

Unstable standard candles – periodic modulation of pulsation in Magellanic Clouds' Cepheids

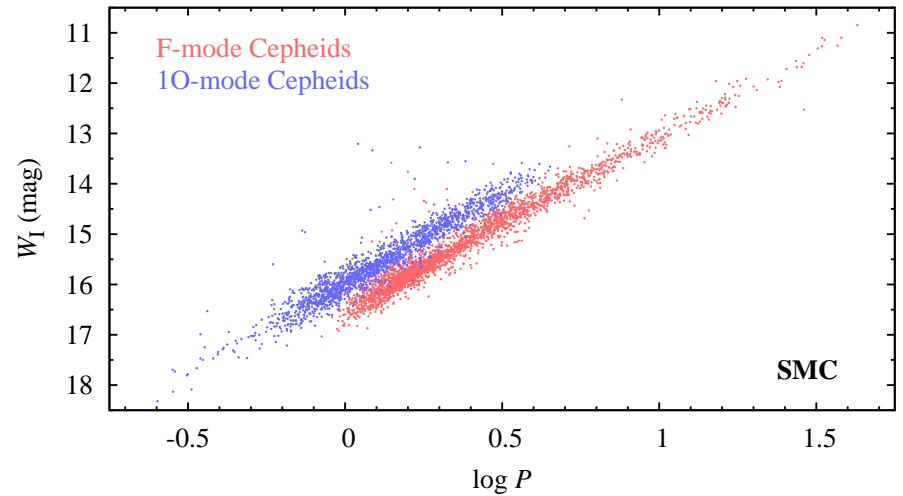
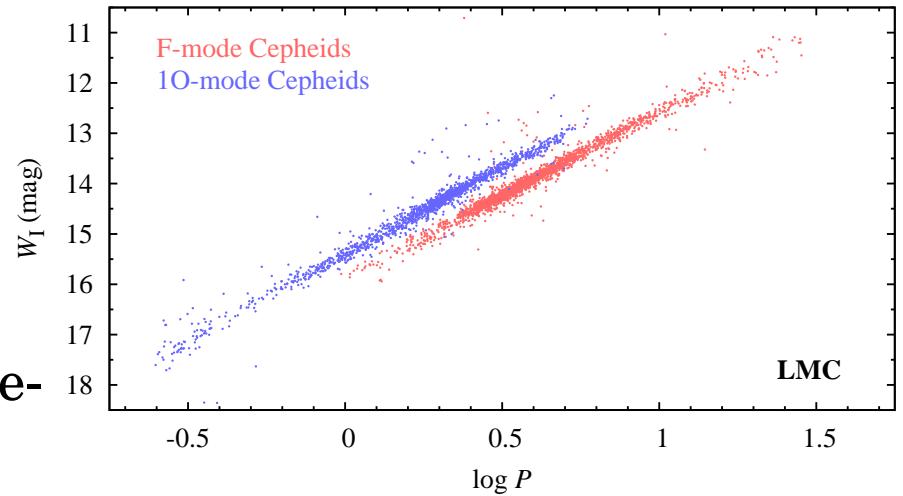
Radek Smolec

Nicolaus Copernicus Astronomical Center, Warsaw



Classical Cepheids

- ▶ textbook examples of simple, radial, typically single-periodic pulsators
- ▶ well understood, except some connoisseur topics, like excitation of double-mode pulsation
- ★ excellent standard candles of crucial importance for cosmology and astrophysics

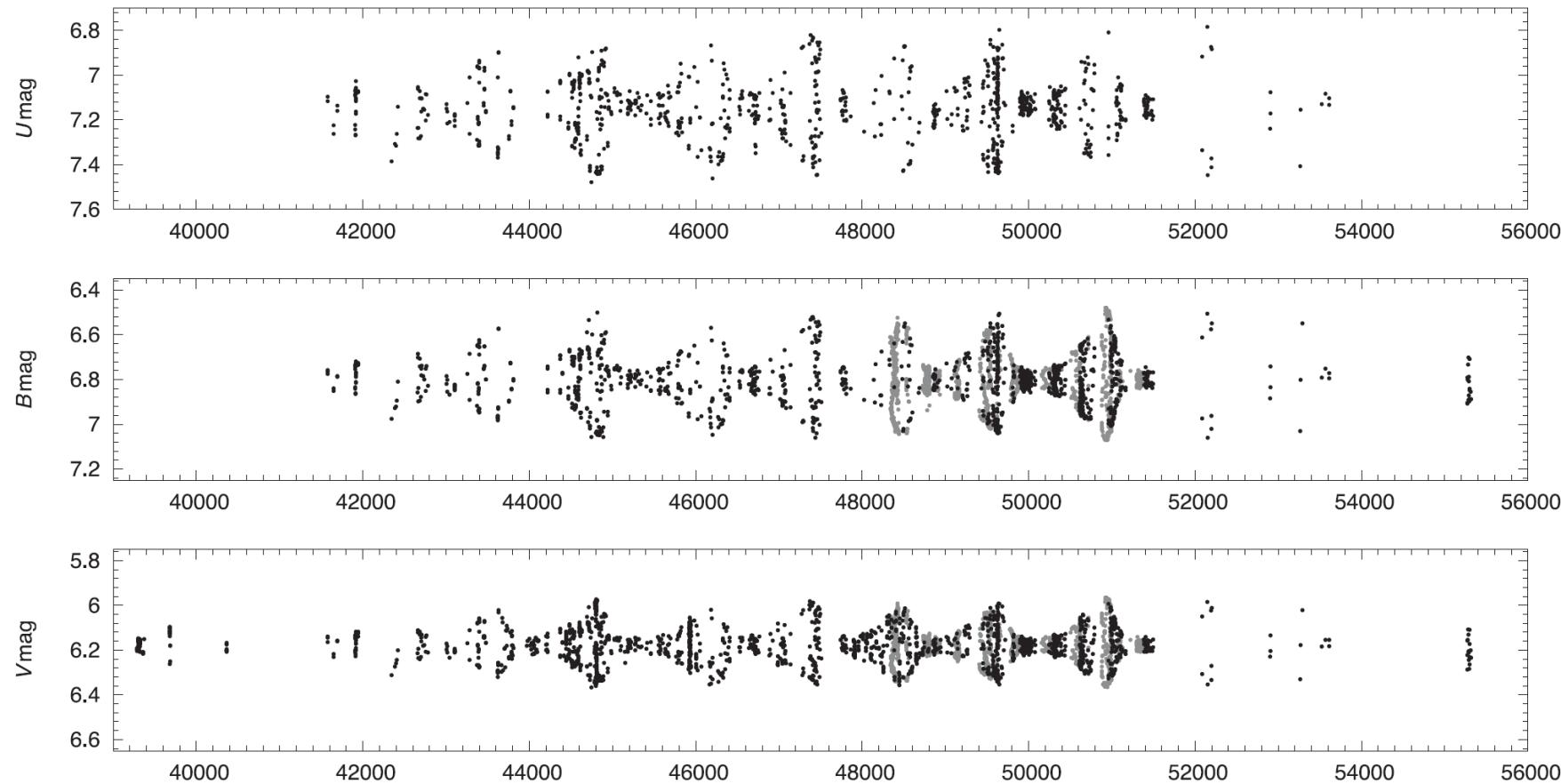


Periodic modulations in classical pulsators

- ★ RR Lyr stars
 - ▶ Blazhko effect in RRab stars (up to 50%), RRc and RRd stars
- ★ classical Cepheids
 - ▶ V473 Lyr – a unique 2O, modulated star (e.g. Molnar & Szabados, 2014)
 - ▶ 1O Cepheids (Soszyński et al. 2015; poster by Kotysz & Smolec)
 - ▶ double-overtone, 1O+2O Cepheids (Moskalik & Kołaczkowski, 2009)
 - ▶ V1154 Cyg, the only Cepheid in the original *Kepler* field (Kanев, Savanov & Sachkov 2015; Derekas et al. 2017)
 - ▶ F-mode Cepheids form the OGLE collection (Smolec, 2017)



