

Study of extragalactic sources with H.E.S.S.

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Abstract.

The field of Very High Energy (VHE) γ -ray emitting extragalactic sources has considerably evolved since the new generation of atmospheric Čerenkov telescopes (ACT) of improved sensitivity, such as H.E.S.S. array and the MAGIC ACT, have started operating. This has led to a wealth of new clues about emission mechanisms at high energy through the discovery of new sources, more accurate spectra and temporal studies of sources known previously, and simultaneous multi-wavelength (MWL) campaigns since broadband variability is a key phenomenon to the underlying physical mechanisms at play. The fact that some of these new sources are located at redshifts close to $z \sim 0.2$ makes them powerful probes of the Extragalactic Background Light (EBL) through the attenuation of γ -rays above 100 GeV.

1. Introduction

The VHE γ -ray emitting extragalactic objects are all of the AGN class, in which the emission is thought to arise from particles accelerated in a relativistic jet directed along our line of sight. In electromagnetic models, the observed radiation stems from different cooling mechanisms of electrons in the ambient magnetic field, with synchrotron and Compton mechanisms dominating the overall output but overlapping very little in the observed spectral energy distribution (SED) which appears double-humped in νF_ν representation. The first hump is usually attributed to the first mechanism, peaking at keV or sub-keV energies, while the second is due to the same electrons scattering off the synchrotron photons themselves (synchrotron self-Compton, SSC) peaking 8 to 10 orders of magnitude above the first hump and extending in nearby objects to above 10 TeV. Searches for simultaneous or time-lagged correlations between both regimes, or the lack thereof, provides information about the extent to which a single population of particles may be responsible for radiation over most of the spectrum.

Since this conference is generally neutrino oriented, the alternatives to leptonic models, the “hadronic models”, should be evoked. In these models the relativistic jet has a significant component of relativistic protons emitting X-rays and γ -rays via synchrotron, photo-production, or pion decay from proton-proton interactions (see e.g. [Costamante(2004)] for a recent review). These models are not excluded since purely leptonic scenarios require a low efficiency of $\sim 10\%$ to reproduce the kinetic energy in jets needed to power the extended radio structures. A way out of the conundrum is found by adding a “cold” proton for each electron in the jet, accounting for 90% of the remaining energy needed [Ghisellini & Celotti(2001)].

2. H.E.S.S. observations of BL Lacs

H.E.S.S. (see Dieter Horns in these proceedings) devotes on average 30% of its observing time to extragalactic observations, most of which consists of pointings on BL Lacs. The subset that are X-ray bright and relatively closeby are prime targets, with PKS 2155-304 ($z = 0.117$) and PKS 2005-489 ($z = 0.071$) being the best examples; the former is the brightest BL Lac object in the EUVE all-sky survey and the latter one of the most powerful X-ray emitters.

PKS 2005-489 is the first H.E.S.S. extragalactic discovery [Aharonian et al. (2005a)], and at a flux level of $\sim 2.5\%$ the flux observed from the Crab Nebula, is a good illustration of the sensitivity of the instrument. The measured spectrum is quite soft ($\Gamma = 4.0 \pm 0.4$), and due to its proximity compared to more distant but harder sources, it can be assumed that this is a clear case where EBL attenuation plays little role in the energy cutoff. The soft spectrum is hence more likely to depict a limit of the acceleration mechanism in this object. The very soft X-ray spectrum in archival data and low variability support the idea that the emission in both energy ranges come at least partially from the same underlying particle distribution. In the SSC scenario, this would mean that the maximal Lorentz factor γ_e of the electrons and the bulk Doppler factor δ from the emission zone are such that $\gamma_e m_e c^2 \frac{\delta}{1+z} \leq 1$ TeV. This is probably the least energetic VHE BL lac γ -ray emitter known to date, but its X-ray history clearly shows the capability for huge outbursts.

