Hard TeV spectra of blazars and the constraints to the IR intergalactic background

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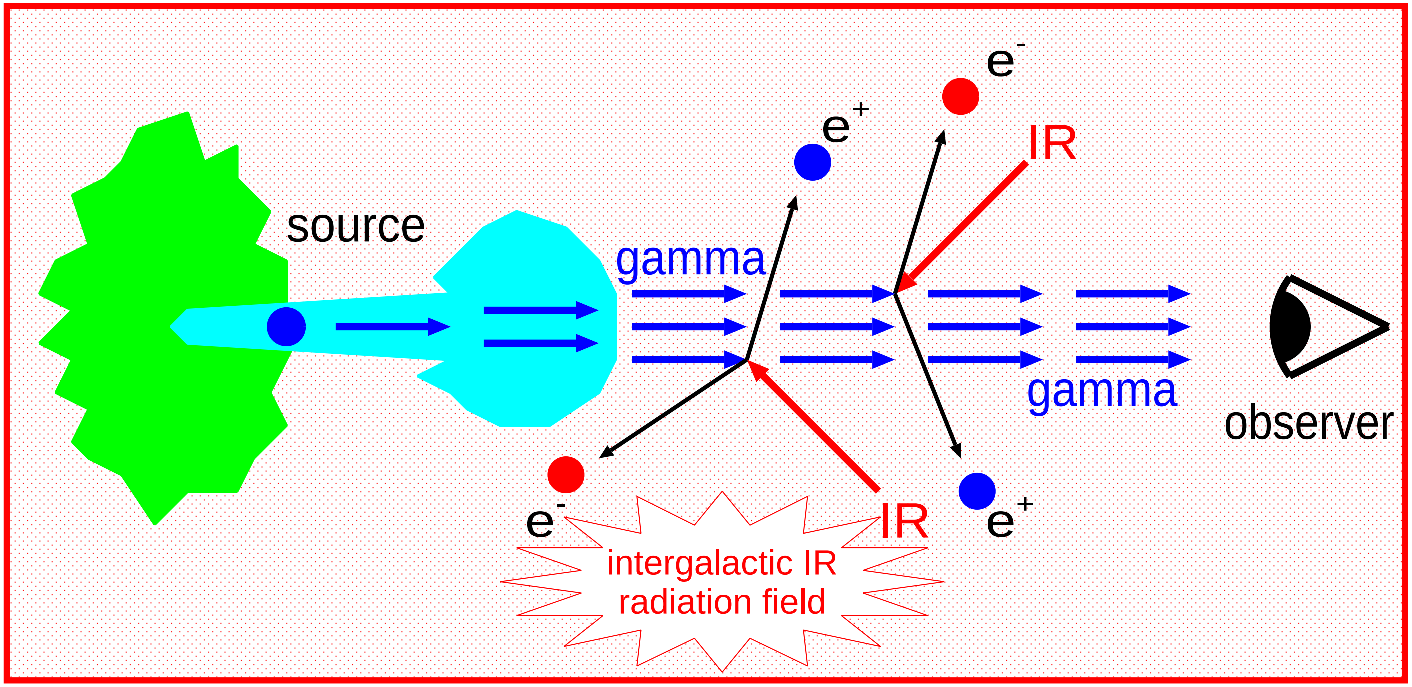
2 Abstract

