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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

S. Cutini, A. Sandrinelli

and

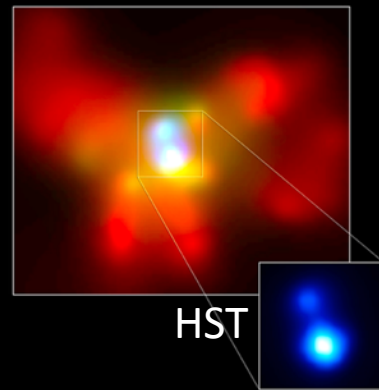
E. Sobacchi, M. C. Sormani



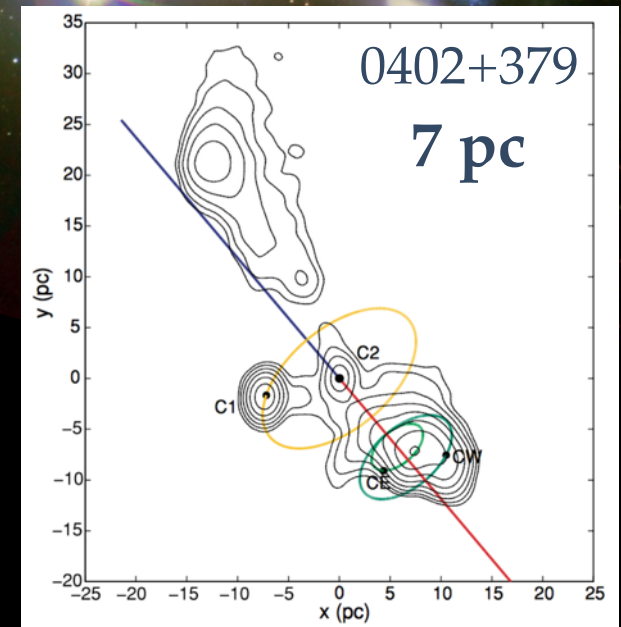
A brief history of the Universe

Hierarchical structure formation

- Mergers
- SMBH pairs and binaries



Komossa et al. 2003

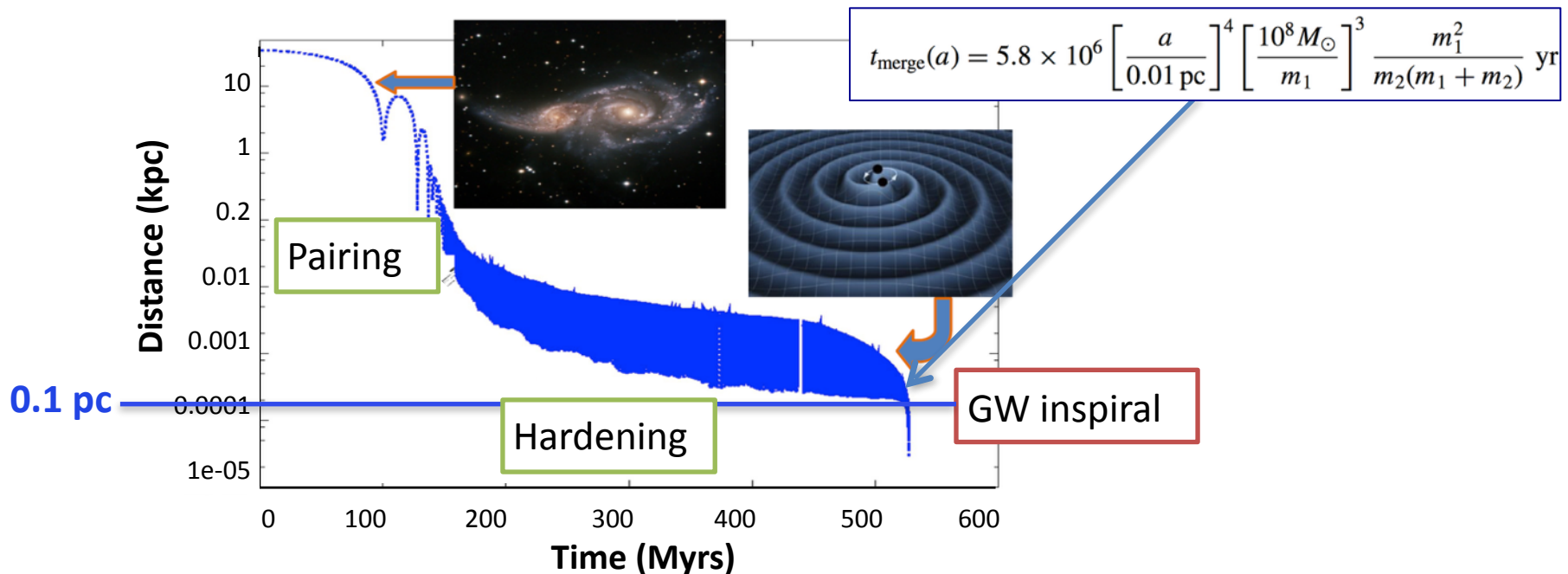


Rodriguez et al. 2006, ApJ, 697

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

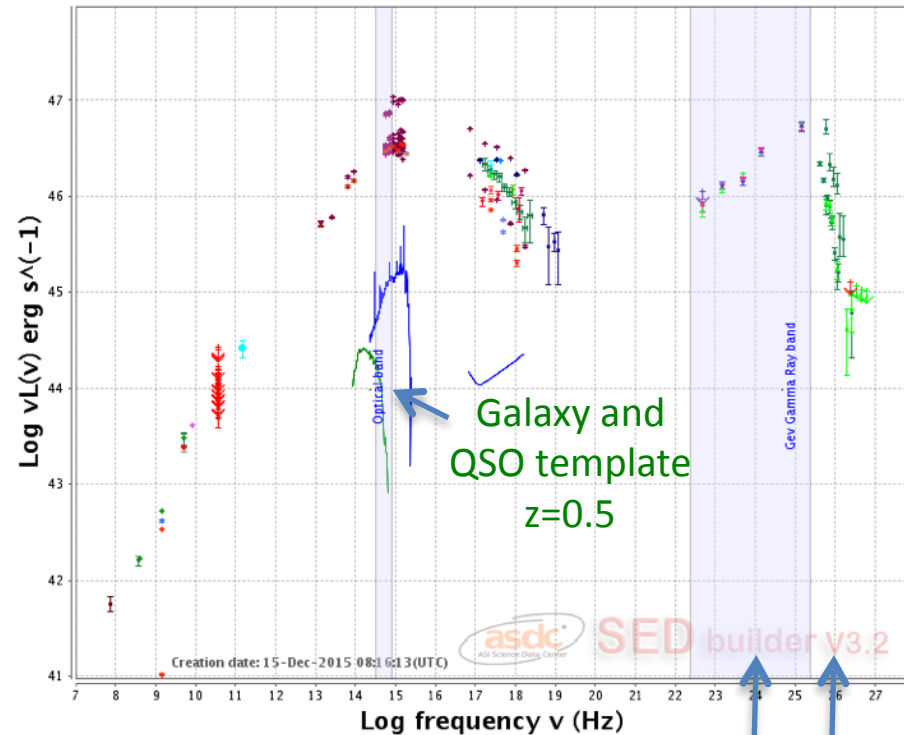
- **AGN periodicity \rightarrow binary BH system?**
 - Different plausible models with single SMBH
 - interpretation needs support by observations

