PRELIMINARY EVIDENCE FOR AN ALP – A CHALLANGE FOR THE CTA

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Introduction and motivation

We consider observed *flaring* BL Lacs at $E \gtrsim 100\,\mathrm{GeV}$. In order to have the most homogeneous sample and a nontrivial statistics we deal with all IBL and HBL out to $z = 0.6$ so as to avoid evolutionary effects in the sources. For each of them we need to know: z, observed spectrum with error bars, and energy range $\Delta E(z)$ wherein it is observed. Only 39 BL Lacs obey these requirements and form the sample $\mathcal{S}$.

We recall that the observed and emitted spectra – namely EBL-deabsorbed – are related by

$$\Phi_{\rm obs}(E_0, z) = P_{\gamma \to \gamma}(E_0, z)\, \Phi_{\rm em}\big(E_0(1+z)\big) \ , \tag{1}$$

and $P_{\gamma \to \gamma}(E_0, z)$ is parametrized as $P_{\gamma \to \gamma}(E_0, z) = e^{-\tau_\gamma(E_0, z)}$. Whence

$$\Phi_{\rm obs}(E_0, z) = e^{-\tau_\gamma(E_0, z)}\, \Phi^{\rm CP}_{\rm em}\big(E_0(1+z)\big) \ , \tag{2}$$

Owing to the exploratory character of our investigation, we fit all observed spectra with a single power law. In order to compare all of them, we normalized them as

$$\Phi_{\rm obs}\left(E_0, z\right) = K_{\rm obs}(z) \left(\frac{E_0}{E_{0,*}}\right)^{-\Gamma_{\rm obs}(z)} . \tag{3}$$

with $E_{0,*} = 300\,{\rm GeV}$. Because of EBL absorption ($\gamma\gamma \to e^+ e^-$), from (2) and (3) we get

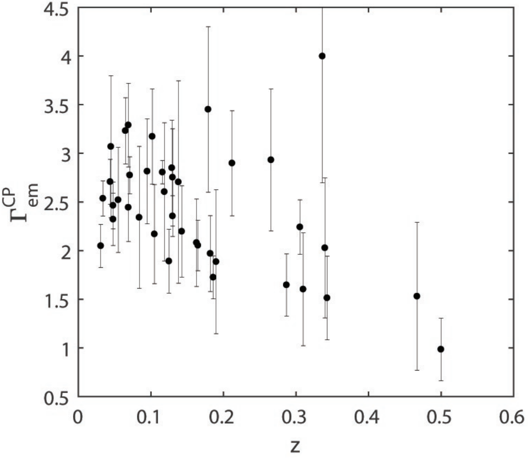
$$\Phi_{\rm em}^{\rm CP}\left(E_0(1+z)\right) = e^{\tau_\gamma(E_0,z)}\, K_{\rm obs}(z) \left(\frac{E_0}{E_{0,*}}\right)^{-\Gamma_{\rm obs}(z)} , \tag{4}$$

which we best-fit to a single power law as

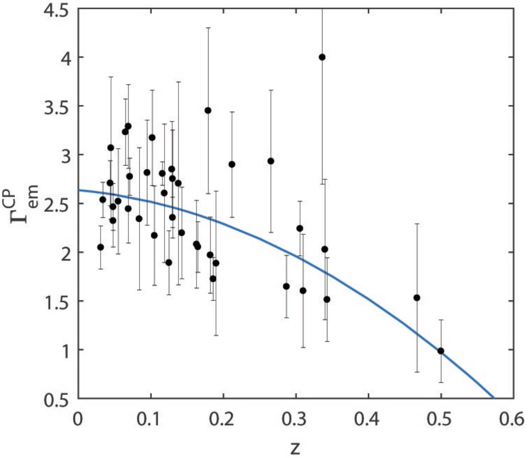
$$\Phi_{\rm em}^{\rm CP,BF}\left(E_0(1+z)\right) = K_{\rm em}^{\rm CP}(z) \left(\frac{E_0(1+z)}{E_{0,*}}\right)^{-\Gamma_{\rm em}^{\rm CP}(z)} \tag{5}$$

over the energy range $\Delta E_0(z)$, so $E_0 \in \Delta E_0(z)$, (EBL $=$ FR 2017).

In this way we find $\Gamma_{\rm em}^{\rm CP}(z)$ for all our 39 sources, which are plotted below



We proceed to carry out a statistical analysis of these data. Using the least square method we try to fit them with 1,2,3 parameters, and we evaluate the associated $\chi^2_{\rm red}$. Its smallest value $\chi^2_{\rm red} = 1.46$ corresponds to a concave parabola shown below



What does it mean? Evidently there is a *statistical correlation* between the $\{\Gamma_{\rm em}(z)\}$ distribution and z, so that flaring blazars with harder spectra are found on average *only* at larger z. Because here evolutionary effects play no role, this result contradicts the physical intuition, according to which the $\{\Gamma_{\rm em}(z)\}$ distribution should be *z-independent*, namely its best-fit regression line should be a *straight horizontal line* in the $\Gamma_{\rm em} - z$ plane. Although we cannot exclude that the above statistical correlation arises from a dimming bias, we strongly argue that quite likely this is not the case for EBL absorption, and we demonstrate that the volume bias is irrelevant. Basically, we subtract all sources with $z \leq 0.3$ and in practice nothing changes. This means that – in spite some our simplifications – *there is a problem with conventional physics*, which we call *VHE BL Lac spectral anomaly*.

