VARIATIONS OF THE COSMIC EXPANSION FIELD AND
THE VALUE OF THE HUBBLE CONSTANT

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Four Hubble diagrams are combined to test for the linearity of the cosmic expansion field. The expansion rate, $H_0$, is found to decrease by $\sim 5\%$ out to 18 000 km s$^{-1}$. Beyond this distance the mean value of $H_0$ is close to the value at 10 000 km s$^{-1}$. The absolute value of $H_0$ is derived in two different ways. The one leads through Cepheids from HST and blue SNe Ia to $H_0 = 57 \pm 7$ (external error) at 30 000 km s$^{-1}$. The other uses various distance indicators to the Virgo cluster whose distance can be extended to 10 000 km s$^{-1}$ by means of only relative cluster distances; the result of $H_0$ is closely the same. Independent distances from purely physical methods (SZ effect, gravitational lenses, and MBW fluctuations) cluster about $H_0$ (cosmic) $\approx 58$.

1 Introduction

At small scales the cosmic expansion field is highly disturbed. The negative recession velocity of the Andromeda nebula (M 31) is telling proof, as well as the local peculiar motion of 630 km s$^{-1}$ relative to the MWB comprising a volume of radius 2000 km s$^{-1}$ at least. The question therefore arises out to what distances one has to go that the observed expansion rate, i.e. the Hubble constant $H_0$, has truly cosmic significance. This problem is addressed in Section 2, where four Hubble diagrams are combined to test for the linearity of the expansion field in function of distance. In Section 3 distance determinations via Cepheid distances from Hubble Space Telescope (HST) and blue SNe Ia are pushed out to 30 000 km s$^{-1}$. The distance of the Virgo cluster is derived in Section 4 using different methods, and this distance is transported to 10 000 km s$^{-1}$ by means of relative cluster distances. Purely physical determinations of $H_0$ are compiled in Section 5. The conclusions are given in Section 6.

2 The linearity of the Cosmic Expansion Field

The fundamental test for the linearity of the cosmic expansion field is provided by the Hubble diagram. In its classical form it is a diagram with the logarithm of the redshift ($\log cz$) plotted against the apparent magnitude of standard candles. Useful standard candles are very luminous objects whose absolute magnitude scatter is $\leq 0.3$. The case of linear expansion requires a slope of 0.2. Any deviations from this slope translate directly into deviations from linearity.

The power of the Hubble diagram is twofold. It uses only directly observable quantities and the resulting scatter about the mean Hubble line is an upper limit of the luminosity scatter of the objects under consideration and therefore tests the basic assumption of standard candles.

Four Hubble diagrams which reach to progressively larger redshifts are shown in Fig. 1-4. The nature of the Hubble diagram in Fig. 4 is somewhat different,
Figure 1: The Hubble diagram of first-ranked E galaxies in nearby groups and clusters. Data from Sandage (1975).

Figure 2: Hubble diagram of 31 clusters with known relative distances. Asterisks are data from Jerjen & Tammann (1993). Open circles are from Giovanelli (1997). Filled circles are the average of data from both sources.
Figure 3: The Hubble diagram of 35 blue SNe Ia with photometry after 1985. Mean $B$ and $V$ magnitudes are plotted. The SNe Ia in elliptical galaxies are systematically fainter by 0.18 than those in spiral galaxies; they are here shifted by this amount. Data mainly from Hamuy et al. (1996) with additions as in Saha et al. (1997) and slightly revised by Parodi & Tammann (1998).

Figure 4: The Hubble diagram of first-ranked cluster galaxies in rich clusters. Data from Sandage, Kristian, & Westphal (1976).
using relative distance moduli of clusters instead of standard candles. These relative
moduli are much more secure than absolute distances which are always very sensitive
to sample incompleteness and selection biases. To allow for the different absolute
magnitudes of the objects in these diagrams (and for the use of relative cluster
moduli in Fig. 3) they are combined into a single Hubble diagram in Fig. 5 by a
Corresponding shift along the abscissa. The data are well fit by a Hubble line of
slope 0.2. A free fit gives a slope of $0.197 \pm 0.003$, which translates into $\log cz =
H_0 r^{0.985 \pm 0.015}$ (cf. Sandage, Tammann, & Hardy 1972; Jerjen & Tammann 1993).
The nearly perfectly linear expansion is therefore demonstrated over a very large
velocity interval.

