INAF
Osservatorio Astronomico di Capodimonte
Napoli – ITALY

Stellar pulsation modeling of Classical Cepheids: new determinations of structural parameters and individual distance

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Outline of the talk

- Fitting pulsation models to observational time series.

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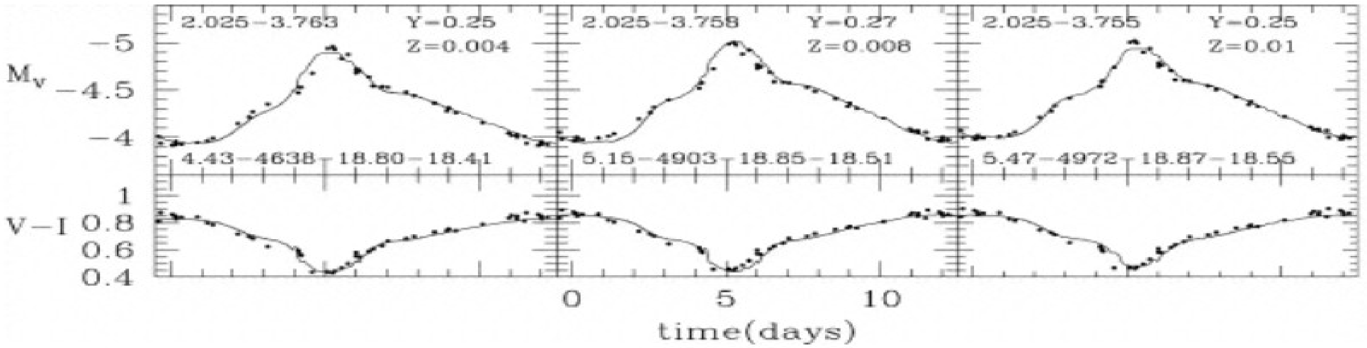
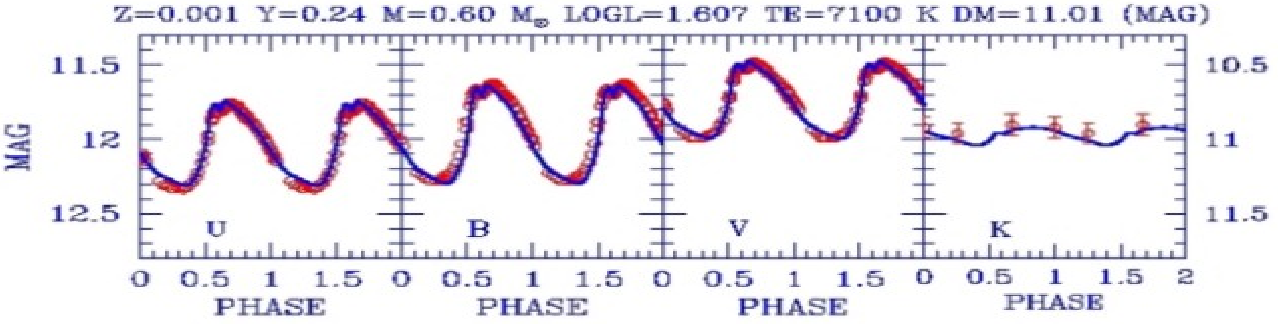
- Conclusions.

Nonlinear convective pulsation models

One of the advantages of nonlinear convective models is the possibility to directly compare observed and predicted light, radial velocity, radius variations



First application to a Magellanic Cepheid by Wood, Arnold & Sebo 1997



First application to a field RR Lyrae by Bono, Castellani, Marconi 2000

Many applications to both Cepheids and RR Lyrae in different Galactic and extragalactic environments followed (e.g. Marconi & Clementini 2005, AJ 129, 2257, Natale+2009 ApJL 674,93, Marconi+2013 ApJL,768,6, Marconi+2013 MNRAS,428, 2185, Marconi+2017 MNRAS,466,3206, Ragosta+2019,MNRAS,490,4975; Paxton+2019 ApJSS,243,10)

New perspectives for model fitting

Pulsation model computation is Time consuming!!!

i) Processing capacity of modern computers allows us to sample the structural parameter space more uniformly and with denser grids of pulsational models.

ii) Interpolation of pulsation model grids, based on artificial neural network (Kumar+, MNRAS, 2023, 522, 1504)

In this context our project is mainly devoted to point i)

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- Combining i) ii) and iii), and applying the preliminary linear non adiabatic analysis, we define the grid of all possible structural parameters (M, L, T_{eff}, $alfa_{ml}$), such that P_{obs} is matched by models within 5%.

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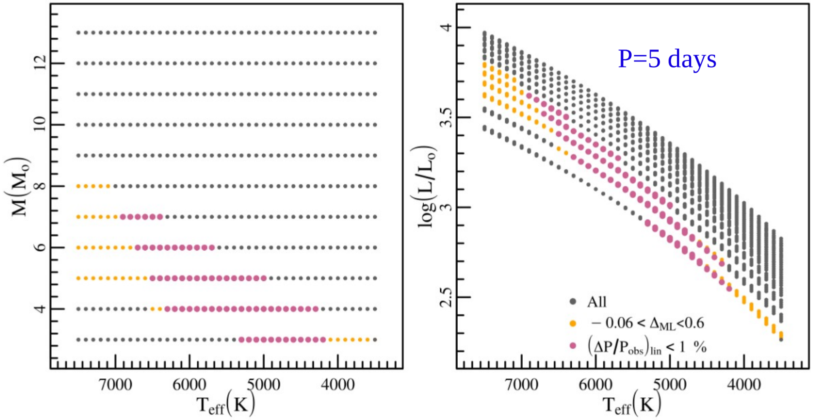
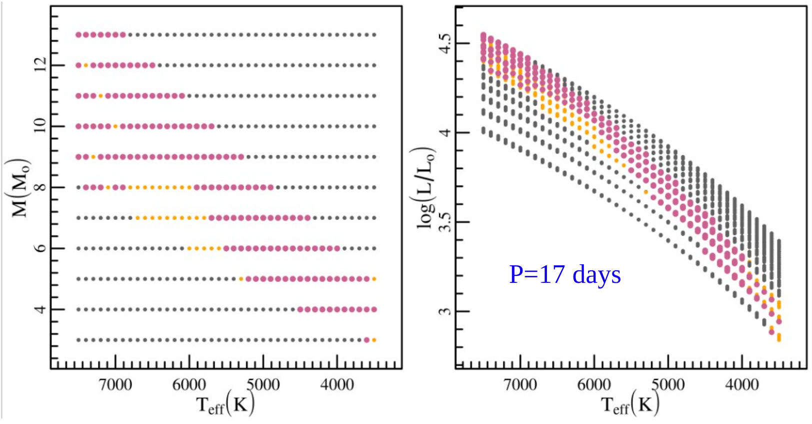
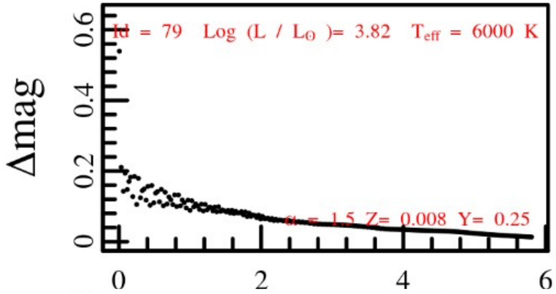
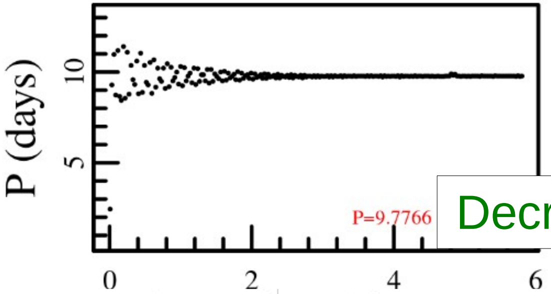




