Gamma-ray and Optical Quasi-periodicities of BL Lac Objects:

Constraints for a Supermassive Binary Black Hole Scenario

A. Treves
S. Covino
M.A. Holgado
A. Sandrinelli
A. Sesana

A DECADE OF AGILE
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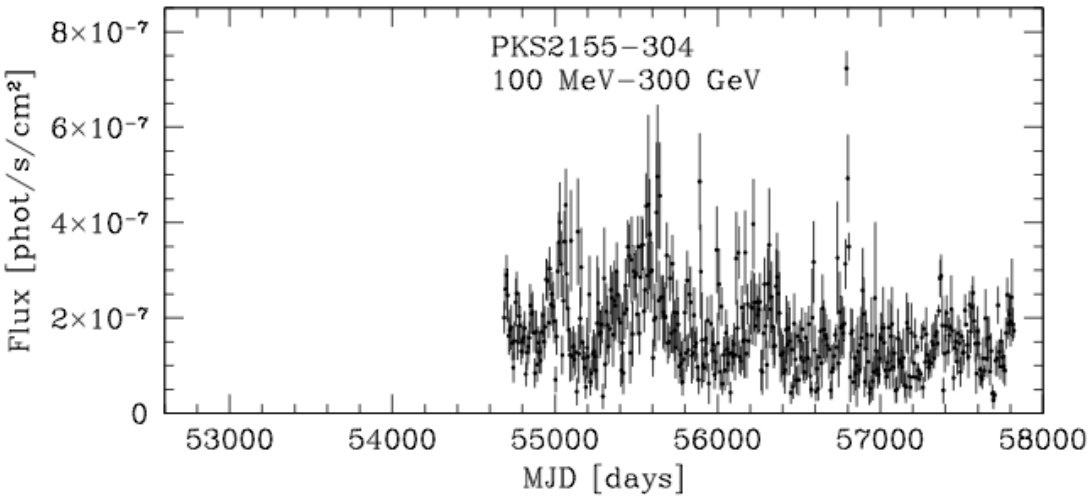
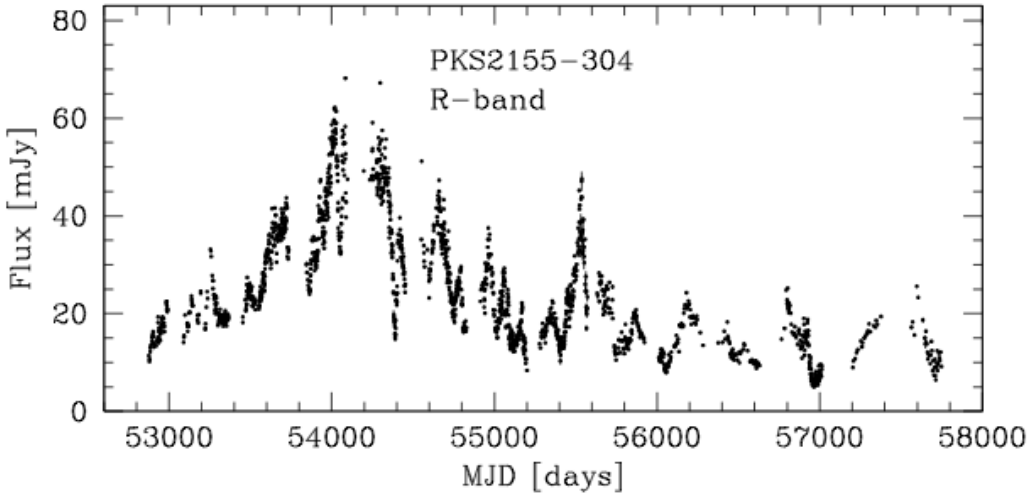
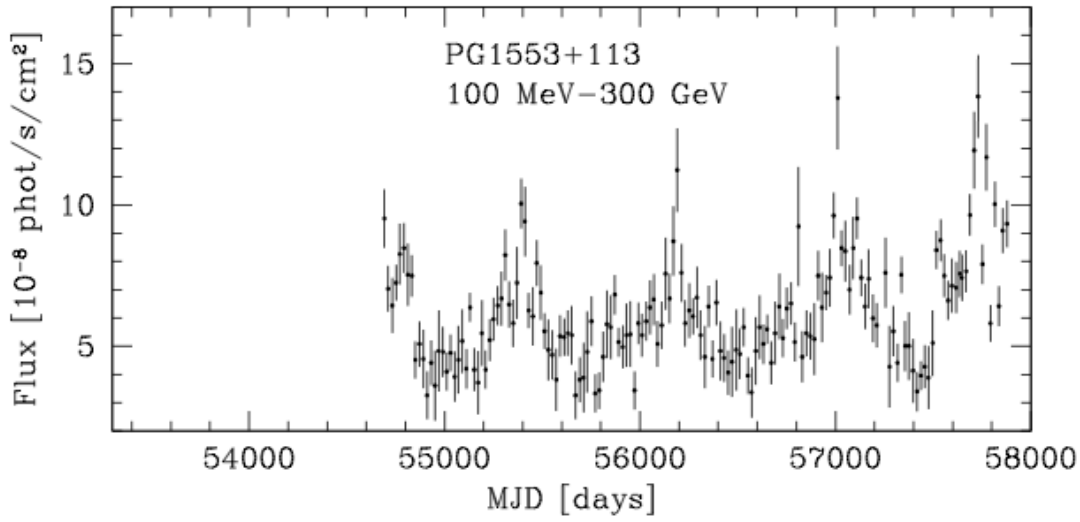
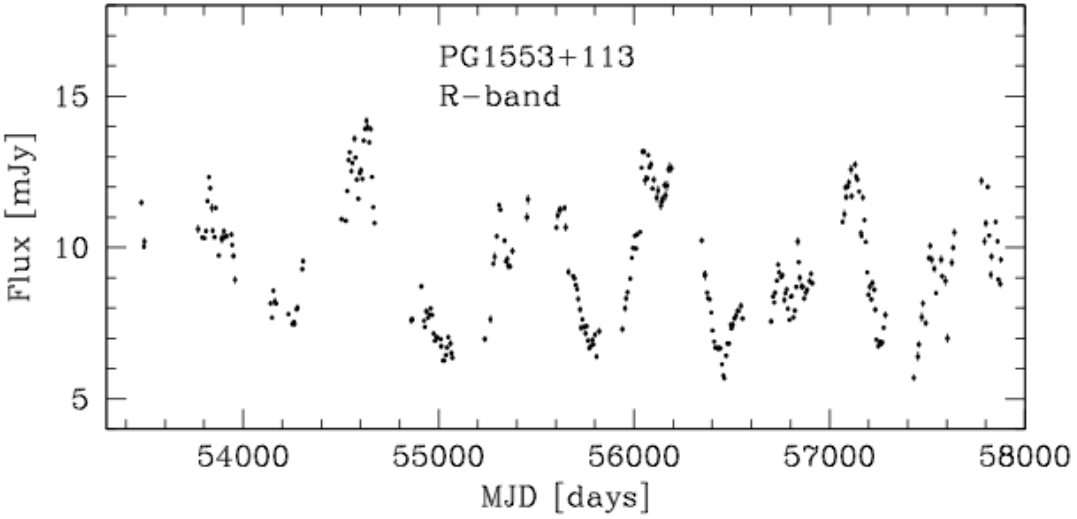

