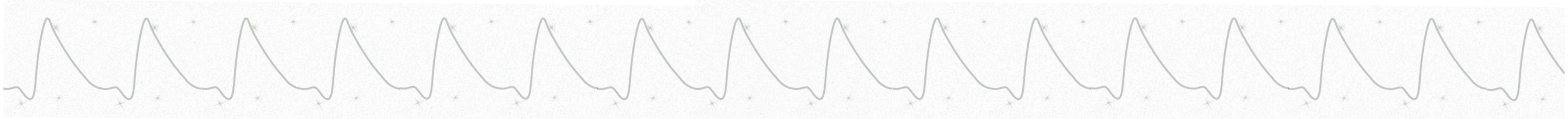


RR Lyrae stars in ultra-faint dwarf galaxies in the era of the large surveys

Clara Martínez-Vázquez

Gemini Observatory / NSF's NOIRLab

In collaboration with wonderful researchers

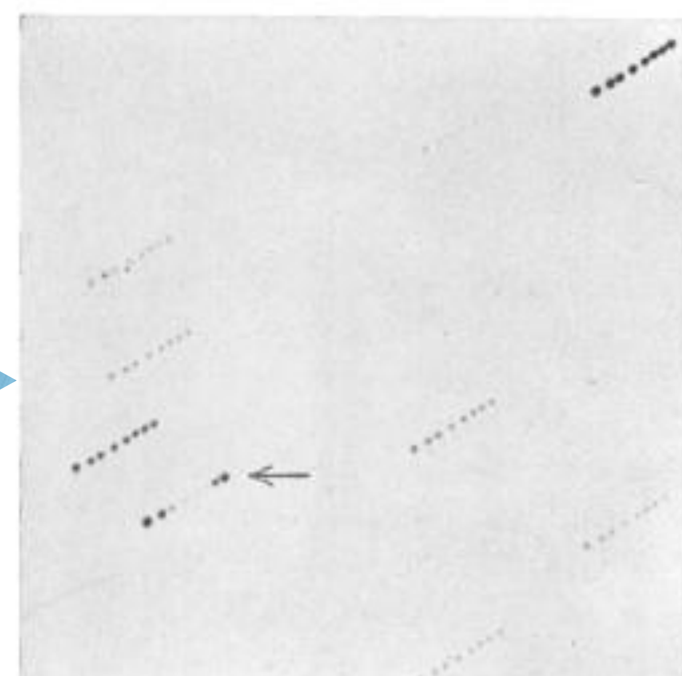
Specially contributing to this work: K. Vivas, A. Walker, A. Drlica-Wagner, K. Stringer, W. Cerny, M. Monelli, S. Cassisi

NSF | NOIRLab AURA CERRO TOLOLO INTER-AMERICAN OBSERVATORY GEMINI OBSERVATORY Exploring the Universe, Sharing its Wonders DARK ENERGY SURVEY DELVE

DECam At 10 Years – Looking Back, Looking Forward | September 12-14, 2022

RR Lyrae

- RR Lyrae was discovered by **Williamina Fleming in 1901**
  - Multiple photographic exposures of a star in a short amount of time on a photographic plate
  - A star in the constellation Lyra was found on a plate from July 13, 1899
  - Examination of this plate by revealed a short-period, high amplitude star



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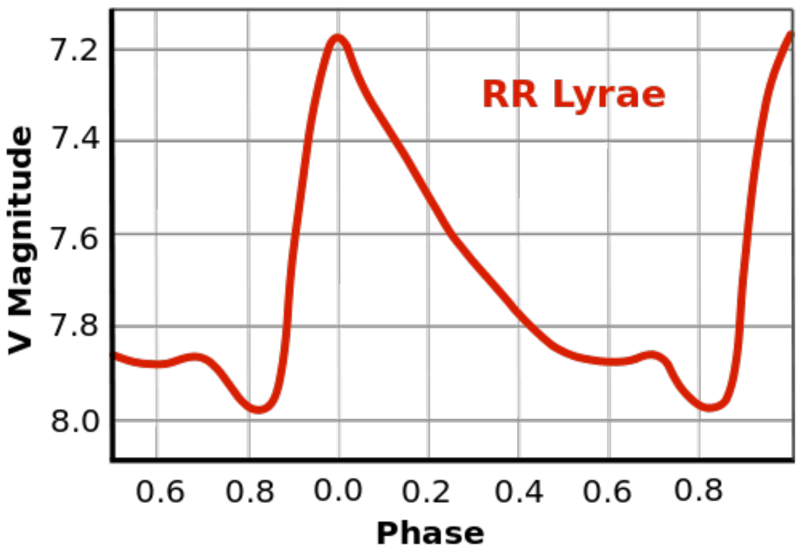
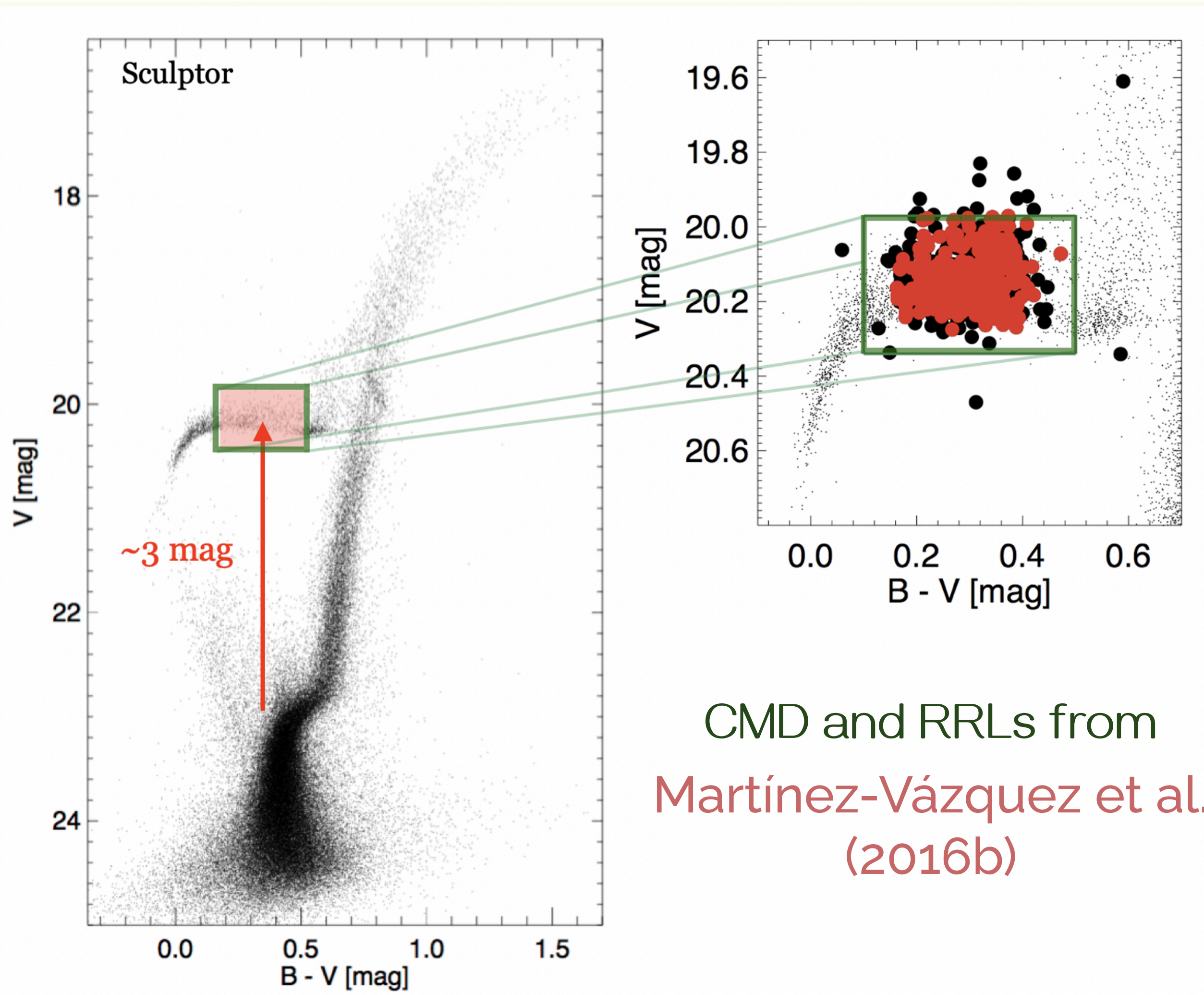
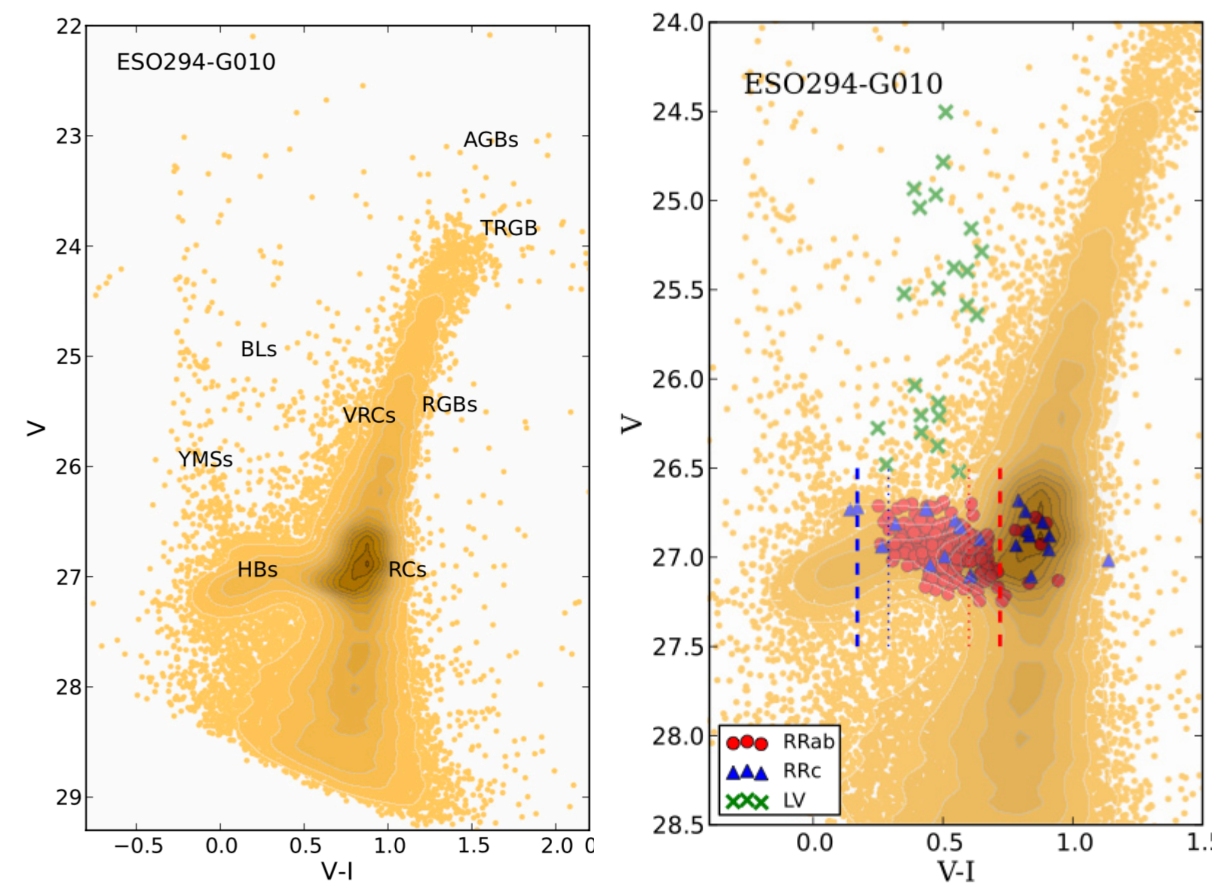


RR Lyrae stars

- RR Lyrae (RRL) stars are pulsating variable stars located in the horizontal branch: $M_V \sim 0.6$ mag
- RRL are detected up to 2 Mpc with HST, i.e., beyond the Local Group