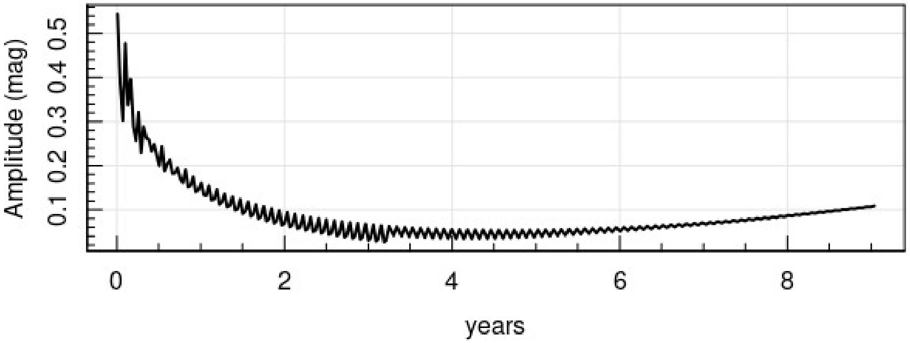
Grid of models definition

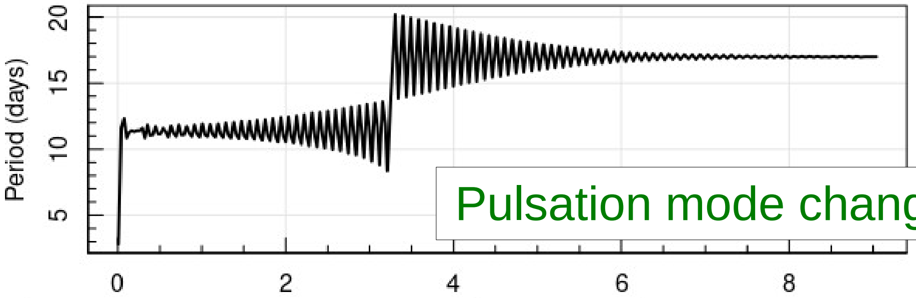
- The non-linear analysis was used to identify, among the previously selected linear models, the ones reaching a stable pulsational cycle.



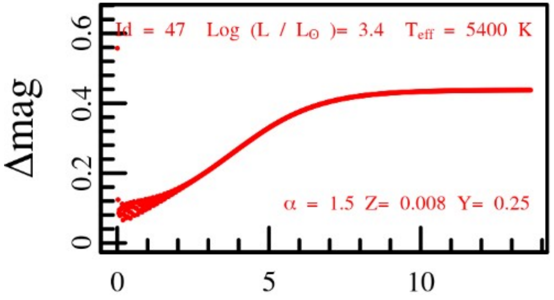


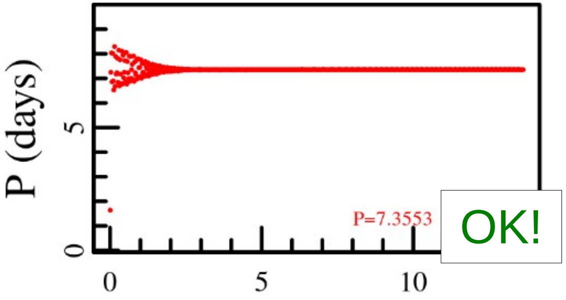
Decreasing amplitude





Pulsation mode changes





OK!

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iv) Points ii) and iii) were repeated for a sample (as large as possible) of bootstrap simulations of the observational light and radial velocity curves.

Application to MW Classical Cepheids from Gaia DR3

Preliminary results for:

12 Fundamental mode Classical MW Cepheids with Period between 4 days and 45 days

i) Good Gaia G, BP, RP light curves

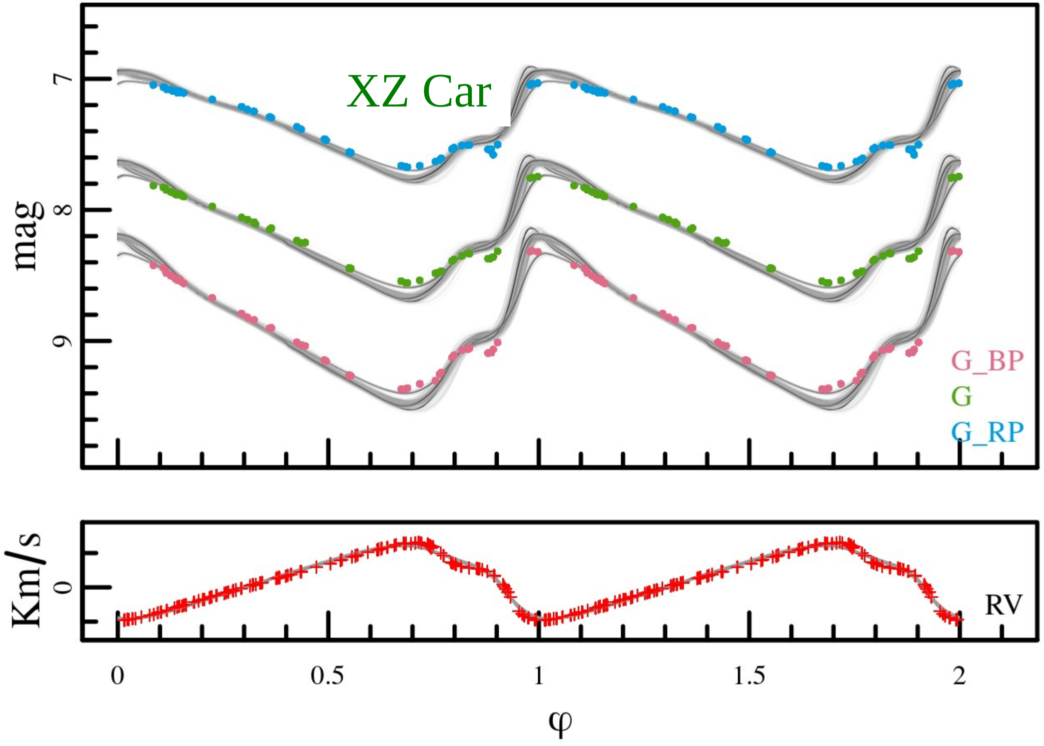
ii) Gaia radial velocity (for 8 sources)

