Evidence for quasi-periodic modulation in the gamma-ray blazar PG 1553+113

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and

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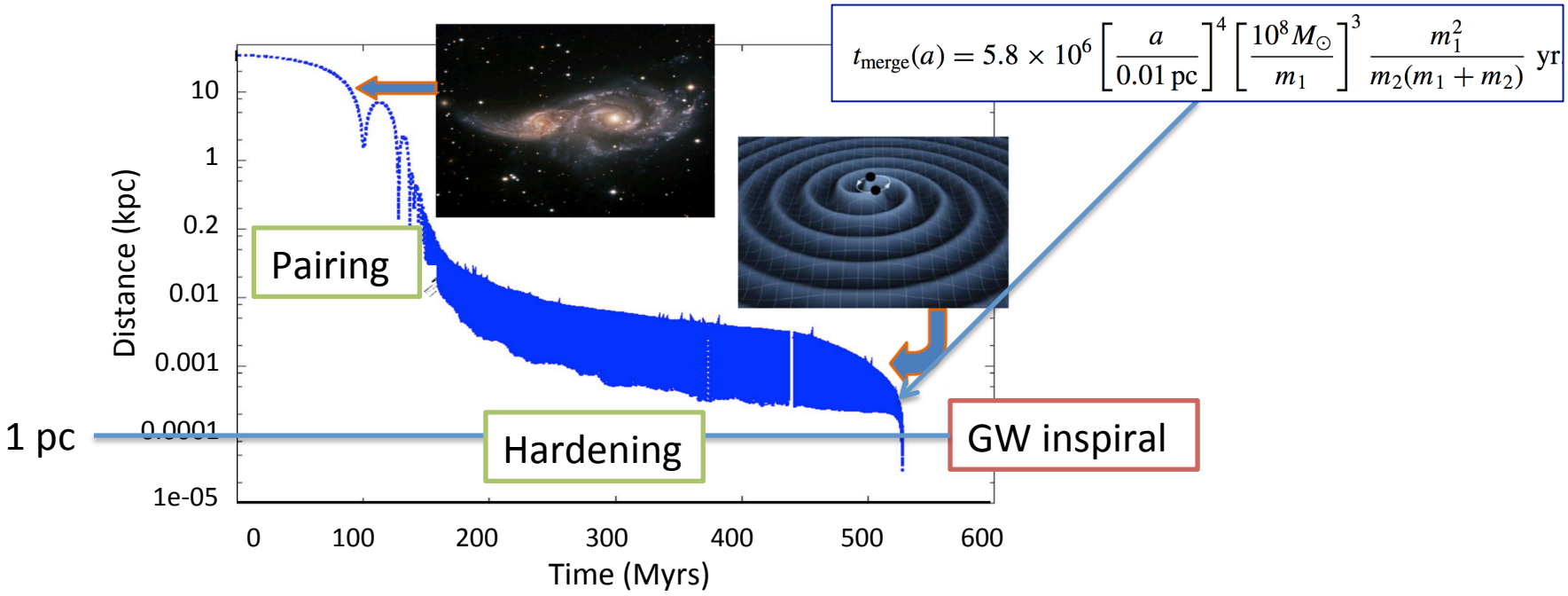
Periodicity and SMBH binaries

- **Binaries (sub-pc systems): indirect search**
  - **Double or asymmetric spectral lines** (but Liu+2015 arXiv:1512.01825)
  - **Helical, distorted jets; TDE dips in ligh-curve**
  - **Periodic light-curve**

➢ **Observational evidence important to solve the theoretical "final pc" problem**



Periodicity and SMBH binaries

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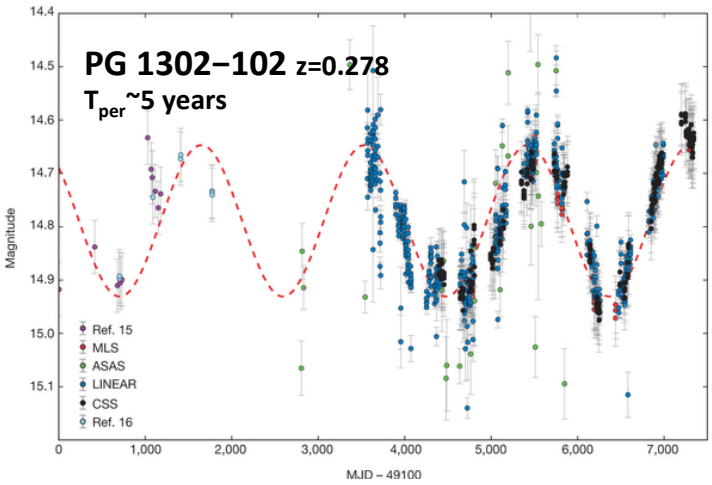
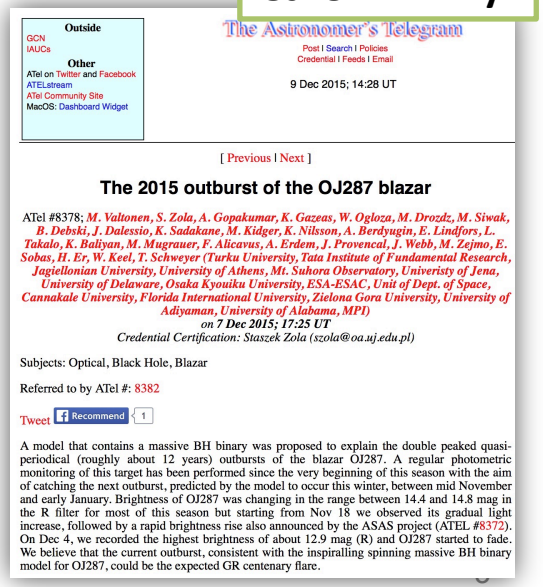
  - Double or asymmetric spectral lines (but Liu+2015 arXiv:1512.01825)
  - Helical, distorted jets; TDE dips in ligh-curve
  - **Periodic light-curve**
- **Quite some claims of periodic AGN lightcurves and binary SMBH interpretations**



Graham et al. 2015, Nature 518

Periodicity → binaries
- Sillanpää+1988
- Lehto&Valtonen 1996
- Raiteri+2001
- Fan et al. 2002
- Rieger 2004
- Liu et al. 2006
- Graham+2015
- Sandrinelli+2014
- …

