Period doubling and Blazhko modulation in BL Herculis-type hydrodynamic models

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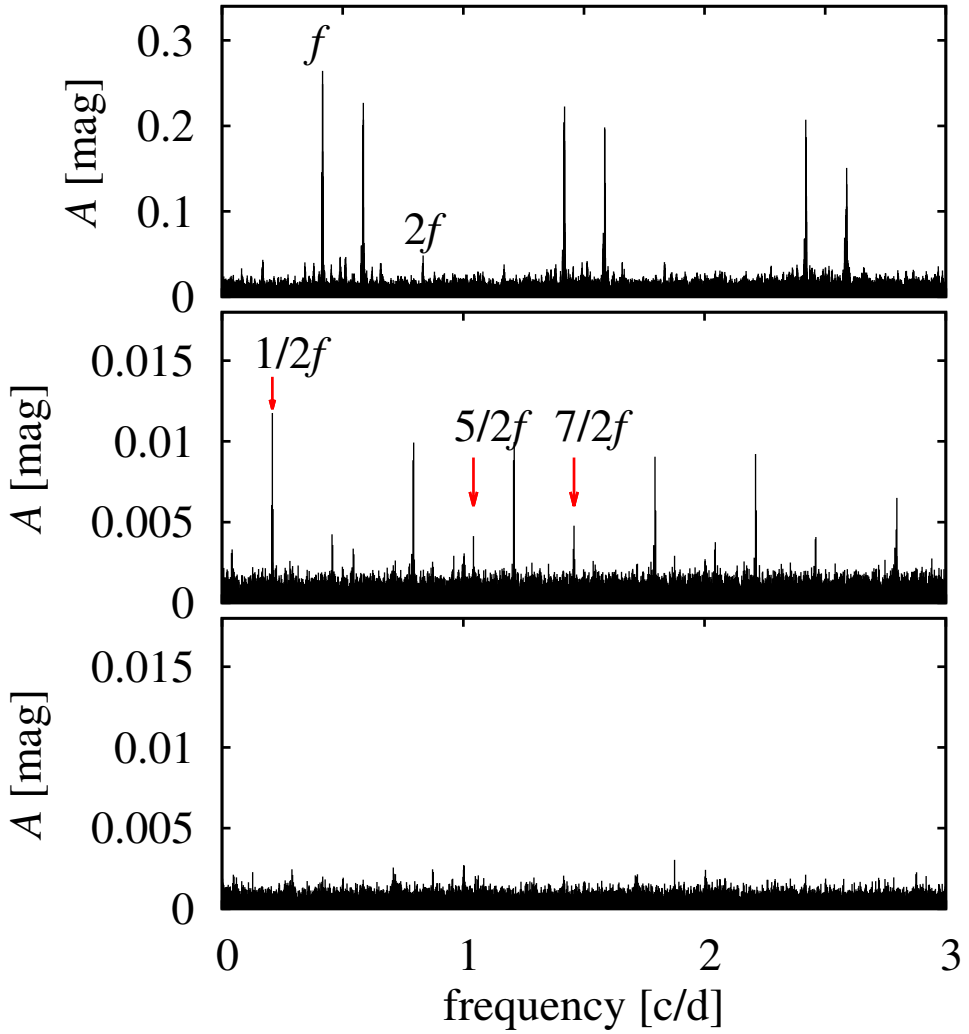
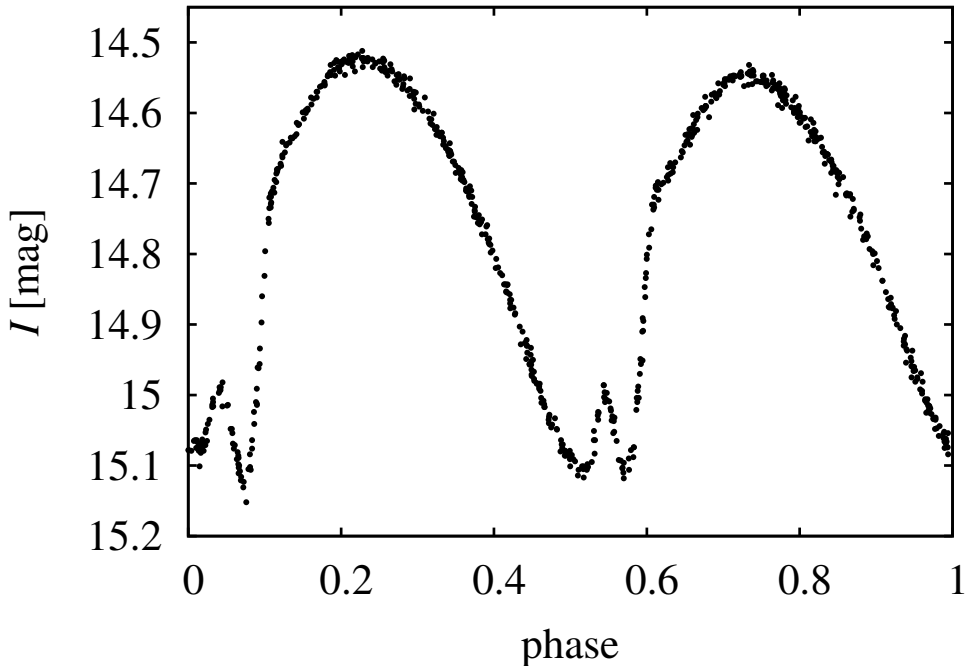
R. Smolec & P. Moskalik, *submitted to MNRAS*

Discovery of period doubling in BL Herculis stars of the OGLE survey. Observations and theoretical models

Smolec R., Soszyński I., Moskalik P. & OGLE, 2012, *MNRAS*, **419**, 2407.

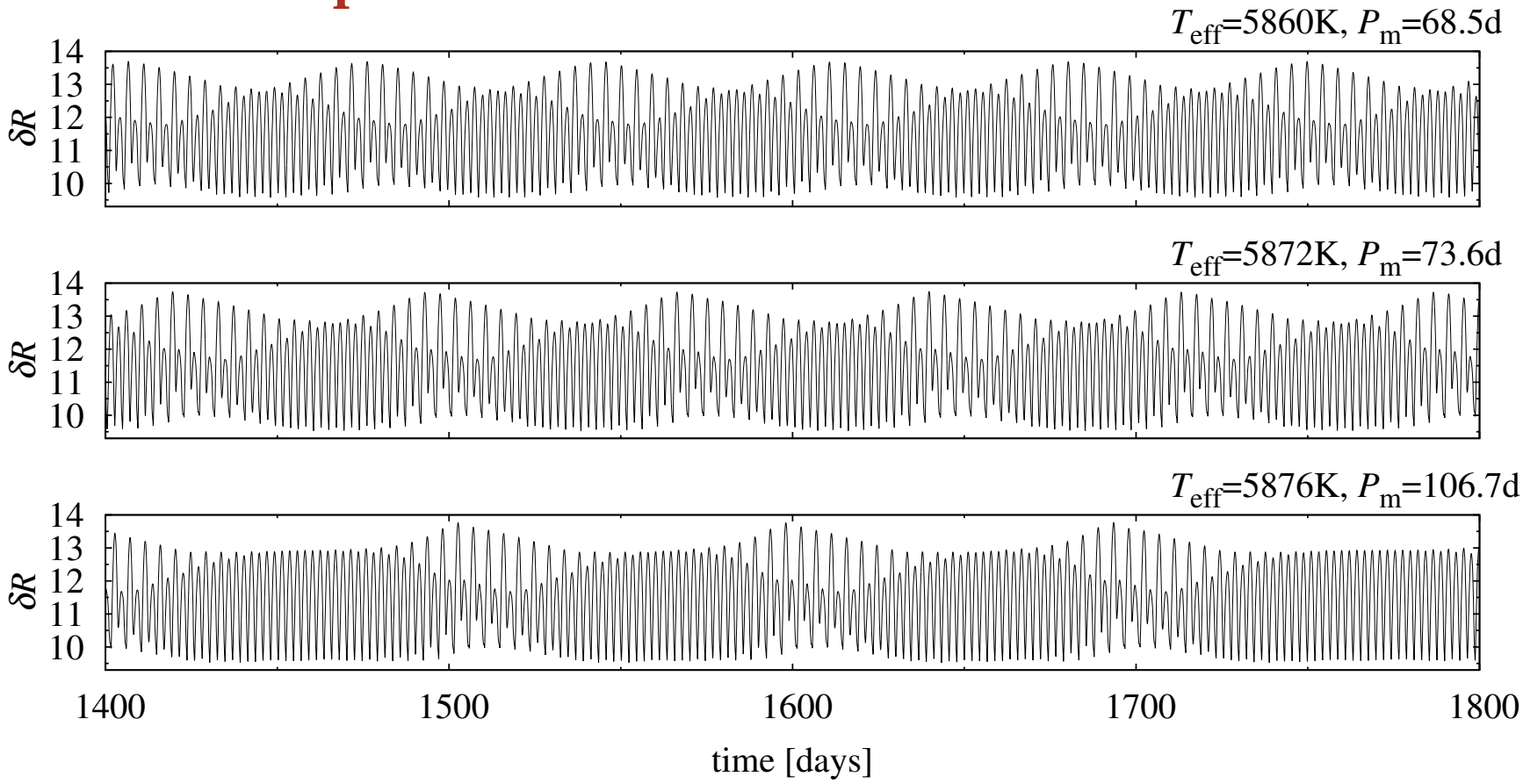




Period doubling in BL Her stars

- predicted to occur by radiative hydromodels of Buchler & Moskalik (1992)
- caused by the 3:2 resonance between the fundamental mode and first overtone, $3\omega_0 = 2\omega_1$
- well reproduced with hydromodels computed with nonlinear convective pulsation code of Smolec & Moskalik (2008)

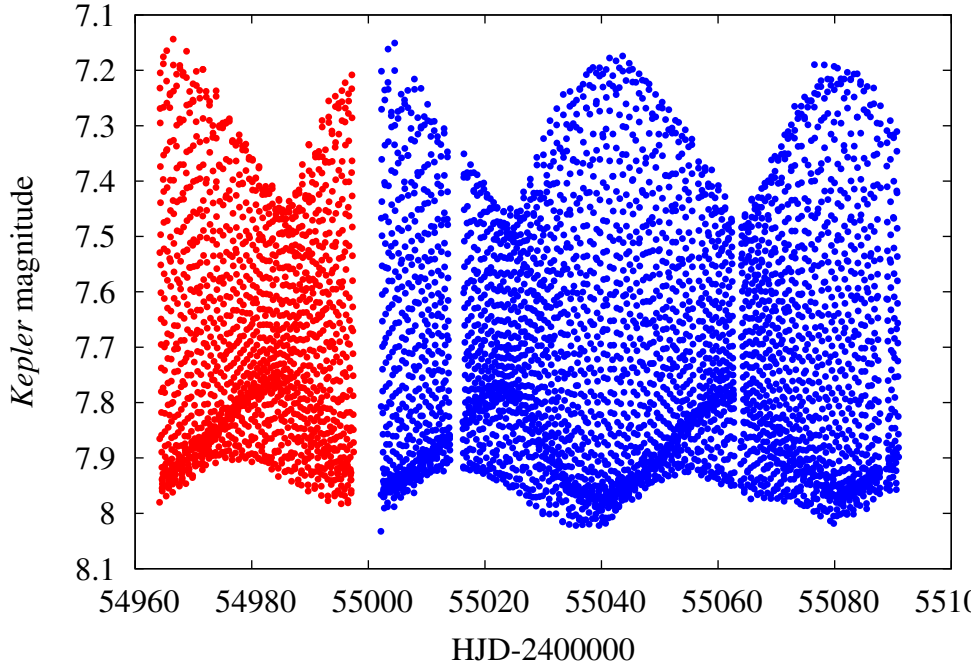
Modulation of pulsation in BL Her models



