Distances to Local Group Galaxies

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Abstract. Distances to galaxies in the Local Group are reviewed. In particular, the distance to the Large Magellanic Cloud is found to be \((m - M)_0 = 18.52 \pm 0.10\), corresponding to \(50,600 \pm 2,400\) pc. The importance of M31 as an analog of the galaxies observed at greater distances is stressed, while the variety of star formation and chemical enrichment histories displayed by Local Group galaxies allows critical evaluation of the calibrations of the various distance indicators in a variety of environments.

1 Introduction

The Local Group (hereafter LG) of galaxies has been comprehensively described in the monograph by Sidney van den Berg [1], with update in [2]. The zero-velocity surface has radius of a little more than 1 Mpc, therefore the small sub-group of galaxies consisting of NGC 3109, Antlia, Sextans A and Sextans B lie outside the LG by this definition, as do galaxies in the direction of the nearby Sculptor and IC342/Maffei groups. Thus the LG consists of two large spirals (the Galaxy and M31) each with their entourage of 11 and 10 smaller galaxies respectively, the dwarf spiral M33, and 13 other galaxies classified as either irregular or spherical. We have here included NGC 147 and NGC 185 as members of the M31 sub-group [60], whether they are actually bound to M31 is not proven. Similarly, Leo I and Leo II are classified as satellites of our Galaxy, however [1] has pointed out that the mass of our Galaxy becomes uncomfortably large if they are indeed bound. Of these 36 galaxies, 23 are classified [1], [2] as being dwarf galaxies with \(M_V < -14.0\). There are no giant ellipticals, the nearest being some 7 Mpc distant in the Leo I group, nor is there anything so exotic as NGC 5128 (Cen A) at 4 Mpc distance in the Centaurus group. However there are some interesting ‘one-off’s’; M32 is a dwarf elliptical, and IC 10 is an irregular galaxy presently undergoing very active star formation (starburst galaxy). The LG as defined above is listed in Tables 1-4. Columns 1-3 give the galaxy name, type and approximate absolute magnitude [1], [2], while column 4 gives an indication of the population mix, which is a guide to the types of distance indicator present. The star formation history of local group dwarf galaxies is remarkably diverse, and the true situation is much more complex than this simple guide, which has divisions of young (less than \(\sim 1\) Gyr), intermediate (1-7 Gyr), and old (7-12 Gyr). Throughout, old populations appear to be ubiquitous, even though their fractional contribution to the total light can be very small, and it is not clear whether the formation times are coincidental, or spread over a few Gyr [3].
The LG is contained in what is termed the ‘Local Volume’, a sphere with radius approximately 10 Mpc, thus a a factor 1000 times the volume of the LG. A systematic census of galaxies likely to lie in this volume [5], those with $V_{\text{LG}} < 500$ km/s, listed 179 members, this number has been doubled by more recent work [6]. These galaxies are clustered in rather ill-defined groups, with substantial volumes (e.g. the ‘Local Void’) free or almost free of galaxies. The closest groups have zero-velocity surfaces that are close to that for the LG, for instance the Sculptor group appears to be very elongated and viewed almost end-on, the nearest members such as NGC 55 are less than 2 Mpc from the LG barycenter. The Centaurus group, which is estimated to be about seven times as massive as the LG [7] has zero-velocity surface only $\sim 2$ Mpc from the LG barycenter. The large numbers of dwarf galaxies recently found in both groups [8] appear more spatially dispersed than do the more massive galaxies, this is also true for the LG.

As far as we know, LG galaxies are typical of the ‘mean’ population of galaxies, thus a detailed study should allow deductions to be made concerning the general properties of galaxies, in particular their formation and subsequent evolution, throughout the Universe. The common dwarf spheroidal (dSph) galaxies are the best places to test the small scale predictions of hierarchical galaxy formation models, and the nature and distribution of dark matter [9]. Indeed, the favored cold dark matter (CDM) formation theory predicts a factor 10 more dSph galaxies in the LG than are known, however it is estimated [10] that we have found more than half of them. Recent successful [11] and on-going [12] searches are helping to refine the total numbers of LG dSph’s, but we have found all the higher surface-brightness members unless they are hidden directly behind the galactic plane.

