THE ENIGMATIC (ALMOST) DARK GALAXY COMA P: DISTANCE MEASUREMENT AND STELLAR POPULATIONS FROM HST IMAGING *

Samantha W. Brunker,[1] Kristen B. W. McQuinn,[2] John J. Salzer,[1] John M. Cannon,[3] Steven Janowiecki,[1,4] Lukas Leisman,[5] Katherine L. Rhode,[1] Elizabeth A. K. Adams,[6,7] Catherine Ball,[3] Andrew E. Dolphin,[8,9] Riccardo Giovanelli,[10] and Martha P. Haynes[10]

[1] *Department of Astronomy, Indiana University, 727 East Third Street, Bloomington, IN 47405, USA*
[2] *University of Texas at Austin, McDonald Observatory, 2515 Speedway, Stop C1402, Austin, TX 78712, USA*
[3] *Department of Physics & Astronomy, Macalester College, 1600 Grand Avenue, Saint Paul, MN 55105, USA*
[4] *International Centre for Radio Astronomy Research, University of Western Australia, 35 Stirling Highway, Crawley, WA 6009, Australia*
[5] *Department of Physics and Astronomy, Valparaiso University, Valparaiso, IN 46383, USA*
[6] *ASTRON, the Netherlands Institute for Radio Astronomy, Postbus 2, 7990 AA, Dwingeloo, The Netherlands*
[7] *Kapteyn Astronomical Institute, University of Groningen, Postbus 800, 9700 AV, Groningen, The Netherlands*
[8] *Raytheon Company, PO Box 11337, Tucson, AZ 85734, USA*
[9] *Steward Observatory, University of Arizona, 933 North Cherry Avenue, Tucson, AZ 85721, USA*
[10] *Center for Astrophysics and Planetary Science, Space Sciences Building, 122 Sciences Drive, Cornell University, Ithaca, NY 14853, USA*

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ABSTRACT

We present *Hubble Space Telescope (HST)* observations of the low surface brightness (SB) galaxy Coma P. This system was first discovered in the Arecibo Legacy Fast ALFA H I survey and was cataloged as an (almost) dark galaxy because it did not exhibit any obvious optical counterpart in the available survey data (e.g., Sloan Digital Sky Survey). Subsequent WIYN pODI imaging revealed an ultra-low SB stellar component located at the center of the H I detection. We use the *HST* images to produce a deep color-magnitude diagram (CMD) of the resolved stellar population present in Coma P. We clearly detect a red stellar sequence that we interpret to be a red giant branch, and use it to infer a tip of the red giant branch (TRGB) distance of $5.50^{+0.28}_{-0.53}$ Mpc. The new distance is substantially lower than earlier estimates and shows that Coma P is an extreme dwarf galaxy. Our derived stellar mass is only 4.3 $\times 10^5$ $M_\odot$, meaning that Coma P has an extreme H I-to-stellar mass ratio of 81. We present a detailed analysis of the galaxy environment within which Coma P resides. We hypothesize that Coma P formed within a local void and has spent most of its lifetime in a low-density environment. Over time, the gravitational attraction of the galaxies located

Изолированные области HI за пределами LG.

These sources have been named “almost dark" galaxies, since most (but not all) have been found to possess extremely faint optical emission when imaged more deeply (e.g, Cannon et al., 2015, Janowiecki et al. 2015; Leisman et al. 2017).

Janowieski et al., 2015 WSRT+WIYN
System HI1232+20 (ALFALFA)

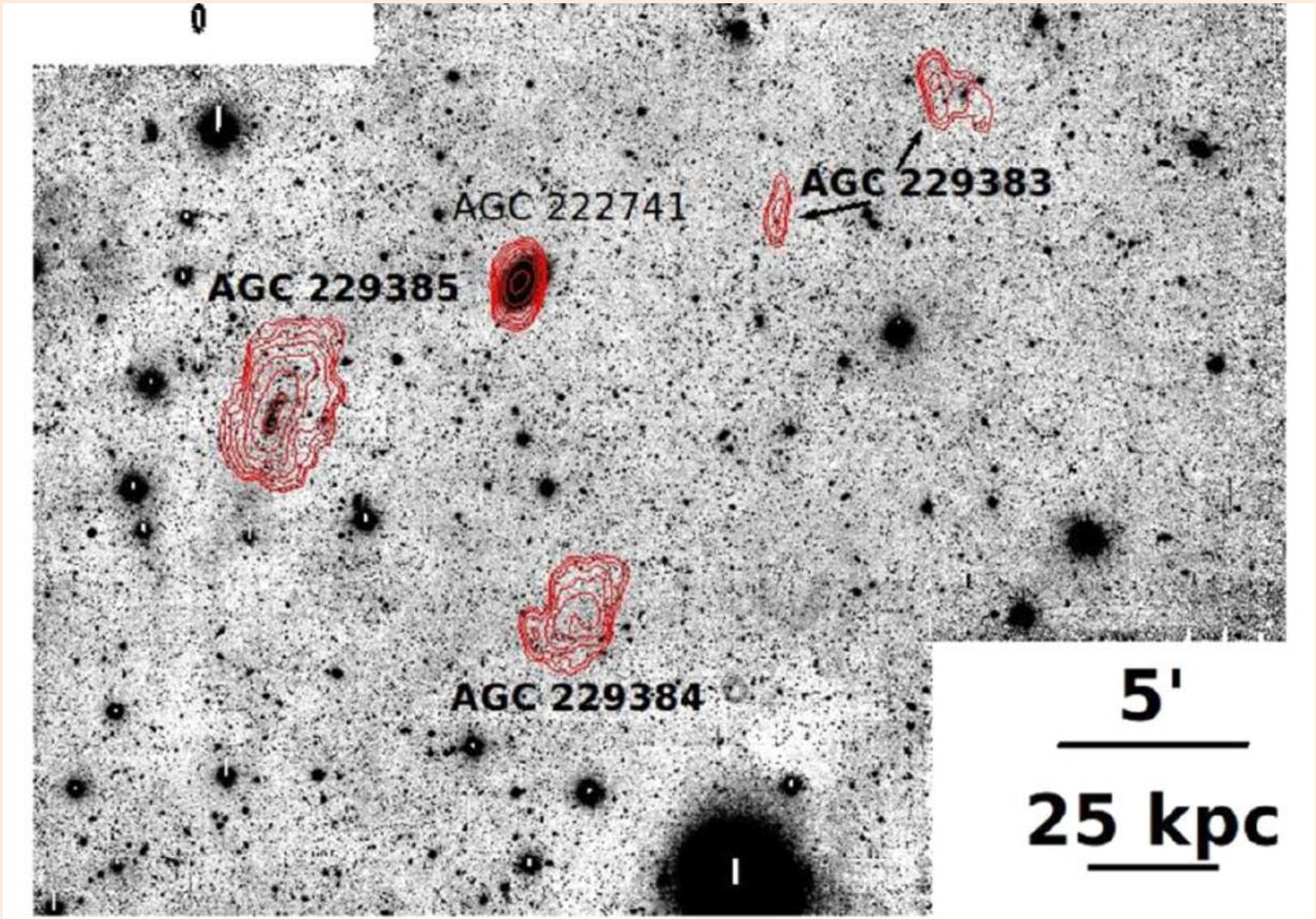


image made from all pODI observations with ALFALFA HI sources in the HI1232+20 system labeled and WSRT contours

