THE ASTROPHYSICAL JOURNAL, 389:L5–L8, 1992 April 10

NO BACK-SIDE INFALL INTO THE GREAT ATTRACTOR

D. S. MATHEWSON, V. L. FORD, AND M. BUCHHORN
Mount Stromlo and Siding Spring Observatories, The Australian National University, ACT 2611, Australia
Received 1991 April 16; accepted 1992 January 30

ABSTRACT

This *Letter* presents the first results of a survey of the peculiar velocities of 1355 spiral galaxies in the southern sky using the Tully-Fisher relation to estimate their distances. The most important result of these measurements is that no back-side infall into the Great Attractor is found, contrary to the findings of Dressler & Faber; rather, evidence is found for a bulk flow of about 600 km s^{-1} on scales greater than 60 h^{-1} Mpc. This, when added to the bulk flow of 450 km s^{-1} recently found by Willick in the opposite part of the sky, suggests that there is bulk flow in the supergalactic plane over very large scales greater than 130 h^{-1} Mpc. The origin of this bulk flow is a puzzle.

Subject headings: galaxies: distances and redshifts — galaxies: kinematics and dynamics — galaxies: photometry

1. INTRODUCTION

In the period 1987–1990, large-scale flows in our local universe have been mapped extensively (e.g., see Dressler et al. 1987; Burstein, Faber, & Dressler 1990; Dressler & Faber 1990a, b). There is agreement among these authors that the data support the simple Great Attractor (GA) model of Lynden-Bell et al. (1988) and Faber & Burstein (1988), in which a large, approximately spherical overdensity of radius ~40 h^{-1} Mpc influences the peculiar motions of galaxies over a large volume of space and is responsible for a large share of the Local Group's motion of 600 km s^{-1} with respect to the cosmic microwave background (CMB). The center of their GA lies at a distance of approximately 4200 km s^{-1} in the direction $l = 309°$, $b = 18°$.

The paper by Dressler & Faber (1990b) is the only work to probe the back-side regions of the GA. Using Hα rotation curves and *R*-band CCD photometry, they measured the peculiar velocities of 117 spiral galaxies in the GA region by means of the Tully-Fisher (TF) relation. They conclude that, for the first time, evidence is found for back-side infall into the GA, which is the crucial step in establishing the reality of the phenomenon.

This *Letter* adds to their measurements, particularly in the region beyond the GA. It is based upon a survey of the peculiar velocities of 1355 spiral galaxies (657 in the GA region) in the southern sky using the TF relation. The observations were carried out over a 3 yr period commencing 1987 November, and the data paper has been accepted for publication in the Astrophysical Journal Supplement Series.

2. THE DATA

The backbone of the sample of spiral galaxies was selected from the ESO–Uppsala Catalog (Lauberts 1982) of types Sb–Sd, diameters ≥ 1′.7, velocities in general less than 7000 km s^{-1}, inclinations greater than 40°, and $|b| > 11°$. In the GA region, galaxies from the Supergalactic Plane Redshift Survey by Dressler (1988) with velocities greater than 7000 km s^{-1} were included. In other areas of the sky, a sprinkling of galaxies with velocities greater than 7000 km s^{-1} was also observed. All together, 657 galaxies were observed in the GA region, $260° < l < 360°$, $-40° < b < +45°$, over a redshift range from 700 to 9000 km s^{-1}. This region was chosen because it encompasses the Hydra-Centaurus, Pavo, Indus, and Telescopium clusters, which are thought to be part of the GA (Lynden-Bell, Lahav, & Burstein 1989).

Hα rotation curves were obtained for 1042 galaxies with the dual-beam-spectrograph (Rodgers, Conroy, & Bloxham 1988) attached to the 2.3 m telescope at Siding Spring Observatory. The slit was 6′ long. A photon-counting detector sampled the spectra at a spatial resolution of 0″.66 pixel^{-1} and a spectral resolution of 0.40 Å pixel^{-1} (18 km s^{-1} pixel^{-1} at Hα). A single exposure of about 1000 s was taken of each galaxy. Generally the Hα and [N II] lines were seen to extend over about 80% of the optical image of the galaxy as judged from the ESO charts.

The first step in the reduction process was to obtain a flat-fielded, wavelength-calibrated, and sky-subtracted galaxy spectrum. Groups of three rows along the spatial dimension were combined to increase the signal-to-noise ratio, giving a spatial resolution of 2″. Each three-row section of galaxy spectrum was cross-correlated with an artificial template spectrum composed of three Gaussian-shaped emission lines at the rest wavelengths of Hα and [N II] lines with intensities appropriate to the particular spectrum. The resultant velocity shift at that point in the galaxy was written to a file and the rotation curve displayed. The maximum velocity width ($2V_{max}$) and systemic velocity of the galaxy were measured directly from the rotation curve. Repeat measurements of 36 galaxies showed an internal consistency of better than 10 km s^{-1}.

