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CLUSTERING OF FAINT GALAXIES

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RESUMEN. Presentamos una revisión del estado de la investigación sobre cúmulos de galaxias débiles haciendo énfasis en la evolución del agrupamiento de los mismos. Un nuevo catálogo de galaxias débiles en un área de 3 grados^2 cercana al Polo Norte Galáctico y completa a J = 24.5 ha sido compilado. Se encontró que la función de correlación angular en pequeñas escalas tiene una pendiente consistente con las predicciones teóricas (−0.8) y se aplana hacia magnitudes más débiles. Esto último nos da una evidencia preliminar para la evolución del patrón de agrupamiento en tiempos pasados.

ABSTRACT. A review of the state of research on the clustering of faint galaxies, emphasizing the evolution of clustering is presented. A new catalogue of faint galaxies on a 3 deg^2 area near the North Galactic Pole and complete to J = 24.5 has been compiled. We find that the angular correlation function on small scales has a slope consistent with theoretical predictions (−0.8) and flattens towards fainter magnitudes. The latter provides preliminary evidence for evolution of the clustering pattern at large look-back times.

Key words: **CLUSTERS-GALAXIES**

I. INTRODUCTION

The observed clustering pattern at low redshifts may be very different form the one at earlier epochs, say at z=1. The clustering of galaxies may have changed. We hope to discover these changes by looking at the properties of galaxies at high redshifts. Although, we know how galaxies are distributed in our nearby space, there are serious uncertainties in their properties at large look-back times. I will try, in this talk, to show the state of research on the clustering of faint galaxies, enphazising on the evolution of clustering.

The Universe is permanently changing. The aging of its stellar content and the depletion of its gas and dust cause galaxies to undergo changes in their light emitting characteristics and chemical properties. Luminosity and color variations constitute what we call the *"intrinsic"* evolution of galaxies, and structural changes in the distribution of matter in the Universe what we call *"dynamical"* evolution. Galaxies form pairs, groups, clusters and superclusters by reorganizing the matter in these structures. The evolution of the universe since the initial singularity has by no means been a smooth process. Violent phenomena, such as explosions, collisions, and mergers of galaxies, have modified the matter in the Universe. It is not an easy task to find a theory to explain how matter evolved from the primordial soup, 17 billion years ago. However, the *Standard Cosmological model*, based on the Friedmann-Lemaitre-Robertson-Walker theories, is able to offer some answers that lead to the big bang version of creation. This model has become a starting point from which we can begin to understand the Universe. Therefore, it is of fundamental importance to obtain the parameters that determine the standard model, namely $q_o, H_o,$ *and* r_o. (q_o refers to the matter content, H_o gives the distance scale, and r_o is the size scale of structures in the universe.) The task of observational cosmology is to measure these quantities and quantify the intrinsic and dynamical evolution of matter in the Universe.

I will start by summarizing the observational facts; glance at what is observed in the Universe beyond our own galaxy, the *Milky Way*. This will be followed by a short discussion about current cosmological theories for the formation of the Large-scale Structure (LSS hereafter). Then, I'll talk about statistical methods employed to study the LSS, describe existing catalogues, and show the results in connection with fashionable theories.

II. BEYOND THE MILKY WAY

We regard galaxies as the building blocks of the LSS simply because we are unable to detect, with the present technology other type of matter. Even though we are almost sure about the existence of dark (undetected) matter in the Universe, there are important theories built on the premise *"What we see is what we get"*. The main issue is: Are galaxies good tracers of matter? Let's assume that they are, and let's try to infer the properties of the LSS by observing galaxies.

Let me give a brief summary of firm, and some not so firm, observational evidence for the building blocks of the LSS.

Galaxies – Galaxies occur in a variety of morphological types, from early to late type and from very luminous to dwarf galaxies. A number of them present flat rotation curves suggesting large amounts of dark matter. Furthermore, there is indirect evidence that their stellar and gas content is evolving. We are almost certain that galaxies have at least undergone through one burst of star formation. There are active galaxies such as Seyfert and radio galaxies and galaxies that are in a quiet state, perhaps waiting for the next burst of star formation.

Clusters of galaxies – Redshift surveys of galaxies reveal that most galaxies like to live in clusters, even at high z. Clusters occur in a range of richness, from a few galaxies to clusters with thousands of members. They occur in a range of smoothness. Some look well relaxed and virialized while other show a clumpy struture suggesting a state of collapse (specialy in high z clusters). Galaxies in clusters are segregated. Early type galaxies tend live near the center while late type mostly form the haloes of clusters. Spiral galaxies outnumber by an order of magnitude elliptical galaxies in the outskirts of clusters. In spite of the fact that observations have been unable to detect significant amounts of intracluster gas, dynamical studies show the existence of large quantities of dark matter in clusters. It has been observed a higher fraction of blue galaxies in clusters at large redshifts ($z \approx 0.5$). These may be galaxies in an early stage of evolution (stellar aging) or galaxies undergoing bursts of star formation.