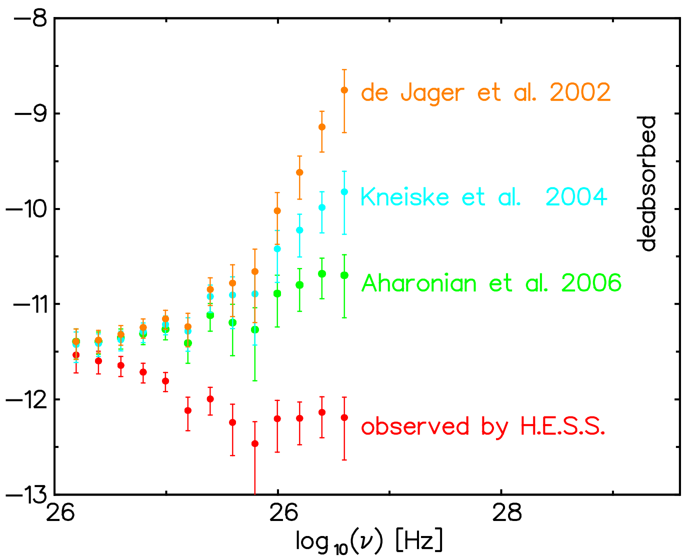
Recent gamma–ray observations of the blazar 1ES 1101–232 (redshift $z = 0.186$) reveal that the unabsorbed TeV spectrum is hard, with spectral index $\alpha \lesssim 0.5$ [$F(\nu) \propto \nu^{-\alpha}$]. We show that simple one–zone synchrotron self–Compton model can explain such hard spectra if we assume a power law energy distribution of the emitting electrons with a relatively high minimum energy. In this case the intrinsic TeV spectrum can be as hard as $F(\nu) \propto \nu^{1/3}$, while the predicted X–ray spectrum can still be much softer. The observations of 1ES 1101–232 can therefore be reconciled with relatively high intensities of the infrared background, even if some extreme background levels can indeed be excluded. We show that the other TeV sources (Mrk 421, Mrk 501 & PKS 2155–304) can be interpreted in the same framework, with a somewhat larger minimum energy.

3 Absorption of TeV photons



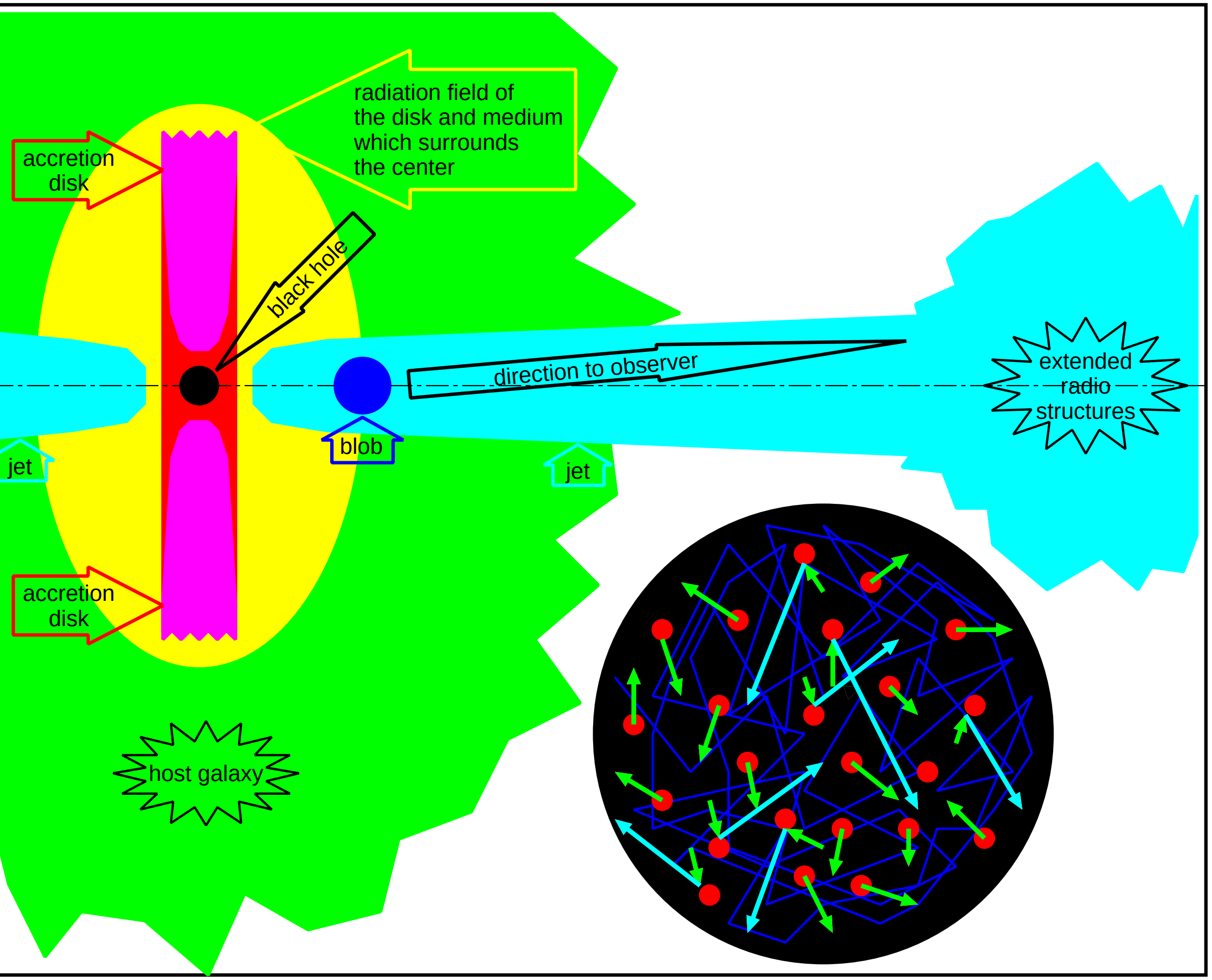
The intrinsic high-energy emission from extragalactic sources is attenuated by the pair-production process. Photons in the TeV range (ϵ_γ) interact with low–energy photons from the extragalactic infrared background ($\epsilon_{\rm IR}$) and produce electron–positron pairs ($\epsilon_{\rm IR} + \epsilon_\gamma \rightarrow e^+ e^-$). The total absorption depends on the history of the reaction rate along the line–of–sight, and therefore, on the distance travelled and on the local density of the low-energy target photon field, both a function of redshift z.

