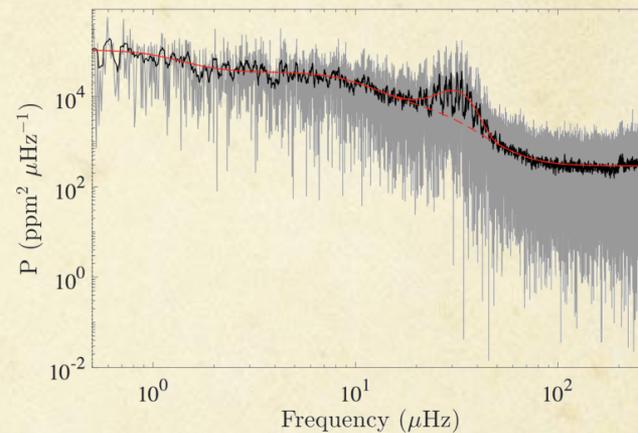
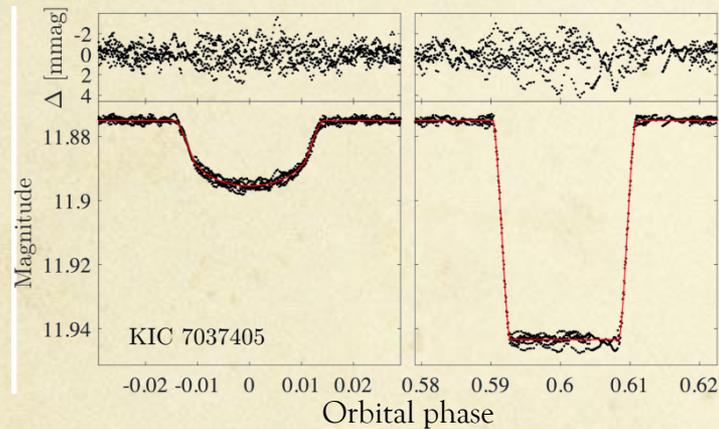


# Benchmarks: what we learnt from oscillating red giants in eclipsing binaries with Kepler

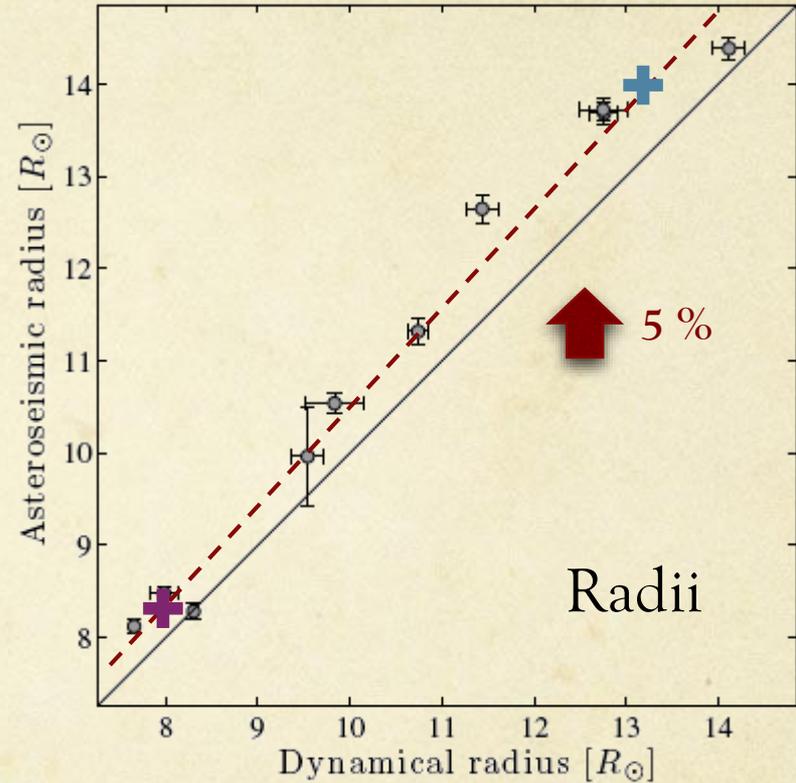
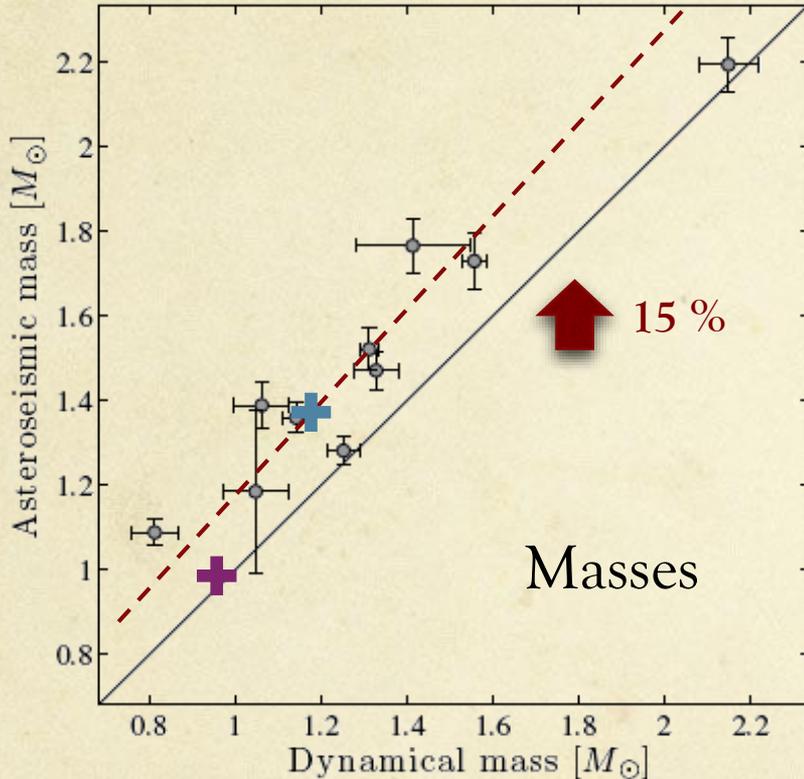


Patrick Gaulme  
Max Planck Institut für Sonnensystemforschung

# Goal and Main Results

- ❑ Goal: test asteroseismology of solar-like stars by measuring M,R of stars independently from oscillation information.
- ❑ Oscillators in eclipsing binaries are among the best targets
  - ✧ Together with hierarchical triples, “heartbeat” binaries, visual binaries
- ❑ Sample of 12 red giants observed by Kepler
  - ✧ Frandsen+13 (1 system), Rawls+16, Gaulme+16 (10, 1 from F13, 1 from R16), Brogaard+18 (3 from F13 & G16), Themeßl+18 (3 incl. 2 from F13 & G16), Benbakoura+? ( $\geq 1$ )
- ❑ Asteroseismology overestimates masses of red giants ( $\approx 15\%$ ), and maybe a little bit radii too ( $\approx 5\%$ )

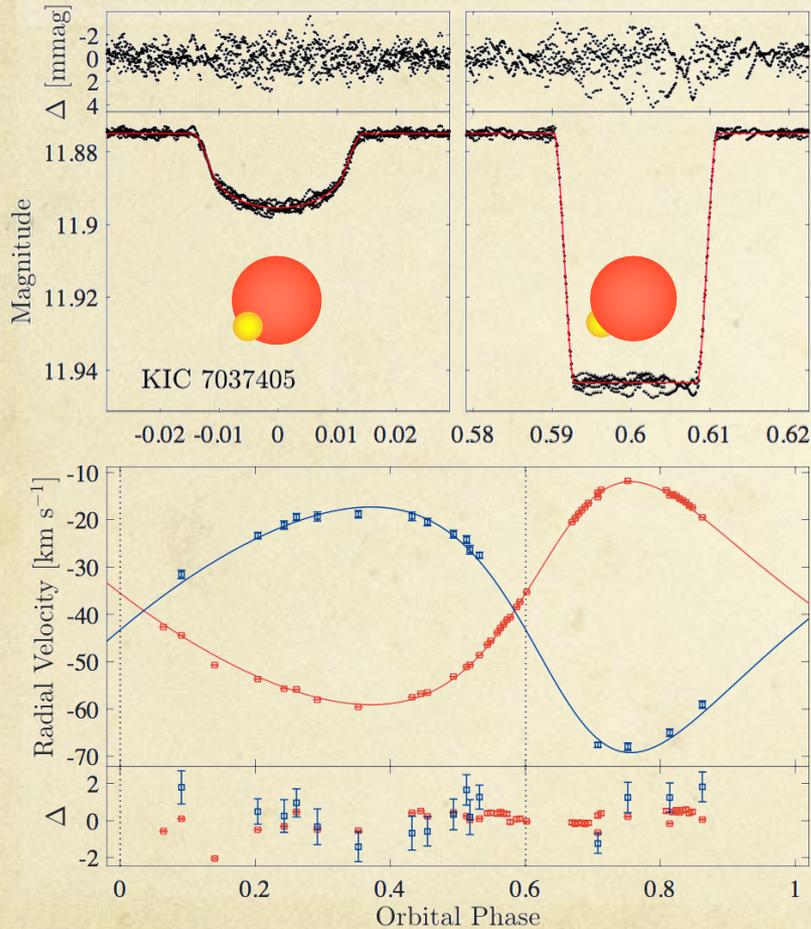
# Goal and Main Results



[from Gaulme+16]

