The formation and evolution of Local group dwarf galaxies told by their RR Lyrae stars

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AURA

NSF | NOIR Lab

In collaboration with

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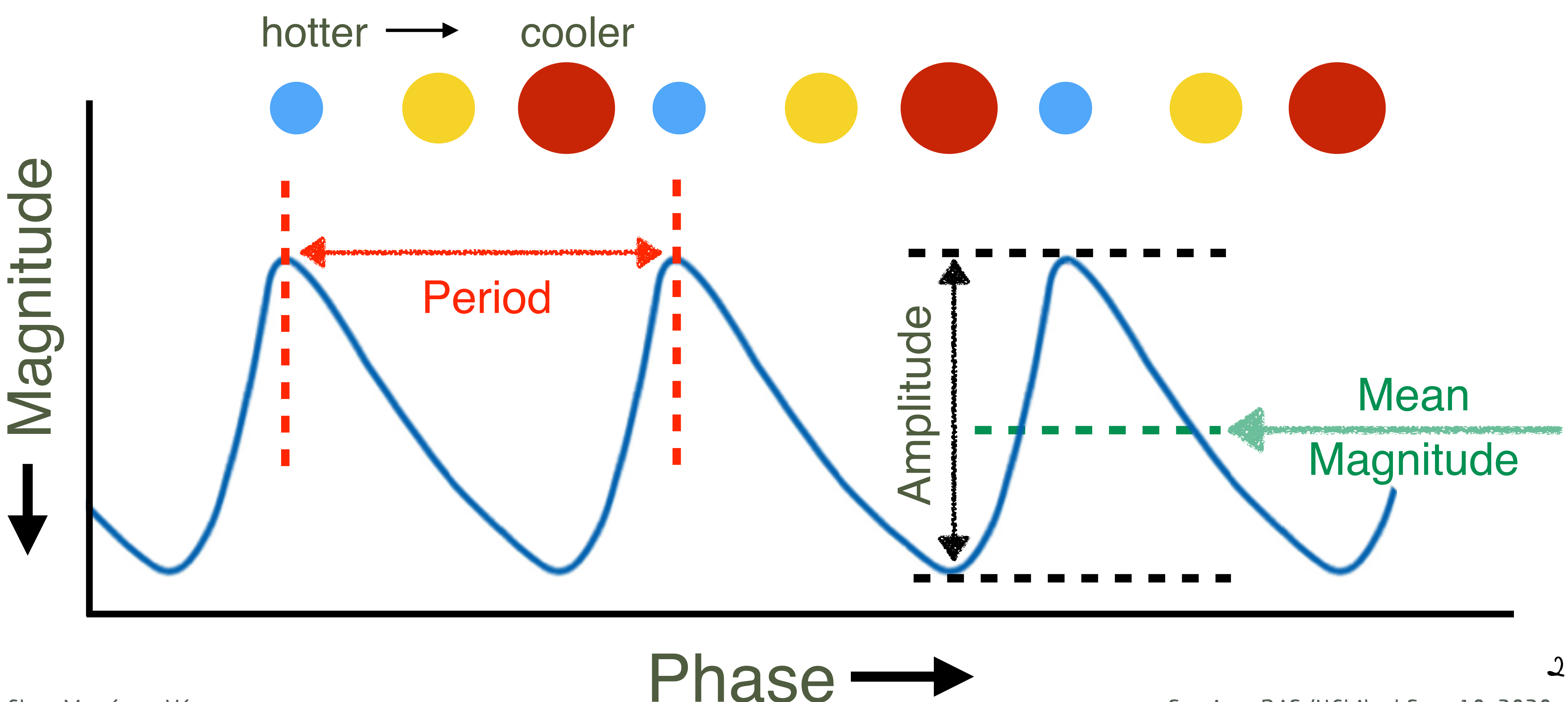
SEMINAR DAS/UCHILE | 10 SEPT 2020

Pulsating stars

- Pulsating variable ➜ intrinsic variables w/periodic variations in brightness due to a physical change within the star.

- Expansion/contraction of the surface layers of the star ➜ increase and decrease in size.

- Different types of pulsating variable, distinguished by their periods and the shapes of their light curves, which are function of the mass and evolutionary stage of the star.



Pulsating stars crossing the Instability Strip

Classical Cepheids (CCs)

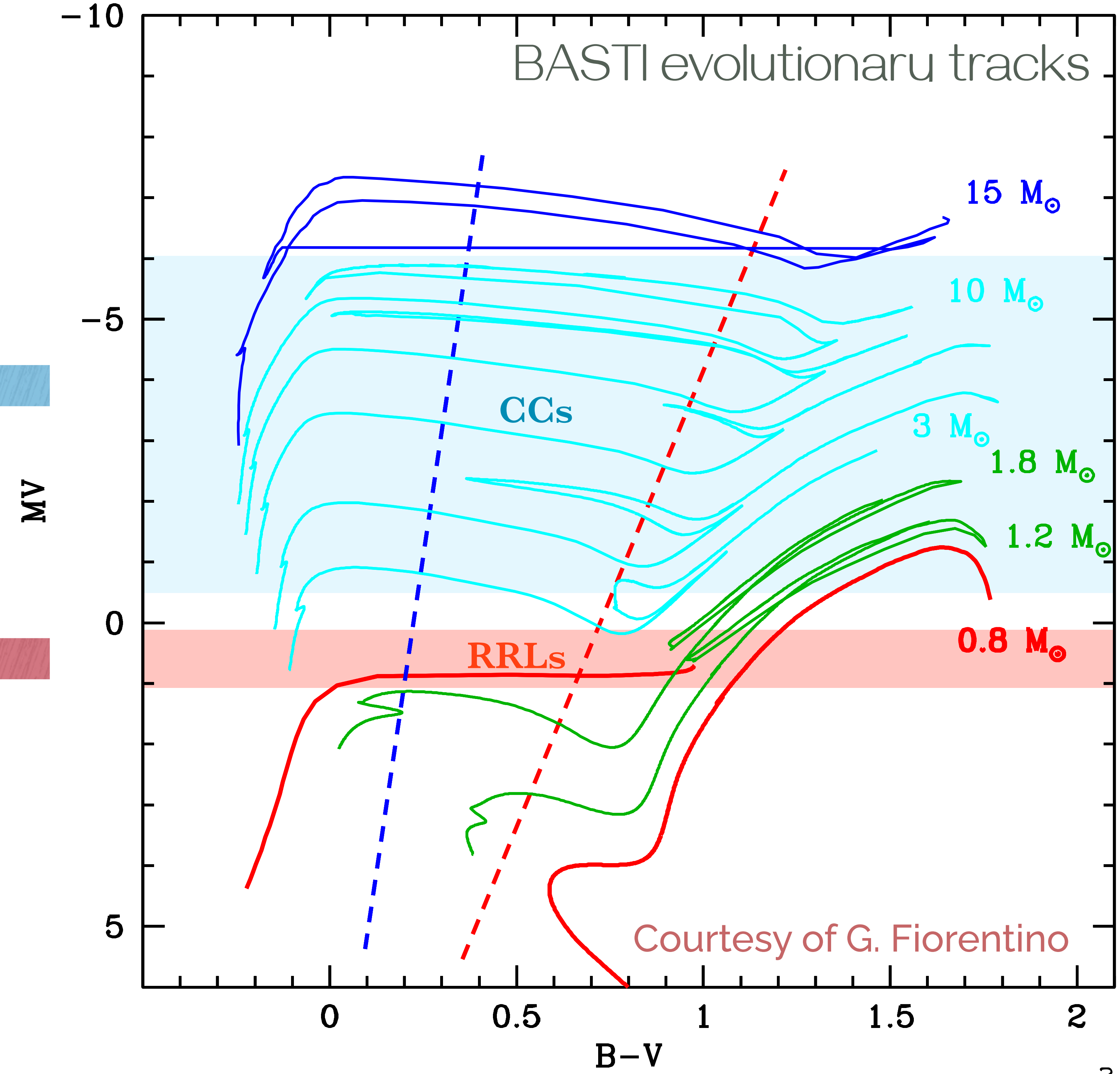
YOUNG (age < 300 Myr)

Periods from few to ~80 days

RRLyrae stars (RRLs)

OLD (age ≥ 10 Gyr)

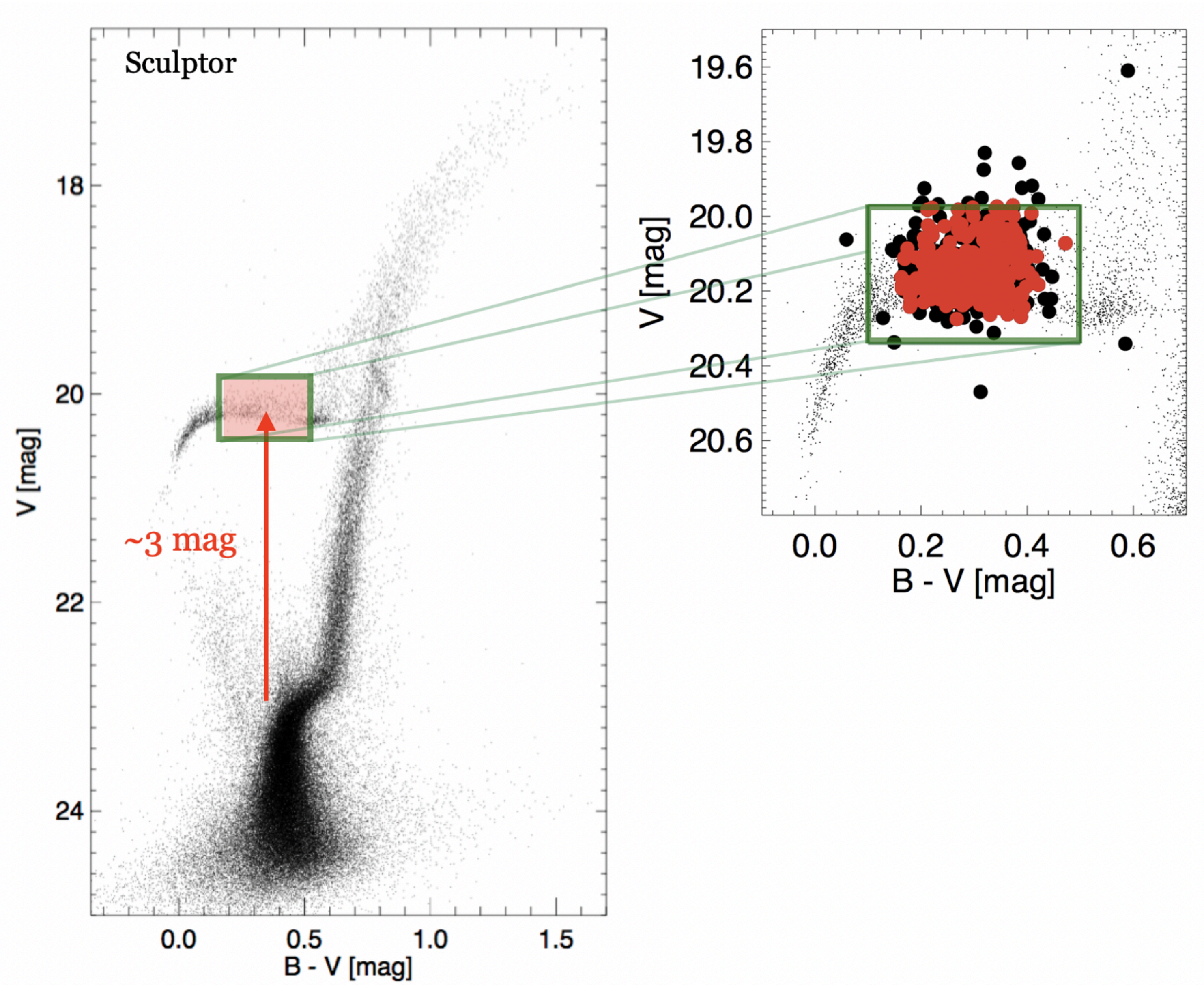
Periods range from 0.2-1 day

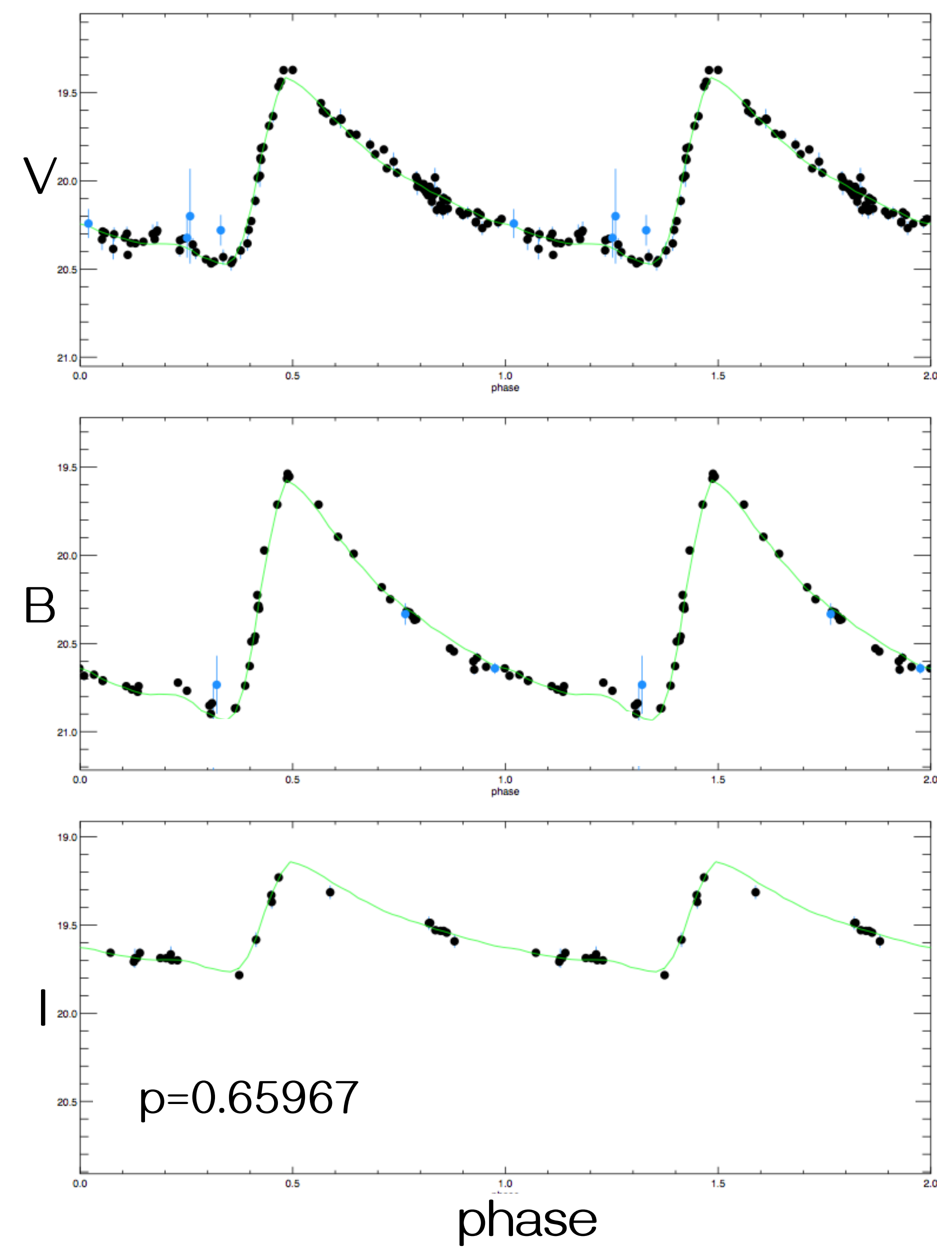


RR Lyrae stars | why are they so interesting?

- RR Lyrae (RRL) stars are pulsating variable stars located in the horizontal branch

Martínez-Vázquez et al. 2016b



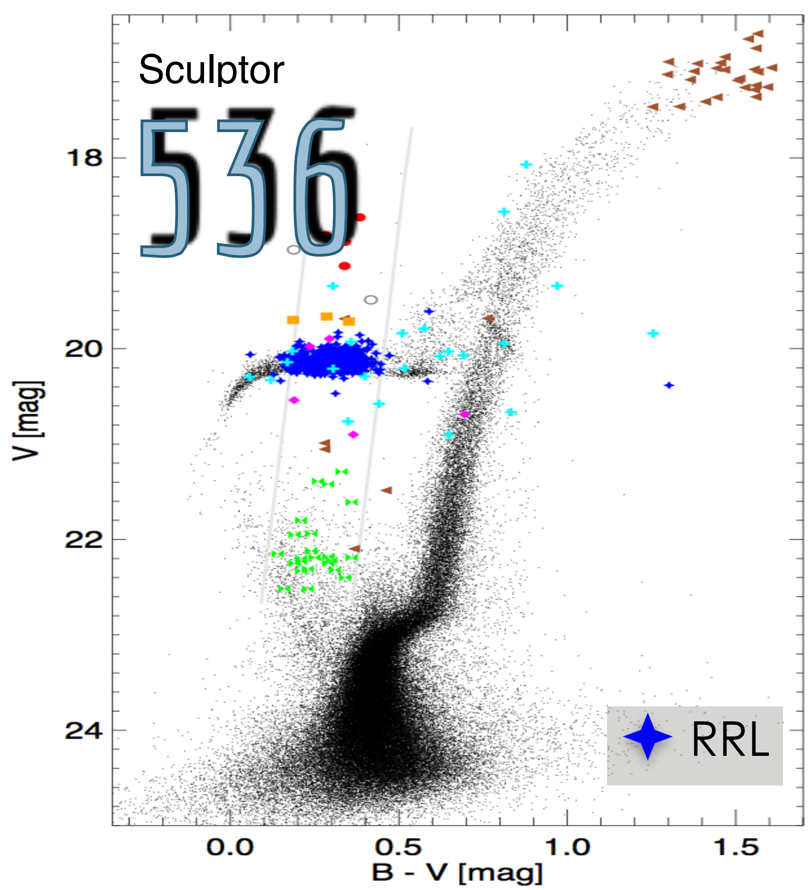


RR Lyrae stars | why are they so interesting?

