On the Origin of Very Hard Energy Spectra of Blazars

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Blazars and EBL

over the last years many papers have been published with an unusual combination of two key words: Blazars and EBL

- ☑ Blazars: higly variably/compact objects of nonthermal emission produced in relativistic jets with $\delta_j \gg 1$
- ☑ EBL: thermal emission produced by stars and dust and accumulated over the entire history of Universe

<u>no apparent links?</u>

yet, they are tightly coupled through effective absorption of GeV/TeV gamma-rays of blazars interacting with EBL

probing EBL with gamma-rays?

- idea - simple: energy-dependent optical depth $\tau(E)$ * and almost one-to-one relation between energies E and ω: maximum of cross-section at $E=4m_ec^2/\omega\approx1(\lambda/1\mu m)$ =>

  deformation of the spectrum $J(E)=Jo(E)\ \exp[-\tau(E)]$

- realization- very difficult: $\tau=\log[J(E)/Jo(E)]$ - we don't know Jo(E). A single-zone, homogeneous SSC allows, derivation of Jo(E) based on multiwavelength studies (Coppi&FA 1999), but in practice it is a reall challenge

- why should one-zone models work in complex systems?

- internal absorption?

* no absorption for $\nu F\nu \propto \nu\ (1/\lambda)$ type spectra:

simplest cases in simple SNRs are more complex than one-zone models of most complex blazars

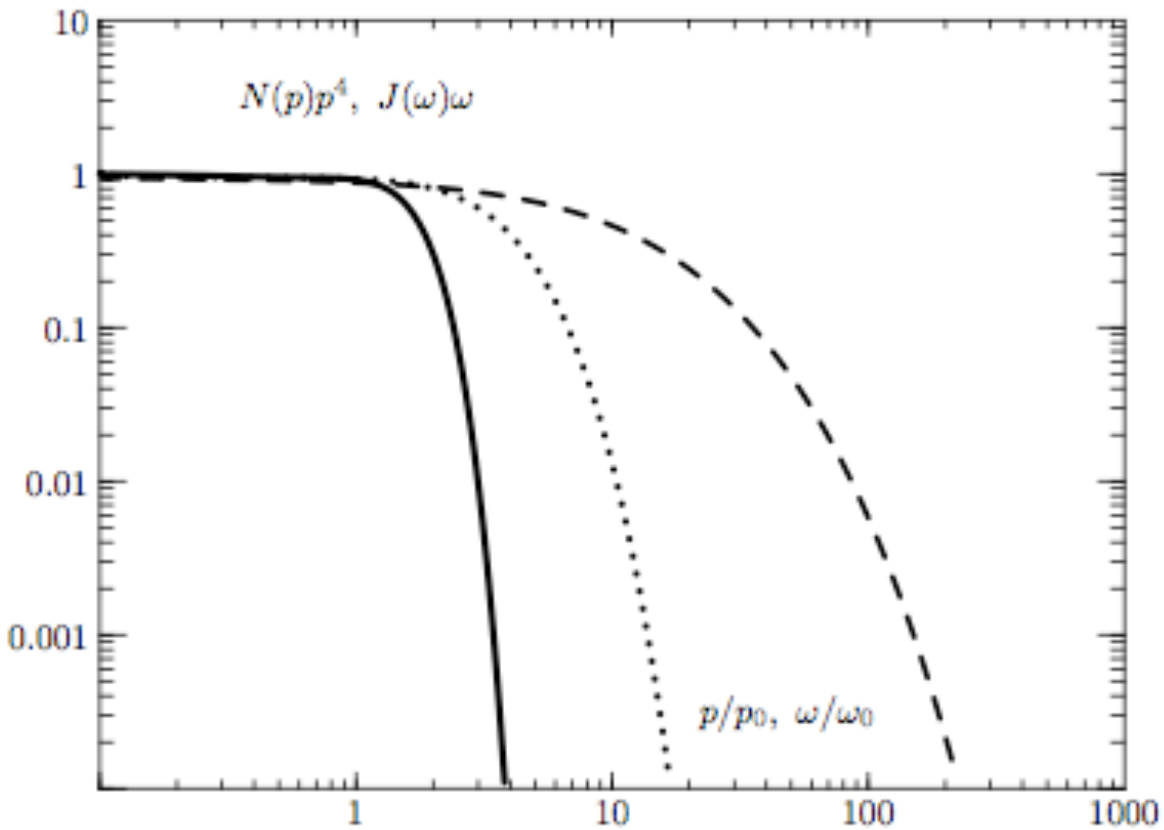


Fig. 2. The electron distribution at the shock front (solid line) and the spatially integrated spectrum of synchrotron radiation (dashed line) produced by electrons accelerated at the shock with compression ratio $\sigma = 4$ and equal upstream and downstream magnetic fields ($\kappa = 1$). The spectrum of synchrotron radiation obtained using the δ-function approximation is also shown (dotted line).

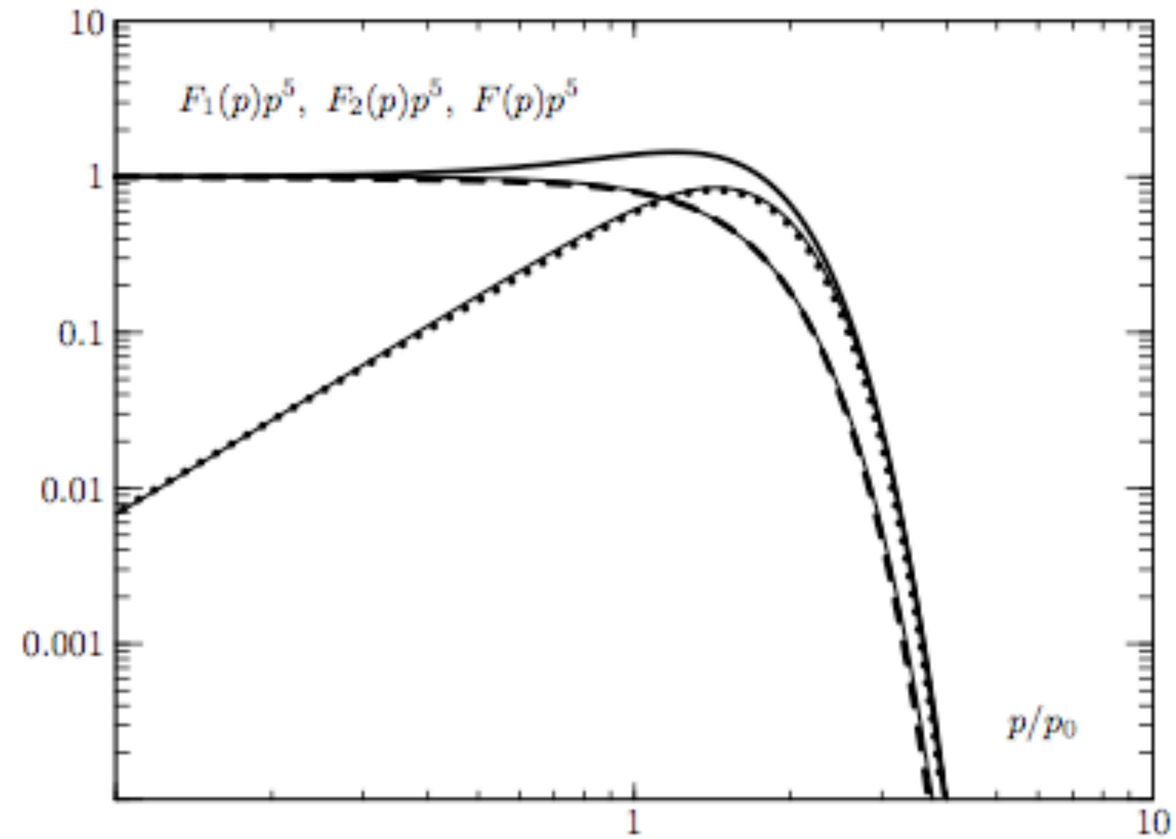
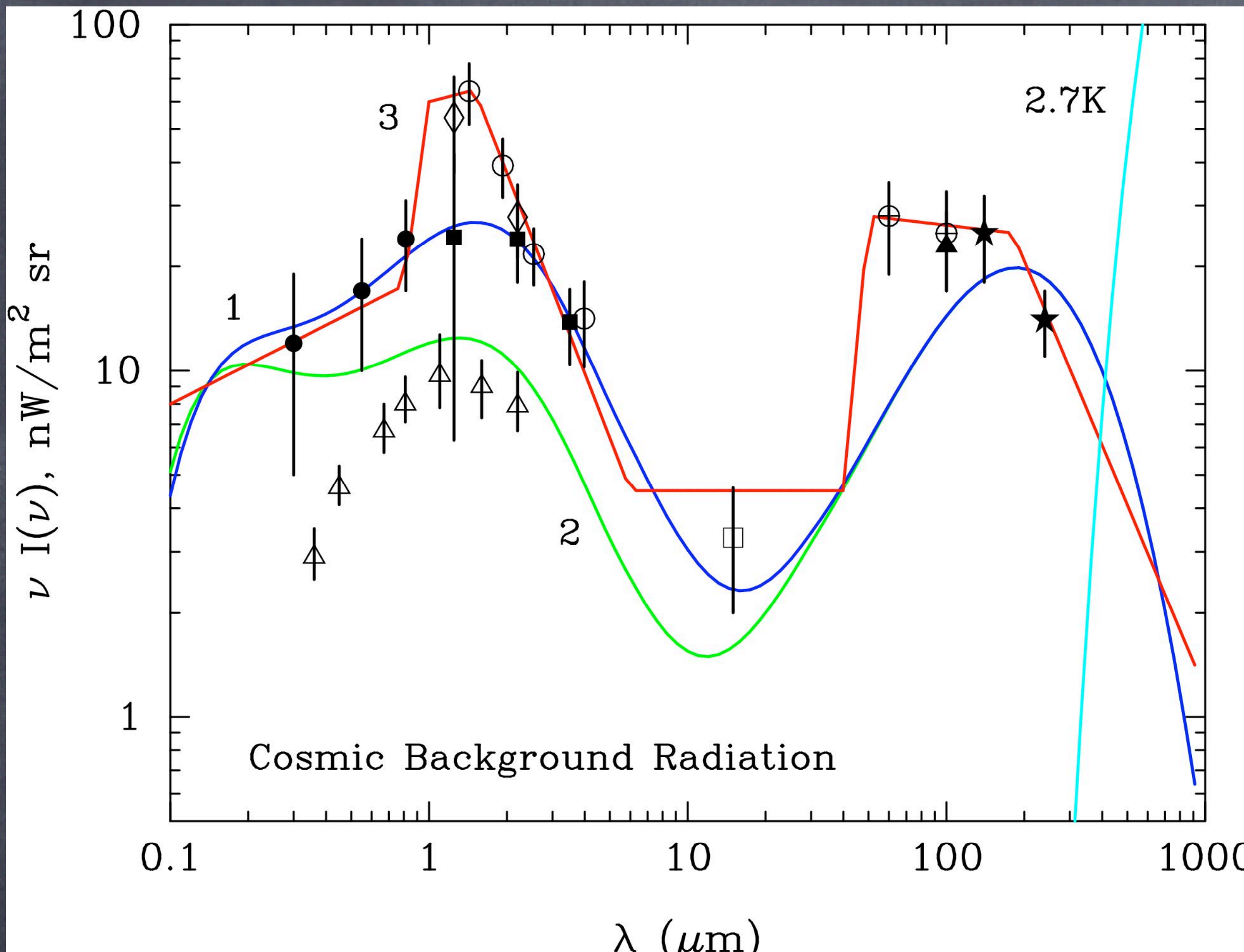
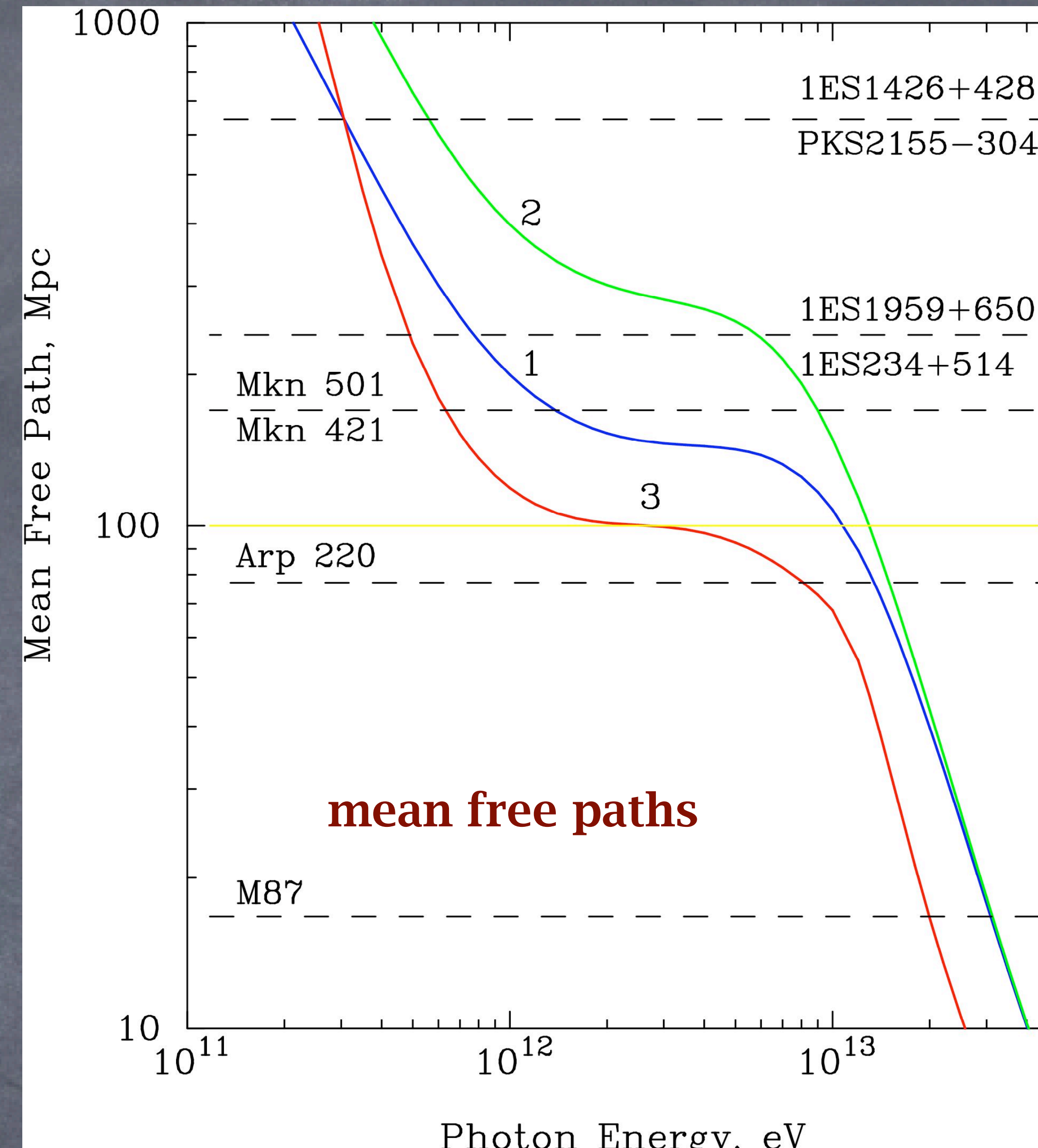


Fig. 3. The integrated upstream (F_1; dotted line) and downstream (F_2; dashed line) electron spectra given by Eqs. (27), (28), as well as the overall $F = F_1 + F_2$ spectrum (solid line) for the shock with compression ratio $\sigma = 4$ and the ratio of the magnetic fields downstream and upstream $k^{-1} = \sqrt{11}$. The spectra F_1 and F_2 obtained numerically are also shown (thin solid lines).

