The binary supermassive black hole conjecture for one jetted gamma-ray blazar

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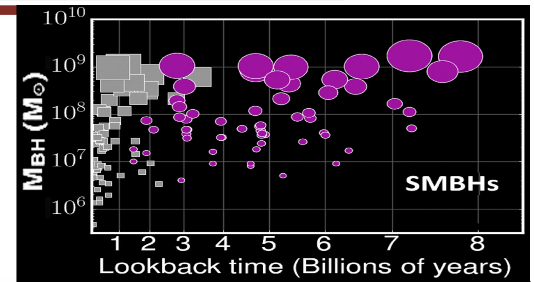
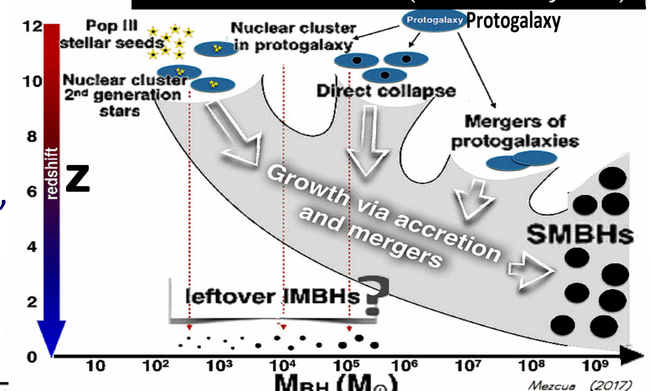
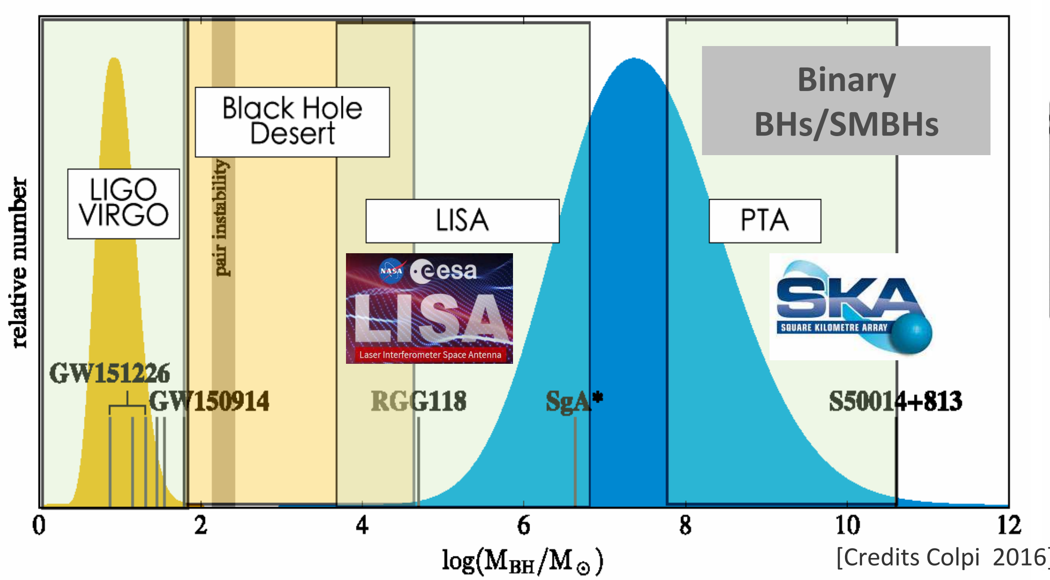
Supermassive Black Holes: Enviroment and Evolution
19-22 June 2019, Corfu, Greece

BHs, SMBHs and binary-SMBHs

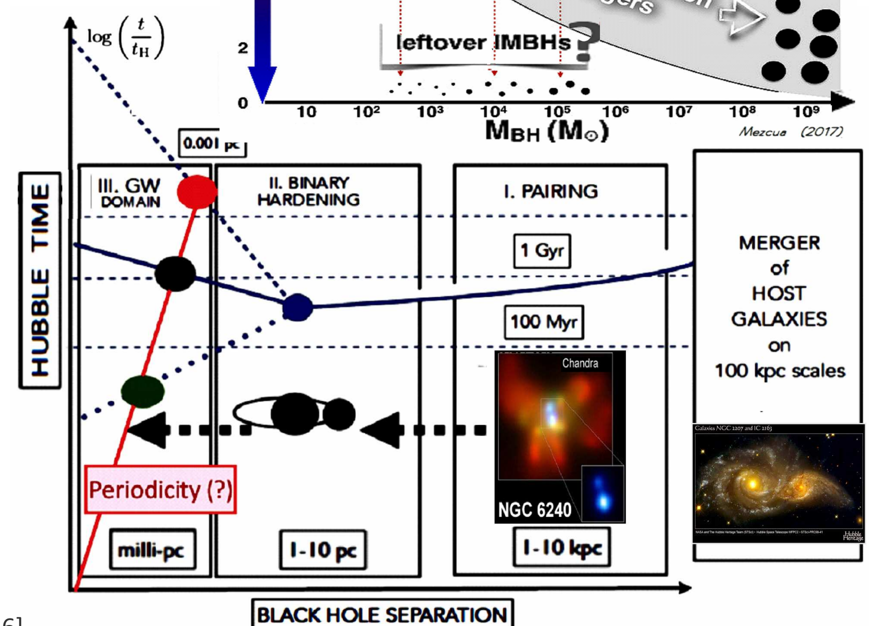
- ❑ Stellar black holes (BHs): ubiquitous, widespread in all galaxies. BHs formed when the first stars started to form and continued to form until the present era.
- ❑ Super Massive Black Holes (SMBHs): ubiquitous in the center of galaxies. SMBHs are formed from seeds, and formed early at the cosmic dawn.
  → Understanding galaxy bulges sheds light on SMBHs growth.
- ❑ Black hole mass desert. Intermediate mass BHs still not detected or a natural genetic divide (inhabited) ? A seeds-migration consequence ? Transitional object population (clustering/accretion of stellar building blocks)?
- ❑ History of the Universe: hierarchical structure formation, galaxy mergers, SMBH pairs → SMBH binaries.
- ❑ Binary black holes: → the gravitational waves universe