ALPs save the situation

Now we suppose that – in addition to EBL-absorption – photon-ALP oscillations take place in extragalactic space. Accordingly, photons acquire a split personality: when they travel as true photons they undergo EBL-absorption, but when they propagate as ALPs they do *not*. So, the effective τ gets reduced, but since $P^{\rm ALP}_{\gamma \to \gamma}(E_0, z) = e^{-\tau^{\rm eff}_{\gamma}(E_0, z)}$ even a small reduction of $\tau^{\rm eff}_{\gamma}(E_0, z)$ implies a great enhancement of $P^{\rm ALP}_{\gamma \to \gamma}(E_0, z)$. Recalling the previous talk, we take the naive domain-like structure of $\mathbf{B}_{\rm ext}$ and define

$$\xi \equiv \left(\frac{B}{\rm nG}\right) \left(g_{a\gamma\gamma}\, 10^{11}\, {\rm GeV}\right) \ . \qquad (6)$$

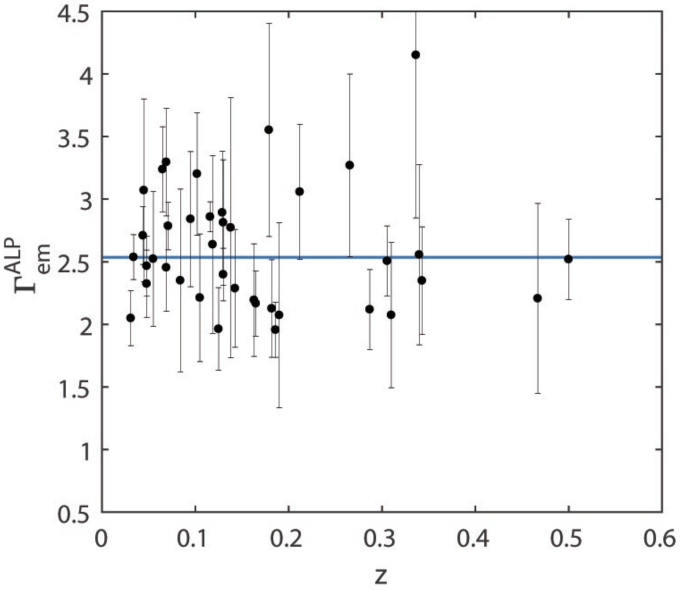
As a consequence, the effective EBL-absorption gets considerably reduced.

Taking the realistic benchmark values $\xi = 0.1, 0.5, 1, 5$; $L_{\rm dom} = 4\,{\rm Mpc}$, $10\,{\rm Mpc}$, for each pair of them we have performed the same best-fitting procedure and data analysis done in the case of conventional physics. For both $L_{\rm dom} = 4\,{\rm Mpc}$ and $L_{\rm dom} = 10\,{\rm Mpc}$ we find the smallest value of $\chi^2_{\rm red}$ for $\xi = 0.5$ – like the preferred value in the previous talk – specifically $\chi^2_{\rm red} = 1.29$, $\Gamma_{\rm em}^{\rm ALP} = 2.54$ and $\chi^2_{\rm red} = 1.25$, $\Gamma_{\rm em}^{\rm ALP} = 2.60$.

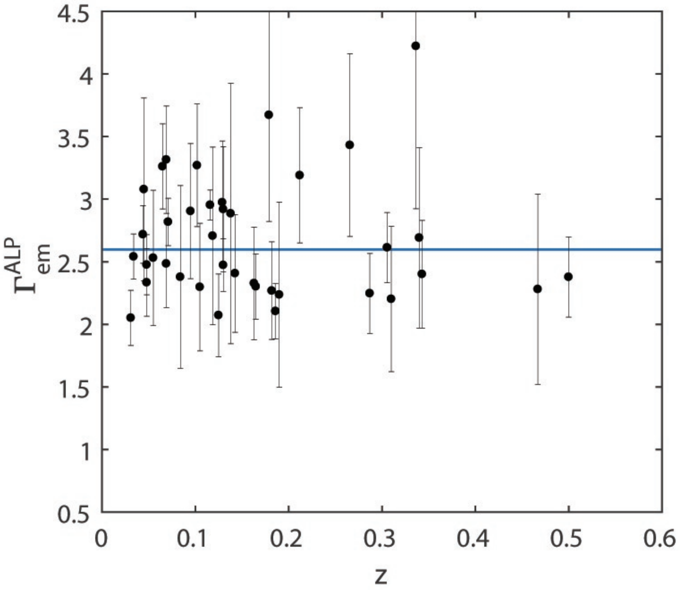
We have also checked that the results are presumably unaffected by selection biases.

Our results are reported in the next 2 slides.

Case $L_{\rm dom} = 4\,{\rm Mpc}$



Case $L_{\mathrm{dom}} = 10\,\mathrm{Mpc}$



Conclusions

It looks astonishing that ALPs select out – among infinitely-many possibilities – just the *only one in agreement with physical intuition* mentioned above. Moreover, the same values of the model parameters which lead to such a conclusion also explain why flat spectrum radio quasars emit up to 400 GeV, in sharp contradiction with conventional physics provided that the emitting region lies before or inside the broad line region (TRGB 2012). Therefore, the combination of the two very different results – taken at face value – leads to a preliminary evidence for an ALP with mass $m \lesssim 10^{-10}\,\mathrm{eV}$ and two-photon coupling $g_{a\gamma\gamma} \sim 10^{-11}\,\mathrm{GeV}^{-1}$. As a bonus, the Universe becomes considerably more transparent above energies $E \gtrsim 1\,\mathrm{TeV}$ than dictated by conventional physics. Our prediction can be tested in the near future not only by the new generation of observatories like CTA, HAWC, GAMMA-400, LHAASO, TAIGA-HiSCORE and HERD, but also thanks to the planned laboratory experiments ALPS II (upgraded), STAX and IAXO. We stress that our analysis is preliminary in nature, and a more thorough treatment is needed to assess our conclusions.