The Distance to Super nova 1998ag in NGC 3982

Peter B. Stetson, Jr.

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Introduction

NGC 3982 is a nearby spiral galaxy located at a distance of 12.5 ± 0.8 Mpc. It is a member of the Local Group of galaxies and is one of the closest spiral galaxies to Earth. The galaxy has a diameter of about 200,000 light-years and is located in the constellation of Andromeda. NGC 3982 is known for its bright nuclear region, which contains a compact nucleus and a number of active star-forming regions.

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Project (HST PID 8100; Saha et al. 2001, and references therein).

Data processing followed the precepts outlined in Gibson & Stetson (2001, and references therein). Instrumental photometry was provided by ALLFRAME (Stetson 1994), while a version of TRIAL (Stetson 1996) — customized for WFPC2 data and the fitting of Cepheid light curves in the V and I photometric bands — was used for calibration and variable finding. A slightly refined version of the Stetson (1998) WFPC2 photometric zero points and charge correction were employed, as was done in Freedman et al. (2001), Gibson & Stetson (2001), and Gibson & Brook (2001). Our quoted systematic error budget includes a ±0.07 mag component that allows for the uncertainties associated with our current understanding of the spatial and temporal properties of the WFPC2 charge-transfer inefficiencies.

Candidate variables returned by TRIAL were culled to a final set of 32 high-quality Cepheids. The criteria employed in this selection were as follows:

- modified Welch & Stetson (1993) index > 0.60
- variable has data from a minimum of ten frame-pairs
- mean V-magnitude \((\langle V \rangle)\) fainter than 24.4 mag
- mean color 0.40 < \((\langle V \rangle - \langle I \rangle)\) < 1.60
- period > 30 days
- semi-amplitude of fundamental harmonic > 0.22 mag
- visual inspection of image
- visual inspection of lightcurve

A selection on the ALLFRAME image-quality index \(\chi\) was considered, but the stars meeting the above eight criteria were found to be completely normal in their \(\chi\) values. The properties of the 32 Cepheids passing this selection are listed in Table 1. Epoch-by-epoch photometry for each of the Cepheids, local calibration standards, and accompanying light curves have been made available at our HST Cepheid archive.†

Figure 1 shows the apparent V- and I-band period-luminosity (PL) relations for the 32 Cepheids in NGC 3892 (upper and middle panels, respectively). Figure 2 shows the positions of these Cepheids in the calibrated \((V, V - I)\) colour-magnitude diagram. After Freedman et al. (2001), the apparent moduli of Figure 1, coupled with the assumption of a standard reddening law, Large Magellanic Cloud (LMC) absolute distance modulus \(m_0(lMC) = 18.50\pm0.10\) mag, and the new OGLE LMC apparent PL relations (Udalski et al. 1999), yield the distribution of deduced true modulus \(m_0\) shown in the bottom panel of Figure 1. The unweighted mean true modulus, based upon all 32 Cepheids, is \(<m_0> = 31.559\pm0.081\) (r), where the total random uncertainty \(\sigma_r\) includes components due to photometry, extinction, and deduced PL fit, added in quadrature (corresponding to \(R_{PL}\), in Table 7 of Gibson et al. 2000).‡ It is reassuring that the median of the distribution \((31.594)\) agrees with the mean \((31.559)\).

Our quoted result — \(<m_0> = 31.559\pm0.081\) (r) — inherently assumes that the Cepheid PL relation is independent of metallicity (i.e., \(\gamma_{VI} = 0.0\) mag dex\(^{-1}\)). If one assumes a metallicity dependence of the form \(\gamma_{VI} = -0.2\) mag dex\(^{-1}\) (Freedman et al. 2001), though, a measure of the mean metallicity for the WFPC2 Cepheid field is required to determine the true metallicity-corrected distance modulus \(m_0\). Unfortunately, no HII regions in this field have thus far been observed. Adopting a conservative metallicity range of 12 + log\((O/H)\) = 8.9 ± 0.4 (as we did for the analysis of the NGC 4527 dataset — Gibson & Stetson 2001) would increase the inferred mean true modulus by ±0.08 mag.