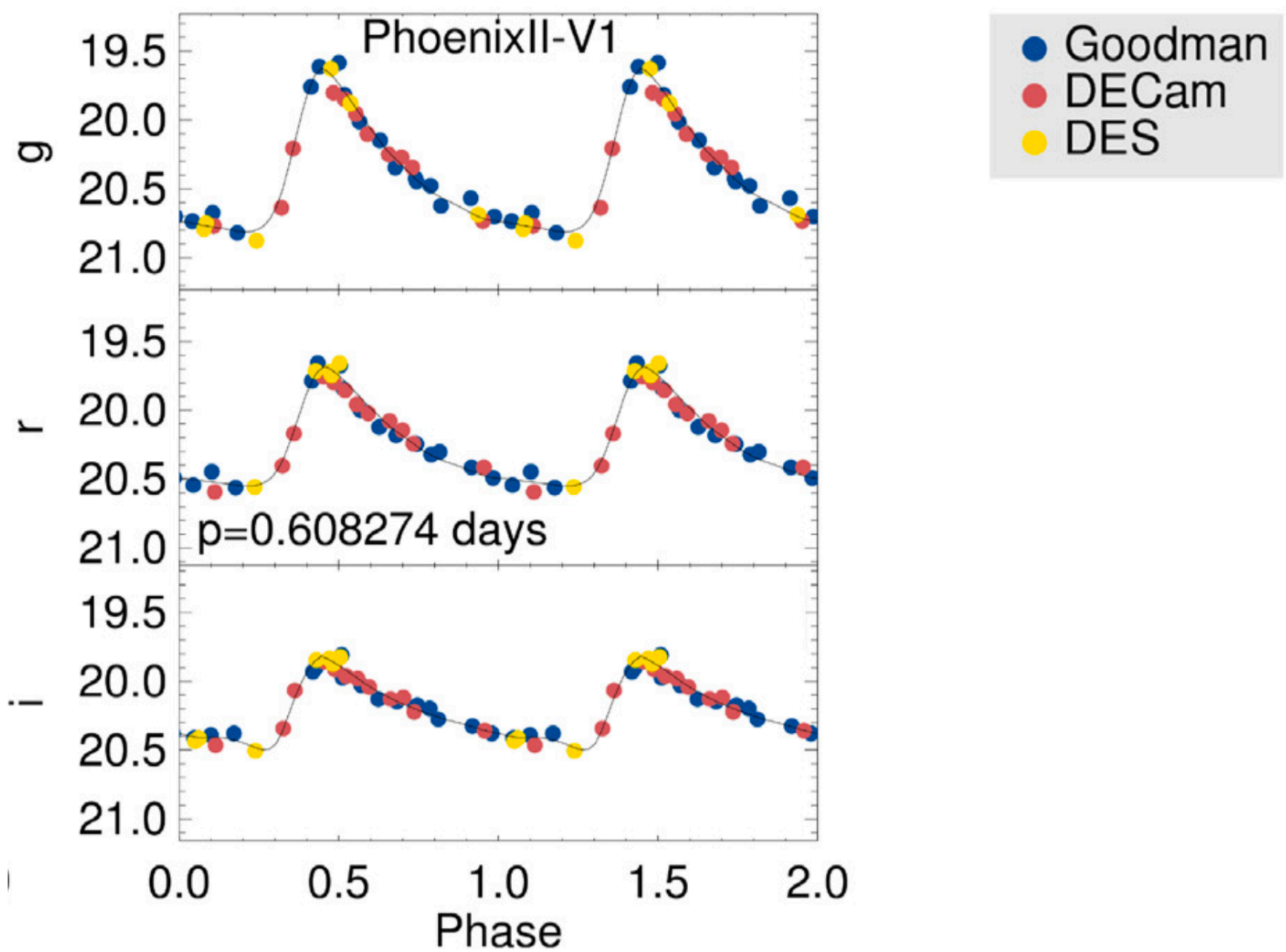
CMD and RRLs from Martínez-Vázquez et al. (2016b)



Yang et al. (2014)

RR Lyrae stars

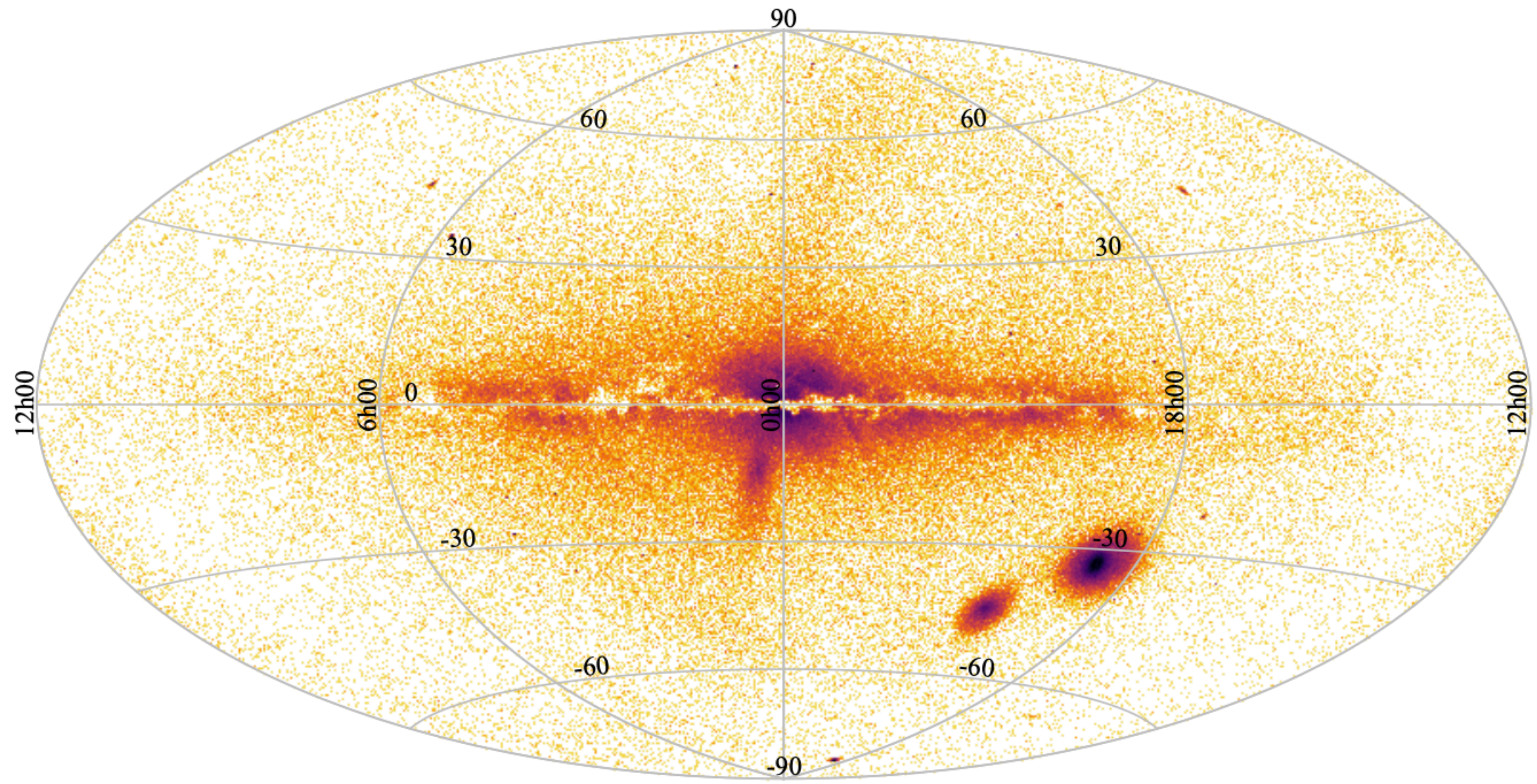
- RR Lyrae (RRL) stars are pulsating variable stars located in the horizontal branch: $M_V \sim 0.6$ mag
- Distinguished by their periods and the shapes of their light curves



Martínez-Vázquez et al. (2019)

Popularity of the RR Lyrae stars

* Enormous detection of RRLs in surveys like ASAS, Catalina, DES, Gaia, OGLE, PanSTARRS, ZTF (and the future Vera Rubin LSST survey)

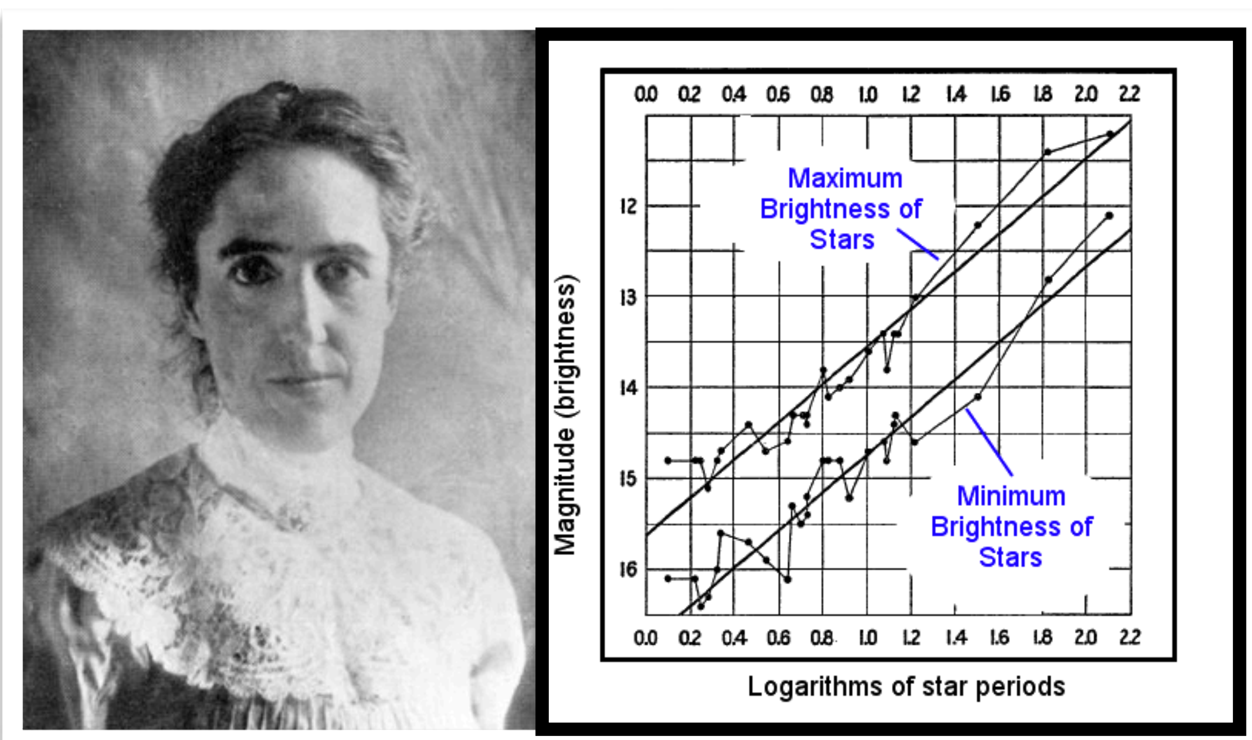


Clementini et al. (2022) — Gaia DR3

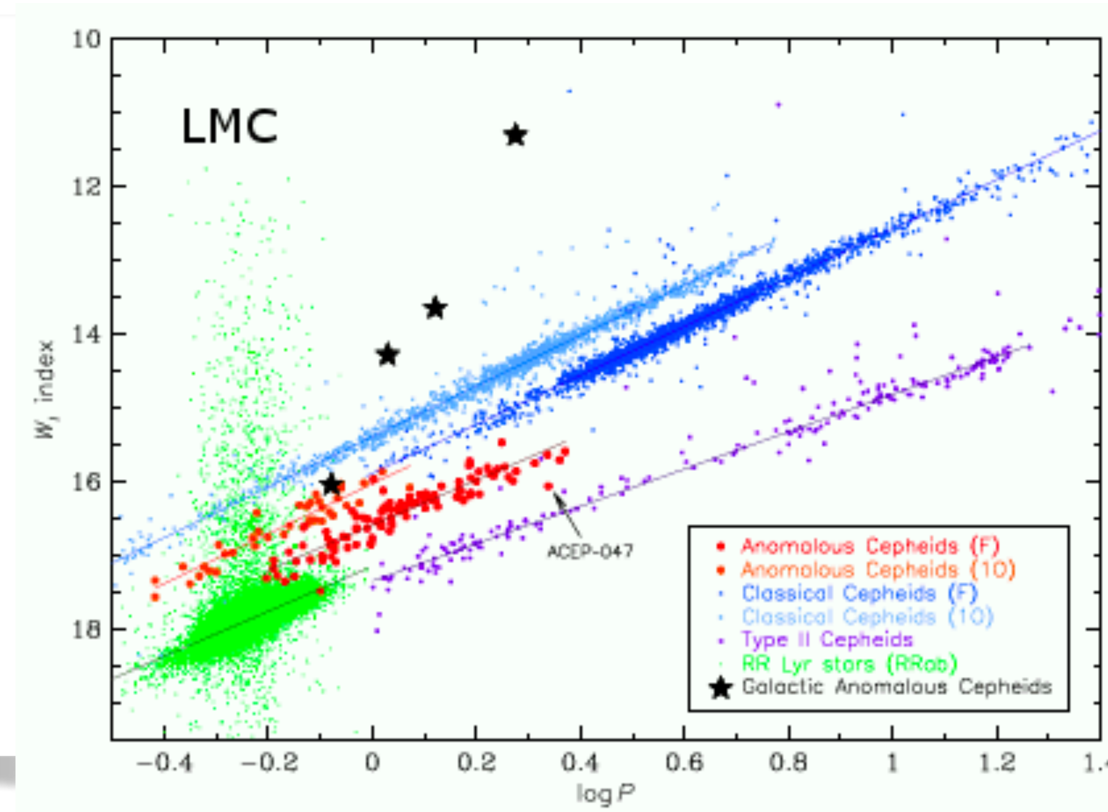
(270 905 RRL stars)

