The role of time-dependent injection in blazar flares

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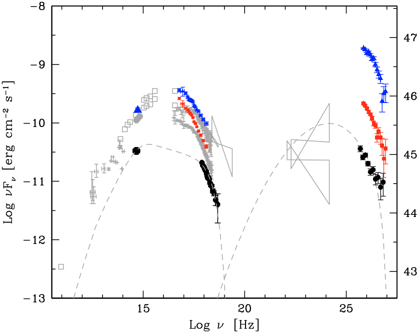
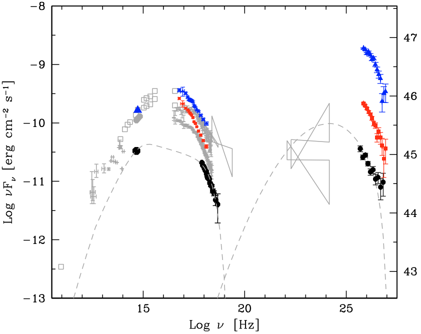


Figure: SEDs of PKS 2155-304 during 1 night in July 2006 (Aharonian et al., 2009, *A&A* 502, 749)

Standard model (even for flares):

- Continuous injection of particles, changing other parameters
- Advantage: Solution of kinetic equation is well known, since it is in equilibrium
- Disadvantage: In many cases complicated electron distributions necessary; rapid flares difficult to reproduce



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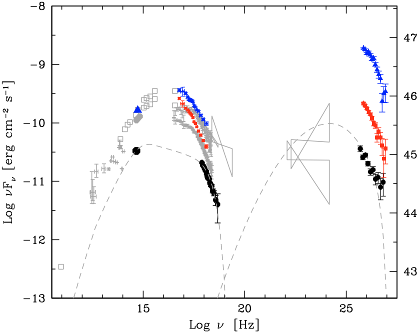

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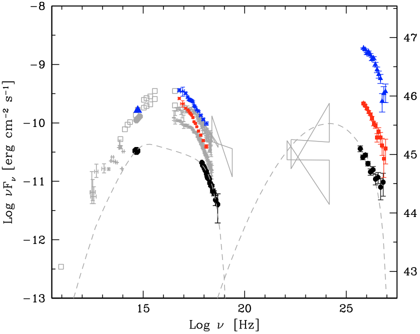

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What happens if the particle injection is time-dependent?

Kinetic equation for electrons:

$$\frac{\partial n(\gamma,t)}{\partial t} - \frac{\partial}{\partial \gamma}\left[|\dot{\gamma}|_{\mathrm{tot}}\, n(\gamma,t)\right] = Q(\gamma,t)$$

Injection: one-time, relativistic

$$Q(\gamma,t) = q_0 \delta(\gamma - \gamma_0)\delta(t)$$

Energy loss rate:

$$\begin{aligned} |\dot{\gamma}|_{\mathrm{tot}} &= |\dot{\gamma}|_{\mathrm{syn}} + |\dot{\gamma}|_{\mathrm{ec}} + |\dot{\gamma}|_{\mathrm{ssc}} \\ &= D_0(1+l_{ec})\gamma^2 + A_0\gamma^2 \int_0^\infty \mathrm{d}\gamma\ \gamma^2 n(\gamma,t) \end{aligned}$$

- Synchrotron cooling and external Compton cooling are linear and not time-dependent
- Synchrotron-self Compton cooling depends on the synchrotron field, which depends on the electron distribution $\Rightarrow$ nonlinear (if injection time-dependent)
  - Nonlinear cooling sets in faster than linear cooling
  - SSC cooling is time-dependent $\Rightarrow$ After a time t_c the linear terms dominate
  - Further injections are strongly influenced by the already present particles

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- $\alpha \ll 1$: Complete linear cooling
- $\alpha \gg 1$: Initial nonlinear cooling

- *The higher the electron density q_0 in the source, the higher the probability of (initial) nonlinear cooling*

