1996ApJ...464L..51S

THE ASTROPHYSICAL JOURNAL, 464:L51–L54, 1996 June 10
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AN ALTERNATE CALCULATION OF THE DISTANCE TO M87 USING THE WHITMORE ET AL. LUMINOSITY FUNCTION FOR ITS GLOBULAR CLUSTERS: H_0 THEREFROM

ALLAN SANDAGE
The Observatories of the Carnegie Institution of Washington, 813 Santa Barbara Street, Pasadena, CA 91101

AND

G. A. TAMMANN
Astronomisches Institut der Universität Basel, Venusstrasse 7, CH-4102 Binningen, Switzerland
Received 1996 January 24; accepted 1996 March 29

ABSTRACT

An alternate calculation to that made by Whitmore et al. (WSLMB) is set out for the distance to M87 using their globular cluster luminosity function (GCLF) for M87 in the Virgo Cluster. They have concluded from these data that $H_0 = 78 \pm 11$ km s^{-1} Mpc^{-1}. Our purpose is to show how a different set of precepts leads to a substantially smaller value of H_0 that is in statistical agreement with other analyses that favor the long distance scale.

Adopting the WSLMB observed turnover apparent magnitude for the GCLF of $V = 23.79 \pm 0.2$ (external), together with $A_V = 0.00$ mag for the foreground Galactic absorption, and $\langle M_V \rangle_0 = -7.62 \pm 0.2$ (external) as the calibration of the turnover luminosity gives $(m - M)_0 = 31.41 \pm 0.28$ for the distance modulus of M87. Using the cosmic velocity of the E galaxy Virgo core as v(cosmic) = 1179 ± 17 km s^{-1} gives $H_0 = 62 \pm 9$ km s^{-1} Mpc^{-1}.

The procedure of WSLMB and others in stepping a Virgo distance to the Coma Cluster and then using a Coma velocity that still contains a random component to determine H_0 is argued. The cosmic velocity for Virgo, calculated by reading a Hubble diagram of relative distances of 17 "remote" clusters versus cosmic microwave background velocities at zero modulus difference to Virgo (Jerjen & Tammann), overcomes this error by circumventing the problem of accounting for any random and/or streaming motions of the Virgo Cluster and/or of the Coma Cluster about the ideal Hubble flow. This procedure cuts to the core of the distance scale problem, eliminating the major uncertainty concerning local random motions.

Four sources of possible systematic errors in the Virgo Cluster modulus using the GCLF method, as applied to M87, are also set out, suggesting that the value of $H_0 = 62$ is an upper limit.

Subject headings: distance scale — galaxies: distances and redshifts — galaxies: individual (M87) — galaxies: star clusters

1. INTRODUCTION

Whitmore et al. (1995, hereafter WSLMB) have determined the luminosity function (LF) for the large population of globular clusters in the Virgo giant E galaxy M87, the central galaxy of subcluster A of the Virgo Cluster. From their observed value of V(turnover) = 23.79 ± 0.06 mag (internal), they derive a Hubble constant of $H_0 = 78 \pm 11$ km s^{-1} Mpc^{-1}. Their conclusion is based on assumptions that are required to convert the turnover magnitude into a distance to M87. They then step this distance outward to Coma by adopting a modulus difference with Virgo. They then use the observed mean Coma Cluster velocity as if it defined the undisturbed Hubble flow.

Their high value for H_0 is in substantial agreement with several methods said to give the short distance scale with $H_0 \sim 85$ (Jacoby et al. 1992). It is this agreement that adds importance to the WSLMB paper, because it appears to add weight to the short distance scale. However, we have argued elsewhere that this scale is flawed by systematic errors in each of the several methods said to support it. We contend that these errors center around the effects of observational selection bias and/or the absolute calibrations of each method in the presence of large intrinsic dispersions for the various indicators (Federspiel, Sandage, & Tammann 1994; Sandage 1994a, 1994b; Sandage, Tammann, & Federspiel 1995; Tammann & Sandage 1996). If, then, each of the methods that give the short distance scale prove to be in error, and if the WSLMB result is in agreement with them, a search for an explanation of the WSLMB result is required. It is this search that is the rationale for this Letter.

We note first that the high value of H_0 is in substantial disagreement with the value of H_0 derived from the Cepheid calibration of the absolute magnitude at maximum of seven "Branch normal" Type Ia supernovae (SNe) (Sandage et al. 1996). This calibration, when used with the Hubble diagram of SNe Ia read at large redshifts beyond all local streaming motions (i.e., $v > 20{,}000$ km s^{-1}), gives the global value of $H_0 = 57 \pm 6$ km s^{-1} Mpc^{-1}.

