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Large Scale Deviations from the Hubble Flow

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Introduction

All standard Big Bang cosmologies have one thing in common. The initial state from which the Universe has developed, was homogeneous and isotropic to a "very high degree". Indeed we now observe that the distribution of galaxies is very homogeneous and isotropic when smoothed over a suitable large area of the sky. Also we observe that galaxies recede from one another in a universal manner described by the Hubble law, and this law is considered as valid on sufficiently "large scales". There is additional observational evidence in the "very high degree" of isotropy of the microwave background radition, neglecting the very well understood dipole anisotropy for the moment.

As the observational techniques have improved tremendously in recent years, the time has also come for the observers to quantify statements like "large scales" and "very high degree". It seems that the determination of the values of these poorly determined quantities finally are approaching the situation, where it is no longer the equipment of the observer but rather the adopted analysis of the observations, which is the crucial factor.

Such quantities have turned out to be some of the most desired physical parameters for tests of cosmological models, and we are now very close to getting important insights into cosmological phenomena. As the accuracy of observationally determined parameters increases, the number of models which can match them all decreases. The gain is therefore twofold. We can increase our knowledge of the present Universe and at the same time reduce the number of theories which claim to describe the evolution of it. The big trouble of course is that human beings can invent new theories all the time, so in reality it is only the former of these two statements which is true.

Previous Work

Almost since the discovery of the microwave background radiation, a dipole anisotropy has been noticed. It can be rather precisely accounted for if the Sun moves at 377 ± 14 km s^{-1} towards (l, b) = (267°, 50°) (Fixen et al. 1983), where (l, b) are galactic coordinates. With the standard de Vaucouleurs convention for the motion of the Sun relative to the Local Group, this means that the Local Group moves at 614 ± 14 km s^{-1} towards (l, b) = (269°, 28°).

In 1976 Rubin and Ford (Rubin et al. 1976) measured the velocity of the Local Group with respect to Sc I galaxies in the redshift range from ≈ 0.01 to ≈ 0.02, corresponding to 3,000 – 6,000 km s^{-1} in the Hubble flow. They considered these galaxies to be standard candles and found a significant motion of the Local Group of 454 ± 125 km s^{-1} towards (l, b) = (163°, −11°). This implied a motion of the frame defined by the Sc I galaxies relative to the microwave background of 862 ± 125 km s^{-1}. Ten years later, Aaronson et al. (1986) found no evidence for any net motion with respect to the microwave background for a sample of cluster spirals in the ring of sky accessible to the large Arecibo radio telescope. Their analysis was based on distances estimated from the infrared Tully Fisher relation. A programme designed to estimate distances to a sample of elliptical galaxies performed by a group of seven collaborators (Lynden-Bell et al. 1988) has changed the game somewhat. This group has demonstrated that the situation is much too complicated to be described by a simple motion of our Local Group towards a system of galaxies as defined above. They have shown that a model in which the bulk flow of galaxies is replaced by the flow generated by a mass concentration centred on (l, b) = (307°, 9°) at a distance corresponding to 4,350 km s^{-1} in the Hubble flow, now baptized "the great attractor", gives a much better understanding of the situation.

Determining Distances to Spiral Galaxies

The original Tully Fisher relation is a correlation between total B magnitude corrected to face-on and the 21 cm linewidth corrected to edge-on. In order to minimize the uncertainties in deprojecting the linewidth, one has to stick to highly inclined galaxies. This on the other hand increases the uncertainties in the estimated total B magnitudes. When the photometry is done in the infrared (H band at 1.6 μm), this problem is expected to be reduced considerably. There is however one disadvantage in using H band photometry. H magnitudes are measured within a standard aperture A, which is determined by the condition that $\log A/D_0 = -0.5$, where D_0 is the isophotal diameter at 25 B mag arcsec^{-2} for the galaxy seen face-on. This choice of aperture has been made primarily because of historical lack of a suitable devise to make detailed surface photometry of galaxies in the near infrared. A nice demonstration of the somewhat complicated situation can be found on one of the figures in Giraud (1987).

