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JOHNS HOPKINS
UNIVERSITY

The Cepheid Distance Scale and its Metallicity Dependence

Collaborators:

Adam G. Riess, Pierre Kervella, Richard I. Anderson, Martino Romaniello

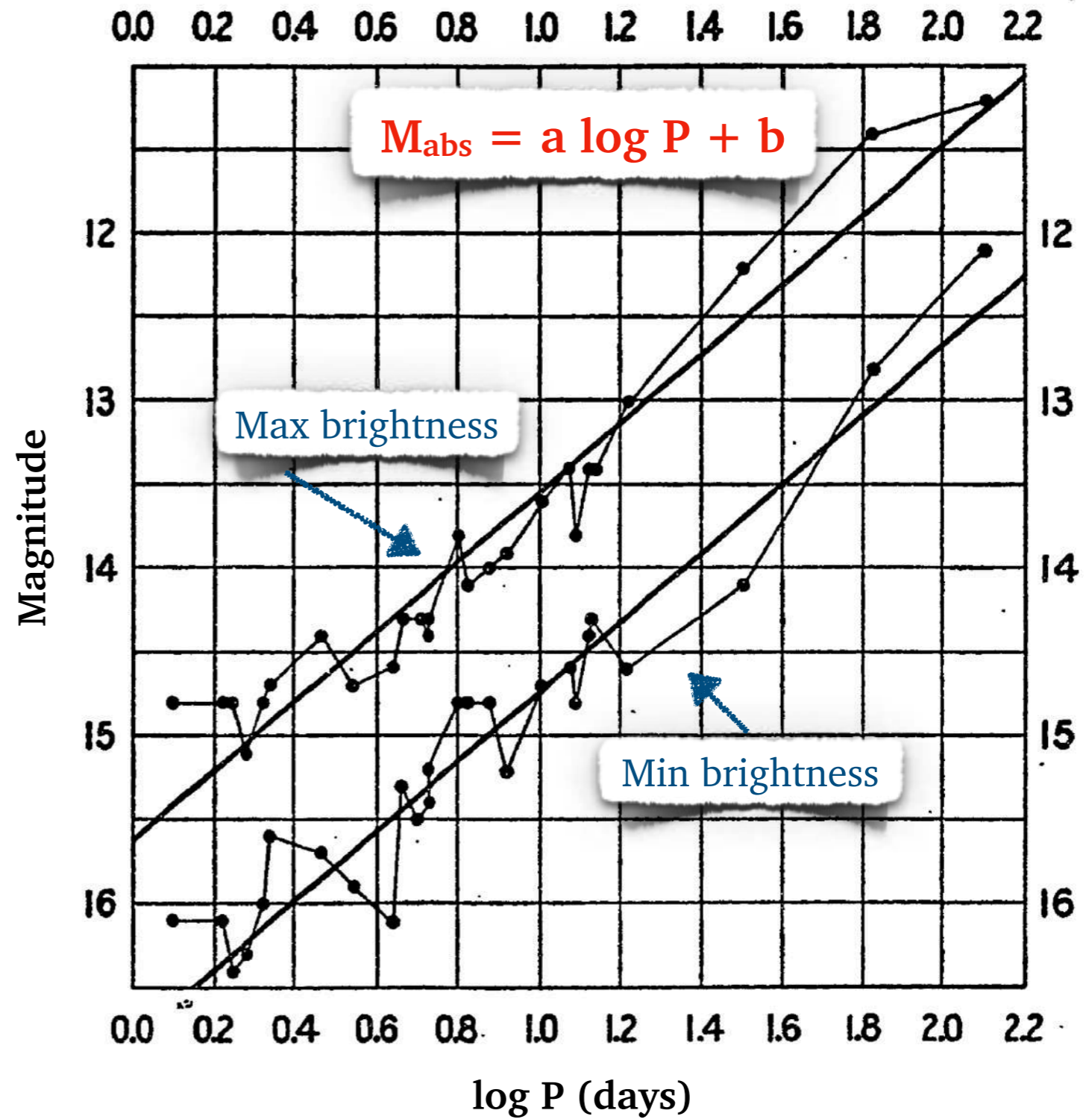


Tensions in Cosmology - Corfu, Greece - 10 September 2022

How to measure distances in astronomy ?



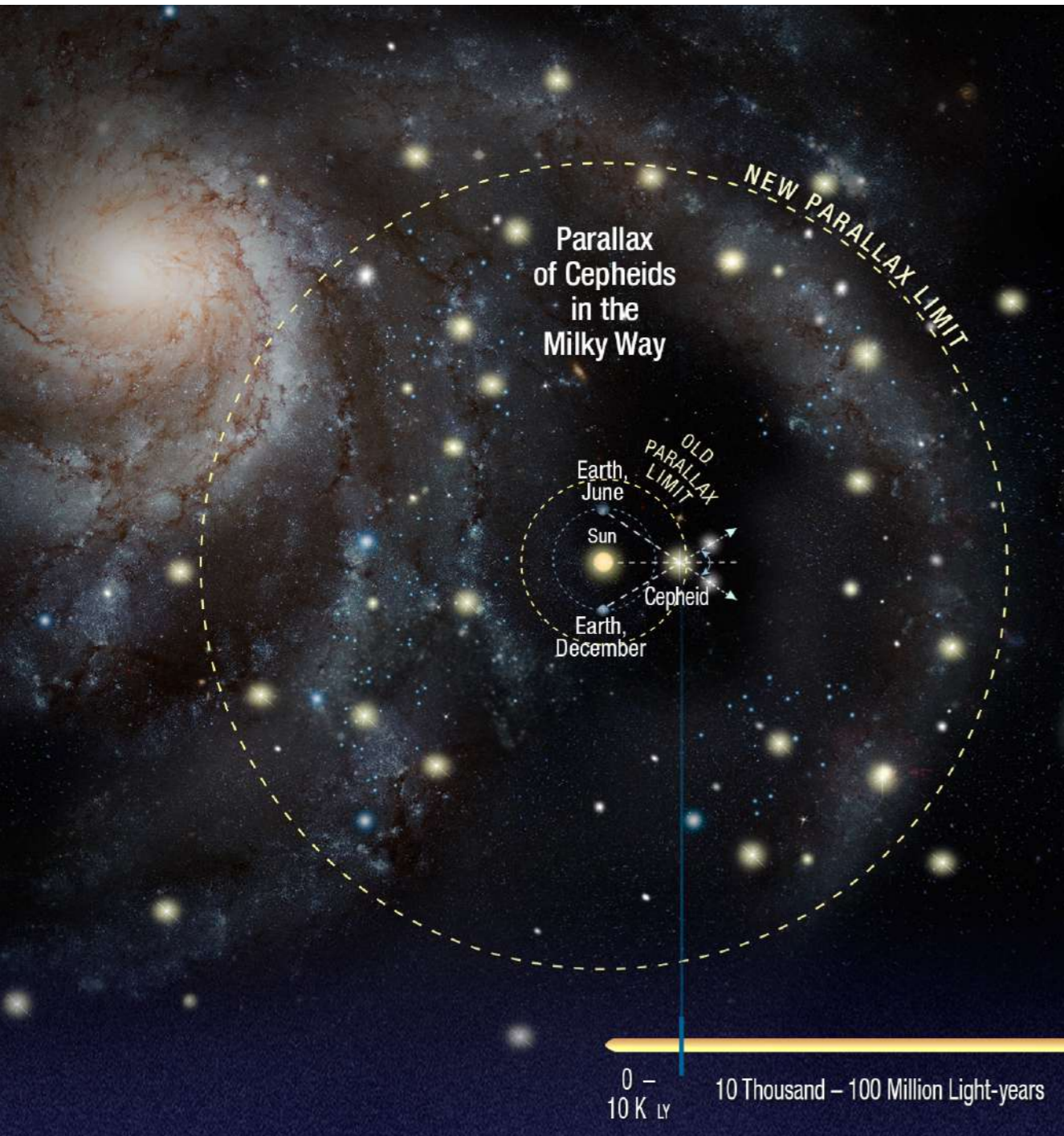
Henrietta Leavitt (1908)



First Period-Luminosity relation calibrated by Henrietta Leavitt in the SMC (Leavitt & Pickering 1912)

The distance scale

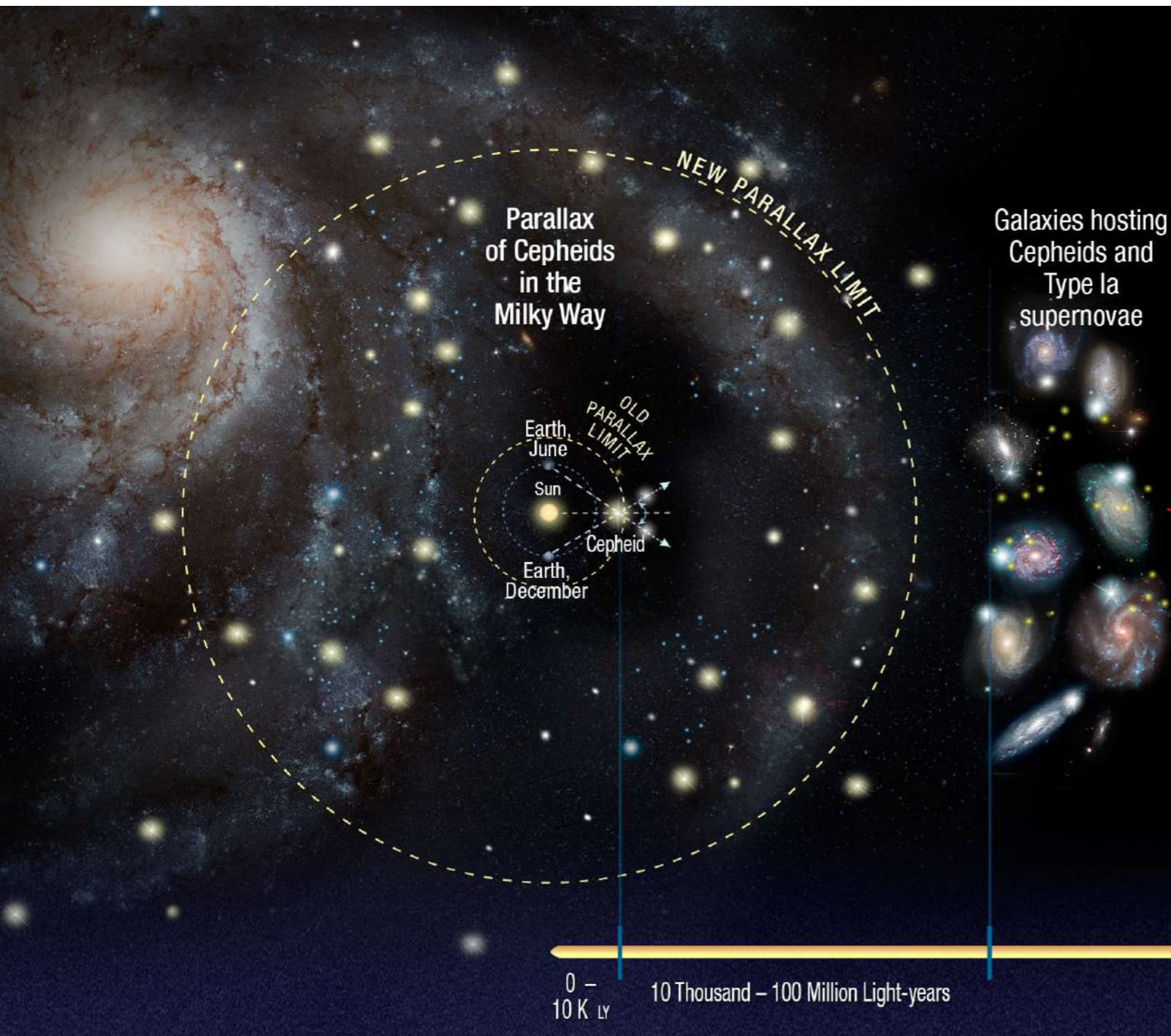
SHOES: 3 "anchors":
Milky Way + LMC + NGC 4258



The SHOES three rung distance ladder (A. Feild and A. Riess, STScI/JHU)