⁕ Old stellar population tracers (t >10 Gyr)

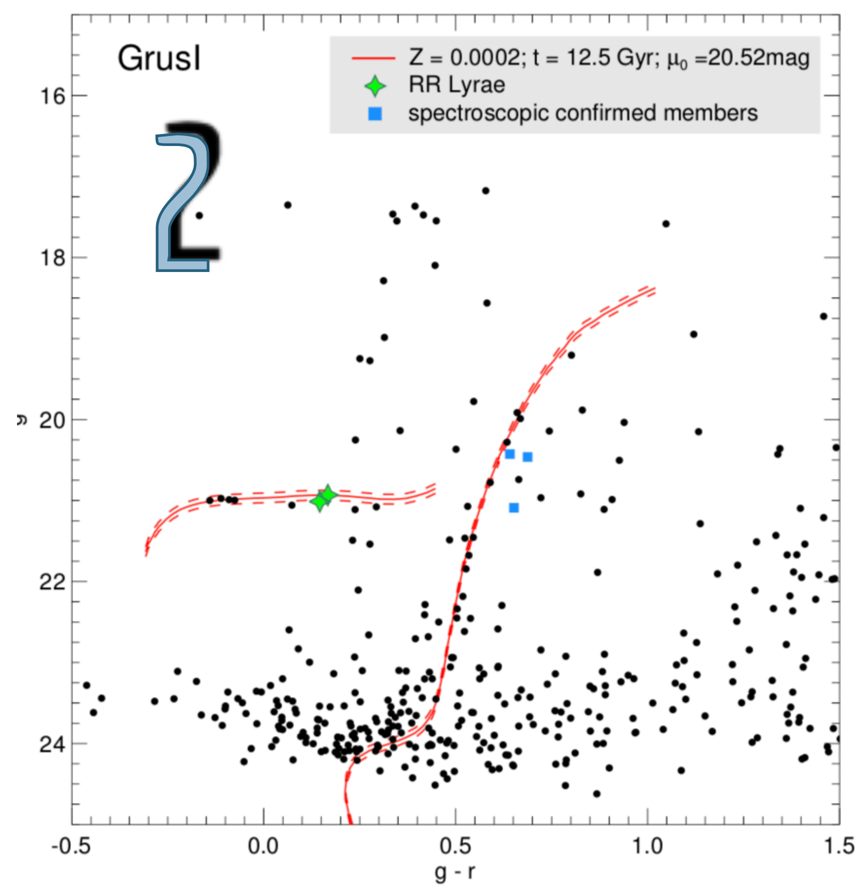
- ☑ Ubiquitous in all galaxies (few exceptions)
- ☑ Tracing the first ~ 3 Gyr of a galaxy's life

Classical



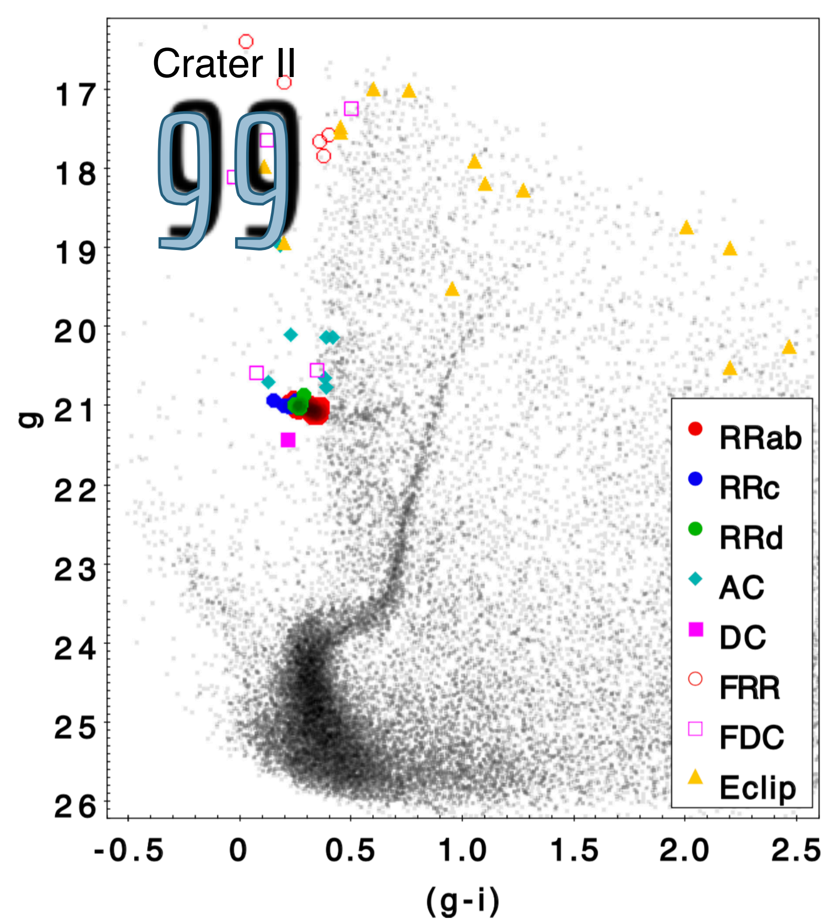
Martínez-Vázquez et al. 2016b

Ultra faint



Martínez-Vázquez et al. 2019

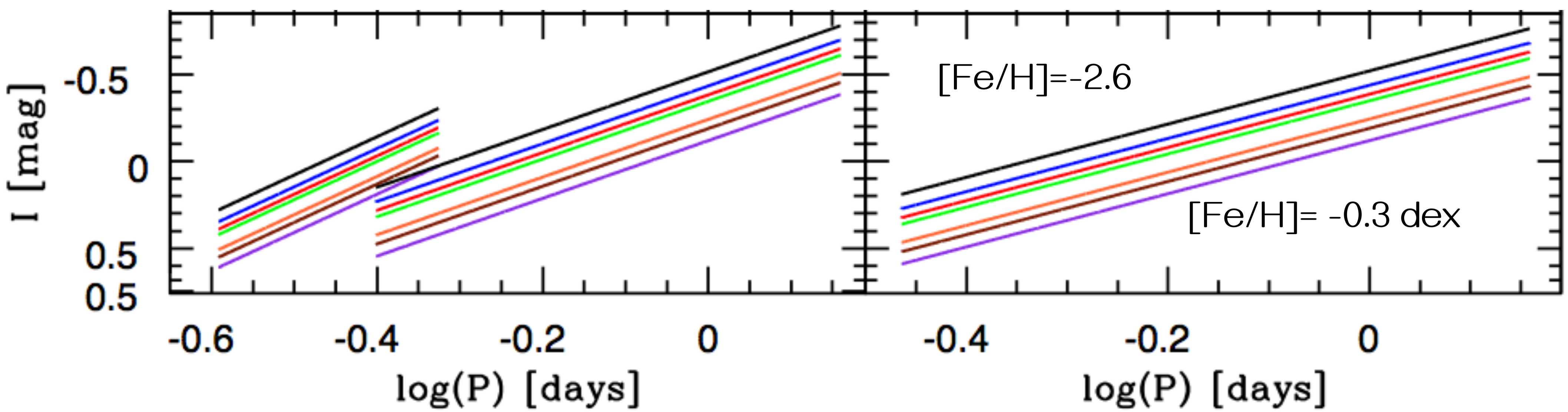
Ultra diffuse



Vivas et al. 2020a

RR Lyrae stars | why are they so interesting?

- RRLs obey a well-known period-luminosity-metallicity relation:
  - ☑ Standard candles —> accurate distances
  - ☑ Metallicity tracers (t > 10 Gyr) —> early chemical enrichment



Marconi et al. 2015

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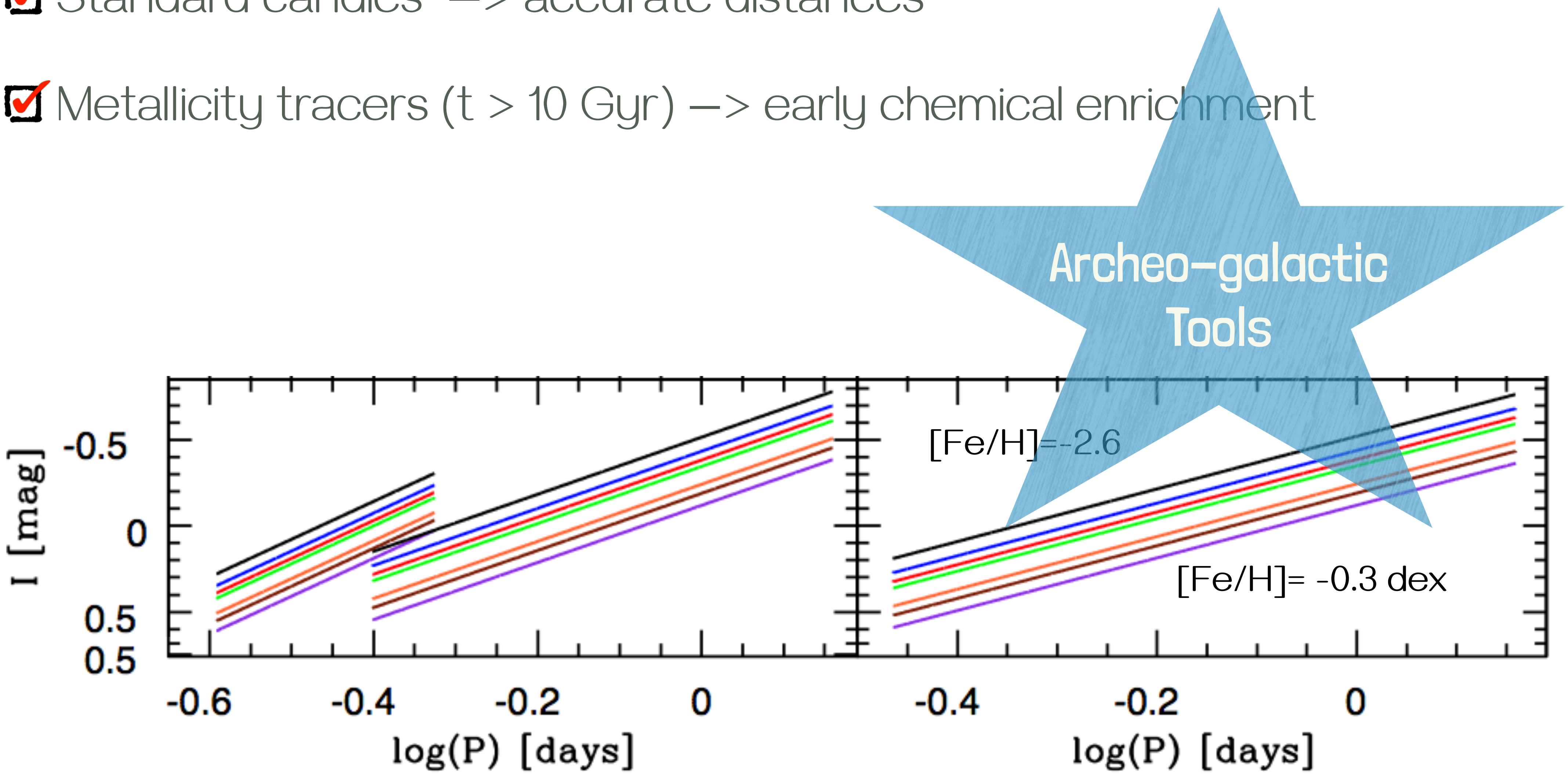
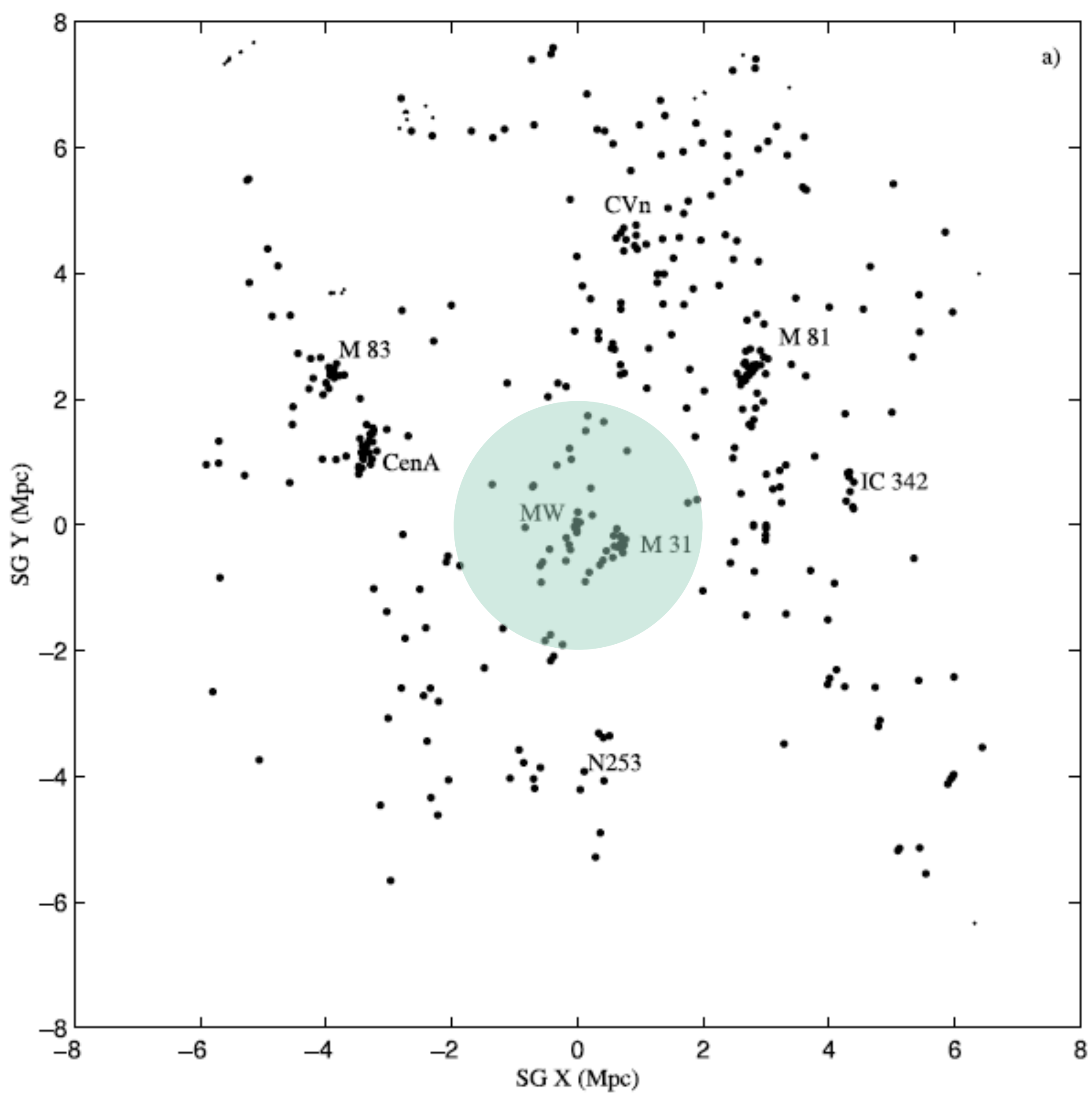


Marconi et al. 2015

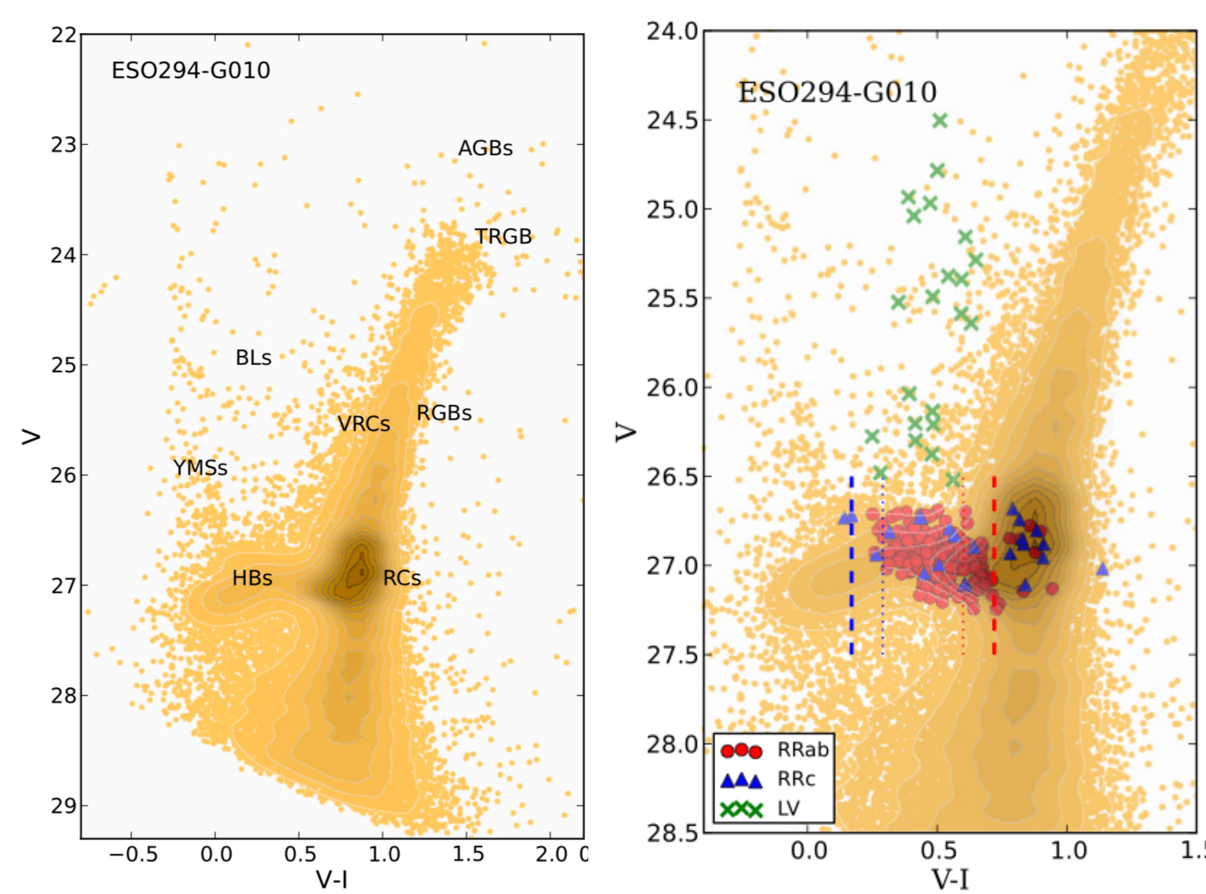
RR Lyrae stars detected beyond the Local Group

