Spatial Fluctuation of the Hubble "Constant"*

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Six samples of objects have been analyzed in order to check whether the redshift asymmetry discovered by Rubin *et al.* is a general effect. The results for all samples are consistent with the existence of the asymmetry. Its average magnitude is $\langle V \rangle = 1300 \pm 210$ km/s. The asymmetry vanishes at large distances. Various interpretations of the effect have been

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discussed. Arguments are given in favour of a non-Doppler redshift occurring in the intergalactic space within the Local Supergalaxy and other concentrations of galaxies.

Homogeneity and isotropy are commonly accepted properties of models of the Universe. However, there also seems to be a tendency to apply these characteristics to the innermost parts of the Metagalaxy, as when predicting a linear redshift-distance relation without regard to existing concentrations of matter such as supergalaxies. This kind of thinking leads to the supposition (Sandage *et al.* 1972) that the dynamical evolution of the Universe is almost completely independent of existing matter.

During recent years observations have been obtained which can be shown to contradict the concept of linear expansion. When determining the value of the Hubble constant H, discrepant results are found which seem to be connected to the positions objects with respect to the Local Supergalaxy (LSG) (Sandage and Tammann 1975a,b, Abell 1972, de Vaucouleurs 1972, Heidmann 1970, Holmberg 1964, Roberts 1972, van den Bergh 1970). Interestingly, this discrepancy (further discussed at the end of this paper) is in the opposite direction to what would be expected from the gravitational retardation of the rate of expansion due to the supergalactic concentration of galaxies.

In 1973 Rubin *et al.* (1973) found that ScI galaxies with $14^{m}.0 \le m \le 15^{m}.0$, hence all at approximately the same distance, have in one hemisphere (region I) the mean velocity $\langle V \rangle = 4966 \pm 122$ km/s and in another (region II) $\langle V \rangle = 6431 \pm 160$ km/s. These values imply a considerable degree of anisotropy of the redshift-distance relation.

The essential data of the redshifts of different kinds of objects in the range of z about 0.01–0.05 has now been analyzed in order to check the possible existence of a similar anisotropy (Jaakkola *et al.*

1975, Karoji *et al.*, Jaakkola *et al.* 1976). The results, including that of Rubin *et al.*, are tabulated in Table 1. Column 1 gives the sample studied; 2- reference to earlier studies; 3- source of data; 4- mean logarithmic velocity of the sample; 5- interval of apparent magnitude (not reduced to a homogeneous site, and for sample 1 uncorrected for galactic absorption); 6- number of objects in regions I and II; 7- mean difference of the Hubble modulus HM = $\log V - 0.2m$ between regions II and I, *i.e.* $\Delta(\mathrm{HM}) = \langle \mathrm{HM} \rangle_{II} - \langle \mathrm{HM} \rangle_{I}$ (HM gives the position of an object in the magnitude-redshift diagram); 8- mean velocity difference between regions II and I (corresponding to Δ(HM)); 9- the difference in the Hubble parameter *H* as a percentage of the value of H in region I; 10- level of significance and 11- chance probability of the differences.

Regions I and II are those defined by Rubin *et al.* (1973) and shown in Figure 1. Since Table 1 refers to various authors, selection of data and details in the methods are not fully homogeneous. Nevertheless, the results refer to roughly similar distance intervals, with small differences as seen in $\langle \log V \rangle$ (column 4), with largest velocities 10,000 to 20,000 km/s and with lowest velocities 2,500 to 3,000 km/s. The lower limit of m results from the lower limit of V, the upper *m*-limit gives the value up to which the anisotropy is present; sample 1 lies in the program interval $14^{m}.0$–$15^{m}.0$ of Rubin *et al.* (1973). The selection present in the upper *m*-limit is justified by the roughly homogeneous distance interval following from this. In correcting galactic absorption the law $A = 0.25 \csc|b|$ has been used and galaxies with $|b| < 20°$ have been excluded except in sample 2 where Sandage's (1972) data has been used.

From Table 1 and from Figure 1, which shows the distribution of the objects studied on the sky, it can be seen that all the present samples consistently reveal the presence of an anisotropy. Excepting sample 4 the results are significant at the $2s$ to $4s$ level. The

Table 1 – Redshift anisotropy at moderate distances for six samples containing a total of 268 objects.

