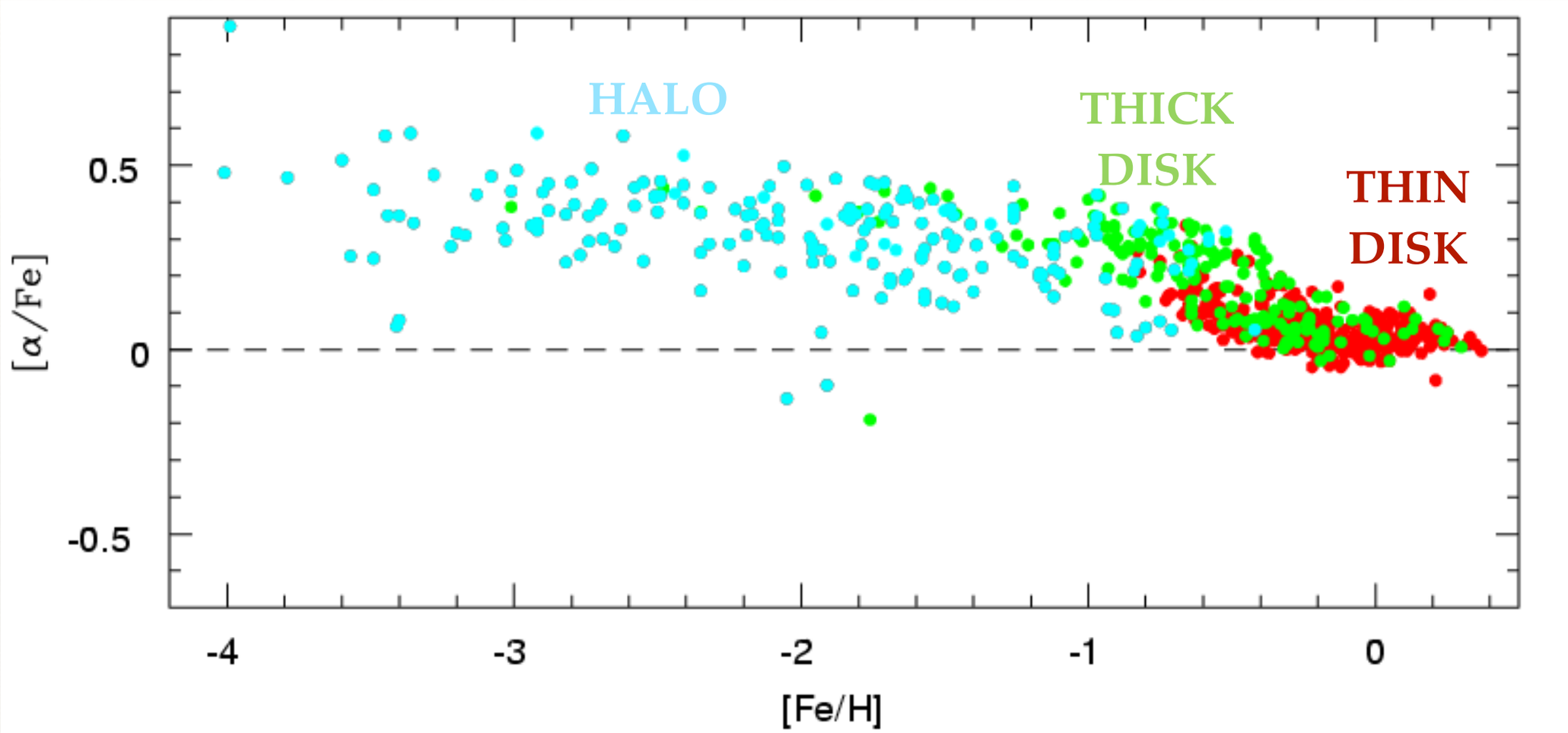
RR Lyrae stars: building-up the Galactic halo with dwarf spheroidals

G. Fiorentino INAF-Osservatorio Astronomico di Bologna

Galactic Archaeology to constrain our Galaxy formation

Venn +04



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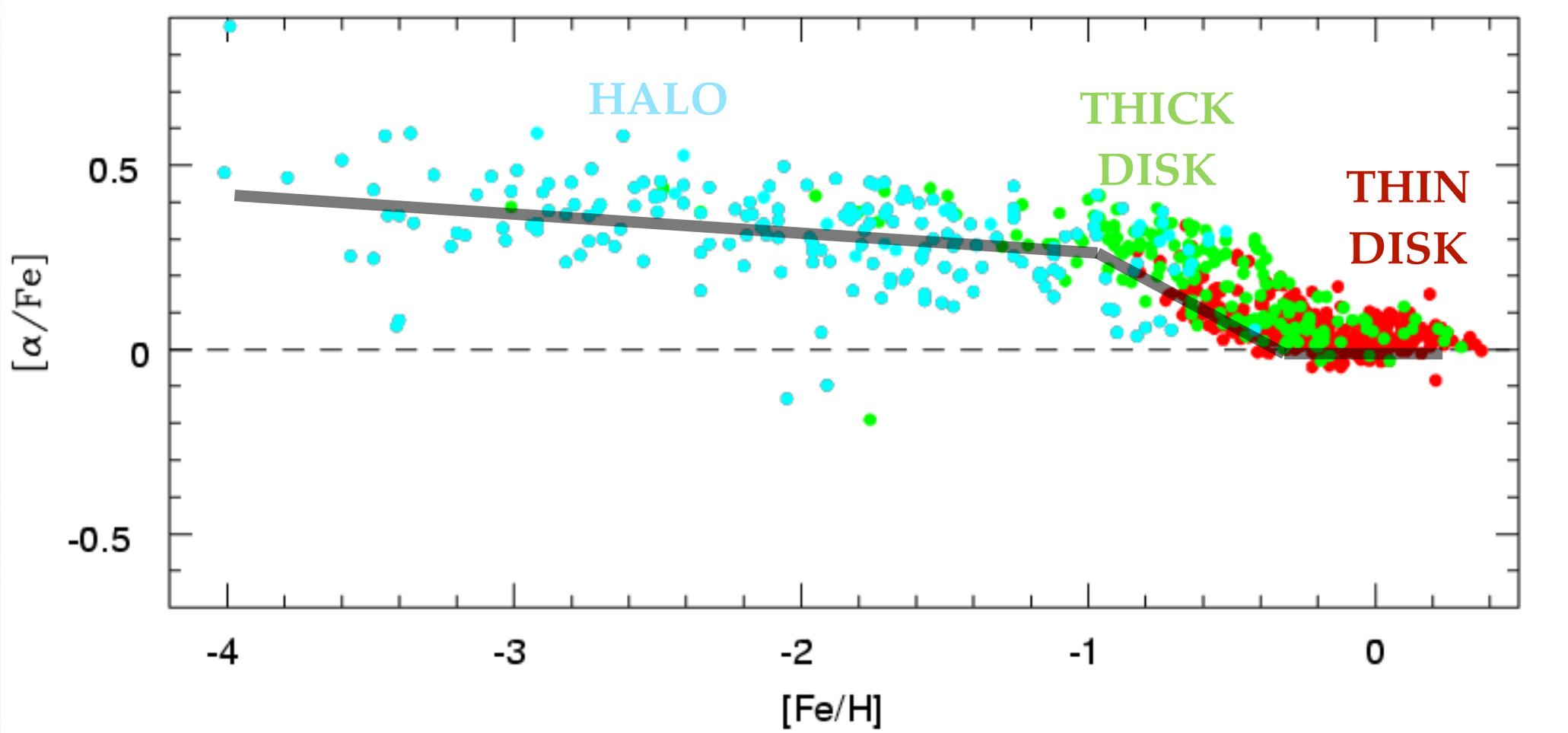

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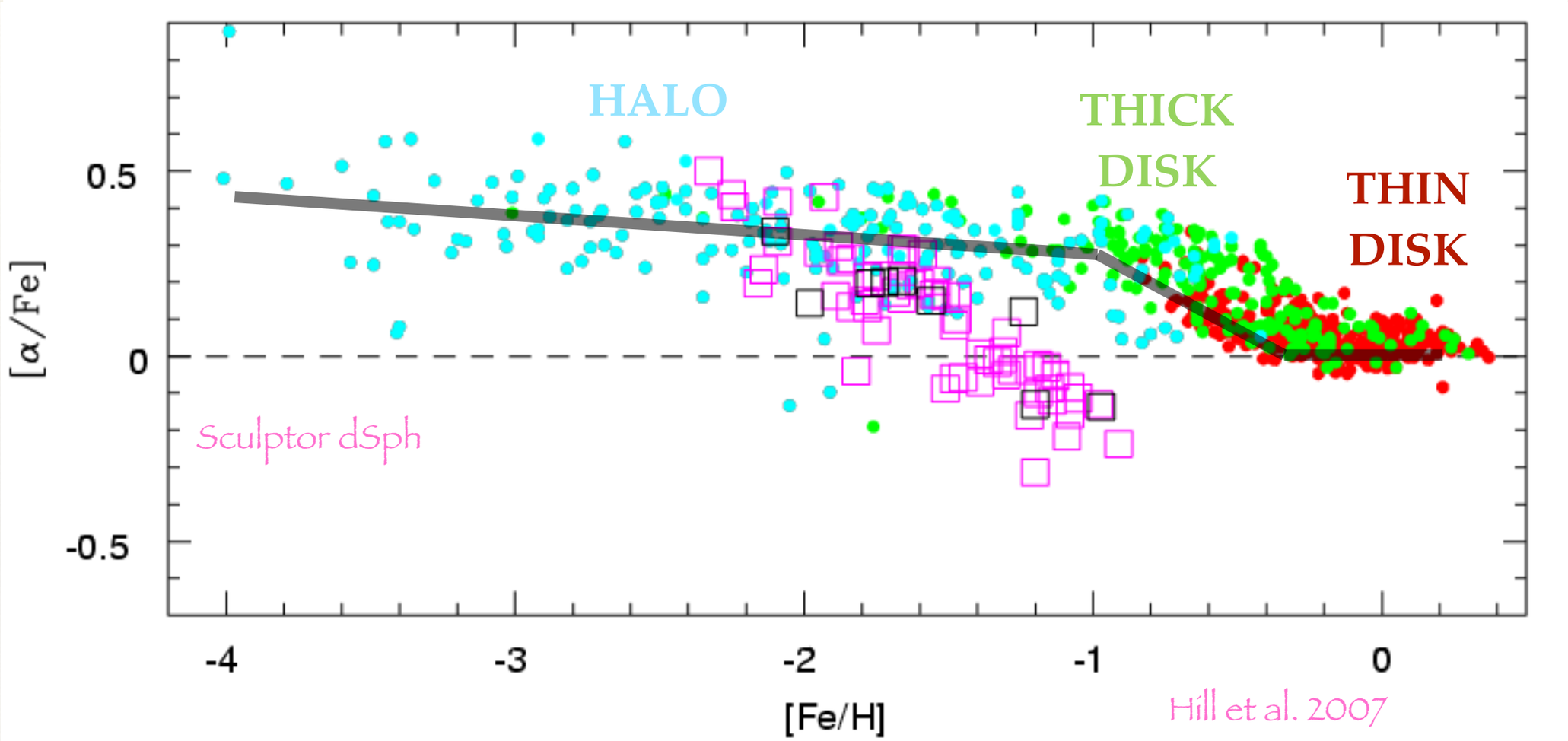

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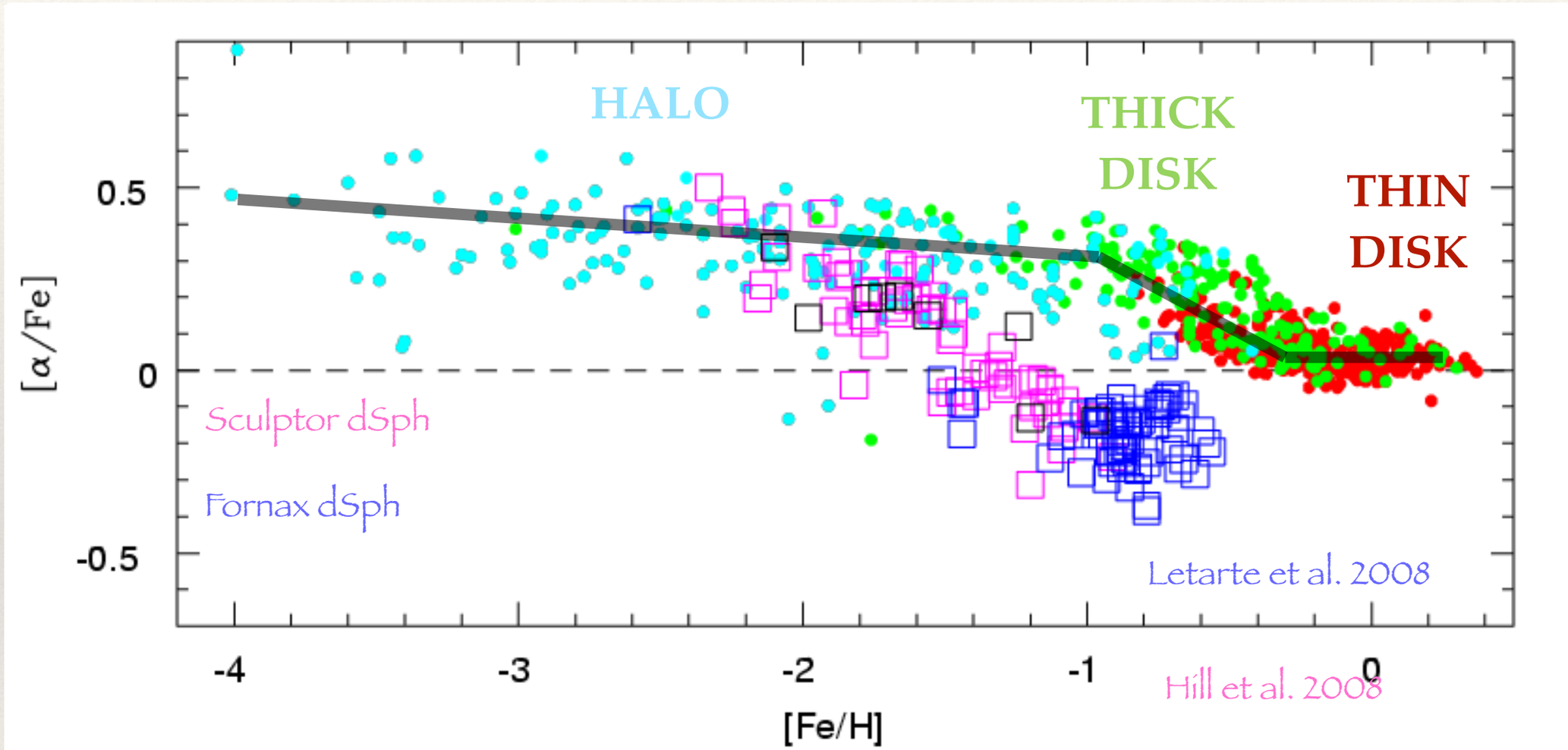

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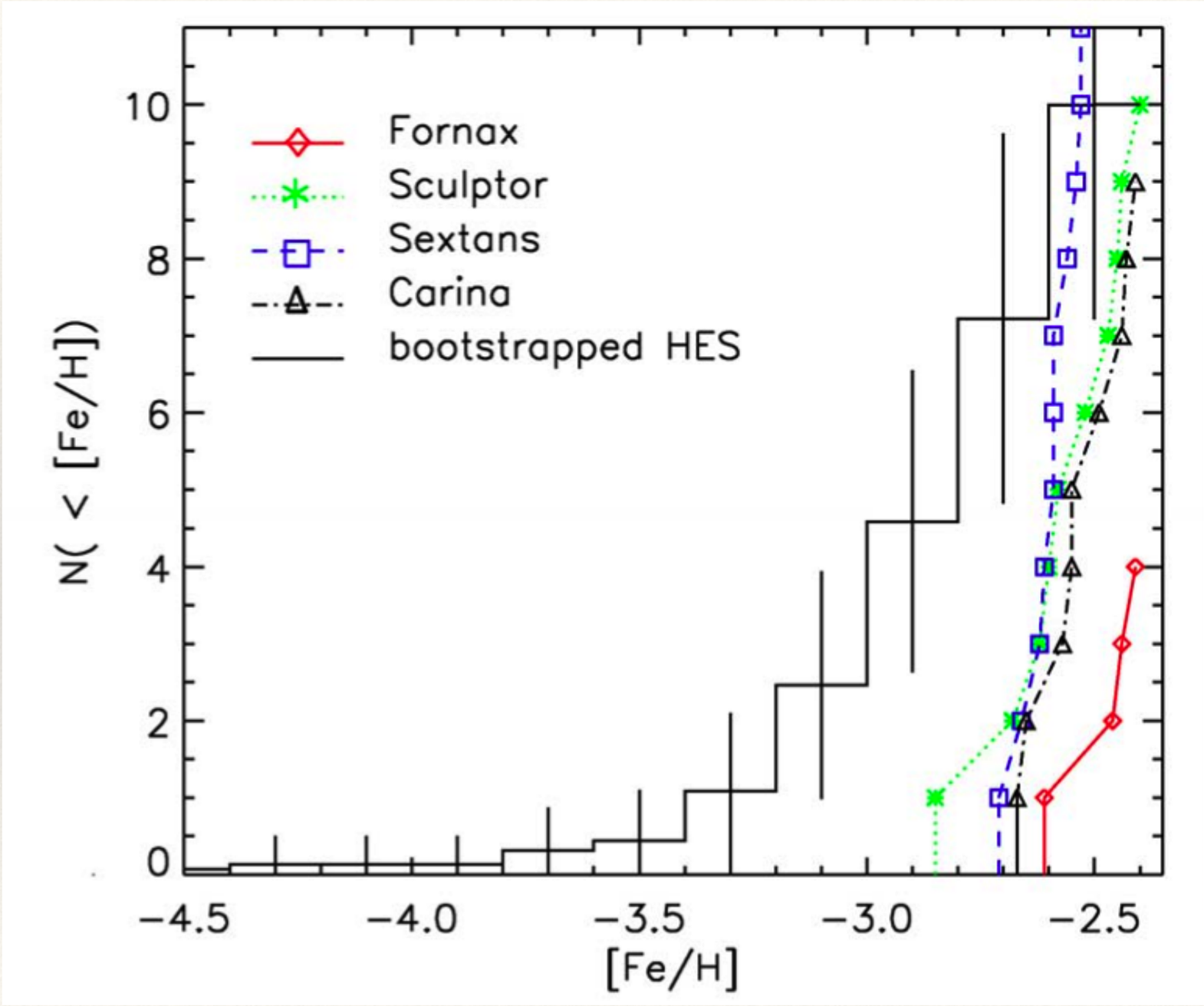
Helmi +06



Galactic Archaeology to constrain our Galaxy formation

Schorck +06

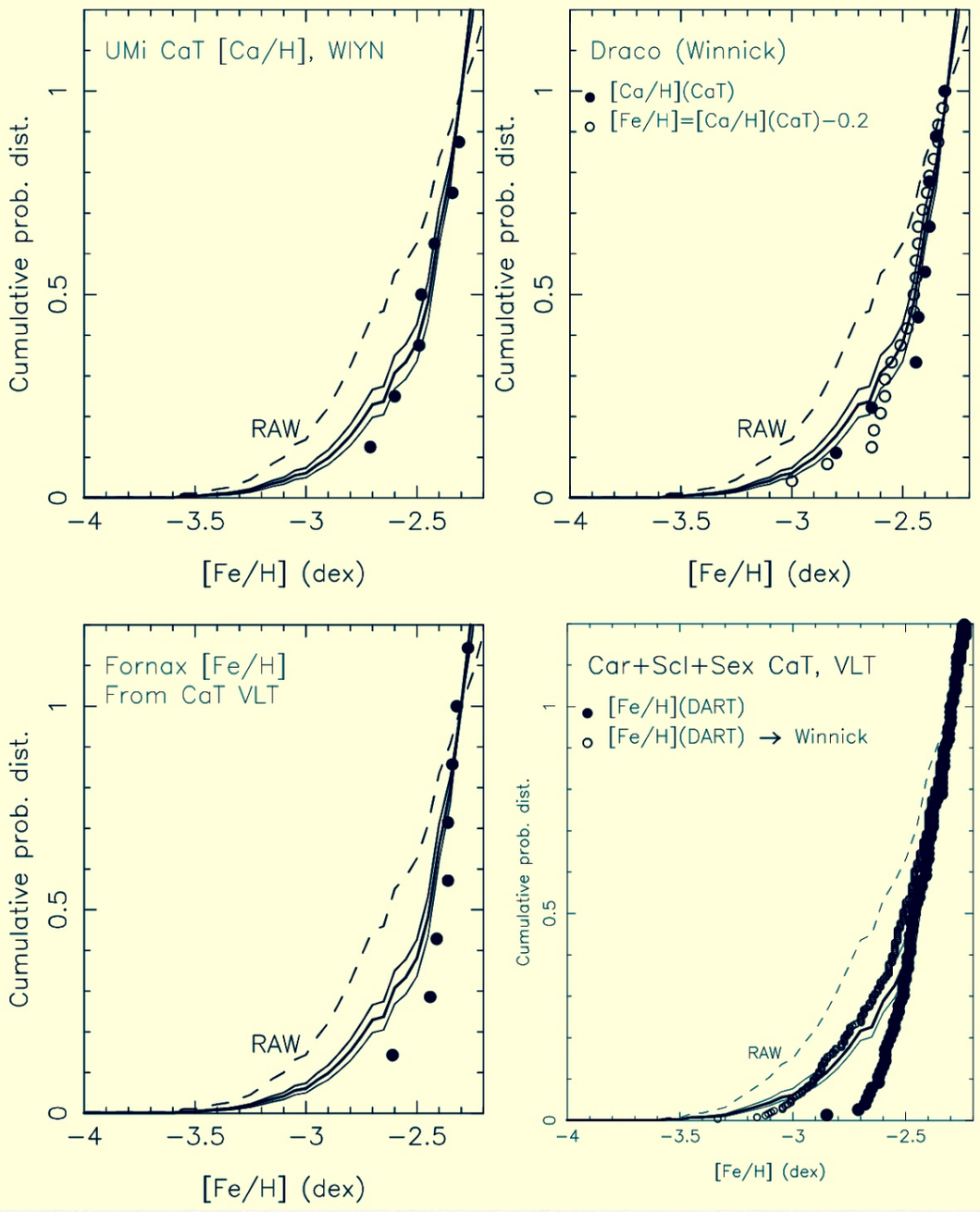


Fig. 18. Cumulative MDF for [Fe/H] < −2.3 as observed in the HES (dashed line), and with corrections for the HES selection efficiency applied (solid lines; see the caption of Fig. 17 and the text for a detailed explanation). The filled circles indicate the cumulative MDFs of Ursa Minor (*upper left*) and Draco (*upper right*), using the [Ca/H] values from Winnick (2003); for Draco we also show an estimate of the MDF for [Fe/H], assuming that [Fe/H] = [Ca/H] − 0.2 (open circles). In *the lower left panel* we show a comparison of the cumulative MDF for Fornax from Battaglia et al. (2006). In *the lower right panel* the combined cumulative MDFs of Carina, Sextans, and Sculptor based on [Fe/H] values determined in the DART project (filled circles; this data was kindly provided by the DART team) is compared to that of the HES. The result adopting the calibration of Winnick (2003) instead is shown as the open circles.

Why RR Lyrae stars are so interesting for Galaxy formation?

- old stellar population tracers
  (HB stars, age > 10Gyr)

- they are distance indicators,
  they can trace different
  components in the Galaxy

- they are almost in everywhere.
  Galactic halo/bulge/thick
  disk, globular clusters,
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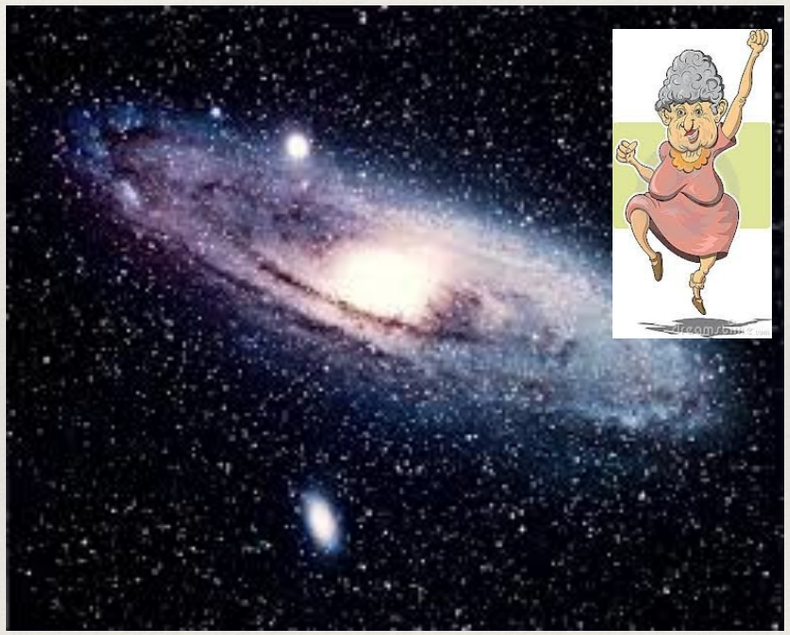

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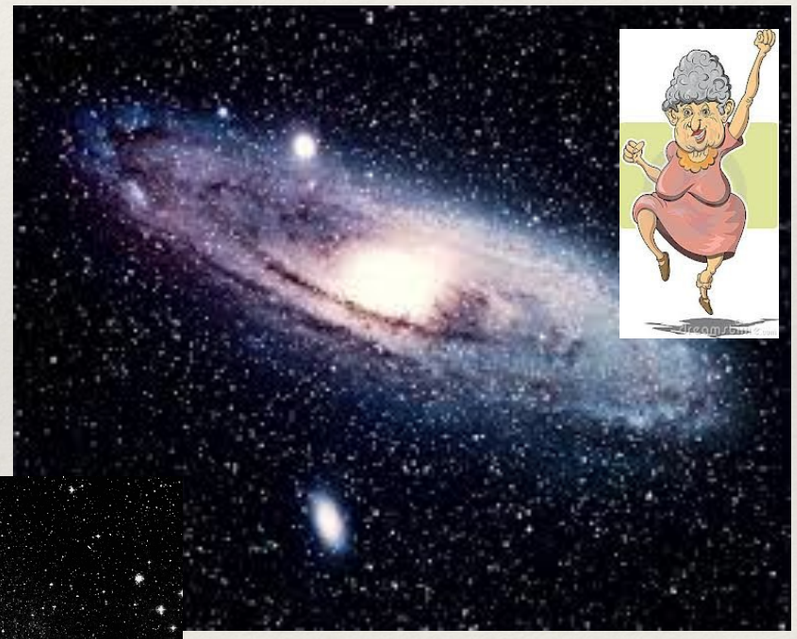

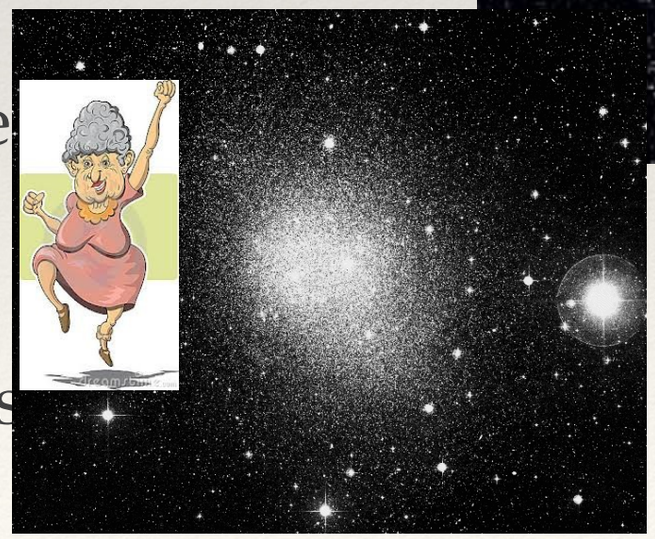

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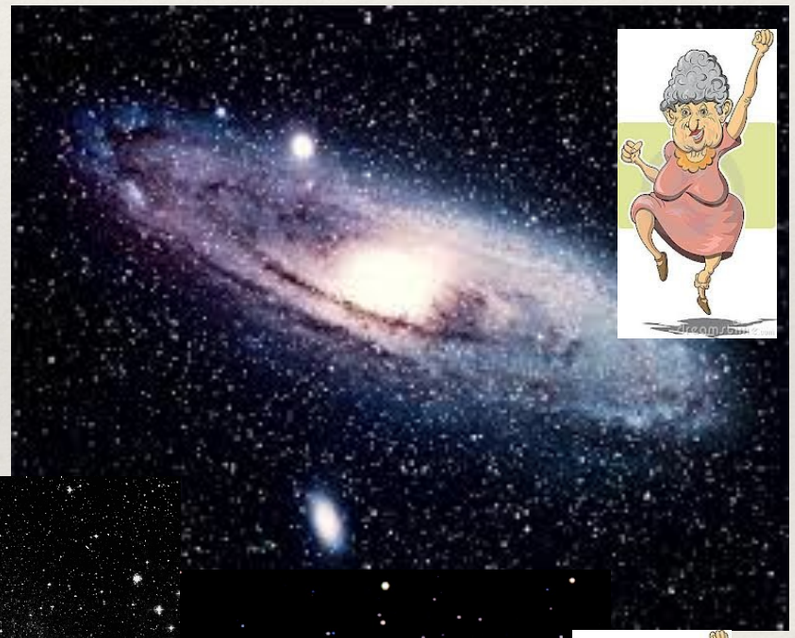