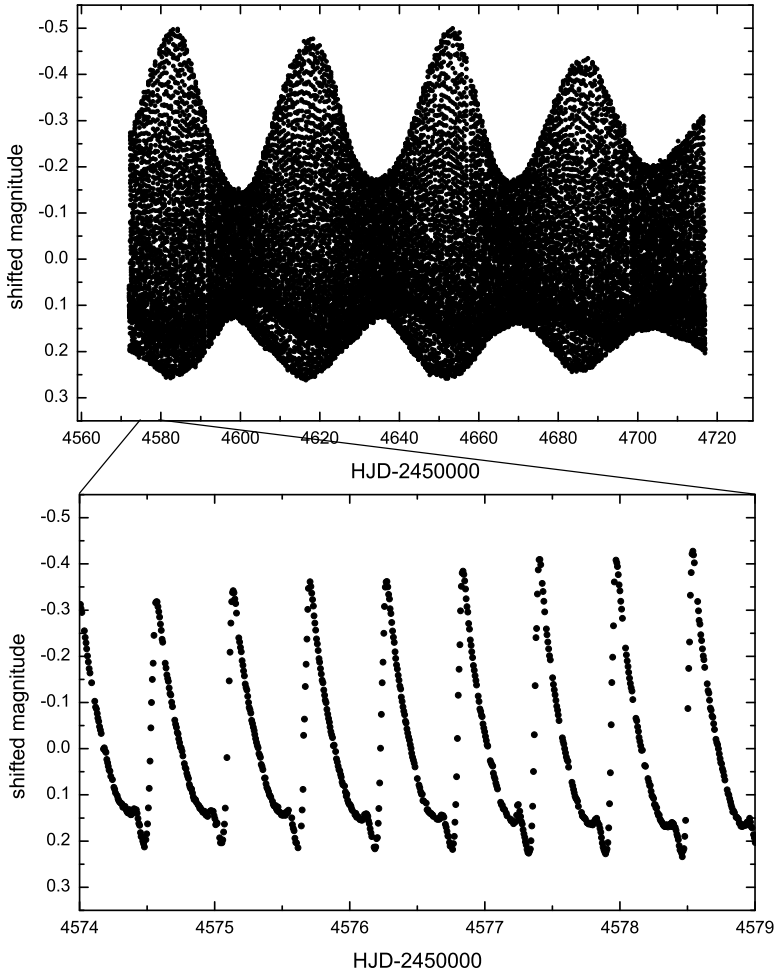
- strongly decreased eddy-viscosity
- not observed in any BL Her star
- **Why bother?**

Blazhko Effect in RR Lyrae stars

Amplitude and phase modulation on timescales of few to hundreds of pulsation period. Detected in nearly 50 per cent of RRab stars.

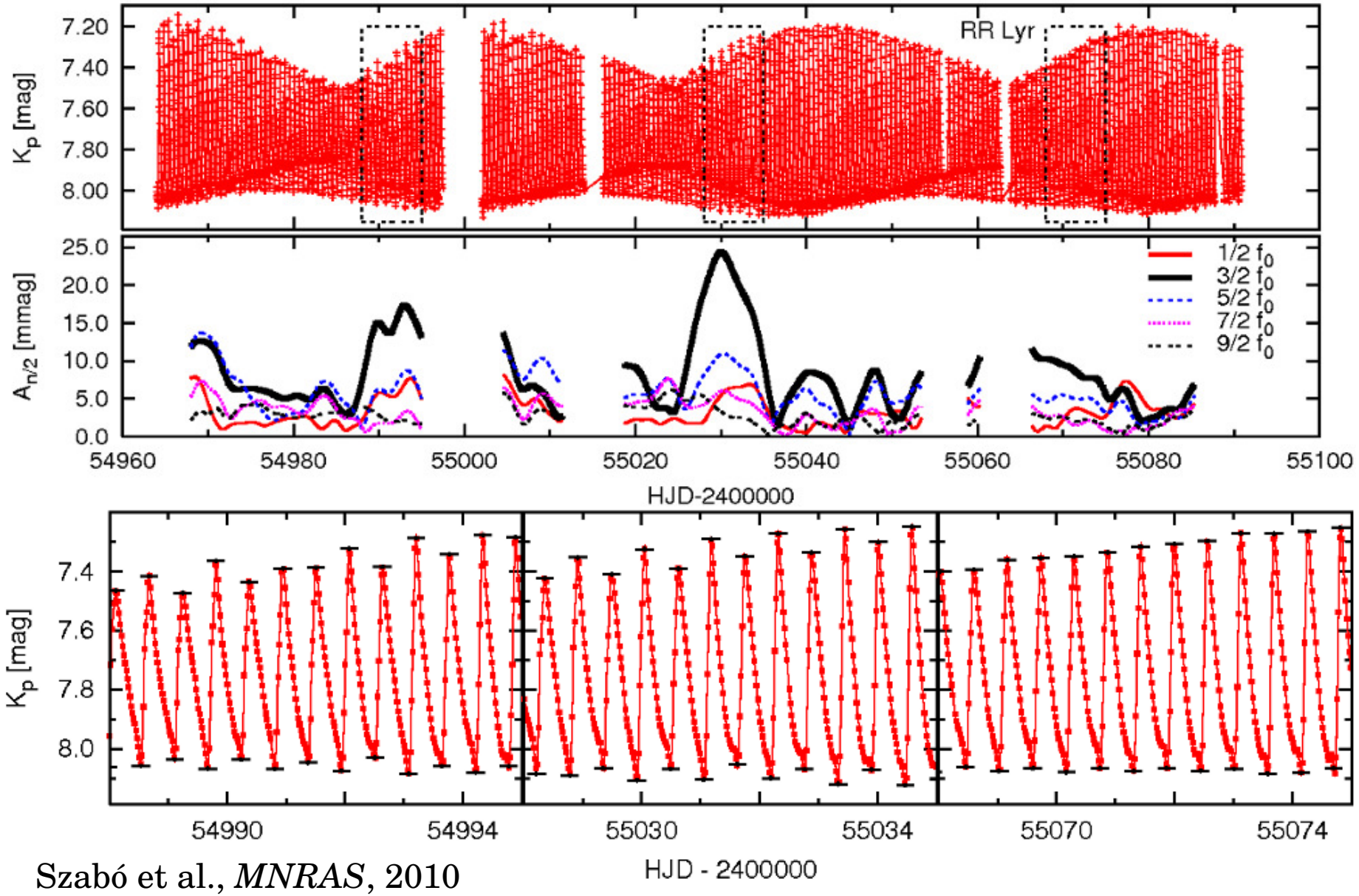


RR Lyr Kolenberg et al. (2011)



CoRoT ID 105288363 Guggenberger et al. (2011)

Blazhko Effect in RR Lyrae stars



Szabó et al., *MNRAS*, 2010

Period doubling a key to the Blazhko enigma?

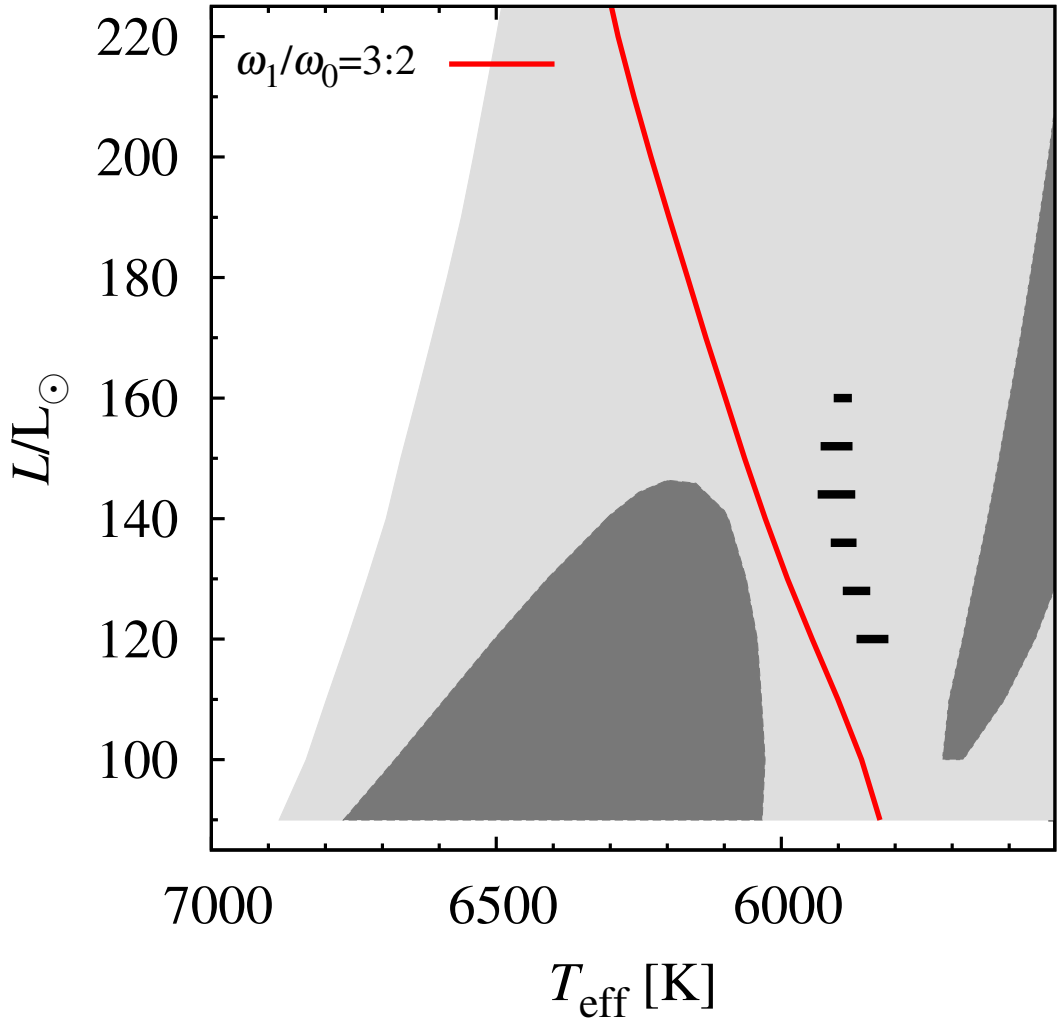
- period doubling caused by 9:2 resonance ($9\omega_0 = 2\omega_9$) in hydromodels (Kolláth, Molnár & Szabó 2011)
- 9:2 resonance: a cause or an effect? $\rightarrow$ hydromodels
  - we cannot reproduce the amplitude modulation in hydrodynamic models (only period doubling, Kolláth, Molnár & Szabó 2011), but
  - surface mode plays a dynamical role: simulations become particularly sensitive to the mixing length parameters, to the zoning and to the surface boundary condition, hence,
    - it might be difficult to make a trustworthy and robust simulations
- Amplitude equations

$$\dot{a} = \left(\gamma_a + q_{aa}a^2 + q_{ab}b^2\right)a + c_a a^{*8} b^2$$
$$\dot{b} = \left(\gamma_b + q_{bb}b^2 + q_{ba}a^2\right)b + c_b a^9 b^*$$

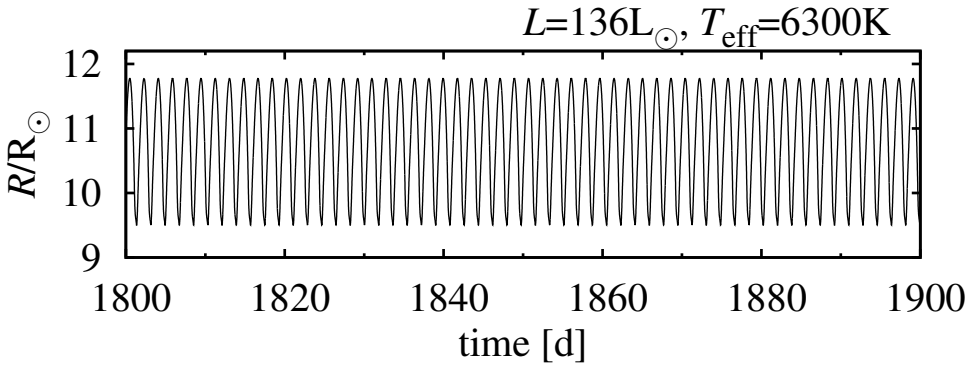
Parametric study by Buchler & Kolláth, *ApJ*, (2011)

