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## INDEPENDENT ANALYSIS OF THE DISTANCE TO NGC1052-DF2

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### CONTEXT

The finding by van Dokkum et al. (2018a, hereafter vD18a) that the dynamical mass of the diffuse galaxy NGC1052-DF2, also called [KKS2000]04 (see Trujillo et al. 2018, hereafter T18), is consistent with its stellar mass, “and leaves little room for a dark matter halo,” has created a stir in the extragalactic astronomy community. The result remains controversial (e.g., Martin et al. 2018). As stated by vD18a, this conclusion depends critically on the adopted distance of 20 Mpc from association with NGC 1052, which is consistent with their surface brightness fluctuations (SBF) result  $d = 19.0 \pm 1.7$  Mpc for NGC1052-DF2 itself.

Following the publication of vD18a, we were contacted by several colleagues about the NGC1052-DF2 SBF distance. We noted some areas of concern: use of the default linear drizzle interpolation kernel can bias the image power spectrum measurement (Cantiello et al. 2005; Mei et al. 2005); information was lacking on the residual variance correction; and the ACS/F814W SBF magnitude calibration (Blakeslee et al. 2010, hereafter B10) was linearly extrapolated beyond the explored color range.

We therefore did a quick SBF analysis using our own well-documented procedures (see B10, Cantiello et al. 2018, and references therein) on this galaxy of unusually low surface brightness and our “best guess” calibration. Our result agreed with vD18a; thus, we saw no need to publish it. However, given the renewed interest sparked by the dueling works of T18 and van Dokkum et al. (2018b, hereafter vD18b), we report a revised, more careful analysis here.

### DISTANCE ANALYSIS

The sinc-like lanczos3 interpolation kernel is preferred for SBF analysis; drizzle-combined F606W/F814W HST/ACS images of NGC1052-DF2 using this kernel were kindly provided by S. Lim. On inspection, the galaxy exhibits clear

SBF, but not an abundantly resolved stellar population.<sup>1</sup> We performed standard SBF and color measurements, described most recently in Cantiello et al. (2018), using a circular annular region of  $0''.4\text{--}12''.8$  centered on the photo-center of NGC 1052-DF2. Omitting any correction for background variance, we find  $\overline{m}_{814} = 29.57 \pm 0.13$  and  $V_{606} - I_{814} = 0.39 \pm 0.02$ , both AB mag.

Our measurement is fainter than  $\overline{m}_{814} = 29.45 \pm 0.10$  mag reported by vD18a, but repeating our analysis using the default drizzle kernel yielded  $\overline{m}_{814} = 29.42$ , very close to vD18a. T18 adopted  $\overline{m}_{814}$  from vD18a, but used for calibration  $\overline{M}_{814} \approx -1.4$ , significantly fainter than  $-1.94$  (vD18a) or  $-1.91$  (vD18b). We note that the color of NGC1052-DF2, and the SED fitting by T18, indicate its stellar population is consistent with halo globular clusters (GCs), for which Ajhar & Tonry (1994) determined  $\overline{M}_I = -2.02 \pm 0.04$ , independent of mean color. Revising this calibration with an updated RR Lyrae magnitude-metallicity relation (Clementini et al. 2003) and the LMC distance modulus of  $18.49 \pm 0.05$  mag from DEBs (Pietrzyński et al. 2013) gives  $\overline{M}_I = -2.22 \pm 0.06$ . Converting from Cousins  $I$  to F814W (Saha et al. 2011) with the latest ACS zeropoints then gives  $\overline{M}_{814} = -1.78 \pm 0.12$  ABmag.

Our  $V_{606} - I_{814}$  measurement is consistent with vD18a; applying their color transformation gives  $(g_{475} - I_{814}) = 0.82 \pm 0.04$ , consistent with  $(g_{475} - I_{814}) = 0.85 \pm 0.02$  from T18. Using the latter value with linear extrapolation of the B10 calibration gives  $\overline{M}_{814} = -1.81$ , but we agree with T18 this is risky; the models plotted by T18 diverge towards  $\overline{M}_{814} < -2$  at these colors. However, the SPoT models used by B10 agree well with the empirical calibration and suggest a natural extension; at  $(g_{475} - I_{814}) = 0.85$ , they predict  $\overline{M}_{814} = -1.75 \pm 0.05$ , in excellent agreement with the GC-based calibration above.

<sup>1</sup> Of course, our customary tool is SBF, and to a child with a hammer, everything looks like a nail.

Using  $\overline{m}_{814} = 29.57 \pm 0.13$  and our GC-based  $\overline{M}_{814}$  calibration, the NGC1052-DF2 distance is  $18.6 \pm 1.9$  Mpc. For the sake of comparison to vD18a, we have not included any correction for background contamination from faint sources. Our standard procedure applied blindly to this diffuse galaxy indicated a correction of  $\sim 0.4$  mag, resulting in the preliminary value of  $\sim 22$  Mpc quoted on PvD’s webpage.<sup>2</sup> On closer inspection, the correction is more likely  $0.2 \pm 0.1$  mag, giving a final distance  $d = 20.4 \pm 2.0$  Mpc.

#### COMMENTARY

Our  $\overline{m}_{814}$  is 0.12 mag fainter than vD18a’s, while our adopted  $\overline{M}_{814}$  calibration is 0.13 mag fainter than vD18b’s, giving a distance, prior to background variance correction, indistinguishable from vD18b’s. The difference in the measured SBF magnitudes is consistent with the shift we find when analyzing images drizzled with a linear kernel rather than the lanczos3 kernel. Since all the vD18b SBF measurements use the linear kernel, their distance ladder is internally consistent. As a further check, we measured the difference in SBF magnitude between NGC1052-DF2 and M96-DF11; our result agreed with theirs within errors. Correcting for

background variance increases our NGC1052-DF2 distance by 10% to  $\sim 20$  Mpc.

The GCs remain intriguing: if they’re “normal,” NGC1052-DF2 is at  $\sim 12$  Mpc with substantial dark matter; if the distance is 20 Mpc, the GCs are bigger and brighter than normal. If we had a bias, it was that any galaxy rich in GCs should be dominated by dark matter, as one of us proposed two decades ago that the number of GCs scales with galaxy halo mass. However, our distance analysis supports the conclusion that the stars can account for the entire dynamical mass, although more kinematic data are needed.

While we think the evidence is strong that  $d > 16$  Mpc (at  $2\sigma$ ), the result is not quite definitive. The SBF method is not well-tested at these colors and low stellar densities, although the vD18b team has made impressive progress. Extremely deep *Hubble* data would resolve the issue by providing a definitive detection of the TRGB.

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<sup>2</sup> <https://www.pietervandokkum.com/ngc1052-df2>