The distance scale

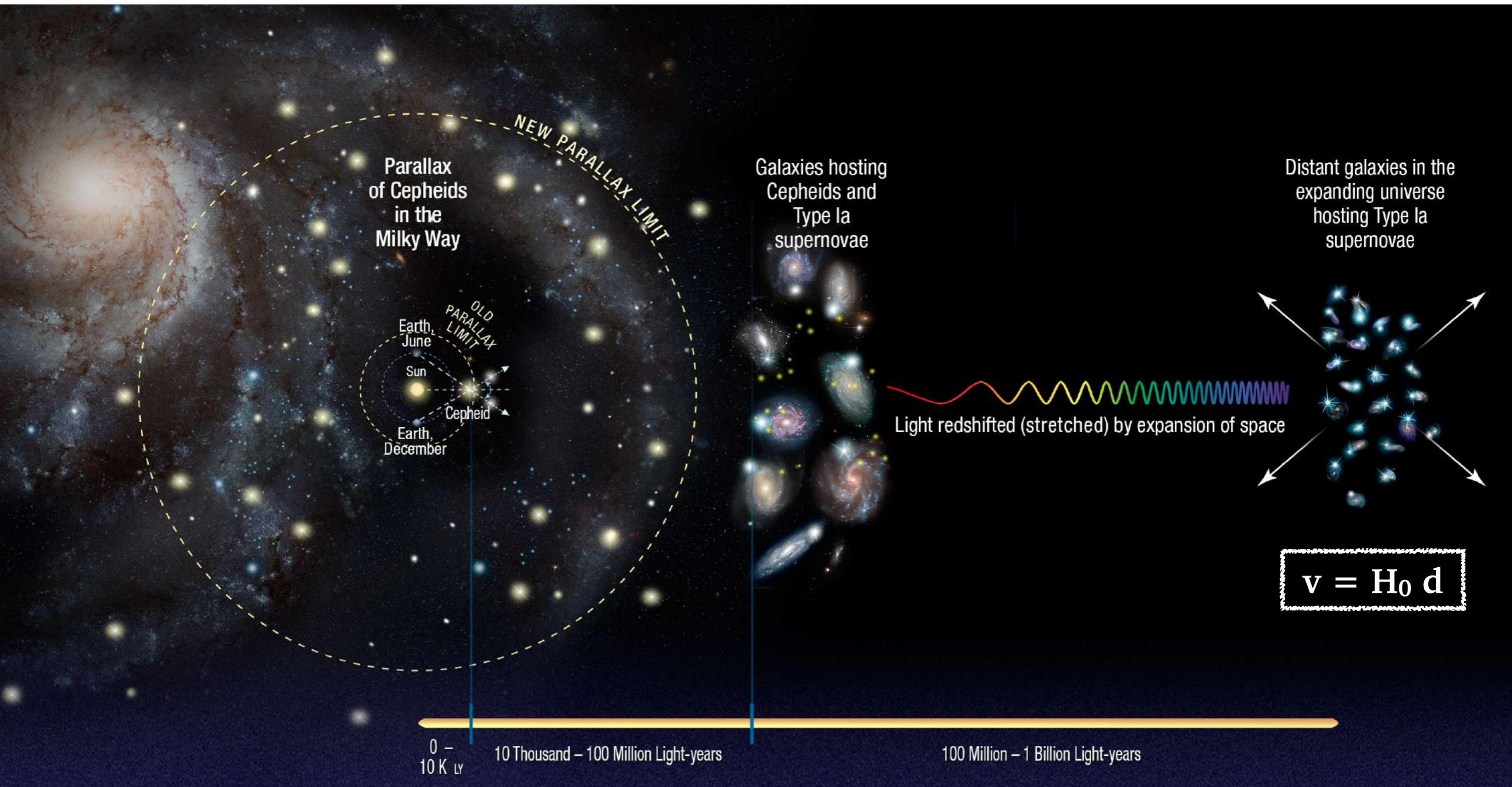
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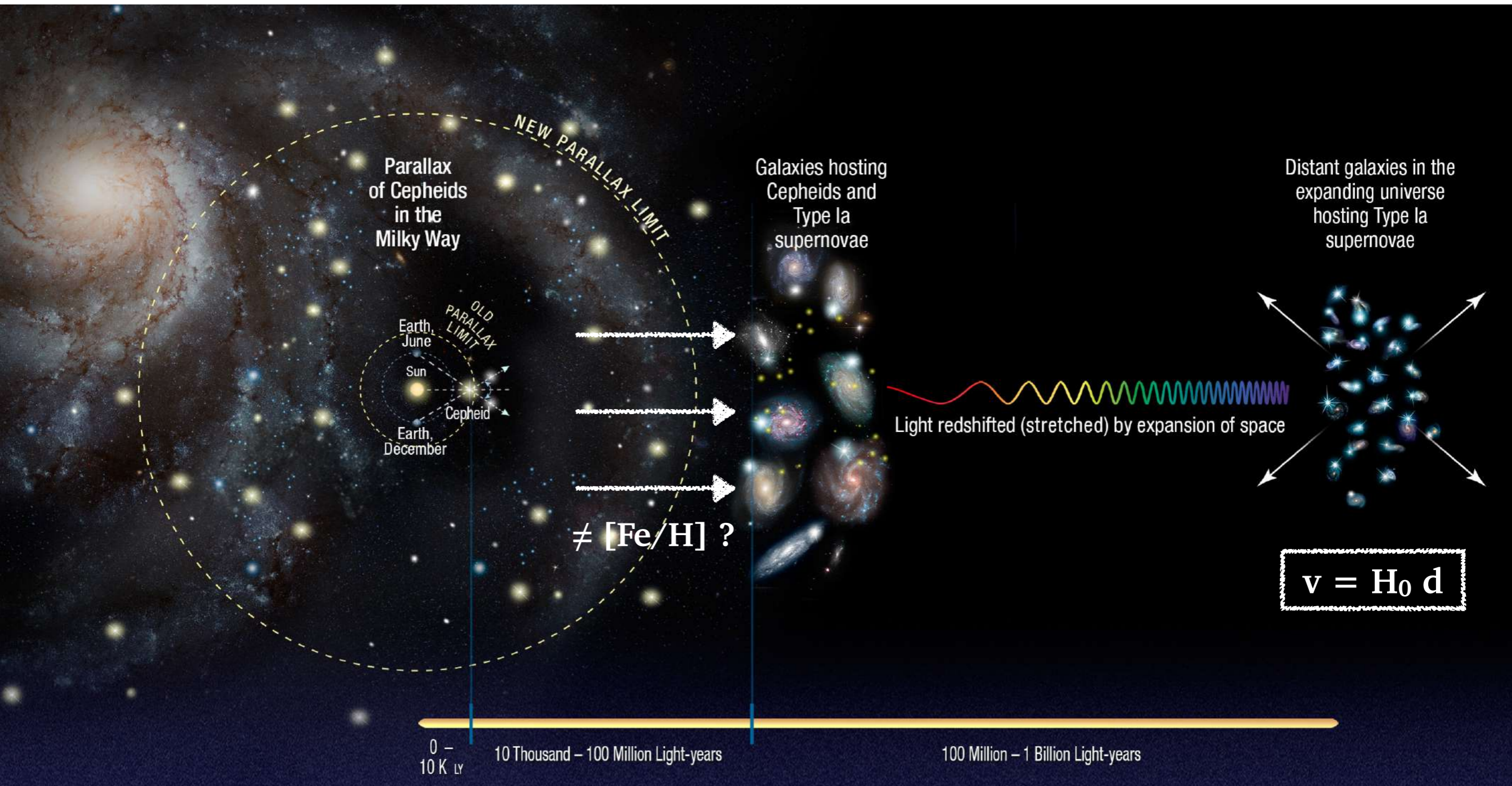


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$$M = a \log P + b + \gamma [\text{Fe}/\text{H}]$$



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The metallicity dependence

- ★ Early non-linear convecting models:
 $\gamma > 0$ (metal-rich Cepheids are fainter)

Bono et al. 1999
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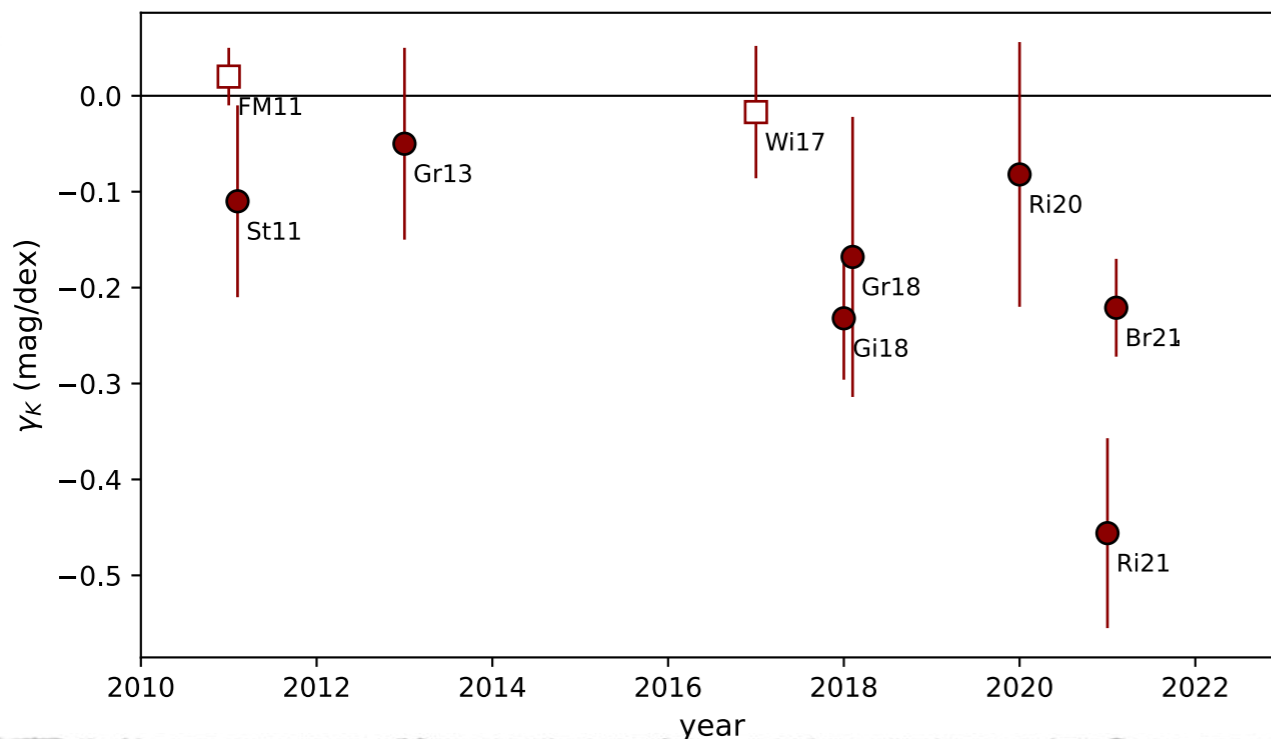
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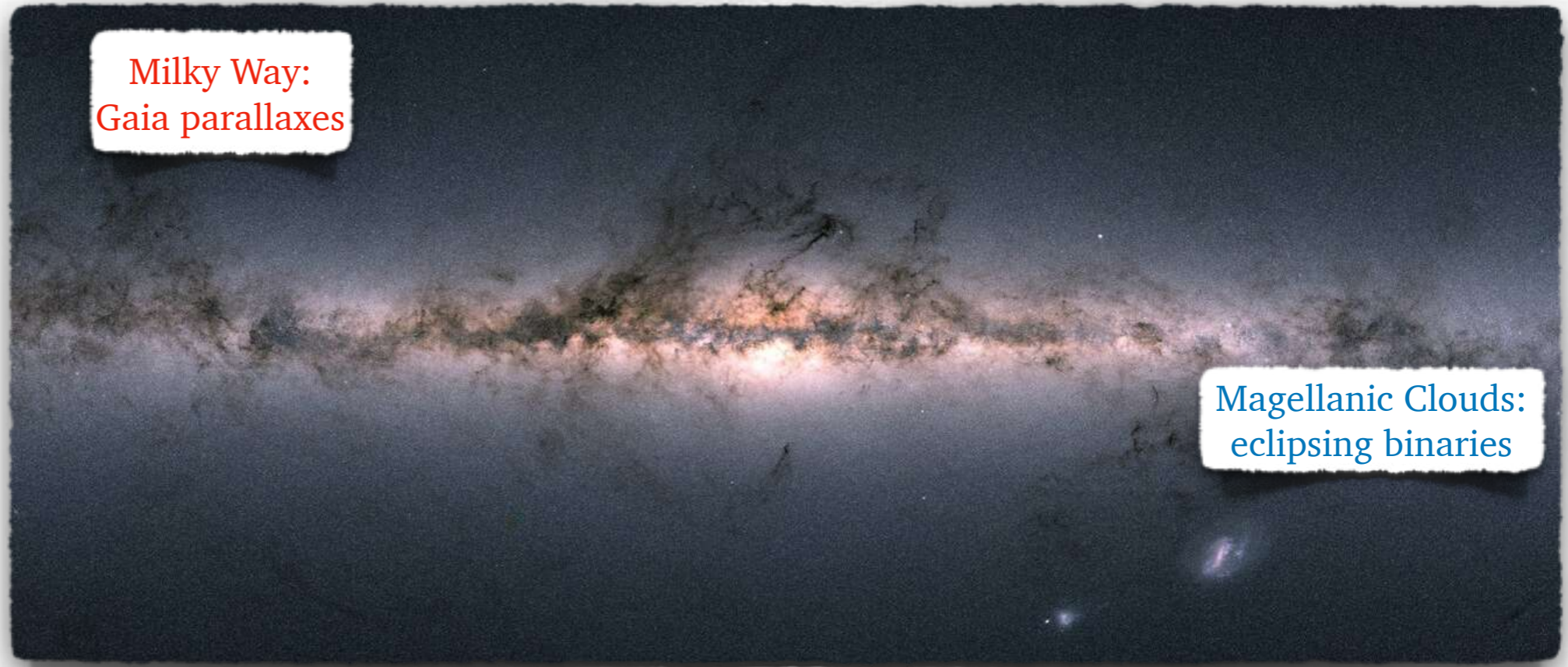
- ★ Main limitations:
 - inaccurate parallaxes
 - short metallicity range
 - elongated shape of the SMC