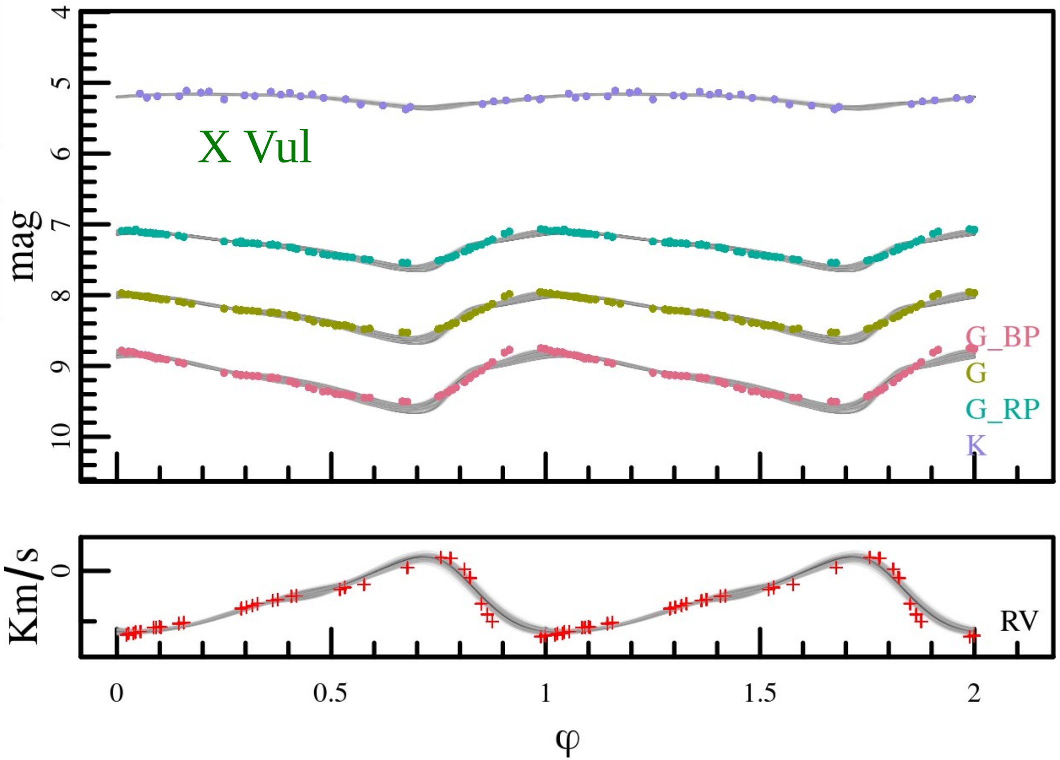
iii) EDR3 parallaxes

iv) Near-infrared K light curves from the literature (for 6 sources)

v) RV data from the literature (for 4 sources)

Preliminary results





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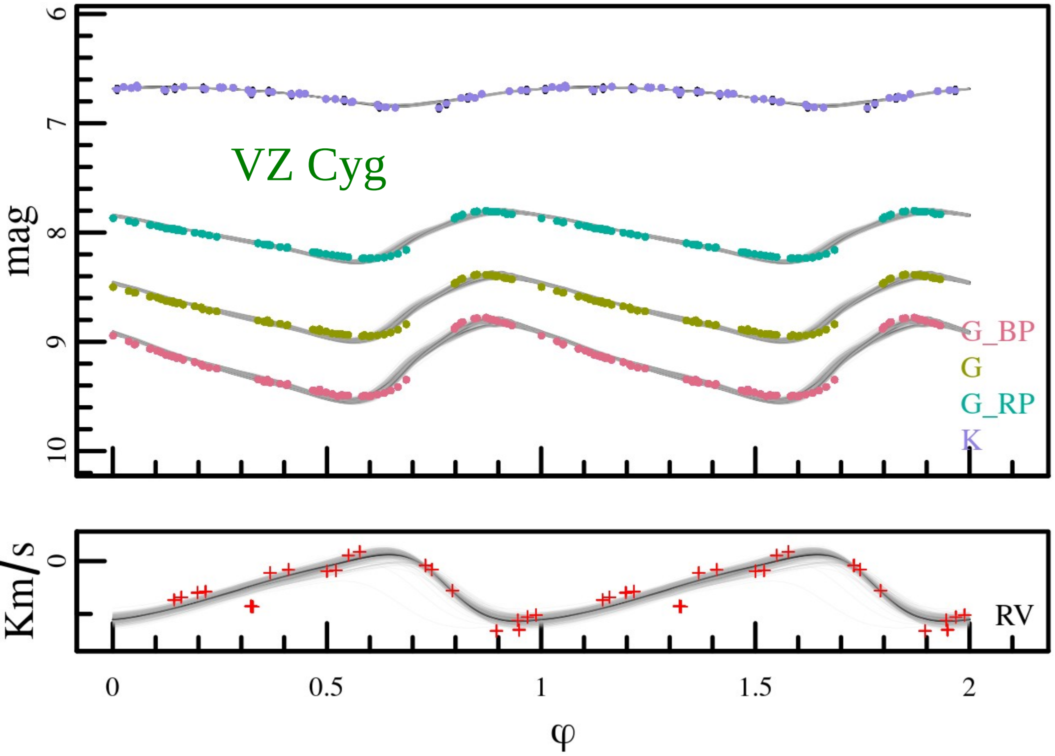