Janowieski et al., 2015 WSRT+WIYN

Peak g-brightness = 26.4, no emission

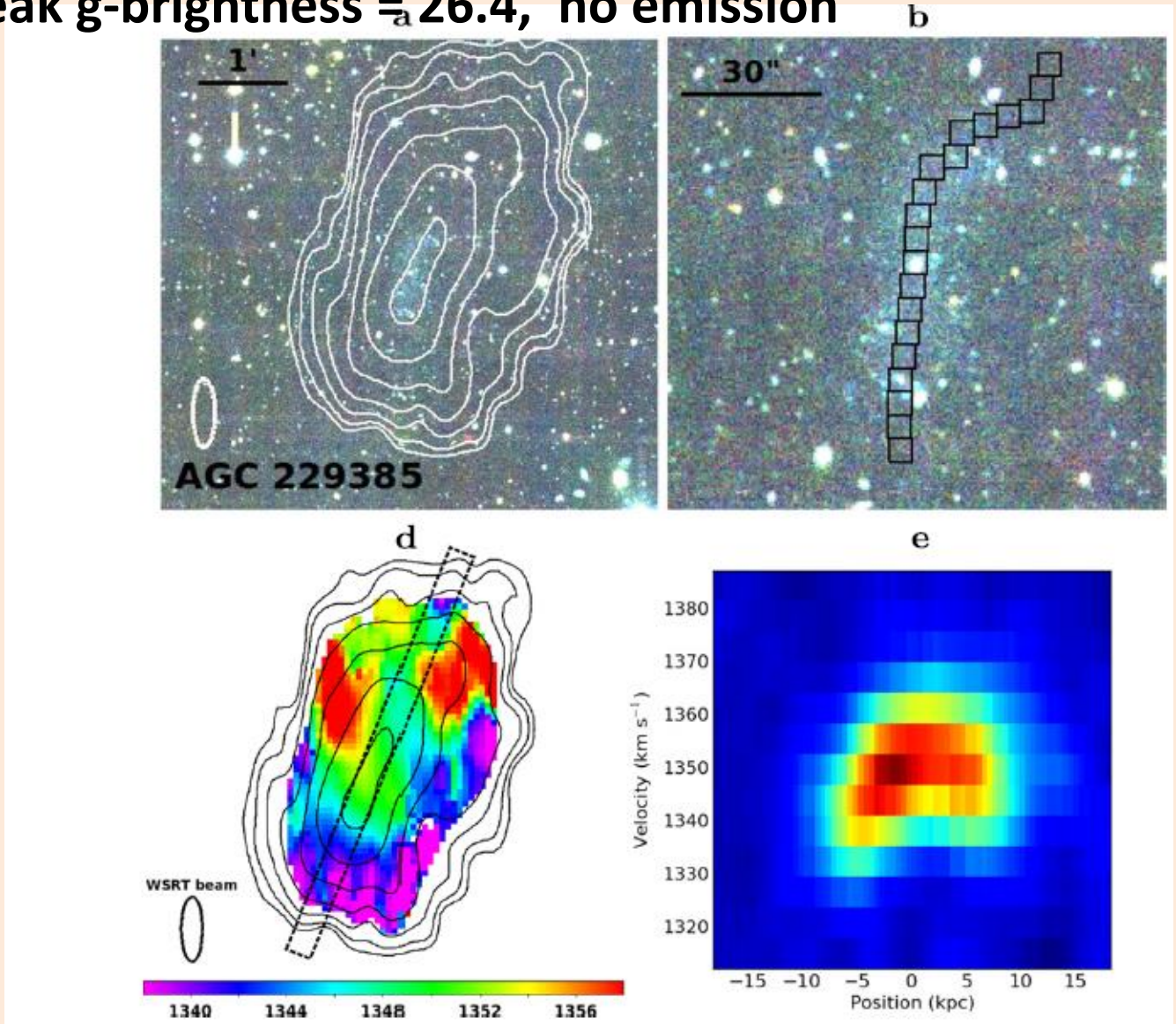
