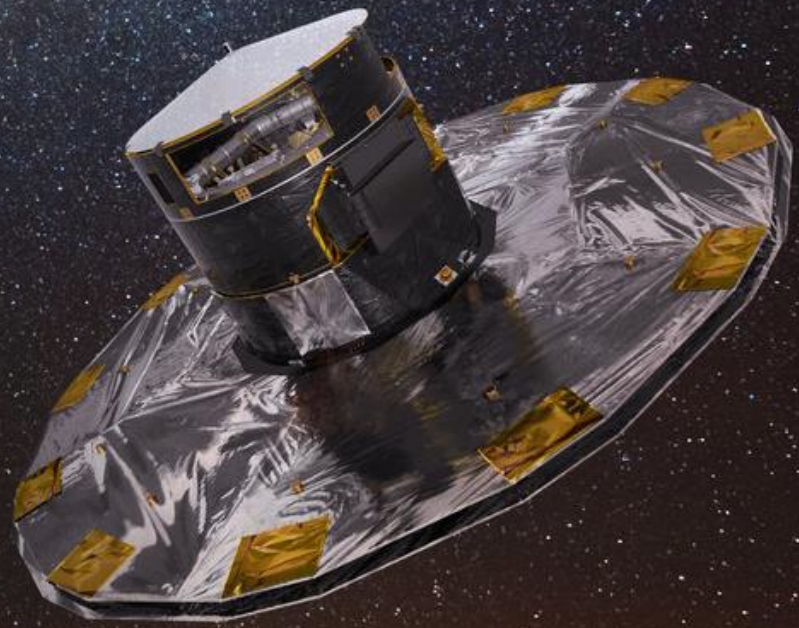
A 0.9% calibration of the Galactic Cepheid luminosity scale based on Gaia DR3 open cluster astrometry

