The Concerning SH_0ES Hubble Constant

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Abstract. Concerns are raised regarding the SH_0ES results, and the present H_0 controversy. The SH_0ES $H_0 \simeq 73$ km/s/Mpc has remained relatively unaltered across 18 years (2005-2023), despite marked shifts in maser and Cepheid distances to the keystone galaxy NGC4258 (M106), and changes in the slope, zeropoint, metallicity, and extinction terms tied to the Leavitt Law, and notwithstanding uncertain photometry for remote Cepheids spanning galaxies with highly inhomogeneous crowding and surface brightness profiles. Concerns raised regarding the SH_0ES findings by fellow researchers are likewise highlighted. An independent blind assessment of the entire suite of raw HST Cepheid images is warranted, while being mindful of *a priori* constraints and confirmation bias that unwittingly impact conclusions.

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1. Introduction

The reputed '*Hubble tension*' stems in part from an offset between the Planck CMB H_0 relative to that reported by the SH_0ES team. The latter argue the difference separating the estimates is significant ($\simeq$ 67 vs. 73 km/s/Mpc), and the Planck team's determination is erroneous. The SH_0ES team purports their conclusion is robust, and uncertainties associated with the Cepheid distance scale were mitigated (e.g., Riess et al. 2016).

Present claims favoring a *bona fide* offset between Cepheid and CMB H_0 determinations are premature given: a lack of consensus on the Leavitt Law (coefficients, zeropoint, and form), errors and anomalies endemic to SH_0ES findings, ongoing challenges to secure uncontaminated Cepheid photometry across remote spiral galaxies (e.g., NGC4258, §2, Fig. 3), a history of underestimated H_0 uncertainties (Fig. 1), and owing to a spread in CMB results (Fig. 4).

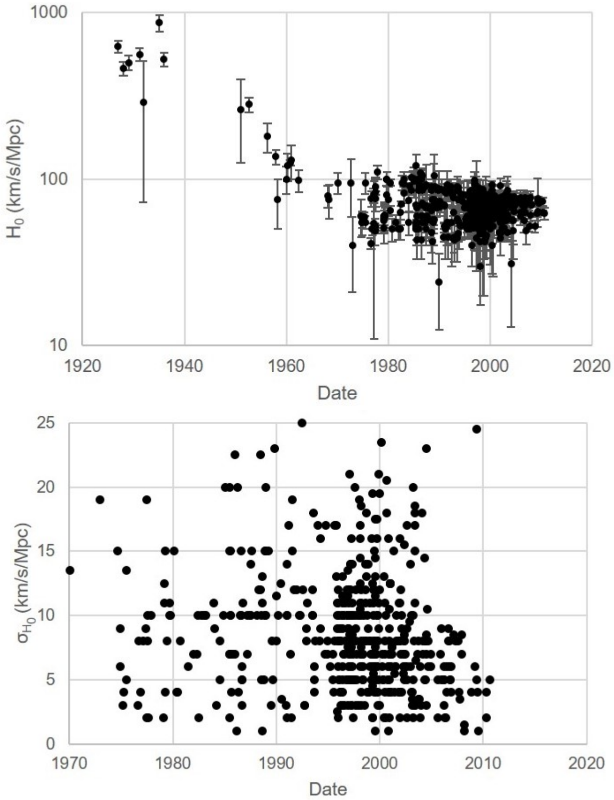

Figure 1. Historical H_0 estimates from the Huchra database. Low uncertainties have been reported for decades. Fig. 2 in Steer (2020) features H_0 data beyond 2010.

2. SH_0ES results & NGC4258 Cepheids

For example, Fig. 12 in Riess et al. (2009, SH_0ES) implies that the slope (α) of the classical Cepheid W_{VI} function for near-solar Cepheids is $\alpha = -2.98 \pm 0.07$, as inferred mainly from SN-host galaxies (e.g., NGC3370). Majaess (2010) and Majaess et al. (2011a) countered that the W_{VI} slope is comparatively constant across a sizable metallicity baseline ($\alpha \simeq -3.3$, Δ[Fe/H] $\simeq 1$), as established from Local Group Cepheids in the Magellanic Clouds, Milky Way, NGC6822, and IC1613 (Fig. 5). The SH_0ES team ostensibly recanted their earlier position by citing a W_{VI} slope tied to near-solar Cepheids of $\alpha \simeq -3.3$ (Riess et al. 2022, SH_0ES), whereas for example Riess et al. (2009, SH_0ES) deduced $\alpha = -2.60 \pm 0.24$ for NGC3021 Cepheids.