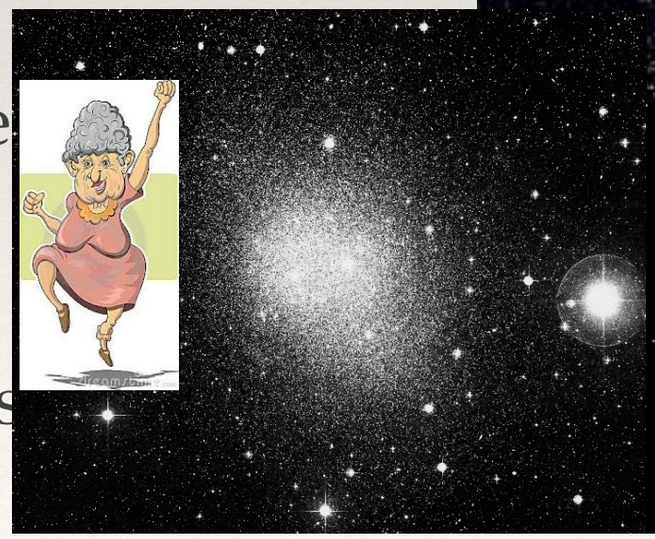

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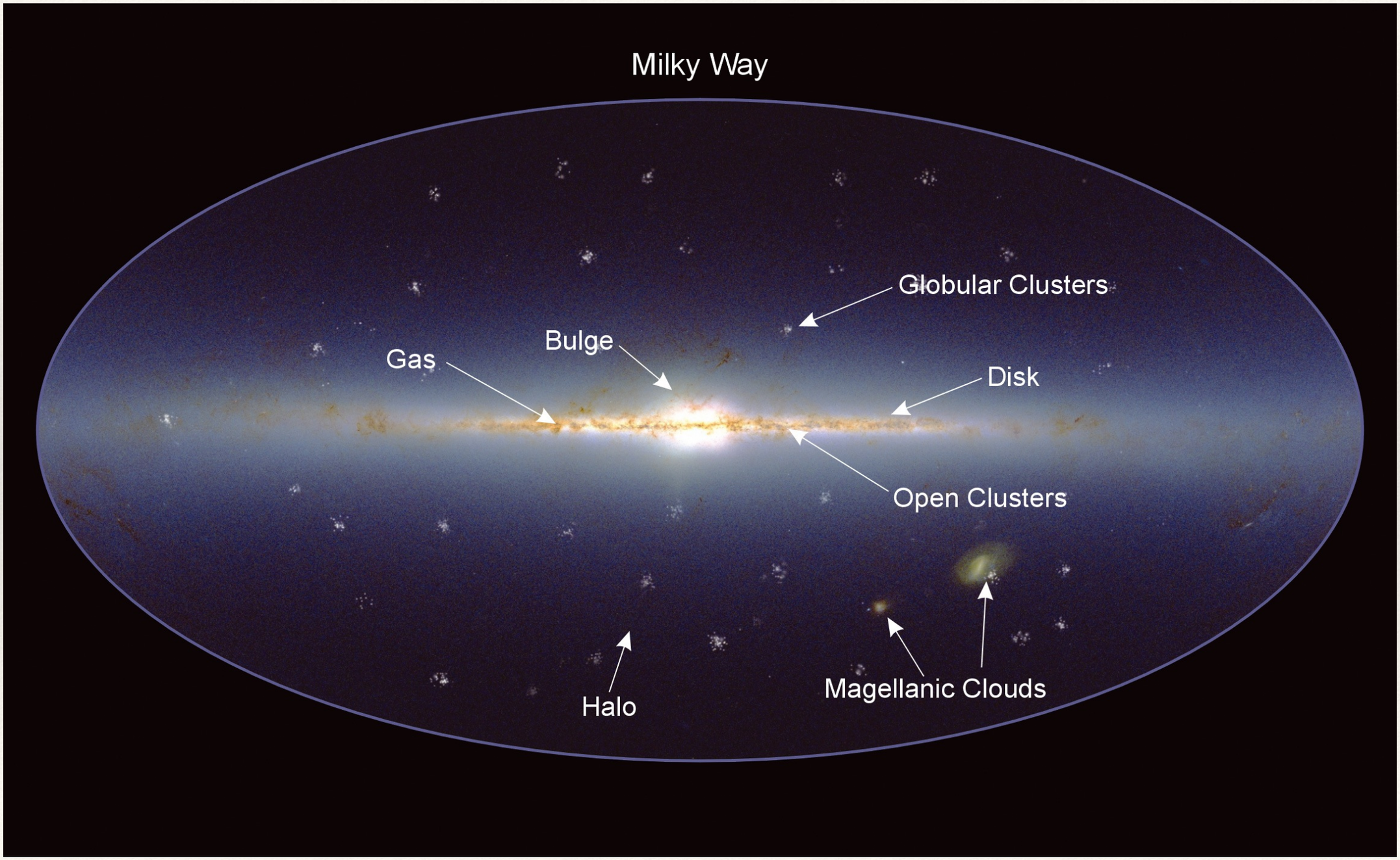

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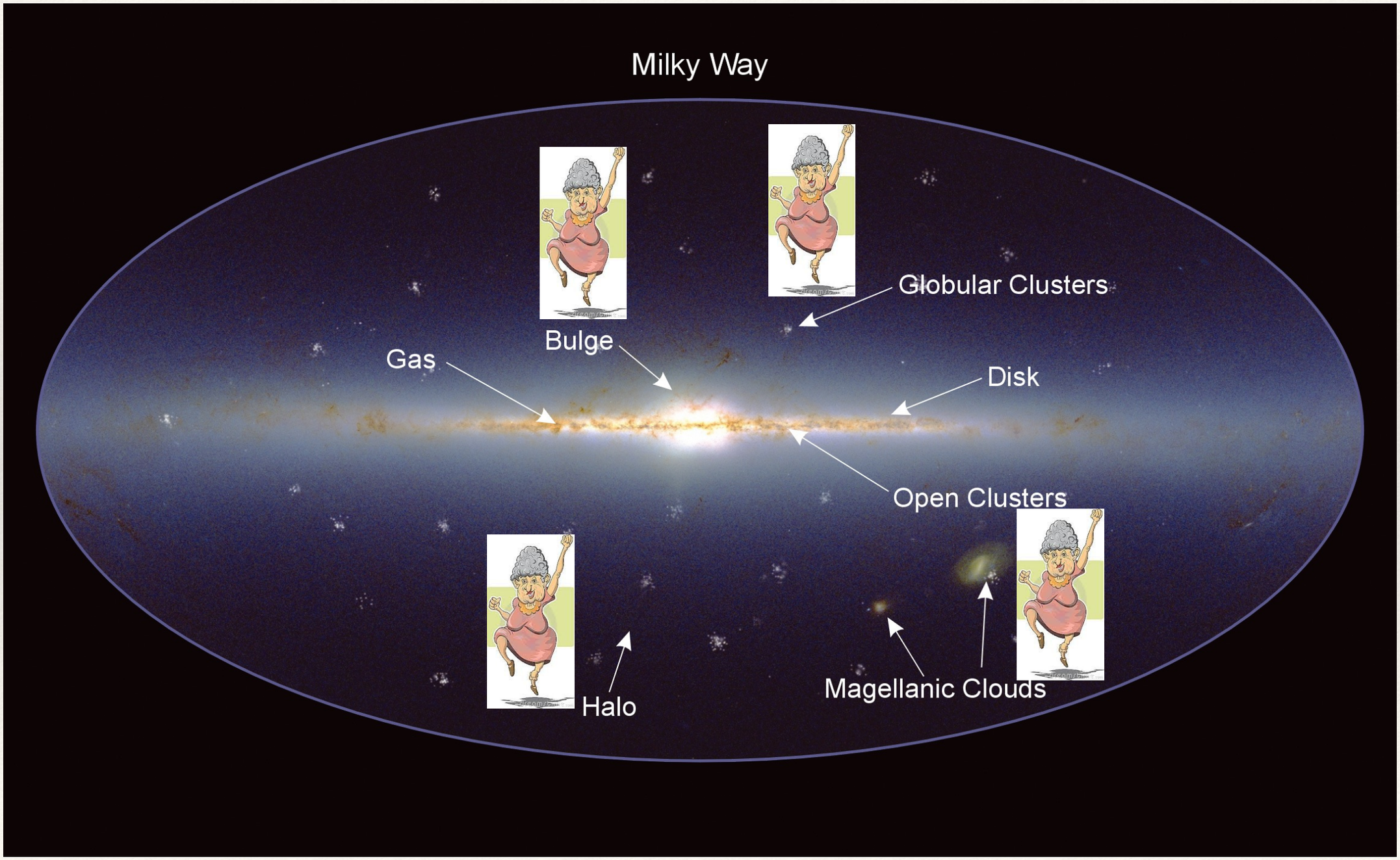
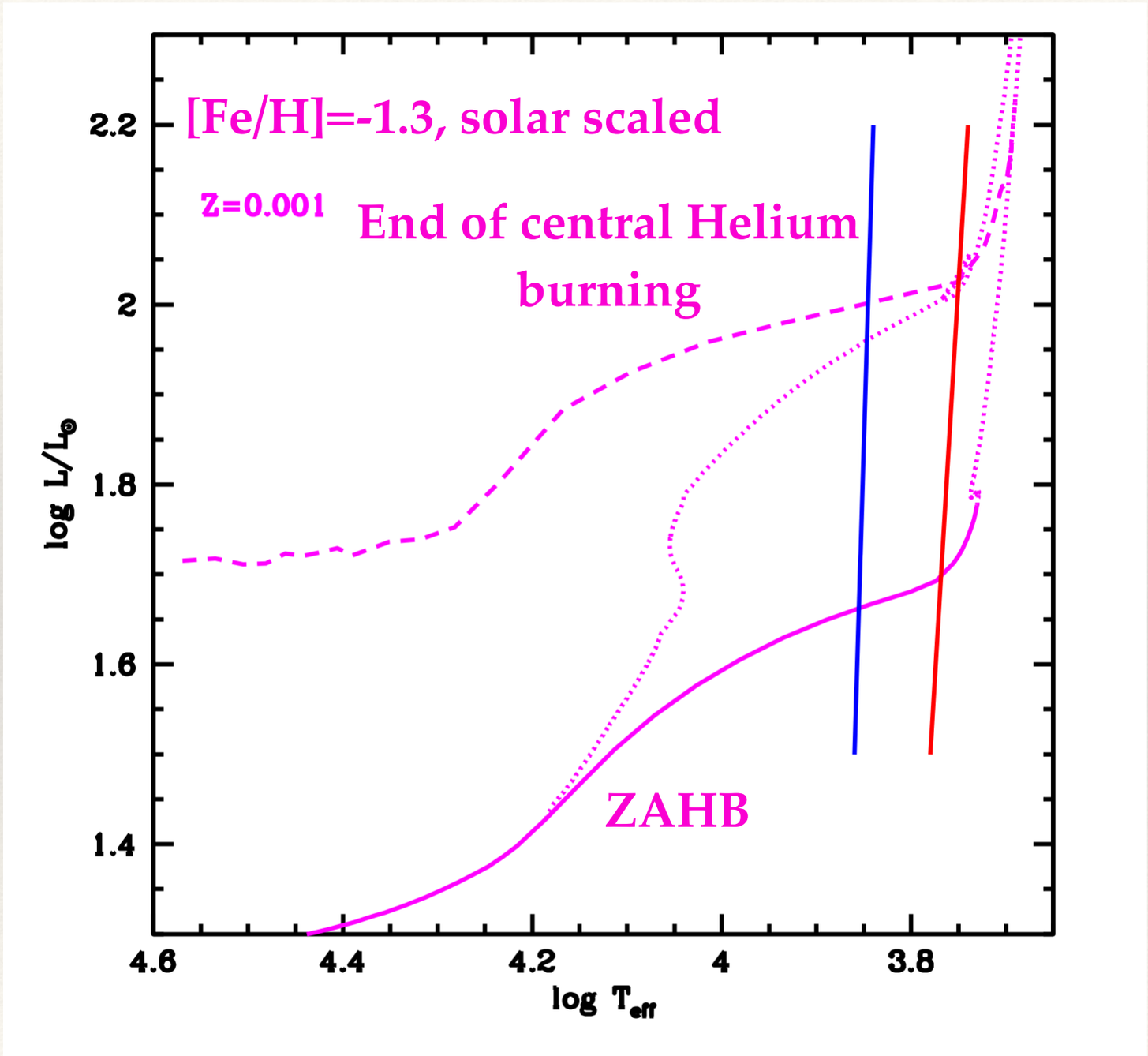


RR Lyrae, evolutionary status



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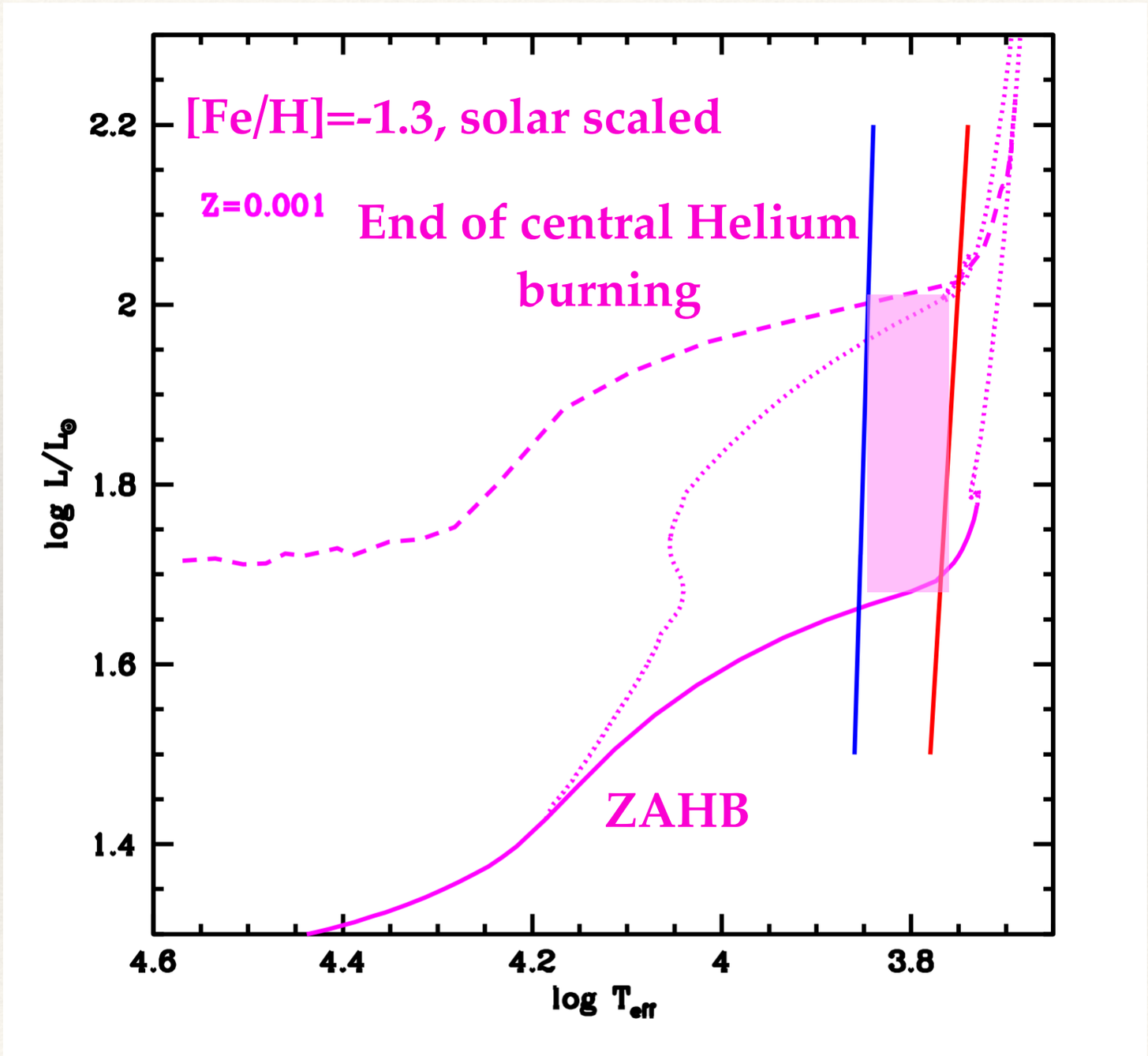
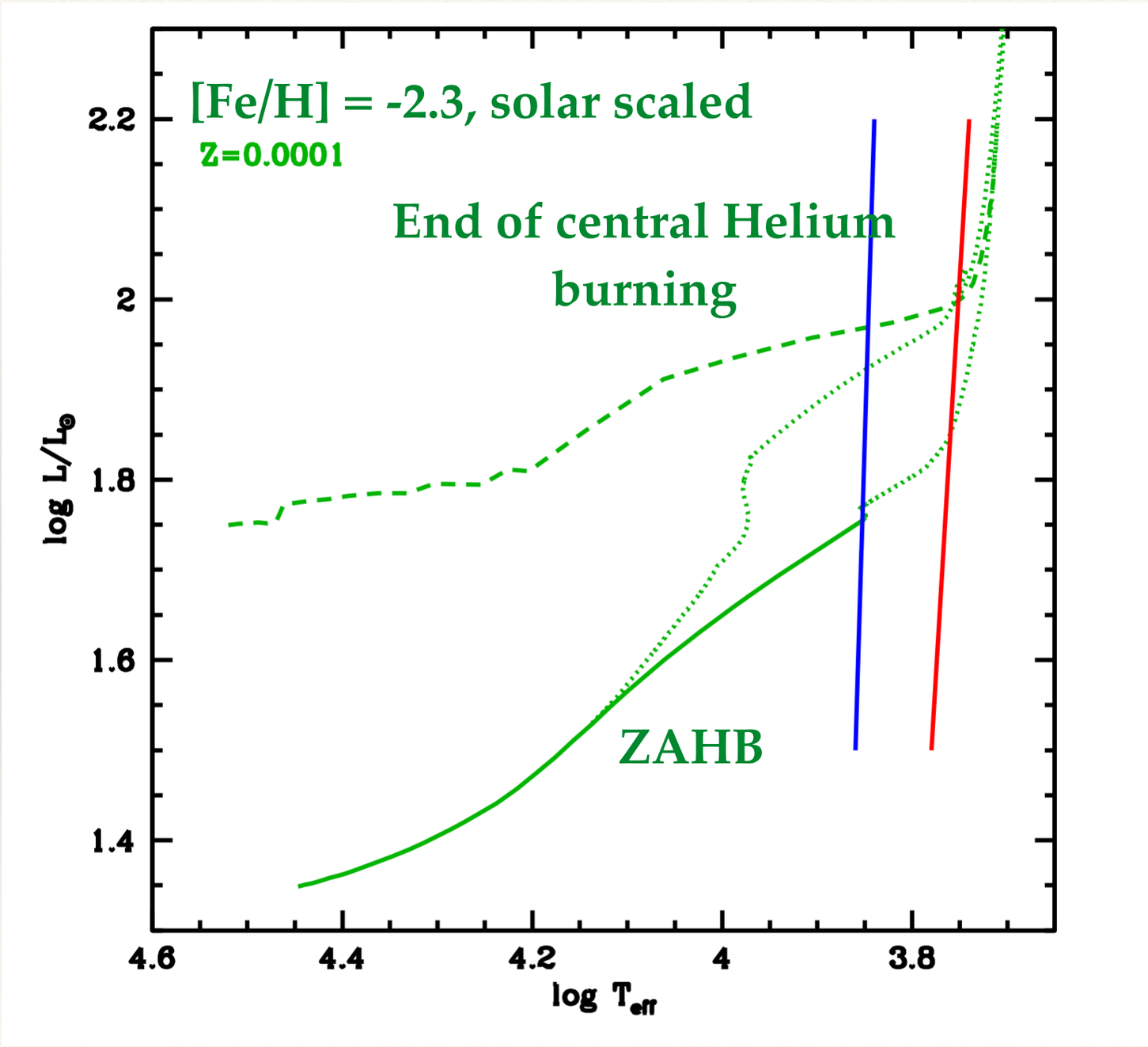


RR Lyrae, evolutionary status: metallicity dependence



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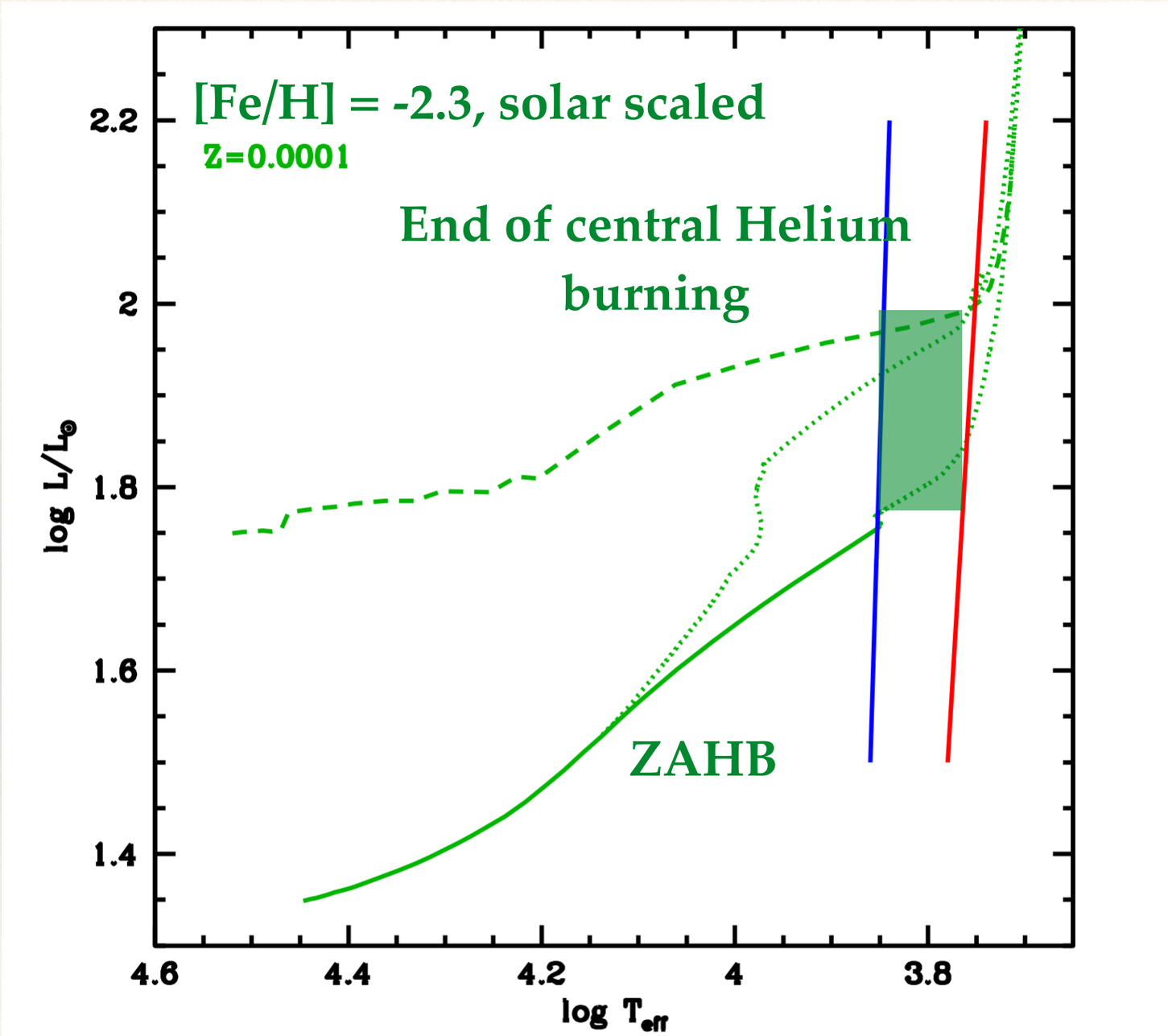

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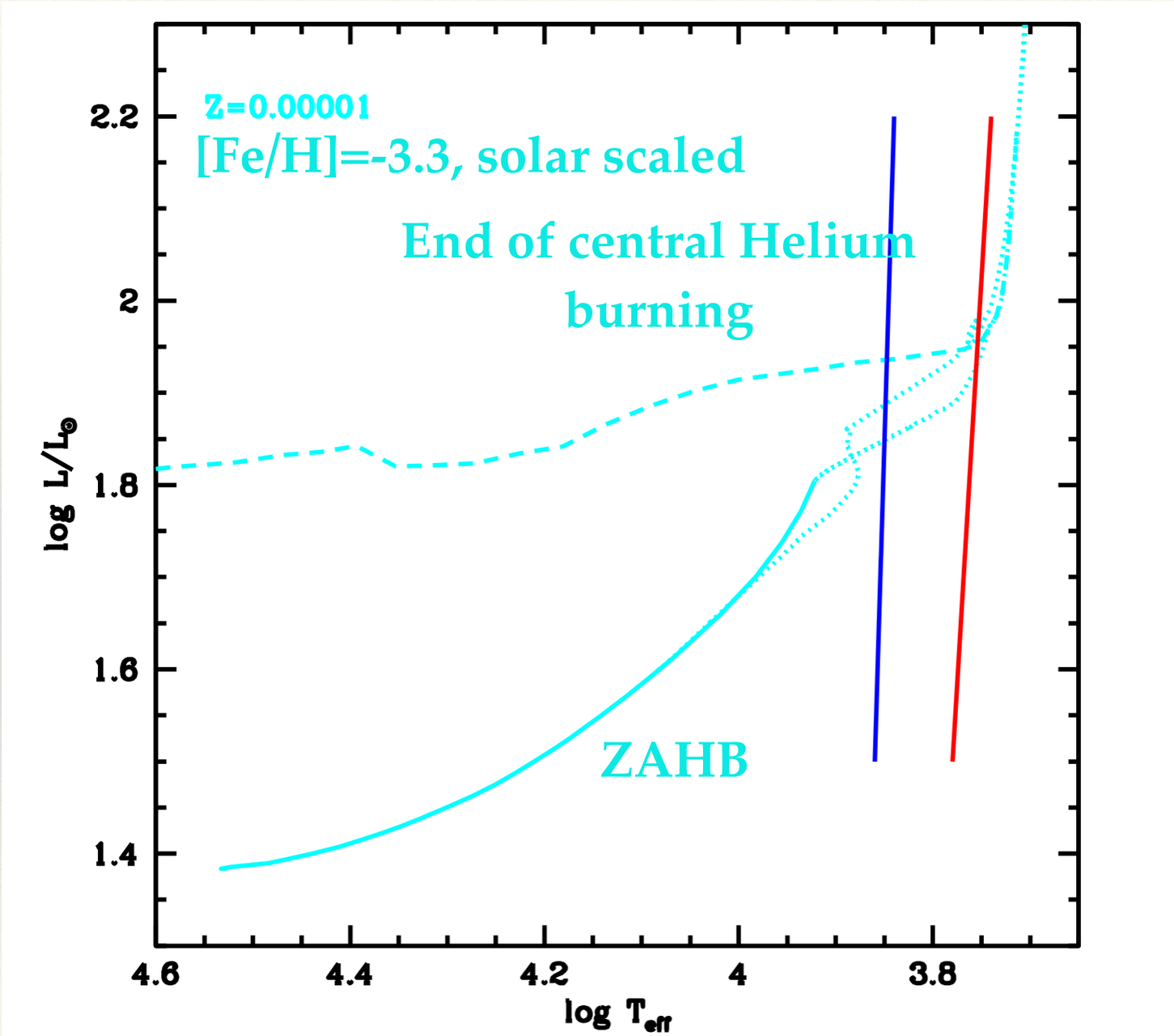

