



# The neutrino-blazar and the new era of multi-messenger Astronomy

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Alberto Franceschini, Simona Paiano

And on behalf of the MAGIC collaboration

Gravi-gamma conference, Perugia  
May 16<sup>th</sup>, 2019

# Overview

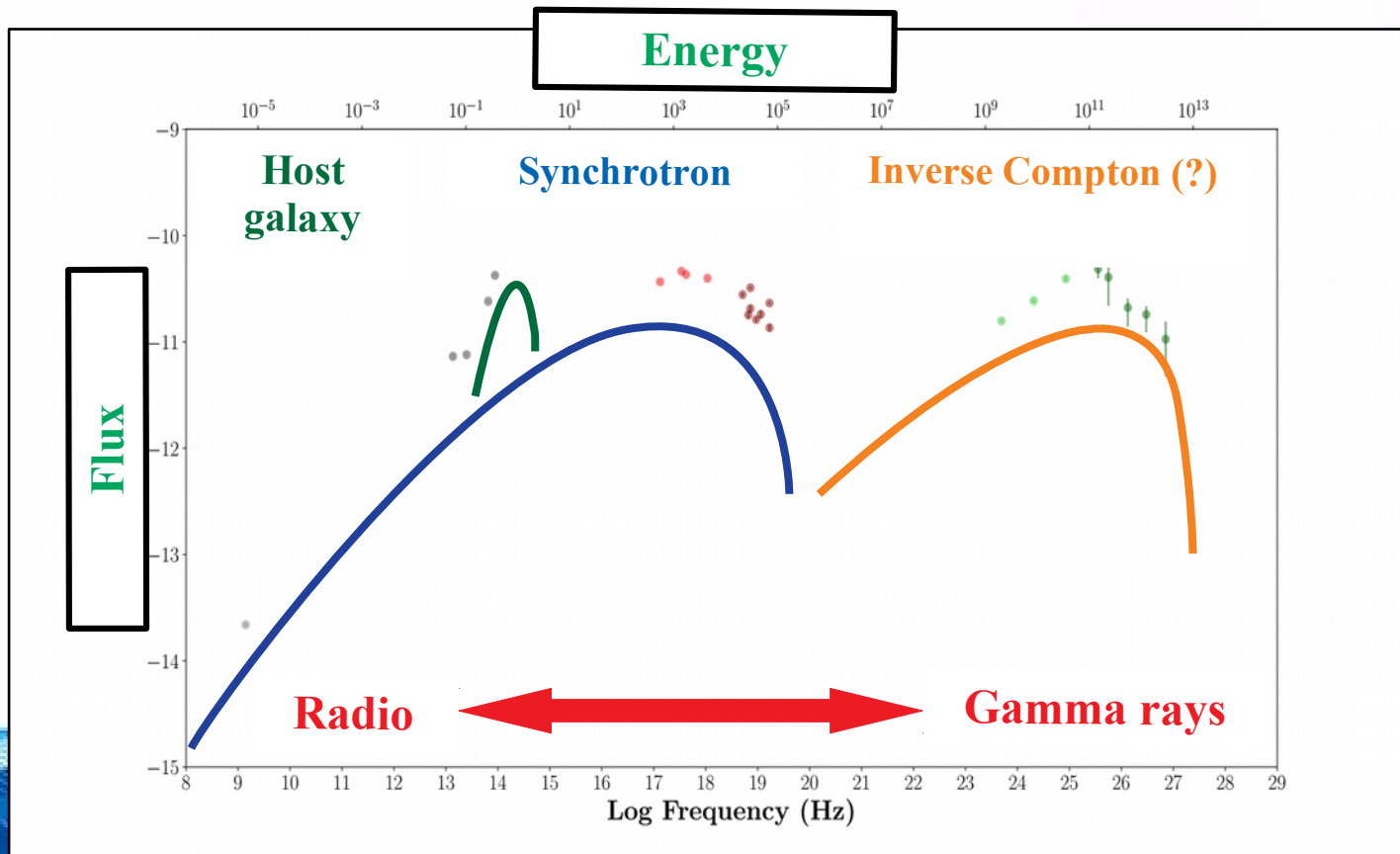
- **Blazars** as key objects of the multi-wavelength Astrophysics
- The **neutrino-blazar** and the birth of multi-messenger Astrophysics
- **Extreme blazars** as new candidates of extreme Physics?



