**H₀ from HST**

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**Abstract.** *HST* has so far provided Cepheid distances to nine galaxies. Although not sufficient yet to determine the distance of the extended Virgo cluster, they are decisive for the distance scale in two ways. (1) Seven of the galaxies contribute to a much improved calibration of the Tully-Fisher relation. Applying this to a complete sample of Virgo spirals one obtains a cluster distance of \((m−M) = 31.79 ± 0.09\). Other distance indicators support this value. The adopted linear distance of \(22.0 ± 0.8\) Mpc combined with the cluster velocity of \(1178 ± 32\) km s\(^{-1}\) (in the CMB frame) gives \(H₀ = 54 ± 2\) (internal error). (2) Six of the galaxies have been the site of seven SNe Ia with well observed maxima. Their resulting calibration in absolute magnitudes gives \(M_B(\text{max}) = −19.53 ± 0.07\) and \(M_V(\text{max}) = −19.49 ± 0.07\) with negligible intrinsic scatter. If this calibration is used to determine the distances of all distant SNe Ia with known maxima and with \(1100 < v < 30\,000\) km s\(^{-1}\), \(H₀\) becomes \(56 ± 3\) (internal error). Systematic errors tend to make this an upper limit; in particular the case \(H₀ ≥ 70\) can be excluded. – The conclusion is that the large-scale value of the Hubble constant is \(H₀ = 55 ± 10\) (external error).

**1. Introduction**

The influence of *HST* on the determination of \(H₀\) is already enormous and it can only grow. In Table 1 a compilation is given of distance determinations with *HST* having some bearing on \(H₀\). The values scatter between 55 and 80 and the formal mean is \(H₀ = 61 ± 3\). This, however, is not the best value, because some values shown are mutually incompatible.

There are now two self-consistent routes to \(H₀\) to which *HST* has heavily contributed. The first route via the Virgo cluster is described in Section 2, the second route using supernovae of type Ia (SNe Ia) is discussed in Section 3.

Much of what follows depends on Cepheid distances. A word on the reliability of their P-L relation is therefore in place. The P-L relation of Madore & Freedman (1991), adopted in the following, assumes an LMC modulus of 18.50. Actual confirmation of this value to better than 0.10 mag comes from the P-L relation calibrated by Galactic Cepheids (Sandage & Tammann 1968; Feast & Walker 1987) and independently from the ring of SN 1987A (Panagia et al. 1991; Gould 1994); further support is given by RR Lyr stars and other distance determinations (cf. Tammann 1996). The zero point of the adopted P-L relation is therefore secure to < 5% in linear distance. The slope of the relation is well determined.
Table 1. \( H_0 \) determinations from \( HST \)

| I. Cepheids              |                     |
|--------------------------|---------------------|
| a) in M101               | Kelson (1995)       |
|                          | confirms Sandage & Tammann (1974), from which follows 55 ± 9 |
| b) in Leo Group         | Tanvir et al. (1995) |
|                          | present paper 57 ± 6 |
| c) in Virgo Cluster     | Freedman et al. (1994) |
| NGC 4321                | Sandage et al. (1996) |
|                         | 80 ± 17             |
|                         | 47 ± 10             |

II. Tully-Fischer distance of Virgo cluster using 11 Calibrators with Cepheid Distances (7 of which from \( HST \))

| Federspiel et al. (1996) | 52 ± 6 |

III. SNe Ia calibrated through Cepheids

| SN 1937C                | Saha et al. (1994) |
|                        | 52 ± 9             |
| SN 1972E               | Hamuy et al. (1995) |
|                        | 65 ± 10            |
| SN 1972E               | Riess et al. (1995) |
|                        | 67 ± 7             |
| SN 1895B               | Schaefer (1995)    |
|                        | 51 ± 7             |
| 6 SNe Ia               | Branch et al. (1996) |
|                        | 57 ± 7             |
| 7 SNe Ia               | Sandage et al. (1996) |
|                        | 58 ± 4             |

IV. Globular Clusters

| in M87                  | Whitmore et al. (1995) |
|                        | 78 ± 11               |
| in Coma                 | Sandage & Tammann (1996) |
|                        | 62 ± 9                |
|                        | Baum et al. (1995)    |
|                        | < 65                  |

by the LMC Cepheids; it is of less importance as long as the Cepheids under consideration cover a sufficient period range, which is also needed to avoid selection effects (Sandage 1988). Metallicity effects are believed to be small (Freedman & Madore 1990; Chiosi et al. 1993).