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**

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



→ *Raiteri, AS, et al. MNRAS 2015*

Radio IR-optical X GeV TeV

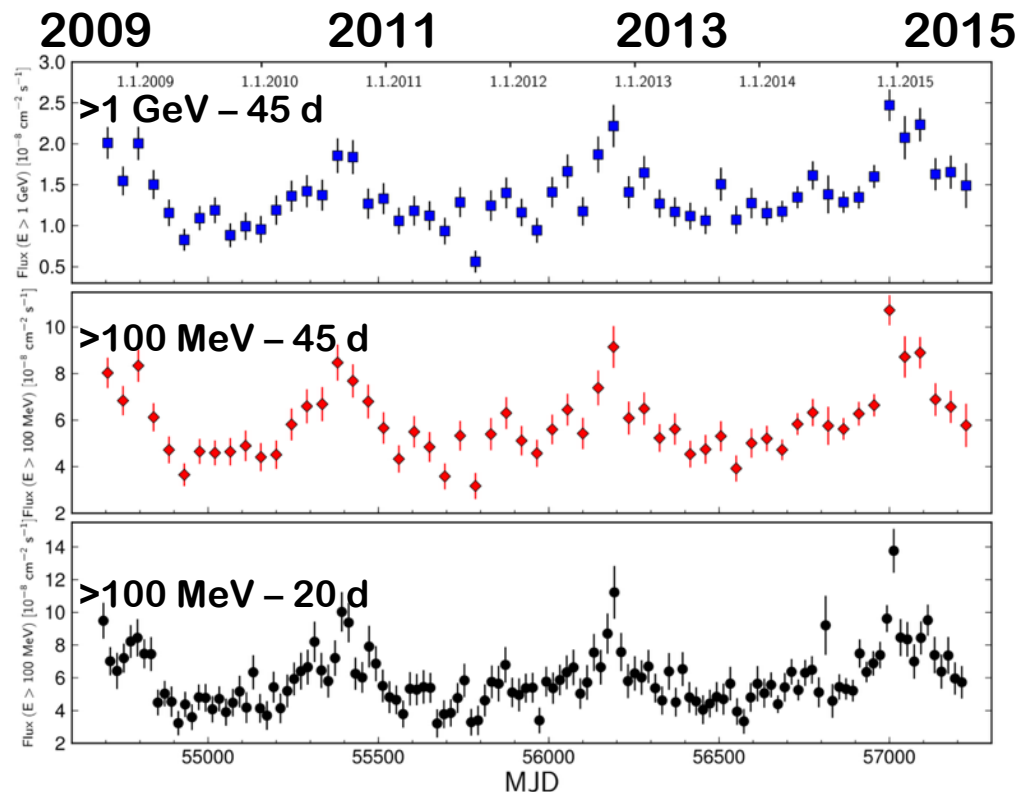
PG1553 periodicity in Fermi/LAT

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



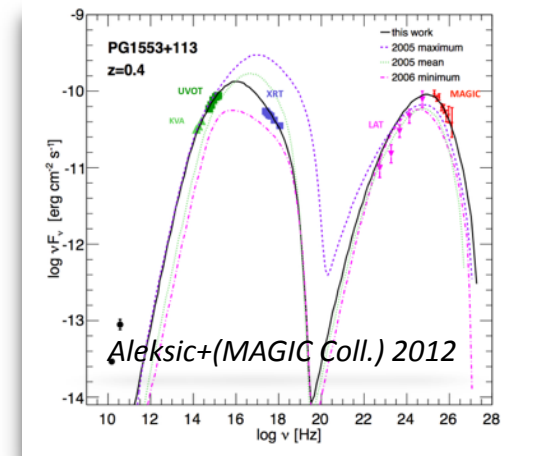
Interpretation of periodicity

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



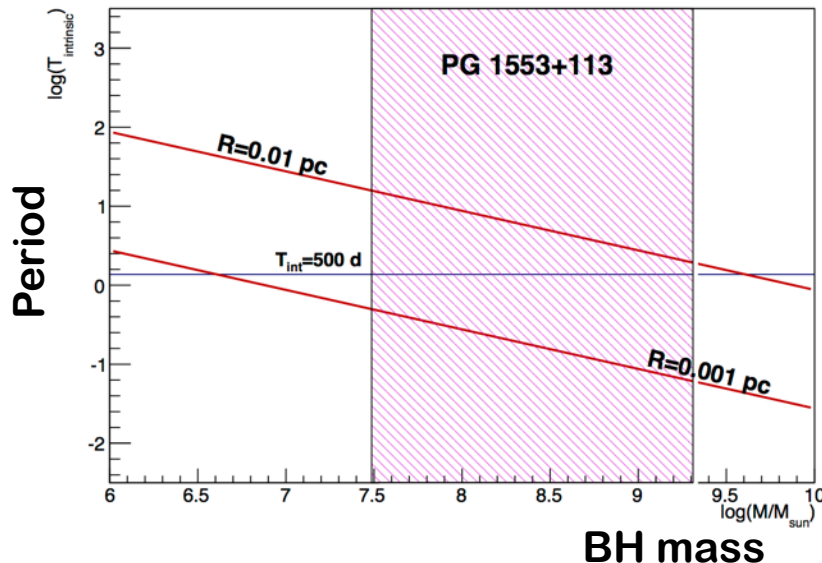
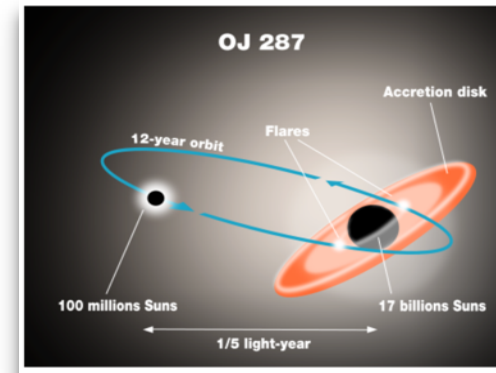
Periodicity may be the result of:

- 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 → Doppler factor $\Gamma \sim 20 \sim 1^\circ \rightarrow \sim 40\% \rightarrow \text{flux} \sim 3$**



milli-pc system: gravitational wave driven inspiral stage!