OJ287 T~12 yr



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9 Dec 2015; 14:28 UT

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The 2015 outburst of the OJ287 blazar

ATel #8378; *M. Valtonen, S. Zola, A. Gopakumar, K. Gazeas, W. Ogloza, M. Drozdz, M. Siwak, B. Debski, J. Dalessio, K. Sadakane, M. Kidger, K. Nilsson, A. Berdyugin, E. Lindfors, L. Takalo, K. Baliyan, M. Mugrauer, F. Alicavus, A. Erdem, J. Provencal, J. Webb, M. Zejmo, E. Sobas, H. Er, W. Keel, T. Schweyer (Turku University, Tata Institute of Fundamental Research, Jagiellonian University, University of Athens, Mt. Suhora Observatory, Univeristy of Jena, University of Delaware, Osaka Kyouiku University, ESA-ESAC, Unit of Dept. of Space, Cannakale University, Florida International University, Zielona Gora University, University of Adiyaman, University of Alabama, MPI)*
on 7 Dec 2015; 17:25 UT
Credential Certification: Staszek Zola (szola@oa.uj.edu.pl)

Subjects: Optical, Black Hole, Blazar

Referred to by ATel #: 8382

A model that contains a massive BH binary was proposed to explain the double peaked quasi-periodical (roughly about 12 years) outbursts of the blazar OJ287. A regular photometric monitoring of this target has been performed since the very beginning of this season with the aim of catching the next outburst, predicted by the model to occur this winter, between mid November and early January. Brightness of OJ287 was changing in the range between 14.4 and 14.8 mag in the R filter for most of this season but starting from Nov 18 we observed its gradual light increase, followed by a rapid brightness rise also announced by the ASAS project (ATEL #8372). On Dec 4, we recorded the highest brightness of about 12.9 mag (R) and OJ287 started to fade. We believe that the current outburst, consistent with the inspiralling spinning massive BH binary model for OJ287, could be the expected GR centenary flare.

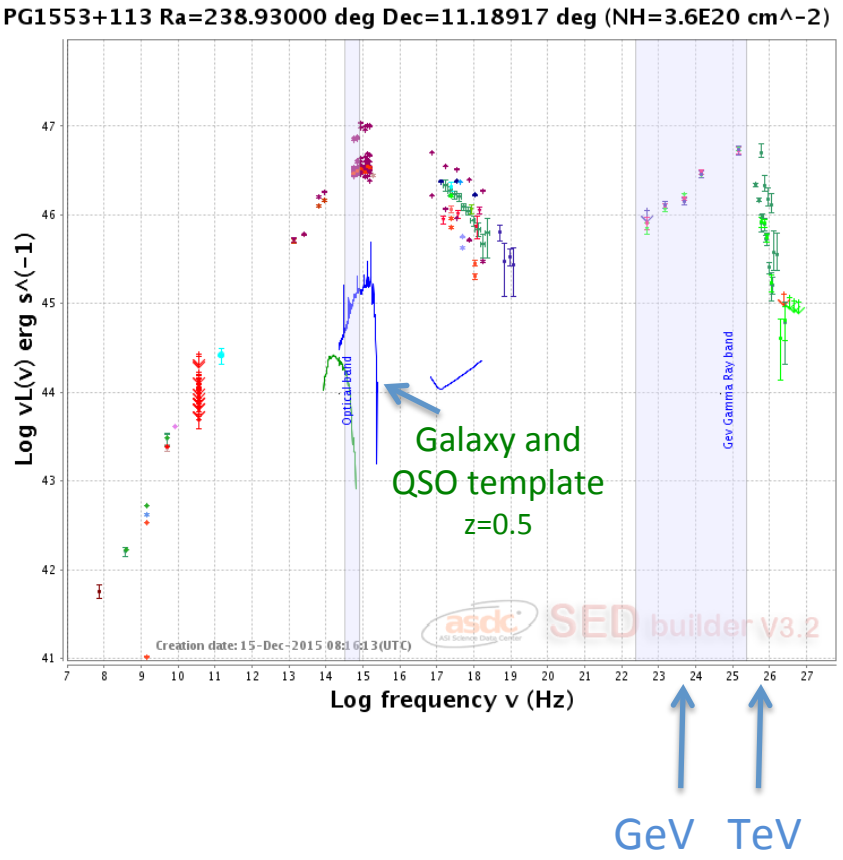
Periodicity and SMBH binaries

- **Reliability of AGN Periodicity**
  - **Yearly periodicity over ~Myr activity**
    - **QPO (quasi-periodic oscillations)**
  - ***The significance of any apparent periodic variation depends on what assumption is made about spurious stochastic variability.***

- **AGN periodicity → binary BH system?**
  - **Different plausible models with single SMBH**

PG 1553+113

- **Blazar, radio-loud, HBL**
  - **Uncertain redshift z~0.5**
    Danforth et al. 2010, also Abramwoski et al. 2015
- **Well established γ-ray emitter and TeV source**
  - **Hard spectrum in Fermi/LAT**
- **Dominant non-thermal emission from the jet**