The latest generation of large telescopes and instrumentation have meant that detailed studies of stellar formation, stellar evolution and chemical evolution have moved from the confines of our Galaxy and the Large and Small Magellanic Clouds (LMC, SMC) to all the LG galaxies. Imaging to faint limits in crowded fields has been made possible with HST, and this has allowed us, with some difficulty, to reach the old main sequence turnoff in M31 and to measure RR Lyraes throughout the LG. For distance scale work this has granted us the extra perspective resulting from the study of distance indicators in a variety of different environments. However interpreting the observations is not an easy task, as almost all galaxies contain multiple populations with complex histories, and we now realize that interactions between many LG dwarf galaxies and the two giant LG spirals are likely to have been a feature throughout their lifetimes, as the present-time assimilation of the Sagittarius dSph by our own Galaxy dramatically illustrates.

Distances to galaxies in the LG are obviously needed as part of the study of the galaxies themselves. Given the large dynamic range of astronomical distances, which means that the distance scale is built up from overlapping indicators starting with those we can calibrate directly nearby, the LG galaxies play an essential role in the verification and extension of the distance scale. In this short
review we will cover a selection of the recent work in the field; given the huge amount of recent and on-going work on LG galaxies no attempt is made to be complete and only work relating to the topic in hand will be addressed. For many of the lower luminosity galaxies our knowledge is still quite rudimentary, albeit rapidly increasing due to the efforts by several groups. In section 2 we comment briefly on distance indicators relevant to the present topic, and then in sections 3 through 6 discuss companions to our own Galaxy, M31 and its companions, luminous isolated galaxies, and finally faint isolated galaxies. We conclude with a short summary. Note that a previous discussion of this topic is [14], and a convenient table listing LG galaxies and their distances from our Galaxy and the LG barycenter is found in [2]. An extensive database of distances and other useful information is contained in [4], as part of the Distance Scale Key Project. The below discussion relies heavily on [1], [2] for details and evaluation of work prior to 2000.

Two other comments are in order. Firstly, the nomenclature for LG galaxies is clearly a mess, with the tradition of naming newly discovered dSph’s after the constellation in which they are found, and only that, is nonsensical and a hinder to computer searches at the very least. This is clearly a matter that the International Astronomical Union should take up. The second comment refers to errors. Unless stated specifically to the contrary, here and elsewhere errors refer to the error associated with the measurement of a distance, and do not include an estimate of the error of the accuracy of the calibration of the distance indicator used. For the latter, systematic errors dominate; these are difficult to evaluate, and are almost always underestimated.

2 Relevant Distance Scale Calibrators

Most of the distance indicators discussed elsewhere in this volume (q.v.) are relevant for use within the LG, and only a few general comments will be made here. The more massive LG systems, with the exception of M32 have had continuing, if in some cases spasmodic, star formation over their whole lifetimes and thus all ‘population I’ and ‘population II’ indicators can in principle be observed. The lower mass galaxies are mostly dominated by a mixture of intermediate and older populations, and thus indicators such as the brightness of the Tip of the Red Giant Branch (TRGB) and RR Lyraes are very useful, although for the more distance LG galaxies the latter are difficult to measure, even with HST. The metal-poor, low-mass irregulars with recent star formation contain ultra-short period Cepheids, and these have been advocated [15] as a useful indicator for these systems. Perhaps most importantly, the diversity of galaxies allows inter-comparison between distance indicators in a wide variety of environments.