The object PKS 2155-304 was a previously known VHE emitter and was confirmed by the first H.E.S.S. observations [Aharonian et al.(2005b)]. It is also a source that H.E.S.S. detects on a nightly basis since 2002, raising the question as to whether PKS 2155-304 is the first BL Lac object that can be seen at its lowest or quiescent level. The fluxes can vary between 10% and 60% of the Crab Nebula flux level, with surprisingly little spectral variability with increasing flux (photon index $\Gamma \approx 3.3 \pm 0.1$ and a spectrum extending to at least 3 TeV). This behaviour resembles that of the northern hemisphere BL Lac Mkn 421, which was also detected by H.E.S.S. at large zenith angles of $60^\circ - 65^\circ$ [Aharonian et al.(2005c)] and for which photons up to ≈ 20 TeV have been observed. Exceptionally bright flares from PKS 2155-304 have been recently observed [Benbow et al.(2006)] with multi-Crab flux levels, for which H.E.S.S. results and details from the MWL campaign that was triggered on that occasion should be available soon.

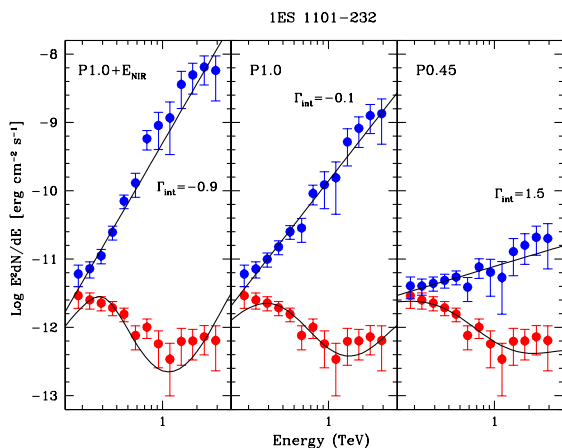


Figure 1. Spectra from 1ES 1101-232 measured by H.E.S.S. (red points) and the derived intrinsic spectrum (blue points) for different assumptions of the EBL spectral density. The phenomenological P shape with the IRTS published data (E_{NIR}), or the P shape alone (left and middle plots) yield too hard an intrinsic spectra ($\Gamma < 1.5$), whereas a scaled P shape gives a limit slightly above the irreducible background coming from resolved galaxies (right). Details are in [Aharonian et al.(2006b)].

A significant advance was made when the distant AGNs H 2356-309 ($z = 0.165$) and 1ES 1101-

232 ($z = 0.186$) were found by H.E.S.S. to be VHE γ -ray emitters, since their distances set a new horizon limit, previously held by the object 1ES 1426+428 ($z = 0.129$). With photon indices of respectively 3.06 ± 0.21 and 2.88 ± 0.18 , it becomes possible to greatly constrain the EBL density in the $0.1 - 10 \mu\text{m}$ range through the theoretical assumption that the intrinsic spectra cannot have indices $\Gamma_{\text{int}} \leq 1.5$ [Aharonian et al.(2006b)]. A phenomenological EBL shape, scaled until the $\Gamma_{\text{int}} \geq 1.5$ limit is reached (1), shows that more than two-thirds of the EBL in the near infrared-optical band is resolved into single sources. The detection of the distant AGN 1ES 1218+304 ($z = 0.182$) by the MAGIC instrument [Albert et al.(2006)], with an observed index of $\Gamma = 3.0 \pm 0.4$, confirms this level of EBL and shows that the Universe is more transparent to VHE γ -rays than initially thought.

3. Multi-wavelength campaigns

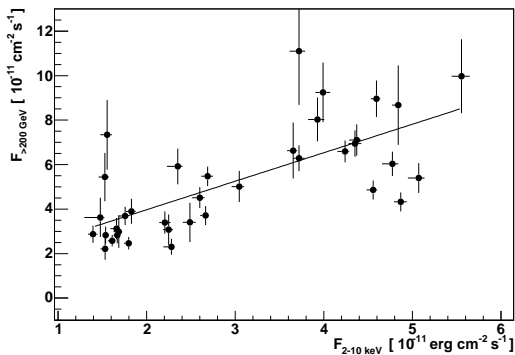


Figure 2. Correlation plot of simultaneous observations of PKS 2155-304 in the VHE γ -ray flux ($E > 200$ GeV) measured by H.E.S.S. and the 2-10 keV flux measured by RXTE, for the 2004 MWL campaign. The correlation factor is $r = 0.71 \pm 0.05$.

