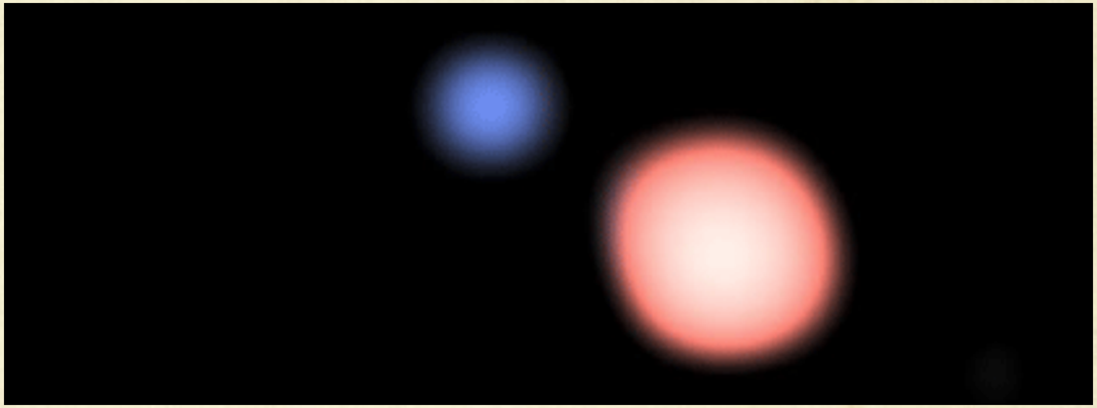
Asteroseismology, Red Giants, and Eclipsing Binaries



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Observatoire de la Côte d'Azur - 06.23.2016

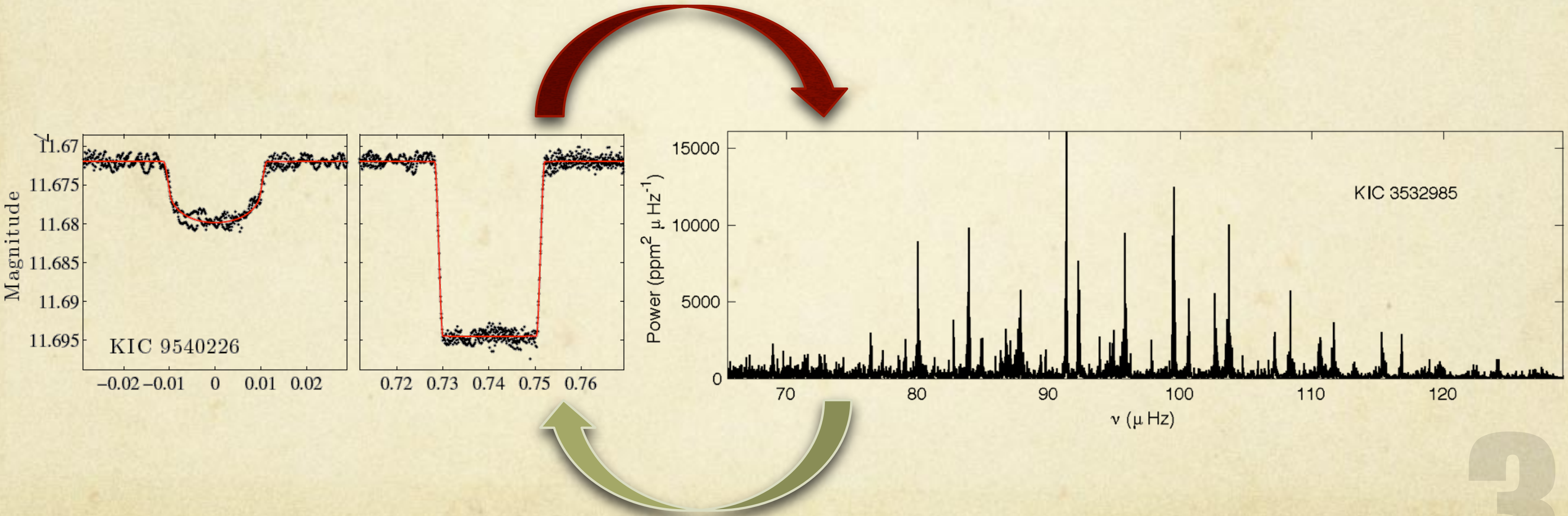
Asteroseismology @ NMSU

- Asteroseismology: Jason Jackiewicz, Patrick Gaulme
- 3.5-m telescope at APO with HR echelle spectrometer, SDSS
- Asteroseismology
  - Red giant in eclipsing binaries from Kepler
  - 200K NASA grant
  - 2 PhD students: M. Rawls & J. McKeever
- Giant Planet seismology: JOVIAL/JIVE
  - Instrument project (NASA, ANR)
  - OCA, NMSU, IAS, NMTech
  - 2 NMSU PhD students: E. Dederick, T. Underwood

Outline

I. Binaries to test asteroseismology

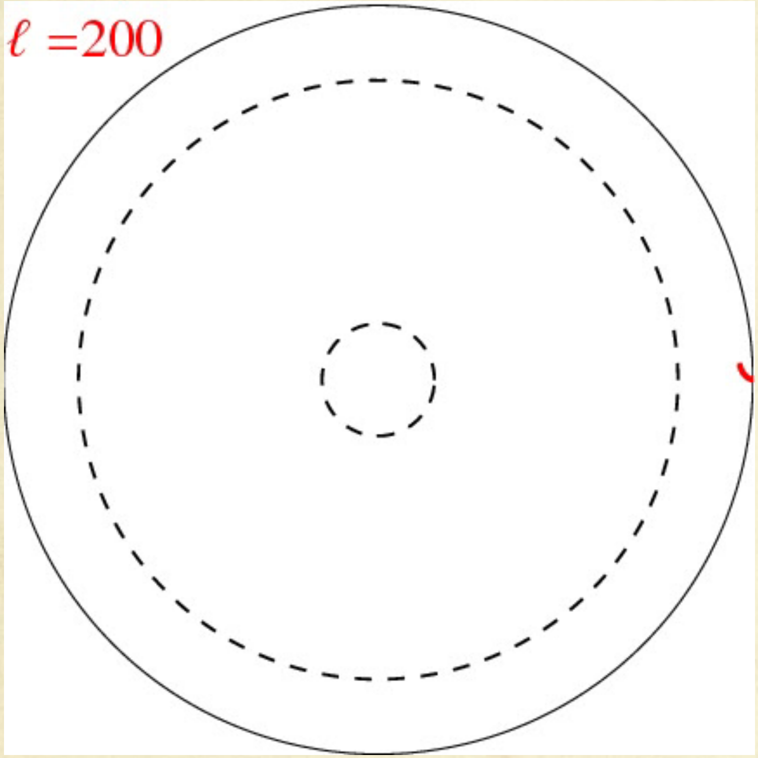
II. Asteroseismology to understand binaries

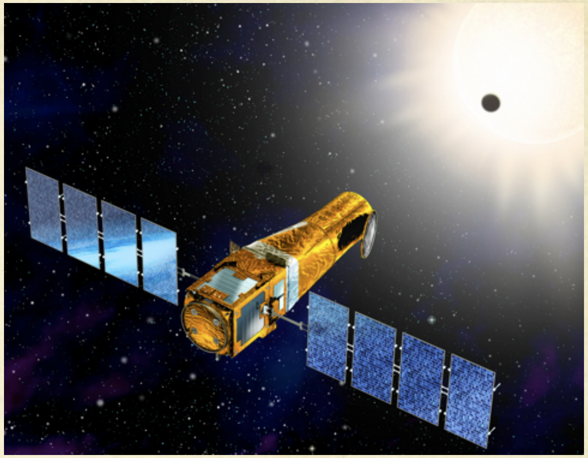


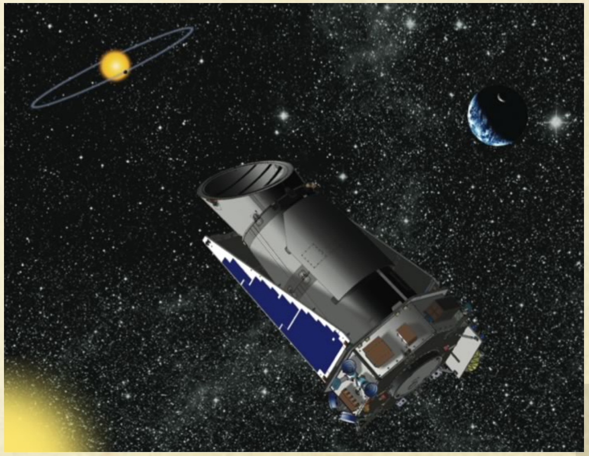
Part 1:

Calibrating Asteroseismology with Red Giants in Eclipsing Binaries

Asteroseismology of Solar-like Stars



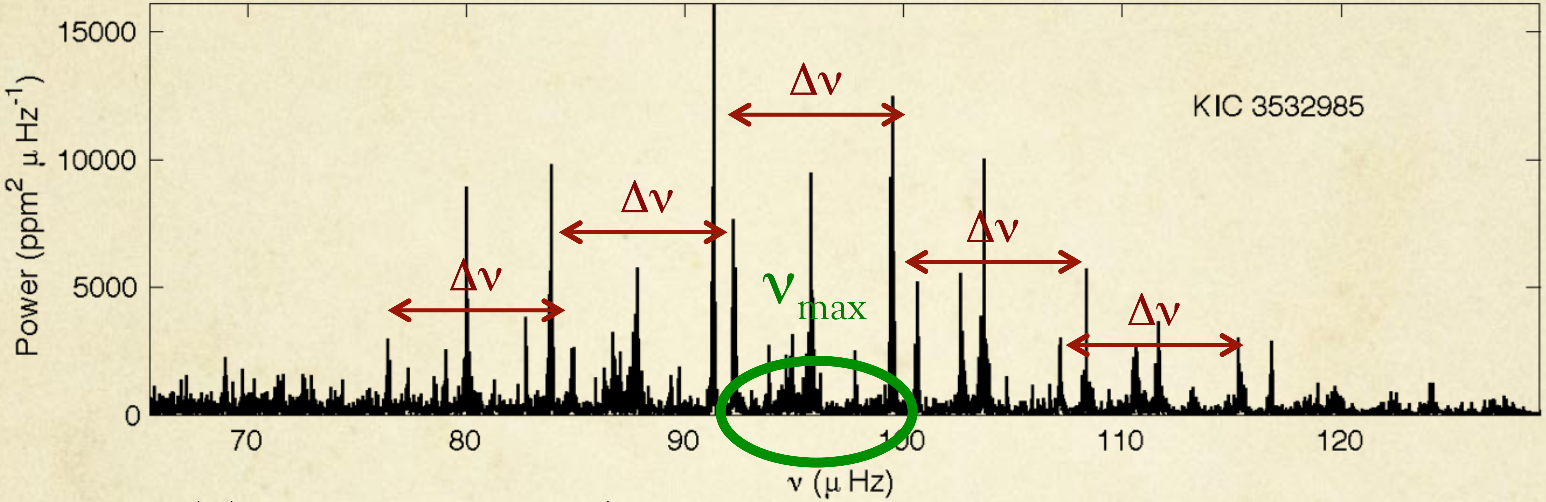




- Masses, Radii, Ages
- CoRoT, Kepler, TESS, PLATO

Asteroseismic Scaling Laws

- Oscillation spectrum



- Ensemble asteroseismology

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

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

Asteroseismic Scaling Laws

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

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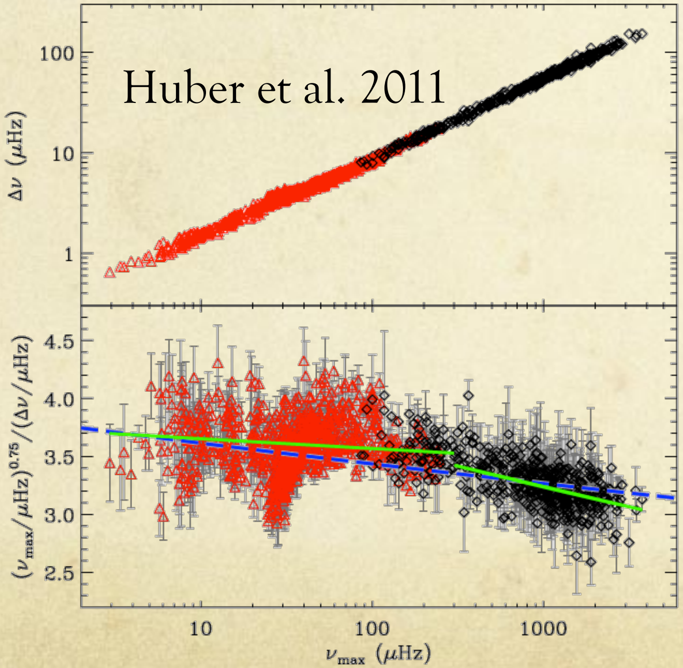
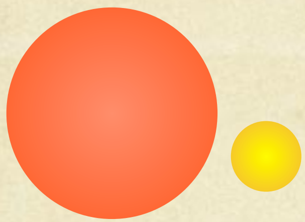
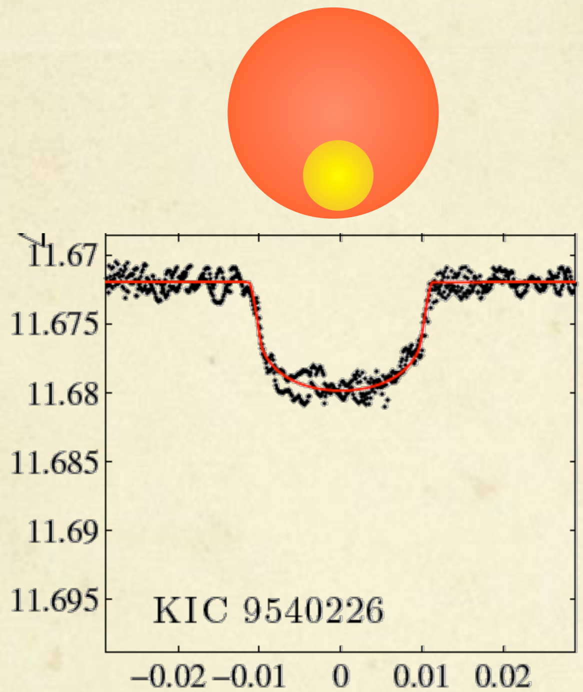
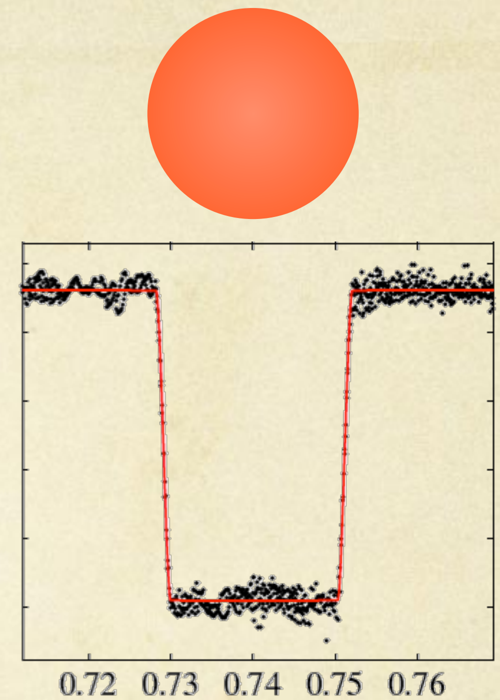


- Tens of thousands of oscillation spectra, mostly RG
- Theory/simulations
  - Stello et al. 2009: 3% agreement on R
  - White et al. 2011: Δν α √<ρ> up to 5%
  - Huber et al. 2011: evolutionary tracks, few percent accuracy.
- R measurements independent from seismology: accurate to few percent
  - Huber 2012, Silva-Aguirre 2012, Baines 2014
- Need for accurate mass measurements

Eclipsing Binaries



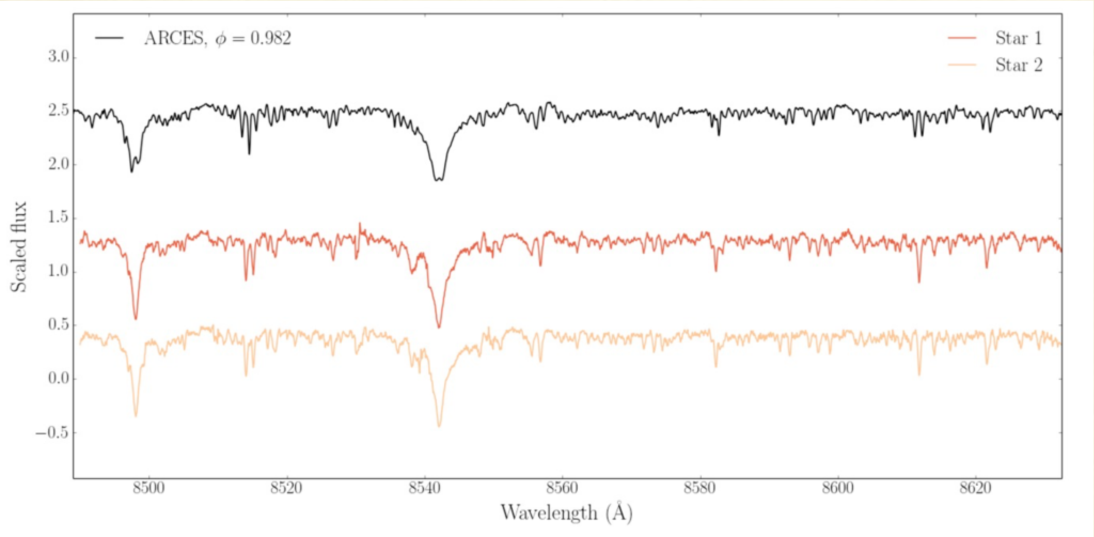


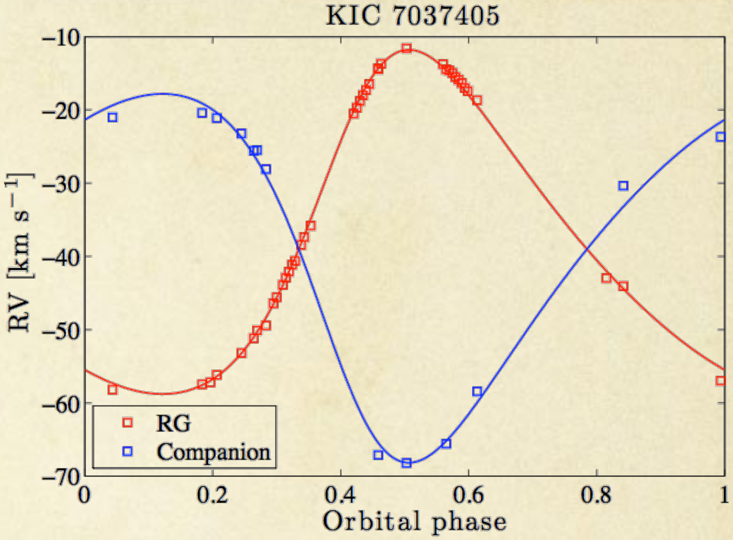


$R_1^2T_1^4 + R_2^2T_2^4$ $R_1^2T_1^4 + R_2^2T_2^4 - R_2^2T_1^4$ $R_1^2T_1^4$

- Eclipses' light curve: R_1/a, R_2/a, $T2/T_1$, e, i, limb darkening

Eclipsing Binaries

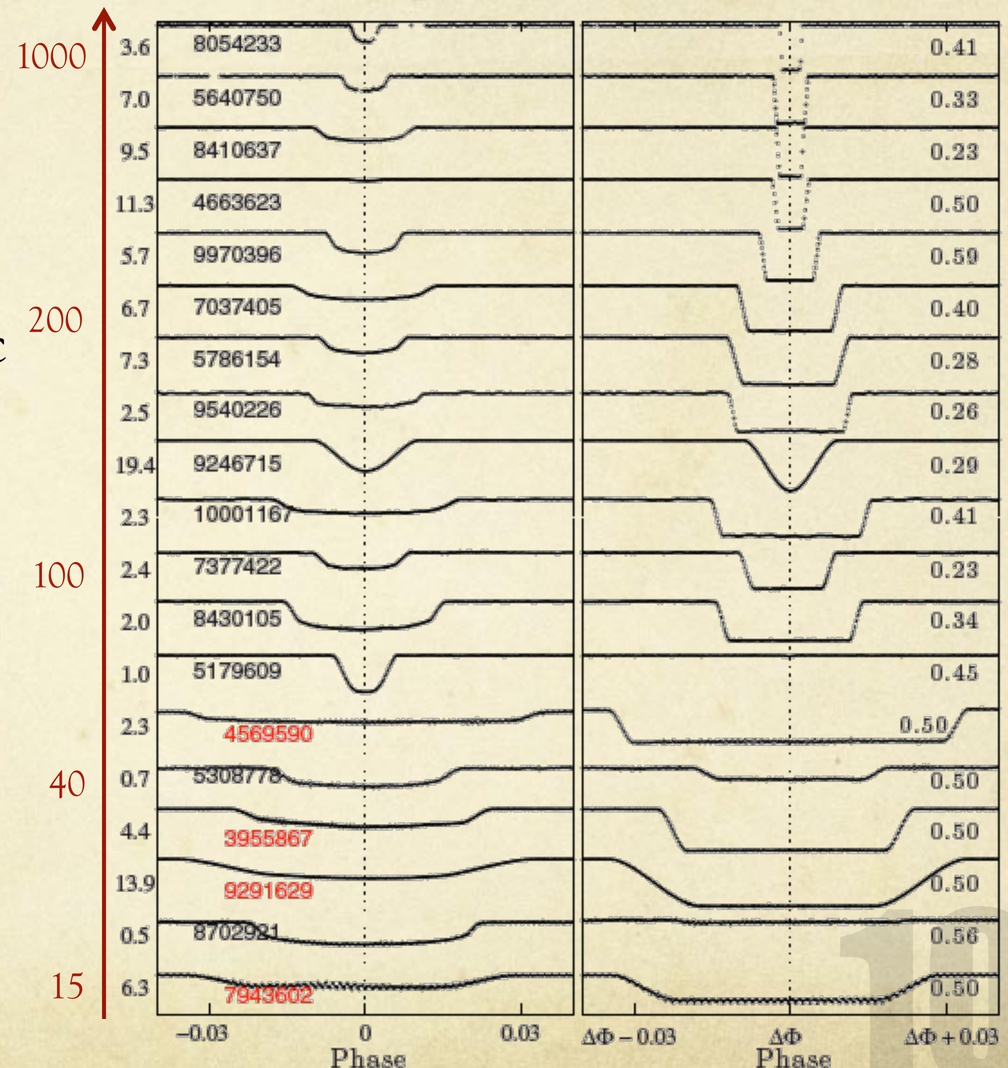




- Radial velocities of double-line spectroscopic binaries (SB2): $M_1 \sin i$, $M_2 \sin i$, a, e