In summary, primary indicators used to find distances to LG galaxies include: Cepheids, Mira variables, RR Lyraes, RGB clump, Eclipsing Binaries and TRGB. Secondary distance indicators whose zeropoint relies wholly or partially on distances to LG galaxies provided by the primary indicators includes Planetary Nebulae Luminosity Function (PNLF), Supernovae, Surface Bright-
Table 1. Our Galaxy and its companions

| Name    | Type$^a$ | $M_V^a$ | Populations$^b$ |
|---------|----------|---------|-----------------|
| Galaxy  | SbcI-II  | -20.9   | all             |
| LMC     | Ir III-IV| -18.5   | all             |
| SMC     | Ir IV-V  | -17.1   | all             |
| Sagittarius | dSph | -14:     | intermediate, old |
| Fornax  | dSph     | -13.1   | (young), intermediate, old |
| Leo I   | dSph     | -11.9   | (young), intermediate, (old?) |
| Leo II  | dSph     | -10.1   | (intermediate), old |
| Sculptor| dSph     | -9.8    | (young, with gas), intermediate, old |
| Sextans | dSph     | -9.5    | intermediate, old |
| Carina  | dSph     | -9.4    | (young), intermediate, old |
| U. Minor| dSph     | -8.9    | (intermediate?), old |
| Draco   | dSph     | -8.6    | old             |

$^a$ From [1], [2]
$^b$ Minority populations are bracketed.

Table 2. M31 and its companions

| Name    | Type$^a$ | $M_V^a$ | Populations$^b$ |
|---------|----------|---------|-----------------|
| M31     | SbI-II   | -21.2   | all             |
| M32     | E2       | -16.5   | (intermediate), mostly old |
| NGC 205 | Sph      | -16.4   | (young), mostly intermediate, (old) |
| And I   | dSph     | -11.8   | mostly old      |
| And II  | dSph     | -11.8   | intermediate, old |
| And III | dSph     | -10.2   | intermediate, (old) |
| And V   | dSph     | -9.1    | old             |
| And VI  | dSph     | -11.3   | mostly old      |
| And VII | dSph     | -12.0   | mostly old?     |
| NGC 147 | Sph      | -15.1   | (young & intermediate), mostly old |
| NGC 185 | Sph      | -15.6   | (young), intermediate, old |

$^a$ From [1], [2]
$^b$ Minority populations are bracketed.
Table 3. Brighter isolated LG galaxies

| Name   | Type   | $M_V$  | Populations |
|--------|--------|--------|-------------|
| M33    | Sc II-III | -18.9  | all         |
| IC 10  | Ir IV   | -16.3  | all, no globular clusters |
| NGC 6822 | Ir IV-V | -16.0  | all         |
| IC 1613 | Ir V    | -15.3  | all, no globular clusters |
| WLM    | Ir IV-V  | -14.4  | all         |

- From [1], [2]
- Minority populations are bracketed.

Table 4. Fainter isolated LG galaxies

| Name   | Type | $M_V$  | Populations |
|--------|------|--------|-------------|
| Pegasus | Ir V | -12.3  | (young), intermediate, old |
| Sag DIG | Ir V | -12.0  | young, intermediate, (old?) |
| Leo A   | Ir V | -11.5  | (young), intermediate, old |
| Aquarius | Ir V | -10.9  | young, intermediate, (old?) |
| Pisces  | Ir/Sph | -10.4 | young, intermediate, (old?) |
| Cetus   | dSph  | -10.1  | intermediate, old? |
| Phoenix | Ir/Sph | -9.8   | all         |
| Tucana  | dSph  | -9.6   | old         |

- From [1], [2]
- Minority populations are bracketed.

Nearest Fluctuations (SBF), Globular Cluster Luminosity Function (GCLF), Novae, and Blue Supergiants. The distinction is not always absolute, for instance TRGB when calibrated by distances to Globular Clusters which themselves are tied to Hipparcos parallaxes of subdwarfs is primary, but if it is calibrated from the brightness of the Horizontal Branch (HB) and thus dependent on the adopted luminosities of RR Lyraes, then it is secondary. Depending on the degree of the reader’s belief in the underlying theory, all the secondary indicators could be considered primary, in principle.

3 Companions of our Galaxy

There are 11 known companions to our Galaxy, although the status of Leo I and Leo II is uncertain. Of these the Sagittarius dSph is in collision with our
Galaxy, and thus plays little part in distance scale studies. Its mean distance is \((m - M)_0 = 17.36 \pm 0.2\) from Mira variables and \((m - M)_0 = 17.18 \pm 0.2\) from RR Lyraes. Given the extended structure of the Sagittarius dSph, such numbers are not particularly meaningful.