Superclusters and Voids On a larger scale, perhaps up to 100 h^{-1} Mpc, structure is still observed. Galaxies and clusters of galaxies tend to be in filaments or shells surrounding large regions completely devoid of galaxies. Rich clusters tend to exist at the intersection of shells.

Hubble flow Expansion of the universe at a rate given today by the Hubble contant

$$V = H_o R \qquad (1)$$

where V is the recessional velocity, R is the distance to the galaxy and H_o is the Hubble constant, $50 \leq H_o \leq 100$ $km/sec/Mpc$.

The 2.7 ^oK **Background Radiation** –It is remarkable the uniformity of this radiation. The current levels are:

$\Delta T/T \leq 2 \times 10^{-5}$ *on scales* $\sim 5'$ and

$\Delta T/T \leq 5 \times 10^{-5}$ *on scales* $\sim 1^o \Rightarrow 100h^{-1} Mpc$

Fluctuations in the microwave backgorund will have been imprinted at z $\sim$ 1000 when photons and plasma decoupled. The limits that we observe today are a good test to probe any density fluctuations at that time on scales of 1^o. At smaller scales things may be a little different, reionization of the gas may have modified the spectrum of fluctuations considerably.

Large-Scale Streaming Motions –Recent observations indicate a bulk flow on scales of $60h^{-1}Mpc$ of about 600 km/sec with respect to the microwave backgound on a sample of elliptical galaxies. A two-component flow model has been fit to the data. The small component is due to Virgo, which induces a velocity at the Local Group of 250 km/sec, and a main component which is due to a more massive object *(The Great Attractor, GA)* located at $v \approx 4350$ km/sec induces a velocity of 570 km/sec. This component falls away from the GA roughly as 1/r.

III. MODELS

The cosmological principle states that the Universe is homogeneous and isotropic. However, galaxies (kpc), cluster of galaxies (Mpc), superclusters (tenth of Mpc) are clumpy structures; they are quite inhomogeneous and unisotropic at all scales studied so far. When does the Universe becomes homogeneous? The task of the theoretician is to find a model which on one hand predicts the high degree of inhomogeneity seen in structures, and on the other account for the initial conditions reflected in the uniformity of the Universe at recombination ($z \approx 1000$). If the structures have grown from seed fluctuations in the early Universe, then there must have been some degree of inhomogeneity of the matter (and radiation in adiabatic conditions) at decoupling.

One might think that large-scale structures have had enough time since recombination to reorganize. Had this being the case, the understanding of the origen of structures would be a dream. In fact, even for typical velocities, $\sim 1000\ km/sec$ objects can move only $\sim 10\ h^{-1}Mpc$ within a Hubble time. Therefore, large structures today are fossils of conditions that existed in the early Universe.

Let me now summarize the status of current models for the formation of the LSS. Any cosmological theory must accomodate the following free parameters:

- Ω ($0.2 \leq \Omega \leq 1$) *density parameter.* $\Omega = \rho/\rho_{cri}$ (ρ_{cri} is the density to close Universe).
- Λ ($= 0, \neq 0$) *cosmological constant.*
- Nature of the dark matter. (Baryons, HDM[1] (*e.g.* 30 eV neutrinos, CDM[2] (*e.g.* axions, photinos, etc. KeV), etc.)
- Initial density fluctuations (Gaussian, Non-Gaussian (Cosmic Strings), Adiabatic or Isothermal)
- Effects of non-gravitational processes. (Cosmic Strings, Explosions)
- Matter follows light? - Biasing

A number of models have been proposed. Among them, we mention the ones based on gaussian primordial fluctuations, *e.g.* isothermal (baryons), or adiabatic (HDM, WDM[3],and CDM), the ones based on non-gaussian primordial perturbation spectrum (cosmic strings), and the ones based on an explosive origen of the LSS. In spite the enormous merits of the cosmic string and explosive theories, the gaussian models have been more popular.

In models with gaussian spectrum of fluctuations the evolution of the perturbations depend on the type of particle (*WIMPS*[4]) left after decoupling at $z \approx 1000$. These WIMPS could be hot, warm, or cold depending on their kinetic temperature. Before decoupling, when radiation dominated over the dark matter, the growth of the fluctuations is inhibited when the fluctuations grow larger than the horizon (*ct*). After decoupling, when the matter begins to dominate the size of the horizon marks the characteristic scale of the perturbation. Depending on the kinetic temperature of the WIMPS the decoupling occurs at different times, *i.e.* at different horizon sizes, therefore setting the scale size of the structures. *CDM* decouples earlier than *HDM*; this being the reason why the first structures to form in the CDM scenario are smaller (globular cluster size) than in the HDM model (supercluster size).