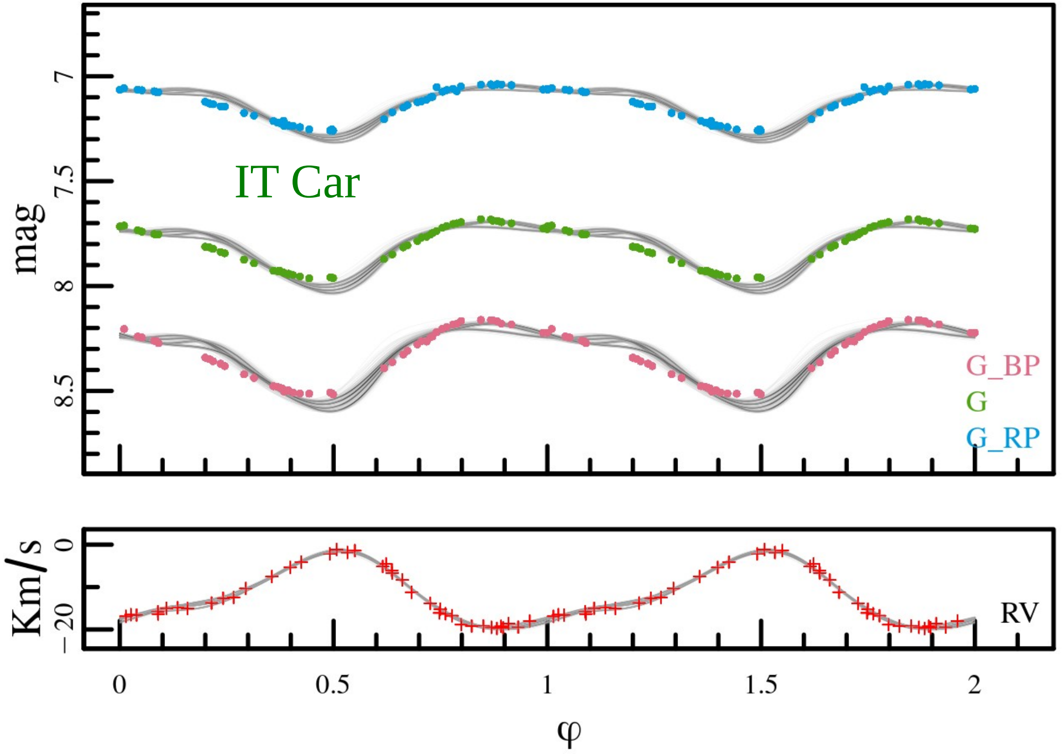

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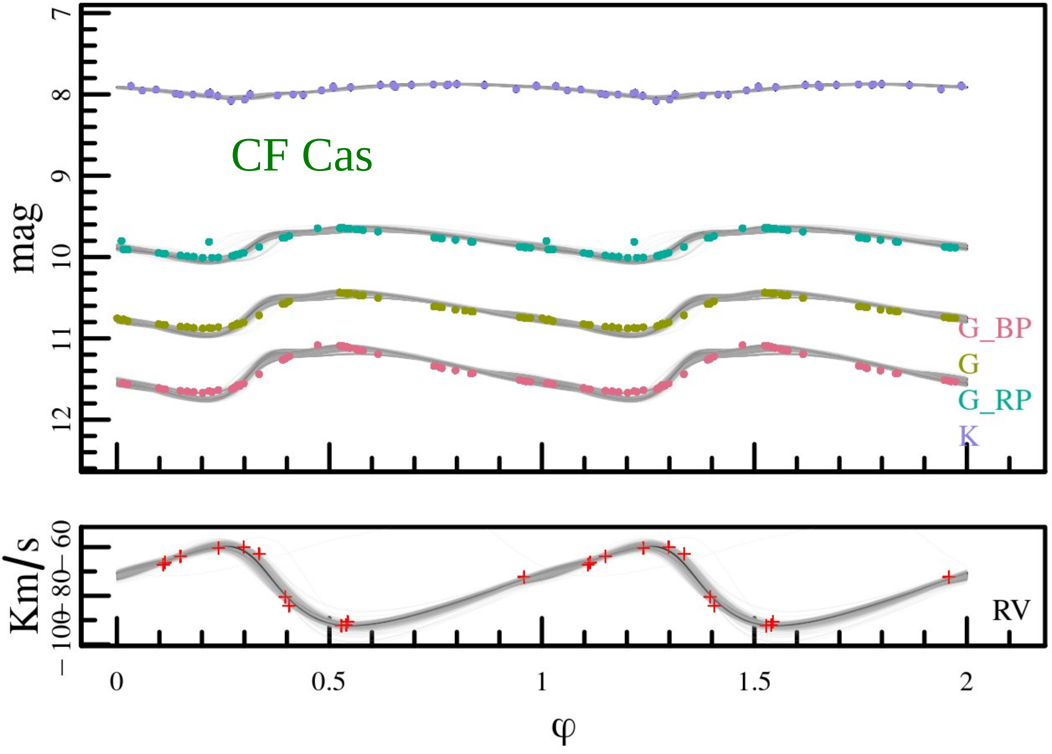