The LMC by contrast is pivotal in distance scale work, and will be discussed in some detail here, and elsewhere in this volume. The major use of the LMC is as a sanity check - it includes most of the popular distance indicators and is close enough so that they can be studied in great detail, yet is far enough away so that to a first approximation its contents can all be considered to be at the same distance from us. Recent reviews see also discuss the topic in great detail, however progress has been rapid with improvements to the primary calibrators that have resulted in improved consistency. The comprehensive figure showing results ranging from \((m - M)_0 = 18.1\) to 18.8, although a good historical summary, is more pessimistic than need be. The smaller moduli mostly come from early results based on using Hipparcos parallaxes for the locally common RGB clump stars, without realization that both age and abundance each have a dramatic effect on the absolute magnitude of the clump. Modeling of these effects has provided quantitative understanding of the evolution of clump stars, and has shown the advantage of observing in the infrared K-band which additionally greatly reduces the significance of reddening corrections compared to observing in the visible. New results for both LMC cluster and field all give LMC moduli near 18.5.

The LMC distance gap between the traditional indicators, Cepheids and RR Lyraes, has also narrowed with the mean RR Lyrae modulus now 18.44 \pm 0.05, even with the traditionally short value given by statistical parallaxes of galactic field RR Lyraes included. The realization in recent years that the galactic halo contains star streams, possibly remnants of accreted dwarf galaxies, makes less certain the assumption of velocity homogeneity assumed in the statistical parallax method. We will adopt, see

\[
< M_V(RR) >= 0.21( [Fe/H] + 1.5) + 0.62
\]  

For Cepheids, the remaining questions are well summarized elsewhere in this volume: the characterization of the effect of metallicity on the PL relation zeropoint still defies solution, and is the most important unknown. Cepheids are well-understood both observationally and theoretically, and with fundamental astrometric and interferometric observations to add to the Hipparcos parallax measurements, the likelihood of there being a significant systematic error in the (metal-normal) PL zeropoint seems remote.

Eclipsing binaries are a promising technique, with the issues very clearly set out by who gives distances for ten SMC binaries found by OGLE, solving the technical difficulty of getting enough large telescope time to measure the radial velocities by observing all the stars at once using the wide-field fiber spectrograph 2DF on the Anglo-Australian telescope. The three LMC systems have been recently (re)discussed, see.

There are still some disquieting problems, and there are still some systematic differences between calibrators that we would like to understand better.
However, the evidence seems strong for an ‘intermediate’ LMC modulus, and here (Table 5) we adopt \((m - M)_0 = 18.52\). It is noteworthy that for the recent determinations by a variety of methods the error bars overlap, this gives confidence that there are not undiscovered systematic errors, and so it seems not too unrealistic to evaluate the overall accuracy of the above mean modulus as \(\pm 0.1\) mag, corresponding to \(\pm 5\%\) in the distance. Many of the estimates for other LG galaxies below are tied to the LMC at a modulus of 18.50; we have made no adjustments for the slight difference with the Table 5 value.

Turning now to the SMC, this galaxy has received far less prominence in comparison to the LMC, mostly due to the considerable extent of the SMC along the line of sight. The degree of this extent is controversial, see [34] for a 3-D model. The SMC Cepheids show considerable dispersion in the period-luminosity (PL) relation, but there is little room from the small dispersion in the period-color relation to allow for a significant range in reddening or possibly metallicity, thus it is difficult to explain the PL dispersion as anything other than a depth effect. Even a ‘mean’ distance to the SMC derived from different distance indicators may not be comparable if there are differences in the spatial distribution of SMC stars as a function of age. Despite this cautionary note, the SMC has mean metallicity substantially lower than the LMC [35] and thus it is of use for investigating the effects of metallicity on distance indicators [74]. Earlier work, as summarized by [16] gives \(m - M = 18.94\) for the LMC at 18.52.