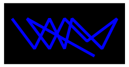
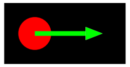
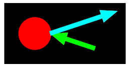
4 TeV spectrum of 1ES 1101-232



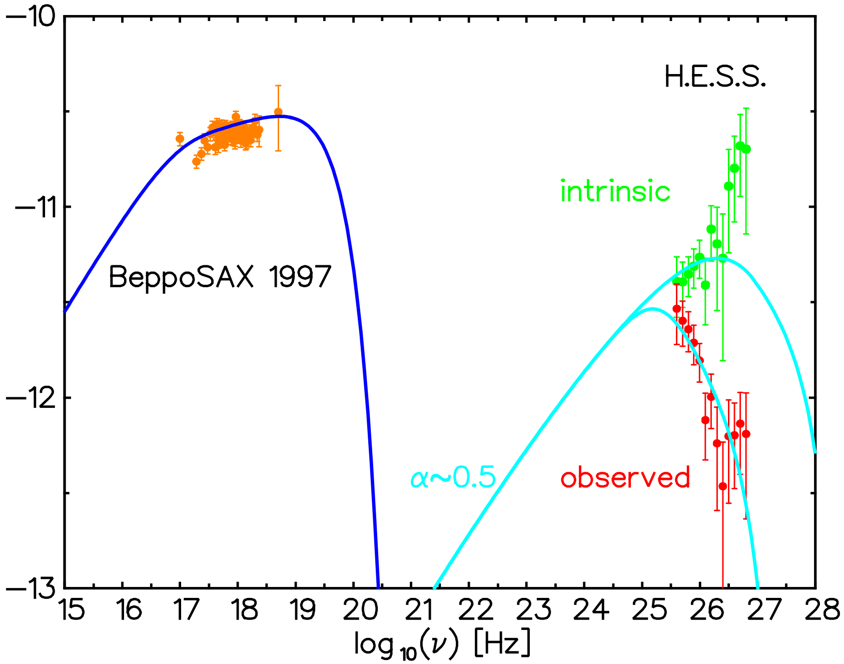
The observed spectra from distant blazars contain information on both the IR background radiation field history and the intrinsic properties of the source. From the viewpoint of blazar studies the latter is just an undesirable extrinsic effect that must be corrected for. In contrast, from the opposite perspective, it allows the measurement of the IR background. The figure shows TeV spectrum of 1ES 1101-232 ($z = 0.186$) observed recently by the H.E.S.S. experiment (Aharonian et al. 2006) and the intrinsic spectra calculated for the different models of the IR background. Aharonian et al. (2006) found that the index of the intrinsic spectrum should be equal to $\alpha = 0.5$ if the level of the IR background is close to the absolute lower limit obtained from direct integration of the light from resolved galaxies (Madau & Pozzetti 2000). They also commented on the theoretical difficulties to explain spectra harder than $\alpha = 0.5$, which would imply quite unexpected physics. These facts led them to prefer the solution of minimal IR background.