PKS2155−304
100 MeV−300 GeV
Flux [phot/s/cm²]
8×10⁻⁷
6×10⁻⁷
4×10⁻⁷
2×10⁻⁷
0
53000
54000
55000
56000
57000
58000
MJD [days]


PKS2155−304
R−band
Flux [mJy]
80
60
40
20
0
53000
54000
55000
56000
57000
58000
MJD [days]


PG1553+113
100 MeV−300 GeV
Flux [10⁻⁸ phot/s/cm²]
15
10
5
54000
55000
56000
57000
58000
MJD [days]


PG1553+113
R−band
Flux [mJy]
15
10
5
54000
55000
56000
57000
58000
MJD [days]

Gamma-ray quasi-periodicity

PKS 2155-304 Sandrinelli+2014

$T_\gamma \sim 1.7$ y

$T_{opt} \sim \frac{1}{2} T_\gamma$

Quasi-periodic γ-ray BL Lac Objects

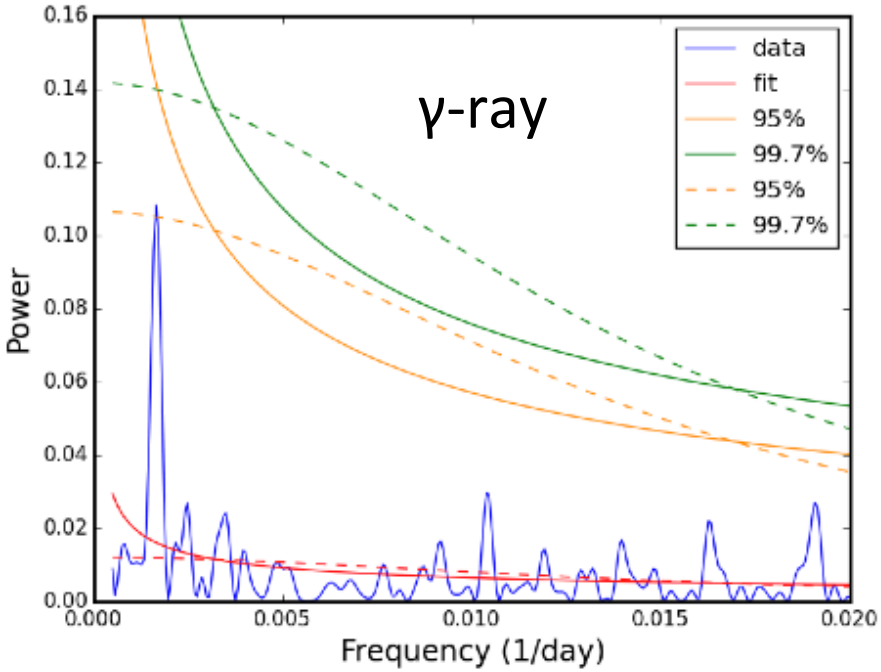
	z	T_γ	T_{opt}	
PKS 0301-24	0.24	2.1 y		Zhang+2017
PKS 0537-44	0.89	0.77 y	1/2 T_γ	Sandrinelli+ 2016
PKS 1553+11	~0.4	2.18 y	T_γ	Ackermann+2015
PKS 2155-30	0.116	1.7 y	1/2 T_γ	Sandrinelli+2014, 2016 Zhang+2017
BL Lac	0.069	1.85 y	T_γ	Sandrinelli+2017