The metallicity dependence

Recent
improvements:

Milky Way:
Gaia parallaxes

Magellanic Clouds:
eclipsing binaries

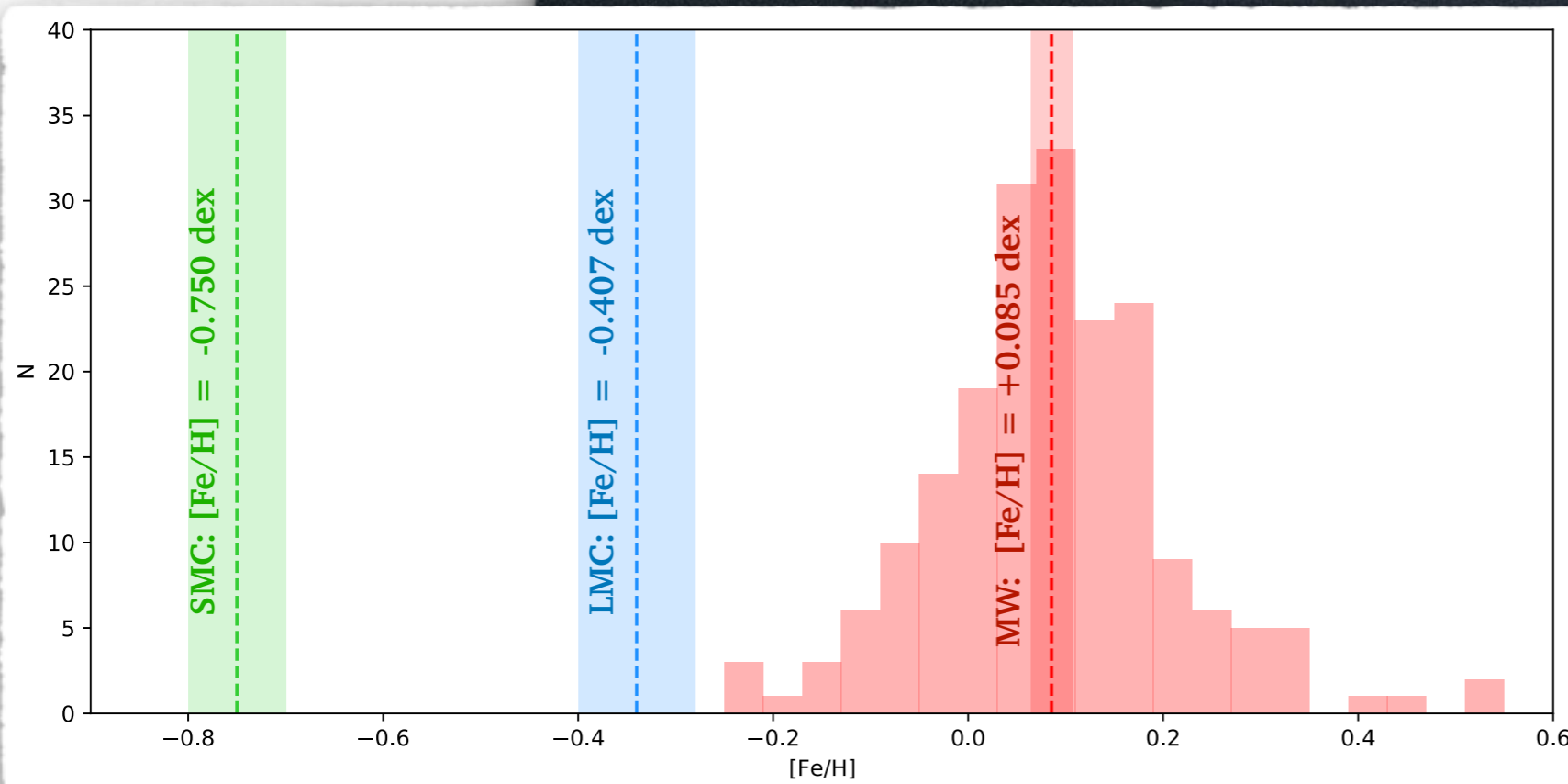


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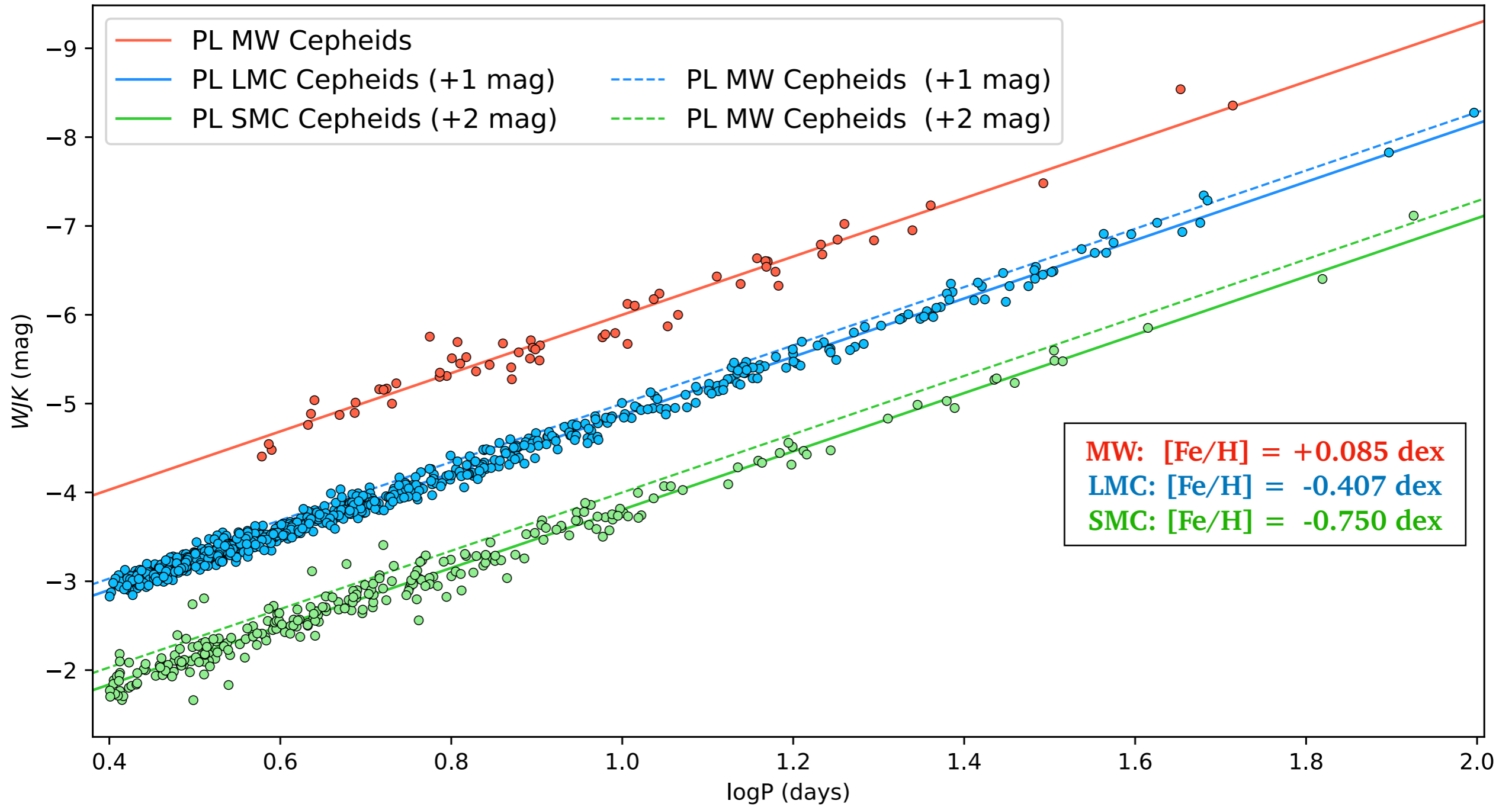
Most precise distances available
and largest metallicity range

+ well covered light curves

+ correction for reddening
($R_V = 3.1 \pm 0.1$)

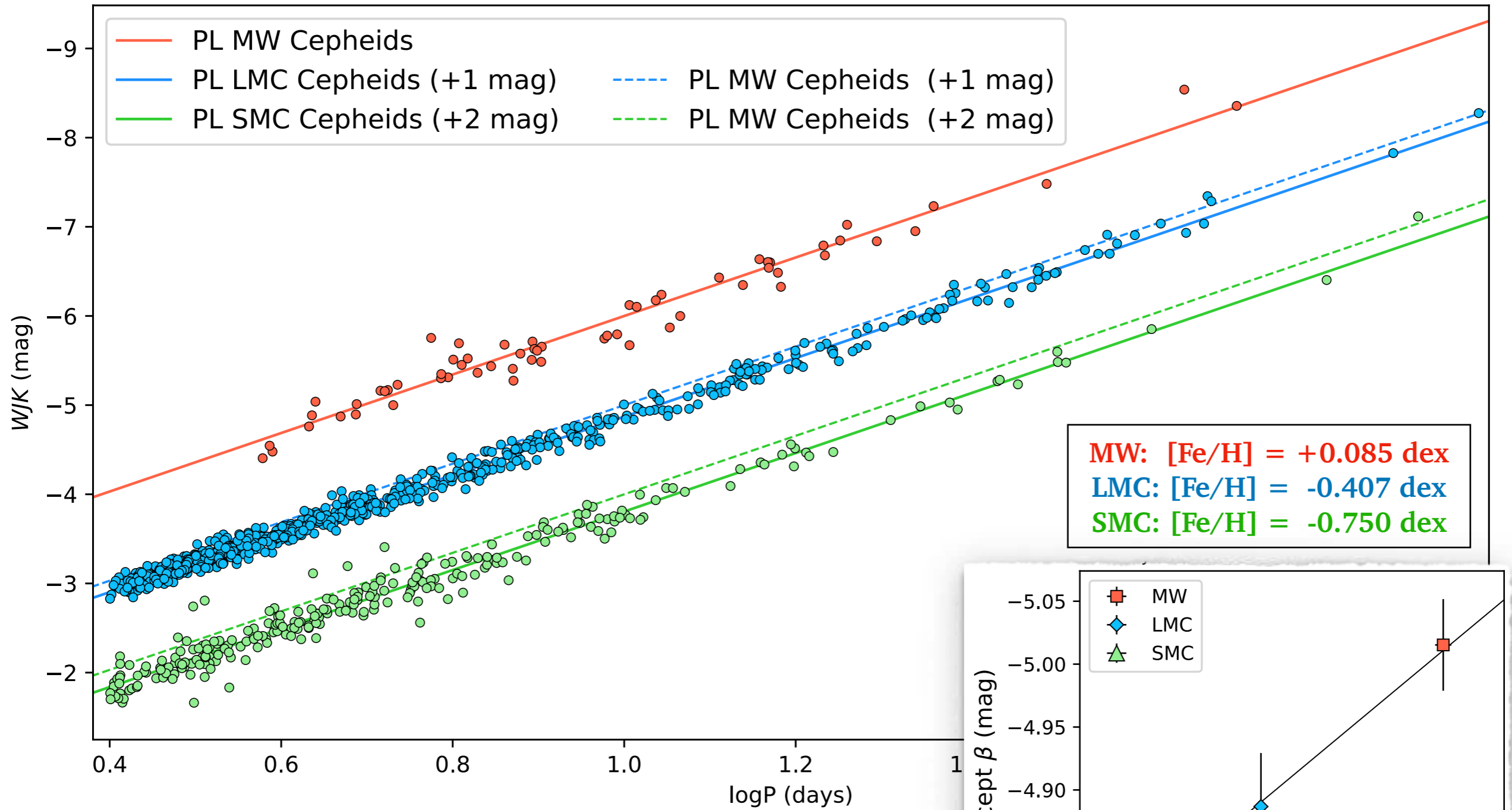
Metallicity of Milky Way and Magellanic Cloud Cepheids