Traditionally V_{max} is measured from integrated H I profiles. The 64 m radio telescope at Parkes Observatory, CSIRO, was used to obtain H I profiles for 609 galaxies. Our definition for the observed line width is the width measured between the points in each profile where the signal level falls to 50% ($2V_{50}$) of the mean value of the highest channels (usually the two horns) in each half of the profile. The velocity resolution was 7 km s^{-1}.

Both methods of measuring rotation velocities were used for 219 galaxies to tie together the two different techniques. The relation between the two methods is

$$V_{max}(\text{H}\alpha)\ \text{km s}^{-1} = 1.03V_{50}(\text{H I}) - 11, \quad \sigma = 10\ \text{km s}^{-1}\ .$$

All rotation velocities derived from H I profiles were converted to the equivalent optical velocities using this algorithm.

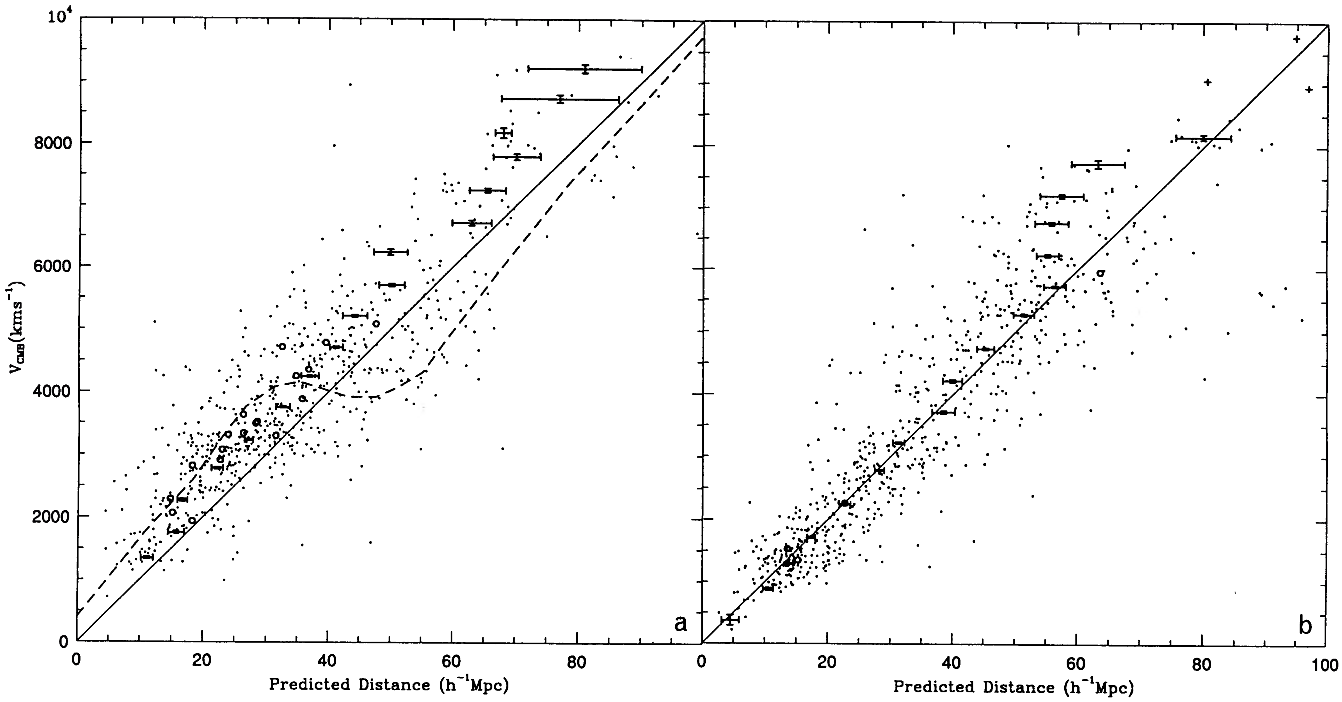

FIG. 1.—(*a*) Hubble diagram for 657 spiral galaxies in the Great Attractor (GA) region, $260° < l < 360°$, $-40° < b < +45°$. Dots refer to galaxies treated singly; open circles represent 179 galaxies collected into 18 clusters. The Hubble line (no motion with respect to the cosmic microwave background) is drawn. The dashed line (the so-called "S-curve") represents the GA model of Faber & Burstein (1988). (*b*) Hubble diagram for 698 spiral galaxies (*dots*) in our survey which lie outside the GA region; 69 of these spirals have been collected into five groups (*open circles*). The uncertainty of the predicted distances of the galaxies in both diagrams is $\pm 16\%$. Both plots have been sliced into horizontal bins of width 500 km s^{-1} in V_{CMB}, and the median points of the bins with their rms errors are shown. The data for both diagrams were taken from Mathewson, Ford, & Buchhorn (1992).

