RR Lyrae pulsation and evolution models tested against EDR3

Outline

- ►Brief detouring to extrasolar planets
- ►Classical double-mode RR Lyraes
- ►Bright Galactic field RR Lyraes
- ►Some current Gaia PLX ZP estimates

“Stellar Evolution along ...”, Naples, September 20-23, 2022

Fernley, Barnes, Skillen et al. 1998, A&A, 330, 515

3. Trigonometric parallaxes

One star, **RR Lyrae** itself, has a reasonably well determined parallax, **π=4.38±0.59** mas which is equivalent to $\sigma\pi/\pi$=0.13. The **remaining stars** are at least a magnitude fainter with correspondingly smaller parallaxes and larger errors and values of **$\sigma\pi/\pi \geq 0.30$**.

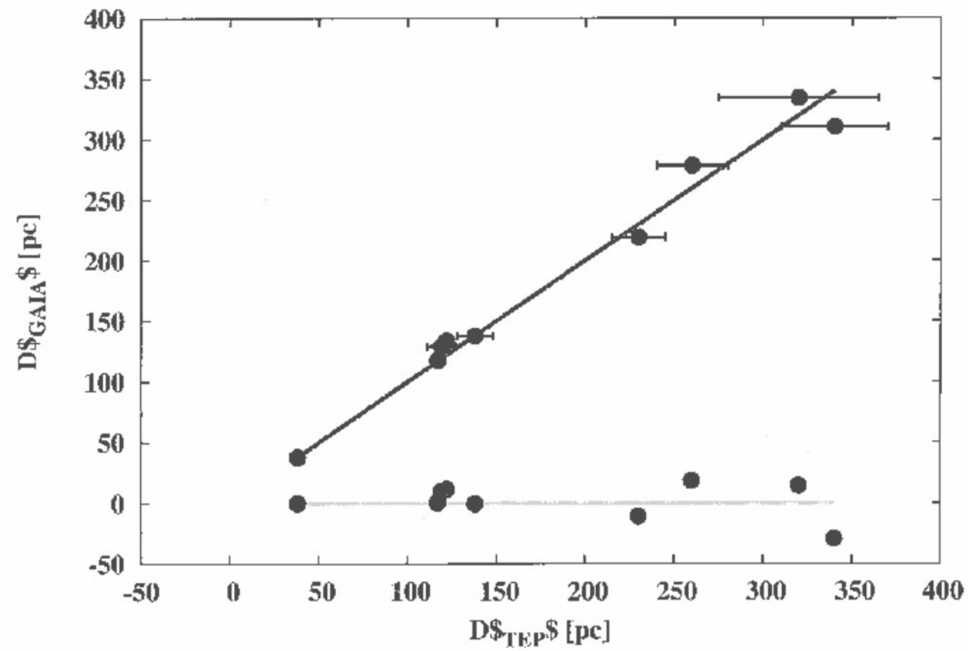
Gaia EDR3:

RR Lyrae: **π = 3.985 ± 0.027**

105 bright RR Lyraes: **$\sigma(\pi)$ / π < 0.03**

Back to 2018 ...

After an enthusiastic discussion with Attila Moor:

