Gamma-ray emission from pair cascades at the border of broad line regions

Christoph Wendel [1]

cwendel@astro.uni-wuerzburg.de

Work together with Josefa Becerra González [2], Amit Shukla [3], David Paneque [4] and Karl Mannheim [1]

[1] Universität Würzburg

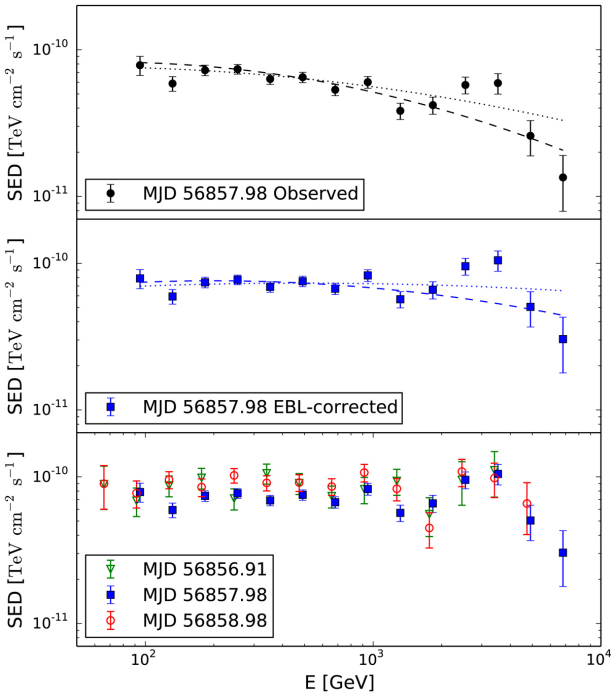
[2] Instituto de Astrofísica de Canarias and Universidad de La Laguna

[3] Indian Institute of Technology Indore

[4] Max-Planck-Institut für Physik

Extragalactic jets on all scales - launching, propagation, termination
June 2021

Peculiar feature in Markarian 501 – A hint to gap activity?



SED of Mrk 501 from 19.07.2014 (top and middle frame) and from 18. - 20.07.2014 (bottom), observed by the MAGIC telescopes.
Dotted lines: Best log-parabola fit
Dashed lines: Neglecting data above 1.5 TeV
Acciari, et al., 2020, A&A

PL, LP and ELP fit of MAGIC data:
Inconsistent at $> 3\sigma$

Likelihood ratio test:
Broad LP + narrow LP preferred at 4σ versus single LP

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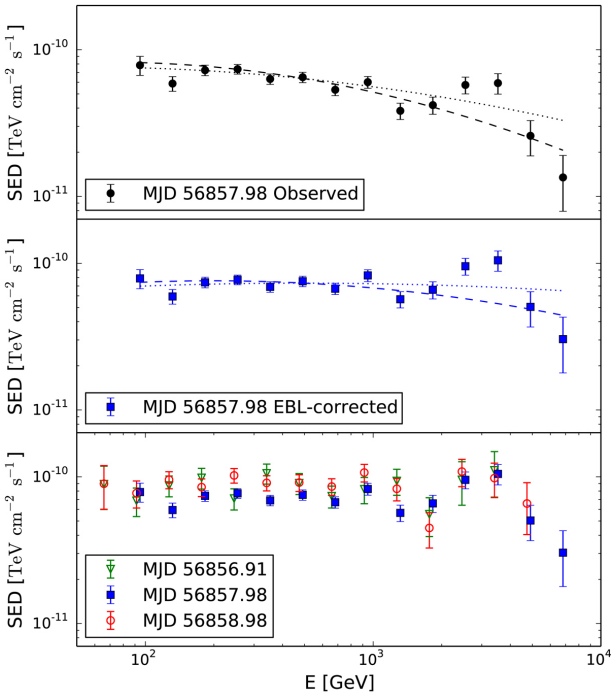