- + 5640750 Dyn =  $1.16 \pm 0.01$   $13.1 \pm 0.1$ , Sis  $1.34 \pm 0.06$   $13.97 \pm 0.20$ ,
- + 4054905: Dyn 0.98, 8.33, seis  $1.00 \pm 0.04$ ,  $8.45 \pm 0.10$

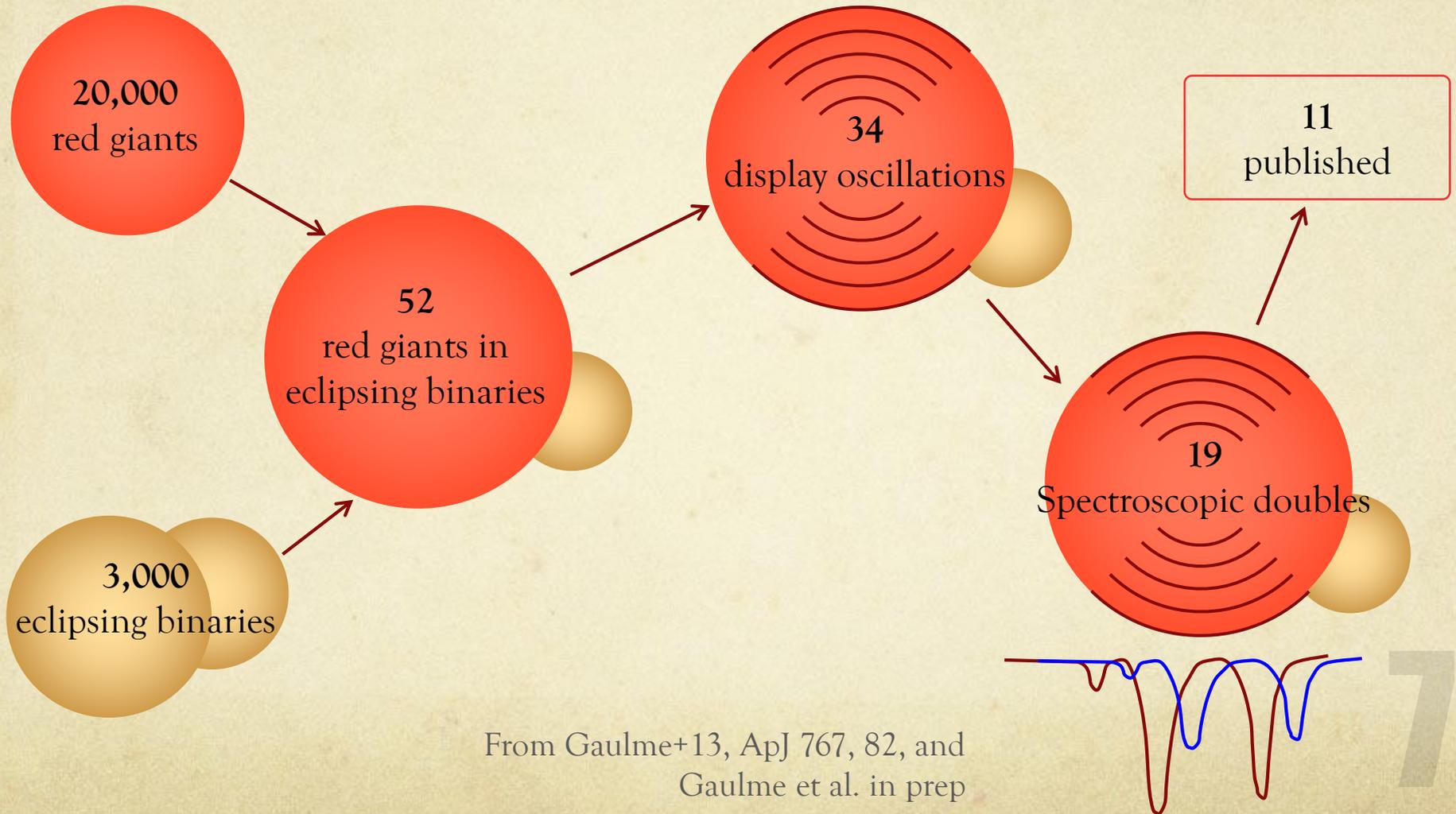
# Masses and radii with eclipsing binaries



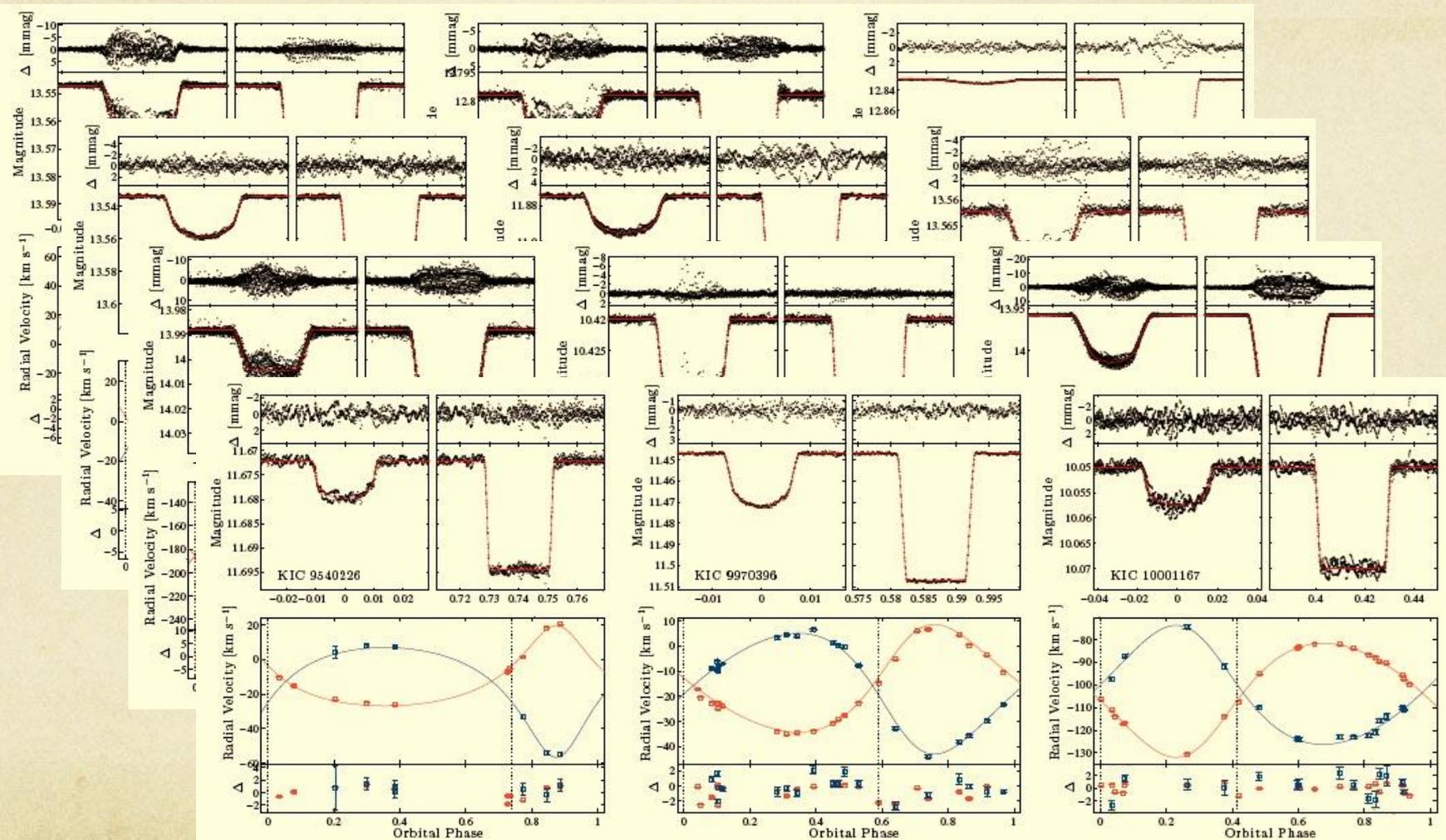
From Gaulme+16, ApJ 832, 121

- Eclipse photometry
  - ◇  $R_1/a$ ,  $R_2/a$ ,  $T_2/T_1$ ,  $e$ ,  $i$ , limb darkening,  $P_{\text{orb}}$ ,  $T_0$
- Radial velocities
  - ◇  $M_1 \sin i$ ,  $M_2 \sin i$ ,  $P_{\text{orb}}$ ,  $T_0$ ,  $e$ ,  $W$
- 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

