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To cite this article: Pieter van Dokkum *et al* 2024 *Res. Notes AAS* 8 135

Manuscript version: AAS-Provided PDF

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DRAFT VERSION MAY 15, 2024

Typeset using L^AT_EX preprint style in AASTeX631

Deep HST/UVIS imaging of the candidate dark galaxy CDG-1

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ABSTRACT

CDG-1 is a tight grouping of four likely globular clusters in the Perseus cluster, and a candidate dark galaxy with little or no diffuse light. Here we provide new constraints on the luminosity of any underlying stellar emission, using HST/UVIS F200LP imaging. No diffuse emission is detected, with a 2σ upper limit of $F200LP > 28.1$ mag arcsec⁻² on the 5'' scale of CDG-1. This surface brightness limit corresponds to a 2σ lower limit of > 0.5 for the fraction of the total luminosity that is in the form of globular clusters. The most likely alternative, although improbable, is that CDG-1 is a chance grouping of four globular clusters in the halo of the Perseus galaxy IC 312.

1. INTRODUCTION

CDG-1¹ ($\alpha = 3^{\text{h}}18^{\text{m}}12.22^{\text{s}}$, $\delta = 41^{\circ}45'58''.3$) was identified in a statistical analysis of the spatial distribution of globular clusters in the Perseus cluster. Selecting globular clusters by their size and brightness, Li et al. (2022) found 11 overdensities in 20 HST images from the PIPER survey (Harris et al. 2020). Ten are associated with known ultra diffuse galaxies (UDGs), but one is not: CDG-1 is comprised of 4 globular clusters within $\approx 5''$, with no obvious smooth light component in the PIPER data (see Li et al. 2022). It is therefore a candidate for a dark galaxy, or rather a galaxy whose stars are mostly or entirely locked up in globular clusters.

The most extreme globular cluster-rich galaxies currently known are NGC 5846-UDG1 (Forbes et al. 2019; Müller et al. 2021), whose ≈ 54 globular clusters comprise $\sim 13\%$ of the total light (Danieli et al. 2022), and UGC 9050-Dw1, with ≈ 52 clusters making up $\sim 20\%$ of the light (Fielder et al. 2023). As discussed in Danieli et al. (2022), these fractions may have been close to unity at birth,

¹ Candidate Dark Galaxy 1

because of the combined effects of mass loss and the disruption of low mass clusters (e.g., [Larsen et al. 2012](#); [Trujillo-Gomez et al. 2019](#)). Turning this argument around, CDG-1 should have some diffuse light associated with it even if all its stars originated in globular clusters.

2. OBSERVATIONS AND RESULTS

We obtained six orbits of Hubble Space Telescope (HST) WFC3/UVIS imaging of CDG-1 to search for diffuse light in between the globular clusters (program GO-17454). HST is generally not well suited for low surface brightness imaging, but the distances between the globular clusters are so small ($1'' - 2''$) that the wings of the PSFs blend together in ground-based seeing. The F200LP filter was used, as this maximizes the sensitivity of HST (see, e.g., [Kelly et al. 2022](#)). The observations can be accessed via [doi:10.17909/14jb-4487](https://doi.org/10.17909/14jb-4487). The data were drizzled after matching the background levels in all chips and exposures. The image is crowded, with several bright stars as well as the S0 galaxy IC 312 (all with associated figure-8 ghosts). The region around CDG-1 is shown in Fig. 1, with the four clusters indicated.²

There is no significant detection of diffuse light between the globular clusters; neither median filtering nor binning nor Gaussian smoothing shows a flux enhancement with respect to the surroundings. The scale-dependent empirical 2σ surface brightness limit, as determined from an object-masked image with the `sbcontrast` code ([Keim et al. 2022](#)), is shown in the bottom left panel of Fig. 1 (after applying a 0.5 mag Galactic extinction correction). On the $\approx 5''$ scale of CDG-1 the F200LP limit is $28.1 \text{ mag arcsec}^{-2}$ (AB). Using the measured F200LP fluxes of the globular clusters and multiplying the surface brightness by the square of the spatial scale to get total diffuse magnitudes, we can calculate the maximum fraction of the total light that is in a diffuse component (bottom right panel in Fig. 1). We find a 2σ upper limit of ≈ 0.5 for this fraction for a galaxy size of $5''$ (1.8 kpc at the 75 Mpc distance of Perseus). The top right panel in Fig. 1 illustrates what an artificial diffuse object of this size and brightness ($m = 24.6$) looks like; as expected, it is just visible. The limit on the fraction is a strong function of size: for larger sizes, the per-arcsec² surface brightness limit is weaker, and the total brightness of the diffuse component is larger by a factor (size)².

