Recent MAGIC Observations of Active Galactic Nuclei: Studies in the E>50 GeV Region

Robert Wagner on behalf of the MAGIC Collaboration
Max-Planck-Institut für Physik & Excellence Cluster “Universe”
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The MAGIC Telescopes

- **Two-dish stereoscopic** Cherenkov telescope, 17 m diameter each
- Located at the **European Northern Observatory, Instituto Astrofísica de Canarias** on the Canary Island of La Palma, Spain
- Currently upgrade of readout, of MAGIC-1 camera in 2012

- **150 physicists**
- **23 institutes**

Roque de los Muchachos observatory, 2200 m a.s.l.
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- Substantially lower energy threshold than other installations:
  - 50-60 GeV nominal
  - 25 GeV pulsar (“sum”) trigger
- Sensitivity: 0.75% Crab in 50 h
- Angular resolution: <0.07°
- Energy resolution: 15-20%
- Enhanced duty cycle (by 20%) thanks to moonlight & twilight observations

150 physicists
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R. M. Wagner: MAGIC AGN Observations

Some Key Features

- Fast repositioning (below 1 minute) ➔ sensitivity to transients: GRB
- Low energy threshold (50-60 GeV, 25 GeV in sum-trigger mode)
  - Overlap with Fermi-LAT
  - Deep universe

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MAGIC I achieved

MAGIC II achieved
(dashed: MC expect.)
Low Threshold: Overlap with Fermi-LAT

(IC peak, cross-calibration)

Most complete SED for Mkn 421 ever

...and, by the way, access to pulsars cutoffs, e.g., Crab
The Extragalactic TeV Sky

Extragalactic VHE $\gamma$-ray sources

$E_\gamma > 100$ GeV

- approx. 50 VHE $\gamma$-ray sources, mostly blazars
- Relativistically beamed gamma-ray emission

http://www.mpp.mpg.de/~rwagner/sources/
Beyond blazars...

New generation IACTs have established new classes of VHE active galaxies different than BL Lacs...

Radio galaxies M87, Cen A, starburst galaxies M82, NGC 253, Perseus cluster galaxies IC310, NGC 1275

- **BL Lacs**
  - Still the vast majority:
  - Approx. 45 discovered — 17 by MAGIC
  - Extensive studies

- **Radiogalaxies**
  - 4 discovered — 2 by MAGIC
  - Study emission in jet: they are nearby (can be resolved in other wavelengths) and jets not aligned with line of sight.
  - May be sources of UHECRs?

- **Starbursts**
  - 2 discovered — none yet by MAGIC
  - No central source, probably global emission of all CR in galaxy

- **FSRQ**
  - 3 discovered — 2 by MAGIC
  - Different physics: intense radiation fields.
  - Very distant: useful to study EBL
Radiogalaxies: M87

- Very close (17 Mpc)
- Very well characterized in other frequencies.
- M87 was the first radiogalaxy discovered a VHE (HEGRA/HESS) and has been extensively studied by HESS, VERITAS & MAGIC.
- In 2008, using all 3 experiments and simultaneous radio VLBI: VHE emission came from very close to the central BH (a few Schwarzschild radii, $R_s \sim 100$ A.U.).

Science 325 (2009) 444
Further cooperation of the 3 experiments and multiwavelength add essential information... but may be complicating the picture!

Results submitted to ApJ:

- Flare in 2010 showed exponential rise and decay. Not so clear for the others.
- 2nd flare was followed by a radio brightening of the core. Science 325 (2009) 444. The others not.
- In 2008 and 2010, VHE simultaneous to increase in X-rays. Unclear in 2005.
- Do all flares come from the same emission site? How are they produced?
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Recently, MAGIC studied only low state: spectral index consistent with high state emission, pointing to the same emission mechanism.
MAGIC has discovered 2 radiogalaxies: IC 310 and NGC 1275, both in the Perseus cluster.
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Detected during enhanced activity seen in Fermi-LAT. Very steep spectrum $\Gamma = -4.0 \pm 0.4$. Detection only possible thanks to stereo threshold and sensitivity.
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“Head-tail” radiogalaxy. Very hard spectrum: $\Gamma = 2.00 \pm 0.14$.
Radio Galaxy IC 310