# So few oscillating spectroscopic doubles in the Kepler data

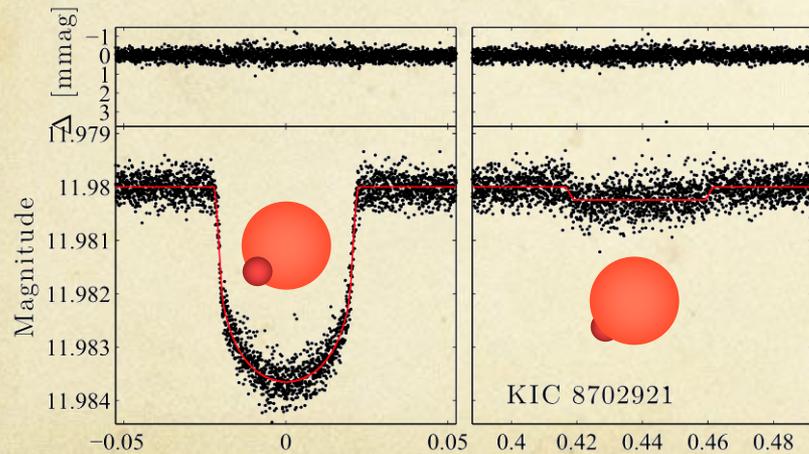
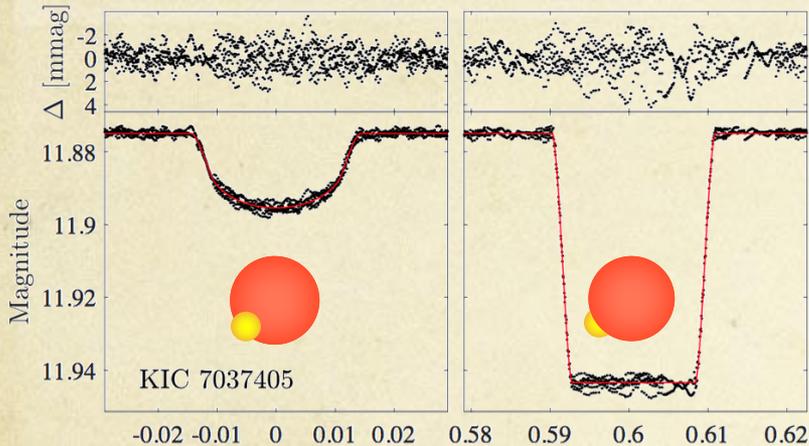


# Time-consuming support



12 systems = 15 spectra per star x 12 x 2 (weather) = 360\*30 min exp = 180 h

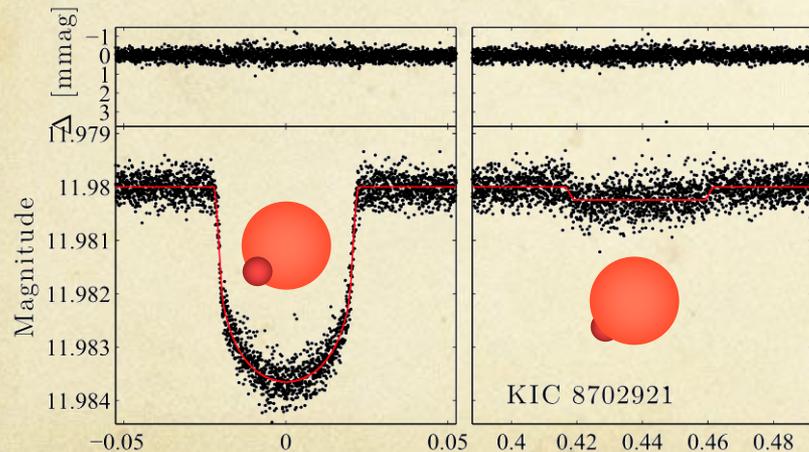
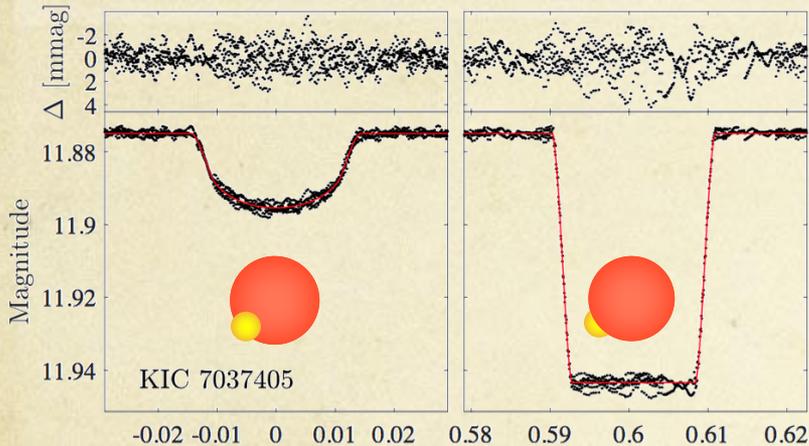
# Intrinsic Limitations



- SB2, not SB1
- Flux contrast  $L2/L2 \geq 2\%$
- ◇ RG + RG
- ◇ RG + F/G MS star
- ~~◇ RG + M/K dwarf~~

From Gaulme+16, ApJ 832, 121

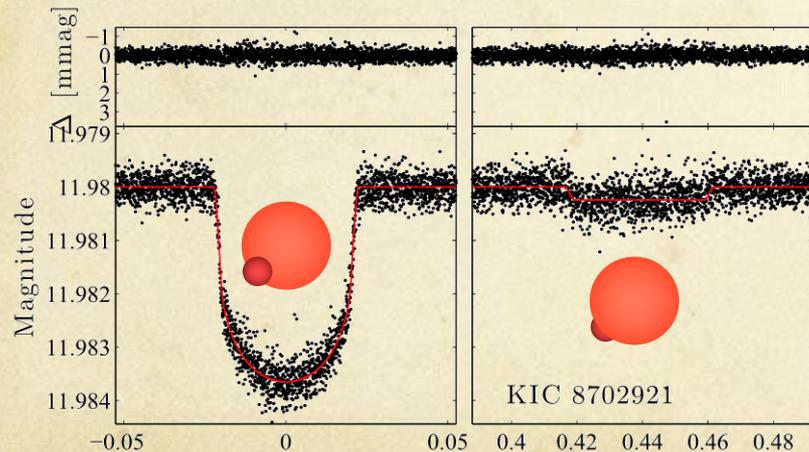
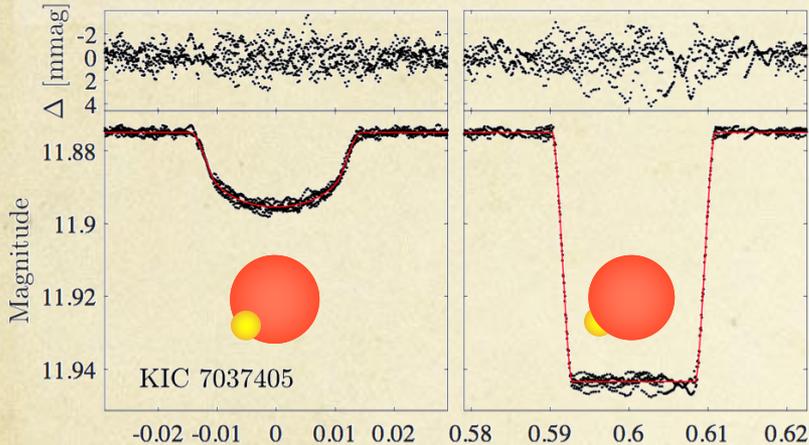
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- ❑ Short orbits are favored, typically less than 800 days

