Blazhko effect in double-mode RR Lyrae stars of the OGLE survey

Radosław Smolec (CAMK PAN, Warsaw)

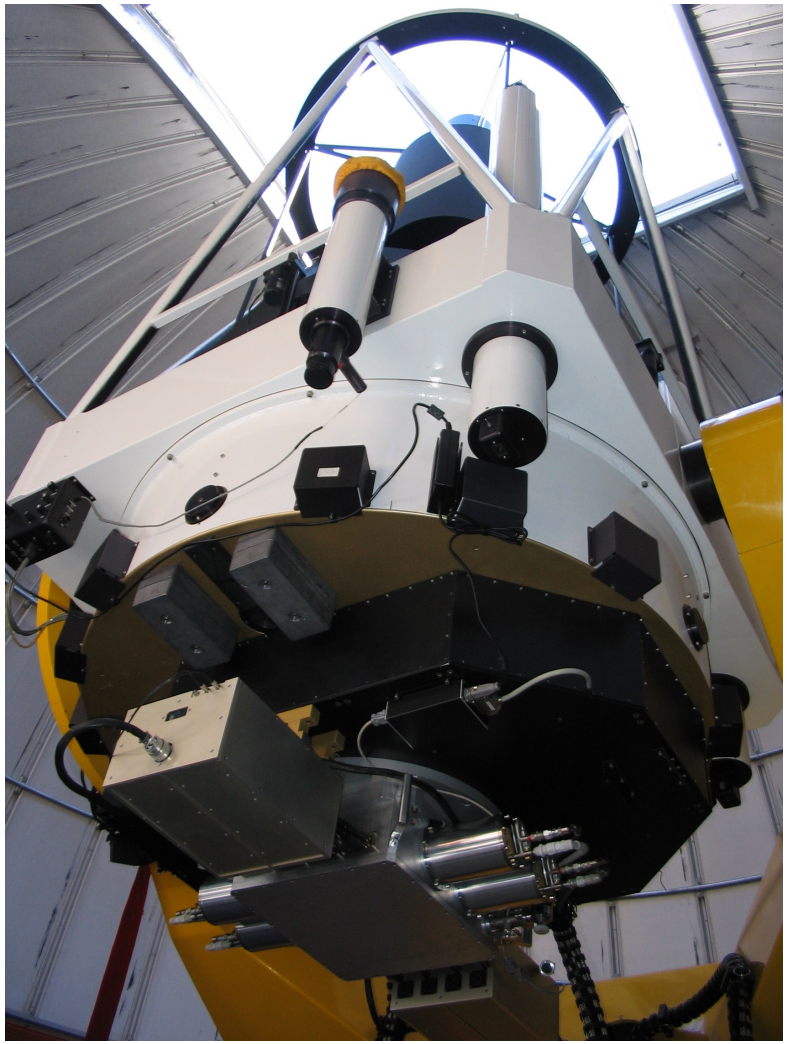
in collaboration with OGLE team

based on Smolec et al., 2015, MNRAS, 447, 3756

RRL2015 High-precision studies of RR Lyrae stars

Visegrád, 19-22.10.2015

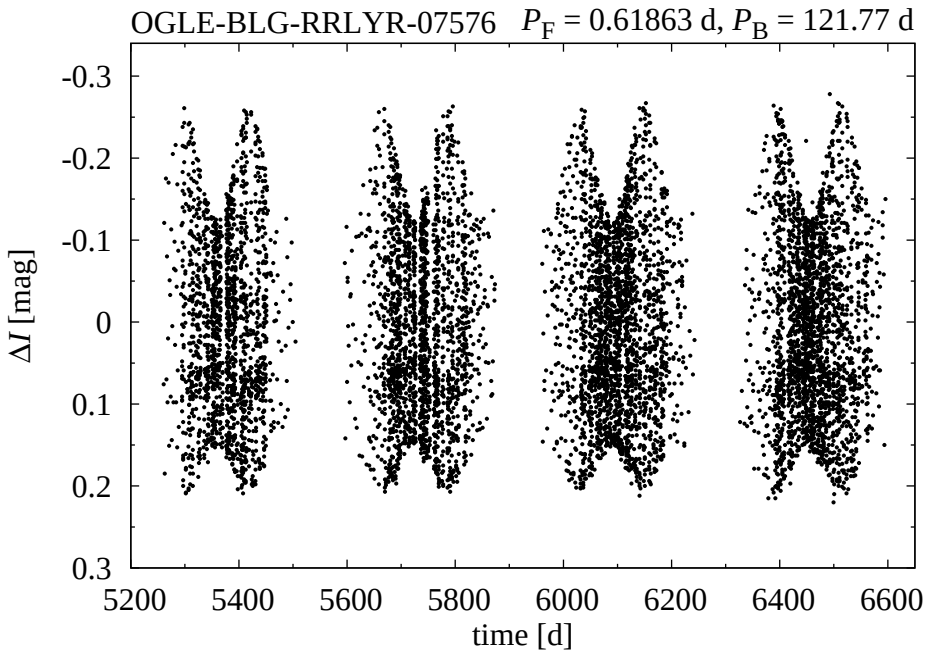
OGLE – Optical Gravitational Lensing Experiment

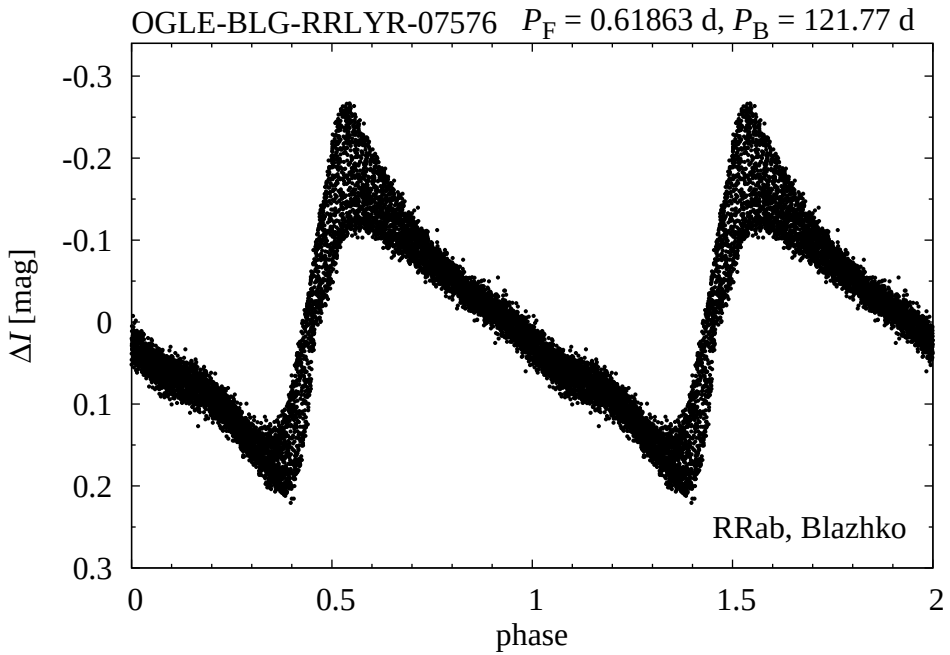


- Warsaw University project
- 1.3 m telescope, Las Campanas, Chile
- regular monitoring of over billion stars, including a few hundred thousand pulsators

photo: www.astrouw.edu.pl

Blazhko effect – modulated RR Lyr stars

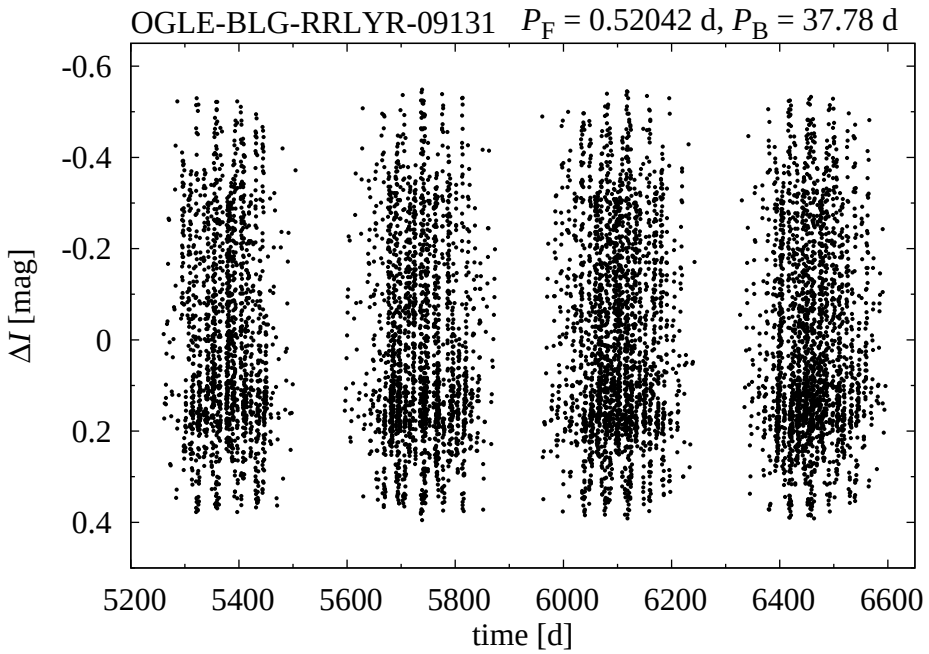


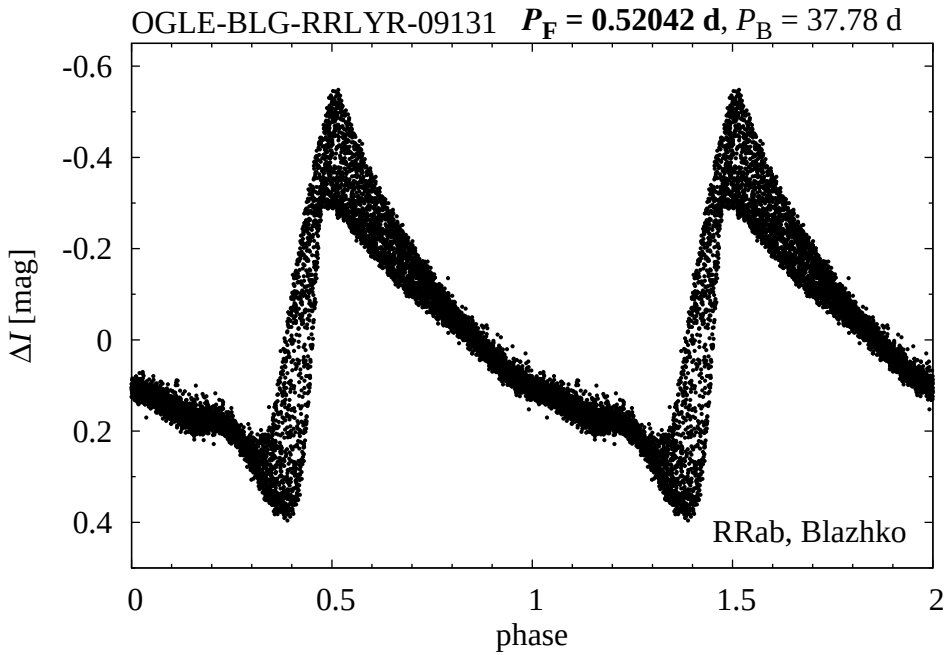


- quasi-periodic modulation of pulsation amplitude and/or phase (S. Blazhko)
- modulation periods vary from a few to more than thousand of days
- Nearly 50% of RRab stars show the effect (and about 10% of RRc stars)
- the mechanism behind the modulation remains unknown