# Multi-wavelength Astrophysics of blazars

# Blazars

A simplified view



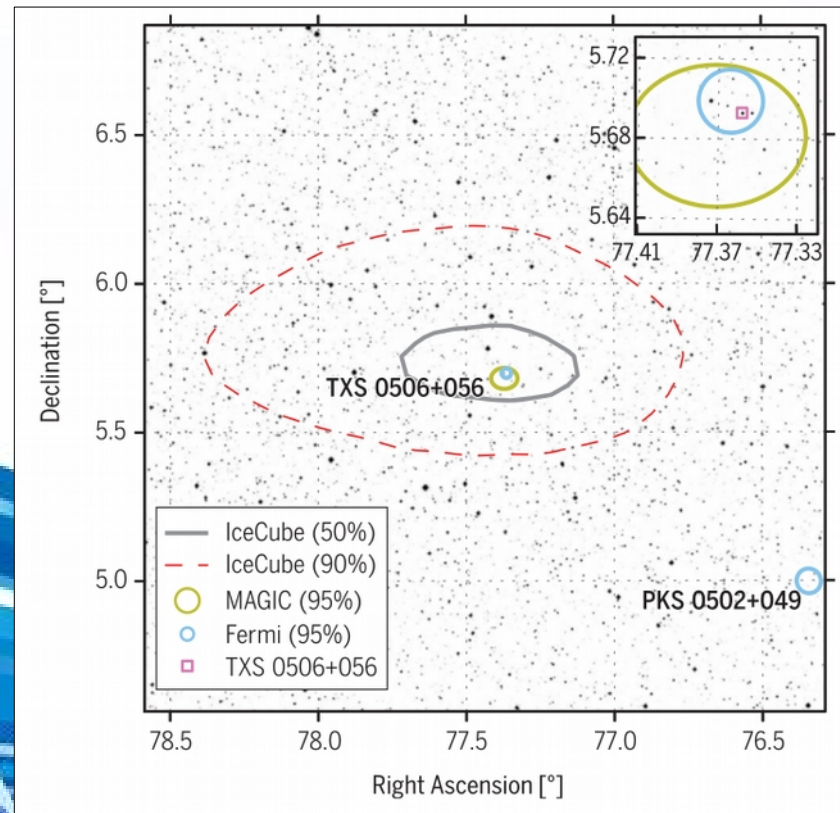
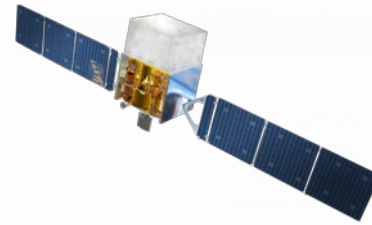
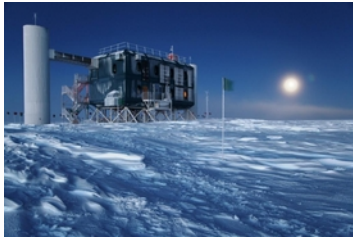
Sketch of blazars' spectral energy distribution (archival data of Mrk 501)

We need multi-wavelength observations!



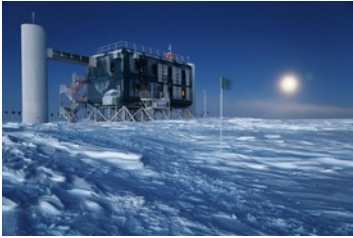
# Multi-wavelength **and multi-messenger** Astrophysics of blazars

# The neutrino-blazar detection



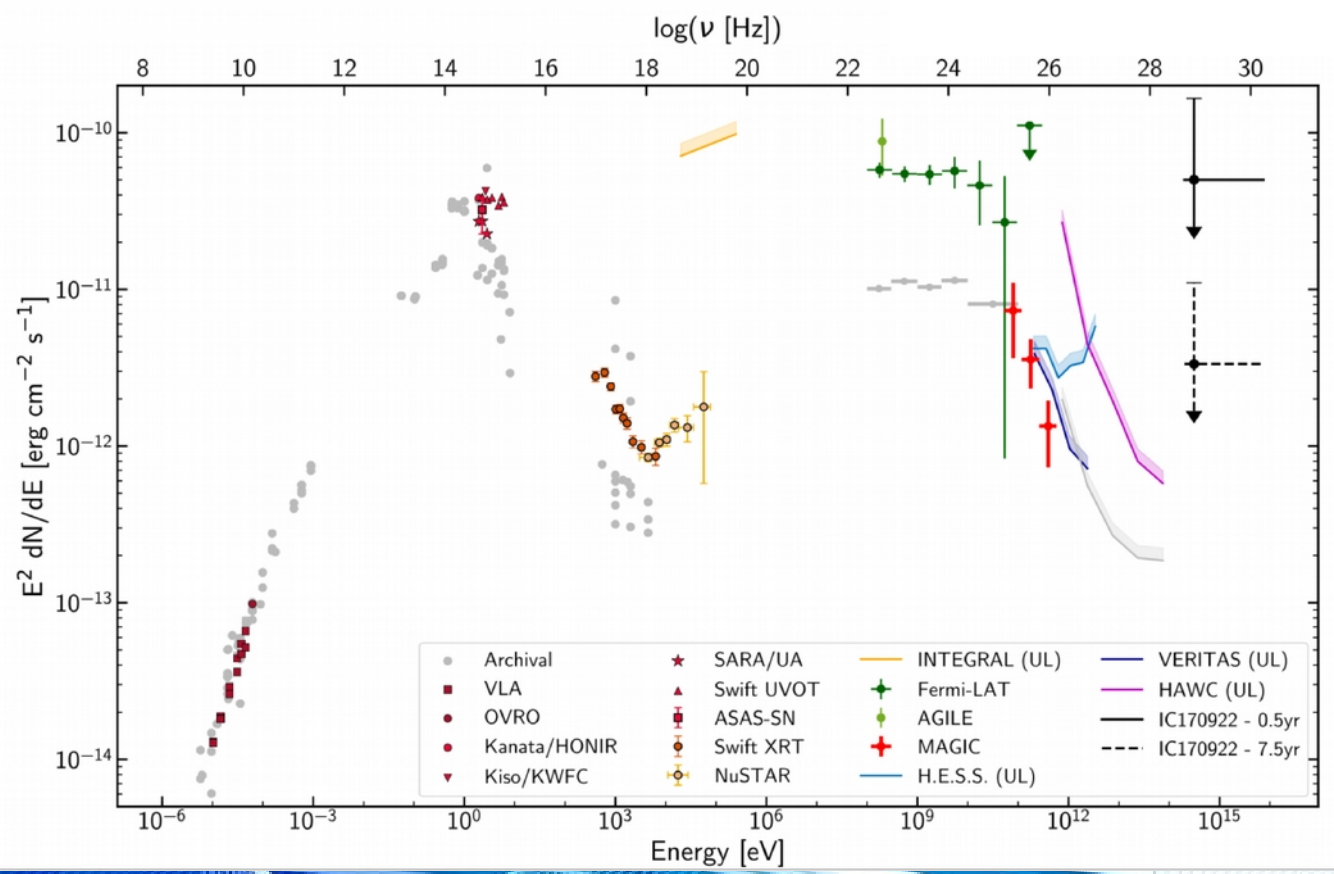
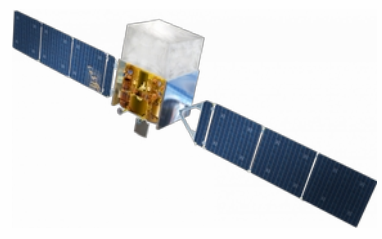
Aartsen et al  
(2018)  
Science, 361,  
eaat1378

