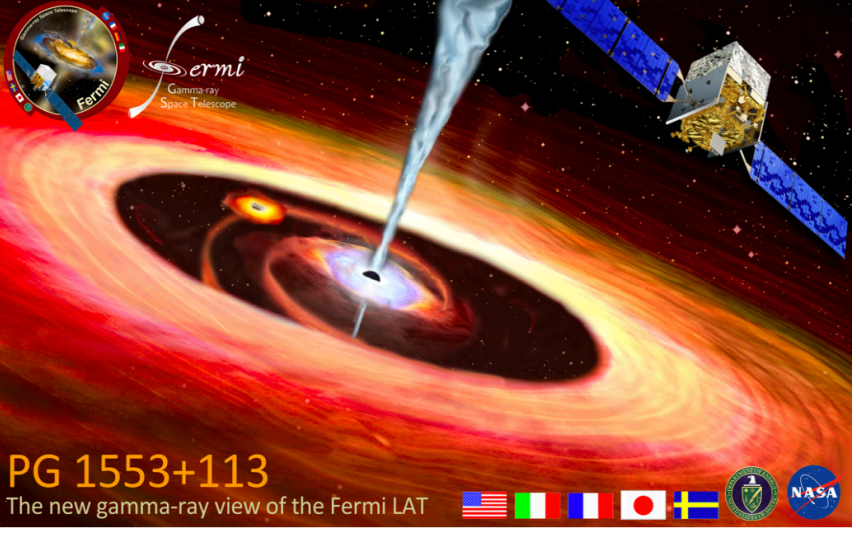


Fermi
Gamma-ray
Space Telescope

Confirmed periodic gamma-ray modulation of the blazar PG 1553+113 by Fermi-LAT and Multi-wavelength Observations

Sara Cutini (INFN, Perugia),

Stefano Ciprini (INFN, RM2), Stefan Larsson (KTH), Paolo Cristarella Orestano (UniPG)

behalf of Fermi-LAT collaboration

PG 1553+113: introduction

- PG 1553+113 is an optically-selected BL Lac object in Palomar-Green Bright Quasar Catalog.

- First citations of this blazar dates back to mid '80s (source seen by IRAS Neugebauer et al. 1986, ApJ 308, 815).

- BL Lac object classification (featureless optical spectrum, Miller & Green 1983)

- The X-ray counterpart is discovered by the Einstein Observatory (1ES catalog, Einstein satellite, 1981 March with count rate 1.27 cts/s), putting it among the brightest BL Lac objects in the X-ray band.

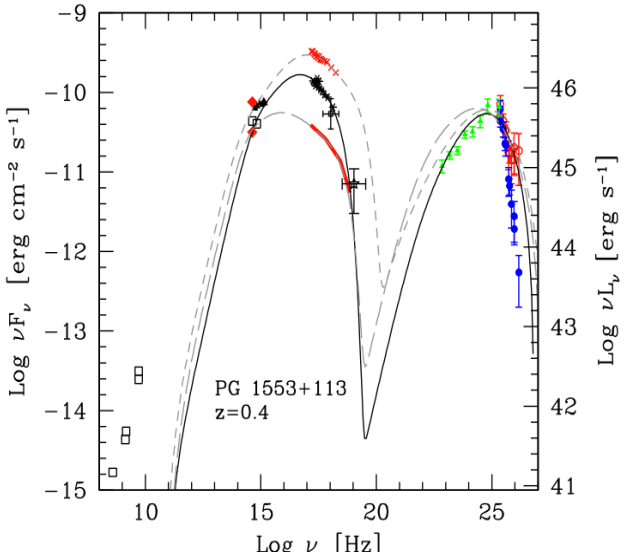
- Host galaxy remains unresolved and optical observations of the spectrum no reveal any spectral features ➔ Limits to the PG 1553+113 redshift value based on indirect measurements Recent/best estimation of the limits constrain the redshift between $0.395 < z < 0.62$ (Danforth et al 2010 and Aliu et al. 2015)

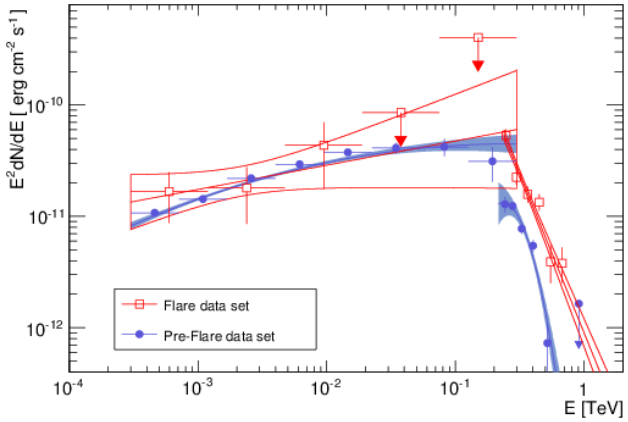
PG 1553+113: in gamma rays

- VHE (E>100GeV) gamma-ray emission discovered independently by H.E.S.S. (Aharonian+ 2006), and by MAGIC (Albert+ 2007; Aleksic+ 2012).

- Fermi LAT 4FGL catalog (4FGL 1555.7+1111): power-law, hard spectral photon index (1.68) and F(E>100MeV) =(4.5X10^-8 ph cm^-2 s^-1). Variable source.

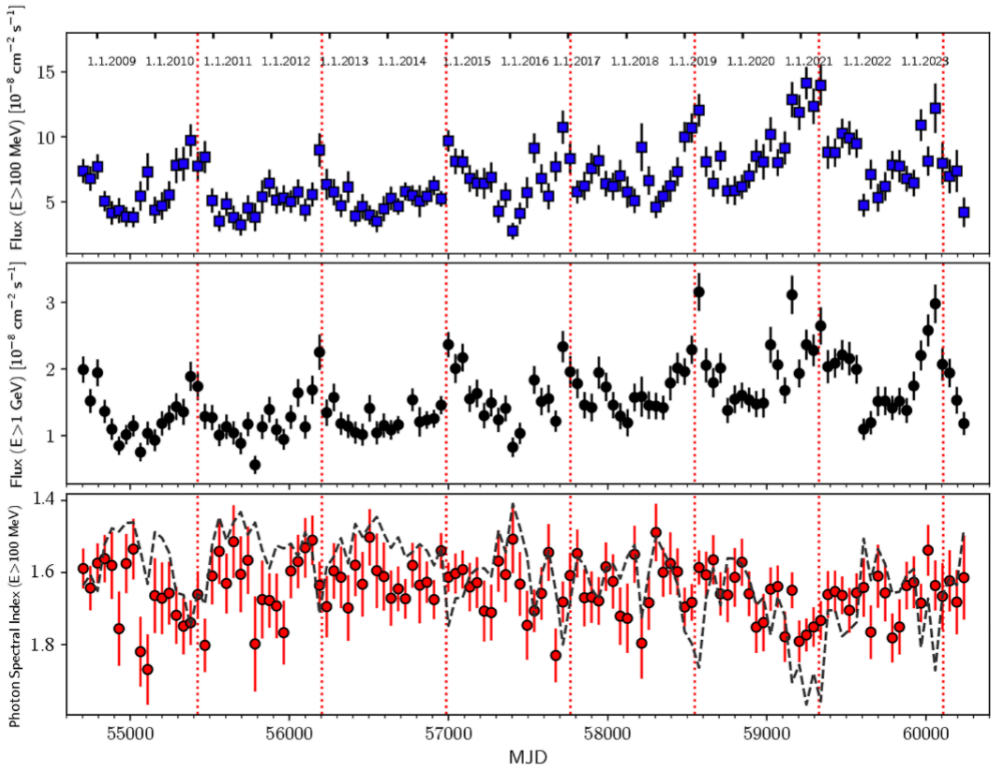
- Many spectral/SED studies—> HBL blazar with dominant non-thermal emission in-jet
- Period modulation discovered in 7 yr of Fermi-LAT data with a T~2.2yr (Ackermann+ 2015, ApJ)



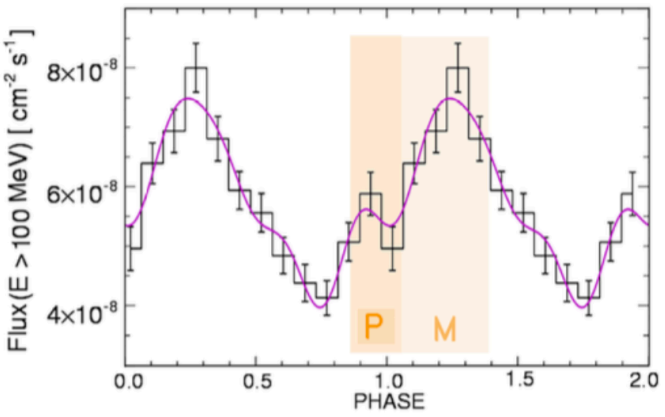


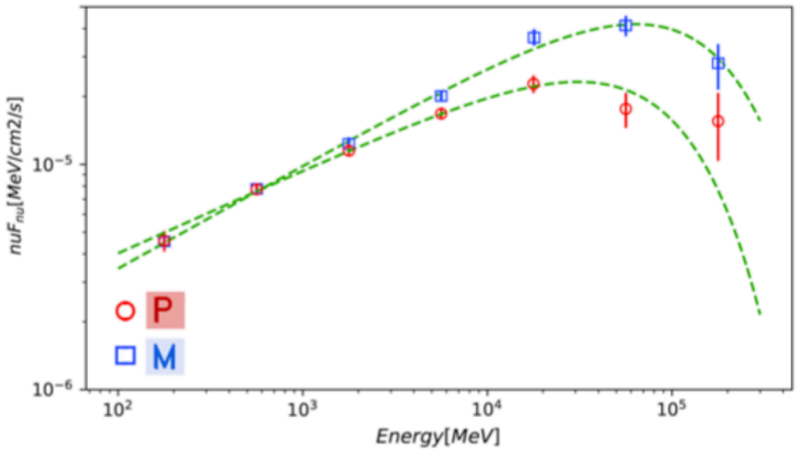
PG 1553+113: Fermi-LAT gamma-ray light curves

- *Fermi* LAT gamma-ray flux (E>100MeV and E>1GeV) light curves o PG 1553+113 based on Pass 8 dataset up to November 2023, produced in regular time bins of 45-day
- A long-term oscillating trend is visually evident from these LAT gamma-ray light curves. —> periodicity in 7.5 cycles
- Modulation of the light curve is visually identified ➔we confirmed the period peaks



PG1553+113: Precursor and main phase

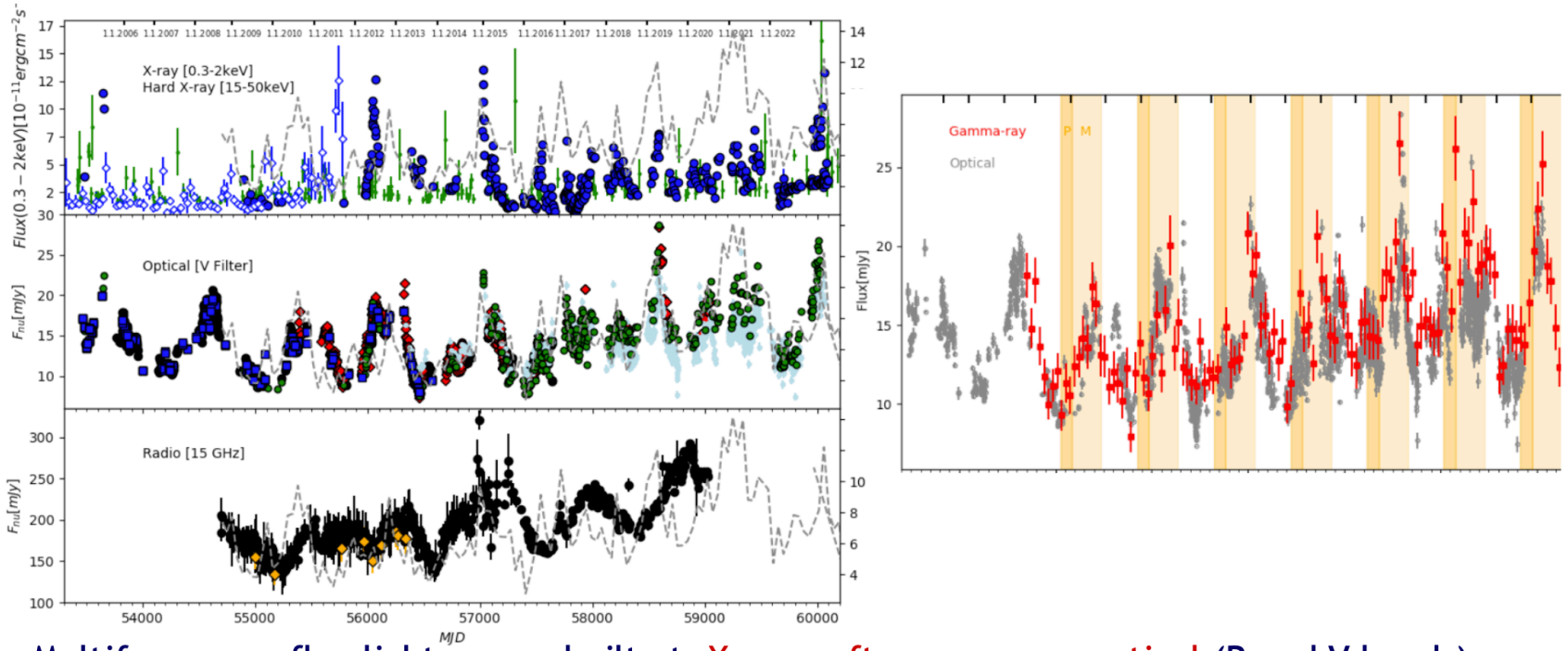




- The light curve is fitted with a coherent pulse consisting of 3+1 Fourier components (1 fundamental + 3 overtones). We can define a precursor phase and main phase.

- Precursor shows a slightly softer spectrum respect the main phase.

PG1553+113: Multifrequency LCs

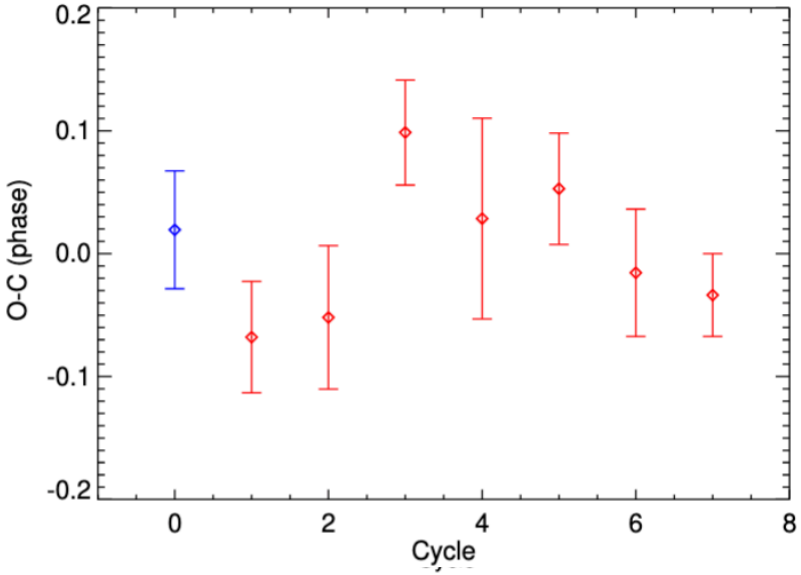


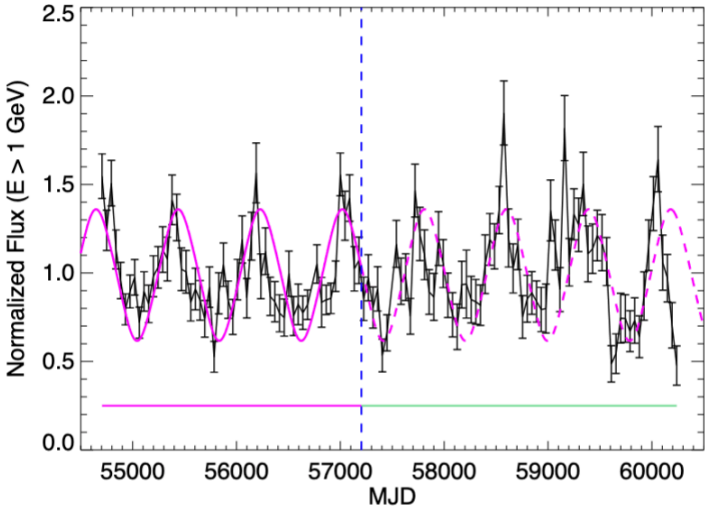
Multifrequency flux light curves built at: X-ray, soft gamma-ray, optical (R and V bands) and radio (15 GHz) band.

➔X-ray data obtained with Swift-XRT (thanks to past MW campaigns and dedicated follow-up program on PG 1553+113 started on Dec.2014), RXTE and Swift-BAT.

➔Optical band is assembled with Tuorla, with Katzman Automatic Imaging Telescope (KAIT) monitoring data Catalina Sky Survey (CSS) data and All Sky Automated Survey for SuperNovae (ASAS-SN) and a dedicated follow-up program of *Swift*-UVOT

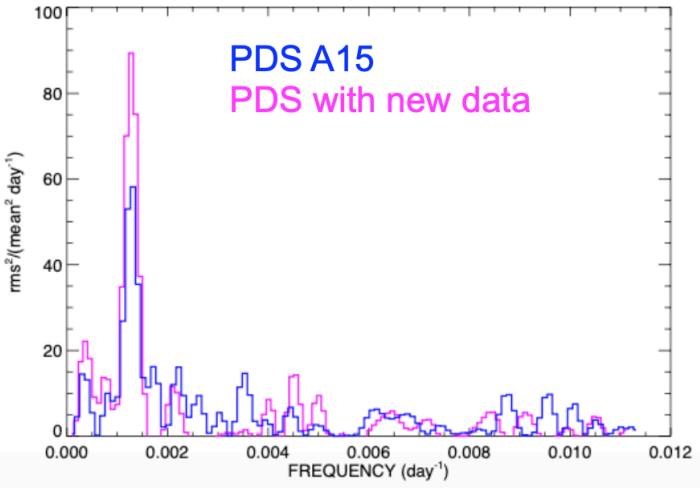
PG 1553+113: Period coherency





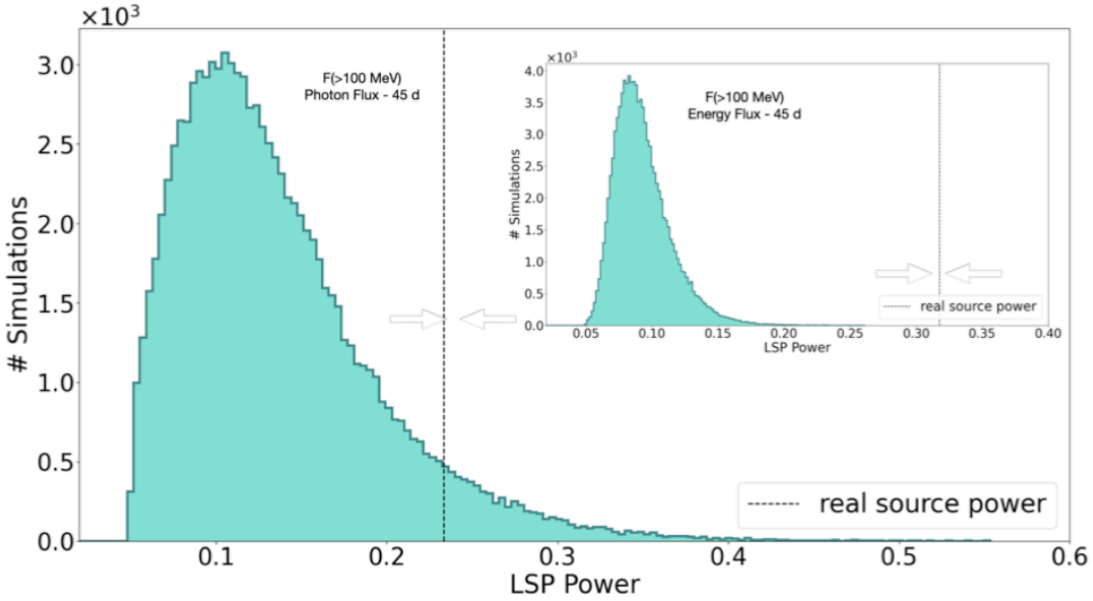
❑ Pulse phase variation relative to a strictly coherent period. The pulse phase for each cycle is estimated by cross-correlation with a Fourier model fitted to the full light curve.

❑ A Fourier fit to the linearly detrended 1 GeV light curve up to 2015. The fitted oscillation is extrapolated and compared to the new data.



PG 1553+113: Significance estimation

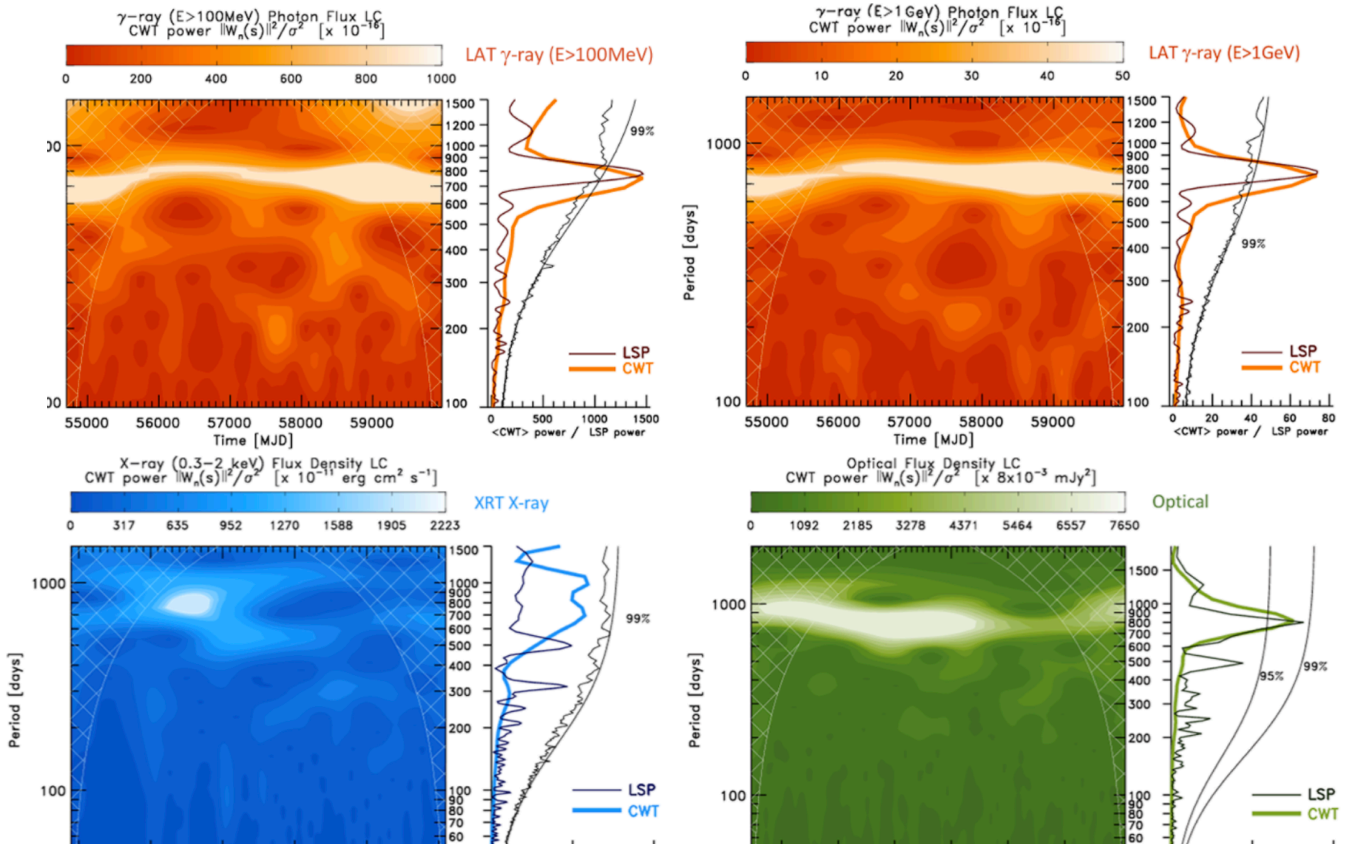
- Estimation of Significance of periodicity using False Alarm Probability—> 10^6 simulation of true LC with Emmanoulopoulos algorithm



γ-ray band	$E > 100$ MeV				$E > 1$ GeV
LC type	Photon flux		Energy flux		Photon flux
Bin size	20 days	45 days	20 days	45 days	45 days
LC original	1.5σ	1.7σ	3σ	$> 4\sigma$	3.5σ
LC detrended	2σ	2.3σ	3σ	4σ	4σ

PG1553+113: Periodicity studies

- 2D plane contour plot of the continuous wavelet transform of the 15-year, 45-day bin, LAT gamma-ray (E>100 MeV) light curve of PG 1553+113.
- Morlet mother function. The right side panel shows the 1D smoothed power spectrum of the CWT scalogram. A signal power peak is in agreement with the 2.2 year value found with epoch fold/pulse shape analysis. This right side panel also include the global Lomb-scargle Periodogram



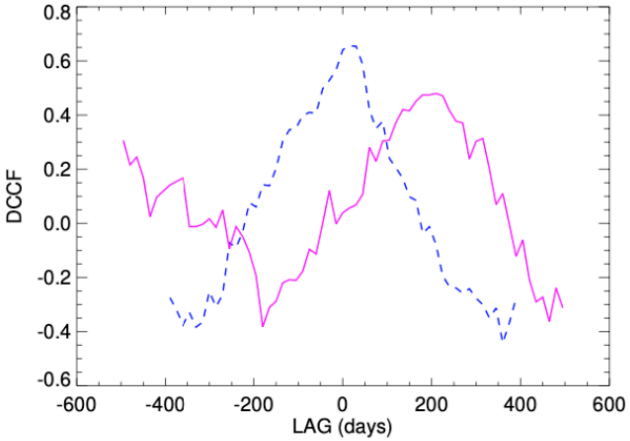
PG 1553+113: Cross correlation with radio LC

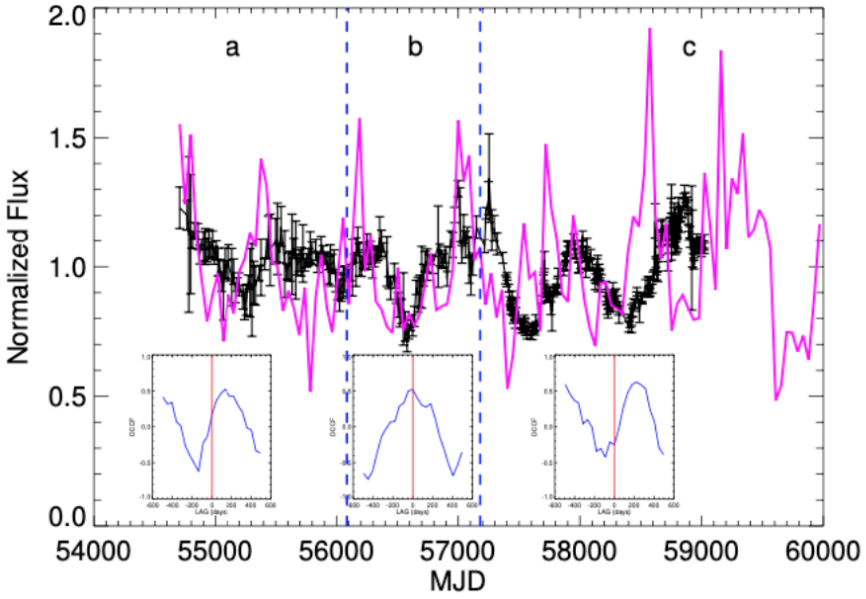
Cross-correlation analysis. Important diagnostic for multifrequency periodicity analysis in AGNs/blazars

- New radio data and new gamma-ray data cross-correlation —> STRONG correlation between radio and gamma-ray with a shift of 188+/-28 days

- Cross correlation with optical data—> Estimated lag is compatible with 0

- Analyzing different timeframe, DCCF with gamma-ray and radio flux shows different time lags.





Possibile interpretation

- Keplerian periodic orbital modulation of the accretion rate onto the primary SMBH induced by the companion —> recurrent fueling of the primary SMBH accretion disk and the activity of its relativistic jet.
- Periodic interpretation for PG 1553+113 is compliant with the new detection of low frequency GW with EPTA—> Following Holgado et al 2018, if we consider it the only one with a confirmed periodic modulation, it is consistent with 10^-3 percentage expected of SMBH-binary in BL Lacs in the Fermi-LAT catalog.
- Perturbation by inclined orbit star-like objects