Coupling Binarity and Asteroseismology: High-Precision Core Masses and Ages from Kepler and TESS

Cole Johnston

29 July, 2019

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Core masses & ages

He-Core mass at TAMS determines the rest of a star's evolution

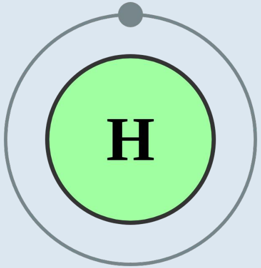
Ages are important for exoplanets / galaxies / clusters / etc.

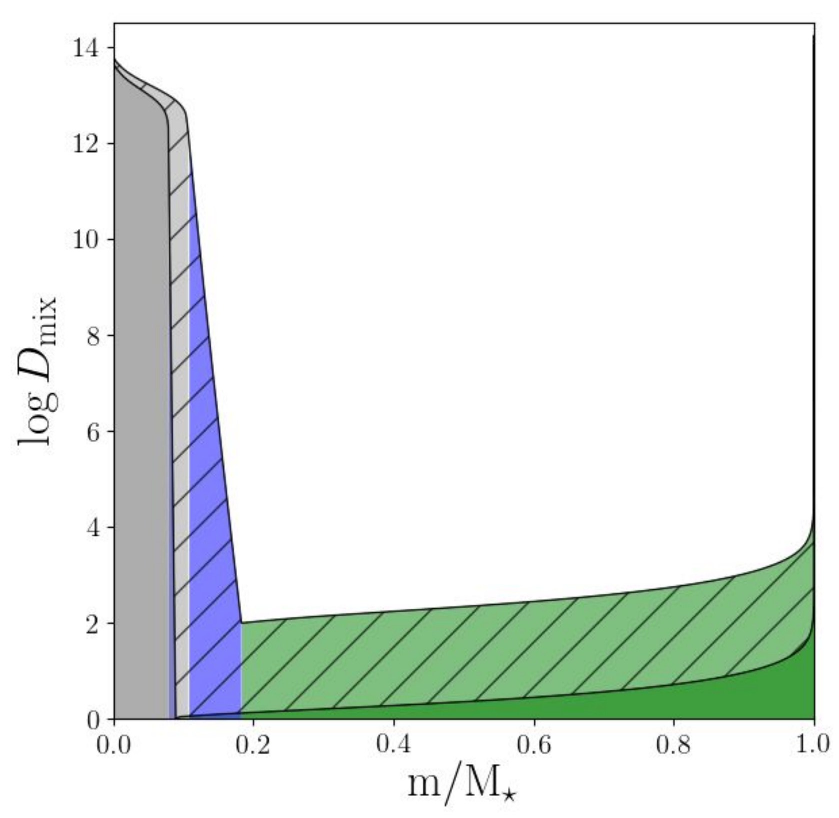
1.2+ $M_\odot$

Convective cores

Core masses & ages

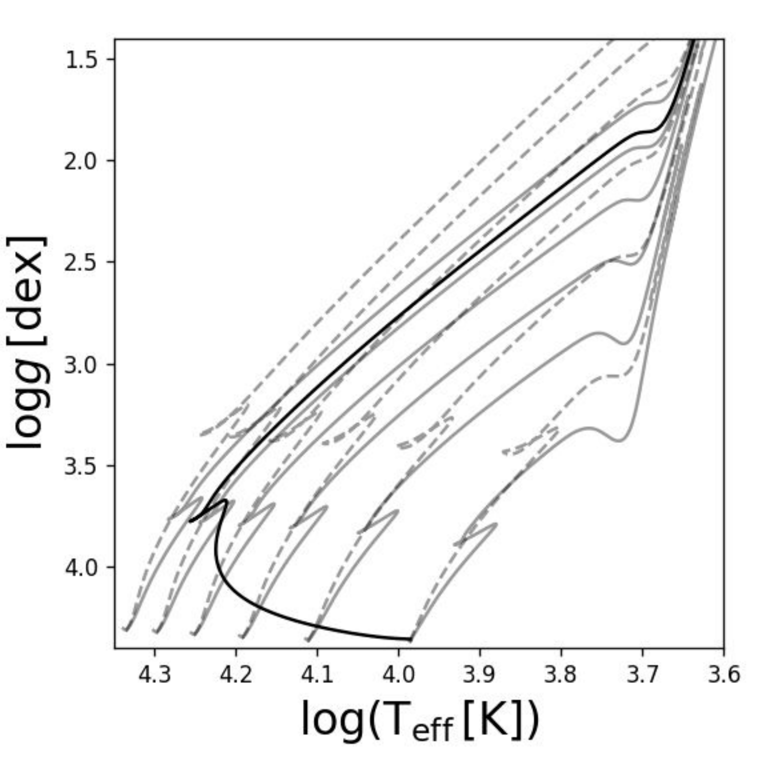
Rotation
Pulsations
Magnetism
Tides
Convective boundary mixing
Atomic diffusion
etc.

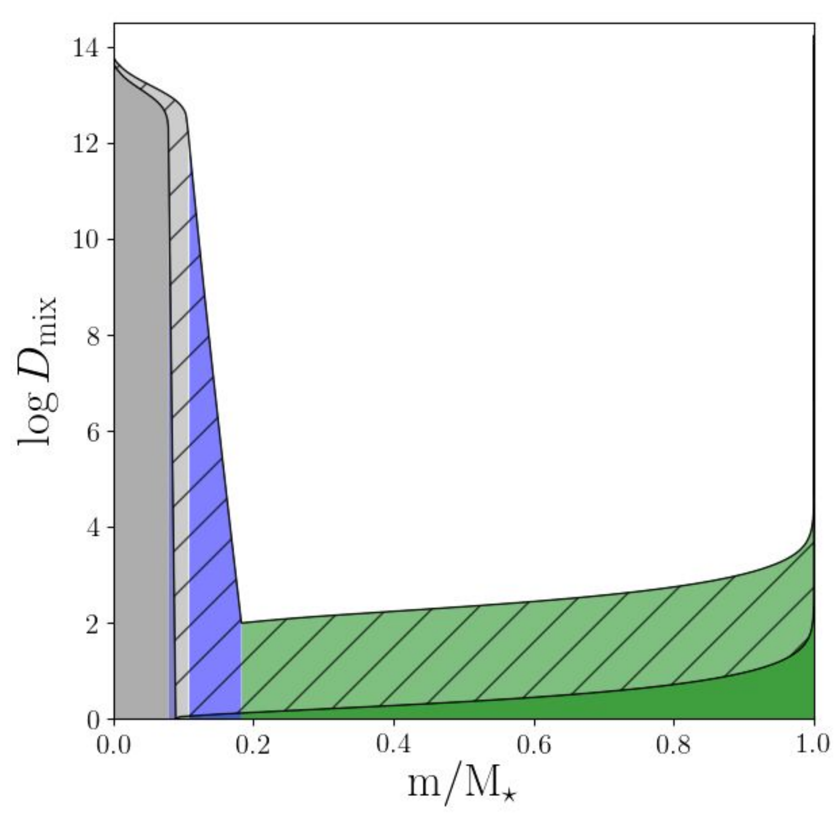




Johnston et al. *in prep.*

Isochrone-clouds





Johnston et al. 2019a

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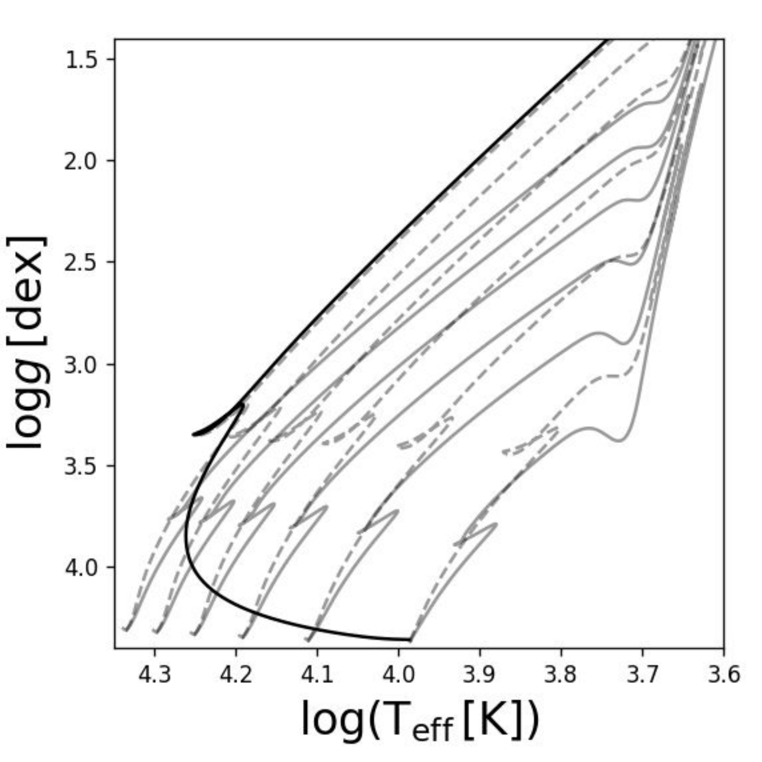