I will divide the models in two large groups, *Gaussian and Non-gaussian.* (See reviews in Bahcall (1989), Peebles (1986,1988), Ostriker (1988), White *et.al.* (1987), and Bond (1987)).

III.1 GAUSSIAN FLUCTUATIONS

III.1.a ISOTHERMAL (See Peebles 1986, 1987a,b)

Characteristics:

- Kinetic temperature of baryons is constant.
- Matter and radiatian are not coupled. $\delta\rho_r = 0$
- $\Omega_b \leq 0.2 \rightarrow$ Open Universe.

[1] Hot Dark Matter
[2] Cold Darck Matter
[3] Warm Dark Matter
[4] Weakly Interacting Particles

- White noise spectrum of fluctuations.
- " What you see is what you get "
- *Bottom-up*, first structures to collapse are globular cluster size.

Problems:

- Nucleosymthesis, unable to produce the right amount of Deuterium.
- Isotropy limits on the microwave background, $\Delta T/T \leq 10^{-4}$ on a 5' scale implying the need of larger fluctuations to ever form galaxies.

III.1.b ADIABATIC

Characteristics of the scale-invariant CDM model (see Blumenthal *et.al. 1984):*

- Dark matter in the form of weakly interacting particles (WIMPS).
- Matter and radiation are bound. $\delta\rho_r/\rho_r = (4/3)\ \delta\rho_m/\rho_m$
- Inflation $\rightarrow \Omega = 1$
- Model can fit observations on small scales very well when a biased galaxy formation is assumed. (Galaxies form on peaks of density fluctuations, White *et.al.* 1987).
- Agrees with the galaxy correlation function, flat rotation curves, velocities on small scales, number density of cluster of galaxies.

Problems:

- LSS results. Not enough power on the primordial density fluctuations to account for structure seen on large scales ($> 20\ h^{-1}Mpc$) like clusters of clusters of galaxies and large scale streaming motions.

The *dynamics* of this Universe is determined by elementary collisionless particles in a pure gravitational field having a low dispersion velocity. Masses of the particles (photinos, gravitinos, axions, and leptons) are in the order of GeV. The primordial fluctuations are assumed adiabatic with a constant curvature power spectrum. At large scales the original form of the spectrum remains, however, at small scales after recombination the power spectrum decreases, $\delta_k{}^2 \propto k^n$ $n = 1$ *large scales*, $n = 3$ *small scales*. For the $\delta\rho/\rho <\ 1$ (non-linear) the collapse is hierarchical going from small to large structures.

Characteristics of the HDM model (see Zeldovich *et.al.* 1982):

- Dark matter in the form of neutrinos with masses $\approx$ 30 eV.
- *Top-down.* The first structures to collapse are of the size of superclusters M $\approx 10^{15}\ M_\odot$.
- Reproduces very well the LSS features (pancakes, filaments, voids).

Problems:

- Not enough time (Hubble time $\sim 10^{10} years$), for pancakes to fragment and form galaxies. (solution antibiasing)

Of course, propositions such as hybrid scenarios are always posible; however, one looses the beauty and the elegance by increasing the number of free parameters in the model. A combination of CDM on small scales and HDM on large scales may reproduce the observations. We would have baryonic and non-baryonic dark matter and isothermal and adiabatic density fluctuations operating together.

III.2 NON-GAUSSIAN FLUCTUATIONS

III.2.a COSMIC STRINGS (Turok 1985)

The idea is that space-time dimensions contract to form loops of DM. These loops subsequently break into subloops and matter is accreted to form galaxies and clusters. This process should produce gravity waves. Experiments involving the detection of gravity waves will test the predictions of this model. This is nice way of getting large-scale density fluctuations without producing large thermal fluctuations.

III.2.b EXPLOSIONS (Ostriker and Cowie 1981)

Blast waves produced in explosions of first generation objects (*e.g.* pop 0 stars) push gas into shells that expand, cool, and fragment to form galaxies. Bubbles of galaxies form in this way of typically 10 $h^{-1}Mpc$ in radius. Bubbles intercept each other creating clusters in the intersections. Recent redshift catalogues of galaxies in thin slices greatly resembles what is expected in this scenario. (*e.g.* deLapparent,Geller, and Huchra 1986). The isotropy of the microwave background is preserved since structures are formed after decoupling. $\xi(r)$ can be reproduced quite well.

IV. STATISTICAL ANALYSIS OF THE LSS

Having stablished on one hand the observational constraints, and on the other the theoretical framework for the formation of the LSS, I proceed to define a statistical tool to connect the initial conditions, *i.e.* the power spectrum of initial fluctuations, and the observed large-scale structure.