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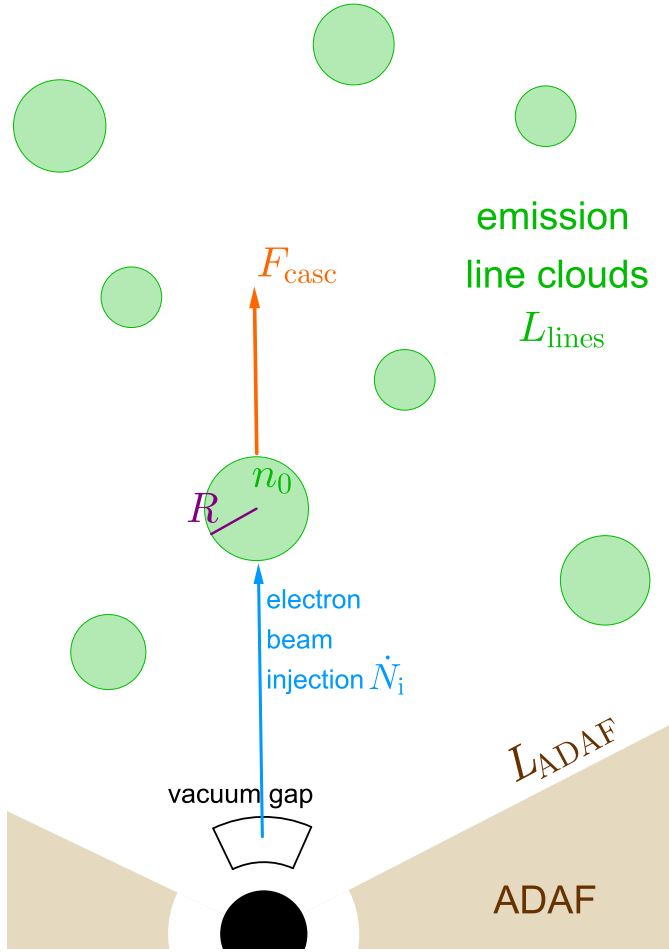
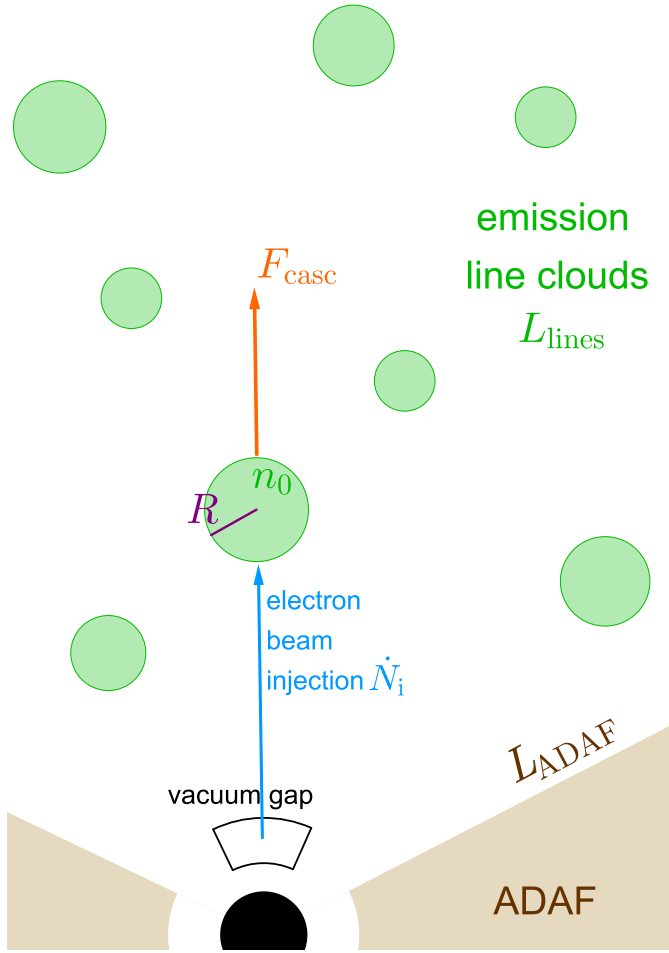


Interaction of electron beam with emission line photons

$$\dot{N}_\mathrm{i}(\gamma) = \frac{K_\mathrm{G}}{\sigma\,\sqrt{(2\pi)}} \cdot \exp\left(-\frac{(\gamma-\gamma_\mathrm{mean})^2}{2\,\sigma^2}\right)$$



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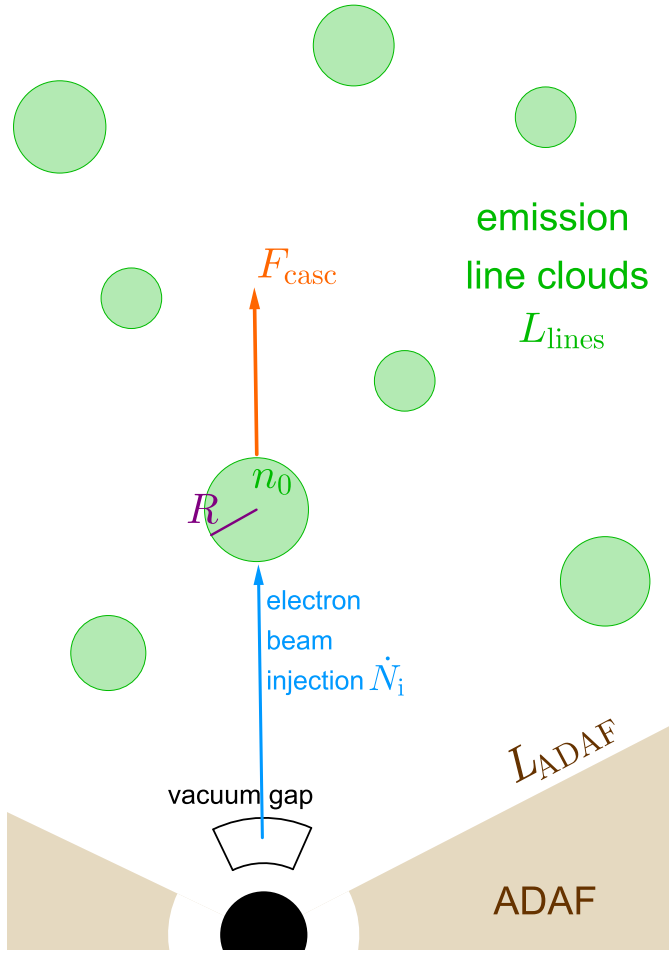
$$n_0(x) = K_\mathrm{lines} \cdot \sum_{i=1}^{4} \frac{K_{\mathrm{line},\,i}}{x_{0,\,i}} \cdot \delta_\mathrm{Dirac}\,(x - x_{0,\,i})$$

