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Constraining helium abundances with precise binary parameters

Jessica Kirkby-Kent

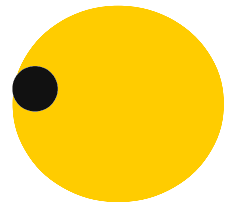
Collaborators: P.F.L. Maxted, A.M. Serenelli, D.R. Anderson, C. Hellier, R.G. West
Astrophysics Group, Keele University, Keele, Staffordshire, ST5 5BG, UK

Image from: http://planetxnews.com/2015/10/17/our-sun-has-a-twin-companion-star/

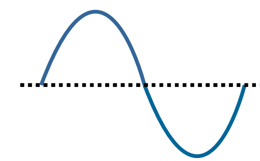
What's this got to do with planets?

To understand the planet you must understand the star

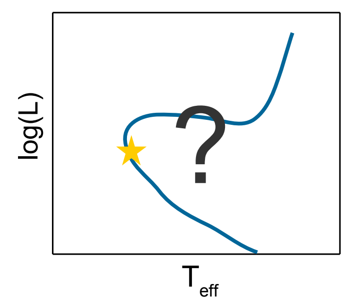
Transit



Planet radius compared to star



RV for mass ratio



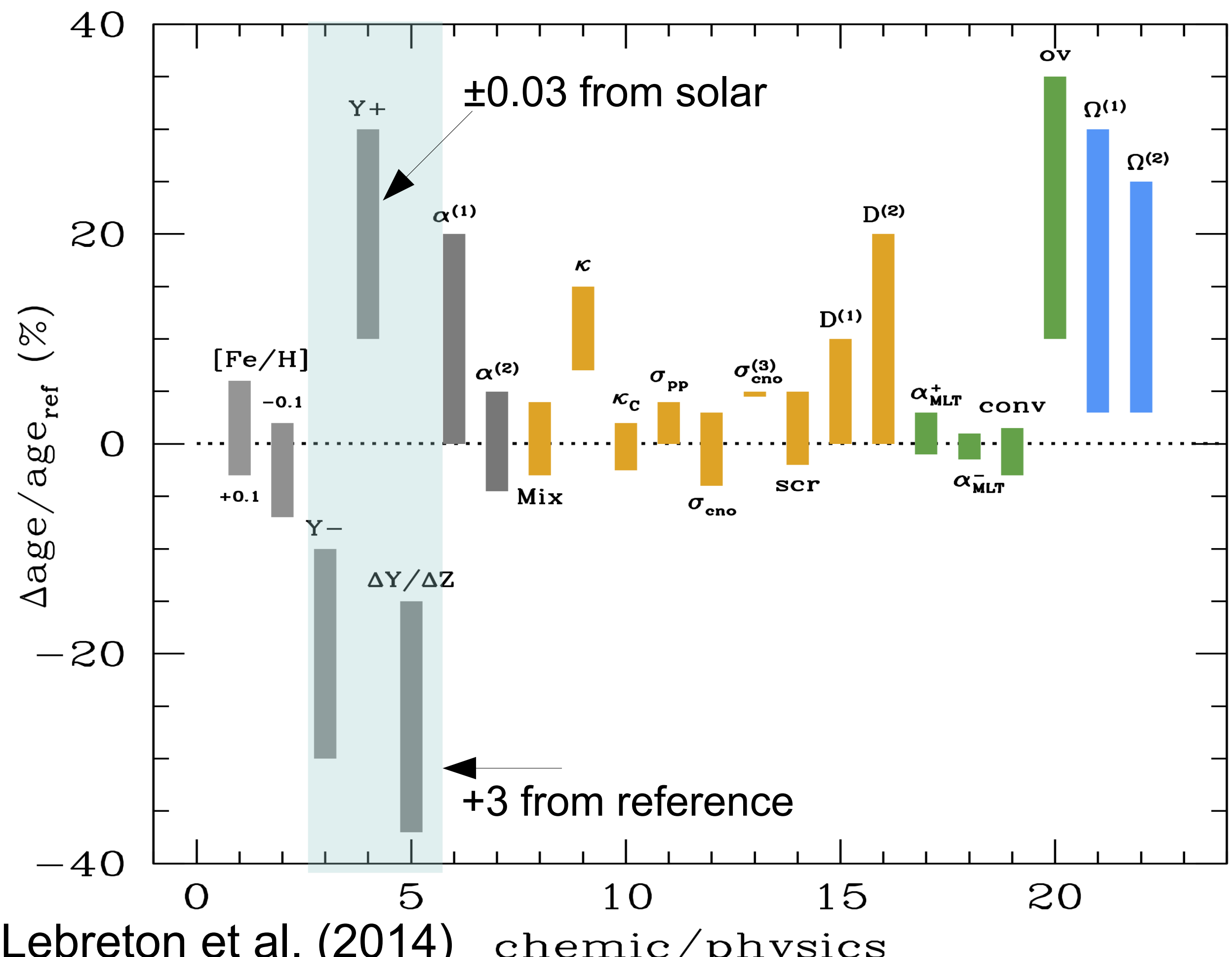
Star/planet parameters

- Want to understand planetary environment, now and in the past

- Stellar evolutionary models used to find the mass and age of a planet-host star.

Physics in the models

> *"To borrow a line from the poet Godfrey Saxe, isochrones, like sausages, cease to inspire respect in proportion as we know how they are made."*
> A. Dotter



Lebreton et al. (2014)

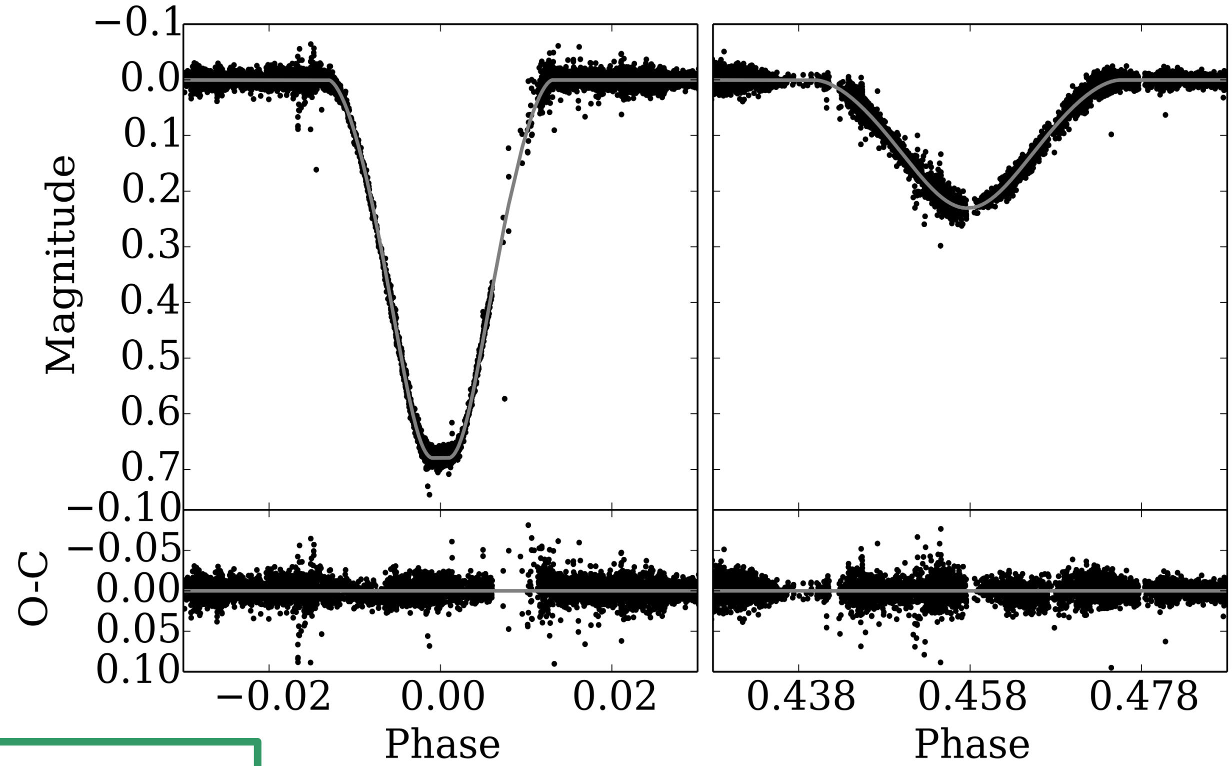
- Complex prescriptions with calibrated free parameters.
- Free parameter poorly constrained by observations. Large sources of uncertainty

