Periodicity in gamma-ray blazars. The case of PG 1553+113

A. Stamerra
(INAF-OATo and SNS-Pisa)

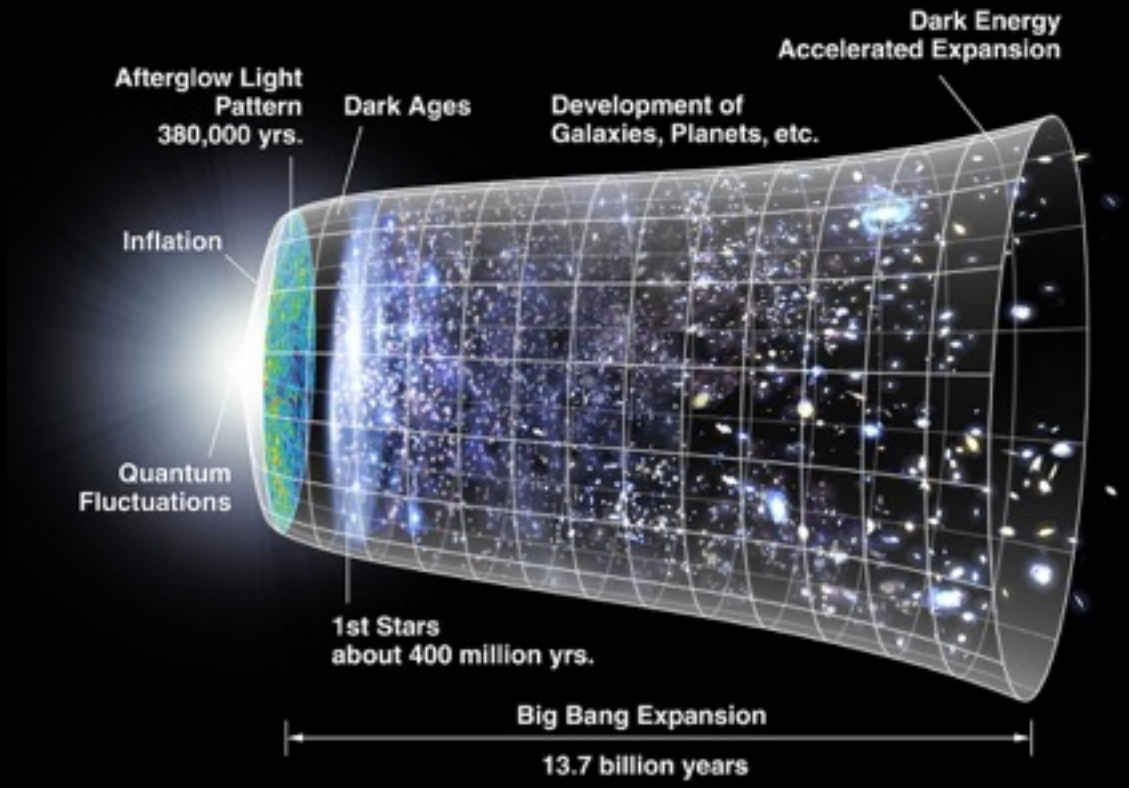
and

S. Cutini, S. Ciprini, R. Corbet, S. Larsson, D. Thompson
*on behalf of the Fermi/LAT collaboration

E. Prandini, S. Paiano, P. Da Vela, H. Gareth
*on behalf of the MAGIC collaboration

A brief history of the Universe

- Hyerarchical structure formation
  - Mergers



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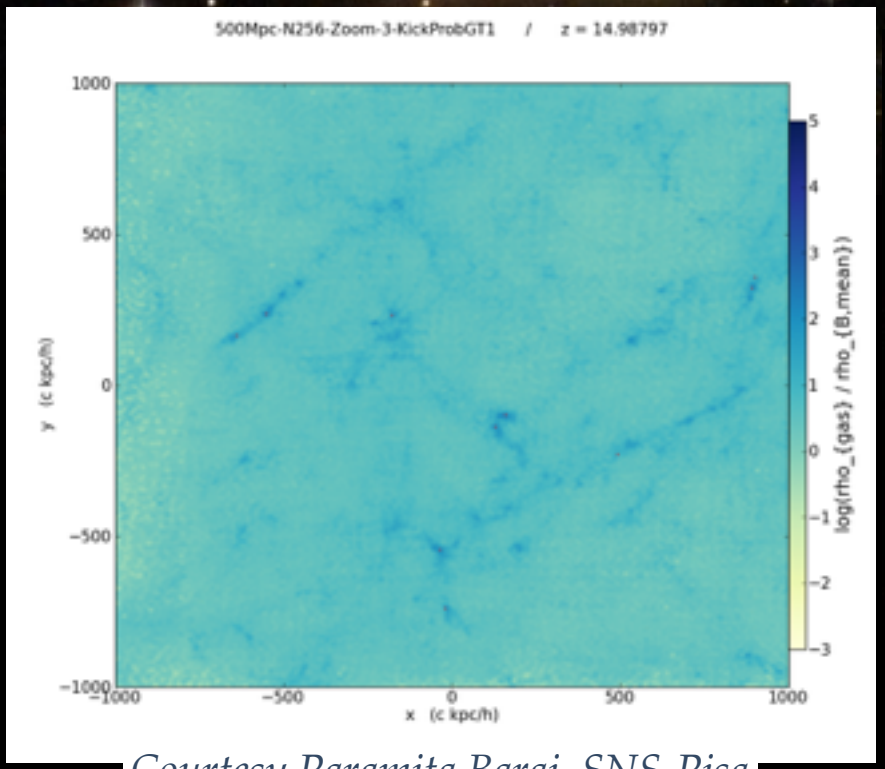
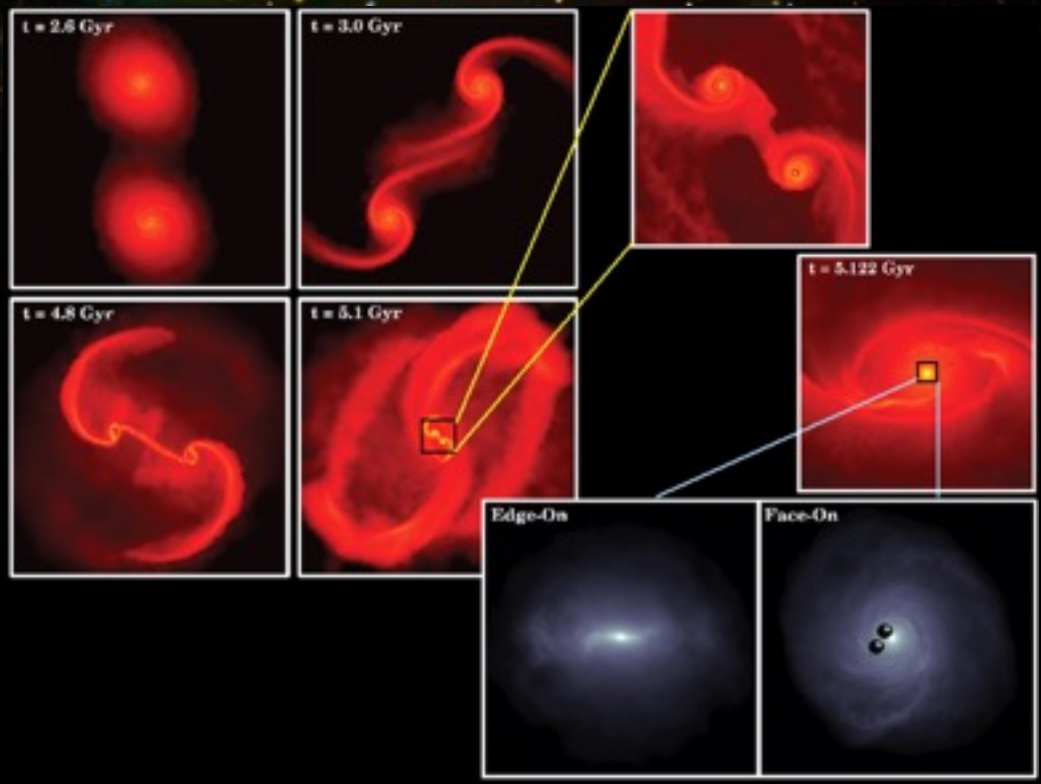
- SMBH pairs and binaries



Courtesy Paramita Barai, SNS-Pisa



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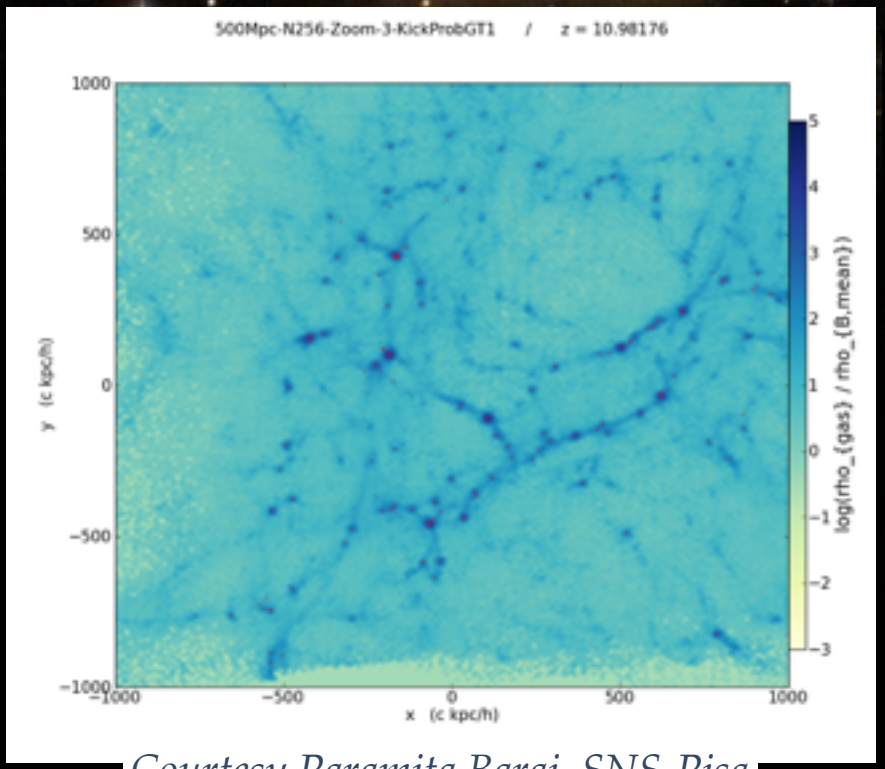

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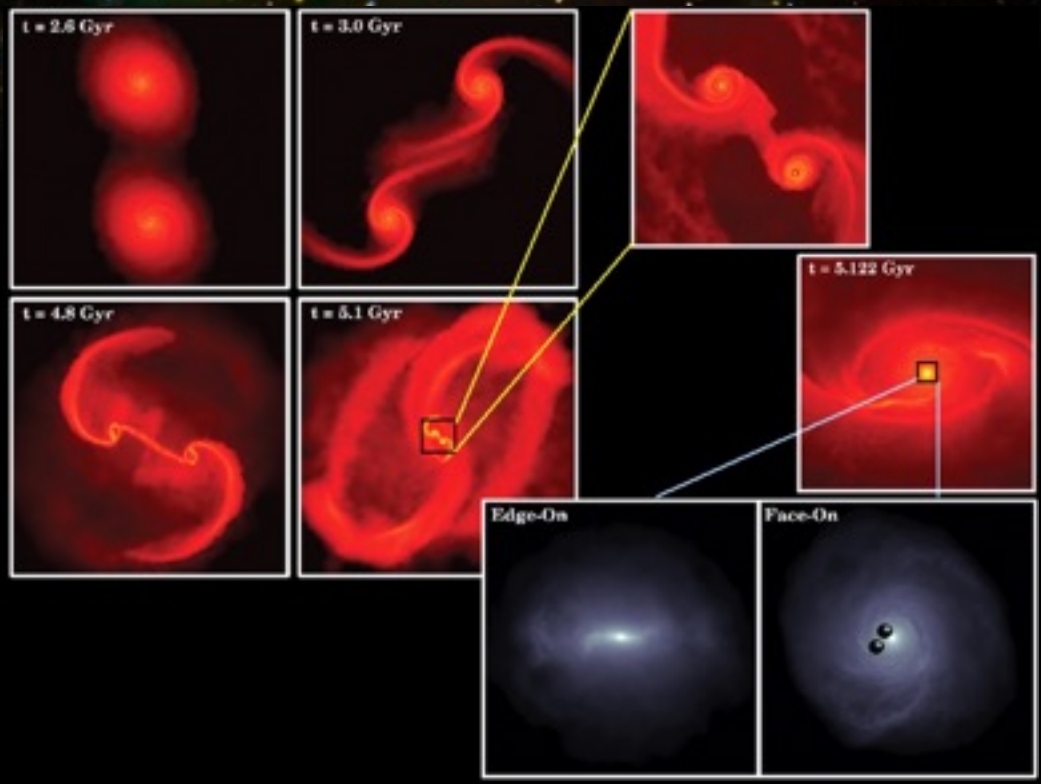

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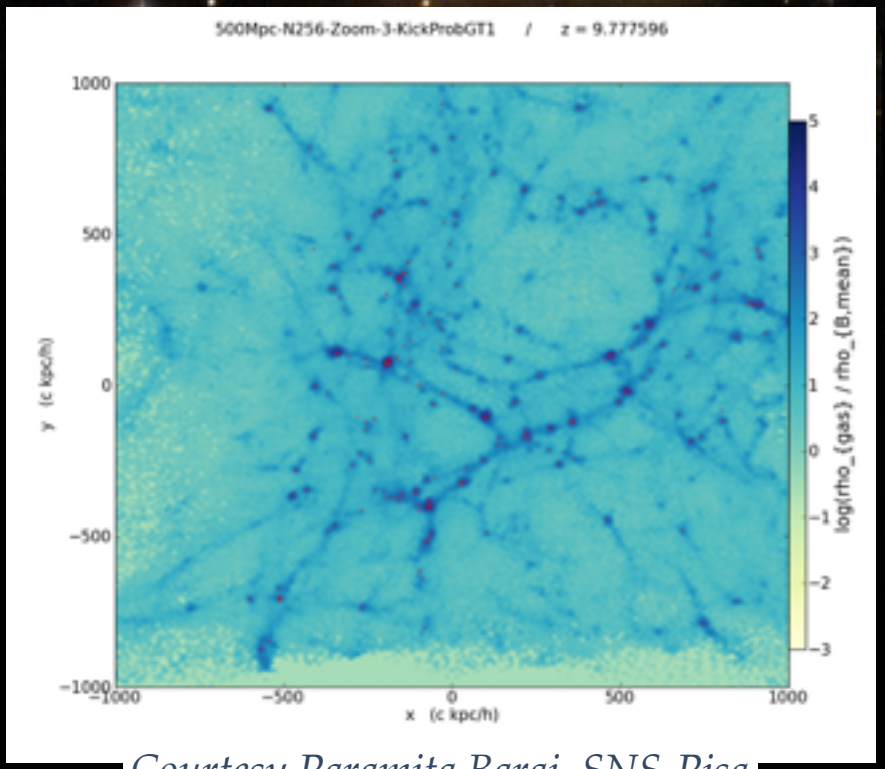

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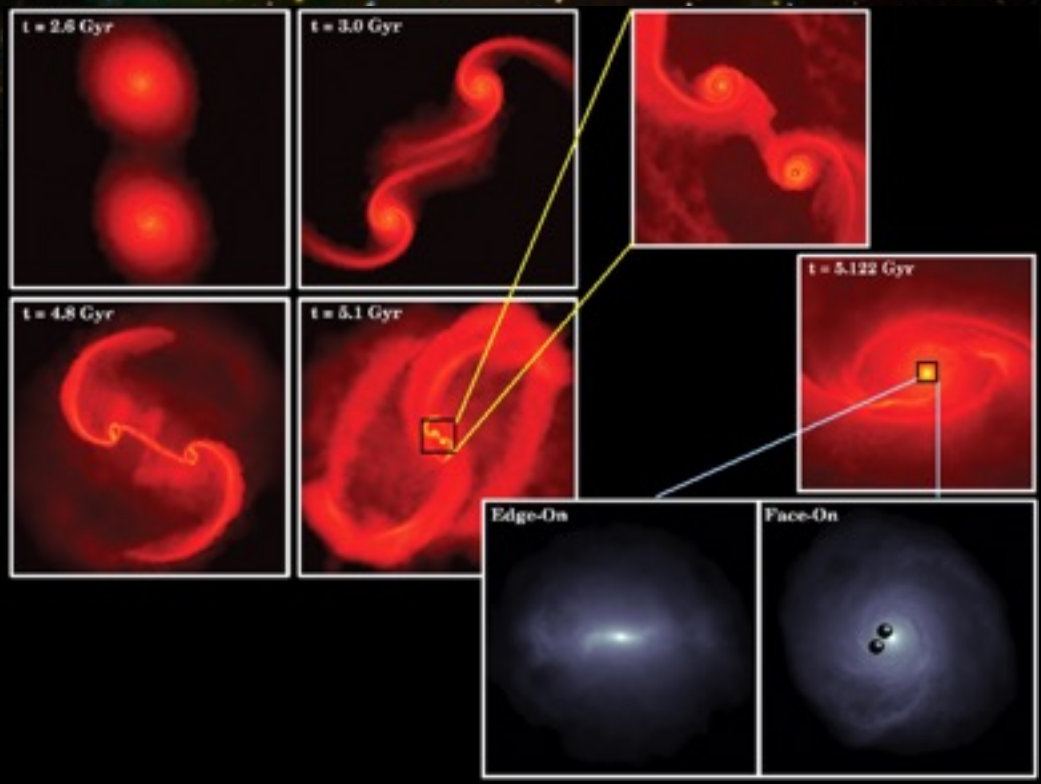