IV.1 POWER SPECTRUM OF DENSITY FLUCTUATIONS

Consider the density function, (see Peebles 1980)

$$\rho(\mathbf{r},t) = \rho_o[1+\delta(\mathbf{r},t)] \tag{2}$$

where $\rho_o(t)$ is the average density of the Universe at time t, and $\delta(\mathbf{r},t)$ represents the density fluctuations. By definition the ensemble average of δ must vanish $<\delta>=0$. The root mean square average is non zero $<|\delta|^2>=(\Delta\rho/\rho)^2$ In the lineal regime, where $\Delta\rho \ll 1$ we take the fourier transform of δ as

$$\delta(\mathbf{r},t) = \int d^3\mathbf{k} e^{i\mathbf{k}\cdot\mathbf{r}}\delta_k \tag{3}$$

where the power spectrum of fluctuations is defined as,

$$P(k) = |\delta_k| \propto k^n, \quad n=0 \; white\ noise, \quad n=1 \; gaussian \tag{4}$$

Note that the phase of the fluctuation is not important and P(k) only depends on k.

IV.2 CORRELATION FUNCTION

The favorite statistical tool to study the LSS is the correlation function of two, three, and four points (Peebles 1980). This function has the great advantage of being simple to calculate and a very stable statistics. On the low side, it is a function that integrates vasts amounts of information, such as galaxy abundances, filaments or morphological types.

Consider points in space; these could be galaxies grouped according to their luminosities or surface brightness or could be clusters of galaxies or even superclusters. Two assumptions are inportant: (i) the distribution of points is a stationary (statistically homogeneous and isotropic) random process, and (ii) that the sample is fair.

The correlation function of one point is defined as the probability of finding a point in a volume dV:

$$dP = n dV \tag{5}$$

where n is the spatial density of points. In an analogous way, the two point correlation function is defined as the joint probability of finding one point in volume dV_1 and a second point in volume dV_2 separated by a distance r.

$$dP = n^2[1 + \xi(r)]dV_1dV_2 \tag{6}$$

If $\xi(r) = 0$ the joint probability of finding points in dV_1 and dV_2 is given by the square of the probability of one point. This case is just a Poisson process where points are distributed randomly in space.

Note that the above definition is analogous to the autocorrelation function of a continuous function $f(x)$.

$$< f(x_1)f(x_2) >=< f >^2 [1 + \xi(x_{12})] \tag{7}$$

For such a function the Fourier transform of the autocorrelation funtion is the power spectrum.

$$\xi(r) = \int d^3\mathbf{k}e^{i\mathbf{k}\cdot\mathbf{r}}P(k) \tag{8}$$

And, since P only depends on k,

$$\xi(r) = 4\pi \int_0^\infty dkk^2P(k)\frac{sin(kr)}{kr} \quad and\ r \equiv |\ \mathbf{r}\ | \tag{9}$$

which becomes the connection between the correlation function, as we measure it today, and the primordial density fluctuations for the linear regime.

It is also posible to define the angular correlation function $\omega(\theta)$ as the joint probability $dP(\theta)$ of finding two points in a two dimensional sample separated by an angle θ and within the solid angles $d\Omega_1$ *and* $d\Omega_2$,

$$dP(\theta) = n^2[1 + \omega(\theta)]d\Omega_1d\Omega_2 \tag{10}$$

where **n** now is the surface number density of points in the sample.

IV.3 HOW DO WE ESTIMATE ξ(r) AND $\omega(\theta)$?

Let's consider each galaxy as a point in Figure 1, the steps are as follow:

1. Use each point as a center, calculate the separations to all other points.
2. Repeat for all points in the sample.
3. Bin the data in separations of constant width in $\Delta log(r)$ *or* $\Delta log(\theta)$ and normalize to the total number of pairs $\Rightarrow N_{gg}(\theta)^5$.

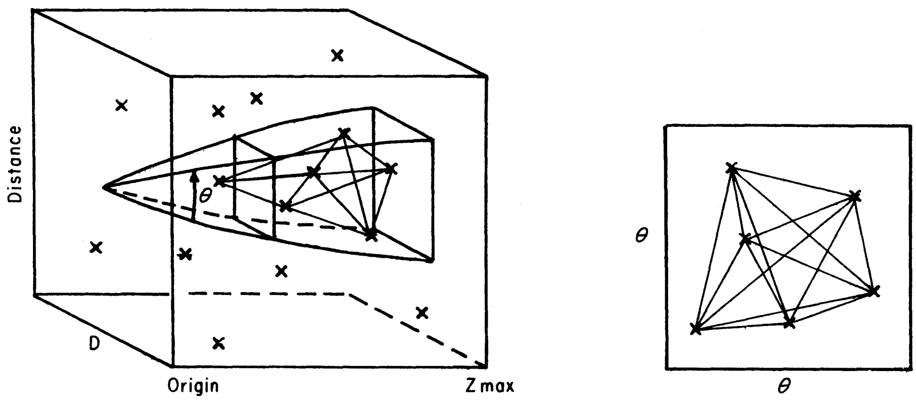

Figure 1: 3-D and 2-D diagrams of the point distribution. Z_m is the maximun redshift allowed in the catalogue: d is proper distance, and θ is the field of view determined by the telescope's scale and aperture.

