



Publication Year	2016
Acceptance in OA	2020-07-20T10:19:40Z
Title	Multi-Wavelength Observations On The Gamma-Ray Blazar PG1553+113 As A Probe For Geometrical Periodical Modulation
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Publisher's version (DOI)	10.5281/zenodo.163826
Handle	http://hdl.handle.net/20.500.12386/26514

Multi-wavelengths observations on the gamma-ray blazar PG1553+113 as a probe for geometrical periodical modulation.



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*on behalf of the MAGIC collaboration

and

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and

E. Sobacchi, M. C. Sormani



SCUOLA
NORMALE
SUPERIORE



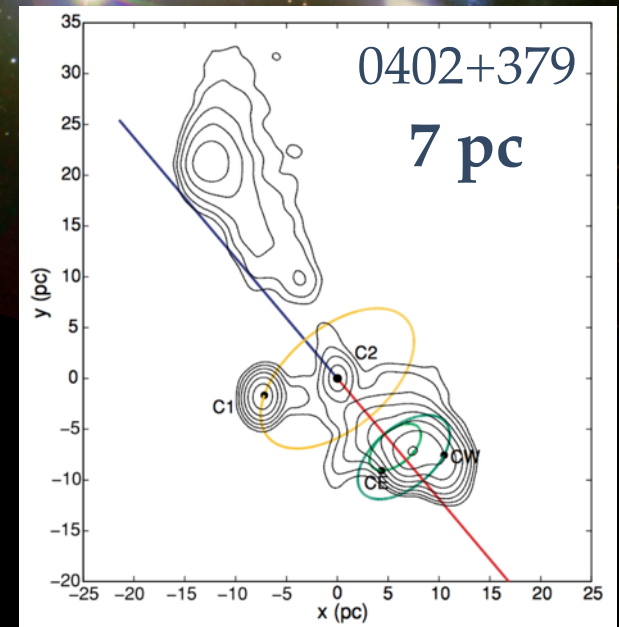
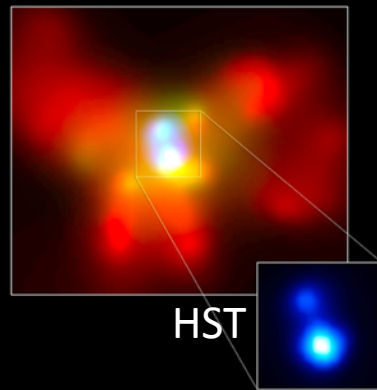
A brief history of the Universe

Hyerarchical structure formation

- Mergers
- SMBH pairs and binaries



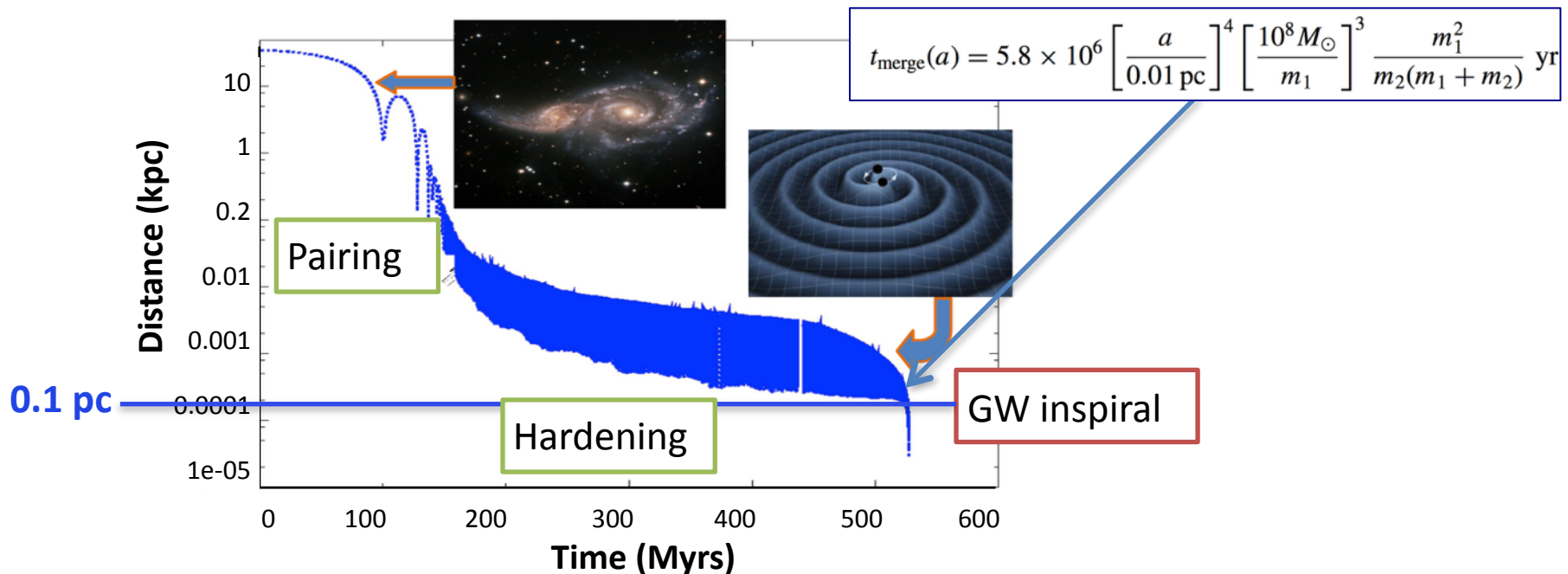
Komossa et al. 2003



Rodriguez et al. 2006, ApJ, 697

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 light-curve
 - **Periodic light-curve**
- **Observational evidence important to solve the theoretical “final pc” problem**



Periodicity and SMBH binaries

- **Reliability of AGN Periodicity**
 - Yearly periodicity over $\sim$ Myr activity
 - The significance of any apparent periodic variation depends on what assumption is made about spurious stochastic variability.
 - Measurement at different wavelength bands
- **AGN periodicity $\rightarrow$ binary BH system?**
 - Different plausible models with single SMBH
 - interpretation needs support by observations

