MAGIC BLAZARS IN A MULTI-WAVELENGTH & MULTI-MESSENGER CONTEXT

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INTRODUCTION

• **Outline**

  • **The extragalactic MAGIC sky: fifteen years of discoveries and exciting news**
  
  • **The MAGIC telescopes for VHE gamma-ray observations**
  
  • **Highlight results:**
    - **BL Lacs**
    - **FSRQs**
    - **Misaligned blazars**
    - **Constraining EBL with MAGIC**

For the blazar science case, multi-wavelength and multi-messenger approach is the way
EXTRAGALACTIC TeV SOURCES (JUNE 2018): MAGIC SELECTION

OBSERVATION STRATEGY

• Always pointing mode (no survey due to limited field of view)
• Monitoring campaigns of known objects
• Scheduled observations of promising targets (one call per year, open to external scientists)
• ToO observations through several trigger strategies of new objects or already known targets
Current MAGIC sensitivity above 220 GeV: 0.66 % Crab Nebula flux in 50 hours
THE MAGIC TELESCOPES

2-telescope stereoscopic system
17 m diameter dish each
Energy range: tens of GeV - tens of TeV (standard trigger)
Angular resolution <0.07 deg (220 GeV)
Energy resolution ~16%
Pointing mode observation ~3.5 deg FoV
THE MAGIC STORY

➤ 2003: Inauguration
➤ Upgrades
  ➤ 2009: MAGIC II in operation
  ➤ 2012: MAGIC-I camera upgrade and electronics upgrade
➤ LST construction: ongoing
BLAZARS

FSRQs & BL Lacs
**TeV FSRQ**

<table>
<thead>
<tr>
<th>Source</th>
<th>z</th>
<th>Discoverer</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>B0218+367</td>
<td>0.944</td>
<td>MAGIC</td>
<td>2014</td>
</tr>
<tr>
<td>PKS 1441+25</td>
<td>0.939</td>
<td>MAGIC</td>
<td>2015</td>
</tr>
<tr>
<td>TON 599</td>
<td>0.72</td>
<td>MAGIC</td>
<td>2017</td>
</tr>
<tr>
<td>3C 279</td>
<td>0.5362</td>
<td>MAGIC</td>
<td>2006</td>
</tr>
<tr>
<td>S4 0954+65*</td>
<td>0.356?</td>
<td>MAGIC</td>
<td>2015</td>
</tr>
<tr>
<td>PKS 1222+216</td>
<td>0.432</td>
<td>MAGIC</td>
<td>2010</td>
</tr>
<tr>
<td>PKS 1510-089</td>
<td>0.361</td>
<td>HESS</td>
<td>2009</td>
</tr>
<tr>
<td>PKS 0736+017</td>
<td>0.189</td>
<td>HESS</td>
<td>2016</td>
</tr>
</tbody>
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1. MAGIC has the **distance record**
2. Ton 599: new source (ATel #11061)
3. Usually detected during flares (role of Fermi-LAT is essential)
**B0218+357—FIRST GRAVITATIONALLY LENSED SOURCE DETECTED IN VHE GAMMA RAYS**


- Gravitationally lensed blazar
- Redshift: **0.944±0.002**, lens: at z=0.68
- A delay of ~10-12 days between the emission from two images is seen in radio and GeV ranges
- **July 2014**: flare by **Fermi-LAT** (MAGIC in moon time *pause*)

* MAGIC detected the delayed emission exactly when expected;
* Photons follow the same paths in the gravitational field up to at least 250 GeV
PKS 1510-089 FLARING IN VHE FOR THE FIRST TIME (2015)

- High optical and gamma-ray state —> trigger MAGIC observations
- VHE gamma-ray flux ~4 times brighter than 2009 and 2012
- Similar VHE spectral shape (intrinsic slope=3.2 +/- 0.8)
- Smooth rotation of the Electric Vector Polarization Angle (EVPA) by ~100 degrees

Ejection of a new radio component during VHE gamma-ray flare

➤ MAGIC follow-up of **EHE neutrino event** IceCube-170922A

➤ Fermi-LAT detected **enhanced gamma-ray emission from the blazar TXS 0506+056** located 6 arcmin from the best fit position of EHE 170922A

