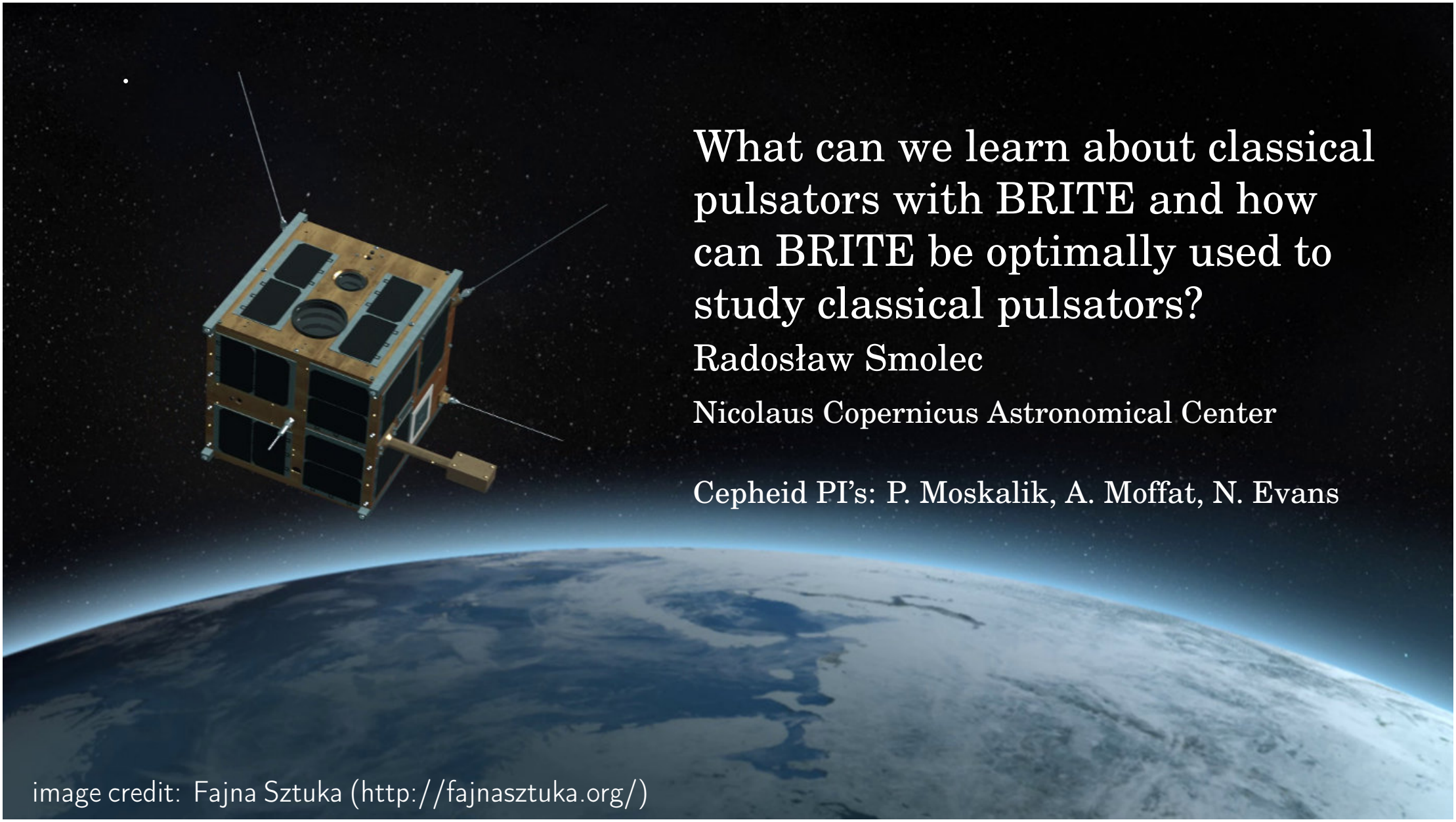


What can we learn about classical pulsators with BRITE and how can BRITE be optimally used to study classical pulsators?

Radosław Smolec

Nicolaus Copernicus Astronomical Center

Cepheid PI's: P. Moskalik, A. Moffat, N. Evans

image credit: Fajna Sztuka (http://fajnasztuka.org/)

BRITE-PL

CBK PAN

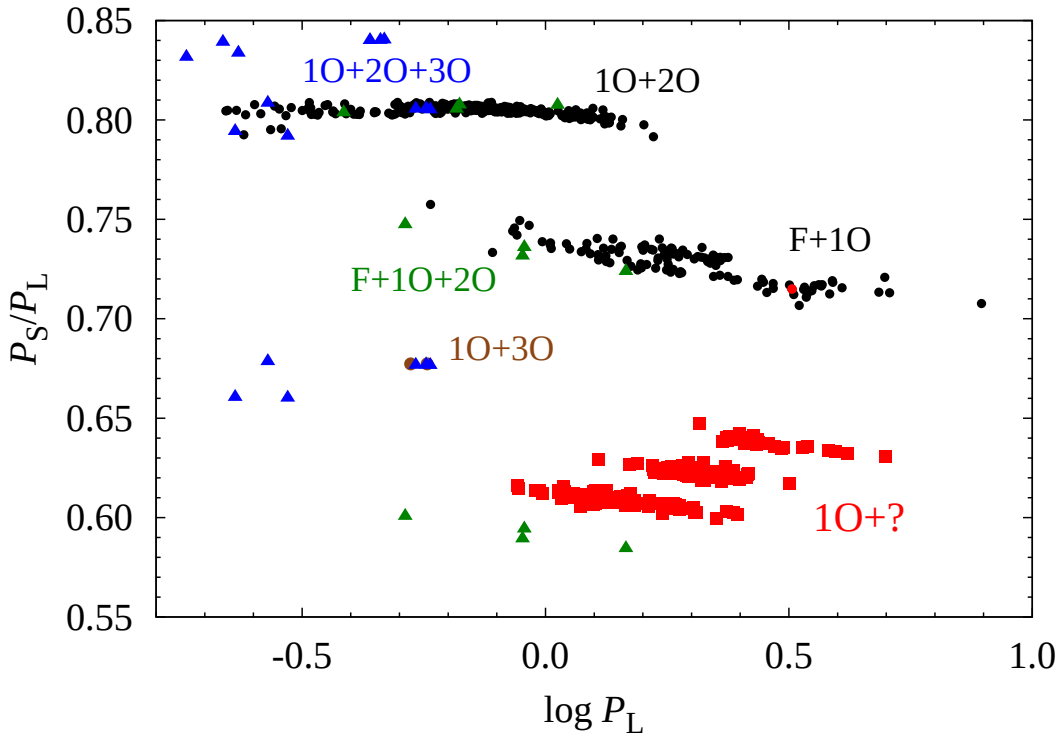
TM

Polish Academy of Sciences
Nicolaus Copernicus
Astronomical Center

Classical Cepheids: what are we looking for?

Based on ground-based observations and modelling we should look for:

- ⋆ additional radial modes
- ⋆ additional non-radial modes
- ⋆ Blazhko effect
- ⋆ period doubling effect



Classical Cepheids observed from space

- **Polaris** (1O) with *WIRE* startracker and SMEI/*Coriolis*; Bruntt et al. (2008), Spreckley & Stevens (2008)
- **V1154** Cygni (F) with *Kepler*; Szabó et al. (2011), Derekas et al. (2012)
- **RT Aur** (F) and **SZ Tau** (1O) with *MOST*; Evans et al. (2015)
- 7 Cepheids (2x1O, 4xF, 1xT2) observed with *CoRoT*; Poretti et al. (2015)
- several Cepheids had been observed with *K2*; Plachy et al. (in prep.)

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- ▸ amplitude increase; non-stationary pulsations, no additional modes

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- ▸ cycle-to-cycle fluctuations in the pulsation period (period jitter), changes in the light curve shape, no additional modes

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- ▸ contrast between pulsation modes (1O more unstable), no additional modes

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- ▸ **see next talk**; no additional modes

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- ▸ additional modes and/or modulation

Classical Cepheids within BRITE's reach

star	P [days]	$\langle V \rangle$	mode	$V_{\max} - V_{\min}$
α UMi	3.9696	1.982	FO	1.98–2.02
l Car	35.551341	3.724		3.35–4.05
β Dor	9.842425	3.731		3.46–4.08
ζ Gem	10.15073	3.918		3.62–4.18
δ Cep	5.36627	3.954		3.48–4.37
η Aql	7.176735	3.897		3.48–4.39
X Sgr	7.012877	4.549		4.20–4.90
W Sgr	7.594904	4.668		4.29–5.14
BG Cru	3.34272	5.487	FO	5.34–5.58
FF Aql	4.470916	5.372	FO	5.18–5.68
MY Pup	5.695309	5.677	FO	5.54–5.76
RT Aur	3.72819	5.446		5.00–5.82
AH Vel	4.227231	5.695	FO	5.50–5.89
DT Cyg	2.499082	5.774	FO	5.57–5.96
V1334 Cyg	3.332804	5.871	FO	5.77–5.96
S Sge	8.382086	5.622		5.24–6.04
T Vul	4.435462	5.754		5.42–6.09
AX Cir	5.273306	5.880		5.65–6.09
SU Cas	1.949322	5.970	FO	5.70–6.18

star	P [days]	$\langle V \rangle$	mode	$V_{\max} - V_{\min}$
Y Sgr	5.77338	5.744		5.25–6.24
V440 Per	7.57	6.282	FO	6.18–6.32
V473 Lyr	1.49078	6.182		5.99–6.35
Y Oph	17.126908	6.169		5.87–6.46
S Mus	9.659875	6.118		5.89–6.49
T Mon	27.024649	6.124		5.58–6.62
V659 Cen	5.6218	6.598	FO	6.45–6.71
R Mus	7.510467	6.298		5.93–6.73
SZ Tau	3.14838	6.531	FO	6.33–6.75
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S TrA	6.323465	6.397		5.95–6.81
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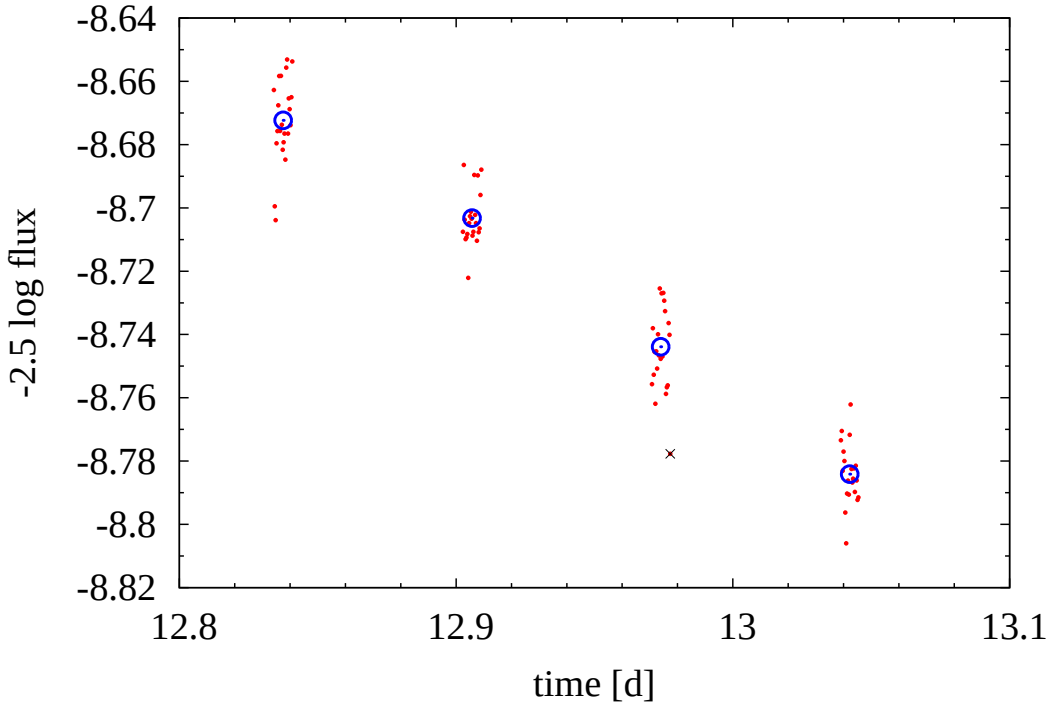
Classical Cepheids vs. other bright stars

- longer variability time-scale
- large amplitude variations
  - averaging
- well known form of large amplitude variability (Fourier series)
  - decorrelation is easier

First step of analysis: averaging & outlier removal

- averaging length dictated by consecutive orbits
- averaging in the flux space, then to magnitudes
- outlier removal during averaging procedure: iterative 3sigma clipping with minimum number of measurement in a group (>5)



T Vul (F-mode) BTr observations

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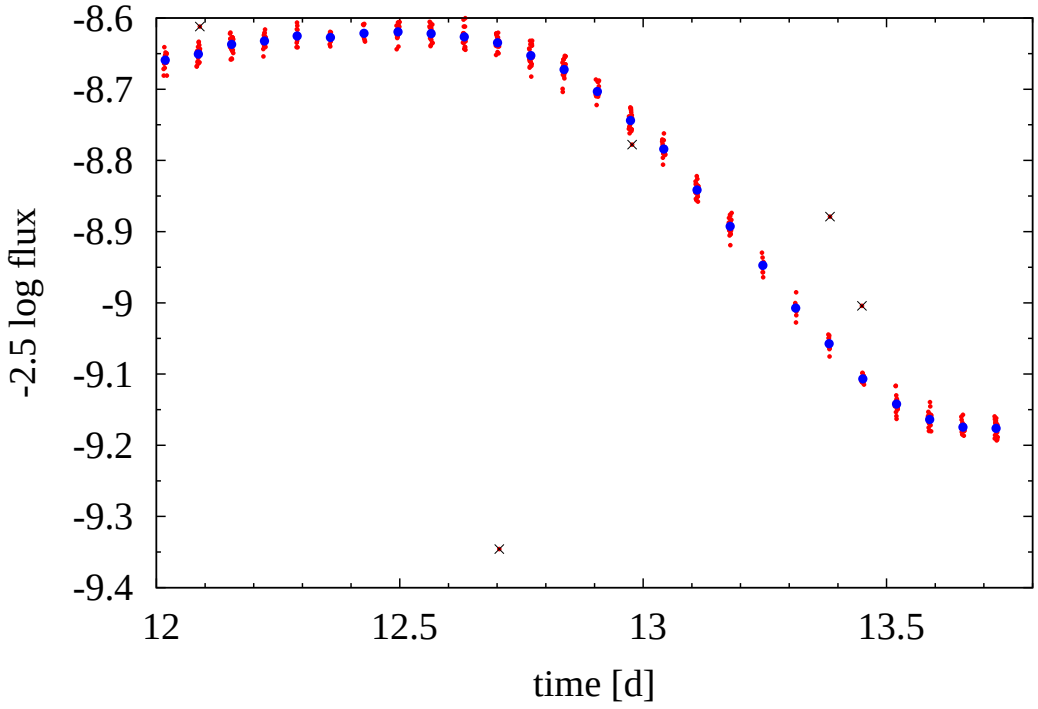

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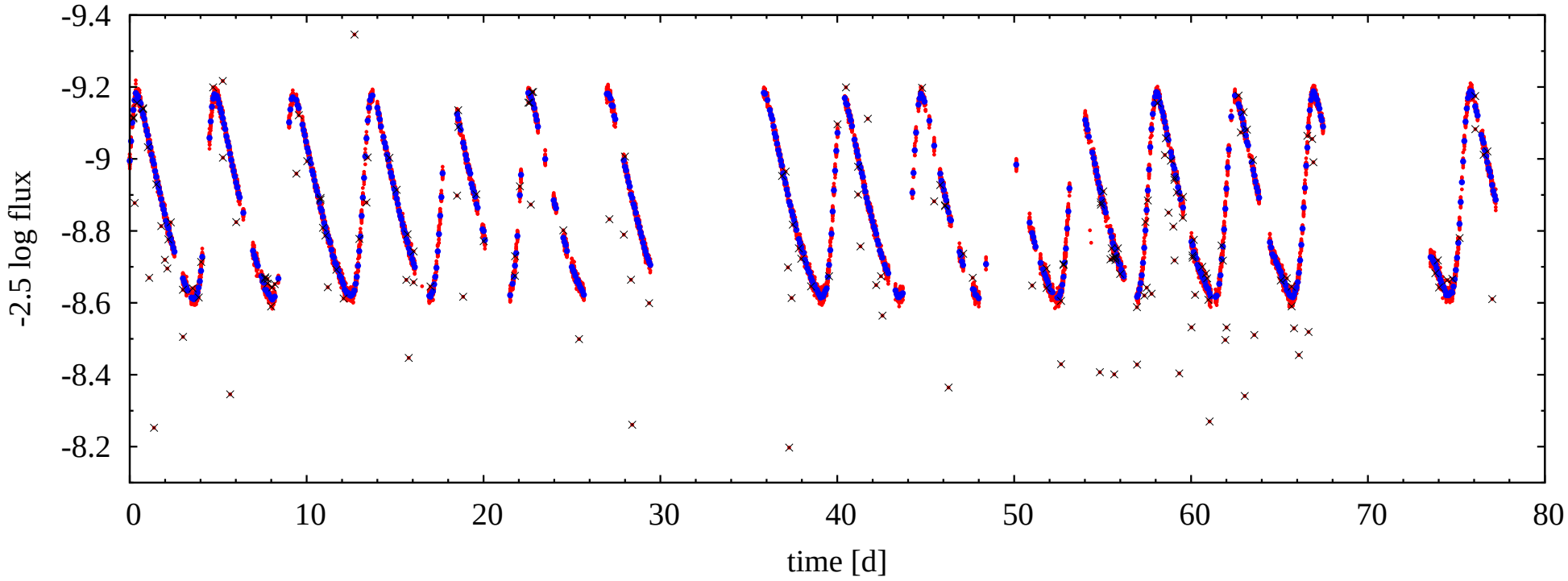