5 Model of the emission



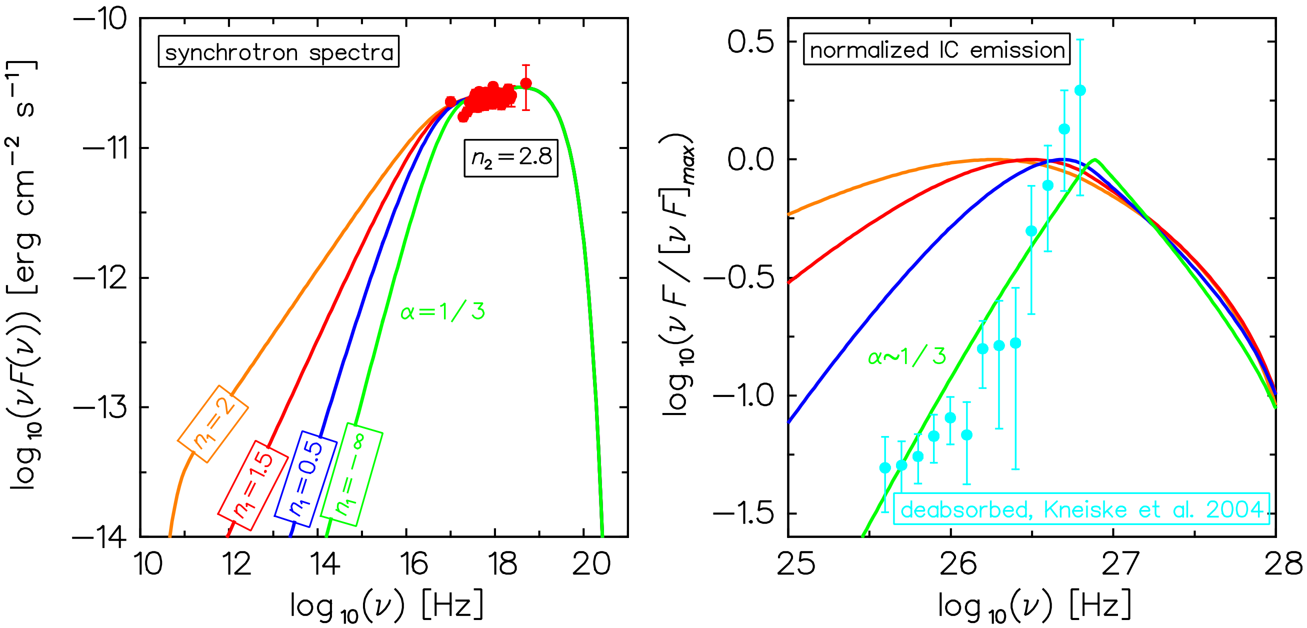
The simplest possible scenario able to explain the X–ray and TeV emission of a blazar assumes a homogeneous, spherical source inside a jet at the distance less than 1 pc to the base of the jet. The source is filed up by tangled magnetic field  and relativistic electrons . The particle energy spectrum is usually assumed to be a power law or double power law distribution. The electrons generate synchrotron emission  and up-scatter the synchrotron radiation field . This is synchrotron self-Compton emission (SSC) that is observed mostly in the gamma rays up to TeV energies.

