THE LAS CAMPANAS DEEP REDSHIFT SURVEY

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ABSTRACT The Las Campanas Deep Redshift Survey is an attempt to survey a sufficiently large volume of the universe to determine the scale of the largest structures, and obtain a fair sample of the universe. We have, to date, obtained about 12500 spectra of galaxies in the North and South Galactic Polar Caps, to depths of about $600h^{-1}$ Mpc. These data suggest that the scale of the largest structures in the universe is about $100h^{-1}$ Mpc.

INTRODUCTION

The nature and size of the largest structures in the universe are of great cosmological interest. Over the past fifteen years, redshift surveys of galaxies have probed to larger and larger scales. Each successively larger survey has found yet larger structures, and in each case the size of those structures has been close to the largest that could be encompassed by the survey. This steady progression of increasingly large structures challenges the Cosmological Principle, which is not only a tenet dear to most cosmologists, but also a natural inference from the near-isotropy of the Cosmic Background Radiation. One expects, then, that the progression to larger and larger structures must have a limit, and the size of that limit is a datum of fundamental importance.

To reach beyond that limit is of equal importance if one is to understand smaller scale phenomena. Only when one has surveyed a volume larger than the largest structures will one have obtained a fair sample of the universe, and only then will one be able to determine such relatively small-scale characteristics of
the galaxy distribution as the correlation function with any reliability. Surveys of large volumes offer other advantages. The frequencies of rare features, such as large voids, tend to be among the most sensitive discriminants between competing cosmological models, and rare features can only be expected in large volumes.

It has, therefore, been clear for some time that a survey of the distribution of galaxies on scales much larger than those extant was necessary. Such a survey needs to cover a three dimensional volume: one dimensional pencil beams provide too limited and ambiguous a sample of the galaxy distribution to be more than suggestive. Surveying a very large volume is not easy; the galaxies within it are both very numerous and very faint. However, taking advantage of recent advances in instrumentation which make such surveys much more efficient than in the past, we have progressed about half way through a survey which probes a volume which is an order of magnitude larger than any previously studied.

NATURE OF THE SURVEY

We wish to survey the distribution of galaxies in a volume with a radius of at least $500h^{-1}\text{Mpc}$. Such a volume contains about $10^7$ galaxies with $L \geq L^*$, an impossibly large number. Even with some form of sparse sampling, such a survey would have been impossible without the advent of multiobject spectrographs. We are using the fiber-fed spectrograph constructed by Shectman (1992) for the Las Campanas DuPont 2.5m telescope. This system was originally capable of simultaneous spectroscopy of 50 objects, and has recently been upgraded to accommodate 100 fibers which cover the 1.5$^\circ$ square field of the telescope.

Observing efficiency dictates that we define a sample of objects which may be easily observed with such a setup. Our original survey area was a checkerboard, aligned in R.A., consisting of 'bricks', each of which was 3.0$^\circ$ wide and 1.5$^\circ$ high. As the survey progressed, it became clear (thanks partially to the impressive results of the extended CFA survey) that there were many advantages to surveying complete strips, and we are now endeavoring to fill in the missing bricks so as to form strips, 1.5$^\circ$ high, at intervals of 3.0$^\circ$ in declination. The present distribution of fields is illustrated in Fig. 1, in which the rectangular regions are those with photometry, and the shaded regions are those for which we have obtained both photometry and redshifts.