# Neutrino follow-up observations with MAGIC



- IACTs agree on efforts in a **transient follow-up program** since 2012
- During the event EHE-170922A, all of them pointed to the blazar TXS 0506+056:
  - **H.E.S.S.:** fastest follow-up after only 4h → no detection
  - **VERITAS:** first obs. after ~12h → no detection
  - **MAGIC:**
    - No observations during the event due to bad weather conditions
    - First observations after ~12h on Sep 24<sup>th</sup>, non-optimal weather, only 1h used for flux upper-limit estimation
    - Regular observations from Sep 28<sup>th</sup> to Oct 4<sup>th</sup>  
→ **detection** reported on ATel#10817

# First multi-wavelength and multi-messenger SED!



**Aartsen et al  
(2018)**  
Science, 361,  
eat1378



# Further MAGIC observations of the blazar TXS 0506+056

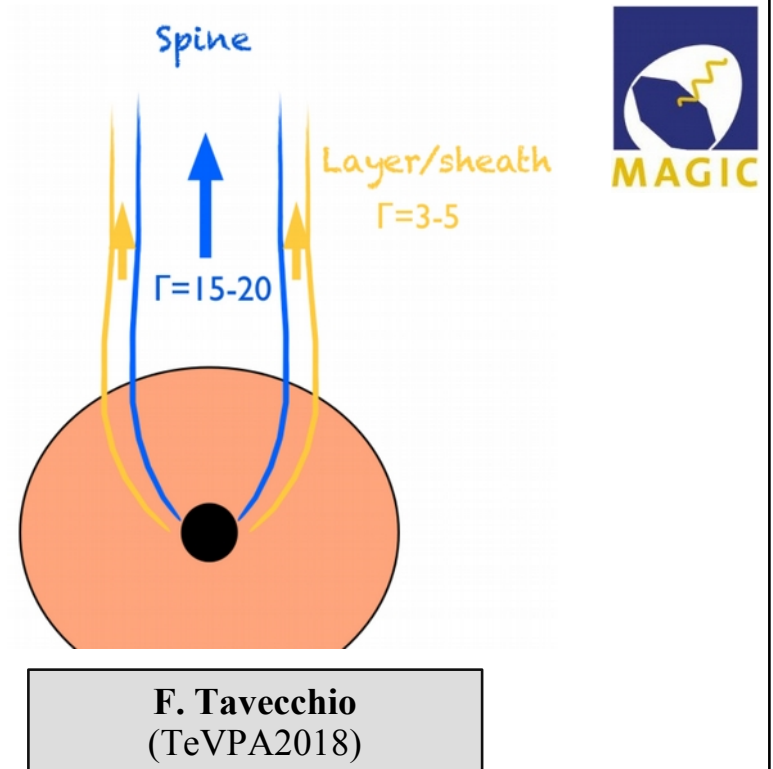
Further observations with MAGIC of the blazar TXS 0506+056 resulted in:



- More than **41h** of good quality data collected between Sep 24<sup>th</sup> - Nov 2<sup>nd</sup>
- 2 **flares** detected on Oct 3<sup>rd</sup>- 4<sup>th</sup> and on Oct 31<sup>st</sup>
- **Lower state** detected above 90 GeV
  
- **Light-curve:**
  - day-scale **variability**
  - constant flux hypothesis below 0.3% probability
  
