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ON VAN DEN BERGH'S METHOD FOR MEASURING THE HUBBLE CONSTANT FROM TYPE Ia SUPERNOVAE

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ABSTRACT

In a recent Letter, van den Bergh used the explosion-model light-curve calculations of Höflich & Khokhlov to calibrate the Hamuy et al. sample of remote Type Ia supernovae (SNe Ia) and obtained low values of H_0 in the range 55–60 km s^{-1} Mpc^{-1}. Citing a higher value of H_0 obtained from Cepheid-based distance determinations to a few galaxies in the Virgo Cluster complex, van den Bergh concluded that unless the Cepheid distance scale is wrong, the models of Höflich & Khokhlov must be much too bright or much too red. Here we calibrate the same sample of remote SNe Ia in the same way as was suggested by van den Bergh, but now relying on Cepheid-based determinations of the distances to SN Ia parent galaxies instead of the explosion-model light-curve calculations. No corrections for extinction of the SNe Ia are required, and no SNe Ia need be excluded on grounds of peculiarity. We obtain $H_0 = 57 \pm 5$ km s^{-1} Mpc^{-1}. Various subsamples of the data give H_0 in the range 54–60 km s^{-1} Mpc^{-1}. This shows that the fault lies not with the SN Ia models, nor with Cepheids, but with the hazardous route through the Virgo complex.

Subject headings: distance scale — supernovae: general

1. INTRODUCTION

An interesting way to use Type Ia supernovae (SNe Ia) to determine the value of the Hubble constant, H_0, has been suggested by van den Bergh (1995; hereafter vdB95). He notes that the wide variety of explosion-model light curves that have been calculated by Höflich & Khokhlov (1996; hereafter HK96) obeys a relation between the peak visual absolute magnitude M_V and the $B - V$ color, with a slope that is similar to that of the standard extinction law, $A_V/E(B - V) = 3.1$. Consequently one can define a parameter

$$M_V^* = M_V - 3.1(B - V), \qquad (1)$$

which is, to a first approximation, independent of both extinction and supernova model. From the models of HK96, vdB95 derived values of M_V^* ranging from -19.60 ± 0.05 to -19.75 ± 0.02, depending on which weights were assigned to the various models. For the 13 real SNe Ia that were observed by Hamuy et al. (1995; hereafter Ha95), which are well out in the Hubble flow ($3000 \leq cz \leq 30{,}000$ km s^{-1}), vdB95 found

$$M_V^* = -19.59 \pm 0.11 + 5 \log (H_0/60) \qquad (2)$$

and therefore obtained values of H_0 ranging from 60 ± 3 to 55 ± 3 km s^{-1} Mpc^{-1}. These values depend on the models and the light-curve calculations of HK96, but they are independent of any astronomical calibration.

Within the last few years distances have been determined to the parent galaxies of six SNe Ia by means of Cepheid variables in their parent galaxies (Sandage et al. 1992, 1994, 1996; Saha et al. 1994, 1995, 1996a, 1996b). *Indirect* Cepheid-based distances also have become available for three other SNe Ia, if one is willing to use the distance to a galaxy in the same group in lieu of the distance to the SN Ia parent galaxy itself. The purpose of this Letter is to determine the value of H_0 in a way that is like that of vdB95, but now using Cepheid distances instead of the HK96 models.

2. DATA

Data for the Cepheid-calibrated SNe Ia for which the peak B and V magnitudes are known are listed in Table 1. (SN 1895B in NGC 5253 cannot be used here because only B is known.) Sources of the data are as follows.

SN 1937C.—Values of B and V are from Schaefer (1994), and the distance modulus, μ, is from Saha et al. (1994). The uncertainty in $B - V$ is less than would be obtained from the quadrature sum of the uncertainties in B and V because, as explained by Schaefer (1994), the uncertainties in B and V are correlated.

SN 1960F.—Values of B, V, and μ are from Saha et al. (1996b).

SN 1972E.—Values of B and V are from Ha95, and μ is from Saha et al. (1995). The uncertainty in $B - V$ is our estimate, taking into account that in the fitting procedure of Ha95 the uncertainties in B and V are correlated.

SN 1981B.—Values of B and V are from Schaefer (1995), and μ is from Saha et al. (1996a).

SN 1986G.—Values of B and V are from Phillips et al. (1987), and μ is equated to that of SN 1972E because their parent galaxies, NGC 5128 and NGC 5253, are both members of the Centaurus group. We include an additional uncertainty of ± 0.4 for SN 1986G because these two galaxies are separated by 11°.8 degrees on the sky, so SN 1986G enters the analysis with low weight.

