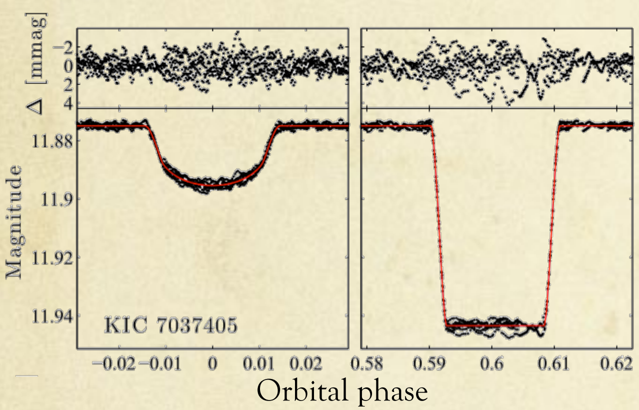
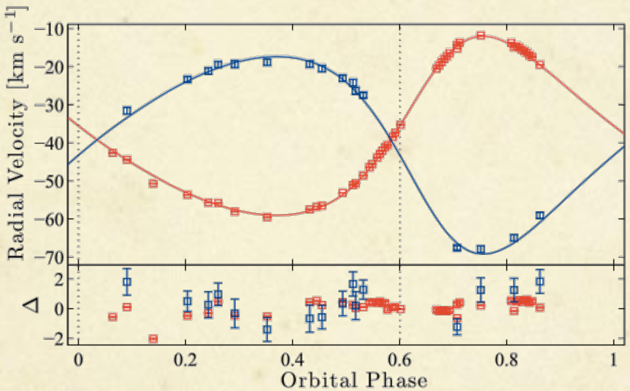
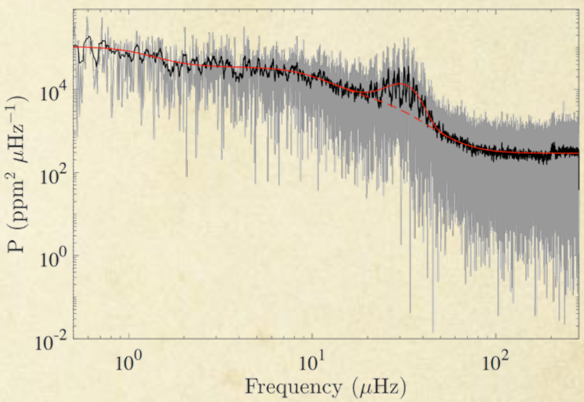
Oscillating Red Giants in Eclipsing Binaries

- The Pet Shop -







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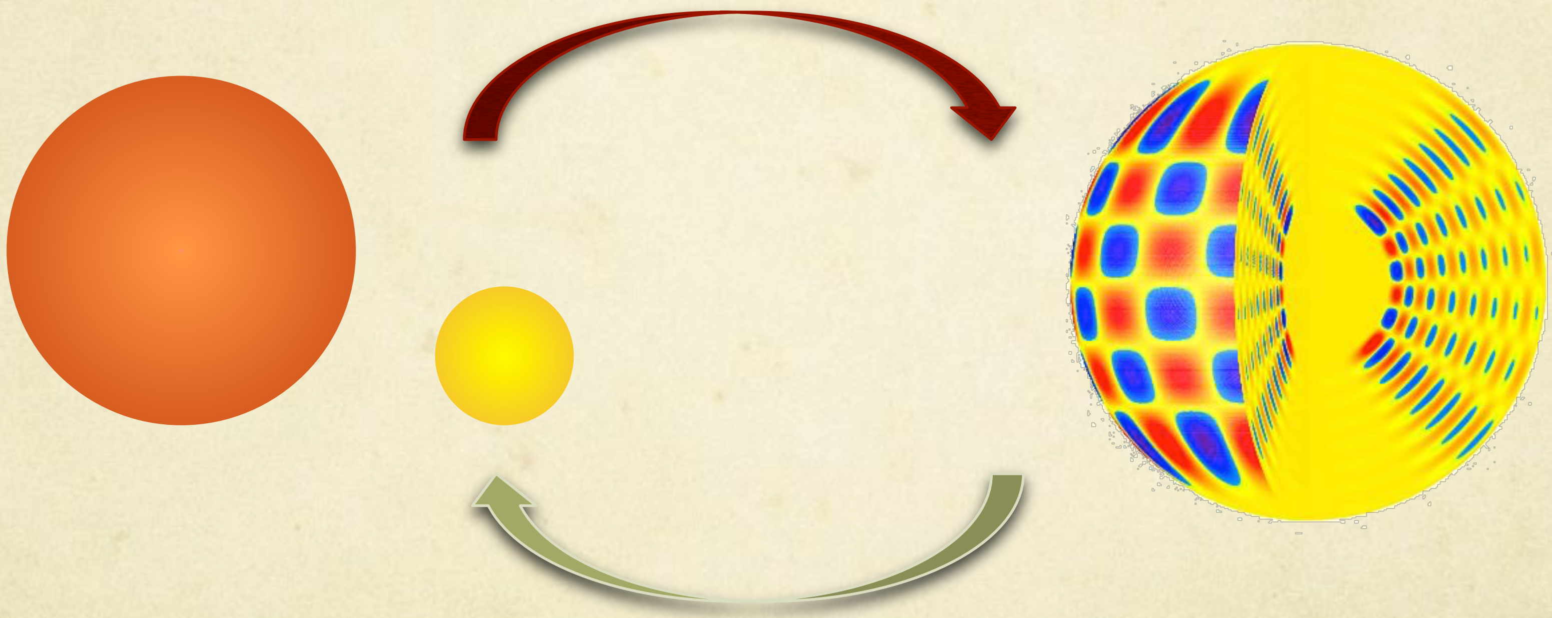
Lund Reference Star Workshop April 28

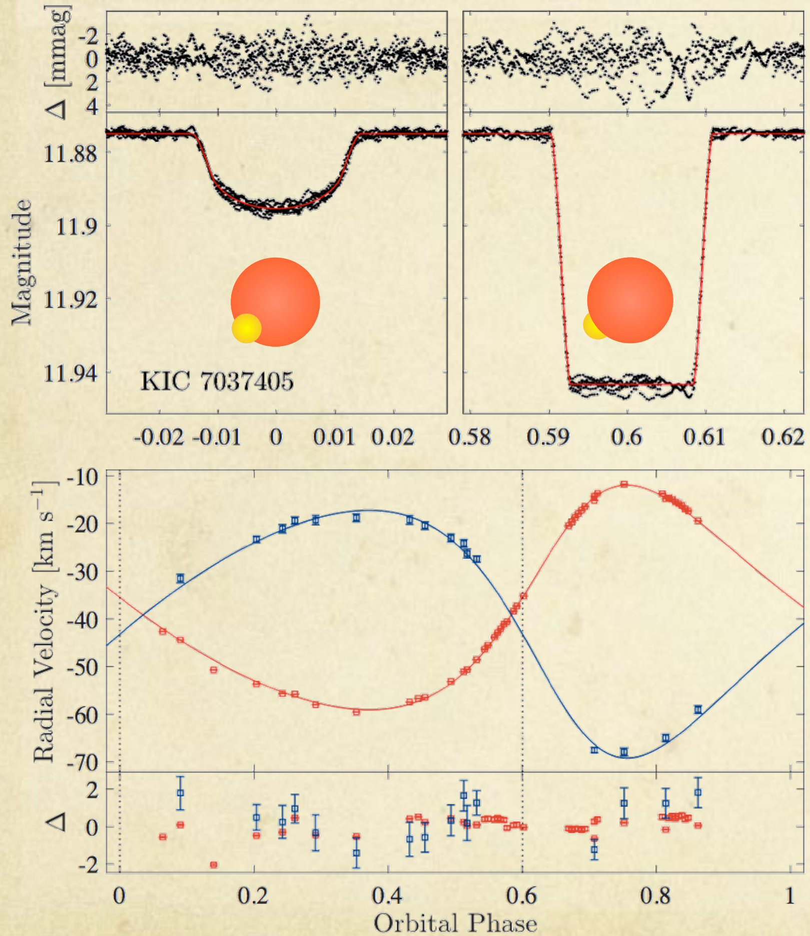
Solar-like oscillators in eclipsing binaries

Testing asteroseismology



Evolution of binary systems

Masses and radii with eclipsing binaries

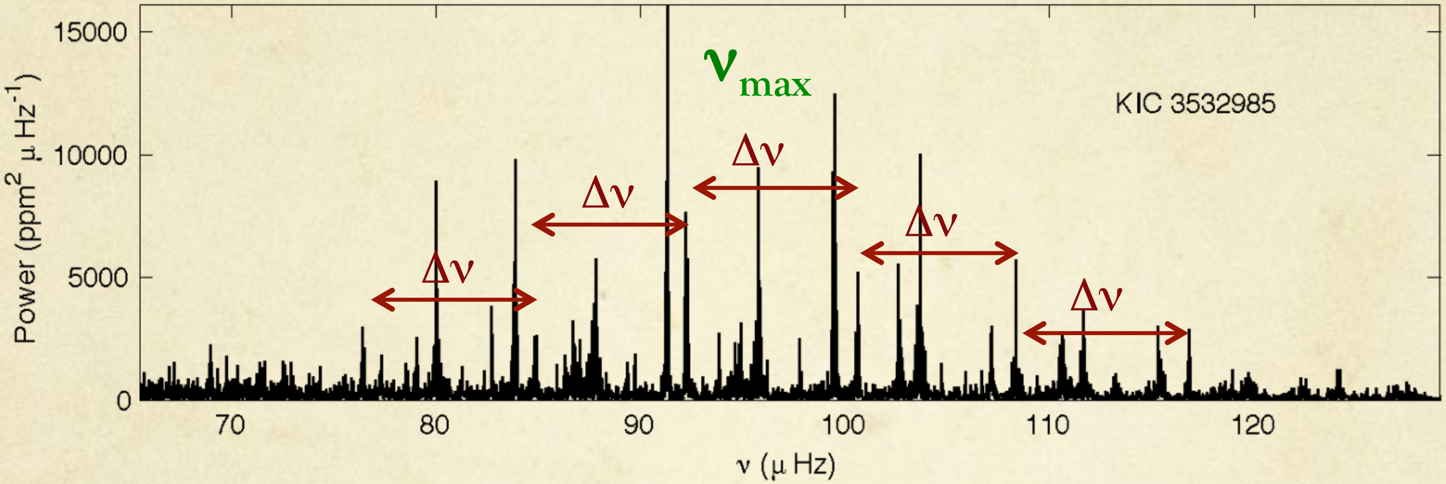


From Gaulme+16, ApJ 832, 121

- Eclipse photometry
  - R_1/a, R_2/a, T_2/T_1, e, i, limb darkening, P_{orb}, T_0
- Radial velocities
  - M_1 sin*i*, M_2 sin*i*, P_{orb}, T_0, e, W
- Double-lined spectroscopic binaries
  - Absorption lines are detectable for both components
- Combination: M_1, M_2, R_1, R_2
- Accuracy 1% on radii, 1-3% on masses

Asteroseismic scaling relations

- Solar-like oscillations



- Asteroseismic scaling relations (Kjeldsen & Bedding 1995)

$$\frac{\bar{\rho}}{\bar{\rho}_\odot} = \left(\frac{\Delta\nu}{\Delta\nu_\odot}\right)^2 \qquad \frac{g}{g_\odot} = \frac{\nu_{\max}}{\nu_{\max_\odot}}\left(\frac{T_{\rm eff}}{T_{\rm eff,\odot}}\right)^{\frac{1}{2}}$$

$$\Longrightarrow$$

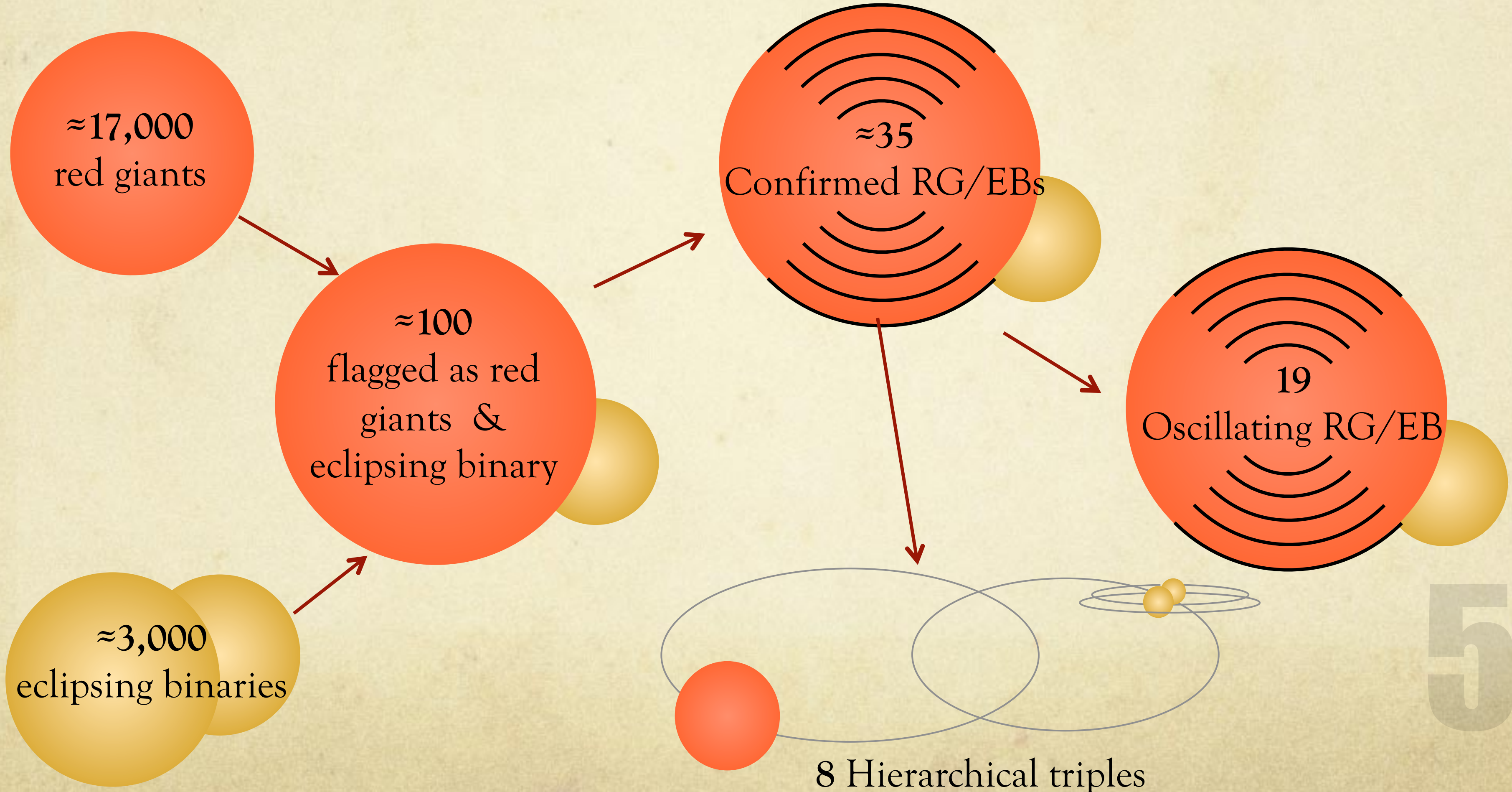
$$\frac{R}{R_\odot} = \left(\frac{\nu_{\max}}{\nu_{\max_\odot}}\right)\left(\frac{\Delta\nu_\odot}{\Delta\nu}\right)^2\left(\frac{T_{\rm eff}}{T_{\rm eff,\odot}}\right)^{\frac{1}{2}}$$

