2.3 EXTRAGALACTIC ASTROMETRY

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BETTER PARALLAXES AND THE COSMIC DISTANCE SCALE

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ABSTRACT. It is generally agreed that the Hubble parameter lies in the range $50 < H_o$ (km s^{-1} Mpc^{-1}) < 100. Recent observations, which are discussed in the present paper, favor $H_o \geq 75$ km s^{-1} Mpc^{-1}. Hubble Space Telescope observations of Cepheids in Virgo cluster galaxies will probably reduce the uncertainty in H_o to ~ 20%. It should be possible to lower this remaining uncertainty in the Hubble parameter by strengthening the calibration of the Cepheid period-luminosity relation, the M_V(RR) versus [Fe/H] relation of RR Lyrae stars, and the luminosity calibration of the subdwarf main sequence, by using parallaxes obtained with Hipparcos.

1. Introduction

A good mystery novel keeps one in suspense until the very last page, when we finally find out who did the evil deed. Papers on the extragalactic distance scale are generally less exciting because the names of the authors usually allow us to guess the value of the Hubble parameter that they will end up with.

Fig. 1, which is adapted from Okamura & Fukugita (1991), shows a plot of the distribution of recent determinations of H_o. In order to reveal my own prejudices the Hubble parameters that I obtained in review papers are shown as open circles. My most detailed discussion of this problem is in van den Bergh (1992), in which a value H_o(local) = 83 ± 6 km s^{-1} Mpc^{-1} was derived for the region of the Universe with V < 10000 km s^{-1}. This value represented an uneasy compromise between supernovae of Type Ia (SNe Ia) and of Type II (SNe II), which both appeared to yield low values of H_o, and planetary nebulae, the Tully-Fisher relation, and surface brightness fluctuations in early-type galaxies, which all yielded higher values of H_o. Finally observations of the luminosities and radial velocities of first-ranked galaxies in rich clusters (Hoessel, Gunn & Thuan 1980) indicated that H_o(global) = (0.92 ± 0.08) H_o(local), so that H_o(global) = 76 ± 9 km s^{-1} Mpc^{-1}.

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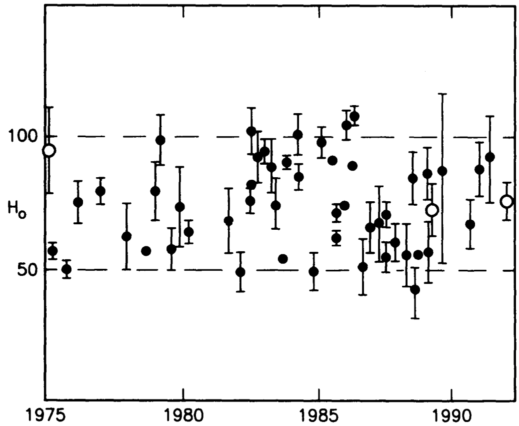

Fig. 1. Recent determinations of the Hubble parameter adapted from Okamura & Fukugita (1991). Results by the present author are shown as open circles.

2. Recent determinations of H_0.

The usefulness of supernovae of Type Ia as standard candles was thrown into doubt by the discovery of the subluminous object SN 1991bg, and by the probably superluminous supernova 1991T. Furthermore high quality observations obtained at Lick and at Cerro Tololo showed that SNe Ia exhibit a remarkable range in lightcurve morphologies and spectral characteristics that had not previously been appreciated. From a reevaluation of old observations of SN 1937C (Jacoby & Pierce 1994), and the maximum magnitude versus rate of decline relation of Phillips (1993), one obtains $H_0 = 75 \pm 12$ km s^{-1} Mpc^{-1}. However, this value is uncertain because observations of SN 1992bc and S Andromedae show that individual SNe Ia may deviate substantially from the mean relation adopted by Phillips.

Application of detailed model atmosphere calculations to the expanding photosphere (Baade-Wesselink) models of SNe II (Schmidt 1994) yields $H_0 = 73$ km s^{-1} Mpc^{-1}, which is significantly larger than values previously obtained by this method. For the two most distant objects so far observed (SN 1990ae, with V = 7800 km s^{-1}, and SN 1992am, with V = 14500 km s^{-1}) Schmidt et al. (1994) find $H_0 = 68$ km s^{-1} Mpc and $H_0 = 81$ km s^{-1} Mpc^{-1}, respectively.