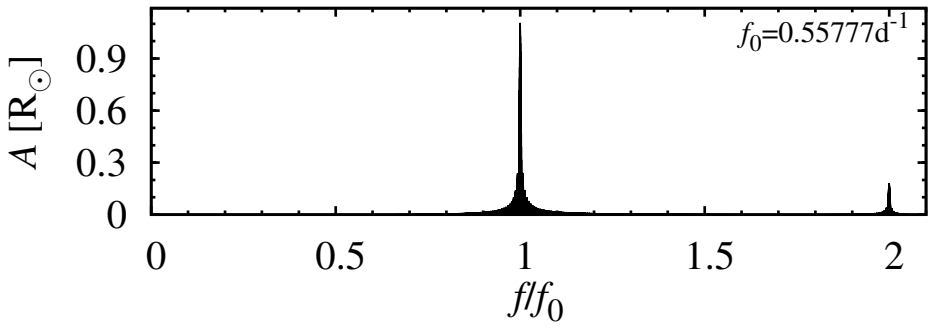
Hydrodynamic BL Her models with modulation of pulsation

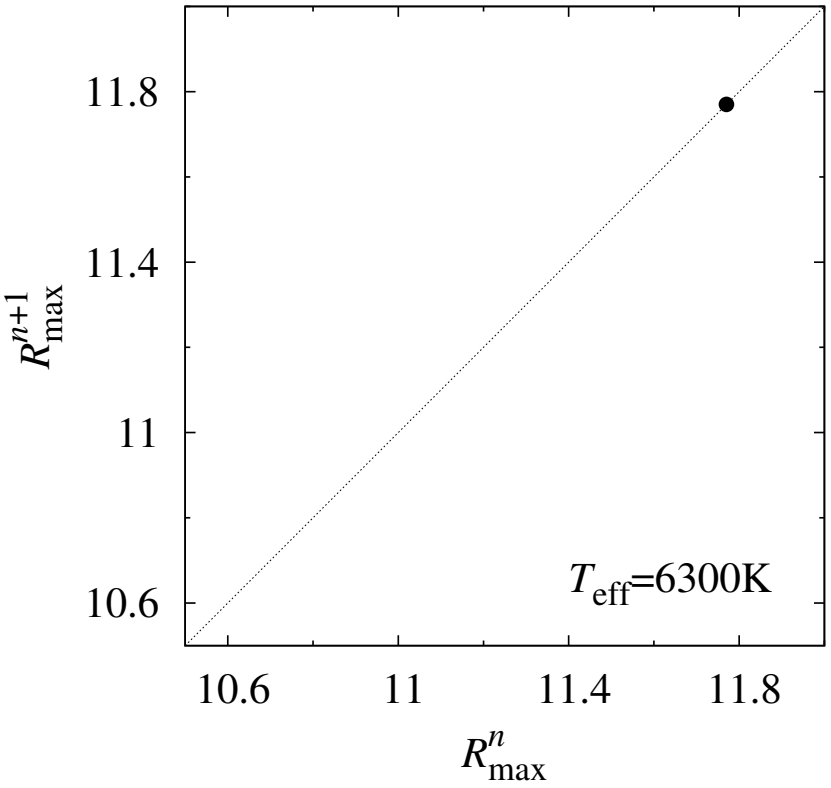
- all models with $M = 0.55\,\mathrm{M}_\odot$ and $Z = 0.0001$
- six stripes of constant luminosity, $L = 120\,\mathrm{L}_\odot$, $128\,\mathrm{L}_\odot$, $136\,\mathrm{L}_\odot$, $144\,\mathrm{L}_\odot$, $152\,\mathrm{L}_\odot$, $160\,\mathrm{L}_\odot$



