



PLATO STESCI — Prospects from eclipsing binaries

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The PLATO challenge ...

“Some corrections for systematics errors are needed to reach the PLATO specification for stellar ages”

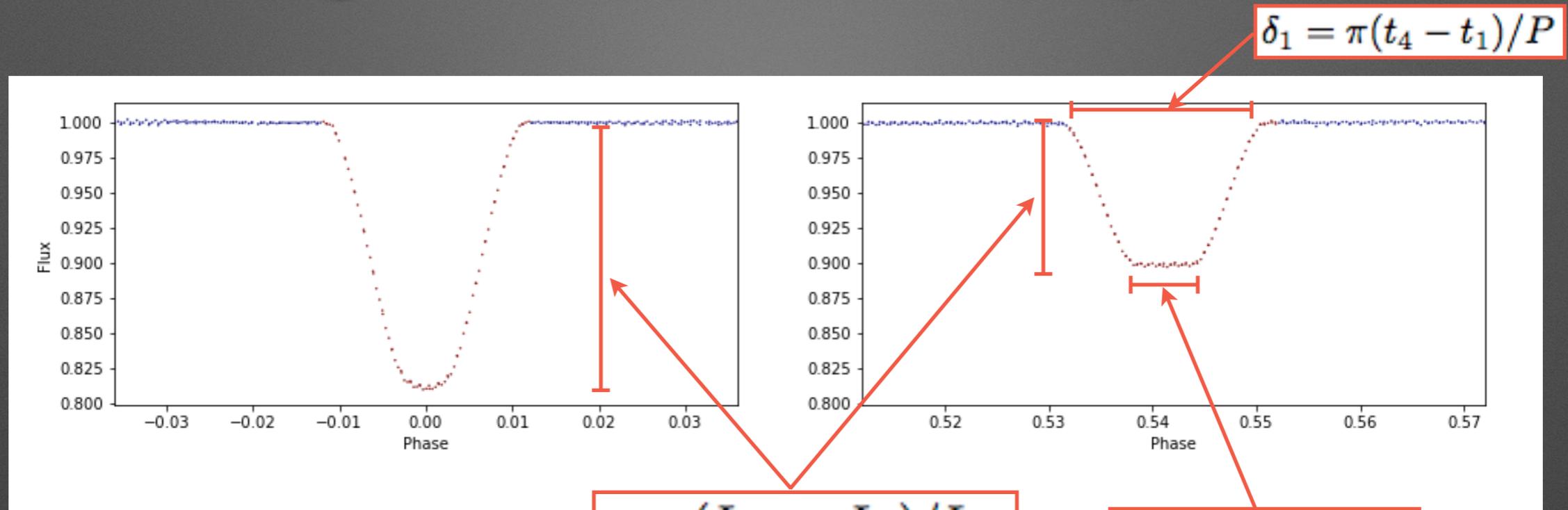
Marie-Jo Goupil (PLATO Stellar science lead)
Goupil, M. et al., 2017EPJWC.16001003G

Aim of this talk

To persuade you that ...

- ... detached eclipsing binary stars (DEBS) are the best option for correcting systematic errors in PLATO ages for dwarf stars,
- ... the work to find suitable DEBS should start now,
- ... so DEBS should be seen as part of the core sample.

Light curve analysis

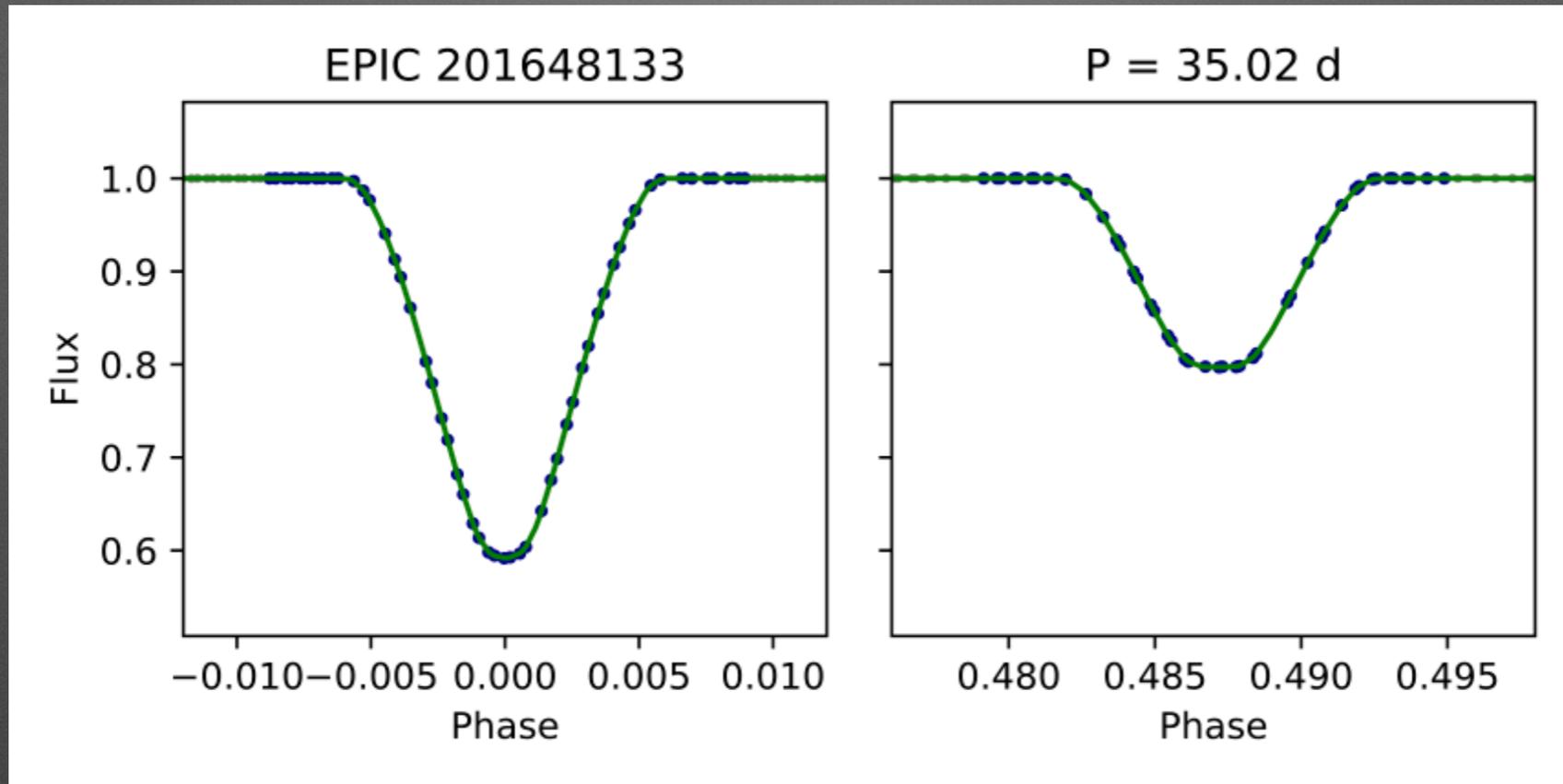


$$r_1 = \frac{1}{2\sqrt[4]{\epsilon}} \sqrt{\sin^2(\delta_1) - \sin^2(\delta_2)}$$

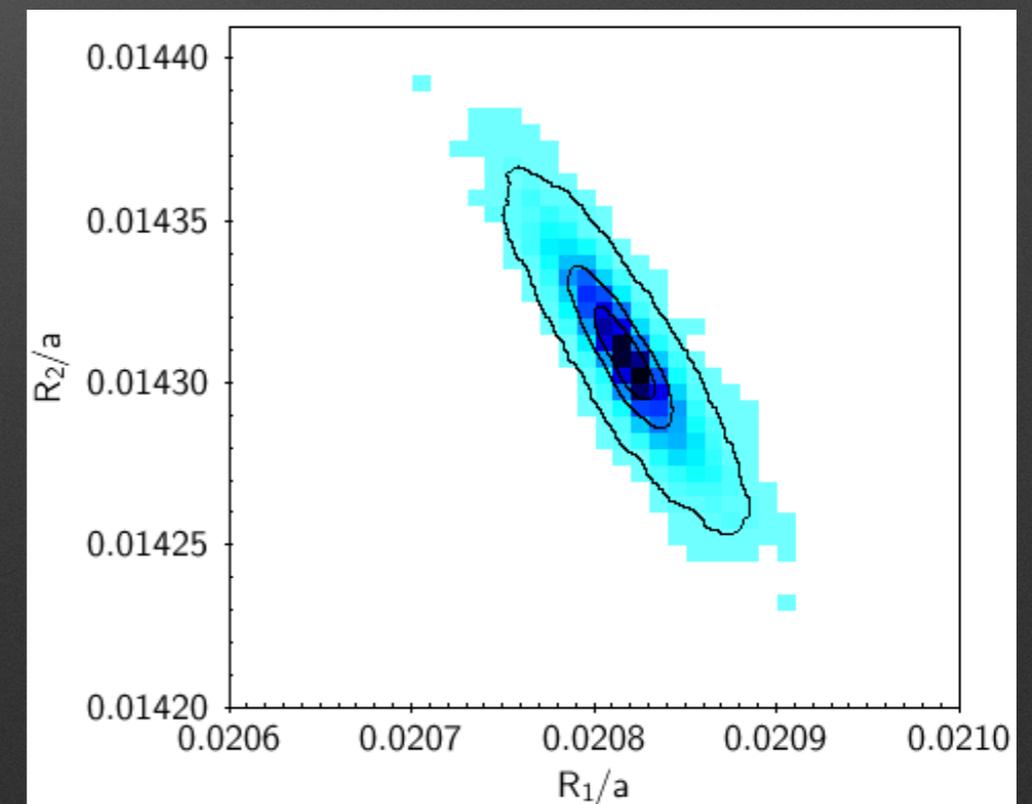
$$r_2 = \frac{\sqrt[4]{\epsilon}}{2} \sqrt{\sin^2(\delta_1) - \sin^2(\delta_2)}$$

- Light curve gives $r_1 = R_1/a$, $r_2 = R_2/a$, i , $e \cos \omega$, $e \sin \omega$
- Narrow total eclipses $\Rightarrow i \simeq 90^\circ$
- Deep partial eclipses give similar accuracy

Example — EPIC 201648133



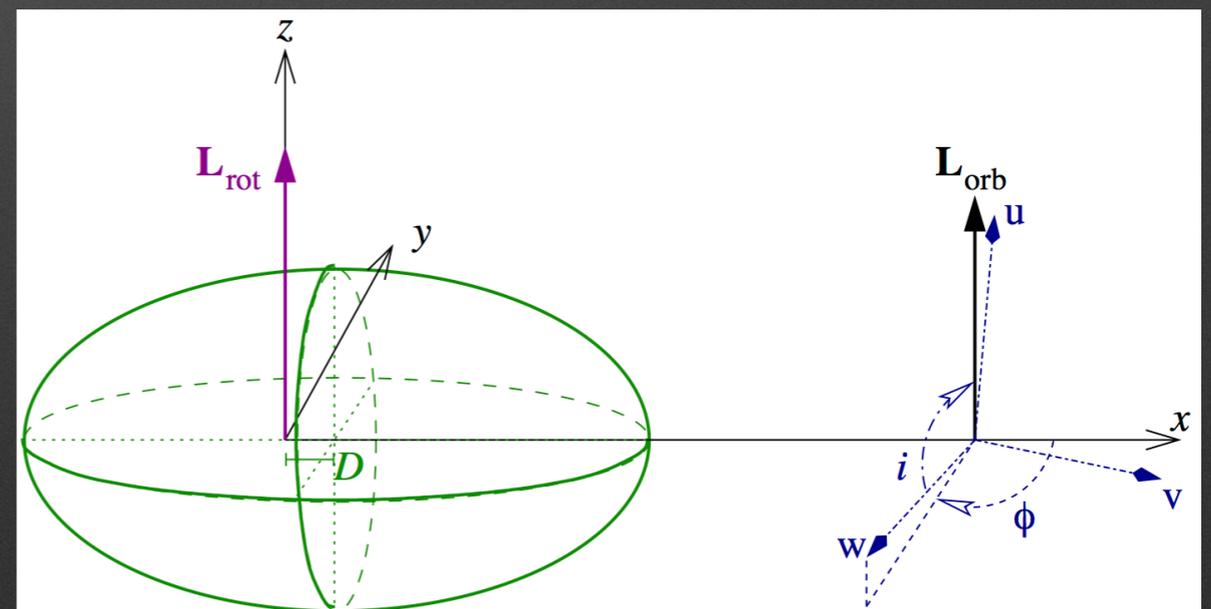
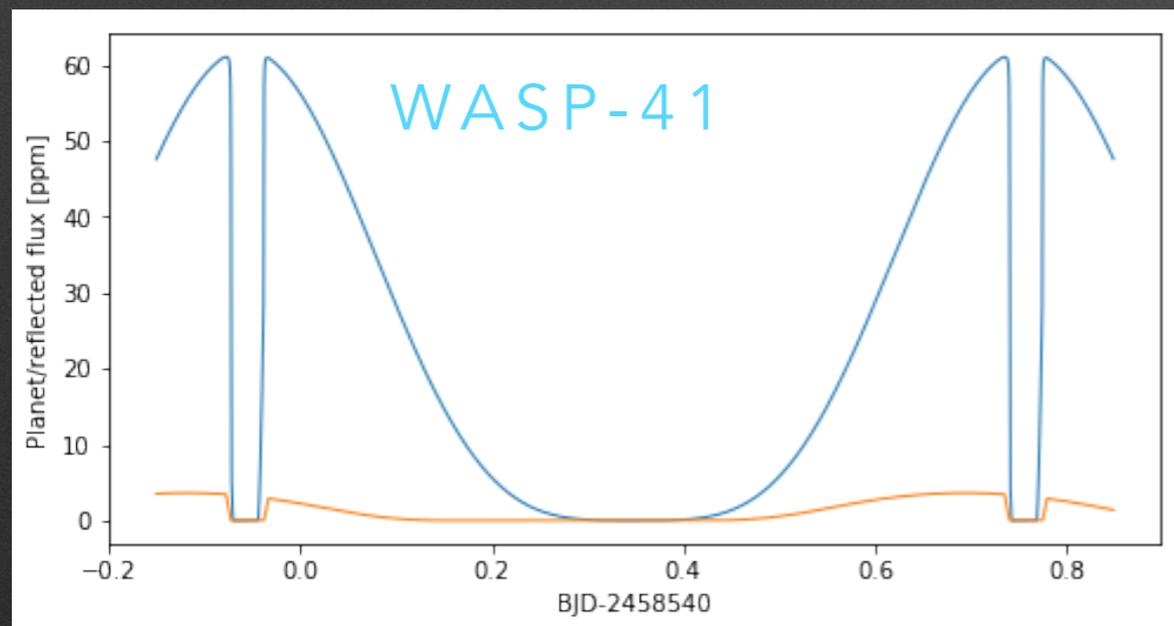
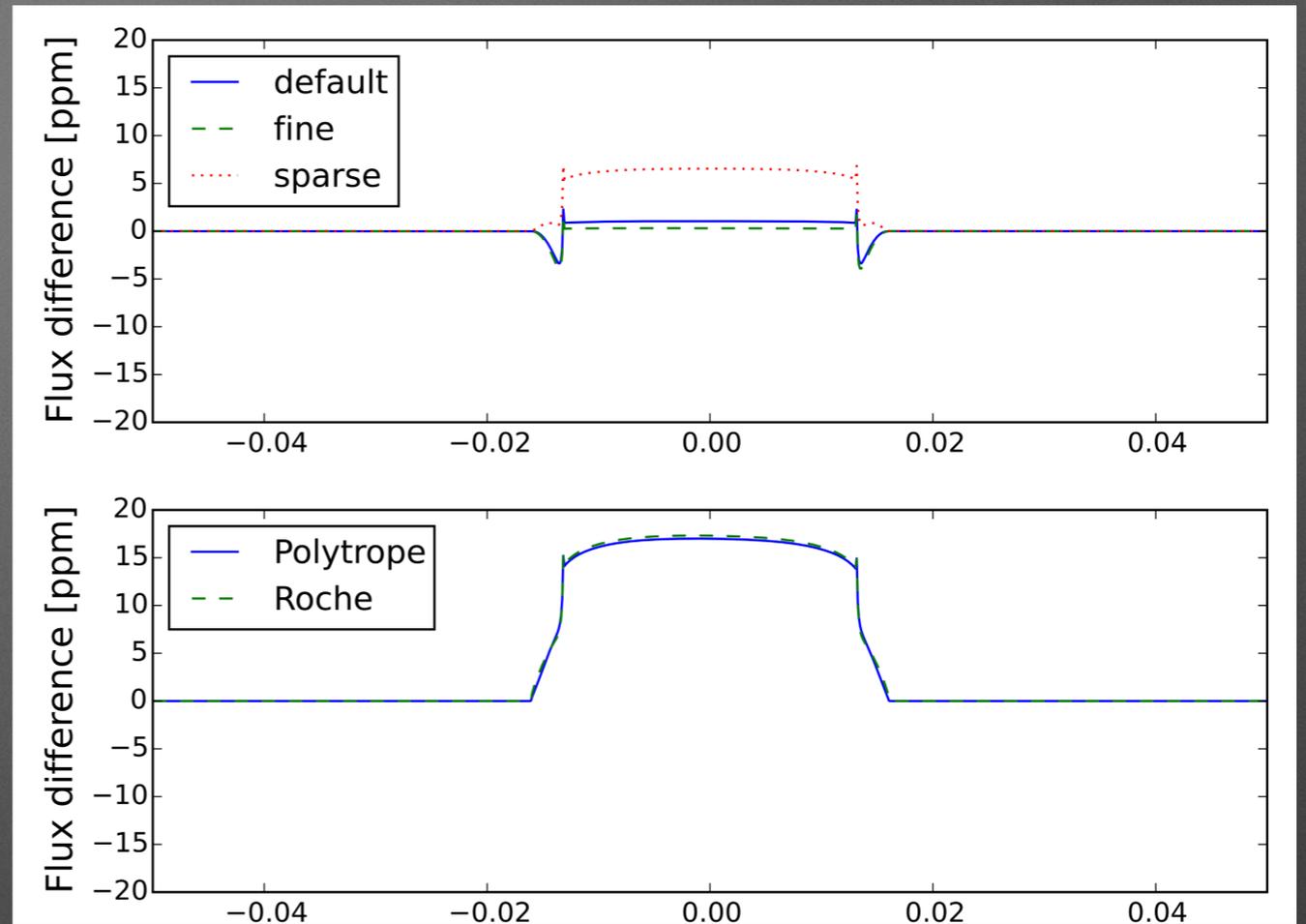
- $P = 35.0\text{d}$
- $K_p = 10.1\text{ mag}$
- $R_1/a = 0.02082 \pm 0.000002$
- $R_2/a = 0.01431 \pm 0.000001$
- $\Delta m = 1.48$



