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THE HUBBLE CONSTANT FROM PRITCHET AND VAN DEN BERGH'S NOVA DISTANCE TO THE VIRGO CLUSTER

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ABSTRACT

A value of $H_0 = 58 \pm 12$ km s^{-1} Mpc^{-1} is justified from Pritchet and van den Bergh's data for novae in the Virgo cluster, using $\langle V \rangle = 1196 \pm 67$ km s^{-1} rather than 1336 ± 54 for the "cosmological" velocity of the Virgo cluster core (corrected for solar motion and Virgo infall), and $m - M = 31.57$ rather than 31.45 for the cluster modulus. The 1 σ limits from this particular data set via the Virgo cluster novae are $45 < H_0 < 75$, consistent with $H_0 = 50 \pm 10$ obtained from a number of unbiased current distance indicators that have been analyzed for the global value of H_0.

Subject headings: cosmology — galaxies: clustering — galaxies: distances — stars: novae

I. INTRODUCTION

From their discovery and photometry of normal novae in Virgo cluster ellipticals, Pritchet and van den Bergh (1987*b*, hereafter PB) have obtained the difference in the apparent blue distance moduli between M31 and the Virgo cluster to be $\Delta(m - M)_{AB} = 6.8 \pm 0.4$ mag. Using their RR Lyrae apparent blue distance modulus for M31 (PB 1987*a*) of $(m - M)_{AB} = 24.65 \pm 0.15$, they obtained $(m - M)_{AB}^{VIRGO} = 31.45 \pm 0.43$ for the apparent blue modulus of the Virgo cluster. They then adopted the "cosmological" redshift of the Virgo cluster to be 1336 ± 54 km s^{-1}, giving $H_0 = 69 \pm 14$ km s^{-1} Mpc^{-1} for the *free expansion Hubble parameter* of the local supercluster (see Tammann and Sandage 1985, hereafter TS, for this concept).

The purpose of the present paper is to call attention to two reasons why this value of H_0 is likely to be too high by $\sim$20%, even adopting, without question, the PB value of $\Delta(m - M) = 6.8 \pm 0.4$ of the M31 − Virgo modulus difference. The first reason concerns the Virgo cluster velocity itself. The second concerns the adopted distance to M31.

II. THE FREE EXPANSION VELOCITY OF THE VIRGO CLUSTER CORE

Pritchet and van den Bergh adopted $V_0 = 1336 \pm 54$ km s^{-1} for the corrected velocity of the Virgo cluster core, obtained by adding $\Delta V = 303 \pm 39$ km s^{-1} (Aaronson *et al.* 1982) for Virgo infall to Huchra's (1985) listed mean Virgo velocity of 1151 ± 38 km s^{-1} and corrected then to the Local Group centroid by applying $\Delta V = -118 \pm 15$ km s^{-1} (Yahil, Tammann, and Sandage 1977).

It is our view that $\langle V \rangle = 1151$ km s^{-1} for the mean heliocentric Virgo velocity is too high because of the inclusion of background field galaxies in Huchra's Virgo sample. From the Virgo cluster survey (Binggeli, Tammann, and Sandage 1987, hereafter BTS), where background objects could generally be identified by their morphological types, BTS obtained a mean heliocentric Virgo velocity of $\langle V \rangle = 1094 \pm 42$ km s^{-1}, which is 56 km s^{-1} lower than Huchra's value. BTS tested for background contamination by comparing the mean $\langle V \rangle$ values for the 4° (radius) cluster core with $\langle V \rangle$ in the 4° to 6° annulus centered on the cluster. The core value is $\langle V \rangle = 1070 \pm 50$ km s^{-1}, even lower than the BTS adopted value of 1094 ± 42. The mean velocity for all galaxies considered by Huchra in the 4° to 6° annulus is $\langle V \rangle = 1292 \pm 55$ km s^{-1}, clearly showing background contamination in this outer region.

It is also our view that ΔV(infall) = 303 km s^{-1} is too large by $\sim$40%. The preferred value of $\Delta V = 220 \pm 50$ km s^{-1} is based on nine determinations (TS, Table 4). A value as large as 300 km s^{-1} is unlikely, based on the weight of determinations that are independent of that used by Aaronson (see also footnote 1).

With these changes in $\langle V \rangle$ and ΔV (infall), an alternative value for the Virgo cluster velocity corrected for solar motion and infall is $1094 \pm (42) - 118\ (\pm 15) + 220\ (\pm 50) = 1196 \pm 67$ km s^{-1}. This[1] is 11% lower than used by PB. If the other parameters $[\Delta(m - M)_{\rm M31,\,VIRGO}$ and the M31 distance] are kept the same, the velocity change reduces the PB Hubble parameter from 69 ± 14 to 62 ± 13 km s^{-1} Mpc^{-1}. The error is calculated from ± 0.43 mag in $(m - M)_{\rm VIRGO}$ as given by PB, and $\Delta V/V = 0.056$ from our estimate of ± 67 km s^{-1} as the Virgo mean velocity error on 1196 km s^{-1}.

