A model for the highly variable orphan flare of Markarian 501

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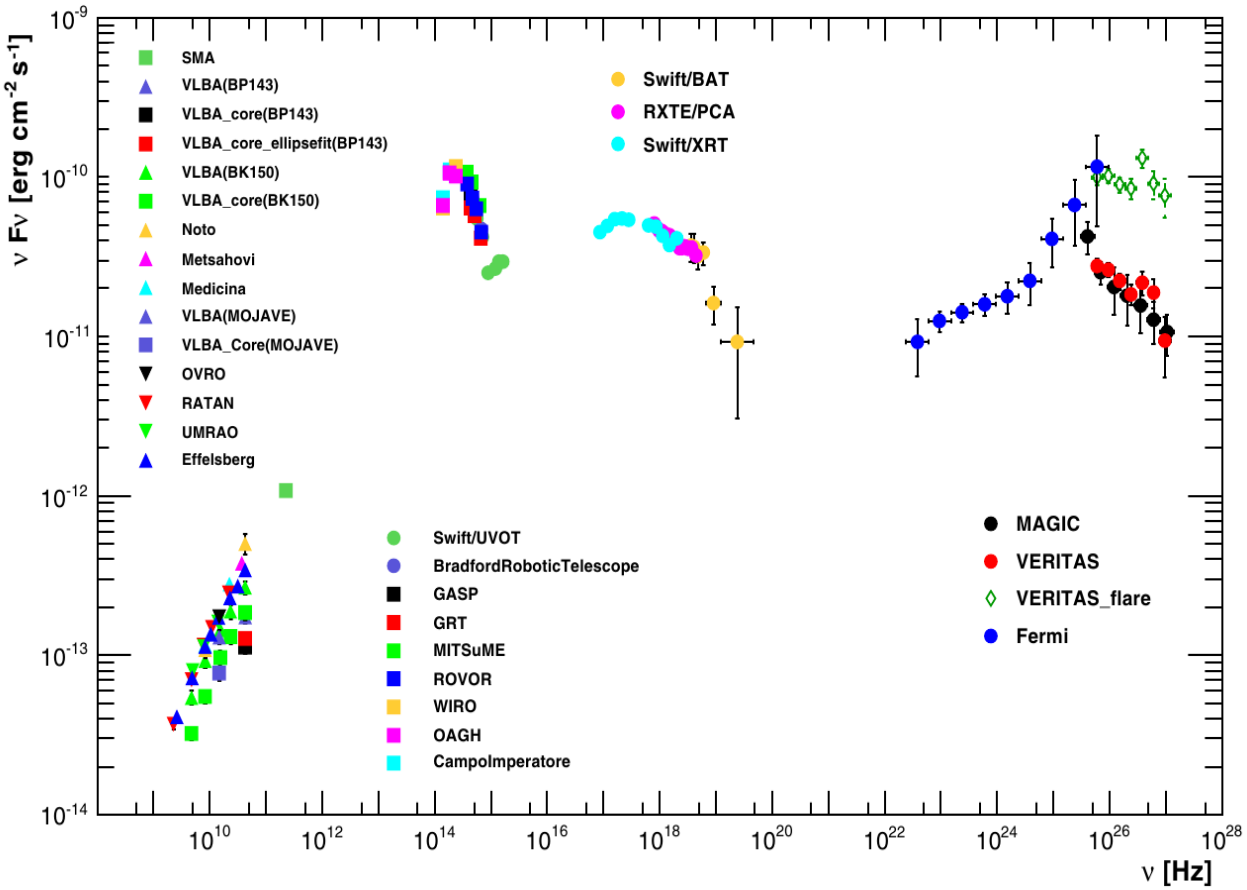
Outline

1. Observation Campaign on *Markarian 501* in 2009
   - average SED
   - the two flares
2. SSC fits
   - steady state
   - short time flare
3. model for (too) short time scales

Observation

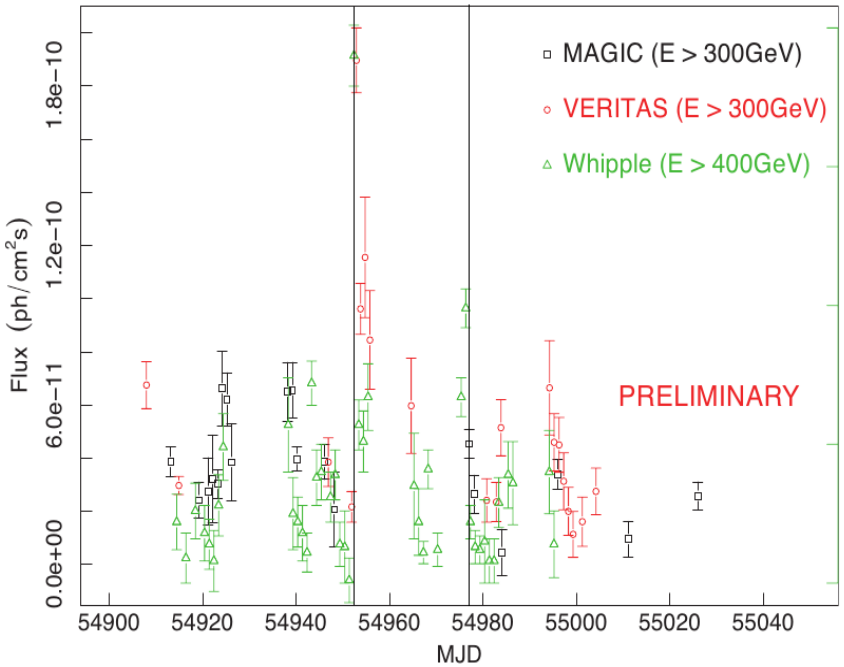
Mrk 501 observed in multi-frequency campaign between March and August 2009 [Abdo et al. (2011)]:

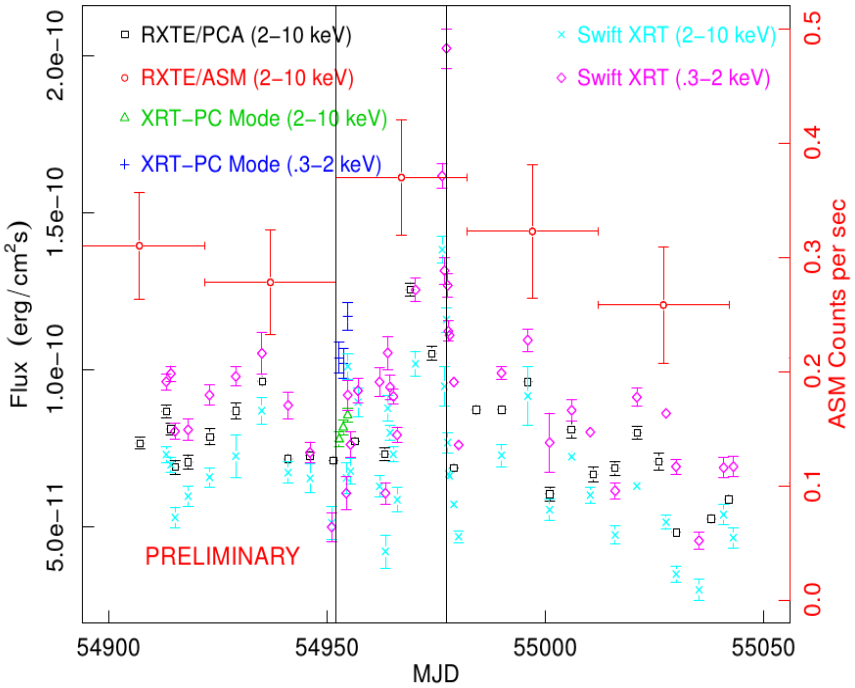


so far nothing special about that..

Observation

during that time two distinct flares occured [de Almeida et al. (2011)]:

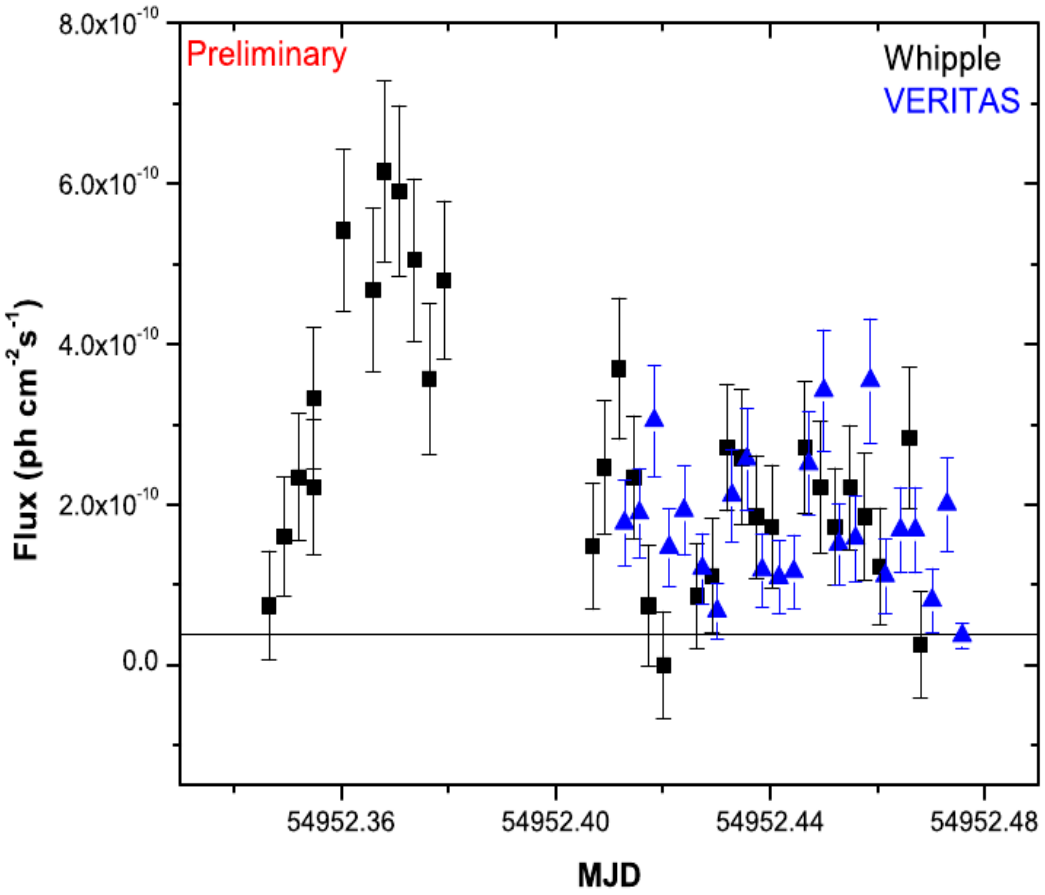




1. first flare (MJD 54952) strong variability in the γ-range, but almost none in the x-rays $\Rightarrow$ orphan flare
2. second flare (MJD 54977) with significant variability from *XRT* and some in the γ-range

Observation

the first flare was also very fast [Pichel and Paneque (2011)]:



Time scales

- 6 times the flux in less than 2000 seconds
- light crossing time in observer frame $t_{lc} = \frac{R}{c \cdot \delta}$
- for typical values $R \sim 10^{15}$ cm, $\delta \sim 10 \Rightarrow t_{lc} \sim 3000\,\mathrm{s}$

$\Rightarrow$ even when ignoring acceleration time scales, we are at the edge of typical variation time scales

furthermore acceleration happens mainly close to the shock, in a small environment

