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The Outbursts of High-Peaked BL-Lac objects

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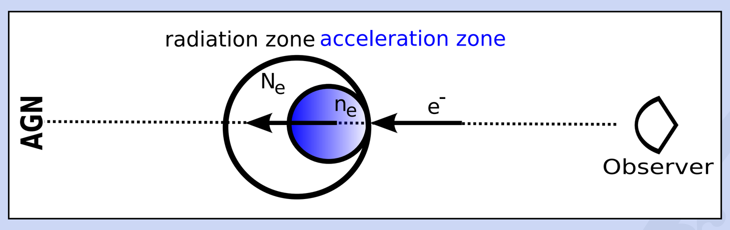
While the jet as the origin of the very high energy (VHE) emission from blazars is beyond doubt, the microphysical processes, the composition as well as typical physical parameters such as the size or location of the emitting region within the jet are still a matter of debate. One successful approach to model the characteristic double-humped **S**pectral **E**nergy **D**istribution from blazars, especially those of High-Peaked BL-Lac objects, is the **S**ynchrotron-**S**elf-**C**ompton Ansatz where the first peak in the SED is due to the synchrotron emission of e^- in the jet's magnetic field while the second peak arises from the Compton upscattering of these photons by the very same e^- distribution. However these models are suffering certain drawbacks concerning e.g. the number of degrees of freedom or the variability in the emission of BL-Lac objects. But to get a hand on the jet's microphysics and to narrow down the parameters used in the models to a physically plausible range, these outbursts seem to be a very promising tool, since the variability timescale is directly linked to the timescales of the physical processes within the jet.
With the **C**ode **O**n **J**etsystems **O**f **N**on-thermally **E**mitting **S**ources we developed a powerfull box-model considering the acceleration of electrons due to diffusive shock acceleration (DSA) as well as all the relevant radiation mechanisms. This allows us i) to model the steadystate SEDs of High-Peaked BL-Lac objects as observed in multiwavelength observation campaigns (X-Ray satellites, Fermi-LAT, Air-Cerenkov telescopes) and ii) to model the lightcurves during an outburst in various energy-bands selfconsistently, simply by changing e.g. the injection rate of e^-. Comparison with observations tightens the range of applicable parameters, hence verifying or falsifying assumptions concerning the jet's microphysics. If applicable our model makes predictions how a leptonic dominated blazar bahaves spectrally resolved during a flare, even if only one energyband has been observed during the outburst.

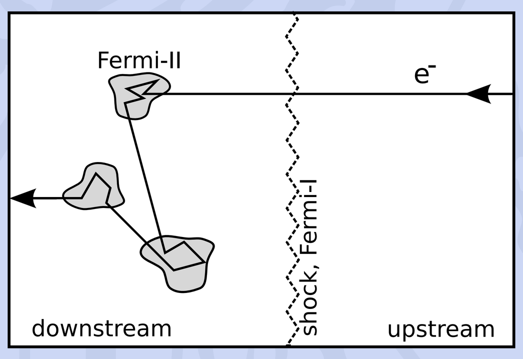
The Model

The emitting region is assumed to be a spherical volume (blob) moving at Lorentz factor Γ towards the observer containing homogeneous & isotropic electron & photon distributions. All calculations are made in the rest frame of the blob. The blob contains a two zones in a nested setup, each zone has its electron distribution, n_e and N_e respectively:



All electrons escaping from the acceleration zone enter the radiation zone. Only this region contributes to the observed SED directly, i.e. its photon field is boosted to the observer.

Cold electrons enter the acceleration zone from the upstream direction where they are continuously accelerated via shock acceleration and stochastic processes (DSA) while synchrotron losses are balancing the process. The response timescale in the steady state is dominated by the escape loss time of the electrons which scales with spatial extend of the zone.