1	2	3	4	5	6	7	8	9	10	11
SAMPLE	**Ref.**	**Data ref.**	**<log*V*>**	**Interval of m**	**N_I N_{II}**	**Δ(*HM*) ±m.e.**	**Δ*V* (km/s)**	**Δ*H* (%)**	**t**	**P**
1. Sc I galaxies	1	1	3.75	(14.0 –15.0)	25 21	+0.110 ±0.029	+1150 ±300	+23 ±6	3.8	0.001
2. First-ranked cluster galaxies	2	2	3.78	10.5 –14.0	17 10	+0.054 ±0.026	+850 ±400	+15 ±7	2.1	0.03
3. Supernovae	2	3	3.83	15.0 –18.5	10 8	+0.204 ±0.054	+2550 ±670	+48 ±13	3.8	0.002
4. Seyfert-like galaxies	2	4	3.92	14.0 –15.0	14 6	+0.103 ±0.109	+2000 ±2100	+28 ±29	0.95	0.2
5. Markarian galaxies	3	5	3.84	13.5 –15.5	109 26	+0.100 ±0.036	+1400 ±500	+23 ±8	2.8	0.004
6. Absorption-line compact galaxies	4	6	3.95	13.0 –15.0	7 15	+0.170 ±0.089	+3400 ±1800	+46 ±24	1.9	0.03

References to earlier studies (column 2): 1- Rubin *et al.* 1973, Jaakkola *et al.* 1976, 3- Karoji *et al.*, 4- Jaakkola *et al.* 1975. Source of data (column 3): 1- Rubin *et al.* 1973, 2- Sandage 1972, 3- Kowal and Sargent 1971, 4- Vorontsov-Velyaminov and Ivanisevic 1974, 5- refs. 8-15 in Teerikorpi 1974, 6- Zwicky 1972.

probability that all the results are due to statistical fluctuation is extremely small.

The weighted mean values of Δ(HM), ΔV and ΔH of Table 1, with the weight proportional to $(N_I+N_{II})/2$ and inversely proportional to variances, give estimates of the size of the anisotropy. These are $\langle\Delta(HM)\rangle = +0.097\pm0.016$, $\langle\Delta V\rangle = +1300\pm210$ km/s, $\langle\Delta H\rangle = +24\pm4$ percent. These give a 6*s* level of significance, but taking into account an inhomogeneity of the upper *m*-limit and the fact that some galaxies belong to more than one sample, an appropriate value would be smaller, still indicating a very small chance probability. The value of $\langle\Delta H\rangle$ means that if, *e.g.*, $H_I = 75$ km s^{-1} Mpc^{-1} is valid in region I, in region II the value is on the average $H_{II} = 93$ km s^{-1} Mpc^{-1}, in the distance interval studied.