Modulation in V473 Lyr

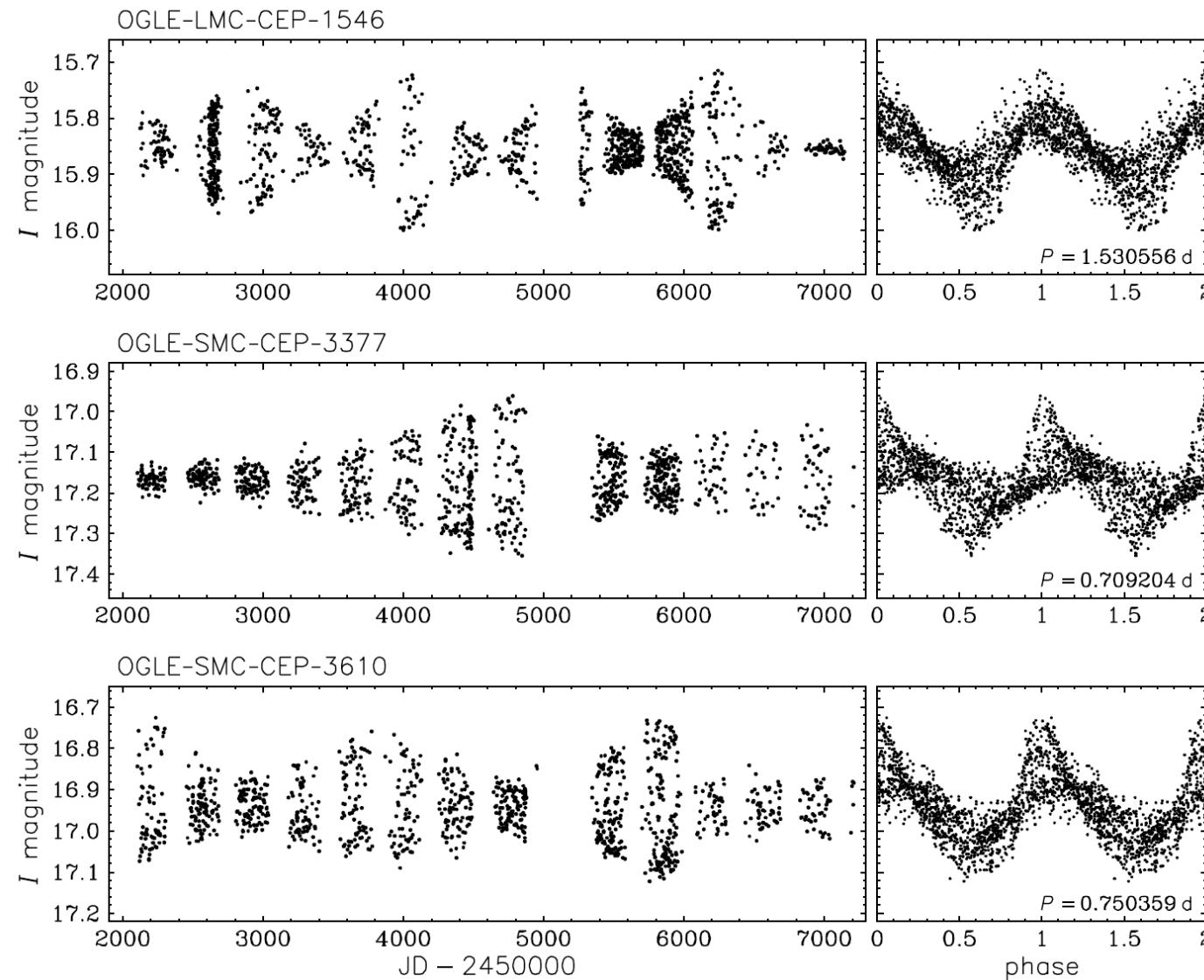


Molnar & Szabados (2014), MNRAS



The RR Lyrae 2017 Conference, Niepołomice, 19.09.2017

Modulation in 10 Cepheids

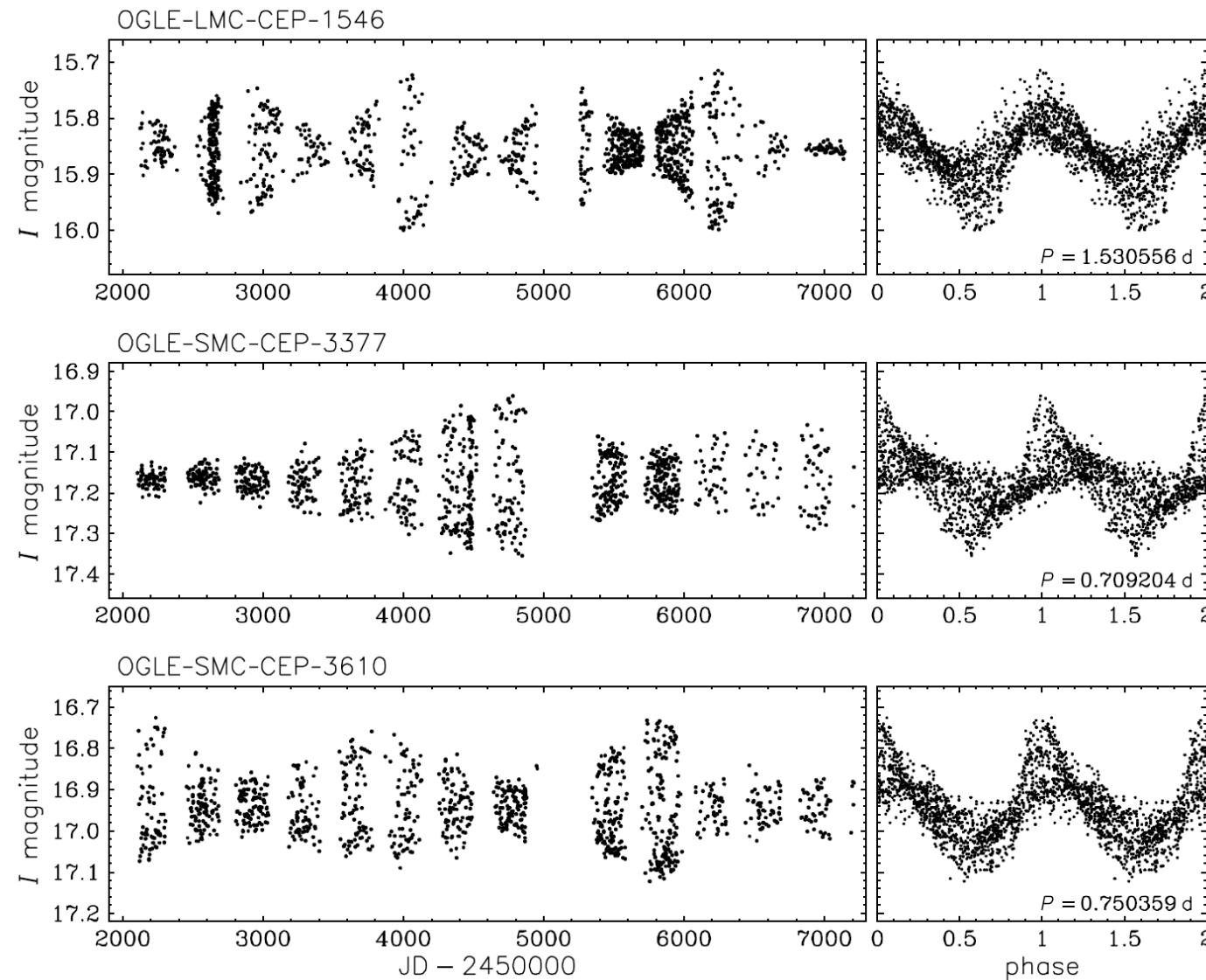


Soszyński et al. (2015)



The RR Lyrae 2017 Conference, Niepołomice, 19.09.2017

Modulation in 10 Cepheids



see also the poster by Kotysz & Smolec

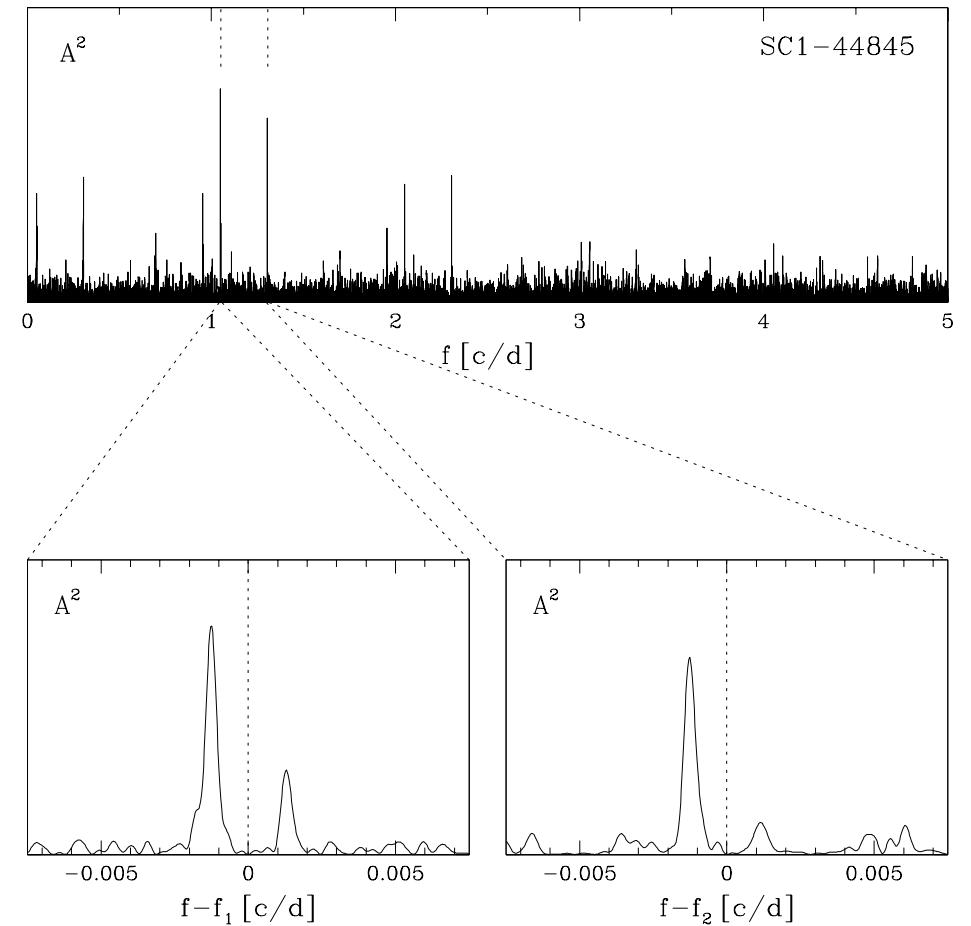
Soszyński et al. (2015)



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Modulation in double-overtone, 1O+2O Cepheids

- ★ OGLE data supplemented with MACHO data
- ★ both 1O and 2O are modulated **with the same period**
- ★ modulation period is always long, > 700 d
- ★ modulation detected in at least 19% of 1O+2O Cepheids
- ★ modes' amplitudes are anticorrelated