Mauricio Cruz Reyes

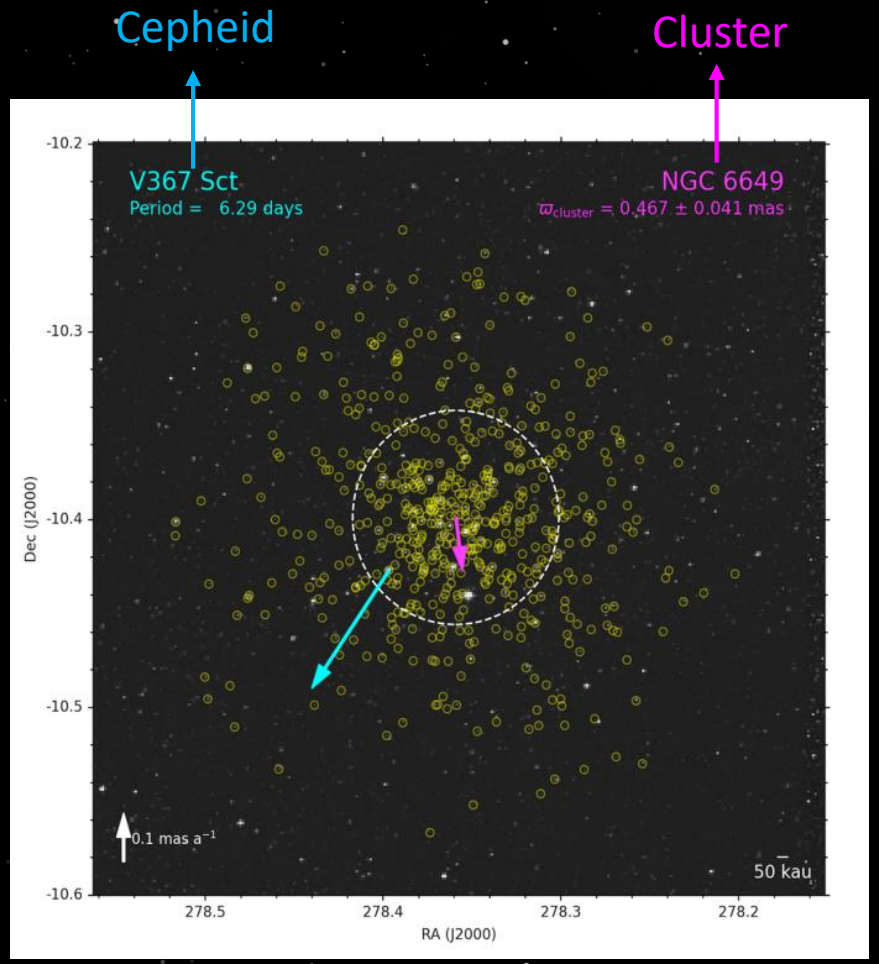
Richard I. Anderson



EPFL

European Research Council

Established by the European Commission



L. Breuval et al. 2021

Cepheids in clusters

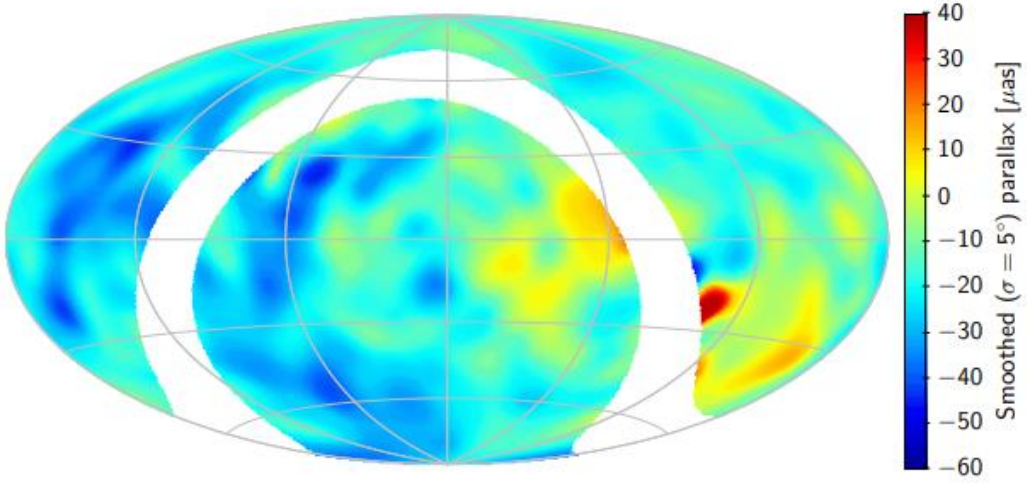
- ~10% of Cepheids reside in clusters.
- Statistical precision in parallax $\propto \sqrt{N_{\rm mem}}$

With respect to Cepheids Cluster members are

- Fainter
- Non-variable
- Bluer

gaia

Global offset of -17 μas



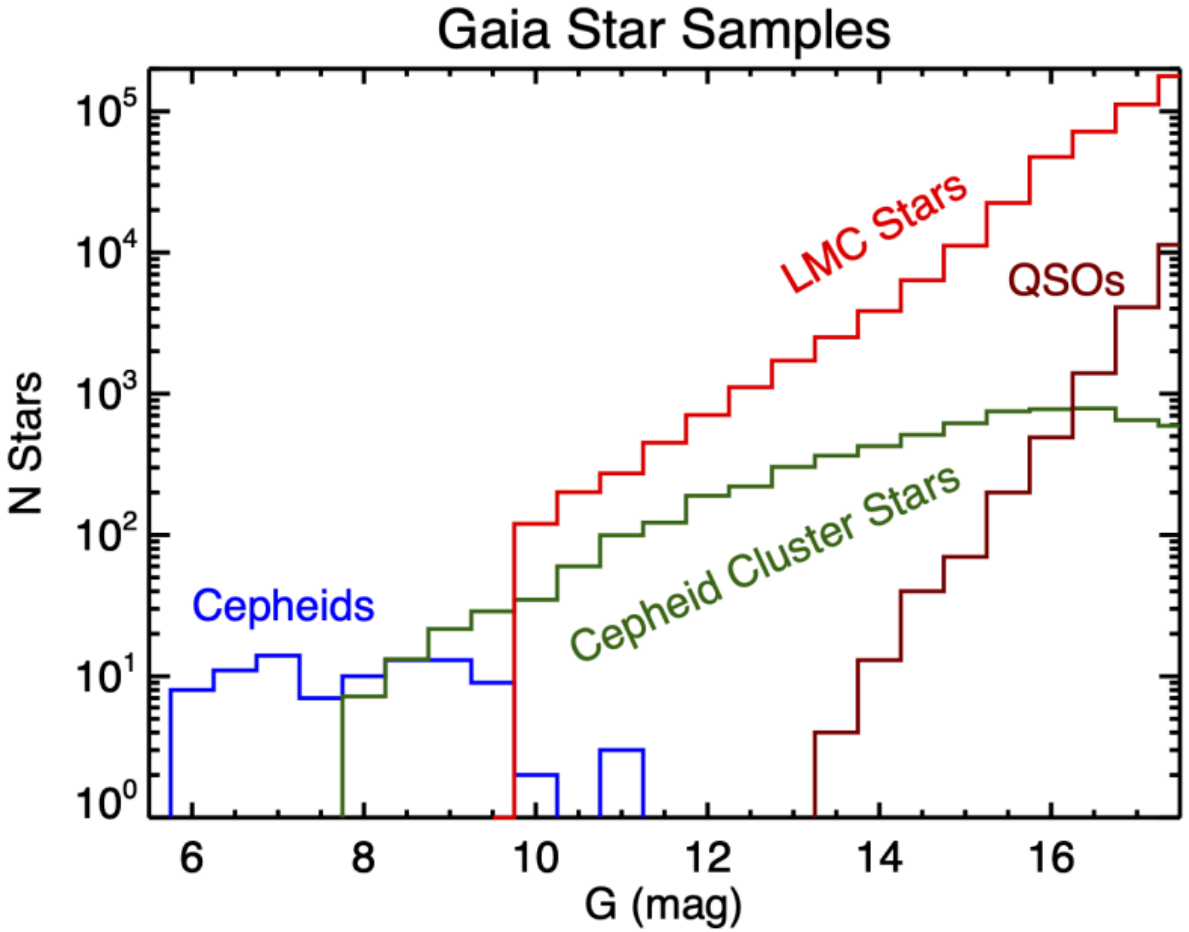
Lindegren et al. 2021. Gaia EDR3

Challenges

- Parallax offset.

(Distances are overestimated)

- Cepheids are bright G <12.
- Correlations.



