The Cepheid period-luminosity relation from Gaia DR2 parallaxes

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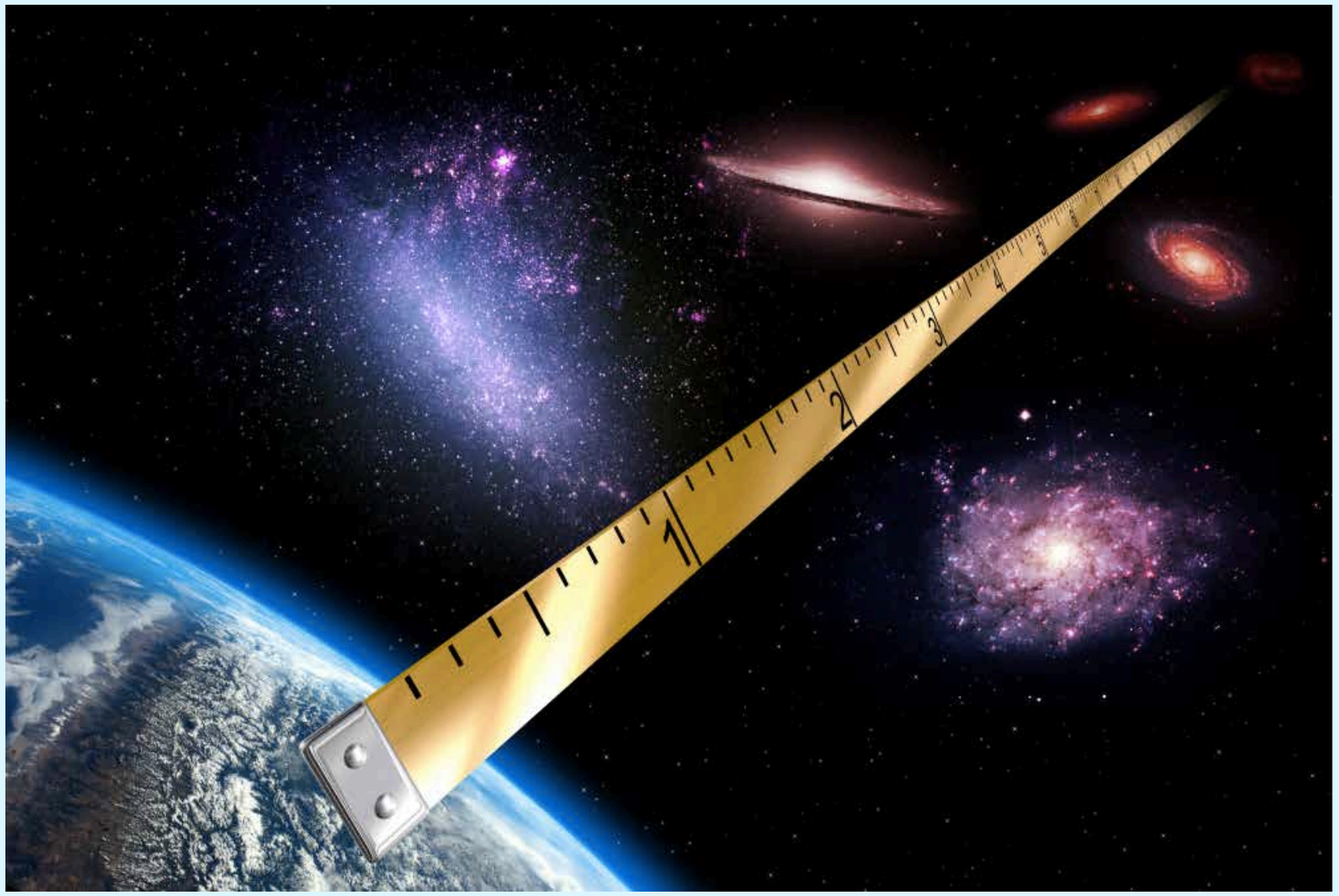
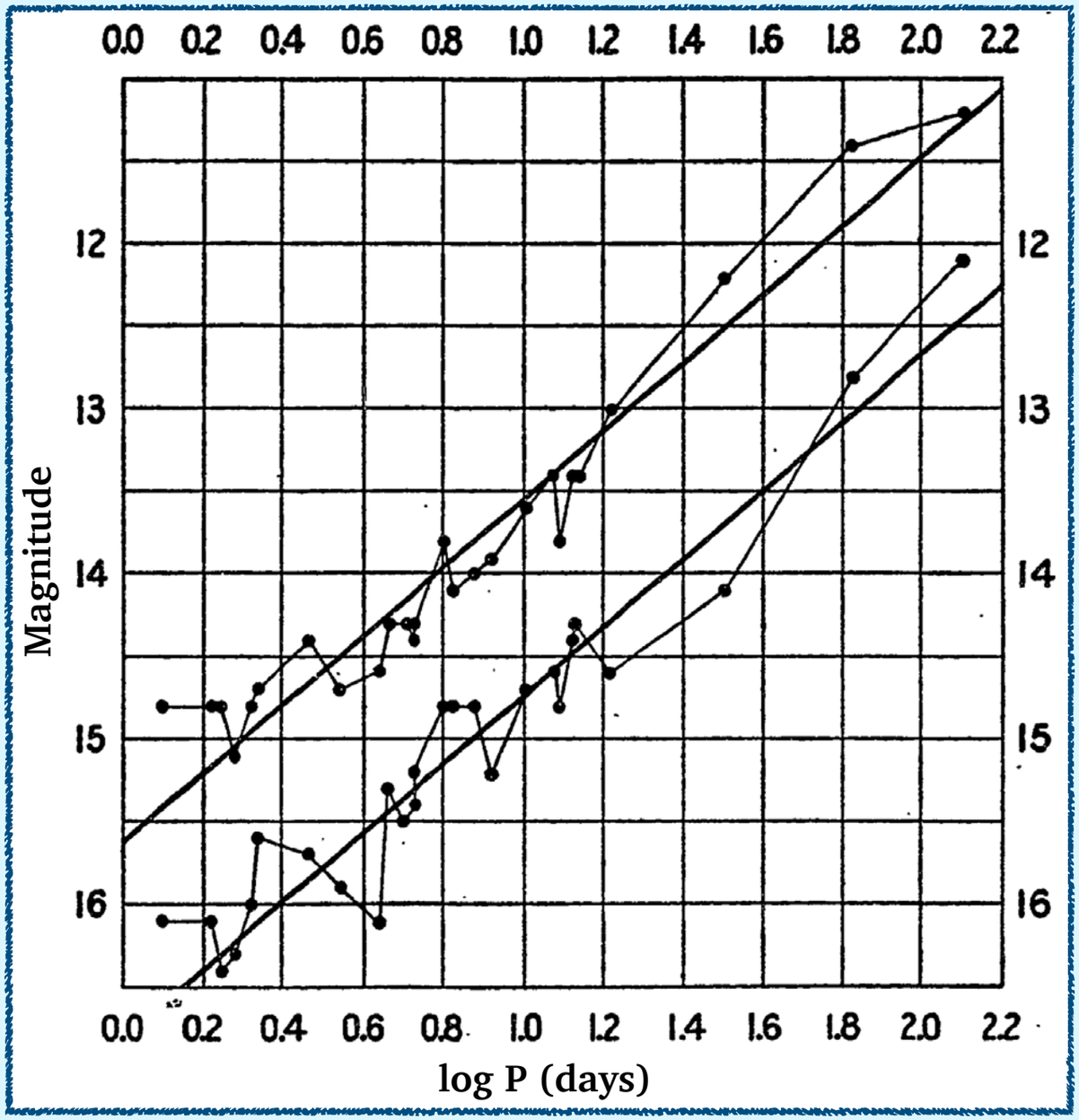
1. Measuring distances in the Universe