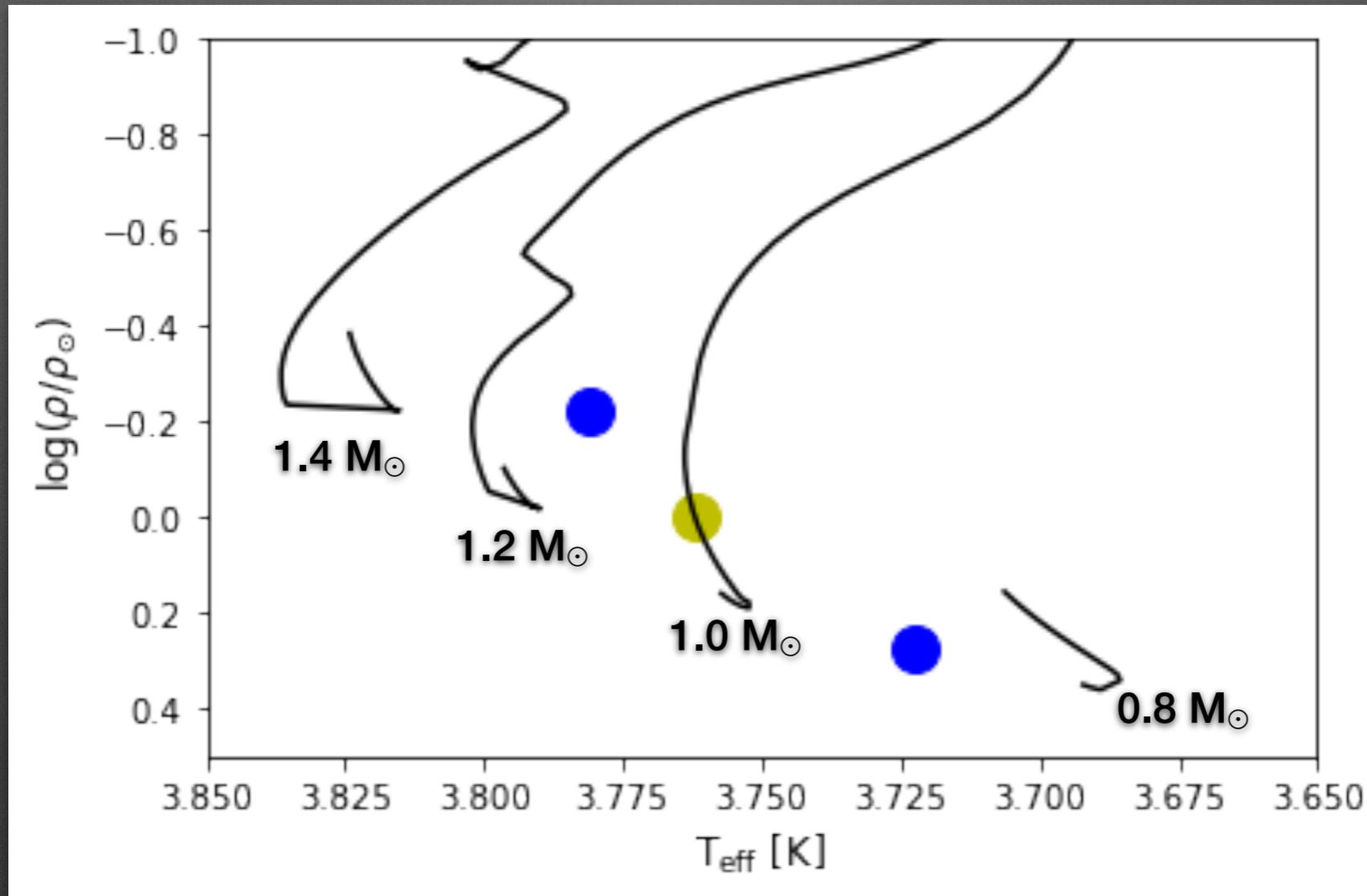
ellic

- Doppler boosting
- Light travel time effect
- Gravity darkening
- Reflection
- Spots
- Fast!

\$ pip install ellic



Example — EPIC 201648133



$$\rho_{\star} = \frac{3M_{\star}}{4\pi R_{\star}^3} = \frac{3\pi}{GP^2(1+q)} \left(\frac{a}{R_{\star}}\right)^3$$

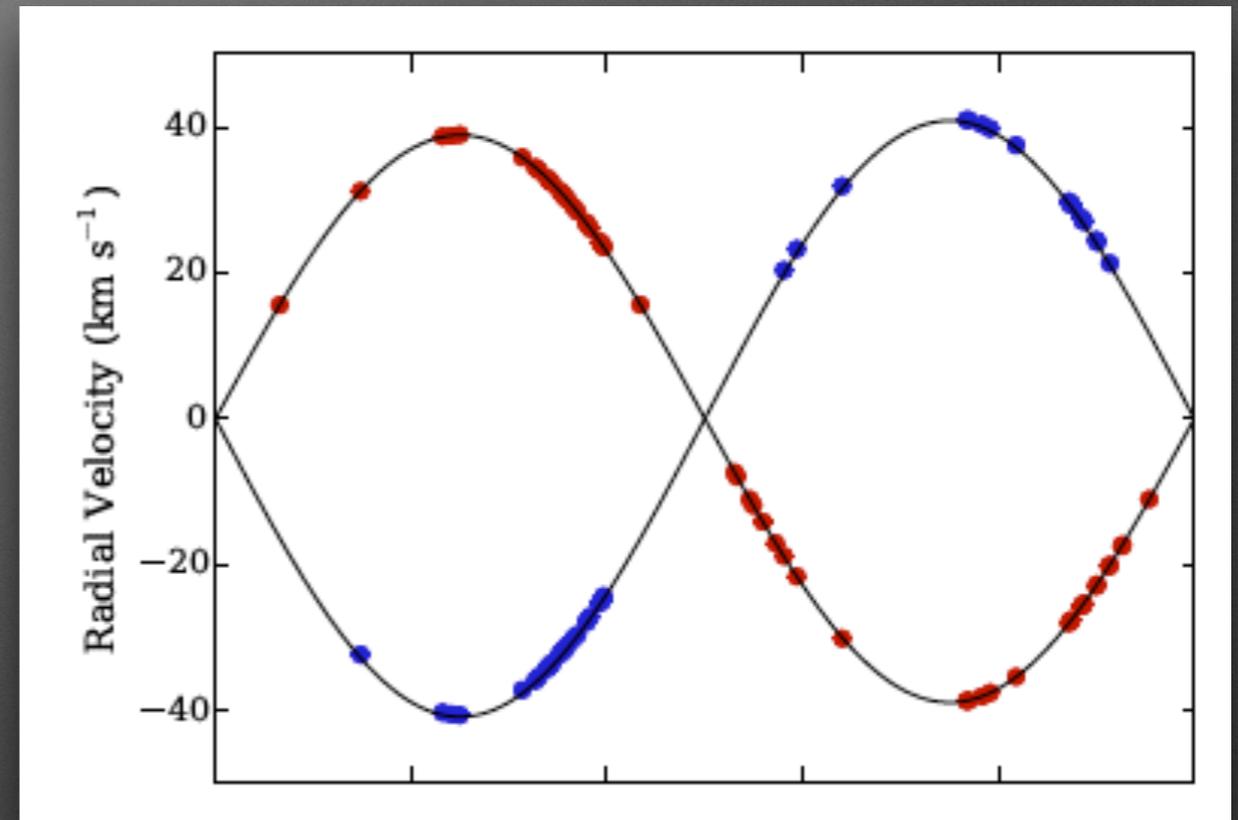
Precision mass measurements

< 1% error in mass generally straightforward if ...

- flux ratio $\gtrsim 10\%$ (SB2)
- stars rotate slowly
 - narrow lines
 - low magnetic activity

Requires

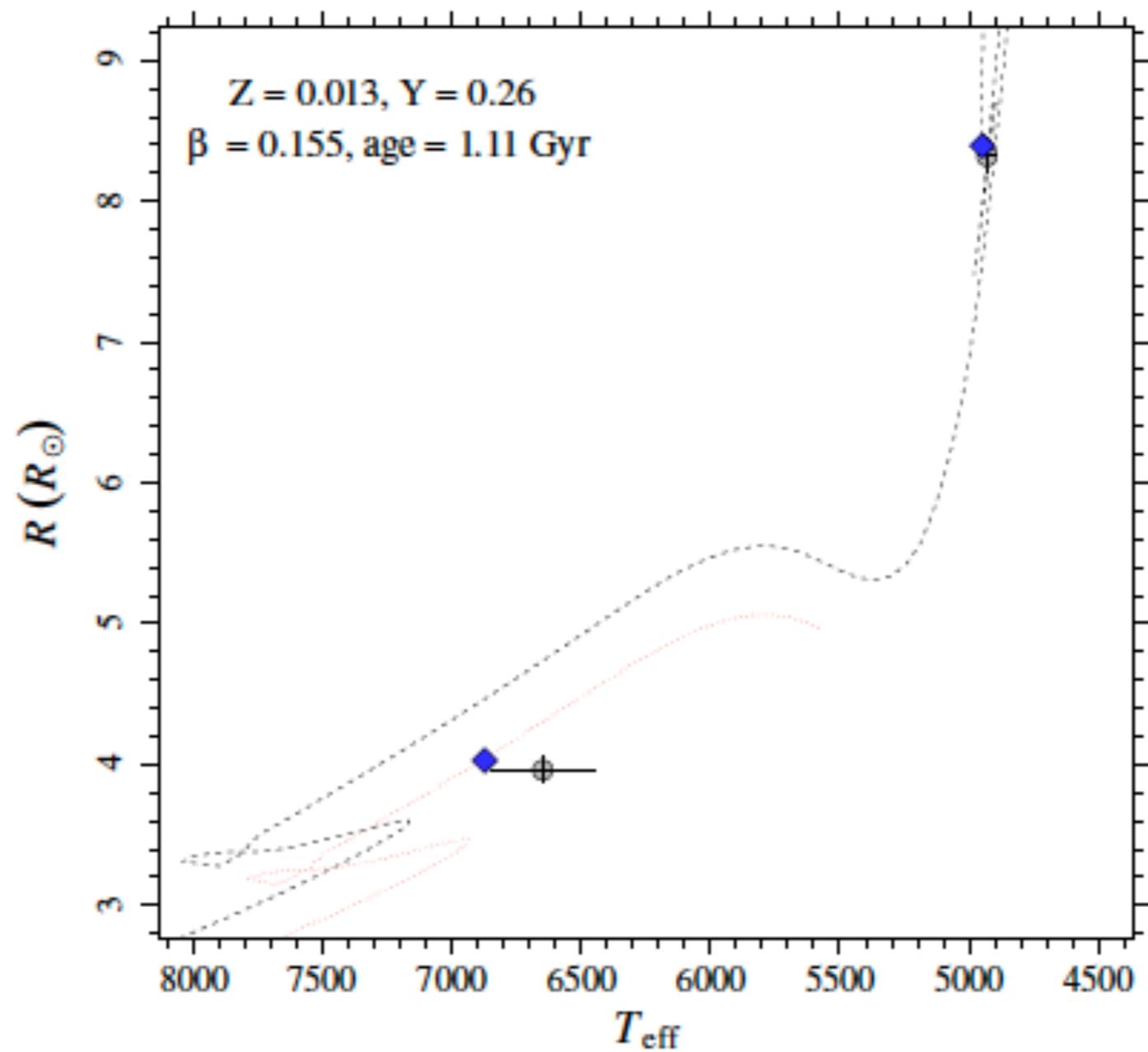
- medium-size telescope
- echelle spectrograph
- ~10+ spectra around the orbit



Ideal case TZ For, HARPS

- $M_1 = 2.057 \pm 0.001 M_\odot$
- $M_2 = 1.958 \pm 0.001 M_\odot$
- $N_{\text{obs}} = 55$