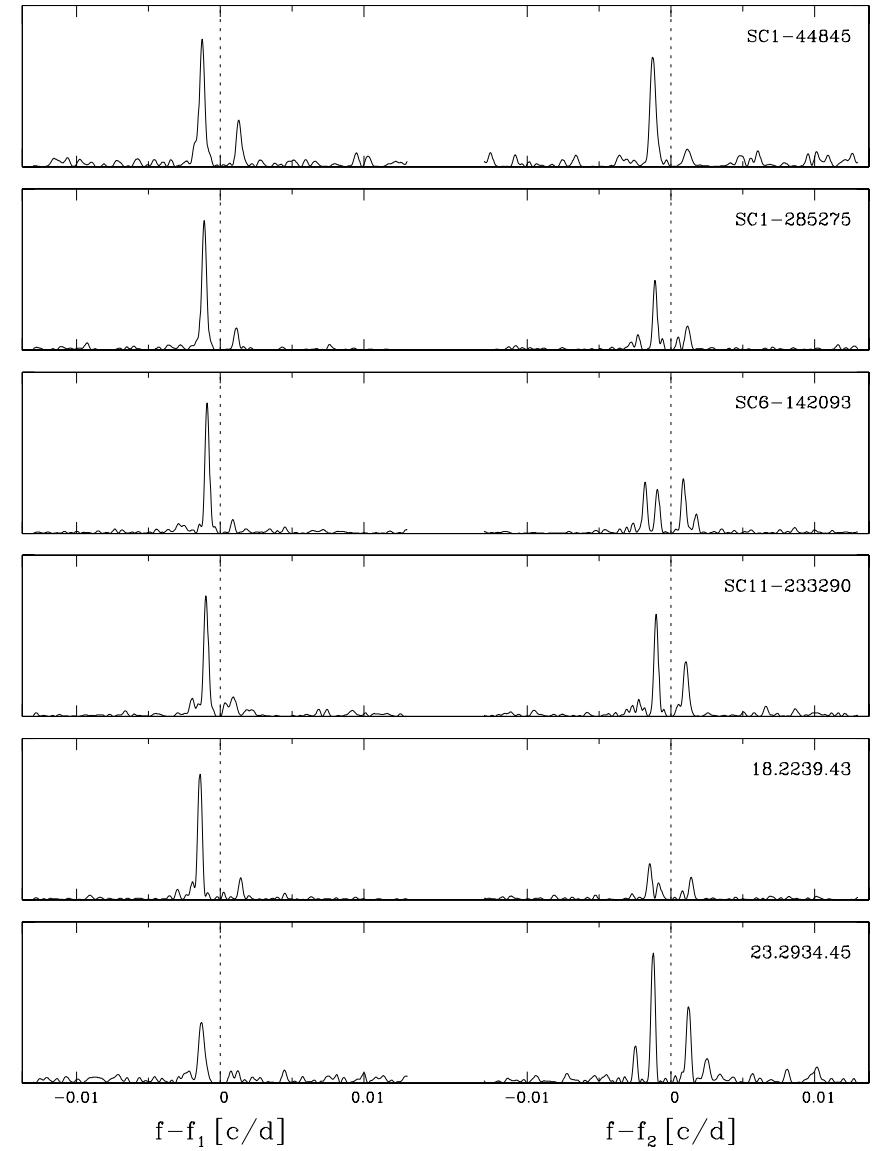
Moskalik & Kołaczkowski (2009), *MNRAS*



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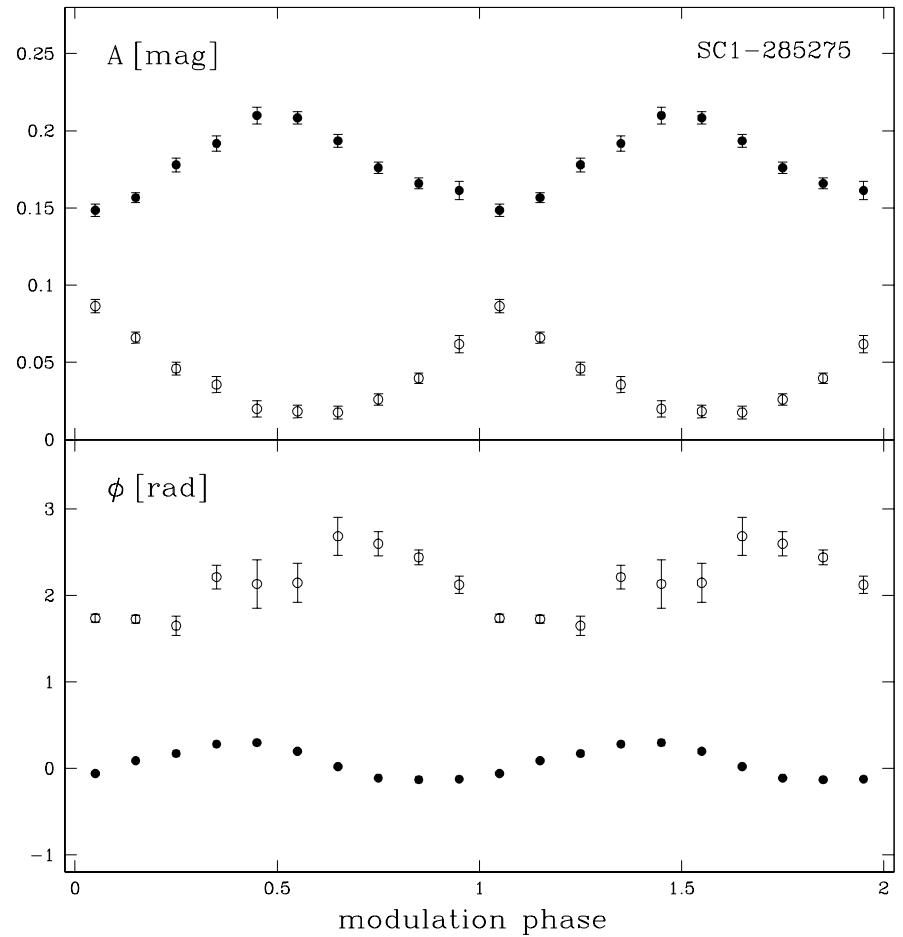


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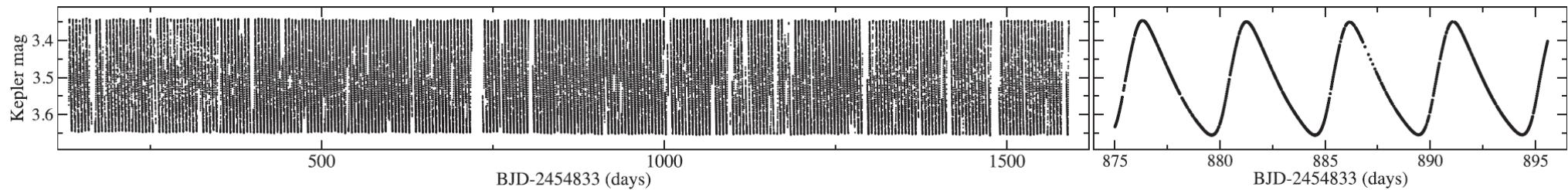


Moskalik & Kołaczkowski (2009), *MNRAS*



The RR Lyrae 2017 Conference, Niepołomice, 19.09.2017

Modulation in V1154 Cyg

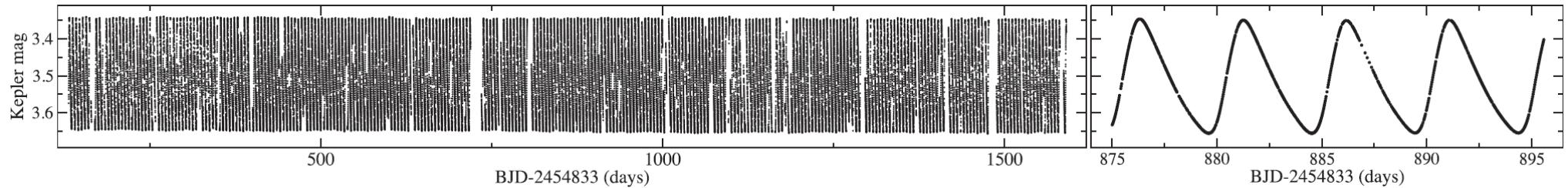


Derekas et al. (2017), *MNRAS*



The RR Lyrae 2017 Conference, Niepołomice, 19.09.2017

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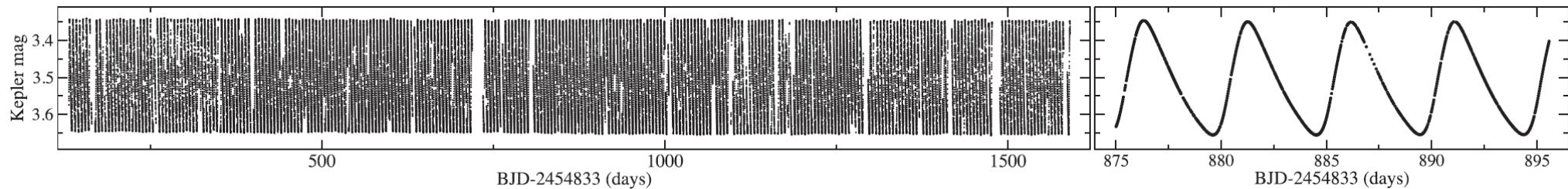


No.	Frequency (d ⁻¹)	Amplitude (mmag)	Phase (rad/2π)	Identification
f_1	0.203 02 70 27(24)	139.662(14)	0.762 573(10)	
f_2	0.406 05 405(9)	37.925(14)	0.973 077(37)	$2f_1$
f_3	0.609 08 108(35)	9.583(14)	0.213 28(15)	$3f_1$
f_4	0.812 10 81(31)	1.066(12)	0.4629(13)	$4f_1$
f_5	1.015 135(6)	0.594(14)	0.0687(24)	$5f_1$
f_6	1.218 162(6)	0.591(13)	0.3080(24)	$6f_1$
f_7	1.421 189(9)	0.374(14)	0.520(4)	$7f_1$
f_8	1.624 216(16)	0.209(14)	0.739(7)	$8f_1$
f_9	1.827 243(29)	0.117(13)	0.951(12)	$9f_1$
f_{10}	2.030 27(6)	0.055(14)	0.177(25)	$10f_1$
f_{11}	0.006 327(9)	0.371(15)	0.8404(38)	f_{m1}
f_{12}	0.196 700(6)	0.554(14)	0.3927(25)	$f_1 - f_{m1}$
f_{13}	0.209 354(10)	0.319(13)	0.884(4)	$f_1 + f_{m1}$
f_{14}	0.399 727(12)	0.289(13)	0.346(5)	$f_2 - f_{m1}$
f_{15}	0.602 754(30)	0.111(15)	0.488(13)	$f_3 - f_{m1}$
f_{16}	0.817 57(8)	0.042(15)	0.037(34)	$f_4 + f_{m1} - f_{m2}$
f_{17}	1.020 60(12)	0.028(13)	0.252(5)	$f_5 + f_{m1} - f_{m2}$
f_{18}	0.412 381(28)	0.121(14)	0.729(11)	$f_2 + f_{m1}$
f_{19}	0.190 374(15)	0.219(13)	0.049(6)	$f_1 - 2f_{m1}$
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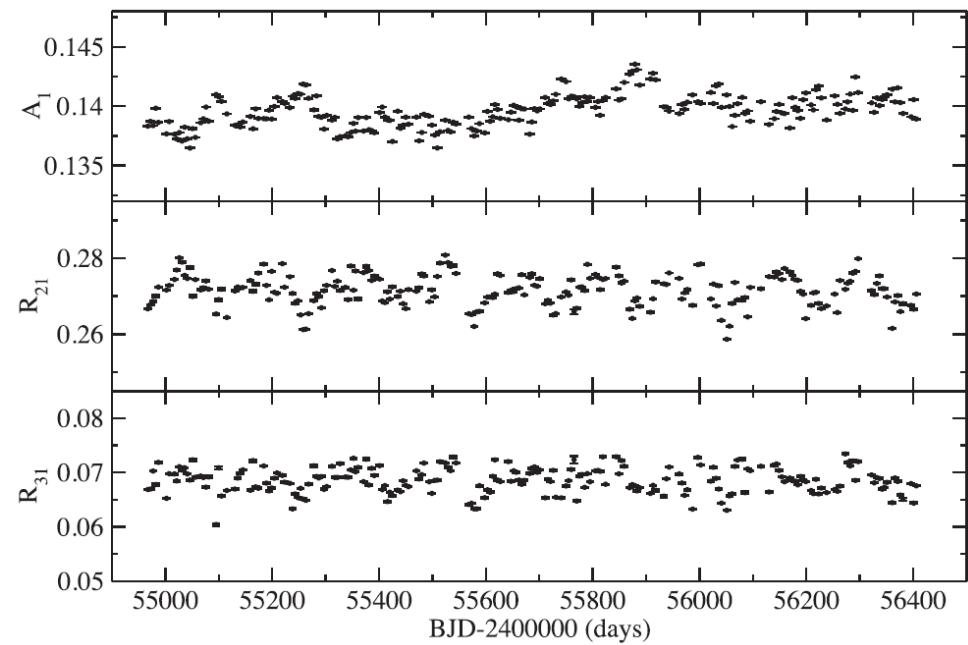
Derekas et al. (2017), MNRAS