Their high value of H_0 also disagrees with $H_0 \sim 55 \pm 10$ derived from eight independent methods using a variety of distance indicators, corrected for observational selection bias (Bottinelli et al. 1986, 1987 when used with the modern Cepheid scale for the local calibrators; Tammann 1986, 1988, 1992; Kraan-Korteweg, Cameron, & Tammann 1988; Sandage 1995 [lectures 8–10], 1996a, 1996b; Sandage & Tammann 1996; Tammann & Sandage 1996). Their high value also differs from our own determination of $H_0 = 55 \pm 7$ km s^{-1} Mpc^{-1} (Sandage & Tammann 1995, hereafter ST95) using the totality of the extant ground-based globular cluster data in the Virgo Cluster (Harris et al. 1991, or Secker & Harris 1993 for entrance to the substantial literature).

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As a response to WSLMB, we examine here the precepts they have used in proceeding from their *Hubble Space Telescope* (HST) data to their global value of H_0. Our purpose is to show how a different set of precepts, based on the corpus of extant external data, leads to $H_0 = 62 \pm 9$ km s^{-1} Mpc^{-1} using their M87 data alone.

We examine (1) the adopted absolute V magnitude of the globular cluster luminosity function (GCLF) turnover luminosity, (2) the adopted value for the foreground Galactic absorption, (3) the assumption made by WSLMB in their tie of Virgo to Coma and their subsequent use of the observed Coma redshift, and (4) the possibility that the M87 globular clusters have an appreciable age variation that would complicate their use in the distance-scale problem.

2. ADOPTED ABSOLUTE MAGNITUDE OF GCLF TURNOVER LUMINOSITY

We argued in ST95 that the mean of the calibrations of the turnover luminosity of the GCLF, based on the globular cluster data in the Galaxy and in M31 used by Secker (1992), is $\langle M_V \rangle_0 = -7.62 \pm 0.2$ mag (external). Our adopted absolute magnitudes for the Galactic globular clusters were based on the calibration of the RR Lyrae star absolute magnitudes as a function of metallicity (Sandage 1993). The steep dependence of that calibration on metallicity is required to explain the Oosterhoff-Arp-Preston period-metallicity relation for RR Lyrae stars. A confirmation of both the brighter absolute magnitude and the steep metallicity dependence, based on new horizontal branch models using the revised OPAL opacities, is by Mazzitelli, D'Antona, & Caloi (1995, their Fig. 10).[1]

WSLMB adopt $\langle M_V \rangle_0 = -7.4 \pm 0.25$ for the turnover luminosity. They derive this value by adopting the average between our value of -7.62 and the value of $\langle M_V \rangle_0 = -7.4$ proposed by Secker (1992), and then by "correcting" the Secker value for an assumed difference of 0.2 mag between elliptical and spiral galaxies (the E galaxy calibration adopted to be fainter than the spiral).

We argue here against the validity of that correction. The supposition that such a difference exists is based on a supposed difference between the distance modulus of Virgo ellipticals determined by the surface brightness fluctuation (SBF) method (Tonry & Schneider 1990), itself in dispute (Tammann 1992; Lorenz et al. 1993), and the distance moduli using the uncorrected GCLF method. To make the two moduli agree requires that the Virgo E galaxy GCLF be fainter than that of the M31 and Milky Way spiral calibrators.

WSLMB also base their correction on a theoretical calculation by Ashman, Conti, & Zepf (1995), which in turn was justified by using the suggested SBF and the GCLF differences in E galaxy moduli as buttressed in part by an observational argument by Fleming et al. (1995). Fleming et al. already adopt an a priori distance modulus to Virgo based on secondary indicators. However, one must not use a correction to the GCLF calibration based on the adopted Virgo distance and then use the resulting "corrected" globular cluster data to determine anew the Virgo Cluster distance by forcing the GCLF calibration to produce the *same* a priori distance. The procedure is circular.

[1] Additional confirmation of the brighter zero point is from Saha et al. (1992), Walker (1992), and Eggen (1994). Contrary evidence may come from a new experiment by Adjar et al. (1996) using M31 clusters, but the sample is small and the observational errors must be reduced for a definitive result.