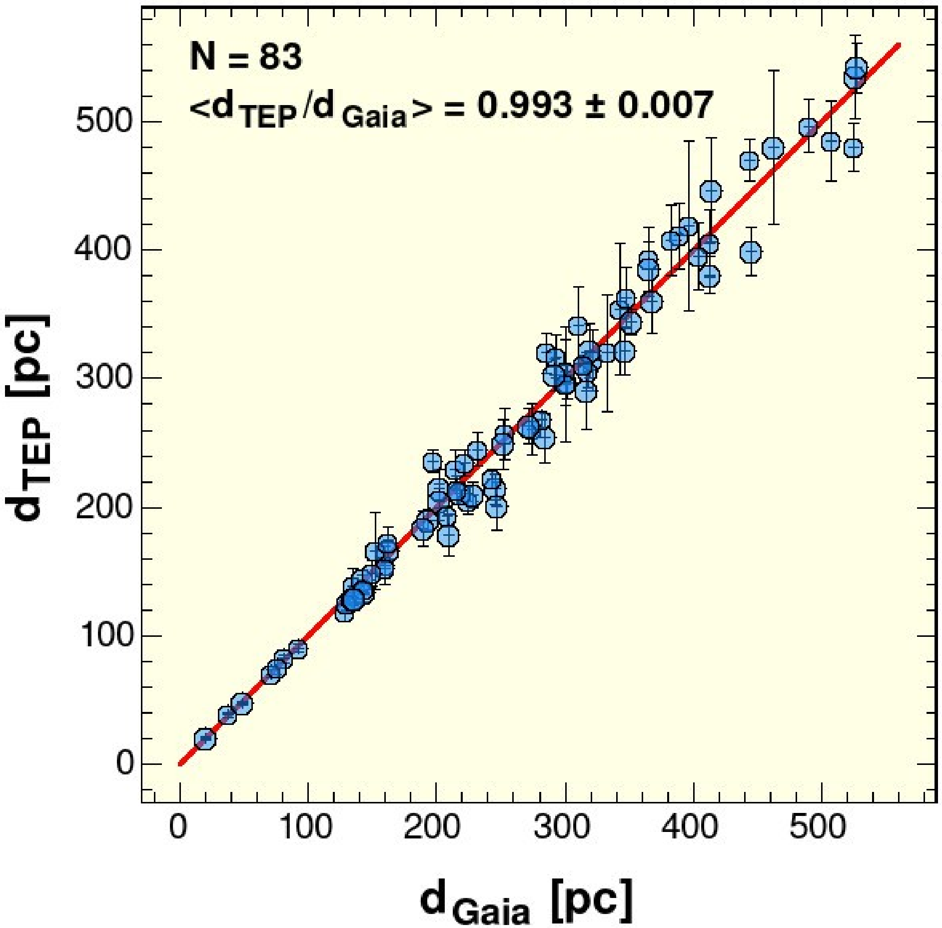


Two COMPLETELY INDEPENDENT datasets

π(Gaia) : Position measurements

π(TEP) : T_{eff} estimate – SED, stellar atm. models
[Fe/H] – spectroscopy
ρ – system parameters a, R, P
L – stellar evolution models
M_V – BC, stellar atm. models
V – photometry, E(B-V)
$\lg(\pi) = -1 - 0.2(V - M_V)$

The 2022 update



PLX_TEP = PLX(Gaia) + Δ PLX

[PLX] = mas

EDR3:
< e_PLX / PLX > = 0.5 %

N = 83

DR	<Δ PLX>	σ(Δ PLX)
2	0.08865 ±0.03161	0.28801
3	0.06766 ±0.03093	0.28182

N = 69 (without KELT):

DR	<ΔPLX>	σ(Δ PLX)
2	0.04638 ±0.02873	0.23864
3	0.02884 ±0.02846	0.23643

RR Lyrae stars*

► **Double-mode stars**

Stellar pulsation:

$P_0 = f_0(M, L, T_{eff}, Z)$

$P_1 = f_1(M, L, T_{eff}, Z)$

Input: T_{eff}, Z

BUT: Z is not known

Stellar evolution:

$E(M, L, T_{eff}, Z, t)=0$

► **Single-mode stars**

Stellar pulsation:

$P_0 = f_0(M,L,T_{eff},Z)$

Input: T_{eff}, Z

Stellar evolution:

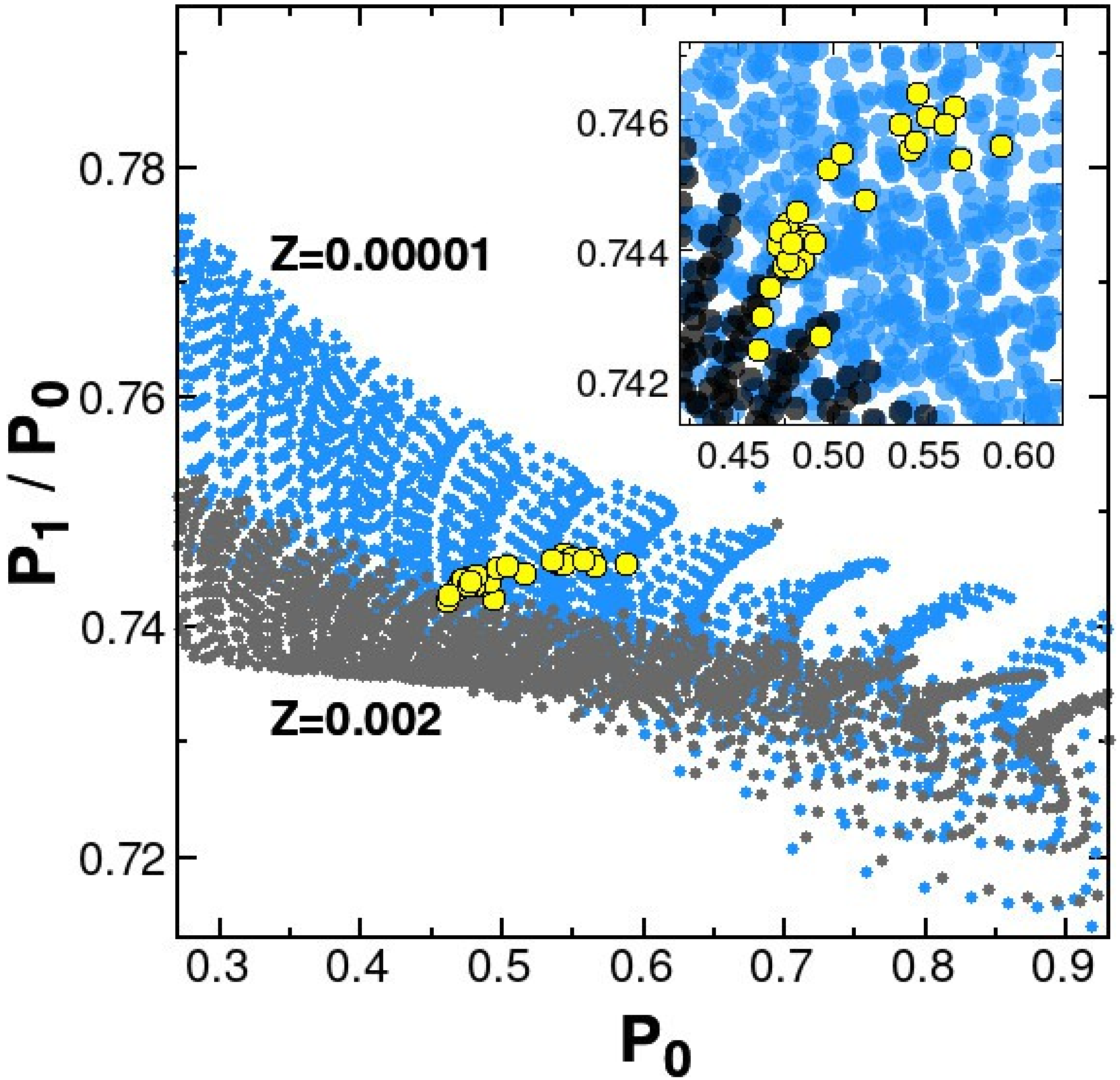
$E(M, L, T_{eff}, Z, t)=0$

L(RRL) ⟷ L(Gaia)

almost independent datasets

* Two A&A papers, co-author: Behrooz Karamiqucham

RRd stars I. — *appetizer*



AQ Leo:
Jerzykiewicz & Wenzel (1977)
M15 RRds:
Sandage, Katem & Sandage (1981)

- Petersen (1973)

@ fixed Z:
straigh lines
@ varying Z:
slices of Z=const lines (MACHO / LMC)
►► degeneracy with mass