FA 2001

3 EBL "models"

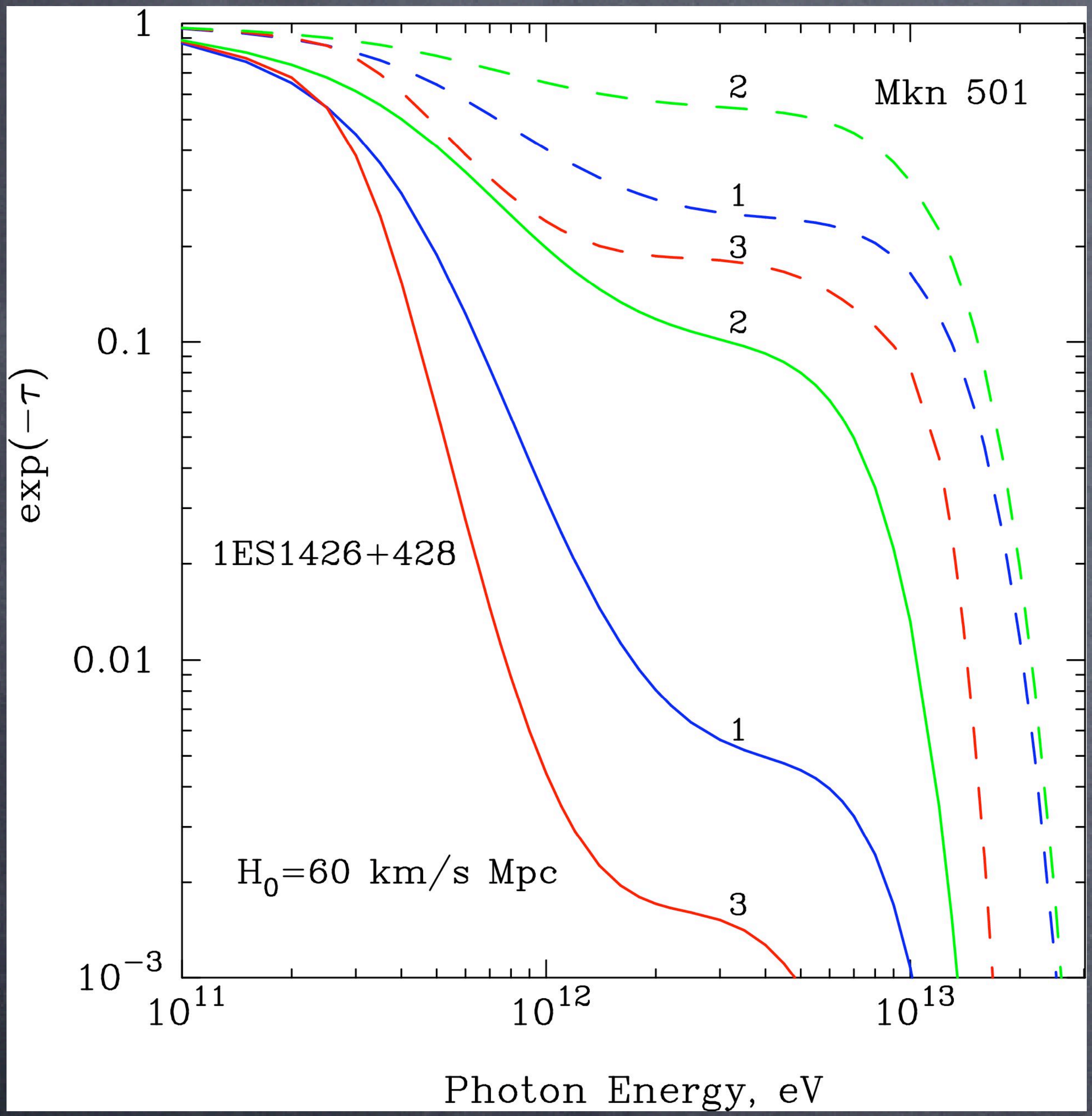


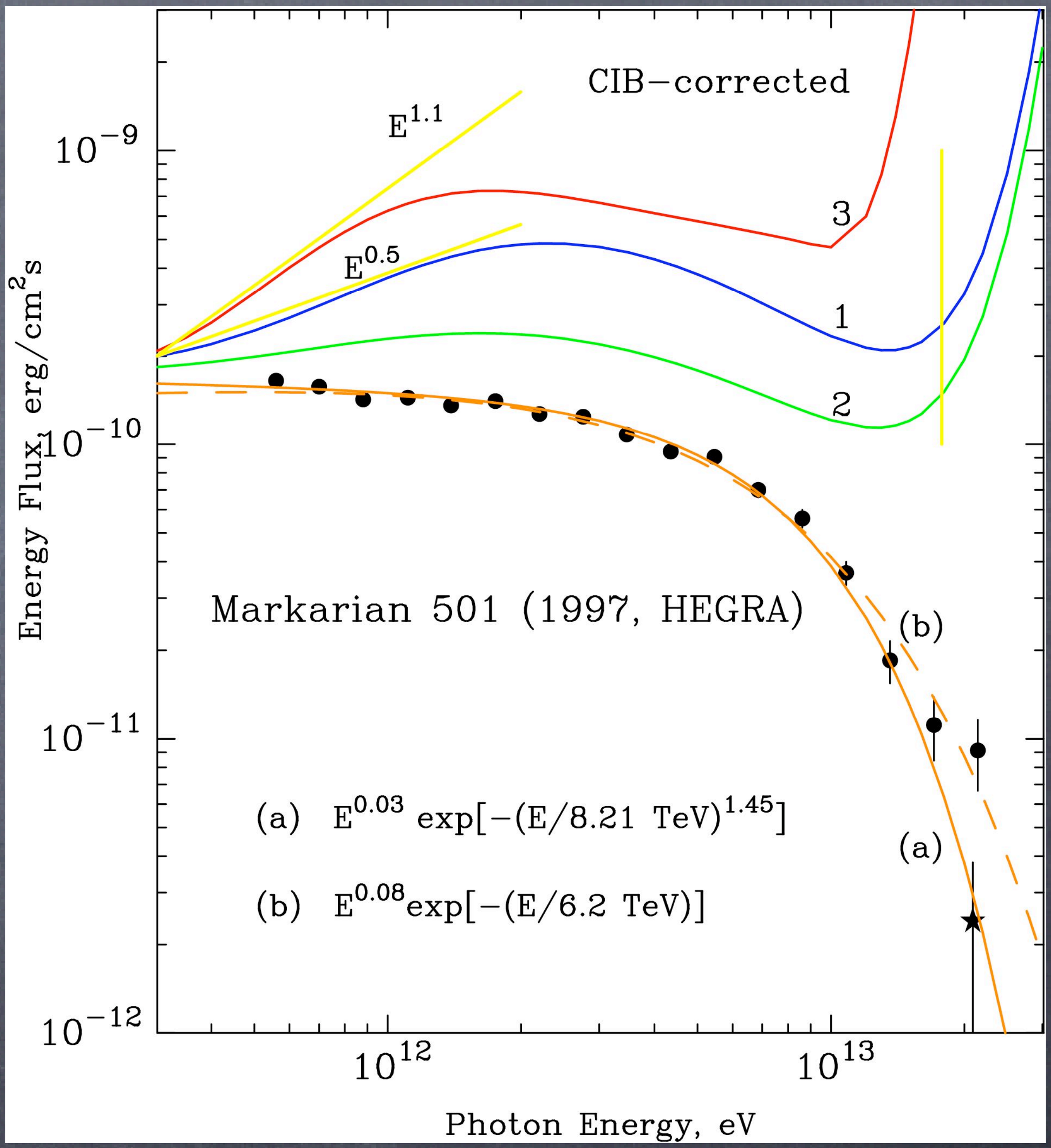


gamma-ray horizon:

10TeV: tens of Mpc; 1TeV: hundreds of Mpc; 100GeV: >1Gpc

“TeV-IR” crisis... with a happy end

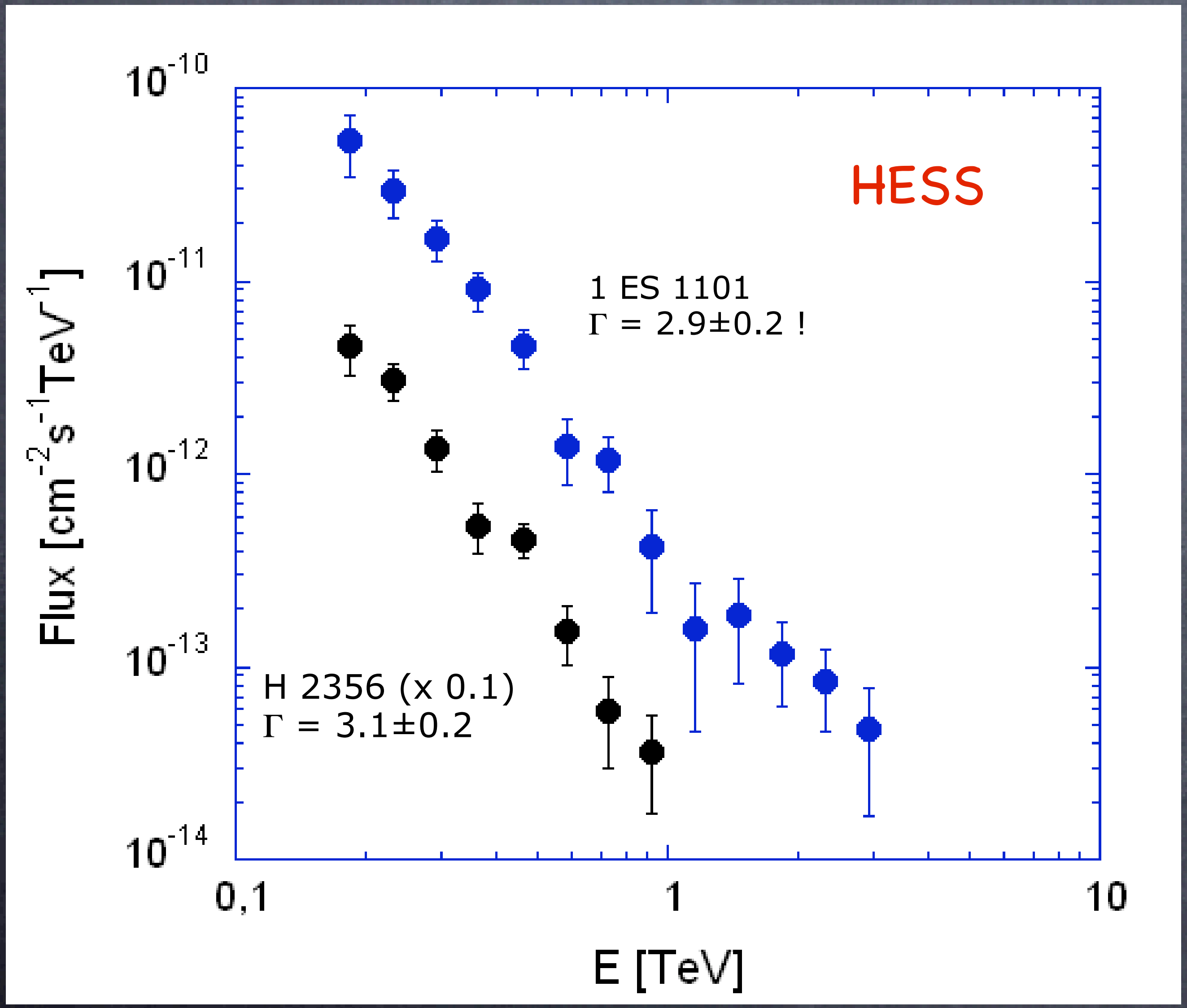




FA 2001

HESS, MAGIC, VERITAS - detection of tens of TeV blazars, with large redshifts, z up to 0.5 !

