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THE ACTIVE GALACTIC NUCLEI SEEN AT VERY HIGH ENERGY

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Abstract. AGNs are a class of objects emitting over a very broad energy range. Most AGNs observed at VHE are Blazars, so named because they have jets which are orientated towards us. In this case, the observed γ-rays, produced by the particle acceleration and emission processes in the jets, benefit from boosting by the Lorentz factor, so that their energies can reach the TeV. The first TeV Blazar, Mkn421, was discovered in 1992 with the Whipple observatory. Today, the known γ-ray sky contains over 20 of these objects, with the detections being carried out mainly by MAGIC and VERITAS for the Northern hemisphere and by H.E.S.S. for the Southern hemisphere. The present generation of Čerenkov telescopes has improved the quality of the spectral characterization and is now sensitive enough to detect variability on time-scales of minutes for the brightest sources. The detected TeV AGN study is essential for the comprehension of the processes taking place in the jets which are at the origin of the γ emission. The spectra of the farthest sources also highly constrain the density of the extragalactic background light.

1 Introduction

Imaging Čerenkov telescopes are observing the sky at very high energies (VHE; > 100 GeV). Thanks to the improvement of the detection technology, the number of active galactic nuclei (AGN) seen at VHE and the quality of the data has both increased in the past few years. Detected AGNs at VHE will be reviewed before giving the panorama of the types of studies that can now be carried out on this type of objects.

2 Description of Active Galactic Nuclei

It is now believed that most galaxies host in their centre a super massive black hole. For 10% of the observed galaxies the massive black hole accretes matter via an accretion disk: the galactic nucleus is active. Jets can then be formed, in which the matter is ejected at velocity close to the speed of light. Those jets host very strong magnetic fields where charged particles are accelerated. The accelerated particles radiate over the whole electromagnetic spectrum, from the Radio to VHE. The spectrum from radio to X-ray can be mainly explained by the synchrotron radiation of the electrons within the magnetic fields. On the other hand the emission at VHE can be explained through two different scenarios: leptonic and hadronic ones. In the leptonic scenario, the VHE photons are produced via inverse Compton whereas in the hadronic scenario they are produced via the disintegration of pions, created by the collision of an accelerated proton with the ambient medium.

There are different types of AGNs now united within the same classification which explain the different aspects from one AGN to another by the various orientations taken by the jets in relation with the line of sight. At VHE the AGNs seen are mostly Blazars, AGNs whose jets are pointing towards us. Indeed this is a very favorable geometry since under this angle the signal is amplified in intensity and in energy by the Lorentz boost.

The radiation processes producing the VHE photons are known, but the nature and the proportion of the particles (leptons and/or hadrons) involved is yet to be clarified. The observation of AGNs at VHE is essential to understand the mechanisms taking place within those objets and the particles responsible for the emission.

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3 A growing catalogue of AGN at VHE

The first detected AGN at VHE was Mkn 421, observed by Whipple in 1992. Whipple, together with HEGRA, CAT, 7 Tel Array and Durham Mark VI constitute the first generation of Čerenkov telescopes to see AGNs at VHE. The new generation benefit from various improvements such as fine imaging, broader collecting area, faster electronics and stereo technology for H.E.S.S, Veritas and Cangaroo. MAGIC was working with one telescope benefiting from a very large mirror area, but a second one has been constructed and MAGIC II will also benefit from stereo technique. In the Northern hemisphere, MAGIC and more recently VERITAS are observing the sources, Whipple is still operating, monitoring the brightest sources. H.E.S.S. is carrying out the observations from the Southern hemisphere.

Up to today, the VHE γ-ray sky contains 22 AGNs (see table 1), from a redshift of 0.004 to $\sim$0.2. H.E.S.S. discovered PG 1553+113 whose redshift is not well determined but considered > 0.250. MAGIC claimed the detection of 3C 279 the farthest seen AGN at VHE at a redshift of 0.536. Fifteen of thoses sources were added to the catalogue thanks to the technical improvements of the new generation of telescopes, and there are more discoveries to come, with the present instruments and with the next generation. All the AGNs seen at VHE are Blazars except for M87, the first non-blazar seen at VHE. The photons from this source don't benefit from the Lorentz boost but M87 is quite close and therefore can be detected. The majority of Blazars observed at VHE are BL Lacertae divided in different families considering the energy position of their double spectral structure composed of the synchrotron peak and the inverse Compton peak.