RRd stars II. — *in & out*

Data: 30 field RRd

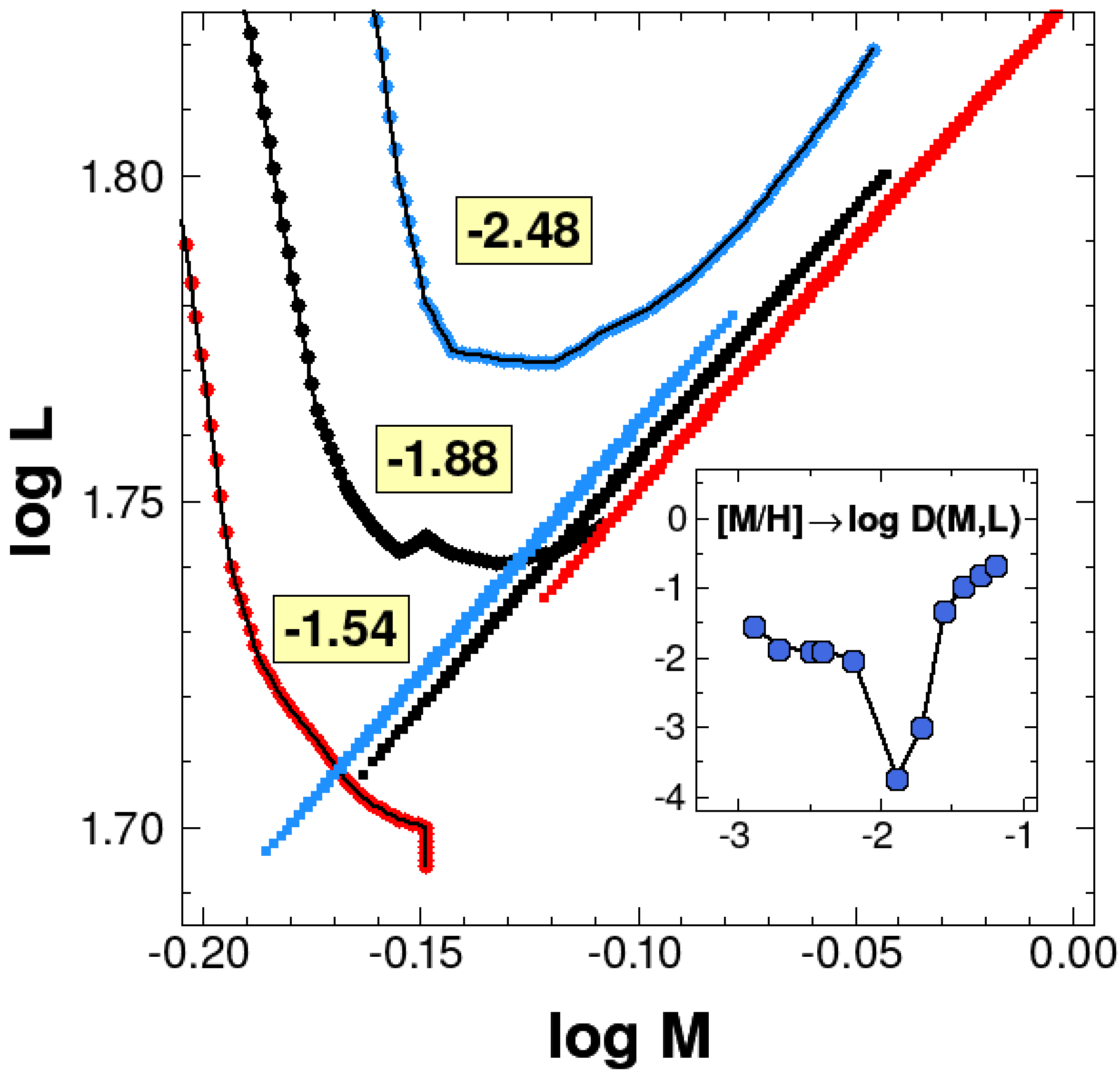
- **<V> :**
  - ASAS (26)
  - from Gaia BP (4)
- **<K> :**
  - from W1, W2 of unWISE
- **E(B-V) :**
  - Schlafly & Finkbeiner (2011)

Models:

- **Teff :**
  - Castelli et al. (1997)
  - IRFM ZP of Gonzalez & Bonifacio (2009)
- **BC :**
  - Castelli et al. (1997)
  - BC_{sun} = -0.082
- **Pulsation, HB evol.:**
  - LNA (Kovacs & Buchler, 1988)
  - BaSTI, Hidalgo et al. (2018)

1. V, K, E(B-V), Z_0 , T_{eff}
2. T_{eff} fixed, P_0 , P_1 match to LNA: $\{M,L,Z\}_{LNA}$
3. T_{eff} fixed, $\{M,L,Z\}_{HB}$ set from BaSTI
4. Match {M,L,Z} from #2, #3
5. Iterate on Z_0