The metallicity dependence

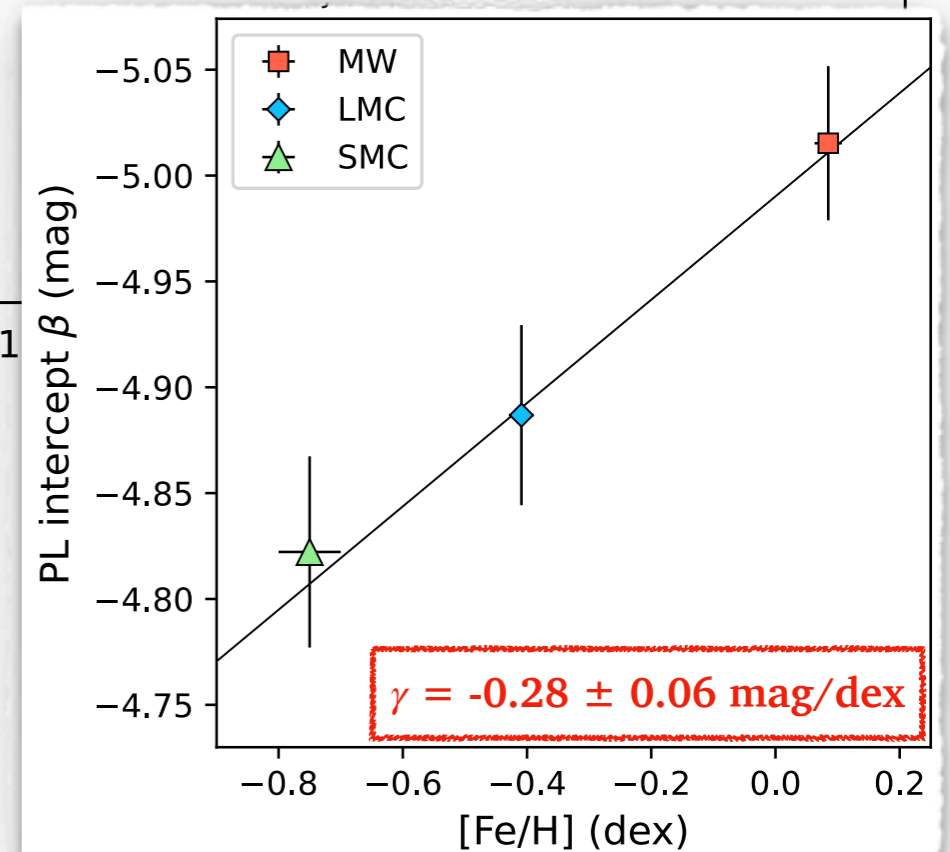


*Cepheid Period-Luminosity (P-L) relation
in three galaxies of different chemical composition*

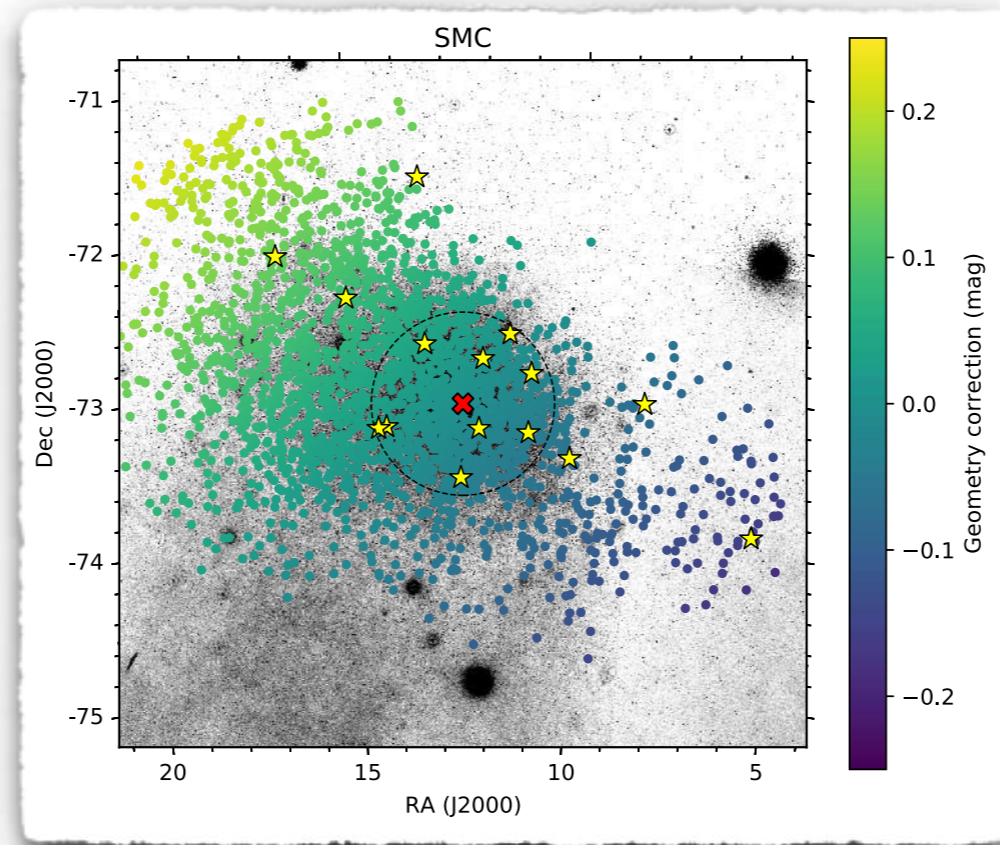
The metallicity dependence



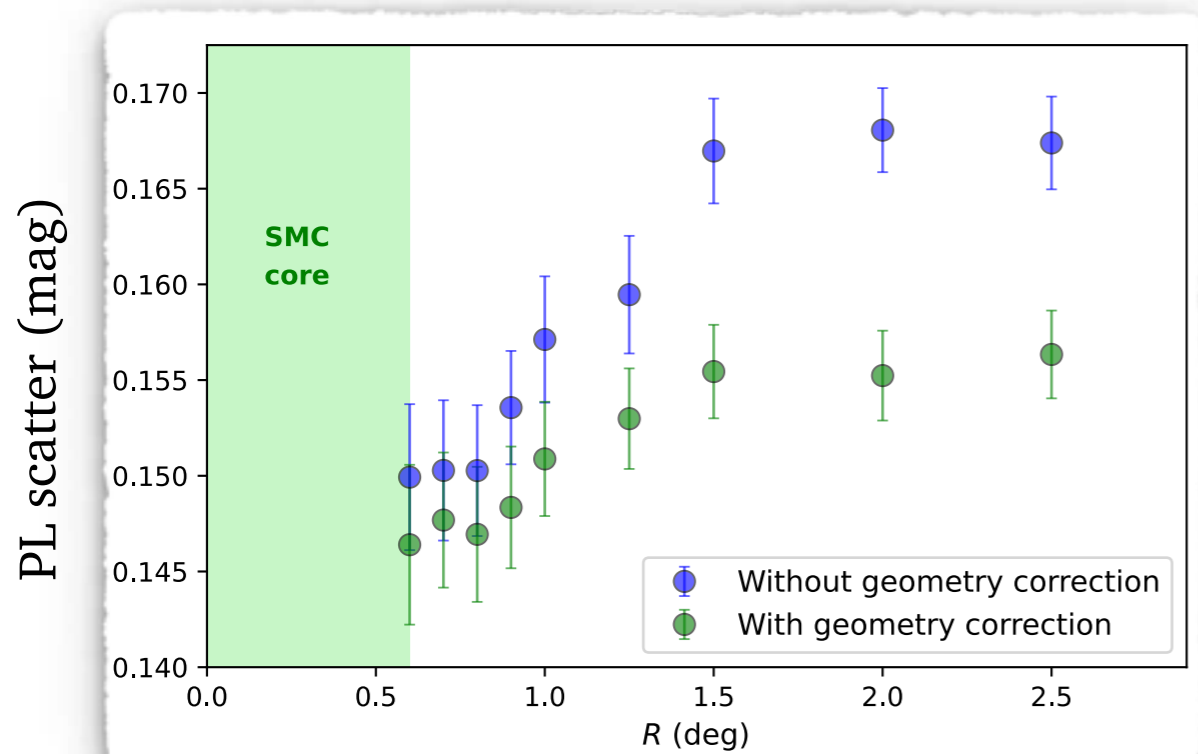
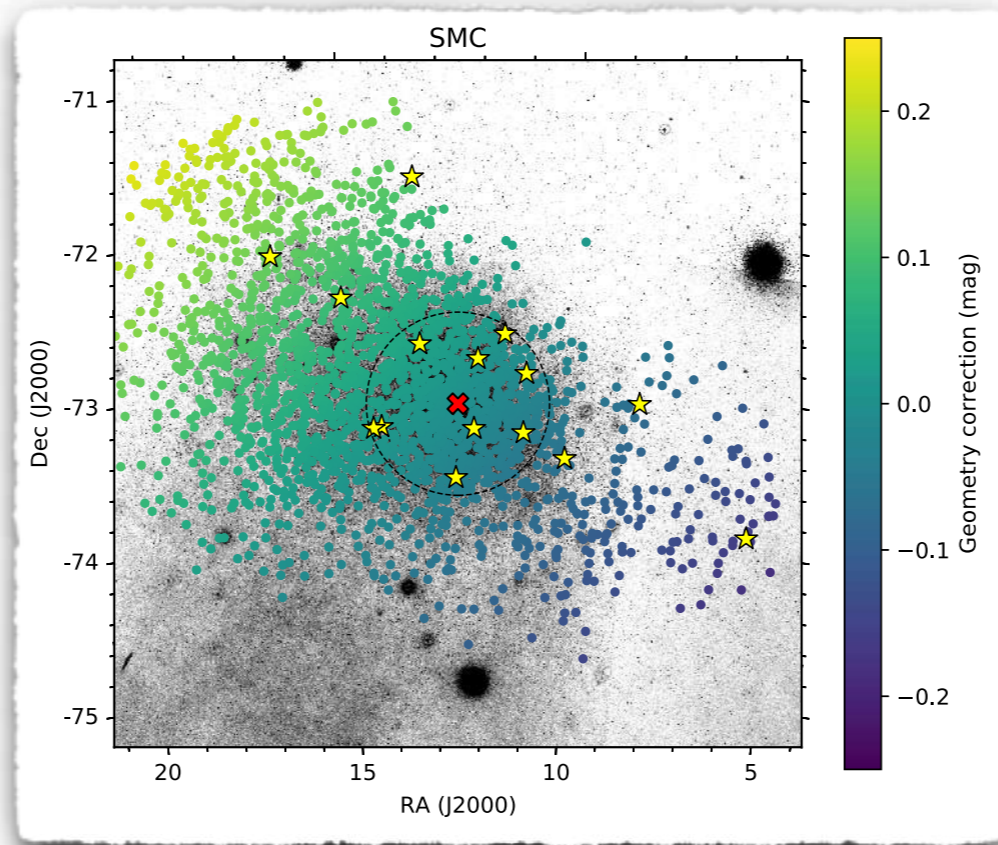
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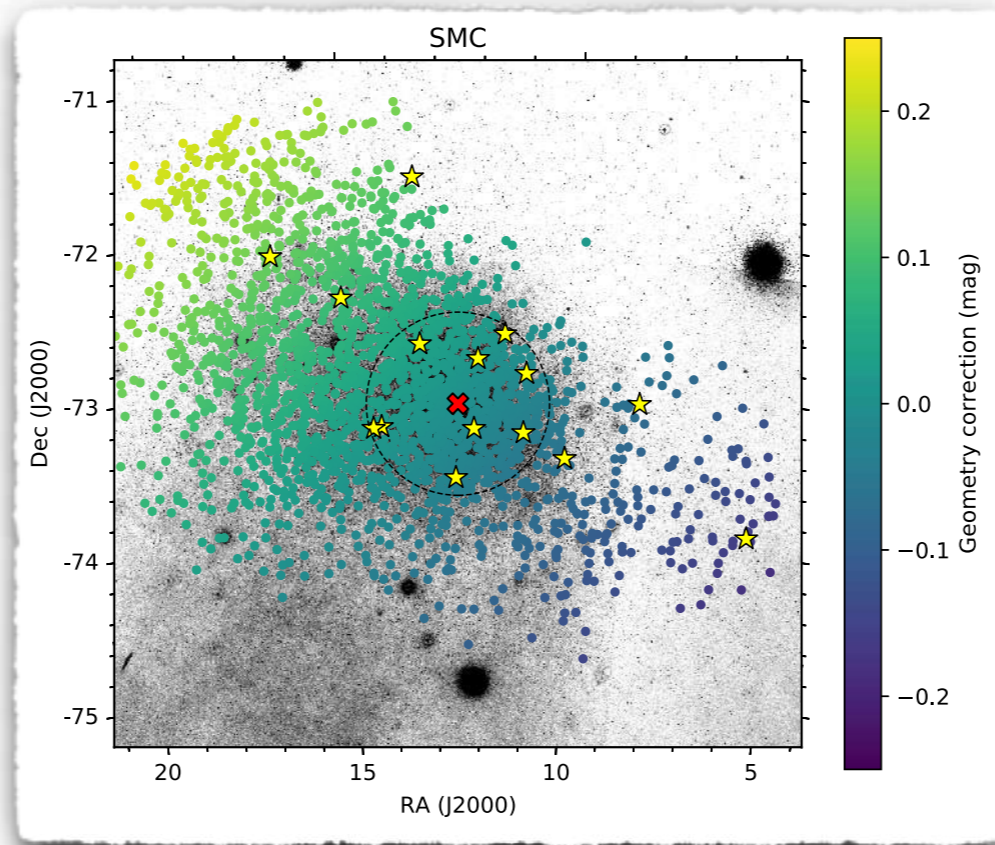
The shape of the Small Magellanic Cloud