The history of Cepheid and maser distances to NGC4258 is disconcerting. Maoz et al. (1999) assessed HST images to determine a Cepheid distance for NGC4258 of 8.1 ± 0.4 Mpc, which was discrepant relative to the Herrnstein et al. (1999) maser distance of 7.2 ± 0.3 Mpc. The Maoz et al. (1999) team revisited their Cepheid distance in Newman et al. (2001), and revised it downward ($7.8 \pm 0.3 \pm 0.5$ Mpc) and marginally closer to the Herrnstein et al. (1999) maser result. At the time various scenarios were proposed aiming to reconcile the two estimates (e.g., Newman et al. 2001; Caputo et al. 2002). Macri et al. (2006) analyzed HST images of Cepheids in two separate NGC4258 fields, and discovered a substantial distance offset between them ($0^{\mathrm{m}}.16$), which is readily discernible in Fig. 3, and that was established in this instance using a Galactic W_{VI} calibration (Majaess et al. 2011a, and references therein). Importantly, an insidious degeneracy exists whereby more crowded fields at smaller galactocentric radii are comparatively metal-rich, whereas increasingly metal-poor Cepheids extend outward to the galaxy's lower surface brightness periphery. That degeneracy can compromise determinations of the impact of chemical composition on Cepheid distances (e.g., Macri et al.

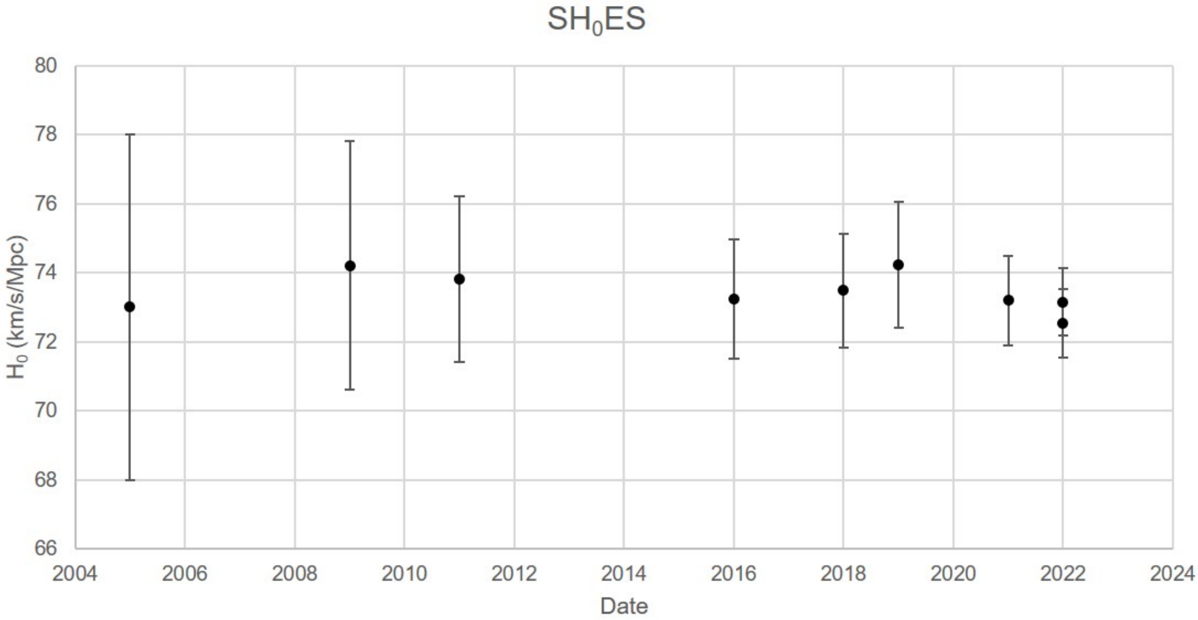

Figure 2. A subsample of SH_0ES H_0 estimates across ~ 18 years (e.g., Riess et al. 2005). Their H_0 remained comparatively unchanged ($\simeq 73$ km/s/Mpc) despite ambiguities in the Leavitt Law, maser and W_{VI} Cepheid distances for NGC4258, etc. (§2).

