METALLICITIES OF DR3 RR LYRAE STARS

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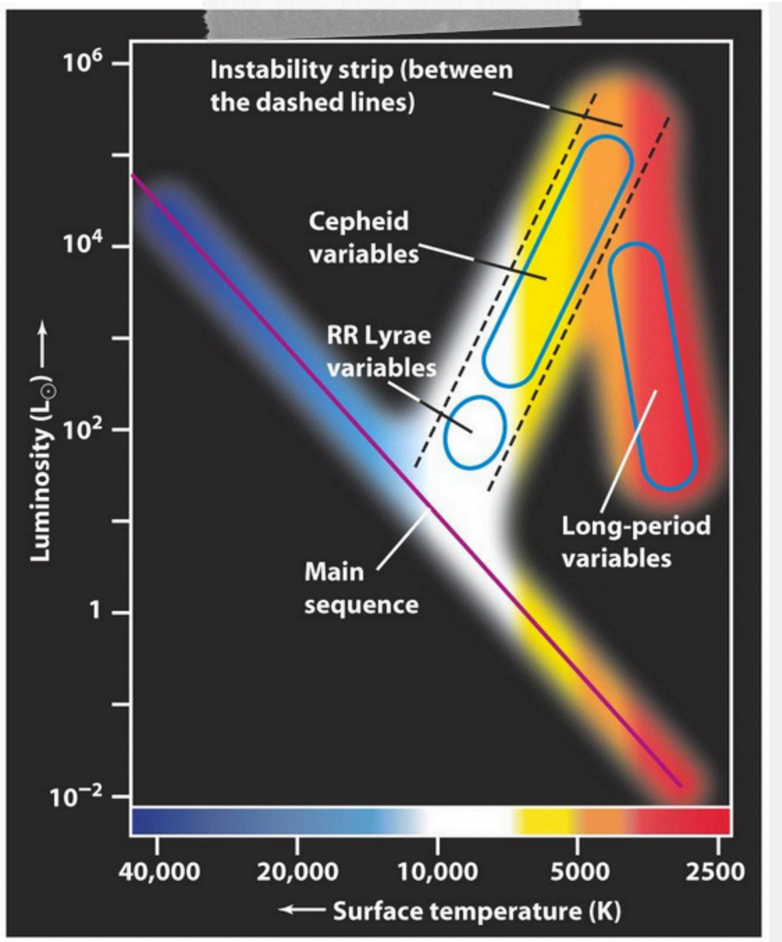
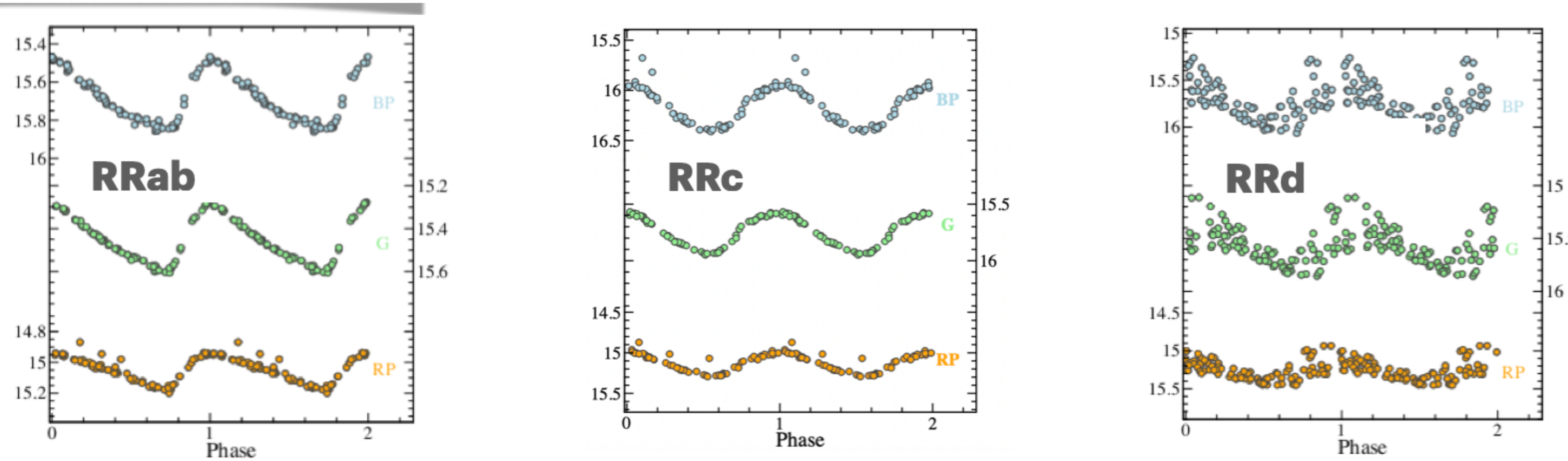
Istituto Nazionale di Astrofisica - Osservatorio di Astrofisica e Scienza dello Spazio Bologna

MW-GAIA WG2 WORKSHOP: STELLAR VARIABILITY, STELLAR MULTIPLICITY: PERIODICITY IN TIME & MOTION, 6-8 JUNE 2023

RR LYRAE STARS, A TERRIFIC MULTI PURPOSE TOOL



- Helium burning, HB stars
- 0.6 - 0.8 M⊙
- 4 - 6 R⊙
- Age > 9-10 Billion Years Old
- [Fe/H] = 0.0 / -3 dex
- Periods from 0. 2 to 1. 0 d
- Thick disk, bulge, globular clusters, stellar halo and substructures
- Teff 6100-7400 K, Logg 2. 5 - 3. 0
- Mv 0. 65 ± 0. 2 mag



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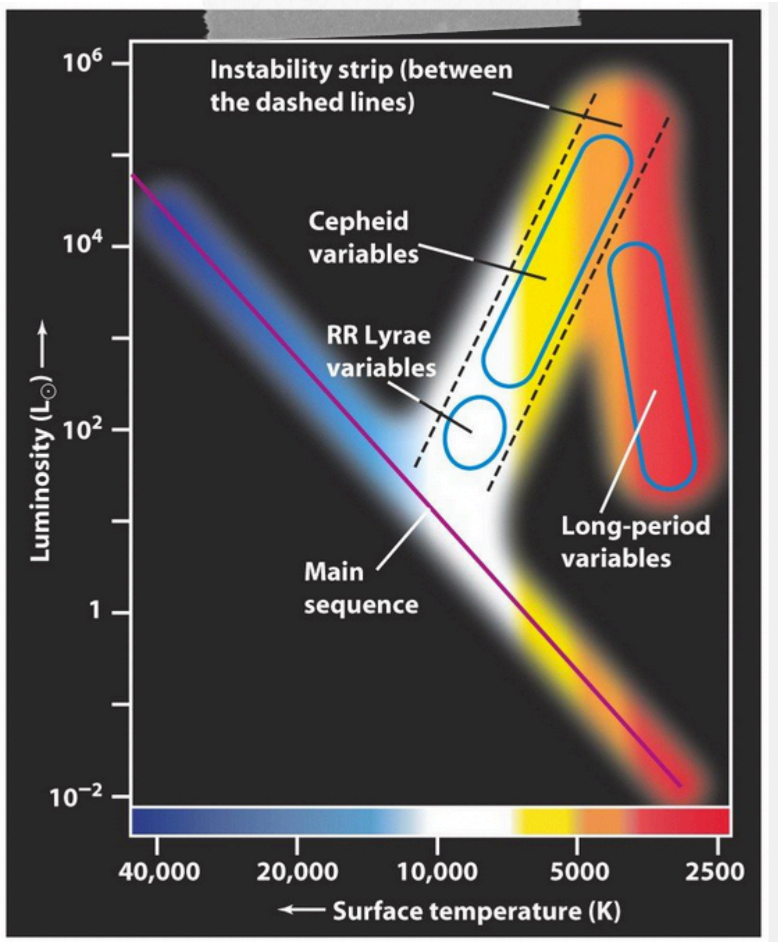

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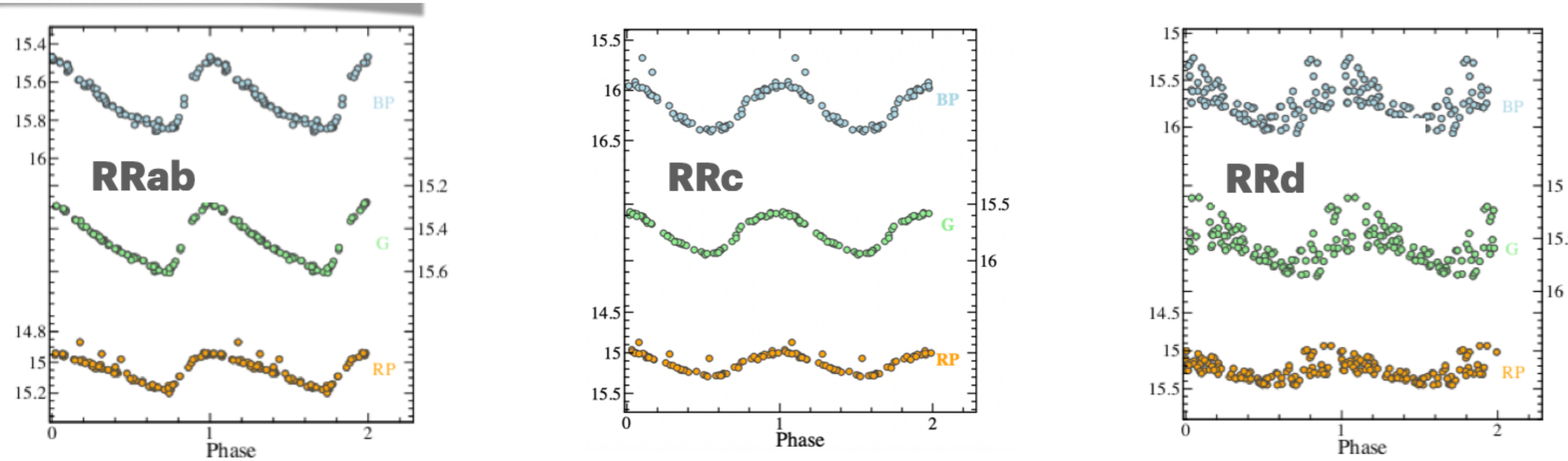

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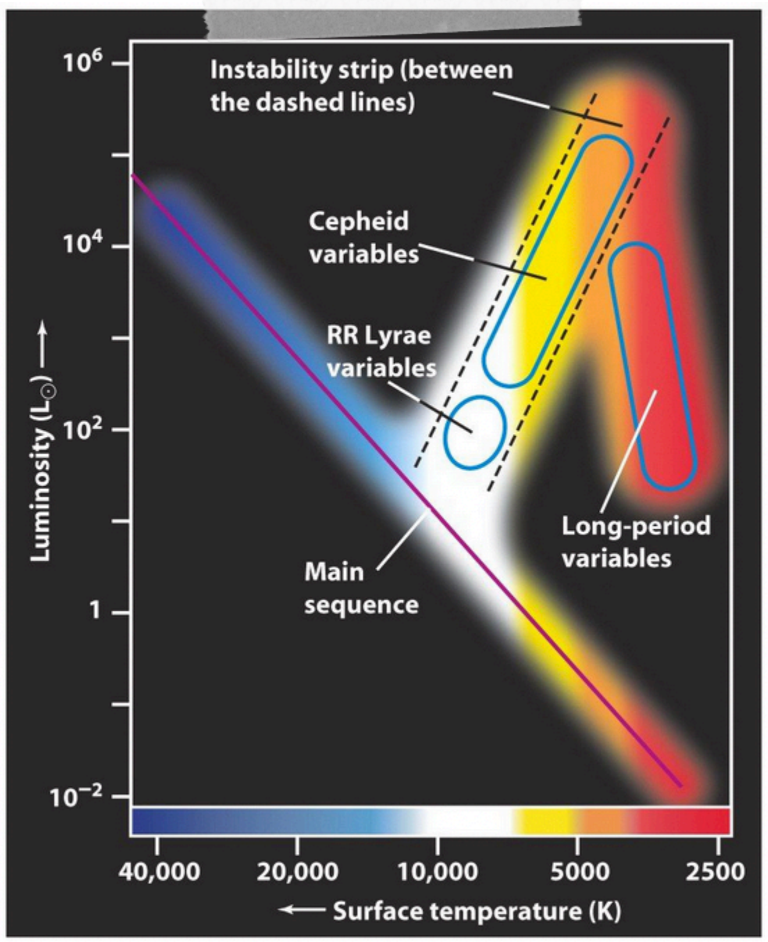

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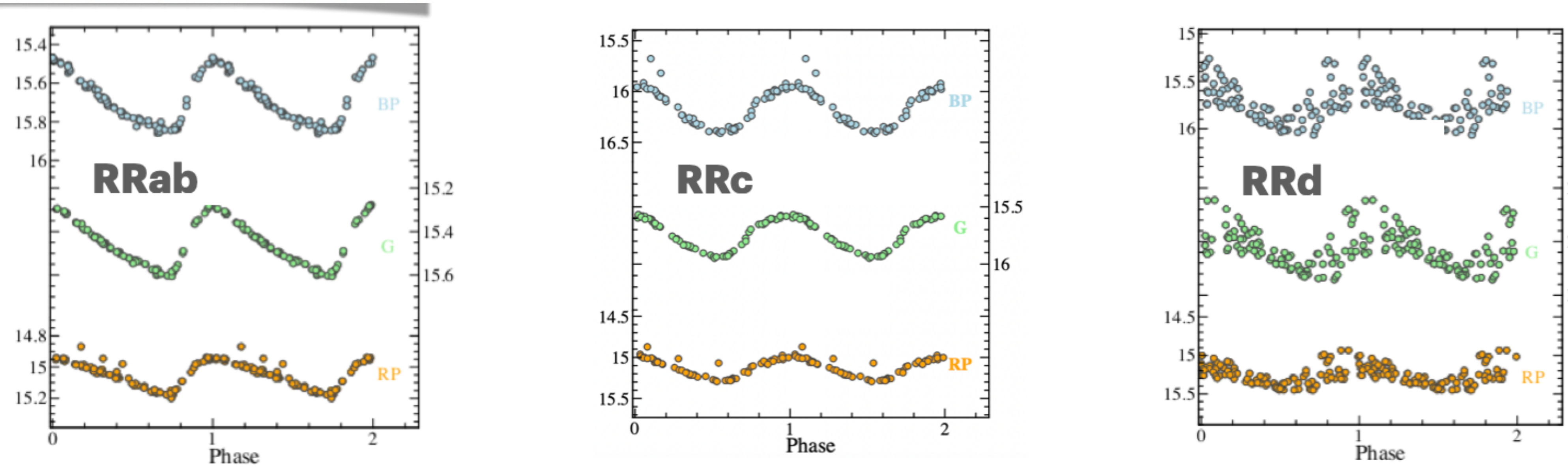

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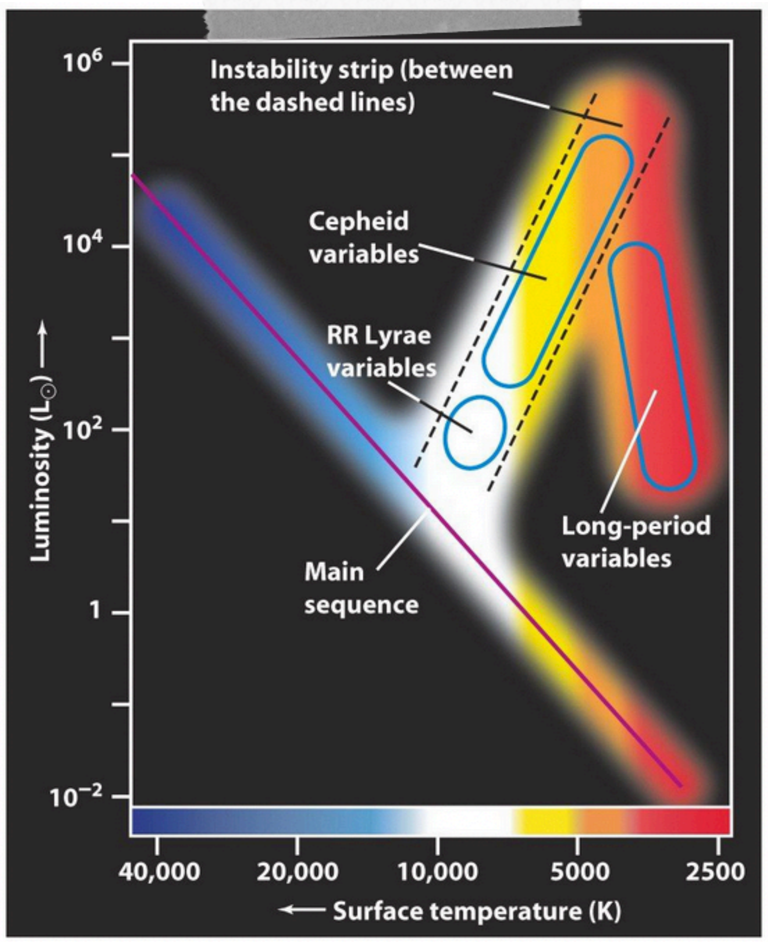