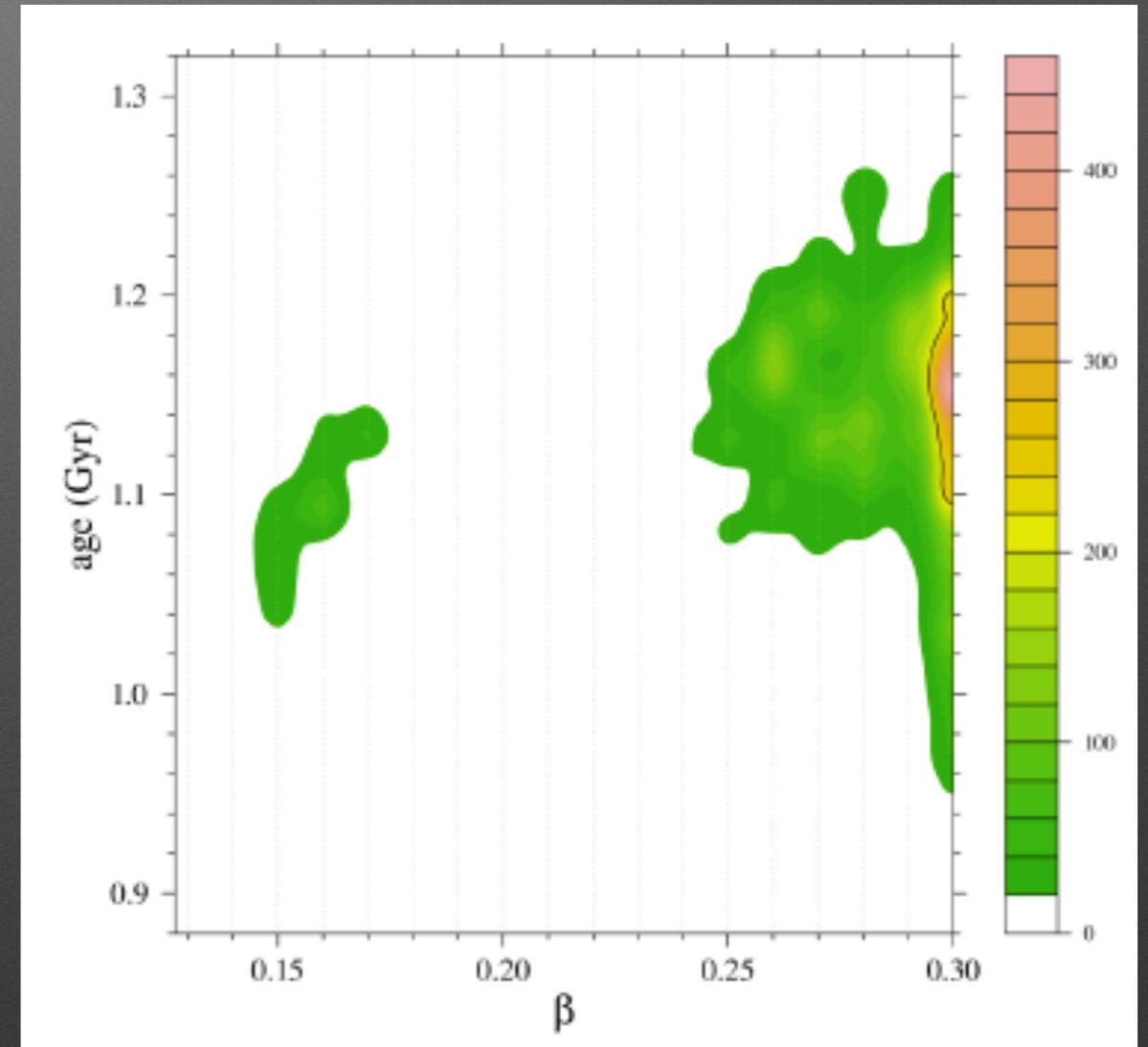
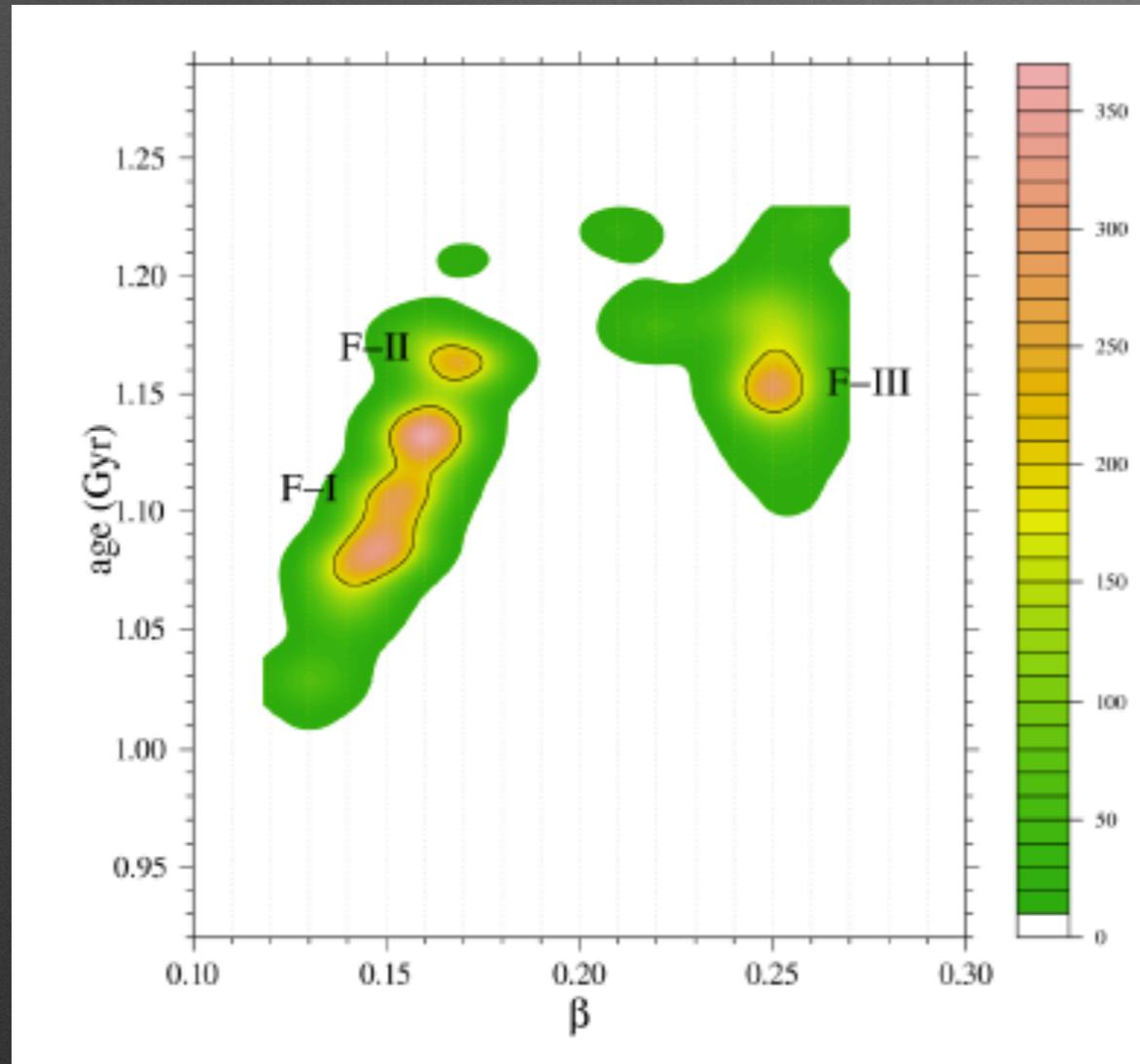
TZ For



TZ For - mass error effect

0.1% mass error

1% mass error



β = “convective overshooting” parameter

Testing v. calibration

Testing

$N_{\text{obs}} < N_{\text{df}}$, e.g. “twin stars”

- $N_{\text{obs}} = 3$ or 4
 - $\langle M \rangle$, $\langle R \rangle$, $\langle T_{\text{eff}} \rangle$, $[\text{Fe}/\text{H}]$
- $N_{\text{df}} = 5$ or 6
 - τ , M , Z_i , Y_i , α_{MLT} , β

Should always be possible to get a good fit, but not clear which parameter is the problem if not

Calibration

$N_{\text{obs}} \geq N_{\text{df}}$, e.g. TZ For, Al Phe

- $N_{\text{obs}} = 7$
 - $M_{1,2}$, $R_{1,2}$, $T_{\text{eff};1,2}$, $[\text{Fe}/\text{H}]$
- $N_{\text{df}} = 6$ or 7
 - M_1 , M_2 , Z_i , Y_i , α_{MLT} , β

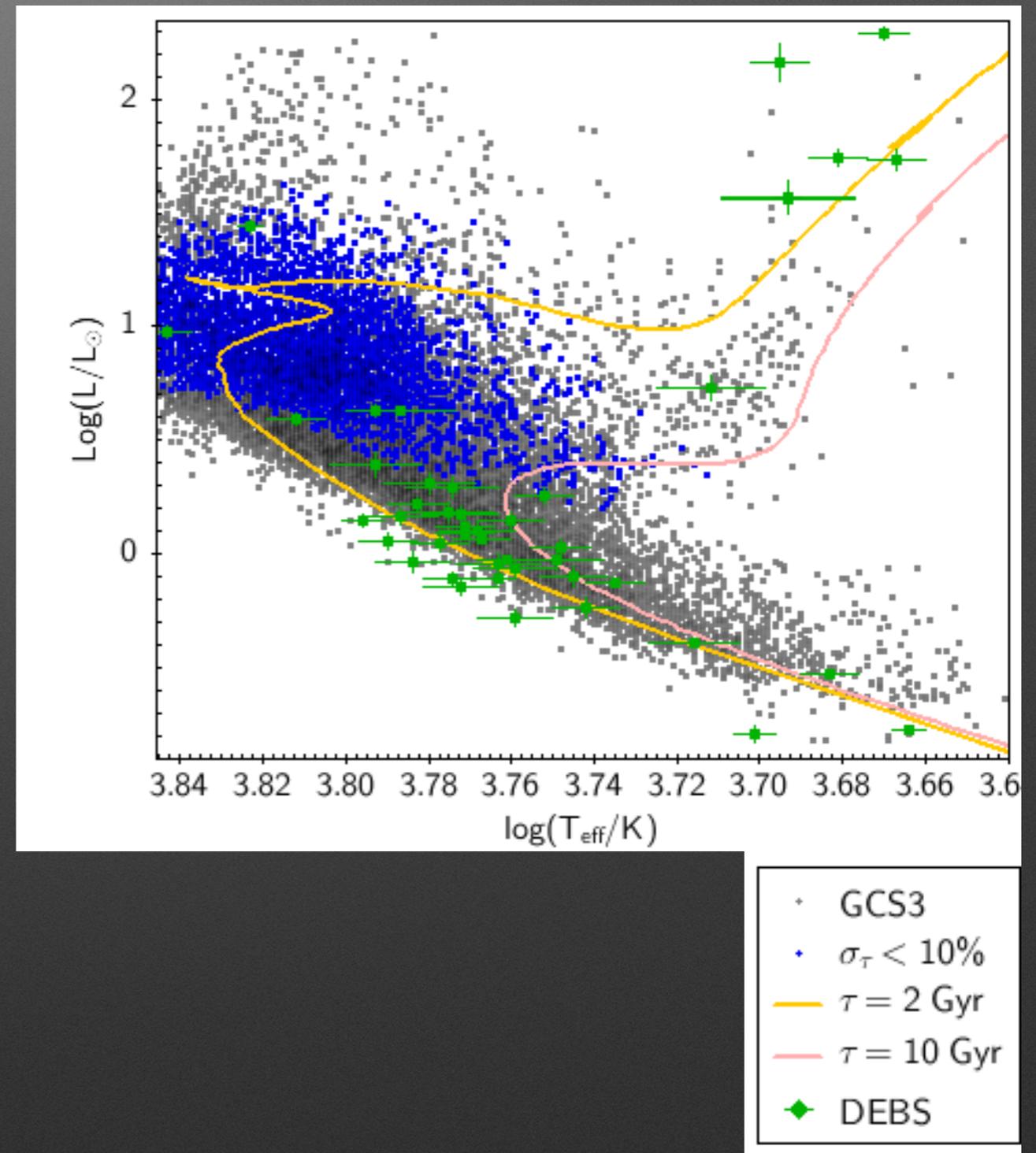
Dissimilar stars have different model dependance to free parameters, so finding a best fit is non-trivial.

Works even better with additional information, e.g., stars in clusters, A_{Li}

Current EB sample

www.astro.keele.ac.uk/jkt/debcat

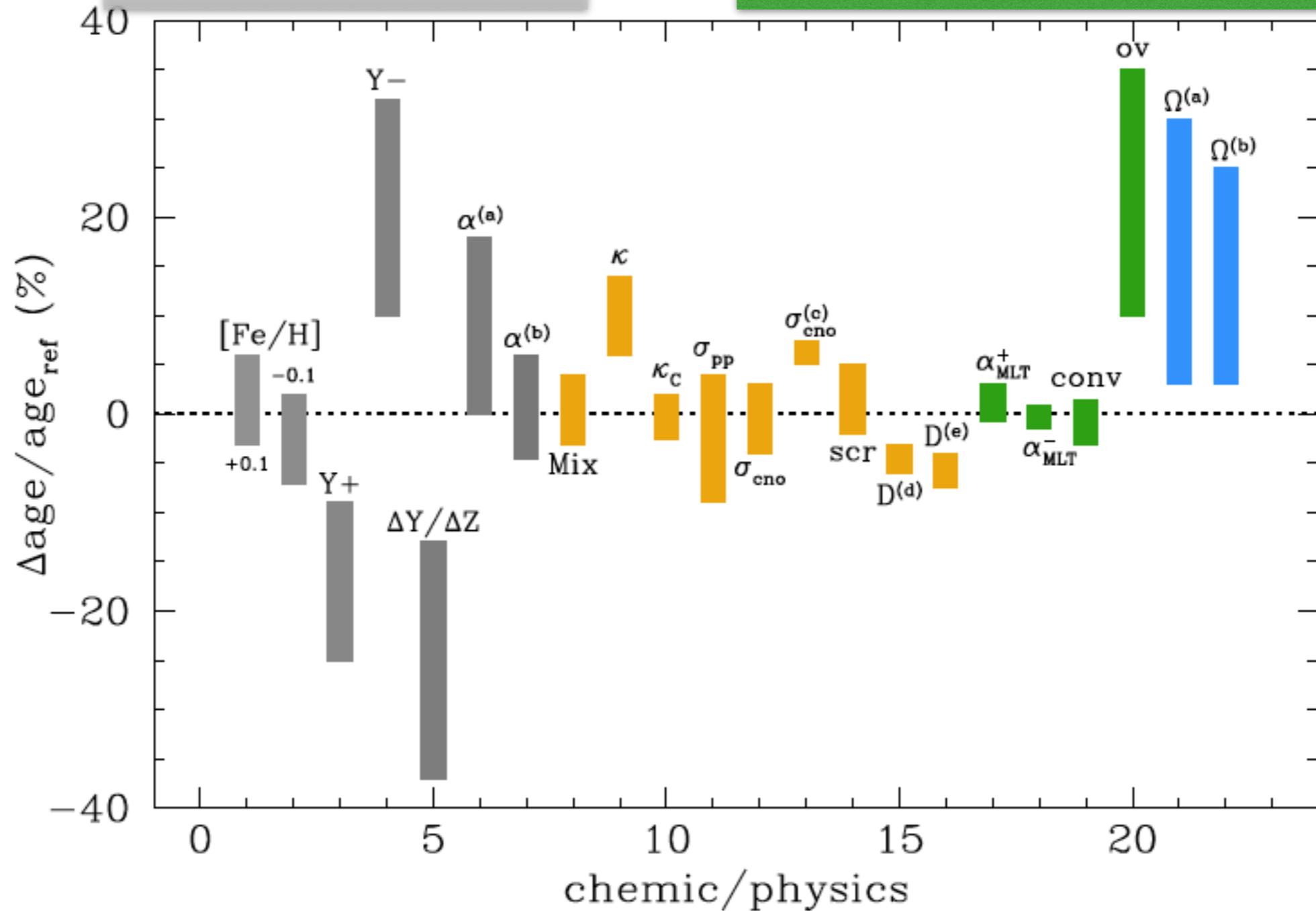
- Mass/radius error typically 2%
- Short orbital period
 - (tidally locked)
- Mostly “twin” stars
- Few low mass stars
- Few evolved stars
- Inhomogeneous T_{eff} scale
- [Fe/H] often missing and not homogeneous



How accurate are stellar ages?