i	Wavelength $\lambda_{0,\,i}/\mathrm{nm}$	Relative flux density contribution $K_{\mathrm{line},\,i}$	Line
1	30.5	2.00	He II Lyman-α
2	93.0	0.17	H Lyman series
3	102.6	0.57	H Lyman-β
4	121.5	5.40	H Lyman-α



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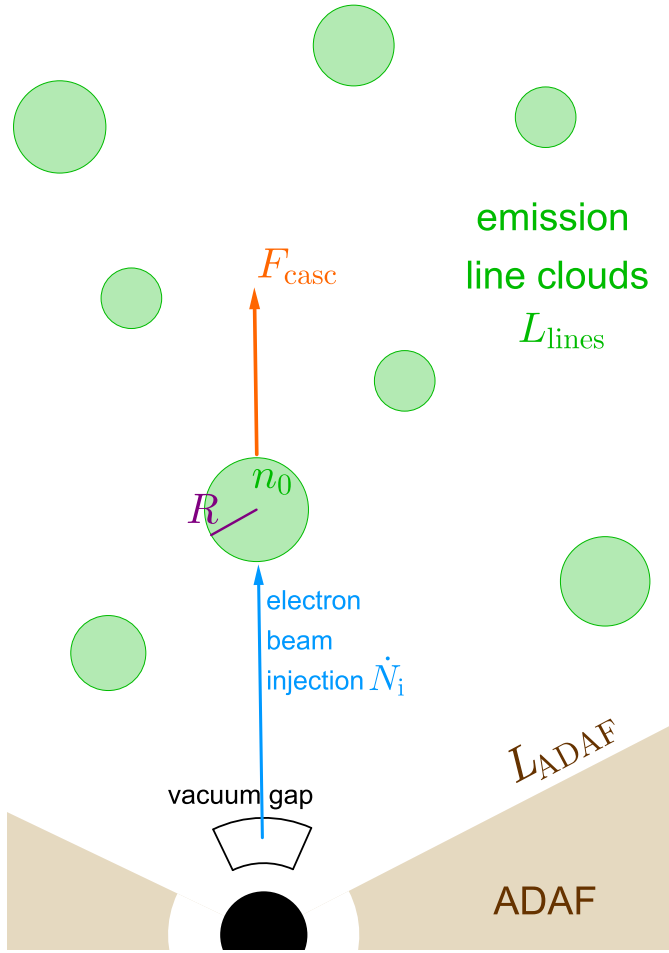
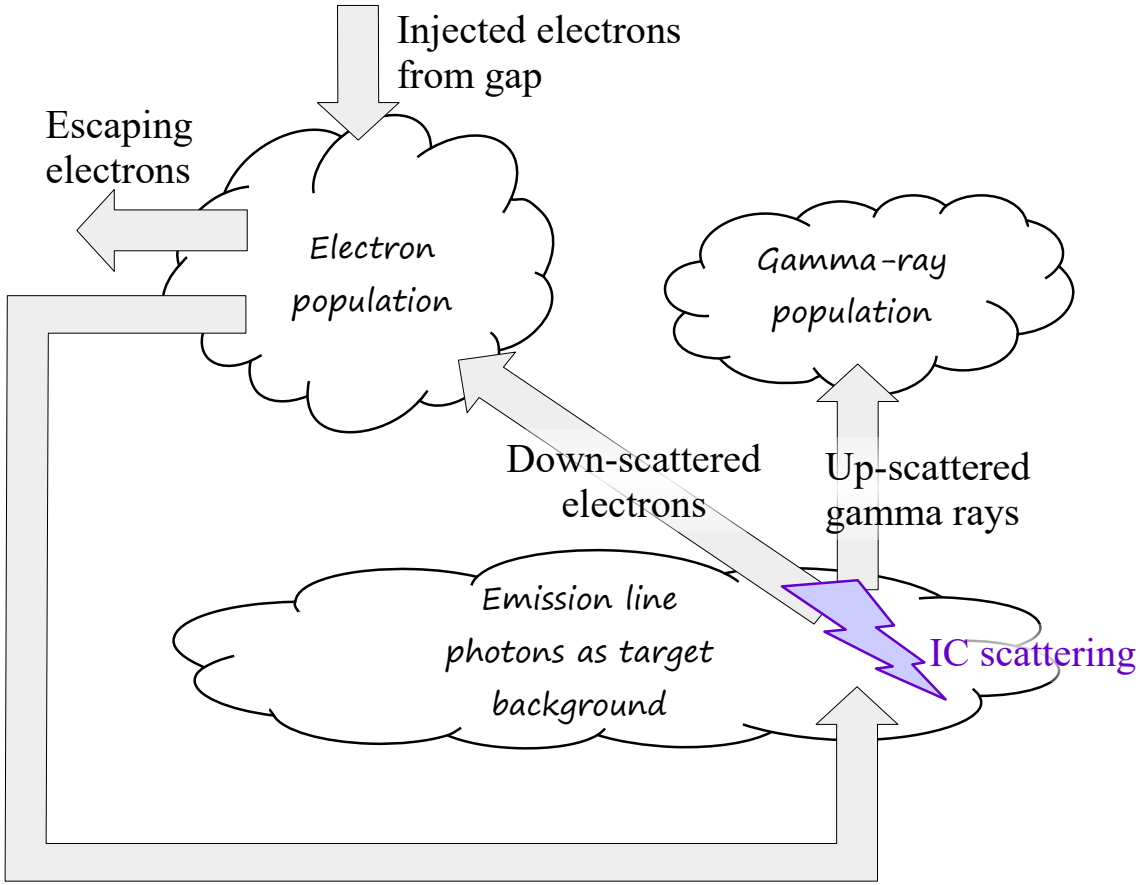
$$T_\mathrm{esc} := \frac{R}{c}$$



