THE CENTER FOR ASTROPHYSICS REDSHIFT SURVEY

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We have completed the survey of radial velocities for all 2400 galaxies brighter than 14.5 at high galactic latitude in the northern hemisphere. This data set has already been used to derive a good measure of the local mean mass density, describe the overdensity and the dynamics of the local supercluster and to analyse the dynamics of groups and clusters of galaxies within the sample volume.

I. INTRODUCTION

Since the discovery by Hubble of a linear relation between radial velocity or redshift and distance and the development of a theoretical basis for cosmology provided by the universe models of Einstein, De Sitter, Lemaitre, and Friedmann, we observational cosmologists have been mapping the universe with surveys of galaxy redshifts. The goals of most such surveys have been to find the mean local luminosity density of galaxies, measure masses for larger systems of galaxies by applying the virial theorem to "bound" clusters of galaxies, and study large scale cosmological effects by measuring deviations from the redshift-magnitude law of Hubble.

The CfA redshift survey has its origins in the theoretical work of Jim Peebles and his students who described the application of "statistical" virial theorems to galaxy catalogs (eg. Geller and Peebles 1973; Peebles 1976; and Davis, Geller, and Huchra 1978). They found that a local mass density estimate could be derived from accurate measurements of the velocity dispersion for galaxies in the field and the potential energy in galaxy clustering measured by the correlation function. Additional impetus was provided by the work of Turner and Gott who used the Zwicky catalog of galaxies (Zwicky et al. 1961-1968) and very limited velocity information to derive local cosmological parameters (eg. Gott and Turner 1976; Turner and Gott 1975; Turner and Gott 1976). By the mid-1970's, a large number of people realized that a careful, complete and relatively deep survey of galaxy redshifts could be used to derive

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considerably more reliable information about the three-dimensional distribution and relative motions of galaxies in space. Also about this time, a small number of observers realized that such a survey was practicable.

Almost all earlier redshift survey work produced velocities with accuracies worse than 100 km/s, not good enough for studies of the "cosmic" virial theorem or of small galaxy systems with small velocity dispersions. Two major advances in the art of redshift measurements, however, improved the obtainable accuracy to better than 30 km/s. The first is 21-cm spectroscopy, unfortunately applicable only to gas rich galaxies. The second and most important for this work is optical spectroscopy with photon-counting detectors and data reduction via cross-correlation techniques. We can now obtain a redshift for almost any galaxy brighter than 15th magnitude on a 60-inch telescope in 60 minutes or less. With instrumental help from Steve Shectman, the NSF and the Smithsonian Institution plus a guarantee of sufficient telescope time on the 1.5 m on Mt. Hopkins, we started observing in the spring of 1978.

II. THE DATA

The original goal of the survey was to obtain accurate radial velocities for all the galaxies in the Zwicky or Nilson (1973, Zwicky missed a few) catalogs brighter than m_{pg} 14.5, above galactic latitude 40°, and north of declination 0°. We extended this goal to include redshifts for those galaxies below galactic latitude -30° and above declination -2.5°. There are 2400 galaxies in this sample which covers 2.7 steradians (1.83 in the north and 0.83 in the south). This survey was basically completed in April of 1981 - we have spent the last year remeasuring poor or discrepant velocities and starting major extensions of this survey which will be described later.

The catalog of redshifts for the above sample has been accepted for publication of the Ap. J. Supplements (Huchra, et al. 1982). We have measured approximately 62% of the velocities in the catalog, with the remainder coming primarily from 21-cm measurements at Green Bank and Arecibo (19%) and the work of Sandage and Tammann (1981, 5%) and de Vaucouleurs, et al. (1976, 5%). The median quoted error in this catalog is 27 km/s, with only 35 velocities (1.5%) with errors larger than 100 km/s.

At present, a total of approximately 5500 spectra have been taken of approximately 4000 galaxies with both the 1.5 m and the Multiple Mirror Telescope. In addition, we have assembled a computer readable catalog containing these plus most other published galaxy radial velocities. This catalog contains the culled velocities for approximately 9000 galaxies, and covers two "complete" samples - the one described above (hereafter called NZ40) and a whole sky sample of approximately 1300 galaxies to m_p 13.2 very similar to the Revised Shapley-Ames sample.