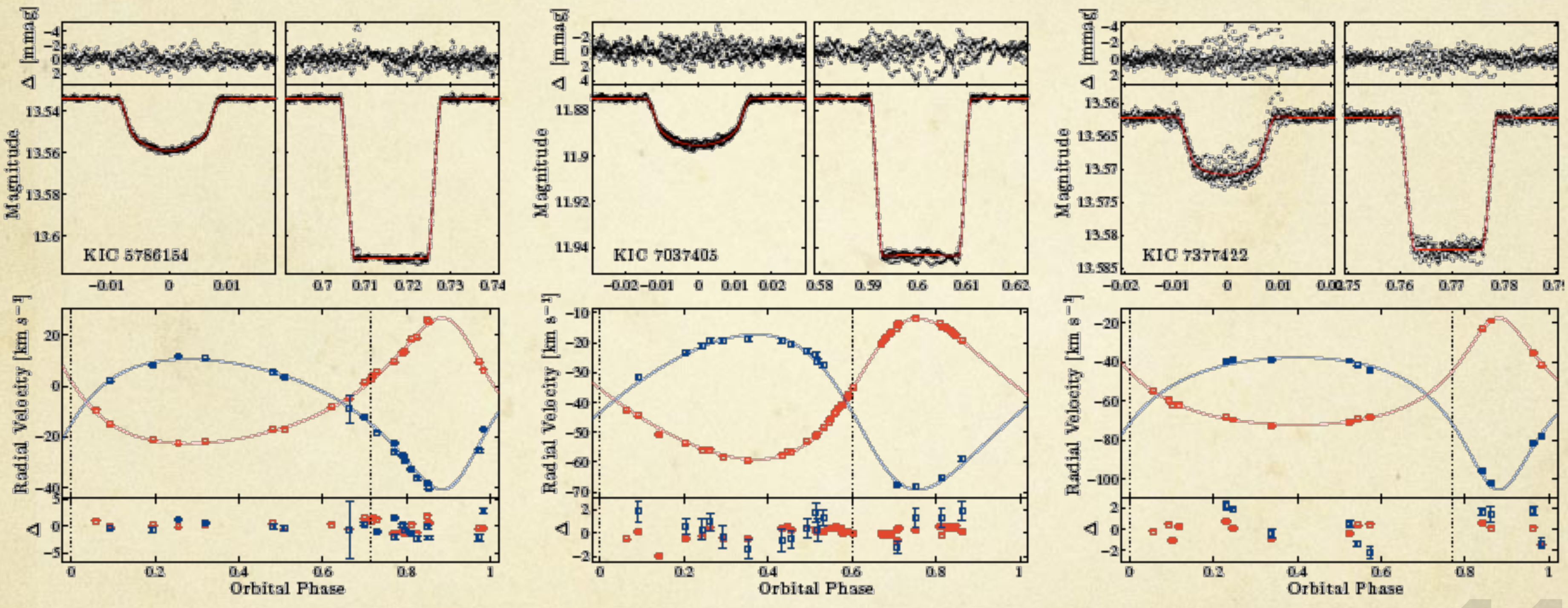
Red Giants in Eclipsing Binaries

- Hekker 2010, Frandsen 2013, Brogaart 2016
  - Dynamical M,R slightly larger than asteroseismic for 2 systems
- Sample of 17 RGs in EBs monitored for 4 years at APO
  - 9 SB2 with oscillations
  - 4 SB1 with oscillations
  - 4 SB2 with no oscillations



Red Giants in Eclipsing Binaries

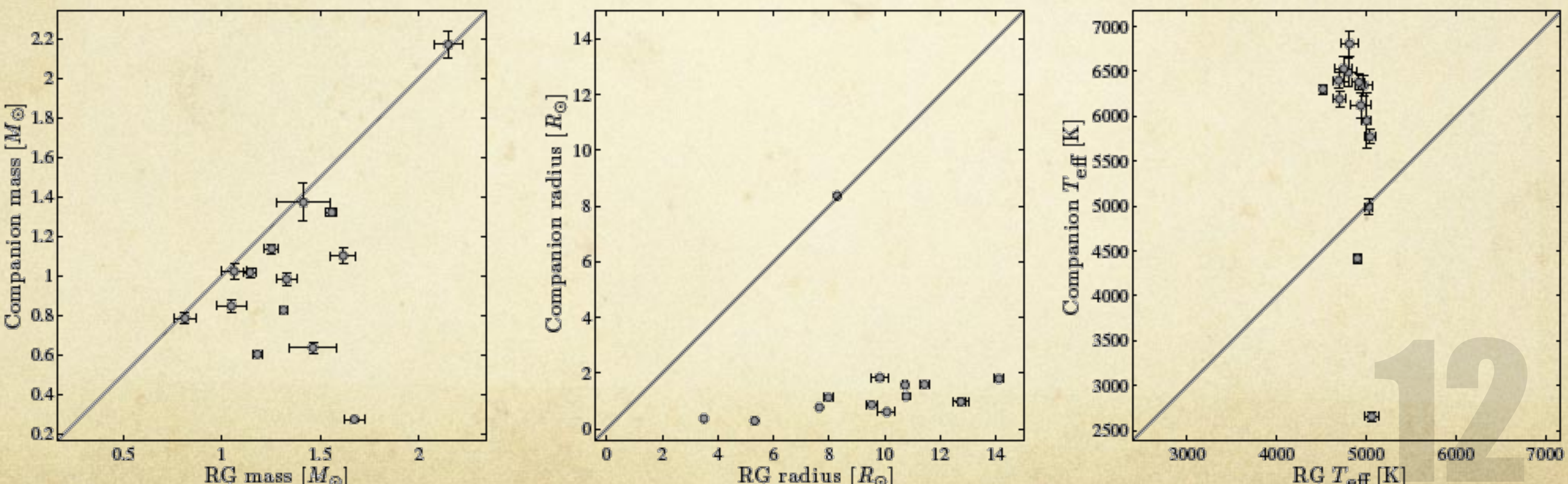
- Example of Kepler light-curves and APO radial velocity curves



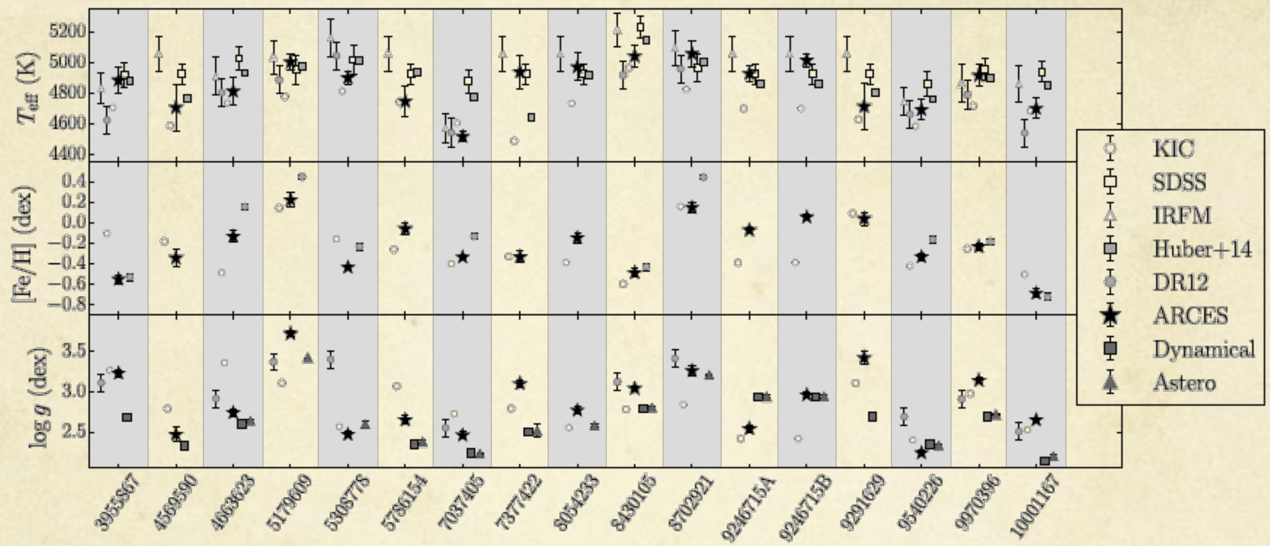
- Precision on masses ≈3% and radii ≈1%

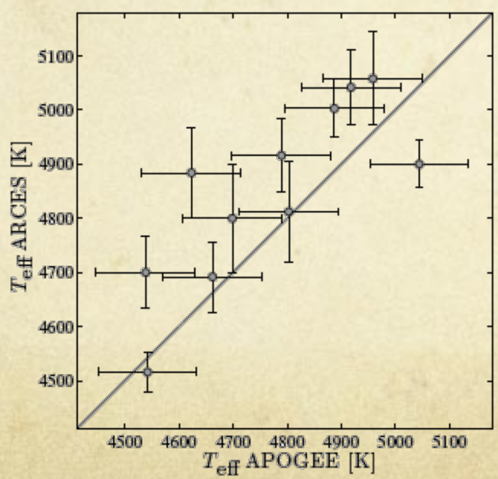
Nature of the Systems

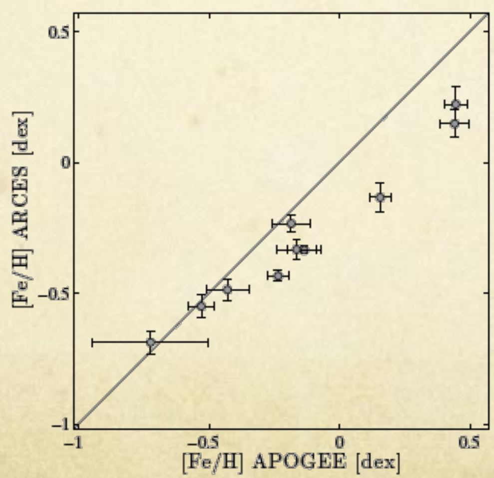
- 18 systems (include Frandsen's). 15 RGB, 3 RC.
- F/G-type companion for SB2
- 1 double red giant (rare!) Rawls et al. 2016
- M-type companion for 3 SB1
  - Test bottom main sequence, one system with M=0.27, R=0.28