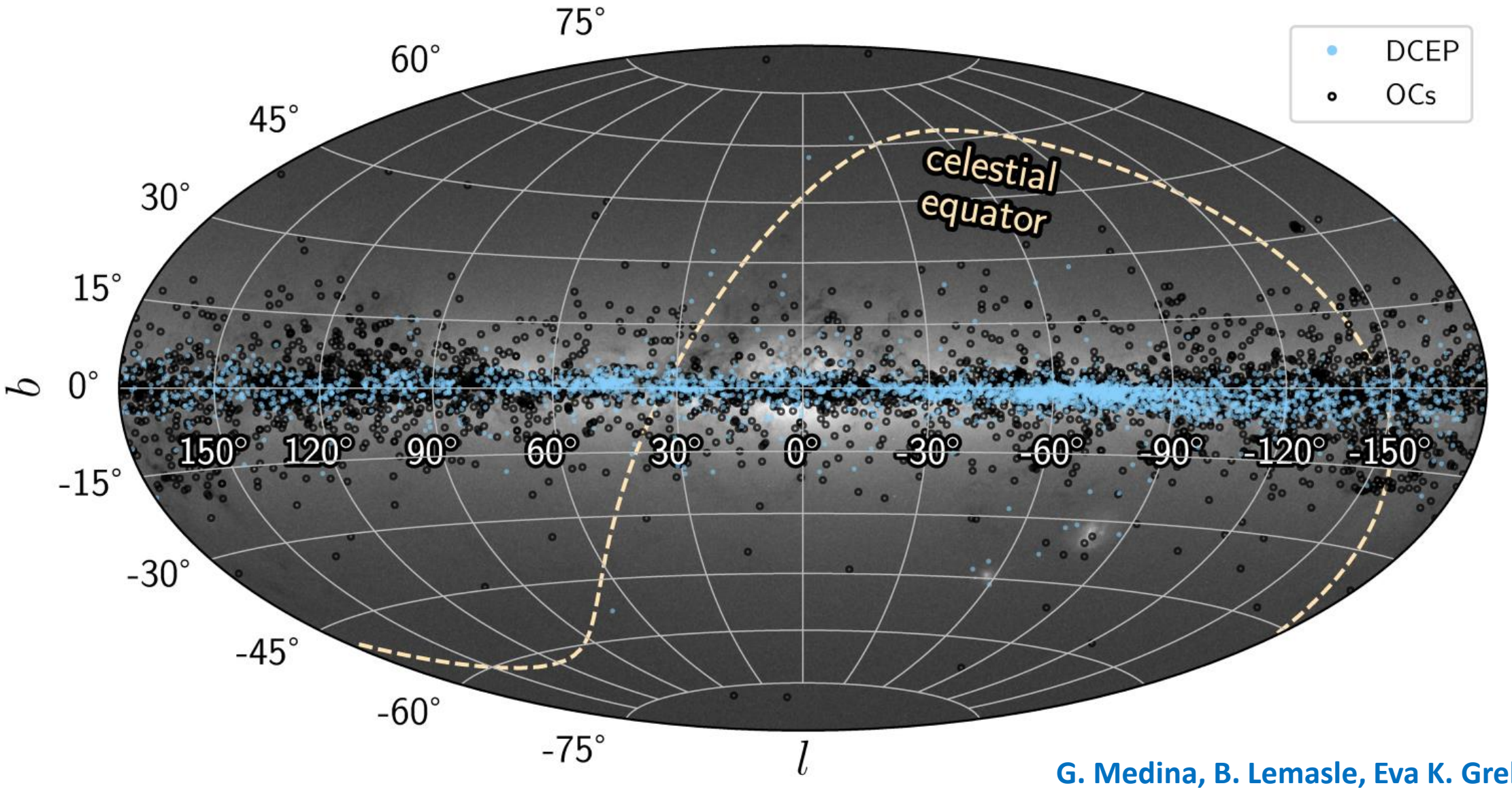
Sources used by L21 to calibrate the Gaia EDR3 parallax offset. Riess et al. 2022.

Opportunities

For cluster members:

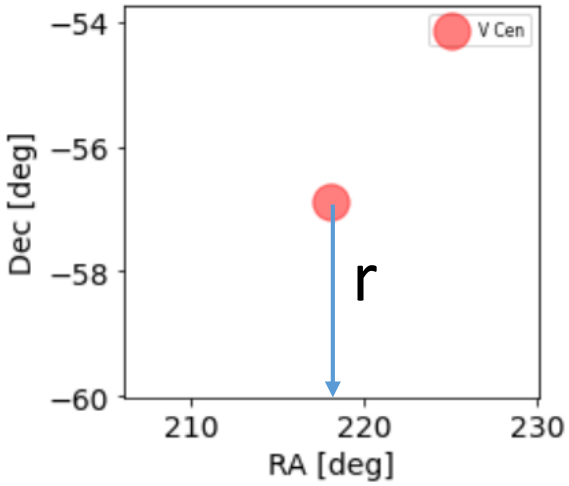
- The parameter space of cluster members and quasars is similar. (magnitude and color)
- L21 correction accurately describes their offset