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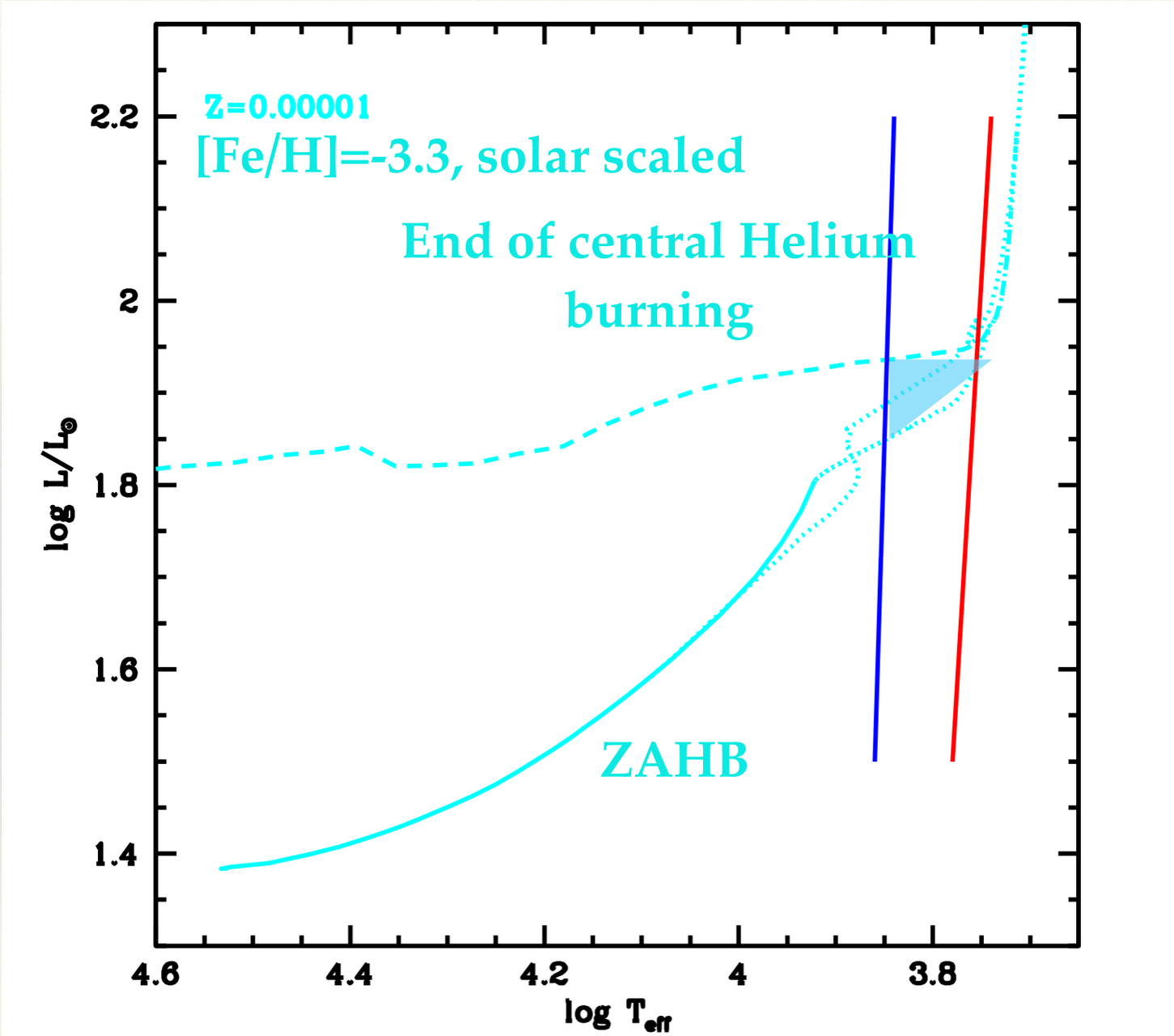
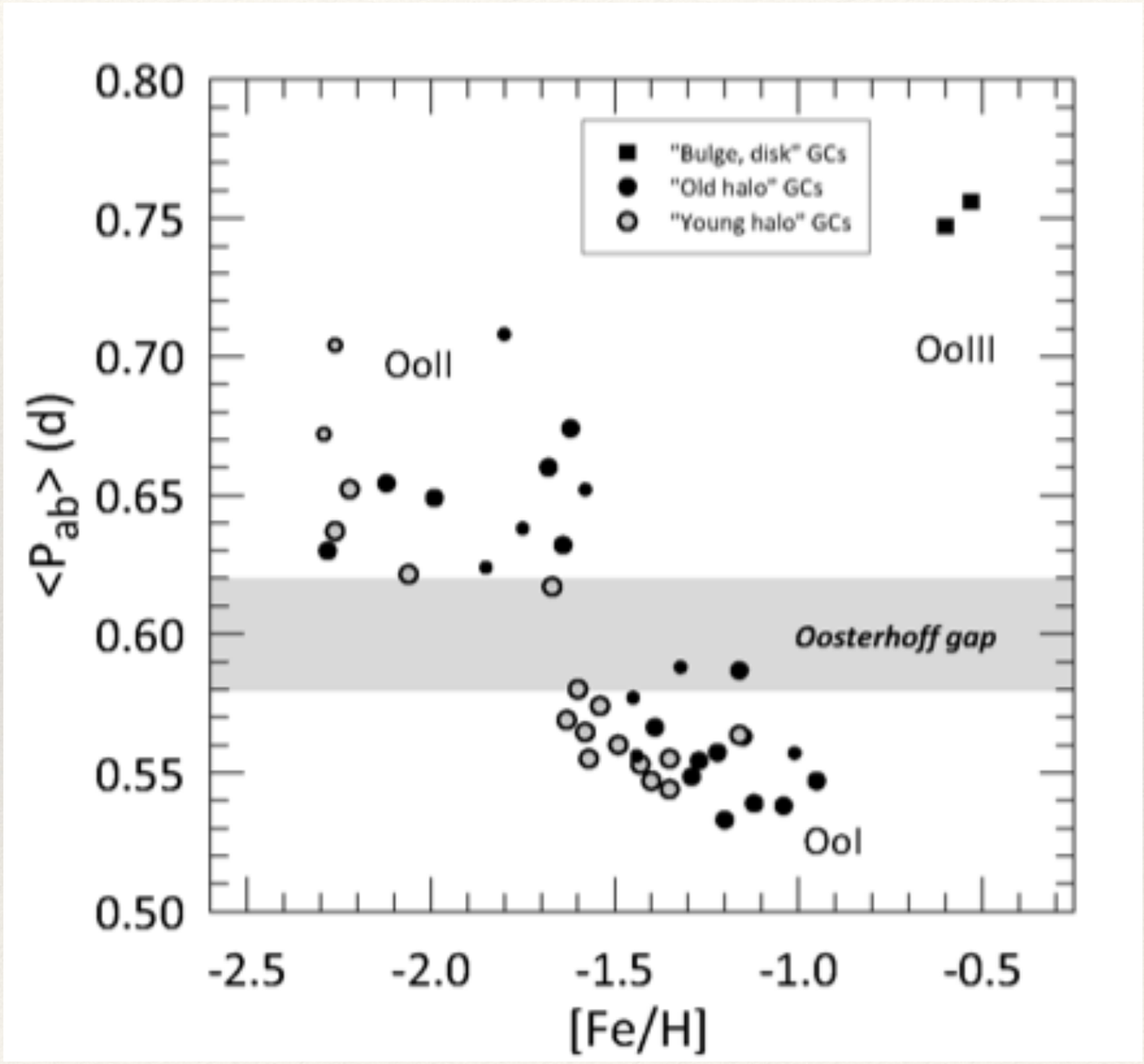


A historical approach, the Oosterhoff dichotomy (1939)



Smith, Catelan & Clementini 2009

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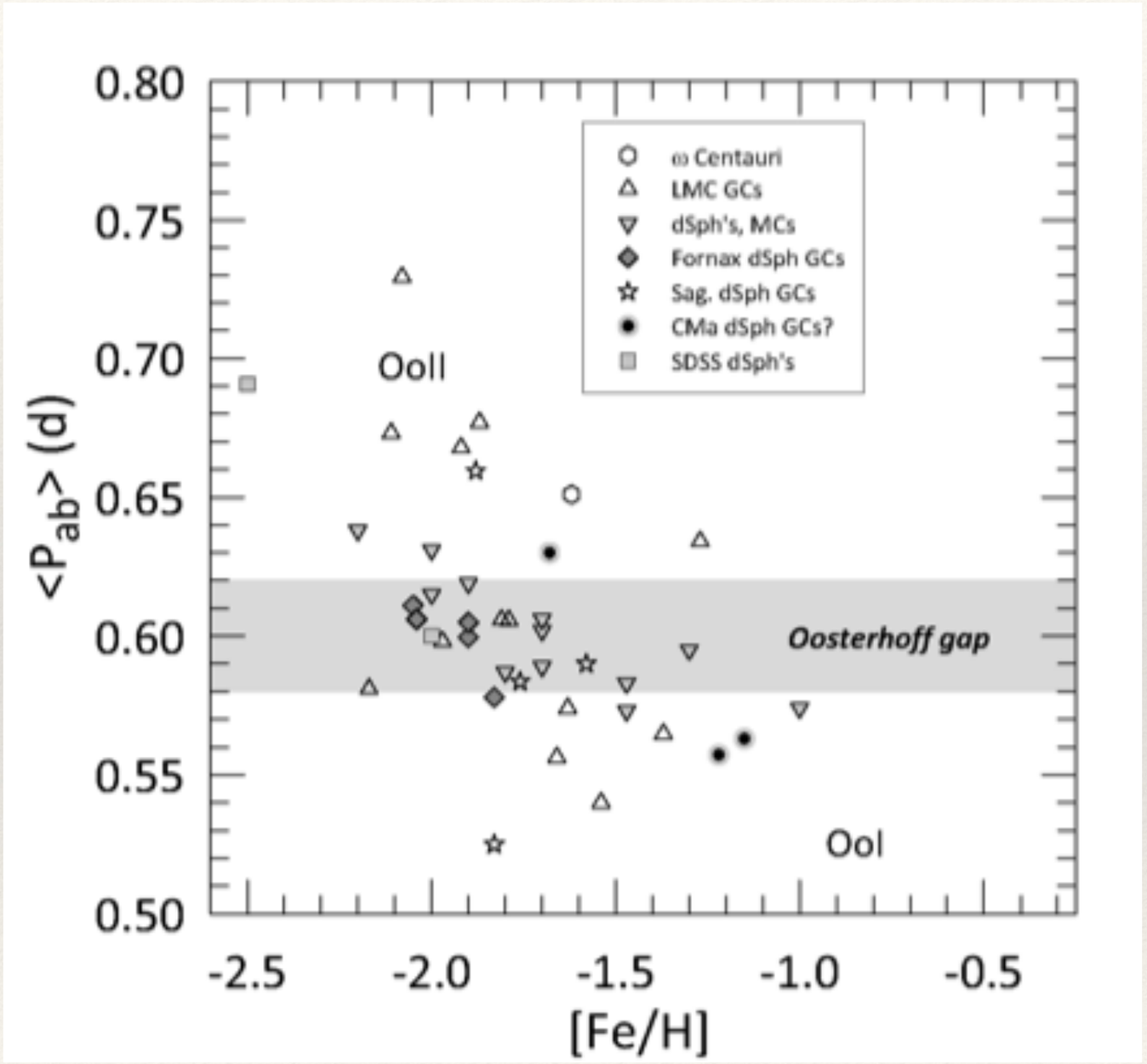

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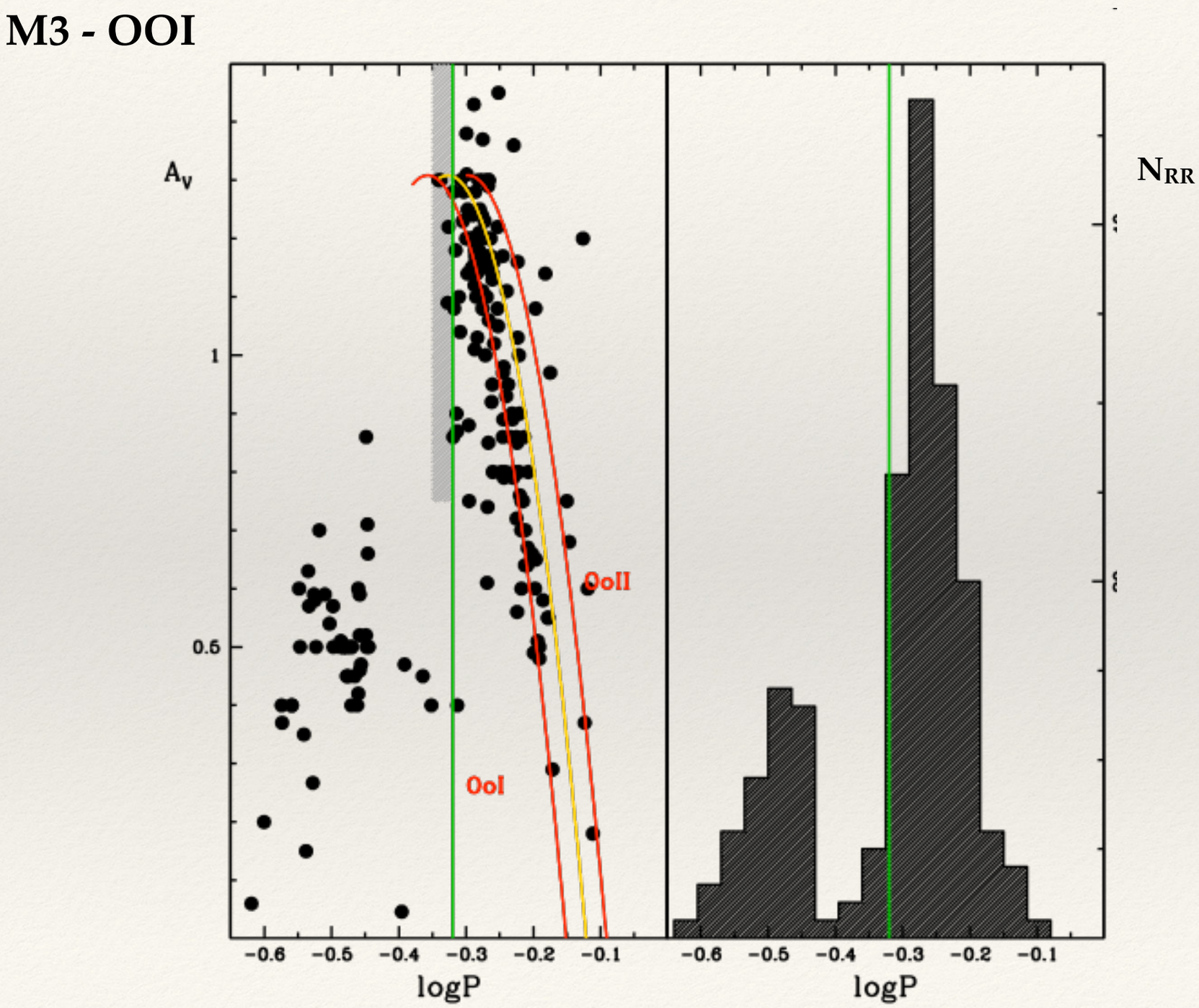
The Oosterhoff dichotomy, another way to see it… the **period-amplitude** diagram and **period** distribution



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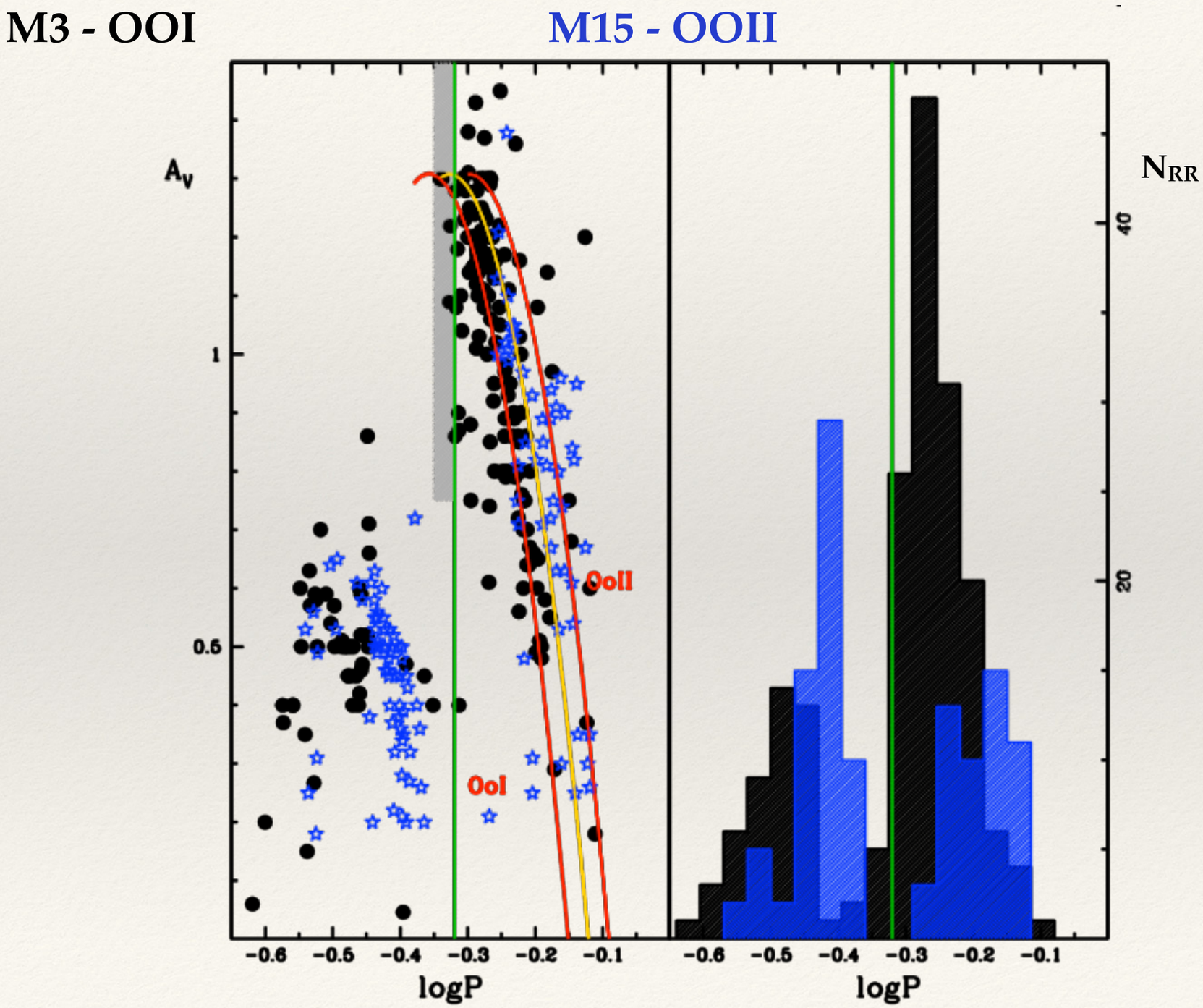

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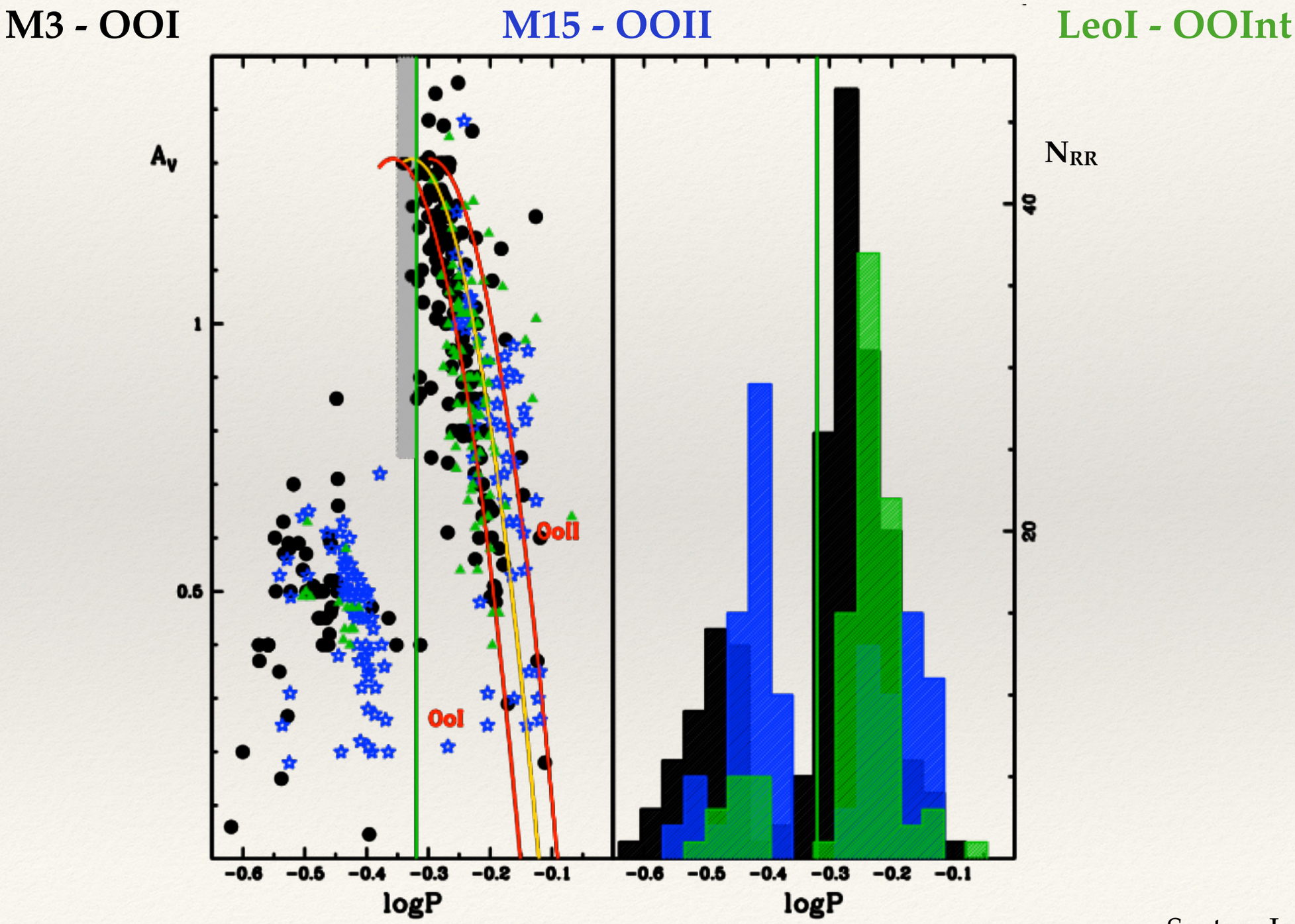
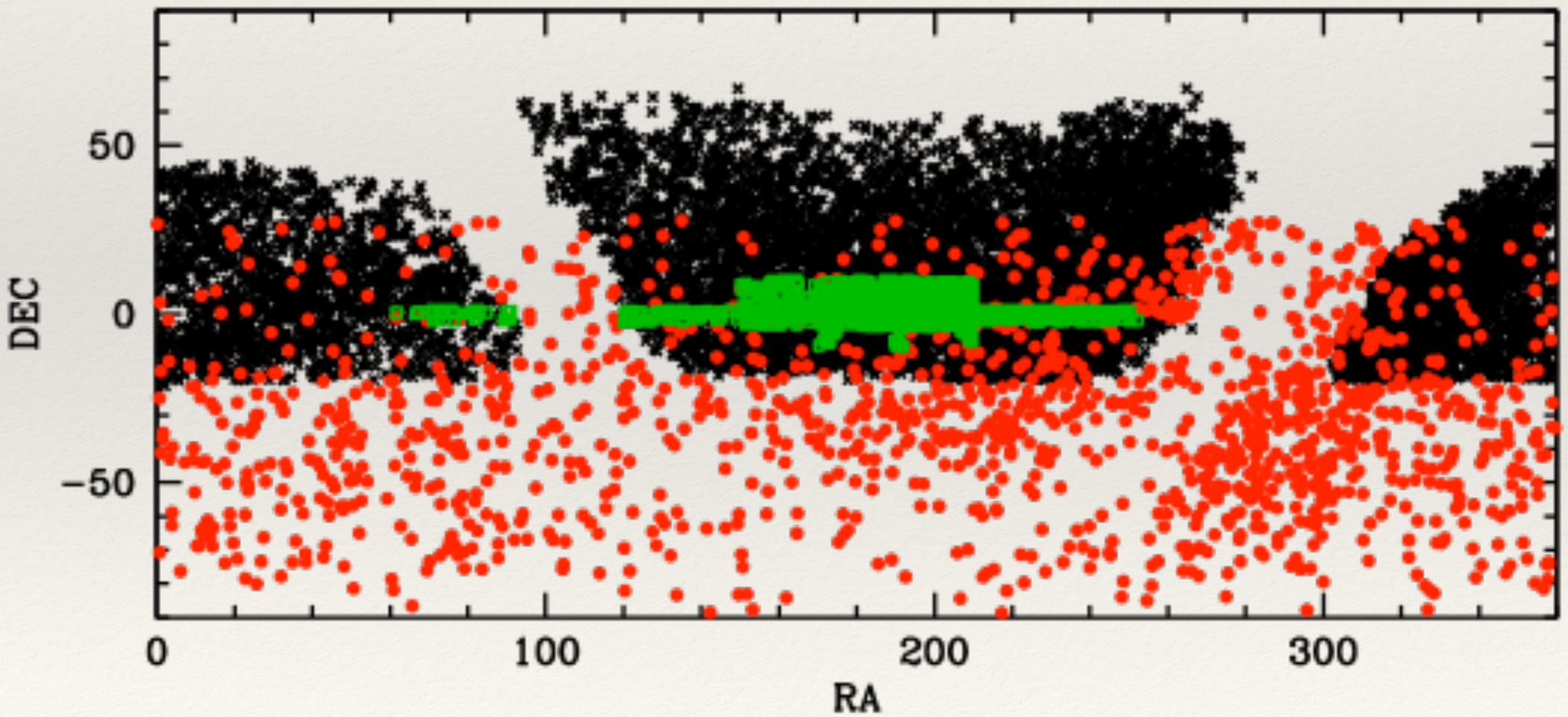


New Results from RR Lyrae star survey

What about the halo RR Lyrae stars?