III. RESULTS

Analyses of the CfA survey have already produced several interesting results. These can be grouped into four catagories: (1) Studies of the local supercluster and its dynamics, (2) the large scale space distribution of galaxies, (3) the identification and dynamics of virialized systems, and (4) the luminosity density of normal and "active" galaxies, I will briefly try to summarize each in the following paragraphs.

With the discovery and "accurate" measurement of the infall of the local group into the local supercluster (see Mould, et al. in this symposium or Aaronson, et al. 1982 for references and a more detailed discussion) we can derive an estimate of the cosmological parameter Ω if we determine the magnitude of the relative overdensity inside our position in the supercluster. The exact determination of the overdensity requires a model for the infall (to place galaxies in their proper positions). With an assumed infall of 250 km/s, the mean internal overdensity is 2.1 and the computed Ω is only 0.2 (Davis and Huchra 1982).

The maps made using the quasi-three-dimensionality of the redshift data show some old friends and some surprises. Figures 1a-c show three cuts in velocity in the northern galactic hemisphere. In fig. 1a we plot all galaxies with velocities between 0 and 3000 km/s. The local supercluster dominates the distribution and Virgo dominates that. The classical Ursa Major and Leo groups are seen as relatively diffuse extensions to Virgo. In fig. 1b we see galaxies between 3000 and 6000 km/s. There is a hint of a long filamentary structure between Abell 1367 and Coma, but extending much further east than Coma itself. There is almost nothing behind Virgo! In fig. 1c, which shows galaxies between 6000 and 10000 km/s, Coma and A1367 stand out, as well as a diffuse group near 14^h and $+10^o$ identified with a Zwicky cluster. There are several structures like this, as well as several empty regions, with scales in excess of 30 Mpc. A comparison of these maps to similar "maps" made from n-body simulations which can reproduce the observed correlation function show no similarity of structure (Davis, et al. 1982).

We have developed several competing algorithms for finding groups of galaxies and clusters in redshift catalogs (Huchra and Geller 1982; Press and Davis 1982). Even with a much deeper survey we can reproduce the classical de Vaucouleurs groups without running into foreground/background confusion problems. All techniques yield roughly the same answer for the mass-to-light ratio for groups - approximately 200 in solar units. With the mean mass density derived below, this also gives a value of Ω of $\simeq$ 0.1. If selection effects are properly taken into account, we do not find any evidence for a correlation between M/L and size for groups and clusters. The measured M/L for Virgo is between 190 and 320. In producing