[5] gg; galaxy-galaxy

4. Repeat the same procedure for a large number of points distributed at random over the same volume or area $\Rightarrow N_{rr}(\theta)$[6].

Thus, the correlation functions will be given by:

$$\omega(\theta) = \frac{N_{gg}(\theta)}{N_{rr}(\theta)} - 1 \text{ and } \xi(r) = \frac{N_{gg}(r)}{N_{rr}(r)} - 1 \tag{11}$$

Three important corrections must to be taken into account:

$\omega_{\mathbf{rg}}(\theta)$. Particular care must be taken to the so called "*edge effects*". A correction $\omega_{rg}(\theta)$ must be included to eliminate effects such as any small amplitude, large-scale gradients across the plates, and/or shape of the field. Normally, these effects are rather small, decreasing the amplitud by $\approx$ 10% at $J \approx 22$ magnitudes. One has to calculate the crosscorrelation between random points, as centers, and objects,

$$\omega_{rg}(\theta) = \frac{N_{rg}(\theta)}{N_{rr}(\theta)} - 1 \tag{12}$$

Integral constraint. For measurements over a bounded region, any power in small scales will result in an estimated $\omega(\theta) < 0$ for large θ. Over the sample the angular correlation function must satisfy:

$$\int \omega(\theta) d\Omega_1 d\Omega_2 = 0 \tag{13}$$

The final estimate of the angular correlation function is,

$$\omega(\theta) = \frac{N_{gg}}{BN_{rr}} - \omega_{rg} - 1 \tag{14}$$

where B is an empirical factor which accounts for the integral constraint. Usually, $B \approx 0.99$.

Contamination by Stars Contamination by stars (or spurious objects), due to faulty star/galaxy discrimination, reduces the amplitud of the correlation function. The slope is unaffected. This is a small effect in samples of faint galaxies since galaxies outnumber stars by a large fraction. For example, at $J = 23$ only 15 % of the objects are stars decreasing to $\leq$ 10 % at $J = 24$.

V. RESULTS

Traditionally, the derivation of $\omega(\theta)$ *or* $\xi(r)$ has been approached in two different ways, on **shallow** and on **deep** surveys of galaxies. These two methods sample clustering properties of the Universe to very different depths.

V.1 SHALLOW SURVEYS

These cover large areas on the sky; some have redshift information allowing a three dimensional study of the clustering.

No Redshift Surveys

- The Abell cataloque (Abell 1958).
- The Zwicky catalogue (Zwicky *et. al.* 1961-1968)
- The Lick (Shane & Wirtanen 1967 galaxy counts). Very old (20 years old) and done by "eye". It was analysed by Groth & Peebles in 1977.
- Edinburgh/Durham UKST plate survey (Heydon-Dumbleton *et.al.* 1988, Collins *et.al.*).
- APM survey from ESO plates (Maddox *et.al.* 1988).

[6] rr; random-random

Redshift Surveys

- CFA redshift survey (deLapparent *et.al.* 1986).
- Southern Redshift survey (da Costa *et.al.* 1988).

The results, in general, are as follow: At small separations it is possible to fit a power law to the correlation function,

$$\xi(r) = (\frac{r_o}{r})^{\gamma} \quad where\ \gamma = 1.77 \quad and\ r_o = 5h^{-1}Mpc \tag{15}$$

$$\omega(\theta) = (\frac{\theta_o}{\theta})^{\delta} \quad where\ \delta = (1-\gamma) \approx 0.8 \tag{16}$$

θ_o depends on the deepness of the sample.

Analysis (and reanalysis) of the Lick survey by Groth & Peebles show a prominent break at angular scales $\approx 2^o.5$ corresponding to a physical size of $\approx 10h^{-1}Mpc$. More recently, Shanks *at.al* (1984) and Stevenson *et.al* (1985) find a similar break on the UKST survey analysis but on smaller scales, $\approx 3h^{-1}Mpc$. The APM survey results are similar to the Lick ones. The Edinburgh/Durham (UKST) survey confirms a break corresponding to $\sim 7h^{-1}Mpc$. Nevertheless, the reality of this break has been challenged by Geller *et.al* in 1984 Their claim is that this feature is just an artifact produced by plate-to-plate zero point variations.