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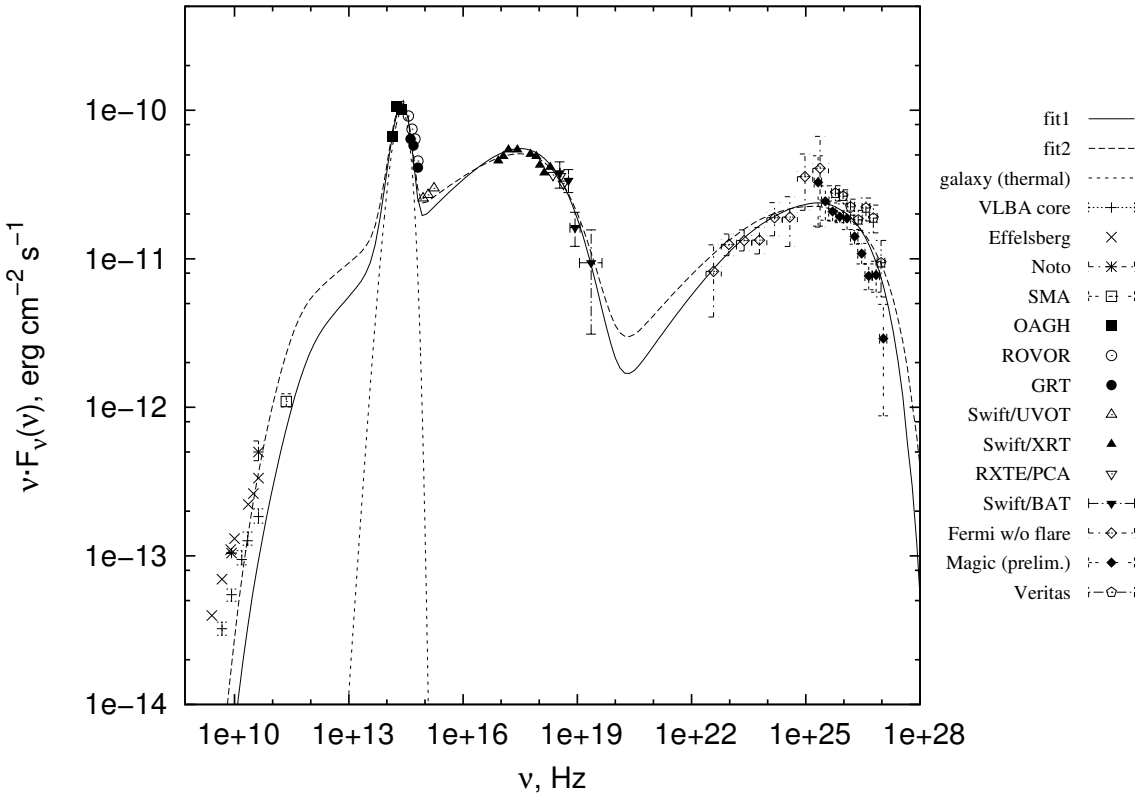
$\Rightarrow$ need of:

a. custom parameter set from the steady state fit
b. accurate, time dependent simulation of flare scenarios

The steady state fit..



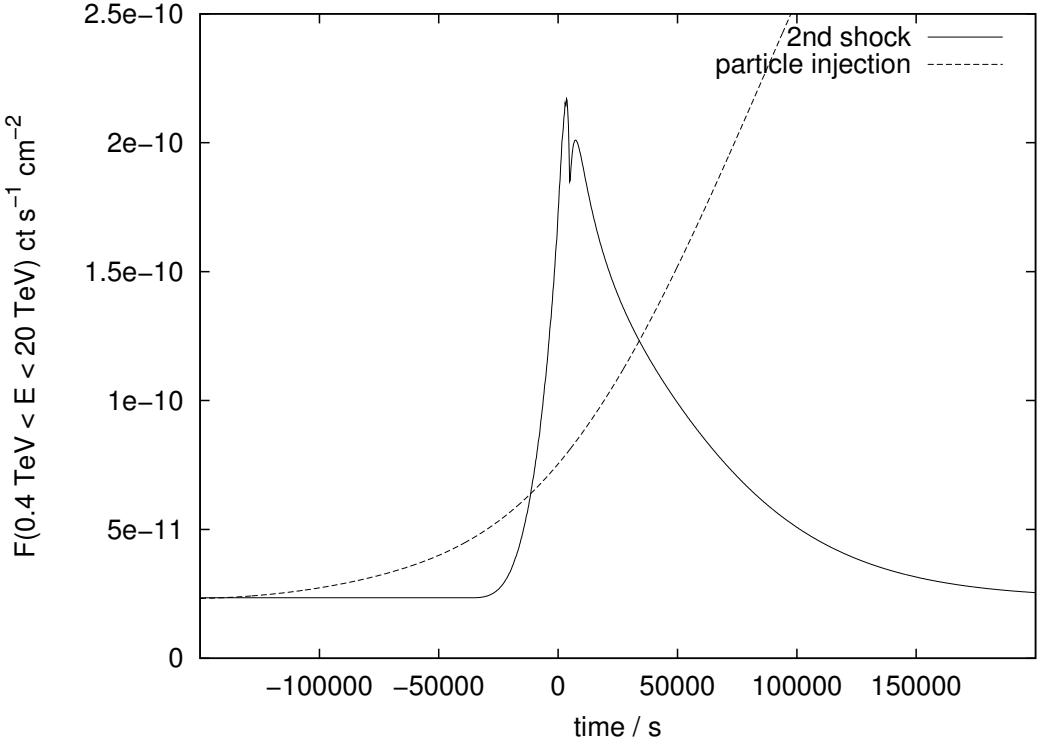
..yields

- 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 $t_{lc} = 14\,900\,\mathrm{s}$

so we already are in trouble!

Lightcurves

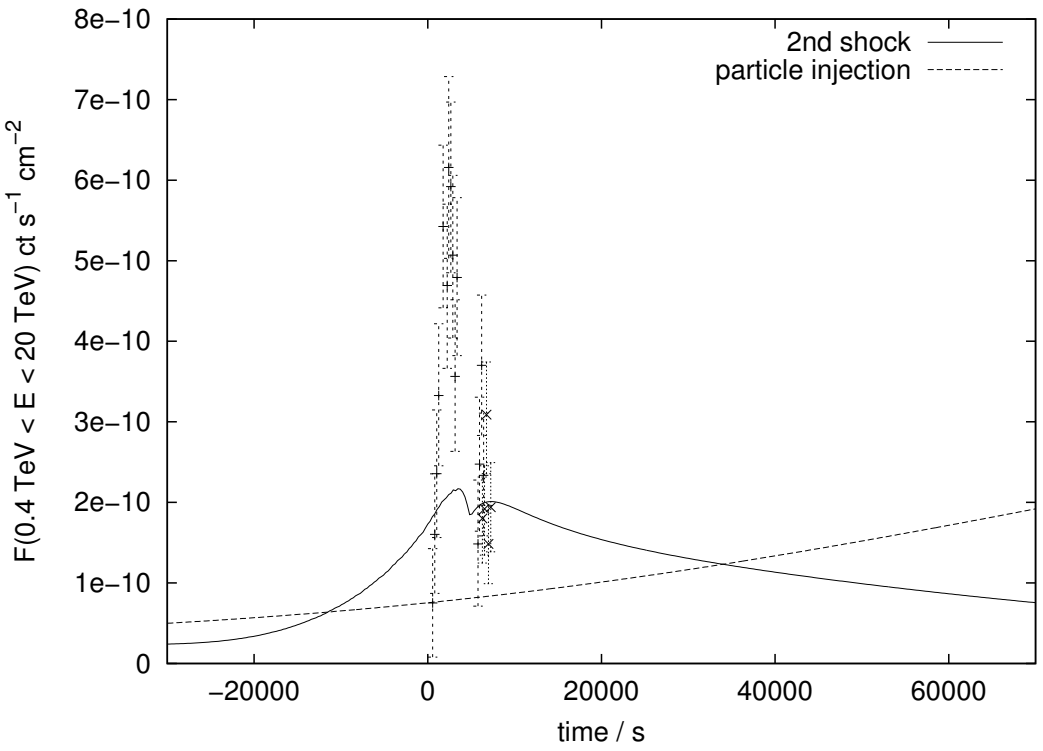
so what about reacceleration within the emission region?