Kinetic equation (acceleration zone)**:**

$$\partial_t n_e = \partial_\gamma \left[(\beta_s \gamma^2 - t_{acc}^{-1}\gamma) \cdot n_e \right] + \partial_\gamma \left[[(a+2)t_{acc}]^{-1} \gamma^2 \partial_\gamma n_e \right] + Q_0 - t_{esc}^{-1} n_e$$

with a being the ratio of Shock- to Alfvén-speed (Fermi-I/Fermi-II)*

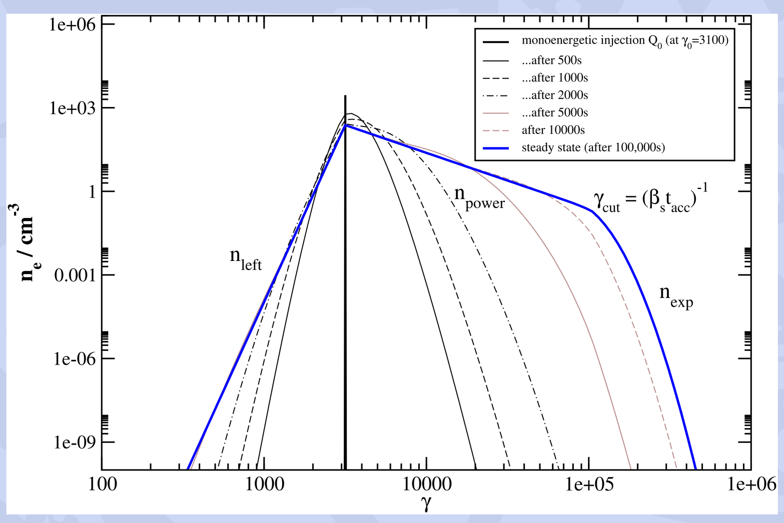
*for further information see arXiv:1001.2145

Sample Electron Distribution

For typical blazar parameters the time-evolution and steady state of monoenergetic, mildly relativistic electrons streaming into our model is shown.

The shape of n_e depends on the competition of acceleration and radiation processes, especially:

- $n_{left} \propto$ Fermi-II processes & synchrotron radiation
- $n_{exp} \propto$ Fermi-II processes, i.e. $\propto a$ and $\propto t_{acc}$
- $n_{power} = a_1 \gamma^\alpha$ where $\alpha \propto t_{acc}/t_{esc}$
- $\gamma_{cut}^{-1} \propto \beta_s$ (Synchrotron losses)