To select galaxies for spectroscopic observation, we have photometered the survey areas by means of overlapping CCD drift scans, obtained with the Swope 1.0 meter telescope at Las Campanas. By scanning at the sidereal rate, we obtain photometry with a resolution of about 1 arc sec and a limiting magnitude fainter than $r_{KC} = 18.5$. Reduction of these data is quite laborious (we have to date obtained over $3 \times 10^9$ pixels of photometry!), but they have the advantage of high photometric accuracy and, more importantly, of high astrometric accuracy, which is essential for the placement of the spectrograph fibers. Observational efficiency demands, again, that the galaxies be within a brightness range such that usable spectra can be obtained for all objects in one exposure. Because of this, we define a sample consisting of galaxies in a magnitude interval, which was typically $16.0 \leq r \leq 17.3$, when we observed with 50 fibers, and is now
15.0 \leq r \leq 17.7. If there are more than 100 (or 50) galaxies within this range, we select a random subset, if less than 100 (or 50), we expand the range. Such a sample definition is unusual; but, in principle, it is no more difficult to handle in the analysis than the more usual magnitude limited sample. In practice, a narrow range of apparent magnitude makes the determination of the selection function more uncertain, but we have a large enough sample to overcome this difficulty.

Fig. 1. Distribution of survey fields in the North (top) and South (bottom) Galactic caps. Filled areas have measured redshifts.

THE DISTRIBUTION OF GALAXIES

To date (October 1992) we have obtained spectra of about 12500 galaxies, and are adding to this total at the rate of about 5000 galaxies per year. We have almost finished 4 declination strips, at -6° and -12° in the North Galactic Cap, and -39° and -42° in the South Galactic Cap. Less than 1/3 of the redshifts have been reduced, and only a preliminary determination of the selection function has been made, but the results so far are quite interesting. Pie diagrams are presented in Fig. 2 for the -6° strip, and for the combined (but incomplete) data in the -39° and -42° strips. The shaded regions are those for which the redshift data has not yet been reduced. For comparison, Fig. 2 also contains the pie diagram from the Extended CFA Survey (Geller & Huchra 1989), plotted to the same scale. Several features of the galaxy distribution are apparent. Our deeper wedges contain structures very similar in form and size to those apparent in the CFA volume. There are voids, filaments, and the suggestion of shells. The contrast of the features appears to be somewhat less than that of the ‘Great Wall’ in the CFA survey. This cannot be due to velocity errors: the uncertainties in velocities are no larger than the size of the dots. In the southern cap, it may be due to the projection effects which result from combining strips
at -39° and -42°, but it may also be true that the Great Wall is an exceptional object.

The most interesting fact is that there do not appear to be any clear structures with scales larger than those found in the CFA strip, despite the much larger size of our sample volume. Without a more quantitative analysis than we have yet performed, we cannot rule out the existence of large, smooth density variations, but a visual inspection suggests that, if present, they must be of rather low amplitude. The large-scale homogeneity of these first two survey regions suggests that we may, at a scale of about 100h⁻¹ Mpc, have reached the limit of structure in the universe.

![Image of galaxy distribution](image)

**Fig. 2.** Distribution of galaxies in the -6° (top) and parts of the -39° and -42° (bottom) slices. Insert- Objects from the Extended CFA Survey with 26.5° < δ < 32.5°.
If true, we can finally calculate the galaxy-galaxy correlation function (and other statistics) with some confidence. All previous 3-dimensional determinations have suffered from the lack of sufficiently large separations to adequately establish $< \rho >$, the cosmic mean density, and from the related uncertainty about whether the survey volume was representative of the universe in the large. Preliminary results are presented in Figures 3. The different symbols are for different galaxy weighting schemes; $\xi_{gg}$ is clearly insensitive to the choice. The error bars were calculated by a brute-force approach which takes into account the correlations within the data.

![Diagram](image_url)

**Fig. 3.** Galaxy-galaxy correlation function, calculated from the data presented in Fig. 2. The dashed line is a $(r/5.5h^{-1}\text{ Mpc})^{-1.8}$ power law.

These results are very preliminary: they use only a fraction of the data, and the estimate of the selection function is very rough. However, the principal consequence of an error in the selection function would be a tilt in $\xi+1$ vs. $r$. The very long baselines which we have, and which are illustrated in Fig. 3, give us an excellent check on such errors. We expect, then, that our final determination of $\xi_{gg}(r)$ will differ from Fig. 3 only in its precision. With this in mind, we can note that the data appear consistent with $\xi_{gg} = (r/5.5h^{-1}\text{ Mpc})^{-1.8}$, which is indicated by the dashed lines in Fig. 3.