Helium abundance

Convective overshooting

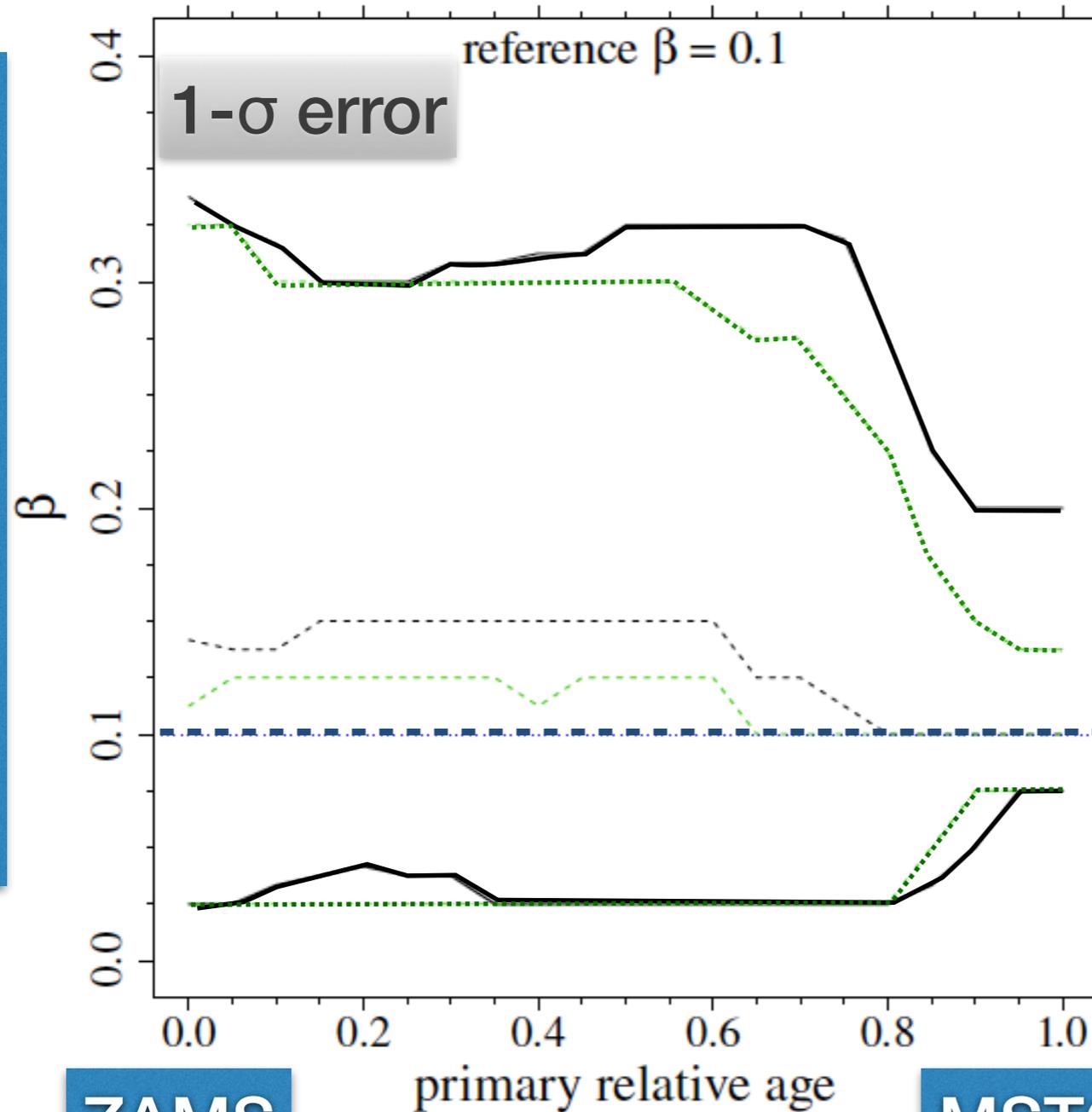


Errors in MSTO ages

Lebreton, Goupil & Montalbán, 2014

Calibrating overshooting is hard

Overshooting parameter



ZAMS

MSTO

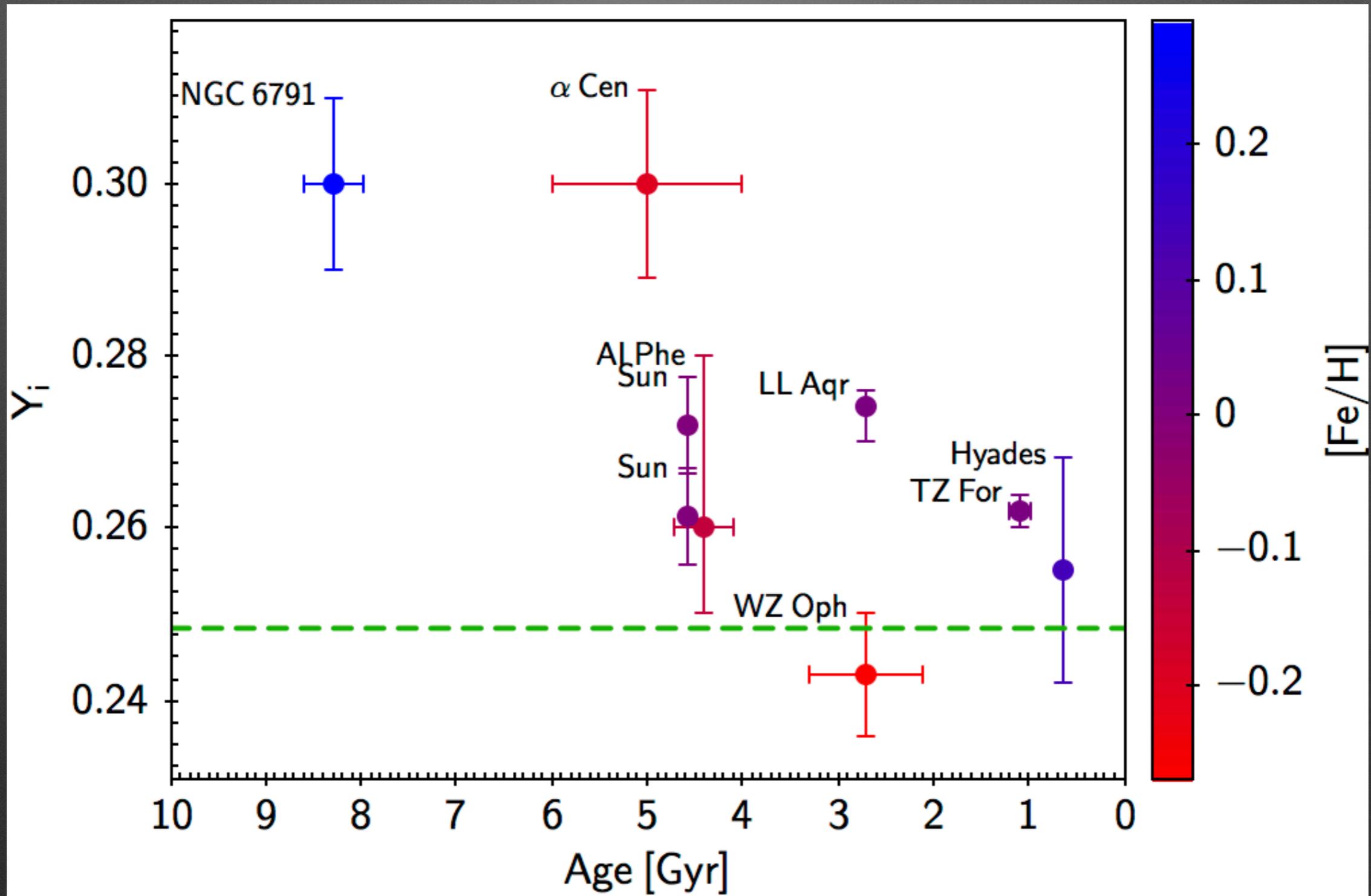
Assuming binary with observed errors ...

- $M \pm 1\%$
- $R \pm 0.5\%$
- $T_{\text{eff}} \pm 100\text{K}$
- $[\text{Fe}/\text{H}] \pm 0.1$

... and (for this plot) ignoring other sources of error.

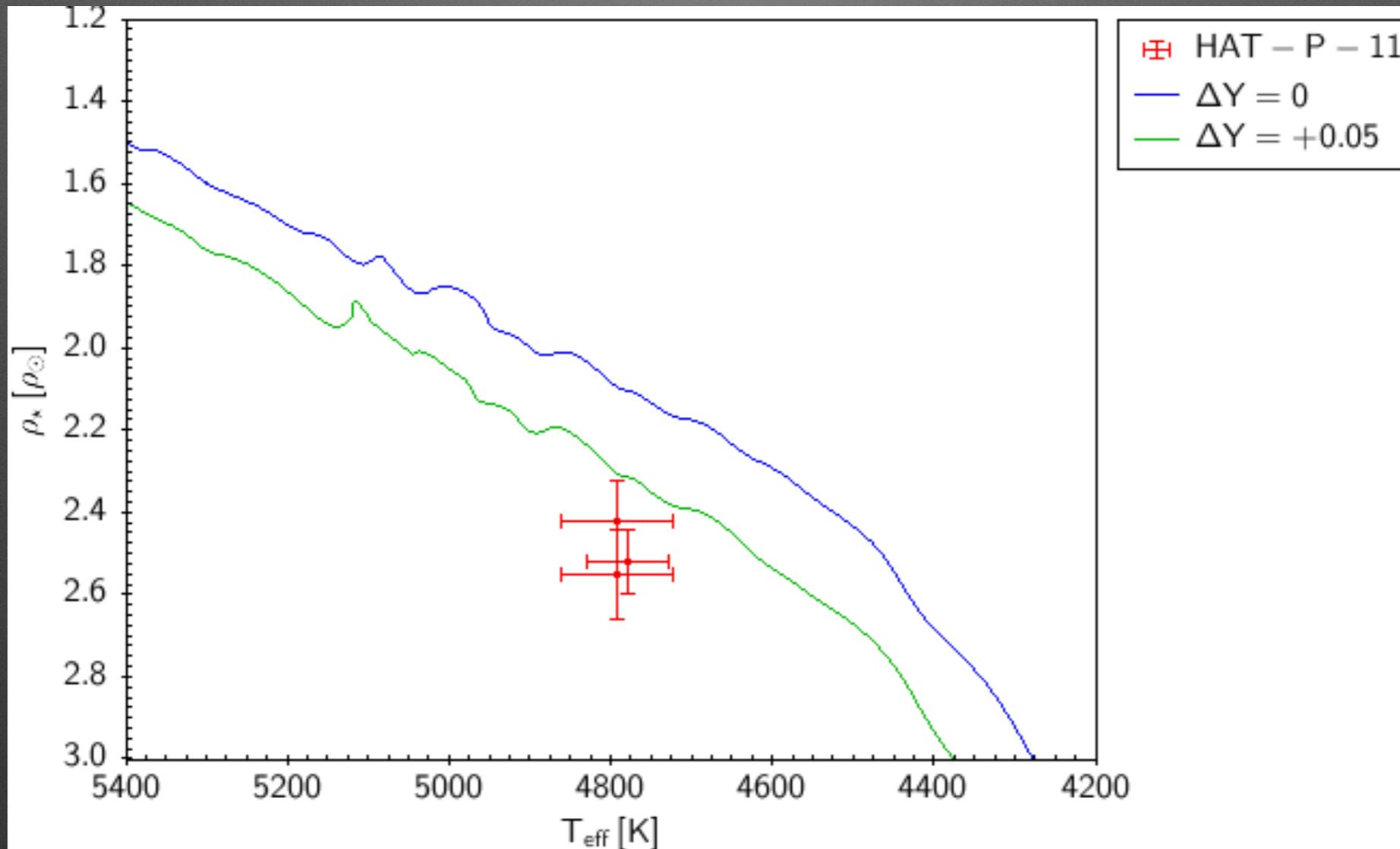
... observed errors $\div 2$

Helium abundance I - estimates from EBs



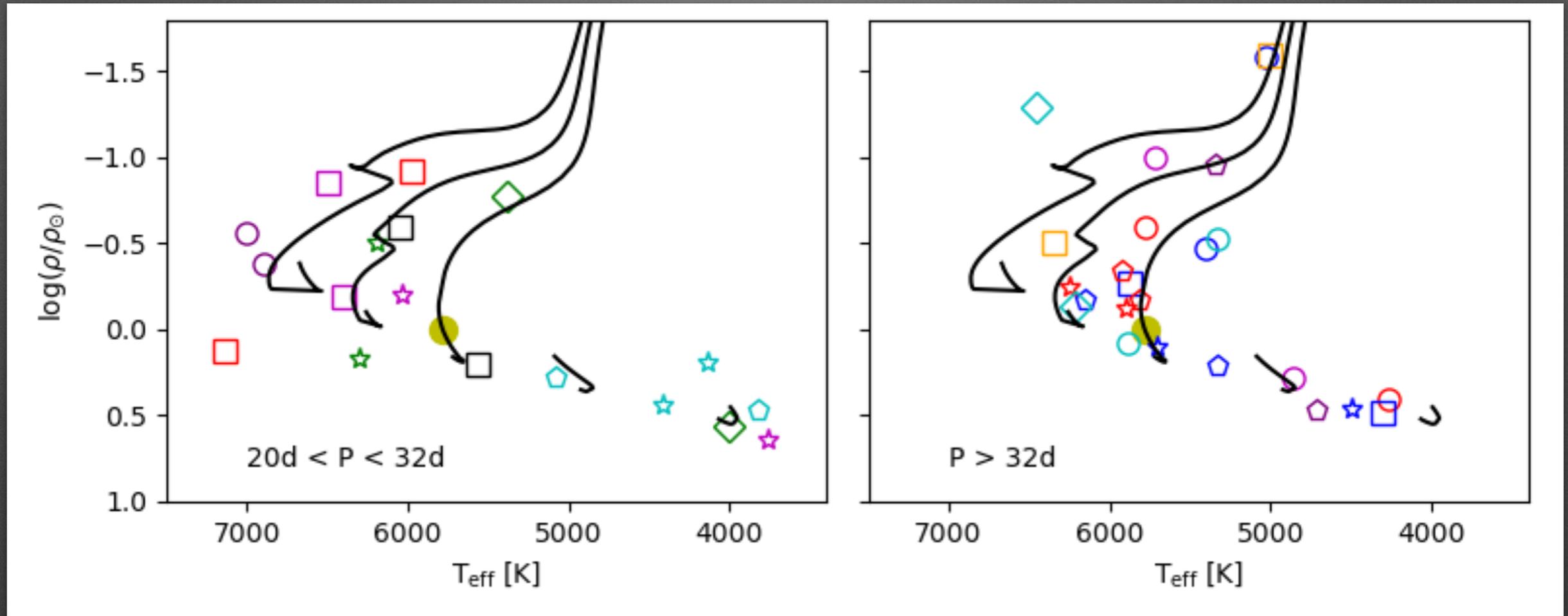
Helium abundance II - HAT-P-11

$$Y = Y_{\text{BBN}} + 0.984 Z + \Delta Y$$



$$\rho_\star = \frac{3M_\star}{4\pi R_\star^3} = \frac{3\pi}{GP^2(1+q)} \left(\frac{a}{R_\star} \right)^3$$

K2 campaigns 1, 2 and 3



Maxted & Hutcheon, A&A, 2018. arXiv:1803.10522

- 1.3 ± 0.3 “interesting” bright targets per K2 field
 - 20 — 30 calibration targets per PLATO f.o.v.
- Suitable targets from TESS + WASP

PLATO calibration/validation sample

Aim to define sample of 10 – 15 EB in the two main PLATO fields ...