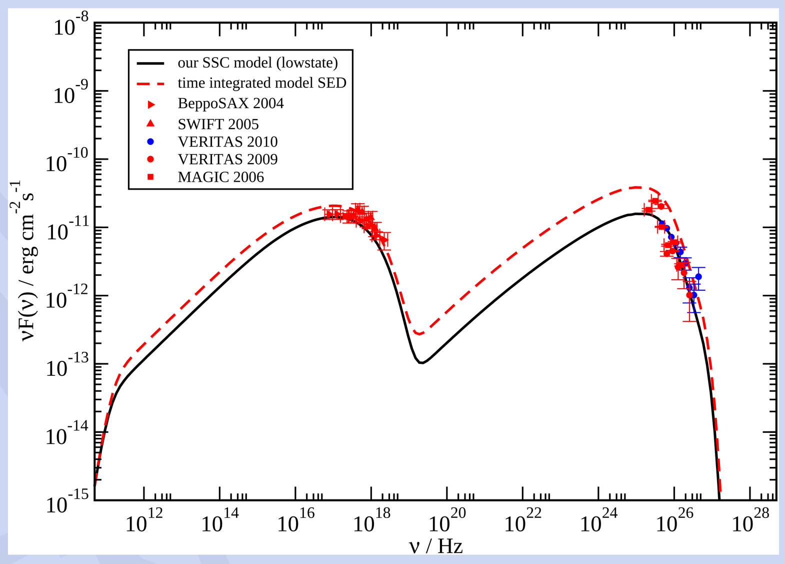


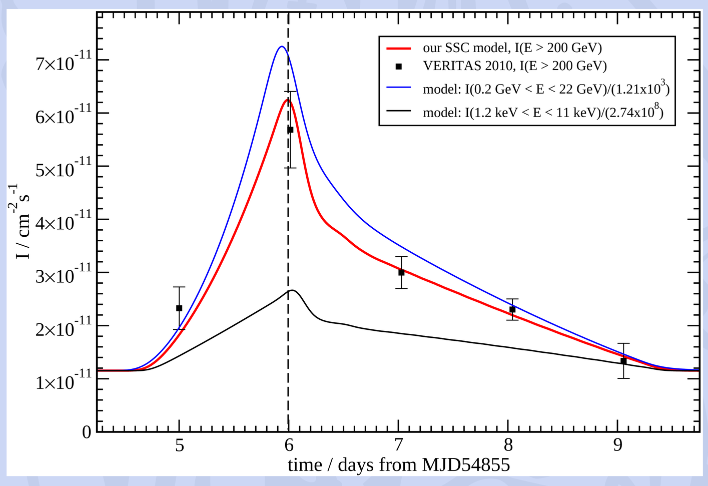
The acceleration timescale is $t_{acc}^{-1} \propto v_{shock}$ and $\propto v_A$, hence directly connected to the microphysical processes of the emitting region (while $t_{esc} \propto R_{acc}$, see above). The stochastic processes strongly account for the rising part of n_e (if there is any) while shock acceleration dominates the spectral index α as well as the cutoff position γ_{cut}.
After entering the radiation zone the electrons do not undergo any further acceleration but being cooled due to synchrotron and inverse Compton losses. The inverse Compton losses are calculated numerically using the full Klein-Nishina cross section. Hereby the photon distribution is built, which eventually is boosted and can be observed as the SED of the High-Peaked BL-Lac object, after accounting for the extragalactic background absorption.
The injection hight, magnetic field, acceleration efficiency can be changed dynamically in the model to account for a blazar flare, see examples on the right side.

Application to 1 ES 1218+30.4

The variability of the High-Peaked BL-Lac object 1 ES 1218+30.4 in the VHE has recently been discovered by VERITAS during the 2009 multiwavelength campaign with Fermi, RXTE and SWIFT with two flares occurring in the observation period.

The RHS figure shows the data as well as our model. As one can see the new VERITAS data agrees well with the MAGIC observation in 2006 within the error bars when considering the whole observation period of VERITAS in 2009 (solid line). However, when only the strongest outburst of 1 ES 1218+30.4 (see lightcurve below) during the VERITAS observation is taken into account there is indeed a notable derivation (dashed line) from the steady state.



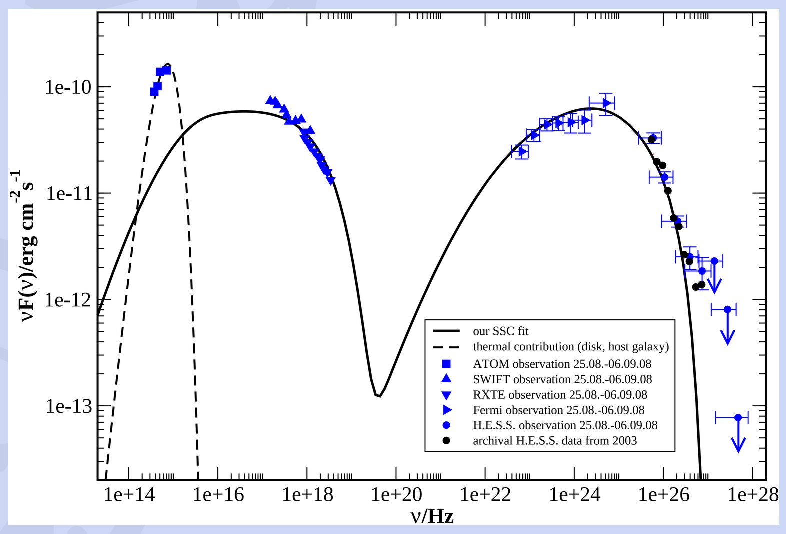


By increasing the number of electrons being accelerated in our model for a short time** the VHE lightcurve of the observed flare can be modelled (see LHS figure). Time-average over this outburst gives the dashed SED of 1 ES 1218+30.4. With the model, the lightcurves in other energybands are also accessible which might be used to verify this model.