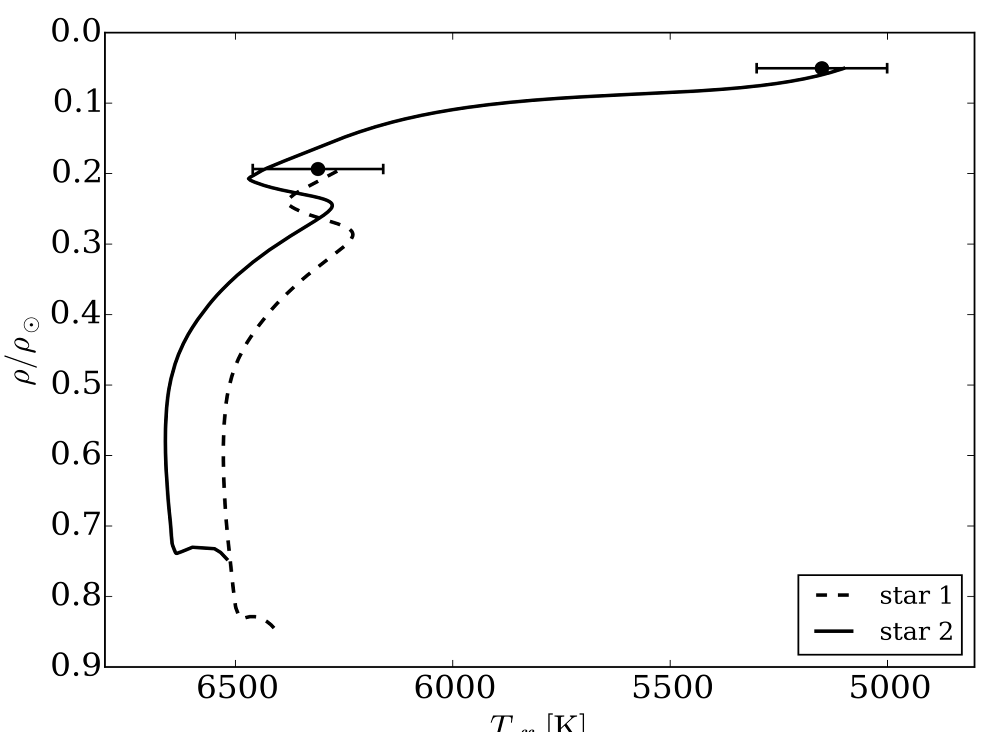
- Use detached eclipsing binary systems, with precise parameters to calibrate these free parameters.

AI Phe

- 0.31% uncertainty in masses.

- 0.76% in R_1, 0.48% in R_2.

