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SOME REMARKS CONCERNING THE VELOCITY AND SPATIAL DISTRIBUTIONS OF GALAXIES

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Nous discutons quelques aspects des rapports entre la distribution spatiale et la distribution des vitesses des galaxies en insistant surtout sur la recherche d'anisotropie. Nous incluons à la fois les relations dynamiques et les effets de selection qui pourraient être importants dans de telles études.

I Introduction

The present, large-scale homogeneity and isotropy of the Universe is a basic hypothesis underlying most cosmological models in use nowadays. It is therefore important to consider the observational basis for these simplifying assumptions in some detail. The conventional wisdom is that the apparent isotropy of the microwave background radiation provides the best evidence in support of this hypothesis. However, because the universal character of this radiation field is not incontrovertible and because if primeval it tells us something about the Universe only in the distant past and therefore on the very largest scales, it is important to study the distribution of luminous matter. These are two related aspects to consider: (i) the spatial distribution and (ii) the velocity distribution.

The first of these has received considerable attention in recent years and, as is well-known, is beset by difficulties in accounting for galactic obscuration and nearby galaxy clustering. However, from the apparent distribution of galaxies and radio sources on the sky and their number-magnitude relations, it seems that presently available data are consistent with the hypothesis of a spatially uniform distribution on the largest observable scales. As Rubin and others have recently emphasized, the velocity distribution also merits careful study. Here, we wish to emphasize that the spatial distribution and the velocity distribution of galaxies are intimately related both on dynamical grounds and in terms of selection effects in the data required for anisotropy studies.

II Selection Effects

First, we consider the role inhomogeneities in the spatial distribution may have in producing an apparent anisotropy in their velocity distribution. The idea here is simply that if we condier a sample of galaxies in a certain magnitude interval, or 'window', then high and low velocity aggregates of galaxies will appear in the distribution of sample galaxies on the sky depending upon clustering in that window, even if their recessional velocities are given exactly by an isotropic Hubble law.

In principle one could avoid this problem by using a sample of 'standard candle' galaxies in a very narrow apparent magnitude window because these galaxies would then be guaranteed to lie at the same distance. Any apparent velocity anisotropy in their distribution on the sky would then reflect a real velocity anisotropy. In practice, one requires a magnitude window of order 1^m in order to obtain a large enough sample and the situation is no longer so simple because the sample will include galaxies at different distances. The finite window and finite dispersion in galaxy luminosities introduces a Malmquist bias into the sample; distant galaxies preferentially sample the bright end of the luminosity function and nearer galaxies the faint end, thus artificially steepening the velocity-magnitude relation. This effect alone would not of course produce an anisotropy in the sample if galaxies were distributed in a spatially uniform manner. However, the real distribution of galaxies is very inhomogeneous, at least on scales less than 50 Mpc or so. Thus, in a sample with finite magnitude window, distant and therefore high velocity galaxies will be over-represented in the direction of a distant cluster whereas nearer and therefore lower velocity galaxies will be over-represented in the direction of a nearer cluster.

We have considered such an effect in relation to the sample of galaxies discussed by Rubin, Ford and Rubin (1973; hereafter denoted RFR). Their sample consists of 74 ScI galaxies in the magnitude window ($13\overset{m}{.}9$, $14\overset{m}{.}9$) for which redshifts were available at that time. RFR commented on the distinctly anisotropic velocity distribution in this sample; the mean recessional velocities in two large regions of the sky, denoted I and II, differed by almost 1500 km s^{-1}, yet the mean apparent magnitudes in the two regions differed by only $0\overset{m}{.}1$ and their mean diameters by only 14 per cent. Since ScI galaxies are thought to be good standard candles this result has often been taken as evidence for anisotropic cosmic expansion.