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$M_{IR} = \alpha \times \log P + \beta \times [Fe/H] + ZP$ **Period - Luminosity - Metallicity (PLZ) relation**

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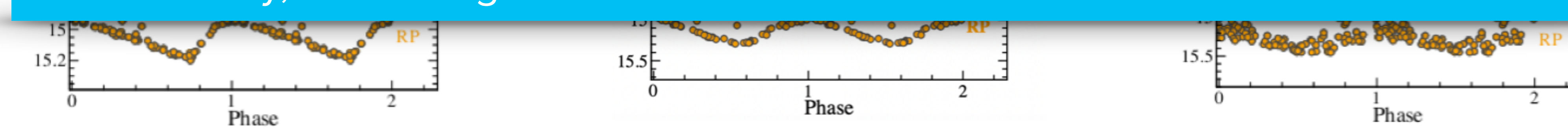

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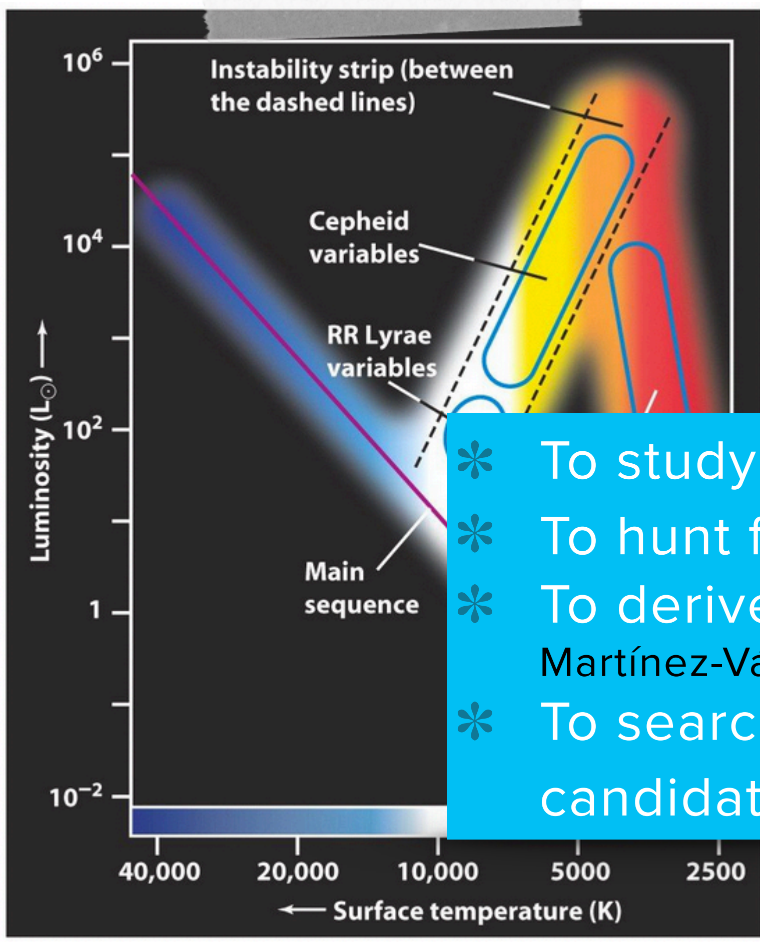

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And many more…

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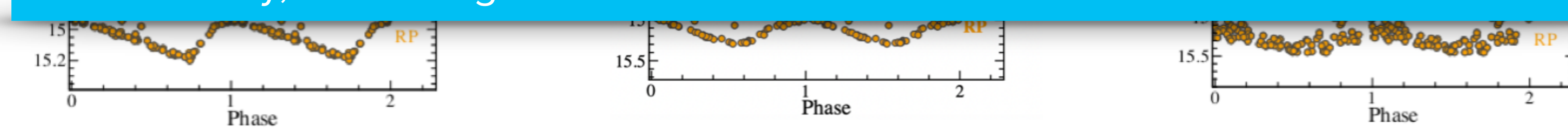
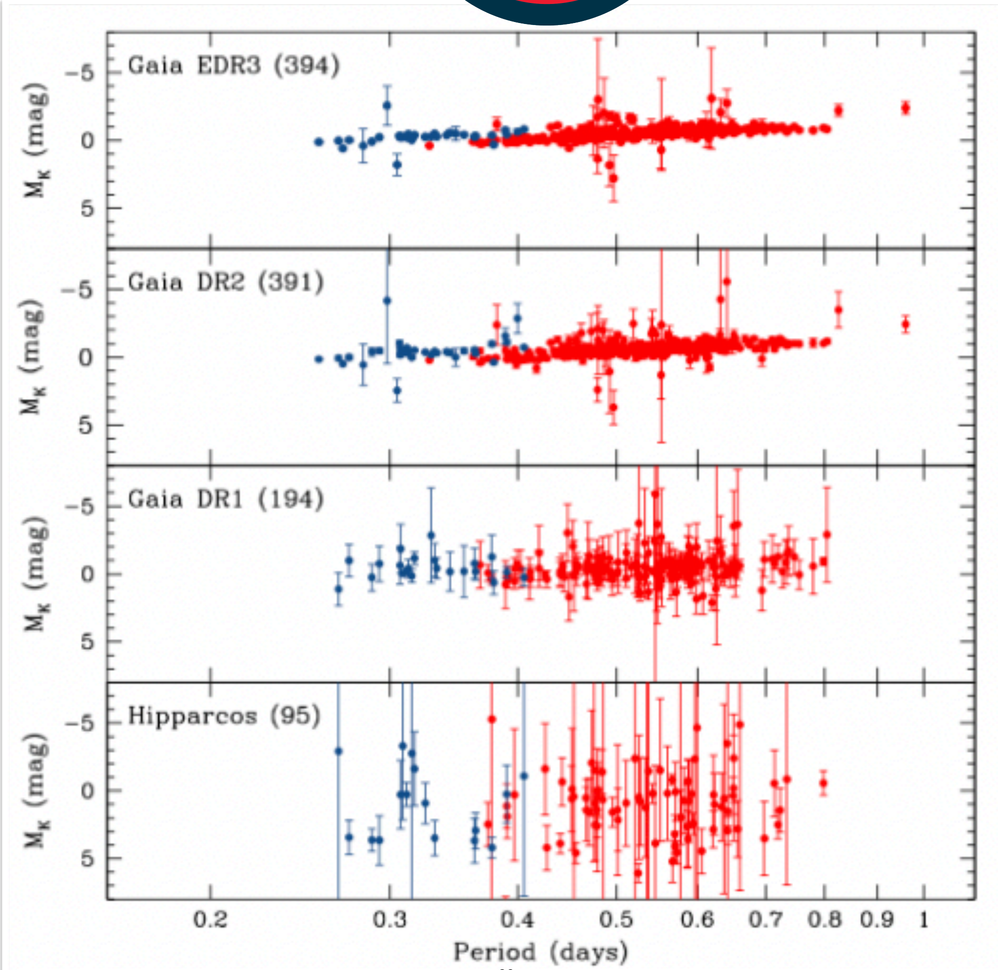


RR LYRAE STARS, A TERRIFIC MULTI PURPOSE TOOL

ACROSS DATA RELEASES

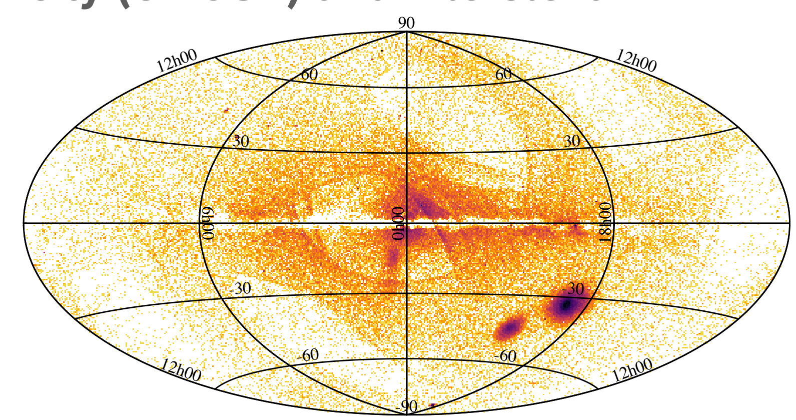
Astrometry + Photometry

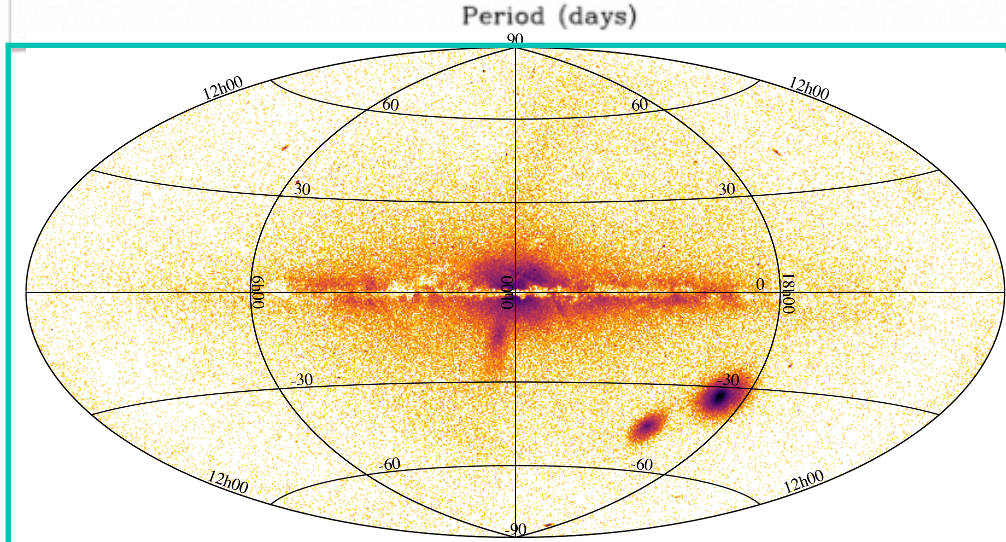


CU7 Specific object study (SOS) of Cepheids and RR Lyrae stars

Clementini, Ripepi, Molinaro, Garofalo, Muraveva et al. 2019 A&A 622, 60

140 784 RR Lyrae stars 50220 new discoveries All-sky
Multi-band time series photometry, <G>, <GBP> and <GRP>
pulsation characteristics: P, type, amplitudes, R21, φ21, R31 and φ31
astrophysical parameters: Metallicity (64 932) and Interstellar Absorption (54 272)





Clementini, Ripepi, Garofalo, Molinaro, Muraveva, Leccia et al. in press arXiv:2206.06278G

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1096 RR Lyrae RVS time series are also published

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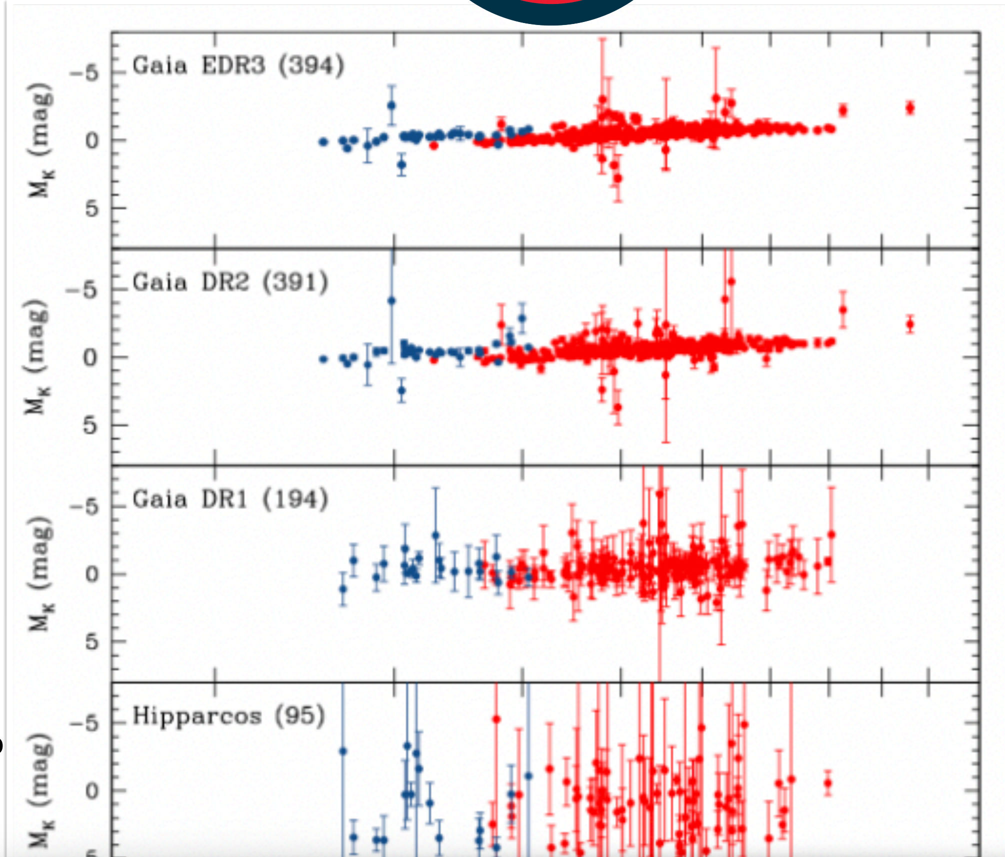

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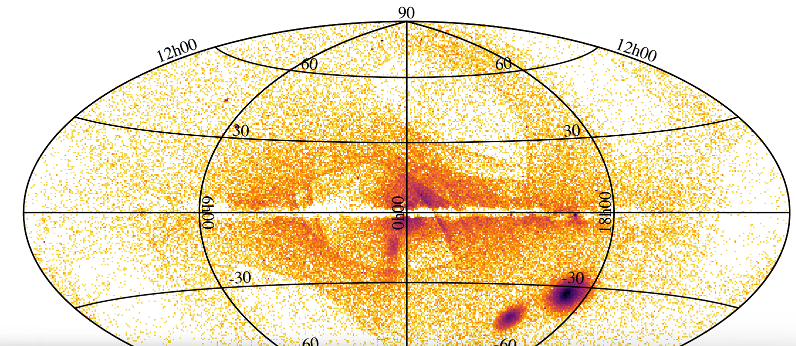
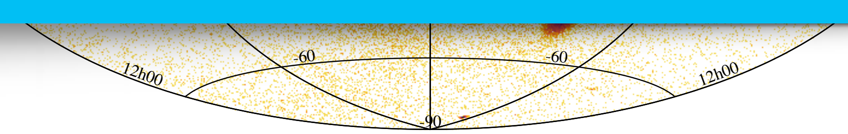


- Gaia data improved our understanding of Galactic RR Lyrae stars and the Milky Way with RR Lyrae stars
  - Discover halo sub-structures (Belokurov et al. 2019, Torrealba et al. 2019)
  - Study the chemo-kinematics of the halo and the disc of the Milky Way with RR Lyrae stars (Iorio & Belokurov 2021)
  - Re-calibration of RR Lyrae PLZ LZ relations (Garofalo et al. 2022, Li et al. 2022, Bhardway et al. 2021, 2023, Mullen et al. 2023 and more)