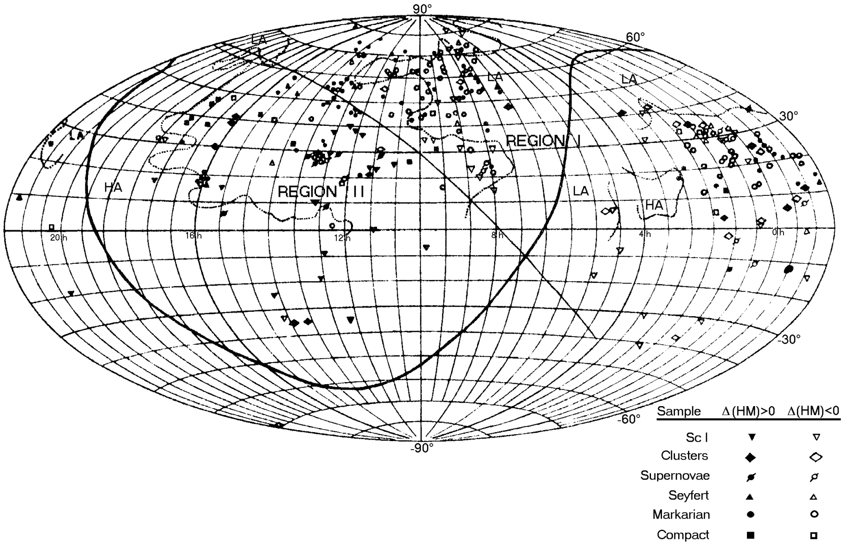

Figure 1 – Distribution on the sky of the objects belonging to the six samples in Table 1. The meaning of the symbols is shown in the figure, with δHM = HM – <HM>, the mean value <HM> referring to both the regions together. The full curve from upper left to bottom right is the borderline between the two regions of the sky. The other full curve shows the galactic equator. The areas between the latter and the dashed curves are those of exceptionally high or exceptionally low absorption, denoted by HA and LA, respectively. These have been converted from Holmberg (1974), and show areas where absorption deviates from the law A = 0.25 cosec |b| by ±0.15 mag or more.

An important property of the anisotropy effect is that it seems to vanish at large distances. This was evident in sample 2 for distant clusters of galaxies. Also this appears in samples 4, 5 and 6 for magnitudes fainter than those in Table 1. Isotropy of H in the metagalactic scale is a plausible result cosmologically.

In principle, the anisotropy of the Hubble modulus HM might be the result of (a) statistical fluctuation, (b) selection effect, (c) galactic or intergalactic absorbing clouds, (d) difference in absolute magnitude of the objects between the two regions, (e) motion of the Local group or of LSG towards region I, (f) large scale velocity perturbation in either of the regions, (g) a general anisotropic expansion of the Metagalaxy, (h) intrinsic redshift in galaxies of region II, or (i) excess non-velocity redshift of the spectra of galaxies in region II originating in the path from the source to the observer.

Case (a) is ruled out by the extremely small probability obtained. It is difficult to find a way in which a selection effect (b) could produce the anisotropy discussed, especially when the observations in the two regions have been obtained mostly by the same observers and with the same instruments. (c) If due to absorption (Hartwick 1975), the anisotropy would be found also at large distances, and this would conflict with the relatively local character of the effect, as found above. Moreover, the results of the studies of the galactic and supergalactic absorption (Holmberg 1974, Takase 1972, de Vaucouleurs 1973) argue against case (c). The regions of exceptionally high or exceptionally low absorption, as given in galactic coordinates by Holmberg (1974) from the counts of clusters of galaxies, are shown in equatorial coordinates in Figure 1. One finds that small HM_s are not associated with areas of high absorption and large HM_s with areas of low absorption as would be expected for an apparent anisotropy due to absorbing clouds.

$<\Delta(HM)> = +0.097$ obtained means $\Delta M = -0^m.5$ if it is expressed as the difference of the mean absolute magnitude in regions II and I (case d). This would be valid in more or less spherically symmetric spatial regions, centred on the Earth, both covering almost whole hemispheres on the sky and having diameters larger than two hundred megaparsecs. This is very improbable, and is further unlikely because of the fact that the luminosity discrepancy would be similarly valid for supernovae and galaxies of several kinds, while these would have the physical properties which define the samples as similar in the two regions.

Case (e) is ruled out if the usual interpretation of the 2.7 K background radiation is adopted. Considerations of geometry and scale, as for (c), also make large scale velocity perturbation (f) very improbable. The fact that most prominent nearby concentrations of mass are in region II (see below) is also evidence against a more rapid expansion in this direction than in region I. The observed local character of the effect rules out a general anisotropic expansion of the Metagalaxy (case g). Arguments against (d) are similarly valid against (h).

Consequently, case (i), an excess non-velocity redshift in the path from the sources in region II to the observer should be considered. The presence in region II of the most prominent nearby concentrations of galaxies such as the central region of LSG (de Vaucouleurs 1971), including the Virgo cluster, the Coma cluster with its large-scale extensions, and the Hercules supergalaxy (de Vaucouleurs 1971), should first be noted. Secondly, the theory of photon-boson interactions developed by two of the present authors (J.C.P. and J.P.V.) with their collaborators (Merat *et al.* 1974) predicts redshift when photons cross luminous concentrations of mass. In accordance with this theory, the redshift anisotropy discussed above may be due to a redshifting medium connected with LSG and the other large-scale concentrations of galaxies mentioned.

