MAGIC Observations of Active Galactic Nuclei

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Abstract The MAGIC Imaging Atmospheric Cherenkov Telescope is located at the Roque de los Muchachos Observatory at La Palma. Currently it is the largest detector of its kind in operation. It is able to study sources of cosmic gamma-rays of energy between 50-60 GeV and some TeV with sensitivity down to less than 2% of the Crab nebula flux in 50 hours. In this contribution we present a review of its recent results for the AGNs in flaring and quiescent states. These results can help in understanding the mechanisms of gamma-ray production in AGN jets, estimate the distribution of Extragalactic Background Light (EBL), and detecting signs of quantum gravity.

1 Introduction

The MAGIC(Major Air Gamma-ray Imaging Cherenkov) Telescope is located at La Palma, Canary Islands, at an altitude of 2200 m above sea level. MAGIC is the biggest single-dish imaging air telescope (IACT) into operation, with a 17 m diameter tessellated dish. It has a trigger threshold of 50-60 GeV(at small zenith angles). MAGIC it is able to access to energies up to tens of TeV, with an energy resolution, depending on the zenithal angel and energy, of 20% -30%. MAGIC has observed several TeV sources, from which one main targets have been the blazar type AGN(Active Galactic Nuclei). In blazars, the main radiation component is believed to be created in a relativistic jet pointed close to the observers line of sight. Blazars are variable in all wavelengths from the radio to the very high energy γ-ray band (VHE defined as $E > 100\text{GeV}$).

The Spectral Energy Distributions (SED) of these sources are characterised by two humps It is generally believed that the first hump (from radio to UV /Xray) is generated by synchrotron radiation from accelerating electrons inside the jet,

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whereas for the second hump (X-ray to VHE γ-rays) is due to inverse Compton scattering. The origin of the seed photons for the second effect may be local synchrotron photons (synchrotron self Compton, SSC models [39]), or external photons (external compton, EC) originatingfrom accretion disk, emission lines, and/or molecular torus. These models are called leptonic models, since they involve only electrons. There is also a family of models where hadrons are responsible for emission of VHE γ-rays [38].

Blazars are classified in 2 types, BL Lac objects and Flat Spectrum Radio Quasars (FSRQ), and BL Lac objects are sub-divided in high and low frequency peaked blazars (HBL and LBL consequently). In total, 24 blazars have been detected so far in TeV, 13 by MAGIC, and out of them 6 cases MAGIC detected them for the first time. In what follows, an authors selection of the highlights of MAGIC experiment main discovers on AGNs will be explained.

Source	Distance	Type	Reference to MAGIC article
M 87	16 Mpc	Radio galaxy	[28]
Mrk 421	0.030	HBL	[22]
Mrk 501	0.034	HBL	[20]
1ES 2344+51.4	0.044	HBL	[21]
Mrk 180	0.045	HBL	[18]
1ES 1959+65.0	0.047	HBL	[36]
BL Lac	0.069	LBL	[23]
PKS 2155-30.4	0.117	HBL	[33]
1ES 1218+30.8	0.182	HBL	[19]
1ES 1011+49.6	0.212	HBL	[24]
S5 0716+71.4	0.033	LBL	[37]
3C 279	0.536	FSRQ	[26]
PG 1553+11.3	$0.42 > z > 0.09$	HBL	[25]

Table 1 Table of observed Blazars by MAGIC. Except for M87 distances are given in redshift

2 Mrk501

The source Markarian 501 is one of the most extensively studied blazars in VHE region. It was observed by MAGIC from 2005 May to July [20]. The high sensitivity of the telescope has enabled us to determine the spectrum and flux in a night by night basis. During this campaign it was observed that the flux of this blazar varied by an order of magnitude in a very short time scale. During the observations, two very intense flares were detected on the nights of June 30 and July 9, where the fastest flux variations ever detected for this source were measured, with doubling times down to 2 minutes. The spectra hardened considerably with increasing flux and during the two most active nights a spectral peak was detected at 0.42 ± 0.06 TeV(for June 30) and 0.25 ± 0.07 TeV (for July 9), whereas in the other nights no peak was detected down to 0.10 TeV. This suggests that the spectral luminosity could be correlated to the source luminosity. The study of the short flare of July 9 shows an indication of a 4 ± 1 min time delay between the peaks of F(<0.25 TeV and F(>1.2 TeV), which may indicate a progressive acceleration of electrons in the emitting plasma blob (see Fig.1). A further study on this flare characteristics [29] show an indication of correlation of the timing with the energy, as some quantum gravity theory (QT) models predict a vacuum refractive index dependant on energy of the particle (and quantum gravity mass scale $M_{QG1,2} r = (E/M_{QGn})^n n = 1,2$. Lower limits to $M_{qG1} > 0.21 * 10^{18}$ GeV and $M_{qG1} > 0.21 * 10^{11}$ GEV at the 95 % C.L. where established. This is a likely observation, that could turn as a firm discovery if other effects on the source are possible to be discarded. The observation of more fast flares in AGNs will help on discarding such effects.