6 Problem – SSC emission in the KN regime



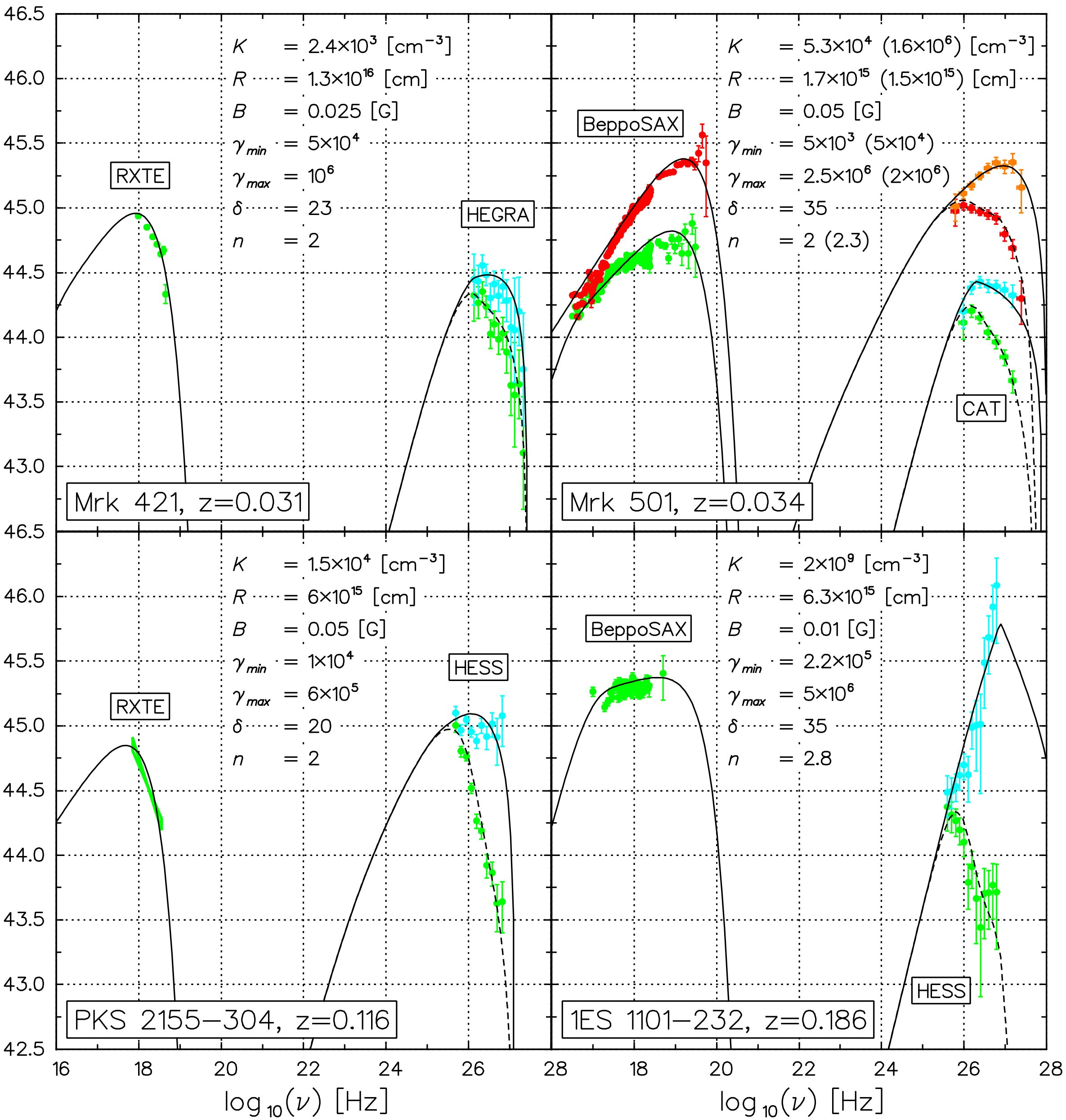
The figure shows non-simultaneous X-ray (Wolter et al. 2000) and TeV (Aharonian et al. 2006) observations of 1ES 1101-232, the intrinsic TeV spectrum obtained for the minimum possible absorption level (according to Aharonian et al. 2006) and the spectra obtained from a simple SSC modeling. The model assumes double (broken) power law electron energy distribution with $n_1 = 2$ ($\alpha = 0.5$) and $n_2 = 2.8$ ($\alpha = 0.9$) below and above the break respectively. The inverse-Compton scattering that produces the TeV emission occurs partially in the Klein-Nishina (KN) regime. This causes the steepening of the spectrum and does not allow to explain precisely the intrinsic spectrum. Note that this steepening introduced by the Klein–Nishina effects is virtually inescapable, since the scattering occurs completely in the Thomson limit only for extremely large values of the beaming factor: $\delta > 1000$ (see e.g. Katarzyński et al. 2005).