data: OGLE-IV

Blazhko effect – modulated RR Lyr stars





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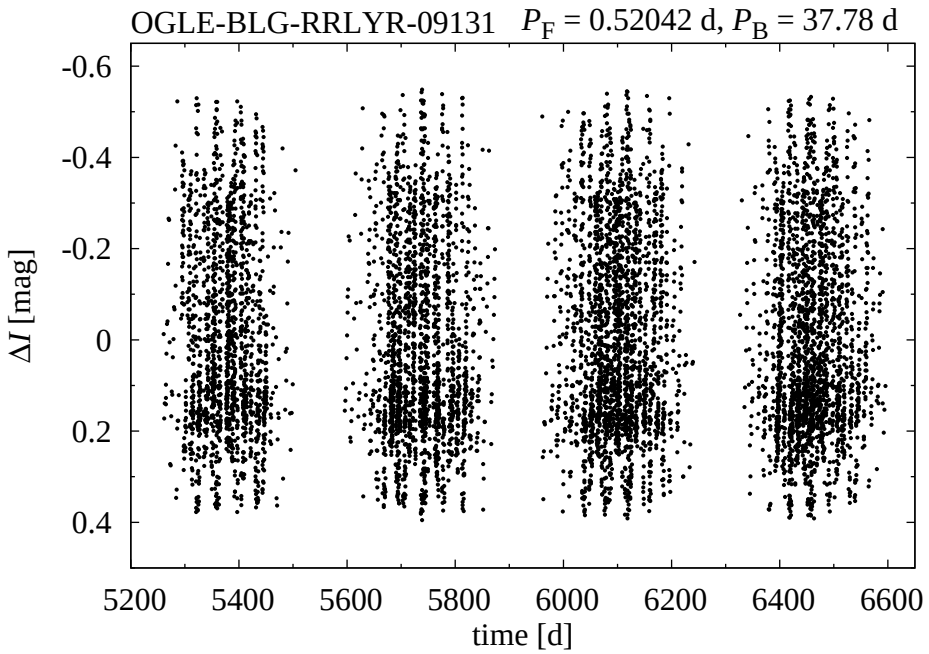
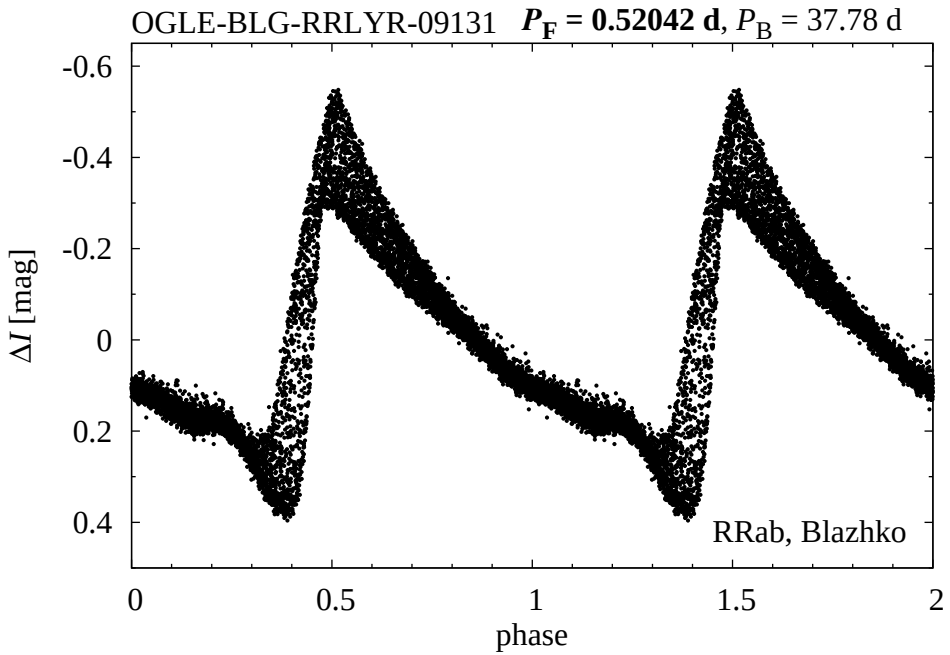
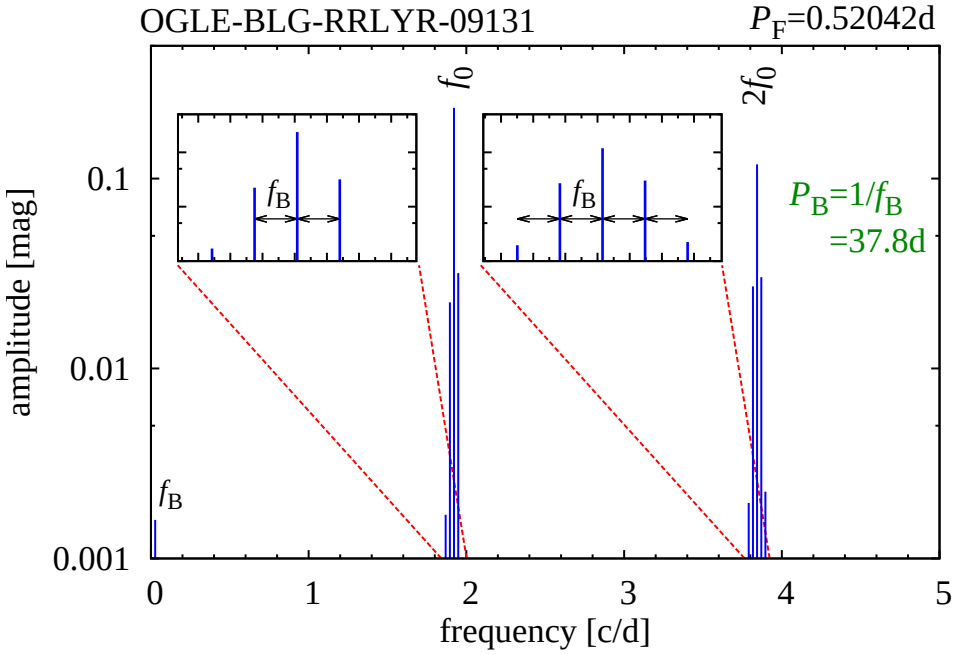
Blazhko effect – modulated RR Lyr stars







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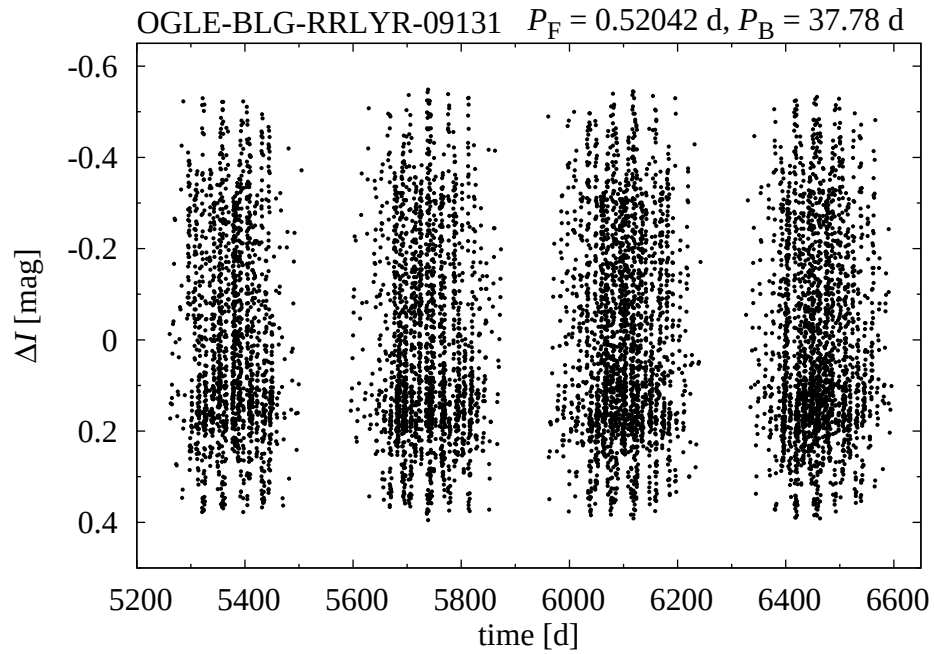
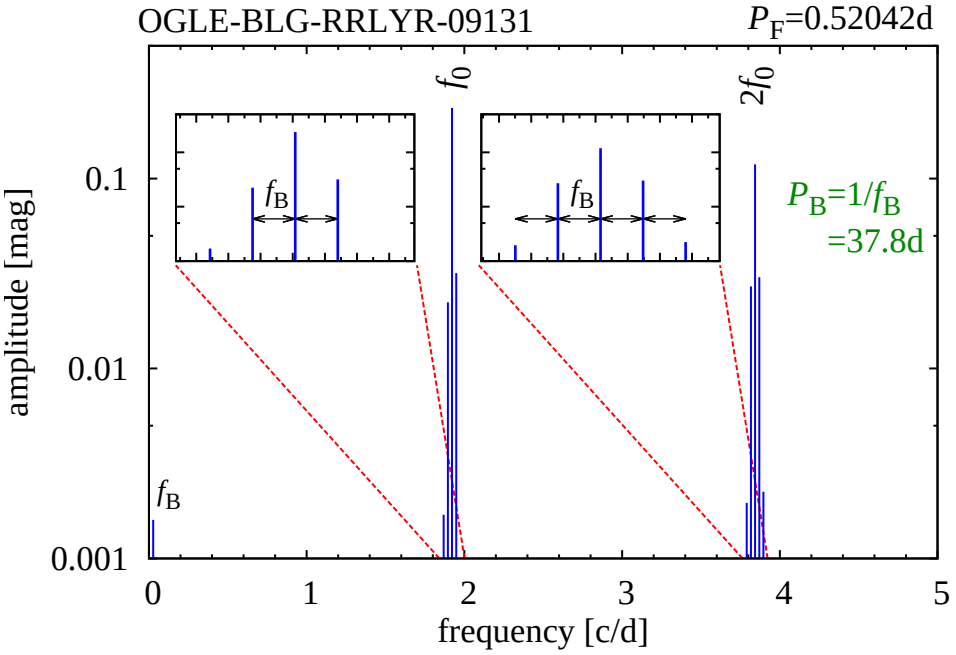
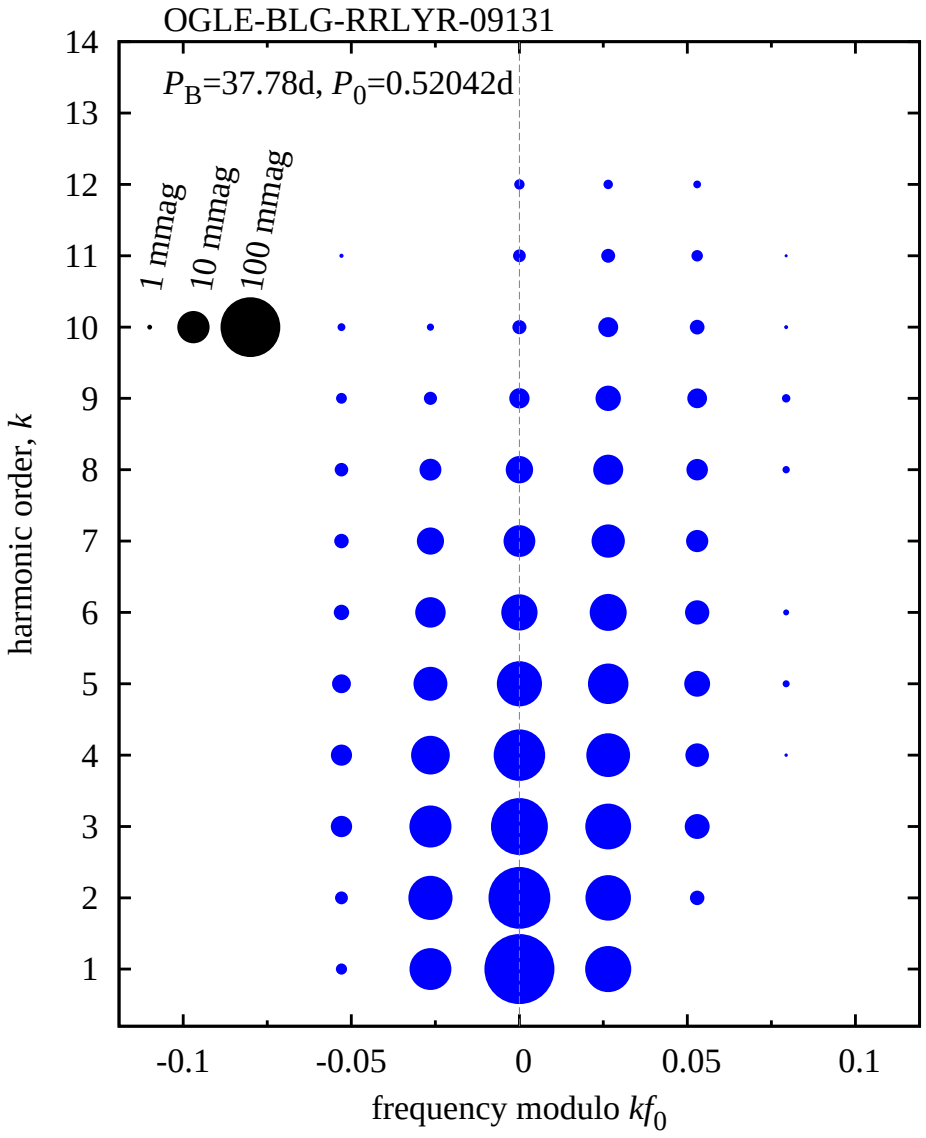
Blazhko effect – modulated RR Lyr stars





'Echelle' diagram:



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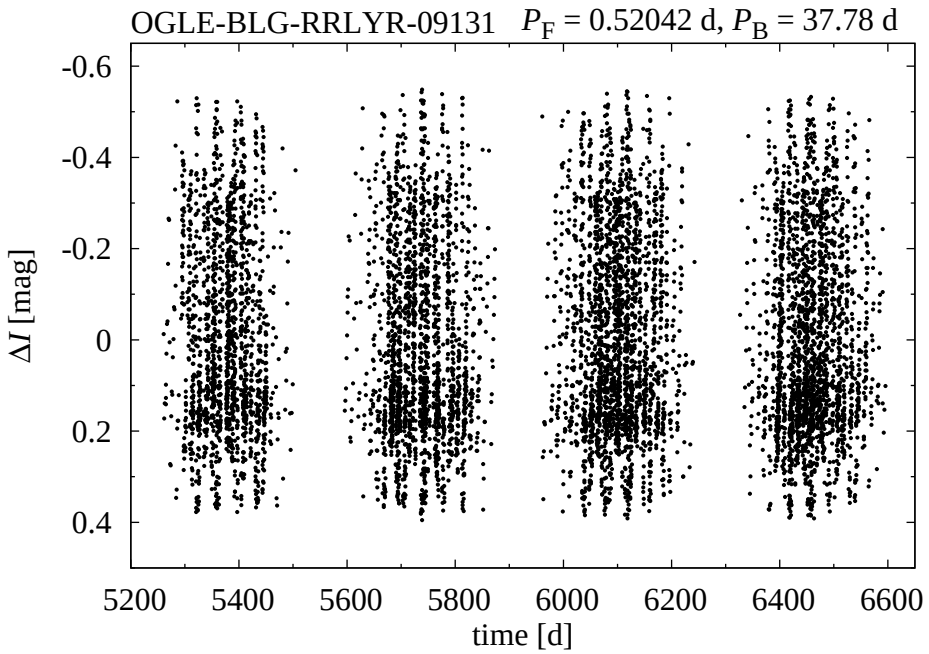
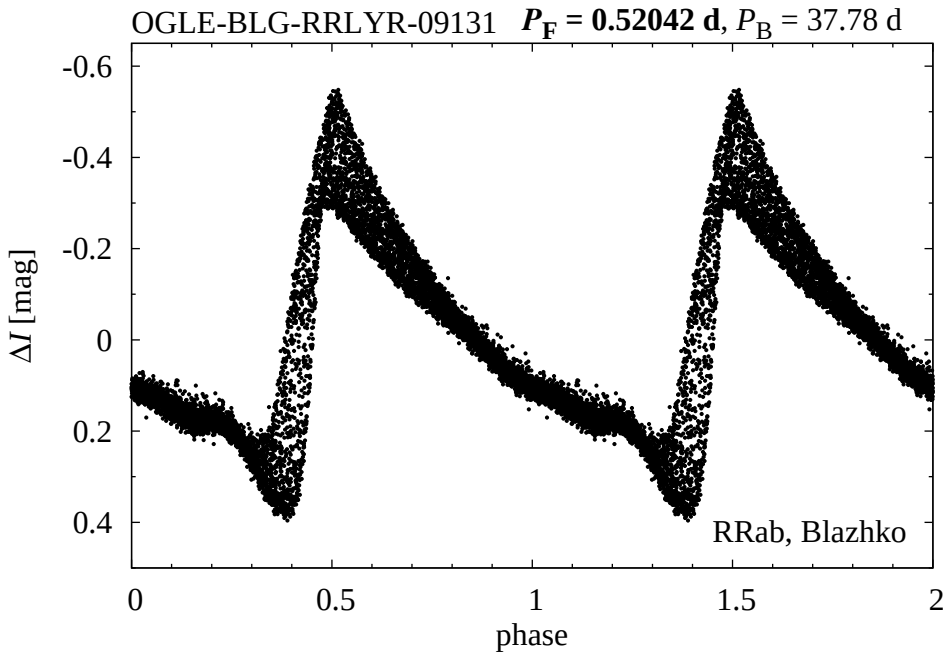
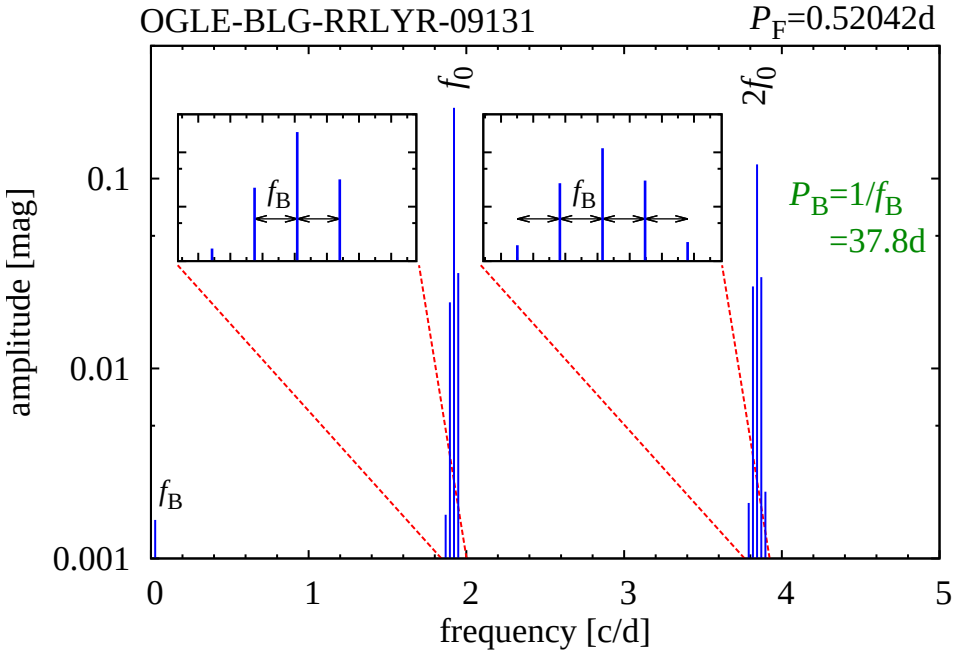
Blazhko effect – modulated RR Lyr stars







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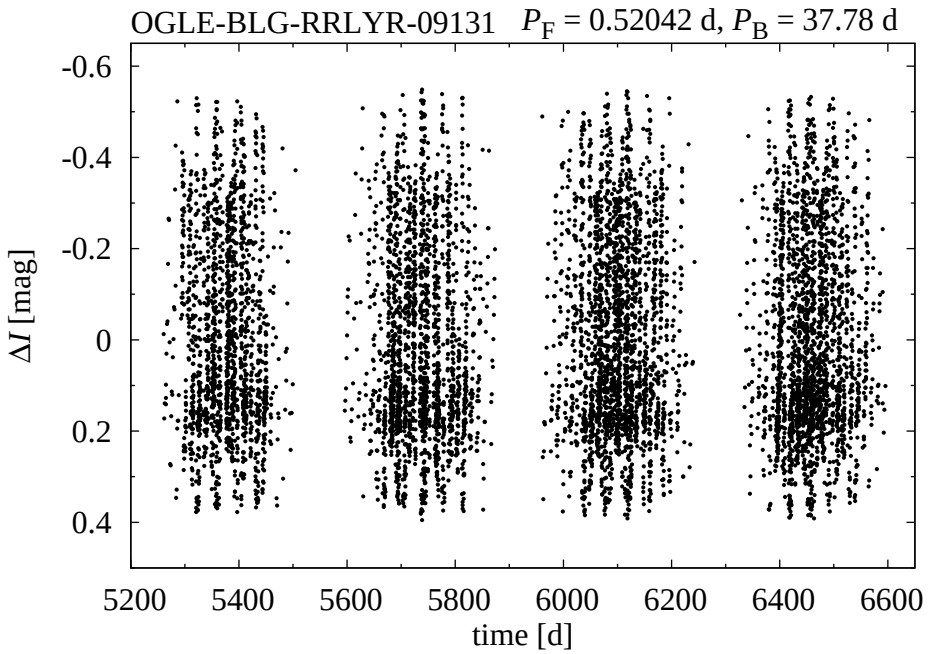