- RR Lyrae are detected up to **2 Mpc with HST**



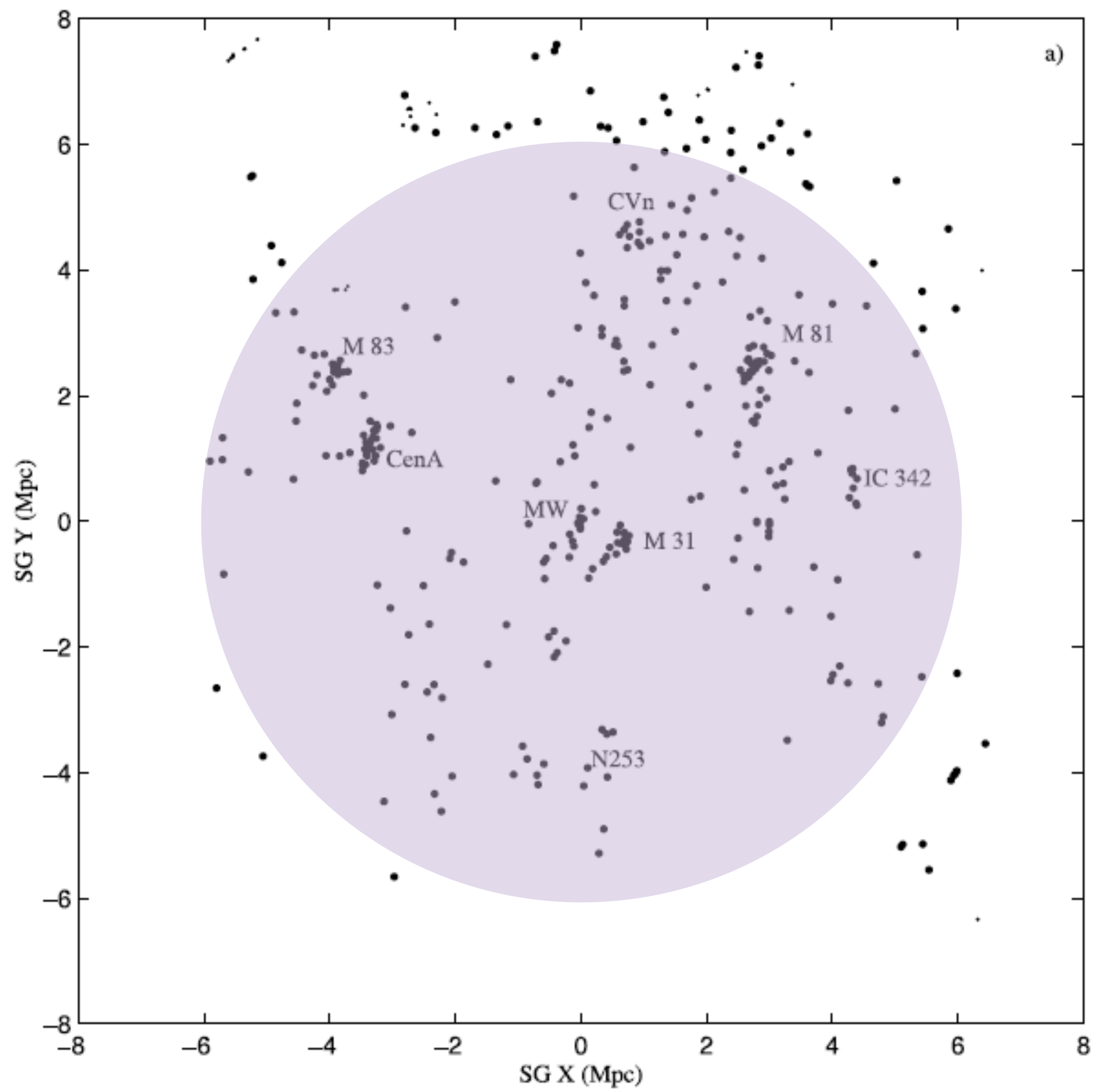
Karachentsev et al. 2004

Yang et al. 2014



RR Lyrae stars detected beyond the Local Group

- RR Lyrae will be detected up to **6 Mpc with ELTs**

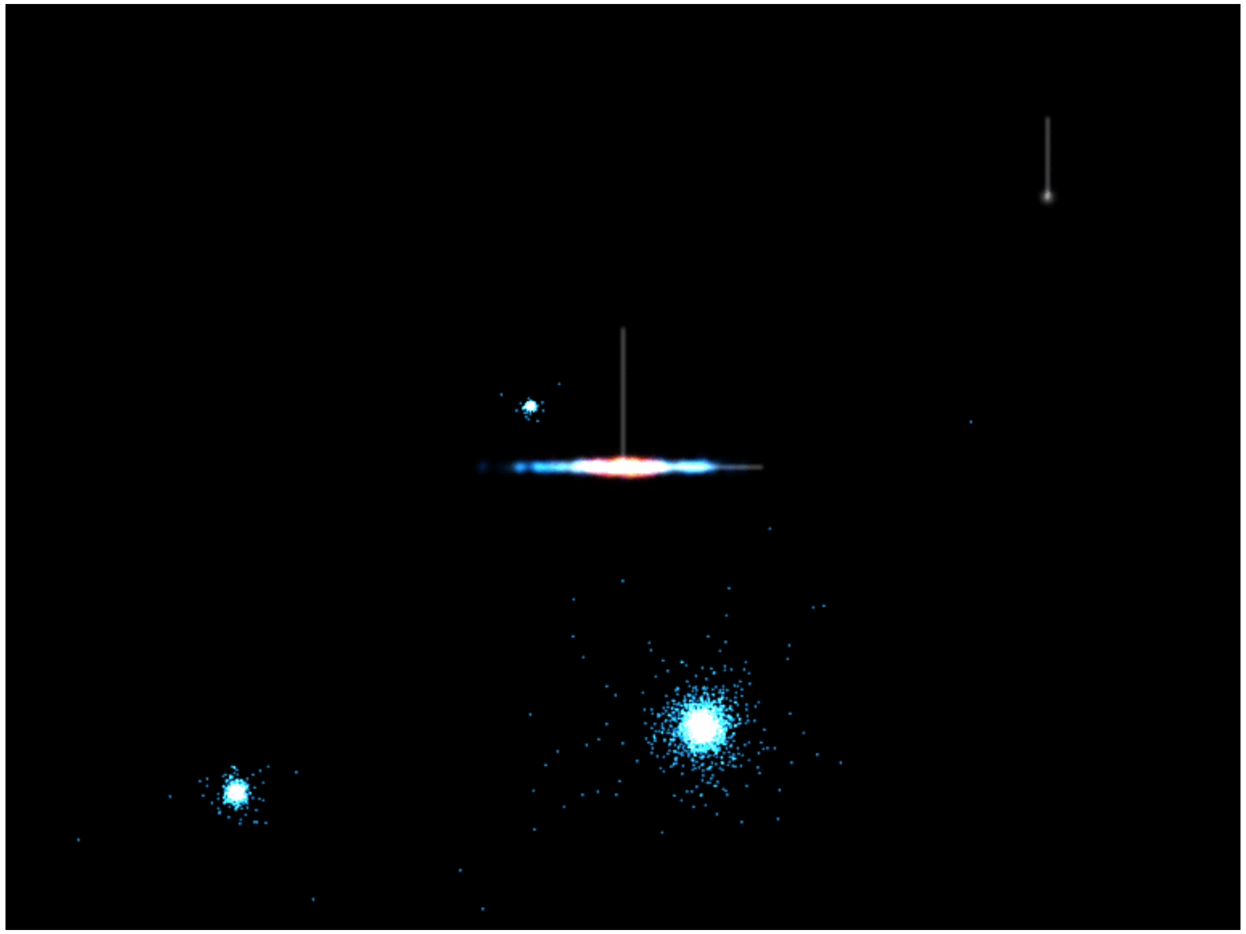


Karachentsev et al. 2004

To study and compare the early star formation of dwarf galaxies in different groups and environment farther than the Local Group

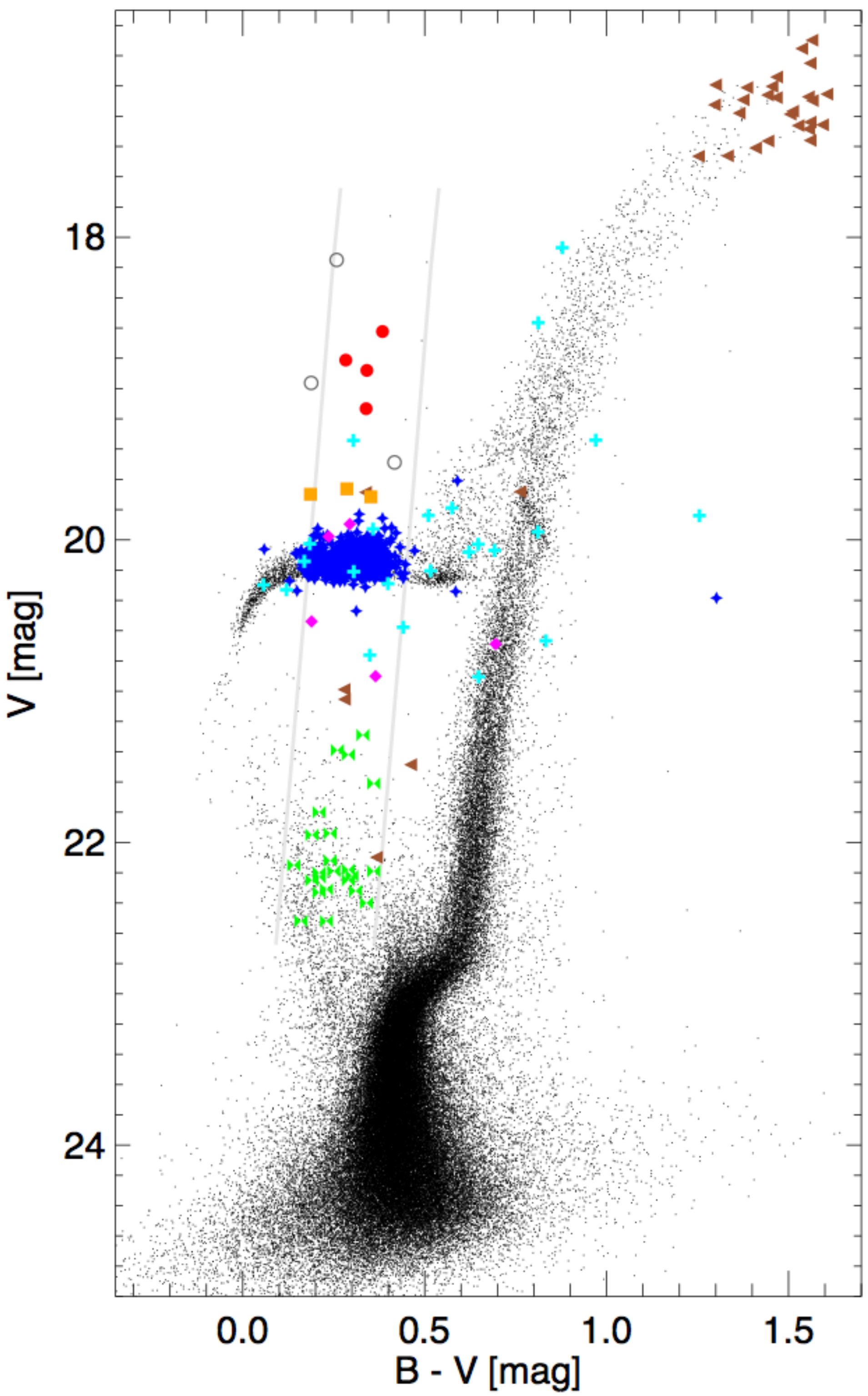
Dwarf galaxies as building blocks

- Dwarf galaxies are the most abundant type of galaxy in the Universe
- Cosmological models (ΛCDM) predict the hierarchical structure of galaxy formation: larger galaxies are formed by a continuous merging of smaller galaxies (Frenk & White, 2012)
- Dwarf galaxies that we observe today may be the relics of this merging process or witnesses of the first structures formed in the Universe

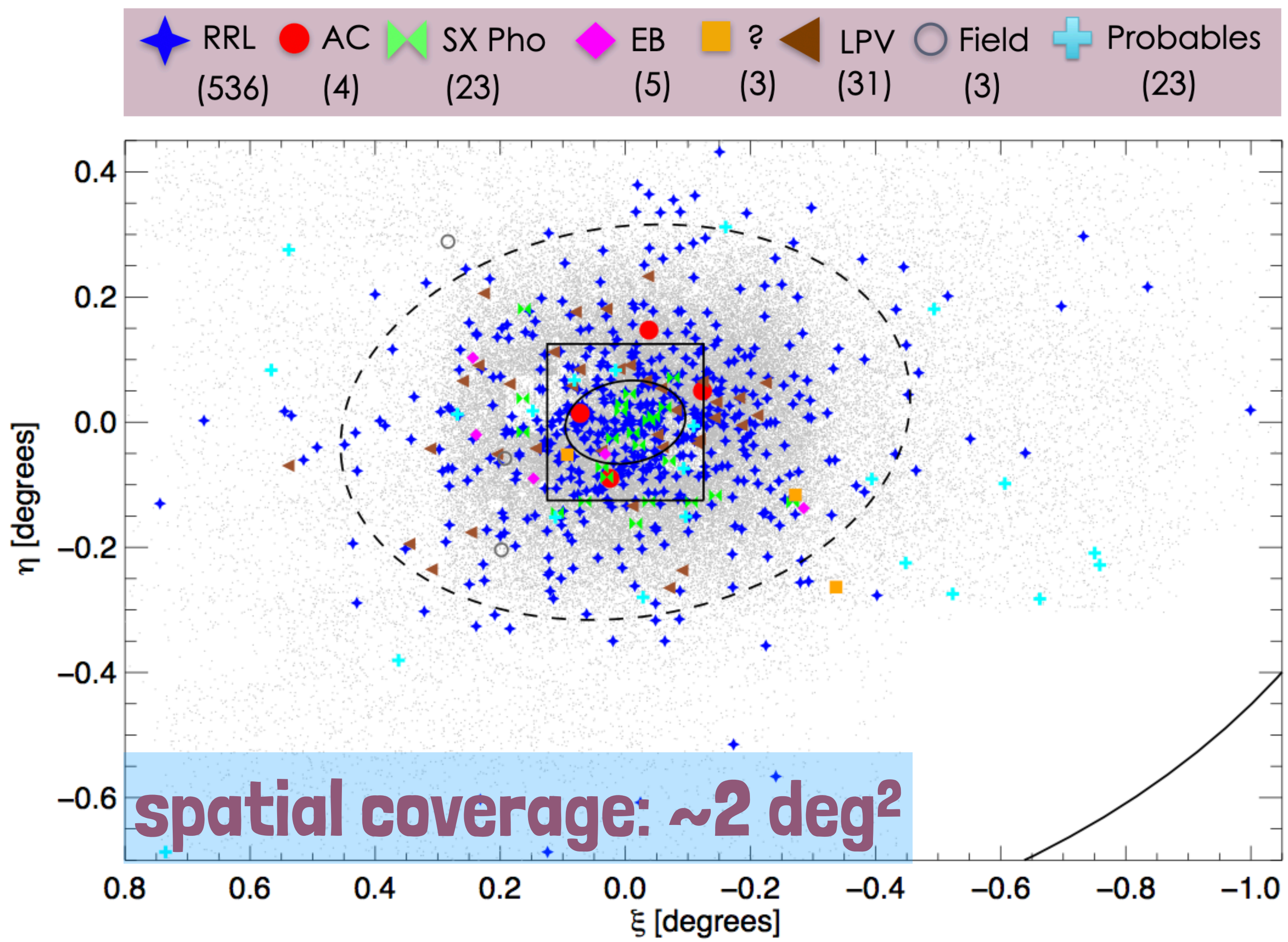


The animation represents 4 Gyr in the Milky Way, ending at the present day. Credit: Rensselaer/Benjamin A. Willett

Sculptor dwarf galaxy



Martínez-Vázquez et al. 2016b



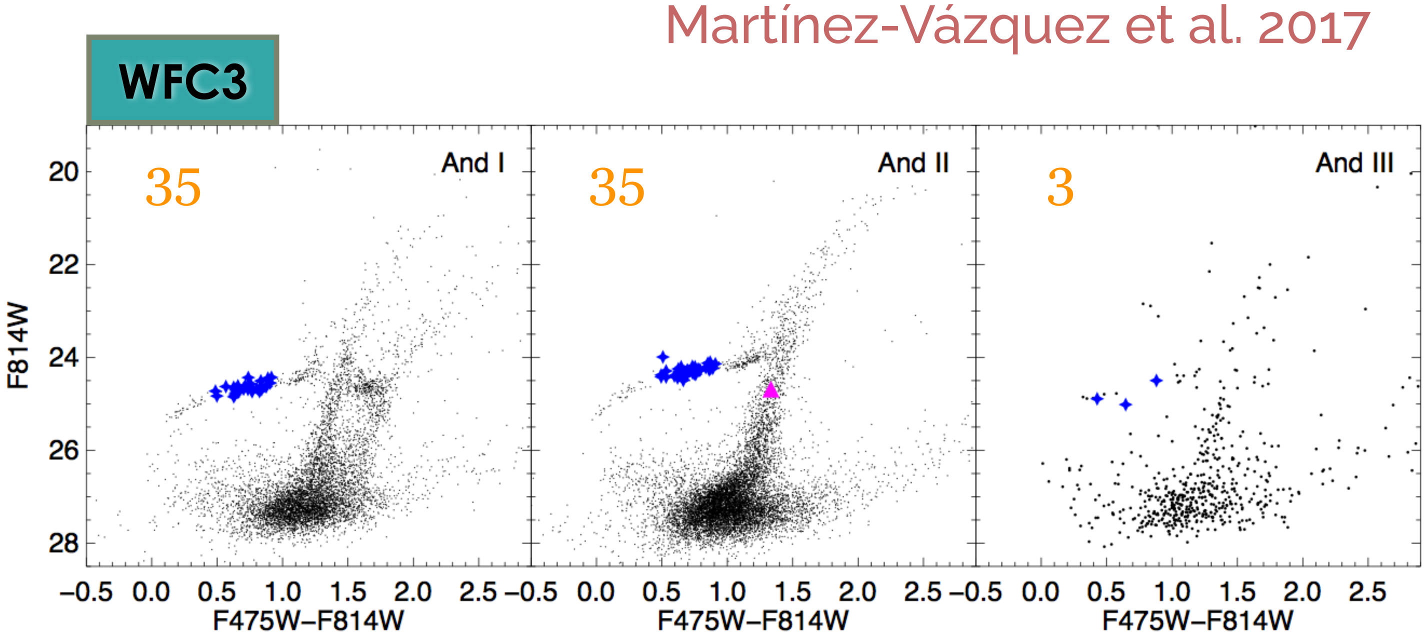
⁎ Based on ~24 years compiled data in different ground-based telescopes by Peter Stetson

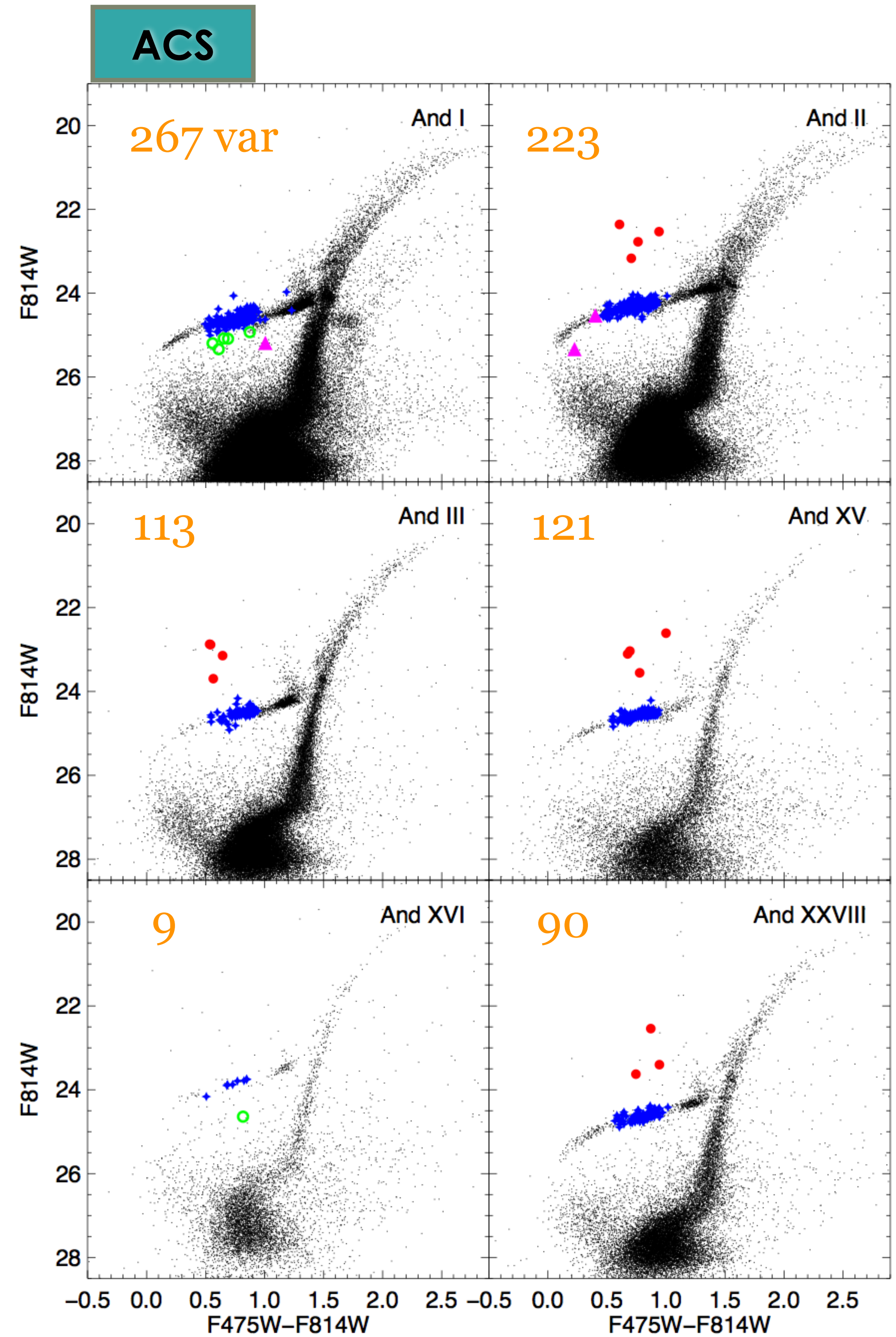
M31 dwarf galaxies

- ISLAndS: "the Initial Star formation and Lives of Andromeda Satellites"
  - P.I. Evan Skillman
  - Large HST proposal. Deep + multi-epoch data in 6 M31 dwarf galaxies.