Interaction of electron beam with emission line photons
⇒ Evolution of IC pair cascade



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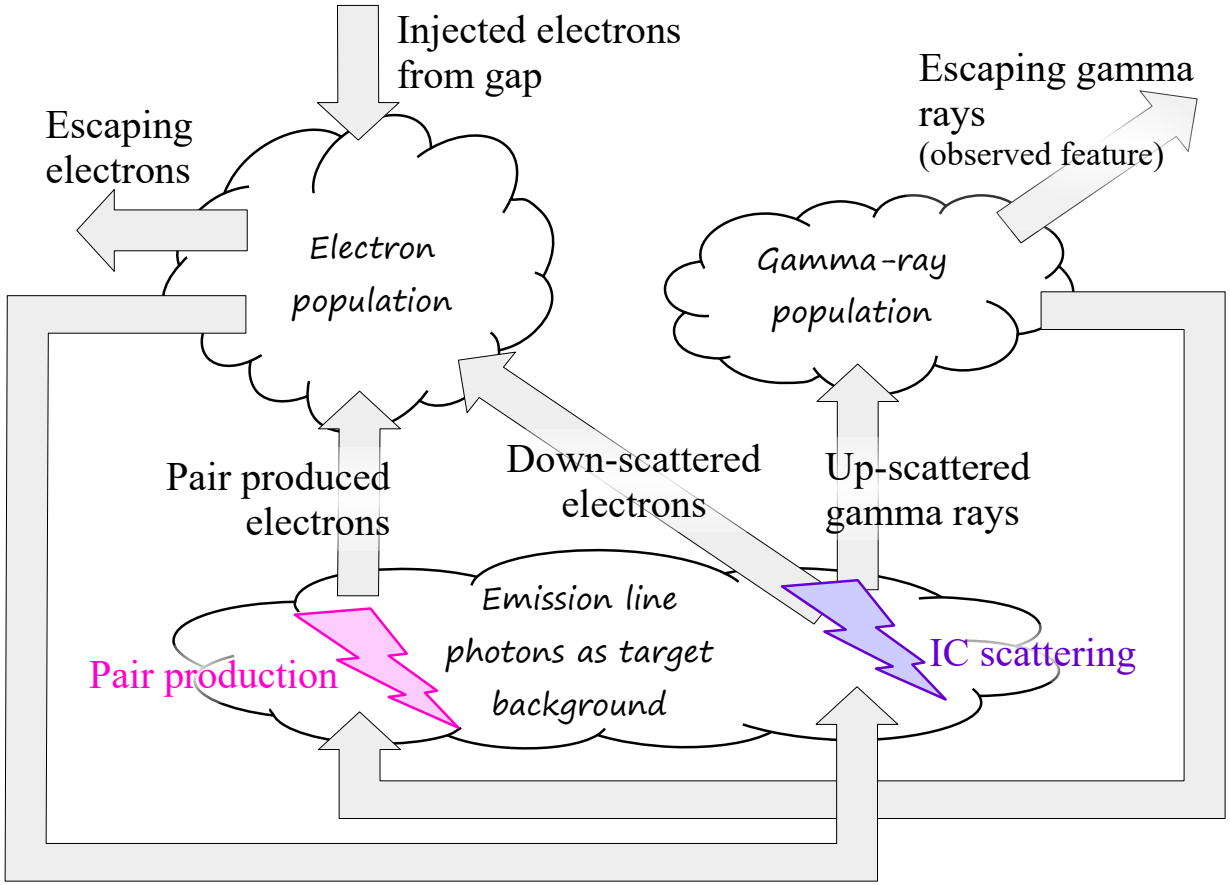