The mean reddening inferred from the 32 Cepheids is \(E(V-I) = 0.388\pm0.029\) mag (internal), of which only ±0.019 mag is due to foreground Galactic extinction (Schlegel et al. 1998). While it might be tempting to assign a field mean metallicity based upon an assumed intrinsic relationship between \(E(V-I)\) and 12 + log\((O/H)\), unfortunately — as already noted in Gibson & Stetson (2001) — for 0.12\(E(V-I)\) 0.3 (a regime which the NGC 3892 Cepheids inhabit), there is no trend seen in the data, with metallicity

\[\text{Figure 1. Apparent period-luminosity relations in the V-} \text{upper panel} \text{and I-bands middle panel} \text{based upon the 32 Cepheids discovered in NGC 3892 (the properties of which are listed in Table 1). The solid lines are least-squares fits to this entire sample, with the slope fixed to be that of the Udalski et al. (1999) LMC PL relations, while the dotted lines represent their corresponding ±1σ dispersion reflecting the width of the LMC instability strip. The inferred apparent distance moduli, ignoring metallicity effects, are then } \mu_V = 31.899\pm0.070 \text{ (internal) and } \mu_I = 31.762\pm0.056 \text{ (internal). Lower Panel: Distribution of individually de-reddened Cepheid true moduli, as a function of period. The mean corresponds to } \langle \mu_V \rangle = 31.559\pm0.081 \text{ (random).}\]

‡Enforcing a lower period cut of 25 days reduces the Cepheid sample from 32 to 20, the unweighted mean true modulus for which is \(<m_0> = 31.626\pm0.096\) (r), consistent with our favoured result of \(<m_0> = 31.559\pm0.081\) (r). This suggests that PL bias of the magnitude encountered for some galaxies (see § 3.4 of Freed

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Table 1. Properties of Cepheids detected in NGC 3982.

<table>
<thead>
<tr>
<th>ID</th>
<th>Chip</th>
<th>X°</th>
<th>Y°</th>
<th>V &gt;</th>
<th>I &gt;</th>
<th>P</th>
<th>i°</th>
</tr>
</thead>
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<tr>
<td>C01</td>
<td>1</td>
<td>240.3</td>
<td>245.6</td>
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<td>25.98±0.07</td>
<td>16.77±0.21</td>
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<td>89.2</td>
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<td>25.87±0.07</td>
<td>21.33±0.24</td>
<td>31.54</td>
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<tr>
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<td>319.8</td>
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<td>25.33±0.06</td>
<td>37.05±1.59</td>
<td>32.00</td>
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<tr>
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<td>1</td>
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<td>24.71±0.03</td>
<td>53.87±2.85</td>
<td>31.50</td>
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<tr>
<td>C05</td>
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<td>25.70±0.08</td>
<td>25.83±0.58</td>
<td>31.74</td>
</tr>
<tr>
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<td>467.2</td>
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<td>25.44±0.03</td>
<td>45.44±2.73</td>
<td>32.18</td>
</tr>
<tr>
<td>C07</td>
<td>2</td>
<td>130.0</td>
<td>741.7</td>
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<td>25.57±0.06</td>
<td>31.03±1.03</td>
<td>31.78</td>
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<td>18.06±0.27</td>
<td>31.97</td>
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<td>25.88±0.06</td>
<td>19.59±0.30</td>
<td>31.64</td>
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<td>24.94±1.16</td>
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<td>25.51±0.05</td>
<td>38.12±0.59</td>
<td>31.62</td>
</tr>
<tr>
<td>C17</td>
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<td>613.2</td>
<td>392.8</td>
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<td>26.26±0.07</td>
<td>34.14±0.22</td>
<td>31.72</td>
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<tr>
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<td>25.07±0.05</td>
<td>31.60±1.25</td>
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<td>446.1</td>
<td>469.9</td>
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<td>25.12±0.04</td>
<td>27.33±0.88</td>
<td>31.47</td>
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<tr>
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<td>25.51±0.07</td>
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<td>25.00±0.04</td>
<td>45.18±2.75</td>
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<td>25.30±0.04</td>
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<td>38.87±1.02</td>
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<td>25.81±0.06</td>
<td>21.09±0.50</td>
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<td>C29</td>
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<td>31.02</td>
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</table>

*Fixed coordinates are references with respect to BST archive image u5ky010r.