871 RRLs detected

Martínez-Vázquez et al. 2017





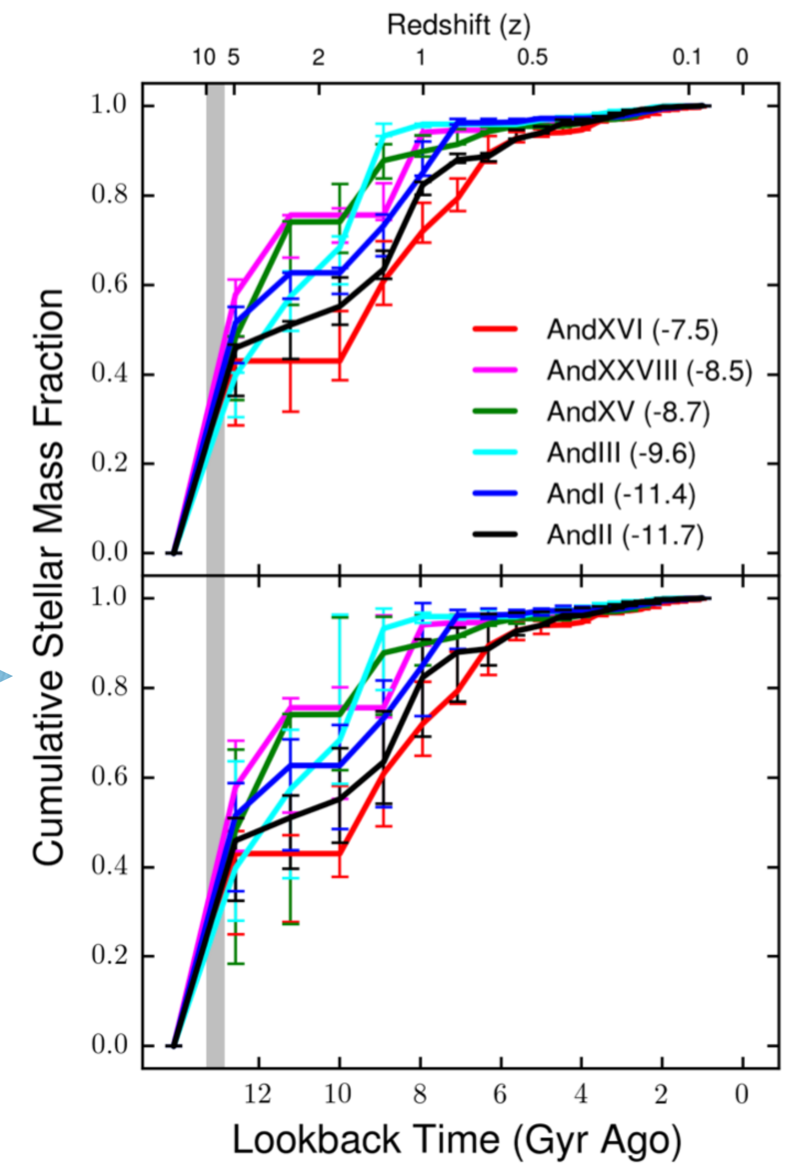
Distances from the RR Lyrae stars

Martínez-Vázquez et al. 2015 (Sculptor)
Martínez-Vázquez et al. 2017 (M31 satellites)

Using Period–Wesenheit relations

Galaxy	Distance
Sculptor	19.62 ± 0.02 (0.09)
And I	24.49 ± 0.08(0.11)
And II	24.16 ± 0.08(0.10)
And III	24.36 ± 0.08(0.08)
And XV	24.42 ± 0.08(0.09)
And XVI	23.70 ± 0.08(0.09)
And XXVIII	24.43 ± 0.08(0.07)

Skillman et al. 2017

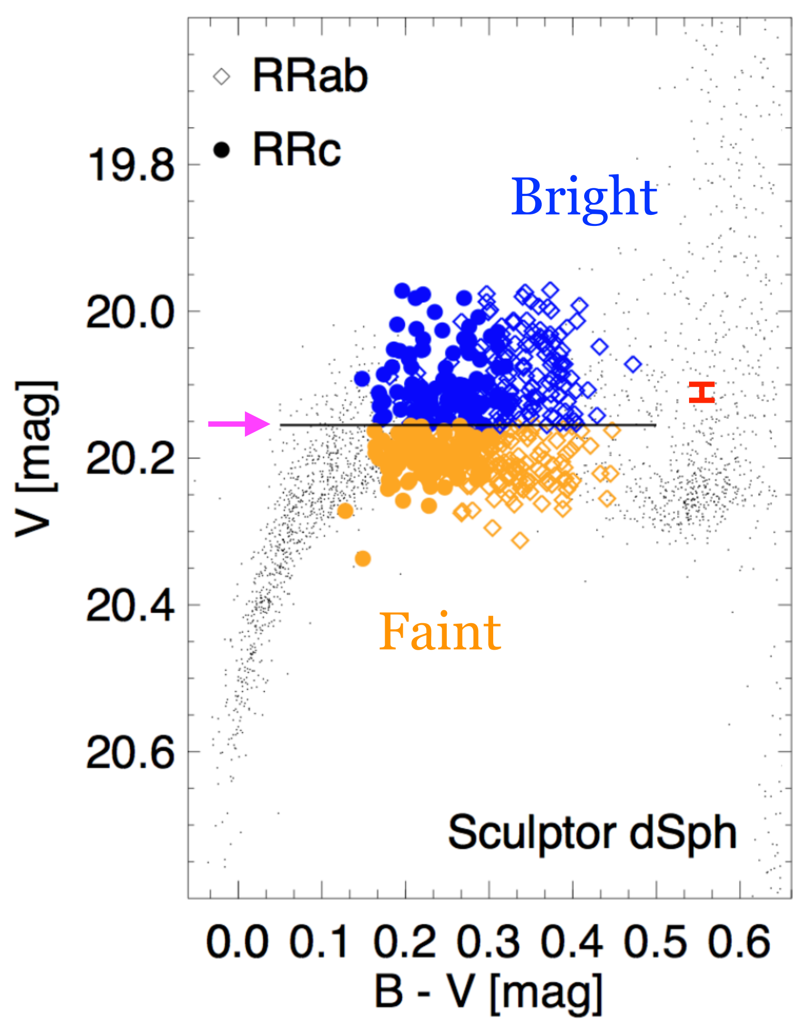


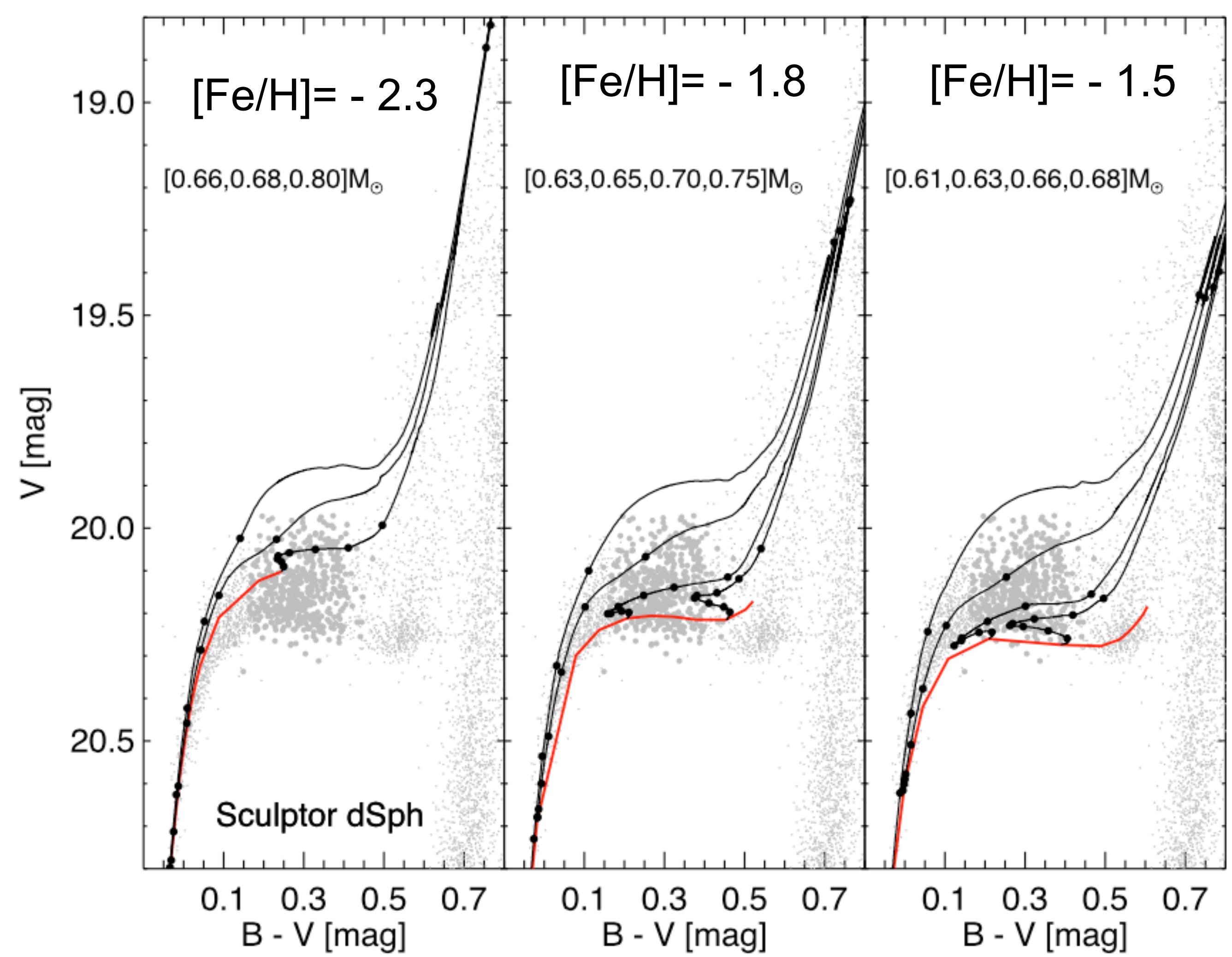
The early chemical enrichment of **Sculptor**

Martínez-Vázquez et al. 2015, 2016a,b

- 536 RRL stars in Sculptor in ~2 sq. deg. (ground-based data collected by P. Stetson)
- Large spread: ΔV_{RRL} ~0.35 mag (larger than photometric uncertainties)

Incompatible with a mono-metallic population



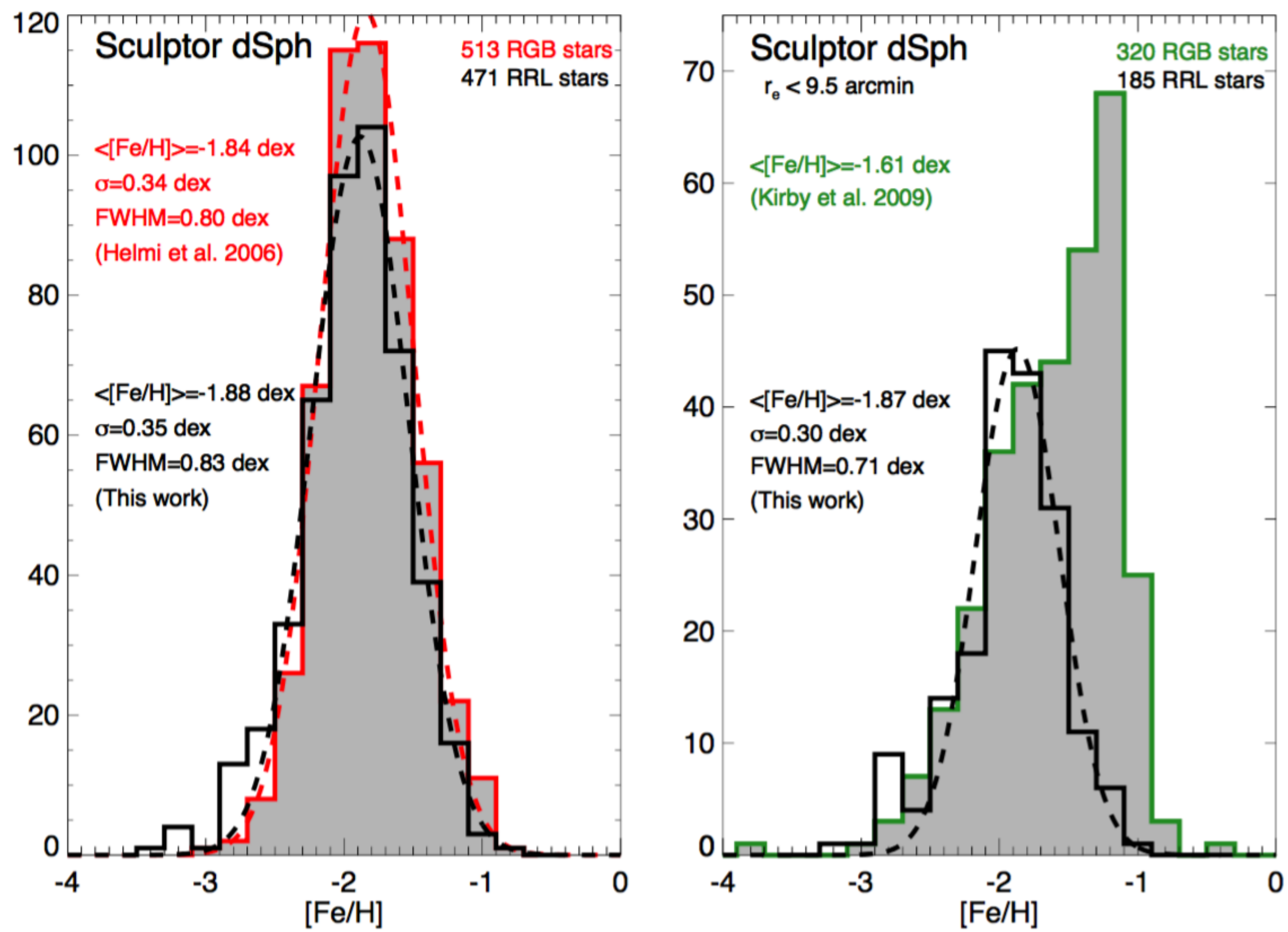


BaSTI ZAHB and evolutionary tracks

The early chemical enrichment of **Sculptor**

Photometric RRL metallicities
versus
Spectroscopic RGB metallicities

Martínez-Vázquez et al. 2016a

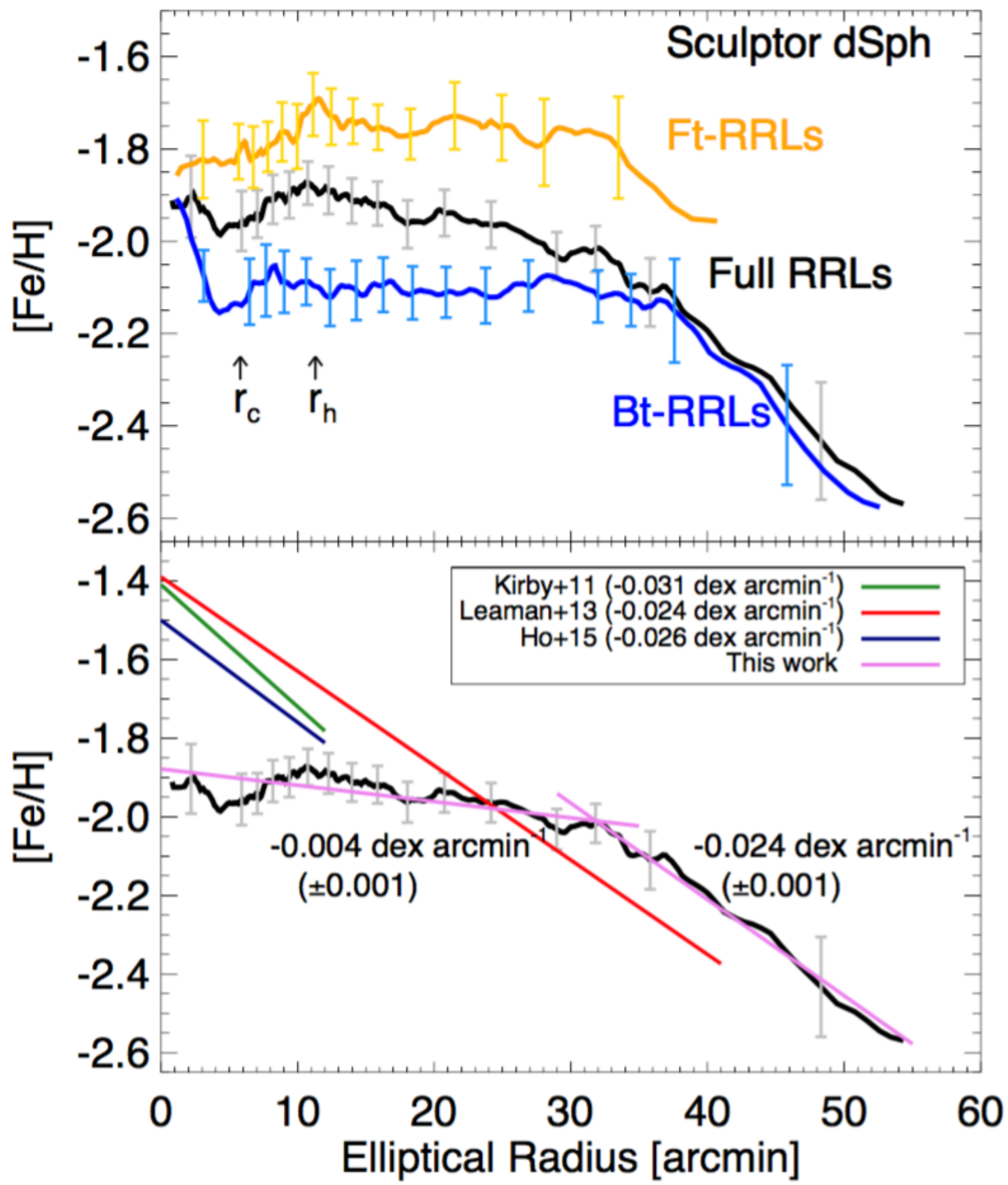


r < 60 arcmin

r < ~10 arcmin

The early chemical enrichment of **Sculptor**

Martínez-Vázquez et al. 2016a



- Outer region: steep negative slope; in agreement with Kirby et al. 2011, Leaman et al. 2013, Ho et al. 2015 (spectroscopic data)
- Inner region: mild negative slope less steep than derived spectroscopically, due to the different populations sampled