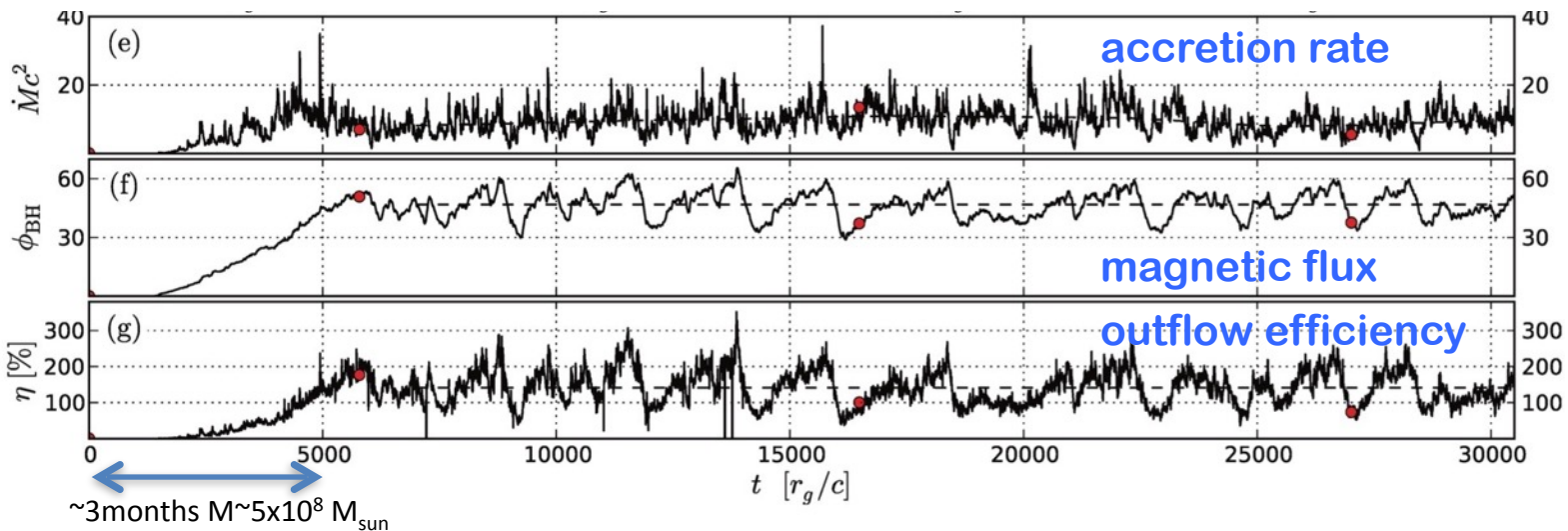
Single SMBH

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

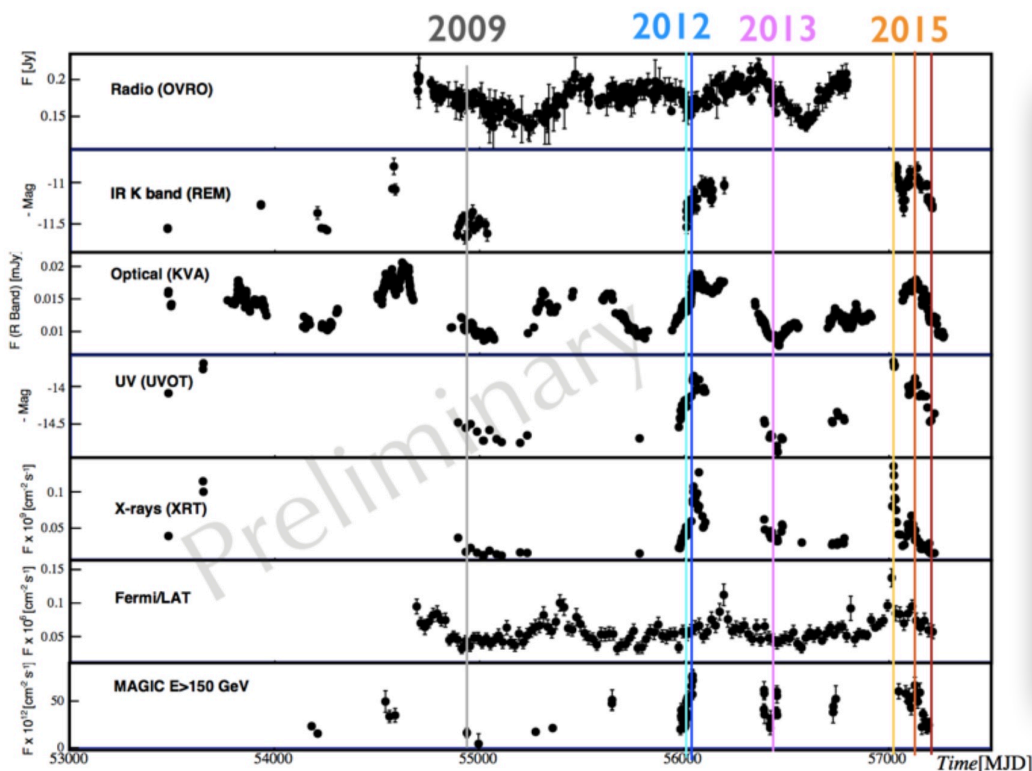
- Regular MWL monitoring started at the end of 2014
 - from radio to VHE gamma-rays
- Make ready for the next high-activity; expected beginning 2017
- Led by the MAGIC collaboration