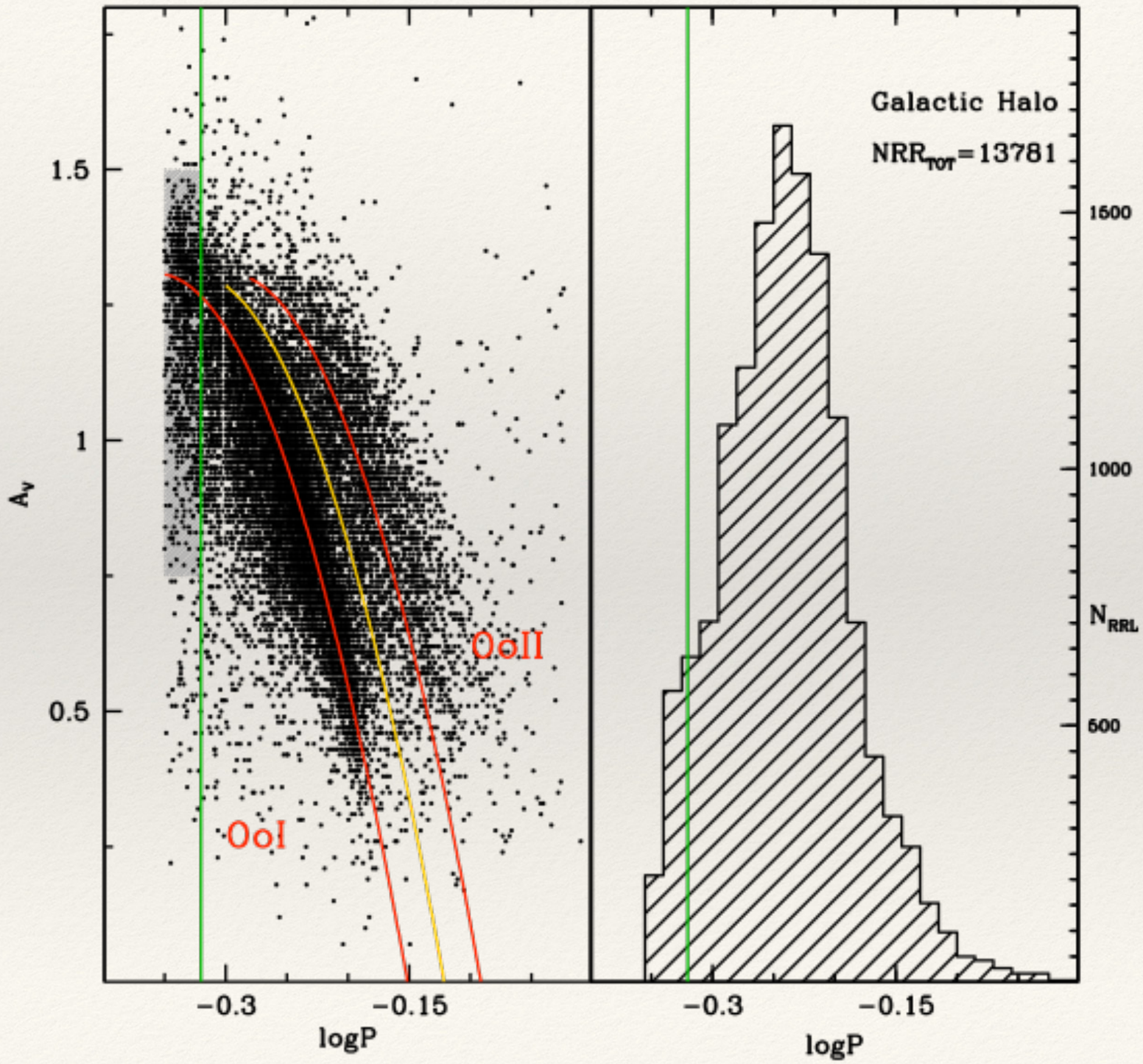
CATALINA (Drake+13)
ASAS (Szczygiel+09)
QUEST (Zinn+14, Vivas+04)

About 14'000 stars with V-band, light curves and amplitudes available



The Galactic halo **period-amplitude** and **period** distribution

selecting only Fundamental mode RR Lyrae (RRab)



Fiorentino et al. 2015, ApJL, 798L, 12

OOI ~70%

OOII ~30%

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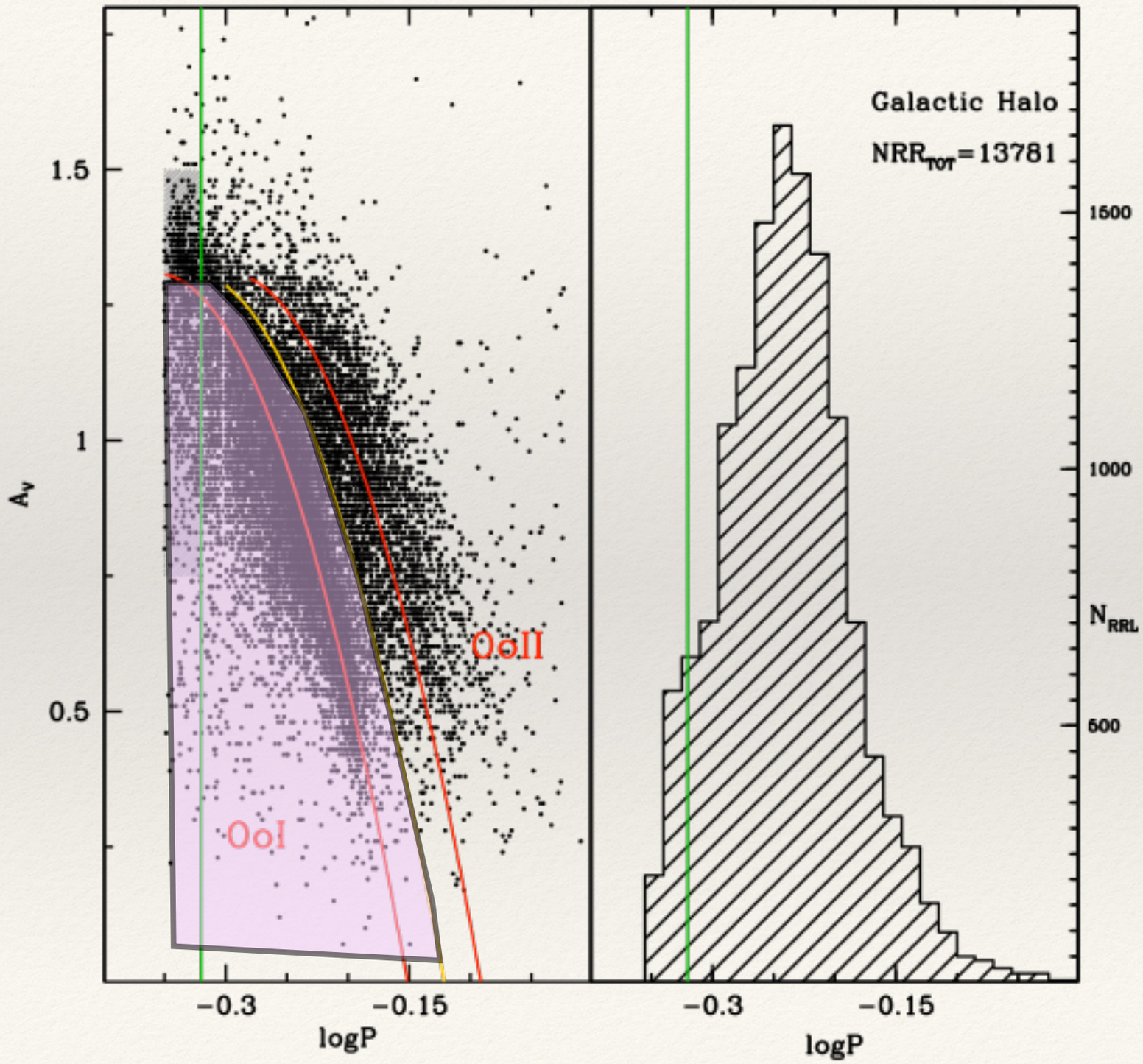

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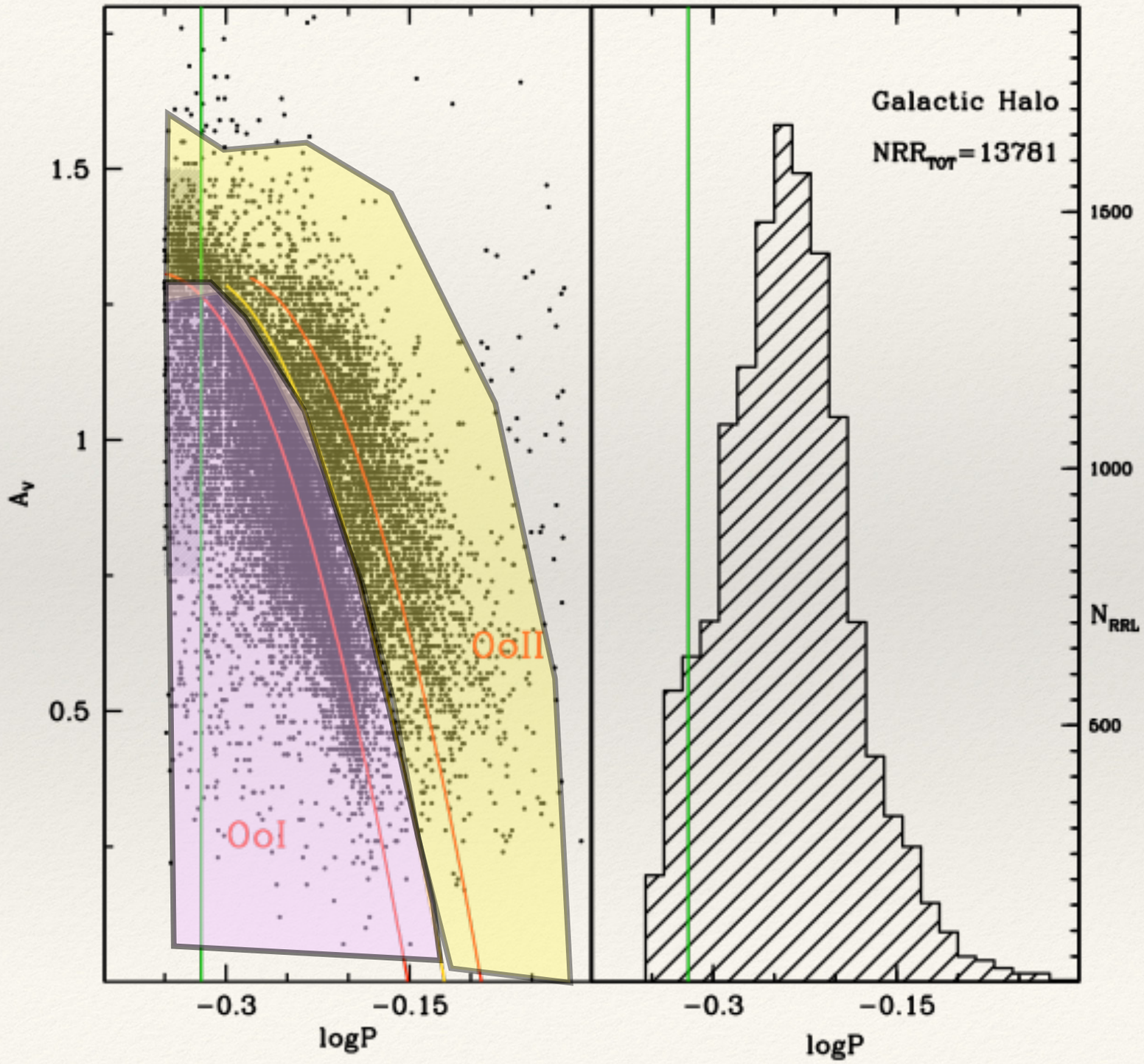

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INNER vs OUTER HALO

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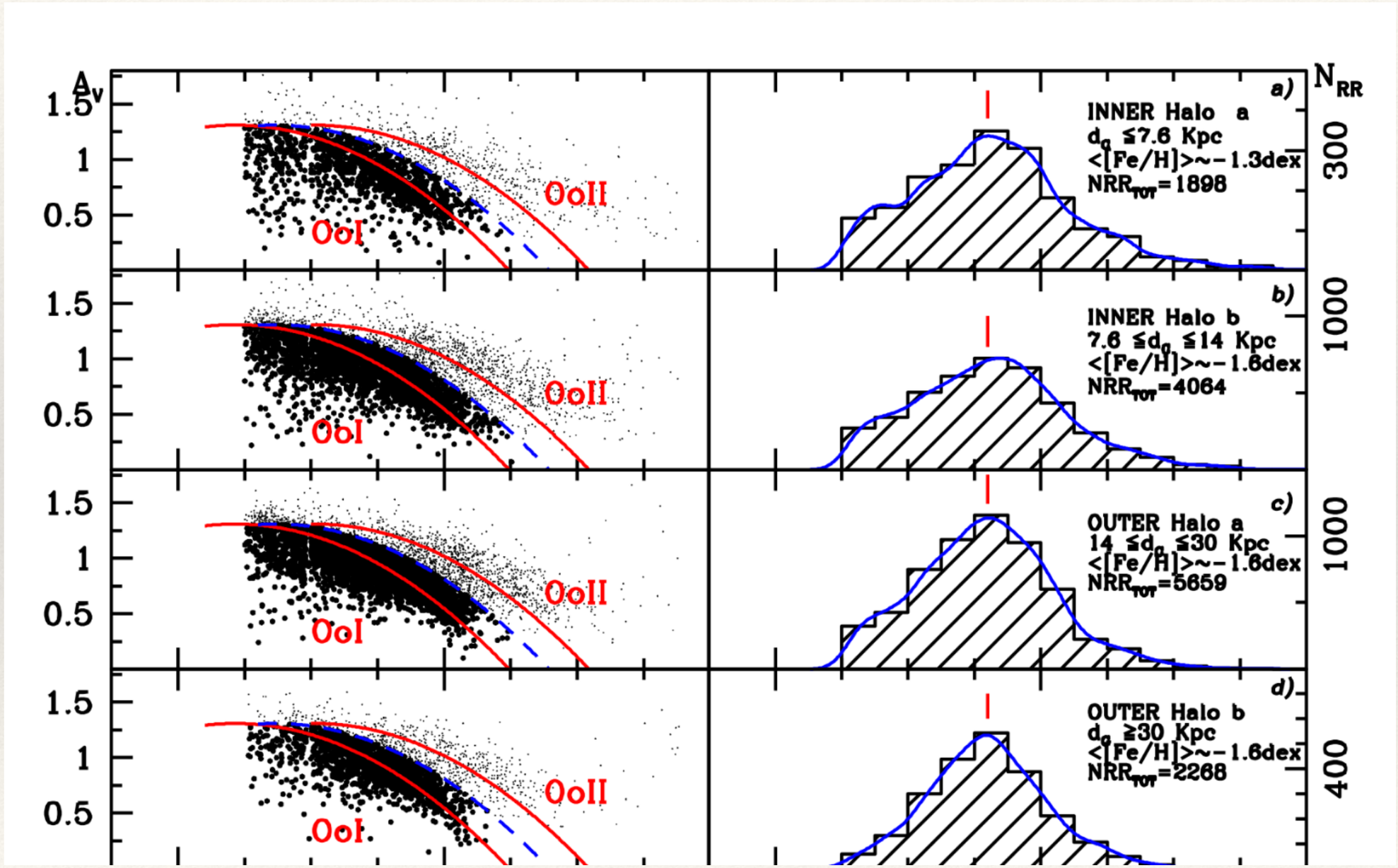
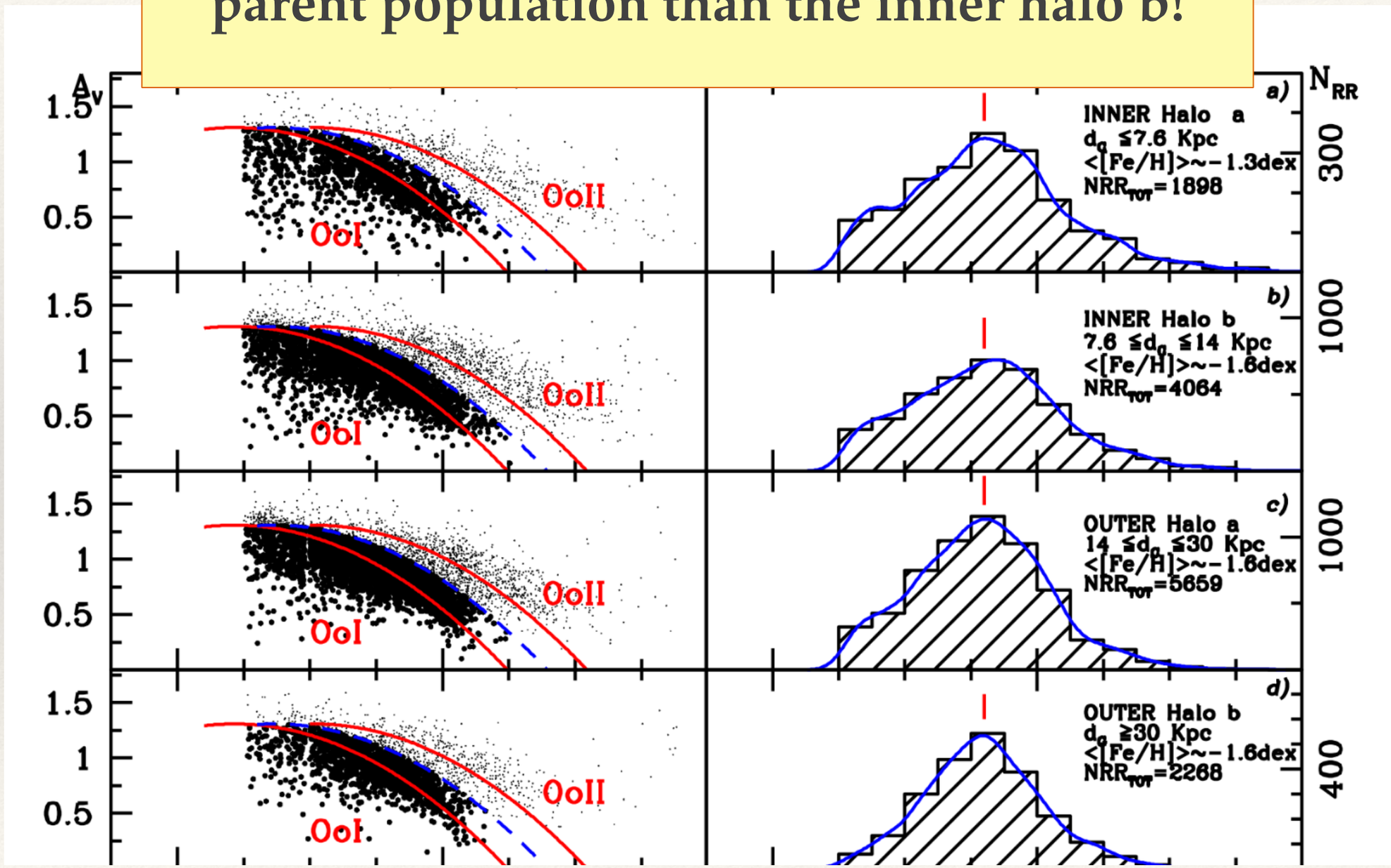


Stetson et al. 2014,PASP, 616,216

INNER vs

KS test returns a probability from 25 to 36% that the inner halo a comes from the same parent population than the inner halo b!



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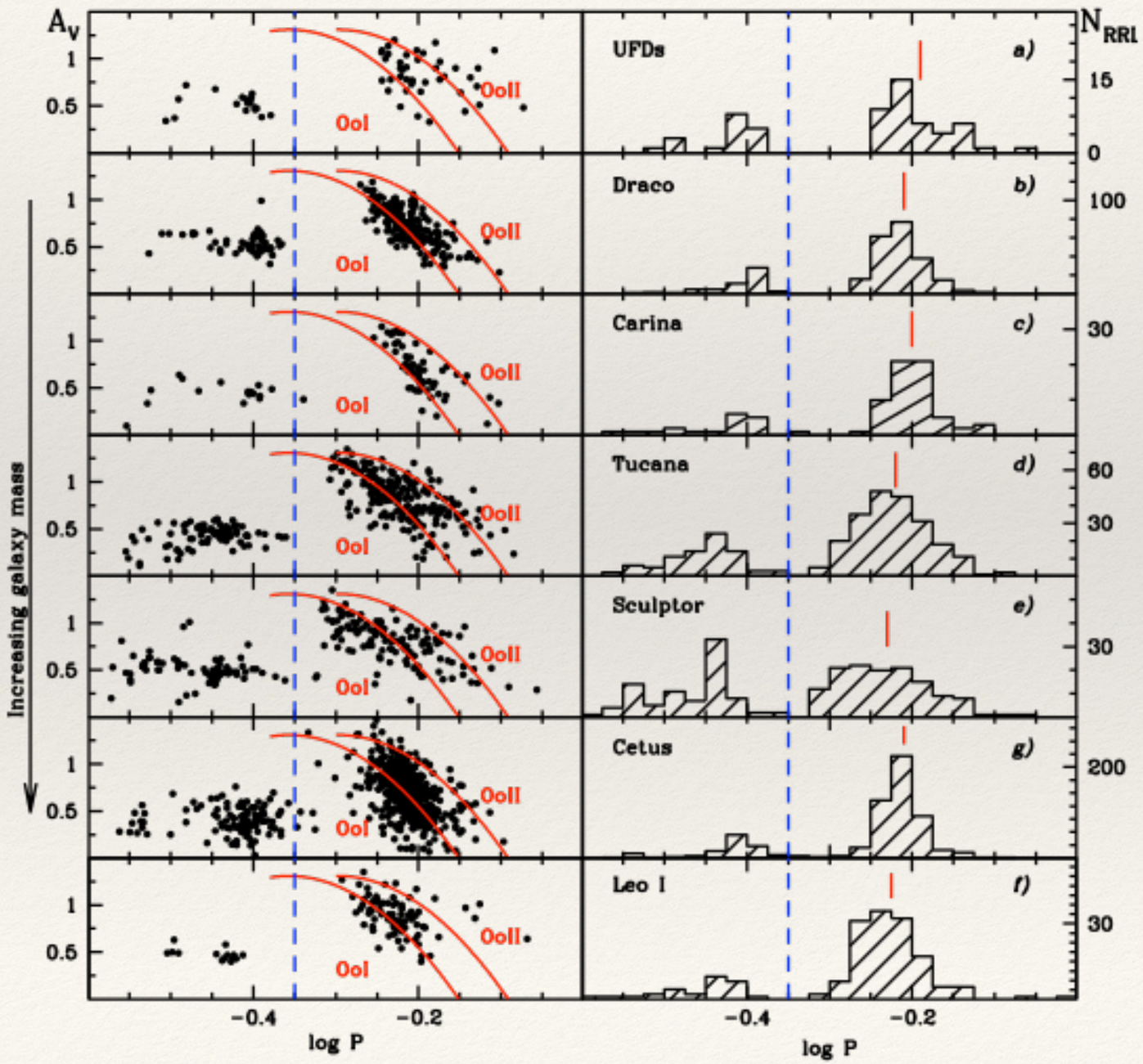
Homogeneous photometry project: dwarf spheroidal galaxies

work in progress with PB Stetson, M. Monelli, G. Bono, C. Gallart, E. J. Bernard, C. Martínez Vázquez

a large and complete data-base of photometric catalogues

using both proprietary and all the accessible archival data for **classical** dwarfs



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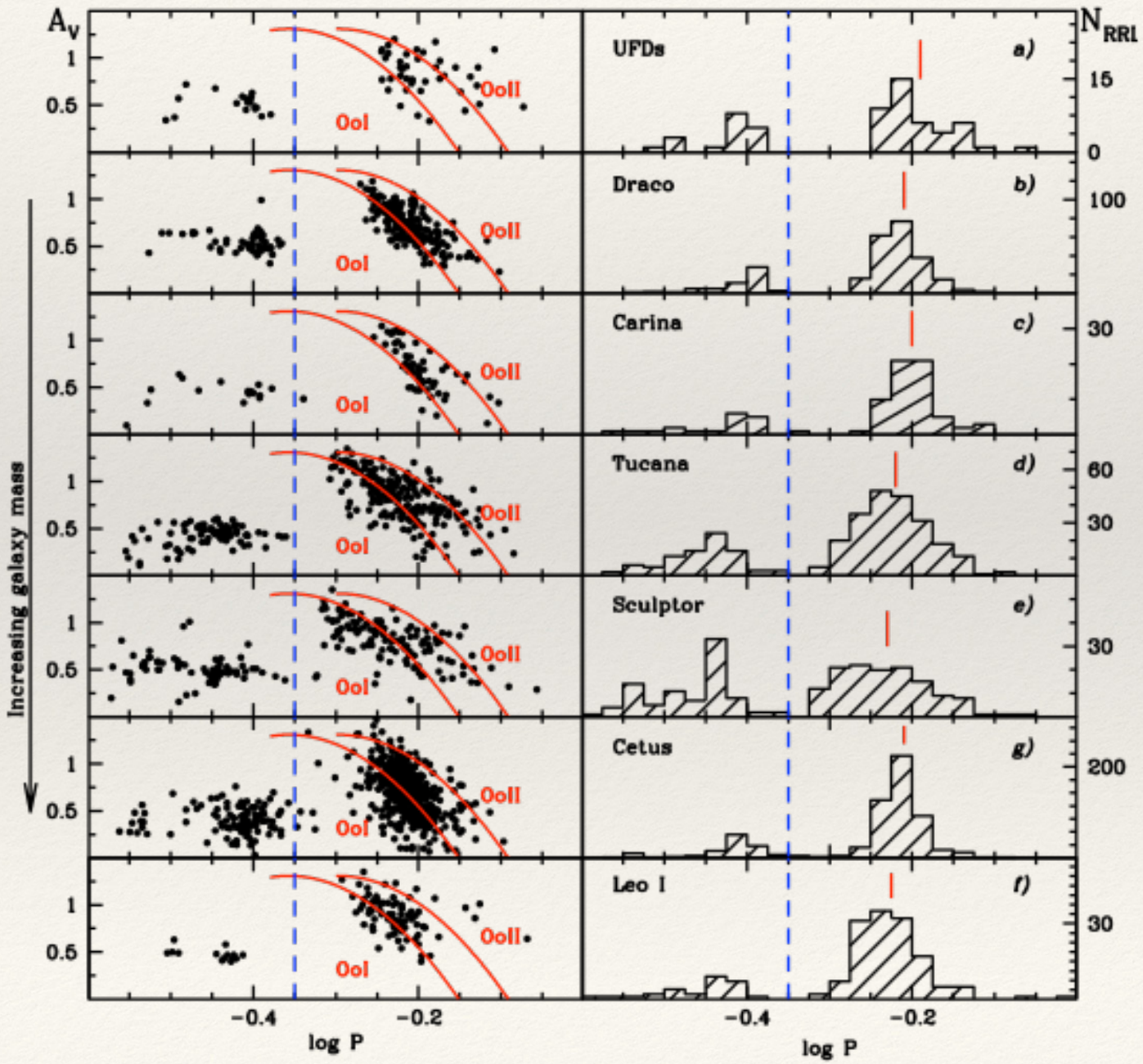

Draco

Carina

Tucana

Sculptor

Cetus

LeoI

Stetson, Fiorentino et al. 2014

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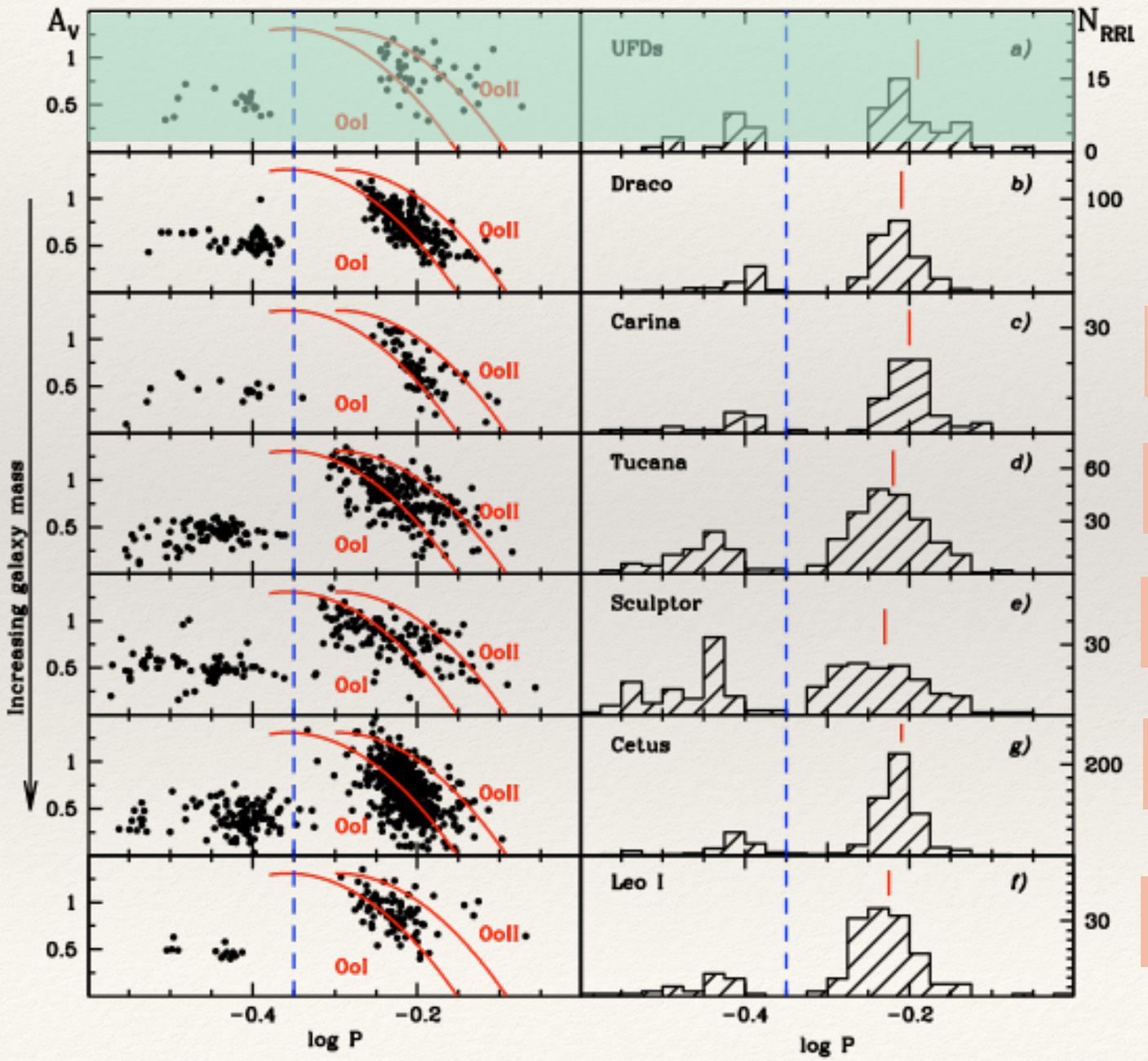