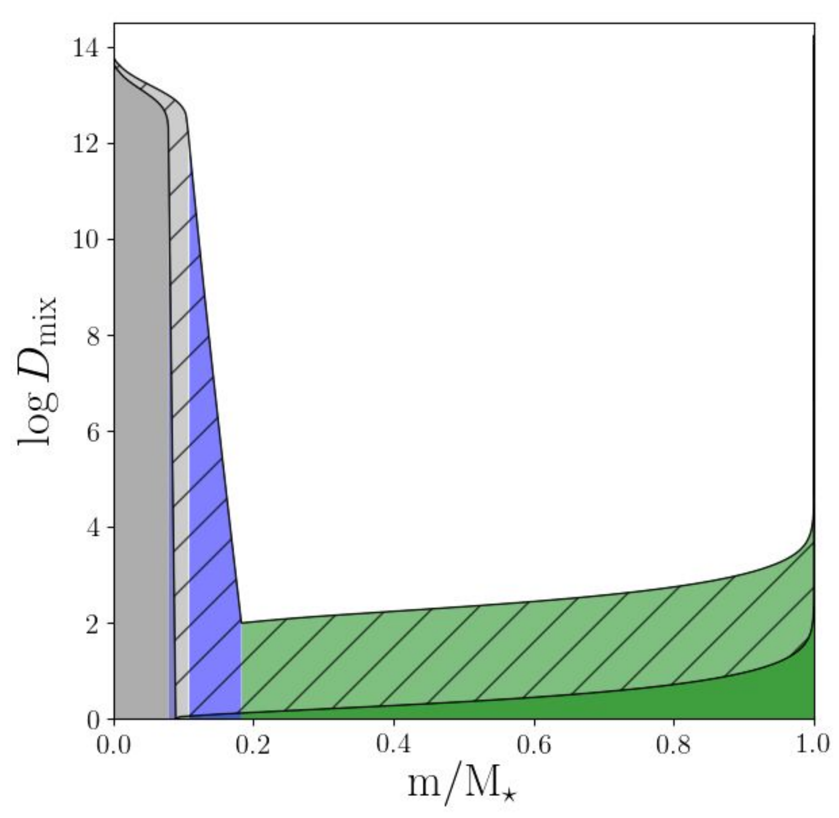

Johnston et al. 2019a

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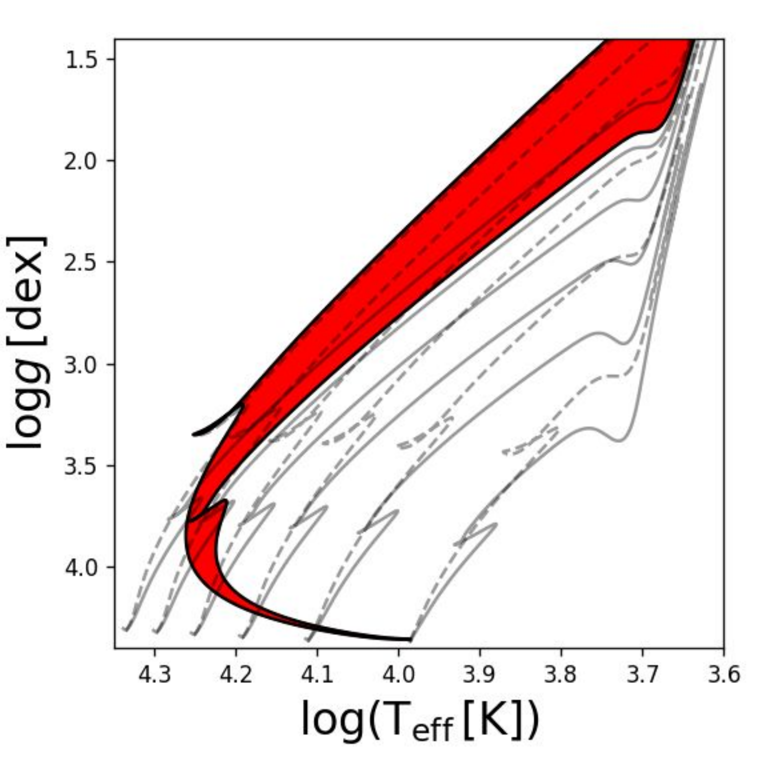
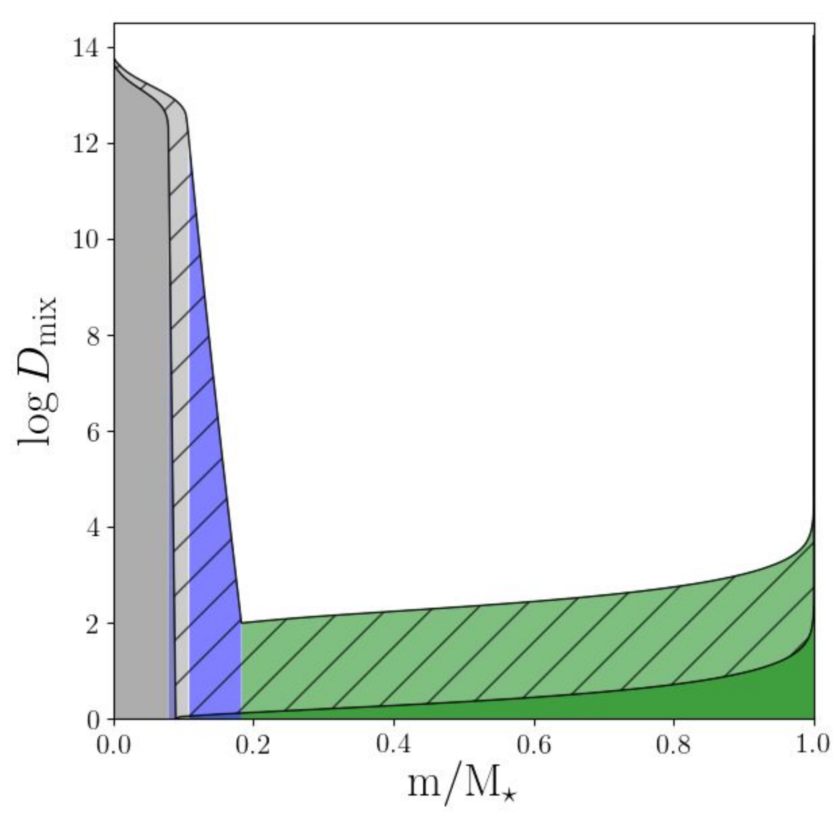
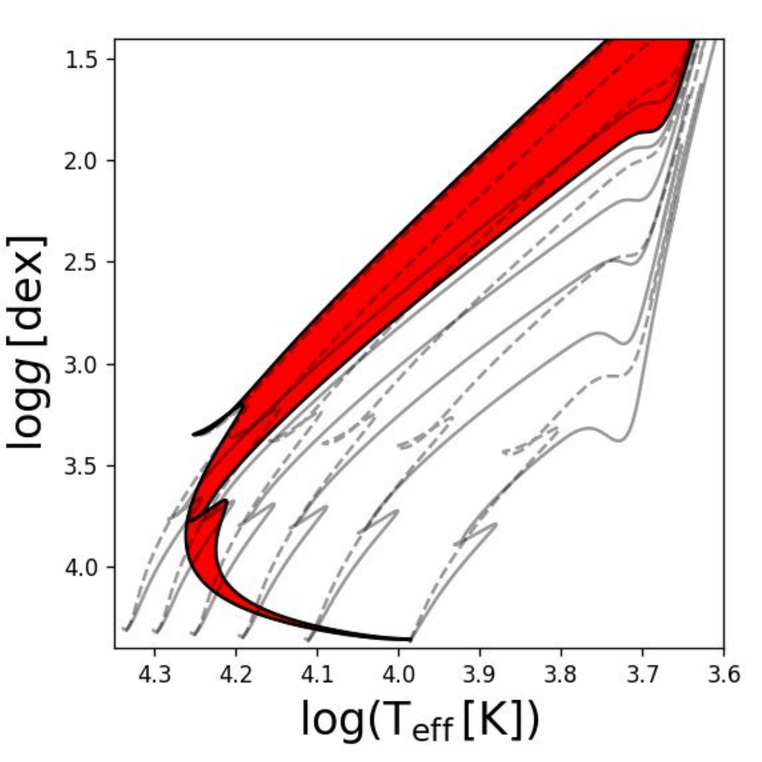




Isochrone-clouds



Model degeneracies!!!

