTION OF HYPERGALAXIES

When studying hypergalaxies, we are interested in luminosity functions of three different kinds: (a) the volume density of hypergalaxies $\Phi(M_O)$, considered as a function of the absolute magnitude of the main galaxy M_O, (b) the differential luminosity function of hypergalaxies $\psi(M')$, considered as function of the magnitude difference $M' = M-M_O$, and (c) the volume density of galaxies $\phi(M)$ (i.e. the conventional luminosity function).

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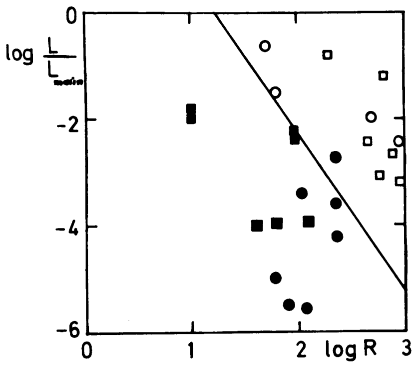

Figure 2. Luminosity L versus distance R from the main galaxy for companions of our Galaxy (circles) and the Andromeda galaxy (squares). Elliptical companions have been designated as filled circles or squares, spiral and irregular companions as open ones. The full line represents the radius of the segregation sphere for companions of different luminosity.

The functions $\Phi(M_o)$ and $\phi(M)$ are defined as the numbers of hypergalaxies or galaxies per volume and per unit interval of absolute magnitude ($M \pm 0.5$). The differential luminosity function of hypergalaxies $\psi(M')$ is defined as the mean number of galaxies in one hypergalaxy per unit magnitude interval ($M' \pm 0.5$). These three functions are mutually connected by the formula (Einasto et al. 1974a)

$$\phi(M) = \int_{-\infty}^{+\infty} \psi(M-M_o)\ \Phi(M_o)\ dM_o \ .$$

Using the first list of hypergalaxies (Einasto et al. 1977) and a preliminary version of the second list of hypergalaxies, Vennik (1977) determined all three functions of interest. The results are given in Figures 3 and 4. We note, first of all, that the conventional luminosity function $\phi(M)$, determined by this non-conventional method, is in good agreement with other recent determinations (Christansen 1975, Kiang 1976).

The luminosity function of hypergalaxies $\Phi(M_o)$ is quite similar to the conventional luminosity function $\phi(M)$. Both functions have a secondary maximum at $M^* = -20.5$, the slope of both functions at high luminosities ($M < M^*$) is much larger than at low luminosities ($M > M^*$). The differential luminosity function of galaxies in hypergalaxies $\psi(M')$ is completely different from both the conventional luminosity function and the luminosity function of hypergalaxies (see Figure 4). It has a maximum at $M' = 0$, caused by the main galaxy. There follows a region in which there are few galaxies. Approximately from $M' = 2.5$ onwards the number of companion galaxies increases, the slope of this section of the function $\psi(M')$ coinciding with the slope of the conventional luminosity function at low luminosities.

Thus the study of hypergalaxies shows that the knee-point in the conventional luminosity function is due to the presence of the corresponding feature in the distribution of hypergalaxies as a function of luminosity. The slope of the high luminosity section of the luminosity

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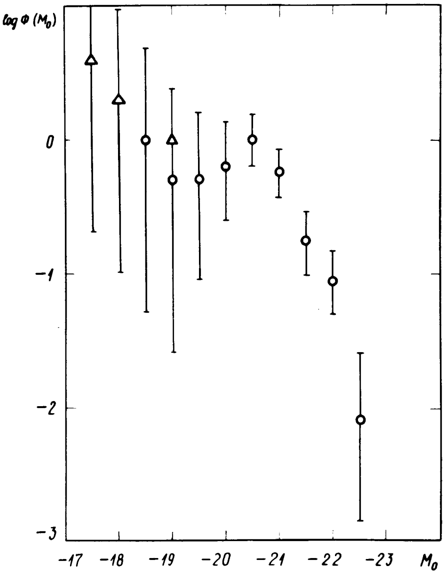

Figure 3. Volume density of hypergalaxies versus the absolute magnitude of the main galaxy M_0. Open circles are numbers of hypergalaxies, per unit volume, calculated from the first two lists of hypergalaxies, triangles - respective numbers of hypergalaxies. 90% confidence limits have been shown.