The remaining galaxies in this group are all of type dSph, and with the exception of Fornax and Sagittarius are amongst the lower luminosity examples of this type, which is likely a selection effect [10]. With their significant old populations, these galaxies all contain many RR Lyraes. We give some updates to the distance estimates tabulated in [1], [2]. For Sculptor, using OGLE photometry [36] and assuming mean \([Fe/H] = -1.9\) for the RR Lyraes, \((m - M)_0 = 19.59\), while restricting the sample to just the double-mode RRd stars, [37] finds \((m - M)_0 = 19.71\).

Photometry for 515 RR Lyraes in Fornax has recently been published [38] who find \(<V_0> = 21.27 \pm 0.10\), with \([Fe/H] = -1.6 \pm 0.2\), \((m - M)_0 = 20.67\). This is in good agreement with their earlier work [39] which gives a TRGB distance of 20.68 mag.

The most recent RR Lyrae photometry for the Carina dSph is by [40]. With \(<V_0> = 20.68\) and assuming a mean \([Fe/H] = -1.7\), \((m - M)_0 = 20.06 \pm 0.12\). This value is in excellent agreement with earlier work [1].

The distance to the Sextans dSph is given [41] as \((m - M)_0 = 19.67 \pm 0.15\), however there are uncertainties in the metallicity which could change this value. These authors also discovered an intermediate age population as evinced by six anomalous Cepheids, and [42] further discuss the multiple populations and their metallicities.

The Draco and Ursa Minor dSphs have recently been compared [43], with respective distances from the horizontal branch magnitude of \((m - M)_0 = 19.84\)
0.14 and 19.41 ± 0.12 being derived. These distances are in good agreement with those found by the TRGB method.

Leo I and Leo II are considerably more distant than the above, and despite morphological similarities have strikingly different star formation histories [78]. The best distances to Leo I appear to be those measured using the TRGB method [77], \((m - M)_0 = 22.16 ± 0.08\), and from RR Lyraes by [72], \((m - M)_0 = 22.04 ± 0.14\). Similar data are available for Leo II, where [1] evaluates the distance as \((m - M)_0 = 21.60 ± 0.15\). For Leo II, the discovery of copious numbers of RR Lyrae variables [90] will likely yield an improved distance.

| Indicator       | Value            | Reference |
|-----------------|------------------|-----------|
| Cepheids        | 18.55 ± 0.06     | [73, 74]  |
| RR Lyraes       | 18.44 ± 0.05     | [27]      |
| RG Clump        | 18.49 ± 0.06     | [21, 22, 23] |
| TRGB            | 18.59 ± 0.09     | [75, 76]  |
| Eclipsing Bin.  | 18.46 ± 0.1      | [30, 31, 32] |
| Miras           | 18.59 ± 0.2      | [15]      |
| SN 1987A        | 18.55 ± 0.17     | [15]      |
| Mean            | 18.52 ± 0.10     |           |

4 M31 and its Companions

M31 contains all the distance indicators mentioned above and, as well stated by [44], *An SB-III giant spiral galaxy provides a much more appropriate local counterpart to the Distance Scale Key Project galaxies than does the LMC... M31 is also an important calibrator for the PNLF zeropoint, and also for the Globular Cluster Luminosity Function (GCLF) method, applicable to massive galaxies with large GC populations. Therefore, in any respect except for ease of observations, M31 is a much more important cornerstone for the distance scale than the LMC. To which might be added the difficulties include both the variable (internal) reddening, and the large angular extent on the sky, the latter now being addressed by the latest generation of wide-field imagers and multi-object spectrometers.*

The distance to M31 has long been established using Cepheids, with a much-quoted result [45], referenced to the LMC at an assumed distance modulus of 18.50 and reddening \(E(B-V) = 0.10\), of \((m - M)_0 = 24.44 ± 0.10\). From HST
photometry of M31 clusters, [46] found $V_0(HB) = 25.06$ at $[Fe/H] = -1.5$, then with $M_V(RR) = 0.62$, $(m - M)_0 = 24.44$, while from isochrone fits to the RGB, [48] found $(m - M)_0 = 24.47 \pm 0.07$. All these results are in remarkably good agreement. A major effort that will improve the amount of data available for M31 Cepheids and Eclipsing Binaries is the DIRECT Project [47] which has the aim of measuring the distance to M31 in one-step via the Baade-Wesselink method for Cepheids and by discovering and measuring a significant number of eclipsing binaries.