Hydrodynamic BL Her models: single periodic pulsation

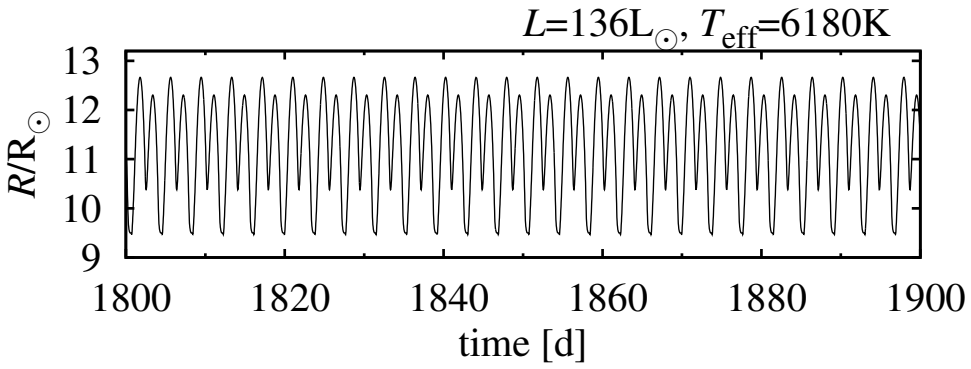


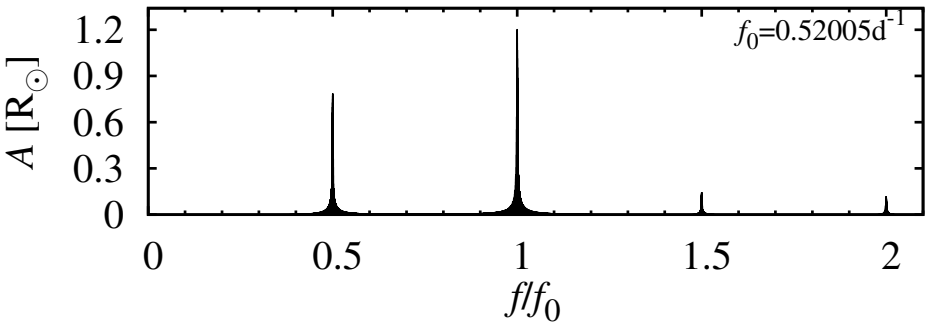


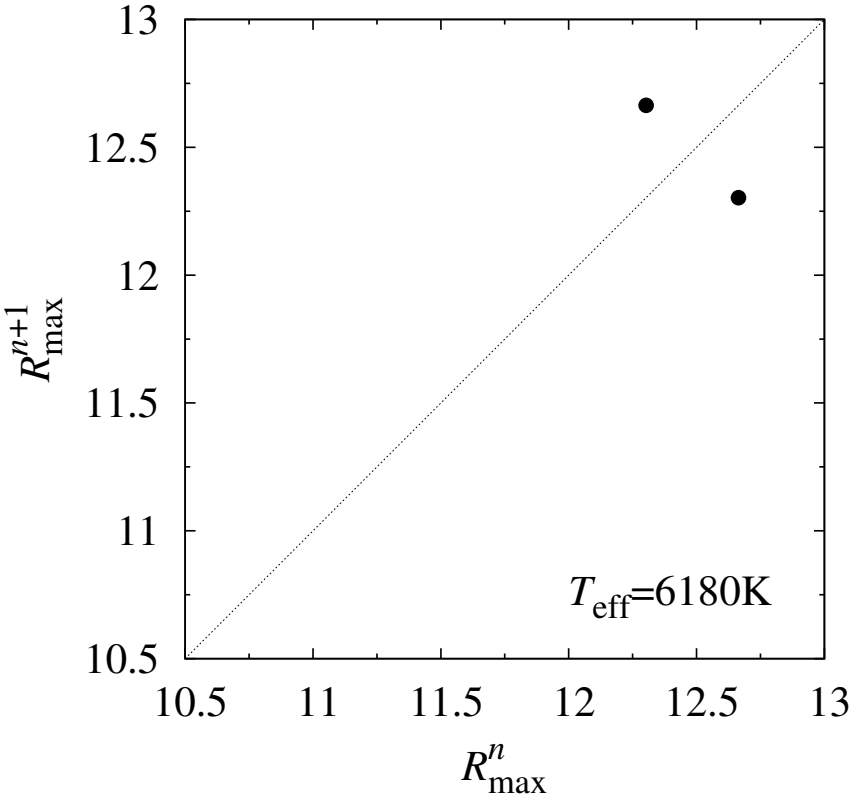


- **return map:** one point
- **Fourier spectrum:** f_0, harmonics

Hydrodynamic BL Her models: period doubled pulsation

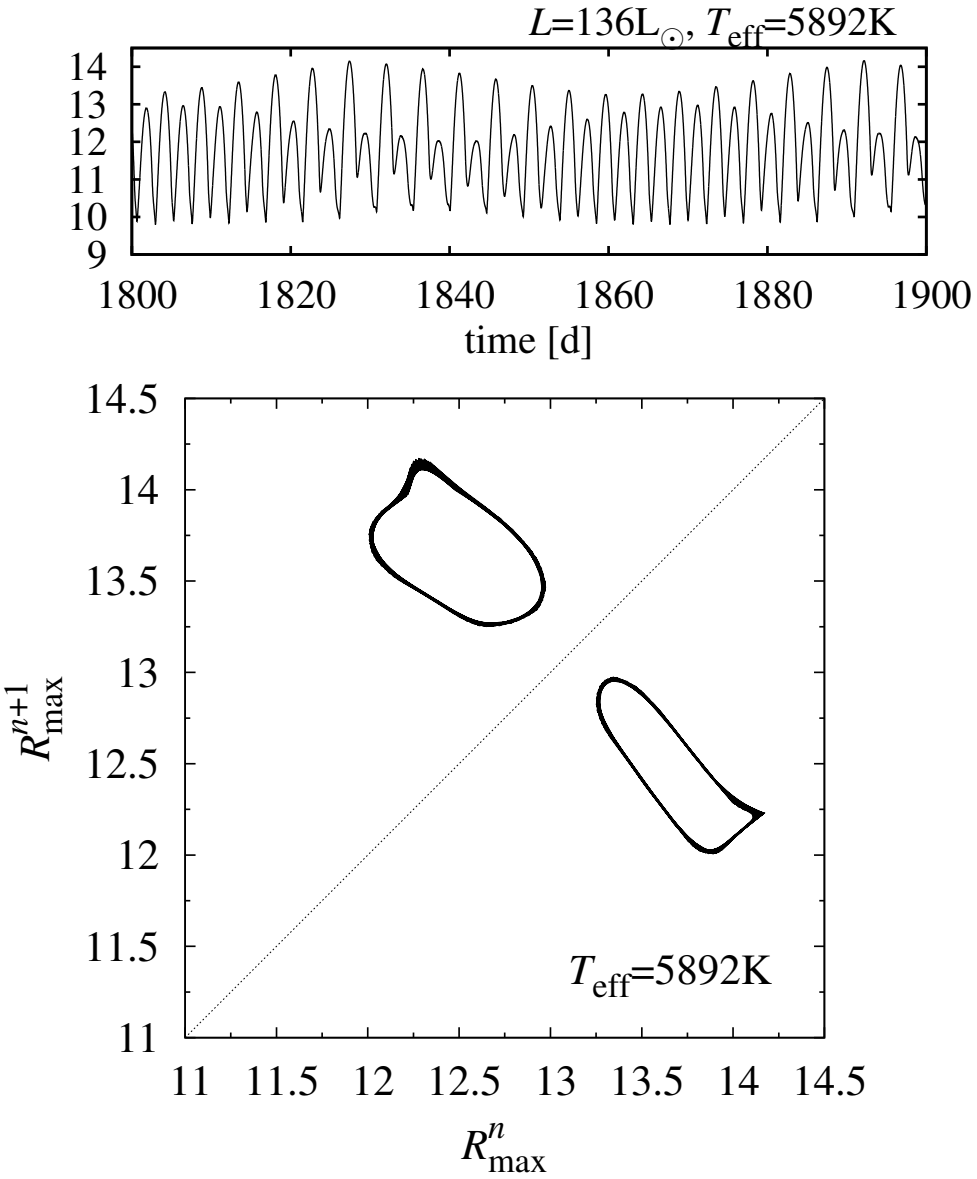


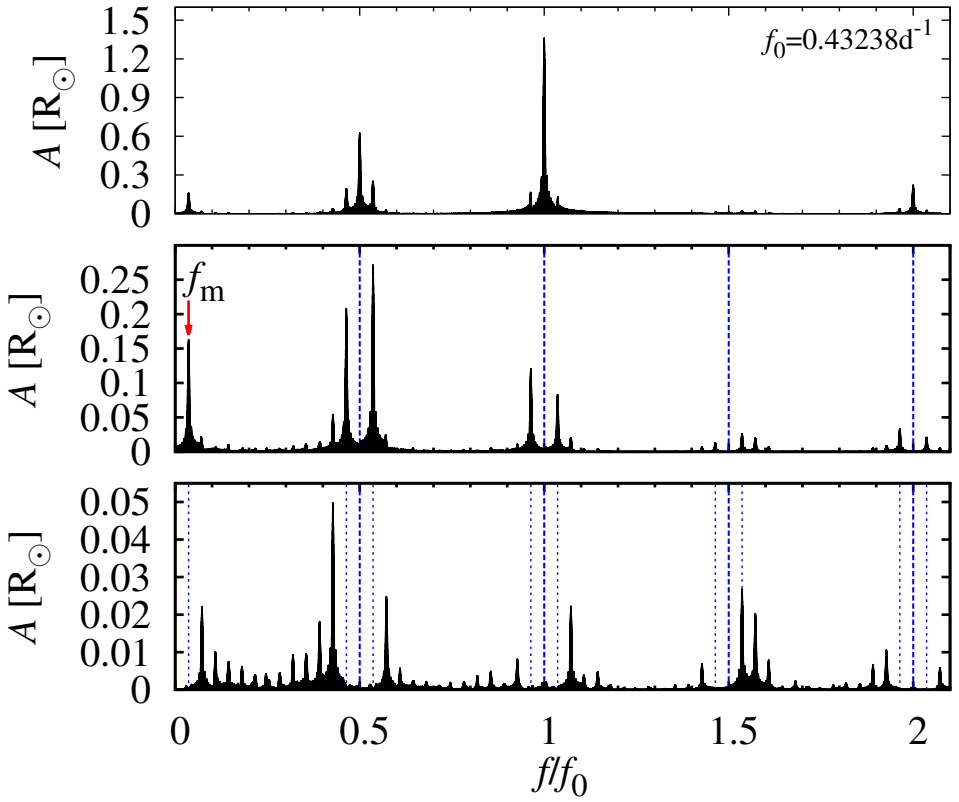




- **return map:** two points
- **Fourier spectrum:** f_0, harmonics, subharmonics

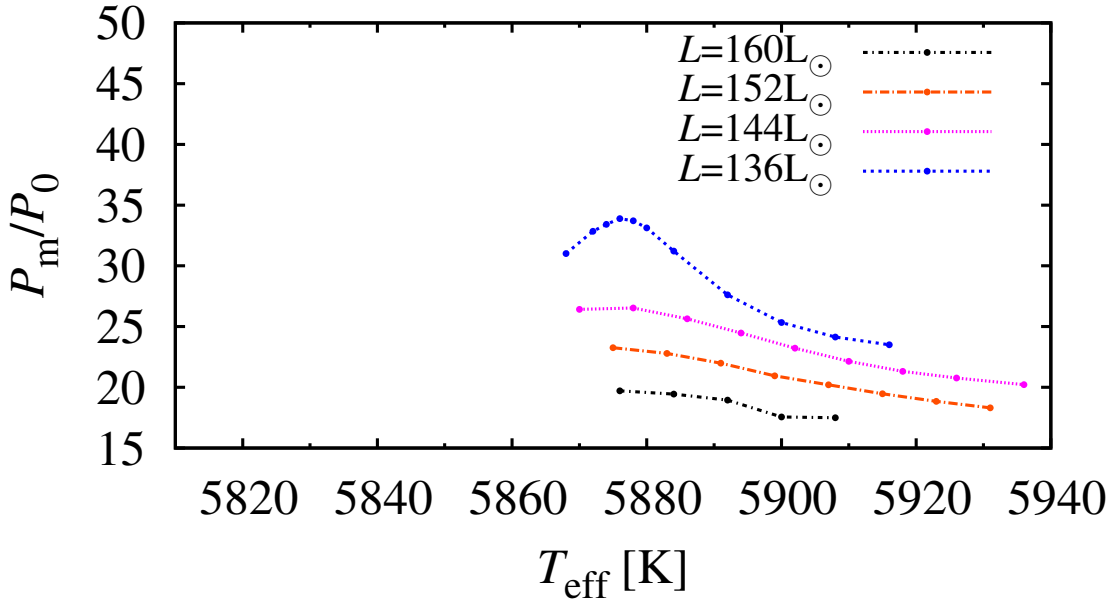
Hydrodynamic BL Her models: strictly periodic modulation

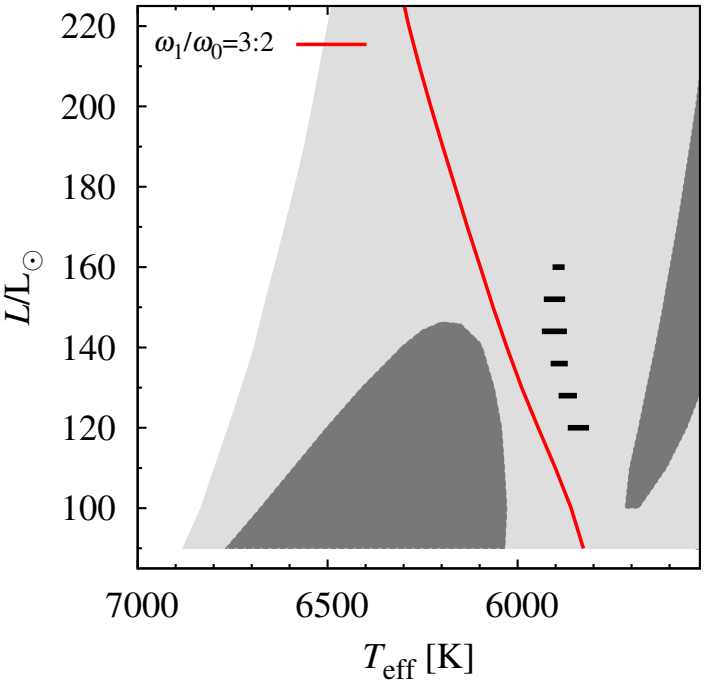


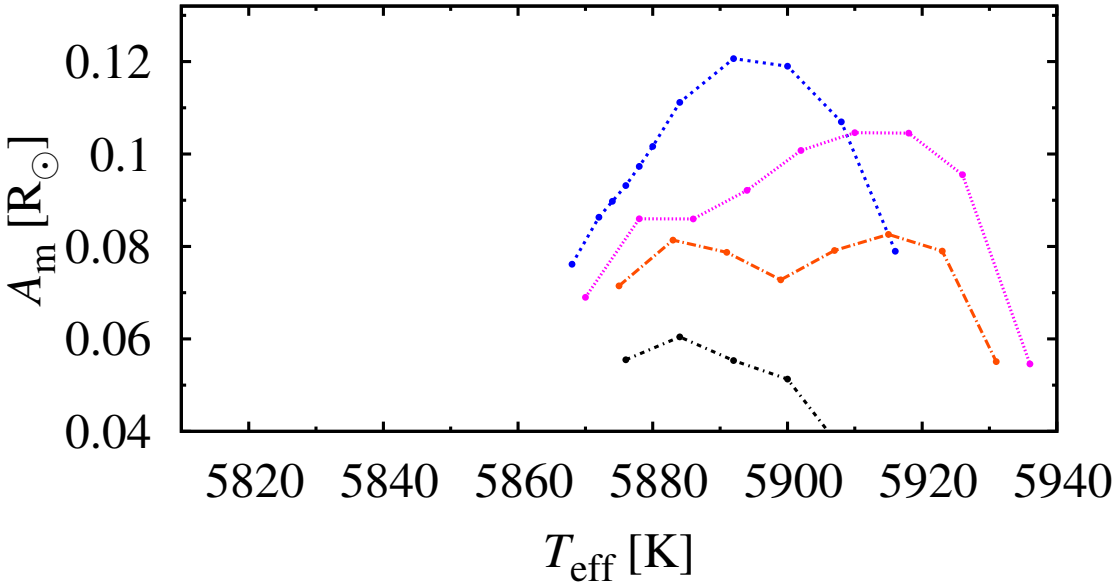


- **return map:** two loops
- **Fourier spectrum:** f_0, harmonics, subharmonics, modulation multiplets

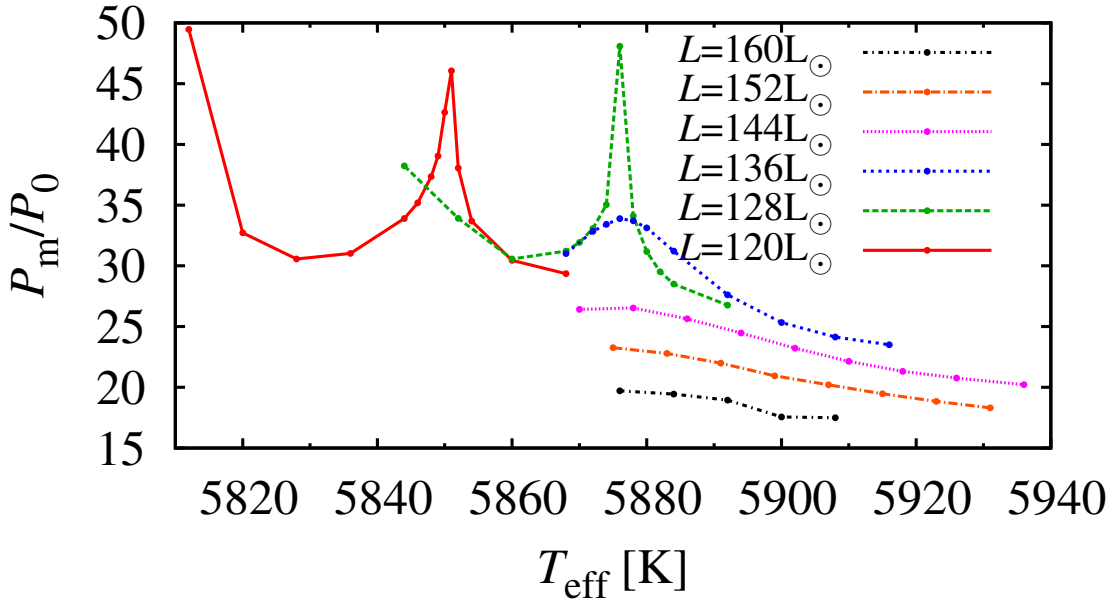
Hydrodynamic BL Her models: strictly periodic modulation