Henrietta Leavitt (1908)

Henrietta Leavitt discovered that the brightest Cepheids have the longest periods !

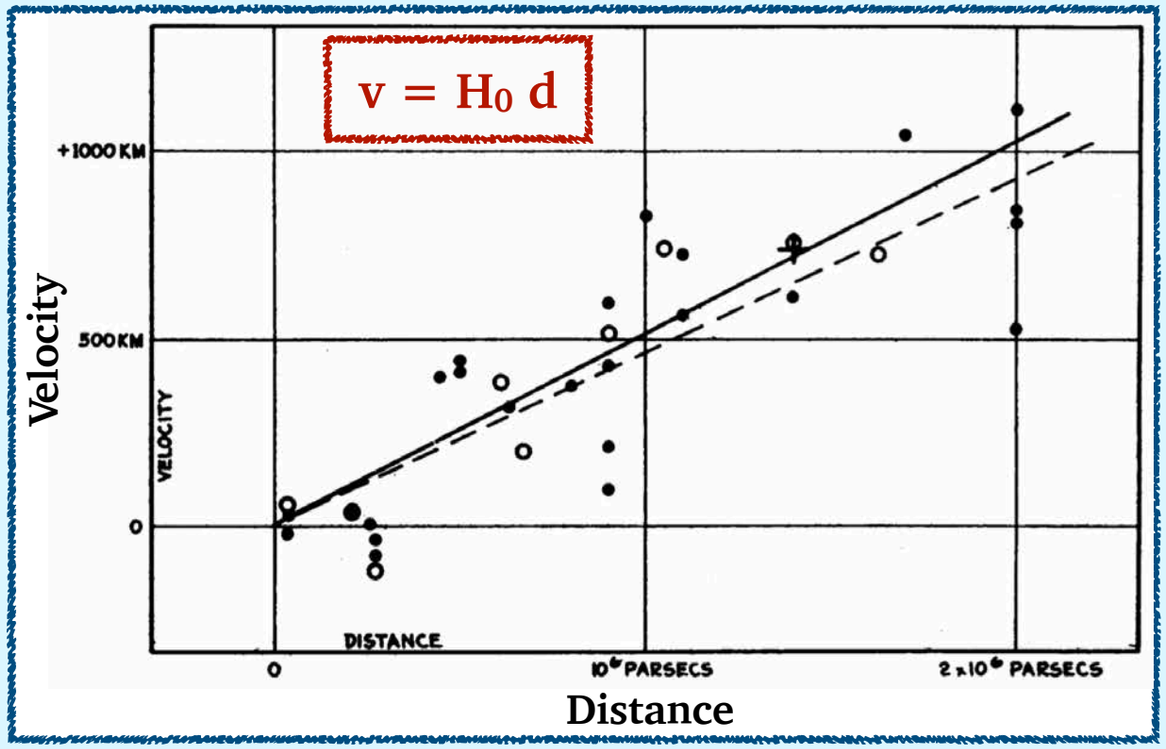
$$M = a \log P + b$$



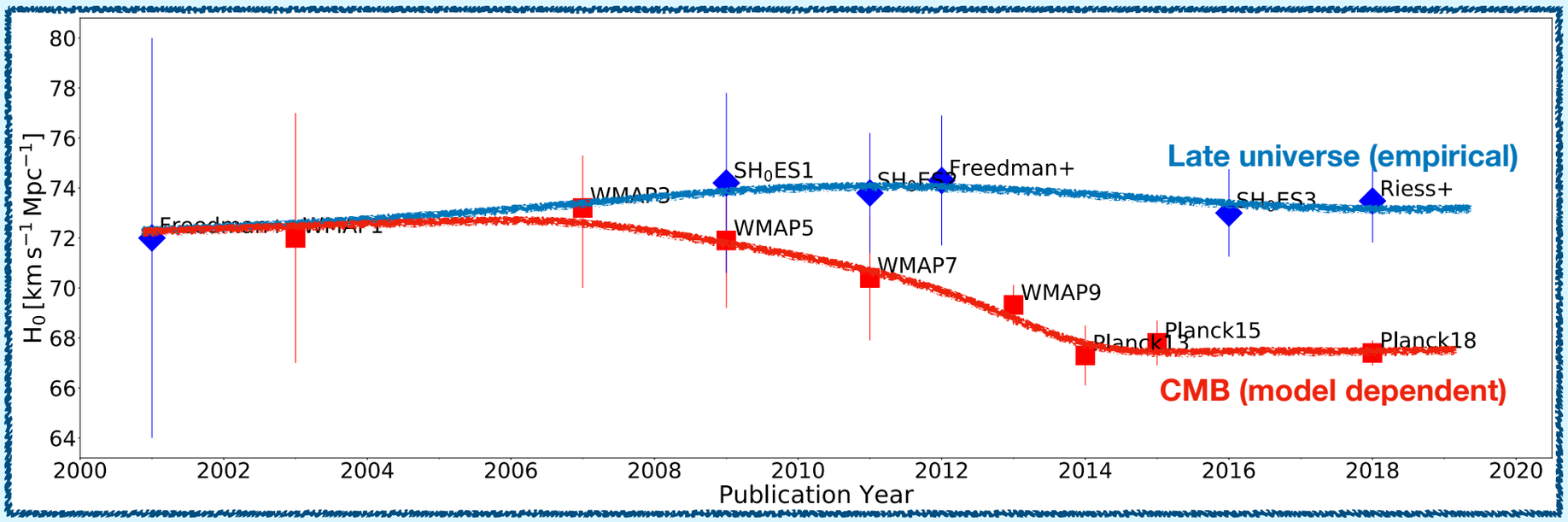
PL relation calibrated by Henrietta Leavitt (Leavitt & Pickering 1912)

