Numerical modelling of radiative and accelerative processes with the JetSeT code

JetSeT

Jets SED modeler and fitting Tool

Andrea Tramacere

https://jetset.readthedocs.io/en/latest/
https://github.com/andreatramacere/jetset
https://www.facebook.com/jetsetastro/

Geneva CTA Group
Feb 2021 zoom lecture

JetSeT

Outline

- Theoretical background
- definition of complex radiative **models** SSC/EC IC against CMB/BLR/DT, plus analytical and template models
- handling observed **data** (grouping, definition of data sets, etc…)
- **constraining** of the model in the pre-fitting stage, based on accurate and already published **phenomenological trends**
- **fitting of multiwavelength SEDs** using both **frequentist** approach (iminuit/scipy) and Bayesian **MCMC** sampling (emcee)
- Textbooks
  - Radiative Processes in Astrophysics, Ribicky & Lightman, John Wiley & Sons, 1991
  - High Energy Radiation from Black Holes: Gamma Rays, Cosmic Rays, and Neutrinos, Dermer & Menon, Princeton University Press 2009
  - Bayesian Reasoning in Data Analysis: A Critical Introduction, D’Agostini G., World Scientific, 2003

Online tutorials

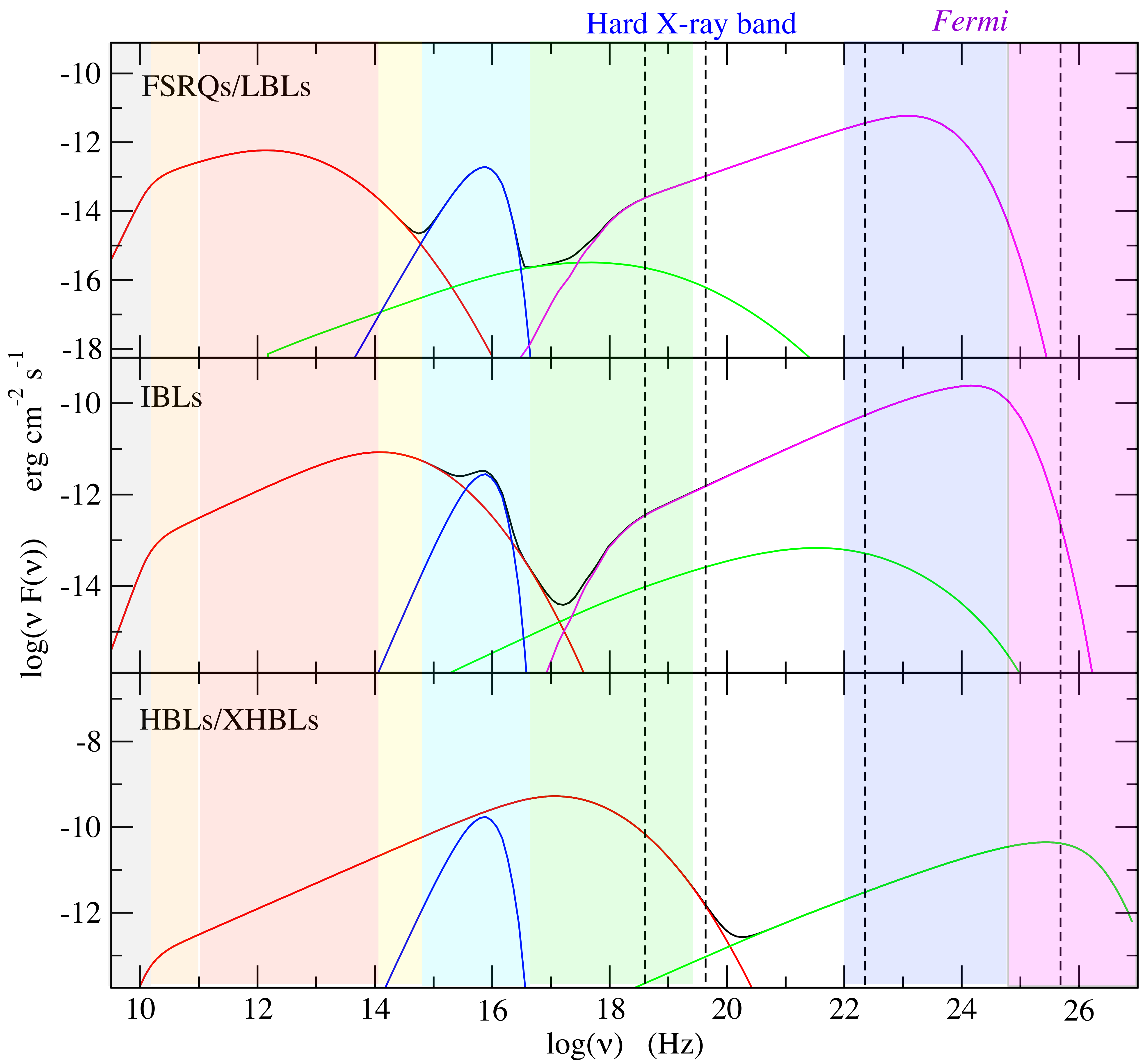
https://github.com/andreatramacere/Linnaeus_JetSeT_Lesson

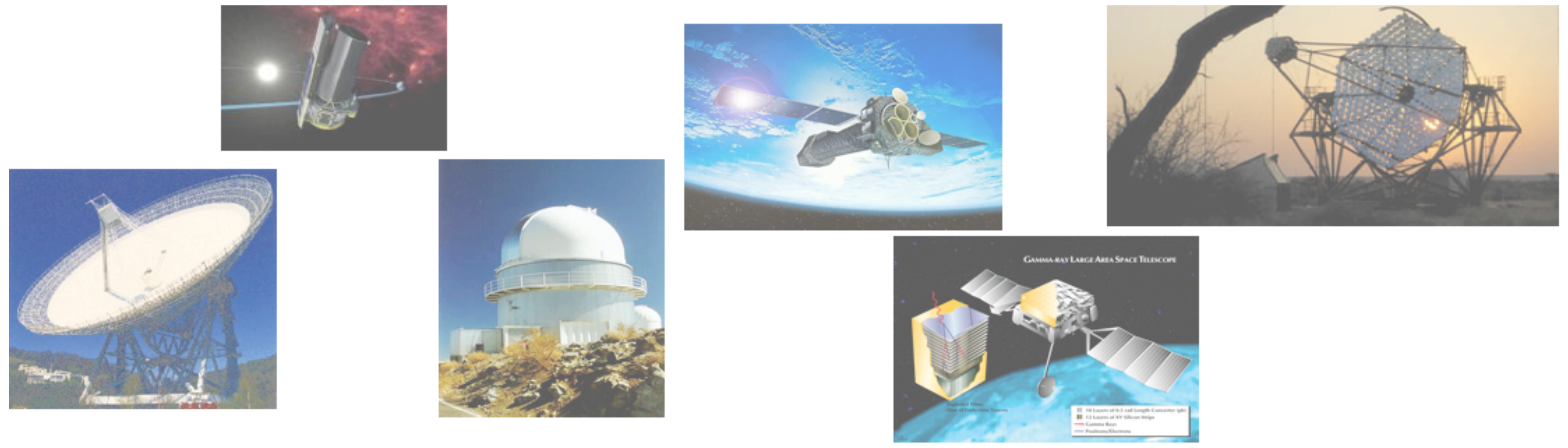
- Tutorial 1: basic operation with jet models
- Tutorial 2: phenomenological trends for synchrotron and SSC emission
- Tutorial 3: phenomenological trends for EC emission
- Tutorial 4: composite models and application to EBL (not covered in these slides)
- Tutorial 5: constraining of the model in the pre-fitting stage, based on accurate and already published phenomenological trends and fitting of multiwavelength SEDs using both frequentist approach (iminuit/scipy) and Bayesian MCMC sampling (emcee)

JetSeT

Blazars in a nutshell

data



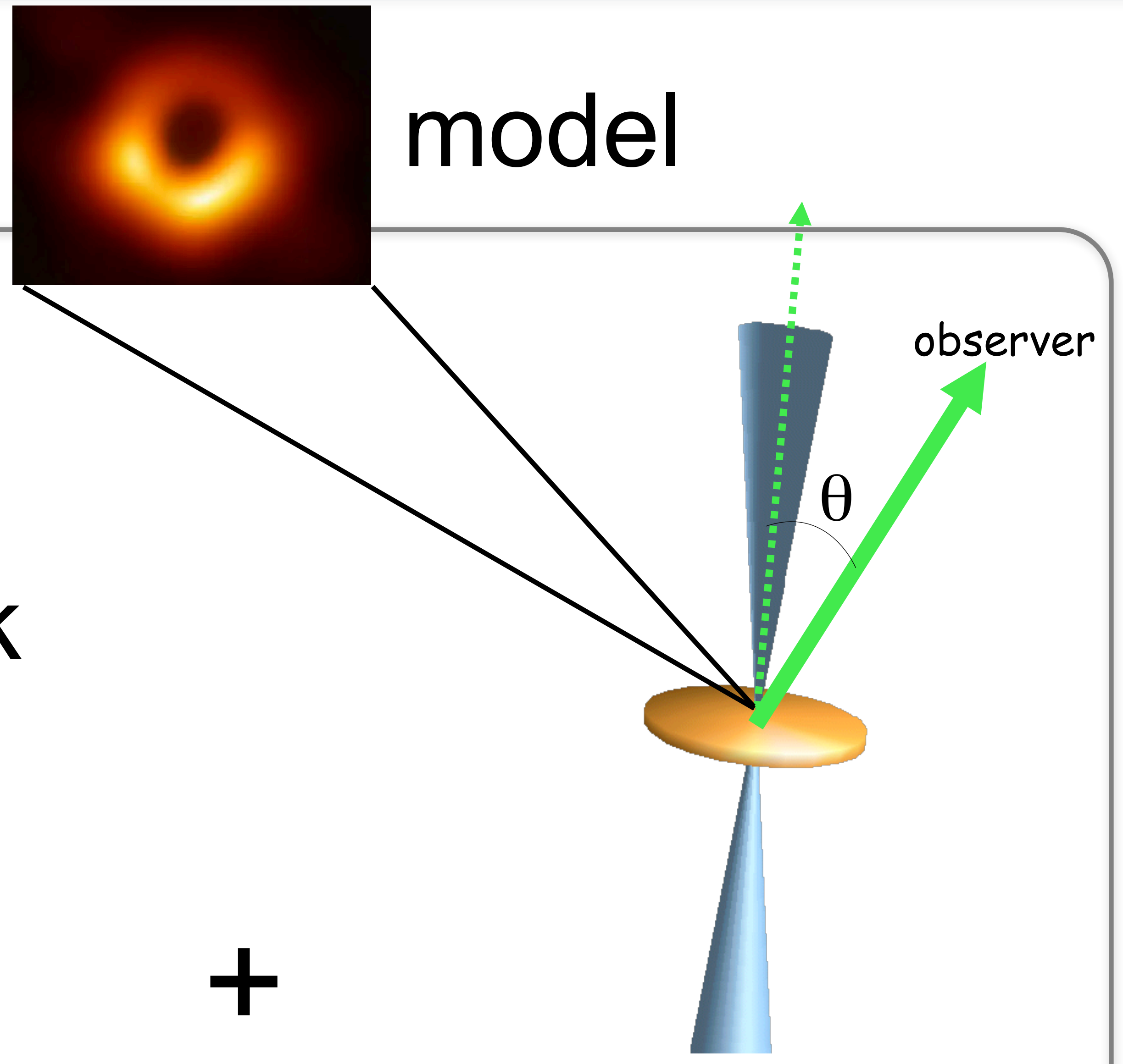


phenomenology

model fit

simulations

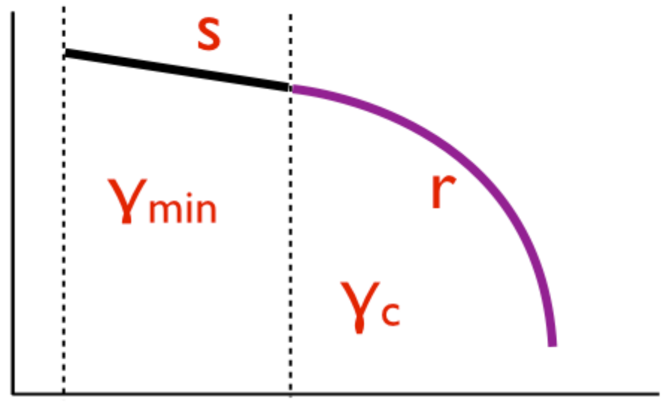
model



jet/disk

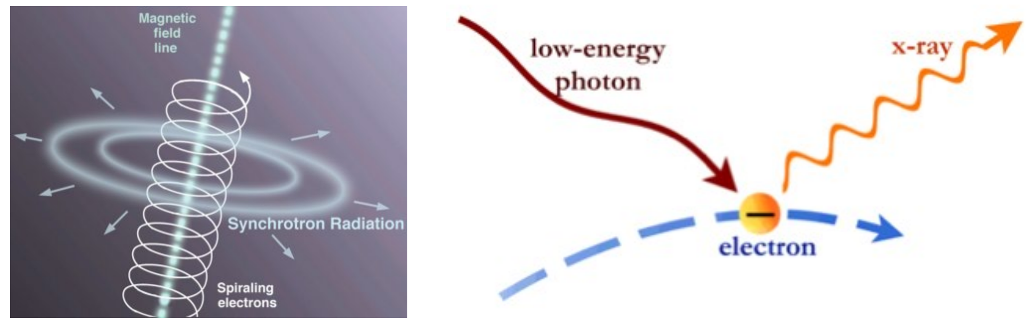
+

acc.



+

em.



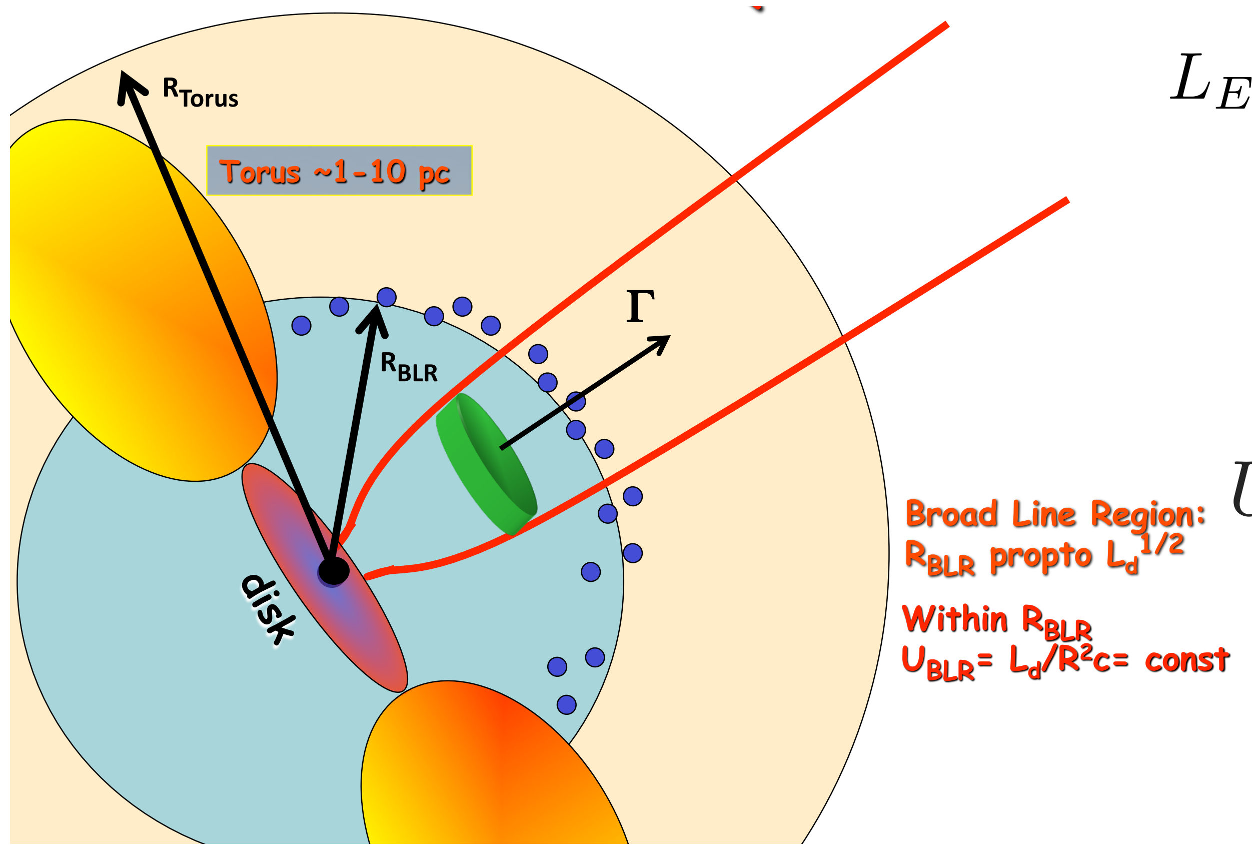
standard picture: acceleration/cooling balance

(Ghisellini,Fossati,Celotti 99-16)

FSRQs
HERGs

rad eff.
$L_d > 10^{-2}\ L_{EDD}$

$$L_{Edd} \approx 1.4 \times 10^{44} \frac{M_{BH}}{10^6 M_\odot} \mathrm{erg\ s^{-1}}$$

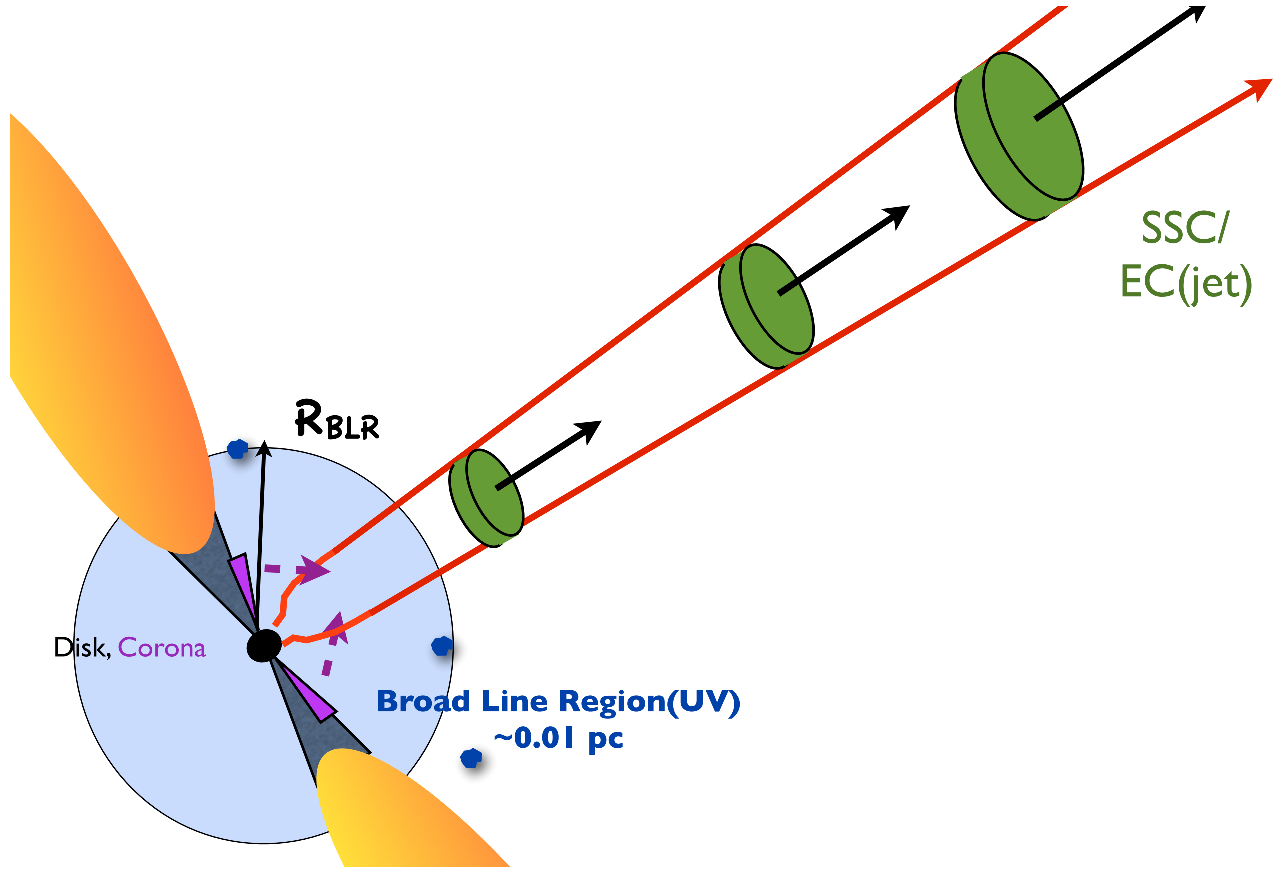


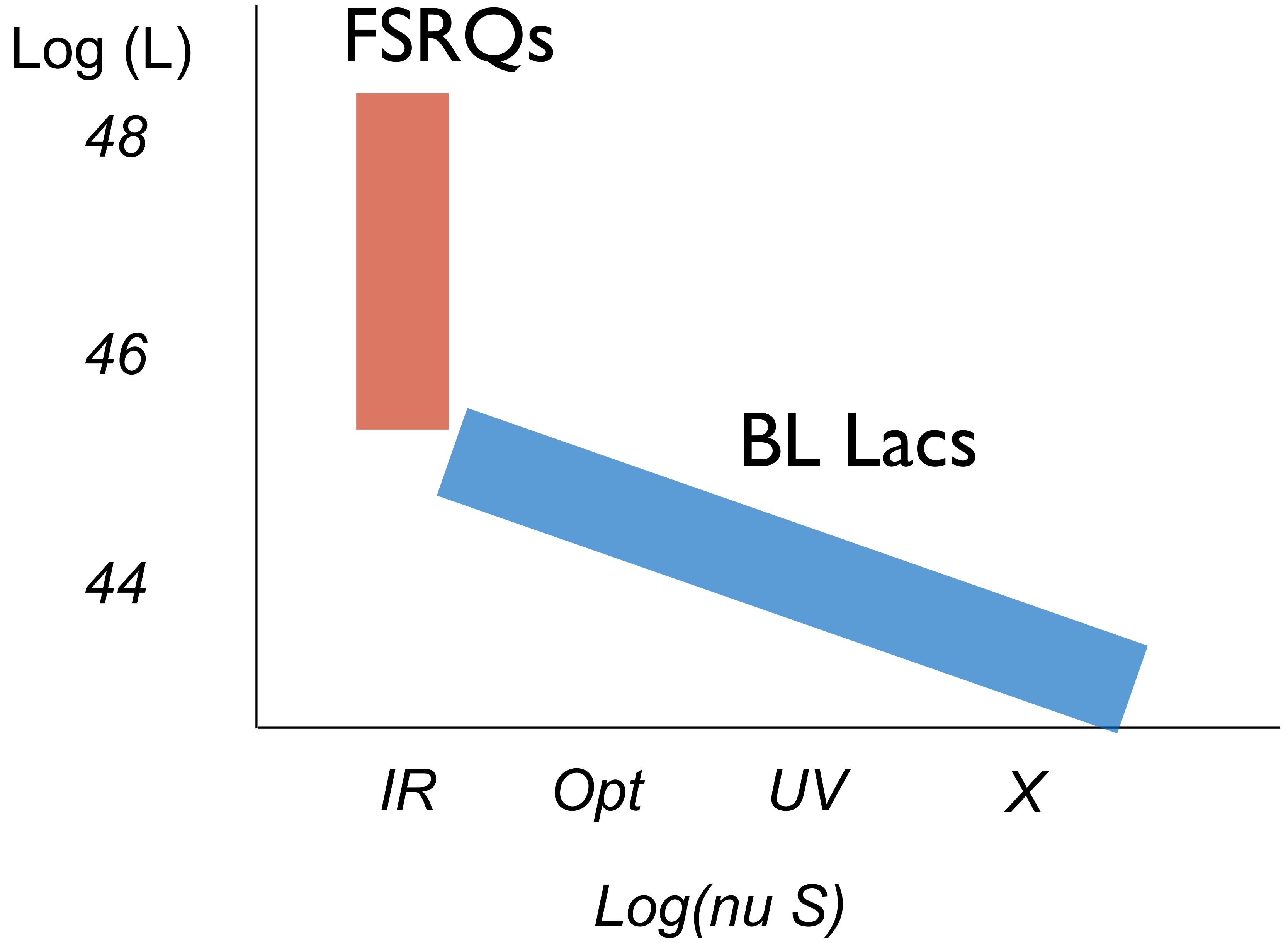
$$\left. \begin{array}{l} U_{ext} \simeq \dfrac{L_d}{R^2{}_{ext} c} \\ R_{ext} \simeq L_d^{1/2} \end{array} \right\} \rightarrow$$