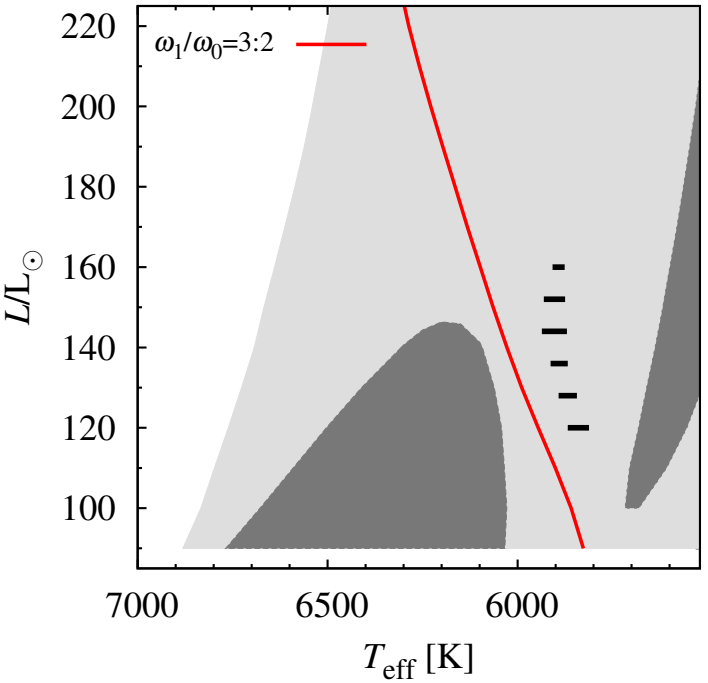


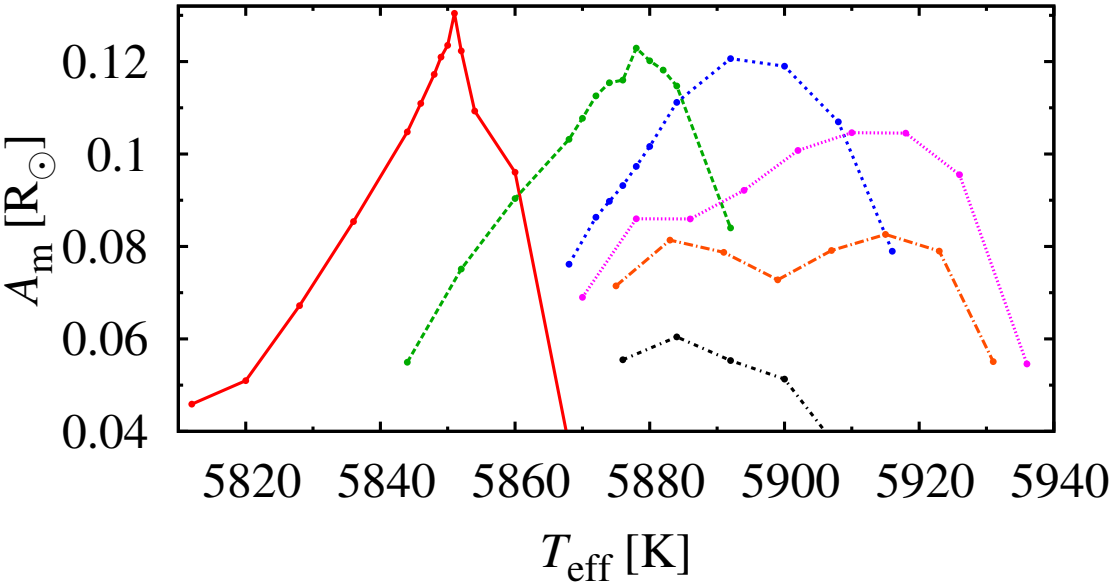




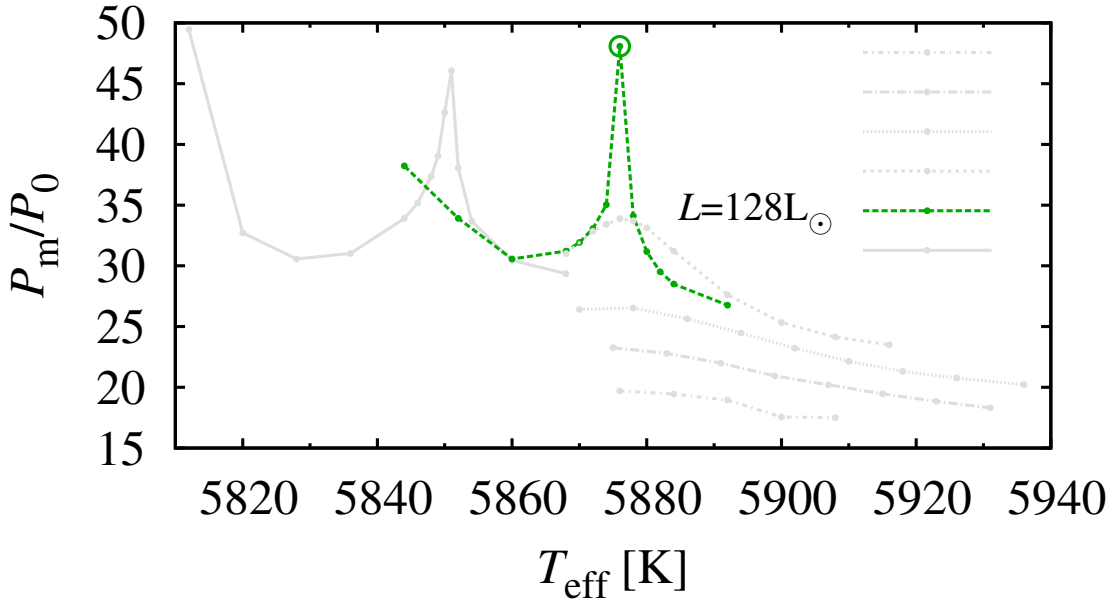
Hydrodynamic BL Her models: strictly periodic modulation

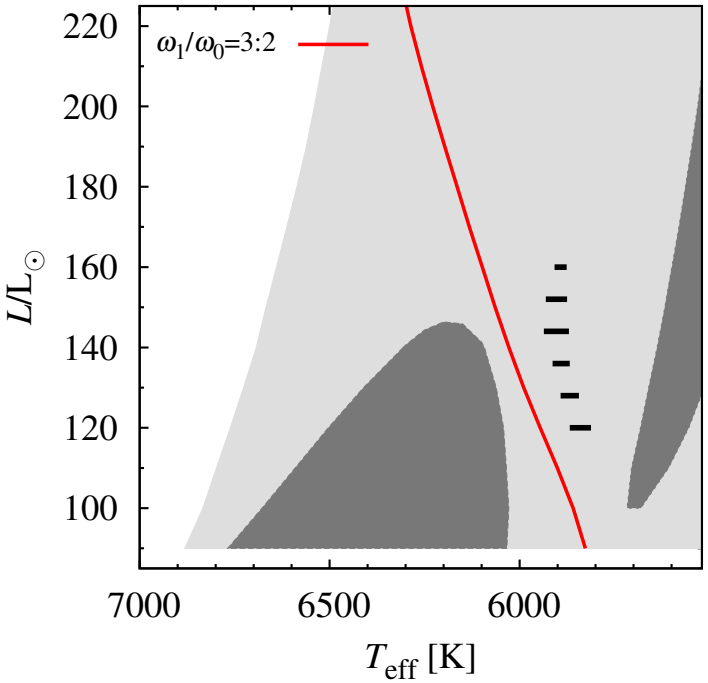


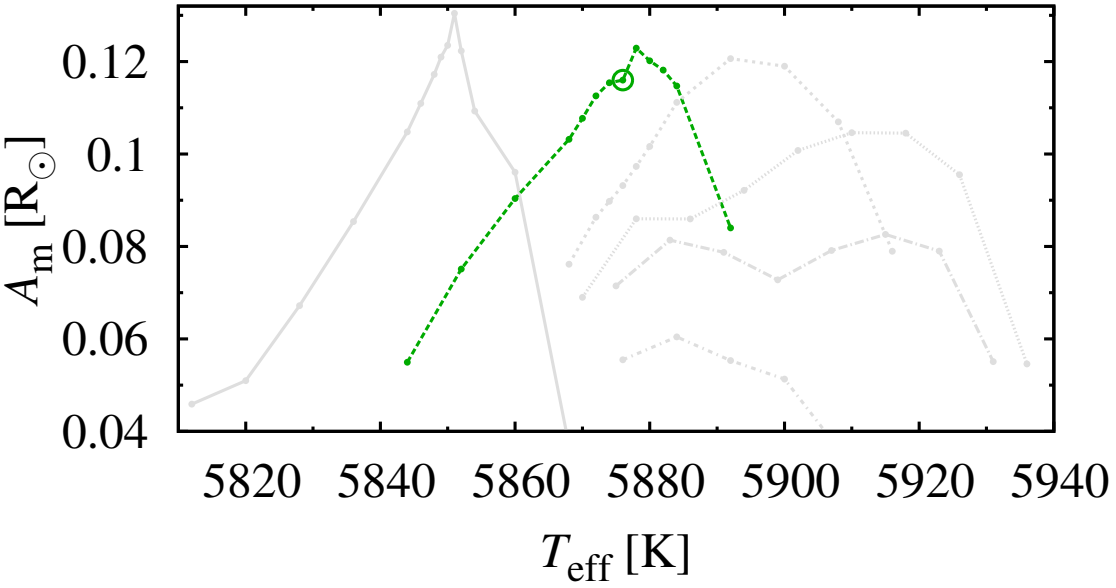




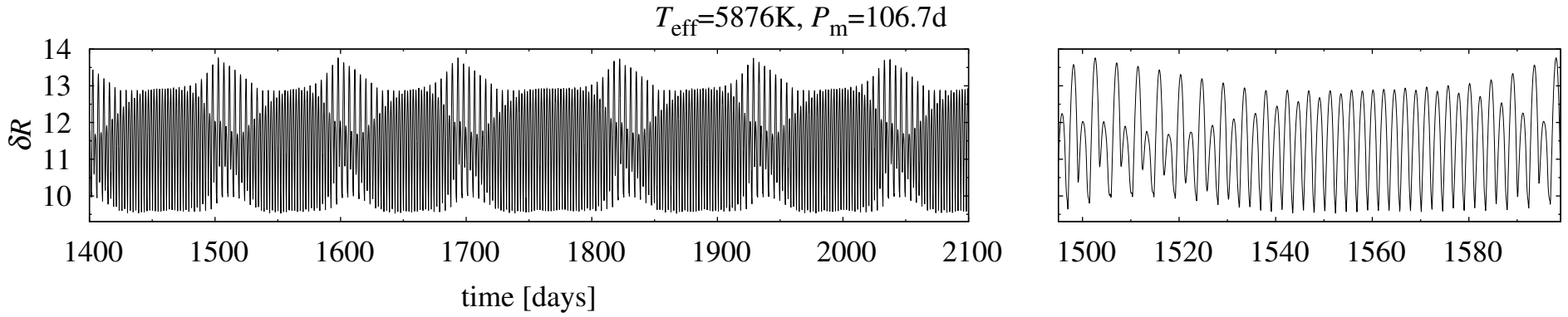
Hydrodynamic BL Her models: strictly periodic modulation