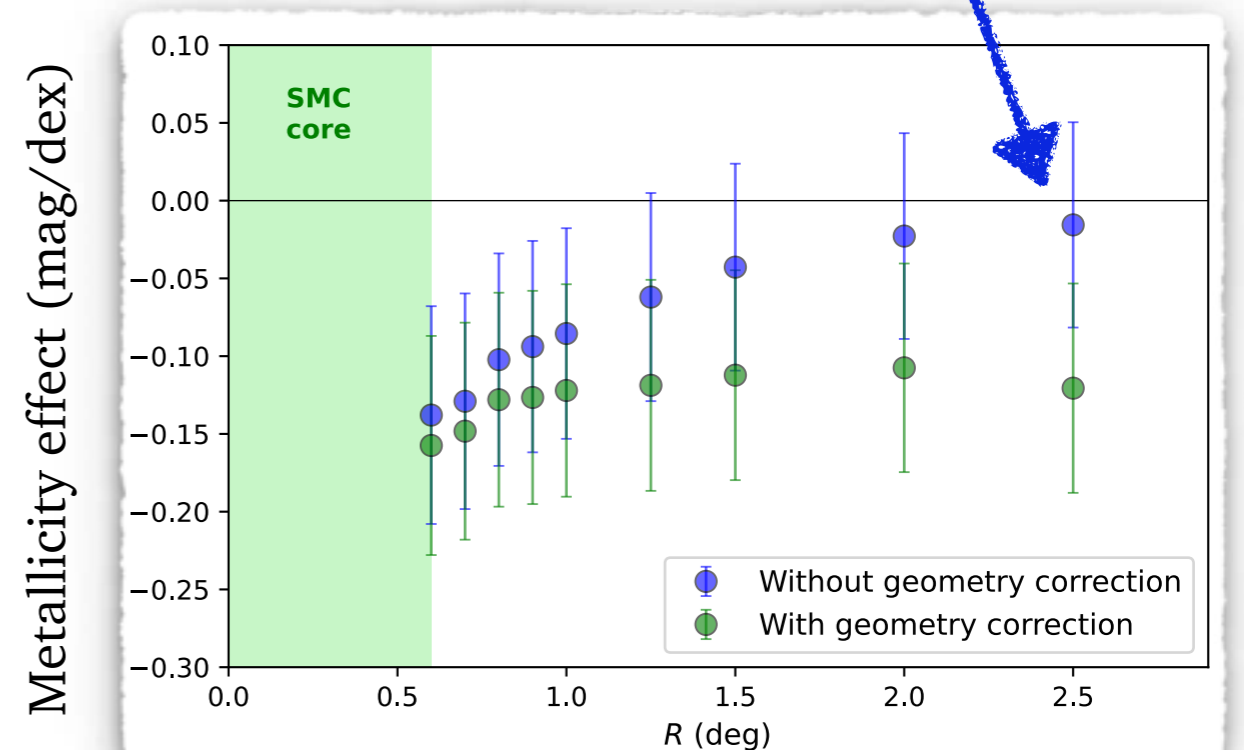
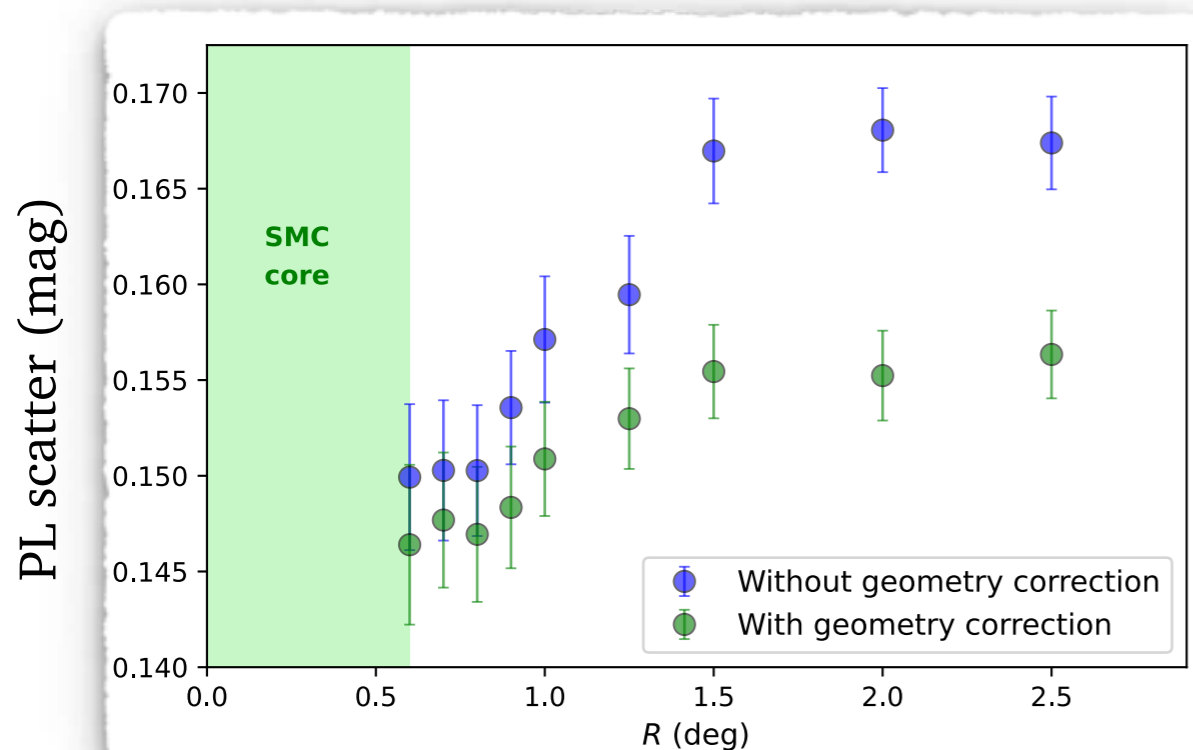
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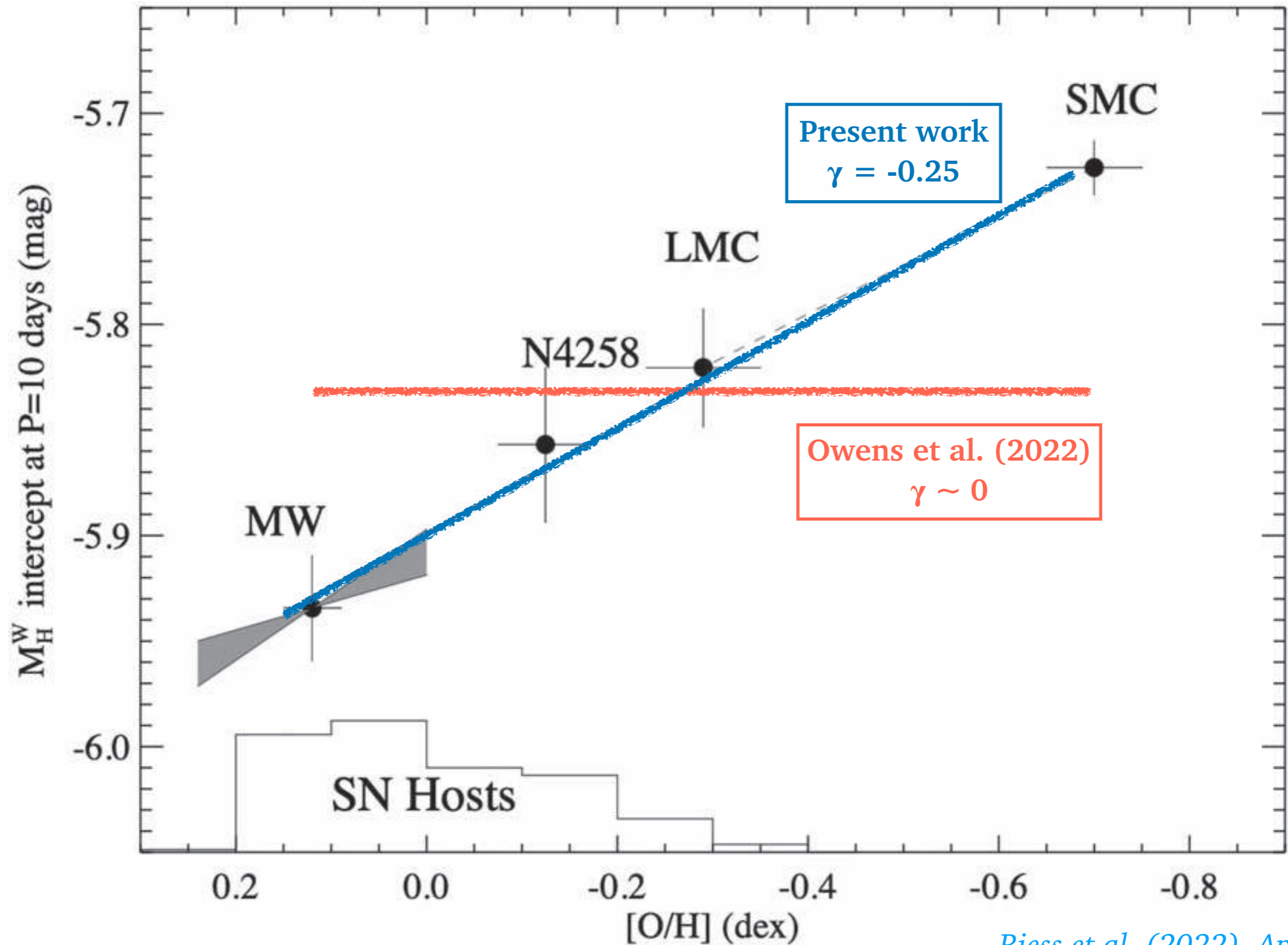
The shape of the Small Magellanic Cloud



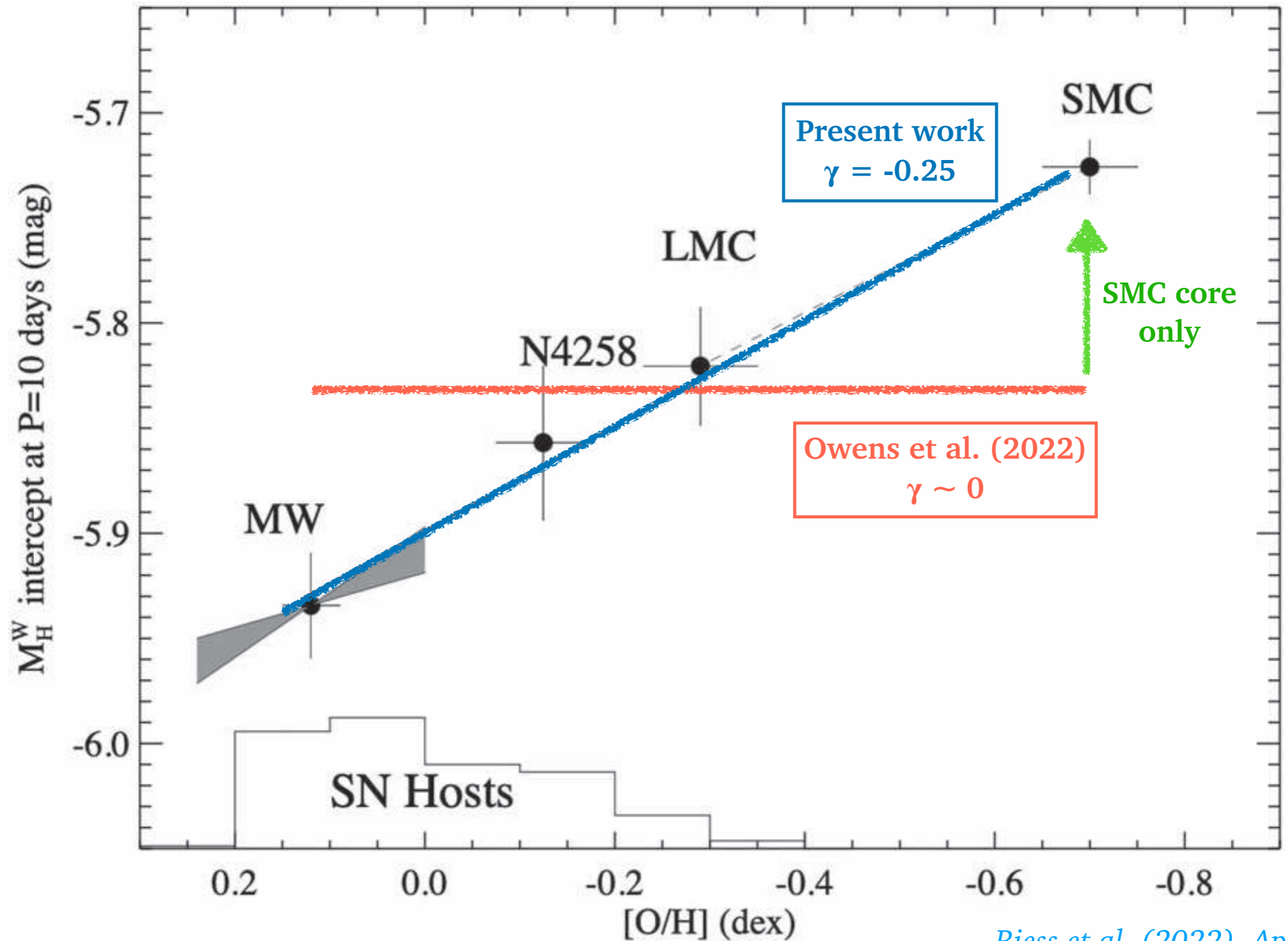
Wielgórski et al. (2017)