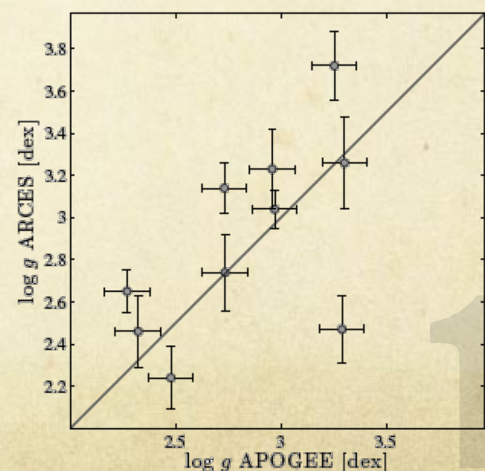


Atmospheric Parameters



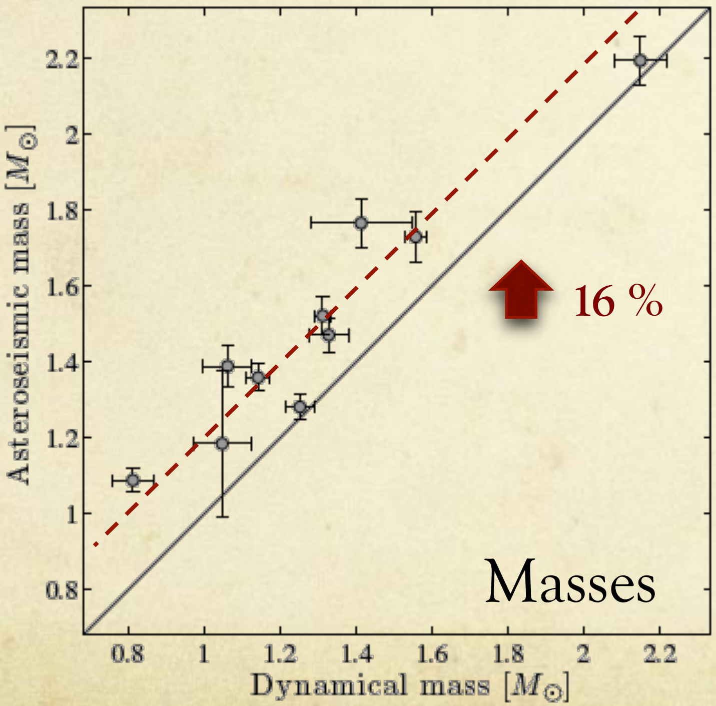


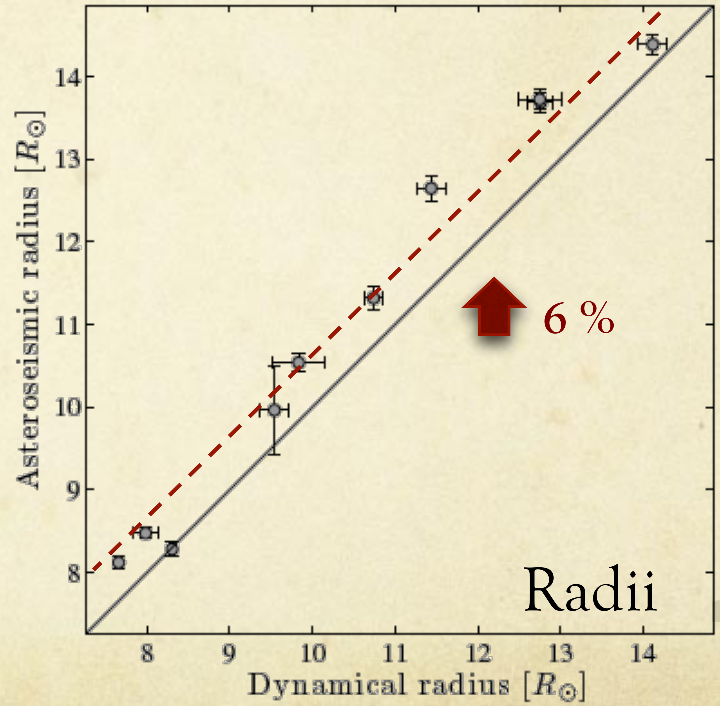




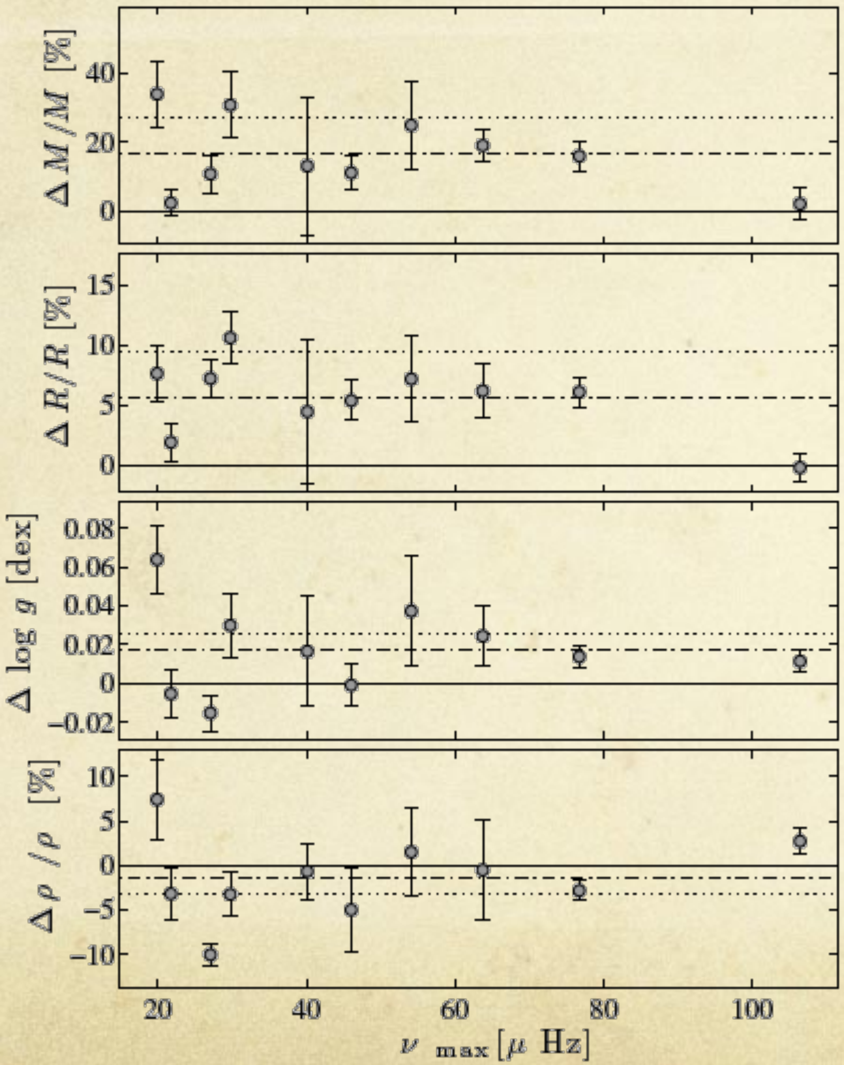
Testing Asteroseismic Scalings

- Asteroseismology systematically overestimate M,R
  - 16% for M, 6% for R
  - Depending on reference solar ν_{max} up to 25 and 10%





Testing Asteroseismic Scalings

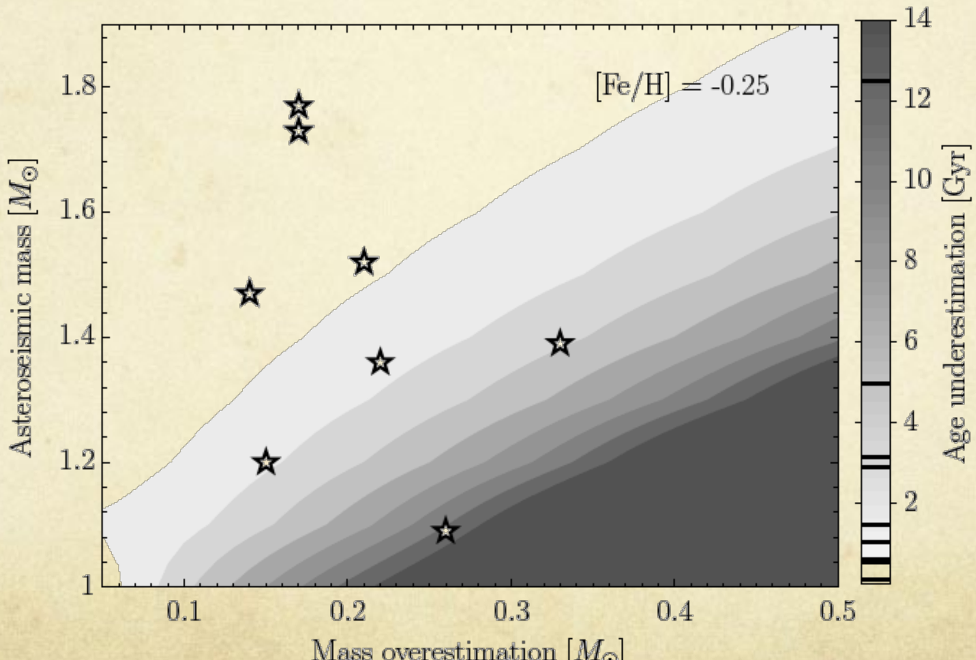


- ❑ No dependence with P_{orb}
  - ✧ Binarity does not seem to have influence
- ❑ No dependence as function of ν_{max}
- ❑ No dependence as function of evolutionary type (RGB vs. RC)
- ❑ T_{eff} influence
  - ✧ if lower than 100K ≈3% mass decrease

Conclusion Part I

- Mass overestimation ⇔ age underestimation

- Galactic archeology, population studies
  - α-enhanced giants (Chiappini 2015, Martig 2015): appear young because of large asteroseismic masses.
  - Galaxy survey (Sharma 2016): models "overestimate" number of low mass star wrt asteroseismic results



Part 2:

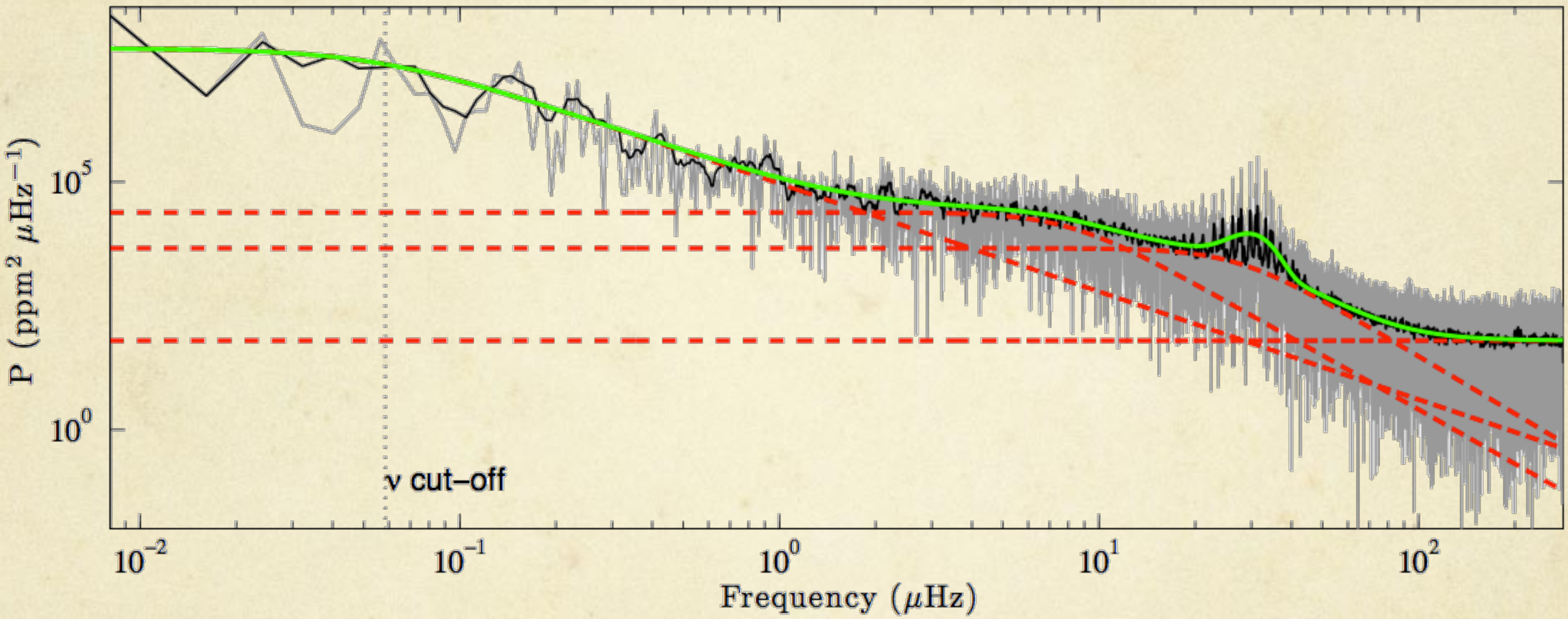
Asteroseismology to help understand binaries