3. DISCUSSION

The apparent lack of diffuse emission in between the globular clusters is, at face value, difficult to reconcile with the notion that CDG-1 is a galaxy. It requires that no stars were formed outside of the four globular clusters and that there was no appreciable mass loss or destruction of low mass clusters (see [Danieli et al. 2022](#)). It is possible, however, that the diffuse emission has a larger spatial extent than the region occupied by the four globular clusters. Specifically, if the galaxy spans $10'' \times 10''$ (3.6 kpc $\times$ 3.6 kpc, a modest-sized UDG), the UVIS data allow diffuse light contributions up to $\approx 90\%$ of the total light (see Fig. 1).

An alternative explanation is that CDG-1 is not a galaxy. It is unlikely that the grouping occurred by chance in the general Perseus cluster field ([Li et al. 2022](#)). However, the four clusters might be part of the outer globular cluster population of IC 312 (see the discussion in [Li et al. 2022](#)). In conclusion, the UVIS data do not definitively tell us whether or not CDG-1 is a dark galaxy. Radial velocities, and the possible detection of other examples ([Li et al. 2023](#)), may provide further constraints.

² The numbering follows Table 3 in [Li et al. \(2022\)](#).

IMAGING OF CDG-1

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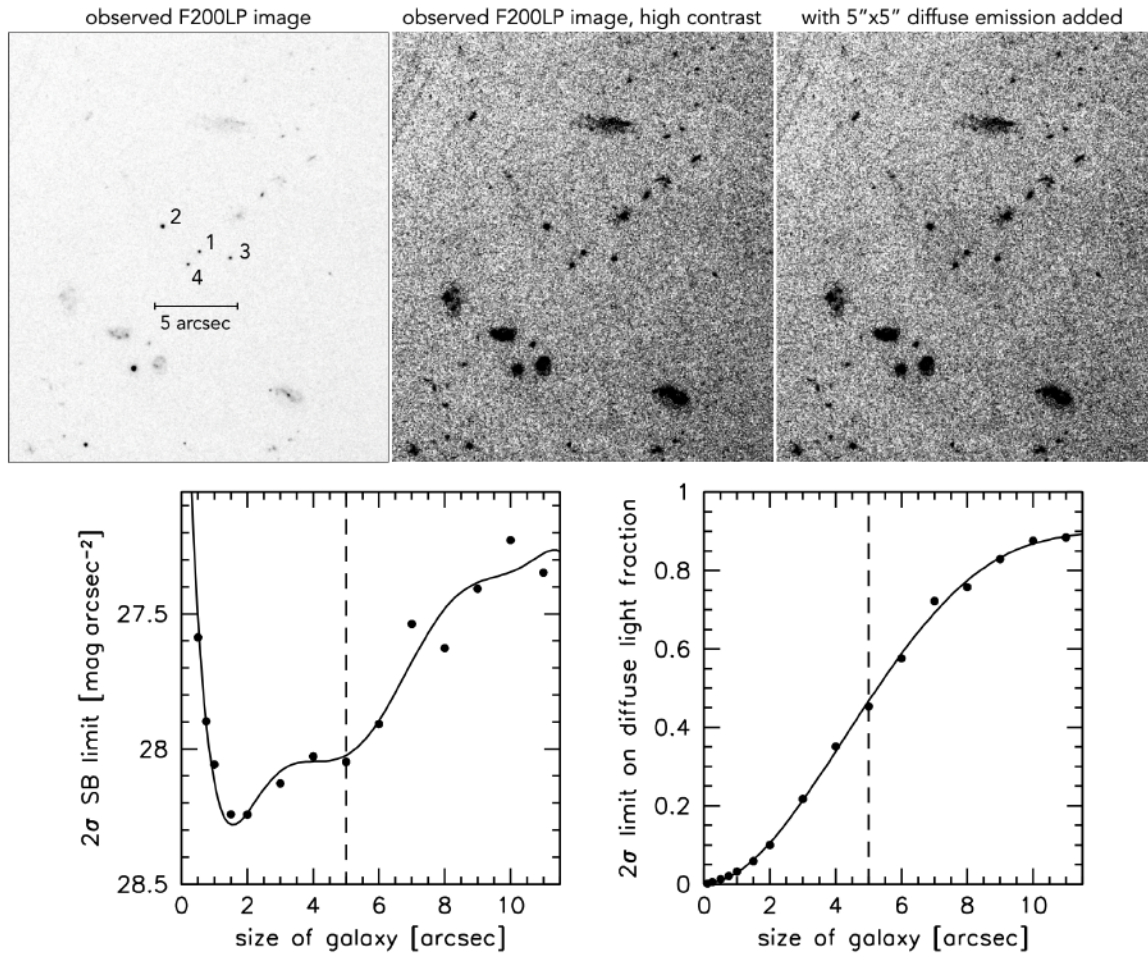


Figure 1. Top left and center: section of the 6-orbit F200LP image, centered on the four globular clusters that constitute CDG-1. No diffuse light is detected between the clusters. Top right: same as top center, with an artificial $5'' \times 5''$ patch of diffuse light added. The patch has the same total brightness as the four globular clusters. Bottom left: F200LP 2σ surface brightness depth as a function of spatial scale. Bottom right: corresponding upper limit on the fraction of the total light that is in a diffuse component.

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