Variable turbulent convection as the cause of the Blazhko effect – testing the Stothers model

Radosław Smolec[1], Paweł Moskalik[2] & Katrien Kolenberg[1]

[1]Institute of Astronomy, University of Vienna

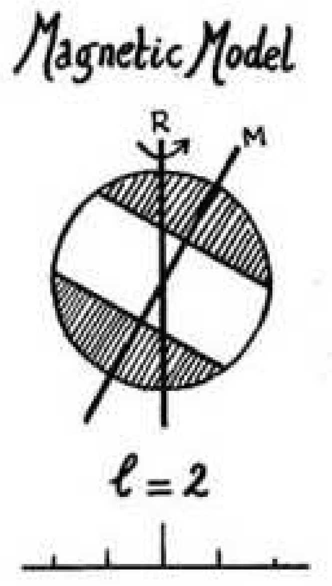
[2]Nicolaus Copernicus Astronomical Center, Warsaw, Poland

institut für astronomie
UNIVERSITÄTSSTERNWARTE WIEN

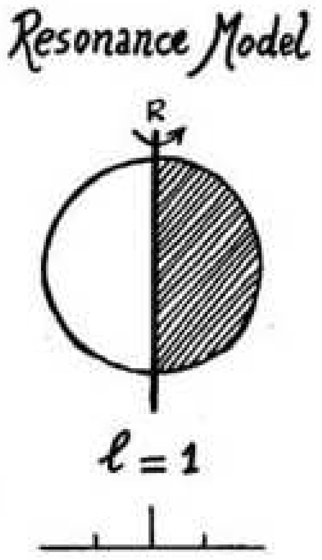
Polish Academy of Sciences
Nicolaus Copernicus
Astronomical Center

Models to explain the Blazhko effect:

Oblique magnetic model (e.g. Shibahashi 2000)



- radial mode deformed by the magnetic field
- additional $l = 2$ component with symmetry axis coinciding with the magnetic axis
- star's rotation causes the amplitude modulation
- quintuplets in the frequency spectra

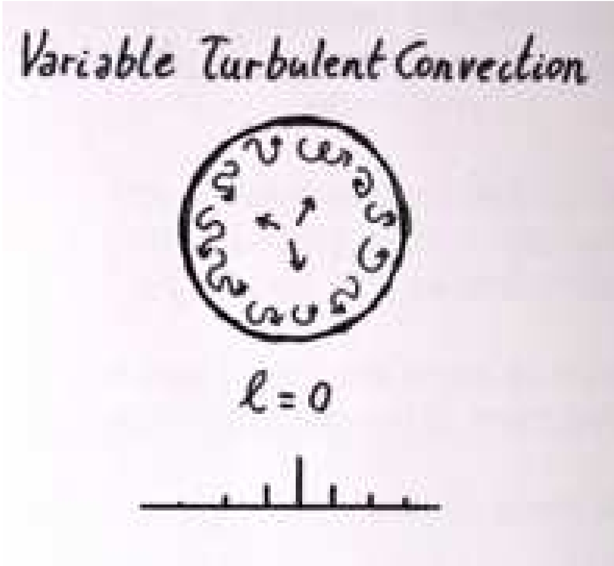


Resonance model (e.g. Dziembowski & Mizerski 2004)

- resonance between the radial mode and non-radial mode of low l ($l = 1$)
- rotationally split $m = \pm 1$ modes
- triplets in frequency spectra

Models to explain the Blazhko effect:

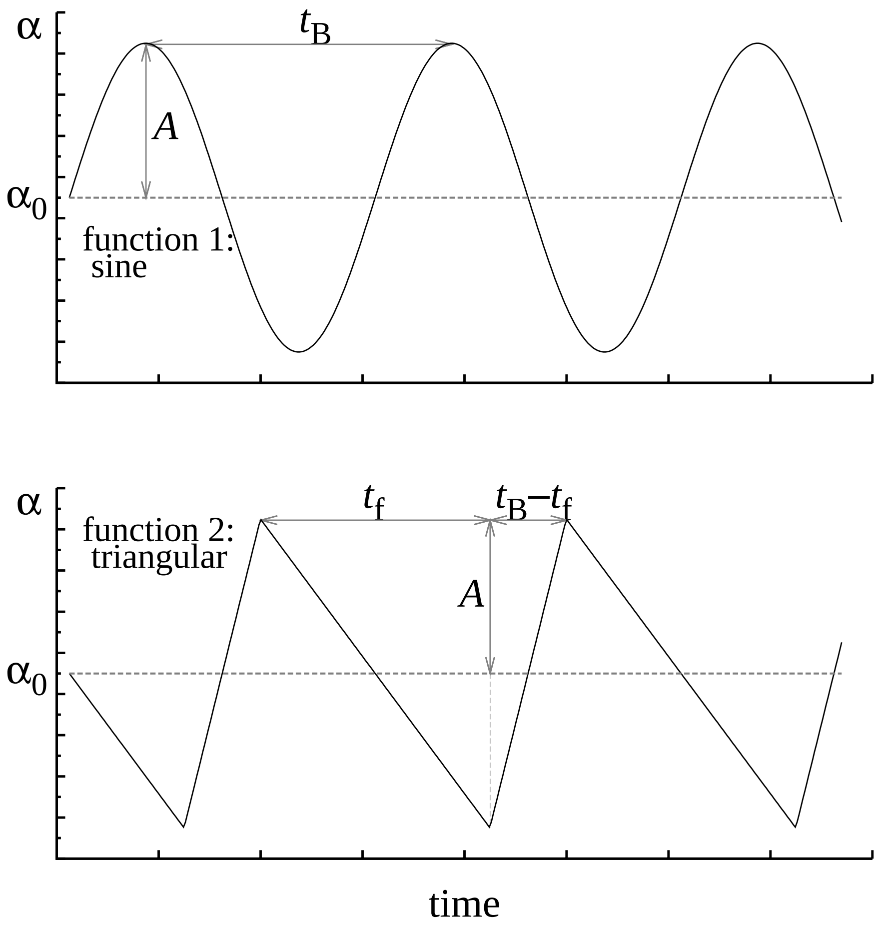
Stothers idea (Stothers 2006):



- pure modulation of the radial pulsation
- turbulent convection in the hydrogen-helium ionization zones becomes cyclically strengthened and weakened by the presence of the transient magnetic fields (amplitude/phase modulation)
- magnetic field built by the turbulent/rotational dynamo
- irregularities in the Blazhko cycle can be explained by the stochasticity of the proposed mechanism
- lack of meaningful predictions (see Kovács 2009)

Model behind the Stothers idea:

⋆ we use our nonlinear convective pulsation hydrocode in which we vary the strength of the turbulent convection



Model behind the Stothers idea:

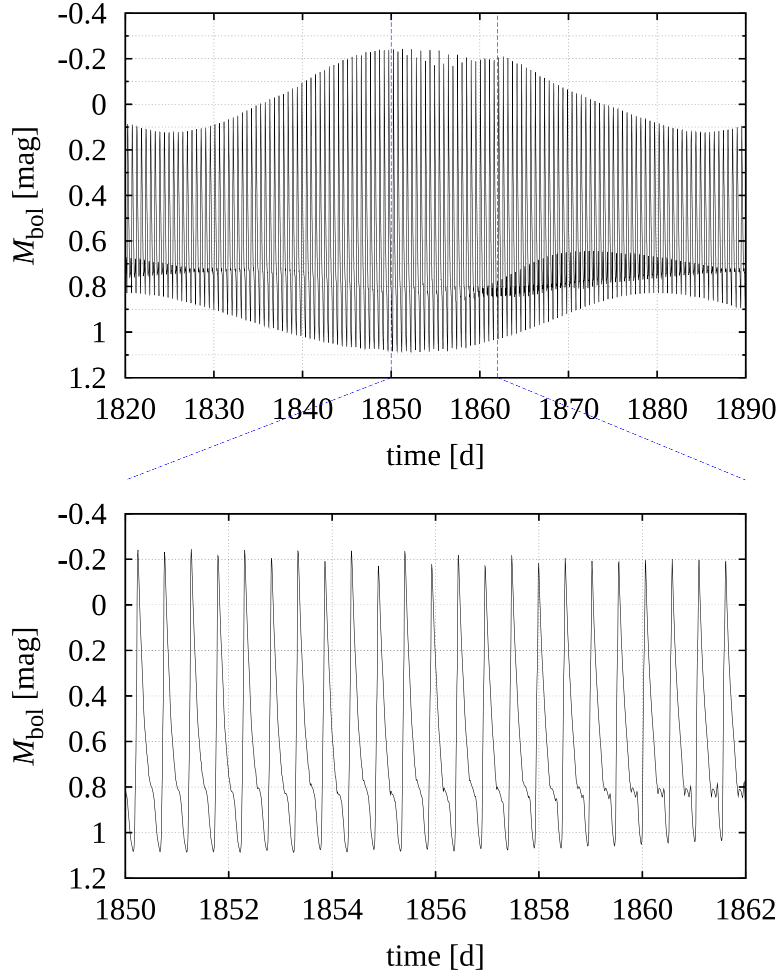
- ⋆ we use our nonlinear convective pulsation hydrocode in which we vary the strength of the turbulent convection
- ⋆ interaction with the postulated variable magnetic field is neglected
- ⋆ therefore, our model includes the dynamical coupling between convection and pulsation, but neglects the dynamical coupling with the magnetic field

Our results are therefore qualitative, however the premise is that,

- ▸ if we can reproduce the most important observational constraints, Stothers idea is certainly worth further more detailed investigation
- ▸ if we don't succeed, Stothers idea needs revision

Model behind the Stothers idea:

- static equilibrium model
- nonlinear model integration till finite amplitude fundamental mode pulsation is reached
- restart of the model with modulated mixing-length
- after computation of several Blazhko periods, Blazhko limit cycle is reached



Comparison with RR Lyr and other Blazhko variables

- Comparison focused on RR Lyr *Kepler* data (Kolenberg et al. 2010)
- Can we reproduce light curve variation through the Blazhko cycle?
- What is the required strength of modulation?
- Can we reproduce the observed frequency spectra?
- Can we reproduce the period-doubling effect for RR Lyr?

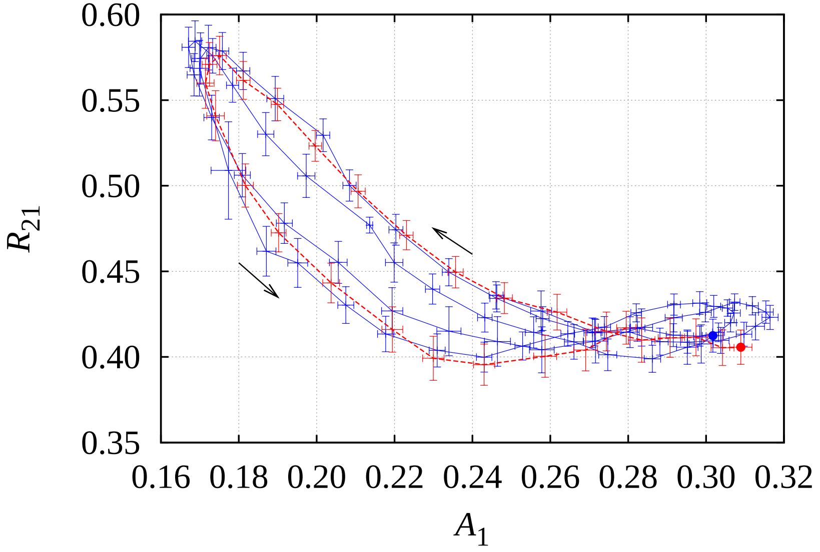
$$m = m_0 + \sum_{k=1}^{N} A_k \sin(2\pi k f t + \phi_k),$$