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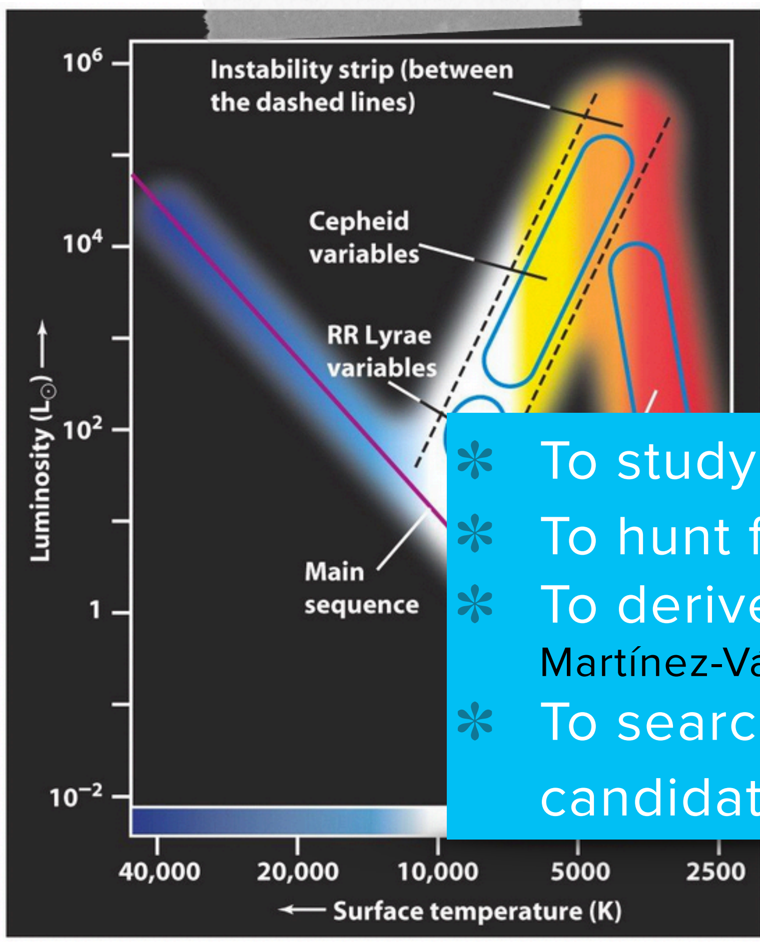

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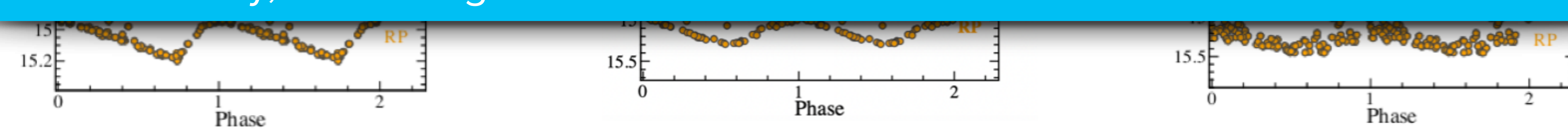

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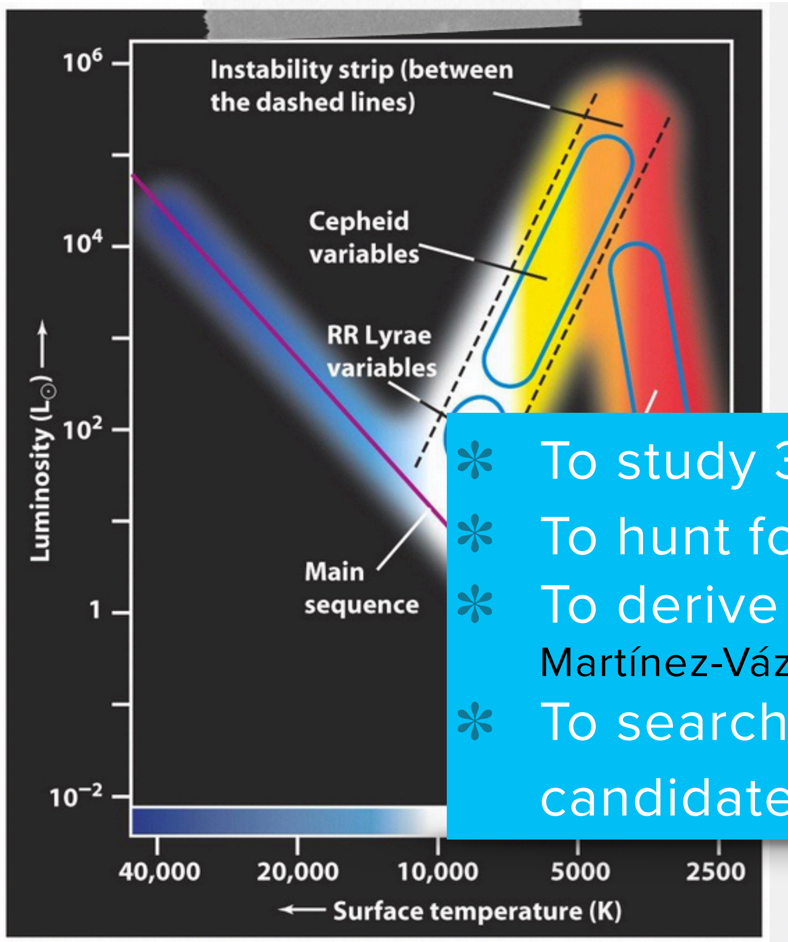

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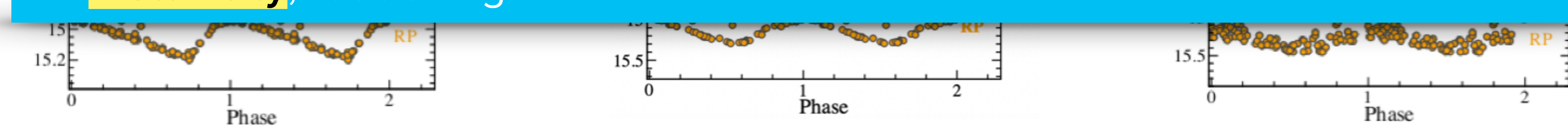
Mv = α[Fe/H] + β **σ[Fe/H] ~0.2–0.3 dex implies σMv~0.06 mag**

RRLs < 1Mpc

M IR= α×logP + β × [Fe/H] + **coefficient of the metallicity term < ~0.15 dex**

* Assuming distance
* Galactic RRLs WITH KNOWN distances (parallaxes)
  Metallicity, reddening



RR LYRAE STARS, A TERRIFIC MULTI PURPOSE TOOL

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→ combination of the first and third phase terms ($\phi31=\phi3-3\phi1$) in a Fourier decomposition of RR Lyrae light curves

$$V(t) = A_0 + \sum_{i=1}^{N} A_i cos(i\omega_0(t-t_0) + \phi_i)$$

- V(t) = observed magnitude at time t of observation; A0 = star mean magnitude
- Ai and ϕi are, respectively the amplitude and the phase coefficients of the i-th Fourier term, corresponding to the i-1 harmonic
- ω0 = angular pulsation frequency of the star
- t0 = time of the maximum light

METALLICITY OF RR LYRAE STARS : GAIA DR3 SOS

Clementini et al. A&A in press, arXiv:2206.06278

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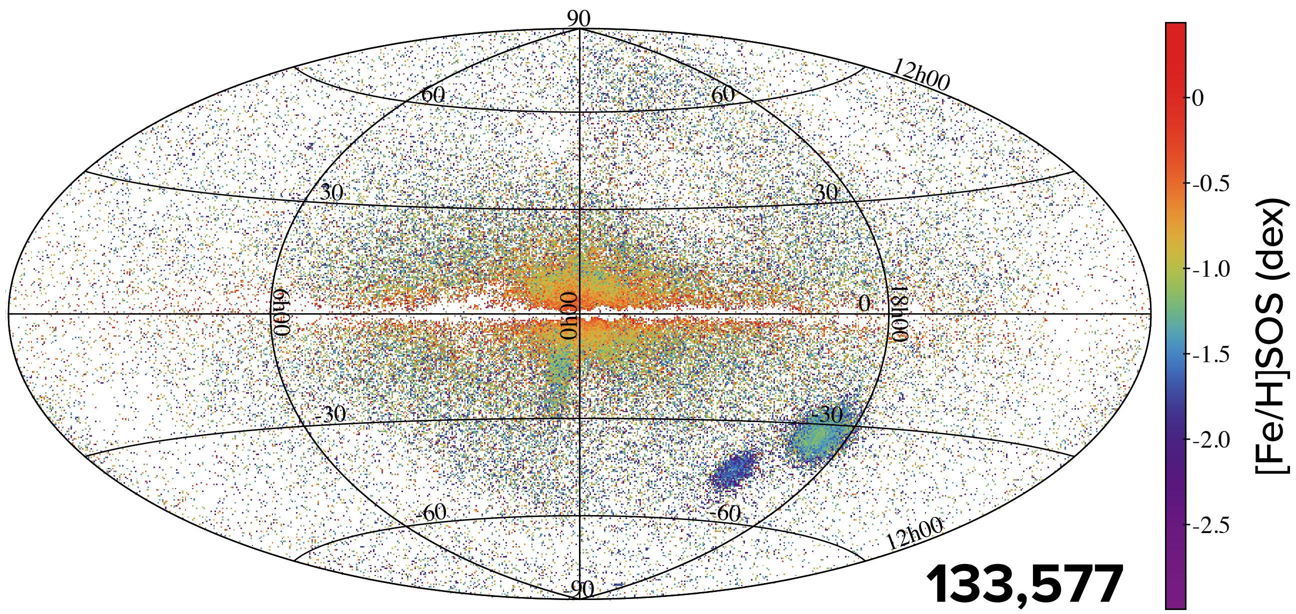

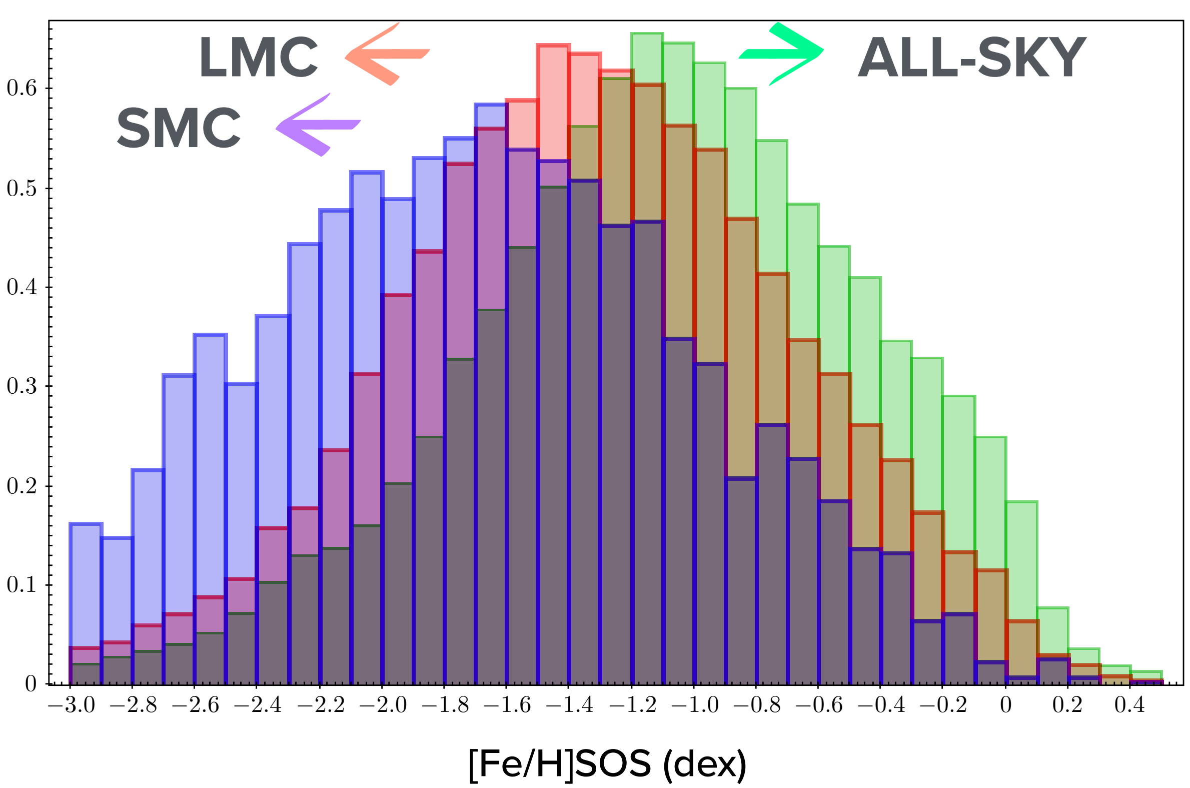

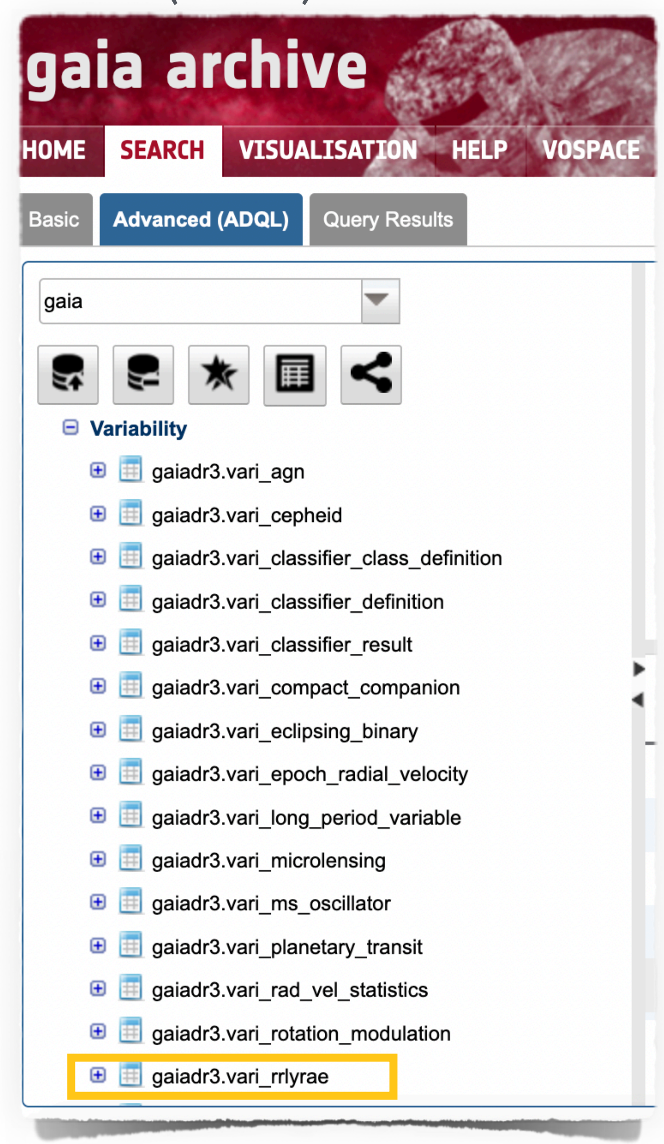

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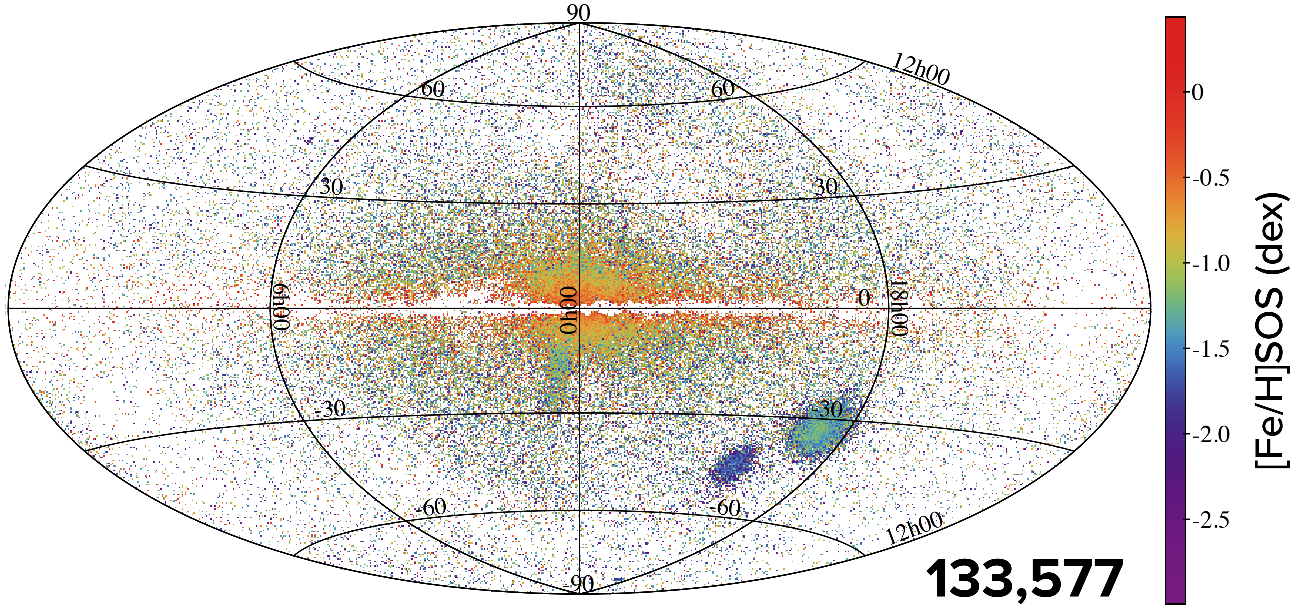