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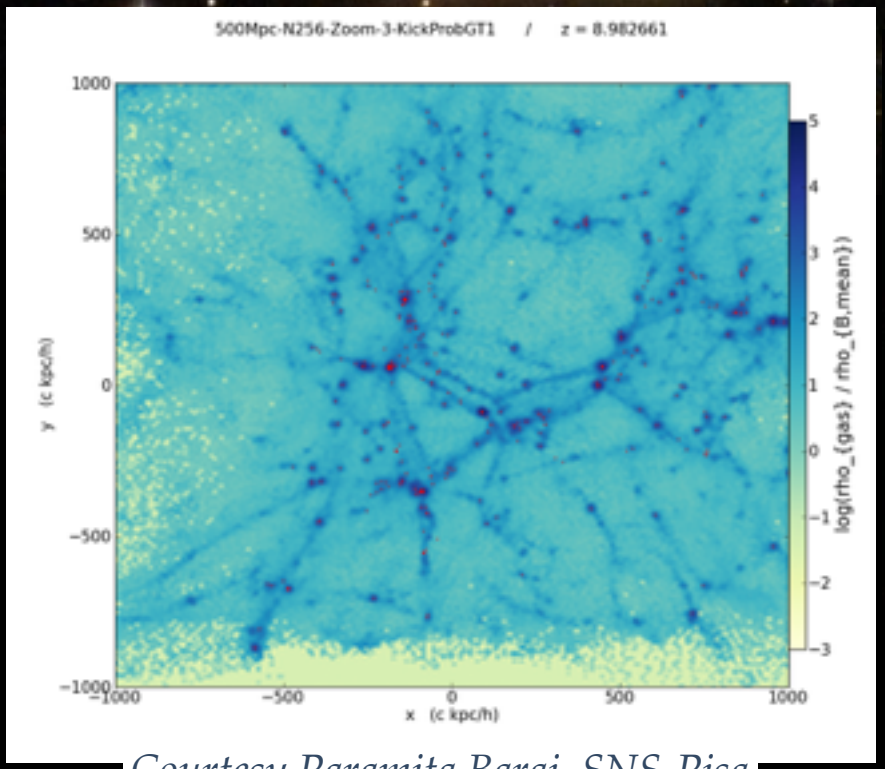

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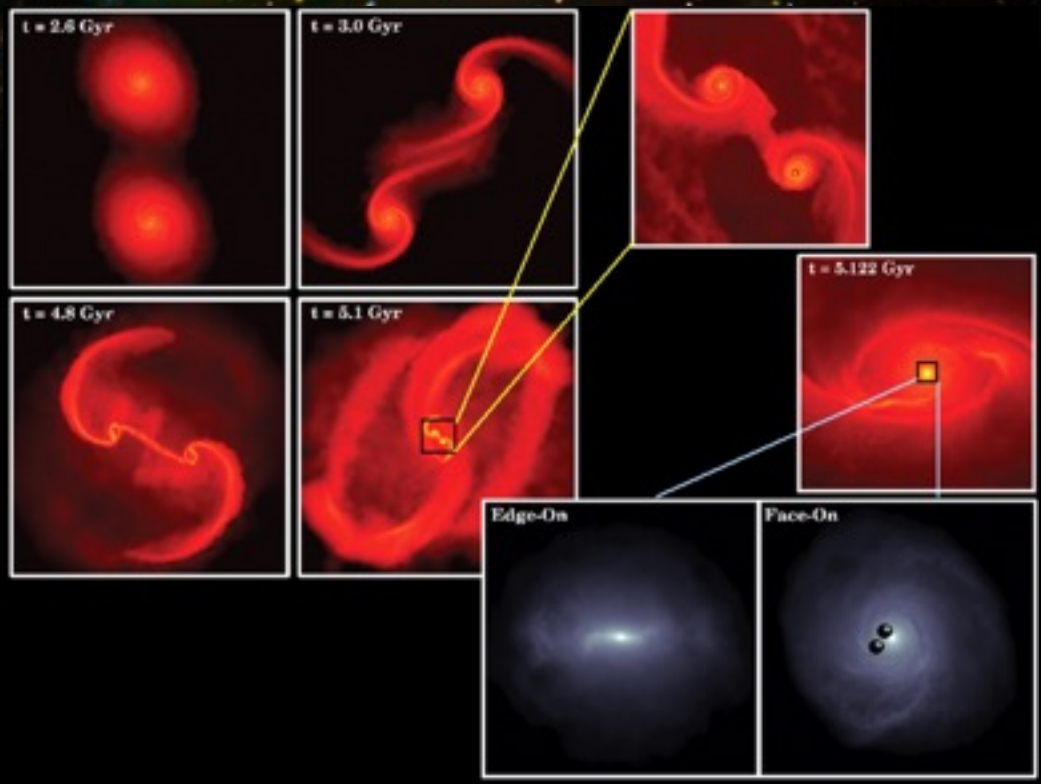

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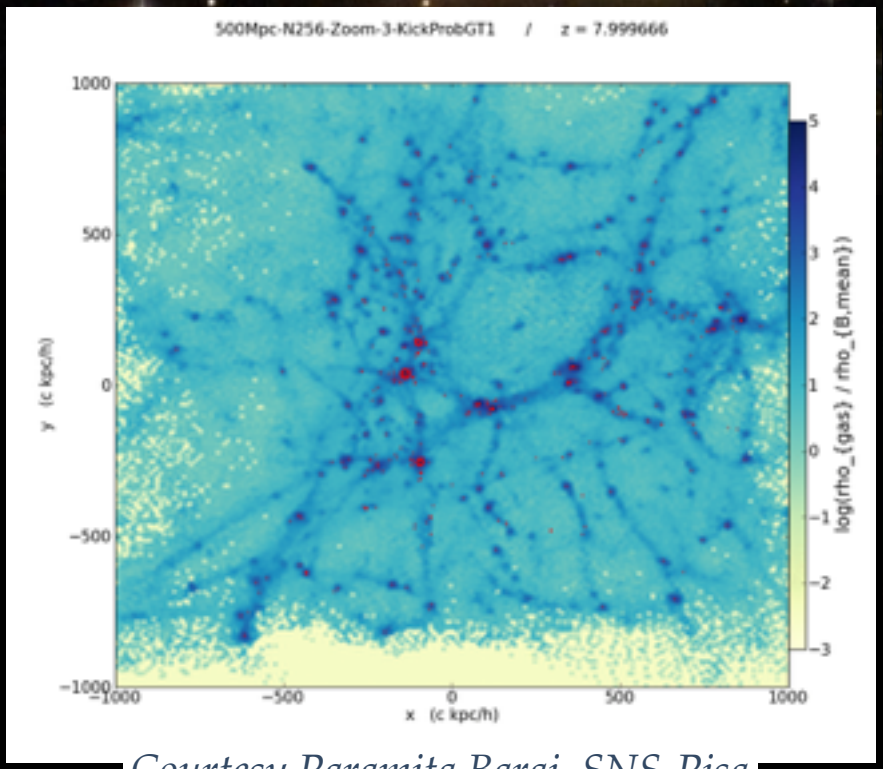

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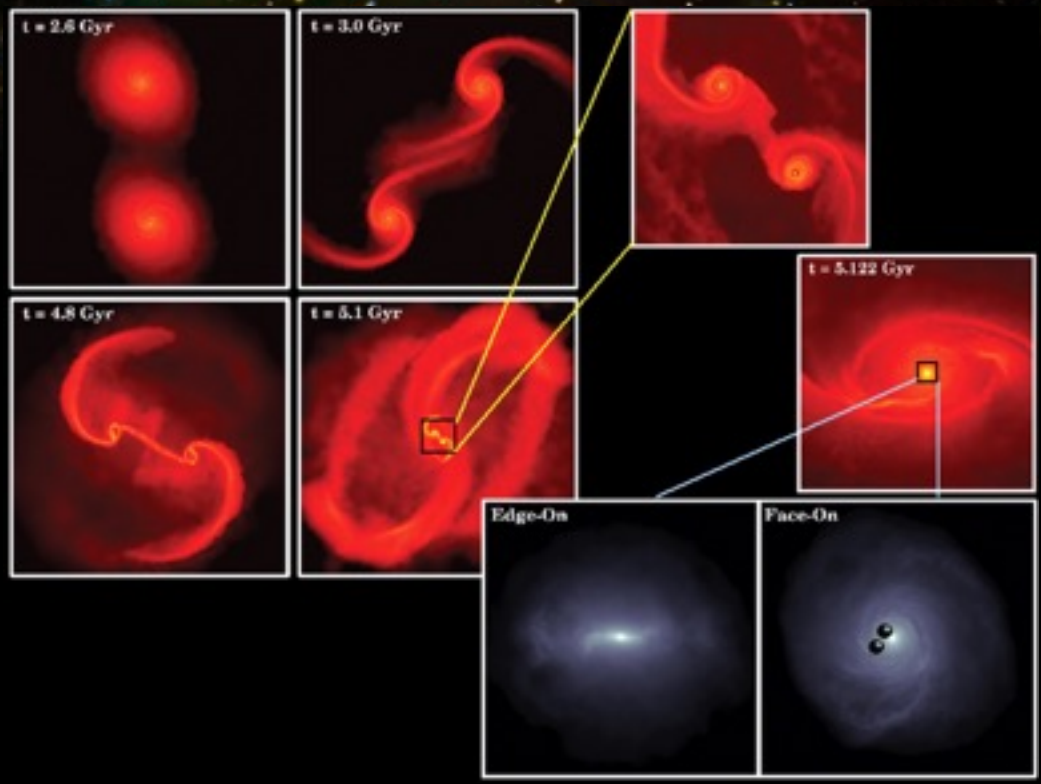

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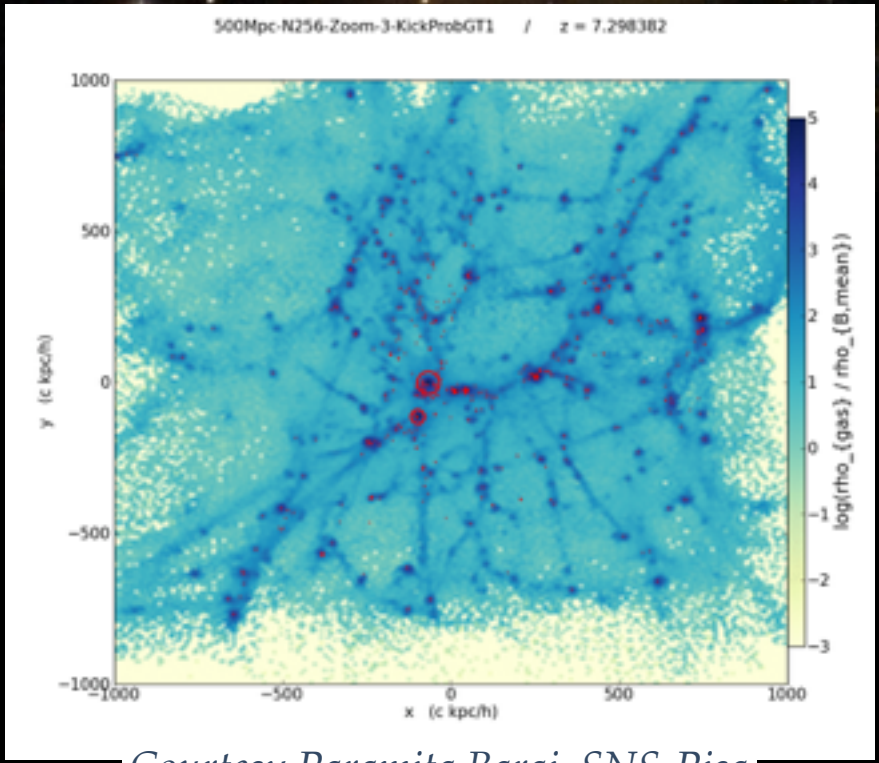

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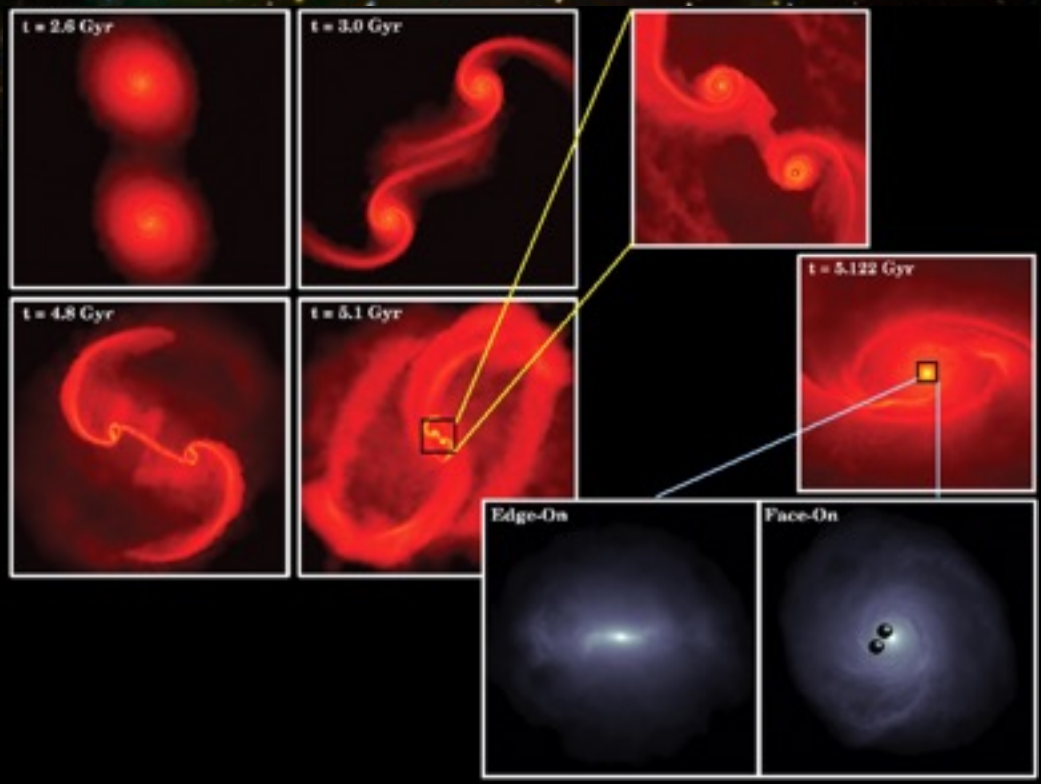

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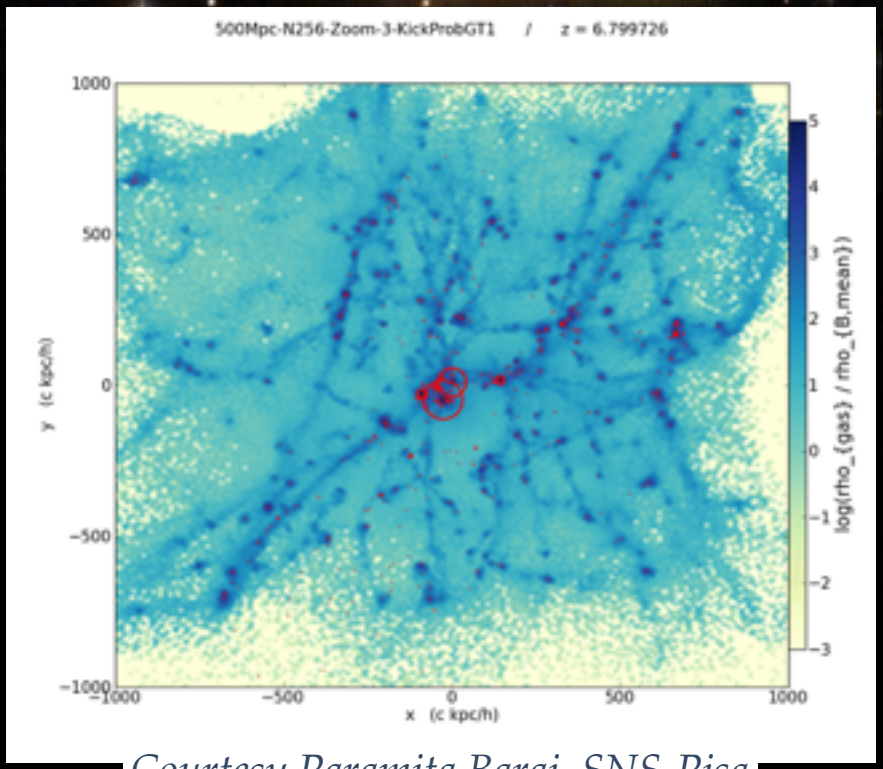