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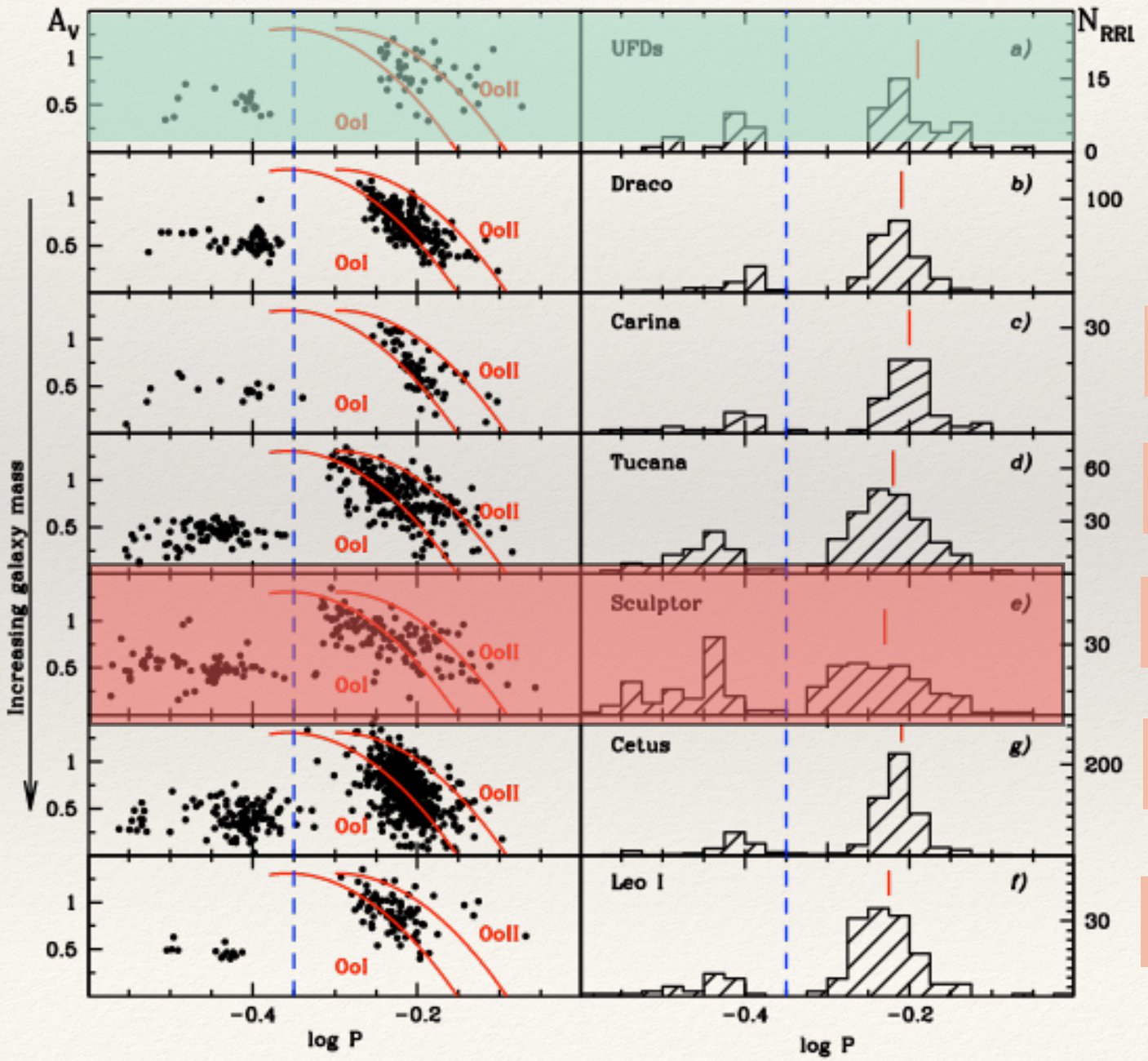

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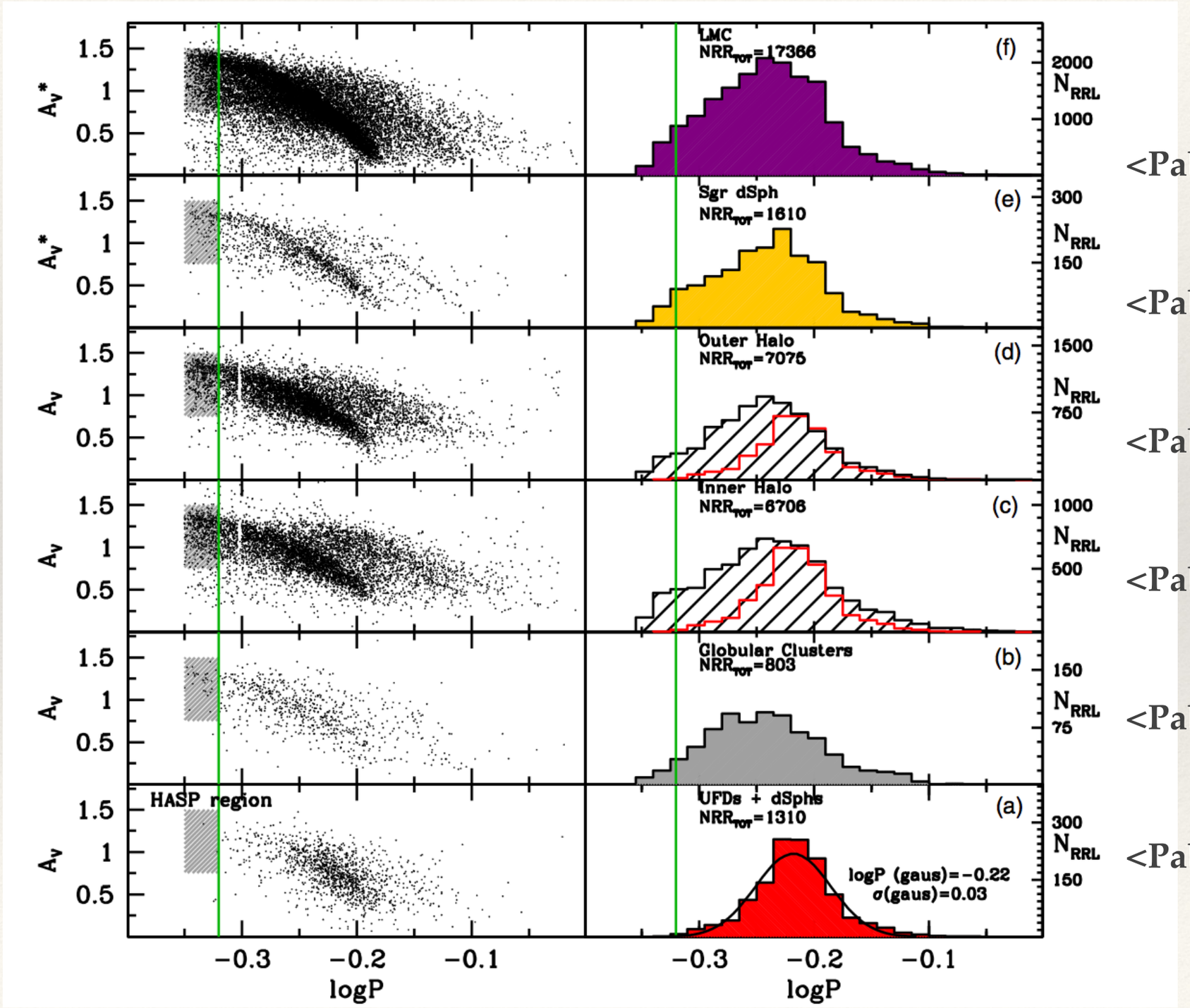
First, **DIRECT** comparison

selecting only Fundamental mode RR Lyrae (RRab)

Fiorentino et al. 2015, ApJL, 798L, 12



LMC
<Pab>=0.575 ± 0.002 (0.07)

SGR dSph
<Pab>=0.576 ± 0.001 (0.07)

OUTER HALO
<Pab>=0.577 ± 0.001 (0.07)

INNER HALO
<Pab>=0.584 ± 0.001 (0.08)

GGCs
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dSphs
<Pab>=0.610 ± 0.001 (0.05)

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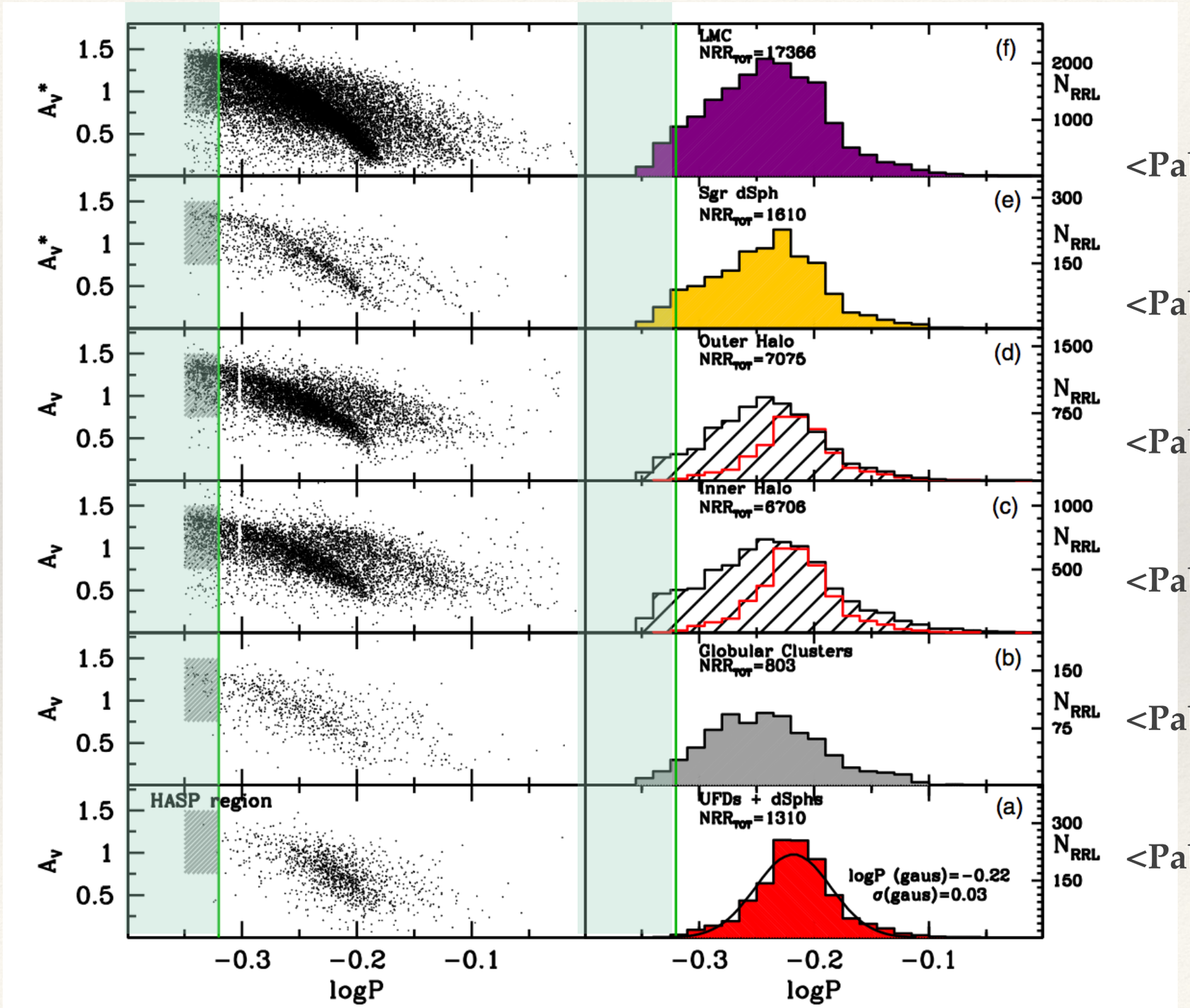
The High Amplitude Short Period (HASP) RRab are missing!!

Fiorentino et al. 2015, ApJL, 798L, 12



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Results-I: It is not possible to build-up the Galactic halo with MW dwarfs

Fiorentino et al. 2015, ApJL, 798L, 12

1) **under extreme assumptions: NOT more than 50% can be made from dwarf spheroidals!!**

2) **Sgr-like dSph may have contributed to the galactic halo. The KS test returns a likelihood of ~10%, so not negligible.**

3) **LMC-like dwarfs have a lower probability to have formed the Galactic halo.**

Comparison with cosmological models

Tissera +14

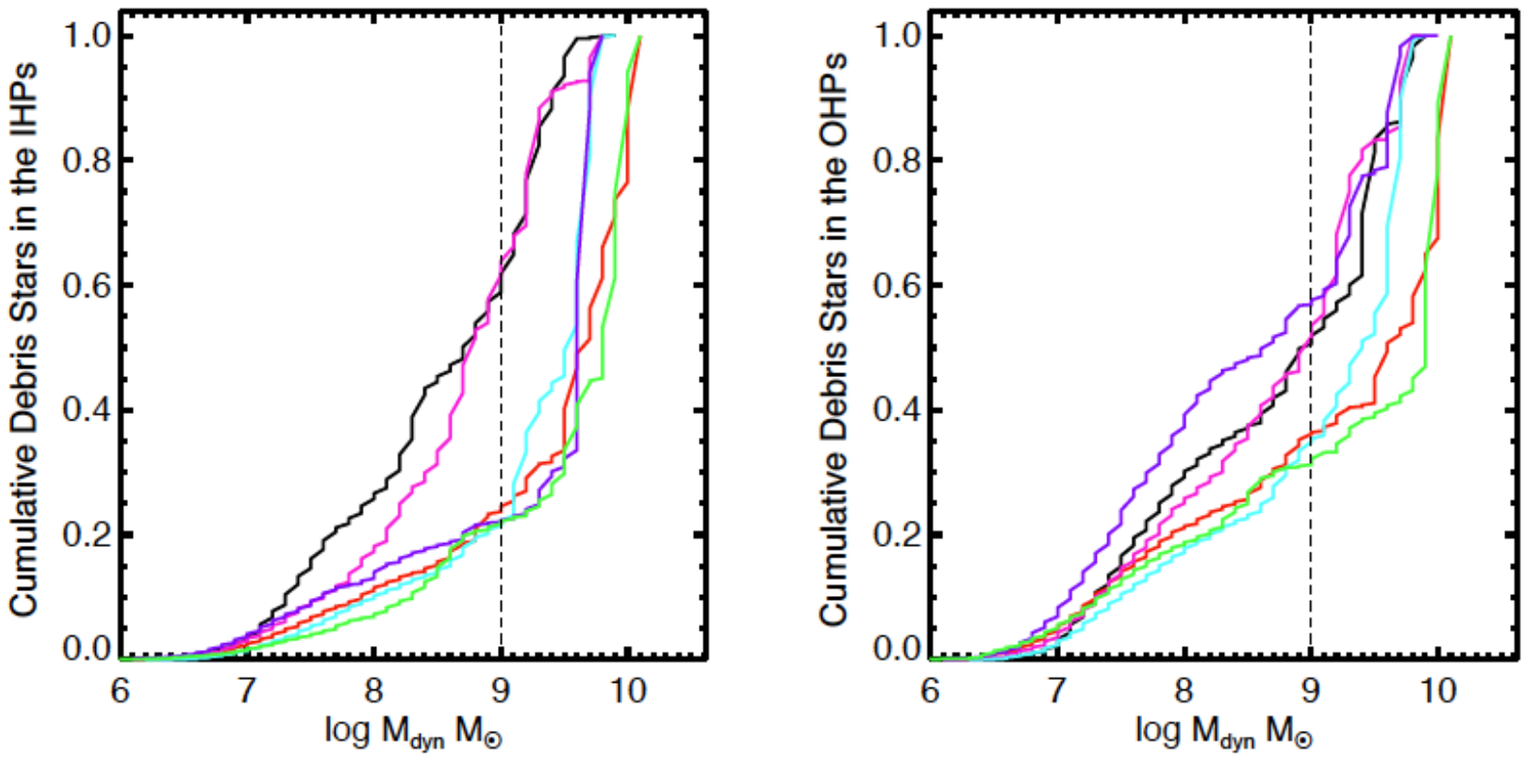

Figure 4. Mass fraction (upper panels) and cumulative mass (lower panels) of debris stars in the IHPs (left panels) and OHPs (right panels), as a function of the dynamical masses of the systems from which they formed. The vertical dashed lines denote the reference value, $M = 10^9$ $M_\odot$, used to separate more-massive from less-massive satellites. See Table 1 for the colour code.

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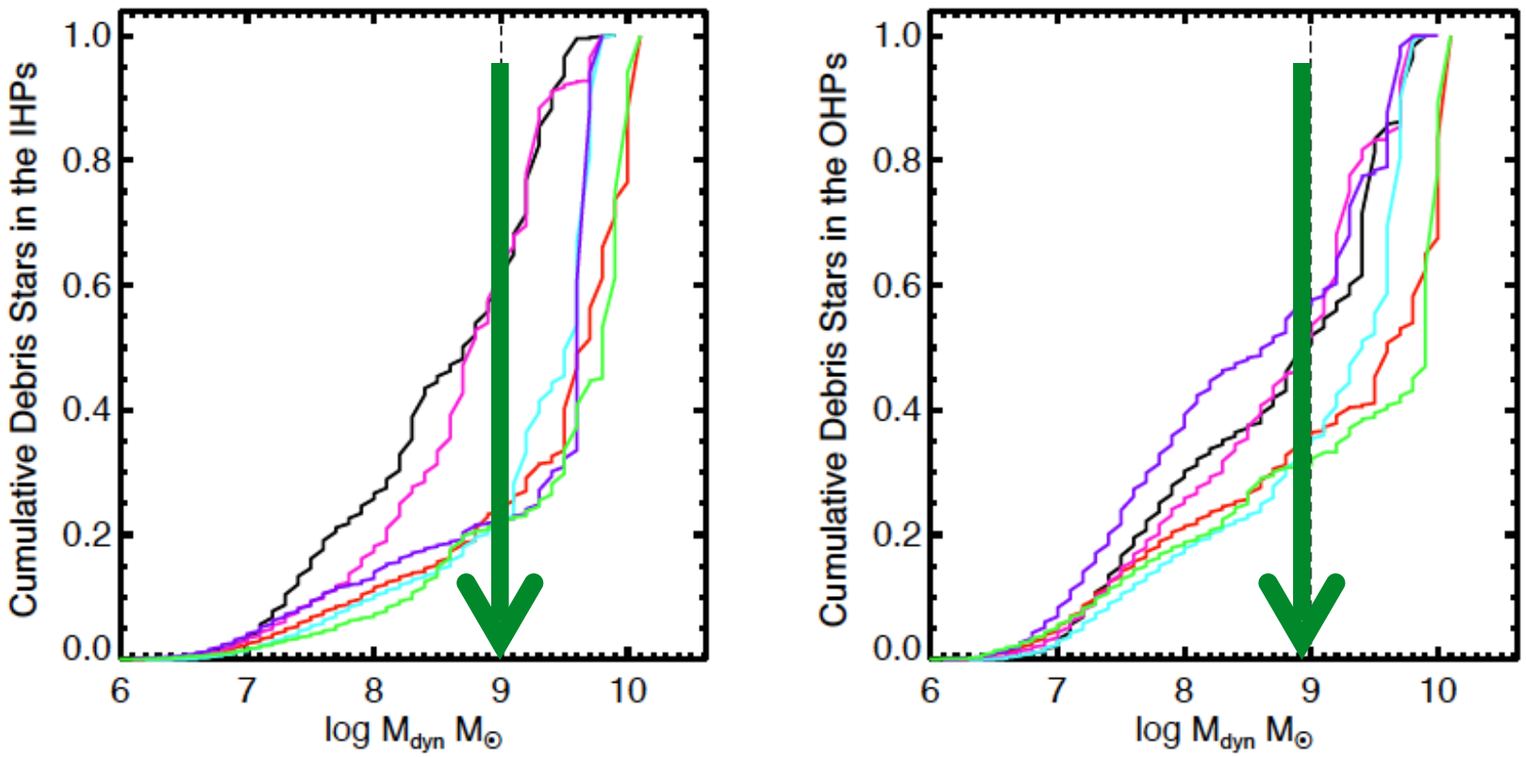

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Why HASPs?

hasp (hɑ:sp)

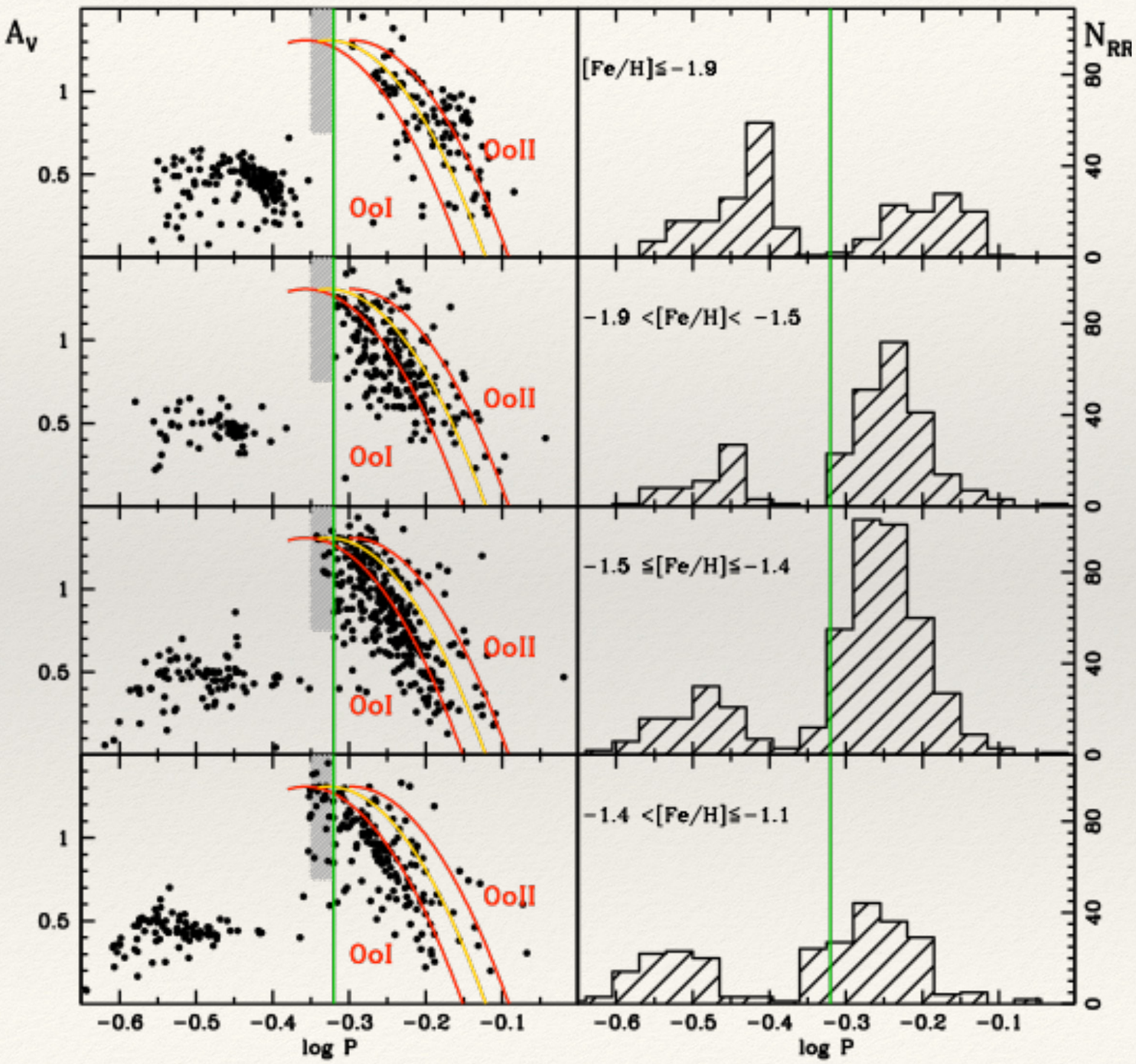
n

1. (Building) a metal fastening consisting of a hinged strap with a slot that fits over a staple and is secured by a pin, bolt, or padlock

vb

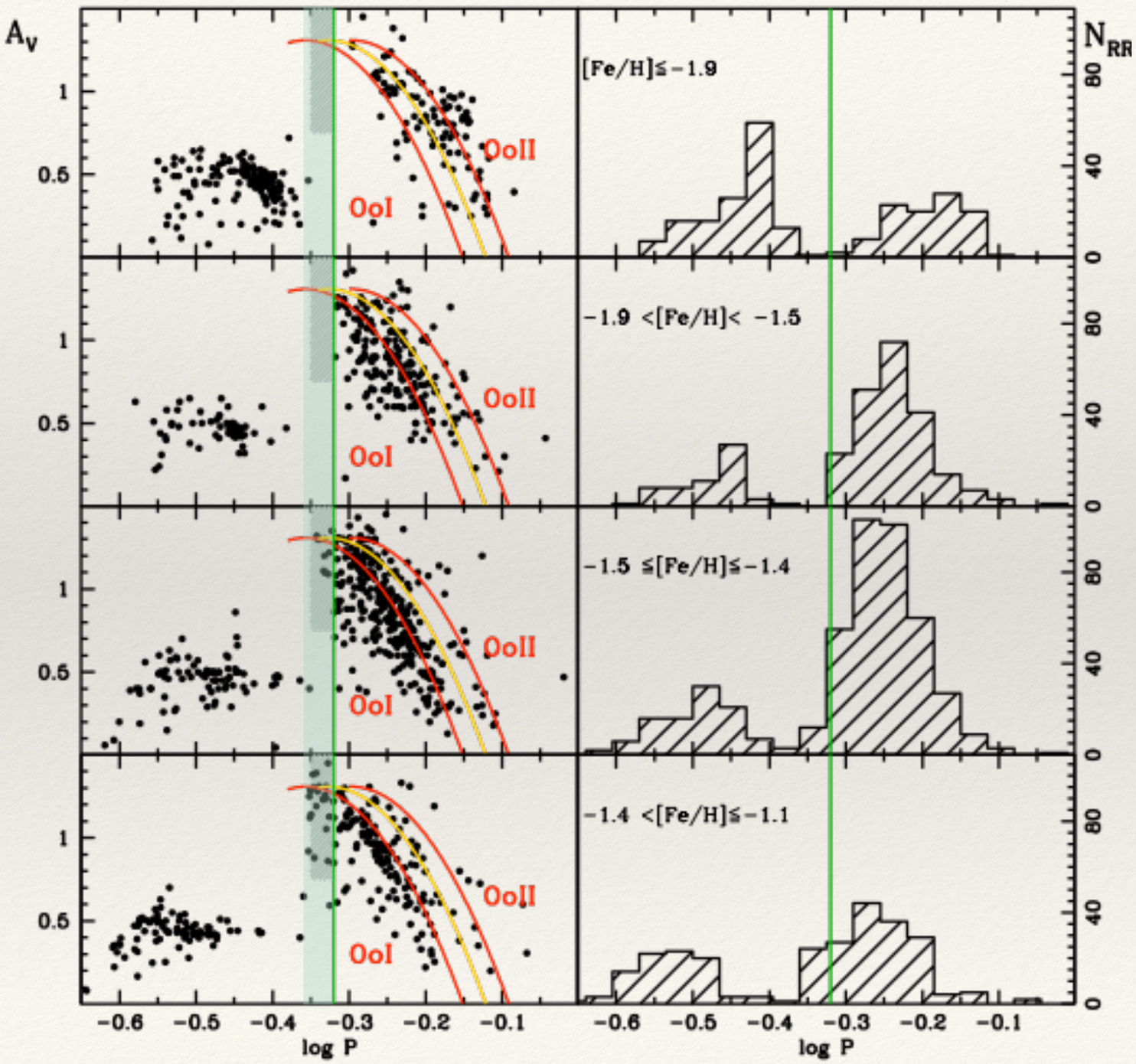
2. (Building) (*tr*) to secure (a door, window, etc) with a hasp

What's happening?