![Figure 2](image_url)  
Figure 2. Calibrated NGC 3982 color-magnitude diagram. The filled circles correspond to the 32 Cepheids of Table 1.

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ble constant are considered significant, including the LMC zero point, crowding, large scale bulk flows, the metallicity dependence of the Cepheid PL relation, the WFPC2 zero points, Cepheid reddening values, and bias in the PL relation. In determining the distance to an individual galaxy, all these error sources are equally applicable except the possibility of large-scale bulk flows. In quadrature, the remaining systematic error budget ($\sigma$) amounts to 0.179 mag. In combination with the already stated total random error budget, our final value for the distance to SN~1998aq in NGC 3982 is

$$\mu_0 = 31.559 \pm 0.081 (r) \pm 0.179 (s) \text{ mag},$$

assuming that a zero slope is the best available estimate for the metallicity dependence of the Cepheid PL relation — i.e., $d = 20.5 \pm 0.8 (r) \pm 1.7 (s) \text{ Mpc}$. If the slope of the metallicity dependence is in fact $-0.2 \text{ mag} \text{ dex}^{-1}$, the modulus is increased by $\sim 0.08 \text{ mag}$ for reasonable assumptions about the metallicity of young stars in NGC 3982.

3 SUMMARY

A Cepheid-based distance to NGC 3982, host to supernova SN 1998aq, has been derived using the same software pipeline and variable-finding algorithms employed throughout the HST Key Project on the Extragalactic Distance Scale. Ignoring any potential metallicity dependence in the Cepheid period-luminosity relation (expected to be on the order of 4% for NGC 3982), we determine a distance to the supernova (and galaxy) of $20.5 \pm 0.8 (r) \pm 1.7 (s) \text{ Mpc}$. Our result is consistent with the Tully-Fisher distance to the Ursa Major Cluster (19.8 Mpc), suggesting that NGC 3982 is indeed a cluster member. Still unpublished multi-colour light curve photometry promises to make SN 1998aq one of the most important calibrators for the extragalactic distance scale.

ACKNOWLEDGMENTS

We would like to thank the staff of the Canadian Astronomy Data Centre for providing an excellent service.

REFERENCES

Armstrong, M. et al., 1998, IAU Circ., 649, 1
Hurst, G.M., Armstrong, M., Arbour, R., 1998, IAU Circ., 6875, 1

Note added in proof: After submission, a preprint from Saha et al. (2001, ApJ, submitted, astro-ph/0107301) appeared which quotes an NGC 3982 distance modulus of $\mu_0=31.72 \pm 0.14$, based upon an independent DoPHOT and HSTphot analysis of the data described herein. The distance found by our ALLFRAME+TRIAL analysis - 31.56 \pm 0.08 (r) \pm 0.18 (s) - is tied to the Udalski et al. (1999) LMC PL relations, while the Saha et al. result is based upon those of Madore & Freedman (1991, PASP, 103, 933). As discussed in Freedman et al. (2001) however, the former are to be preferred over the latter. Regardless, if we were to adopt the Madore & Freedman relations, our inferred NGC 3982 distance modulus would become 31.73 \pm 0.08 (r) \pm 0.18 (s), indistinguishable from that of Saha et al.

Despite these near-identical true distance moduli, there are differences in the analyses - our apparent V- and I-band moduli are 0.13 mag and 0.07 mag smaller than those of Saha et al. - these differences are ameliorated by the inferred reddening $E(V-I)$, ours being 0.06 mag lower than that of Saha et al. ($E(V-I)=0.05$ versus 0.11, for the same Madore & Freedman 1981 LMC PL relations).

A detailed comparison of the photometric differences between the two analyses will have to wait until standard star photometry from the Saha et al. group becomes available. It should be noted though that such Cepheid photometry differences are not uncommon (Gibson et al. 2000; Table 3).

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