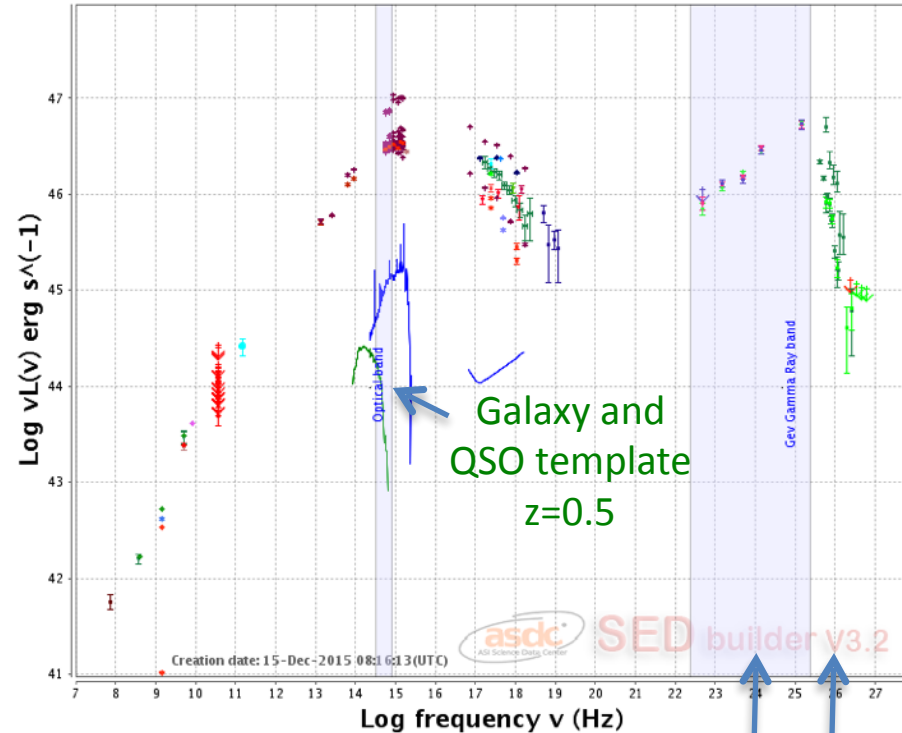
Multi-wavelength (MWL) observations are key in the interpretation!

PG 1553+113

- Blazar, radio-loud, HBL
 - Uncertain redshift $z \sim 0.5$
Danforth et al. 2010, also Abramowski et al. 2015
- Well established γ -ray emitter and TeV source
- Dominant non-thermal emission from the jet

→ *Raiteri, AS, et al. MNRAS 2015*

PG1553+113 Ra=238.93000 deg Dec=11.18917 deg (NH=3.6E20 cm⁻²)



Radio

IR-optical

X

GeV

TeV

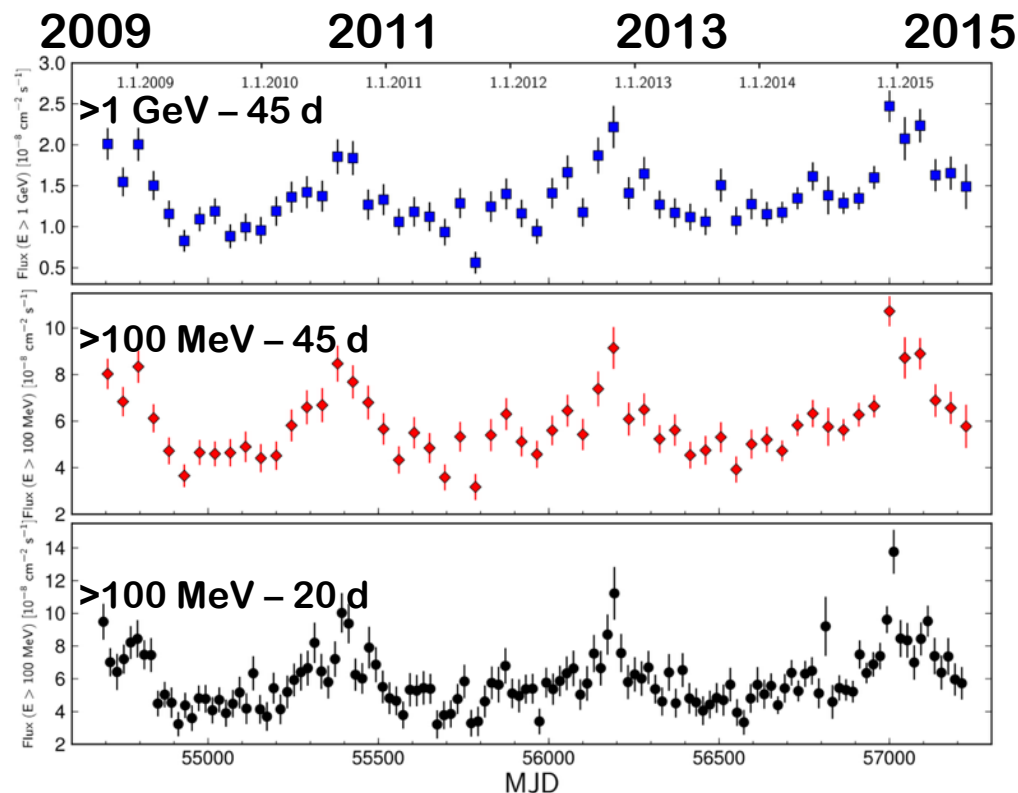
PG1553 periodicity in Fermi/LAT

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

- 3.5 cycles over ~ 7 years
- confirmed in optical!

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

► S. Cutini
talk



Interpretation of periodicity

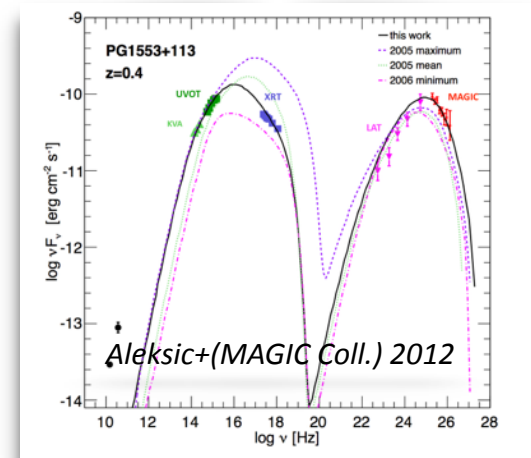
PG1553+113 dominated by non-thermal emission from the jet.



Periodicity may be the result of:

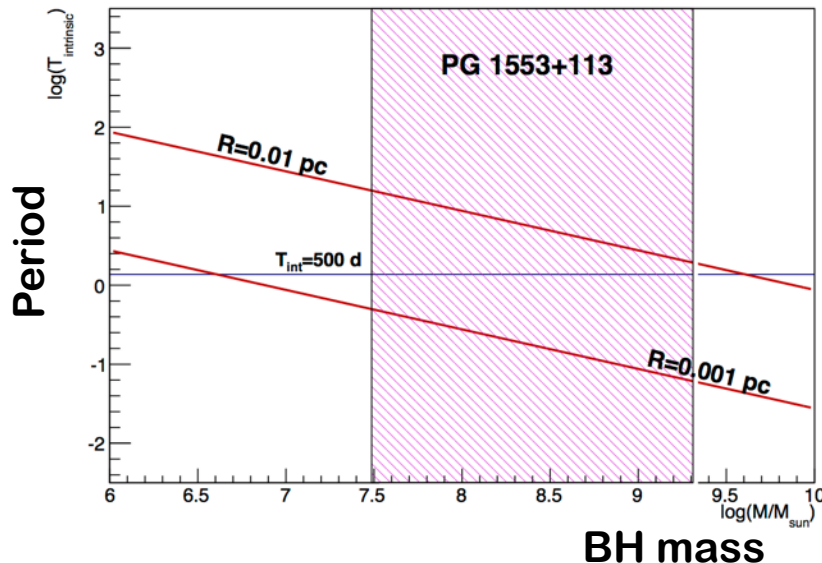
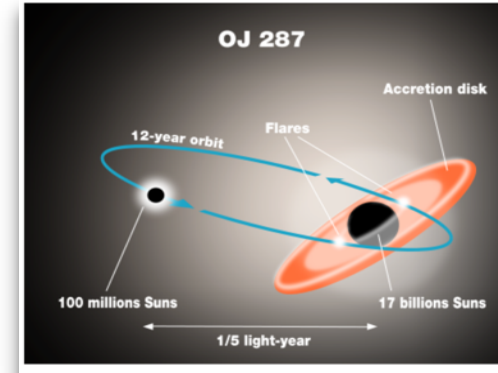
- Processes at the base of the jet inducing quasi-periodic oscillations
- Geometrical effects on the jet