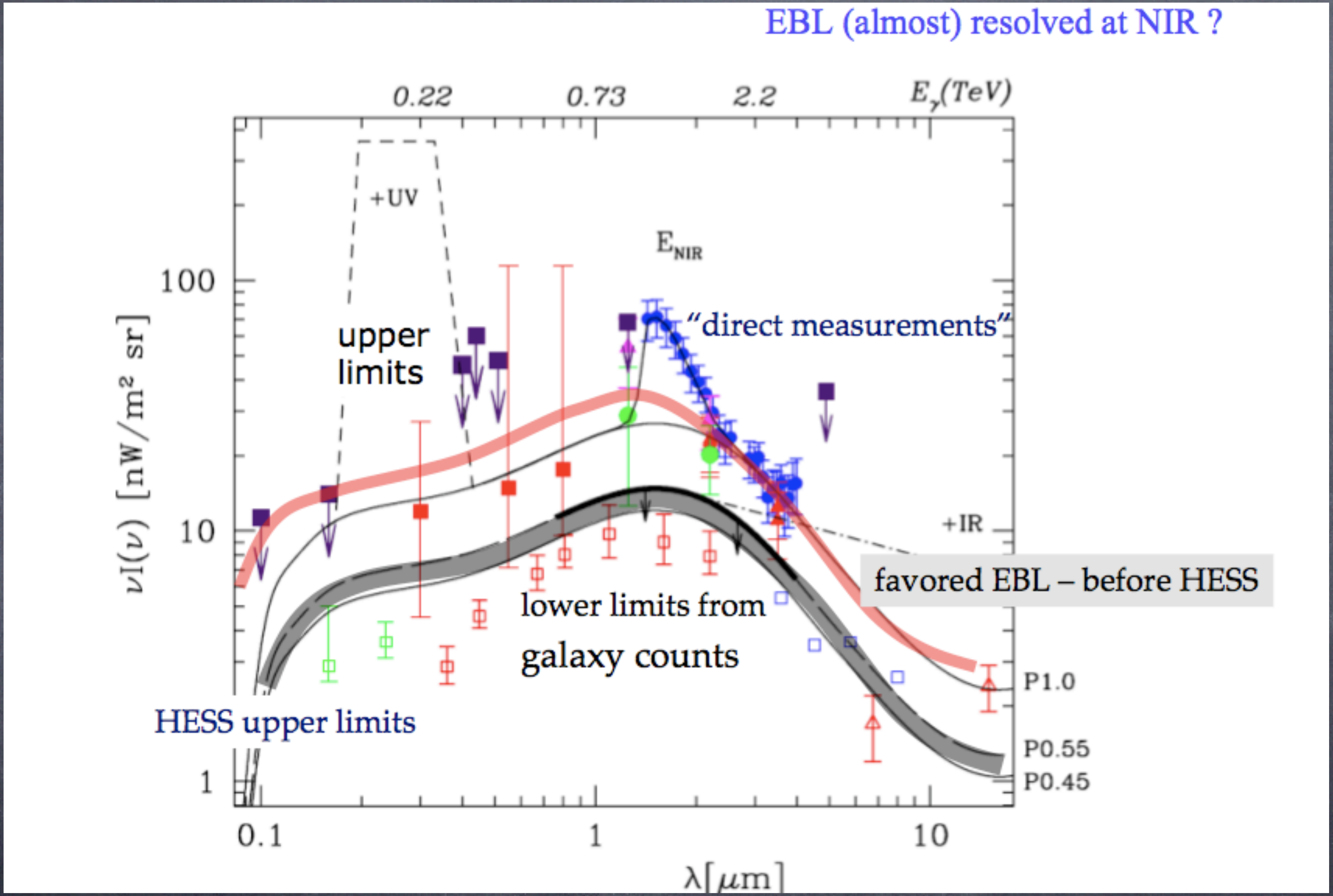
strong impact both on Blazar Physics and EBL models



condition: corrected for IG absorption spectrum should be reasonable/"decent" e.g. not harder than $E^{-\Gamma}$ with Γ=1.5

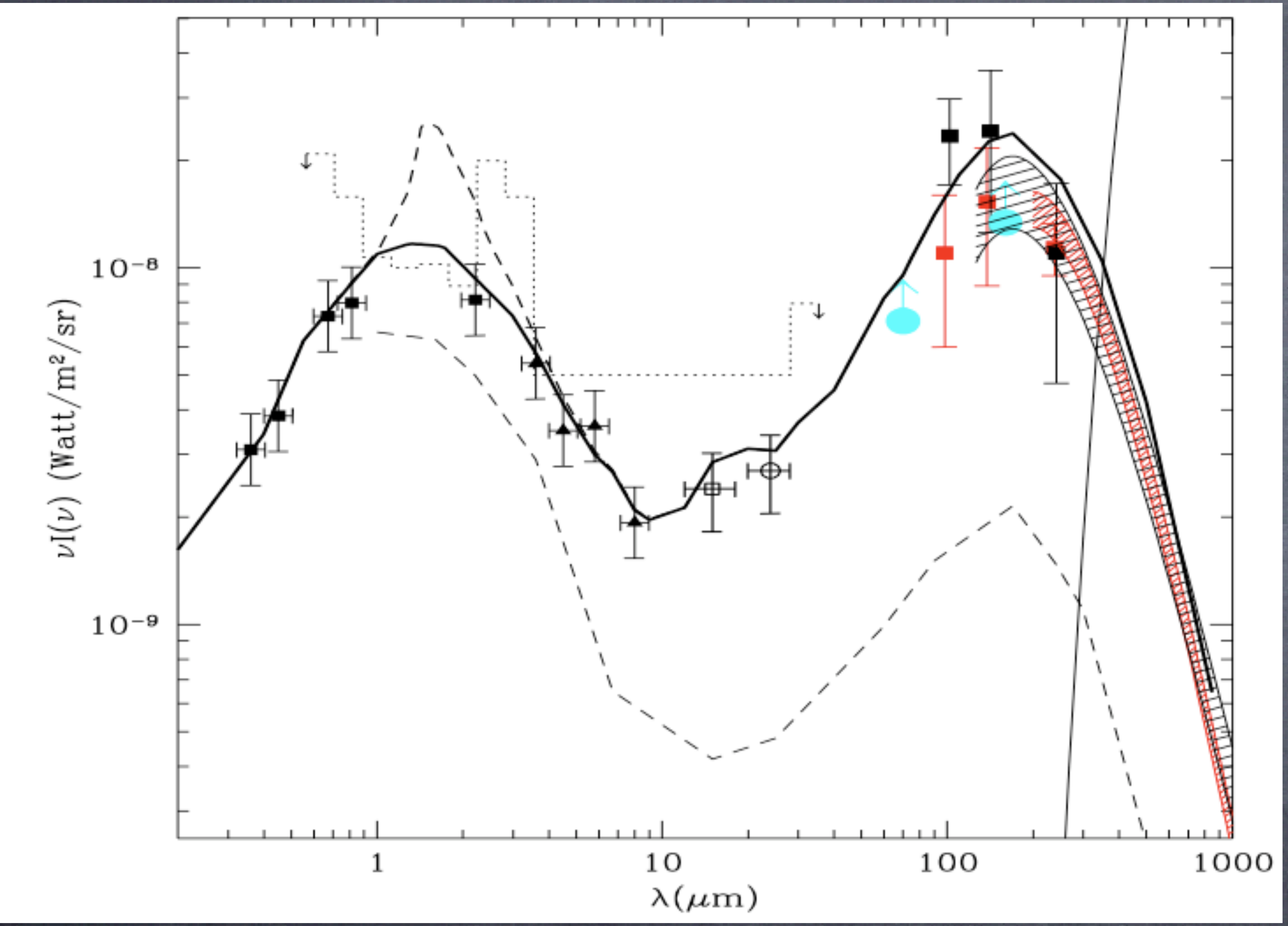
why Γ=1.5 ?
any hard injection spectrum of electrons, even the monochromatic one after strong radiative (synchrotron or Thompson) losses, gets a standard form "E_e^{-2}" with corres-ponding IC gamma-ray spectrum $E^{-1.5}$

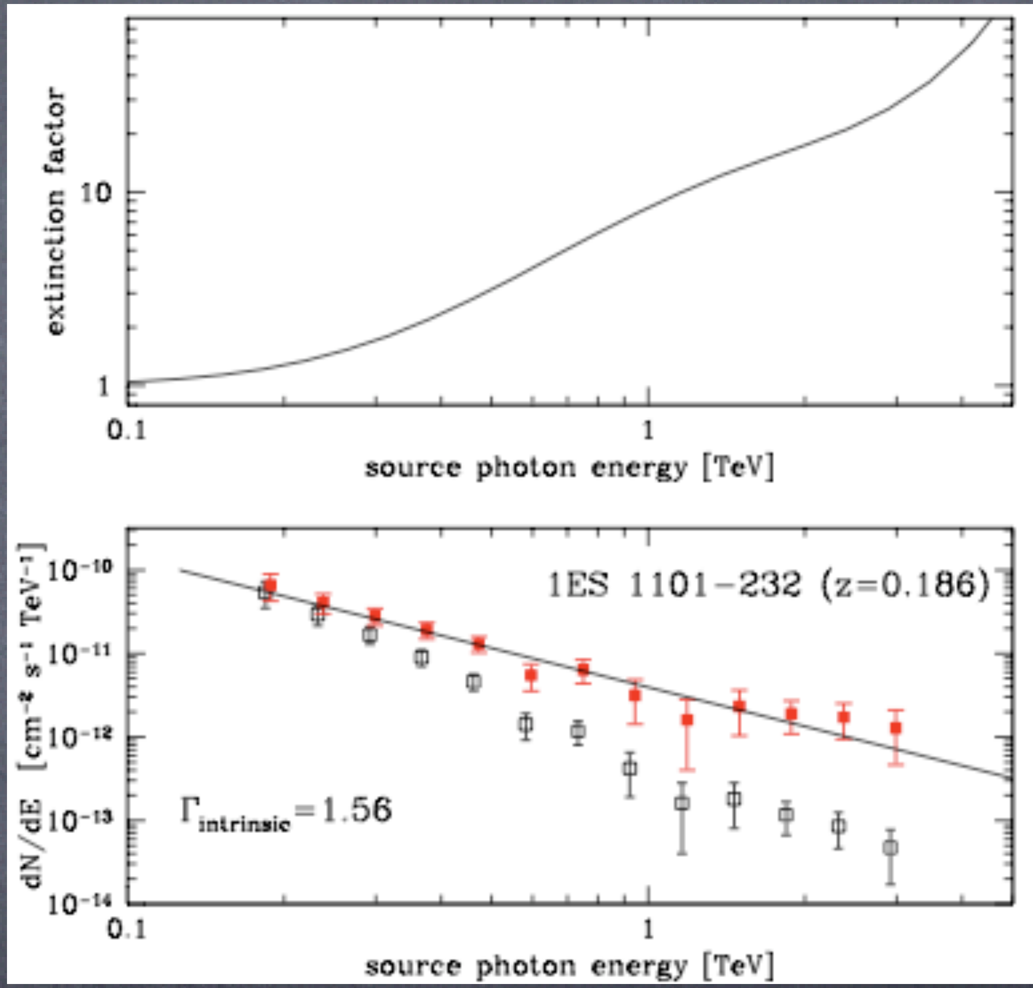
HESS - upper limit on EBL at O/NIR to MIR



very close to the limits from the galaxy counts!

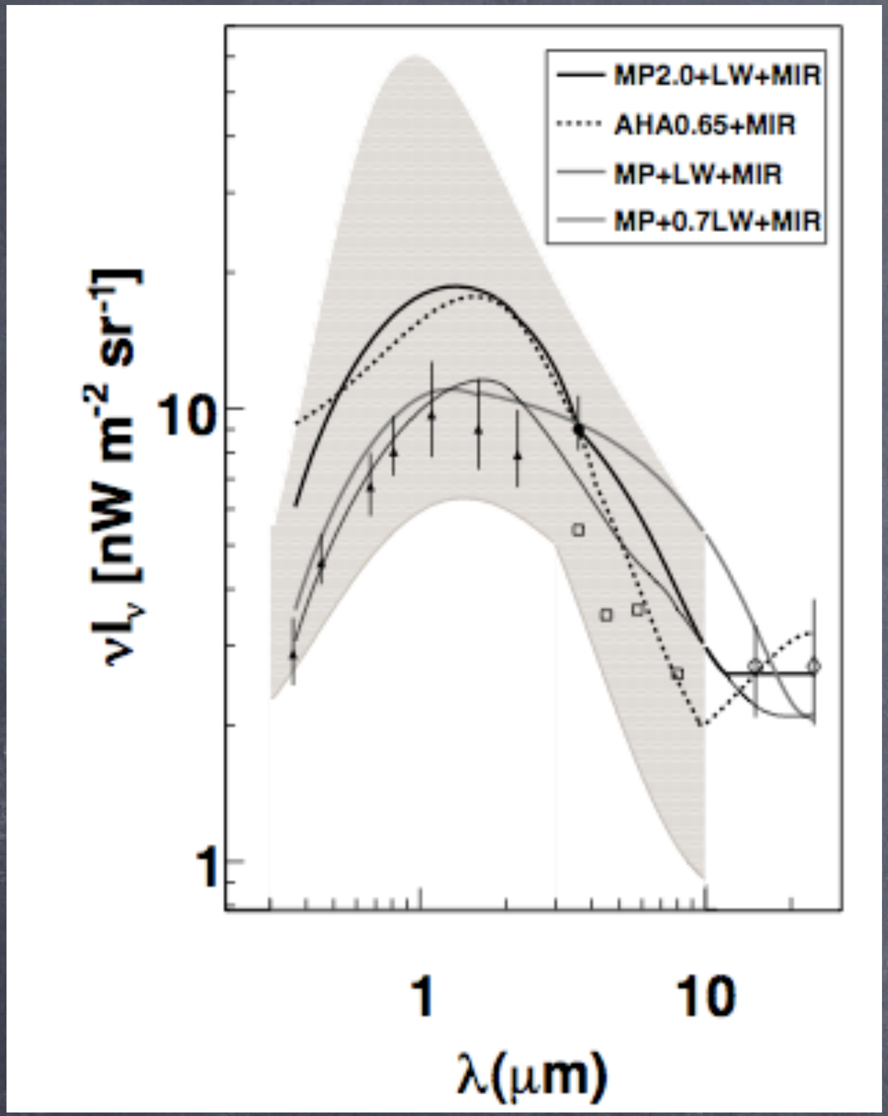
Franceschini et al. 2008: “The extragalactic optical-infrared background radiation, its time evolution and the cosmic photon-photon opacity”