III. APPARENT DISTANCE MODULUS OF M31

From their mean magnitude of $\langle B \rangle = 25.68$ for the RR Lyrae stars in the M31 disk, PB (1987*a*) deduce $(m - M)_{AB} = 24.65 \pm 0.15$ as the apparent blue modulus for the disk region of M31 that they searched. They made the reasonable assumption that the M31 novae observed by Arp (1956) and Rosino (1973) have this modulus. Most of the novae are in the bulge

[1] Our adopted Virgo velocity of 1196 km s^{-1} agrees well with 1182 ± 20 km s^{-1} which is the predicted mean *unperturbed* velocity of the Virgo cluster as obtained from a comparison with field and cluster galaxies (for a compilation of the relevant data cf. TS, Table 3). The value also agrees well with 1197 ± 52 km s^{-1} which follows from scaling down the Coma cluster velocity to the relative Virgo cluster distance, *if* the modulus difference of the two clusters is $(m - M)_0 = 3.90 \pm 0.10$ (cf. TS, Table 5). Both routes are independent of any assumed Virgocentric infall velocity and, of course, of H_0.

which is assumed to have no internal absorption, similar to the Population II disk.

Our view is that the appropriate apparent blue modulus for M31 is ~0.1 mag larger than assumed by PB. The evidence is from three sources.

1. Mould and Kristian (1986) obtain a *true* modulus of $(m - M)_0 = 24.4 \pm 0.25$ from I band magnitudes of giants in the M31 disk. To this we must add $A_B = 0.44 \pm 0.08$ for foreground absorption in our own Galaxy (McClure and Racine 1969). This procedure, which assumes that there is no *internal* absorption of those parts of the disk that are well away from the spiral arms, gives $(m - M)_{AB} = 24.4 \pm 0.44 = 24.84 \pm 0.26$.

2. Infrared observations of Cepheids give $(m - M)_0 = 24.26 \pm 0.08$ (Welch *et al.* 1986) for the *true* modulus. In Field IV of Baade and Swope (1963), Welch *et al.* estimate the H band absorption to be $A_H = 0.05 \pm 0.02$ mag. This corresponds to a B band absorption of $A_B = 0.38 \pm 0.15$. This is smaller than $A_B = 0.64$ obtained from $E(B-V) = 0.16$ of Baade and Swope (1963) but is close to $A_B = 0.44 \pm 0.08$ for the foreground reddening by McClure and Racine (1969). This value of A_B applied to $(m - M)_0 = 24.26$ gives $(m - M)_{AB} = 24.70 \pm 0.11$, a value that depends on a Cephied calibration that gives $(m - M)_H = 18.52$ for the apparent H band distance modulus to LMC, leading to a true modulus for LMC of 18.51. There is now general support for this value (Feast 1986; Tammann 1978*a*, *b*). It is 0.09 mag smaller than determined by Sandage and Tammann (1971, hereafter ST) from the *P-L-A* Cepheid relation.

3. Direct measurement of $(m - M)_{AB}$ from Field IV M31 Cepheids, corrected for amplitude effect, is $(m - M)_{AB} = 24.76 \pm 0.2$ (ST). If there is no internal absorption in Field IV itself, this is the appropriate apparent modulus to use with the M31 novae.

The advantage of method (3) is that it gives the *apparent* blue modulus of Field IV directly, not a value obtained from a true modulus value corrected for A_B as in methods (1) and (2). Of course, the same is true for the PB (1987*a*) RR Lyrae star method of obtaining $(m - M)_{AB}$ directly in which, however, they had to assume an $\langle M_B \rangle$ value for their RR Lyrae sample—an uncertain procedure because of the intrinsic range of ~0.4 mag for RR Lyrae stars in a *given* metal rich cluster (Sandage 1987). The problem of the RR Lyrae star spread in M at a given [Fe/H], due to evolution from the zero age horizontal branch, is different from that of a possible mean absolute magnitude dependence on metallicity (Sandage 1982), which is still unproved.