better, but....

Lightcurves

..not good enough:



in general: the contrast between the performance of SSC in fitting steady state and variability, respectively is quite puzzling

Our "fast orphan flare" model

- basic idea: use another boost to shorten the time scale
- use an external photon field to explain orphan character

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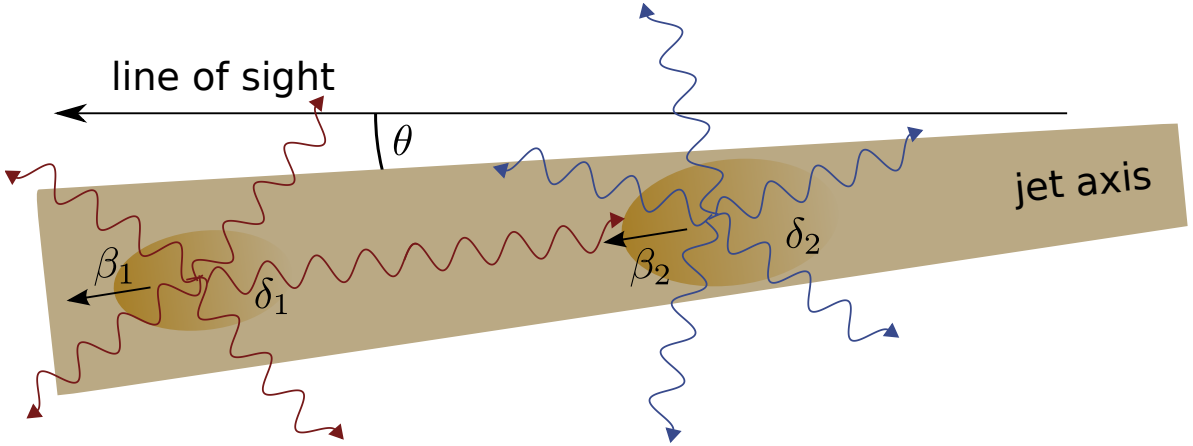
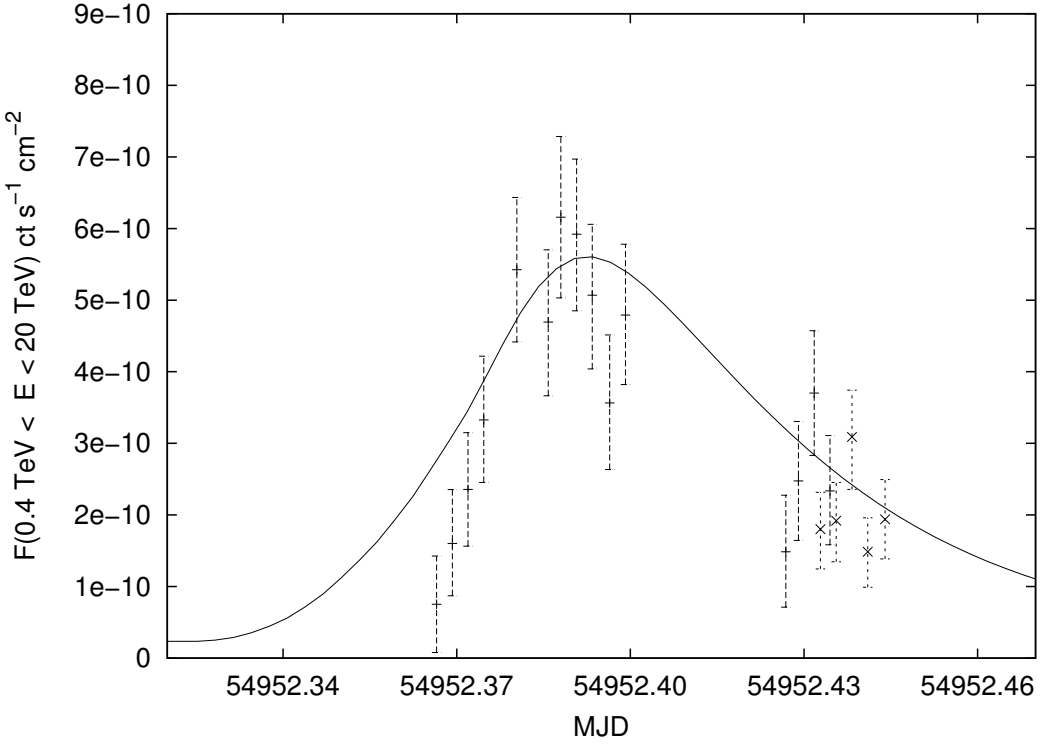


- assume a second photon field with moderate energy
  - no direct detection, since lower Doppler factor
  - apart from that similar to the "main" blob
- when these photons hit the blob they are upscattered by inverse compton and boosted into the "main" blob frame