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



Binary SMBH system

- **Accretion rate perturbations**
 - claims on e.g. PG1302-102 Graham+2015 or OJ287 Sillampää+1988, Lehto&Valtonen 1996
- **Variation of jet viewing angle $\rightarrow$ Doppler factor $\Gamma \sim 20 \sim 1^\circ \rightarrow \sim 40\% \rightarrow \text{flux} \sim 3$**



milli-pc system: gravitational wave driven inspiral stage!

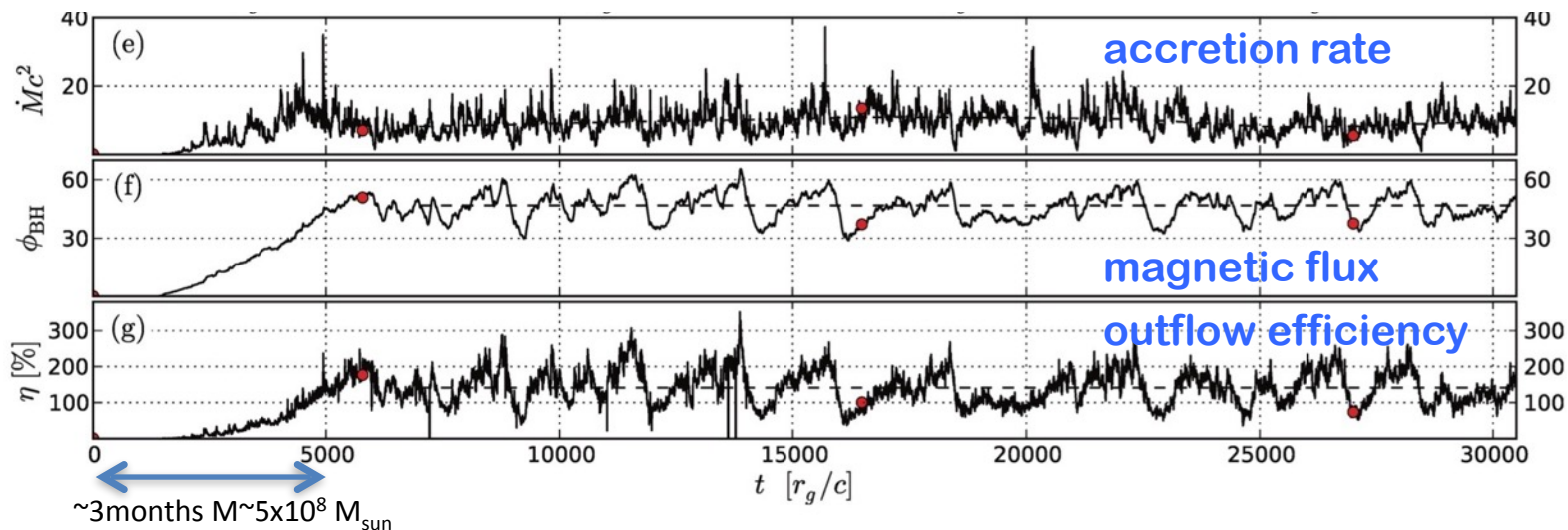
Single SMBH

Jet feeding

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

Geometrical