We don’t know what mixing mechanism is at work.

Don’t try to fit efficiency of mechanism.

Calibrate core mass

Isochrone-clouds

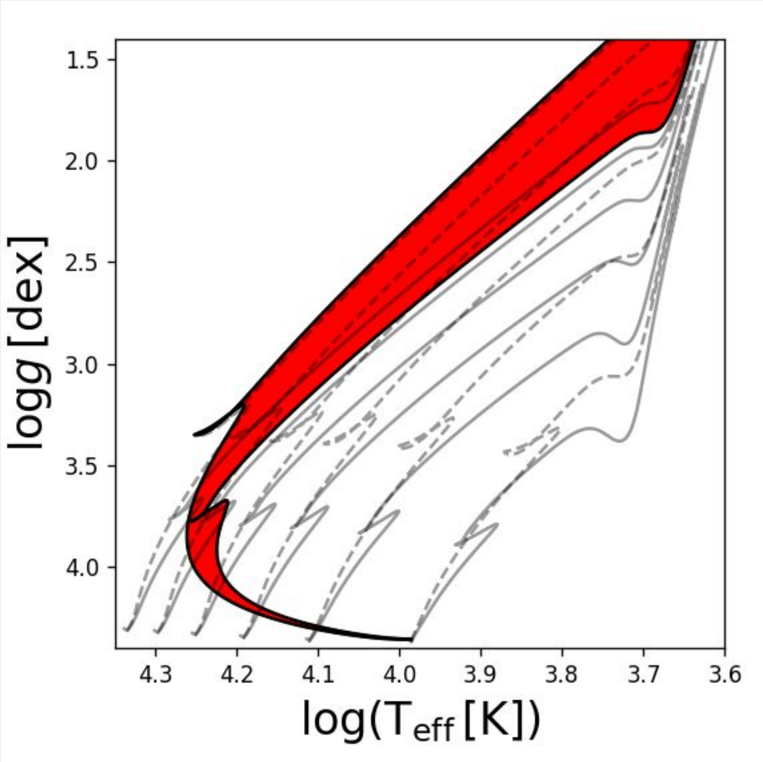


Table 6. Monte Carlo Isochrone-cloud modelling 95% confidence intervals for CW Cep and U Oph.

Parameter	CW Cep	U Oph
Age [Myr]	7.0_{-1}	$57.5^{+5.0}_{-2.5}$
M_1 [$M_\odot$]	$13.00^{+0.1}_{-0.16}$	$5.08^{+0.07}_{-0.06}$
M_2 [$M_\odot$]	$12.00^{+0.11}_{-0.12}$	$4.60^{+0.05}_{-0.05}$
$X_{c,1}$	$0.54^{+0.01}_{-0.03}$	$0.48^{+0.02}_{-0.04}$
$X_{c,2}$	$0.57^{+0.01}_{-0.03}$	$0.51^{+0.03}_{-0.02}$
$M_{cc,1}$ [$M_\odot$]	$4.34^{+0.11}_{-0.29}$	$1.05^{+0.08}_{-0.11}$
$M_{cc,2}$ [$M_\odot$]	$3.86^{+0.12}_{-0.19}$	$0.93^{+0.06}_{-0.05}$

Pols+1997 / Stancliffe+2015 / Higel & Weiss 2017 / Claret & Torres 2016,2017,2018,2019 / Constantino & Baraffe 2018