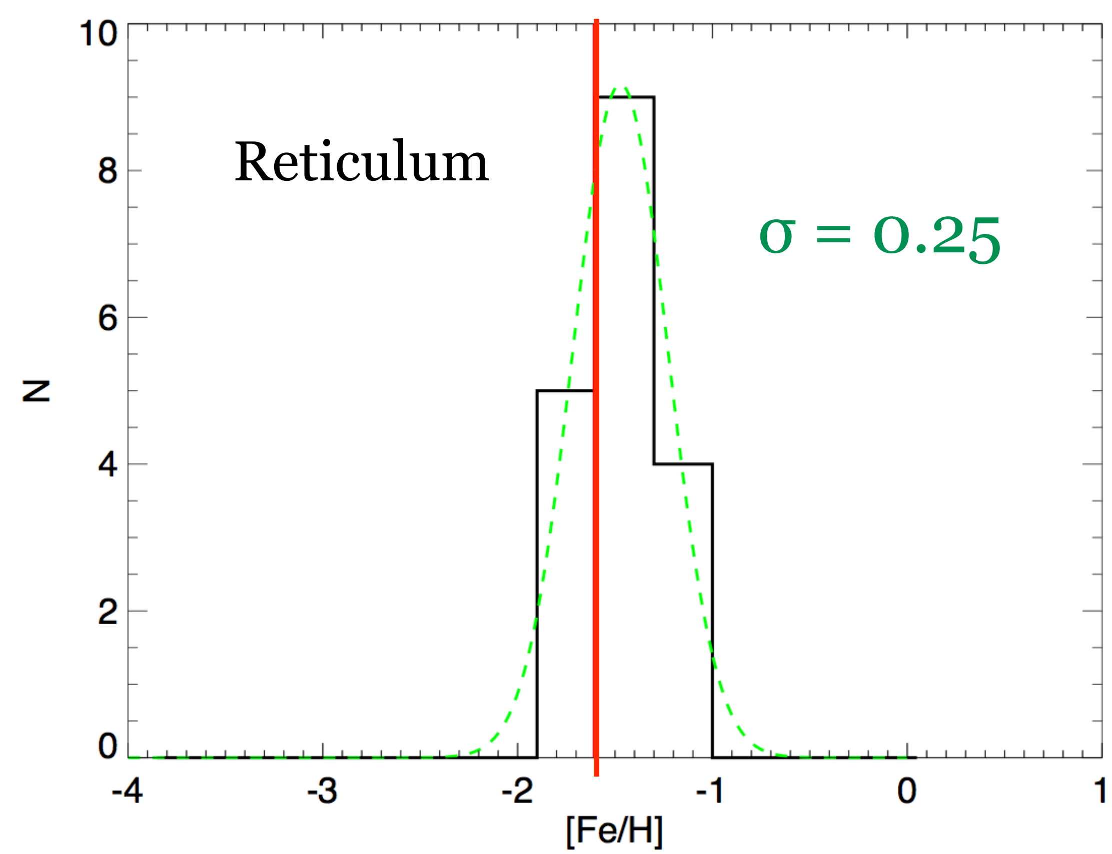
The star formation in the center last longer than in the outer parts.

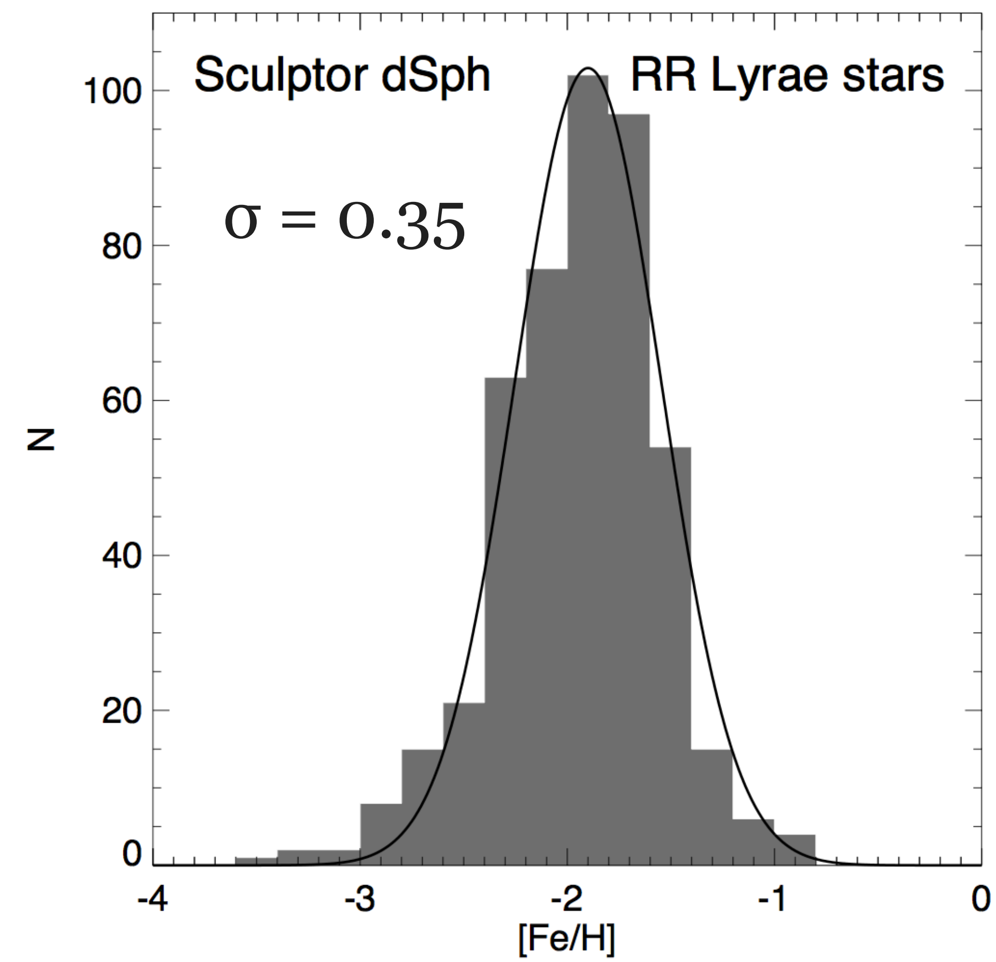
Consistent with the SFH calculated by de Boer et al. 2012

The early chemical enrichment of **Sculptor**

Martínez-Vázquez et al. 2016a

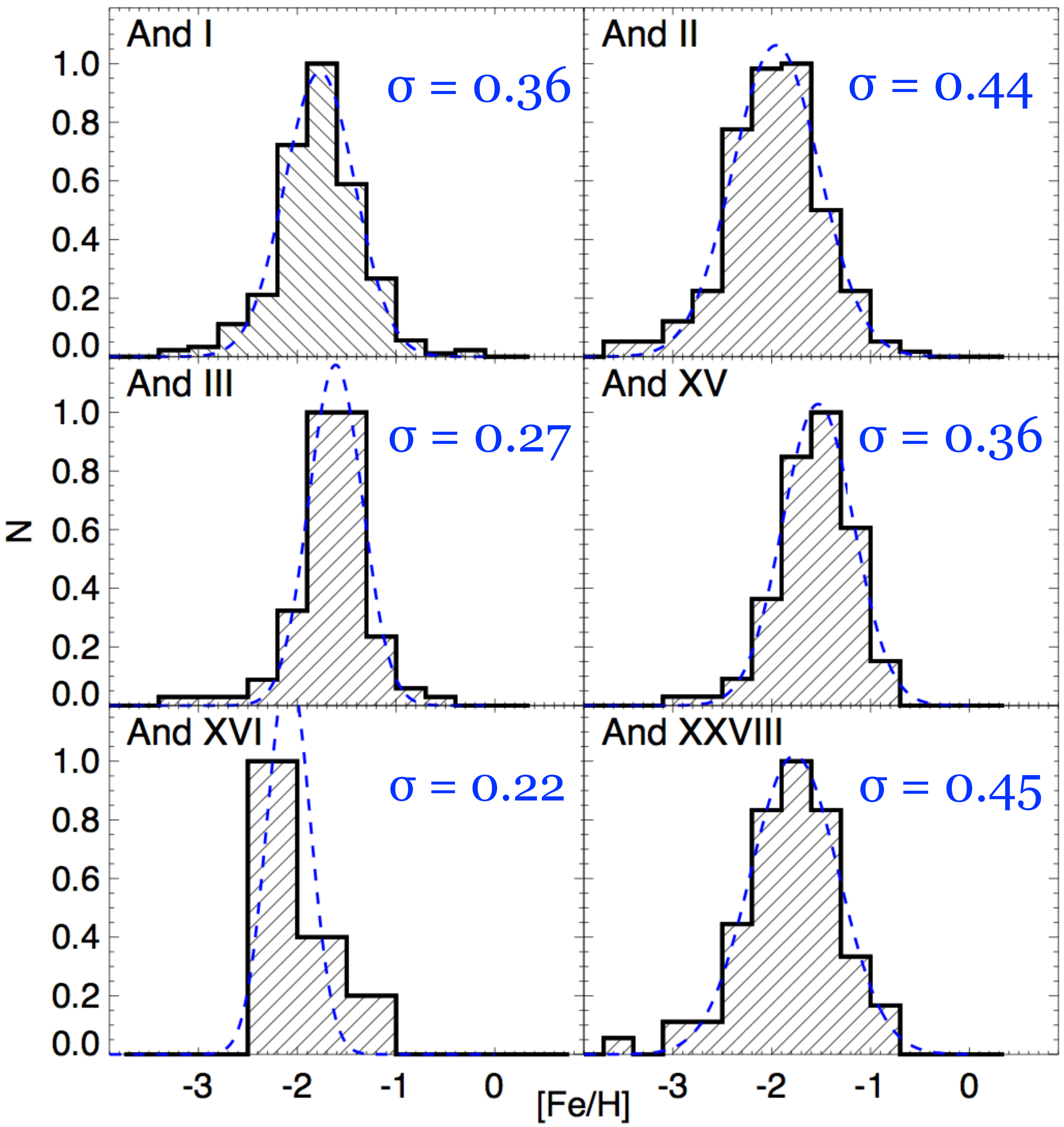
- We tested the method with RRLs of the globular cluster Reticulum (Kuehn et al. 2013) ➜ -1.49 dex and **σ**=0.25 dex.

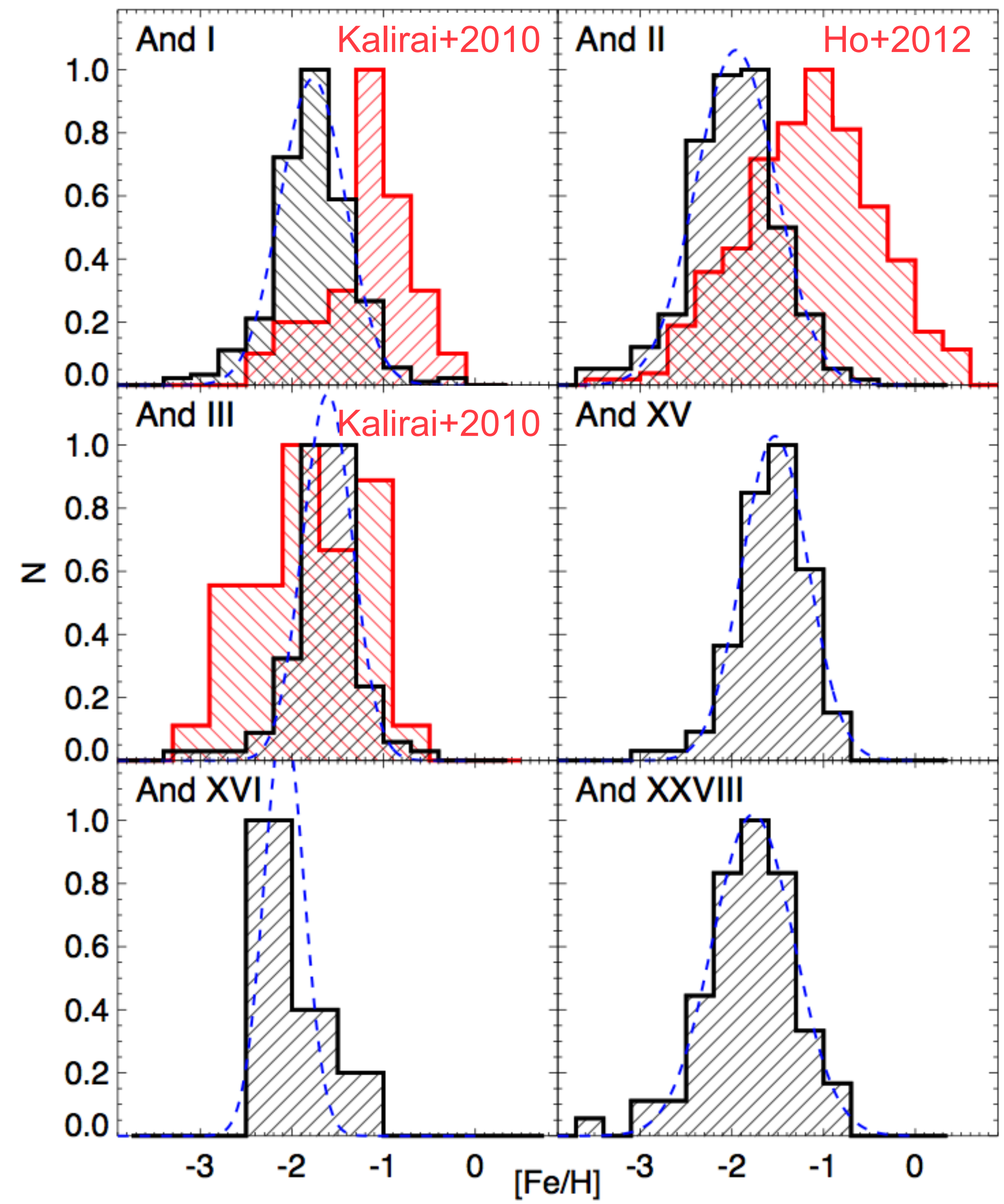




The early chemical enrichment of the **M31** dwarf galaxies

Martínez-Vázquez et al. in preparation

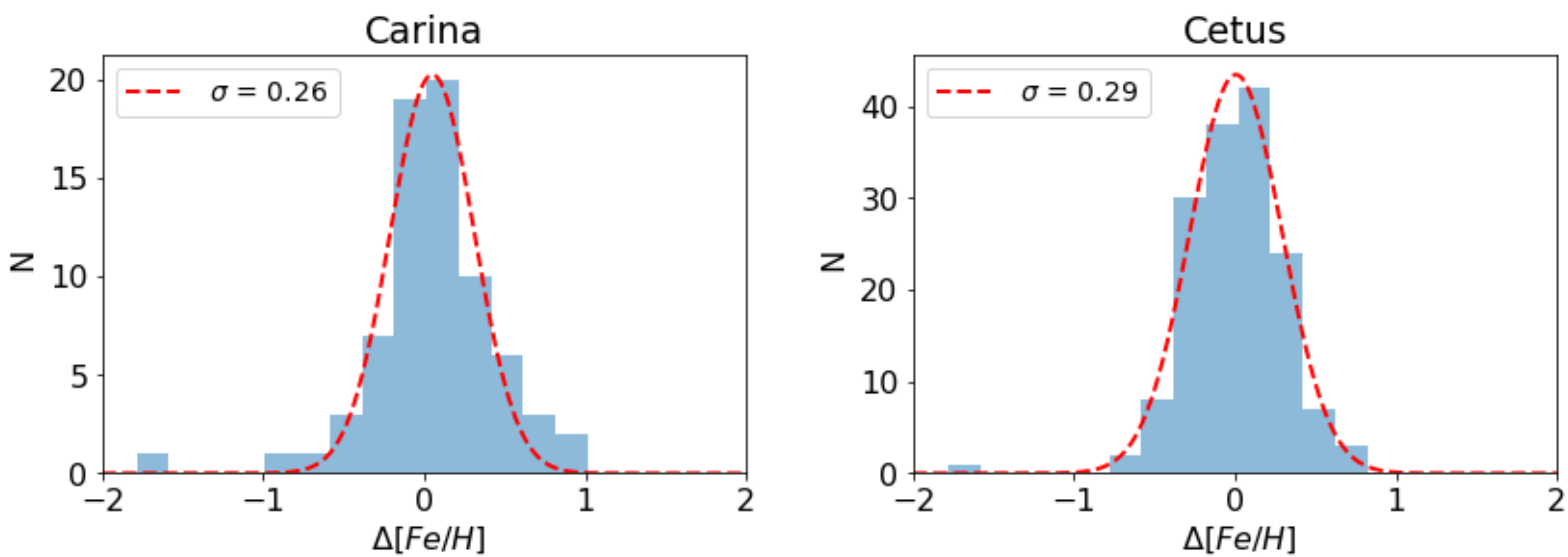




The early chemical enrichment of **Local Group** dwarf galaxies

Martínez-Vázquez et al. in preparation

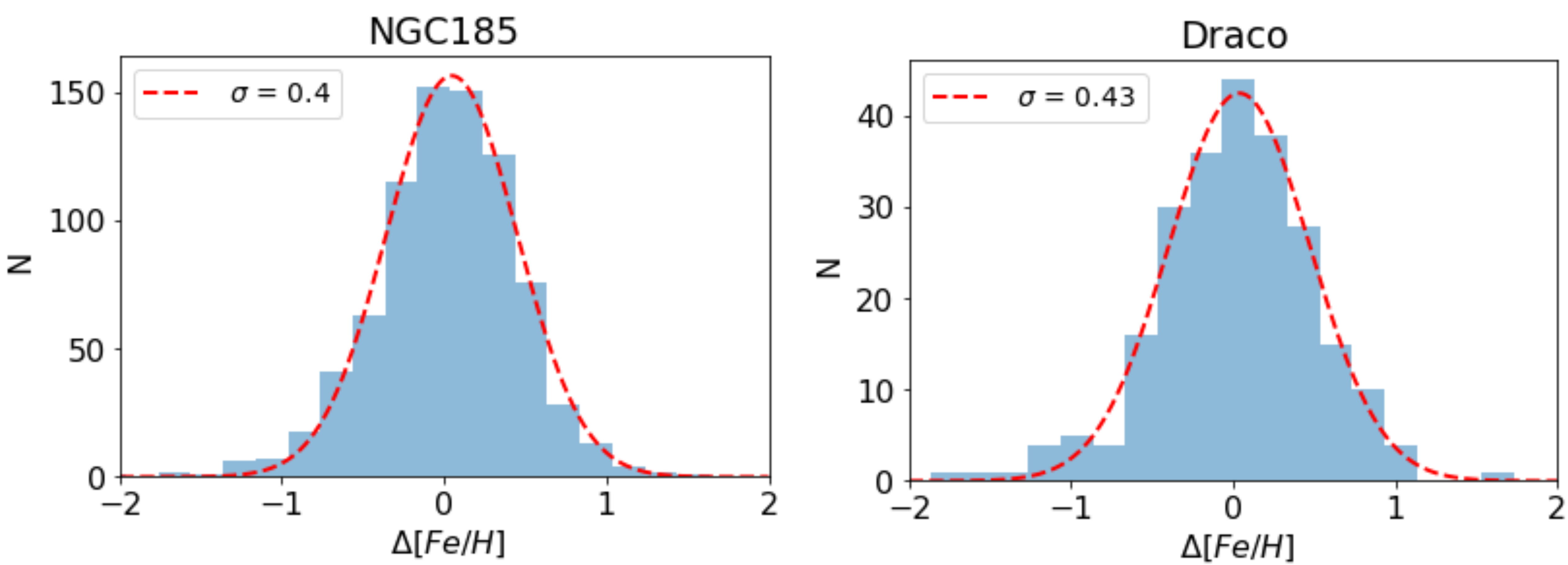
No evidences of early chemical enrichment