2. The Distance of the Virgo Cluster

2.1. Cepheids

When the first reliable Cepheid distance of a Virgo galaxy (NGC 4321) became available from \( HST \) (Freedman et al. 1994) it was precipitately hailed the Virgo cluster distance (Mould et al. 1995; Kennicutt et al. 1995), although the value of 17 Mpc was suspiciously low. The next two Virgo galaxies, NGC 4536 (Saha et al. 1996a) and NGC 4496A (Saha et al. 1996b), again had very low distances. Only the fourth galaxy, NGC 4639, revealed the important depth of the cluster (note for comparison: the spiral members span ~ 15° in the sky!). Its distance is 25 Mpc (Sandage et al. 1996) and yet it is a bona fide cluster member; with a small velocity of 800 km s\(^{-1}\) it cannot be assigned to the background.

It is no accident that the first three Virgo spirals with Cepheid distances lie on the near side of the cluster. They were selected from Sandage & Bedke’s (1988) atlas of galaxies most suited for \( HST \); they were thus biased to begin with. NGC 4639 looks much more difficult and would not have been selected had it not produced the archetypal SN 1990N.

It is now clear that it will take at least a dozen Cepheid distances of a randomly selected sample of Virgo members to obtain a meaningful mean cluster distance.

Meanwhile Tanvir et al. (1995) have suggested to step up their Cepheid-based Leo group distance of \((m - M) = 30.32 ± 0.16\) out to the Virgo cluster by means of relative distance determinations. The best available relative distances are compiled in Table 2. Adding the mean difference of \(\Delta(m - M) = 1.25±0.13\) to the above distance modulus gives
a Virgo cluster modulus of $(m - M)_{\text{Virgo}} = 31.57 \pm 0.21$. For brevity we will refer to this value in the following as the “Cepheid distance of the Virgo cluster”.

### Table 2.

| Method                  | $\Delta(m - M)_{\text{Virgo-Leo}}$ | Source              |
|-------------------------|------------------------------------|---------------------|
| Tully-Fisher            | 1.35 ± 0.20                        | Federspiel et al. (1996) |
| Globular clusters       | 1.47 ± 0.42                        | Harris (1990)       |
| $D_n - \sigma$          | 0.97 ± 0.29                        | Faber et al. (1989) |
| Planetary nebulae       | 1.15 ± 0.30                        | Bottinelli et al. (1991) |
| Velocities              | 1.30 ± 0.30                        | Kraan-Korteweg (1986) |
| mean:                   | 1.25 ± 0.13                        |                     |

### 2.2. The Tully-Fisher Relation

There are now 11 spiral galaxies with Cepheid distances (seven of which come from $HST$) which are useful for the calibration of the relation between absolute magnitude and log $w$ ($w = \text{inclination-corrected 21cm-line width}$). Two close companions of M101 bring the number of useful calibrators to 13 (cf. Table 3). Two galaxies (M101 and M100) are less inclined than the frequently adopted limit of $i = 45^\circ$; yet their inclinations are so well defined by mapping their velocity field that they are still useful as calibrators.