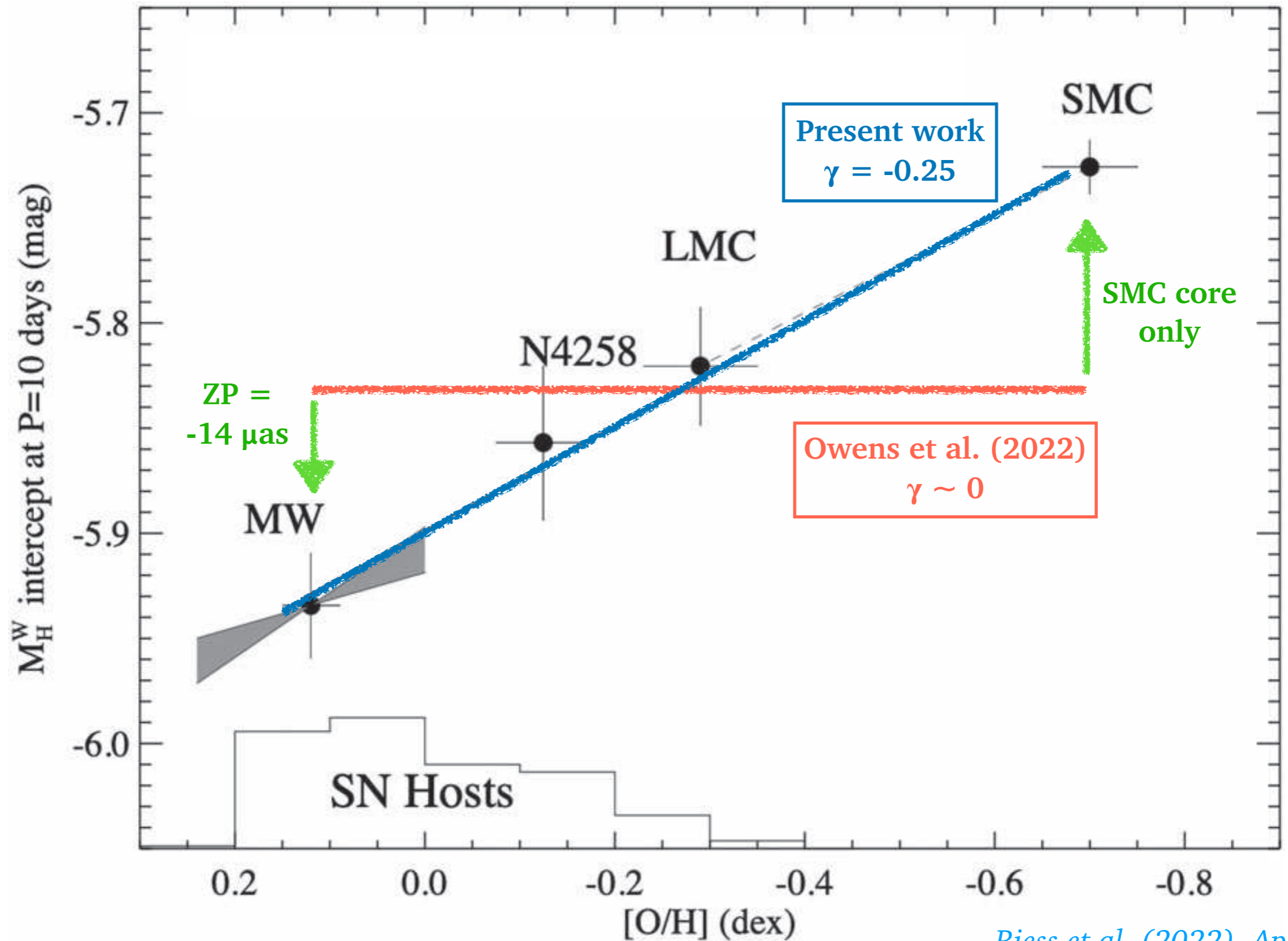
Dependence with Gaia DR3 parallax offset



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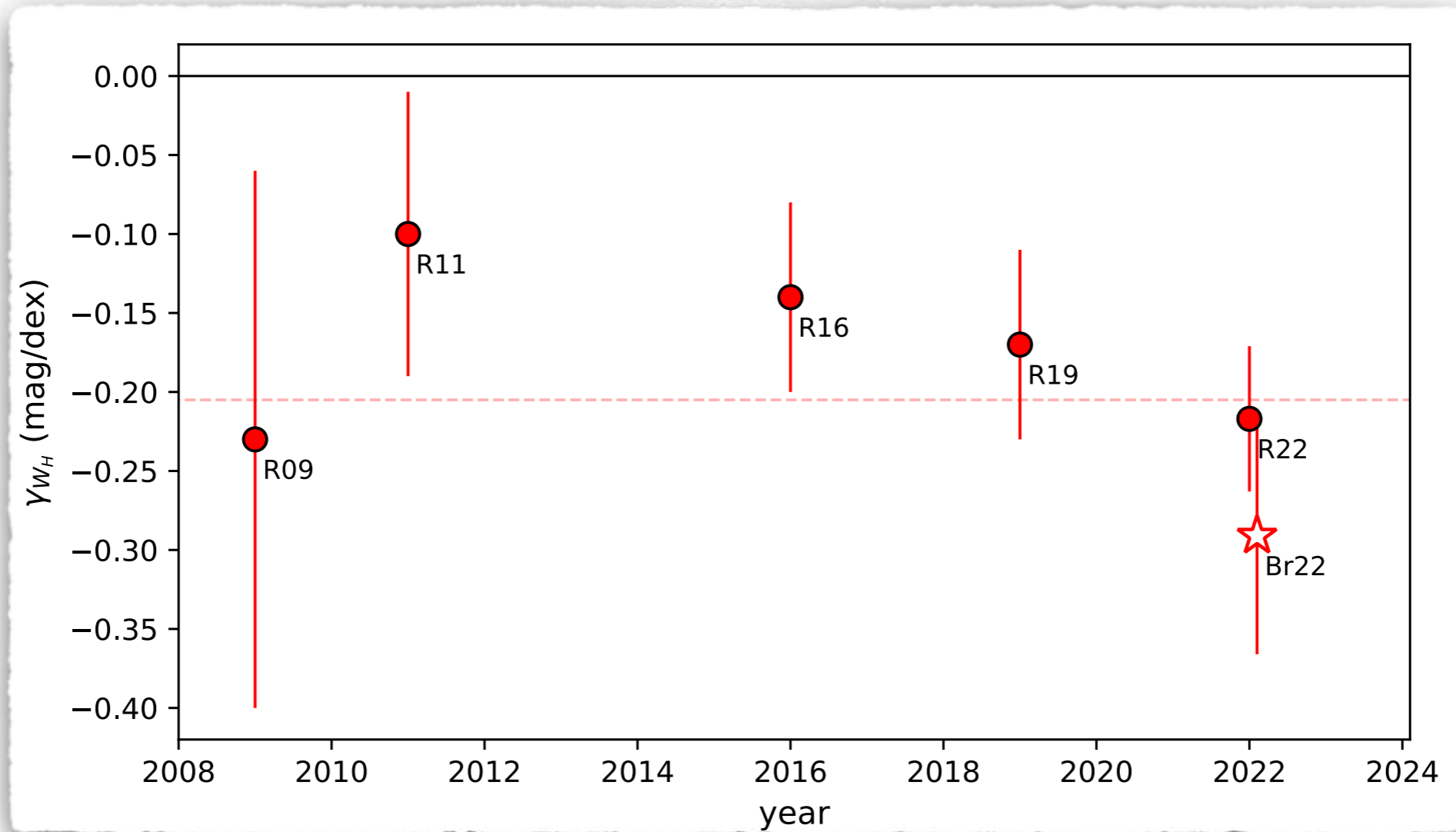


Dependence with Gaia DR3 parallax offset



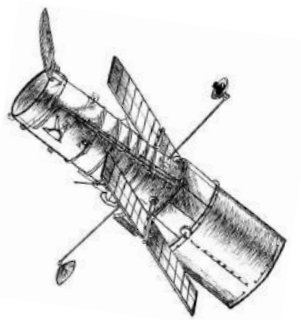
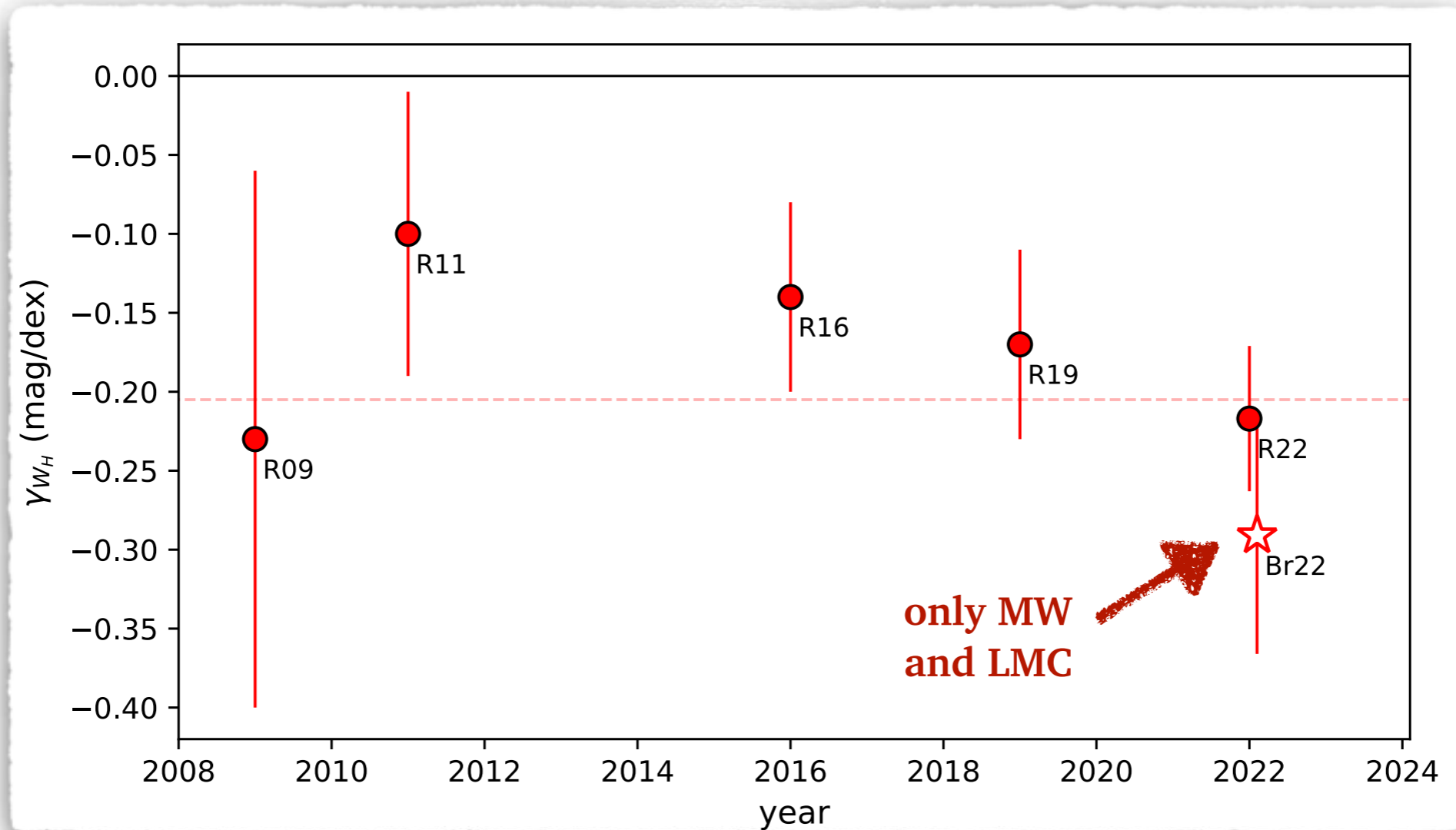
The metallicity dependence