3 1ES1218+30.4

The object 1ES 1218+30.4, which is a HBL at z=0.182, has been studied by the WHIPPLE and HEGRA experiments in the past, where they where able to derive upper limits $F(> 350GeV)$ 8% of the Crab Nebula Flux(Crab units, C.U.) and F(>750GeV) 12% C.U.. The MAGIC experiment has detected a clear signal for the first time of 6.4 σ) [19] . A differential energy spectrum with a threshold of 120 GeV was possible to fit to a simple power law $F_E(E) = (8.1 \pm 2.1)(E/250)^{-3.0\pm0.4} TeV^{-1} s^{-1}$. The integral flux was also measured as $F(> 100GeV) = (8.7 \pm 1.4)10^{-7}$ what is a 16% of the flux of the Crab. Gamma rays at very high energies from distant sources are expected to be strongly attenuated in intergalactic space by the interaction with low-energy photons(extragalactic background light, EBL). Since this source is very distant, we tried to put a constraint on the EBL using the measured spectrum. We tried to obtain the intrinsic spectrum of the source from the measured one using with 6 different EBL models. The hardest intrinsic rising slope Γ of $dN/dE\ E^{-\Gamma}$ that is believed possible is 1.5, [16]. All the reconstructed de-absorbed spectra were compatible with the original assumption. Therefore, no constrain was able to establish on the EBL.

4 1ES1011+49.4

1ES 1011+49.4 is a HBL type object. MAGIC observation was triggered by an optical outburst, thanks to the 4 year blazar monitoring program of the KVA and Tuorla telescopes. This was the second source discovered in the VHE region following optical trigger. The first one was Mrk 180, also discovered by MAGIC. Previous observations of 1ES1011+49.4 by the MAGIC telescope did not show a clear signal. After an observation of 18.7 hr, an excess of 6.2 σ was detected. The redshift of this source is z = 0.212 which was determined from an optical high state measured on 2007 March 12 [24]. This made this source the most distant VHE $\gamma - ray$ source at the moment of the discovery (now it is the third one, after 3C279 and S5 0716+714, that were detected later). A differential energy spectrum was obtained from the data, getting a good fit to a simple power law: $F_E(E) = (2.0 \pm 0.1) 10^{-10} (E/0.2TeV)^{-4.0\pm0.5} TeV^{-1} cm^{-2} s^{-1}$ from 120 GeV to 700 GeV, and also an integrated flux of $F(>200GeV) = (1.58 \pm 0.32) 10^{-11} ph.cm^{-2} s^{-1}$ (10% C.U.). As said before, the observed spectra are affected by the EBL, so to obtain the intrinsic spectrum of the source a correction was applied. The optical depth and the consequent attenuation of the VHE $\gamma - rays$ coming from this source were derived using the density of evolving EBL provided by the best-fit model of Kneise et al.[31]. Giving the actual uncertainties, this model is in good agreement with alternative models [34],[35]. After the correction, the slope of the spectrum is $\Gamma = 3.3 \pm 0.7$, still very soft compared with the observed other HBLs in VHE range.

5 S5 0716+714

The object S5 0716+714 is a HBL (or IBL) BL Lac object that has been studied in all energy bands. It is known that shows rapid variations from the radio to the X-ray bands. The redshift (z) of this source is still not very well determined, because the brightness's of its nucleus outshines the host galaxy. Recent measures suggest z = 0.26 could be a possible value. MAGIC observations were triggered by an speciallly high flux on the optical, measured by the KVA telescope [32]. In three nights the optical flux doubled(from April 14 to 17), reaching the historical maximum of this source. The triggered VHE γ-ray observations caused the discovery of the source in this energy band, as was announced in one Astronomers Telegraph on April 30th 2008 (6.8 σ in 2.8 hours of observation)[37] . The source was also high in X rays during the observations. The preliminary flux estimation is that the integral flux is $F(>400GeV)\ 10^{-11} phcm^{-2} s^{-1} \simeq 25\%$ C.U.. A detailed analysis on the MAGIC results is in preparation. This discovery provides further evidence of the importance of the optical triggers for ground VHE gamma ray observations.