- Belongs to Perseus cluster
- 7.6 sigma significance from 20.6 hrs stereo
- 2.5% Crab nebula flux
- **Radio galaxy** at z=0.019
- 22×/5× further away than Cen A, M87
- must be **intrinsically much more luminous**
  (could also be weakly beamed blazar)

**Mechanism?**

- Close to black hole
- at shocks with cluster medium?
- **Variability excludes** CR/medium interaction
- very hard spectrum:
  probably IC scattering off IR photons, difficult in SSC

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Fermi-LAT
MAGIC

E^{-2} from 2GeV to 7TeV
• 3C 279 (z=0.536) is the farthest VHE source, discovered by MAGIC in 2006.

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Quasars: 3C 279 & PKS 1222+21

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- PKS 1222+21 (z=0.432) discovered by MAGIC in 2010. Spectrum confirms past claims on EBL!

- 2010 June 17, flare state

- PKS 1222+21 (4C +21.35) is a high redshift FSRQ
  (only 3C279, PKS1510-089 so far)

- Observations triggered by a high state reported by Fermi-LAT
Quasars: 3C 279 & PKS 1222+21

- PKS 1222+21 and recent observations of 3C279 show the same problem
- Emission up to hundreds of GeV
- Fast variability (9 min doubling time in PKS 1222+21)

Why is this a problem?
FSRQs: the “canonical” scenario

Dermer+09
Ghisellini+Tavecchio09
Sikora+09

Accretion disk
X-ray corona
BLR

DUSTY TORUS

Blazars
FSRQs: the “canonical” scenario

If $\gamma$-rays produced inside BLR by IC scattering of BLR photons: strong absorption and Klein-Nishina suppression (cutoff $<100$ GeV)

- Dermer+09
- Ghisellini+Tavecchio09
- Sikora+09
FSRQs: the “canonical” scenario

If γ-rays produced inside BLR by IC scattering of BLR photons:
- strong absorption and Klein-Nishina suppression (cutoff <100 GeV)

If γ-rays produced outside BLR by IC scattering of dusty torus photons: less absorption but hard to explain fast variability!

Dermer+09
Ghisellini+Tavecchio09
Sikora+09

Accretion disk
X-ray corona
BLR
DUSTY TORUS
Blazars
**4C +21.35 aka PKS 1222+21**

- **A strong signal of 8.7 σ significance in just 0.5h of observations!**
  - → allows short-term variability studies
- Flux ≥30% of the Crab Nebula flux
- Also detected by *Fermi*-LAT in 100-300 GeV energy range

### Very fast! Must come from small region

**VHE not from inside BLR**
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**Possible solutions:**
- Strong recollimation of the jet
  - e.g. Nalewajko & Sikora 2009
  - Bromberg & Levinson 2009
- “Blobs” or “minijets” inside of the jet. Already proposed for PKS 2155-304

**Very fast!**
- $\approx 10$ min

**Must come from small region**

**VHE not from inside BLR**
3C 279: Re-detected in 2007

while high in opt and X-rays

MAGIC (>150 GeV)

2007 January 16
Detected again on 5.6-σ level

9^2 discovery plot

\[
dF/dE = (5.7 \pm 1.3) \times 10^{-7} \frac{E^{3.1 \pm 1.1}}{300\text{GeV}} \text{ TeV m}^{-2}\text{s}^{-1}\text{m}^{-2}
\]
3C 279: Re-detected in 2007

SEDs of simultaneous optical, X-ray and γ-ray data at the epochs of MAGIC observations.