Using HST, [44] have shown that it is possible to measure M31 cluster RR Lyraes, but the observational task is less formidable for field RR Lyraes in the companion galaxies to M31. For instance [49] give HST lightcurves for 111 RR Lyraes in And VI, and derive intensity-mean $<V> = 25.10 \pm 0.05$, with $[Fe/H] = -1.58 \pm 0.20$ [50], and the RR Lyrae magnitude-metallicity relation above, $(m - M)_0 = 24.50 \pm 0.06$. The And VI distance from the TRGB method, is $(m - M) = 24.45 \pm 0.10$ [50]. Systematic HST photometry of other dSph companions to M31 are yielding distances via the magnitude of the horizontal branch or mean magnitudes of the RR Lyraes. For And II, [51] measure $(m - M)_0 = 24.17 \pm 0.06$, while for And III they find [52] $(m - M)_0 = 24.38 \pm 0.06$. Clearly, with accurate distances relative to M31 the true spatial distribution of the M31 dSph companions can be mapped; this requires accurate photometry and a knowledge of the metallicity.

M32 is the closest companion to M31, it is a dwarf elliptical, with clear indications of interactions and likely tidal stripping by M31 [1]. It is an important site for stellar population studies, until the recent discovery [53] of luminous AGB stars it was argued that M32 contained only an old population. The distance to M32 is usually assumed to be the same as for M31 [1].

NGC 205 is also a close companion of M31, distance estimates are well summarized by [1], with for example a TRGB distance of 24.54 [33]. HST CMDs for NGC 205 clusters are discussed in a preliminary report by [55].

NGC 147 and 185 lie close together on the sky and the evidence is strong that they are bound to each other [1], less certain is whether they are bound to M31 [60]. Early distance measurements, including those via RR Lyraes, are summarized by [1]. The TRGB estimate for NGC 147 by [54] is 24.27, they also give 24.12 for NGC 185, with an independent TRGB estimate [61] of 23.95 \pm 0.10. Both galaxies therefore are slightly closer to us than M31, and as pointed out by [1], lie close to the LG barycenter.

5 Luminous Isolated LG Galaxies

The spiral galaxy M33 is the third most luminous galaxy in the LG, although it is only slightly brighter than the LMC [1]. Recent distance measurements have shown considerable dispersion, although it has been suggested [59] that they may all be reconciled by reasonable adjustments of the reddening, and it will be interesting to see whether or not that is indeed the case. They also suggest that to circumvent the reddening problem for Cepheids, a technique of determining
the periods using optical photometry, followed by a single-epoch infrared K-band observation, should be used. As the phasing is known, the K-band observation need not be taken at random phase but can instead be chosen to correspond to phases near mean light, since although the K band amplitudes of Cepheids are small, they are not negligible. Using periods from the DIRECT Project [47] together with single-epoch HST I-band observations, [56] find for 21 Cepheids $(m - M)_0 = 24.52 \pm 0.14 (\text{stat}) \pm 0.13 (\text{sys})$ assuming $E(B - V) = 0.20$ for M33 and based on an LMC distance of 18.50 mag. and $E(B - V)_0 = 0.10$. The Key Project Cepheid distance, for 11 stars, is very similar at $24.56 \pm 0.10$. Using the same HST data set, [57] found a rather larger distance from RGB stars in multiple fields, $24.81 \pm 0.04 (\text{stat}) \pm 0.13 (\text{sys})$ from the TRGB and $24.90 \pm 0.04 (\text{stat}) \pm 0.05 (\text{sys})$ from the RGB clump. Photometry of M33 halo clusters [58] gives very similar values, from the horizontal branch magnitude in two clusters $(m - M)_0 = 24.84 \pm 0.16$, while from the position of the RGB clump in 7 clusters $(m - M)_0 = 24.81 \pm 0.24$.

