Studies of Blazar emission using a spatially resolved SSC

Stephan Richter, Felix Spanier
Universität Würzburg

Institut für Theoretische Physik und Astrophysik

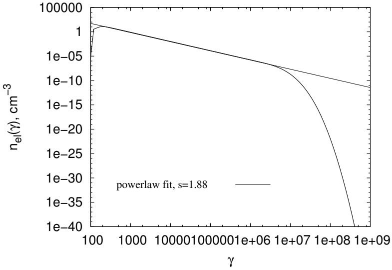
13th June 2013

Outline

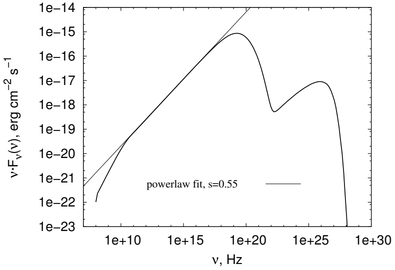
1. A spatially resolved model
   - Why?
   - Acceleration at shock
   - Radiation
   - Photohadronics
2. Results
   - SED of Mkn501 in 2009
   - Modelling of ultra short variability
   - Spectral index of the radio emission
3. Outlook
   - Hybrid acceleration
   - Oblique, relativistic shocks

SSC

- get an electron distribution from somewhere (powerlaw, kinetic equation, shock simulations)
- assume these electrons to live in a small region within a jet (a so called blob)
- account for and compute any relevant radiative processes to gain the spectrum eimitted from that region



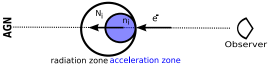
$\Longrightarrow$



Why?

- modelling variability on timescales smaller than the light crossing time
- time dependent modelling of acceleration without artifical boundary between acceleration and radiation region
- in a hybrid model full treatment of intermediates (cooling, reacceleration(?)) is possible
- connection between the spectra of the central emission region ($\sim 10^{15}$ cm) and VLBI blobs ($\sim 10^{18}$ cm)
- $\Rightarrow$ origin of VHE radiation from modelling correlation between VHE and radio regime
- one first step towards modelling of polarisation

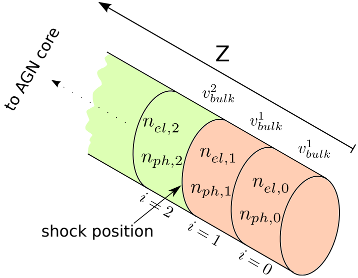
Geometry



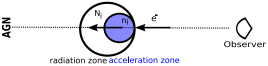
expand two-zone-model to N-zone-model

$\Downarrow \quad \Downarrow$

move from nested to aligned setup



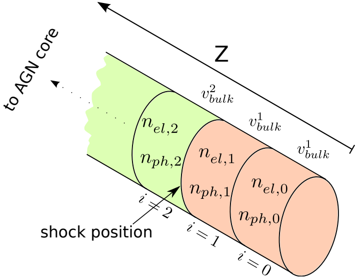
Geometry



expand two-zone-model to N-zone-model

⇓ ⇓

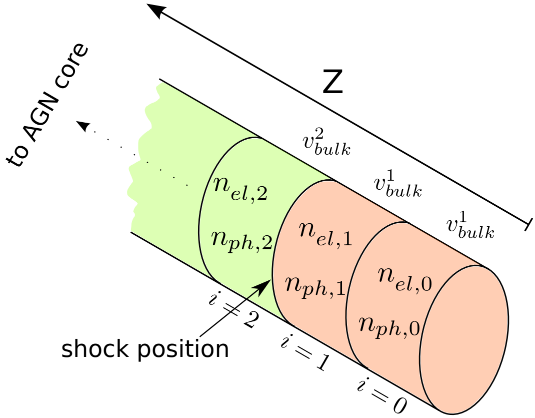
move from nested to aligned setup



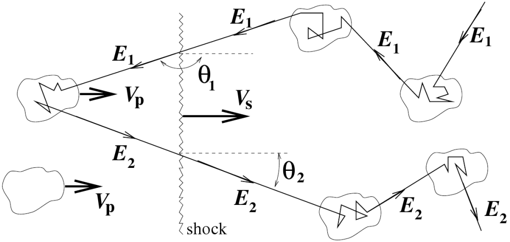
Not a multi component model!