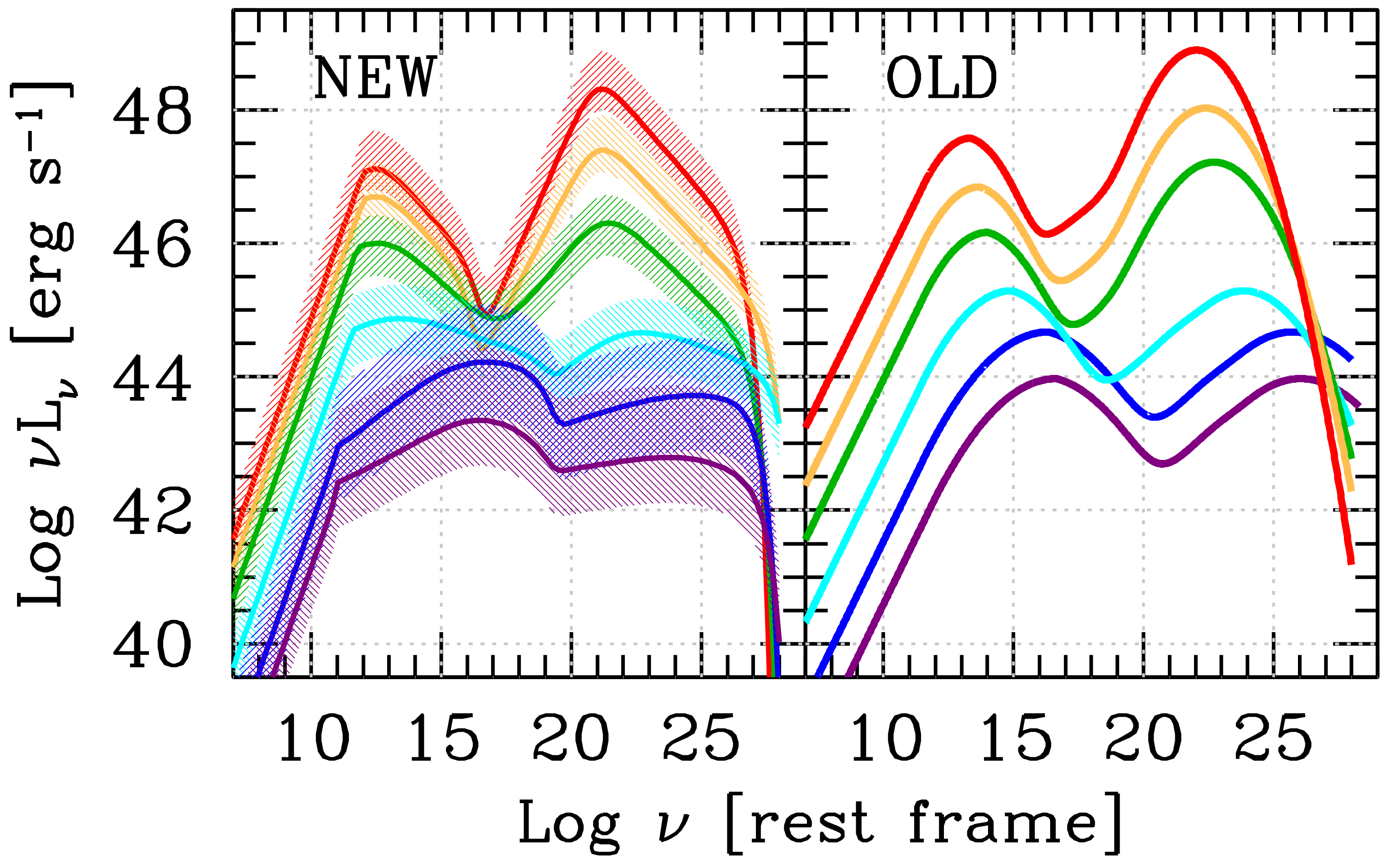
~0.1 erg/cm^3 BLR
~0.01 erg/cm^3 DT

BL Lacs
LERGs

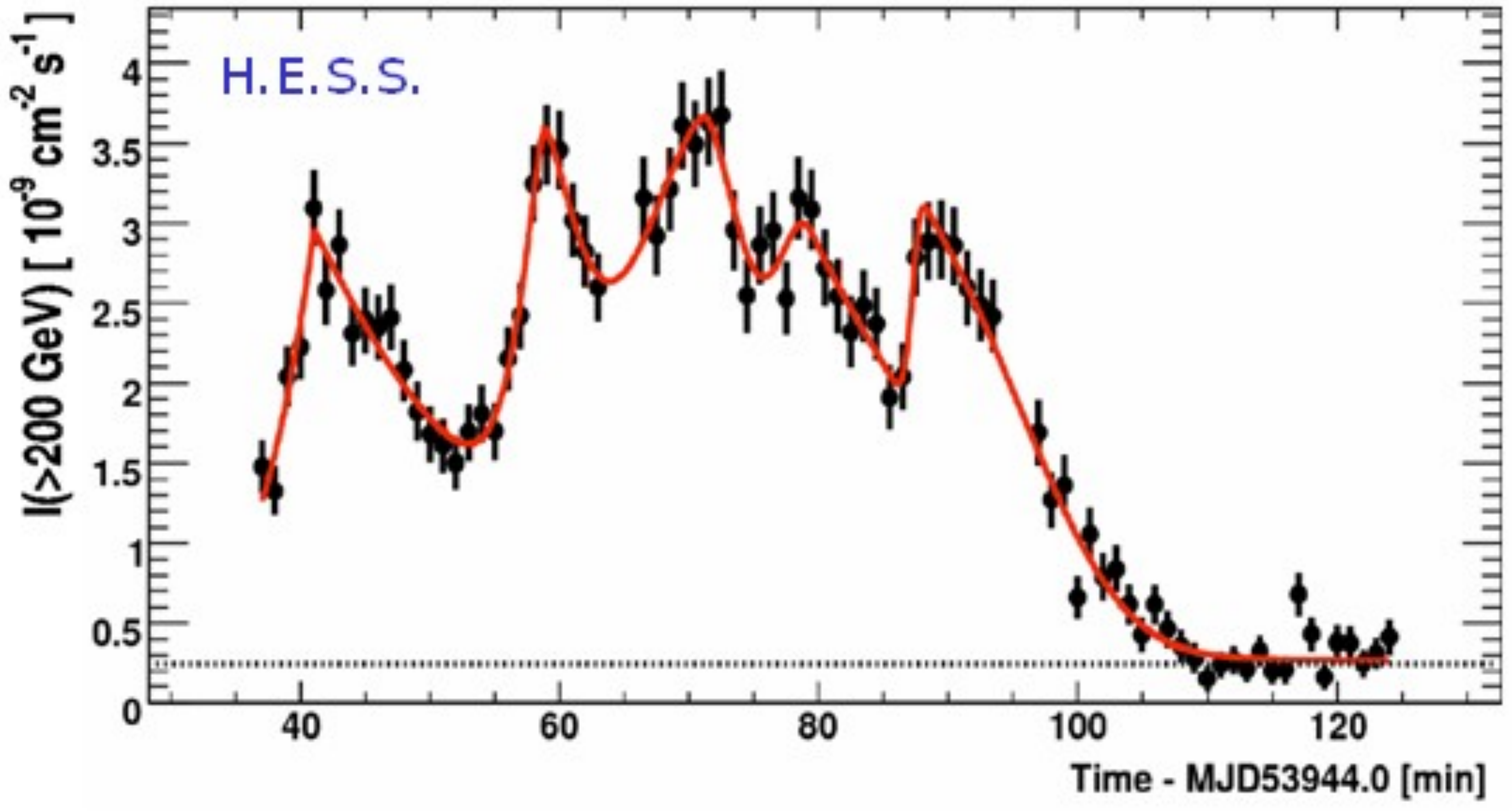
rad ineff.
$L_d < 10^{-2}\ L_{EDD}$

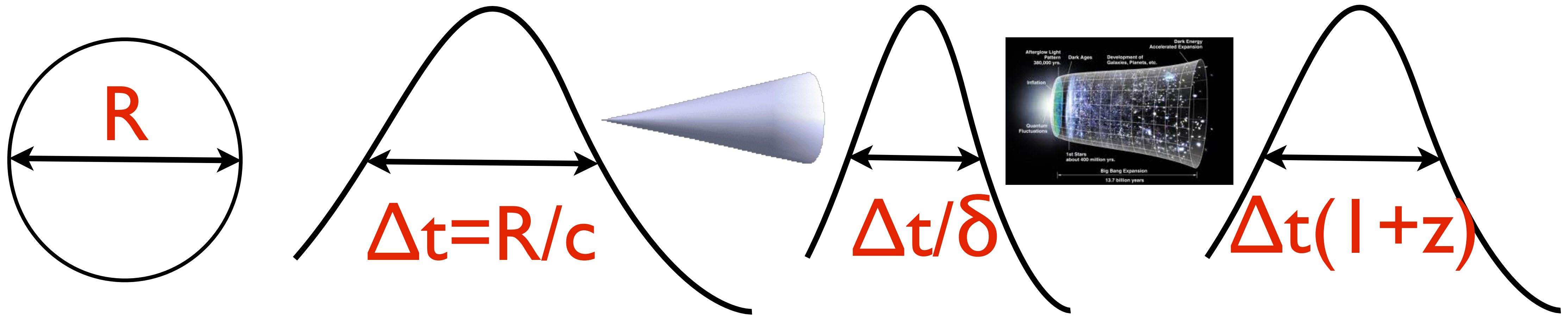




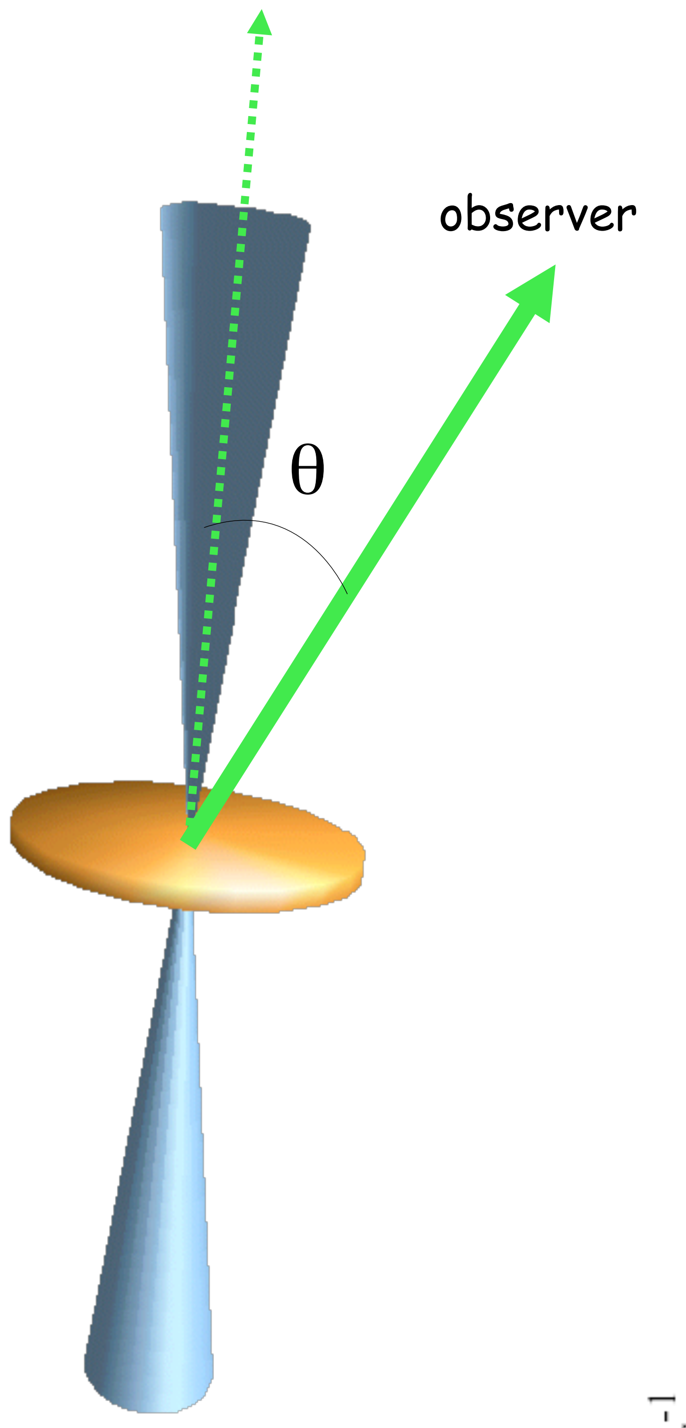


Beamed Emission





R<= c Δtδ/(1+z)

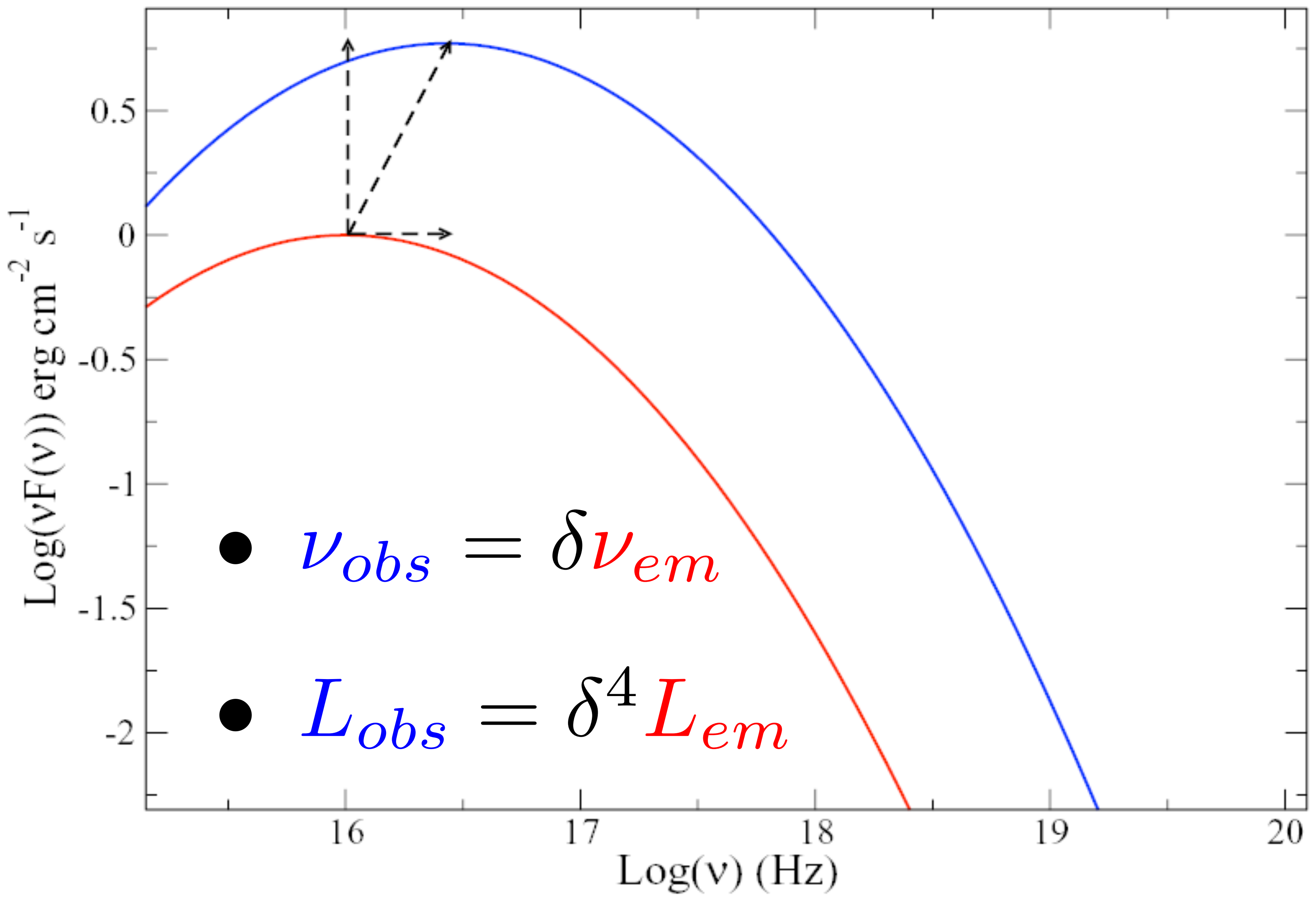


rest frame :
isotropic emission

Observer frame: beamed

Beaming factor:

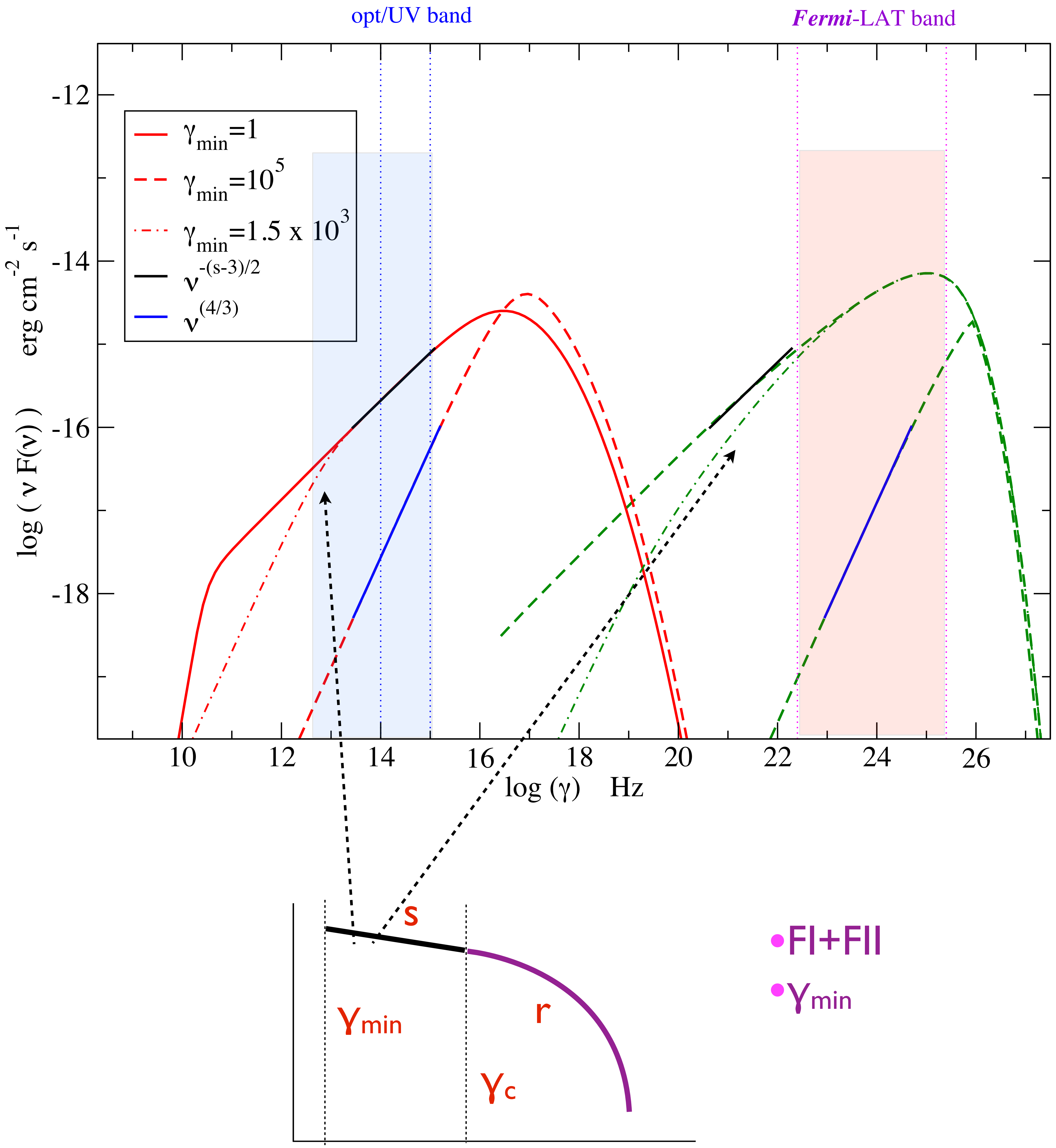
- $\delta = \frac{1}{\Gamma(1-\beta cos(\theta))}$
- $\theta = 1/\Gamma$



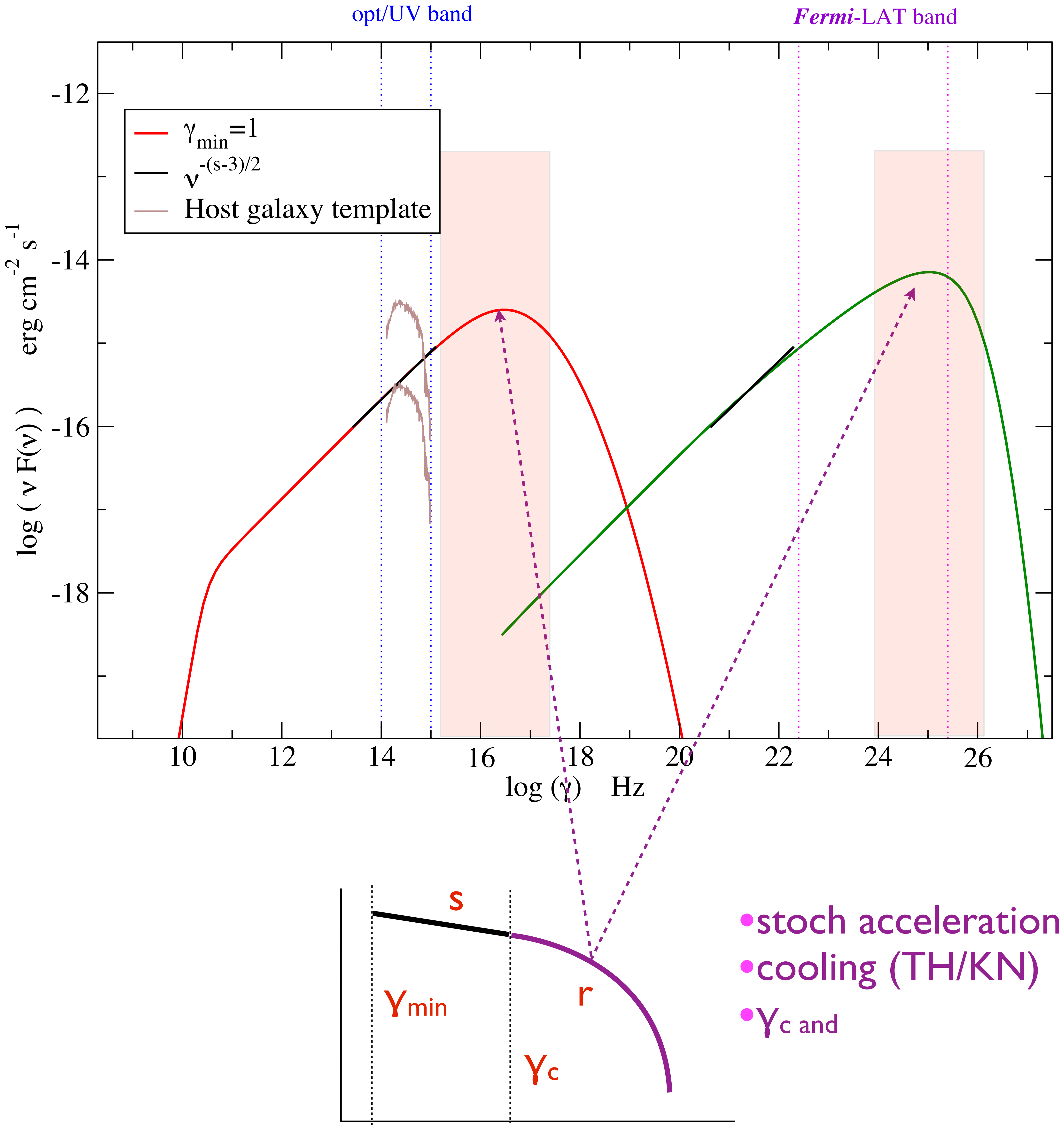
- $\nu_{obs} = \delta \nu_{em}$
- $L_{obs} = \delta^4 L_{em}$