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



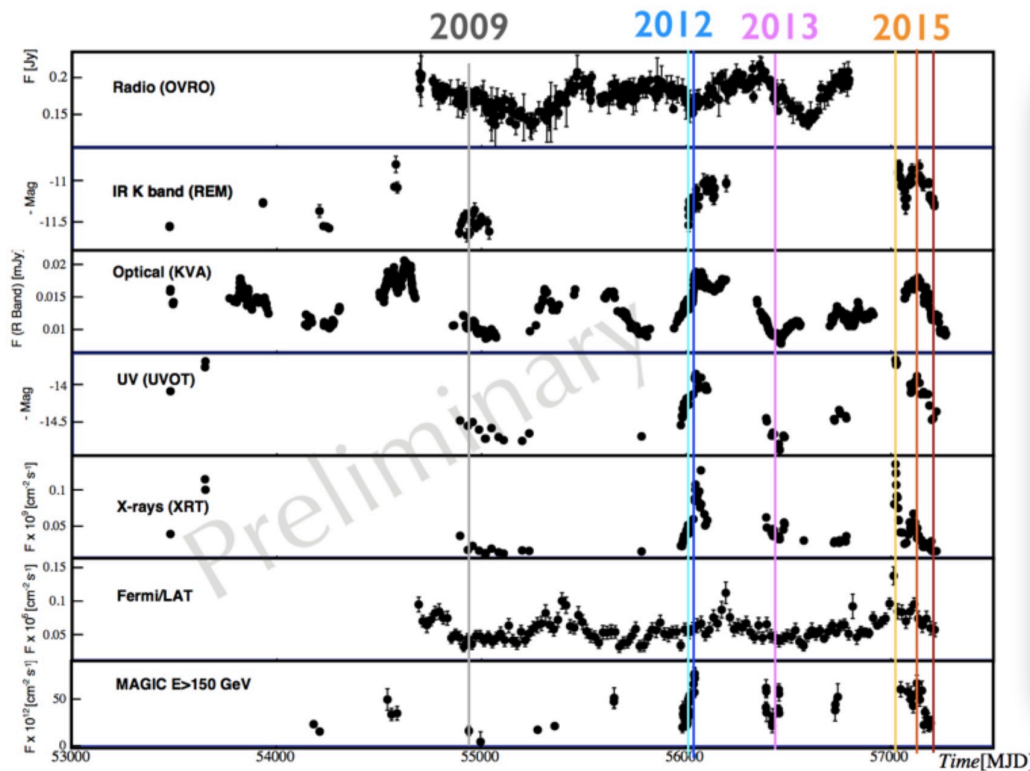
MWL campaign

- 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

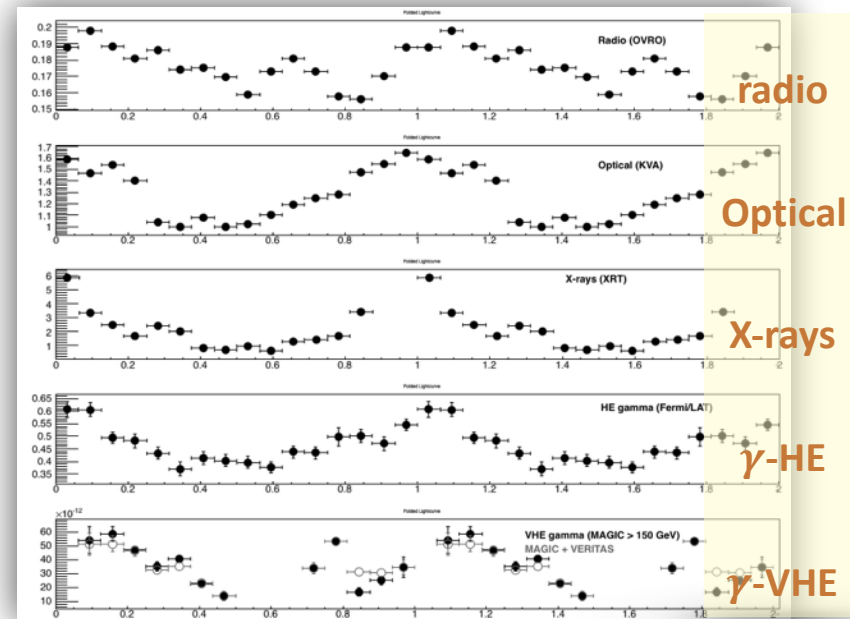
The baseline: a old MAGIC friend with a young touch on periodicity

- Long-term observations with MAGIC since 2005

MAGIC coll. + MWL partners, in prep.



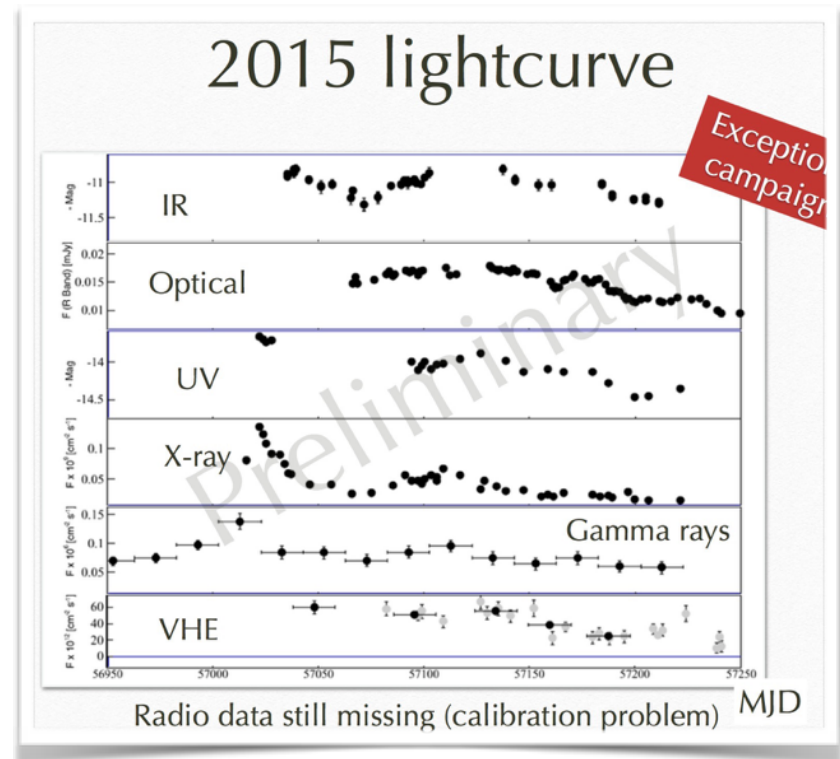
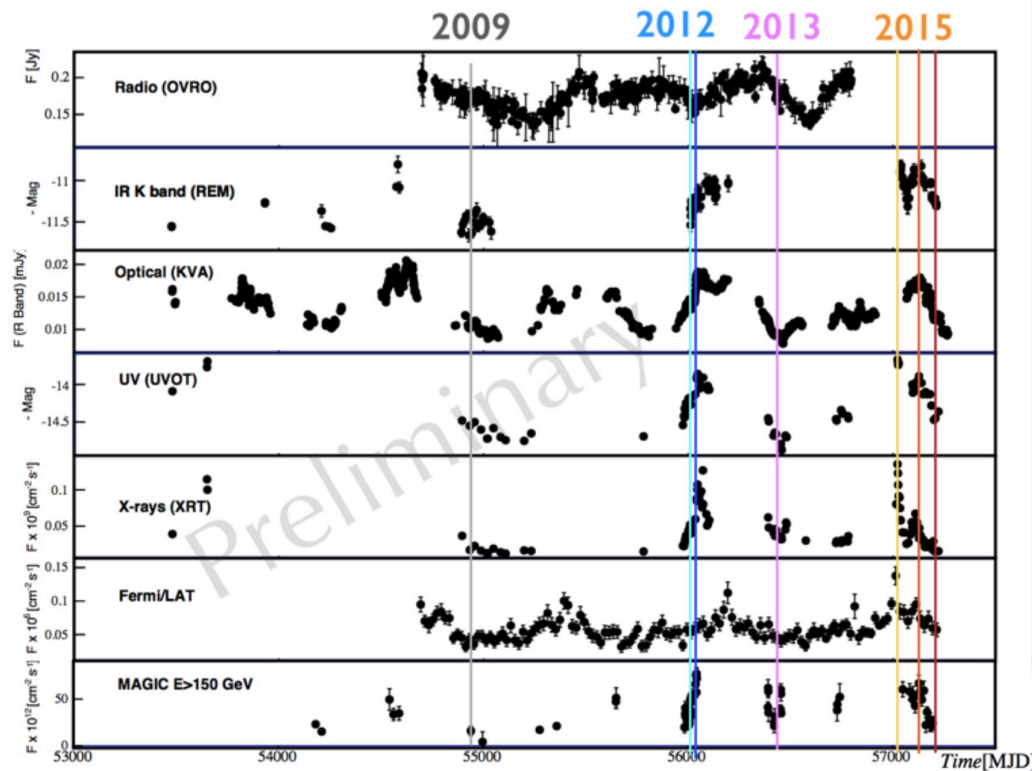
Folded light curves $P=783$ days



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

MAGIC coll. + MWL partners, in prep.