Model fit

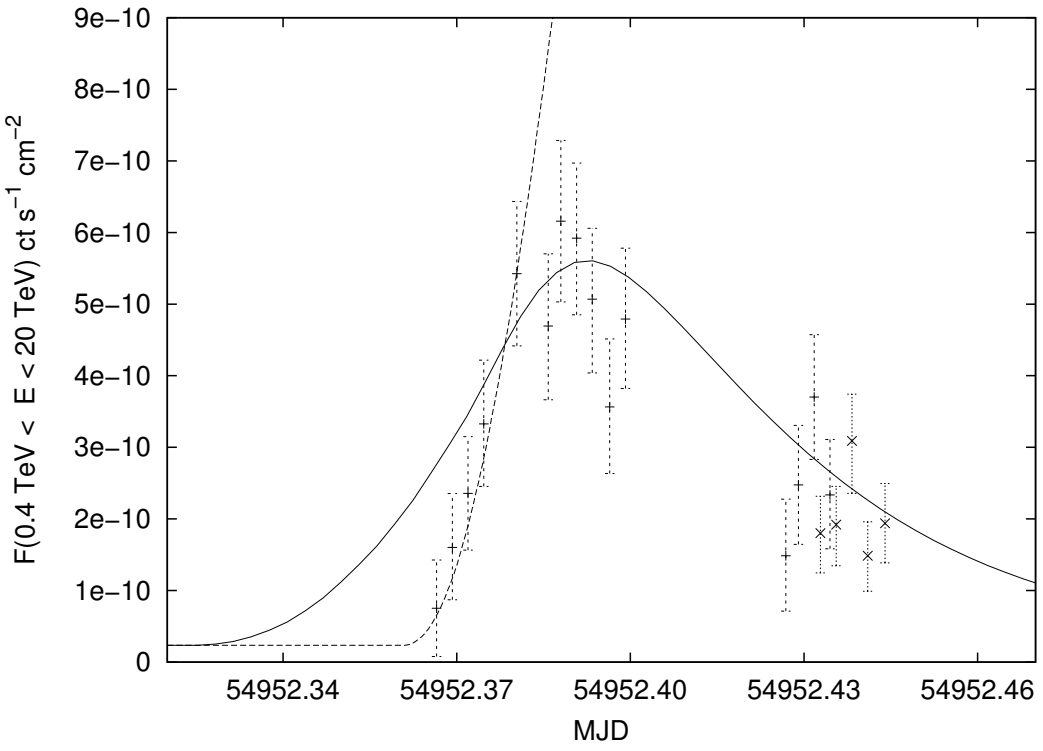
although lc-time in main blob remains, we get:



injection of a *Melrose*-spectrum [Brown et al. (1983)] photon distribution ($\nu_{cut} = 10^{14}$ Hz, $n(\nu_{cut}) = 3 \cdot 10^{-5}\,\mathrm{cm}^{-3}$)

Model fit

even better:



Model fit

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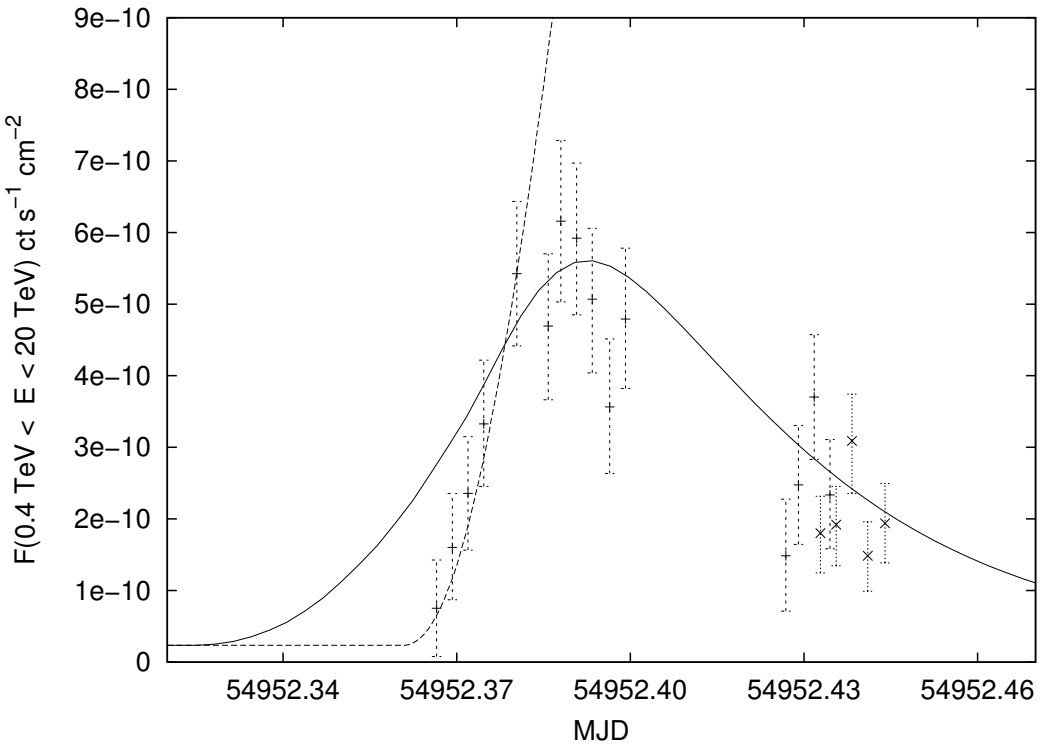
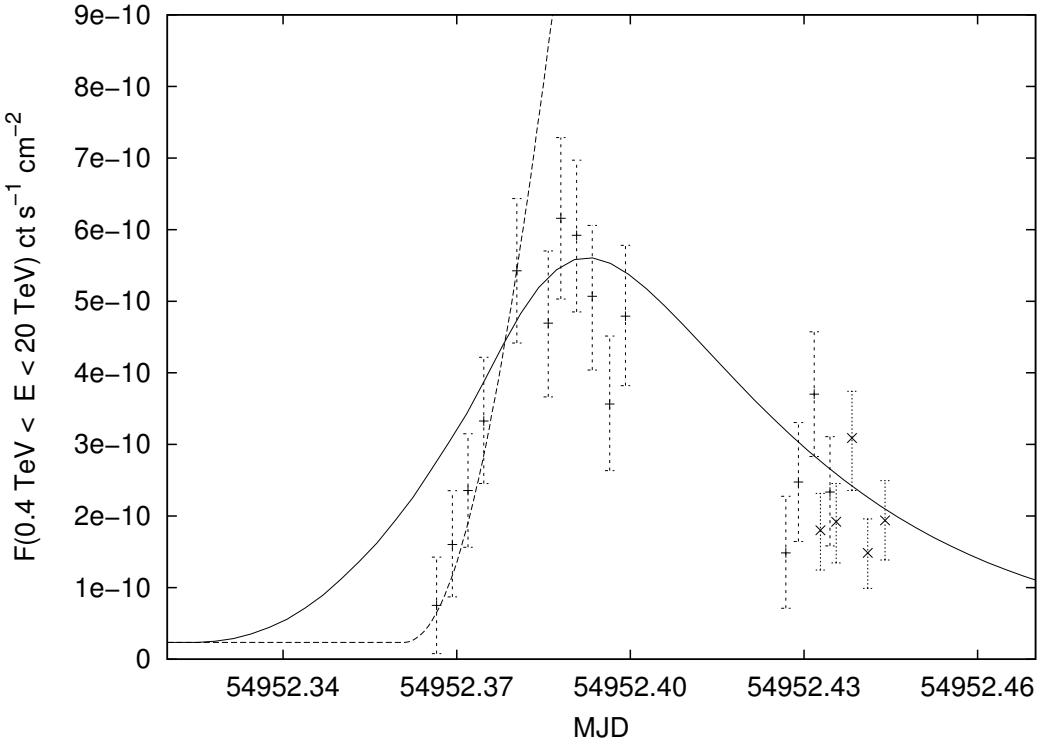