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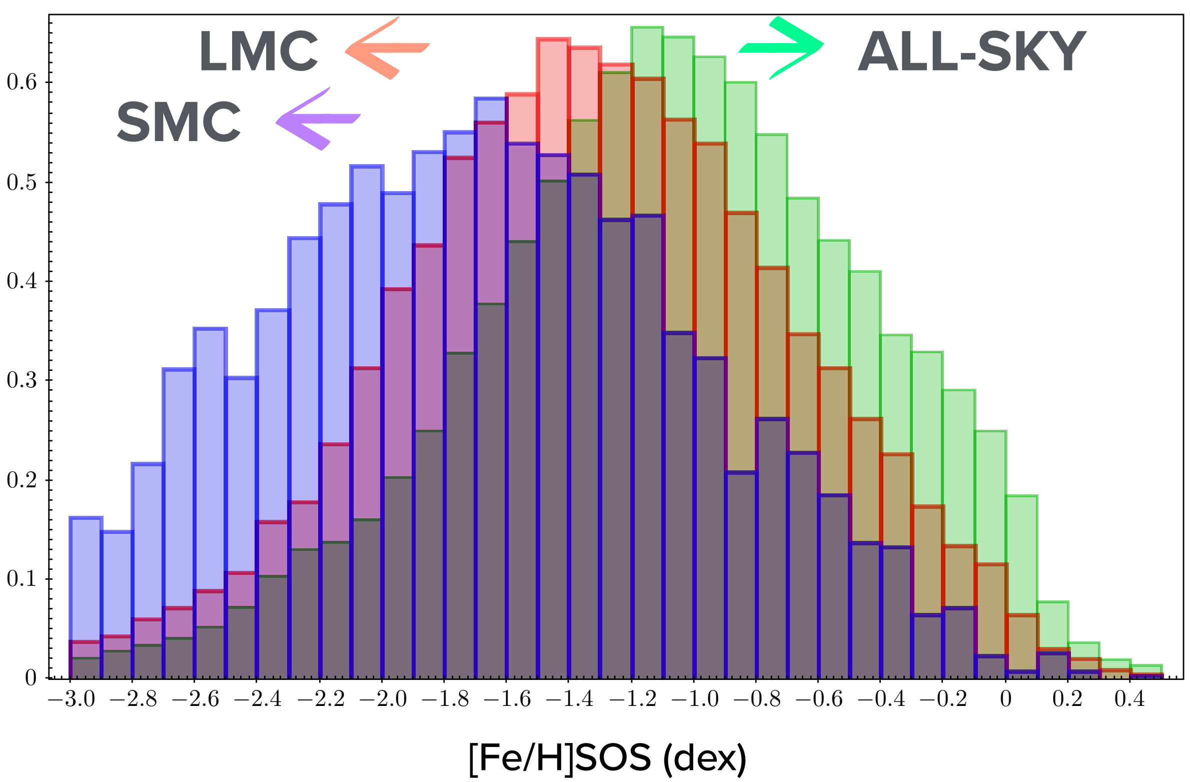

- [Fe/H]sos= −1.07± 0.63 All-Sky
- [Fe/H]sos= −1.31± 0.62 LMC

  [Fe/H]Lit=-1.48± 0.03 dex **Gratton et al. (2004)**
  [Fe/H]Lit=-1.53 ± 0.02 dex **Borissova et al. (2006)**

- [Fe/H]sos= −1.66 ± 0.66 SMC

  [Fe/H]Lit= −1.85 ± 0.33 dex **Skowron et al. (2016)**

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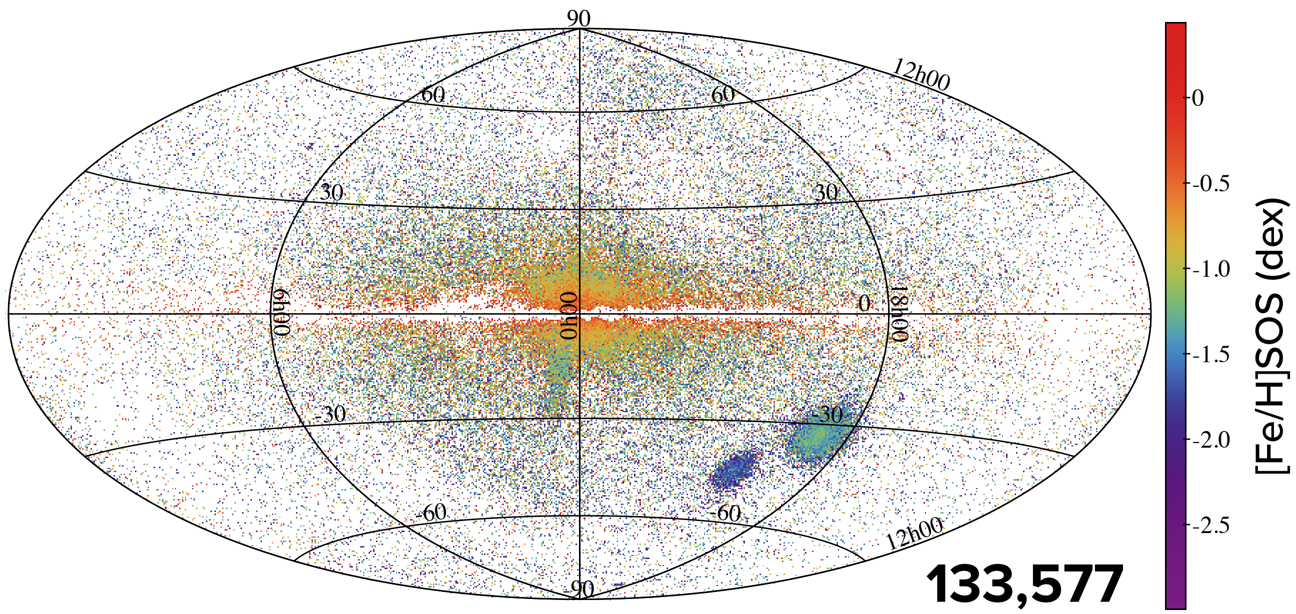
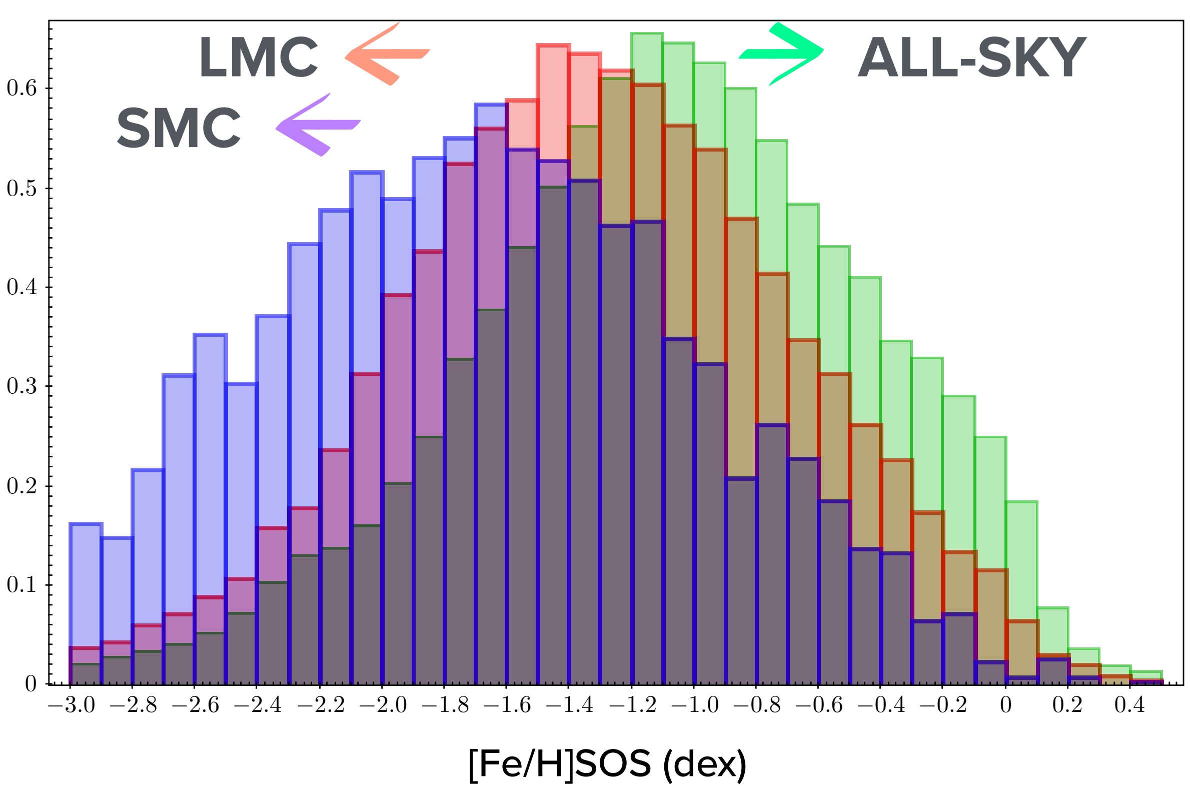
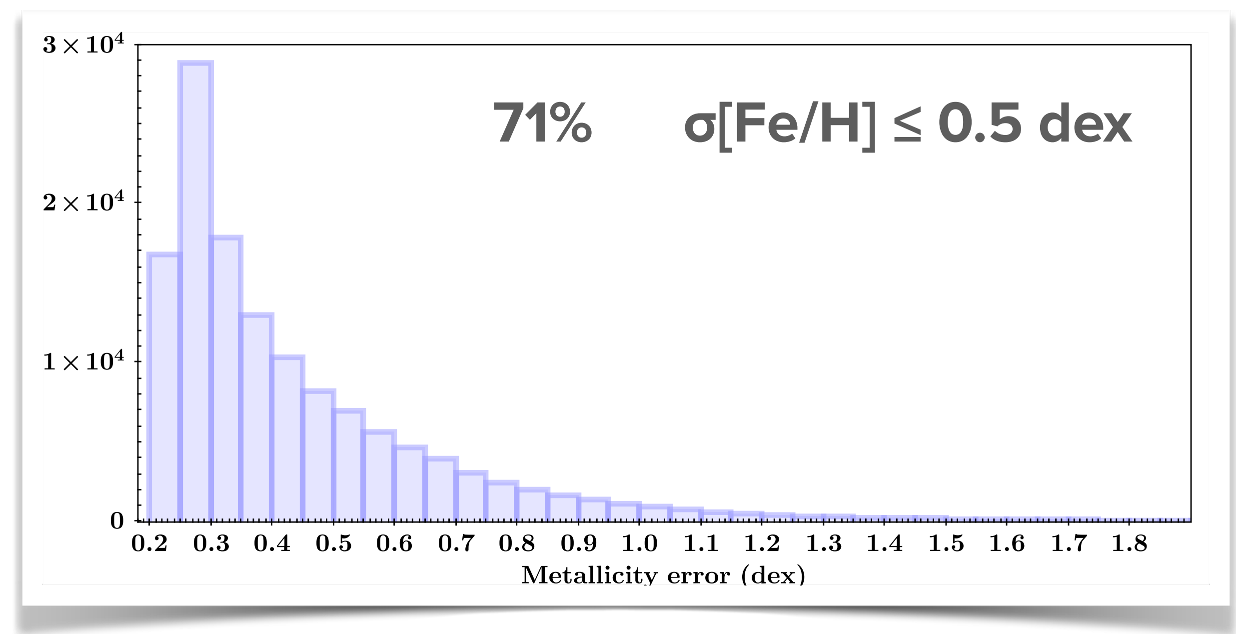


- Individual [Fe/H] are published for 133 557 RR Lyrae stars
- P and the φ31 parameter of the G light curve Fourier decomposition, using the relations for RRab and RRc stars derived in Nemec et al. (2013)
- Overestimation of the metallicity uncertainties → Errors + **systematic error of (+0.2 dex)**

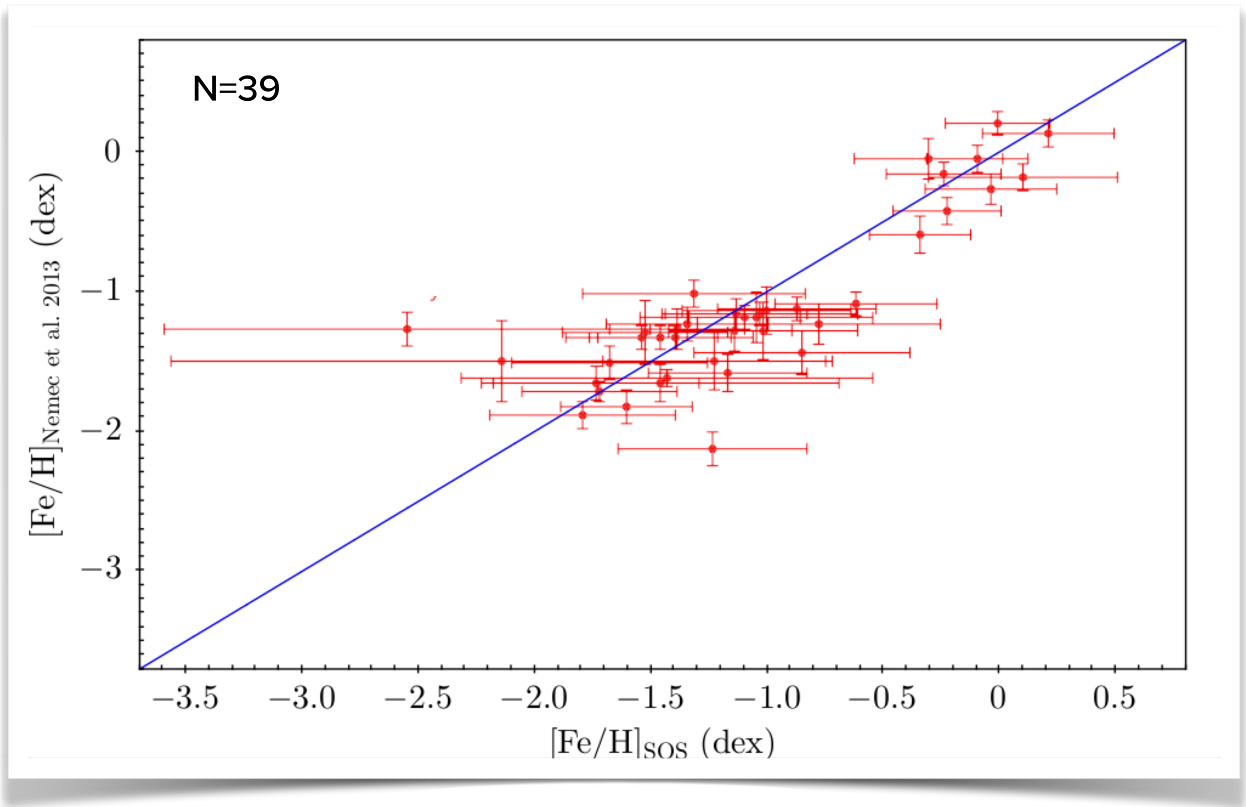




- Be careful with Gaia DR3 SOS astrophysical parameters for faint (G> 18.5 mag) RR Lyrae stars or/and in crowded fields → φ31