Fiorentino et al. 2015, ApJL, 798L, 12

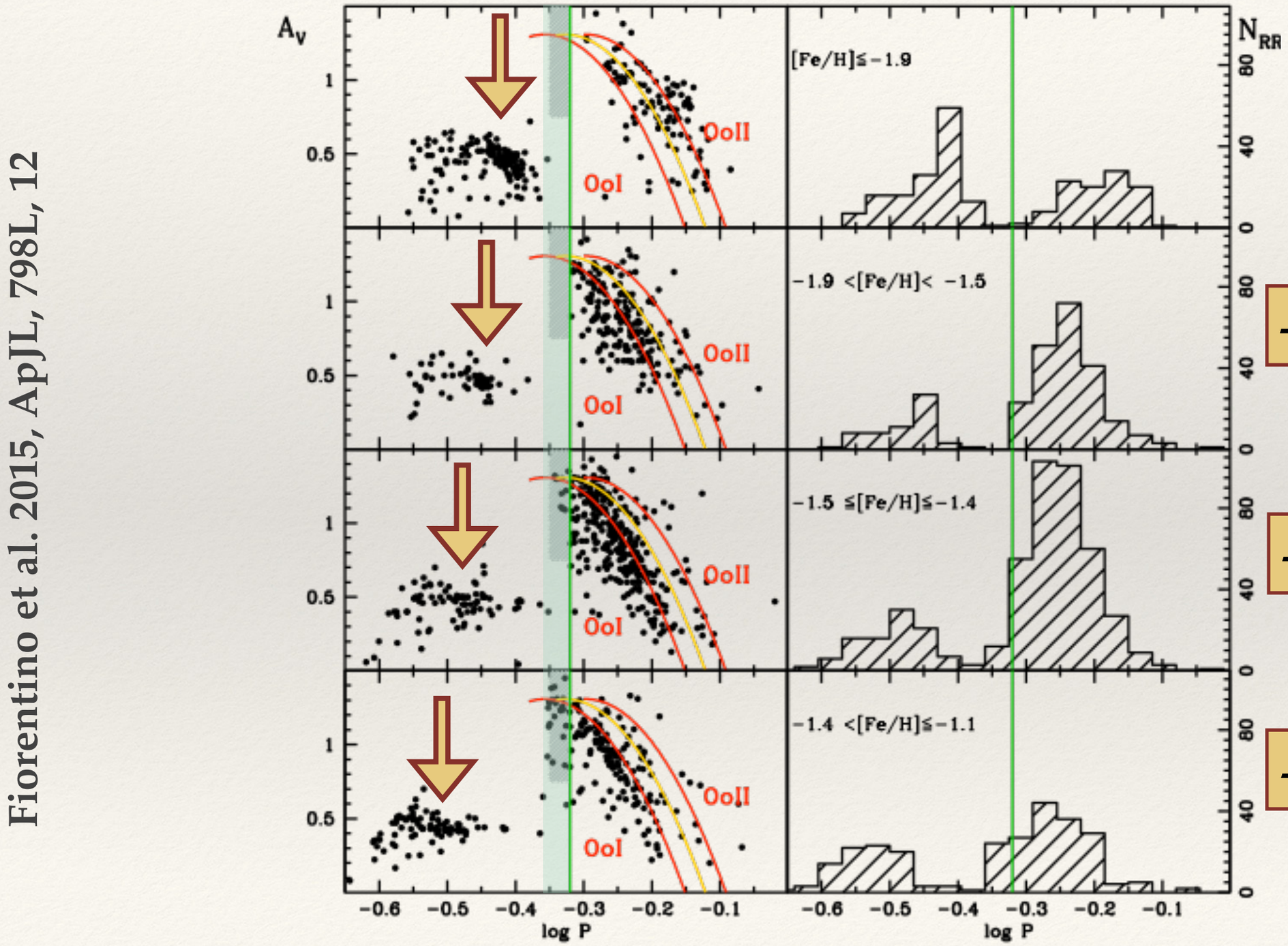
What's happening?



Fiorentino et al. 2015, ApJL, 798L, 12

What's happening?

HASPs appear when increasing the metallicity...



[Fe/H]≤-1.9

-1.9<[Fe/H]<-1.5

-1.5≤[Fe/H]≤-1.4

-1.4<[Fe/H]≤-1.1

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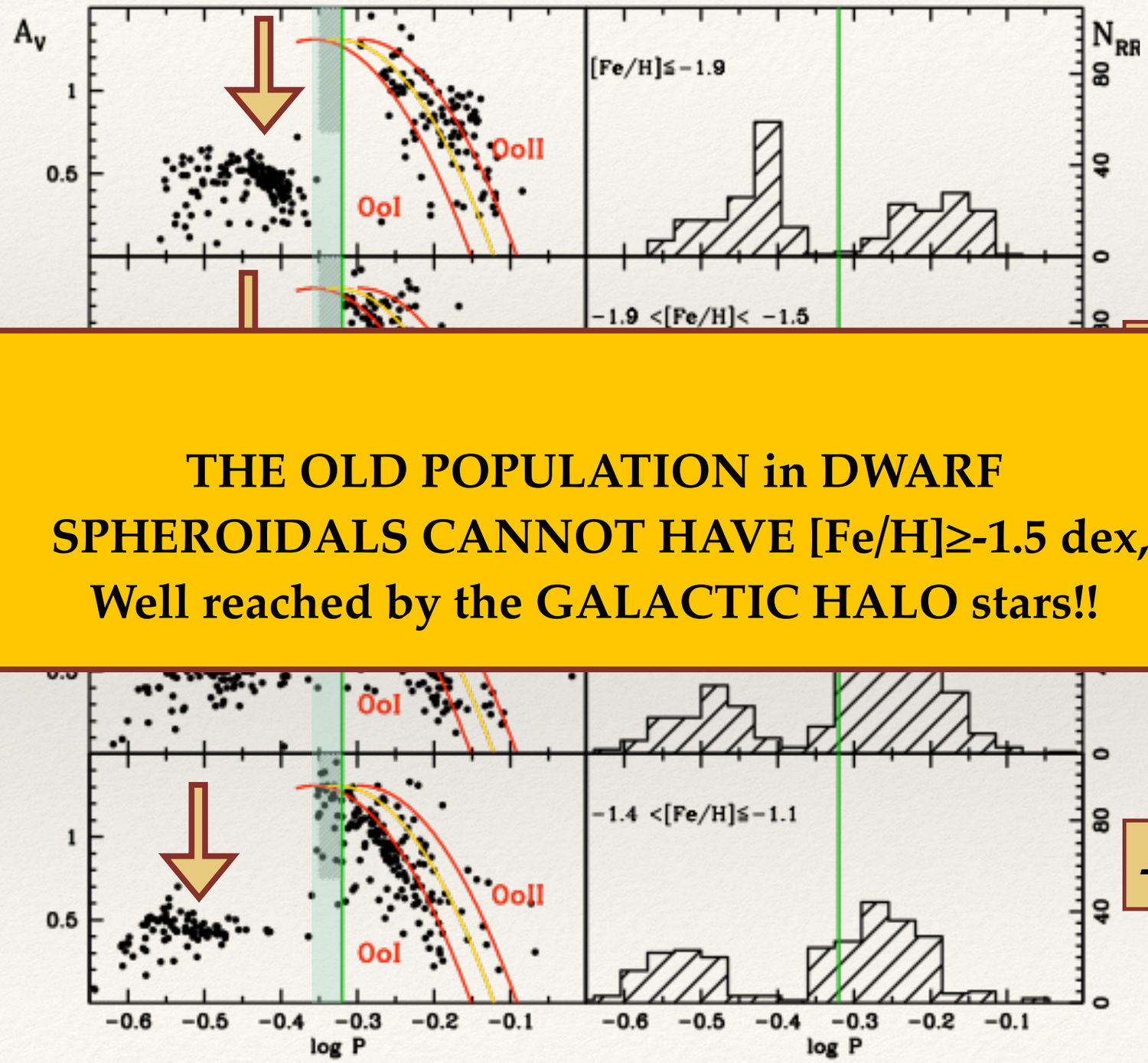

Fiorentino et al. 2015, ApJL, 798L, 12

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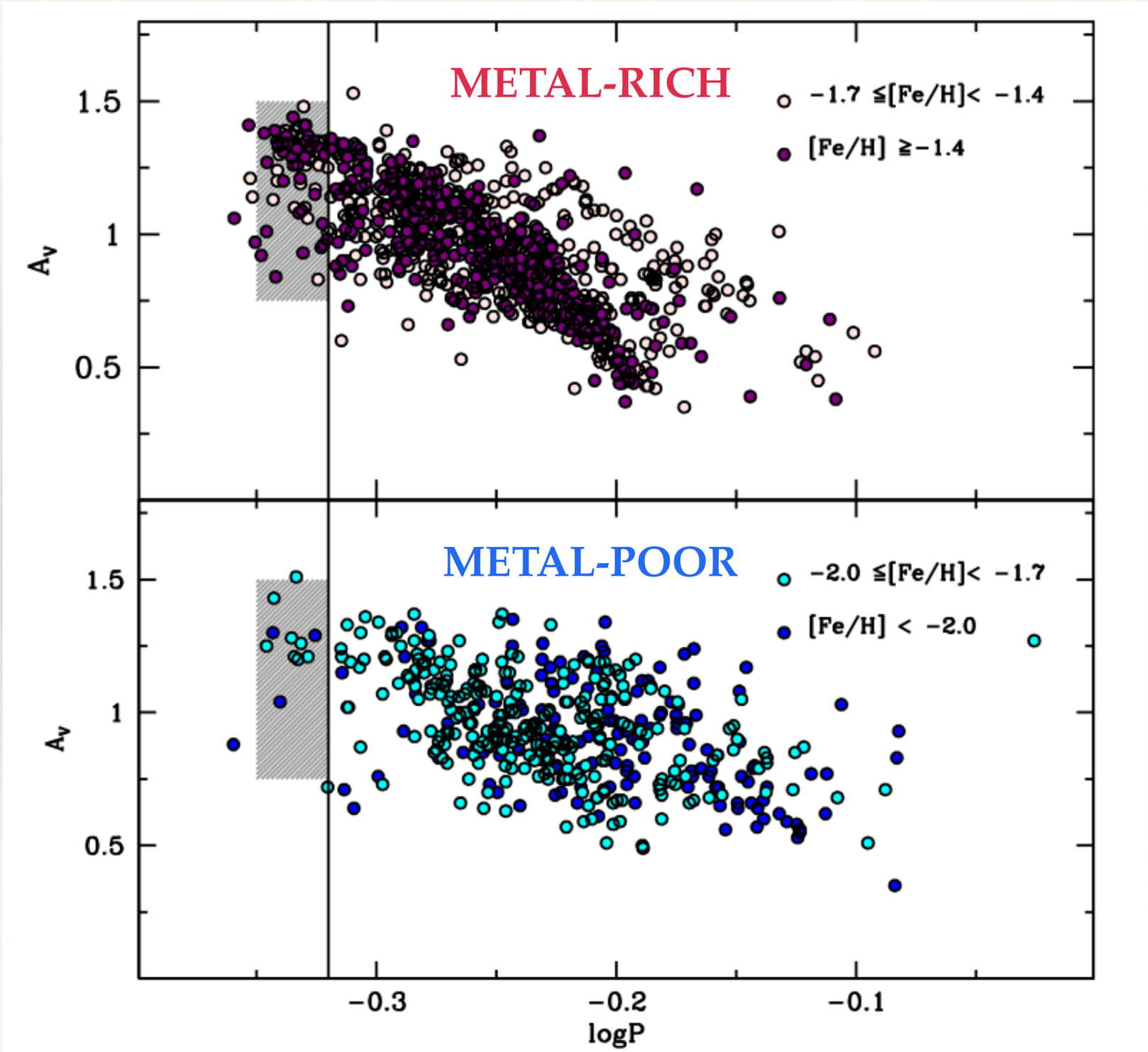
THE OLD POPULATION in DWARF SPHEROIDALS CANNOT HAVE [Fe/H]≥-1.5 dex, Well reached by the GALACTIC HALO stars!!

[Fe/H]≤-1.4

-1.4<[Fe/H]≤-1.1

Medium resolution spectra from SDSS (Drake+13)



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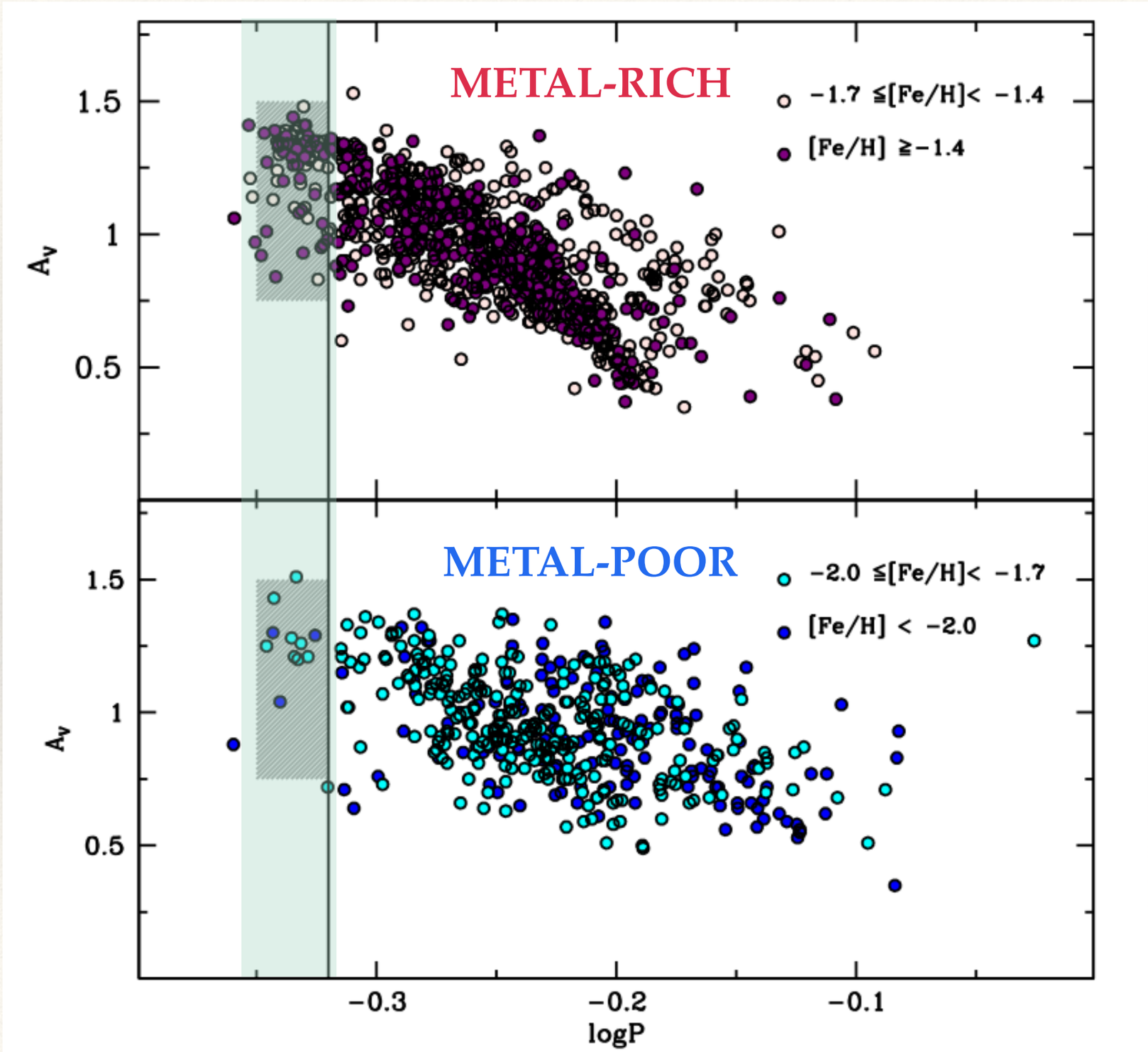

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Halo metallicity

Drake +13

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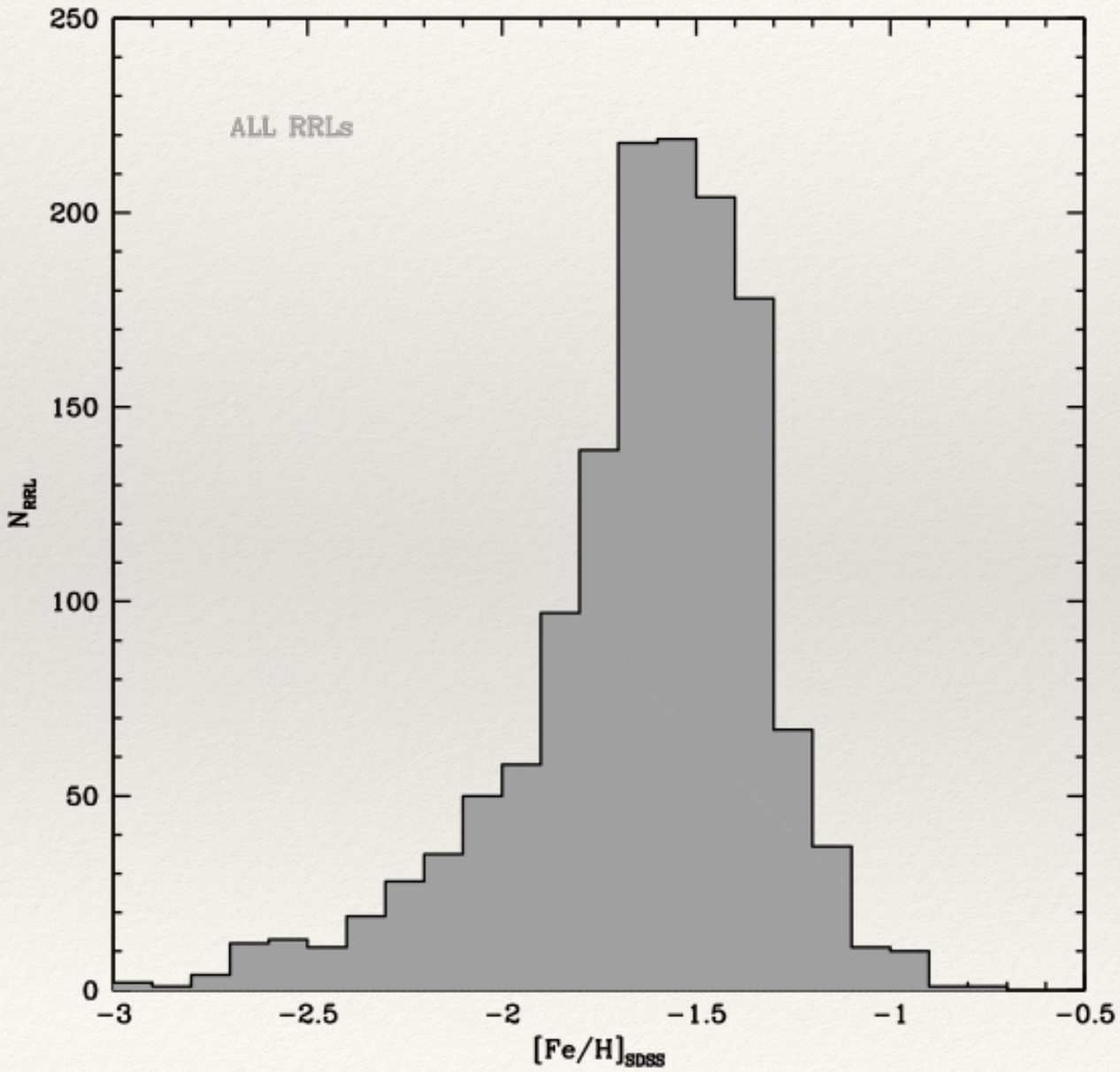


```
HASP RRL
<[Fe/H]> = -1.458352941 +- 0.2381018542
ALL RRL
<[Fe/H]> = -1.63575265 +- 0.3159196331
```

Halo metallicity

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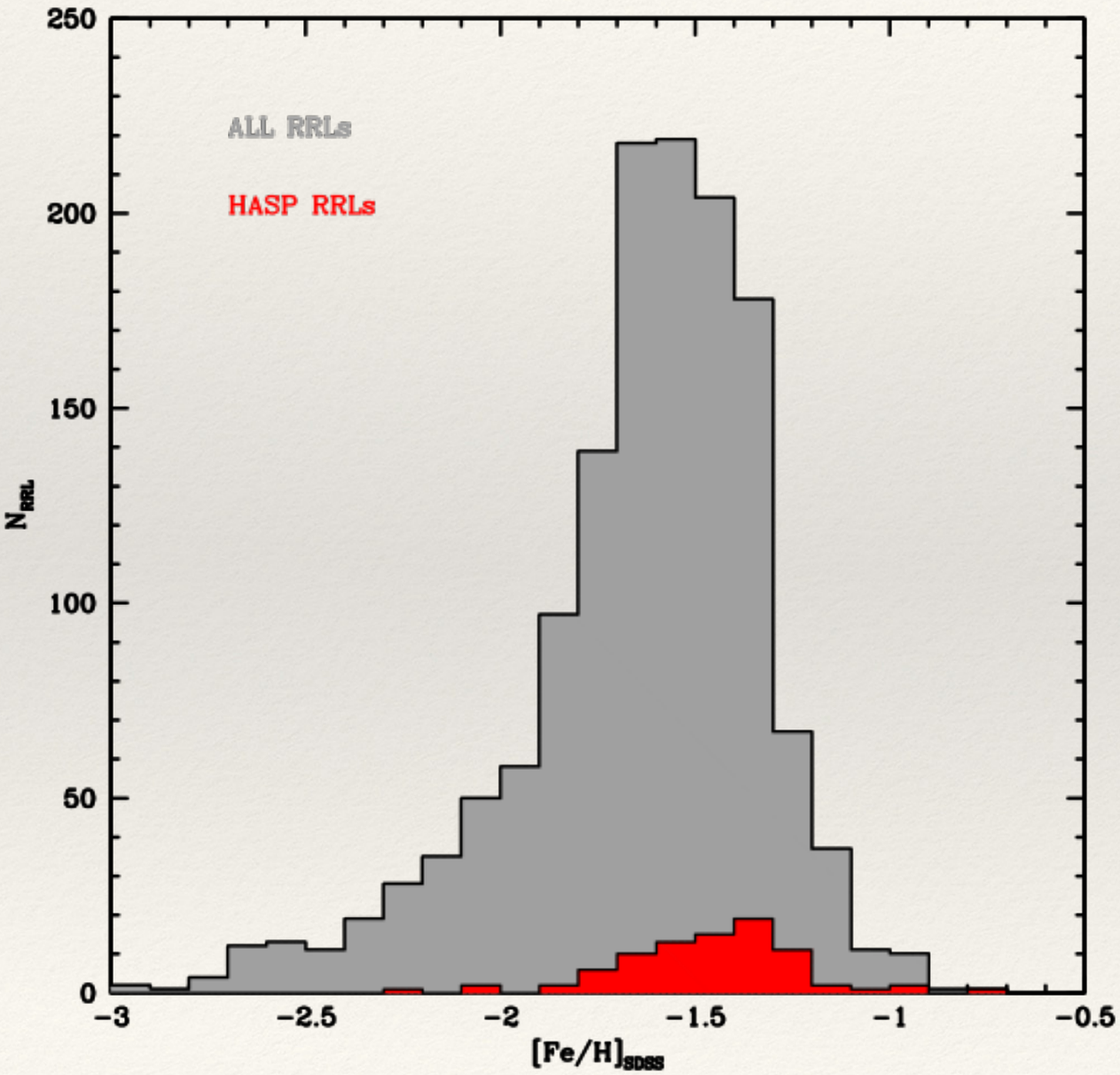


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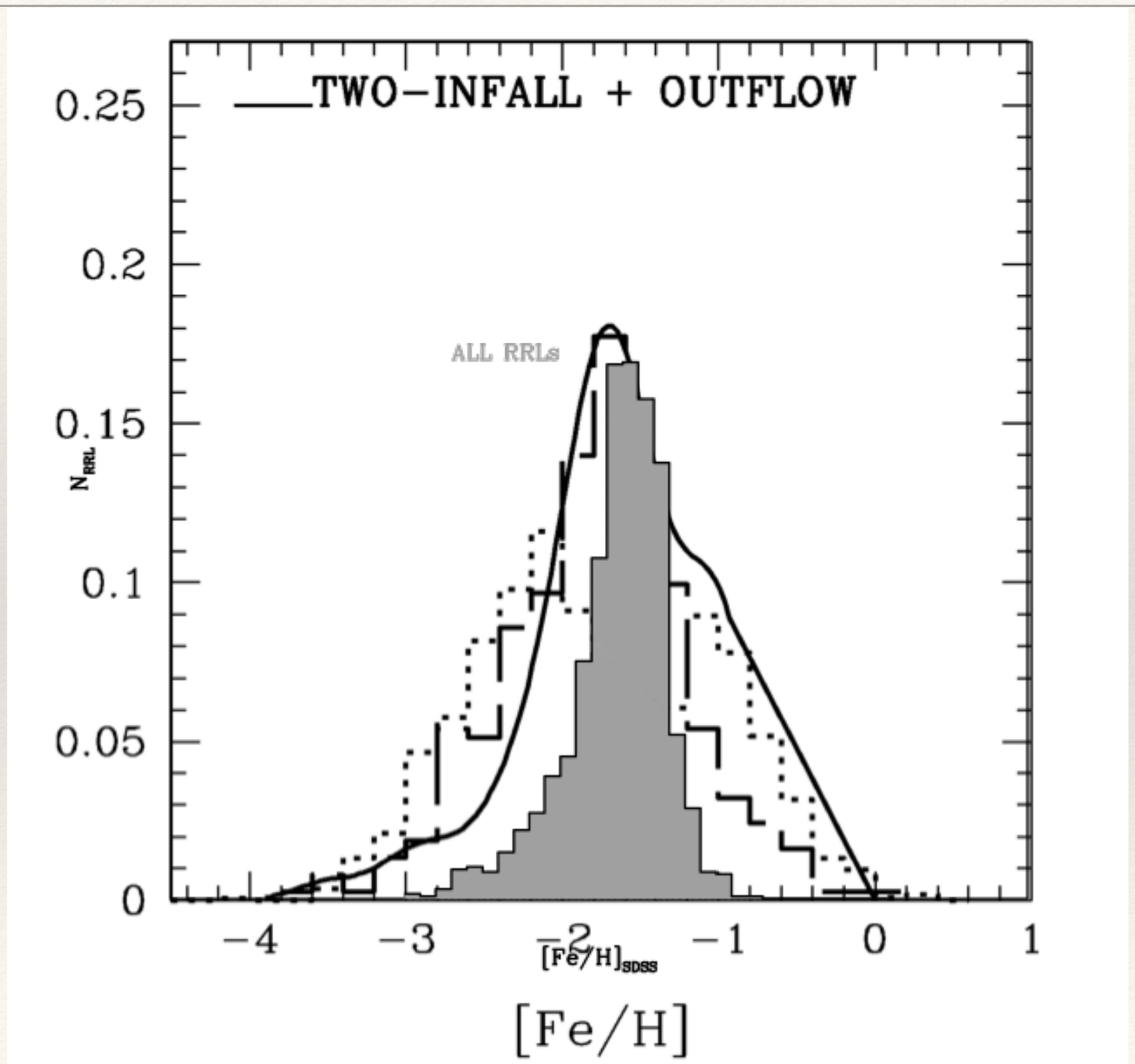
Chemical evolutionary models

Brusadin +13



HASP percentage and mean galaxy metallicity

$P<0.48$ d and $Av> 0.75$, i.e. $A_{F606W}>0.69$ and $A_I>0.47$

$A_{F606W}/A_V=0.92$ (Brown et al. 2004), $A_I/A_V=0.63$ (Di Criscienzo et al. 2011)

	dSphs	SMC	LMC	HALO	M31	Sgr	M32	BULGE
$\frac{N_{HASP}}{N_{RRab}}$	0%	3%	7%	8-6%	6-11%	6%	7%	17%

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Fiorentino et al. 2015, ApJL, 798L, 12

Increasing the metallicity

Results-II

Fiorentino et al. 2015, ApJL, 798L, 12

1) **The major contributors must have had an old population with a metallicity higher than classical dwarfs, excluding Sgr.**

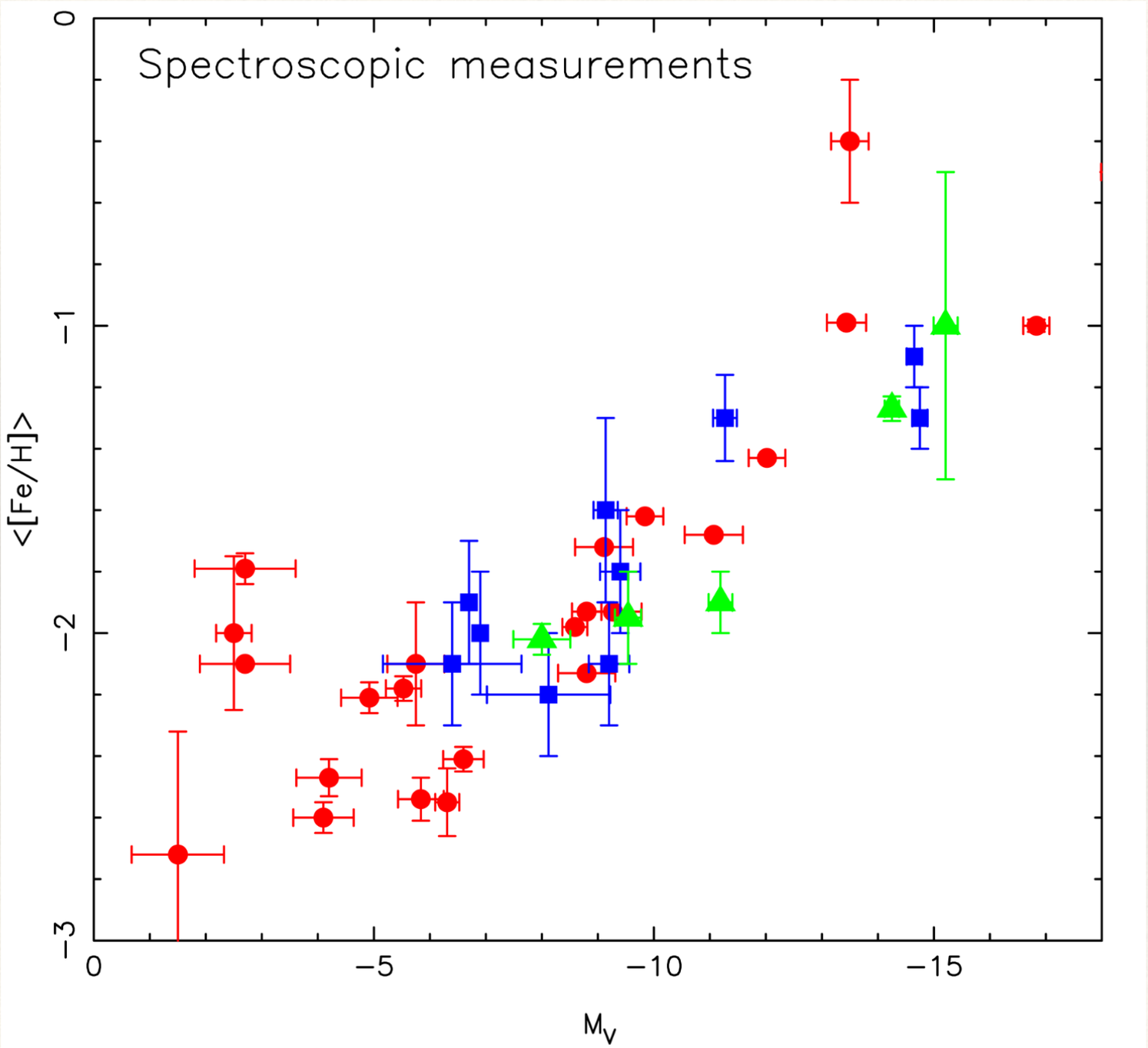
2) ***Photometric* detection and characterization of the HASPs might be a useful tool to constrain the metallicity of the old population in far away galaxies!**

some work in progress....