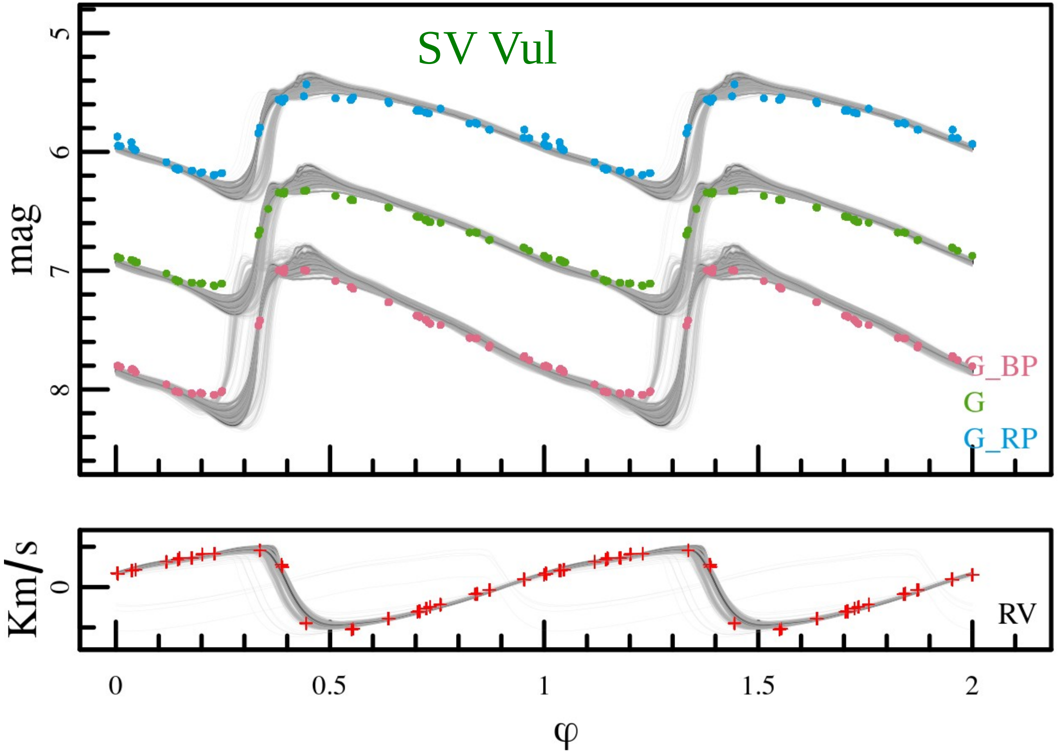

star	data	Period	α_{ml}	M/M_o	$\log(L/L_o)$	T_{eff}	Δ_{ML}	μ_0	A_V	p
ASPer	DR3(phot+RV)	$4.977^{+0.039}_{-0.039}$	$1.50^{+0.05}_{-0.05}$	$5.30^{+0.35}_{-0.35}$	$3.18^{+0.04}_{-0.04}$	5525^{+75}_{-75}	$0.029^{+0.081}_{-0.081}$	$10.814^{+0.051}_{-0.071}$	$1.879^{+0.103}_{-0.066}$	$1.236^{+0.077}_{-0.099}$
CFCas	DR3(phot+RV);K	$4.848^{+0.034}_{-0.034}$	$1.60^{+0.05}_{-0.05}$	$5.4^{+0.5}_{-0.5}$	$3.190^{+0.045}_{-0.045}$	5575^{+62}_{-62}	$0.01^{+0.12}_{-0.12}$	$12.494^{+0.024}_{-0.109}$	$1.684^{+0.022}_{-0.110}$	$1.15^{+0.14}_{-0.12}$
ITCar	DR3(phot);RV	$7.493^{+0.042}_{-0.042}$	$1.55^{+0.05}_{-0.05}$	$6.40^{+0.25}_{-0.25}$	$3.37^{+0.02}_{-0.02}$	5250^{+37}_{-37}	$-0.060^{+0.042}_{-0.042}$	$11.164^{+0.022}_{-0.022}$	$0.372^{+0.027}_{-0.029}$	$1.2906^{+0.046}_{-0.043}$
RYCMa	DR3(phot+RV);K	$4.647^{+0.039}_{-0.039}$	$1.50^{+0.075}_{-0.075}$	$4.90^{+0.15}_{-0.15}$	$3.140^{+0.015}_{-0.015}$	5625^{+75}_{-75}	$0.113^{+0.044}_{-0.044}$	$10.441^{+0.021}_{-0.033}$	$0.649^{+0.058}_{-0.051}$	$1.158^{+0.125}_{-0.105}$
SYNor	DR3(phot+RV)	$12.743^{+0.108}_{-0.108}$	$1.40^{+0.05}_{-0.05}$	$5.2^{+0.1}_{-0.1}$	$3.380^{+0.015}_{-0.015}$	4725^{+50}_{-50}	$0.258^{+0.035}_{-0.035}$	$11.531^{+0.042}_{-0.046}$	$1.255^{+0.086}_{-0.069}$	$1.36^{+0.26}_{-0.51}$
UVul	DR3(phot+RV);K	$7.886^{+0.037}_{-0.037}$	$1.45^{+0.05}_{-0.05}$	$6.60^{+0.25}_{-0.25}$	$3.47^{+0.03}_{-0.03}$	5450^{+75}_{-75}	$-0.010^{+0.036}_{-0.036}$	$9.234^{+0.040}_{-0.030}$	$1.581^{+0.066}_{-0.010}$	$1.105^{+0.508}_{-0.111}$
VZCyg	DR3(phot);K;RV	$4.814^{+0.017}_{-0.017}$	$1.55^{+0.05}_{-0.05}$	$5.3^{+0.4}_{-0.4}$	$3.220^{+0.025}_{-0.025}$	5725^{+50}_{-50}	$0.071^{+0.097}_{-0.097}$	$11.388^{+0.008}_{-0.090}$	$0.760^{+0.015}_{-0.014}$	$1.14^{+0.27}_{-0.12}$
XCru	DR3(phot+RV)	$6.165^{+0.036}_{-0.036}$	$1.450^{+0.075}_{-0.075}$	$5.2^{+0.4}_{-0.4}$	$3.250^{+0.035}_{-0.035}$	5425^{+50}_{-50}	$0.122^{+0.084}_{-0.084}$	$10.93^{+0.07}_{-0.08}$	$0.66^{+0.06}_{-0.06}$	$1.08^{+0.09}_{-0.06}$
XVul	DR3(phot+RV);K	$6.278^{+0.054}_{-0.054}$	$1.45^{+0.05}_{-0.05}$	$6.2^{+0.4}_{-0.4}$	$3.330^{+0.025}_{-0.025}$	5500^{+25}_{-25}	$-0.051^{+0.075}_{-0.075}$	$10.16^{+0.02}_{-0.09}$	$2.087^{+0.033}_{-0.046}$	$1.113^{+0.108}_{-0.066}$
XXCen	DR3(phot);K;RV	$10.758^{+0.018}_{-0.018}$	$1.65^{+0.05}_{-0.05}$	$4.5^{+0.3}_{-0.3}$	$3.34^{+0.05}_{-0.05}$	5000^{+87}_{-87}	$0.427^{+0.082}_{-0.082}$	$10.81^{+0.01}_{-0.01}$	$0.296^{+0.017}_{-0.017}$	$1.22^{+0.29}_{-0.26}$
XZCar	DR3(phot);RV	$16.481^{+0.128}_{-0.128}$	$1.60^{+0.05}_{-0.05}$	$7.60^{+0.25}_{-0.25}$	$3.71^{+0.03}_{-0.03}$	4950^{+75}_{-75}	$0.013^{+0.054}_{-0.054}$	$11.935^{+0.068}_{-0.055}$	$0.780^{+0.081}_{-0.079}$	$1.16^{+0.05}_{-0.11}$
SVVul	DR3(phot+RV)	$45.770^{+0.585}_{-0.585}$	$1.45^{+0.05}_{-0.05}$	$10.0^{+0.5}_{-0.5}$	$4.16^{+0.05}_{-0.05}$	4550^{+125}_{-125}	$0.090^{+0.067}_{-0.067}$	$11.458^{+0.137}_{-0.085}$	$0.77^{+0.12}_{-0.18}$	$1.06^{+0.062}_{-0.015}$
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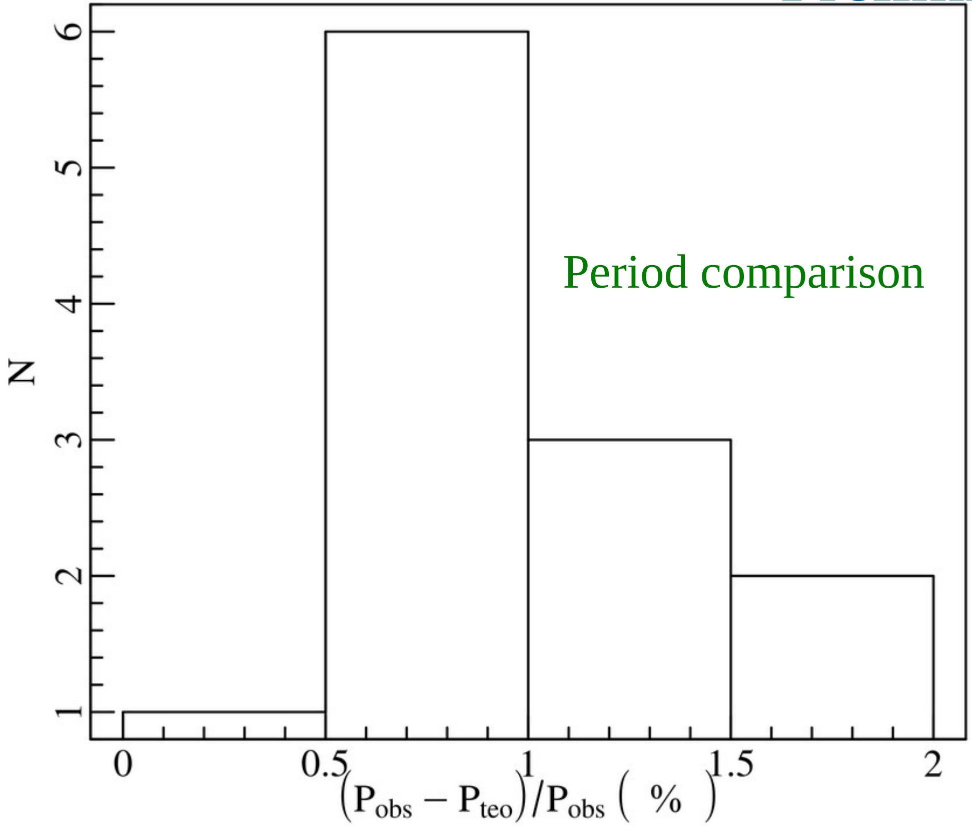
Preliminary results