The next step is to test for local deviations from the linear flow. To do this the
relative peculiar motions $\Delta v/v_c$ are plotted against the distance $r$ (or in sufficient
approximation against the recession velocity $v$). If $H_i = (v_c + \Delta v)/r$ is the perturbed
value of the Hubble ratio of the $i$-th object at distance $r$, and $H_0 = <H_i> = v_c/r$
the true Hubble constant, than $\Delta H/H_0 = (H_i - H_0)/H_0 = \Delta v/v_c$. In Fig. 6 all
residuals $\Delta v/v_c$ are read and combined within 5000 km s$^{-1}$ bins. Sliding means in
2500 km s$^{-1}$ steps are plotted in Fig. 6 against redshift.

Inspection of Fig. 6 suggests that the Hubble constant decreases from 1000 km s$^{-1}$

![Figure 5: Combined Hubble diagram from Fig. 1-4.](image)
to about 18 000 km s$^{-1}$ by $\sim$ 5%. This trend is independently supported by the first-ranked cluster galaxies of Lauer & Postman (1994), which have not been used here. Beyond 18 000 km s$^{-1}$ the scatter becomes large, leaving the possibility of local $\pm$10% variations of $H_0$, but the distant overall mean of $H_0$ lies close to the value found at $\sim$ 10 000 km s$^{-1}$.

A proviso should be added. In Figure 6 different objects were combined into a single Hubble diagram necessitating a shift for different absolute magnitudes and introducing additional degrees of freedom. Correspondingly the behavior of $\Delta H/H_0$ in Fig. 6 is not as robust as one would wish. In particular the position of the minimum at 18 000 km s$^{-1}$ depends only on a few points. A well occupied Hubble diagram with only one kind of objects would provide a stronger test. A continua-
tion of the Cerro Tololo programme (Hamuy et al. 1996) to discover and measure SNe Ia at all distances would therefore be of utmost importance. This will not only provide – if carried to very large distances – \(q_0\) and \(\Lambda\) (cf. Perlmutter et al. 1998; Schmidt et al. 1998), but also to a mapping of the Hubble flow in function of distance.

The consequences of deviations from linear expansion on the determination of \(H_0\) are clear. If our peculiar motion of \(630 \text{ km s}^{-1}\) is taken to be typical, a 10\% error is to be expected from a single object as far out as \(6000 \text{ km s}^{-1}\). In addition \(H_0\) determinations within \(10000 \text{ km s}^{-1}\) may be systematically too large by a few percent and in the range \(10000 – 20000 \text{ km s}^{-1}\) too low by the same amount. At \(10000 \text{ km s}^{-1}\) \(H_0\) is apparently closely the same as the mean value of \(H_0\) (cosmic) over very large scales.

3 \(H_0\) through Cepheids and SNe Ia

The most direct and reliable route to \(H_0\) became accessible when it was reliazed that SNe Ia at maximum light are very useful standard candles (Kowal 1968; Sandage & Tammann 1982, 1993; Cadonau, Sandage, & Tammann 1985; Branch & Tammann 1992; Tammann & Sandage 1995; Hamuy et al. 1995, 1996). If one excludes the few red SNe Ia, which are underluminous because of absorption and/or intrinsic peculiarities, and restricts oneself to blue, spectroscopically uniform ("Branch-normal"; Branch, Fisher, & Nugent 1993) SNe Ia with \((B_{\text{max}} – V_{\text{max}}) \leq 0.2\), their luminosity scatter is \(\sigma_M \leq 0.25\). The corresponding Hubble diagram, averaged over \(B_{\text{max}}\) and \(V_{\text{max}}\) magnitudes (cf. Fig. 3) is defined by 21 SNe Ia which have occurred in spiral galaxies (see below) and with good photometry after 1985 to be

\[
\log cz = 0.2 m_{B,V} + (0.659 \pm 0.031),
\]

which is easily transformed into

\[
\log H_0 = 0.2 M_{B,V} + (5.659 \pm 0.031),
\]