Fit to observational SED

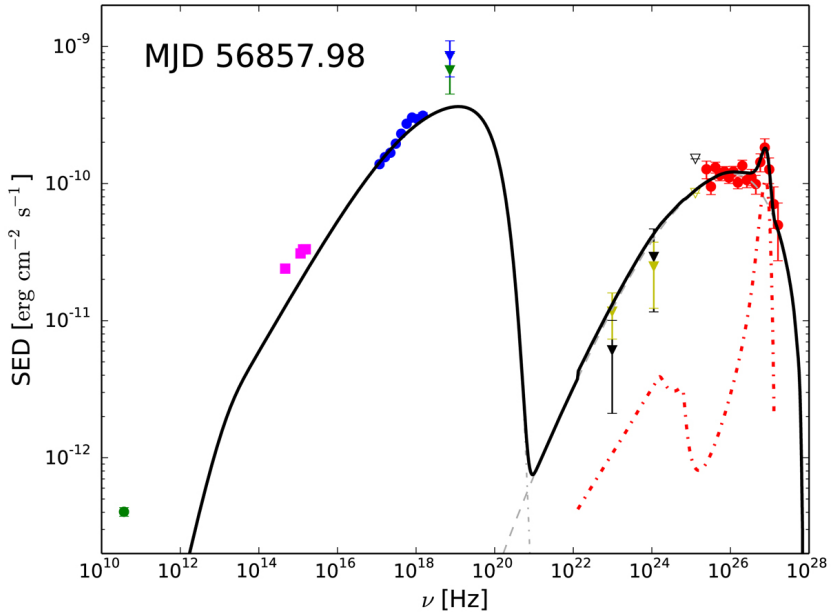
- Input parameters
  $\Rightarrow$ electron distribution
    $\Rightarrow$ gamma-ray photon distribution
      $\Rightarrow$ F_{casc}

- Add SSC component:

$$F = F_{\mathrm{casc}} + F_{\mathrm{SSC}}$$

Quantity	Used value
γ_{min}	10^3
γ_{break}	$4.0 \cdot 10^5$
γ_{max}	$3.0 \cdot 10^6$
α_1	2.0
α_2	3.1
R	$2.9 \cdot 10^{13}$ m
B	$1.2 \cdot 10^{-5}$ T
δ	20
Electrons' number density	$2.1 \cdot 10^{10}$ m^{-3}

The SSC parameters used for fitting.



Broadband SED of Mrk 501 from 19.07.2014 (MJD 56857.98).
Red dots: MAGIC
Black / yellow triangles: Fermi LAT
Blue / green: Swift BAT / XRT
Pink: KVA / Swift UVOT
Green: Metsähovi
Grey lines: SSC emission
Red line: Cascaded emission
Black line: SSC + cascaded emission
Acciari, et al., 2020, A&A

Fit to observational SED

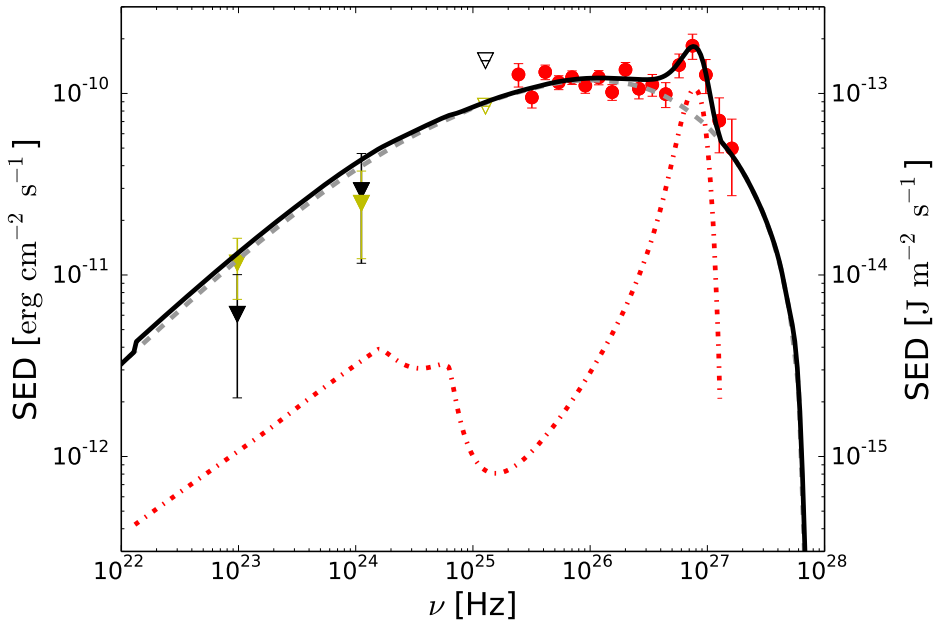
- Input parameters
  $\Rightarrow$ electron distribution
  $\Rightarrow$ gamma-ray photon distribution
  $\Rightarrow$ F_{casc}