Sexten, January 22

Where do the HASP appear?

McConnachie +12



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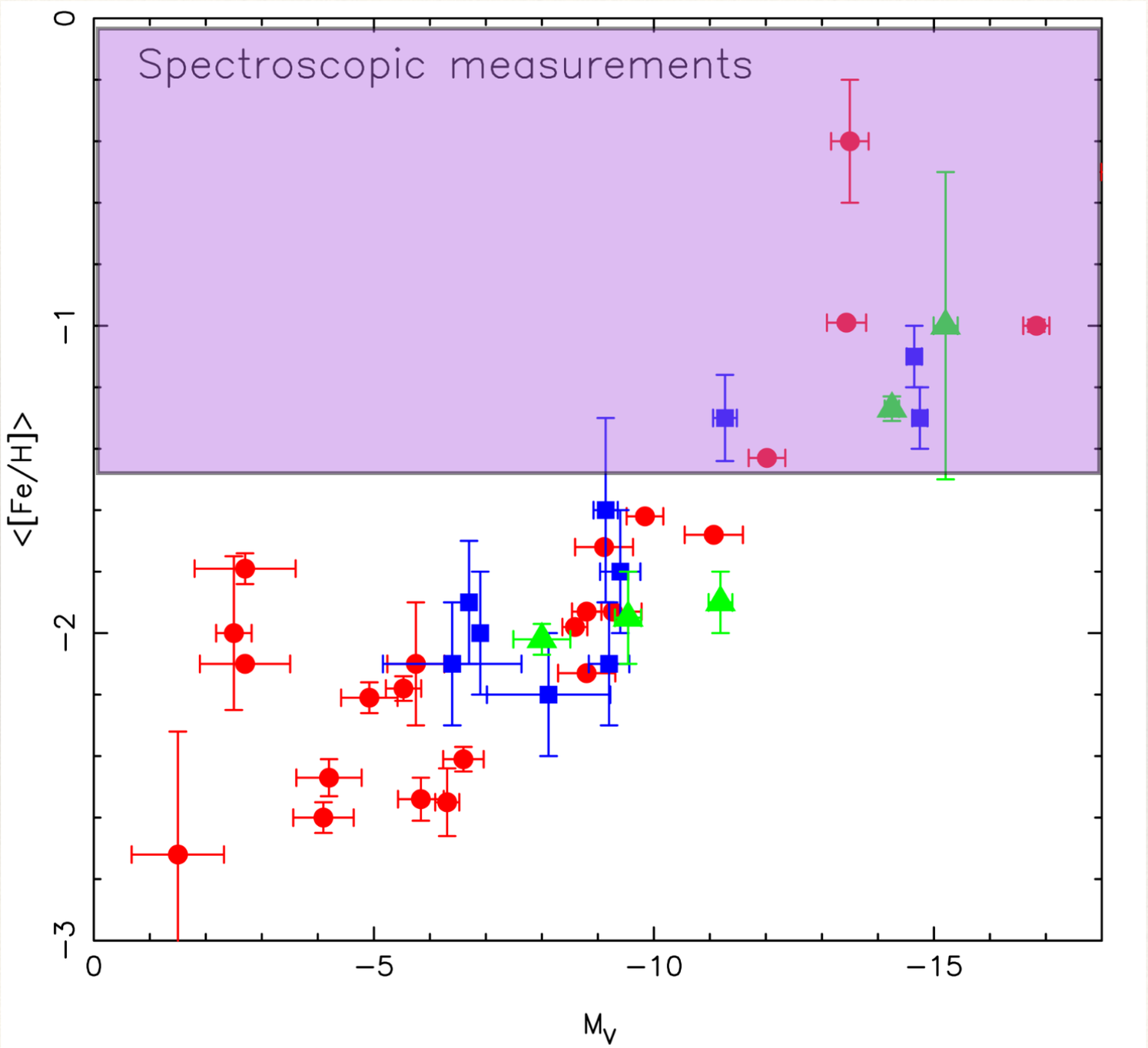

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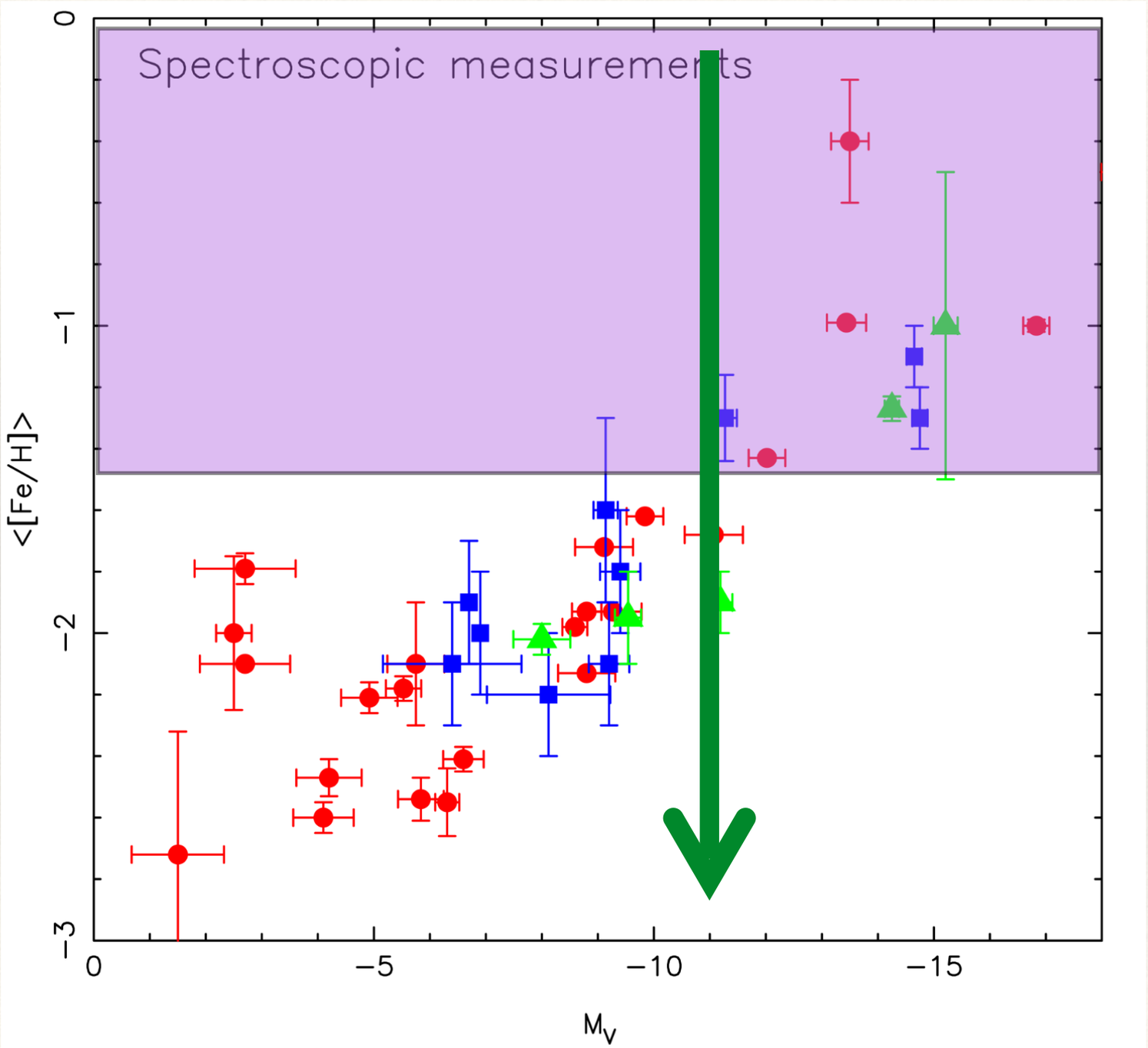

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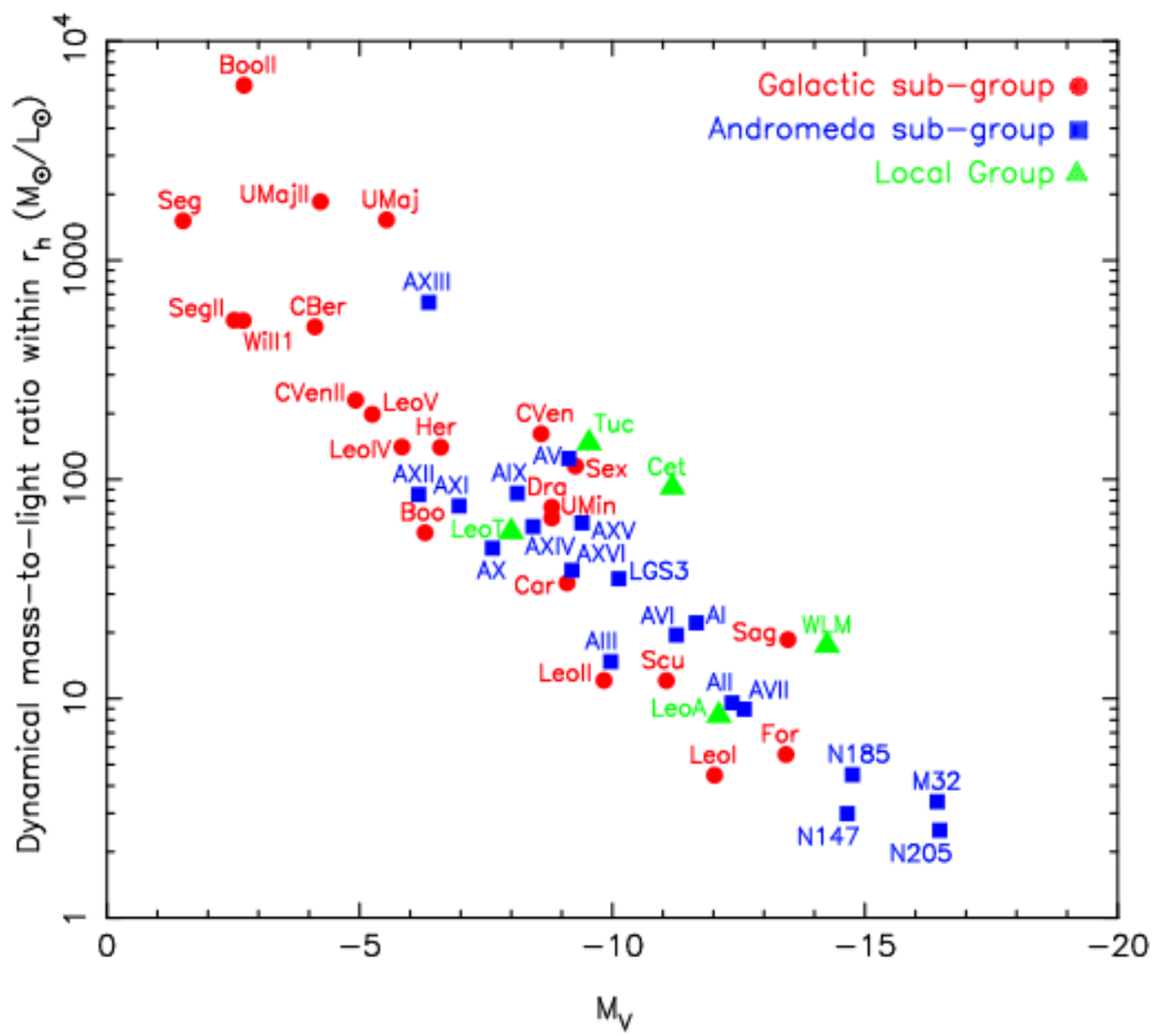

Fig. 11.— Mass-to-light ratio, in solar units, calculated within the half-light radius for all dwarf galaxies for which the necessary data exist, as a function of absolute visual magnitude.

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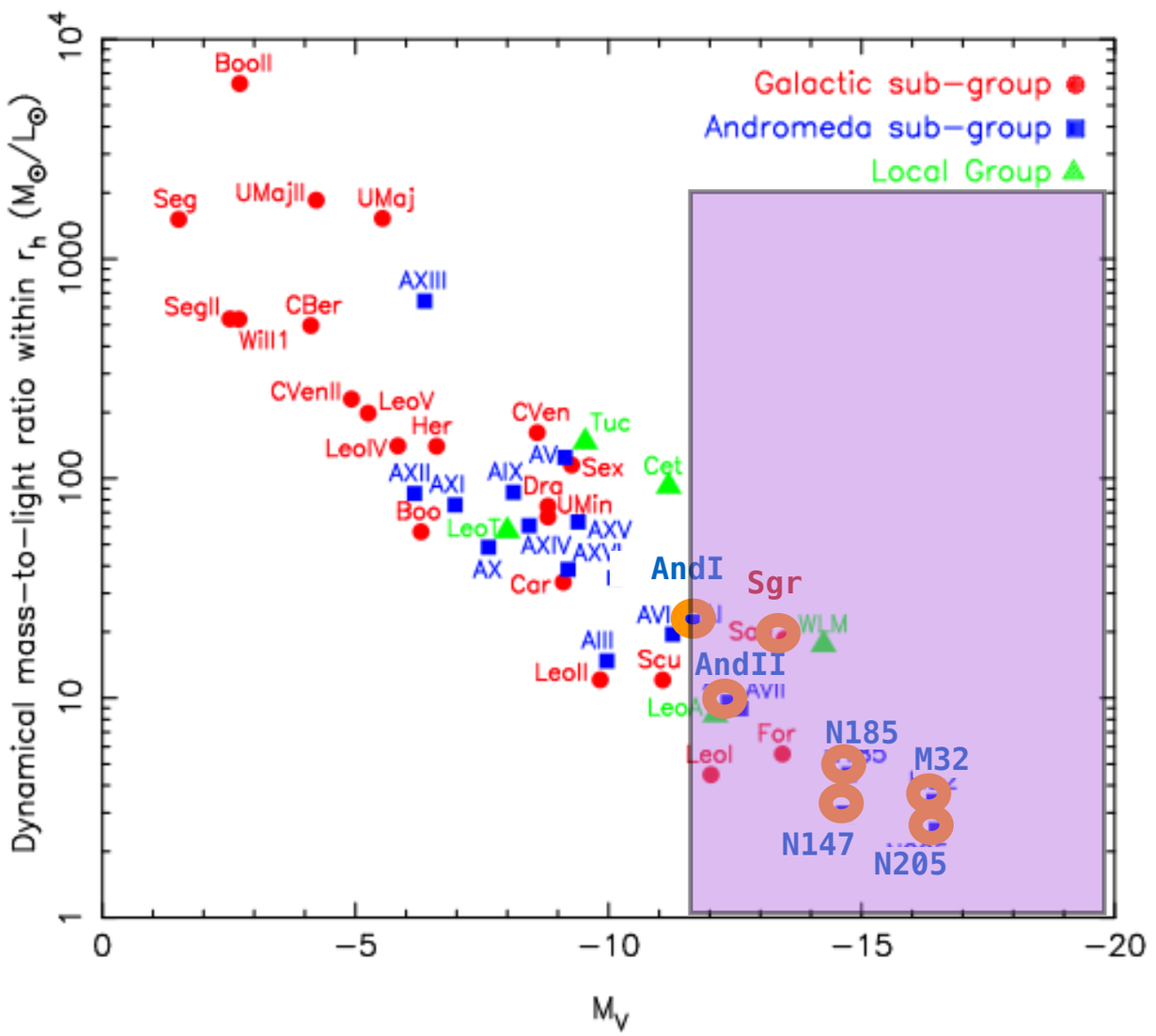

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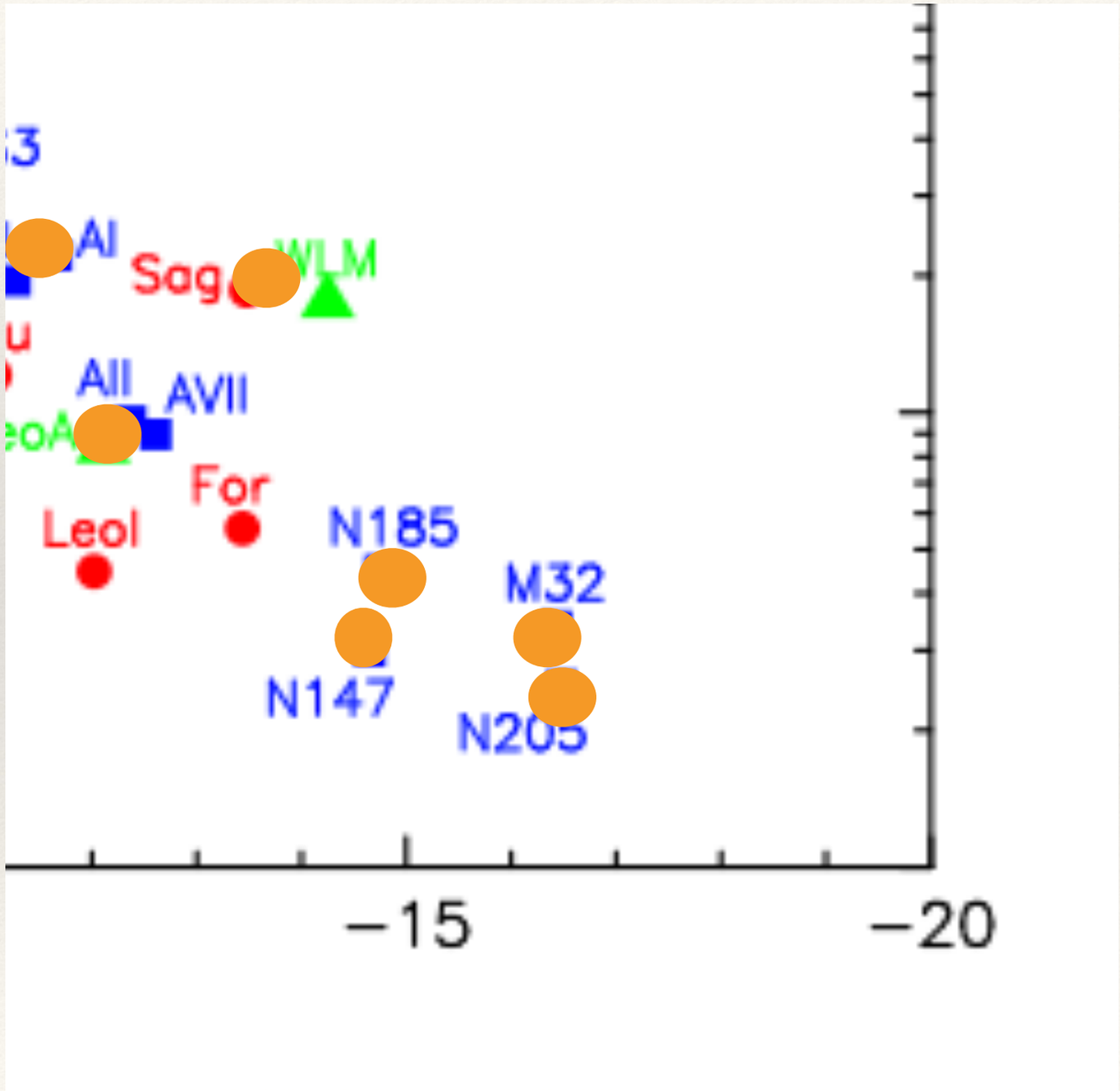
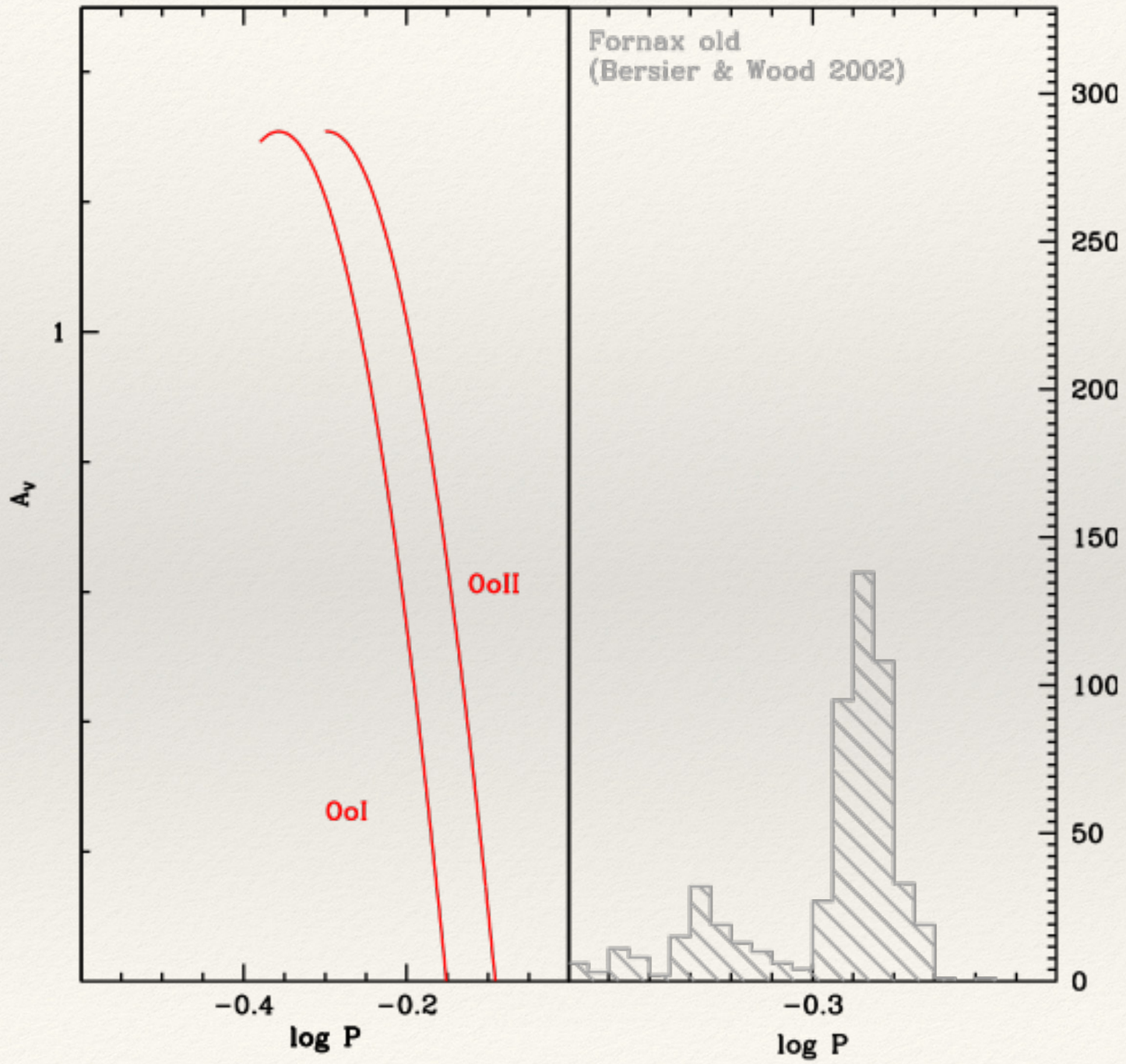


The special case of Fornax

Fiorentino et al. in prep



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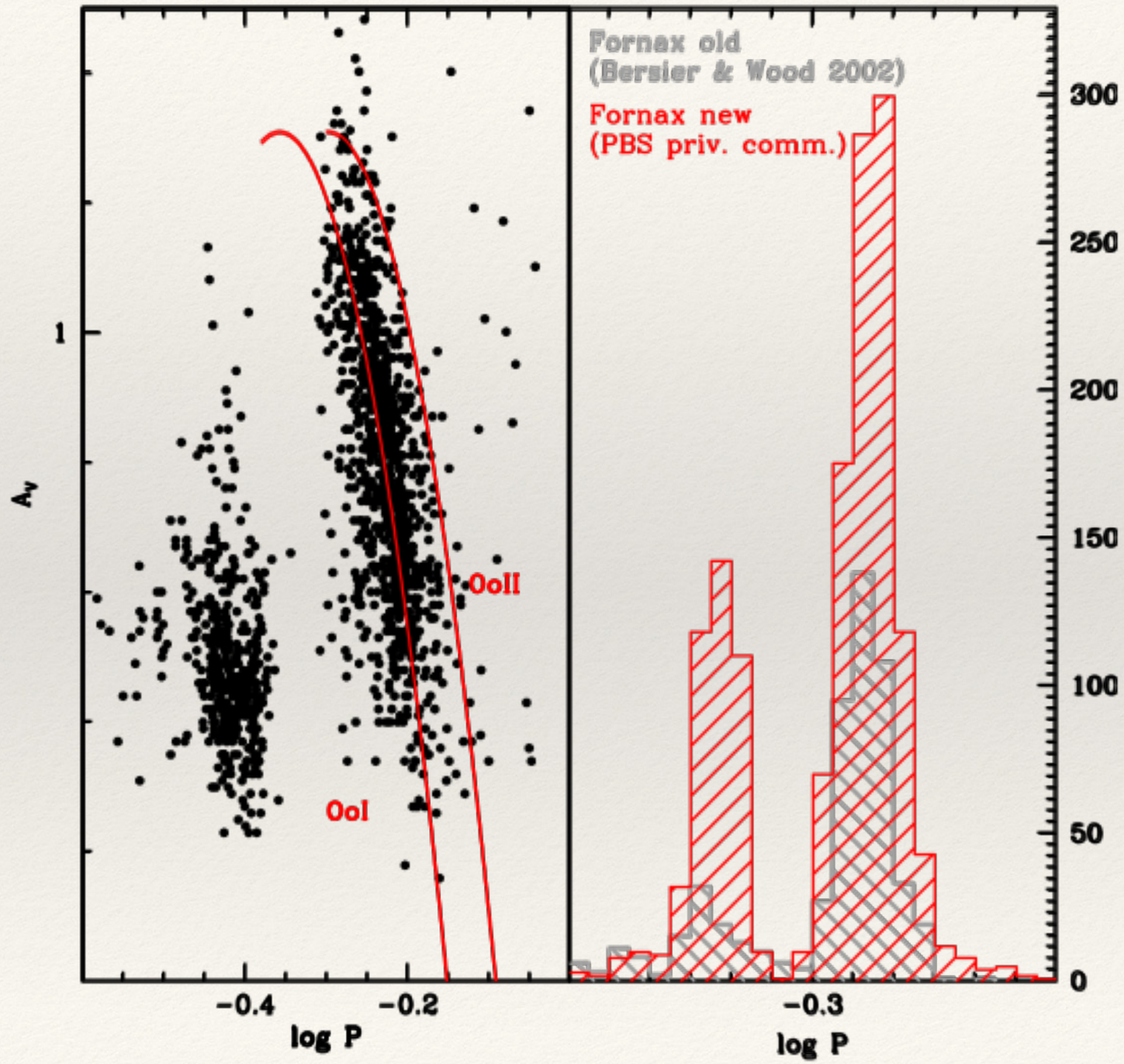