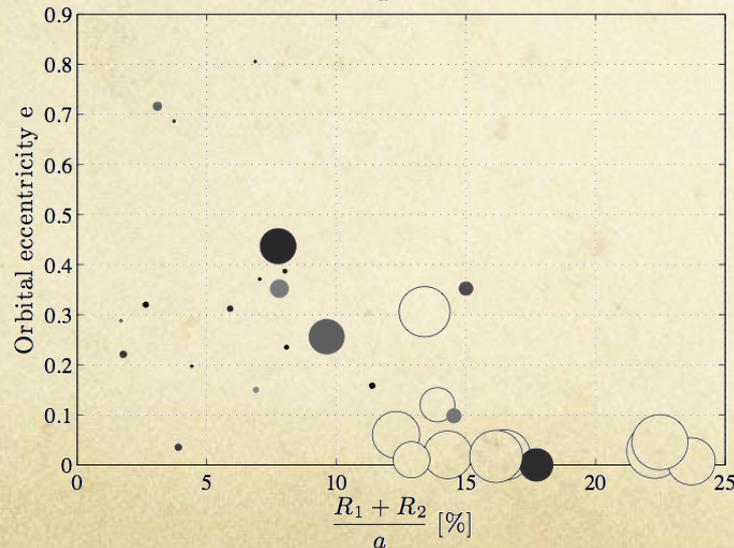
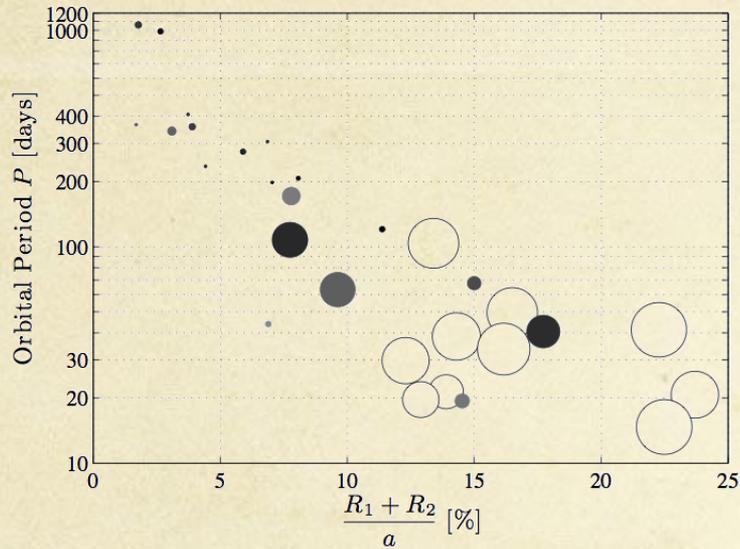
# Intrinsic Limitations



From Gaulme+16, ApJ 832, 121

- ❑ SB2, not SB1
- ❑ Flux contrast  $L2/L2 \geq 2\%$ 
  - ✧ RG + RG
  - ✧ RG + F/G MS star
  - ~~✧ RG + M/K dwarf~~
- ❑ Short orbits are favored, typically less than 800 days
- ❑ No fast rotation
  - ✧ line broadening

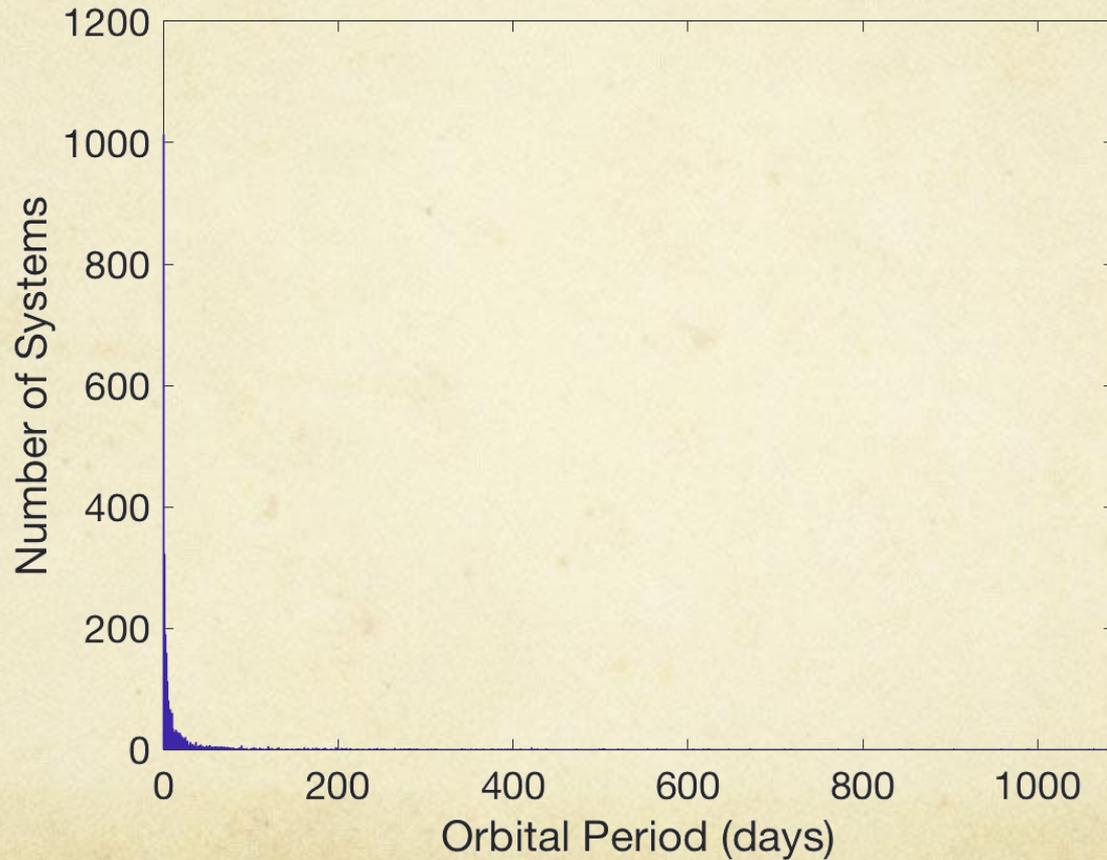
# Intrinsic Limitations



- ❑ Oscillations can be suppressed because of binarity (Gaulme+14)
- ❑ Spin-orbit resonances, incl. circ+synchr
  - ✧ Surface activity
  - ✧ Reduced surface convection
  - ✧ Partially/totally Suppressed modes
- ❑ Limitation is then:
  - ✧ Favors long orbits ( $\geq 100$  days)
  - ✧ Neither synchronization nor circularization
- ❑ NB: mode suppression reduces mode visibility, incl. mixed modes