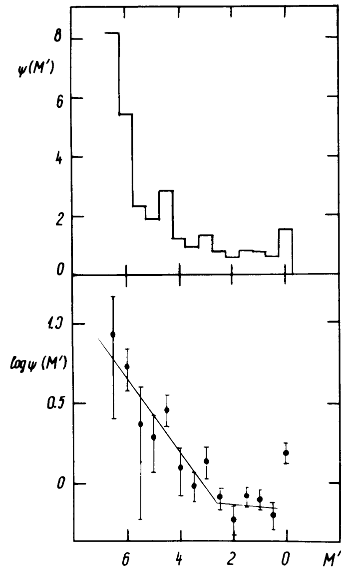

Figure 4. Mean differential luminosity function of hypergalaxies, derived by Vennik (1977) for all nearby hypergalaxies from the first list. Rms error bars have been given.

function is determined by the distribution of hypergalaxies, whereas the slope of the low luminosity section is fixed by the distribution of galaxies in hypergalaxies.

6. THE MASSES AND MASS-TO-LUMINOSITY RATIOS OF HYPERGALAXIES

According to a recent determination by Einasto et al. (1976c), the mean mass-to-luminosity ratio of S-hypergalaxies is about 80 in solar units and that of E-hypergalaxies and clusters of galaxies is about 250.

7. INTERACTION BETWEEN HYPERGALACTIC GAS AND GALAXIES

Hypergalaxies contain some gas. Radio data show the presence of neutral hydrogen clouds. Interferometric data indicate the presence of ionized hydrogen, the mass of ionized hydrogen being approximately equal to the mass of the visible galaxies (Golev and Scheglov 1975). X-ray data show that hot gas, having a temperature about 10^6 K, also surrounds the Galaxy (Field 1975). According to presently available data the gaseous populations fill just the potential well of hypergalaxies associated with their massive coronas and have the same density distribution law $\rho \propto R^{-2}$ (Einasto et al. 1974b). For this reason it is expected that the interaction between gas and galaxies is confined to the whole volume of groups of galaxies.

In hypergalaxies at least three kinds of interaction between hypergalactic gas and galaxies take place. When moving in gaseous coronas of hypergalaxies, companion galaxies are subject to ram pressure and dynamical friction; hypergalactic gas clouds may collide with the main galaxy.

(a) Ram pressure will sweep the gas out of companion galaxies, if the gravitational field of the companion is insufficient to bind the gas. This mechanism may explain the segregation of companion galaxies according to morphological types as suggested by Chernin (Chernin, Einasto and Saar 1976).

(b) Dynamical friction brakes the motion of companion galaxies. This results in a decrease of the major semi-axis of the orbit until the companion is destroyed by tidal forces (Tremaine 1976). The debris of the companion falls onto the main galaxy. This process can increase the mass and luminosity of the main galaxies and of the clusters of galaxies by cosmologically significant amounts (Ostriker and Tremaine 1975, Gunn and Tinsley 1976). Dynamical friction predicts the absence of companions of very low density near giant galaxies, which has been confirmed by observations.

(c) Gas infall to main galaxies has been suggested by Oort (1970) and Quirk and Tinsley (1973) as an important factor in the evolution of galaxies. This infall may account for the very stable chemical composition of the disks of galaxies (Lynden-Bell 1975) or the high metal content of the galactic gas (Ostriker and Thuan 1975).

The concentration of the hypergalactic gas towards a plane perpendicular to the galactic plane may give rise to the formation of the spiral structure (Jaaniste and Saar 1976, 1977a) and to the warping of the distribution of galactic gas (Haud 1977).