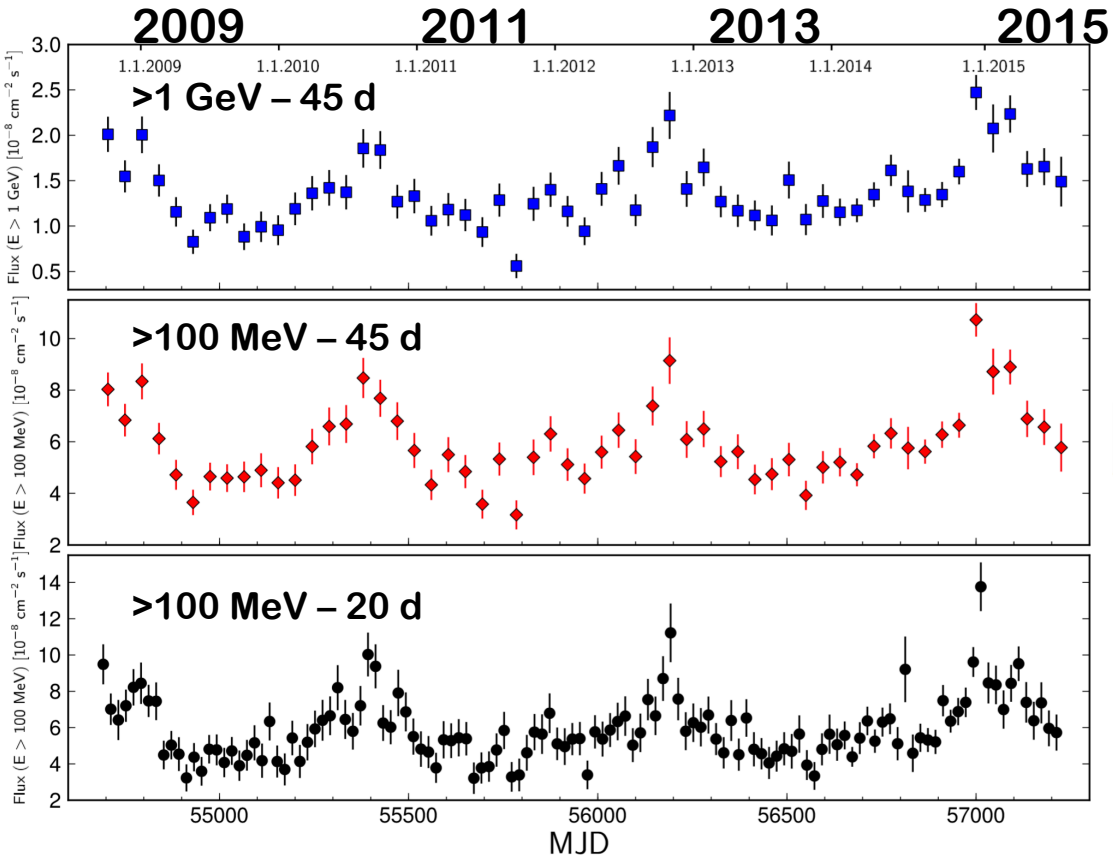
→ *Poster Raiteri, AS, Villata, this conf.*

PG1553 periodicity in Fermi/LAT

First clear detection of γ-ray periodicity in a BL Lac

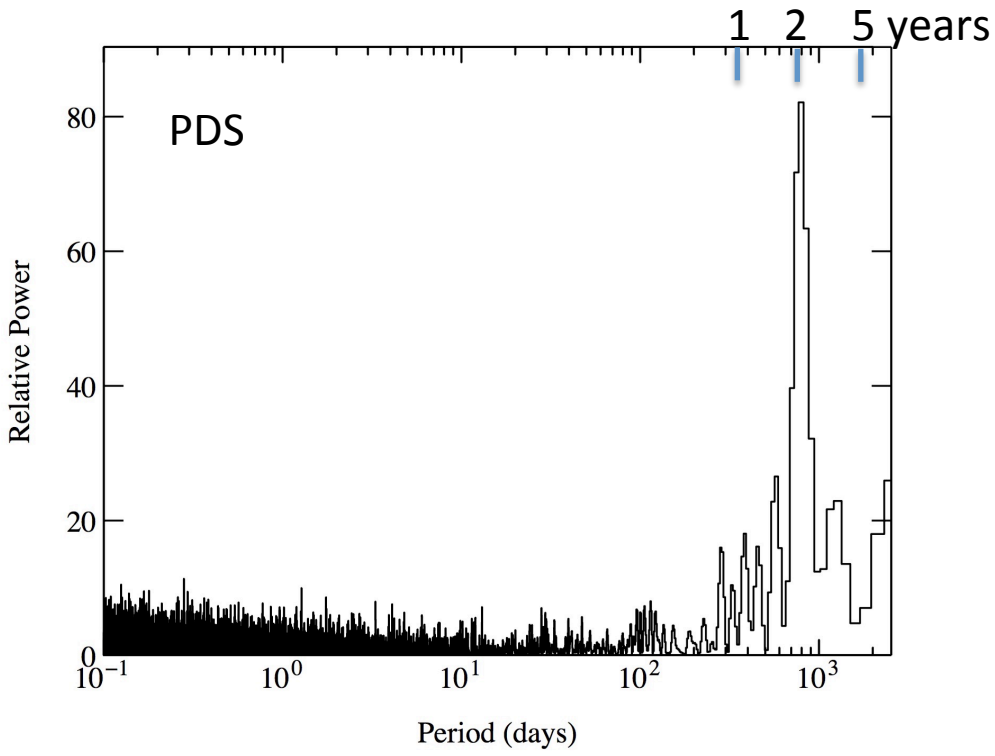
- **3.5 cycles over ~7 years**

Fermi/LAT Coll.+AS, ApJL, 2015, 816, 41



PG1553 periodicity in Fermi/LAT

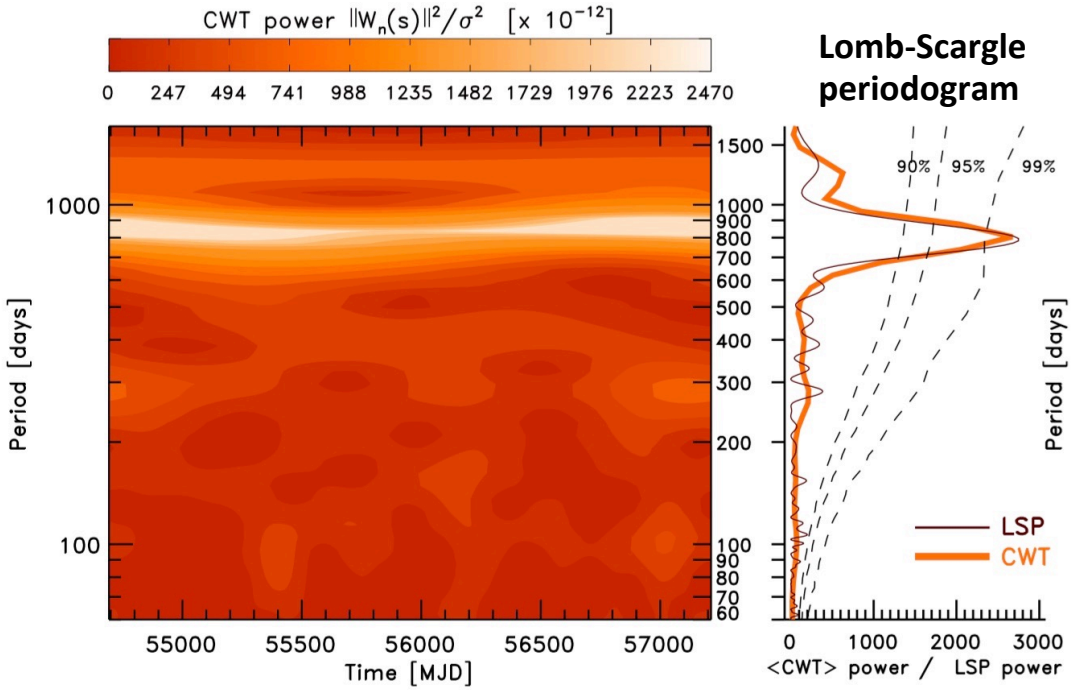
- **Periodicity analysis: Power Density Spectrum (E>100 MeV, 600s time bin)**
  - **Period γ: 2.16+/-0.08 yr**