6 3C279

The FSRQ 3C279, at z = 0.536, was observed by MAGIC during Feb 2006 [26]. After a marginal detection on 22 Feb 2006, a clear detection of 6.15 σ was archieved. This is the most distant VHE source discovered so far. It also means that with this detection, all types of Blazars in the so-called "blazar Sequence" have been detected. Simultaneous optical (R band) observations where taken by the blazar monitoring Program of the 1m telescope of Tuorla Observatory and the KVA telescope at La Palma, revealing that the source was in a high optical state (twice from the baseline standard optical flux) but with no evidence of short time variability on these wavelengths was seen. The observed spectrum can be described as a simple power law $F_E(E) = (5.2 \pm 1.7)10^{-10}(E/0.2TeV)^{-4.11 \pm 0.68} TeV^{-1} cm^{-2} s{-}1$ The measured integrated flux above 100 GeV on 23 February is $(5.15 \pm 0.82stat \pm 1.5syst) \cdot 10^{10}$ ph. $cm^2 s^1$. The EBL influences considerably the observed spectrum of a so distant source. A study of the effect of some of the models on the measured spectrum for 3C279 has been done. The application of the model of Primack [34] (close to the lowest possible attenuation) and Stecker [35](highest attenuation) where applied to the measured spectrum, to obtain the possible range of intrinsic spectrum. Additionally, a fine tuned model based on [31], such that the intrinsic spectral index is 1.5 (hardest expected) allows to determine a region of the possible EBL. The region between the maximum EBL obtained here and the minimum obtained by galaxy counts is rather small [fig. 2]. This is consistent with models that assume a maximum star-formation a z≤1 by[34] and similar.

7 Conclusions

MAGIC has proved to be a very good instrument on the detection and study of the VHE gamma-ray blazars, having detected 13 of these sources, and 6 of them for the first time. From the total number of detected VHE AGNs, 20 are HBL. The other ones are: BL Lac (LBL), 3c279(FSRQ), M87(Radio), S5 0716+714(LBL). The studies of Mrk 501 measures have proved to have possible implications on fundamental physics, as they may point to a possible violation of the Lorenz invariance The detection of the distant AGN 3C279 has proved to be an important input for EBL studies. The optical trigger target of opportunity observation for MAGIC led to discover Mrk180 (2006), 1ES1011+496 (2007) and S5 0716+714 (2008), proving it has been a successful strategy as it made possible to discover 3 new sources out of a total of 5 alerts. We tried to fit models to the measured spectra of these sources. So far, the leptonic ones seem to be the most favoured, but based on these data sets we cannot fully discard the hadronic models. We need more simultaneous multiwavelength data to understand these sources.

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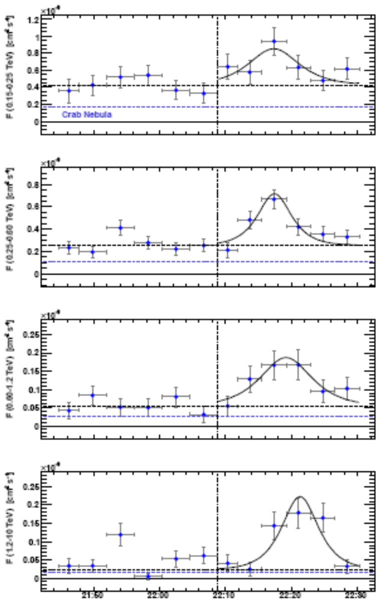

Fig. 1 Light Curve for the night July 9 with a time binning of 4 minutes, and separated in different energy bands, from the top to the bottom, 0.15-0.25 TeV, 0.25-0.6 TeV, 0.6-1.2 TeV, 1.2-10 TeV. The vertical bars denote 1 σ statistical uncertainties. For comparison, the Crab emission is also shown as a lilac dotted horizontal line. The vertical dot-dashed line divides the data into 'stable'(i.e., pre-burst) and 'variable' (i.e., in-burst) emission. The horizontal black dashed line represents the average of the 'stable' emission. The 'variable' (in-burst) of all energy ranges were fit with a flare model [20]

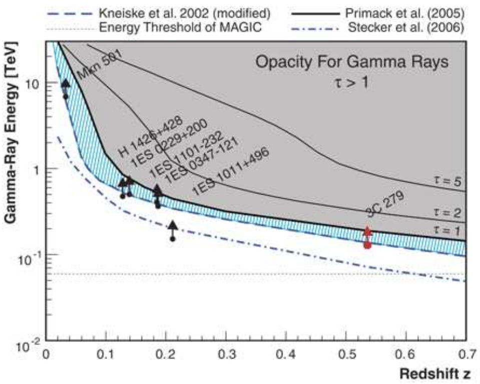

Fig. 2 The γ-ray horizon. The redshift region over which the γ-ray horizon can be constrained by observations has been extended up to z = 0.536. The prediction range of EBL models is illustrated by [34] (thick solid black line) and [35] (dashed-dotted blue line). The tuned model of [31] (dashed blue line) represents an upper EBL limit based on our 3C 279 data, obtained on the assumption that the intrinsic photon index is $\geq$ 1.5 (red arrow). Limits obtained for other sources are shown by black arrows, most of which lie very close to the model [31]. The narrow blue band is the region allowed between this model and a maximum possible transparency (i.e., minimum EBL level) given by [34], which is nearly coincident with galaxy counts. The gray area indicates an optical depth tau > 1, i.e., the flux of gamma rays is strongly suppressed. To illustrate the strength of the attenuation in this area, we also show energies for $\tau = 2$ and $\tau = 5$ (thin black lines), again with [34] as model.

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