2001, their §5). Indeed, the lack of consensus on the Leavitt Law partly stems from the aforementioned degeneracy. Majaess et al. (2012a,b, 2016) noted that photometric contamination was likewise problematic for certain globular clusters and the Galactic Center sightline.† Yuan et al. (2020) identified that Cepheids in high surface brightness regions of the Seyfert 1 galaxy NGC4151 exhibited a systematic shift (their Fig. 9, right panel). Rather than favoring the contamination scenario, Macri et al. (2006) attributed their NGC4258 variations to a Leavitt Law zeropoint that's metallicity dependent ($\gamma = -0.29 \pm 0.09 \pm 0.05$ mag/dex). However, Majaess (2010) and Bresolin (2011) argued that the abundance gradient across NGC4258 may be shallower‡ than that finally selected by Macri et al. (2006, §4.3), which would markedly expand their cited Cepheid metallicity effect to an unrealistic value. Yet there are those favoring an extreme Cepheid metallicity effect, such as Shappee & Stanek (2011, -0.80 ± 0.21 mag/dex) and Fausnaugh et al. (2015, -0.61 ± 0.21 mag/dex). Critically, Majaess et al. (2011a) disagreed with those conclusions by relaying that applying such an immense metallicity dependence yielded spurious Cepheid distances for the Magellanic Clouds (e.g., $\mu_{0,LMC} \neq 18.1$). Udalski et al. (2001), Majaess et al. (2011a), Wielgórski et al. (2017), and Madore & Freedman (2023) concluded that W_{VI} functions are relatively insensitive to metallicity,¶ whereas Riess & Breuval (2023, SH_0ES) advocate for a larger zeropoint dependence by comparison (e.g., -0.22 ± 0.04 mag/dex). Madore & Freedman (2023) relayed TRGB-Cepheid distances (their Fig. 1) which overturn the existing Sakai et al. (2004) analysis, and likewise contest Breuval et al. (2022, -0.201 ± 0.071 mag/dex). Moreover, the reader is encouraged to examine Fig. 6 in Yuan et al. (2022, SH_0ES) where a constant (indicating a null-dependence) can represent their latest NGC4258 analysis rather than the fits they overlaid. Yuan et al. (2022, SH_0ES) constrained the dependence to -0.07 ± 0.21 mag/dex, which together with their overall data are in stark contrast to the Macri et al. (2006) and Hoffmann et al. (2016, SH_0ES) interpretations of NGC4258, and the reader can arrive at their own conclusion by inspecting Fig. 3 (see also §4 in Yuan et al. 2022). Alarmingly, there's a significant I-band (F814W) and W_{VI} discrepancy between Hoffmann et al. (2016, SH_0ES) and Yuan et al. (2022, SH_0ES), which is characterized by a considerable mean difference ($\gtrsim 0^{\mathrm{m}}.15$). Regardless of applying a Galactic W_{VI} Cepheid calibration (Benedict et al. 2007; Majaess et al. 2011a) or the Breuval et al. (2022) metallicity-dependent W_{VI} function to the NGC4258 datasets of Maoz et al. (1999), Newman et al. (2001), Macri et al. (2006), Fausnaugh et al. (2015), Hoffmann et al. (2016, SH_0ES), and Yuan et al. (2022, SH_0ES): discrepant results arise.

Offsets in Cepheid distances across remote galaxies possessing non-uniform crowding and surface brightness are comparatively unassociated with a W_{VI} metallicity effect, but rather point to serious shortcomings in establishing homogeneous uncontaminated photometry, as echoed previously (e.g., Majaess et al. 2011a). The offset highlighted by Macri et al. (2001, their §5) resides elsewhere in extragalactic Cepheid data.

