NON-UNIFORMITIES IN THE HUBBLE FLOW: RESULTS FROM A SURVEY OF ELLIPTICAL GALAXIES

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ABSTRACT. We have used a new distance estimator for elliptical galaxies to determine the peculiar velocities, with respect to a uniform Hubble flow, of approximately 400 galaxies. The relative distances of five clusters in common with those of Aaronson et al. (1981, 1986), based on the infrared Tully-Fisher relation for spirals, are in good agreement.

We do not see the reflex of the Local Group motion with respect to the microwave background out to recession velocities of 6000 km s^{-1}. Rather, the frame of elliptical galaxies appears to be moving with respect to the microwave background with a velocity of 600 km s^{-1} towards l = 312°, b = +6°. This motion is consistent with a re-analysis of the Rubin et al. (1976) data on the magnitude-diameter relation for ScI galaxies and with the nearby and cluster samples of Aaronson et al. (1982, 1986).

1. INTRODUCTION

We have carried out a survey of elliptical galaxies, measuring both spectroscopic and photometric parameters (Davies et al. 1987, Burstein et al. 1987a), that is 84% complete to B = 13.0 magnitude. Fainter galaxies were studied in clusters and a few in the field. Our aim was to discover the nature of the second parameter in the Faber-Jackson relation and use this to form a more accurate luminosity indicator to determine relative distances that can be compared with those predicted on the basis of a uniform Hubble flow model.

Sandage and Tammann (1984) have suggested that the motion of the Local Group (LG) with respect to the microwave background (MWB), 600 km s^{-1} toward l = 268°, b = +27° (Smoot & Lubin 1979), is caused by the combination of the gravitational pull on the LG towards the center of the Virgo Supercluster, together with that on the Virgo Supercluster towards the next nearest supercluster in Hydra-Centaurus. Aaronson et al. (1986), using the infrared Tully-Fisher relation (IRTF) for spirals, claim to have detected this bulk

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motion of the Local Supercluster towards the microwave anisotropy, in their survey of 10 clusters.

We discuss here the non-Hubble velocities that we derive using our new distance indicator for ellipticals and refer the reader to the other papers in this series for more details of the method and survey.

2. RESULTS

We have used the relationship between the diameter enclosing a mean surface brightness of 20.75 with central velocity dispersion, $D_n \propto \sigma^{1.33}$ to predict the relative distances of galaxies and aggregates of galaxies (Dressler et al. 1987a).

We have determined the motion of the Local Group with respect to the frame of ellipticals by fitting a model of a uniform Hubble flow, plus a dipole motion for the LG, and maximizing the likelihood of obtaining the observed peculiar velocities. We find that the LG is moving at 480 km s^{-1} towards $l = 193°$, $b = +28°$ with respect to the frame of ellipticals with recession velocities less than 6000 km s^{-1}. Thus, the elliptical galaxies do not show the reflex of the LG motion with respect to the MWB, indicating that they are not at rest with respect to it. In fact, we find that the frame of elliptical galaxies is moving at 600 km s^{-1} towards $l = 312°$, $b = +6°$ with respect to the MWB (Dressler et al. 1987b). We have not reached a shell of galaxies that is at rest with respect to the MWB and cannot identify the mass causing the LG microwave motion, if indeed it is of gravitational origin. However, we can eliminate the Hydra-Centaurus supercluster as a candidate for such a mass because its peculiar motion is directed away from the LG, not towards it, as would be the case if the two superclusters were falling towards each other.

This large velocity of the local universe, roughly 120h Mpc in diameter, is a somewhat surprising result. In the following section we compare the result obtained here with those from other independent methods.

3. COMPARISON WITH OTHER METHODS

The IRTF method for spirals has been used to determine the relative distance moduli to Virgo of 10 clusters (Aaronson et al. 1986) and the Fornax-Virgo relative distance modulus (Aaronson et al. 1981). Of these 11 clusters there are 5 in common with the elliptical galaxy survey and for these the two estimates of relative distance modulus agree to within the errors. These two methods are completely independent and suffer quite distinct systematic errors, so their mutual agreement is encouraging.

We have looked for evidence of large scale coherent motions in both the Aaronson et al. nearby and cluster samples (1982, 1986) and the ScI galaxies of Rubin et al. (1976). Our re-analysis of the magnitude-diameter data from Rubin et al. has used the Peterson and Baumgart (1986) photometry and a new treatment of the Malmquist bias;