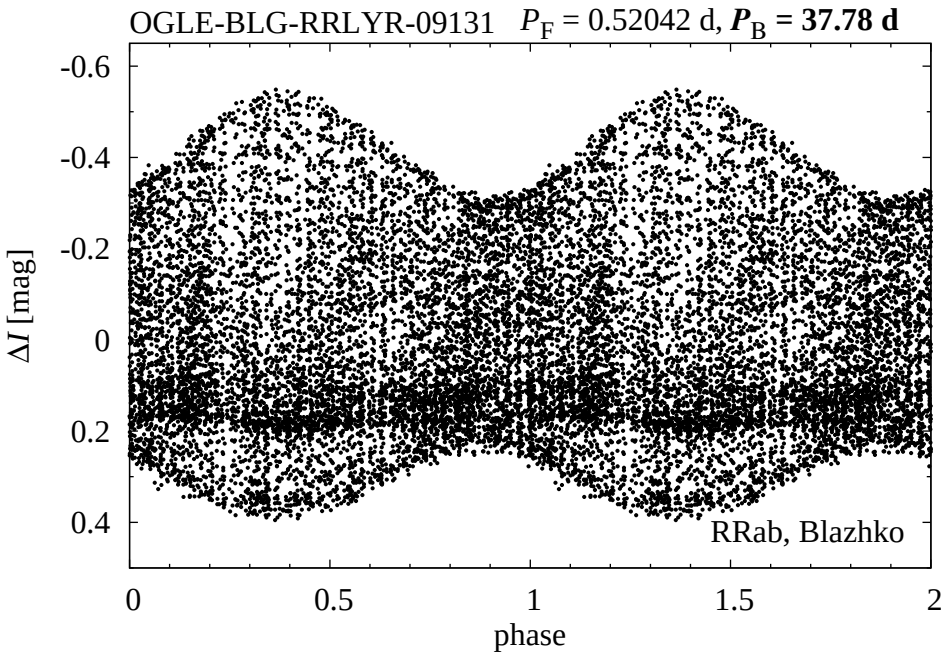

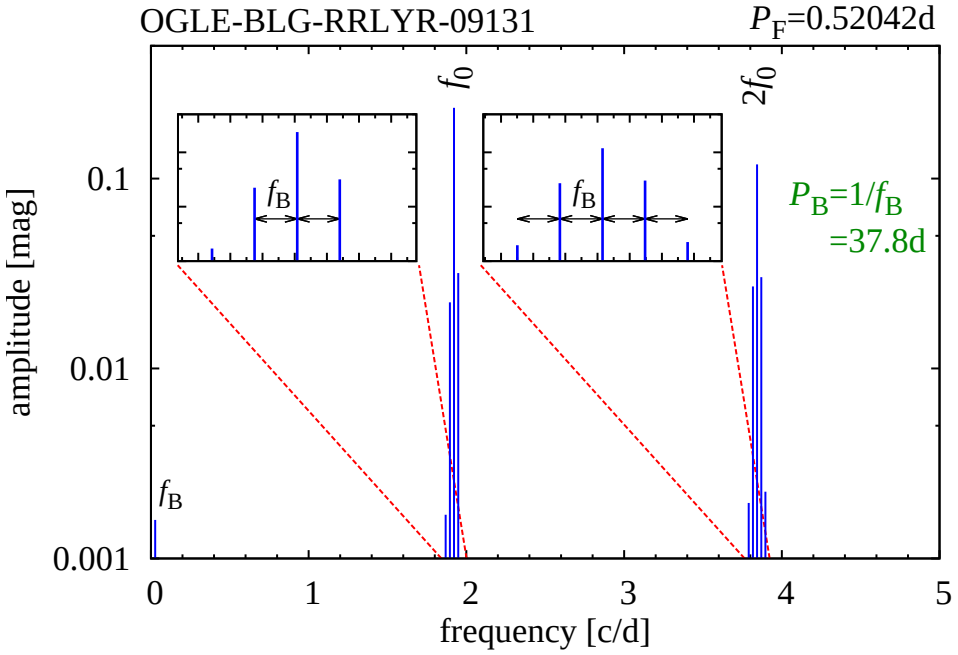

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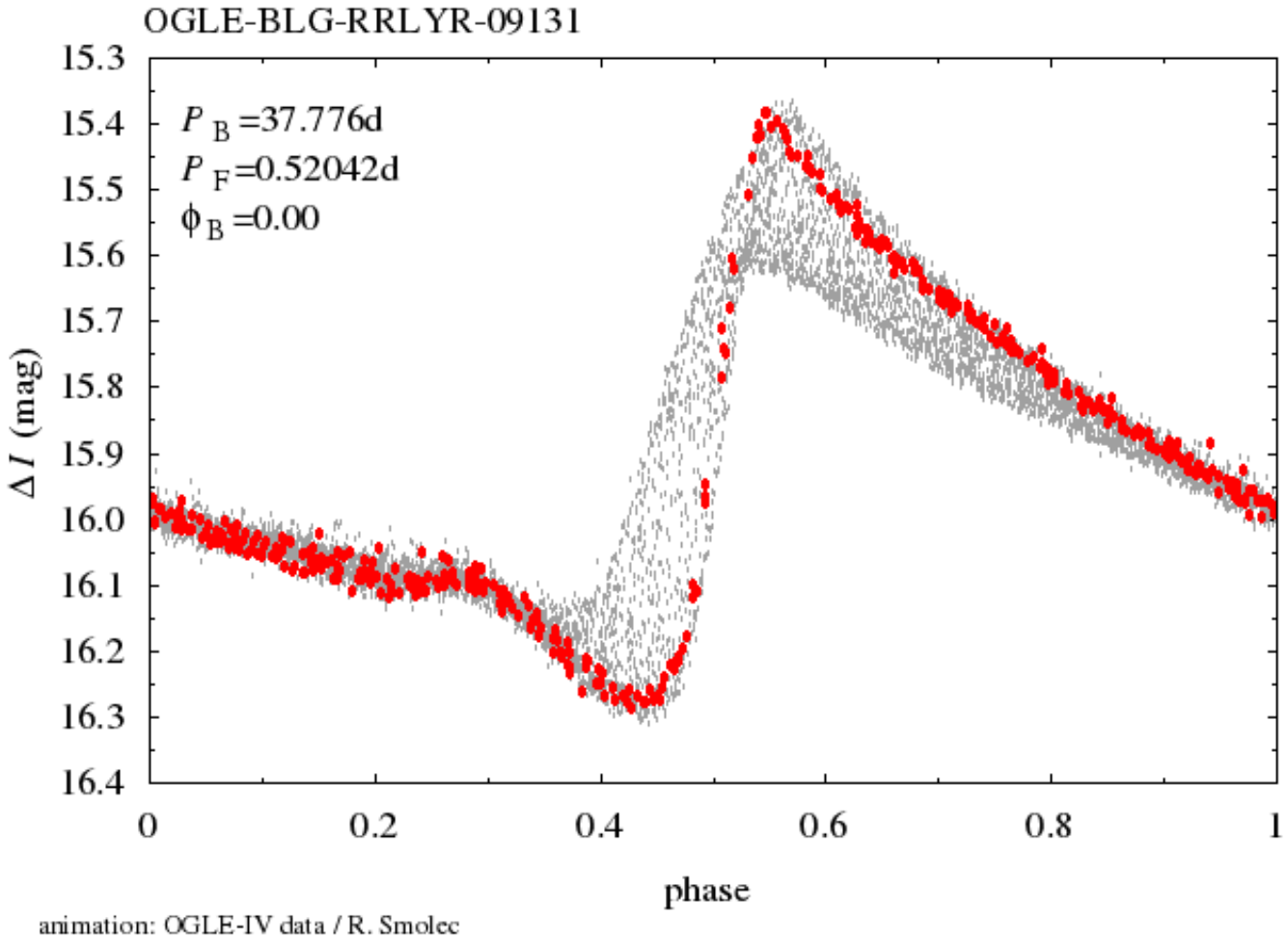
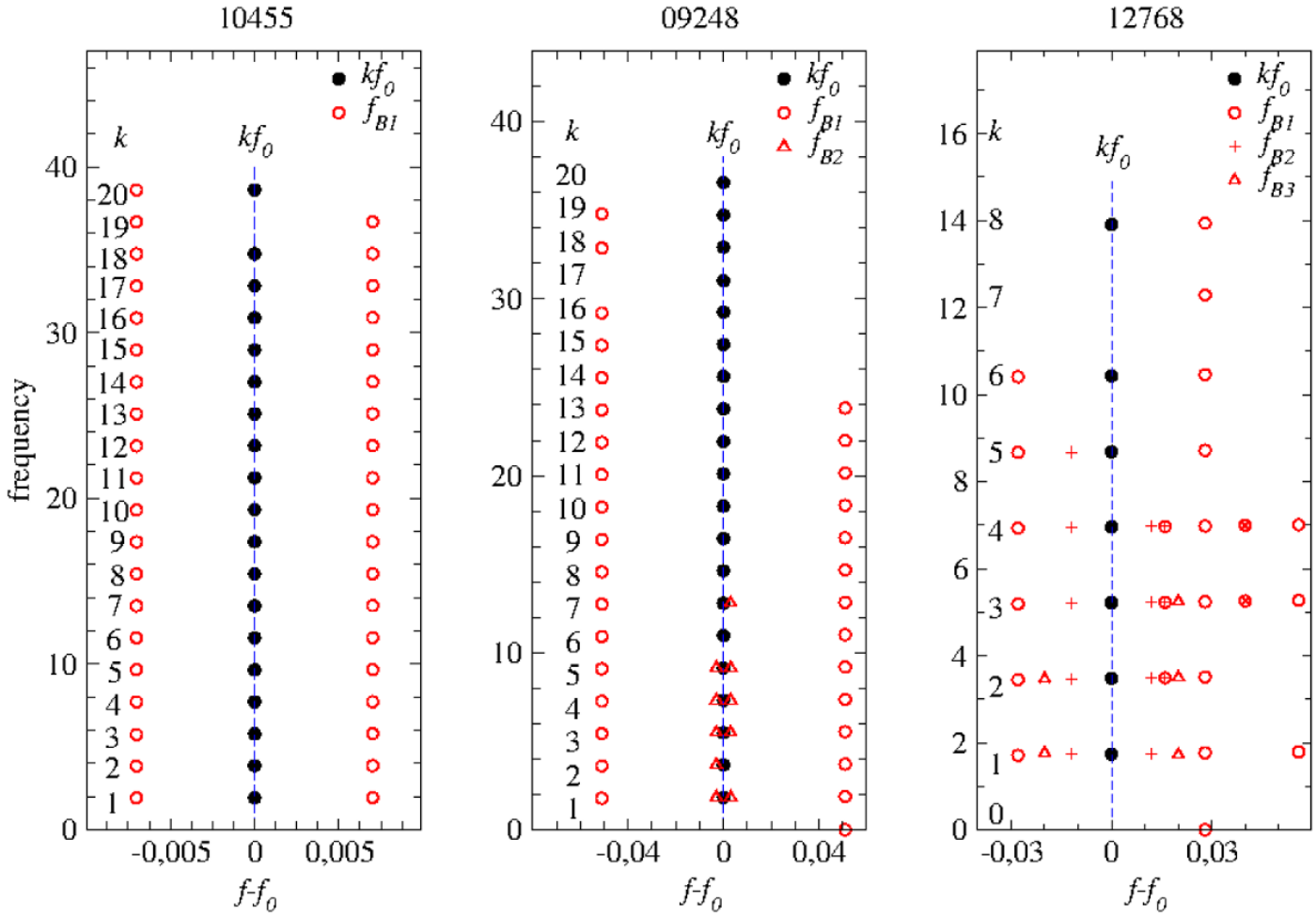
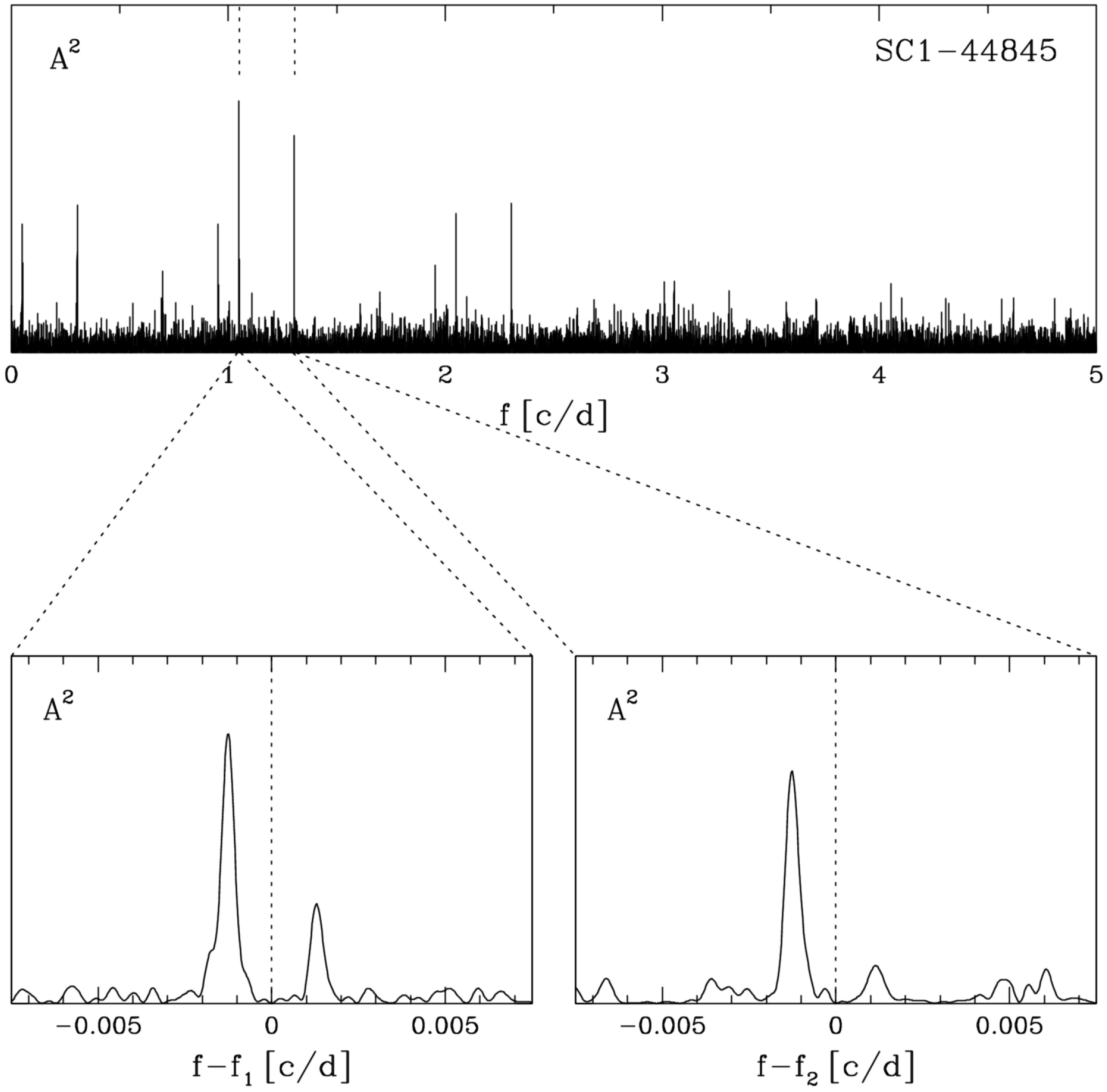


animation: OGLE-IV data / R. Smolec

OGLE-IV data are invaluable for the study of the Blazhko effect – see a poster by Bąkowska & Smolec



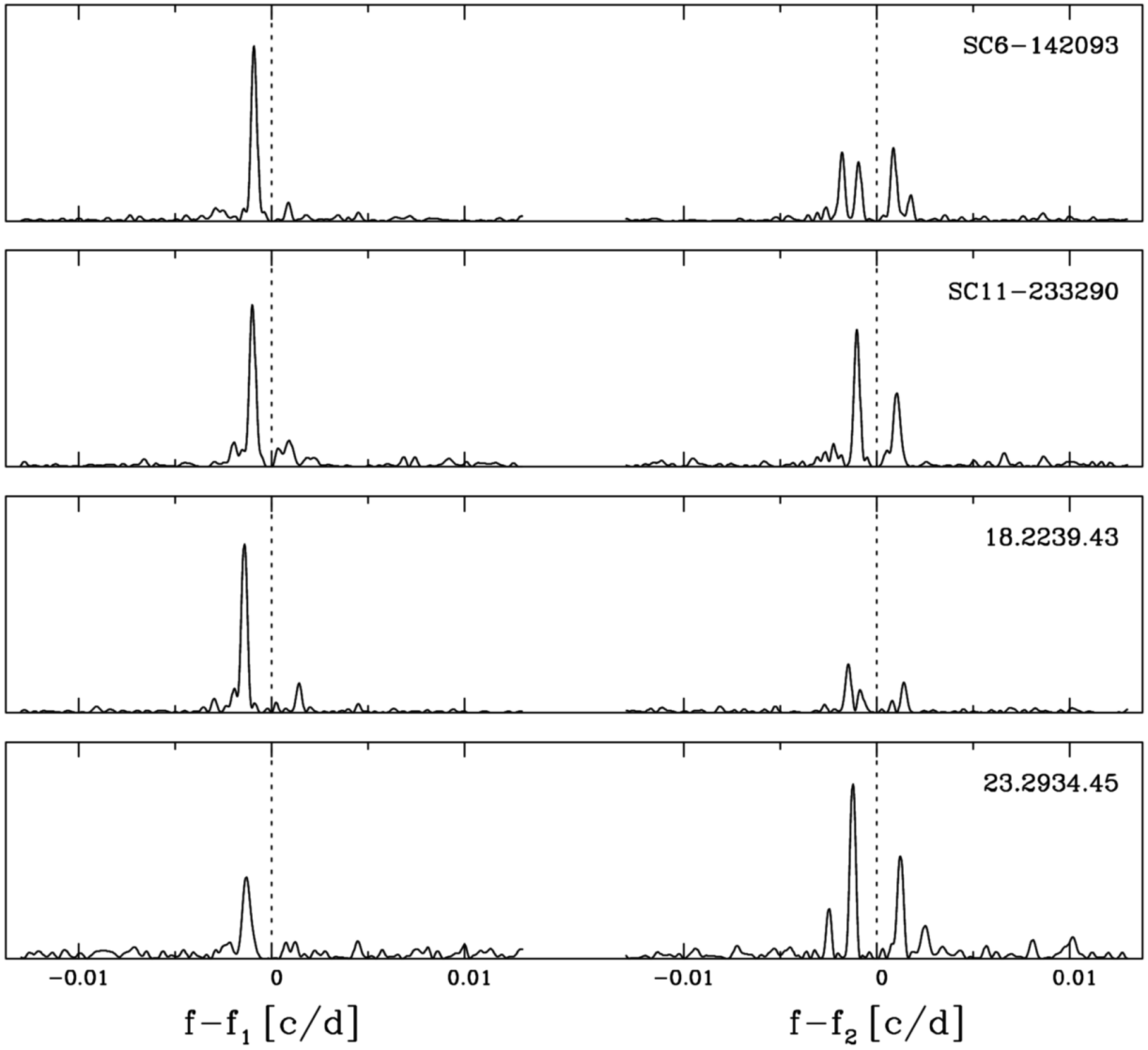
Blazhko effect in double-overtone Cepheids