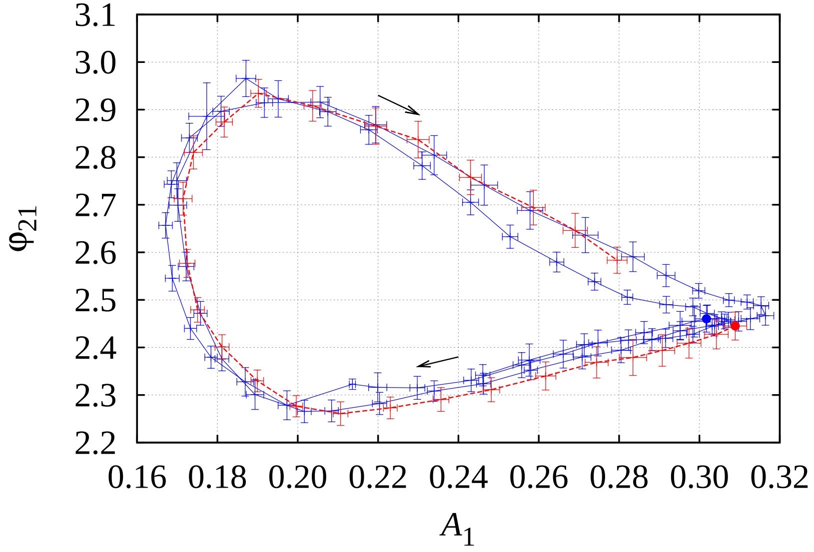
$$R_{k1} = \frac{A_k}{A_1},$$

$$\varphi_{k1} = \phi_k - k\phi_1.$$

Comparison with RR Lyr and other Blazhko variables

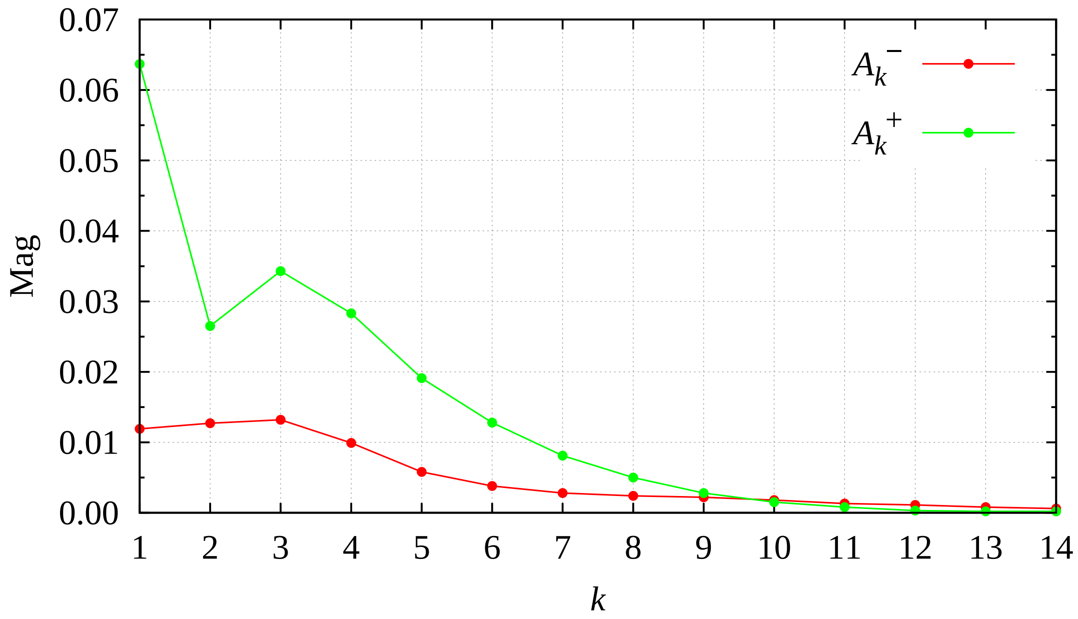
- Comparison focused on RR Lyr *Kepler* data (Kolenberg et al. 2010)
- Can we reproduce light curve variation through the Blazhko cycle?
- What is the required strength of modulation?
- Can we reproduce the observed frequency spectra?
- Can we reproduce the period-doubling effect for RR Lyr?





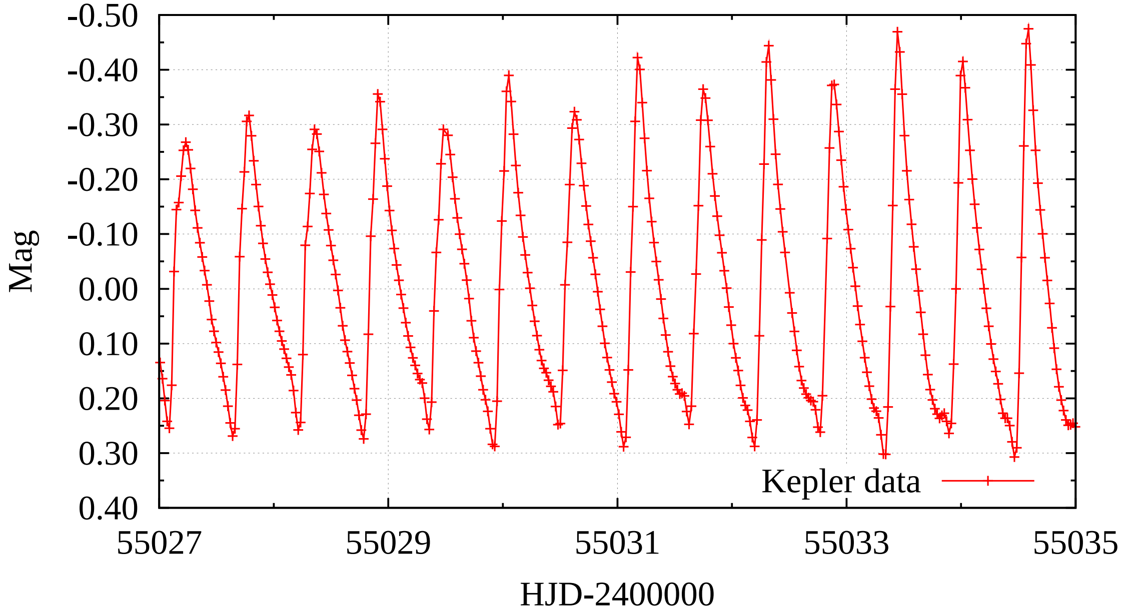
Comparison with RR Lyr and other Blazhko variables

- Comparison focused on RR Lyr *Kepler* data (Kolenberg et al. 2010)
- Can we reproduce light curve variation through the Blazhko cycle?
- What is the required strength of modulation?
- Can we reproduce the observed frequency spectra?
- Can we reproduce the period-doubling effect for RR Lyr?



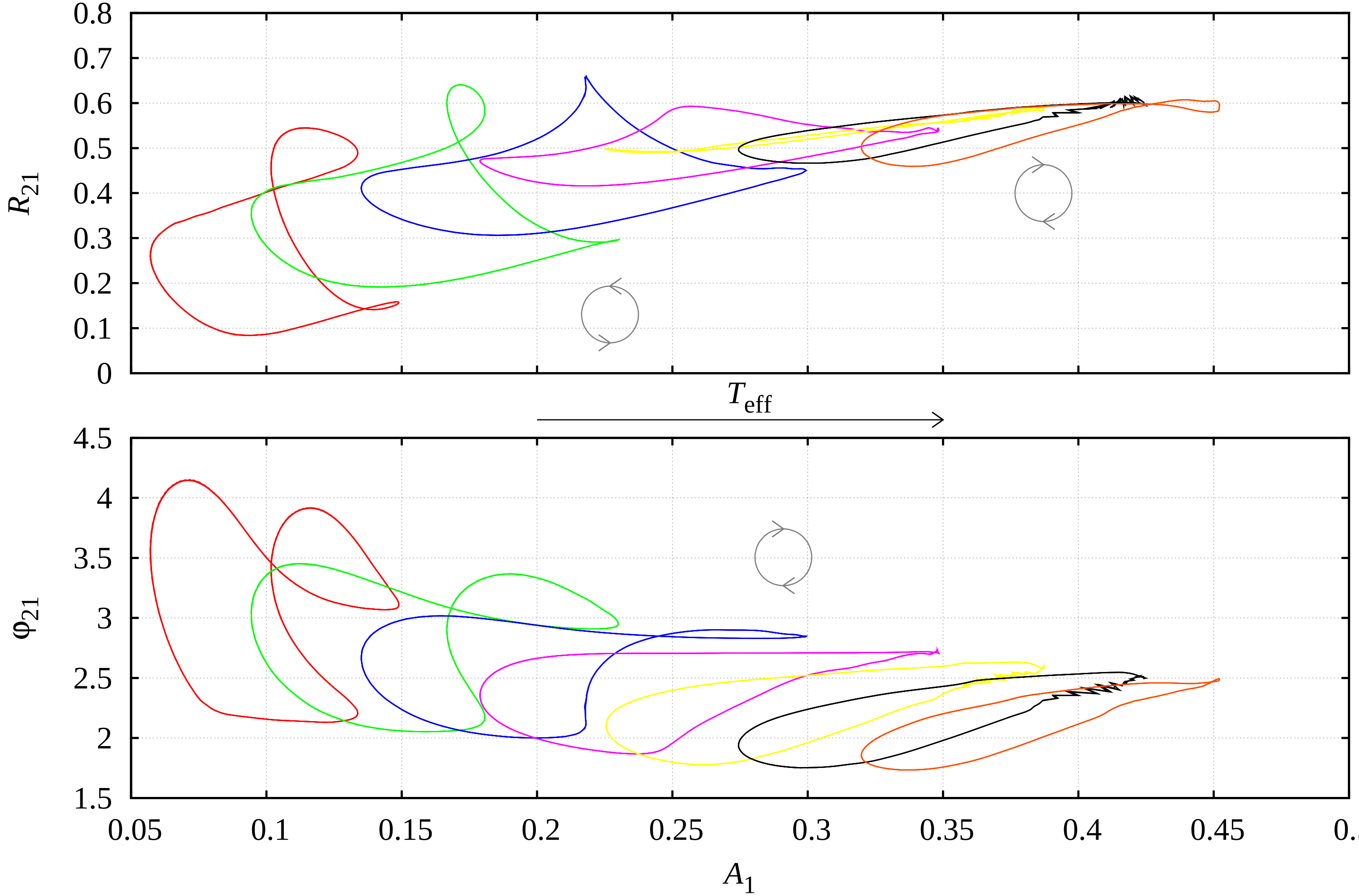
Comparison with RR Lyr and other Blazhko variables

- Comparison focused on RR Lyr *Kepler* data (Kolenberg et al. 2010)
- Can we reproduce light curve variation through the Blazhko cycle?
- What is the required strength of modulation?
- Can we reproduce the observed frequency spectra?
- Can we reproduce the period-doubling effect for RR Lyr?