- Add SSC component:
  $F = F_{\mathrm{casc}} + F_{\mathrm{SSC}}$

- Fit peaky feature:

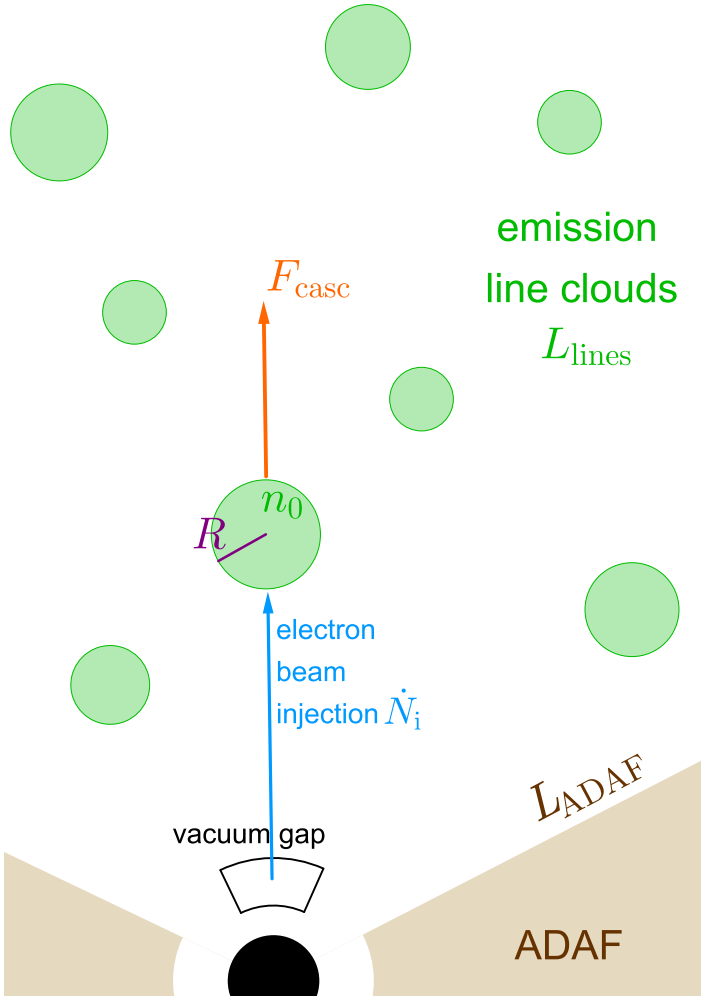
Quantity	Used value
ϕ	$1.8°$
R	$3.0 \cdot 10^{11}$ m
K_{G}	$3.3 \cdot 10^{4}\,\mathrm{s}^{-1}\,\mathrm{m}^{-3}$
K_{lines}	$9.7 \cdot 10^{12}\,\mathrm{m}^{-3}$
γ_{mean}	$3.4 \cdot 10^{12}\,\mathrm{eV}/(m_{\mathrm{e}}c^2)$
σ	$0.23\,\gamma_{\mathrm{mean}}$

The cascade parameters used for fitting.



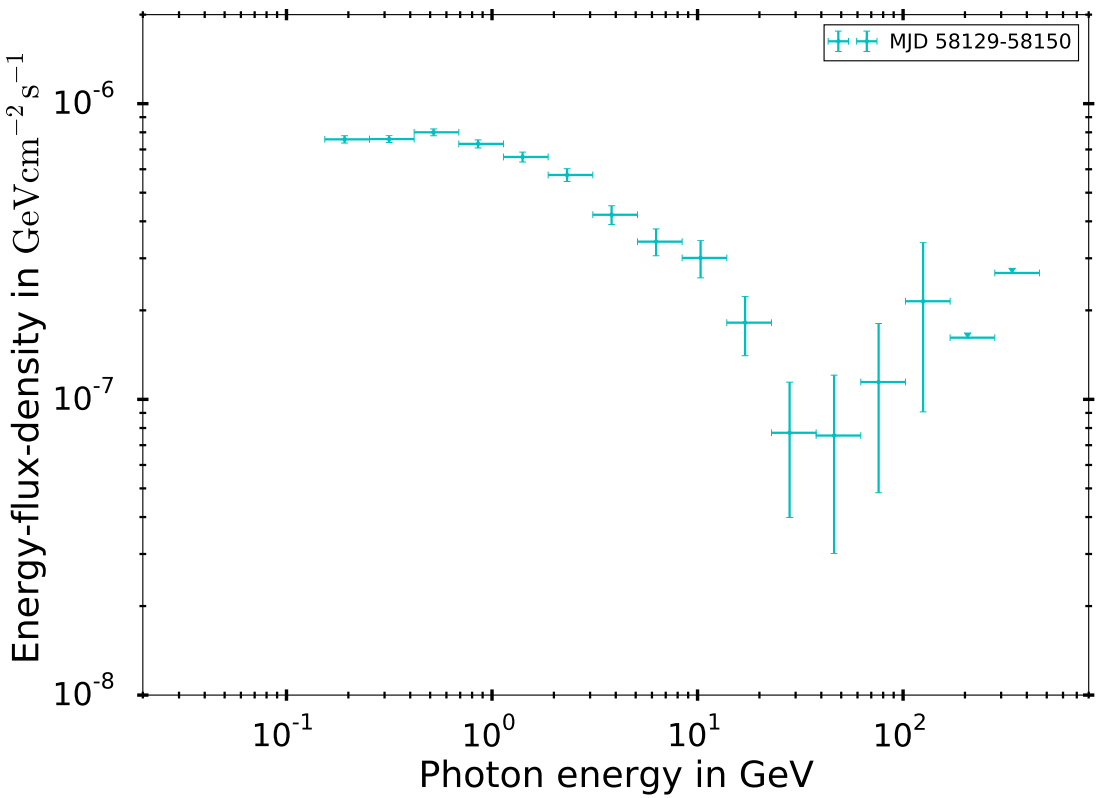
HE and VHE SED of Mrk 501 from 19.07.2014 (MJD 56857.98).
Red dots: MAGIC
Black / yellow triangles: Fermi LAT
Grey lines: SSC emission
Red line: Cascaded emission
Black line: SSC + cascaded emission
Wendel, et al., 2021, A&A