METALLICITY OF RR LYRAE STARS : GAIA DR3 SOS

Clementini et al. A&A in press, arXiv:2206.06278

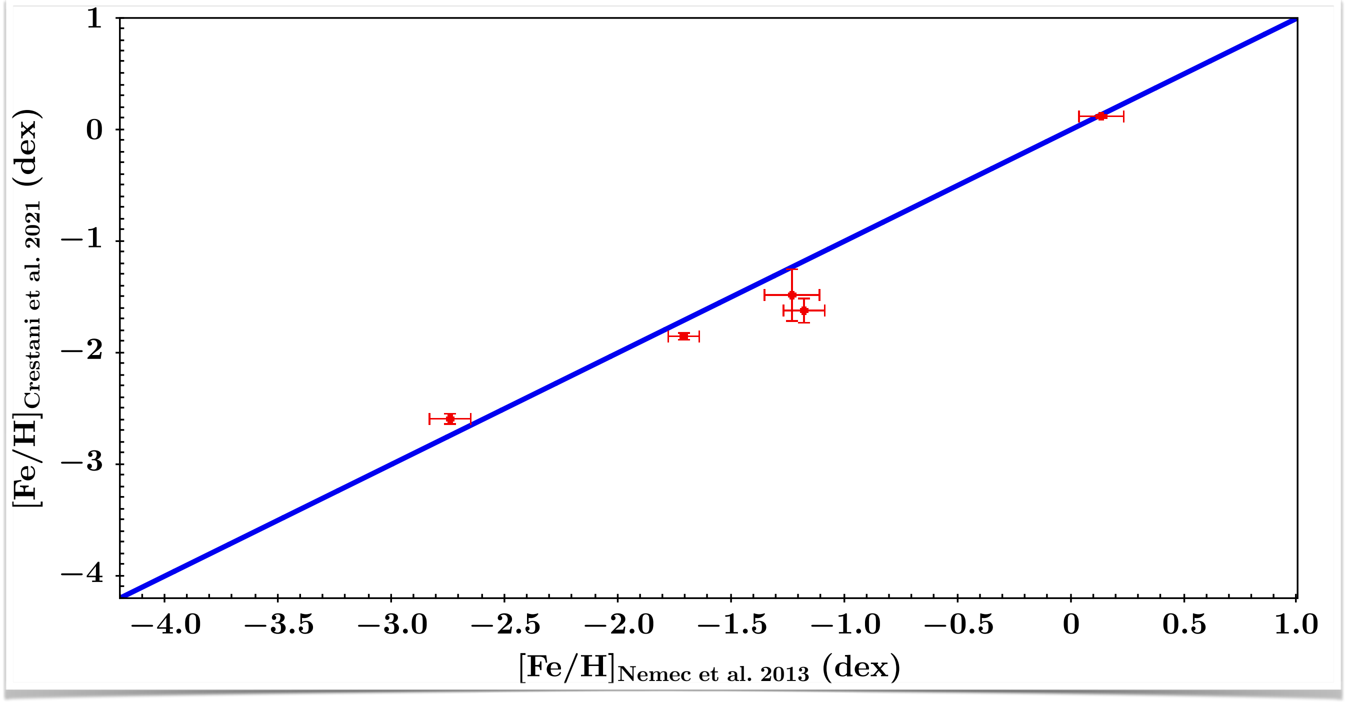


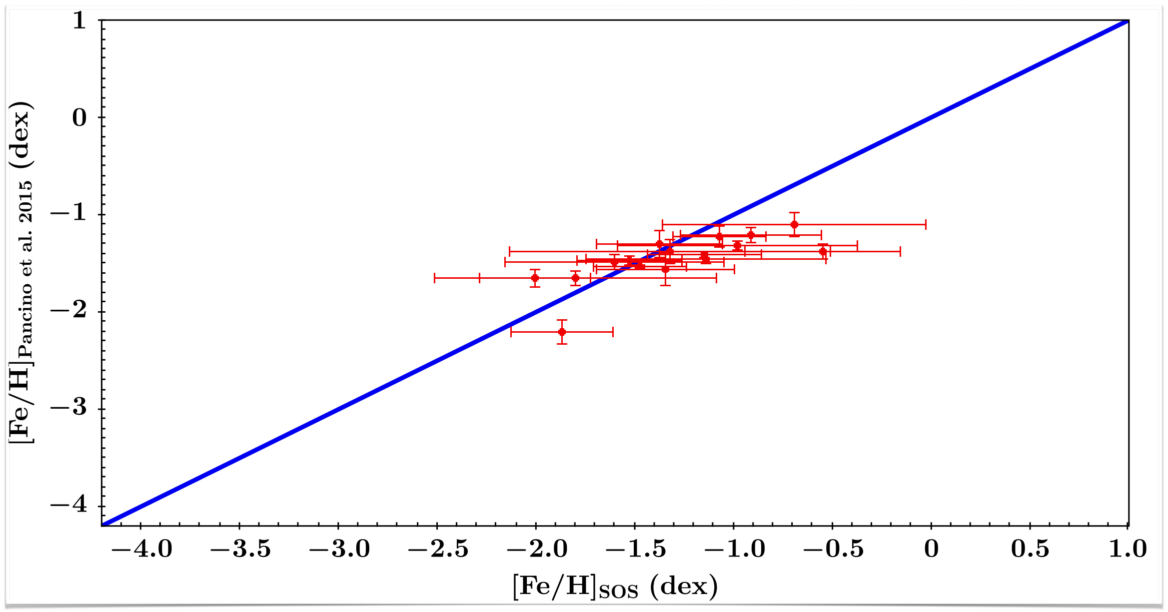
- Nemec et al. (2013) provide a revision and recalibration of the φ31 - [Fe/H] relations (with scatters of about 0.1 dex) based on very accurate light curves of 41 field (RRab and RRc) stars observed by Kepler, along with metallicities derived from abundance analysis of high-resolution spectroscopy (R~36 000 and 65 000). The spectroscopic [Fe/H] range from −2.54. to −0.05 ± 0.13 dex.
- the photometric [Fe/H] inferred from the [Fe/H]-P-φ31 relation better represent the <[Fe/H]> of a population of RR Lyrae stars than the metallicity of the individual sources (as already noted in DR2)

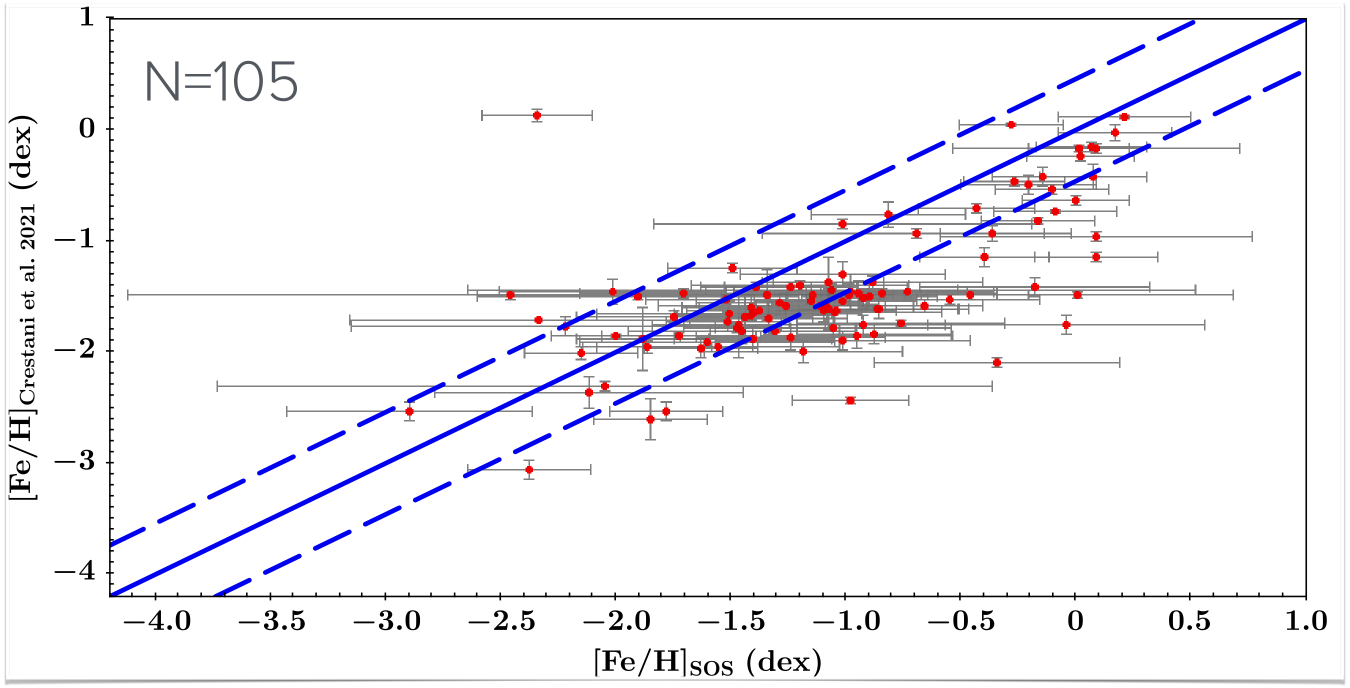
GAIA SOS DR3 VS LITERATURE

Clementini et al. A&A in press, arXiv:2206.06278

- Nemec et al.(2013)'s metallicities 0.1-0.2 dex higher than Crestani et al. (2021)'s for [Fe/H]~ −1.5 dex
- Consistency between photometric [Fe/H] derived by the SOS Cep&RRL pipeline and the [Fe/H] from high resolution spectra from Crestani et al. (2021) and Pancino et al. (2015)
- Large errors of the SOS values

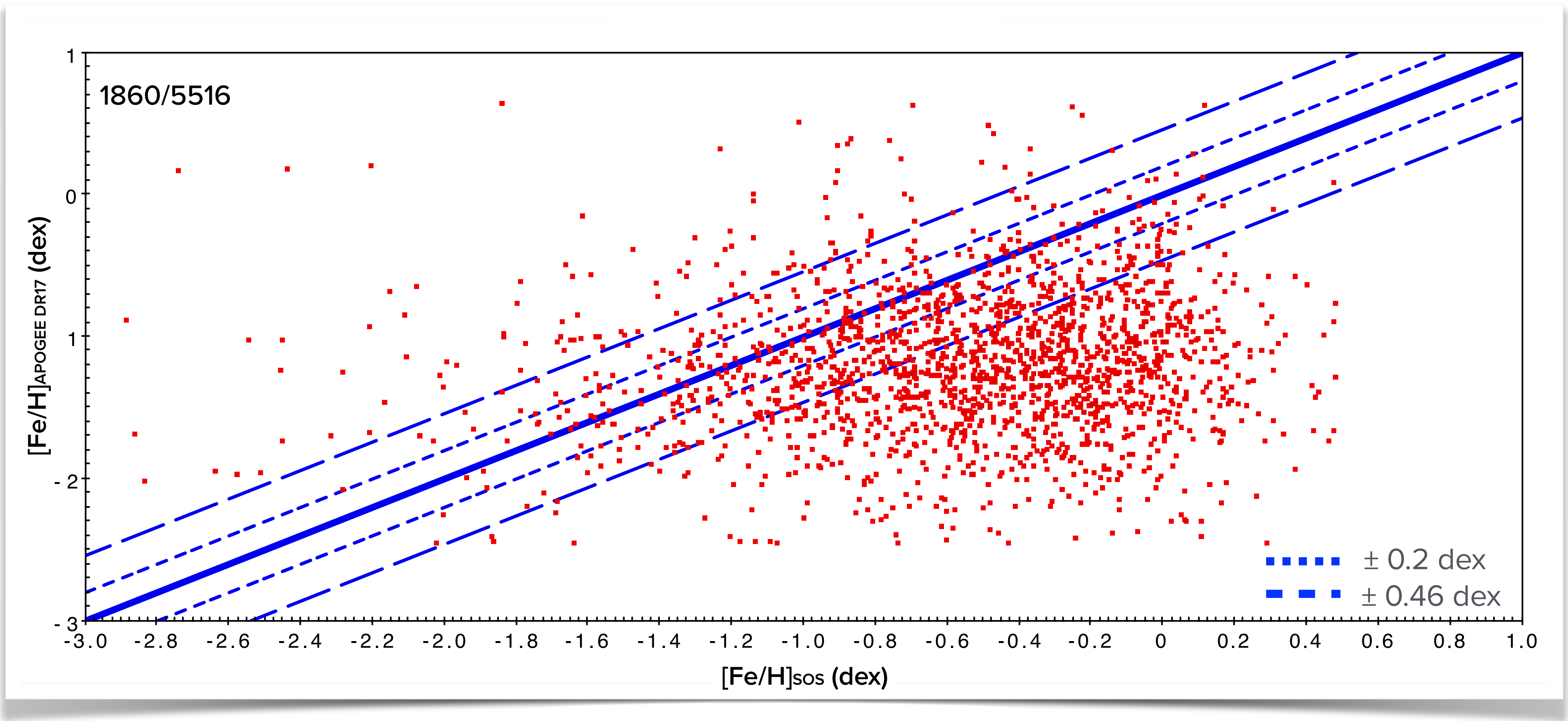






GAIA SOS DR3 VS LITERATURE

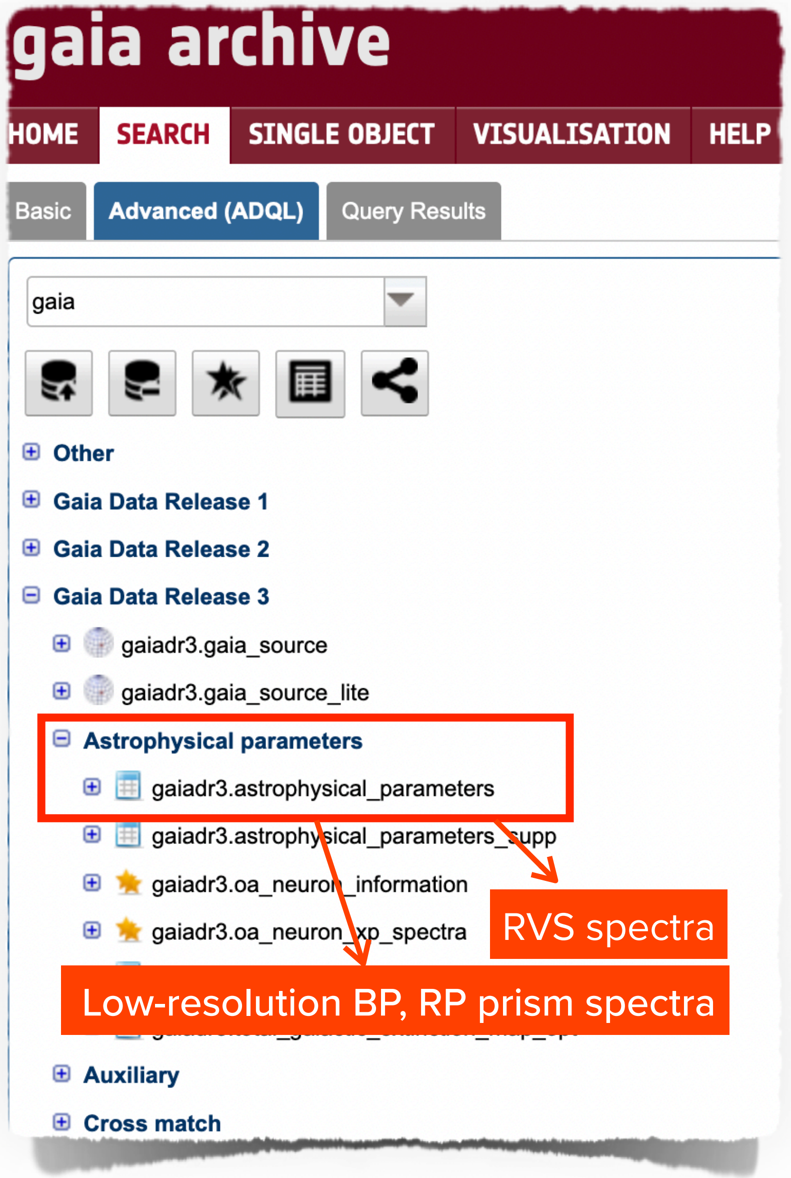
APOGEEE DR17 **(Abdurro'uf et al. 2022)** approximate resolution of 22,500