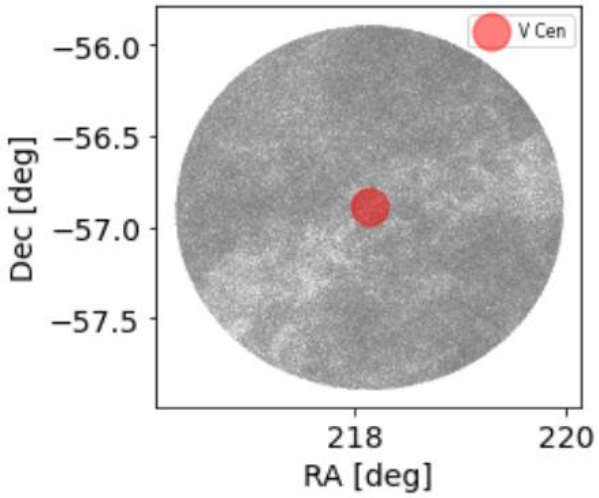
Detection of Cluster Cepheids



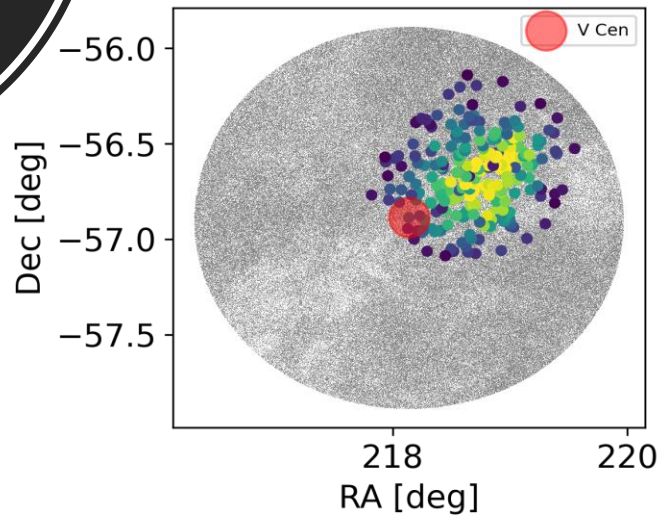
G. Medina, B. Lemasle, Eva K. Grebel 2021

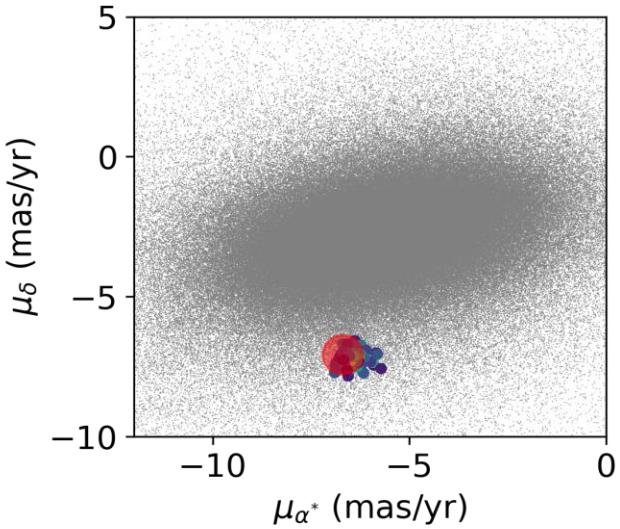
How it works?

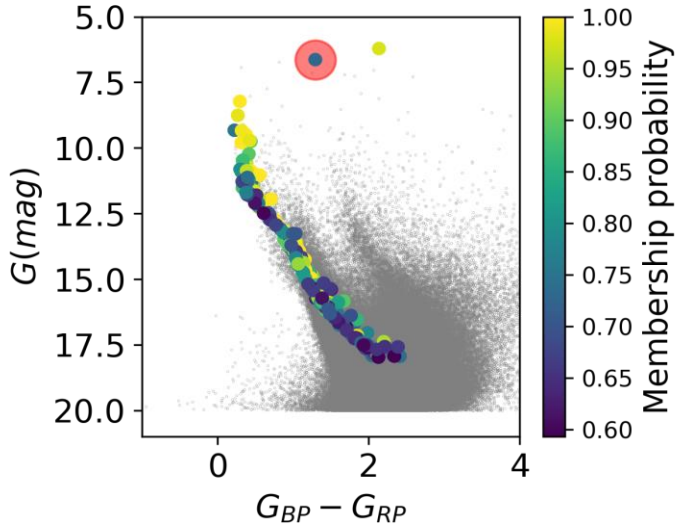




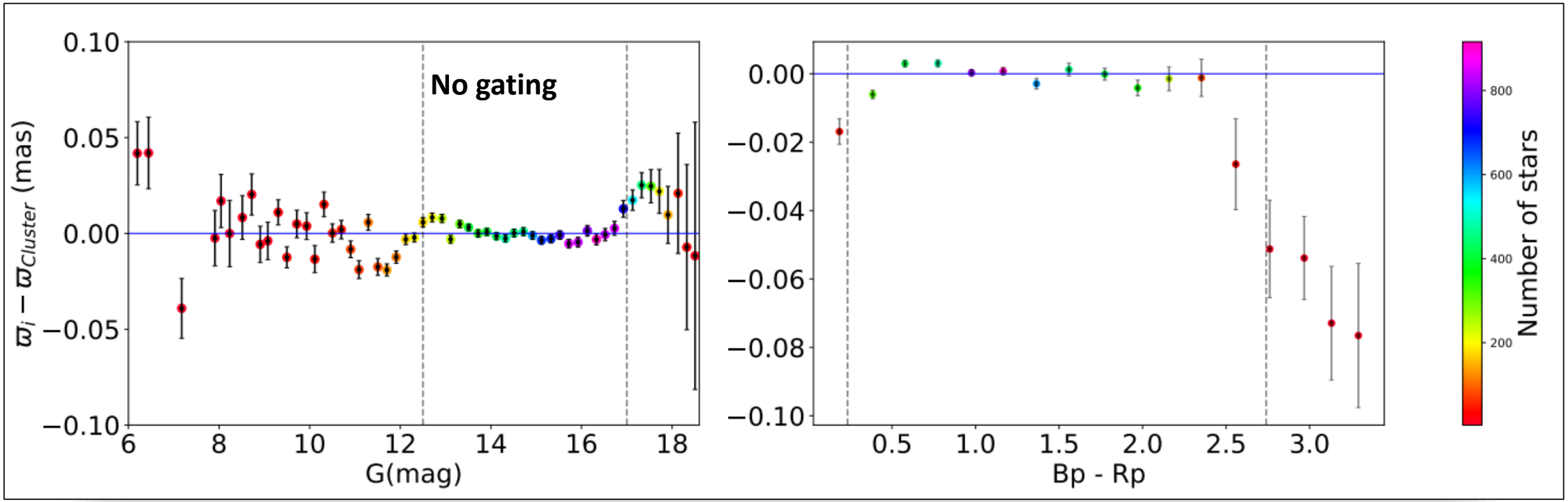
Positions: *l,b*
Velocities: $\mu_{\alpha^*}, \mu_\delta$
Parallaxes: ϖ
(l,b,$\mu_{\alpha^*}, \mu_\delta, \varpi$)