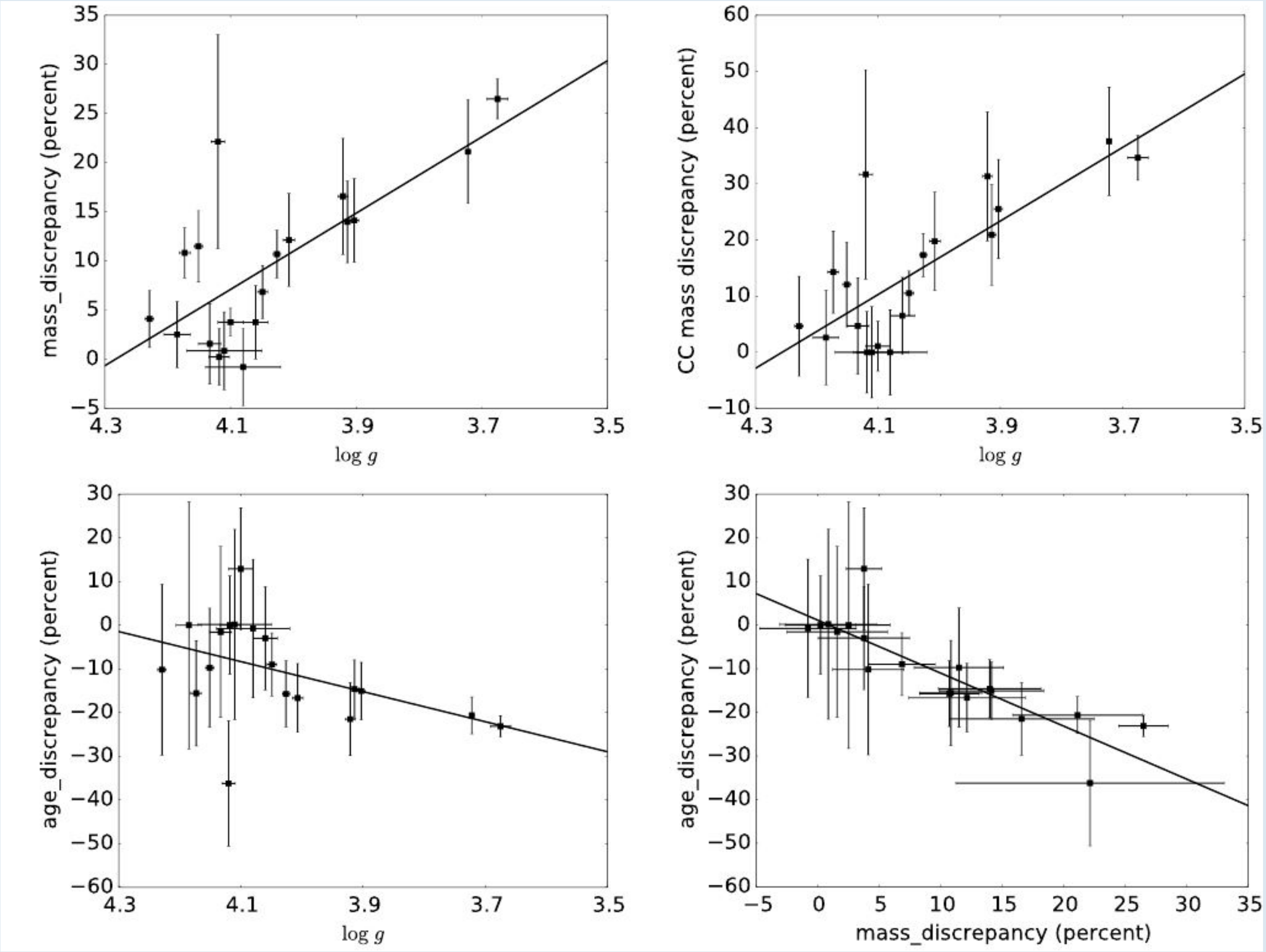
Calibrating Core-masses

10 systems / 20 stars

4.5-20 $M_\odot$

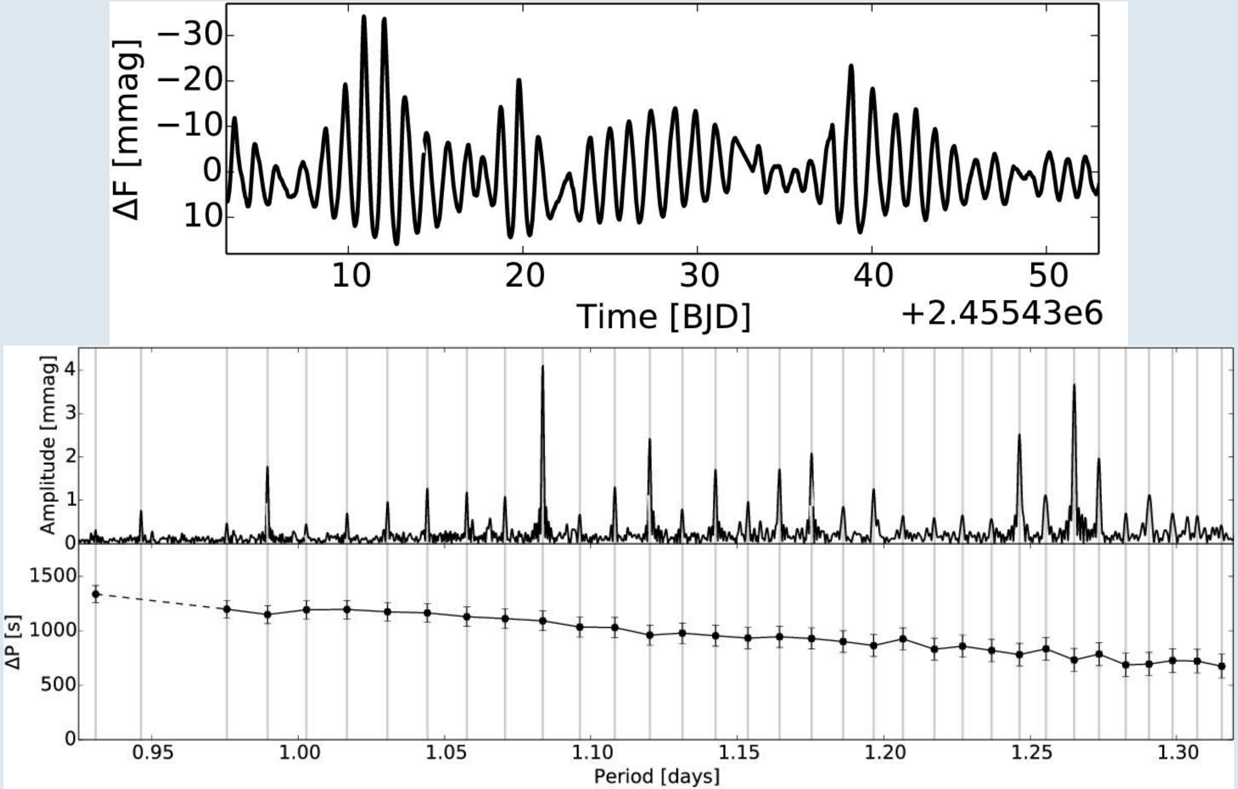
χ^2_1: M,T_{eff},log*g*

χ^2_2: T_{eff},log*g*



Tkachenko et al. *in prep.*

Add asteroseismic info…



g-modes:

1. Sensitive to core-mass
2. Near-core mixing
3. Core hydrogen content

Add asteroseismic info...

Combined information changes solution!

	KIC 4930889	SB2	KIC 6352430	SB2
Age [Myr]	85	103	140	205
f_{ov}	0.02	0.025	0.005	0.04
M_{cc} [$M_{\odot}$]	0.58	0.54	0.51	0.56

Johnston et al. 2019a

Add asteroseismic info...

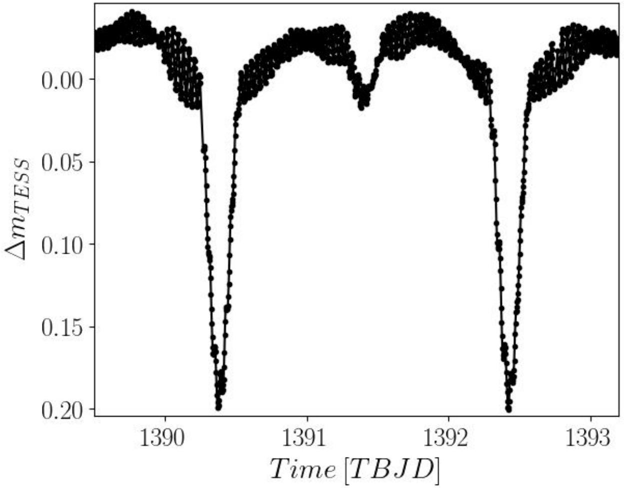
Combined informati[illegible] changes solu[illegible]

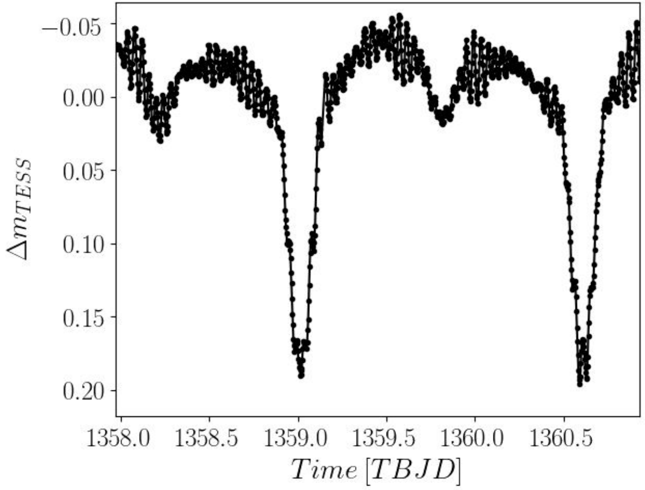
We need to cross-calibrate core-masses!!

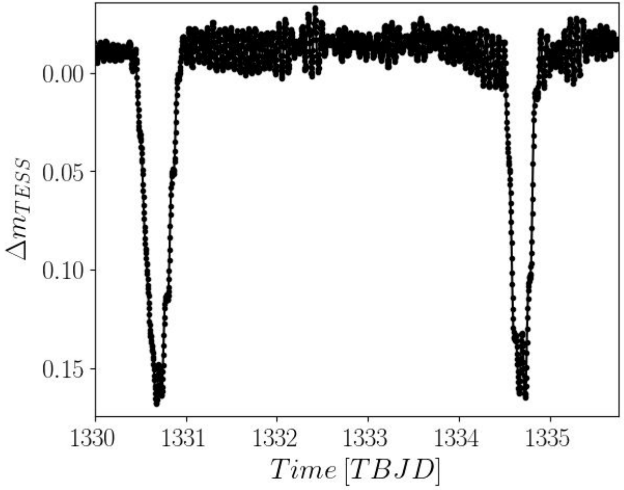
	KIC 49308[illegible]	[illegible]	[illegible]30	SB2
Age [M[illegible]	[illegible]	[illegible]	140	205
[illegible]	[illegible]02	0.025	0.005	0.04
M_{cc} [[illegible]$_{\odot}$]	0.58	0.54	0.51	0.56