RR Lyrae stars are distance indicators

- RRLs obey a well-known period-luminosity relations:
  - ☑ Standard candles ➜ accurate distances



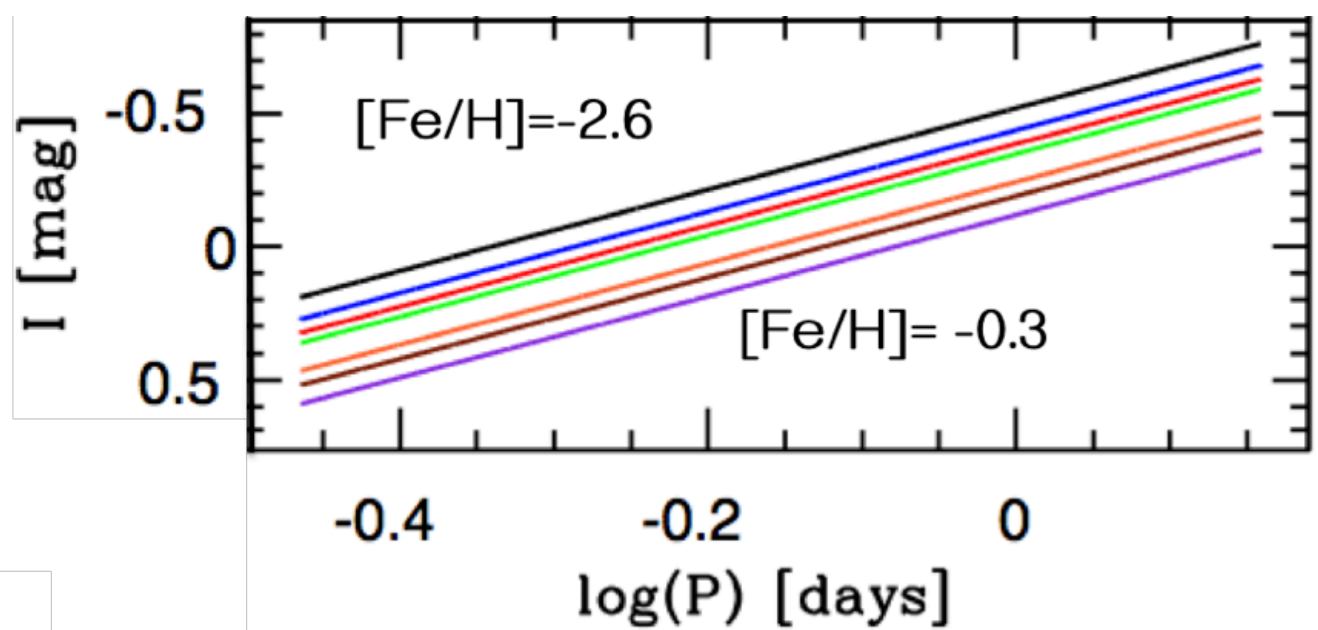
“the brighter variables have the longer periods”
Henrietta Leavitt (1908)
Leavitt Law



Soszynski et al. (2015)

RR Lyrae stars are metallicity tracers

- RRLs obey a well-known period-luminosity-**metallicity** relations:
  - ☑ Metallicity tracers (t > 10 Gyr) ➜ early chemical enrichment



Marconi et al. (2015)

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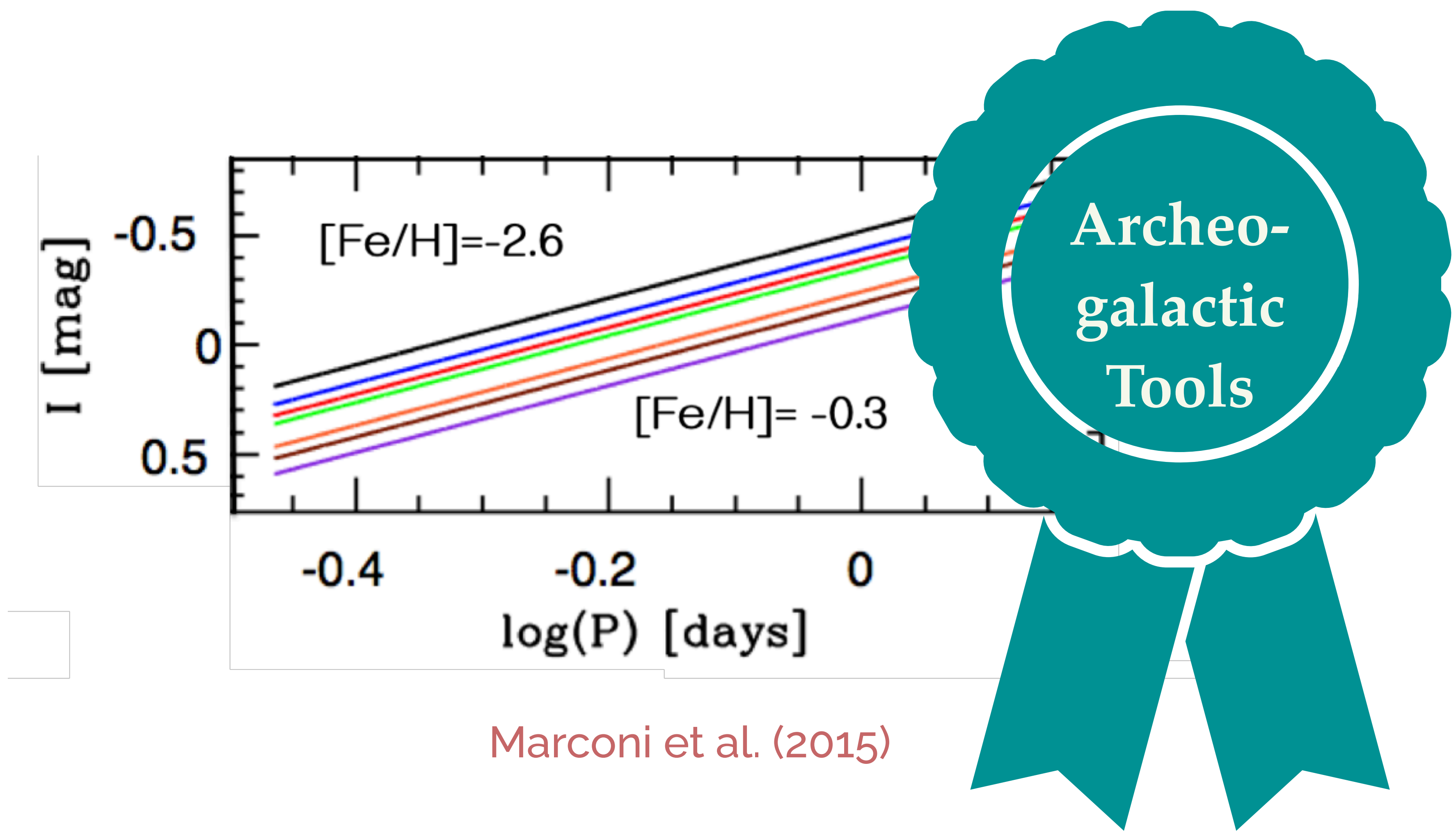
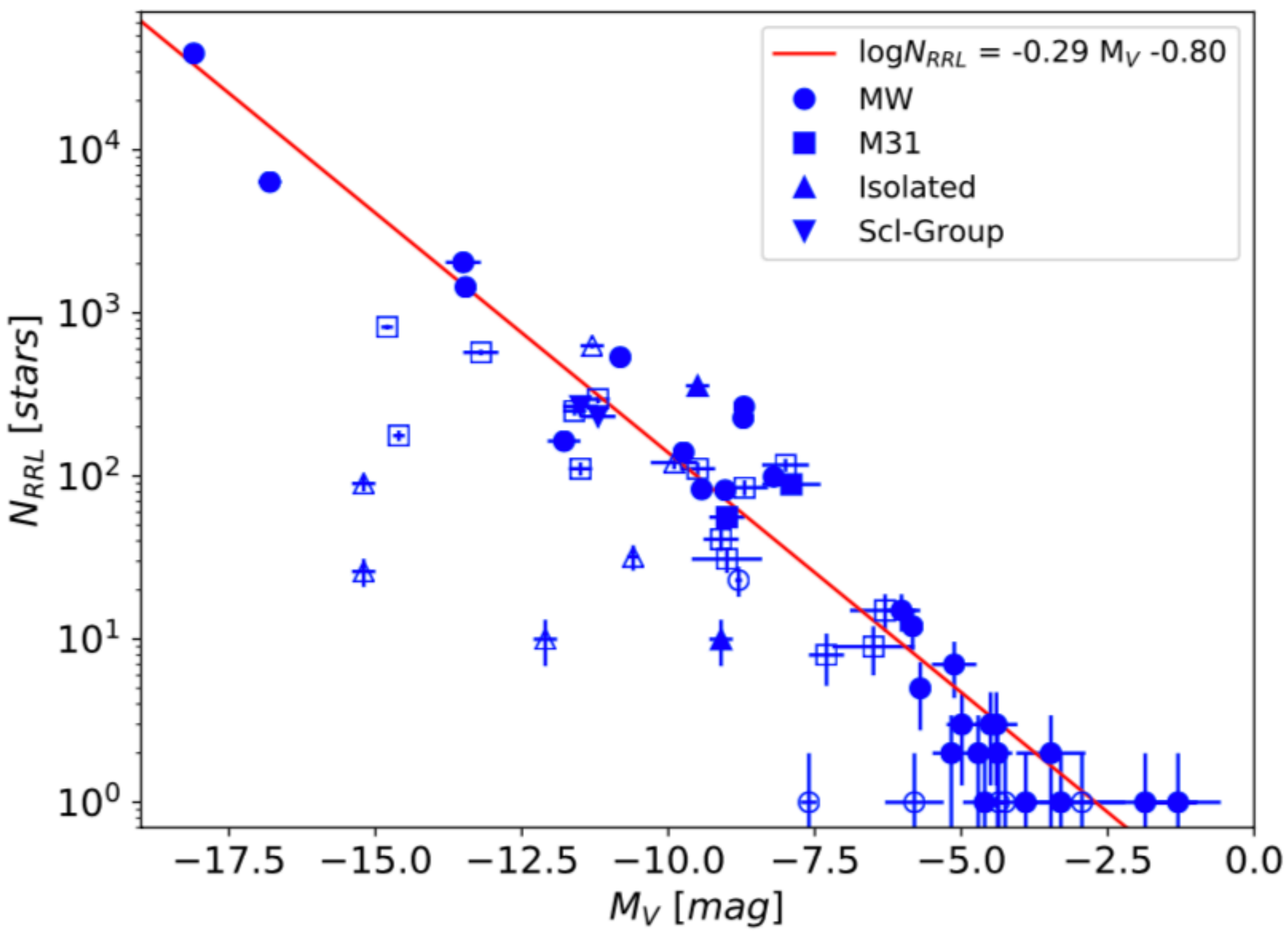


Marconi et al. (2015)

RR Lyrae stars | why are they so interesting?