Cluster parameters



Cuts

- Magnitude: 12.5 < G < 17
- Color: 0.23 < Bp – Rp < 2.75

Advantages

- Good characterization of the offset
- Accurate parallaxes
- Cluster parallax: Average uncertainty 7 μas. (Including the angular covariance)

Gold sample

Cluster parallaxes for the calibration of the Leavitt Law (N=34)

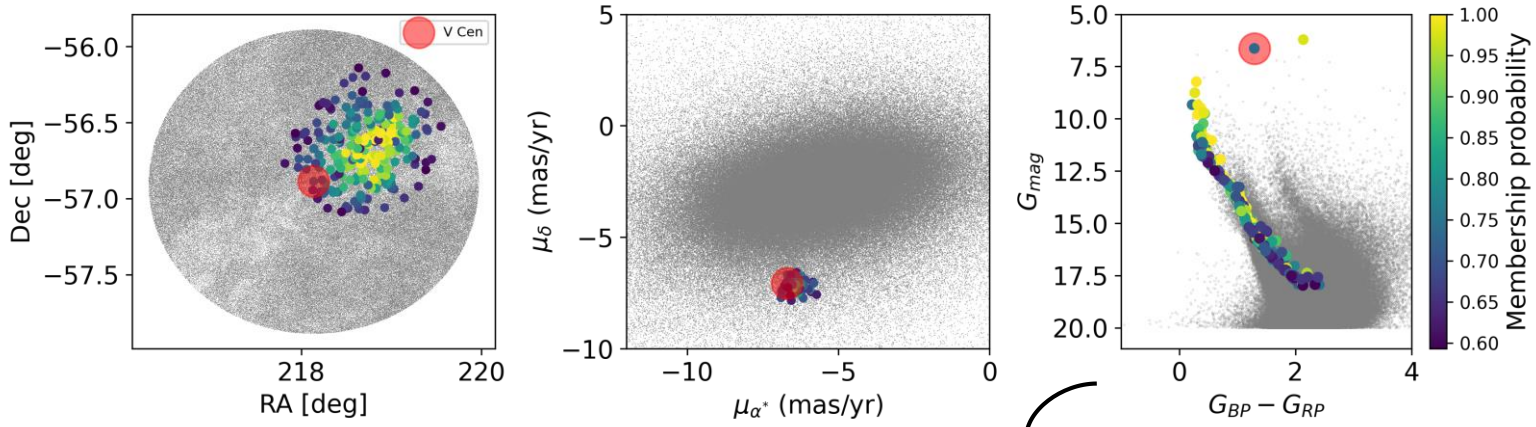
Fundamental mode: **27**

First overtone: 7

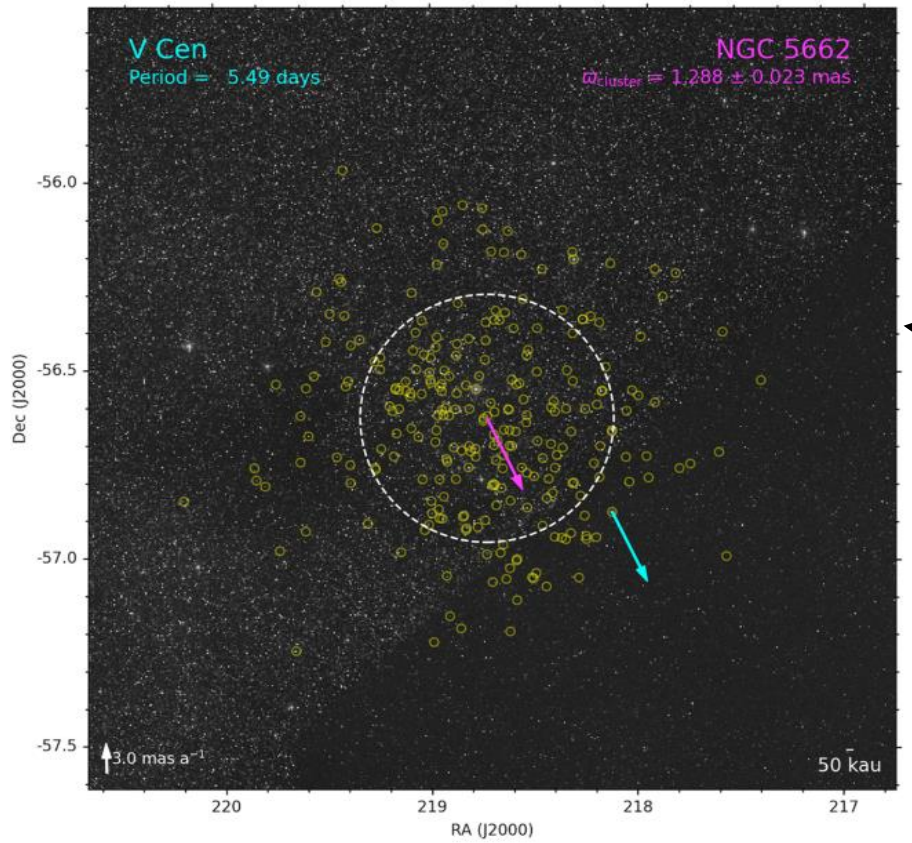
Three new and three corrected host clusters