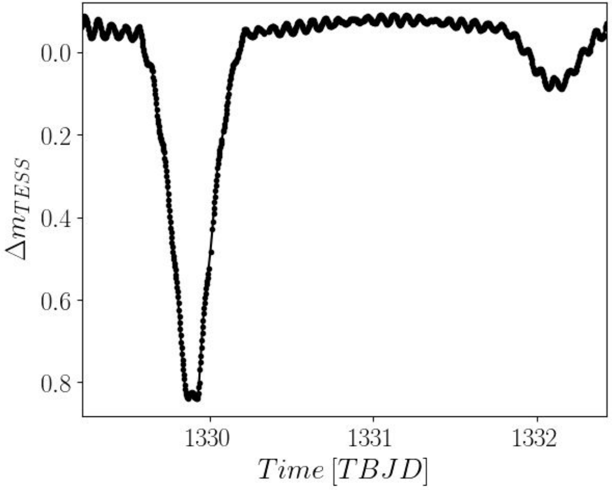
Johnston et al. 2019a

Extend asteroseismic sample



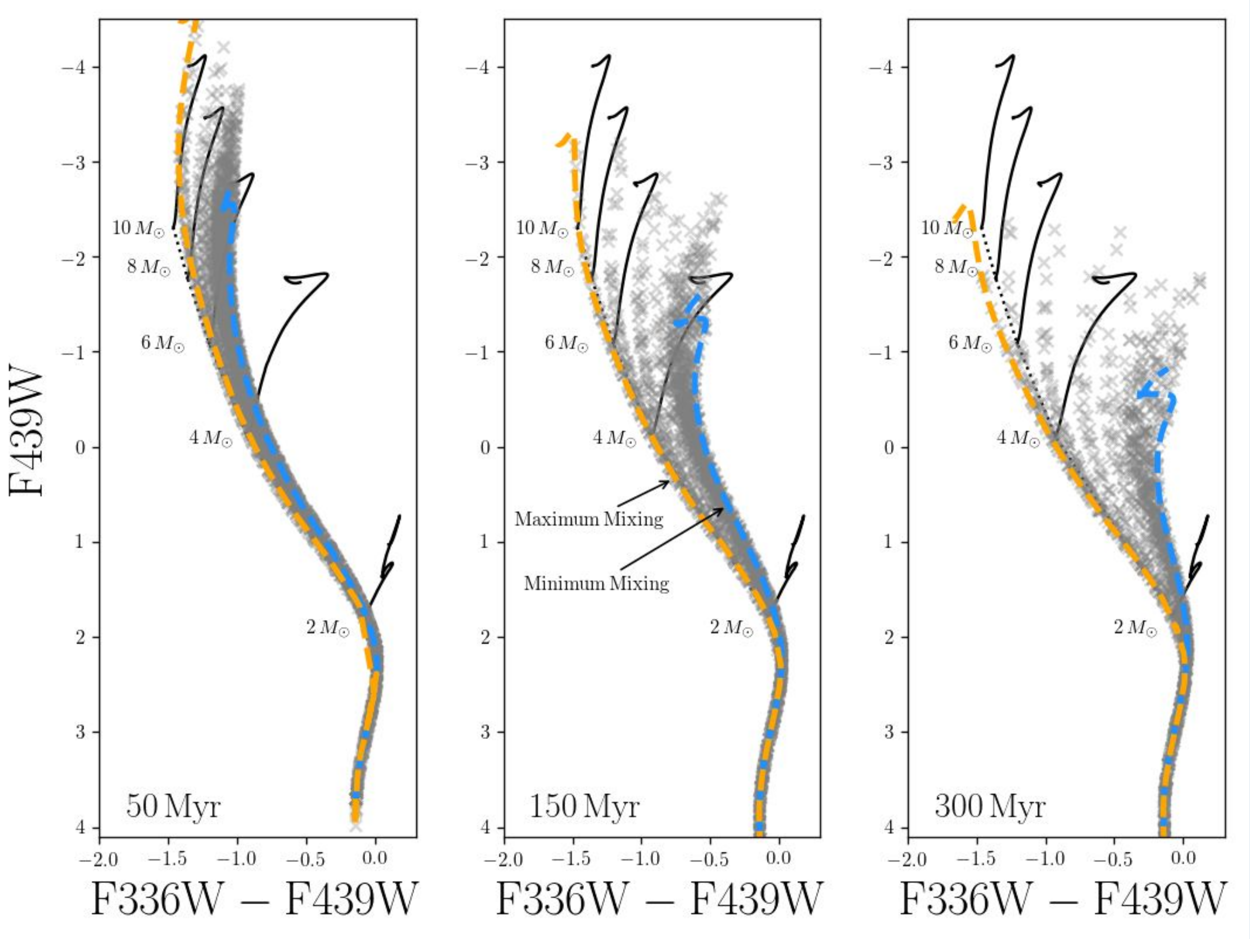






Can explain eMSTO of YMCs <u>for free!</u>

We find ages <u>~20%</u> different to those when fit with a single isochrone



Take home messages

1. <u>MUST</u> account for range of internal mixing efficiencies
2. We should calibrate core-mass across spectral type, evol. stage, etc
3. TESS will deliver **<u>MANY</u>** more pulsating EBs
4. YMCs with TESS