- **Spectrum:**
  - **no spectral index variability** measured
  - simple PL, index softer than *Fermi*-LAT
  - additional **internal absorption** at play (apart from EBL effect)

The MAGIC Collaboration, ApJL 863, 1,  
arXiv:1807.04300

- The MAGIC collaboration provided an interpretation of the neutrino-blazar coincidence in terms of the **spine-layer model** (Ghisellini+2005)

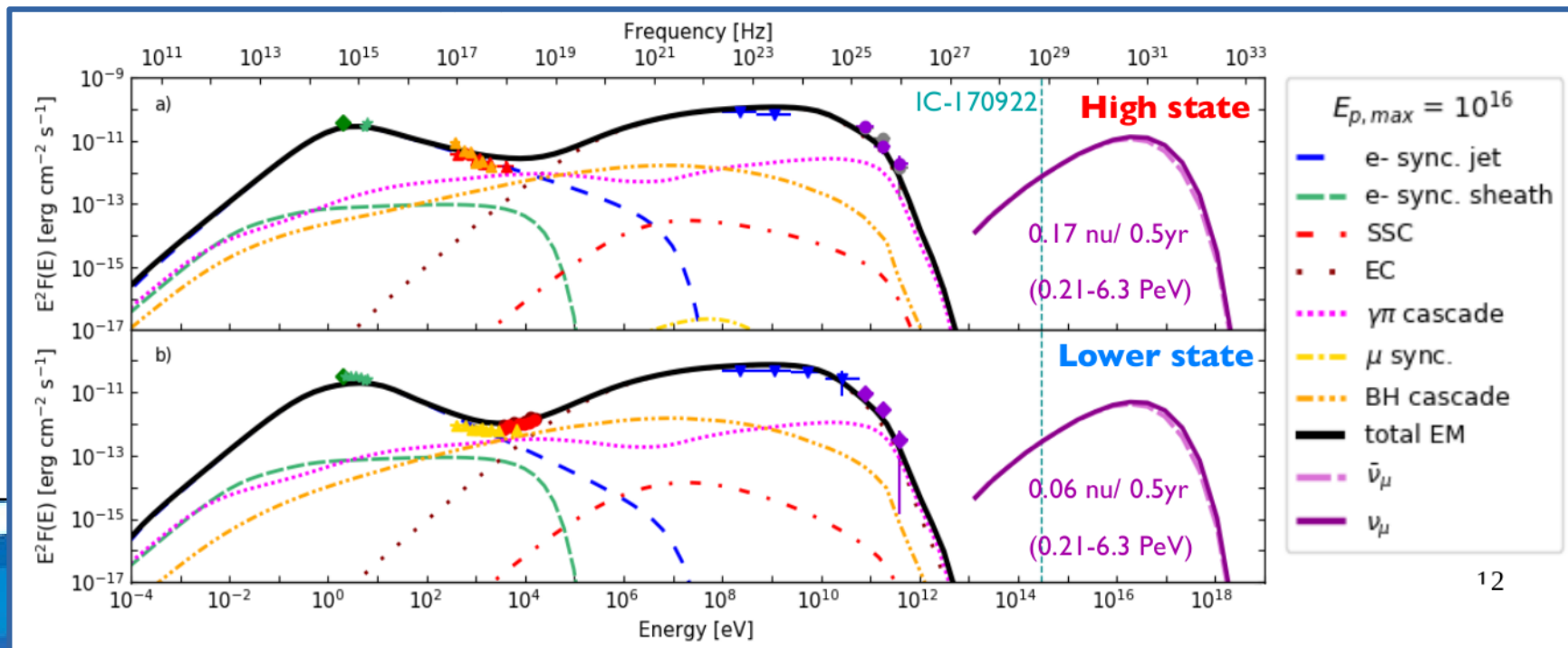


- Components:
  - leptonic (synchrotron, SSC, EC)
  - and hadronic (photo-meson cascade, BH cascade, synch. rad. from pions and muons)

The MAGIC Collaboration, ApJL 863, 1,  
arXiv:1807.04300

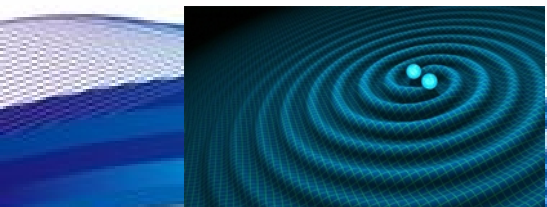
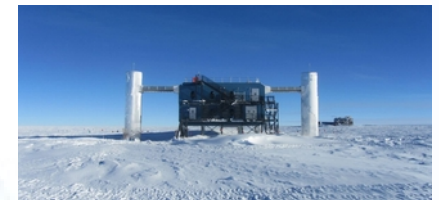
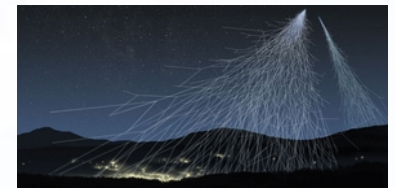