Geometry

- devide simulation region into N slices in the direction parallel to shock normal
- each slice has local bulk speed, electron density, photon density (, magnetic field, radius)



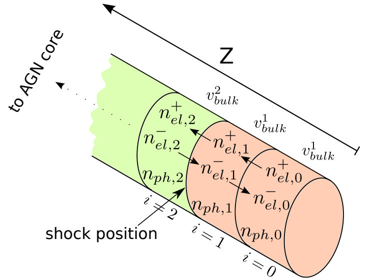
Acceleration



mimic Fermi I acceleration

1. advection between up- and downstream region
2. pitch angle scattering that is isotropic in the local bulk frame

Acceleration



- split electron population into two half spheres; one moving downstream (n^+), the other moving upstream (n^-)
- advection in the shock frame:

$$\frac{\partial n}{\partial t} + \frac{v_{bulk} + \mu}{1 + v_{bulk}\mu} \frac{\partial n}{\partial x} = 0$$

- averaging over μ for each half-space
- scattering from one half space into the other (including boost)

Radiation

time evolution of photon density

$$\frac{\partial N}{\partial t} = -c \cdot \kappa_{\nu,\mathrm{SSA}} \cdot N + \frac{4\pi}{h\nu} \cdot (\epsilon_{\nu,\mathrm{IC}} + \epsilon_{\nu,\mathrm{sync}})$$

- $\kappa_{\nu,\mathrm{SSA}}$ - Synchrotron Self Absorption coefficient

  calculated using the Melrose Approximation
- $\epsilon_{\nu,\mathrm{IC}}$ - changes due to invers compton scattering

  full integration of photon and electron density using the Klein-Nishina cross section
- $\epsilon_{\nu,\mathrm{sync}}$ - yields due to synchrotron radiation

  integration of electron density using the Melrose approximation for a single electron spectrum

see Richter and Spanier 2012 for details

Add photo hadronics

cooling (and maybe acceleration) of intermediates is relevant in AGNs

implementation

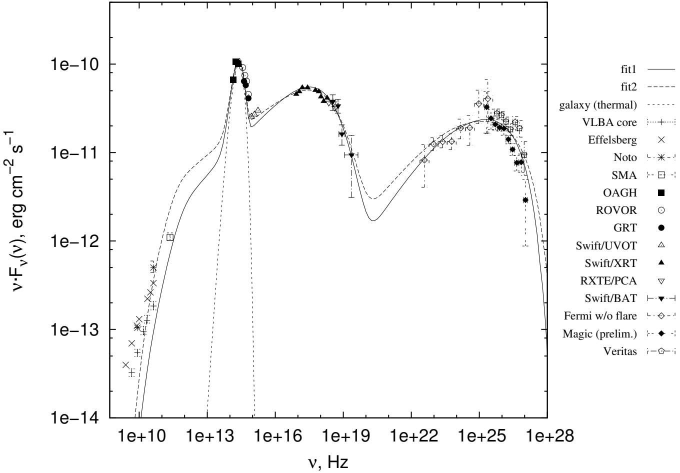
- using model by Hümmer et al. 2010
- full treatment of intermediate species
- e.g. calculation of realistic, flavour splitted neutrino spectra

status

- arbitrary combinations of particle species and all relevant processes implemented
- problem: what's the correct treatment of electron and proton acceleration in a parallel shock? ⇒ see outlook