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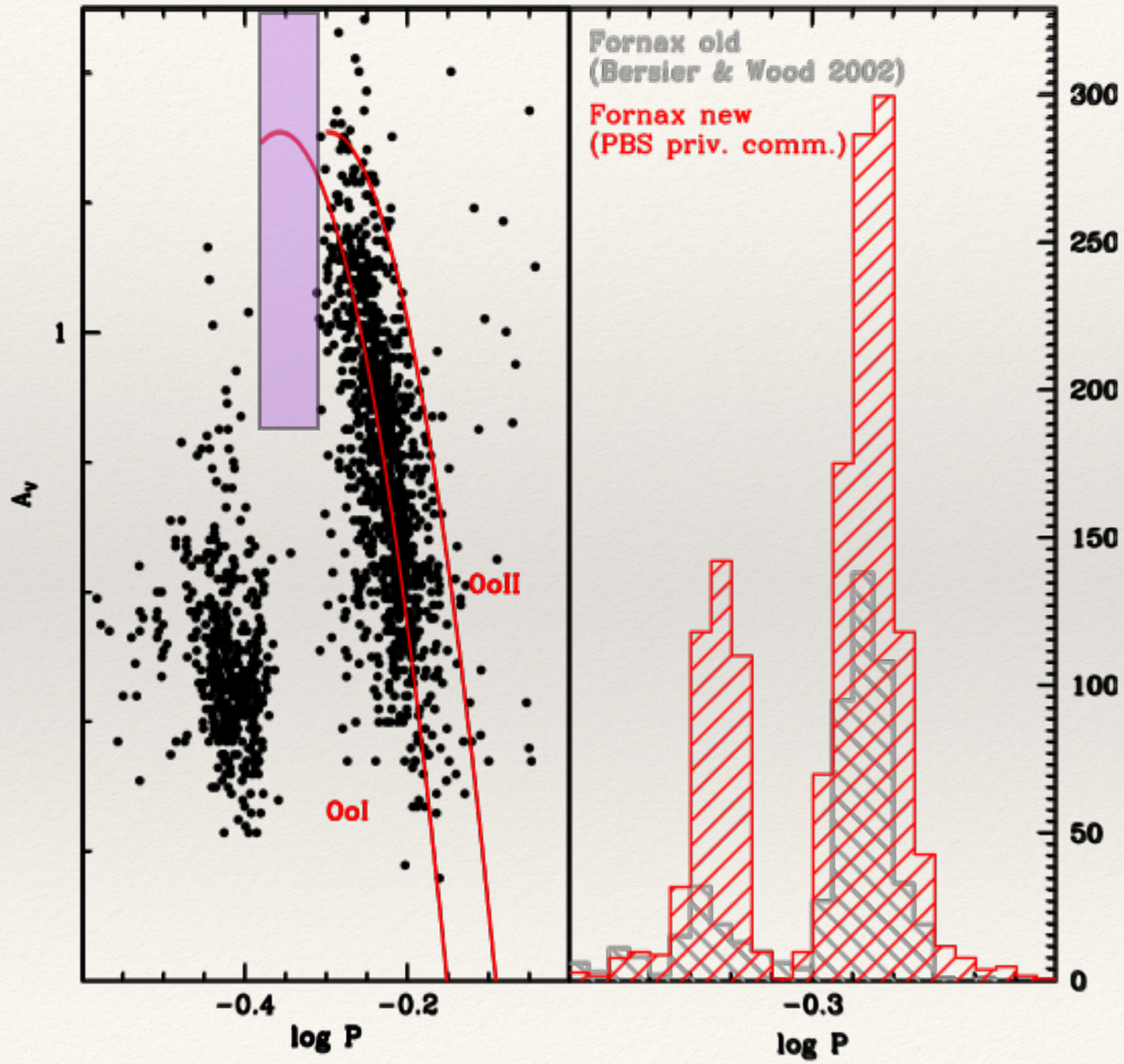

The special case of Fornax

De Boer +13

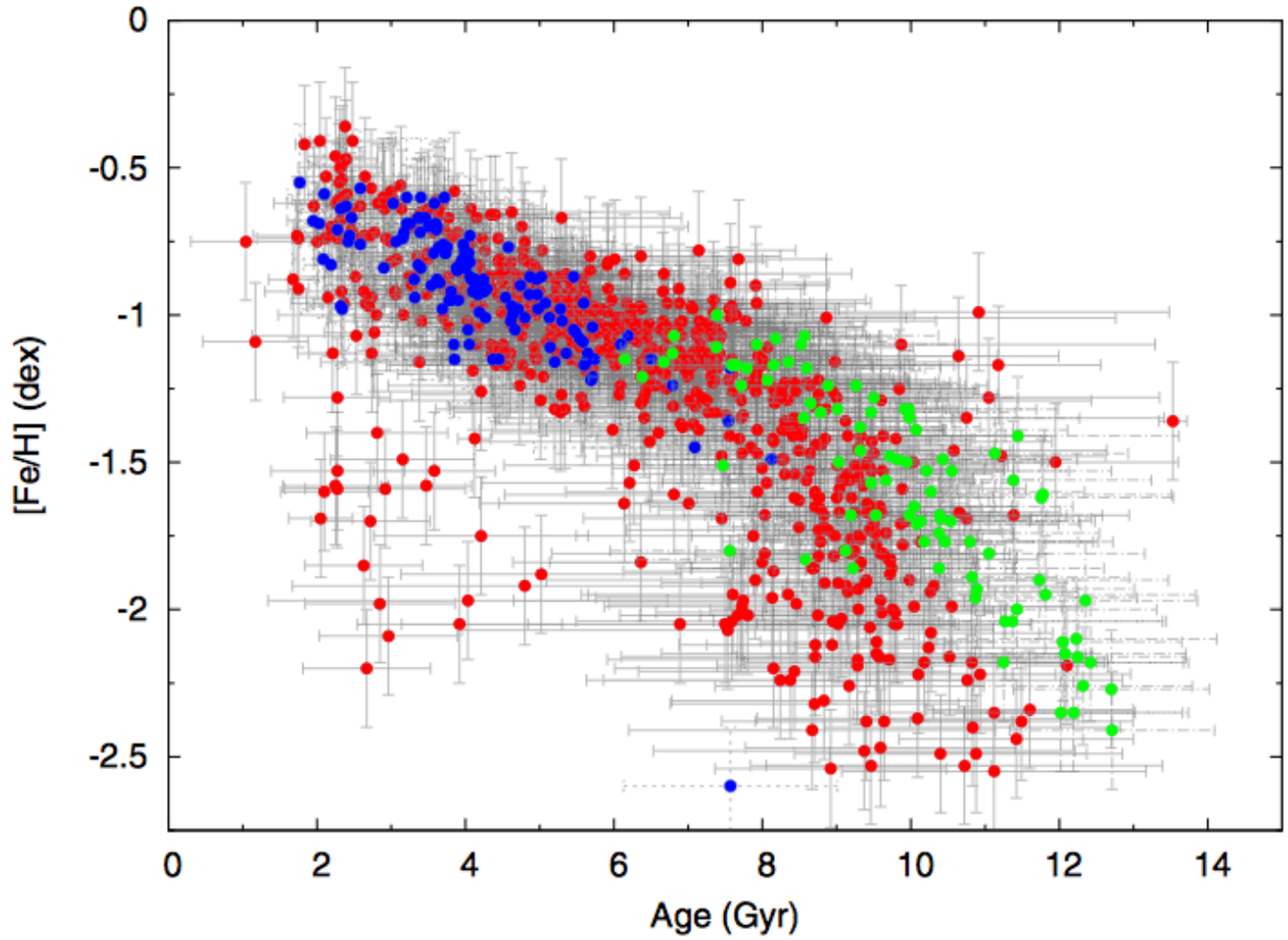

Fig. 18. The Age-Metallicity Relation of stars on the upper RGB in the Fornax dSph, incorporating the full SFH and MDF information. Medium and high resolution spectroscopy from Letarte et al. (2010); Kirby et al. (2010) is shown as blue points, while Ca II triplet spectroscopy from Battaglia et al. (2008) is shown in red. The AMR of the Sculptor dSph, from HR spectroscopy, is shown as green points (de Boer et al. 2012).

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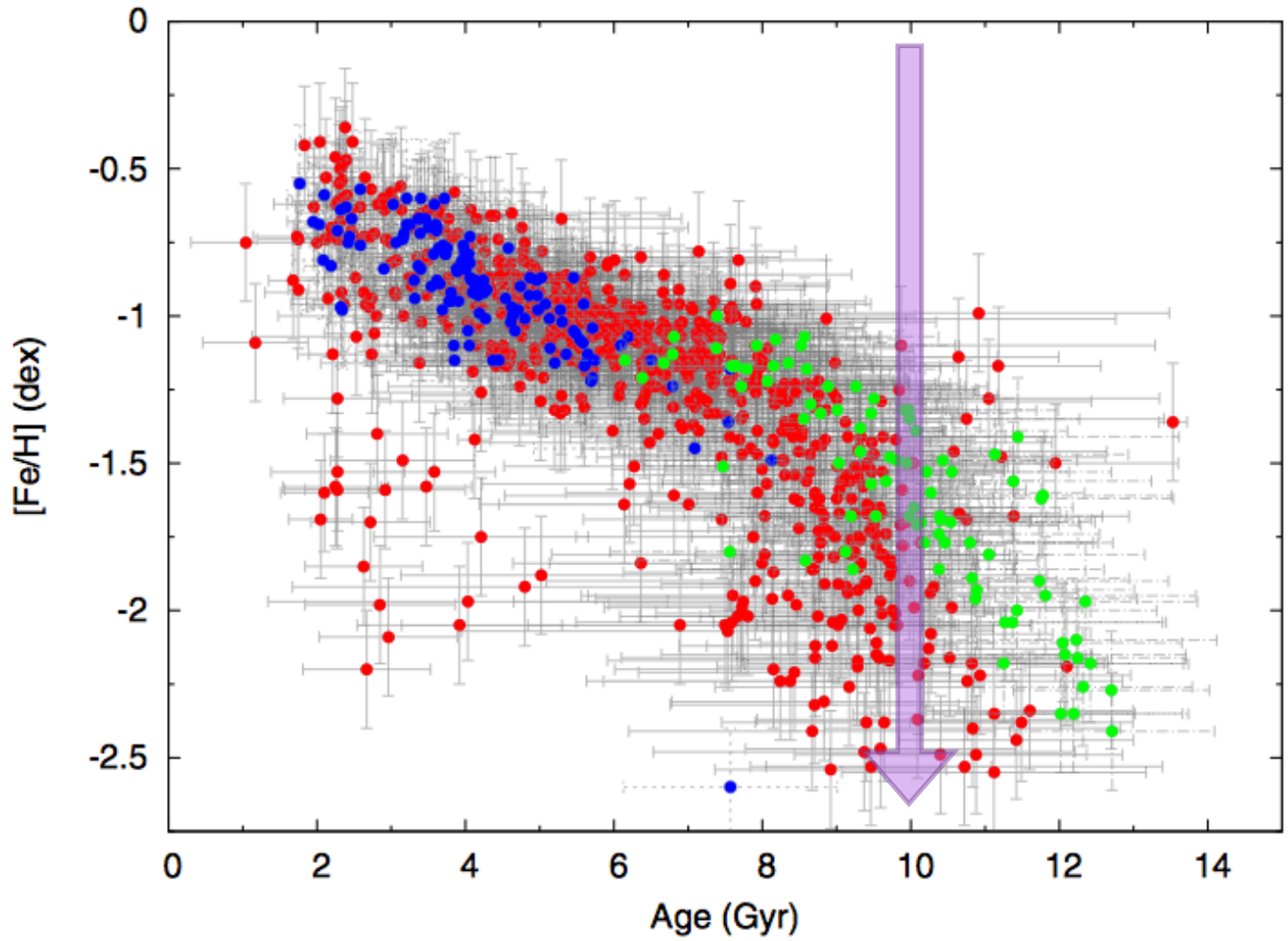

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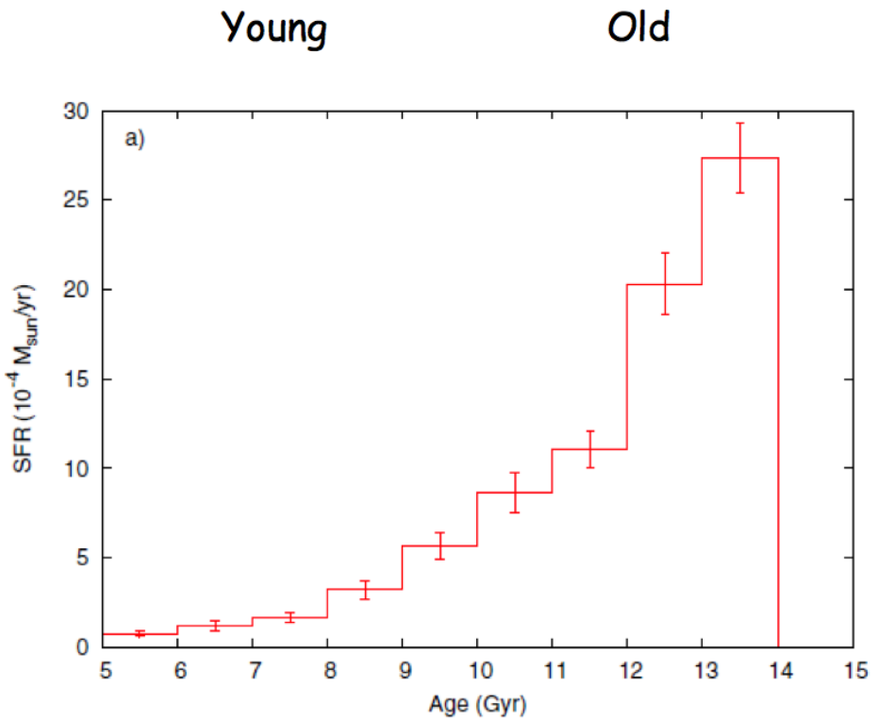
SLOW and FAST SF in dSph galaxies

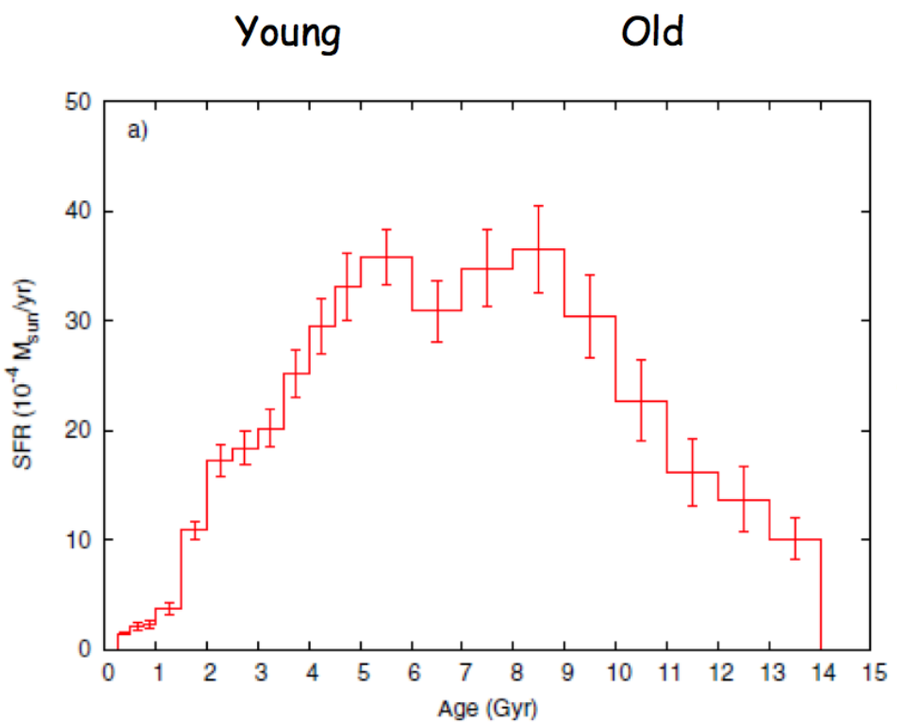
Gallart +in prep.

Sculptor dSph



FAST

...and Fornax dSph

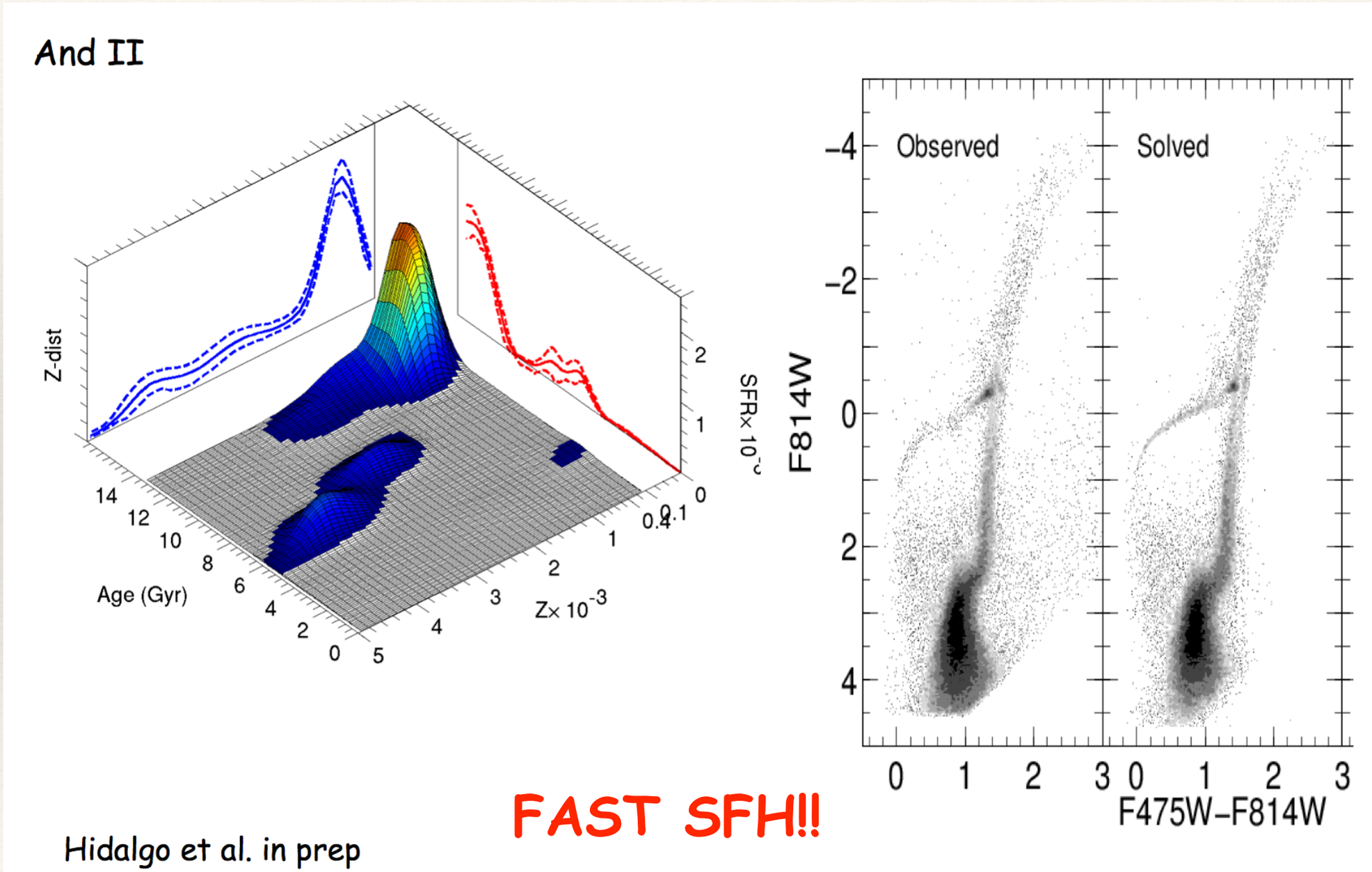


SLOW

courtesy of M. Monelli

The case of AndII

Hidalgo +in prep.



courtesy of M. Monelli

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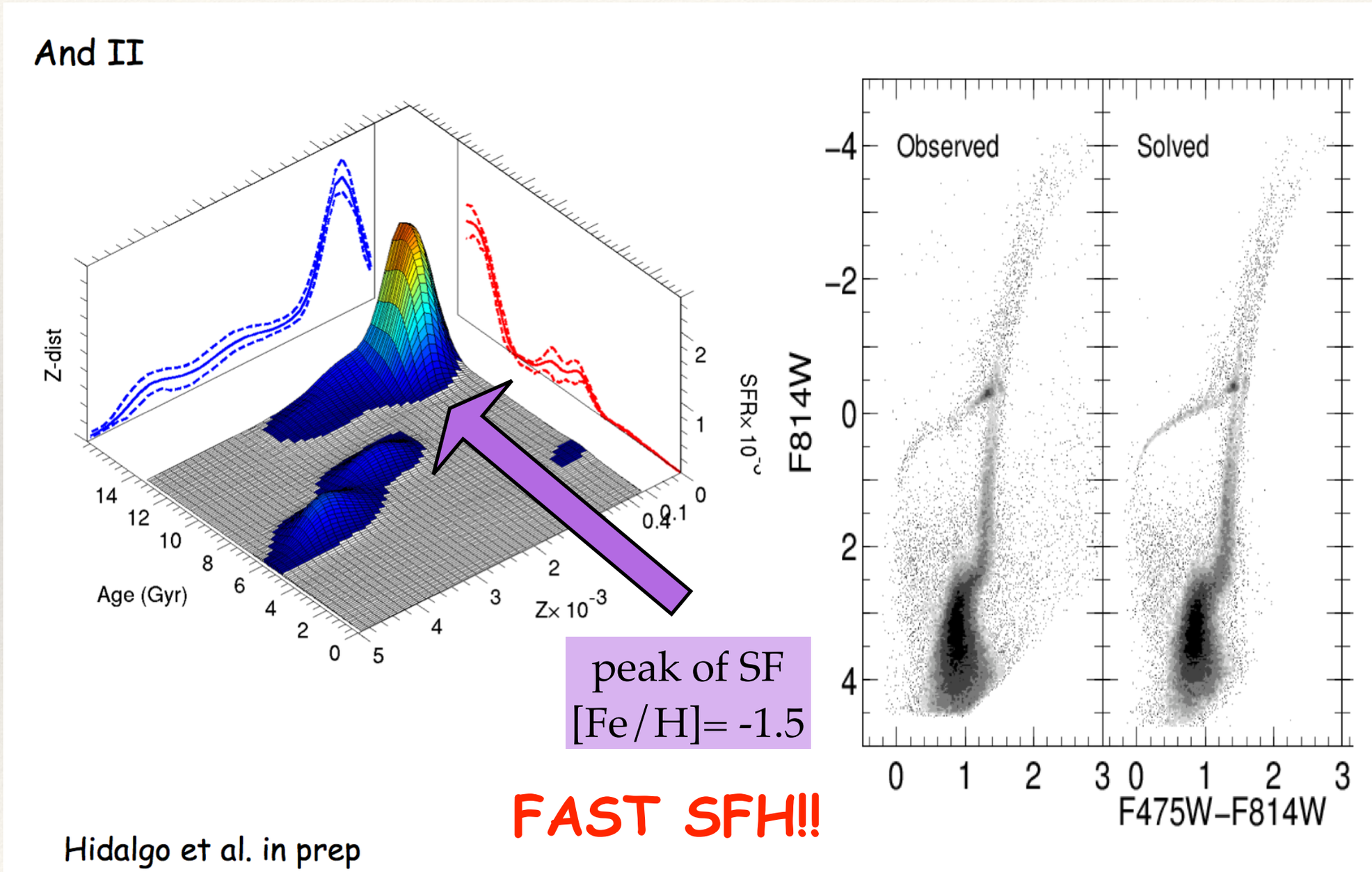

courtesy of M. Monelli

THANKS for your attention

...a lot to learn from the elders

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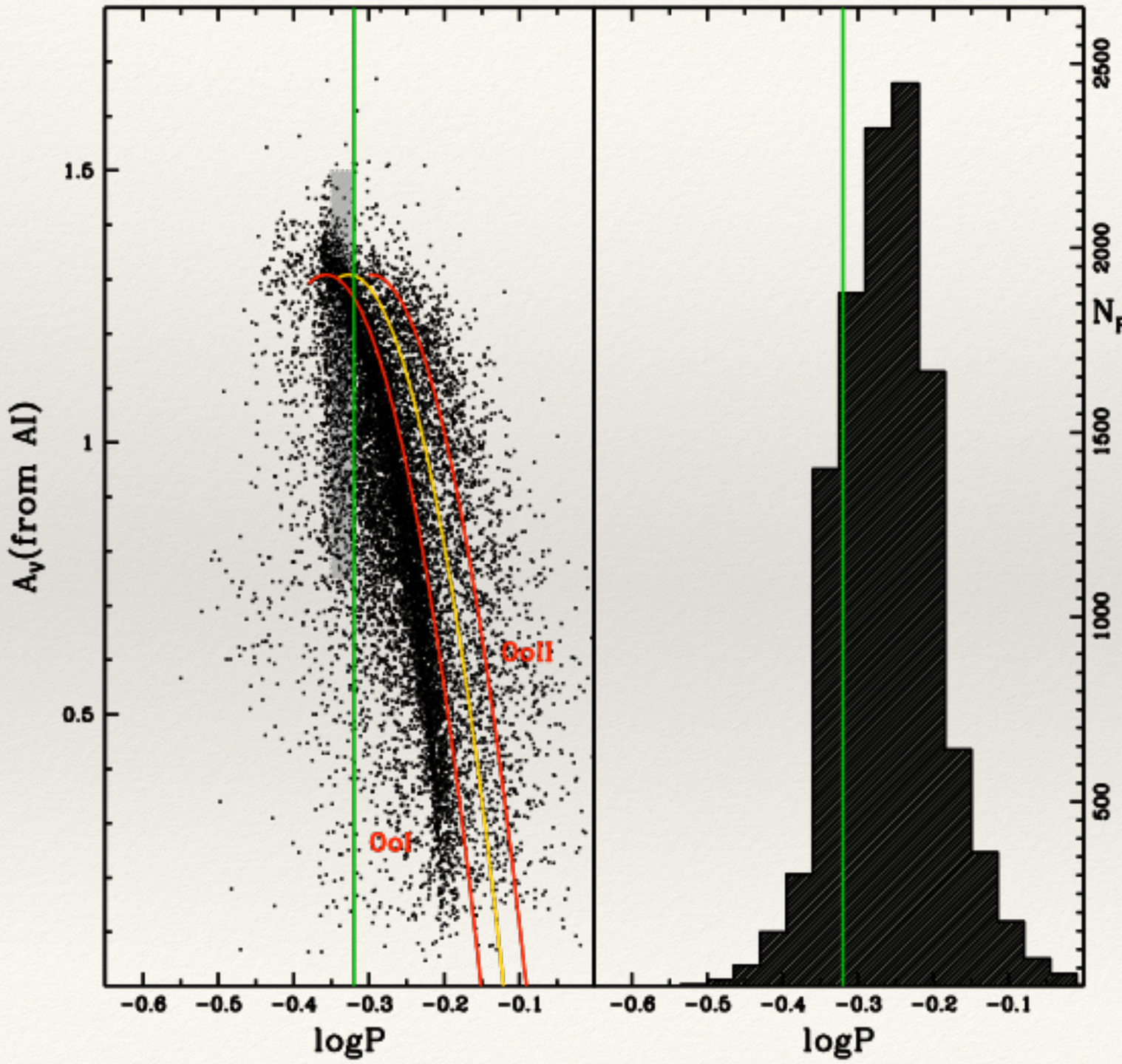
Our Bulge: Bailey diagrams and period distribution



BULGE

<Pab>=0.5561 ± 0.0008 (0.09)

OOI 77% OOII 23%