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



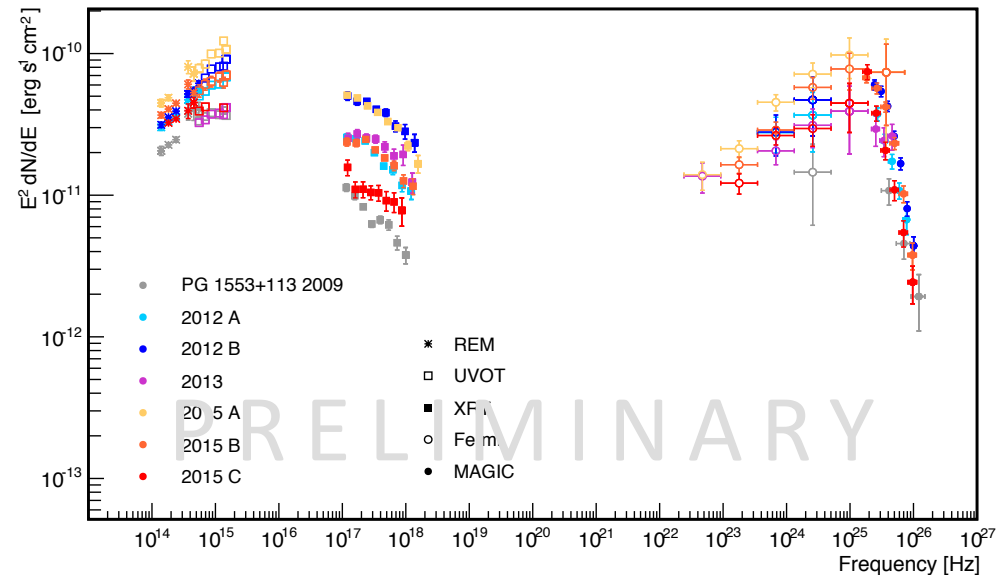
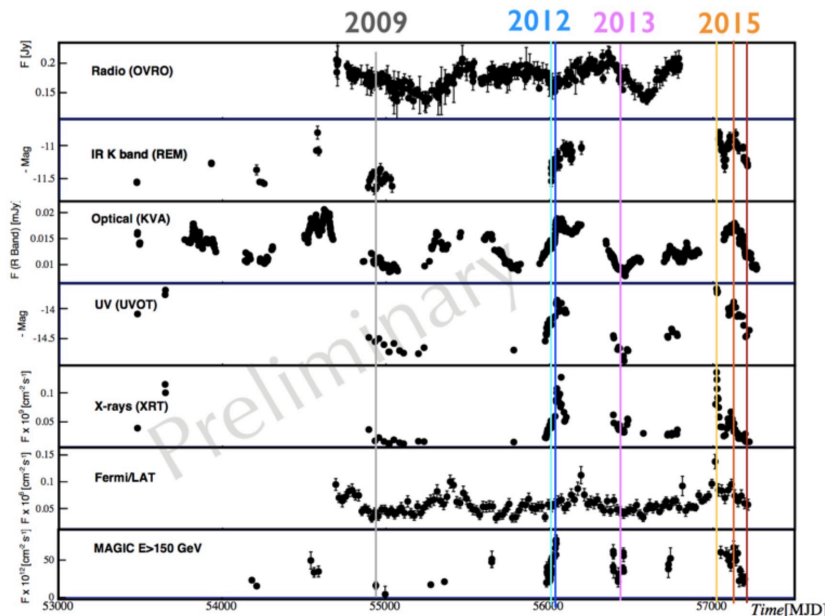
ssenger perspective – Napoli

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

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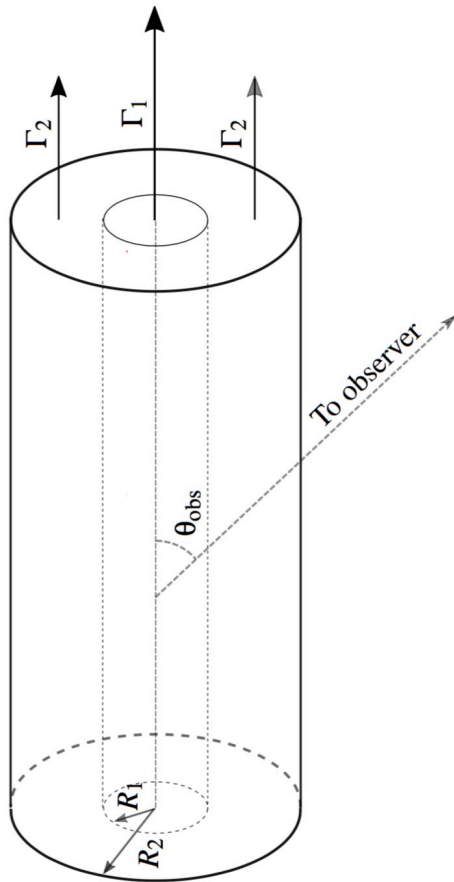
- Long-term observations with MAGIC since 2005
- MAGIC regular monitoring since 2014
- correlation studies, time lags, SED,... in progress

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



A geometrical model

E. Sobacchi, M. Sormani, AS (subm.)



- **Structured jet** (spine+sheath)

$$F_{\text{tot}} = \frac{\pi L R_2^2}{D^2} \left(\int_{-\infty}^{+\infty} j_0(y) dy \right) \left[\lambda \delta_1^3 + (1 - \lambda) \delta_2^3 \right]$$