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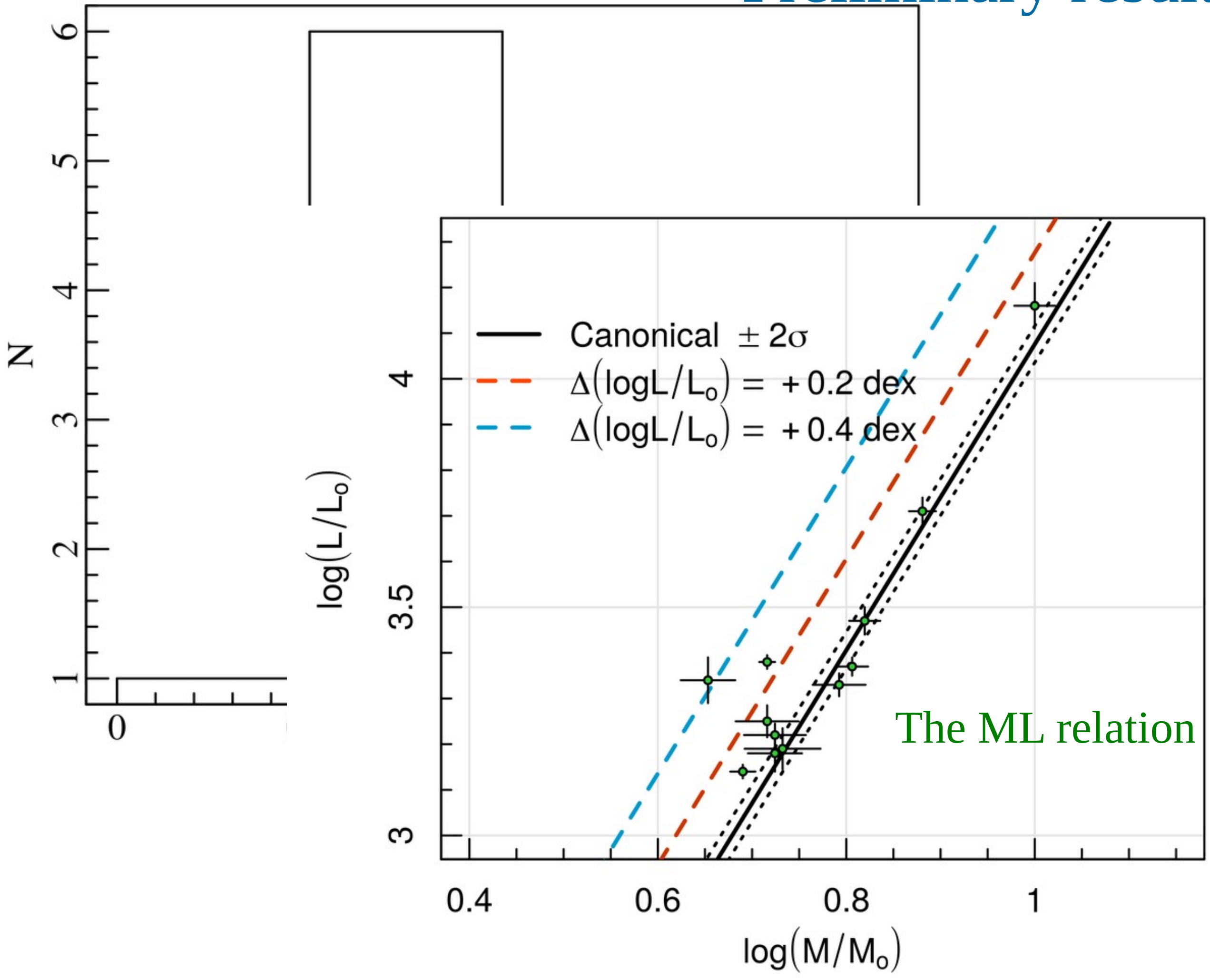
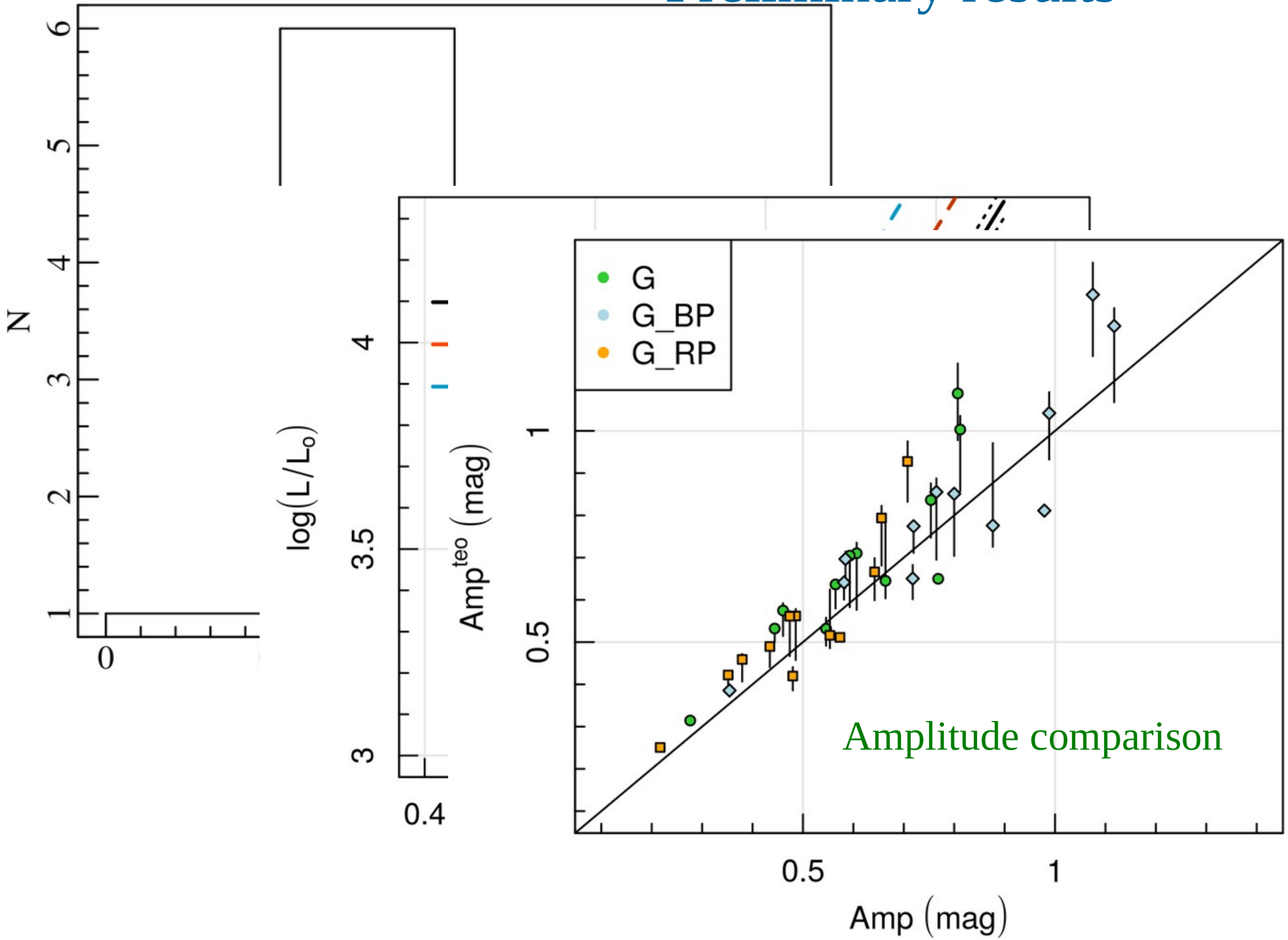