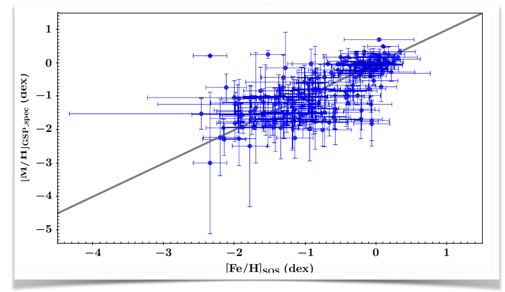


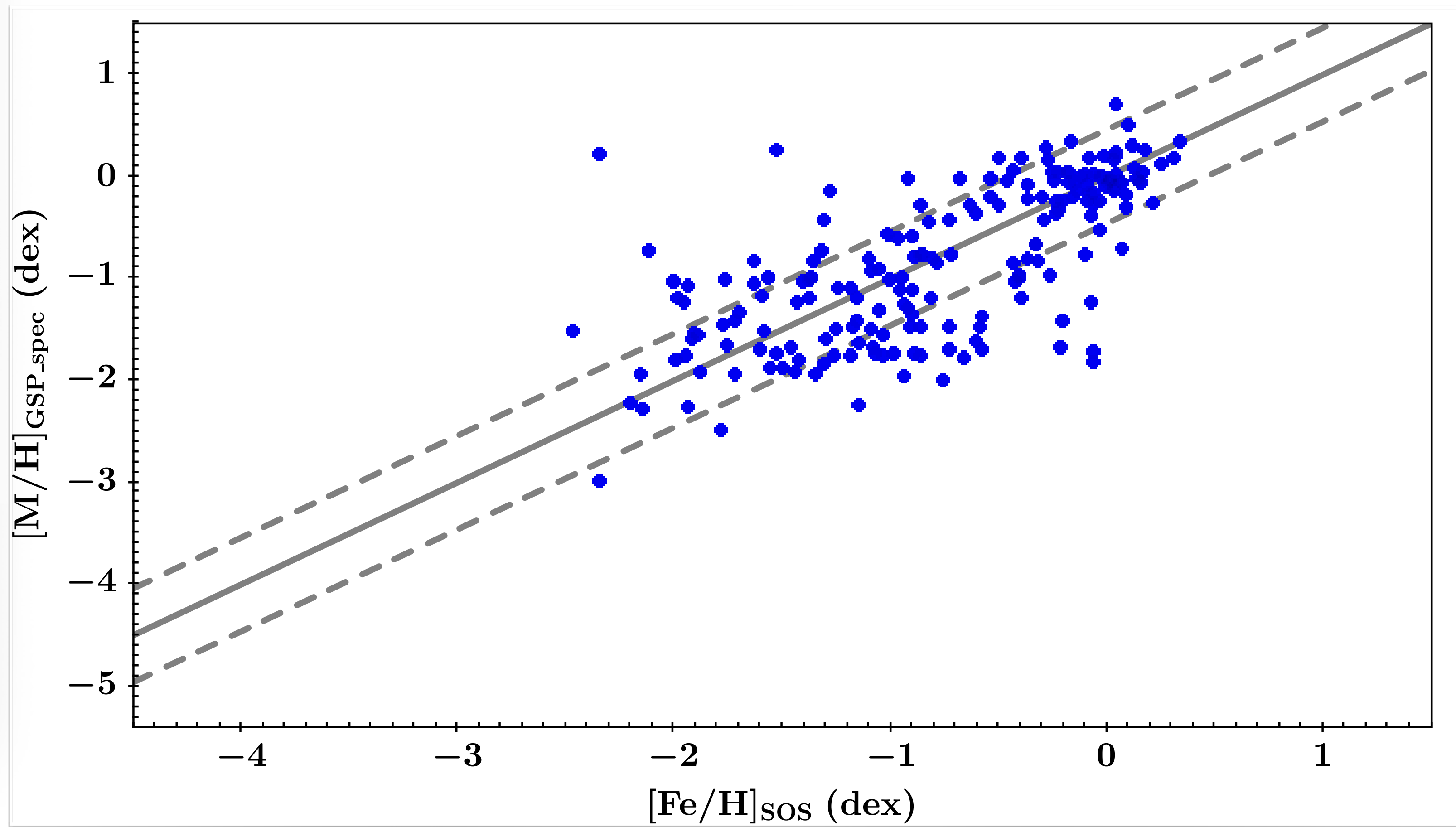
- [Fe/H] APOGEE more metal-poor than [Fe/H]sos
- high S/N → Maximum light → high Teff → H lines ↑ Metallicity lines ↓

GAIA DR3 ASTROPHYSICAL_PARAMETERS TABLE

Clementini et al. A&A in press, arXiv:2206.06278







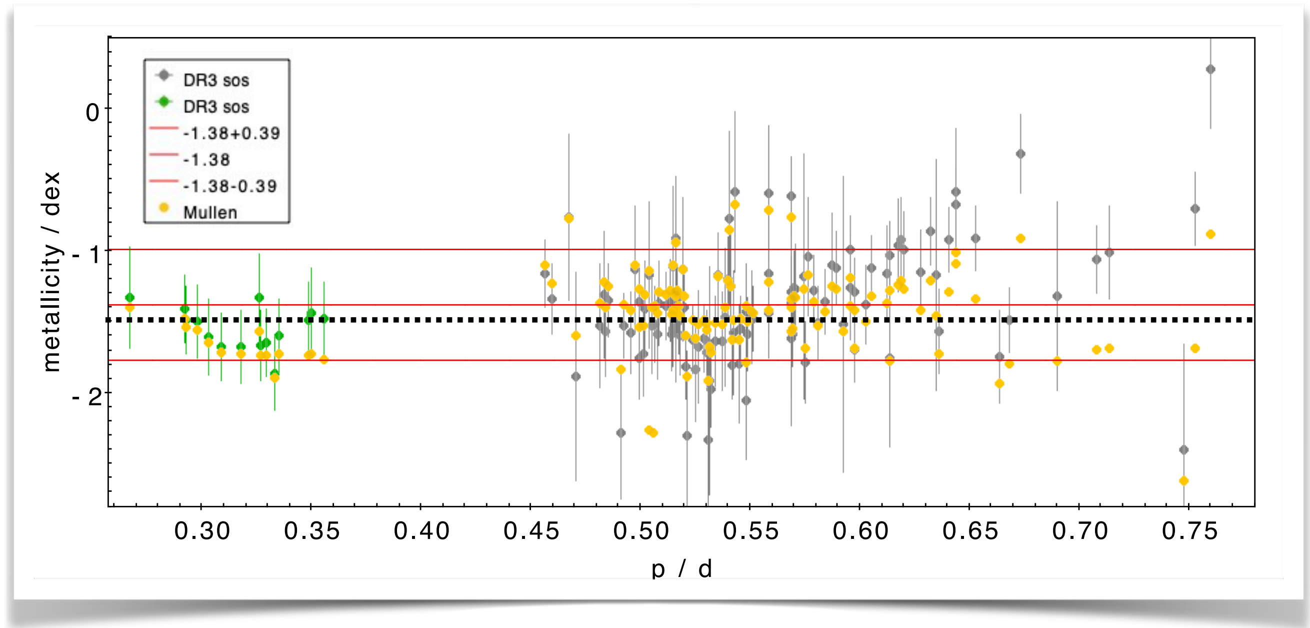
- **[M/H]GSP_spec=mh_gspspec** from the astrophysical_parameters table in the Gaia DR3 (**Gaia RVS spectra**)
- GSP_spec quality flag (flags_gspspec; Recio-Blanco et al. 2022) applied
- ~ 70% of the sources laying within ±0.46 dex from the one-to-one line over the whole range ([Fe/H]~ −2.5 to ~+0.3 dex)

NEW [FE/H]-P-Φ31 RELATIONS

- **case of GC M3**: mean value [Fe/H]sos= -1.38 dex (average on 125 stars; std =+/-0.39 dex). [Fe/H] from HRS by Carretta et al. (2009; [Fe/H]= -1.50 dex)

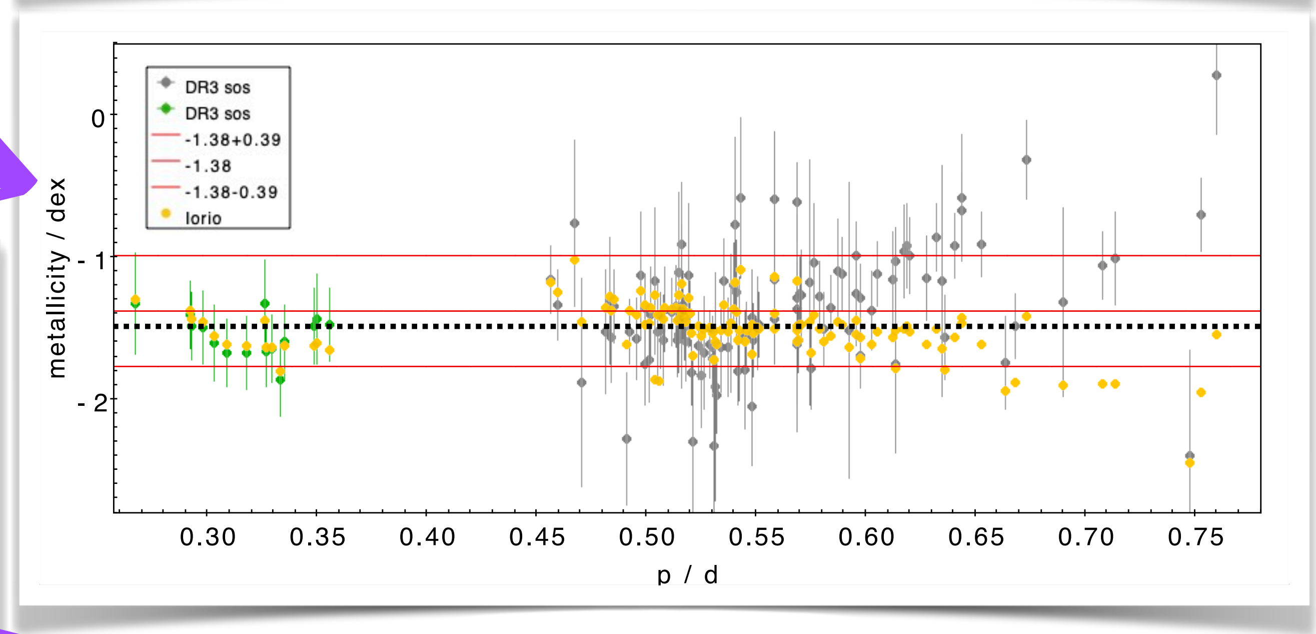
Mullen et al. 2021, 2022 V, IR bands

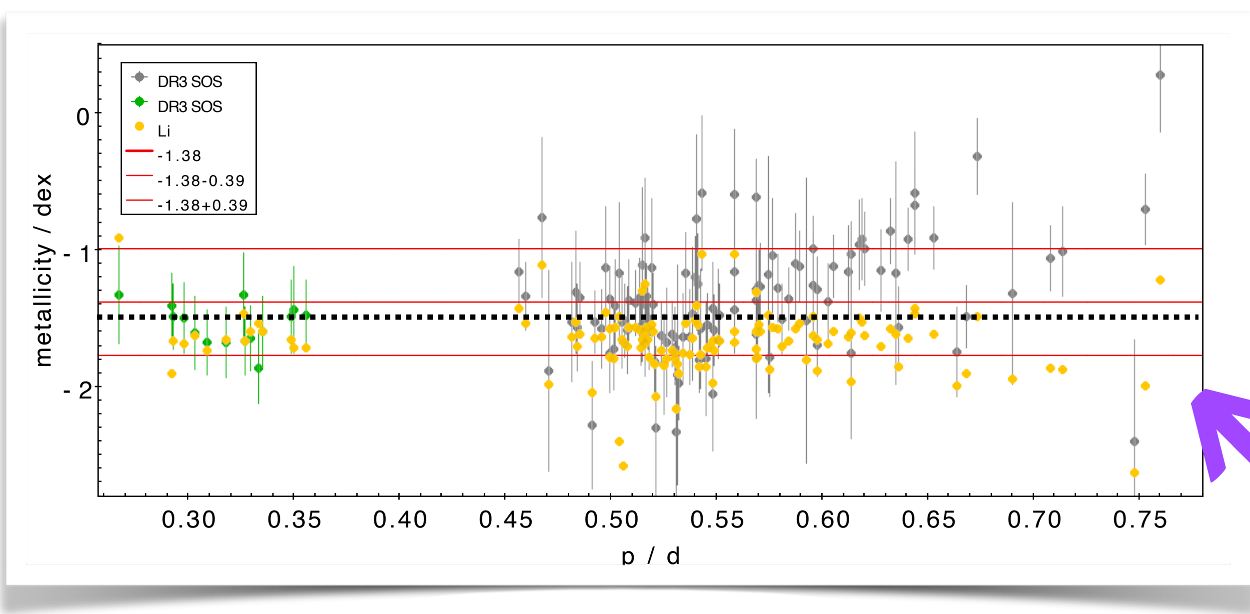
Derived from HR spectra and the ΔS method. Sample cover a broad range of metallicities (−2.5 dex [Fe/H] 0.0 dex). Carretta et al. 2009 metallicity scale



Iorio& Belokurov 2021 Gaia bands DR2 data relation (in the ZW84 scale)

Relation based on the light curve properties reported in the Gaia DR2 SOS catalogue for a sample of RRab stars with spectroscopic metallicity estimate. Zinn & West 1984 scale



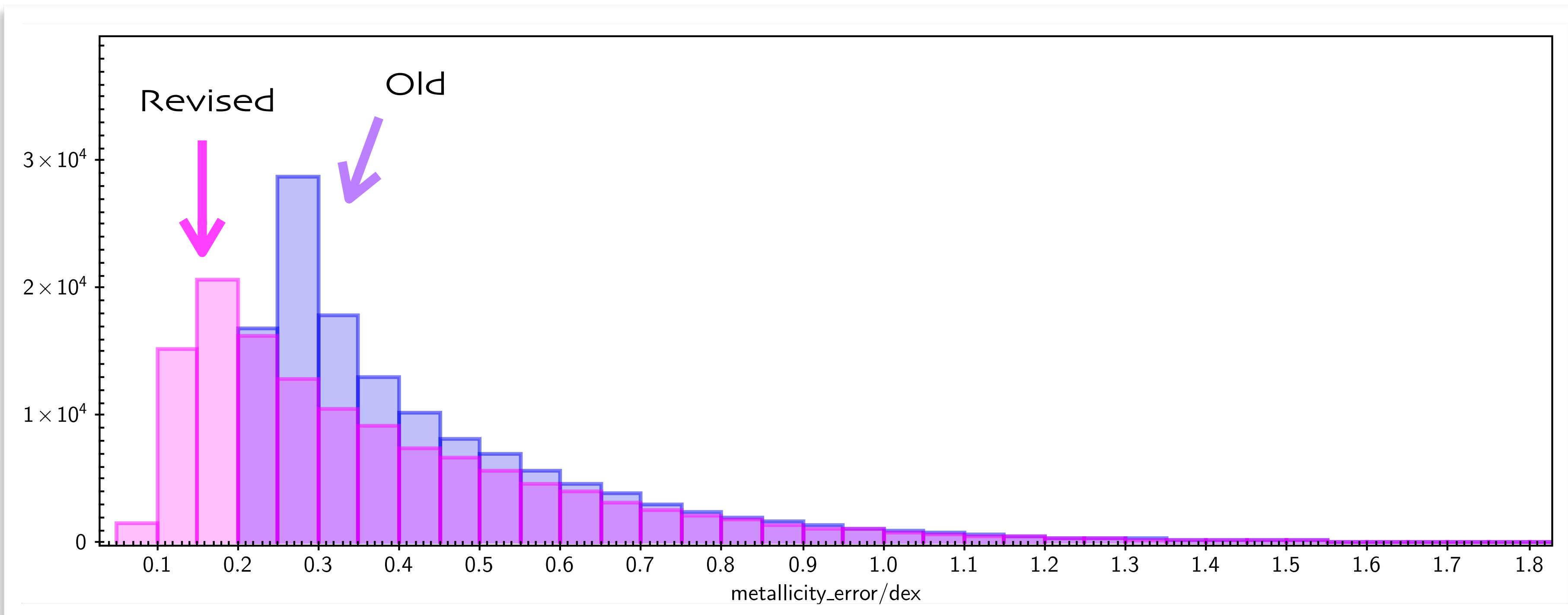


Li et al. 2022 Gaia bands DR3 data

Calibration of P –φ31–R21–[Fe/H] and P –R21–[Fe/H] relations based on 2700 stars with metallicity estimates from (LAMOST and SEGUE low-to-medium resolution spectra, ΔS method), and period, φ31, R21 measurements from the DR3 Gaia G-band

METALLICITY OF RR LYRAE STARS : GAIA DR4

- **SOS Cep&RRL** Metallicity errors are currently overestimated → Revision of the error in metallicity computations



- **SOS Cep&RRL** Implementation of new [Fe/H] - phi31 - P relations to estimate photometric metallicities directly from the Gaia G-band light curves using a sample of RR Lyrae stars with metallicity determinations from high-resolution spectra

- **DPAC** Gaia cross-CU, taskforce to optimized processing of Cepheids and RR Lyrae stars (A. RecioBlanco, G. Clementini, V. Ripepi et al.)