JetSeT

SED shaping and constraining the electron distribution



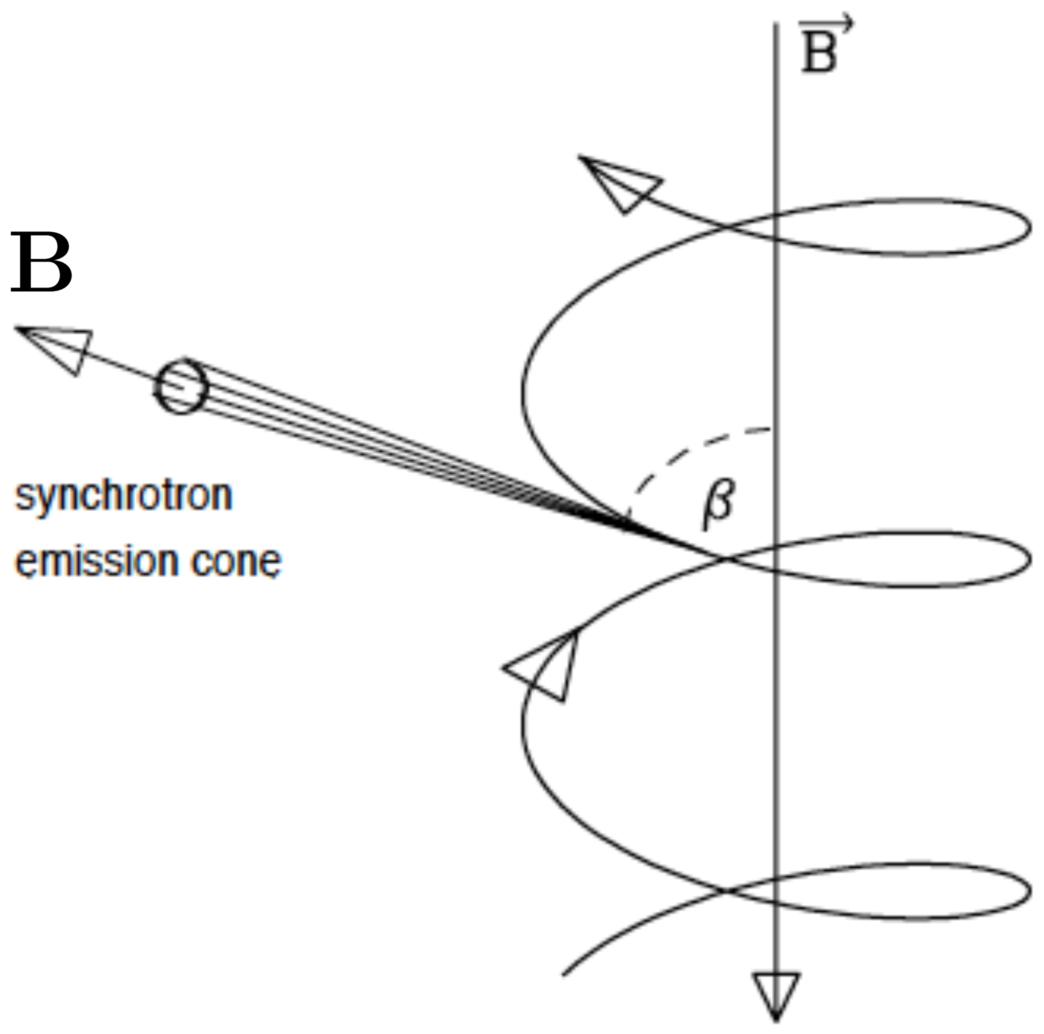
- FI+FII
- γ_{min}



- stoch acceleration
- cooling (TH/KN)
- γ_c and

synchrotron basics single particle

$$m\gamma \frac{d(\mathbf{v})}{dt} = \frac{q}{c}\mathbf{v} \times \mathbf{B}$$



$$a_{\parallel} = 0$$

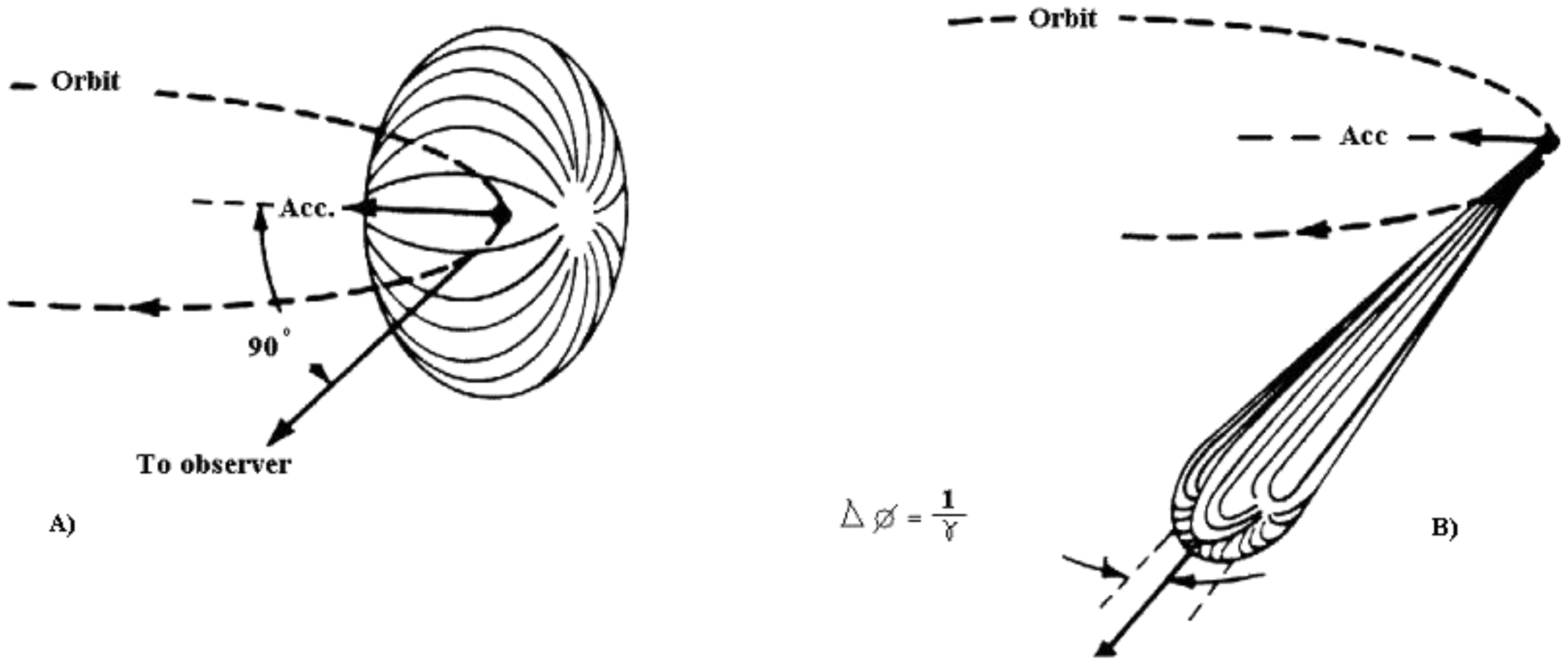
$$a_{\perp} = \frac{evBsin\alpha}{\gamma m_e c}$$

$$\nu_{\mathrm{B}} = \frac{eB}{2\pi\gamma mc} = \frac{\nu_{\mathrm{L}}}{\gamma}$$

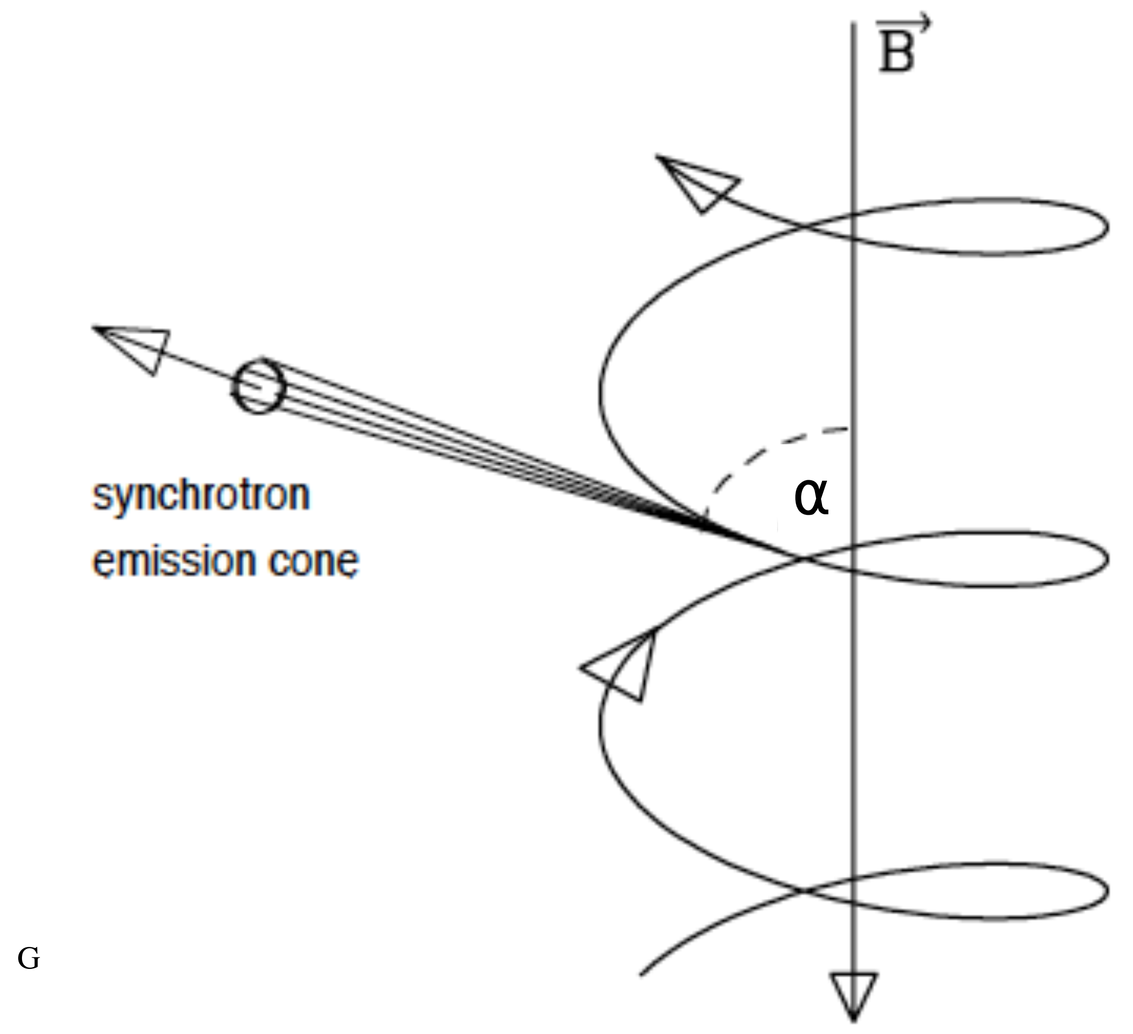
total emitted power

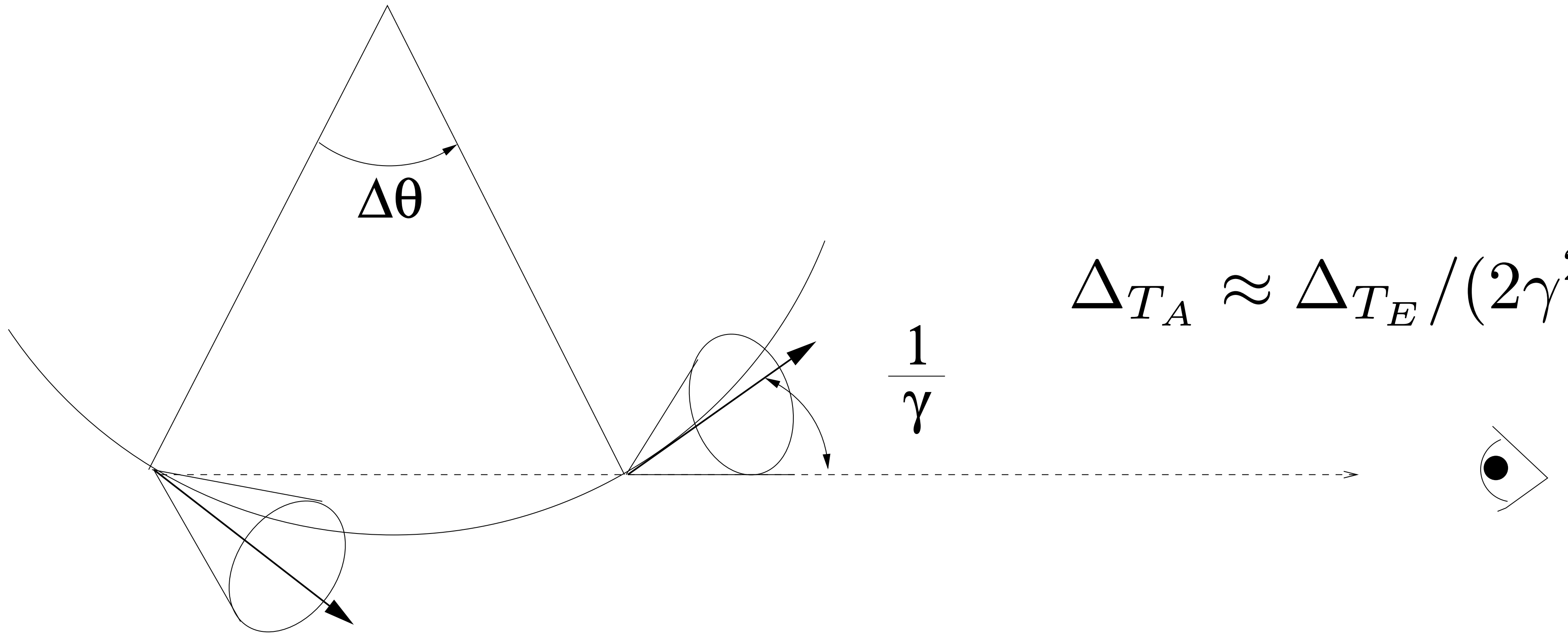
$$P_{\mathrm{e}} = P'_{\mathrm{e}} = \frac{2e^2}{3c^3}a'^2 = \frac{2e^2}{3c^3}[a'^2_{\parallel} + a'^2_{\perp}]$$

$$P_S = \frac{2e^4}{3m_e c^3}B^2\gamma^2\beta^2 sin^2\alpha$$

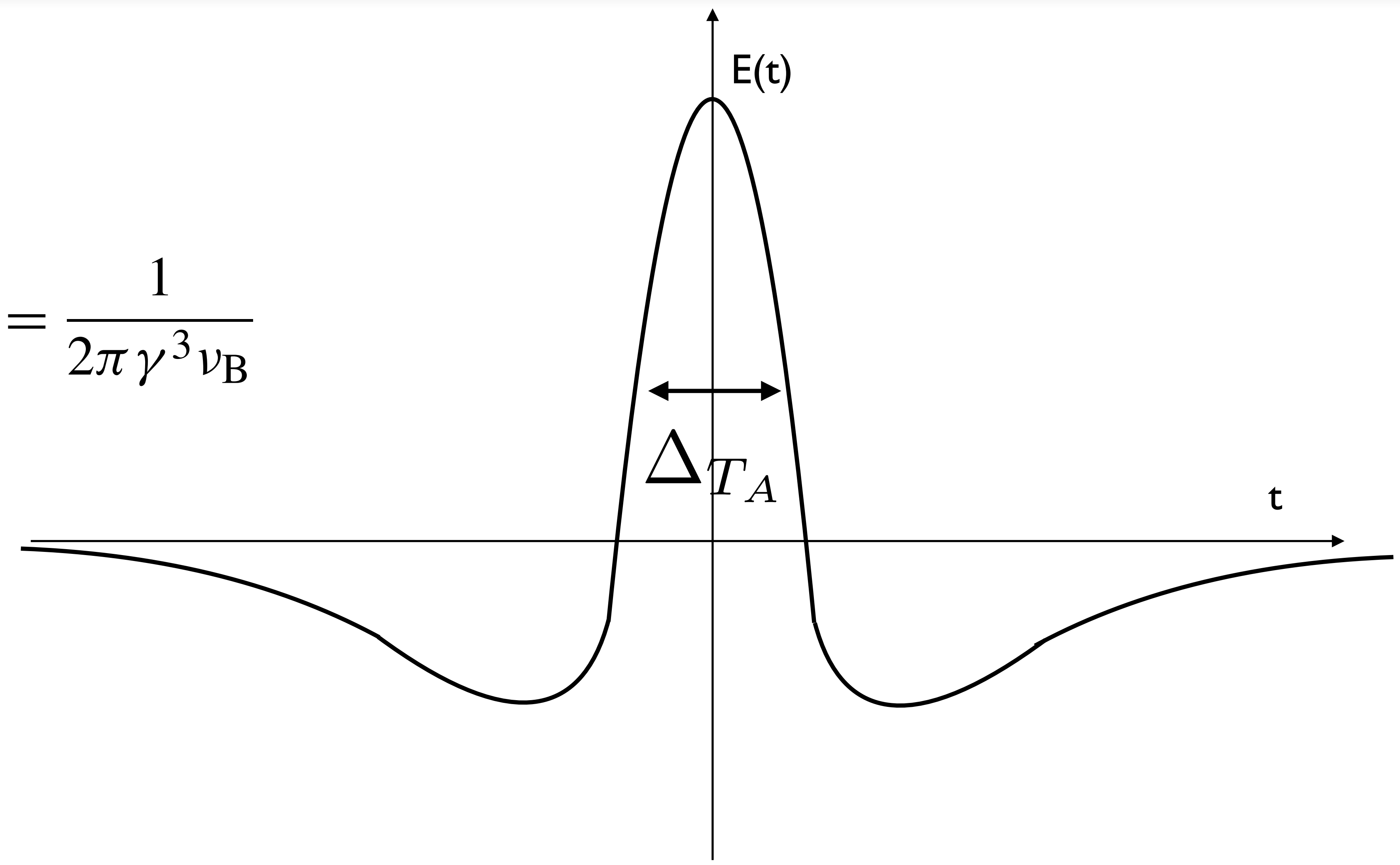


synchrotron basics single particle





$$\Delta_{T_A} \approx \Delta_{T_E}/(2\gamma^2) = \frac{1}{2\pi\gamma^3\nu_B}$$

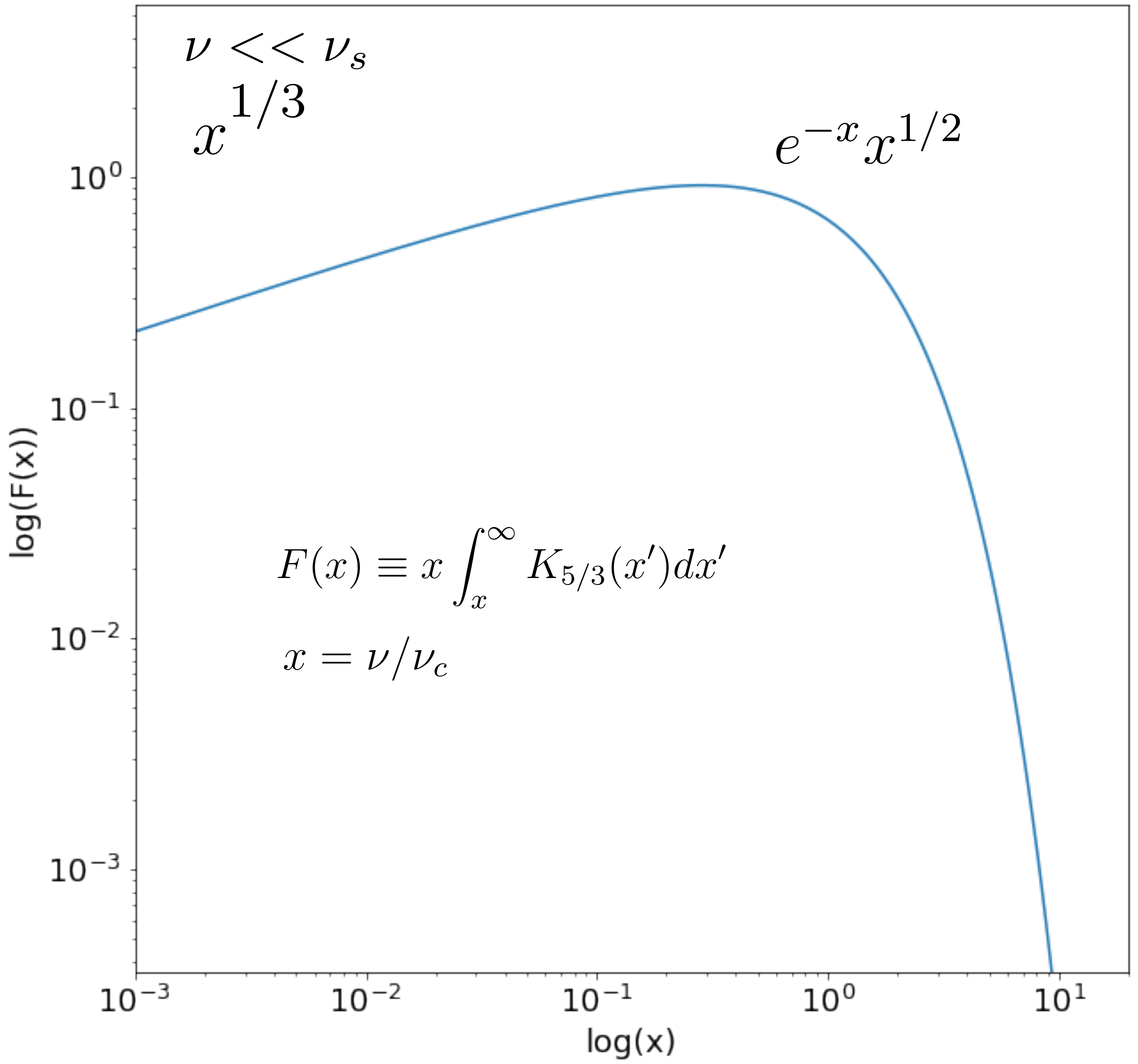


power spectrum

$$\Delta_{T_A}\nu_T = \frac{1}{2\pi} \longrightarrow \nu_T = \gamma^3\nu_B$$

emitted spectrum

$$P_e(\nu,\gamma) = \frac{\sqrt{3}e^3 B\sin\alpha}{2m_e c^2}F(x) \longrightarrow$$



