On the Nature of Ultra-faint Dwarf Galaxy Candidates. II. The Case of Cetus II

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Abstract

We obtained deep Gemini GMOS-S $g$, $r$ photometry of the ultra-faint dwarf galaxy candidate Cetus II with the aim of providing stronger constraints on its size, luminosity, and stellar population. Cetus II is an important object in the size–luminosity plane, as it occupies the transition zone between dwarf galaxies and star clusters. All known objects smaller than Cetus II ($r_0 \sim 20$ pc) are reported to be star clusters, while most larger objects are likely dwarf galaxies. We found a prominent excess of main-sequence stars in the color–magnitude diagram of Cetus II, best described by a single stellar population with an age of 11.2 Gyr, metallicity of $[\text{Fe}/\text{H}] = -1.28$ dex, an $[\alpha/\text{Fe}] = 0.0$ dex at a heliocentric distance of $26.3 \pm 1.2$ kpc. As well as being spatially located within the Sagittarius dwarf tidal stream, these properties are well matched to the Sagittarius galaxy’s Population B stars. Interestingly, like our recent findings on the ultra-faint dwarf galaxy candidate Tucana V, the stellar field in the direction of Cetus II shows no evidence of a concentrated overdensity despite tracing the main sequence for over six magnitudes. These results strongly support the picture that Cetus II is not an ultra-faint stellar system in the Milky Way halo, but made up of stars from the Sagittarius tidal stream.

Key words: galaxies: dwarf – galaxies: individual (Sagittarius) – Galaxy: halo – globular clusters: general – Hertzsprung–Russell and C–M diagrams – Local Group

1. Introduction

In Paper I (Conn et al. 2018), we demonstrated that the ultra-faint dwarf galaxy candidate Tucana V, also known as DES J2337–6316 (Drlica-Wagner et al. 2015), does not have the stellar concentration typical of an ultra-faint star cluster or dwarf galaxy.

Our results based on deep stellar photometry led to the conclusion that Tucana V, originally detected at a significance level of $\sigma = 8.0$, must be either the debris of a completely tidally disrupted star cluster or an excess of stars in the halo of the Small Magellanic Cloud. In regard to the search for ultra-faint stellar systems in the Milky Way halo, we propose that Tucana V is an example of a false-positive detection. This raises concern that other candidates reported in the literature and taken at face value by other researchers are in fact false-positives too. We highlighted the region around Tucana V in the size–luminosity plane as a “Trough of Uncertainty” (TUC) regarding these types of objects. The other two known objects that reside in that region are Draco II (Laevens et al. 2015a) and Cetus II (Drlica-Wagner et al. 2015, DES J0117–1725). Cetus II is the focus of this paper.

Cetus II (Figure 1) has a reported heliocentric distance of $d_0 = 30 \pm 3$ kpc, a half-light radius $r_h = 1.9^{+1.9}_{-1.5}$ arcmin and a total luminosity of $M_V = 0.00 \pm 0.68$ (Drlica-Wagner et al. 2015). It also has the lowest detection significance ($\sigma = 5.5$) of all objects reported by Drlica-Wagner et al. (2015) as estimated from their stellar density map search method. These authors further noted that Cetus II should be treated with caution due to inter-CCD gaps in the DES$^5$ data available at that time. However, if confirmed, it would be the least luminous galaxy known to date. In this paper, we seek to better understand the phenomenon Cetus II and refine the object’s properties by obtaining deep photometry with the GMOS-S instrument. We also want to determine whether its location in the TUC unveils it as another false-positive detection or a true ultra-faint dwarf galaxy candidate.

The rapid increase in the number of known Milky Way satellites over the last couple of years (Balbinot et al. 2013; Belokurov et al. 2014; Laevens et al. 2014; Bechtol et al. 2015; Drlica-Wagner et al. 2015; Kim et al. 2015a, 2015b, 2016; Kim & Jerjen 2015a, 2015b; Koposov et al. 2015; Laevens et al. 2015a, 2015b; Martin et al. 2015; Luque et al. 2016; Martin et al. 2016b; Torrealba et al. 2016a, 2016b; Koposov et al. 2017) has important implications on our understanding of galaxy formation and near-field cosmology. In particular, the newest discoveries are some of the smallest bound stellar systems and thus constitute prime laboratories to study star formation on the smallest scales, in pure baryonic and dark matter dominated environments. At the ultra-faint end of the satellite galaxy luminosity function, there are still relatively few objects that receive a high statistical weight in studies that correct observed satellite counts for detection efficiency. Consequently, any misclassification of an ultra-faint dwarf galaxy can skew the results significantly. Hence, it is imperative to know the true nature of every single object.