AGNs	**Redshift**	**Type**	**First Detection**	
			Year	**Instrument**
M87	0.004	FRI	2003	HEGRA
Mkn 421	0.030	HBL	1992	Whipple
Mkn 501	0.034	HBL	1996	Whipple
1ES 2344+514	0.044	HBL	1998	Whipple
Mkn 180	0.046	HBL	2006	MAGIC*
1ES 1959+650	0.047	HBL	1999	7-Tel. Array
BL Lac	0.069	LBL	2008	MAGIC*
PKS 0548-322	0.069	HBL	2007	H.E.S.S.*
PKS2005-489	0.071	HBL	2005	H.E.S.S.*
RGB J0152+017	0.080	HBL	2007	H.E.S.S.*
W Comae	0.102	IBL	2008	VERITAS*
PKS2155-304	0.116	HBL	1999	Mark VI
H 1426+428	0.129	HBL	2002	Whipple
1ES 0806+524	0.138	HBL	2008	VERITAS*
1ES 0229+200	0.139	HBL	2006	H.E.S.S.*
H 2356-309	0.165	HBL	2006	H.E.S.S.*
1ES 1218+304	0.182	HBL	2006	MAGIC*
1ES 1101-232	0.186	HBL	2006	H.E.S.S.*
1ES 0347-121	0.188	HBL	2007	H.E.S.S.*
1ES 1011+496	0.212	HBL	2007	MAGIC*
PG 1553+113	>0.250	HBL	2006	H.E.S.S.*
3C 279	0.536	FSRQ	2008	MAGIC*

Table 1. *AGNs detected at VHE, classified by increasing redshift. The HBL (High-energy-peaked BL Lacs), LBL (Low-energy-peaked BL Lacs) and IBL (Intermediate BL Lacs) are BL Lacertae (BL Lacs), a subcategory of Blazars. The SED of BL Lacs is dominated by synchrotron emission at low energy and inverse Compton (IC) emission at high energy, a double peak structure. The FRI (Fanaroff and Riley type 1) are radio galaxies. The FSRQ (Flat Spectrum Radio Quazar) are Blazars without radio emission. The instruments with a* * *are from the new generation.*

4 Tools to understand those objects

4.1 The multi-wavelength campaigns

Since the AGNs emit over a very broad energy range, getting a global view of the objects is the motivation to organize multi-wavelengths campaigns. A good illustration of such a campaign is given by that led on PKS 2155-304 during the the months of October and November 2003 (see paper 2), involving H.E.S.S., Rossi X-Ray Timing Explorer (RXTE), Robotic Optical Transient Search Experiment (ROTSE) and Nançay Radio Telescope (NRT). The spectral energy distribution (SED) of the source with the data obtained during the campaign is shown in Fig. 1. The experimental data set gives constraints to the emission models. Considering the leptonic and the hadronic radiative models presented on the SED (Fig. 1) the discrimination is yet to be done and could be achieved with H.E.S.S II [1] thanks to its lower energy threshold.

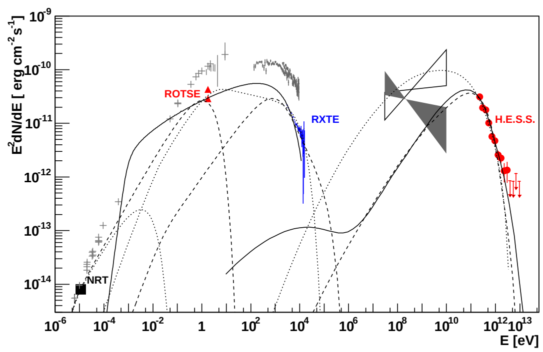

Fig. 1. *Spectral energy distribution of the AGN PKS2155-304. The coloured and labeled points represent data taken during the multi-wavelengths campaign in October and November 2003. The SED is from paper 2.*

When multi-wavelength campaigns are carried out on a source in a very bright state the data set obtained is well enough sampled to study the correlation between X-ray and γ-ray fluxes. This scenario happened during Mkn 421 multi-wavelength campaign in 2001 (see paper 3), and that of PKS 2155-304 in 2006 (see proceeding 4). In each case both sources have been observed during a flaring state allowing the evolution of their flux with time to be measured. For Mkn 421, a linear correlation has been found considering the whole period of observation. A more complex behavior is revealed when looking at intra-night flux correlations. On certain nights a quadratic correlation has been found which is understood within the frame-work of 1 zone synchrotron self-Compton (SSC) emission model (for more detail see paper 3). On the other hand the correlation between the X-ray and γ-ray fluxes of PKS 2155-304 show a cubic correlation, this can be explained only by a 2 zone SSC emission model. For more details on the interpretation of correlation between X-ray and γ-ray fluxes see paper 4. The complexity of those behavior is challenging the emission models.

