Year-long quasi-periodicities of gamma-ray blazars: a cautious approach

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The background

Fermi was launched on June 2008:

- a natural product of such a mission is a large database of almost uninterrupted HE observations.
- Periodicities studies are then possible, at least for the brightest and persistent sources.
- No surprise then that claims for (hint of) periodicities have been reported for several blazars.

Periodicity in blazars. If true...

- it might be due to SBBH systems (e.g. Letto & Valtonen 1996; Graham et al. 2015);
- or to instabilities in the relativistic jet or in the accretion disk (e.g.Camenzind & Krockenberger 1992; Marscher 2014; Raseri et al. 2017).

- Not here to discuss the plausibility of these ideas, yet they are intriguing and worth some consideration.

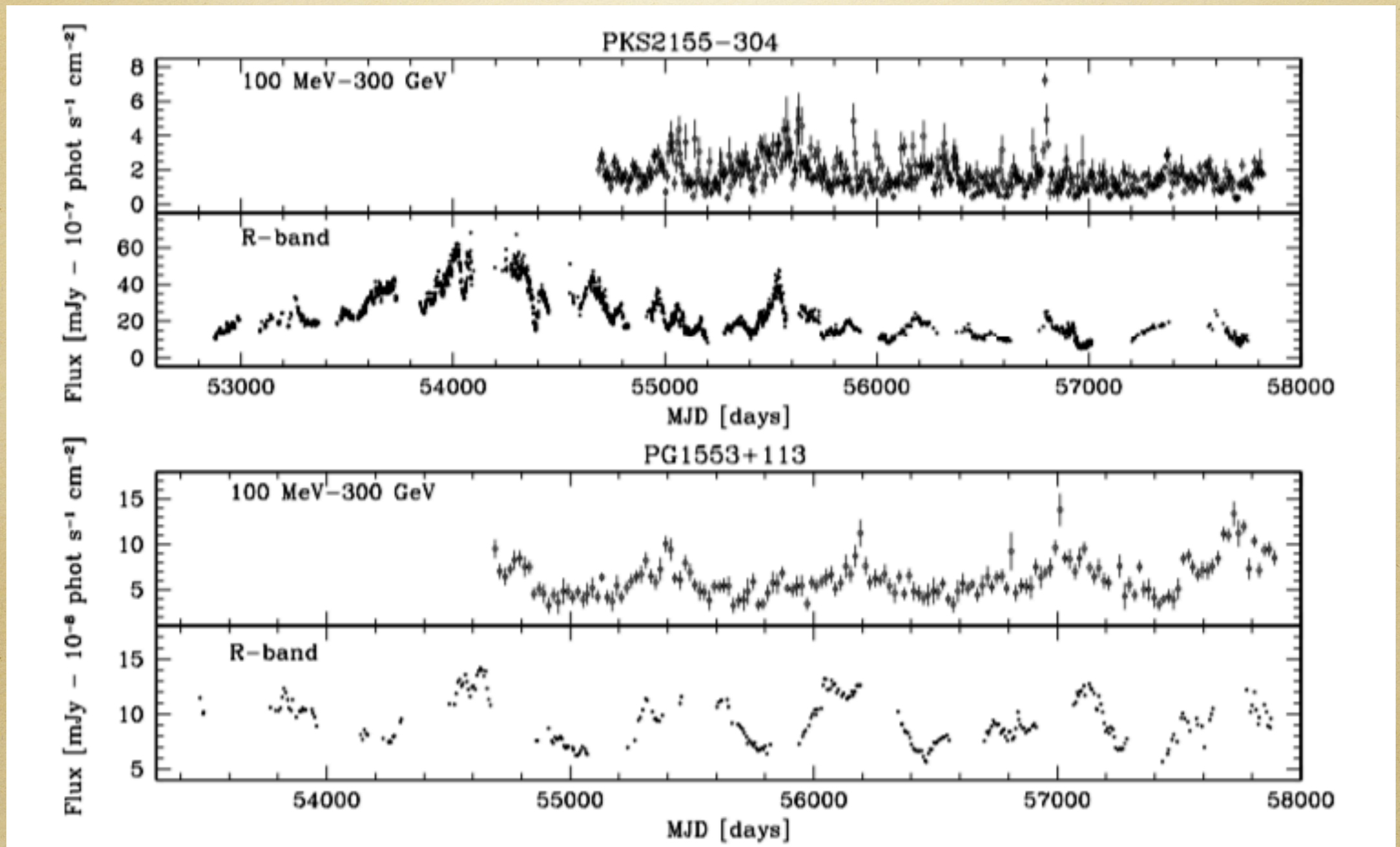
The sample of analysed blazars

- 9 objects, chosen because possible periodicities in their Fermi light-curves have been reported (with various level of confidence) in the literature (e.g. Ackermann et al. 2015; Prokhorov & Moraghan 2017; Sandrinelli 2014, 2016a,b, 2017, 2018; Tavani et al. 2018; Zhang et al. 2014; Zhang et al. 2017);

- PG1553+113, PKS2155-304, BL Lac, PKS0301-243, 4C+01.28, 0716+714, PKS0805-077, PKS0537-304 and PKS2052-474

- This is, clearly, a highly biased sample.

Typical curves:



(Sandrinelli et al. 2018)

Time series

- Time series analysis is undoubtedly a very complex field. The availability of reliable and easy to use software tools might tend to hidden the real troubles.

- A few items, with no claim of completeness…
  - our theorems strictly hold for infinite, stationary, time-series;
  - if noise is structured (correlated, red, etc.) it must be properly modelled;
  - red-noise can mimic non-persistent periodical behaviours (e.g. Quinn & Hannan 2001; Rao 2016);
  - if sampling is uneven a large number of additional factors have to be considered (e.g. Vaughan 2012; Vio et al. 2013; Kelly et al. 2014; VanderPlas 2017; etc.).

Fermi temporal analysis

- Regular sampling (after rebinning):
  - analysis can be carried out at the Fourier frequencies;
  - powers form an orthonormal space;
  - We chose curves with 30 day binning.

- PDS are fit assuming a power-law shape for the noise with a proper (Whittle) likelihood and Leahy normalisation (Leahy et al. 1982; Barret & Vaughan 2012; Guidorzi et al. 2016).

$$S_{PL}(f)=Nf^{-\alpha}+B$$

$$S = -2\ln\mathcal{L} = \nu\sum_{j=1}^{N-1}\left\{\frac{I_j}{S_j}+\ln S_j+\left(\frac{2}{\nu}-1\right)\ln I_j + c(\nu)\right\}$$

Fermi temporal analysis (cont'd)

- Fully Bayesian analysis:

  - Jeffreys prior for normalisation, strictly positivity for the slope, and white noise in a Gaussian distribution centred on the expected value of 2 (e.g. Guidorzi 2011, 2016);

  - artificial PDS are generated by sampling the posterior distribution derived by affine-invariant Hamiltonian MCMC integration ("emcee" library);

  - PDS fit quality evaluated by posterior predictive assessment (Gelman et al. 1996);

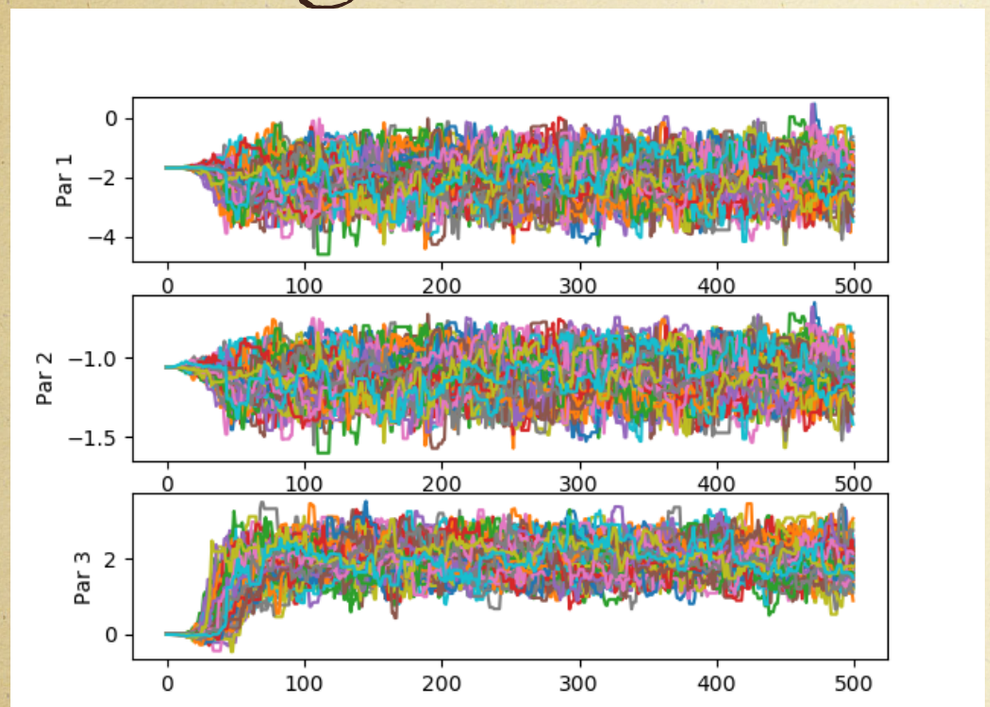
Fermi temporal analysis (cont'd)

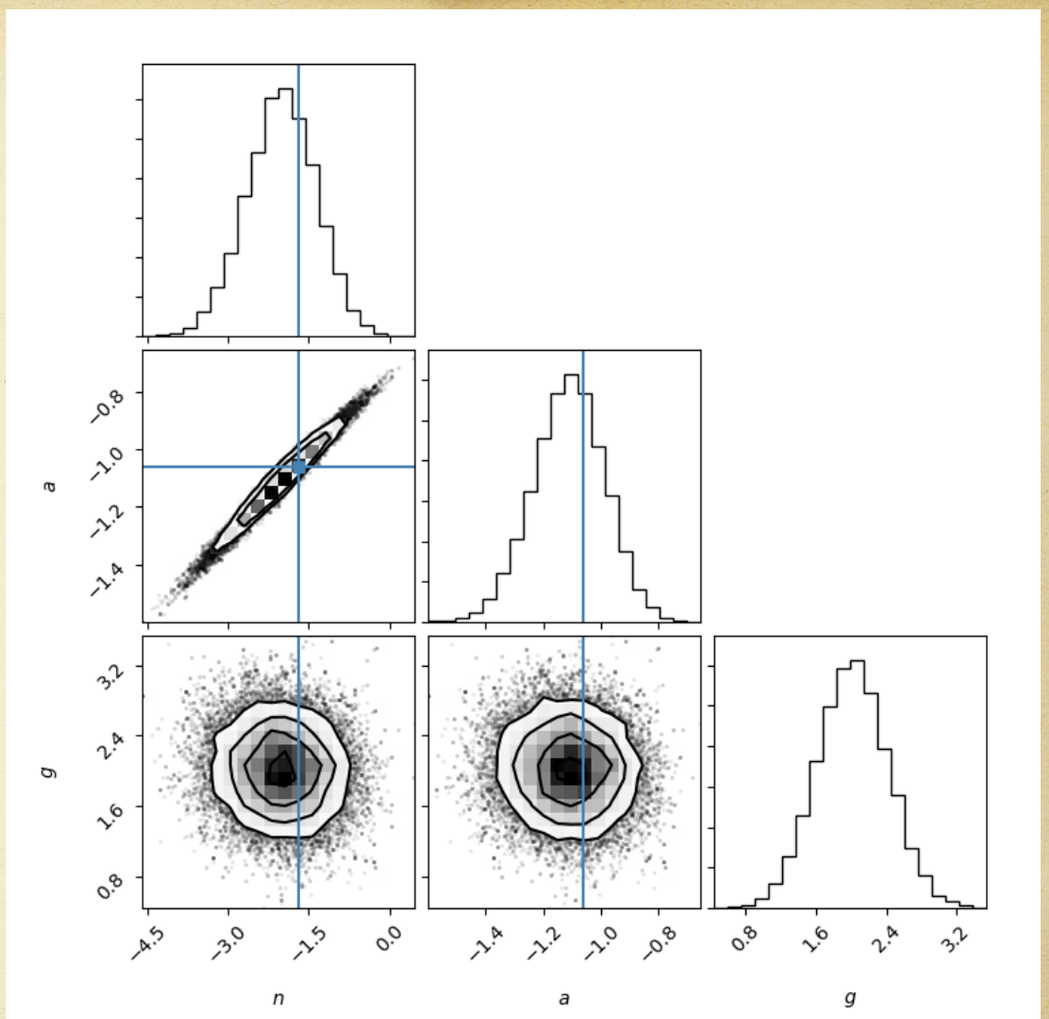
- Global significance curves are derived by the distribution of the "test" statistics R = 2P/S , where P are the simulated PDS, and S is the best-fit PDS (Vaughan 2010);

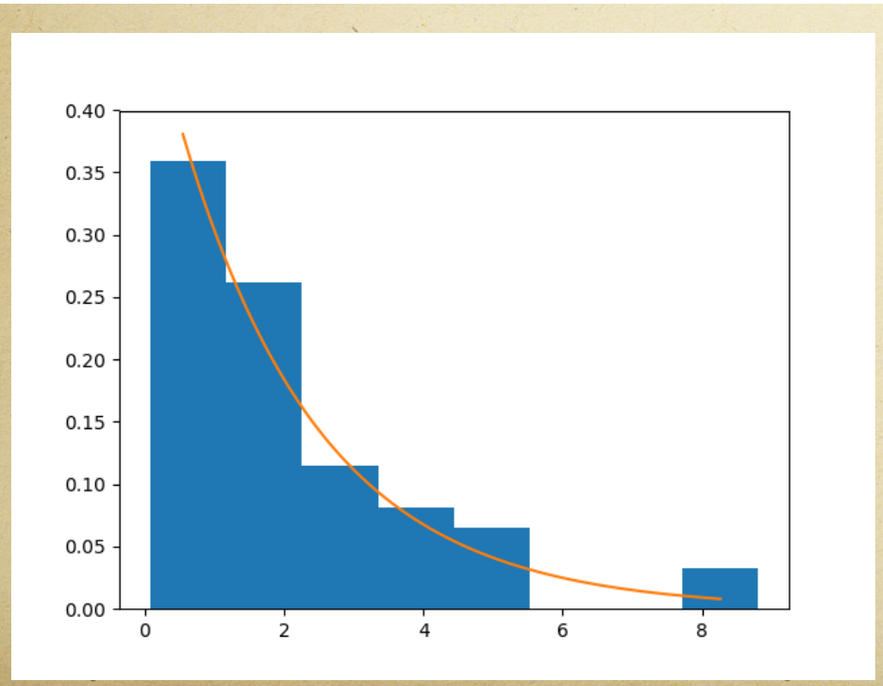
- The trial factor, i.e. the number of independent analysed frequencies, is intrinsically included in the analysis;

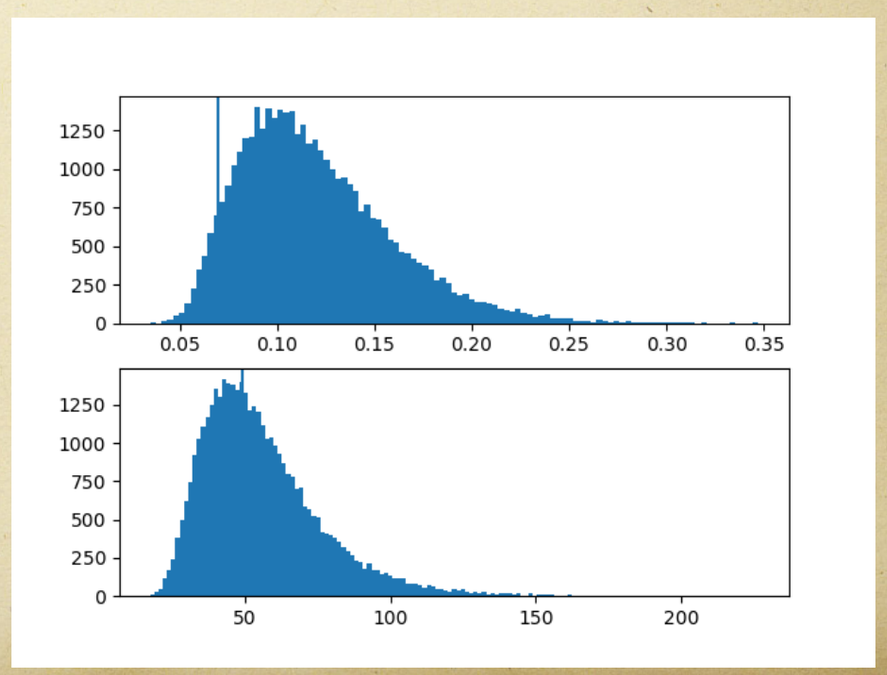
- The procedure has been developed mainly by: Vaughan 2010; Guidorzi 2011; Vaughan 2012; Barret & Vaughan 2012; Guidorzi et al. 2016.

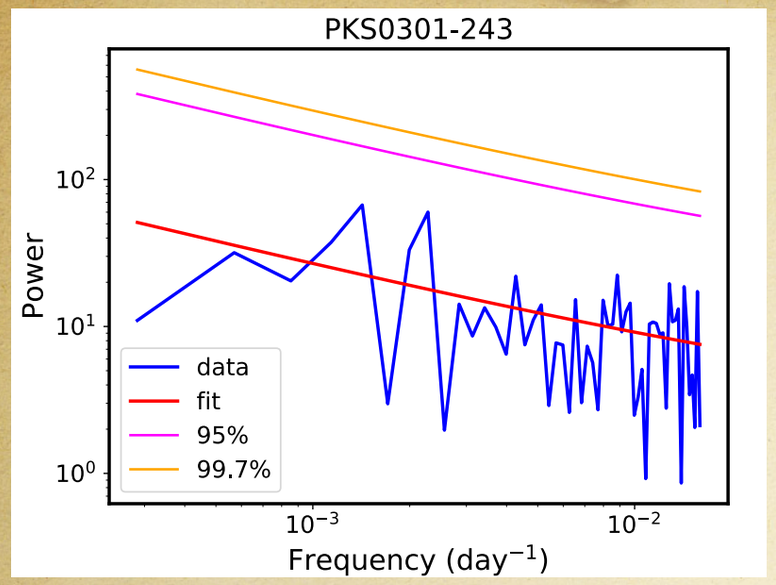
Analysis output (e.g. 0716+714)

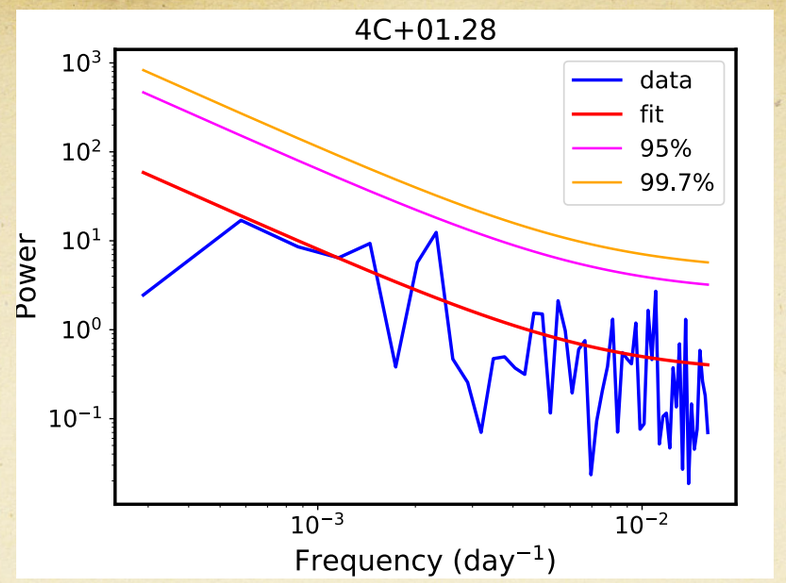


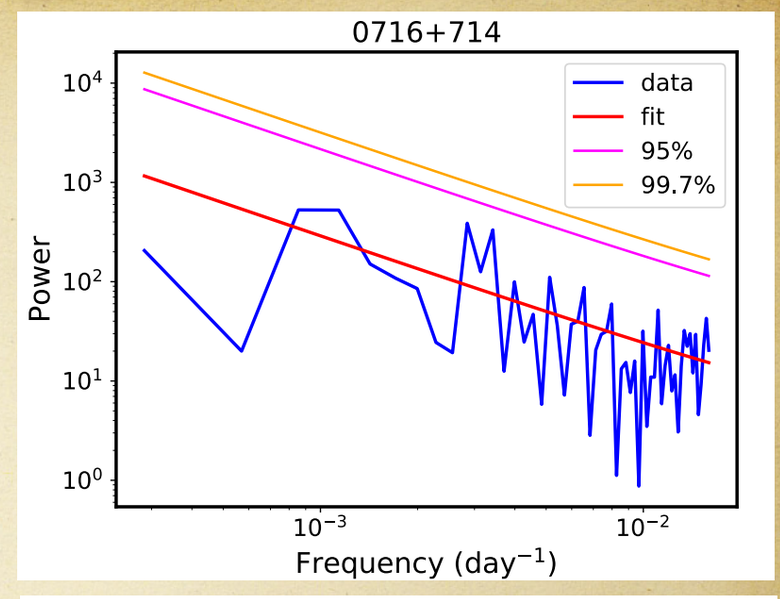


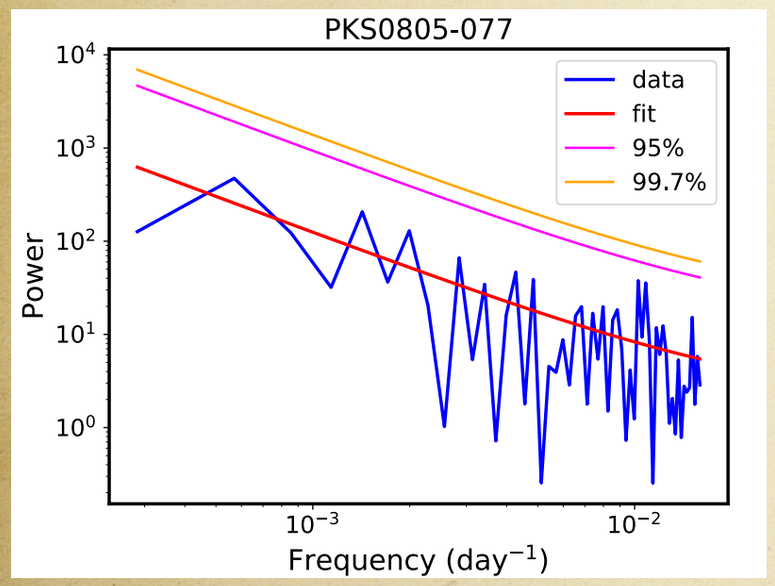


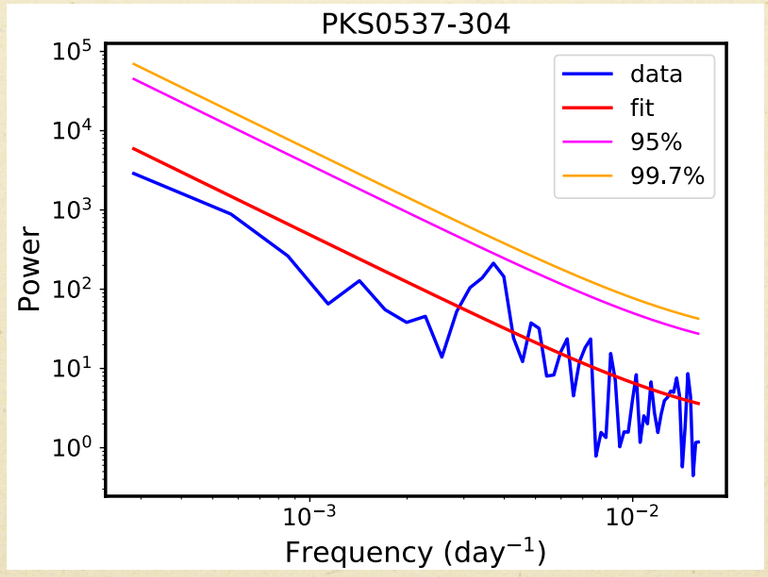


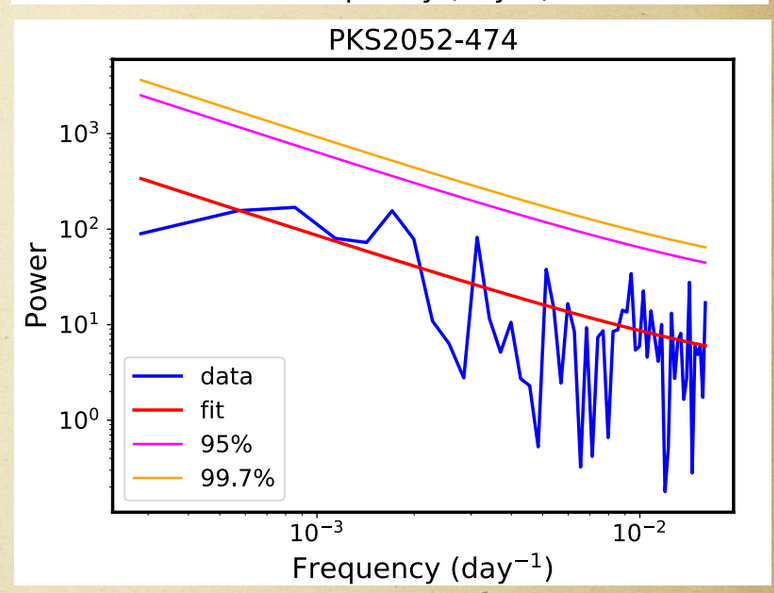

PKS0301-243
Power
Frequency (day^{-1})
data
fit
95%
99.7%

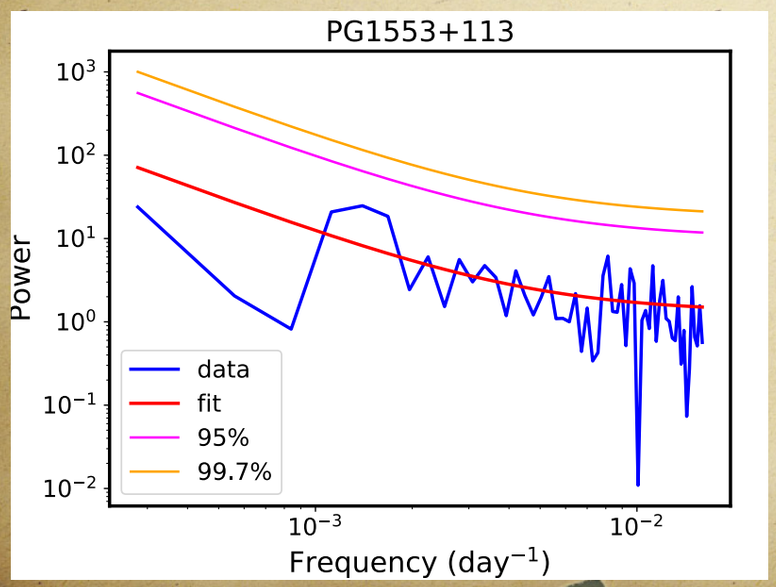

4C+01.28
Power
Frequency (day^{-1})
data
fit
95%
99.7%

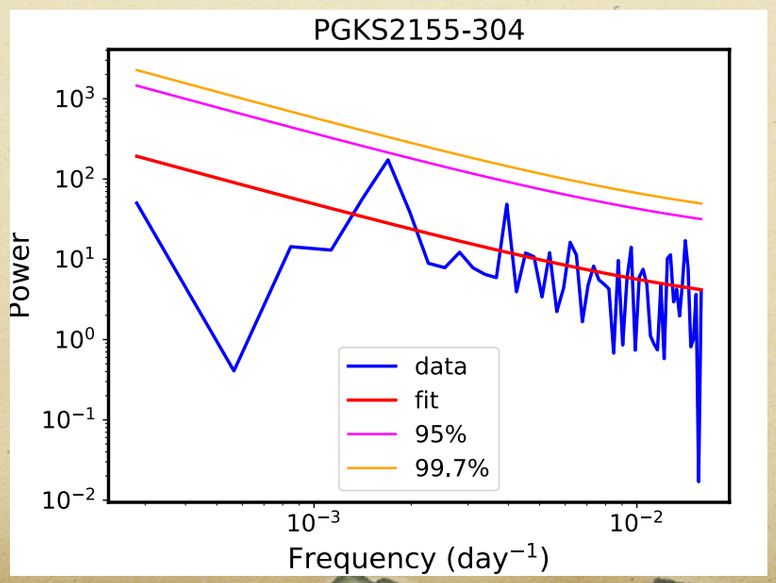

0716+714
Power
Frequency (day^{-1})
data
fit
95%
99.7%

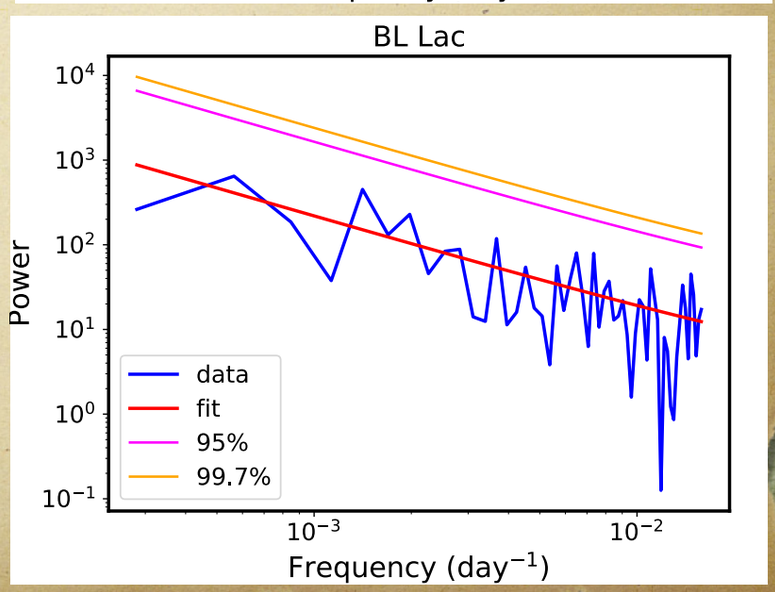

PKS0805-077
Power
Frequency (day^{-1})
data
fit
95%
99.7%


PKS0537-304
Power
Frequency (day^{-1})
data
fit
95%
99.7%


PKS2052-474
Power
Frequency (day^{-1})
data
fit
95%
99.7%


PG1553+113
Power
Frequency (day^{-1})
data
fit
95%
99.7%


PGKS2155-304
Power
Frequency (day^{-1})
data
fit
95%
99.7%


BL Lac
Power
Frequency (day^{-1})
data
fit
95%
99.7%

Caveats and considerations

- Let's make the whole matter simple: all the analysed power spectra are consistent as just due to noise!

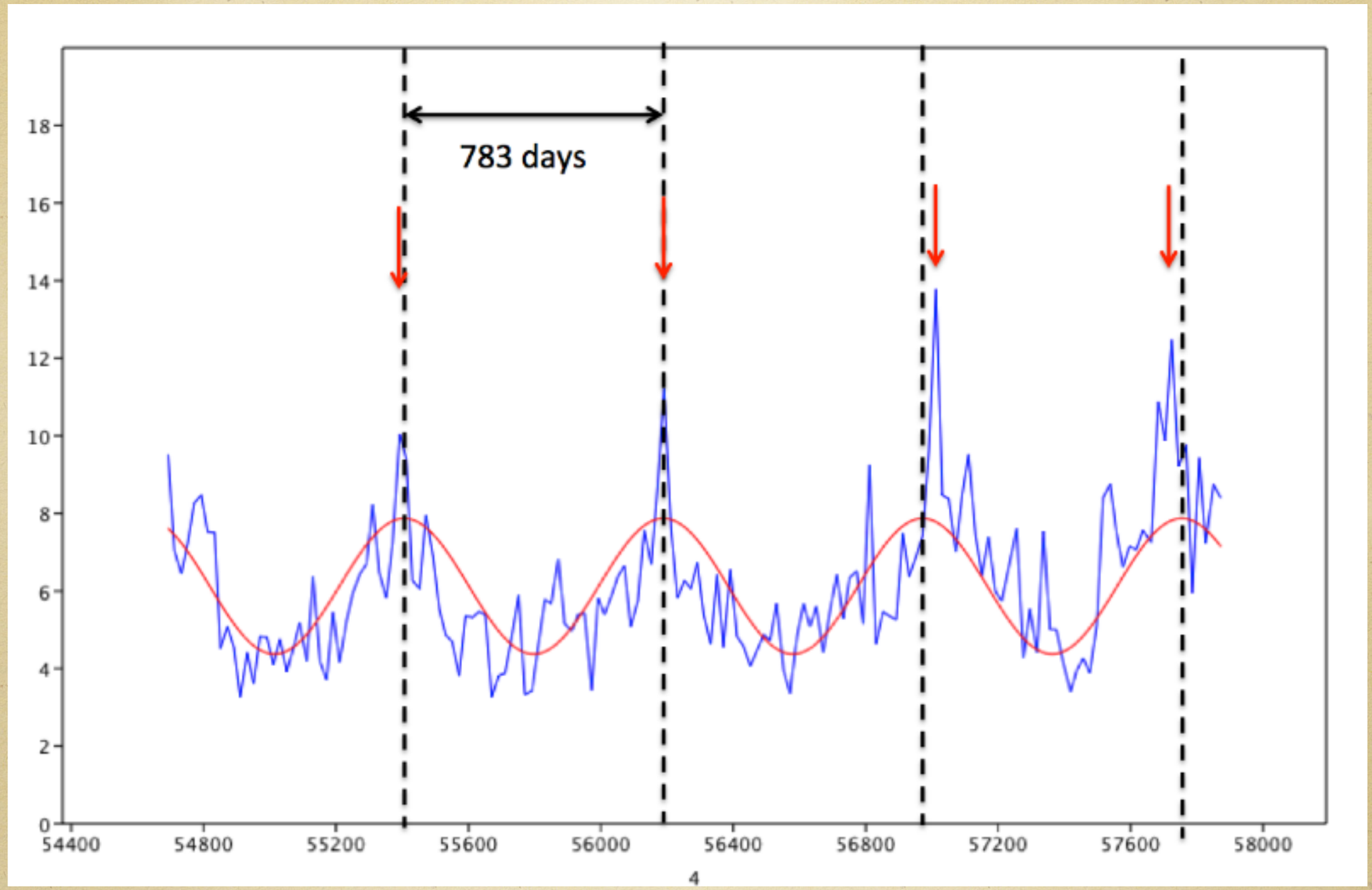
- In several cases reported in literature, only "hint of" periodicities are mentioned. No surprise nothing very meaningful is found.

- Let's not forget, anyway, that with long (quasi-)periodicities, the total duration of the Fermi monitoring makes possible to study only a few cycles.

Caveats and considerations (2)

- Yet, for PKS0537-441 and PKS2155-304 (and PG1553+113) it is still true that some interest is raised by the simultaneous presence of low-significance QPOs in multiple bands.

- A more technical point: Fourier analysis identifies sinusoidal possible periodicities. Analyses not assuming a specific functional form (e.g. non parametric) are possible, with pros and cons.


783 days
18
16
14
12
10
8
6
4
2
0
54400
54800
55200
55600
56000
56400
56800
57200
57600
58000
4

PG1553+113