- F/G V + G/K IV/V (dwarf + MSTO/sub-giant)
- bright enough for measurable solar-like oscillations in dwarf star
- with measured masses/radii measured to $\pm 0.5\%$ (?) or better
- with T_{eff} to $\pm 50\text{K}$ from Gaia parallax + photometry
- with precise and homogeneous $[\text{Fe}/\text{H}]$, $[\alpha/\text{Fe}]$, A_{Li} , ...
- spanning a range of mass, age, $[\text{Fe}/\text{H}]$, S_{HK} , etc.

PLATO calibration/validation sample

Sample must be ready 2-3 years before launch

- Time needed to tune stellar models
- Predict p-mode frequencies before launch
- Calibration DEBS should be considered in deciding PLATO fields

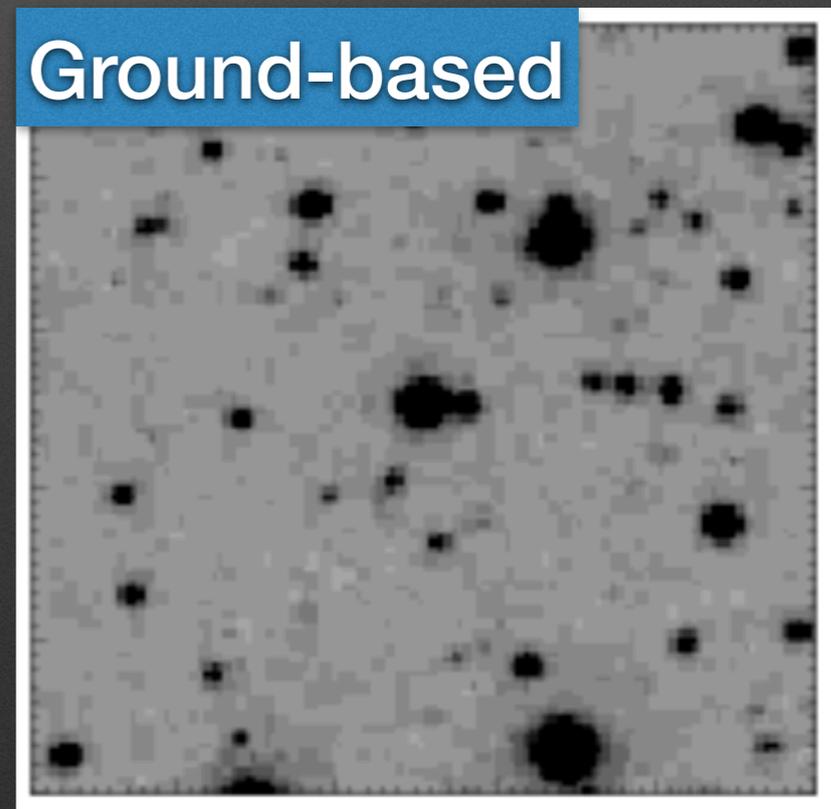
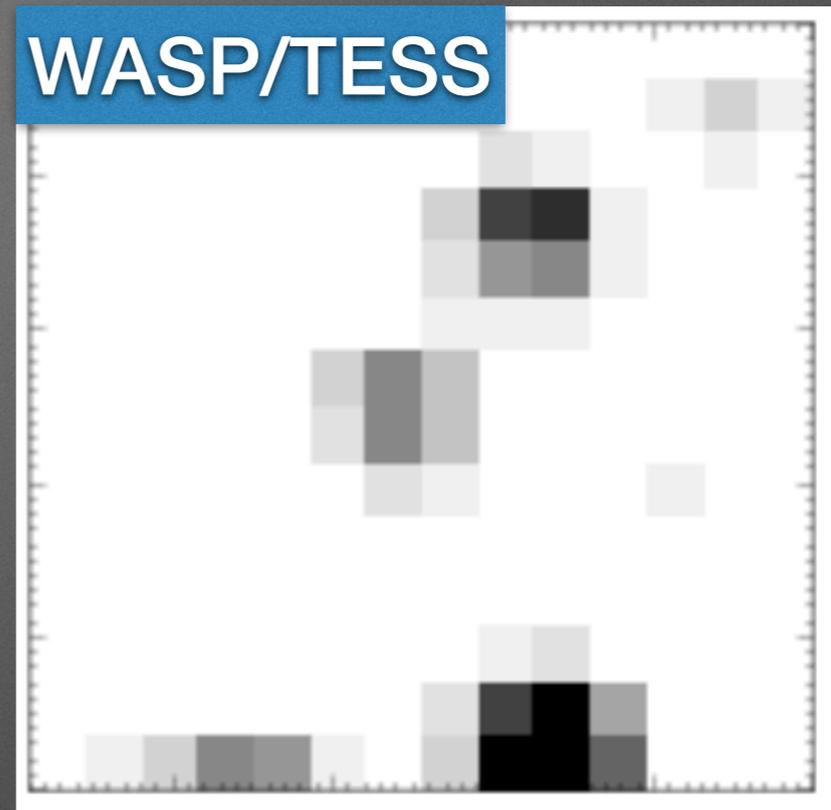
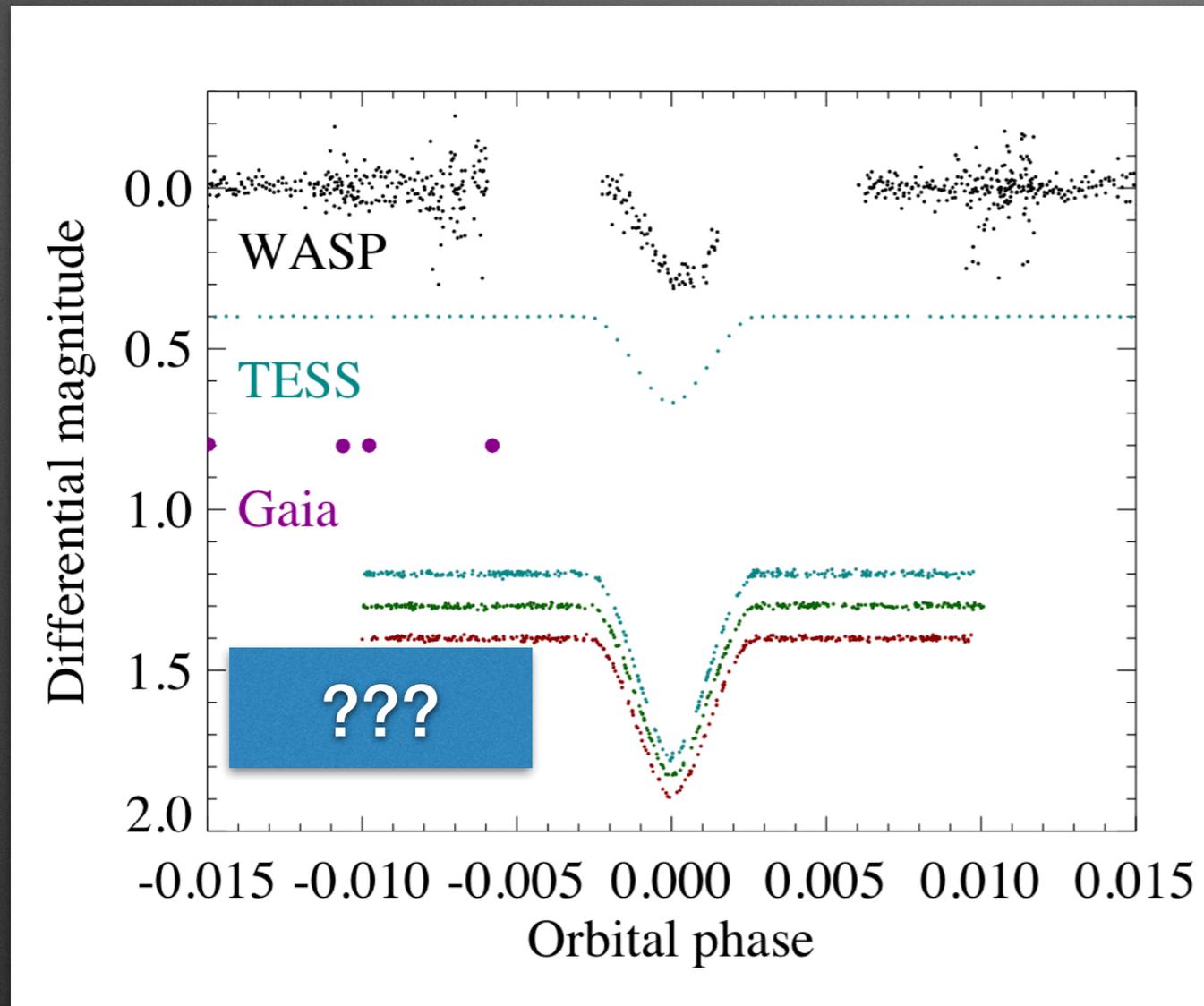
Will require planning/effort/funding

- First detailed Kepler EB analysis published 3 years after DR1
- First model v. observations paper published 5 years of DR1

What is needed from PLATO/STESCI?

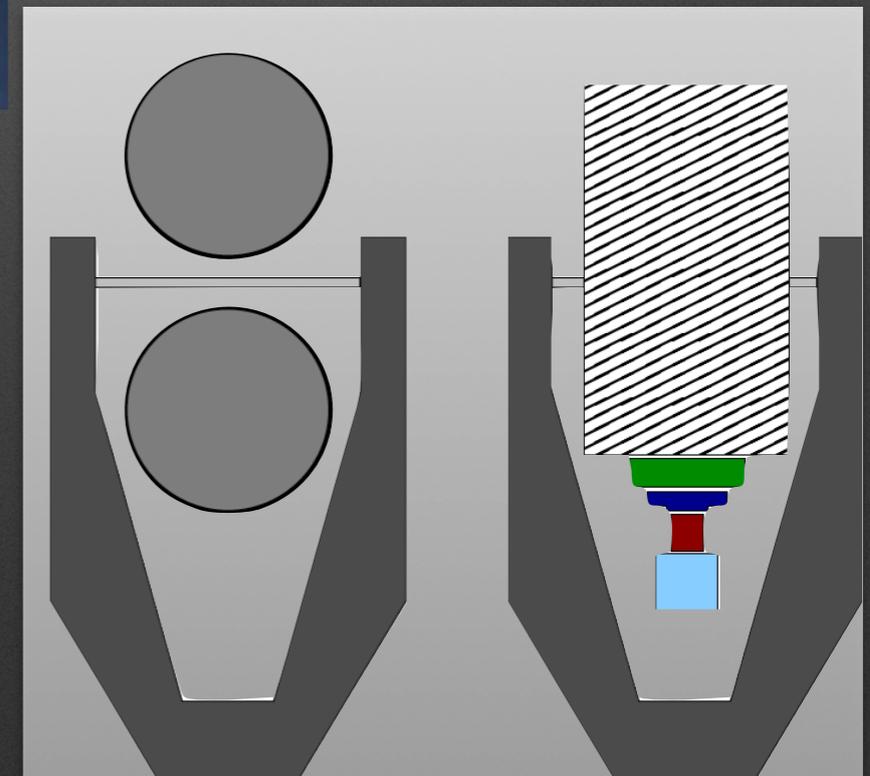
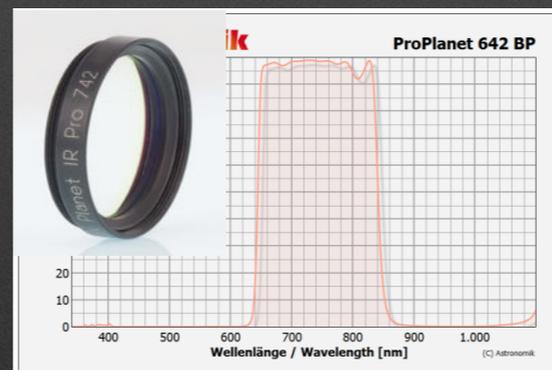
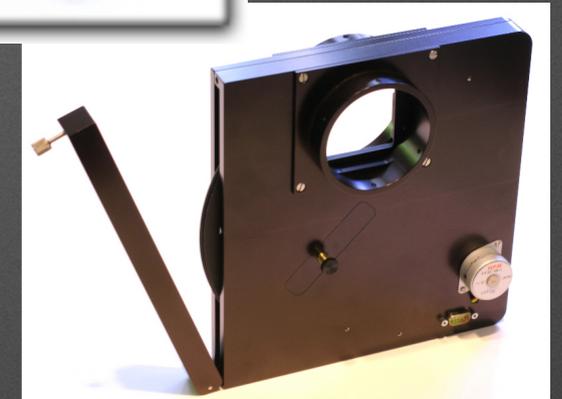
- A clear statement that DEBS calibration sample is part of the PLATO core science objective
 - e.g., allocating it to a work package
- Support for grant applications
 - help writing proposals
 - writing letters of support
- Support for the ground-based observing time
 - help with proposal writing
 - sending observers
 - time on private/institutional facilities
- target management for DEBS within core program

Follow-up light curves ...