Our reserve concerning a spiral-to-E galaxy correction is further strengthened by an independent test for a metallicity dependence of the turnover luminosity, done by dividing Secker's (1992, his Table 2) sample of M31 halo clusters into two presumed metallicity groups by $B - V$ color. The M31 clusters with $B - V$ between 0.60 and 0.77 have a mean observed magnitude of $\langle V \rangle = 16.70 \pm 0.16$, whereas the redder group with colors between 0.78 and 1.10 (more metal rich) have $\langle V \rangle = 16.55 \pm 0.18$. Although the difference is not statistically significant, it is in the opposite sense from the correction used by WSLMB.

3. ADOPTED VALUE OF FOREGROUND ABSORPTION

WSLMB adopt a foreground V absorption of $A_V = 0.067 \pm 0.04$ mag, based on the H I column density as changed to an $E(B-V)$ reddening (Burstein & Heiles 1984).

The precept concerning zero optical absorption in the Galactic polar cap as used in the Revised Shapley-Ames Catalog (Sandage & Tammann 1987) is based on color-color data following the model by McClure & Crawford (1971). The evidence for statistical–near-zero absorption for $b > 50°$ is from the color-color data by Westerlund (1963), Sandage (1964, 1969, 1972), McNamara & Langford (1969), Helfer & Struch (1970), and Philip & Tifft (1971), and the definitive, intermediate-band, study by Perry & Johnston (1982).

We are aware of the contrary microspatial result of Knude (1977) on the characteristics of discrete cloudlets, but the results of Perry & Johnston belie a general, uniform, finite absorption at high Galactic latitudes. The result that $\langle A_V \rangle = 0.00$ mag for $b > 50°$, which we adopt here, is also consistent with the result of Snowden (1986) as summarized in the review of the local interstellar medium by Cox & Reynolds (1987, Fig. 1).

4. ADOPTED VALUE OF CLUSTER REDSHIFT REDUCED TO COSMIC FRAME OF MICROWAVE BACKGROUND

WSLMB step their modulus of $(m-M)_0 = 31.12$ for M87 out to the Coma Cluster by applying an adopted modulus difference between Coma and Virgo of 3.71 ± 0.10 mag, thereby obtaining a Coma modulus of 34.83. They then adopt a cosmic velocity for Coma of 7188 km s^{-1}, given by the *observed* mean Coma redshift as corrected to the microwave frame. They assume that this value defines the unperturbed global Hubble flow at Coma. These precepts give $H_0 = 78 \pm 11$ km s^{-1} Mpc^{-1} using their adopted Coma distance of $D = 92.5$ Mpc.

This procedure is incorrect. It neglects any random motion of Coma, and it relies on the uncertain adopted modulus difference between Virgo and Coma. Neither problem exists by using a different procedure that cuts to the core of the distance-scale problem, circumventing all uncertainties concerning any local-velocity anomalies.

The unperturbed Hubble flow (freed from random and streaming motions) in the kinematic frame of the microwave background (MWB) has been determined in a fundamental way by Jerjen & Tammann (1993, hereafter JT93) following the method set out in *steps* IX (Sandage & Tammann 1990). The Hubble diagram using *relative distances to Virgo* for 17 "remote" clusters using a variety of methods, reduced to the frame of the microwave dipole, has the equation

$$\log v^{\rm CMB} = 0.2\Delta(m-M) + 3.072 \pm 0.006 \qquad (1)$$

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(JT93, Fig. 4). Here $\Delta(m - M)$ is the difference between the distance modulus of a given cluster and the modulus of Virgo (no absolute values are required). The weight of equation (1) is much higher than any single determination. The use of 17 clusters averages out the individual random motions of any given cluster relative to the MWB frame, leaving a statistical error 4 times smaller than any individual determination for any random motion component.

If we were to follow WSLMB in adopting $\Delta(m - M) = 3.71$ of Coma relative to Virgo, the correct cosmic velocity to use for Coma itself would be 6516 km s^{-1}, calculated from equation (1), not 7188 km s^{-1} as used by them.[2]

Note that use of equation (1) in stepping to Coma with an assumed distance ratio, and thereby calculating the expected ideal cosmic expansion velocity at that distance, is equivalent to simply using the cosmic redshift of Virgo as $v(\text{cosmic})_{\text{Virgo}} = 1179 \pm 17$ km s^{-1} as read from equation (1) at zero modulus difference. This Virgo Cluster, core cosmic velocity has the entire weight of the 17 clusters used by JT93. This point is often overlooked.