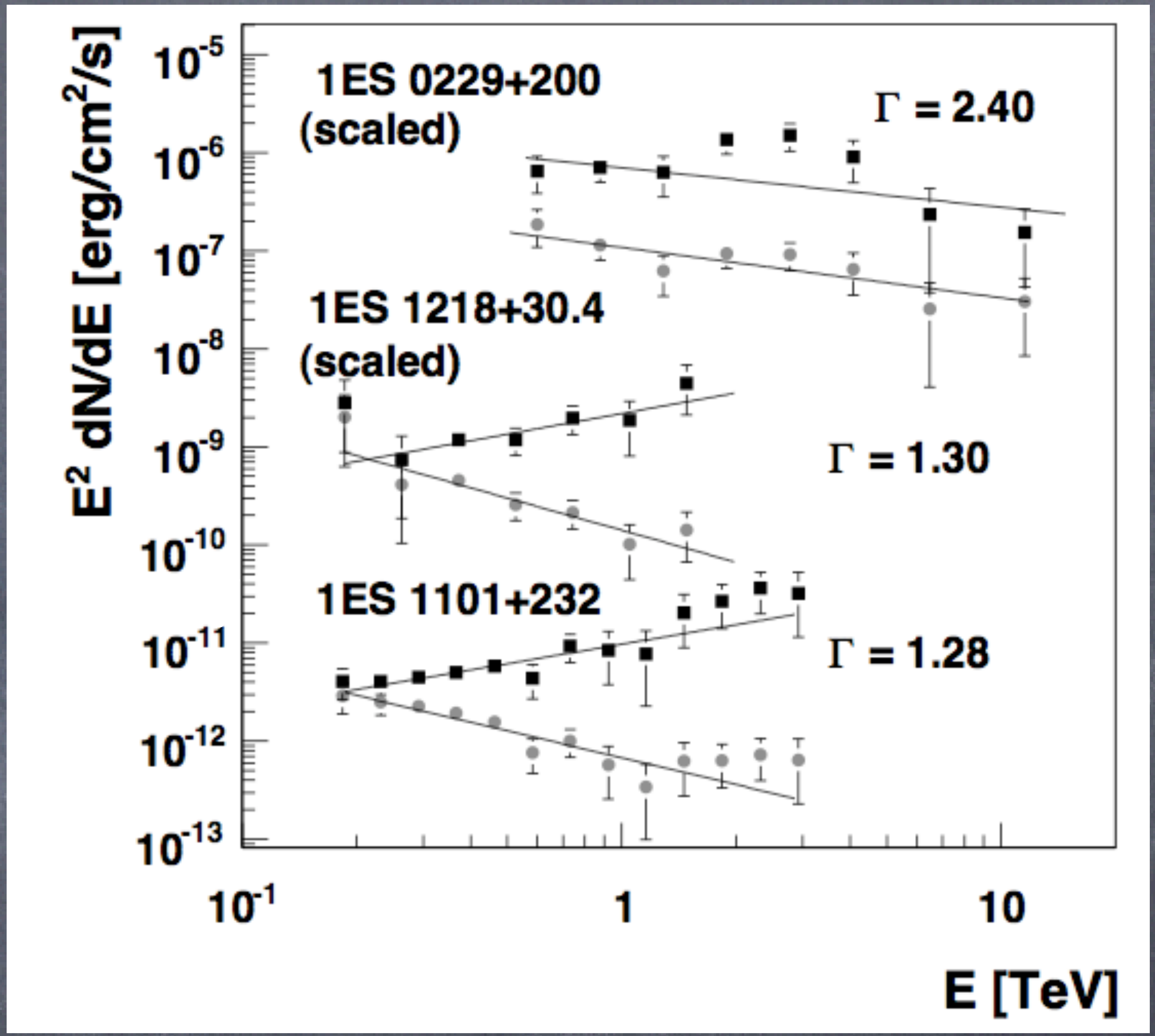




nice/low EBL - relax and enjoy decent blazar TeV spectra?

but what if the EBL is slightly higher than the generally accepted level (Franceschini et al. 2008, and some others)?





Krennrich, E. Dwek & Imran 2008 referring to Levenson & Wright (2008)

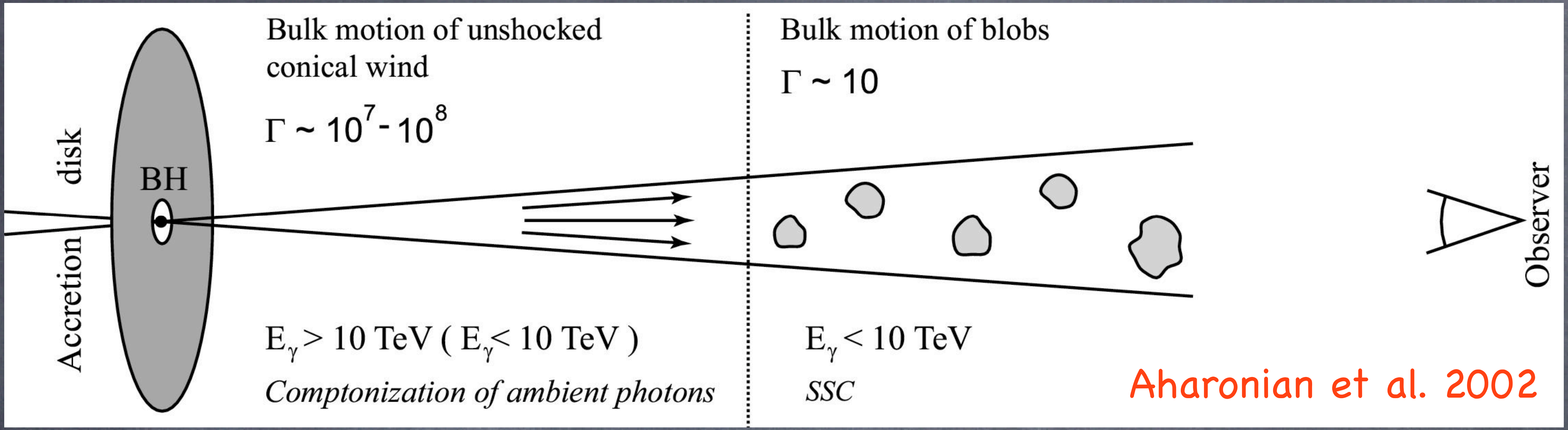
the model of Franceschini does not allow flexibility for (1) extension of the energy spectra of some of the reported blazars with energy spectra beyond 1 TeV and (2) detection of VHE gamma-rays from objects with redshifts beyond z=1 are “harder-than-$E^{-1.5}$” spectra trouble makers ?

of course they are not comfortable, nevertheless can be explained within conventional scenarios although with somewhat non-standard assumptions

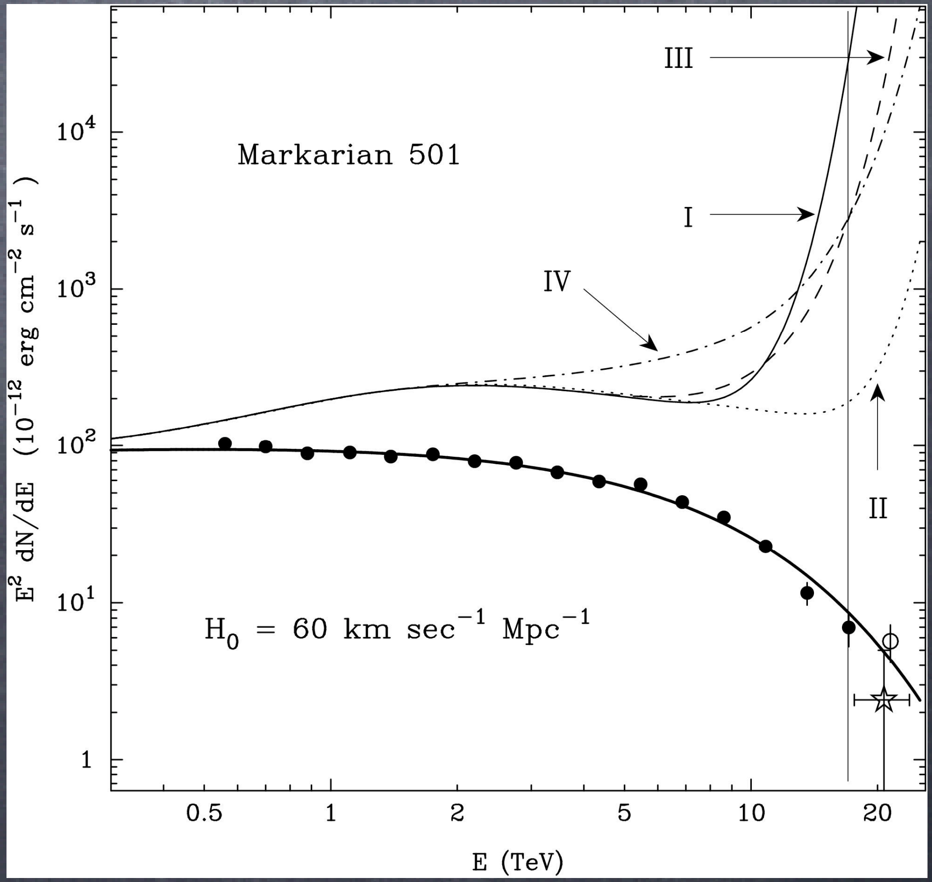
e.g. due to

(1) very hard (narrow) electron spectra
(2) internal absorption of gamma-rays

Gamma Rays from a cold ultrarelativistic wind ?



in fact, not very exotic scenario,
an analog of "cold" pulsar winds



probing the "birth place" and Lorentz factor of the Pulsar Wind

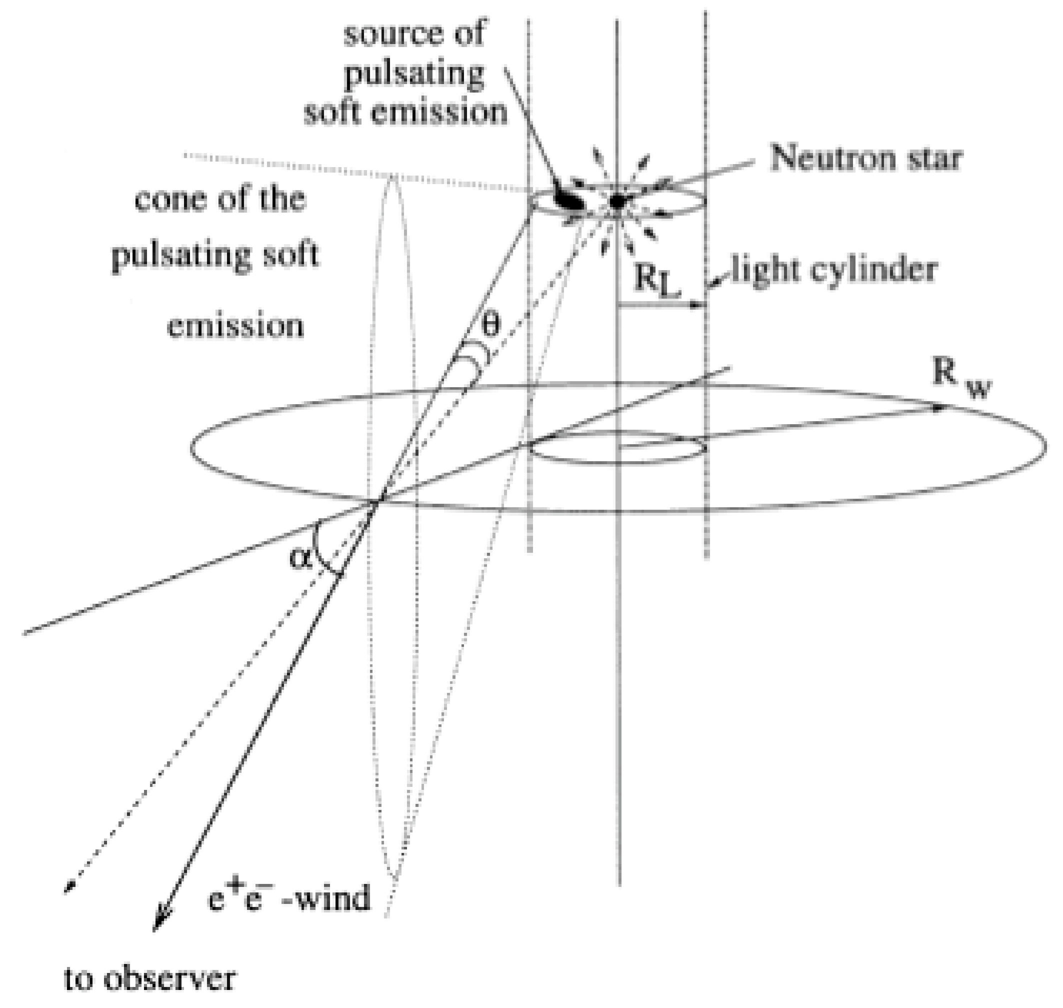


Figure 1. A sketch of the trajectories of plasma after acceleration, and the assumed position of sources of soft photons.