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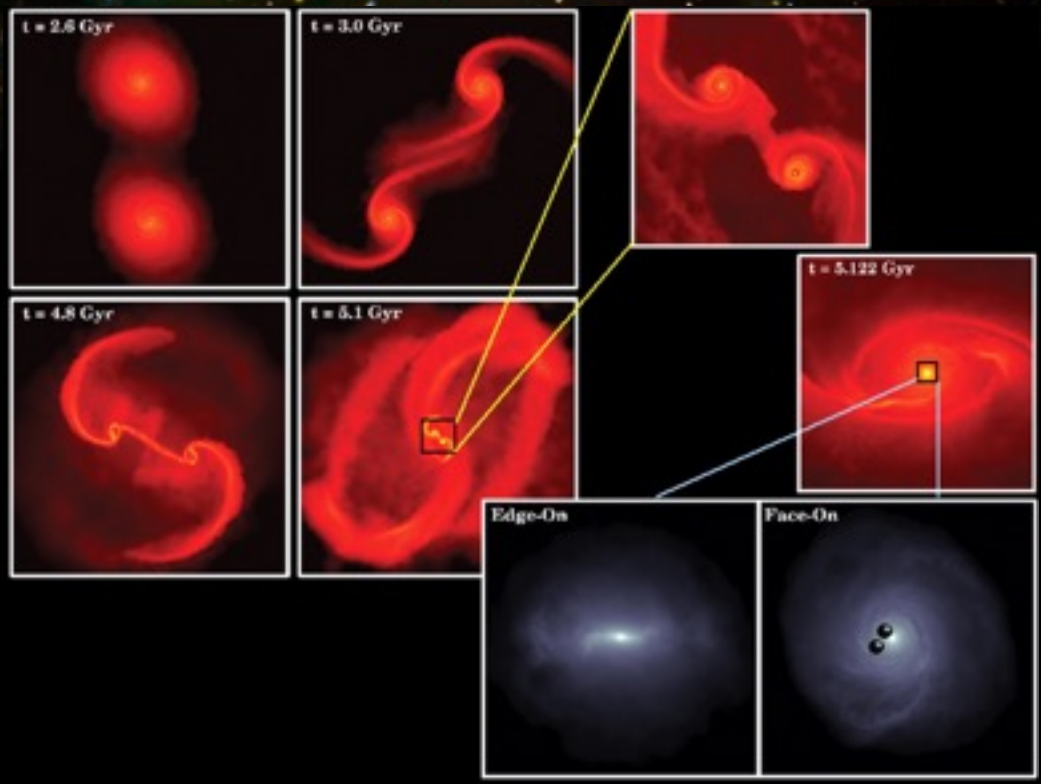

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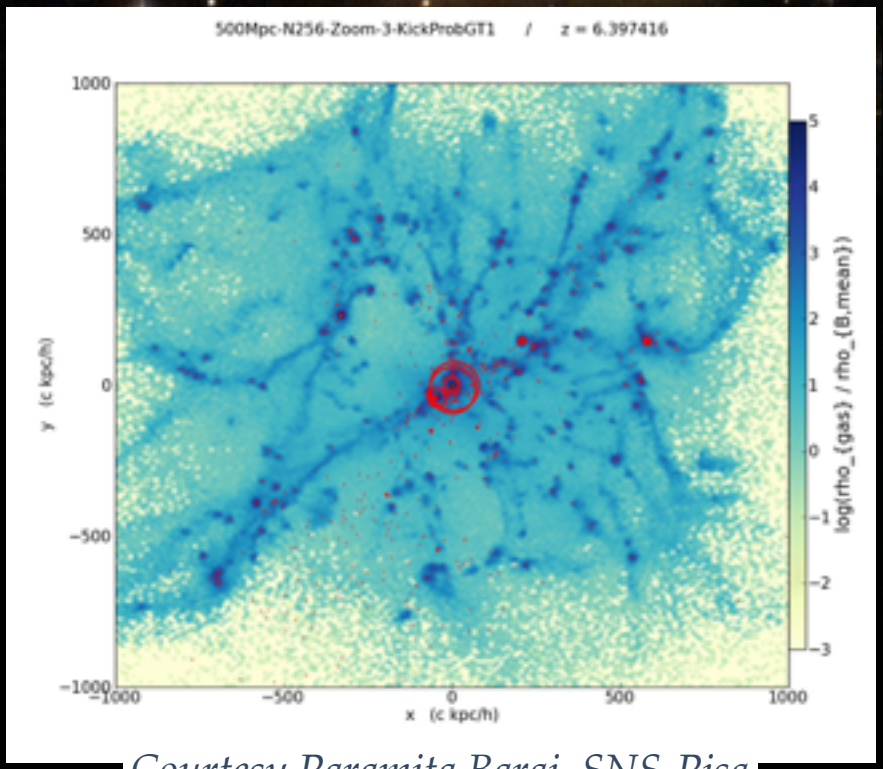

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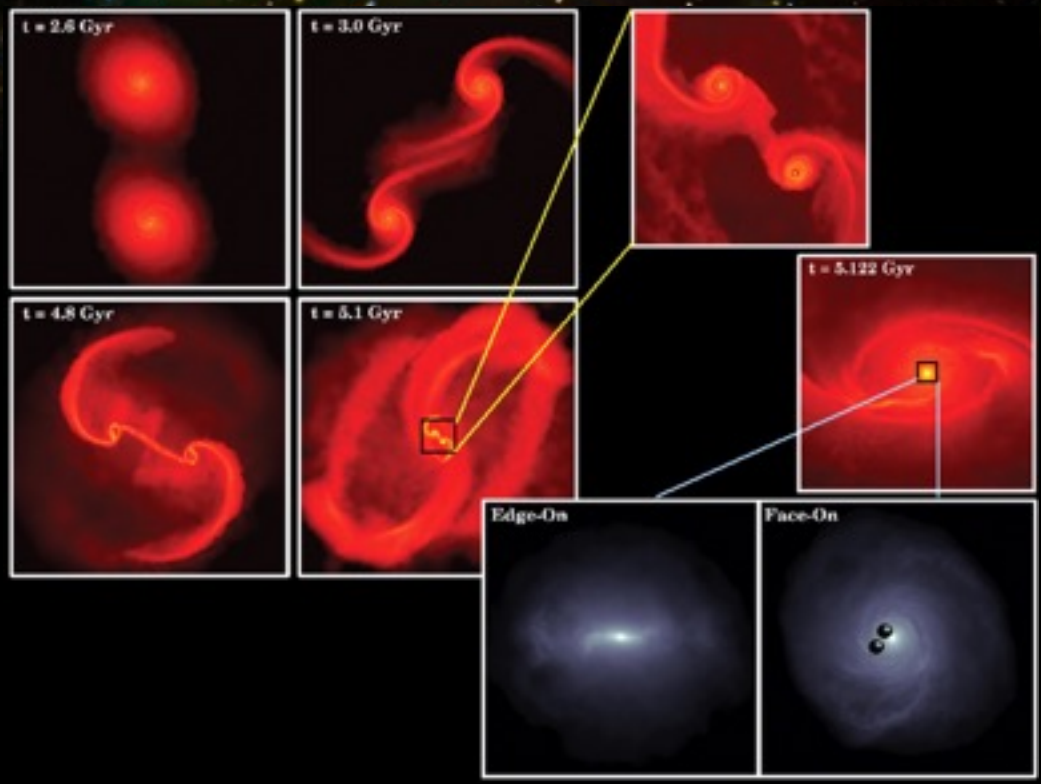

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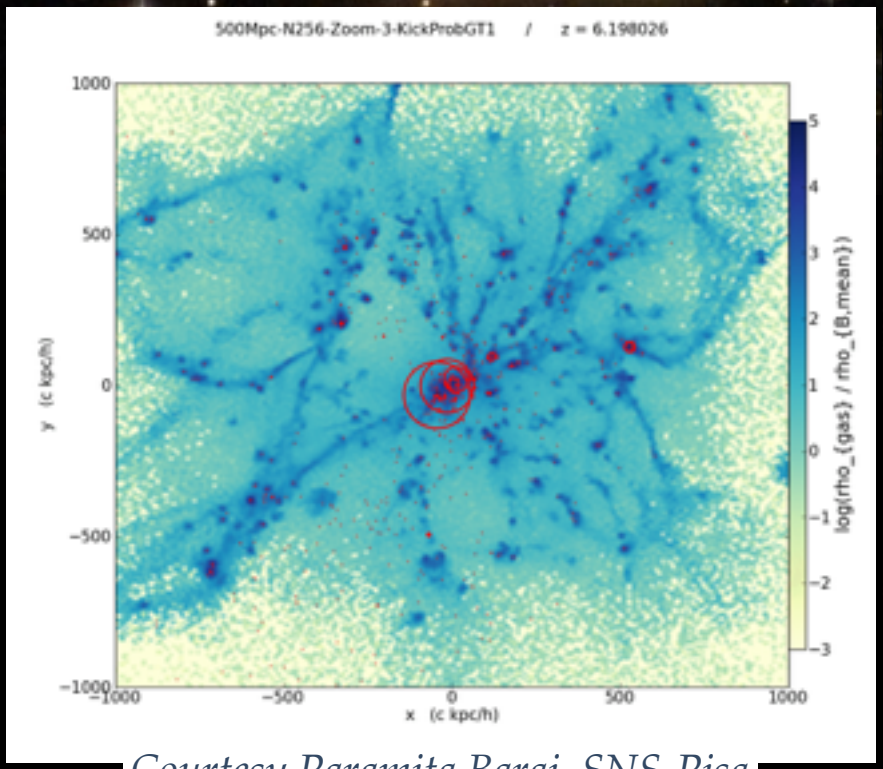

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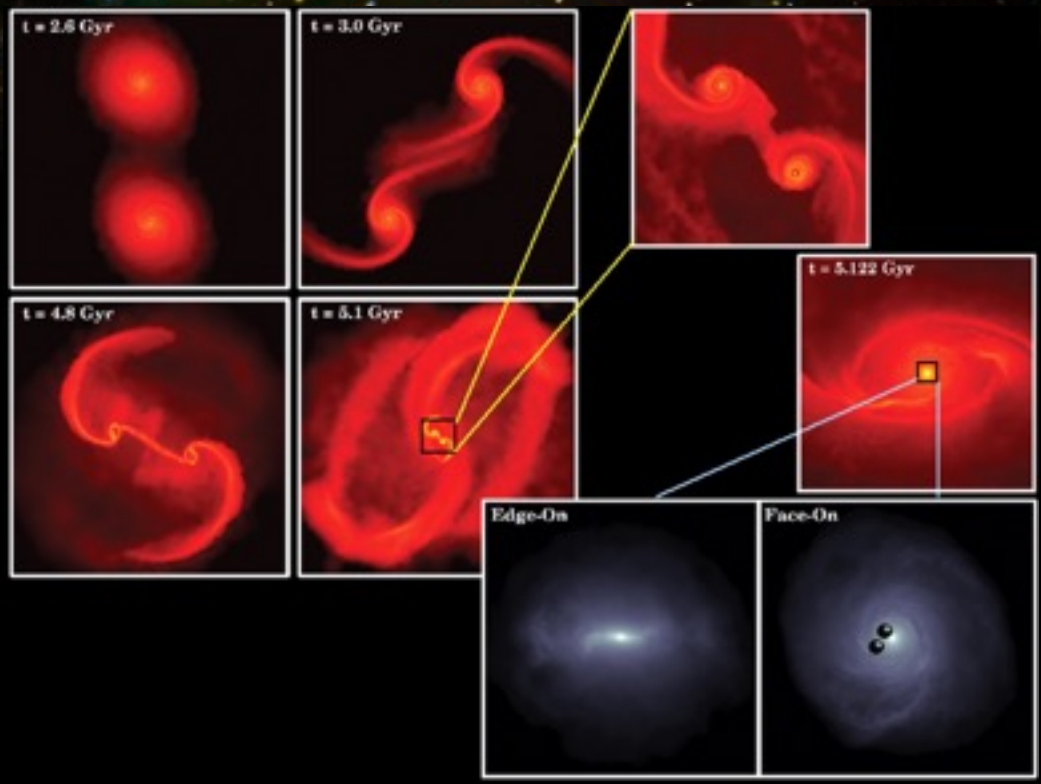

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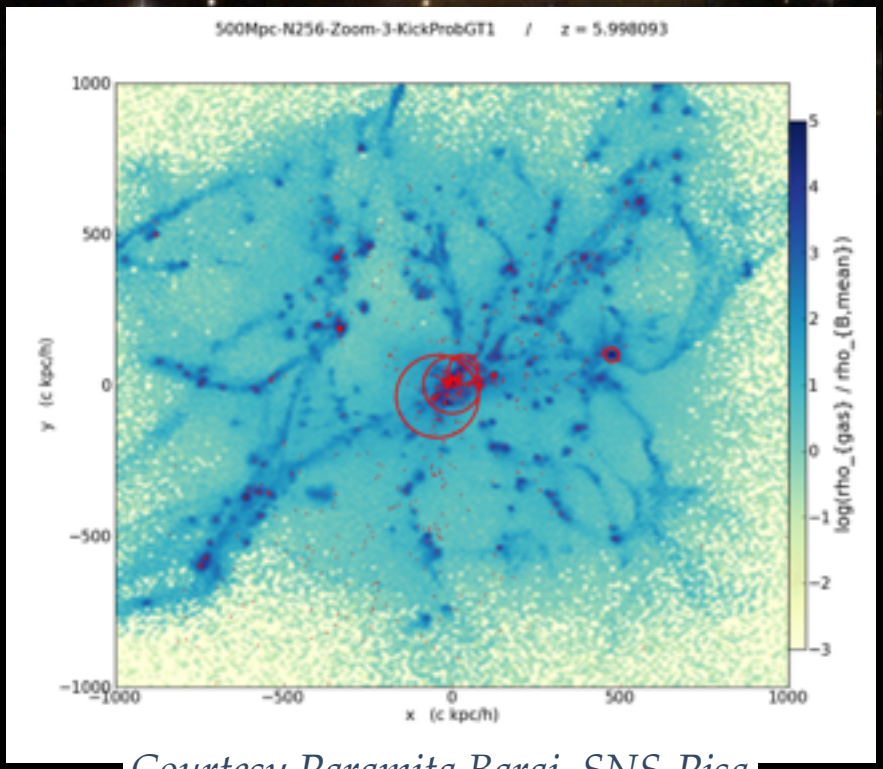

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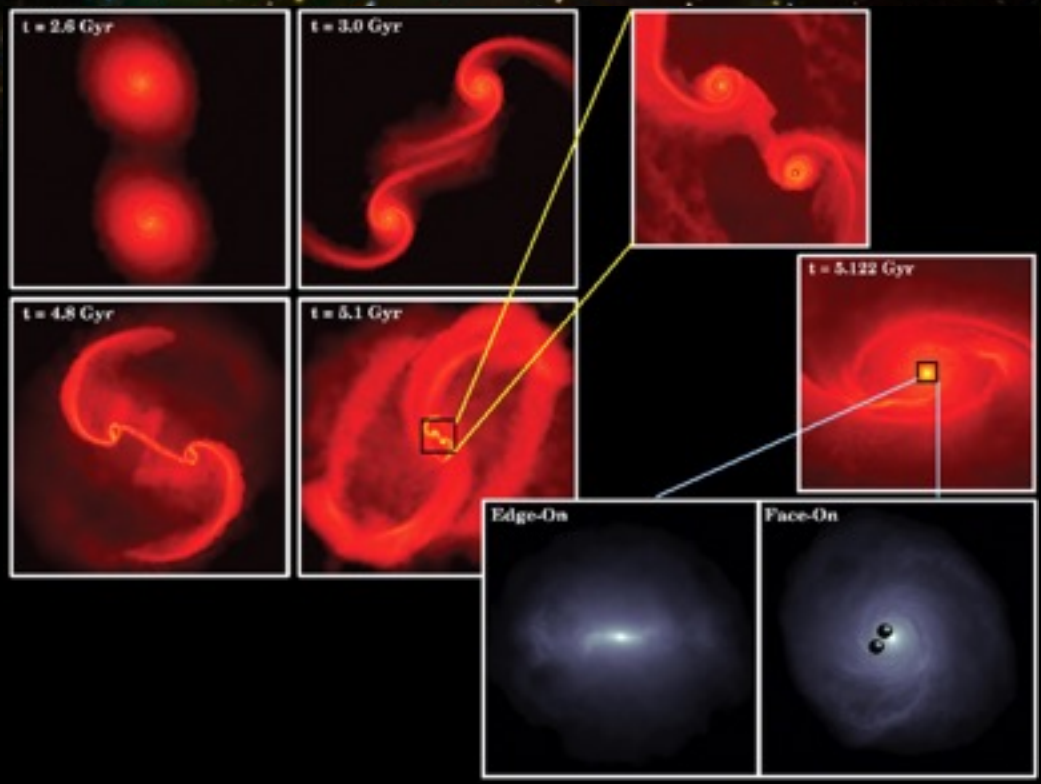
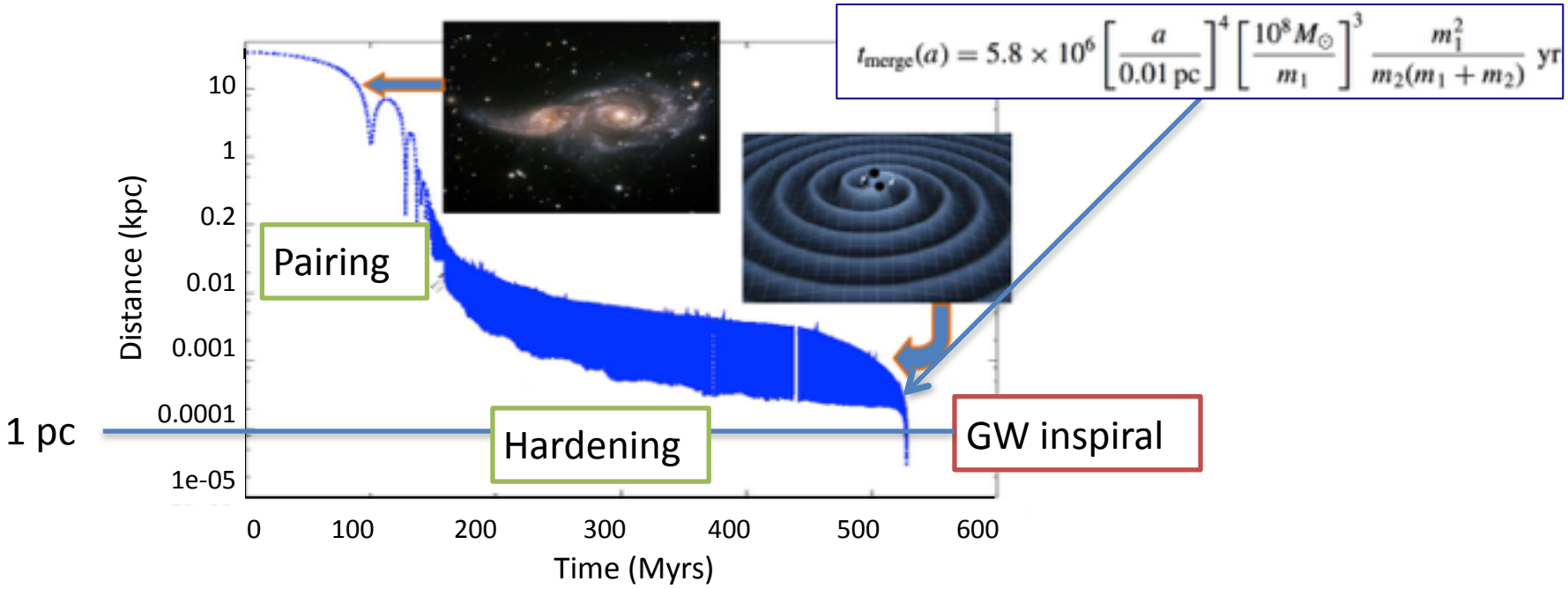