- Old stellar population tracers (t >10 Gyr; Walker et al. 1989, Savino et al. 2020)
  - ☑ Tracing the first ~ 3 Gyr of a galaxy's life
  - ☑ Ubiquitous in all galaxies (few exceptions)

Martínez-Vázquez et al. (2019)



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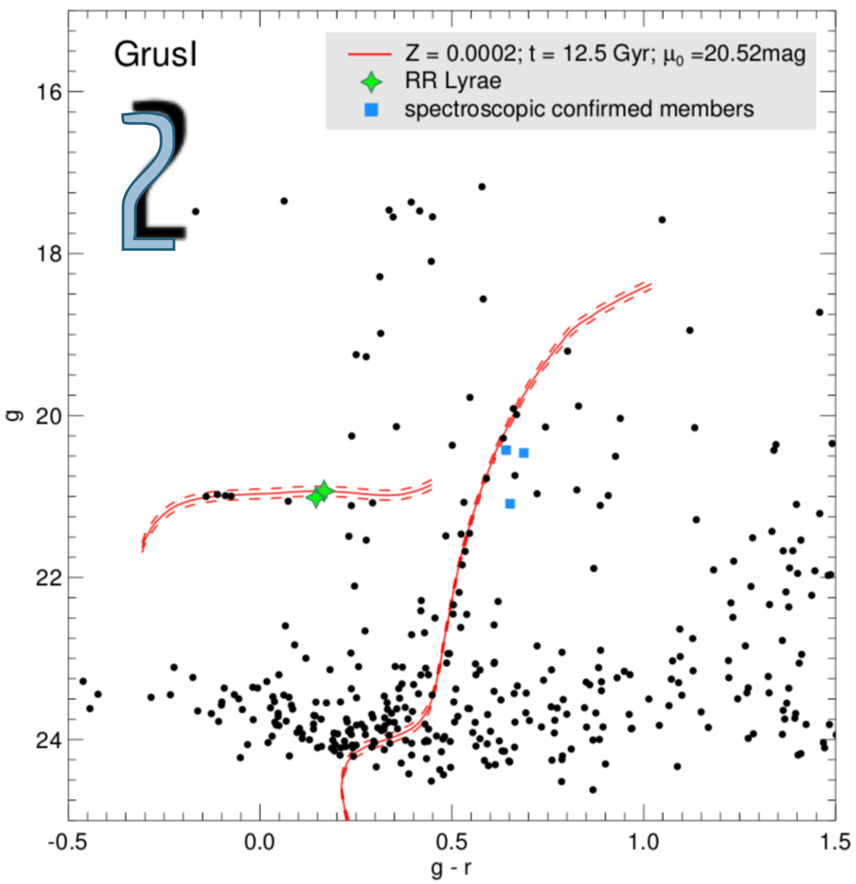
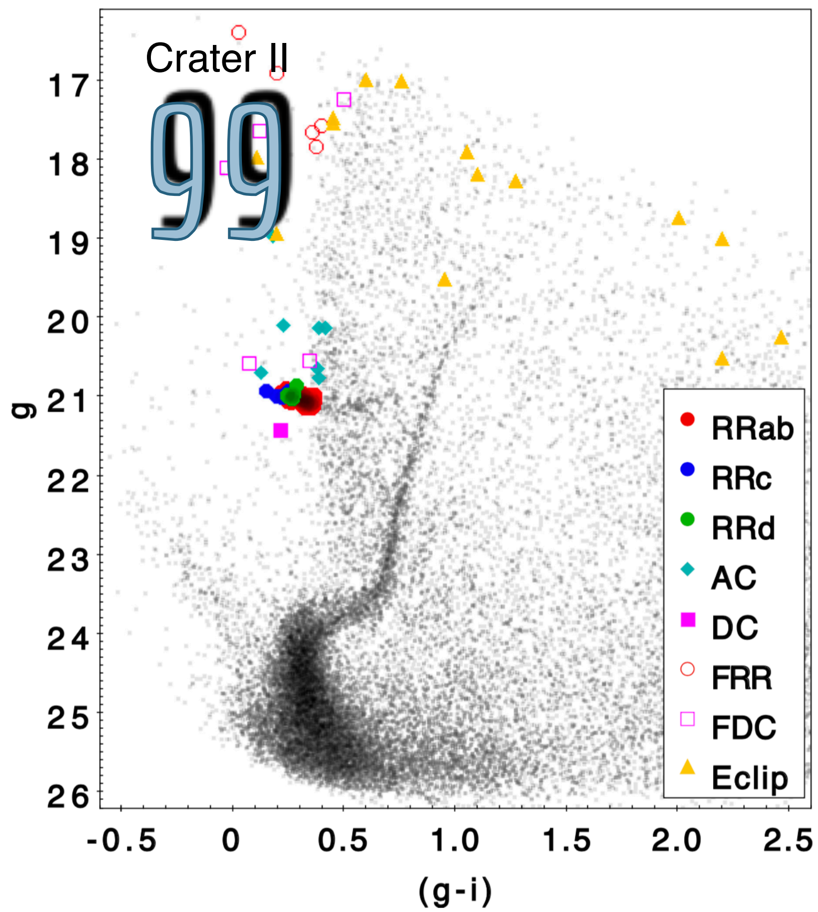
See Kathy Vivas' talk

Ultra faint



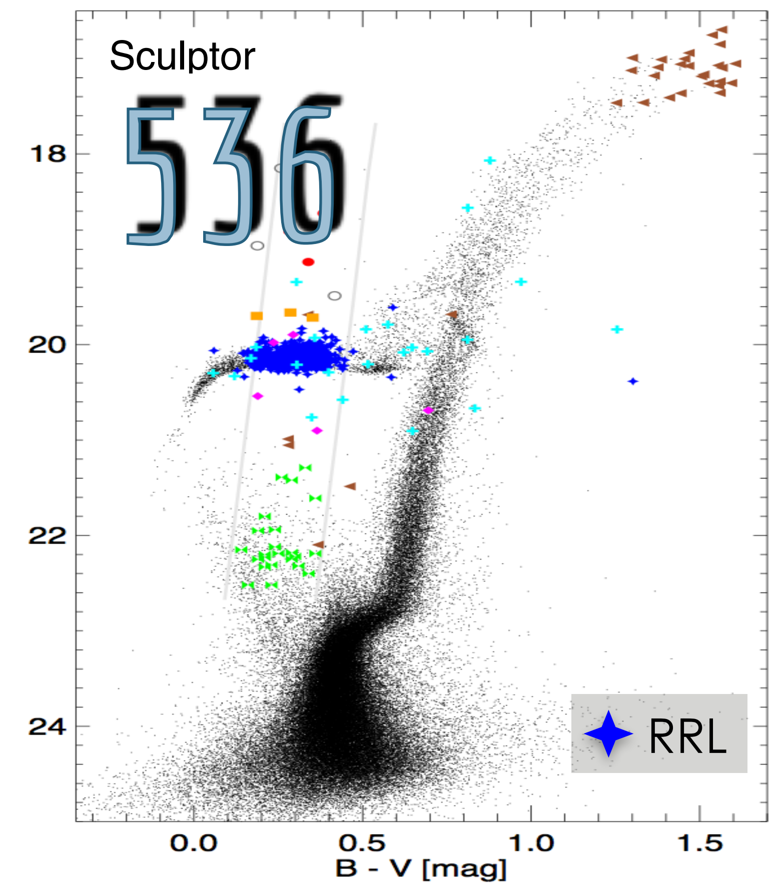
Martínez-Vázquez et al. (2019)

Ultra diffuse



Vivas et al. (2020a)

Classical

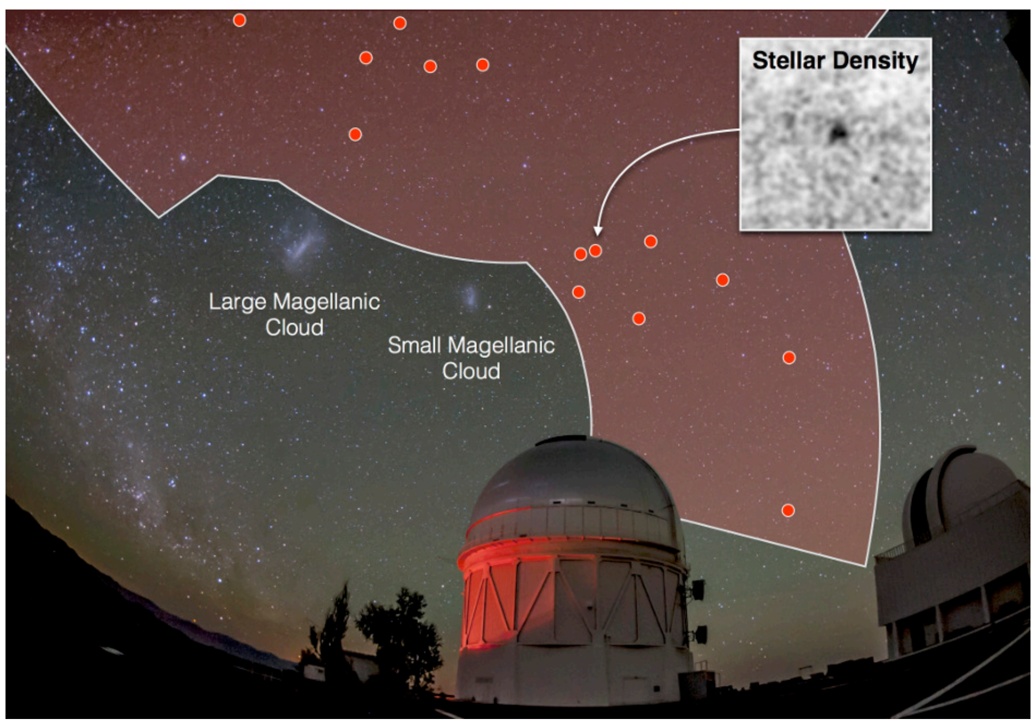


Martínez-Vázquez et al. (2016b)

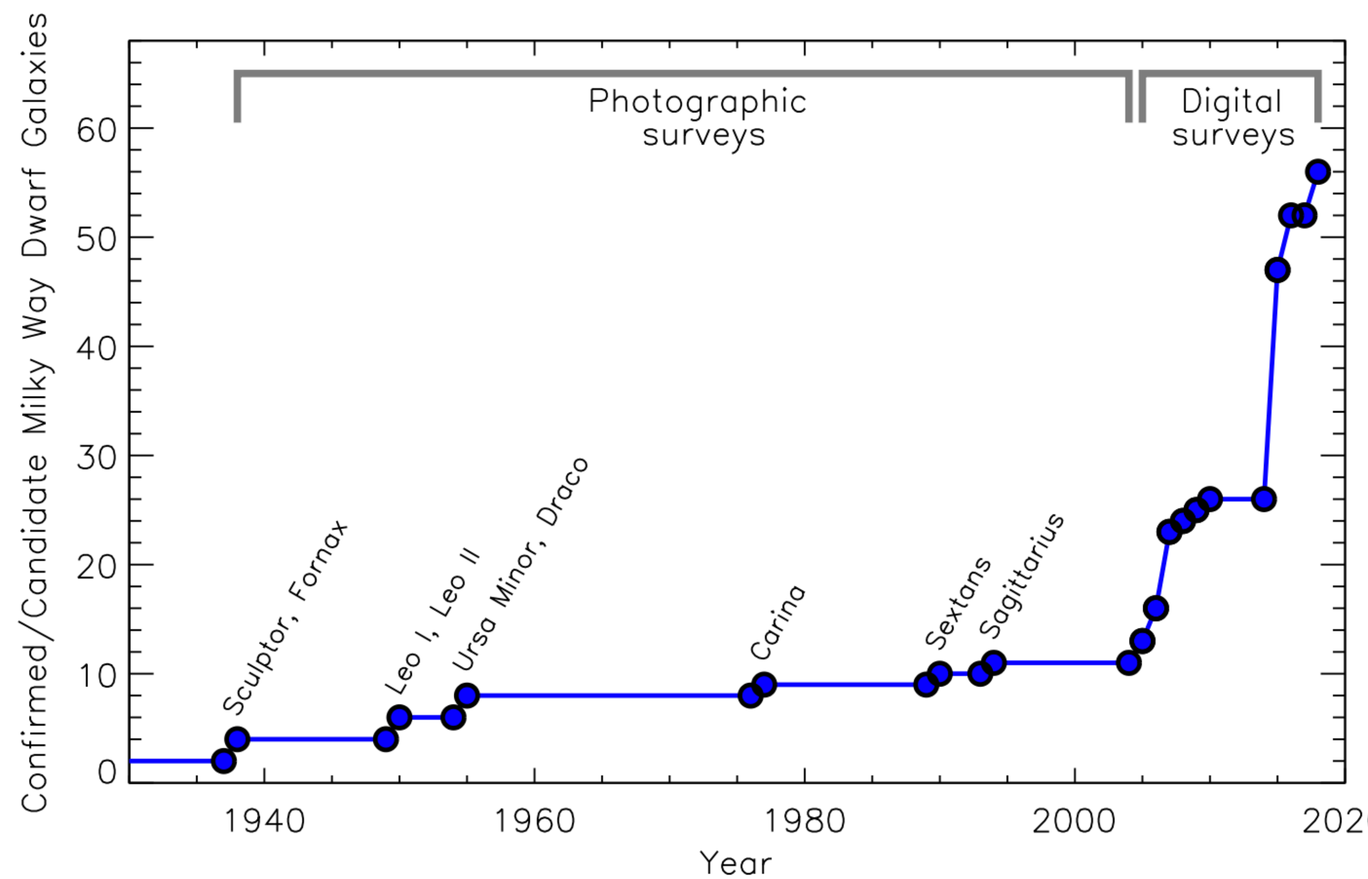
Ultra-faint dwarf (UFD) galaxies

* Numerous ultra-faint dwarf galaxy satellites of the Milky Way have been discovered by DES and DELVE