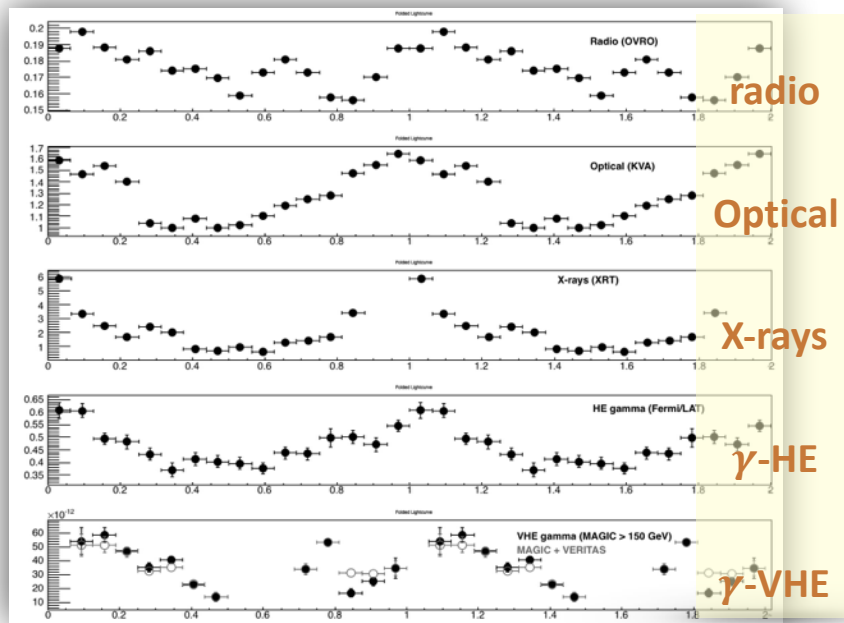
The baseline: a old MAGIC friend with a young touch on periodicity

- Long-term observations with MAGIC since 2005

MAGIC coll. + MWL partners, in prep.



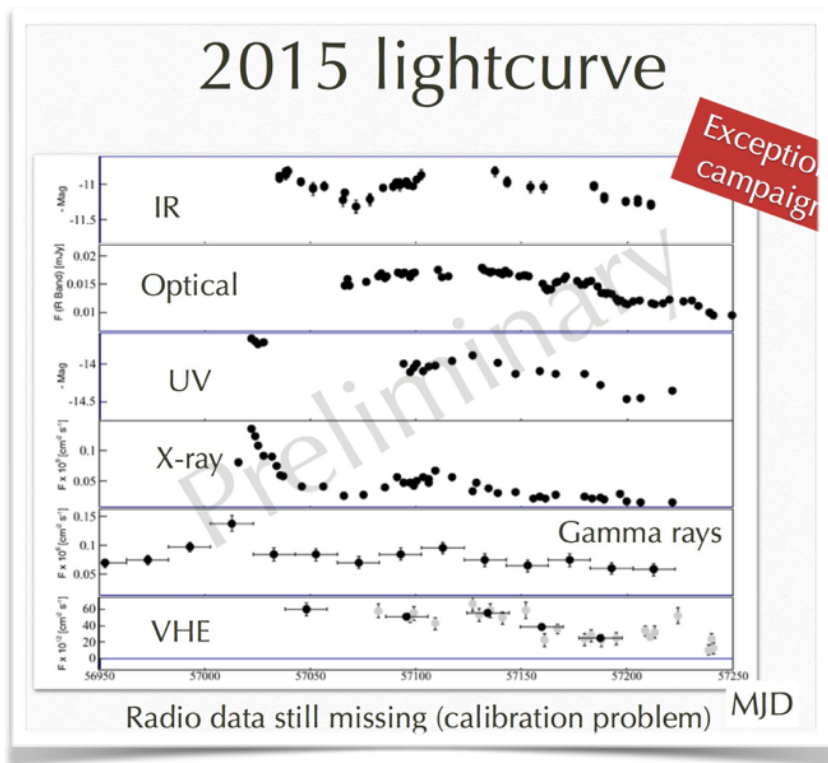
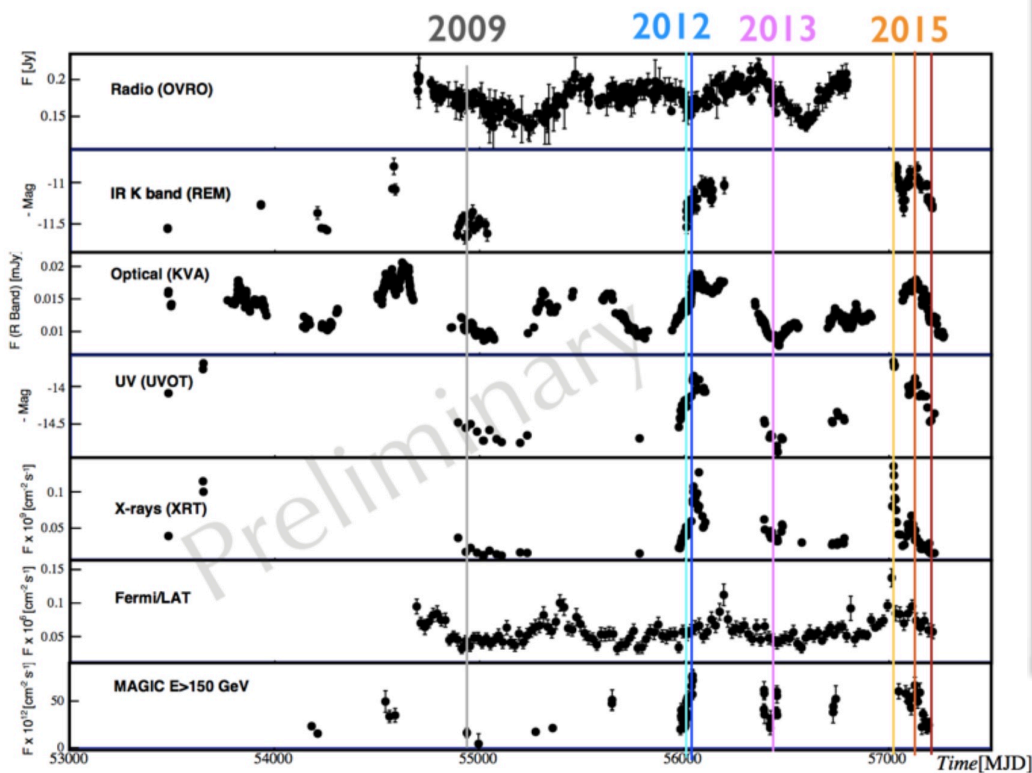
Folded light curves $P=783$ days