Figure 1 shows that the RFR sample galaxies are clustered in the sense

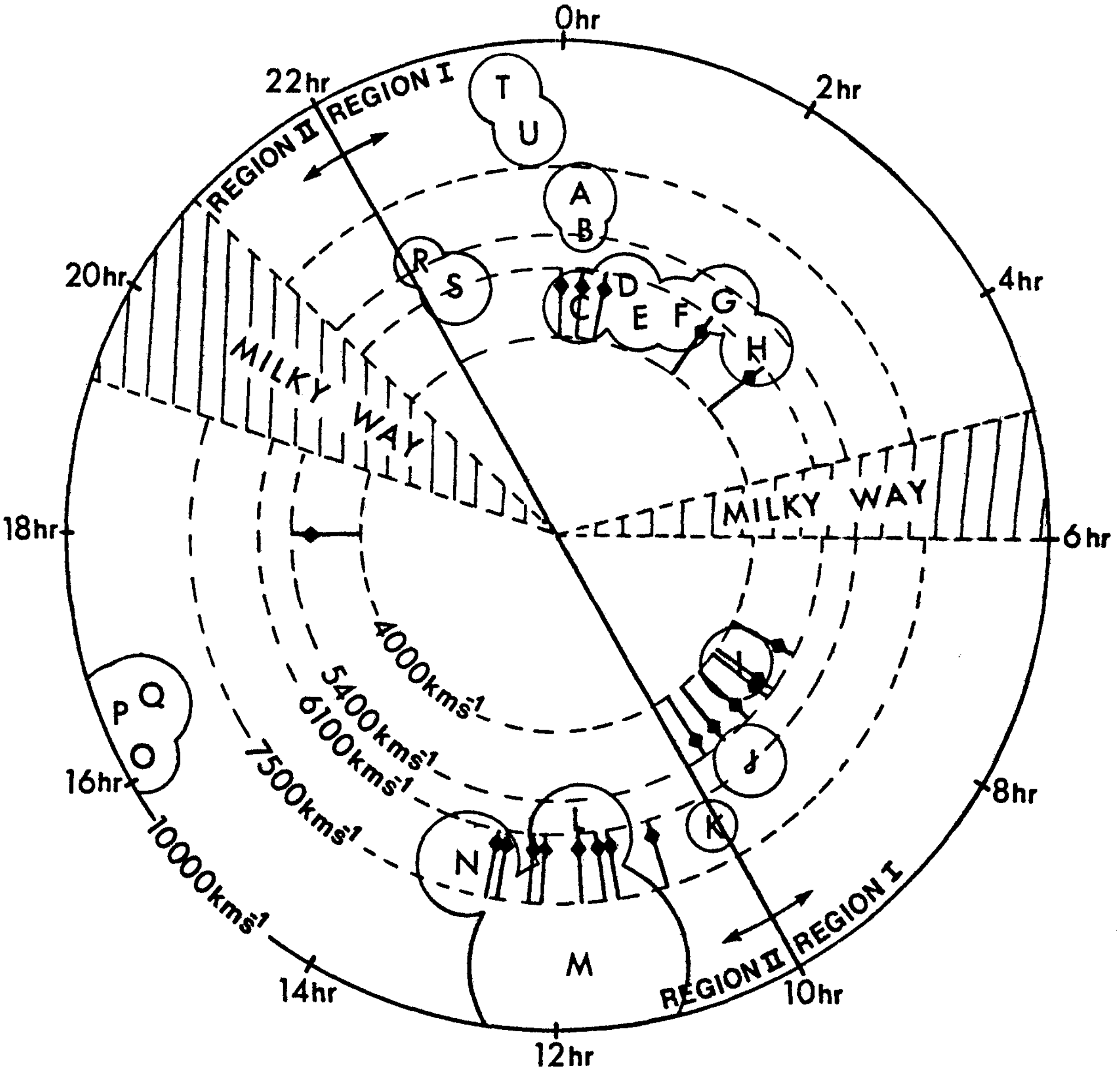

Fig. 1 Clusters (○) and Rubin-Ford Sc I galaxies (—◆—) with $20^{\circ} < \delta < 42^{\circ}$.

required to give an apparent anisotropy even if the real velocity field is isotropic so long as the mean distance of galaxies in Region II is greater than the mean distance of galaxies in Region I. (Other declination bands show a similar but less pronounced correlation between clusters and sample galaxies.) To test this we have idealized to a model in which the low velocity band of clusters and sample galaxies in Region I is considered as a single 'cloud' and the high velocity band of clusters and sample galaxies in Region II is considered as another 'cloud', each cloud having the mean