$$\frac{M}{M_\odot} = \left(\frac{\nu_{\max}}{\nu_{\max_\odot}}\right)^3\left(\frac{\Delta\nu_\odot}{\Delta\nu}\right)^4\left(\frac{T_{\rm eff}}{T_{\rm eff,\odot}}\right)^{\frac{3}{2}}$$

- Corrections of the scaling relations: Kallinger+10,+18, White+11, Chaplin+11, Mosser+13, Sharma+15, Guggenberger+16, Rodrigues+17, Themeßl+18.

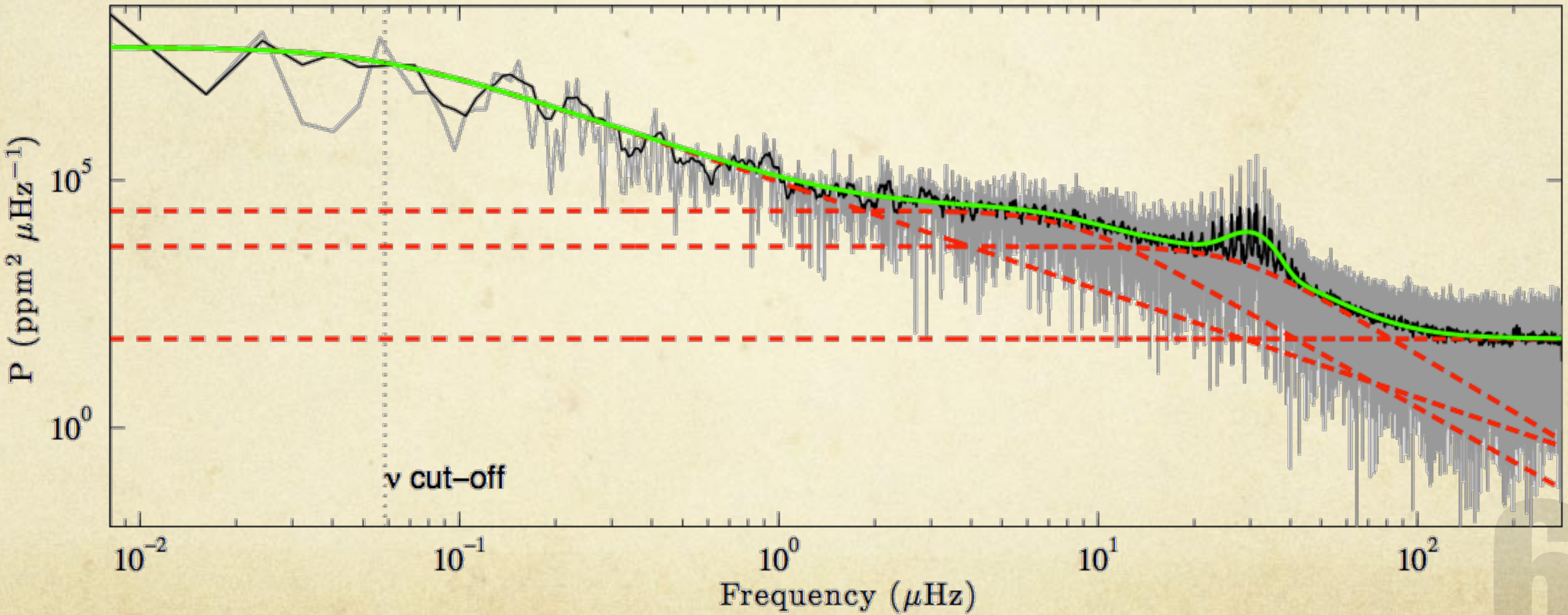
Rare systems

- First system: KIC 8410637 (Hekker+2010, Frandsen+2013)
- Kepler: RG catalog + Villanova EB catalog: about 35 systems total (Gaulme+2013, Gaulme & Guzik 2019)



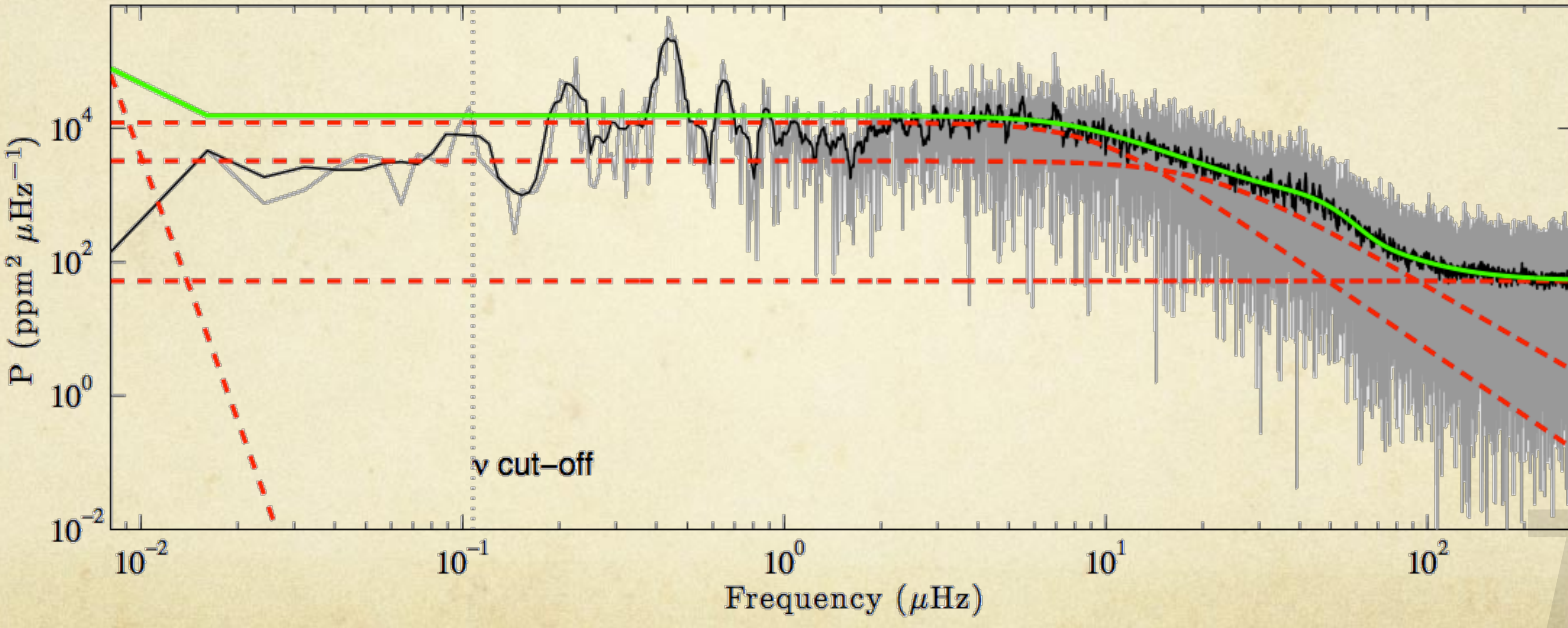
Oscillations, Activity, Binarity

- Some red giants in eclipsing binaries oscillate nicely (18/35)



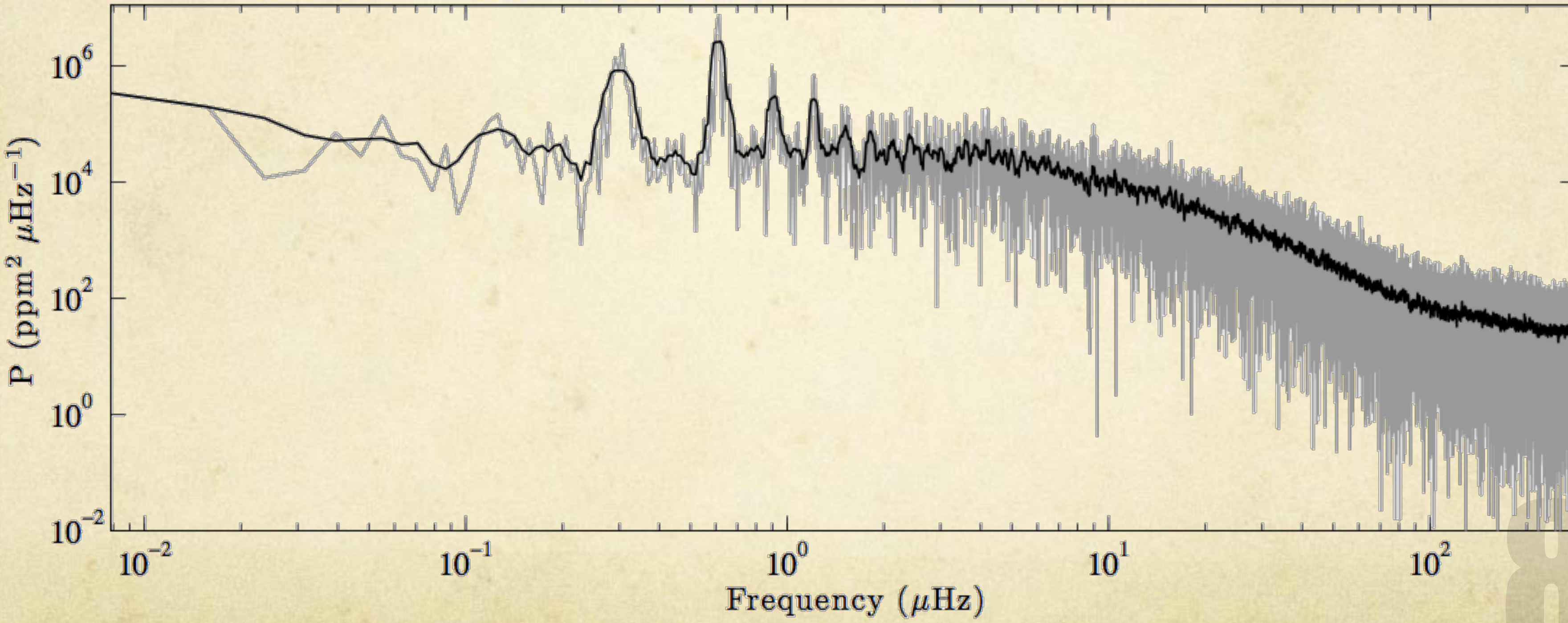
Oscillations, Activity, Binarity

- Some red giants in eclipsing binaries oscillate nicely (18/35)
- … some weakly (7/35)