To obtain \(H_0\) out to \(30000 \text{ km s}^{-1}\) it is necessary to calibrate the absolute magnitude of blue SNe Ia at maximum light. This is possible since some SNe Ia have been observed in galaxies sufficiently close to determine their distances by means of their Cepheids. However, this is possible only since the advent of HST.

For the luminosity calibration of SNe Ia a small HST team has been formed comprising A. Sandage, A. Saha, L. Labhardt, F.D. Macchetto, N. Panagia, & G. A. Tammann. They have observed so far the Cepheids in six galaxies having produced seven SNe Ia. The resulting Cepheid distances yield the corresponding values of \(M_{B,V}\). The latter turn out to be quite uniform confirming the basic assumption of standard candles. If the resulting mean value of \(M_{B,V} = -19.52 \pm 0.04\) (Saha et al. 1997) for the seven SNe Ia is inserted into equation (2) one obtains

\[
H_0 (30000 \text{ km s}^{-1}) = 57 \pm 3.
\]

It must be stressed that the empirical luminosity calibration agrees within 0\% with present theoretical models (cf. Branch 1998)!
The above value of \( M_{B,V} \) can also be applied to the seven blue SNe Ia in the Virgo cluster and the three SNe Ia in the Fornax cluster (cf. Fig. 7). The resulting distance of the Fornax cluster is not very useful because the peculiar velocity of this cluster is unknown. If one assumes \( v_{\text{Fornax}} = 1350 \pm 250 \, \text{km s}^{-1} \) one can state only \( H_0 = 58 \pm 10 \). The resulting distance of the Virgo cluster is more significant because this cluster is tightly tied through relative cluster distances into the Hubble
field out to 10,000 km s\(^{-1}\) (Figure 2). The Hubble line in Figure 2 implies

\[ H_0 = 0.2 (m - M)_{\text{Virgo}} - (8.070 \pm 0.011). \]  

(4)

If the Virgo modulus from SNe Ia is then inserted into equation (4) one obtains

\[ H_0 (10,000 \text{ km s}^{-1}) = 59 \pm 6 \]  

(5)

in perfect agreement with equation (3).

There has been considerable discussion whether the peak luminosity of blue SNe Ia (slightly) depends on second parameters (cf. Saha et al. 1997). There is indeed some dependence on SN decline rate, SN color, and Hubble type of the parent galaxy. Almost all of these dependences can be accounted for by allowing for a luminosity dependence on Hubble type, SNe Ia being fainter by 0.18 in B and V in E/S0 galaxies than their brethren in spiral galaxies. This effect has been allowed for in the foregoing. Conservatively the seven calibrating SNe Ia have been assumed to comply with spiral populations (actually two calibrators are in the Am galaxy NGC 5253 and are, if anything, underluminous). Equations (4) and (5) represent only the SNe Ia in spiral galaxies, and the underluminosity of the SNe Ia in the Fornax cluster, which have occurred in E/S0 galaxies, has been accounted for.

Special choices of the second-parameter corrections can drive \( H_0 \) up to 62. However, the increase of \( H_0 \) through second-parameter corrections is paradoxical because it implies that uncorrected calibrators are observed too bright and distant SNe Ia too faint. In reality the distant SNe Ia must be strongly biased in favor of the most luminous objects, which are more easily detected and stay longer above the detection limit. This fundamental effect of stellar statistics makes the value of \( H_0 \) in equation (3) an upper limit (cf. Tammann et al. 1997).