In Section 2, we present the details of our follow-up observations of Cetus II, the photometric calibration procedure, the artificial star experiment and the color–magnitude diagram for all the stars we detected in the Cetus II field. In Section 3, we revisit the adopted procedure for determining the age, metallicity, and distance of the Cetus II stellar population and present the results. In Section 4, we discuss our findings and draw conclusions about the nature of Cetus II in Section 5.

$^5$ Dark Energy Survey. http://des.nesa.illinois.edu/releases/sva1D.
2. Observations and Data Reduction

The imaging data presented here were obtained with the Gemini Multi-object Spectrograph South (GMOS-S) at the 8 m class Gemini South Observatory through Program ID: GS-2017B-Q-40. The observing conditions required for the observations to be scheduled, following the Gemini Observatory standards, were dark 6 percentile, clear skies 7 and excellent seeing. 8 On average, we achieved 0.60 in the g-band (g\_G0325) and 0.54 in the r-band (r\_G0326) for the night of 2017 September 17 (see Table 1). The superb seeing obtained in IQ20 conditions allowed us to utilize the 1 × 1 binning mode of GMOS-S, which affords a pixel scale of 0.08. The GMOS-S field of view is 5.5 × 5.5 and our observing strategy involved having a short 60 s exposure centered on the target and three dithered exposures of 600 s each. We employed the THELI pipeline (Schirmer 2013) to perform the basic data reduction of creating a master bias and master twilight flats, bias subtraction, flat fielding, astrometry, and coaddition. To generate the object catalogs, we used the Point Spread Function (PSF) photometry package DOLPHOT (Dolphin 2000) on the combined stacked images (Figure 2).

| Field             | R.A. (deg, J2000) | Decl. (deg, J2000) | Position Angle (deg) | Filter  | Observation Date | Airmass | Exposure (s) | Seeing (") |
|-------------------|-------------------|--------------------|----------------------|---------|------------------|---------|--------------|------------|
| Cetus II (DES J0117–1725) | 19.4667 | -17.425 | 90 | g\_G0325 | 2017 Sep 17 | 1.04–1.06 | 1 × 60, 3 × 600 | 0.60 |
|                   | 90                |                    | g\_G0326 | 2017 Sep 17 | 1.07–1.12 | 1 × 60, 3 × 600 | 0.54 |

Figure 1. All-sky view in Galactic coordinates showing the distribution of known Milky Way satellite dwarf galaxies (filled circles) and star clusters (open circles). Cetus II (yellow dot) is found close to the Galactic South pole at $l = 156^\circ 47$, $b = -78^\circ 53$, superimposed on the Sagittarius stellar tidal stream (contours) and close to the neutral hydrogen gas of the Magellanic Stream (gray scale image). The star density contours of the Sagittarius stream are inferred from the Law & Majewski (2010) tidal debris model, which adopts a triaxial dark matter halo for the Milky Way.

DOLPHOT has approximately 80 parameters that need to be set to process the data, the majority of these relate to the fundamental details of the files being processed: file names, filters, offsets between frames in pixels, initial estimates of the seeing in pixels, exposure time, read noise, bad pixel value, saturation value, airmass, etc. We chose to use a PSF based on a linear Gaussian + Lorentzian solution and we set the detection threshold to 2.5σ above the noise.

