PROFILE OF A KEY PROGRAMME:

A Galaxy Redshift Survey in the South Galactic Pole Region

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Introduction

The determination of the fundamental parameters of the galaxy distribution and of the typical scales of the spatial inhomogeneity of the Universe is an outstanding astrophysical problem. On the one hand, the galaxy distribution observed in the nearby Universe is highly inhomogeneous. On the other hand, the observed isotropy of the Cosmic Microwave Background strongly suggests that the Universe is homogeneous on very large scales. Spatial homogeneity lies at the basis of the "standard" Friedmann-Robertson-Walker cosmological model: *it is of fundamental importance to determine whether and on which scales homogeneity is reached* (Stoger et al., 1987, Scaramella et al., 1991). This information has also great relevance for the reliable determination of the zero-point, "local" (on a cosmological scale) properties of the luminous Universe, such as the galaxy luminosity function and the correlation function of galaxies and systems of galaxies. Well-determined zero-points are critical to several tests of cosmic models.

Our present view of the galaxy distribution within the "local" Universe is mainly the product of the observational efforts of the last decade and is based on several qualitative evidences but on few *reliable* measurements of the galaxy distribution. This picture cannot be confidently extrapolated to the unsurveyed Universe since none of the available galaxy surveys appear to cover a "fair sample" of the Universe yet (see below). Therefore, even the best measurement of the galaxy distribution might change as the size of the sampled Universe increases in depth and/or angular extent. Some important properties of the galaxy distribution have been convincingly demonstrated by the existing observations as, for example:

1. Galaxies are clustered on scales less than 10 h^{-1} Mpc in dynamical systems of different richness (from poor groups to rich clusters). Clusters are, in turn, clustered in superclusters on scales of about 25–30 h^{-1} Mpc (for a review see Bahcall (1988)).

2. Large underdense regions, "voids", have been detected in the redshift maps of the galaxy distribution. We assume here, and in what follows, that redshift maps are good representations of the true three-dimensional spatial distribution on scales larger than 10 h^{-1} Mpc. The sizes of the largest voids detected so far are of the order of 50 h^{-1} Mpc. It is important to note, however, that the largest detected voids are as large as they can be, given the depth and/or the areal coverage of the existing surveys (for a review see Rood, 1990).

3. The "field" galaxies around the voids form structures which are connected and bidimensional. Their typical thickness is about 500 km sec^{-1} (de Lapparent et al., 1991, Ramella et al., 1992).

Furthermore, there are other potentially very exciting observations which still await further confirmation and/or deeper understanding as, for example:

(1) The large-scale peculiar streaming motions of galaxies (i.e. gravitationally induced distortions of the Hubble flow).