★ In the reddening-free Wesenheit magnitude (HST photometry) used by the SH0ES team:



The metallicity dependence

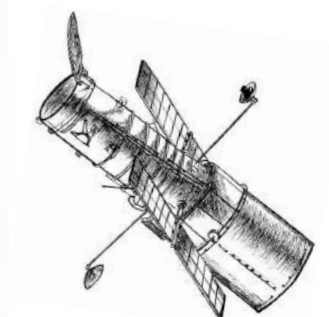
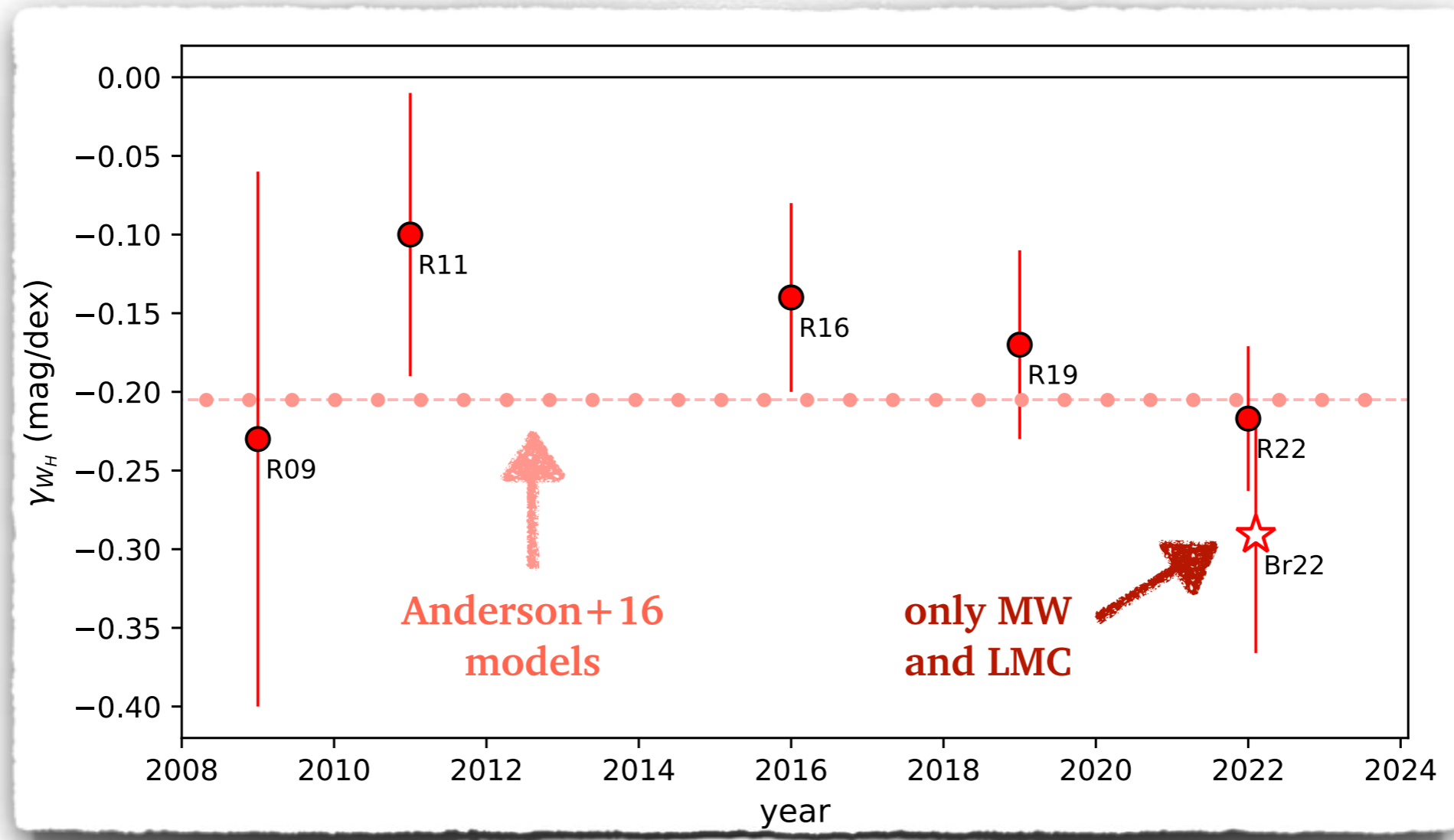
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+ SMC soon!

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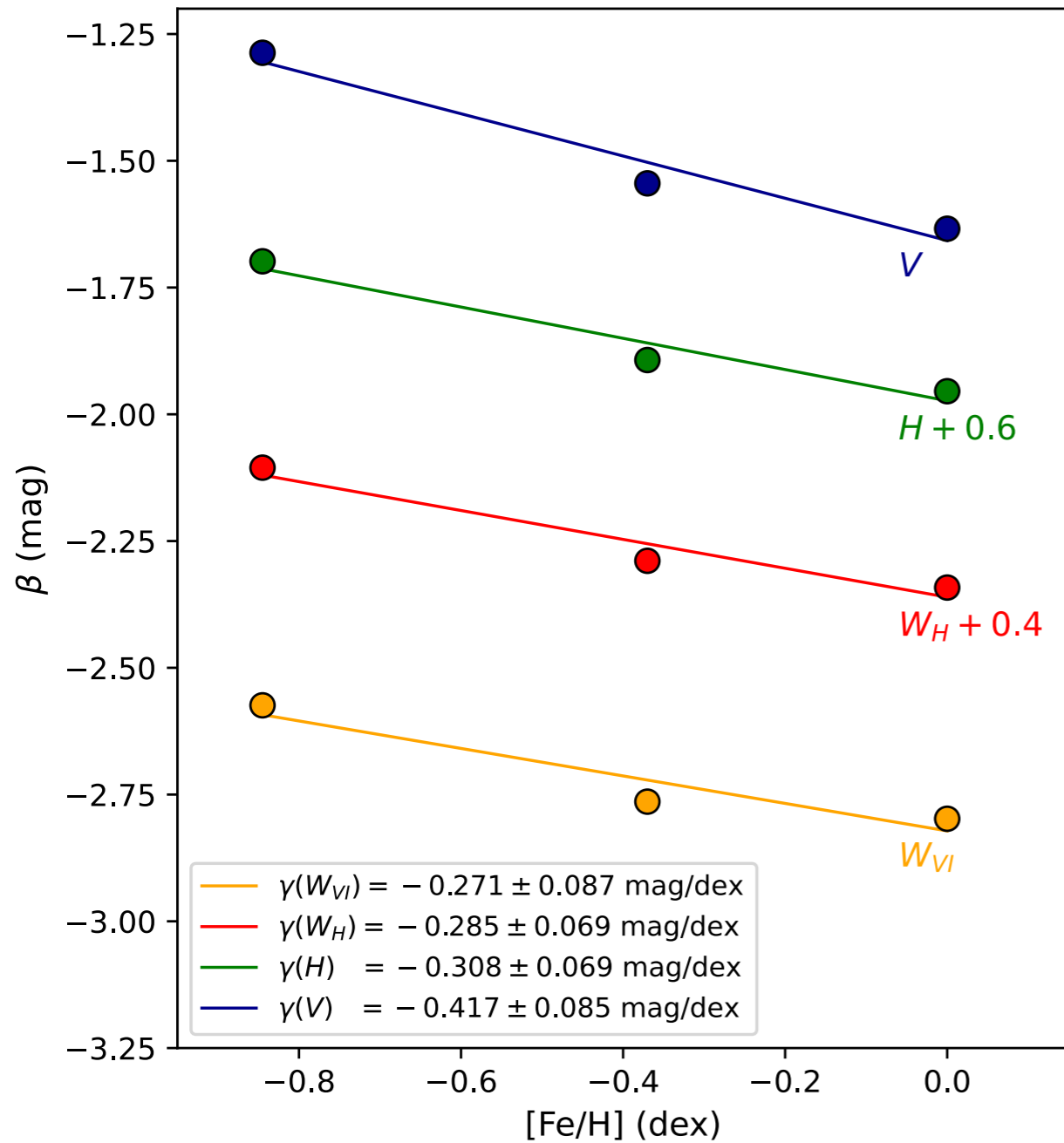
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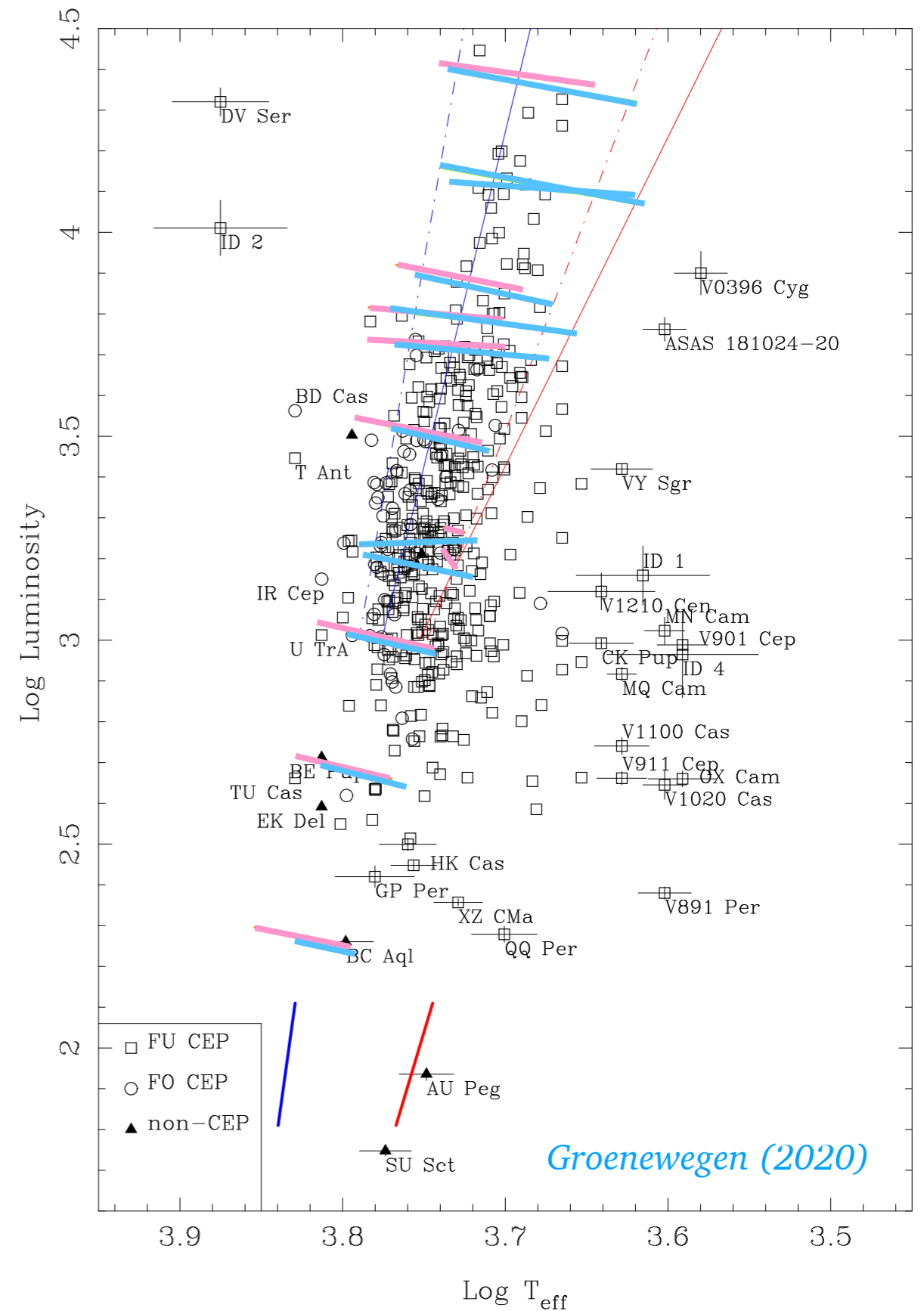
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→ good agreement with SH0ES results and with stellar models.