Inferences about Mrk 501



- Accretion flow: $T_{\rm e} \approx 10^{10}\,{\rm K}$, $\dot{m} \approx$ few 10^{-4}
  - Pair production in gap and subsequent multiplication by 10^6 $\Rightarrow$ electron beam
  - Cloud reprocessing fraction ≈ 0.01 $\Rightarrow$ emission lines
- Electron beam + emission lines $\Rightarrow$ IC pair cascade
- Escaping gamma rays can account for narrow SED feature
- Narrow SED feature can indicate gap activity

Gamma-ray emission from 3C 279



SED of 3C 279, observed by the Fermi LAT. Wendel, Shukla and Mannheim, submitted to ApJ

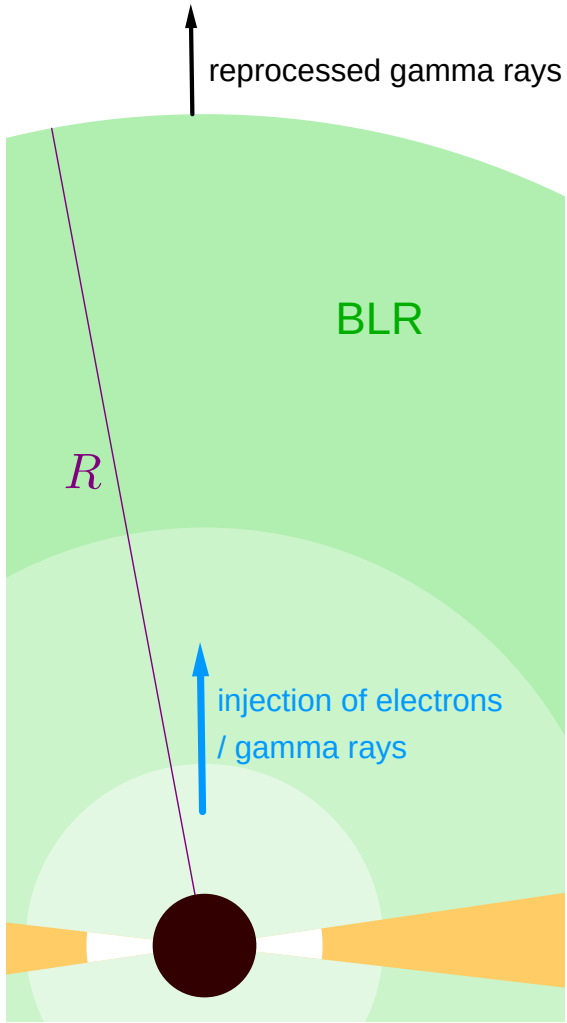
Gamma-ray emission from 3C 279

Injection: Relativistic electrons / HE gamma rays

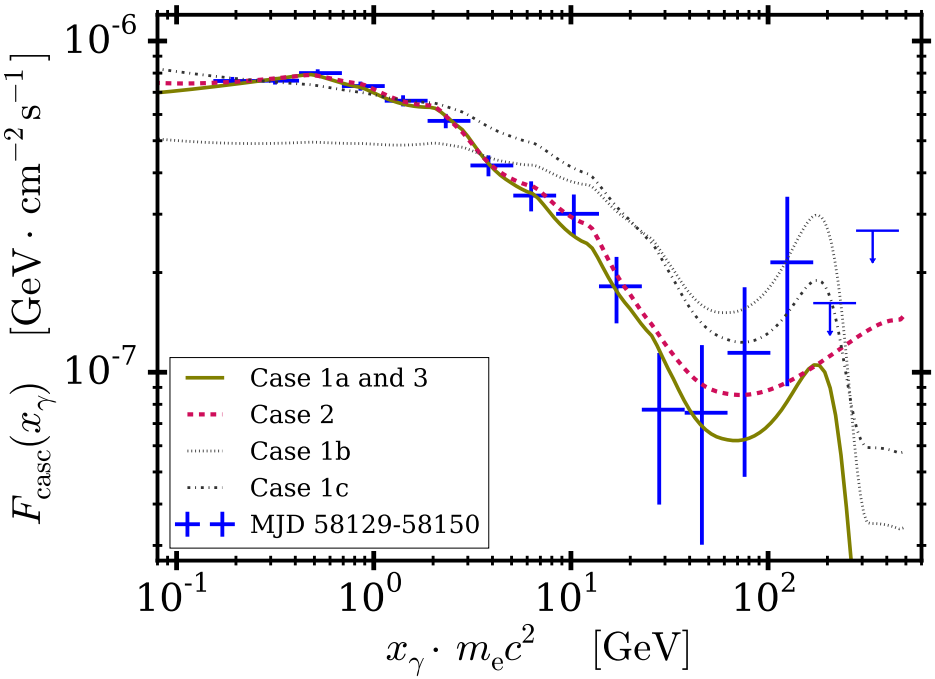
$n_0(x)$: Sum of emission lines

Most prominent lines: O VII, C V, Fe XVIII, Fe XXIII, He II Lyman-α, He I, H I Lyman-α

