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Extragalactic Sources of Very High Energy Gamma-Ray Emission: Highlights from Imaging Atmospheric Cherenkov Telescopes

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Outline





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- Extragalactic sky at VHE gamma rays
- BL Lacs
- FSRQs
- Radio galaxies
- EBL/IGMF studies
- Lorentz invariance Violation limits (Fundamental physics)

IMBO= in my biased opinion



Outlook



Image intensityShower energy

Image orientationShower direction

Image shape→ Primary particle

Systems of Cherenkov telescopes

A

Better background reduction Better angular resolution Better energy resolution

Current status: 3 major observatories



Current status: 3 major observatories



Differential Sensitivities

 $\Delta_{p} \cdot \Delta_{g} \ge \frac{1}{2} t$



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TeV Sky 2015





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Fermi/LAT (E>50GeV)





Adaptively Smoothed

More sources but less photons

2FHL, see Dominguez on Monday

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BLAZARS





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The "LEGO" structure of AGN/Blazars

Of all galaxies:

~1% Active Nucleus

~0.1% relativistic jets



BLAZAR = an AGN with a relativistic jet pointing at angles close to the line of sight, and whose emission is dominated by relativistic effects

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BL Lacs



Cosmic Ray Research

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Most popular source class (47)

- Best studied class of extragalactic TeV sources
- "Easy" to detect because the jet points towards us with a very small angle (Doppler boosting)
- Probably all are flaring on time scales of than ~month
- Some min-scale variability detected
- Vast on spectra, light curves and Multiwavelength correlations



HBL/IBL/LBL



- High Peaked / Intermediate Peaked / Low Peaked BL Lacs (based on 5GHz / 1keV ratio)
- "New" classification based on synchrotron peak position:
- HSP / ISP / LSP





HBL highlights: Mrk 421 / 501

MAGIC+VERITAS

- Extensive MWL campaign (VHE data by MAGIC + VERITAS) in Jan 2013 showed a shift of both peaks to lower energies
- Such HBL moving towards IBL has never been seen before for any blazar





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- Flare in June 2014
- Flux doubling time scale < 10 minutes

20 TeV?

HBL highlights: Mrk 421 / 501

$\Delta_{p}.\Delta_{g} \ge \frac{1}{2}t$

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ICRRR Institute for Cosmic Ray Research University of Tokyo

MAGIC+VERITAS



HBL highlights: PG 1553





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Periodic P=(785+/-14)d emission from a blazar! Not yet at TeV but ... Radio (OVRO) 0.18 F [Jy] 0.17 0.16 0.15 0.14 Optical (KVA) F (R band) [mJy] 0.8 X rays (XRT) Counts/s HE gamma (Fermi-LAT, E>300 NeV 04 0.35 0.3 90 80 70 60 50 40 30 20 coordinated campaign with VHE gamma (MAGIC, E > 150 G V) F x 10²[cm⁻²s⁻¹] HESS/MAGIC and VERITAS starts 2015 0.2 0.40.6 0.8 1.2 14 1.8 1.6

Prandini et al, ICRC2015

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Phase

IBL highlights





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- three new IBLs (now in total 8 IBLs)
 - Discovery of S3 1227+25 (z=0.135) VERITAS
 - Discovery of RGB J2243+203 (z>0.39) VERITAS
 - Discovery of BL Lac S2 0109+22 (0.265) MAGIC
- BL Lacertae flare (z=0.069) MAGIC confirms daily variability time scale

MAGIC detects an increased activity from BL Lacertae at very high energy gamma-rays

ATel #7660; Razmik Mirzoyan (Max-Planck-Institute for Physics) on behalf of the MAGIC collaboration on 18 Jun 2015; 19:02 UT Credential Certification: Razmik Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de)



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FSRQs highlights: PKS 1441+25





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- Redshift reminder: z=0.940!!
- Very strong detection by MAGIC
- High statistics allows one to better reconstruct energy spectrum
- About 10 spectral points between 40 and 300 GeV
- Spectrum is very soft, suggests intrinsic origin and an IC peak around 10-30 GeV (below MAGIC measurement)



FSRQs highlights: PKS 1441+25



Triggered by MAGIC alert, VERITAS observed and detected the source, too
Missed the night with the highest flux though...