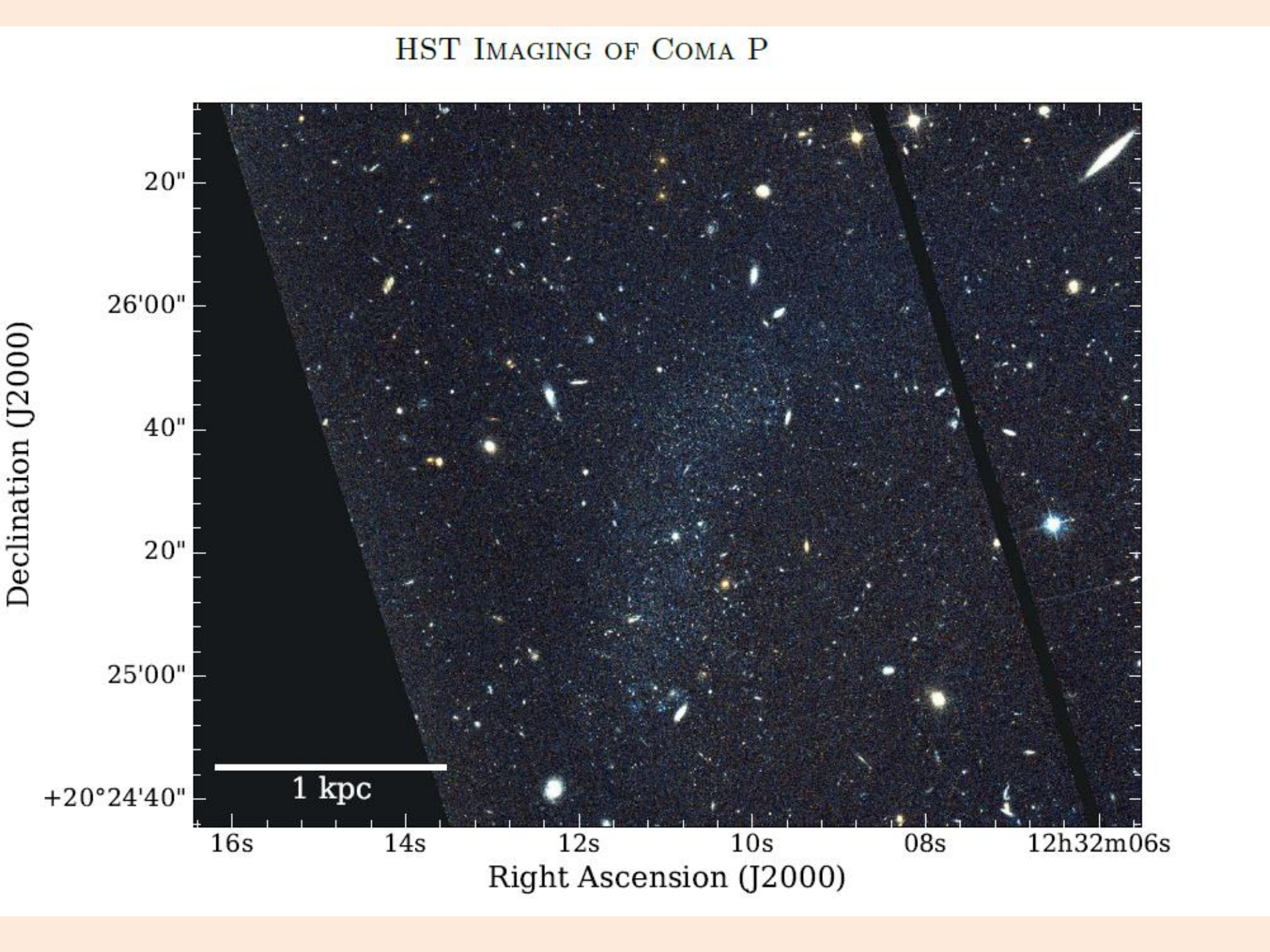
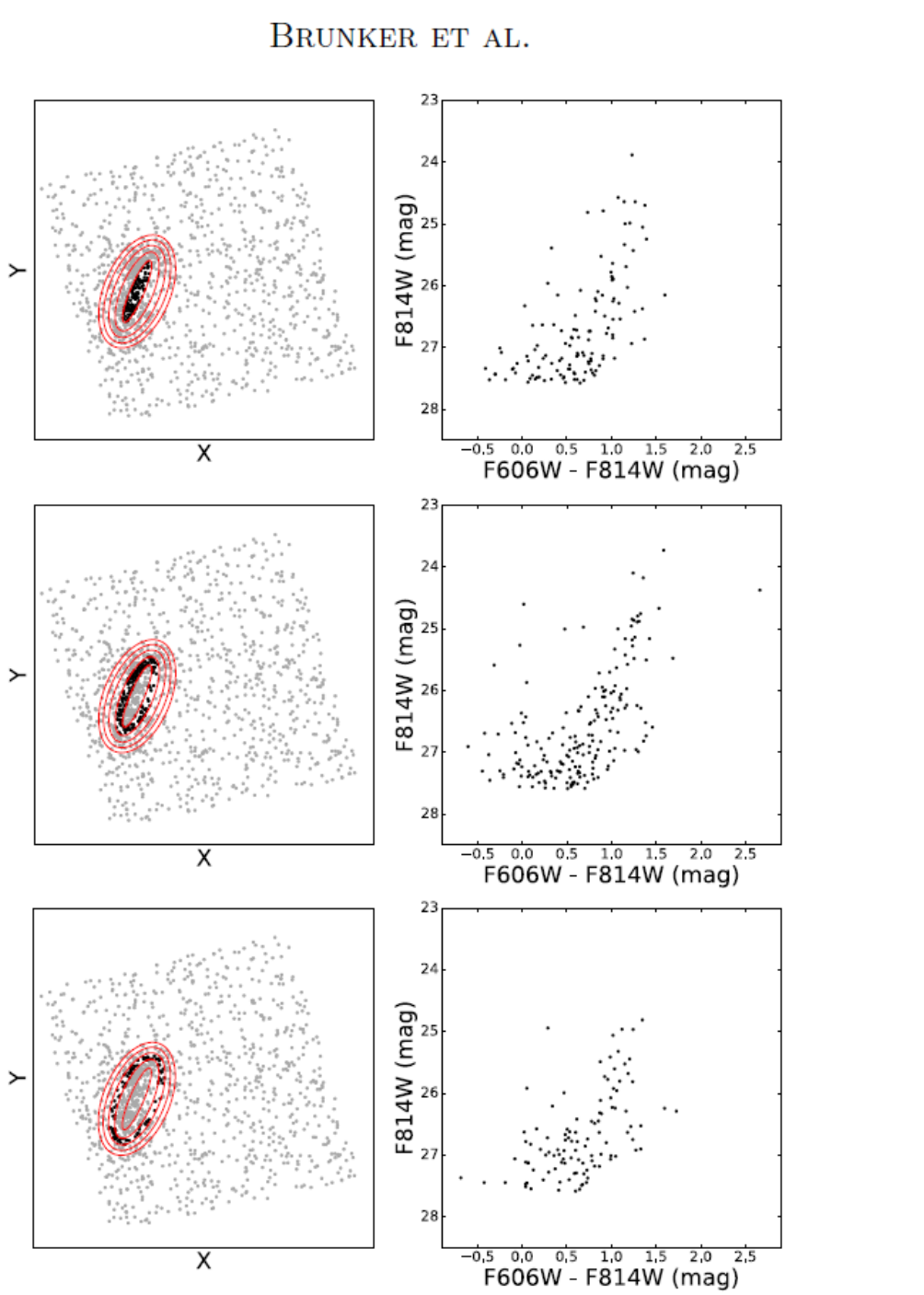
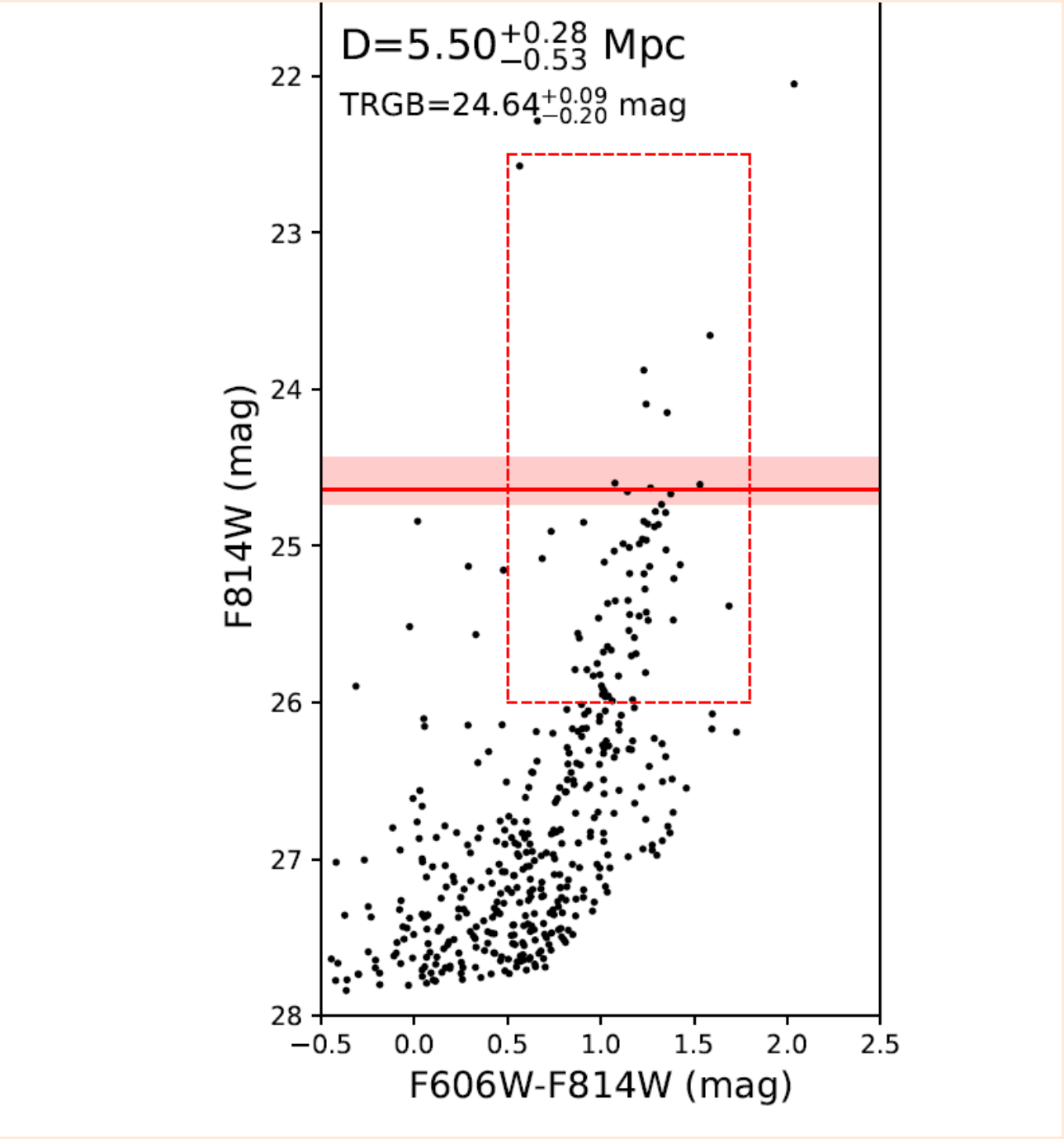