4.2 AGNs' variability

On the brightest sources, the study of VHE AGNs' variability is now possible on short time-scales thanks to the high sensitivity of the instruments. Spectral variability measured during Mkn 421 (2001 and 2004) and Mkn 501 (2005, see paper 5) flaring states show, in each case, a hardening spectrum when the flux increases. PKS 2155-304 flared twice in 2006 (see paper 6 for the first flare). In the case of PKS 2155-304 2006 flares the behavior might be more complex (see proceeding 9).

Temporal variability of the VHE flux is observed on some AGNs ,on month scale even day scale for the brightest sources. For M87, time variability on day scale has been observed, so the size of the emission region was then constrained by causality to be of the order of the Schwartchild radius (see paper 1). PKS 2155-304 first

[1] A fifth telescope is to be added to the present H.E.S.S telescope array, the new telescope will be operational in autumn 2009, H.E.S.S.II . This telescope will be 30m in diameter, bigger than the other H.E.S.S. telescopes; this size should lower the energy threshold down to around 30GeV.

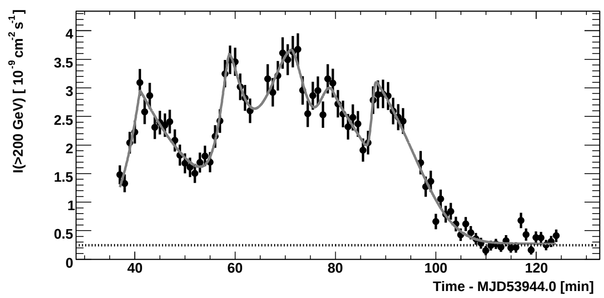

Fig. 2. *PKS 2155-304 light curve on minutes intervales, 2006 flare, fitted by 5 flares and a constant component. (from paper 6)*

flare in 2006 was an historical event. Time variability of the order of the minutes was measured (see Fig. 2), this was a first for AGNs at VHE but also considering other wavelengths. Such variability also puts constraints on the size of the emission region; hadronic radiative models are not good candidates to explain such a rapid variability. This highly sampled data set allows other type of variability studies: descriptioon as random process (see proceeding 10), constraints quantum gravity (see 8), etc.

5 Constraining the extragalactic background light

The study of AGNs at VHE also contributes constraining the extragalactic background light (EBL). The EBL is the accumulated light from all galaxies and the first stars. A VHE photon colliding with an infrared EBL photon will produce an electron positron pair. Therefore, the farther the VHE photon is coming from the higher is the probability for this photon to be absorbed by the EBL . The VHE spectrum of a fairly distant AGN can give contraints on the density of the EBL, with simple assumptions on the emission spectrum. By observing the unexpectedly hard spectra of H 2356-309 (z=0.165) and 1ES 1101-232 (z=0.186) H.E.S.S. gave a very constraining value for the upper limit of EBL density, close to the lower limit given by the galaxy counting (see paper 7). This is an important achievement since a direct measure of the EBL is made very difficult by the zodiacal light.

6 Conclusion

The catalogue of VHE AGNs contains 22 sources, and we're still counting. The quality of the data taken in observations of AGNs at VHE and other energies now allows fine correlation studies between X-ray and γ-ray emission; it also opens the short time-scales variability studies. The emission models are then better constrained and the understanding of the objects improve. Besides, the EBL density has been highly constrained thanks to the observation of hard spectra from fairly distant sources.

References

Aharonian, F. et al., Science, 2005, 314, 1424

Aharonian, F. et al., A&A, 2005, 442, 895

Fossati, G. et al., ApJ, 2008, 677, 906-925

Costamante, L. et al., High Energy Phenomena in Relativistic Outflows (Dublin), 2007, proceeding

Katarzyński, K. et al., A&A, 2005, 433, 479-496

Aharonian, F. et al., ApJ, 2007, 664, L71-L74

Aharonian, F. et al., Nature, 2006, 440, 1018-1021

Aharonian, F. et al., Phys. Rev. Letter, 2008, accepted for publication

Lenain, J. et al., International Symposium on High Energy Gamma-Ray Astronomy (Heidelberg), 2008, proceeding

Superina, G. et al., Workshop on Blazar Variability across the Electromagnetic Spectrum (Palaiseau), 2008, proceeding