SN 1989B.—Values of B and V are from Wells et al. (1994), and μ is equated to that of NGC 3368 (Tanvir et al. 1995) because NGC 3627, the parent galaxy of SN 1989B, and NGC 3368 are fellow members of the Leo spur (Tully 1987). According to Tully, the Leo spur stretches out close to the plane of the sky and has relatively little depth from our viewing position. We have included an additional uncertainty of ± 0.14 in the distance modulus of SN 1989B to allow for possible differences in distance between NGC 3627 and NGC 3368, and

TABLE 1

CEPHEID-CALIBRATED TYPE Ia SUPERNOVAE

SN	Galaxy	B	V	$B - V$	μ	M_V
1937C.............	IC 4182	8.71 ± 0.14	8.72 ± 0.06	−0.01 ± 0.13	28.36 ± 0.09	−19.64 ± 0.11
1960F.............	NGC 4496	11.60 ± 0.10	11.51 ± 0.15	0.09 ± 0.18	31.04 ± 0.14	−19.53 ± 0.26
1972E.............	NGC 5253	8.61 ± 0.21	8.61 ± 0.12	0.00 ± 0.09	28.08 ± 0.10	−19.47 ± 0.16
1981B.............	NGC 4536	12.04 ± 0.04	11.98 ± 0.04	0.06 ± 0.06	31.10 ± 0.13	−19.12 ± 0.14
1986G.............	NGC 5128	12.45 ± 0.05	11.40 ± 0.05	1.05 ± 0.07	28.08 ± 0.41	−16.68 ± 0.42
1989B.............	NGC 3627	12.34 ± 0.05	11.99 ± 0.05	0.35 ± 0.07	30.37 ± 0.21	−18.38 ± 0.22
1990N.............	NGC 4639	12.70 ± 0.05	12.61 ± 0.05	0.09 ± 0.07	32.00 ± 0.23	−19.39 ± 0.24
1991T.............	NGC 4527	11.64 ± 0.05	11.50 ± 0.04	0.14 ± 0.06	31.07 ± 0.13	−19.57 ± 0.14

0.05 has been added for the *HST* "long exposure" effect (Sandage et al. 1996).

SN 1990N.—Values of B and V are from Leibundgut et al. (1991), and μ is from Sandage et al. (1996).

SN 1991T.—Values of B and V are from Phillips et al. (1992). According to the Nearby Galaxies Catalog (Tully 1988), NGC 4536, 4496, and 4527, the parent galaxies of SNe 1981B, 1960F, and 1991T, respectively, are members of the same small group of galaxies (group 11-4 in Tully's notation). Further evidence that these three galaxies are at practically the same distance is discussed by Branch et al. (1996a). From Cepheids, Saha et al. (1996a, 1996b) find $\mu = 31.10 \pm 0.13$ for NGC 4536 and $\mu = 31.03 \pm 0.14$ for NGC 4496. We assume that NGC 4527 is at $\mu = 31.07 \pm 0.14$.

3. RESULTS

The quantity M_V, uncorrected for extinction, is plotted against $B - V$ (more precisely, $B_{\max} - V_{\max}$) in Figure 1*a*. The eight Cepheid-calibrated SNe Ia are plotted as filled circles, and the 13 SNe Ia of Ha95 are plotted as triangles. We retain the K-corrections applied by Ha95, but for this application we have removed the corrections for Galactic extinction that were applied by Ha95. The general trend is for the data points to lie along the extinction line. SN 1989B, intrinsically normal but extinguished (Wells et al. 1994), and SN 1986G, intrinsically dim and red *and* extinguished (Phillips et al. 1987), lie near the extinction line. SN 1990Y, probably intrinsically normal but extinguished (Ha95), and SN 1992K, intrinsically dim and red (Hamuy et al. 1994), are somewhat farther off. We proceed on the assumption that equation (1), with the standard reddening slope, is correct as it stands; i.e., we make no allowance for departures from the adopted slope of 3.1.

Using all the data, and matching the 13 SNe Ia from Ha95, for which $M_V^* = -19.45 \pm 0.12 + 5 \log (H_0/60)$ (we weighted the data according to their errors and took into account the fact that the errors in M_V and $B - V$ are correlated, and we were unable to reproduce the value given by vdB95), to the eight Cepheid-calibrated SNe Ia, for which $M_V^* = -19.57 \pm 0.12$, gives $H_0 = 57 \pm 5$ km s^{-1} Mpc^{-1}. If we omit SN 1937C on the grounds that its B and V are disputed (Pierce & Jacoby 1995; Schaefer 1996b) we obtain the same value. If, instead, we omit SN 1986G, SN 1991T, and SN 1989B because the Cepheid distances are not to their own parent galaxies, we obtain $H_0 = 60 \pm 6$ km s^{-1} Mpc^{-1}. If, instead, we omit the six SNe Ia of Ha95 that were discovered more than 10 days after maximum light (inverted triangles in Fig. 1), we obtain $H_0 = 54 \pm 6$ km s^{-1} Mpc^{-1}.

Because the effects of extinction and of intrinsic differences among SNe Ia surely are not identical in the (M_V, $B - V$) plane, it might be safer to apply a color cut, thus using a smaller color baseline. If we restrict our attention to the clustered, "normal color" SNe Ia that have $|B - V| \leq 0.25$ (Vaughan et al. 1995) and match the 11 such SNe Ia from Ha95 to the six such Cepheid-calibrated SNe Ia, we obtain $H_0 = 54 \pm 5$ km s^{-1} Mpc^{-1}.