[Credits Colpi 2016]



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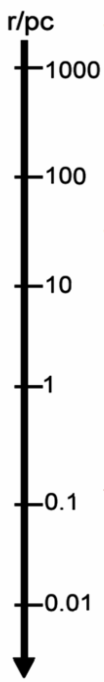
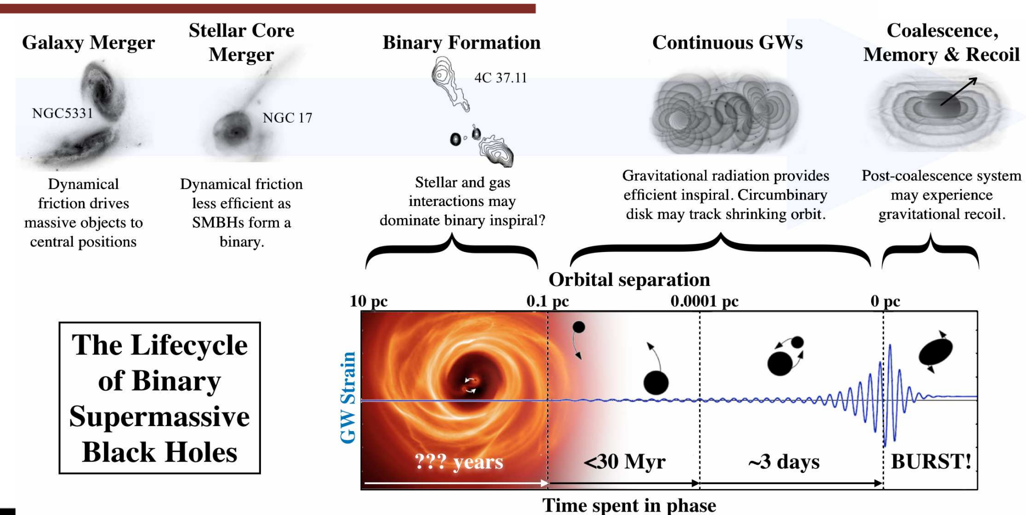
SMBHs pairs/binaries



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 binary-SMBHs 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)



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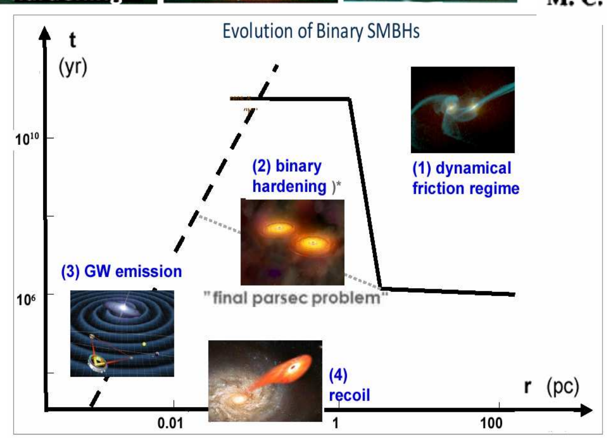
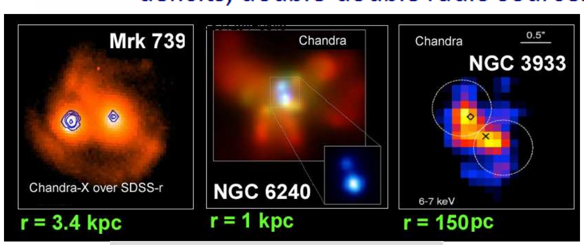
Massive black hole binaries in active galactic nuclei

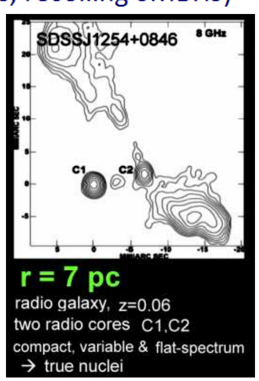
M. C. Begelman*, R. D. Blandford† & M. J. Rees‡



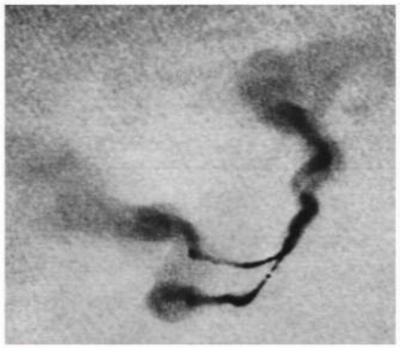
Komossa et al.