There are four other relatively luminous isolated galaxies, all are Irregulars of type IV or V. Due to its very low galactic latitude and consequent high foreground reddening, IC 10 is difficult to study. Reddening estimates in the literature range over a very wide value, and to complicate matters the internal reddening seems highly variable, perhaps not surprising given the high star formation rate. From V and I observations of Cepheids [64] derive $(m - M)_0 = 24.1 \pm 0.2$, and $E(B - V) = 1.16 \pm 0.08$. With this reddening, their TRGB distance is $(m - M)_0 = 23.5 \pm 0.2$, but they regard this as a lower limit since there is no reason to expect the halo of IC 10 to have reddening as high as the inner regions where the Cepheids are located. To force the TRGB distance to be the same as given by the Cepheids implies that the IC 10 halo has reddening of $E(B - V) = 0.85$, which would then be primarily the amount of galactic foreground reddening. A new estimate of $(m - M)_0 = 24.4$, with $E(B - V) = 0.77$, is given by [65], but with no details. Clearly, infrared measurements for the IC 10 Cepheids would be of value in reducing the distance error for this very interesting galaxy.

There do not appear to be any distance estimates for NGC 6822 more recent that those evaluated by [1], who derives $(m - M)_0 = 23.48 \pm 0.06$ from a weighted mean. Recently, [65] have found many more Cepheid variables in a survey, the reference describes those in a single 3.77 x 3.77 arcmin field.

For IC 1613, [1] derives $(m - M)_0 = 24.3 \pm 0.1$. From the TRGB method, [67] find $(m - M)_0 = 24.53 \pm 0.10$, and also determine $[Fe/H] = -1.75$. As a by-product of the OGLE project [68] measured 138 Cepheids in a central field, and compared to distances from the RR Lyraes and the TRGB, and concluded that the distance is $(m - M)_0 = 24.20 \pm 0.02 (\text{stat}) \pm 0.07 (\text{sys}).$ A similar study is that by [69], who compare Cepheids, RR Lyraes, RGB clump stars. and TRGB using deep HST V and I photometry, to find $(m - M)_0 = 24.31 \pm 0.06$. In later work, [62], [63], they examine the question of whether ultra-short period Cepheids (USPC’s, Population I Cepheids with periods less than two days) are useful distance indicators, comparing the properties of such stars in the SMC,
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LMC, IC 1613, Leo A, and Sextans A. It has been long known that metal-poor systems with young populations contain more USPC’s than do more metal rich systems. They find that USPC’s do indeed appear to be good distance indicators, with excellent agreement between the USPC’s and TRGB, RGB clump, longer period Cepheids, and RR Lyraes for Sextans A, Leo A, IC 1613 and the SMC, but not for the LMC where such stars appear to be 0.2 mag. too luminous. In the LMC USPC’s are uncommon, and thus it is postulated that these stars are fundamentally different from those in the more metal-poor systems. It is well-known that the light curve amplitudes are much smaller for the LMC USPC’s compared to those in the SMC, for example.

The WLM galaxy has a distance \( (m - M)_0 = 24.83 \pm 0.1 \) from several Cepheid and TRGB estimates. There are two recent measurements, \( [70] \) observed a field with STIS on HST, reaching the level of the horizontal branch. Assuming \([Fe/H] = -1.5 \) and \( M_V = 0.7 \), they find \( (m - M)_0 = 24.95 \pm 0.13 \). Reddening to WLM is low, they adopt \( E(V - I) = 0.03 \). A rather similar result is found by \( [71] \), who give \( (m - M)_0 = 24.88 \pm 0.09 \) from HST WFC2 photometry.

In conclusion, the luminous, isolated galaxies in the LG provide a wealth of information relevant to the distance scale. They are relatively rich, so that they contain good-sized samples allowing statistically significant comparisons to be made, and environs sufficiently different one to the other that metallicity and age effects can be investigated in depth. Such work is on-going. Distances are in relatively good agreement for the galaxies with low reddening, objects like IC 10 are clearly much easier to study in the infrared.