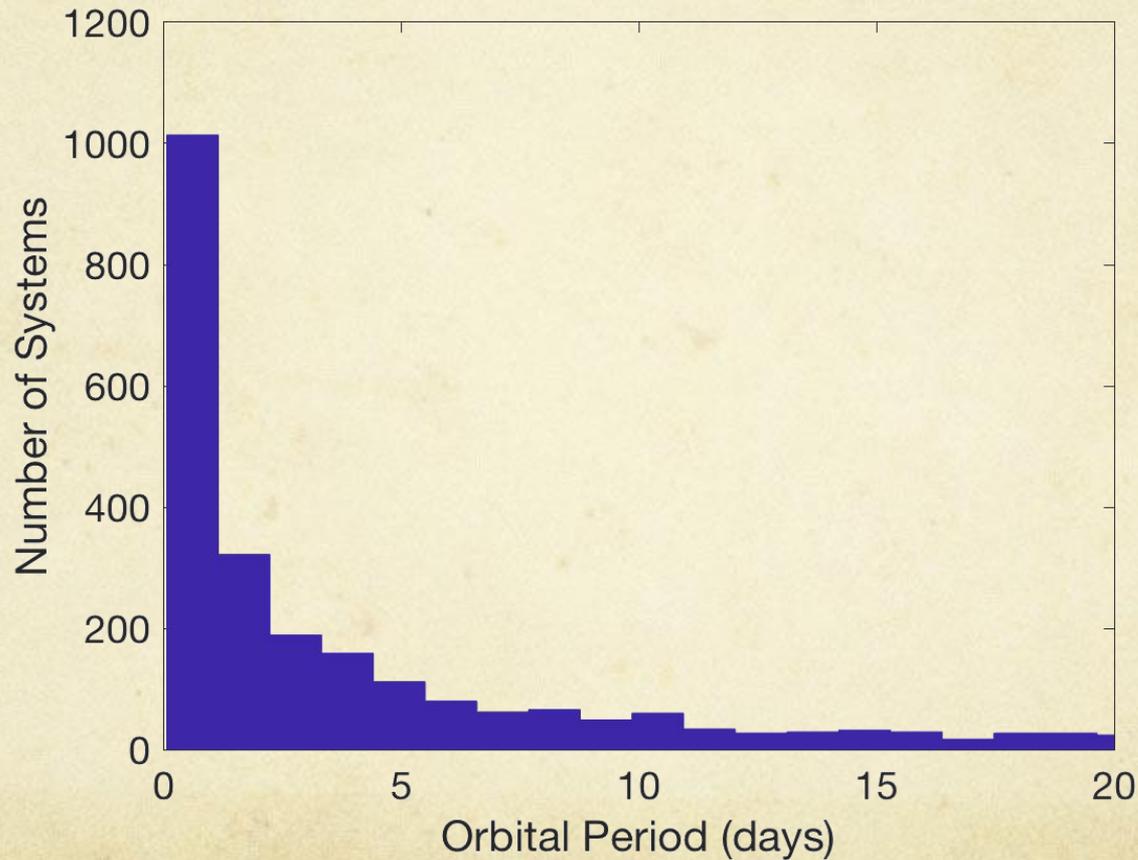
# Orbital periods

- Orbital periods of Kepler EBs: 167 with  $P \geq 100$  days



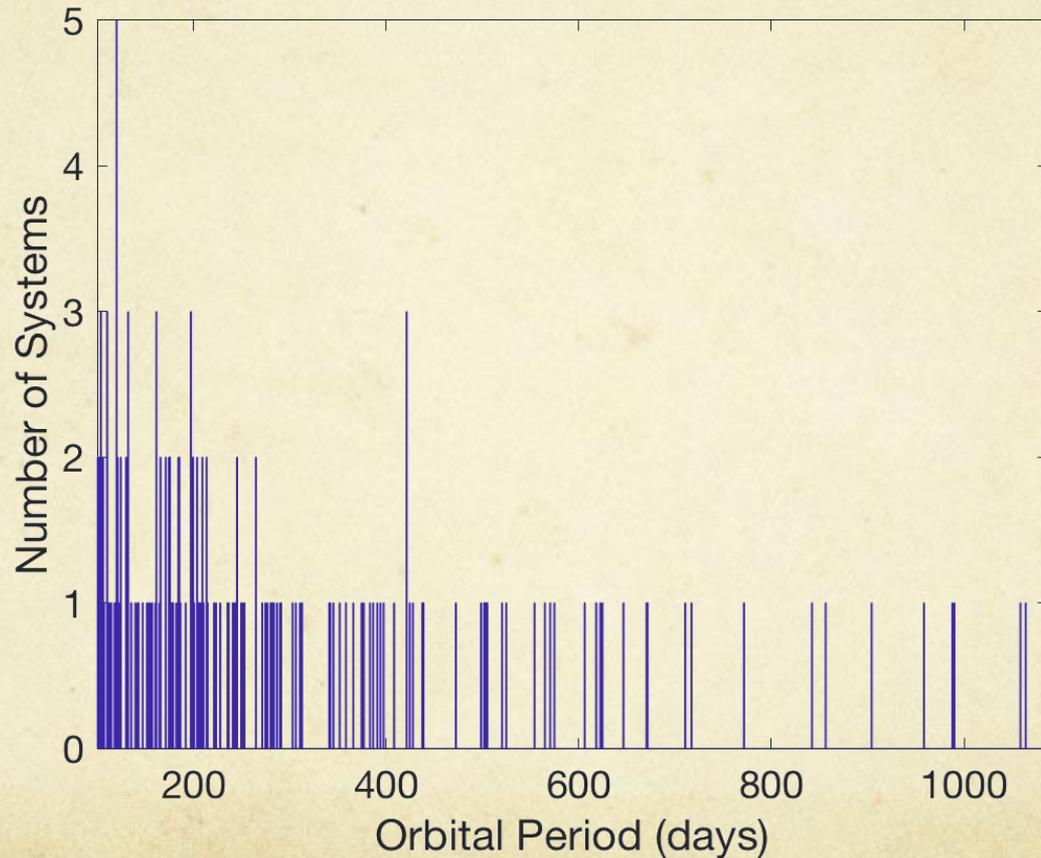
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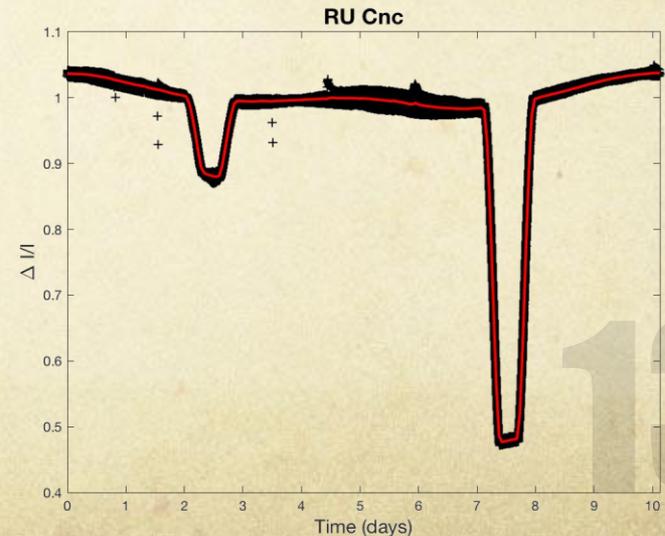
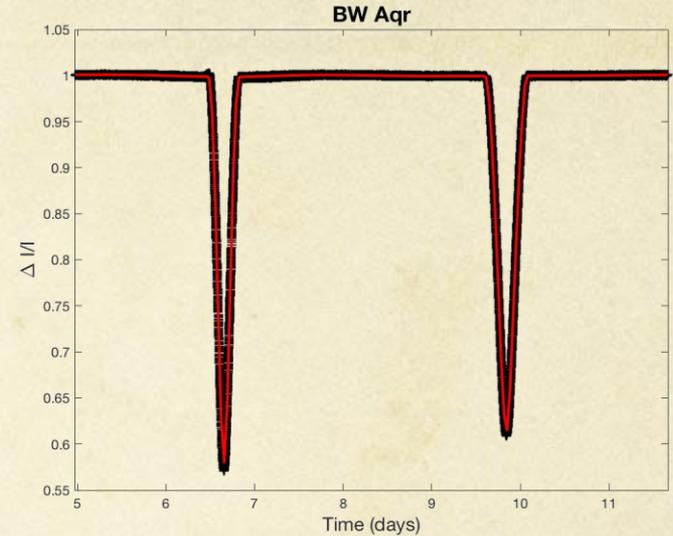
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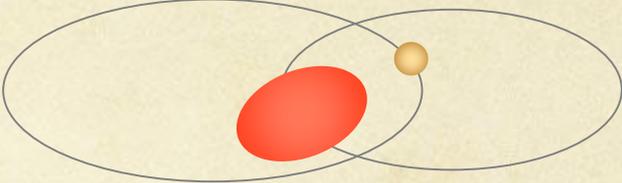
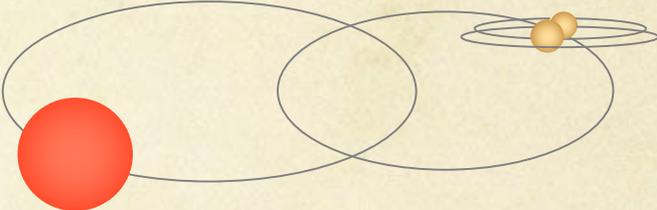


# K2 program to find benchmarks

- ❑ Targets from General Catalog of Variable Stars (GCVS)
- ❑ About 30 EB with observed at short cadence
  - ✧ F/G main-sequence
  - ✧ Kep mag [8-11]
  - ✧ Orbits  $\leq 16$  days (mostly 1-3)
- ❑ No detection of oscillations so far
  - ✧ Faint
  - ✧ Short periods

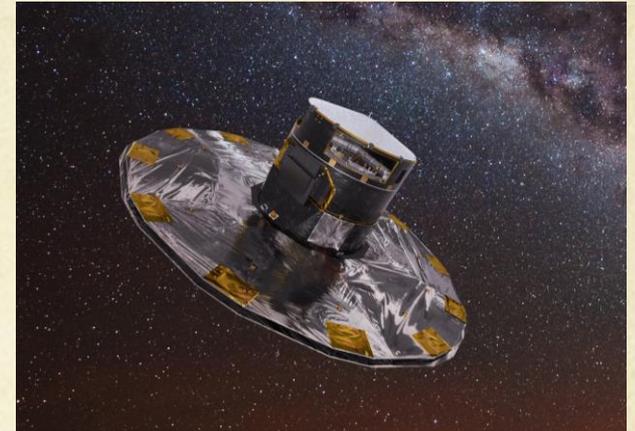


# Alternative to Eclipsing Binaries

<ul style="list-style-type: none"><li>❑ Highly eccentric binaries (Beck+14)<ul style="list-style-type: none"><li>✧ Tidal distortion at periastron.</li><li>✧ Tidal impact is not negligible</li><li>✧ Small companion, otherwise already circularized/synchronized <math>\Leftrightarrow</math> SB1</li></ul></li></ul>	
<ul style="list-style-type: none"><li>❑ Hierarchical triple systems (Borkovits+17)<ul style="list-style-type: none"><li>✧ Eclipse timing variations</li><li>✧ RVs are needed still for accuracy</li><li>✧ SB1s are fine</li></ul></li></ul>	
<ul style="list-style-type: none"><li>❑ Visual binaries<ul style="list-style-type: none"><li>✧ RV are needed</li><li>✧ Very long orbits</li><li>✧ So far one case (Marcadon+18) with barely sufficient accuracy</li></ul></li></ul>	