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

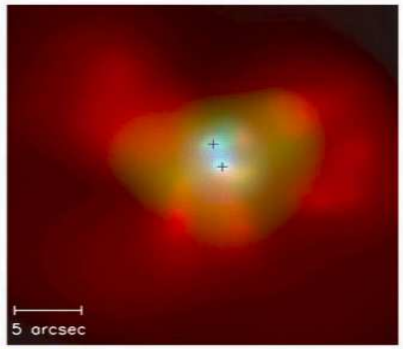




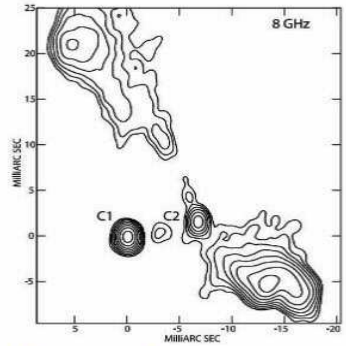
Observational evidence for SMBHs pairs/binaries



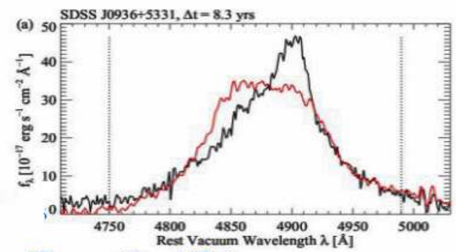
Dual jets (3C 75, a~7kpc) [Owen+ 1985]



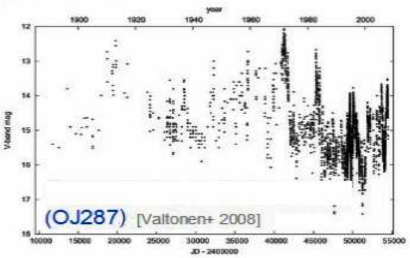
Dual X-ray sources (NGC 6240, a ~ 1.5 kpc) [Komossa+ 2003]

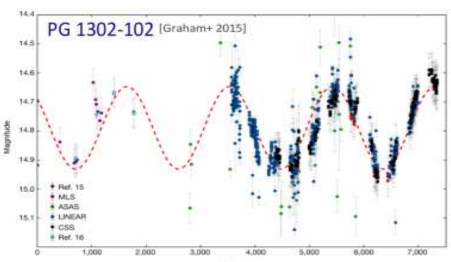


Binary radio sources (0402+379, a ~ 7pc) [Owen+ 1985]

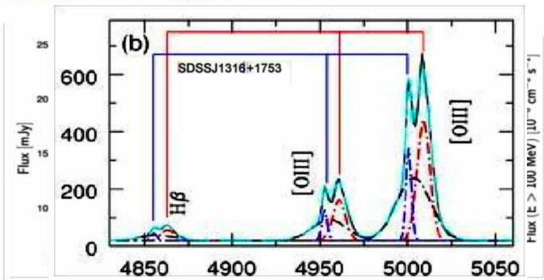


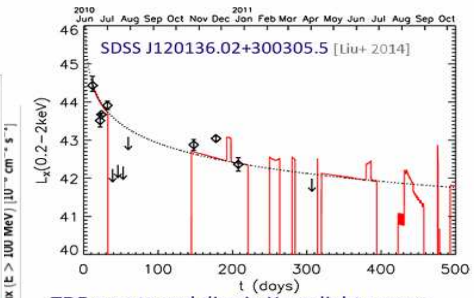
Kinematic shift in multi-epoch observations [Liu+ 2013]





Quasi periodicity in light curves (still controversial topic)



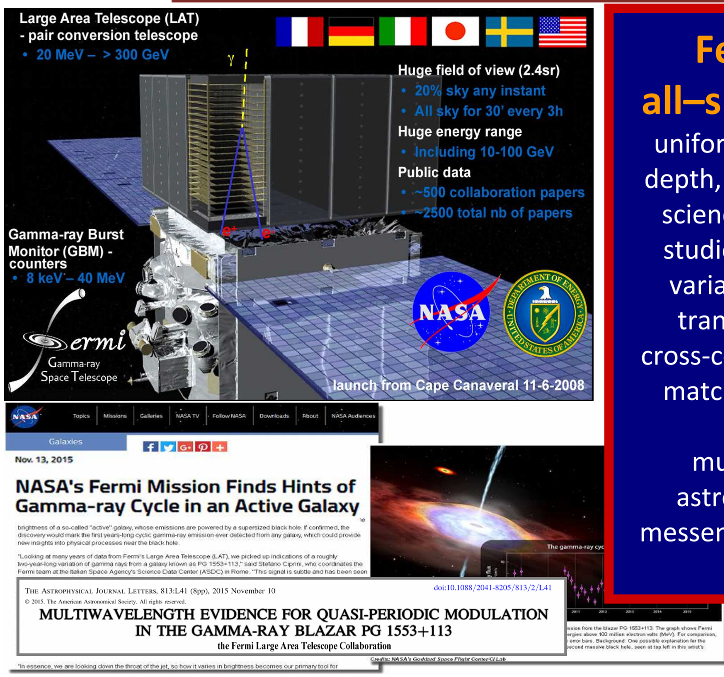


TDE events and dips in X-ray light curves

- ❑ Many binary SMBHs candidates but few non-controversial confirmations! Why so few ? Large distances (difficult to resolve). Perhaps obscured. Distinguish from other phenomena (in-jet knots, lensing, etc.). Close pairs: current methods require at least one SMBH to be active.
- ❑ Big challenge: to identify inactive binary SMBHs (the most abundant maybe). But they are also the most difficult to identify. Most binary SMBHs may form quiescently either in gas-poor or minor galaxy mergers without driving AGN activities.