Discoveries with DECam: ~30 UFDs



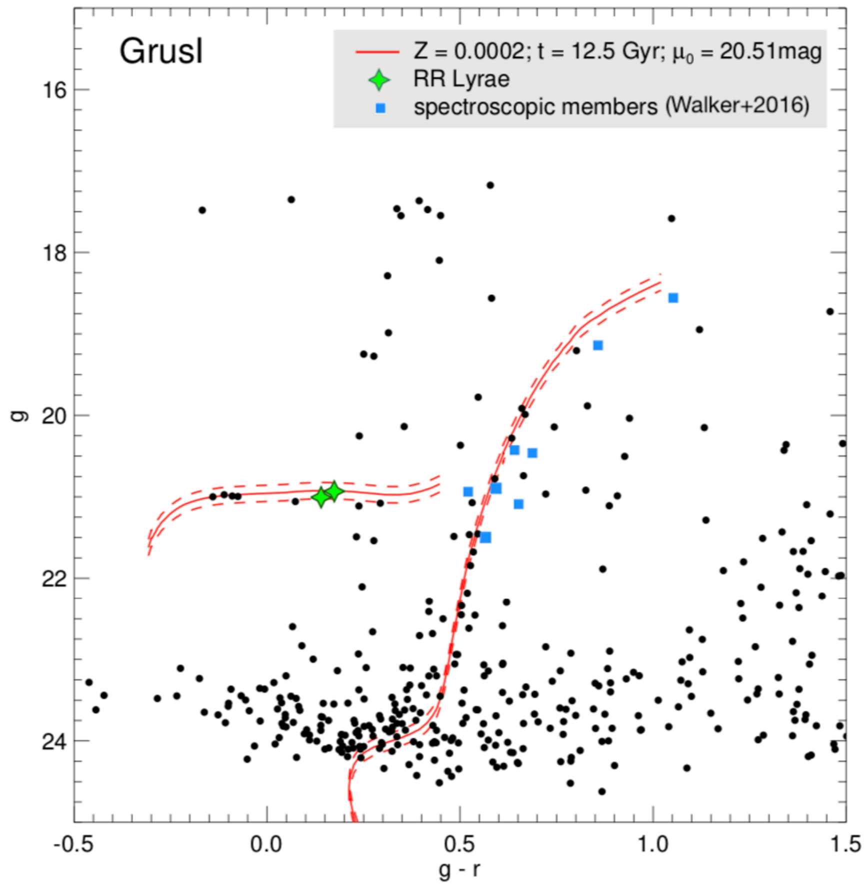
Simon (2019)

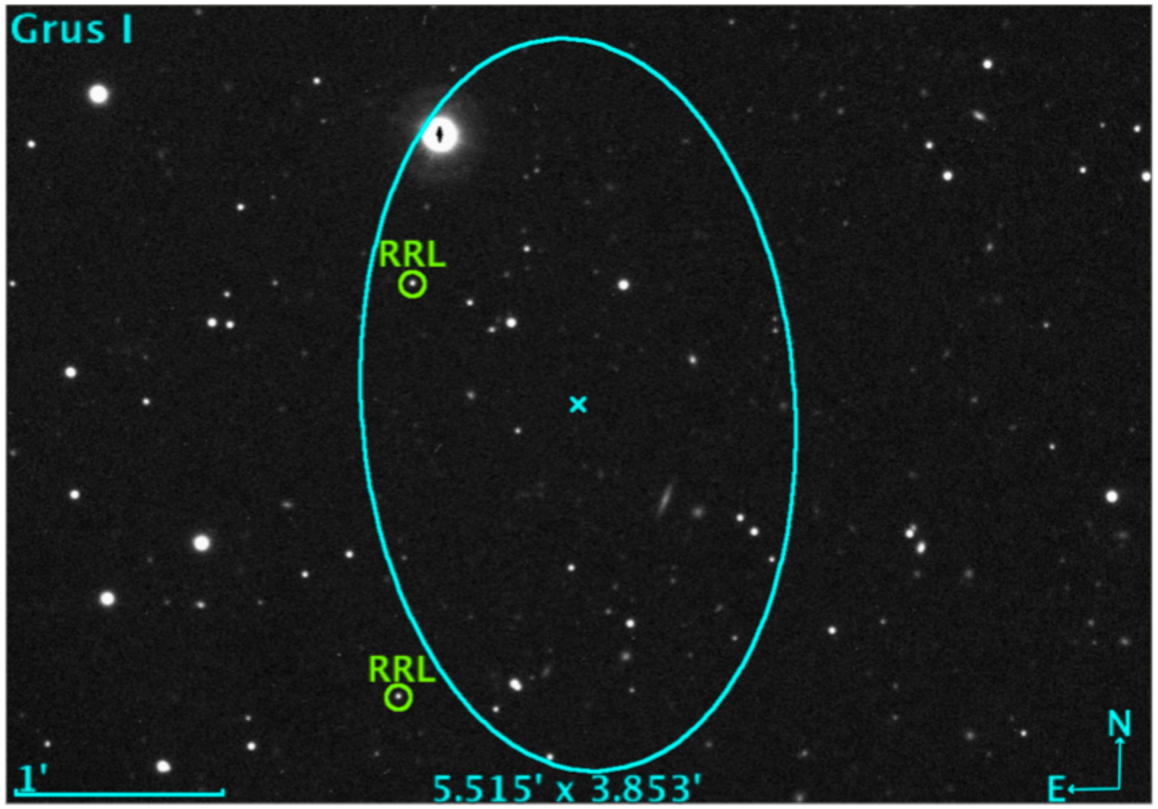


Burçin Mutlu-Pakdil & Alex Drlica-Wagner's talks

RR Lyrae stars in UFD galaxies

* On-going project to process time-series for UFDs to obtain accurate and precise distances in the smallest UFDs using RRL stars





In UFD galaxies, the large contamination by field stars makes the calculation of the distance and/or morphological parameters a very challenging task

Martínez-Vázquez et al. (2019)

RR Lyrae stars in UFD galaxies

derived using the RRL stars

Galaxy	N_{RRL}	Distance modulus	Reference
Grus I	2	20.51 ± 0.10	Martínez-Vázquez et al. (2019)
Phoenix II	1	20.01 ± 0.10	
Grus II	1	18.71 ± 0.10	
Cen I	3	20.35 ± 0.03	Martínez-Vázquez et al. (2021c)
Eridanus II	67	22.84 ± 0.05	Martínez-Vázquez et al. (2021b)
Peg IV	3	17.33 ± 0.10	Cerny et al. (2022)
Eri IV	2?	—	Cerny et al. (2021b)

Only a few RR Lyrae stars

Changes from previous measurements

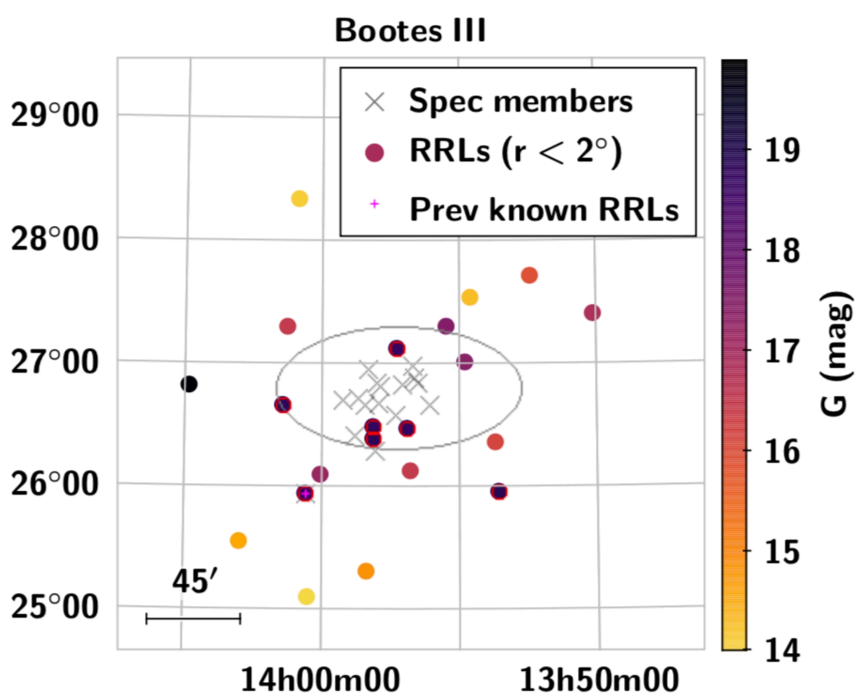
$r_h = 65$ pc	> 5 %
$r_h = 44$ pc	> 33 %
$r_h = 96$ pc	> 3 %

Constraint better their physical sizes

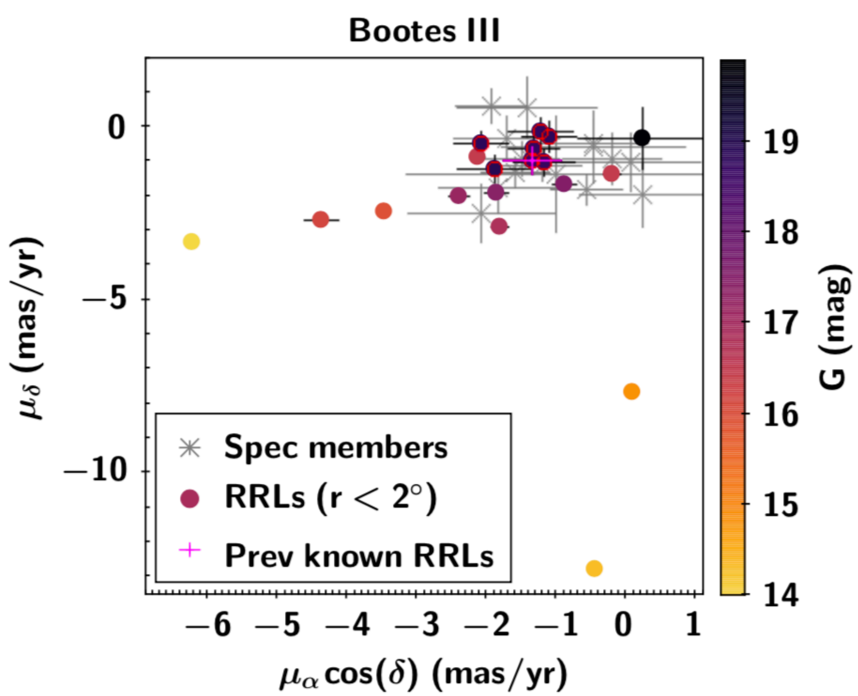
RR Lyrae stars in UFD galaxies

- Using Gaia DR2 RRL catalog, we search for RRLs in 27 UFD galaxies within < 100 kpc, since more distant galaxies would have RRLs beyond the Gaia DR2 limits (G ~ 21 mag)

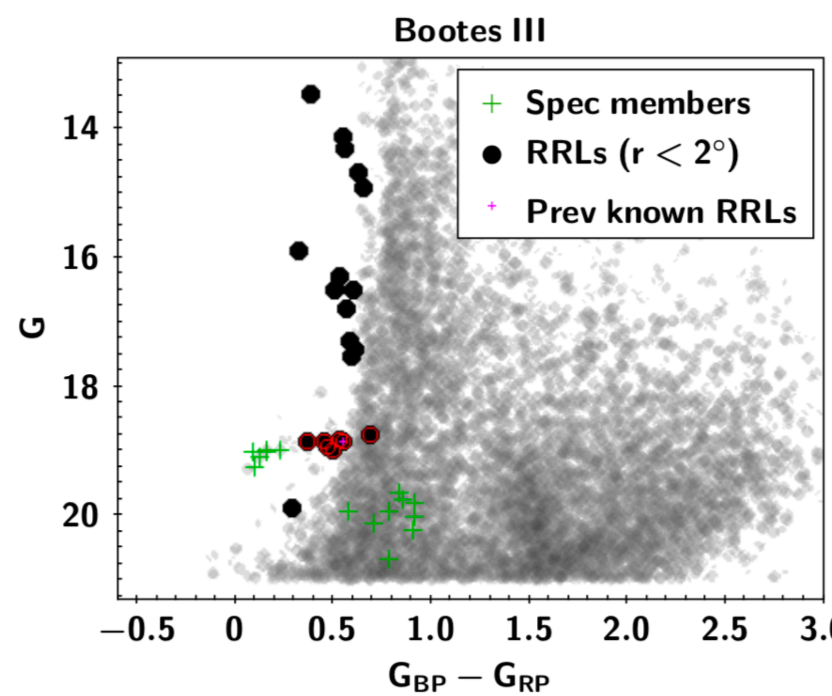
Sky location



Proper Motion



CMD



Vivas, Martínez-Vázquez & Walker (2020)

RR Lyrae stars in UFD galaxies

- Using Gaia DR2 RRL catalog, we search for RRLs in 27 UFD galaxies within < 100 kpc (more distant galaxies would have RRLs beyond the Gaia DR2 limits, G ~ 21 mag)