  Spectra per transit (Epoch Spectra) instead → averaged spectra of stacked spectra

CLIFFSNOTES

- Gaia Photometric [Fe/H] errors are currently overestimated
- Gaia photometric metallicities 0.1-0.2 dex higher than HRS
- Before blindly trusting the photometric [Fe/H], Check ϕ_{31} uncertainties
- About 190 RR Lyrae have GSP_spec available and attendible
- DR4(66months): photometric [Fe/H] error revision, new photometric [Fe/H] relations, cross-CU taskforce

THANK YOU

RR LYRAE STARS, A TERRIFIC MULTI PURPOSE TOOL

Fabrizio et al. 2019 Liu et al. (2013) and Gilligan et al.(2021)

- High-resolution spectroscopy
- ΔS method (Preston 1959; low-resolution spectra)
- Photometric metallicity (shapes of light curves)

(I) [Fe/H] - P -AV relation Alcock et al. (2000) togliere

(II) ϕ31 - [Fe/H] - P relation Jurcsik & Kovács (1996) Morgan et al. (2007)

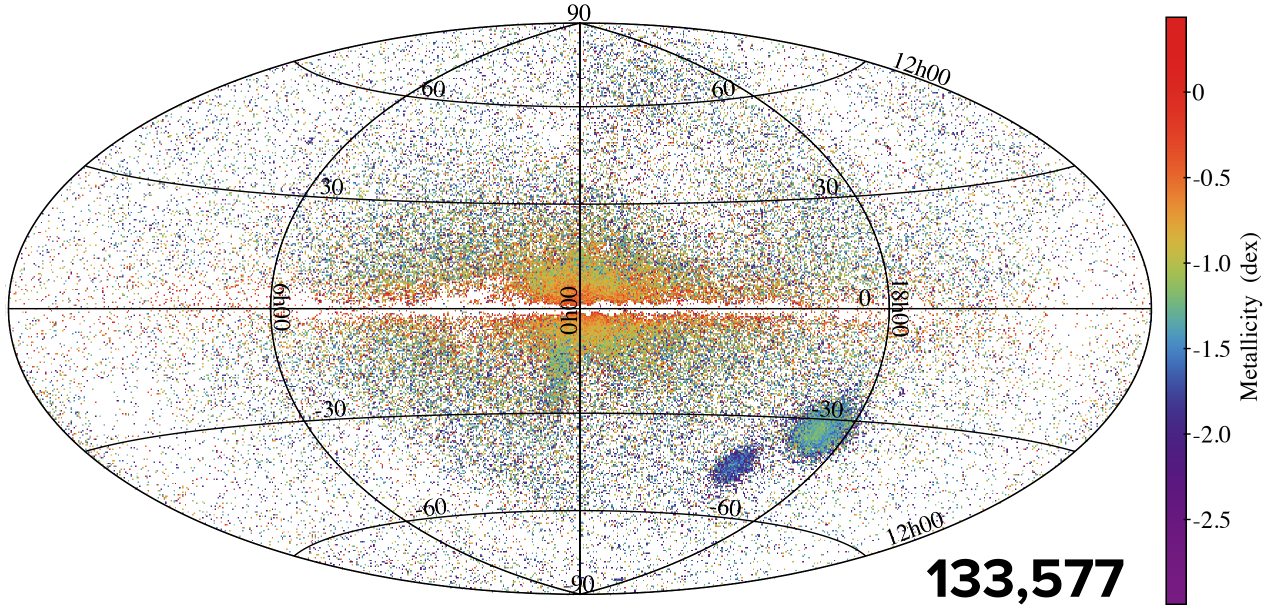
combination of the first and third phase terms ($\phi_{31}=\phi_3-3\phi_1$) in a Fourier decomposition of RR Lyrae light curves

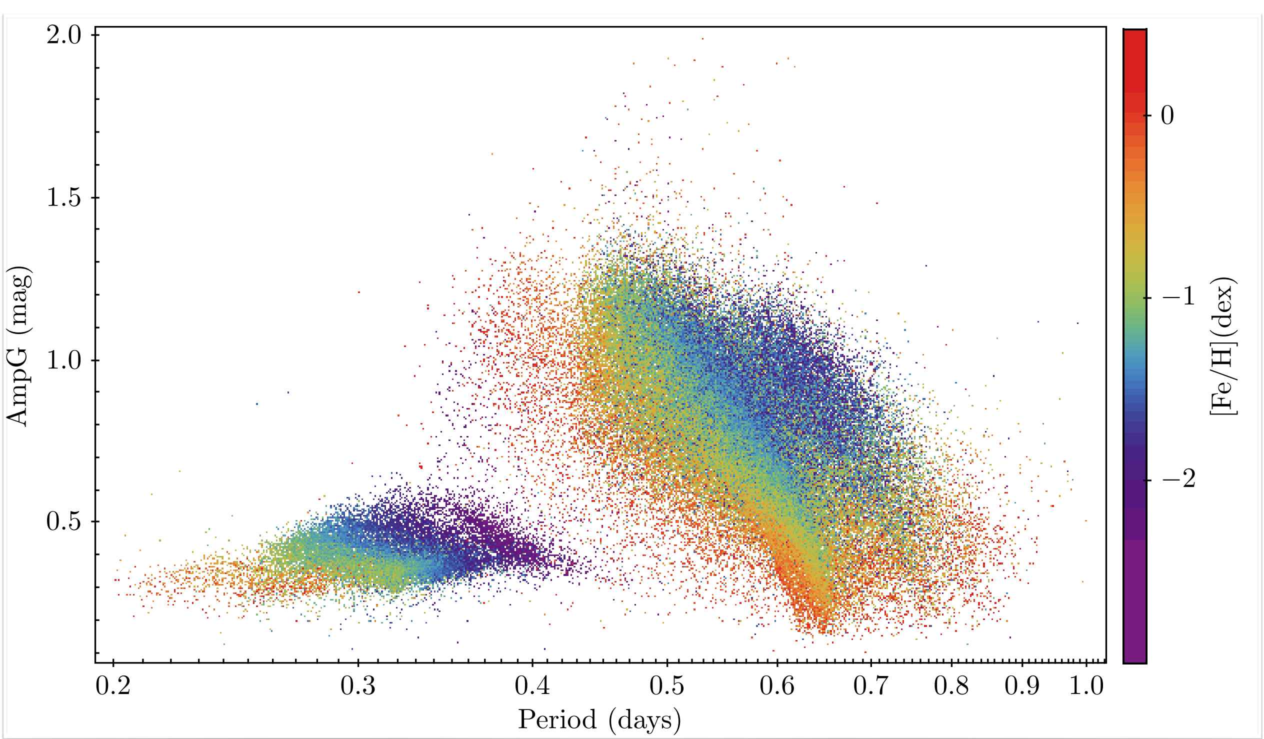
$$V(t) = A_0 + \sum_{i=1}^{N} A_i cos(i\omega_0(t - t_0) + \phi_i)$$

- V(t) = observed magnitude at time t of observation; A0 = star mean magnitude
- Ai and ϕi are, respectively the amplitude and the phase coefficients of the i-th Fourier term, corresponding to the i-1 harmonic
- ω0 = angular pulsation frequency of the star
- t0 = time of the maximum light

METALLICITY OF RR LYRAE STARS : GAIA DR3 SOS

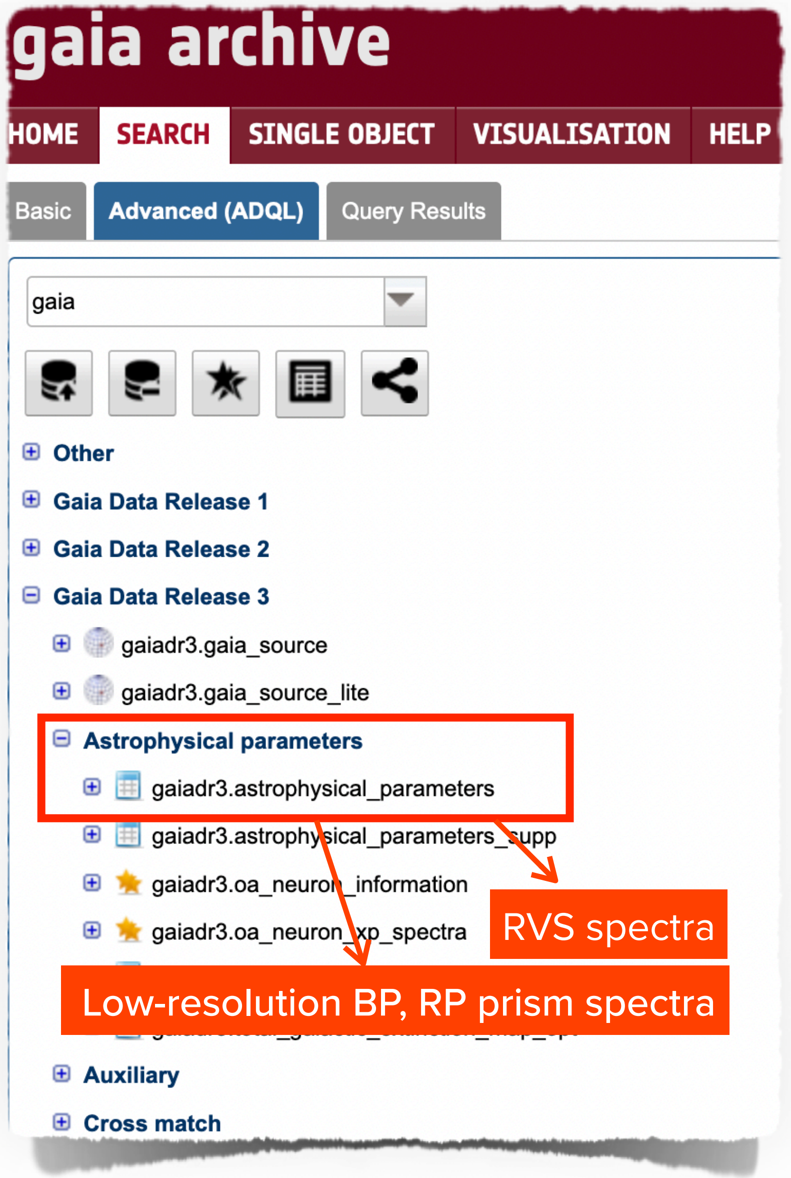
Clementini et al. A&A in press, arXiv:2206.06278