### Table 3.

| Name                   | Hubble-type | $(m - M)_{\text{mag}}$ | Source                        | $M_B_{\text{mag}}$ | $i_{\text{RC3}}$ | $\log w$ |
|------------------------|-------------|------------------------|-------------------------------|--------------------|------------------|----------|
| N224 (M31)             | 3           | 24.44                  | Madore & Freedman (1991)      | -21.10             | 78               | 2.739    |
| N300                   | 5           | 26.67                  | Madore & Freedman (1991)      | -18.14             | 44               | 2.344    |
| N598 (M33)             | 5           | 24.63                  | Madore & Freedman (1991)      | -18.89             | 55               | 2.373    |
| N2403                  | 5           | 27.51                  | Tammann & Sandage (1968)      | -19.19             | 62               | 2.484    |
| N3031 (M81)            | 3           | 27.80$^*$              | Freedman & Madore (1994)      | -20.49             | 65               | 2.697    |
| N3368 (M96)            | 2           | 30.32$^*$              | Tanvir et al. (1995)          | -20.55             | 50               | 2.656    |
| N4321 (M100)           | 5           | 31.16$^*$              | Freedman et al. (1994)        | -21.25             | 36               | 2.786    |
| N4496A                 | 5           | 31.13$^*$              | Saha et al. (1996b)           | -19.46             | 43               | 2.428    |
| N4536                  | 4           | 31.11$^*$              | Saha et al. (1996a)           | -20.64             | 66               | 2.546    |
| N4639                  | 3           | 32.00$^*$              | Sandage et al. (1996)         | -20.10             | 50               | 2.626    |
| N5204                  | 7           | 29.30                  | like M101                     | -17.93             | 57               | 2.146    |
| N5457 (M101)           | 5           | 29.30$^*$              | Kelson (1995)                 | -21.11             | 27               | 2.588    |
| N5585                  | 7           | 29.30                  | like M101                     | -18.26             | 52               | 2.290    |

* Cepheid distance from $HST$

The date in Table 3 yield the following calibration of the TF relation

$$M_B = -6.39 \log w - 3.80 \quad (\sigma = 0.44) \quad (1)$$

(Federspiel et al. 1996), where the slope is taken from the Virgo cluster.

An objective and complete sample of Virgo spirals is defined by the 48 non-peculiar galaxies of type Sab–Sdm from the Virgo Cluster Catalog (Binggeli et al. 1985) with $i \geq 45^\circ$ and lying within the isopleths of substructures A and B (see Binggeli et al. 1993) or, without changing the result, within the X-ray contour of the cluster (Böhringer et al. 1994).
This sample together with equation (1) gives \((m - M)_{\text{Virgo}} = 31.79 \pm 0.15\). The use of infrared instead of \(B\) magnitudes does not bring an advantage (Schröder 1995), nor does the application of the inverse TF relation. For the robustness of the result against variations of the input parameters the reader is referred to Federspiel et al. (1996).

### 2.3. Other Distances to the Virgo Cluster

The peak of the luminosity function (LF) of globular clusters (GC) has frequently been used as a standard candle. A modern calibration of the GCs in the Galaxy and in M31 combined with a compilation of published GCLFs in five Virgo ellipticals has led to a Virgo modulus of \((m - M)_{\text{Virgo}} = 31.75 \pm 0.11\) (Sandage & Tammann 1995). Meanwhile Whitmore et al. (1995) found a very bright peak magnitude in \(V\) and \(I\) for NGC 4486, which is well determined with \(HST\) and which corresponds, with our precepts, to a modulus of 31.41 \(\pm\) 0.28 (Sandage & Tammann 1996). However, the GCs in NGC 4486 have a bimodal color distribution which is suggestive of age differences and possible merger effects (Fritze-von Alvensleben 1995; Elson & Santiago 1996). Turning a blind eye to this problem and averaging over all available GCLFs in Virgo we obtain \((m - M)_{\text{Virgo}} = 31.67 \pm 0.15\). We are aware that the method may still face considerable problems.

The \(D_n - \sigma\) method, normally applied to ellipticals, was extended to the bulges of S0 and spiral galaxies by Dressler (1987). Using the bulges of the Galaxy, M31, and M81 as local calibrators, one obtains \((m - M)_{\text{Virgo}} = 31.85 \pm 0.19\) (Tammann 1988).