2.1. Photometric Calibration

For the calibration of the instrumental magnitudes generated by the DOLPHOT photometry, we followed the same steps as those discussed in Paper I. The GMOS-S data were cross-matched with APASS 9 (Henden et al. 2015) calibrated DECam photometry. 10 We utilized the same technique as that described in Paper I, applying the same color term and then calculating the linear offset (a combination of a zeropoint offset and atmospheric extinction correction) from a generic instrumental zeropoint. The calibration proceeds by first applying the offset directly to the raw magnitudes and then iterating the magnitudes using the color and color term to achieve the final

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6 SB50—Sky Brightness 50th percentile.
7 CC50—Cloud Cover 50th percentile.
8 IQ20—Image Quality 20th percentile.
solution, as shown in Equation (1). Apply the offset

$$\text{rawmag} = \text{rawmag} + \text{offset}. \quad (1)$$

Iterate the magnitudes using

$$\text{newmag} = \text{rawmag} + \text{Color Term} \cdot (g - r). \quad (2)$$

After each iteration, update rawmag to the new newmag value then repeat until the solution converges. These color terms and offsets, applied to the Cetus II field, are listed in Table 2. The selection criteria for objects to be included in the final catalog consisted of finding objects where

1. in either filter, sharpness$^2 \leq 0.1$;
2. in both filters, signal-to-noise ratio $\geq 3.5$;
3. and the object type corresponds to “good stars” (Objtype = 1).

Spurious or saturated objects were removed from the catalog through either their extremely large magnitude errors or zero magnitude error respectively.

### 2.2. Artificial Star Experiments

Following the procedure described in Paper I, the photometric completeness of the Cetus II field was determined using the DOLPHOT built-in artificial star experiment by generating a flat luminosity function with around 500,000 stars covering the magnitude interval $20 < m < 29$ and subdivided in $0.3$ mag bins. The recovery rate in each filter was fitted with a Logistic function:

$$\text{Completeness} = \left(1 + e^{(m - mc)/\lambda}\right)^{-1}, \quad (3)$$

where $m$ is the magnitude, $mc$ is the 50% completeness value, and $\lambda$ is the width of the rollover. The parameters of the best-fit solutions are listed in Table 3 and Figure 3.

To explore the impact of the bright stars in the field on both the photometric completeness and any potential overdensity in the field, we show the position of the unrecovered artificial stars sorted by $g$-band magnitude in Figure 4. Here we can see clearly the effect of the bright stars and their halos in the field. Interestingly, the biggest effect is in the magnitude range $24 < g < 26$, whereas at fainter magnitudes (greater than the 50% completeness level) the distribution of unrecovered stars becomes much smoother. In general, the amount of the field lost to the bright stars is quite small as can be seen in Figure 3 where, at the brighter magnitudes, the completeness is very close to 100%. Significant loss of coverage would lower the maximum completeness level proportional to the amount of contamination.

### Table 2

Photometric Calibration Results

| Filter  | $g$ band  | $r$ band |
|---------|-----------|----------|
| Color term $(g-r)^a$ | $+0.026^{+0.043}_{-0.048}$ | $-0.059^{+0.042}_{-0.041}$ |
| Cetus II offsets | $-3.018^{+0.028}_{-0.029}$ | $-2.771^{+0.026}_{-0.027}$ |

Note. Color terms and offsets derived from comparison with APASS calibrated DES photometry. All photometry assumed a zeropoint of 30.00 for both filters prior to the offsets being applied. The offset values listed are a combination of the true zeropoint correction and the atmospheric extinction correction.

$a$ From Conn et al. (2018).

### Table 3

50% Photometric Completeness Estimates

| Filter | $mc$ | $\lambda$ | $mc$ | $\lambda$ |
|--------|------|-----------|------|-----------|
| $g$    | $26.33 \pm 0.04$ | $0.473 \pm 0.030$ | $26.06 \pm 0.03$ | $0.486 \pm 0.030$ |

Figure 2. False color RGB image of the GMOS-S field centered on Cetus II, made using ALADIN SKY ATLAS V8.840. The $g$- and $r$-band coadded images were used for the blue and red channel, respectively. Owing to the exquisite seeing, a large number of background galaxies are recognizable. However, no stellar overdensity is visible in the field. The bar in the lower left corner has a length of 1 arcmin.

Figure 3. Recovery rate for artificial stars in the Cetus II field. The points show the photometric completeness per 0.3 mag bin, while the solid line shows the best-fit solution with the dashed lines highlighting the 90th percentiles.