7 Solution – truncated electron spectrum



ynchrotron emission (left panel) and SSC radiation (right panel) for different values of n_1. The green spectra, enerated by the truncated single power law particle energy spectrum ($n_1 = -\infty$), provides the best fit for the oservations of 1ES 1101–232. Note that the spectra on the lower panel have been normalized to the peak vel and the H.E.S.S. observations has been unabsorbed according to the model proposed by Kneiske et al. 004) that provides significantly higher level of the absorption 4. The single power law particle distribution th the minimum energy significantly higher than lowest possible value ($\gamma_{\rm min} \gg 1$ where energy $E = \gamma m_e c^2$) ay explain hard intrinsic spectra of blazars up to spectral index $\alpha = 1/3$. This limit is related to the slope of e low frequency synchrotron emission that is scattered by the electrons in this particular scenario.

8 Application to the other sources



X–ray and TeV emission of four TeV blazars: Mrk 421 (Krawczynski et al. 2001), Mrk 501 (Pian et al. 1998, Djannati-Atai et al. 1999), PKS 2155-304 (Aharonian et al. 2005a) and 1ES 1101-232 (Aharonian et al. 2005b) located at different redshifts. For all the sources we have applied the same SSC scenario, assuming that the emitting electrons are distributed in energy as a single power law with a low energy cut-off at $\gamma_{\rm min}$. All the TeV spectra have been unabsorbed according to the model of Kneiske et al. (2004). Solid lines are the best fits for the expected intrinsic emission whereas dashed lines indicate the observed spectra. For an easier comparison of the different sources, we transformed the observed flux in luminosity.

9 Conclusions

- We have shown that the standard SSC model can explain the specifi c observations of the relatively distant TeV blazar 1ES 1101–232. Assuming a truncated power law energy distribution, with $\gamma_{\rm min} \gg 1$, we can well explain the intrinsic TeV spectrum even assuming a stronger absorption than the upper limit suggested by Aharonian et al. 2006.
- Our results appear in very good agreement with the recent estimations of the IR intergalactic background (Kneiske et al. 2004, Stecker et al. 2005).
- The limit on how hard an SSC spectrum can be is $\alpha = -1/3$. This limit in turn translates in a limit on the amount of absorption suffered by TeV photons, and hence on the level of the IR background.

10 References

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