- Moskalik & Kołaczkowski (2009): analysis of OGLE-II and MACHO data for LMC Cepheids
- discovery of non-radial modes
- discovery of Blazhko effect in 1O+2O stars
- both modes modulated with common and long (>700 d) period

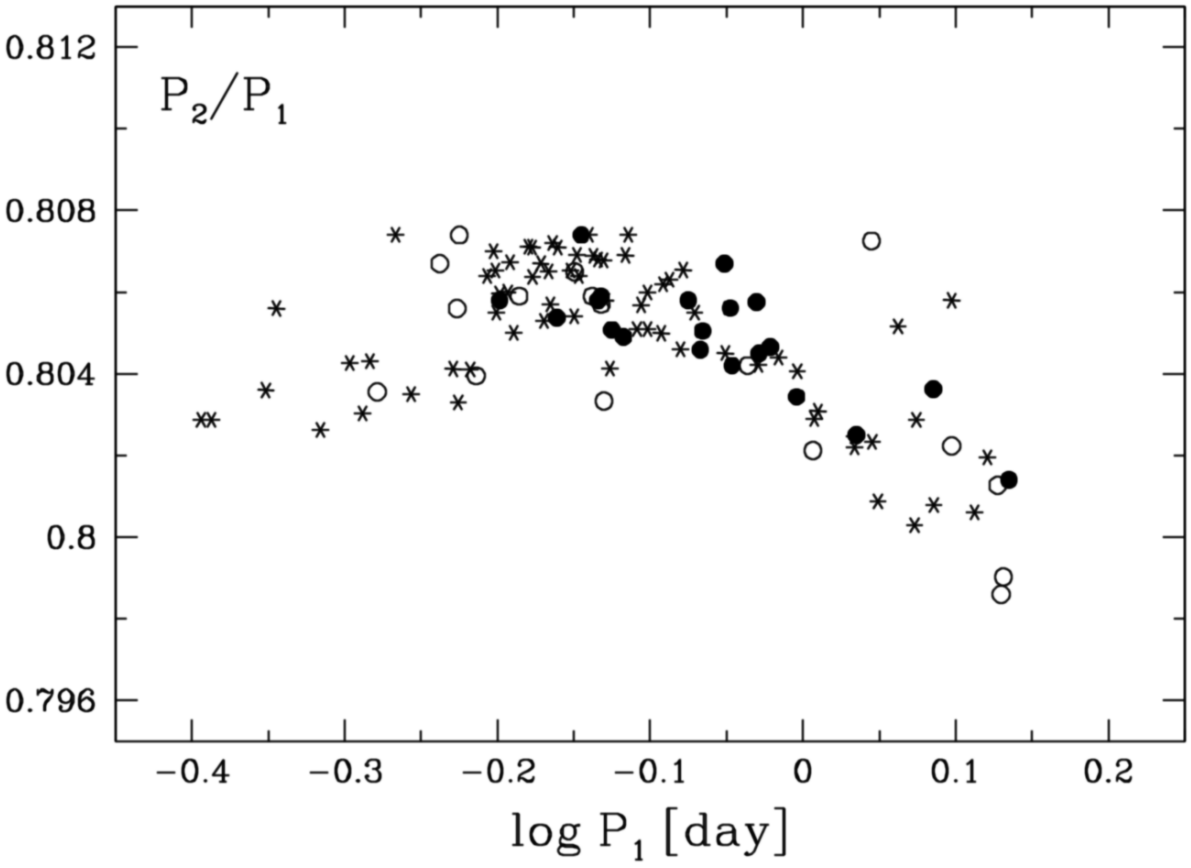
Moskalik & Kołaczkowski (2009)

Blazhko effect in double-overtone Cepheids



Moskalik & Kołaczkowski (2009)

Blazhko effect in double-overtone Cepheids

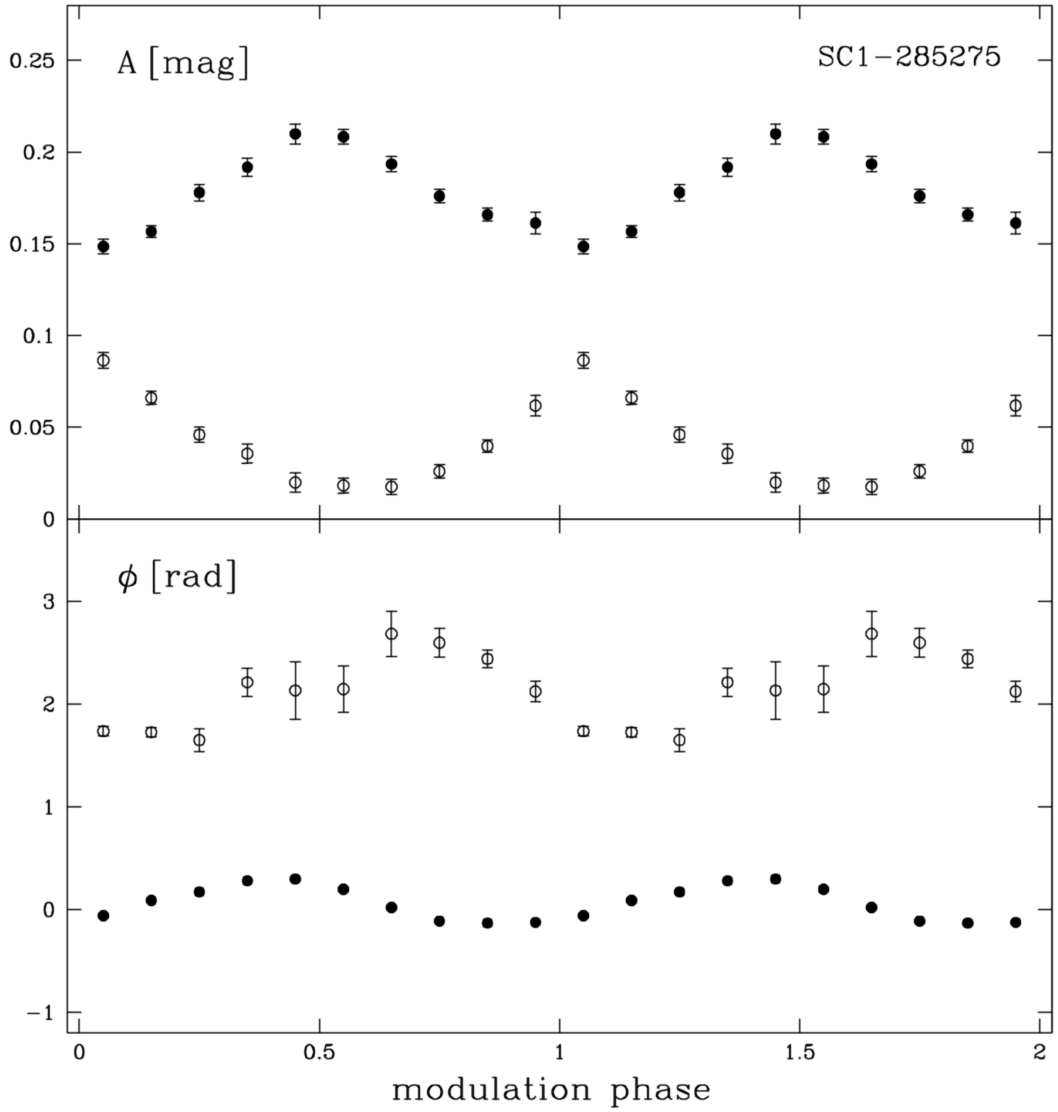


- Blazhko effect
- ○ period change

- ▸ Incidence rate is at least 18.7%
- ▸ Period ratios for the modulated stars are typical

Moskalik & Kołaczkowski (2009)

Blazhko effect in double-overtone Cepheids



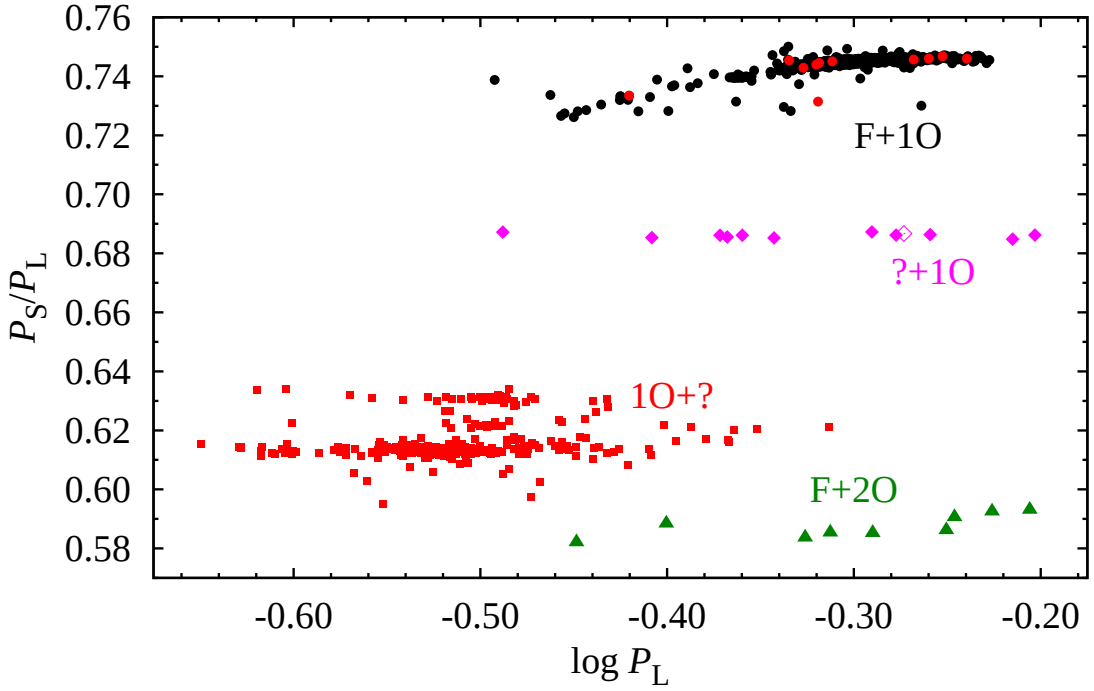
- 1O
- 2O

- Amplitudes are anti-correlated

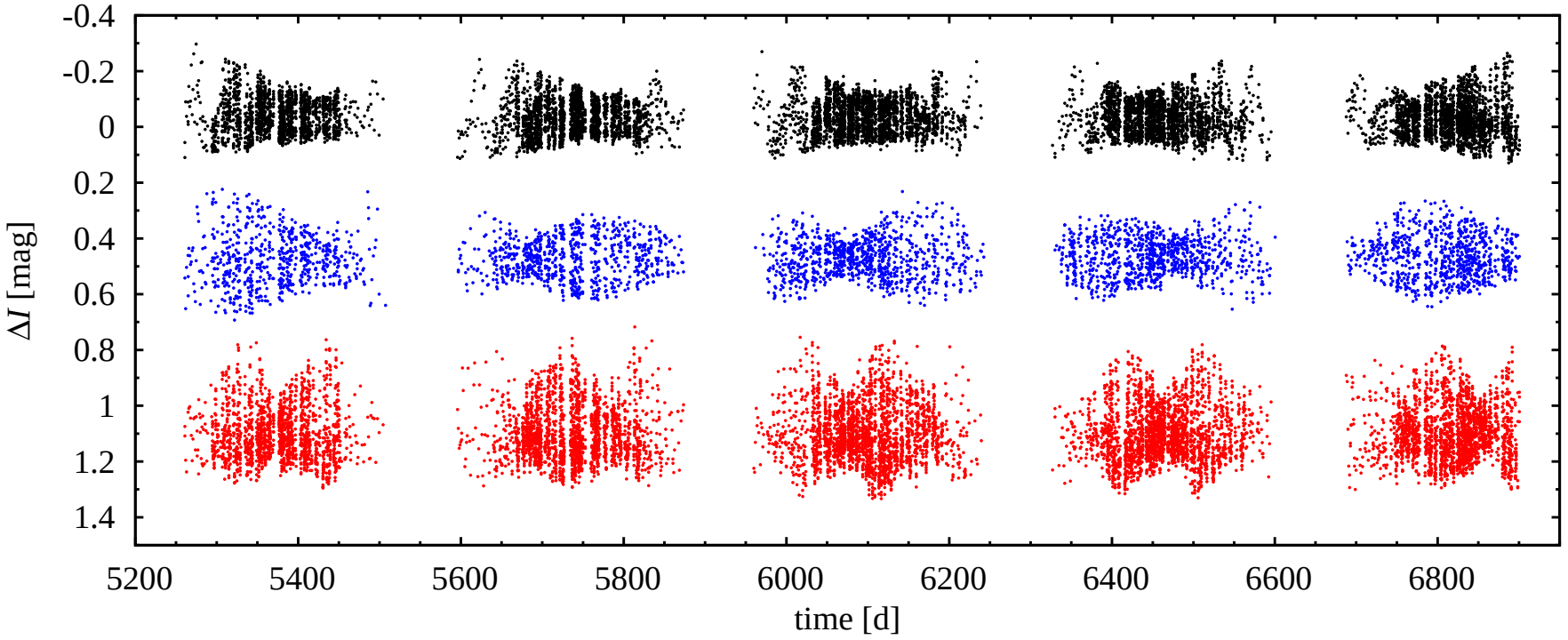
Moskalik & Kołaczkowski (2009)