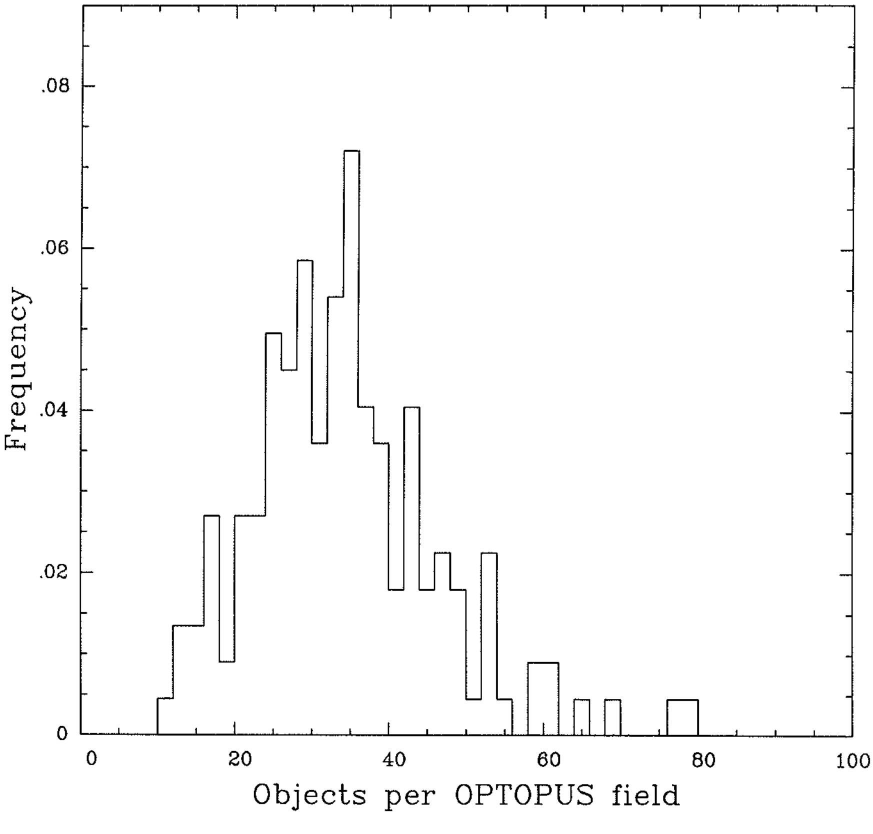

Figure 1: *Histogram of the number of galaxies brighter than* $b_j = 19.4$ *per OPTOPUS field in the area of our survey.*

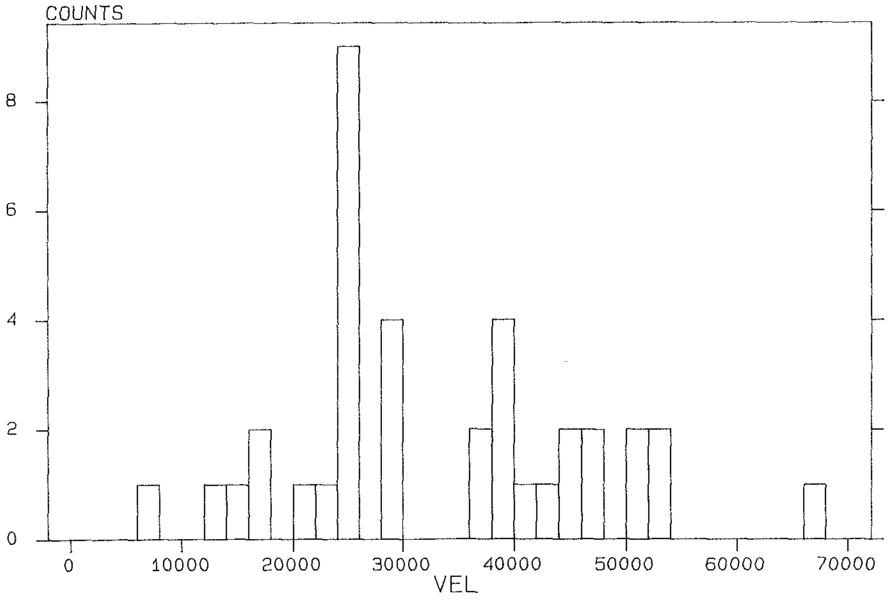

Figure 2: *Histogram of the redshift distribution of the galaxies in one OPTOPUS field.*

Detected outside the Local Supercluster, their origin and interpretation is still largely debated.

(2) The rapid luminosity evolution of galaxies. The amount and the details of the inferred evolution rate depend critically on the shape and normalization of the luminosity function at present times (Colles et al., 1990, Maddox et al., 1990). As already noticed, the local luminosity function of galaxies is rather poorly known.

(3) The detection of periodical peaks in the distribution of galaxies in two deep ($z \geq 0.3$) pencil beam surveys in opposite directions. The period is of the order of 130 h^{-1} Mpc (Broadhurst et al., 1990, BEKS). These beam surveys have, however, such a small areal coverage that the noise induced by the small-scale clustering may significantly reduce the significance of the detection of peaks from which the periodicity is derived.