emissivity *geometrical factor*

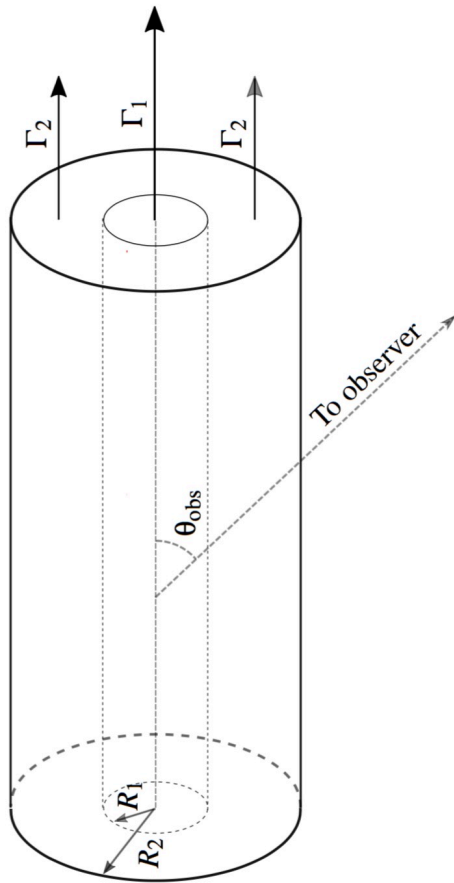
λ : relative contribution sheath/spine

δ : Doppler factor



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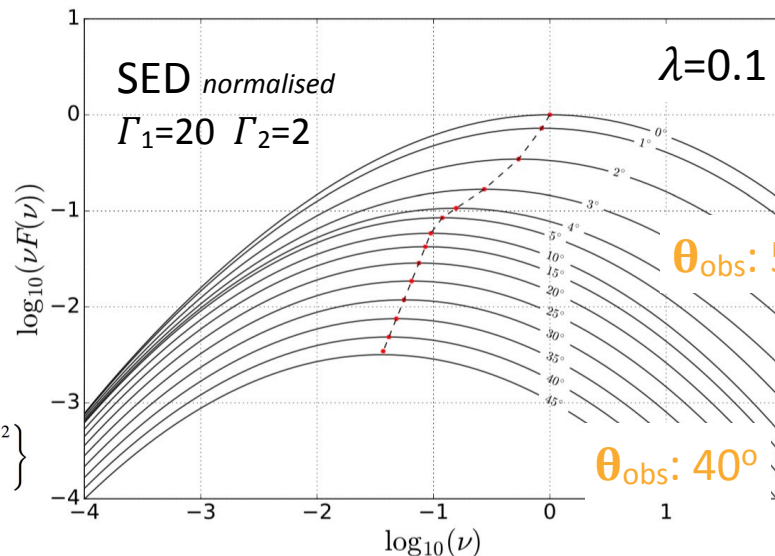
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Logpar SED

$$\frac{\nu F(\nu, \hat{n})}{\nu_P F(\nu_P)} = \lambda \delta_1^3 \exp \left\{ -b \left[\log \left(\frac{\nu}{\delta_1 \nu_P} \right) \right]^2 \right\} + (1 - \lambda) \delta_2^3 \exp \left\{ -b \left[\log \left(\frac{\nu}{\delta_2 \nu_P} \right) \right]^2 \right\}$$



$\theta_{\text{obs}}: 0^\circ$

slope: 1

$\theta_{\text{obs}}: 5^\circ$

slope: 3

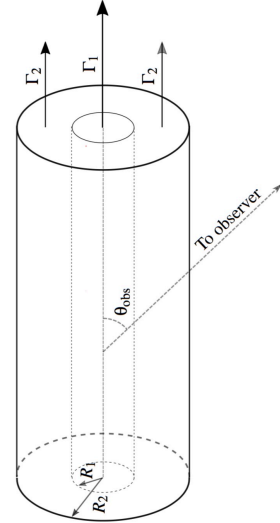
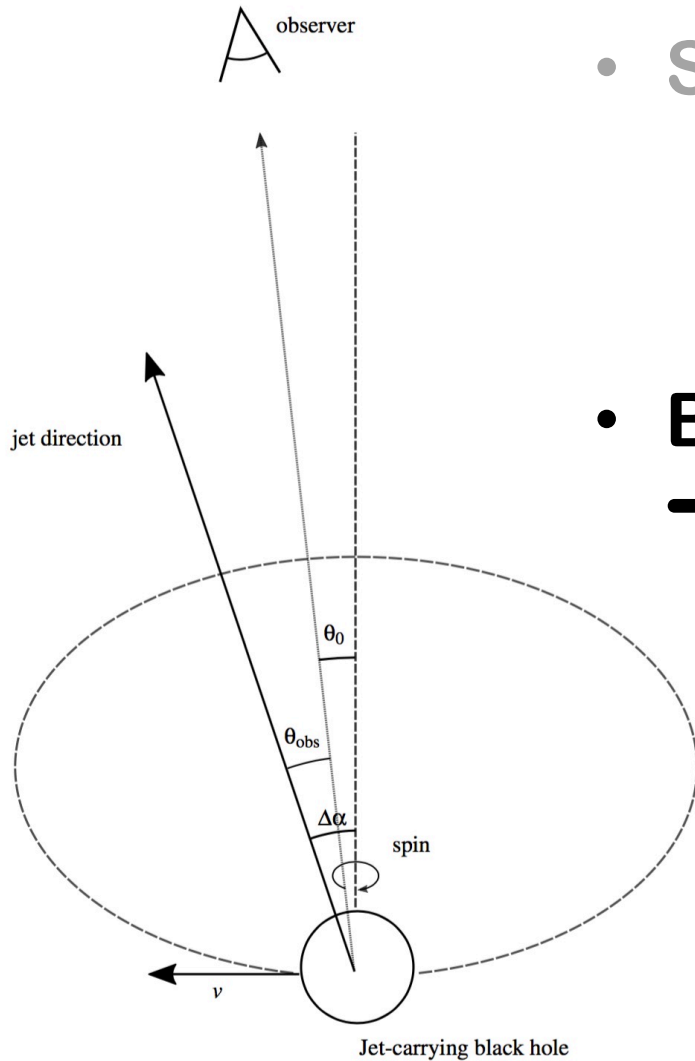
$\theta_{\text{obs}}: 40^\circ$

A geometrical model

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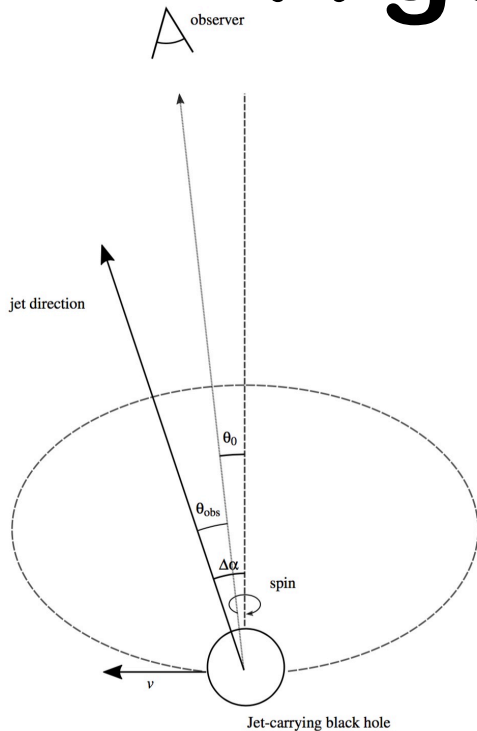
- **Structured jet** (spine+sheath)

- **Binary system**
→ orbital velocity + beam

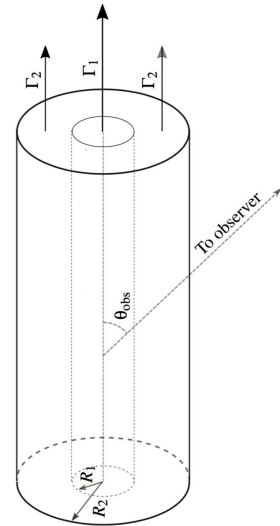


A geometrical model

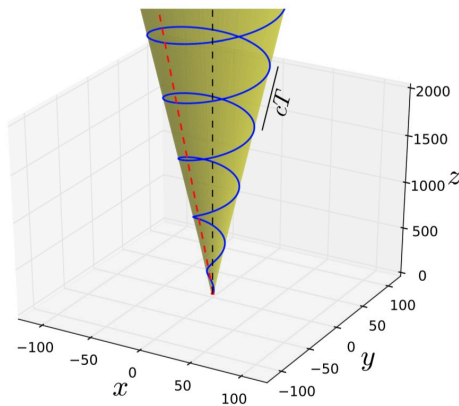
E. Sobacchi, M. Sormani, AS (subm.)