$$T_{\mathrm{esc}} := \frac{R}{c}$$



Gamma-ray emission from 3C 279



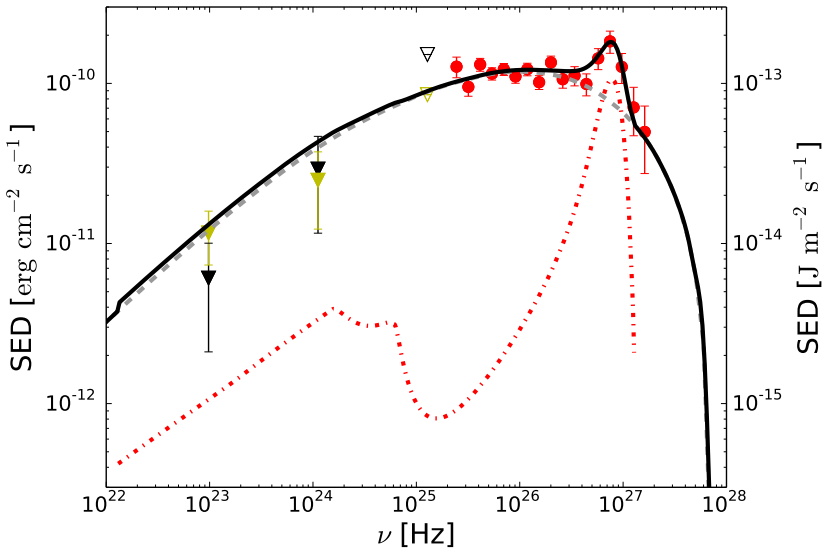
Fermi SED (MJD 58129 - 58150, blue markers) with cascade modeling fits.
Brown and red lines: Cascade in BLR photon field
Grey lines: Cascade outside of BLR
Wendel, Shukla and Mannheim, submitted to ApJ

Fail to meet points for same R, diluted n_0 and non-extreme injection

$\Rightarrow$ Emission not from outside of BLR

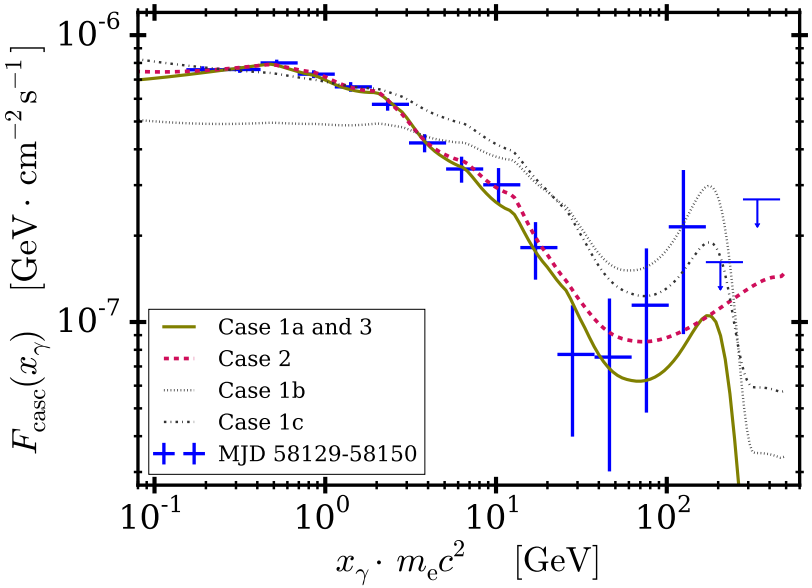
Summary

Mrk 501



Wendel, et al., 2021, A&A

3C 279



Wendel, Shukla and Mannheim, submitted to ApJ

Precision gamma-ray observations reveal complexity beyond the predictions of spherical blob models but in line with the predictions of pair cascade models in external radiation fields.