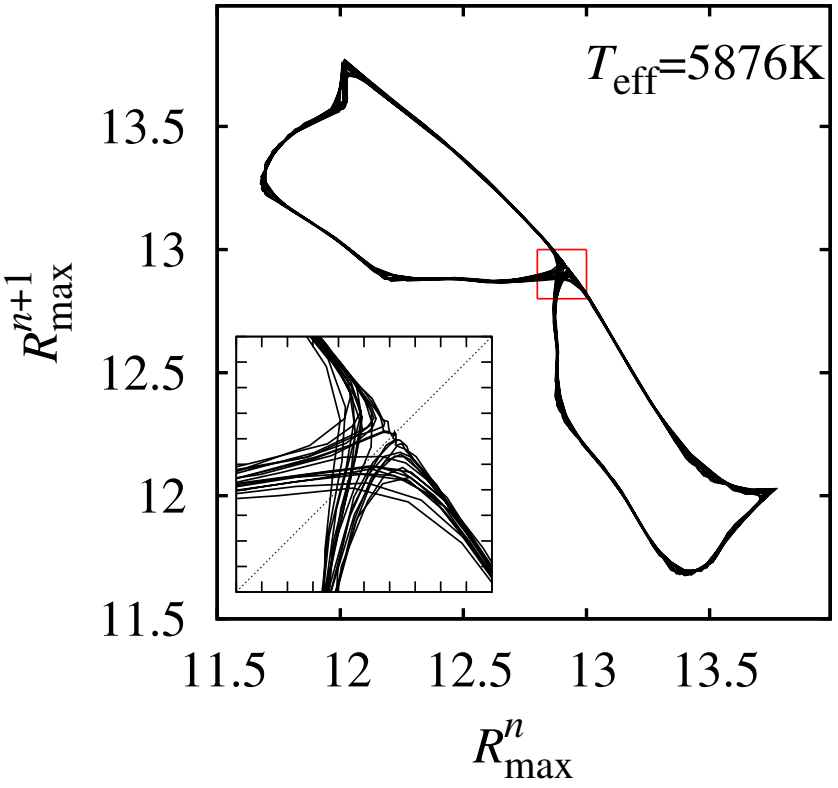


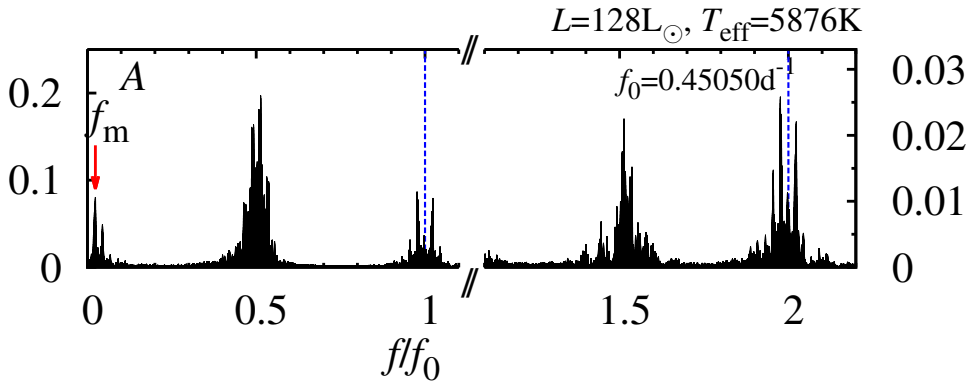




Hydrodynamic BL Her models: quasi-periodic modulation







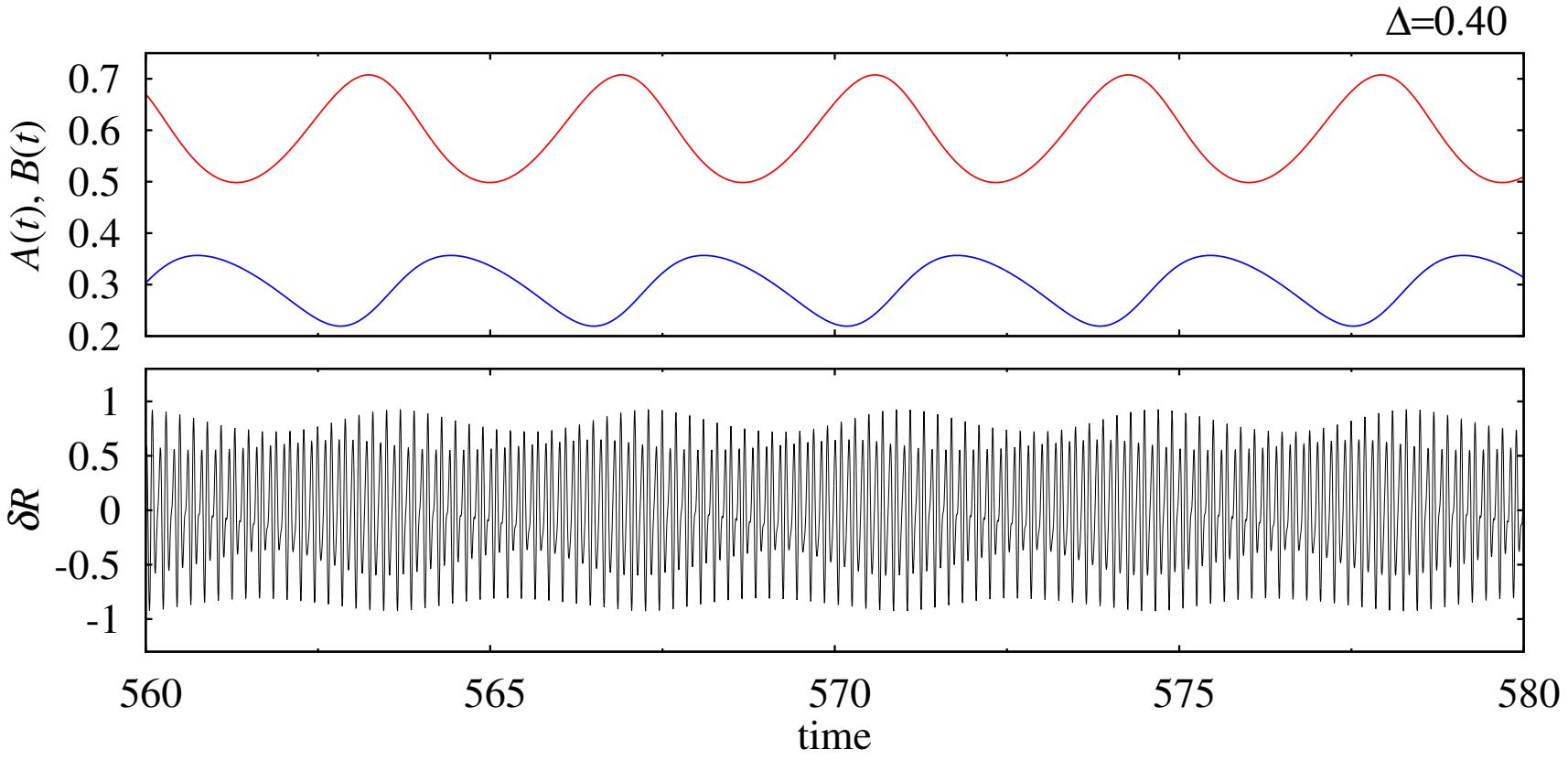
- consecutive modulation cycles differ
- ∼multiplet at f_0 and harmonics, $1/f_{\rm m}$ – mean modulation period
- incoherent signal at subharmonic freq.

Amplitude equations

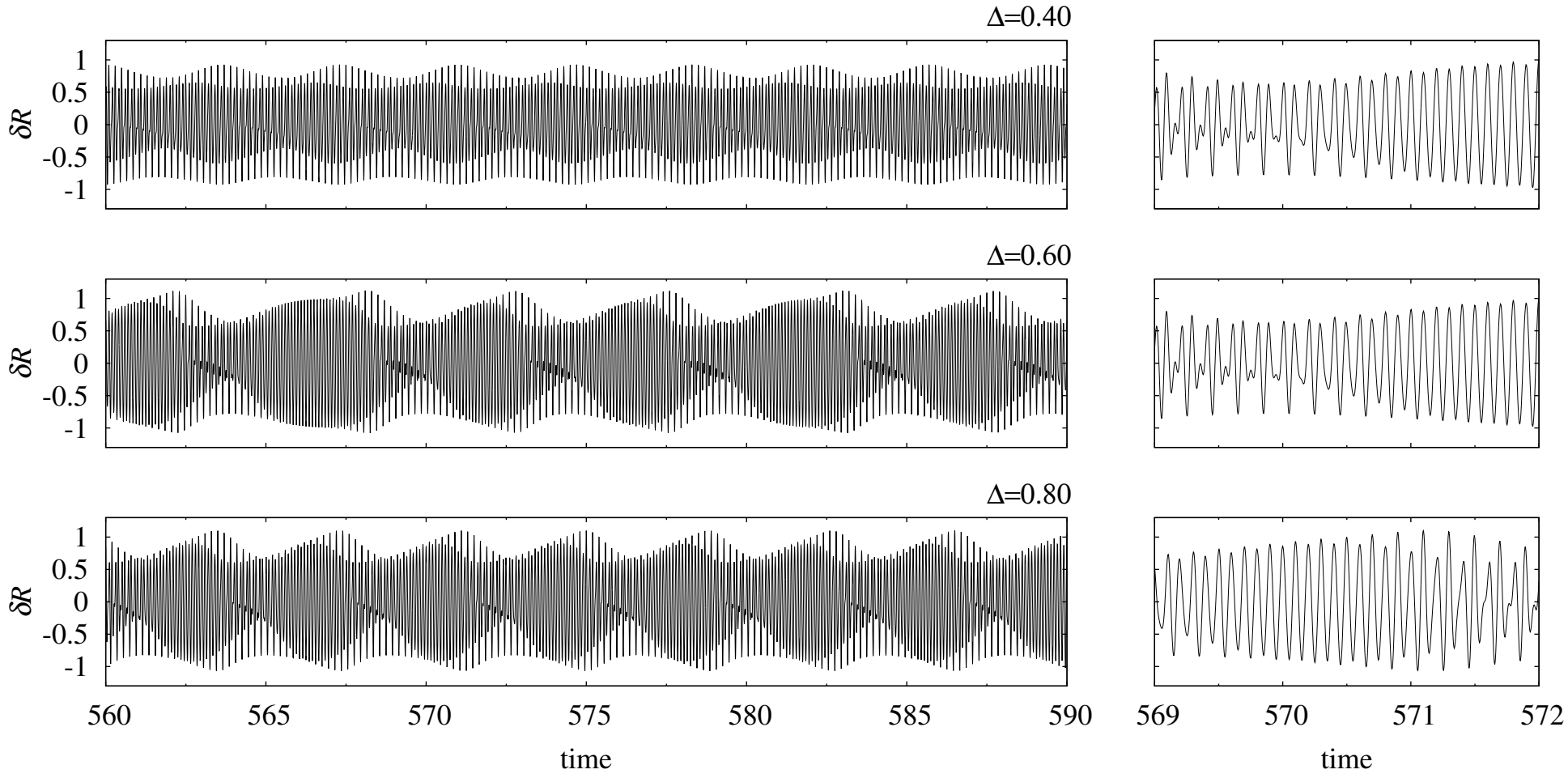
$$\dot{a} = \left(\gamma_a + q_{aa}a^2 + q_{ab}b^2\right)a + c_a a^{*2}b^2$$
$$\dot{b} = \left(\gamma_b + q_{bb}b^2 + q_{ba}a^2\right)b + c_b a^3 b^*$$

$$\delta R(t) = A\mathrm{e}^{\mathrm{i}\omega_a t} + B\mathrm{e}^{\mathrm{i}(\Gamma/2)}\mathrm{e}^{\mathrm{i}(3/2)\omega_a t} + \mathrm{h.o.t.}$$

Amplitudes, $A(t)$ and $B(t)$, and radius reconstruction for $\Delta = 0.4$



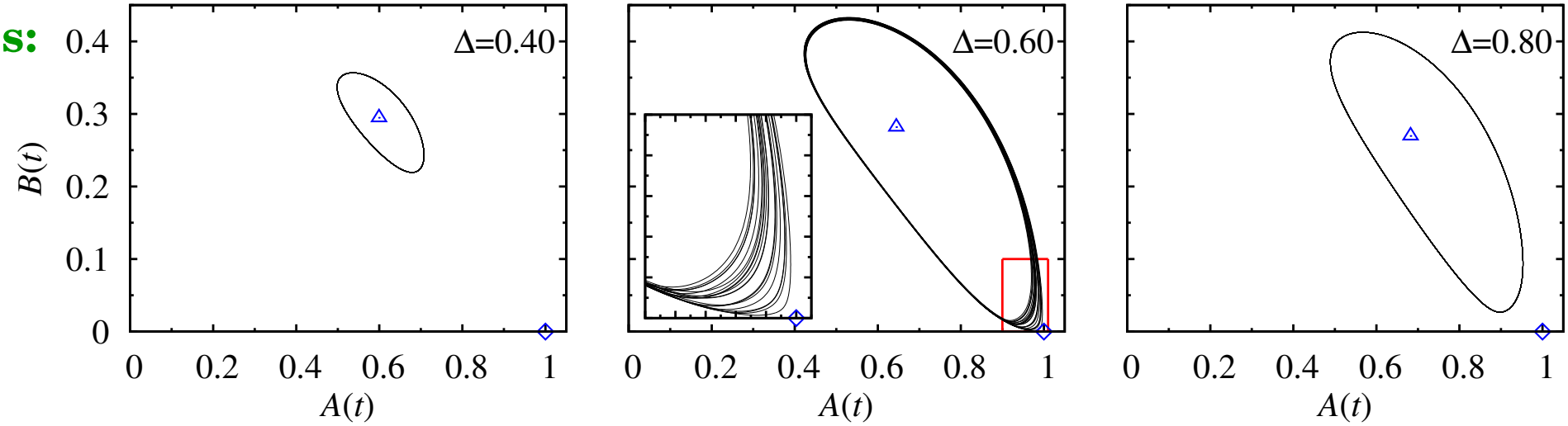
Amplitude equations: radius variation



- periodic modulation for $\Delta = 0.4$ and $\Delta = 0.8$
- quasi-periodic modulation for $\Delta = 0.6$