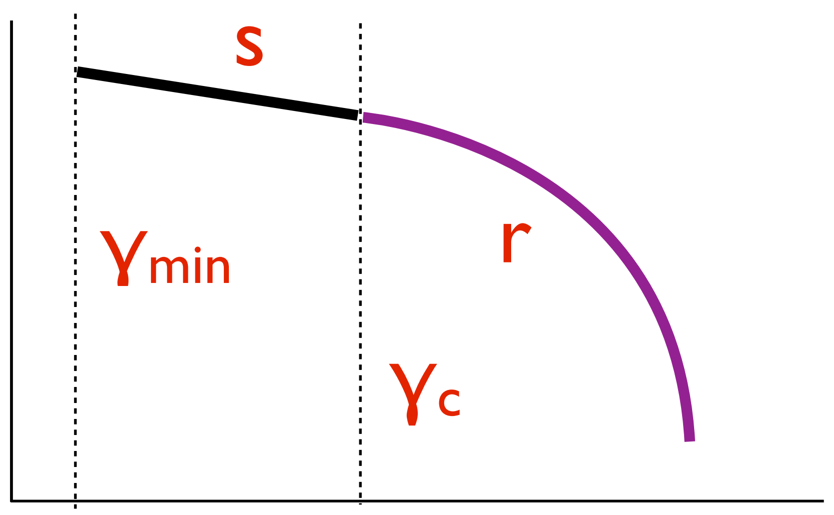
$$\nu_c = \frac{3}{2}\nu_B\gamma^3 sin\alpha = \frac{3\gamma^2 eBsin\alpha}{4\pi m_e c}$$

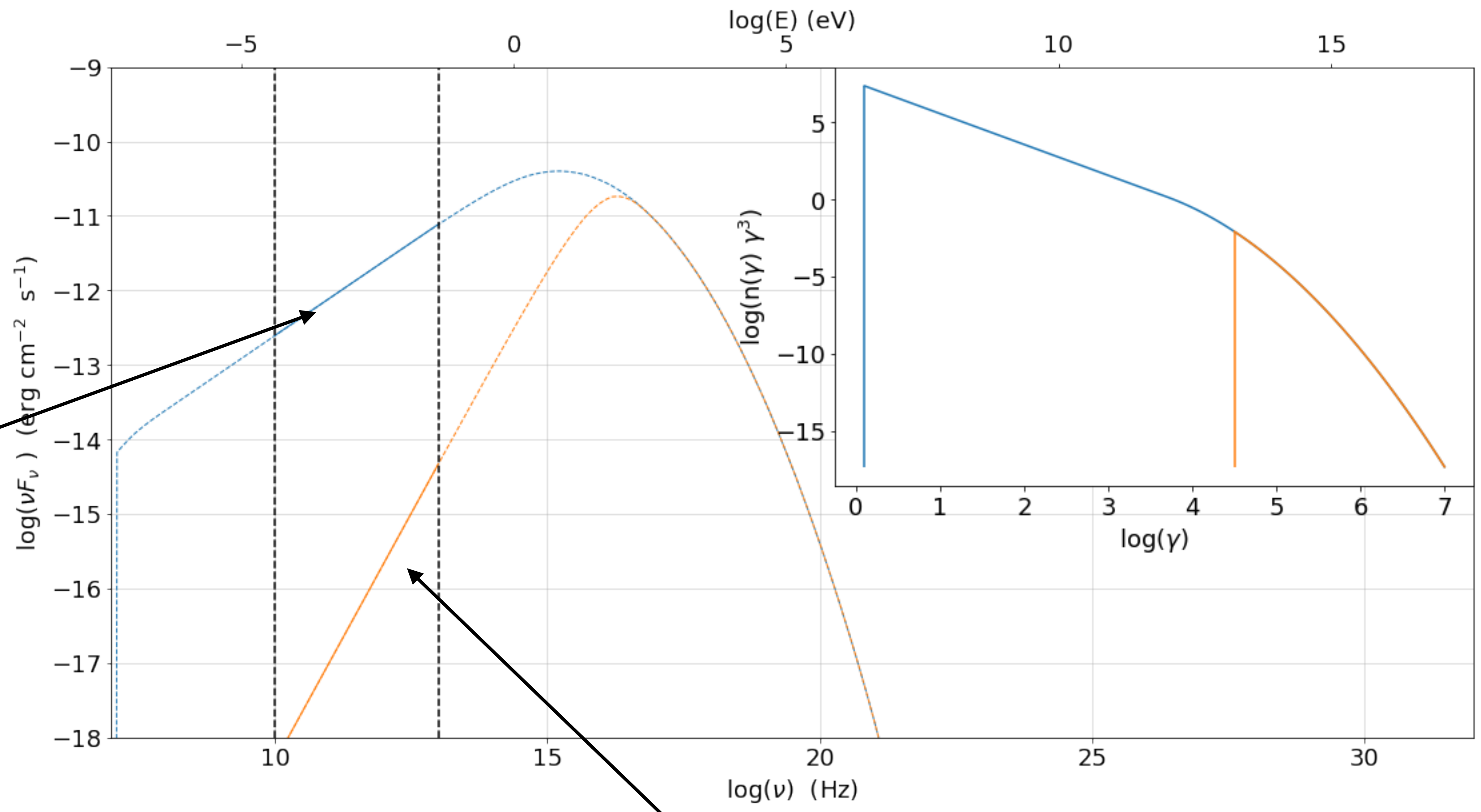
$$\nu_s \propto 10^6 B\gamma^2 sin(\alpha) \ \text{Hz}$$

synchrotron basics particle distribution

Tutorial 2

$$N(\gamma) \propto \gamma^{-s}$$



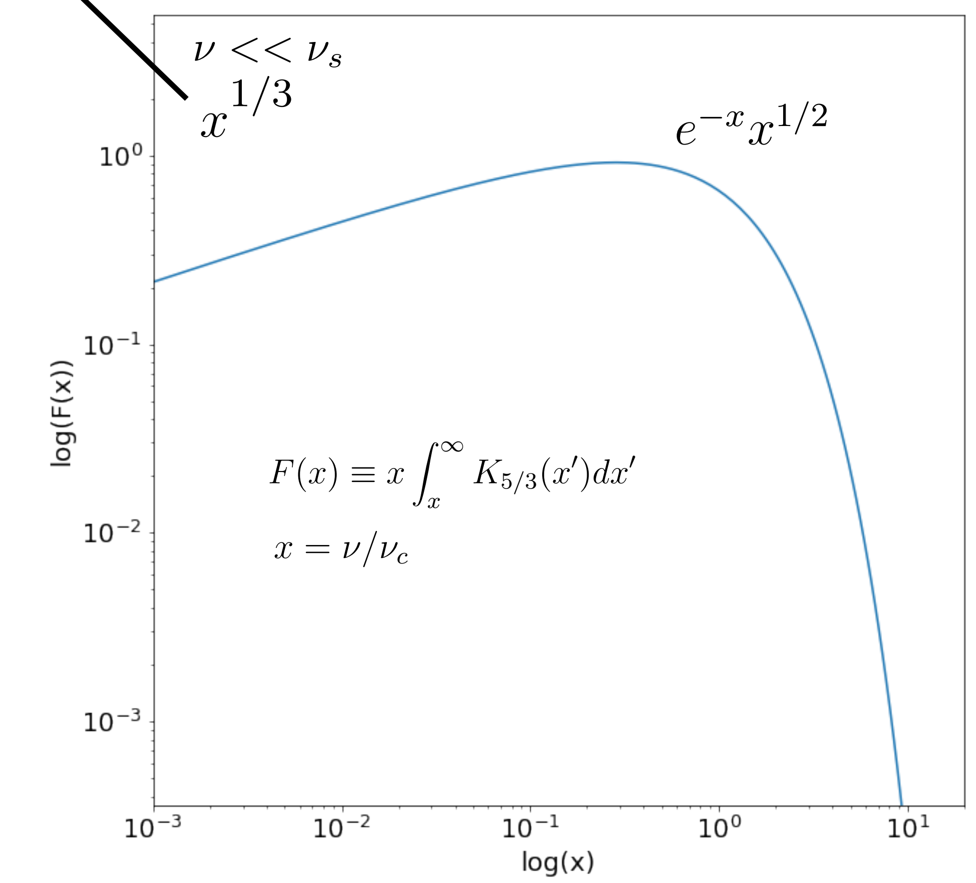


$$j^S_\nu(\nu) = \frac{1}{4\pi}\int_{\gamma_{min}}^{\gamma_{max}} P(\nu,\gamma)N(\gamma)d\gamma \ \propto \nu^{-\frac{s-1}{2}}$$

F_ν	refers to spectral index => SED=	νF_ν
I_ν		νI_ν
L_ν		νL_ν

δ-approx relations $\quad \mathrm{SED} \propto N(\gamma)\gamma^3$

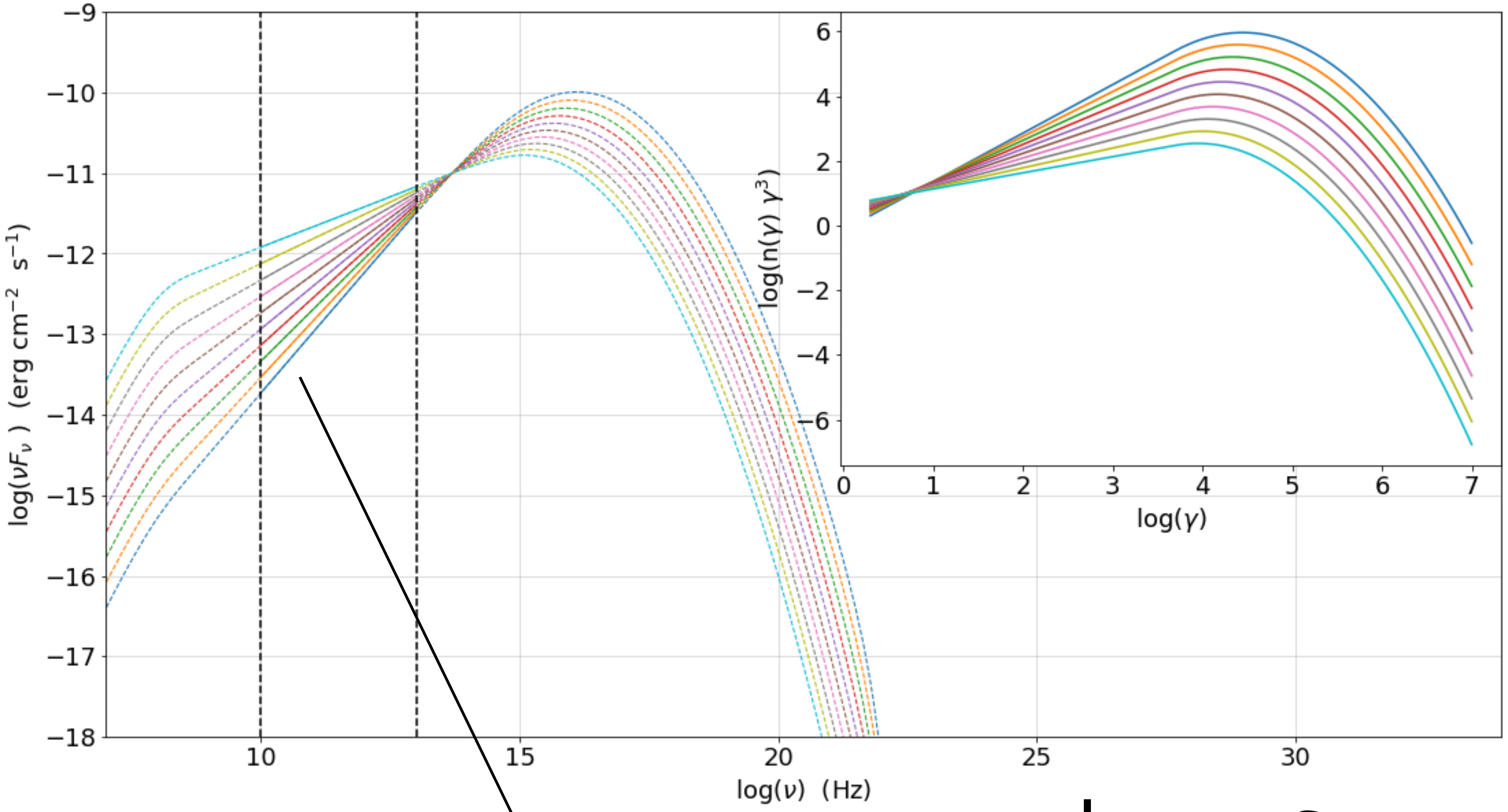
$$S_p^{Sync} \sim \frac{dN(\gamma)}{d\gamma}\gamma_{3p}^3 \ B^2 \ \delta^4 \quad \nu_p^{Sync} \sim 3.2\times 10^6 \ (\gamma_{3p})^2 \ B \ \delta$$

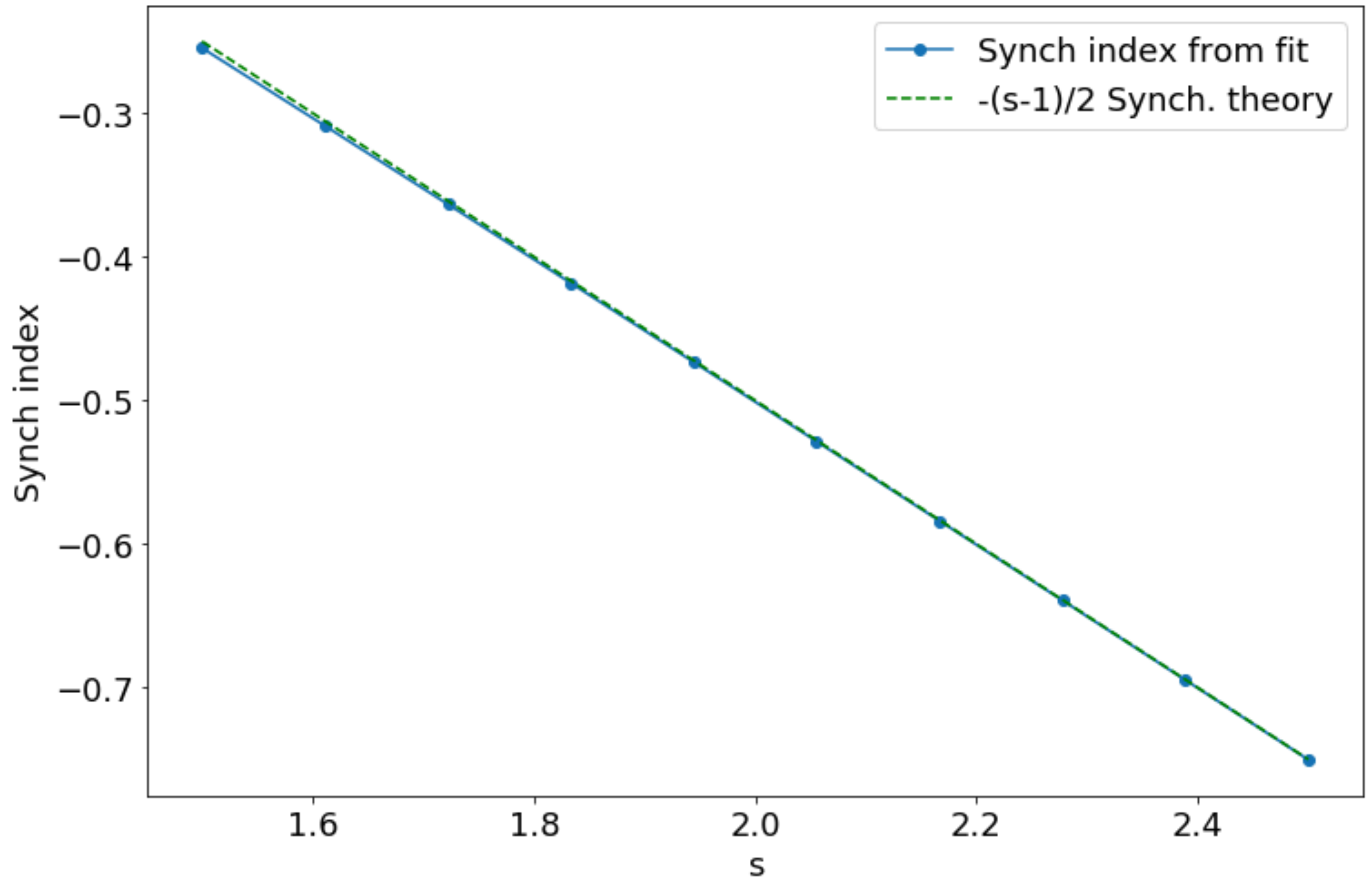


4/3 in SED corresponds to 1/3 in spectral index

Synchrotron emission Estimate of *s* from spectral index

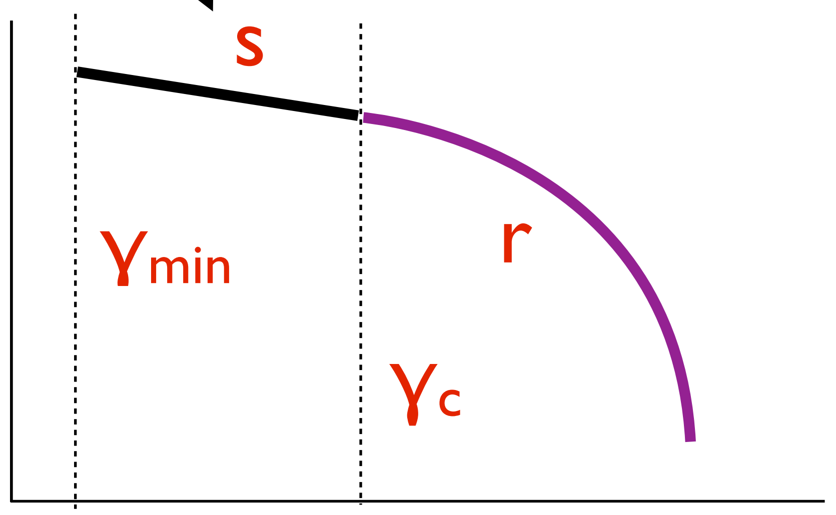
Tutorial 2





$$j_\nu^S(\nu) = \frac{1}{4\pi}\int_{\gamma_{min}}^{\gamma_{max}} P(\nu,\gamma)N(\gamma)d\gamma \propto \nu^{-\frac{s-1}{2}}$$

change s

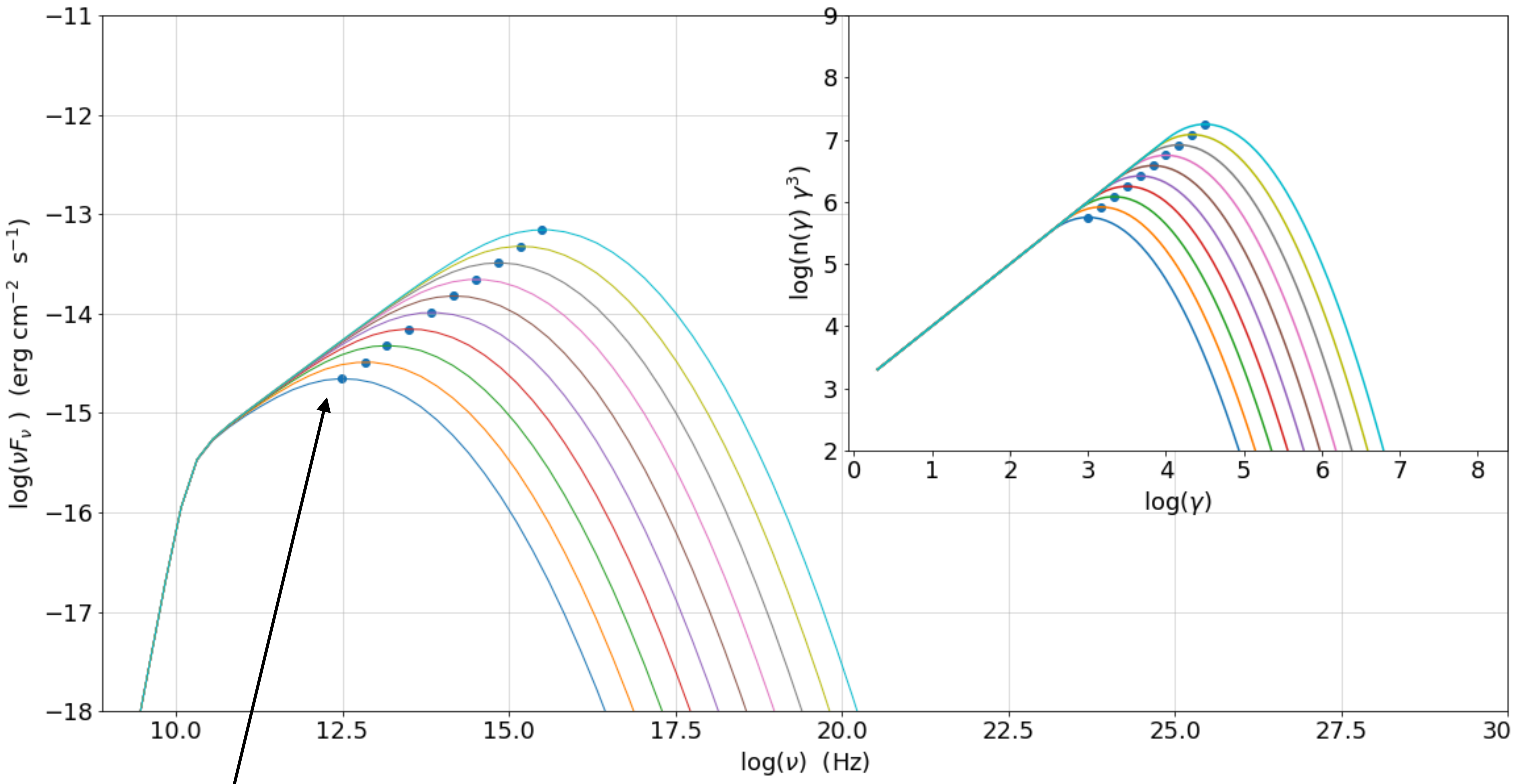


obs. data → model

- synch. spectral index
- s el. distr.