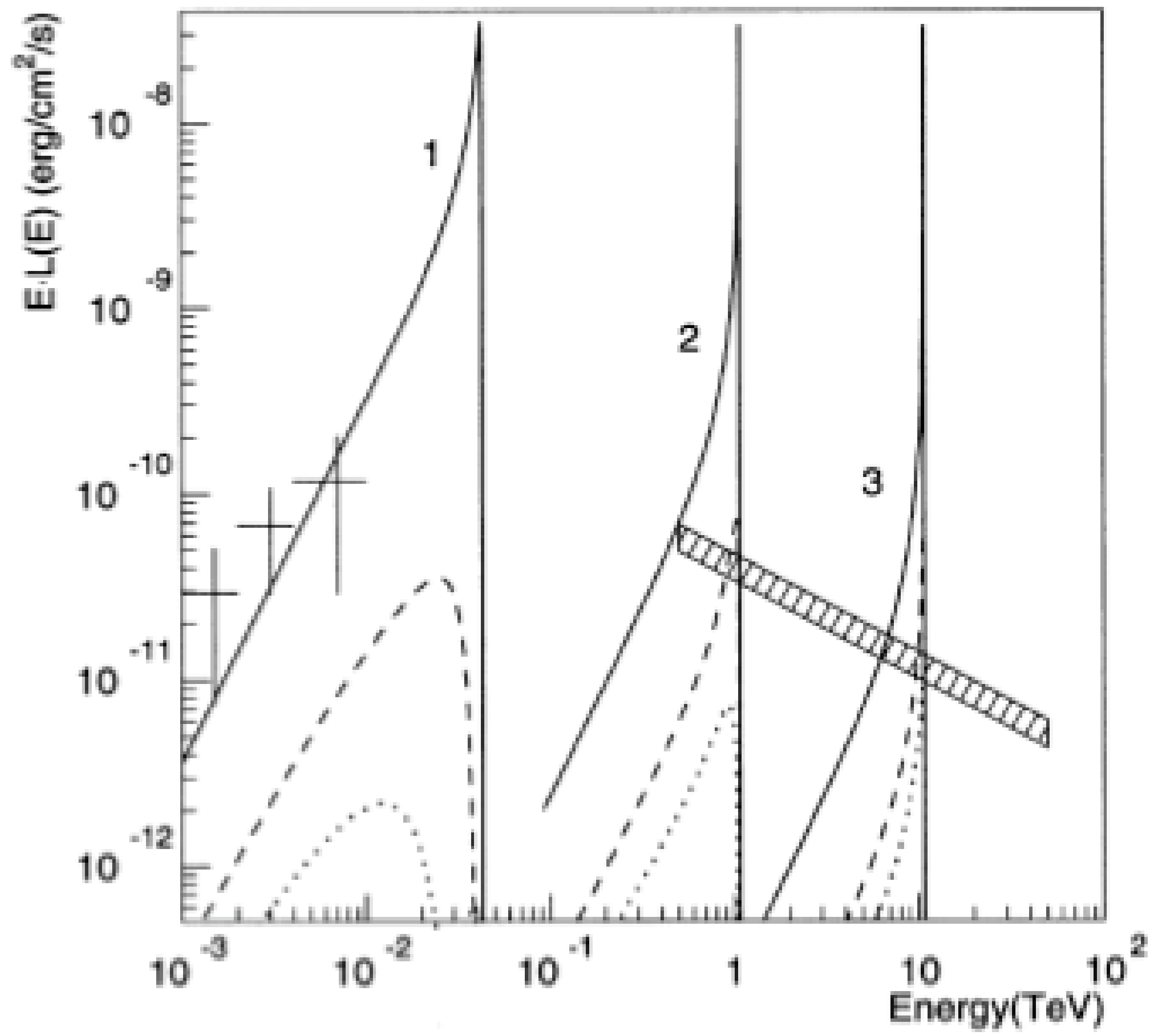


Figure 4. The spectra of IC radiation of the wind illuminated by the thermal emission of the pulsar. It is assumed that the kinetic-energy dominated wind is formed at distances of 1 (solid), 5 (dashed) and 10 (dotted) light cylinders from the pulsar. The curves 1, 2 and 3 correspond to $\gamma_{max} = 1.2 \times 10^5$, 3×10^6 and 3×10^7. The range of observed fluxes of γ-rays in the region above 500 GeV detected by the CAT, CANGAROO, HEGRA and Whipple telescopes is shown by a shadowed region. The points with error bars below 10 GeV correspond to the unpulsed fluxes measured by EGRET.

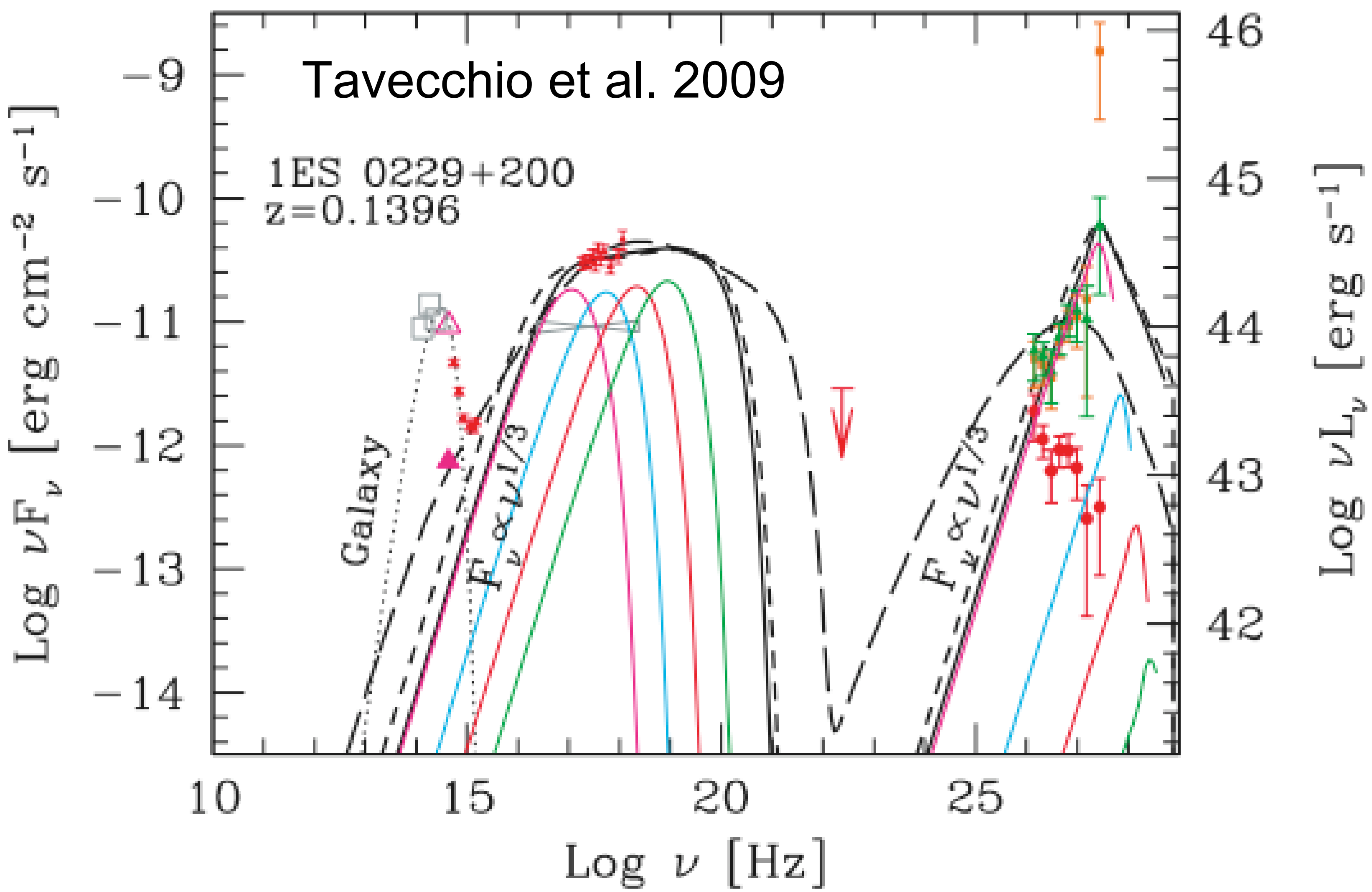
Bogovalov, Aharonian 2000

SSC model with a power-law electron spectrum with low-energy cutoff - no cooling!

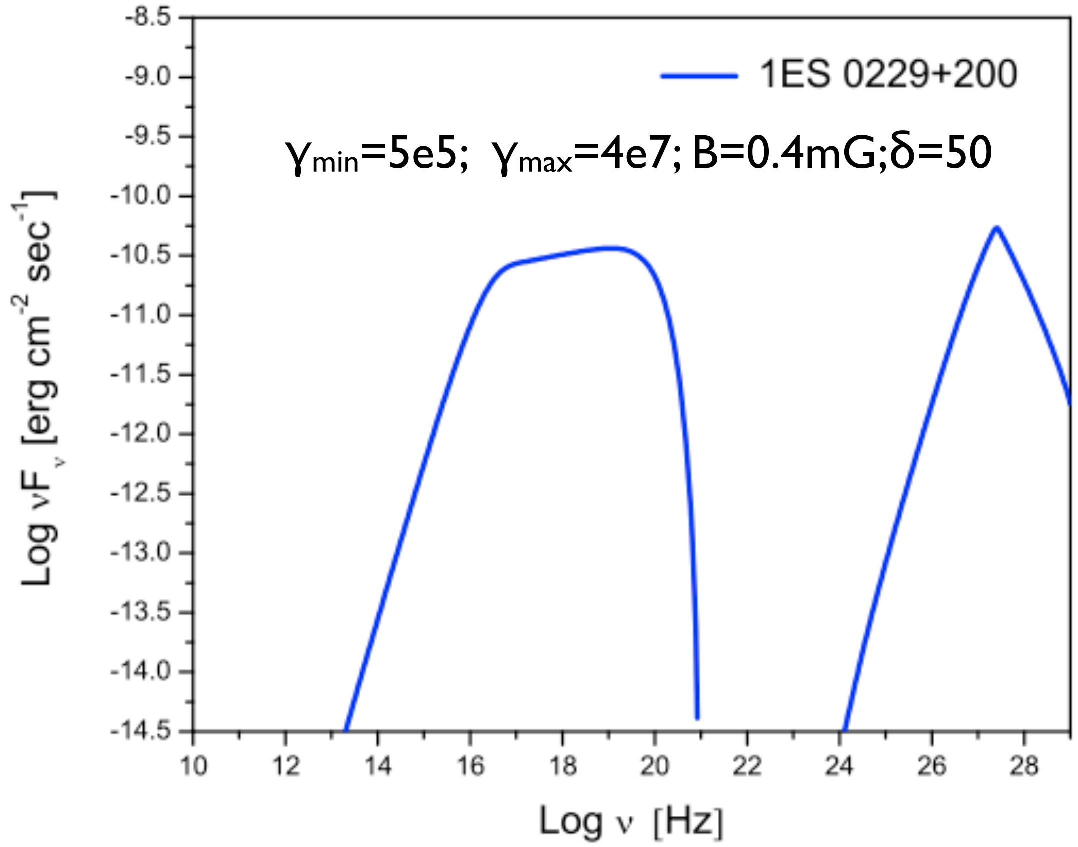
Table 2. Input parameters for the models shown in Fig.1 (Model 1: long dashed line; Model 2: solid line; Model 3: short dashed line). See text for definitions.

	$\gamma_{\rm min}$	$\gamma_{\rm b}$	$\gamma_{\rm max}$	n	n_2	B (G)	K (cm^{-3})	R (cm)	δ
1	10^4	6×10^5	3×10^7	1.5	3.4	8.5×10^{-3}	6	10^{16}	50
2	8.5×10^5	–	4×10^7	2.85	–	5×10^{-4}	3.5×10^9	5.4×10^{16}	30
3	5×10^5	–	4×10^7	2.85	–	4×10^{-4}	6.7×10^8	5.4×10^{16}	50

B~10^{-3} G: deviation from equipartition by many orders of magnitude!