Modulation in V1154 Cyg



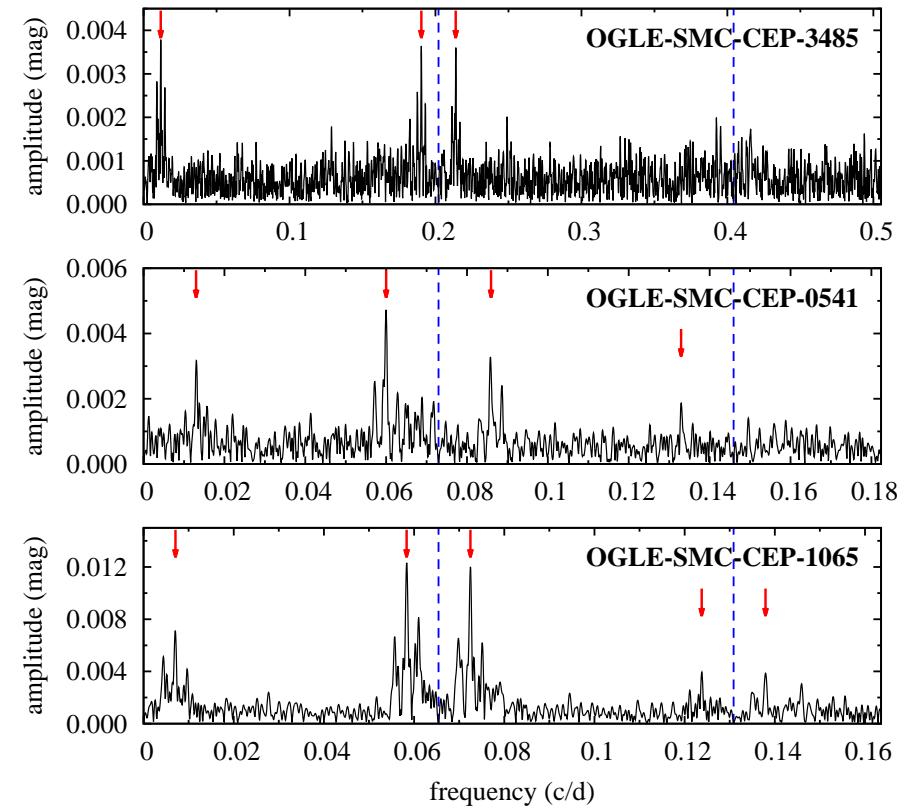
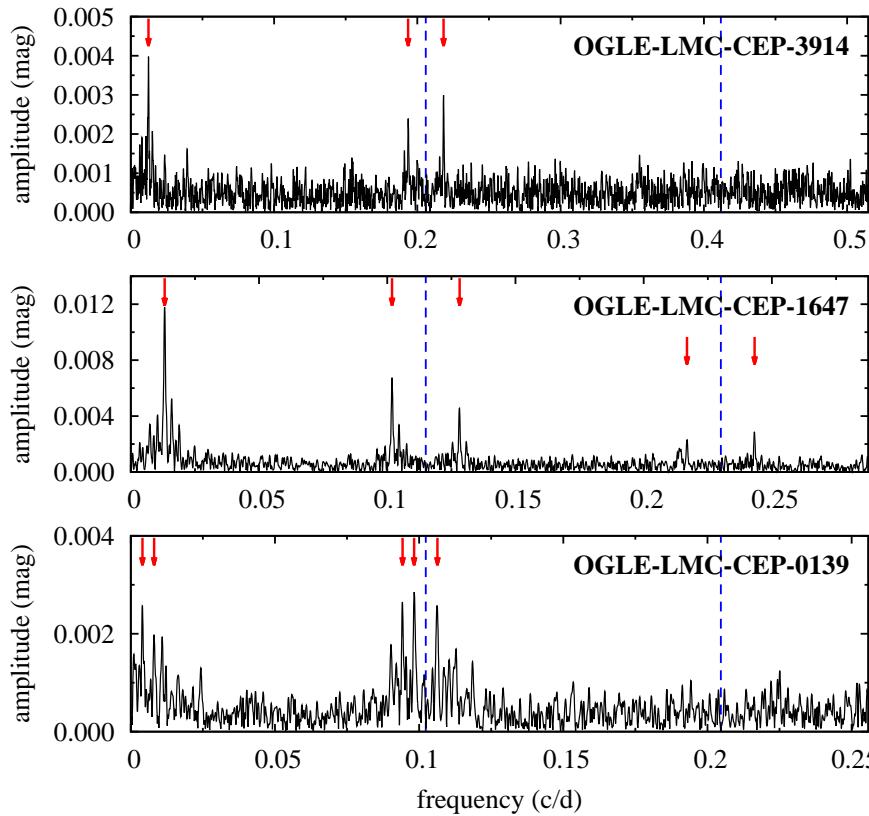
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Derekas et al. (2017), MNRAS



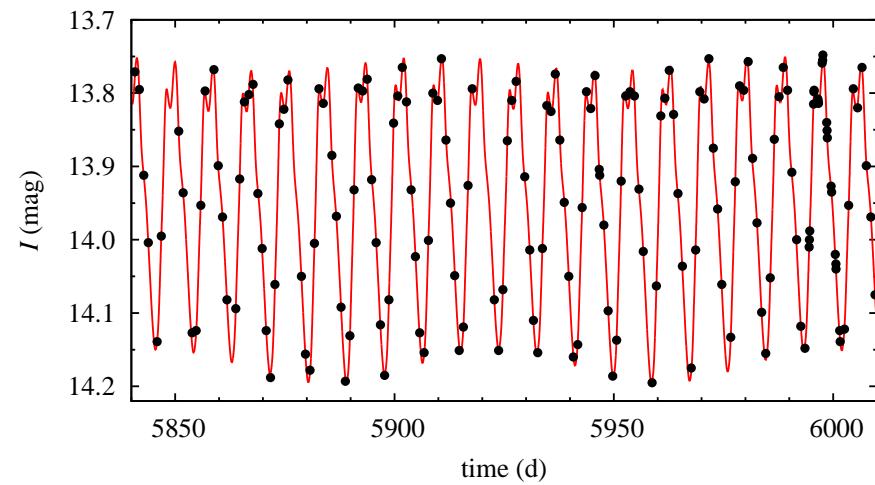
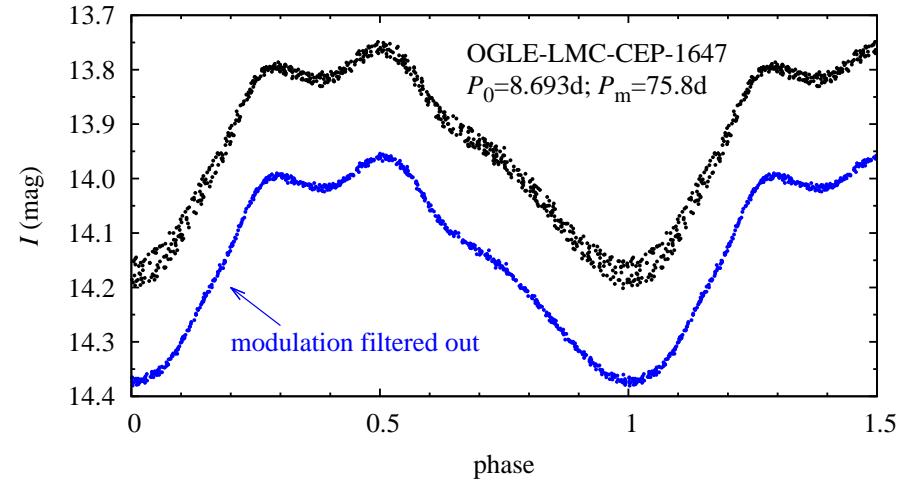
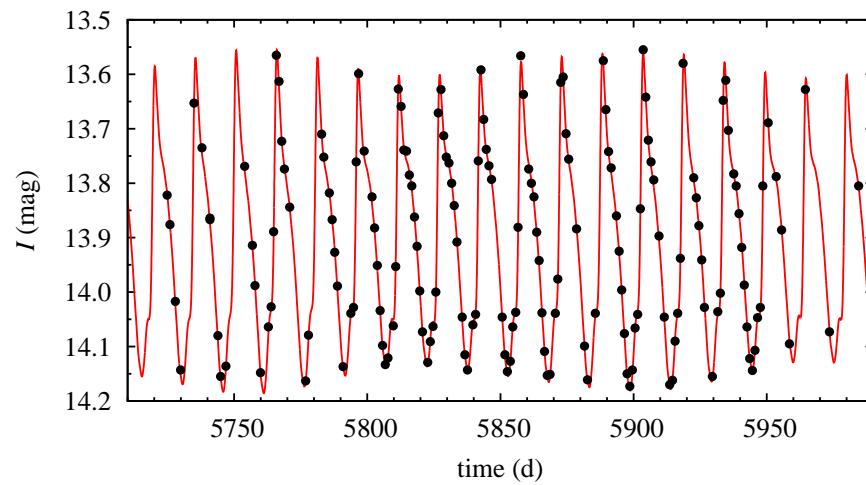
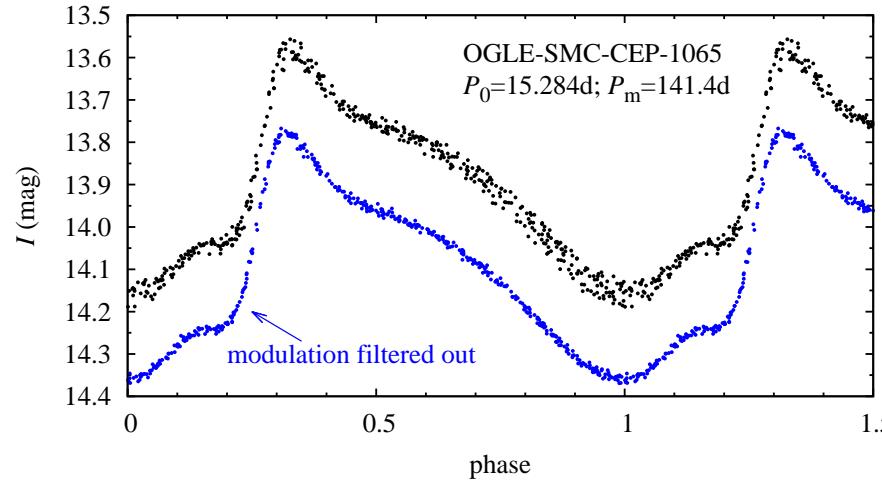
Modulation in classical, F-mode Cepheids