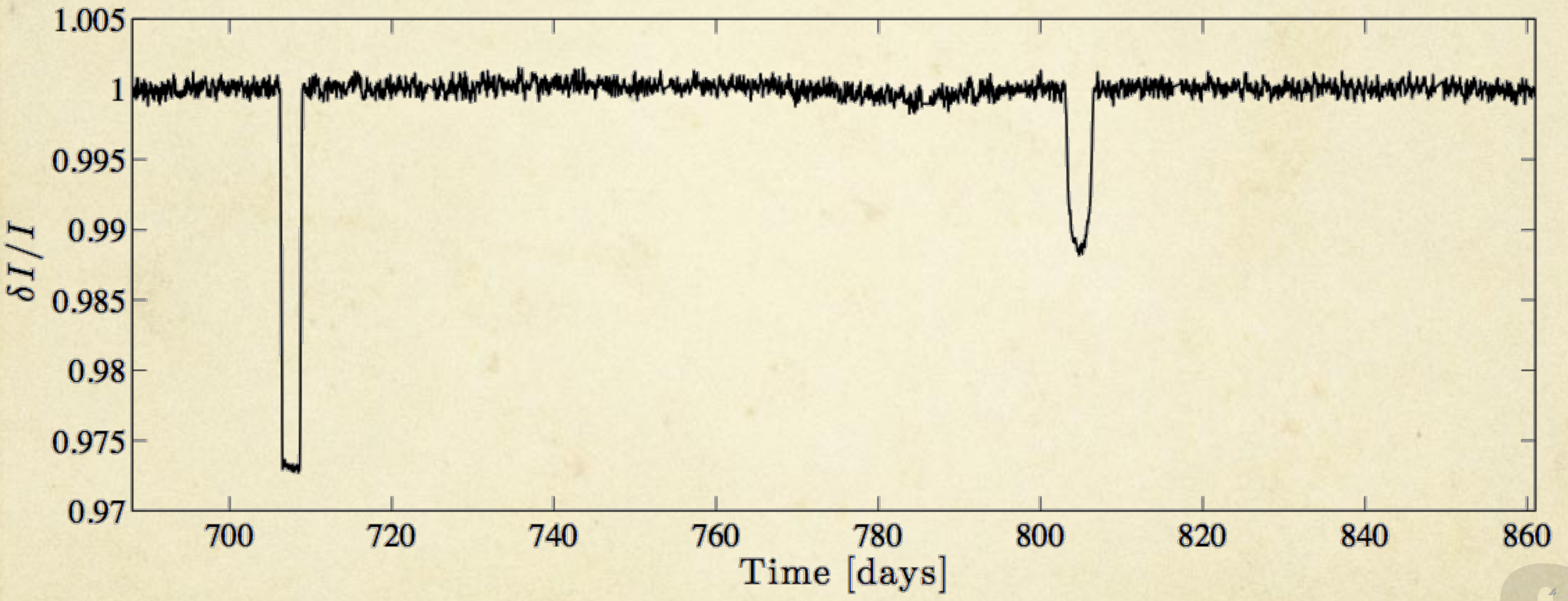
Oscillations, Activity, Binarity

- Some red giants in eclipsing binaries oscillate nicely (18/35)
- ... some weakly (7/35)
- ... some don't at all (10/35)



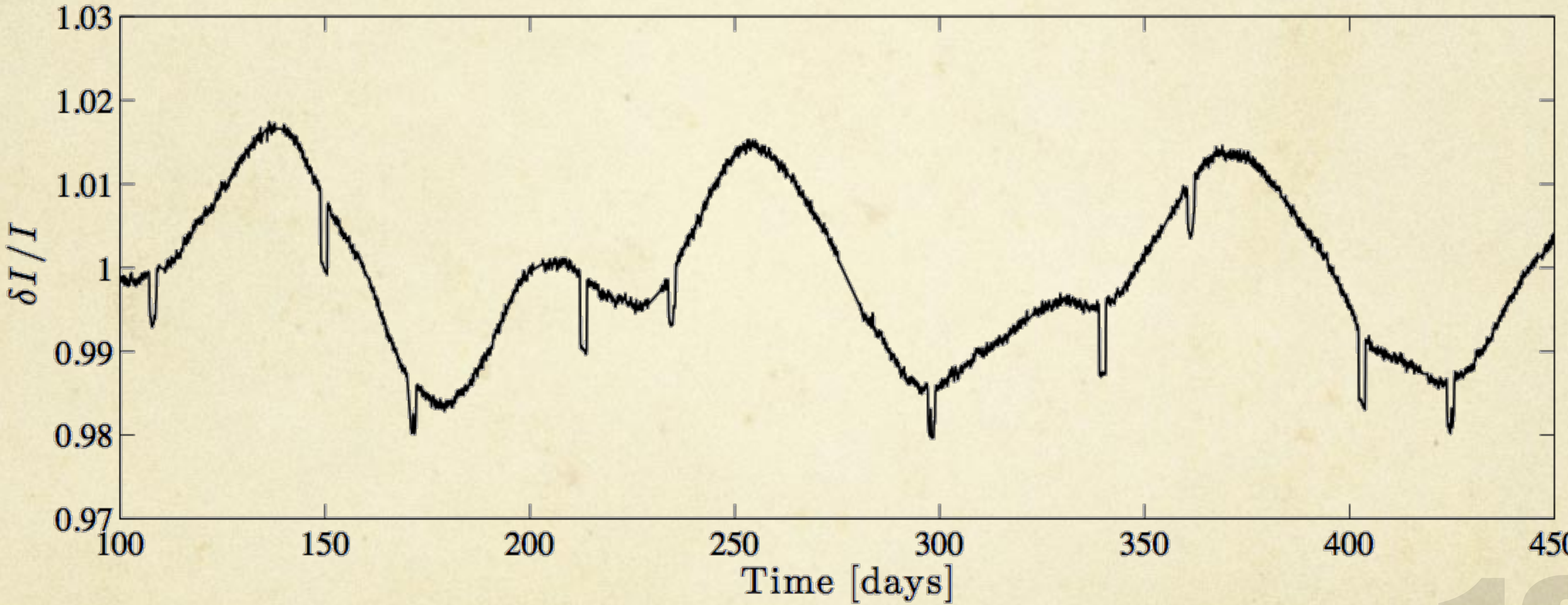
Oscillations, Activity, Binarity

- Some display negligible stellar variability (18/35)

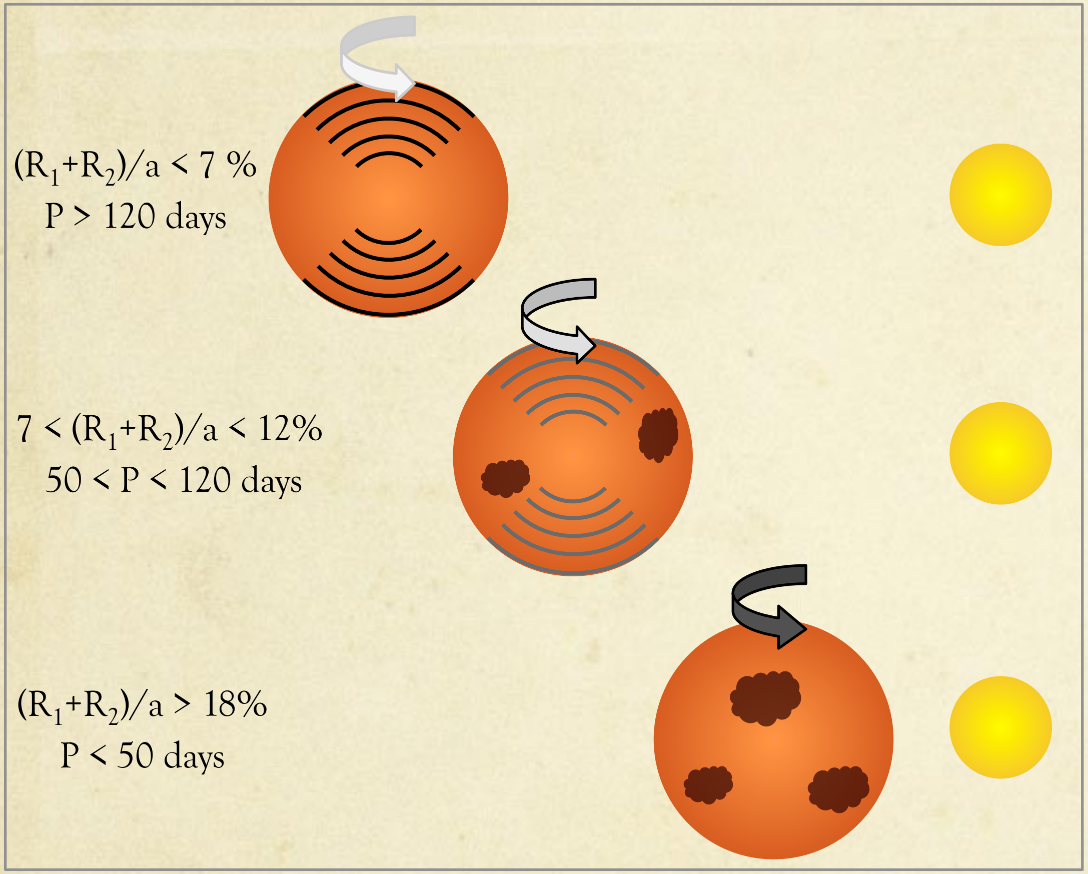


Oscillations, Activity, Binarity

- Some display negligible stellar variability (18/35)
- … some display large variability (17/35) up to Sph = 10%



Oscillations, Activity, Binarity



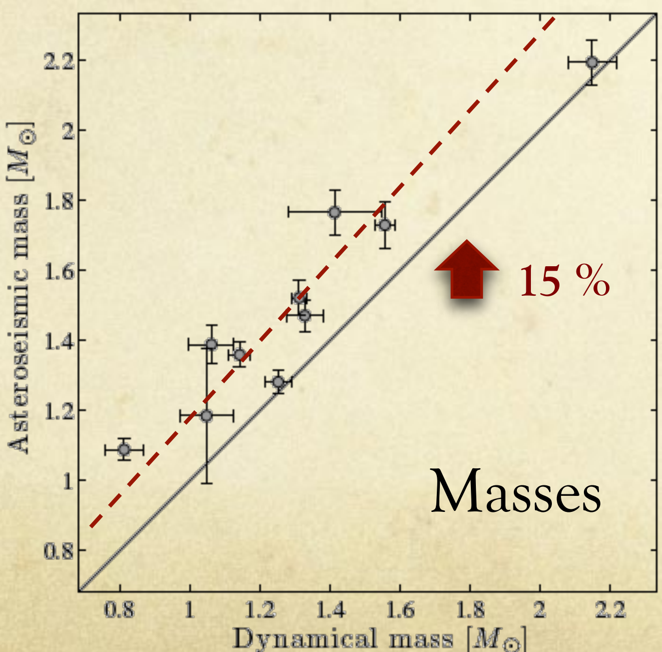
- Distant binaries
  No activity, regular oscillations
- Relatively close binaries
  Activity, weak oscillations
  Pseudo-synchronization
- Close binaries
  Large activity, no oscillations
  Synchronization

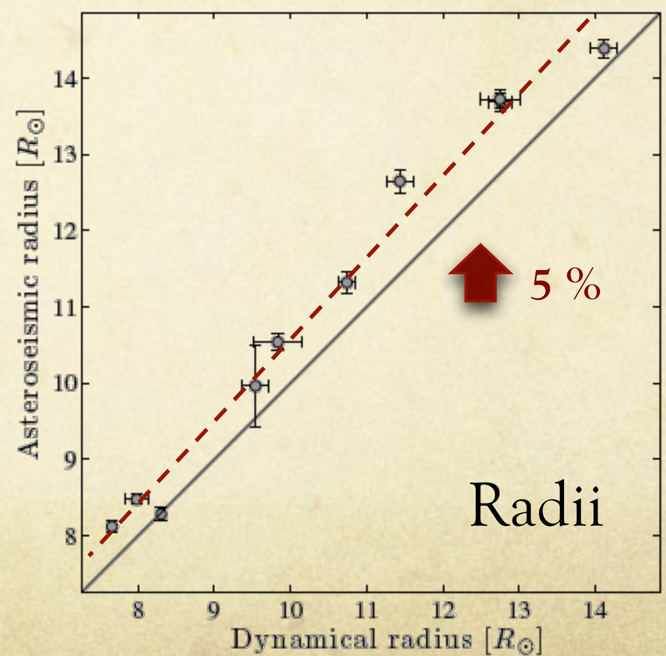
<u>Qualitative interpretation (Gaulme+14, Benbakoura+21):</u>

- Synchronization by tidal forces: red giants spun up, dynamo kicks off
- Oscillations damped by spots + convection reduced by magnetic fields

Testing Asteroseismic Scaling Relations

- Gaulme+16: sample of 10 red giants in eclipsing binaries
  - 4 years of Kepler light curves + 4 years of ground-based RV support
- Asteroseismology overestimates M,R (15% for M, 5% for R)
- Updates: Themeßl+18 (1 syst), Benbakoura+21 (3 syst), Gaulme & Guzik +19 (2-3 syst), Brogaard+18 (reobservation of 3 systems)





Selecting the best RG(s)

- Some of these will become gold standards: precise M, R and oscillations. Not all are worth the same though.
- Selection criterion
  - Red giant branch (RGB) vs red clump (RC)
  - “Long” orbital period (>120 days) to avoid mass transfer and oscillation suppression
  - Neither synchronized nor circularized
  - Mixed modes vs no detectable mixed modes
  - SB2, not SB1: favors short orbits
  - Accurate RV precision: short orbits are favored (larger K1, K2)
  - Accurate atmospheric parameters. All my RG/EBs have been extensively observed with Apache Point 3.5-m telescope’s high resolution spectrometer ($R \approx 30{,}000$)

Shortlist

- Dynamics vs asteroseismic parameters (Gaulme+2016)

Table 4
Stellar Physical Parameters from Dynamical Modeling (Subscripts "rv") and Asteroseismic Scaling Relations (Subscripts "ast")