Intrigue:

Among 30 red giants in eclipsing binaries, 10 do not display “solar-like” oscillations

Intrigue

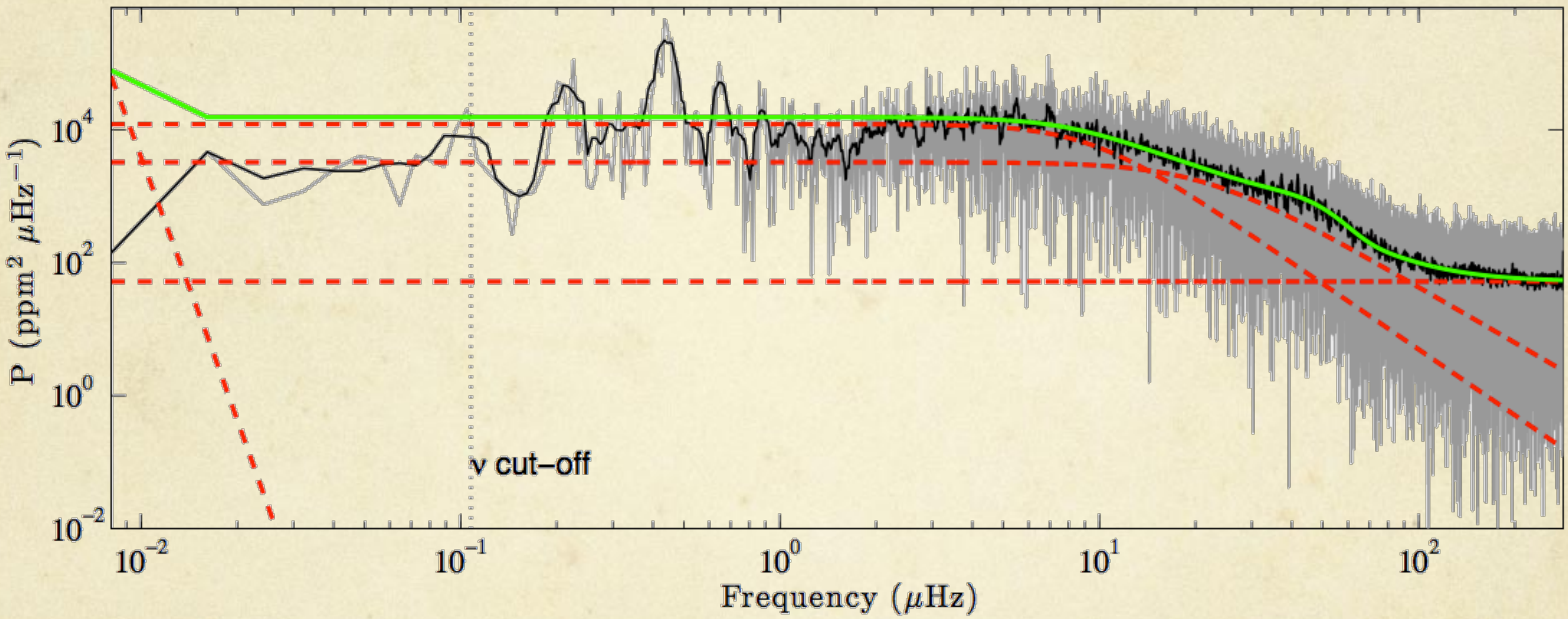
- Some oscillate nicely (about 15)



KIC 5866138

Intrigue

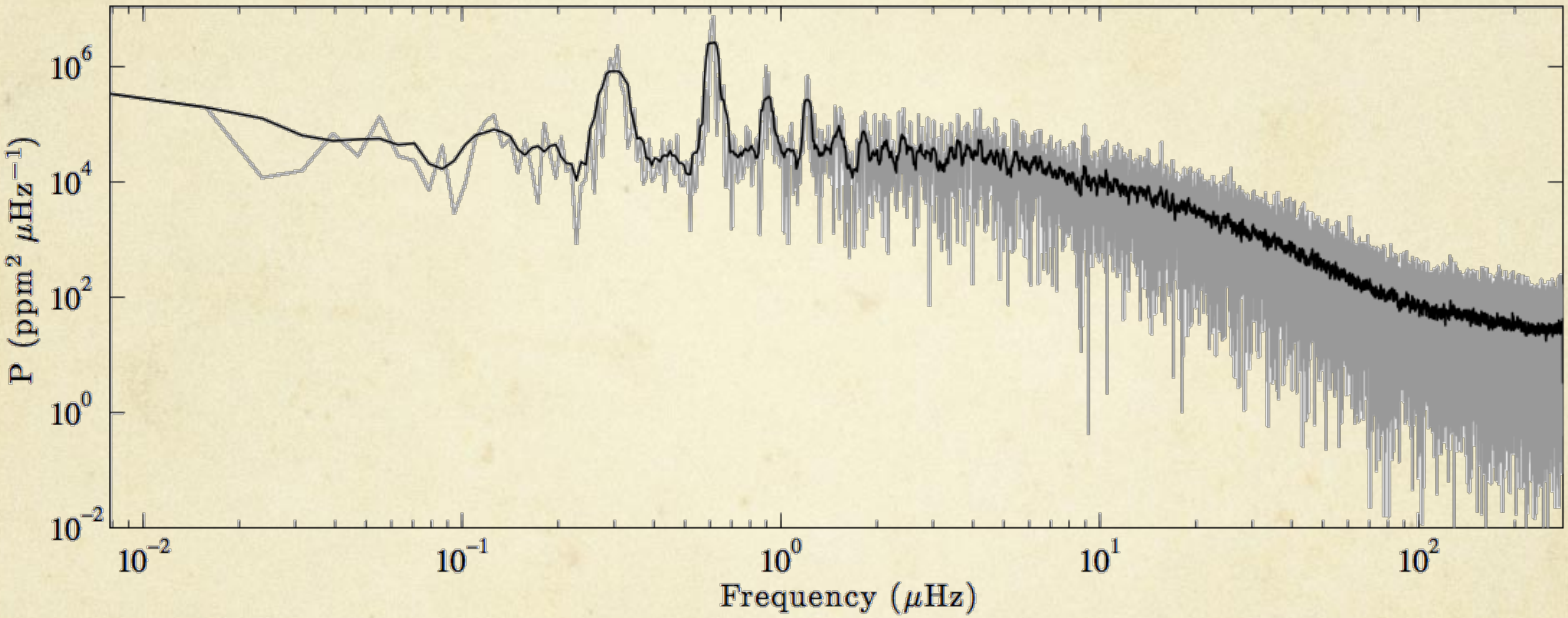
- ... some weakly (about 5)



KIC 5308778

Intrigue

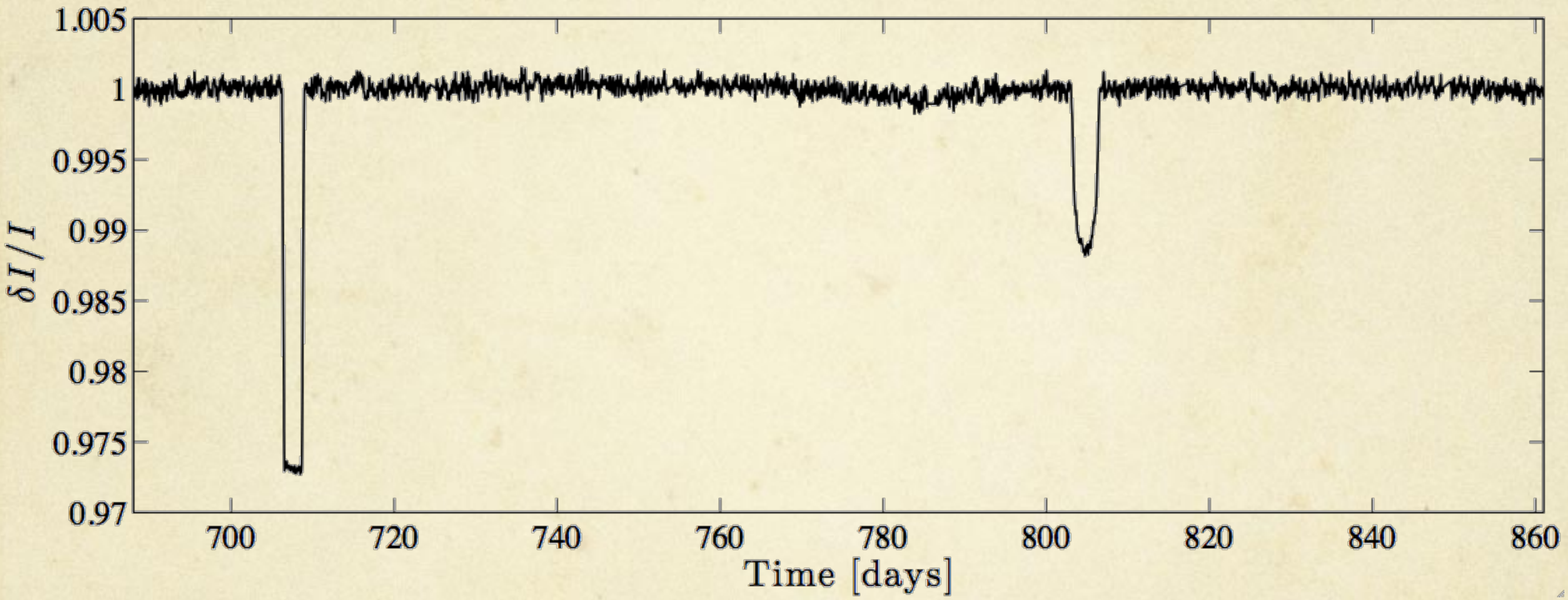
- ... some don't at all (10)



KIC 7133286

Intrigue

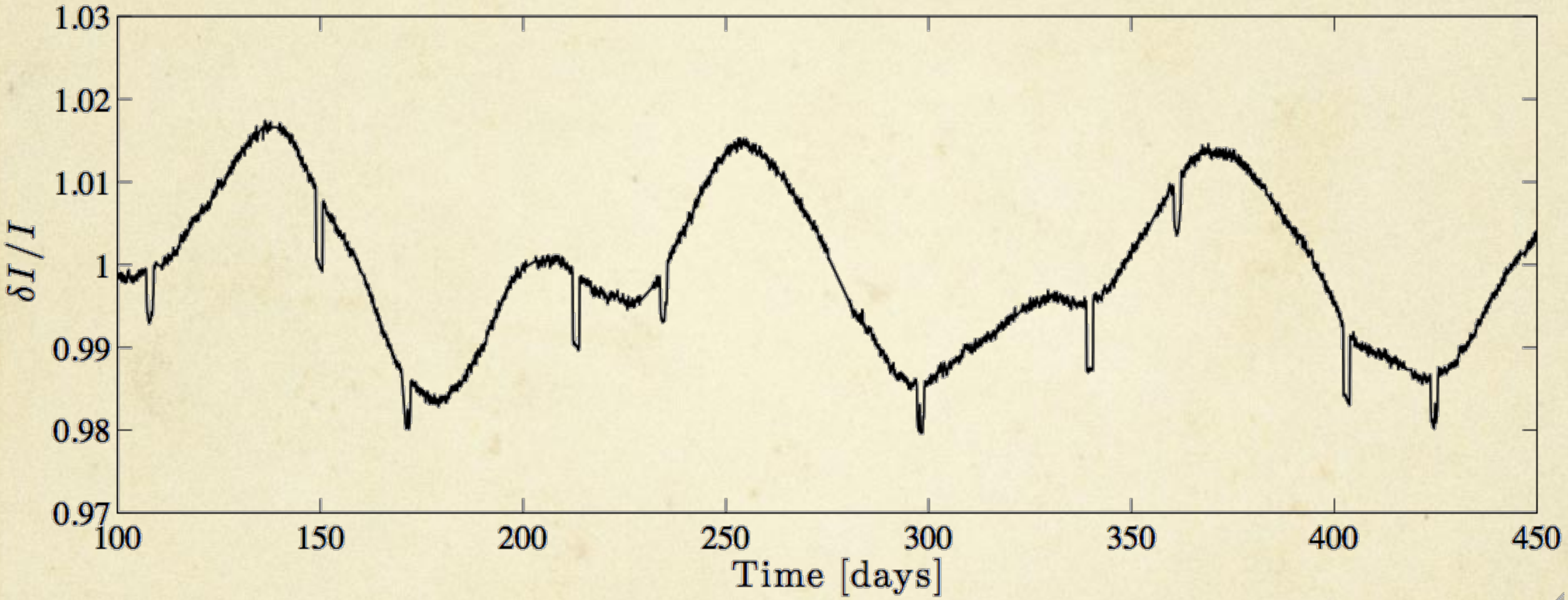
- Some display negligible stellar variability (about 15)