V.2 DEEP SURVEYS

The catalogues are obtained form the analysis of deep 4m class telescope plates. Normally, these surveys go as deep as $J \approx 24$ and cover $\leq 1\ deg^2$ on the sky. No complete redshift information is yet available for any such surveys. Recent determination of the angular correlation function are the following:

- Ellis 1980, from AAT plates ($\leq 0.5\ deg^2$)
- Koo & Szalay 1984, from KPNO 4m plates ($\leq 0.5deg^2$)
- Pritchet & Infante 1986, from CFHT 3.6m plates ($\approx 0.6\ deg^2$)
- Jones *et.al.* 1987, from COSMOS AAT plates ($\leq 2.0\ deg^2$)
- Infante & Pritchet 1989, from CFHT 3.6m plates ($\approx 3.0\ deg^2$)

V.2.a SGP SURVEY

The angular correlation function of faint galaxies was measured down to a limiting magnitude of $J = 23.5$ in a 0.5 deg^2 area near the South Galactic Pole. $\omega(\theta)$ was computed on angular scales ranging form $0^o.002$ to $0^o.5$ (Figure 2).

The main results obtained from this catalogue are as follow. $\omega(\theta) = A_\omega \theta^{-\delta}$ with $\delta = 0.7 - 0.8$ at $J \leq 22.5$ in agreement with Koo & Szalay (1985) survey at similar magnitudes. At $J \geq 23$ we find that δ decreases. This suggest a posible evolution of the clustering with time. Data at $J < 22.5$ and $J < 23.5$ show evidence for a cutoff or break in $\omega(\theta)\ at\ \theta \geq 0^o.2$. This may be the break seen in $\xi(r)\ at\ r = 5 - 9h^{-1}Mpc$. For galaxies at $< z >= 0.3$ a cutoff at $5h^{-1}Mpc$ will occur at a scale $\sim 0^o.3$. However, it occurs at an angular scale comparable to the sample size.

V.2.b NEW NGP SURVEY

Further progress in the study of the galaxy clustering demands deep (*i.e.*$J \leq 23$) catalogues over extended areas of the sky ($\theta \geq 0^o.5$). We have obtained data from *J and F 3.6m CFHT* prime focus plates in an area near the NGP covering $3deg^2$ and to a limiting magnitude of *J=24.5*. The large angular extent and the deepness of the catalogue allow us to sample a volume similar to the existing shallow surveys ($\approx 10^6 Mpc^3$) at a large look-back time ($z \approx 0.7$). The goals of the project are (a) to study the angular correlation function for deep samples of galaxies at large angular separations in order to test for the reality of the break seen in shallow survey at scales $\approx 10Mpc$, and (b) to obtain $\omega(\theta)$ as function of morphological type, color, and surface brighteness of galaxies.

The plates were scanned using the Cambridge APM machine in image and raster mode. We have

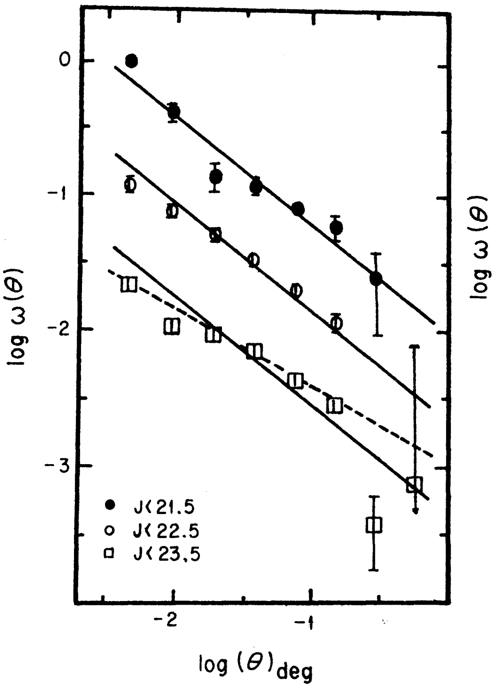

Figure 2: Autocorrelation function of galaxies ω as a function of angular separation θ (from Pritchet and Infante 1986). The points for $J \leq 22.5$ and $J \leq 23.5$ have been shifted by -0.5 and -1.0 in $log(\theta)$ respectively. Note the flattening of the slope at fainter magnitudes.

done the photometry, calibrated the zero points as a function of plate position using CCD photometry of selected fields, obtained ***isophotal and total*** magnitudes, and image moments for a catalogue containing more than 150000 real images. We also scanned a POSS plate of the area to get secondary standards and do precise, to *0.3 arcsec*, astrometry.