Average statistical error: 3 µas

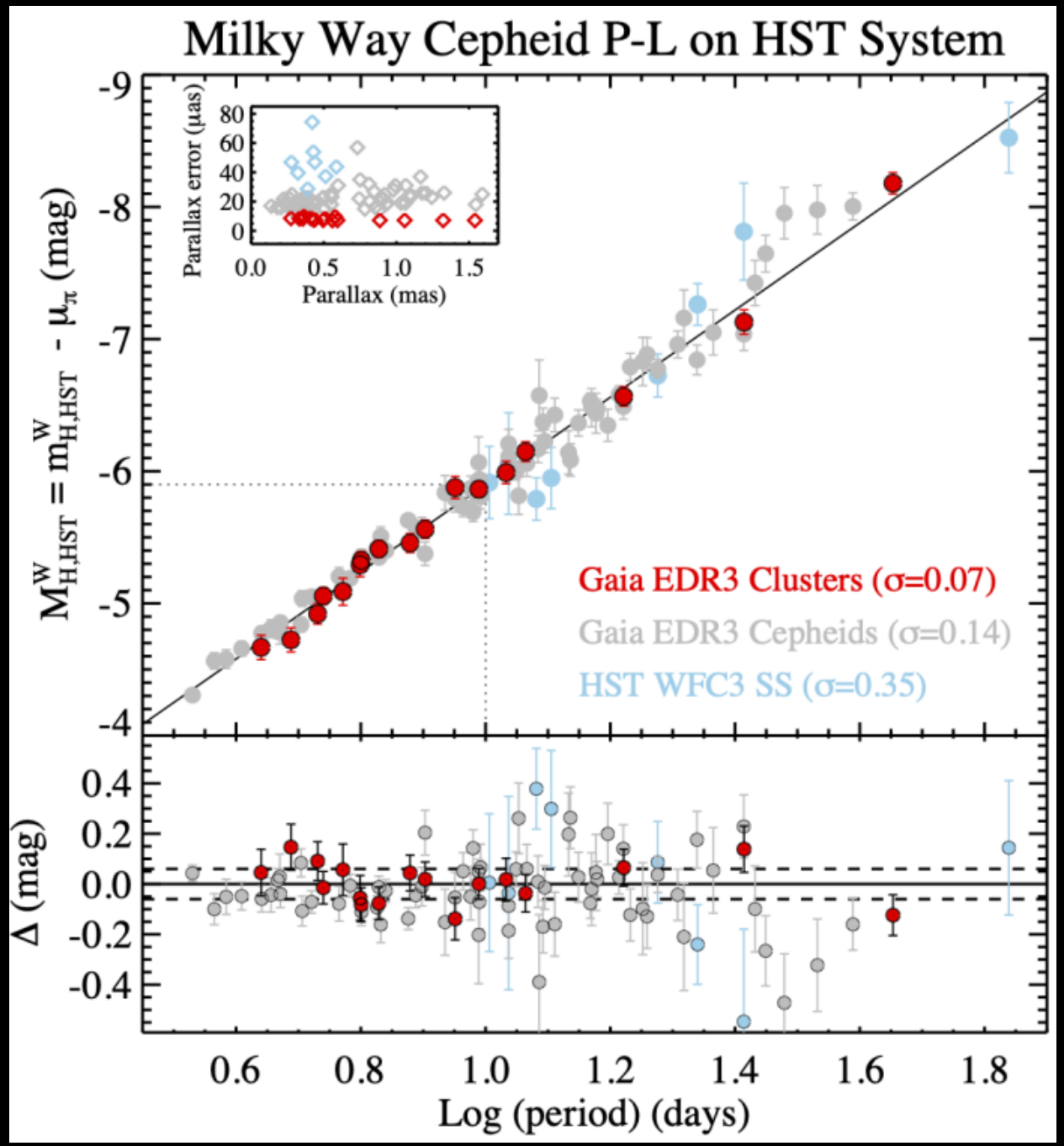
Angular covariance: 7 µas



From this work



L. Breuval et al. 2021



Gaia astrometry and ***Hubble*** Photometry for Cluster Cepheids

H_0 =73.15 ± 0.97 km/s/ Mpc.

$M^W_{H,1}(P = 10d)$ = −5.907 ± 0.018 mag.

Riess et al. 2022.

Cross-check:

68 Field Cepheids + 15 Cluster Cepheids:

$M^W_{H,1}(P = 10d)$ = −5.915 ± 0.017 mag.

$\Delta\varpi_{cep} = -13 \pm 5$ μas.

Cruz and Anderson 2022.

Gaia only: consistent $\Delta\varpi_{cep}$ & 0.9% calibration in $M^W_{G,1}$

Riess et al. 2022.

Final remarks

- No evidence of residual offsets in cluster parallaxes.

Flynn et al. 2022, Maíz Apellániz 2022.

- Precise characterization of the offset for MW Cepheids.

$\Delta\varpi_{cep} = -13 \pm 5$ μas.

Field and Cluster Cepheids.
Cruz and Anderson 2022.

$\Delta\varpi_{cep} = -14 \pm 6$ μas.

Field Cepheids.
Riess et al 2021.

- **A 0.9% calibration of the Galactic Leavitt Law in the:**

HST and Gaia **Wesenheit formulations**.