KIC	Red Giant									Companion			
	M_{rv} ($M_\odot$)	M_{ast} ($M_\odot$)	R_{rv} ($R_\odot$)	R_{ast} ($R_\odot$)	$\log g_{rv}$ (dex)	$\log g_{ast}$ (dex)	$\bar{\rho}_{rv}$ ($10^{-3}\bar{\rho}_\odot$)	$\bar{\rho}_{ast}$ [$10^{-3}\bar{\rho}_\odot$]	T_{eff} (K)	M [$M_\odot$]	R ($R_\odot$)	T_{eff} (K)	d (kpc)
Double-line Spectroscopic Binaries (SB2)													
8410637†	1.56(3)	1.70(7)	10.7(1)	11.2(2)	2.57(1)	2.569(5)	1.26(6)	1.205(9)	4800(100)	1.32(2)	1.57(3)	6490(160)	0.87
4663623	1.36(9)	1.74(7)	9.7(2)	10.5(1)	2.60(2)	2.640(5)	1.48(6)	1.52(1)	4812(92)	1.34(7)	1.82(6)	6808(140)	1.92
9970396	1.14(3)	1.36(4)	8.0(2)	8.47(7)	2.69(2)	2.716(3)	2.2(1)	2.234(7)	4916(68)	1.02(2)	1.12(2)	6378(91)	0.92
7037405	1.25(4)	1.25(4)	14.1(2)	14.2(2)	2.24(1)	2.230(3)	0.45(1)	0.436(4)	4516(36)	1.14(2)	1.80(2)	6303(53)	1.43
5786154	1.06(6)	1.36(6)	11.4(2)	12.5(2)	2.35(2)	2.377(5)	0.71(2)	0.694(6)	4747(100)	1.02(4)	1.59(3)	6527(138)	2.82
9540226	1.33(5)	1.45(5)	12.8(1)	13.6(2)	2.349(8)	2.334(4)	0.639(8)	0.578(5)	4692(65)	0.98(3)	0.99(1)	6399(90)	1.29
9246715†	2.149(7)	2.19(6)	8.30(4)	8.28(8)	2.932(4)	2.943(4)	3.76(5)	3.86(2)	5030(45)	2.171(7)	8.37(5)	4990(90)	0.39
10001167	0.81(5)	1.06(4)	12.7(3)	13.6(2)	2.14(2)	2.200(4)	0.39(2)	0.427(4)	4700(66)	0.79(3)	0.98(2)	6191(91)	0.69
7377422	1.05(8)	1.2(2)	9.5(2)	9.9(6)	2.50(2)	2.52(2)	1.21(4)	1.21(3)	4938(110)	0.85(3)	0.87(2)	6120(143)	2.59
8430105	1.31(2)	1.52(6)	7.65(5)	8.1(1)	2.788(4)	2.802(4)	2.93(3)	2.85(3)	5042(68)	0.83(1)	0.770(5)	5771(78)	0.61
4569590	1.56(10)	…	14.1(2)	…	2.33(1)	…	0.56(1)	…	4706(152)	1.05(4)	0.96(2)	6456(211)	2.37
3955867	1.10(6)	…	7.9(1)	…	2.68(1)	…	2.19(4)	…	4884(83)	0.92(3)	0.90(1)	6312(108)	2.19
9291629	1.14(3)	…	7.99(5)	…	2.691(5)	…	2.24(2)	…	4713(151)	1.12(2)	1.86(1)	6041(194)	2.28
7943602	1.0(1)	…	6.6(2)	…	2.79(2)	…	3.40(9)	…	5096(100)	0.78(5)	0.83(2)	6431(128)	2.68
Single-line Spectroscopic Binaries (SB1)													
8054233	…	1.60(6)	…	10.7(1)	…	2.581(5)	…	1.294(8)	4971(90)	1.10(4)	1.16(2)	6344(117)	1.61
5179609	…	1.18(3)	…	3.50(3)	…	3.423(3)	…	27.6(1)	5003(54)	0.60(1)	0.370(3)	5950(304)	0.88
5308778	…	1.5(1)	…	10.1(3)	…	2.60(1)	…	1.43(3)	4900(44)	0.64(3)	0.61(2)	4416(52)	1.47
8702921	…	1.67(5)	…	5.32(5)	…	3.209(4)	…	11.07(2)	5058(86)	0.274(9)	0.284(3)	2654(49)	0.97

Note. The parameters M, R, $\log g$, and $\bar{\rho}$ refer to stellar masses, radii, surface gravities, and mean densities, T_{eff} effective temperatures, and d system distances. Systems are sorted by decreasing orbital period. The dagger symbols † indicate that the dynamical values of KICs 8410637 and 9246715 are taken from Frandsen et al. (2013) and Rawls et al. (2016), respectively. For SB1 systems, the parameters of the companion stars are deduced by combining asteroseismic masses and radii of the RG with the mass function obtained from light curve and radial velocity modeling.

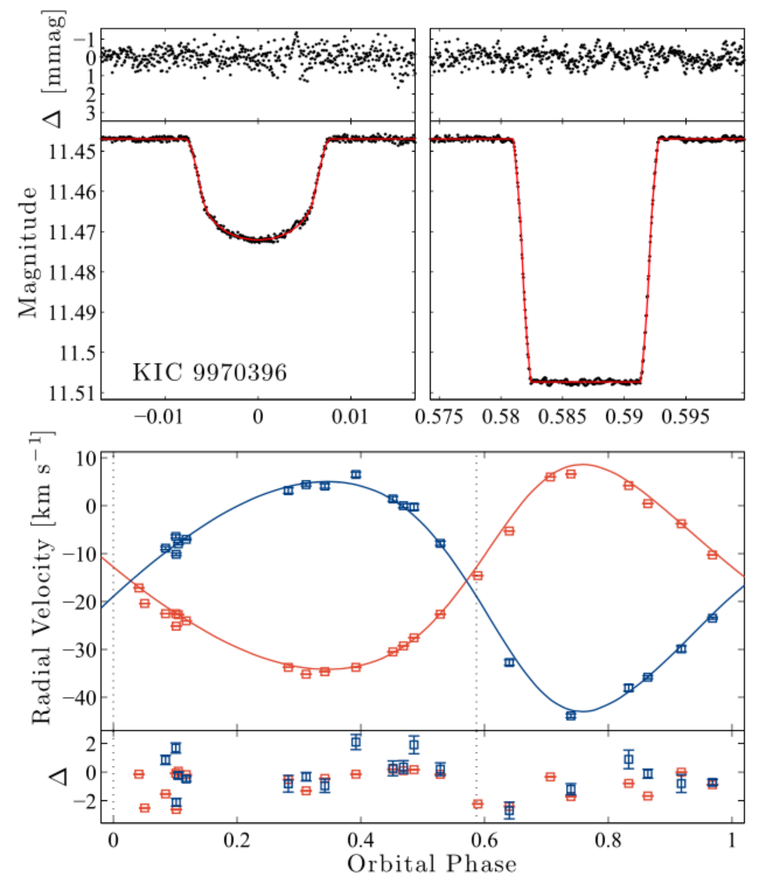
Shortlist

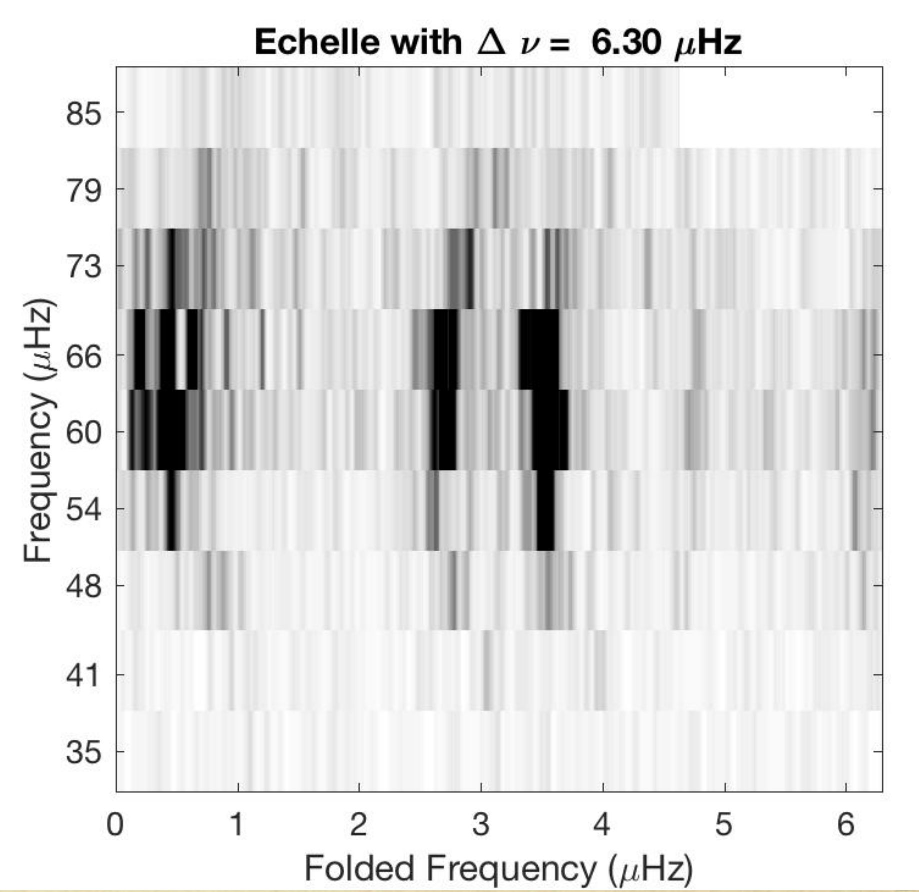
- Dynamics vs asteroseismic parameters (Benbakoura+2021)

KIC	Evol	$M_{1,\mathrm{dyn}}$ ($M_\odot$)	$M_{1,\mathrm{seis}}$ ($M_\odot$)	$R_{1,\mathrm{dyn}}$ ($R_\odot$)	$R_{1,\mathrm{seis}}$ ($R_\odot$)	$\log g_{\mathrm{dyn}}$ (dex)	$\log g_{\mathrm{seis}}$ (dex)	$T_{\mathrm{eff},1}$ (K)	[Fe/H] (dex)	M_2 ($M_\odot$)	R_2 ($R_\odot$)	$T_{\mathrm{eff},2}$ (K)	e	P_{orb} (days)	P_{rot} (days)	Age (Gyr)	Notes
	Red giant									Companion			Spin/orbit				
								Double-line spectroscopic binaries (SB2)									
4054905	RC	0.95(4)	0.91(6)	8.19(8)	8.2(2)	2.589(9)	2.571(9)	4790(190)	−0.7(3)	0.93(1)	3.11(3)	5100(197)	0.37	274.7	...	7.9(1.6)	
4663623	...	1.41(8)	1.52(6)	9.8(2)	10.0(1)	2.60(1)	2.623(5)	4812(92)	−0.13(6)	1.41(10)	1.83(5)	6827(140)	0.40	358.1	...	2.0(0.2)	$l = 1$ depleted
5193386	RGB	1.39(3)	...	4.49(5)	...	3.274(4)	...	4780(100)	−0.36(6)	1.17(5)	1.37(1)	6622(127)	0.01	21.4	26(2)	2.5(0.6)	Flares, Ca H&K em
6307537	RGB	1.29(7)	...	4.45(6)	...	3.25(1)	...	4960(240)	−0.0(4)	1.06(4)	1.17(2)	6387(306)	0.01	29.7	78(6)	5.3(3.0)	Flares, Ca H&K em
7133286	...	1.05(3)	...	9.21(8)	...	2.532(7)	...	4500(110)	−0.6(2)	1.02(3)	1.58(1)	6075(148)	0.01	38.5	38(3)	5.4(0.9)	Flares, Ca H&K em
7293054	...	1.6(1)	1.56(10)	...	11.4(2)	...	2.518(8)	4790(160)	0.1(3)	1.4(1)	4.0(3)	5900(374)	0.80	671.8	...	0.9(0.3)	Cmp eclipsed
8435232	...	1.20(4)	...	12.9(2)	...	2.297(8)	...	4460(130)	−0.1(2)	1.04(3)	1.28(2)	6347(174)	0.00	49.6	48(3)	5.3(1.7)	Ca H&K em
9153621	...	1.1(2)	1.16(8)	10.4(6)	10.4(2)	2.45(4)	2.470(9)	4760(190)	−0.3(2)	0.93(10)	1.02(6)	6170(235)	0.70	305.8	...	7.8(5.2)	
11235323	RGB	1.03(1)	...	3.578(9)	...	3.342(4)	...	4840(200)	−0.4(2)	0.989(2)	1.544(4)	6319(254)	0.01	19.7	24(2)	7.2(1.7)	Flares, H_α em., Ca H&K em
								Single-line spectroscopic binaries (SB1)									
4360072	RC	...	1.05(8)	...	10.7(2)	...	2.402(9)	5020(210)	−0.1(2)	0.71(3)	0.5(1)	5923(530)	0.15	1084.8	...	11.5(5.0)	
4473933	...	...	...	...	...	...	...	4530(220)	−0.4(3)	...	...	7172(344)	0.28	103.6	68(6)	...	Ca H&K em
5866138	RC	...	1.57(7)	...	8.1(1)	...	2.820(6)	4960(120)	0.1(1)	0.49(2)	0.456(10)	3252(93)	0.72	342.3	...	2.0(0.6)	
6757558	RGB	...	0.88(3)	...	4.96(6)	...	2.992(5)	4590(110)	−0.0(1)	0.217(9)	...	...	0.22	421.2	...	12.1(3.5)	RG eclipsed
7768447	RGB	...	1.12(7)	...	8.3(2)	...	2.650(8)	4760(160)	0.2(2)	0.63(3)	0.59(3)	4115(555)	0.32	122.3	...	8.8(3.2)	
9904059	RGB	...	0.98(6)	...	4.96(8)	...	3.039(7)	4830(160)	0.0(3)	0.46(2)	...	...	0.32	103.0	...	9.9(4.0)	Cmp eclipsed
10015516	RC	...	1.75(9)	...	9.6(2)	...	2.716(7)	4830(130)	−0.4(2)	1.33(6)	1.52(3)	6909(177)	0.00	67.7	66(6)	0.8(0.2)	Ca H&K em
10074700	...	...	0.84(4)	...	3.53(5)	...	3.267(6)	5070(100)	−0.4(1)	0.6(3)	0.56(1)	4020(520)	0.29	365.6	...	13.9(3.9)	Faint