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

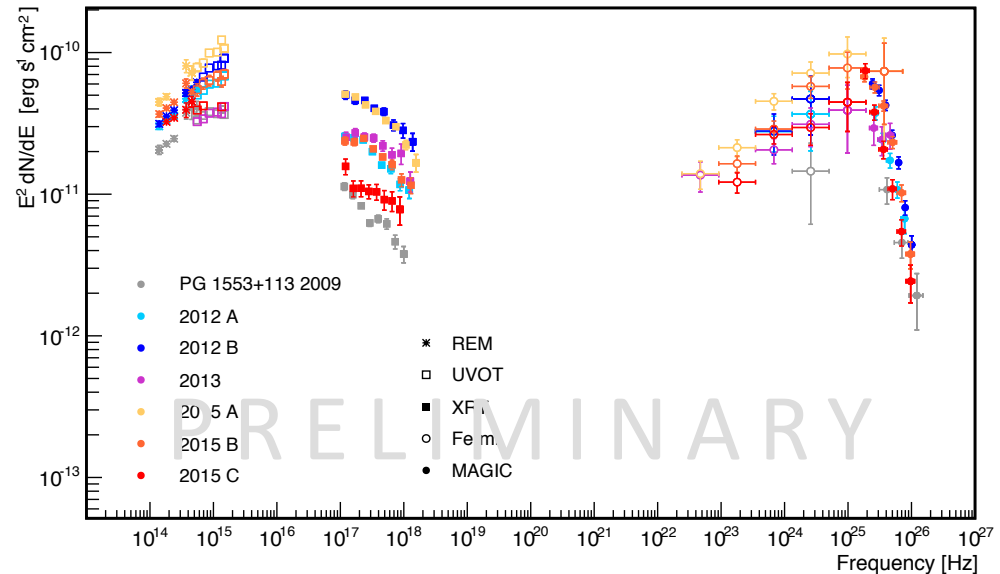
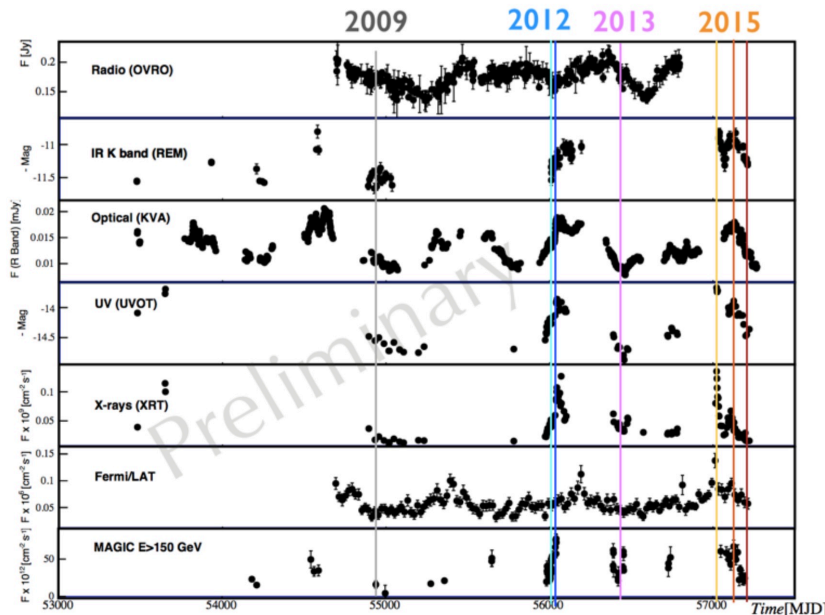


The baseline: a old MAGIC friend with a young touch on periodicity

MAGIC coll. + MWL partners, in prep.

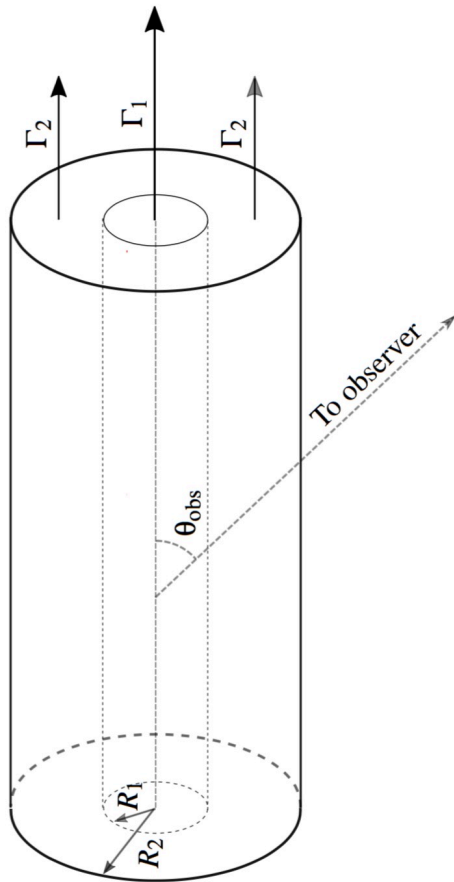
- Long-term observations with MAGIC since 2005
- MAGIC regular monitoring since 2014
- correlation studies, time lags, SED,... in progress

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



A geometrical model

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



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

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

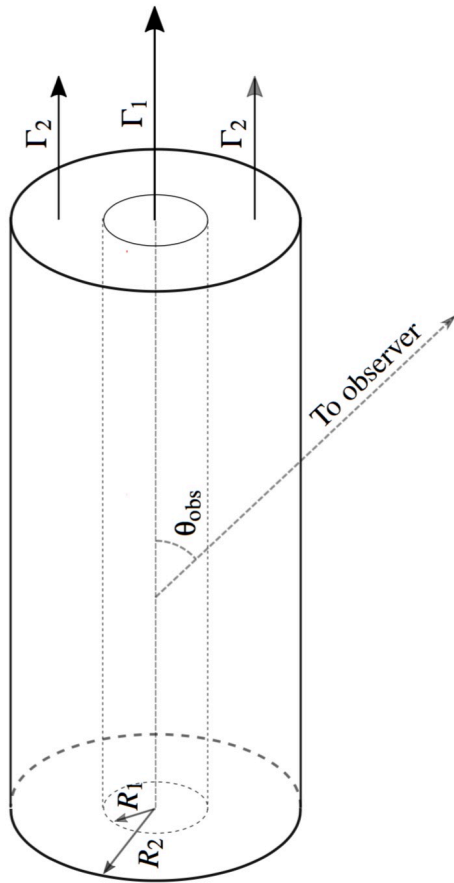
emissivity *geometrical factor*

λ : relative contribution sheath/spine
 δ : Doppler factor



A geometrical model

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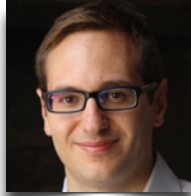