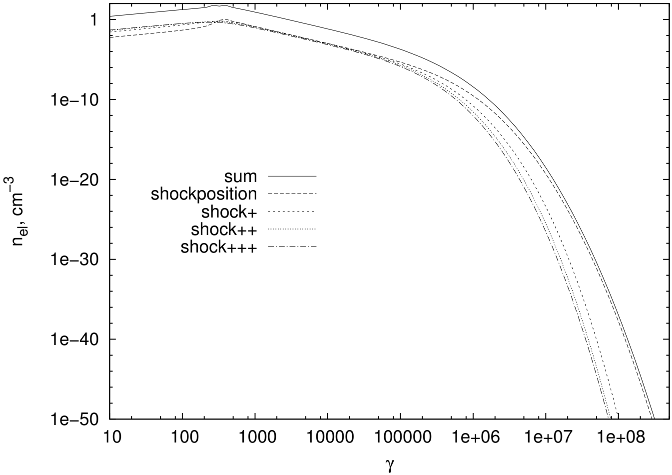
Results

Steady state fit

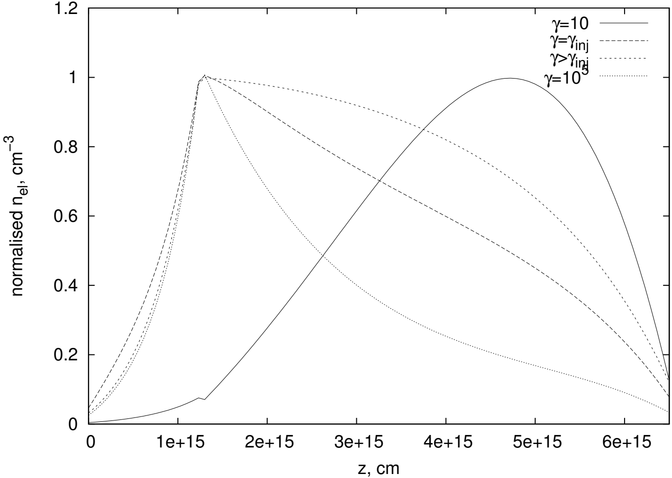


Data taken from Abdo et al. (2011).

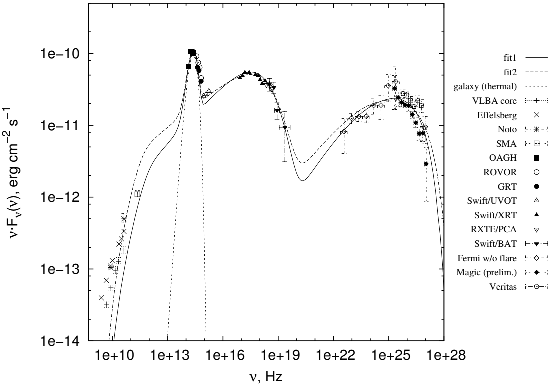
Electron distribution



Morphology


γ=10
γ=γinj
γ>γinj
γ=10^5
normalised n_el, cm^-3
z, cm
1.2
1
0.8
0.6
0.4
0.2
0
1e+15
2e+15
3e+15
4e+15
5e+15
6e+15

Variability



..yields

- fit1: $R = 6.5 \cdot 10^{15}$ cm and $\delta = 37$, hence $t_{lc} = 5856\,\mathrm{s}$
- fit2: $R = 2.1 \cdot 10^{16}$ cm and $\delta = 47$, hence $t_{lc} = 14\,900\,\mathrm{s}$

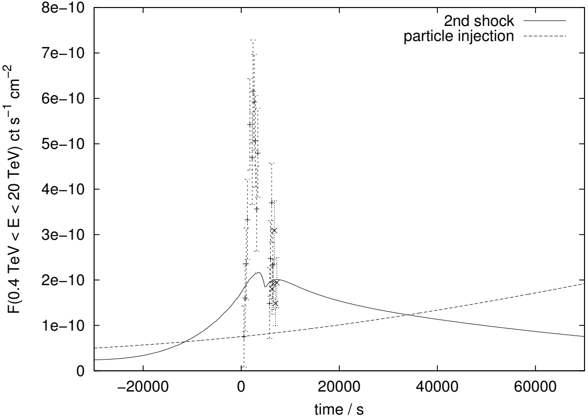
comparable parameters to one zone fits

Variability

- but variability is restricted by acceleration timescale

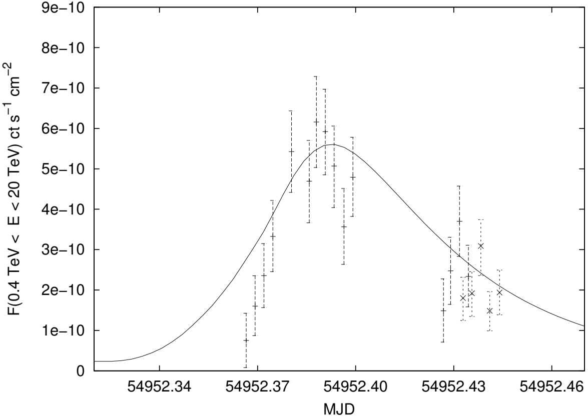
$$t_{var} \gtrsim max(t_{lc}, t_{acc} \vee t_{cool})$$

- variability due to multiple shocks



Variability

- but variability is very similar to IC timescale



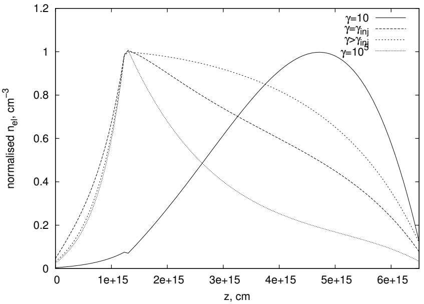
possible scenario summarised in Richter & Spanier (submitted)

Radio

- naive spectral index: $F_\nu \propto \nu^{5/2}$ (self absorbed regime)
- in homogenous fits either ignored or circumvented by high γ_{inj} and γ_{min}, respectively (don't do the latter)