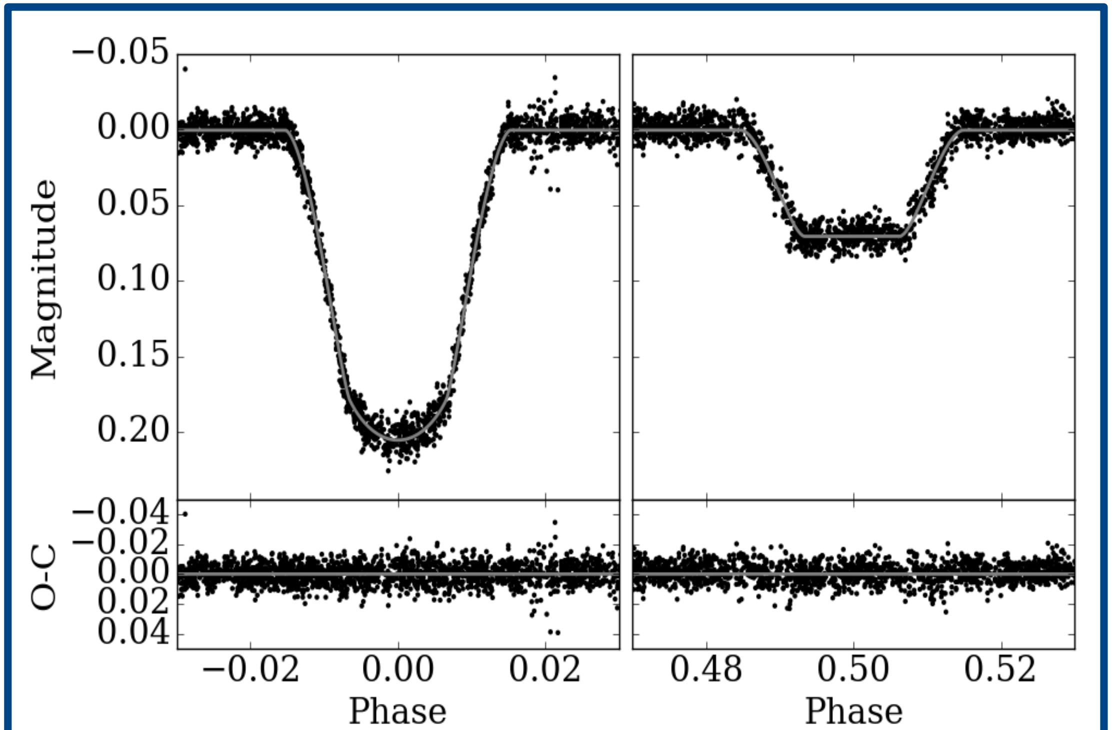


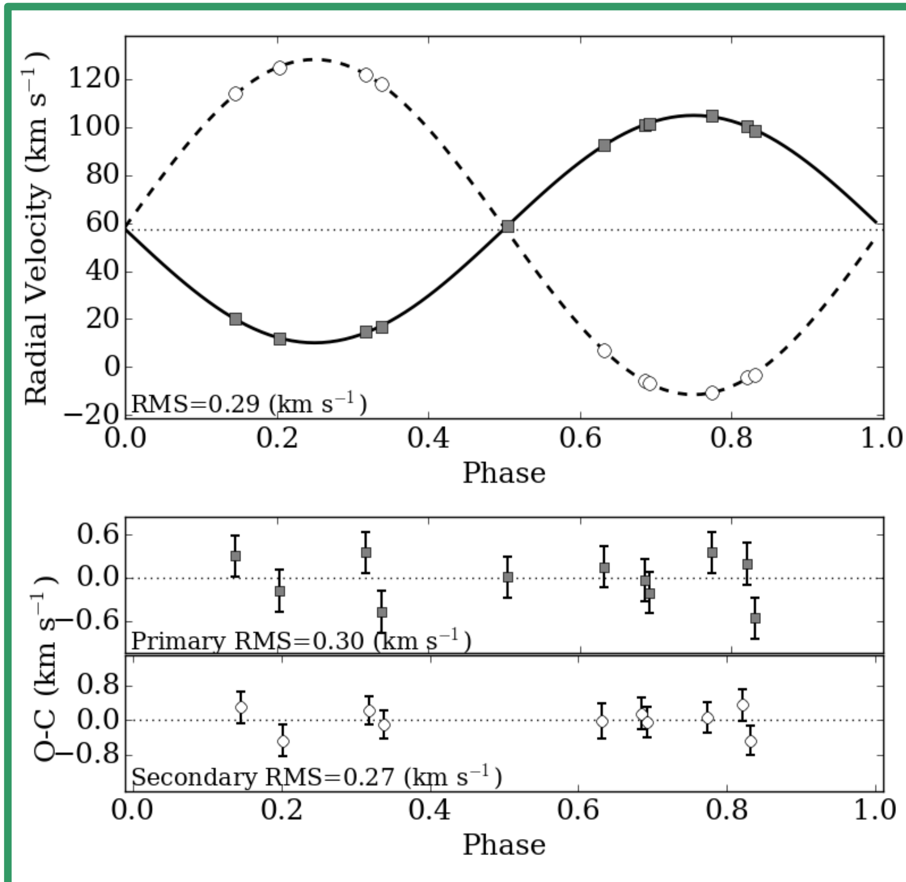


Parameter	Star 1	Star 2
M ($M_\odot$)	1.1973(37)	1.2473(39)
R ($R_\odot$)	1.835(14)	2.912(14)
$T_{\rm eff}$ (K)	6310±150	5010±120
[Fe/H]	-0.14±0.1	

More details in Kirkby-Kent et al. (2016)

WASP 0639-32





- 0.37% uncertainty in masses, 1.3% R_1 and 1.1% in R_2

Parameter	Star 1	Star 2
M ($M_\odot$)	1.1544(43)	0.7833(28)
R ($R_\odot$)	1.834(23)	0.7291(81)
T_{eff} (K)	6430±80	5300±65
[Fe/H]	-0.17±0.08	-0.18±0.07