Light curve variation through the Blazhko cycle

- variation through the instability strip



Light curve variation through the Blazhko cycle

We investigate effects of:

10%,

⋆ different modulation strength

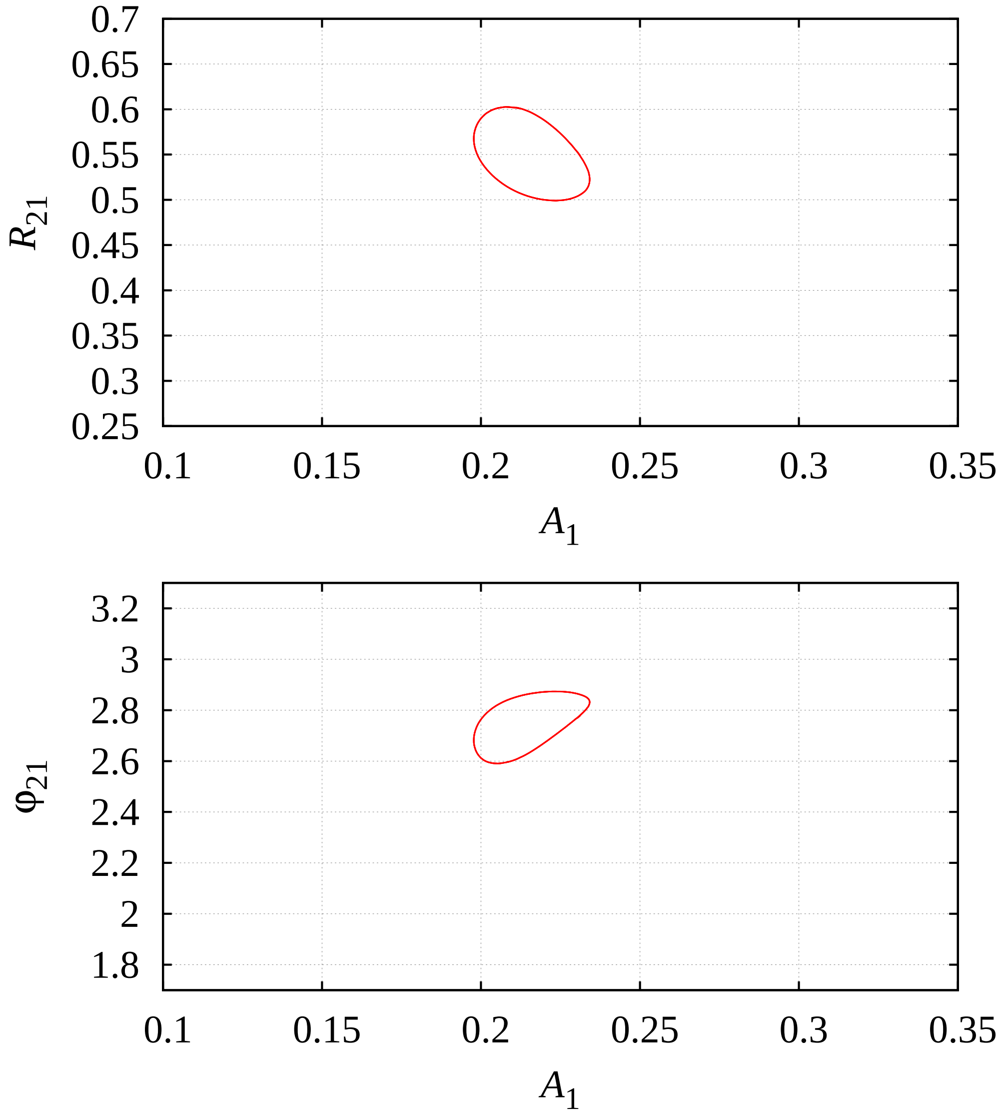
▸ $P_\mathrm{B} = 60\mathrm{d}$, sine

⋆ different modulation period

▸ $A = 50\%$, sine

⋆ different modulation shape

▸ $P_\mathrm{B} = 60\mathrm{d}$, $A = \%$



Light curve variation through the Blazhko cycle

We investigate effects of: 10%, 30%,

⋆ different modulation strength

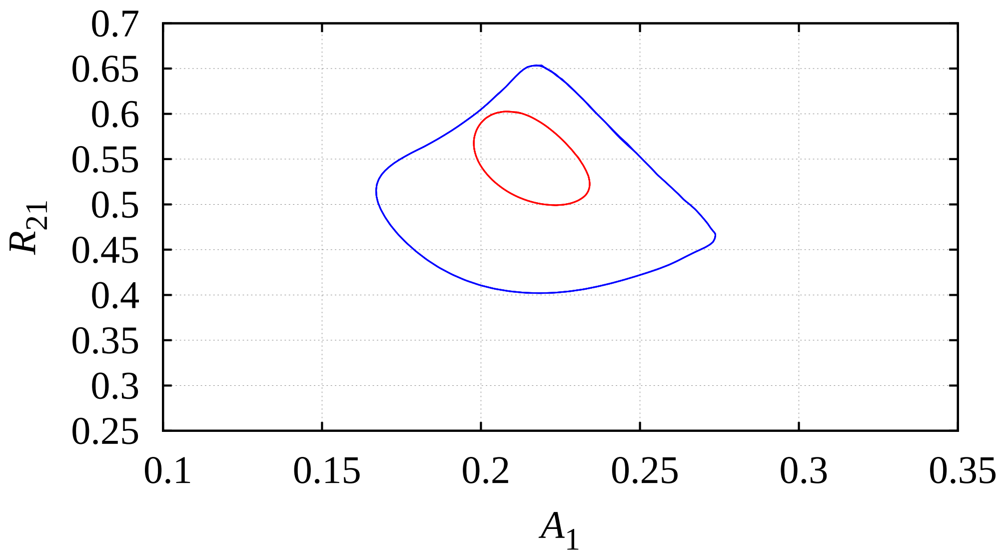
▸ $P_{\mathrm{B}} = 60$d, sine

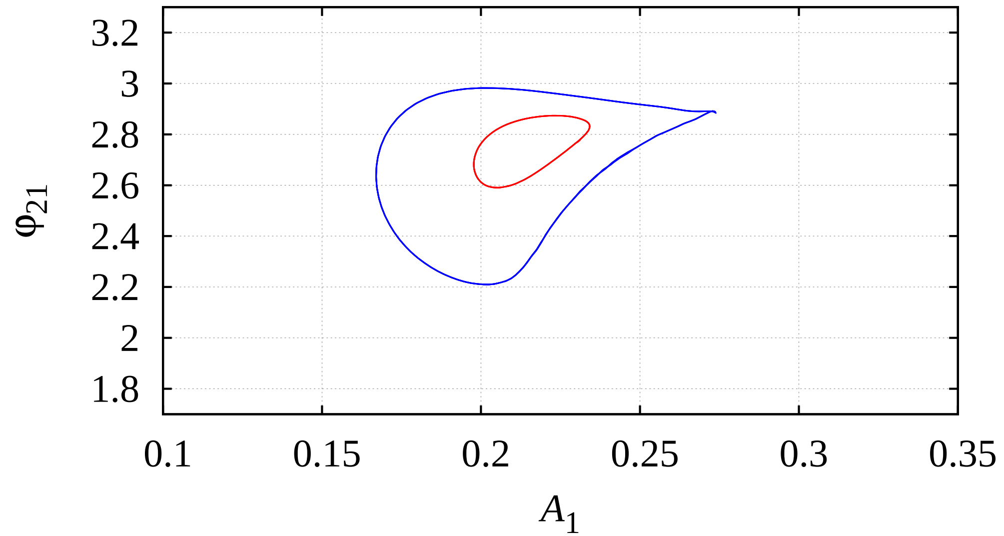
⋆ different modulation period

▸ $A = 50\%$, sine

⋆ different modulation shape

▸ $P_{\mathrm{B}} = 60$d, $A = \%$

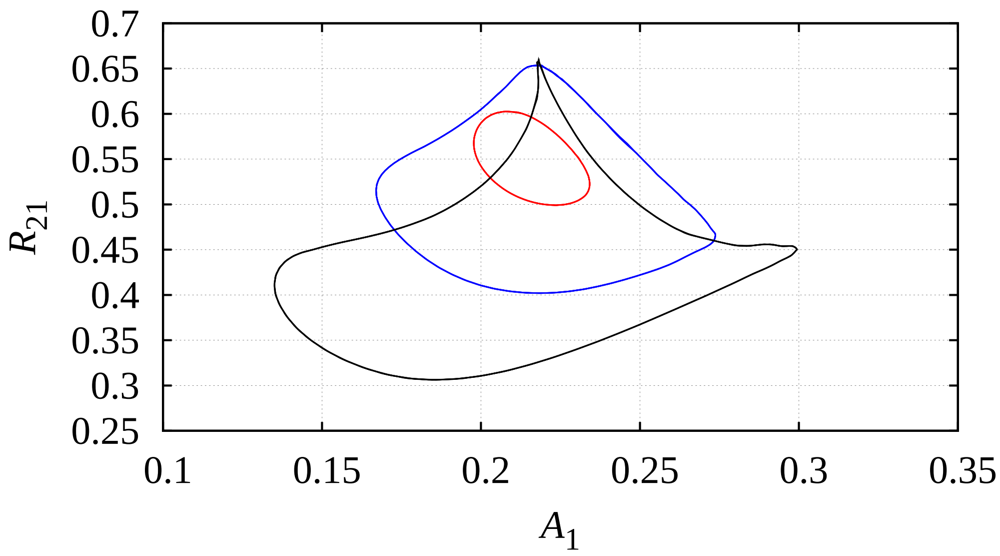


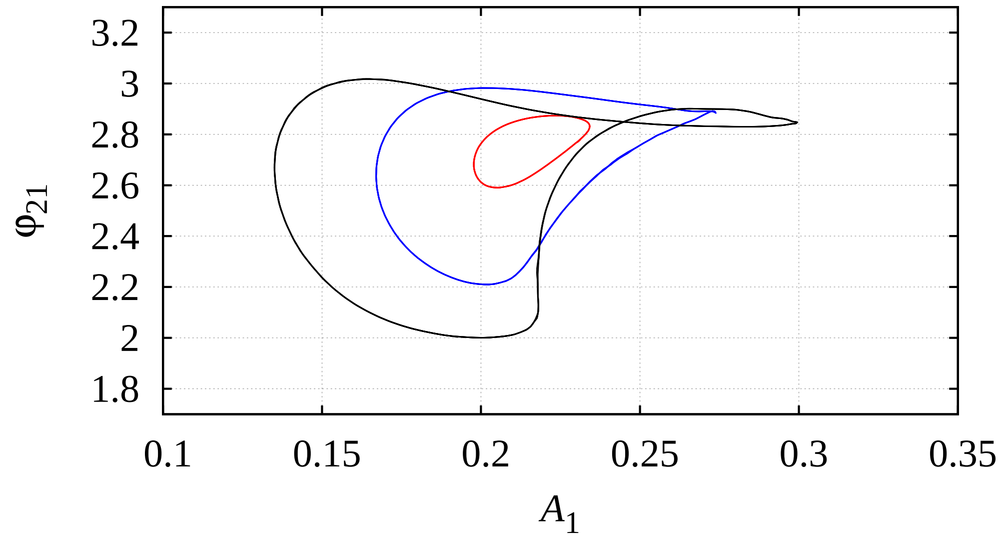


Light curve variation through the Blazhko cycle

We investigate effects of: 10%, 30%, 50%,

- ⋆ different modulation strength
  - ▸ $P_{\mathrm{B}} = 60$d, sine
- ⋆ different modulation period
  - ▸ $A = 50\%$, sine
- ⋆ different modulation shape
  - ▸ $P_{\mathrm{B}} = 60$d, $A = \%$