Photometry was obtained in the Kron-Cousins *I* passband with a GEC 576 × 380 CCD (0″56 pixel^{-1}) at the 1 m telescope at Siding Spring Observatory. Observations were only made on photometric nights. The GASP software package written by M. Cawson (see Davis et al. 1985) was used to measure the ellipticity and position angle of each galaxy image and a total *I*-magnitude down to an isophote 1% or less of the sky. Repeat measurements of 121 galaxies taken over the 3 yr period showed internal consistency of 0.03 mag rms. Possible systematic errors were minimized by observing standard stars with colors close to those of the sample galaxies. The *K*-correction was taken from Schneider, Gunn, & Hoessel (1983) and applied to all magnitudes. The "zero-velocity" H I was observed in the direction of each galaxy and used to measure the extinction in our Galaxy following Burstein & Heiles (1978). The extinction in *I* is taken to be 42% of that in *B*. Corrections were made for internal absorption following Tully & Fouqué (1985) to yield "face-on" magnitudes.

The velocity of rotation, V_{rot}, of the spiral galaxies was calculated from V_{max}, corrected for relativistic effects, using inclinations derived from the measured major-to-minor axis ratios following Bothun et al. (1985). These ratios were obtained from the ellipse-fitting routine over the range in radius dominated by the disk. It should be noted that Hα widths measure pure rotational velocity. Turbulence broadens the emission lines, but the width of each rotation curve is measured from the center of the maximum of the curve on either side of the nucleus.

The Fornax Cluster was used to calibrate the TF relation. The relation obtained is

$$I = -7.96 \log V_{rot} + 27.68 , \quad \sigma = 0.25 \text{ mag} .$$

The distance to Fornax is taken to be 1340 km s^{-1} (Aaronson et al. 1981). The reason why some astronomers (e.g., Aaronson et al. 1986) obtain a nonlinear TF relation is most likely due to the increasing influence of nonrotational support in galaxies of smaller mass (Tully & Fouqué 1985) and to the heavy smoothing of Arecibo H I profiles (effective velocity resolution ~30–40 km s^{-1}; see Bothun et al. 1985), which also increases in importance for low-rotation galaxies.

3. LARGE-SCALE COHERENT FLOWS

The resultant Hubble diagram for the 657 spiral galaxies inside the GA region is shown in Figure 1*a*. Observed velocities have been corrected to the CMB frame. Based on the prescription of Lynden-Bell et al. (1988) and taking an error in the TF relation of 0.32 mag ($\pm 16\%$), the predicted distances have been multiplied by 8% to correct for a homogeneous Malmquist-like bias. The error of 0.32 mag has been obtained by averaging the rms scatter in the TF relations for the seven most populous clusters in our sample.

For comparison, the Hubble diagram for the remainder of the galaxies in our survey that lie outside the GA region is shown in Figure 1*b*. The dots in both figures are for galaxies treated singly; the open circles represent 248 of these galaxies collected into 23 clusters. For these, the observational errors and Malmquist bias errors are much reduced (Lynden-Bell et al. 1988). The Hubble line (no motion with respect to the CMB) is drawn in both figures.

The errors in predicted distance are $\pm 16\%$, whereas the errors in V_{CMB} are negligible. Therefore, a best fit to these data is obtained by binning them horizontally in bins of 500 km s^{-1} in V_{CMB}. The median point of each bin is plotted together with its rms error bars in Figure 1.

The Hubble line is an excellent fit to the median points for outside the GA region (Fig. 1*b*) up to $V_{\rm CMB} = 6000$ km s^{-1} when the points diverge—probably due to distance selection effects, since our sample is based on apparent galaxy diameter and more distant galaxies may be excluded. For the GA region (Fig. 1*a*) the median points lie close to a straight line which runs parallel to and almost 600 km s^{-1} above the Hubble line. Using Figure 1*b* as a control below $V_{\rm CMB} = 6000$ km s^{-1} to minimize selection effects, this is strong evidence for bulk flow of 600 km s^{-1} in the direction of the GA, certainly up to a distance of 60 h^{-1} Mpc.