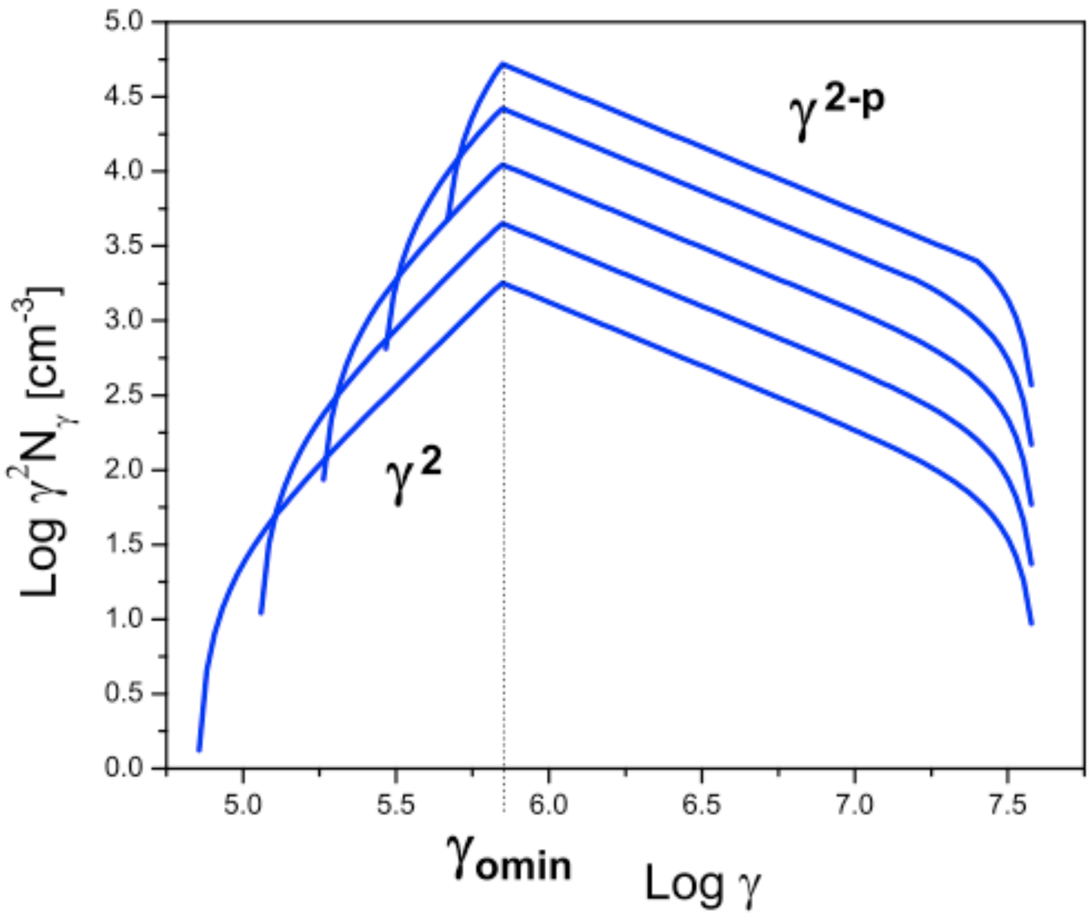


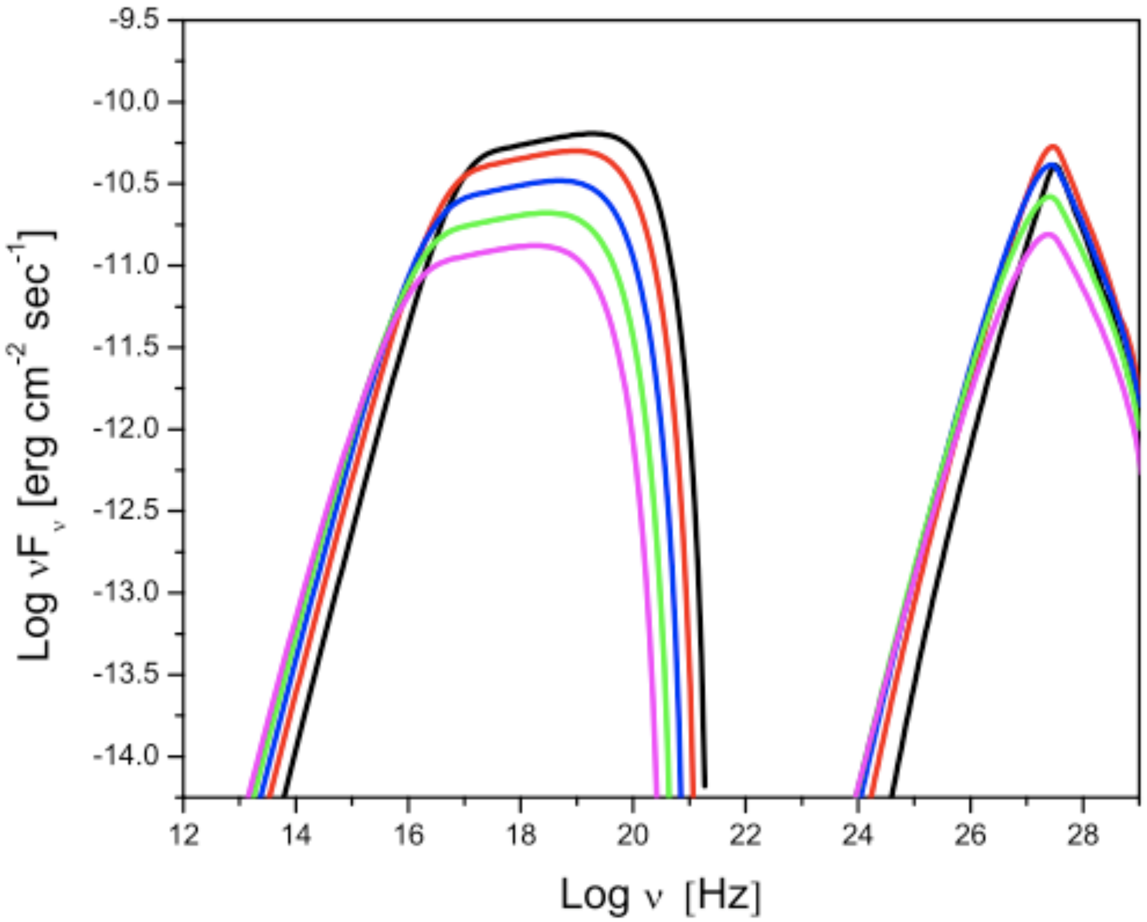
E.Lefa et al. (in preparation)

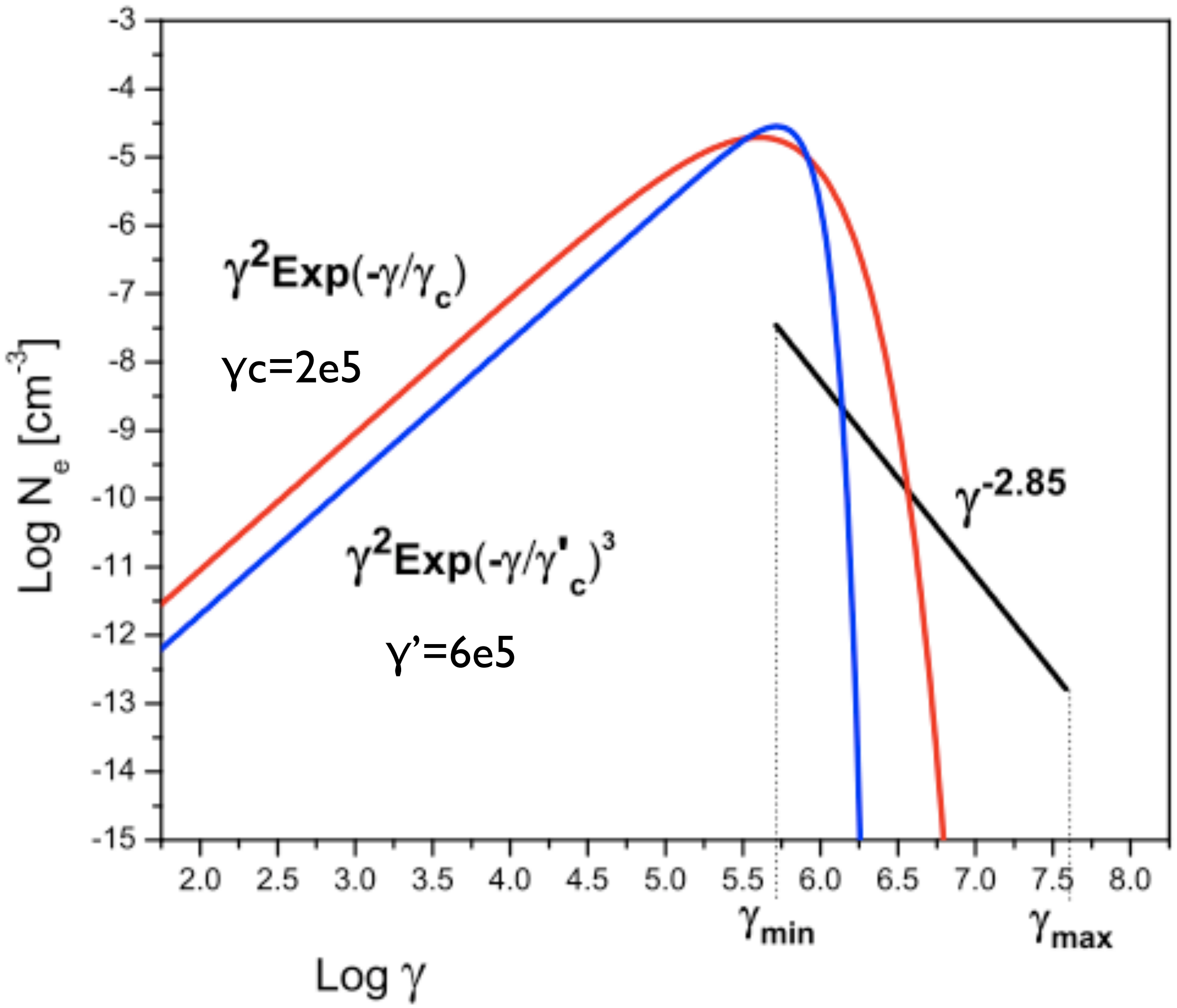


one can avoid formation of E^{-2} type electron spectra below γ_{min}, assuming that adiabatic losses dominate over synchrotron losses; in this case B-field can be increased up to B≈0.01G or so (depends on R)

time-evolution of the electron and radiation spectra







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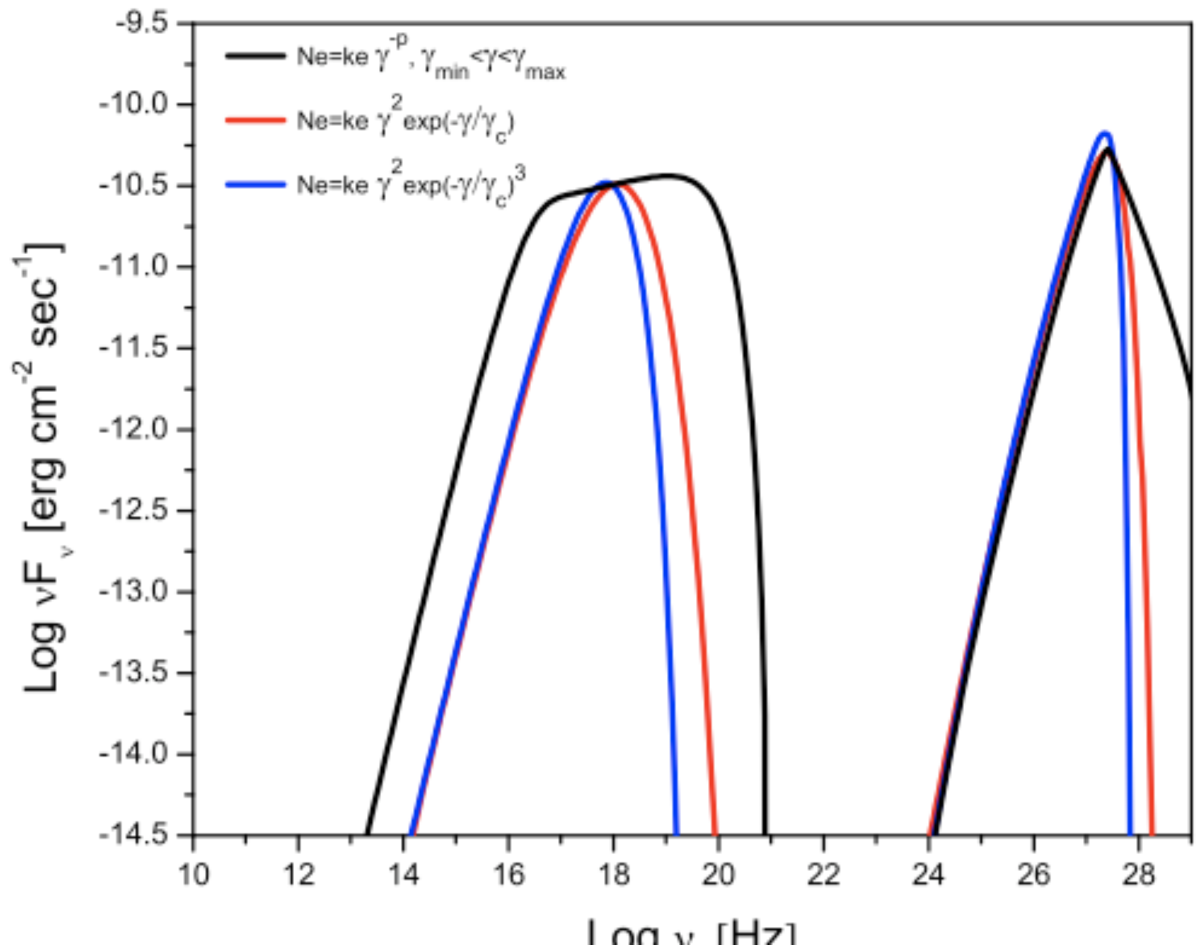
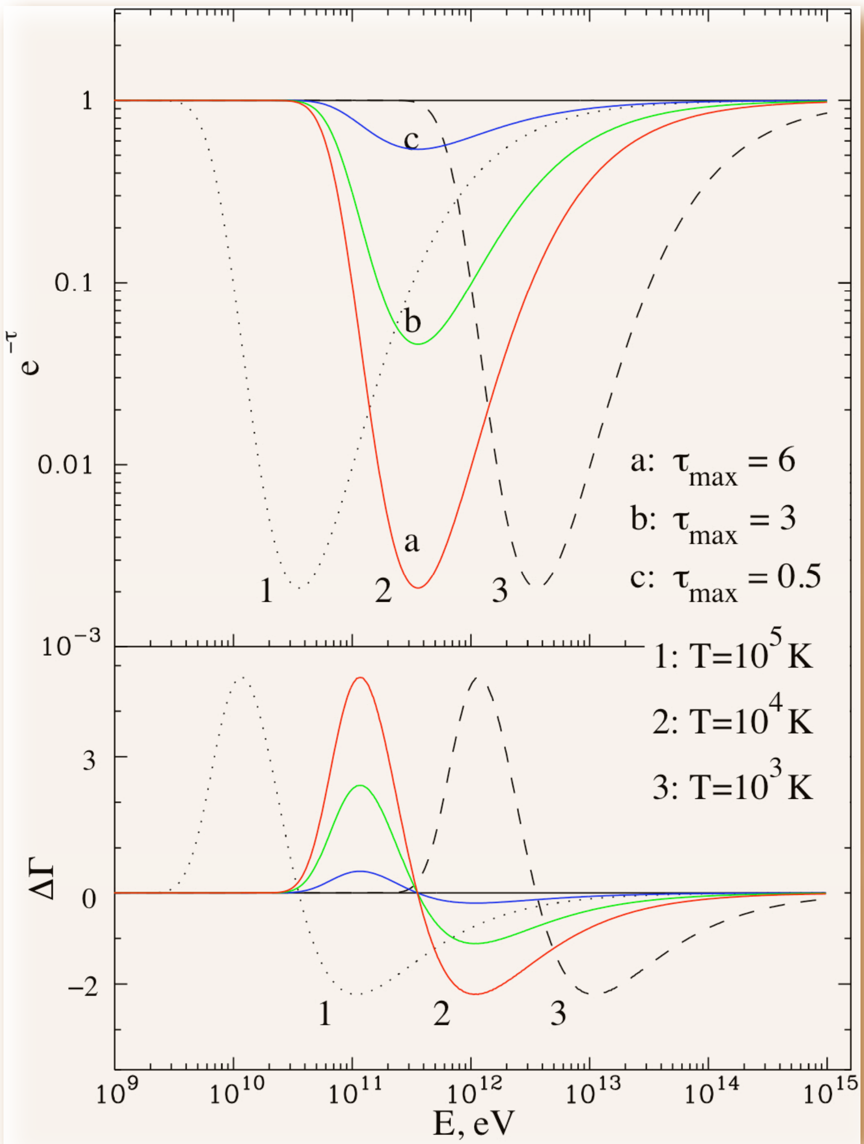