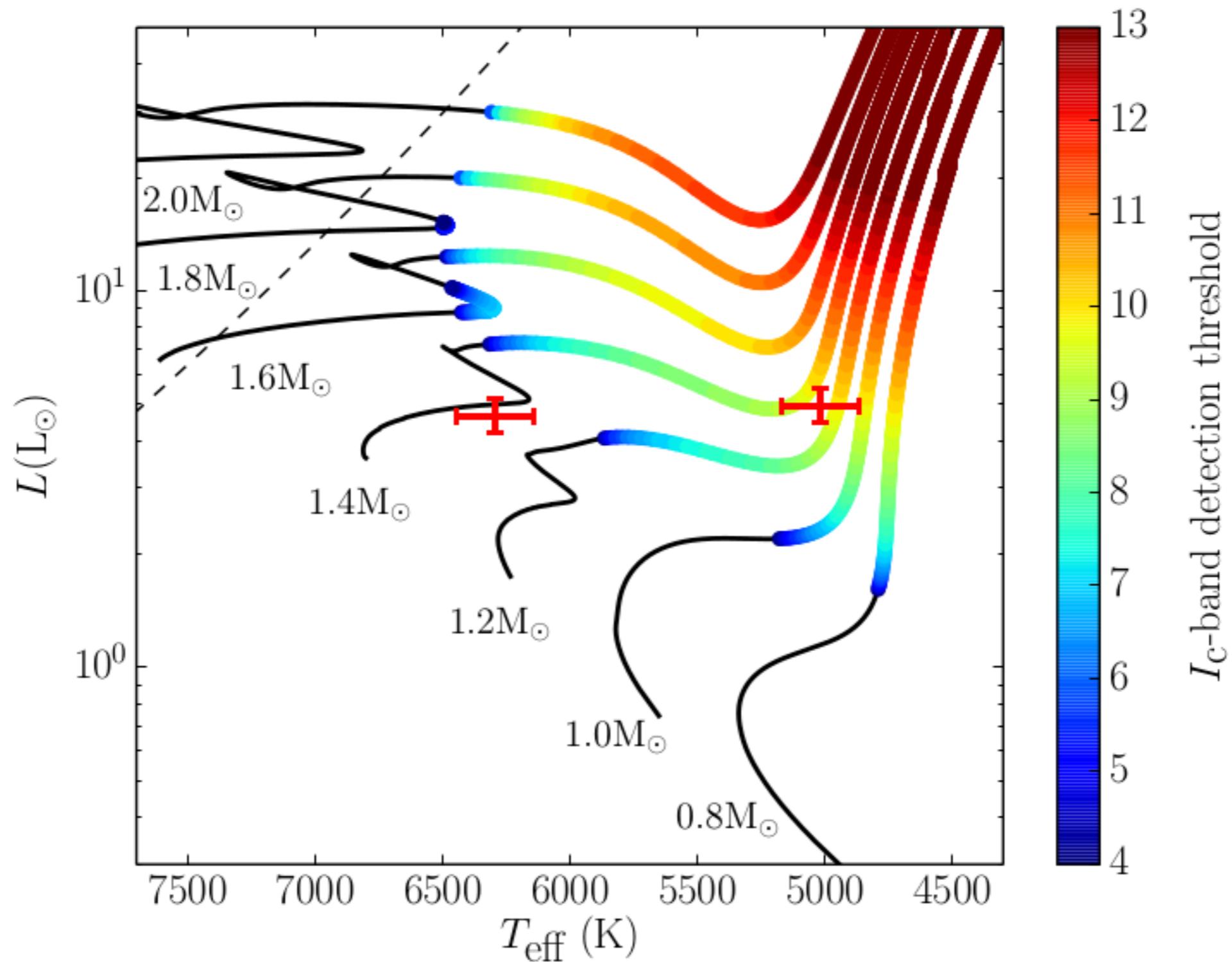
WASP South 2.0 / KATARINA project

Keele
Automatic
Twin
Aperture
Research
Instrument for
New
Astrophysics



2x Orion Optics ODK16

Observing AI Phe with TESS

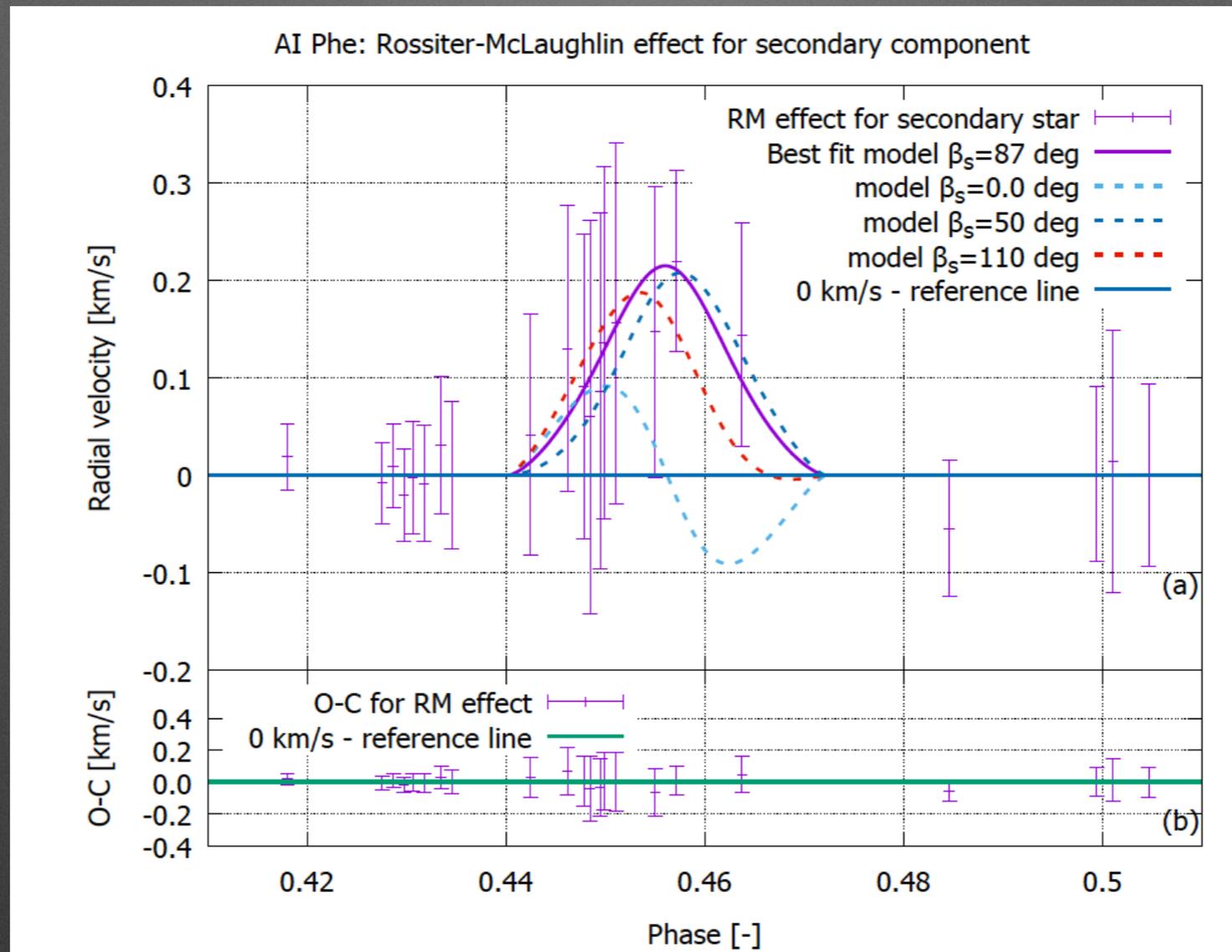




Twinkle Twinkle double star
I don't wonder what you are
Orbit and eclipse don't lie
They tell me your mass and size
Twinkle Twinkle double star
You'll bring my models up to par

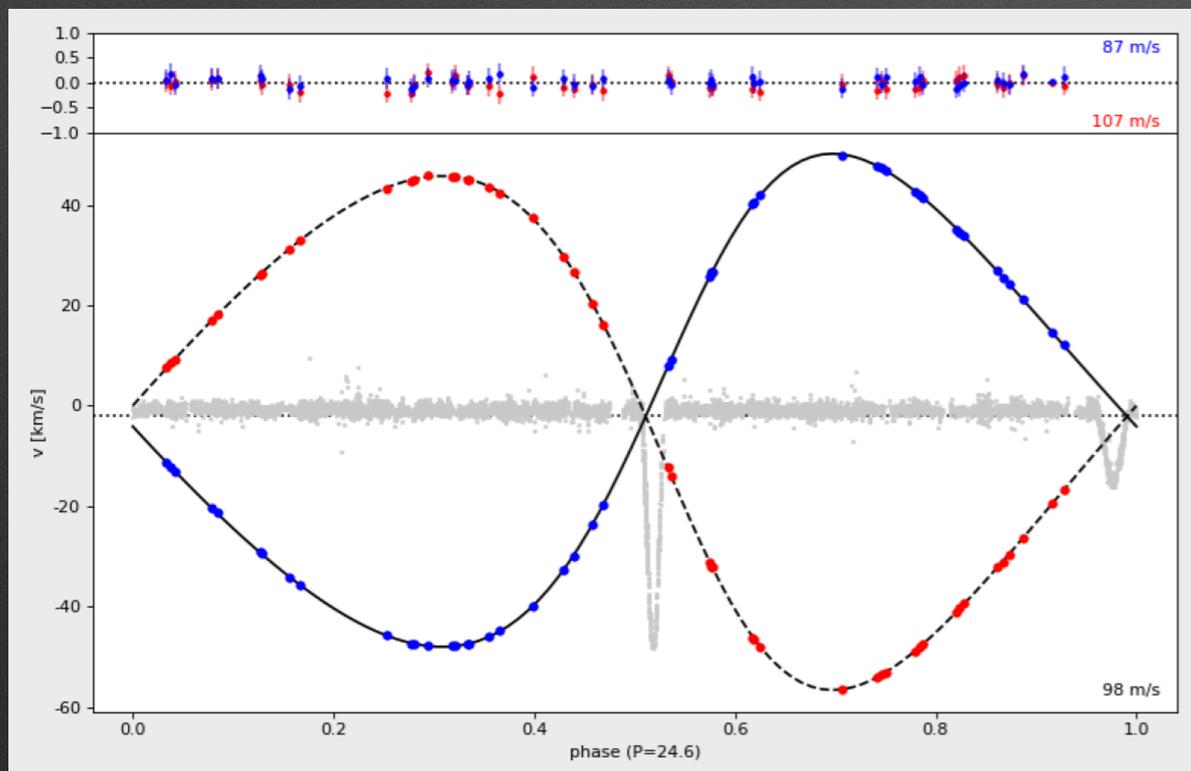
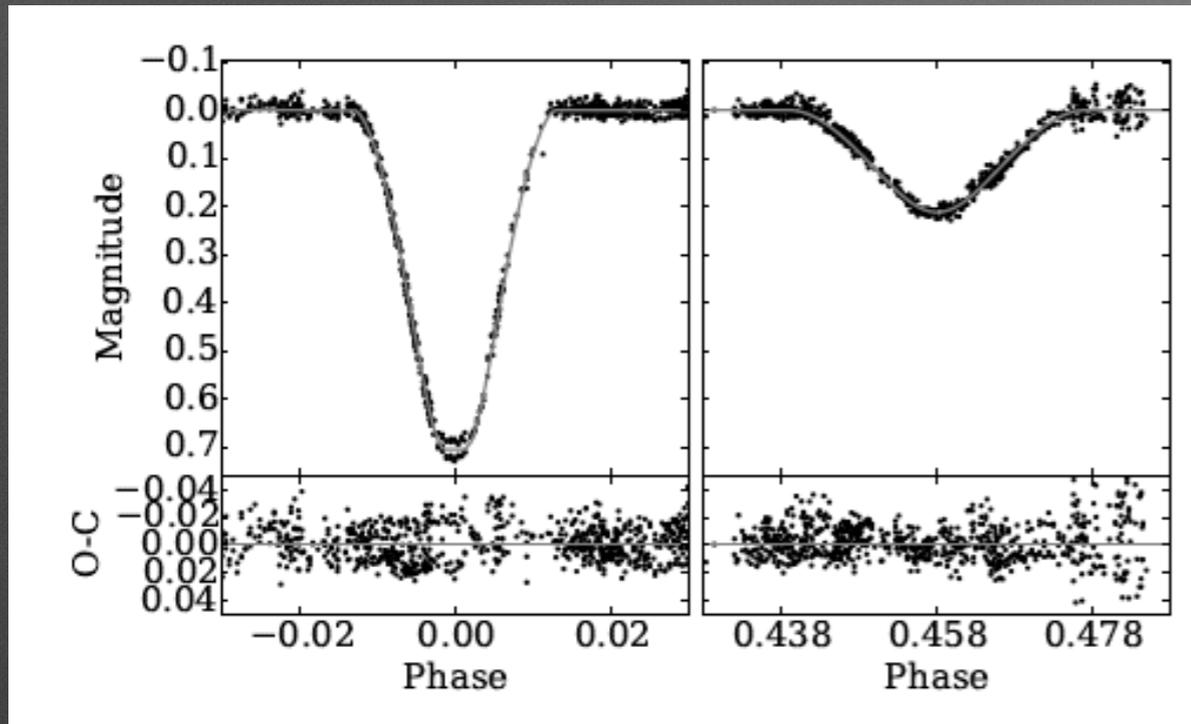