1. Measuring distances in the Universe

Edwin Hubble and the 2.5m telescope at Mount Wilson Observatory

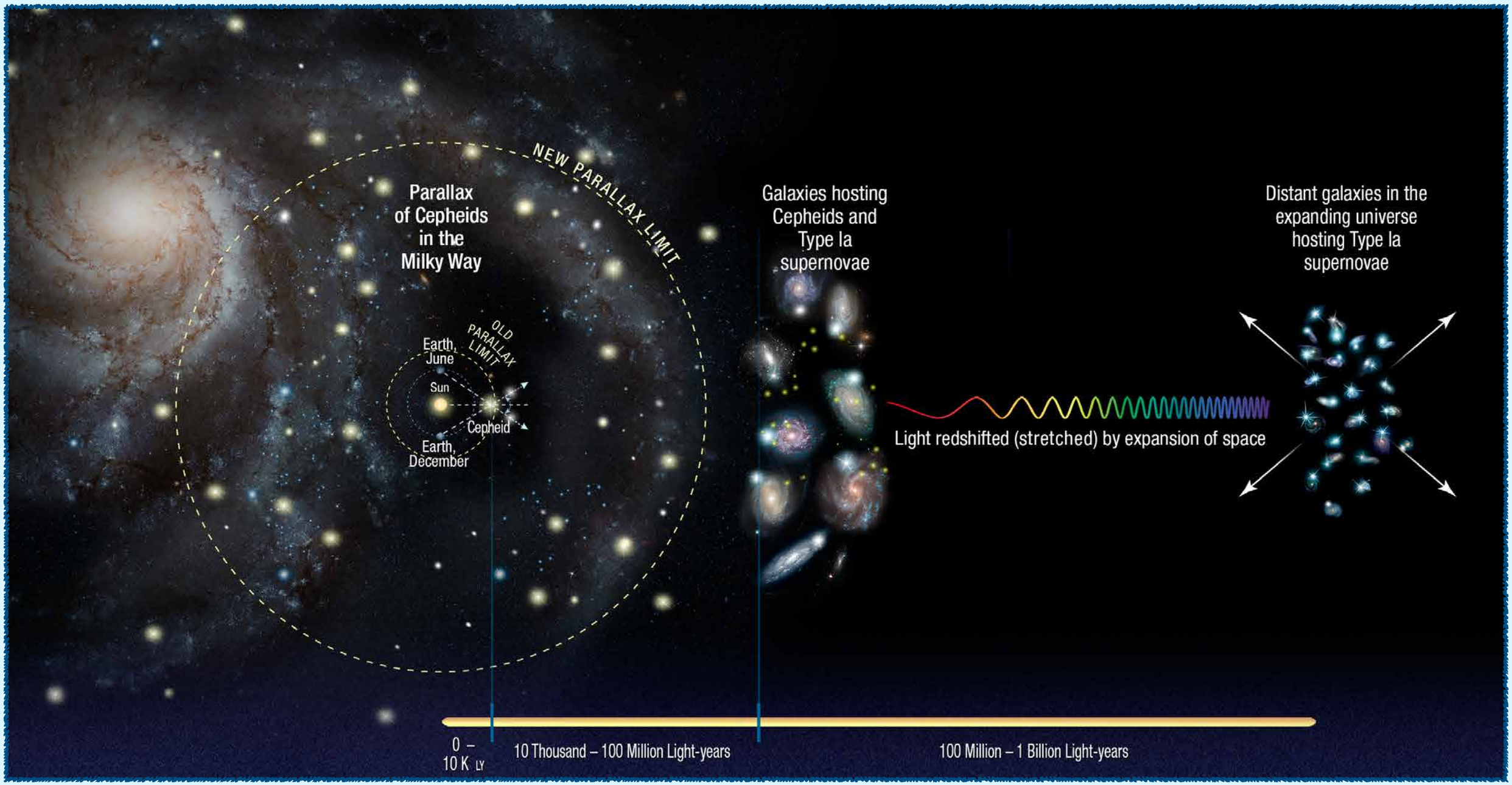


Relation between galaxies distance and velocity (Hubble 1929)



The tension on the Hubble constant (Javanmardi & Kervella 2019)

1. Measuring distances in the Universe



The distance scale (Credit: NASA, ESA, A. Feild (STScI), A. Riess (STScI/JHU))

2. Calibration of the PL relation with Gaia DR2 parallaxes

Gaia construction at ESA

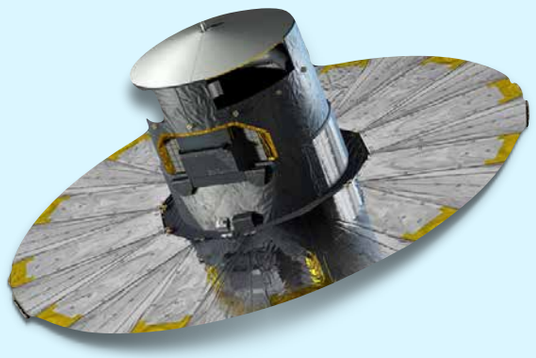
2. Calibration of the PL relation with Gaia DR2 parallaxes

- We **need very precise distances** to calibrate the PL relation.

Hubble Space Telescope (NASA, ESA)

- Over the past 20 years, only the Hubble Space Telescope (HST) provided precise geometrical paxallaxes of Cepheids :
  - → Freedman et al. (2001)
  - → Sandage et al. (2006)
  - → Benedict et al. (2002, 2007)
  - → Riess et al. (2011, 2014, 2016, 2018, 2019)

- GAIA satellite : first alternative to HST parallaxes.