- in the majority of cases, modulation detected thanks to analysis of frequency spectra only



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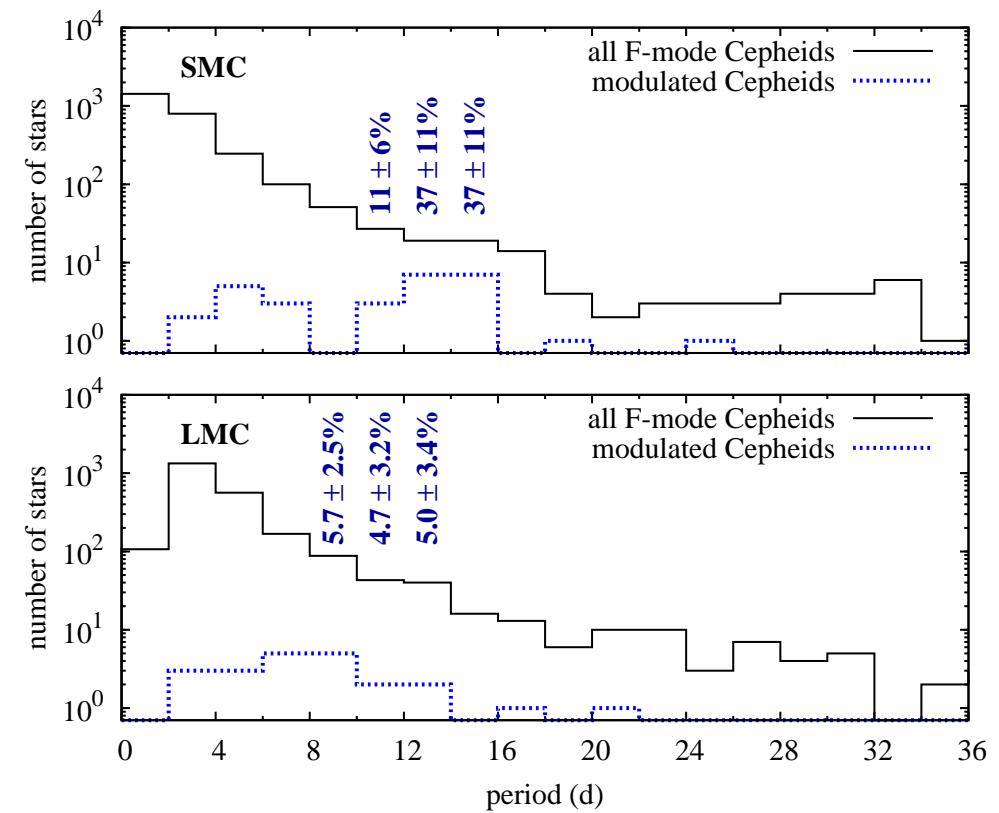


- ▶ in the majority of cases, modulation detected thanks to analysis of frequency spectra only
- ▶ in a few cases modulation is well visible directly in the light curve



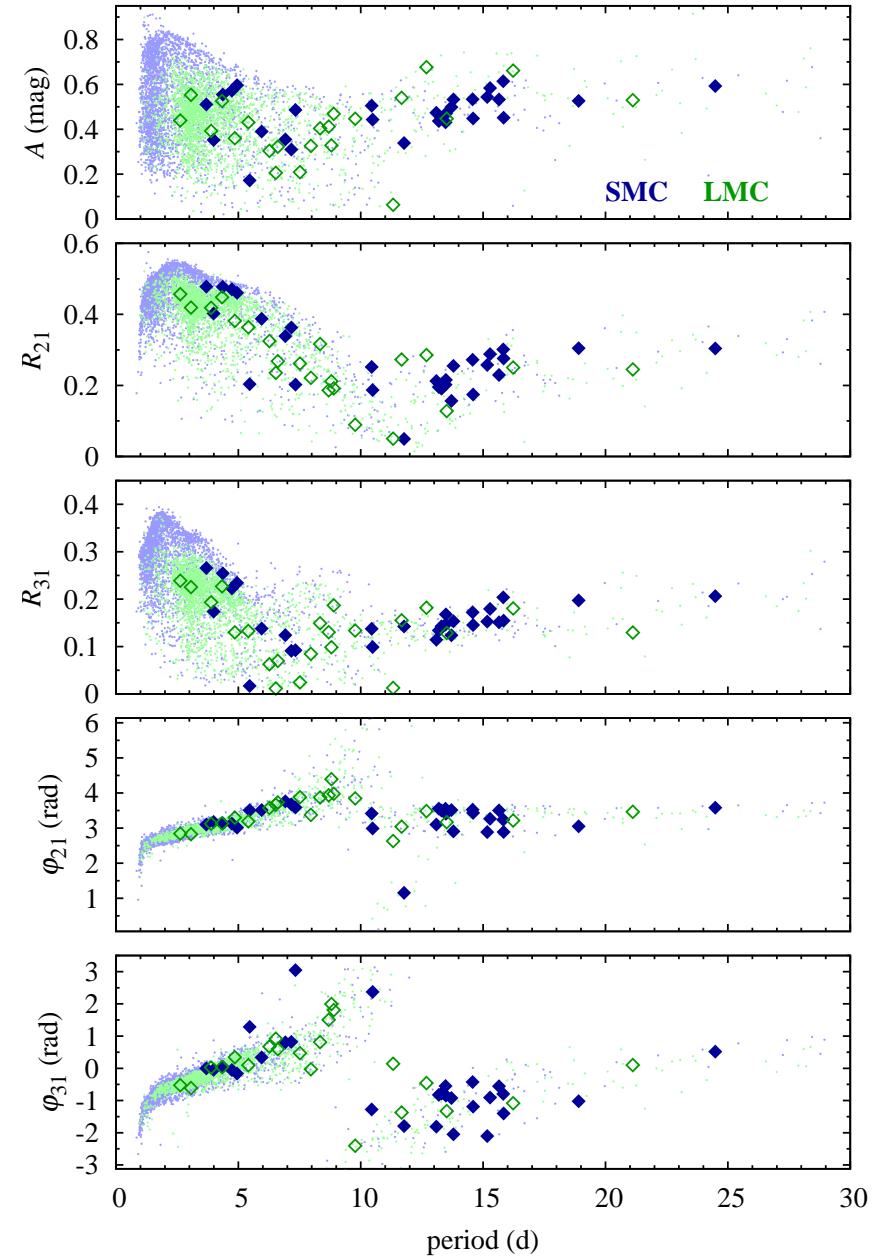
Modulation in classical, F-mode Cepheids

- ★ 29 stars in SMC, 22 in LMC ($\sim 1\%$)
- ★ in SMC for $12 \text{ d} < P_F < 16 \text{ d}$ the effect is very frequent ($\sim 40\%$)



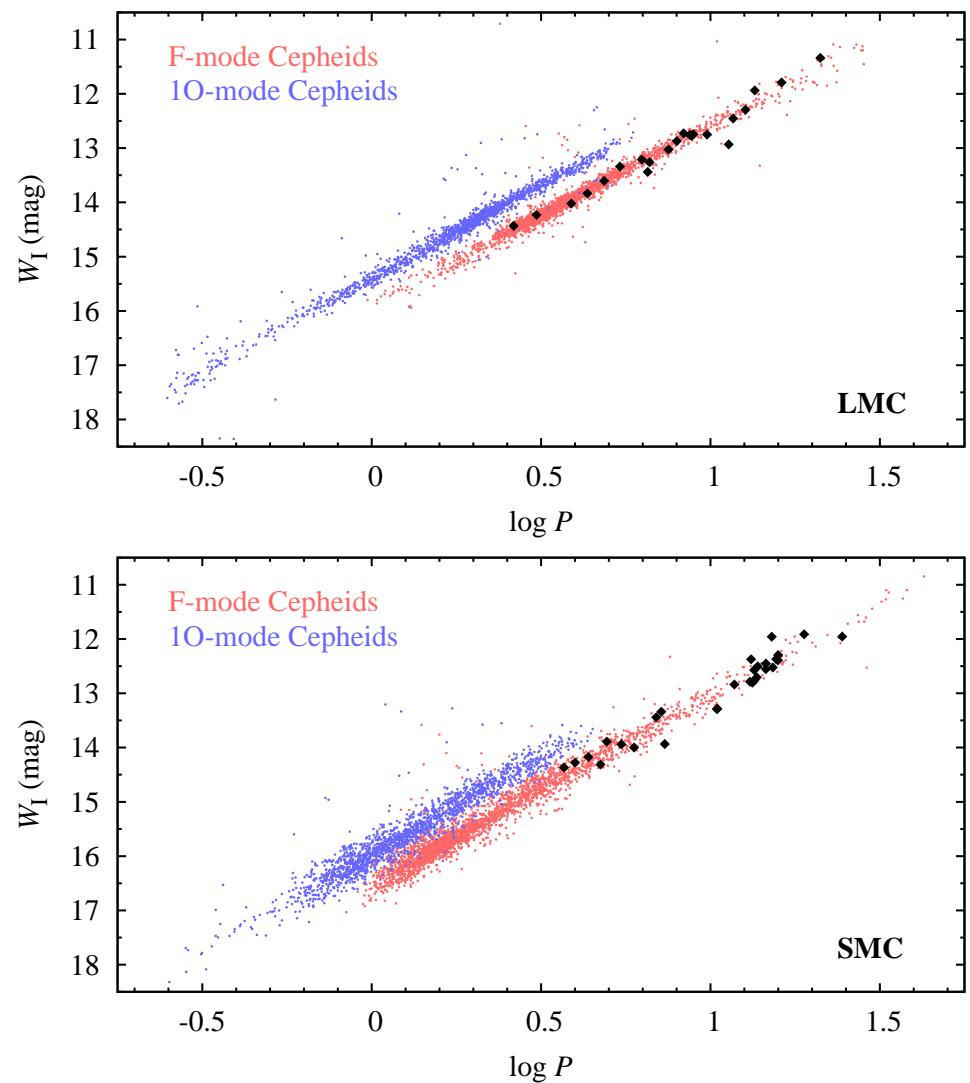
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- * typical light curves