The ML relation

Preliminary results



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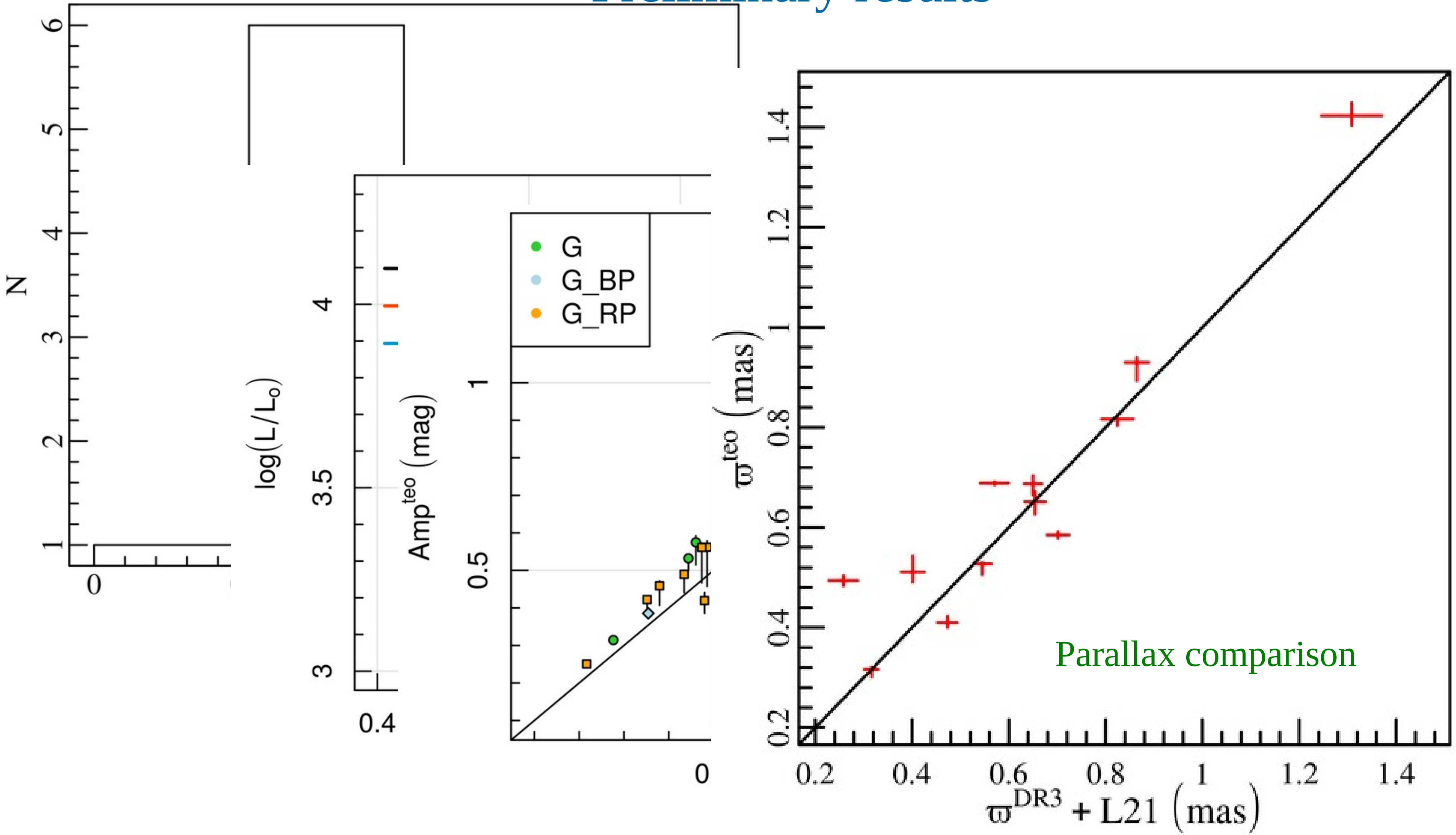

