Implications of Time-dependent Injection in Relativistic Jets

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Abstract

Time-dependent injection can cause non-linear cooling effects, which lead to a faster energy loss of the electrons in jets. The most obvious result is the appearance of unique breaks in the SED, which would normally be attributed to a complicated electron distribution. The knowledge of the observation time is important to interpret the observed spectra, because of the non-trivial evolution of the SED. Intrinsic gamma-gamma absorption processes in the emission region are only of minor importance.

Introduction

- Minute-short flares are difficult to explain in standard one-zone models
- The profound effects due to time-dependent injection in a one-zone model are presented

Important Assumptions & Equations

- Assumptions:
  - Spherical, homogeneous zone ("one-zone model")
  - Tangled magnetic field
  - External photon field isotropic in galactic frame
  - Only cooling losses
- Cooling Terms:
  - Synchrotron + external cooling $|\dot{\gamma}(\gamma)| = D_0(1+l_{ec})\gamma^2$
  - External Compton parameter: $l_{ec} = \frac{|\dot{\gamma}|_{ec}}{|\dot{\gamma}|_{syn}}$
  - Synchrotron and external Compton coolings linear
  - SSC-cooling $|\dot{\gamma}(\gamma,t)|_{ssc} = A_0\gamma^2 \int_0^\infty \gamma^2 n(\gamma,t)\mathrm{d}\gamma$
  - SSC cooling non-linear and time-dependent
- Injection: instantaneous and monochromatic
- Kinetic equation:
  $\frac{\mathrm{d}n(\gamma,t)}{\mathrm{d}t} - \frac{\mathrm{d}}{\mathrm{d}\gamma}\left[|\dot{\gamma}(\gamma,t)|_{tot}\, n(\gamma,t)\right] = q_0\,\delta(\gamma-\gamma_0)\,\delta(t)$
- Direct consequences:
  - Time-dependent injection: No equilibrium possible
  - Non-linear cooling sets in quicker than linear cooling
  - Shorter "half-energy" cooling time

Injection Parameter

- Ratio of non-linear to linear cooling:
  $\alpha^2 = \frac{|\dot{\gamma}(\gamma,t)|_{ssc}}{|\dot{\gamma}(\gamma)|} = \frac{A_0}{D_0}\,\frac{q_0\gamma_0^2}{(1+l_{ec})}$
- Properties:
  - $\alpha \ll 1$: Total linear cooling
  - $\alpha \gg 1$: Initial non-linear cooling
  - Transition time: $t_c = \frac{\alpha^3-1}{3\alpha^2 D_0(1+l_{ec})\gamma_0}$
  - Change in cooling behavior at t_c
  - α correlates with the "SSC dominance" in the spectrum

References

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Results

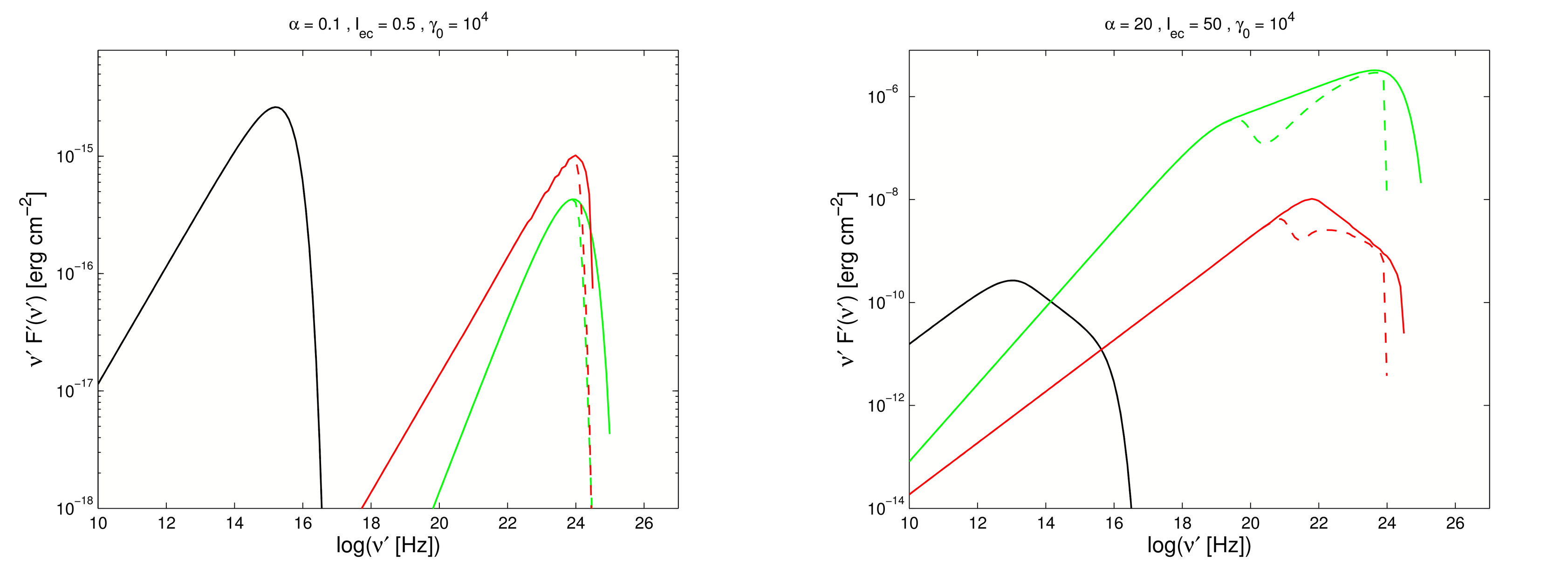

Figure 1 : Model SEDs with synchrotron (black), SSC (green), and external Compton (red). Dashed lines with internal and external absorption. *Left:* SED for $\alpha \ll 1$ and $l_{ec} \ll 1$. *Right:* SED for $\alpha \gg 1$ and $l_{ec} \gg 1$. Note the different scales on the y-axis.

- Compton dominance depends on α and l_{ec}
- For $\alpha \ll 1$ (left panel):
  - Single power-laws with exponential cut-off
- For $\alpha \gg 1$ (right panel):
  - All components exhibit breaks due to change in cooling
  - Synchrotron + External: $\Delta s = 1$
  - SSC: $\Delta s = 0.5$
  - No complicated electron distribution needed
- Time-dependent SED:
  - SED is gradually built up during flare
  - Break is created at $t = t_c \Rightarrow$ SSC evolves faster
  - Time since beginning of flare is important for modeling
  - Movie ($\alpha \ll 1$): `www.tp4.rub.de/~mz/SEDa01.mp4`
  - Movie ($\alpha \gg 1$): `www.tp4.rub.de/~mz/SEDa10.mp4`
- γ-γ absorption:
  - External photon field causes reduction at high energies
  - Internal absorption time-dependent
  - Source optically thick for intermediate IC energies
  - Observable feature only for extreme parameters
- Lightcurves:
  - Light crossing time (LCT) is minimal variability time
  - Shorter time scales hidden behind the LCT
  - $\Rightarrow$ Some problems of one-zone models remain

Summary & Conclusions

- Time-dependent injection results in non-linear effects
- Non-linear cooling acts much quicker than linear cooling
- Change in cooling behavior causes breaks in the SED
- Internal absorption not a serious issue
- Problems of one-zone models (e.g., LCT) not completely avoided

- **In combination with other models time-dependent injection might be very useful to explain rapid flares**

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