The Herrnstein et al. (1999, 7.2 ± 0.3 Mpc) maser distance for NGC4258 was superseded by Humphreys et al. (2013, $7.60 \pm 0.17 \pm 0.15$ Mpc, see also §3 in Riess et al. 2016). Reid et al. (2019) subsequently determined $d = 7.576 \pm 0.082 \pm 0.076$ Mpc.

† Paradoxically, Majaess (2020) confirmed that blending with say red clump giants may advantageously thrust otherwise faint extragalactic targets (e.g., RR Lyrae variables) into the range of detectability (see also §2.4 of Majaess et al. 2018).

‡ Table 12 in Riess et al. (2009) and Fig. 4 in Majaess (2010).

¶ Bono et al. (2008) and Anderson et al. (2016) disagree regarding what models produced relative to the Leavitt Law's dependence on metallicity. §5.5 of Breuval et al. (2022) presents their viewpoint concerning the Wielgórski et al. (2017) result.

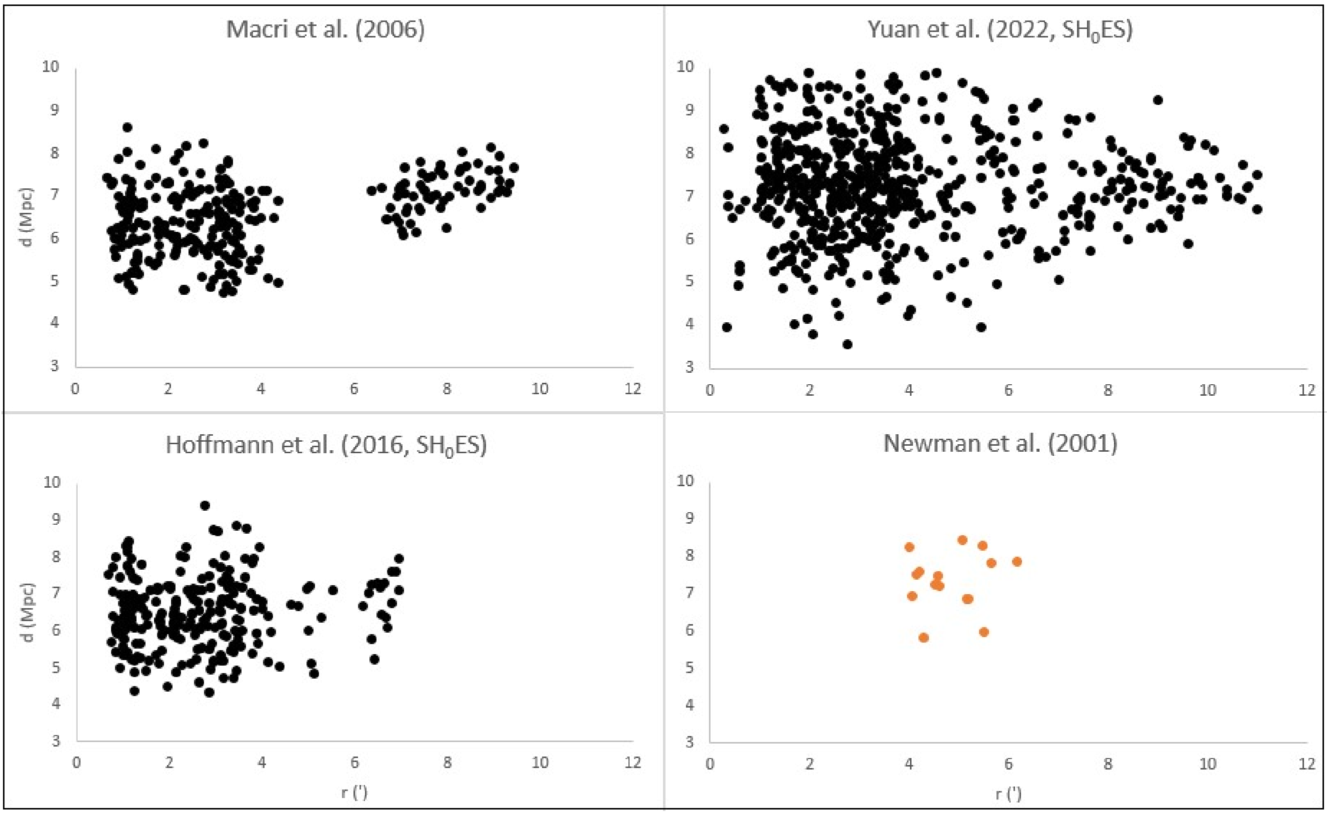

Figure 3. NGC4258 Cepheid datasets exhibit striking differences with regards to: their distances as a function of apparent galactocentric radius (x-axis), a (null-)dependence on abundance, and the mean distance. Discrepancies emerge irrespective of whether a W_{VI} Galactic Cepheid calibration (Majaess et al. 2011a, and references therein) is used (shown), or the metallicity-dependent W_{VI} relationship of Breuval et al. (2022).

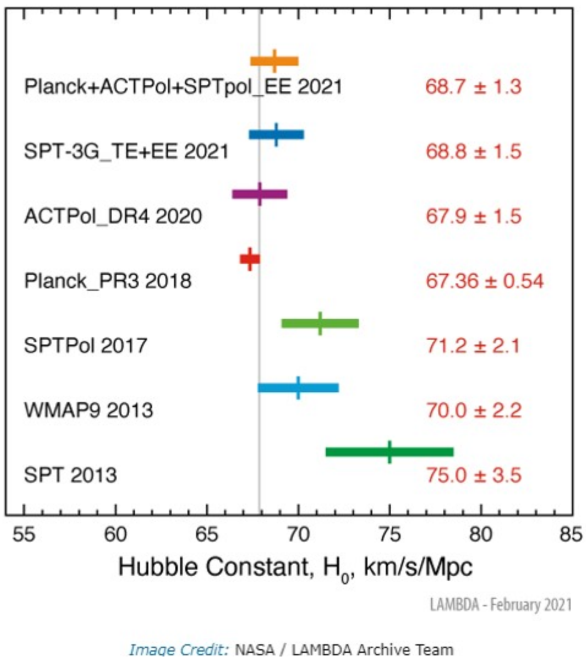

Figure 4. H_0 estimates from diverse CMB surveys. There exist solutions beyond the Planck CMB, and which are comparable within the uncertainties to the Freedman & Madore (2023a, and references therein) TRGB analysis.

3. Independent Cepheid-TRGB Analyses