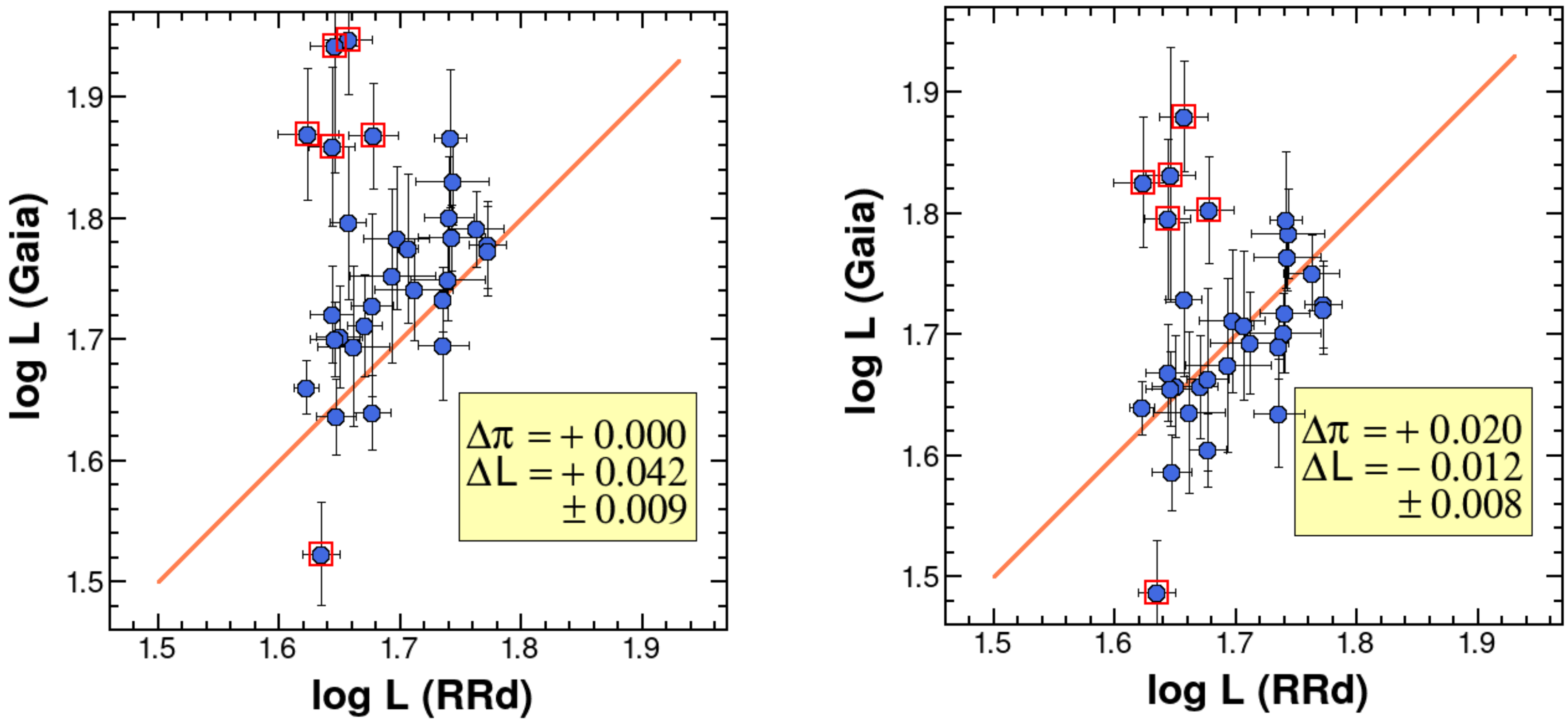
RRd stars III. — *LNA-HBEV match*



AQ Leo

- Teff = 6595 K
- LNA lines are shifted in L
- No shift for —

RRd stars: Gaia parallax shift



$$\Delta L = \lg L(\text{Gaia}) - \lg L(\text{RRd})$$
$$\lg L_1 = \lg L_2 + 2\lg(\pi_2/\pi_1)$$
$$\Delta\pi = \pi_2 - \pi_1$$

WARNING: Blending may play a role in L(Gaia)

Also: an increase of 0.005 in $\log T_{eff}$ makes $\Delta\pi = 0.0$

Single-mode RR Lyrae stars

► As for the RRd stars, but [Fe/H] is known

- Input: P, V, RP, W2, [Fe/H], E(B-V)

  - RP, W2 —► Ks
  - V, Ks, log g, [Fe/H], E(B-V) —► T_{eff}
    [T_{eff} ZP by IRFM of Gonzales & Bonifacio (2009)]
  - *Stellar pulsation:* (M,L) via $P_0 = f_0(M,L,T_{eff},Z)$
  - *Stellar evolution:* (M,L) via $E(M,L,T_{eff},Z,t)=0$
  - Metric:

$$D(M,L,Z)=\sqrt{\log^2\left(\frac{L^{HB}}{L^{LNA}}\right)+\log^2\left(\frac{M^{HB}}{M^{LNA}}\right)}$$

Datasets

- **Brightness:** $8 < V < 13$
- **EDR3 relative PLX error:** $< 10\%$
- **Reliable [Fe/H] accessibility**
- **V:** Dambis et al. (2013)
  Monson et al. (2017)
  ASAS
- **Ks: Calibrated (W2, RP) to Layden et al. (2019):**
  145 stars with $\sigma_{fit} = 0.03$
- **156 stars:**