Perfect time to start reporting core masses

Extra slides

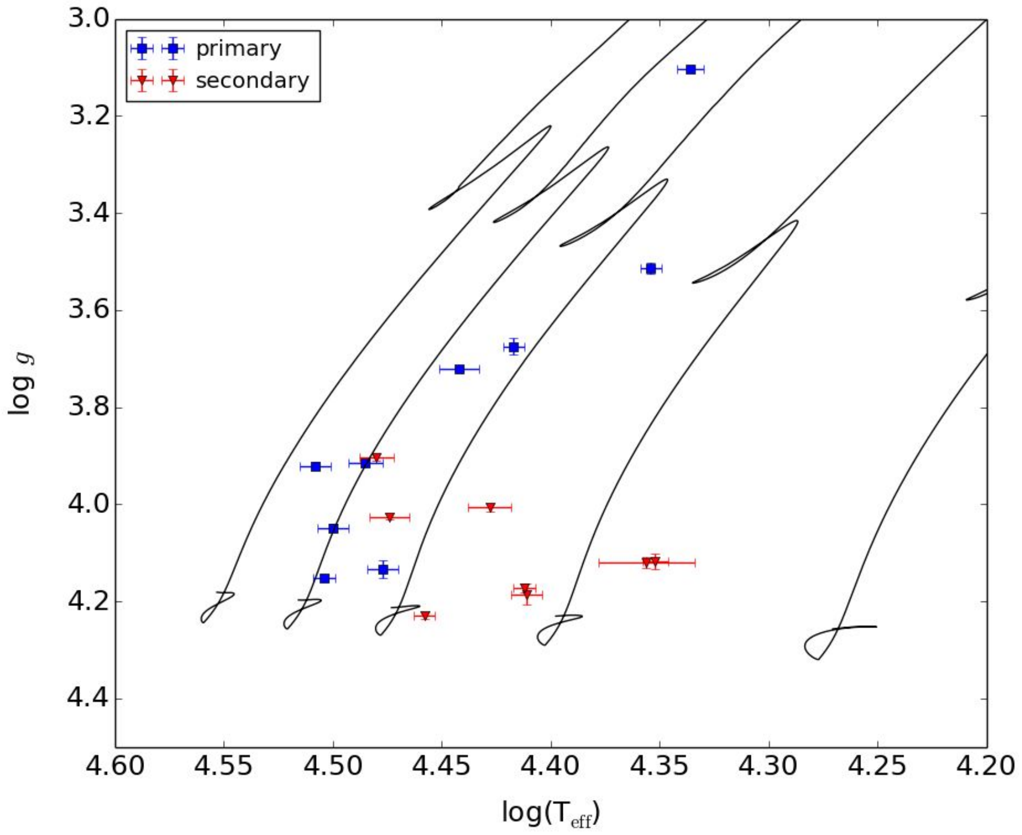
Calibrating Core-masses

10 systems / 20 stars

4.5-20 $M_\odot$

χ^2_1: M,T_{eff},log$g$

χ^2_2: T_{eff},log$g$



Tkachenko et al. *in prep.*

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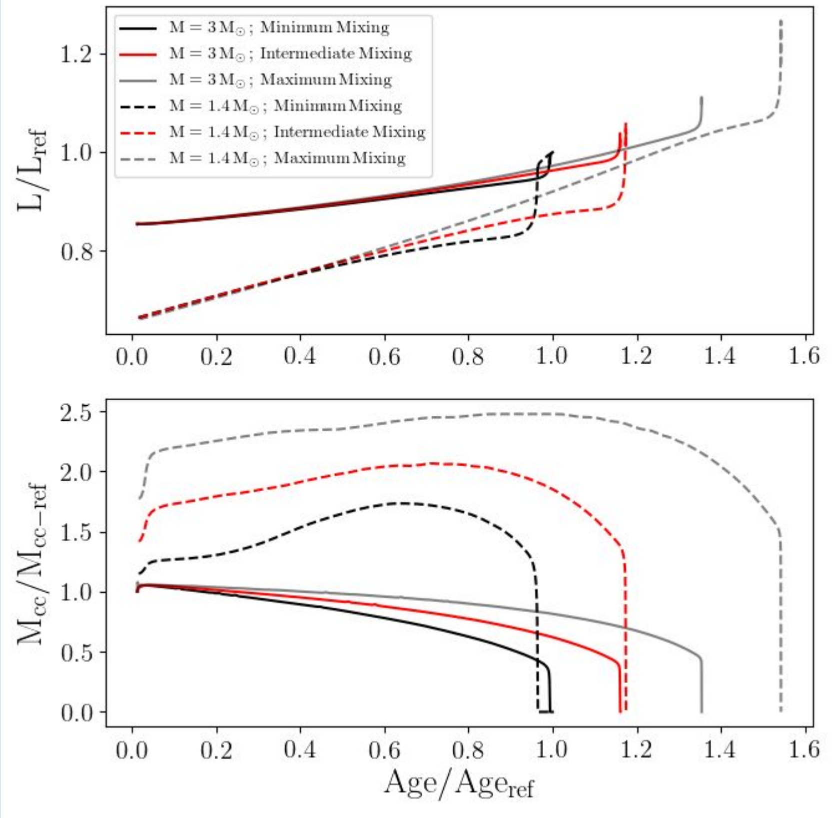
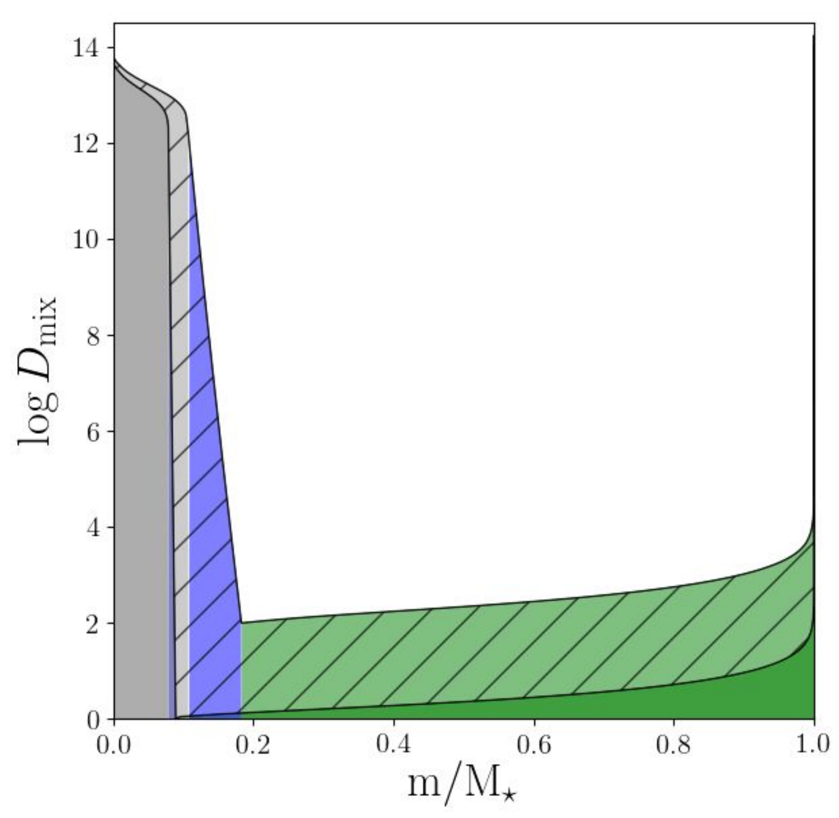
Core masses & ages





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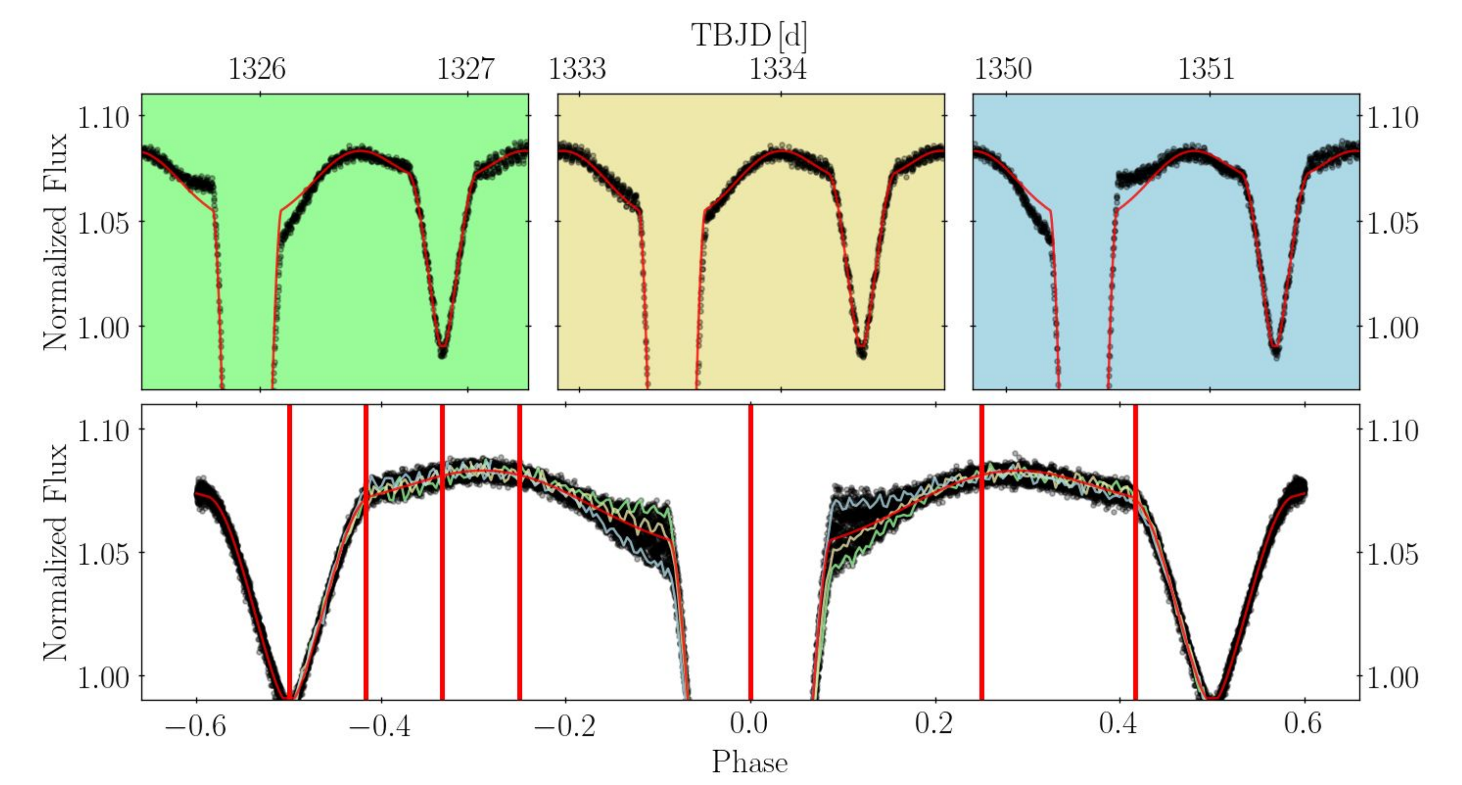
The curious case of U Gru