The early chemical enrichment of **Local Group** dwarf galaxies

Martínez-Vázquez et al. in preparation

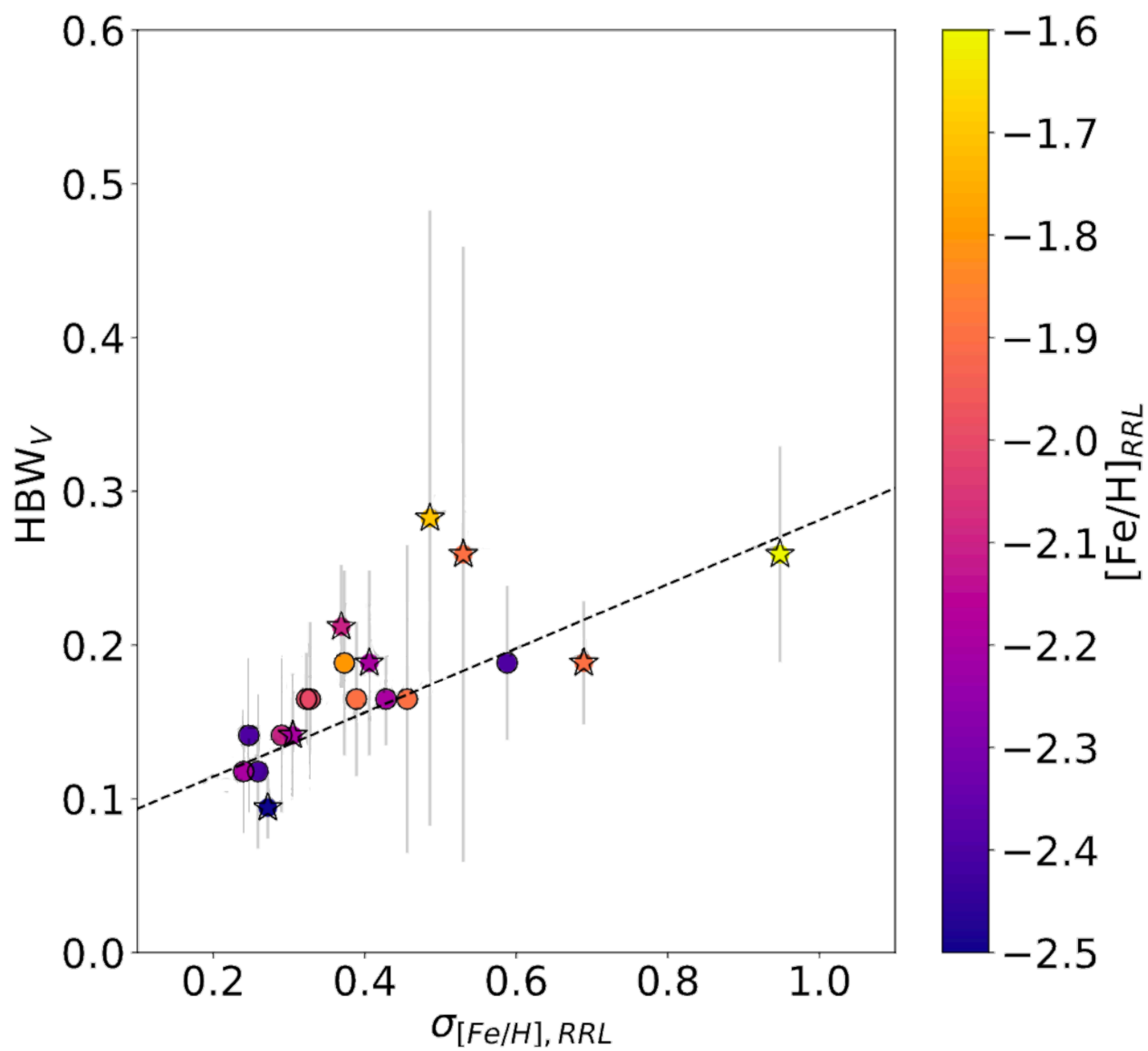
Evidences of early chemical enrichment



Correlation between HB width, [Fe/H] and [Fe/H] dispersion

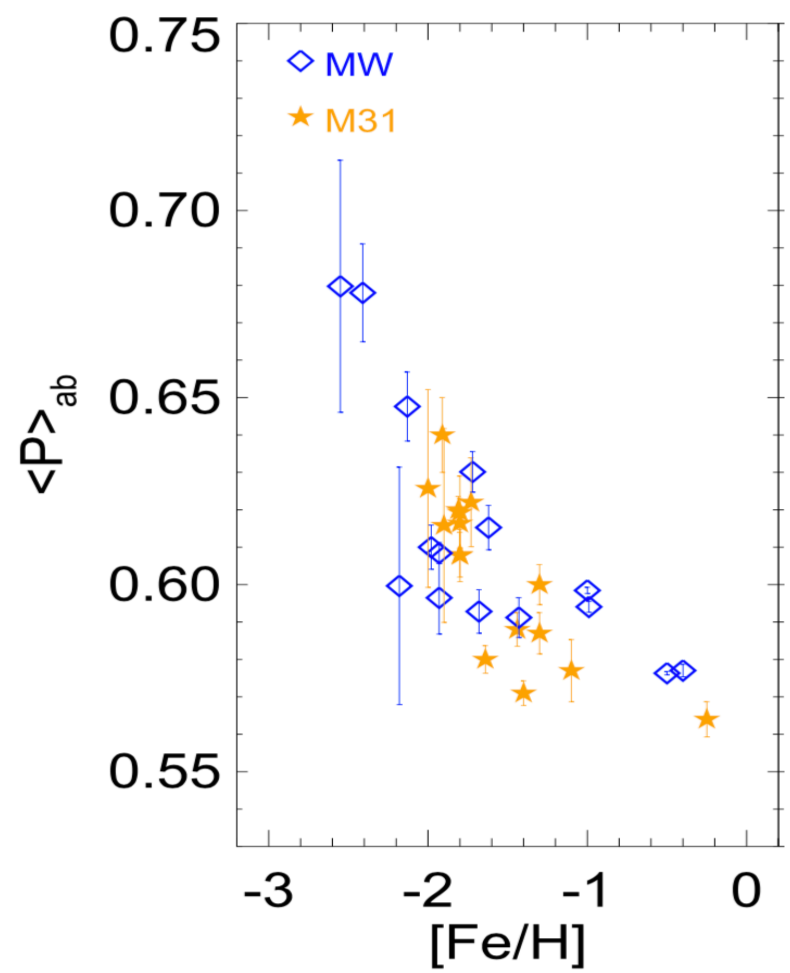
- The with of the HB in dwarf galaxies (measured in the V band) is correlated with the metallicity and with the inferred metallicity dispersion of the old population

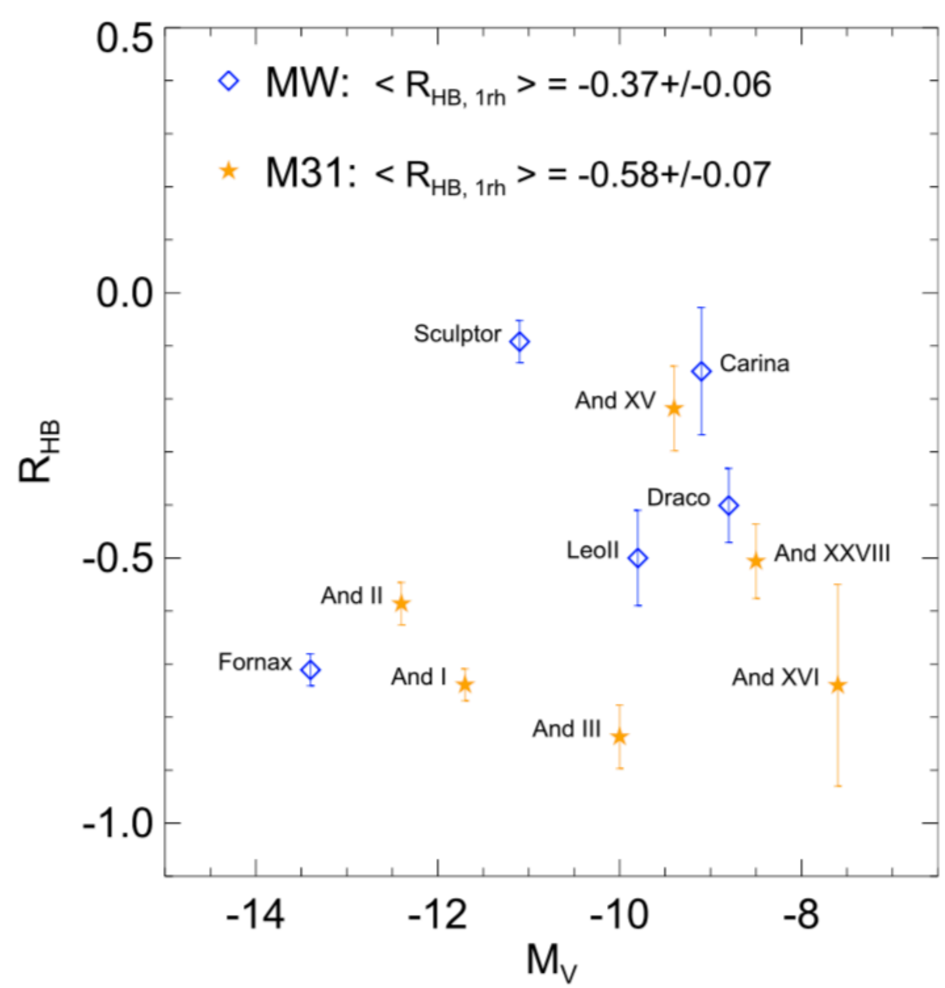
Martínez-Vázquez et al. in preparation



Similarities & differences between the M31 and MW environments

* The mean period of the RRab stars decreases when the mean metallicity of the host system increases.
* The old RRL progenitors were similar at early epochs in the two environments, suggesting very similar characteristics for the earliest stages of evolution of both satellite systems.
* But... the HB of the M31 satellites are slightly redder than those of the MW (also seen by Martin et al. 2017).





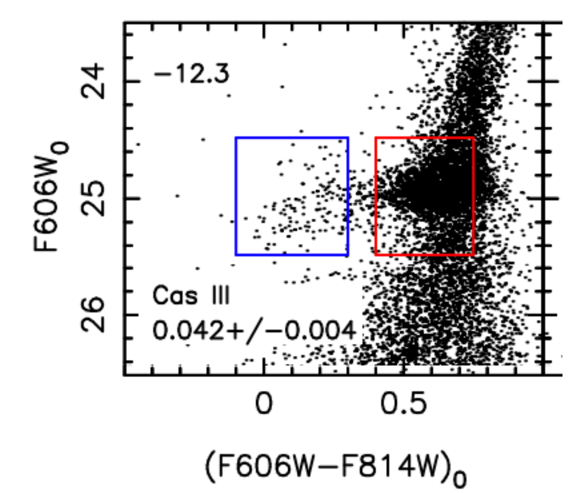
Martínez-Vázquez et al. 2017

$R_{HB} = (B-R)/(B+V+R)$

Lee 1990

$R_{HB} = +1$ —> blue HB

$R_{HB} = -1$ —> red HB

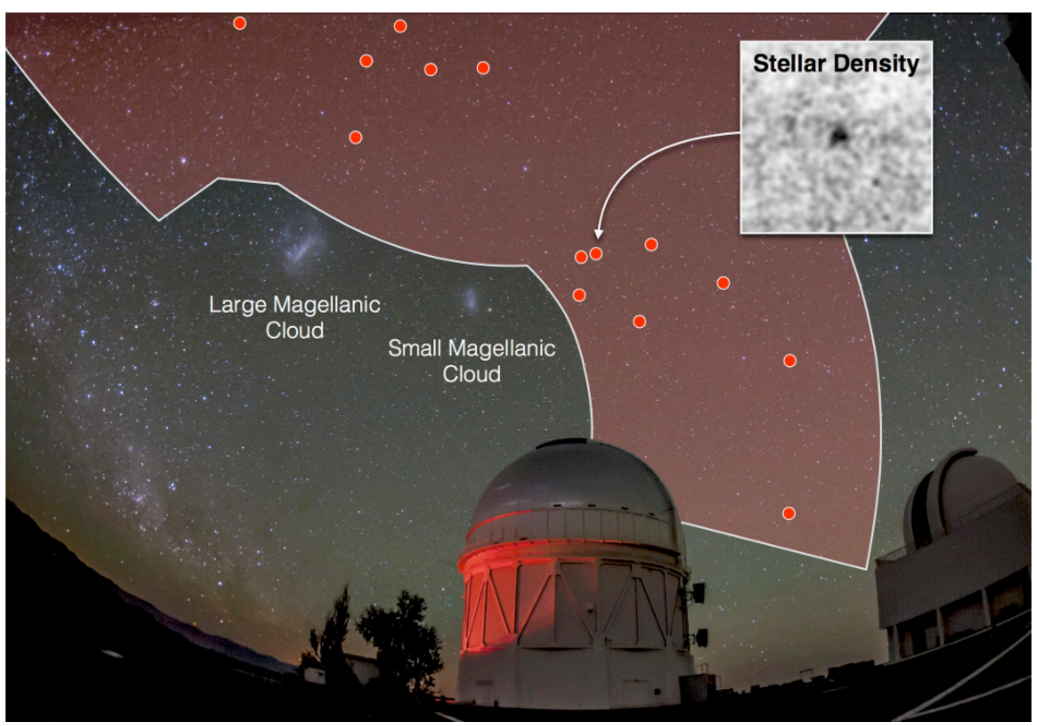


Martin et al. 2017

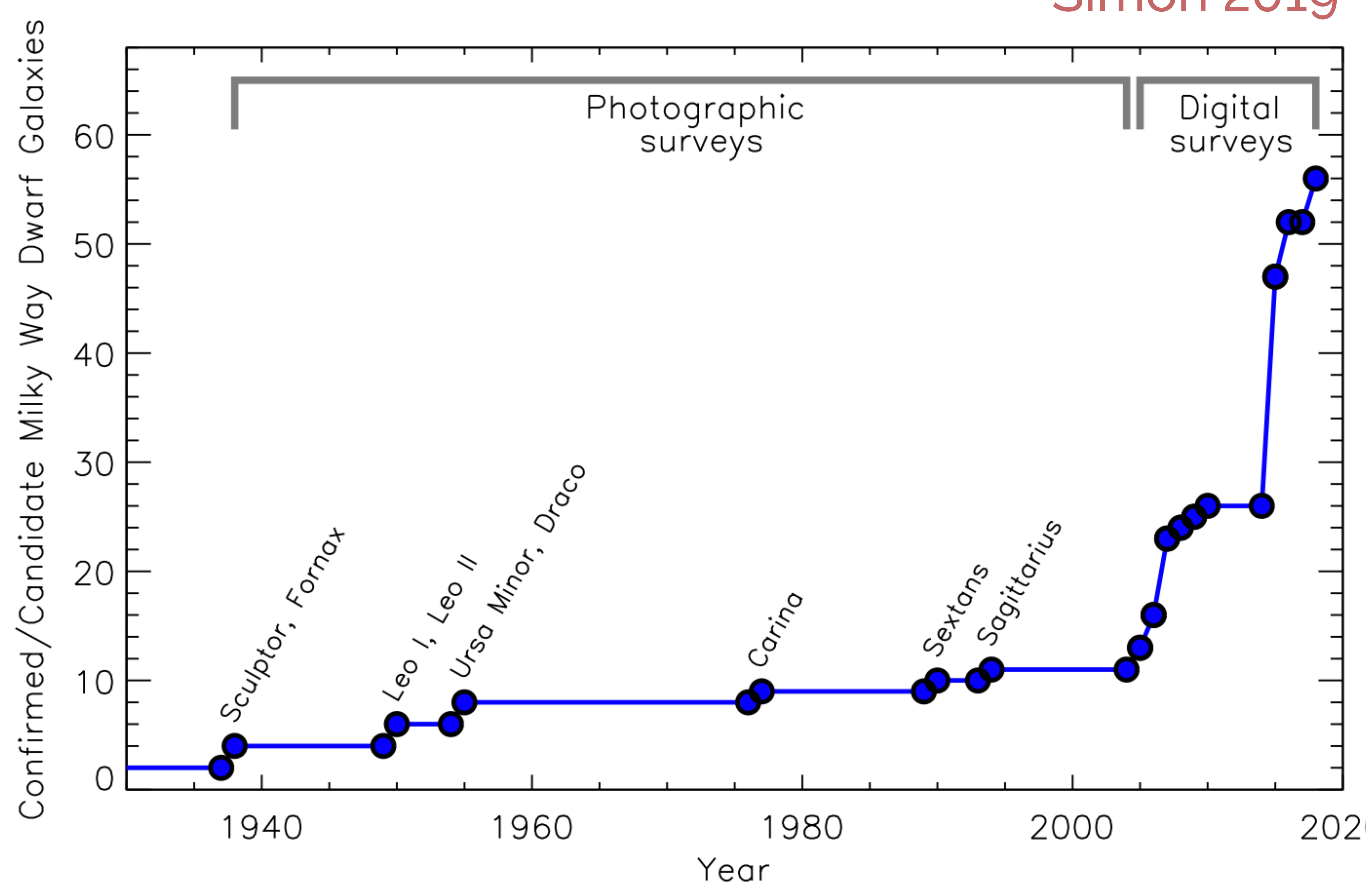
Ultra-faint dwarf (UFD) galaxies

- Simulations: Milky Way should be surrounded by ~125 dwarf galaxies (Newton et al. 2018)
  - ~45 ultrafaint dwarf galaxies ($-8 < MV \leq -3$)
  - ~60 hyperfaint dwarfs ($-3 < MV \leq 0$)
- SDSS and DES data have discovered numerous dwarf galaxy satellites of the Milky Way
- Challenging effort: they are faint and diffuse
- The LSST Survey will detect some of this faint population of dwarf galaxies yet to be discovered