Figure 3. Our observations of AGC 229385. (a) Three-color optical image from WIYN pODI binned 4 × 4 s


HST Imaging of Coma P
20"
26'00"
40"
20"
25'00"
+20°24'40"
Declination (J2000)
1 kpc
16s
14s
12s
10s
08s
12h32m06s
Right Ascension (J2000)

There is a clear RGB ,
But no strong
presence
of upper MS stars
is detected.




D=5.50$^{+0.28}_{-0.53}$ Mpc
TRGB=24.64$^{+0.09}_{-0.20}$ mag
F814W (mag)
F606W-F814W (mag)
22
23
24
25
26
27
28
−0.5
0.0
0.5
1.0
1.5
2.0
2.5

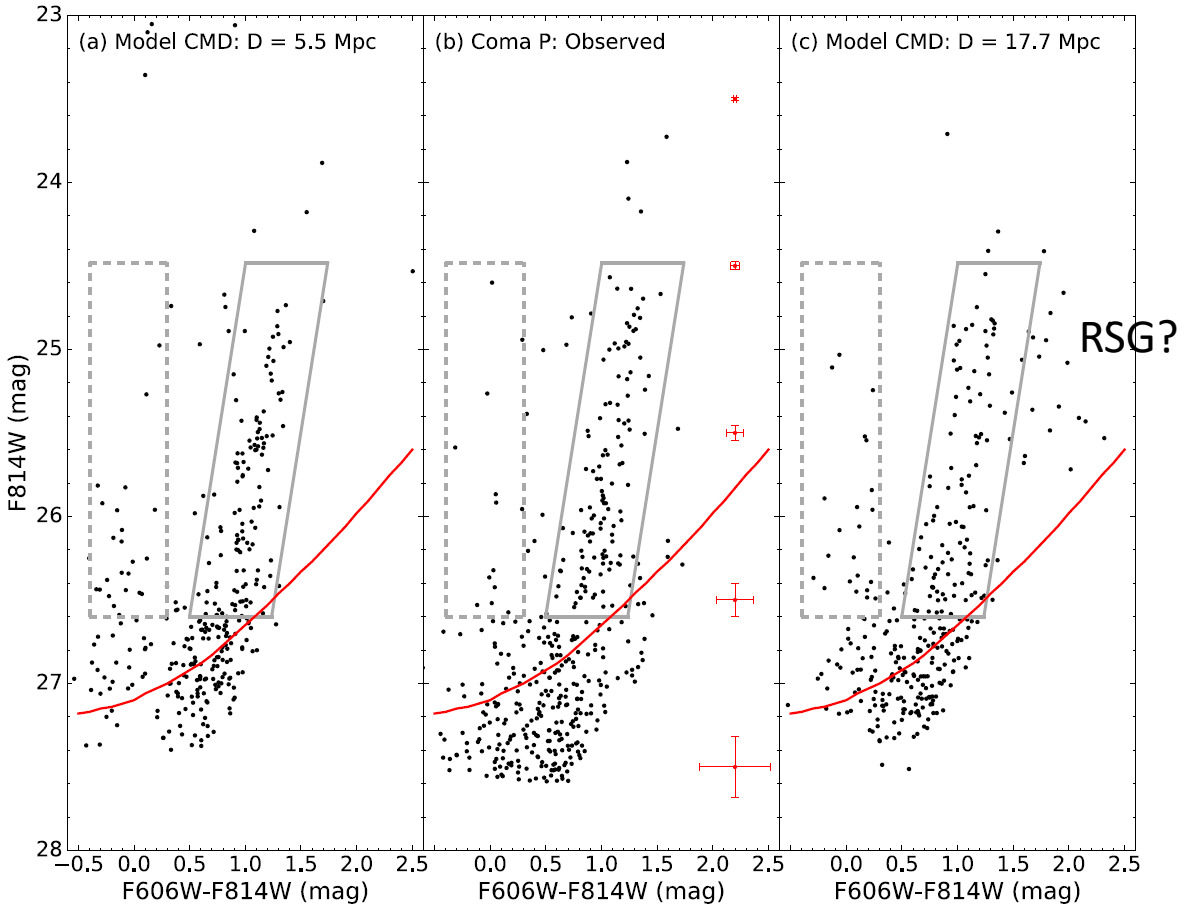


Figure 6. CMD comparison between stellar population models for two possible distances to Coma P and the observed *HST* data. Panel (a) shows the model CMD for an assumed distance of 5.5 Mpc, the value adopted in this paper based on the TRGB-fitting process. Panel (b) shows the observed CMD (same data as the left panel in Figure 4). Panel (c) presents a model CMD assuming a distance of 17.7 Mpc, as described in the text. Two regions that denote the blue-sequence region (dashed lines) and the red-sequence region (solid lines) are delimited. The location of these regions is identical in all three panels.

The ML method determines the TRGB luminosity by fitting a parametric form to the F814W LF transformed for metallicity eects (e.g., Sandage et al. 1979; Mendez et al. 2002; Makarov et al. 2006). We assumed the theoretical shape of the RGB LF from Makarov et al. (2006).