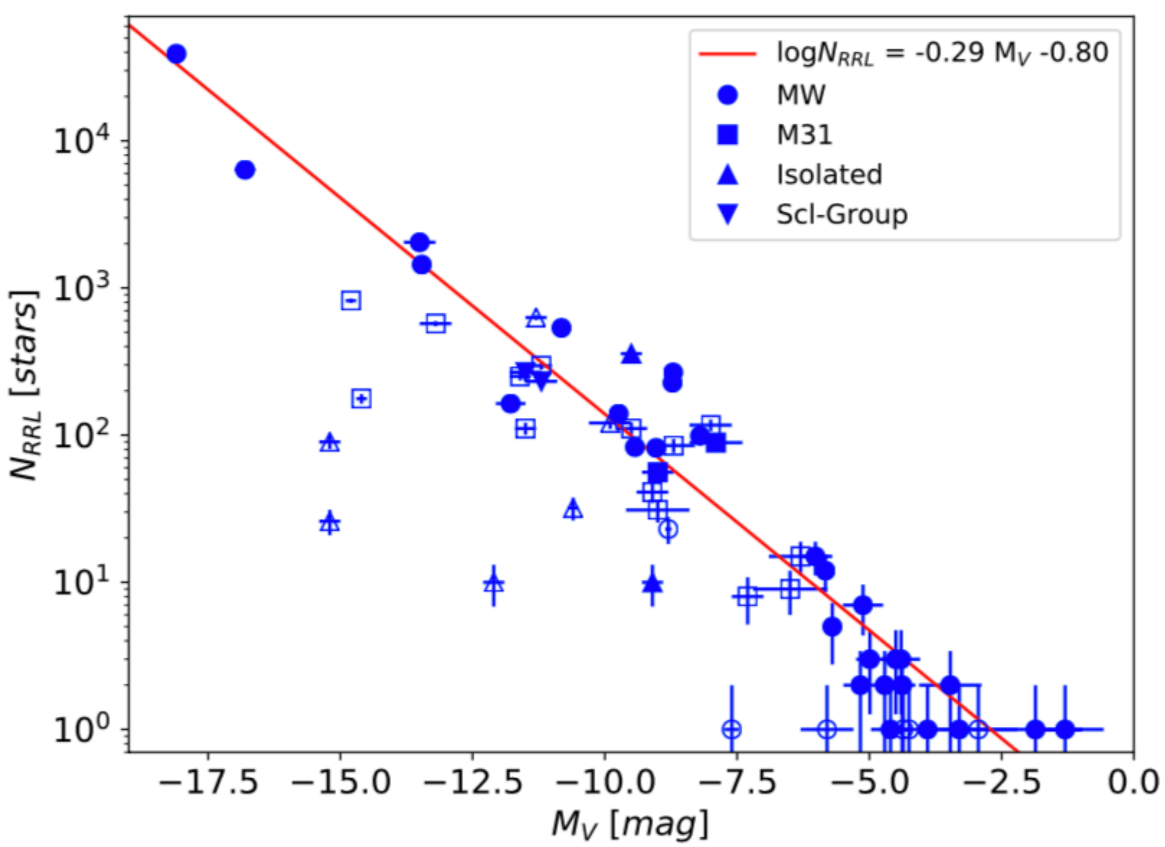
- 47 Gaia RRLs associated to 14 UFDs.
    - First RRL detection in Tuc II
    - Additional RRL members: UMa II, Com Ber, Hyd I, Boo I, Boo III
    - Extra-tidal RRLs: Boo I, Boo III, Sgr II, Tuc III, Eri III, Ret III (radial velocities are needed to confirm these stars)

Vivas, Martínez-Vázquez & Walker (2020)

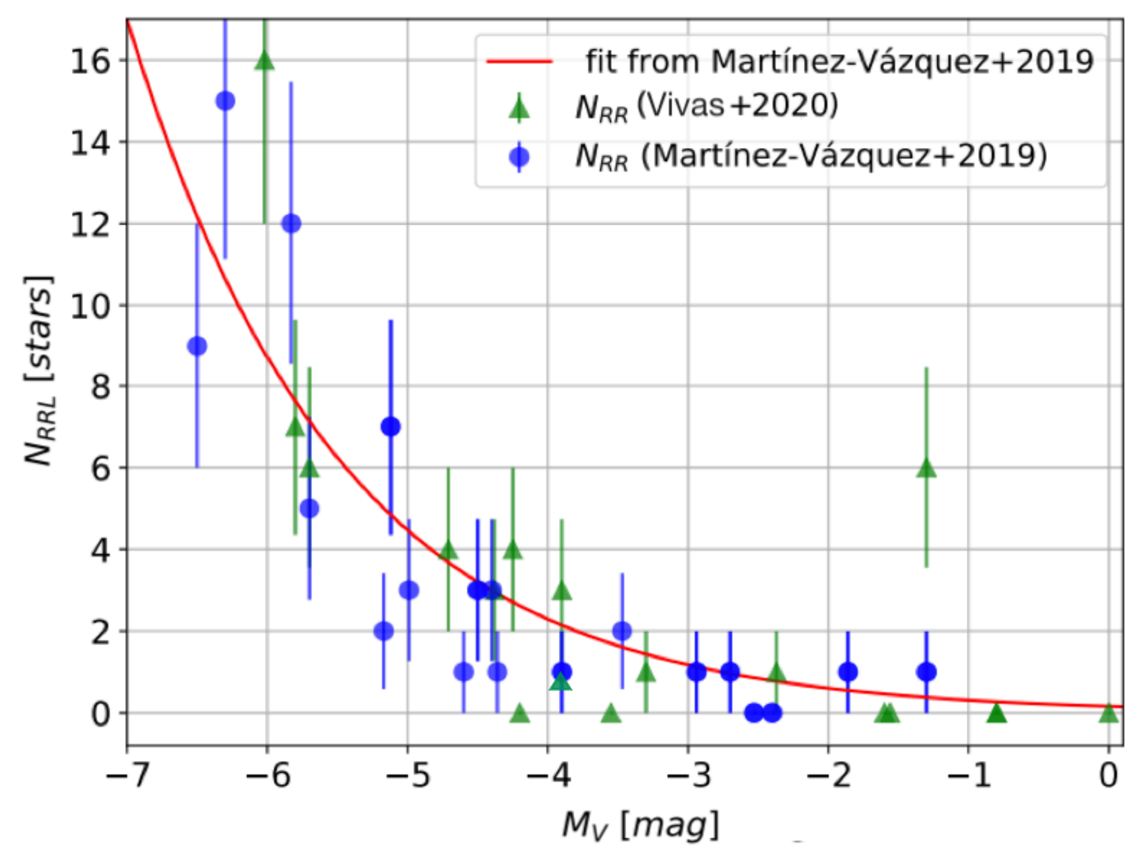
Number of RR Lyrae stars in dwarf galaxies

- Classical satellites show correlation between the number of RRLs and the M_V of the host: **$\log N_{RRL} = -0.29\,MV - 0.80$** (Martínez-Vázquez et al. 2019)

- The method of finding new UFDs by using two or more clumped RRLs may work only for systems brighter than $M_V \sim -5$ mag



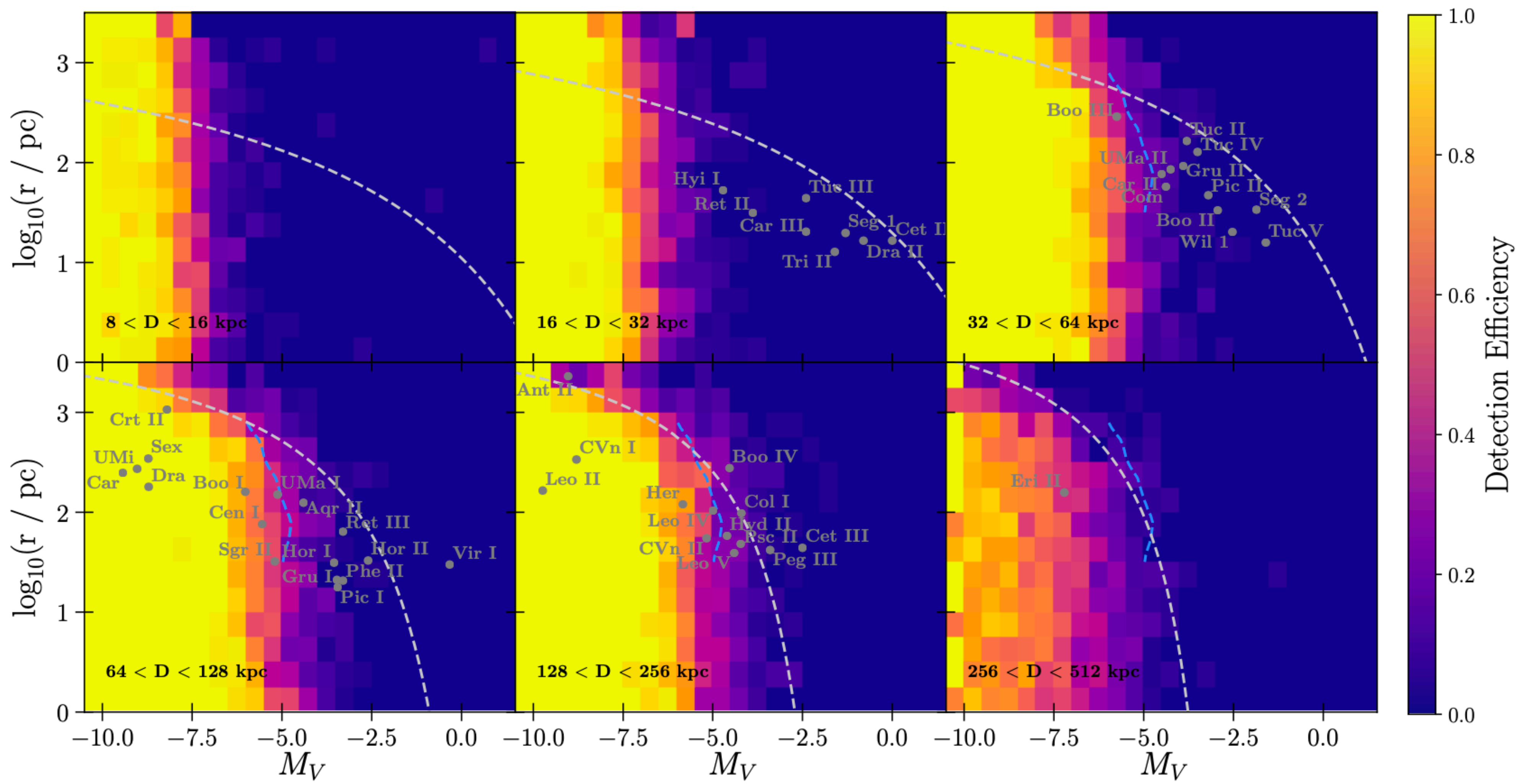
Martínez-Vázquez et al. (2019)



Vivas, Martínez-Vázquez & Walker (2020)

Number of RR Lyrae stars in dwarf galaxies

- Stringer et al. (2021) found that an RRL-based search is more sensitive than those using resolved stellar populations in the regime of **large** (r > 500 pc), **low-surface-brightness** dwarf galaxies