Periodicity and SMBH binaries

- **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**



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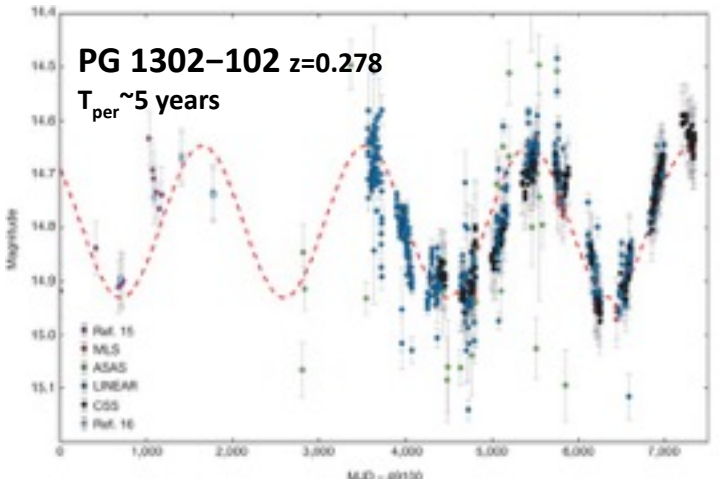
  - Double or asymmetric spectral lines (but Liu+2015 arXiv:1512.01825)
  - Helical, distorted jets; TDE dips in ligh-curve
  - **Periodic light-curve**
- **Quite some claims of periodic AGN lightcurves and binary SMBH interpretations**



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** (opt+γ)
- …

OJ287 T~12 yr

The 2015 outburst of the OJ287 blazar

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 #8772). 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 precessing spinning massive BH binary model for OJ287, could be the expected OR centenary flare.

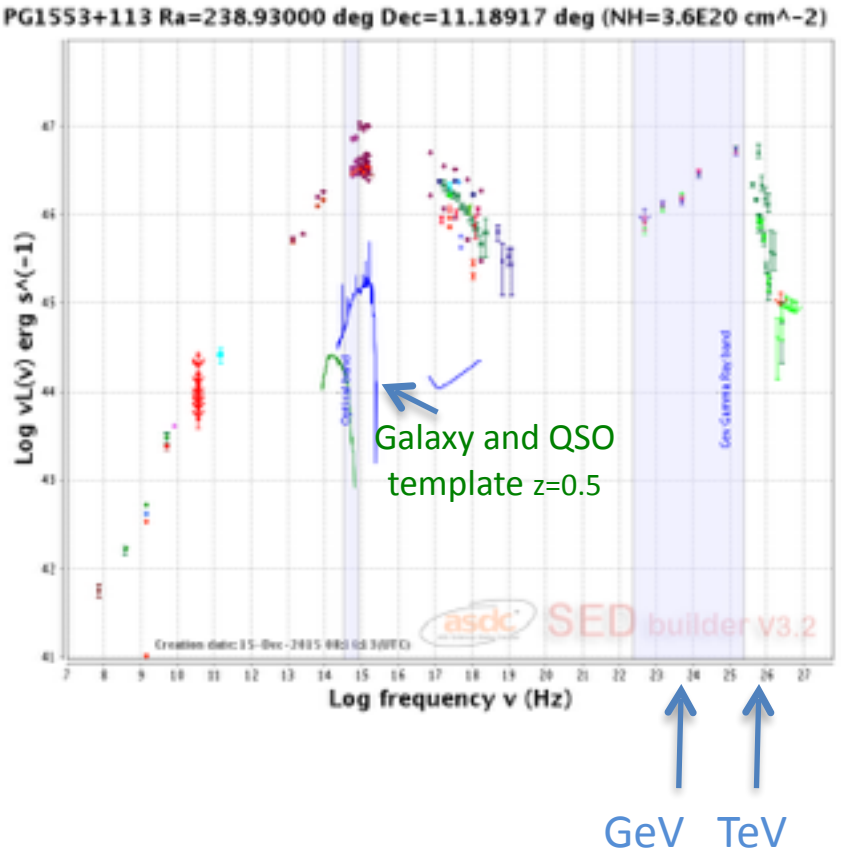
Periodicity and SMBH binaries

- **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

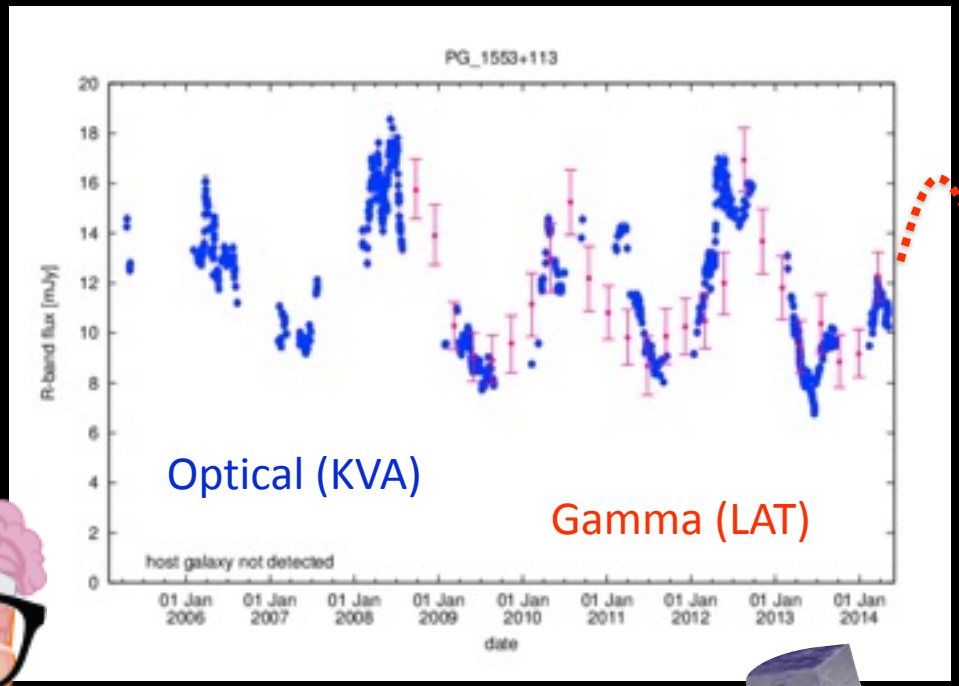
- **Blazar, radio-loud, HBL**
  - **Uncertain redshift z~0.5**
    Danforth et al. 2010, also Abramwoski et al. 2015
- **Well established γ-ray emitter and TeV source**
  - **Hard spectrum in Fermi/LAT**
- **Dominant non-thermal emission from the jet**



→ *Raiteri, AS, et al. MNRAS 2015*

A caccia di sistemi binari supermassivi

JUNE
2014



?


Sara Cutini


Dario Gasparrini


Stefano Ciprini

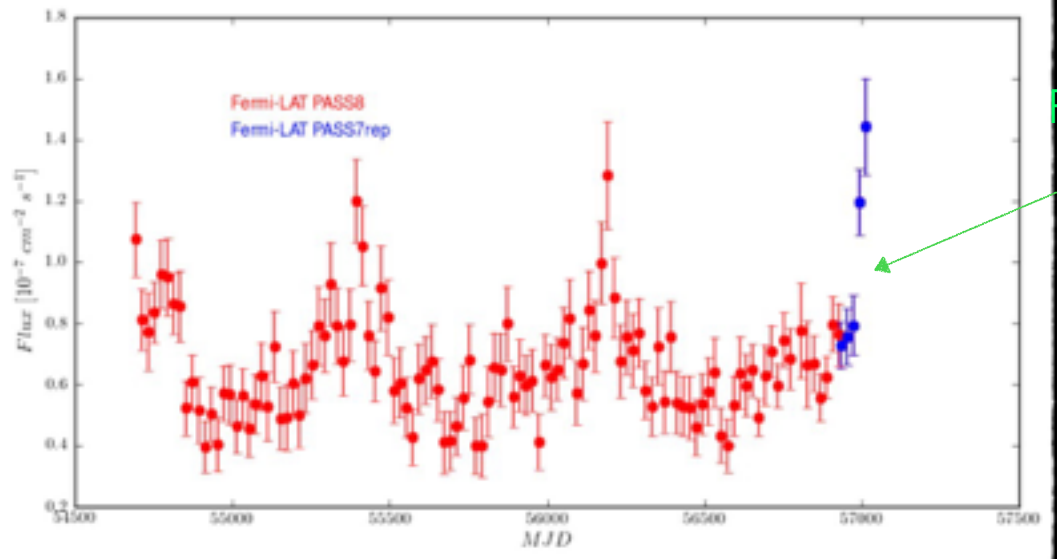
A caccia di sistemi binari supermassivi

JANUARY 2015

sara cutini 9 January 2015 at 15:23

To: Antonio Stamerra, stefano ciprini asdc

4 picco ;)



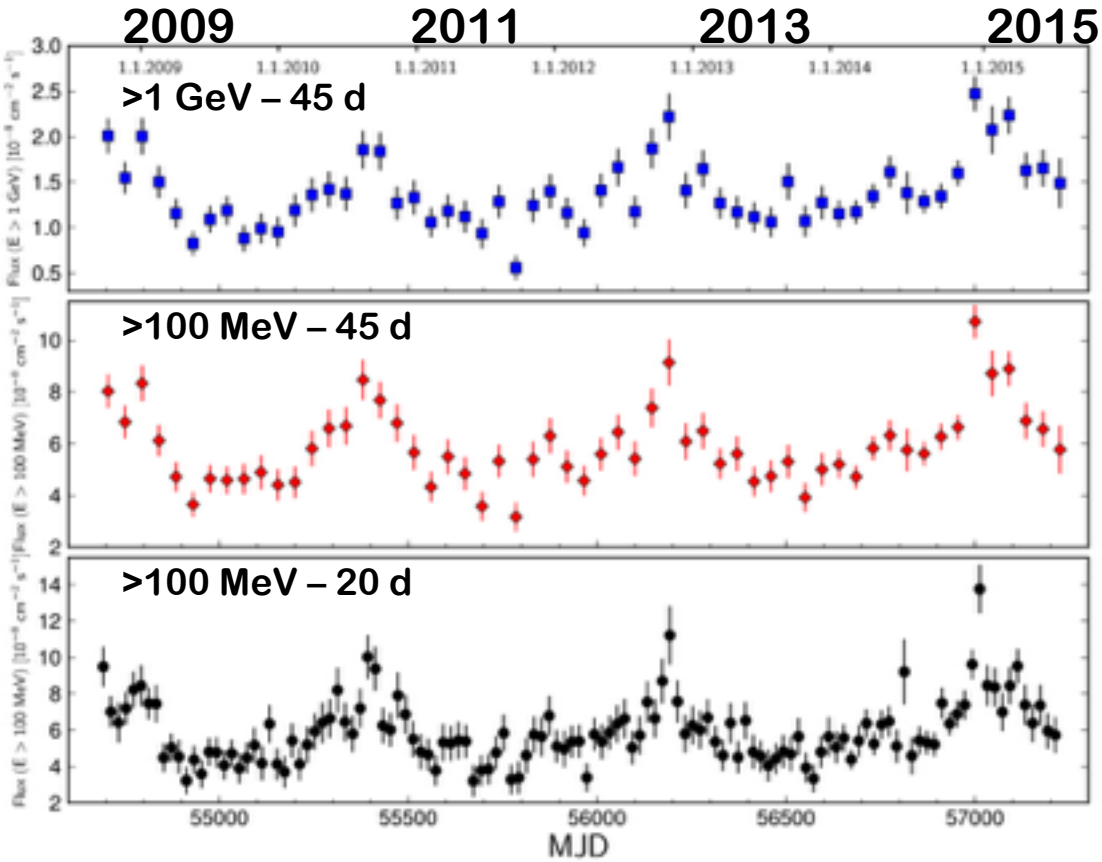
New Fermi/LAT data!

PG1553 periodicity in Fermi/LAT

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

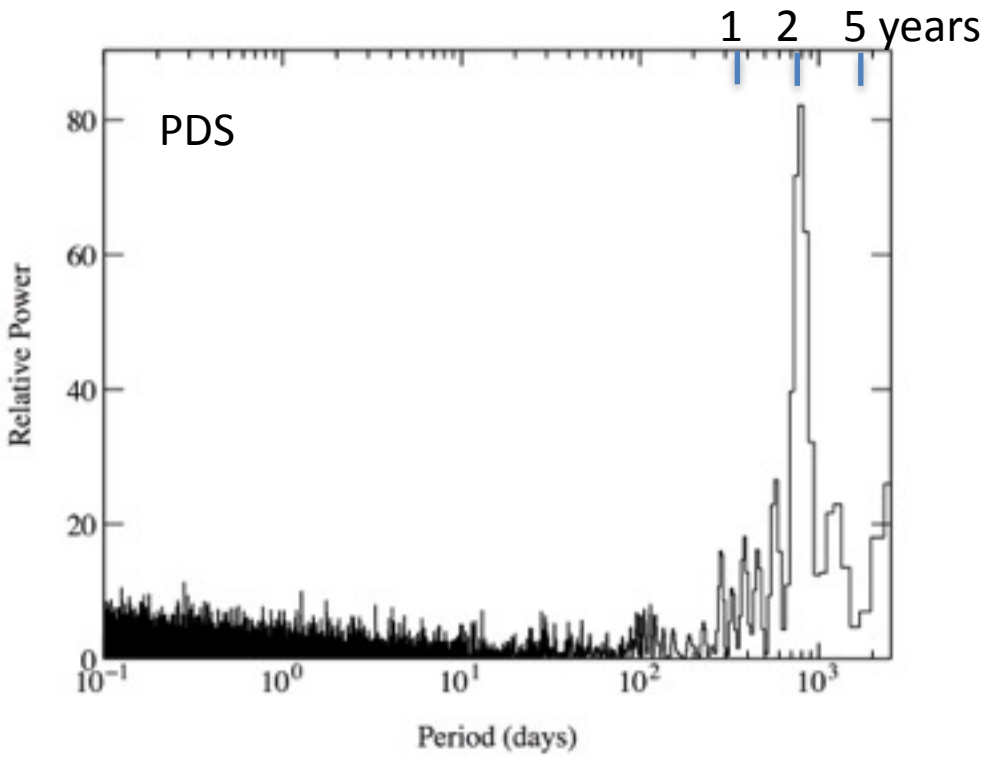
- **3.5 cycles over ~7 years**

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



PG1553 periodicity in Fermi/LAT

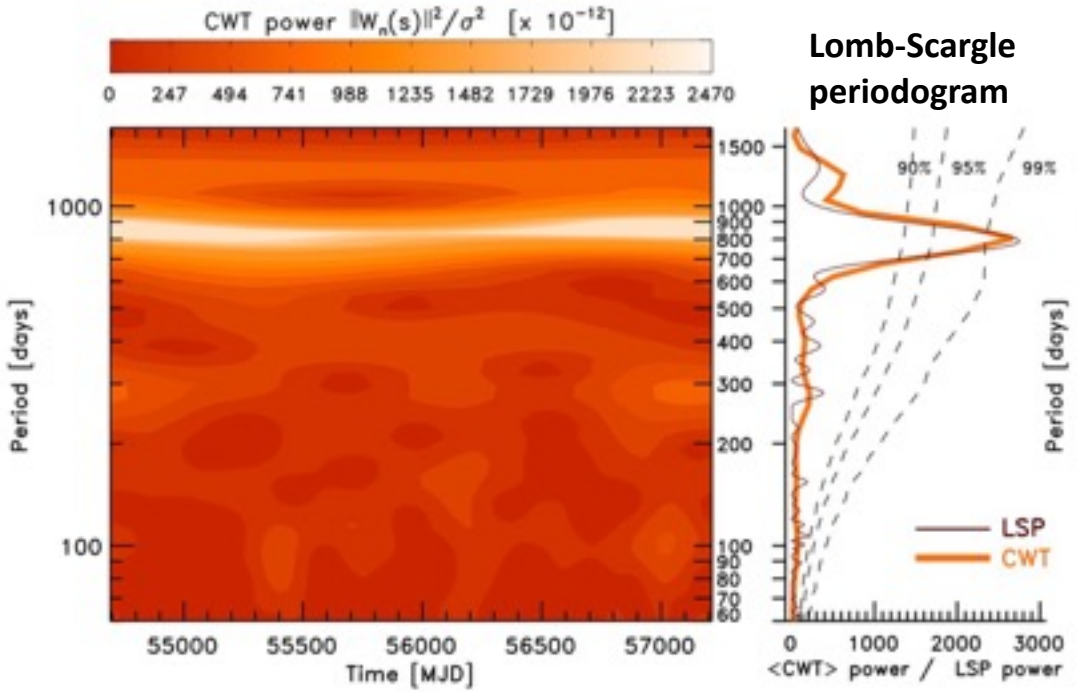
- **Periodicity analysis: Power Density Spectrum (E>100 MeV, 600s time bin)**
  - **Period γ: 2.16+/-0.08 yr**