Padova library
Kroupa' IMF

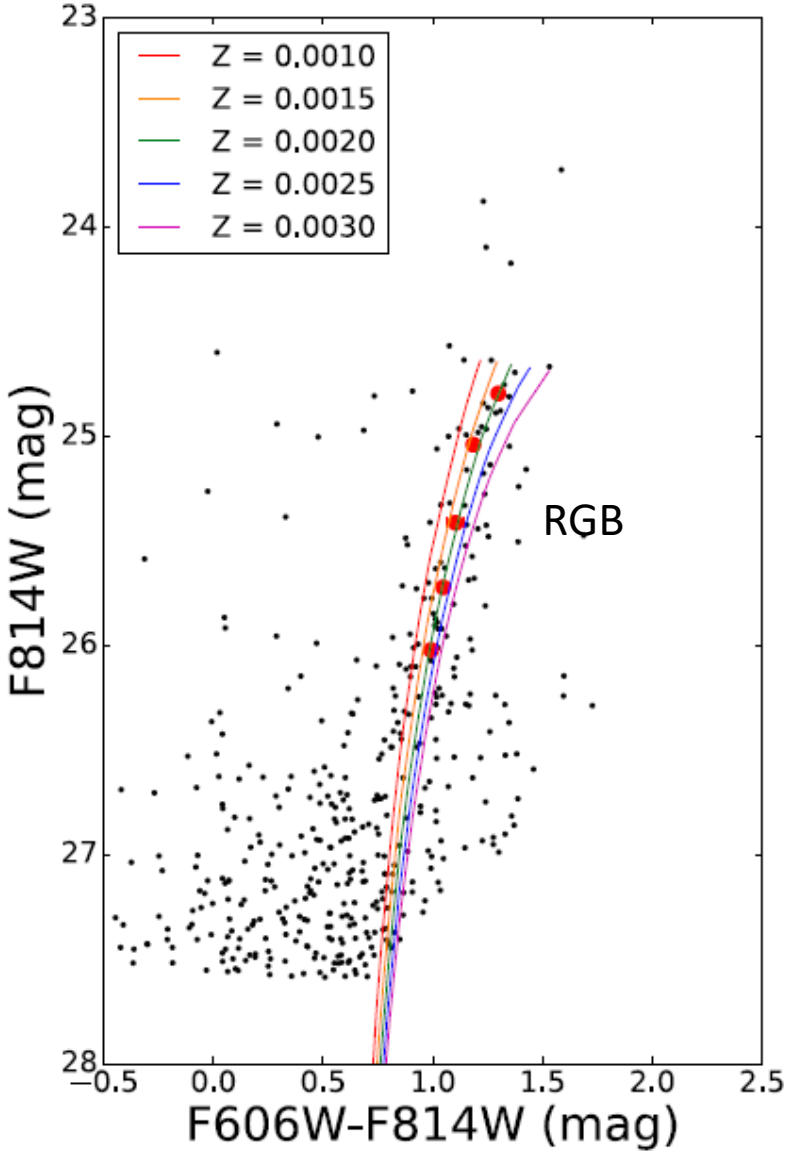
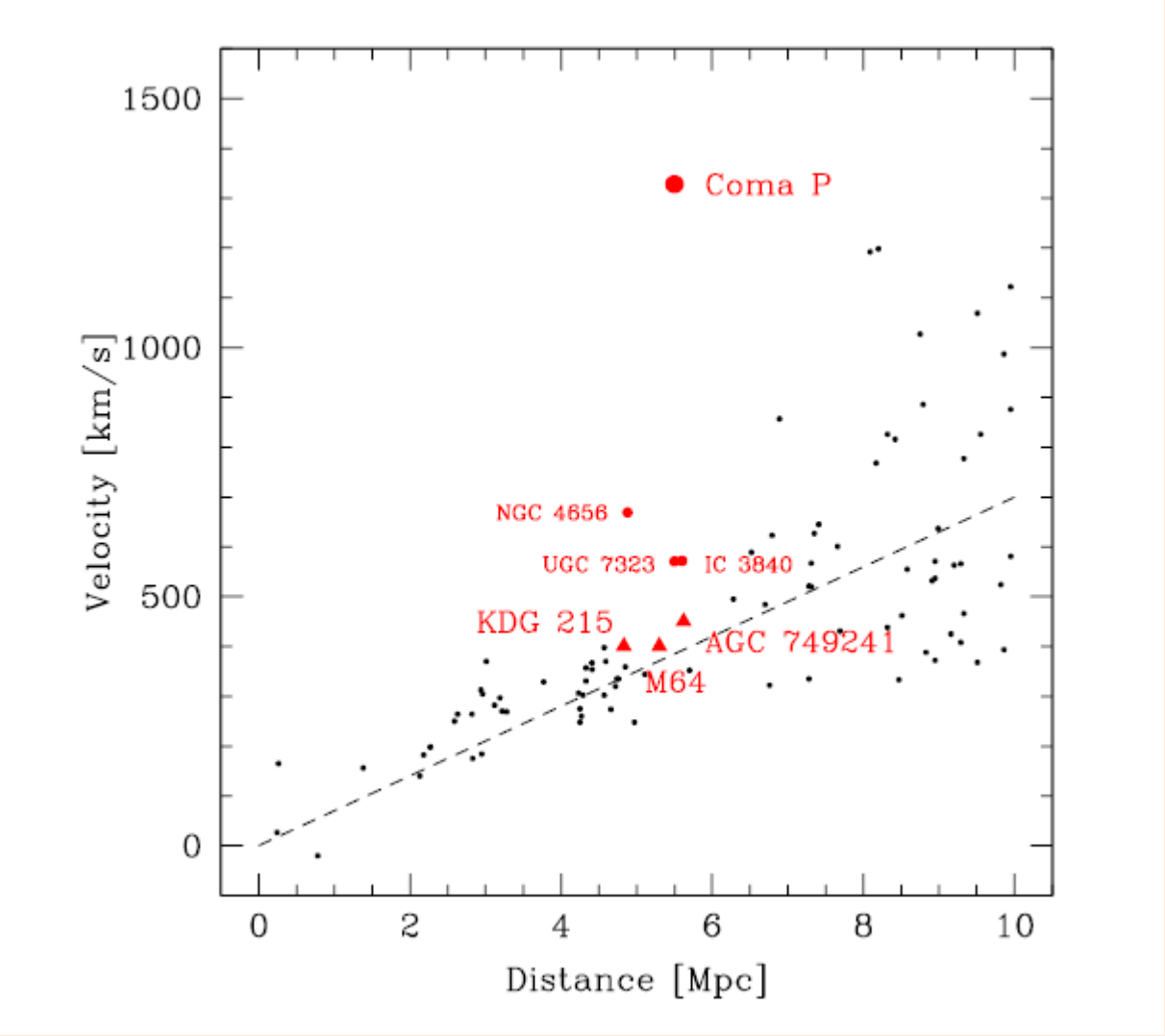


Figure 7. CMD of Coma P overplotted with PARSEC isochrones for a 10 Gyr population with metallicities ranging from $Z = 0.0010$ to $Z = 0.0030$ in increments of 0.0005. We binned the data along the RGB because it was difficult to estimate the metallicity with the scatter in the RGB. The average locations of the RGB stars are plotted as large red circles. The binned RGB points appear to lie along the $Z = 0.0020$ isochrone with a scatter of 0.0005.

COMA P

Derived Quantities	Value
$(m - M)$	$28.70\ ^{+0.11}_{-0.21}$
Distance (Mpc)	$5.50\ ^{+0.28}_{-0.53}$
M_B	$-9.75\ ^{+0.13}_{-0.22}$
Diameter (pc)	$2080\ ^{+170}_{-240}$
H I mass ($M_\odot$)	3.48×10^7
Stellar mass ($M_\odot$)	
SFH model:	$4.7\pm1.0\times10^5$
M/L *estimate:*	3.9×10^5
Average:	4.3×10^5
M_{HI}/M_* [d]	81
M_{HI}/L_B ($M_\odot/L_\odot$)	28

Одна неувязка…….



