COHERENT LARGE-SCALE MOTIONS FROM A NEW SAMPLE OF SPIRAL GALAXIES

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"The stellar milky way, in the region of which, according to Argelander's admirable observations, the brightest stars of the firmament appear to be congregated, is almost at right angles with another milky way, composed of nebulae.... The milky way composed of nebulae does not belong to our starry stratum, but surrounds it at great distance without being physically connected with it, passing almost in the form of a large cross through the dense nebulae of Virgo, especially the northern wing, through Coma Berenicis, Ursa Major, Andromeda's girdle, and Pisces Boreales." These words, published 140 years ago by Alexander von Humboldt (1849), outline the program which brings us all to Hungary for this conference.

Following the result of the Faber group (Burstein 1987, Faber 1987), I have investigated the large-scale motions exhibited by a group of spiral galaxies which my colleagues and I had previously studied for individual rotation properties. Rotation curves are a good diagnostic of galaxy luminosity; velocities rise rapidly with radius for high luminosity galaxies, and they rise to higher rotational velocities. These properties lead to the Tully-Fisher relation. These properties also make it possible to construct synthetic rotation curves (Rubin 1985), templates which can be employed to estimate the absolute magnitude of any spiral with a known rotation curve and Hubble type.

For each program spiral, a distance is found from its corrected apparent magnitude, and from its absolute magnitude estimated from its rotation curve. Such distance is independent of its observed velocity. For a value of H_o=50 km sec^{-1} Mpc^{-1}, I then calculate the difference between the velocity predicted at its distance by a smooth Hubble flow, and the observed velocity. As in the Faber work, the rest frame is defined by the cosmic background radiation (CBR). The motion of the observer with respect to the Local Group, and the motion of the Local Group with respect to the CBR, are removed. The inclusion of a Virgo infall component does not alter the solution.

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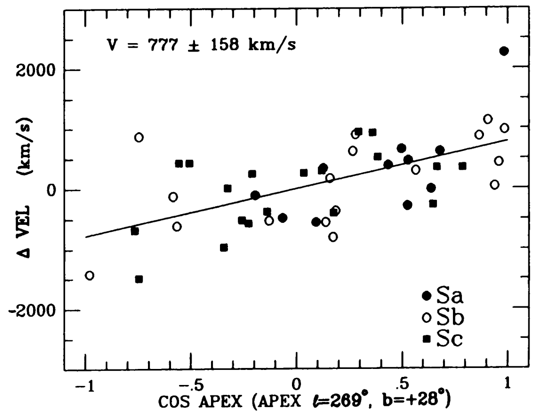
Figure 1. Residual velocities from a smooth Hubble flow, for 47 spirals, 400<V<3600 km/s, plotted as a function of angular distance from the derived apex. A bulk motion of 777±158 km/s is indicated. The sample is reasonably well distributed on the sky for declinations above -10°, but there are almost no galaxies below $\delta=-30^{\circ}$.

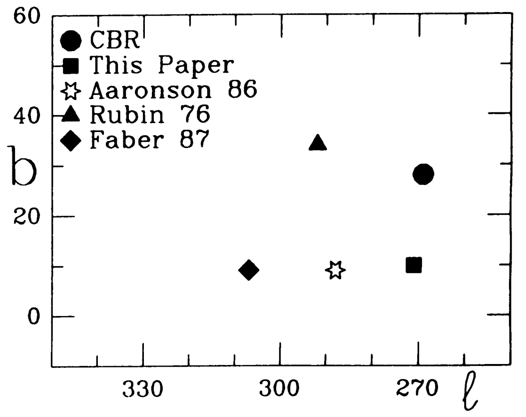


Results from a sample of 47 spirals are shown in Fig. 1, where I plot for each galaxy ΔV versus the cosine of the apex distance. ΔV is defined as the difference between the observed velocity, corrected for the motion of the observer with respect to the Local Group and the motion of the LG with respect to the CBR, and the Hubble velocity predicted at the distance of the galaxy. A bulk motion of the set of galaxies will be indicated by a diagonal line on such a plot, with the amplitude of the motion equal to the value of ΔV at cos(apex)=1. The apex of the motion is found ultimately from a least squares solution of an equation of the form ΔV=V cos(apex), which minimizes errors in the velocity coordinate.

The resultant bulk motion of V=777±158 km/s toward $\ell=271^{\circ}$, $b=+10^{\circ}$, is close to the direction of motion of the LG with respect to the CBR; it agrees well with other recent determinations (Fig. 2), as well as with the Rubin et al. (1976) result, after that result is transformed (Faber 1987) to the CBR rest frame. I would like to put the 1976 result into perspective with a few comments. In our 1976 work, we determined a solar motion of 600 km/s with respect to ScI galaxies with velocities less than 6500 km/s; this corresponds to a Local Group motion of 450 km/s toward ℓ near 170°, b near 0°. This result conflicted with results from early efforts to detect a dipole variation of the CBR (Partridge 1974 is the reference we quote), which implied a small velocity, $V_{\odot}$ < 300 km/s. Not surprisingly, the optical results were met with the comment that "the motion of the sun can't be so large". Shortly thereafter, the dipole variation in the MBR was detected (Smoot 1977) and ultimately interpreted as a motion of the Local Group of about 600 km/s), but in a direction more than 90° from the optical dipole.

The question then repeatedly asked, "Why isn't the optical dipole in the direction of the CBR dipole?" can now be answered. The Local Group and the Sc I optical sample are moving together in the direction of the CBR dipole. In our 1976 solution we were determining only the "small-scale" motion of the LG with respect to the set of Sc I galaxies.

Figure 2. The location, in galactic coordinates, of the apex of the bulk motion of the relatively nearby galaxies, as determined from some recent studies.



Because such LG motion (450 km/s) is small compared with the motion (614 km/s) with respect to the CBR, the vector sum of the two produces a velocity in a direction close to that of the MBR dipole (Fig. 2). Thus, part of the agreement of all of the apices in Fig. 2 arises because each is the vector sum of a smaller motion of the LG with respect to the sample, plus the larger motion of the LG with respect to the rest frame defined by the CBR.

Questions remain concerning the interpretation of all of these results. Is a model based on the attraction of a dominant large mass a better fit than a model based on a bulk flow? Are the differences between solutions significant, or are they all merely approximations to the direction and magnitude of the CBR dipole? Finally, can we rule out the possibility that there are differences in galaxies in different regions of the sky, which we erroneously interpret as a velocity? At a distance where V=3500 km/s, a change in absolute magnitude by 0.4 magnitude will mimic a velocity of 600 km/s. It seems unlikely that a variation across the sky of twice this amount will have gone unnoticed.

REFERENCES

Aaronson, Bothun, Mould, Huchra, Schommer, Cornell, 1986, Ap. J. **302**, 536; revised: Collins et al. 1986, Nature, **320**, 506.

Burstein et al., 1986, in Galaxy Distances and Deviations from Universal Expansion (Reidel: Dordrecht), p. 255.

Faber, 1987, this volume.

Partridge, 1974, in Confrontations of Cosmological Theories with Observation (Reidel: Boston), p. 157.

Rubin, Thonnard, Ford, and Roberts, 1976, Astron. J. **81**, 719.

Rubin, Burstein, Ford, and Thonnard, 1985, Ap. J. **289**, 81.

Smoot, Gorenstein, and Muller, 1977, Phys. Rev. Letters **39**, 898.

von Humboldt, A., 1849, in Cosmos, translated from the German by E. C. Otte (Bohn: London), Vol I, p. 141.