Figure 4. Position of the unrecovered artificial stars sorted by $g$-band magnitude in Figure 4. Here we can see clearly the effect of the bright stars and their halos in the field.
2.3. Color–Magnitude Diagram

Figure 5 shows the extinction-corrected \((g-r)_0\), \(g_0\) CMD of the GMOS-S field using all point sources from our photometry analysis found in the vicinity of Cetus II. The window in the brighter section of the CMD highlights the region that was investigated in the discovery paper derived from DES data (Figure 14 in Drlica-Wagner et al. 2015). The Galactic extinction correction is based on the Schlegel et al. (1998) reddening map along with the correction coefficients of Schlafly & Finkbeiner (2011). The Cetus II main sequence is prominently visible and extends from \(g_0 \approx 20.5\) mag down to \(g_0 = 26.3\) over three magnitudes fainter than the discovery data. The limiting magnitude of the data is \(g_{\text{lim}} \sim 27.5\). Unresolved background galaxies appear as plume below \(g_0 = 24.2\) and \(-0.5 < (g-r)_0 < +0.6\). The red stars in the color interval \(1.0 < (g-r)_0 < 2.0\) are the population of local Milky Way M dwarfs. The 50% photometric completeness is indicated as a dashed line and reaches \(g_0 = 26.08\) mag.

3. Properties of Cetus II
3.1. Stellar Population

For determining the properties of the Cetus II population, we computed the model isochrone that best describes the main-sequence stars distributed over the entire GMOS-S field (Figure 5) using the maximum-likelihood method introduced in Frayn & Gilmore (2002). This method was employed in our previous studies (Kim & Jerjen 2015a; Kim et al. 2015b, 2016). In brief, we calculated the maximum-likelihood values \(L_i\) over a grid of Dartmouth model isochrones (Dotter et al. 2008) as defined by Equations (1) and (2) in Fadely et al. (2011). The grid points cover ages from 7 to 14 Gyr, a broad range of chemical composition \(-2.5 \leq \frac{[Fe/H]}{H} \leq -0.8\) dex, \(-0.2 \leq \frac{[\alpha/Fe]}{H} \leq +0.6\) dex, and a distance interval \(16.88 < (m-M) < 17.88\), where the central
value of 17.38 mag is the reported distance modulus for Cetus II from the discovery paper. Grid steps were 0.5 Gyr, 0.1 dex, 0.2 dex, and 0.05 mag, respectively.

Figure 6 shows the maximum-likelihood density map of the age–metallicity space for Cetus II. The well-defined location that corresponds to the best-fitting isochrone is marked with a cross. Cetus II’s stellar population is found to have an age of 11.2 Gyr, an \([\text{Fe}/\text{H}]\) of \(-1.28\) dex, an \([\alpha/\text{Fe}]\) of 0.0 dex and a distance modulus of \((m-M)_{\odot} = 17.10 \pm 0.10\) (26.3 ± 1.2 kpc). The corresponding isochrone is superimposed on the CMD in Figure 7 together with the associated mask. The mask has an upper and lower magnitude limit of \(g_0 = 19.5\) and \(27.2\), respectively. The color width of the mask for a given magnitude \(g_0\) was determined from the photometric uncertainties:

\[
(2\pi\sigma_{\text{tot}}^2)^{-1/2} \exp\left(-((g_0 - r_0) - (g_0-r)_{\text{iso}})^2/2\sigma_{\text{tot}}^2\right) > 0.5,
\]

where \((g-r)_{\text{iso}}\) is the color of the model isochrone at \(g_0\) and \(\sigma_{\text{tot}}^2 = \sigma_{\text{int}}^2 + \sigma_{g_0}^2 + \sigma_{r_0}^2\). The quantity \(\sigma_{\text{int}} = 0.07\) mag was chosen as the intrinsic color width of the isochrone mask and \(\sigma_{g_0}, \sigma_{r_0}\) are the photometric uncertainties of a star.

We apply the isochrone mask to select the most likely Cetus II stars and plot their on-sky distribution in Figure 8. To highlight the positions of bright foreground stars in the field, we also overplotted objects from the AllWISE1 catalog as red circles. The sizes of these circles correlate with the apparent magnitudes of the objects. We further show a large, dashed circle that represents the center and half-light radius of Cetus II as reported in Drlica-Wagner et al. (2015). Although we trace the main-sequence stars over six magnitudes, there is no evidence of any concentration of stars in the Cetus II field that would indicate the presence of an ultra-faint star cluster or dwarf galaxy candidate. We note that the two bright AllWISE stars in the field (see also Figure 2) are not affecting our ability to identify an overdensity of stars at the Cetus II location.