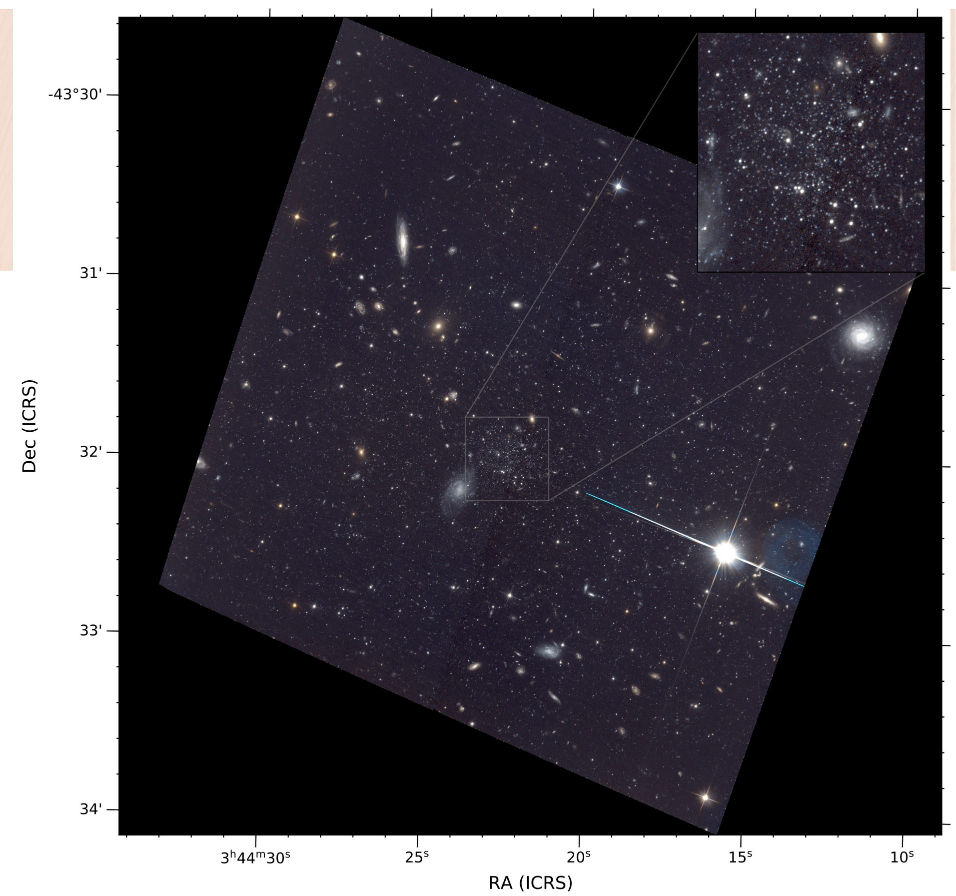


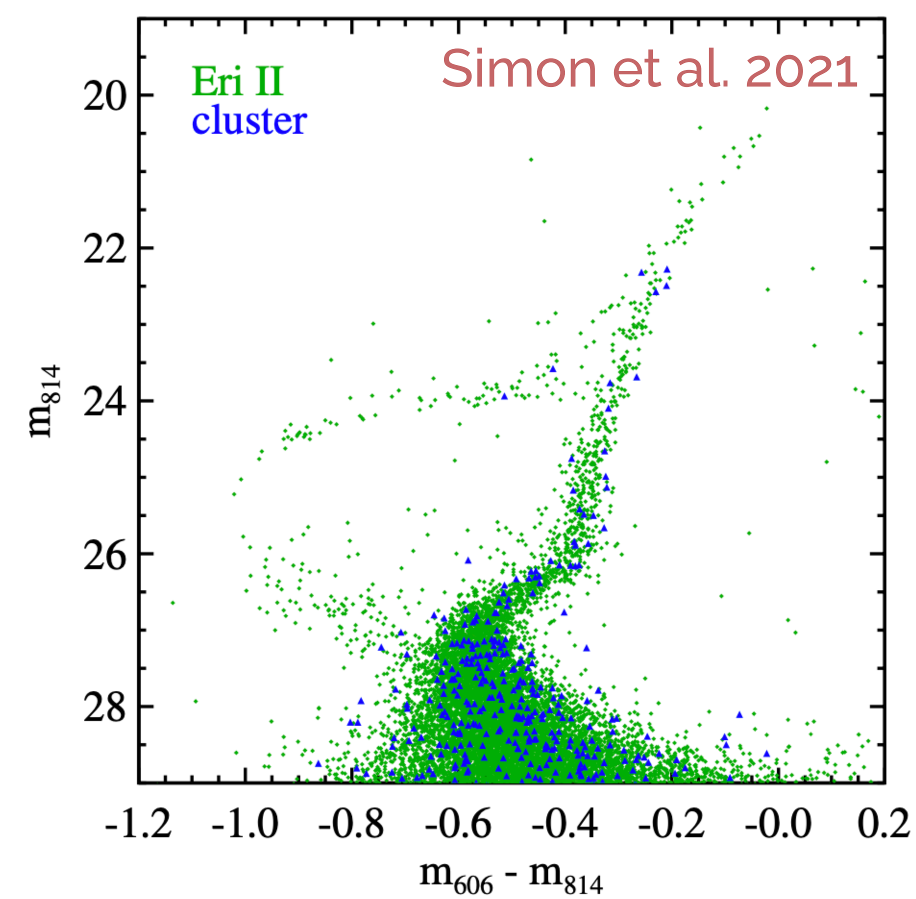
Stringer et al. (2021)

Eridanus II

Burçin Mutlu-Pakdil's talk

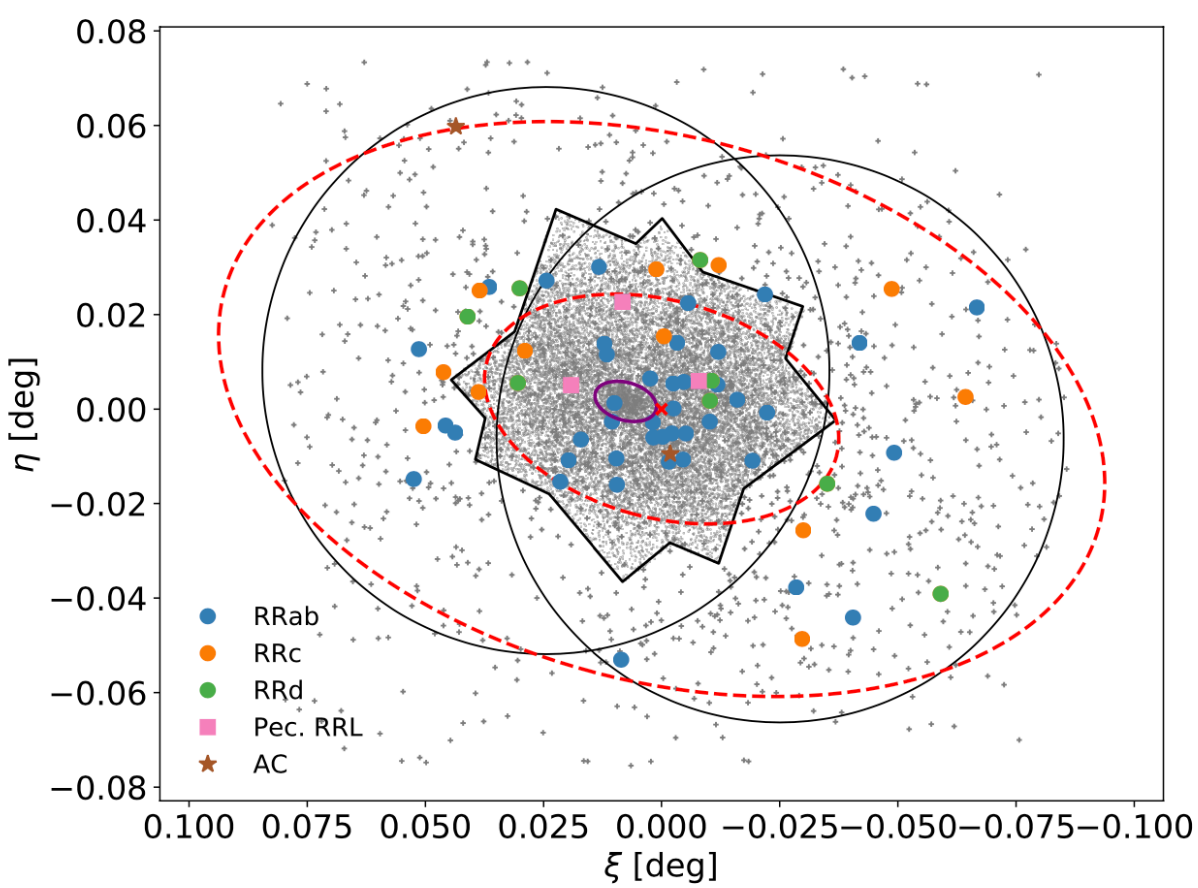
- Ultra faint dwarf galaxy discovered in DES (Bechtol et al. 2015, Koposov et al. 2015)
- Most distant known possible MW satellite
- Faintest galaxy (M_V = −7.1) known to host a cluster (Crnojevic et al. 2016, Simon et al. 2021)
- Approaching the MW (Li et al. 2017)
- Possibly bound (Fritz et al. 2018)
- Metal-poor system with a [Fe/H] ~ −2.4 and a non-negligible metallicity dispersion σ[Fe/H] = 0.47 (Li et al. 2017)
- Contrary to other distant satellites (Leo I, Leo II, and Leo T) does not shows evidence of an intermediate-age population (Simon et al. 2021, Gallart et al. 2021).
- Formed the vast majority of its stars early (before z ~6), with a possible residual population not younger than 9 Gyr.

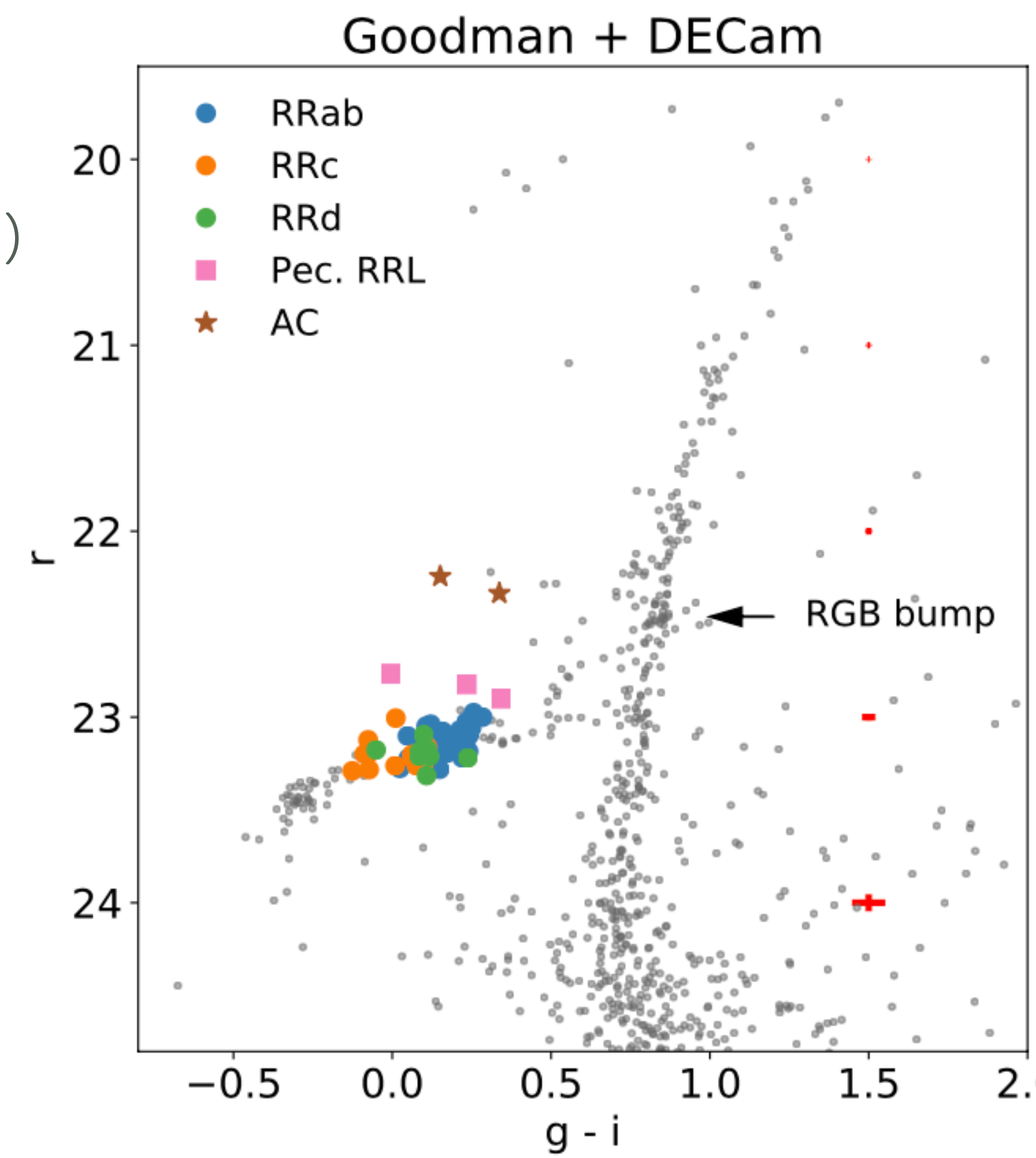




RR Lyrae stars in Eridanus II

- Multi epoch Goodman + DECam g, r, i
- Derived structural parameters in agreement with previous studies (Crnojevic et al. 2016, Simon et al. 2021)
- Detected 67 RRL stars (Martínez-Vázquez et al. 2021b)
  - μ_0 = 22.84 ± 0.07 mag ($D_\odot$ = 370 ± 12 kpc)