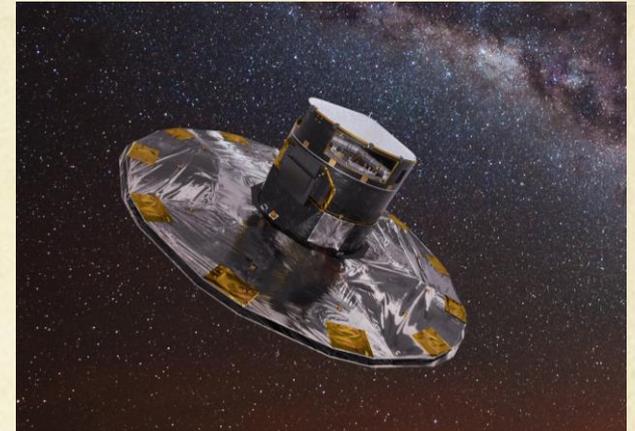
# Prospects

- ❑ Where to find targets?
  - ✧ Few more EBs in Kepler among  $\approx 3,000$  EB catalog
  - ✧ K2: catalog of  $\approx 700$  EBs. Orbits  $\leq 90$  days
  - ✧ CoRoT: 2,000 EBs + a few triple. Orbits  $\leq 180$  days
- ❑ Main issue: so far, no solar-like oscillating main sequence and subgiant star in EBs
- ❑ GAIA: expects 250,000 EBs that are SB2
  - ✧ 40 RV measurements per star, poor photometry
  - ✧ NASA TESS mission will be able to observe some
- ❑ PLATO
  - Workbench targets from GAIA EB catalog
  - ✧ Ground-based support: photometry, spectrometry



# Conclusion

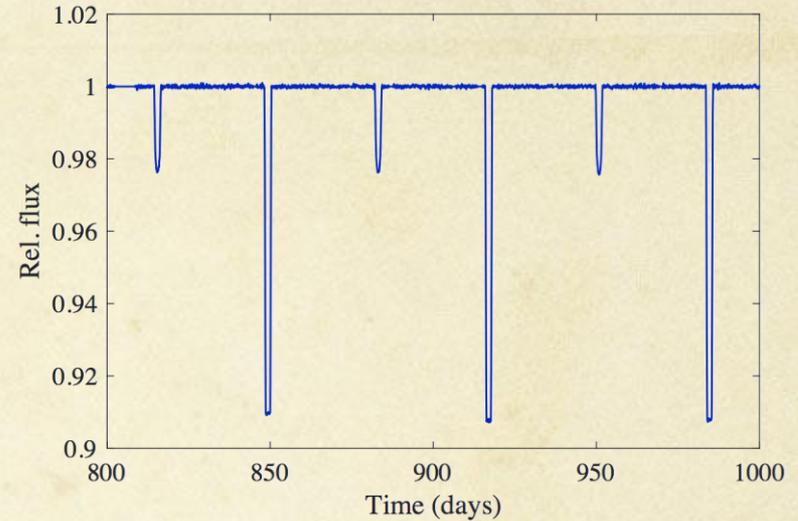
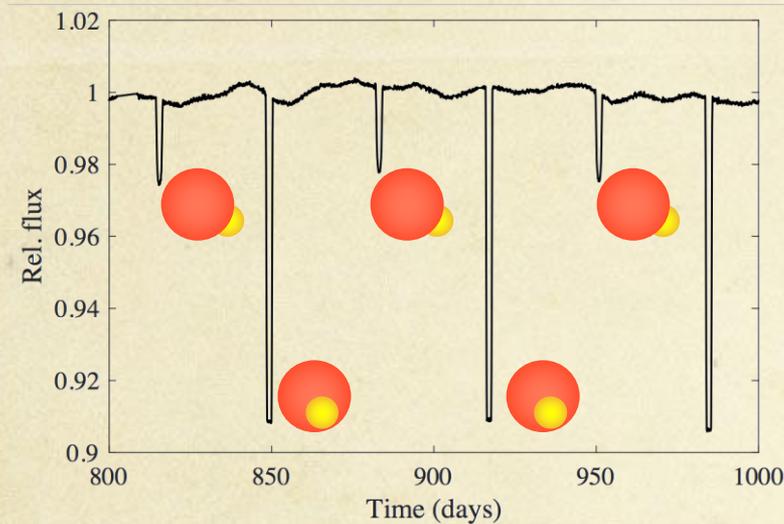
- ❑ Sweet spot for orbital periods: [100-600] days
  - ✧ Oscillations properties not altered
  - ✧ RV amplitude large enough
- ❑ Companion star
  - ✧ “Hot” MS
  - ✧ RG
- ❑ Important ground-based follow up needed
- ❑ Not many EB candidates
  - ✧  $\approx 20$  out of 3000 EBs from Kepler
  - ✧ CoRoT, K2, TESS limited to short periods
  - ✧ Visual + RV binaries, triples



# Additional slides

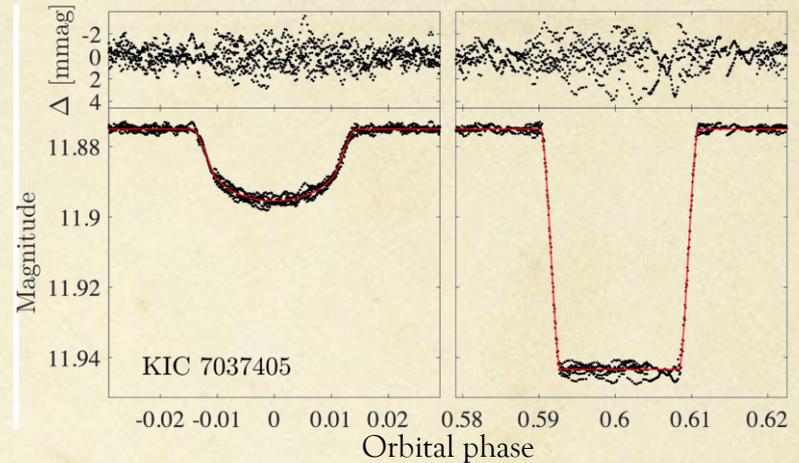
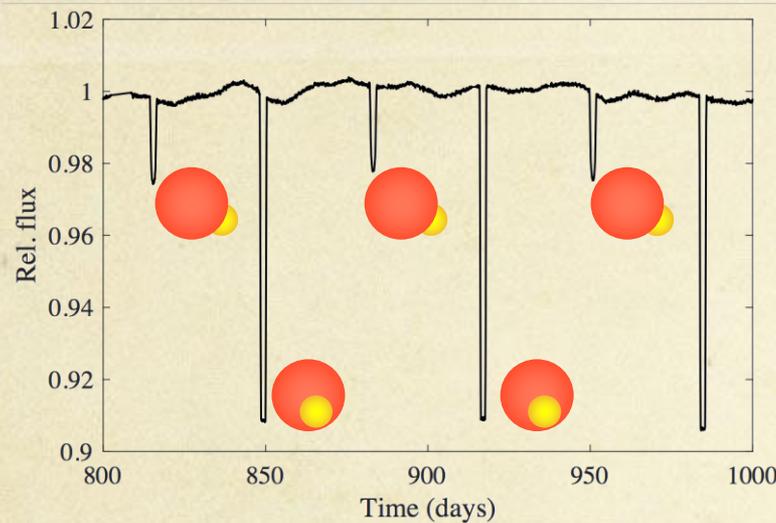
(in case of questions)

# Light curves of eclipsing binaries



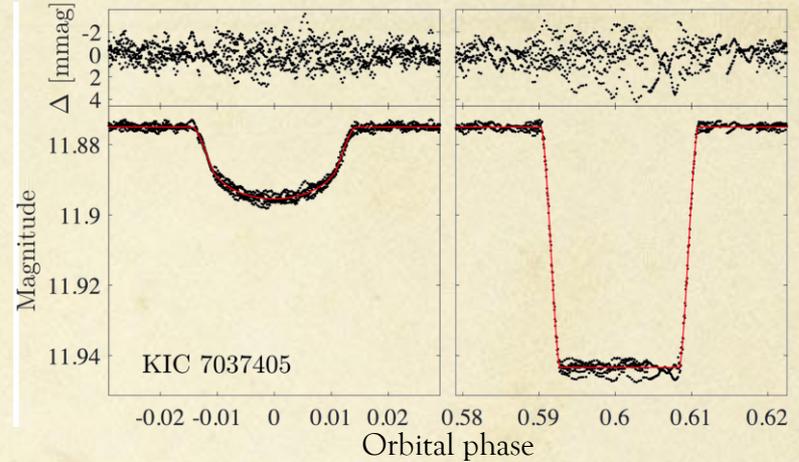
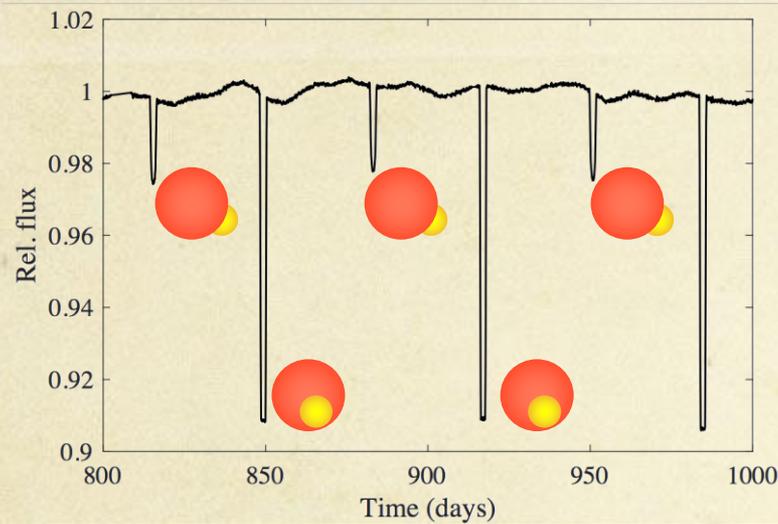
- ❑ Light curve content
  - Eclipses
  - Rotation
  - Oscillations + granulation
  