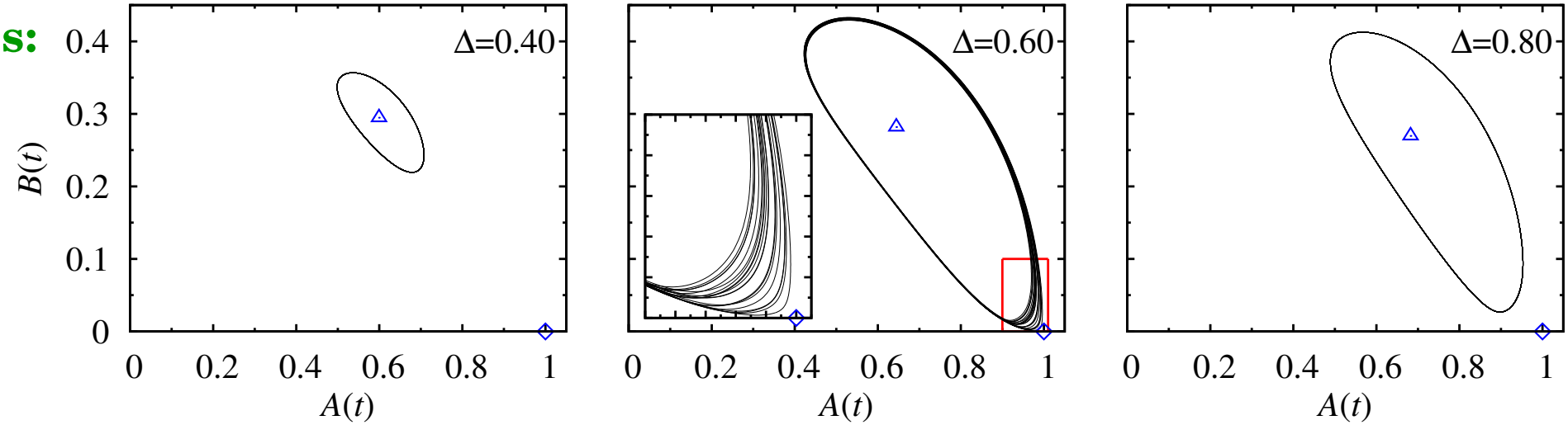
Amplitude equations: phase plots

AEs:



Amplitude equations: phase plots

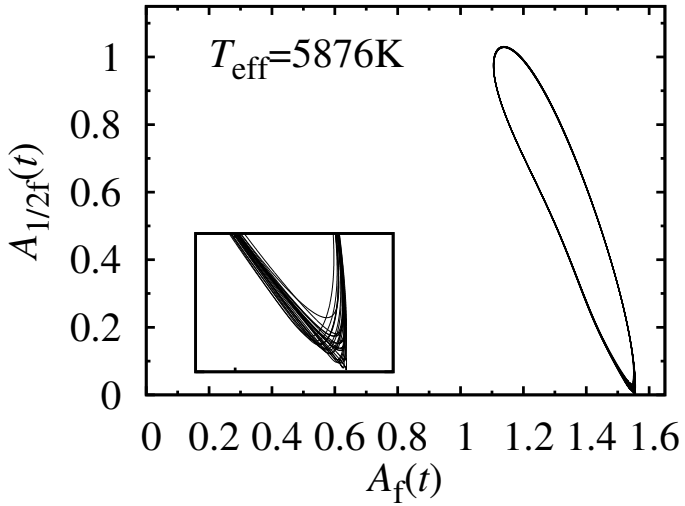
AEs:



hydro:

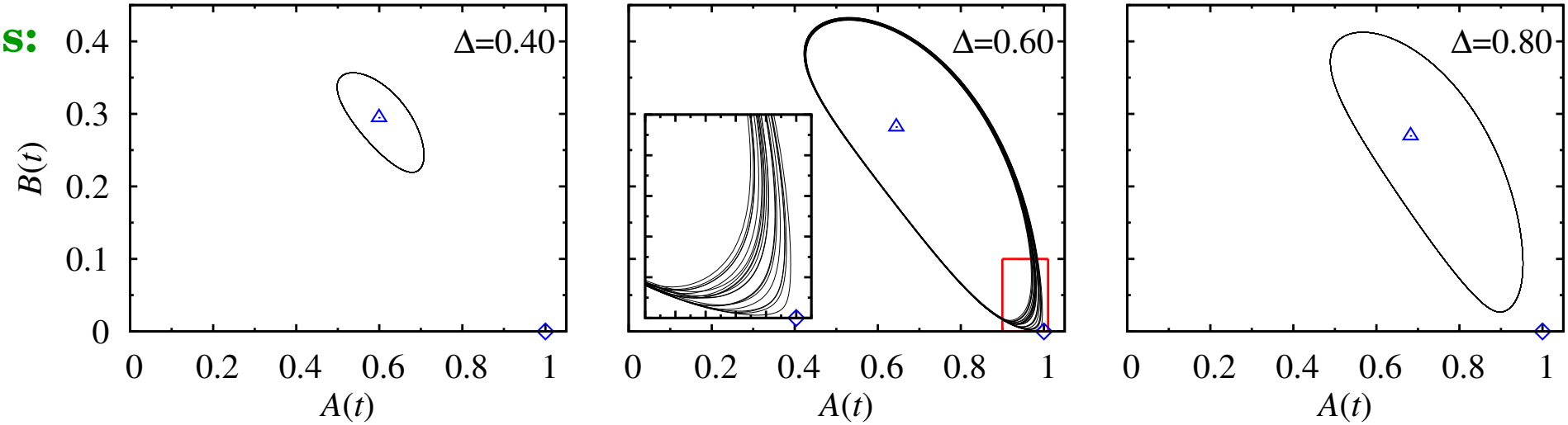
(analytic signal method,

e.g. Kolláth et al. 1998)



Amplitude equations: phase plots

AEs:



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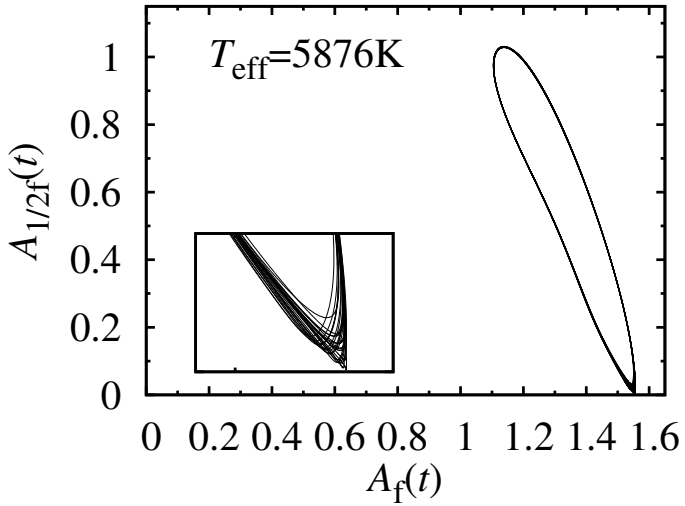
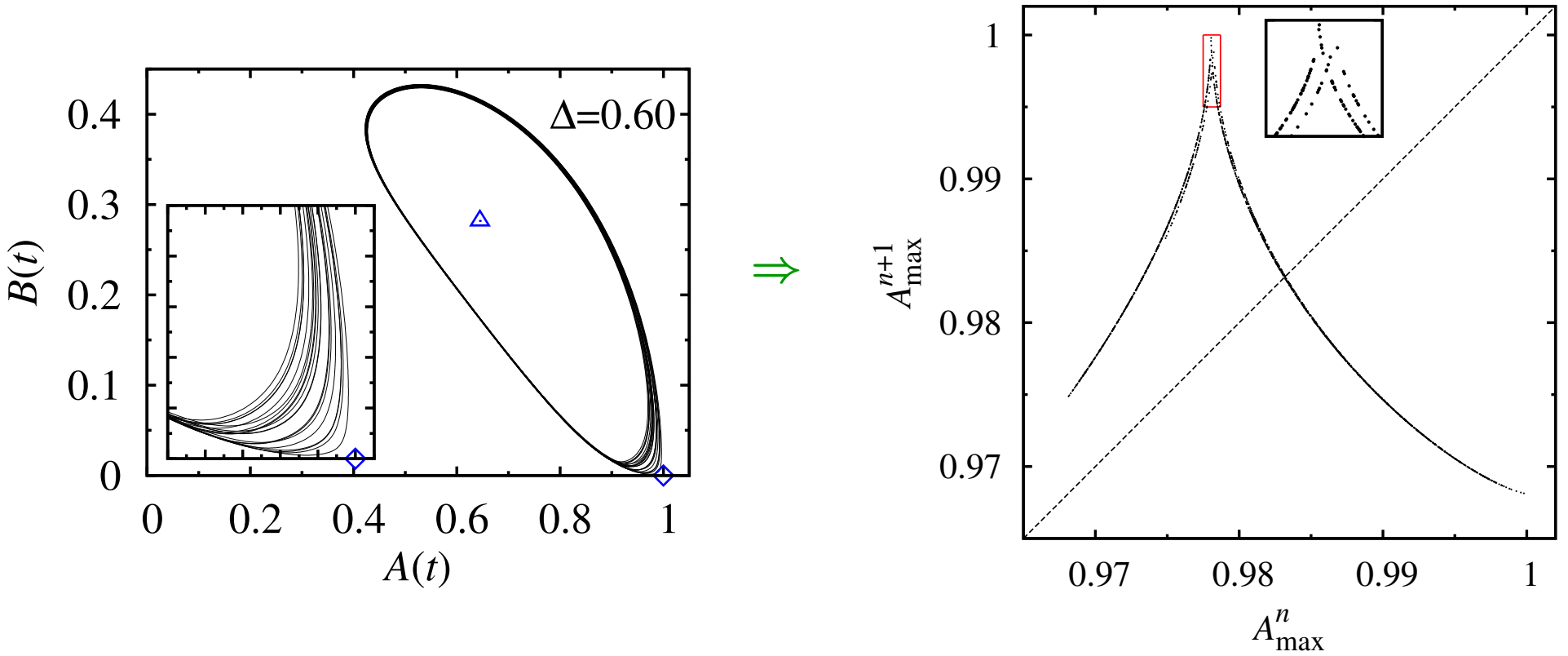


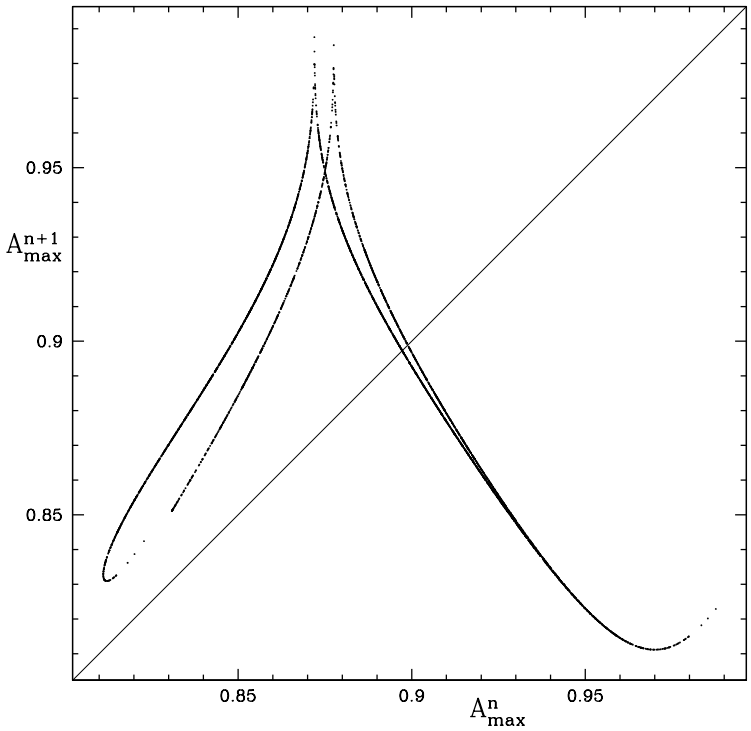
Is it multiperiodic or chaotic behaviour?