**3C 279: SEDs 2006 / 2007**

One-zone models EC/BLR and EC/IR require, however, rather large MeV-GeV flux.

2-zone model would also work.

Two-zone: VHE outside BLR, minimizes gamma absorption.
Do Optical Triggers Work?

**Mkn 180**
- **ToO trigger**
- Optical light curves: KVA telescope, La Palma
  - March 2006
  - $S = 6.2 \sigma$
  - March-May 2007
  - $S = 6.8 \sigma$

**1ES 1011+496**
- **ToO trigger**
  - March 2006
  - MAGIC
  - 18.7 h
  - $S = 6.2 \sigma$

**S5 0716+714**
- April 2008
- $S = 6.8 \sigma$
A Continuing Success Story...

- Included in stacked HBL sample, no detection with MAGIC –I (Aleksić+ 2010)
- Another successful optical trigger, detection consistent with previous MAGIC upper limit -> variability unclear
- Integral flux (E > 200 GeV): \approx 2.3\% C.U.
- Soft power law spectrum: 
  \(-3.2 \pm 0.5_{\text{stat}} \pm 0.5_{\text{sys}}\)
- SED: narrow peaks, similar to PG 1553+113
- SSC model fit with parameters typical for HBLs
New Discoveries: 1ES 0647+250

- HBL
- $z=0.45$ (Meisner+Romani10)  
  $z=0.41$ (Kotilainen+11)
- Tentative detection at 4.9 sigma
- One of the best extragalactic TeV candidates after 2 years of Fermi-LAT data
- 30 hrs observations during 6 months w/ Swift, RXTE,Fermi-LAT
- prelim. flux estimation: $(3.0\pm0.7)\%$CU above 100 GeV
- Analysis in progress

De Lotto et al. (Proc. TAUP 2011)  
MAGIC Collab. released 9 Sept 2011

ϑ² discovery plot

PRELIMINARY
New Discoveries: 1ES 1741+196

- HBL, $z=0.083$
- Host galaxy one of the most luminous and largest of all BL Lacs
- Triplet of interacting galaxies with tidal streams? Heidt+99
- Promising candidate from Costamante & Ghisellini list
- 60h of data, clear 5$\sigma$ signal
- Hard spectrum
- Weakest AGN detected by MAGIC so far, start to explore mCrab regime
- Analysis ongoing

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**9^2 discovery plot**

Time = 60.82 h
$N_{\text{on}} = 332; N_{\text{off}} = 234.0 \pm 8.8$
$N_{\text{ex}} = 98.0$
Significance (Li&Ma) = 5.13$\sigma$
And one more: 1ES 0033+595

Previous upper flux limit: 8.55% CU (Ethr=165 GeV)
Season 2009: 19.7h, 357 excess events
August-October 2009
1.5% CU (Ethr=150 GeV)

- Host unresolved: no photometric redshift
- Morphology unclear:
  HST observes two point sources (comparable brightness)
- BUT VLBA (1997) only one radio counterpart
MAGIC-II fully commissioned and highly successful. Currently being upgraded with new readout electronics and camera (MAGIC-I)

truly largest Cherenkov telescope, lowest energy threshold

Stereoscopic system fully competitive with other installations +

**only instrument to access the energy region between 50 GeV and 100 GeV** overlap with Fermi-LAT

Recent results on extragalactic sources: AGNs, galaxy clusters

Revealing the location of the TeV engine in Blazars: M87

3C279, distant quasar, 2006 flare + 2nd detection 2007

PKS 1222+21 discovered, distant source, EBL, fast variability

Perseus cluster of galaxies: IC 310 (shedding light on nature?/LAT-triggered), NGC 1275 discovered

Some recent new MAGIC additions to the TeV blazar catalog:

1ES 1741+196  B3 2247+381, 1ES 1215+303
1ES 0033+595  (all “Costamante-Ghisellini” sources) 1ES 0806+524...

Fermi-LAT inspired discovery of 1ES 0647+250