PG1553 periodicity in Fermi/LAT

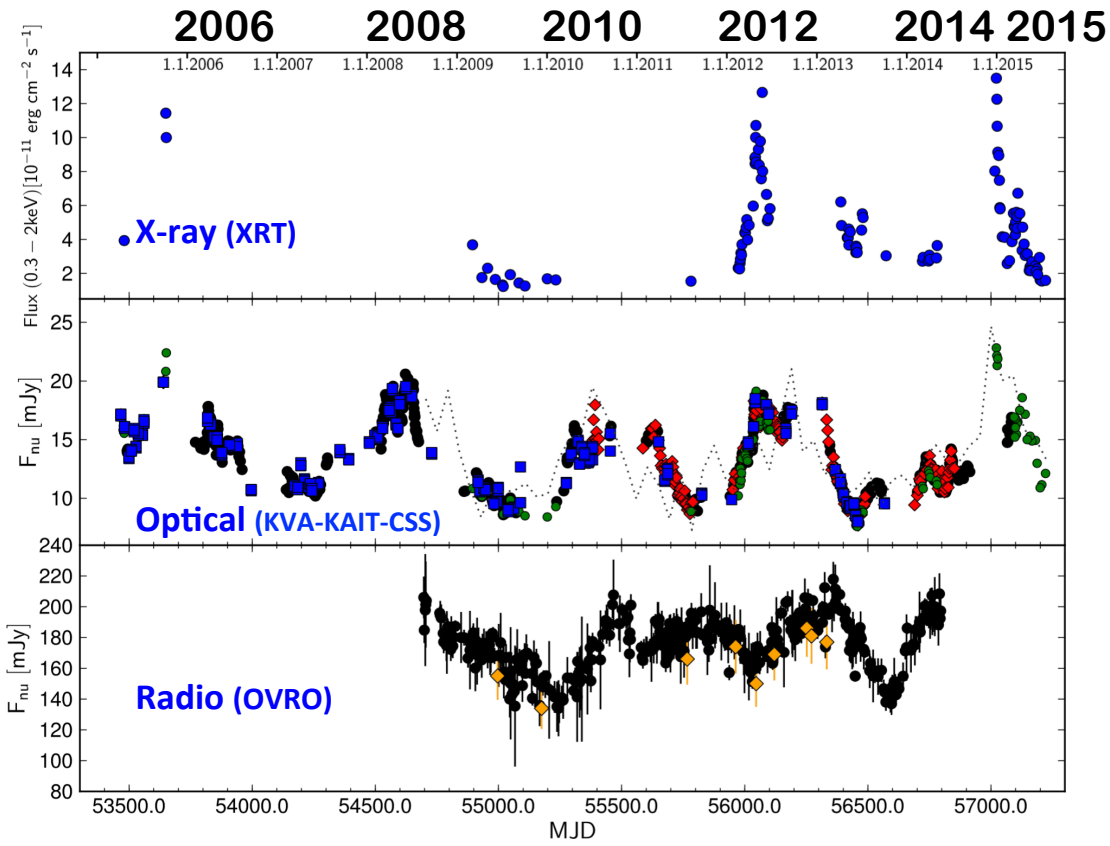
- **Periodicity analysis: period and significance**
  - **Period γ: 2.18+/-0.08 yr**
  - **< 1% random fluctuation from LSP (red noise spurious model)**
  - **~1% chance probability of random line up of 3.5 peaks**