KIC 9970396

Intrigue

- Some do



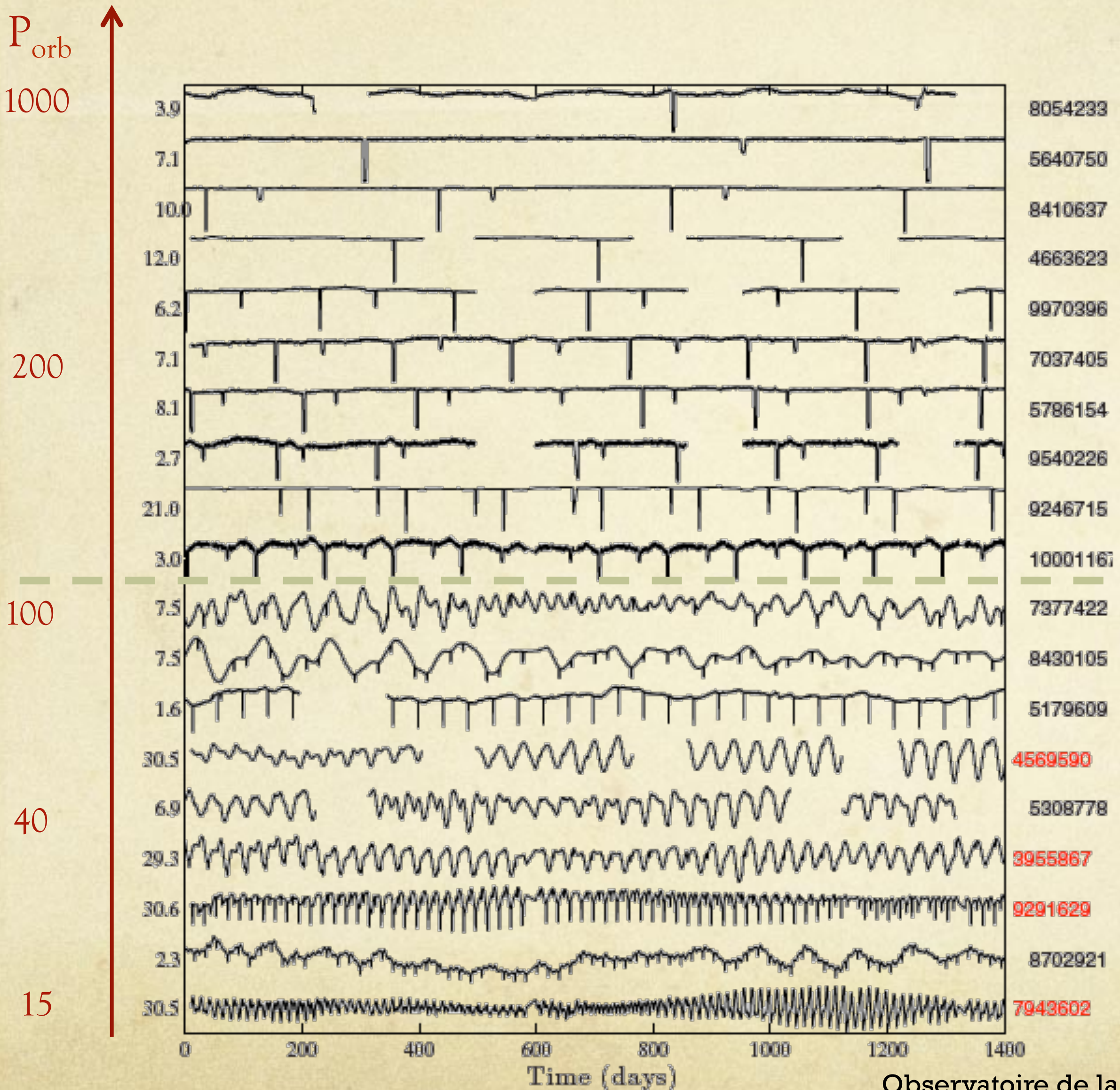
KIC 8430105

- 30 Red Giants in Eclipsing binaries (Hekker et al. 2010, Gaulme et al. 2013 & 2014)

- 15 with nice oscillation patterns
- 5 with confused oscillation patterns
- 10 with no oscillations at all

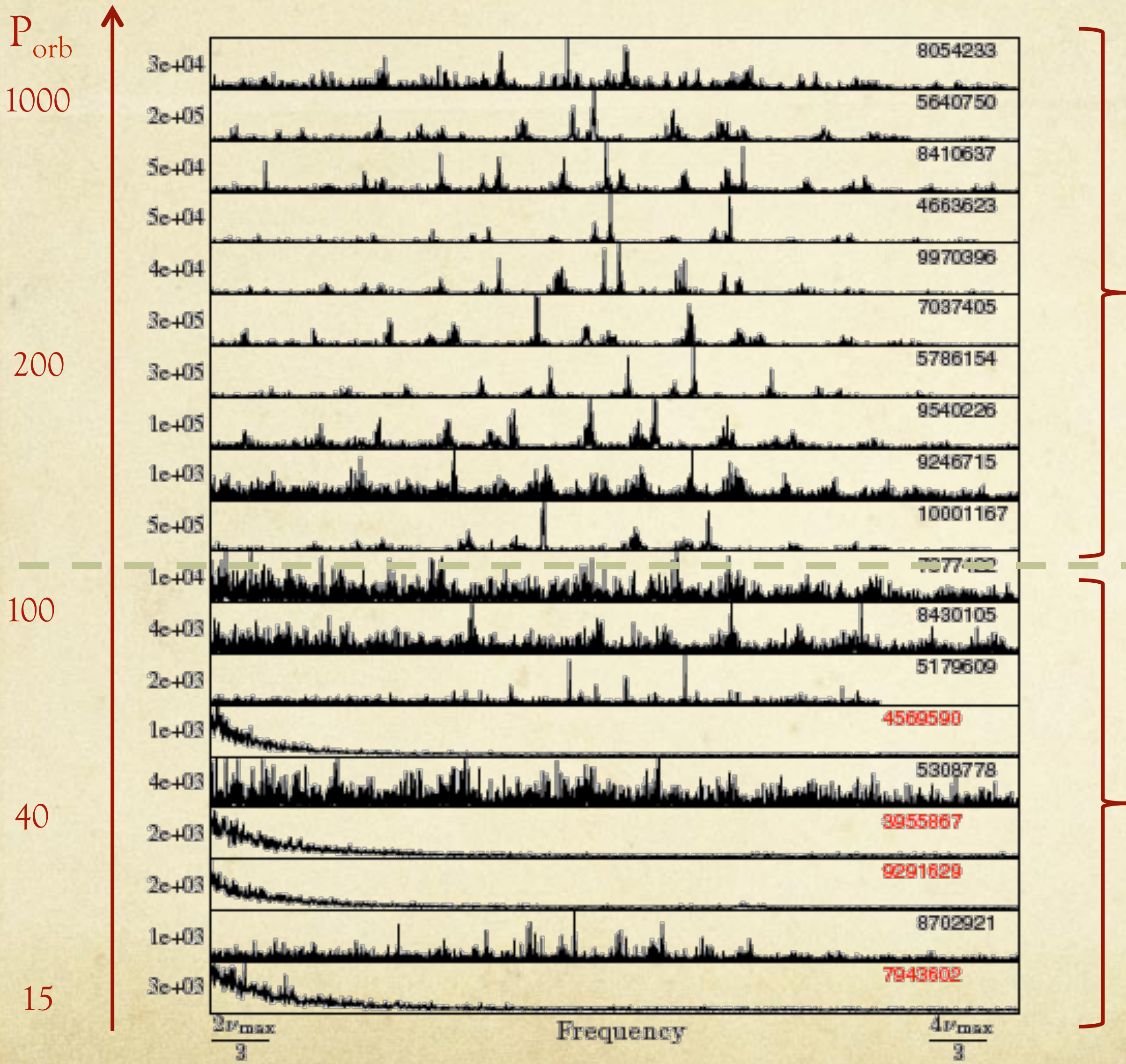
- 15 with significant variability (spots)

Orbital Period vs. Activity



- Spots on the giant, because the companion represents at maximum 10 % of total luminosity