Several MWL campaigns targeting AGN have been carried out in which H.E.S.S. has participated. PKS 2155-304 was the subject of such campaigns during a VHE γ -ray high state [Aharonian et al.(2005d)] and on a fixed observation campaign [Giebels & H.E.S.S. Collaboration(2005)] where this source was established as the first southern-hemisphere AGN for which the X-ray and VHE γ -ray emissions correlate (Fig.2), in agreement with the single radiative particle distribution mentioned earlier. During the first campaign a 1.2 ks X-ray flare was also detected, one of the fastest seen in this object. Single-zone SSC leptonic models and single-zone SPB hadronic models were tested against the data. All models need generally high values for the Doppler factor ($\delta > 20$) in order for the γ -rays not to be absorbed by the photons at the source. A more detailed correlation analysis with a larger data set from the 2004 MWL campaign is in preparation. Other successful campaigns have been carried out on the BL Lacs H 2356-309 [Aharonian et al.(2006a)] and 1ES 1101-232 (in preparation) with results which cannot be covered in these proceedings for reasons of space.

4. Non-BL Lac objects

The confirmation by H.E.S.S. that the giant radio galaxy M87 is a VHE γ -ray emitter is probably one of the most interesting developments in the AGN field. Indeed its proximity ($z = 0.00436$ or barely 16 Mpc) and its measured jet pointing $\sim 30^\circ$ away from our line of sight makes it the only extragalactic VHE emitting object not belonging to the BL Lac class. The fact that the γ -ray source appears as a point-source compatible with the position of M87's nucleus already excludes the outer radio regions of M87 as possible origin of the VHE γ -rays. The intra-cluster gas and cosmic rays interacting in M87 are excluded due to the observed variability, as is the large-scale jet. The SSC and SPB models mentioned above, used in the modelling of BL Lac SEDs, are likely to be challenged by the relatively hard spectrum and the large line-of-sight

angle. Correlated X-ray variability seen with instruments having a good angular resolution might further constrain the spatial origin of the γ -ray emission.

Note also that many H.E.S.S. observations of radio loud/weak galaxies and non-detected BL Lacs, with distances between $z = 0.00183$ and $z = 0.333$ have yielded solid upper limits that are published in [Aharonian et al.(2005e)].

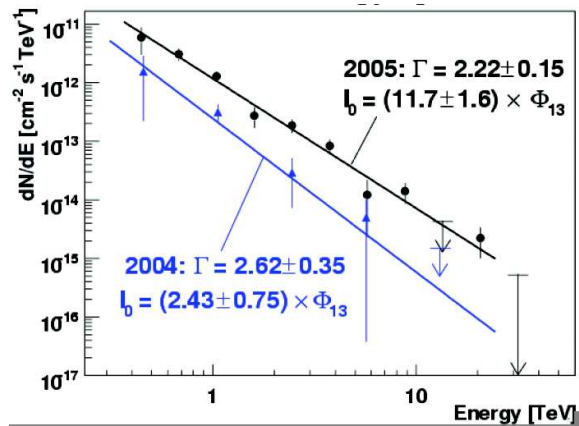


Figure 3. Spectrum of M87 measured in 2004 (triangles) and 2005 (circles) where a 3.2σ yearly variability in the VHE γ -ray flux is apparent while the index of the spectrum appears to be consistent with a constant over that period (2.62 ± 0.35 vs 2.22 ± 0.15). Such variability can readily exclude some γ -ray production scenarios such as local cosmic rays or mechanisms in the extended jet.

5. Conclusions

Since the discovery of Mrk 421 [Punch et al.(1992)] in 1992, the number of VHE extragalactic γ -ray emitters has reached 13, double of the number quoted in 2003 [Krawczynski(2004)]. The H.E.S.S. experiment has considerably enriched the AGN field in the past few years, exploring the southern hemisphere sky at unprecedented sensitivities. Through the study of the spectra and lightcurves, along with multi-wavelength campaigns, our studies have revealed a remarkable quiescence in most of them, while the now well-established X-ray/VHE γ -ray flux correlation in high emission states also holds in PKS 2155-304 which has been the only southern AGN in a truly high/variable state. More is now also known about M87, the only radio-loud galaxy detected in VHE γ -rays, which will likely be a challenge for emission models. At the current pace, we expect more exciting results in the years to come.

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