but injecting a distribution with ($\nu_{cut} = 10^{17}$ Hz, $n(\nu_{cut}) = 6 \cdot 10^{-8}\,\mathrm{cm}^{-3}$) raises more difficulties

Model fit



shape can be modeled qualitatively with an additional photon component, using only two parameters, without occuring time scale constraints

Derived limits

keen assumption: both flares are connected

- using component 1 as injection for second flare $\Rightarrow$ 21 d is the time it takes them to catch up each other
- hence

$$d = 21\,\mathrm{d} \cdot \delta_1 \gamma_1 c \frac{\beta_2 - \beta_1}{1 - \beta_1\beta_2 - \beta_2 + \beta_1} \tag{1}$$

- injected photon density and the one in the first blob then translates as

$$n_{ph,inj}(\nu_c) = n_{ph}^{(1)}(\widetilde{\nu_c}) \cdot \left(\frac{\delta_2}{\delta_1}\right)^2 \left(\frac{R_1}{d}\right)^2 \tag{2}$$

- non direct detection can be expressed as

$$\frac{(\delta_1^4 R_1^2) n_{ph}^{(1)}}{(\delta_2^4 R_2^2) n_{ph}^{(2)}} < 10\% \tag{3}$$

(SRT kinematics in the backup slides ;))

Derived limits

this yields for

the parameters

$\delta_1 = 1.3 \quad d = 4.4 \cdot 10^{19}\,\mathrm{cm} \quad n_{ph}^{(1)} = 1.5 \cdot 10^{-2}\,\mathrm{cm}^{-3}$

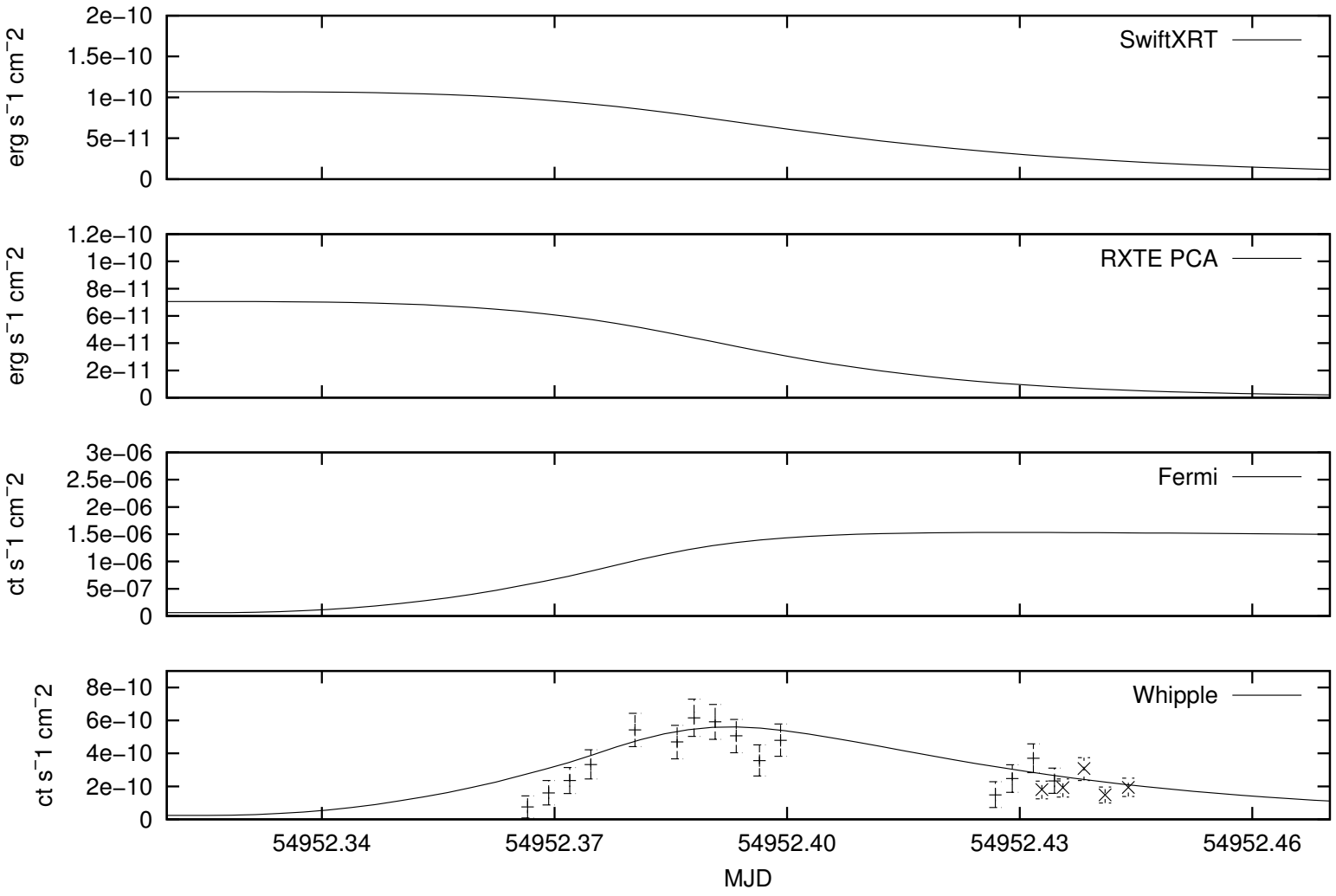
the electron distribution in component 1