Coma-I region
Karachentsev et al., 2011

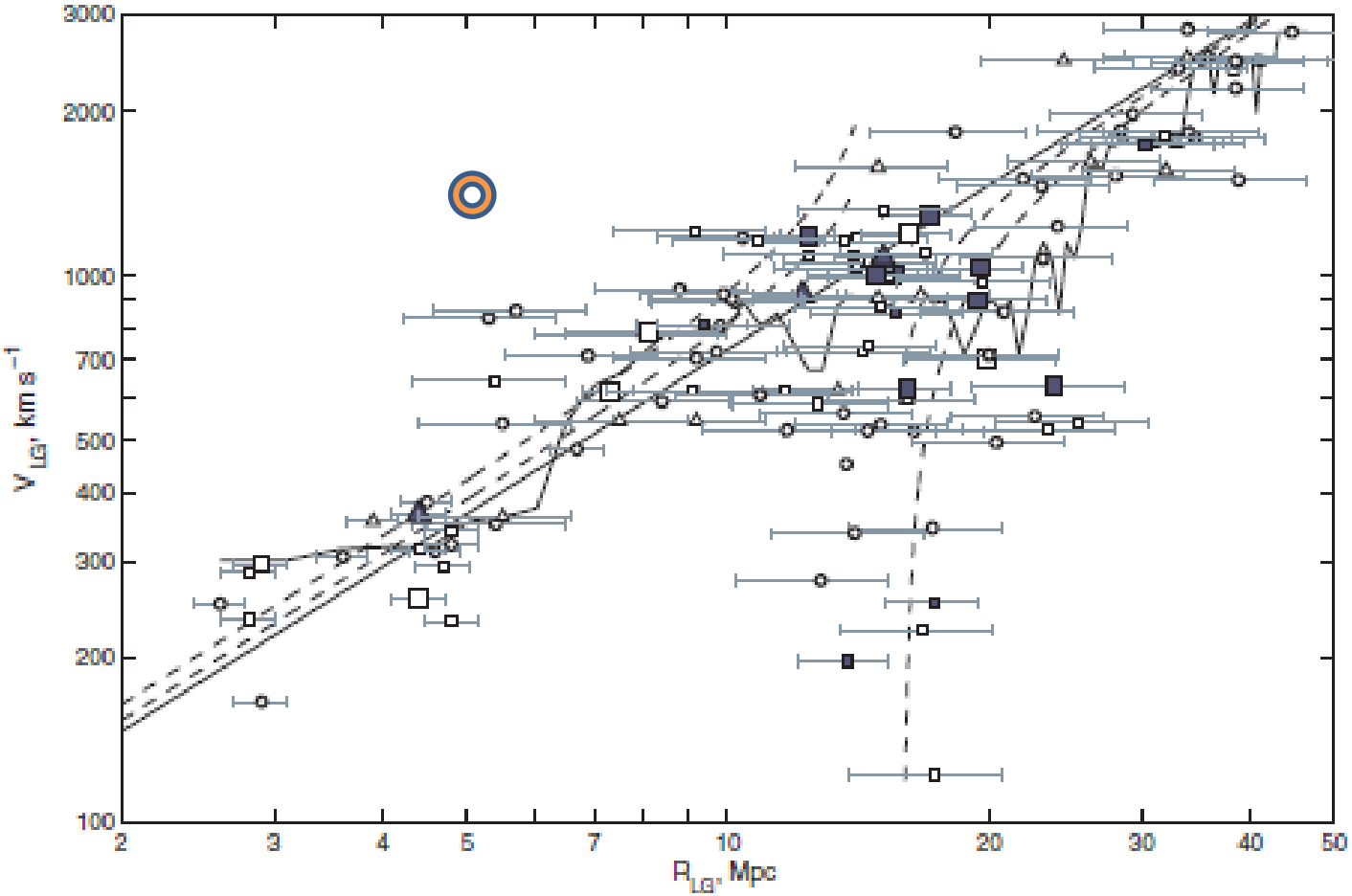
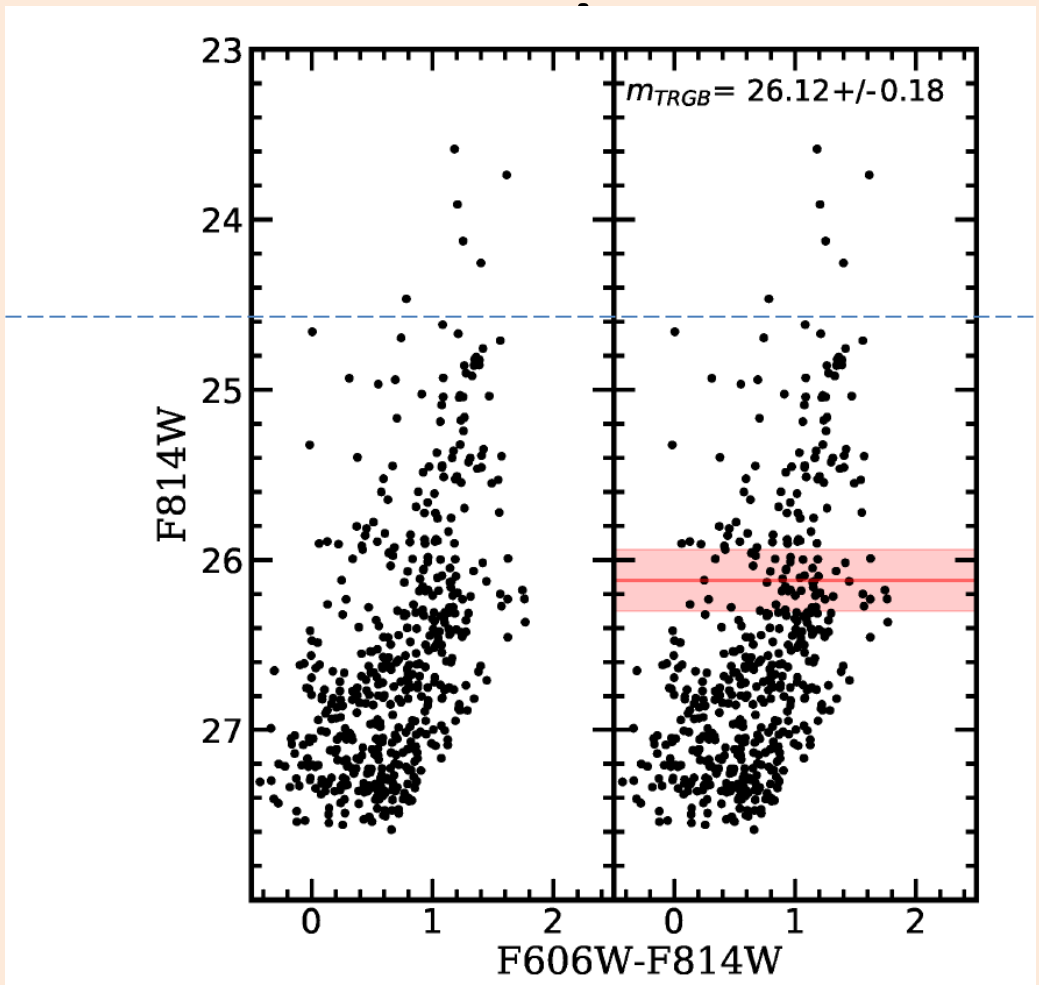


Figure 4. Velocity–distance relation for 122 galaxies in the Coma I region shown in the linear (top) and log–log (bottom) presentations. The straight line corre to the unperturbed Hubble flow with the parameter $H_0 = 73$ km s^{-1} Mpc^{-1}. The symbols marking different galaxies are the same as those in Figure 3. Distanc bars are shown. The broken line demonstrates the behavior of the running median with a window of 2 Mpc. Two dashed lines correspond to the pattern of the infall toward a point-like attractor with a mass of $0.5 \times 10^{14}\ M_\odot$ and $2.0 \times 10^{14}\ M_\odot$, located at a distance of 15 Mpc (where the line of sight passes throu attractor's center).

Другая интерпретация CMD
Anand et al, 2018

Brunker+ 2019



AGN?

Figure 1. Color magnitude diagram of stars in close proximity of Coma P. *Left:* uninterpreted. *Right:* TRGB fit
uncertainty.

Проблема расстояния

	Расстояние	Метод
Janowiecki et al 2015	25 mpc	Velocity flow model
Anand et al	10.9 mpc	Best match CMD, AGB, HST
This work	5.5 Mpc	Best match CMD, RGB, HST

Расстояние до ближайшей галактики (M64)- ок. 560кпс (this work)

- Еще одна проблема:

reddening-corrected (g-r) and (B-V) colors are quite blue, especially for a system that is not currently forming new stars.

- **g-r= -0.05**
- **B-V = 0.19**

The composite color of the resolved stars in the CMD corresponds to F606W-F814W = 0.80 (corresponding roughly to (r-i) =1.0), far redder than the global photometry. However, due to the extremely low SB nature of Coma P, the global photometry is quite uncertain. Our analysis reveals that small variations in the background measurements can lead to large (0.2 -0.3 mag) changes in the magnitudes and colors. Hence, our “formal" photometric errors are likely to be lower limits.