The value of \( H_0 \) in equation (5) depends, of course, on the goodness of the Cepheid distances. These, however, seem now secure and uncontroversial with systematic errors of \( \leq 5\% \). For the HST observations in I and V the period-luminosity relations of Madore & Freedman (1991) has been used. The zeropoint of the relation is independently confirmed by the calibration through Galactic clusters (Sandage & Tammann 1971; Feast 1995), the LMC distance derived by other means (cf. Federspiel, Tammann and Sandage 1998), stellar radii (Di Benedetto 1997), the Baade-Becker-Wesselink method (Laney & Stobie 1992), and trigonometric parallaxes (Madore & Freedman 1998; Sandage & Tammann 1998). — Attempts to improve Cepheid distances with the help of a period-luminosity-color (PLC) relation (e.g. Kochanek 1997) are doomed because stellar evolution models combined with a pulsation code show that the basic assumptions going into a PLC relation are not met (Saio & Gautschy 1998). The same models show that the much-discussed metallicity has minimal effect on the P-L\(_{bol}\) relation; remaining metallicity effects enter only through the bolometric correction and the possibly conic shape of the instability strip (Sandage 1998).

Typical errors of individual Cepheid distances derived from HST data are \( \pm 10\% \) due to the width of the instability strip and restricted sample size and due to absorption. For five of the seven calibrating SNe Ia the error is smaller because they suffer closely the same absorption as the Cepheids, and hence only apparent distance moduli are needed.
4 \(H_0\) from the Virgo Cluster and other Methods

It is in addition possible to build the extragalactic distance scale independent of the blue SNe Ia. This not only provides a valuable consistency check but also yields a calibration of \(H_0\) in its own right.

The only interdependence of the two routes is the use of Cepheid distances, but here they do not yield the only basis. The period-luminosity relation of RR Lyrae stars (Sandage 1993a) now confirmed through trigonometric parallaxes from the Hipparcos satellite (Gratton et al. 1997; Reid 1998), and the physical distance determination of LMC through the ring of SN 1984A (Panagia 1998) are also involved.

The intertwined network of the second route is schematically shown in Fig. 8. The center piece is the distance of the Virgo cluster which follows from various methods (Table 1).

A special note is required on the Virgo cluster distance from Cepheids. There are now three bona fide cluster members and two outlying members with Cepheid distances from \(HST\) (Table 2; cf. Freedman et al. 1998). The wide range of their distance moduli, corresponding to 14.9 to 25.5 Mpc, reveals the important depth

| Method        | \((m - M)_{Virgo}\) | Hubble type | Source |
|---------------|-------------------|-------------|--------|
| Cepheids      | 31.52 ± 0.21      | S           | 1      |
| Tully-Fisher  | 31.58 ± 0.24      | S           | 2      |
| Globular Clusters | 31.67 ± 0.15    | E           | 3      |
| \(D_n - \sigma\) | 31.85 ± 0.19      | S0, S       | 4      |
| Novae         | 31.46 ± 0.40      | E           | 5      |

Mean: 31.66 ± 0.09 (⇒ 21.5 ± 0.9 Mpc)

Sources:
1. See text
2. Federspiel, Tammann, & Sandage 1998
3. The luminosity function of globular clusters (GC) peaks at \(M_R = -6.90 ± 0.11\) and \(M_V = -7.60 ± 0.11\) as determined from Galactic GCs with modern RR Lyrae star distances and Cepheid-calibrated GCs in M31 (Sandage & Tammann 1995). Apparent peak magnitudes of Virgo members from various authors are compiled by Sandage & Tammann (1995; cf. also Tammann & Federspiel 1997).
4. A reasonably tight \(D_n - \sigma\) relation of S0 and spiral galaxies in the Virgo cluster has been published by Dressler (1987). The zeropoint calibration rests on the distance of the Galactic bulge (7.8 kpc) and the Cepheid distances of M31 and M81 (Sandage & Tammann 1988; Tammann 1988).
5. Pritchet & van den Bergh (1987) found from six novae in Virgo cluster ellipticals that that they are \(7^{+0.4}_{-0.1}\) more distant than the apparent distance modulus of M31 of \((m - M)_{AB} = 24.58 ± 0.10\) from Cepheids (Madore & Freedman 1991) and Galactic novae (Capaccioli et al. 1989). Livio (1997) found from a semi-theoretical analysis of the six Virgo novae \((m - M)_{Virgo} = 31.35 ± 0.35\). A low-weight mean of 31.46 is adopted.
effect of the cluster. The first four galaxies in Table 2 have been chosen from the atlas of Sandage & Bedke (1988) because they are highly resolved and seemed easy as to their Cepheids. They are therefore expected to lie on the near side of the cluster. In contrast NGC 4639 has been chosen as parent to SN 1990N and hence independently of its distance; correspondingly this distance is expected to be statistically more representative. A straight mean of the distances in Table 2
Table 2: The Virgo cluster members with Cepheid distances