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**

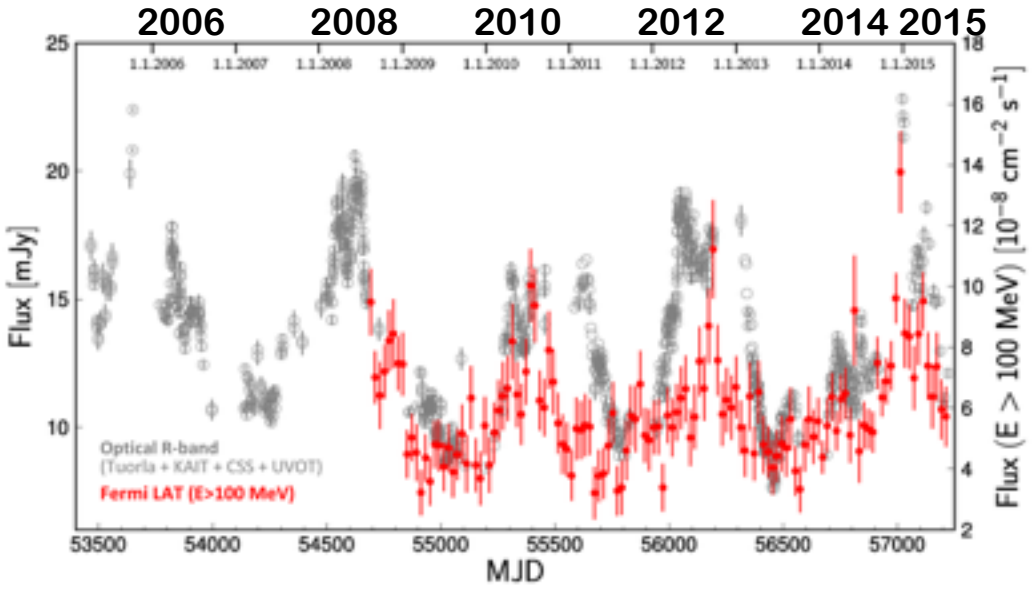
Continous wavelet transform



Lomb-Scargle periodogram

PG1553 periodicity: MWL

- **MWL: optical, radio, X-ray**
  - **X-ray (XRT) too sparse**
- **Optical Periodicity analysis** (over ~10 years, ~4.5 cycles)



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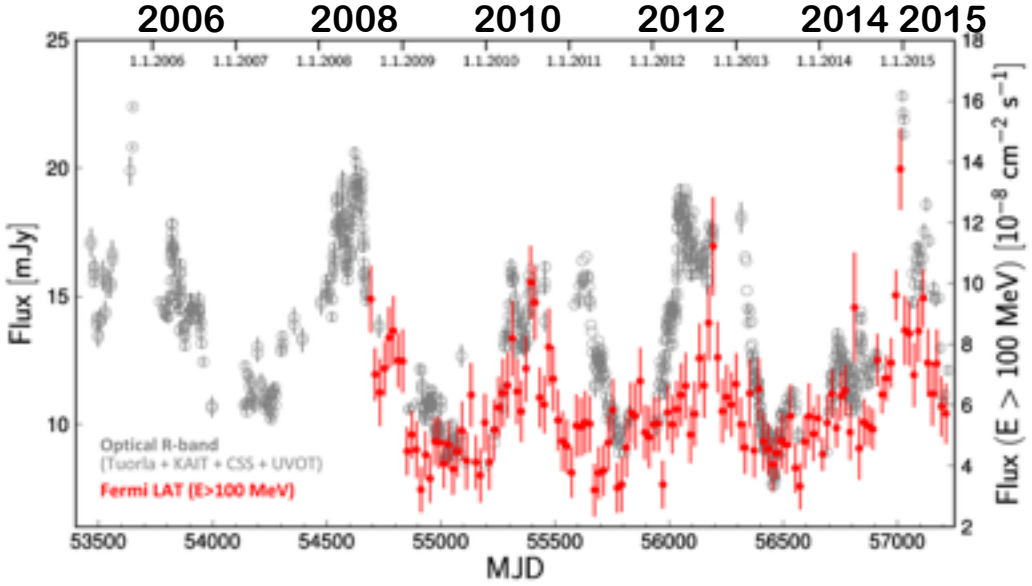
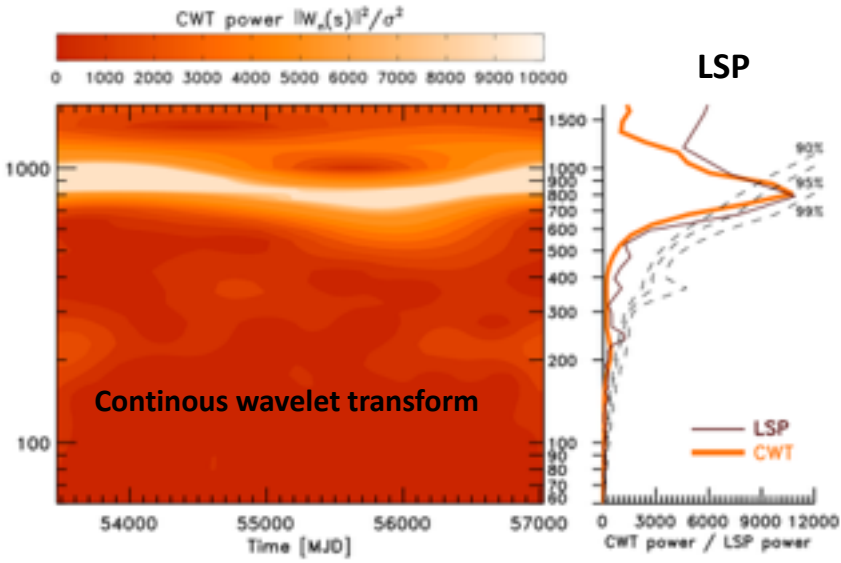
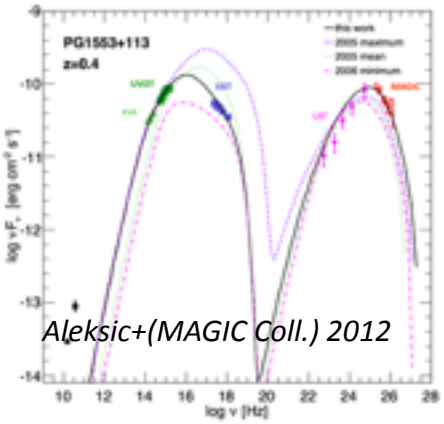
- **MWL: optical, radio, X-ray**
  - **X-ray (XRT) too sparse**
- **Optical Periodicity analysis** (over ~10 years, ~4.5 cycles)
  - **Period γ: 2.05+/-0.05 yr**
  - **< 5% random fluctuation from LSP (red noise spurious model)**





Interpretation of periodicity

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



Aleksic+(MAGIC Coll.) 2012

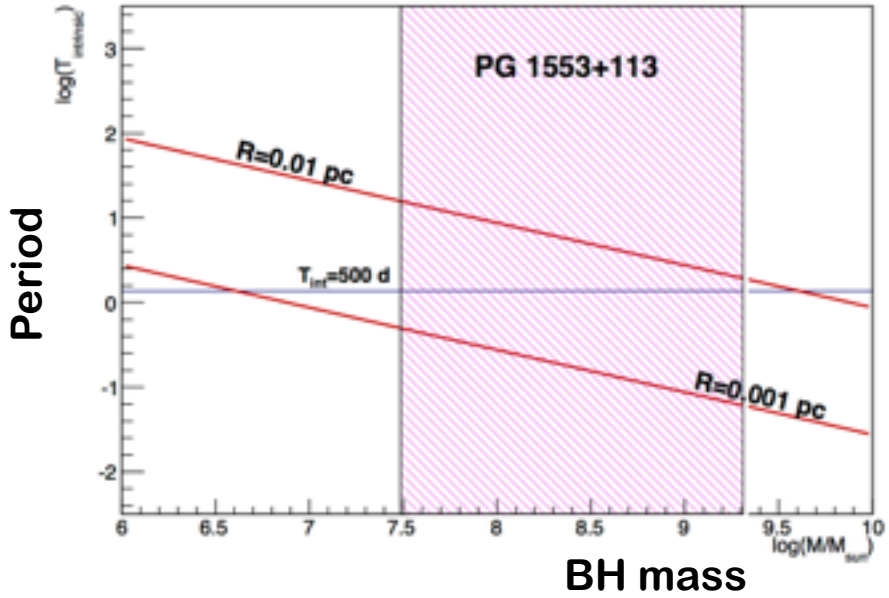
Periodicity may be the result of:

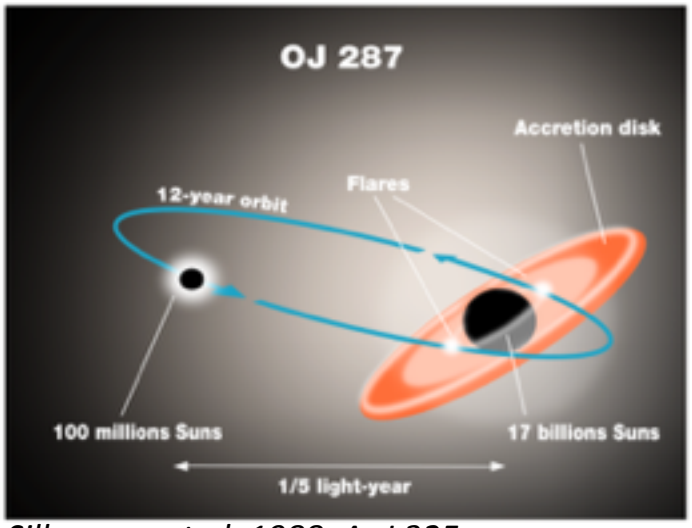
- **Processes at the base of the jet inducing quasi-periodic oscillations**
- **Geometrical effects on the jet**
  - **Binary and single SMBH can be invoked**