Simon 2019



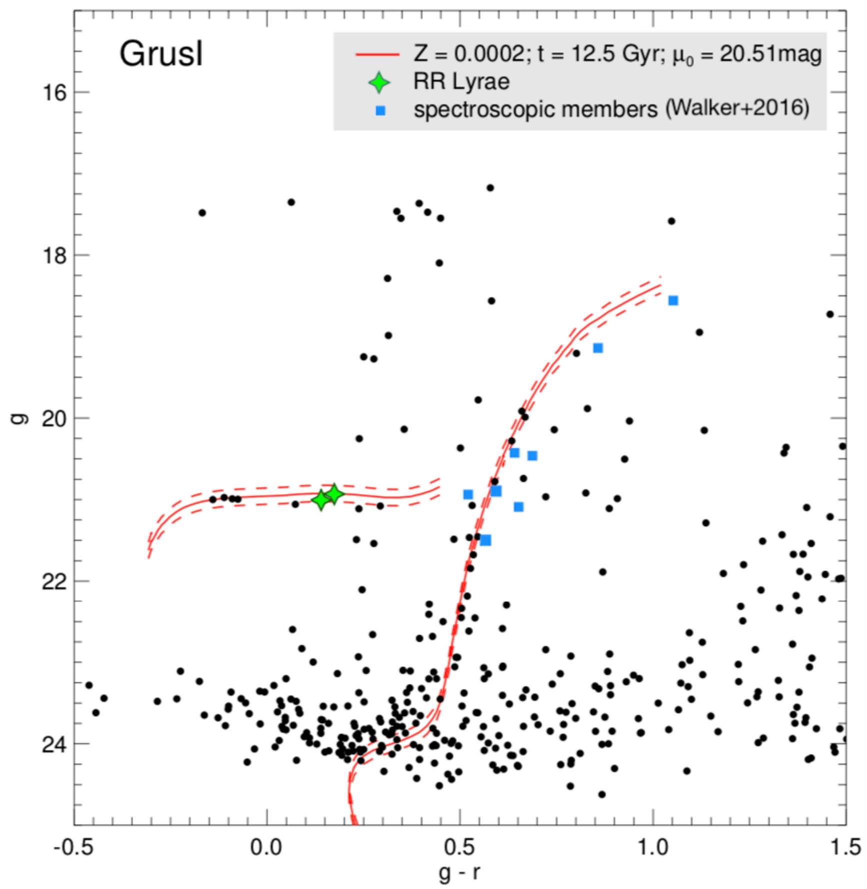
Discoveries with DECam: 22 UFDs

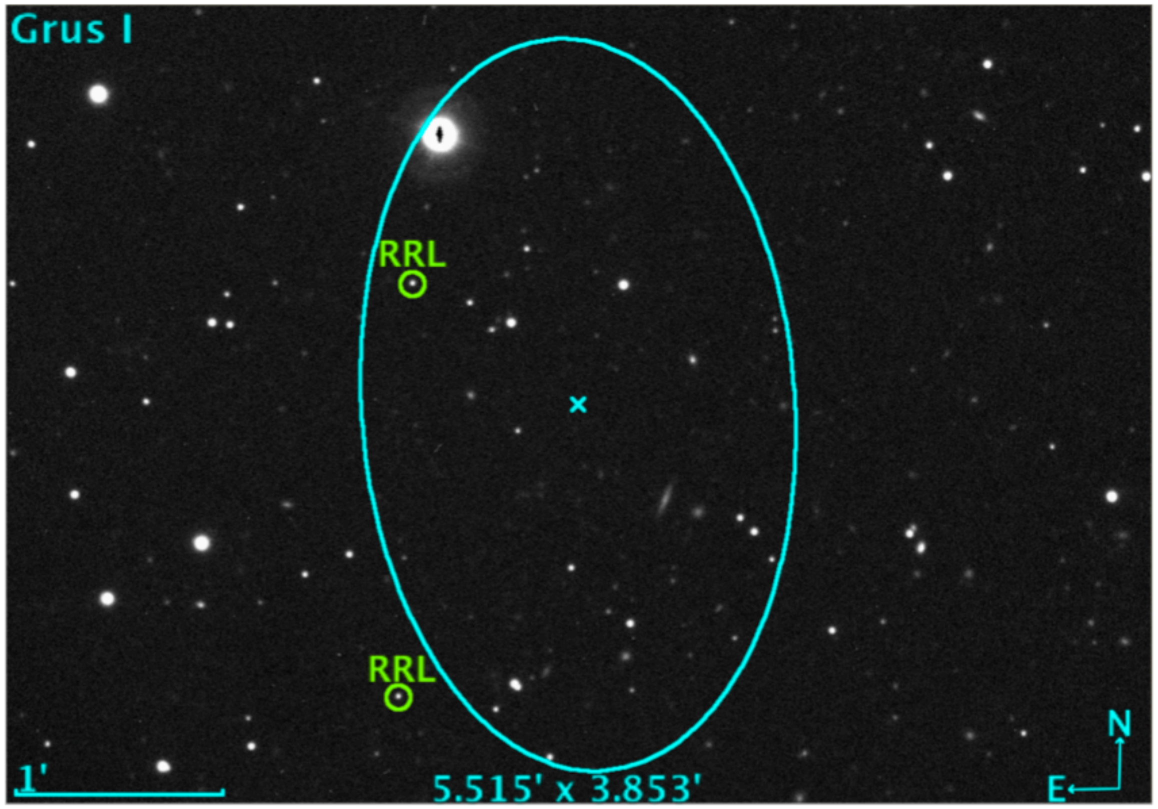


UFD galaxies

* On-going project. Various programs (PI: K. Vivas, PI: C. Martínez-Vázquez) to make time-series for UFDs
* Main goal: To obtain accurate and precise distances in the smallest UFDs using RRLs
* Results for 4 of them are already published in Martínez-Vázquez et al. 2019

Martínez-Vázquez et al. 2019





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

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Only a few RR Lyrae stars

But… better distance estimations

- ☑ Phoenix II – 1 RRL (Mv=-2.7) → $D_\odot$ = 127 ± 6 kpc → r_h = 44 pc — 33 %
- ☑ Grus I – 2 RRLs (Mv=-3.4) → $D_\odot$ = 100 ± 5 kpc → r_h = 65 pc — 5 %
- ☑ Grus II – 1 RRL (Mv=-3.9) → $D_\odot$ = 55 ± 2 kpc → r_h = 96 pc — 3 %
- ☑ Indus I = Kim 2 – 0 (Mv=-1.5) probable GC
- ☑ Reticulum III – 0 (Mv=-3.3)

Constraint better their physical sizes

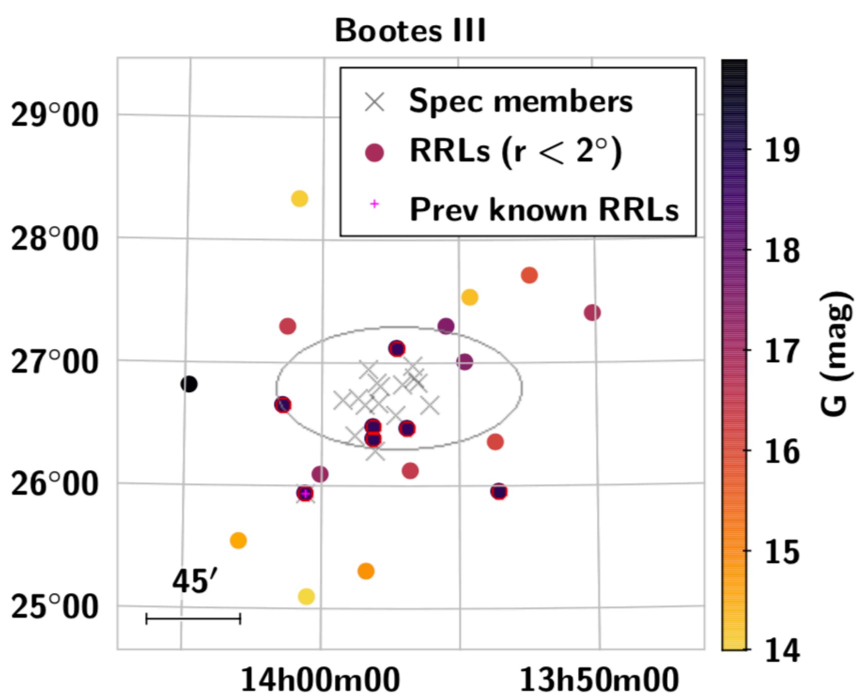
Martínez-Vázquez et al. 2019

UFD galaxies

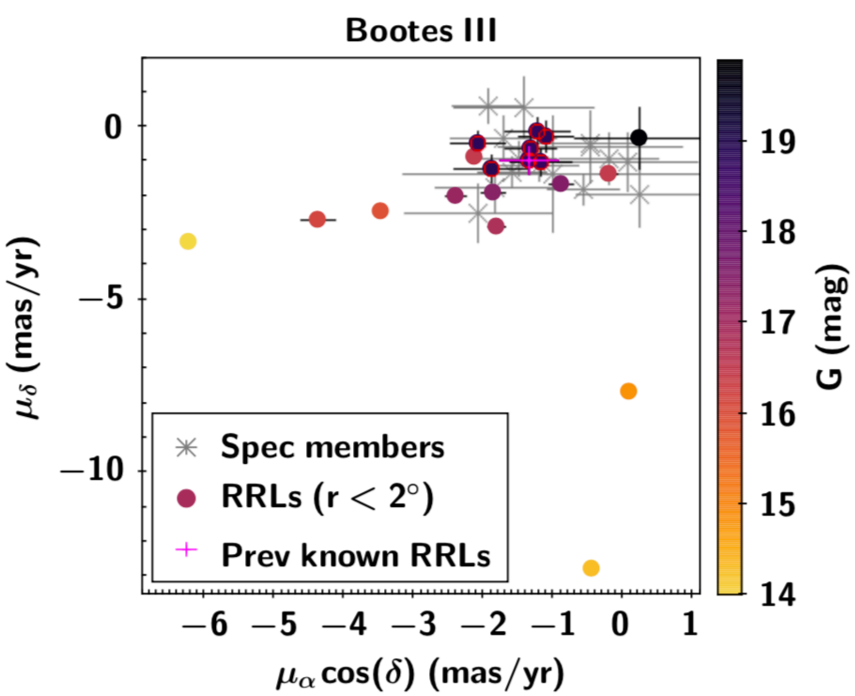
Vivas, Martínez-Vázquez & Walker, 2020

- 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)

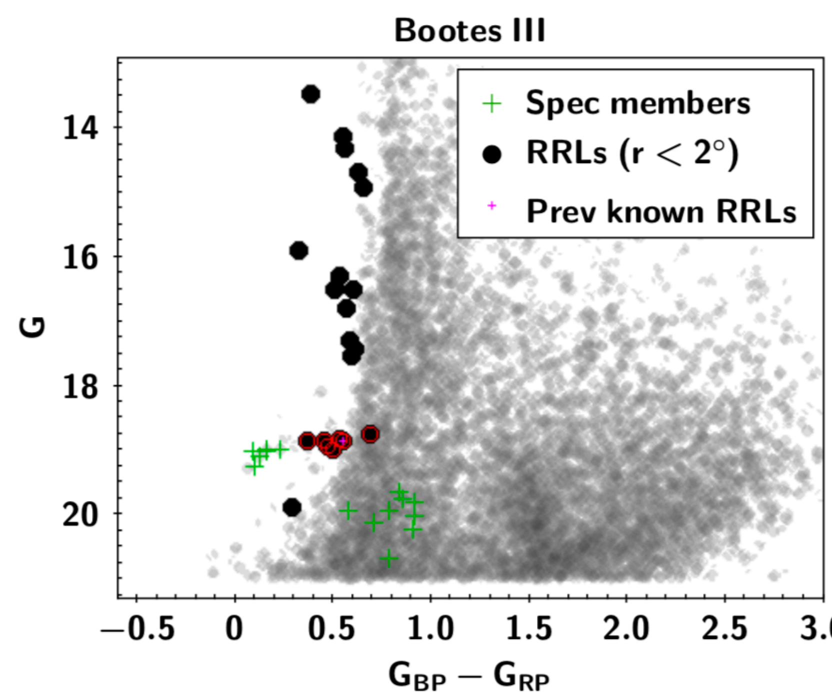
Sky location



Proper Motion



CMD



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Vivas, Martínez-Vázquez & Walker, 2020

- 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.

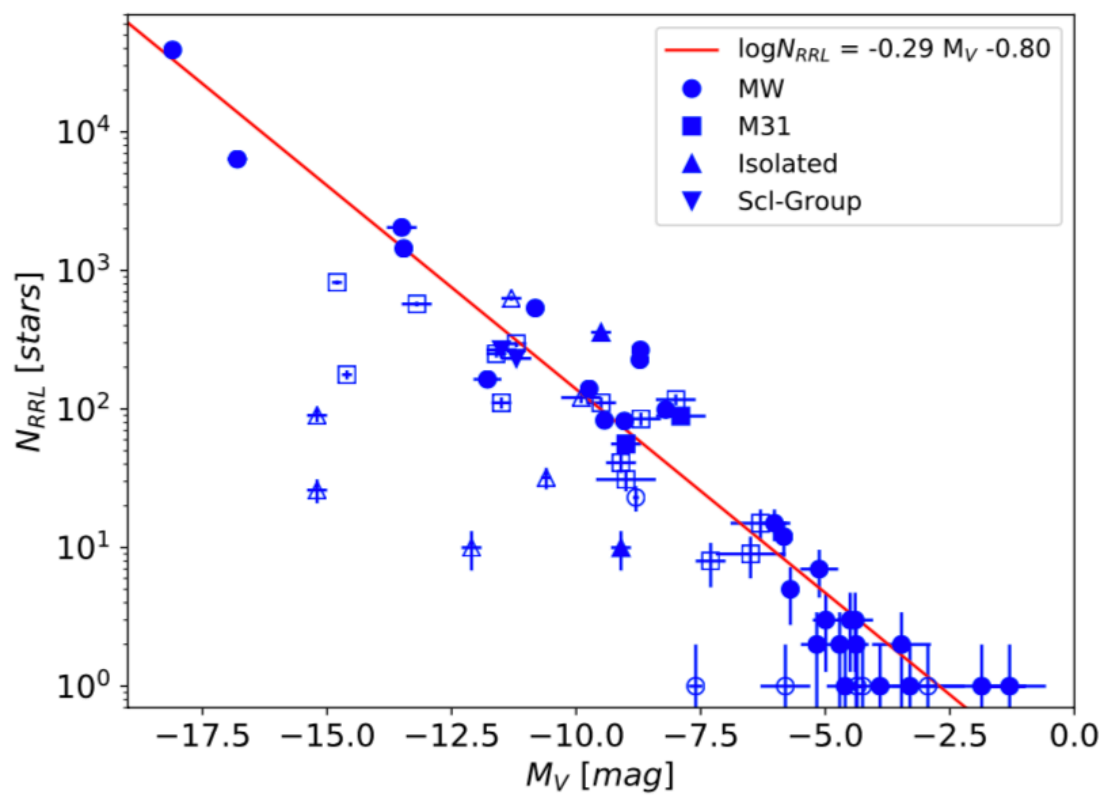
  - First RRL detection in Tuc II

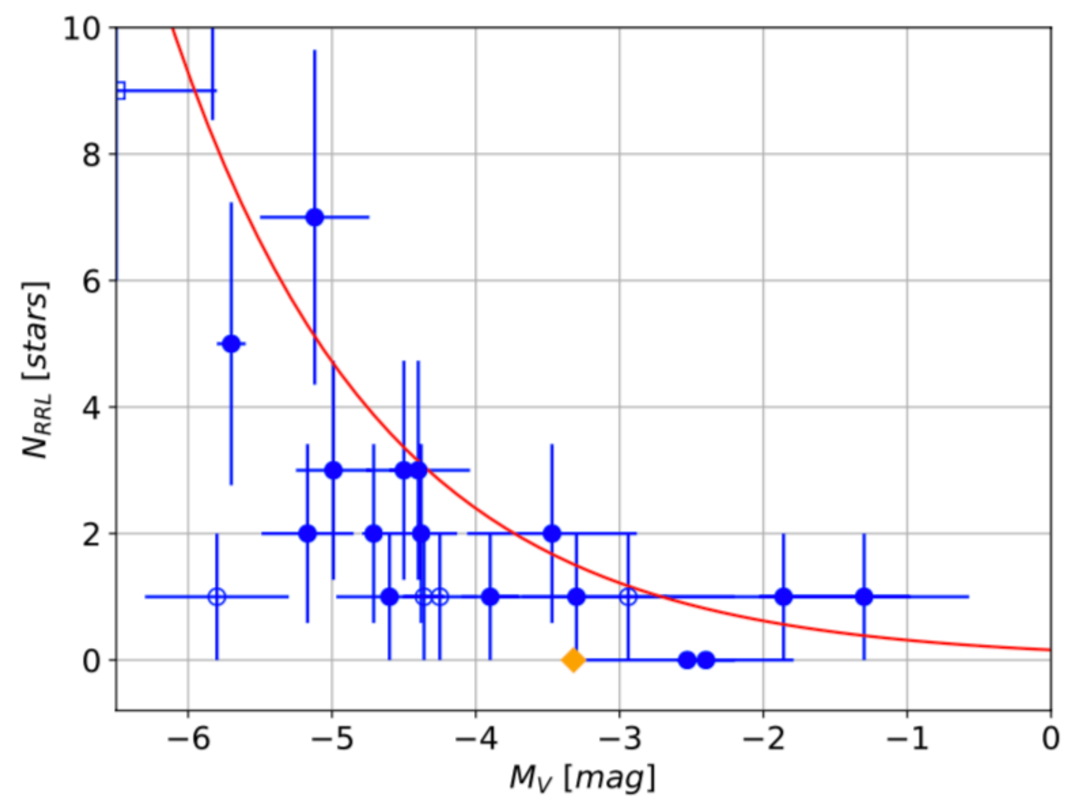
  - Additional RRL members: UMa II, Com Ber, Hyd I, Boo I, Boo III

  - Extra-tidal RRLs: Boo I, Boo III, Sgr II, Tuc III, Eri III, Ret III (radial velocities are needed to confirm these stars)

Number of RR Lyrae stars in dwarf galaxies

- Classical satellites show correlation between the number of RRLs and the M_V of the host
- The method of finding new UFDs by using two or more clumped RRLs may work only for systems brighter than M_V ~ −5 mag