- **Day-scale variability** → Size of emitting region  $\sim 10^{16}$  cm
  - Spectral break at VHE compatible with **internal absorption**:  $\tau_{\gamma\gamma} \sim 1$  at  $E_\gamma \sim 100$  GeV
  - **Constraints on max proton energy**  $E_{p,max}$  set by X-ray and VHE gamma-ray data:
  - Scan of  $E_{p,max}$ :  $10^{14}$  -  $10^{18}$  eV in the co-moving frame
- **TXS 0506+056 able to accelerate CR to UHE!**



The MAGIC Collaboration, ApJL 863, 1,  
arXiv:1807.04300

# The multi-wavelength and multi-messenger era of Astrophysics



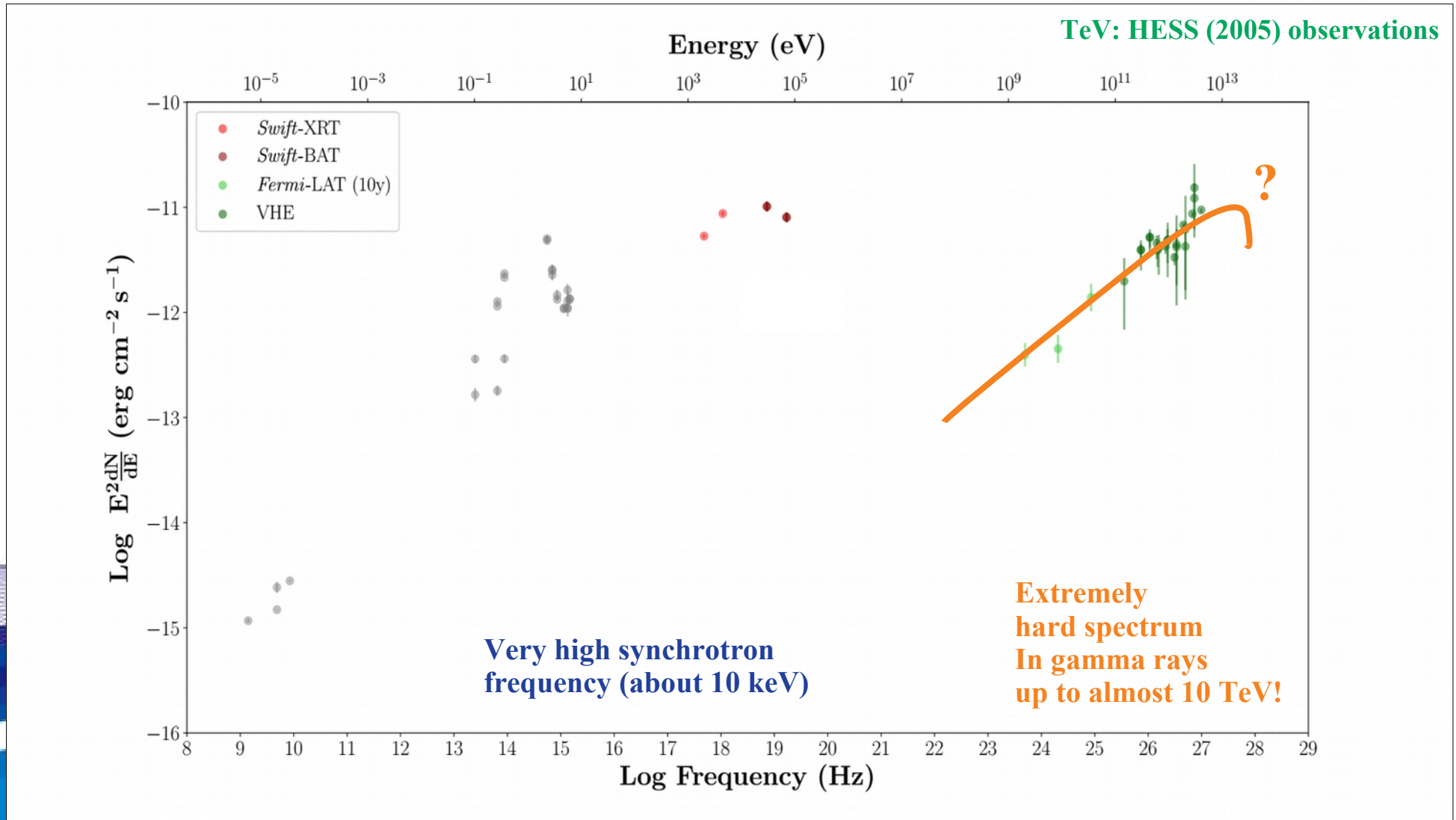


# Blazars and neutrinos



# **Extreme** blazars and neutrinos

# Extreme blazars



Broad-band intrinsic SED of 1ES 0229+200 - archival data (SSDC)



# Extreme blazars

- They produce the **highest photon energies** ever observed in blazars
- Only **few objects** currently classified as extreme blazars in gamma rays
- They need **large integration time** to be detected in gamma rays
- We need **MWL studies** in order to select them
- Their emission mechanism could be contributed by hadronic processes → **neutrinos**
- Their spectral energy distribution is **challenging for the standard modeling** of blazars