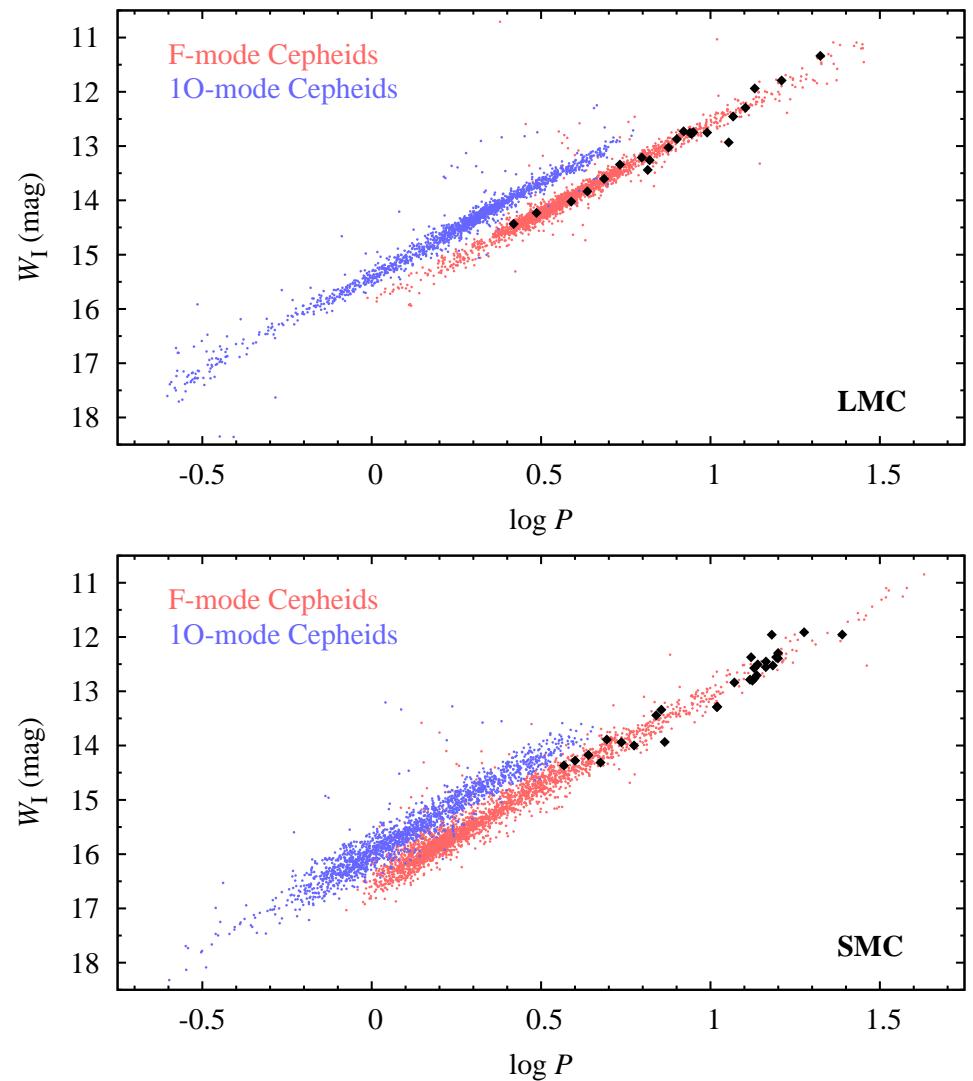
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- * typical brightnesses



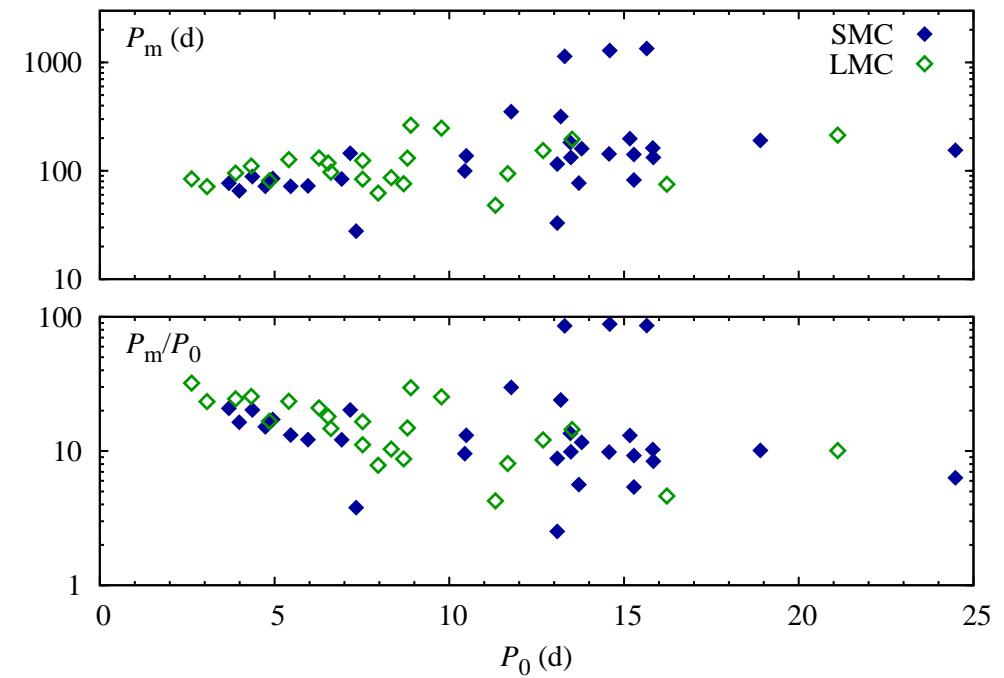
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- ★ typical brightnesses
- ★ no modulation in SMC for $P_F < 3.6 \text{ d}$ (the effect is real)



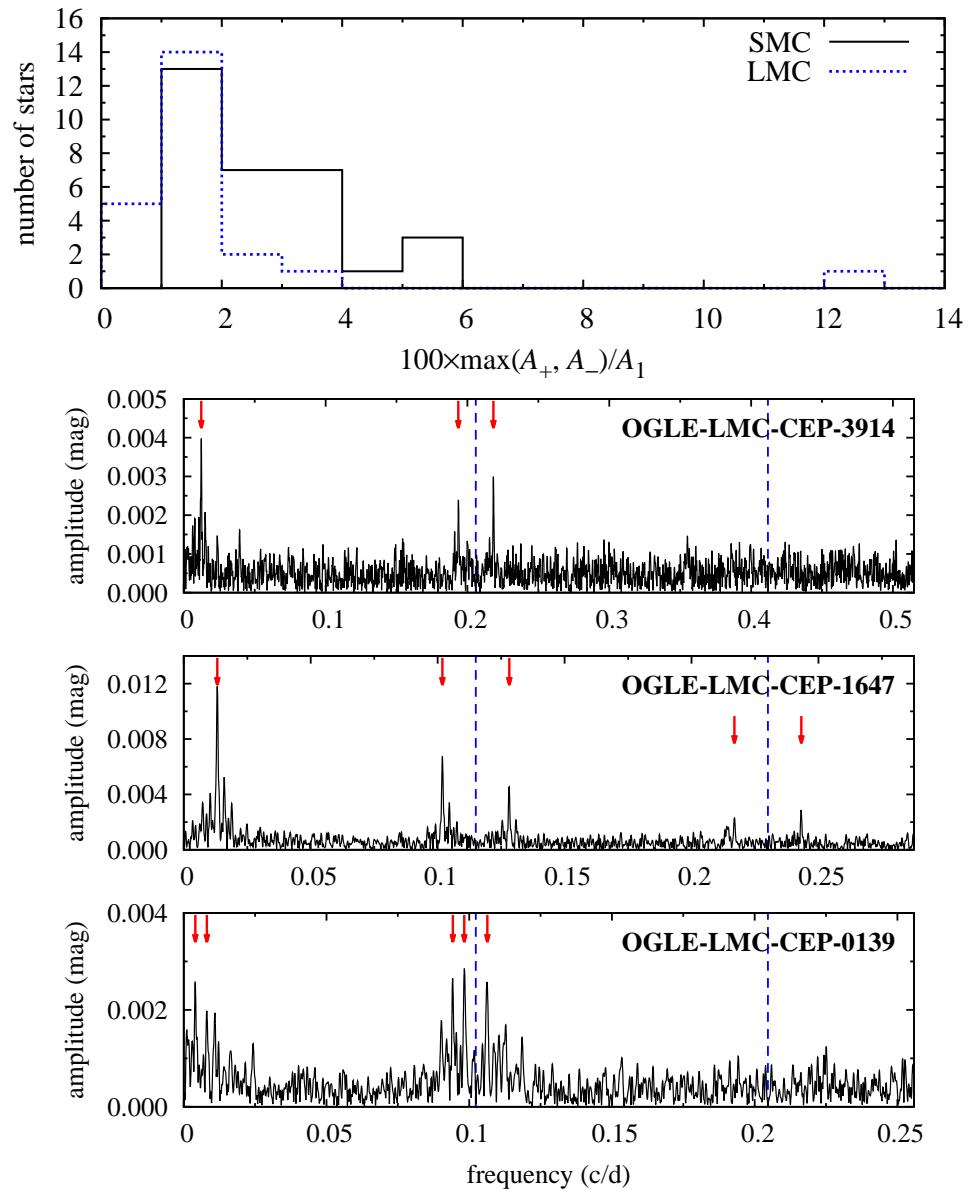
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- ★ typical modulation period is $10 \times P_F$