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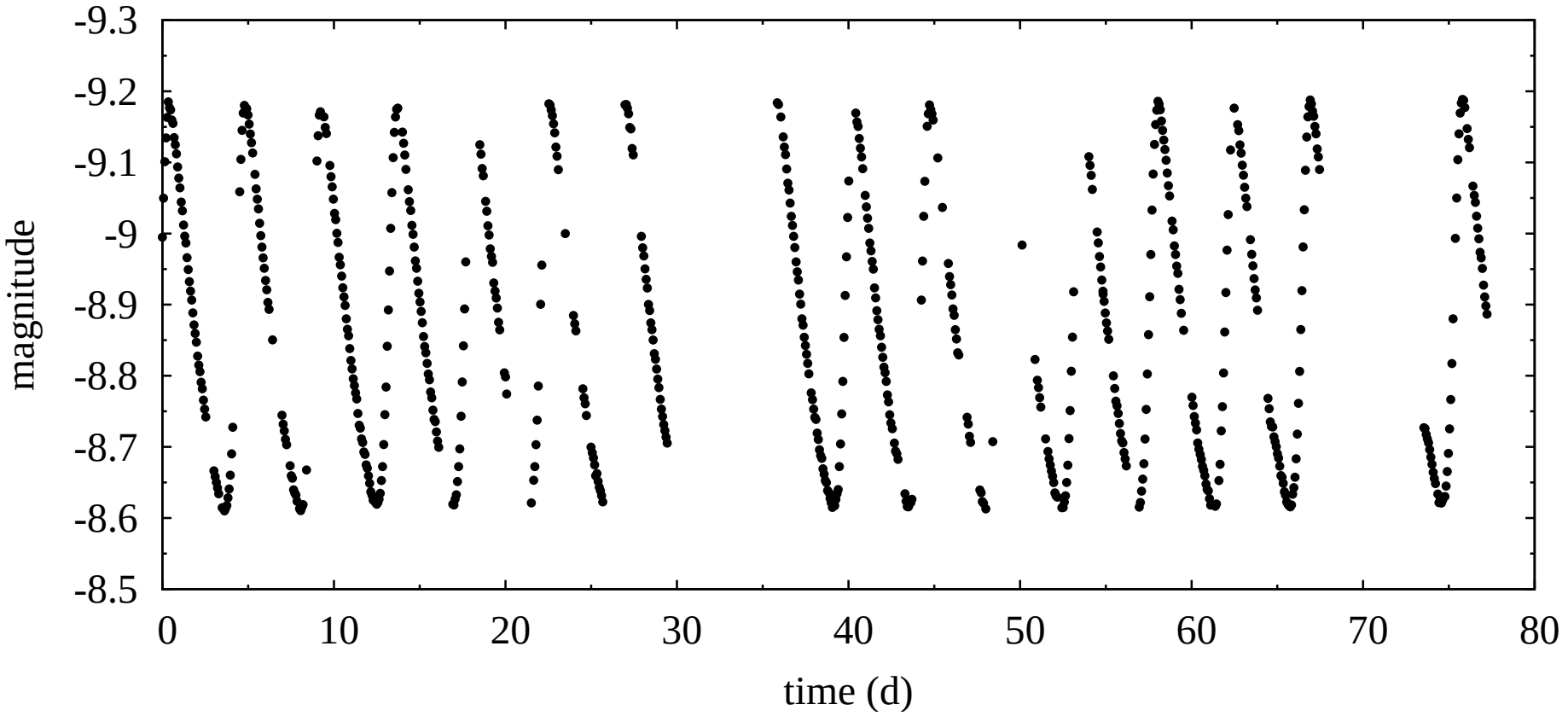
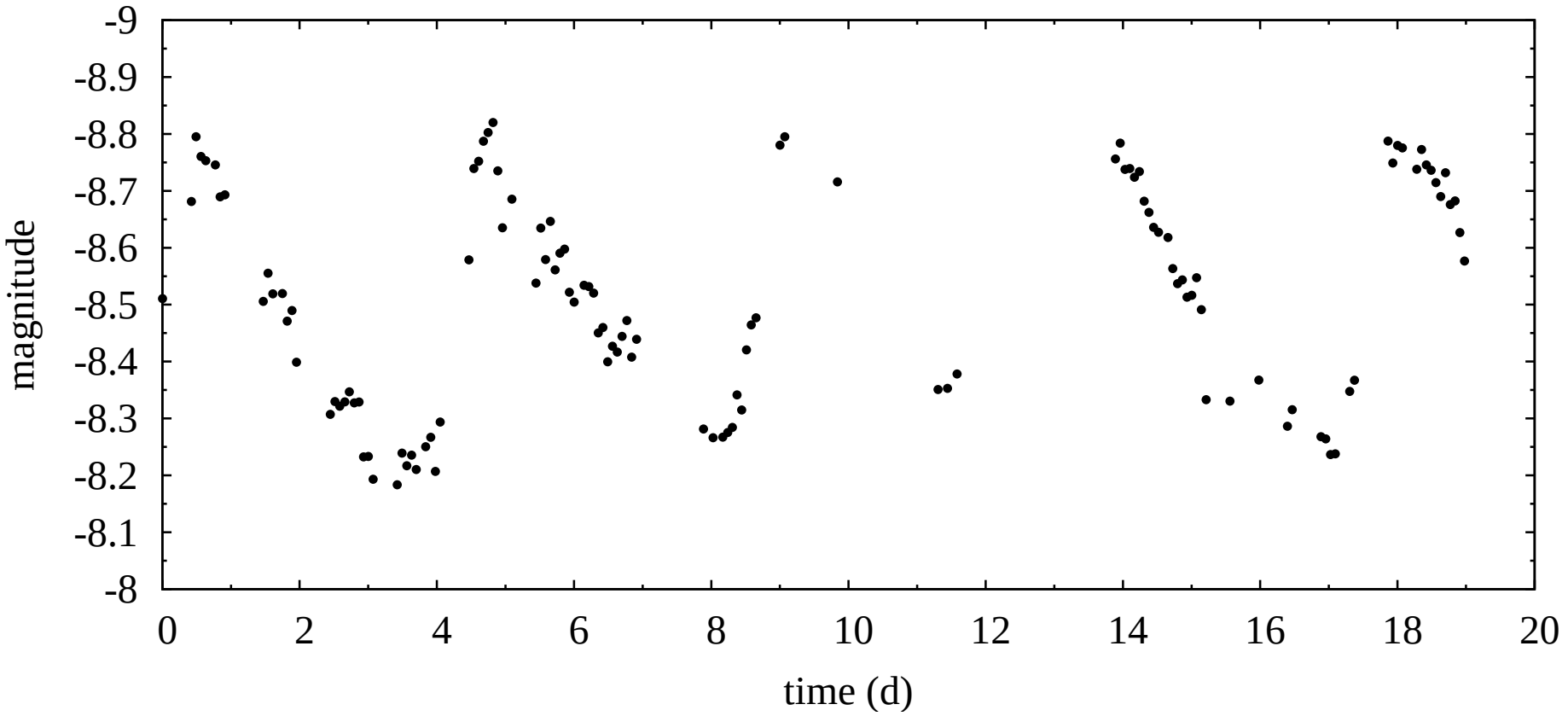


⋆ **BTr data**

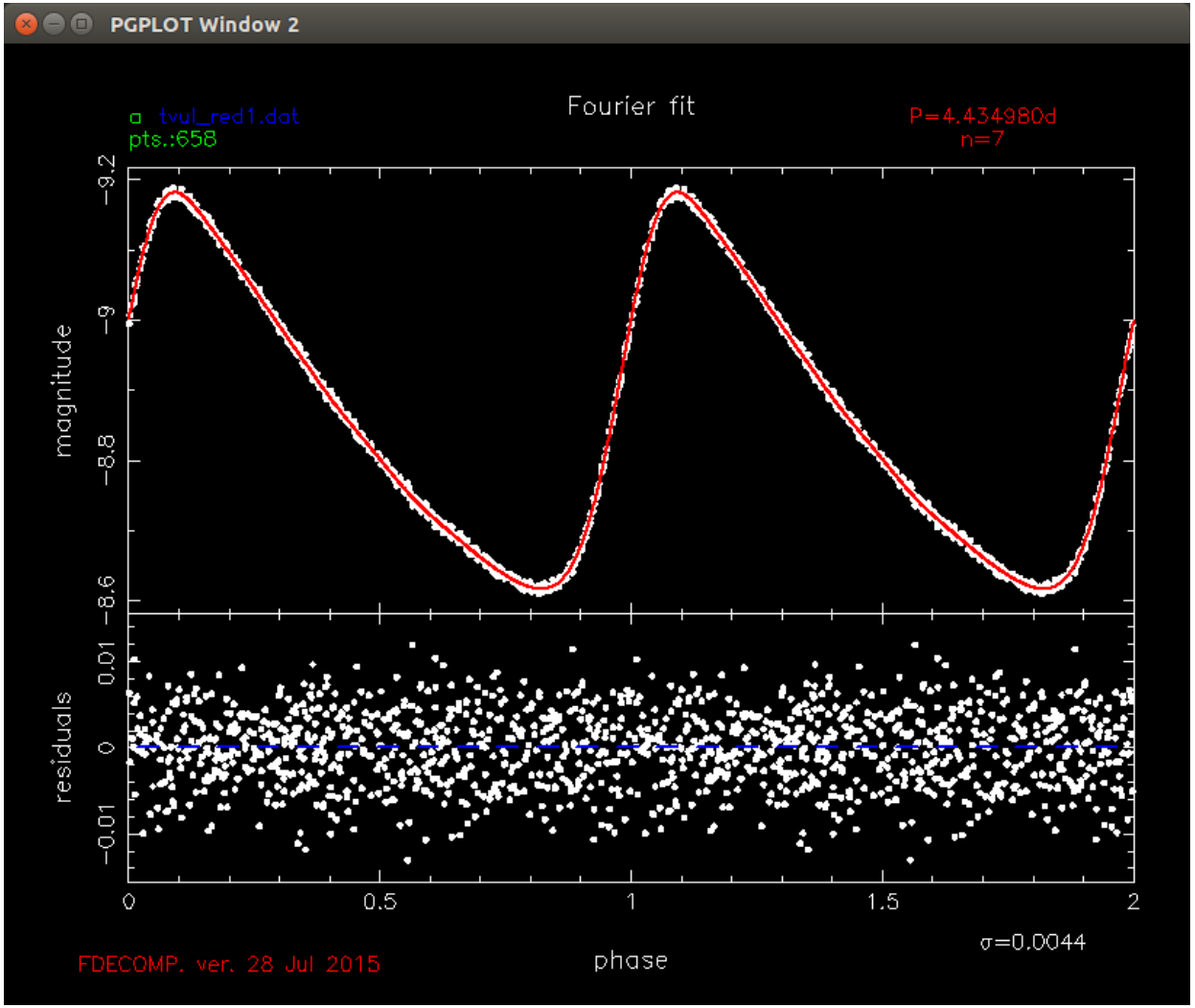
First step of analysis: averaging & outlier removal



⋆ **UBr data**

Second step of analysis: decorrelations

- high amplitude intrinsic variability modelled with Fourier series



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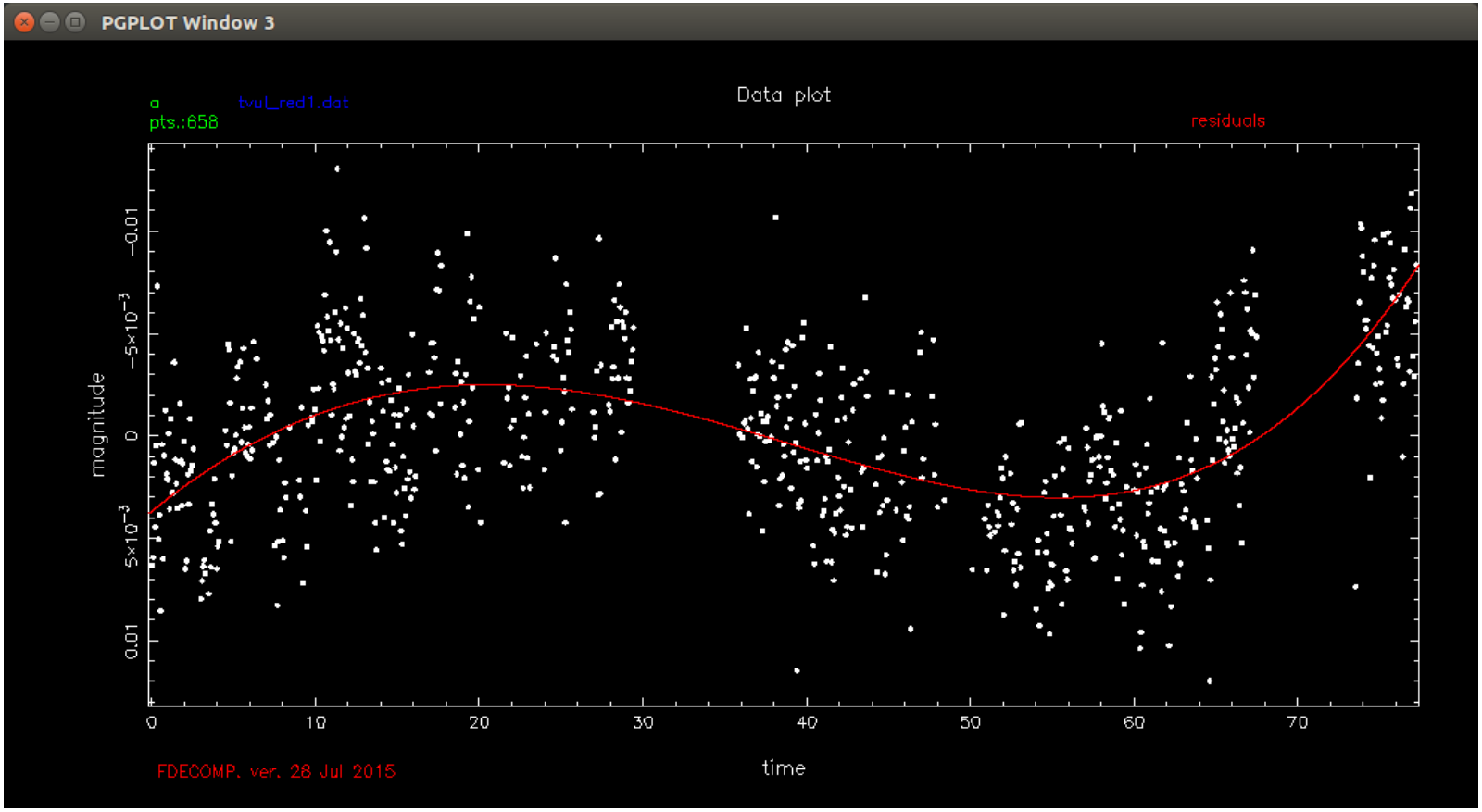
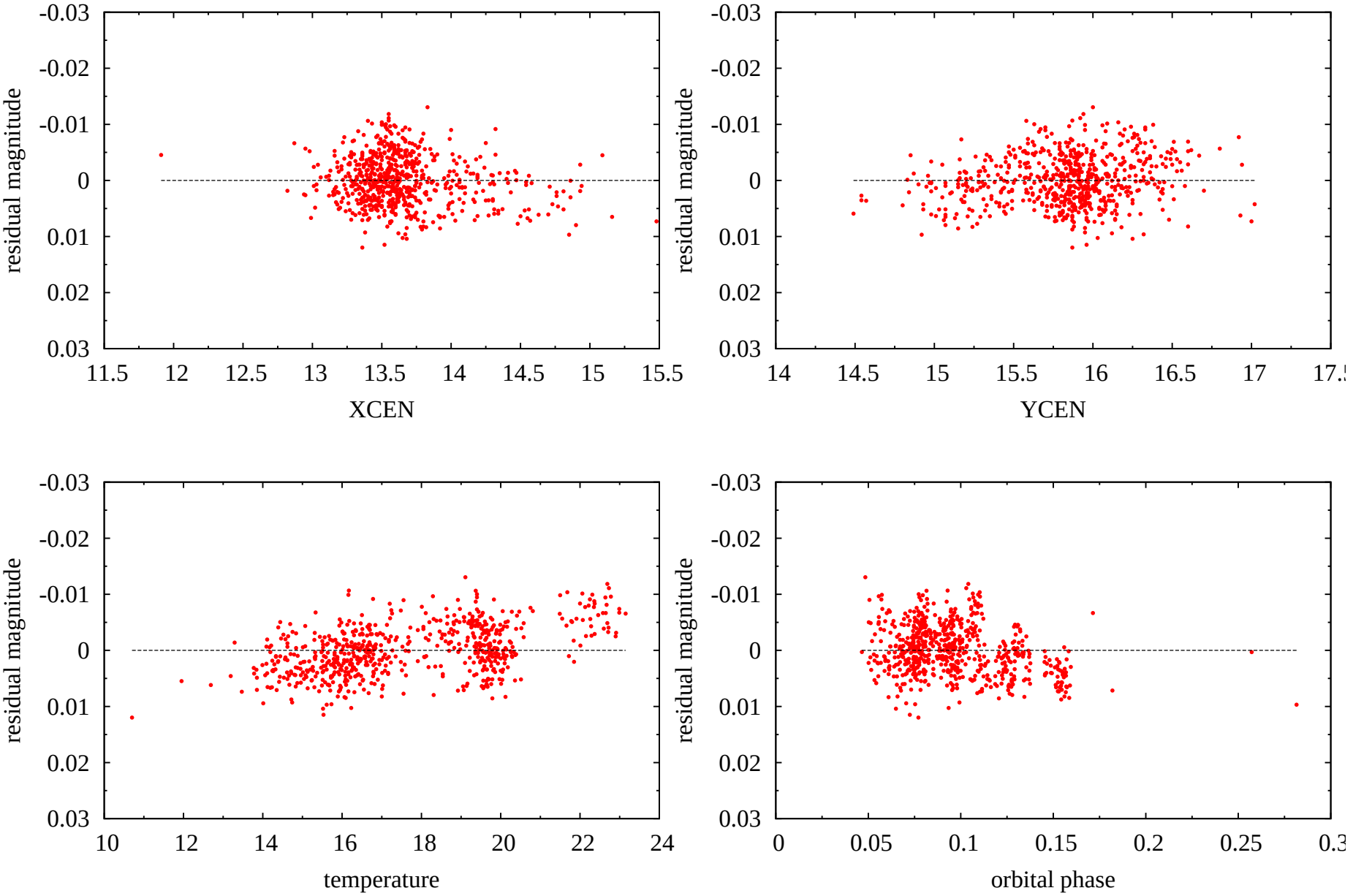


Second step of analysis: decorrelations

- high amplitude intrinsic variability modelled with Fourier series
- XCEN, YCEN, CCD-temperature averaged in the same way as fluxes
- orbital phases computed with orbital period determined from DFT
- decorrelation procedure follows BRITE cookbook approach and uses slightly modified Andrzej Pigulski's codes