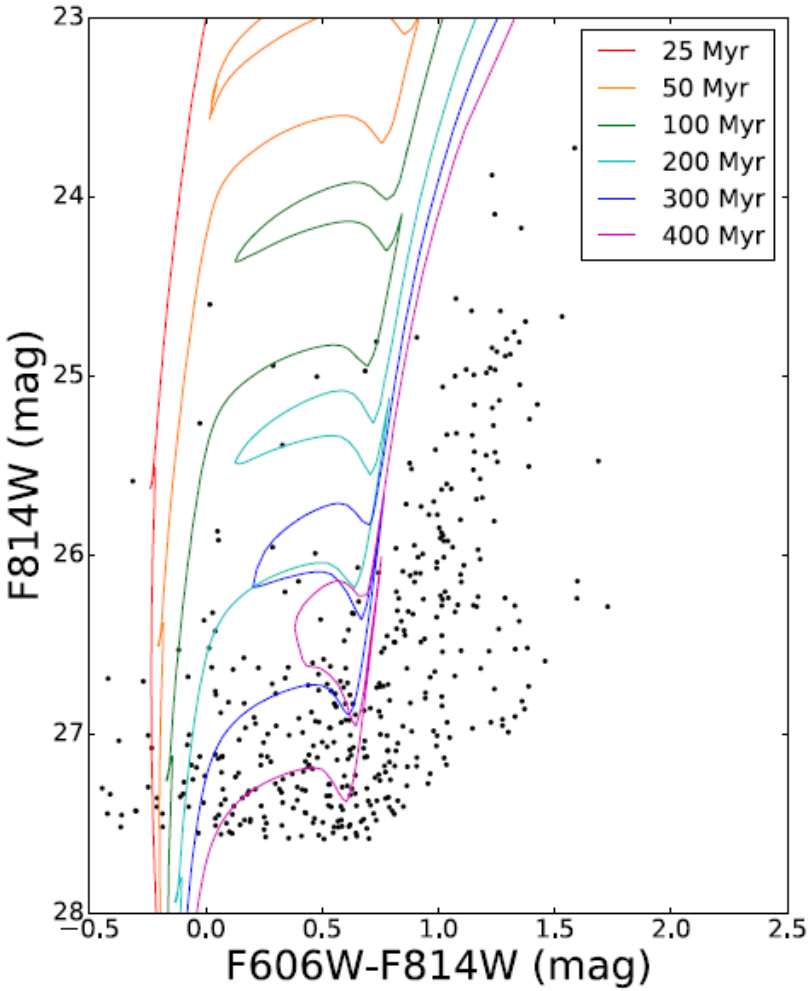
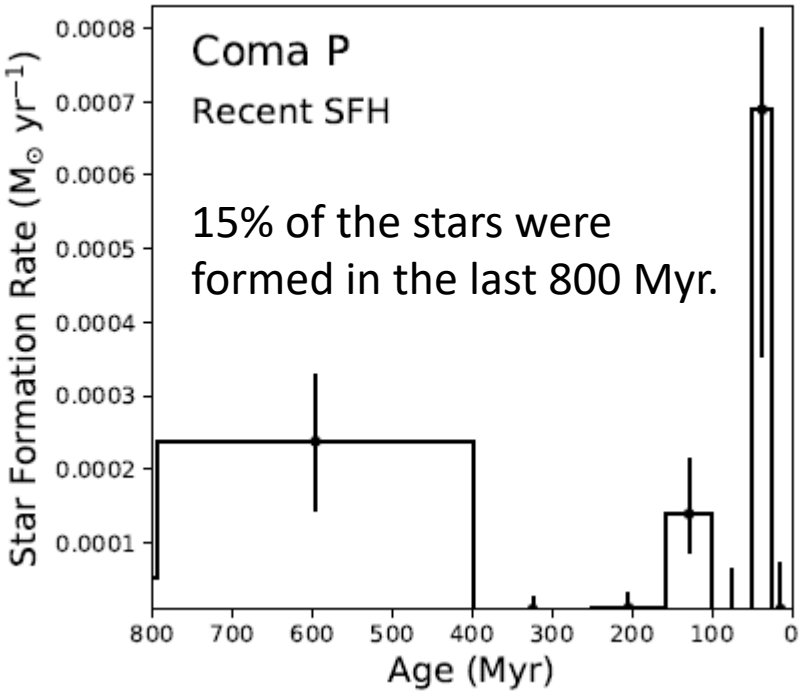


Figure 8. CMD of Coma P overplotted with PARSEC isochrones ($Z = 0.0020$) with ages ranging from 25 to 400 Myr. There is a small group of stars that could be the main sequence and helium-burning stars of a 100-200 Myr stellar population (the green and cyan isochrones). A few objects that could be associated with a younger (∼50−100 Myr) population of main-sequence stars

There is a small group of stars that are consistent with a helium-burning sequence of a stellar population with an age of approximately 100-200 Myr.



МЕТОД:

resolved stellar populations using the CMD-fitting routine match (Dolphin 2002). The technique uses the photometry, artificial stars, a stellar evolution library, and an assumed initial mass function (IMF) to create a series of synthetic simple stellar populations with varying ages and metallicities.

- По соотношению SFR-FUV текущий темп SF:

SFR = (3.1pm1.8) 10^{-4} Ms/yr

- По CMD (усредн.за 10^{8} лет)

SFR= (1.7pm0.8)10^{-4} Ms/yr

Эволюционный сценарий

- Была классической LSB- галактикой в очень разреженном войде. Низкая SFE. Ускорение к более плотным областям. Взаимодействие с M64 (у нее есть counter-rotating gas components) стимулировало SF. Часть потерянного газа наблюдается как соседние облака HI с MHI~10^7Ms.

- *We do not claim that this scenario is the correct explanation for Coma P; undoubtedly, additional scenarios could be developed that also cover the observational facts.*

The *HST* Large Programme on NGC 6752. I. Serendipitous discovery of a dwarf Galaxy in background⋆

L. R. Bedin[1]†, M. Salaris[2], R. M. Rich[3], H. Richer[4], J. Anderson[5], D. Bettoni[1], D. Nardiello[6], A. P. Milone[6], A. F. Marino[6], M. Libralato[5], A. Bellini[5], A. Dieball[7], P. Bergeron[8], A. J. Burgasser[9] and D. Apai[10,11]

[1]*INAF-Osservatorio Astronomico di Padova, Vicolo dell'Osservatorio 5, I-35122 Padova, Italy*
[2]*Astrophysics Research Institute, Liverpool John Moores University,146 Brownlow Hill, Liverpool L3 5RF, UK*
[3]*Department of Physics and Astronomy, UCLA, 430 Portola Plaza, Box 951547, Los Angeles, CA 90095-1547, USA*
[4]*Department of Physics and Astronomy, University of British Columbia, Vancouver, BC, V6T 1Z1, Canada*
[5]*Space Telescope Science Institute, 3800 San Martin Drive, Baltimore, MD 21218, USA*
[6]*Dipartimento di Fisica e Astronomia Galileo Galilei, Universit di Padova, Vicolo dellOsservatorio 3, Padova I-35122, Italy*
[7]*Argelander Institut für Astronomie, Helmholtz Institut für Strahlen-und Kernphysik, University of Bonn, Germany*
[8]*Département de Physique, Université de Montréal, C.P. 6128, Succ. Centre-Ville, Montréal, QC H3C 3J7, Canada*
[9]*Center for Astrophysics and Space Science, University of California San Diego, La Jolla, CA 92093, USA*
[10]*Department of Astronomy and Steward Observatory, The University of Arizona, 933 N. Cherry Avenue, Tucson, AZ 85721, USA*
[11]*Lunar and Planetary Laboratory, The University of Arizona, 1640 E. University Blvd., Tucson, AZ 85721, USA*

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ABSTRACT

As part of a large *Hubble Space Telescope* investigation aiming at reaching the faintest stars in the Galactic globular cluster NGC 6752, an ACS/WFC field was the subject of deep optical observations reaching magnitudes as faint as $V \sim 30$. In this field we report the discovery of *Bedin I*, a dwarf spheroidal galaxy too faint and too close to the core of NGC 6752 for detection in earlier surveys. As it is of broad interest to complete the census of galaxies in the local Universe, in this Letter we provide the position of this new object along with preliminary assessments of its main parameters. Assuming the same reddening as for NGC 6752, we estimate a distance modulus of $(m-M)_0 = 29.70 \pm 0.13$ from the observed red giant branch, i.e., $8.7^{+0.5}_{-0.7}$ Mpc, and size of $\sim$840×340 pc, about 1/5 the size of the LMC. A comparison of the observed colour-magnitude diagram with synthetic counterparts that account for the galaxy distance modulus, reddening and photometric errors, suggests the presence of an old ($\sim$13 Gyr) and metal poor ([Fe/H]~-1.3) population. This object is most likely a relatively isolated satellite dwarf spheroidal galaxy of the nearby great spiral NGC 6744, or potentially the most distant isolated dwarf spheroidal known with a secure distance.