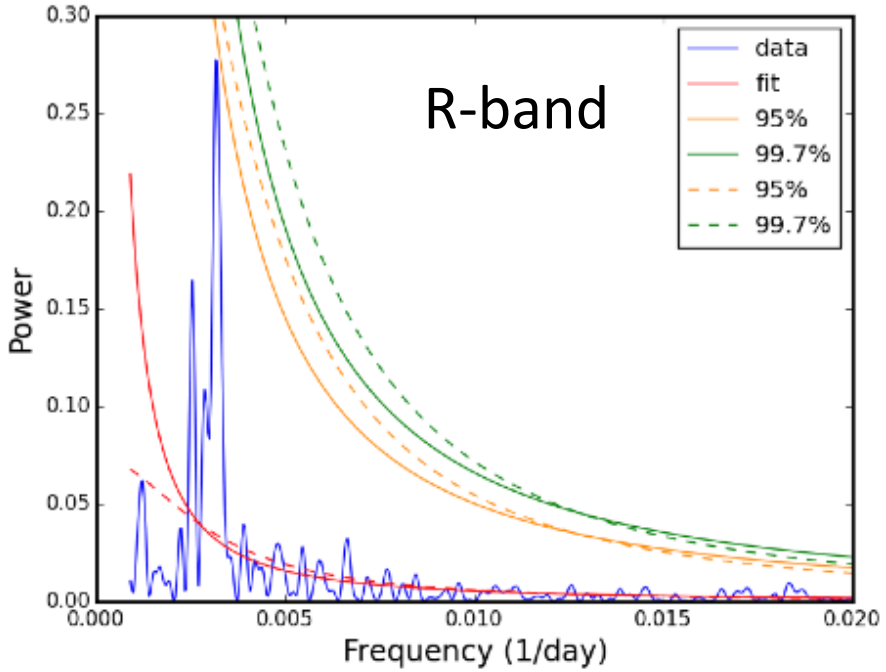
Significance of Periodicity

- Lomb/Scargle
- Red noise : Power Law (PL) model
  Autoregression function (AR1) model
- Multi-trial correction: independent sampled frequencies

Vaughan 2005, 2010
Guidorzi+2016
Sandrinelli+2017

Periodograms of PKS 2155-304





Significance of Periodogram Peaks

Source	T [days]	light curve	Significance					
			single-frequency		global-frequency		global-frequency, combined	
			PL %	AR1 %	PL %	AR1 %	PL %	AR1 %
PG1553+113	780 ± 53	100 MeV-300 GeV	99.9	99.97	80	95	80	80
	810 ± 52	R	95	98	(*)	(*)		
PKS2155−304	620 ± 41	100 MeV-300 GeV	99.9	99.99	(*)	95		
	315 ± 25	R	99.99	99.97	95	90		
BL Lac	680 ± 35	100 MeV-300 GeV	95	99.7	(*)	(*)	95	99.7
	670 ± 40	R	99.5	99.9	80	80		

Fraction of Quasi-periodic BL Lac Objects

Prokhorov+Moraghan 2017

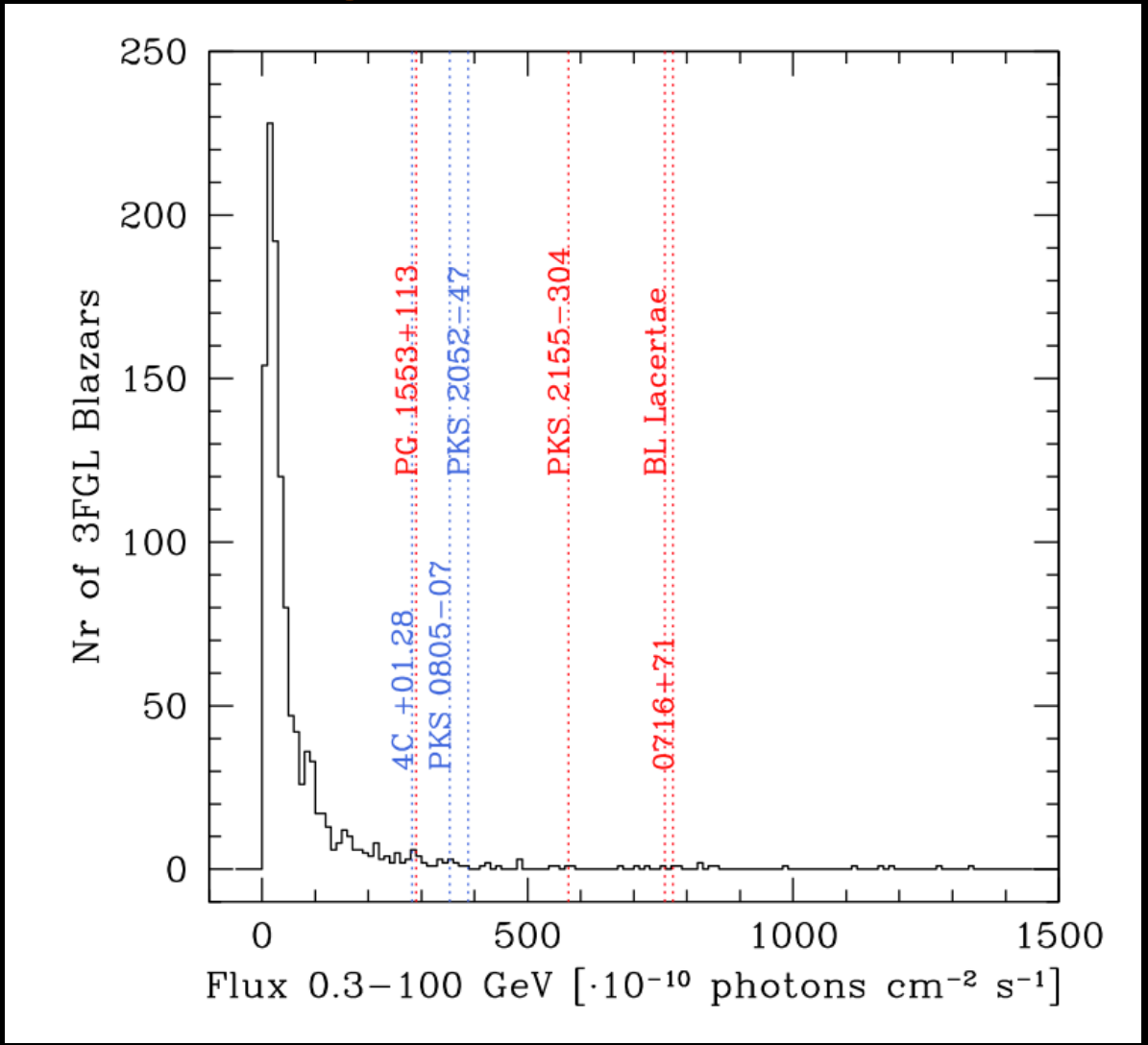
- Tiling 8 years of FERMi sky : N_{tiles} = 12228
- 1 month <T< 2.5 y
- 7 periodic tiles
- all contain a blazar
- 4 BL Lac objects : 0716+71, 1553+11, 2155-30, BL Lac

Fraction of Quasiperiodic BL Lac Objects

$N = 45$

$N_{periodic} = 4$

$\xi_{BL} \sim 0.1$



3FGL catalog (Acero et al. 2015)

Nature of Quasi-periodicity in BL Lac Objects

- Relativistic Jet instabilities

- Supermassive Binary Black Holes

  Binary Period

  Precession Period

Analogy with Quasars

Quasi-periodicities in the optical band
Graham+2015, Charisi+2016

$N = 250000$ $N_{periodic} \sim 100$

$\xi_Q \sim 10^{-4}$

Cosmic density of Quasi-periodic BL Lac Objects and Quasars z~1

$$\rho_P = \xi \rho$$

$$\rho_P^{BL} \sim 10^{-9} \ \mathrm{Mpc}^{-3}$$

$$\rho_P^{Q} = 10^{-10} - 10^{-11}$$

$$\rho_P^{BL} > \rho_P^{Q}$$

Croom+2004, Ajello+2014

Constraints from the upper limit of the Gravitational Wave Background from the Pulsar Timing Array

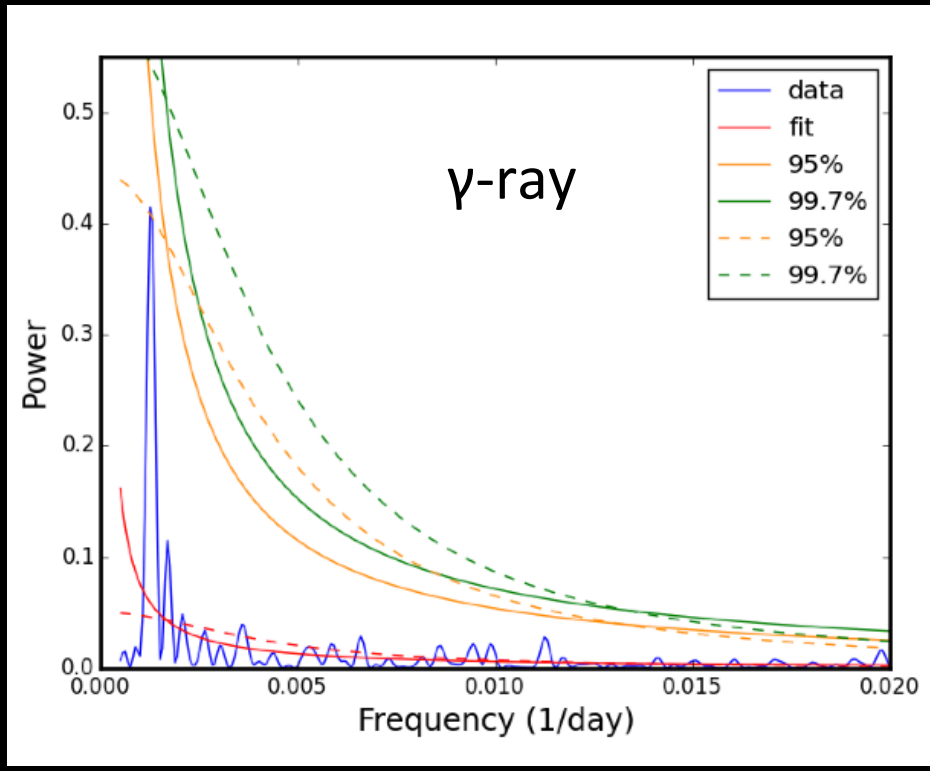
Tension for ρ_P^Q

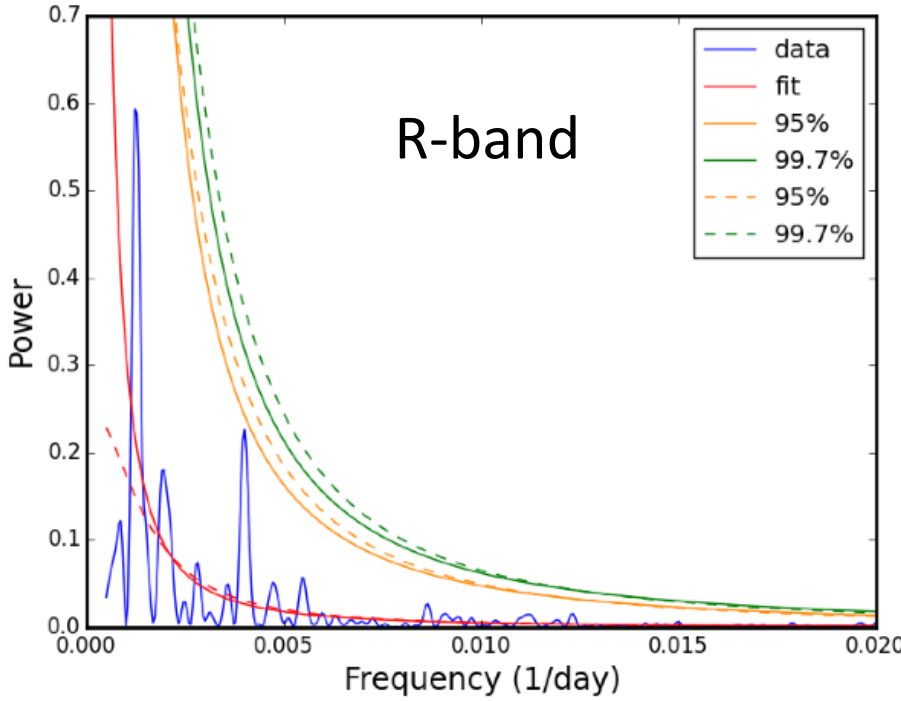
Not all quasi-periodic quasars are SBBHs

Sesana+2017

Year Long Quasi-periodicities of BL Lac Objects in general are not related to supermassive black hole binaries

Periodograms of PG1553+11





Wavelet Analysis of PKS 2155-304