Preliminary results (see figure 3) show that the angular correlation function for small separations and $J \leq 23$ follow a power law with a slope of ≈ 0.8 consistent with previous results. For fainter magnitudes the slope decreases significantly, perhaps due to evolution of the clustering pattern in the past. We do not see a break in $\omega(\theta)$ at $\theta \approx 0^o.2$ as in the SGP.

V.3 EVOLUTION OF CLUSTERING

In order to say anything about the evolution of clustering with time, one must have a complete redshift survey to at least z $\approx$ 1. Presently, we have no convincing data to probe the clustering evolution.

In principle, one can imagine three posibilities for the history of clustering: stronger in the past, stable, and stronger now. In co-moving coordinates (no Hubble expansion) these correspond to collapse, stable, and expanding. Let's assume a simple model where the evolution is represented by one parameter, ε,

$$\xi(r) = (\frac{r_o}{r_p})^\gamma \frac{1}{(1+z)^{3+\varepsilon}} \tag{17}$$

where r_p : proper distance and r_o : clustering length. $\varepsilon < 0$: clustering stronger in the past. $\varepsilon = 0$: clustering stable. $\varepsilon > 0$: clustering stronger now.

Attempts to measure the clustering evolution:

- Loh 1988 - from a sample of 1000 galaxies and redshits determined from narrow-band photometry in the range $0.15 < z < 0.85$ and using $r_o = 4.5h^{-1}Mpc$ finds $\varepsilon = -0.5 \pm 0.5$ ***if*** $\Omega = 1$ and

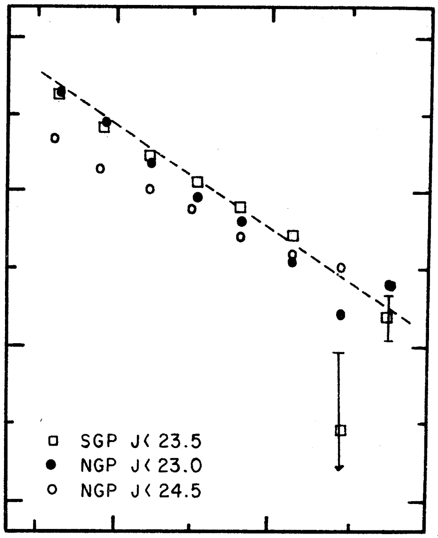

Figure 3: Autocorrelation function of galaxies in the SGP and NGP surveys. Data are binned in θ using a binning width of 0.3 in $log(\theta)$. The dashed line represents a weighted least-square fit to the SGP data with and exponent of $\delta = -0.7$ and $log(A_\omega) = 1.90$.

$\varepsilon = -1.3 \pm 0.5$ *if* $\Omega = 0$. Since from their (m *vs* z) relation they find that $\Omega = 1$, they conclude that the clustering is stable; that clusters have expanded at the same rate as the Universe.

- Phillips *et.al.* 1978 and Jones *et.al.* 1988 have used the angular correlation function to deduce the clustering evolution. Their procedure is similar to the one above but the fit is to the angular correlation function.

$$\omega(\theta) = A_\omega \theta^{-\delta}(1+z)^{-\beta} \quad (18)$$

they find that clustering was stronger in the past.

Problems: The k-corrections and luminosity evolution of galaxies are not well determined. In addition, the evolution of the luminosity function of galaxies, specially at the blue end, is poorly known. These problems are reduced if one does the analysis in the red.

Theories N-body simulations in the CDM framework do predict an increasing in the clustering amplitud. The clustering scale length decreases in co-moving coordinates, therefore the clustering amplitude increases. Clusters are more clustered now than before.

VI. CONCLUDING REMARKS

I have tried in this talk to present a brief summary on some of the ideas and some of the obervational facts that researches are faced while studying the Large-Scale-Structure of the Universe. Observations and theories are presently in a state of constant evolution. Even though there are still fundamental contradictions one is hopeful that the present research is pointing to the right direction.

The "homogeneity problem" is one of the most important issues that must be seriously considered. On one hand, we observe a feature (a break) in the correlation function which is independent of the volume observed. Perhaps it is a transition scale; a scale at which the non-linear turns to the linear regime of structure formation. This may be the point where the Universe becomes homegeneous. On the other hand, in every survey we see fluctuations as large as the sample, like a fractal behaviour where the correlation lenght scales with the survey radius.

What is the scale size of the largest structures in the Universe? Is it possible to reconcile the uniformity of the microwave background radiation with the chaos and clumpiness that is observed today in the Universe? These are two questions that we hope to solve promptly. We need deeper observation and look at higher redshift objects. In particular redshift survey are extremely important in order to sample the Universe in large volumes. This will provide the clues as whether or not the largest structures in the Universe have been reached.