- **Structured jet (spine+sheath)**



- **Binary system**
→ orbital velocity + beam
- **Preceding ballistic jet**
→ variation of emission angle
→ helical structure in space
→ Doppler factor variation



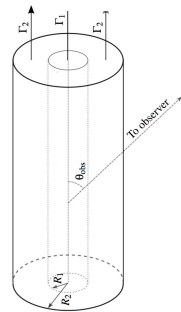
A geometrical model: PG 1553+113

E. Sobacchi, M. Sormani, AS (subm.)

- QPO Light curve

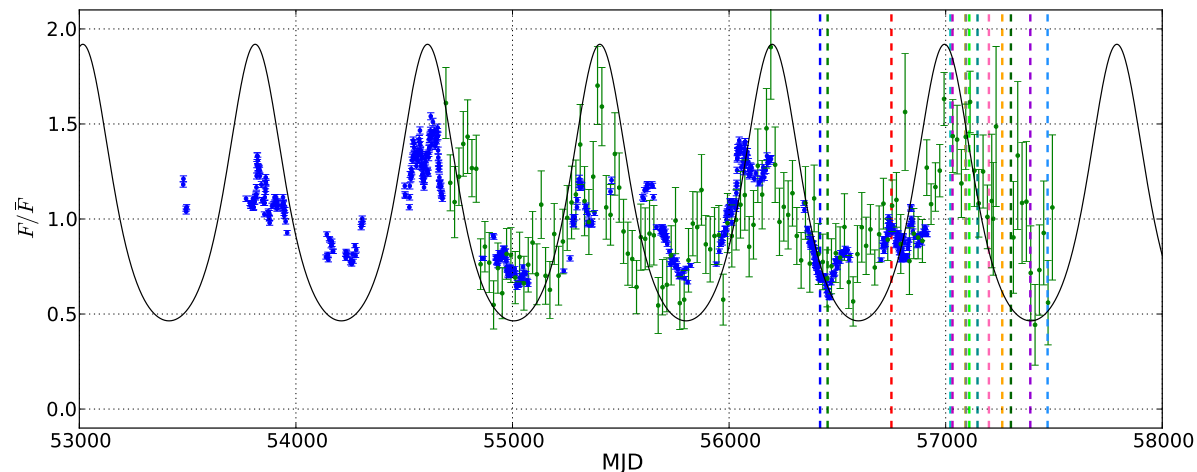
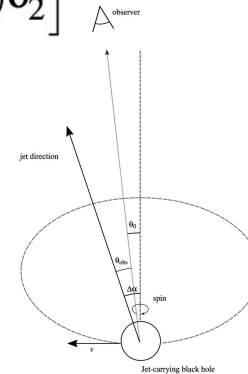
$$F_{\text{tot}} = \frac{\pi L R_2^2}{D^2} \left(\int_{-\infty}^{+\infty} j_0(y) dy \right) \left[\lambda \delta_1^3 + (1 - \lambda) \delta_2^3 \right]$$