Kirkby-Kent et al. submitted

Stellar Evolutionary Models

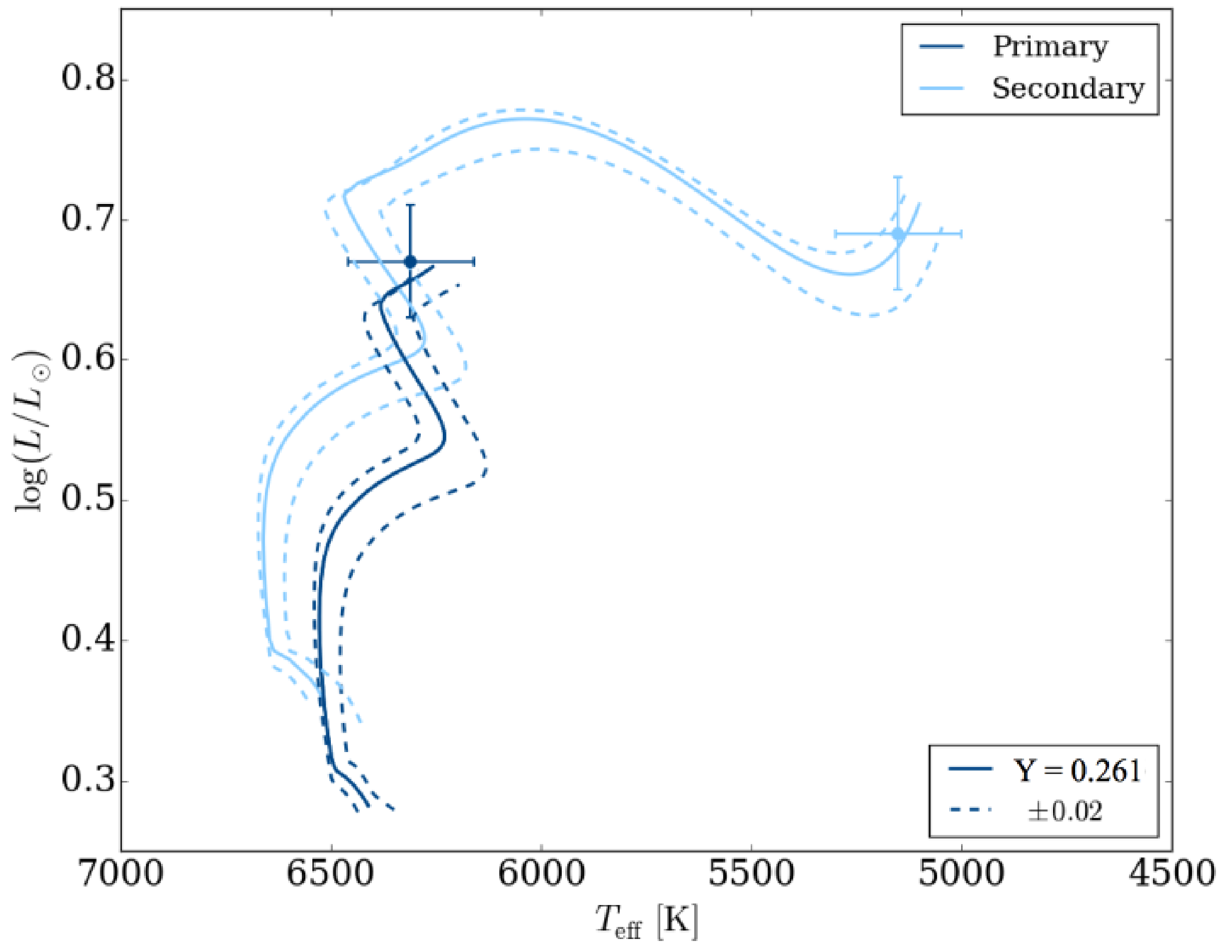
- Use GARSTEC stellar evolution code.
- Code used in Bagemass for fitting planet host stars.
- MCMC procedure to fit observed parameters for different initial helium abundances.

- Models used for AI Phe only allow either the mixing length or helium abundance to be explored.
- Fitted parameters: T_1, T_2/T_1, ρ_1, ρ_2, M_2/M_1, M_{sum}, $[Fe/H]_s$

- For WASP 0639-32, mixing length fitted for each initial helium abundance.
- Fitted parameters: T, ρ, M, $[Fe/H]_s$ for each star.