Some important observations give support to this latter hypothesis. The local character of the anisotropy which disproved the absorption model supports the excess redshift model. Although all the galaxies in the background of the concentrations would suffer from the extra redshift, a small effect of $\Delta z = 0.003–0.006$ would not be observable in the (m,z)-diagram for z larger than 0.04 or 0.05 with the present

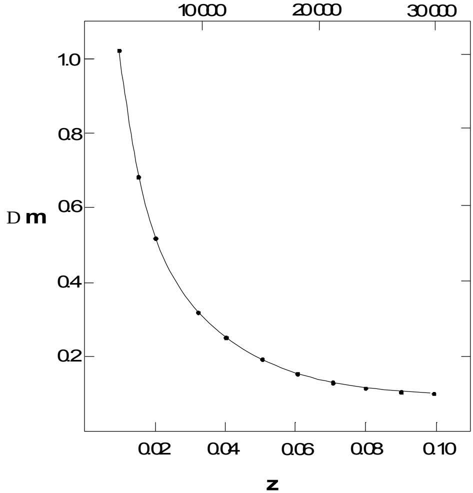

Figure 2 – (*m*,*z*) diagram Shows how a local excess redshift affects the position of a galaxy in the (*m*,log*V*)-diagram at various distances. $\Delta m = 5\Delta \log V$, where $\Delta \log V$ corresponds to $\Delta V = 1300$ km/s.) It is readily apparent that a local excess redshift cannot be resolved for distant galaxies.

accuracy of observations and with other existing sources of dispersion (see Figure 2).

Secondly, the excess redshift model is supported by the discrepancy in the values obtained for *H*. This is because low values, $H \sim 50$ km s^{-1} Mpc^{-1}, have been obtained for distant objects (Sandage and Tammann 1975a, Abell 1972) and high values, $H \sim 100$ km s^{-1} Mpc^{-1} for nearby objects mostly belonging to the Local Supergalaxy (de Vaucouleurs 1972, Heidmann 1964, Holmberg 1964, Roberts 1972, van den Bergh 1970, see also Sandage and Tammann 1975b). There are differences in calibration of the distance scale which partly explain the difference (Jaakkola and le Denmat 1976). Nevertheless, an excess in H remains within the Local Supergalaxy, by $\Delta H \sim 30$ s^{-1} Mpc^{-1}. This supports the existence of an excess redshifting medium in

LSG, as also indicated by the results on the anisotropy in the supergalactic background summarized in Table 1. The alternative explanation would be that LSG expands more rapidly than the less dense regions of the Metagalaxy. But taking into account the gravitation in the LSG concentration of mass, the latter explanation remains very unphysical, while it also fails to explain the Rubin-Ford anisotropy.

There also exists evidence of excess redshifts in other mass concentrations of smaller scale, such as clusters, groups and pairs of galaxies (Jaakkola 1975), single galaxies (Holmberg 1961, Arp 1970, Jaakkola 1971, Bottinelli and Gouguenheim 1973, Jaakkola 1973, de Vaucouleurs and de Vaucouleurs 1973, Collin-Souffrin *et al.* 1974, Jaakkola *et al.* 1975a), quasars (Arp 1974, Jaakkola *et al.* 1975b) and stars (Kuhi *et al.* 1974). The common feature in these observations is that excess redshifts appear in objects of higher-than-average compactness, and according to the present results, this is also valid for LSG which is denser than the Metagalaxy average. Hence redshift seems not be a phenomenon connected with space, resulting from a mysterious event, the big bang, at the "beginning of the universe", and since then, in the "open" universe (Sandage *et al.* 1972, Sandage and Tammann 1975a, Gott *et al.* 1974), appearing as independent of matter. On the contrary, redshift seems to be an effect bound to the presence of matter. The evidence given in the present paper that non-velocity redshifts occur between a source and an observer favours the view that the systematic cosmological redshifts commonly explained by expansion can be understood on the same basis as the excess redshifts, namely through the interaction mechanism within the framework of a no-expansion cosmology (Jaakkola *et al.* 1975c).

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