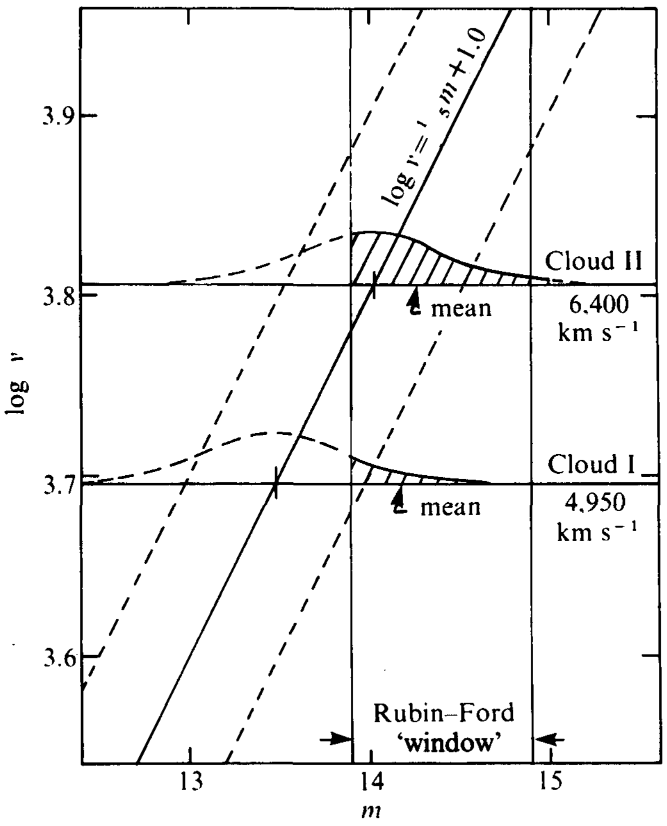

Fig. 2 Graph illustrating the calculation of mean apparent magnitudes for low and high velocity galaxies on the two-cloud model. The dashed diagonal lines are σ = 0.50 mag away from the mean velocity-magnitude line. All velocities are in km s^{-1}.

velocity of sample galaxies in the two separate regions. Figure 2 shows how the apparent magnitude window and dispersion in the absolute magnitudes of Sc I galaxies may contrive to produce the mean apparent magnitude difference of $0\overset{m}{.}1$ found by RFR for their sample galaxies in the two regions. A simple calculation based on this two-cloud model also 'predicts' the required 14 per cent difference in angular diameters for the two regions. Details of the argument are given elsewhere (Fall and Jones 1976; see also Sandage and Tammann 1975).

Although the model discussed above is very schematic in that it attempts to model a complicated distribution by a simple one, it is consistent with all of the data reported by RFR and the hypothesis of isotropic expansion. Thus it would seem to point up the importance of this kind of selection effect in anisotropy studies. Since the original RFR analysis, Rubin, Ford, Thonnard, Roberts and Graham (1976a,b; hereafter referred to as RFTRG) have obtained redshifts and 21 cm data for the larger sample of 184 Sc I galaxies discussed by Rubin in her review at this symposium. The new data show a velocity anisotropy very similar to that of the earlier RFR data and, when divided into two distinct velocity ranges, has a distance dependence consistent with a peculiar motion of the local group of galaxies of about 500 km s^{-1}.

From the new data RFTRG argue that the observed anisotropy cannot be explained in terms of the kind of selection effect discussed above. This is because the diameters and 21 cm line widths of their sample galaxies do not show a systematic variation across the sky as is required by an explanation based on inhomogeneities. However, it is not yet clear that these tests are sensitive enough to rule out even large contributions to the anisotropy arising from selection effects involving inhomogeneities. (Since RFTRG have neglected variations in distance, they have over estimated the expected variation in diameters when testing for effects due to inhomogeneities.) The spatial distribution of galaxies is inhomogeneous and its effect is bound to enter anisotropy studies at some level, if only because the data are not independent and the errors thus under-estimated.

III Dynamical Effects

Finally, we offer some remarks on the dynamical relation between the spatial distribution and the velocity distribution of matter in the Universe.

One possible cause of velocity anisotropy is a shearing motion on scales much larger than inhomogeneities in the spatial distribution. However, this seems to be ruled out by the RFTRG data and is difficult to reconcile with the primeval interpretation of the microwave background radiation. This is because such shearing motions would not be expected to increase as the Universe expands. The existence of such large-scale shearing motions would force us to the conclusion that the early universe was very anisotropic and it would then be difficult to understand why the Universe is as homogeneous as it appears to be.

Velocity perturbations on scales comparable with spatial inhomogeneities are often referred to as peculiar motions and they require less drastic measures. They may arise in two ways: as the result of (i) large primordial peculiar velocities or (ii) accelerations produced by the lower gravitational potential near inhomogeneities. There does not appear to be enough non-gravitational energy available on scales larger than individual galaxies for its effect to be important, now or in the past. (See Peebles 1974 for a lucid discussion of this point.)