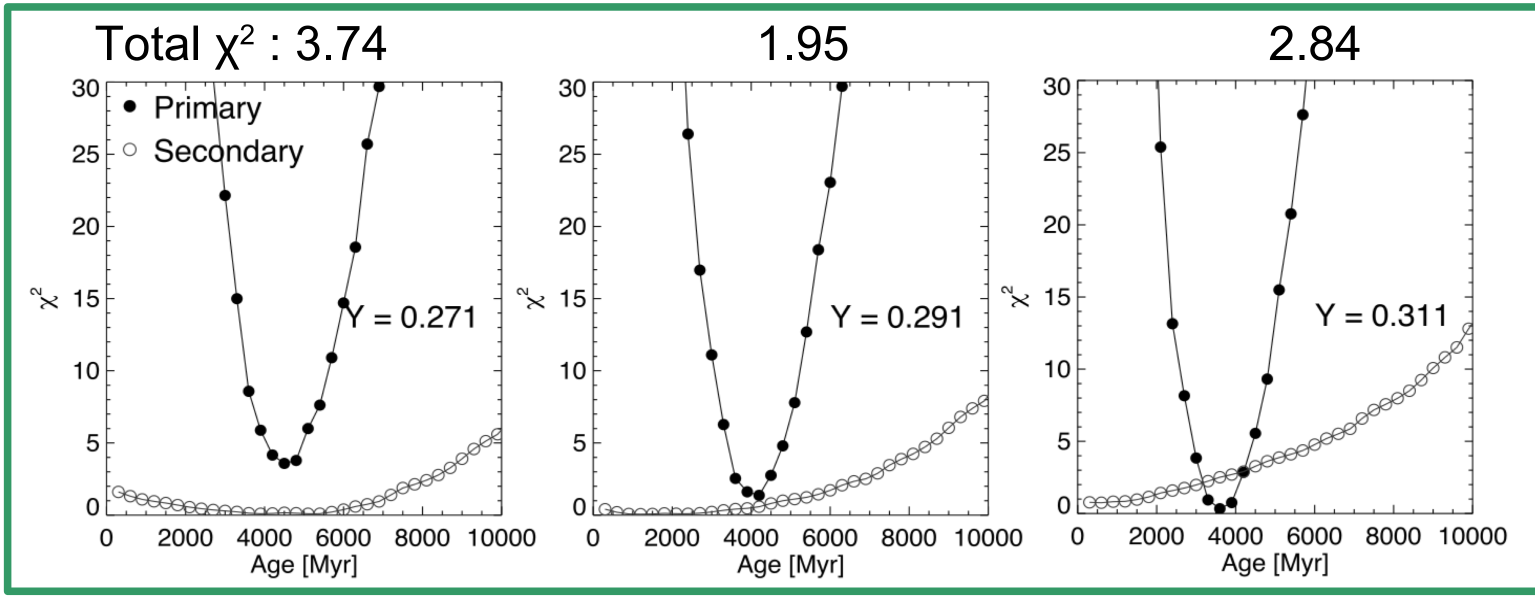
AI Phe: Stellar Models

α_{ml}	ΔY	τ_{best} (Gyr)	χ^2
1.22	0.00	3.47	32.8
1.36	0.00	3.60	21.7
1.50	0.00	5.03	16.4
1.78	0.00	4.39	2.4
2.04	0.00	4.02	6.5
2.32	0.00	3.77	20.0
1.78	–0.05	4.95	41.0
1.78	–0.04	4.71	28.5
1.78	–0.03	4.52	20.0
1.78	–0.02	4.63	9.1
1.78	–0.01	4.47	4.1
1.78	0.00	4.39	2.4
1.78	0.01	4.34	3.2
1.78	0.02	4.27	5.2
1.78	0.03	4.17	8.2
1.78	0.04	4.06	11.7
1.78	0.05	3.91	15.5