From studies of two volume elements, in the direction of (but beyond) the Virgo cluster, and another in the opposite direction Lu et al. (1994) find $H_0 = 84 \pm 8$ km s^{-1} Mpc^{-1}. This value includes a small correction for Malmquist bias, and is independent of the adopted infall (retardation) velocity of the Local Group into the Virgo cluster.

Tonry & Schneider (1988) have shown that surface brightness fluctuations of galaxies containing old stellar populations can be used to derive their distances. Using this technique Jacoby et al. (1992) derive a distance of 15.0 ± 1.4 Mpc to the elliptical galaxies in the core of the Virgo cluster. Combining this distance with the cosmic velocity V = 1311 ± 132 km s^{-1}, that van den Bergh (1992) derives from the Coma cluster velocity, and the Coma/Virgo distance ratio yields $H_0 = 87 \pm 12$ km s^{-1} Mpc^{-1}.

From a careful study of the luminosity functions of planetary nebulae in early-type Virgo galaxies Méndez et al. (1993) derive a Virgo distance modulus of 30.9 ± 0.4 mag. In conjunction with the cosmological velocity of the Virgo cluster this yields $H_0 = 86 \pm$ km s^{-1} Mpc^{-1}.

From observations of planetary nebulae in three galaxies in the Fornax cluster (McMillan, Ciardullo & Jacoby 1993) $H_0 = 75 \pm 8$ km s^{-1} Mpc^{-1}. From surface brightness profiles of early-type dwarfs in Fornax, Young & Currie (1994) find $H_0 = 99 \pm 16$ km s^{-1} Mpc^{-1}.

Distance determinations based on intercomparisons of the peaks of the luminosity functions of distant globular clusters, with those of globulars in M31 and the Galaxy, are based on the (as yet unproven) hypothesis that globulars in nearby spiral galaxies are similar to those in distant spirals. This technique has been discussed by Sandage & Tammann (1994) and more recently by van den Bergh (1994), who obtains $H_0 \geq 73$ km s^{-1} Mpc^{-1}.

Additional estimates of H_0 based on observations of the gravitational lens system 0957 + 561 (Bernstein, Tyson & Kochanek 1993), the Sunyaev-Zel'dovich effect in the cluster Abell 2218 by Jones et al. (19930, and from VLBI observations of compact radio sources (Roland 1994) are listed in Table 1. Taken in their entirety the data in this table suggest that $H_0 \geq 75$ km s^{-1} Mpc^{-1}.

Finally Lauer & Postman (1992), who studied brightest cluster galaxies, found no evidence for a systematic change in the value of H_0 over the range $0.01 \leq z \leq 0.05$.

Table 1. Compilation of recent H_0 determinations.

Method	H_0 (km s^{-1} Mpc^{-1})
SNe Ia	75 (± 12?)
SNe II	68 - 81
Tully-Fisher	84 ± 8
Surface brightness fluctuations	87 ± 12
Planetary nebulae (Virgo)	86 ± 18
Planetary nebulae (Fornax)	75 ± 8
Galaxy diameters	76 - 124
Globular clusters (Virgo)	≳ 73
Surface brightness profiles (Fornax)	99 ± 16
Gravitational lens	< 87
Sunyaev-Zel'dovich effect	~ 50
Compact radio sources	~ 100

3. Hipparcos and the distance scale

Hopefully the Hubble Space Telescope will start observing Cepheid variables in Virgo spiral galaxies later this year. To derive a value of the Hubble parameter H_0 from these observations it will be necessary to obtain reddening values of individual Cepheids from multi-color observations. Secondly, we shall have to improve our understanding of the rather complex structure of the Virgo region, so as to prevent contamination of the sample by background galaxies. Spirals with high negative velocities, relative to the mean cluster velocity, are most likely to be situated close to the cluster core. Finally the calibration of the zero point of the Cepheid period-luminosity relation (Turner 1992), and of the Cepheid period-color relation (Turner 1994 et al.) will have to be strengthened. This is where Hipparcos can make a major contribution.