Novae are potentially powerful distance indicators through their luminosity-decline rate relation. Using the Galactic calibration of Cohen (1985), Capaccioli et al. (1989) have found the apparent distance modulus of M31 to be \((m - M)_{\text{AB}} = 24.58 \pm 0.20\) (i.e. somewhat less than indicated by Cepheids). From six novae in three Virgo ellipticals Pritchet & van den Bergh (1987) concluded that the cluster is more distant by 7.0 \(\pm\) 0.4 mag than the apparent modulus of M31, implying \((m - M)_{\text{Virgo}} = 31.58 \pm 0.45\) (zero absorption is adopted for the Virgo cluster, see Section 2.6). The result carries still small weight, but is interesting because it is based on novae exclusively. \(HST\) observations, although time-consuming, of novae in the Virgo cluster could much improve this independent result.

Theoretical models of SNe Ia by various authors converge towards \(M_B = -19.45 \pm 0.15\) for “Branch normal” objects (Branch 1996; Höflich & Khokhlov 1996; Ruiz-Lapuente 1996). It is true that fainter, nearby SNe Ia are known, but being red and spectroscopically peculiar they can easily be singled out, and they do not contaminate distant, luminosity-selected samples of SNe Ia (cf. Section 3). Eight SNe Ia which have occurred in the Virgo cluster have \(<m_B(\text{max})> = 12.10 \pm 0.15\) mag. This value combined with the theoretical calibration gives \((m - M)_{\text{Virgo}} = 31.55 \pm 0.25\). Had we used instead the empirical calibration of Table 5 below, the Virgo modulus would have become larger by 0.08 mag. We refrain from using this value because the routes towards \(H_0\) in Sections 2 and 3 are to be kept strictly apart.

### 2.4. Suspicious Distance Indicators

The assumption that the LF of the shells of planetary nebulae (PN) in the light of the 5007 Å line had a universal cutoff at \(M_{5007} = -4.48\) mag has led to a Virgo modulus significantly lower than obtained from the six methods discussed above (Jacoby et al. 1990). Yet it was pointed out that the cutoff magnitude depends on the sample size (i.e. the absolute magnitude of the parent galaxy; Bottinelli et al. 1991; Tammann 1993). Numerically simulated LFs of the shell luminosities confirm indeed the dependence on sample size and population age (Méndez et al. 1993). As a consequence the published PN distances deviate systematically from the Cepheid distances. The deviations increase with distance from M81 (Jacoby et al. 1989), NGC 5253 (Jacoby & Ciardullo 1993), and the Leo group (Ciardullo et al. 1989) to reach at the Virgo cluster (Jacoby et al. 1990) 0.74 mag! A new method
to derive PN distances, allowing for sample size and other effects, has been proposed by Soffner et al. (1995); the first result for the nearby galaxy NGC 300 is encouraging.

Surface brightness fluctuations (SBF) have also been proposed as distance indicators (Tonry & Schneider 1988). The first “test” has remained rather unconvincing, spreading the elliptical Virgo cluster members over an interval of 12 to 24 Mpc (Tonry et al. 1990); this interval was interpreted as real although early-type galaxies are known to be concentrated in the cores of galaxy clusters. Moreover the individual distances correlate with the Mg index (Lorenz et al. 1993). Finally we note that the SBF distances of NGC 5253 (Phillips et al. 1992), the Leo group (Tonry 1991), and the Virgo cluster (Tonry 1991) are smaller than Cepheid distances by as much as 0.97, 0.48, and 0.56 mag, respectively.

For the said reasons we use neither the PN nor the SBF distances.