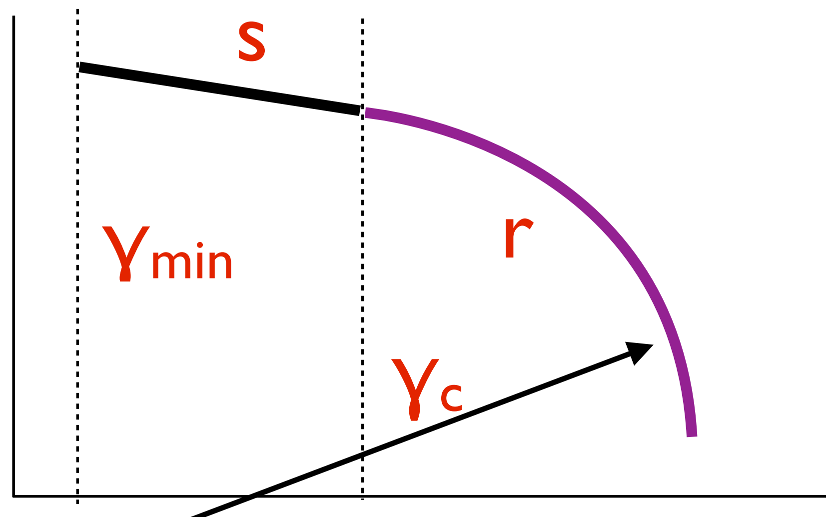
Synchrotron emission Estimate of $\gamma_p{}^s$ from $\nu_p{}^s$

Tutorial 2

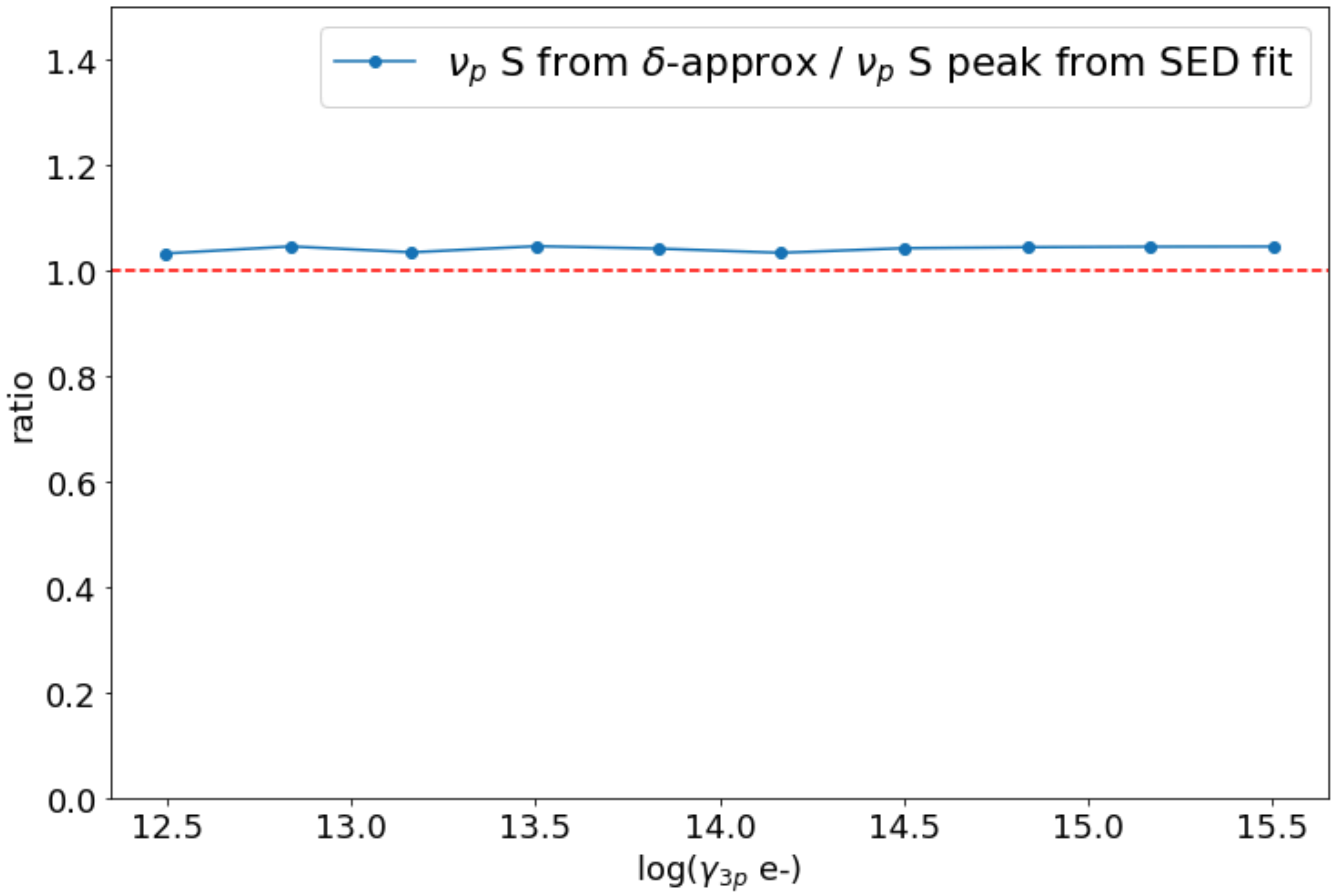


$$\nu_p^{Sync} \sim 3.2 \times 10^6 \ (\gamma_{3p})^2 \ B \ \delta$$

$$S_p^{Sync} \sim \frac{dN(\gamma)}{d\gamma} \gamma_{3p}^3 \ B^2 \ \delta^4$$



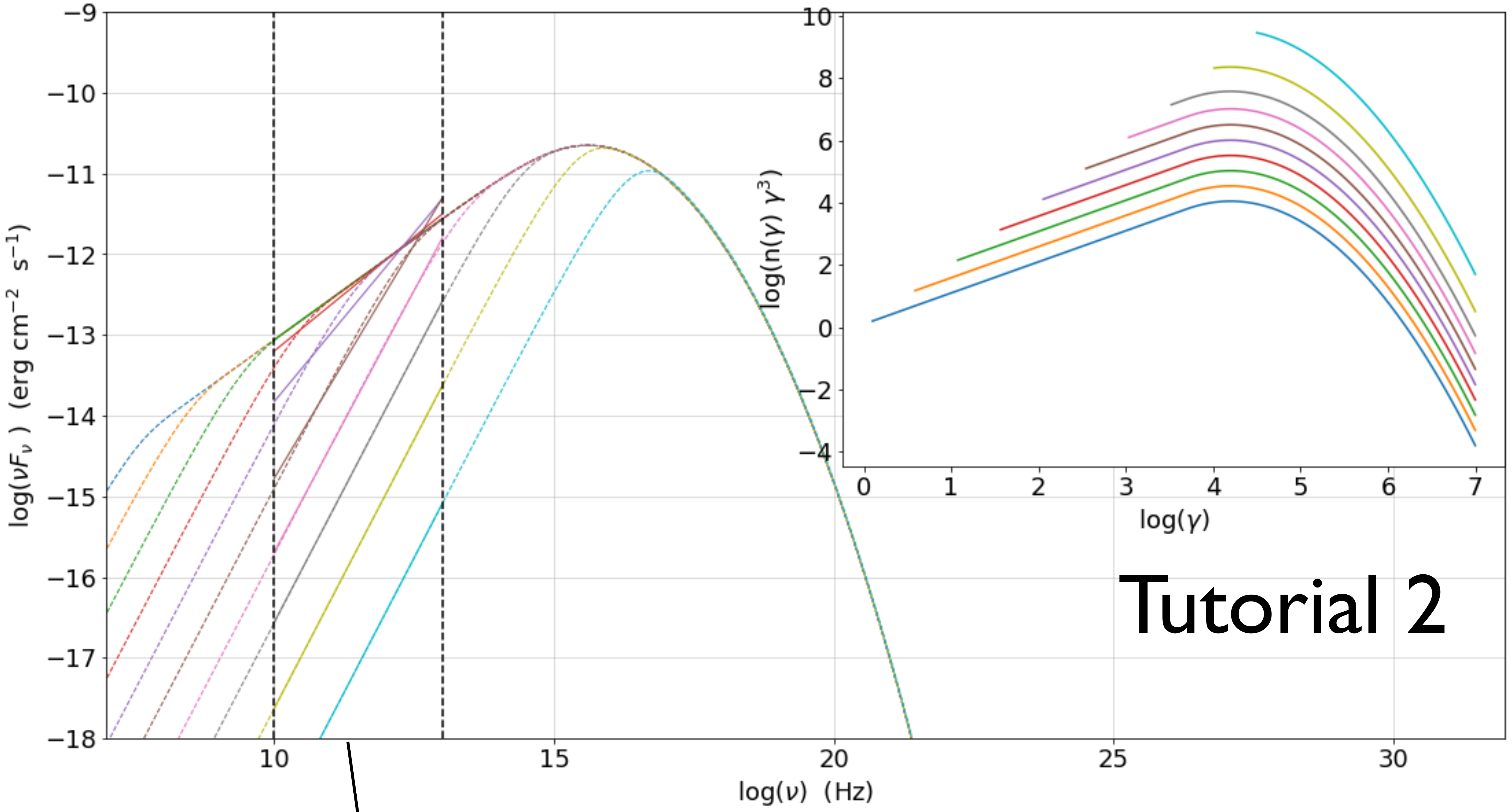
change γ_c



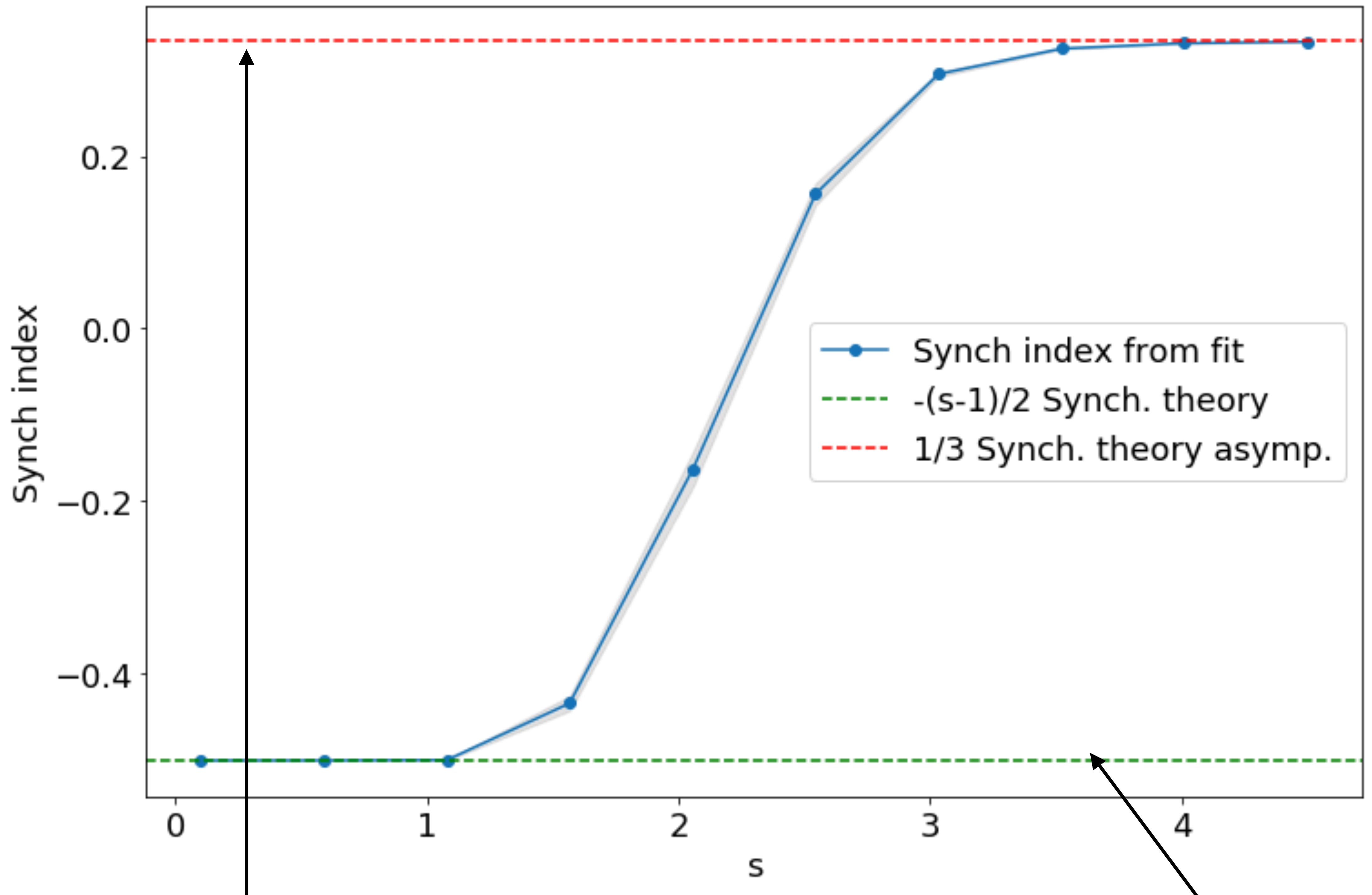
obs. data $\longrightarrow$ model

- $\nu_p{}^s$ → • $\gamma_p{}^s$

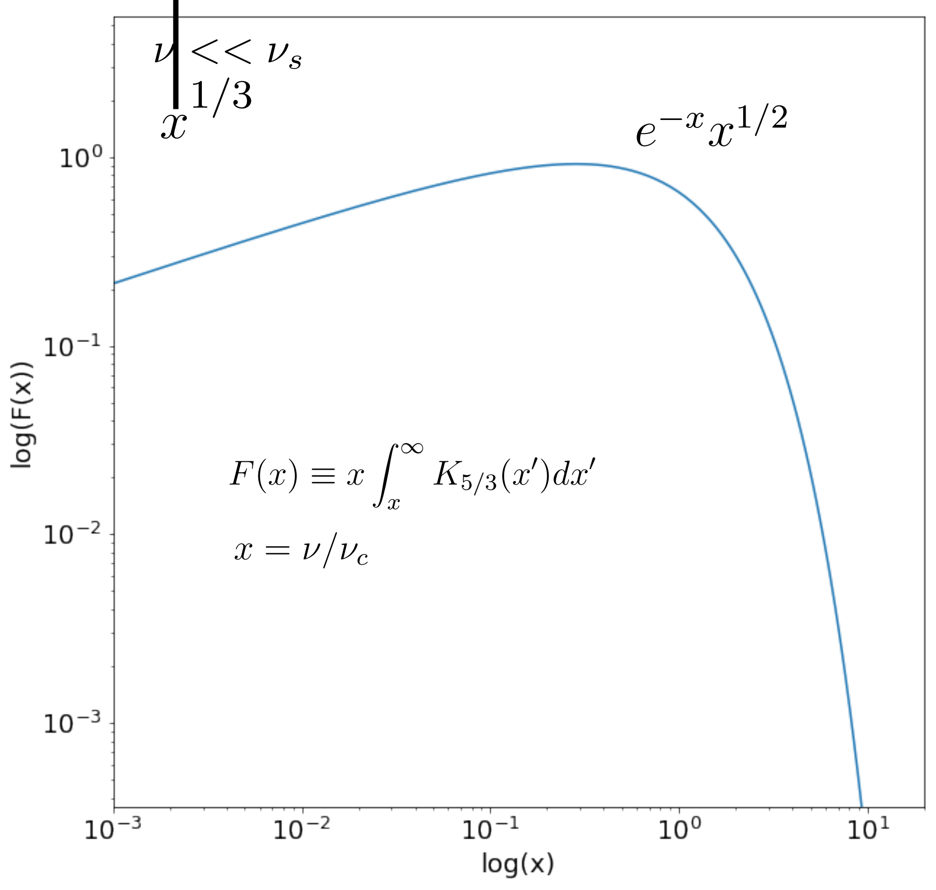
Synchrotron emission Estimate of γ_{min} from spectral index



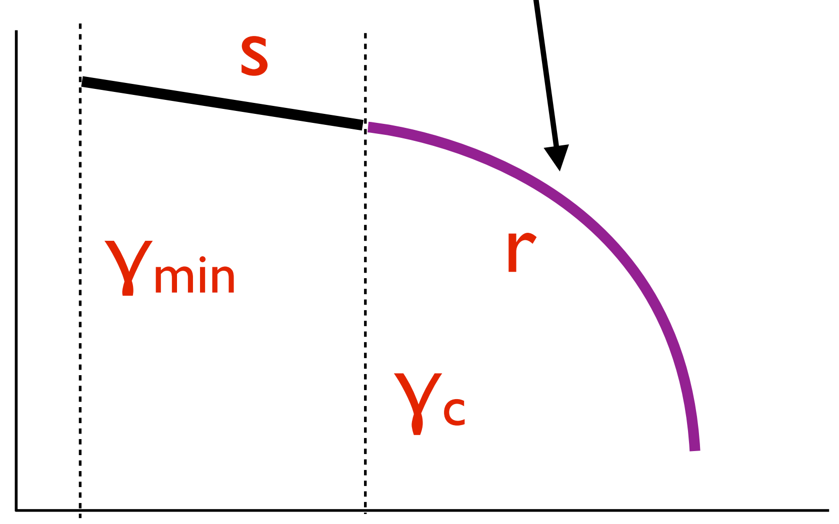
Tutorial 2



s is fixed



$$j_\nu^S(\nu) = \frac{1}{4\pi}\int_{\gamma_{min}}^{\gamma_{max}} P(\nu,\gamma)N(\gamma)d\gamma \propto \nu^{-\frac{s-1}{2}}$$



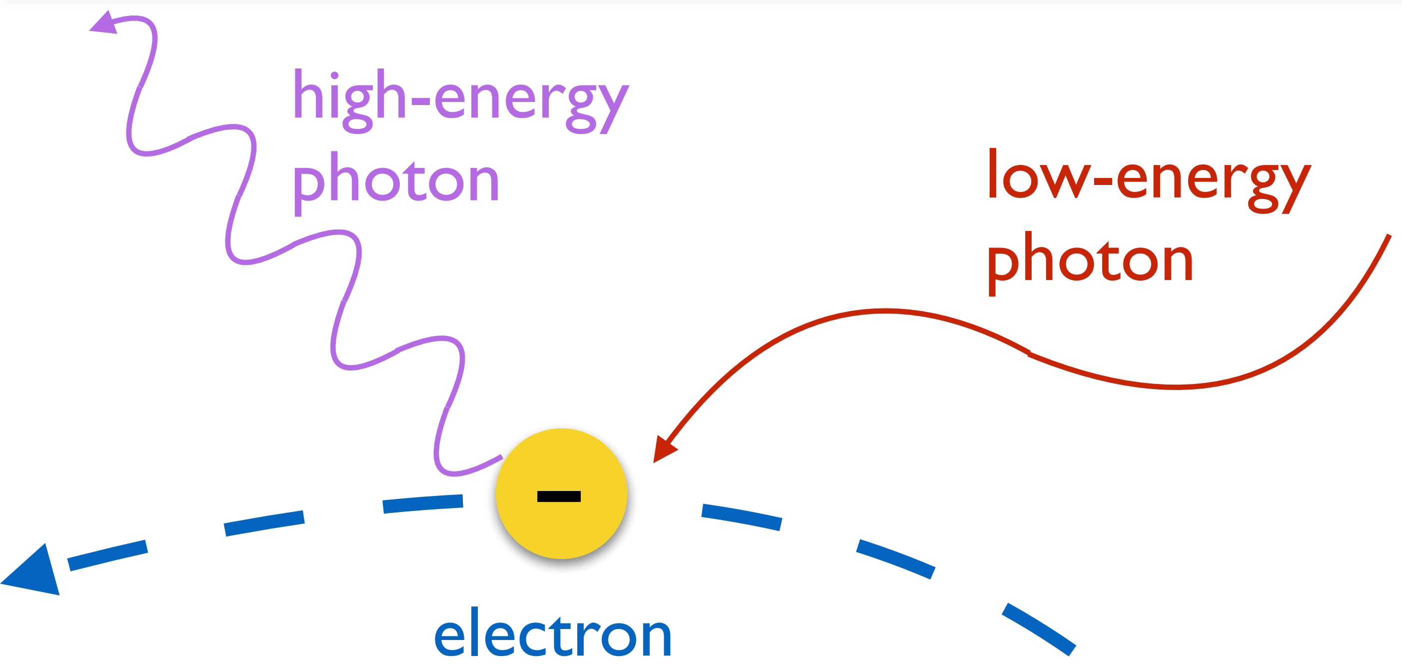
obs. data → model

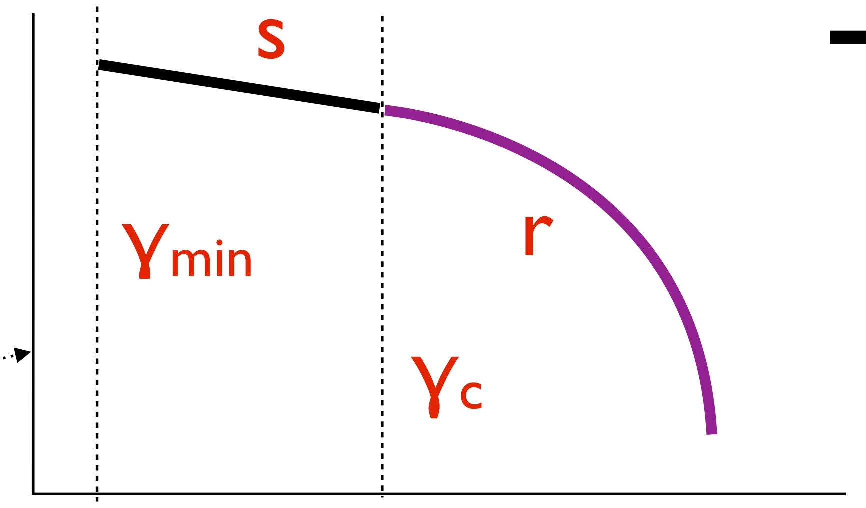
- synch. spectral index

- s el. distr.
- γ_{min}

IC emission basics

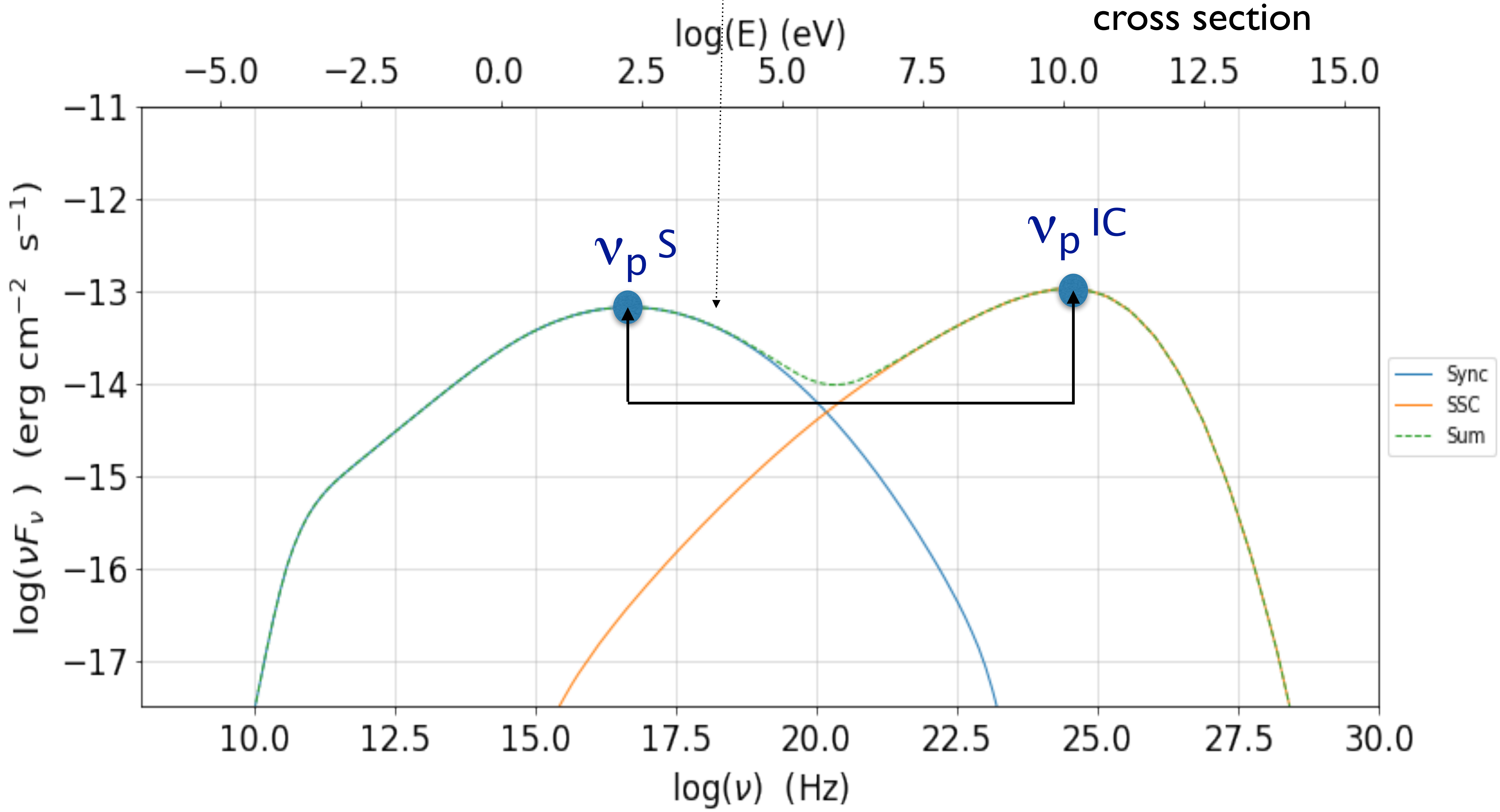
Tutorial 2





$$j_\nu^{SSC} = \frac{3}{4}\frac{h\nu\sigma_T c}{4\pi}\int_0^\infty n(\nu_0)d\nu_0 \int_{\gamma_{min}}^{\gamma_{max}} \frac{N(\gamma)}{\gamma^2} F_c(\gamma,\nu,\nu_0)d\gamma$$