$\sigma(\pi) / \pi$	N_stars
0% - 2%	62
2% - 3%	43
3% - 10%	51

Iron abundances

►Lack of homogenized HDS [Fe/H]

- **Input:**
  HDS & LDS [Fe/H]
  177 stars

○ **LDS – linear transf.**
○ **HDS – ZP shift**

J96 = Jurcsik & Kovacs (1996)

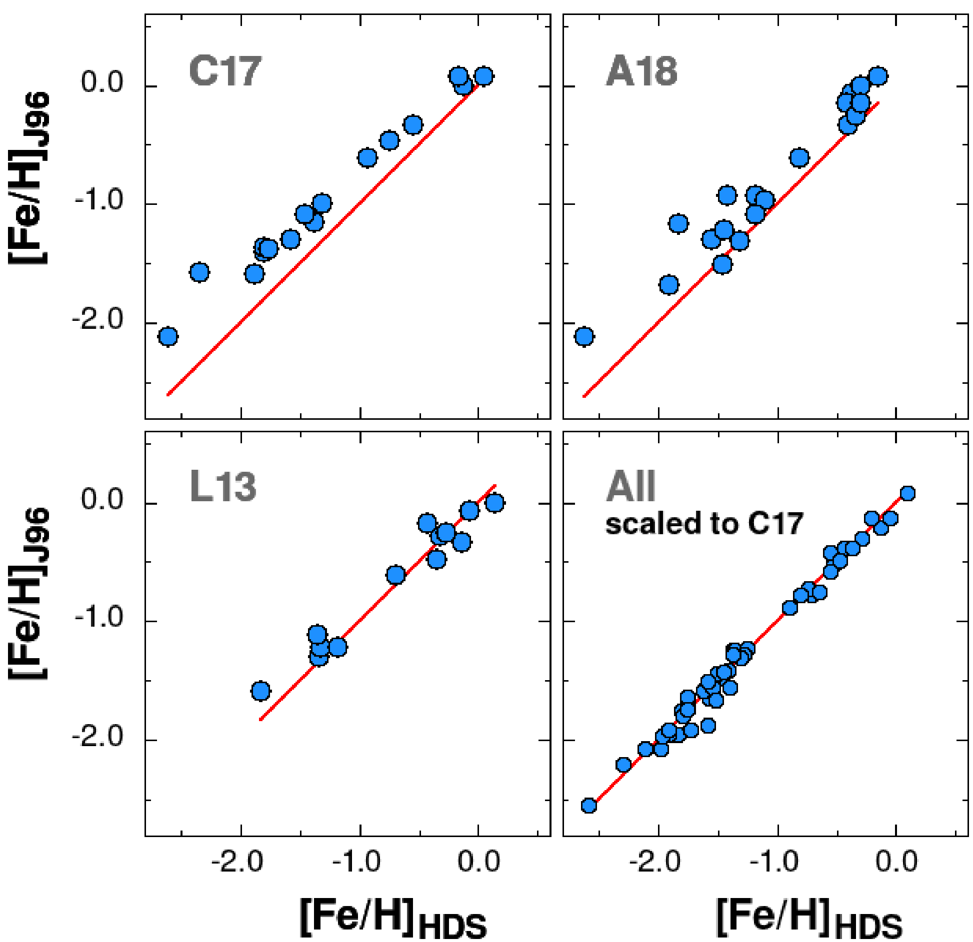
L13 = Liu et al. (2013)

C17 = Chadid et al. (2017)

A18 = Andriewsky et al. (2018)

