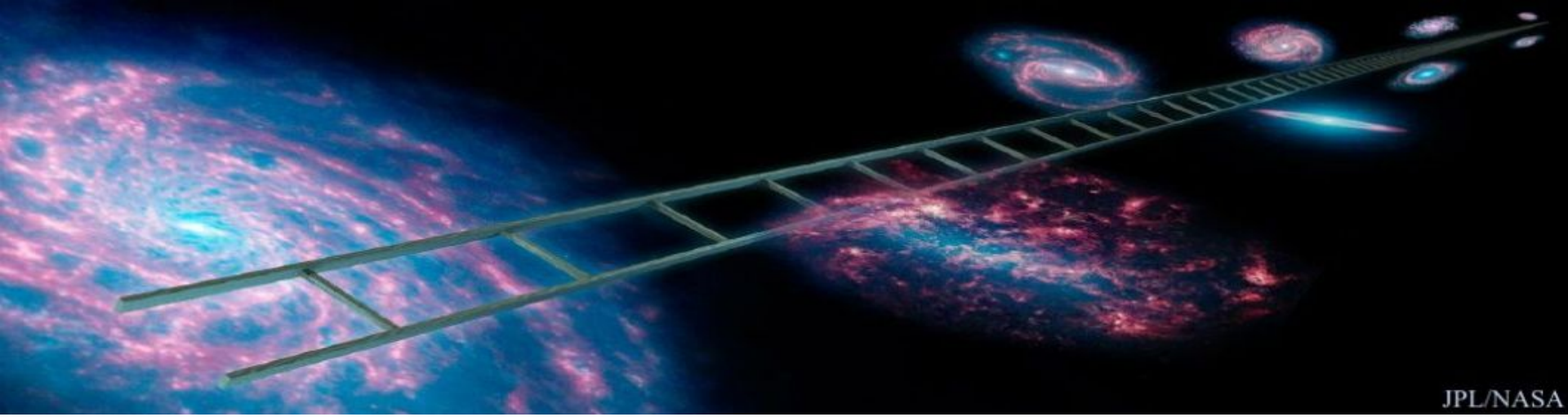

Absolute calibration of Type II Cepheid and RR Lyrae distance scales using Gaia DR3

Anupam Bhardwaj
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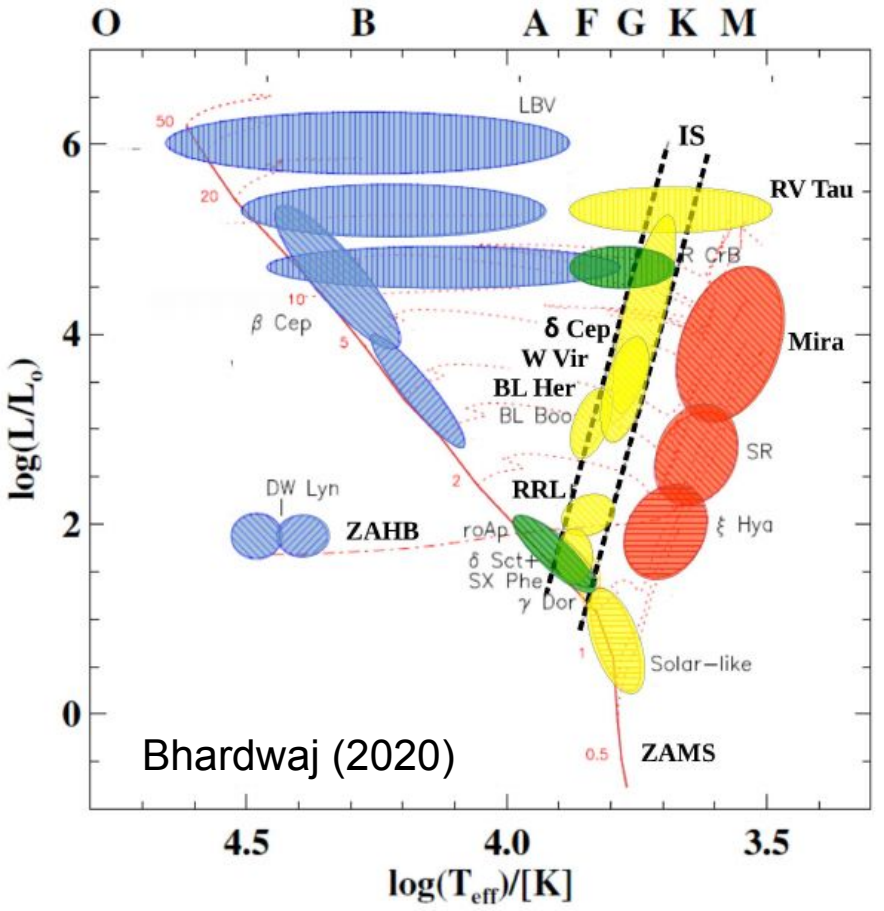
INAF - Osservatorio Astronomico di Capodimonte, Naples, Italy

MW/Gaia Workshop, Naples, Italy - September 2022

Radially Pulsating Stars

Variable stars located within the “Instability Strip” in the HR diagram

- **Classical or Type I Cepheids**
  - On the Blue Loop
- **Type II Cepheids (T2C)**
  - BL Herculis : Post Horizontal Branch
  - W Virginis : Towards AGB, temporary excursions to IS
  - RV Tauri : Post AGB
- **RR Lyrae (RRL)**
  - Horizontal branch



Pulsating Stars as standard candles

Period-Luminosity relation (PLR)

Period – Mean density eq.

$$P\sqrt{\rho} = \text{const.}$$

Stefan – Boltzmann law

$$M_{bol} = \text{const.} + 5\log(R) + 10\log(T)$$

Period-Wesenheit relation (PWR)

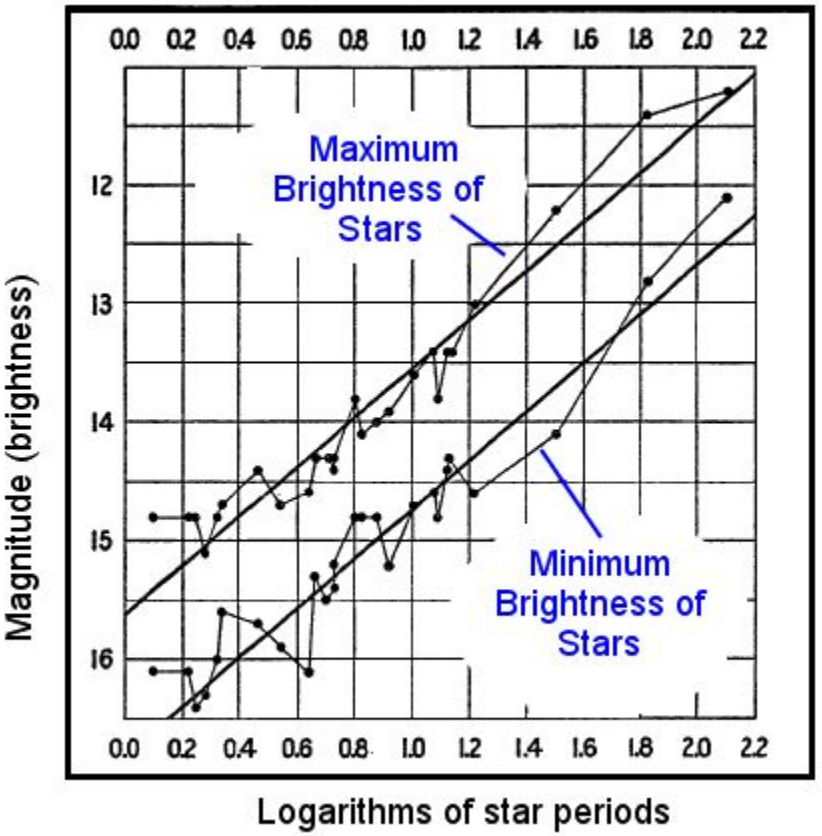
$$W^{\lambda_3}_{\lambda_2,\lambda_1} = m_{\lambda_3} - R^{\lambda_2,\lambda_1}_{\lambda_3}(m_{\lambda_2} - m_{\lambda_1}),$$

$$R^{\lambda_2,\lambda_1}_{\lambda_3} = \left[\frac{A_{\lambda_3}}{E(m_{\lambda_2} - m_{\lambda_1})}\right],$$

Wesenheit magnitudes (Madore 1982)