cross section



soft photon energy
in the e- rest frame

$$\epsilon' = \frac{h\nu'}{m_e c^2}$$

$\epsilon' << m_e c^2$

TH regime

$\nu_p^{IC} / \nu_p^{S} \sim (4/3)\,\gamma_p^2$

$\epsilon' \geq m_e c^2$

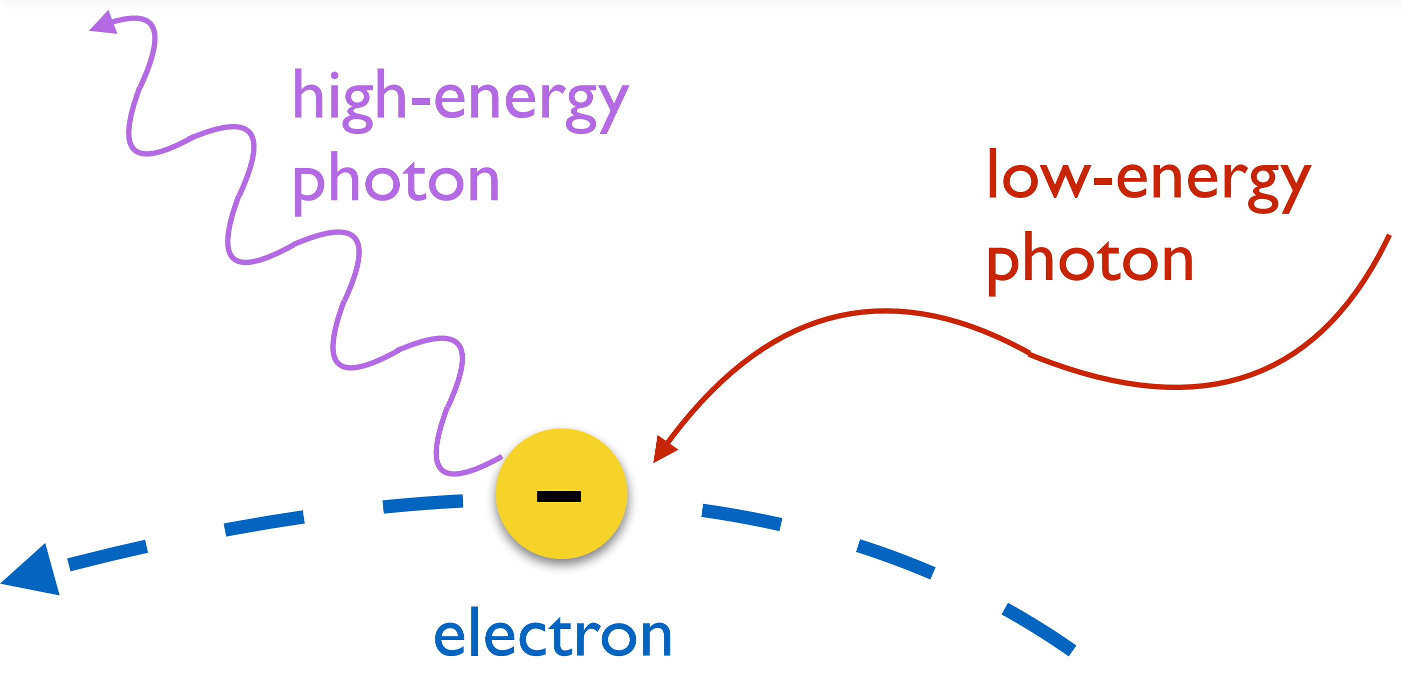
KN regime

$\nu_p^{IC} / \nu_p^{S} \sim \gamma_p$

$h\nu_p^{IC} \sim m_e c^2 \gamma_p$

JetSeT

IC emission basics

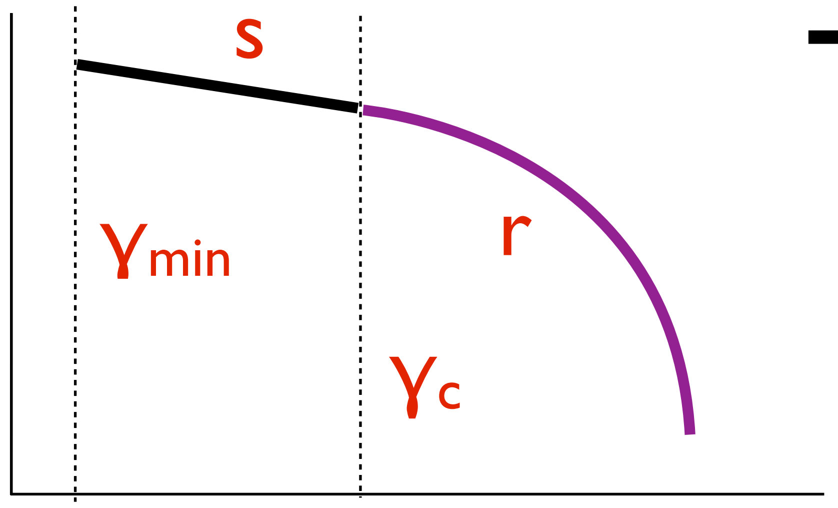


soft photon energy in the e- rest frame

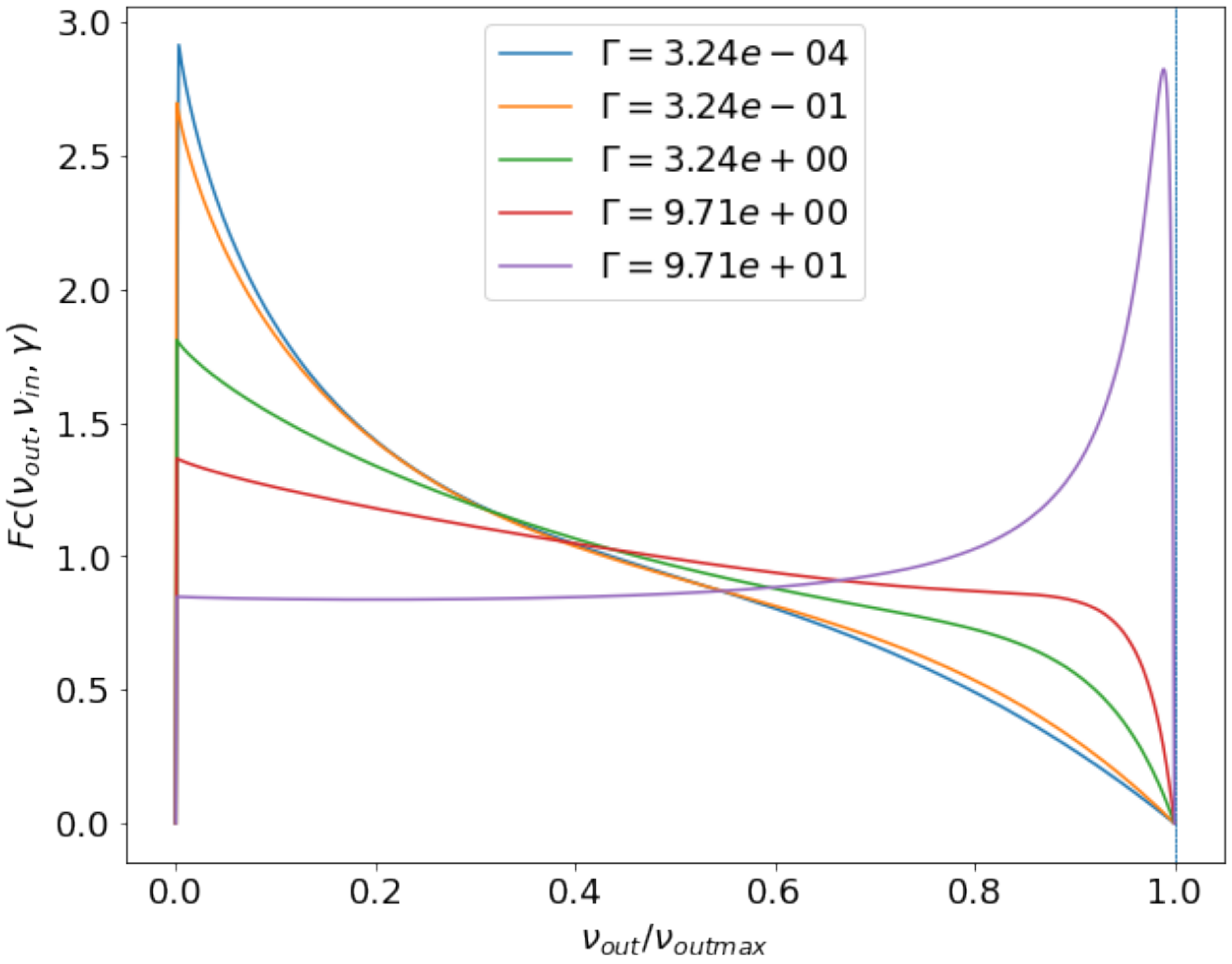
$$\epsilon' = \frac{h\nu'}{m_e c^2}$$

$$\nu_{\rm out\ max} = \frac{4\nu_{\rm in}\gamma_e^2}{1+4\gamma_e\epsilon'}$$

$$\Gamma = 4\epsilon'\gamma_e$$



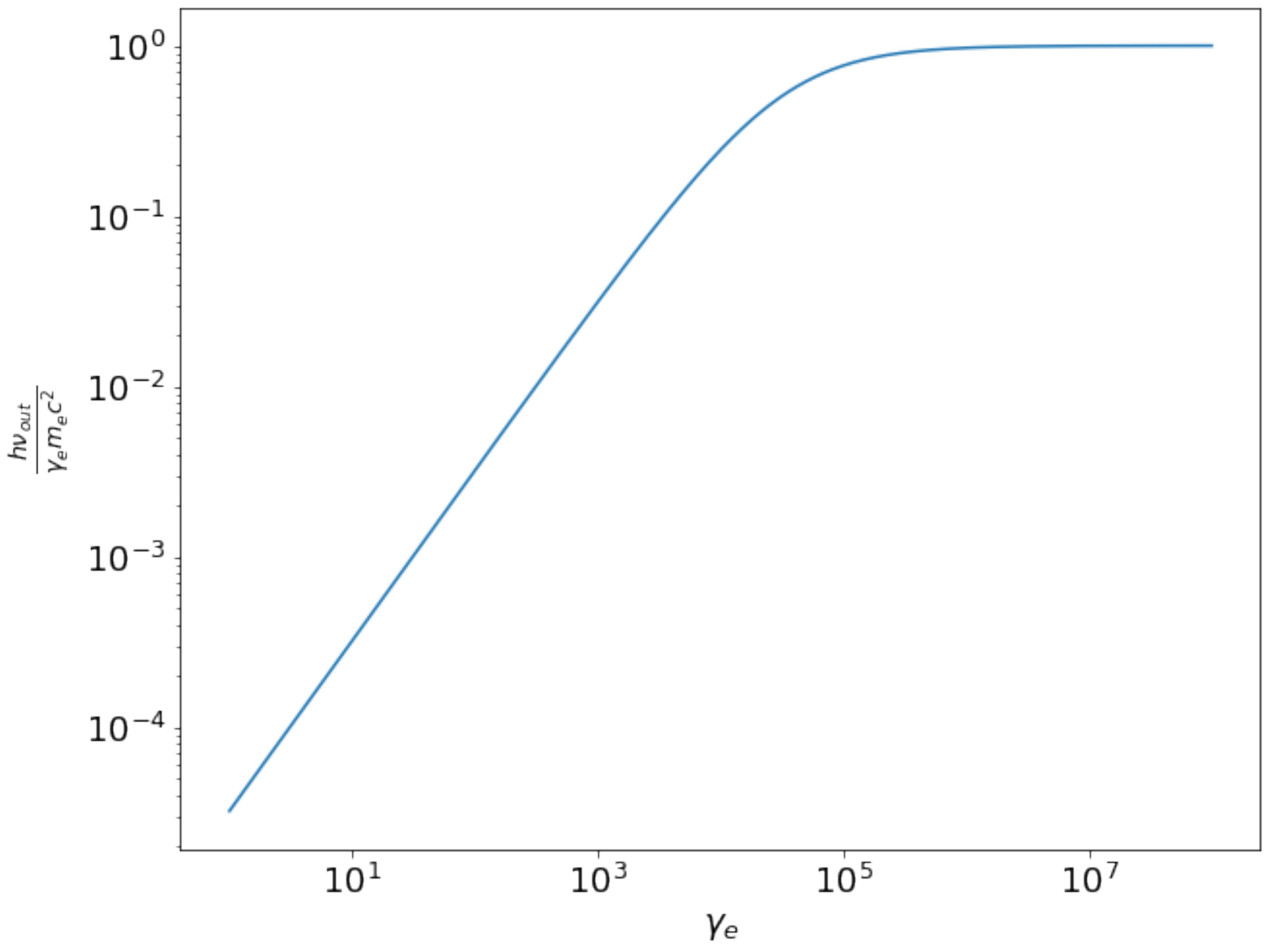
Tutorial 2



TH regime

$\epsilon' << m_e c^2$

$\nu_p^{IC} / \nu_p^{S} \sim (4/3)\, \gamma_p^2$



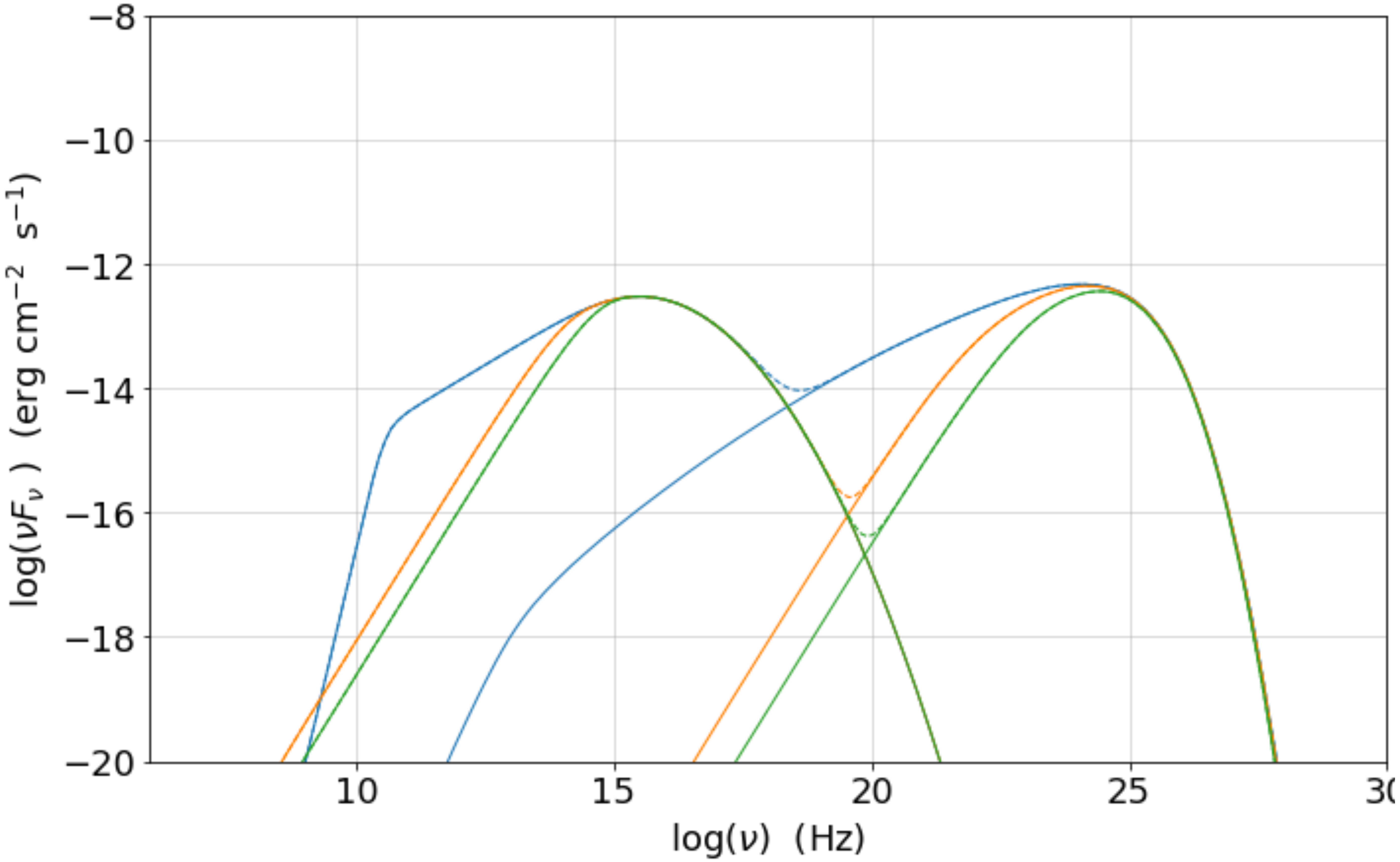
KN regime

$\epsilon' \geq m_e c^2$

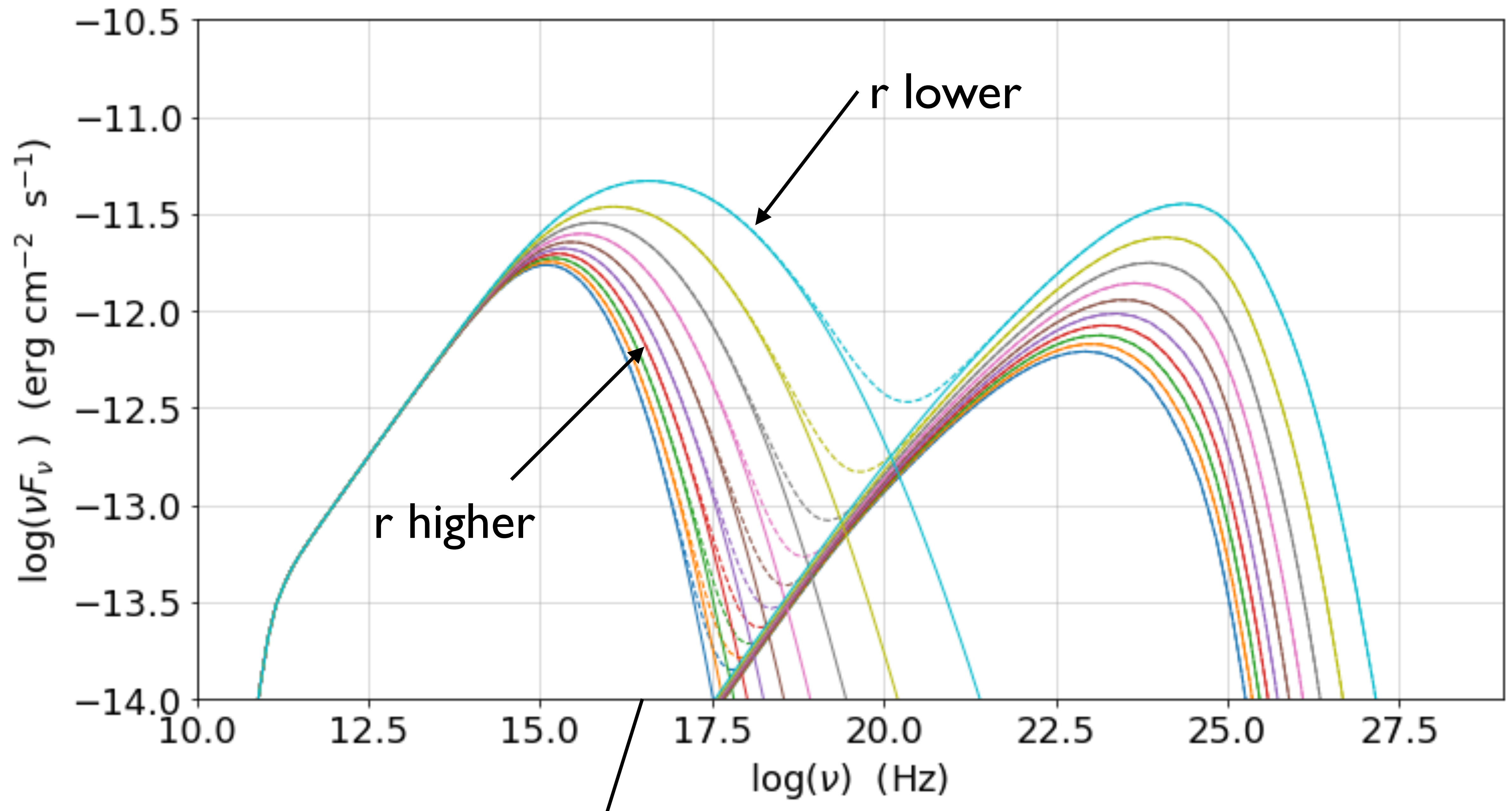
$\nu_p^{IC} / \nu_p^{S} \sim \gamma_p$

$h\nu_p^{IC} \sim m_e c^2 \gamma_p$

Adding the IC emission SSC case

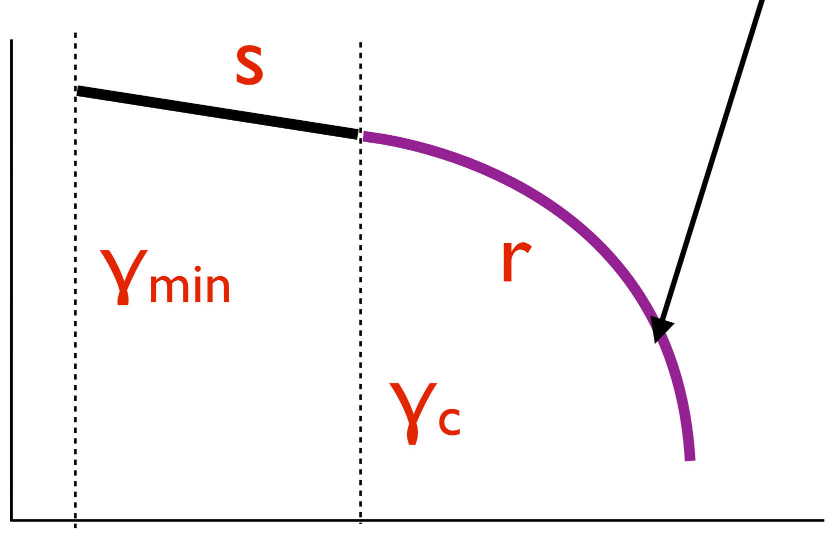


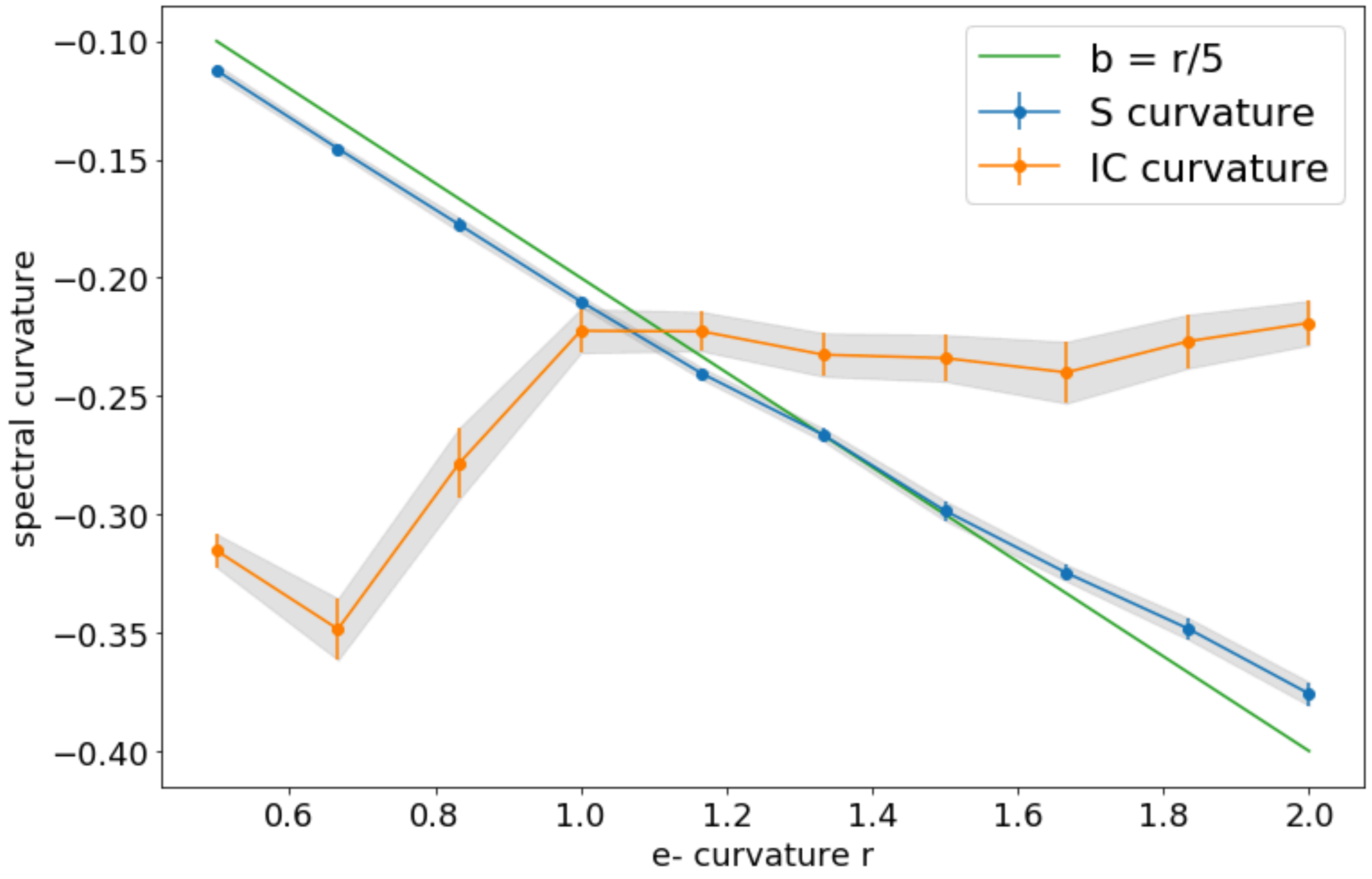
IC emission TH/KN regime and peak curvature