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11 All Wide-field Infra-red Survey Explorer mission, http://wise2.ipac.caltech.edu/docs/release/allwise/.
### Table 4

| Cetus II |
|----------|
| (l, b)   | (156°47′, −78°53′) |
| (λ_s, B_0) | (86°17′, 8°02′) |
| (λ_m, B_0) | (273°83′, −8°02′) |
| E(B−V)   | 0.0171 |
| (m−M)_0  | 17.10 ± 0.10 |
| D (kpc)  | 26.3 ± 1.2 |
| age (Gyr) | 11.2^{+0.1}_{−0.3} |
| [Fe/H] (dex) | −1.28 ± 0.07 |
| [α/Fe] (dex) | 0.0 |

4. Discussion

As shown in Section 3, the Cetus II field contains a well-defined, coherent stellar population that can be traced almost six magnitudes below the main-sequence turn-off. These Cetus II stars are not concentrated into a distinct stellar overdensity, and thus it was not viable to determine the center coordinates, half-light radius, ellipticity, and total luminosity of Cetus II. Nevertheless, the properties of the underlying stellar population such as an accurate distance, age, metallicity, and alpha abundance are now accurately determined and listed in Table 4. We also list the Galactic coordinates, Sagittarius spherical coordinates (λ_0, B_0) from Majewski et al. (2003), (λ_0, B_0) from Belokurov et al. (2014) and the local dust extinction estimate from Schlegel et al. (1998), based on the coordinates provided in Drlica-Wagner et al. (2015). The Cetus II stars are old, moderately metal-poor and occupy a narrow heliocentric distance range. The lack of a clear overdensity suggests that these stars belong to a tidally disrupted stellar population.

4.1. Possible Connection to Sagittarius Dwarf Tidal Stream

As seen in Figure 1, Cetus II is projected onto the stellar density contours of the Law & Majewski (2010) model for the Sagittarius (Sgr) tidal stream. The presence of the Sgr stream at this location is observationally confirmed in Figure 1 (bottom panel) from Bernard et al. (2016). In Figure 9, we use the Law & Majewski (2010) model to further explore the possibility that the Cetus II stars are associated with the Sagrid tidal stream. In the top panel (d_0 versus R.A.), the distance and location of Cetus II is populated by model particles that were stripped on the previous pericentric passage of Sgr (Pcol=1). The Law & Majewski (2010) particles in a 4° × 4° window around the nominal center of Cetus II with a Pcol value of 1 (40 particles in total) have an average heliocentric distance of 23.4 kpc and a scatter of σ = 2.9 kpc. Our derived Cetus II distance is in excellent agreement.

We further compare the Cetus II distance with the Sgr Stream distance map generated from RR Lyrae stars of type ab identified in the Pan-STARRS1 3π survey (Hernitschek et al. 2017). In their Figure 1, the Cetus II stellar population is at the same distance as the Sgr stream stars cover at (λ_0, B) ≈ (274°, −8°). In Figure 4 of the same paper, we find that the Cetus II stars reside in the Sagittarius trailing arm.

In terms of age and metallicity, we also find excellent agreement between the Cetus II population ([Fe/H] = −1.28 ± 0.07, age = 11.2^{+0.1}_{−0.3}) and the metal-poor Population B of Sgr ([Fe/H] = −1.2 ± 0.1, age = 11 ± 1 Gyr), e.g., Law & Majewski (2010) and Siegel et al. (2007). The final confirmation of these stars belonging to the Sagittarius tidal stream would be a spectroscopic investigation to determine their radial velocities. The Law & Majewski (2010) model prediction for stars in this part of the Milky Way halo is velocities in the range −95 km s^{-1} < v_{GSR} < −60 km s^{-1} with a mean of −78 km s^{-1} and a standard deviation of 9 km s^{-1}, see Figure 10. At the location and distance of Cetus II, the Population B (Pcol=1) Sgr stars represent approximately 75% of the Sgr stars in the field. The photometry presented here will be used as the basis for future spectroscopic follow-up of the Cetus II region.