Constructed to be reddening independent

Classical Cepheids in the SMC

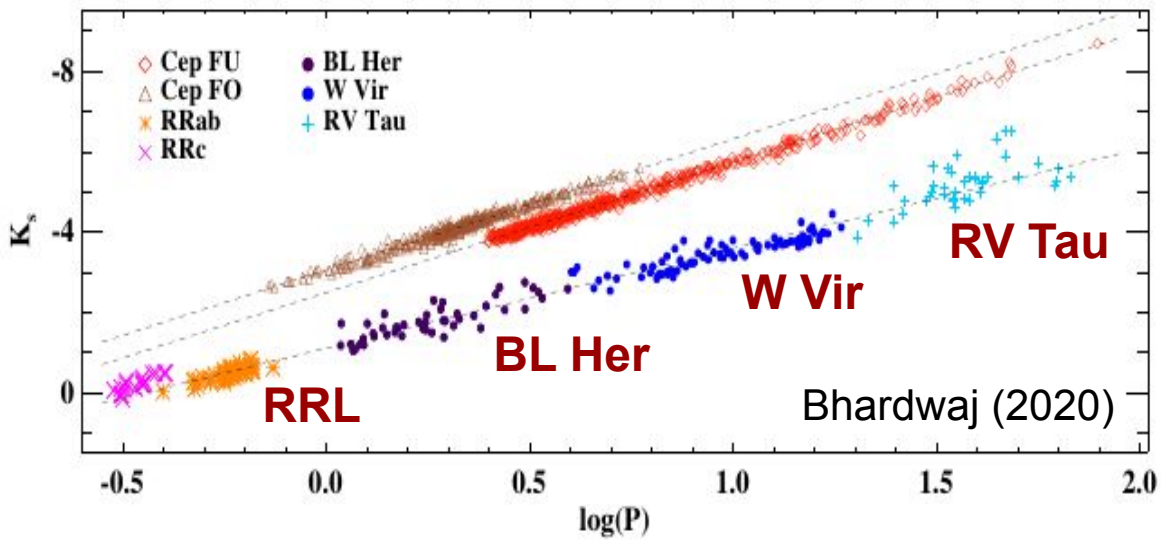


Leavitt & Pickering (1912)

Type II Cepheids and RR Lyrae variables

RR Lyrae and T2C as distance indicators

- Tight PLRs in infrared
- Fainter than Classical Cepheids and TRGB



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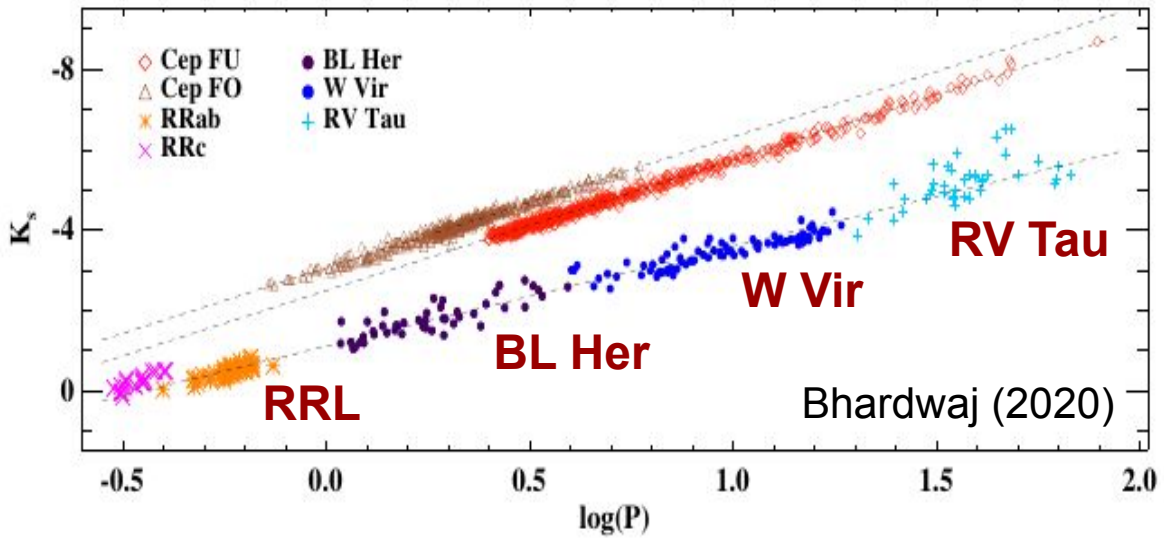
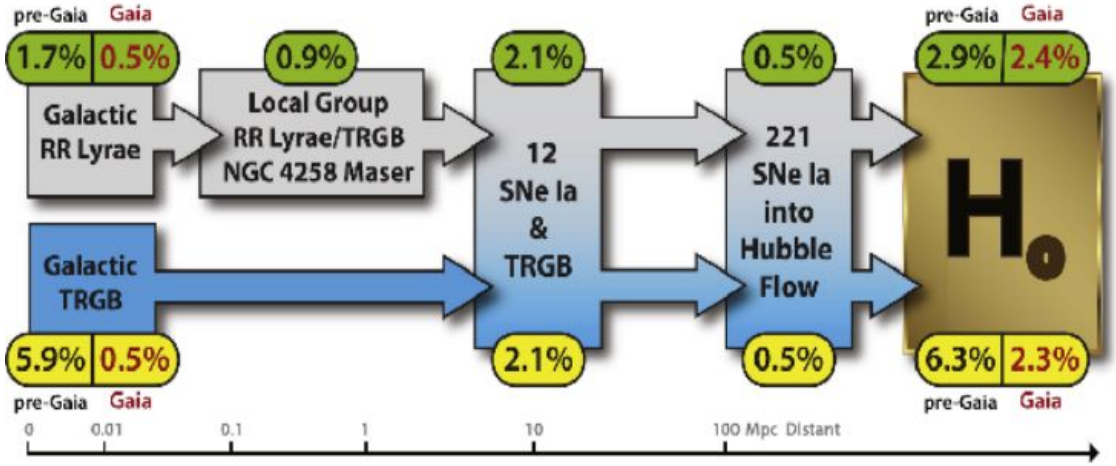


Independent primary calibrators of the population II distance ladder (Beaton+2016, Freedman+2022)



Theoretical Framework

Non-linear convective hydrodynamical 1D models of RR Lyrae and T2Cs
(e.g., Stellingwerf+1982, Bono+1998, Marconi+2015, Smolec+2016, Das+2021)

Topology of the IS, Predicted light and radial velocity curves, theoretical PLRs

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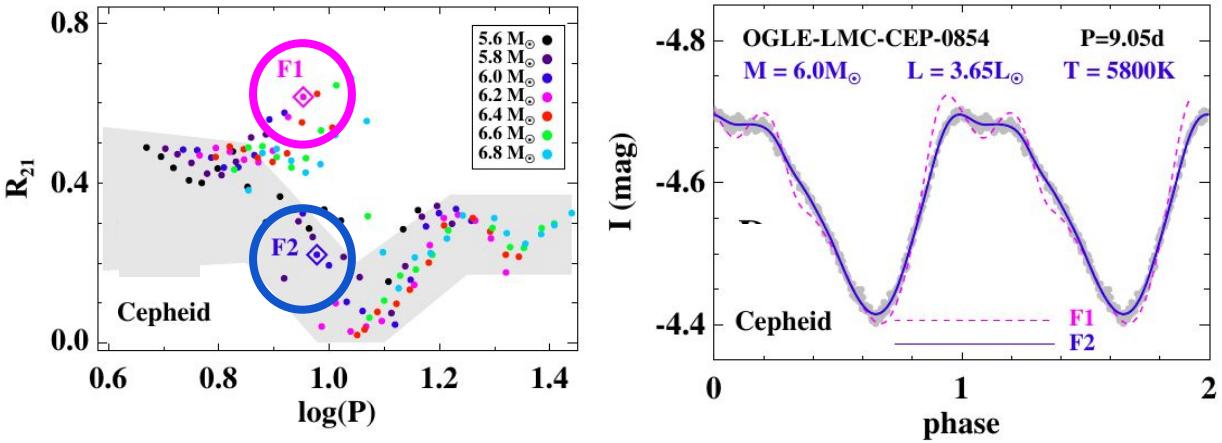
Multiband light curve comparison: Theory vs observations



- Model light curve fitting (e.g., Marconi+2013, 2017)
- Quantitative comparison of light curve parameters
  (e.g. Bono+2000, Bhardwaj+2017, Das+2018)

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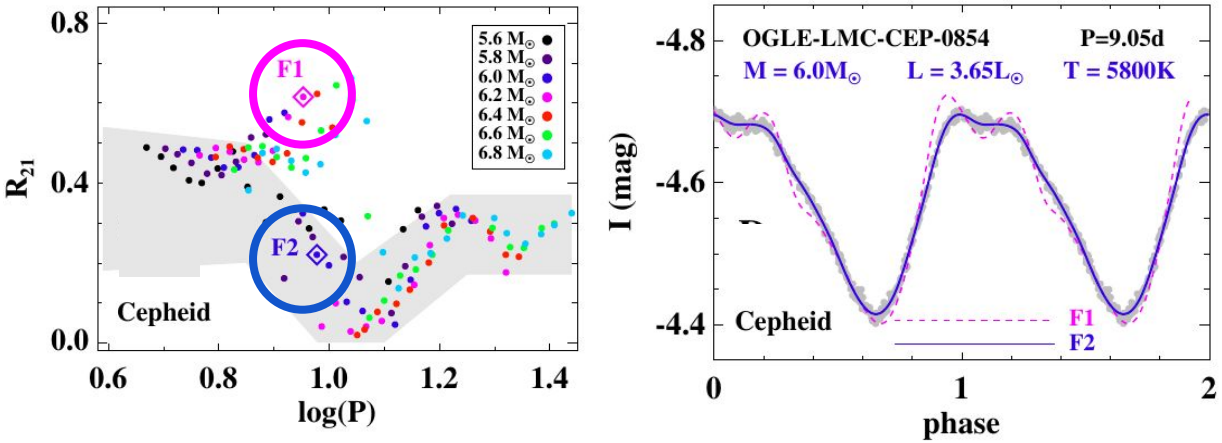
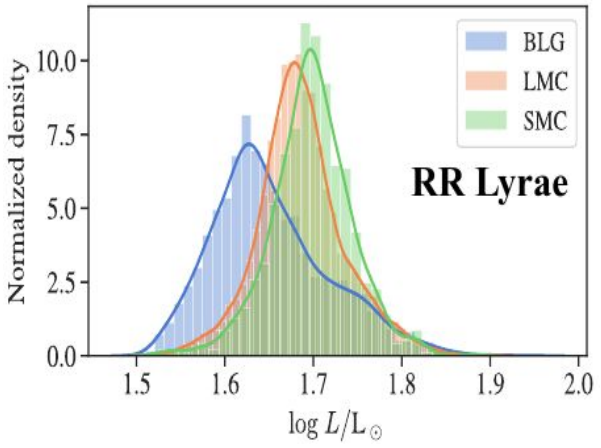