As already mentioned above, despite the large amount of the existing observational work, we still lack a "fair sample" of the Universe (for a definition of "fair sample", see Peebles, 1973). In fact, the average properties of the observed structures are different even in different surveys of similar depth but covering different areas of the sky. For example, the first "slices" of the CfA extended survey (see Geller, 1989) are dominated by the presence of thin (about 5 h^{-1} Mpc), bidimensional sheets surrounding voids which have typical sizes ranging from 30 to 60 h^{-1} Mpc. On the contrary, a "filament" (the Perseus Supercluster) is the dominating structure detected by the Arecibo survey. This survey is oriented orthogonally with respect to the CfA survey and is of comparable depth (see Haynes and Giovanelli, 1989). The Perseus Supercluster is extended along the right ascension direction throughout the survey, i.e. it is about 50 h^{-1} Mpc long. The other two dimensions, width and thickness, are both roughly 5 h^{-1} Mpc.

Because of the lack of a fair sample, even the values of fundamental quantities such as the *mean number density of galaxies* have so far been determined with significant uncertainties (deLapparent et al., 1989). Therefore, even more uncertain are the results of less direct and more sensitive statistical estimators, such as the two- and three-point correlation functions, the void probability function, the multifractal spectrum and the genus of the isodensity surfaces. For these reasons the possible comparisons between the data and both the linear and non-linear (N-body) predictions of various cosmogonic theories are relatively poor. However, even within the large observational uncertainties, no theory can yet account for *all* the observed features of the galaxy distribution, from the small ($\leq 10\ h^{-1}$ Mpc) to the large ($\gg 10\ h^{-1}$ Mpc) scales. Several scenarios have been investigated to model the formation and evolution of the large-scale structure. Many of them consider dark matter as the main constituent of the Universe and assume a closure value for the mass density ($\Omega = 1$). Since the best discriminative power of most models lies at large scales ($\gg 10\ h^{-1}$ Mpc), observations of a fair sample of the galaxy distribution on these scales would allow us to discriminate among different theories.

The Survey

The main goal of the present survey is to study and constrain the space distribution of galaxies at very large scales ($\geq 100\ h^{-1}$ Mpc) and to address most of the critical aspects of the large-scale structure we discussed above. Our adopted observational strategy meets the following requirements:

(a) it can be completed in a reasonable number of nights and it is well tuned to the existing ESO instrumentation;

(b) it is wide enough to ensure the detection of most structures above the small clustering noise;

(c) it has one angular dimension and a depth which are large enough to detect structures on scales larger than those previously known (50–100 h^{-1} Mpc);

(d) it is characterized by a well-defined selection function which will allow us to measure the galaxy luminosity function, should the survey show that no structures larger than 100 h^{-1} Mpc exist.

We use the multifiber spectrograph (OPTOPUS) presently available at the Cassegrain focus of the 3.6-m ESO telescope at La Silla. In its present configuration, OPTOPUS allows us to obtain spectra for up to about 45 objects (plus 5 sky exposures) simultaneously in a field of 32 arcmin diameter.

Our strategy is to cover a rectangular strip of 23 × 1.6 degrees with three adjacent lines of 46 tangent OPTOPUS fields. We plan to observe all galaxies with $b_j \leq 19.4$ in each field. The total area sampled by these fields is 27 square degrees corresponding to about 70% of the total area of the strip. The strip is centred near the South Galactic Pole, to minimize absorption problems.

We extracted the list of our targets from the Edinburgh-Durham Southern Galaxy Catalogue which is based on digitized scans of UK Schmidt plates made by the Cosmos measuring machine. This catalogue (see Heydon-Dumbleton et al., 1988 for a detailed description) is complete to the limiting magnitude $b_{j,lim} \simeq 20.5$ and is of extremely high quality. Both the algorithm for star-galaxy separation and the constancy from plate to plate of the magnitude scale have been extensively tested. Interplate limiting magnitude variations are smaller than 0.04 magnitudes, and the internal measurement accuracy for individual magnitudes within a plate is of the order of 0.03 magnitudes. It represents therefore an ideal data-base for performing a deep redshift survey.