| Galaxy       | (m − M)$_{\text{Cepheids}}$ | Remarks            | (m − M)$_{\text{TF}}$ |
|--------------|-------------------------------|--------------------|------------------------|
| NGC 4321*   | 31.04 ± 0.21                  | highly resolved    | 31.21 ± 0.40           |
| NGC 4496A** | 31.13 ± 0.10                  | highly resolved    | 30.67 ± 0.40           |
| NGC 4536**  | 31.10 ± 0.13                  | highly resolved    | 30.72 ± 0.40           |
| NGC 4571    | 30.87 ± 0.15                  | extremely resolved | 31.75 ± 0.40           |
| NGC 4639    | 32.03 ± 0.23                  | poorly resolved    | 32.53 ± 0.40           |

* From a re-analysis of the HST observations Narasimha & Mazumdar (1998) obtained (m − M) = 31.55 ± 0.28.
** In the W-cloud outside the confidence boundaries of the Virgo cluster (cf. Feder-spiel et al. 1998).

is therefore likely to be an underestimate. Indeed the mean Tully-Fisher (TF) distance modulus of the five galaxies is 0.1 ± 0.2 (corresponding to 10% in distance) smaller than the mean distance of a complete and fair sample of TF distances (Federspiel, Tammann, & Sandage 1998).

A preliminary Cepheid distance of the Virgo cluster is obtained by taking the Cepheid distance of the Leo group of (m − M) = 30.27 ± 0.12, based now on three galaxies with Cepheids from HST, and to step up this value by the modulus difference of Δ(m − M) = 1.25 ± 0.13 (Tammann & Federspiel 1997) between the Leo group and the Virgo cluster. The corresponding result is shown in Table 1.

If the adopted Virgo cluster modulus in Table 1 is inserted into equation (1) one obtains

\[ H_0 \left(10^3 \text{ km s}^{-1}\right) = 55 \pm 4. \] (6)

The Virgo cluster distance modulus can be used to derive the distances of the Fornax and Coma clusters by adding the respective modulus differences to the former. The relevant modulus differences are compiled in Tables 3 and 4. Although there are strong reservations against distances from planetary nebulae and surface brightness fluctuations the differential distances from these methods have been included here, because they are independent of the zeropoint calibration and less sensitive to selection effects. Also the absolute Coma cluster distance from the surface brightness fluctuation method has been tentatively included. The globular cluster distance of the Coma cluster is based on the same zeropoint calibration as the Virgo cluster (cf. Table 1).

The resulting values of \( H_0 \) from the Fornax and Coma clusters are shown in Figure 8. They carry larger errors than \( H_0 \) from the Virgo cluster because the former are poorly tied into the cosmic expansion field. Cosmic velocities of \( v_{\text{Fornax}} = 1350 \pm 250 \text{ km s}^{-1} \) and \( v_{\text{Coma}} = 7000 \pm 650 \text{ km s}^{-1} \) have been assumed. The Fornax cluster offers the additional problem that the spiral “members” may be closer than the E/S0 cluster galaxies (Tammann & Federspiel 1997). It is, however, satisfactory that the independent distances of the Fornax cluster in Figures 7 and 8 are closely the same.