Shortlist

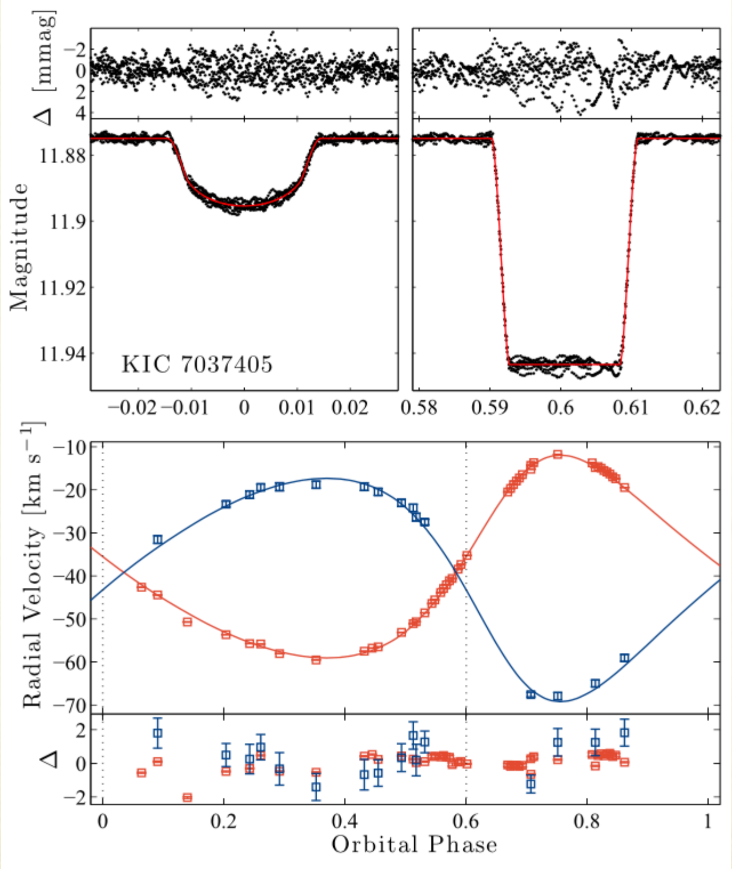
- KIC 9970396
  - RGB, P =235 d, e = 0.2, M = 1.2, R = 8.0, mixed modes

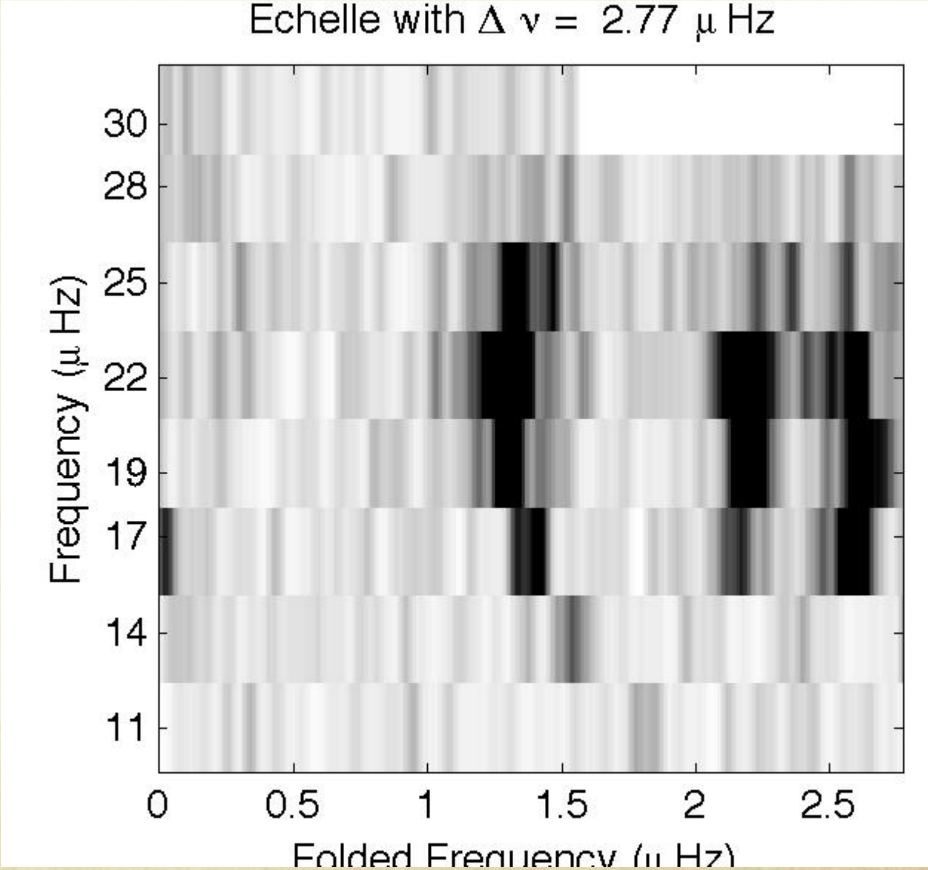




Shortlist

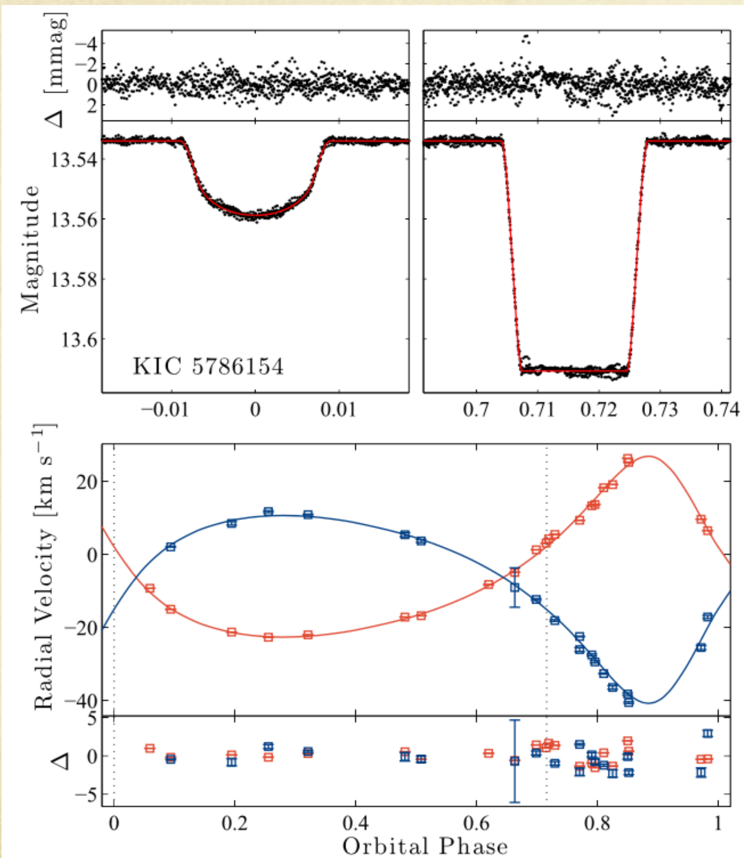
- KIC 7037405 (Gaulme+16, Brogaard+18)
  - RGB, P =207 d, e = 0.24, M = 1.3, R = 14.2, NO mixed modes

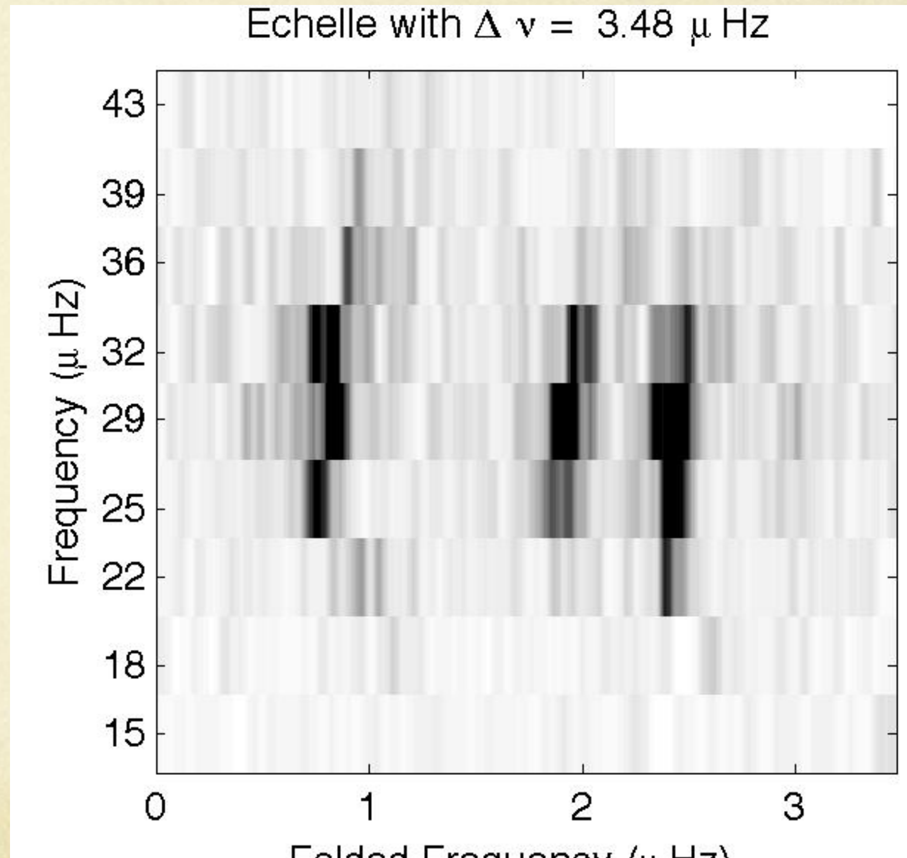




Shortlist

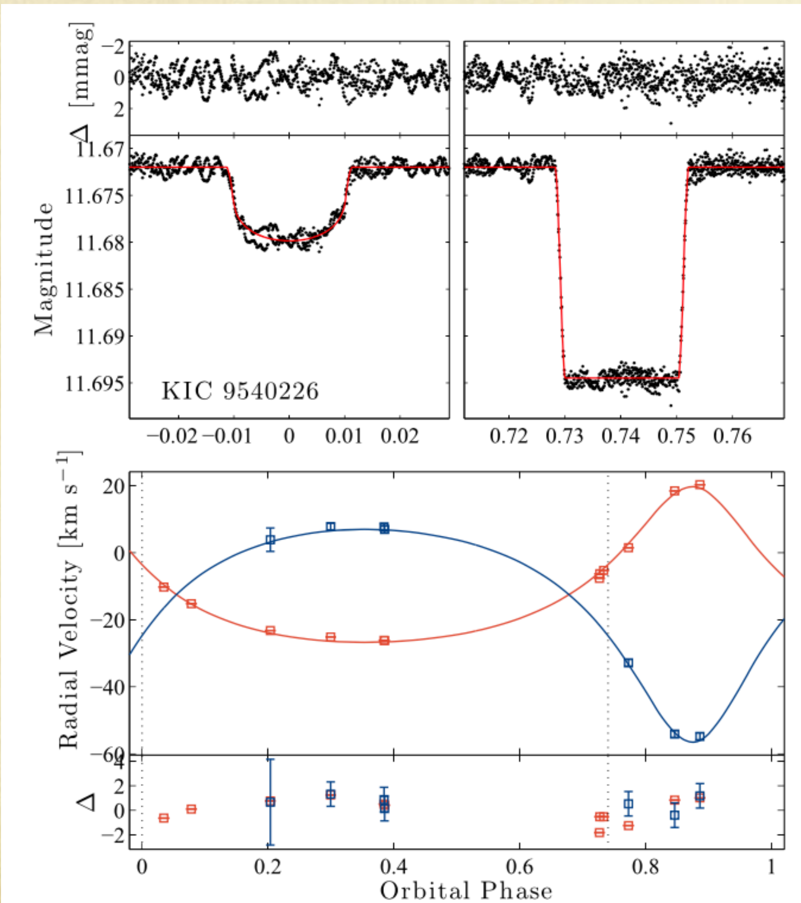
- KIC 5786154 (Gaulme+16)
  - RGB, P = 198 d, e = 0.38, M = 1.1, R = 11.4, mixed modes