Figure 1 shows the histogram of the number of galaxies brighter than b_j =

19.4 in 155 OPTOPUS fields. The average number of galaxies is 35 per field and 75 % of the fields contain 20 to 40 galaxies, which is perfectly suitable for OPTOPUS.

With a limiting magnitude $b_{j,lim} = 19.4$, the effective depth of the survey is about 600 h^{-1} Mpc ($z \sim 0.2$). At this depth our strip has an area of about $3.7 \cdot 10^3$ $(h^{-1}\ \mathrm{Mpc})^2$ and includes a volume of about $7.4 \cdot 10^5$ $(h^{-1}\ \mathrm{Mpc})^3$. The total number of redshifts expected in our survey is $\simeq$ 5000.

Scientific Objectives

The main goal of our survey is to determine whether structures like "voids" and "walls" exist on scales larger than those seen in the much shallower surveys like the Arecibo, CfA and SSRS (Da Costa et al., 1988) surveys. Should the few structures seen in the shallow surveys turn out to be fairly typical for the galaxy distribution, then our survey will determine the average properties of these structures. In particular, our survey will provide a very accurate determination of the galaxy luminosity function.

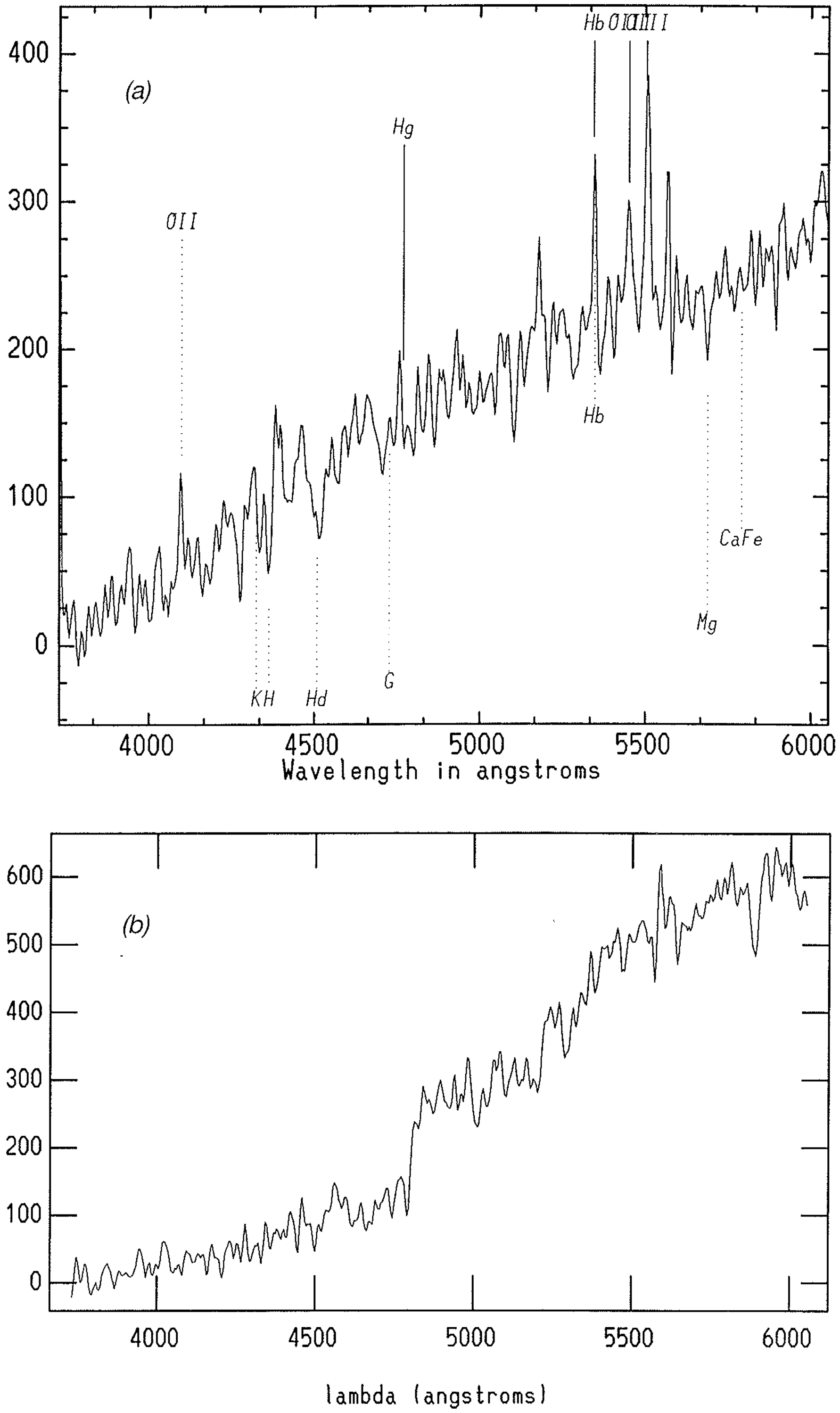

Figure 3, panel (a): *Optopus spectrum of a galaxy of* $b_j = 19.3$ *at* $z = 0.10$*; panel (b): Optopus spectrum of a galaxy of* $b_j = 19.0$ $z = 0.208$*.*

(A) The size and the distribution of inhomogeneities on large scales

With respect to the detection of "voids" and "walls" the key characteristics of our survey are the following:

(1) A characteristic depth of $\simeq$ 600 h^{-1} Mpc. This depth is ~ 6 times the depth of both the CfA and Arecibo surveys. While in principle we do not know how large the size of the largest inhomogeneity is, several evidences from other ongoing surveys of galaxies and of clusters of galaxies seem to indicate that homogeneity should be reached on scales $\simeq$ 50–100 h^{-1} Mpc, well within the limit of our survey.