R-M effect in AI Phe



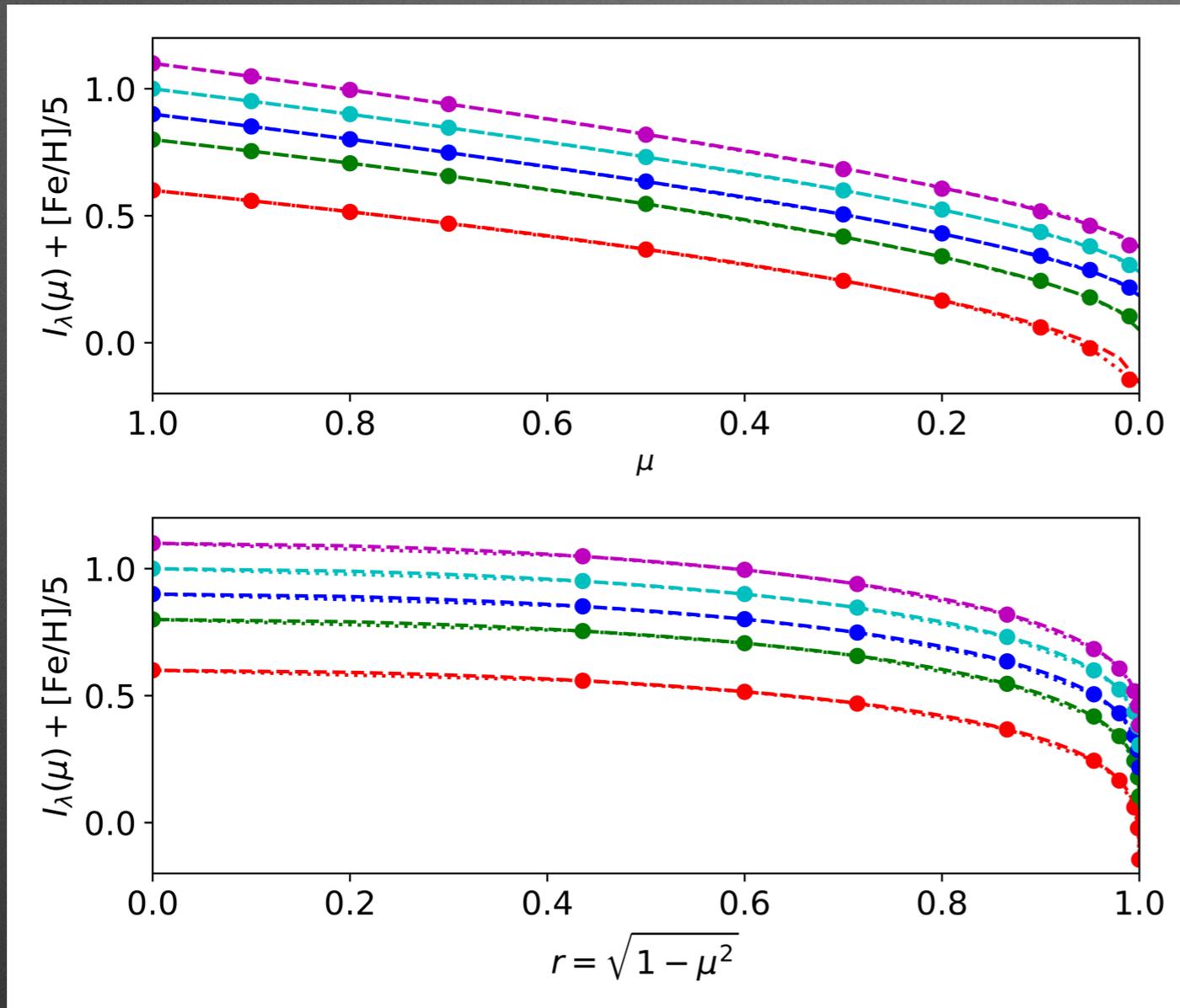
$$|\lambda_2| = 87^\circ \pm 17^\circ$$

AI Phe — a prototype calibration sample target



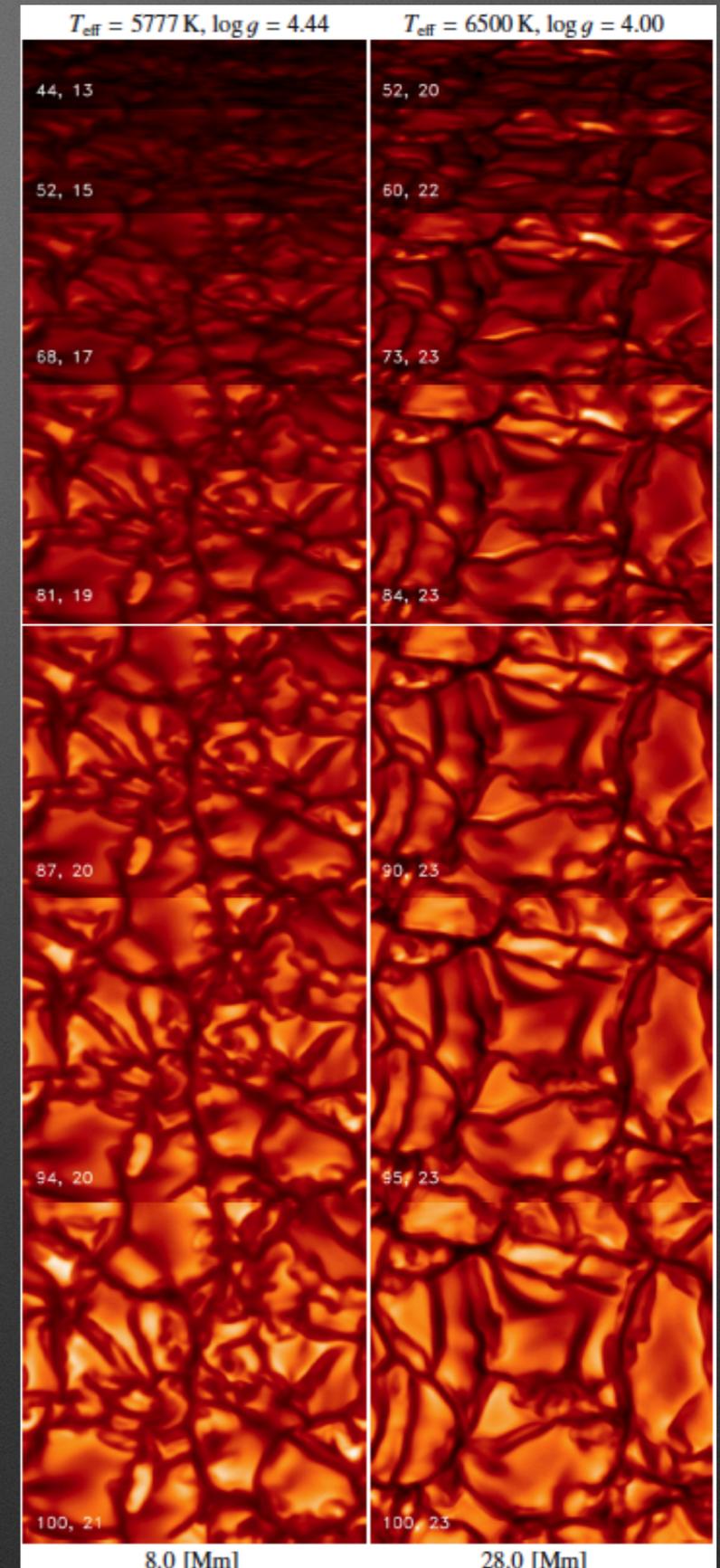
- $l_c = 9.5$
- $P = 24.6$ d
- F7V + K0IV
- $M_{F7} = 1.1933 \pm 0.0023 M_{\odot}$
- $R_{F7} = 1.833 \pm 0.014 R_{\odot}$
- $M_{K0} = 1.2438 \pm 0.0023 M_{\odot}$
- $R_{K0} = 2.909 \pm 0.014 R_{\odot}$

Power-2 limb darkening law



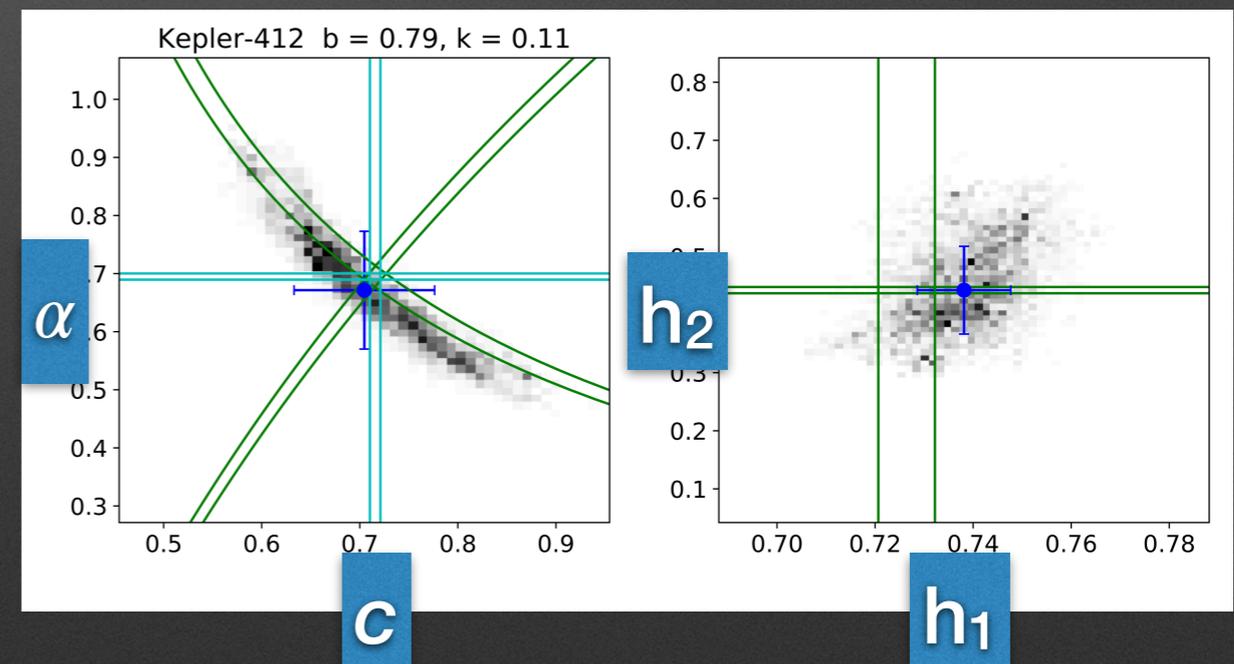
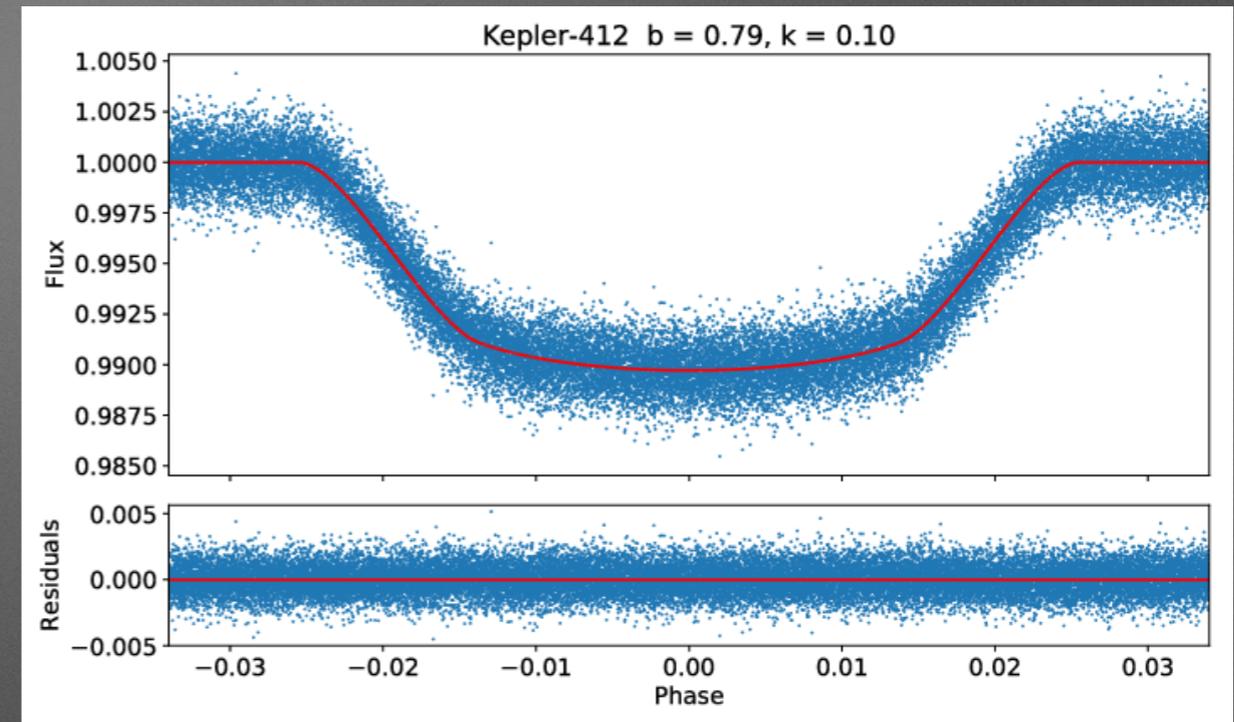
Power-2 law fit to limb-darkening profile from STAGGER-grid

$$I_\lambda(\mu) = 1 - c(1 - \mu^\alpha)$$



Observed power-2 law parameters

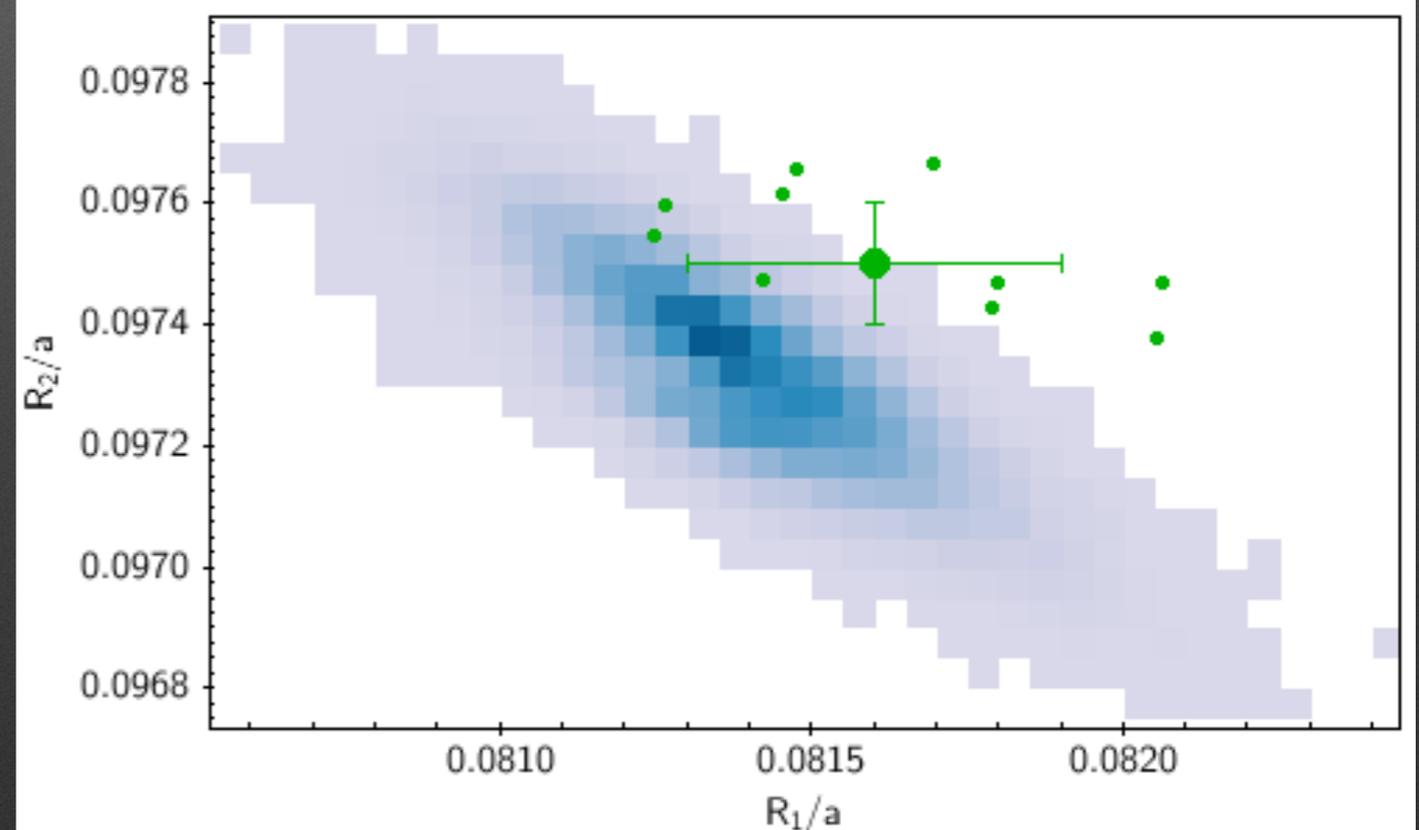
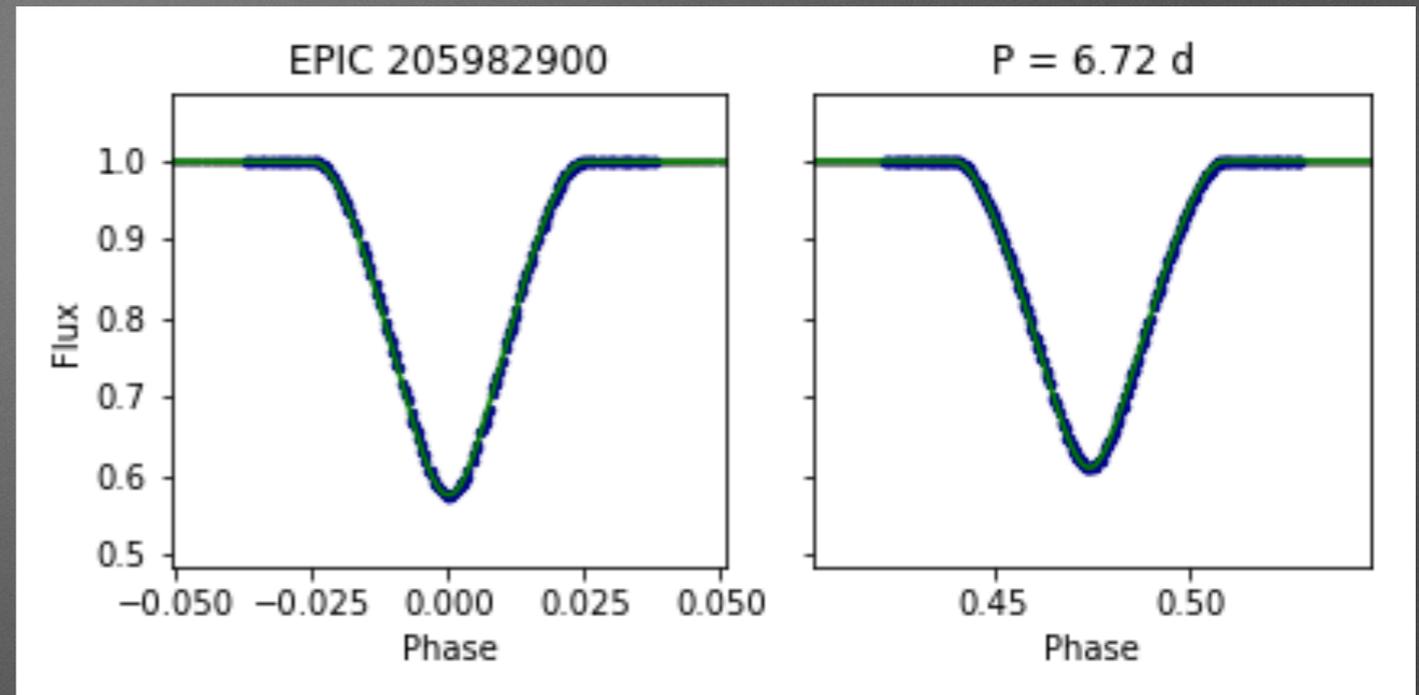
- Fit Kepler DR25 SC light curves of transiting exoplanets
- Include c and α as free parameters
- Compare to models using
 - $h_1 = I_\lambda(1/2) = 1 - c (1 - 1/2^\alpha)$
 - $h_2 = I_\lambda(1/2) - I_\lambda(0) = 1/2^\alpha c$