Predicting physical parameters



- Model light curve fitting (e.g., Marconi+2013, 2017)
- Quantitative comparison of light curve parameters (e.g. Bono+2000, Bhardwaj+2017, Das+2018)

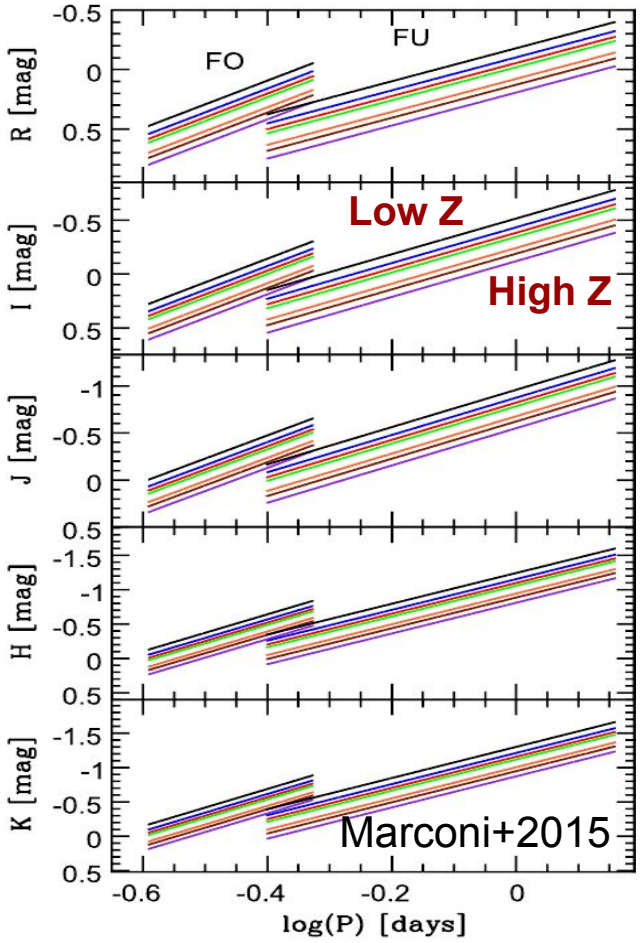
Machine-learning methods (Bellinger+2020)

Theoretical PLR of RR Lyrae and BL Her variables

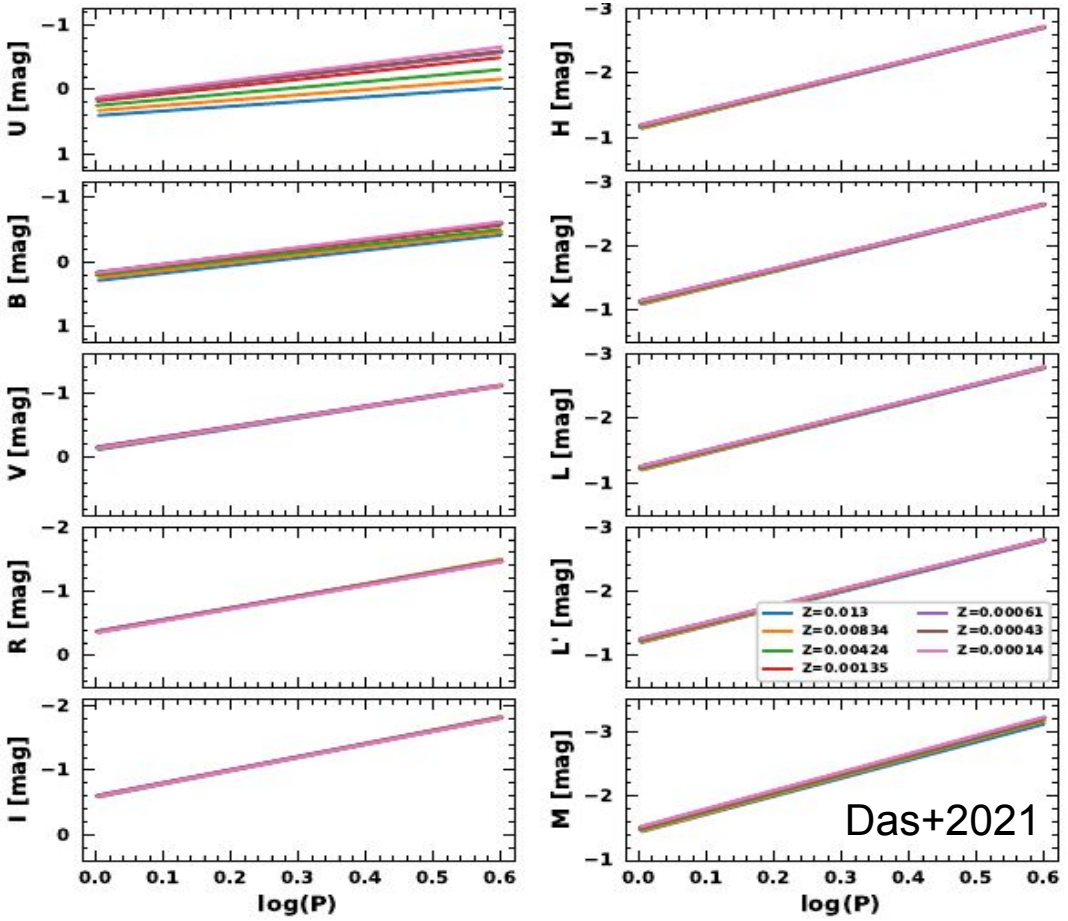
RR Lyrae PLRs are metallicity dependent but not T2C PLRs (except U/B)

Metallicity coefficient: 0.14:0.19 mag/dex (RRL), -0.01:0.05 mag/dex (T2Cs)