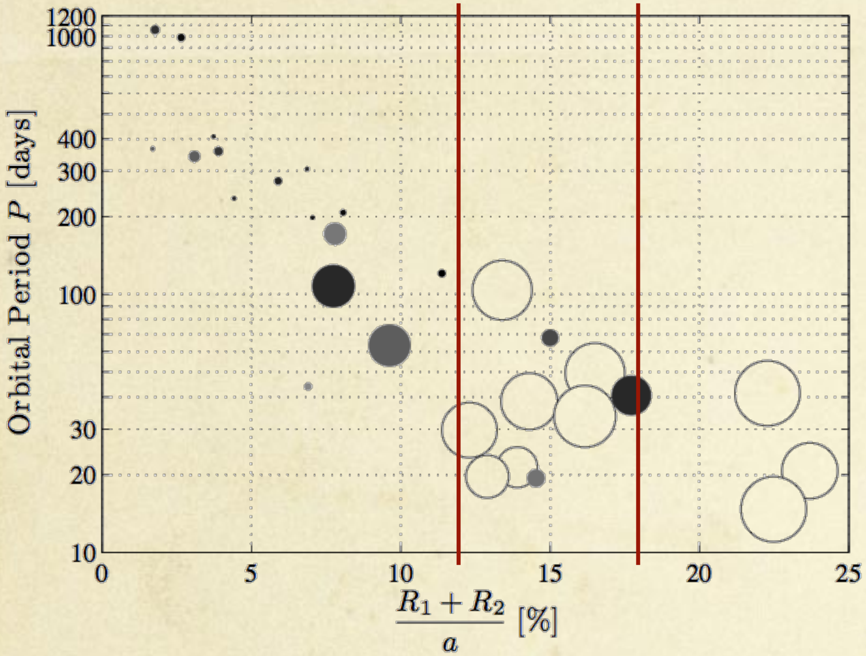
Orbital Period vs. Oscillations

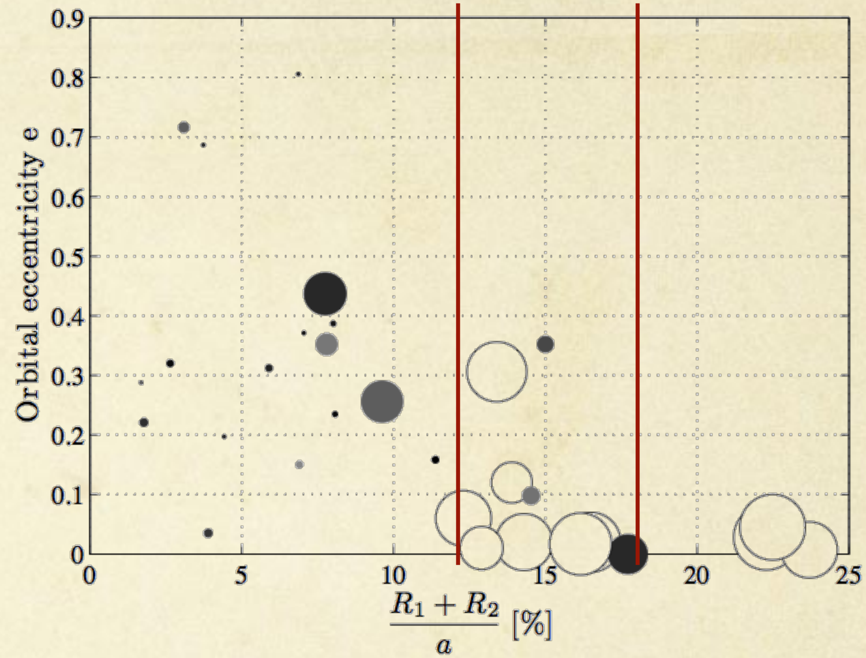


Clear amplitudes, well defined peaks

Noisier or no oscillations, but for KICs 5179609 & 8702921

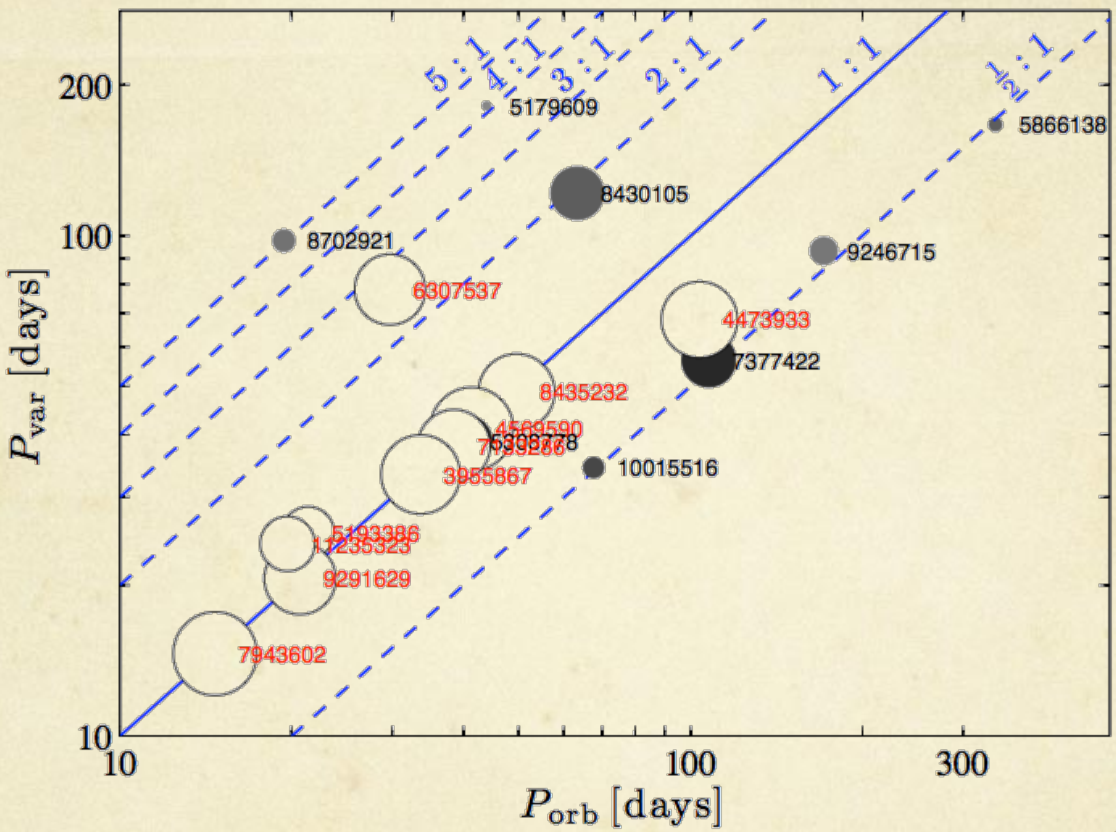
Orbital Parameters vs. Oscillations & Activity





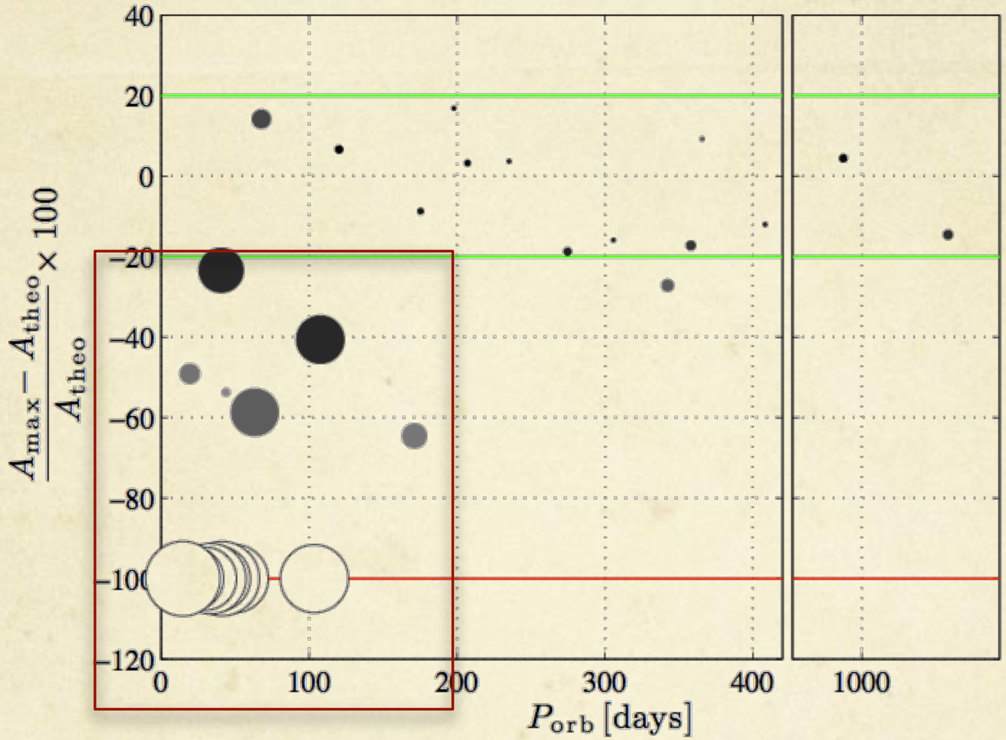
- [R1+R2]/a < 12 % always oscillations
- [R1+R2]/a > 18 % no oscillations
- Non-oscillating RGs:
  - 10 of the 13 with shortest [R1+R2]/a
  - 9 of the 12 with smallest eccentricities

Resonance vs. Activity



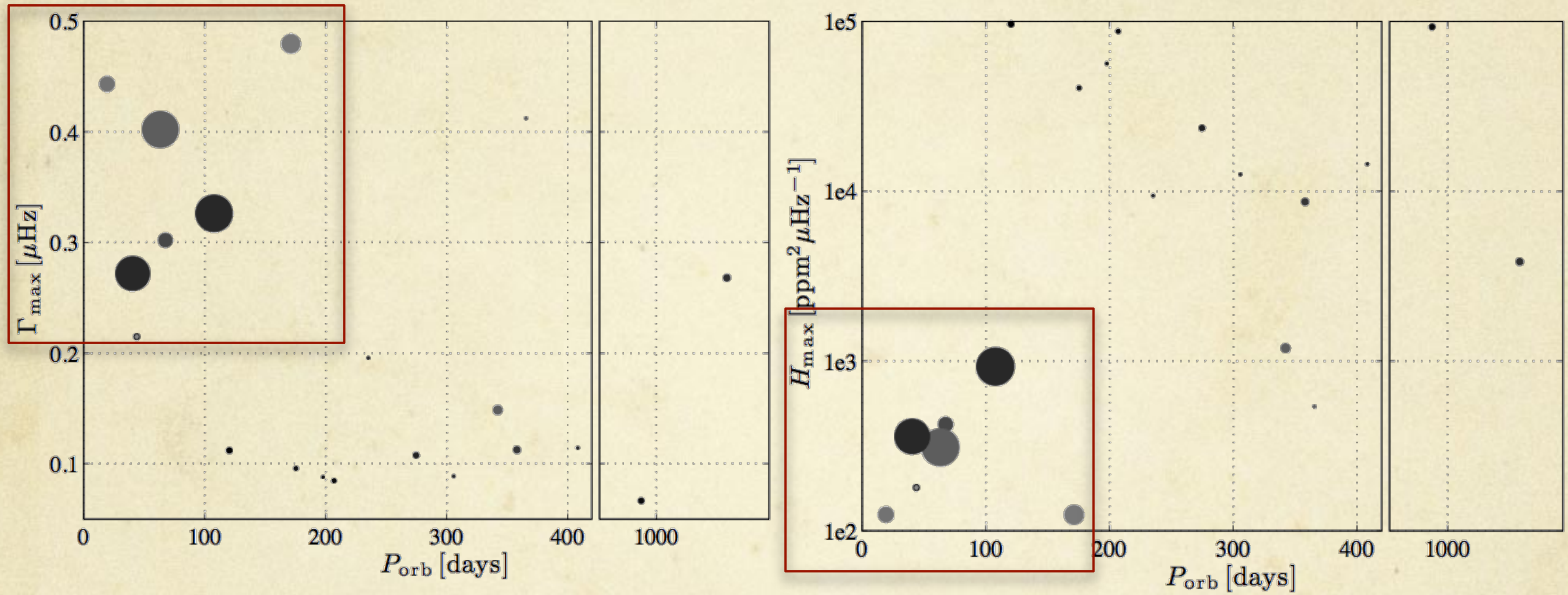
- ❑ Non-oscillating RGs:
  - ➢ 8 of the 9 with synchronized orbit and variability
  - ➢ 9 of the 12 with shortest orbits

Orbital Period vs. Mode Amplitude



- Based on expected oscillation amplitudes from Corsaro et al. 2013.
- Evidence of mode depletion for systems with:
  - Short orbital periods
  - Circularized and synchronized orbits
  - Spotty surfaces