2.5. The Structure and Velocity of the Virgo Cluster

A census of the Virgo cluster containing almost 2000 certain and possible members (Binggeli et al. 1985) reveals a complex structure with two main subclusters A and B and additional concentrations some of which, particularly in the south-western part, are more distant. To obtain a genuine cluster sample we restrict the sample to the 364 galaxies with known redshifts lying within the outer isopleths of subclusters A and B (Binggeli et al. 1993; the individual galaxies are listed there). Their mean velocity is \( \langle v_0 \rangle = 918 \pm 35 \text{ km s}^{-1} \) (with respect to the Local Group centroid). If one considers instead the 361 galaxies within the very similar X-ray contour of the cluster (Böhringer et al. 1994) the mean velocity becomes 983 \( \pm \) 39 km s\(^{-1}\). Taking all 385 galaxies with redshifts in the Virgo survey area, excluding only background objects, we find \( \langle v_0 \rangle = 937 \pm 35 \text{ km s}^{-1} \). From this we adopt a best cluster velocity of \( \langle v_0 \rangle = 950 \pm 30 \text{ km s}^{-1} \). This result supersedes an early value of \( \langle v_0 \rangle = 1073 \pm 50 \text{ km s}^{-1} \) (Huchra 1988) which was based on only 250 galaxies and a less well defined area.

To obtain the cosmic recession velocity of the Virgo cluster the observed value must still be corrected for the deceleration of the Local Group. We adopt \( v_{\text{infall}} = 220 \pm 50 \text{ km s}^{-1} \) (cf. Tammann 1996) and find for Virgo \( v_{\text{cosmic}} = 1170 \pm 61 \text{ km s}^{-1} \).

Yet we prefer a very similar value the rational of which, however, is quite different. Many authors step up the Virgo distance out to the Coma cluster using the relative distance modulus between Virgo and Coma, and find \( H_0 \) at the distance of Coma. One can repeat that with any cluster whose distance relative to Virgo is known. In fact there are at least 14 clusters with rather good relative distances and velocities \( 4000 < v_{\text{CMB}} < 11\,000 \text{ km s}^{-1} \) (\( v_{\text{CMB}} \) is the velocity in the frame of the microwave background). The best cosmic value of \( H_0 \) is then the all-sky mean over 14 different \( H_0 \) determinations. But more elegant is the reverse method: the relative distances are used to scale down the velocities of the 14 clusters and to predict a mean Virgo cluster velocity, i.e. the \( v_{\text{Virgo}} \) velocity which the cluster would have in the absence of all local deviations from an ideal expansion field. The result of this procedure is \( v_{\text{Virgo}} = 1178 \pm 32 \text{ km s}^{-1} \) (Sandage & Tammann 1990, Jerjen & Tammann 1993; Jerjen 1995 for a more rigid error determination).

2.6. The Mean Virgo Cluster Distance and \( H_0 \)

The six independent distance determinations of the Virgo cluster in Sections 2.1 – 2.3 are repeated in Table 4.

All distance moduli are taken to be true values, i.e. zero absorption is assumed towards the Virgo cluster. If the \( B \)-absorption implied by Burstein & Heiles (1984) is applied individually to all galaxies used for the distance determinations, the modulus becomes lower by only 0.06 mag. Even this almost negligible amount may be an overestimation as discussed by Sandage & Tammann (1996).
Table 4. Distance moduli of the Virgo cluster

| Method                     | \( (m-M)_{\text{Virgo}} \) |
|----------------------------|-----------------------------|
| Cepheids (via Leo)         | 31.57 ± 0.21                |
| Tully-Fischer              | 31.79 ± 0.15                |
| Globular clusters          | 31.67 ± 0.15                |
| \( D_n - \sigma \)        | 31.85 ± 0.19                |
| Novae                      | 31.58 ± 0.45                |
| Theor. Supernovae          | 31.55 ± 0.25                |

unweighted mean: 31.67 ± 0.05  
weighted mean: 31.71 ± 0.08  
mean linear distance: 22.0 ± 0.8 Mpc

If the adopted mean cluster distance of 22.0 ± 0.8 Mpc is combined with \( v_{\text{Virgo}}^{\text{CMB}} = 1178 ± 32 \text{ km s}^{-1} \) one obtains

\[
H_0 = 54 \pm 2 \text{ (internal error).} \tag{2}
\]