m_{lim}=30

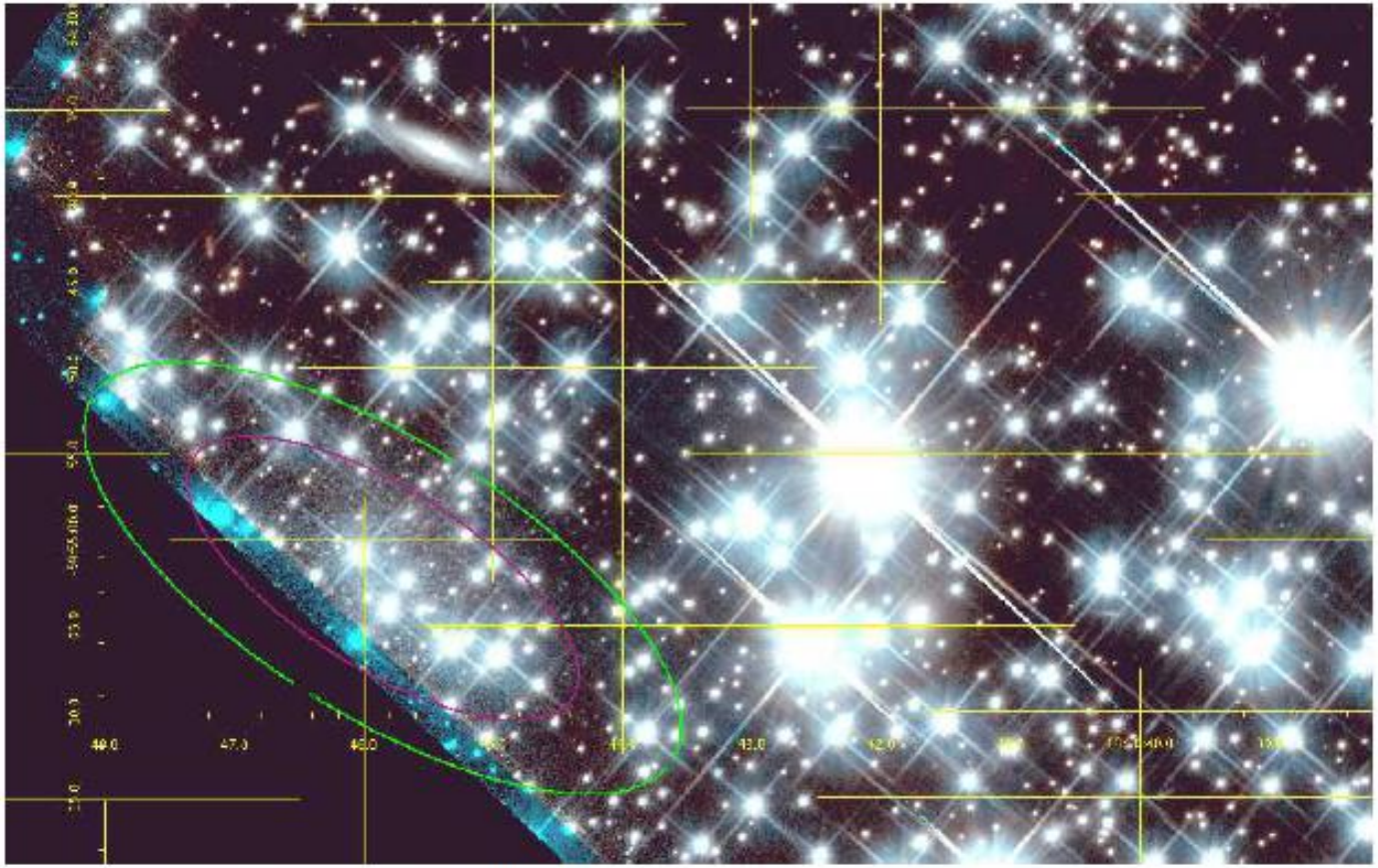

Figure 1. A 80″ × 50″ portion of the ACS/WFC field containing Bedin I. North is up, East to the left (ICRS coordinates grid in yellow). Unfortunately, Bedin I is very close to the border of the field of view (fov), where the large dithers gave us an overall incomplete (particularly in the red filter) and shallower view with respect to the centre of the fov. This portion of the field contains what is available to us of the new dwarf spheroidal, and extends West to show an adjacent region for comparison. The green ellipse marks the limit to where Bedin I seems to extend, while the one in magenta denotes the fitted half-light radius (see text).

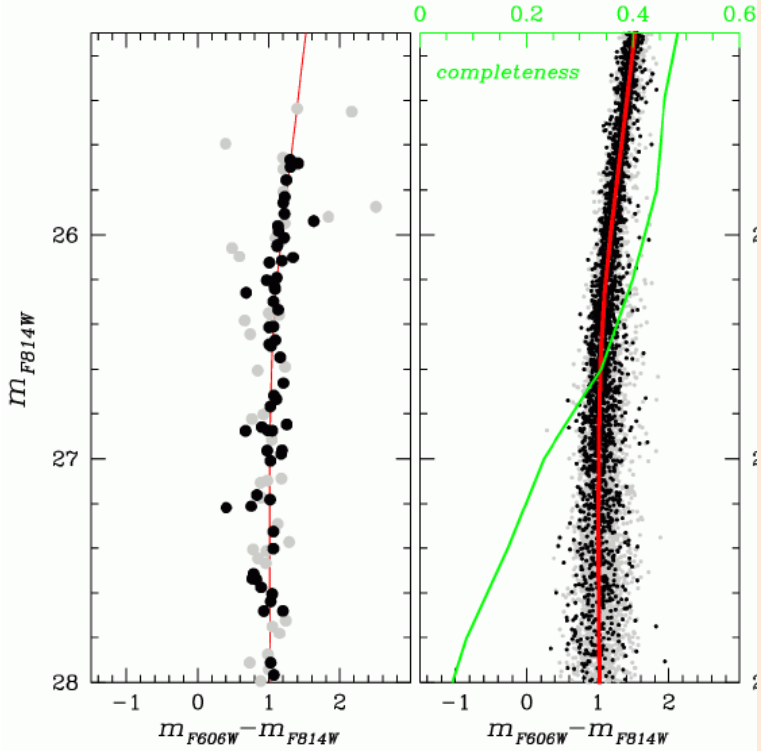

Figure 2. *(Left panel:)* CMD of all stars in the region of Bedin I (grey) and for just those ones closest to its centre (in black, see text). The fiducial line defined by-eye and used to generate artificial stars, is displayed in red. *(Right panel:)* Same CMD but for the artificial stars in the same regions (using same colour code) added along the fiducial line (in red). We also show the derived completeness function (in green), whose values can be read on the top axis.

By using the TRGB absolute magnitude calibration we obtained a distance modulus $(m-M)_0$ = 29.70±0.13, corresponding to a linear distance of about 8.7+0.5 −0.7 Mpc.

Table 1. Properties of *Bedin I* dwarf spheroidal galaxy.

$\alpha_{\rm ICRS}$	$19^{\rm d}{:}10^{\rm m}{:}45^{\rm s}.85$
$\delta_{\rm ICRS}$	$-59^\circ{:}55'{:}02''.25$
ℓ	$336\,^\circ\!.56365$
b	$-25\,^\circ\!.60333$
r_e (*effective* half-light radius)	$\sim 8.3''$ ($\sim$350 pc)
$\epsilon = \frac{a-b}{a}$	0.6
$a_{\rm max}$-axis	$\sim 20''$ ($\sim$840 pc)
$b_{\rm max}$-axis	$\sim 8''$ ($\sim$340 pc)
P.A.	58°
$E(m_{\rm F606W} - m_{\rm F814W})$	0.04
$(m-M)_0$	29.70 ± 0.13
d	$8.7^{+0.5}_{-0.7}$ Mpc
$m_{\rm F606W}$	19.94
$M_{\rm F606W}$	-9.76
$\mu_{\rm F606W}$	26.78 mag/arcsec^2

Вывод

- Это изолированная dSph (редкий случай!). Ближайшая галактика SBb– NGC 6744 (D=9 Mpc) на расстоянии ~650 kpc (в проекции).
- Крайне узкая полоса RGB говорит об отсутствии значительного самобогащения металлами (как и в случае шаровых скоплений). Система сформировалась за короткое время, и звездообразование после не возобновлялось.