This result is in marked contrast to that obtained by Dressler & Faber (1990b), who find evidence for back-side infall into the GA. In their Figure 2*a* they plot the data for 156 E and S0 galaxies (Dressler & Faber 1990a; Burstein et al. 1990) and 117 spiral galaxies in the GA region defined as $290° < l < 350°$, $-30° < b < +45°$ (Dressler & Faber 1990b). They believe that the agreement between the GA model of Faber & Burstein (1988) and their data is good. The dashed line (the so-called "S-curve") in their Figure 2*a* and our Figure 1*a* represent the GA model of Faber & Burstein at a radius of 15° from the GA center. This does not fit our data, and there is no sign of back-side infall into a GA situated at 42 h^{-1} Mpc.

We have compared our Malmquist bias–corrected distances for 16 of the spiral galaxies with redshifts ranging from 2000 to 6700 km s^{-1} in the GA region with those of Dressler & Faber. The agreement is good. The ratio of our distances to those of Dressler & Faber is 0.99, $\sigma = 0.13$. The 13% dispersion of the differences in the distances corresponds to 9% if the values are shared equally; this is a small contributor to the TF scatter of 16%. The difference in our conclusions is due to the fact that we have many more data, particularly at distances beyond the putative GA.

4. DISCUSSION

The most important result of this paper is that back-side infall into the GA is not detected, certainly out to distances of 60 h^{-1} Mpc. This implicitly questions the existence of the GA. However, there is evidence for bulk flow of about 600 km s^{-1} on scales of at least 60 h^{-1} Mpc.

In a recent survey of peculiar velocities in the direction of Perseus-Pisces (P-P), which is opposite in the sky to the GA, Willick (1990) finds bulk flow of about 450 km s^{-1} over scales of some 70 h^{-1} Mpc. This, when added to our result, suggests that there is bulk flow in the supergalactic plane over scales in excess of 130 h^{-1} Mpc. Figure 2*a* plots Willick's peculiar velocity data and ours against $V_{\rm CMB}$. The bulk flow is evident from the upward and downward displacements of the median lines of the peculiar velocities of the GA and P-P regions, respectively.

The origin of this bulk flow is puzzling. If it was induced by biases in the reduction procedures, errors in Galactic extinction would be most suspect, since the GA and P-P are at low Galactic latitudes and this would affect both spiral and elliptical galaxies equally. However, no correlation of peculiar velocity with Galactic extinction is found (Mathewson, Ford, & Buchhorn 1992); also, it would need to be opposite in sign for the GA and P-P regions, which is most unlikely.

Predictions of peculiar velocities in the GA region using the *IRAS* redshift surveys (Yahil 1988; Rowan-Robinson et al. 1990; Kaiser et al. 1991) do not agree with our measurements or with other measurements by Lynden-Bell et al. (1988) and Mould et al. (1991). For example, they do not predict the high peculiar velocity of the Centaurus clusters toward a more distant point. This implies that light does not trace mass, but the very large concentrations of dark matter required seem to be excluded by the absence of small-scale fluctuations in the temperature of the CMB ($\Delta T/T < 3 \times 10^{-5}$). Of course it is remotely possible that the bulk flow is not induced by gravitational forces.

An alternative (but heretical) explanation is that the CMB does not define an absolute rest frame and the CMB dipole is not the result of our motion toward $l = 269°$, $b = 28°$. However, Burstein et al. (1990) list many powerful arguments in favor of the CMB as the standard of rest (but see Turner 1991). Though it is interesting how, if the peculiar velocities for