The injection parameter α

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Calculating the intensity:

$$I_i(\nu, t) \propto \int \mathrm{d}\gamma \; n(\gamma, t) p_i(\nu, \gamma)$$

- p_i: power of the respective emission process

Calculating the time-integrated SED

$$f_i(\nu) \propto \nu \int \mathrm{d}t \; I_i(\nu, t)$$

- Total SED: Unlimited integration ($0 \rightarrow \infty$)
- Fractional SED: Limited integration ($t_a \rightarrow t_e$)

Calculation steps

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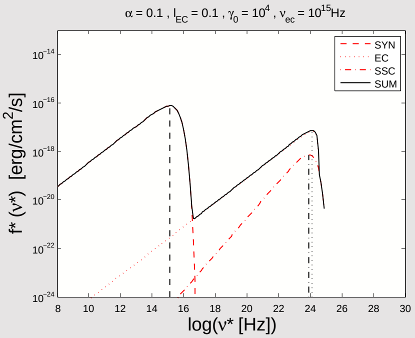
Total SED

SED with $\alpha, l_{ec} \ll 1$:



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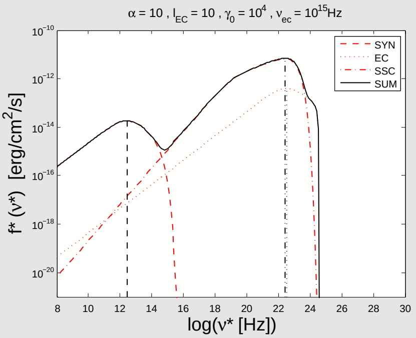

Results:

- Compton dominance is determined by α and l_{ec}
- Total SED for $\alpha \ll 1$ resembles the SED of continuous injection
- In case of $\alpha \gg 1$ all components exhibit an additional break (position depends on α)
- Form of energy injection does not influence the main results (only the highest energies)

Fractional SED (synchrotron component)

- Energy losses set in much earlier for $\alpha \gg 1$
- After t_c the SEDs become indistinguishable
- Time of observation is very important for modelling!

Summary

- Time-dependent injection influences strongly the cooling behaviour
- Nonlinear cooling causes quicker electron cooling and additional breaks in the total SED
- Time of observation is very important!
- Time-resolved spectra might become an interesting opportunity to test different models
- Effects can also be seen in the light curves

Due to the nonlinearities and the resulting effects, time-dependent injection should be considered as a viable option to model rapid blazar flares

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Suggested reading

- Zacharias & Schlickeiser 2012b, *ApJ* 761, 110
- Zacharias & Schlickeiser 2012a, *MNRAS* 420, 84
- Zacharias & Schlickeiser 2010, *A&A* 524, A31
- Schlickeiser, Böttcher & Menzler 2010, *A&A* 519, A19
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Thank you for your attention!

Model:

- Complementary tool to obtain/check source parameters
- Using a simple model:
  - Only retardation and geometry of the source taken into account:

$$L_i(\epsilon, t) = \int_0^1 l_i(\epsilon, t - \lambda_0\lambda) \mathrm{H}\left[t - \lambda_0\lambda\right] \frac{dV(\lambda)}{V(\lambda)}$$

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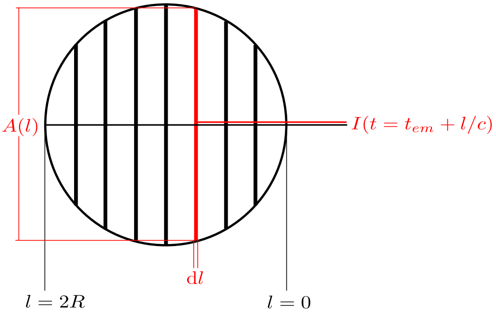
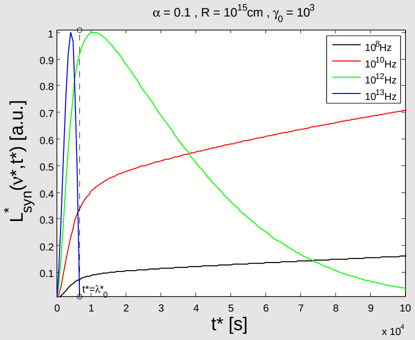