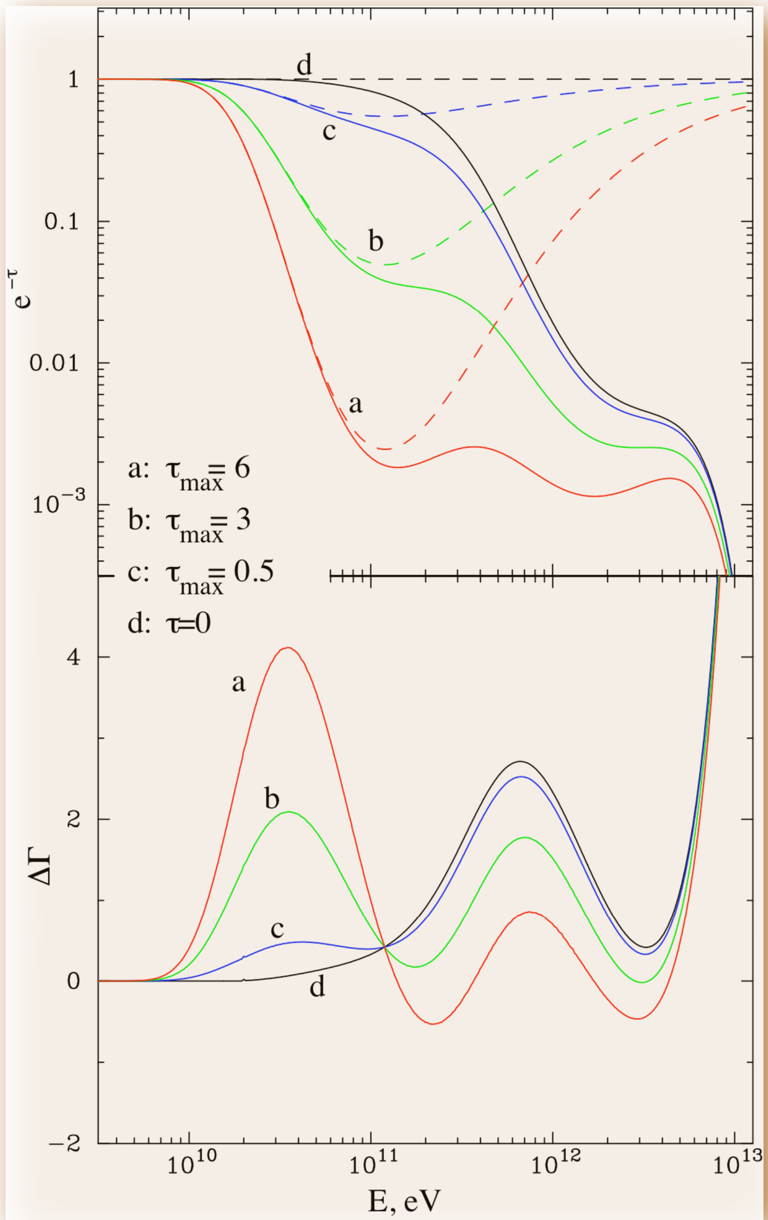
Maxwellian type distributions of electrons: not injection spectrum, but established ones
Schlikeiser 1985 (2nd order Fermi), Aharonian et al 1986 (resonant Lengmuir waves), Henri and Sauge 2006, ... has been argued by some authors to be (more) appropriate for modeling of gamma-rays from blazars (e.g. Katazynski et al 2003 Giebels et al. 2007)

internal absorption through photon-photon pair production

target?: e.g. local BB radiation with T~10^4 K

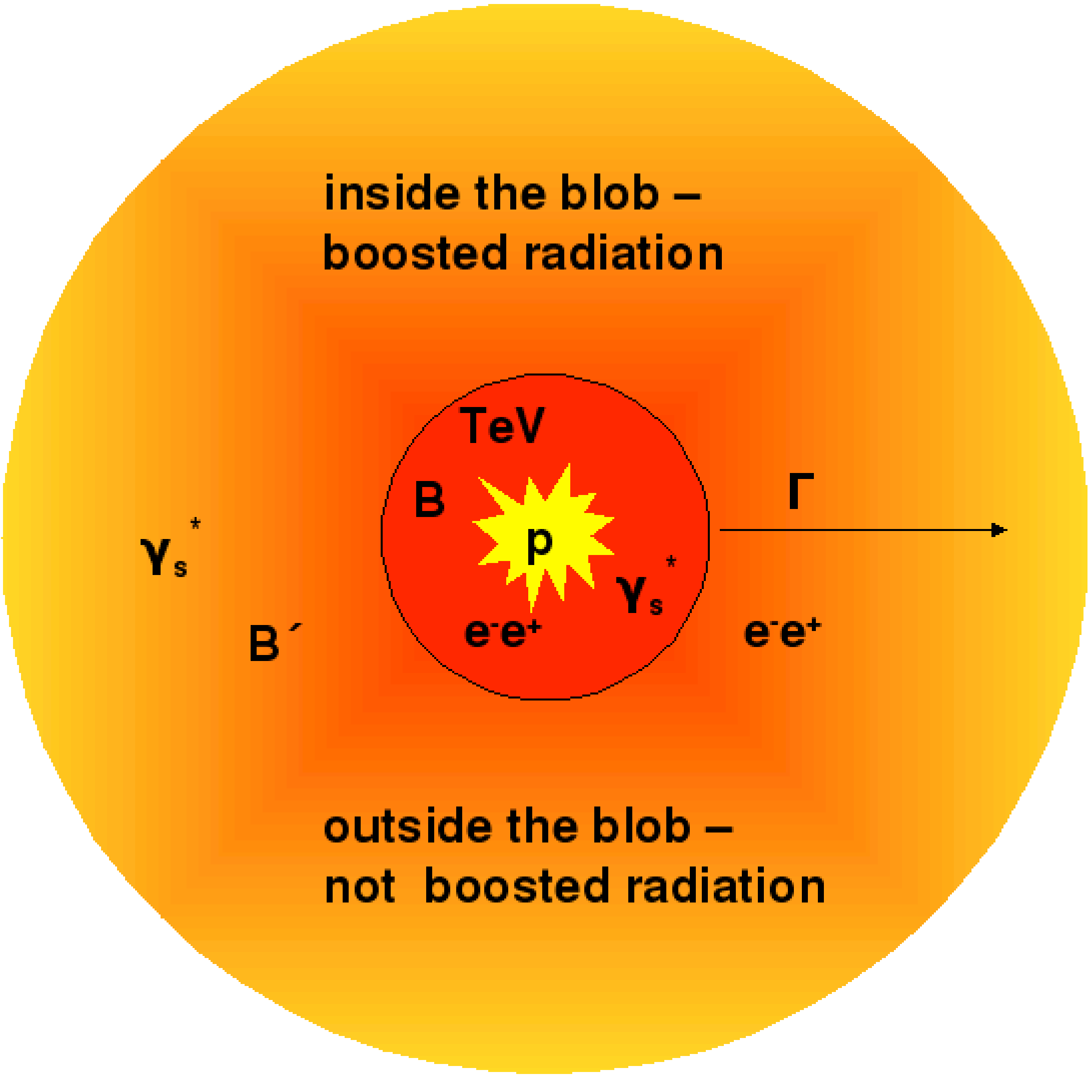


EBL+ local BB



Aharonian et al 2008

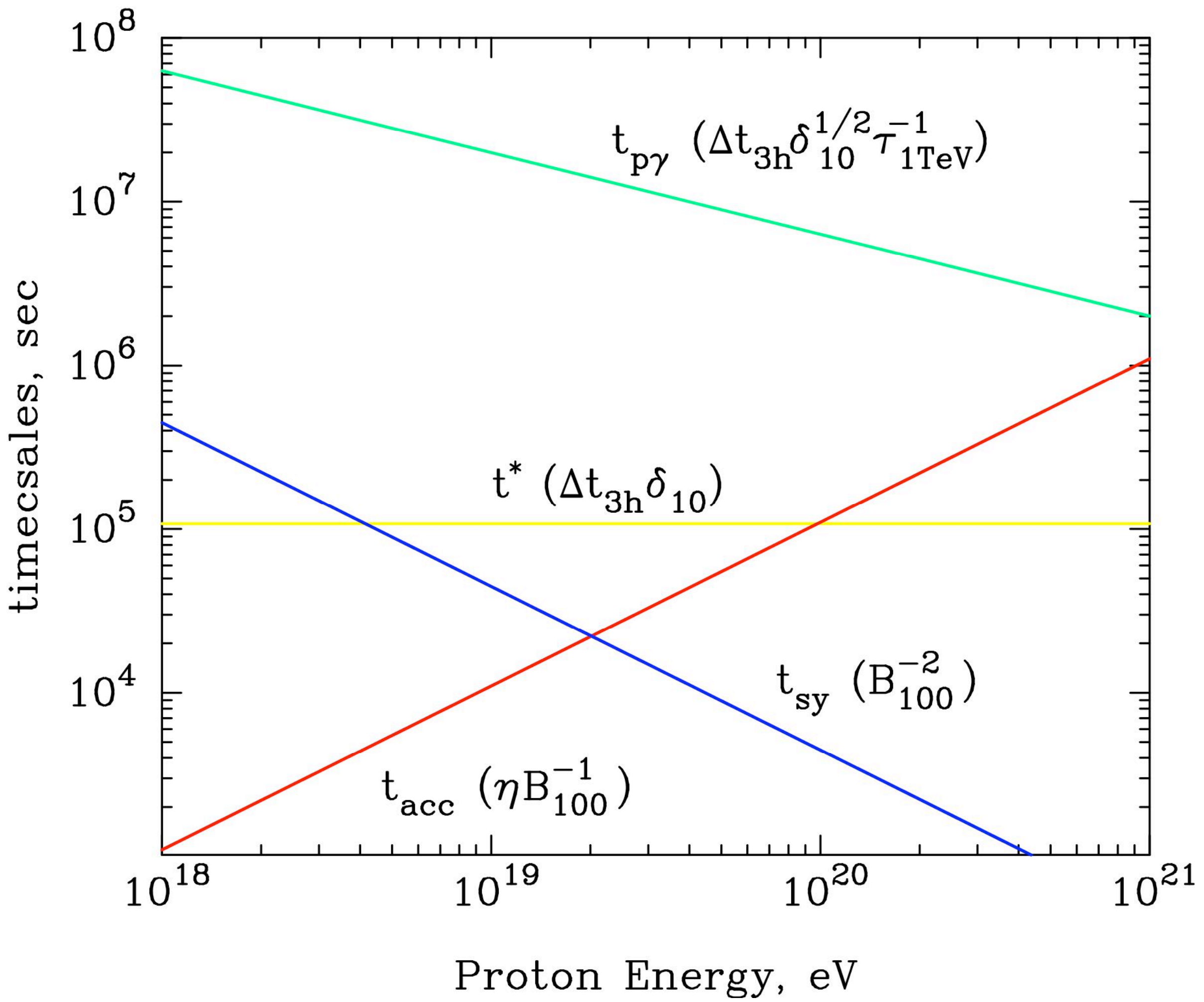
in the case of narrow target photon distribution (e.g. Planckian), internal absorption can make the spectrum arbitrary hard without a serious problem from the point of view of energetics, given that the losses can be compensated by a larger Doppler factor, δ >30



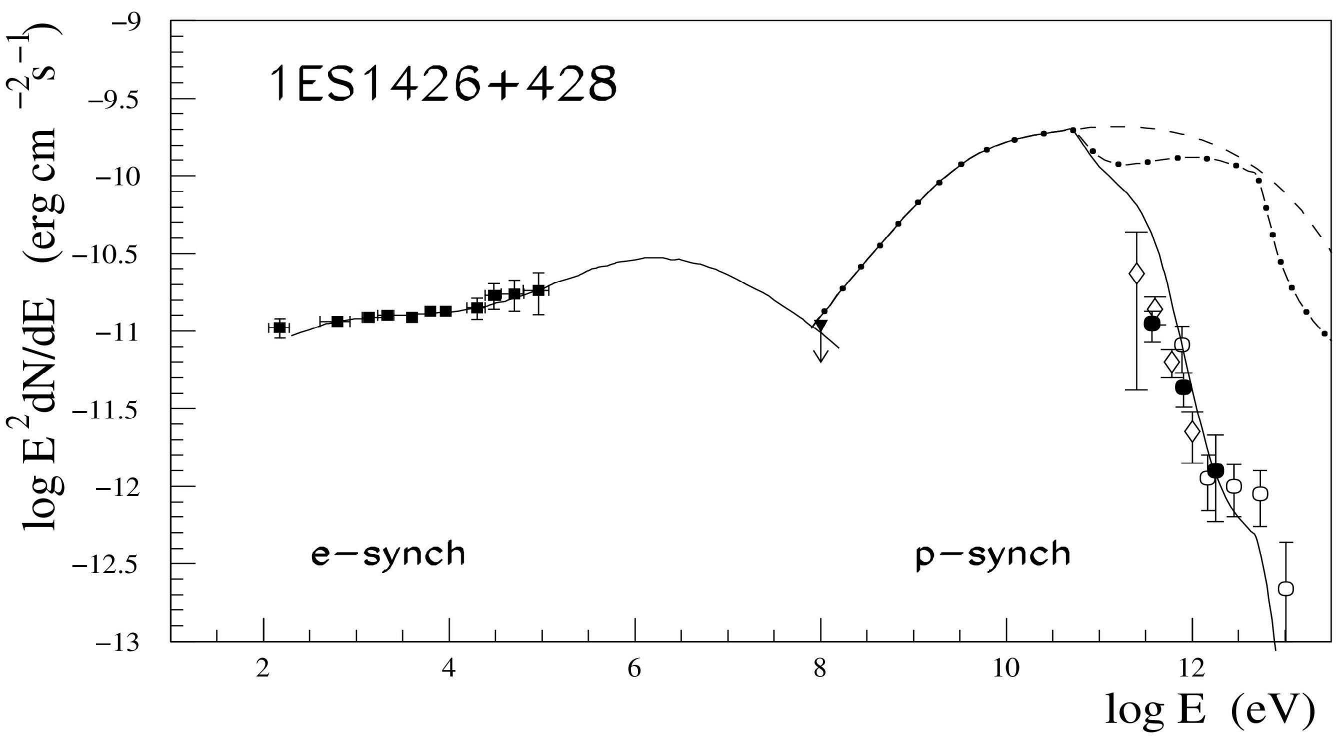
internal absorption can help to make very hard spectra, but B-field should be large (typically >>10 G) to avoid the cascading in the radiation field unless γ-rays are absorbed outside the source

on the other hand if a fraction of gamma-rays are absorbed inside the blob the synchrotron radiation of secondary electrons can explain (in principle) the low frequency) bump (typically at hard X-rays)

protons synchrotron radiation coupled with internal absorption is an interesting scenario for very hard spectra TeV blazars *magnetized compact blobs (B~100G) in blazar jets with Γ~10 as accelerators of protons to $E\sim10^{20}$ eV ?*