RR Lyrae

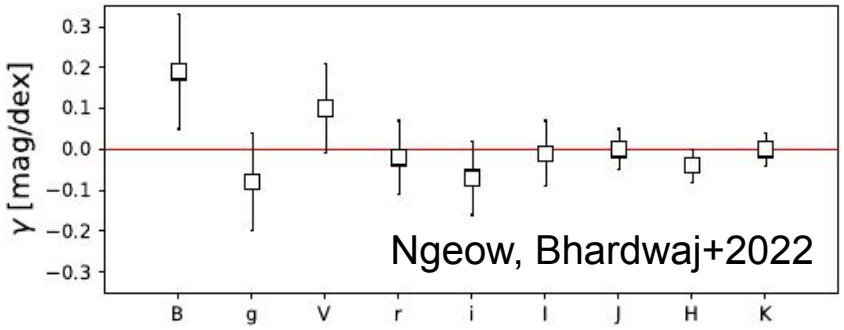


BL Her



Galactic Type II Cepheids

No significant metallicity dependence on T2C PLR in globular clusters



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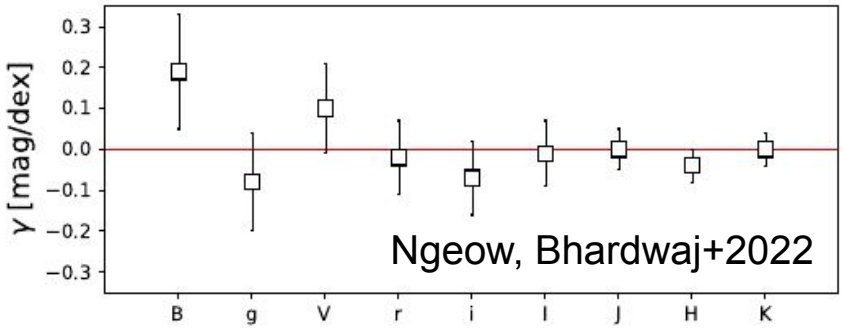
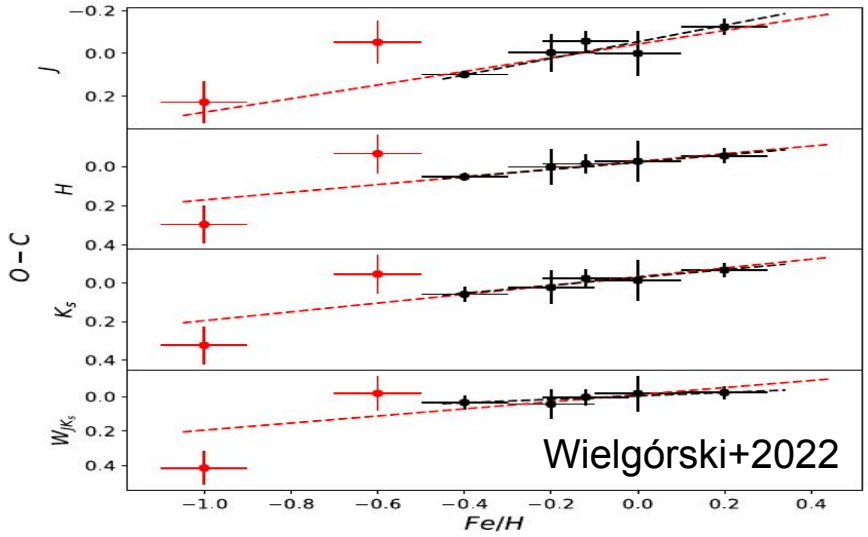
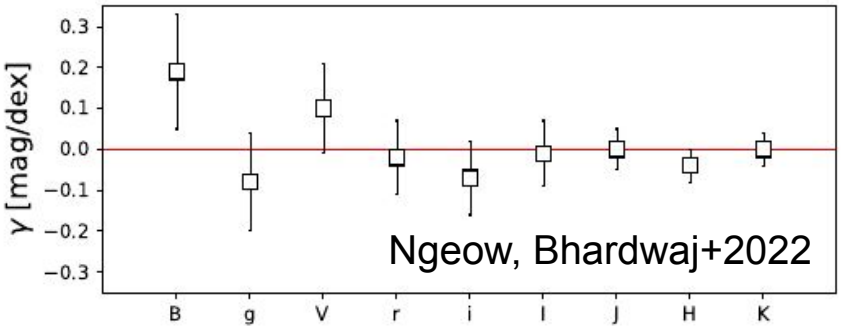


Significant metallicity coefficient of NIR PLR for field T2C (-0.1 to -0.3 mag/dex)



Galactic Type II Cepheids in Gaia DR3

No significant metallicity dependence on T2C PLR in globular clusters



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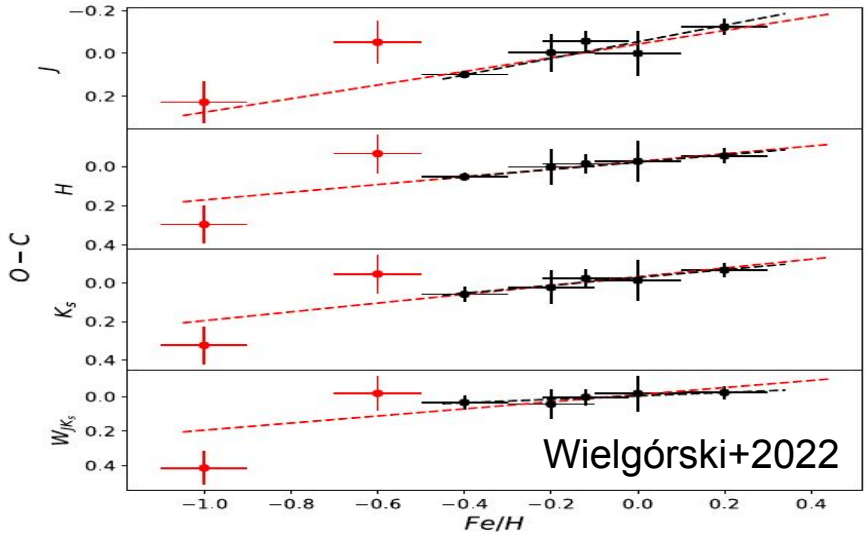
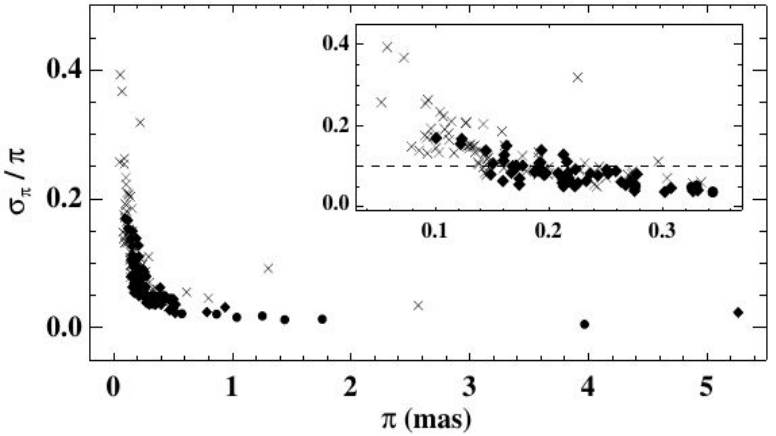
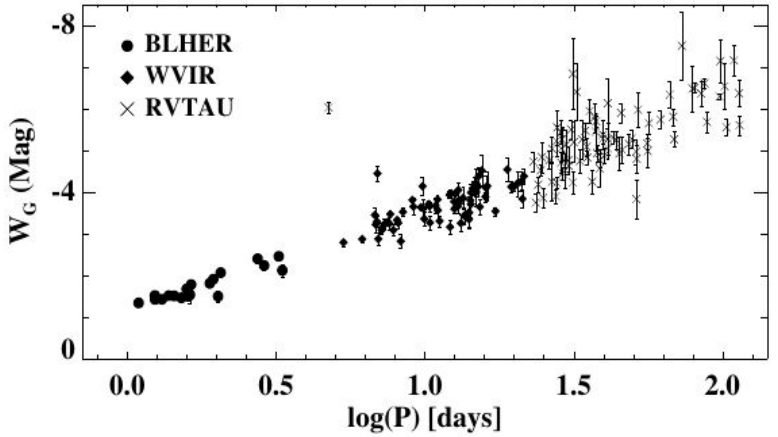


1635 T2Cs in DR3 (Ripepi+2022)

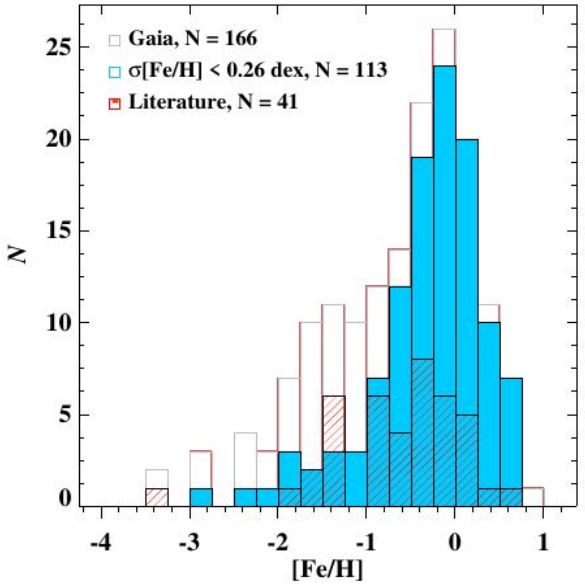
166 with Gaia RVS metallicities





Gaia RVS metallicities of field T2C

- [M/H] for 113 T2C with acceptable quality flags
- 41 have spectroscopic [Fe/H] from high/medium resolution spectra in literature (inhomogeneous)