# Looking for new extreme blazars



within the MAGIC collaboration

Mrk 501 during some flaring activities showed EHBL behaviour with synchrotron peak above  $10^{17}$  Hz

→ Being EHBL might be a temporary state

*Astronomy & Astrophysics* manuscript no. Mrk501\_MW2012  
August 16, 2018

©ESO 2018

**Ahnen M. L., et al., 2018, A&A**

## The extreme HBL behaviour of Markarian 501 during 2012

M. L. Ahnen<sup>1</sup>, S. Ansoldi<sup>2,19</sup>, L. A. Antonelli<sup>3</sup>, C. Arcaro<sup>4</sup>, A. Babić<sup>5</sup>, B. Banerjee<sup>6</sup>, P. Bangale<sup>7</sup>, U. Barres de Almeida<sup>7,22</sup>, J. A. Barrio<sup>8</sup>, J. Becerra González<sup>9</sup>, W. Bednarek<sup>10</sup>, E. Bernardini<sup>11,23</sup>, A. Berti<sup>2,24</sup>, W. Bhattacharyya<sup>11</sup>, O. Blanch<sup>12</sup>, G. Bonnoli<sup>13</sup>, R. Carosi<sup>13</sup>, A. Carosi<sup>3</sup>, A. Chiantera<sup>6</sup>, S. M. Chiodi<sup>12</sup>, P. Chiaberge<sup>7</sup>, F. Claret<sup>15</sup>, J. L. Gómez<sup>8</sup>, J. G. García<sup>12</sup>, S. Gruber<sup>3</sup>, P. Guaita<sup>12</sup>, P. D. V. H. Hebringer<sup>13</sup>, A. D.



# Looking for new extreme blazars



within the MAGIC collaboration

The MAGIC collaboration is preparing a **mini catalog** paper with the results on the observations of new EHBLS





# Looking for new extreme blazars



within the MAGIC collaboration

**First detection of very-high-energy gamma-ray  
emission from the extreme blazar PGC  
2402248 with the MAGIC telescopes**

ATel #11548; *Razmik Mirzoyan (Max-Planck-Institute for Physics,  
Munich), on behalf of the MAGIC collaboration*

**Paper on PGC 2402248 and modeling  
within the extreme blazar context**

**COMING  
SOON**



# Looking for new extreme blazars

Presented in

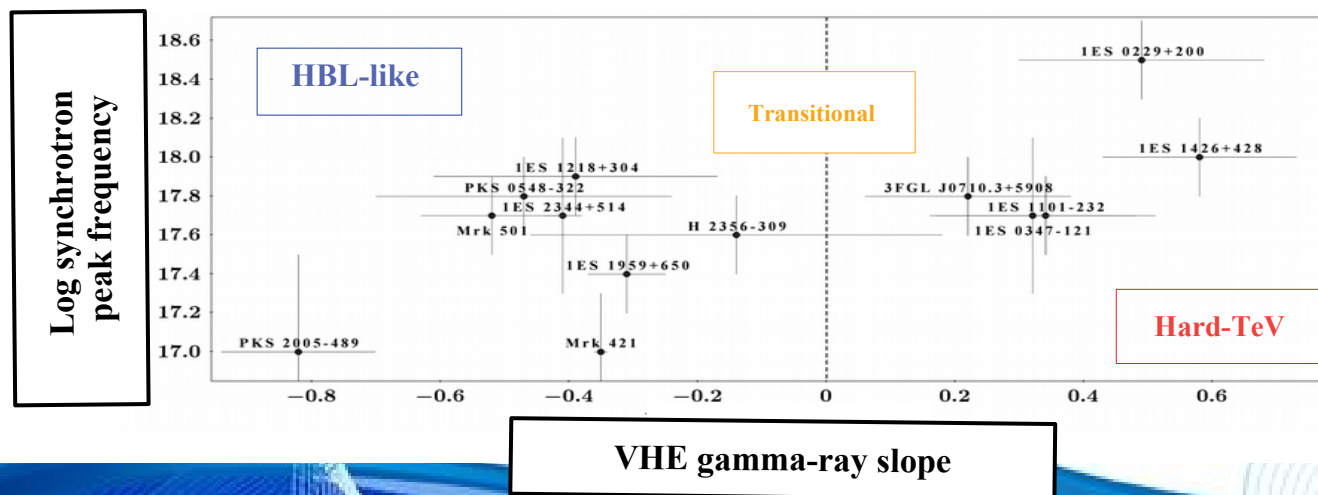
L. Foffano, E. Prandini, A. Franceschini, S. Paiano (2019)

# Results

LF+2019

Some results of this analysis:

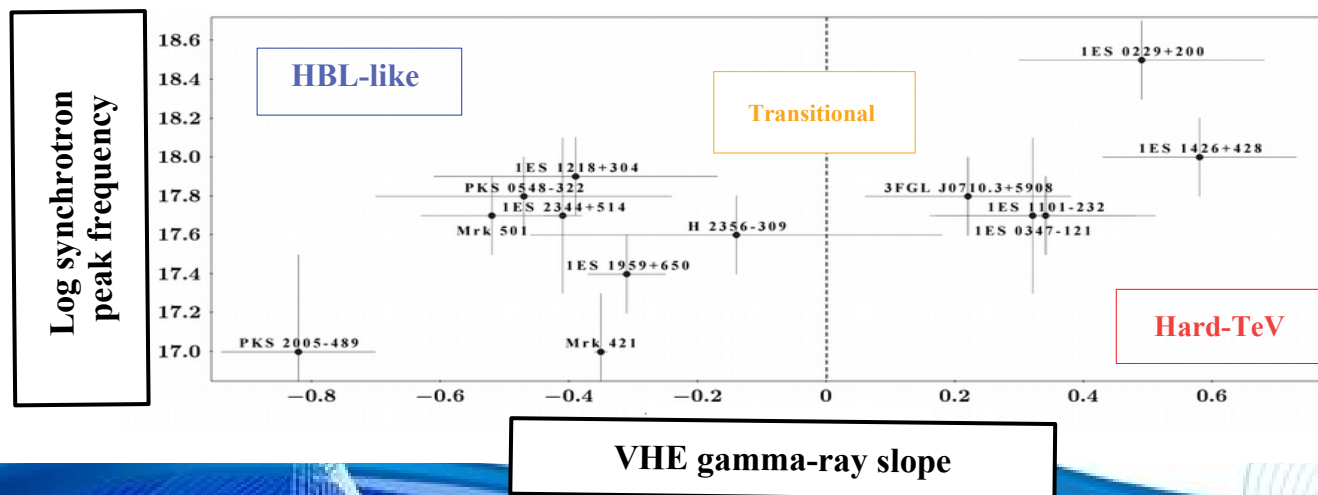
- EHBLs might present **sub-classifications** depending on their **TeV gamma-ray properties**
- Such differences might be correlated to **differences in the particle acceleration mechanism!**
- MWL studies are needed
- We need good candidates to be observed in the TeV gamma-ray band
- In our work, we propose a sample of new EHBL candidates with promising properties in TeV gamma rays