4.2. Other Stellar Streams

Although we found strong evidence that Cetus II stars are part of the Sgr Stream trailing arm, we briefly want to look into other potential explanations for the Cetus II phenomenon. Is there another stream candidate that might explain the Cetus II stellar population? In their recent study of Milky Way halo substructures from the Pan-STARRS1 3π Survey, Bernard et al. (2016) did not report a new stream nor is there any obvious candidate stream visible in their Figure 1 at the Cetus II location. The next best alternative origin for the Cetus II stars would be the Cetus Polar Stream (CPS) (Newberg et al. 2009).
is significantly more metal-poor than the stellar population in the Cetus II field.

4.3. False-positive Photometric Detections

The Cetus II case, as with Tucana V (Conn et al. 2018), highlights the complication that there are objects within the current set of candidate Milky Way satellites that are potential false-positive detections. Since they consist of a coherent stellar population but with no central overdensity, these detections could be part of tidally disrupted stellar systems, which have either small physical sizes (e.g., Kim 1, Kim & Jerjen 2015) or are part of a much larger stream (e.g., Sgr tidal Stream). The shallow photometric depth of typical discovery data combined with perhaps the apparent random clustering of stars are driving the discovery of these objects prior to a robust confirmation of their status.

The presence of a coherent stellar population combined with marginal evidence for clustering does not automatically guarantee that they belong to a stellar overdensity as was demonstrated in Jerjen et al. (2013), where multiple stellar populations were detected without being associated with a specific object or overdensity. How then are these stellar populations being identified as overdensities? Can we attribute this to solely the chance clustering of member stars or are they examples of some underlying substructure?

Before the revision of their nature, Tucana V and Cetus II curiously occupied a very similar regime in the size–luminosity plane that we have dubbed the “TUC” in Conn et al. (2018). There were four objects in TUC of which two are now known not to be star clusters or dwarf galaxies.

4.4. Is Spectroscopy the Solution?

Of the two remaining objects, Draco II is the brightest TUC object and has been tentatively confirmed as an ultra-faint dwarf galaxy by Martin et al. (2016a) using KECK/DEIMOS spectroscopic data, but without improving on the shallow PanSTARRS1 discovery CMD ($g_{\text{lim}} \sim 22.0$, Figure 1, Laevens et al. 2015a). DES J0225+0304 (Luque et al. 2017) has yet to be followed up.

While spectroscopy is a good tool to test the presence of a discrete stellar overdensity, the measured velocity dispersion often used to derive the total mass is not a clean cut indicator of what type of object is being probed. For example, the classical Milky Way dwarf galaxy satellites have velocity dispersions of $\sim 10 \text{ km s}^{-1}$ (Walker et al. 2007) while the ultra-faint dwarf satellites are in the range $3.3–7.6 \text{ km s}^{-1}$ (Simon & Geha 2007; Kirby et al. 2015; Simon et al. 2015). The Milky Way globular cluster population on the other hand has velocity dispersions of approximately $6 \pm 4 \text{ km s}^{-1}$ (Harris 1996). In many cases, the values are broadly consistent with the expected velocity dispersion of stars in a stellar stream, e.g., the Sagittarius tidal stream of $\sim 9 \text{ km s}^{-1}$ at the location of Cetus II. It is for this reason that confirmation and refinement of the physical properties (e.g., half-light radius, radial profile, ellipticity, and evidence of tidal disruption) of candidate ultra-faint objects are vital if we are to determine what sort of structures we are probing at these scales. However, as has been seen with Tucana V (Conn et al. 2018), scaling relations such as those presented in Forbes et al. (2014) are not applicable if, as with Cetus II, a central overdensity cannot be identified.

In Figure 11, we compare the density distribution of particles from the Sgr Stream simulation (Law & Majewski 2010) with five positions along the CPS measured using blue horizontal branch stars by Yam et al. (2013). The width of the CPS stream for each data point ($\sigma_t$ in Table I of Yam et al. 2013) is represented by a horizontal error bar. The ($l$, $b$)$^3$ coordinates of Cetus II disagree with the N-body simulation of a satellite on the best-fitting CPS orbit (see Figure 18 in Yam et al. 2013). Moreover, the heliocentric distance of the CPS increases systematically from 27.2 kpc at $b \sim -36^\circ$ to 32.5 kpc at $b \sim -66^\circ$. This gradient is suggesting an extrapolated distance of $\approx 35$ kpc at the Galactic latitude of Cetus II. Hence, the measured distance of Cetus II (26.3 $\pm$ 1.2 kpc) seems incompatible. Finally, the CPS is reported in Yam et al. (2013) to have a metallicity of $-2.5 < [\text{Fe/H}] < -2.0$ which
the object has a 2D Gaussian profile centered on the Cetus II position published in Drlica-Wagner et al. (2015) and is populated with the 393 stars located in the Cetus II mask (see Figure 7). The three panels correspond to the 1σ range of possible half-light radii reported in the discovery paper: \( r_h = 1.9^{+1.0}_{-0.5} \) arcmin. For each half-light radius, the stellar distribution was drawn 1000 times and a radial density profile was calculated. The lines plotted in each panel represent the properties of the total sample for a given radius. The solid line is the median, the dotted lines delimit the 1st and 3rd Quartiles and the dashed lines show the minimum and maximum values at that radius. The solid circles are the radial profile as generated using our GMOS-S data.