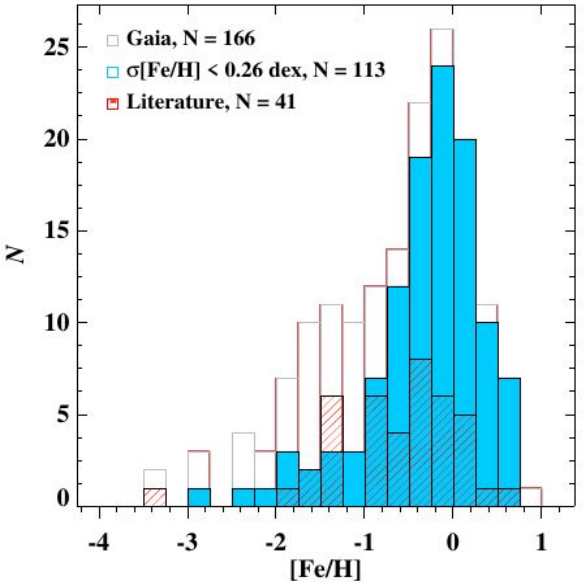
Gaia RVS metallicities of field T2C

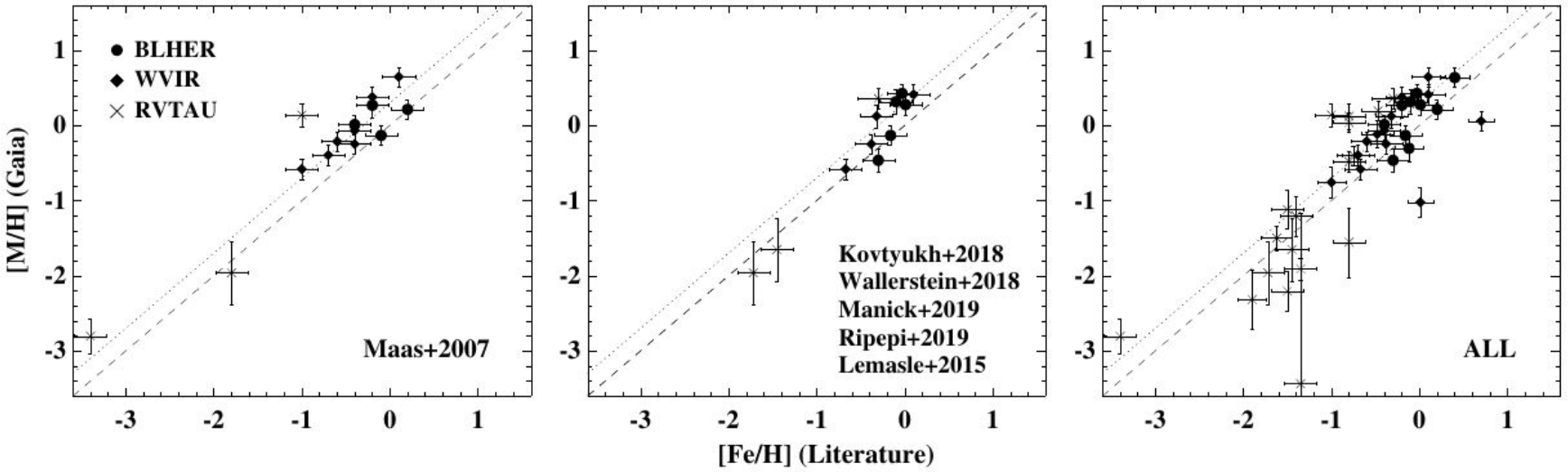
- [M/H] for 113 T2C with acceptable quality flags
- 41 have spectroscopic [Fe/H] from high/medium resolution spectra in literature (inhomogeneous)

BL Her and W Vir - good agreement of [Fe/H]

RV Tau - exhibit larger uncertainties

+0.30 dex median offset : Gaia - literature



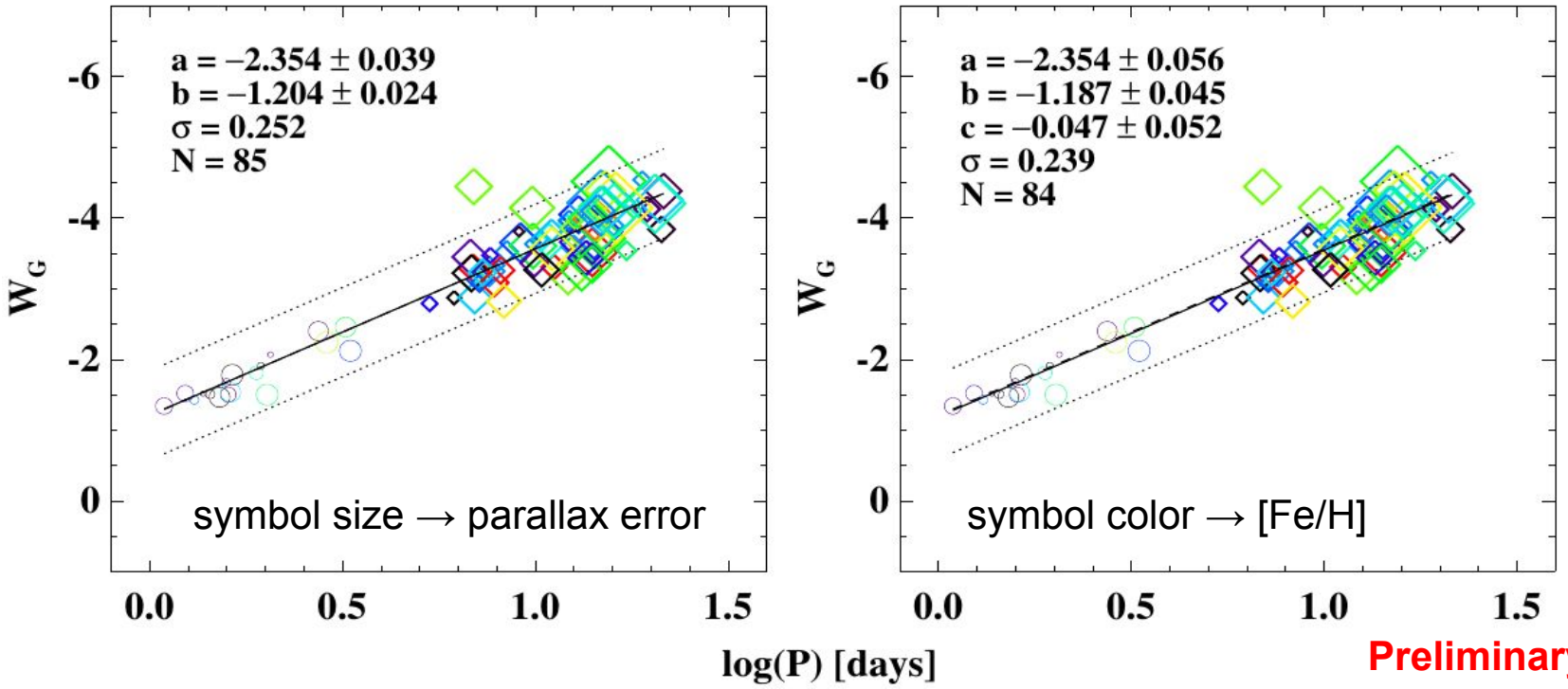


Metallicity effects on PLRs of T2C

Gaia Wesenheit function : $W_G = G - 1.90\,(G_{BP} - G_{RP})$

- 86 BL Her and W Vir - all BL Her have parallax uncertainties < 5%
- △[Fe/H] = 2.6 dex : largest sample with homogeneous [Fe/H]

Metallicity coefficient consistent with zero - no dependence



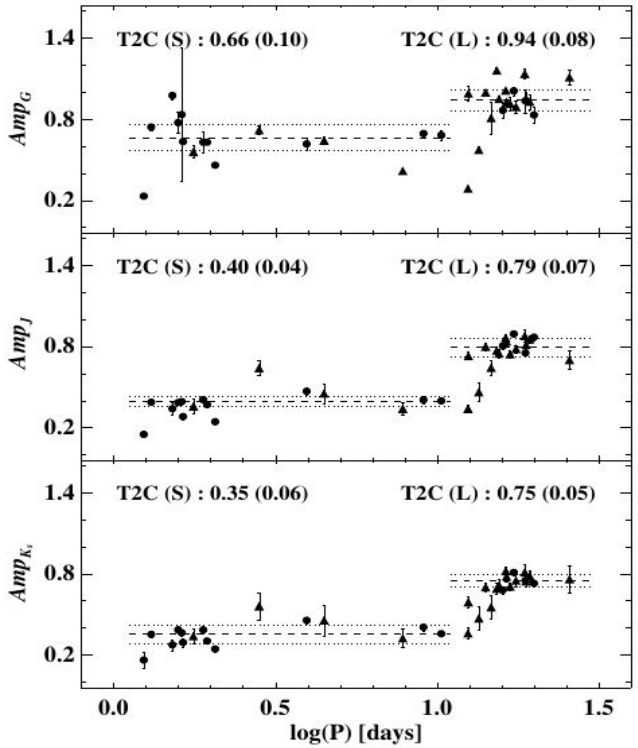
Preliminary!!!!

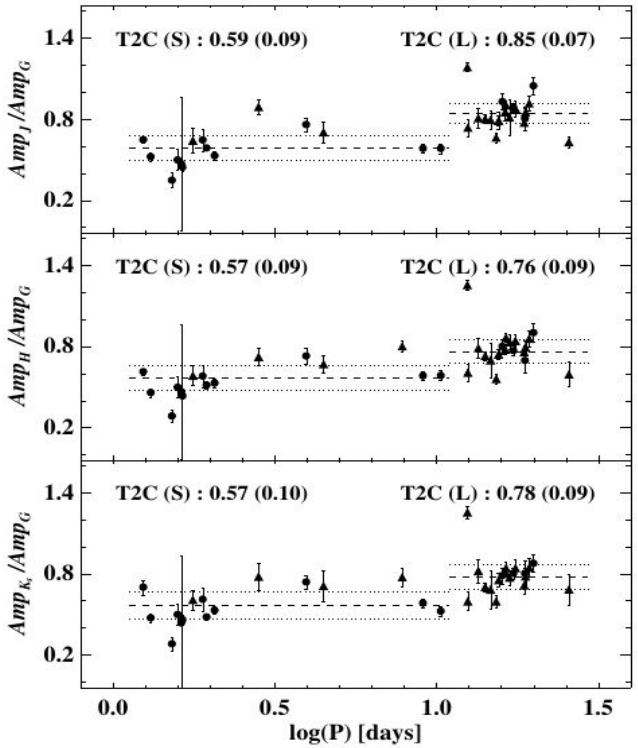
Optical/NIR Amplitudes

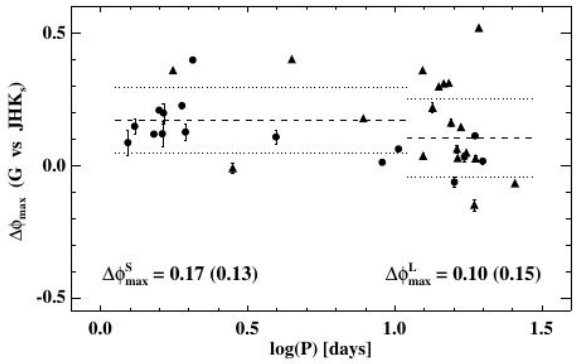
NIR photometry from 2MASS - single-epoch observations

- Amplitude ratios and reference phase are needed for template fitting
- JHK_s time-series for T2Cs in globular clusters (Matsunaga+2006)

Amplitude ratios are accurate, but phase lag is not well constrained.