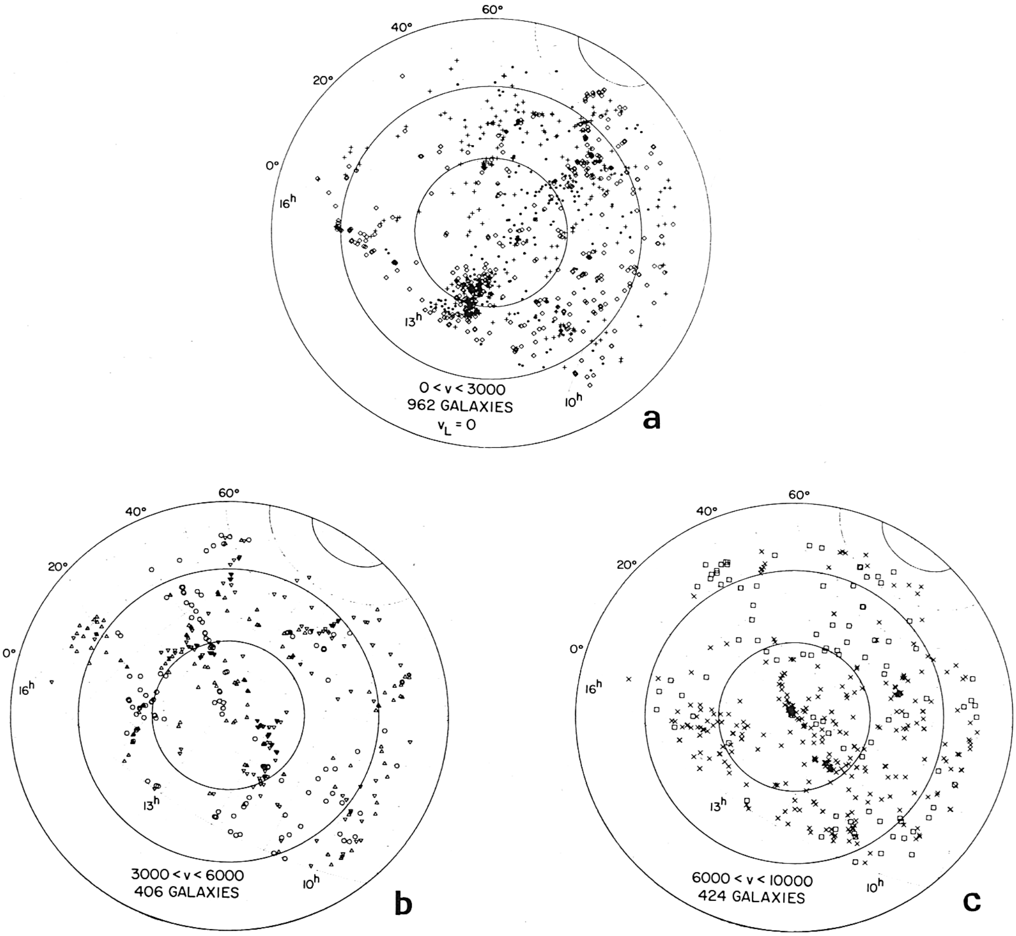

Figure 1. The surface distribution of galaxies with velocities between 0 and 3000 km/s (a), 3000 and 6000 km/s (b), and 6000 and 10000 km/s (c).

density enhancement contours to search for groups, we see both heirarchical and concentric (self similar?) structures (Fig. 2).

Because this sample is deeper and/or contains more galaxies than all previous samples used to find the luminosity density, we can do quite a reasonable job. Parametric and non-parametric techniques give very similar results for the shape of the function - which is relatively poorly fit by a Schechter form. The bright end does not turn over as fast as an exponential, and the faint end has too much curvature. The best Schechter function parameters (assuming H_o = 100 km/s/Mpc and an infall velocity of 250 km/s) are $\alpha = -1.3$, $M^* = -19.4$ and $\phi^* = 12.5 \times 10^{-3}$ Gal/Mpc^3/mag. The luminosity function is still very poorly determined below $M_p = -15.5$ because of the sample statistics and clustering.

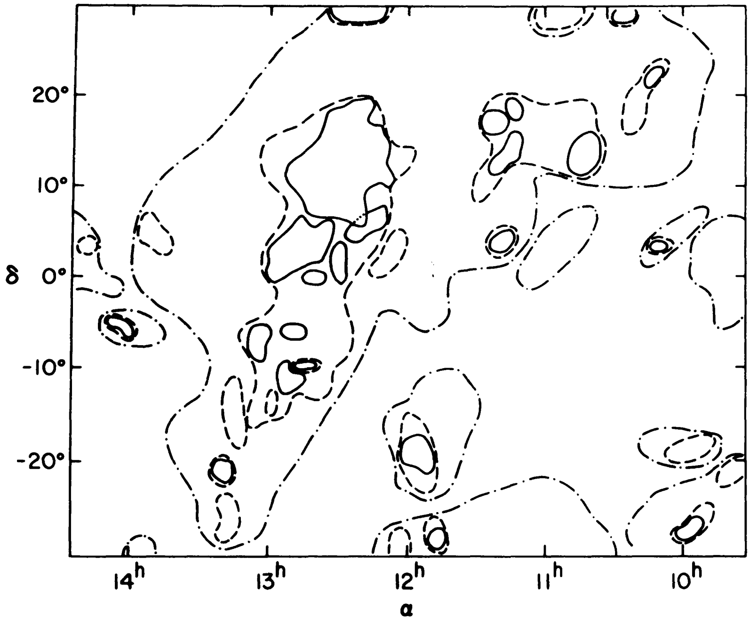

Figure 2. Three dimensional contour plot for groups of galaxies in the Virgo region.

One interesting byproduct of this survey was the discovery of a large number of new Seyfert galaxies (Huchra, Wyatt and Davis 1982). The spectroscopic coverage includes both Hβ - [OIII] and Hα - [NIII] - [SII]. We have doubled the number of bright Seyfert 1 and 2 galaxies, thus almost doubling their estimated space density. This includes finding objects that show broad Hα but no visible broad Hβ - objects that could not have been classified without coverage in the red. Curiously, almost all the absolutely bright galaxies in our sample of 2400 are active. Even more curiously, we found no active nucleus in any galaxy with an absolute magnitude less than -18.5.