In the top panel of Figure 12, the most compact of the three scenarios, with a half-light radius of 1.4 arcmin, demonstrates that there are significant discrepancies between the data and model. Inside the half-light radius, the model consistently overpredicts the star density per radius compared to the data, while, at larger radii, the data outstrips the model. The middle panel, with \( r_h = 1.9 \) arcmin, the model is marginally more consistent at larger radii but the core density is still overpopulated. For the largest half-light radius \( (r_h = 2.9 \) arcmin), the median radial profile is very flat, but once again the model predicts at least 20 more stars in the innermost radii, which are not seen in the data. Even with such a flat profile, an extra 20 stars at the center of the field would be easily detected in high-quality data like those presented here.

5. Conclusion

We have confirmed the presence of the Cetus II stellar population and detected member stars up to six magnitudes below the main-sequence turn-off. Despite this finding, there is no overdensity in the GMOS-S field that could represent an ultra-faint star cluster or dwarf galaxy. Our photometric completeness estimates and examination of the field show that there is neither a crowding issue nor significant loss of coverage due to bright stars. Comparisons with model ultra-faint dwarf galaxies of various sizes has illustrated that even in the case with the largest half-light radius, the object should still be detectable by GMOS-S with a small field of view. It appears that the original detection of an overdensity is perhaps another chance grouping of bright member stars, as is suspected with Tucana V.

The Cetus II stars bear striking resemblance to the Population B stars of the Sagittarius dwarf galaxy tidal stream (Law & Majewski 2010) in age, metallicity, and distance. It is almost certain that this is the best explanation for these stars. The Law & Majewski (2010) models make predictions for the radial velocity distribution of these stars in the Cetus II field and spectroscopic follow-up of these stars would provide the final confirmation of their status.

Cetus II is the second object that we confirm as a false-positive detection of a stellar overdensity and it accentuates the fine line that survey teams employ when setting the criteria for their detection thresholds. This is partly due to the desire to detect the missing Milky Way satellites predicted by lambda cold dark matter cosmological models and partly due to the lack of a good understanding of what objects like Cetus II and Tucana V might actually entail and how to classify them. It cannot be stressed enough that these objects consist of a single age–metallicity stellar population and thus are not misinterpretations of the color–magnitude space. They do reside at the distances originally estimated, but they do not form overdensities that conform to our understanding of star clusters or

4.5. Detection Thresholds for Targeted Deep Imaging

The original discovery of Cetus II was made using DECam with its very wide field of view; however, for low surface brightness systems such as these, the question then arises, can deep observations on a smaller field of view adequately describe the system? In Figure 12, we present the expected radial density profile for a Cetus II-like model galaxy assuming the parameters from Drlica-Wagner et al. (2015) and comparing them with the radial density profile as calculated using our data. In each case,
dwarf galaxies. It is most likely that they represent the stochastic process of tidal disruption and as such may be providing clues regarding the structure of the object from which they were stripped.

Given the accumulation of false-positives and the prospect of even more such detections in upcoming surveys, it is highly desirable to avoid giving ultra-faint dwarf galaxy candidates names based on the constellation they are found in, so as not to confuse the community. Candidates should keep their working names until their true nature has been unambiguously established.

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Software: Aladin (Bonnarel et al. 2000; Boch & Fernique 2014), Astropy (Astropy Collaboration et al. 2013), DOLPHOT (Dolphin 2000), TOPCAT (Taylor 2005).

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