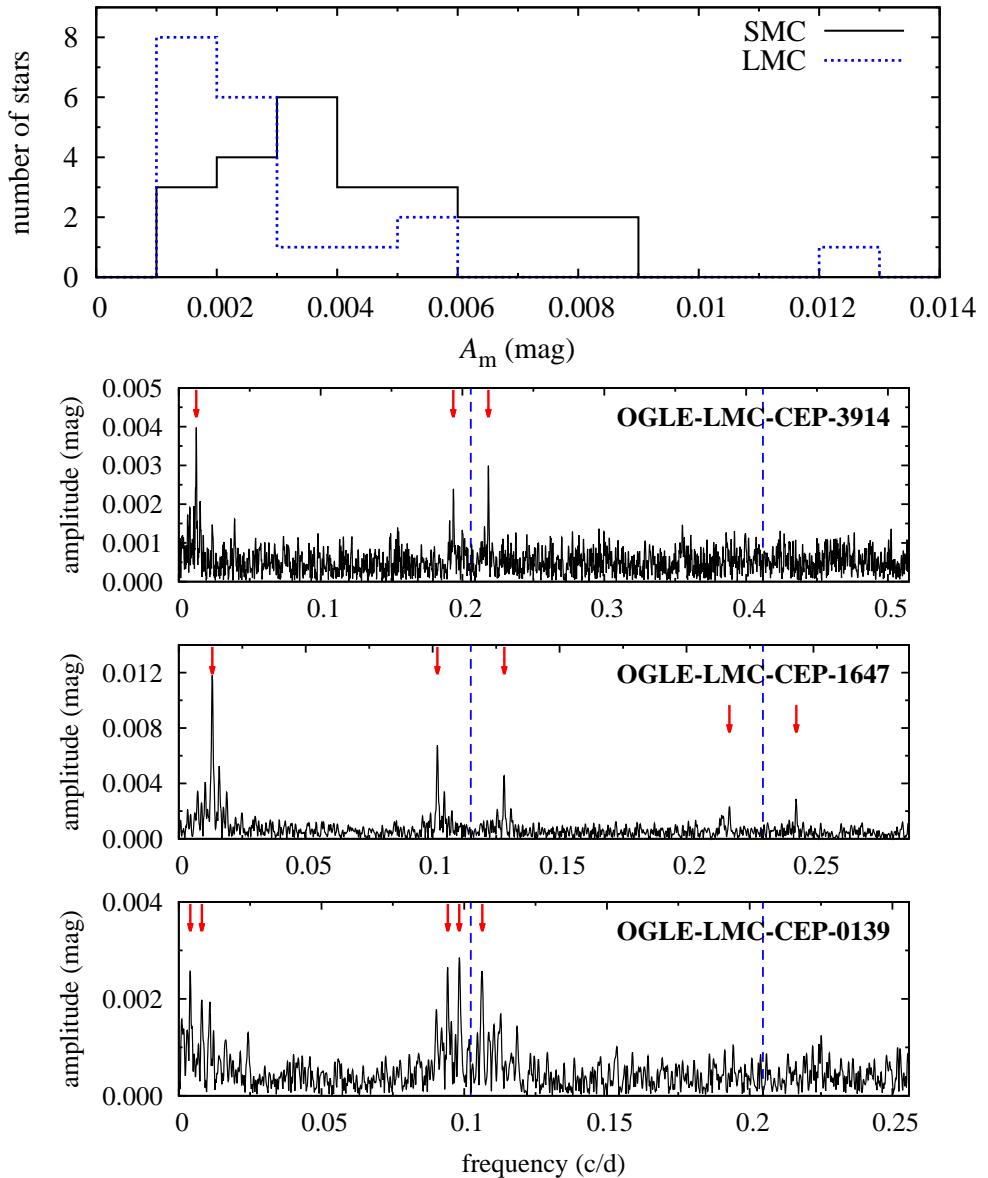
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- * typical light curves
- * typical brightnesses
- * no modulation in SMC for $P_F < 3.6 \text{ d}$ (the effect is real)
- * typical modulation period is $10 \times P_F$
- * relative modulation amplitude $< 6\%$

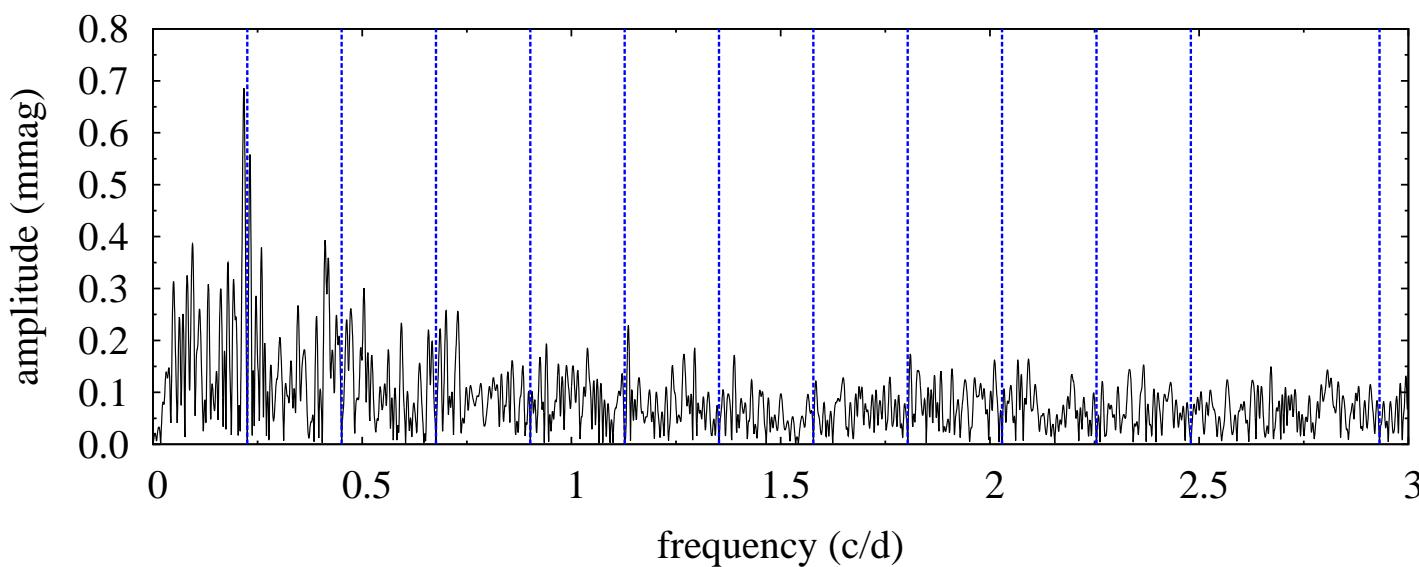
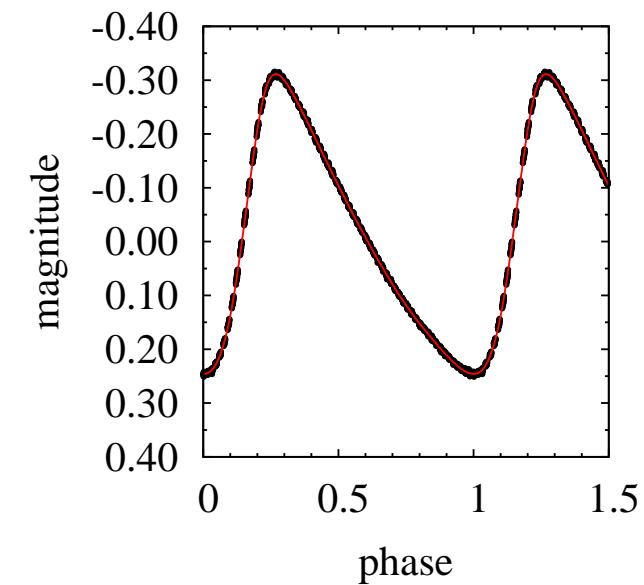
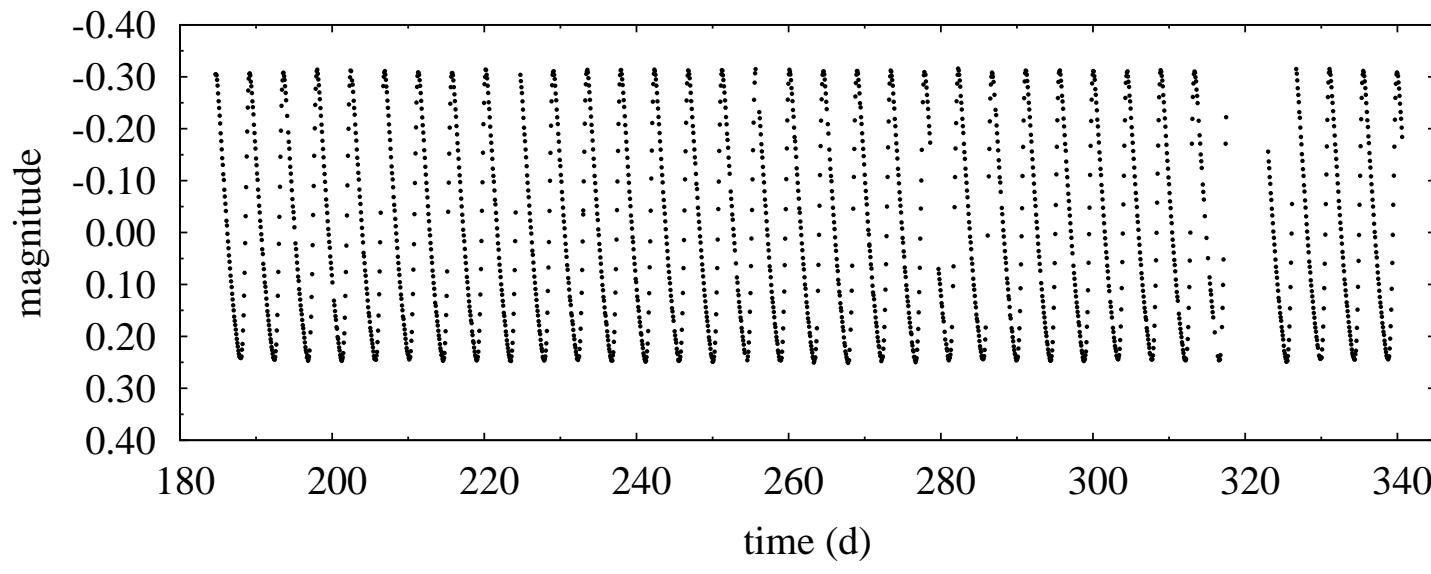