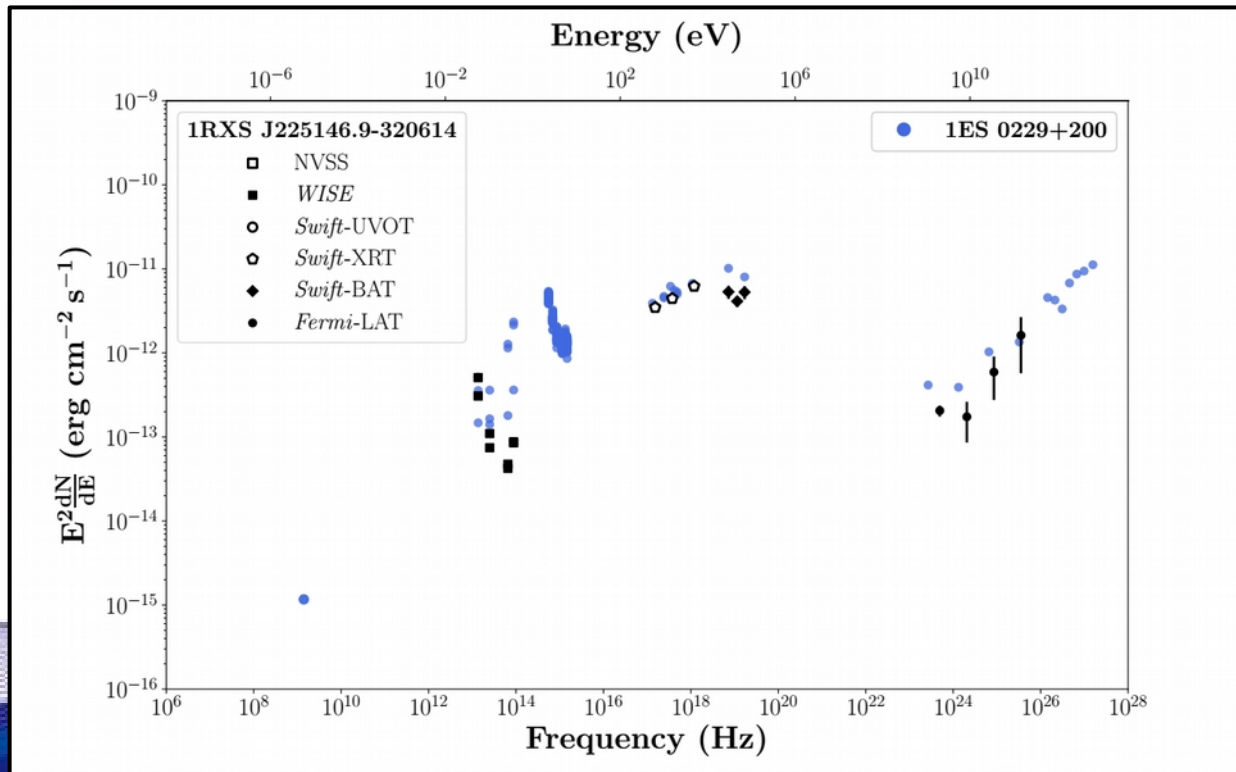
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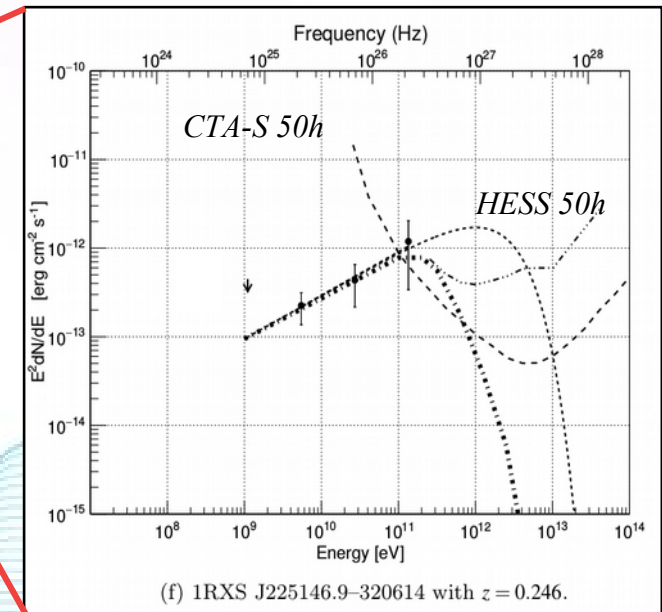
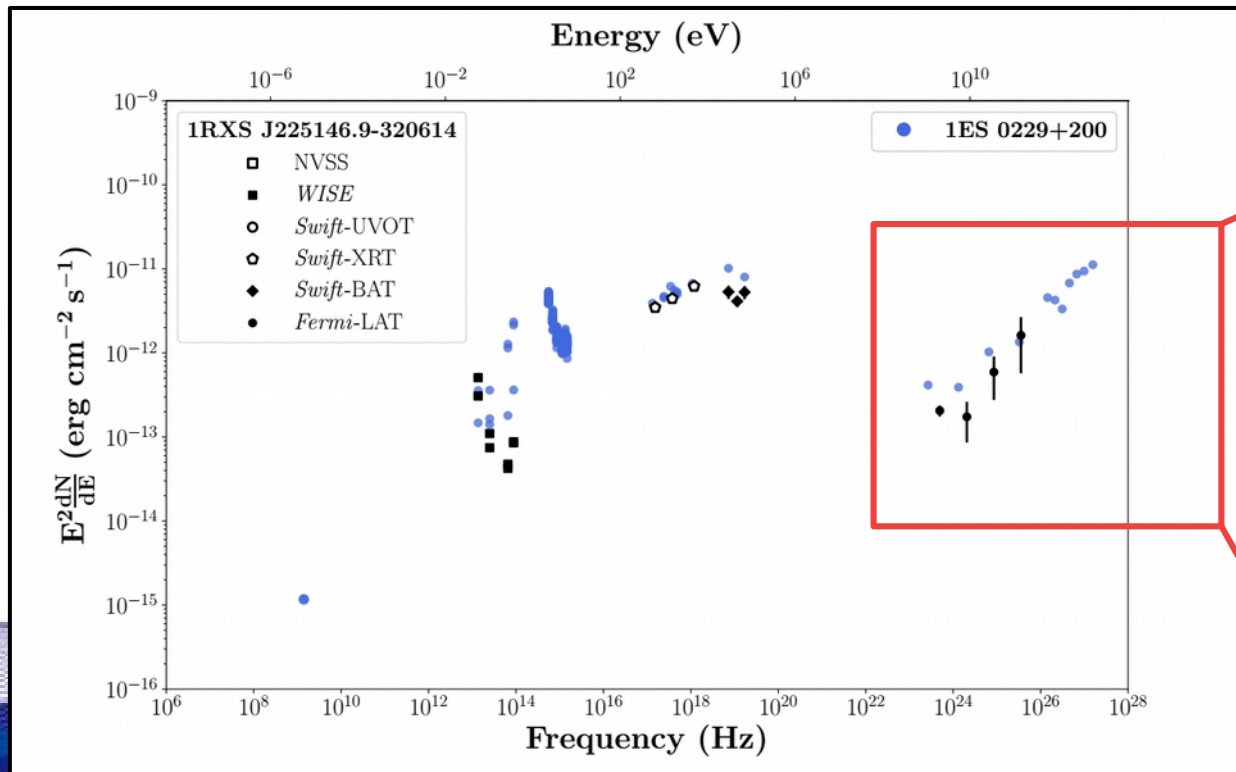
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# Looking for new TeV EHBL candidates



# Looking for new TeV EHBL candidates



Power-law + cut-off extrapolations  
on EBL deabsorbed data (Franceschini + 17)



# Conclusions

- We are facing with the opening era of **multi-messenger** and **multi-wavelength** Astrophysics
- Science will gain a lot from this
- We need to work on the interface between the different messengers and wavelegths, and their instruments

Our contribute in this exciting field:

- We studied a new sample of extreme blazars, finding hints of **sub-classification**
- We propose new targets to be observed with multi-wavelength **observations**
- These objects might reveal different physical **interpretation** in term of jet emission models

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*Thank you!*