Double-mode RR Lyrae stars (RRd stars)

Petersen diagram:

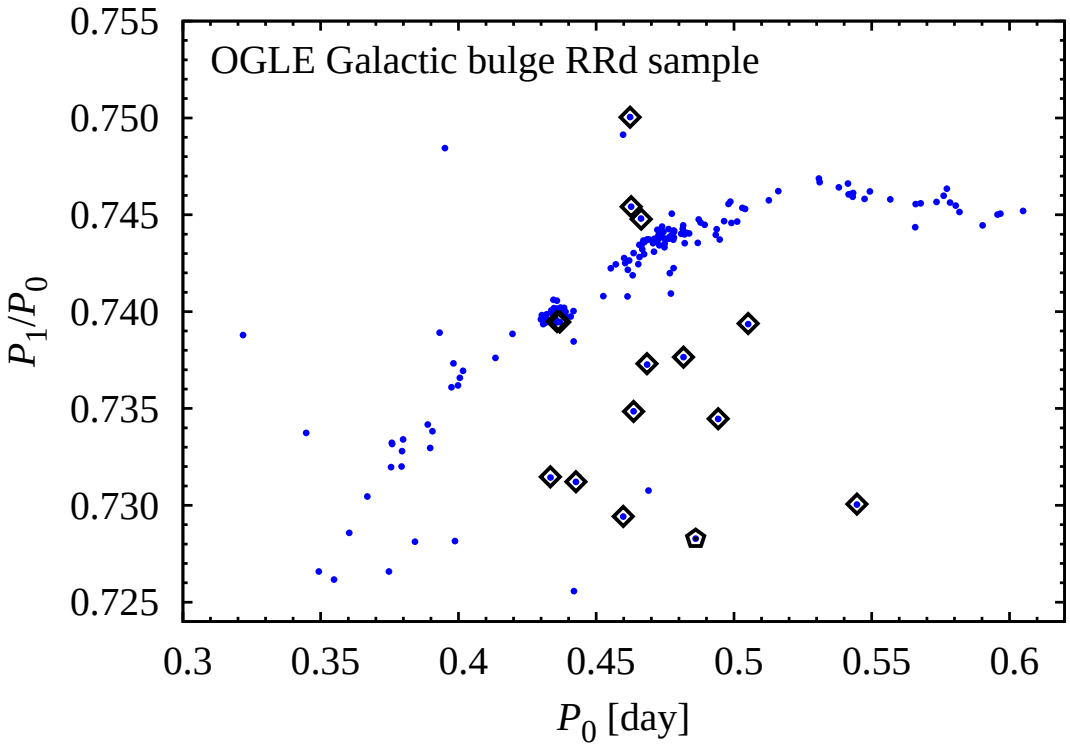


Blazhko effect in double-mode RR Lyr stars



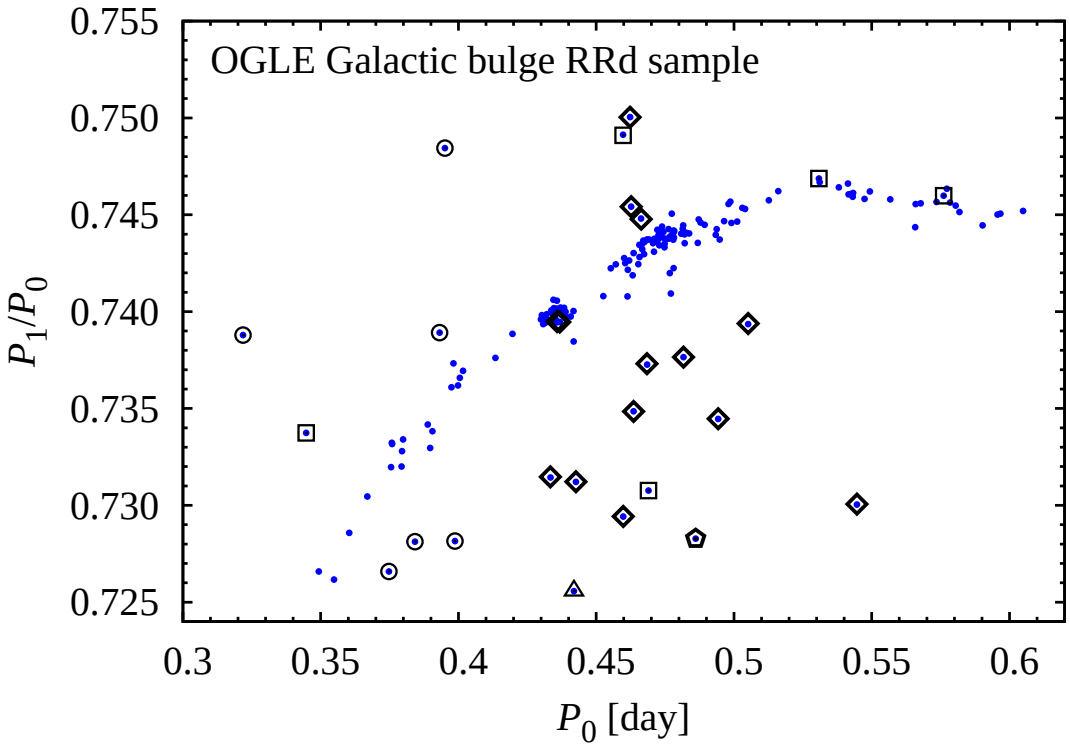
- ⋆ The effect discovered by Soszyński et al. (2014) in a few RRd stars
- ⋆ These stars and several candidates subjected to detailed analysis
- ⋆ The majority of the modulated RRd stars have atypical period ratio
- ⋆ Candidate stars and all stars with atypical period ratios were analysed in Smolec et al. (2015a)

Blazhko effect in double-mode RR Lyr stars



Smolec et al. (2015)

Blazhko effect in double-mode RR Lyr stars



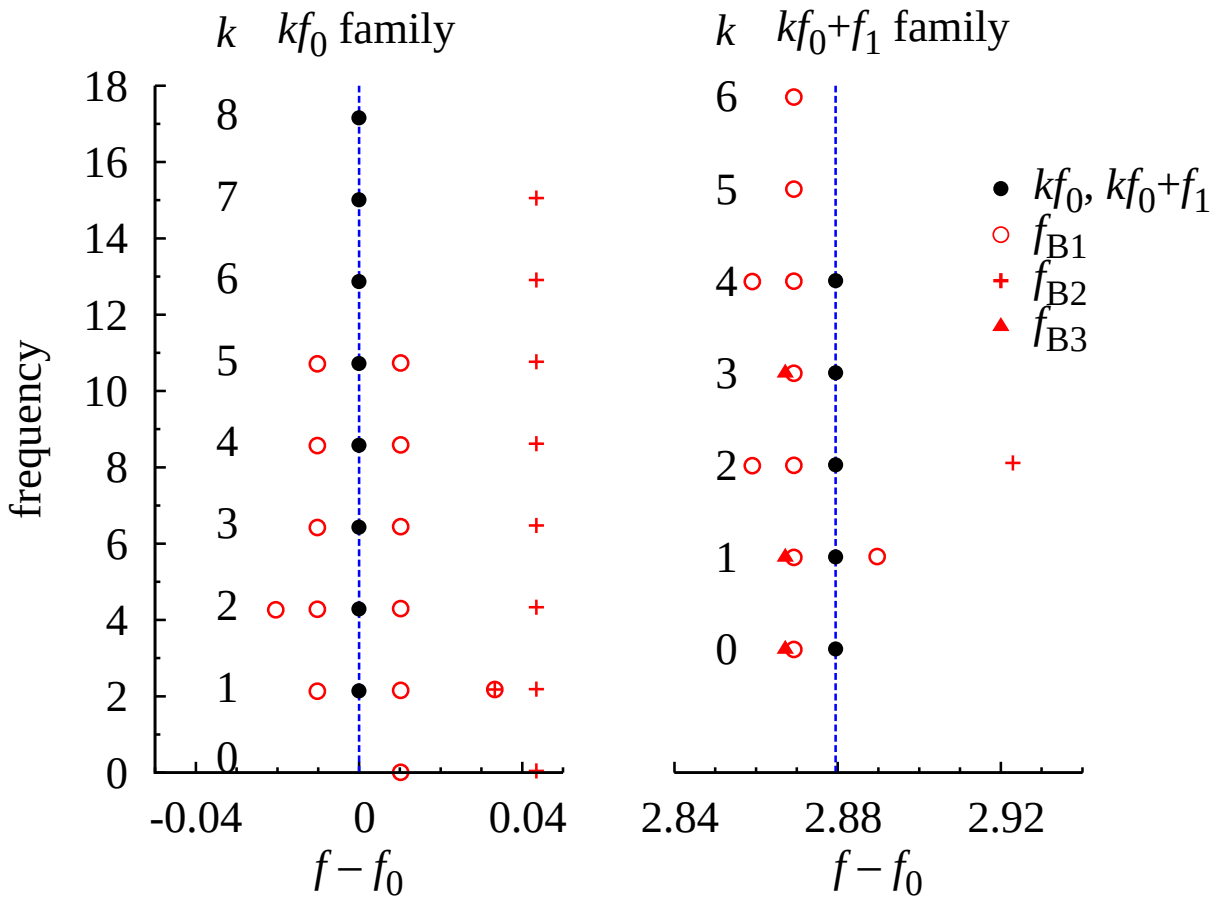
- ○ no close secondary peaks
- □ long-term variation of first overtone
- △ triple-mode RR Lyr with period doubling (Smolec et al. 2015b)

Smolec et al. (2015)

Blazhko effect in double-mode RR Lyr stars

star	P_0 [d]	P_1 [d]	P_1/P_0	A_0 [mmag]	A_1 [mmag]	remarks
RRLYR-00951	**0.5446346(5)**	0.3976184(3)	0.7301	*73.4	*58.0	
RRLYR-02530	**0.463563(1)**	0.3406466(7)	0.7348	95.6	*67.3	
RRLYR-02862	0.459812(1)	**0.3354003(6)**	0.7294	*51.1	80.6	
RRLYR-04598	0.4622854(6)	**0.3467316(4)**	0.7500	65.0	*71.0	$P_1:P_0 = 3:4$
RRLYR-05762	**0.4662964(1)**	0.3472844(2)	0.7448	94.5	*51.5	
RRLYR-06283	0.5051447(4)	**0.3734973(2)**	0.7394	52.4	*62.5	
RRLYR-07393	0.4626908(7)	**0.3448965(3)**	0.7454	44.7	*56.7	$P_x/P_1 = 0.6163$
RRLYR-09284	0.4367995(4)	**0.3229961(1)**	0.7395	25.5	59.9	tidal stream
RRLYR-10728	**0.4816759(3)**	0.3553089(5)	0.7377	*179.7	*54.6	
RRLYR-11311	0.468425(1)	**0.3453771(4)**	0.7373	*50.0	*91.5	
RRLYR-13442	**0.486091(1)**	0.354019(1)	0.7283	*115.3	*44.3	mode switch
RRLYR-14915	**0.4333759(6)**	0.3170019(4)	0.7315	*99.9	*64.1	
RRLYR-22356	**0.4426324(2)**	0.3236620(7)	0.7312	*147.3	21.8	
RRLYR-30986	0.494275(1)	**0.3630309(8)**	0.7345	63.8	73.6	
RRLYR-32462	0.4357846(7)	**0.3222566(3)**	0.7395	*67.7	*82.7	tidal stream