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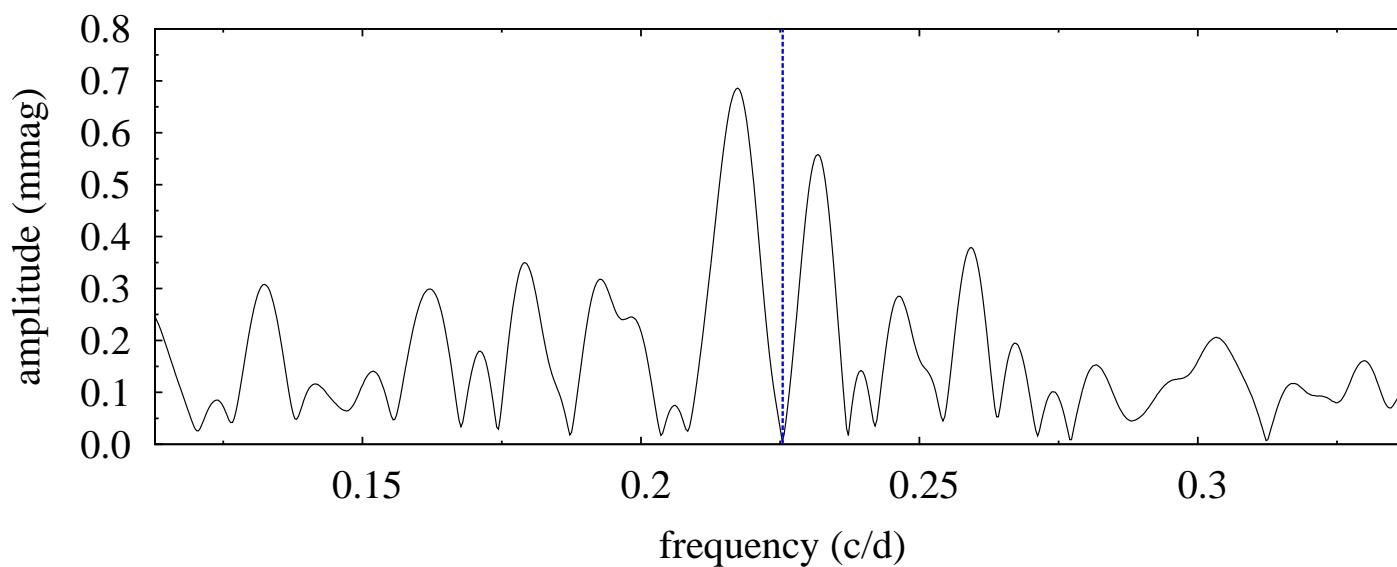
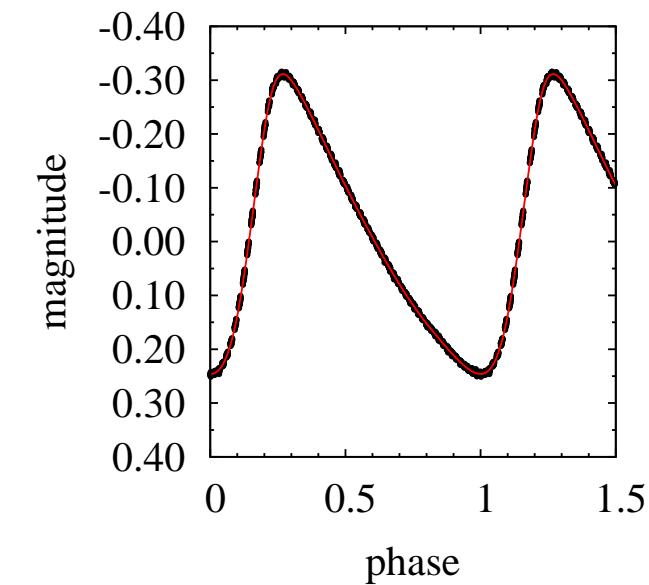
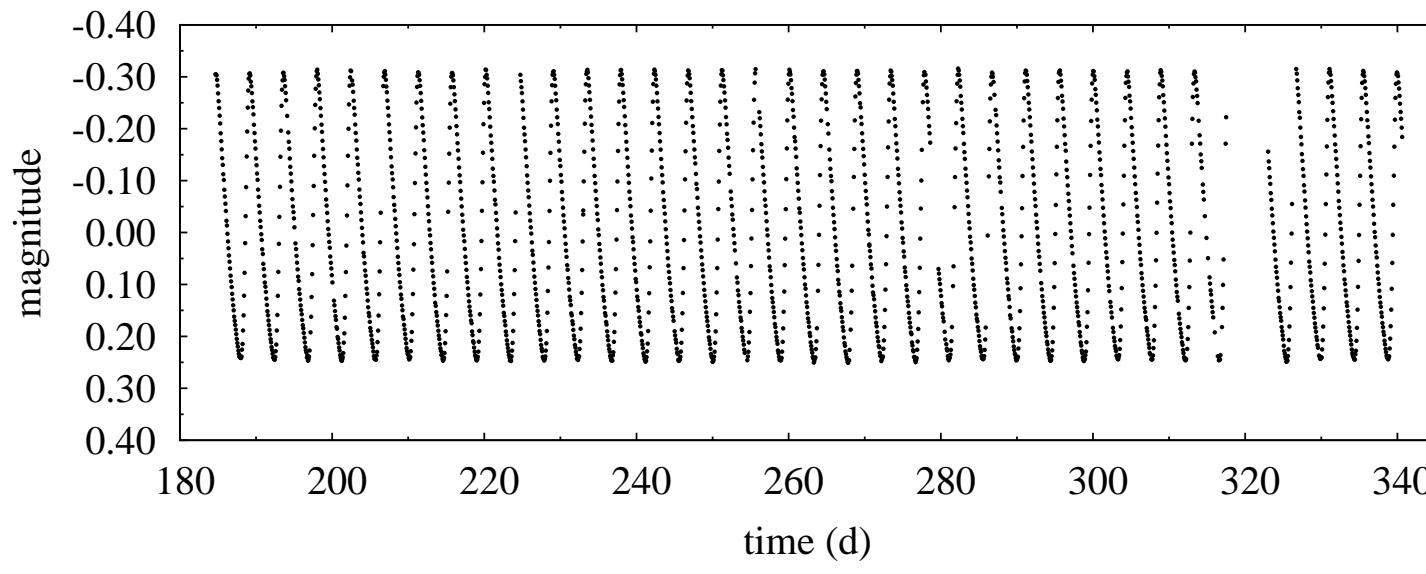
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- ★ typical light curves
- ★ typical brightnesses
- ★ no modulation in SMC for $P_F < 3.6 \text{ d}$ (the effect is real)
- ★ typical modulation period is $10 \times P_F$
- ★ relative modulation amplitude $< 6\%$
- ★ mean brightness modulation typically below 0.01 mag



F-mode Cepheid T Vul



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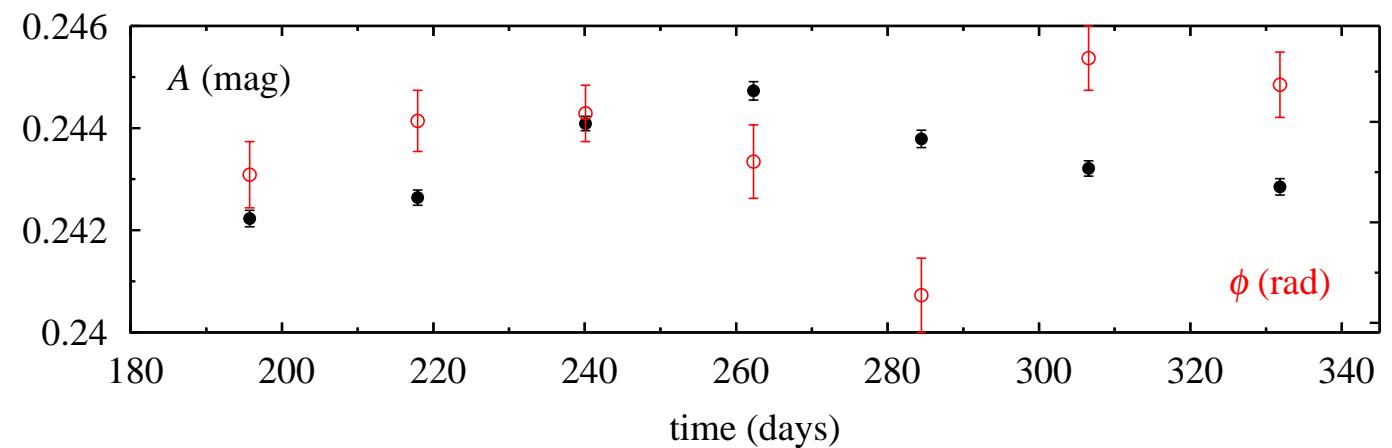
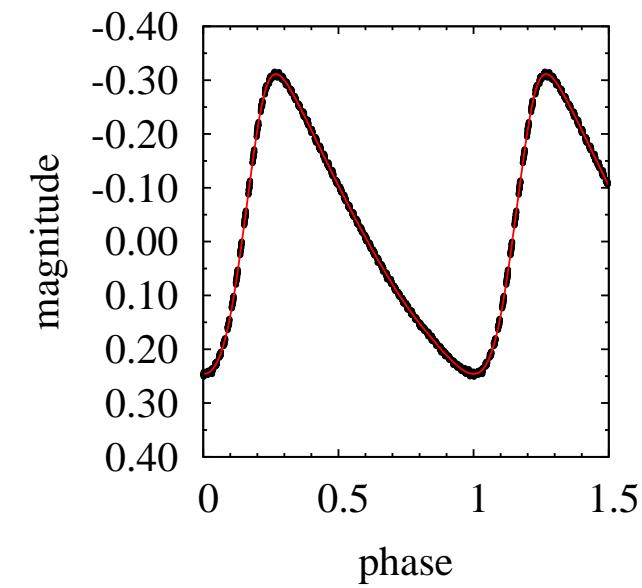
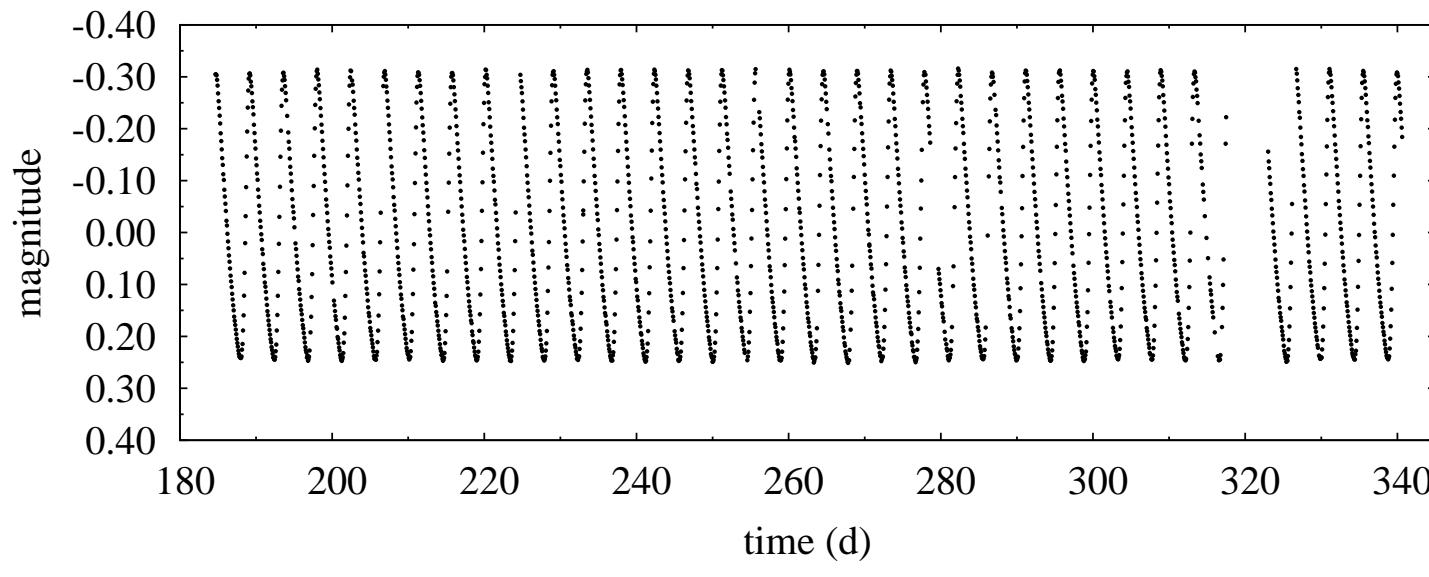


$$\sigma = 0.0021 \text{ mag}$$

- ▶ long- P modulation?
- ▶ more observations needed to confirm



F-mode Cepheid T Vul



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