(2) A large extension in one angular coordinate (R.A.). At the depth where our survey has the maximum sensitivity to the structures, $z \simeq 0.15$, the linear dimension corresponding to 23 degrees is $\simeq$ 170 h^{-1} Mpc. This dimension is enough to cover 3 of the largest "voids" of the CfA survey. If our survey, deep rather than wide, will detect structures larger than $\simeq$ 100 h^{-1} Mpc along the line of sight, its angular extension will be very important to discriminate between the peaks of the galaxy distribution corresponding to isolated clusters and those corresponding to the intersection with bidimensional connected structures or "walls".

(3) An extension in the other angular coordinate (DEC) sufficient to eliminate the problem of the small-scale clustering noise affecting the counts of galaxies in each distance bin. At $z \simeq 0.15$ the linear dimension corresponding to the width in declination (1.6 degrees) is $\simeq$ 12 h^{-1} Mpc, larger than the galaxy-galaxy correlation length. As Szalay et al., 1991) point out, the previous condition is necessary for a robust determination of the existence of "walls" in the galaxy distribution along the line of sight. The width of our survey will allow us to determine correctly the geometry of those connected structures which will be elongated in Right Ascension and roughly perpendicular to the line of sight, should they exist.

(4) A complete sampling of all the galaxies, within our limiting magnitude, in each OPTOPUS field. The complete sampling ensures that we will see all the structures with the highest possible signal-to-noise ratio, including those which might be poorly populated by groups

and clusters and still trace the Large-Scale Structure.