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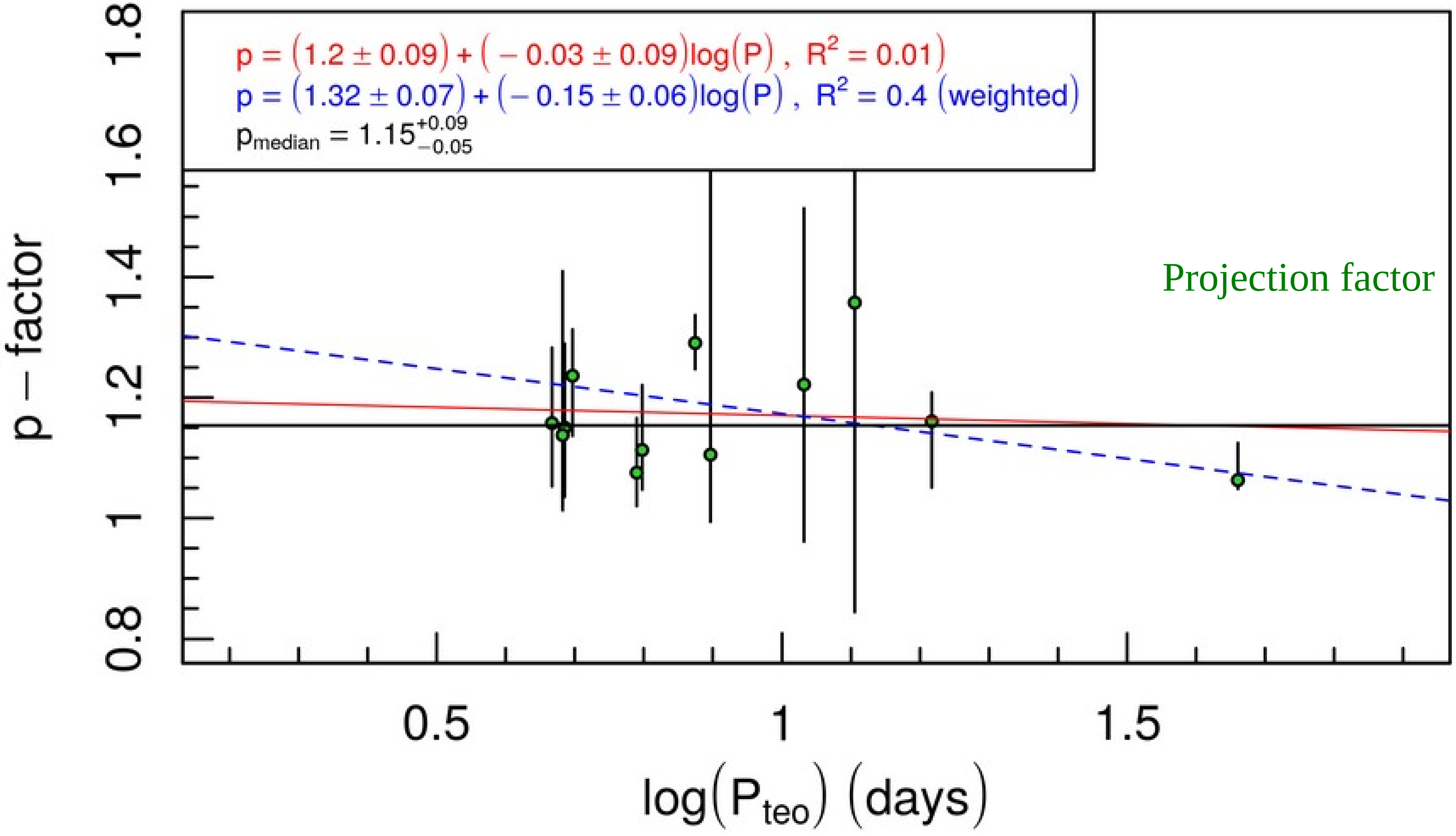

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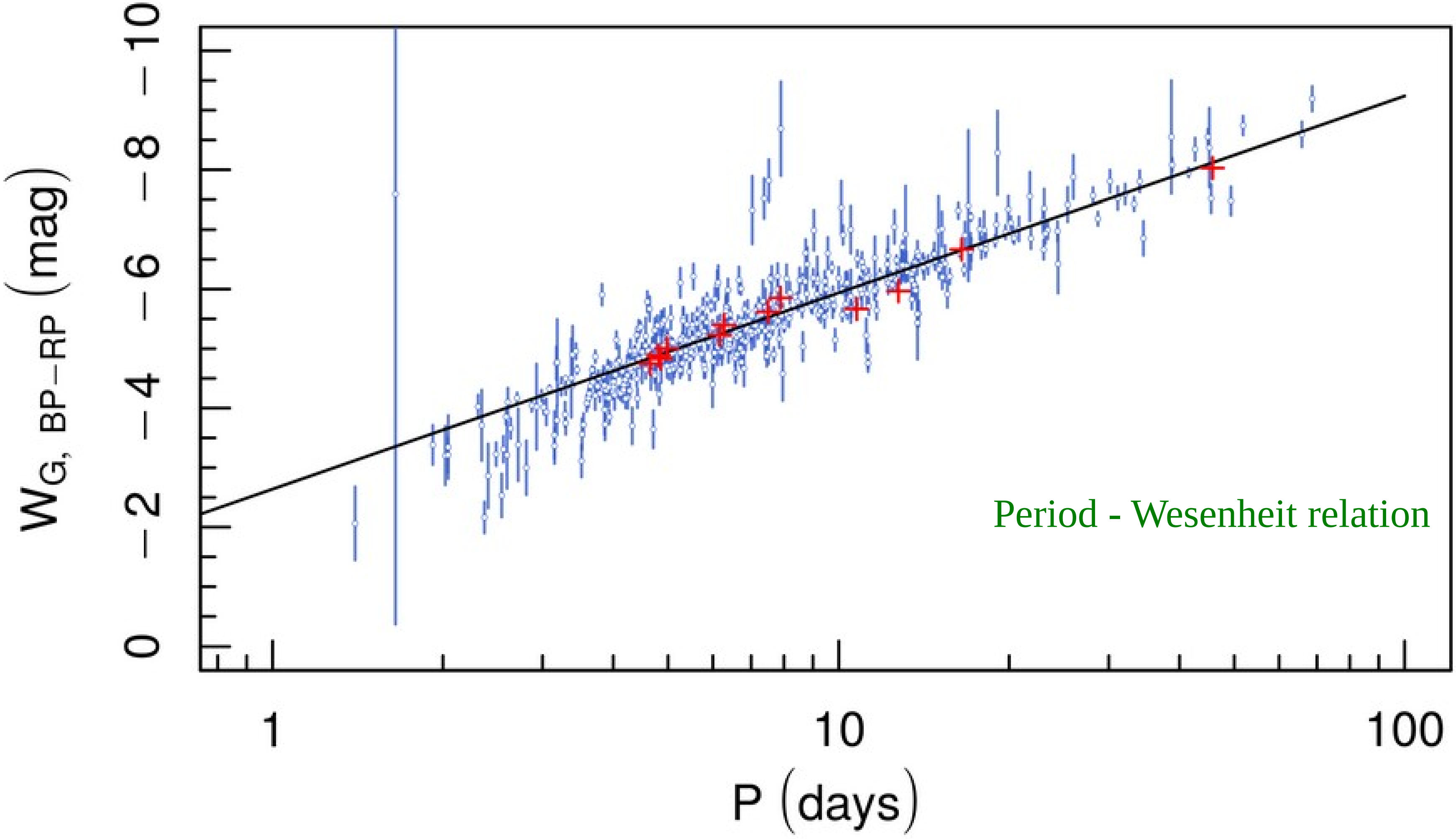

Conclusions

1) Non-linear hydrodynamical convective models are able to predict light and radial velocity curves of pulsating variables.

2) Traditional model fitting procedure is updated with Monte Carlo simulations

3) The method is applied to MW Classical Cepheids from the Gaia database

4) Preliminary results provide intrinsic stellar properties and good agreement with independent evaluations.

5) The sample needs to be enlarged in order to provide more conclusive results concerning the projection factor trend with period.