Continous wavelet transform



PG1553 periodicity: MWL

- **MWL: optical, radio, X-ray**
  - **X-ray (XRT) too sparse**



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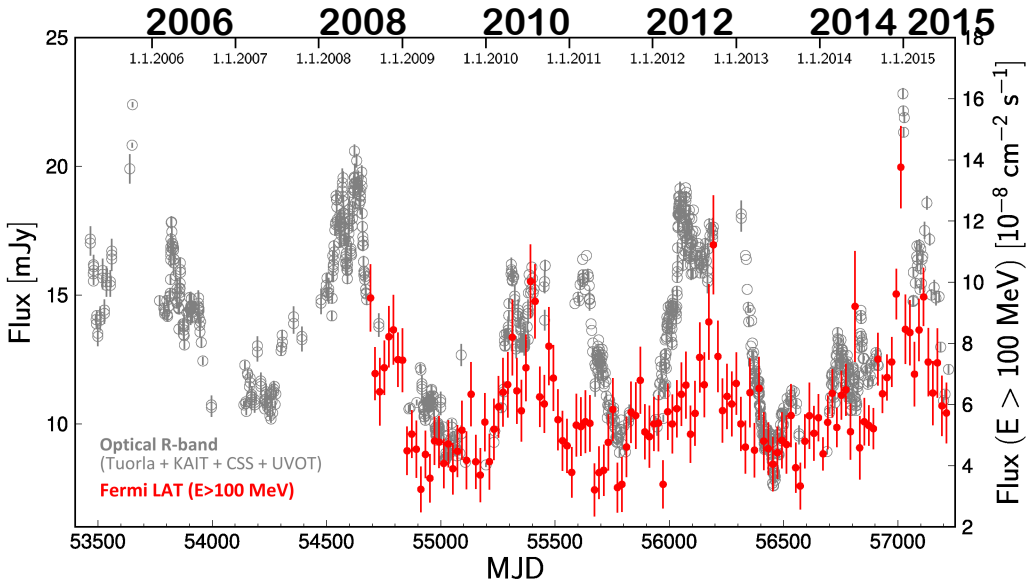
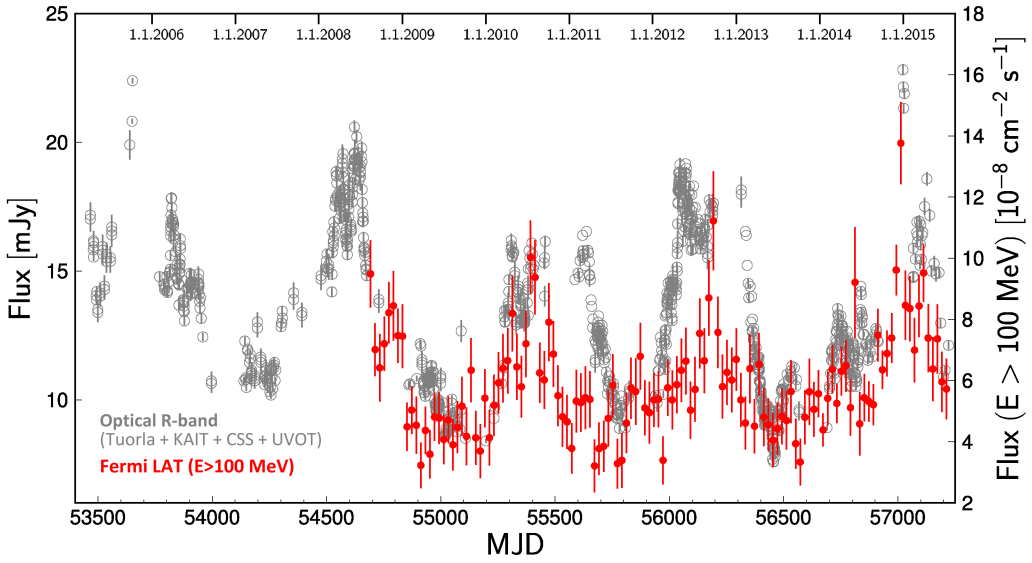
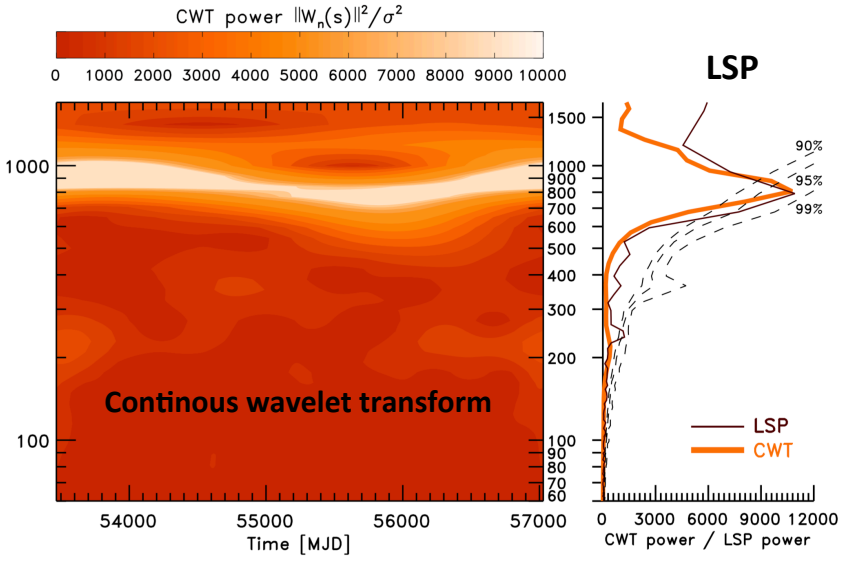
- **Optical Periodicity analysis** (over ~10 years, ~4.5 cycles)



PG1553 periodicity: MWL

- **MWL: optical, radio, X-ray**
  - **X-ray (XRT) too sparse**
- **Optical Periodicity analysis** (over ~10 years, ~4.5 cycles)
  - **Period γ: 2.05+/-0.05 yr**
  - **< 5% random fluctuation from LSP (red noise spurious model)**

