Extreme TeV Bl Lacs: a stochastic acceleration model

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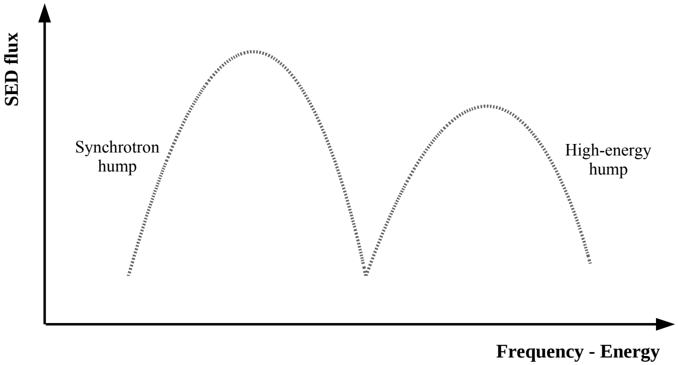
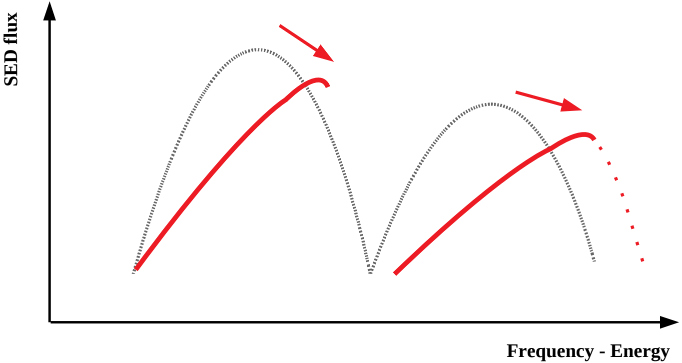
Blazar



- AGN with a relativistic jet pointing toward the Earth
- The spectral energy distribution displays two broad peaks
- Blazars can be classified on the synchrotron peak frequency

Extreme TeV Bl Lacs



- The second SED peak beyond 1 TeV
- A hard sub-TeV intrinsic spectrum
- The TeV emission is stable over years

The model

- Low magnetization is required (see Biteau et al. 2020)
- Thermal plasma: recollimation shock + turbulence
- Non-thermal particles: diffusive shock acceleration + stochastic acceleration
- One zone leptonic model: Synchrotron Self Compton model

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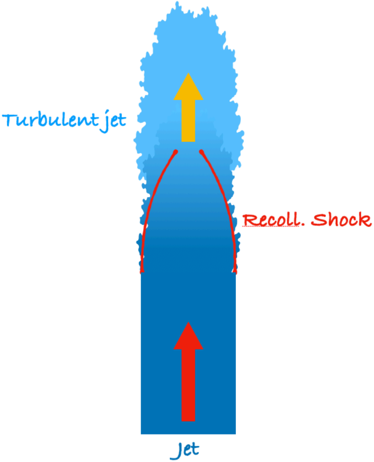

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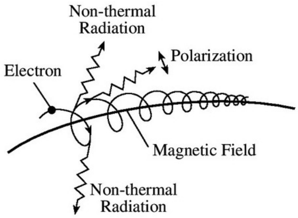

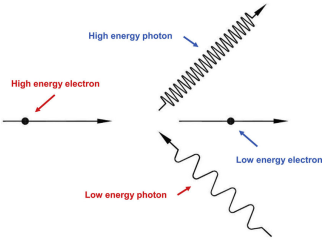

First attempt

- Assumption: constant turbulence spectrum
- The rise in the sub-Tev range steeper than the data
- $t_{\rm damp}/t_{\rm cas} \sim \beta_a^{-1} U_e/U_B \ll 1$
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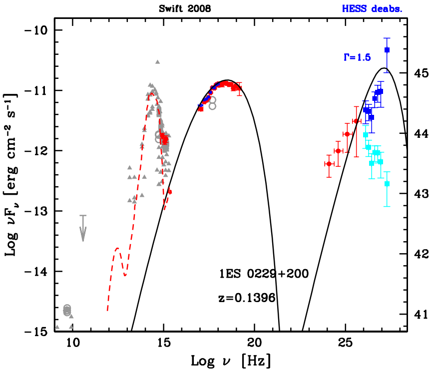

See Tavecchio et al. 2022

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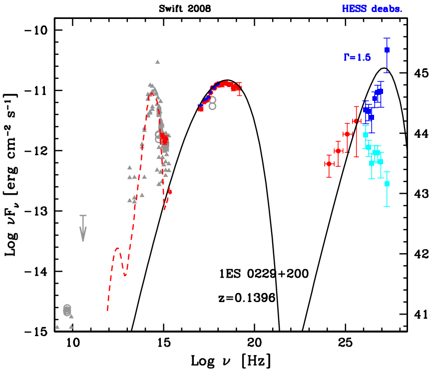

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Numerical method

Assuming isotropy and homogeneity (i.e. no spatial diffusion):