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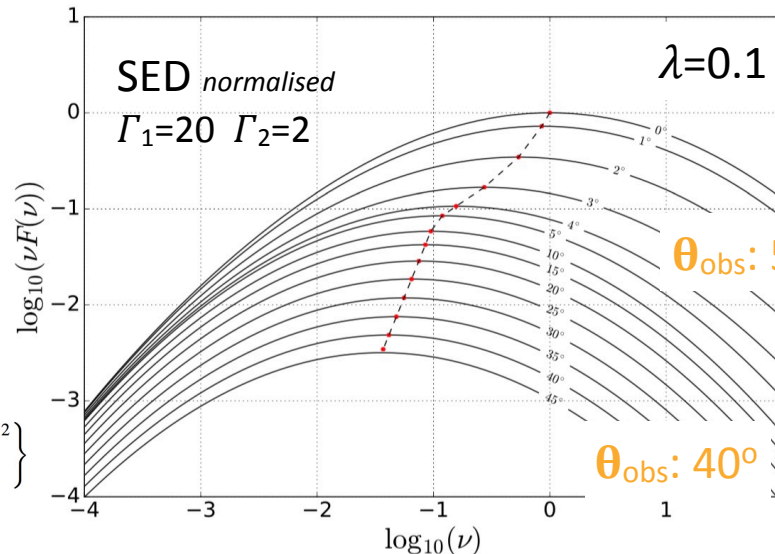
emissivity geometrical factor

λ : relative contribution sheath/spine
 δ : Doppler factor



Logpar SED

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



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

slope: 1

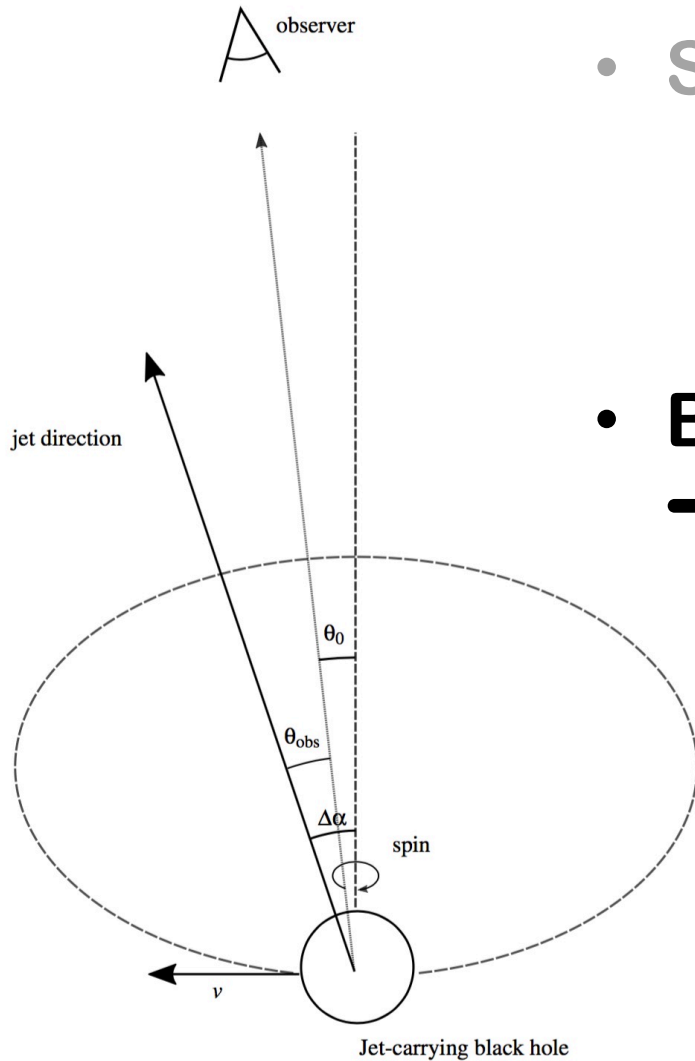
$\theta_{\text{obs}}: 5^\circ$

slope: 3

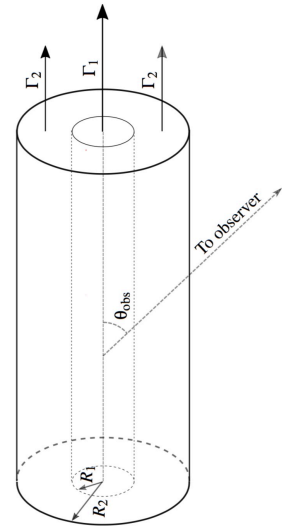
$\theta_{\text{obs}}: 40^\circ$

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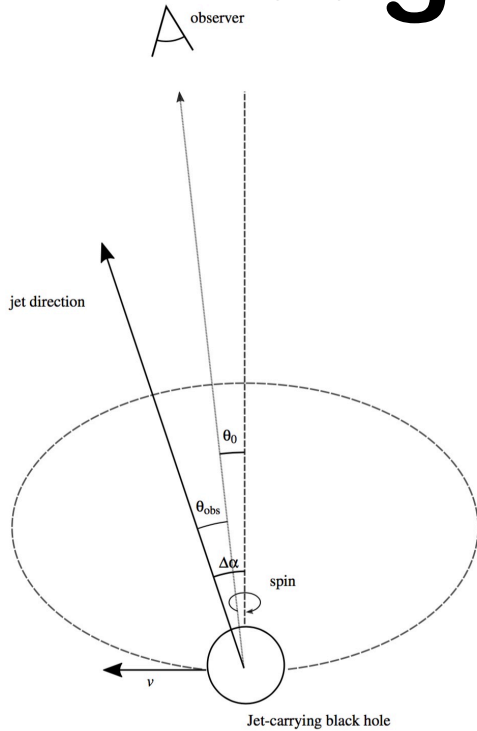