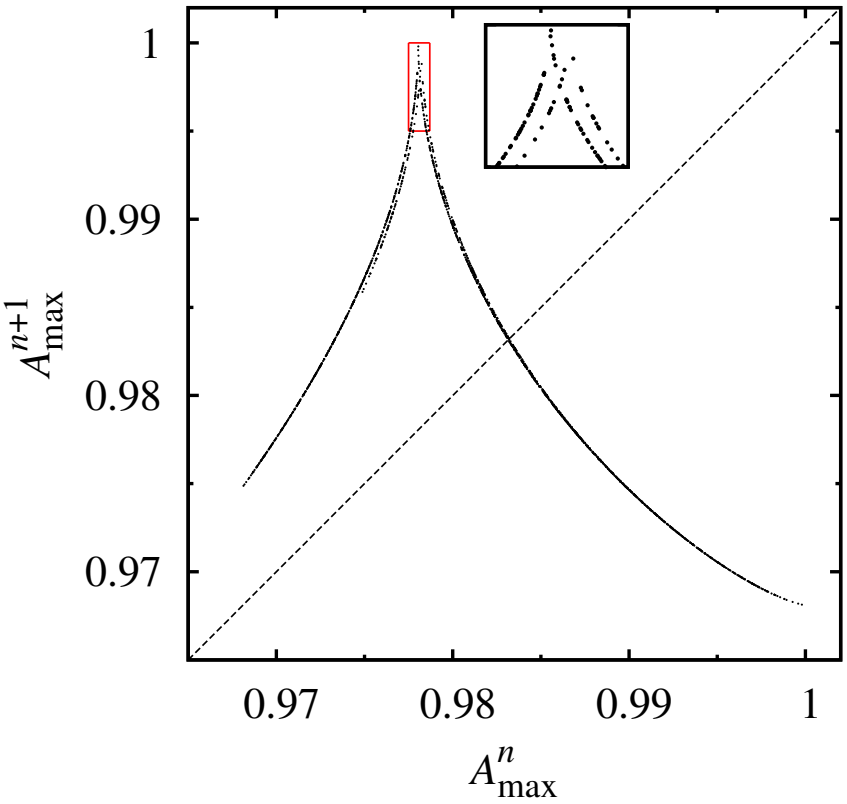
Amplitude equations: phase plots



- chaotic attractor (tent-like structure akin to Lorentz attractor)

Amplitude equations: phase plots





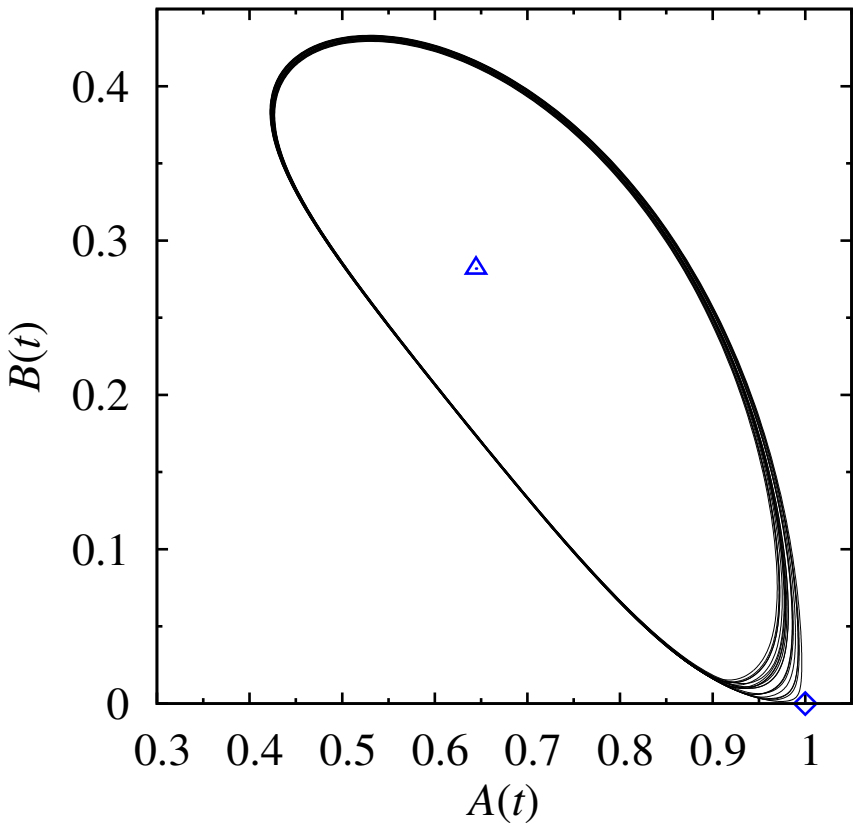
9:2 (RR Lyr)

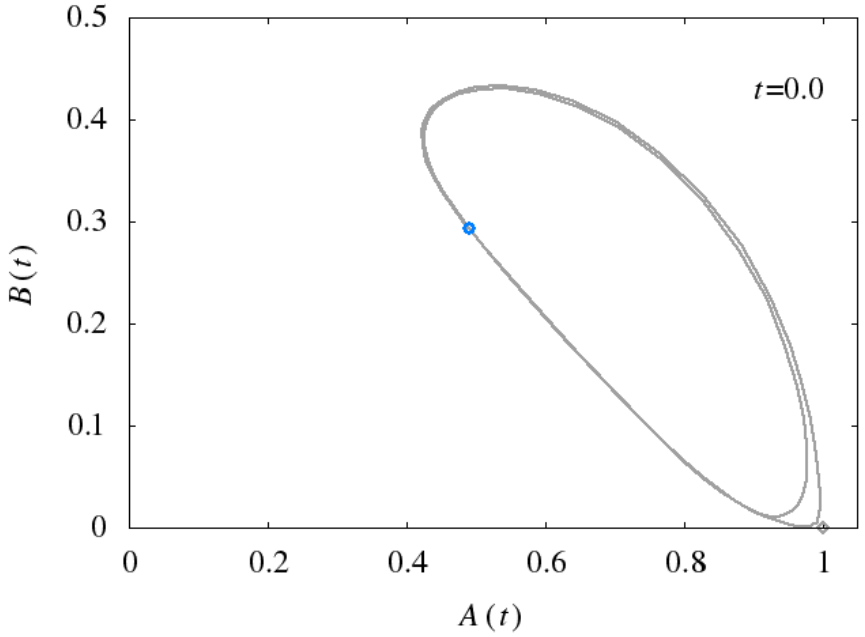
Buchler & Kolláth (2011)

3:2 (BL Her)

- chaotic attractor (tent-like structure akin to Lorentz attractor)
- dynamics of the 3:2 (BL Her) and 9:2 (RR Lyr) resonances is very similar

Amplitude equations: modulation period





- closer to saddle slower the evolution
- modulation period and irregularities depend on the distance to saddle point

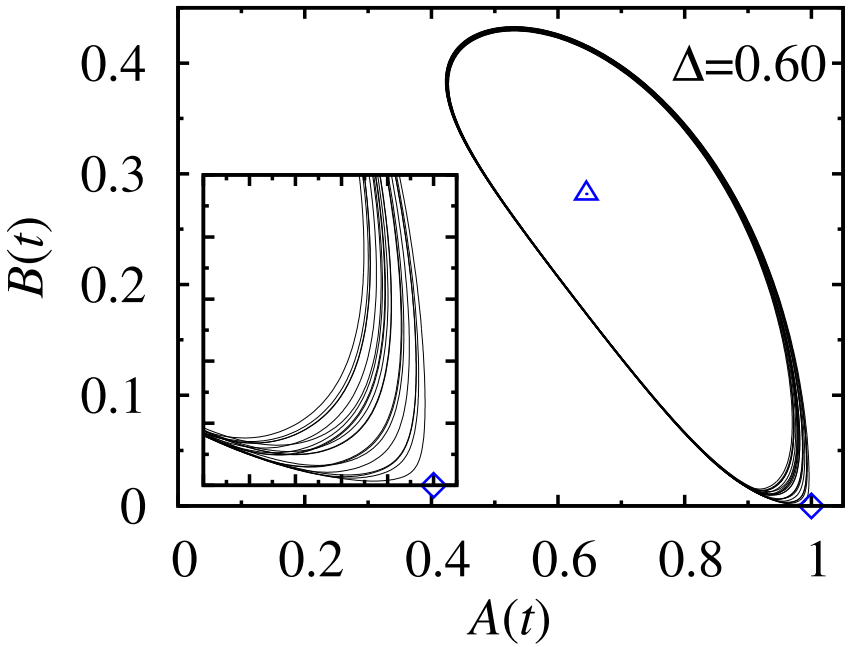
Discussion: implications for Blazhko effect in RR Lyrae stars

- radial resonance mechanism works in hydrodynamic models of BL Her stars – higher luminosity siblings of RR Lyr stars
- dynamics of the 3:2 (BL Her) and 9:2 (RR Lyr) resonances is very similar
- both periodic and irregular (chaotic) modulation present in the models
- reasonable modulation periods and amplitudes
- onset of chaotic behaviour at the vicinity of unstable single-mode fixed point (saddle)

Discussion: implications for Blazhko effect in RR Lyrae stars

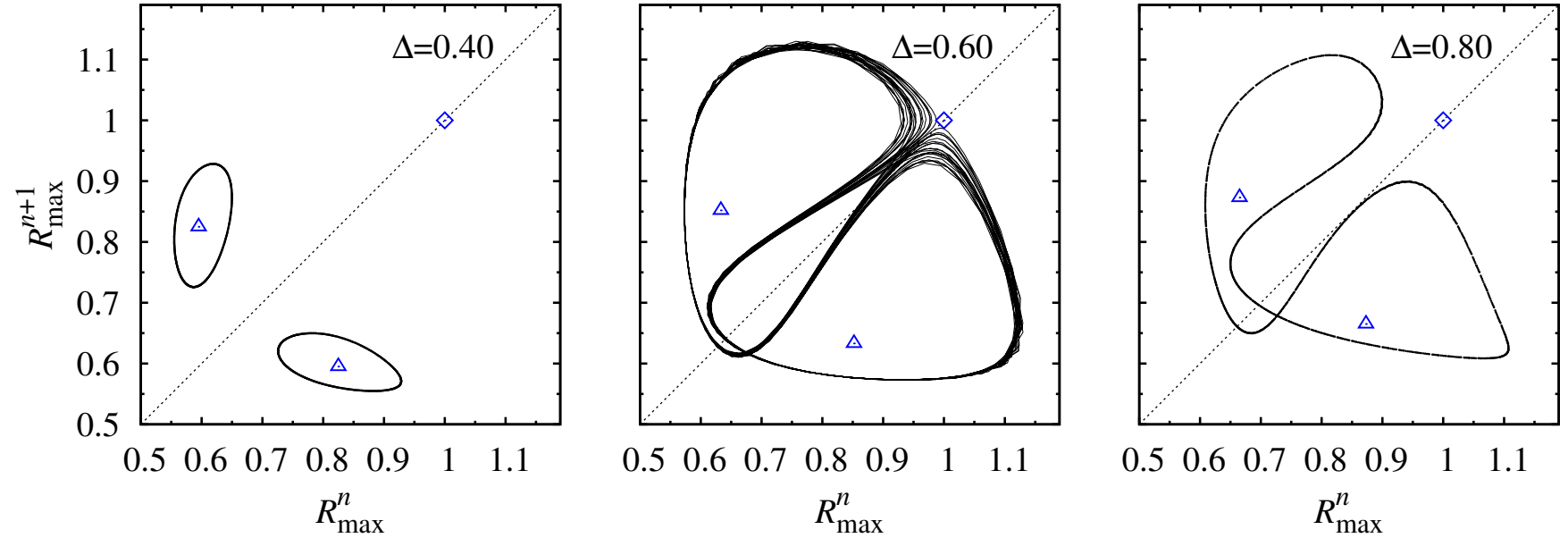
Challenges:

- period doubling is always very strong, while it is rather weak in Blazhko RR Lyr stars (and in several stars the effect is not detected)
- two modulation periods – additional resonance?
- nearly 50 per cent of the RRab stars display Blazhko effect – is one resonance enough?



Amplitude equations: return maps

AEs:



hydro: