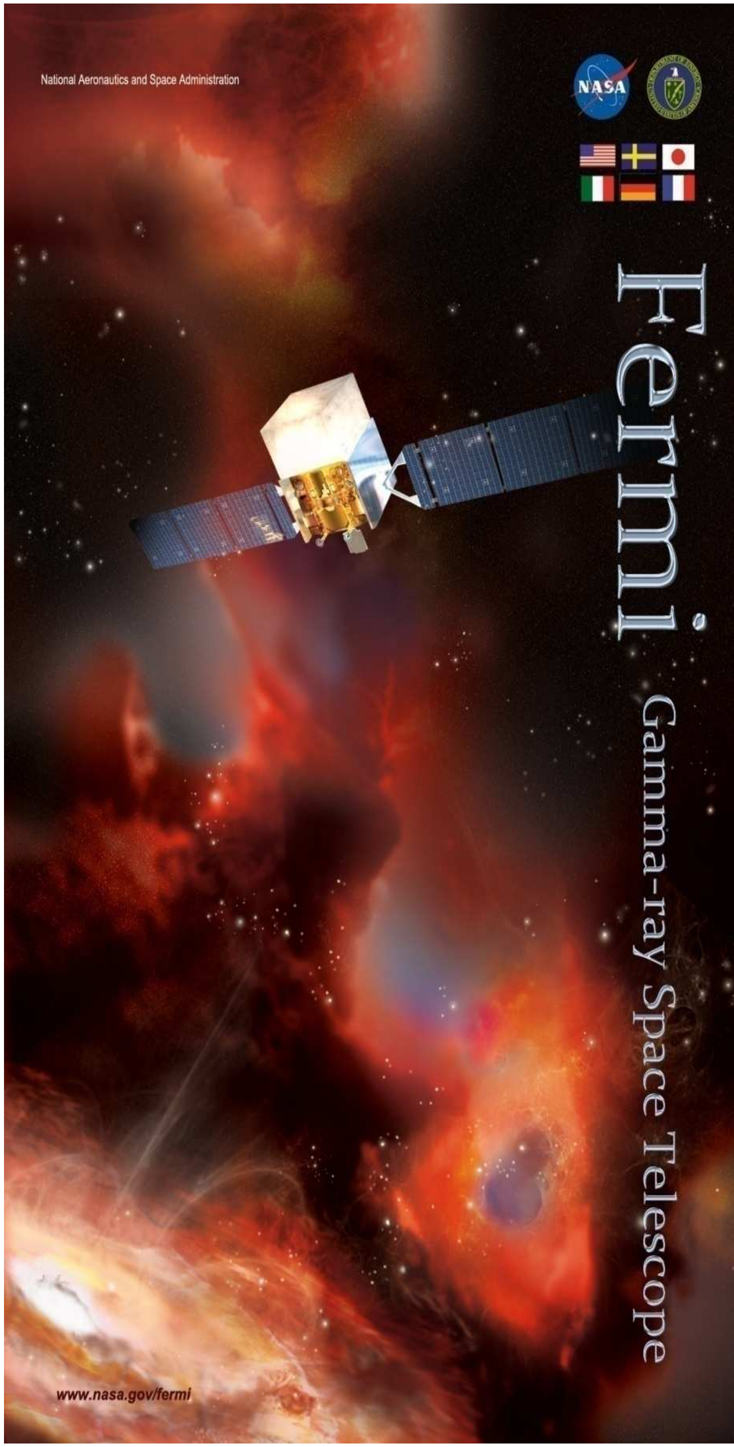

AGN Light Curves and Periodicity: to Be or Not to Be ?

Two examples: PG 1553+113 and OJ 287

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On behalf of the *Fermi* LAT Collaboration

1. ASI Science Data Center, Rome, Italy
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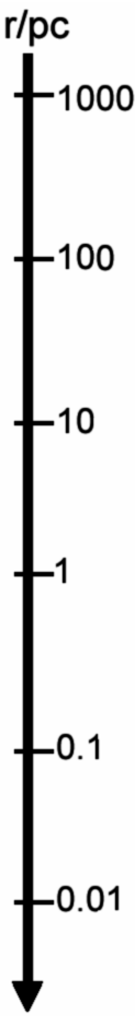
Sixth International Fermi Symposium, November 9-13, 2015
Sheraton Pentagon City, Arlington, VA, USA

asdc ASI Science Data Center | INFN Istituto Nazionale di Fisica Nucleare | asi agenzia spaziale italiana

Observational evidence for SMBHs pairs/binary



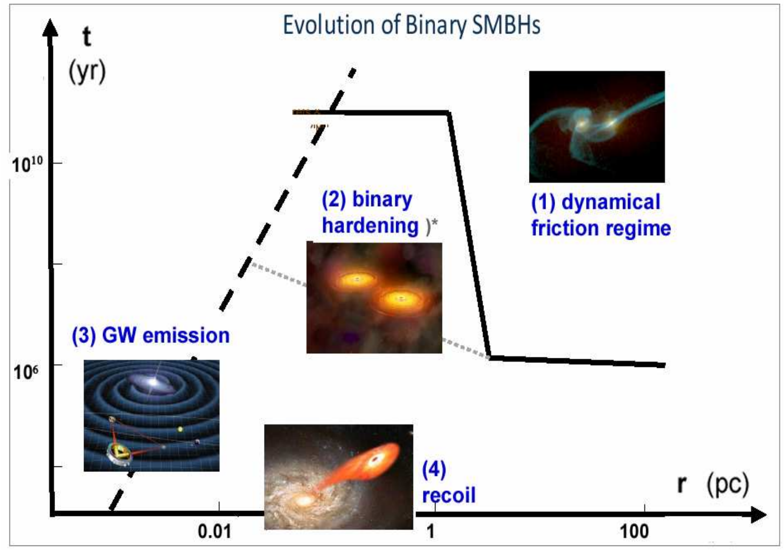
Observational evidence for SMBH pairs and gravitationally bound binary systems:

- ❑ quasar pairs, AGN in clusters of galaxies
- ❑ pairs of active galaxies, interacting galaxies in early phase of interaction/merging (double-peaked narrow optical emission lines, if both galaxies have NLR)
- ❑ SMBH pairs in "single" galaxies and advanced mergers, kpc/100-pc scales (ex.: two accreting SMBHs spatially resolved, often heavily obscured --> X-ray/radio observations)
- ❑ spatially unresolved BSMBHs candidates
  ❑(1. pseudo/quasi/semi-periodic signals in radio/optical flux light curves; 2. pc-scale spatial radio-structures distorted/helical-patterns in jets; 3. double-peaked broad lines)
- ❑ a few post-merger candidates (X-shaped radio sources, galaxies with central light deficits, double-double radio sources, recoiling SMBHs)

Nature Vol. 287 25 September 1980 **307**

Massive black hole binaries in active galactic nuclei

M. C. Begelman*, R. D. Blandford† & M. J. Rees‡



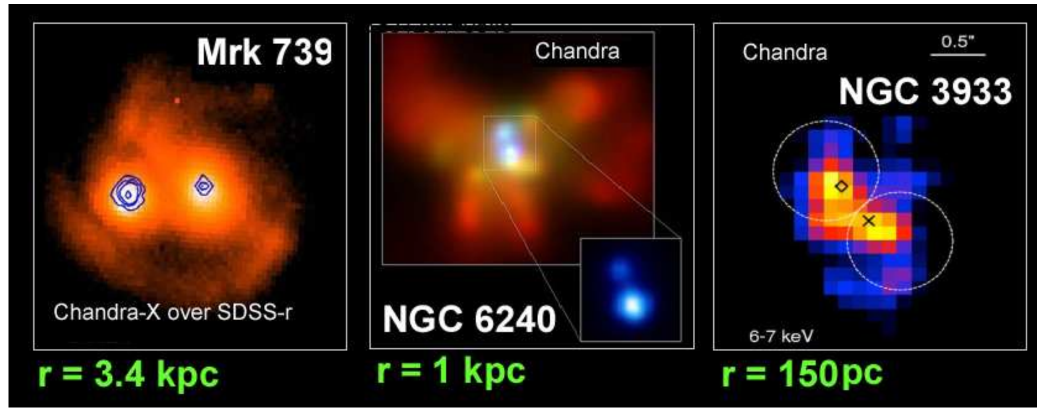
- Galaxy mergers. Sites of major BH growth & feedback processes
- Coalescing BSMBHs. Powerful emitters of GWs and e.m. radiation
- GW recoil. SMBHs oscillate about galaxy cores or even escape

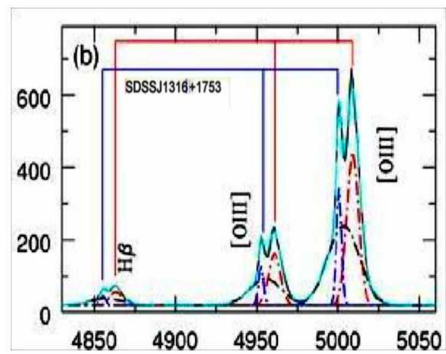
Observational evidence for SMBHs pairs/binary

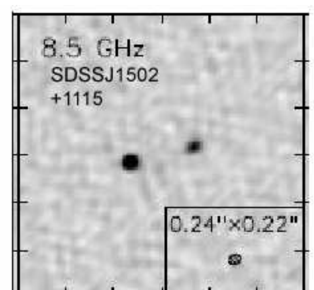
Pair of accreting SMBH in "single" galaxies (spatially resolved 10-pc to 100-pc): NGC 6240; 4C +37.11/S4 0402+37, NGC 3933, LBQS 0103-2753, Mkn 739, ESO 509-IG 066, ...

Spatially unresolved (close if <0.1pc) binary SMBH candidates:

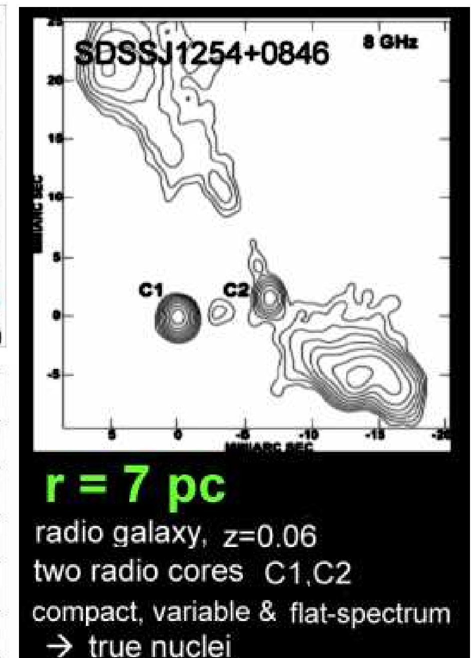
- ❑ from claims of quasi-periodic variability signatures: OJ 287, PG 1302-102, 3C 345, PSO J334.2028+01.4075, AO 0235+16, 3C 273...
- ❑ from observed helical distorted radio jets (jet-emitting 2ndary SMBH orbiting primary OR precession): 3C 345, NRAO 530/PKS 1730-13, 3C 120, 3C 66B, Mkn 501...
- ❑ from observed double-peaked broad lines: SDSS J0927+2943, SDSS J1316-1753, SDSS J150243.1+111557, PG 1302-102 (non-double but asymmetric). Only small fraction of all “dbl-peakers“ are good candidates; only a few confirmed as “detections”.







r = 7.4 kpc



Many binary BSMBHs candidates but few non-controversial confirmations! Why so few ? Large distances (difficult to resolve). Perhaps obscured. Need to distinguish other phenomena (in-jet knots, lensing, ...). In close pairs most current methods require at least one SMBH to be active (many may not be).

Possible quasi-periodic variability signatures

- Long-term radio/optical light curves of blazars → possible periods several years (OJ 287, PG 1302-102, CGRaBS J1359+401, 3C 345, PSO J334.2028+01.4075, AO 0235+16, 3C 273, TXS 0059+581, BL Lac...)

- Short-term optical/X-ray/TeV light curves of blazars → possible periods of several tens of days (Mkn 501, Mkn 421, PKS 2155-304, 3C 66A, S5 0716+714 , OJ 287, Sy 1 KUG 1031+398/RX J1034.6+3938…)

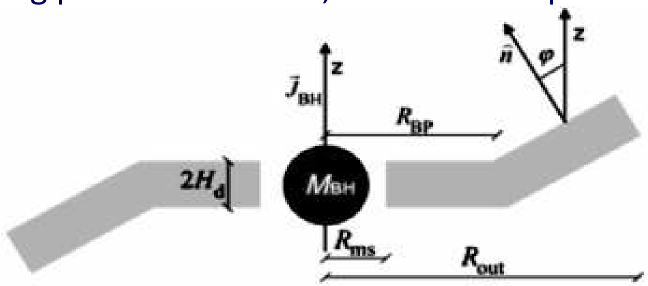
name	redshift z	periods P_{obs}	$(m+M)/10^8 M_\odot$	P_k [yr]	$d/10^{16}$ cm	$\tau_g/10^8$ yr
Mkn 501	0.034	23.6 d (X-ray)	(2-7)	(6-14)	(2.5-6)	≤ 5.5
		~ 23 d (TeV)				
		10.06 yr (optical)				
BL Lac	0.069	13.97 yr (optical)	(2-4)	(13-26.1)	(4.8-9.7)	≤ 29
		~ 4 yr (radio)				
3C 273	0.158	13.65 yr (optical)	(6-10)	(11.8-23.5)	(6.5-12)	≤ 3.5
		8.55 yr (radio)				
OJ 287	0.306	11.86 yr (optical)	6.2	(9.1-18.2)	(5.5-8.8)	≤ 1.7
		~ 12 yr (infrared)				
		~ 1.66 yr (radio)				
		~ 40 d (optical)				
3C66A	0.444	4.52 yr (optical)	≥ 1	(3.1-6.3)	≥ 1.5	2.08
		65 d (optical)				
0235+16	0.940	2.95 yr (optical)?	≥ 1	(1.5-3.1)	≥ 0.95	≤ 0.3
		8.2 yr (optical)?				
		5.7 yr (radio)				

Candidate BSMBHs in literature based on some reported quasi-periodicity evidence. Associated gravitational lifetime tg is estimated for mass ratios m/M > 1/100 (Rieger 2008, 2007).

Possible quasi-periodic variability signatures

❑ Long-term radio/optical light curves of blazars → possible periods several years (OJ 287, PG 1302-102, CGRaBS J1359+401, 3C 345, PSO J334.2028+01.4075, AO 0235+16, 3C 273, TXS 0059+581, BL Lac...).
❑ Short-term optical/X-ray/TeV light curves of blazars → possible periods of several tens of days (Mkn 501, Mkn 421, PKS 2155-304, 3C 66A, S5 0716+714 , OJ 287, Sy 1 KUG 1031+398/RX J1034.6+3938…).

Quasi periodicity / quasi periodic oscillations, may be caused by a variety of mechanisms (without the need of a driving binary system):
❑1. specific disk instabilities (pulsational accretion flow instabilities, approximating periodic behavior, are able to explain modulations in the energy outflow efficiency);
❑2. internal jet rotation, jet precession, helical structure (resulting Doppler magnification factor changes periodically, no need for intrinsic variations in outflows and efficiency);
❑ 3. orbiting disk hot spots;
❑4. QPO-like accretion–outflow coupling mechanism (QPO Lense–Thirring precession, Bardeen–Petterson warp).



Schematic representation of the Bardeen-Petterson effect.

Quasi periodicity / quasi periodic oscillations, may be driven by a binary system anyway:
❑ 1. accretion disk interactions in close BSMBHs (interactions of the companion with the accretion disk around the primary, interactions of circumbinary disk, can provide a natural trigger for periodicity of several years;
❑ 2. helical jet paths can naturally arise in binary systems where (at least) one of the BH produces a collimated jet, orbital motion lead to the appearance of helical jet paths on small scales (differential Doppler boosting may shorten the physical driving periods in the source frame);
❑3. precession-driven helical motion due to gravito-magnetic relativistic effects due to the gravitational field or the motion of the companion (they are likely too slow anyway). Newtonian-type jet precession that may arise, for example, due to tidally induced perturbations in the disk around the jet-emitting primary is more promising;

Problems

❑ Problem: single band light curves. Too strong claim to argue for unresolved close (<0.1 pc) BSMBH system based on periodicity in 1 single energy band. To observe multifrequency quasi-periodicy and cross-correlations can support the claim. To observe helical pc-scale radio-jet patterns and observe periodical polarization patterns can support the claim.

❑ Problem: single portion of the light curve ("cherry pick" of data). The full time interval of the available data must be considered and analyzed (not only the one that portion that conveniently shows a periodicity). Periods that are intrinsically transient (do not last more than a few cycles) are not a result on "periodicity".

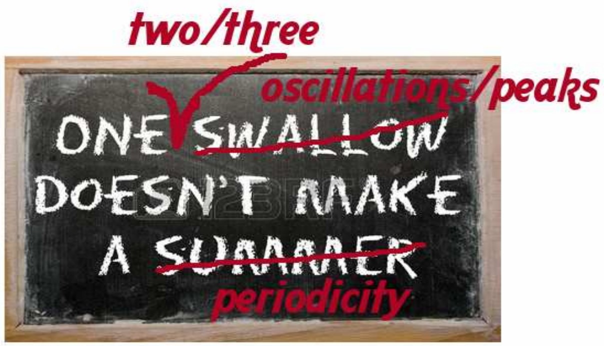
❑ Problem: data gaps (especially optical light curves). How gaps influence our analysis results?

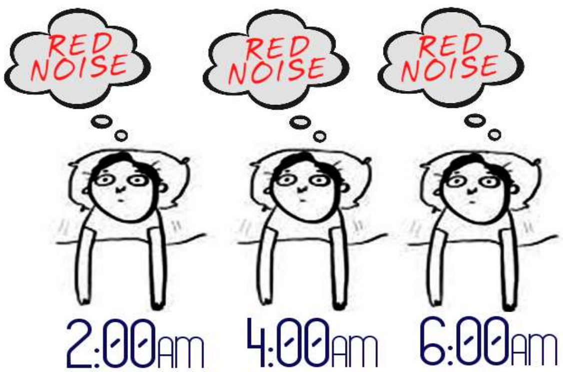
❑ Problem: quality of the light curve and significance of the period. To be convinced the light curves and fit would have to be comparable to what we see in X-ray binaries but in most cases they are not (very different samplings, gaps, errors, dispersion/confusion given by heterogeneity of different instruments/telescopes…).

❑ Problem: red-noise. The periodicity significance is difficult to assess given the usually limited length of the light curves. Red-noise, i.e. random and relatively enhanced low-frequency fluctuations (Brownian noise) over intervals comparable to the sample length, hinders the evaluation of significance. Essentially stochastic variability can build red noise and it can show up and mimic a misinterpreted periodic trend.

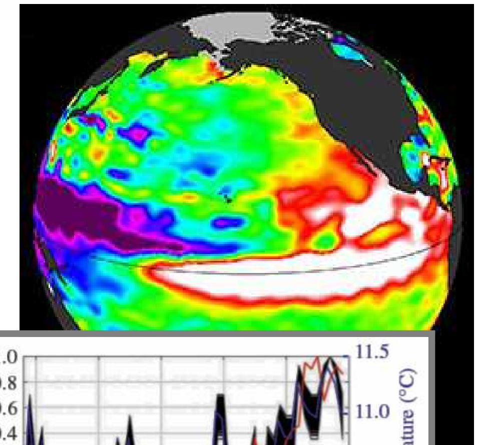
(...one swallow does not a summer make! ...red-noise takes you awake during the night!). Simulations can help.

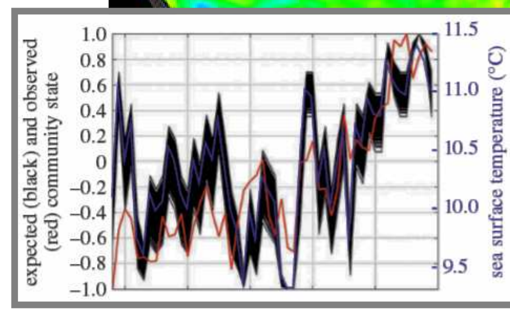
❑ Problem: when blazar luminosities range over maybe 4–5 orders of magnitude, why claimed periods all have similar time scales of a few years (1–25 years) ? If real this can be puzzling.

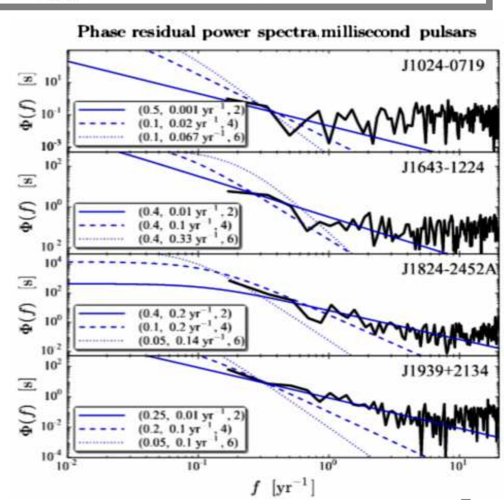




Red noise everywhere (ecosystems, PTA, etc.)







- ❑ Sudden dynamic environmental/ecosystems/ climate changes (irreversible-changes/complex/pathological-behaviours) → huge pressing concerns / worries / public policy implications.
- ❑ Question: essentially stochastic processes (white/red/brown noise) tracking external physical variability o<u>r</u> dominant nonlinear-shift/catastrophic environmental/ecological/biological regimes?
- ❑ Ecological/biological metrics (ex: populations of marine species) show strong variations at decadal time-scales, often correlated with large-scale climate indices, (El Niño-Southern Oscillation /La Niña", ENO or Pacific Decadal Oscillation, PDO).
- ❑ Hsieh et al. 2005, Nature, 435, 336 "*Distinguishing random environmental fluctuations from ecological catastrophes for the North Pacific Ocean":* large-scale marine ecosystems are dynamically nonlinear --> capacity for dramatic change in response to stochastic, red noise, fluctuations in basin-scale physical states.
- ❑ White-noise atmospheric weather --> red-noise in ocean physics --> even redder (lower frequency) biological trends. Many biological time-series arise not so simply/randomly and exhibit more truly interesting nonlinear behavior.

- ❑ Sensitivity of pulsar timing arrays (PTA) to gravitational waves limited by timing red noise (stochastic wandering of pulse arrival times has a red spectrum). Red timing noise spectrum plateaus below some critical frequency (Lasky et al. 2015, MNRAS, 449, 3293).

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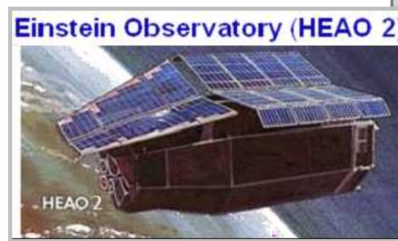
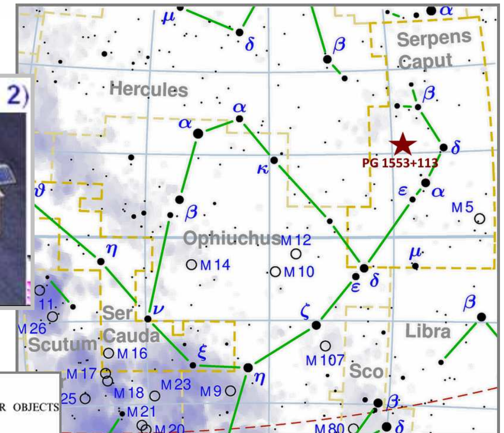
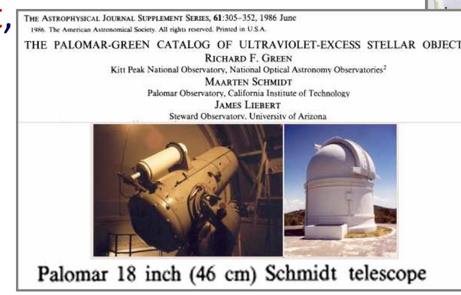
The case of PG 1553+113

- ❑ PG 1553+113 (a.k.a. 1ES 1553+113): optically/X-ray-selected BL Lac object (Green, Schmidt & Liebert 1986; Falomo & Treves 1990).
- ❑ X-ray counterpart is discovered by the Einstein Observatory (1ES cat., obs#10608 in 1981 March 12, 3.3ksec, 1.27 cts/s), among the brightest BL Lac objects in the X-ray band.
- ❑ Detailed observations by XMM, Chandra, Suzaku, Swift, etc. Chandra observed warm-hot intergalactic medium (WHIM, Nicastro et al. 2013, ApJ, 769, 90).
- ❑ Redshift constraints: $0.395 < z < 0.62$ (Danforth et al 2010 and Aliu et al. 2015). More recent estimation $z=0.49+/-0.04$ (Abramowski et a. 2015).
- ❑ VHE (E>100GeV) gamma-ray emission discovered independently by H.E.S.S. (Aharonian et al. 2006, A&A, 448, L19), and by MAGIC (Albert et al. 2007, ApJL., 654, L119, Aleksic et al. 2012 ApJ, 748, 46).
- ❑ Recent MAGIC data: see the POSTER AGN.24 with new MAGIC (and MW) data comparison).
- ❑ Recent discovery of HE neutrinos of astrophysical origin (up the PeV) by IceCube. PG 1553+113 plausible gamma-ray counterpart with IceCube event ID 17 (Padovani & Resconi 2014, MNRAS, 443, 474).






THE ASTROPHYSICAL JOURNAL SUPPLEMENT SERIES, 61:305–352, 1986 June

THE PALOMAR-GREEN CATALOG OF ULTRAVIOLET-EXCESS STELLAR OBJECTS

RICHARD F. GREEN

Kitt Peak National Observatory, National Optical Astronomy Observatories

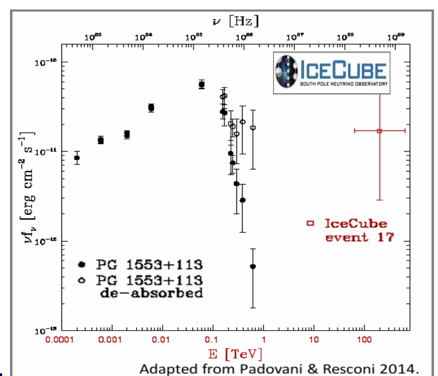
MAARTEN SCHMIDT

Palomar Observatory, California Institute of Technology

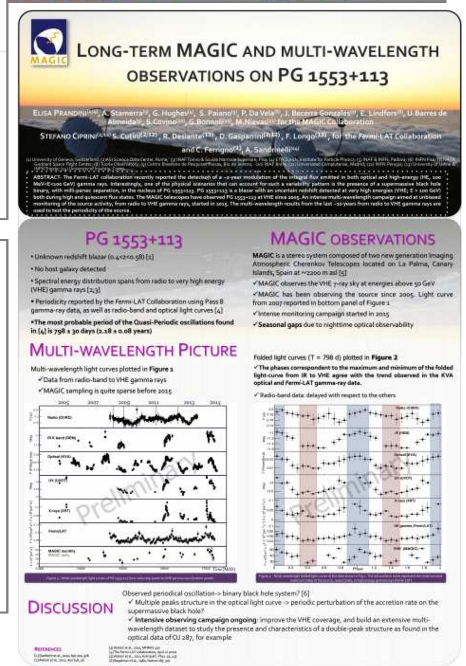
JAMES LIEBERT

Steward Observatory, University of Arizona

Palomar 18 inch (46 cm) Schmidt telescope



Adapted from Padovani & Resconi 2014.



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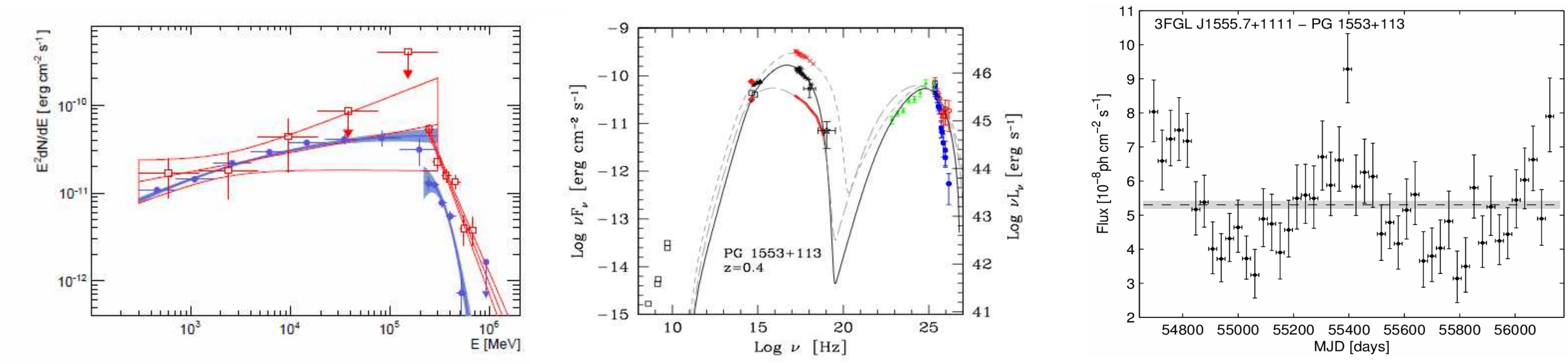
PG 1553+113: *Fermi* LAT results

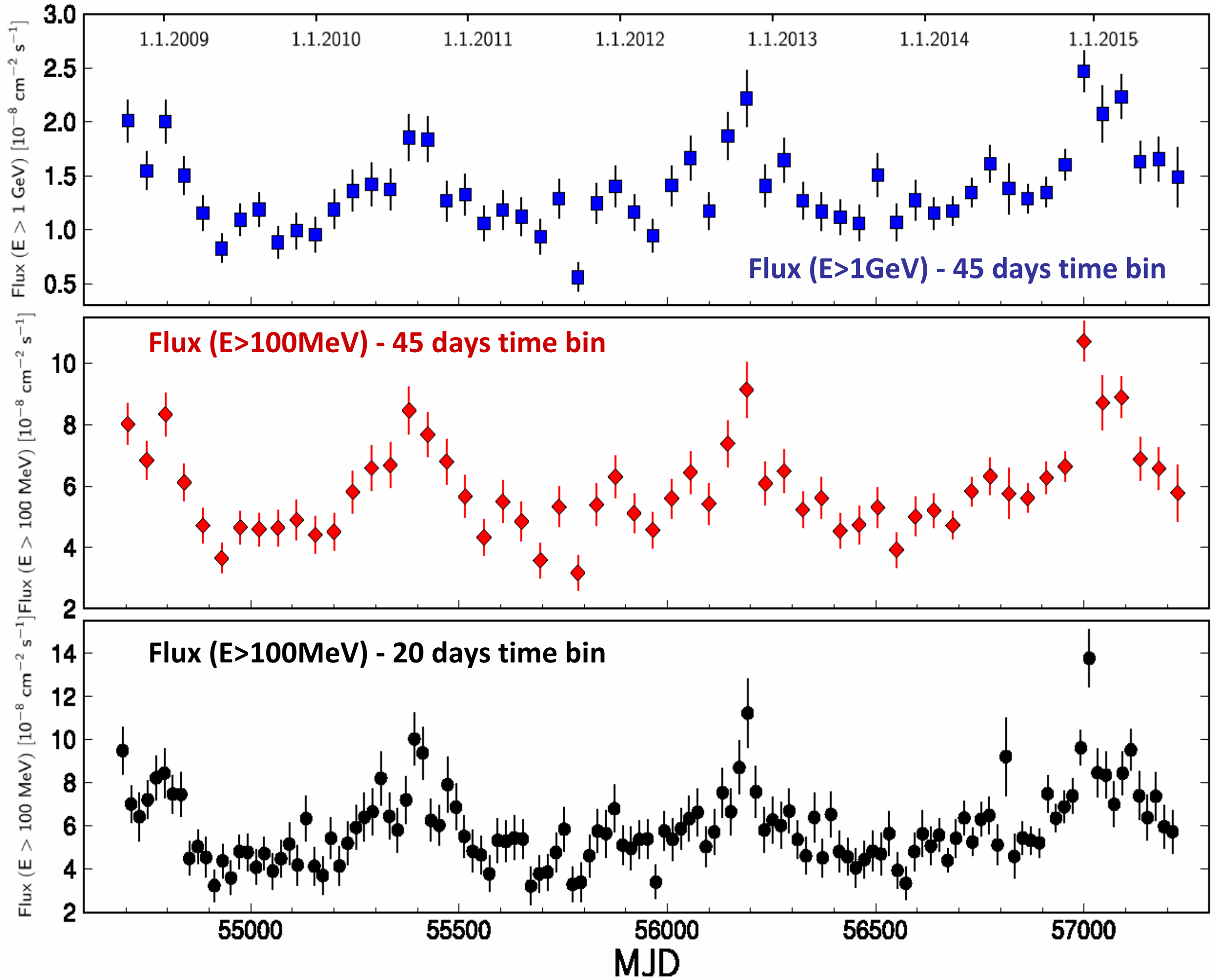
- PG 1553+113 appears already in the first LAT catalog (Bright Source List - 0FGL J1555.8+1110).
- 3FGL catalog (3FGL 1555.7+1111): spectrum well fitted by a power-law, hard spectral photon index (1.604+/-0.025 and F(E>100MeV)=(1.32+/-0.03)X10^-8 ph cm^-2 s^-1). It is found variable in GeV gamma-rays based on 1-month bin light curves.
- Several paper on PG 1553+113 (mainly spectral/SED studies) were released by the LAT collaboration in cooperation with MAGIC and H.E.S.S (contact names: D. Sanchez, S. Buson, J. Becerra, D. Horan…).



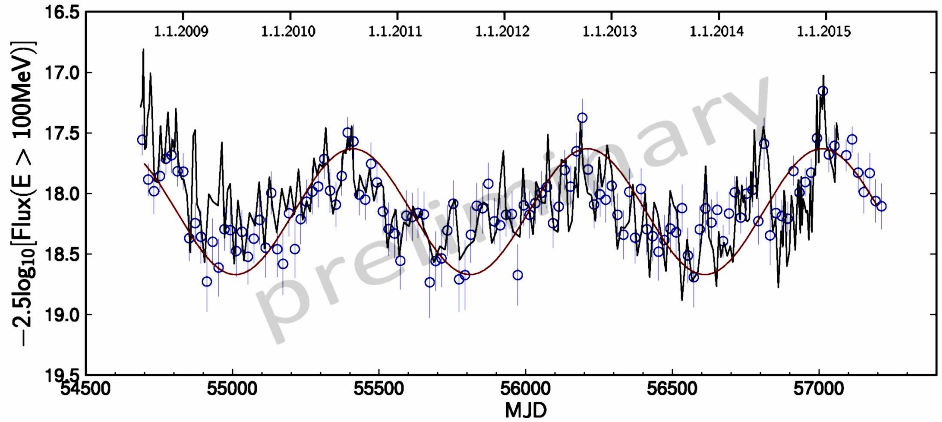
- First LAT+multifrequency long-term light curve study in Ackermann et al. 2015, ApJL, in press (cooperative work of S. Ciprini, S. Cutini, S. Larsson, S. Stamerra, D.J. Thompson, R. Corbet, W. Max-Moerbeck among the other).
- LAT light curves based on 6.9-year Pass 8 dataset: Aug.4,2008 – Jul.19,2015, gamma rays from 100 MeV to 300 GeV, P8R2_SOURCE_V6 IRFS in a Region of Interest of 10°, unbinned maximum likelihood model fit in each regular-size time bin using a power law model.

PG 1553+113: gamma-ray LAT light curves

- ❑ *Fermi* LAT gamma-ray flux (E>100MeV and E>1GeV) light curves of PG 1553+113 based on Pass 8 dataset up to July 19, 2015, produced in regular-size time bins of 45-day and 20-day size.
- ❑ A long-term oscillating trend is visually evident. Sinusoidal modulation (using magnitude-like log-flux scale). Rather regular periodicity in about 3.5 cycles. Significance still marginal against red-noise but strengthen by MW cross-correlations and detection o similar oscillation trend in optical data.
- ❑ ➔ In case of long-lived coherence in this flux oscillation/modulation the next quasi-periodic peaks are foreseen 2017 and 2019.



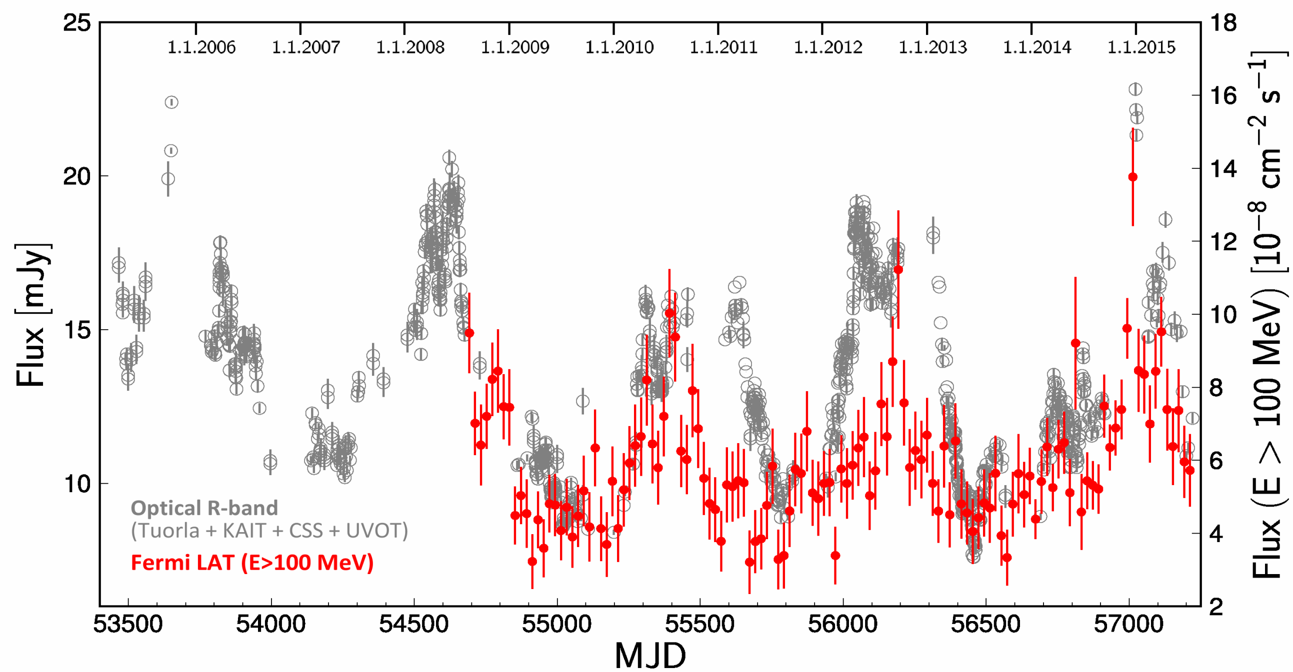
PG 1553+113: gamma-ray overlapped optical light curve



❑ 6.9-year LAT gamma-ray flux light curve (E>100MeV 20-day bin, open circle symbols and adaptive-bin light curve, black line) reported in log10 Y-scale (gamma-ray “magnitude”). A strict sinusoidal curve (P=2.18y) curve is superposed.

❑ 6.9-year LAT gamma-ray flux (E>100MeV 20-day bin) light curve of PG 1553+113 (red datapoints).

❑ 9.9-year optical (R-band) light curve of PG 1553+113 (grey datapoints).
Collected from: Tuorla+KVA monitor program data + Catalina CSS archive data + KAIT monitor data + Swift UVOT data.



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PG 1553+113: radio/optical/X-ray light curves

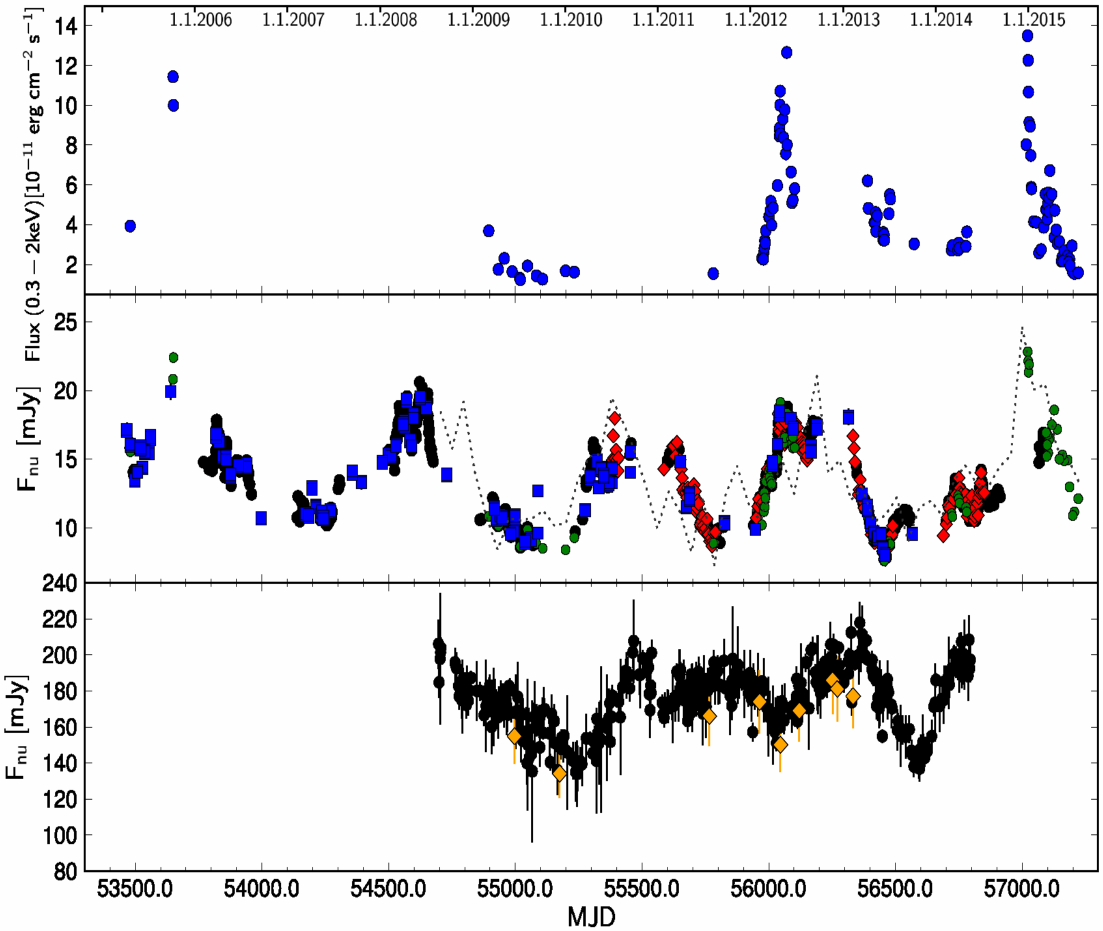
- Multi-wavelength flux light curves are assembled at: X-ray, optical (R and V bands) and radio (15 GHz) band

➔X-ray data obtained with Swift-XRT (thanks to past MW campaigns and dedicated follow-up program of the source from Dec.2014).

➔ Long-term Rossi-XTE (ASM) and Swift-BAT also analyzed (no result because of insufficient counts statistics)

➔ Optical band is assembled with Tuorla monitoring program* (Takalo et al. 2008, AIP Conf. Proc. 1085, 705; mostly unpublished) with Katzman Automatic Imaging Telescope (KAIT) monitoring data Catalina Sky Survey (CSS) data and a dedicated follow-up program of Swift-UVOT.

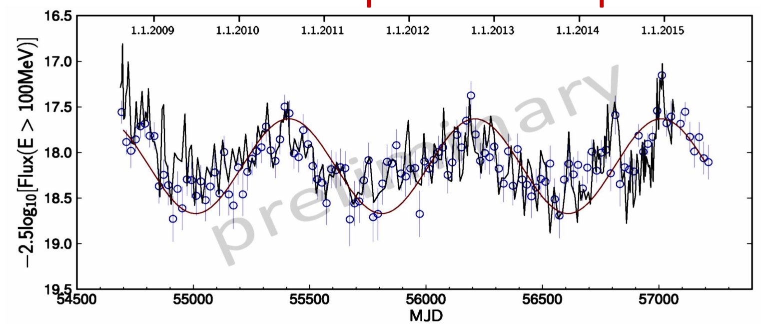
➔ Radio band at 15 GHz is assembled with 40m Owens Valley Radio Observatory (OVRO) with blazar monitoring program supporting *Fermi* (Richards et al. 2011, ApJS, 194, 29) and Monitoring Of Jets in Active galactic nuclei with VLBA Experiments (Lister et al., 2009, AJ, 137, 3718)

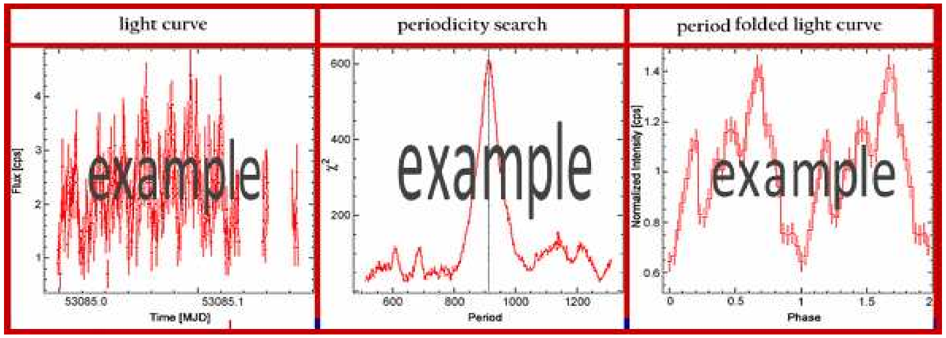


* 9.5 years (2004-2014) of long-term light curve (Tuorla optical monitoring program, partly unpublished data). Data are collected from several telescopes participating to the Tuorla monitoring program (users.utu.fi/kani/1m): 1) Tuorla Observatory telescope, Finland; 2) KVA observatory on La Palma, Canaryislands, Spain; 3) Searchlight Observatory Network telescope, San Pedro de Atacama, Chile; 4) Searchlight Observatory Network telescope, New Mexico, USA; 5) Belogradchik telescope, Bulgaria.

PG 1553+113: temporal variability analysis

- A classical 3-step "How-to" periodicity: →





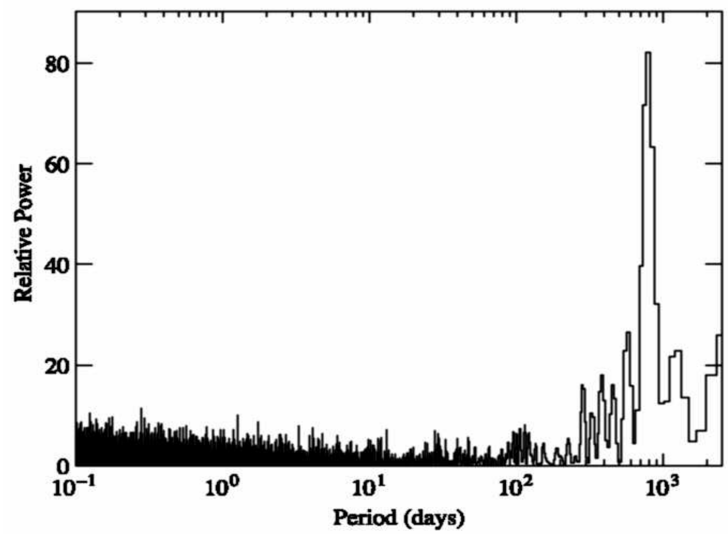
- 1) The epoch folding / pulse shape analysis. The epoch folding, pulse shape analysis, is the driving method in presence of a mostly regular sampling and coherent sinusoidal oscillations. Gamma-ray period-folded pulse shape light curve. A peak of power is found at a gamma-ray characteristic period timescale of 798+/-30 days (2.18+/-0.08 yr) .

- 2) Direct discrete Fourier transform and power density spectra (PDS) using aperture photometry technique, confirms the same (2.16+/-0.07 yr) timescale with this method.

- 3) Lomb-Scargle algorithm periodogram. P-value =10-7

- 4) Continuous Wavelet Transform Morlet-mother waveform. (Coherent signal peak along all the light curve epoch).

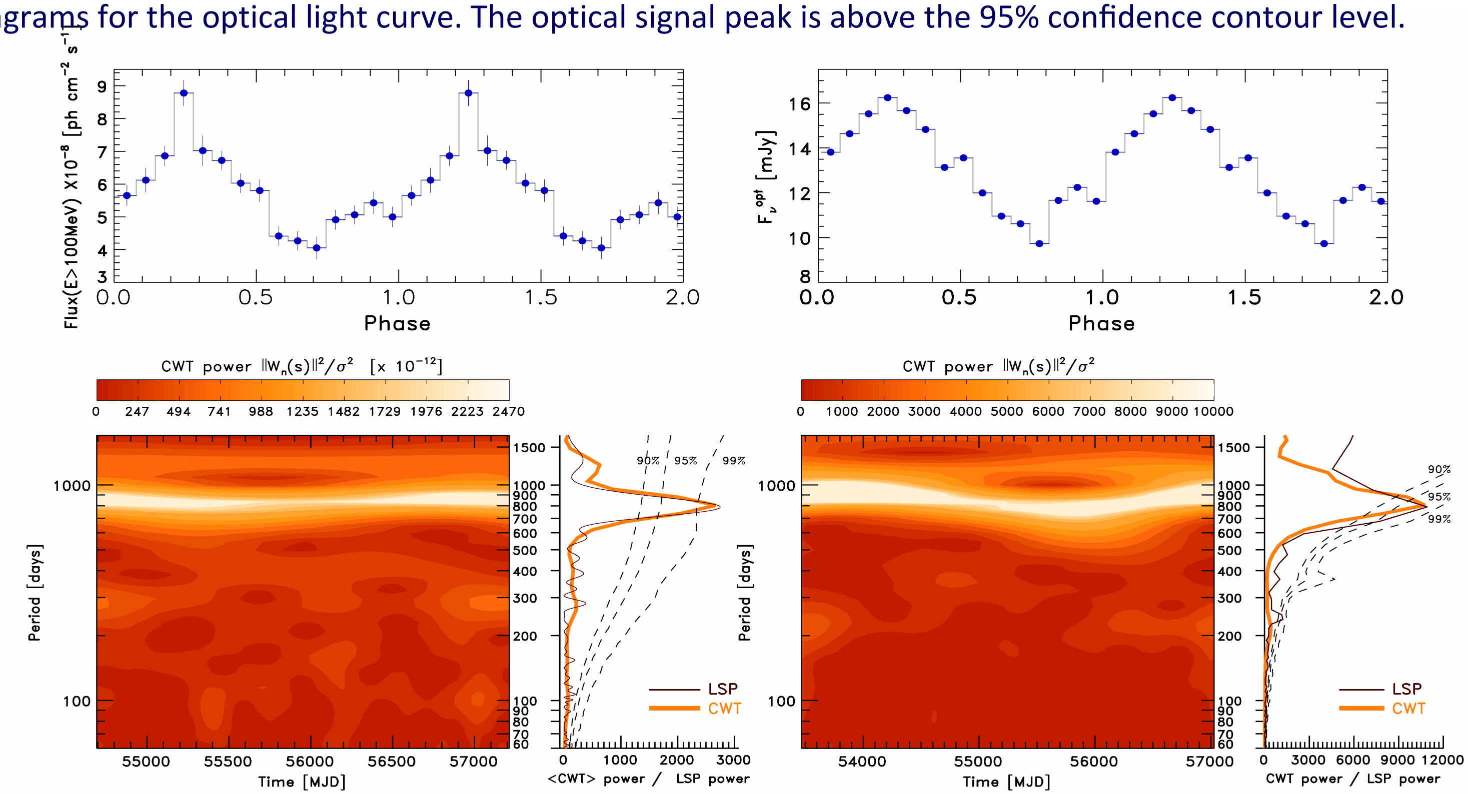
Two approaches to significance estimation against red-noise.



PG 1553+113: temporal variability analysis

❑ Upper panels: pulse shape (epoch-folded) gamma-ray (E > 100 MeV) flux light curve at the 2.18 year period (two cycles shown) (left) and pulse shape (epoch-folded) optical flux light curve at the 2.18 year period (two cycles shown, right).

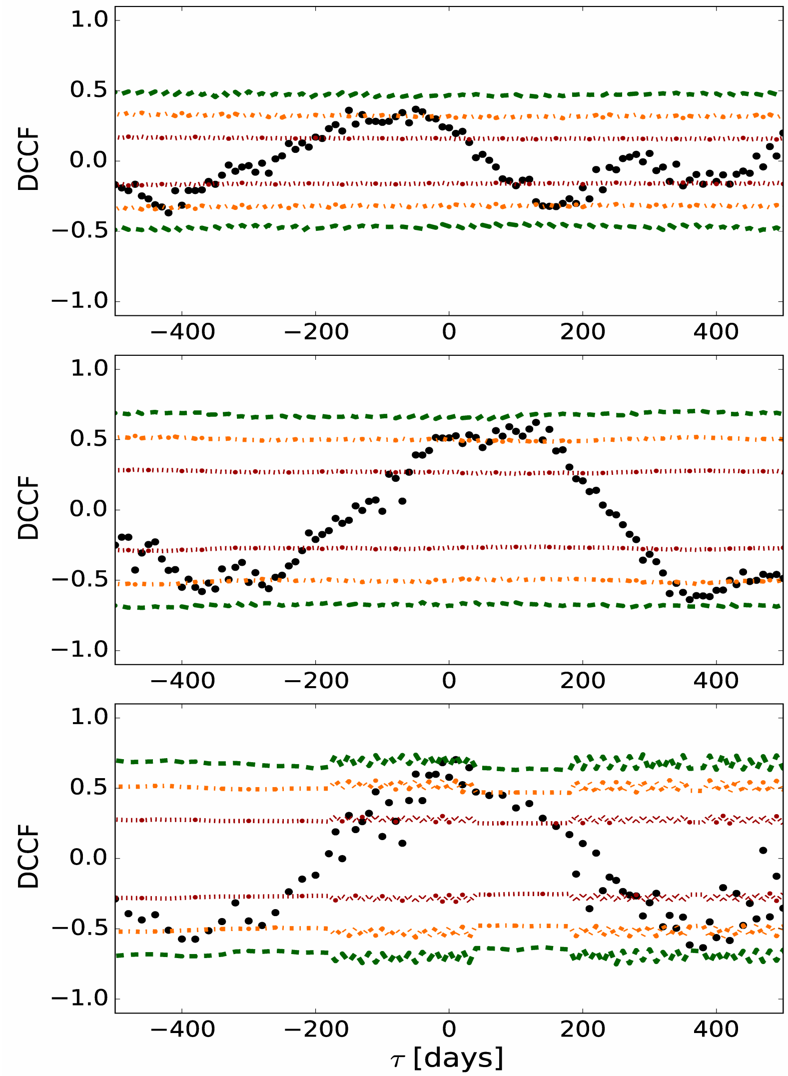
❑Bottom panels: left is 2D plane contour plot of the continuous wavelet transform power spectrum (scalogra, CWT) of the gamma-ray light curve using a Morlet mother function (filled color contour). The side panel to this is the 1D smoothed, all-epoch averaged, spectrum of the CWT scalogram showing a signal power peak in agreement with the 2.18 year value, also showing the Lomb-scargle Periodigram. Dashed lines depict increasing levels of confidence against red noise calculated with Monte Carlo simulations. The gamma-ray signal peak is above the 99% confidence contour level (<1% chance probability of being spurious). Right is the same CWT and LSP diagrams for the optical light curve. The optical signal peak is above the 95% confidence contour level.



PG 1553+113: cross-correlation analysis

Cross-correlation analysis. Important diagnostic for multifrequency periodicity analysis.

- ❑ Two independent and complementary approaches.
- ❑ 1) Flux variations modeled assuming a 1/f^alpha (with f = 1/t) power law in the PDS as measured directly from the light curve data --> cross-correlation estimated significance (Max-Moerbeck et al. 2014).
- ❑ 2) In the second procedure, the significance of the gamma-ray–radio correlation was estimated to be 95% using a mixed source correlation procedure (Fuhrmann et al. 2014), cross-correlating the PG 1553+113 light curve with those of 132 comparison sources in that work, and evaluating the average DCCF level for time lags of −100 to +100 days.
- ❑ The gamma-ray optical correlation is significant at 99%, the gamma-ray and optical at 98%.
- ❑ Optical is leading gamma-ray of 75 days. Optical is leading radio of 158 days. Gamma-ray is leading radio of 83 days.
- ❑ The possible reverse gamma-ray–optical time lag decreases to 28 ± 27 days when the optical light curve is binned.



PG 1553+113: first, open, physical scenarios

- ❑ 1) Pulsational accretion flow instabilities, approximating periodic behavior, are able to explain modulations in the energy outflow efficiency. Magnetically arrested and magnetically dominated accretion flows (MDAFs) could be suitable regimes for radiatively inefficient TeV BL Lacs (Fragile & Meier 2009), characterized by advection-dominated accretion flows and subluminal, turbulent, and peculiar radio kinematics.

- ❑2) Jet precession, jet rotation, or helical structure in the jet (geometrical models), the presence of a jet wrapped by a sufficient strong magnetic field, could have a net apparent periodicity from the change of the viewing angle (Doppler magnification changes periodically).

- ❑3) Similar mechanim to low-frequency QPO from Galactic high-mass binaries/microquasars (Fender & Belloni 2004, King et al. 2013). PG 1553+113 has a low accretion rate. QPO Lense–Thirring precession requires that the inner accretion flow forms a geometrically thick torus rather than a standard thin disk as the latter warps (Bardeen–Petterson effect, Bardeen & Petterson 1975) rather than precesses (Ingram et al. 2009). ADAF-disk anyway can give precessing jet (Fragile & Meier 2009). Lense–Thirring precession could affect the jet direction, giving the QPO.

- ❑4) Binary, gravitationally bound, SMBH system (total mass of 1.6X10^8 Msun, milliparsec separation, early inspiral gravitational-wave driven regime. Keplerian binary orbital motion --> periodic accretion perturbations or jet nutation. Significant acceleration of the disk evolution and accretion onto a binary SMBH system is depicted by modeling. Probability of observing such a milliparsec system, estimated from the binary mass ratios ~0.1–0.01 and the GW-driven regime lifetime (Peters 1964) = 10^5−10^6 years, might be too small.
If the periodic flux modulation is real and coherent then subsequent maxima would be expected in 2017 and 2019.

The case of OJ 287

- 12-year quasi-periodic optical outbursts in the famous BL Lac object OJ 287 (optically bright and LAT detected).

- Last optical outburst was at the end of 2005 with secondary activity in 2006. Next 2016-2019 years can be exciting for possible Fermi LAT observation of enhanced activity.

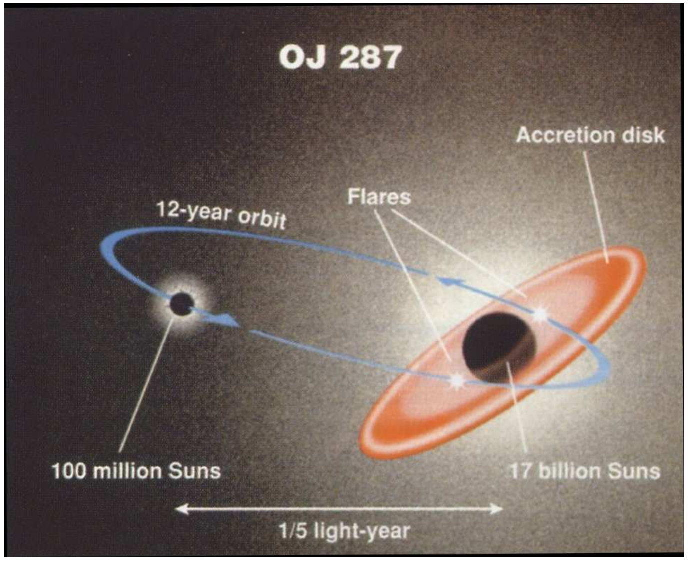
- Precursor events /different models might predict that already in 2016 there could be the occurrence of another periodic optical outburst.

- Swift program and ToO are preliminary planned. Fermi will possible monitor this active phase for the first time. 2017 and 2018 will be important to see if something happens at GeV gamma rays.

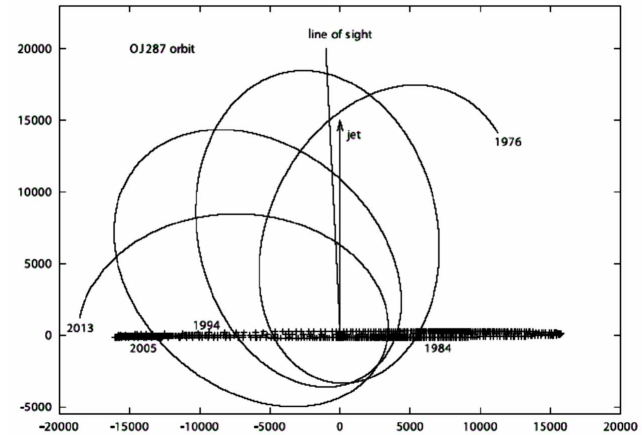
- Already claimed evidence for the loss of orbital energy, shrinklage, in the OJ 287 system, in agreement (within 10 per cent) with the emission of gravitational waves from the system.

- This is based only on usual gapped/irregular-sampling optical light curves, but is corroborated by polarization data.

- This has driven to a test of general relativity where OJ 287 was used to demonstrate the correctness of General Relativity up to the third Post-Newtonian expansion order (Valtonen et al. 2008, Nature, 452, 851).



Precessing-binary model of OJ 287



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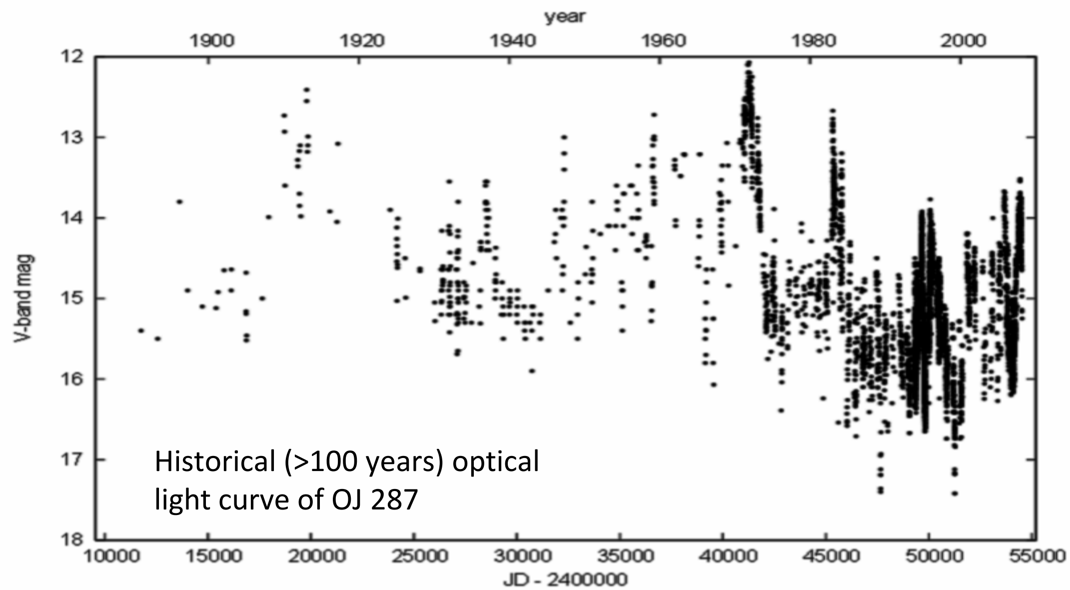
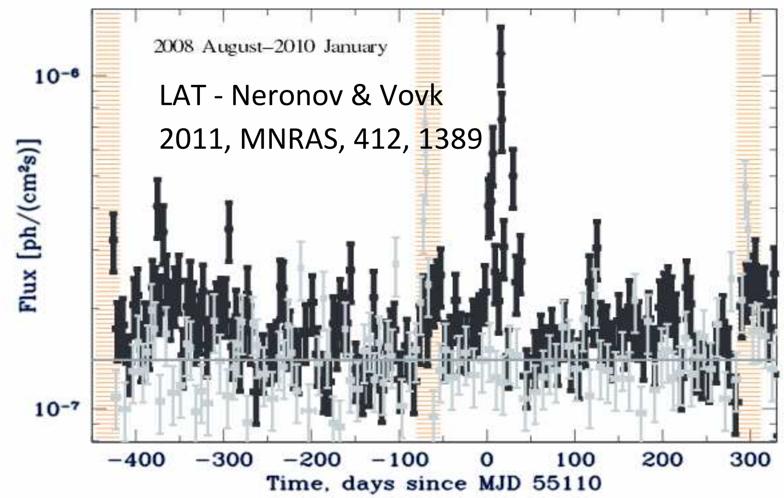
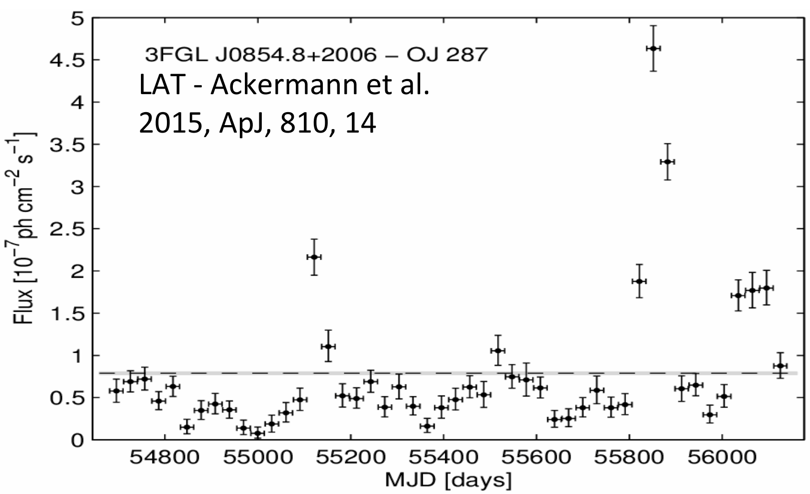
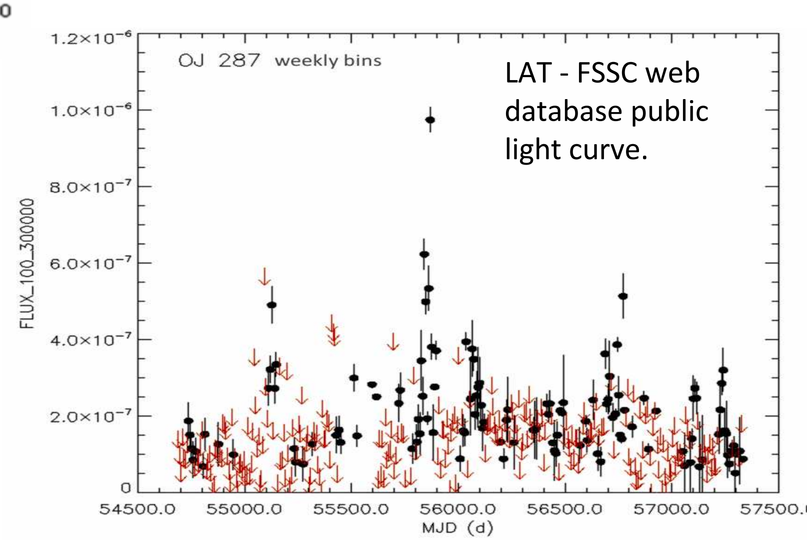
OJ 287: Fermi LAT light curves





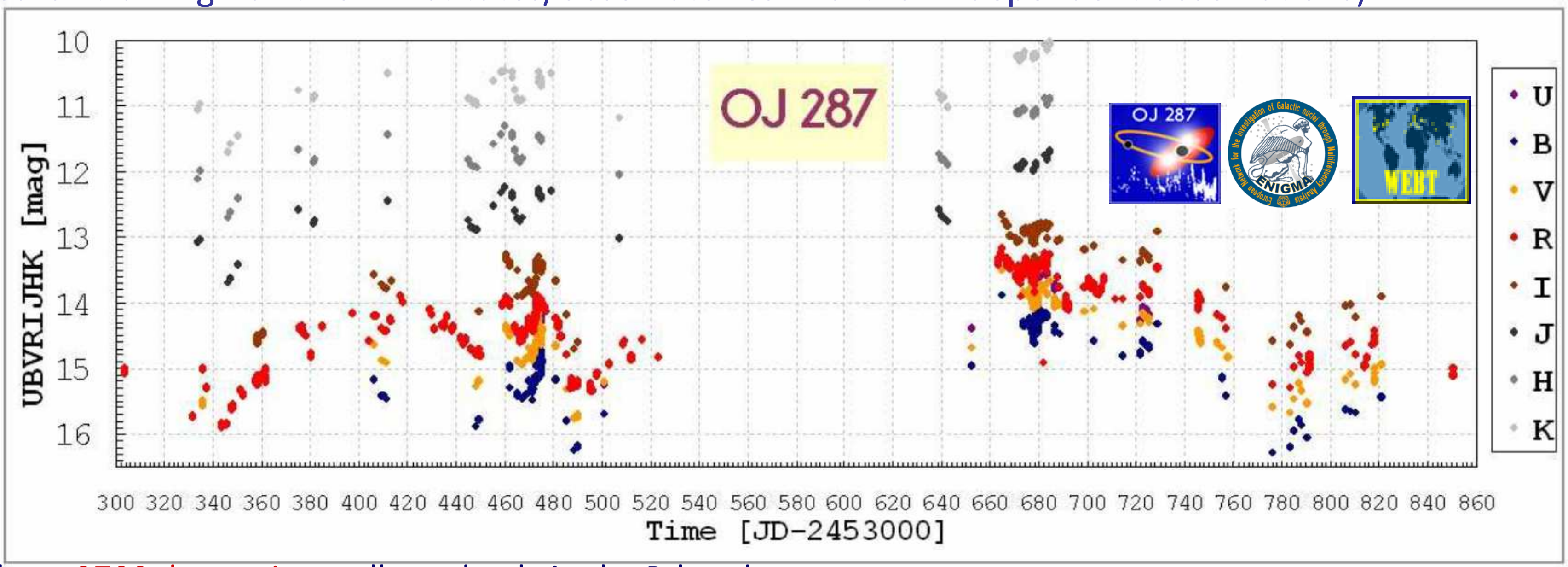




OJ 287: intensive/extensive MW campaing of 2004-2006

A radio, near-IR, optical and X-ray (3 XMM pointings). Light curve: Oct. 2004 – April 2006.

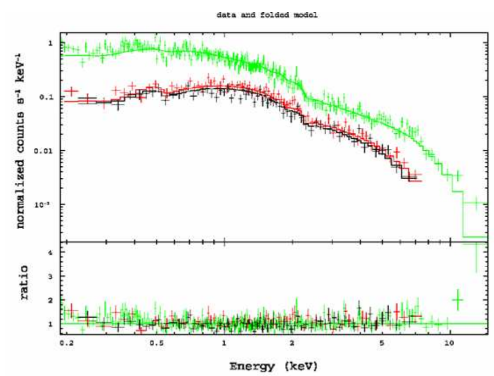
- Data from: WEBT intensive & coordinated campaign and long-term monitor (from ENIGMA European research training newtwork institutes/observatories + further independent observations).



- About 3700 data points collected only in the R-band.
- XMM-Newton observed OJ 287 during two active optical states of the source.
- An enduring, symmetrical, and time structured optical outburst observed in Oct.-Nov. 2005, around the 2nd XMM pointing. Broken power law component (break ~0.7 keV, synchrotron tail/thermal component +IC) X-ray break signature typical of intermediate energy peaked blazars.
- Radio flux on the average and any outburst observed. Radio IDV (3%) found.
- Frequency dependence of the mean structural position angle of the radio-jet in VLBA maps, consistent with jet precession model.

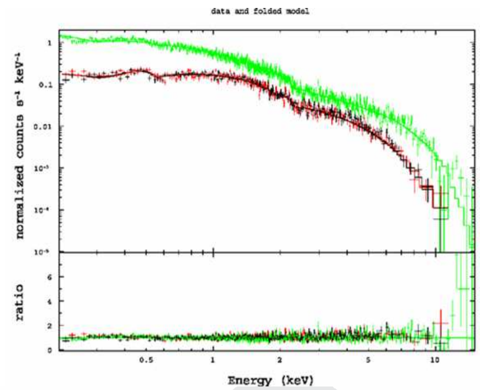
OJ 287: MW campaing of 2004-2006

Date: April 12, 2005 - OJ 287, z=0.306.
XMM-Newton *EPIC: PN* + *MOS1* + *MOS2* spectra
Model: single power law + galactic absorption in the 0.2-10 KeV range

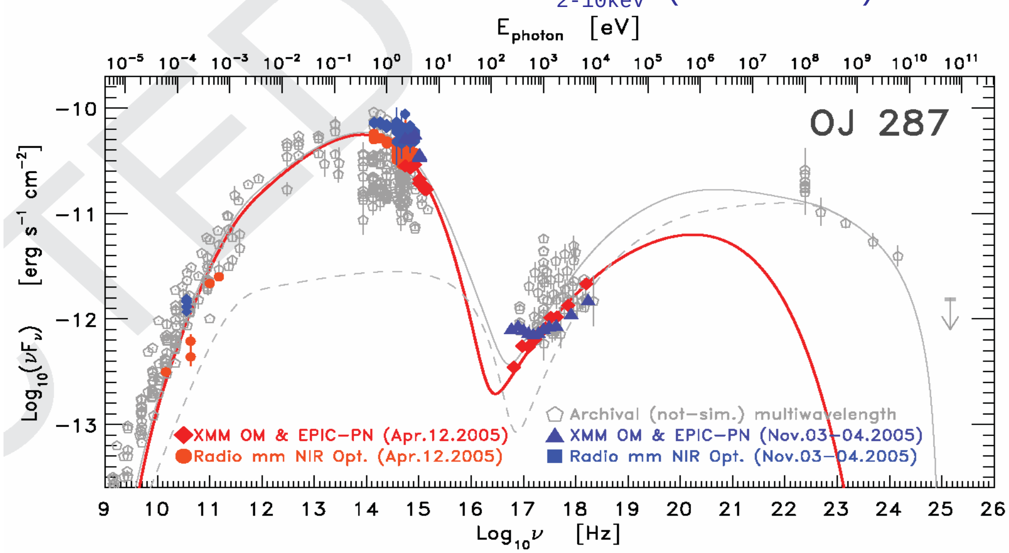


H column density:
N_H=3.09 x 10^{20} cm^{-2}
Power-law photon index:
Γ=1.63 ± 0.02
Reduced chi-squared:
χ_r^2 =1.03, d.o.f.=367
Flux density (2-10 KeV):
$F_{2-10keV}$=(2.5±0.8)x10^{-12}erg s^{-1} cm^{-2}

Date: November 3-4, 2005 - OJ 287, z=0.306.
XMM-Newton *EPIC: PN* + *MOS1* + *MOS2* spectra
Model: broken power law + galactic absorption in 0.2-10 KeV range

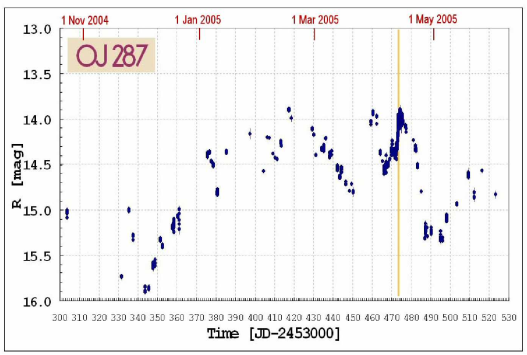


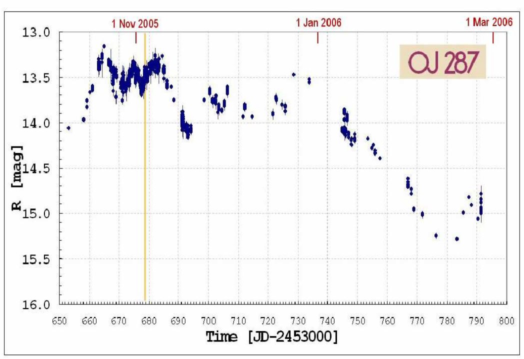
H column density:
N_H=3.09 x 10^{20} cm^{-2}
Broken power-law photon indexes:
Γ_1=2.65(-0.07/+0.12)
Γ_2=1.79 ± 0.02
E_break: 0.69 KeV (-0.05/+0.04)
Reduced chi-squared:
χ_r^2 =1.03, d.o.f.=927
Flux density (2-10 KeV):
$F_{2-10keV}$=(1.82±0.07)x10^{-12}erg s^{-1} cm^{-2}

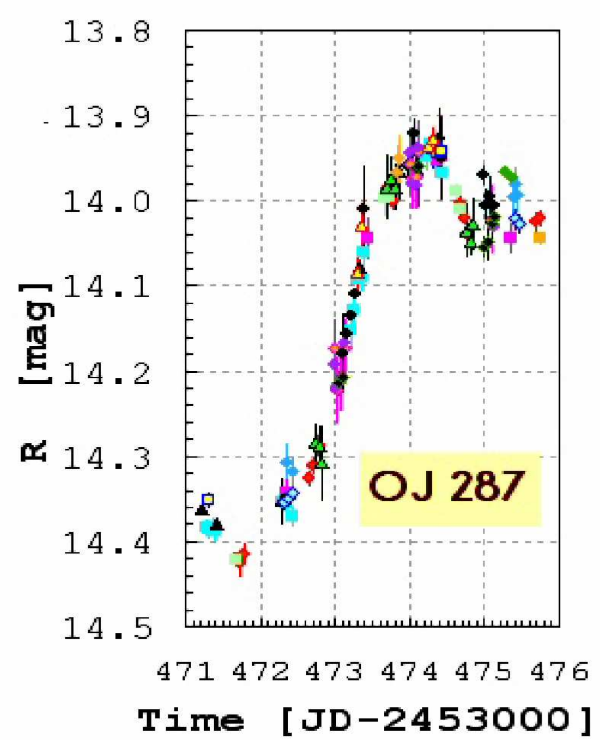


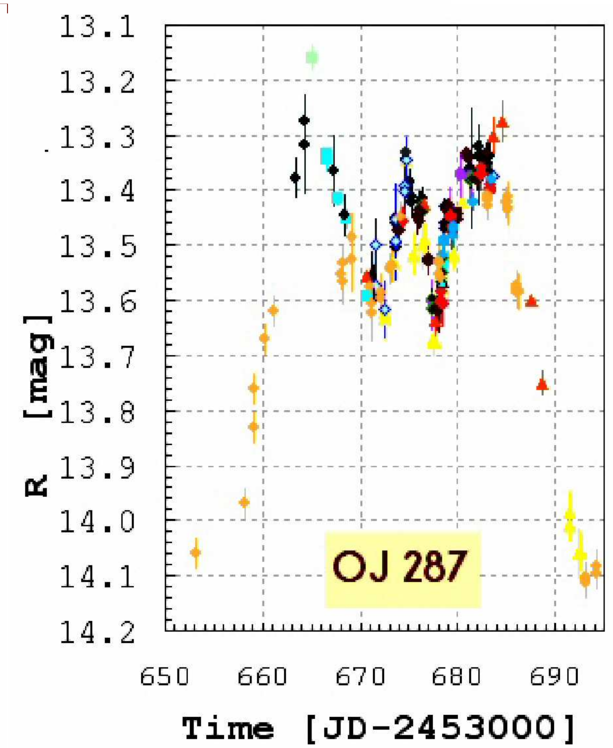
OJ 287: MW campaing of 2004-2006

R-band best sampled light curve.
During both the 2 GO XMM-Newton observations performed in 2005, OJ 287 was flaring in the optical bands.
(…The source was not shy when observed by XMM).

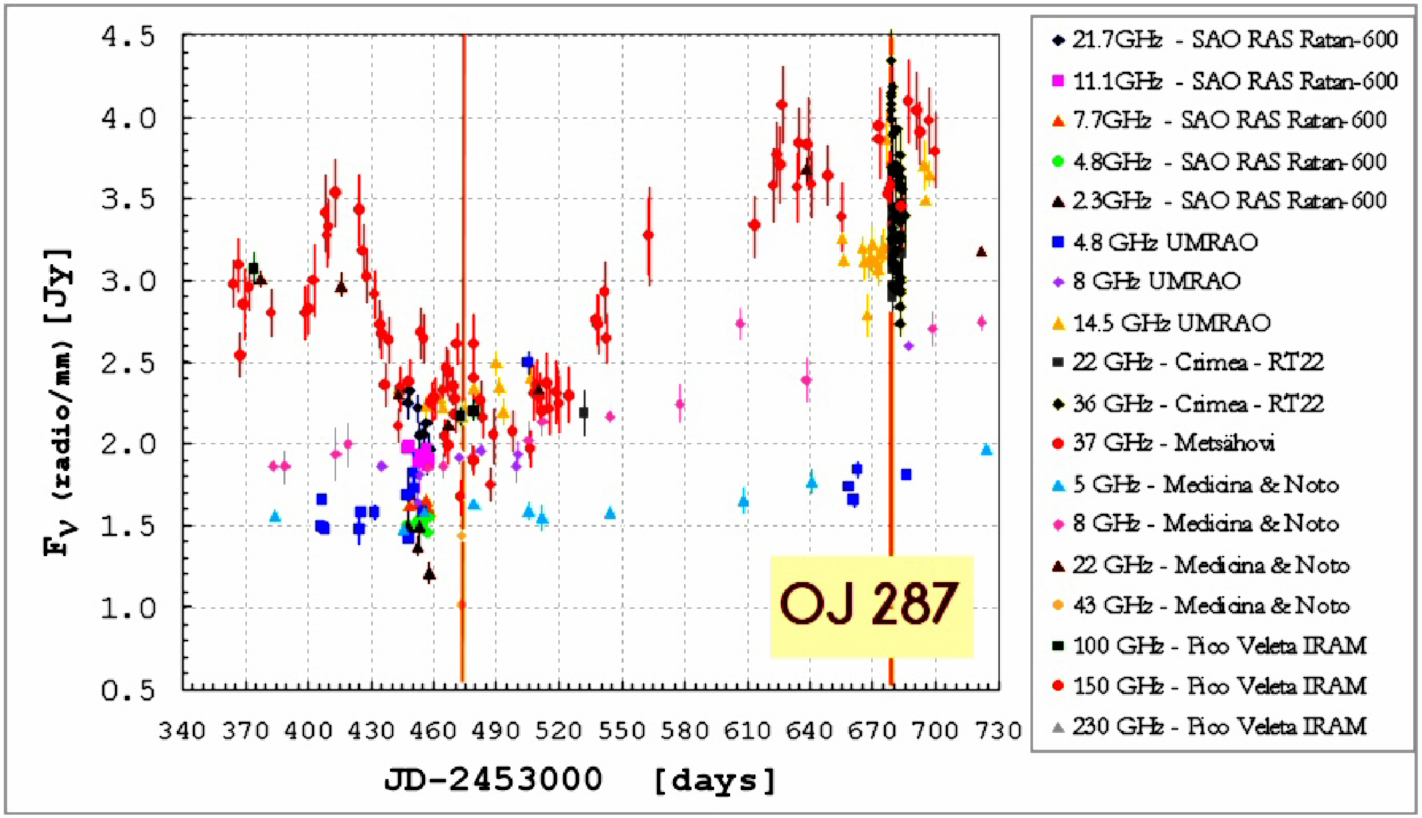


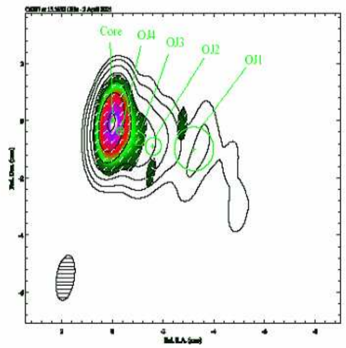


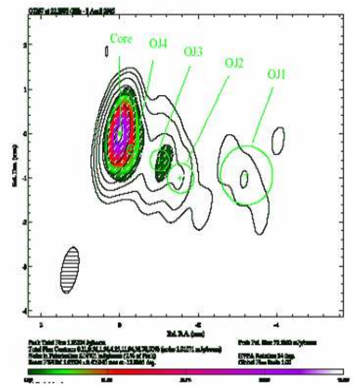


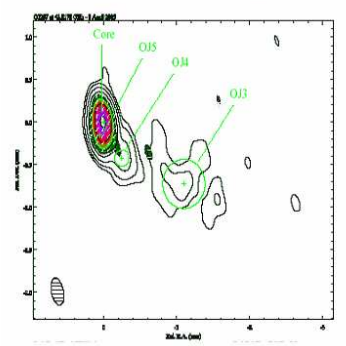


OJ 287: MW campaing of 2004-2006









Conclusions

- ❑ AGN/blazar periodicity potential interesting topic starting from ’80s (OJ 287…).

- ❑ Many binary BSMBHs candidates in general but still few non-controversial confirmations.
Large distances (difficult to resolve with direct observations), perhaps obscured, to be distinguished from other phenomena (in-jet knots, lensing, ...), incomplete/gapped/noisy time series, many binary systems may be non e.m. active (no jet, radio faint, etc.).

- ❑ Strong claims needs strong evidence.

- ❑ Beware of systematics, red noise and personal biases.

- ❑ Multifrequency analysis is now powerful thanks to the Fermi 7+ years era.

- ❑ PG 1553+113: potential significant periodicity found (to be confirmed or not in next 2/4 years); long-term LAT data analysis + multifrequency long-term monitor data collection and analysis.

- ❑ 3 basic facts allowed this discovery I PG 1553+113: 1) the unique and continuous all-sky survey of Fermi that is opening an unexplored discovery window for long-term time domain;
2) the increased potentiality given by the new Fermi-LAT Pass 8 data; 3) important efforts by ground-based telescopes and collaborations in perform long-term optical and radio variability monitor programs of Fermi blazars/AGN.

- ❑ OJ 287 (12-year optical periodicity) might enter in the cone of interest of Fermi (the next optical peak within a few months, followed by possible more features in the next 2 years).