IV. FUTURE GOALS

In order to accomplish the original goals of the CfA redshift survey, we have established considerable machinery in terms of computers, detectors, software and staff. We can efficiently and effectively obtain accurate radial velocities for galaxies. As usual, while analysing the CfA survey we have come across a number of problems that can only be answered with more information. As seen in the last section, we see structures on scales almost as large as our sample depth. We are blind to 80% of the sky. Well known nearby clusters show correlated velocity and spatial structure. We still don't know the shape of the luminosity function at the faint end, nor have we accurately discerned the density of "active" galaxies.

We are thus continuing the CfA redshift survey. Our basic goals are to:

(1) Extend the survey to uncovered areas of the sky.
(2) Increase the sample depth in NZ40 to magnitude 15.5.
(3) Perform wide field velocity surveys of nearby clusters.
(4) Complete the sample of high quality digital spectra of the bright galaxies in NZ40.

Our present projects include extending the survey to the southern hemisphere, wide field surveys of Virgo, Pegasus and a few other nearby Abell clusters, and completing the spectroscopic surveys of bright galaxies and remeasuring poor and discrepant redshifts. We are extending the survey into the southern hemisphere using the Vorontsov-Velyaminov catalog and the ESO catalog to select objects. This work is being done in collaboration with a group from Brazil using both Mt. Hopkins and the Brazilian National Observatory 1.5 m with a photon-counting reticon built at CfA. We expect to produce in excess of 1000 high quality redshifts per year. In addition. we already have velocities for 4000 of the approximately 8000 galaxies in NZ40 to magnitude 15.5.

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REFERENCES

Aaronson, M., Huchra, J., Mould, J., Schechter, P., and Tully, R. B.: 1982, Ap. J. 258, 64.
Davis, M., Geller, M., and Huchra, J.: 1978, Ap. J. 221, 1.
Davis, M., Huchra, J., Latham, D., and Tonry, J.: 1982, Ap. J. 253, 423.
Davis, M., and Huchra, J.: 1982, Ap. J. 254, 437.
de Vaucouleurs, G., de Vaucouleurs, A., and Corwin, H.: 1976, Second Reference Catalog of Bright Galaxies, Austin, University of Texas Press.
Geller, M., and Peebles, P. J. E.: 1973, Ap. J. 184, 329.
Gott, J. R. II, and Turner, E.: 1976, Ap. J. 209, 1.
Huchra, J., and Geller, M.: 1982, Ap. J. 257, 423.
Huchra, J., Wyatt, W., and Davis, M.: 1982, A. J. in press.
Nilson, P.: 1973, Uppsala General Catalog of Galaxies, Uppsala Astron. Obs. Annuals V, Vol. 1.
Peebles, P. J. E.: 1976, Ap. J. 205, L109.
Press, W., and Davis, M.: 1982, Ap. J. in press.
Sandage, A., and Tammann, G.: 1981, Revised Shapley-Ames Catalog, Washington, Carnegie Institution of Washington.
Turner, E., and Gott, J. R. III: 1975, Ap. J. 197, L89.
Turner, E., and Gott, J. R. III: 1976, Ap. J. 209, 6.
Zwicky, F., Herzog, E., Wild, P., Karpowicz, M., and Kowal, C.: 1961-1968, Catalog of Galaxies and of Clusters of Galaxies, Vol. 1-6, Pasadena, California Institute of Technology.

DISCUSSION

Wampler: Is the velocity dispersion in the filaments that connect clusters and superclusters lower than the dispersion found in the clusters and superclusters?

Huchra: Yes, it appears to be lower by perhaps a factor of two, which is similar to what is expected in cluster collapse.

I.E. Segal: Your proposed motion toward Virgo, when added to the redshifts of various samples due to Visvanathan, de Vaucouleurs, etc., and represented as complete, generally impairs the (m,z) relation, independently of cosmology, unlike, for example, the CBR-determined motion. That is, for example, the standard deviation of the residuals from the theoretical relation become larger. Can you explain this?

Huchra: You really want to ask this question of Jeremy Martel later today, but a quick answer is that Yahil, Sandage and Tammann find a result substantially in agreement with ours for the Virgo infall by using a technique similar to the one you describe. Note both their result and ours assumes the direction to be radial towards Virgo. Also, the infrared Tully-Fisher technique is much more powerful than the magnitude-redshift relation.

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