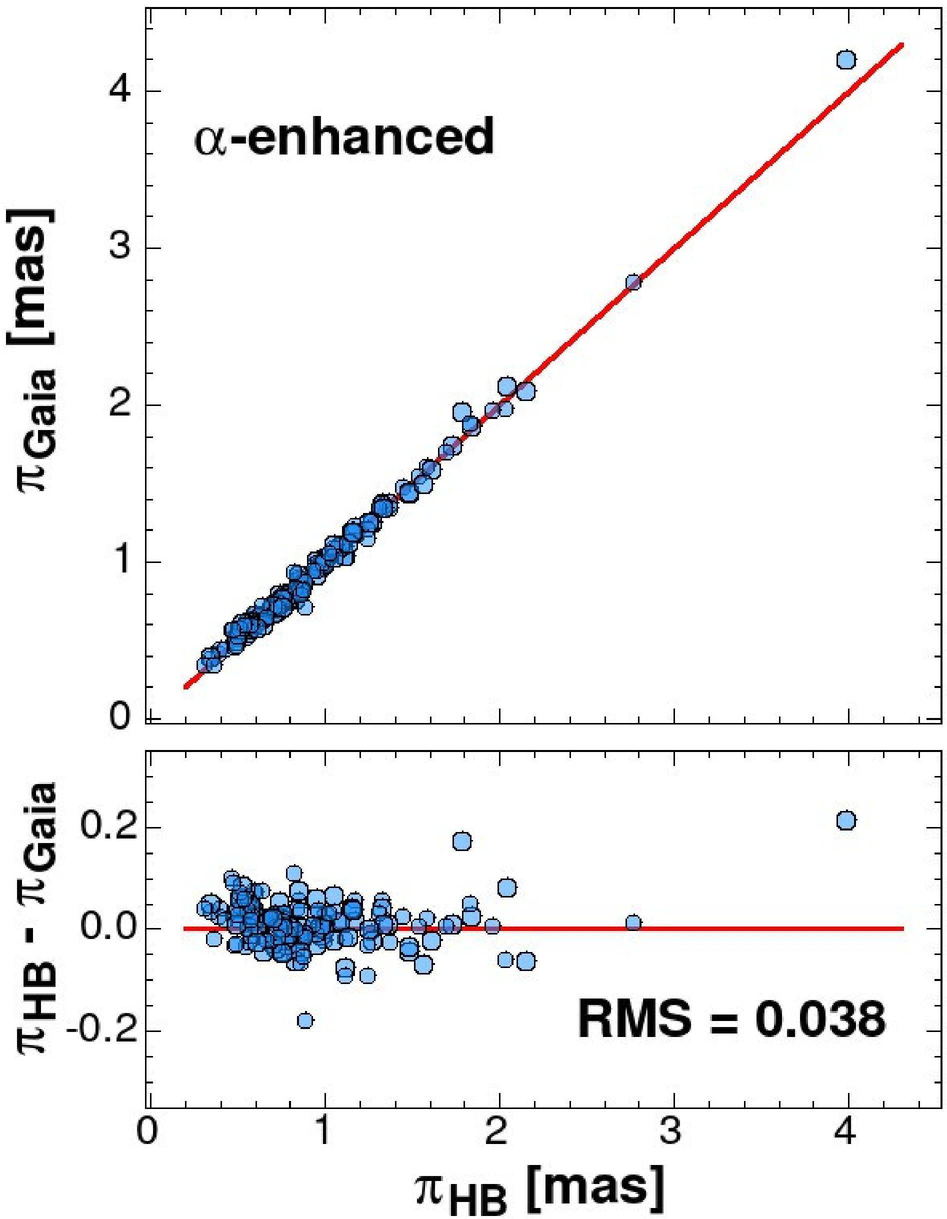
Note: “All” = All sources

$$[Fe/H]_{C17} = 1.10[Fe/H]_{J96} - 0.22$$



J96 —► C17

HB/LNA vs Gaia



► HB models:
[α/Fe] = 0.0
[α/Fe] = +0.4

► All 156 stars:
- 3 ~outliers
(including
RR Lyrae:)

► For [α /Fe] = 0.0
RMS = 0.042

Note in passing ...