Blazhko effect in double-mode RR Lyr stars



		F-mode		1O-mode		
star	P_B [d]	A	struct.	A	struct.	
RRLYR-00951	142.6(3)			5.4	BL2	a
RRLYR-02530	469(3)	22.9	BL1+	*18.7	BL1+	a
RRLYR-02862	173.6(5)	28.3	BL2	10.9	BL1−	a
RRLYR-04598	281(1)	12.8	BL1−			a
	85.7(2)	10.8	BL1−			a
RRLYR-05762	97.95(2)	*53.0	BL2	5.6	BL1−	a, b
	23.000(4)	7.2	BL1+			a, b
	81.10(8)			7.3	BL1−	a
RRLYR-06283	332.8(3)	*37.0	BL1−			a, b
RRLYR-07393	209.7(2)	3.5	BL1+	51.5	BL2	a, b
	322.7(5)	*34.2	BL1+	21.3	BL2	a
RRLYR-09284	41.77(2)	6.3	BL1+			a
	40.75(2)	3.8	BL1−			a
	47.70(5)	2.9	BL1+			a
RRLYR-10728	98.71(8)	26.8	BL1+	8.1	BL1−	a, b
	313(1)	9.3	BL1−			a
RRLYR-11311	49.14(2)			*32.3	BL1−	a, b
	87.1(2)	13.7	BL1+			s
RRLYR-13442	179.1(9)	*14.0	BL1+			
RRLYR-14915	62.86(1)			*39.2	BL1−	a, b, s
RRLYR-22356	255.3(4)	40.0	BL1−			a, b
	51.59(4)			15.0	BL1+	a
	32.46(1)	7.4	BL1−			
RRLYR-30986	111.4(1)	51.0	BL1−	14.4	BL1−	a
RRLYR-32462	190.1(3)			*31.4	BL1+	a, b
	125.6(2)	23.3	BL1+	8.9	BL1−	a

Properties of the modulation:

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Properties of the modulation:

- periods $\sim 40 - 470$ d
- up to three modulation periods
- typically, different modulation periods for F and 1O

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Properties of the modulation:

- periods $\sim 40 - 470$ d
- up to three modulation periods
- typically, different modulation periods for F and 1O
- triplet structures in only 4 stars
- doublet structure is common

		F-mode		1O-mode		
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	32.46(1)	7.4	BL1−			
RRLYR-30986	111.4(1)	51.0	BL1−	14.4	BL1−	a
RRLYR-32462	190.1(3)			*31.4	BL1+	a, b
	125.6(2)	23.3	BL1+	8.9	BL1−	a

Properties of the modulation:

- periods $\sim 40 - 470$ d
- up to three modulation periods
- typically, different modulation periods for F and 1O
- triplet structures in only 4 stars
- doublet structure is common
- modulation amplitudes $\sim 5 - 50$ mmag
- nonstationary modulation side-peaks

		F-mode		1O-mode		
star	P_B [d]	A	struct.	A	struct.	
RRLYR-00951	142.6(3)			5.4	BL2	a
RRLYR-02530	469(3)	22.9	BL1+	*18.7	BL1+	a
RRLYR-02862	173.6(5)	28.3	BL2	10.9	BL1−	a
RRLYR-04598	281(1)	12.8	BL1−			a
	85.7(2)	10.8	BL1−			a
RRLYR-05762	97.95(2)	*53.0	BL2	5.6	BL1−	a, b
	23.000(4)	7.2	BL1+			a, b
	81.10(8)			7.3	BL1−	a
RRLYR-06283	332.8(3)	*37.0	BL1−			a, b
RRLYR-07393	209.7(2)	3.5	BL1+	51.5	BL2	a, b
	322.7(5)	*34.2	BL1+	21.3	BL2	a
RRLYR-09284	41.77(2)	6.3	BL1+			a
	40.75(2)	3.8	BL1−			a
	47.70(5)	2.9	BL1+			a
RRLYR-10728	98.71(8)	26.8	BL1+	8.1	BL1−	a, b
	313(1)	9.3	BL1−			a
RRLYR-11311	49.14(2)			*32.3	BL1−	a, b
	87.1(2)	13.7	BL1+			s
RRLYR-13442	179.1(9)	*14.0	BL1+			
RRLYR-14915	62.86(1)			*39.2	BL1−	a, b, s
RRLYR-22356	255.3(4)	40.0	BL1−			a, b
	51.59(4)			15.0	BL1+	a
	32.46(1)	7.4	BL1−			
RRLYR-30986	111.4(1)	51.0	BL1−	14.4	BL1−	a
RRLYR-32462	190.1(3)			*31.4	BL1+	a, b
	125.6(2)	23.3	BL1+	8.9	BL1−	a

Properties of the modulation:

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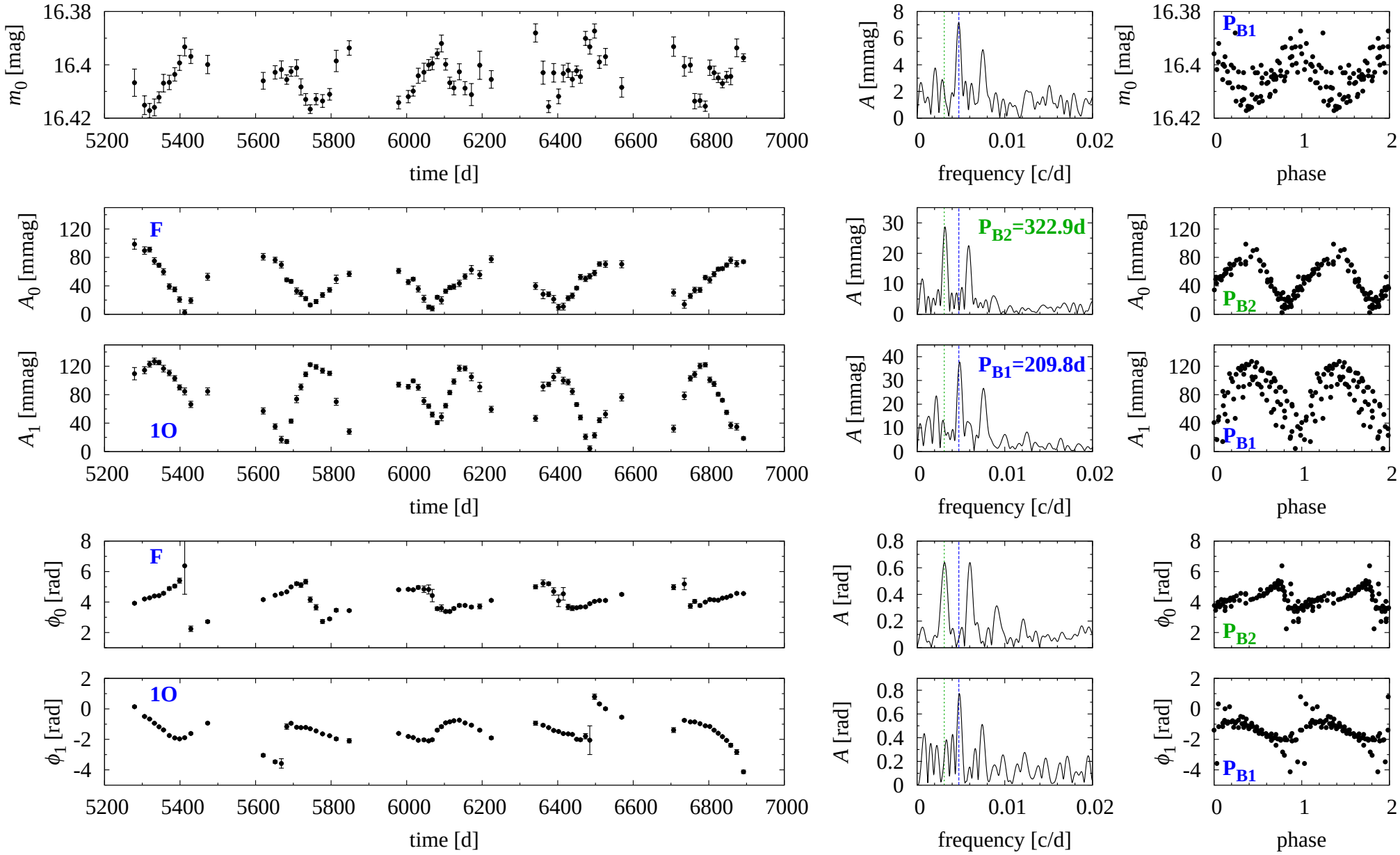
- a – side-peak at comb. freq.
  b – peak at modulation freq.
  s – sub-harmonic of mod. freq.

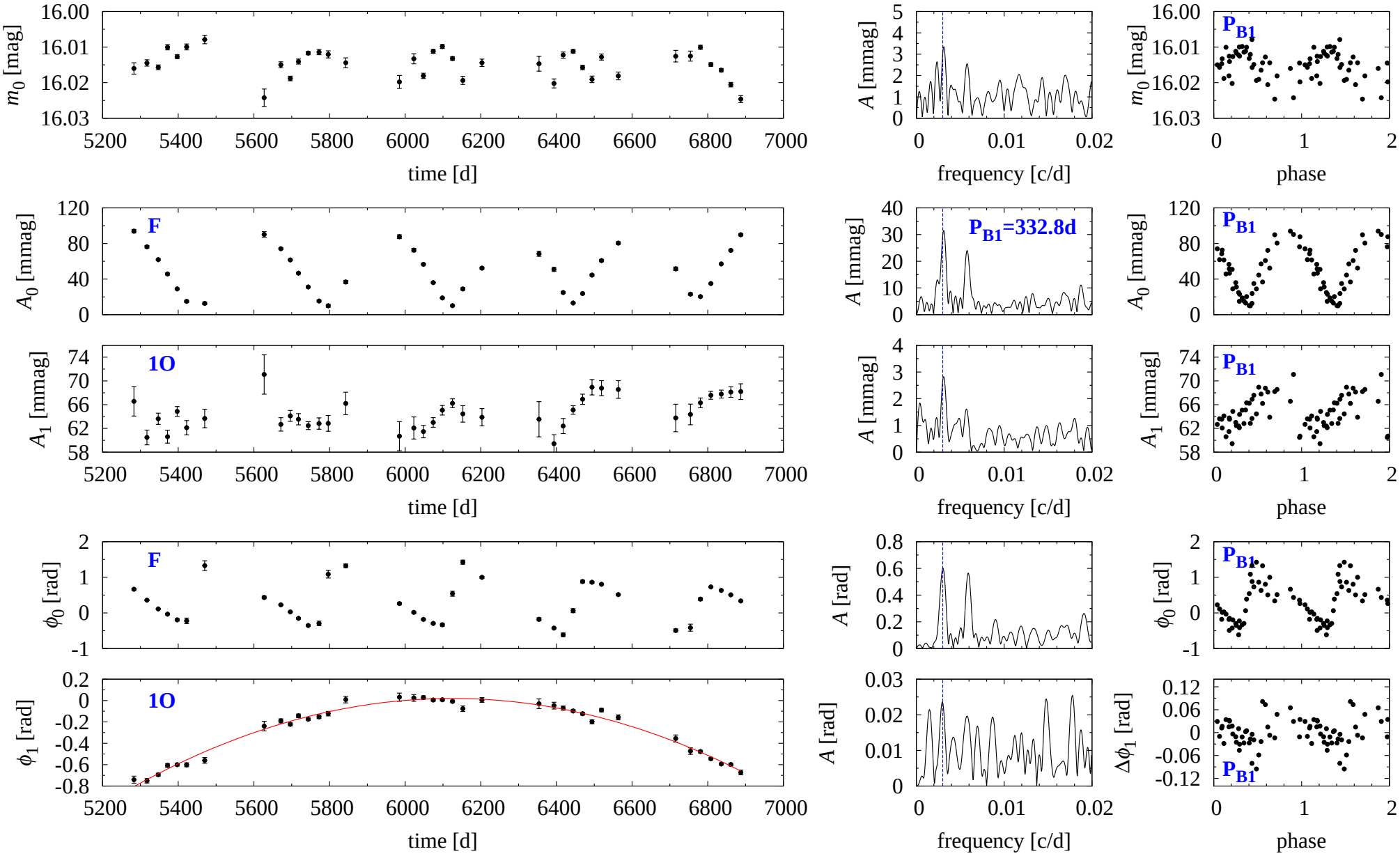
Blazhko effect in double-mode RR Lyr stars