$\gamma = 2800 \quad n_{el}^{(1)} = 4.9\,\mathrm{cm}^{-3} \quad N_{el,inj} = 2 \cdot 10^{43} \approx 4 \times N_{el}$ of steady state

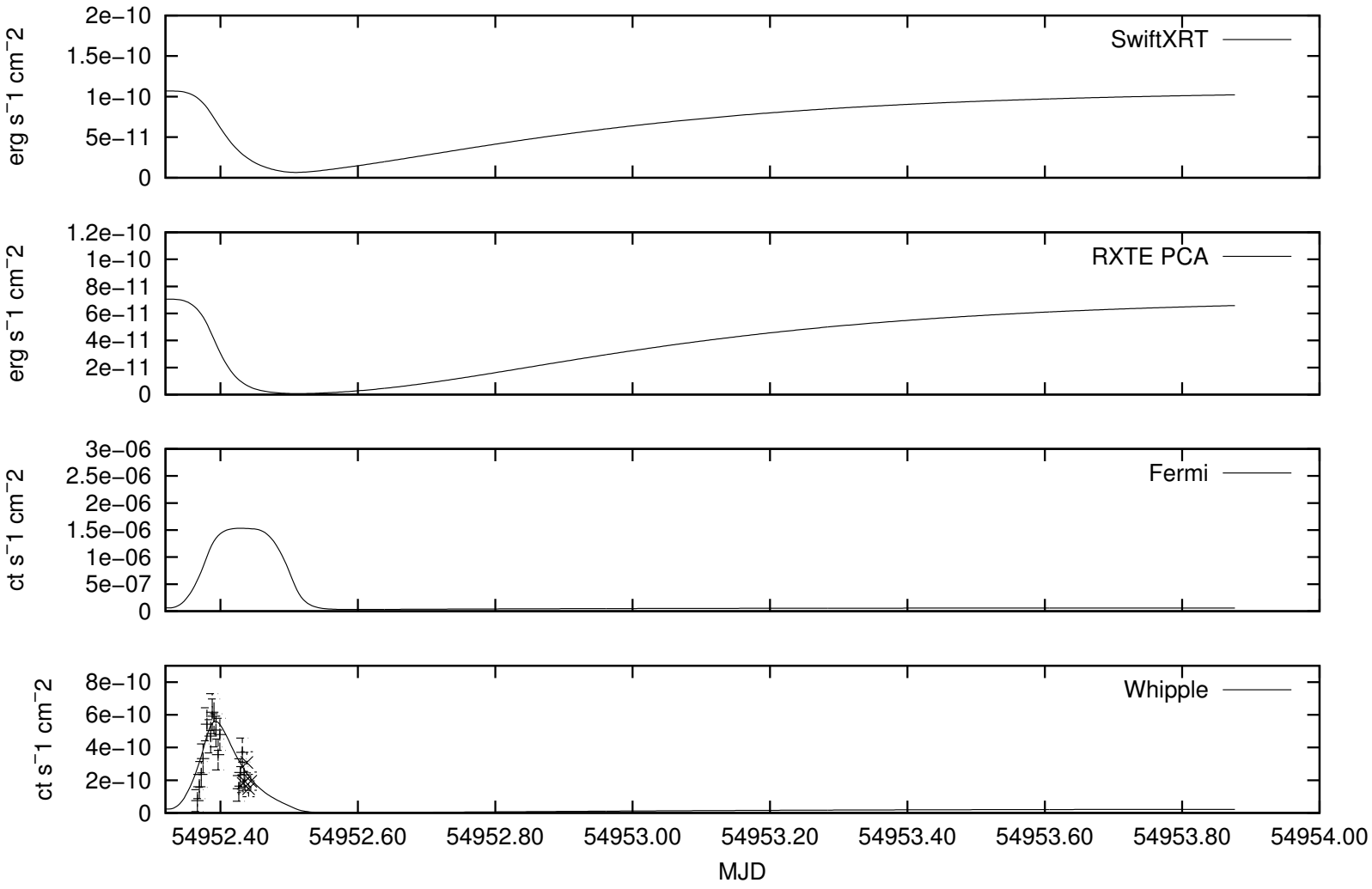
the timescales

$t_{inj}^{max} = t_{cool}(\gamma)\frac{\delta_1}{\delta_2^2} = 24\,600\,\mathrm{s} \quad t_{var}^{max} = \frac{R_1}{c}\frac{\delta_1}{\delta_2^2} = 1500\,\mathrm{s}$

Model fit


SwiftXRT
RXTE PCA
Fermi
Whipple
erg s⁻1 cm⁻2
ct s⁻1 cm⁻2
2e−10
1.5e−10
1e−10
5e−11
0
1.2e−10
8e−11
6e−11
4e−11
2e−11
3e−06
2.5e−06
2e−06
1.5e−06
1e−06
5e−07
8e−10
6e−10
4e−10
54952.34
54952.37
54952.40
54952.43
54952.46
MJD

Model fit


SwiftXRT
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erg s^-1 cm^-2
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2e−10
1.5e−10
1e−10
5e−11
0
1.2e−10
8e−11
6e−11
4e−11
2e−11
3e−06
2.5e−06
2e−06
1.5e−06
1e−06
5e−07
8e−10
6e−10
4e−10
2e−10
54952.40
54952.60
54952.80
54953.00
54953.20
54953.40
54953.60
54953.80
54954.00
MJD

Conclusion

- orphan flares with very short time scales can be modeled with an additional, simple photon component
- falsification possible with detailed, simultaneous observation of the synchrotron peak
- a possible origin of these photons is an older, less energetic blob, with a small doppler factor (or almost stationary)
- other photon sources (e.g. accretion disk) might work as well

Thank you

Bibliography I

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J. C. Brown, I. J. D. Craig, and D. B. Melrose. Inversion of synchrotron spectra. *Astrophysics and Space Science*, 92(1):105–112, 1983. ISSN 0004-640X. doi: 10.1007/BF00653590. URL `http://adsabs.harvard.edu/abs/1983Ap%26SS..92..105B`.