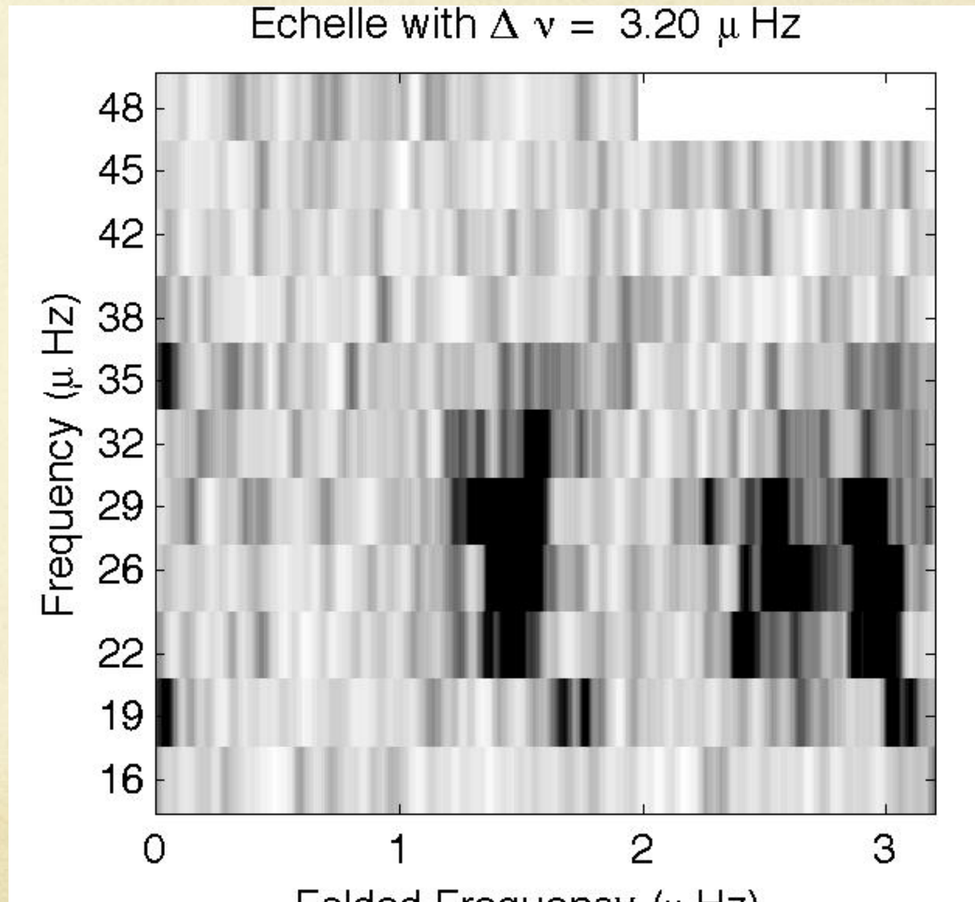




Shortlist

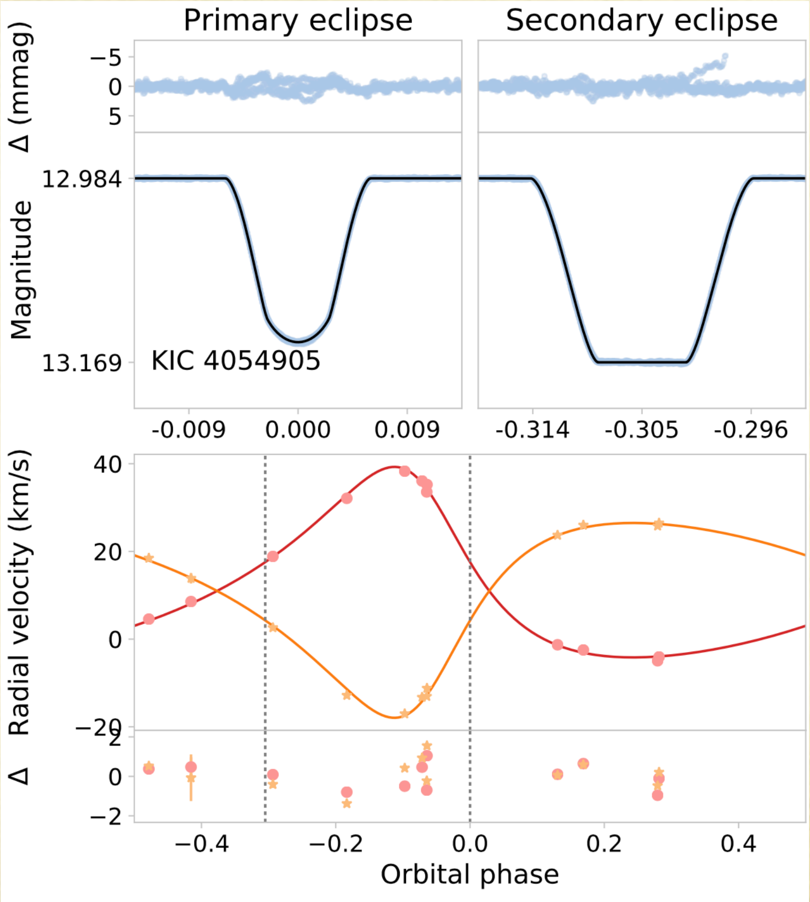
- KIC 9540226 (Beck+14, Gaulme+16, Brogaard+18)
  - RGB, P = 198 d, e = 0.38, M = 1.1, R = 11.4, mixed modes

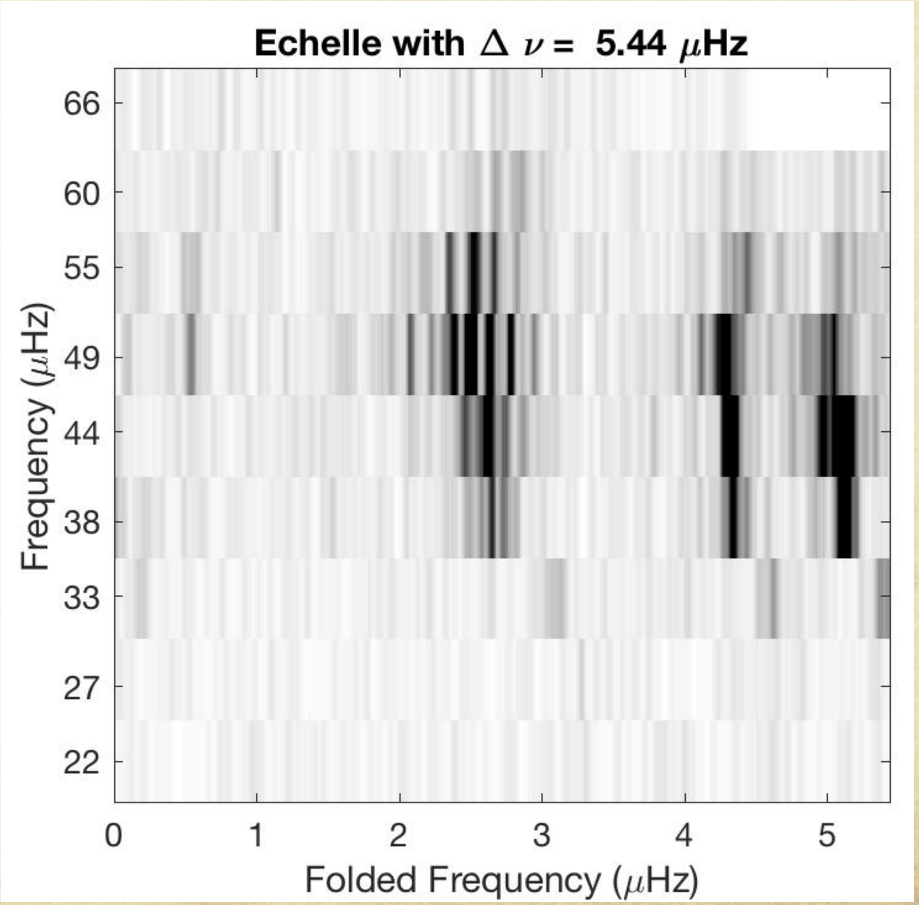




Shortlist

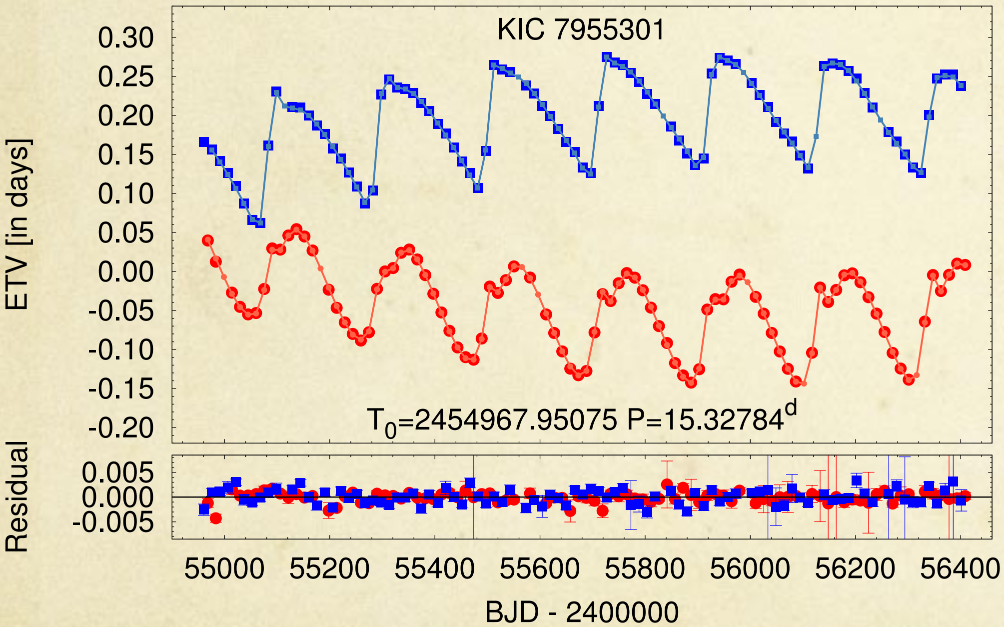
- KIC 4054903
  - Double RG (! one oscillates) , P = 274 d, e = 0.37, **M = 1.0**, R = 8.3, mixed modes (clump). Complex history.

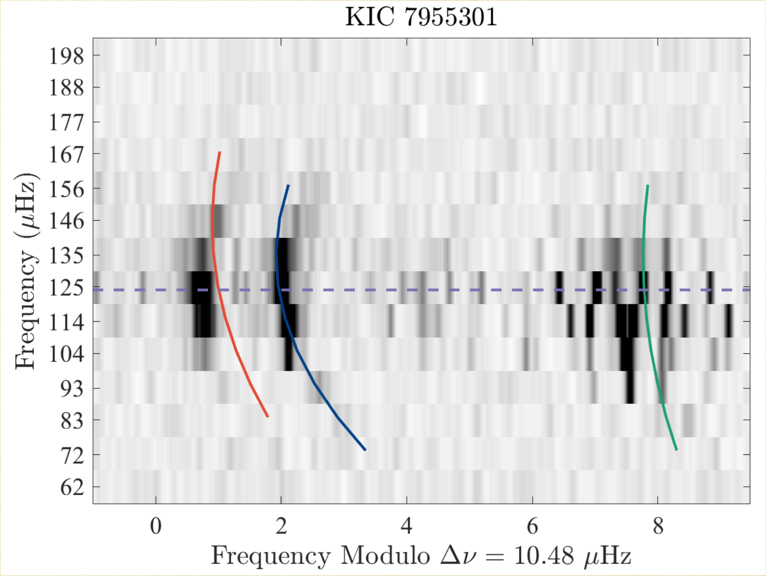




Shortlist: bonus track

- KIC 7955301
  - Hierarchical triple 209 days, 4-h amp, eclipse timing variations, 1.3-Msun RGB, SB1 (Gaulme+13, Gaulme et al., in prep.)



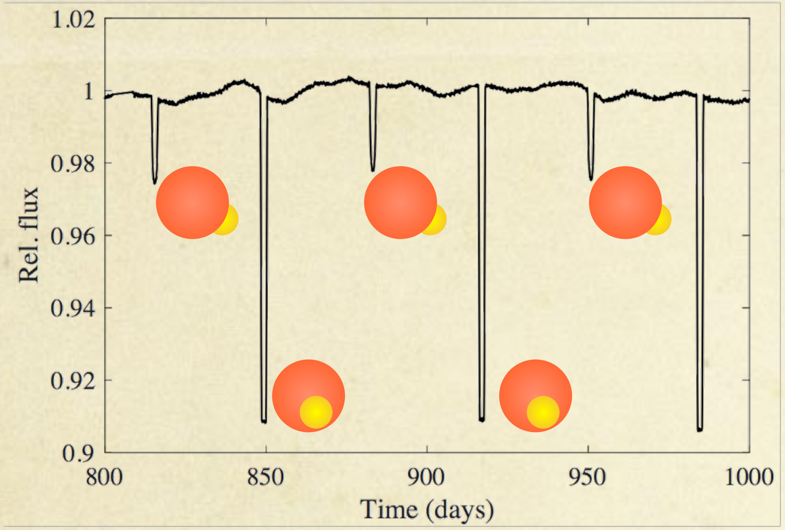


Conclusion & Prospects

- Today: 18 oscillating RGs in EBs, ≈10 oscillating RGs in hierarchical triple
  - Not equally good: luminosity ratio, mode quality, evol status => shortlist
  - Current accuracy on masses ≈ 3%
  - So far spectroscopic obs @ APO (ARCES spectro)
- Margin for improvement
  - Revised eclipse modeling. So far JKTEBOP, next PHOEBE, ELC, ELLC ?
  - Reobservation with hi-res spectroscopy: ARCES reaches 1 km/s. Going to 10 m/s accuracy at key moments along orbit would help.
- Looking for collaborations in this direction.