Traditionally extragalactic distances have been determined by using the slope of the P-L relations of Cepheids in the Magellanic Clouds, in conjunction with zero point calibrations derived by fitting the main sequences of clusters and associations containing Cepheids, to that of the Pleiades. A difficulty with this approach is that (1) individual Galactic Cepheids may have metallicities that differ significantly from that of the Pleiades (Fry & Carney 1994). This difficulty can be circumvented by measuring the distances to a significant number of individual nearby Cepheids directly with Hipparcos. A problem that still remains to be resolved is whether the Cepheid period-luminosity relation is itself metallicity dependent. By *assuming* that the wavelength dependence of extinction is independent of distance from the center of M31 Freedman & Madore (1990) found that Cepheids at different distances from the nucleus of the Andromeda nebula (which presumably have differing metallicities) yield the same distance modulus $(m-M)_0$. However, using the same observational data Gould (1994) arrives at a different conclusion. He finds that $\Delta(m-M)_0 = (0.56 \pm 0.20)\,\Delta[Fe/H]$ *i.e.* distance modulus and metallicity are related at the 2.8 σ confidence level. A different parameterization of the relationship between distance modulus and metallicity is given by Caldwell & Coulson (1986).

Observations of Population II distance indicators, such as RR Lyrae stars, W Virginis variables, and globular clusters add significant weight to the distance determinations of nearby galaxies, that are used to calibrate the extragalactic distance scale. Hipparcos can contribute by providing accurate parallaxes of subdwarfs of various metallicities, to which globular cluster main sequences can be fit. Furthermore parallax observations of nearby RR Lyrae stars should allow one to chose between the (significantly different) M_V(RR) versus [Fe/H] relations (see Fig. 2) that have recently been proposed by Carney, Storm & Jones (1992), Sandage (1993) and Walker (1992).

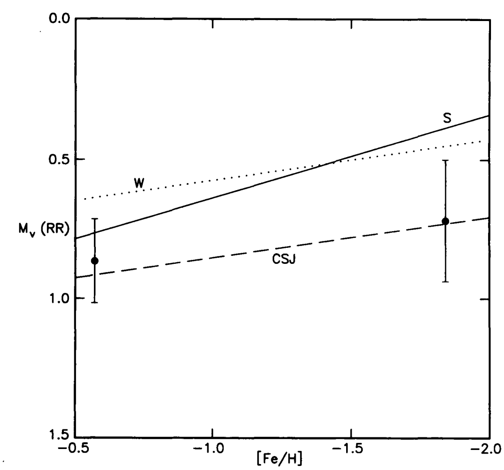

Fig. 2. M_V(RR) versus [Fe/H] relations proposed for RR Lyrae stars by CSJ (Carney, Storm & Jones 1992), S (Sandage 1993), and W (Walker 1992). The two observational points are the horizontal branch magnitudes of the M31 clusters K58 (left) and K219 (right) that have recently been measured with the Hubble Space Telescope (Ajhar et al. 1994). These data appear to favor the faint calibration of CSJ.

It is concluded that recalibration of the luminosities of Cepheids of Population I and of RR Lyrae stars of Population II with Hipparcos, in conjunction with further elucidation of the spatial structure of the Virgo cluster, can probably improve the accuracy with which H_o is determined to ~ 10%.

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Question:

E. Høg: Could you be more specific about various contributions to the quoted error of H_0 ?

S. van den Bergh: The three main sources of error in the determination of the Hubble parameter from observations of Cepheids in the Virgo cluster are: (1) Uncertainty in the zero-point of the Cepheid Period-Luminosity relation,which probably amounts to 0.1-0.2 mag. (2) Uncertainty in the location of the Cepheid parent galaxy relative to the core of the Virgo Cluster. This uncertainty probably amounts to a few tenths of a magnitude in the distance modulus difference for M100, but is probably much smaller for NGC4571 because its low hydrogen abundance indicates that it has recently been swept by intra-cluster gas in the Virgo cluster core. (3) Large-scale motions in nearby region of the Universe introduce uncertainty in the cosmic velocity of the Virgo cluster that are of the order of 10 percent. The errors resulting from (1) can be greatly reduced by HIPPARCOS observations of Cepheids. The uncertainty introduced by (3) can be minimized by deriving H_0 from the Coma cluster velocity and the Coma/Virgo distance ratio, which is known to better than 5 percent.