EXTRA SLIDES

Leavitt Law

$$M_W = \alpha(\log_{10} P - 1) + \beta$$

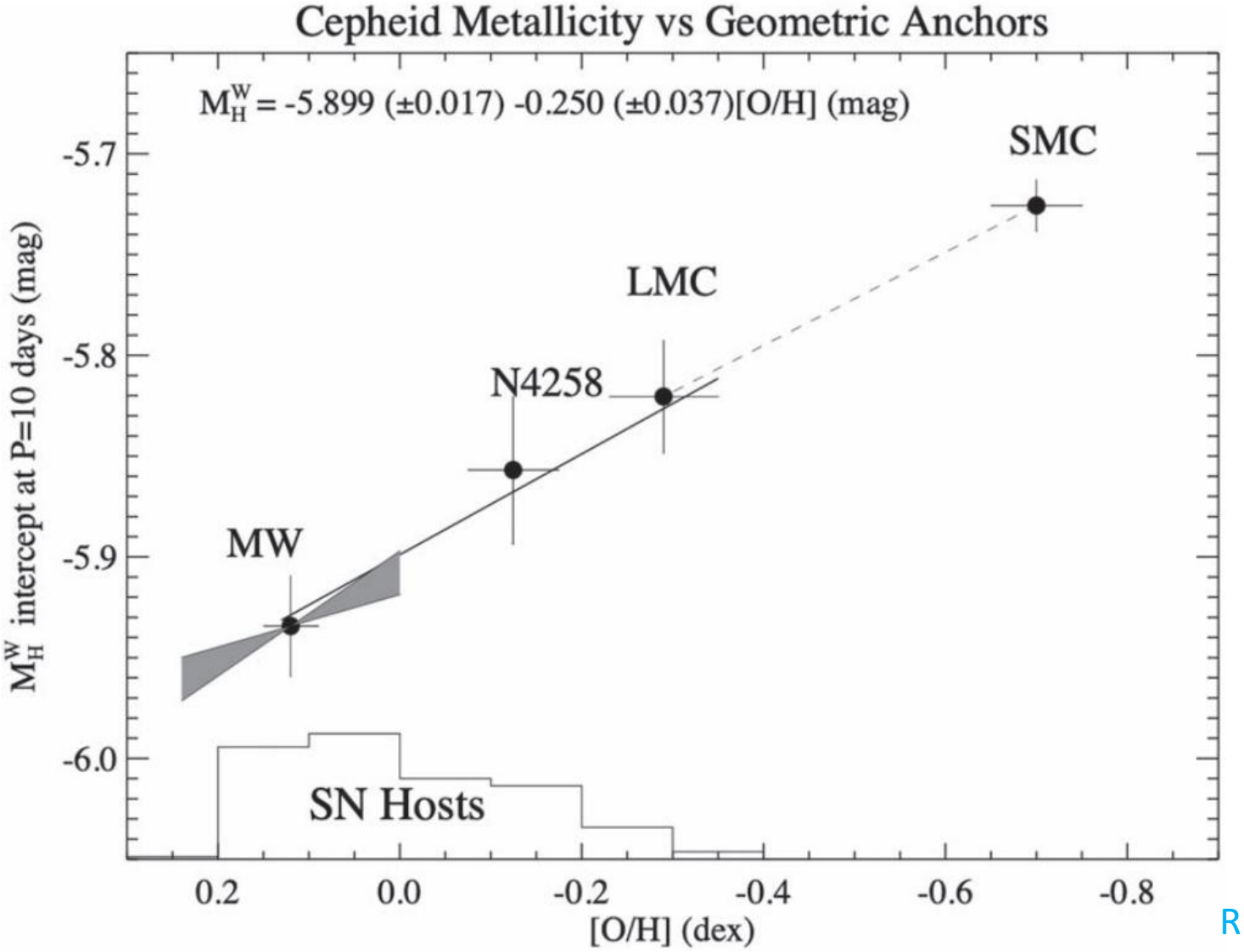
Filter	α (mag/log P)	β (mag)	$\Delta\varpi_{\rm Cep}$ (μas)	$\langle$[Fe/H]$\rangle$	$N_{\rm Cep}$	$N_{\rm cl}$
W_H^a	-3.412 ± 0.053	-6.003 ± 0.020	-19 ± 5	0.086	67	15
W_G	-3.303 ± 0.049	-6.051 ± 0.020	-22 ± 3	0.069	225	26
Bp	-2.526 ± 0.079	-4.229 ± 0.036	-20 ± 6	0.069	243	23
V	-2.553 ± 0.071	-4.377 ± 0.033	-22 ± 5	0.069	246	22
G	-2.751 ± 0.077	-4.612 ± 0.035	-22 ± 5	0.068	240	23
Rp	-2.829 ± 0.070	-5.019 ± 0.032	-22 ± 5	0.068	240	23
$F160W^a$	-3.353 ± 0.060	-5.729 ± 0.023	-23 ± 6	0.088	67	15
W_H^b	-3.406 ± 0.052	-5.953 ± 0.020	-18 ± 5	0.086	67	15
$F160W^b$	-3.346 ± 0.060	-5.679 ± 0.023	-22 ± 6	0.088	67	15

Notes. [a] Does not include the CRNL correction. [b] Includes the CRNL correction to facilitate comparison with extragalactic Cepheid samples (Riess et al. 2022).

Metallicity effect

$$M_W = \alpha + \beta(\log_{10} P - \log_{10} P_0) + \gamma\,[Fe/H],$$

$$\mathrm{ABL} = 10^{\frac{M}{5}} = (\varpi + \Delta\varpi)10^{\frac{m-10}{5}}\ .$$



Riess et al. 2022.