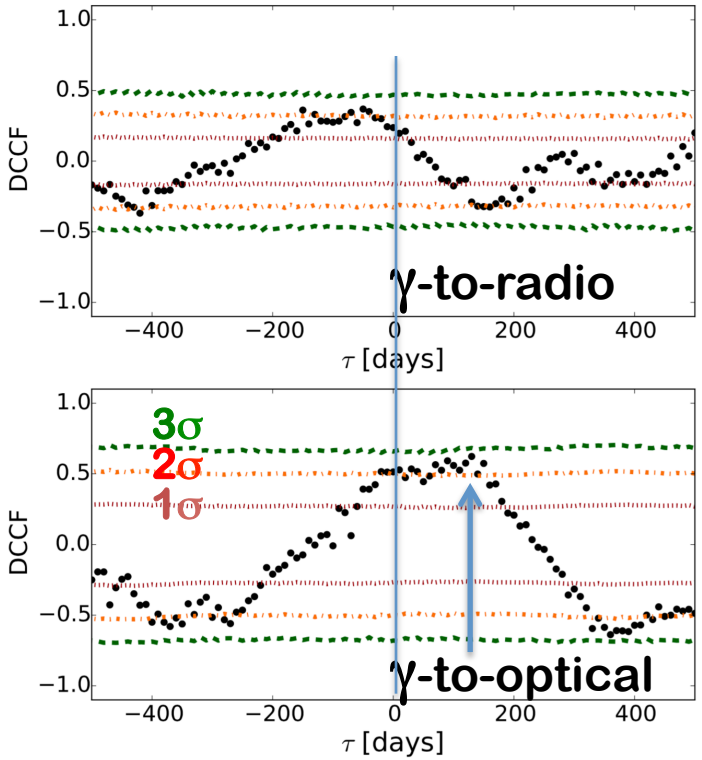




PG1553 periodicity: time lags

Possible clues on underlying periodic process

- **Radio-γ: 50+/-10 days (98% CL)**
- **Optical-γ: 130 to 10 days**



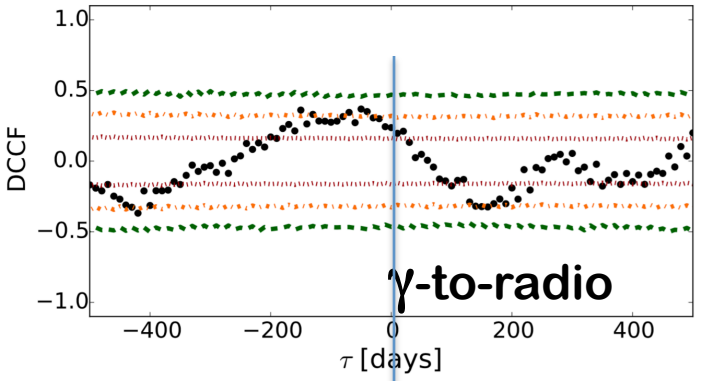
PG1553 periodicity: time lags

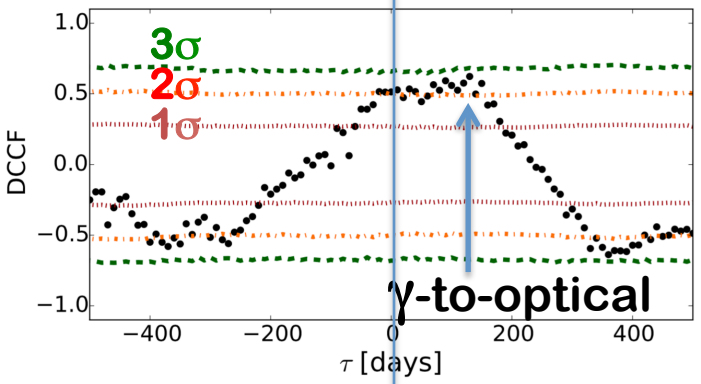
Possible clues on underalying periodic process

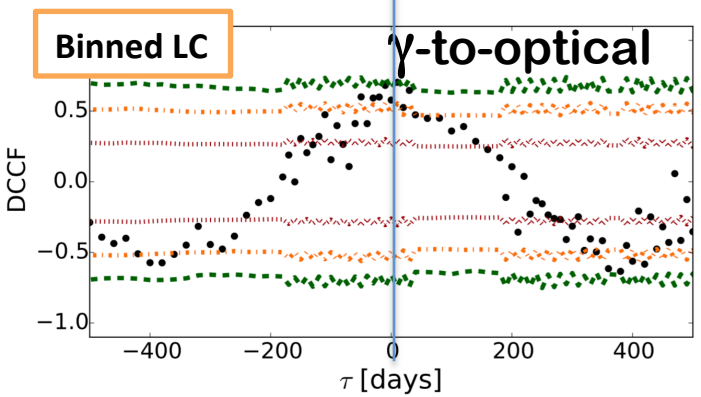
- **Radio-γ: 50+/-10 days (98% CL)**
- **Optical-γ: 130 to 10 days**
  - **No lag with binned opt-LC**

➢ **Time lags depend on short structures in LC**

  - **E.g. peaks seen in optical band not resolved in LAT**
  - ***IACTs sensitivity may solve this!***

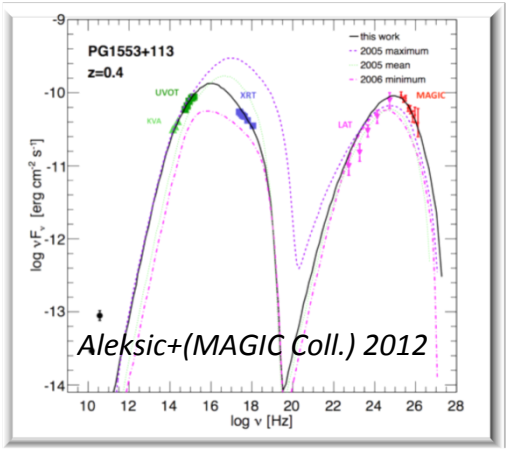






Interpretation of periodicity

PG1553+113 dominated by non-thermal emission from the jet.



Aleksic+(MAGIC Coll.) 2012

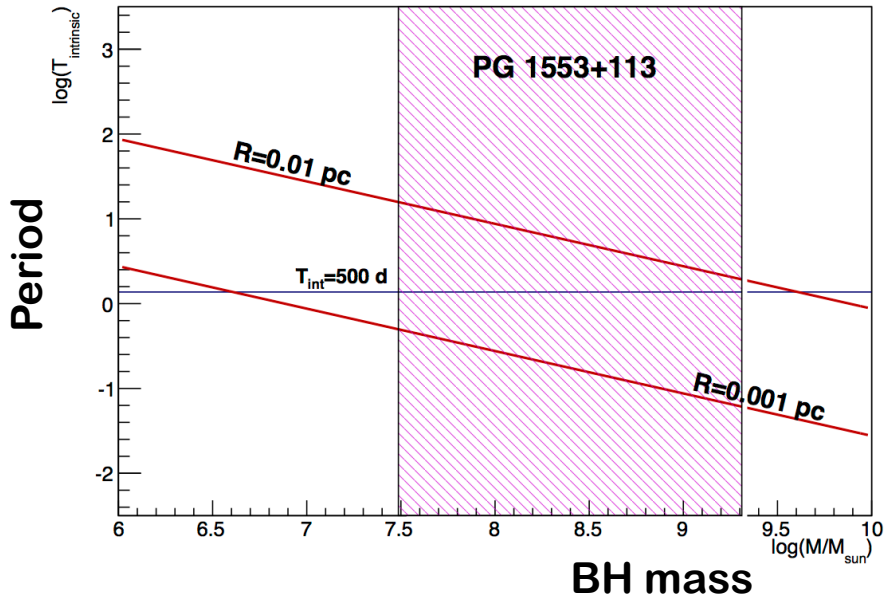
Periodicity may be the result of:

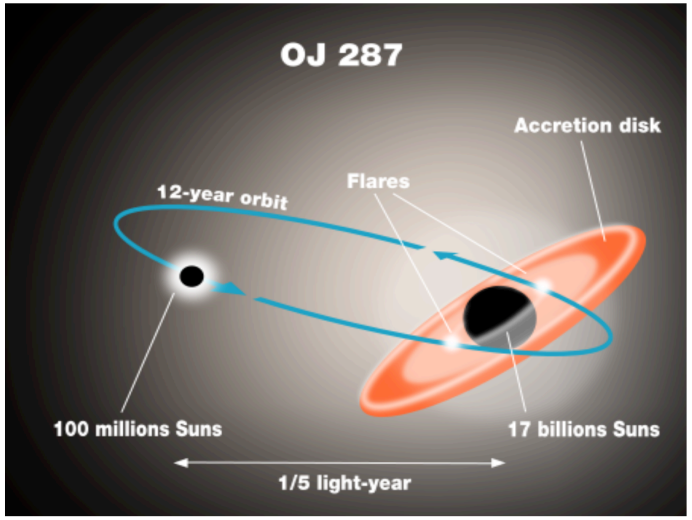
- **Processes at the base of the jet inducing quasi-periodic oscillations**
- **Geometrical effects on the jet**