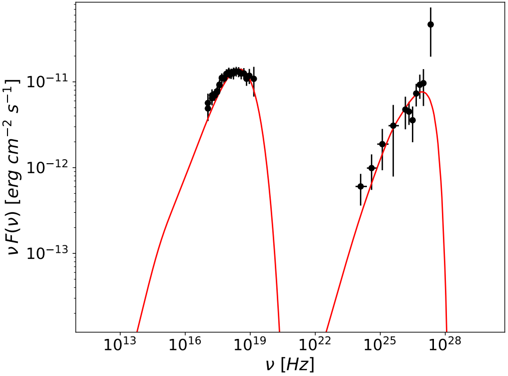
$$\begin{cases} \dfrac{\partial f}{\partial t} = \dfrac{1}{p^2}\dfrac{\partial}{\partial p}\left[p^2 D_p \dfrac{\partial f}{\partial p} + p^2 \left(\dfrac{\partial p}{\partial t}\right)_{\rm rad} f\right] + \dfrac{f}{t_{\rm esc}} + I_f \\ \dfrac{\partial Z}{\partial t} = \dfrac{1}{k^2}\dfrac{\partial}{\partial k}\left(k^2 D_k \dfrac{\partial Z}{\partial k}\right) + \Gamma Z + \dfrac{I_W}{k^2} \quad \text{with} \quad Z = \dfrac{W}{k^2} \end{cases}$$

- We must solve a system of two coupled Fokker-Planck equations
- We decided to use the robust implicit Chang-Cooper algorithm
- Kolmogorov phenomenology $\implies D_k = D_k(k, W) \implies$ Non-linearity
- We need a trick (see Larsen et al. 1985)

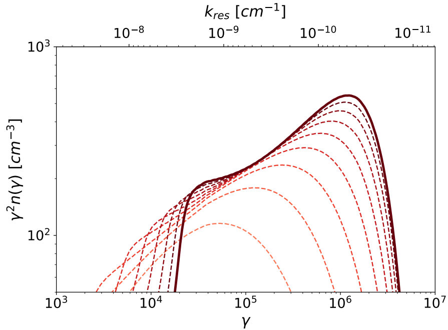
1ES 0229+200

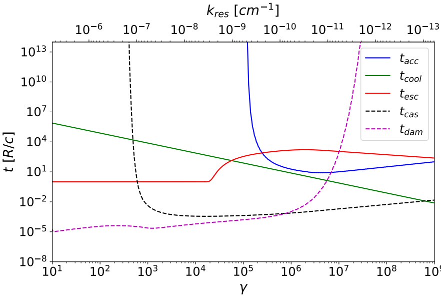
We apply our model to the prototypical extreme TeV Bl Lacs, i.e. 1ES 0229+200

- Downstream region radius
  $R = 1.2 \times 10^{16}$ cm
- Alfvén velocity
  $v_a = 2 \times 10^{9}$ cm/s
- Mean magnetic field
  $B = 15.9$ mG
- Injected electrons power
  $P'_n = 7 \times 10^{39}$ erg/s
- Injected turbulence power
  $P'_W = 7 \times 10^{39}$ erg/s



Electrons and turbulence spectra



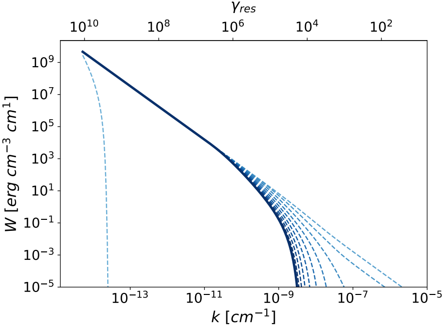


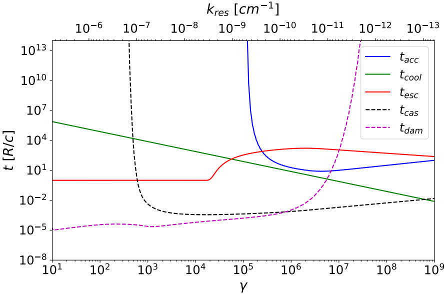
Peak at $\gamma \sim 10^6$ (when $t_{\rm acc} \sim t_{\rm cool}$)

Cut-off at $\gamma \gtrsim 10^6$ (when $t_{\rm cool} \ll t_{\rm acc}$)

Cut-off at $\gamma \lesssim 10^4$ (when $t_{\rm esc} = R/c$)

Electrons and turbulence spectra





Cut-off at $k \gtrsim 10^{-10}\ \mathrm{cm}^{-1}$ (when $t_{\mathrm{dam}} \ll t_{\mathrm{cas}}$)

Power law at $k \lesssim 10^{-10}\ \mathrm{cm}^{-1}$ (when $t_{\mathrm{cas}} \ll t_{\mathrm{dam}}$)

Conclusions and future perspectives

Our model was able to reproduce the SED of the prototypical extreme TeV Bl Lacs 1ES 0229+200

- Caveats
  - Necessary comparison with other SEDs
  - Check with MHD simulations (see Costa's slides)
- Improvements
  - Addition of IC cooling term (other non-linear term)
  - More accurate algorithm (e.g. Runge-Kutta Implicit-Explicit schemes)

For further details, see Sciaccaluga & Tavecchio 2022 (see arXiv:2208.00699)