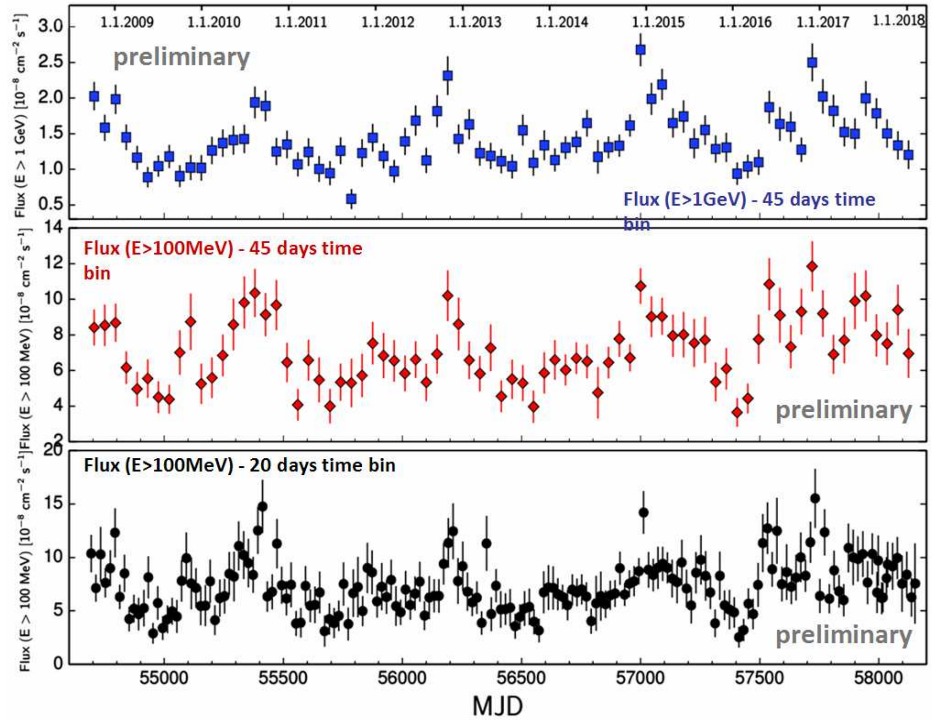
- ❑ Pair of accreting SMBH in "single" galaxies (spatially resolved 10-pc to 100-pc)
- ❑ Spatially unresolved (close if <0.1pc) binary SMBHs:
  - from claims of quasi-periodic variability signatures:
  - from observed helical/distorted/x-shape radio jets
  - from observed double-peaked broad lines:
  - other evidences: candidate TDEs, recoils, more exotic ones.

PG 1553+113: 9.5-year Fermi LAT gamma-ray light curves

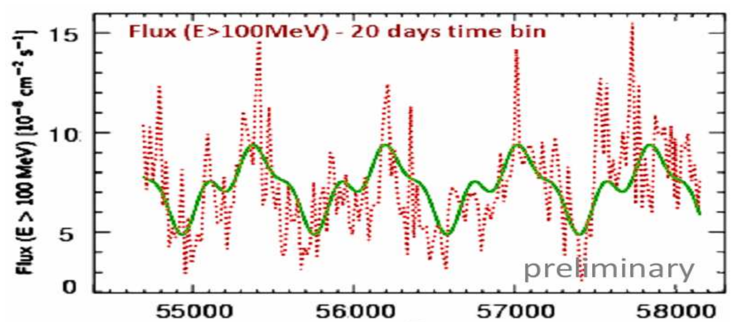


Fermi LAT all–sky SURVEY:

uniformity, sensitivity depth, diffuse emission science, populations studies, serendipity, variability monitor, transients search, cross-correlation, cross-match, time domain science, multifrequency astronomy, multi-messenger astroparticle physics