8. GALACTIC AND HYPERGALACTIC POPULATIONS

Table 1 presents a summary of the principal galactic and hypergalactic populations according to our present knowledge. Galactic populations are given according to Oort (1958) and Einasto, Jôeveer and Kaasik (1976). The hypergalactic populations of our own Hypergalaxy are also given.

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Table 1

Galactic and hypergalactic populations

Name	ε	a_o (kpc)	M ($M_\odot$)	Z
		Populations of the Galaxy		
Nucleus	0.5	0.005	10^8	0.04
Bulge	0.8	0.4	10^{10}	0.02
Halo (stars, globular clusters)	0.3	2.5	10^{10}	10^{-3}
Disk (stars, galactic clusters)	0.1	7	$6x10^6$	0.02
HI	0.02	6	$3x10^9$	0.02

Name	ε	a_o (kpc)	M (M_o)	Z
		Populations of the Hypergalaxy		
Nucleus (Galaxy)	0.2	4	10^{11}	10^{-3}–0.03
Core (Galaxy+LMC+SMC)		30:	10^{11}	10^{-2}
E-disk (dwarf ellipticals)	0.1	100:	10^9	10^{-4}
S-disk (dwarf irregulars)	0.1	200:	10^9	10^{-4}
HI (Magellanic Stream, Northern Streams)	0.1	60	10^9	
Massive corona	1:	75	10^{12}	
Hot gas	1:	75:	10^{11}:	

We note that there exists a definite analogy between galactic and hypergalactic populations. The main galaxy corresponds to the nucleus of a galaxy, the central core - to the bulge of a galaxy. Galactic and hypergalactic disks have also similar properties, both being quite flat populations with an axial ratio of ~ 0.1. But there also exist important differences. A galactic disk is relatively homogeneous, a hypergalactic disk can be divided into two parts, E-disk and S-disk. An E-disk contains elliptical galaxies which have no gas of their own; an S-disk contains spiral and irregular galaxies containing their own gas. Both populations are spatially segregated. A second difference is in

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the spatial orientation of the planes of symmetry: the hypergalactic disk is inclined to the galactic disk at 70°. The third difference lies in the chemical composition: the metal content of objects in the hypergalactic disk is very low (Hartwick and McClure 1974, Canterna 1975, Norris and Zinn 1975, Kunkel and Demers 1977), whereas in the galactic disk the composition is close to solar composition. Of course, the dimensions are also different.

Globular clusters seem to be a heterogeneous population. Most globular clusters are strongly concentrated towards the galactic centre and form a part of the galactic halo. Globulars with low central concentration (classes XI and XII) have a very low metal content, their distances from the galactic centre are large, and many of them are concentrated towards the hypergalactic plane. Apparently these globulars belong to the hypergalactic E-disk.

The next population is neutral hydrogen. This population is also clearly divided into two parts - galactic and hypergalactic hydrogen.

The list of populations ends with the massive corona and hot gas. Both the massive corona and the hot gas can be considered either as a galactic or as an extragalactic population. Here the dual nature of hypergalaxies is seen very clearly: as indicated in the introduction, hypergalaxies can be equally well defined as giant galaxies with their permanent environs or as groups of galaxies with one concentration centre.

9. HYPERGALAXIES AS GALAXY COMMUNITIES

The bulk of available information suggests that hypergalaxies form permanent aggregates which can be regarded as galaxy communities. Different hypergalactic populations are bound into a single system by the gravitation of the massive corona; these populations are in mutual interaction due to both gravitational and gas dynamical effects.

The presence of a close dynamical link between systems of galaxies and their main galaxies is very difficult to explain if galaxies in hypergalaxies had been born independently. We conclude that galaxies had already been born in hypergalaxies, i.e. galaxy formation is a collective phenomenon. Statistical arguments indicating the collective nature of galaxy formation have already been given by Ambartsumian (1958).

Galaxies can be divided into two classes: main galaxies and companion galaxies.