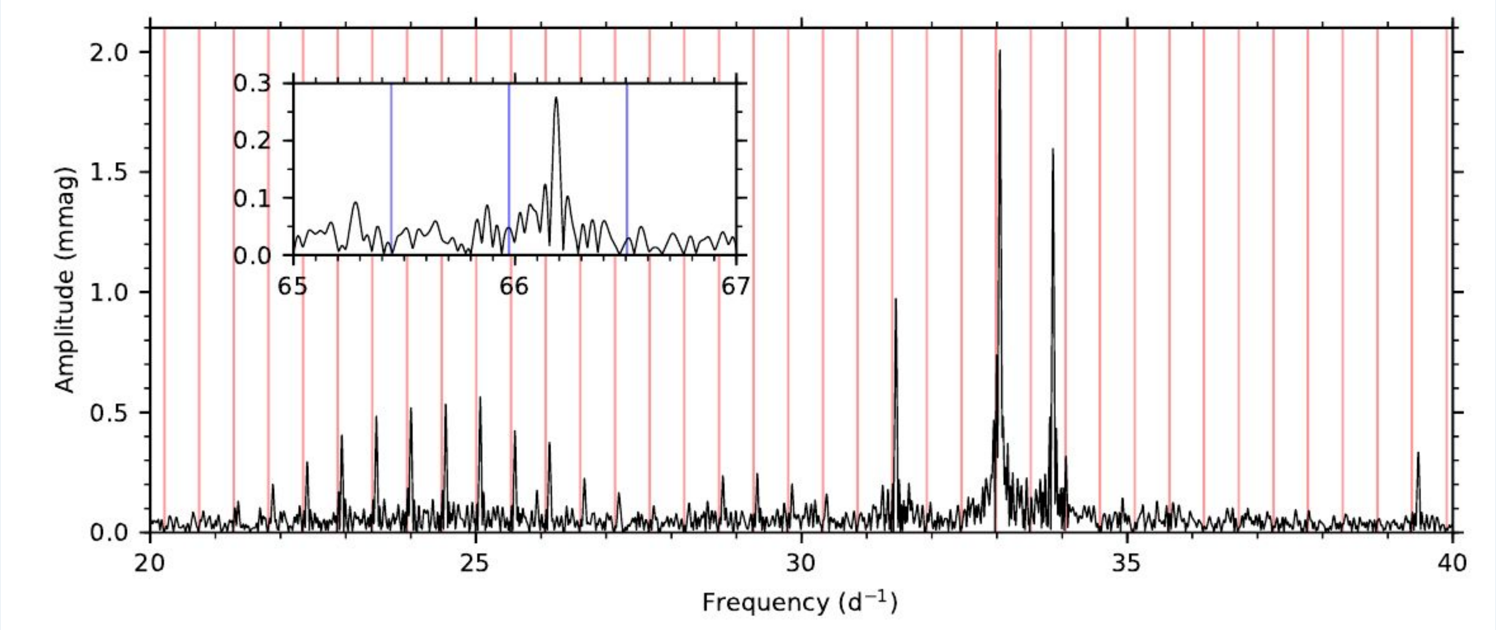


UVES
DDT

The curious case of U Gru

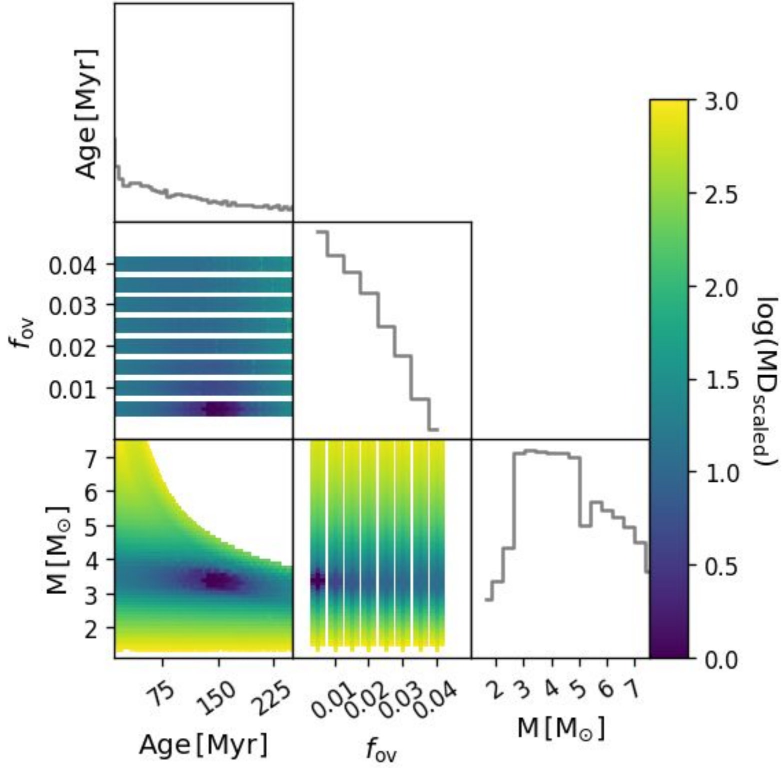
Circular eclipsing pulsating Algol system (oEA)

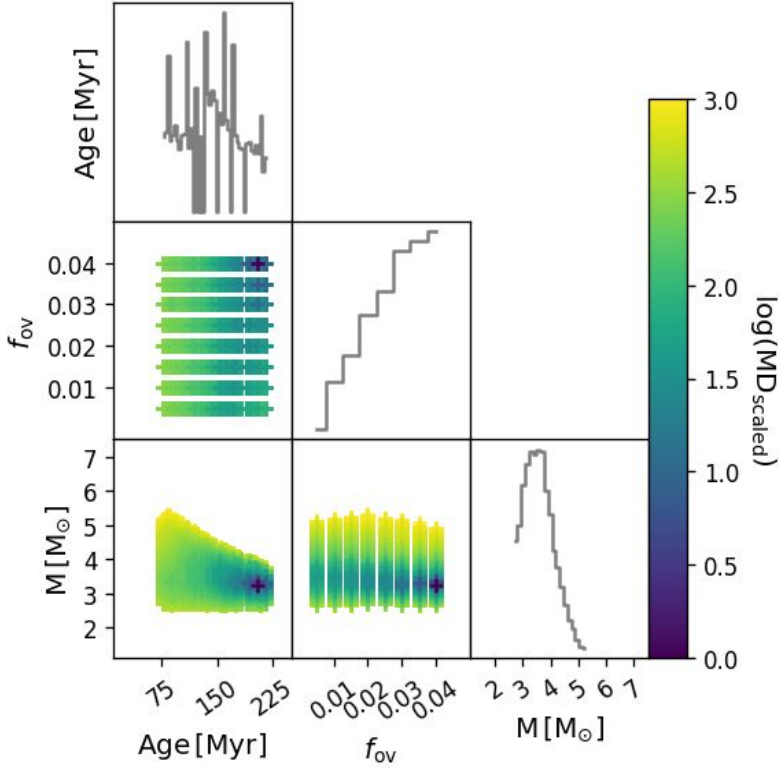
A-type primary + cooler companion



Vertical red lines denote orbital harmonics

Binary Asteroseismology





Absolute Dimensions

CW Cep					
Parameter	Gimenez et al. (1987)	Clausen & Gimenez (1991)	Han et al. (2002)[a]	Han et al. (2002)[b]	This Work
M_1 [$M_\odot$]	11.9 ± 0.1	11.82 ± 0.14	13.49	12.93	$13.00^{+0.07}_{-0.07}$
M_2 [$M_\odot$]	11.2 ± 0.1	11.09 ± 0.14	12.05	11.84	$11.94^{+0.08}_{-0.07}$
R_1 [$R_\odot$]	5.40 ± 0.1	5.48 ± 0.12	6.03	5.97	$5.45^{+0.03}_{-0.06}$
R_2 [$R_\odot$]	4.95 ± 0.1	4.99 ± 0.12	4.60	4.56	$5.09^{+0.06}_{-0.03}$
$\log g_1$ [dex]	4.05 ± 0.02	4.03 ± 0.02	4.01	3.99	$4.079^{+0.010}_{-0.005}$
$\log g_2$ [dex]	4.10 ± 0.02	4.09 ± 0.02	4.19	4.19	$4.102^{+0.005}_{-0.010}$

U Oph				
Parameter	Holmgren et al. (1991)	Vaz et al. (2007)	Budding et al. (2009)	This Work
M_1 [$M_\odot$]	4.93 ± 0.05	5.273 ± 0.091	5.13 ± 0.08	$5.09^{+0.06}_{-0.05}$
M_2 [$M_\odot$]	4.56 ± 0.04	4.783 ± 0.072	4.56 ± 0.07	$4.58^{+0.05}_{-0.05}$
R_1 [$R_\odot$]	3.29 ± 0.06	3.483 ± 0.020	3.41 ± 0.03	$3.44^{+0.01}_{-0.01}$
R_2 [$R_\odot$]	3.01 ± 0.05	3.109 ± 0.034	3.08 ± 0.03	$3.05^{+0.01}_{-0.01}$
$\log g_1$ [dex]	4.10 ± 0.01	4.068 ± 0.010	4.08 ± 0.01	$4.073^{+0.004}_{-0.004}$
$\log g_2$ [dex]	4.14 ± 0.02	4.128 ± 0.012	4.12 ± 0.01	$4.131^{+0.004}_{-0.004}$

Notes. Table compares derived fundamental parameters from this work to previous studies of CW Cep (top) and U Oph (bottom).
[(a)] Solution derived using spectroscopic values obtained by Popper & Hill (1991) [(b)] Solution derived using spectroscopic values obtained by Stickland et al. (1992)