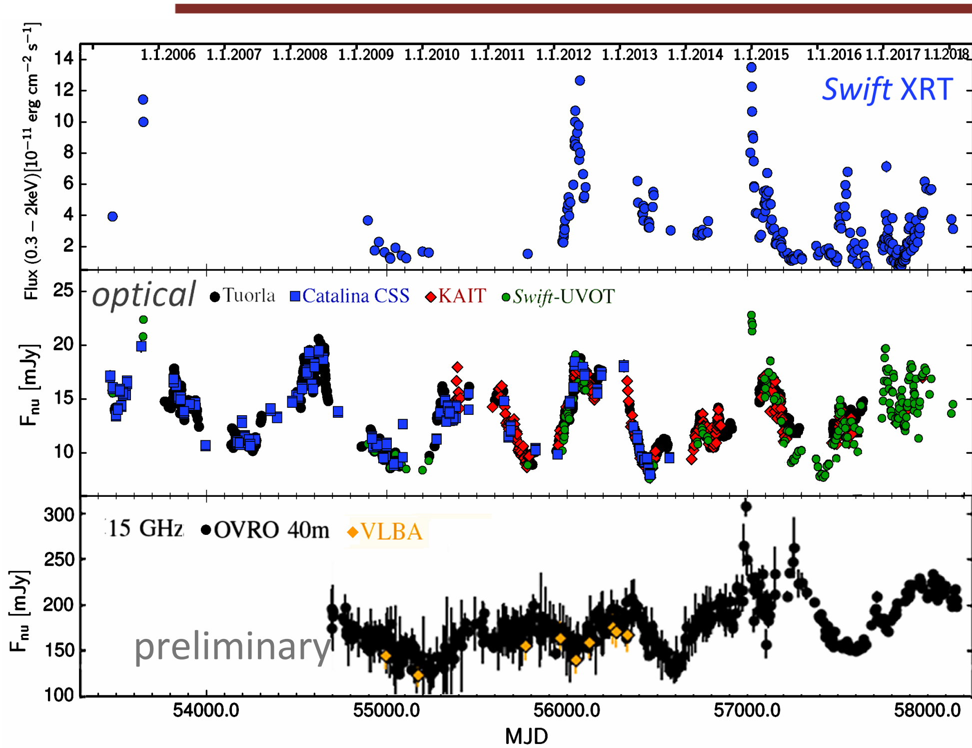


- ❑ 2015's paper claims confirmed by the 9.5-year dataset
- ❑ *Fermi* LAT gamma-ray flux (E>100MeV and E>1GeV) light curves (lc) of PG 1553+113. (updated 11-year baseline in the paper in completion).
- ❑ Regular/large-size time bins of 45-day and 20-day bin size. Temporal analysis cross-checks on adaptive bin and aperture photometry lcs.
- ❑ Long-term 2.2-year period oscillating trend visually evident, last oscillation more noisy. Predicted oscillation maximum observed. → 2.2-year quasi-periodicity in 4.5 cycles.



The light curve is fitted (green curve) with a coherent pulse consisting of 4 Fourier components.

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



- 9.5-year LAT gamma-ray flux (E>100MeV 20-day bin) light curve of PG 1553+113 (red datapoints).
- 12.5-year optical (R-band) light curve of PG 1553+113 (grey datapoints). Data: Tuorla+KVA monitor + Catalina CSS archive + KAIT monitor + Swift UVOT. Swift program on PG 1553+113 since 2015.

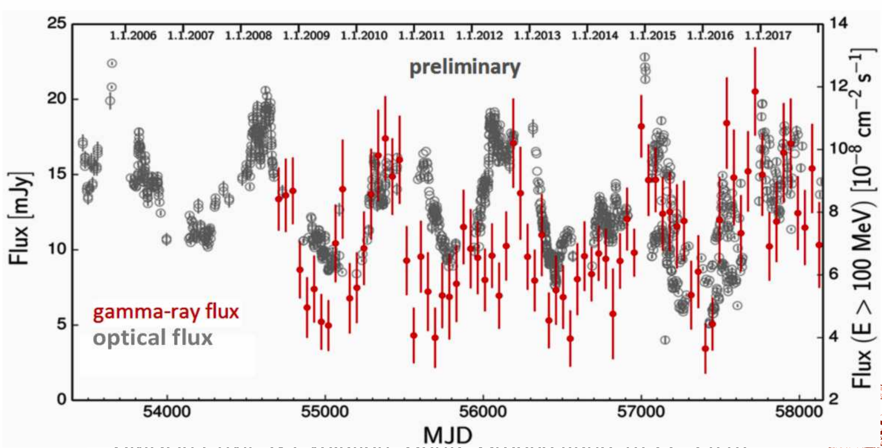
Multifrequency flux light curves built at: X-ray, optical (R and V bands) and radio (15 GHz) band.

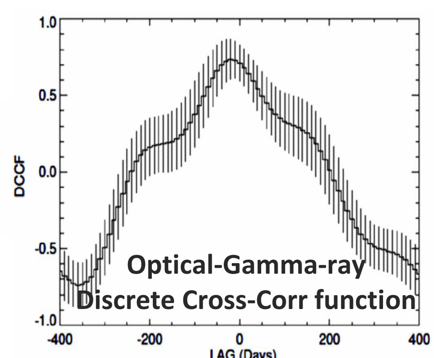
➔X-ray data obtained with Swift-XRT (thanks to past MW campaigns and dedicated follow-up program on PG 1553+113 started on Dec.2014).

➔ Rossi-XTE (ASM) and Swift-BAT also under re-analysis.

➔ Optical band is assembled with Tuorla monitoring program, with Katzman Automatic Imaging Telescope (KAIT) monitoring data Catalina Sky Survey (CSS) data and follow-up of *Swift*-UVOT.

➔ Radio 15 GHz from 40 OVRO (Richards+ 2011) and from MOJAVE(Lister+ 2009)