The combination of the optical and infrared Tully Fisher relations has suggested another distance indicator. This is an infrared colour-magnitude (C-M) relation which is based upon an observed correlation between $(B\text{-}H)_{-0.5}$ colour and $H_{-0.5}$ magnitude (Wyse 1982), where the subscript$_{-0.5}$ refers to the standard aperture described above. This relation has the advantage over the Tully Fisher relation that galaxies, which are seen face-on, can be used and thereby reduce the uncertain correction procedures for deprojecting inclined galaxies to face-on. However small these corrections at first may seem to be in the infrared, one can forsee that there are at least three potential problems. The aperture is related to D_0, and this parameter becomes still more badly determined the more inclined the galaxy is. And secondly, it is not simple to deproject a spiral galaxy to face-on, when it is seen through a relatively small aperture. At least to my knowledge it has in theoretical work only been studied in detail how one can hope to deproject a whole galaxy. Finally the majority of galaxies with $H_{-0.5}$ photometry only have B magnitudes at large apertures, and, therefore, extensive use of mean growth curves in order to extrapolate to the required $B_{-0.5}$ magnitudes, increases the uncertainties in the $(B-H)_{-0.5}$ colour further.

Modelled Inclination Effects

I have tried to investigate some of the effects induced by corrections for inclinations. This is done on the basis of a simple model for an exponential disk galaxy, which includes absorbtion.

The change of the modelled B and H observations with inclination, within 5 different standard apertures for a model galaxy is shown in Figure 1. The apertures chosen correspond roughly to 1, 2, 3, 4 and 5 times the standard aperture diameter previously defined. From the figures we see that although the galaxy at the largest aperture appears monotonically fainter with increasing inclination, the situation is more complicated at the smaller apertures. One should naturally take into account that this simple model only emphasizes the problems. In particular it is worth mentioning that the influence of a bulge component is totally neglected here. The model may only be a good approximation for Sc-Sd galaxies.

The curves in the two plots are the result of two effects: optical thickness and geometry. For an optically thin system, as a galaxy is expected to be in the H band, we will get more and more light from the outer part of the galaxy into the fixed aperture as we turn it towards edge-on. This explains most of what is seen on Figure 1a. An optically thick system will, due to inner absorption, lack this effect, and at the same time the amount of light coming from the internal parts will be reduced with increased inclination. Therefore, in a system with a moderate optical thickness, as is expected to be the situation in the B band, these two effects will compete. This is seen on Figure 1b.

As mentioned earlier there are problems with the analysis of existing $B_{-0.5}$ and $H_{-0.5}$ photometric data. To achieve some insight on their importance, I have tried to model them. In Figure 2 I have shown how a model galaxy by an inadequate treatment of the inclination corrections, that is without any correction for any of the mentioned effects, will be shifted from its locus in the C-M diagram for different inclinations, as indicated by the labels. Notice that for a face-on galaxy the shift is purely due to the use of mean growth curves. To see how this can influence the distance estimate to a cluster, I have simulated "observations" of cluster spirals. The spatial orientations were chosen at random – although all inclined more than 50° to be comparable with existing observations, see next section. The B-H magnitudes were chosen at random between 2.0 and 4.0 and the H magnitudes were generated from a linear C-M relation. Figure 3 is a plot of these observations. Also shown is the linear C-M relation from which the galaxies have been generated. It is evident that the data points still are in agreement with a linear correlation but the intersection differs from the original by a few tenths of a magnitude. This results in an error in the distance estimate of the order of 10–20 %, which is crucial for the study of large scale motions.

Observations

Existing data on B and H magnitudes are biased towards highly inclined galaxies. This is because until now H band photometry has been focused on applicability to Tully Fisher. Thus select-