Binary SMBH system

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**

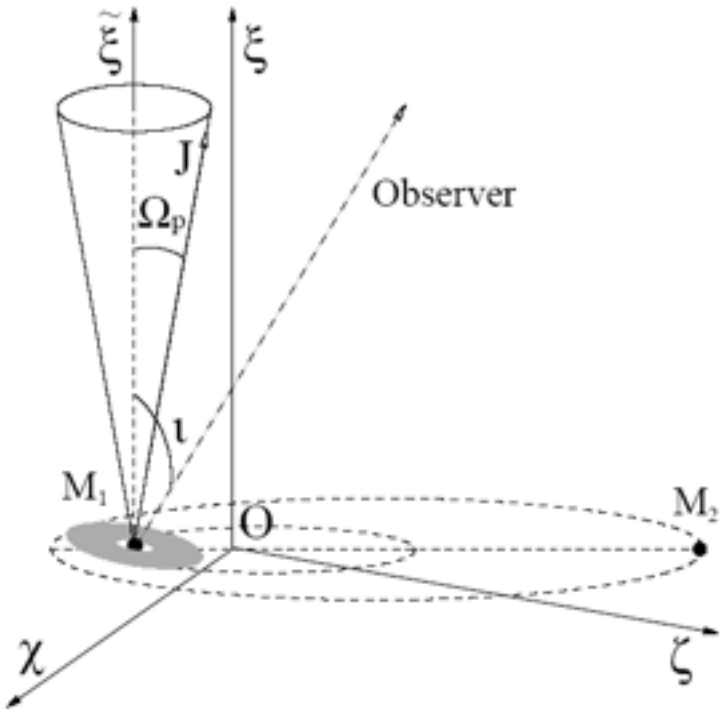




Sillampaa et al. 1988, ApJ 325

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*

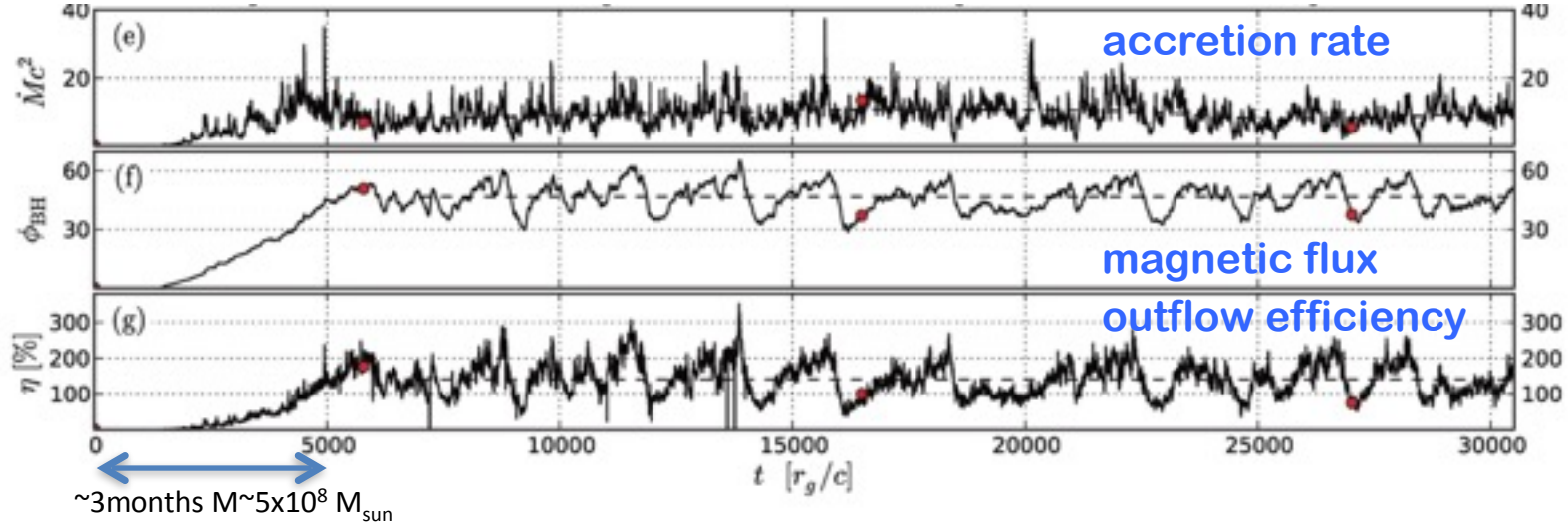


Single SMBH

Alternative models

Jet feeding

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



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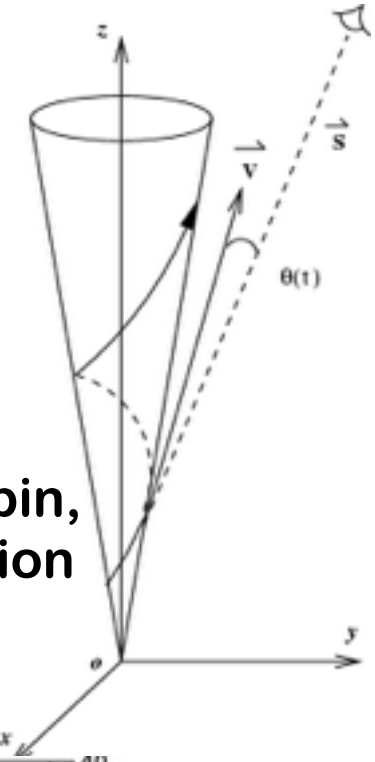
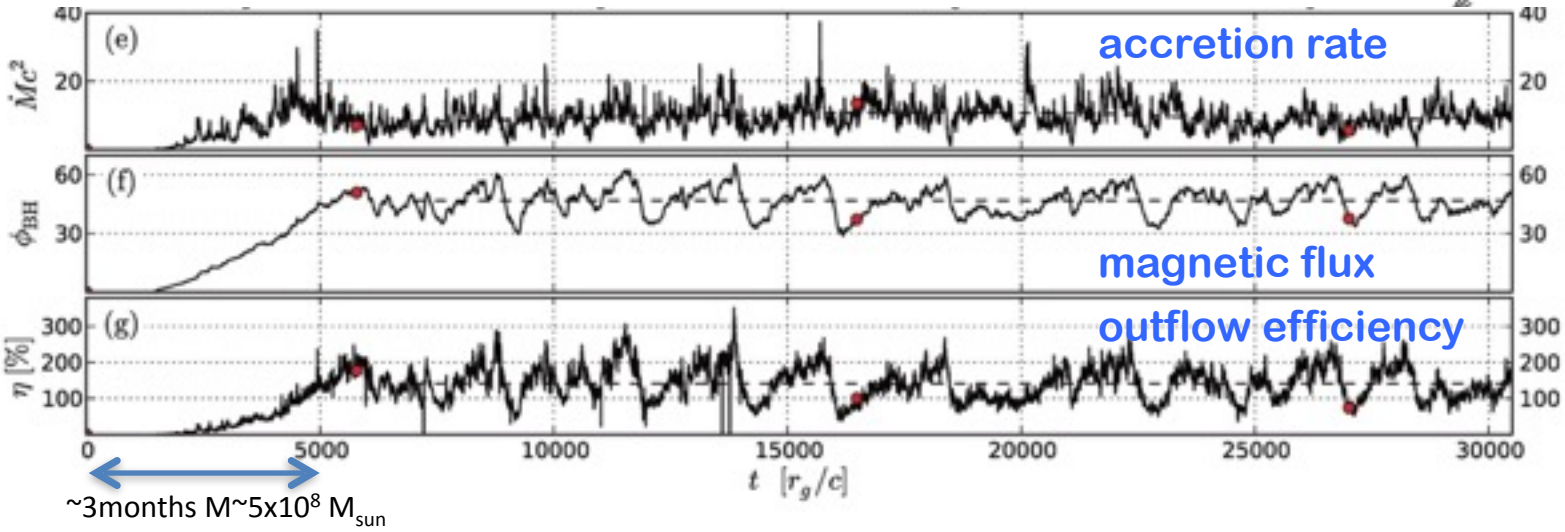
Geometrical

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





~3months M~5x10^8 M$_{sun}$

MWL campaign

- Regular MWL monitoring started at the end of 2014
  - from radio to VHE gamma-rays
- Make ready for the next high-activity; expected beginning 2017
- Led by the MAGIC collaboration

The MAGIC Experiment

- Active from 2004
- In stereo configuration since 2009
- New MAGIC1 camera since 2012
- New mirrors for MAGIC 1 from august 2014
- At least 5 more years foreseen

New technologies to lower the threshold energy:

- 2x17m diameter (A=472 $m^{2)}$
- High resolution cameras (PSF ~0.06°, **FoV = 3.5°**)
- Hemispherical PMT with enhanced QE

Fast repointing capability: ~8 degree/s

The MAGIC Collaboration

~170 Collaborating Astro-Physicists from 10 Countries

Bulgaria Sofia

Croatia Consortium (Zagreb, +...)

Finland Consortium (Tuorla, +...)

Germany DESY Zeuthen, TU Dortmund, MPI Munich, U. Würzburg

India Saha Inst. of Nuclear Physics, Kolkata

Italy INFN & U. Padova, INFN Pisa & U. Siena, INFN Como/Milano Bicocca, INFN Udine/Trieste & U. Udine, INAF

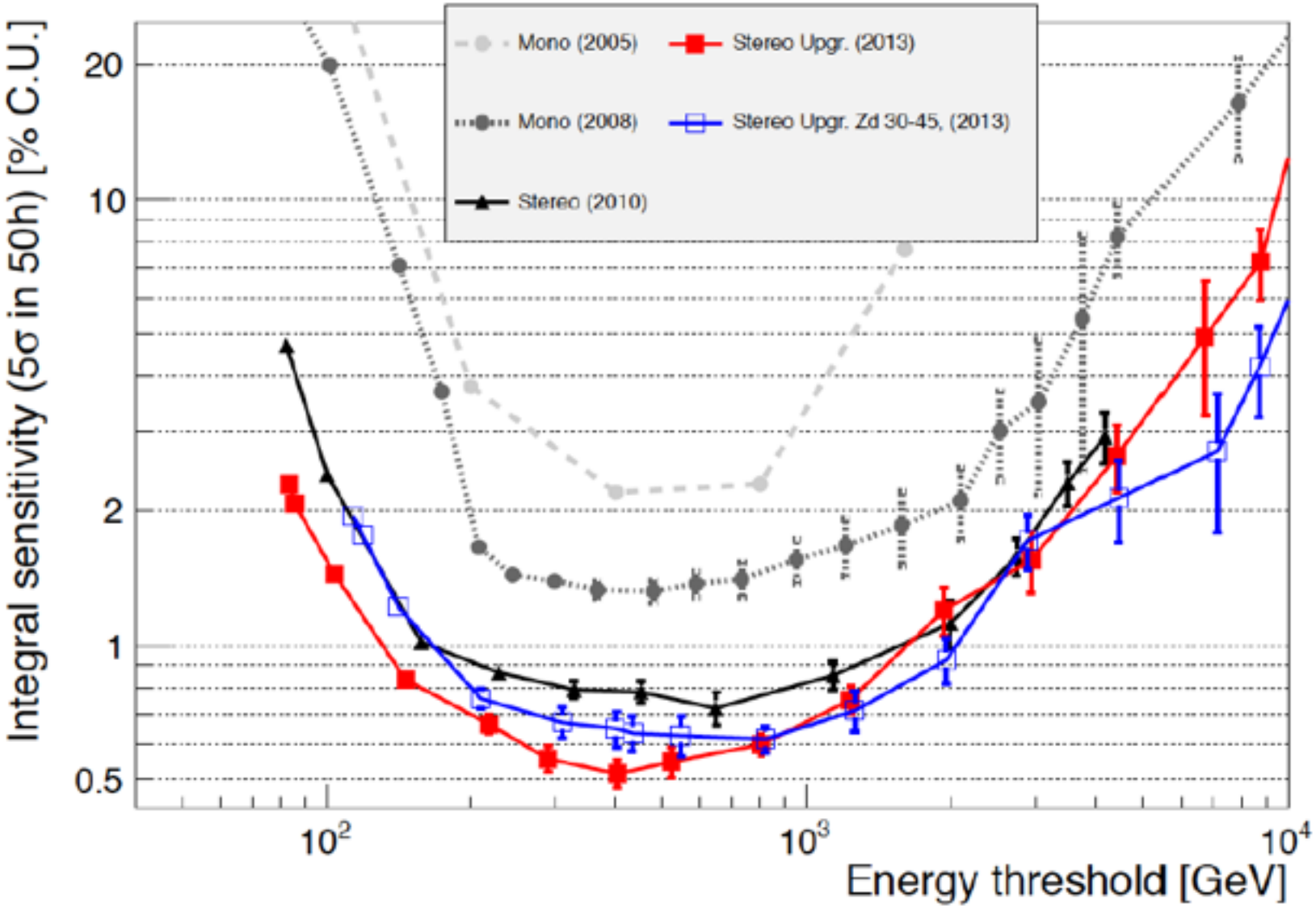
Japan Consortium (Kyoto, +...)

Poland Lodz

Spain U. Barcelona, UAB Barcelona, IEEC-CSIC Barcelona, IFAE Barcelona, IAA Granada, IAC Tenerife, U. Complutense Madrid, CIEMAT Madrid

Switzerland ETH Zurich

MAGIC sensitivity

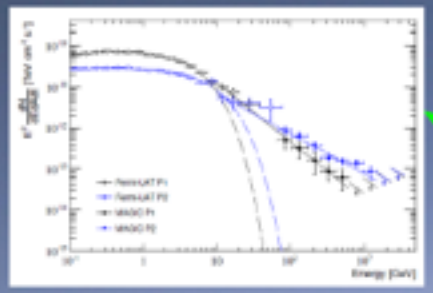


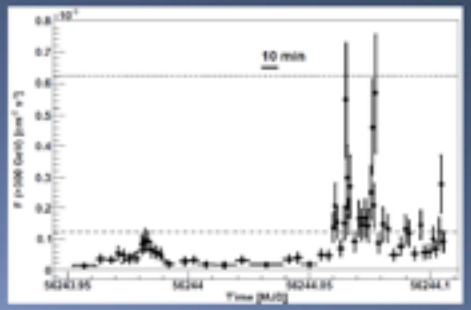
Aleksić et al. (MAGIC) Astropart.Phys, 72, 2016

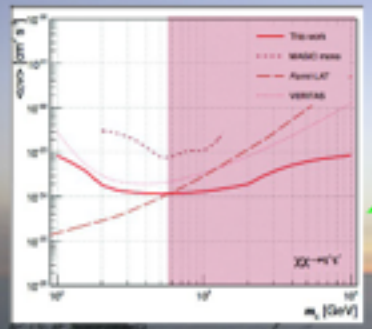
MAGIC Science

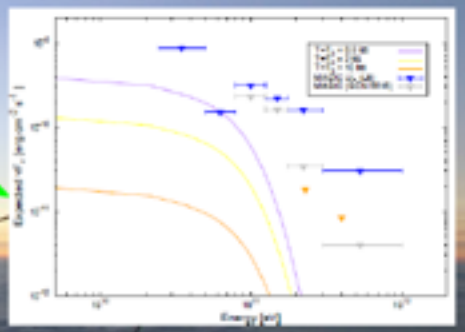
Galactic sources:
Pulsars, PWN, SNR, Binaries

AGNs: Blazars, Radio Gal., …
Galaxies & RQ AGNs: RC accel.









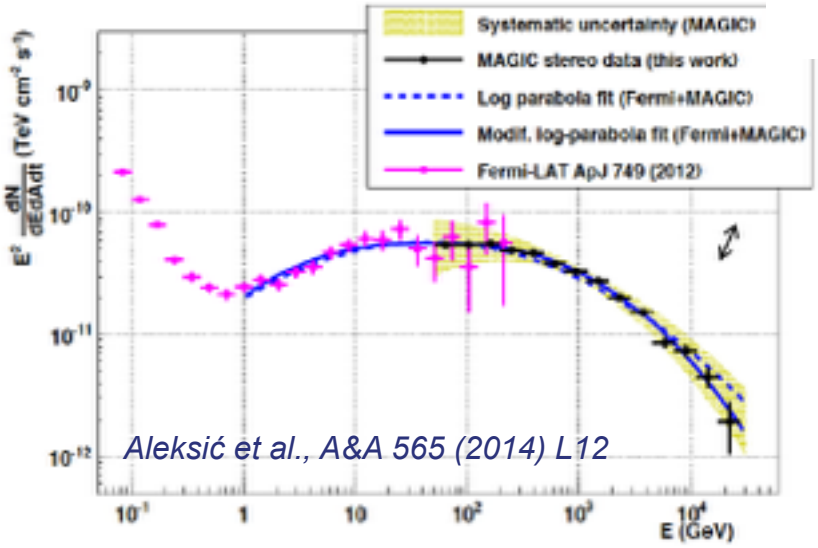
Fundamental physics:
Dark matter, LIV, EBL, IGMF & cosmology

GRBs, GW, Transients

Exploring CRAB with MAGIC

CRAB Nebula:

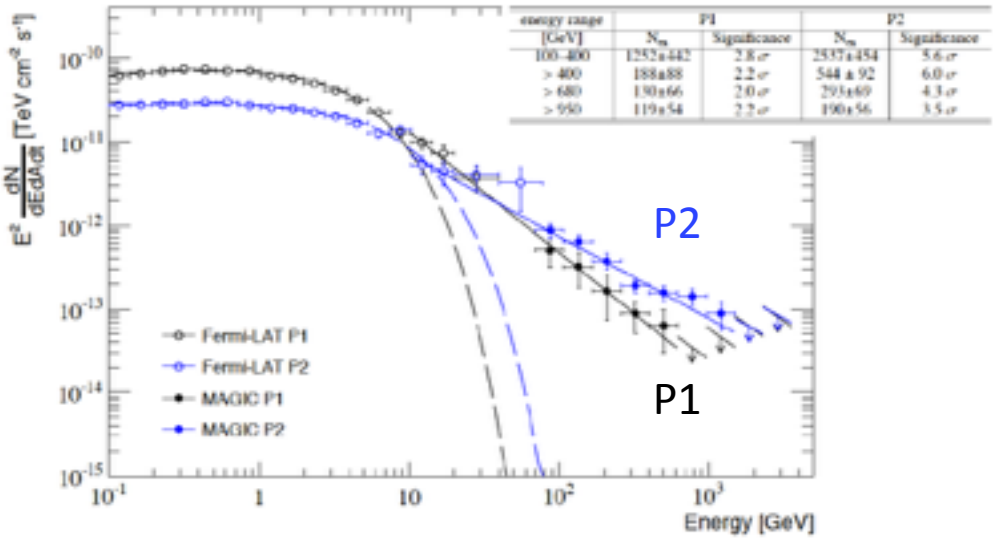
- High precision energy spectrum: 50 GeV to ~30 TeV, 5 bins per decade.
- Observations at E > 80 TeV (high-Zd) are allowing the K-N regime exploration.
- Combined fit with Fermi data yields the most precise measurement of the IC peak: 52.5 +/- 1.6 GeV



Aleksić et al., A&A 565 (2014) L12

CRAB Pulsar:

- First detection of Crab Pulsar at VHE back in 2008 (E>25 GeV).
- 320 hours of observation: detection above 400 GeV; spectrum extending up to TeV energies.
- A VHE emission “bridge” up to 400 GeV

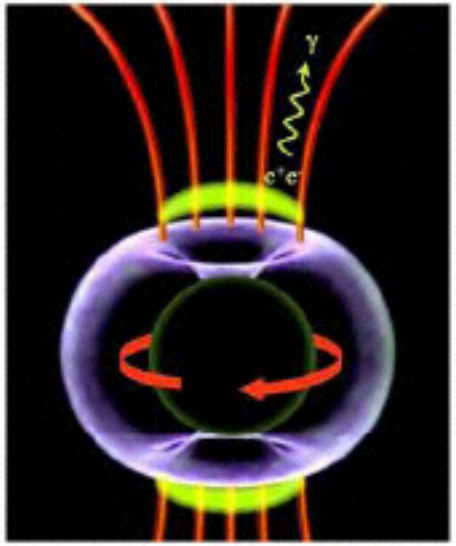


Ansoldi et al., A&A 582 (2016) A133

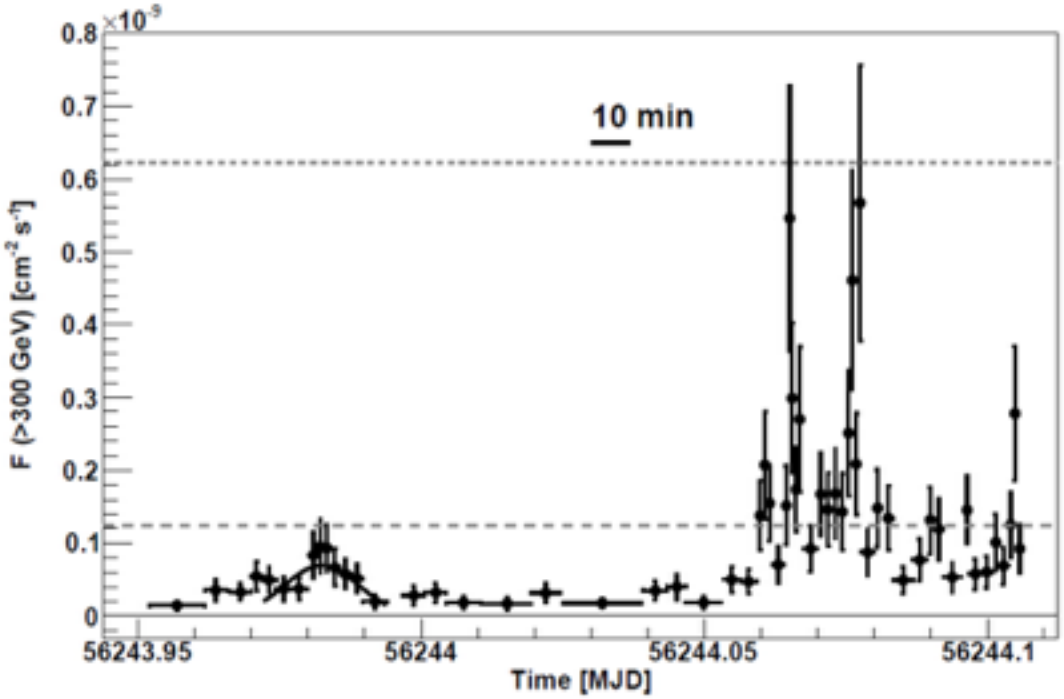
Extreme Flares: the case of IC310

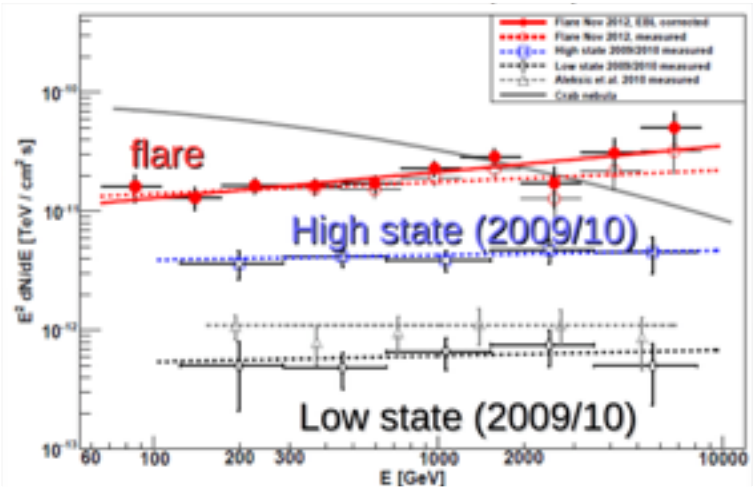
Flaring activity with ultra-fast variability (< 5 min) detected in 2012
=> sub-horizon variability challenges shock-in-jet models.
Possible scenarios:

- mini-jet
- jet-cloud interactions
- magnetospheric origin of gamma-rays



Aleksić et al. (MAGIC) Science 346, 2014





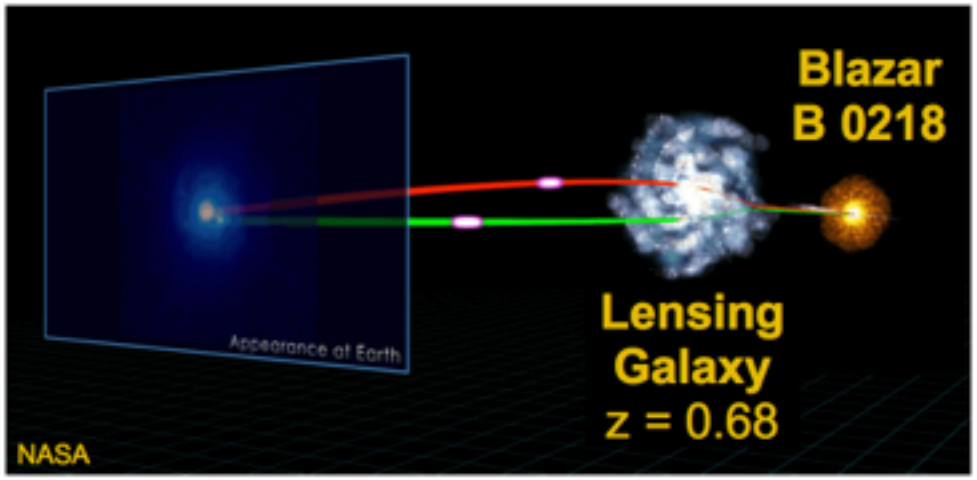
FSRQs

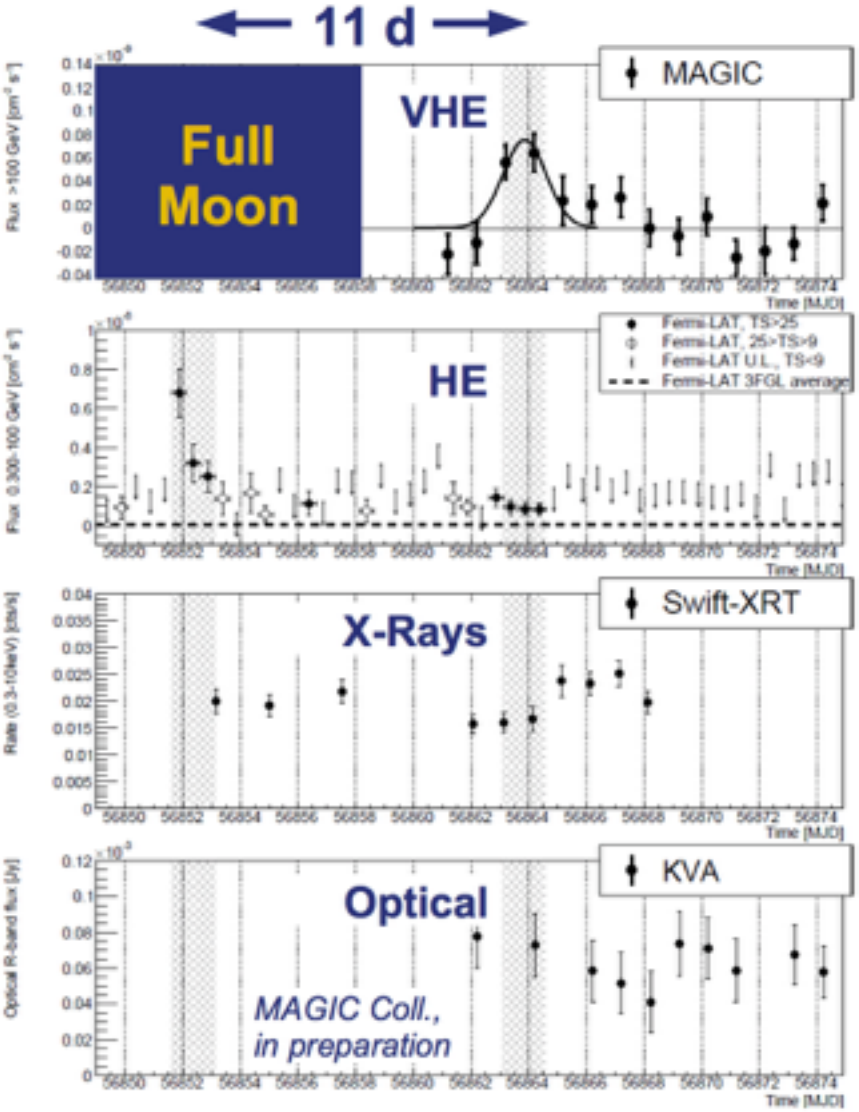
- **Most distant TeV objects ➜ gamma-ray horizon (EBL absorption)**
- **Strong BLR ➜ internal γ-γ absorption (PKS 1222+216)**
- **Delayed lensed emission (B0218+35)**
- **In perspective: precision spectral measurements (wiggles, axions, detailed flare description, IGMF,...)**

FSRQ	*Redshift*	*First VHE detection by:*	*Year*
3C 279	0.536	MAGIC	2006
PKS 1510-089	0.361	HESS	2009
PKS 1222+216 (4C +21.35)	0.432	MAGIC	2010
B0218+35	**0.944**	MAGIC	**2014**
PKS 1441+25	**0.939**	MAGIC	**2015**
S4 0954+65*	0.368	MAGIC	**2015**

B 0218+357

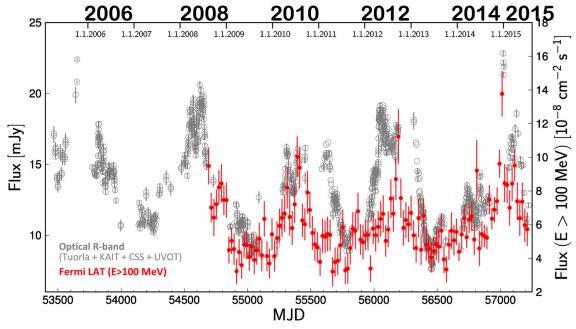
- FSRQ at z = 0.944
- Gravitationally lensed
- Flare in July 2014 → **Discovery**
- Variability in V/HE, none in sub-TeV

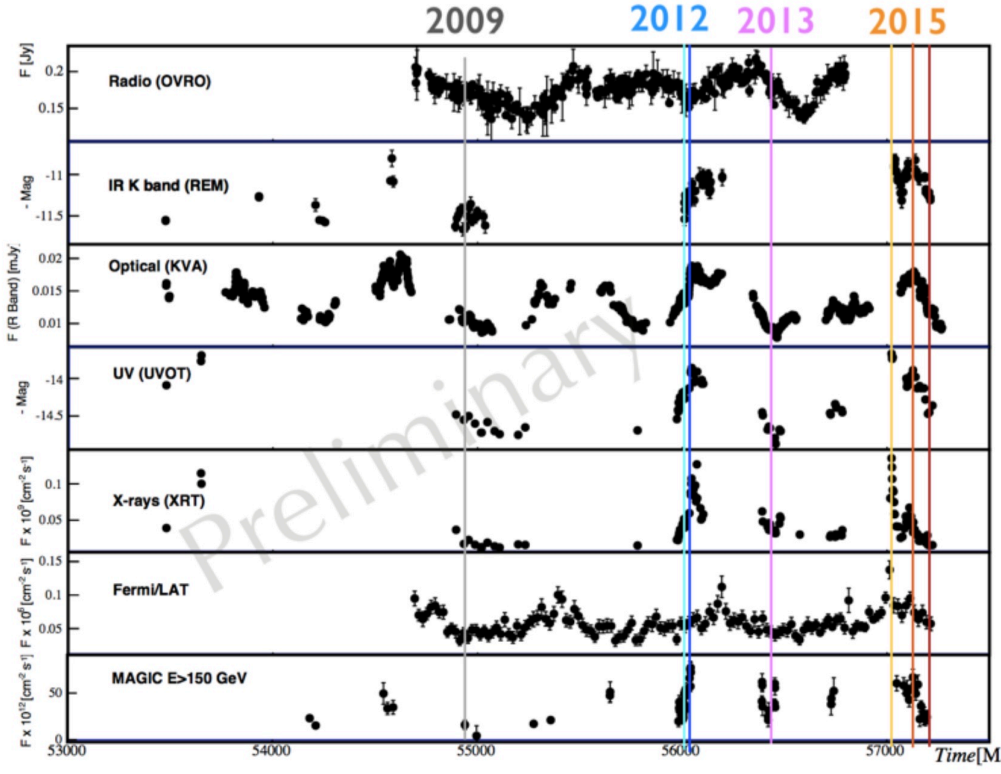




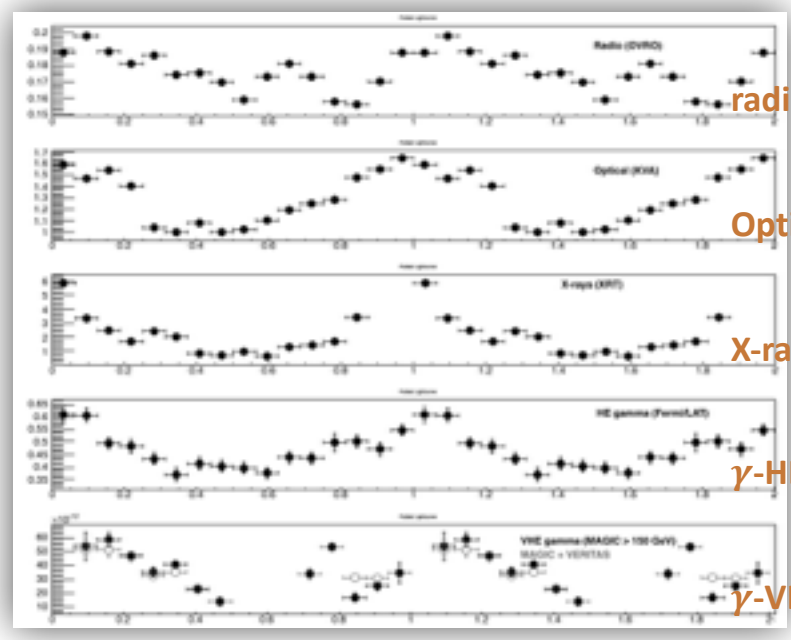
The baseline: a old MAGIC friend with a young touch on periodicity

- Long-term observations with MAGIC since 2005
- MAGIC regular monitoring since 2014





Folded light curves P=783 days



SI Roma

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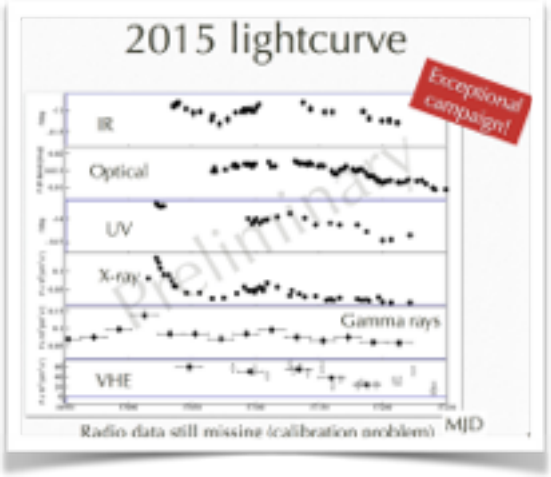
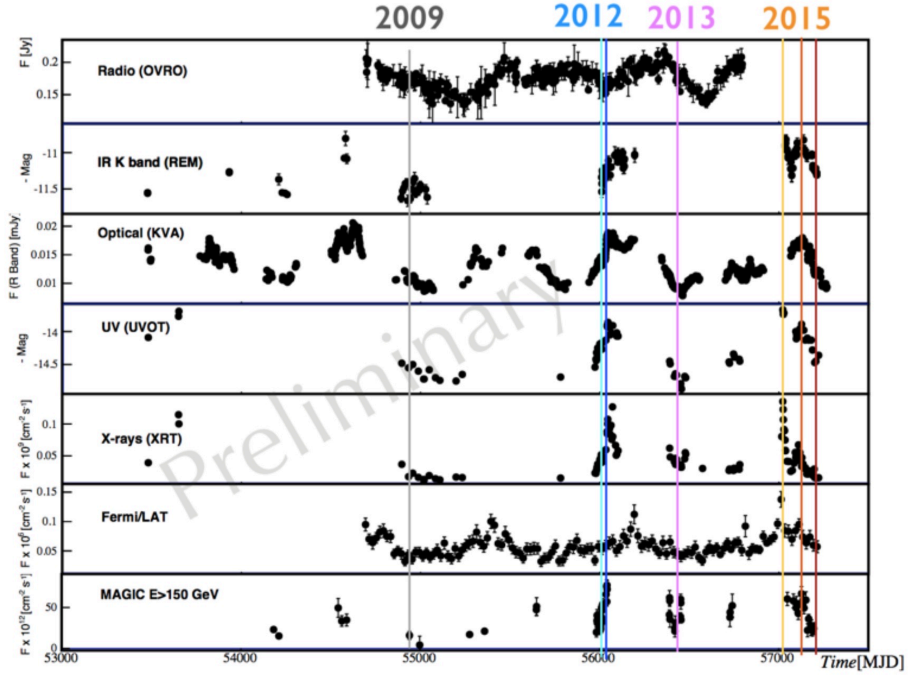
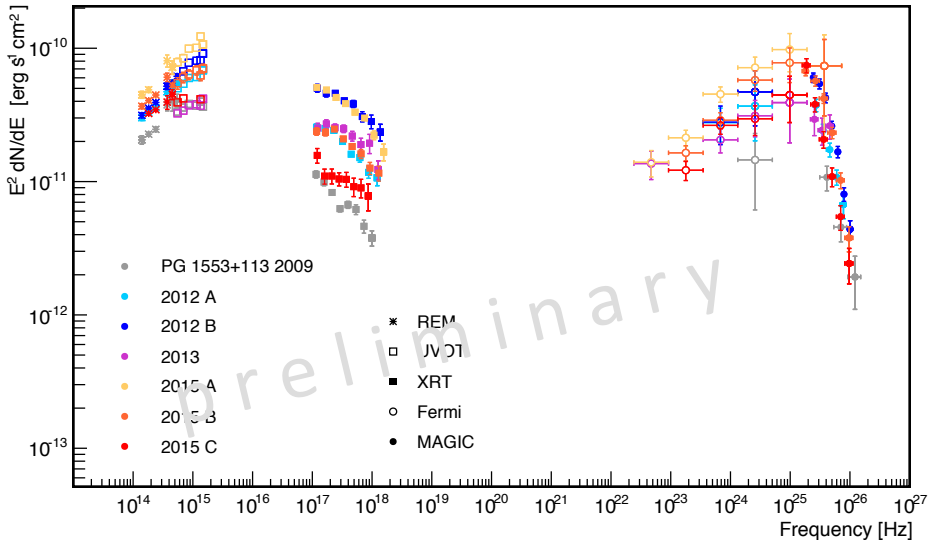




PG 1553+113 in seven different flux states (2009-2015)



hop – ASI Roma

MAGIC coll. + MWL partners, in prep.