6 Faint Isolated LG Galaxies

This category consists of the faint dwarf irregulars: Pegasus, Aquarius, Sag DIG and Leo A, together with the fainter ‘transition’ objects Pisces and Phoenix, plus two dwarf spheroidals: Tucana and Cetus. For the dwarf irregulars, by definition, star formation has occurred at some level up to the present time, however the occurrence of rare stages of star formation depends critically on the star formation rate at any given time. Even for more luminous galaxies this effect is well-seen, an example is the lack of long-period Cepheids in WLM compared to the situation in the rather similar galaxy Sextans A.

The Pegasus dwarf irregular galaxy (DDO 216) appears to have had little attention since the summary by \( [11] \), who points out that differences in the reddening adopted between the several studies he quotes means that the distance is not well determined, and he adopts \( (m - M)_0 = 24.4 \pm 0.25 \). Depending on the true distance, Pegasus may possibly be a distant member of the M31 sub-group.

The most recent distance to the Aquarius dwarf irregular galaxy (DDO 210) is that of \( [89] \), who from the TRGB method finds \( (m - M)_0 = 24.9 \pm 0.1 \)

The Sagittarius Dwarf Irregular galaxy (Sag DIG) has a distance from the TRGB method by \( [79] \) of \( (m - M)_0 = 25.36 \pm 0.10 \), and as such it is the outermost galaxy in the LG according to \( [2] \).
Leo A has been studied recently by [80], who found a distance by the TRGB method of $(m - M)_0 = 24.5 \pm 0.2$, and by [81], who from HST observations measured the brightness of the RR Lyraes, to find $(m - M)_0 = 24.51 \pm 0.07$.

Pisces, also widely referred to as LGS 3, has been observed by [82], who find from the TRGB, the brightness of the clump RGB stars, and the level of the horizontal branch, that $(m - M)_0 = 23.96 \pm 0.07$. Classified as a transition object, there is still active star formation in a small area approximately 60 pc in diameter near the center of the galaxy.

The central regions of Phoenix were studied using HST by [83], who measured the level of the horizontal branch at $V(HB) = 23.9 \pm 0.1$ which using the calibration of equation (1) corresponds to $(m - M)_0 = 23.3 \pm 0.1$. Their TRGB distance is somewhat shorter, $(m - M)_0 = 23.11$, very similar to earlier results [84], [85].

The Tucana dSph is one of the most isolated galaxies in the LG, TRGB distances [87], [86] average to $(m - M)_0 = 24.76 \pm 0.15$. HST imaging of this galaxy [88] has never been published in detail, the CMD appears to show a single, old population.

Finally, the Cetus dSph galaxy was recently discovered [11] and the first stellar populations study, from HST observations, has just appeared [58]. From the TRGB method, $(m - M)_0 = 24.46 \pm 0.14$, for $E(B - V) = 0.03$, identical to the ground-based distance found by [11] using the same method.

7 Summary

The LG is a very important place, where we can study galaxies in detail and thus extrapolate our findings to the Universe at large. and it is where we set up and verify the distance scale ladder. With the development of large format imaging mosaics, and the advent of very large telescopes with powerful spectrographs, together with the unique capabilities of HST, there has been an explosion in the amount of high quality data available for LG galaxies, while in parallel there has been substantial progress on the theoretical understanding for most of the popular standard candles, and substantial improvements in their calibrations. Specifically, it appears that the ‘long-short’ problem for the distance to the LMC has largely vanished. Distances from the reliable indicators are now within one sigma of each other, and although it is clear there are still systematic differences, they have shrunk, and the LMC modulus of $(m - M)_0 = 18.52 \pm 0.10$ seems reasonably secure. Reduction in the size of the error, and improvement in the agreement between distance indicators, will be aided by comparisons made in a variety of environments, and here the LG galaxies are of key value. The wealth of new work reported above will be invaluable in this respect.

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