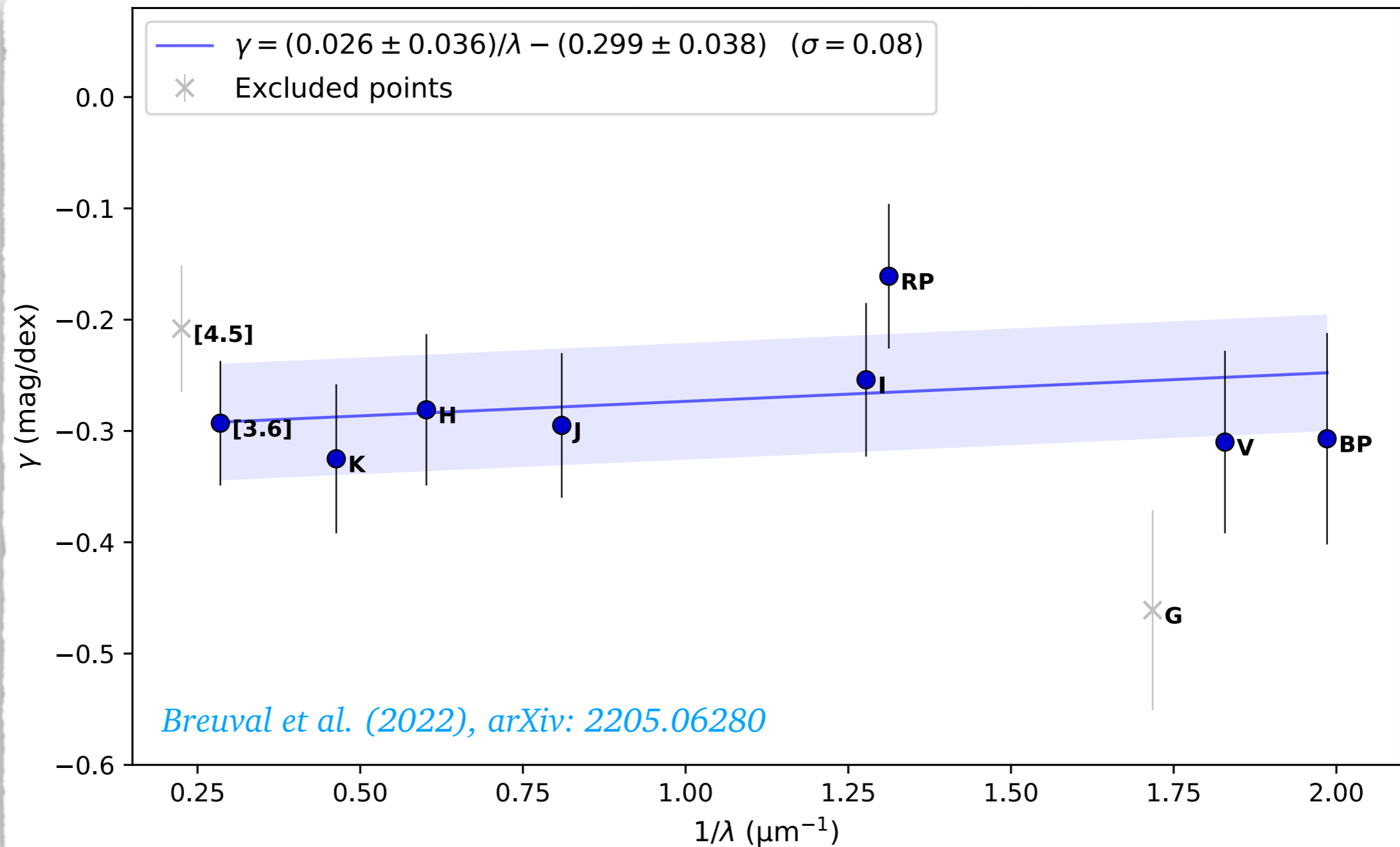
Theory vs Observations today



→ Geneva stellar models fit our observational data very well



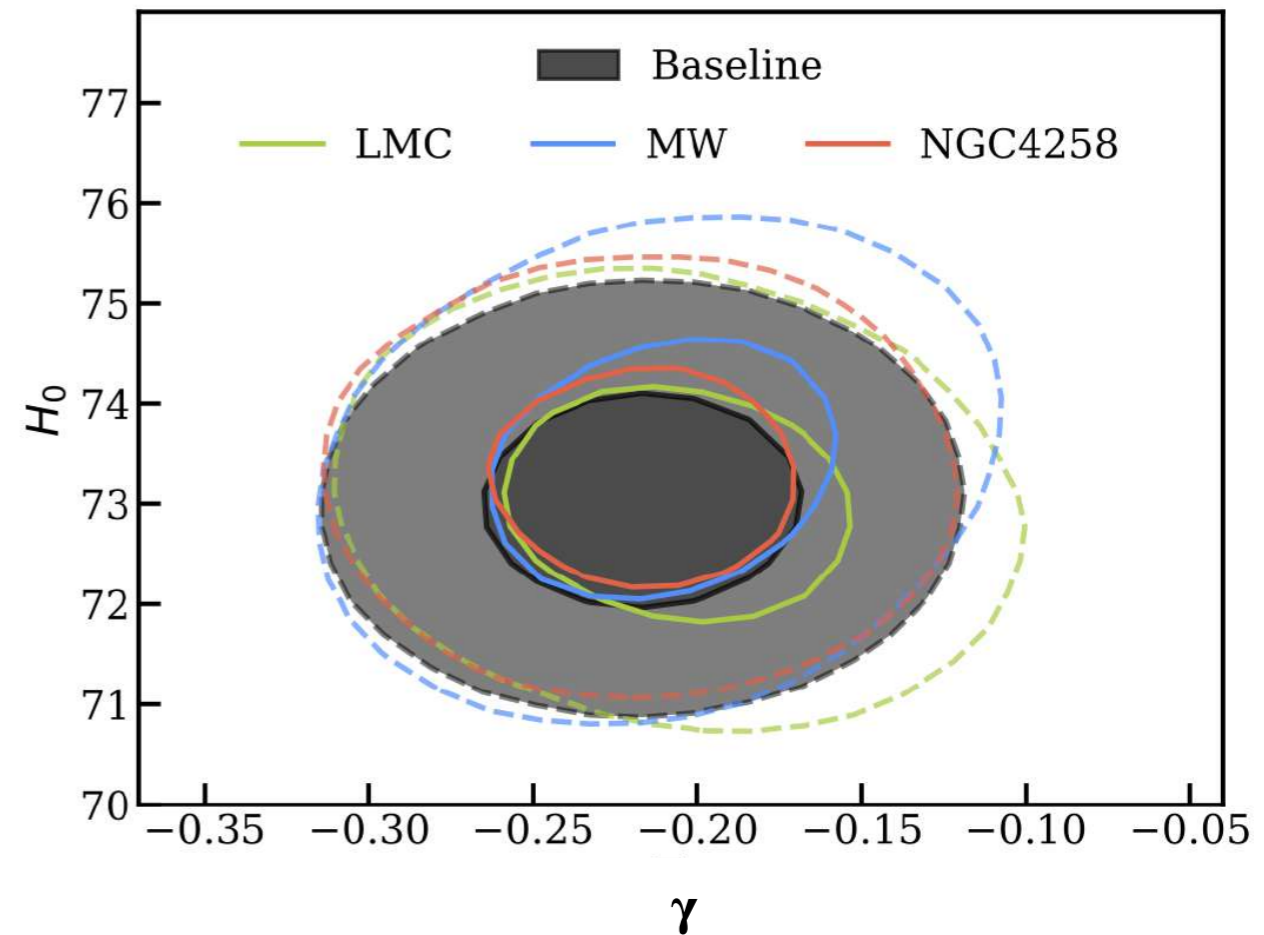
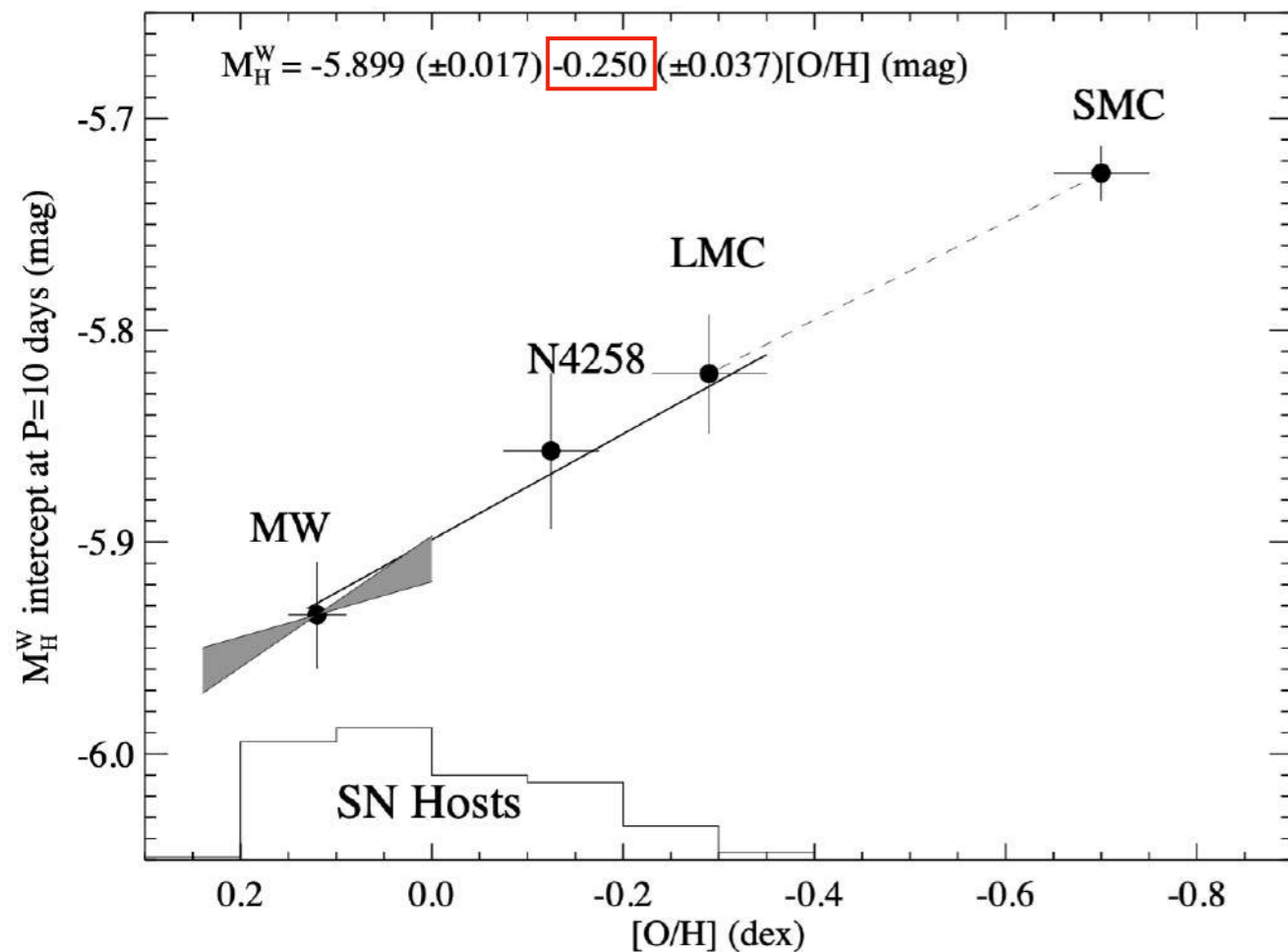
The metallicity dependence



- 10 filters (*Gaia*, *Spitzer*, ground NIR and optical) + 5 reddening-free Wesenheit magnitudes
- No evidence for a wavelength dependence

The metallicity dependence: implications for the Hubble constant

- ★ No correlation between H_0 and the metallicity term



- ★ Overall same metallicity between anchors and Cepheids in host galaxies
- ★ Need to account for this term to make anchors consistent (we fit simultaneously anchors that have a different metallicity)

Summary

- ★ The calibration of the Cepheid metallicity effect has significantly improved over the last few years.
- ★ Most precise distances available to calibrate the PL relation in 3 different galaxies: Gaia DR3 in MW and eclipsing binaries in the Magellanic Clouds
- ★ Largest metallicity range (from metal-rich MW to metal-poor SMC)
- ★ Best data set (limit systematics: avoid to combine too many different catalogs, full light curves when possible, large wavelength coverage from optical to mid-IR)
- ★ Geometry correction in the Magellanic Clouds
- ★ No evidence for a dependence with wavelength
- ★ Soon: more precise metallicities in the SMC, together with HST photometry

 **Breuval, L. et al., 2022, ArXiv: 2205.06280**

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