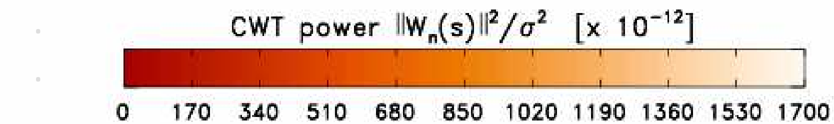


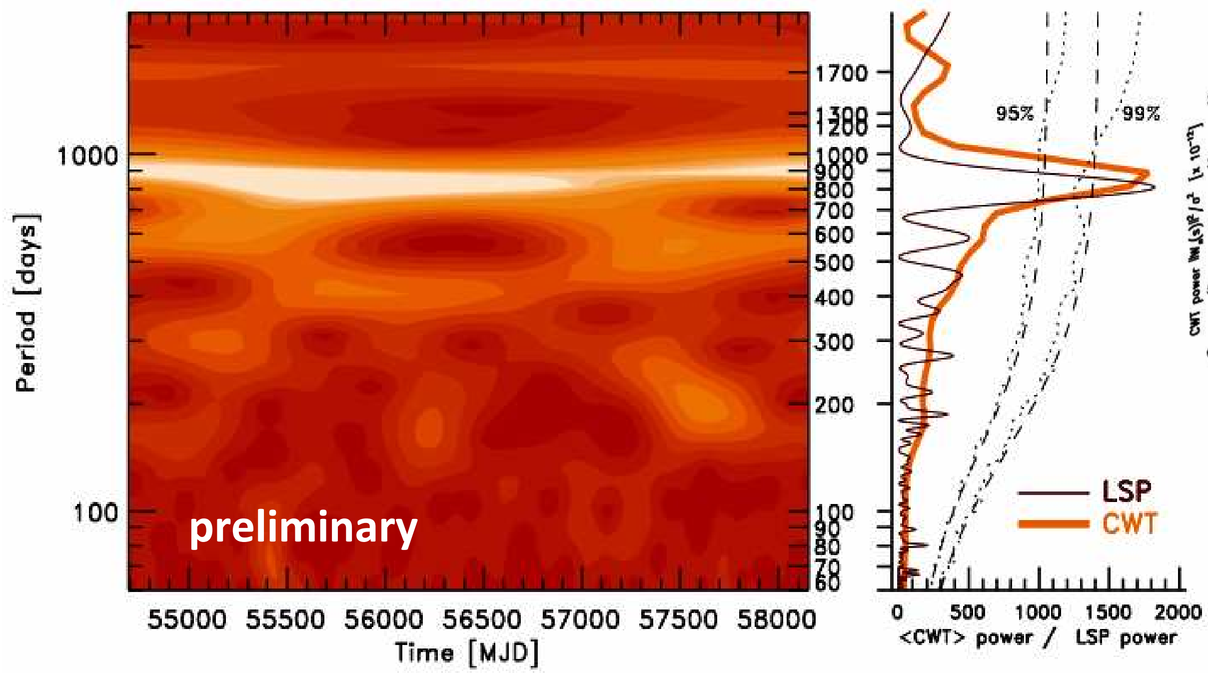


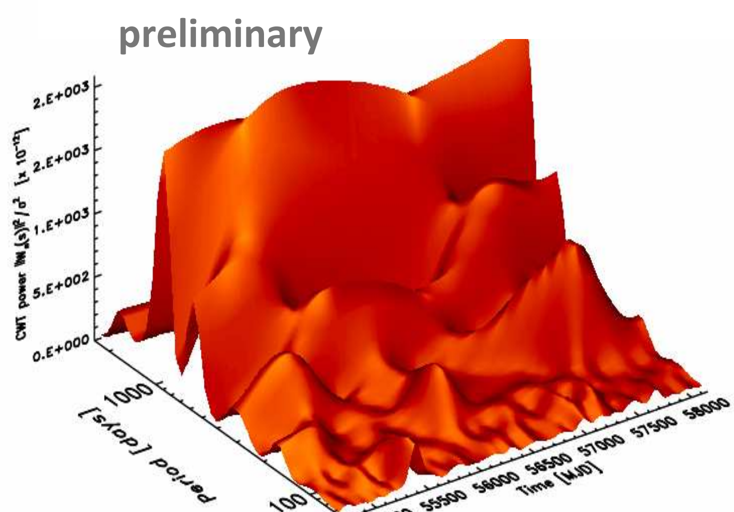
Optical-gamma-ray cross-correlation supports periodicity:
1) optical covers additional time epochs, more backwards in time
2) the optical-gamma energy bands can be described with similar periodicity plus erratic faster variations.
But optical/gamma noise and sampling different → found similar quasi periodicity strengthen its reality. Cross-corr. significance >95%.

PG 1553+1113: gamma-ray light curve wavelets and LSP

- 2D plane contour plot of the continuous wavelet transform (CWT, i.e. a 2D power density spectrum), a.k.a. wavelet scalogram, of the 9.5-year, 20-day bin, LAT gamma-ray (E>100 MeV) light curve of PG 1553+113.
- Morlet mother function (filled color contour). The right side panel shows the 1D smoothed (all-time-epoch-averaged) 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 Lomb-scargle Periodogram (LSP). Dashed lines depict increasing levels of confidence against red noise.







The same CWT scalogram in a 3D surface representation.

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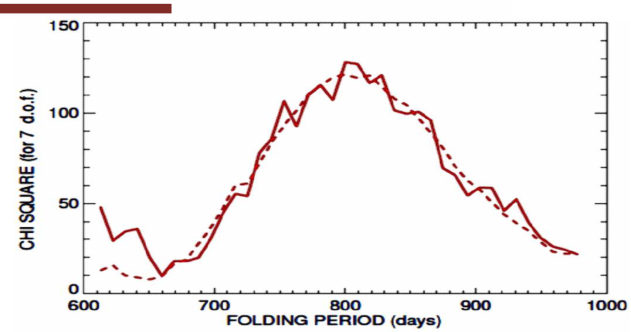
PG 1553+113: EP, SF, DACF, PDS