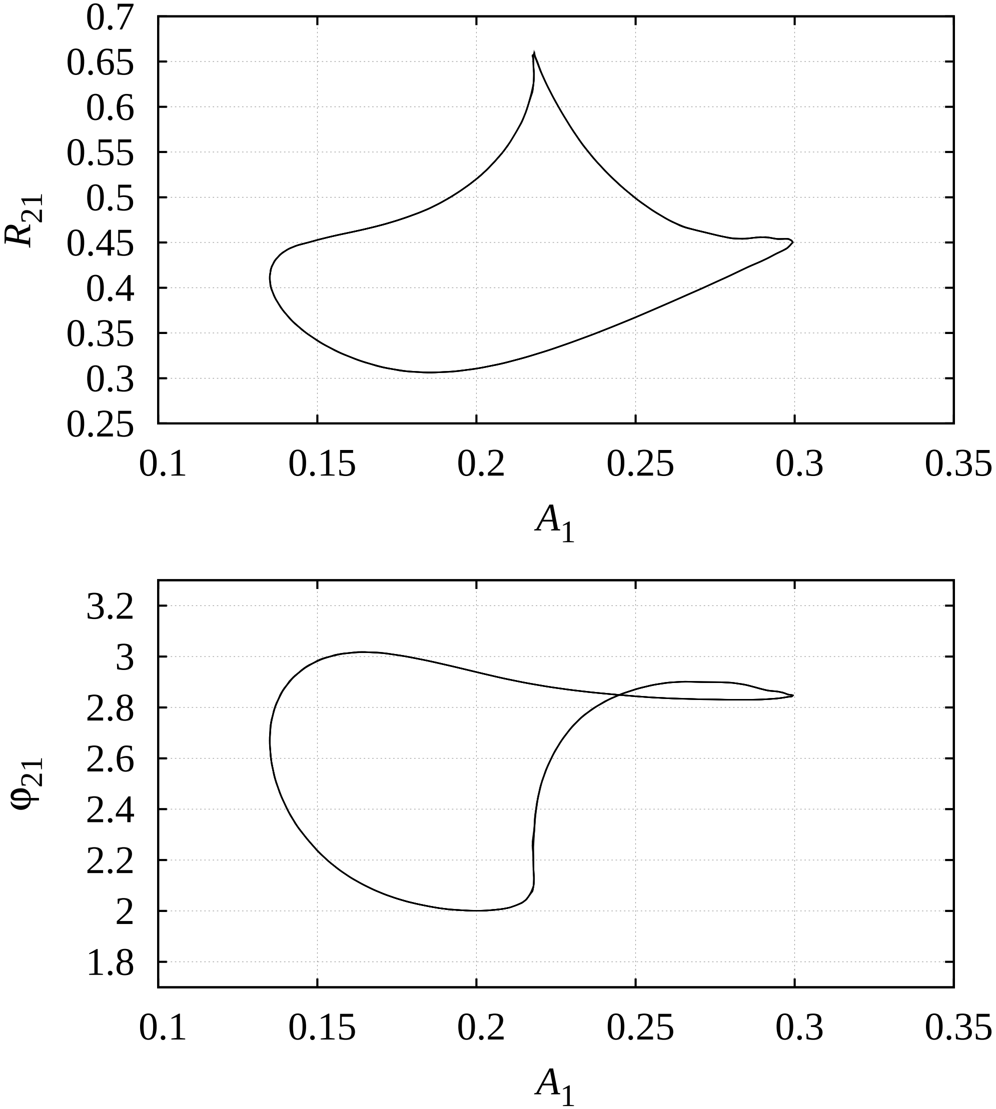


Light curve variation through the Blazhko cycle

We investigate effects of:

60d,

- ⋆ different modulation strength
  - ▸ $P_{\mathrm{B}} = 60\mathrm{d}$, sine
- ⋆ different modulation period
  - ▸ $A = 50\%$, sine
- ⋆ different modulation shape
  - ▸ $P_{\mathrm{B}} = 60\mathrm{d}$, $A = 50\%$

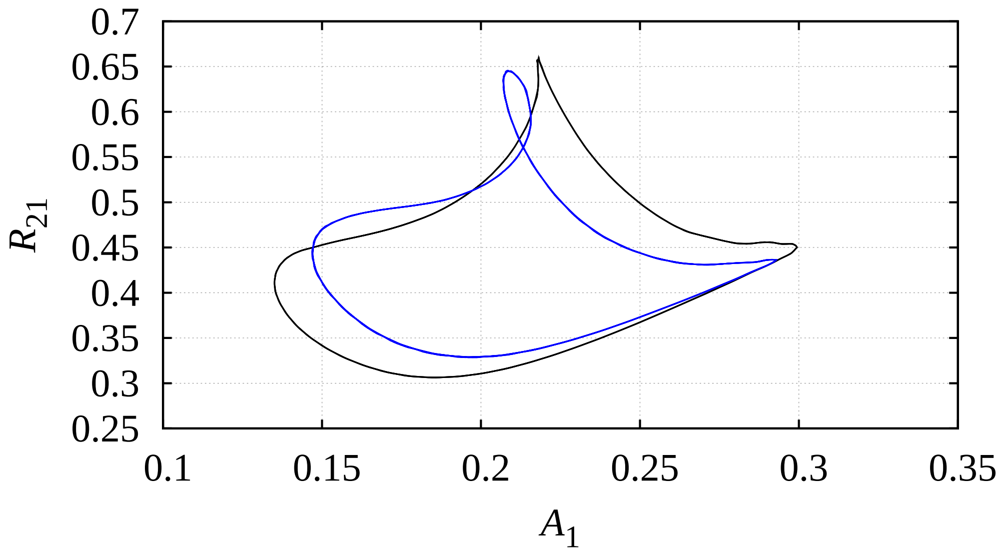


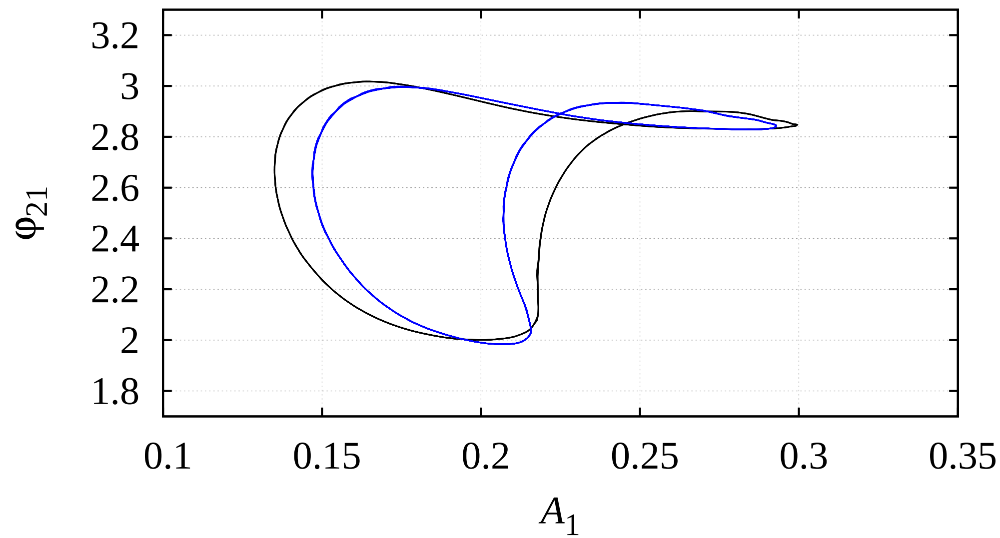
Light curve variation through the Blazhko cycle

We investigate effects of:

- ⋆ different modulation strength
  - ▸ $P_B = 60\text{d}$, sine
- ⋆ different modulation period
  - ▸ $A = 50\%$, sine
- ⋆ different modulation shape
  - ▸ $P_B = 60\text{d}$, $A = 50\%$

60d, 40d,





Light curve variation through the Blazhko cycle

We investigate effects of:

⋆ different modulation strength

▸ $P_{\rm B} = 60$d, sine

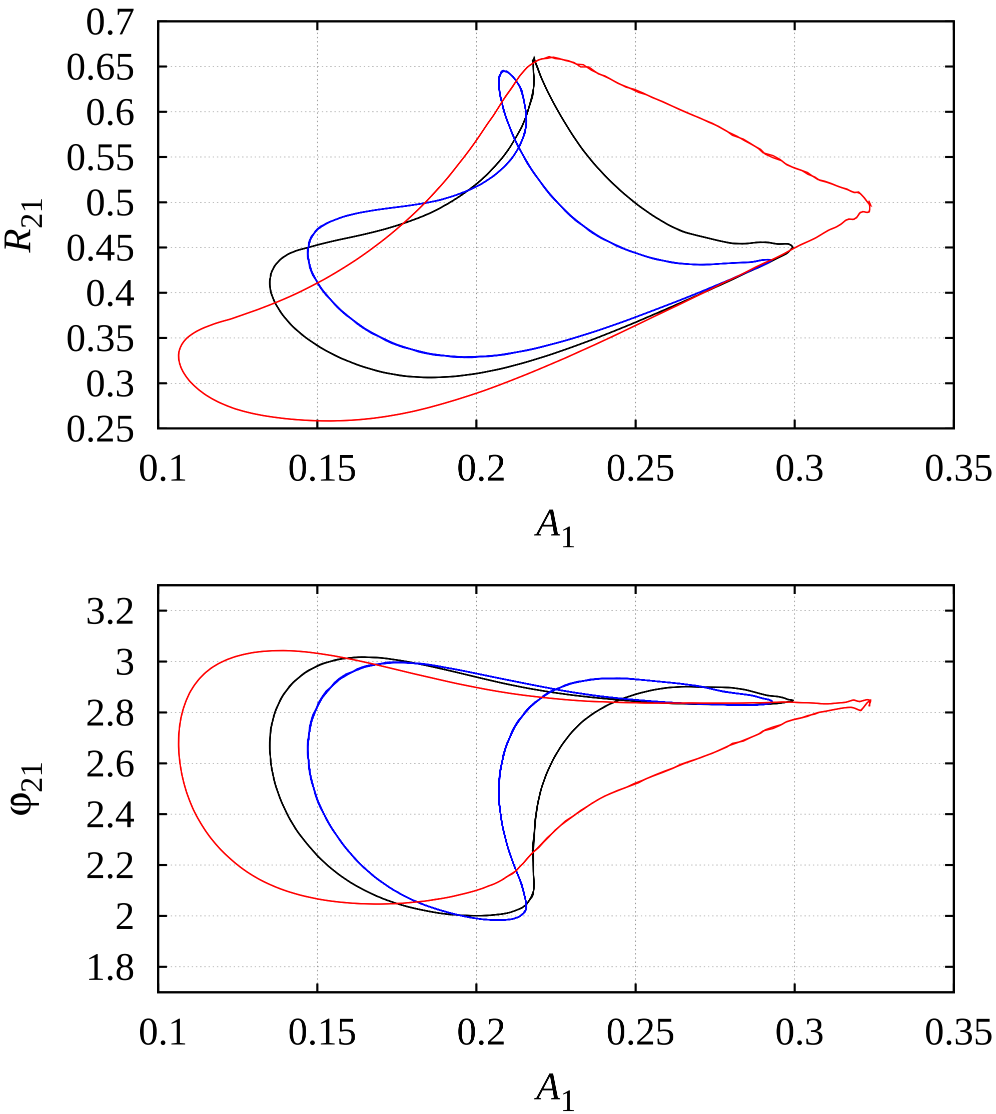
⋆ different modulation period

▸ $A = 50\%$, sine

⋆ different modulation shape

▸ $P_{\rm B} = 60$d, $A = 50\%$

60d, 40d, 120d,

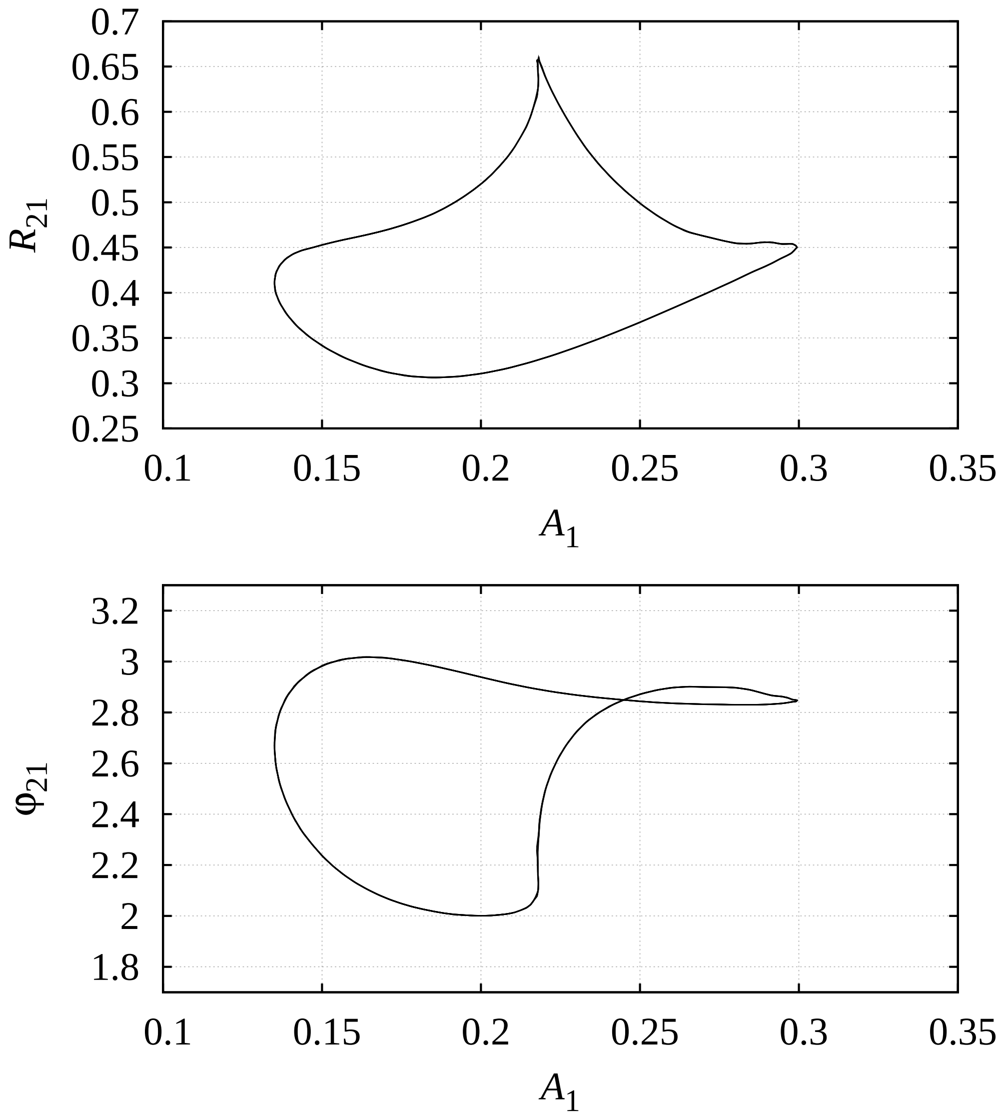


Light curve variation through the Blazhko cycle

We investigate effects of:

- ⋆ different modulation strength
  - ▸ $P_{\mathrm{B}} = 60\mathrm{d}$, sine
- ⋆ different modulation period
  - ▸ $A = 50\%$, sine
- ⋆ different modulation shape
  - ▸ $P_{\mathrm{B}} = 60\mathrm{d}$, $A = 50\%$

sine,

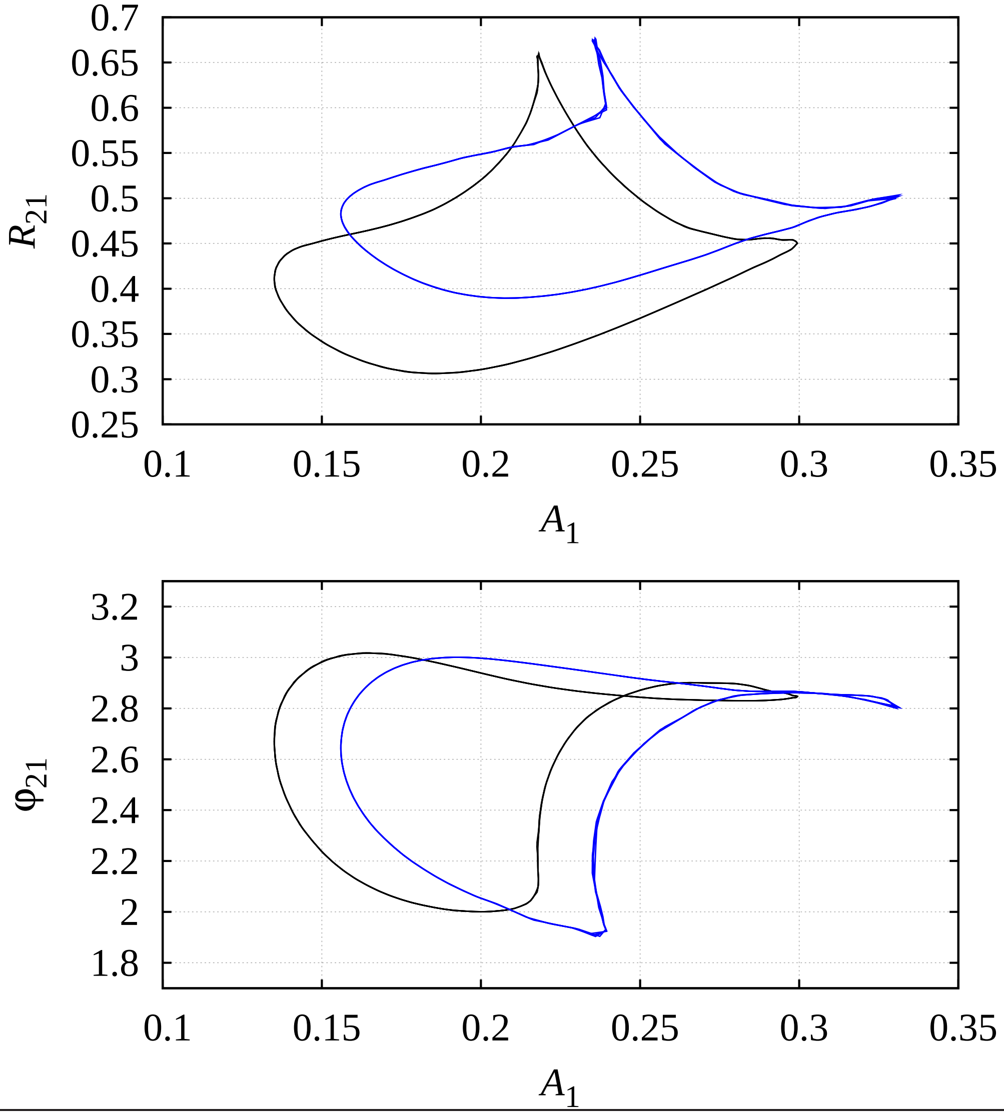


Light curve variation through the Blazhko cycle

We investigate effects of:

- ⋆ different modulation strength
  - ▸ $P_{\mathrm{B}} = 60$d, sine
- ⋆ different modulation period
  - ▸ $A = 50\%$, sine
- ⋆ different modulation shape
  - ▸ $P_{\mathrm{B}} = 60$**d**, $A = 50\%$

sine, triang. 1,



Light curve variation through the Blazhko cycle

We investigate effects of:

⋆ different modulation strength

▸ $P_{\rm B} = 60$d, sine

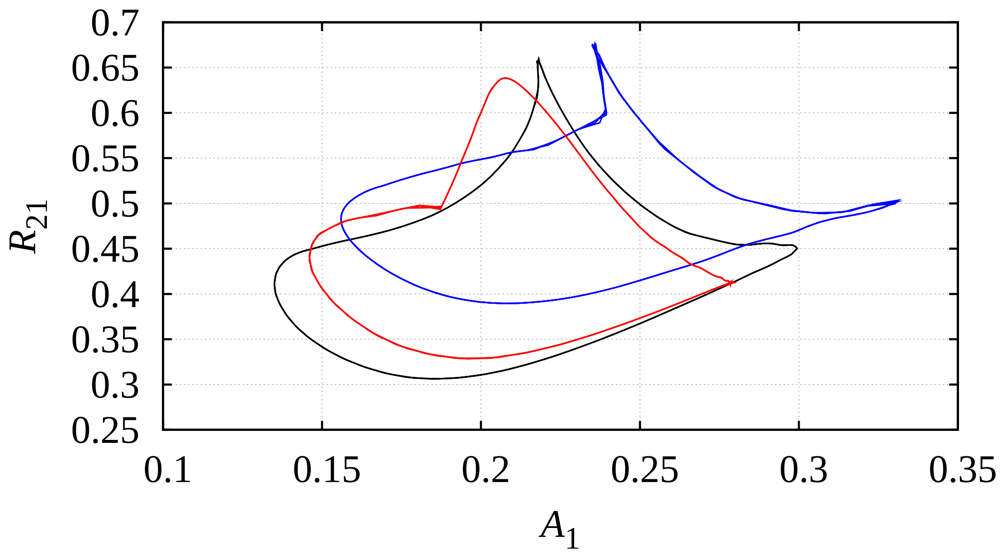
⋆ different modulation period

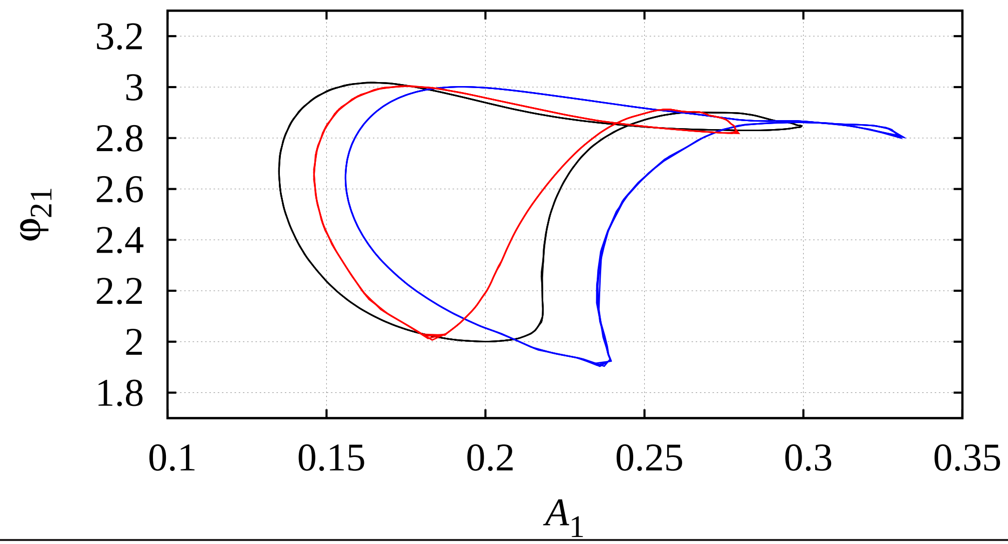
▸ $A = 50\%$, sine

⋆ different modulation shape

▸ $P_{\rm B} = 60$**d**, $A = 50\%$

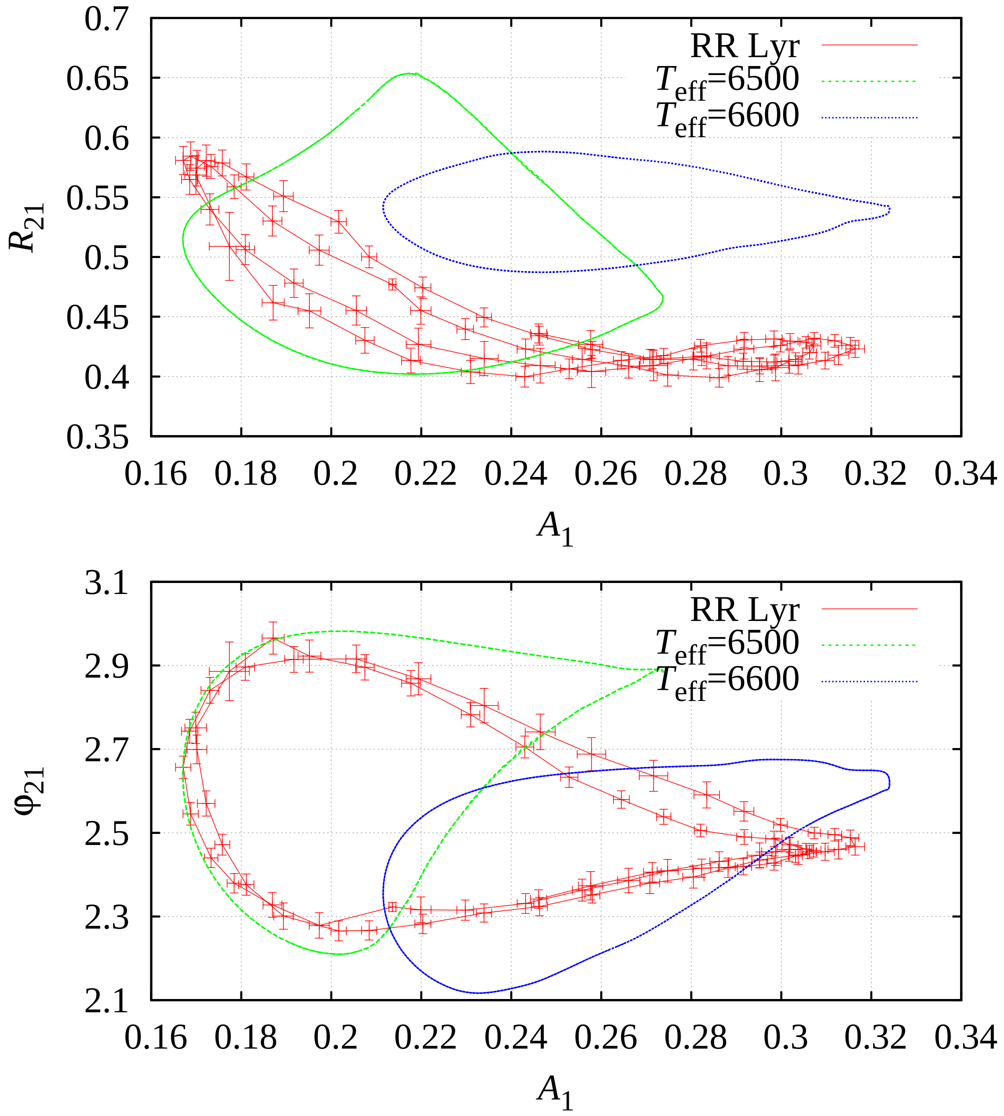
sine, triang. 1, triang. 2,





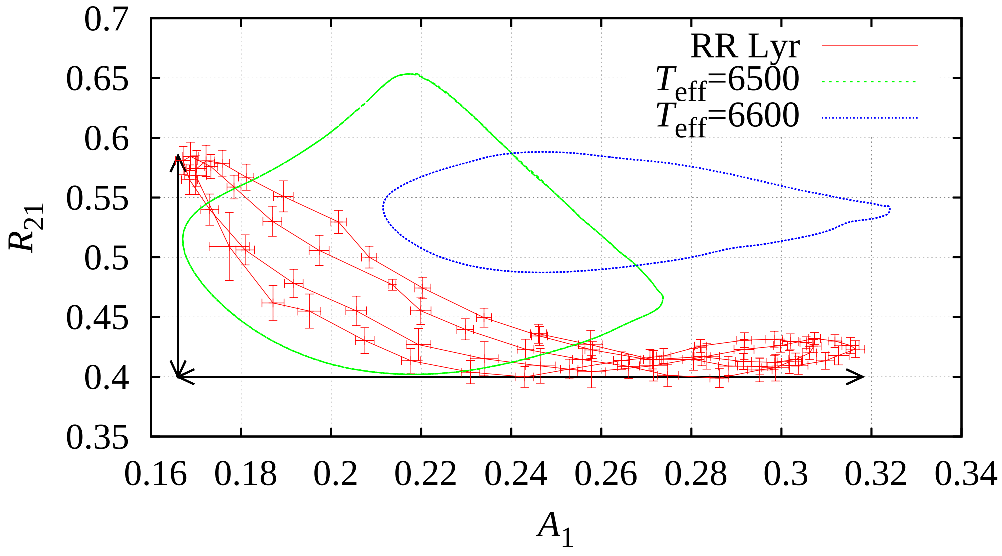
Light curve variation through the Blazhko cycle

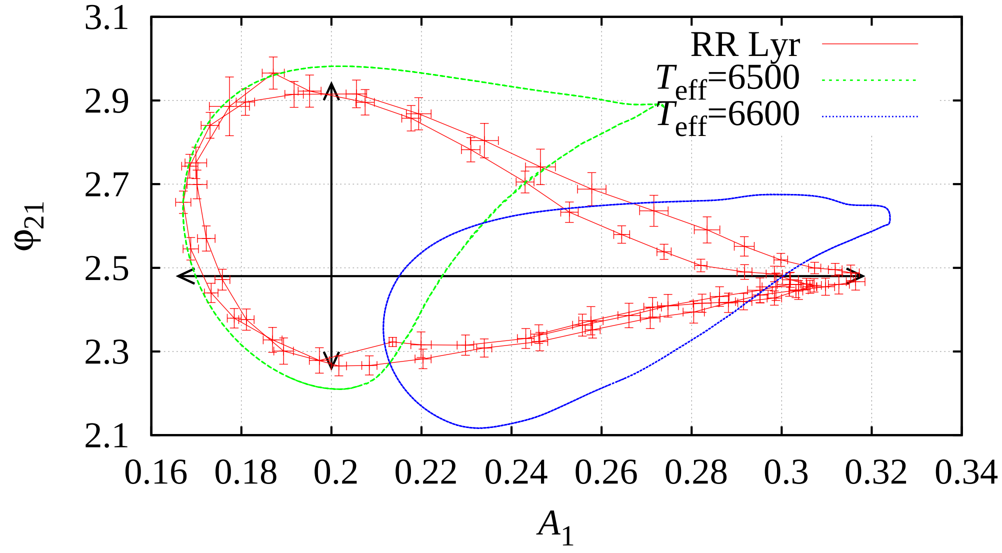
- we cannot reproduce decreasing R_{21} with increasing A_1
- the model and observed runs of φ_{21} vs. A_1 are similar, except location of the cusp



Light curve variation through the Blazhko cycle

- we cannot reproduce decreasing R_{21} with increasing A_1
- the model and observed runs of φ_{21} vs. A_1 are similar, except location of the cusp





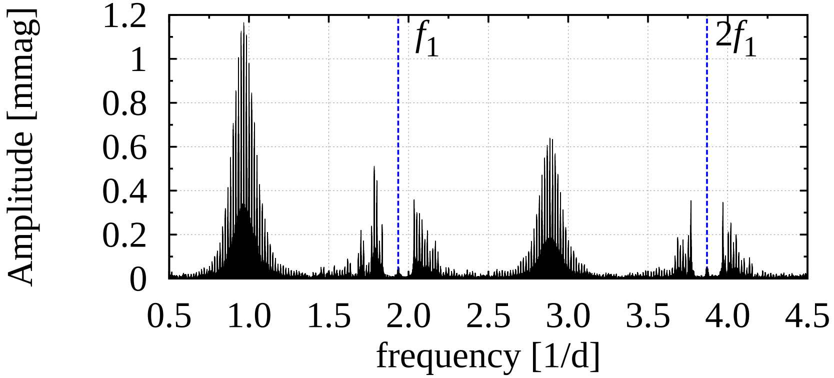
More quantitative comparison: ranges of variation

$$\Delta c = 2\frac{c_{\max} - c_{\min}}{c_{\max} + c_{\min}}$$

for $c \in \{A_1,\ R_{21},\ \varphi_{21}\}$

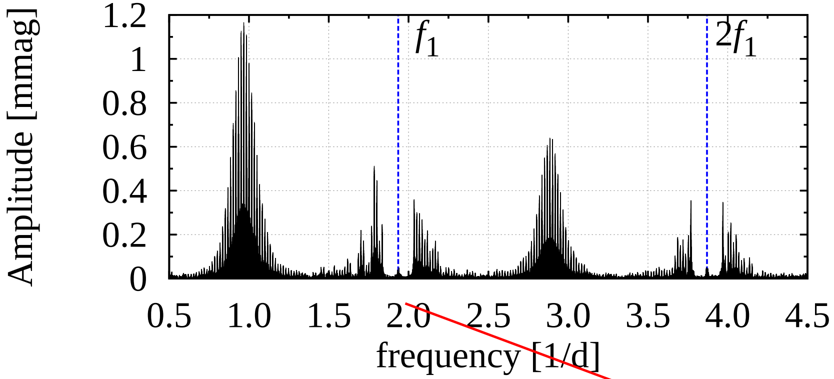
⇒ required strength of modulation: ∼50% ($\alpha = 0.75 \ldots 2.25$)

Frequency analysis

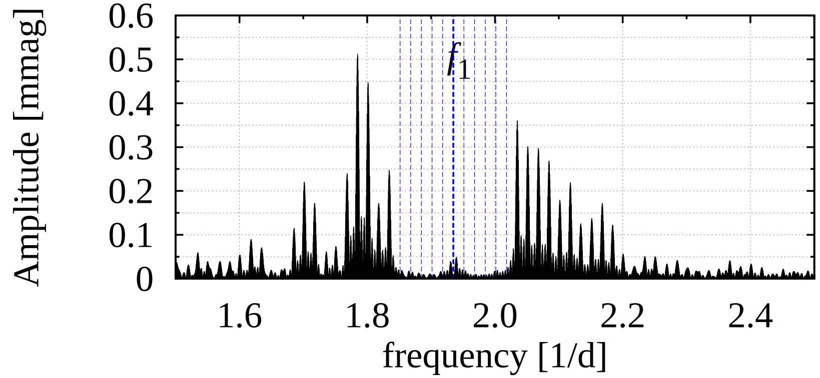


- ⋆ frequency analysis with Period04
- ⋆ only one frequency fitted
- ⋆ successive prewhitening

Frequency analysis

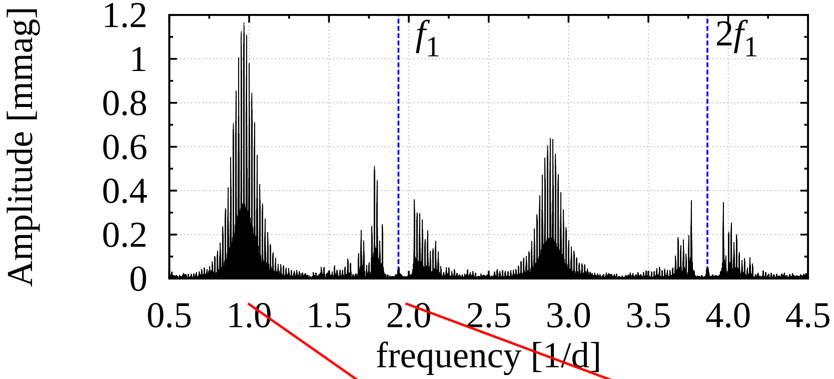


- ⋆ frequency analysis with Period04
- ⋆ only one frequency fitted
- ⋆ successive prewhitening