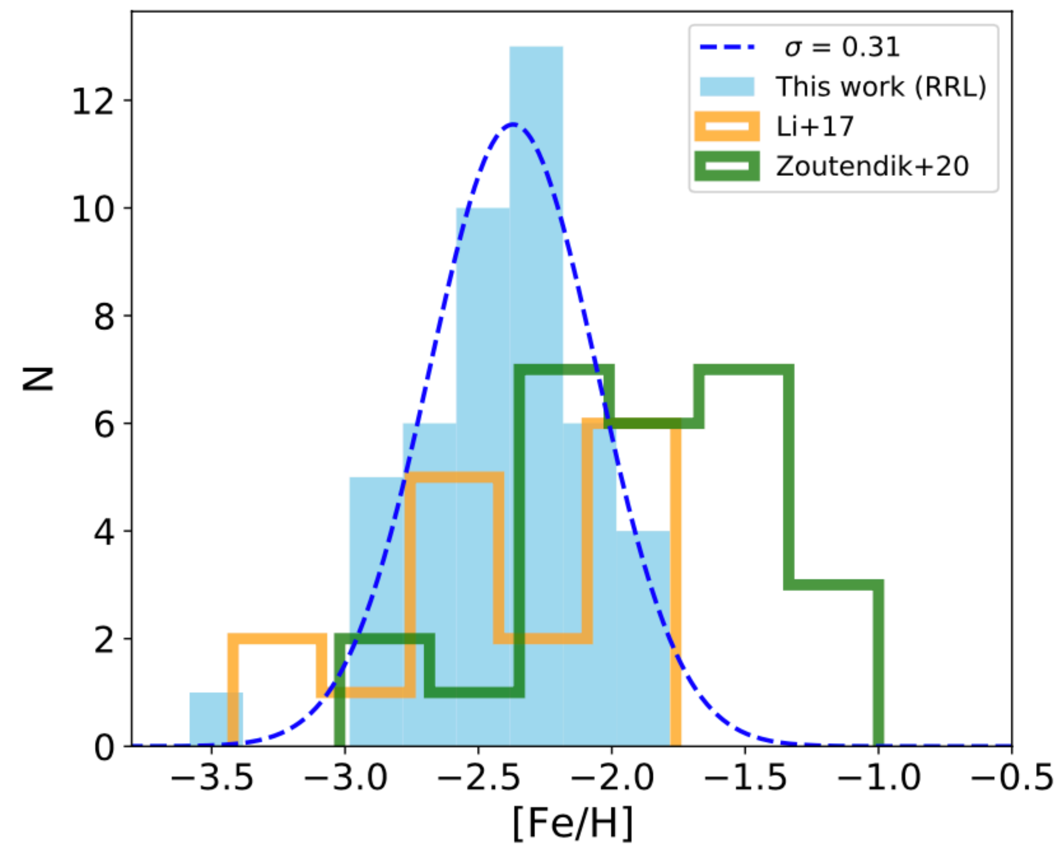




Martínez-Vázquez et al. (2021b)

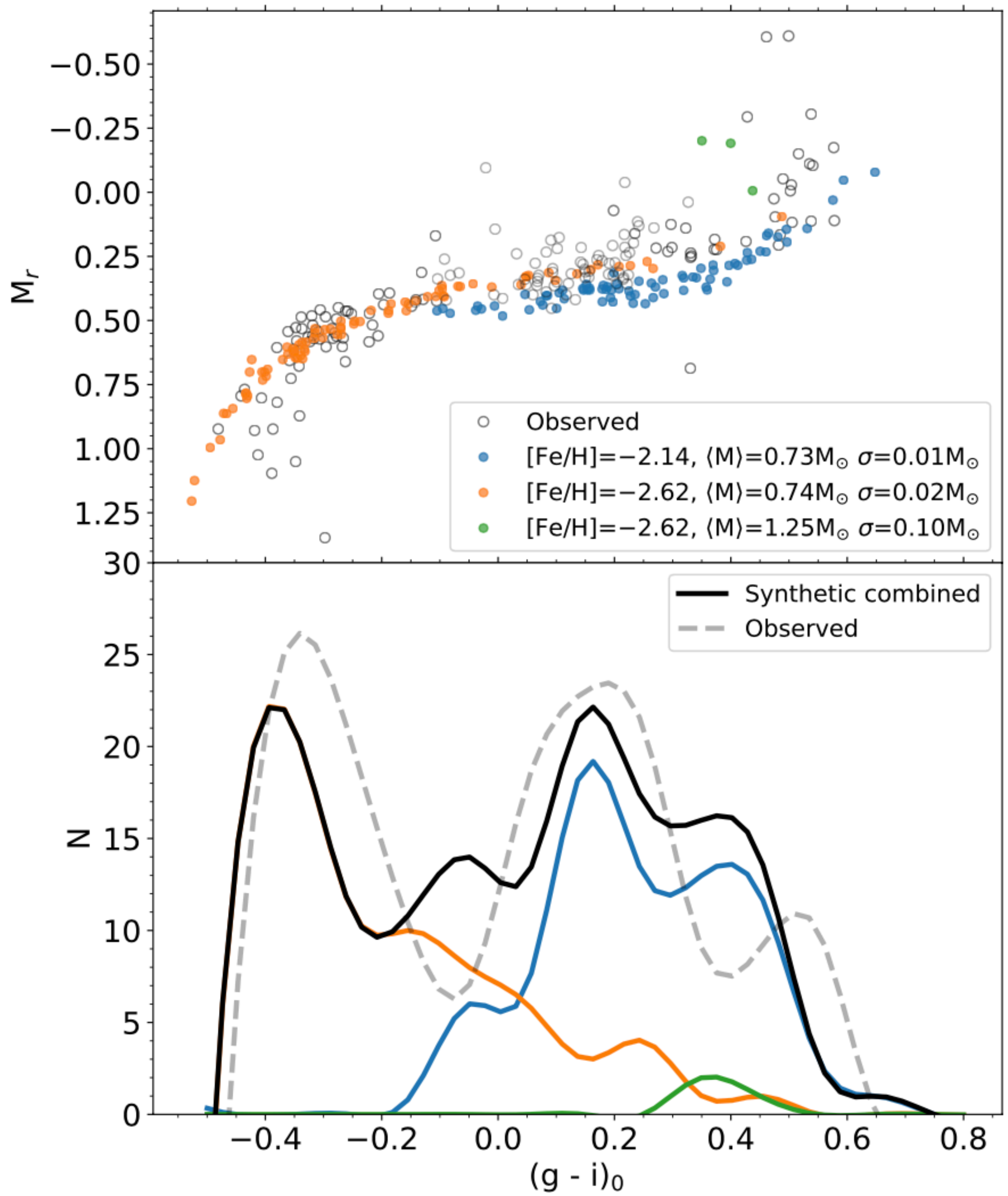
Metallicity distribution in Eridanus II

- The metallicity distribution obtained with the RRL describes the old and metal-poor population of Eri II
- The dispersion of the metallicity distribution derived from the RRL stars of Eri II is slightly smaller than spectroscopy
- This could be partly explained considering that the RGB samples could include slightly younger stars for which there is no counterpart in the RRL group
- Also, the most metal-poor and most metal-rich tails of the distribution are probably not producing RRL stars because these stars do not fall into the instability strip



Martínez-Vázquez et al. (2021b)

HB simulations in Eridanus II

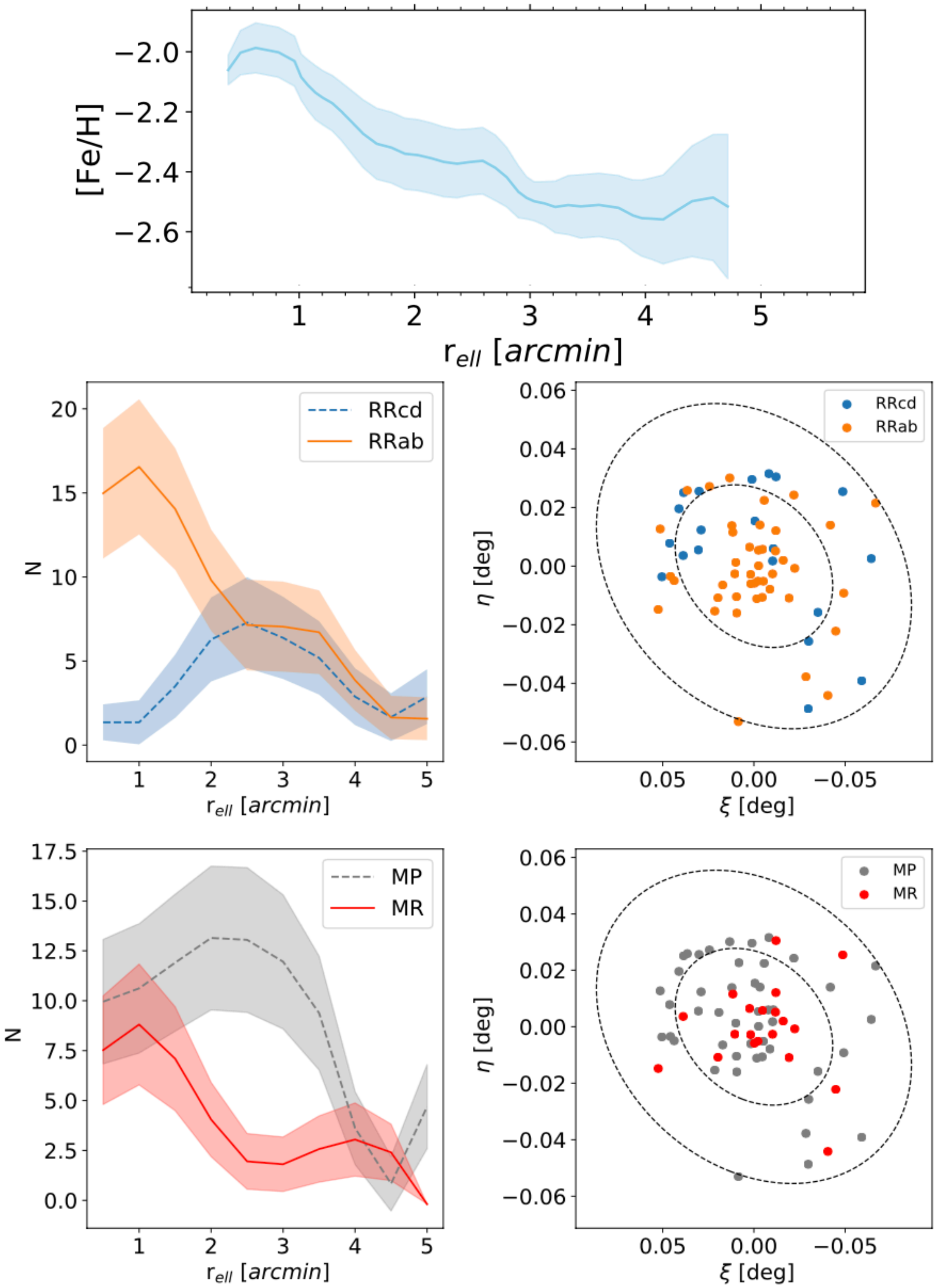


- Synthetic HB models computed by adopting the HB tracks from α-enhanced BaSTI stellar models (Pietrinferni et al. 2004, 2006)

- [Fe/H]= −2.62 + Fe/H]= −2.14 based on the metallicity distribution obtained

Martínez-Vázquez et al. (2021b)

Metallicity Gradients in Eridanus II



- Highest values in the innermost 1' (-2.0 dex) and then steadily decreases by ~ 0.6 dex at a distance of 4' (430 pc)
- The inner region (0.5' to 3') is characterized by a gradient of **−0.199 ± 0.014 dex/arcmin** while outermost region (3' to 4.7') has a milder negative gradient of −0.007 ± 0.016 dex/arcmin
- There is a clear distinction between the distribution of RRab (centrally concentrated) and the distribution of RRc+RRd (located in the outer parts of Eri II)
- The MR ([Fe/H] > −2.4) are clearly more centrally concentrated than the MP RRL stars ([Fe/H] < −2.4), that are spread over the entire body of Eri II

Martínez-Vázquez et al. (2021b)

Summary & Conclusions

- ✓ RRL stars are the most numerous variable stars found in dwarf galaxies.
- ✓ RRL stars are the best, unambiguous tracers of old (> 10 Gyr) stellar populations in dwarf galaxies.
- ✓ They are one of the best standards candles so they can provide accurate and precise distances to their host. This is very important for UFDs where the large contamination by field stars makes the calculation of the distance using isochrone fitting a very challenging task.
- ✓ The metallicity dispersion obtained from the RRL stars in Eri II it is a further confirmation that this low mass galaxy was substantially enriched in its very short star formation burst, similar to what also occurred in much more massive galaxies.
- ✓ The study of the metallicity gradients and the spatial distribution of RRL stars yields interesting findings;
    - Metal-poor RRL stars are spread around Eri II while the metal-rich stars are centrally concentrated. This behavior is similar to what is seen in galaxies like Sculptor (Martínez-Vázquez et al. 2016a) and it is in agreement with outside-in galaxy formation scenarios.
    - Eri II is a very interesting galaxy in terms of its fast and early chemical enrichment. It is surprising how such a low-mass galaxy can harbor a strong metallicity gradient (-0.199 ± 0.014 dex/arcmin between 0.5' and 3') at its early epochs, comparable with galaxies like Sculptor (which is ~ 50 times more massive).

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