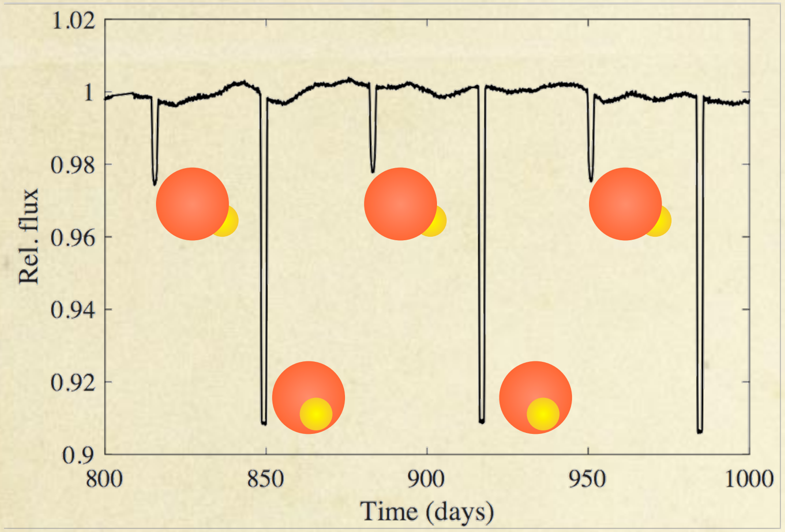
Back-up slides

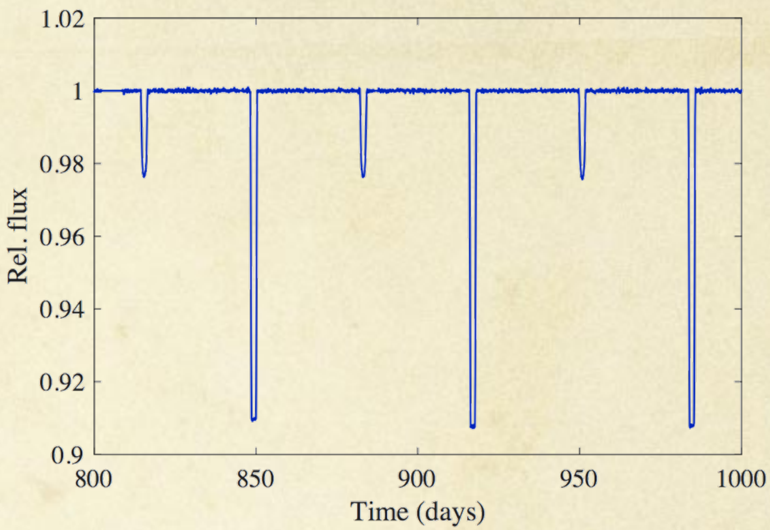
Light curves of eclipsing binaries



- ❑ Light curve content
  - ➢ Eclipses
  - ➢ Rotation
  - ➢ Oscillations + granulation
- ❑ Automatic procedure (Gaulme+13,+16)

Light curves of eclipsing binaries





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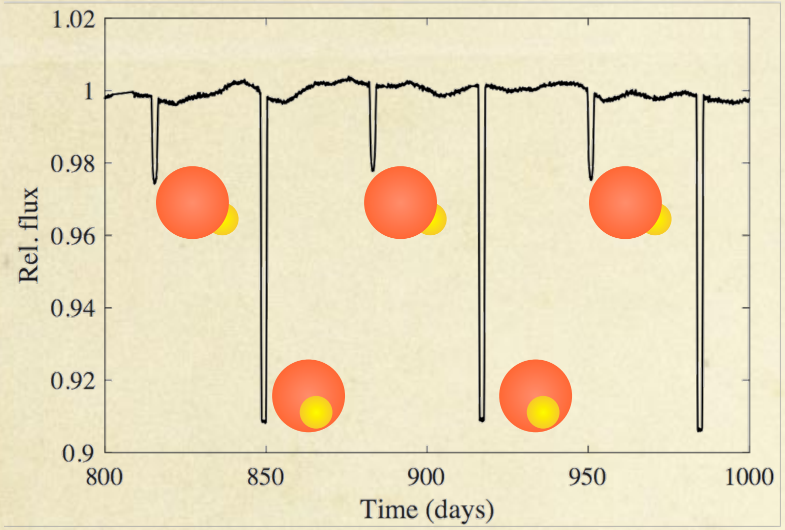
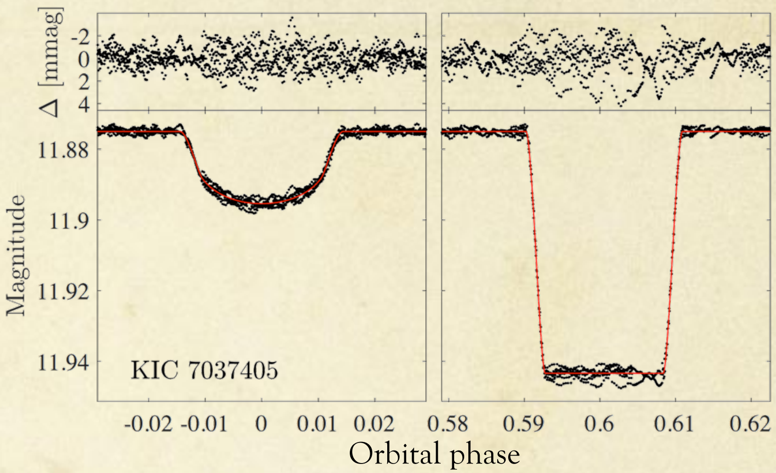
Light curves of eclipsing binaries





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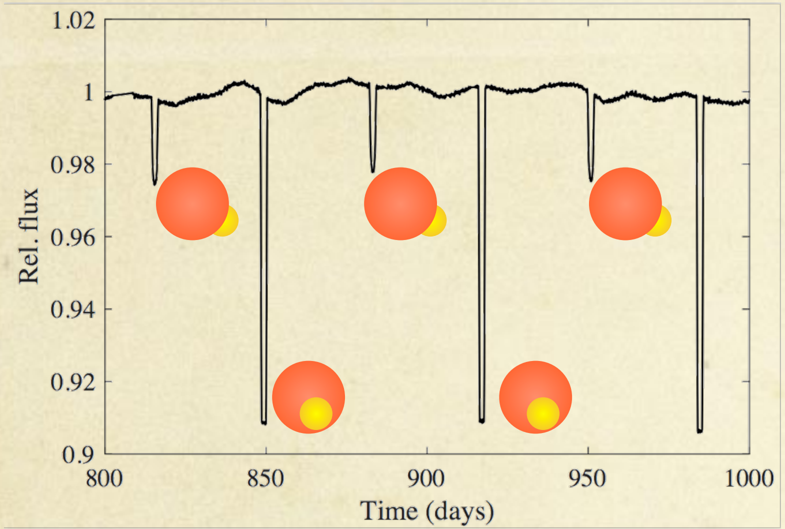

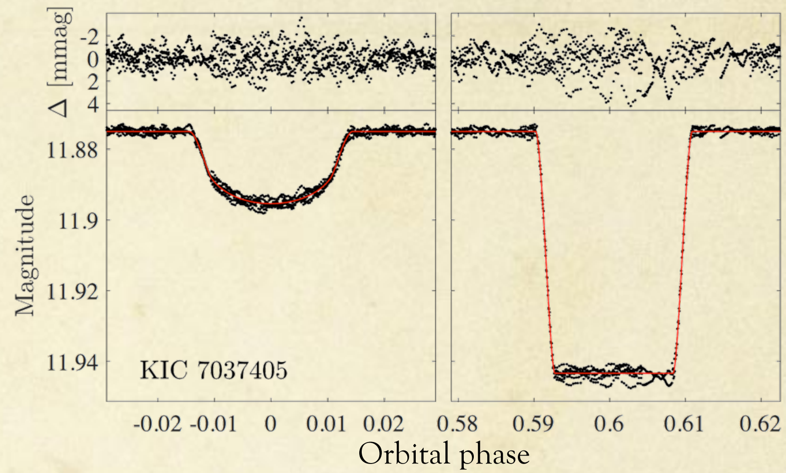

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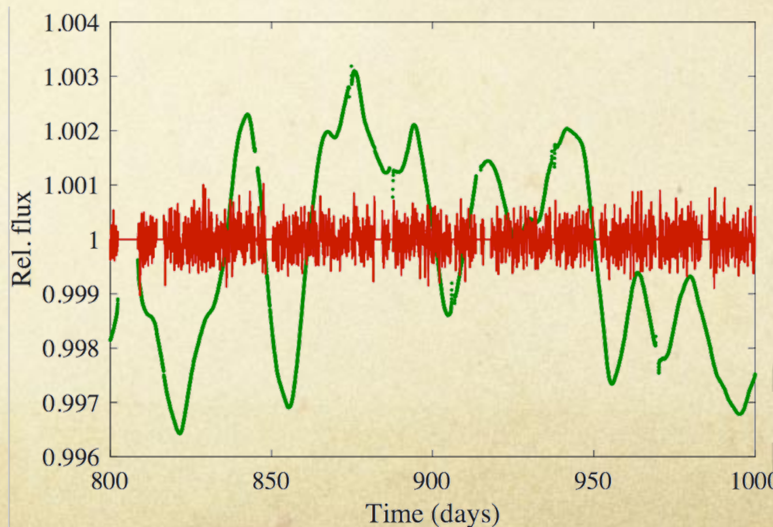
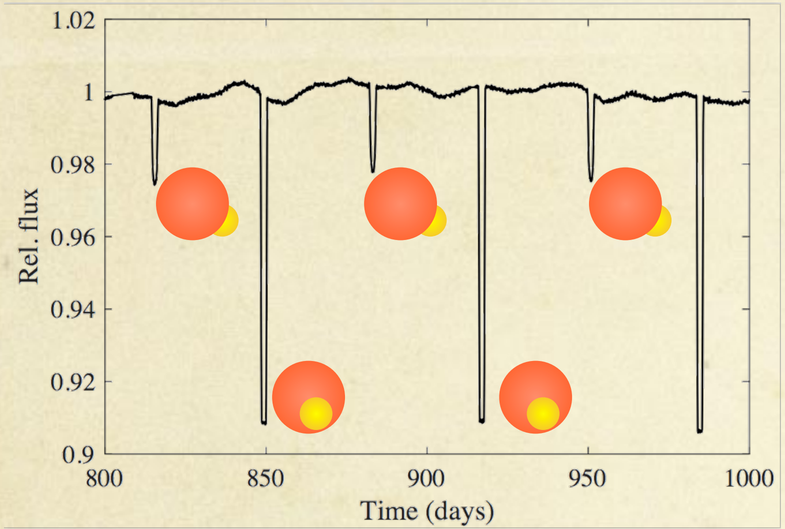
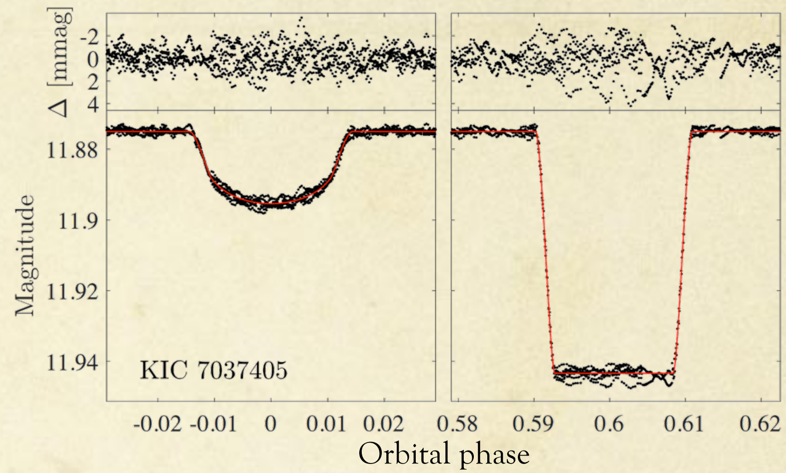


Light curves of eclipsing binaries





- Light curve content
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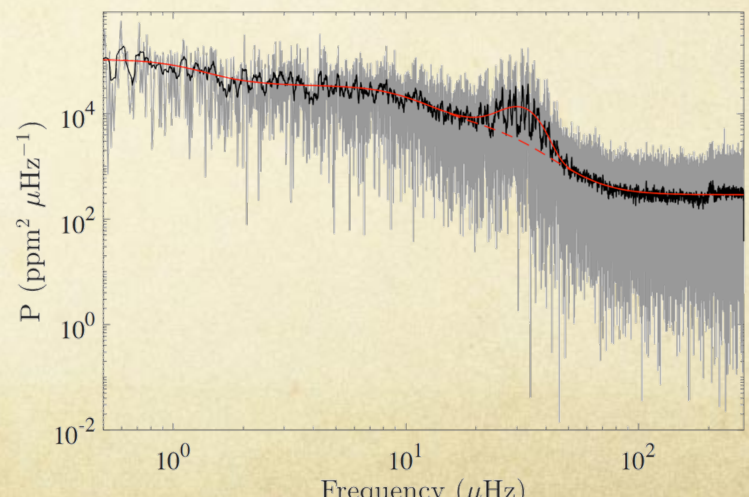
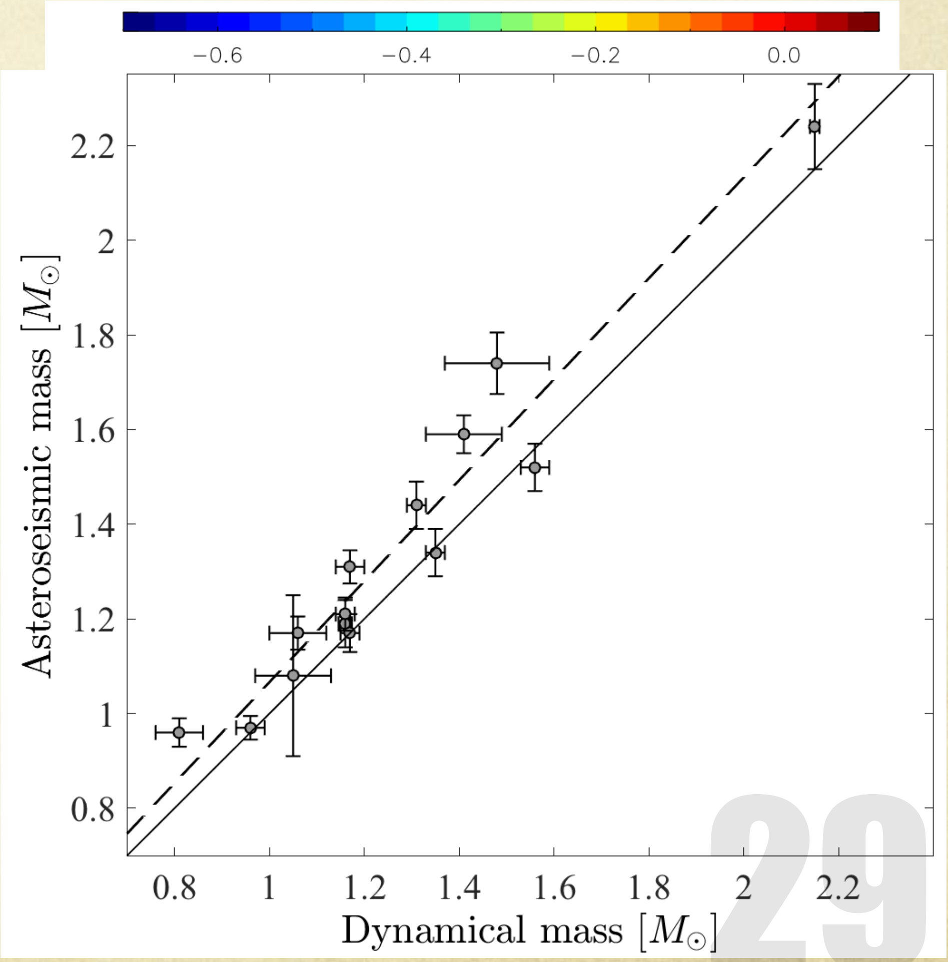


- Automatic procedure (Gaulme+13,+16)

2018-2019 updates

- Rodrigues+2017
  - Replace direct application of asteroseismic scaling relation with grids of models: 3 to 5% accuracy on masses claimed.
  - Includes mixed mode spacing and stellar luminosity
  - Simple surface effect treatment
  - Test on open cluster so so
  - Public routine PARAM 1.4
- Brogaard+2018
  - Test on RG in EBs (reobservation of 3 systems)
  - Good agreement when applying Rodrigues corrections
  - I did it too!