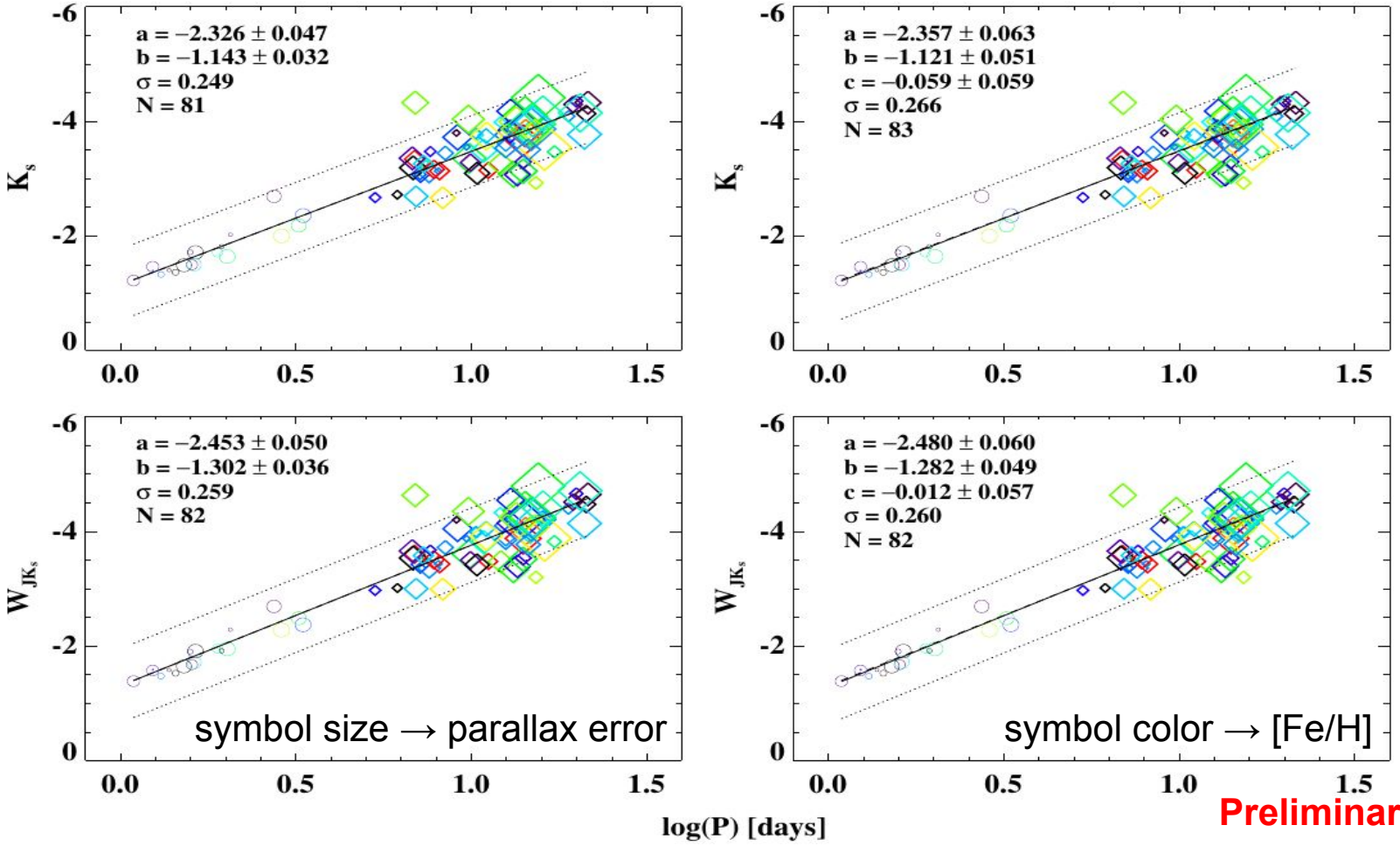






Metallicity effects on PLRs of T2C

No significant metallicity coefficient of NIR PLRs - consistent with theoretical predictions

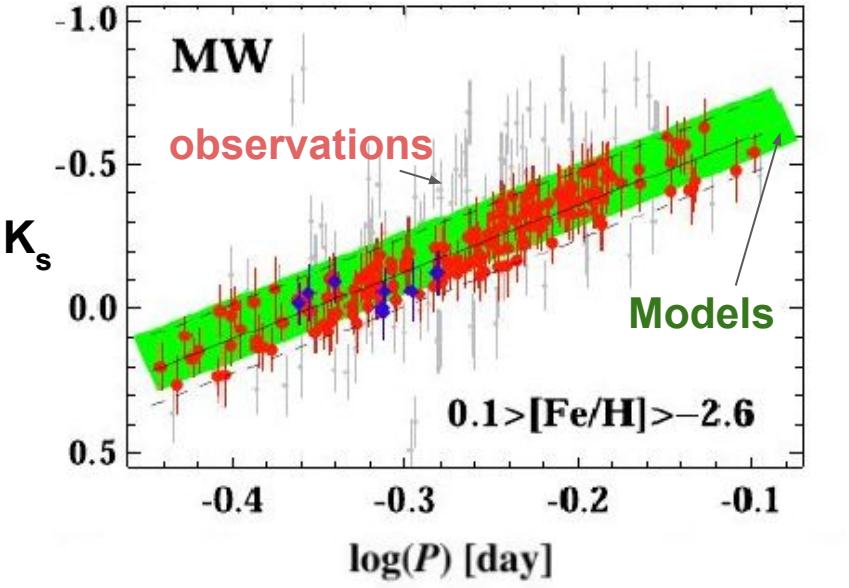


Preliminary!!!!

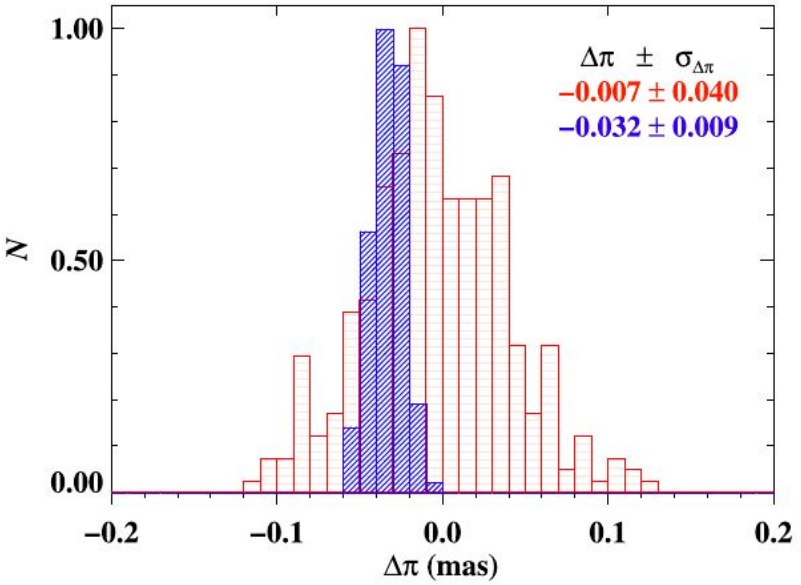
Galactic RR Lyrae variables

- 403 Galactic field RR Lyrae with metallicities from the literature (Dumbis+2013)
- Absolute zero-point using Gaia EDR3 parallaxes and theoretical RRL models

Inhomogeneous compilation, parallax uncertainties lead to a large scatter



Bhardwaj+2021



Small parallax correction with photometric parallaxes

RR Lyrae in globular clusters

NIR observations of RR Lyrae variables in globular clusters with different [Fe/H]

Quantification of metallicity dependence: $\triangle$[Fe/H] = 1 dex => $\triangle m_{Ks}$ = 0.18 mag

Evident variation in luminosity if the PLR dispersion ~ 0.05 mag

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Evident variation in luminosity if the PLR dispersion ~ 0.05 mag

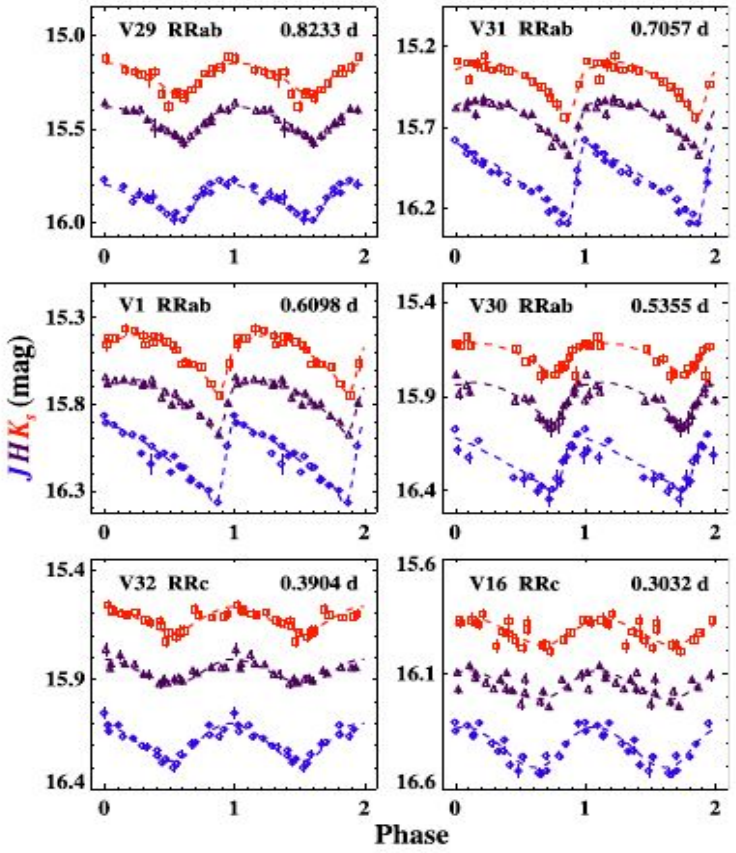
- **CFHT-WIRCam RR Lyrae Program: globular clusters**