$$1^\circ < \theta_{\text{obs}} < 7^\circ$$



jet-param. binary-syst

Γ_1	Γ_2	λ	θ_0	$\Delta\alpha$	Ω_{obs}
7.0	1.1	0.1	4°	3°	2.88 yr^{-1}



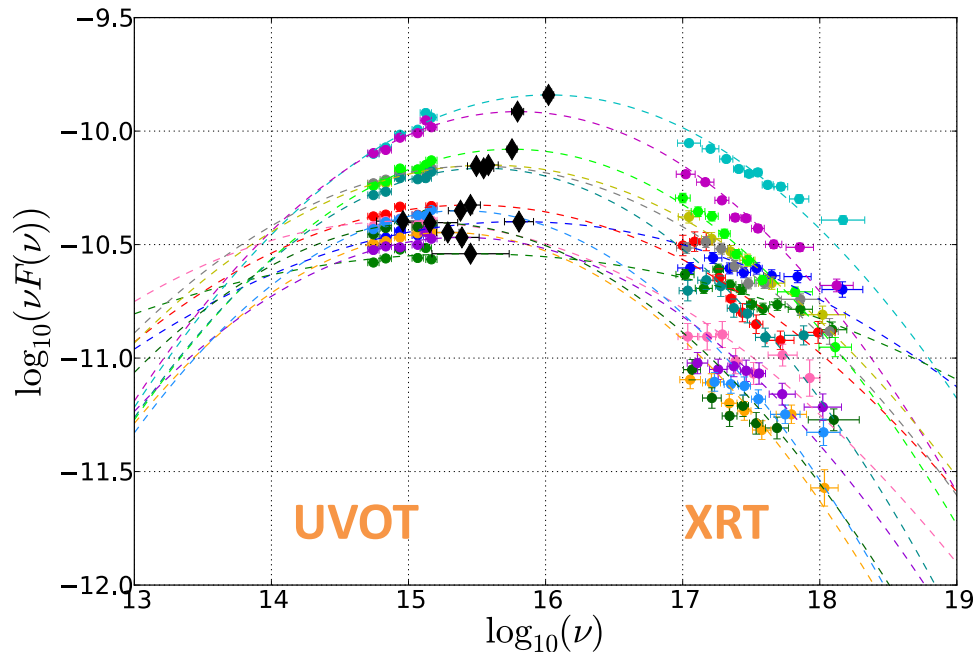
Fermi/LAT

Optical

A geometrical model: PG 1553+113

E. Sobacchi, M. Sormani, AS (subm.)

- Synchrotron SED
 - Swift UVOT and XRT
 - Logpar fit to get peak

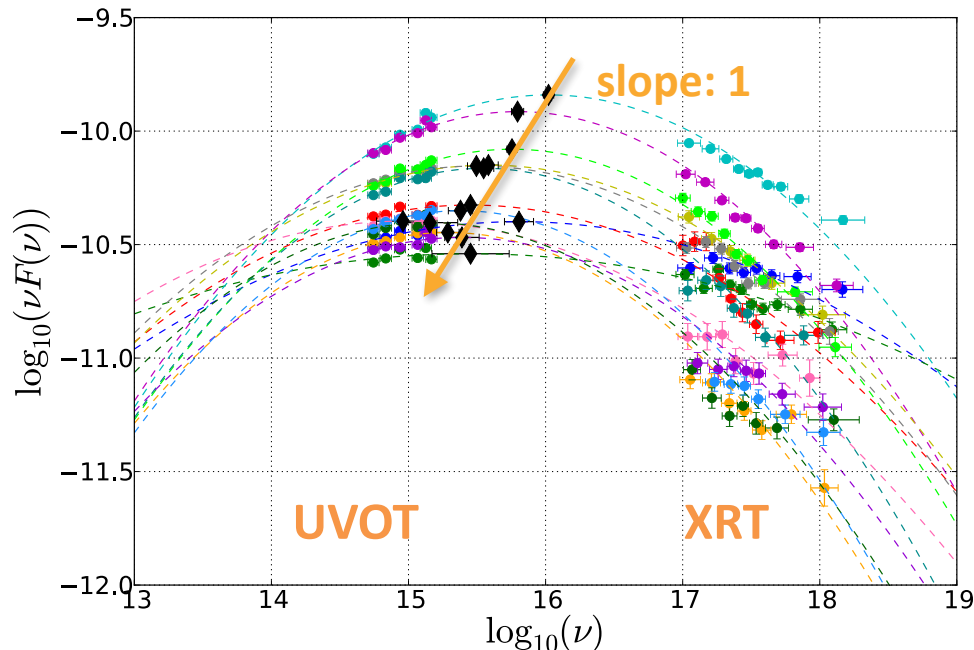


◆ synch-Peaks

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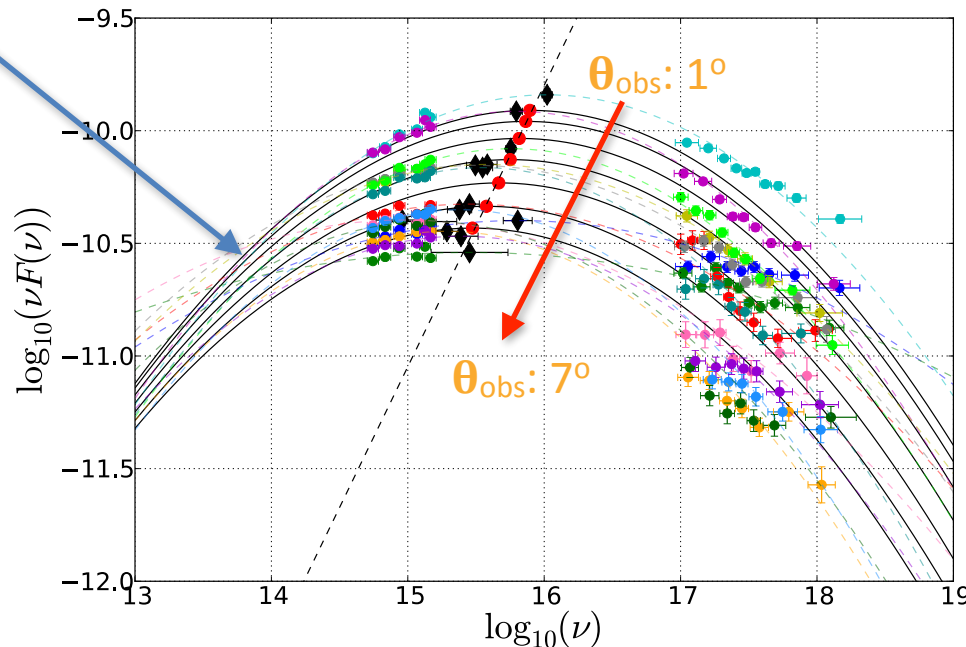
- **Synchrotron SED**

Good agreement of BOTH SED and light curve!

$$\frac{\nu F(\nu, \hat{n})}{\nu_P F(\nu_P)} = \lambda \delta_1^3 \exp \left\{ -b \left[\log \left(\frac{\nu}{\delta_1 \nu_P} \right) \right]^2 \right\} + (1 - \lambda) \delta_2^3 \exp \left\{ -b \left[\log \left(\frac{\nu}{\delta_2 \nu_P} \right) \right]^2 \right\}$$

Γ_1	Γ_2	λ	θ_0	$\Delta\alpha$	Ω_{obs}	b	ν_P	$\nu_P F(\nu_P)$
7.0	1.1	0.1	4°	3°	2.88 yr ⁻¹	0.16	7.1 × 10 ¹⁴ Hz	4.3 × 10 ⁻¹² erg cm ⁻² s ⁻¹

Logpar
SED



◆ synch-Peaks

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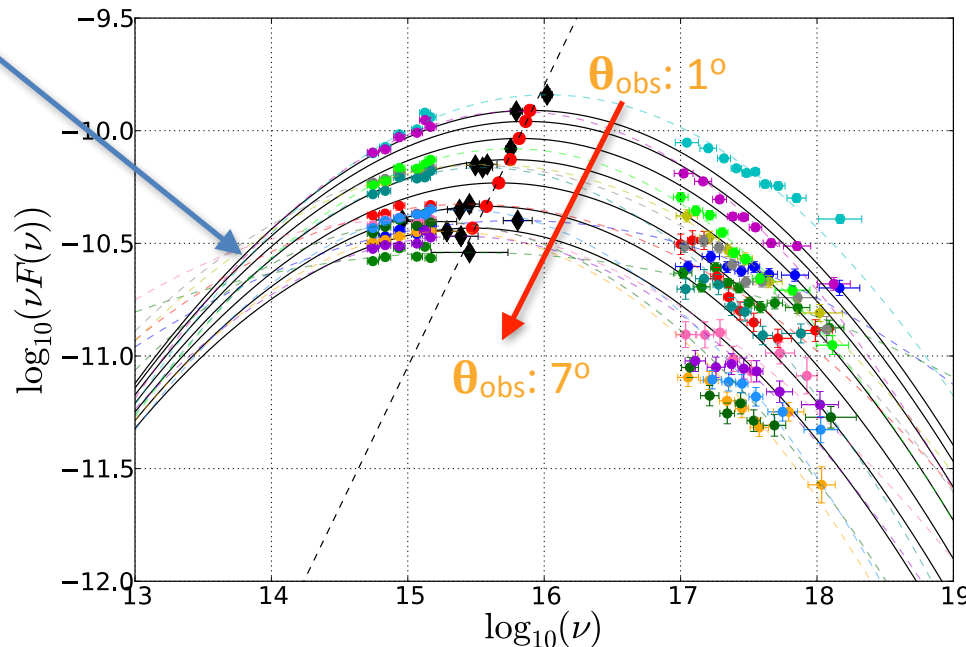
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Logpar
SED



◆ synch-Peaks

Estimated parameters
of the binary system

$$R = 1.1 \times 10^{16} \left(\frac{1+q}{q} \right) \text{ cm}$$

$$M = 2.1 \times 10^8 \left(\frac{1+q}{q} \right)^3 M_{\odot}$$

$q \sim 1$

Summary

- PG 1553+113 first AGN with evidence of multi-frequency periodic emission.
- Interpretation still open
 - Possible milli-pc SMBH binary system
 - QPO from helical paths or flow instabilities
- Dedicated geometrical model explains light-curve and behaviour of SED variability
- Regular MWL observations led by MAGIC 
 - Disentangle flaring episodes from long-term modulation
 - MAGIC TeV observations and MWL campaign
- ✦ **Next maximum expected from January 2017**