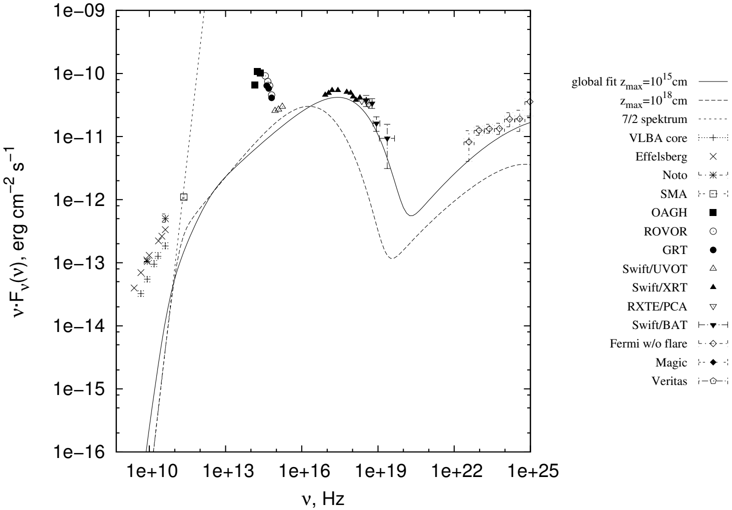
Radio

- naive spectral index: $F_\nu \propto \nu^{5/2}$ (self absorbed regime)
- in homogenous fits either ignored or circumvented by high γ_{inj} and γ_{min}, respectively (don't do the latter)



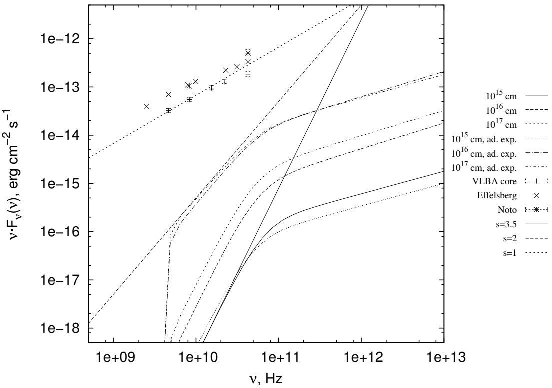
$\Rightarrow$ far downstream there will be a powerlaw also for $\gamma < \gamma_{inj}$

Radio



Effect of significant larger simulation region.

Radio

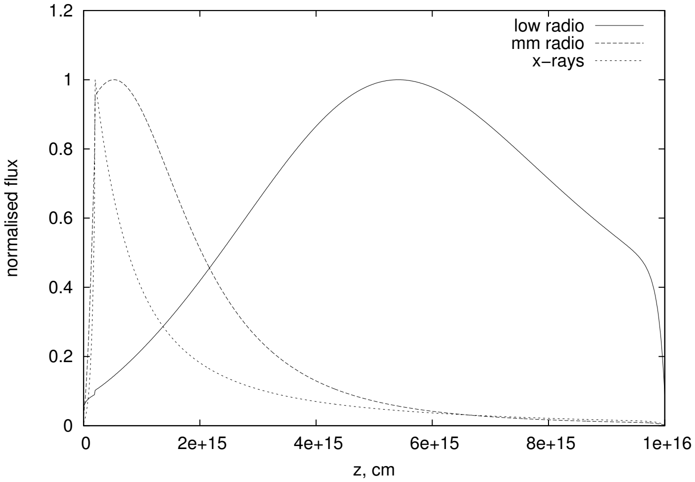


Effect of adiabatic expansion in the downstream.

$\Rightarrow$ yields opening angle of order $\tan(\alpha) \sim 1$

$\Rightarrow$ models in 2D or spherical geometry needed

Radio



Flux morphology.

Outlook

Timescales during acceleration

(parallel) shock escape time

- even homogenous models assume first order acceleration $\Rightarrow$ shock is needed (as far as we know)
- since scattering assumed isotropic in plasma frame $\Rightarrow$ escape time basically determined by shock speed and $D_{\mu\mu}$

consequences for acceleration timescale

- t_{esc} and t_{acc} have opposite dependence on $D_{\mu\mu}$, but we see powerlaws
- hence $D_{\mu\mu}$ (therefore acceleration efficiency) should be independent from energy and mass

- crucial for timescale predictions (see talk by M. Weidinger)
- identification of hadronic sources could give hints to the underlying turbulence
- oblique/relativistic jets? time dependent implementation?