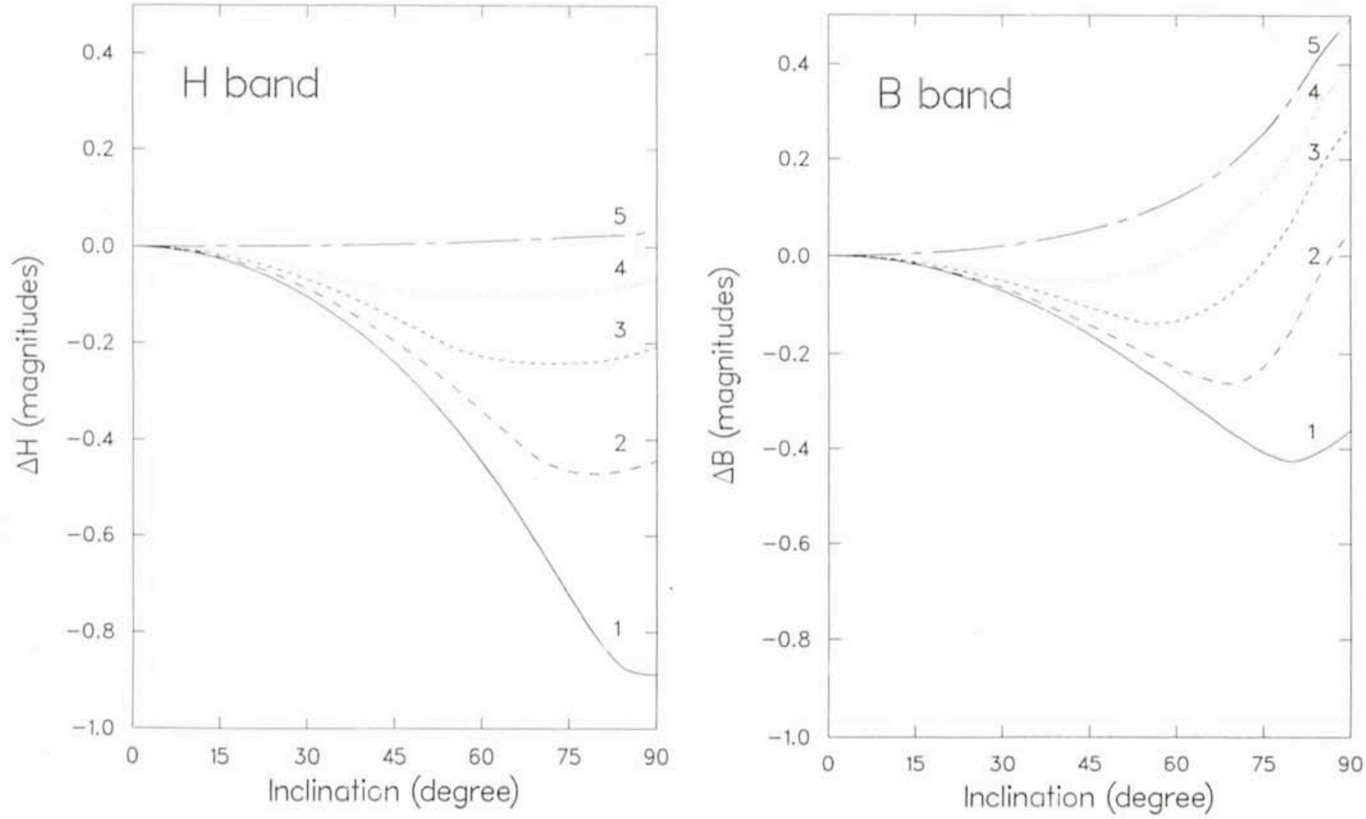

Figure 1: *(a) Change in "observed" H magnitude with respect to inclination for an exponential disk model, including absorbtion. Labels refer to aperture size, see text. (b) The same for B magnitudes.*

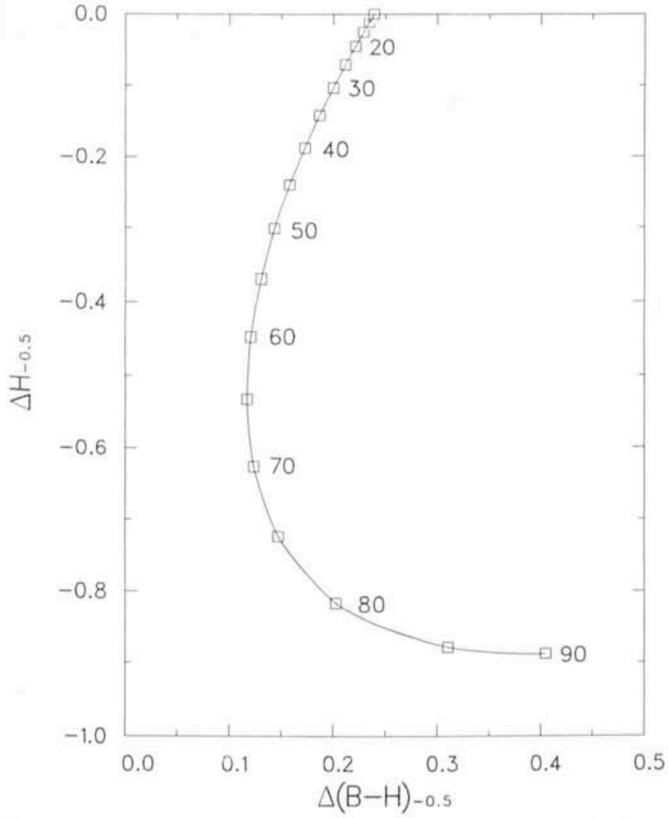

Figure 2: *Displacement in (B-H) and H due to the inclination effects at log $A/D_0 = -0.5$, and extrapolation of $B_{-0.5}$ from large aperture photometric data by means of mean growth curves.*