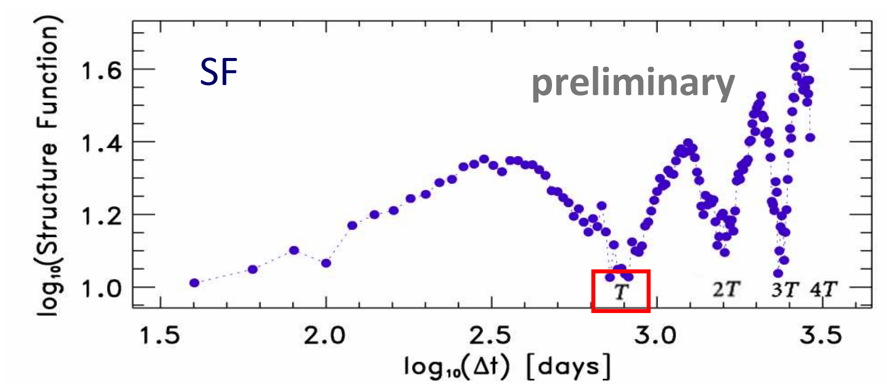
❑ Cross checks with further analysis methods and functions of the LAT 20-day bin, gamma-ray (E>100 MeV) light curve of PG 1553+113 are consistent with quasi-periodicity signal of T=2.2-year period.



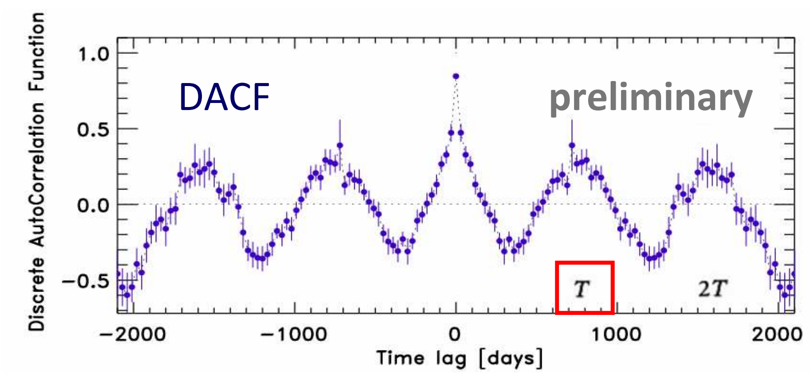
Epoch folded light curve (flux E>100 MeV 20-day bin)

The epoch folding / pulse shape analysis.

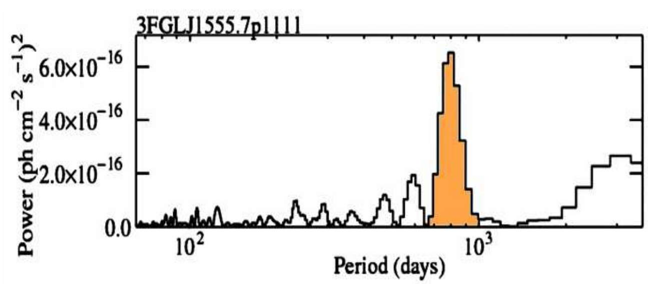
- The driving method in presence of a mostly regular sampling and coherent sinusoidal oscillations.
- Analysis based on period-folded and pulse shape light curve (4 Fourier components).
- Power is confirmed at a gamma-ray characteristic periodical timescale of 2.2+/-0.2 years in all the 9.5-year LAT gamma-ray light curves.



1st order Structure Function (SF) plot



Discrete Auto-Correlation function (DACF) plot



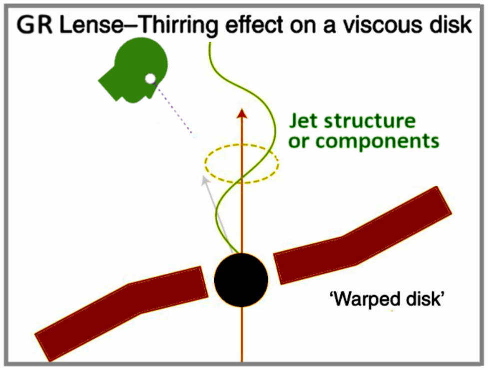
FFT PDS using aperture photometry counts and exposure weighted light curve *[Credits NASA GSFC]*

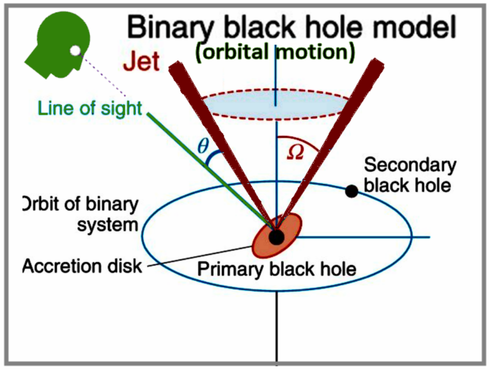
Two approaches for signal significance estimation against the red-noise (analysis in progress on the 11 year dataset).