GAIA satellite (ESA)

2. Calibration of the PL relation with Gaia DR2 parallaxes

Issue 1: The large uncertainty on the Gaia DR2 parallax zero-point (ZP_{GDR2}).
→ large systematics in the results.

Recent estimates of the Gaia DR2 parallax zero-point (Breuval et al. 2020)

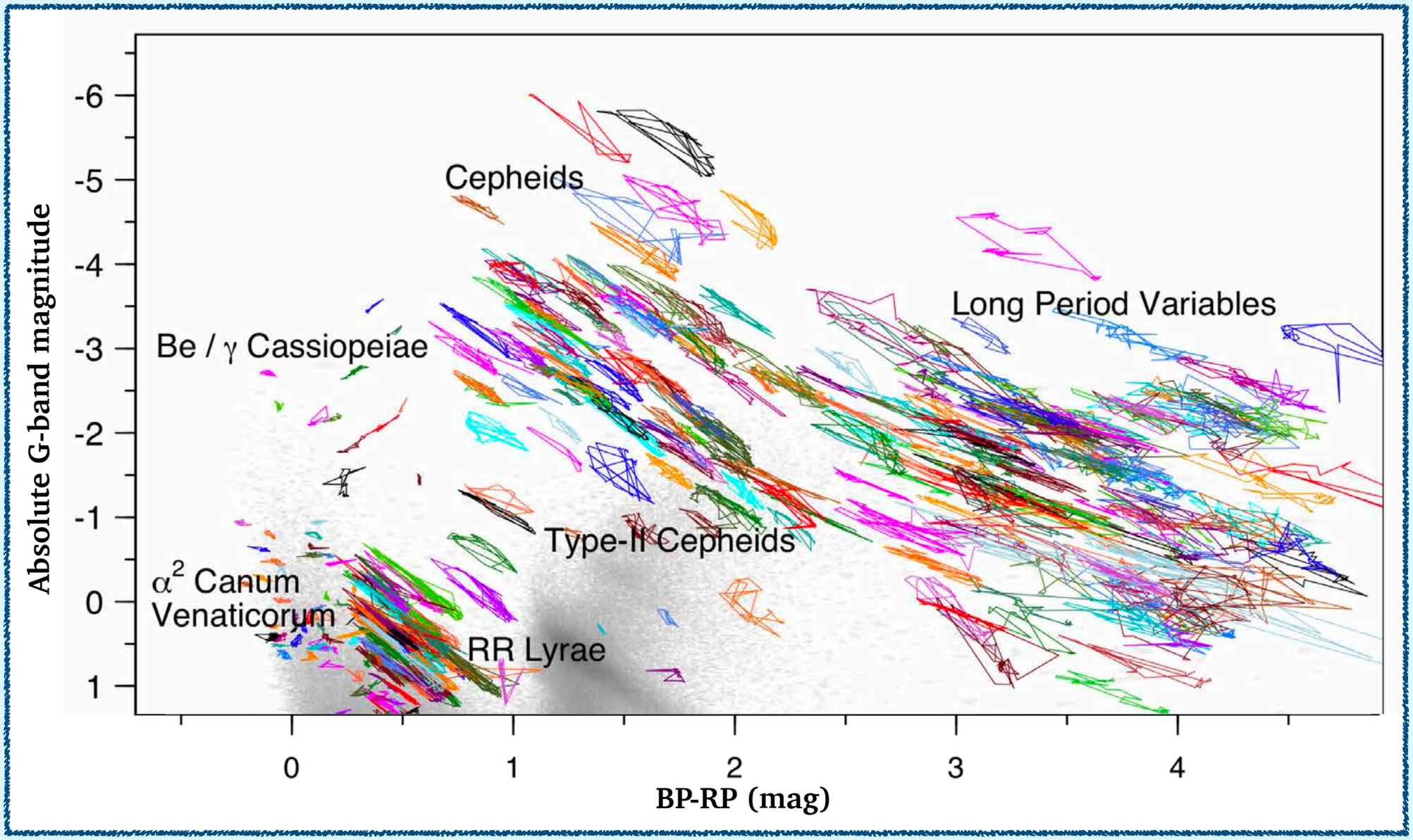
ZP_{GDR2} (mas)	Reference	Type of sources	Typical G (mag)
−0.029	Lindegren et al. (2018)	Quasars	19
$-0.031_{\pm 0.011}$	Graczyk et al. (2019)	Eclipsing binaries	9
$-0.0319_{\pm 0.0008}$	Arenou et al. (2018)	MW Cepheids	8
$-0.035_{\pm 0.016}$	Sahlholdt & Silva Aguirre (2018)	Dwarf stars	9
$-0.041_{\pm 0.010}$	Hall et al. (2019)	Red giants	13
$-0.046_{\pm 0.013}$	Riess et al. (2018b)	MW Cepheids	9
$-0.049_{\pm 0.018}$	Groenewegen (2018)	MW Cepheids (HST)	8
$-0.053_{\pm 0.003}$	Zinn et al. (2019)	Red giants	13
$-0.054_{\pm 0.006}$	Schönrich et al. (2019)	GDR2 RV	12
$-0.057_{\pm 0.003}$	Muraveva et al. (2018)	RR Lyrae	12
$-0.070_{\pm 0.010}$	Ripepi et al. (2019)	LMC Cepheids	15
$-0.082_{\pm 0.033}$	Stassun & Torres (2018)	Eclipsing binaries	9