Thank you

Bibliography I

A. A. Abdo, M. Ackermann, M. Ajello, A. Allafort, L. Baldini, J. Ballet, G. Barbiellini, M. G. Baring, D. Bastieri, K. Bechtol, and E. al. et al. Insights into the High-energy {γ}-ray Emission of Markarian 501 from Extensive Multifrequency Observations in the Fermi Era. *The Astrophysical Journal*, 727(2):129, Feb. 2011. ISSN 0004-637X. doi: 10.1088/0004-637X/727/2/129. URL http://stacks.iop.org/0004-637X/727/i=2/a=129?key=crossref.3481d95923711c6992ac11403c374cdf.

S. Hümmer, M. Rüger, F. Spanier, and W. Winter. Simplified Models for Photohadronic Interactions in Cosmic Accelerators. *The Astrophysical Journal*, 721(1232):630–652, Sept. 2010. doi: 10.1088/0004-637X/721/1/630. URL http://iopscience.iop.org/0004-637X/721/1/630.

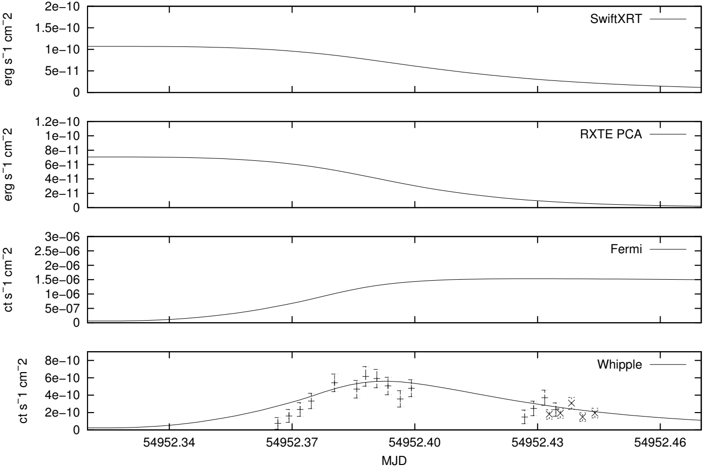
S. Richter and F. Spanier. A Spatially Resolved SSC Shock-in-Jet Model. *International Journal of Modern Physics Conference Series (IJMPCS)*, 08 (01):392–395, Jan. 2012. ISSN 2010-1945. URL http://adsabs.harvard.edu/abs/2012IJMPS..08..392R.

spatially resolved SSC

Motivation

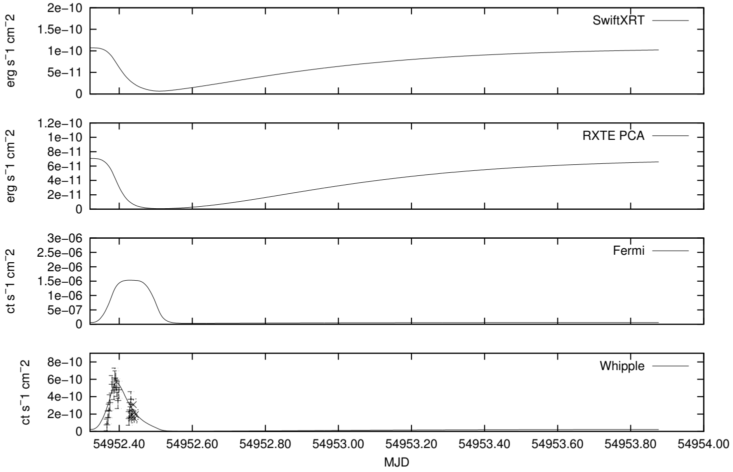
- acceleration due to Fermi I happens at finite size shock
  $\Rightarrow \quad R_{acc} \ll R_{rad}$
- acceleration efficiency should depend on distance to shock
- for energies with $t_{cool} < lct$ the blob simply isn't homogenous
  - example values from Abdo et al. (2011):
    $B = 0.015\,\mathrm{G}, \;\; R = 1.3 \cdot 10^{17}\,\mathrm{cm}, \;\; \gamma_{max} = 1.5 \cdot 10^{7}$
  - $t_{cool} = 5.7 \cdot 10^{4}\,\mathrm{s} \ll t_{esc} = 4.3 \cdot 10^{6}\,\mathrm{s}$
- compute *multiple shock*-scenarios
- homogenous modells constrain time variability to $\Delta t > R_{rad}/c \Rightarrow$ inhomogenous models allow shorter timescales while preserving causality

Variability



Lightcurves for EC orphane flare.

Variability



Lightcurves for EC orphane flare.