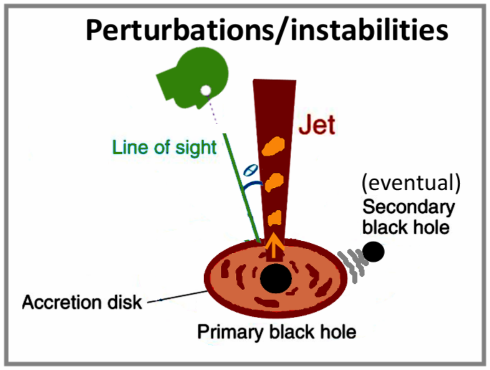
Open astrophysical scenarios for PG 1553+113

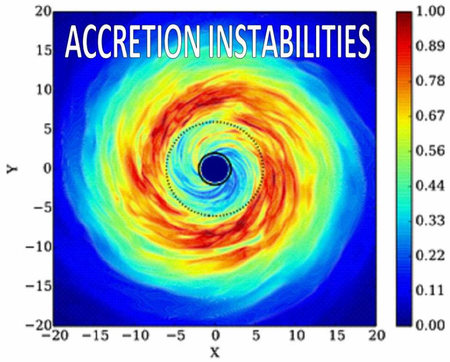
- ❑ Jet wobbling/precession/rotation/nutation on parsec scales (too short scale?).
- ❑ Curvature and helical-like structure of the relativistic jet, and/or of the radiating in-jet components (differential Doppler bulk beaming)
- ❑ Alternatively disc-jet connection and symbiosis with induced quasi-periodical triggers and ejections (warped disks; accretion perturbations; intermittence, MHD/magneto-rotational instabilities, MHD stresses…).
- ❑ Physical origin of jet wobbling is in changes in direction at the jet nozzle (disk precession, GR Lense-Thirring, orbital Keplerian motion, jet nutation, perturbations, thin disk warps Bardeen-Petterson effect, stresses)
  → binary SMBHs scenario.

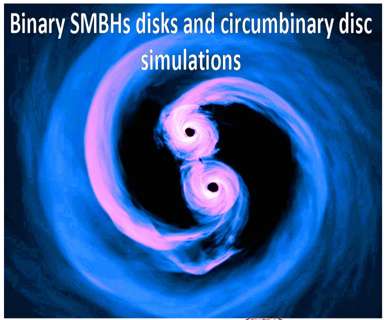
- ❑ Pulsational accretion flow instabilities (MDAF) approximating periodic behavior → periodic modulations in energy outflow efficiency. Or mechanims similar to low-freq. QPO of Galactic high-mass binaries. ADAF-disks can give precessing jets.
- ❑ Binary, gravitationally bound, SMBH system (total mass of 1.6X10^8 Msun, milliparsec separation, early inspiral gravitational-wave driven regime. Keplerian binary orbital motion with periodic accretion perturbations or jet nutation.











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Conclusions

❑ Time to consider supermassive BHs (SMBHs) in the search for (micro/nano-Hz) GWs. → Next prospects for SKA, next generation PTAs projects and LISA.

❑ Indirect astrophysical evidence for sub-pc spatially unresolved binary-SMBHs candidates (quasi periodic signals, pc-scale distorted radio-structures or helical patterns in jets, double-peaked broad lines, etc.) is an interesting BUT very-debated topic.

❑ Blazar periodicity in blazar light curves is not a trivial problem and is not a trivial data analysis. Strong claims needs strong evidence.

❑ Multifrequency cross-correlations and polarization data are important. Beware of sparse data, systematics, and ubiquitous red-noise.

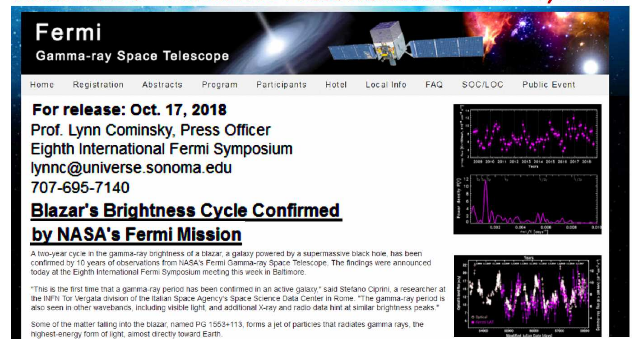
❑ Periodicity can be also explained by a variety of mechanisms different by a binary SMBH system. Anyway some astrophysics here works better with a binary system.

❑Discovery of about 2-year gamma-ray (and optical) periodicity in PG 1553+113 seems coherent and maintained also in the 10 year *Fermi* LAT dataset, with improving significance. Well correlated gamma-ray and optical light curves (important!).

❑ Importance of astrophysical knowledge about the universal accretion phenomenon in classical astrophysics → provides a useful contribution to accreting SMBH physics in AGN, to jets physics, to GW and multimessenger physics.

❑ Reasoning in a demography point of view:
1) the observed binary SMBH fraction;
2) nano-Nz gravitational radiation background and constraints by the current PTAs projects; → smaller secondary BH masses and lower power AGN are likely to be preferred; minor mergers are more likely to be observed electromagnetically.

NASA-GSFC + Fermi LAT Press Release of Oct. 17, 2018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For release: Oct. 17, 2018
Prof. Lynn Cominsky, Press Officer
Eighth International Fermi Symposium
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Blazar's Brightness Cycle Confirmed by NASA's Fermi Mission

A two-year cycle in the gamma-ray brightness of a blazar, a galaxy powered by a supermassive black hole, has been confirmed by 10 years of observations from NASA's Fermi Gamma-ray Space Telescope. The findings were announced today at the Eighth International Fermi Symposium meeting this week in Baltimore.

"This is the first time that a gamma-ray period has been confirmed in an active galaxy," said Stefano Ciprini, a researcher at the INFN Tor Vergata division of the Italian Space Agency's Space Science Data Center in Rome. "The gamma-ray period is also seen in other wavebands, including visible light, and additional X-ray and radio data hint at similar brightness peaks."

Some of the matter falling into the blazar, named PG 1553+113, forms a jet of particles that radiates gamma rays, the highest-energy form of light, almost directly toward Earth.