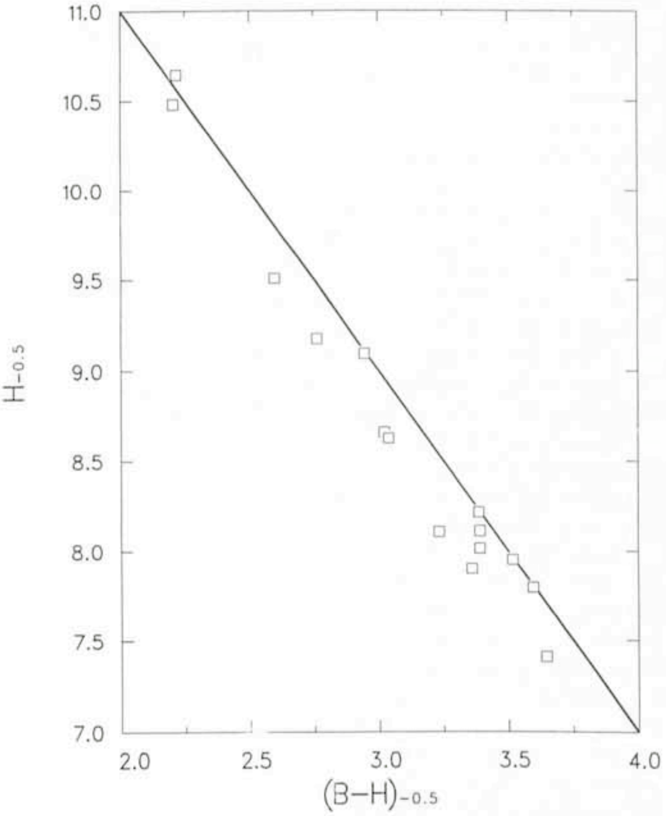

Figure 3: *Simulated $(B\text{-}H)_{-0.5}-H_{-0.5}$ relation for a sample of model galaxies, when no corrections for inclinations are made. Straight line shows the C-M relation from which the data has been generated.*

ing a sample of primarily face-on galaxies for observations in B and H, at apertures near log $A/D_0 = -0.5$, would seem to be a good opportunity to study the C-M relation in more detail. When at the same time one chooses to use galaxies with known redshifts, the full step of making a contribution to our further understanding of "large scale deviations from the Hubble flow" is within reach.

Thirteen nights in two runs (September/October 1987 and May/June 1988) at the ESO 1-m telescope have until now been allocated to a project, where this is the main goal. The data were acquired using a single channel photometer with the "Quantacon" in the B band, and after a change of setup to infrared in the middle of the observing period, with an infrared photometer using an InSb detector for the H band photometry. Unfortunately, very poor weather conditions were encountered during the major part of the first observing period. Useful observations under photometric conditions could be performed in B for less than 1 night and in H for 1 night so far. Since each galaxy has to be observed through a couple of apertures in each band, only observations of an uninterestingly small number of galaxies have been finished so far. Thus there is hardly enough to comment on yet. Hopefully I shall be in a better position after my next run at La Silla.

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Searching for Double Degenerates

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The Elusive Progenitors of Type I Supernovae

The majority of stars are members of binary systems; this is a frequently referred aphorism. The majority of stars also terminate their evolution as white dwarfs (WDs), as only few stars are born massive enough to experience a supernova explosion. We can easily conclude that the majority of binary systems must at some stage become a double WD binary, and that a good fraction of the stars listed in our catalogues as WDs may indeed be double.

Very few WDs, however, are known for being double, and indeed Greenstein (1986) lists just six such objects. These are very wide pairs, visual double degenerates, in which each component has evolved independently of the other, as if it were a single star. An example of this kind may be provided by the Sirius system: in less than one billion years also Sirius A will be a WD, and Sirius A+B will become a wide double degenerate (DD) system. But in *close* binaries the evolution of each component is severely affected by the presence of the companion: The system can experience