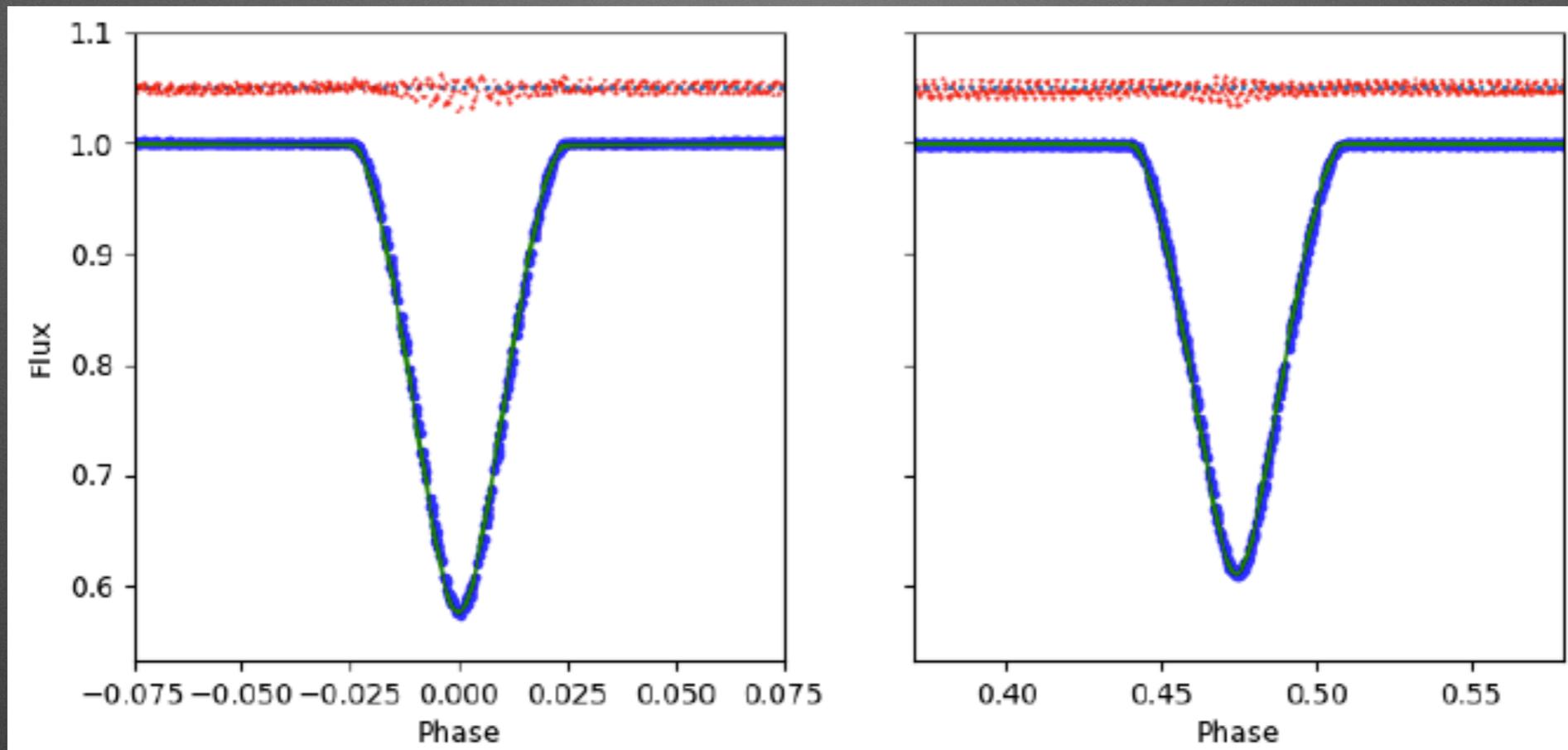
Example - BW Aqr, K2 data

$K_p = 10.2$, $P = 6.72$ d, F7V+F7IV

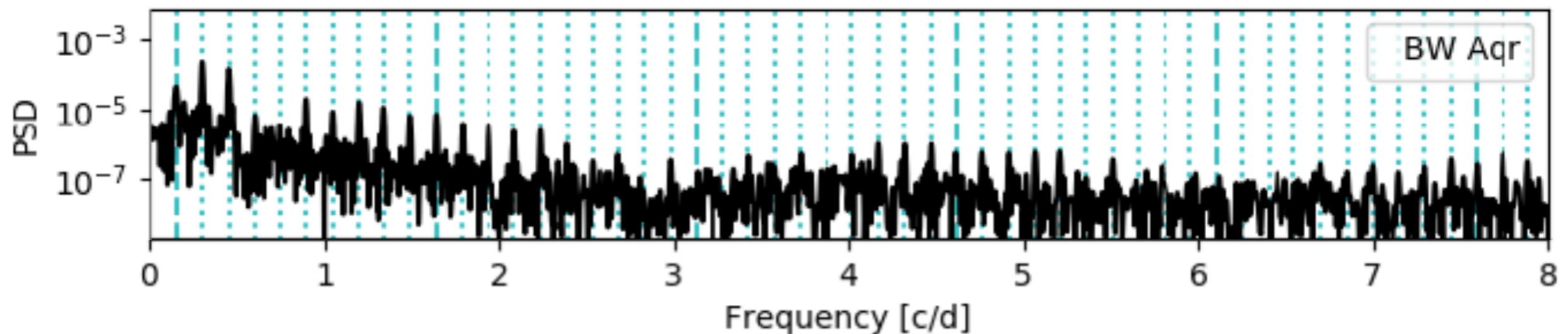
- $R_1/a = 0.0816 \pm 0.0003$
- $R_2/a = 0.0975 \pm 0.0001$
- $i = 88.65^\circ \pm 0.03^\circ$
- $e = 0.1776 \pm 0.0004$
- $\omega = 102.9^\circ \pm 0.3^\circ$
- $\text{rms} = 170$ ppm



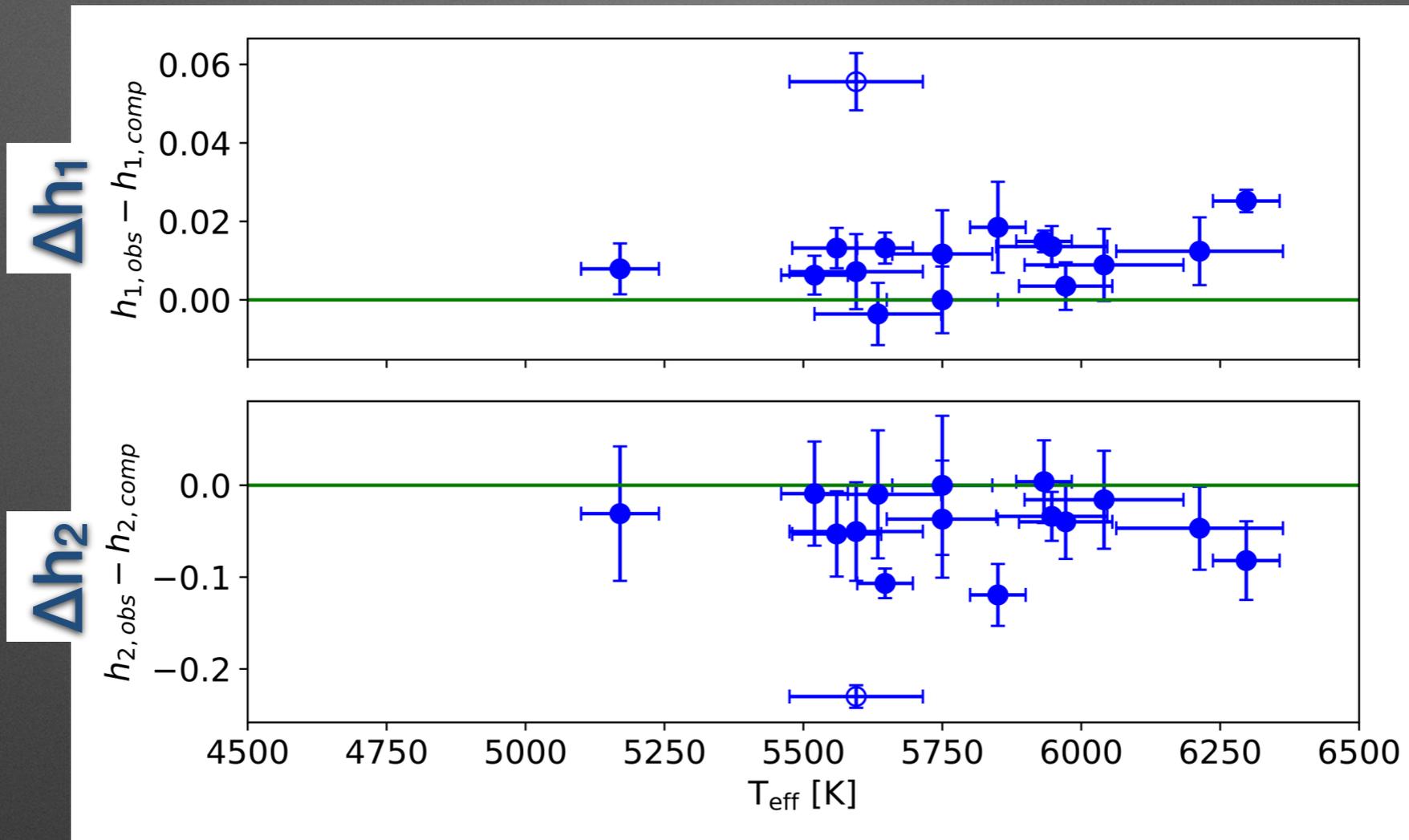
Tidally induced pulsations



BW Aqr, $P = 6.72\text{d}$, $e = 0.18$



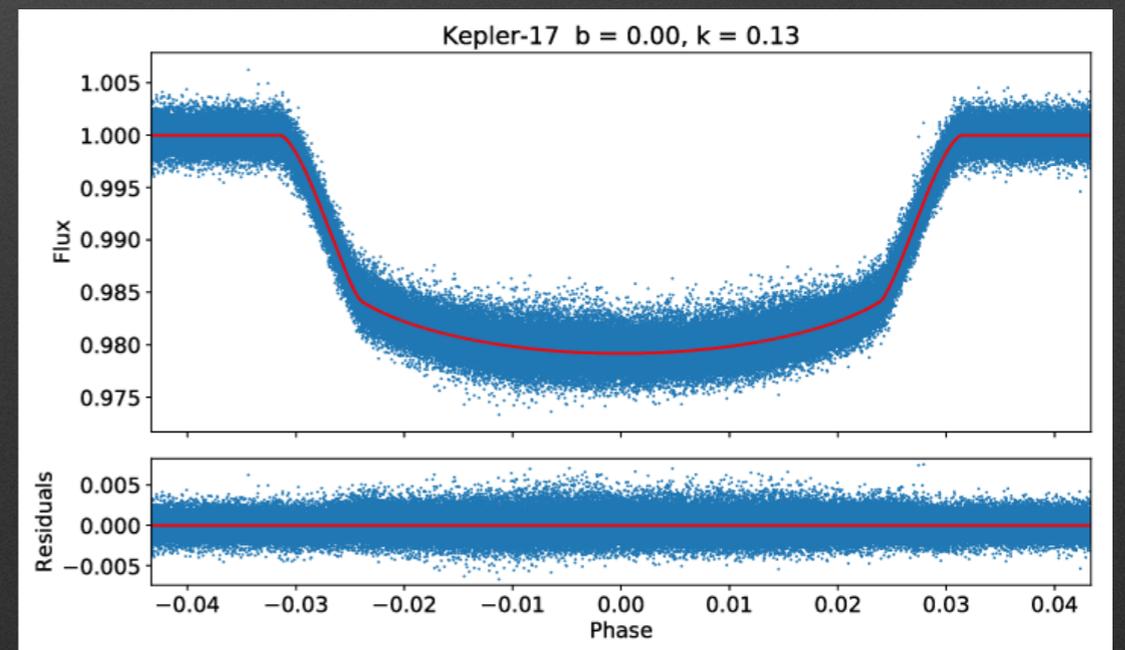
Power-2 law — model v. observations



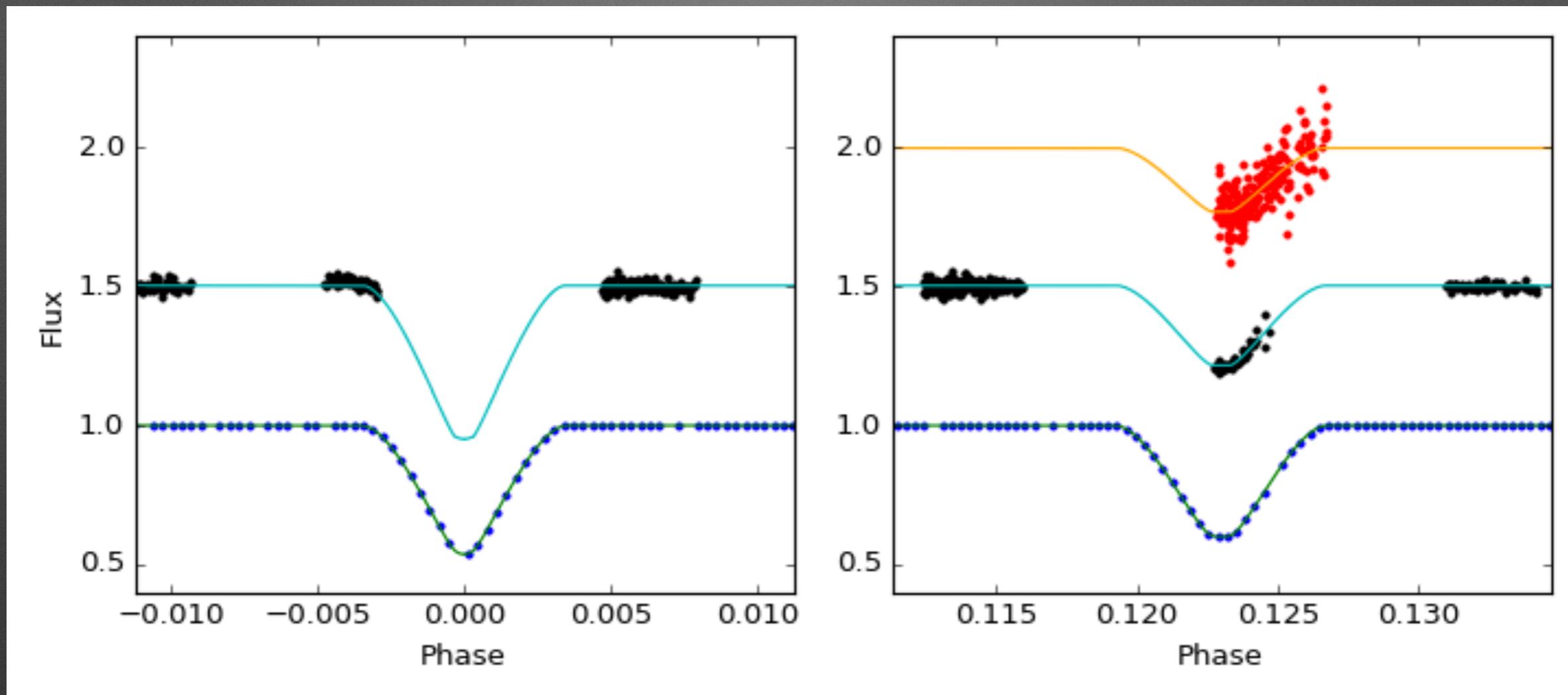
$$\langle \Delta h_1 \rangle = +0.010 \pm 0.002 \quad (\sigma = 0.011)$$

$$\langle \Delta h_2 \rangle = -0.042 \pm 0.010 \quad (\sigma = 0.045)$$

... excluding Kepler-17 (star spots)



K2 + WASP



$P=62.59\text{d}$, $e = 0.64$, $K_p = 12.4$

Star spot modulation