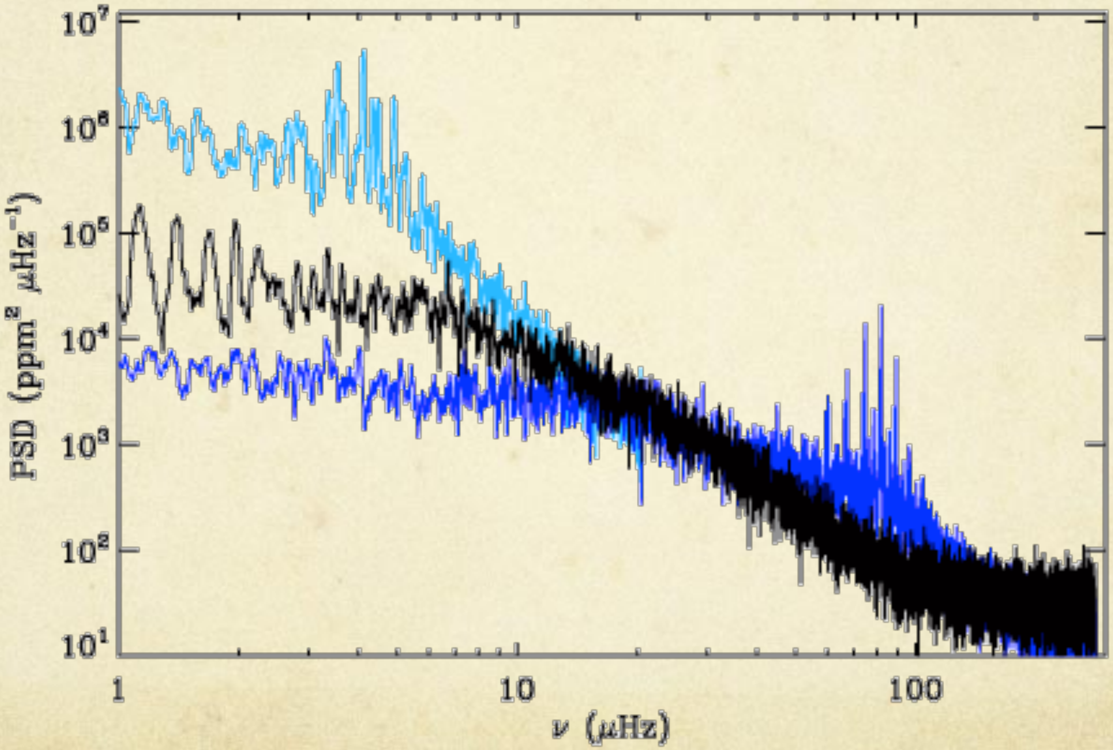
Orbital Period vs. Mode Height & Width



- ❑ Mode lifetime reduced at shorter periods, hence small heights
  - ➢ Excitation is present but damping is very strong

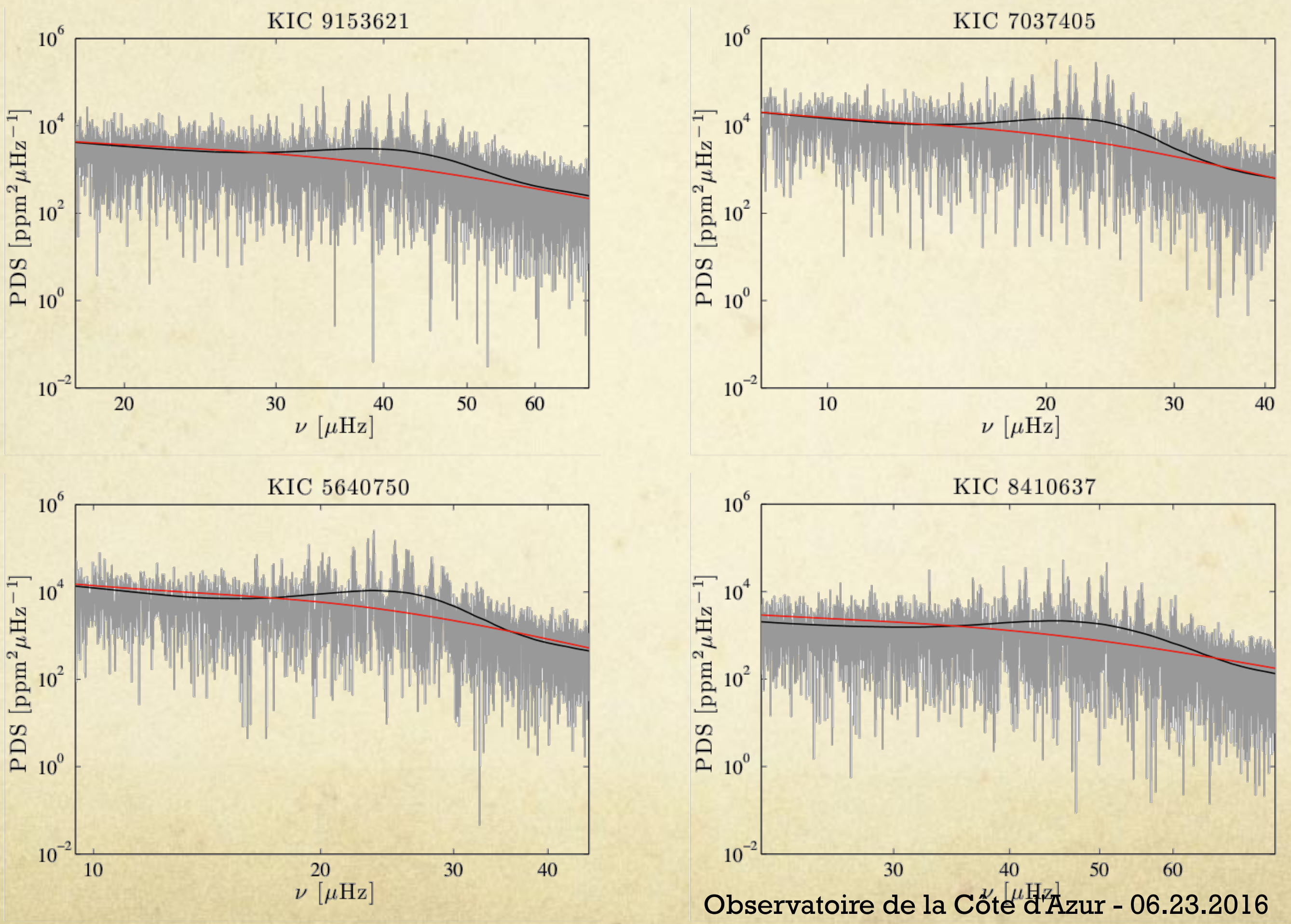
Oscillation excitation

- Systems with no modes display granulation
  - Three RGs with same magnitudes, one with no modes (black line)



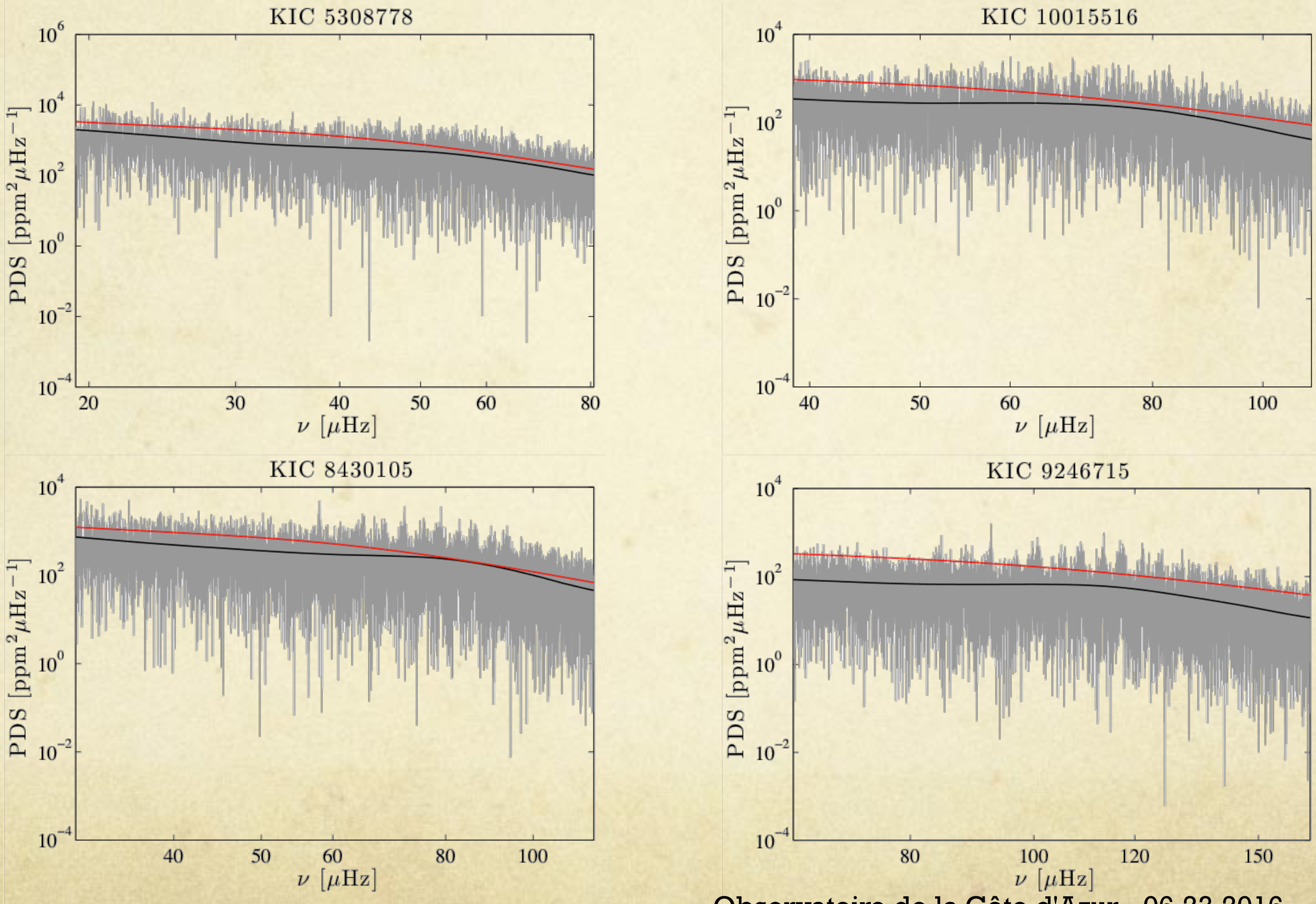
Oscillation excitation

- ❑ Comparison between expected (Kallinger et al. 2014) and actual granulation
  - ➢ Those with regular modes: regular granulation



Oscillation excitation

- Comparison between expected actual granulation
  - Those with damped modes: damped granulation



Conclusion Part II (1)

- One third of RGs in EBs do not display oscillations
- RGs with damped or no oscillations display spotty surfaces
- RGs with damped or no oscillations are circularized and synchronized
- Excitation mechanism is always present but modes are damped
- Granulation is weaker than expected

Conclusion Part II (2)

- Chaplin 2011: when activity, lower modes. But Huber et al. 2011 don't see that
- Derekas observed the absence of oscillations in triple system
- Active RG, when spinning faster. Observed with Zeeman Doppler Imaging (ZDI)
- Here: tides lock systems. Entails RG fast rotation, B field, & activity.
  - P-modes absorbed in spots
  - Convection looks affected too

General Conclusion

- RG in EB are excellent benchmarks for testing asteroseismology
  - We observe M and R overestimate (16 and 6%)
  - We need more systems (about 10 more RG under study)
  - We need other evolutionary stages. K2 opens opportunities
  - Future benchmarks for TESS PLATO, from catalogs and GAIA

- Tides have influence on oscillations and surface
  - Oscillation suppression, spots
  - Circularization, synchronization
  - Fast rotation, magnetic fields
  - Short-lived modes, damped convection

- Our papers: Gaulme et al. 2013 (ApJ 767,82), Gaulme et al. 2014 (ApJ 785, 5), Rawls et al. 2016 (ApJ 818, 108), Gaulme et al. 2016 (ApJ, in process, soon on Arxiv).