The Hubble Constant from the Fornax Cluster Distance

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Abstract. Type Ia supernovae are the best cosmological standard candles available. The intrinsic scatter of their decline-rate- and colour-corrected peak brightnesses in the Hubble diagram is within observational error limits, corresponding to an uncertainty of only 3\(\text{km s}^{-1}\text{Mpc}^{-1}\) of the Hubble constant. Any additional uncertainty, resulting from peak-brightness calibration, must be kept small by measuring distances to nearby host galaxies most precisely.

A number of different distance determinations of the Fornax cluster of galaxies agree well on a distance modulus of 31.35\(\pm\)0.04 mag (18.6\(\pm\)0.3 Mpc). This leads to accurate absolute magnitudes of the well-observed Fornax type Ia SNe SN 1980N, SN 1981D, and SN 1992A and finally to a Hubble constant of \(H_0 = 72\pm6\text{km s}^{-1}\text{Mpc}^{-1}\).

1 The Hubble diagram of type Ia SNe

Supernovae (SNe) of type Ia are known to be excellent standard candles. In order to construct a reliable Hubble diagram it needs more than just to plot the data from the standard SNe catalogue \cite{1} but requires highly uniform spectroscopic and, especially, photometric observations as are now available from the Calán-Tololo survey \cite{2} or the CfA campaign \cite{3}.

Fig. 1 shows the Hubble diagram for 29 classified Ia SNe from the Calán-Tololo survey \cite{2}. The intersection \(Z\) of the straight line (slope 5!) with the \(y\)-axis is related to the Hubble constant \(H_0\) and the absolute magnitude \(M\) of the standard candles by the well-known equation:

\[
\log H_0 = 0.2 \cdot (M - Z) + 5
\]  

(1)

For the knowledge of an accurate Hubble constant, one would of course aim at determining the distances to as many SNe as possible.

The quality of the SNe Ia Hubble diagram can be improved further if one corrects the brightness at maximum for the decline rate \(\Delta m_{15}\) of the \(B\) lightcurve (e.g. \cite{2}) and the colour \((B_{\text{max}} - V_{\text{max}})\) \cite{4}:

\[
B_{\text{corr}} = B_{\text{max}} + b(\Delta m_{15} - 1.1) + R(B_{\text{max}} - V_{\text{max}})
\]  

(2)

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A new analysis of the Calán-Tololo SNe sample has been made recently by Drenkhahn & Richtler [5,6]. The derived correction terms are quoted in the upper part of Fig. 1. As a result of the correction process the scatter in the Hubble diagram is reduced to 0.14 mag (even smaller in V and I), which is already consistent with the observational errors. Therefore, the intrinsic scatter must be distinctly smaller than 0.1 mag. This fixes the zero-point $Z$ with high precision and the accuracy of $H_0$ in (1) depends only on the absolute magnitude $M_{\text{corr}}$. Determining $M_{\text{corr}}$ within $\pm 0.1$ mag corresponds to measuring $H_0$ with an uncertainty of only $\pm 3$ km s$^{-1}$ Mpc$^{-1}$.

2 The distance of the Fornax cluster of galaxies

With respect to the accurate calibration of the absolute magnitudes of Ia SNe, the Fornax cluster of galaxies is one of the most suitable sites. It hosts the type Ia SNe SN 1992A (in NGC 1380), SN 1980N, and SN 1981D (both in NGC 1316). In contrast to the Virgo cluster, which is the permanent but precarious target of distance measurements, the Fornax cluster has a compact structure without distinct substructures. Promising attempts to tighten the distance to Fornax have been made [8,10,15], but have been criticised when hunting for a small value of the Hubble constant [7]. The last year has brought
convincing new results for the Fornax distance (for the following discussion refer to Table 1).

**Planetary nebula luminosity function (PNLF).** Distances to Fornax galaxies using the PNLF have been deduced by Jacoby and co-workers [8,9]. Their zero-point is based on M31 with a distance of 710 kpc (or distance modulus $m - M = 24.26$ mag) and a reddening of $E_B - V = 0.11$ mag. Changing to the more recent distance modulus of $m - M = 24.44$ mag [17] but keeping the reddening one arrives at a Fornax modulus of $31.33 \pm 0.08$ mag.