✧ **Binary and single SMBH can be invoked**

Processes at the base of the jet

- **Accretion rate perturbations model**
  - **milli-pc system: gravitational wave driven inspiral stage!**
    - **claims on other sources, e.g. PG1302-102** ***Graham+2015*** **or OJ287** ***Sillampää+1988,Lehto&Valtonen 1996***

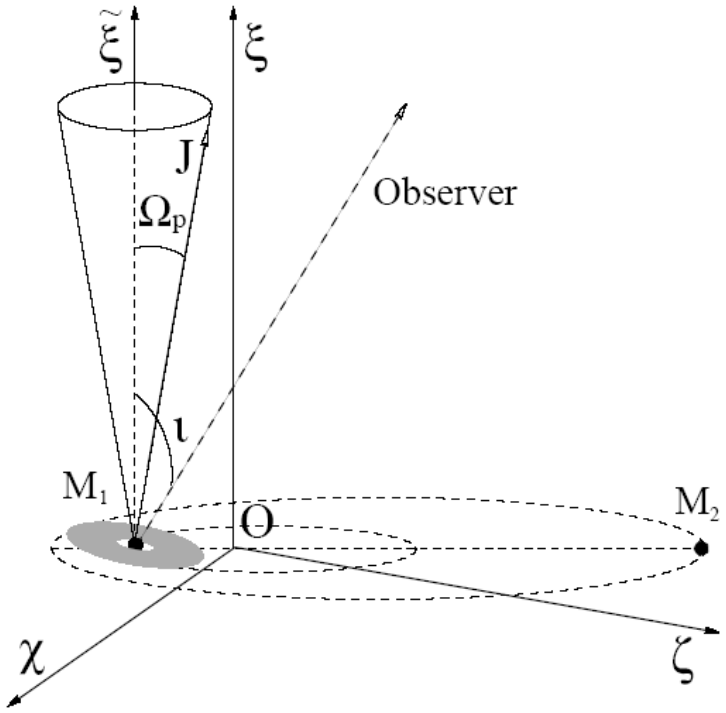




Sillampaa et al. 1988, ApJ 325

Geometrical models

- **Variation of jet viewing angle**
  → **doppler factor** ~40% → ~3 γ-rays, 1°
- **Jet precession (induced by the binary system)**
  - T_{prec} ~ 600 yr *Begelmann et al. 1980*
  - **Possible beaming effect**
    $T_{obs} = T_{int}/\Gamma^2$ *Rieger 2004, ApJL 615*



Single SMBH

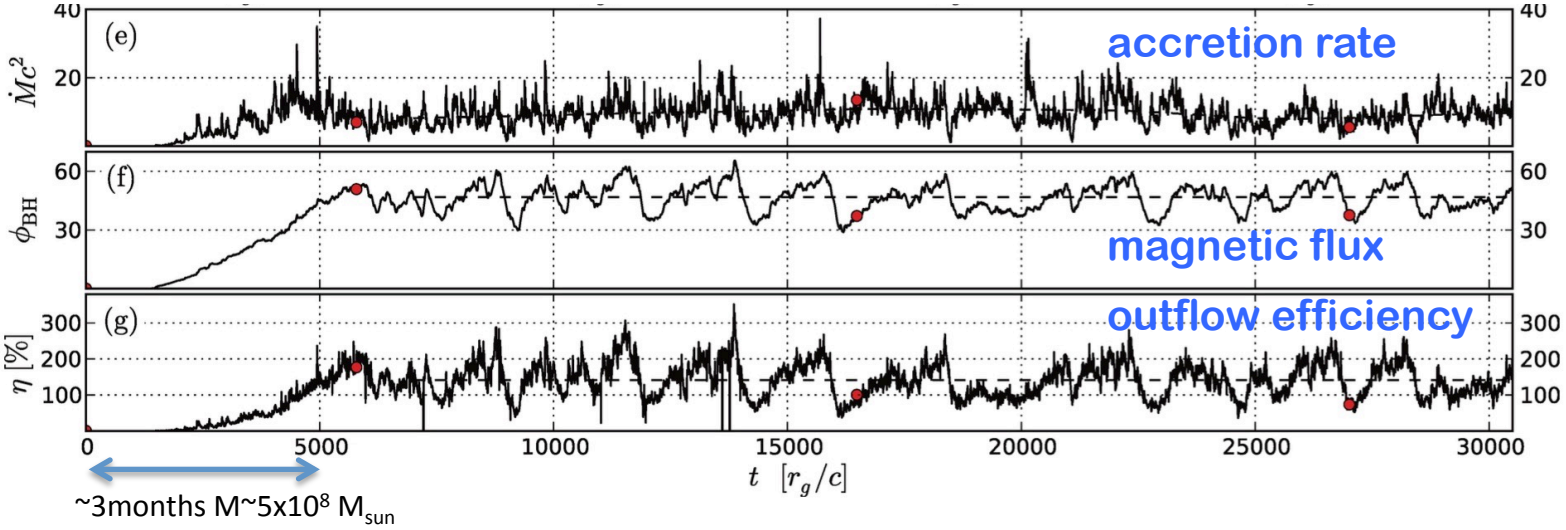
Alternative models

Jet feeding

- **QPO from warped disk**
  e.g. Nealon+2015 this conf.
- **QPO from choking of magnetic arrested disk (MAD, *Tchekhovskoy et al. 2011*)**

Geometrical

- **Helical jet (QPO)**
  Villata&Raiteri 1999
- **Jet precession (BH-spin), rotation**
  Long periods expected *(but Rieger 2004)*