We adopt ZP_{GDR2} = -0.046 ± 0.015 mas

2. Calibration of the PL relation with Gaia DR2 parallaxes

Issue 2: Gaia DR2 parallaxes are derived assuming that all the stars have a constant color and a constant brightness. (Lindegren et al. 2018, Mowlavi et al. 2018)

→ Without chromaticity correction, GDR2 parallaxes of Cepheids may be **potentially unreliable**.



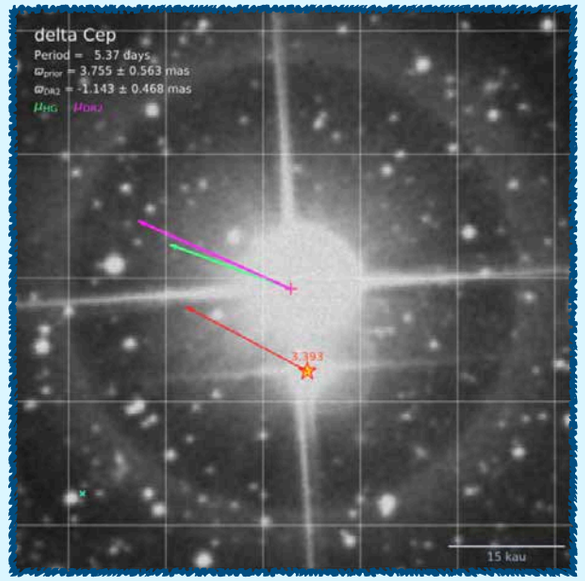
Gaia Collaboration, Eyer L. et al. (2019)

2. Calibration of the PL relation with Gaia DR2 parallaxes

Gaia DR2 parallaxes of Cepheids are affected by **systematics** and may be **potentially unreliable**.
→ We look for **stable** (non-variable) and **faint** stars in the close neighbourhood of Cepheids.

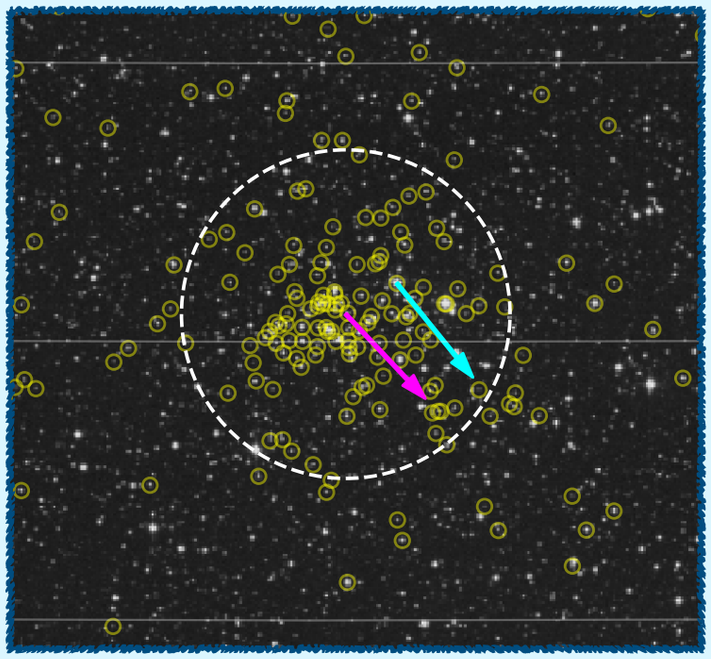
Cepheids with close companions

- Kervella et al. (2019b): **22 candidates**.
- not variable, unsaturated (~6 mag fainter than Cepheids)
- not sensitive to flux contamination by the Cepheid
- resolved !