➤ MAGIC observations during 12 h from September 28th to October 3rd

➤ MAGIC detection at > 5 sigma C.L. above 100 GeV
A CASE STUDY: PG 1553+113

- **Unknown redshift VHE blazar**: $0.4 < z < 0.58$ (Danforth et al., 2010)
- **Quasi-periodic flux variability** detected by Fermi-LAT and optical observations (Ackermann et al. 2015)
- MAGIC observed PG 1553+113 since 2005
- **Dense monitoring campaign** started in 2015
MKN 421 – MWL CAMPAIGN IN 2013

- Mkn 421 MAGIC+ VERITAS
- Hard X-rays: NuSTAR
- Monitoring in a low state: shift of the synchrotron peak
  - LBL - HBL could be temporary characteristics

MWL data: suggest that there are multiple compact regions contributing to the broadband emission of Mrk 421 during low-activity states

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EXTREME BLAZARS

- A new emerging population of TeV emitting blazars (Bonnoli et al. 2015)
- The SED peaks are located at extremely high energies
  - Faint in Fermi/LAT
  - Hard X-rays are essential
- Hard spectrum: ideal probes for cosmological studies
EXTREME BLAZARS WITH MAGIC

- **PGC 2402248** discovered this year (ATel #11548)
- In 2010-2017 **extreme blazar observation campaign**: MAGIC and Swift-XRT observations of 9 objects
- Modelled with **SSC model** (1D steady model, Asano et al. 2014)

![Graph showing εf(ε) vs. ε [eV] for 1ES 2037+521]

- **1ES 2037+521**

In collaboration with K. Asano

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- Extremely low magnetisation **required**
EBL RESULTS

In agreement with state of the art EBL models

- 32 highly significant spectra from 12 blazars in $z=0.030$ to 0.944
- 316 h of stereoscopic observations over 7 years (2010-2016)
- contemporaneous Fermi-LAT data

$\alpha = 0.95 \pm 0.11, -0.12_{\text{stat}}$

$\alpha = 0.91 \pm 0.07, -0.06_{\text{stat}}$

Dominguez’11

Dominguez’11

MAGIC only

MAGIC+LAT

E. Prandini - MAGIC blazars in a MWL & MM context

Moralejo et al. ICRC 2017
Limited by systematics
MISALIGNED BLAZARS

Unique opportunity to localise and characterise the emitting region of blazars (aligned counterpart)
NGC 1275 FLARING AT VHE GAMMA RAYS

- In the Perseus cluster
- MAGIC monitors the source
- Oct/Nov 2016 at 16% C.U. (ATel #9689) and Jan 2017 at 150% C.U. (ATel #9929)
- **Doubling time scale** of 10.2 +/- 1.7 h

- Hard and curve spectrum
- The Doppler factor constraint due to the fast variability is not compatible with large view angles;
- **Alternative emission scenarios** are needed.
M87 MWL OBSERVATIONS

- Best studied radio galaxy in VHE gamma rays
- Monitored by MAGIC: over 150 h gathered between 2012 and 2015
- No flares observed in that time
- VHE gamma-ray spectrum extends up to 20 TeV and connects smoothly to the GeV spectrum

In collaboration with K. Asano

Extremely low magnetisation required
SUMMARY

The last few years were very exciting for MAGIC!

➤ **FSRQs**: more and more objects known (ToO, e.g. Ton 599), up to redshift ~1. Strong cooperation with Fermi-LAT: delayed emission from a *gravitationally lensed blazar* (B0218+357). MWL flare of PKS 1510-089, associated to the ejection of a new radio component in the jet.

➤ **BL Lac**: *New sources* every year (e.g. PGC 2402248) and *long-term monitoring* of known sources (e.g. Mkn 421, PG 1553+113). A *new blazar population*, the extreme blazars (1ES 2037+521) under study. In September 2017, *MM astronomy* with the discovery of a VHE gamma-ray emission from a flaring blazar (TXS 0506+056) in the region of a EHE neutrino detected by IceCube.

➤ **Radio Galaxies**: *fast flares* from NGC 1275, long-term *MWL monitoring* of M87: blazars from a different perspective.

Multi-wavelength / multi messenger approach is essential
In January 2019 we will organise in Padua the conference eXtreme19 focused on extreme blazars.

If you are interested in receiving the first circular and other info, please send an email to info.extreme19@dfa.unipd.it

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