U. B. de Almeida, D. Paneque, N. Nowak, N. Strah, D. Tescaro, for the Fermi-LAT, MAGIC, and V. Collaborations. Multifrequency Variability and Correlations from Extensive Observing Campaigns of Mkn 421 and Mkn 501 in 2009. Sept. 2011. URL `http://128.84.158.119/abs/1109.5887`.

Bibliography II

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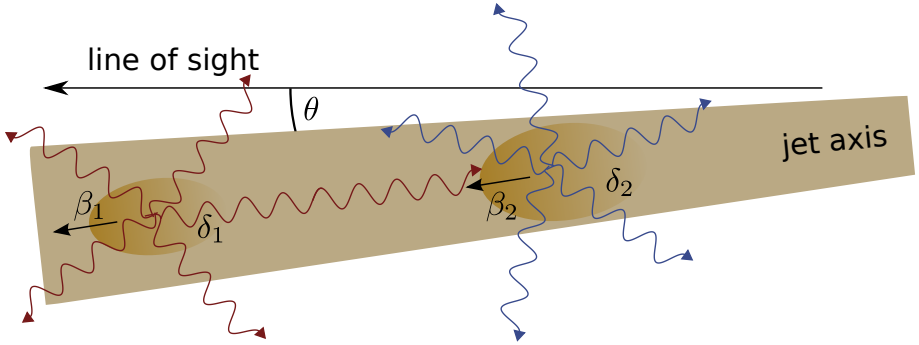
SRT kinematics



in the 1-frame, the difference between the liht travel time and the time component 2 is travelling is:

$$\frac{\widetilde{d}}{c\widetilde{\beta}_2} - \frac{\widetilde{d}}{c} = \widetilde{\Delta t} = \delta_1 \cdot \Delta t \tag{4}$$

using relativistic velocity addition

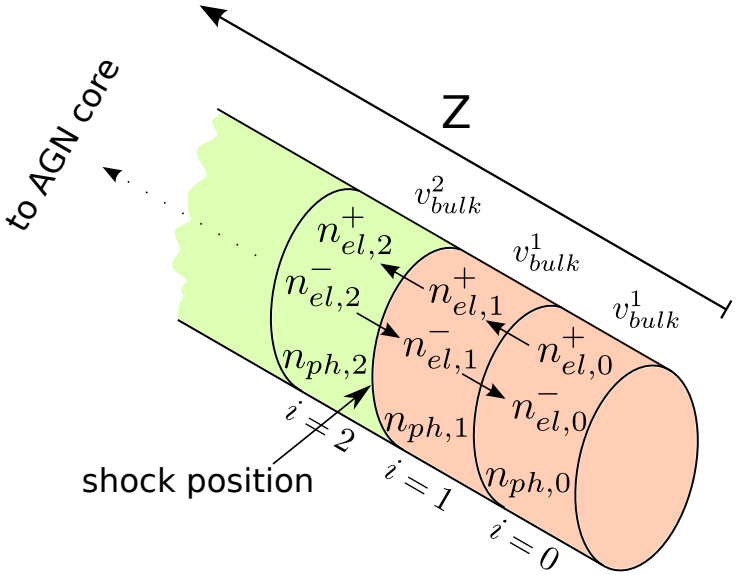
$$\widetilde{\beta}_2 = \frac{\beta_2 - \beta_1}{1 - \beta_1 \beta_2} \tag{5}$$

yields

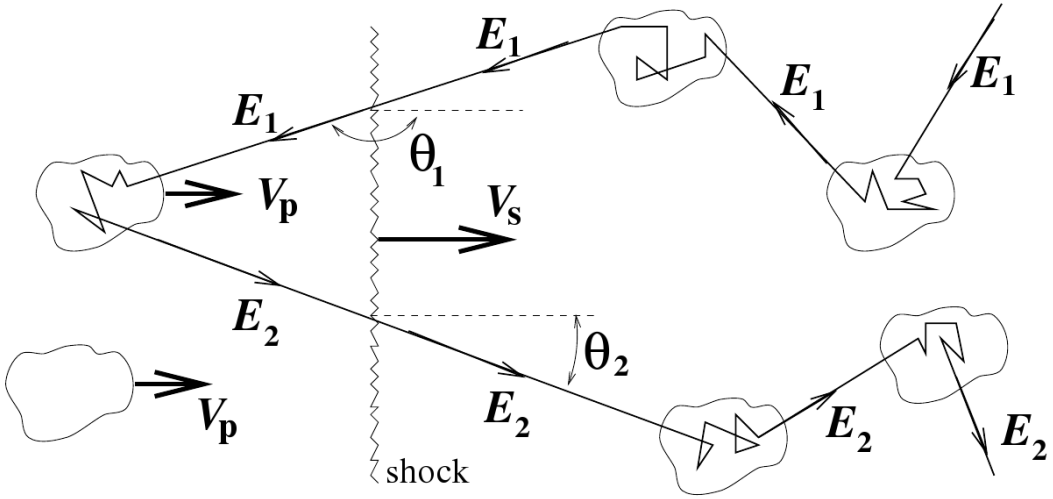
$$d = 21\,\mathrm{d} \cdot \delta_1 \gamma_1 c \frac{\beta_2 - \beta_1}{1 - \beta_1 \beta_2 - \beta_2 + \beta_1} \tag{6}$$

Model

- devide simulation box into N zones
- modelling the jet propagating through the zones
- describing acceleration via scattering around the shock (Fermi I process)
- calculating the SEDs in each zone and sum up taking into account light travel times



Model - Fermi-I



- shock is represented by jump in bulk velocity u between neighboured zones
- in shock frame: $u_u = -V_S$, $u_d = V_P - V_S$, $R = \frac{u_u}{u_d}$
- scattering is controlled via the probability for an electron to change its propagation direction