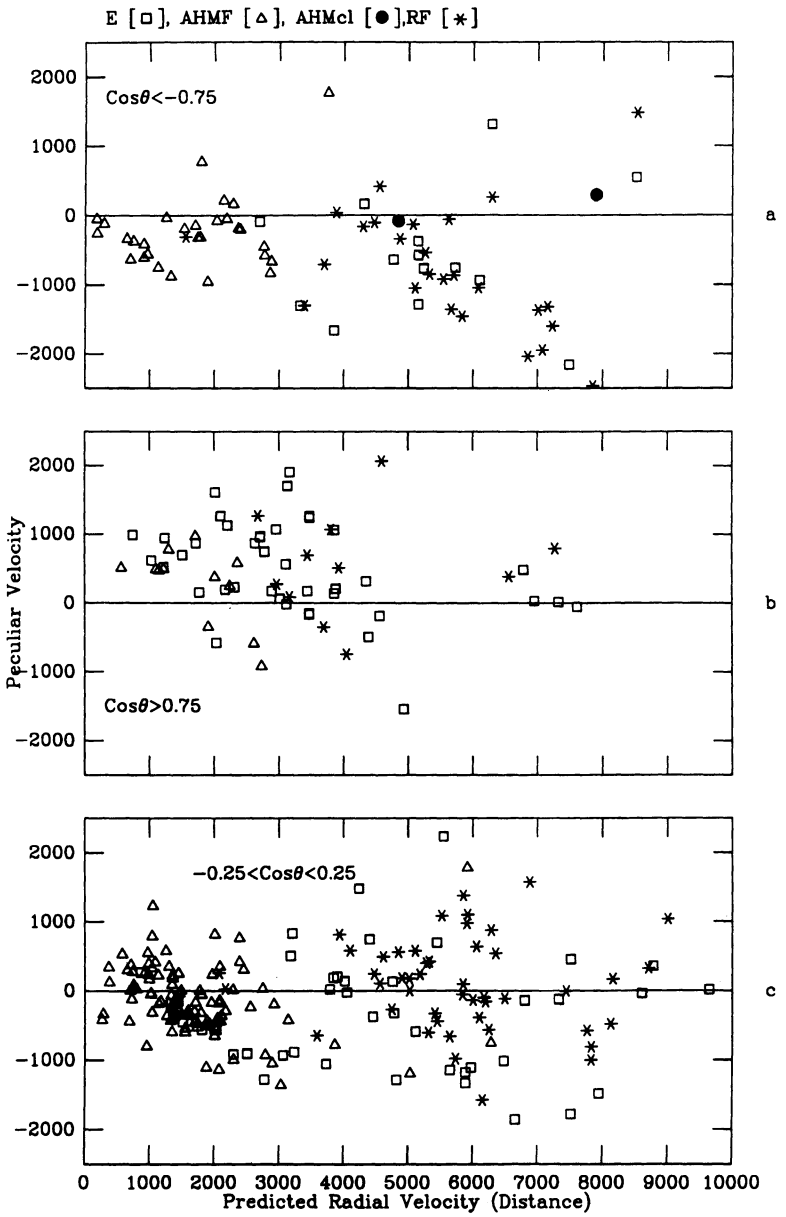

Figure 1. The peculiar velocity of galaxies taken from the four samples plotted as a function of predicted distance expressed as a recession velocity. The elliptical galaxies from this survey are plotted as open squares, the Aaronson et al. (1982) field spirals as open triangles, the Aaronson et al. (1986) clusters as filled circles and the Rubin et al. (1976) ScIs as asterisks.

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this analysis is reported more fully in Burstein et al. (1987b). Preliminary results are shown in Figure 1 (a) - (c) which plot the peculiar velocity against predicted distance, expressed as a recession velocity, for the four samples. Fig. 1(a) is for the direction of the antapex of the motion and shows that the field spirals from Aaronson et al., the Rubin et al. ScIs, and the ellipticals all show a net negative peculiar velocity in this direction. Fig 1(b) shows the apex direction where all the samples have a net positive peculiar velocity for recession velicities less than 5000 km s^{-1}, beyond which there are few galaxies in our sample. Figure 1(c) shows that there is no net peculiar velocity in the directions perpendicular to the motion. Note that in neither the apex nor antapex direction is there any indication of a reduction in the peculiar velocity as the galaxies become more distant.

4. CONCLUSIONS

1. We have used a new distance estimator for elliptical galaxies to show that the local volume of the universe 120 Mpc across is moving at 600 km s^{-1} towards $l = 312°$, $b = +6°$ with respect to the MWB.

2. We do not see the mass causing the Local Group's microwave motion out to recession velocities of 5000 km s^{-1}, beyond which there are few galaxies in the direction of the apex of the motion. We can eliminate the possibility that it is caused by a combination of the gravitational pulls of the Virgo Supercluster and the next nearest, Hydra-Centaurus Supercluster, because the peculiar motion of Hydra-Centaurus is away from, not towards, the LG.

3. Our method gives good agreement with the IRTF method applied by Aaronson et al. (1986) to 5 clusters we have in common. Further, the pattern of peculiar velocities across the sky that indicates a large scale coherent motion is present in both a re-analysis of the Aaronson et al. (1982) field data and the Rubin et al. (1976) data using the ScI magnitude-diameter relation. The detailed agreement among clusters in common, and the use of three independent methods to confirm the presence of a large coherent motion, suggest that the motion is real rather than an artifact of the changing properties of ellipticals from place to place in the universe.

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DISCUSSION

R.D. DAVIES: L. Staveley-Smith and I have investigated the local velocity field out to 4000 kms^{-1} for 350 Sb, Sbc and Sc galaxies using the Tully-Fisher relation for blue magnitude and diameter. We find that the apparent direction of the local group motion varies with the redshift range taken for the reference shell. It agrees with the CMB at 2000 km s^{-1} but progressively moves away up to 4000 km s^{-1} by 60^{o}; implying large-scale streaming motions of about 200-300 km s^{-1} on scales of 20-30 Mpc or larger. Local departures on scales of 10-20 Mpc are of similar magnitude. These values are significantly less than the values you quote. Do you think that the apparent increased streaming motion at your larger distances is a consequence of the distance uncertainty (which increases linearly with distance)?

R.L. DAVIES: No. We have divided our sample into $0 \leq v < 2000$, $2000 \leq v < 4000$ and $4000 \leq v < 6000$ km s^{-1} and find no significant differences in the vector. I believe that apparent discrepancies can only be resolved by comparing the relative distances to clusters and groups in common between different methods and samples. When we do this with the few Aaronson et al. clusters in common the agreement is good.

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