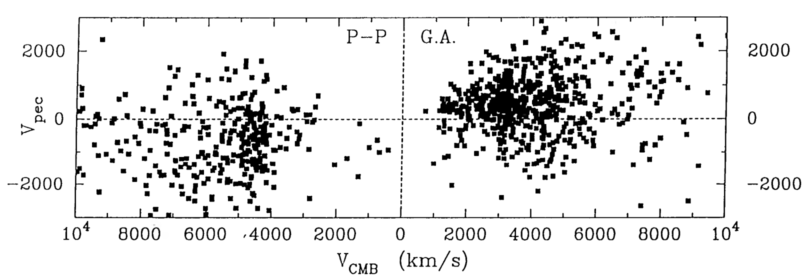

FIG. 2*a*

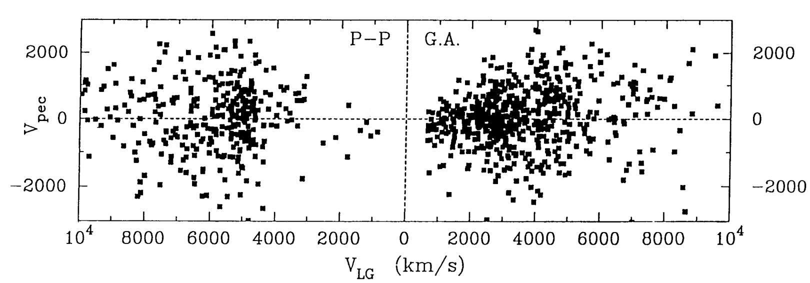

FIG. 2*b*

FIG. 2.—(*a*) Peculiar velocities of spiral galaxies in the CMB frame in the direction of the Great Attractor (GA) region and the Perseus-Pisces supercluster (P-P) as a function of redshift relative to the CMB. The data for the P-P region were taken from Willick (1990). (*b*) Same as (*a*), except that the peculiar velocities of the galaxies and their redshifts are relative to the Local Group (LG) frame.

the GA and P-P regions and their redshifts are plotted in the frame of the Local Group, the median lines of the peculiar velocities lie about the zero peculiar velocity line for both regions (Fig. 2*b*).

However, whatever the explanation of this bulk flow may be, one result is clear: there is no back-side infall into the GA which suggests that the GA does not exist.

The authors thank A. Dressler for communicating some of his data on distances to spiral galaxies so that a comparison with our survey could be made; C. Grillmair, E. Vassiliadis, A. Samuel, S. Ryder, J. English, and A. Koekemoer, postgraduate students at Mount Stromlo Observatory, who each worked for 4 months on the project as part of their first-year program; also A. Savage of the UK Schmidt Telescope Unit for help with some of the observations at Parkes and with the 1 m telescope; and the staff of Mount Stromlo and Siding Spring Observatories and of the Parkes Observatory, CSIRO, for maintaining the telescopes and equipment in perfect order throughout the observations over the three-year period.

REFERENCES

Aaronson, M., Bothun, G., Mould, J., Huchra, J., Schommer, R. A., & Cornell, M. E. 1986, ApJ, 302, 536
Aaronson, M., Dawe, J. A., Dickens, R. J., Mould, J. R., & Murray, J. D. 1981, MNRAS, 195, 1P
Bothun, G. D., Aaronson, M., Schommer, B., Mould, J., Huchra, J., & Sullivan, W. T., III. 1985, ApJS, 57, 423
Burstein, D., Faber, S. M., & Dressler, A. 1990, ApJ, 354, 18
Burstein, D., & Heiles, C. 1978, ApJ, 225, 40
Davis, L. E., Cawson, M., Davies, R. L., & Illingworth, G. 1985, AJ, 90, 169
Dressler, A. 1988, ApJ, 329, 519
Dressler, A., & Faber, S. M. 1990a, ApJ, 354, 13
———. 1990b, ApJ, 354, L45
Dressler, A., Faber, S. M., Burstein, D., Davies, R. L., Lynden-Bell, D., Terlevich, R. J., & Wegner, G. 1987, ApJ, 313, L37
Faber, S. M., & Burstein, D. 1988, in Large-Scale Motions in the Universe, ed. V. C. Rubin & G. V. Coyne (Princeton: Princeton Univ. Press), 116
Kaiser, N., Efstathiou, G., Ellis, R., Frenk, C., Lawrence, A., Rowan-Robinson, M., & Saunders, W. 1991, MNRAS, 252, 1
Lauberts, A. 1982, The ESO/Uppsala Survey of the ESO(B) Atlas (Garching: ESO)
Lynden-Bell, D., Faber, S. M., Burstein, D., Davies, R. L., Dressler, A., Terlevich, R. J., & Wegner, G. 1988, ApJ, 326, 19
Lynden-Bell, D., Lahav, O., & Burstein, D. 1989, MNRAS, 241, 325
Mathewson, D. S., Ford, V. L., & Buchhorn, M. 1992, ApJS, in press
Mould, J. R., et al. 1991, ApJ, 383, 467
Rodgers, A. W., Conroy, P., & Bloxham, G. 1988, PASP, 100, 626
Rowan-Robinson, M., et al. 1990, MNRAS, 247, 1
Schneider, D. P., Gunn, J. E., & Hoessel, J. G. 1983, ApJ, 264, 337
Tully, R. B., & Fouqué, P. 1985, ApJS, 58, 67
Turner, M. S. 1991, A Tilted Universe, Fermilab Pub.-91/43-A
Willick, J. A. 1990, ApJ, 351, L5
Yahil, A. 1988, in Large-Scale Motions in the Universe, ed. V. C. Rubin & G. Coyne (Princeton: Princeton Univ. Press), 219