Martínez-Vázquez et al. 2019

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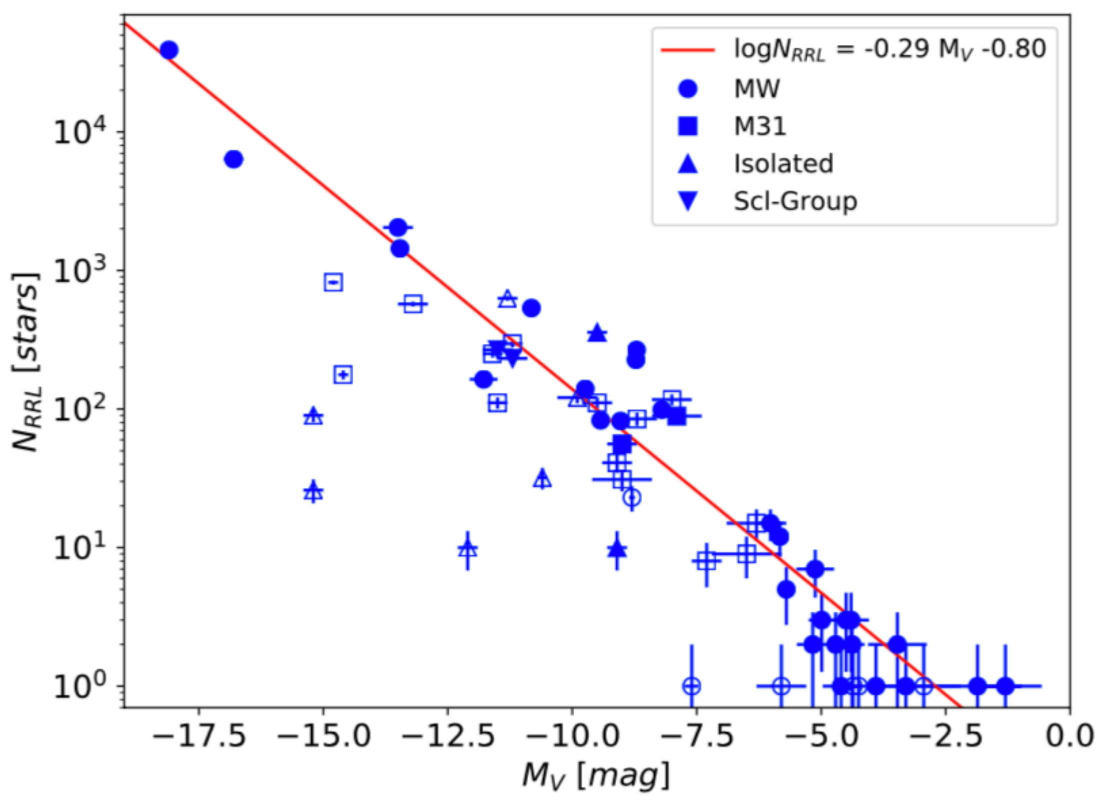
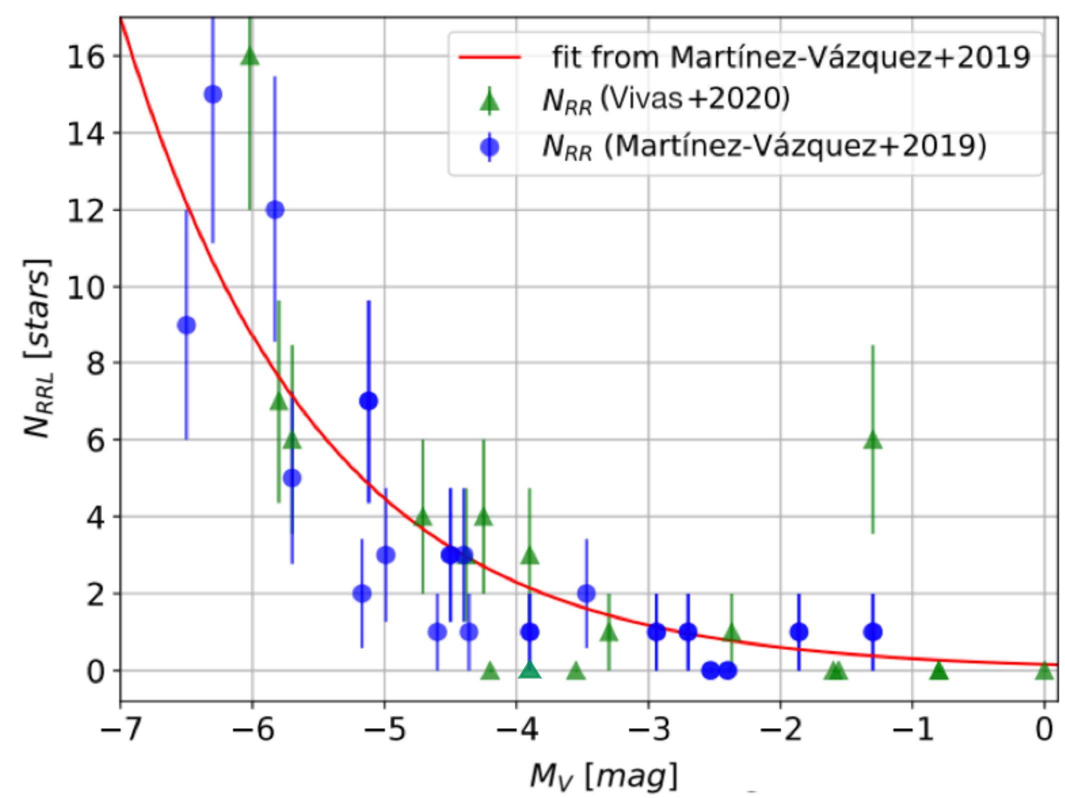




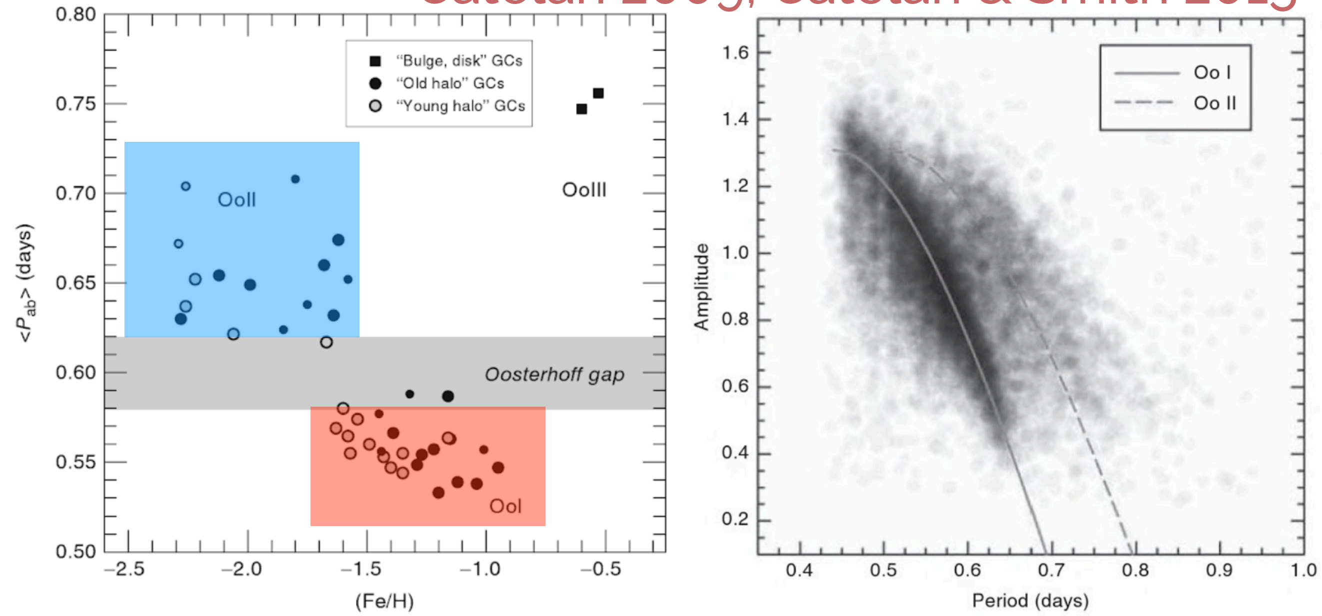
Martínez-Vázquez et al. 2019

Vivas, Martínez-Vázquez & Walker, 2020

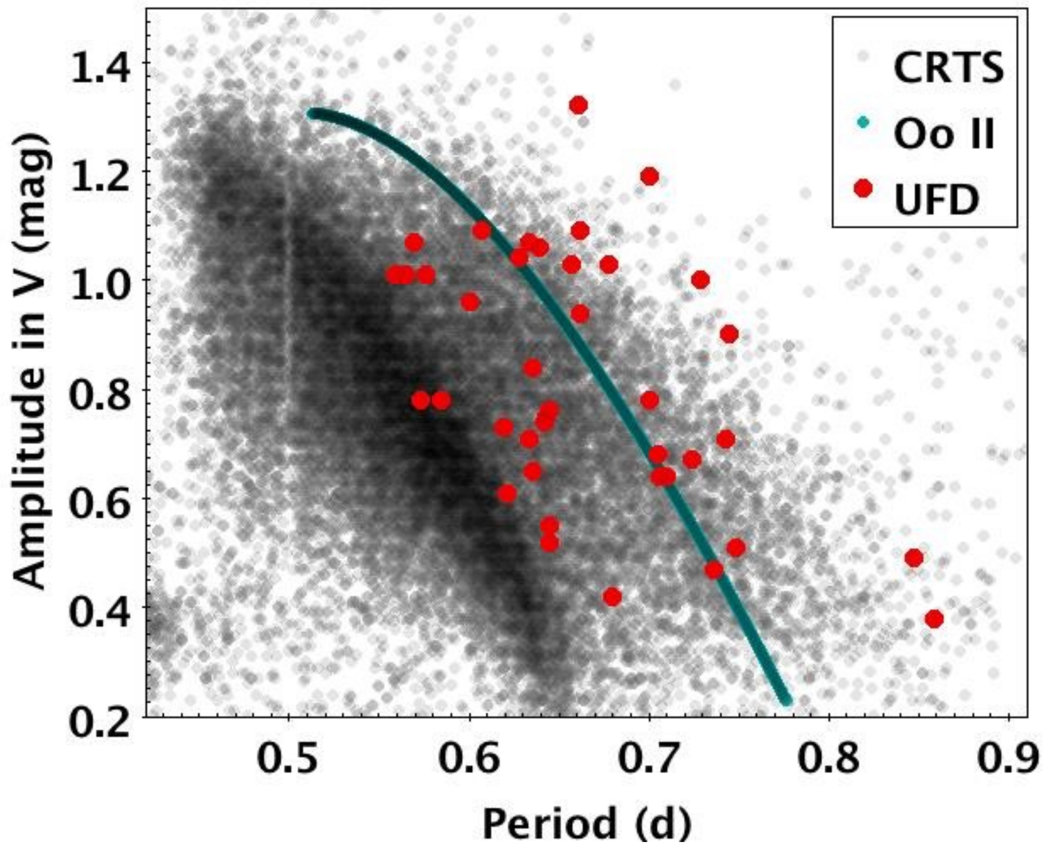
Insight into the Halo formation

* Period-Amplitude distribution of RRLs in UFDs is different than that of the population of the halo (up to ~90 kpc)

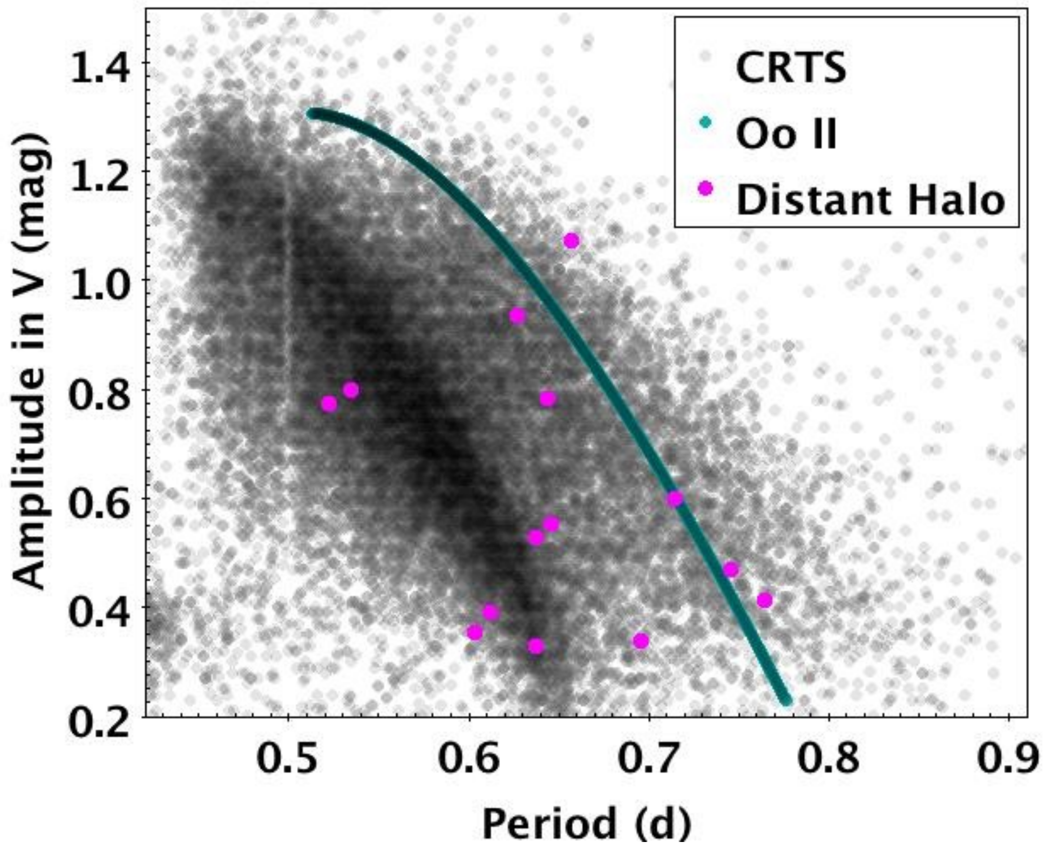
Catelan 2009, Catelan & Smith 2015



Vivas et al. 2016 + updates



Using Medina et al. 2018 data



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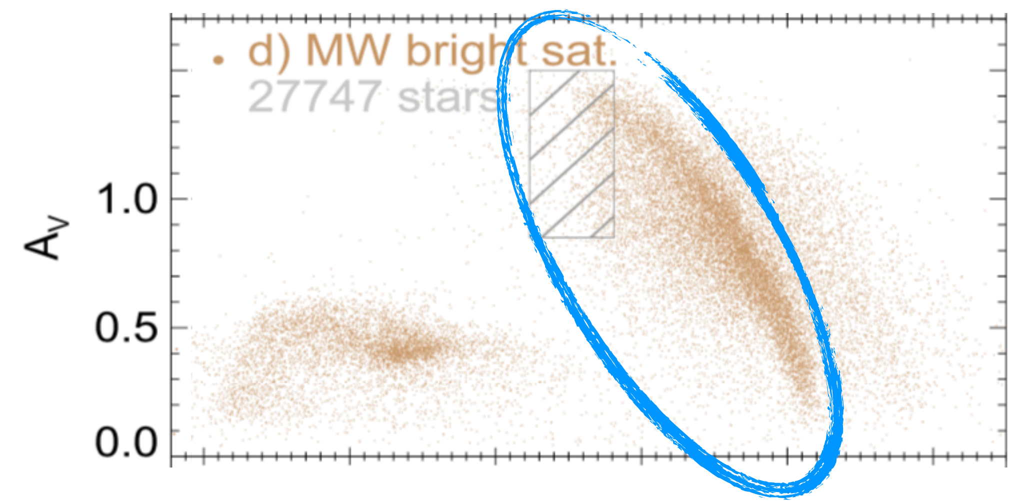
Monelli et al. 2017



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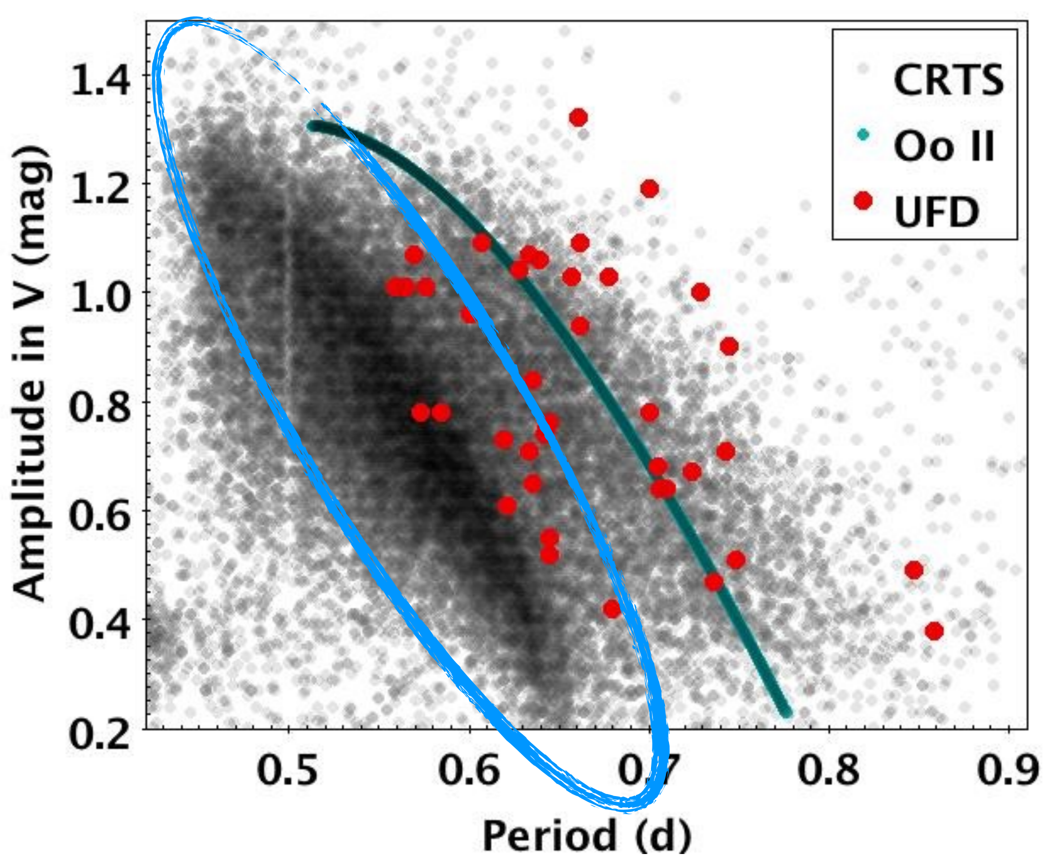

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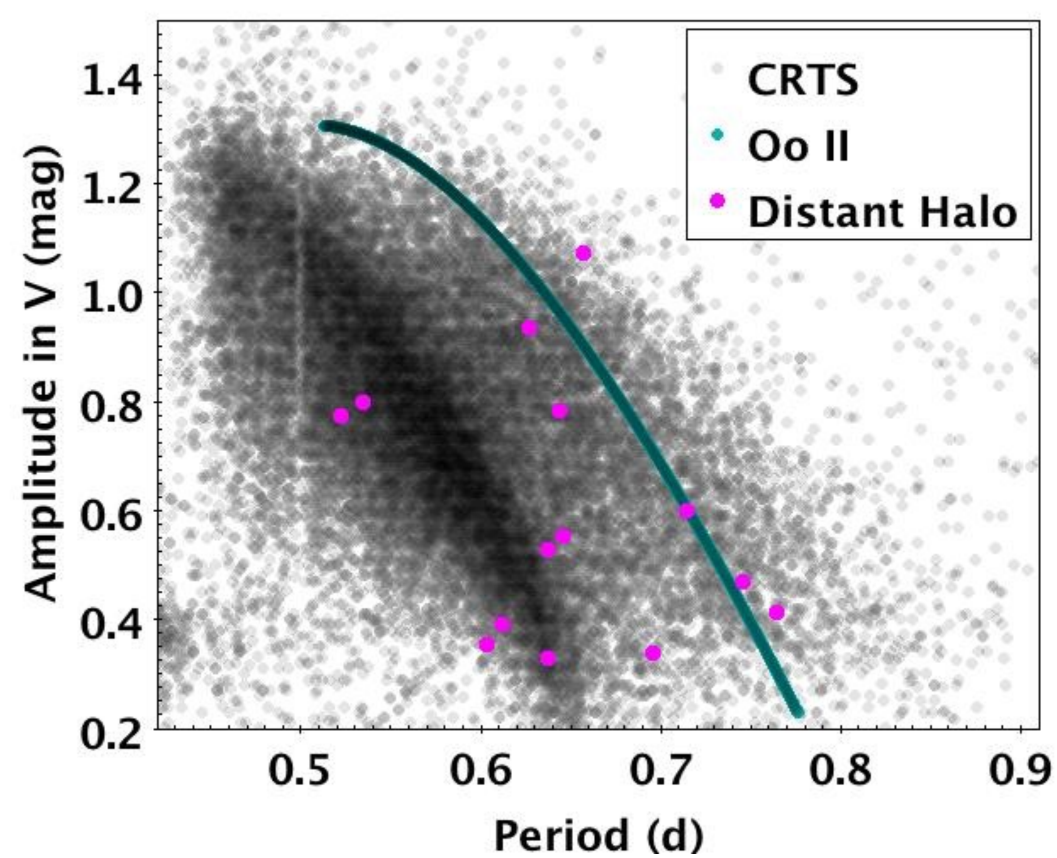

Summary

- ✓ 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. They provide a direct observable to trace the early star formation of the host galaxy, and constraints to galaxy formation and evolution models.
- ✓ The RRL stars can be used to derive the metallicity gradients of a purely old population of galaxies out to 2 Mpc (6 Mpc with ELTs), getting insights into their early evolution.
- ✓ 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.