- ▸ plenty of side peaks

Frequency analysis



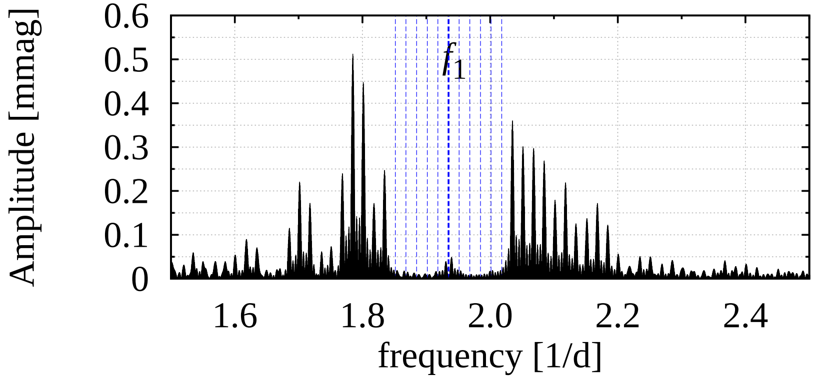
⋆ frequency analysis with Period04

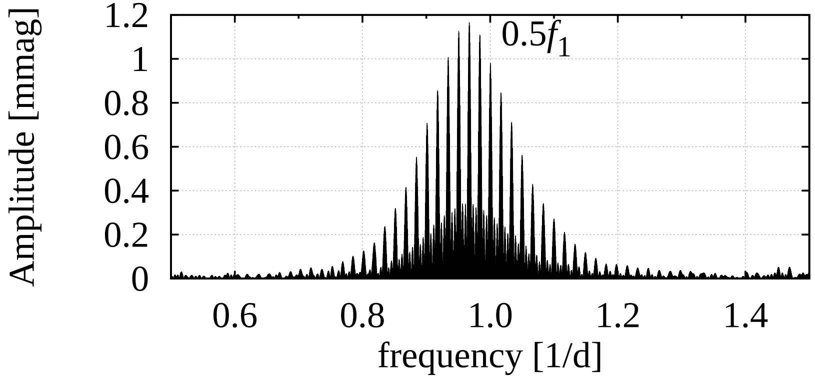
⋆ only one frequency fitted

⋆ successive prewhitening

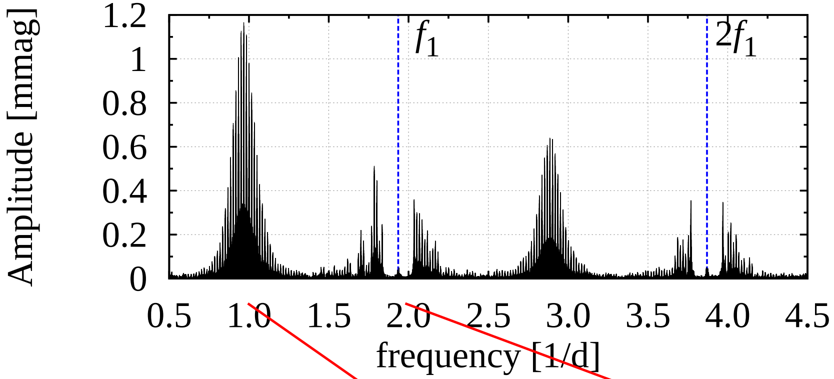
▸ plenty of side peaks

▸ bunch of peaks at half integer frequency

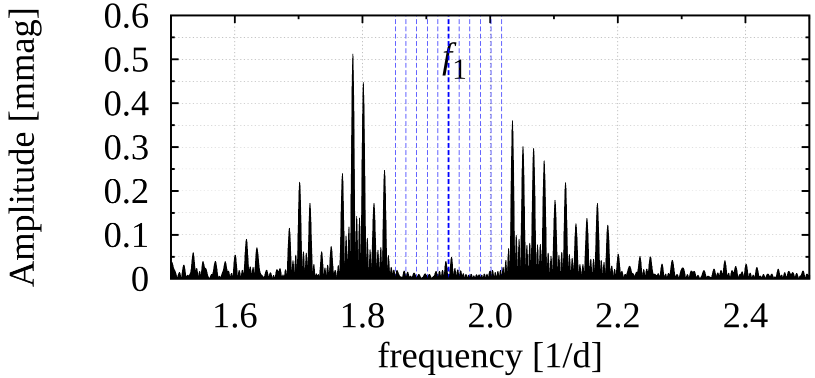




Frequency analysis

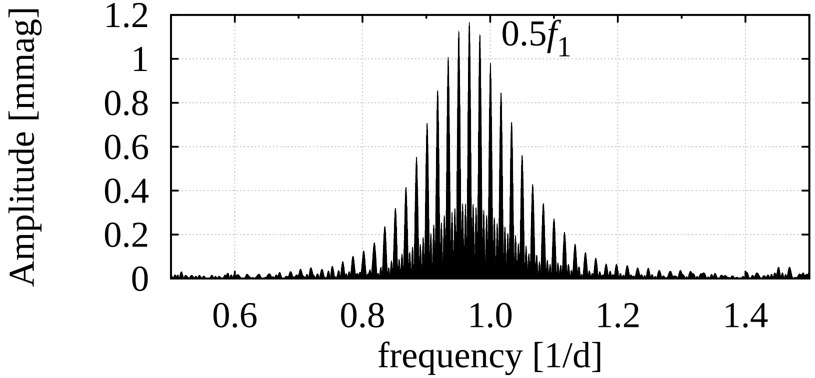


- ⋆ frequency analysis with Period04
- ⋆ only one frequency fitted
- ⋆ successive prewhitening



- ▸ plenty of side peaks
- ▸ bunch of peaks at half integer frequency
- ▸ we analyze the triplet components only

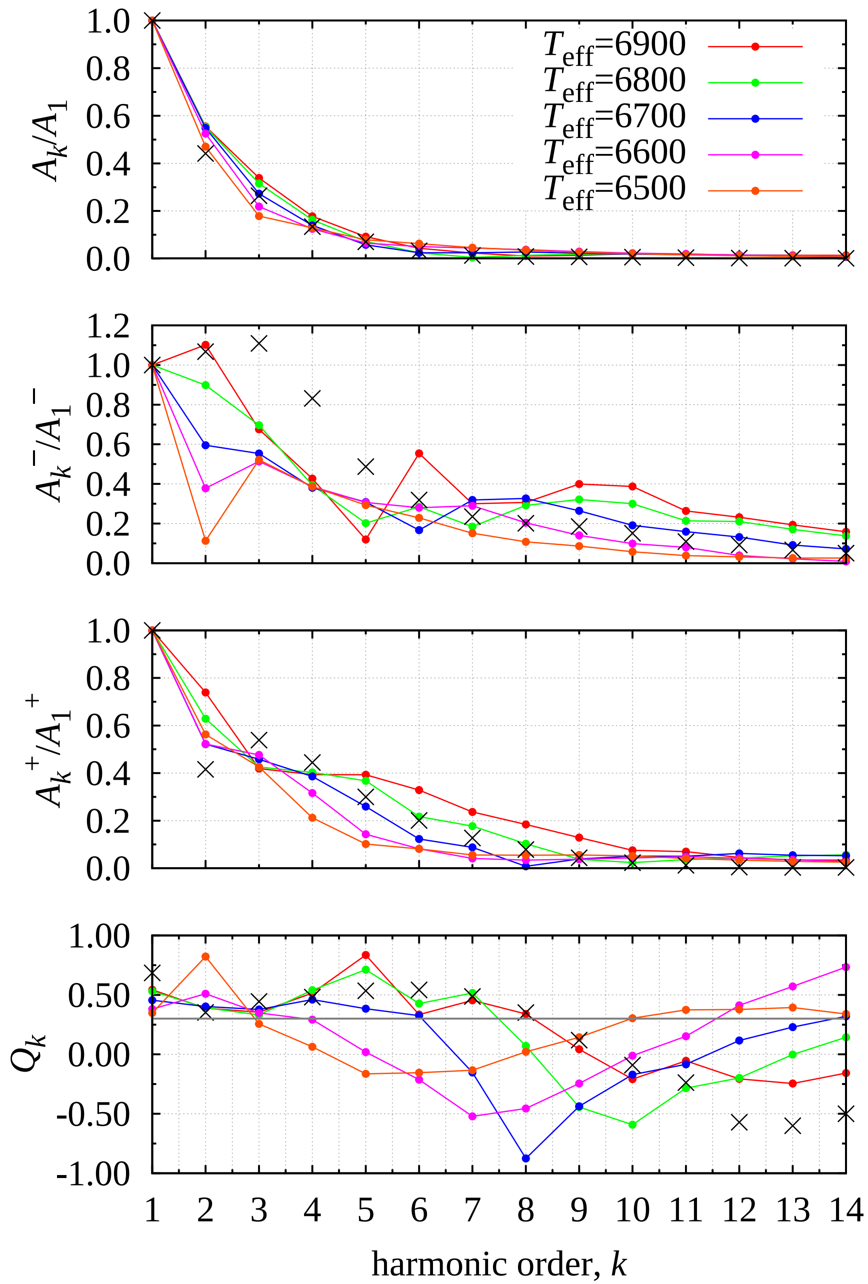
$$A_k^-,\ A_k^+,\ Q_k = \frac{A_k^+ - A_k^-}{A_k^+ + A_k^-}$$



Frequency analysis

- considering amplitude ratios, A_k/A_1, A_k^+/A_1^+ and A_k/A_1, A_k^+/A_1^+ we reproduce the less steep decrease for the modulation components
- we focus on the triplet of the lowest harmonic order
- side peak's asymmetry

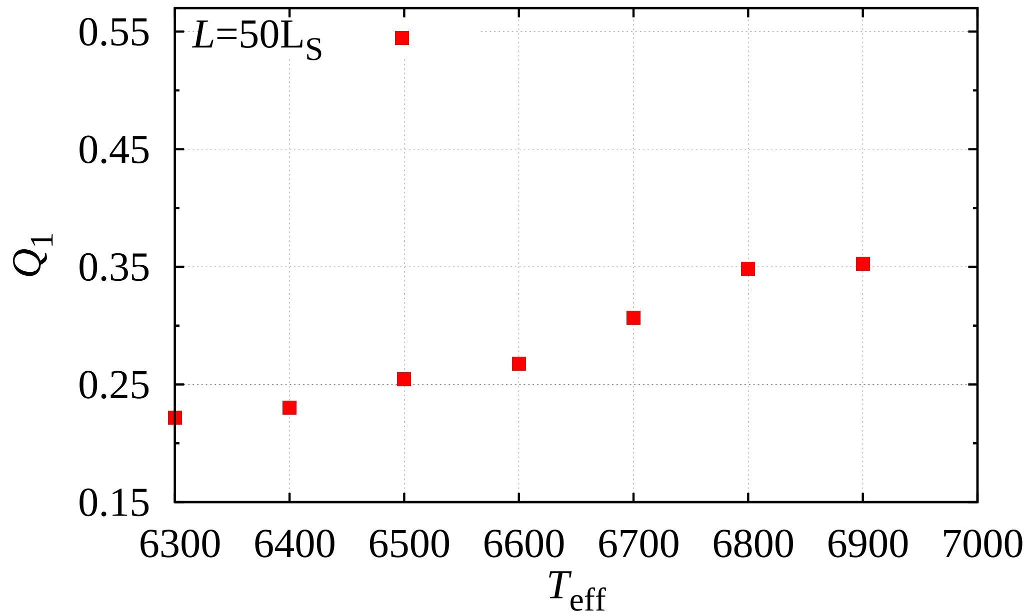
$$Q_1 = \frac{A_1^+ - A_1^-}{A_1^+ + A_1^-}$$



Frequency analysis

Side peak's asymmetry – Q_1

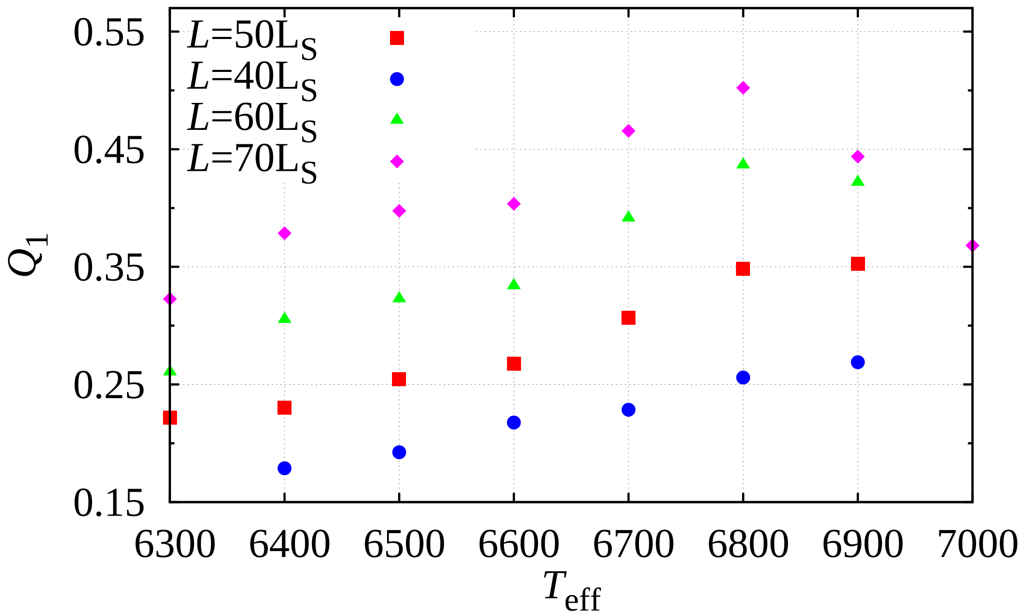
- $Q_1 > 0$ through the instability strip for $L = 50\mathrm{L}_S$