As a consequence, the route through Coma used by Freedman et al. (1994), Tanvir et al. (1995), and now WSLMB, is superfluous. Said differently, any assumed distance to Coma *disappears from the calculation* (it could have any value) when equation (1) is used to determine the proper cosmic velocity *at that assumed distance*.

Said still differently, this route to H_0 through equation (1) circumvents all requirements to know the *observed* mean velocity of the Virgo Cluster, corrected by *any* value of the "infall velocity" because equation (1) ties Virgo directly to the external expansion field. Hence, all arguments such as made by Huchra (1988), Freedman et al. (1994), Tanvir et al. (1995), and WSLMB are moot if equation (1) is used with *any* assumed relative distance of Virgo and Coma.

5. H_0 FROM THE GCLF USING REVISED PRECEPTS

We adopt the observed apparent magnitude of the GCLF of $V = 23.79 \pm 0.2$ (external) determined by WSLMB. With an adopted zero absorption in high Galactic latitudes (§ 3), this observed value is taken to be the absorption-free value.

Using the calibration of $\langle M_V \rangle_0 = -7.62 \pm 0.2$ (external) from ST95 gives a true modulus of M87 as $(m - M)_0 = 31.41 \pm 0.28$ (or $D = 19.1 \pm 2.7$ Mpc). Then, using the cosmic velocity of the E core of the Virgo Cluster as $v(\text{cosmic}) = 1179 \pm 17$ km s^{-1} from equation (1) gives

$$H_0 = 62 \pm 9 \text{ km s}^{-1} \text{ Mpc}^{-1}, \quad (2)$$

now in statistical agreement with the methods through type Ia supernovae and the eight others discussed in the references cited earlier.

6. A CAVEAT

Our rediscussion of the WSLMB data is not an endorsement of the value of H_0 in equation (2). Four unanswered questions remain.

1. For five Virgo ellipticals, the GCLFs in B or V were known previously. Although of lower accuracy, they consistently require a Virgo modulus of $(m - M) = 31.75 \pm 0.07$ (Sandage & Tammann 1995). This is larger than the proposed value of WSLMB by 0.56 ± 0.33 mag and still marginally larger than the corrected modulus of $(m - M) = 31.41 \pm 0.28$ in § 5.
2. The M87 turnover luminosity in V by WSLMB of $V = 23.79 \pm 0.06$ and the corresponding blue turnover magnitude of $B = 24.78 \pm 0.13$ in M87 (Harris et al. 1991) give a mean globular cluster (GC) color of $(B - V) = 0.99 \pm 0.14$. This is significantly redder than $(B - V) = 0.69 \pm 0.11$ for the calibrating GCs in the Galaxy and in M31 (Sandage & Tammann 1995).
3. The inferred distance of the Coma Cluster by WSLMB falls short by more than 15% of the *minimum* distance of $(m - M) > 35.17 \pm 0.20$, which is based on the GCLF of NGC 4881, an off-center elliptical galaxy in the Coma Cluster (Baum et al. 1995).
4. These inconsistencies could be interpreted as a hint for the GC population of M87 having a young (merger-induced?) component (Zepf & Ashman 1993; Fritze-von Alvensleben & Gerhard 1994; Fritze-von Alvensleben & Burkert 1995; Elson & Santiago 1996). The double-peaked $(V - I)$ color distribution of the GCs in M87 (WSLMB) is interpreted in this sense by Fritze-von Alvensleben (1995). The same bimodal color distribution of the independent data by Elson & Santiago (1996) is particularly telling (their Fig. 3) in this regard. Such a young component in the M87 cluster system would cause the observed V turnover magnitude to be too bright, and therefore the value of H_0 in equation (2) to be too large. Hence, equation (2) would be an upper limit.

A. S. thanks NASA for publication support through the Space Telescope Science Institute for this and earlier reports concerning the Hubble constant using *HST* data. G. A. T. thanks the Swiss Science Foundation for continuing support covering all aspects of our Hubble constant project. We both thank Jerome Kristian, and a helpful referee for reading and commenting on the manuscript.

[2] The same objection holds against Freedman et al. (1994) and Tanvir et al. (1995). They stepped their distance of M100 and NGC 3368, respectively, to Coma but then did not enter eq. [1], or some independent version of it, to determine the proper cosmic redshift to use at that distance. Each of their derived Hubble constants is incorrect by the error resulting in their adopted "cosmic velocity" for Coma, not corrected for random motion by the precepts contained in eq. [1].

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