- ❑ Automatic procedure (Gaulme+13,+16)

# Light curves of eclipsing binaries



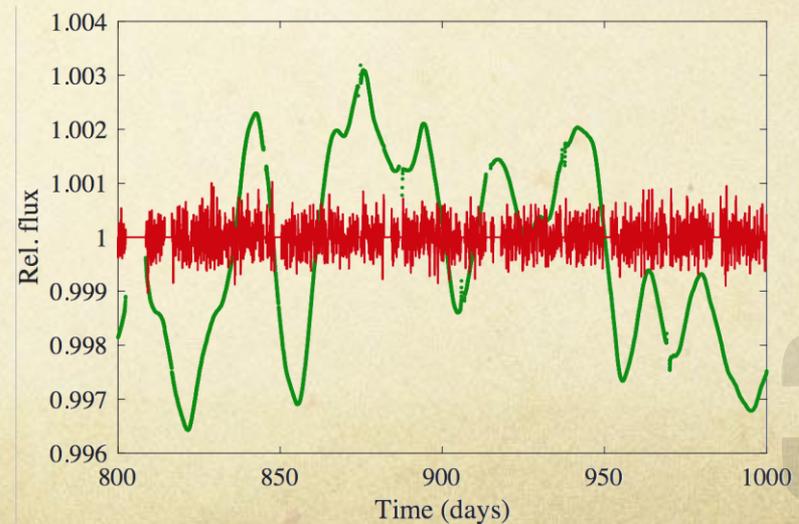
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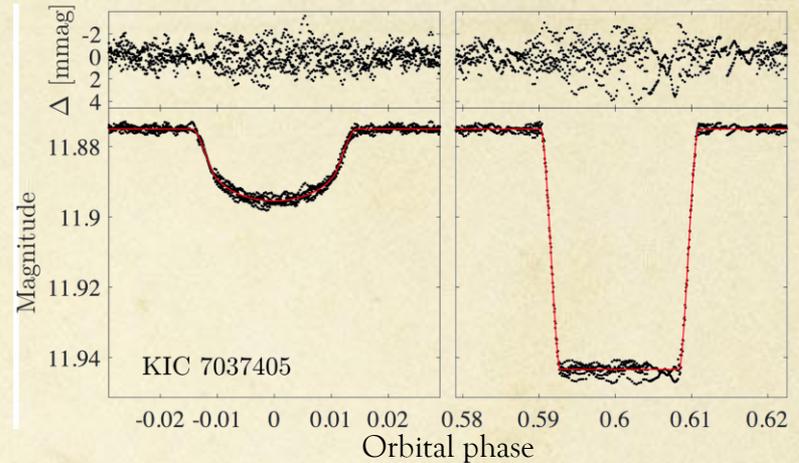
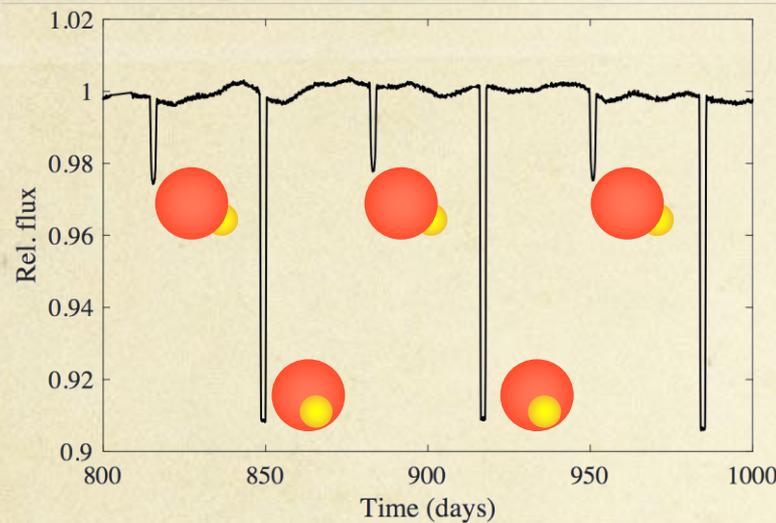


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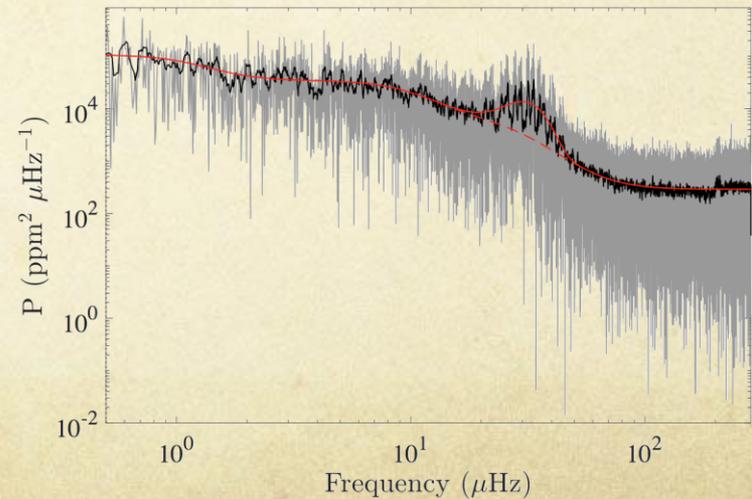


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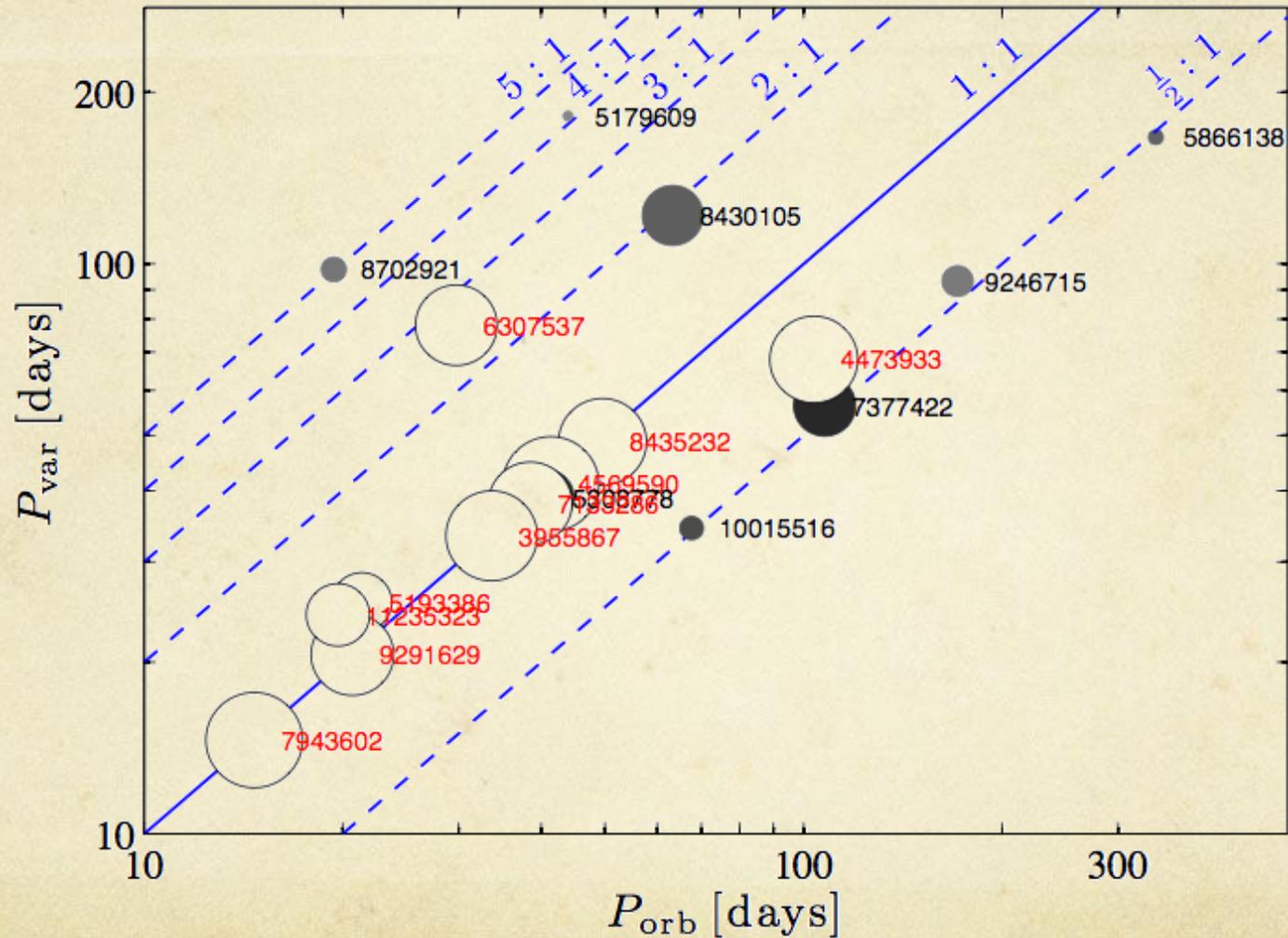