The principal properties of hypergalaxies are determined by their main galaxies. The density of the main galaxy determines its morphological type as well as the mass and the mass-to-luminosity ratio of the whole hypergalaxy. Dense proto-hypergalaxies evolve into E-systems, less dense proto-hypergalaxies to S-systems. Elliptical galaxies have a smaller angular momentum than spirals. The dependence of the morphological type of the main galaxies on only one parameter - the initial density - shows that in denser regions the momentum is also smaller.

The morphology of companion galaxies seems to be determined by the initial conditions as well as by environment.

The evolution of the main and of the companion galaxies is different because of environmental differences. The main galaxies possess coronas; the companions move in these coronas and may be swept clean of their own gas by the ram pressure of the coronal gas and destroyed by tidal forces. Thus the main galaxies can grow at the expense of their weaker companions. The main galaxies can also grow as a result of the infall of gas. This process may be of importance for the chemical evolution of galaxies, as well as for the formation of the spiral structure and the bending of the large scale distribution of galactic gas.

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DISCUSSION

Ostriker: Do you find any correlation between the luminosity and the separation of companion dwarf galaxies? In a recent study E. Turner and I found an inverse correlation in his sample, that is, the more luminous galaxies tend to be further away.

Einasto: In our analysis, we found the opposite result: bright galaxies are strongly concentrated towards the main galaxy. To resolve this discrepancy, original data should be compared.

Kiang: The Local Group has 2 hypergalaxies -
(1) How many has the Coma Cluster?
(2) How many hypergalaxies are there in Stephen's Quartet or Quintet?
(3) How many hypergalaxies have you discovered?

Einasto: (1) In rich clusters hypergalaxies have probably been destroyed by close encounters.
(2) Stephen's Quartet is probably the core of a hypergalaxy.
(3) We have studied hypergalaxies in the northern hemisphere; our first catalogue contains 60 objects.

Gursky: I am puzzled by your requirement that there should be an enveloping corona around a hypergalaxy. How does your description change if there is no such corona?

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Einasto: Available kinematic and morphological data strongly suggest the presence of a massive corona. But formally a hypergalaxy can be defined as a compact group of galaxies with one concentration centre.

Morton: What evidence do you have that other hypergalaxies besides our own are distributed in a plane?

Einasto: In the NGC 4631 hypergalaxy, the main galaxy is seen edge-on and has a flat rotation curve at a large distance, indicating the presence of a massive corona. The optical companions have velocities equal to those of the main galaxy. This is to be expected if the hypergalaxy is seen face-on.

Ekers: Westerbork HI observations of NGC 4631 (Weliachew and Sancisi, *Astron. Astrophys.*, in press) do not confirm the observations by Krum and Salpeter that the flat rotation curve extends to a very great distance. Further analysis of the Westerbork data by Sancisi shows that there is no HI at the level claimed for the outer points. Consequently, the flat rotation curve is only established to distances slightly greater than the Holmberg radius.

Einasto: The Westerbork data show that the gas population has a smaller extent. But over the whole observed range the rotation curve is flat according to both the Arecibo and the Westerbork data.

Abell: In some respects, your work seems to me to parallel a similar study by Holmberg of dwarf companions to galaxies. Do you find that your data on the statistics of companion galaxies are in agreement with those of Holmberg?

Einasto: Professor Holmberg studied companions up to a distance of 100 kpc from the main galaxy (for $H = 50$ km s^{-1} Mpc^{-1}). We study companions up to a distance of ~ 1 Mpc. For this reason the results are different. Our study is a natural continuation of Holmberg's work.

Holmberg: In my paper, I showed that one cannot find dwarf companions at distances greater than 50 kpc because they get drowned in the background of unrelated distant galaxies.

Einasto: We do not agree with this conclusion.

Tifft: Is it correct (from your comments on NGC 4631 and the Local Group diagram) that the plane of the hypergalaxy and that of the central galaxy appear to be perpendicular?

Einasto: Yes, that is so.