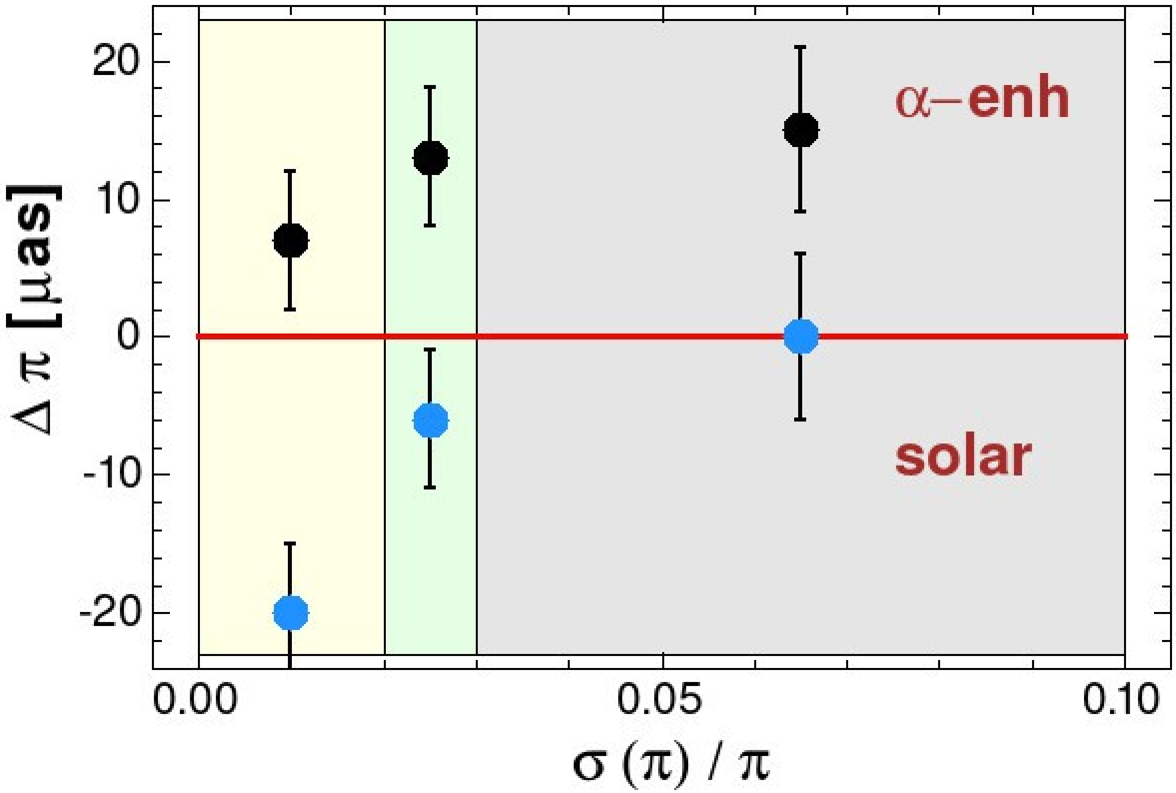
Don VandenBerg et al. 2000, ApJ, 532, 430
(see also Ben Dorman 1992)

>>> for the SAME [Fe/H]:
α-enhanced models are fainter by ~ 0.02 in log L

20-30 years later, from BaSTI:

		Enhanced	Solar	Sol-Enh
Set	N	$\lg(L_{Gaia}/L_{HB})$	$\lg(L_{Gaia}/L_{HB})$	$\lg(L_{sol}/L_{enh})$
A	62	+0.006	-0.012	+0.018
B	43	+0.015	-0.003	+0.018
C	51	+0.026	+0.007	+0.019

Gaia PLX ZP shift



π(HB) – π(Gaia) = Δπ

The bright end suggests preference for α-enhanced models

For 156 stars:

[α/Fe]= 0.0
Δπ = -9 ±3 μas

[α/Fe]= +0.4
Δπ = +11 ± 3 μas

T_{eff} and [Fe/H] ZPs

Can we save the non-enhanced models?

Likely not ...

Δlg Teff = + 0.0045	$\Delta\pi$ = - 0.021, RMS= 0.045
Δ[Fe/H] = + 0.20	$\Delta\pi$ = + 0.005, RMS= 0.038

Increasing [Fe/H] is like α-enhancement at a lower [Fe/H]

Other EDR3 PLX ZP shift estimates

A highly incomplete list

* True external parallax

- Lindegren et al. (2021): <Δπ>=+30 μas in 9 < G < 13

		Δπ
Cepheids:		
- Riess+ 2022:	17 OC + GF Cepheids	+27 ± 4
- Reyes & Anderson 2022:	34 OC +members	+22 ± 3
RR Lyrae:		
- Bhardwaj+ 2021*:	400 GF RR Lyrae PK_sZ	+7 ± 3
- Garofalo+2022*:	700 GF, GC RRL, PW_GZ	+33 ± 5
Non-Gaia PLX:		
- Groenewegen 2021*:	57 0.4 < π < 3.0 mas stars	+35 ± 14
Eclipsing Binaries:		
- Stassun & Torres 2021*:	76 EBs	+37 ± 20
- Ren+ 2021:	110000 W Uma PL	+29 ± 1
AGB stars:		
- Andriantsaralaza+ 2022*:	17 stars with VLBI PLX	+77 ± 4

Summary

► For BRIGHT field stars of $\sigma(\pi)/\pi < 0.02$, α-enhanced HB tracks yield good match to EDR3 *bare* parallaxes

► The overall PLX ZP shift from the α-enhanced models is in good agreement with the ZP shift of Bhardwaj+ 2021 from PLC

► α-enhancement could be verified on a star-by-star basis for the brightest RR Lyraes with $\sigma(\pi)/\pi < 0.010 – 0.015$