Proper motion of Delta Cep and its companion (Kervella et al. 2019b)

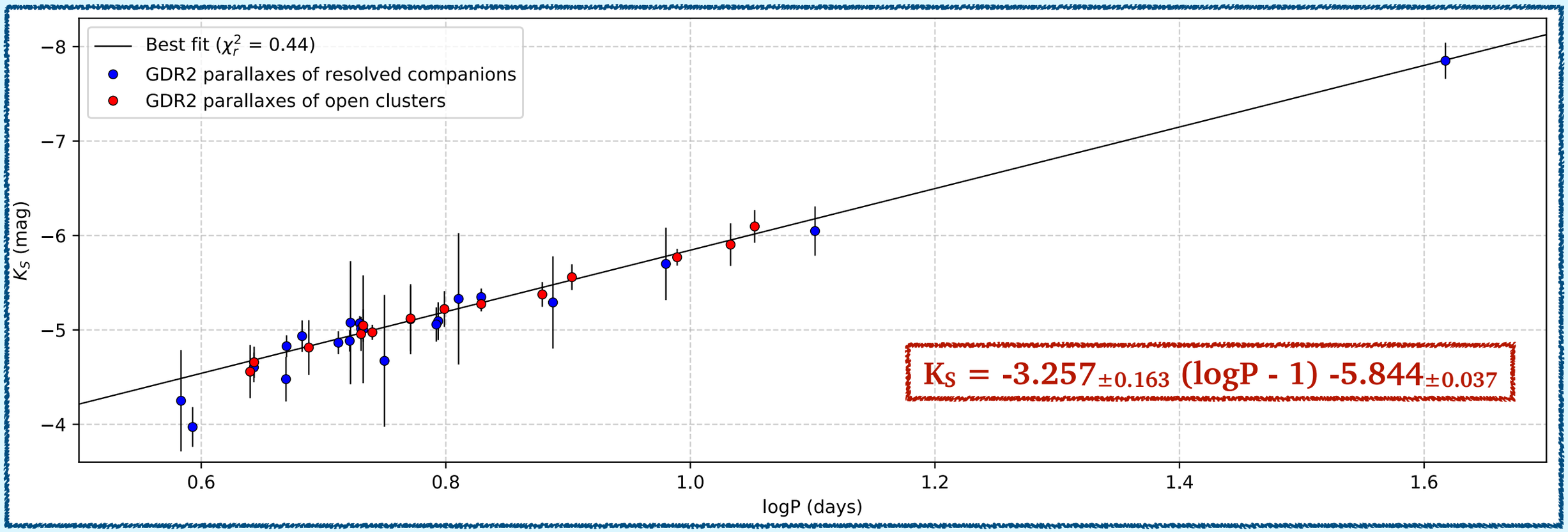
Proper motion of the Cepheid CF Cas and its host open cluster NGC 7790 (Breuval et al. 2020)



Cepheids in open clusters

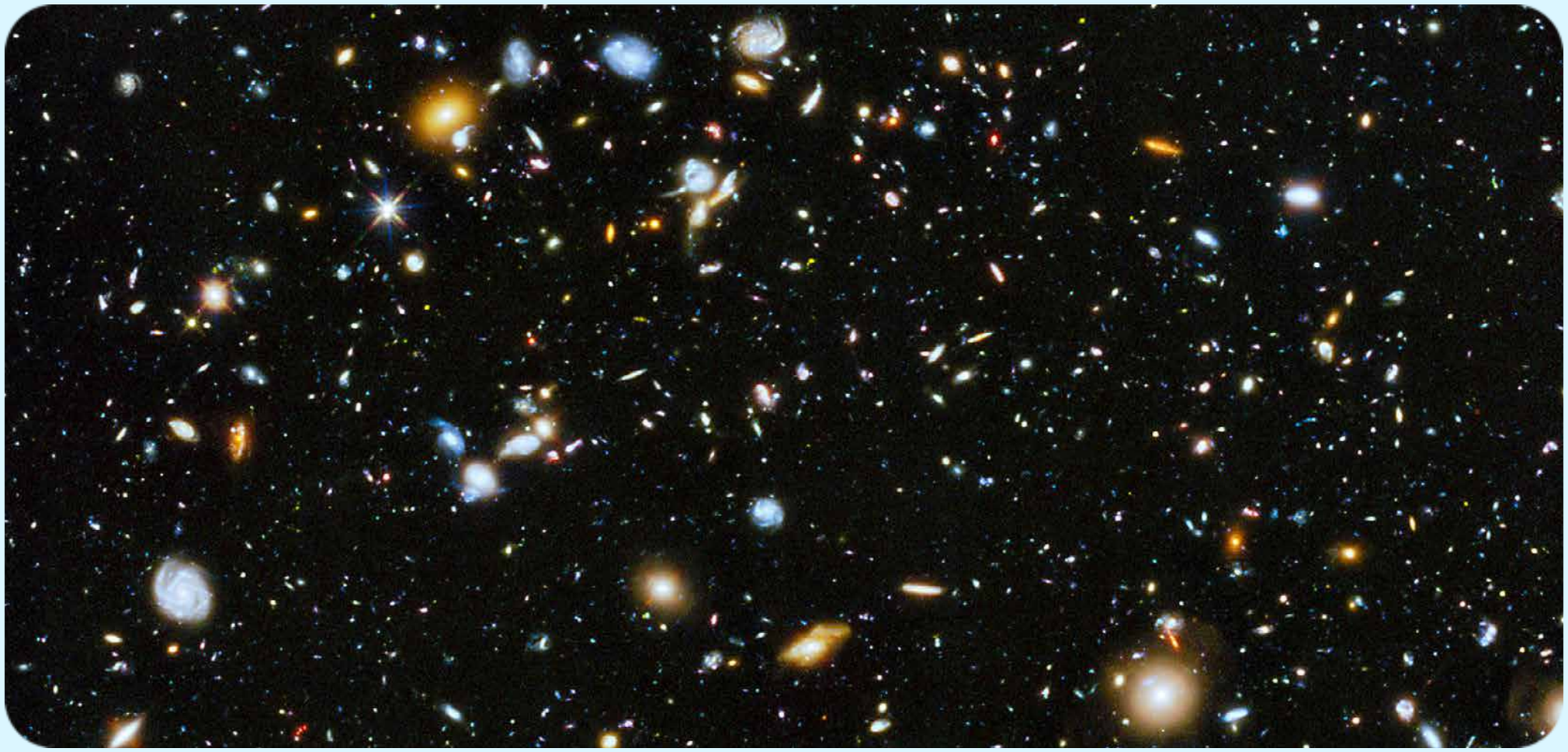
- cross-match between a catalog of open clusters (Cantat-Gaudin et al. 2018) and Milky Way Cepheids: **14 candidates**.
- gain in precision by averaging over the cluster members
- members are not variable stars and are generally fainter than Cepheids