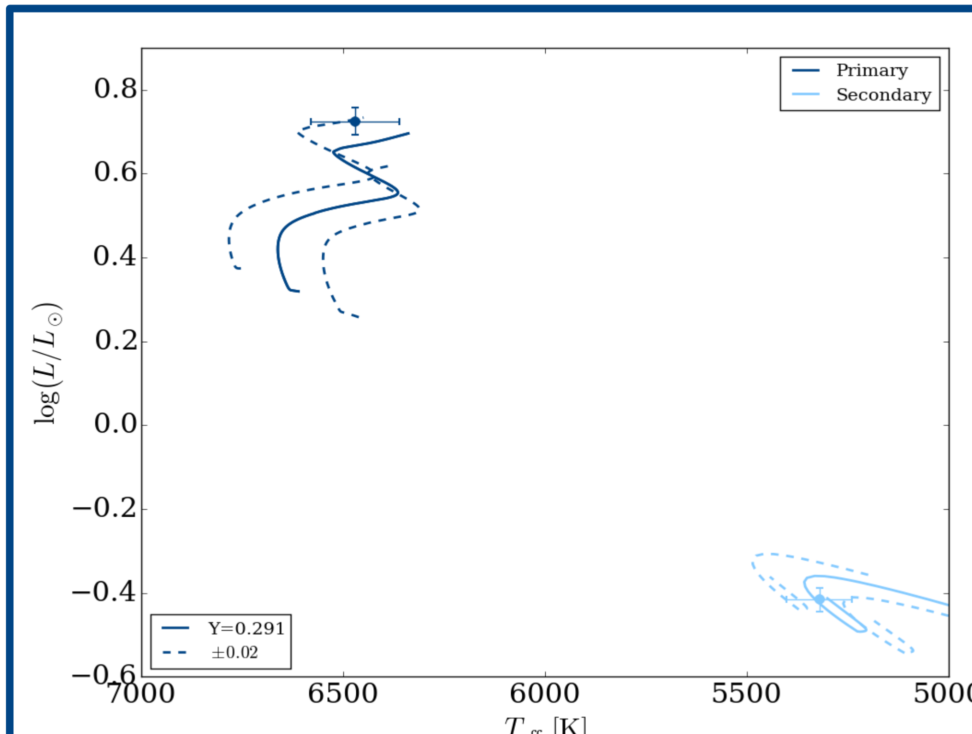


- Doesn't explore all options, there could be a better solution in the parameter space

WASP 0639-32: Stellar Models



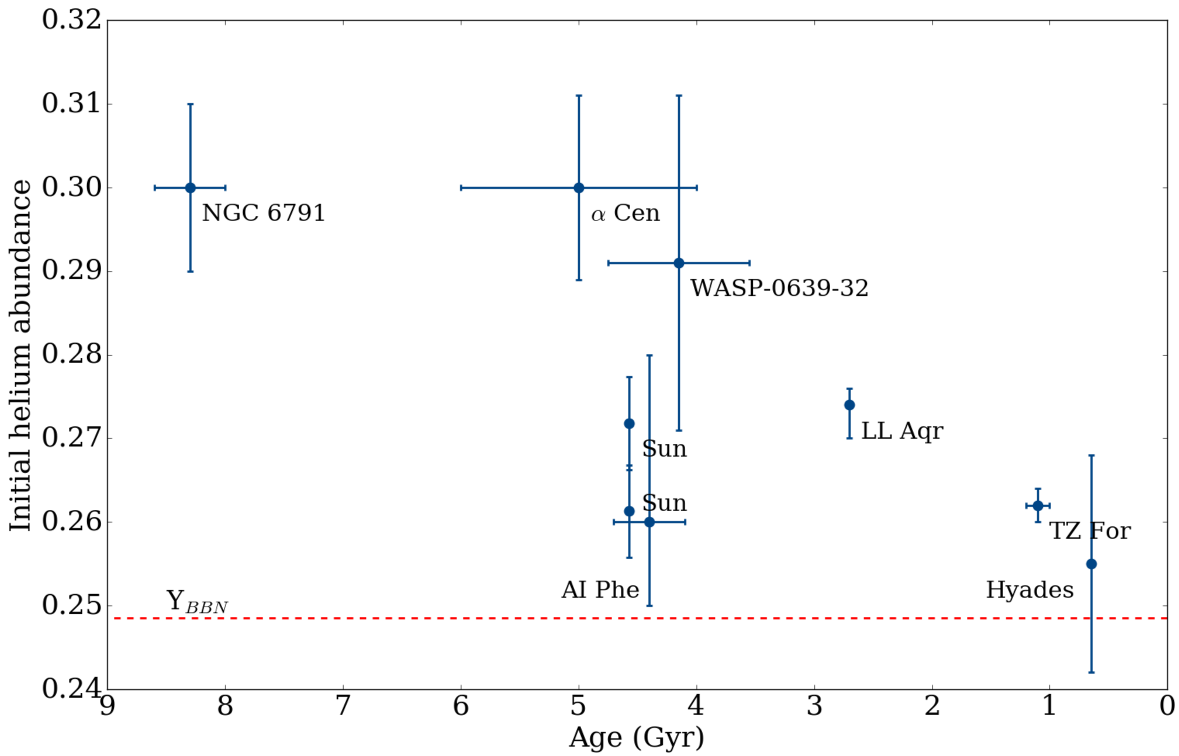
Parameter	Y_i 0.231	0.251	0.271	0.291	0.311	0.331
τ_{best} (Gyr)	5.38	5.09	4.47	4.15	3.58	3.30
T_1 (K)	6275	6276	6333	6368	6446	6473
M_1 $(M_\odot)$	1.1758	1.1692	1.1713	1.1561	1.1557	1.1481
R_1 $(R_\odot)$	1.7963	1.7916	1.8106	1.8219	1.8468	1.8634
ρ_1 $(\rho_\odot)$	0.2024	0.2028	0.1971	0.1908	0.1831	0.1772
α_{ml_1}	2.058	2.056	2.019	2.020	1.917	1.875
χ^2_1	10.31	6.37	3.58	1.37	0.33	0.16
T_2 (K)	5169	5176	5200	5246	5296	5312
M_2 $(M_\odot)$	0.8002	0.7947	0.7814	0.7697	0.7612	0.7489
R_2 $(R_\odot)$	0.7349	0.7336	0.7265	0.7248	0.7247	0.7217
ρ_2 $(\rho_\odot)$	2.0123	2.0072	2.0317	2.019	1.9958	1.9874
α_{ml_2}	2.035	2.031	1.960	1.871	1.769	1.700
χ^2_2	4.04	1.13	0.16	0.58	2.51	5.92
χ^2_{tot}	14.35	7.50	3.74	1.95	2.84	6.08