FA 2004



E_{cut}=90 (B/100G)(Ep/10^{19} eV)^2 GeV

t_{synch}=4.5x10^4(B/100G)$^{-2}$ (E/10^{19} eV)$^{-1}$ s

t_{acc}=1.1x10^4 (E/10^{19}) (B/100G)$^{-1}$ s

synchrotron radiation of protons: a viable radiation mechanism

E_{max} =300 η^{-1} δj GeV
requires extreme accelerators: η ~ 1

- gamma-ray spectrum partly absorbed inside the source and in IGM
- X-ray emission from synchrotron radiation of secondary e+e- pairs

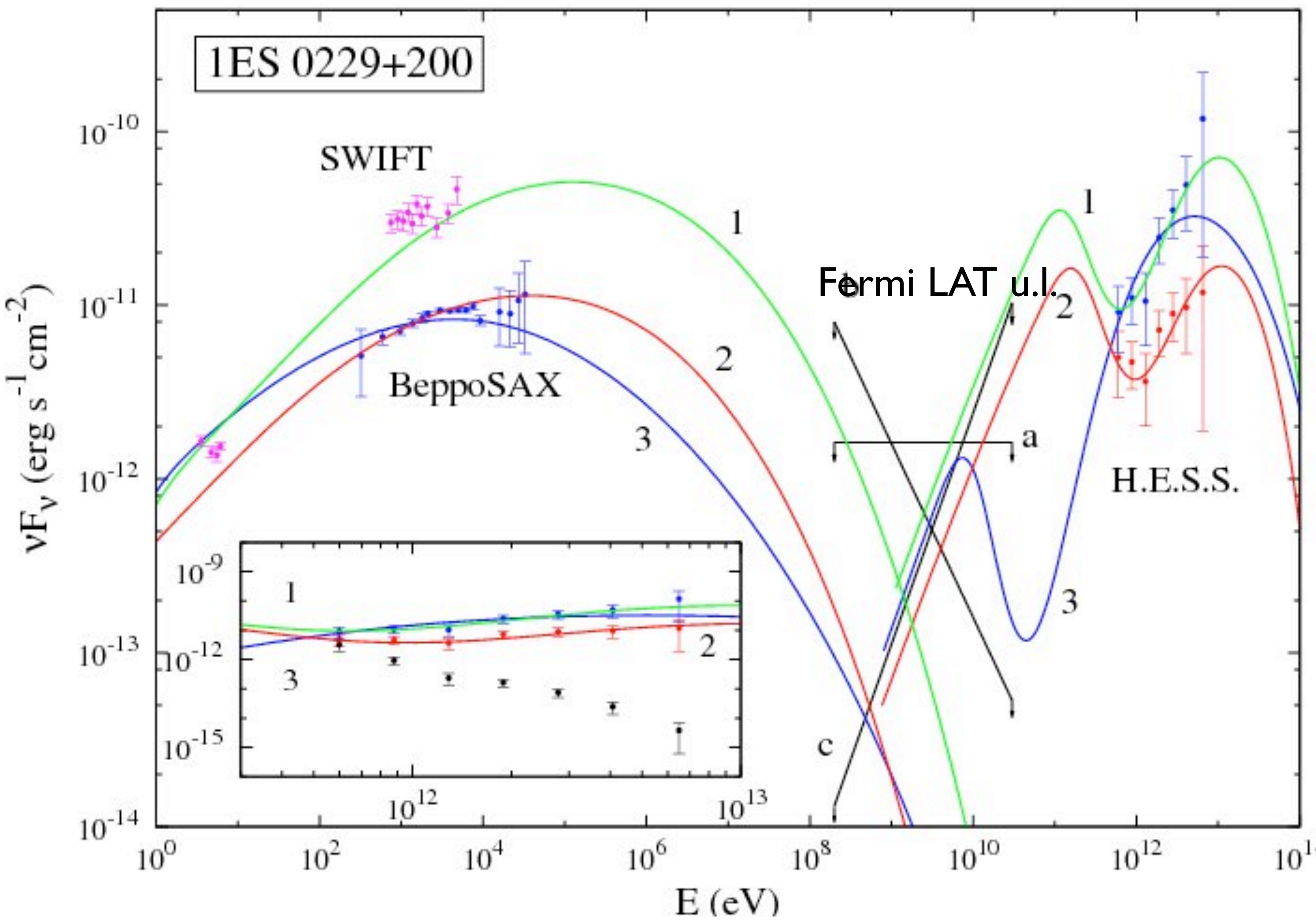
severe constraints from Fermi: very high "low energy" cutoff or very hard spectrum

proton spectra:
1 and 2: $E^{1/2}\exp(-E/Eo)$ (converter mechanism?)

3. $E^{-2}\exp(-E/Eo)$ (shock accelerate) with low-energy cutoff at 10^{17}eV

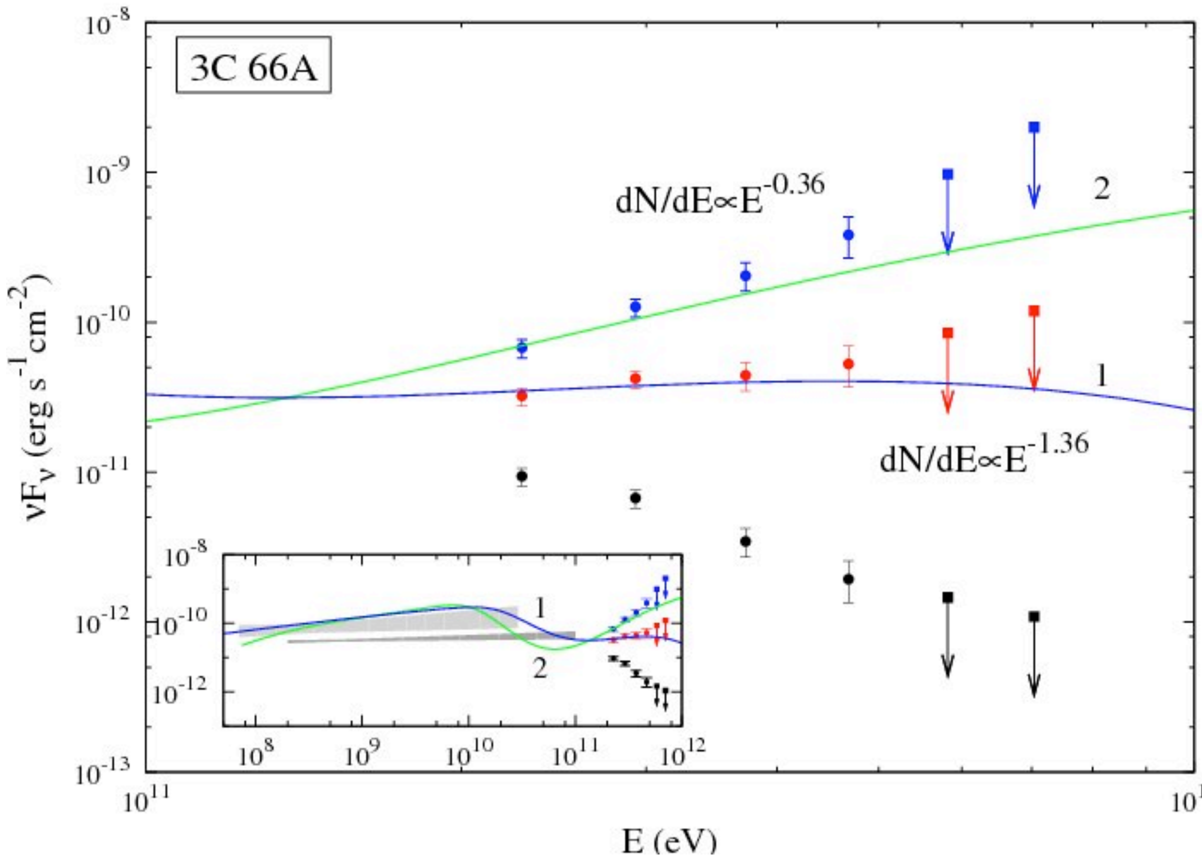
proton synchrotron + internal absorption

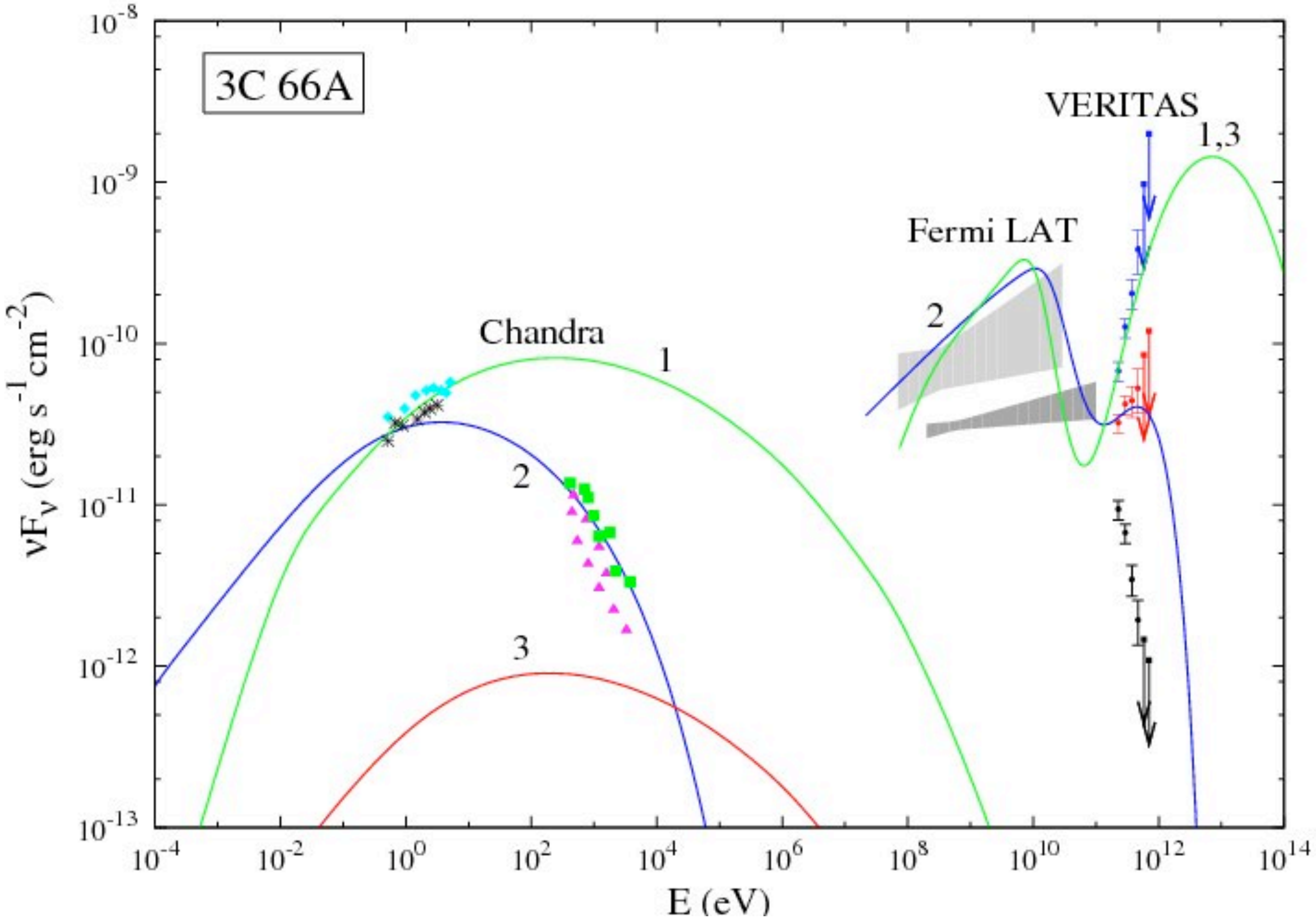
a unique source: z=0.18 and E>1 TeV



the range of parameters: B ~100G, τ_{tot}~3, τint ~1, R~10^{15}cm, T ~10^4 K, Lo ~10^{41} erg/s, L_γ~ 10^{42} erg/s

3C 66A: z=0.44
very hard spectra even for "nominal" EBL (red points)





no low -energy cutoff in the p-spectrum is needed: self-consisitent explanation of keV-GeV-TeV bands ?

Zacharopoulou et al. 2010 (to be submitted)

Conclusion:

even extremely hard gamma-ray spectra from TeV blazars can be explained within standard astrophysical scenarios with standard parameters

- ✓ IC: narrow electron distribution + B<0.01 G
- ✓ p-synchrotron: internal absorption + B>10 G