OGLE-BLG-RRLYR-07393



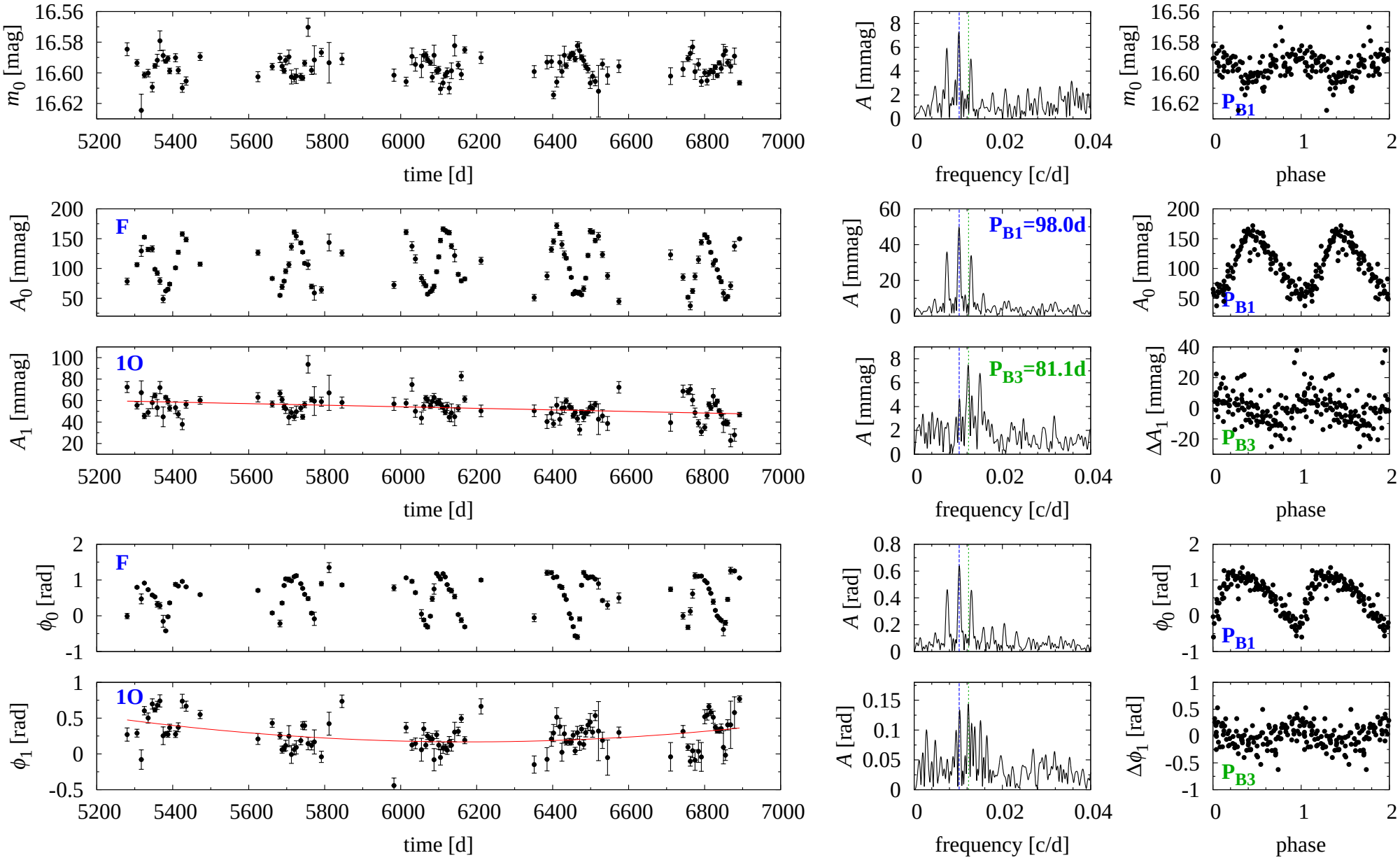
Blazhko effect in double-mode RR Lyr stars

OGLE-BLG-RRLYR-06283

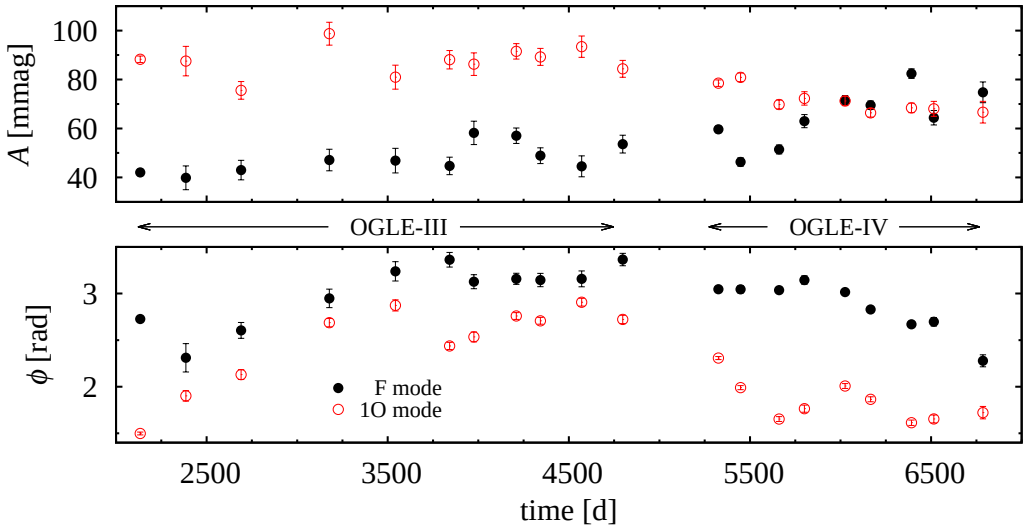


Blazhko effect in double-mode RR Lyr stars

OGLE-BLG-RRLYR-05762



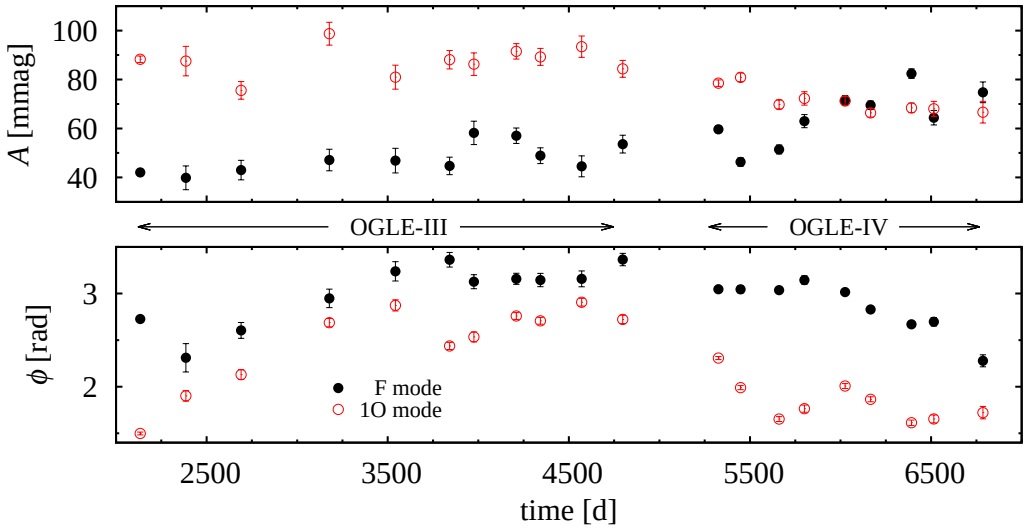
Blazhko effect in double-mode RR Lyr stars



- ⋆ amplitudes and phases of the radial modes vary irregularly on a long time-scale of a few hundred or thousand days
- ⋆ the short-term modulations are also irregular

Smolec et al. (2015)

Blazhko effect in double-mode RR Lyr stars



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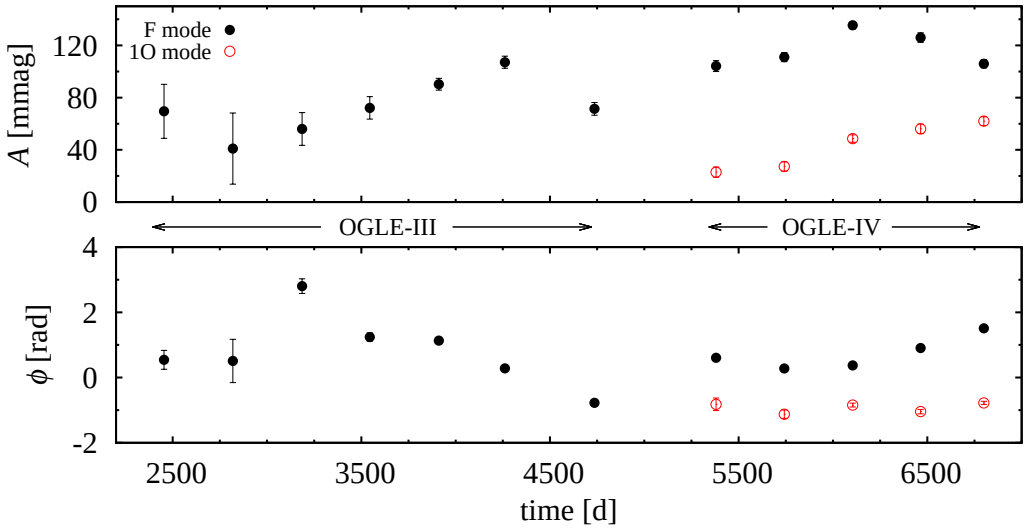
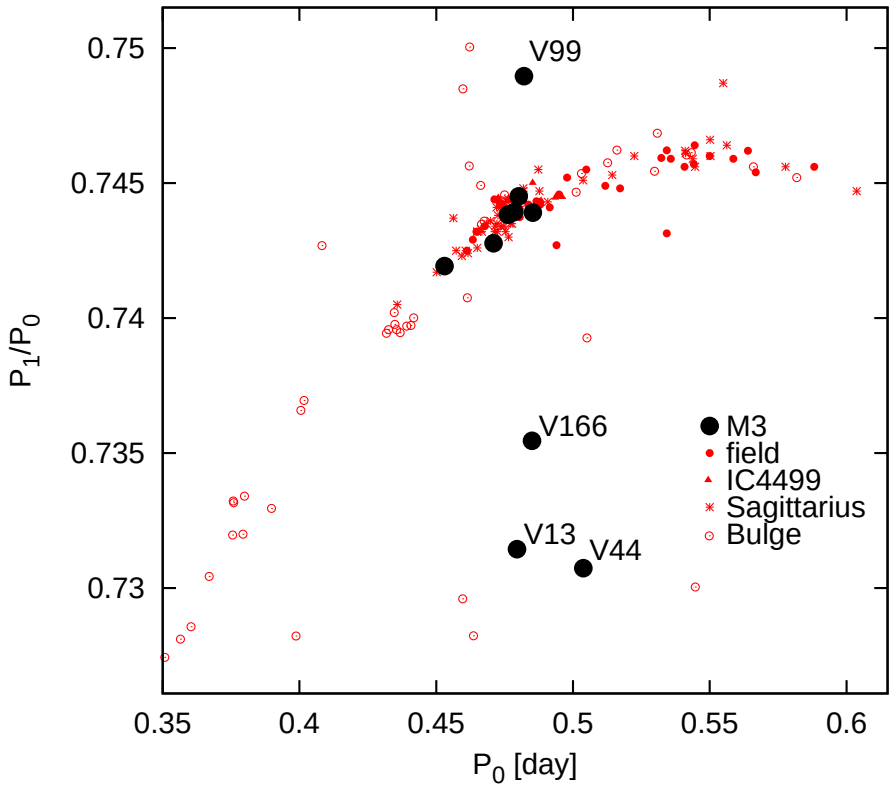
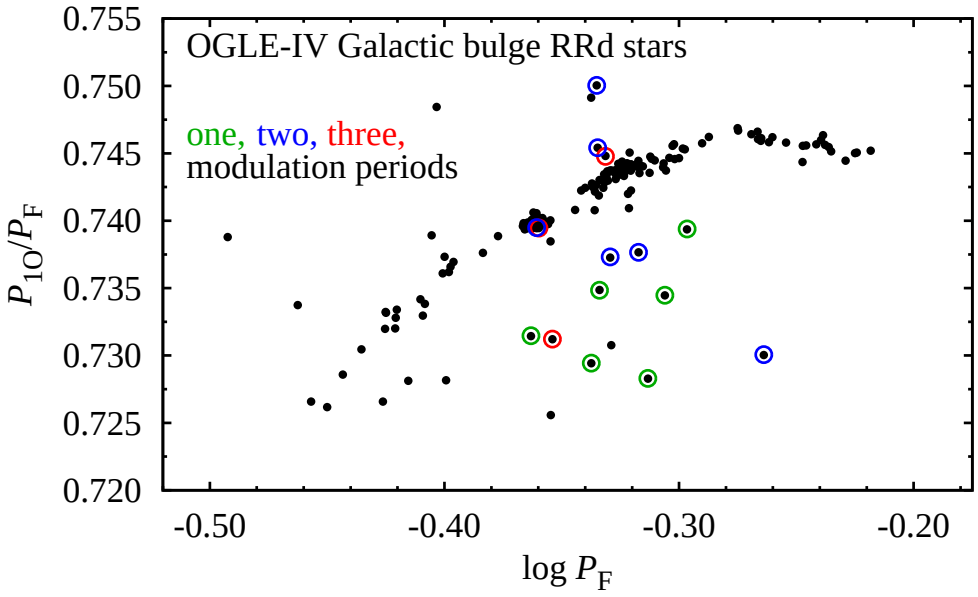


- ⋆ OGLE-BLG-RRLYR-13442 has switched the pulsation mode (RRab→RRd; Soszyński et al. 2014)

Smolec et al. (2015)

Blazhko effect in double-mode RR Lyr stars – M3





Jurcsik et al. (2014)

Blazhko effect in double-mode RR Lyr stars

- properties of modulated RRd stars qualitatively similar in the Galactic bulge and in M3
  - ⋆ non-typical period ratio
  - ⋆ non-stationary variations
- cause of the modulation remains unknown
  - ⋆ in Smolec et al. (2015) we hypothesize that modulation and mode switching may be connected