Astrometric and photometric constraints applied to MW Cepheid sample

Astrometric constraints	Photometric constraints
RUWE < 1.4	$0.8 < Bp - Rp < 2.75$
$\sigma_{\varpi}/\varpi \geq 8.5$	num_clean_epochs_g > 15
astrometric_chi2_al < 3000	num_clean_epochs_bp > 15
astrometric_excess_noise < 0.25	num_clean_epochs_rp > 15
astrometric_excess_noise_sig < 70	ipd_frac_multi_peak< 7
	int_average_g> 6

All bands

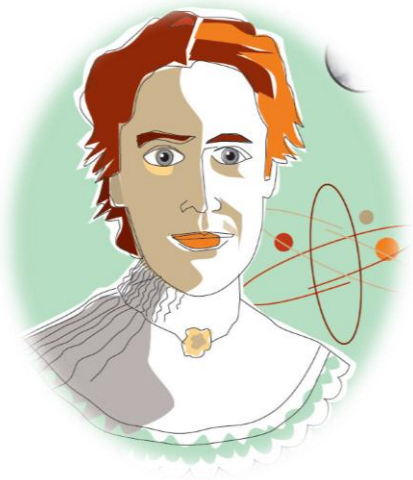
Only Gaia bands

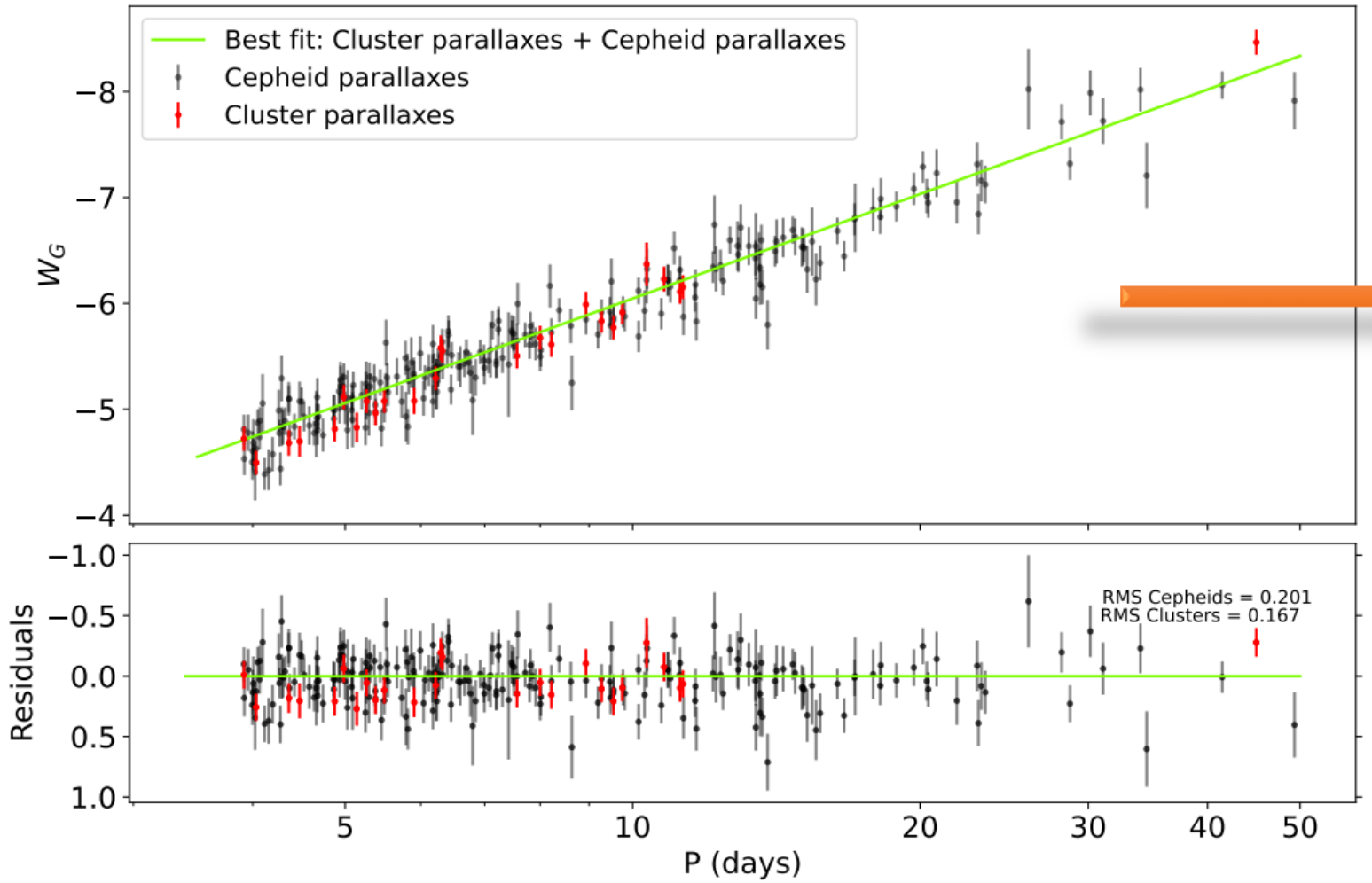
Leavitt Law

$$M_W = \alpha + \beta(\log_{10} P - \log_{10} P_0) + \gamma\,[Fe/H],$$

$\Delta\varpi = -17 \pm 5$ μas. For MW Cepheids (NIR - HST Wesenheit)

$\Delta\varpi = -19 \pm 3$ μas. For MW Cepheids (Optical Gaia Wesenheit)





Cepheids = 225

Clusters = 26