We are interested in differences in clustering properties among different types of galaxies: luminous vs. faint, elliptical vs. spiral, red vs. blue. We have obtained galaxy colors by swapping our $r$ photometry for the $b_J$ photometry.
of Maddox et al. (1990). We separate the galaxies into two groups at a color equivalent to $(B-V)_0 \simeq 0.85$. Pie diagrams of the two classes suggest that red and blue galaxies form very similar structures, although the blue galaxies may have a slightly more diffuse distribution. A more quantitative measure of the relative clustering properties is provided by $\xi_{\text{red}}/\xi_{\text{blue}}$ vs. $r$, a preliminary determination of which is presented in Fig. 4. It suggests that red galaxies are more strongly clustered than blue ones, but only on scales less than about $8h^{-1}\text{Mpc}$. On larger scales, $\xi_{\text{blue}} \geq \xi_{\text{red}}$, confirming the visual impression that the large scale distributions are very similar. We are also examining the group properties of our galaxies. Preliminary results are presented by Tucker, elsewhere in this volume.

![Graph showing ratio of $\xi(r)$ of red and blue galaxies.](image)

**Fig. 4.** Ratio of $\xi(r)$ of red and blue galaxies.

**FUTURE DIRECTIONS**

We are now about half way through the intended extent of the survey. We shall probably continue until we have obtained roughly 20000 redshifts. Meanwhile, we intend to begin publishing the results from each strip as we complete it. We are particularly anxious to begin distributing the redshift and photometric data to the community. There are many things which can be done with them, and we shall not be able to do more than a fraction ourselves. The sooner the data are available for others to work on, the better for everyone. We expect the -6° strip to be available in the first half of 1993, and subsequent strips to appear at intervals of 6 months to a year.

**REFERENCES**

DISCUSSION:

Vogeley: Your cone diagrams indicate a lower density contrast for dense structures than we observe in the CfA survey. I suspect that this effect is caused by undersampling of fields which include clusters of galaxies. Do you anticipate a program to measure redshifts for the missing galaxies? This undersampling may also affect the correlation function. How do you correct for variation of the selection function among the beams?

Tucker: It is possible that undersampling may be the cause of the visual impression of lower contrast features in our survey as compared with those in the CfA survey, but I doubt that the undersampling has any strong effect on the correlation function. We correct for the variation of the sampling among the fields by including the fraction of galaxies in a given field as a factor in the Schechter-type selection function of that field. We have no plans to re-observe fields in order to get the “missing” galaxies.

Dekel: Any evidence for a “break” in the correlation function in a log-log plot at 10 $h^{-1}$ Mpc or anywhere beyond?

Tucker: There does not appear to be evidence for a “break” from a power law on scales $\leq 15 - 20$ $h^{-1}$ Mpc, although there is evidence for a “break” in the linear plot on scales not larger than $30 - 40$ $h^{-1}$ Mpc, at which point $\xi(s)$ appears to drop below zero. The Las Campanas data need to be studied in more detail at these scales before a definite conclusion can be drawn.

Wampler: It seems to me that your deeper survey does not show the cell structure as sharply defined as the earlier Harvard Survey. Is your redshift determination less well defined, or do you go to intrinsically fainter galaxies that are filling in the voids?

Tucker: We are not sure as to the cause of this effect at this time. It may be due to the differences between our galaxy selection criteria and those of the CfA Survey, or due to the relative “thinness” of the Las Campanas slices.

Martinez: At what scale the Universe starts to look smooth in your deep sample?

Tucker: Visually, it appears that the Universe starts to look smooth on scales of $\geq 100h^{-1}$ Mpc. We have not yet performed an in-depth quantitative analysis, though.

Martinez: Have you seen any periodicity in the galaxy distribution?

Tucker: For complete slices, no. To do a proper test, we would want to check the redshift distribution for individual “pencil beams” which we have not done at this time.