There are many determinations of \( H_0 \) from field galaxies in the literature. The difficulty here is that catalogs of field galaxies are limited by apparent magnitude,
### Table 3: The relative distance Fornax - Virgo cluster (E/S0 galaxies)

| ∆(m − M)_{For−Vir} | Method                            | Reference                  |
|---------------------|----------------------------------|----------------------------|
| 0.44 ± 0.30         | first-ranked galaxy              | Sandage et al. 1976        |
| 0.14 ± 0.16         | D_n − σ method                   | Faber et al. 1989          |
| 0.28 ± 0.08         | surface brightness               | Jerjen & Binggeli 1997     |
| 0.20 ± 0.08         | surf. brightness fluctuations    | Tonry 1997                 |
| 0.32 ± 0.10         | planetary nebulae                | Jacoby 1997                |
| −0.09 ± 0.12        | globular clusters                | Whitmore 1997              |

0.19 ± 0.04 mean ⇒ (m − M)_{For} = 31.85 ± 0.10

### Table 4: The distance of the Coma cluster (E/S0 galaxies)

| (m − M)_{Coma} | Method                            | Reference                  |
|----------------|----------------------------------|----------------------------|
| > 35.22 ± 0.20 | globular clusters                | Baum et al. 1995          |
| 35.34 ± 0.20   | globular clusters                | Baum et al. 1997          |
| 35.04 ± 0.31   | surf. brightness fluctuations    | Thomsen et al. 1997       |

| ∆(m − M)_{Coma−Vir} | Method                            | Reference                  |
|---------------------|----------------------------------|----------------------------|
| 3.34 ± 0.30         | first-ranked galaxy              | Sandage et al. 1976        |
| 4.16 ± 0.20         | 10 brightest galaxies            | Weedman 1976               |
| 3.74 ± 0.14         | D_n − σ method                   | Faber et al. 1989          |

3.74 ± 0.20 mean difference ⇒ (m − M)_{Coma} = 35.40 ± 0.22

35.29 ± 0.11 overall mean ⇒ 114 ± 6 Mpc

which causes the mean galaxian luminosities to increase with distance because of the progressive loss of the less luminous galaxies. The corresponding Malmquist corrections are difficult to apply: their neglect leads always to too high values of \( H_0 \). Recent determinations of \( H_0 \) from bias-corrected field galaxies are compiled in Table 5.

Field galaxies offer the advantage of full-sky coverage outside the zone of avoidance. But they are not only the most difficult route to \( H_0 \), but also the least satisfactory, having their main thrust as close as 1000 – 3000 km s\(^{-1}\), i.e. at a distance where \( H_0 \) (local) may still be a few percent higher than \( H_0 \) (cosmic) (cf. Fig. 6).
Table 5: $H_0$ from bias corrected field galaxies

| Method                              | $H_0$       | Source             |
|-------------------------------------|-------------|--------------------|
| Tully-Fisher                        | < 60        | Sandage 1994       |
| M 101 look-alike diameters           | 43 ± 11     | Sandage 1993b      |
| M 31 look-alike diameters            | 45 ± 12     | Sandage 1993c      |
| Spirals with luminosity classes     | 56 ± 5      | Sandage 1996a      |
| M 101, M 31 look alike luminosities | 55 ± 5      | Sandage 1996b      |
| Tully-Fisher                        | 55 ± 5      | Theureau et al. 1997|
| Galaxy diameters                     | 50 – 55     | Goodwin et al. 1997|
| Tully-Fisher                        | 60 ± 5      | Federspiel 1998    |
| mean                                | 53 (±3)     |                    |

5 Physical Determinations of $H_0$

One distinguishes between astronomical and physical distance determinations. The former depend always on some adopted distance of a celestial body, be it only the Astronomical Unit in the case of trigonometric parallaxes. Physical methods derive the distance solely from the observed physical or geometrical properties of a specific object.