Norm. Synchrotron LC for $\alpha \ll 1$:



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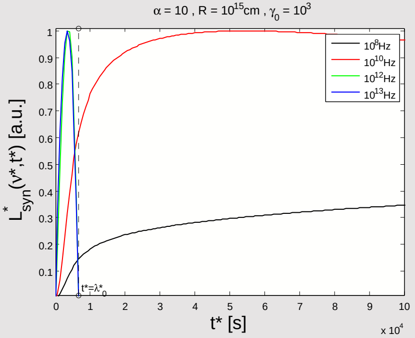

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- Light curves exhibit different temporal behaviour
- Shape of the light curves depends on the frequency

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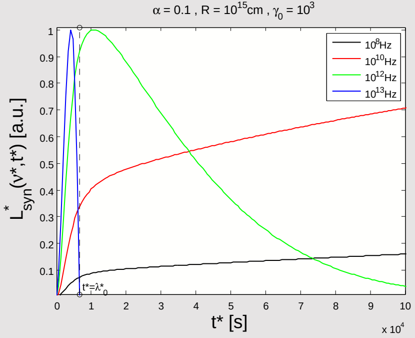

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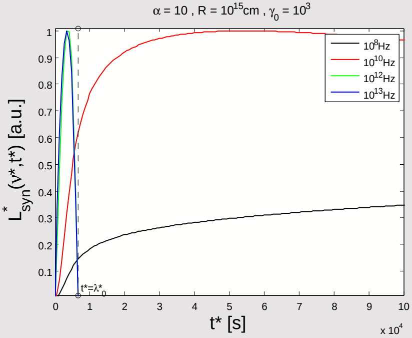

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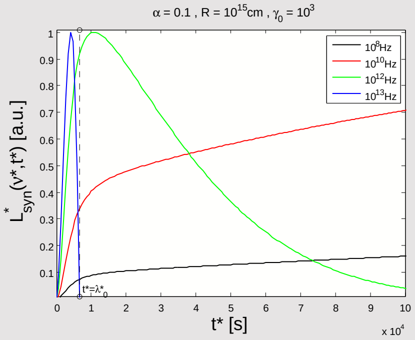

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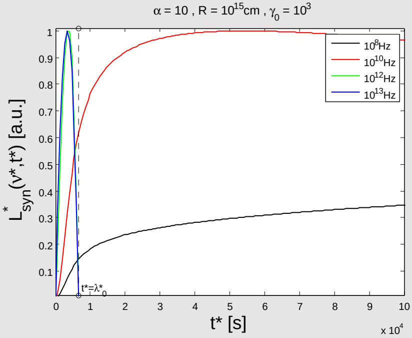

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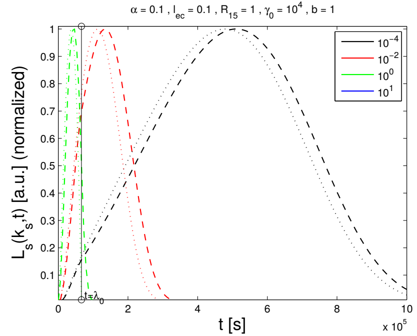

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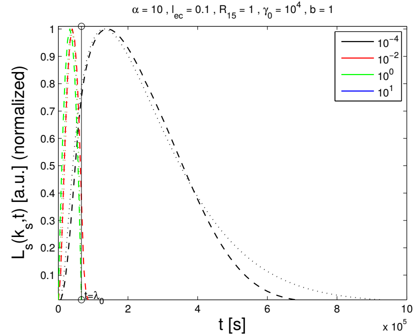

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- SSC and EC light curves have similar characteristics