  M2, M3, M14, M15, M53, NGC 6934
- **Metal-rich peculiar bulge clusters with Gemini-F2**

  NGC 6441, NGC 6388, NGC 2808
- M4 (Stetson+2014)
- Omega Cen (Braga+2018)

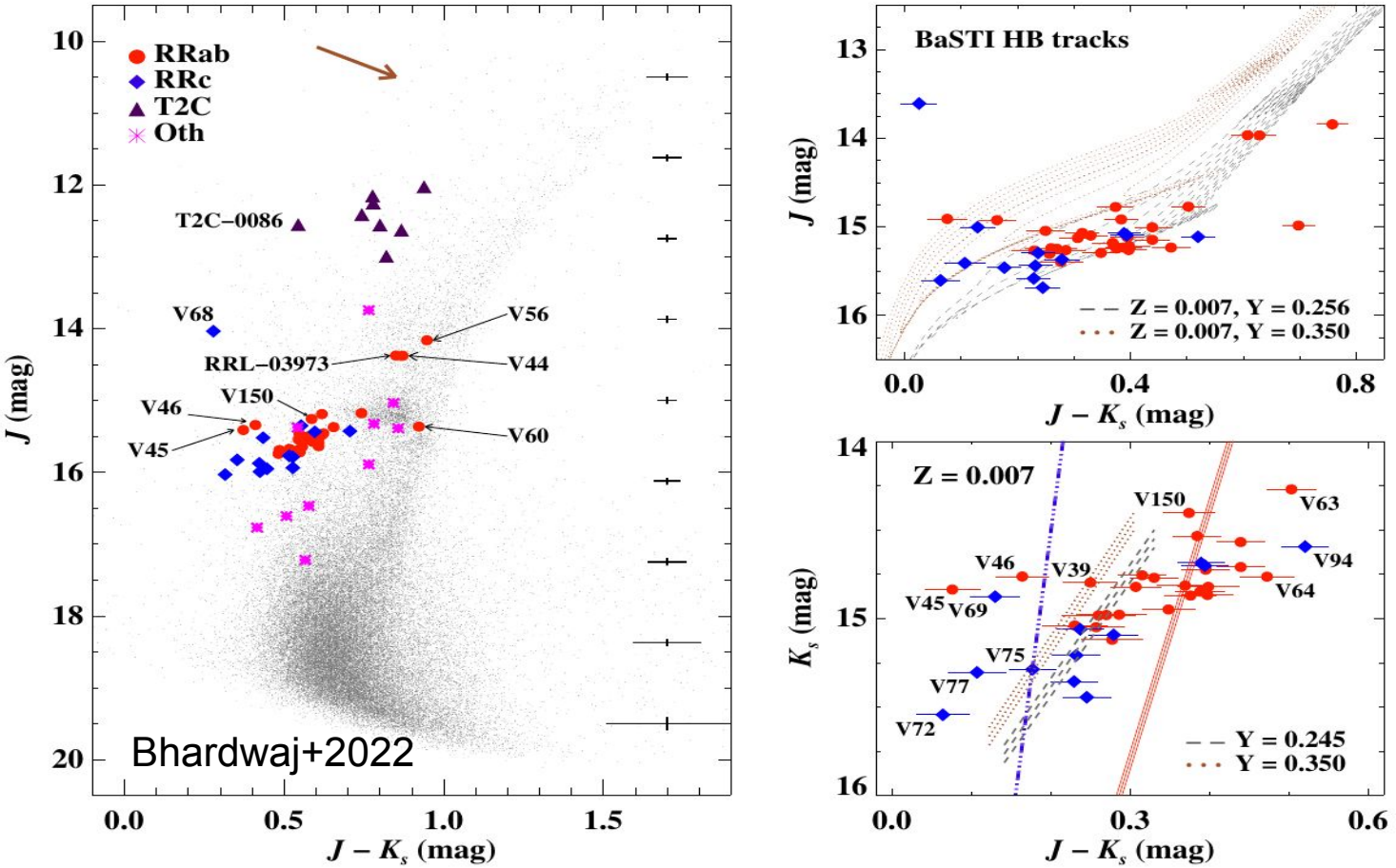
  [Fe/H] = -0.45 to -2.35 dex

  Host > 20 RRL, 10-25 epochs



RR Lyrae in NGC 6441 ([Fe/H]=-0.45)

- Unusually long periods of RR Lyrae stars (<P_{RRab}> = 0.76 days)
- Helium enhancement in NGC 6441 (Catelan+2006, Bellini+2013)