Second step of analysis: decorrelations



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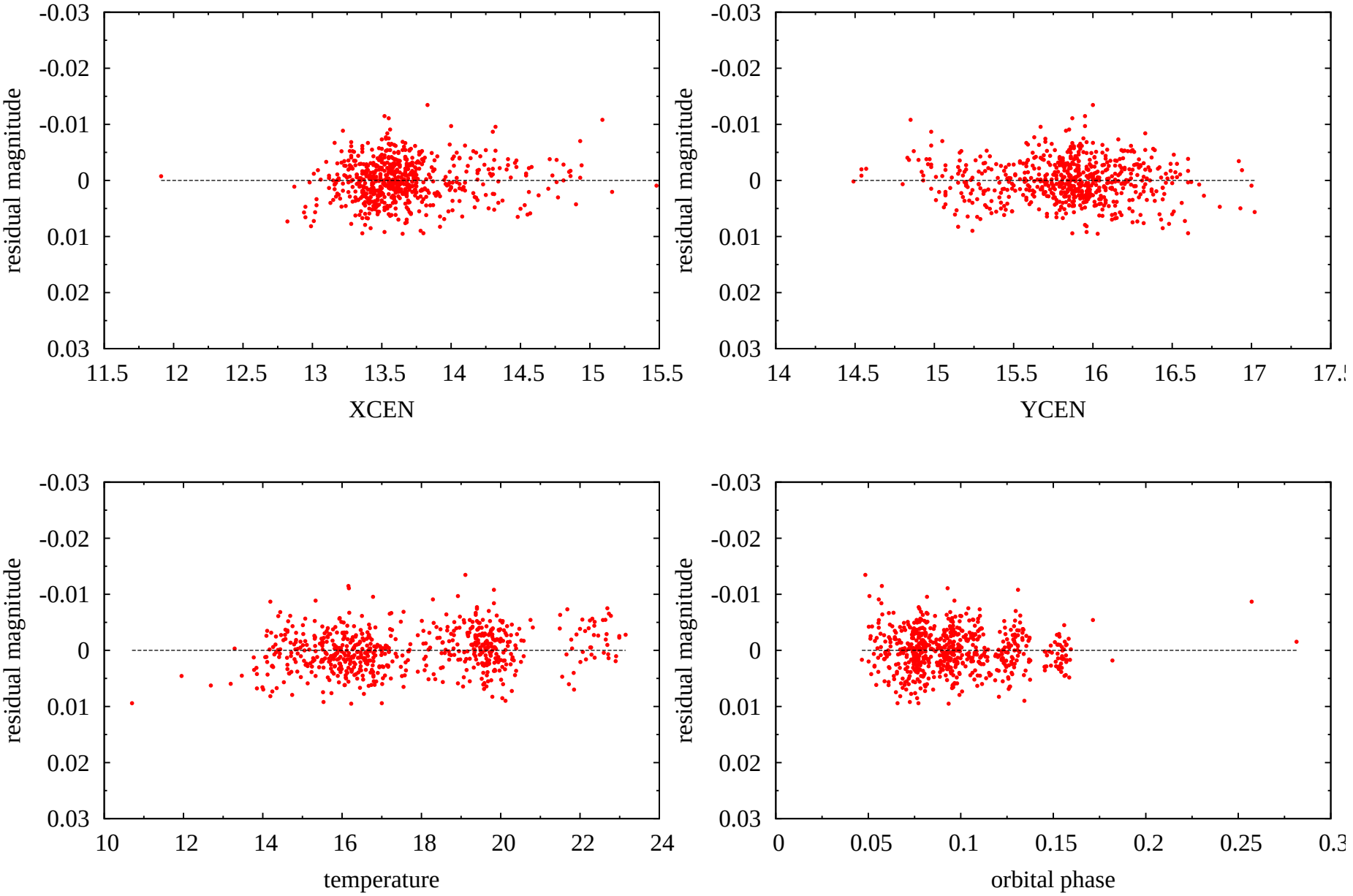
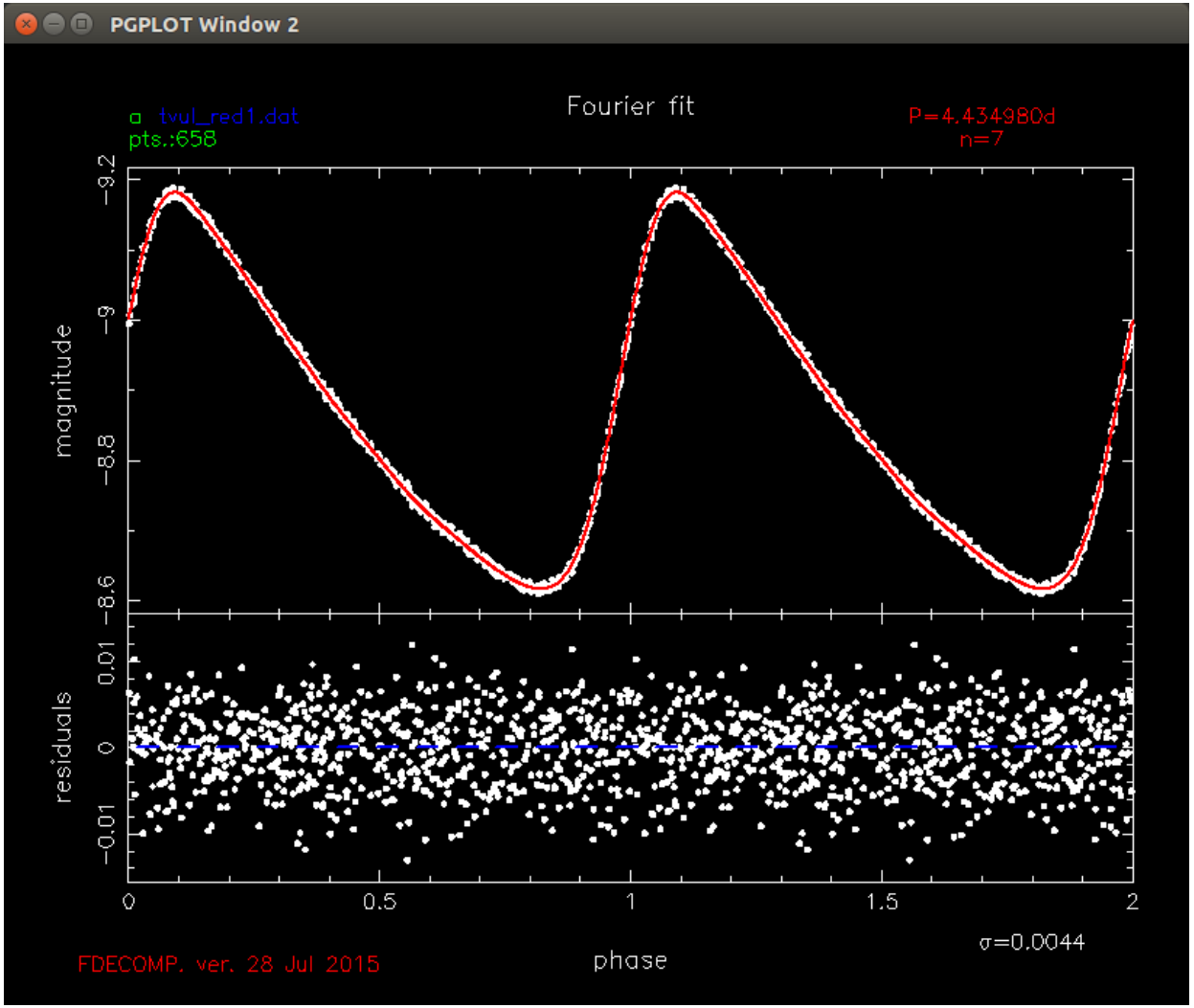


Second step of analysis: before – after



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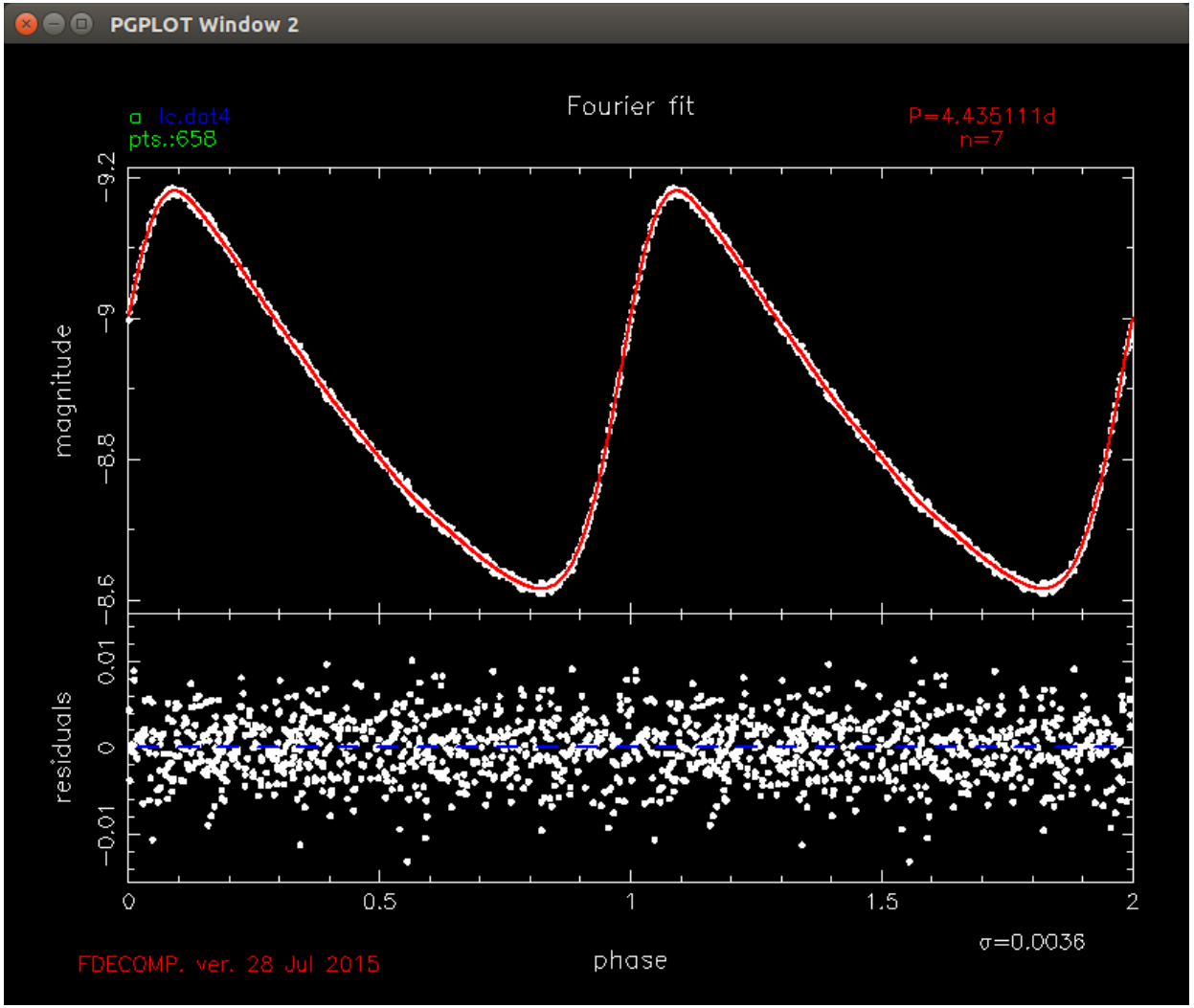

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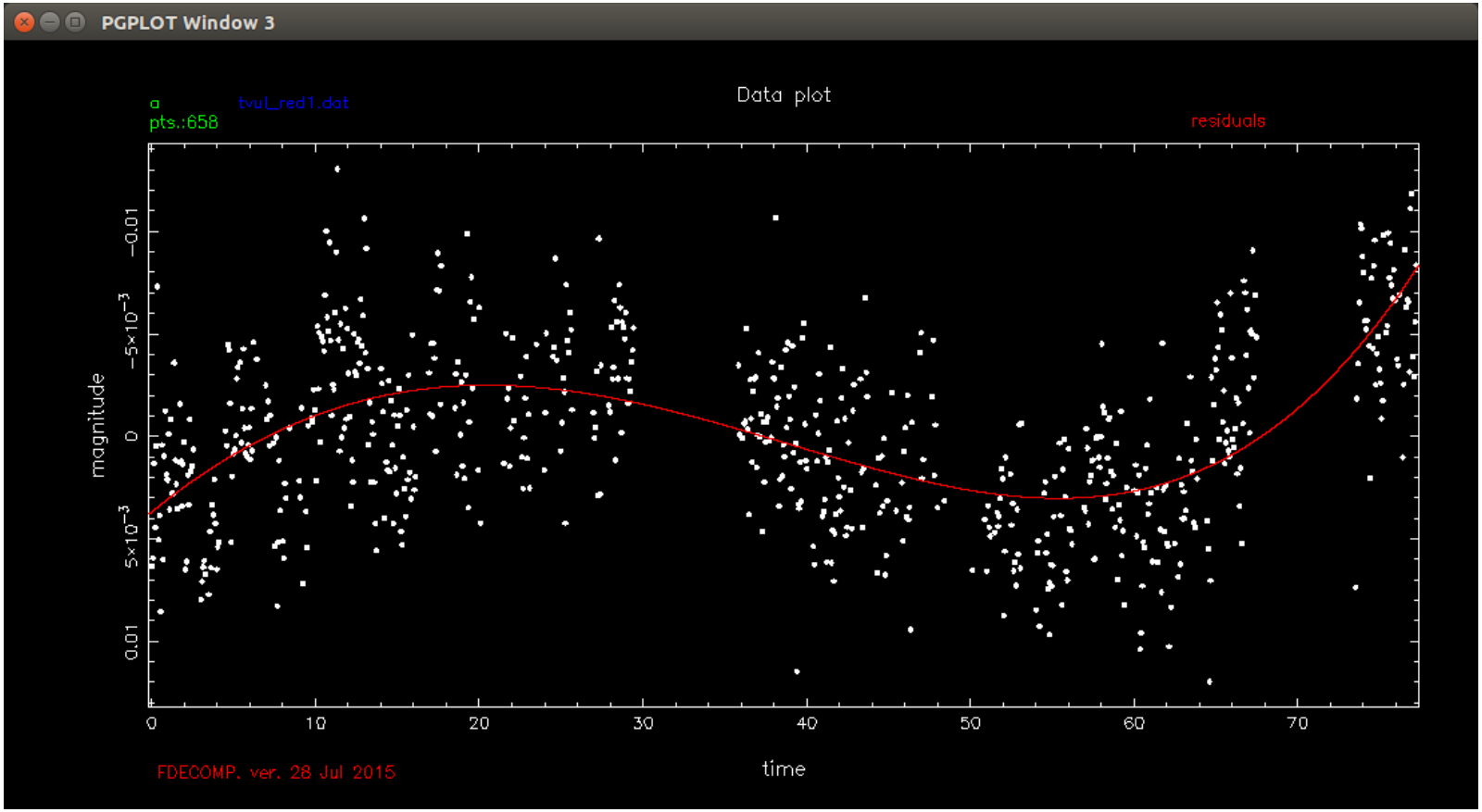

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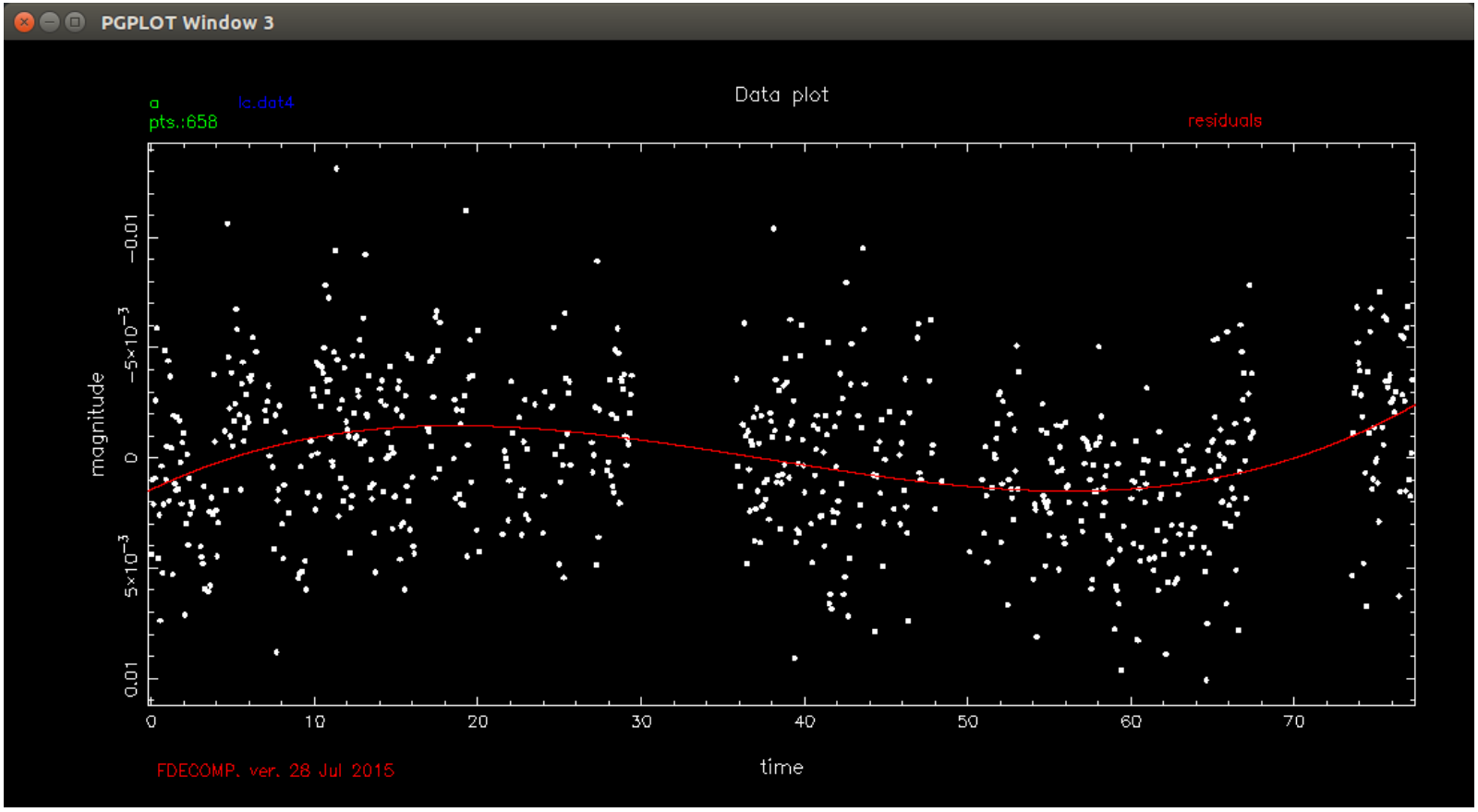