**Globular cluster luminosity function (GCLF).** The turn-over magnitude (TOM) of the GCLF of four Fornax galaxies has been derived by Kohle et al. [10] to be $V_{TO} = 23.69 \pm 0.06$ mag (error weighted and skipping NGC 1379). Applying a more recent calibration of the TOM of the Galactic globular cluster system: $M_{V, TO} = -7.61 \pm 0.08$ mag [14], one gets a Fornax distance modulus of $31.30 \pm 0.13$ mag. The GCLF of NGC 1380 has also been analysed using ESO NTT data [11], which result in a modulus of $31.35 \pm 0.16$ mag. Presently, we are investigating the GCLF of the Fornax galaxy NGC 1316 [12]. The preliminary result of $31.32 \pm 0.15$ mag agrees well with the other values.

**Cepheid distances.** Now there is also a Cepheid distance of one Fornax galaxy, NGC 1365, available (HST Key Project [13]). The value of $31.35 \pm 0.07$ mag agrees very well with the results of the previously mentioned methods.

**Surface brightness fluctuations (SBF).** Jensen et al. [14] report new infrared SBF measurements for five Fornax galaxies. They find a distance modulus of $31.37 \pm 0.12$ mag.

**Tully-Fisher relation (T-F).** Finally, a Tully-Fisher distance from 21 cm data for 18 Fornax galaxies can be derived: when combining published 21 cm line widths $\Delta V_{20}$ [15] with dereddened integrated $B$ magnitudes $B^0_{tot}$ [16], one finds the relation: $B^0_{tot} = -6.990(\pm 0.426) \log \Delta V_{20} + 29.312(\pm 0.365)$ (N.B.: The galaxy ESO 357-G25 which has an extremely large error in the line width has been skipped from the sample [15, their Table 1].) We then use the absolute magnitudes $M_B$ of all non-Fornax calibrating galaxies from the work of Federspiel et al. [17, their Table 2] and obtain $31.43 \pm 0.12$ mag.

Table 1 suggests that the distance of the Fornax cluster is now very well determined. The mean value of the distance modulus is $31.35$ mag with a scatter of only $\pm 0.04$ mag (linear distance $18.6 \pm 0.3$ Mpc).

### 3 The absolute magnitudes of type Ia SNe in Fornax and the Hubble constant

Table 2 lists the parameters of the three Fornax Ia events. The photometry is taken from [2]. For shortness, only the brightness $B$ is given. SN 1992A in NGC 1380 is one of the best ever observed SNe. After correction for decline rate and colour and with the new distance modulus of the Fornax cluster the
Table 1. Distance modulus determinations of the Fornax cluster

| Galaxy          | $m - M$ | $\sigma$ | Method* | Reference |
|-----------------|---------|----------|---------|-----------|
| NGC 1316, 1399, 1404 | 31.33   | 0.08     | PNLF    | [8], [9]  |
| NGC 1374, 1399, 1427 | 31.30   | 0.11     | GCLF    | [10]      |
| NGC 1380         | 31.35   | 0.16     | GCLF    | [11]      |
| NGC 1316         | 31.32   | 0.15     | GCLF    | [12]      |
| NGC 1365         | 31.35   | 0.07     | Ceph    |           |
| NGC 1339, 1344, 1379, 1399, 1404 | 31.37   | 0.12     | SBF     |           |
| 18 galaxies      | 31.43   | 0.12     | T-F     | [13], [14], [15] |

mean value        31.35   0.04

* PNLF: planetary nebulae luminosity function
  GCLF: globular cluster luminosity function
  Ceph: Cepheid distance; HST Key Project
  SBF: surface brightness fluctuations
  T-F: Tully-Fisher relation

absolute magnitudes $M_B^{corr}$ have been calculated. Eq. (1) and the corresponding data in the $B$, $V$, and $I$ bands for the listed SNe yield a Hubble constant of $H_0 = 72 \pm 6$ km s$^{-1}$ Mpc$^{-1}$.

Table 2. Type Ia SNe in the Fornax cluster of galaxies

| SN   | Host Galaxy | $B_{max}$ | $\sigma$ | $\Delta m_{15}$ | $B_{max} - V_{max}$ | $B_{corr}$ | $M_B^{corr}$ |
|------|-------------|-----------|----------|-----------------|----------------------|------------|--------------|
| SN1992A | NGC 1380   | 12.57     | 0.03     | 1.47            | 0.02                 | 12.36      | −18.99       |
| SN1980N | NGC 1316   | 12.49     | 0.03     | 1.28            | 0.05                 | 12.33      | −19.02       |
| SN1981ID | NGC 1316  | 12.66     | 0.06     | 1.20            | 0.24                 | 12.25      | −19.10       |

Parameters of SN 1981D from own light-curve fit

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