Any primordial velocities unsupported by inhomogeneities must now be less than about 300 km s^{-1} in order that they be subluminal at a redshift of 1000 when recombination is supposed to have occurred. However, such large primordial velocities are difficult to understand in view of the rapid damping of motion by Thompson scattering which must have occurred in the primeval fireball plasma. Thus the standard cosmological picture forces us to look to inhomogeneities as the major dynamical cause of peculiar galaxy motions. Part of this motion may result from the orbits of galaxies in bound and relaxed aggregates while part of it may result from expansion which has been slowed or reversed as galaxies fall towards such aggregates.

This line of reasoning suggests that we seek such an explanation for the large peculiar velocity of the local group indicated by the recent RFTRG data. Here we offer several remarks along these lines. If the hypothetical matter responsible for our peculiar motion is less than about 5 h^{-1} Mpc away (h is Hubble's constant in units of 100 km s^{-1} Mpc^{-1}), then there would have been time to complete at least half an orbit and the direction of our motion may not reflect the direction of the perturbing matter. However, this possibility can be ruled out because it would lead to a tidal field which is larger than is allowed by the small velocities within the local group. Thus the perturbing matter must lie roughly in the direction of motion ($\ell = 163^{o}$, $b = -11^{o}$). Since the anisotropy reported by RFTRG decreases with distance beyond about 30 h^{-1} Mpc or less, the perturbing matter must lie within that distance. Furthermore, since the RFTRG motion has a very small component in the direction of the Virgo cluster of galaxies, the mass-to-light ratio of the perturbing matter must be much higher than that of the Virgo cluster, independent of its distance. This follows from the simple fact that the ratio of apparent luminosity to gravitational acceleration is distance-independent as has been recently emphasized by Gott and Gunn in a slightly different context.

To summarize: the simplest explanation for the motion reported by RFTRG may be a massive but faint object lying in the direction of motion at some distance greater than about 5 h^{-1} Mpc and less than about 30 h^{-1} Mpc. In order to test this hypothesis it would be of interest to study the velocity distribution in several other magnitude windows, particularly (13^{m}, 14^{m}).

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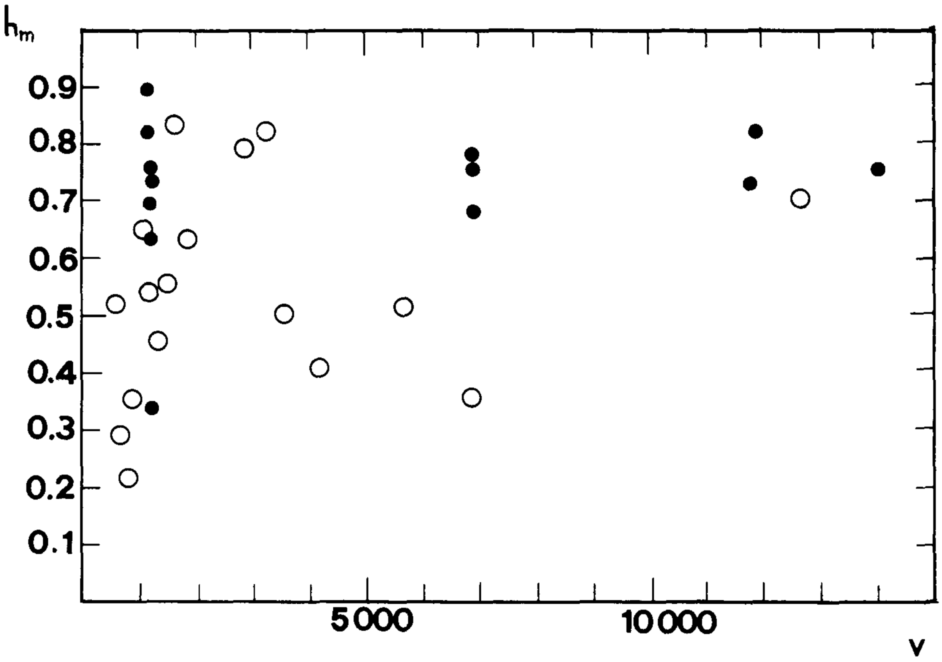
DISCUSSION

H. KAROJI: We have also looked for the explanation of the Rubin-Ford effect, and effectively we have found that the existence of clusters of galaxies is very important, but in a different way from that of Jones and Fall.



The figure shows the distribution of hm's of 30 type I supernovae (hm: Hubble modulus) versus radial velocity, v. The hm values of galaxies <u>in and behind</u> a cluster (filled circles) are greater than those of galaxies whose light does not encounter any cluster (open circles). One can see that, even if we divide the sample in small intervals of velocity, the filled circles are always situated higher than the open circles.

Our tentative conclusion is that clusters of galaxies may be a source of an increase in the Hubble modulus.