change *r*

Tutorial 2





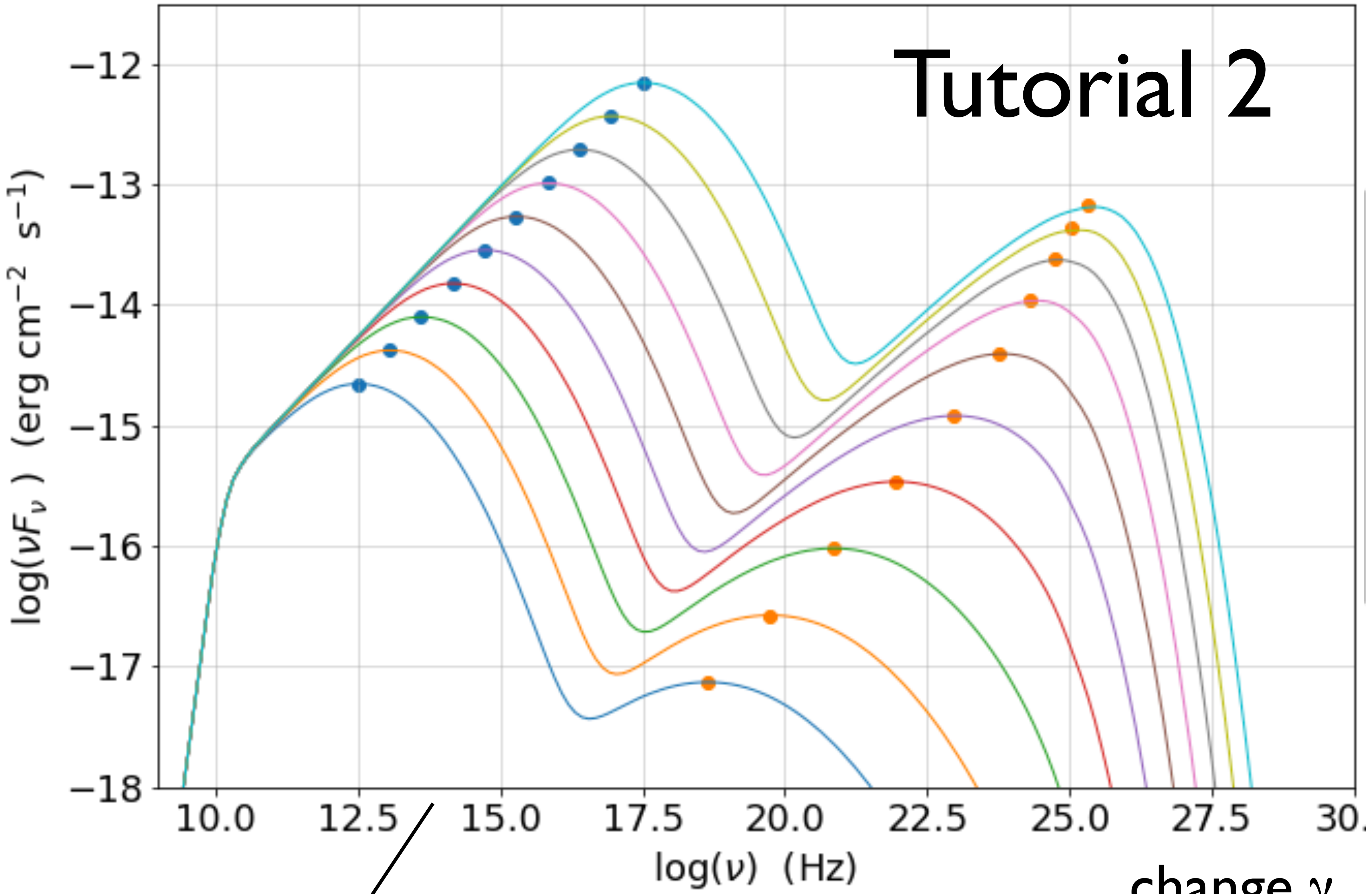
obs. data → model

- spectral curvature

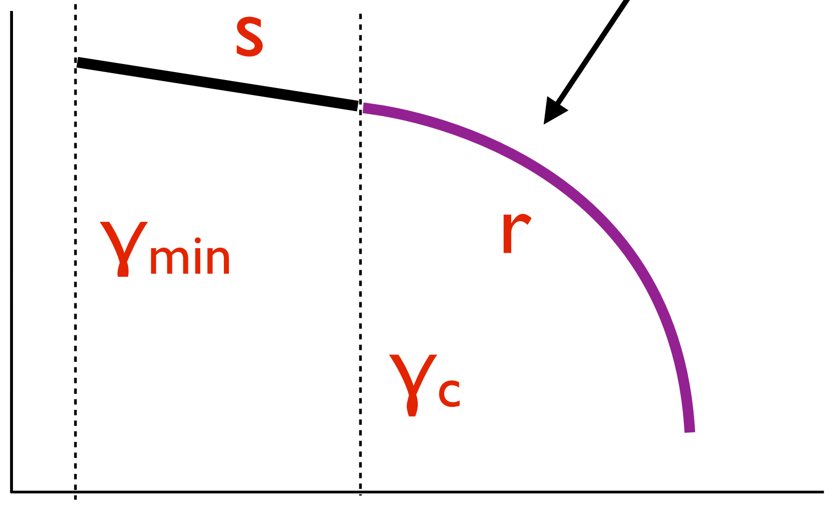
- KN regime
- r

IC emission TH/KN regime and peak freq.

- $\nu_p^{IC} / \nu_p^{S} \sim (4/3)\, \gamma_p^2 \equiv \gamma^2{}_p^{IC}$ is true only in TH regime

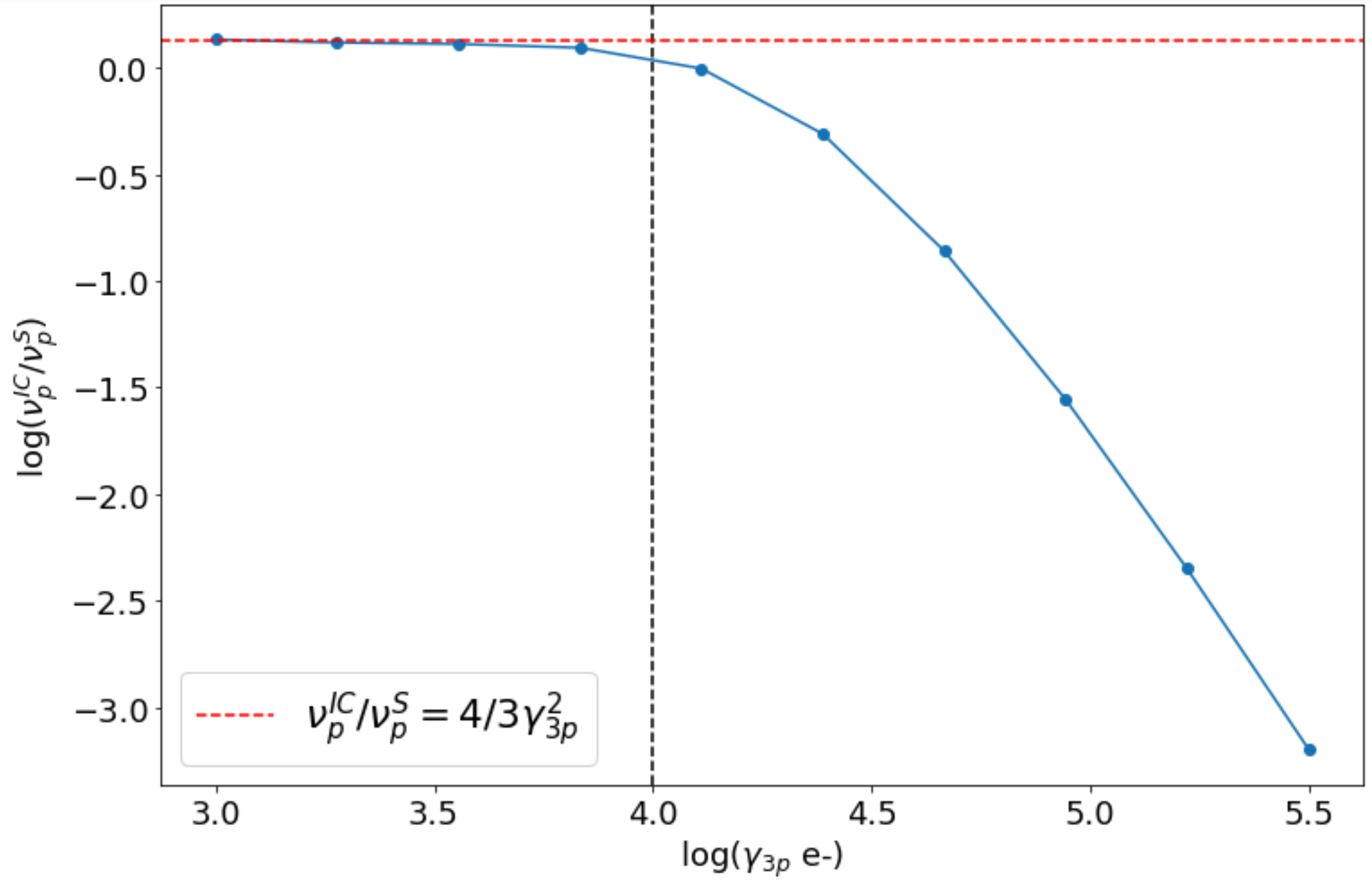


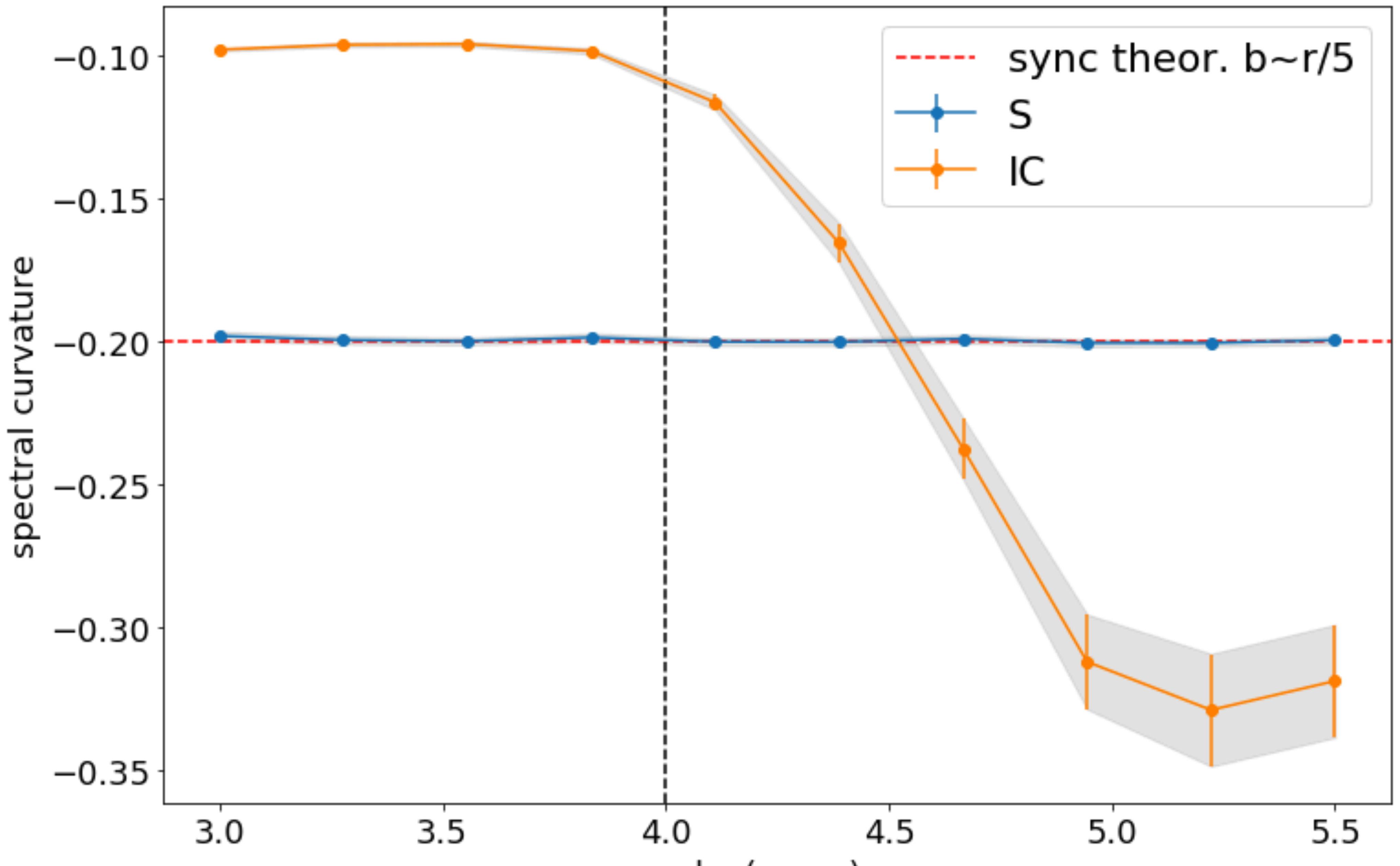
change γ_c



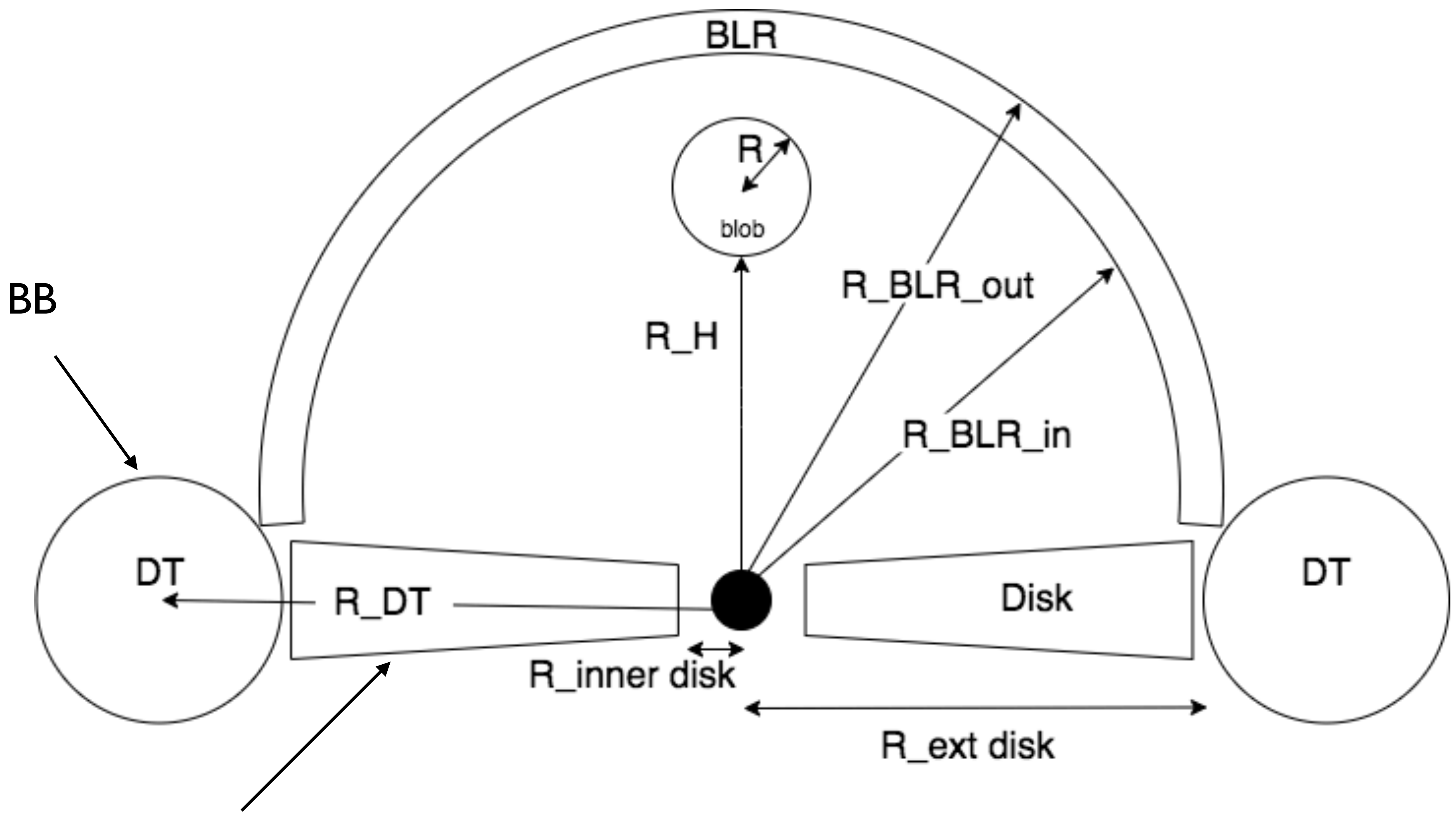
obs. data
- spectral curvature
- peak freq.

model
- KN regime
- γ_p, γ_c

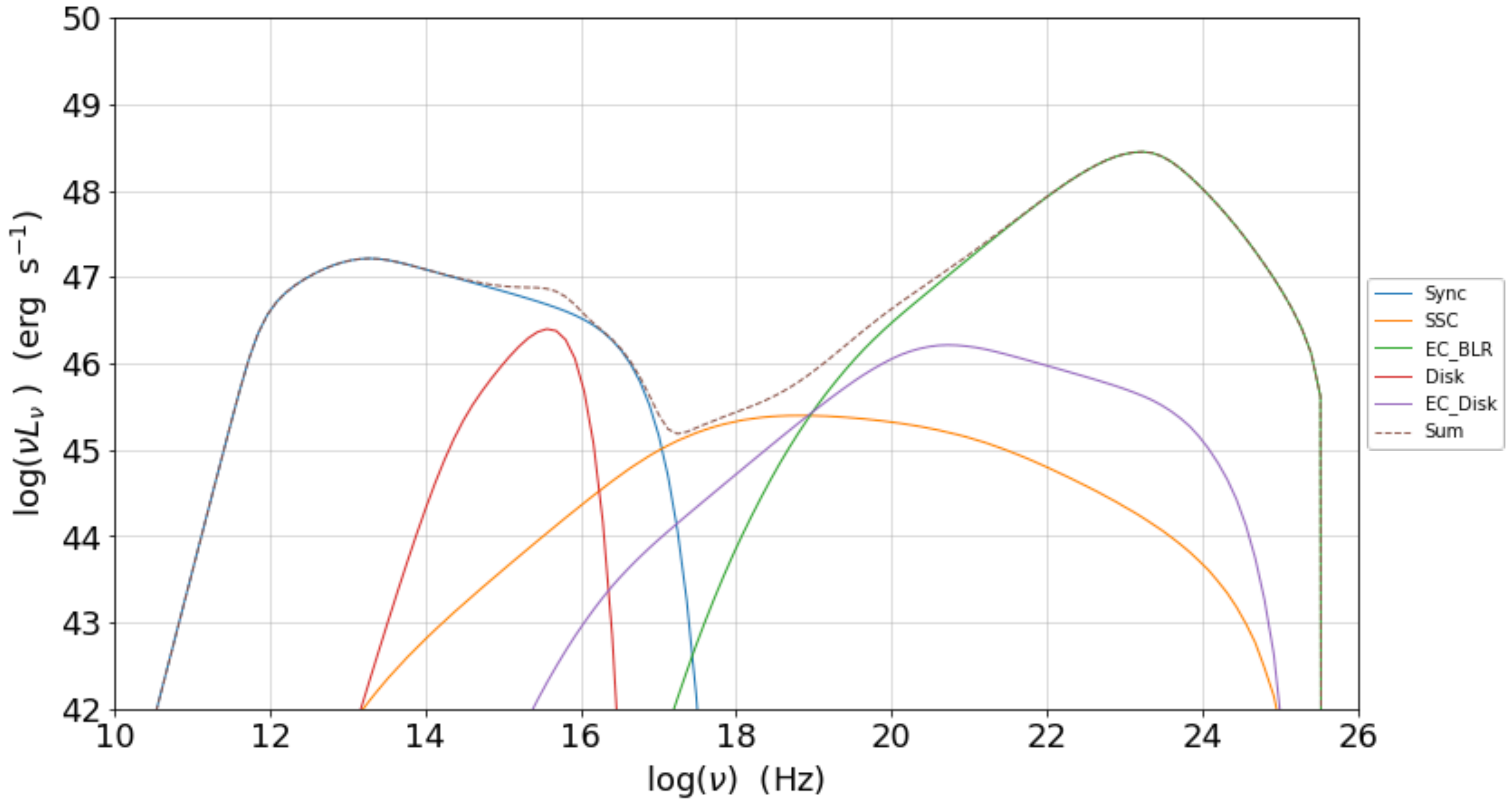




External Compton Scenario



multi T BB $T(R) \approx T_*(R/R*)^{-3/4}$



Transformation of the radiative fields

$$\epsilon^{-3} I_\epsilon \text{ and } \epsilon^{-2} j(\epsilon, \Omega)$$

$$\frac{u(\epsilon, \Omega)}{\epsilon^3} = \frac{u'(\epsilon', \Omega')}{\epsilon'^3} = inv.$$