Frequency analysis

Side peak's asymmetry – Q_1

- $Q_1 > 0$ through the instability strip for $L = 50\mathrm{L}_S$
- $Q_1 > 0$ also for other luminosities



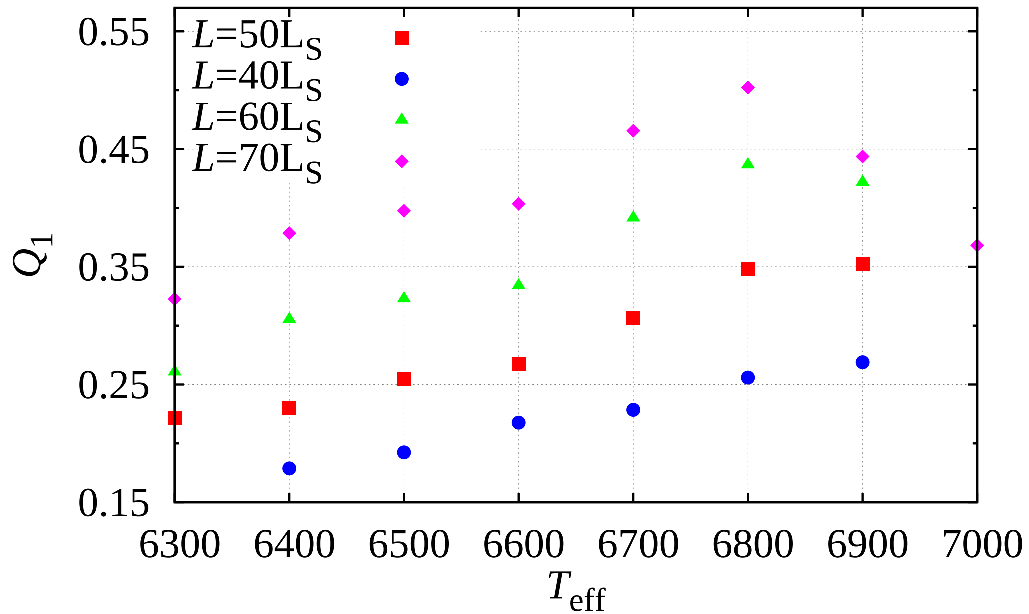
Frequency analysis

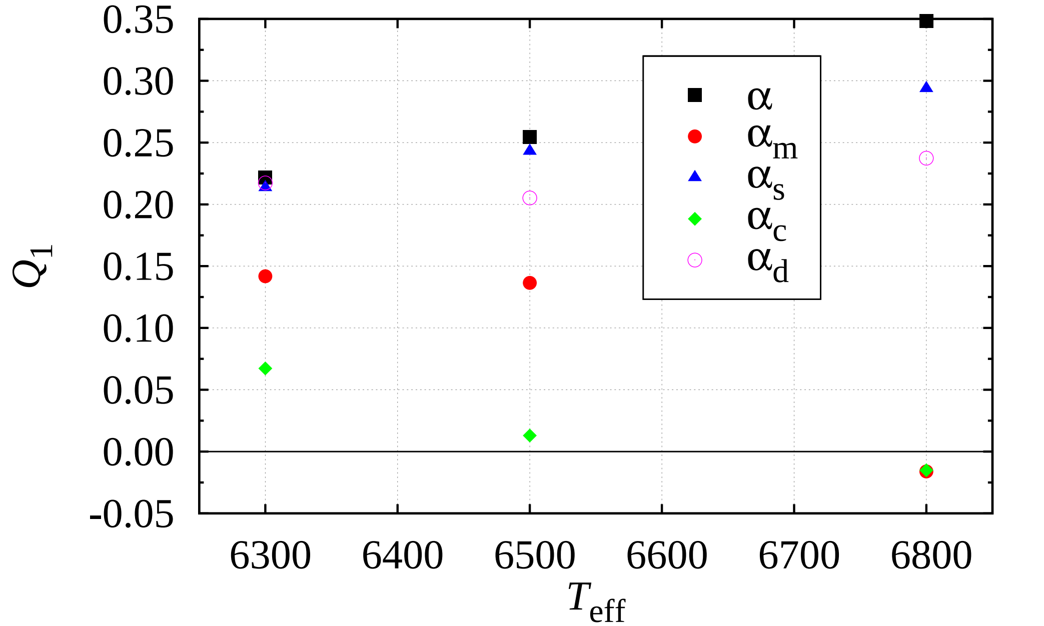
Side peak's asymmetry – Q_1

- $Q_1 > 0$ through the instability strip for $L = 50\mathrm{L}_S$
- $Q_1 > 0$ also for other luminosities

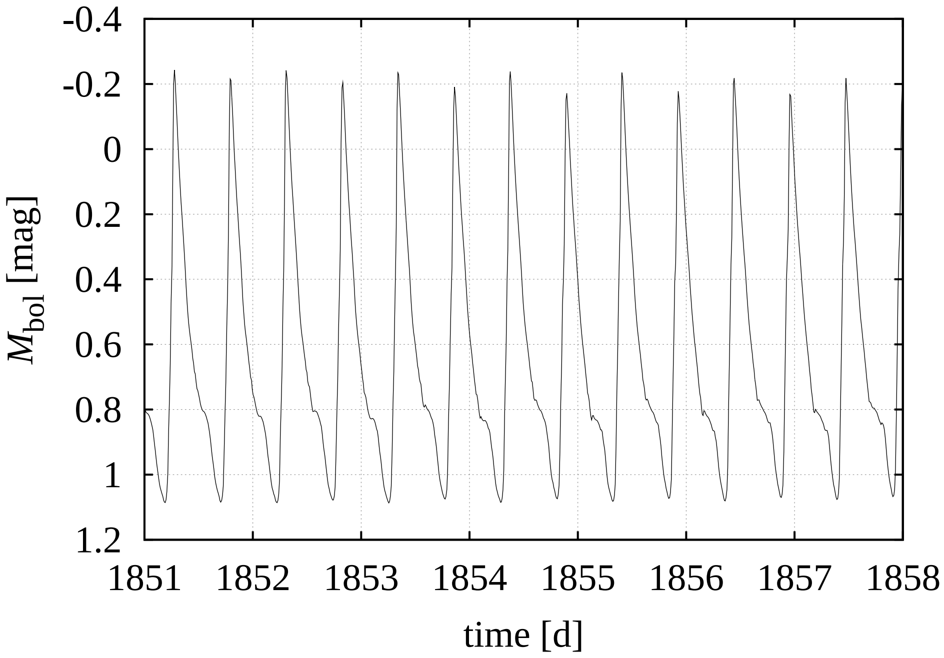
Can modulation of other convective model components help?

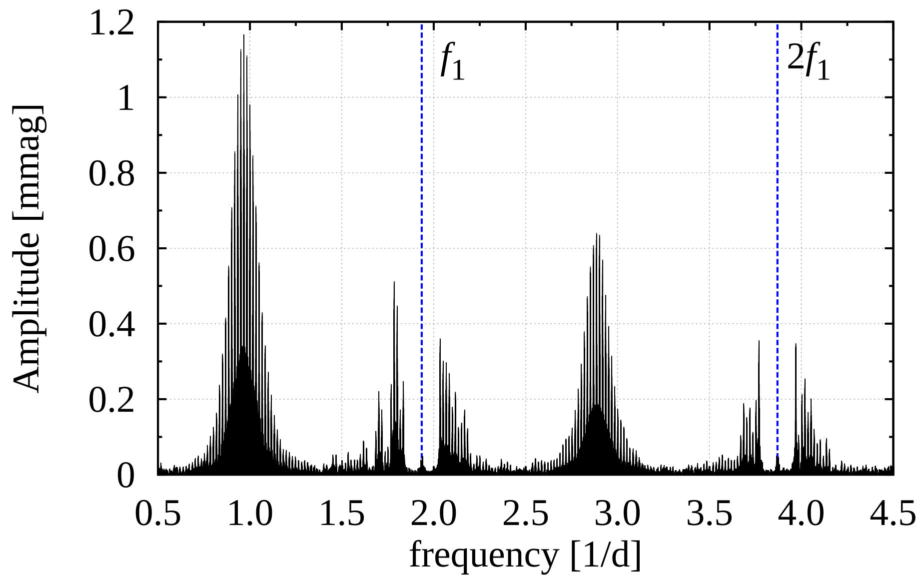
- $Q_1 < 0$ if convective flux or eddy-viscous dissipation are modulated, only, and for high $T_{\rm eff}$ (but $Q_1 \lesssim 0$)
- ranges of variation of Fourier parameters are small





Period-doubling

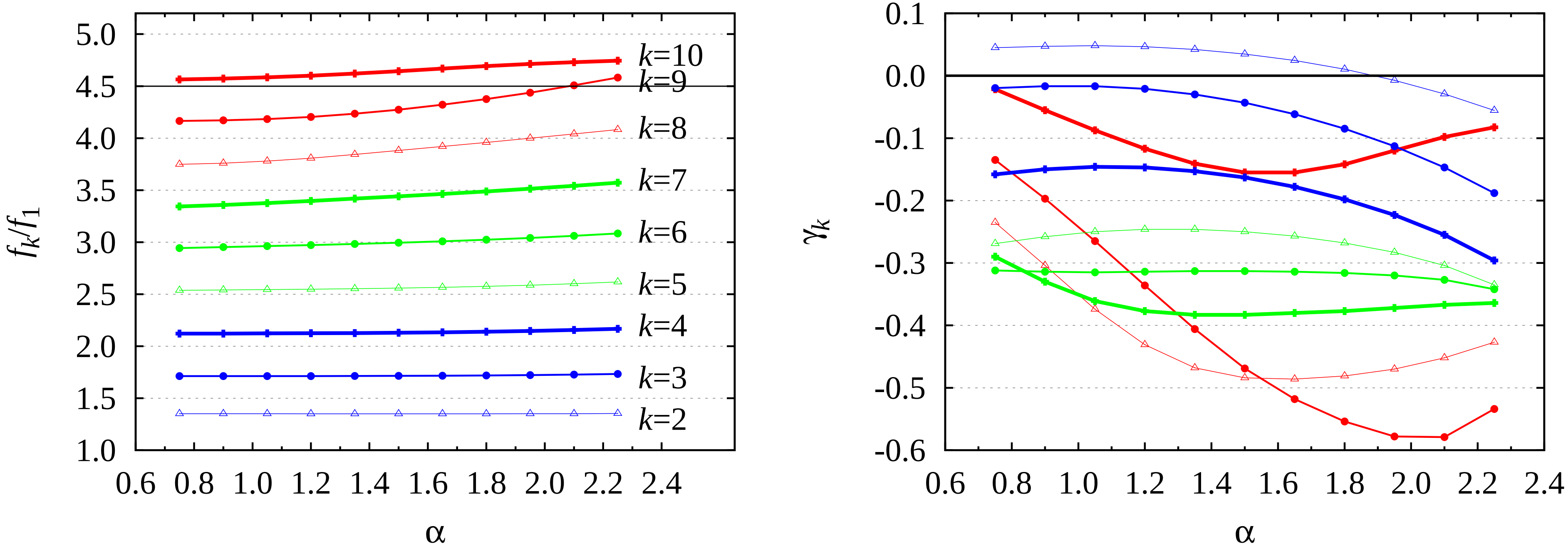




We get the period doubling however,

- for longer fundamental mode period than observed for RR Lyr
- period doubling is restricted to phases of maximum pulsation amplitude (minimum mixing-length)

Period-doubling



- PD explanation 9:2 resonance (Szabó et al. 2010)

Summary & conclusions

We have investigated several model sequences

- with different modulation amplitudes, modulation periods and modulation shapes
- our models run through the instability strip and have different M/L ratio

Our models cannot reproduce

- the dependence of R_{21} vs. A_1 we observe for RR Lyr
- asymmetries in the triplet components observed for some Blazhko stars

In addition

- for strongly modulated stars, mixing length modulation on order of 50%, $\alpha = 0.75 \ldots 2.25$ is necessary to reproduce the observed variation