In the foregoing use has been made to physical luminosity and distance determinations of the SN 1987A remnant, Cepheids, RR Lyr stars, and SNe Ia. But in addition there are a number of physical distance determinations which lead to the value of $H_0$ over very large scales. They are still model-dependent, but as the number of objects increases and the models improve, their weight is steadily increasing.

For brevity the most recent physical determinations of $H_0$ are compiled in Table 5. Following Rephaeli & Yankovitch (1997) all previous values of $H_0$ from the SZ effect should be lowered by ~10 units due to relativistic effects.

The overall impression from the values in Table 5 is that $H_0$ will settle around $H_0 \approx 58$.

6 Conclusions

Two separate routes to the Hubble constant require consistently $55 < H_0 < 60$. The one is based on Cepheid-calibrated blue SNe Ia and their Hubble diagram out to 30 000 km s$^{-1}$. The other relies on the Virgo cluster distance from various methods and relative cluster distances out to 10 000 km s$^{-1}$. The conclusion that $H_0$ (cosmic) = 57 ± 7 (external error) is in perfect agreement with present physical distance determinations like the Sunyaev-Zeldovich effect, gravitational lenses, and the CMB fluctuation spectrum.

It is not understood in the face of this evidence why values of $H_0$ as high as ~70 are still occasionally proposed (cf. Freedman, Madore, & Kennicutt 1997; Freedman et al. 1998). Principal reasons are the neglect of the Malmquist correction.
Table 6: $H_0$ from Physical Methods

| Method                                | $H_0$    | Source |
|---------------------------------------|----------|--------|
| Sunyaev-Zeldovich effect              |          |        |
| for cluster A 2218                    | $45 \pm 20$ | (1)    |
| for 6 other clusters                  | $60 \pm 15$ | (2)    |
| cluster A 2163                        | $42 \pm 10$ | (4)    |
| 2 clusters                            | $54 \pm 14$ | (5)    |
| 3 clusters                            | $44 \pm 7$  | (6)    |
| incl. relativ. effects                |          |        |
| Gravitational lenses                  |          |        |
| QSO 0957 + 561                        | $62 \pm 7$  | (7)    |
| B 0218 + 357                          | $52 \pm 82$ | (8)    |
| PG 1115 + 080                         | $60 \pm 17$ | (9)    |
|                                         | $52 \pm 14$ | (10)   |
|                                         | $62 \pm 20$ | (11)   |
| MWB fluctuation spectrum              | $58 \pm 11$ | (12)   |
|                                         | $47 \pm 6$  | (13)   |

* Sources: (1) McHardy et al. 1990; Birkinshaw & Hughes 1994; Lasenby & Hancock 1995 (2) Rephaeli 1995; Herbig, Lawrence, & Readhead 1995 (3) Holzapfel et al. 1997 (4) Lasenby & Jones 1997 (5) Myers et al. 1997 (6) Rephaeli & Yankovitch 1997 (7) Falco, Lehár, & Shapiro 1997 (8) Nair 1996 (9) Keeton & Kochanek 1997 (10) Kundić et al. 1997 (11) Schechter et al. 1997 (12) Lineweaver 1998 (13) Webster et al. 1998.

for selection effects and the adopted too small Virgo cluster distance. The latter is based only on the Cepheid distance of M 100 (Ferrarese et al. 1996), which actually lies on the near side of the Virgo cluster (cf. Table 3). The small Virgo distance is only seemingly supported by planetary nebulae (Ciardullo et al. 1998) and the surface brightness fluctuation method (Tonry 1997), i.e. two distance indicators which have been included in Table 3 for the determination of relative distances, but have utterly failed for absolute distances in several cases (cf. Tammann 1998).

The determination of $H_0$ through blue SNe Ia has presently the highest weight. Forthcoming additional calibrators with Cepheid distances from HST will further strengthen the calibration. If more SNe Ia will become available with redshifts up to $\sim 30,000$ km s$^{-1}$ and good photometry near maximum, they will lead to an even tighter Hubble diagram. In this way it will be possible not only to better map the variations of $H_0$ with distance, but also to push the error of $H_0$ well below 10%.

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