SH_0ES-independent Cepheid and TRGB based analyses include the HST key project to measure H_0, namely 68 ± 5 and 72 ± 8 km/s/Mpc (Gibson et al. 2000; Freedman et al. 2001). Moreover, Tammann & Reindl (2013) cite a final determination of $H_0 = 64.1 \pm 2.0$ km/s/Mpc (see also Tammann & Sandage 2010). The '*Hubble tension*' debate emerged because of the latter's passing. Admittedly, Majaess (2010) and others argued that the Sandage et al. (2004) distance scale was too remote (e.g., Benedict et al. 2007; Riess et al. 2009), and hence their H_0 was underestimated. However, the impact of photometric contamination was not comprehensively addressed by that team and would shift H_0 in the opposite direction.

Concerns emerged near the conclusion of the HST key project to secure H_0 that extraneous flux from stars along the Cepheid's sightline could lead to an overestimated expansion rate (e.g., Stanek & Udalski 1999), and the reader is encouraged to review the debate and rebuttals in §8.5 of Freedman et al. (2001), §7 in Mochejska et al. (2000), and §8 in Mochejska et al. (2001). Freedman et al. (2001) attributed a sizable uncertainty to the phenomenon ($0^{\rm m}.1$), and the Freedman et al. (2012, CHP) Cepheid effort shouldn't be leveraged to support the SH_0ES Cepheid H_0 since it relies on the earlier potentially contaminated HST key project data (c2000).† Importantly, the current Freedman & Madore (2023a) TRGB efforts are pertinent in part because the team's *modus operandi* is to avoid crowded regions. Their H_0 is comparable to diverse CMB measurements (Fig. 4). Indeed, a consensus framework on the topic of photometric contamination remains outstanding, in tandem with the terminology employed (Majaess 2020, §4 in Yuan et al. 2022, and see also the disparate discussions in Riess & Breuval

† Freedman et al. (2012) advance a separate position in their §3.3 and appendix.