- **Structured jet (spine+sheath)**
- **Binary system**
→ **orbital velocity + beam**

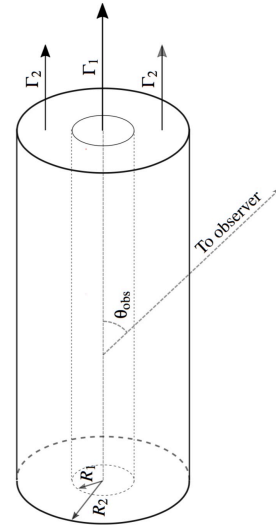


A geometrical model

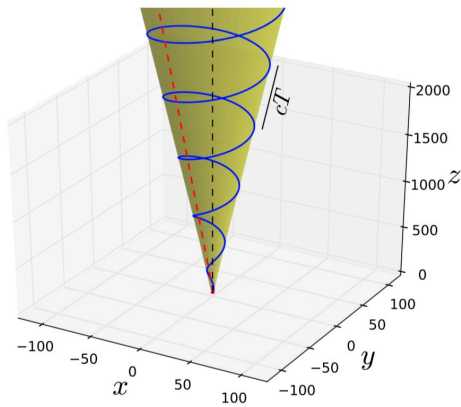
E. Sobacchi, M. Sormani, AS (subm.)