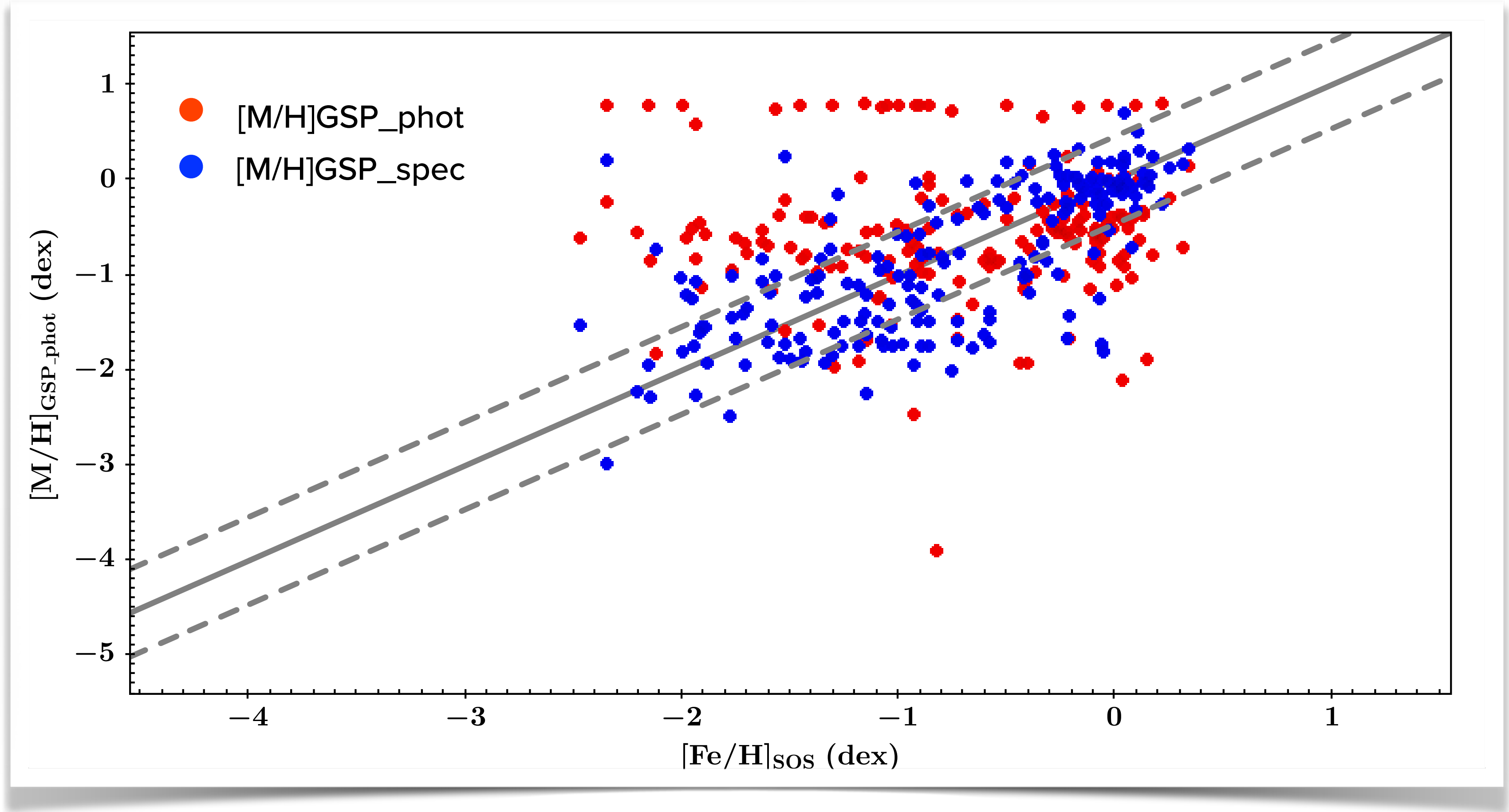




GAIA DR3 ASTROPHYSICAL_PARAMETERS TABLE

Clementini et al. A&A in press, arXiv:2206.06278

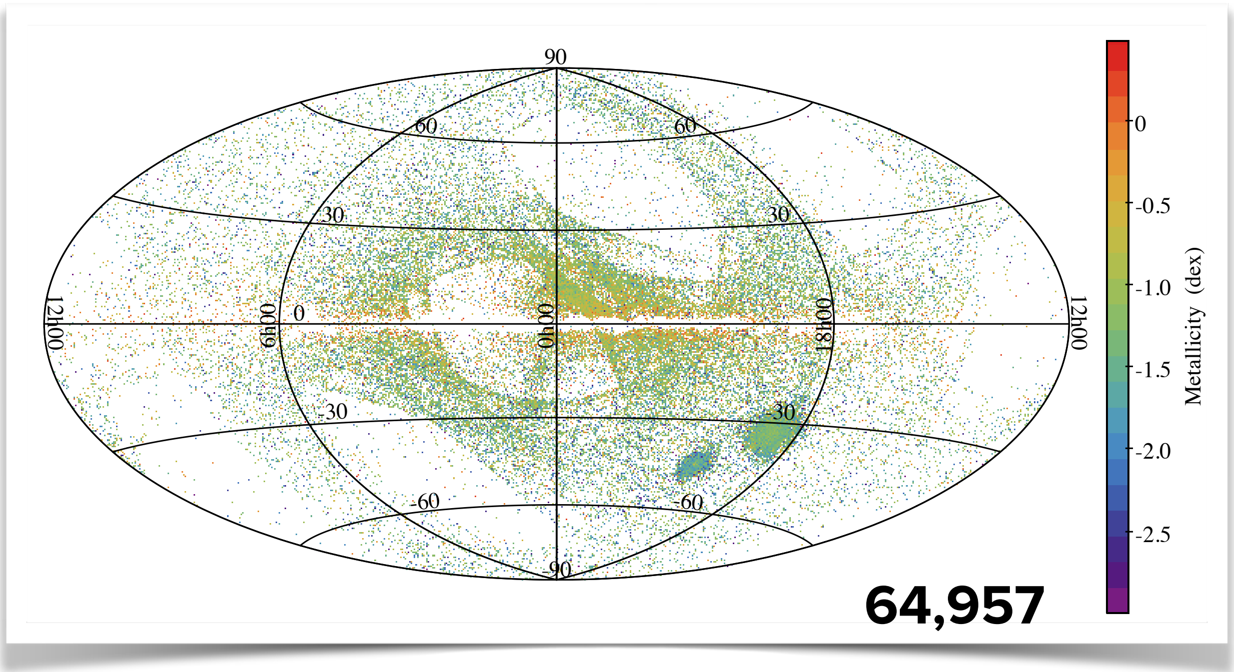


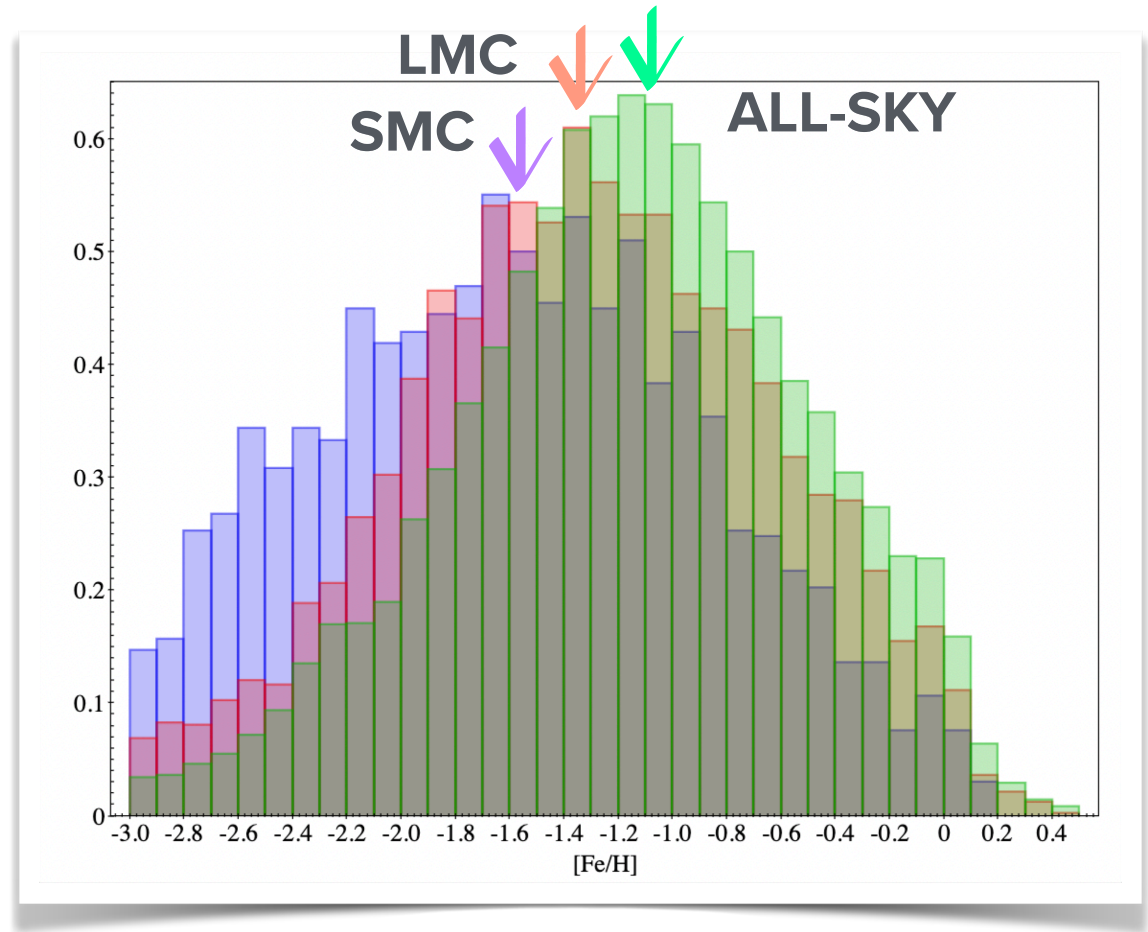


- **[M/H]GSP_phot=mh_gspphot** from the astrophysical_parameters table in the Gaia DR3 (**Gaia low-resolution BP, RP prism spectra**)
- GSP_phot metallicities of RR Lyrae stars appear to be affected by very large uncertainties and systematic effects
- GSP_Phot metallicities are systematically offset from both the GSP_Spec and SOS estimates by more than 1 dex towards larger abundances.

METALLICITY OF RR LYRAE STARS : GAIA DR2 SOS

Clementini et al. 2019 A&A 622, A60

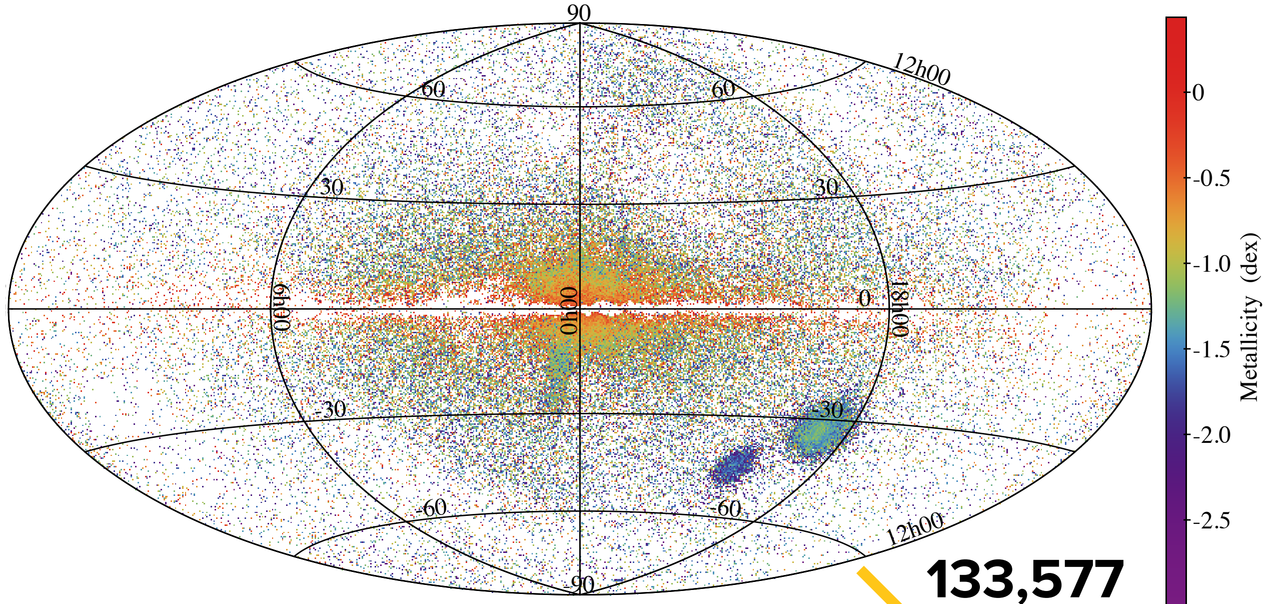




the ϕ31 parameters calculated by fitting the observed time series in the Kepler photometric system through a Fourier series of sine functions for RRab stars and cosine functions for RRc sources.
In order to use eqs. of Nemec et al. (2013), which are valid for RRab and RRc stars, respectively,
we firsthave transformed the ϕ31 parameters from the Gaia G band into the Kepler photometric system according to the following steps:
i) the ϕ31 parameter in the G band was first transformed into
the V band using the relation $\phi31(V)= \phi31(G) -0.104$;
ii) the ϕ31parameter in the Kepler system was then obtained using the fol-
lowing relations: $\phi s31 = \phi31(V)+ \pi + 0.151$ and $\phi c31 = \phi31(V)+ 0.151$ (Nemec et al. 2011) for RRab and RRc stars, respectively, where the superscript s stands for sine function while c indicates the use of the cosine function.

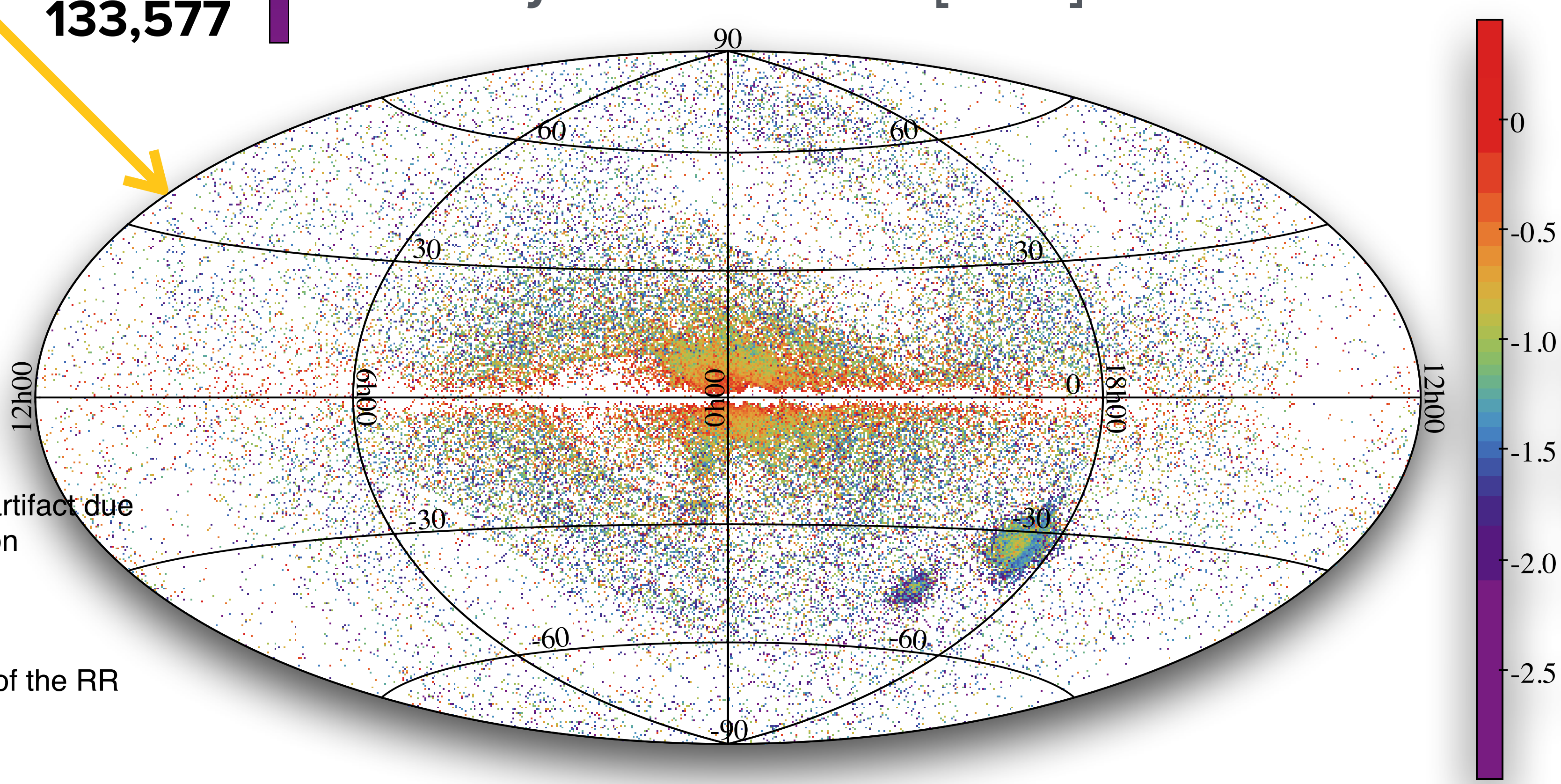
METALLICITY OF RR LYRAE STARS : GAIA DR3 SOS

Clementini et al. A&A in press, arXiv:2206.06278

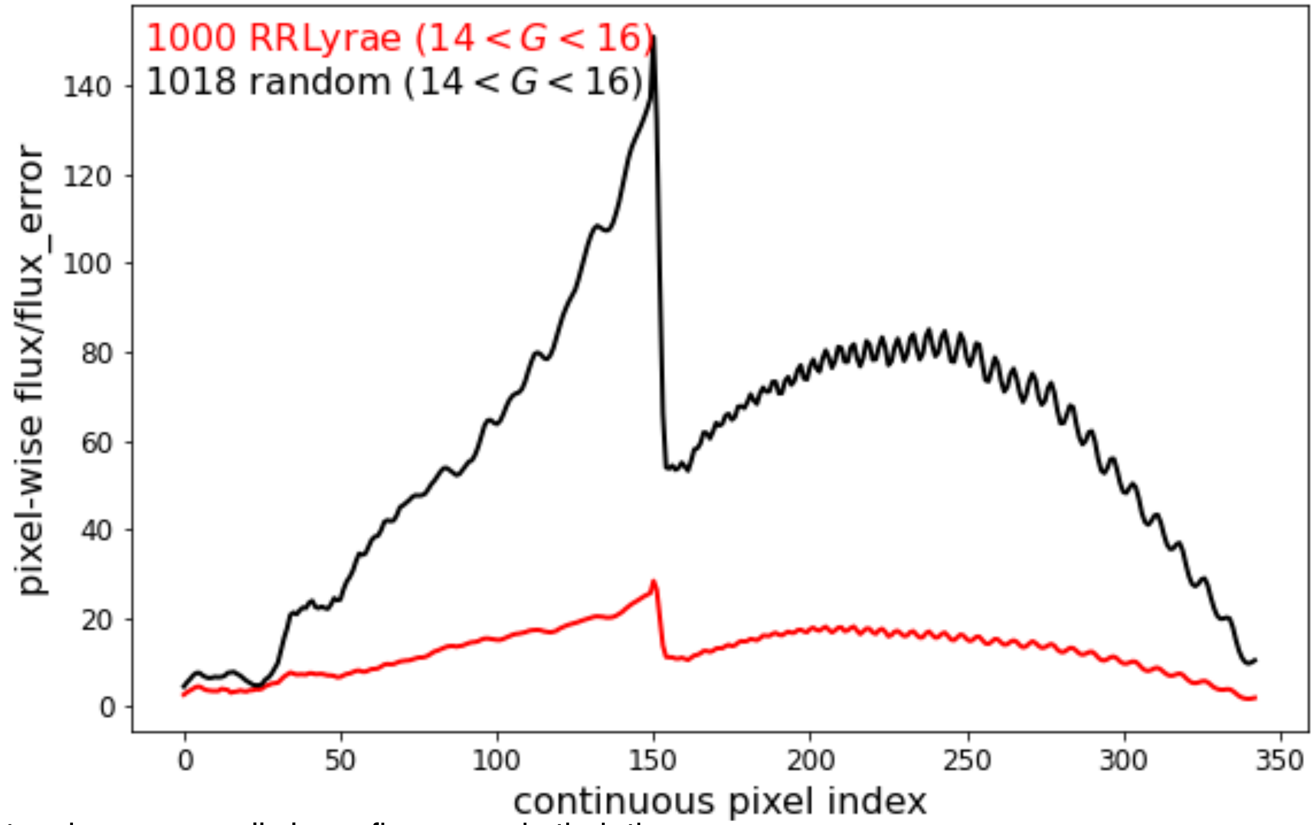


133,577

RR Lyrae stars with σ[Fe/H] ≤ 0.46 dex



To make sure that the features we see in Fig. 33 are not an artifact due to measurement errors, or to the adopted metallicity calibration (Nemec et al. 2013), in Fig. 34 we show only RR Lyrae stars with metallicity errors σ[Fe/H] ≤ 0.46 dex (the mean error of the SOS Cep&RRL metallicity estimates according to Fig. 19 in Sect. 5.1)CIRCA 88K. The relative difference in metallicity of the RR Lyrae stars in the LMC, SMC, Galactic halo, and in the bulge and thin disc of our Galaxy is still rather cleanly visible



RR Lyrae stars have unusually large flux errors in their time-averaged BP/RP spectra, compared to non-variable sources. This is because when computing the mean BP/RP spectra, the amplitude of the light variation, that in the G band can range from ~0.2 mag for RRc to more than 1 magnitude for RRab stars, enters as an extra flux error in the computed time-averaged BP/RP spectra.

This is clearly shown by the comparison between the signal-to-noise ratios (median of each sample in each pixel) of the continuous BP/RP spectra of a sample of 1 000 RR Lyrae stars with $14 < \langle G \rangle < 16$ extracted from the `vari_rrlyrae` table and the continuous BP/RP spectra of a comparison sample composed by 1 000 random sources again within $14 < G < 16$ presented in Fig. B.3.
The larger BP/RP flux uncertainties cause larger uncertainties in the temperatures derived for RR Lyrae stars, thus opening the room for temperature-extinction degeneracies in the GSP_Phot absorption estimates for RR Lyrae stars as well as causing large uncertainties and systematic offsets in the GSP_Phot metallicities for these variable stars.