3. \( H_0 \) from SNe Ia

An *HST* program has been mounted to determine the large-scale value of \( H_0 \). The aim is to derive Cepheid distances (in \( V \) and \( I \) to control absorption effects) of up to ten galaxies which have produced well observed SNe Ia. So far we have calibrated the peak luminosity of six SNe Ia. A seventh object has become available through Tanvir’s et al. (1995) Cepheid distance of the Leo group. (It can be assumed that the member galaxies of this compact group lie practically at the same distance.) The resulting absolute magnitudes of the seven SNe Ia are shown in Table 5. Detailed discussions of the input parameters are given elsewhere (Sandage et al. 1996; Tammann et al. 1996; negligible differences between these sources are due to a different weighting of individual sources). The agreement to within the errors between the individual luminosities supports the claim that SNe Ia are (nearly) perfect standard candles. Independent confirmation of the luminosities comes from Höflich et al. (1996) who have three SNe Ia in common with Table 5. Their model luminosities are the same to within 0.12 ± 0.21 mag. Branch’s (1996) model luminosity of SN 1981B agrees fortuitously well with ours, and two SNe Ia of Ruiz-Lapuente (1996) are fainter by only 0.26 ± 0.25 mag judging from their late spectra and the inferred \(^{56}\text{Ni} \) mass.

Table 5. Absolute Magnitudes of SNe Ia at Maximum.

| Supernova | \( M_B(\text{max}) \) | \( M_V(\text{max}) \) | Reference\(^a\) |
|-----------|---------------------|---------------------|-----------------|
| SN 1937C  | −19.53 ± 0.15       | −19.50 ± 0.17       | 1               |
| SN 1972B  | −19.87 ± 0.22       | −19.67 ± 0.22       | 2               |
| SN 1972E  | −19.52 ± 0.22       | −19.49 ± 0.14       | 2               |
| SN 1981B  | −19.47 ± 0.17       | −19.45 ± 0.14       | 3               |
| SN 1981F  | −19.53 ± 0.14       | −19.62 ± 0.18       | 4               |
| SN 1990N  | −19.30 ± 0.24       | −19.39 ± 0.24       | 5               |
| SN 1989B  | −19.51 ± 0.21       | −19.49 ± 0.20       | 6               |

unweighted mean: −19.53 ± 0.07  
weighted mean: −19.49 ± 0.07

\(^{a}\)References.– (1) Sandage et al. 1992; Saha et al. 1994;  
(2) Sandage et al. 1994; Saha et al. 1995; (3) Saha et al. 1996a;  
(4) Saha et al. 1996b; (5) Sandage et al. 1996; (6) Tanvir et al. 1995.
Figure 1. Hubble diagrams in $B$ and $V$ of all non-red SNe Ia with known maximum magnitudes. Open circles and crosses are from the older archive literature. Filled circles are the modern data provided by Phillips (1993) and Hamuy et al. (1995). The very small $K$-corrections are applied.

The Hubble diagram of all SNe Ia beyond 1100 km s$^{-1}$ with reasonably well determined maximum magnitudes is shown in Fig. 1 (Tammann & Sandage 1995). Their intrinsic luminosity scatter must be considerably less than 0.35 mag, because much of the scatter is expected from observational errors and peculiar motions. Indeed the intrinsic scatter must be very small because even the most distant SNe Ia lie very close to the theoretical Hubble line of slope 0.2. The argument goes as follows. The most distant SNe Ia occupy a volume about 18,000 times larger than that of the local calibrators. The large volume must contain exceptionally luminous SNe Ia – if they existed – and they have a much enhanced discovery chance for two reasons: their apparent magnitude is brighter than average and they stay longer above the detection limit. But still, there are no objects significantly above the Hubble line, not even at large distances. This means: The sample of SNe Ia shown in Fig. 1 constitutes a homogeneous class of very luminous and unabsorbed objects.

When in the following the calibration of Table 3 is applied to the SNe Ia in Fig. 1, it should be kept in mind that “Branch normal” SNe Ia (cf. Branch et al. 1993) are compared
with the most luminous SNe Ia known. Therefore the resulting value of \( H_0 \) can only be, if anything, an upper limit.