2. Calibration of the PL relation with Gaia DR2 parallaxes



Period-Luminosity relation in the K_S band derived from Gaia DR2 parallaxes of companion stars and open clusters hosting Cepheids (Breuval et al. 2020)

3. Implications on the Hubble constant H_0



Anchor(s)	Value ($km\ s^{-1}\ Mpc^{-1}$)
One Anchor	
NGC 4258: Masers	72.25 ± 2.51
MW: 15 Cepheid Parallaxes	76.18 ± 2.37
LMC: 8 Late-type DEBs	72.04 ± 2.67
M31: 2 Early-type DEBs	74.50 ± 3.27
Two Anchors	
NGC 4258 + MW	74.04 ± 1.93
NGC 4258 + LMC	71.62 ± 1.78
Three Anchors (Preferred)	
NGC 4258 + MW + LMC	$\mathbf{73.24 \pm 1.74}$

Best estimates of H_0 from Riess et al. (2016), based on several anchors

3. Implications on the Hubble constant H_0

Riess et al. (2016)

15 parallaxes of Milky Way Cepheids
HST/FGS, HST/WFC3, *Hipparcos*

↓

$H_{0,\,R16} = 76.18 \pm 2.37$ km/s/Mpc

Breuval et al. (2020)

22 parallaxes of Cepheids companions
14 parallaxes of open clusters hosting Cepheids
Gaia DR2

↓

$H_{0,\,B20}$ = ???

Rescale of the Milky Way Hubble constant: $H_{0,\,B20} = (\pi_{B20} / \pi_{R16})\, H_{0,\,R16}$

$$H_{0,\,B20} = 72.76 \pm 1.86\ \text{(statistics, systematics)} \pm 1.89\ \text{(ZP)}\ \text{km/s/Mpc}$$

→ Still large errors because of the uncertainty on the Gaia DR2 parallax zero-point.
→ New value in better agreement with the other anchors from R16

NGC 4258: Masers	72.25 ± 2.51
MW: 34 Gaia DR2 parallaxes (Breuval+ 2020)	72.76 ± 2.65
LMC: 8 Late-type DEBs	72.04 ± 2.67
M31: 2 Early-type DEBs	74.50 ± 3.27

Conclusion

- Using Gaia DR2 parallaxes of **companions** and **open clusters** instead of Cepheids parallaxes allows us to :

  → bypass the systematics on GDR2 Cepheids parallaxes
  → calibrate the PL relation with non-HST parallaxes

- We revise the Milky Way value of the Hubble constant by using our sample of Gaia DR2 parallaxes instead of previous non-Gaia parallaxes (mostly HST). From an initial value of **76.18** km/s/Mpc (Riess et al. 2016), we obtain **72.8** km/s/Mpc.

- We need to investigate the metallicity effect on PL relations !

- We expect the Gaia DR3 to :

  → provide a precise (and smaller) value of the parallax zero-point
  → provide more accurate parallaxes for Cepheids (but still no chromaticity corrections)

Thank you !

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Breuval et al. (2020), A&A, 643, A115