REFERENCES

Abell, G.O., 1958,*Ap.J. Suppl.* **3**:211

Bahcall, N.A., 1988, *Annual Revieus of Astron. and Astrphys.* **26**

Bond, J.R., 1987, *Nearly Normal Galaxies* Proceedings of Santa Cruz Conference 1986, (eds. Faber, S.M. New York:Springer-Verlag).

Blumenthal, G.R., Faber, S.M., Primack, J.R., Rees, M.J., 1984, *Nature /bf 311*:517

daCosta, L.M., Pellegrini,P.S., Sargent,W.L.W., Tonry,J. Davis,M., Meiksin,A.,Latham,D., 1988, *Ap.J.* **327**:544

de Lapparent,V., Kurts,M.J., and Geller,M.J., 1985, *Ap.J.*

de Lapparent,V., Geller,M.J., and Huchra, J. 1986, *Ap.J. Let* **302**:L1

Ellis, R.S., 1980 *Phil. Trans. R. Soc. London* **A296**:355

Geller,M.J., de Lapparent,V., Kurts,M.J., 1984 *Ap.J. Lett.* **287**:L55

Geller,M.J., de Lapparent,V., Kurts,M.J., 1985 *Ap.J. Lett.* **302**:L1

Groth, E.J., and Peebles, P.J.E, 1977 *Ap.J.* **217**:385 GP

Heydon-Dumbleton, N.H., Collins, C.A., MacGillivray, H.T., 1988, *Large-Scale Structures in the Universe Observational and Analytical Methods* Proceedings (eds. Seitter, W.C., Duerbeck, H.W., Tacke, M.).

Infante,L., Pritchet,C.J., and Quintana,H. 1986 *Astron.J.* **91**:217

Jones, L.R., Shanks, T., Fong, R., 1987, *High Redshifts and Primeval Galaxies* (eds. Burgeron, Kunth, Racca-Volmerange, Tran Thanh Van)

Koo, D.C., and Szalay,A.S. 1984 *Ap.J.* **282**:390 KS

Loh, D., 1988, *Large-Scale Structures of the Universe* (eds. Audouze, J., Palletan, M., Szalay, A.)

Maddox, S.J., Efstathiou, G., Loveday, J., 1988, *Large-Scale Structures of the Universe* (eds. Audouze, J., Palletan, M., Szalay, A.)

Ostriker, J.P., and Cowie, L.L., 1981, *Ap.J. Lett.* **243**:L127

Ostriker, J.P., 1988, *Evolution of the Large-Scale Structure*, Proceedings of the IAU Symp. 130, Hungary 1987, (eds. Audouze, J. and Szalay, A. Dordrecht:Reidel)

Peebles, P.J.E., 1980 *The large scale Structure of the Universe.* Princeton University Press.

Peebles, P.J.E., 1986 *The Early Universe*, Proceedings, (eds. Unruch, W.G., Audouze, J., Schramm, D., Dordrecht:Reidel)

Peebles, P.J.E., 1987a, *Ap.J. Lett.* **315**:L73

Peebles, P.J.E., 1987b, *Nature* **327**:210

Peebles, P.J.E., 1988, *Evolution of the Large-Scale Structure*, Proceedings of the IAU Symp. 130, Hungary 1987, (eds. Audouze, J. and Szalay, A. Dordrecht:Reidel)

Phillips,S. Fong,R., and Shanks,T. 1981 *Mon. Not. R. Astron. Soc.* **194**:49 PFS

Pritchet,C.J., and Infante,L. 1986 *Astron.J.* **91**:1

Shane, C.D., Wirtanen, C.A., 1967, *Pub. Lick Obs.* **22**:1

Shanks,T., Fong,R., Ellis,R.S., and McGillivray,H.T. 1980 *Mon. Not. R. Astr. Soc.* **192**:209 SFEM

Shanks,T., Stevenson, P.R.F., Fong,R., McGillivray,H.T. 1984 *Mon. Not. R. Astr. Soc.* **206**:767

Stevenson, P.R.F., Shanks,T. Fong,R., and McGillivray,H.T. 1985 *Mon. Not. R. Astr. Soc.* **213**:953 SSFM

Turok, N., 1985, *Phys. Rev. Letters* **55**:1801

White, S.D.M., Davis, M., Efstathiou, G., Frenk, C.S., 1987, *Nature* **330**:452

Zeldovich, Ya. B., Einasto, J., Shandarin, S.F., 1982, *Nature* **300**:407

Zwicky, F., Herzog, E., Wild, P., Karpowics, M., Kowal, L.T., 1961-1968, *Catalog of Galaxies and Clusters of Galaxies*, 6 volumes, Pasadena: Calif. Inst. of Technology

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