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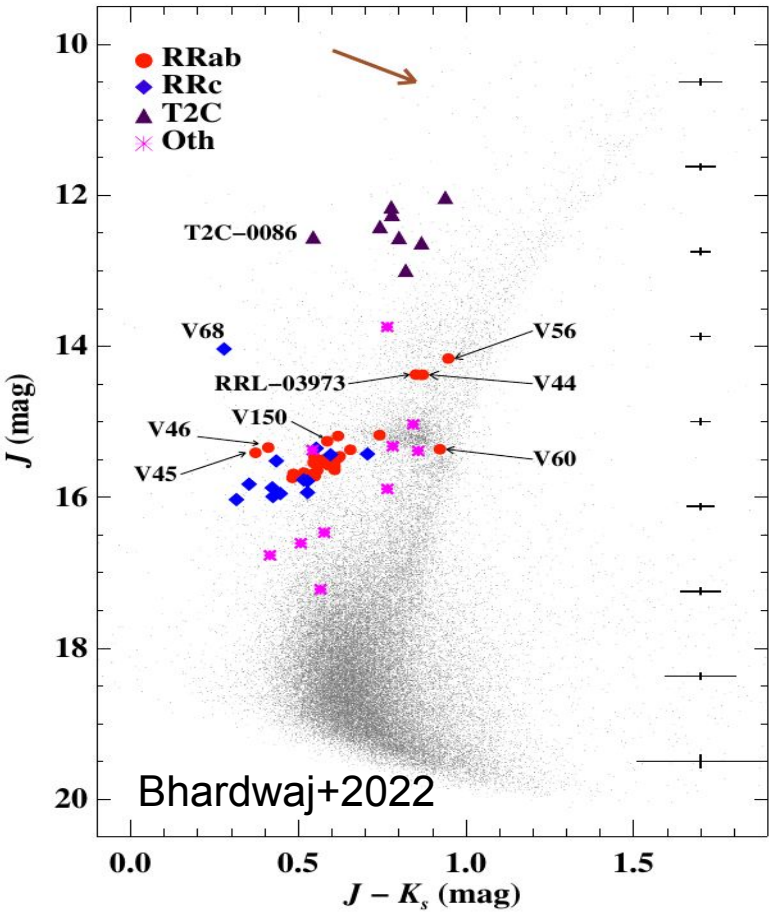
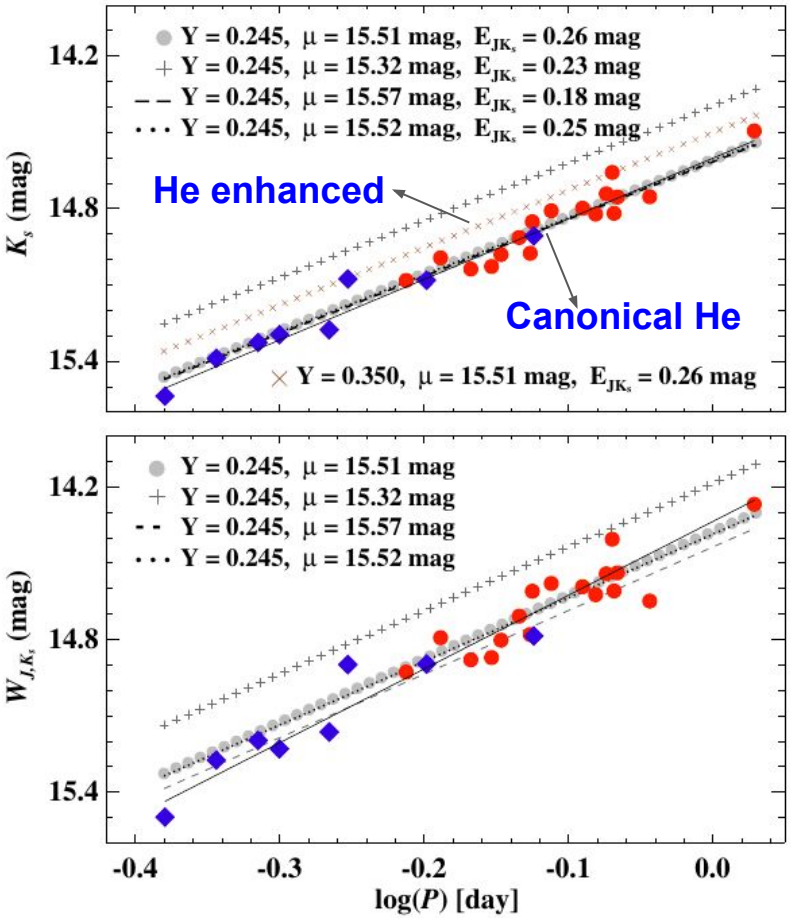
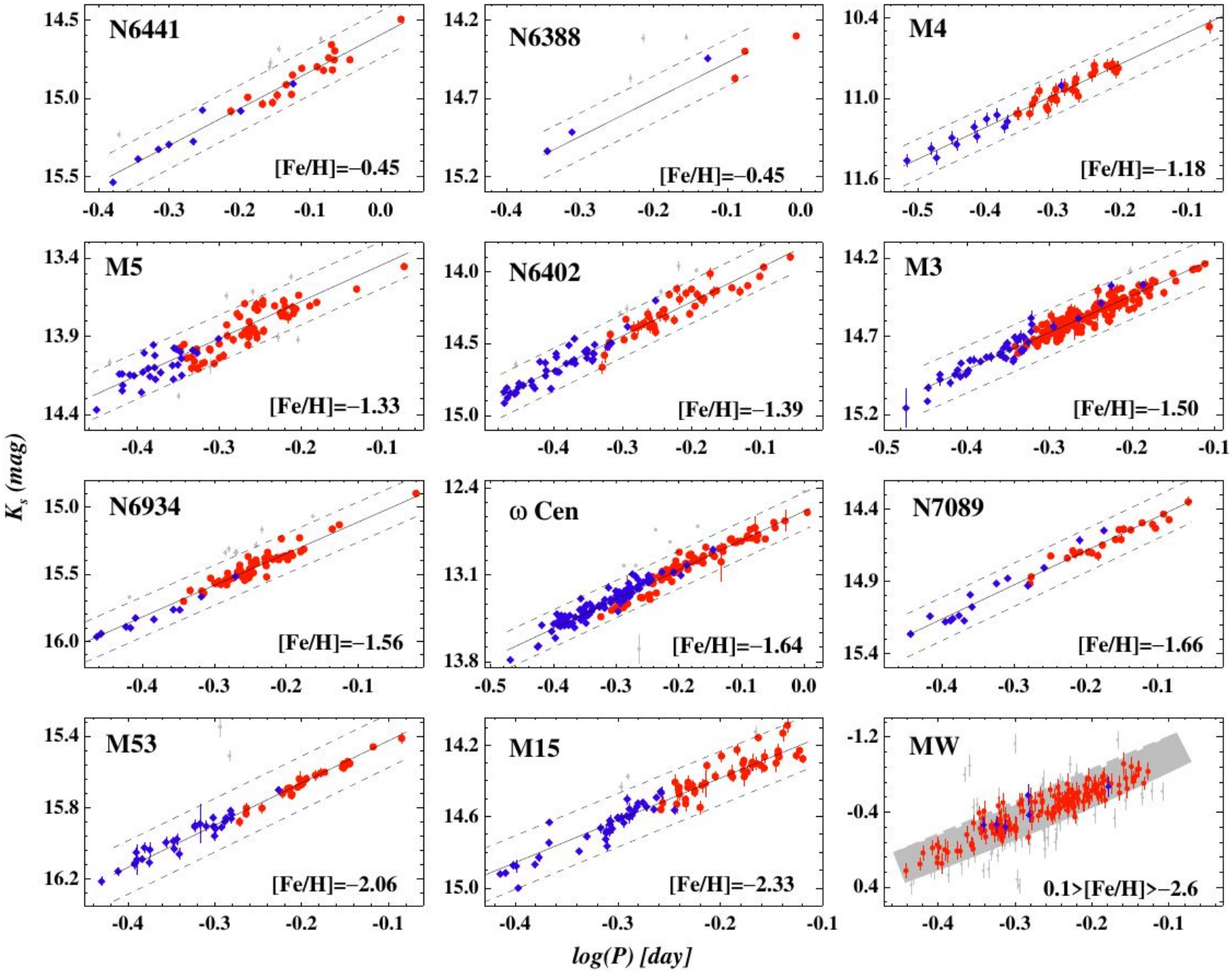
NIR PLRs of RR Lyrae are consistent with models of canonical He content






N6441
[Fe/H]=−0.45
N6388
[Fe/H]=−0.45
M4
[Fe/H]=−1.18
M5
[Fe/H]=−1.33
N6402
[Fe/H]=−1.39
M3
[Fe/H]=−1.50
N6934
[Fe/H]=−1.56
ω Cen
[Fe/H]=−1.64
N7089
[Fe/H]=−1.66
M53
[Fe/H]=−2.06
M15
[Fe/H]=−2.33
MW
0.1>[Fe/H]>−2.6
K_s (mag)
log(P) [day]

RR Lyrae Period-Luminosity-Metallicity relations

Relative quantification of metallicity

(M3 as anchor)

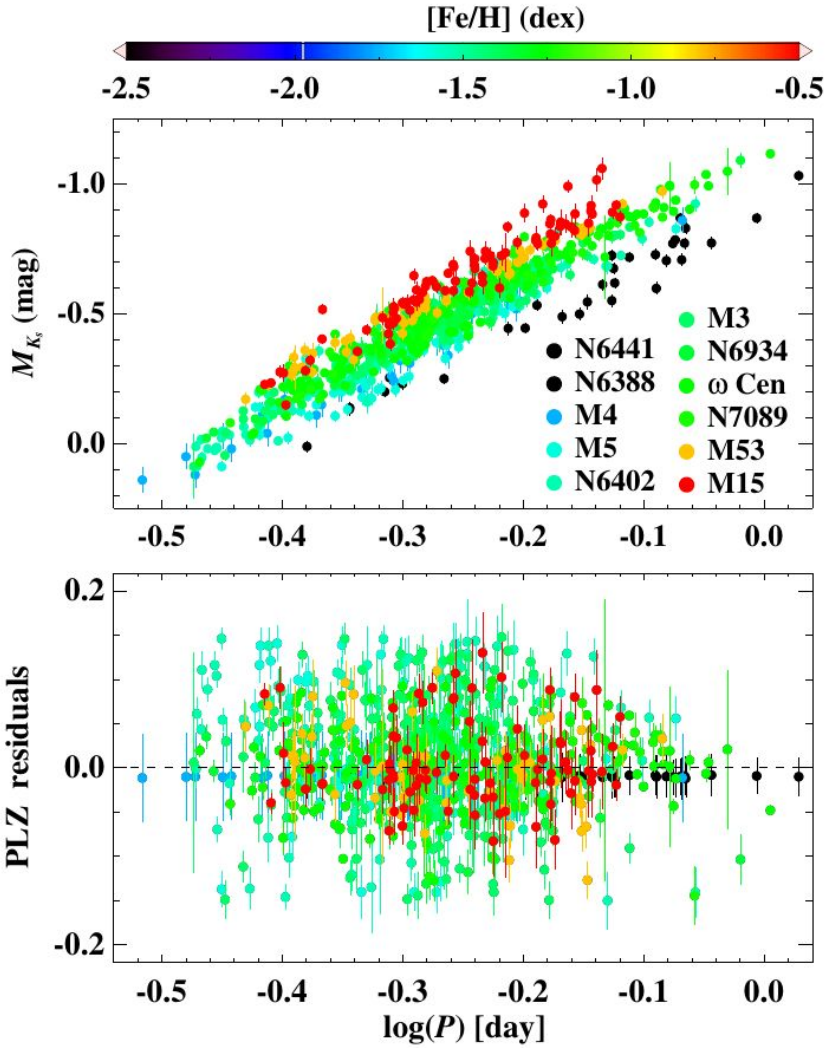
0.17 mag/dex in K_s band

(Bhardwaj+2021)

Independent zero-point calibrations

- Gaia parallaxes
- Theoretical magnitudes
- LMC RR Lyrae

Metallicity coefficients are consistent with the theoretical predictions



Bhardwaj (2022, in prep.)

Take away messages

- NIR Period-Luminosity relations for BL Herculis and W Virginis variables in the Milky Way and globular cluster **do not exhibit any significant metallicity dependence** in agreement with the theoretical predictions.
- NIR Period-Luminosity-Metallicity relations for RR Lyrae in globular clusters provide the **most precise quantification of metallicity effects** that are also consistent with the theoretical predictions of the pulsation models.
- NIR pulsation properties of RR Lyrae variables in NGC 6441 are well fitted with the theoretical models of canonical helium content. This suggests that these population II variables are **either not significantly helium enhanced** as previously thought or the **impact of such enhancement is smaller in NIR** than the predictions of the pulsation models.
- Efforts to obtain homogeneous photometry and spectroscopic metallicities of Galactic field pulsating stars are needed to fully utilize final Gaia parallaxes.