Figure 1*b* is just like Figure 1*a* except that H_0 is set to 85 rather than 57 km s^{-1} Mpc^{-1}. This causes the remote SNe Ia to move down by 5 log (85/57) = 0.87 mag. Now *all* of the normal-color Cepheid-calibrated SNe Ia are brighter than *all* of the normal-color SNe Ia of the remote sample. This is unacceptable on astronomical grounds and shows that SNe Ia cannot be reconciled with $H_0 = 85$.

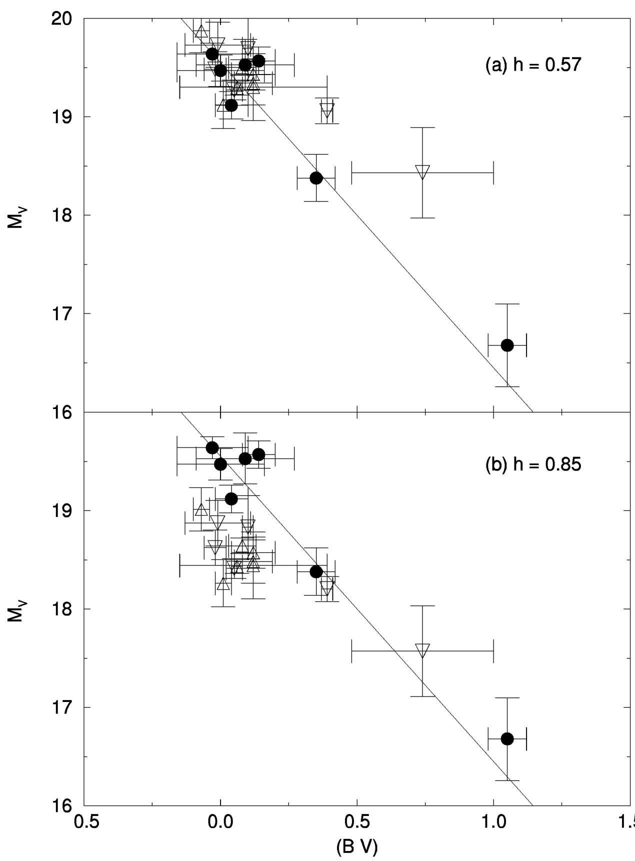

FIG. 1.—(*a*) Peak visual absolute magnitude, uncorrected for extinction, is plotted against $B - V$ for Cepheid-calibrated SNe Ia (*filled circles*) and the Ha95 sample of remote SNe Ia (*triangles*; for those SNe Ia discovered 10 or more days after maximum light the triangles are inverted). The straight line has the extinction slope, $A_V/E(B - V) = 3.1$. Fitting the Cepheid-calibrated SNe Ia to the SNe Ia of Ha95 gives $H_0 = 57 \pm 5$ km s^{-1} Mpc^{-1}. (*b*) Same as (*a*), using $H_0 = 85$ instead of 57.

4. DISCUSSION

van den Bergh (1995) suggested that the conflict between the low value of H_0 that he obtained using the HK96 models of SNe Ia and a higher value obtained by him and others (Pierce et al. 1994; Freedman et al. 1994) using Cepheid-based distance determinations to a few spiral galaxies in the Virgo cluster complex implied that unless Cepheids are unreliable distance indicators, the HK96 models must be either much too red or much too bright. However, we have shown that *the method of vdB95, using Cepheids rather than the HK96 models, gives the same low value of H_0*. This shows that the fault lies not with the HK96 models, nor with the Cepheids, but with the hazardous route through the Virgo complex (Sandage & Tammann 1996; Branch, Nugent, & Fisher 1996b; Tammann et al. 1996; Tammann 1996). High values of H_0 are excluded.

The present results for H_0 are in excellent agreement with the straightforward standard candle treatments of Sandage et al. (1996) and Schaefer (1996a) and with the result of Branch, Romanishin, & Baron (1996c), who distinguish between SNe Ia in blue and red galaxies; this is not very surprising because all these results rely on the same Cepheid-based determinations of SN Ia parent galaxies. The agreement of the present results with those that we have obtained by means of Cepheid-independent, physically based methods (e.g., Branch 1992; Baron, Hauschildt, & Branch 1994; Nugent et al. 1995a, 1995b; Branch et al. 1996b) gives us some confidence that future modifications to the Cepheid period-luminosity law will not have strong effects on the value of H_0 obtained from SNe Ia. Some (Ha95; HK96; Riess, Press, & Kirshner 1995, 1996) find slightly higher values of H_0 from SNe Ia, in the mid-60s. While all values obtained from SNe Ia are in agreement within the uncertainties (e.g., $H_0 = 60 \pm 6$ could serve as a current consensus value), it is important for cosmology to further reduce the uncertainties and narrow the possible range of H_0.

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