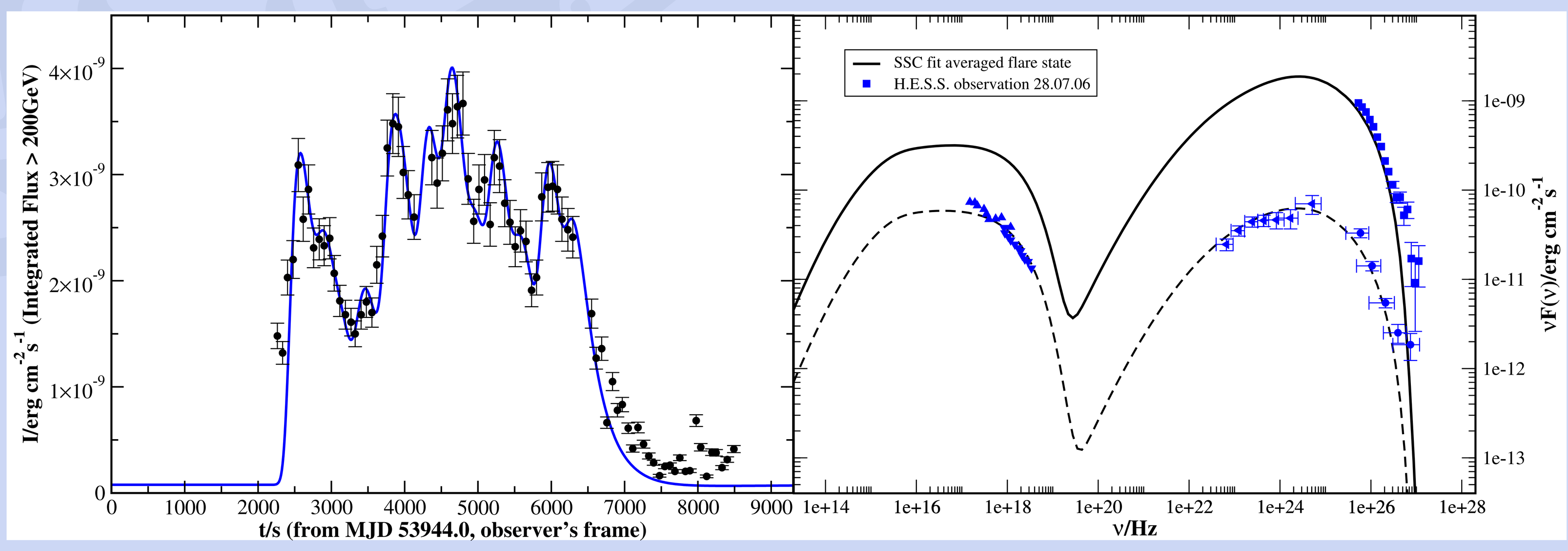
**details: see arXiv:1005.3747

Application to PKS 2155-304

The Fermi data of PKS 2155-304 indicates a notable feature: a strong curvature in the VHE leading to a deep dip between the synchrotron and the inverse Compton peak in the SED. The steady state SED of PKS 2155-304 can be modelled by moving the injection energy of the electrons towards mildly relativistic ones (see the sample electron distribution). The result is shown on the RHS, including archival H.E.S.S. data and the latest Fermi data.



This lowstate is again used to model the VHE flare of PKS 2155 observed by H.E.S.S. in 2006, with remarkably short timescales down to fife minutes in the observer's frame, just by injecting more e^- at γ_0 for certain amount of times***. When integrating over the whole outburst in 2006 the averaged SED as observed by H.E.S.S. is met. The model can hence be used to investigate the other, observationally not covered, energybands.



***details: see arXiv:1005.4999

Model SEDs and lightcurves of blazars are derived selfconsistently: Parameters not constrainable by other observations like superluminal motion are directly linked to the microphysical processes within the emitting region making plausibility arguments and physical interpretations possible, especially when outbursts are used to tighten the parameterrange.
All the standard High-Peaked BL-Lac objects can be modelled in their steady states with our box-model. The timeresolution allows for variability studies of blazars, including the most extreme one PKS 2155-304.
Not only the lightcurves in various energybands become accessible by the model but also the time resolved SEDs, hence the spectral evolution of High-Peaked BL-Lac objects during such an outburst.
Comparison with observations narrows down the parameterrange and the type of flare, e.g. more particle injection or more acceleration during the outburst, can be determined by the model, thus making a systematic investigation possible.
If applicable the model would give predictions to the flaring behaviour in all energybands although only one energyrange was observationally covered, like often the case since multiwavelength campaigns of flares are rather coincidental events, even though Fermi has improved the situation.