The average of the three methods to the M31 modulus, treated with equal weight, is $(m - M)_{AB} = 24.77 \pm 0.2$ which is 0.12 mag fainter than adopted by PB. This reduces the Hubble parameter by an additional 6% as follows. Using the PB value of $\Delta(m - M) = 6.8 \pm 0.4$ gives $(m - M)_{AB}^{VIRGO} = 31.57 \pm 0.43$. The corresponding distance, assuming $A_B = 0$ (Virgo is in the north Galactic pole), is $D = (20.6 \pm 20\%)$ Mpc which, with $\langle V \rangle_0 = 1196 \pm 67$ km s^{-1} gives $H = 58 \pm 12$ km s^{-1} Mpc^{-1}, being 20% smaller than PB's estimate.

An independent test of this conclusion, based again only on the high weight distance to M31, is possible from the $D_n - \sigma$ relation for bulges of spiral galaxies (Dressler 1987), where D_n is a photometric diameter to the isophotal level of $B = 19.75$ mag s^{-2}, and σ is the central velocity dispersion. Dressler obtained a modulus to Virgo of $(m - M)_0 = 31.64 \pm 0.2$ (21.3 Mpc) using a true modulus for M31 of $(m - M)_0 = 24.20$. Although this Virgo modulus is in excellent agreement with the PB nova method that gave $(m - M)_0 = 31.57 \pm 0.43$ in the preceding paragraph, Dressler's Virgo modulus may, itself, be systematically slightly too low.

First it is 0.06 mag smaller than would have been obtained had $(m - M)_0 = 24.26$ been used, as above (Welch *et al.* 1986). Second, D_n for M31 depends on the adopted front absorption A_B, because it is an isophotal diameter. Dressler assumed $A_B^{M31} = 0.31$, which is lower than $A_B = 0.44$ we have adopted here. This increases D_n^{M31} (arcsec) as measured on the plane of the sky; the true isophote at 19.75 mag s^{-2} is at a larger angular distance from the center than the measured (apparent) isophote in the presence of front absorption. For a difference of 0.13 mag in A_B, the difference in D_n is 6% [for an r^2 falloff in $I(r)$ for the M31 bulge]. This changes the absolute calibration of the $D_n - \sigma$ relation in the direction of increasing the Virgo $(m - M)_0$ modulus via this method.[2]

The conclusion is that although the independent check of the nova value of $(m - M)_0^{VIRGO} = 31.57 \pm 0.43$ via the $D_n - \sigma$ calibration of Dressler is excellent at $(m - M)_0 \geq 31.64 \pm 0.2$, this latter value is likely itself to be a lower limit, and therefore that $H = 58 \pm 12$ km s^{-1} Mpc^{-1} for the *free expansion* rate of the local supercluster is likely an upper limit when these two methods are considered together. If the Virgo cluster modulus is taken to be $(m - M)_0 = 31.7$ (Sandage and Tammann 1976), then $H = 55$ via this route using the Virgo cluster directly. If $(m - M)_0 = 31.85$, then $H = 51$ km s^{-1} Mpc^{-1}.

IV. THE GLOBAL VALUE OF H_0

To this point we have ignored the motion of the Virgo extended supercluster toward the microwave background (MWB). The problem of transforming various velocity frames (i.e., the Local Group to the Virgo center, then to the MWB frame) had been considered elsewhere (TS, 1985) where we concluded that the global value of H_0 is given by

$$H_0 = (50 \pm 7)(21.6/D_{VIRGO}) \text{ km s}^{-1} \text{ Mpc}^{-1}$$

if our velocity-frame corrections are valid.

This value was based, in part, on the modulus difference between Virgo and Coma of $\Delta(m - M) = 3.90 \pm 0.10$ (TS, Table 5). Modern data, including new high weight values by Lucey (1986) and Lynden-Bell (1986), reduce this to 3.78 ± 0.05 (Tammann 1978*a*, Table 5). The consequence, via a detailed chain from Virgo to Coma to the general field (Tammann 1987*b*, Fig. 1), gives $H_0 = (53 \pm 7)(21.6/D_{VIRGO})$. Hence, from the above interpretation of the PB data we obtain

$$H_0(\text{global}) = 56 \pm 12 \text{ km s}^{-1} \text{ Mpc}^{-1} .$$

We should, however, emphasize that we do not, at this writing, believe that this *is* the value of H_0, considering all alternate routes (Tammann 1978*a*, *b*), but only that it *need not* be as high as 69 using only the PB novae data. A fair summary of the 1 σ limits from these particular data is $45 < H_0 < 75$ km s^{-1} Mpc^{-1}.

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[2] Lynden-Bell *et al.* (1987) give an absorption correction of $\Delta \log D_n = 0.32 \Delta A_B$. With $\Delta A_B = 0.13$ mag, this corresponds to a factor of 1.10 D_n which is even larger than our value of 6%. The resulting Virgo modulus would then be $(m - M)_0 = 31.85$.

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