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



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

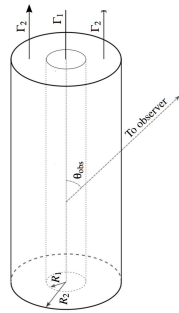


A geometrical model: PG 1553+113

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

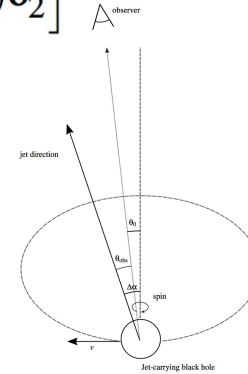
- QPO Light curve

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

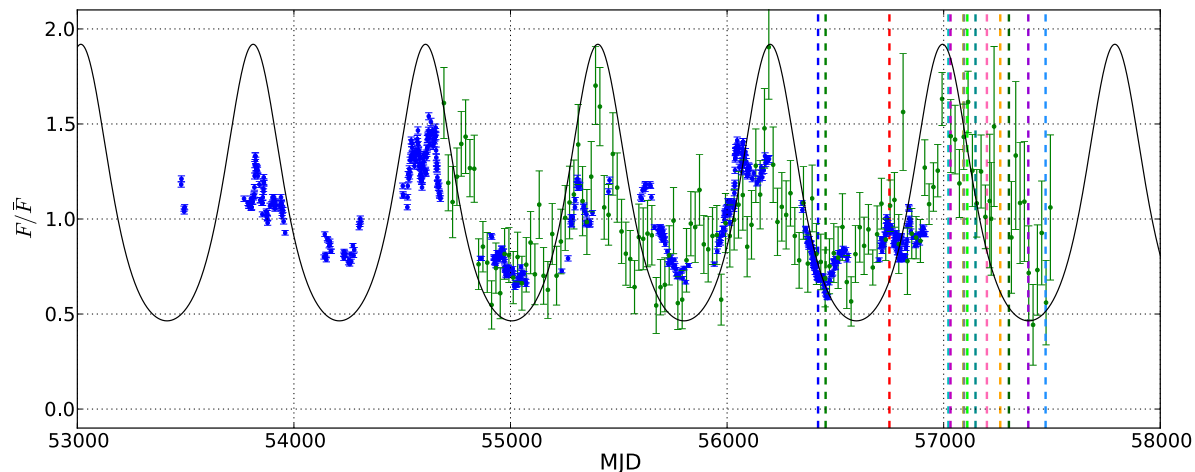


jet-param. binary-syst

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



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



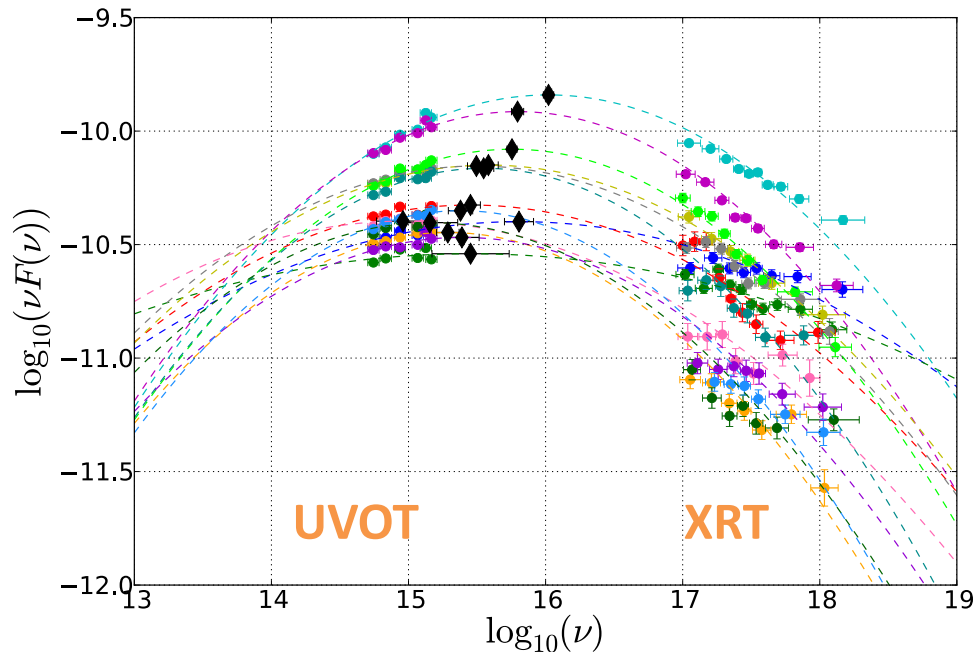
Fermi/LAT

Optical

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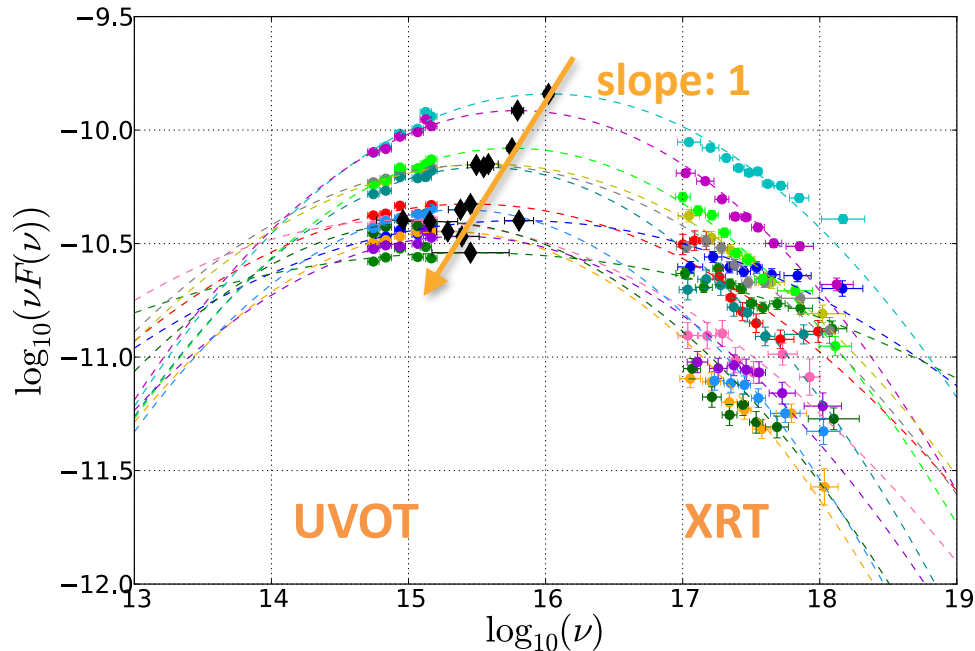
- **Synchrotron SED**
 - **Swift UVOT and XRT**
 - **Logpar fit to get peak**



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◆ synch-Peaks

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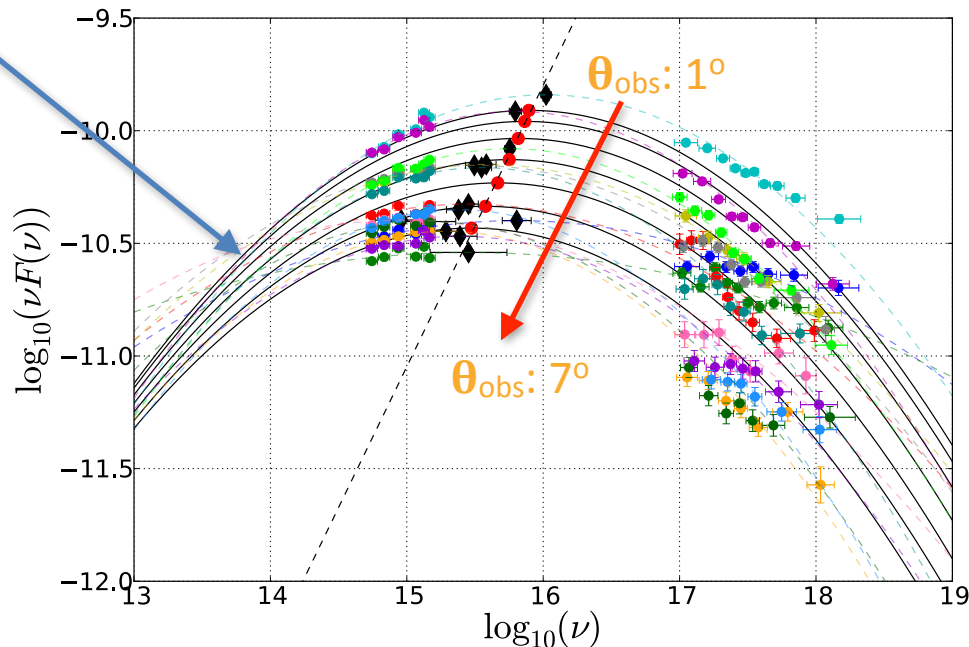
- **Synchrotron SED**

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



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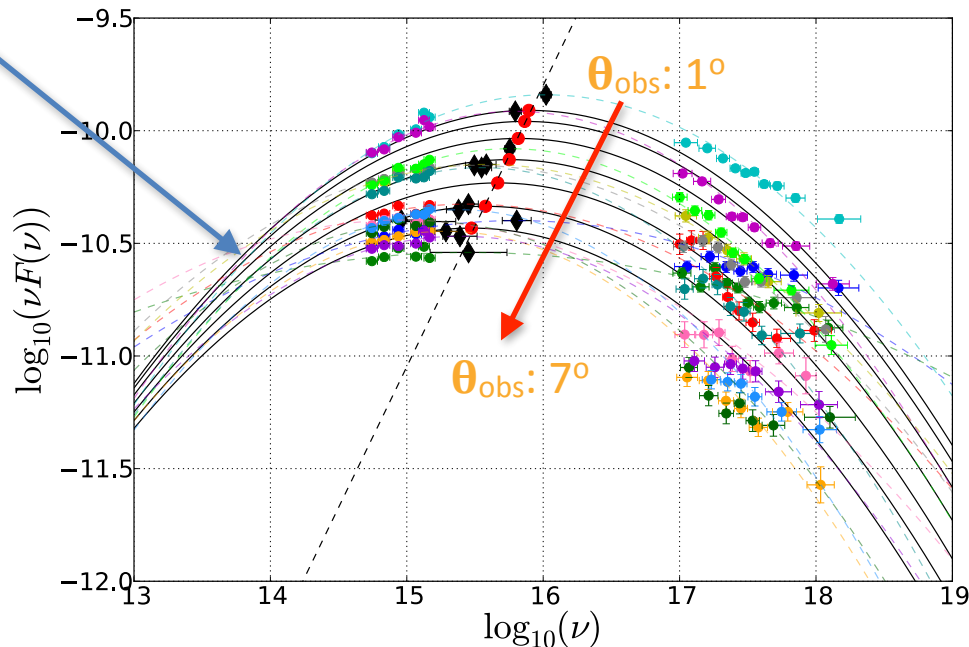
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Logpar
SED



◆ 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**