- Light curve content
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- Automatic procedure (Gaulme+13,+16)



# Orbital Parameters vs. Oscillations & Activity



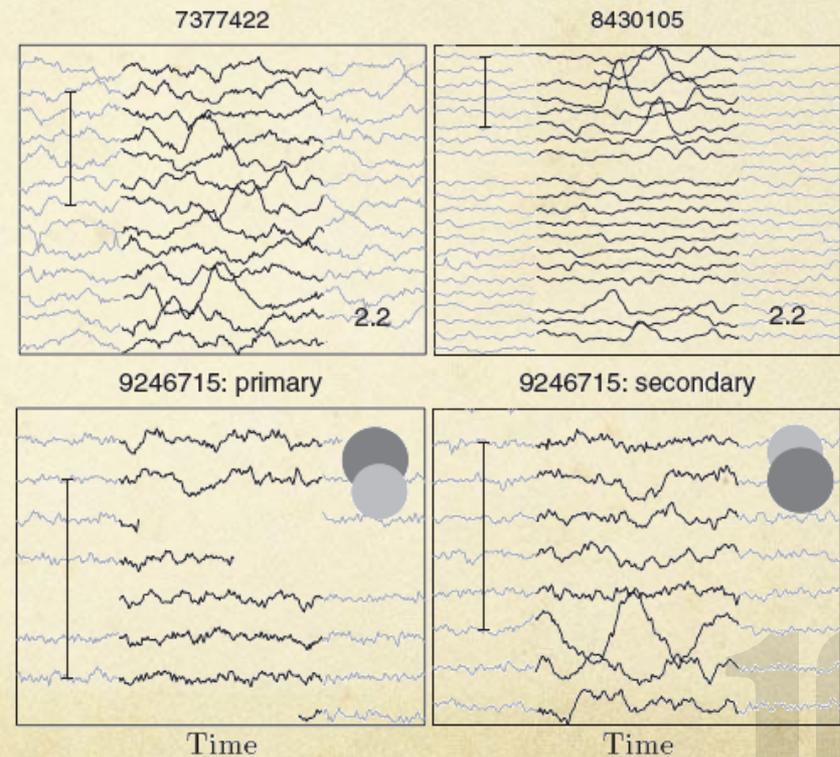
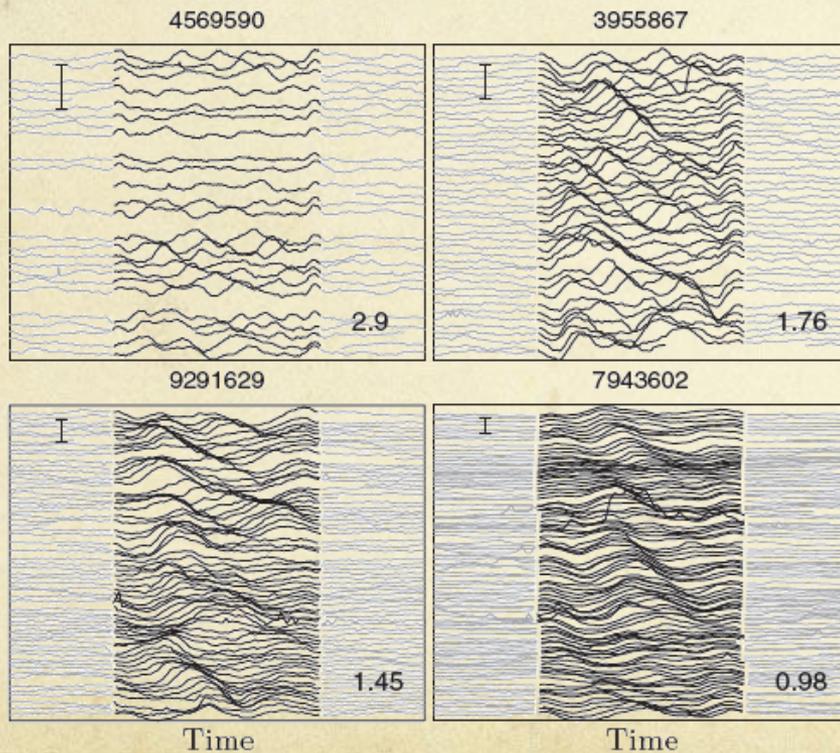
# Unprecedented view of stellar surface activity

□ During eclipses

◇ Small star scans the big star's surface

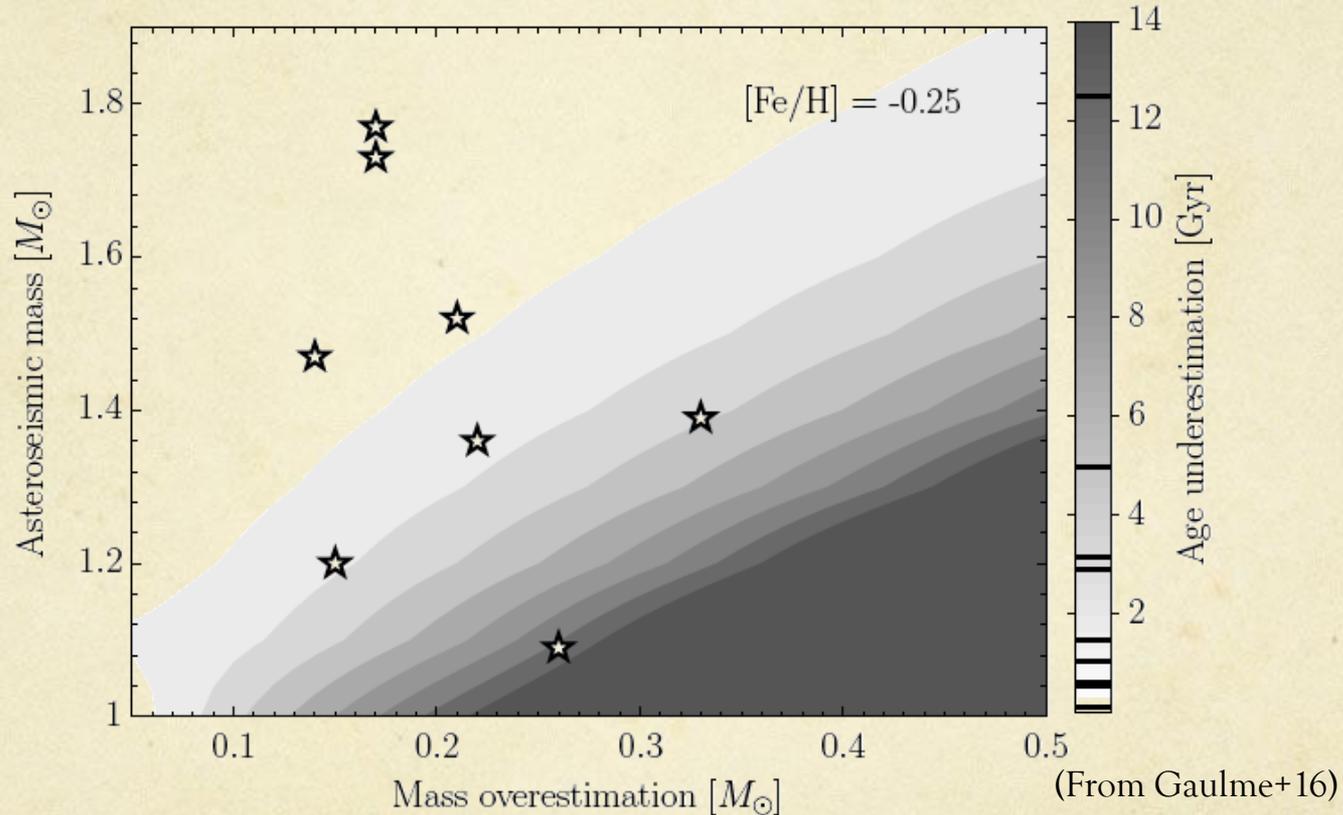
□ Measurements

◇ Spots' size, lifetime, temperature



# Implication of mass overestimation

- Mass overestimation  $\Leftrightarrow$  age underestimation



- Galactic archeology: asteroseismology to study population studies