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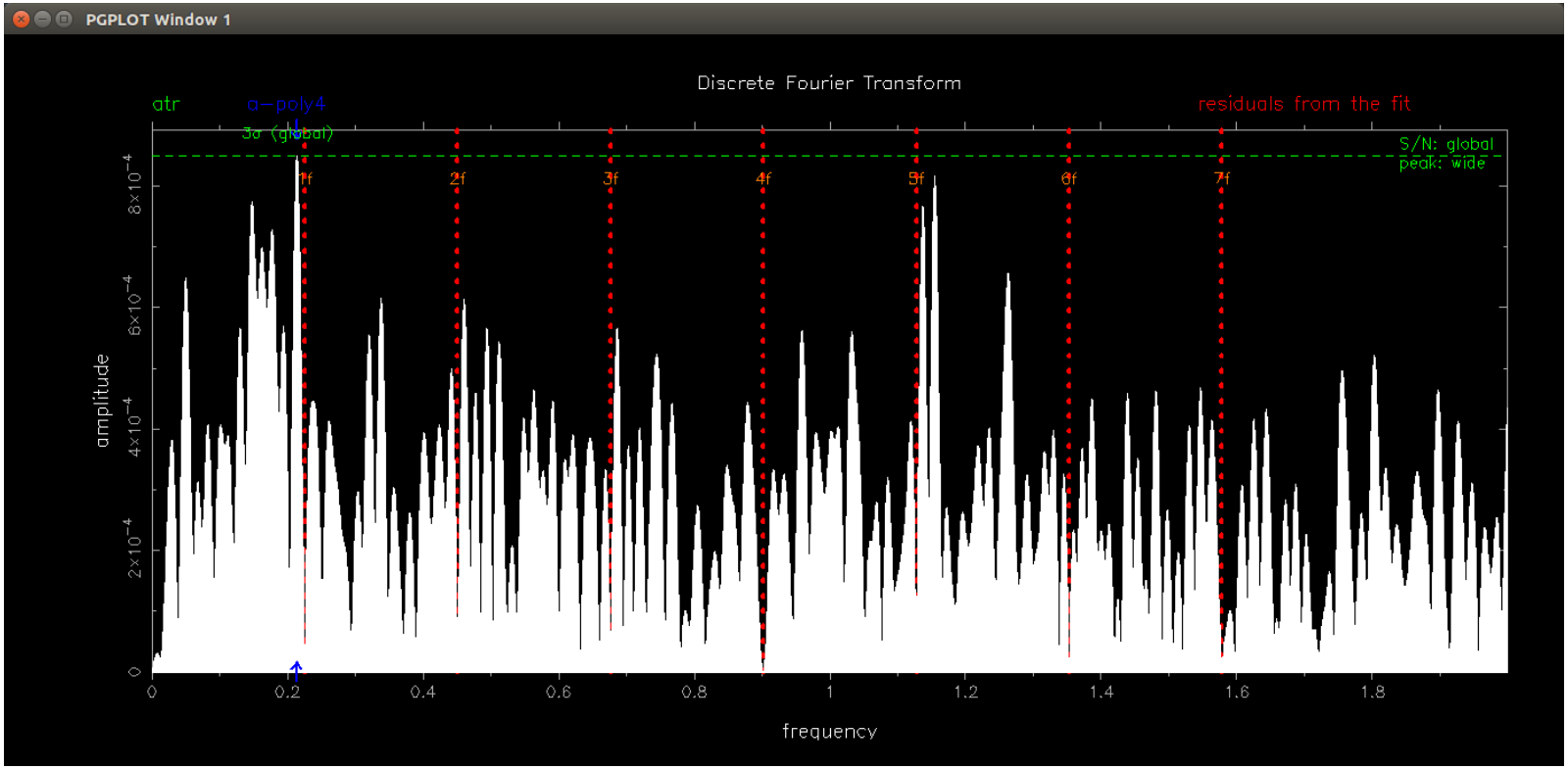
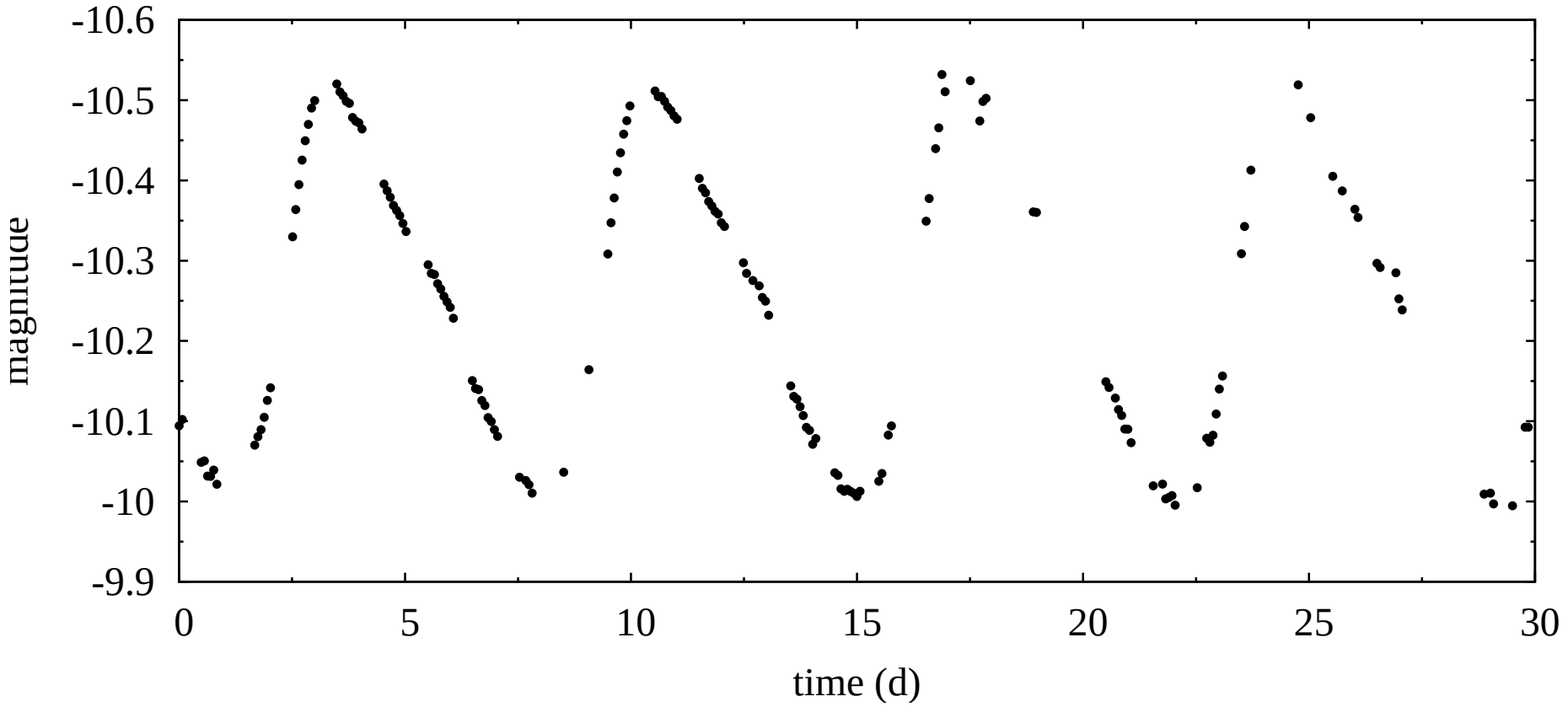


F mode Cepheid: X Sgr (4.55 mag)



⋆ **UBr data**, the only we have

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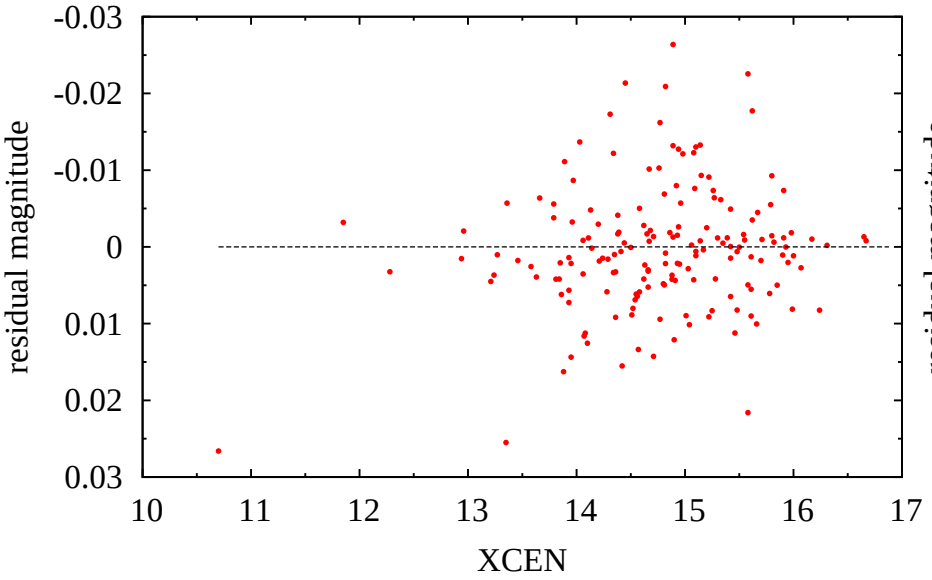
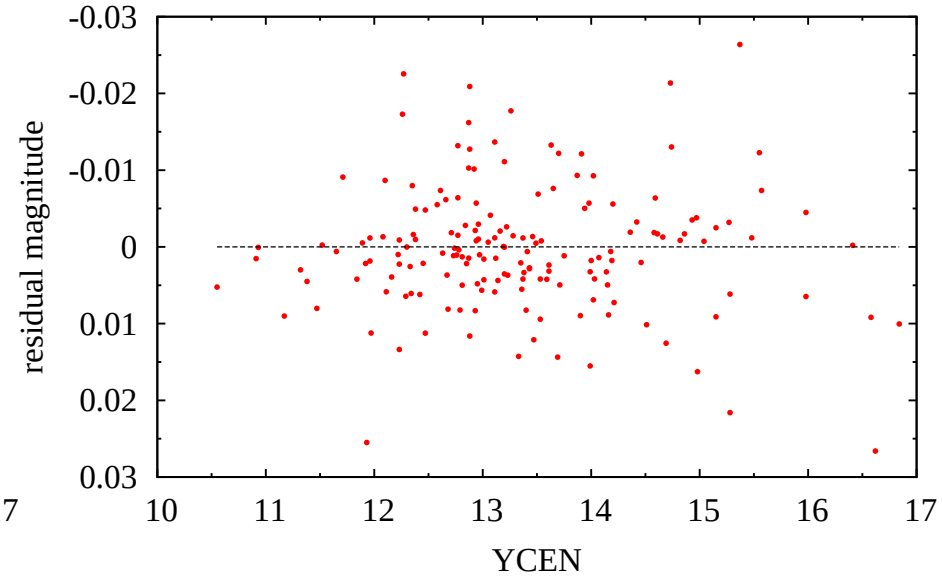
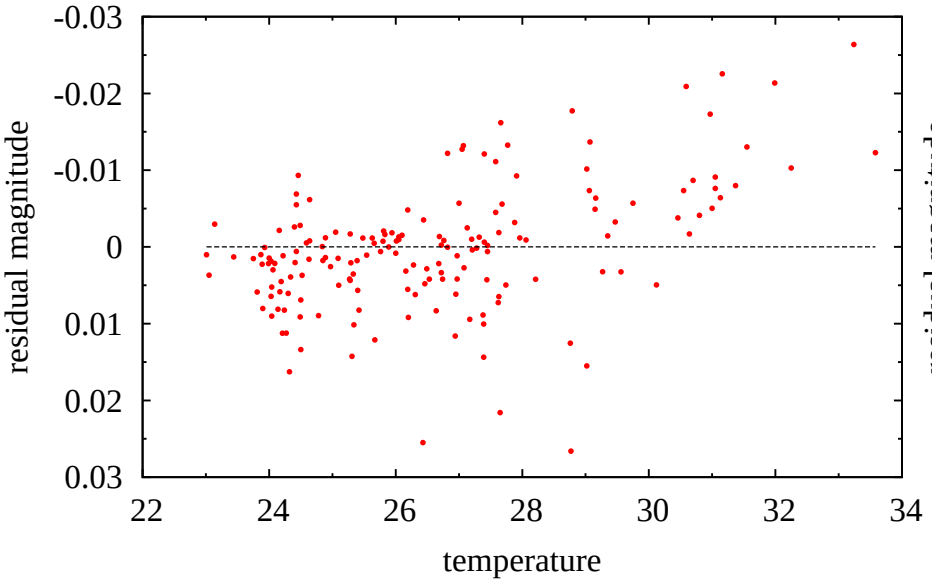
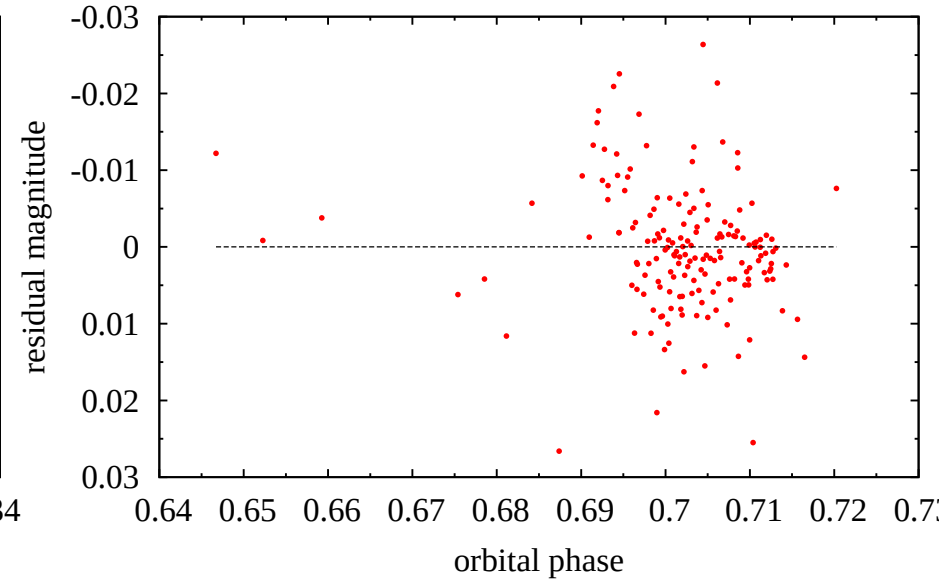
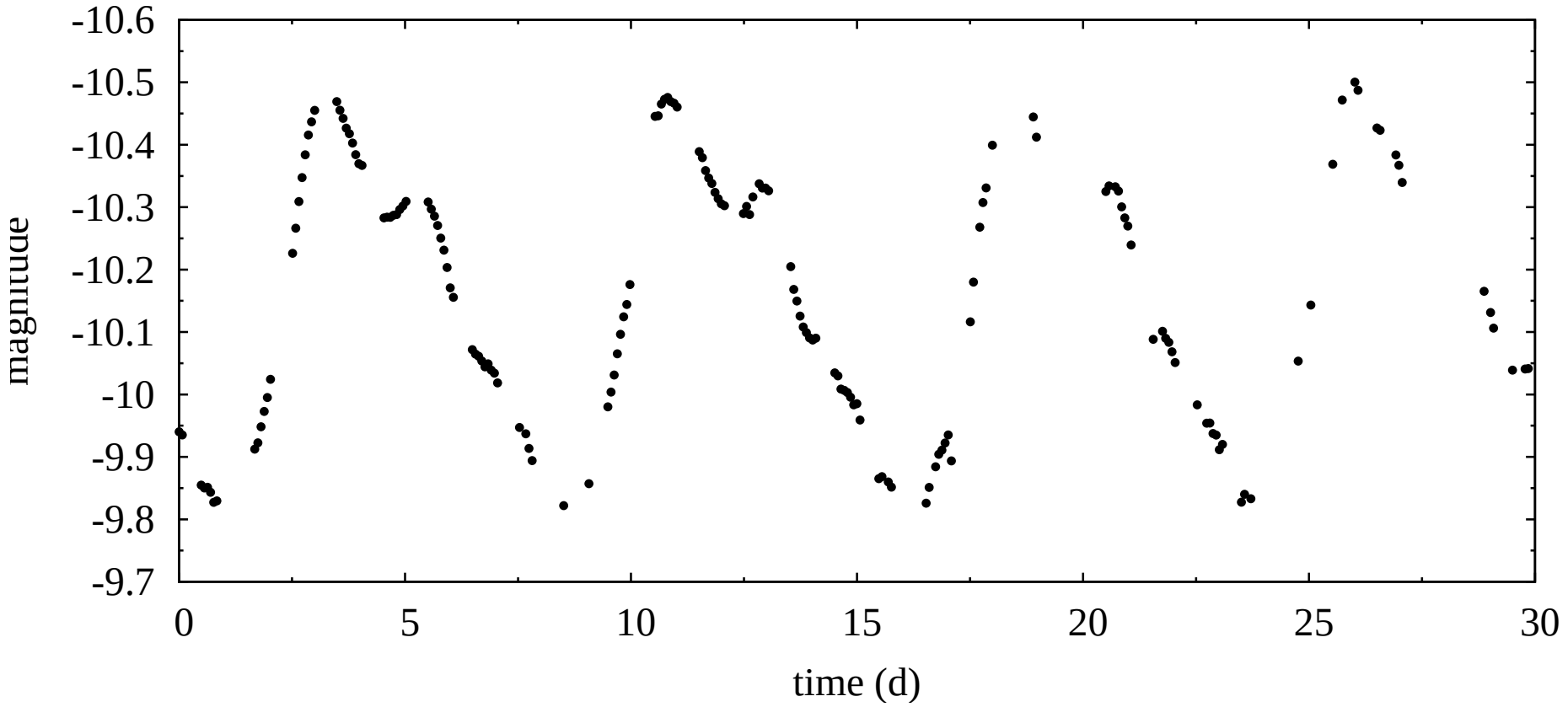








F mode Cepheid: W Sgr (4.67 mag)



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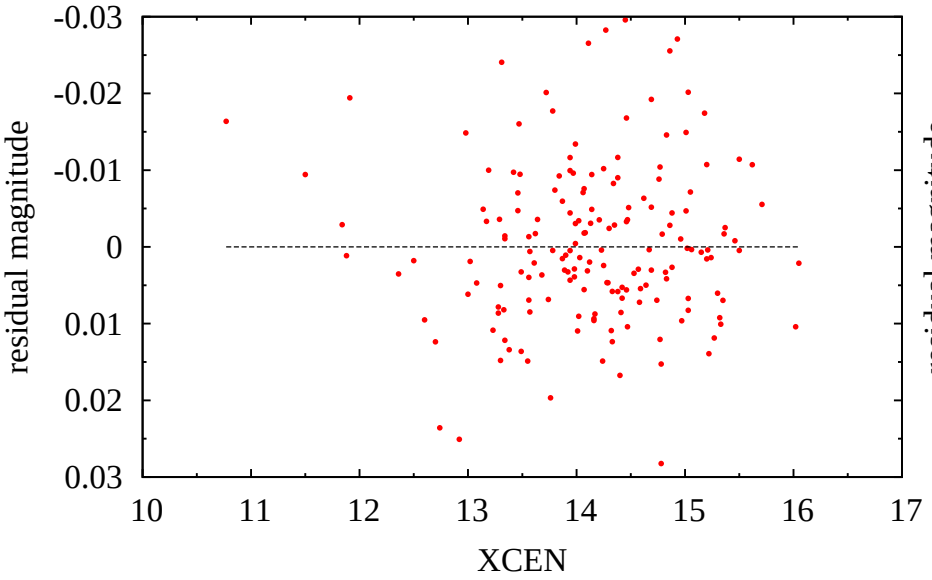
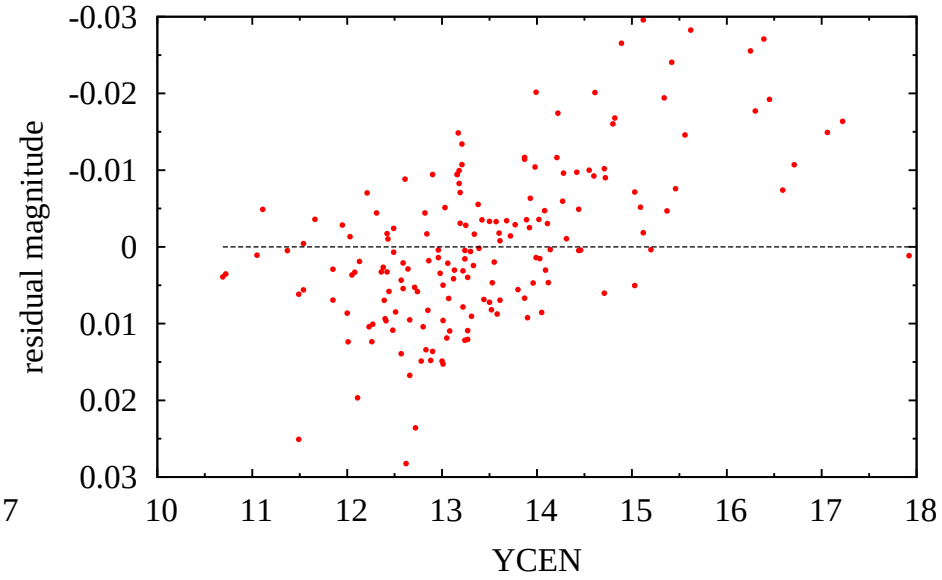
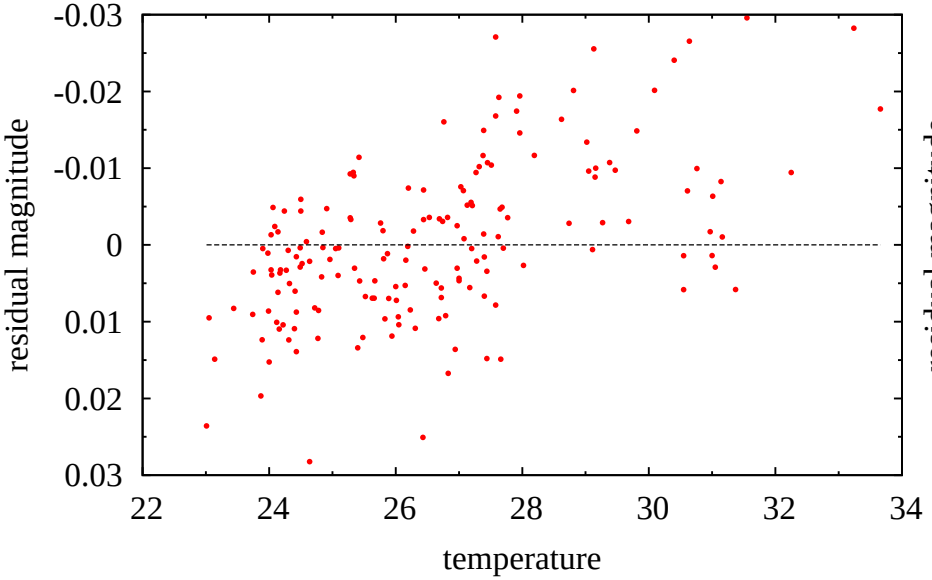
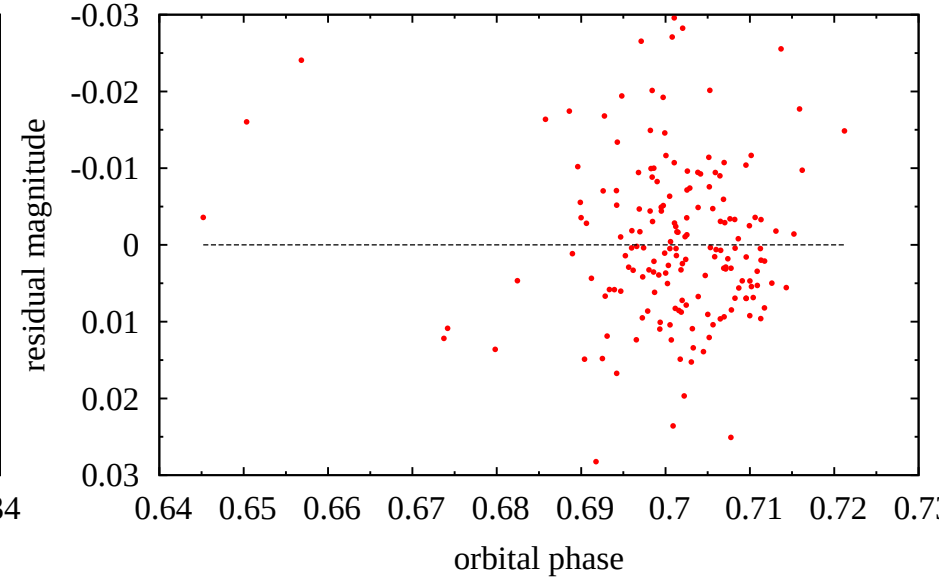
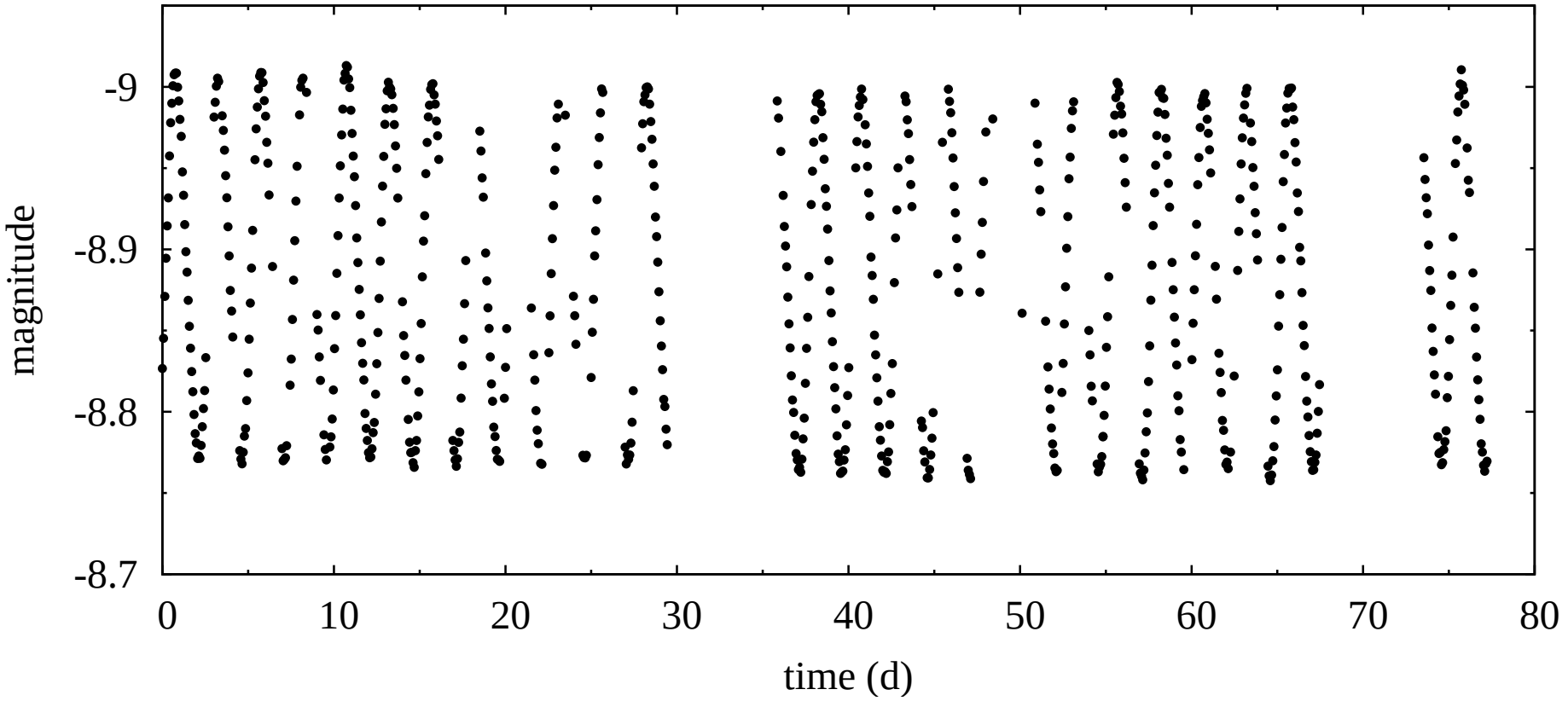






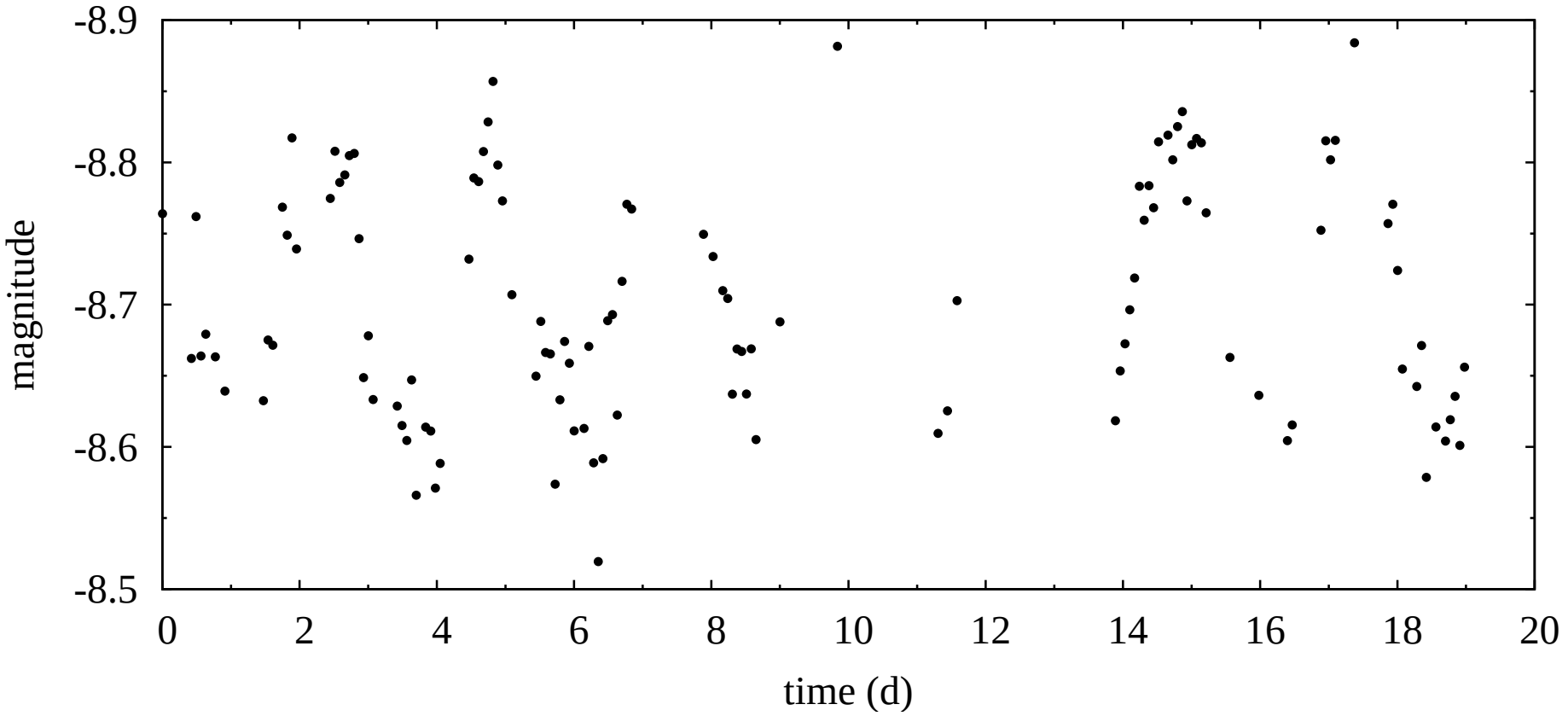


1O mode Cepheid: DT Cyg (5.77 mag)



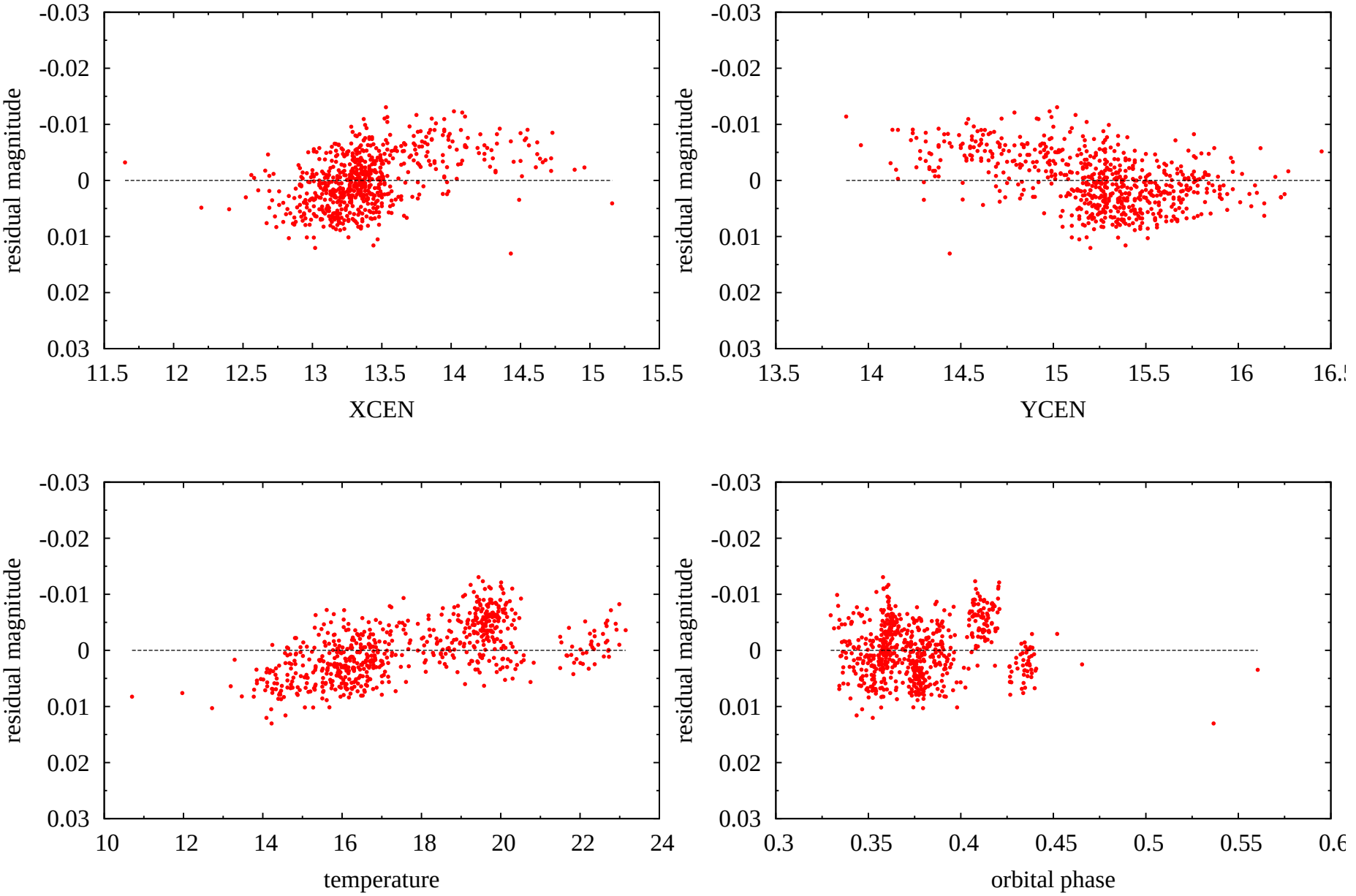
⋆ **BTr data**

1O mode Cepheid: DT Cyg (5.77 mag)

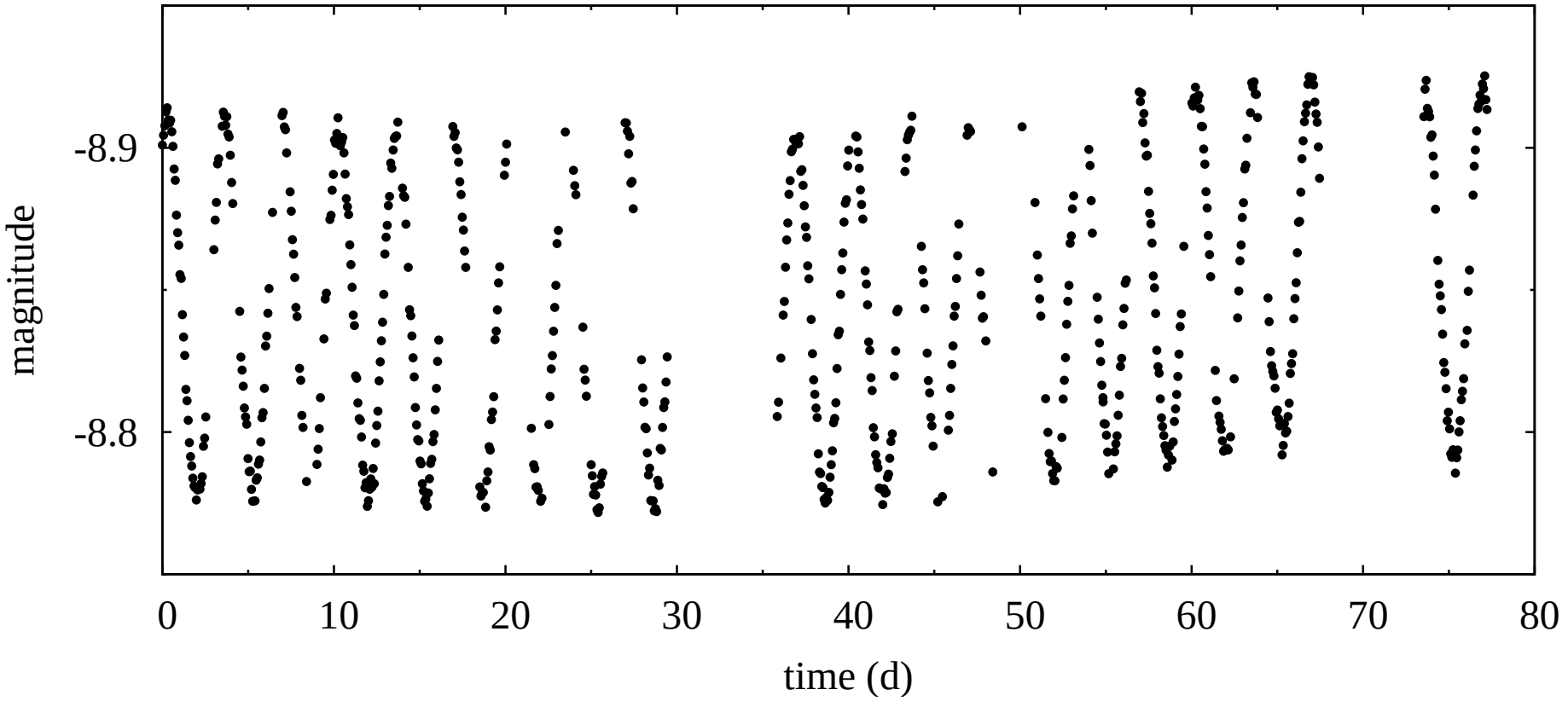


⋆ **UBr data**

1O mode Cepheid: DT Cyg (5.77 mag)

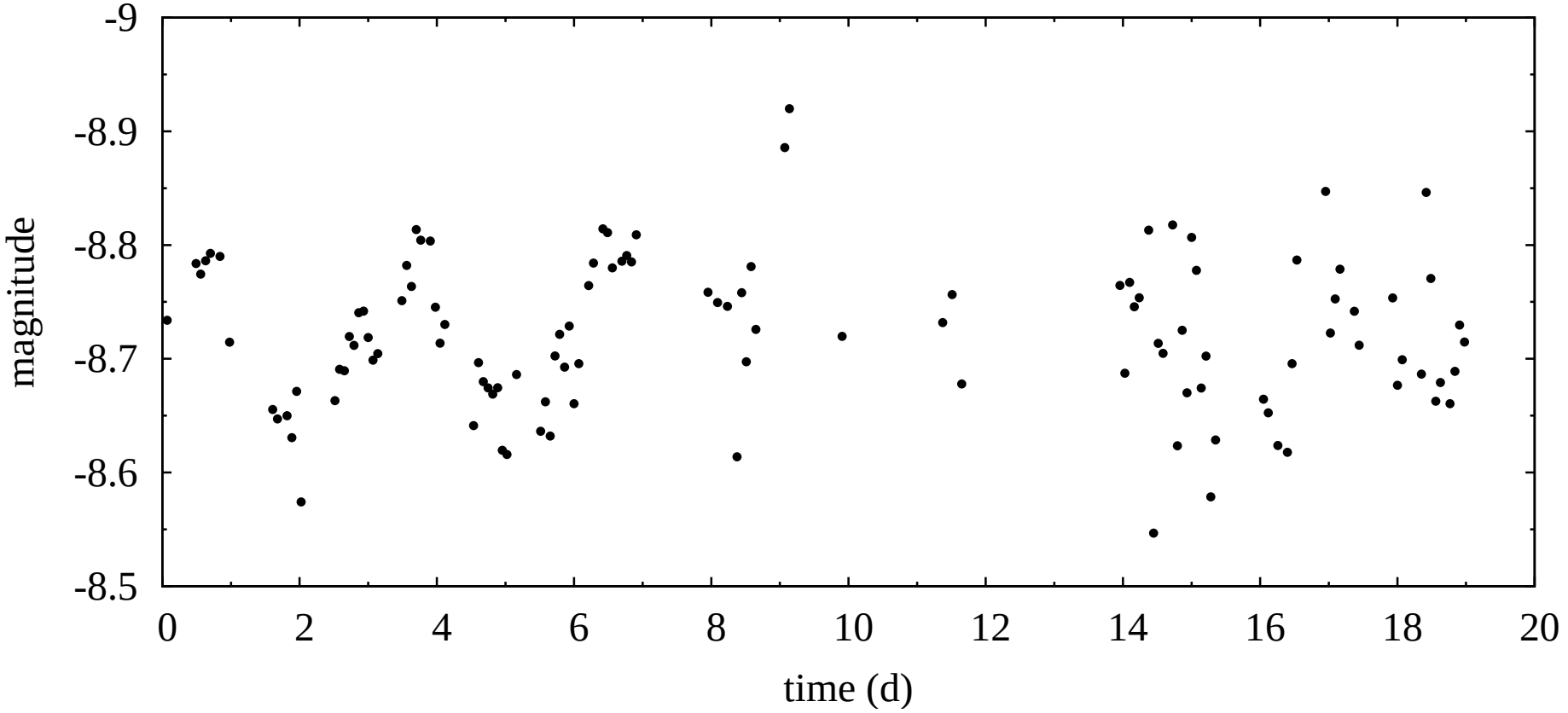


1O mode Cepheid: V1334 Cyg (5.87 mag)



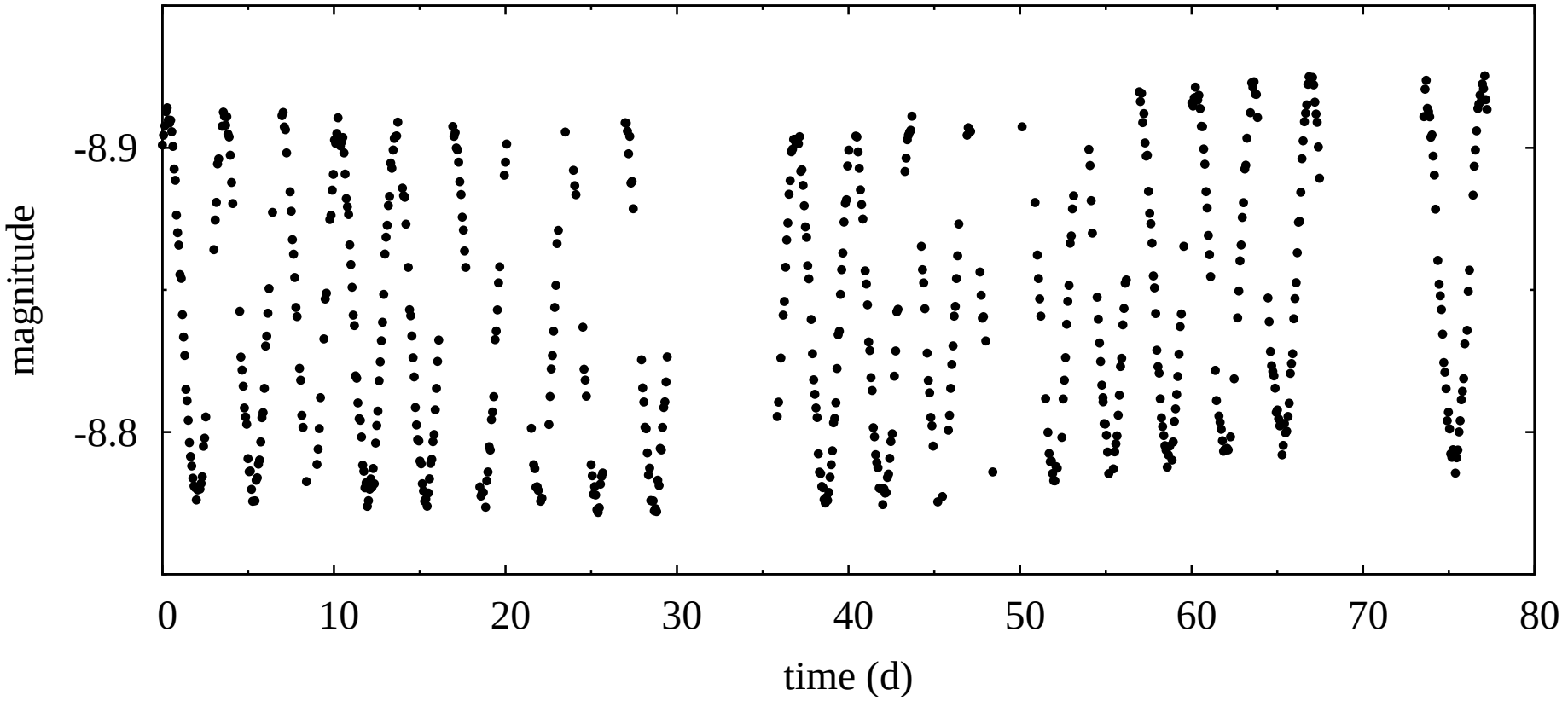
⋆ **BTr data**

1O mode Cepheid: V1334 Cyg (5.87 mag)



⋆ **UBr data**

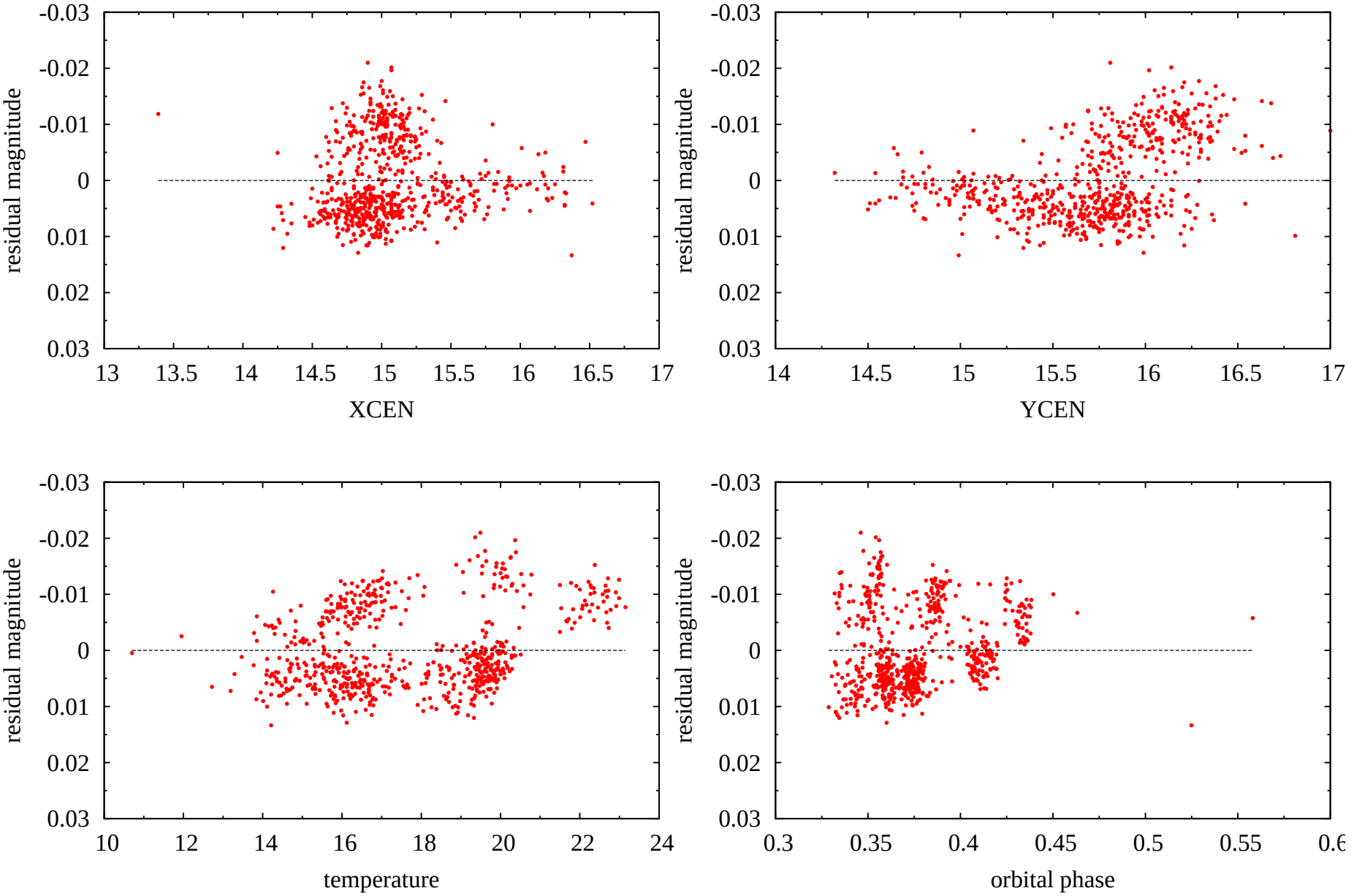
1O mode Cepheid: V1334 Cyg (5.87 mag)



⋆ **BTr data**

⋆ significant trend is obvious and hampers the decorrelations using standard approach

1O mode Cepheid: V1334 Cyg (5.87 mag)



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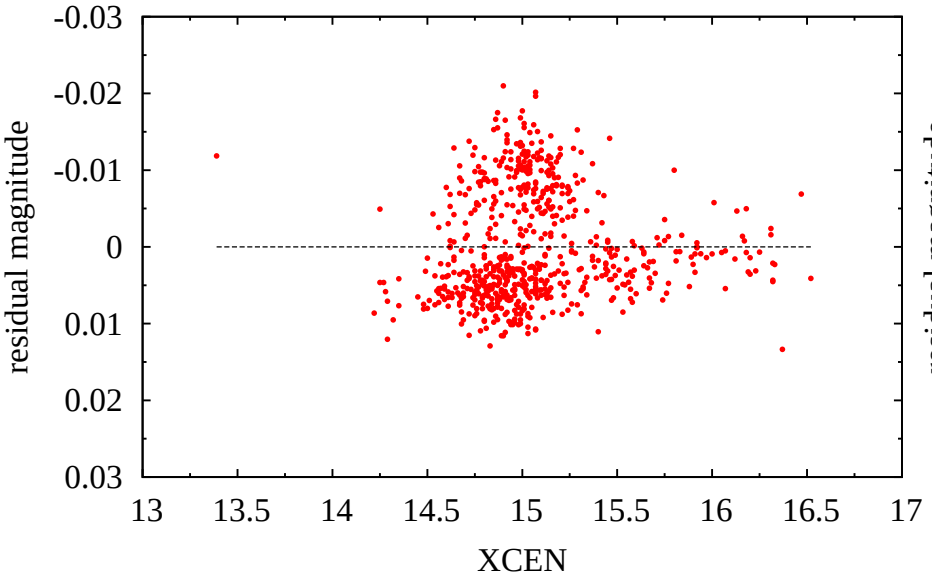
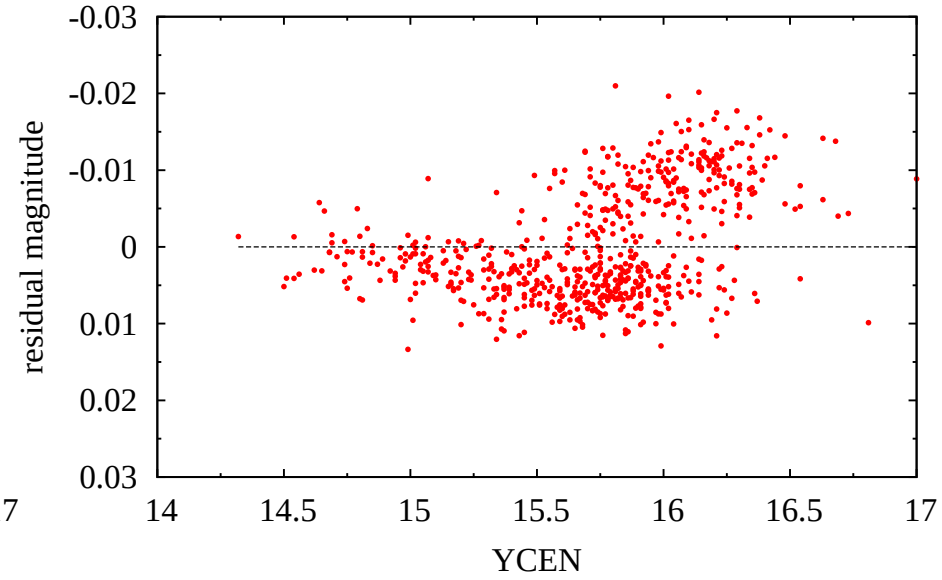
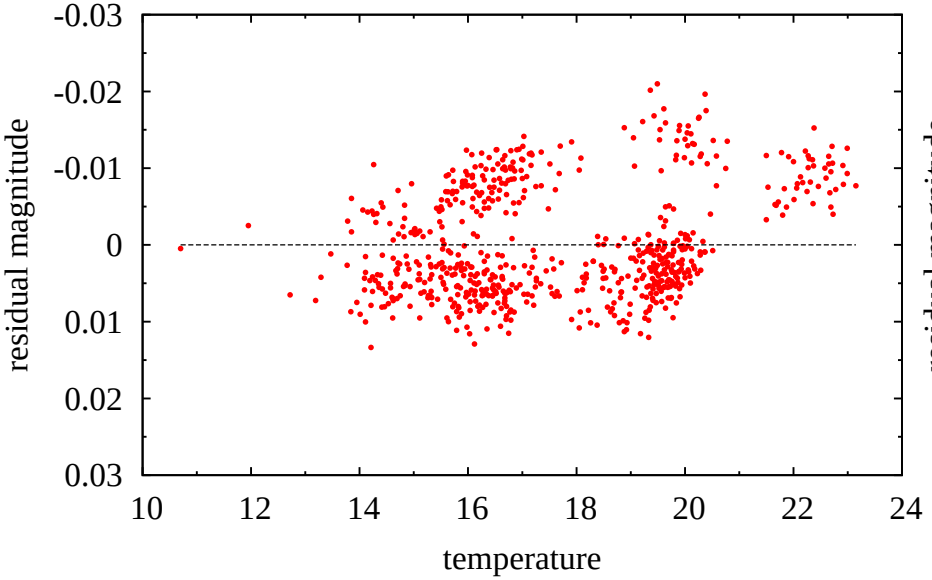
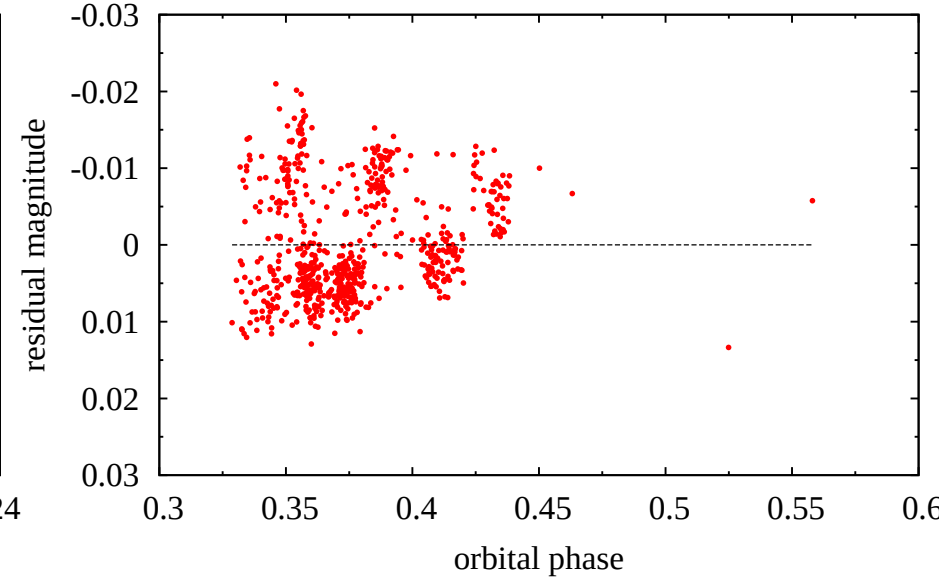


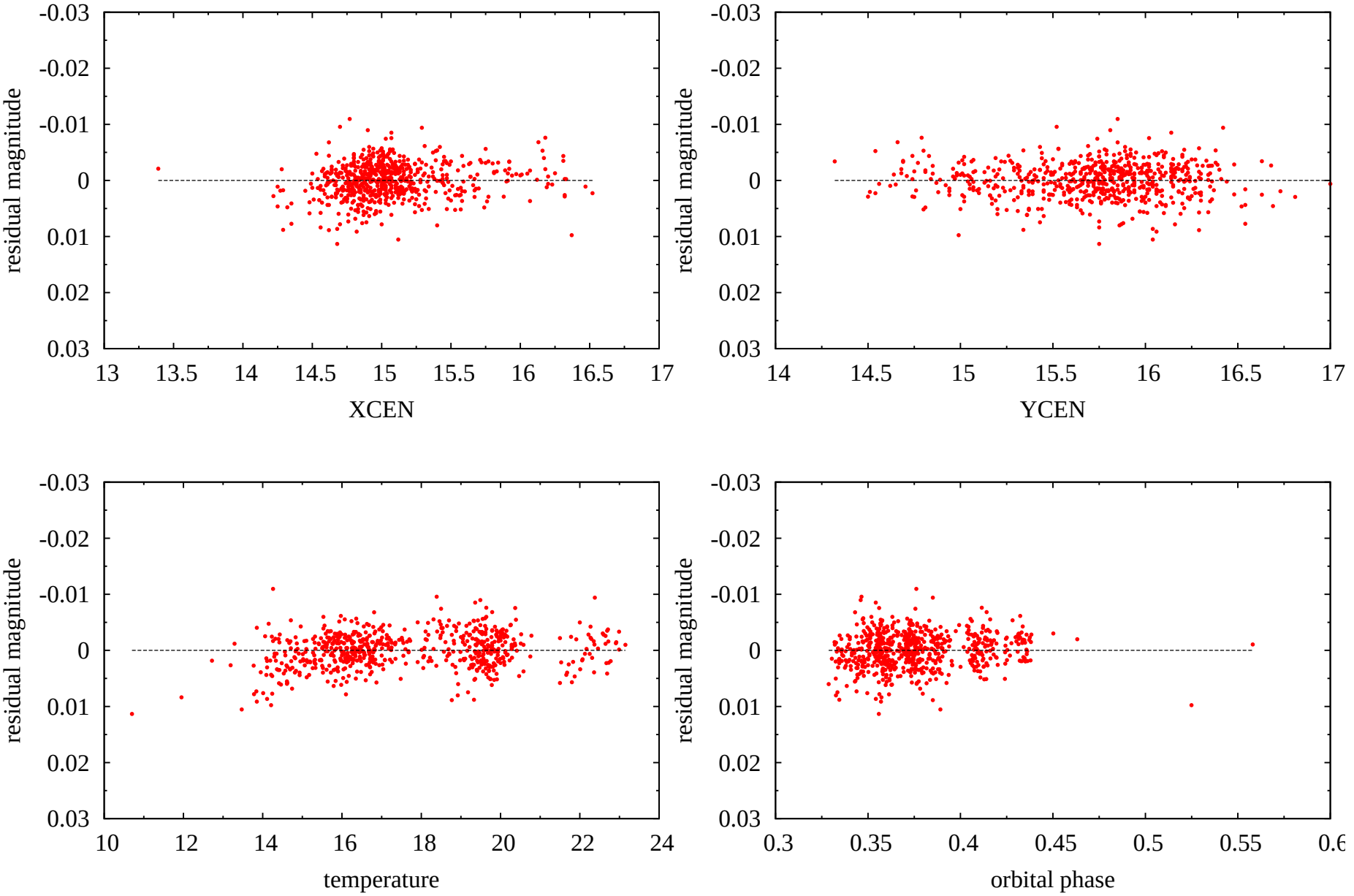


we simply model the trend with polynomial

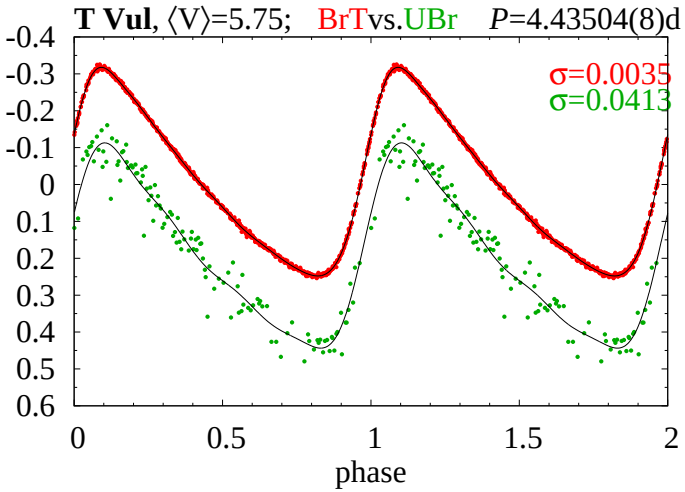


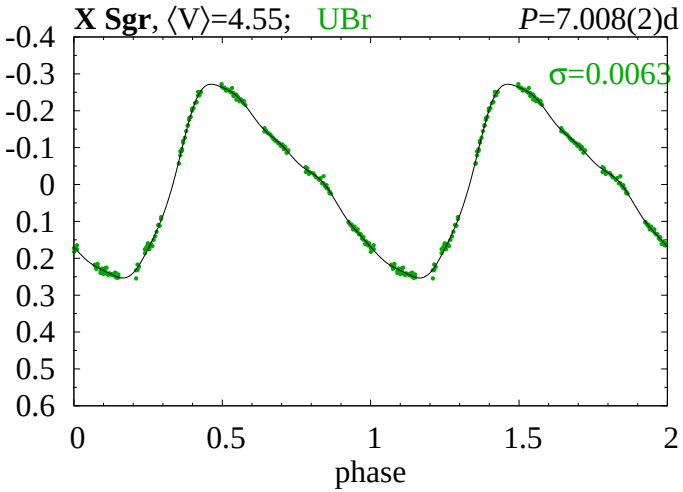


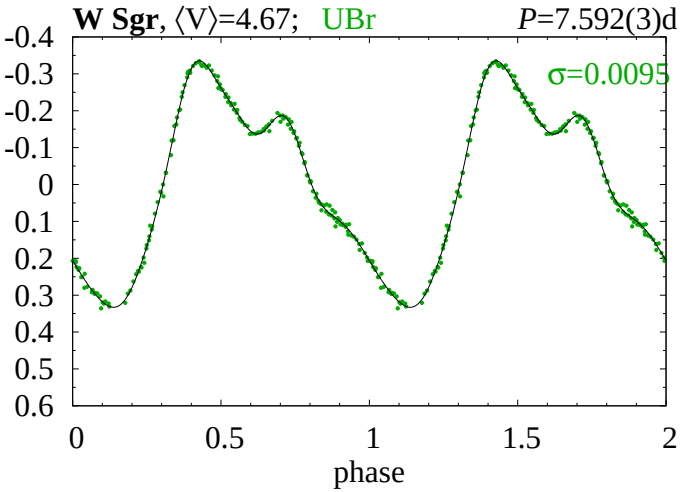
1O mode Cepheid: V1334 Cyg (5.87 mag)

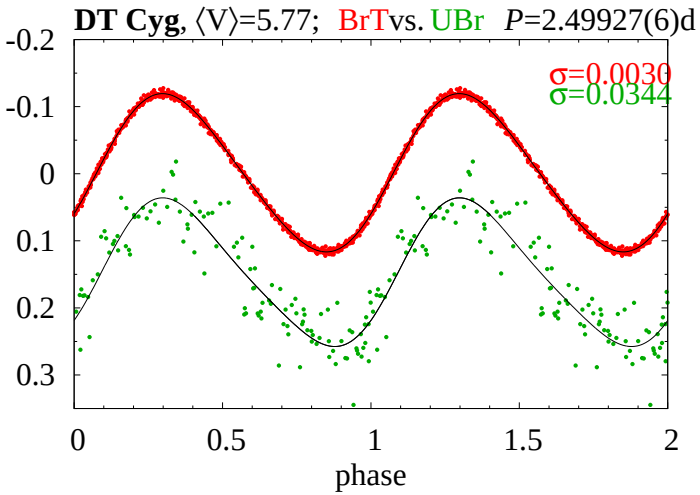


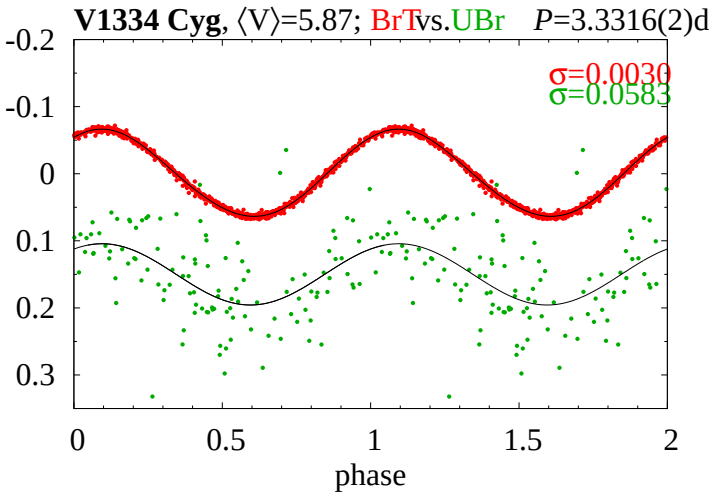
BRITE's classical Cepheids – a family photo



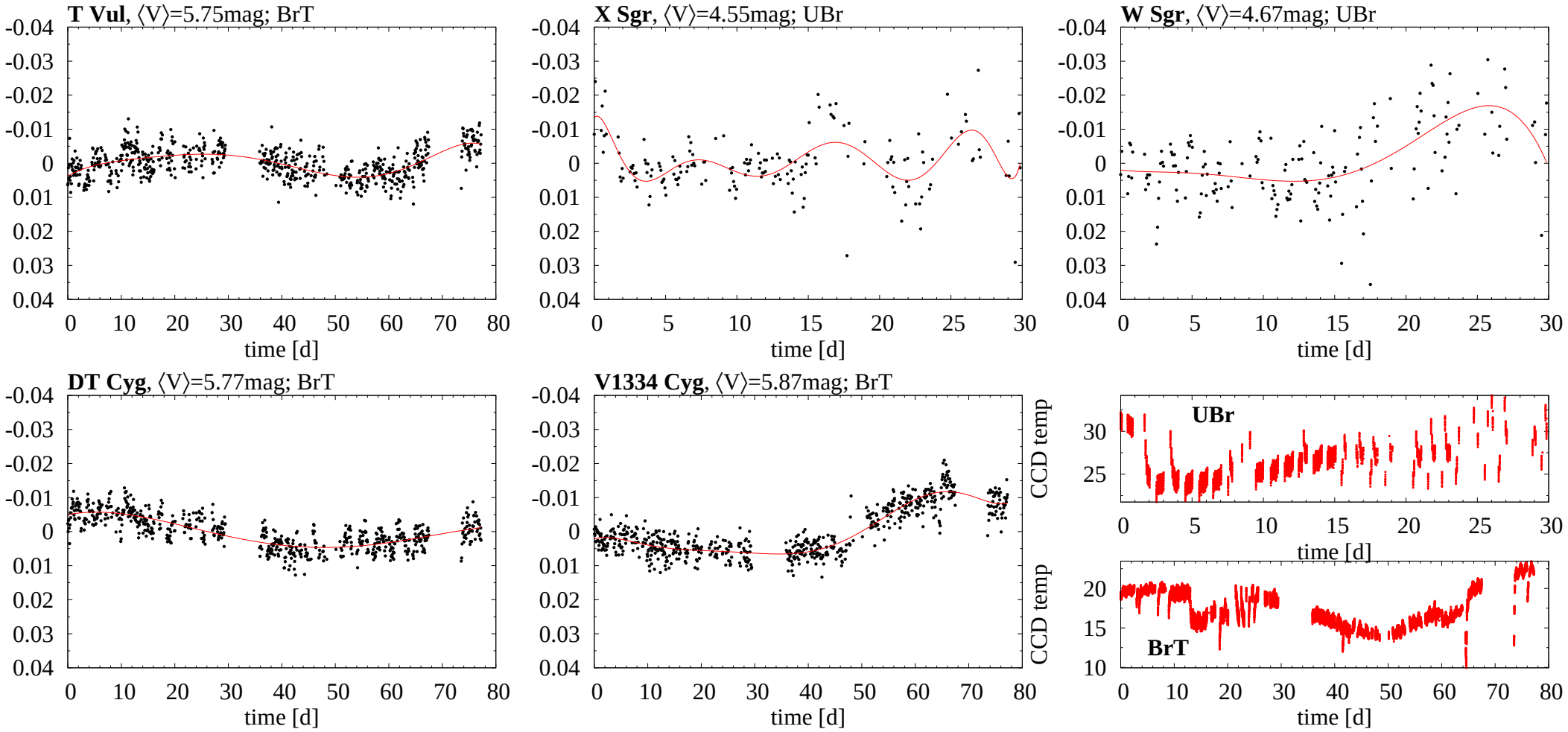








BRITE's classical Cepheids – a family photo



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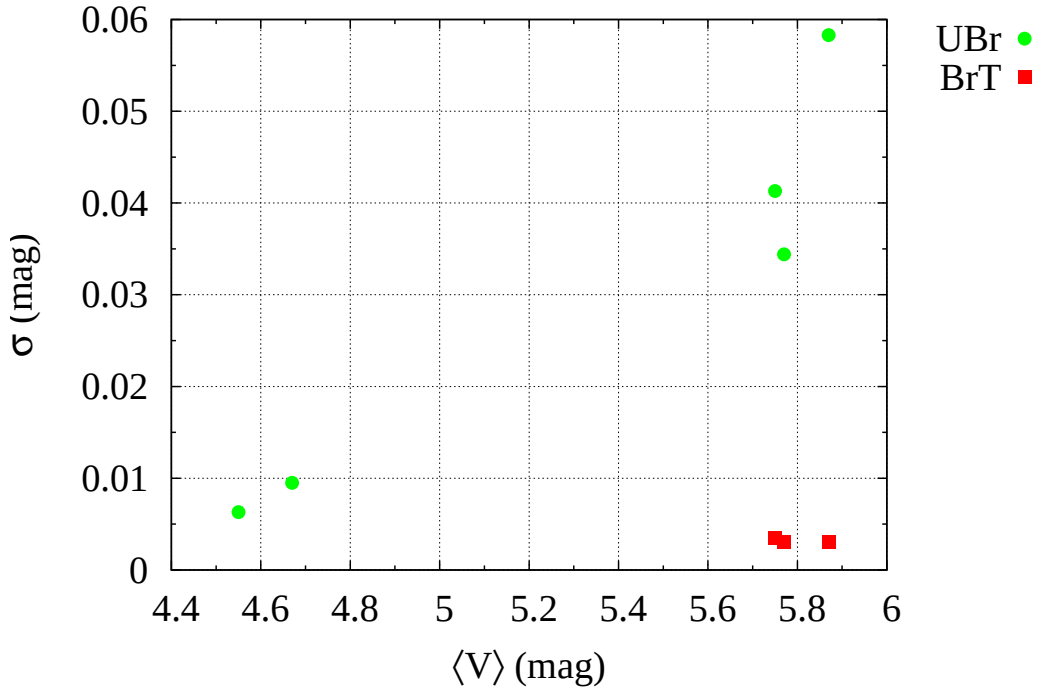

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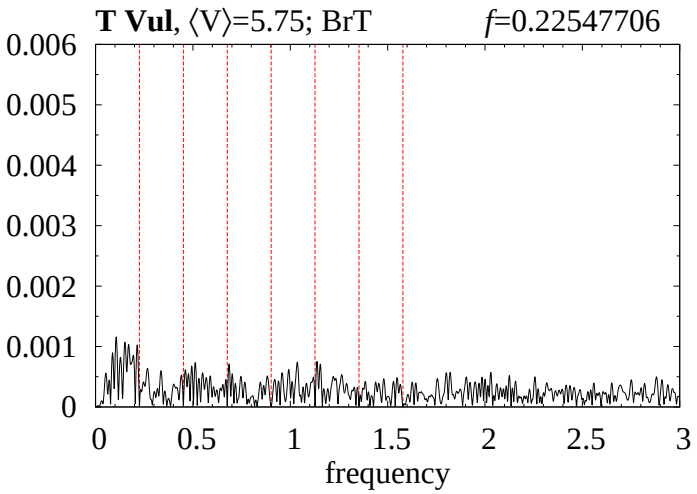

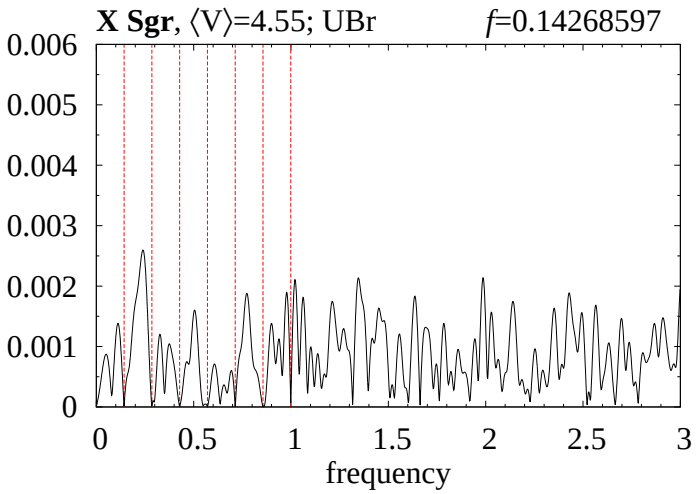

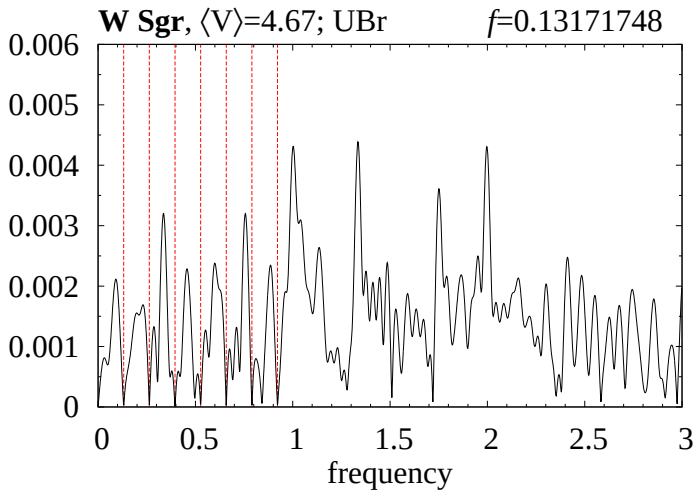

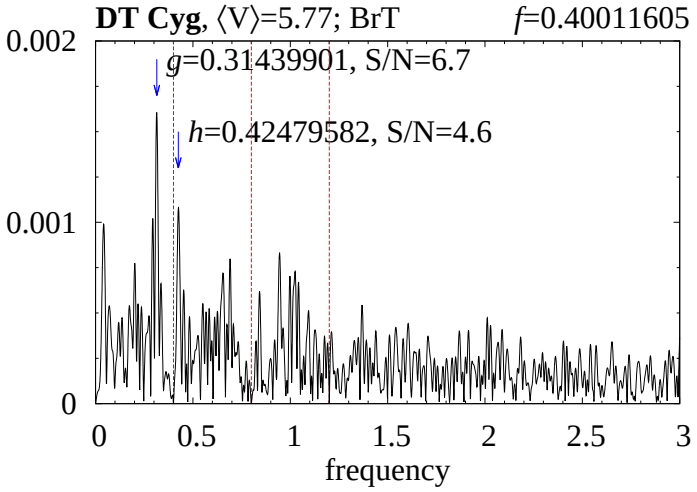

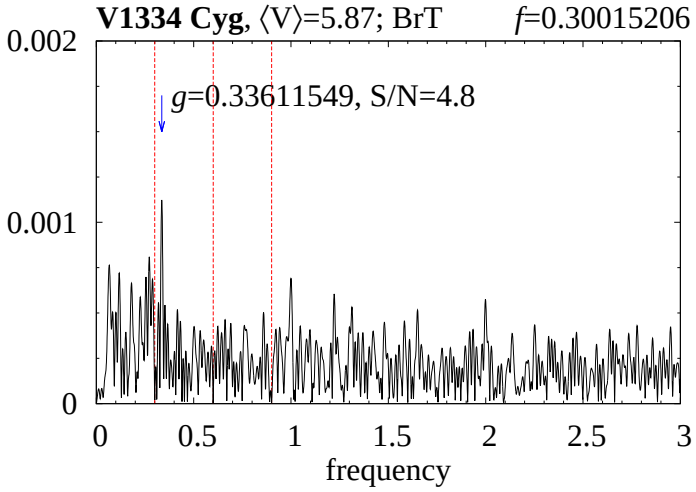

BRITE's classical Cepheids – technical conclusions

- ⋆ BRITE-Toronto is capable to collect superb photometry of Cepheids at least down to 6 mag and even below (mean brightness in V)
- ⋆ quality of data gathered with UniBRITE is lower, still the photometry gathered for bright Cepheids if of very good quality. For dimmer targets UniBRITE performance is poor
- ⋆ BHr observations of MY Pup are of comparable quality to BTr (more work is needed for this target)
- ⋆ all Cepheids down to 6.5mag (in brightness minimum) are good targets for BRITE
- ⋆ obviously, we would like to have more pulsation cycles and better duty cycle

BRITE's classical Cepheids – scientific conclusions

- ⋆ F-mode pulsators seem more stable, in agreement with previous studies (and just as in the case of RR Lyr stars)
- ⋆ additional variability detected in 1O pulsators (not at *familiar* period ratio to first overtone), but these are not firm detections
- ⋆ can we study cycle-to-cycle variations? In principle yes, but:
  - ▸ the precision of the photometry may be too low
  - ▸ better duty cycle would help
  - ▸ all instrumental effects/systematics should be well understood first (smearing!)
  - ▸ observations of SZ Tau and RT Aur and comparison of results with MOST data would be useful
- ⋆ BRITE seems best to search for additional modes (and these are expected, at least in 1O pulsators)

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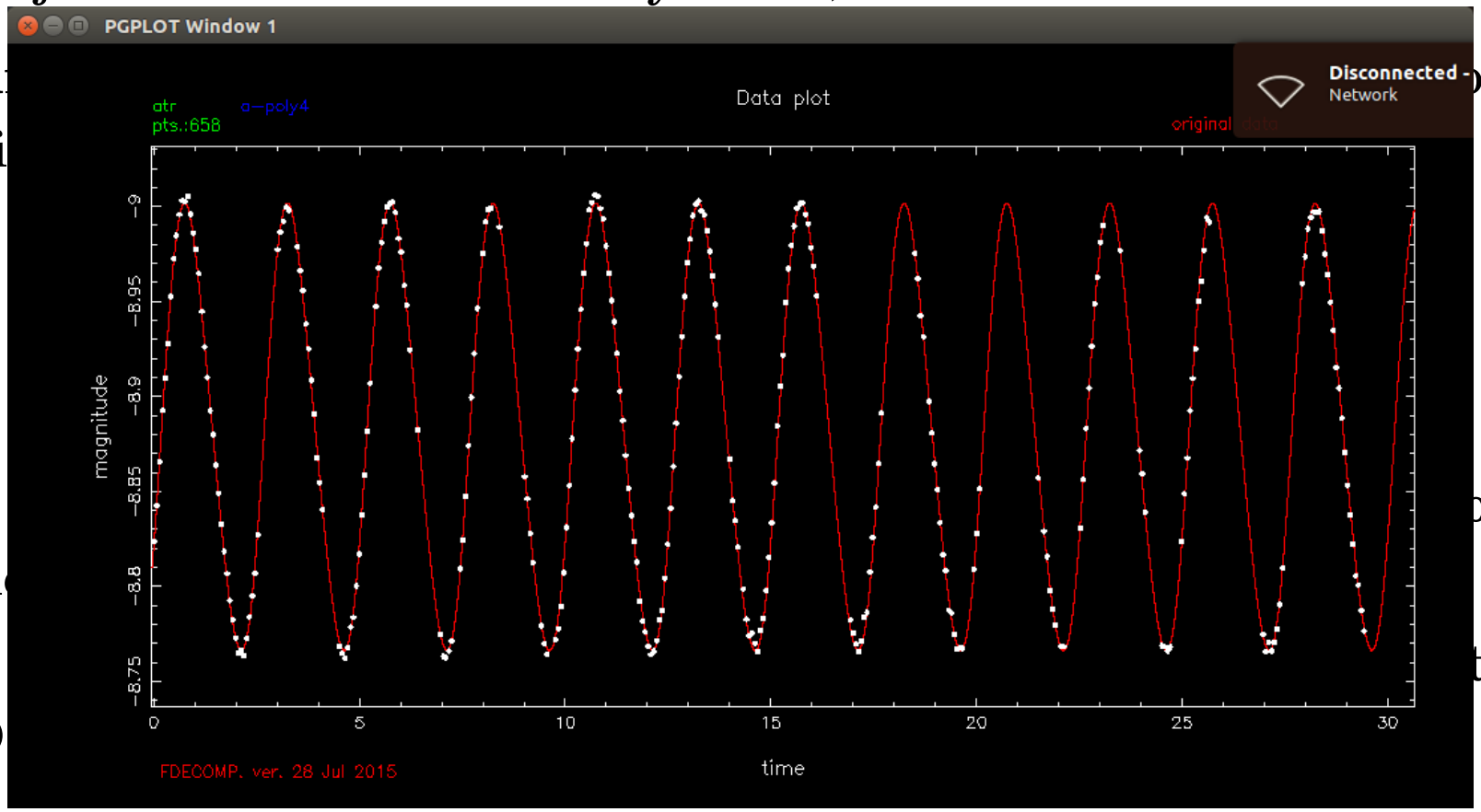

BRITE's classical Cepheids – scientific conclusions

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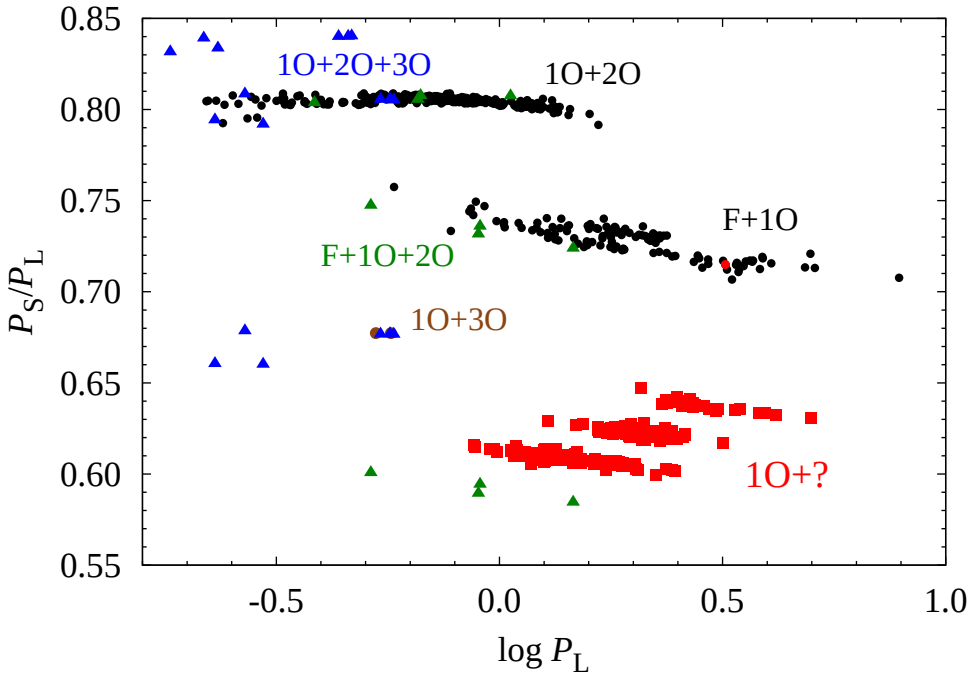
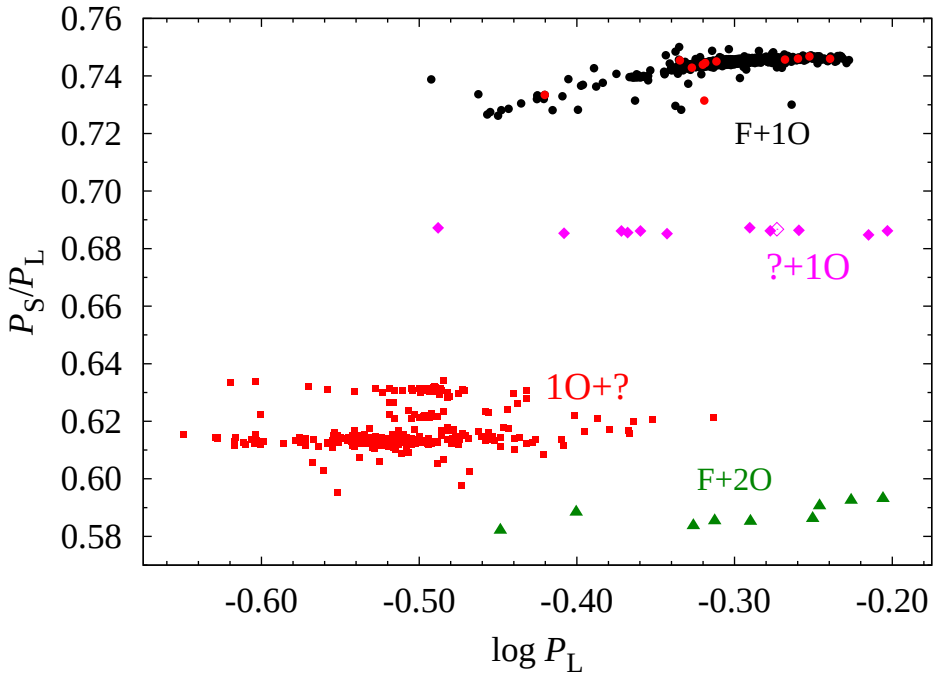
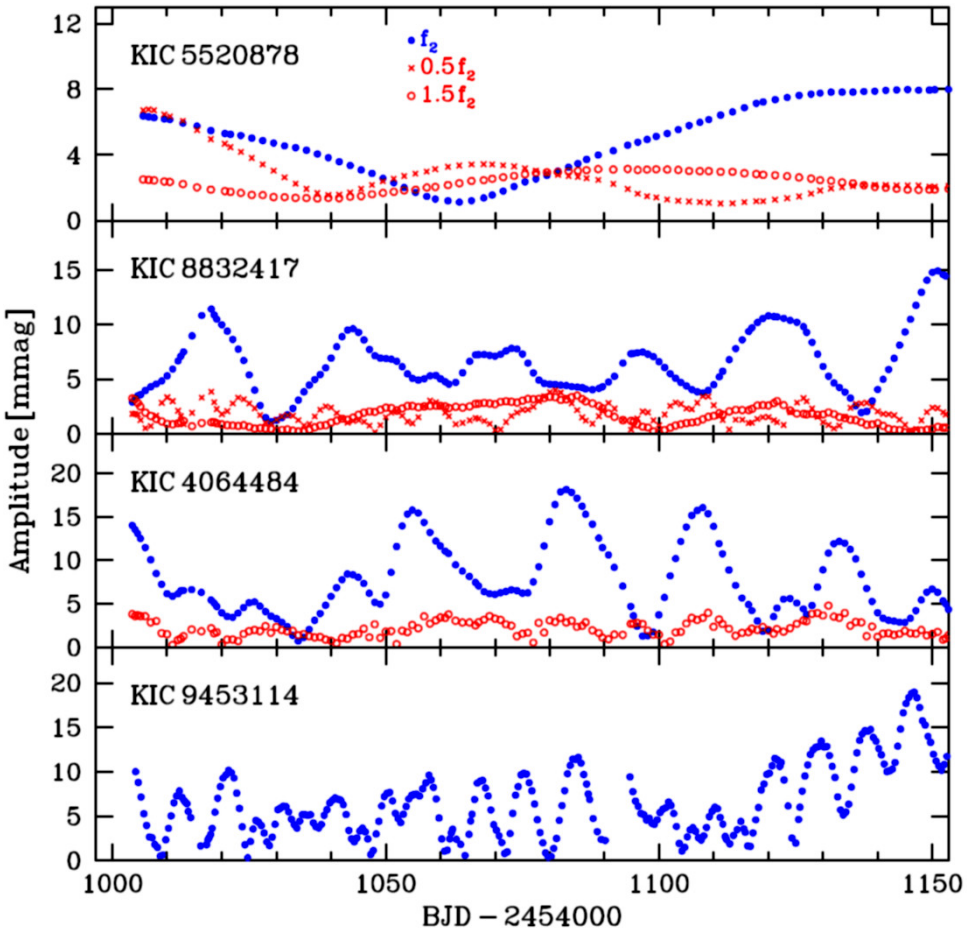
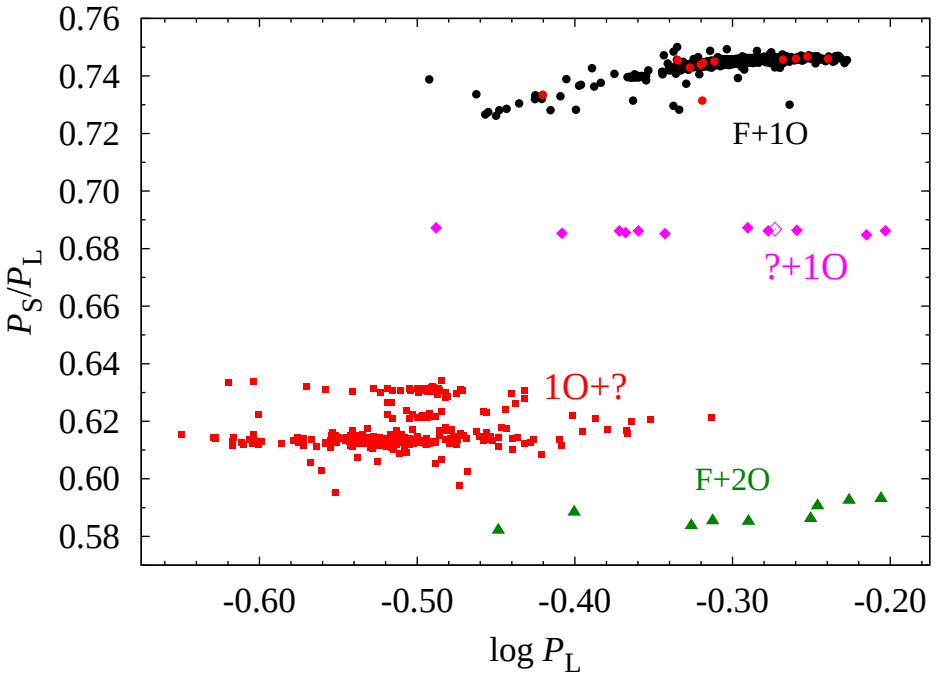
BRITE's classical Cepheids – additional modes



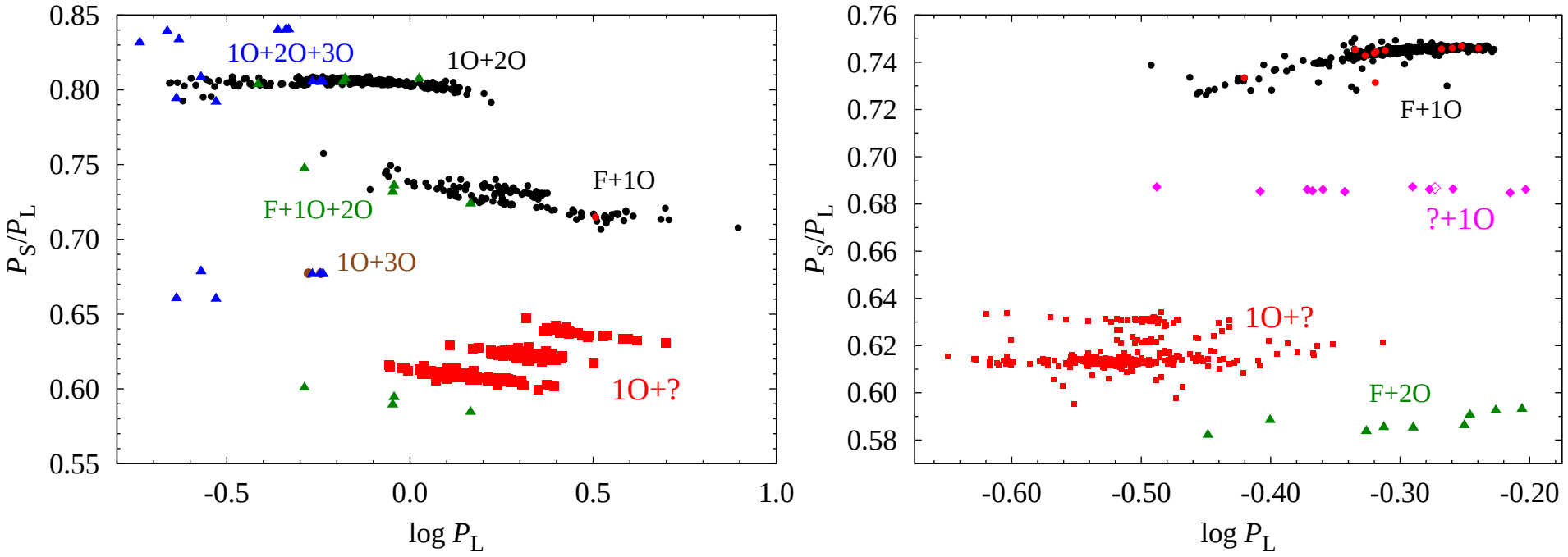


BRITE's classical Cepheids – additional modes





BRITE's classical Cepheids – additional modes



⋆ additional modes may be non-stationary ⇒ re-observing targets is a good idea