Forcing a slope of 5 (corresponding to linear expansion) to the data in Fig. 1 gives

\[ B(\text{max}) = 5 \log v - (3.186 \pm 0.054), \]

and

\[ V(\text{max}) = 5 \log v - (3.289 \pm 0.055). \]

An easy calculation shows that the constant term \( C_\lambda \) in equations (3) and (4) is determined by

\[ C_\lambda = 5 \log H_0 - M_\lambda - 25. \]

Inserting \( M_B \) and \( M_V \) from Table 5 leads directly to \( H_0(B) = 54 \pm 3 \) and \( H_0(V) = 58 \pm 3 \), from which we adopt

\[ H_0 = 56 \pm 3 \text{ (internal error)}. \]

Equations (3) and (4) are defined out to 30 000 km s\(^{-1}\). The value of \( H_0 \) therefore represents the truly cosmic expansion rate.

At a time when only the very first calibrating SNe Ia were known it was suggested that SN 1972E was overluminous on the basis of its light curve shape (Hamuy et al. 1995; Riess et al. 1995) and that consequently the true value of \( H_0 \) was larger. In the light of seven calibrators this argument is now impossible. From first principles of stellar statistics it is known that seven nearby objects can on average not be more luminous than a distant, luminosity-segregated sample. This point is illustrated in Fig. 2, where the absolute magnitudes of the seven calibrators are compared to the absolute magnitudes of the distant SN sample. The latter are calculated once with \( H_0 = 50 \) and once with \( H_0 = 70 \). For \( H_0 = 70 \) the absurd situation arises that the distant SN Ia are systematically fainter than the nearby calibrators. The firm conclusion from this is that \( H_0 < 70 \).

A more detailed discussion of all external errors is given elsewhere (Tammann et al. 1996). It yields a confidence range of \( 44 < H_0 < 64 \).

4. Conclusion

The two independent routes towards the large-scale value of \( H_0 \), via the Virgo cluster and SNe Ia, give \( 54 \pm 2 \) and \( 56 \pm 3 \) (internal errors), respectively. Their only interdependence is that they rely on Cepheids (predominantly observed with \( HST \)), which are the least controversial distance indicators at present. Together they make a strong case for \( H_0 = 55 \pm 10 \) (external error). Values of \( H_0 < 40 \) are equally unlikely as values of \( H_0 > 70 \).

The relatively low value of \( H_0 \) is supported by additional methods, e.g. TF and other distances of field galaxies (Sandage 1994, 1996 and references therein), and the Zeldovich-Sunyaev effect (Lasenby & Hancock 1995, Rephaeli 1995). Baum’s et al. (1995) \( HST \) photometry of globular clusters in the Coma cluster requires \( H_0 < 65 \). A gravitationally lensed quasar sets \( H_0 < 70 \) (Dahle et al. 1994). Models of SNe Ia could not be understood if \( H_0 \) was \( \geq 60 \) (Branch et al. 1996) or in no case \( \geq 70 \) (Höflich & Khokhlov 1996; Ruiz-Lapuente 1996).

We believe that literature values significantly larger than \( H_0 = 65 \) are explained by an unwarrantedly high Virgo velocity, the unrealistic hope to fathom the depth of the Virgo cluster with only a single galaxy, the myth of a sharp, dispersionless cutoff of the luminosity function of planetary nebula shells, the reliance on the suspicious surface brightness fluctuation method, and/or simply by Malmquist bias which always artificially increases the value of \( H_0 \).
Figure 2. The absolute magnitude $M_B(\text{max})$ of all SNe Ia in or beyond the Virgo cluster with known $B(\text{max})$ versus velocity distance. Also shown are all faint red SNe Ia; they illustrate our point that no underluminous (or absorbed) SNe Ia are found at large distances. The distant objects must therefore be among the very brightest ones. $M_B(\text{max})$ of the calibrators (squares) is based on their Cepheid distances. For all other SNe Ia $M_B(\text{max})$ is calculated from the recession velocities and $H_0 = 55$ (upper panel) and $H_0 = 70$ (lower panel). Note that for $H_0 = 70$ the impossible case arises that the distant SNe Ia are on average less luminous than the nearby calibrators.

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