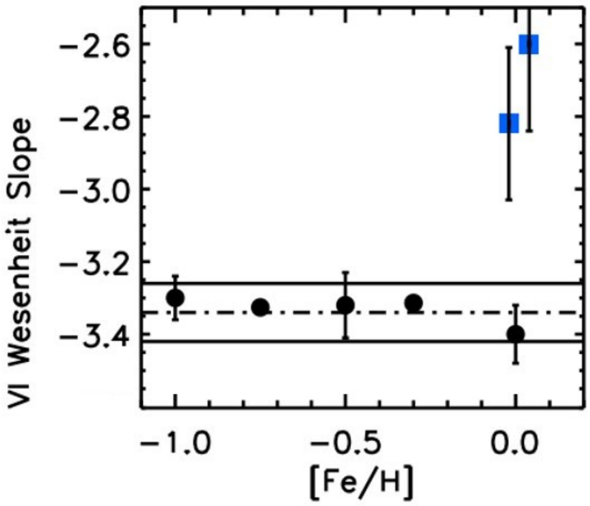

Figure 5. Majaess (2010) indicated the W_{VI} Leavitt Law's slope ($\alpha \simeq -3.3$) is insensitive to metallicity. Riess et al. (2009, SH_0ES) argued that near-solar Cepheids adhered to $\alpha = -2.98 \pm 0.07$, a result they subsequently overturned ($\alpha \simeq -3.3$, Riess et al. 2022, SH_0ES). For example, Riess et al. (2009, SH_0ES) determined that NGC3021 Cepheids follow $\alpha = -2.60 \pm 0.24$.

2023 and Freedman & Madore 2023b). The reader can promptly grasp the difficulties faced by inspecting Fig. 1 in Mochejska et al. (2001), Fig. 2 in Majaess et al. (2012b), and critically Fig. 8 in Freedman & Madore (2023b), which conveys HST crowding relative to JWST.

4. Conclusion

Historical H_0 uncertainties (Fig. 1), errors and anomalies existing within SH_0ES and NGC4258 data (§2), a relatively unchanged SH_0ES H_0 across $\sim$ 18 years (Fig. 2), diversity among CMB measurements (Fig. 4), and independent results from Madore & Freedman (2023) and Freedman & Madore (2023a,b): indicate in concert that claims of a *bona fide* offset between Cepheid and CMB H_0 findings should be viewed cautiously.

The aforementioned ambiguities continue a long established trend tied to H_0 research (Fig. 1), from say Sandage and de Vaucouleurs (Overbye 1991), to Freedman et al. (2001) and Sandage et al. (2004), and now between Riess et al. (2016, SH_0ES), Freedman & Madore (2023a), and others. TRGB and Cepheid research by groups and (co)authors beyond SH_0ES and (C)CHP are desirable, and that includes a reassessment of the entire raw HST Cepheid imagery without biased constraints that inadvertently sway conclusions. The case of NGC4258 broadly illustrates that a chief concern regarding H_0 determinations is the challenging task of obtaining precise, commonly standardized, multiepoch, multiband, uncontaminated remote extragalactic Cepheid photometry (e.g., Majaess 2010).

Continued research is needed to assess Gaia's data. The spurious Hipparcos distances to the Pleiades and Blanco 1 are key lessons pointing toward enhanced vigilance (Majaess et al. 2011b). Moreover, oft-cited NGC4258 and LMC distances could likewise be incorrect, and certain results may require adjustment that conspire to sway H_0 unidirectionally. Lastly, challenging degeneracies not only exist between blending and characterizing the effect of metallicity on Cepheid distances, but possibly also with respect to non-standard extinction across a galaxy (e.g., Turner 2012; Carraro et al. 2013). On that note a discrepant Cepheid distance exists for NGC5128 or Cen A (Ferrarese et al. 2007; Majaess 2010; Harris et al. 2010), and a non-canonical extinction law has been debated in that case (see also Fausnaugh et al. 2015 regarding NGC4258).

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