In addition, our survey will also be useful for a verification of the interesting and challenging BEKS results mentioned in the introduction. They have interpreted the observed peaks as the intersections of their pencil beam with regularly spaced "walls". Under this interpretation, structures like the Great Wall would be common in the universe and the scale of the "voids" would be of the order of 130 h^{-1} Mpc. However, the reality of the characteristic scale is still debatable and the need of a verification of the BEKS results derives essentially from the small angular size of their beam which is narrower than the "local" correlation length of the galaxies within the walls (Ramella et al., 1992). As a consequence, BEKS might have missed several walls and correspondingly overestimated the scale of the voids. This possibility seems to be supported by recent studies of the spatial distribution of clusters of galaxies in the region of BEKS probes, which show that the peaks strictly coincide with concentrations of clusters (see Chincarini et al., 1992 for discussion). On the other hand, there is no way to know whether all the peaks along their beam really correspond to "walls". In principle, at least some of the peaks might correspond to isolated clusters of galaxies. In this opposite case BEKS would have underestimated the scale of the "voids". Given the depth of our survey, we will cover distance equivalent to at least 5 of the peaks. Thanks to the angular extension of the survey we will be able to distinguish between isolated clusters and "walls", well above the small-scale clustering noise.

(B) Determination of the mean galaxy density and galaxy luminosity function

The existing shallow surveys might have already revealed the largest structures of the galaxy distribution. In this case our survey will represent a "fair sample" of the Universe. Therefore, the choice of a well-defined and controlled selection criterium for our galaxy list, i.e. the magnitude limit, allows us to measure both the shape and the normalization (i.e. the mean galaxy density) of the luminosity function of galaxies. As mentioned above, no survey, up to now, has yielded a "fair sample": the sizes of the inhomogeneities detected are as large as the sizes of the surveys. As a consequence, no truly reliable determination of the luminosity function has been possible yet.

A well-determined luminosity function is the key to several important measurements of the galaxy distribution. For example, the luminosity function must be known in order to measure the two-point correlation function of galaxies directly from magnitude-limited samples. A good determination of the luminosity function is also necessary to detect the effects of the evolution of galaxies on the galaxy counts. In fact galaxy counts at faint magnitudes ($b_j \geq 20$) are significantly higher than the euclidean predictions, while the redshift distribution of the same galaxies is in good agreement with those predictions. Galaxy evolution has been called for in order to explain the apparent paradox. The recent LDSS (Colless et al., 1990) survey, with a limiting magnitude of $b_j \leq 22.5$, does not detect any galaxy with z greater than 0.7 and strongly suggests that the required galaxy evolution must be luminosity dependent: the galaxies at the faint end of the luminosity function should evolve more rapidly than the galaxies at the bright end. Clearly, any evolution of this kind can only be measured if the *local luminosity function and*, in particular, its faint end is very well known.

(C) The statistical properties of clustering at large separations

The reliable determination of the statistical properties of galaxy clustering provides one of the key observational tests for any model aiming to explain the formation of the large-scale structure of the Universe. This is particularly true at large separations ($r \gg 10\,h^{-1}$ Mpc), where the theoretical framework is much simpler, since it is not complicated by the non-linear effects arising on smaller scales. By the use of several statistical methods, this allows one to directly study the properties of primordial density fluctuations (e.g. spectral shape, Guzzo et al., 1991, and possible luminosity segregation effects, Valls-Gabaud et al., 1989), which can powerfully discriminate among different cosmological models.

The First Observing Runs

Observations for the first two observing runs were made during nine nights in September and October 1991; unfortunately bad weather spoiled 5 nights. Some of the fields obtained so far have already been analysed. These data reassure us about the overall feasibility of the project.

Figure 2 shows the redshift distribution of the galaxies in one Optopus field. Figure 3 shows two spectra of galaxies at the magnitude limit of our survey. Two exposures of half an hour each were added. Radial velocities were measured using emission lines (for the object in panel (a) or cross correlating with galaxies of known radial velocity (for the object in panel (b). The overall accuracy of the redshifts so far measured ranges from 30 to 90 kms^{-1}.

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Correction

Two errors have been signalled by D. Hutsemékers in his article on "Unusual Solar Halos Over La Silla" (*The Messenger* No. **66**, page 18):

Figure 3 *should be rotated by 180 degrees* and line 5 in column 3 on page 19 should be read: "Fresnel formulae for reflectance times *the projected area* of the reflecting faces predict the intensity to be nearly constant . . ."