Il MAGIC team su PG 1553+113

Simona Paiano - INAF Padova

Elisa Prandini - Università Ginevra e INFN-Padova

Paolo Da Vela - INFN Pisa

Il MAGIC team su PG 1553+113

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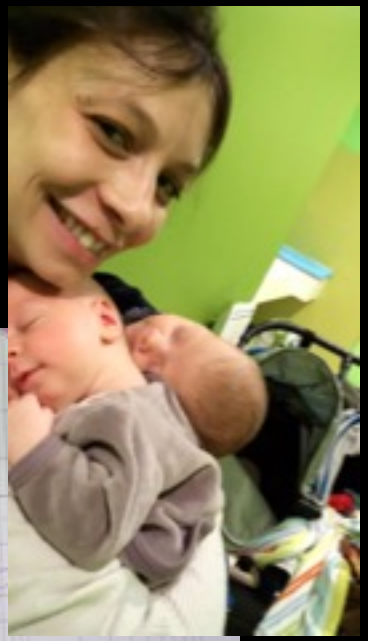


Elisa Prandini - Università Ginevra e INFN-Padova

Paolo Da Vela - INFN Pisa

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
  - MAGIC TeV observations and MWL campaign
- Next maximum expected ~January 2017

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

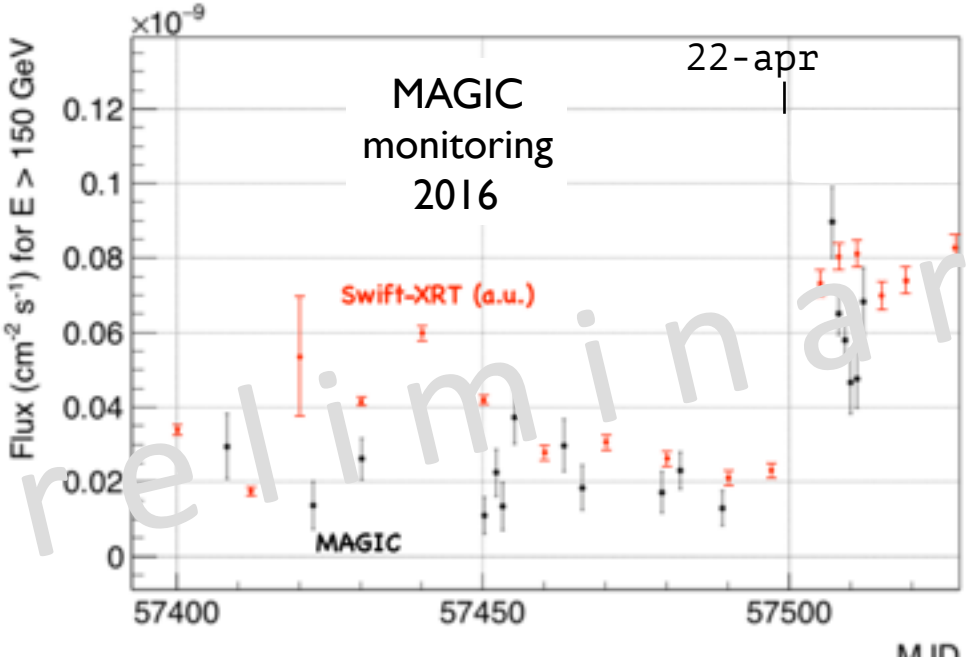
Last month update


The Astronomer's Telegram

The Advent of X-ray Flare in PG 1553+113

- An enhancement of the X-ray flux detected at the end of April (ATel #8998)
- Very good coverage by MAGIC and Swift
- Similar to the flare on April 2012

*Aleksić et al. (MAGIC coll.), 2015 MNRAS, **450***



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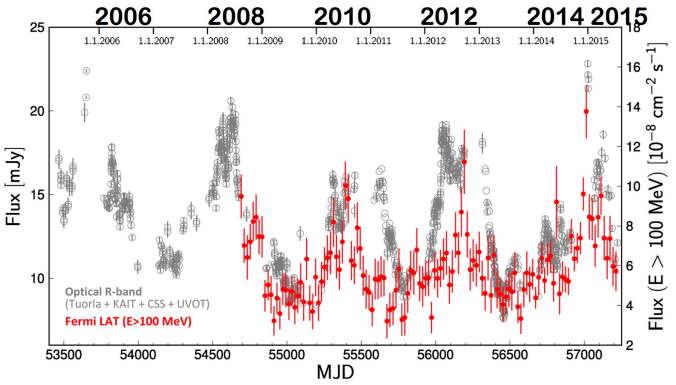
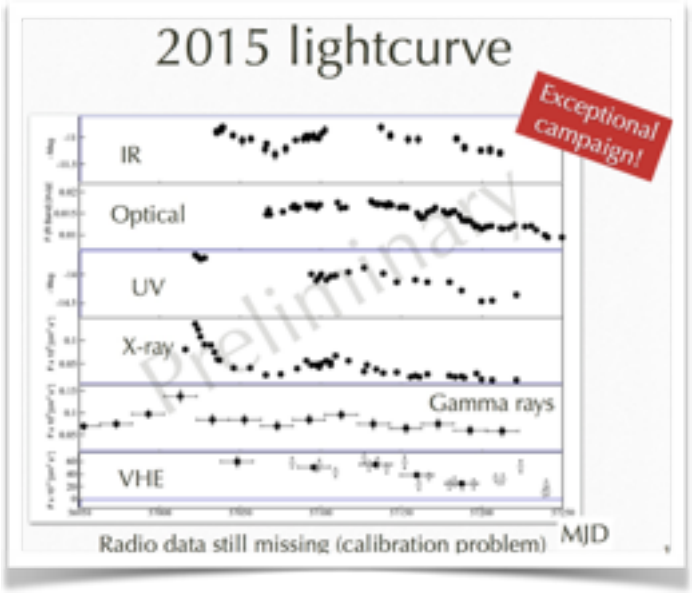
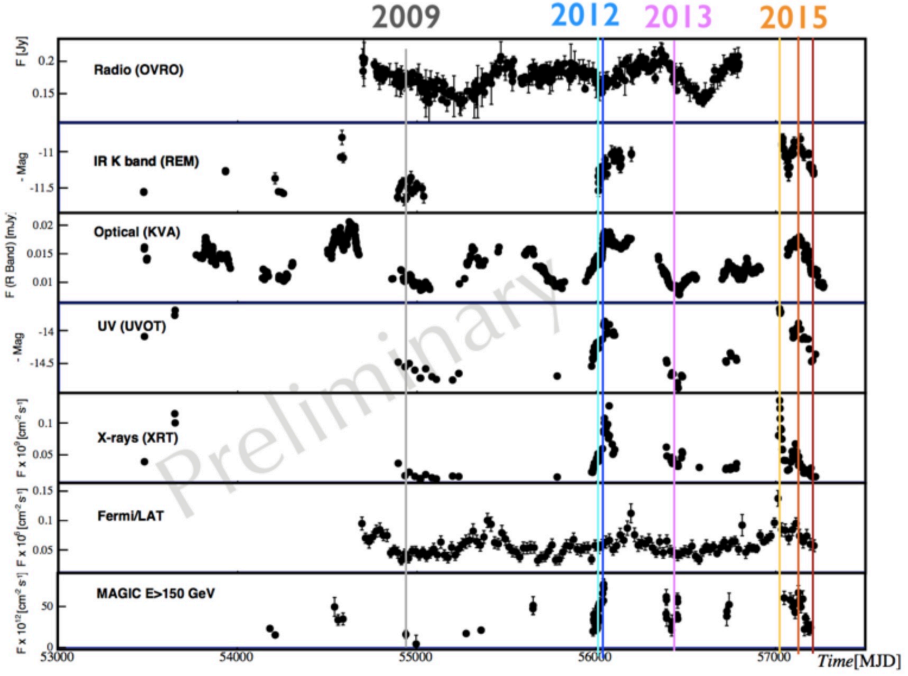


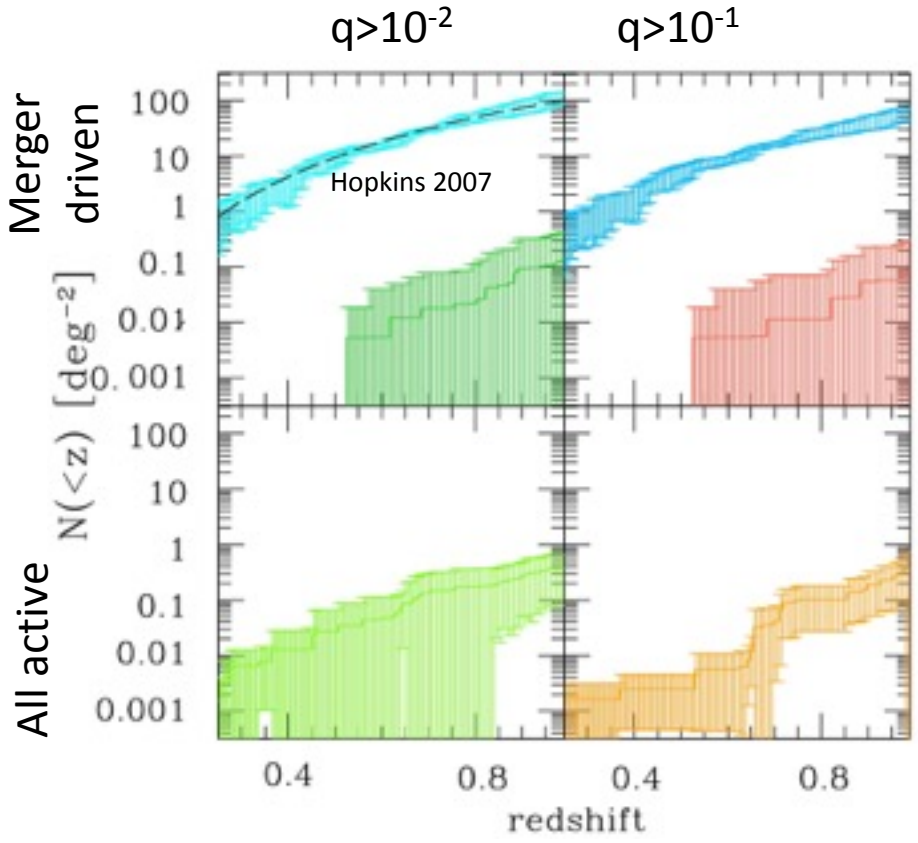




Periodicity and SMBH binaries

- **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?**

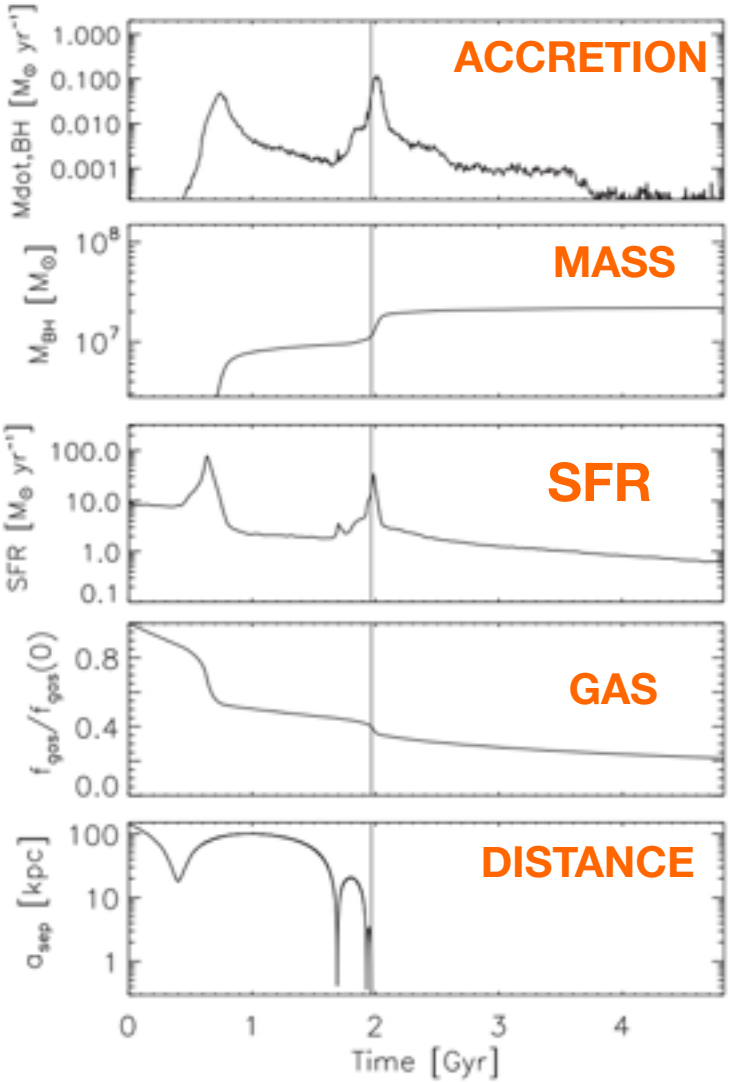
Sub-pc binary quasars
from merger history *Volonteri+2009*



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

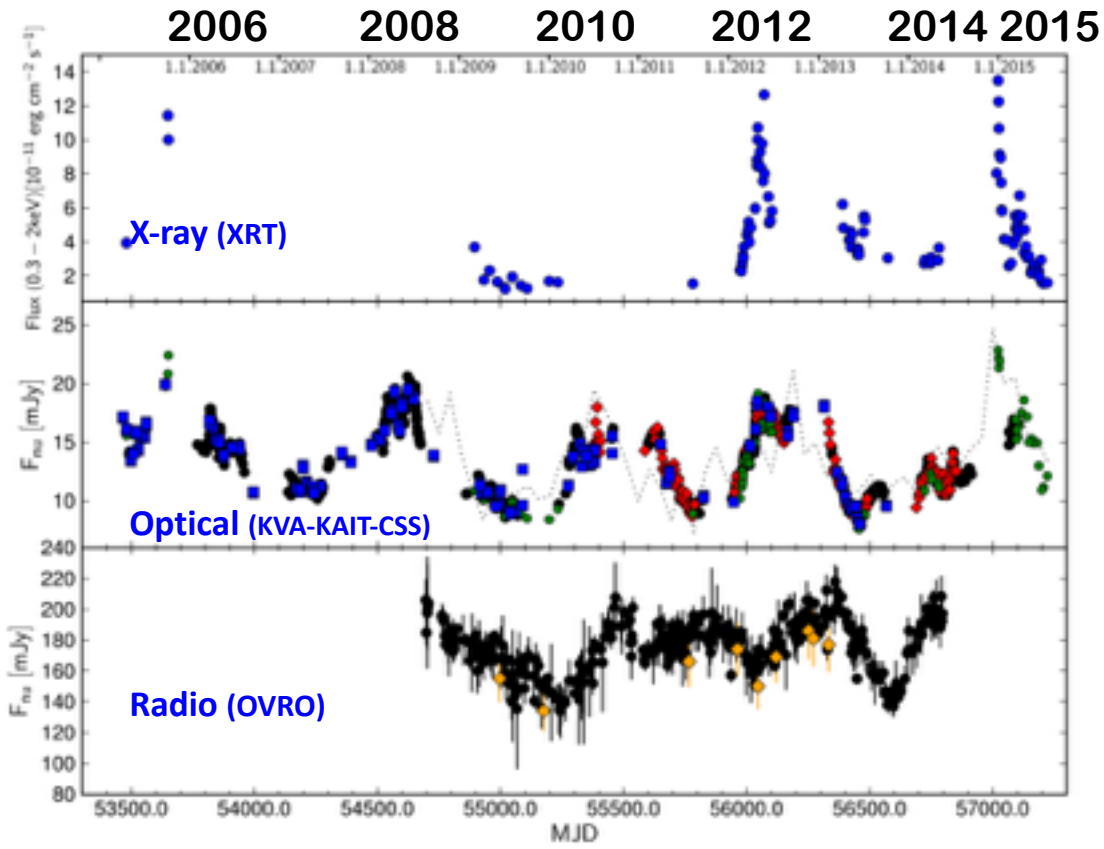
➢ **BL Lac as preferred hosts of SMBH binaries?**



L. Blecha et al. 2011 MNRAS 412

PG1553 periodicity: MWL

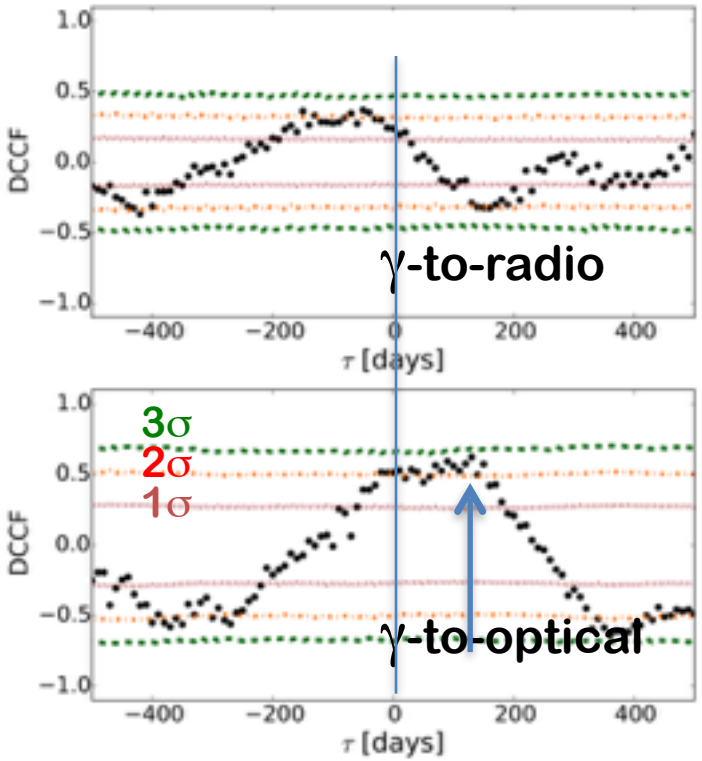
- **MWL: optical, radio, X-ray**
  - **X-ray (XRT) too sparse**



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!**