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Gravitationally lensed blazar





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- Delay of ~11days known from radio and Fermi/ LAT
- Original flare (Fermi-trigger) missed by MAGIC due to the full moon period
- QSO B0218+357 was observed during expected delayed flare by MAGIC for 14 consecutive nights (all good weather), 1-2 hrs per night
- The flare duration is about 4 days
- The flare can be fitted with a symmetric Gaussian shape centered at MJD=56863.7 and σ≈1day



See talk by D. Dominis on Monday

Radio galaxies



Dyrda et al 2015 (ICRC2015)

No variability in VHE seen Spectral index ~ 2.8 4% C.U. >580 GeV

10-14

10⁻¹⁵

Radio galaxies



Long term monitoring of M87 with MAGIC. No flare since 2010!

- Perfect match with Fermi/ LAT
- TeV index: ~2.5
- almost 5 orders of magnitude in energy with very little curvature in the spectrum



Blazar highlight: IC310



Rapid flare from IC310, z=0.018 (MAGIC). Radio angle 10-20deg

Variability time scale < 4.8 min is shorter than the light crossing time of the event horizon of the IC 310 central black hole

Hard spectrum without a cutoff up to TeV energies

Shock in the jet models have troubles explaining IC 310 flare

- Plausible alternative: pulsar-like emission from the magnetosphere of the BH (e.g. Levinson & Rieger 2011)
- But: see critics of M. Barkov yesterday



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The EBL energy density: models





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Imprint of the EBL on spectra of HE/VHE gamma ray spectra of distant sources





z = 0.1, 0.3, 0.6, 1.0

 10^{1}

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- peaks at ~4*Ethreshold
- Delta function approximation is not precise



- Attenuation of Gamma-ray flux is calculated by integrating over number density of EBL, angles between photons, and distance to the source.
- The attenuation factor is sensitive to the EBL density



1ES 1011+496 flare (Feb'14)





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- Highest ever flux from this source in X- and γ rays
- Large VHE flux variability in day timescales
- No evidence for intra-night variability (~40' /night snapshots)
- Relatively stable spectral shape through the flare

See talk by A. Moralejo on Monday

1ES 1011+496 flare (Feb'14)





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EBL constraints with many sources





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Also distant sources available!





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	Classification	Discoverer	Date	Redshift
S3 0218+35	Blazar	MAGIC	2014.07	z = 0.944
PKS 1441+25	FSRQ	MAGIC	2015.04	z = 0.939
PKS 1424+240	HBL	VERITAS	2009.06	z ~ 0.6
3C 279	FSRQ	MAGIC	2008.06	z = 0.5362
PG 1553+113	HBL	H.E.S.S./MAGIC	2006.03	z ~ 0.5
IES 0647+250	HBL	MAGIC	2011.09	z = 0.45
4C +21.35	FSRQ	MAGIC	2010.06	z = 0.432

PKS 1441+25 flare (z=0.939)





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Not sure about details of the analysis

but derived upper limits by VERITAS are similar as the ones derived by MAGIC



See talk by A. Viana later today

Lorentz invariance Violation limits







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- Using flare Mrk 501 data
- Can check if there is a delay / lag between higher and lower energies
- IACTs are best for quadratic term

95% CL Quantum Gravity limits				
	Linear term	Quadratic term		
Sub-luminal	8.5 x 10 ¹⁷ GeV	1.15 x 1011 GeV		
Supra-luminal	6.4 x 10 ¹⁷ GeV	1.0 x 10 ¹¹ GeV		
PKS 2155-304 (sub.)	2.1 x 10 ¹⁸ GeV	6.4 x 10 ¹⁰ GeV		
GRB 090510 (sub. / sup.)	(1.8 x 10 ¹⁹ / 3.2 x 10 ¹⁹) GeV	(4.0 x 10 ¹⁰ / 3.0 x 10 ¹⁰) GeV		
Mrk 501 (MAGIC 2005)	2.1 x 1017 GeV	2.6 x 10 ¹⁰ GeV		







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The instruments are getting better!



IACT sensitivities

De Naurois & DM, C.R.Physique 16 (2015)

Outlook



Field far from being saturated

Missing (even after CTA): large FoV to look for transients



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BACKUP

Extreme objects in the LMC

- First glimpse of the LMC population of (stellar-type) particle accelerators
- Extreme environment:
 - Large CR density
 - Large IR

First

extragalactic

Stellar

Sources

- \rightarrow Very efficient radiation mechanisms
- First TeV superbubble
 - Possible sources of UHECRs



H.E.S.S.



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First

Superbubble

FSRQs highlights: PKS 1441+25



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MAGIC

- shift of synchrotron and IC peaks to higher energies
- significant variation of the X-ray and HE ray spectral indexes
- VHE variable, HE stable!
- emitting region originating in the jet just outside the broad line region
- high degree of optical polarization-the emission may come from a compressed region in the jet, like an internal shock



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See talk by Nievas on Monday

Limits from IACTs: axions





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