Summary

- First clear evidence of gamma-ray periodic emission from a AGN
  - Confirmed in optical; hint in radio
- Interpretation still open
  - Possible milli-pc SMBH binary system
  - QPO from helical paths or flow instabilities
- Regular MWL observations
  - Disentangle flaring episodes from long-term modulation
  - TeV observations and MWL campaign foreseen → Hughes+ (MAGIC coll.), this conference

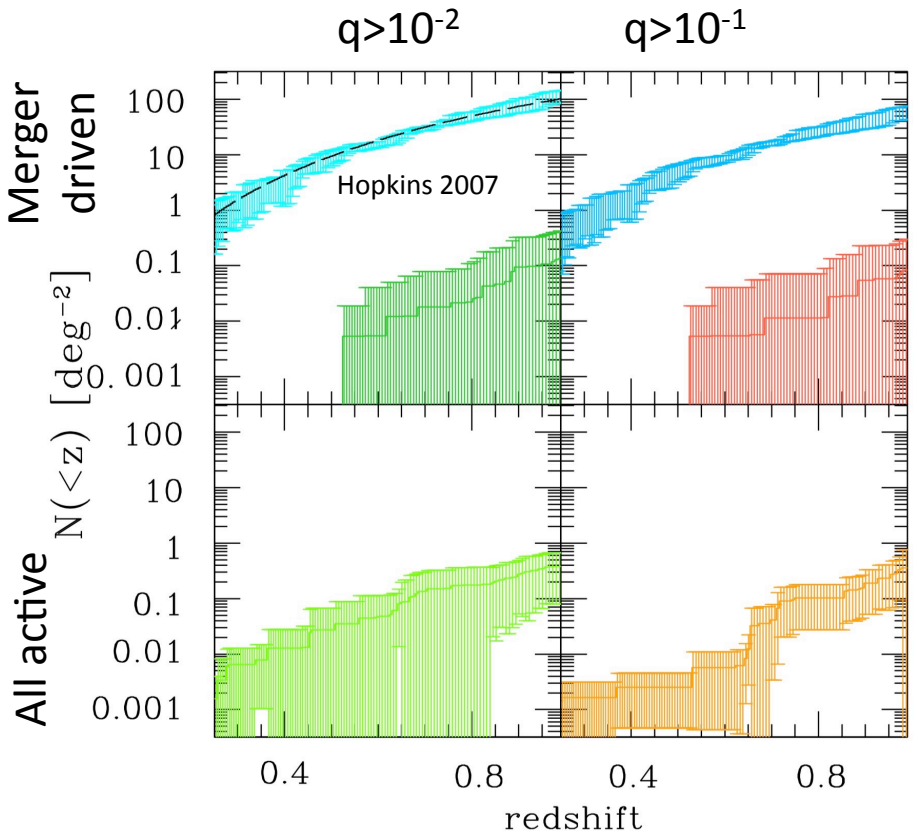
✧ Next maximum expected ~January 2017

Credits:
NASA's Goddard Space Flight Center/CI Lab

Periodicity and SMBH binaries

- **Binary SMBH predicted by hierarchical models**
  - **Prediction *(Volonteri+2009)*: 10 over 10000 sample at z<0.7**
- **Selective effects ?**
  - **AGN as mergers** *Fu+2014, Chiaberge+2015*
  - **Evolution** *Cavaliere+2002, Ajello+2014*
  - ➢ ***BL Lac as preferred host of SMBH binaries?***

Sub-pc binary quasars
from merger history *Volonteri+2009*



AGN as mergers

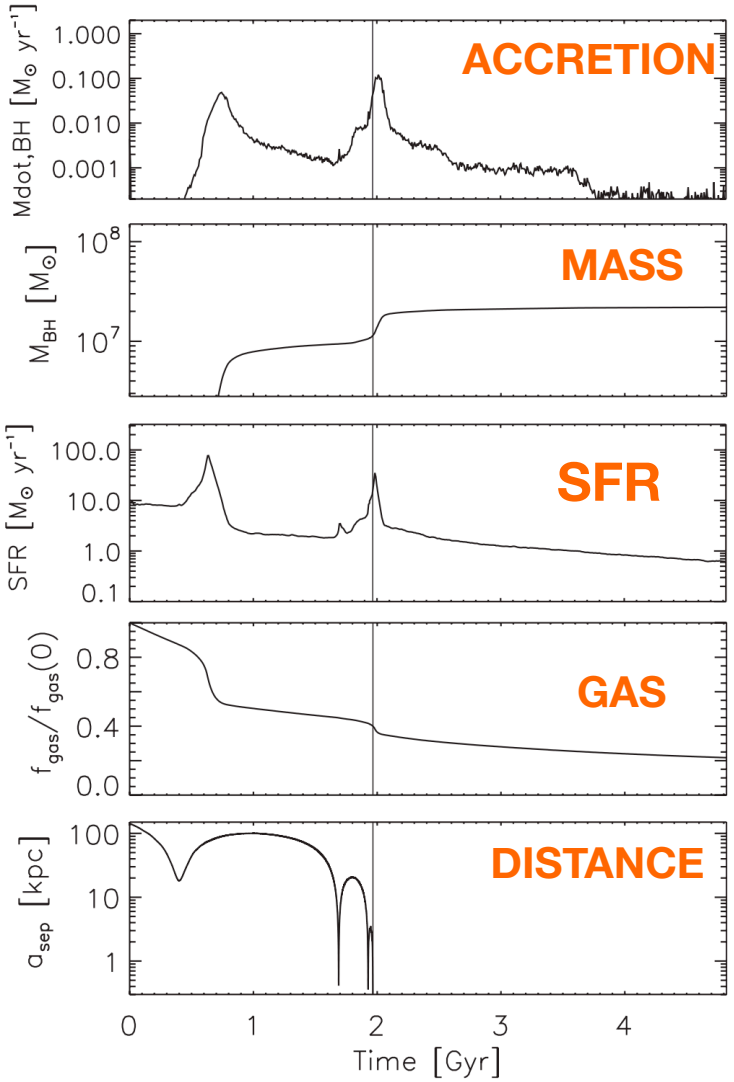
- Mergers → SMBH accretion → AGN activity
- Higher fraction of AGN radio loud in mergers

  Fu et al. 2014, Chiaberge et al. 2015

- FSRQ → BL Lac evolution

  Cavaliere et al. 2009, Ajello et al. 2014

➢ BL Lac as preferred hosts of SMBH binaries?



L. Blecha et al. 2011 MNRAS 412