Helium abundance

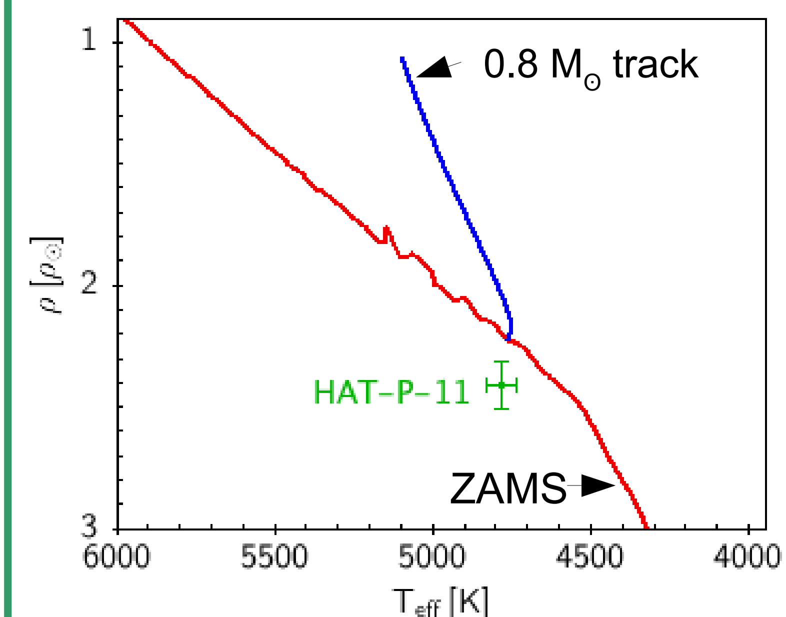
AI Phe: $Y_{ini} = 0.261^{+0.02}_{-0.01}$

WASP 0639-32: $Y_{ini} = 0.291 \pm 0.02$



- Different standard solar models, or different enrichment?

- Requires high helium abundance models



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Summary

- With high-precision masses, radii and temperatures, it is possible to constrain the initial helium abundance in stellar evolutionary models.

- Very few system currently met the required precision, but we are working to obtain more systems.

- There is a lot of uncertainty in how the initial helium abundance in the evolutionary models is calibrated, and it varies between different evolutionary codes.

- Ultimately this is going to be affecting the ages of planet-host stars, and further work will be needed to understand why some planet-hosts (HAT-P-11) have such high helium abundances.