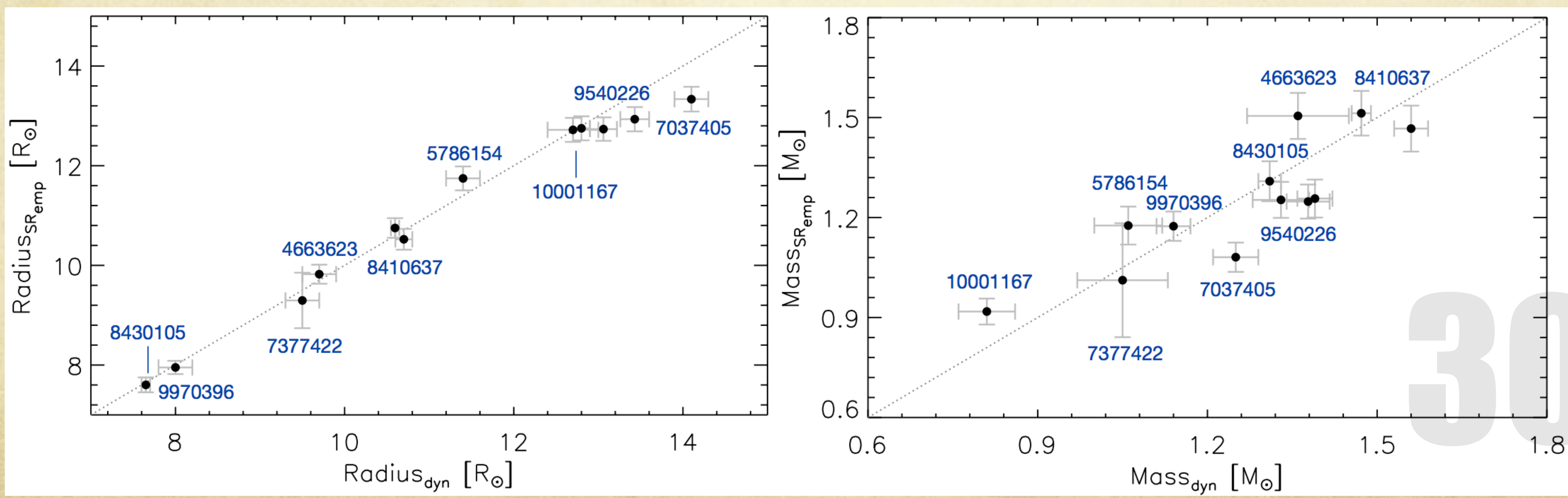


2018-2019 updates

- Themeßl+2018
  - Empirical correction by tuning solar reference Δv to 130 μHz (instead of 135)
  - Works relatively well (kills the offset by definition) but still large dispersion in masses

Oscillating red giants in eclipsing binary systems: empirical reference value for asteroseismic scaling relation

N. Themeßl[1,2,3,⋆] S. Hekker[1,2], J. Southworth[4], P. G. Beck[5,6,7], K. Pavlovski[8], A. Tkachenko[9], G. C. Angelou[10,1,2], W. H. Ball[11,2], C. Barban[12], E. Corsaro[13,5,6,7], Y. Elsworth[11,2], R. Handberg[2] and T. Kallinger[14]



2018-2019 updates

Modelling Kepler Red Giants in Eclipsing Binaries: Calibrating the Mixing-Length Parameter with Asteroseismology

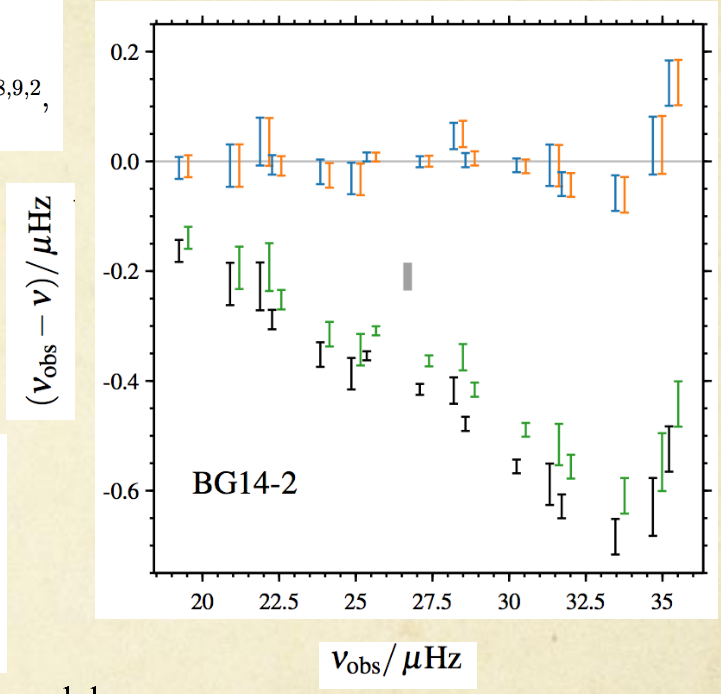
Tanda Li[1,2,3⋆], Timothy R. Bedding[1,2], Daniel Huber[4,1,5,2], Warrick H. Ball[7,8,9,2], Dennis Stello[1,2,6], Simon J. Murphy[1,2], Joss Bland-Hawthorn[1]

Tanda Li: optimize M, Z, α, overshoot, age, surface term

- ➢ RG mixing length 14% larger than solar
- ➢ Surface term correlates with logg, Teff, α
- ➢ Issues with surface term for mixed modes

Surface effects on the red giant branch

W. H. Ball,[1,2⋆] N. Themeßl[3,2,4] and S. Hekker[3,2]
[1]*School of Physics and Astronomy, University of Birmingham, Edgbaston, Birmingham B15 2TT, United Kingdom*
[2]*Stellar Astrophysics Centre, Department of Physics and Astronomy, Aarhus University, Ny Munkegade 120, DK-8000 Aarhus C, Denmark*
[3]*Max-Planck-Institut für Sonnensystemforschung, Justus-von-Liebig-Weg 3, D-37077 Göttingen, Germany*
[4]*Institut für Astrophysik, Georg-August-Universität Göttingen, Friedrich-Hund-Platz 1, 37077 Göttingen, Germany*



Ball: suppress gravity modes (g-modes) in the cores of their stellar models

- ➢ significantly discrepant masses and radii compared with the orbital solutions, similar to the roughly 15 and 5 per cent in mass and radius found by Gaulme+2016
- ➢ The initial helium abundance Y0 changes the most when the masses and radii are constrained to match the dynamical values, which suggests that the difference might be caused by the composition profile of the stellar models through processes like gravitational settling and rotation, which have been ignored here.

Shortlist

- Orbital parameters

Orbital Parameters from Dynamical Modeling with JKTEBOP

KIC	P_{orb} (days)	T_{p} [a] KJD	ω (°)	e	i (°)	$\frac{R_2}{R_1}$ (%)	$\frac{R_1+R_2}{a}$ (%)	$\left(\frac{T_2}{T_1}\right)^4$	$\frac{L_2}{L_1}$ (%)	K_1 (km s^{-1})	K_2 (km s^{-1})	γ (km s^{-1}]
8054233	1058.16(2)	−27.69(2)	302.22(6)	0.2718(4)	89.45(1)	10.83(6)	1.924(7)	2.65(4)	3.453(5)	12.3(2)	…	−8.68(5)
4663623	358.0900(3)	129.73(2)	270.25(2)	0.43(1)	88.562(6)	18.7(3)	3.91(5)	4.0(1)	14.400(7)	23.0(7)	23(1)	−8.3(4)
9970396	235.2985(2)	142.050(2)	314(2)	0.194(7)	89.5(1)	14.05(7)	4.39(8)	2.83(4)	5.808(4)	21.4(2)	24.0(3)	−15.70(5)
7037405	207.1083(7)	87.194(9)	310.9(10)	0.238(4)	88.65(9)	12.73(6)	8.08(8)	3.79(4)	6.663(5)	23.6(2)	26.0(3)	−39.21(9)
5786154	197.9180(4)	170.865(3)	24.7(4)	0.3764(9)	88.74(3)	13.93(6)	7.14(3)	3.57(2)	7.560(4)	24.7(4)	25.7(7)	−6.3(4)
9540226	175.4439(6)	131.415(9)	4.1(4)	0.3880(2)	90[b]	7.72(6)	7.89(2)	3.46(3)	2.110(4)	23.2(3)	31.4(5)	−12.51(9)
10001167	120.3903(5)	110.368(9)	213(2)	0.159(3)	87.5(2)	7.66(4)	11.4(2)	3.01(5)	1.849(4)	25.1(1)	25.9(8)	−103.40(6)
7377422	107.6213(4)	165.185(7)	356(1)	0.4377(5)	85.82(8)	9.15(6)	8.84(8)	2.36(7)	1.92(1)	27.5(2)	34(1)	−56.78(8)
8430105	63.32713(3)	152.7374(4)	349.3(2)	0.2564(2)	89.01(10)	10.06(2)	9.78(3)	1.716(8)	1.720(3)	27.5(2)	43.7(3)	16.29(7)
5179609	43.931080(2)	137.3016(3)	124.1(1)	0.150(1)	86.47(5)	10.57(2)	6.92(1)	2.0(4)	2.4(1)	25.0(4)	…	−21.4(2)
4569590	41.3710(1)	164.286(5)	261(4)	0.004(1)	88.6(6)	6.85(4)	21.7(1)	3.54(7)	1.615(6)	34.1(5)	51(1)	24.6(1)
5308778	40.5661(3)	137.281(5)	272(3)	0.006(5)	82.6(2)	6.02(3)	17.4(3)	0.66(2)	0.222(2)	23.8(1)	…	17.406(9)
3955867	33.65685(7)	160.104(3)	254(2)	0.019(2)	88.0(1)	11.38(5)	15.98(6)	2.79(3)	3.923(8)	37.9(2)	45(1)	14.82(4)
9291629	20.68643(4)	154.288(1)	265(2)	0.007(2)	84.10(3)	23.23(4)	23.65(5)	2.70(1)	15.10(2)	50.2(2)	51.2(5)	−30.97(5)
8702921	19.38446(2)	141.0929(7)	173(3)	0.0964(8)	86.2(3)	5.34(2)	15.6(3)	0.076(2)	0.0227(6)	14.0(3)	…	−10.28(9)
7943602	14.69199(4)	142.542(3)	103(5)	0.001(3)	81.55(7)	12.63(6)	24.40(9)	2.54(3)	3.48(2)	46.0(8)	58(3)	−185.0(1)

Notes. Systems are sorted by decreasing orbital period P_{orb}. Here, T_{p} stands for the time of periastron in *Kepler* Julian date, ω the argument of periastron, e the eccentricity, i the orbital plane inclination, (R_1, T_1, L_1) and (R_2, T_2, L_2) the RG and companion's radii, effective temperatures, and luminosities. The quantities K_1, K_2 are the RV semiamplitudes, and γ is the RV offset. The least significant digit in brackets after the value indicates the uncertainty.

[a] *Kepler* Julian dates KJD are related to barycentric Julian dates BJD by KJD = BJD—2,454,833 days.

[b] As regards 9540226, we fixed the inclination at 90° because JKTEBOP would not converge properly and its inclination is almost 90°, as the almost-vertical ingress and egress of the companion star indicate (Figure 3).

Shortlist

- Dnu and nu_max

Table 3
Asteroseismic Frequencies at Maximum Amplitude ν_{max} and Observed Mean Large Spacings $\Delta\nu_{obs}$ of the Oscillating RG of Our Sample

KIC	ν_{max} (μHz)	$\Delta\nu_{obs}$ (μHz)
4663623	54.09 ± 0.24	5.212 ± 0.019
5179609	321.84 ± 1.00	22.210 ± 0.050
5308778	48.47 ± 1.10	5.050 ± 0.050
5786154	29.75 ± 0.16	3.523 ± 0.014
7037405	21.75 ± 0.14	2.792 ± 0.012
7377422	40.10 ± 2.10	4.643 ± 0.052
8054233	46.49 ± 0.33	4.810 ± 0.015
8410637	46.00 ± 0.19	4.641 ± 0.017
8430105	76.70 ± 0.57	7.138 ± 0.031
8702921	195.57 ± 0.47	14.070 ± 0.010
9246715	106.40 ± 0.80	8.310 ± 0.020
9540226	27.07 ± 0.15	3.216 ± 0.013
9970396	63.70 ± 0.16	6.320 ± 0.010
10001167	19.90 ± 0.09	2.762 ± 0.012

Note. Systems are sorted by increasing KIC number. All ν_{max} were obtained with DIAMONDS except for KIC 7377422, where the low signal-to-noise ratio of the oscillation spectrum prevented the routine from giving an accurate estimate. This specific ν_{max} was fine-tuned with the help of the échelle diagram.