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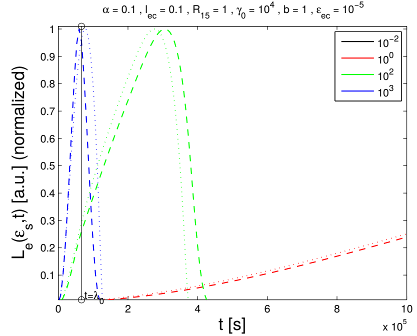

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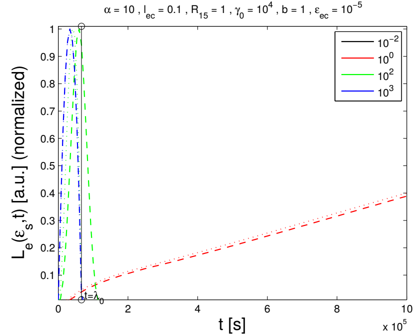

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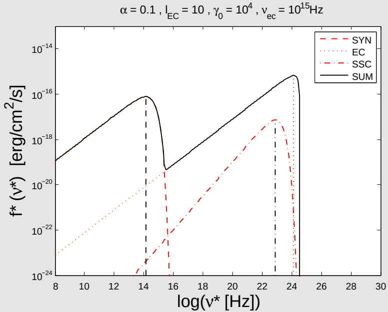

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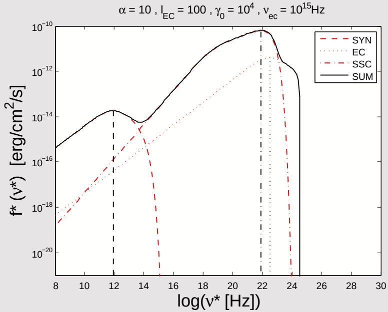

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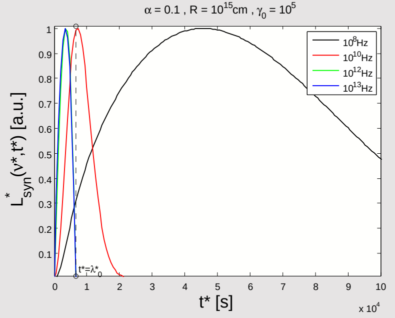

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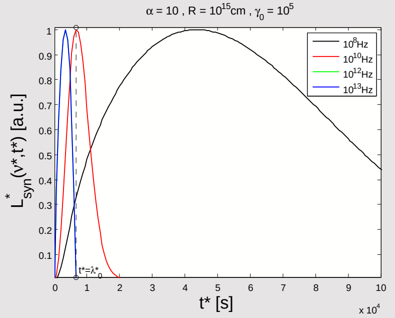

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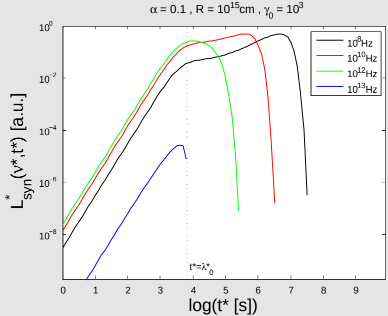

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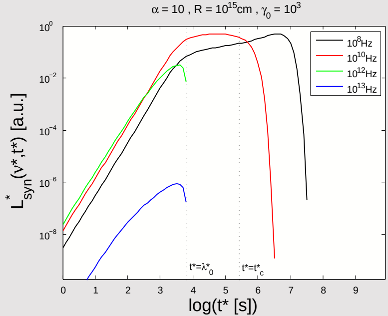

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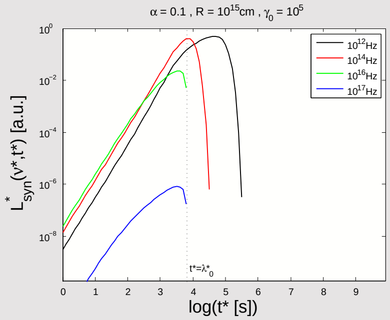

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