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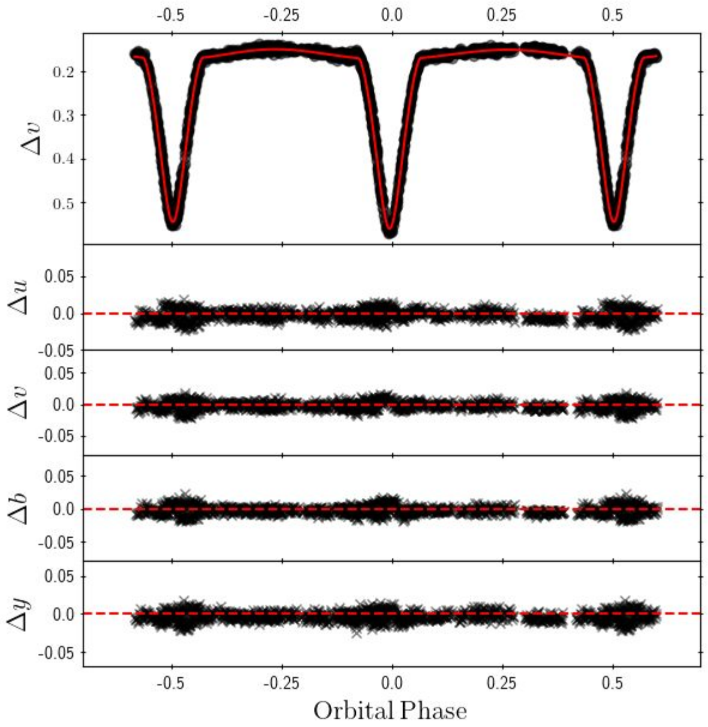
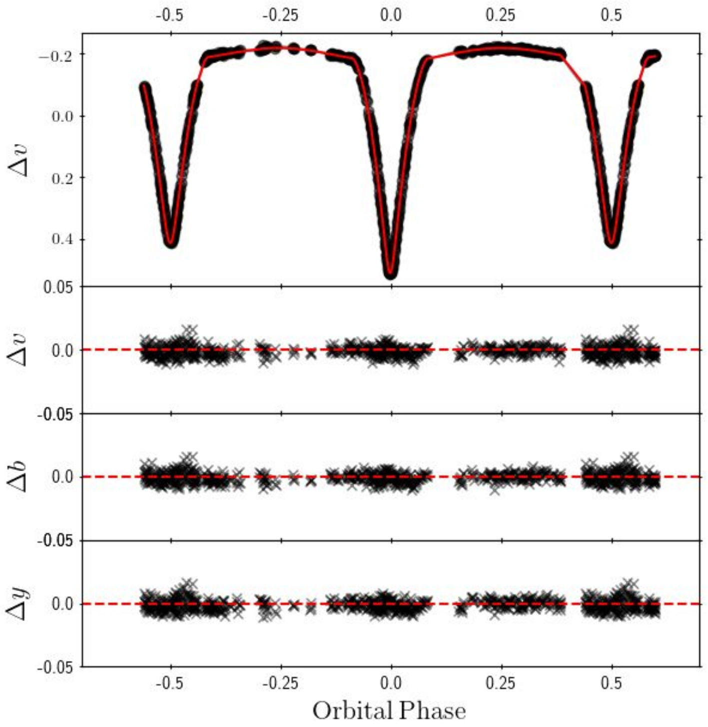
CW Cep & U Oph





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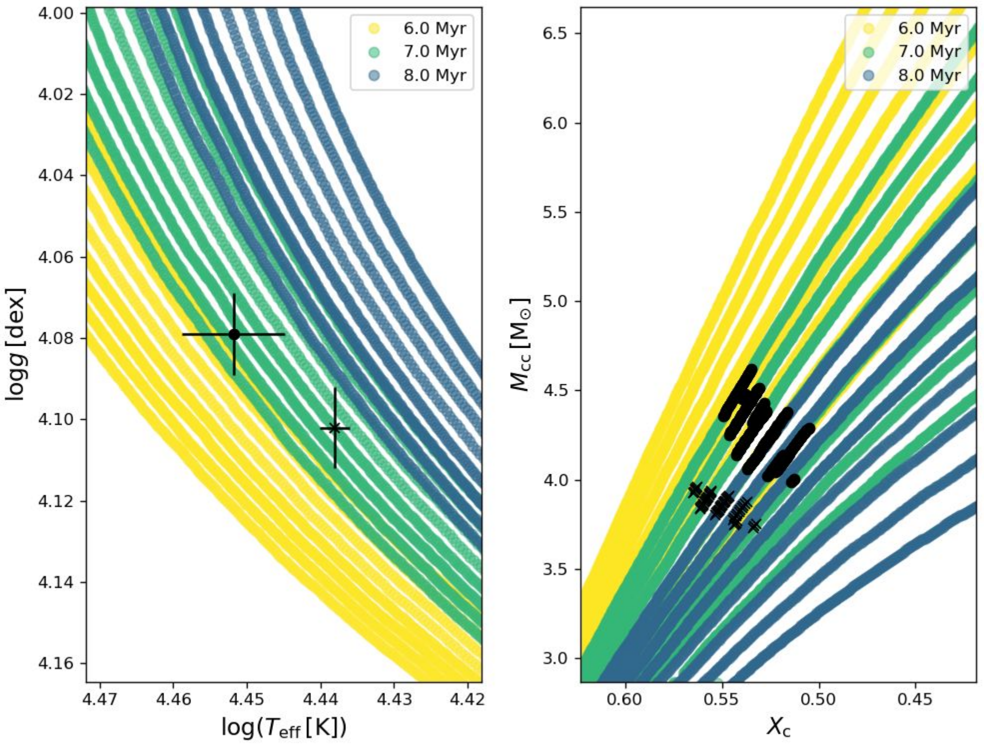
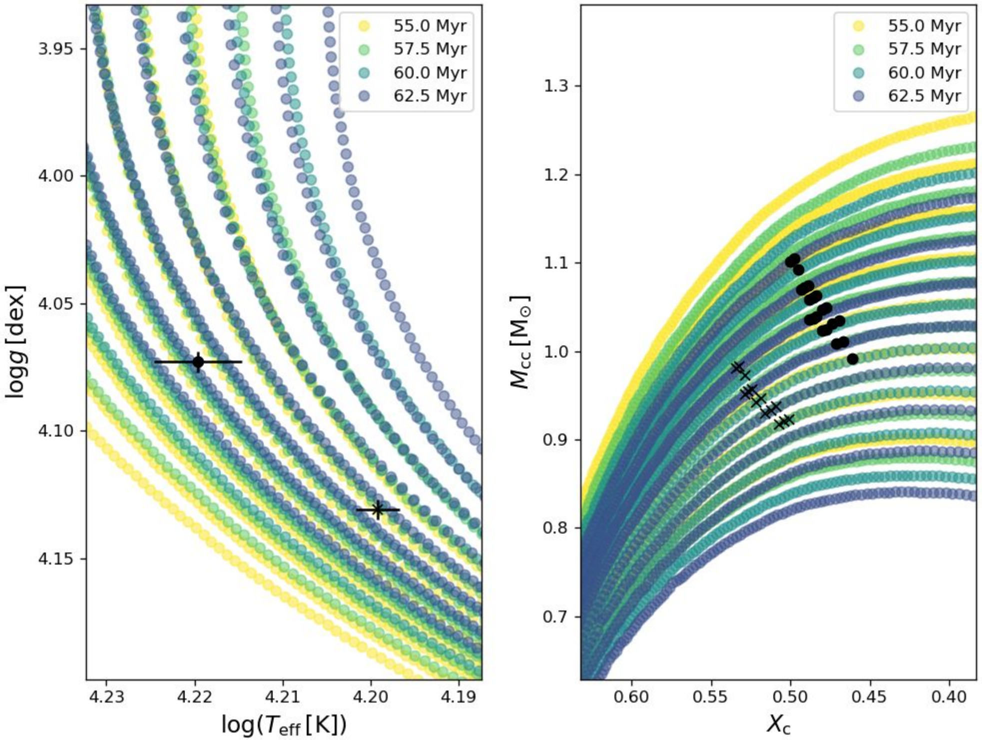
CW Cep


6.0 Myr
7.0 Myr
8.0 Myr
log g [dex]
log(T_eff [K])
4.00
4.02
4.04
4.06
4.08
4.10
4.12
4.14
4.16
4.47
4.46
4.45
4.44
4.43
4.42
6.0 Myr
7.0 Myr
8.0 Myr
M_cc [M⊙]
X_c
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
0.60
0.55
0.50
0.45

& U Oph


55.0 Myr
57.5 Myr
60.0 Myr
62.5 Myr
3.95
4.00
4.05
4.10
4.15
log g [dex]
4.23
4.22
4.21
4.20
4.19
log(T_{eff} [K])
55.0 Myr
57.5 Myr
60.0 Myr
62.5 Myr
1.3
1.2
1.1
1.0
0.9
0.8
0.7
M_{cc} [$M_\odot$]
0.60
0.55
0.50
0.45
0.40
X_c