$$I_{\nu'} = \frac{1}{4\pi} \int d\Omega' \, \delta^3 I_{\nu=(\nu'/\Gamma)}$$

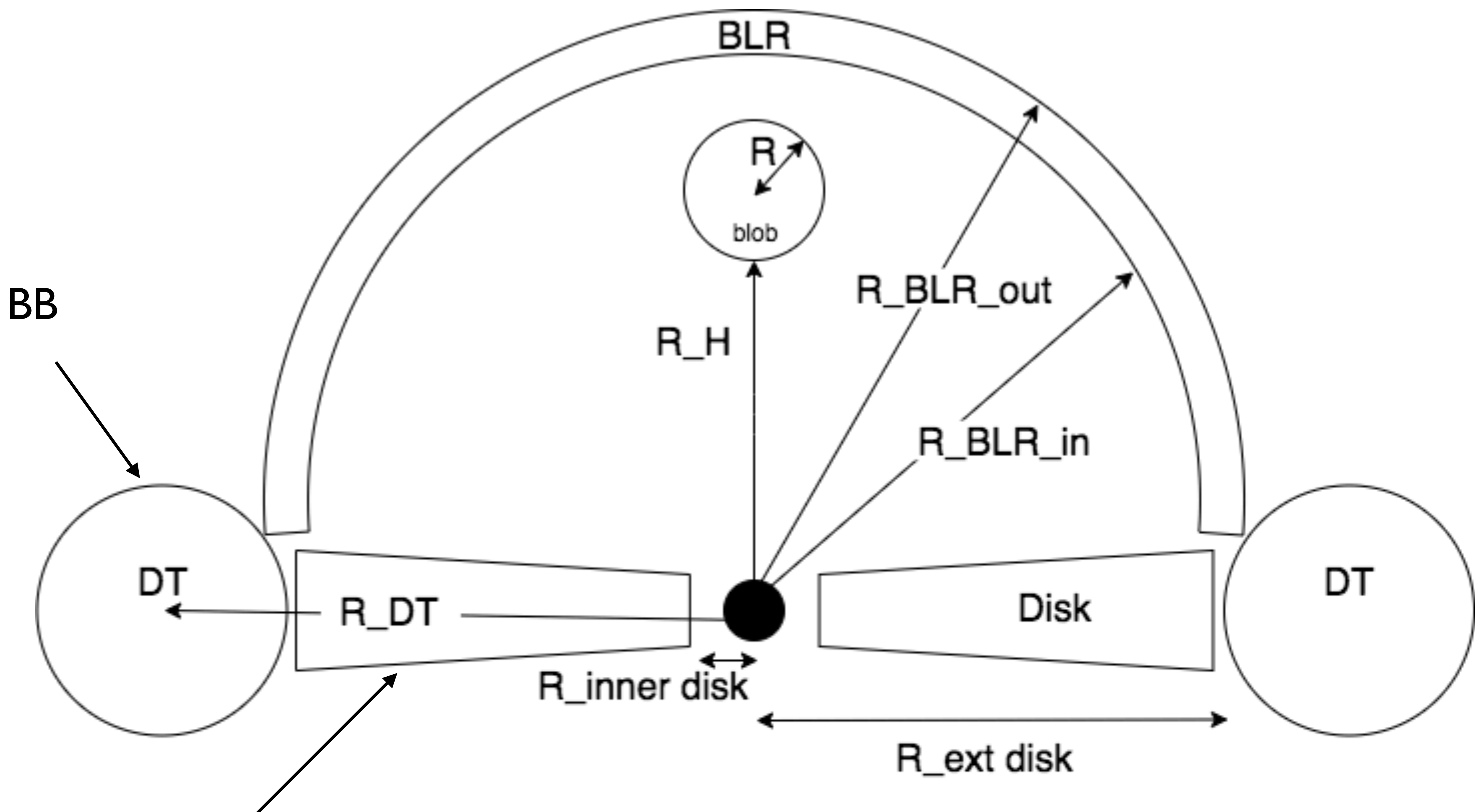
$$= \Gamma\tau \frac{L_{\rm nuc}}{4\pi R^2} f_{\nu=(\nu'/\Gamma)}(T_{\rm ext})$$

$$u'_{ext} \simeq \Gamma^2 u_{ext}$$

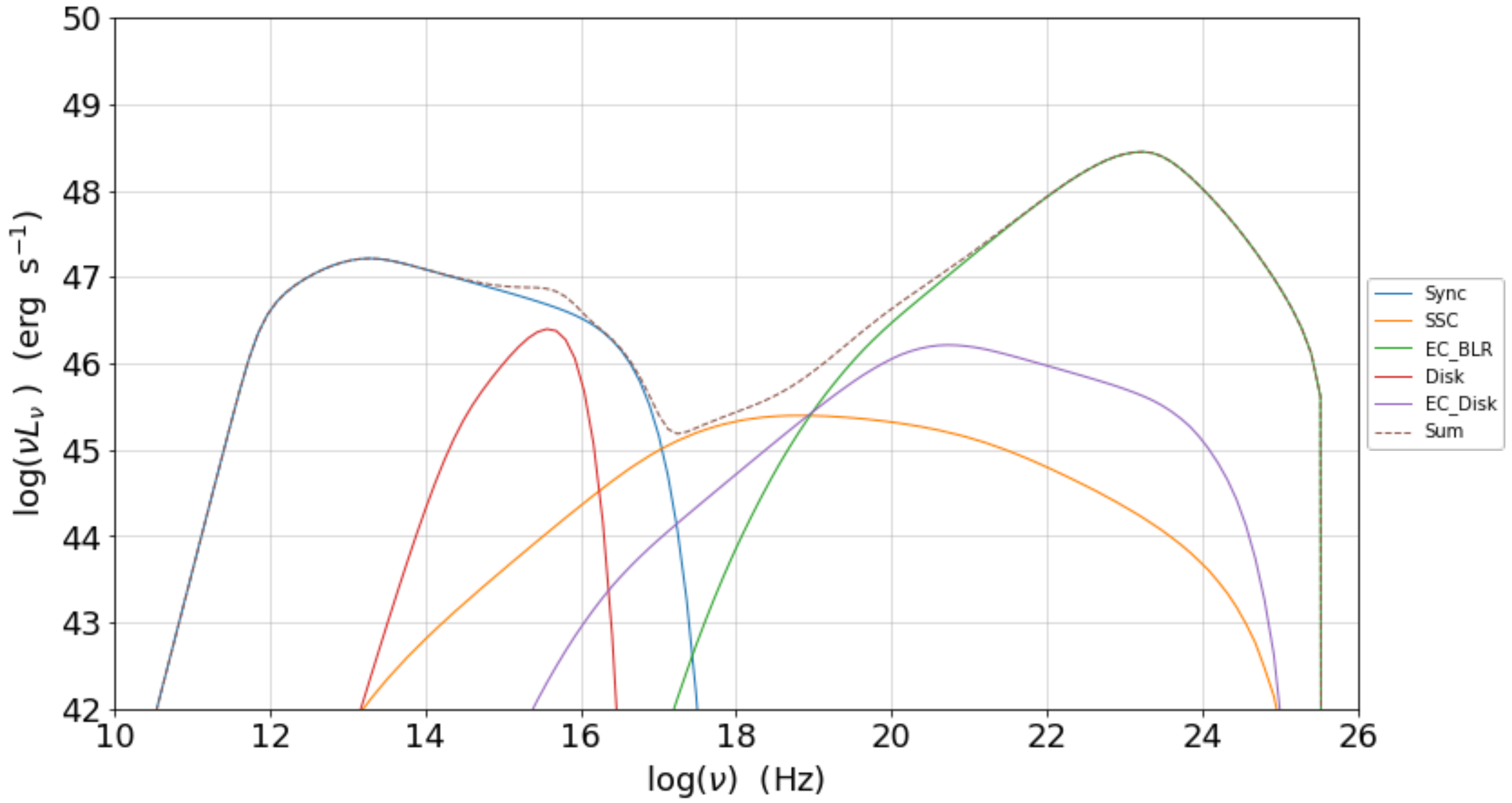
$$L_{ERC} \simeq \Gamma^6 U_{ext}$$

$$\eta = \frac{\dot{\gamma}_{IC}}{\dot{\gamma}_{sync}} = \frac{U_{ph}}{U_B}$$

External Compton Scenario



multi T BB $T(R) \approx T_*(R/R*)^{-3/4}$



$$n'(\gamma', \Omega') = n'(\gamma')/4\pi$$ Isotropic emitters distr.

$$n/\gamma^2$$ Invariant.

Transformation of the emissters distribution

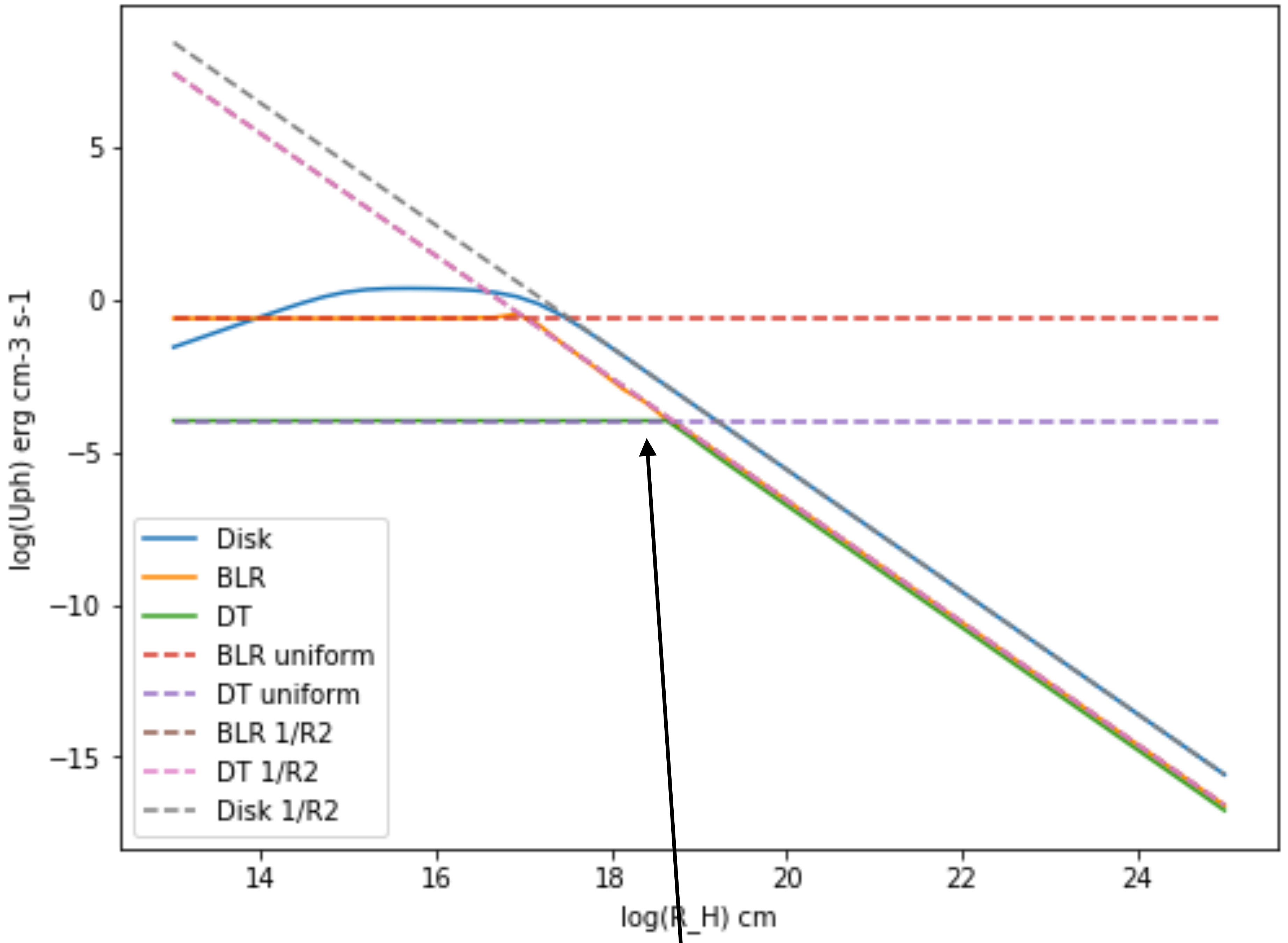
$$n(\gamma, \Omega) = \delta^2 n'(\gamma', \Omega) = \delta^2 n'(\gamma')/4\pi$$

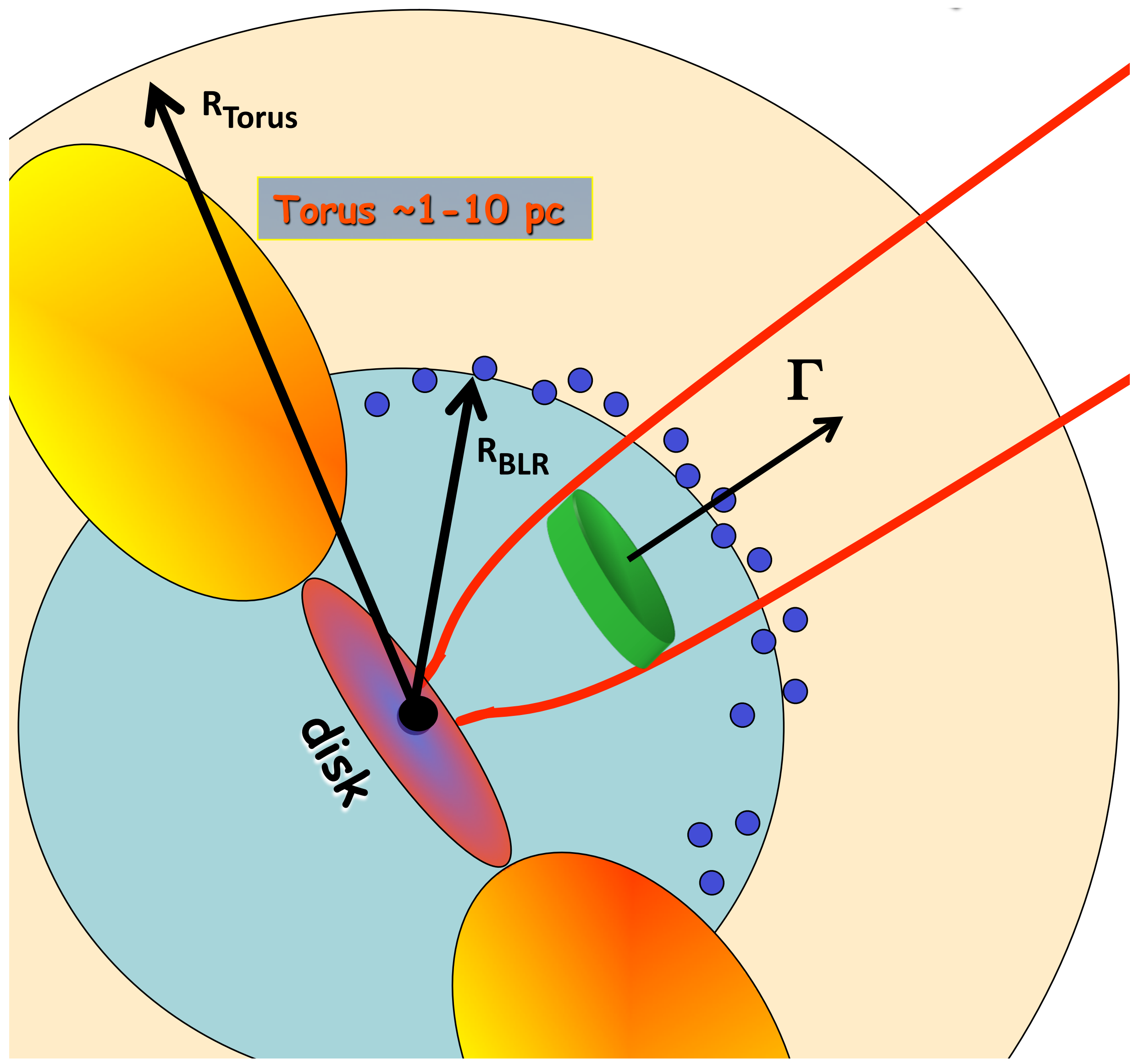
$$\gamma = \delta\gamma'$$

$$V = V'\delta$$

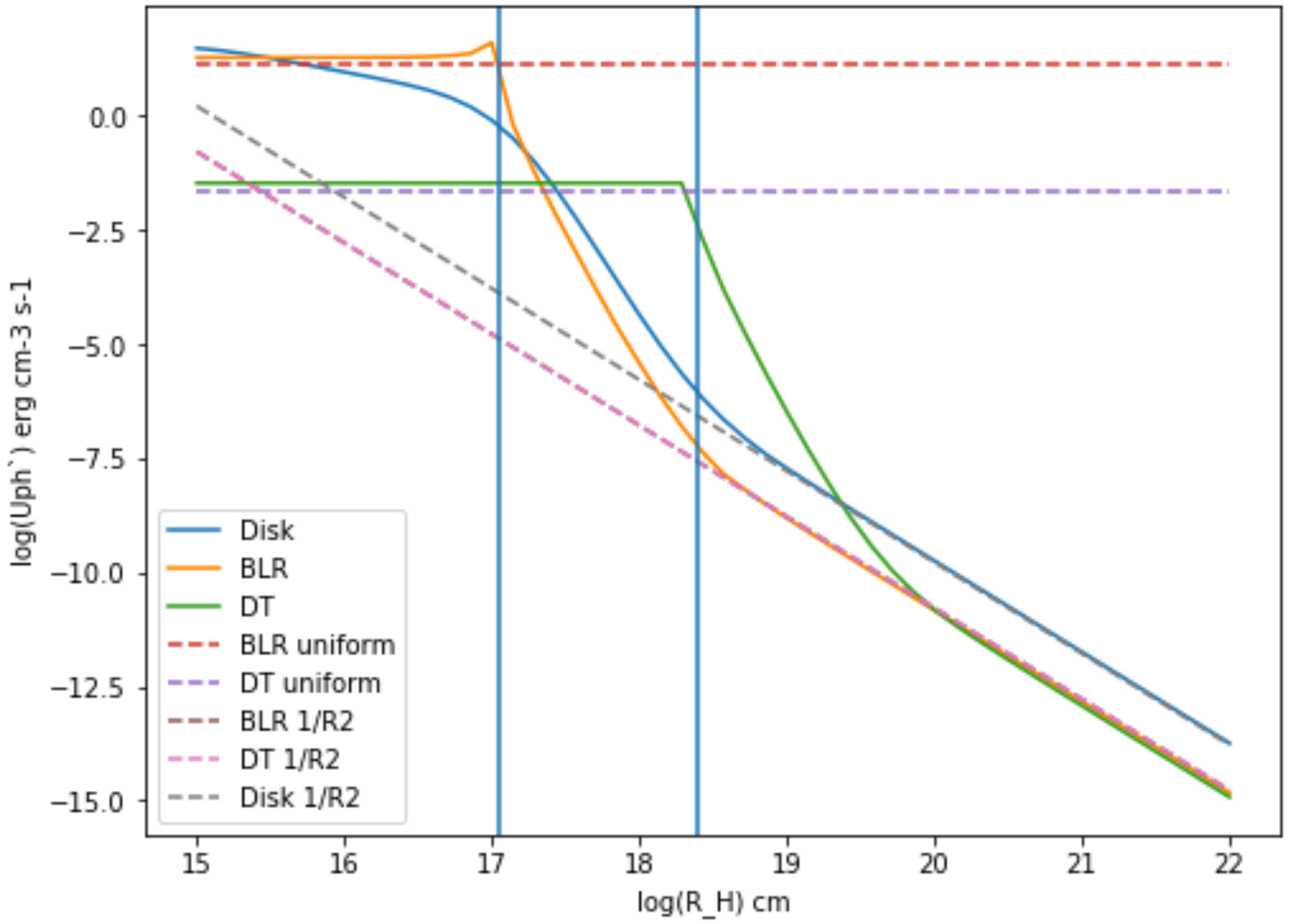
External Compton Scenario

external photon fields in the disk rest frame





external photon fields in the blob rest frame

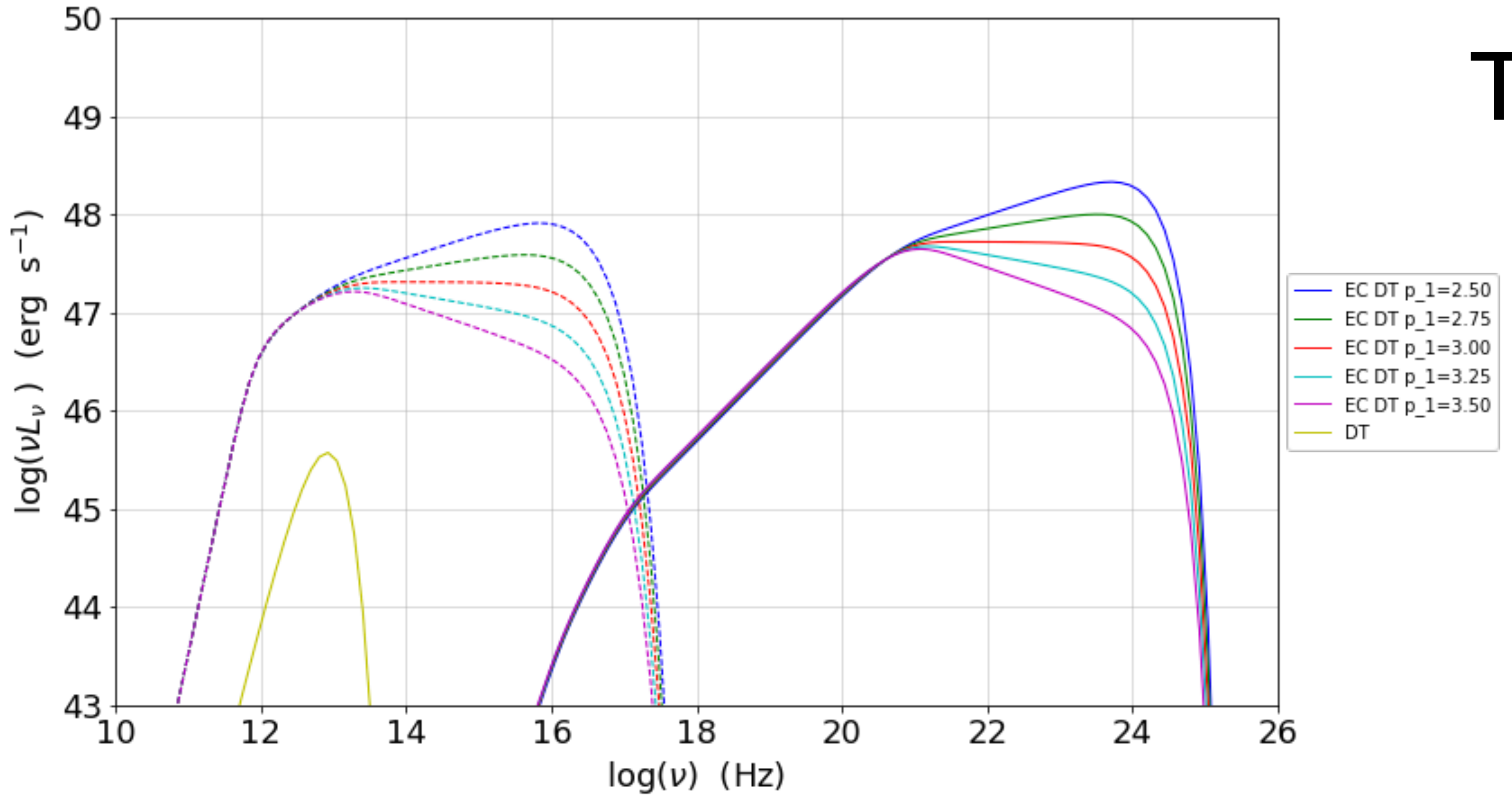


$$u'_{ext} \simeq \Gamma^2 u_{ext}$$

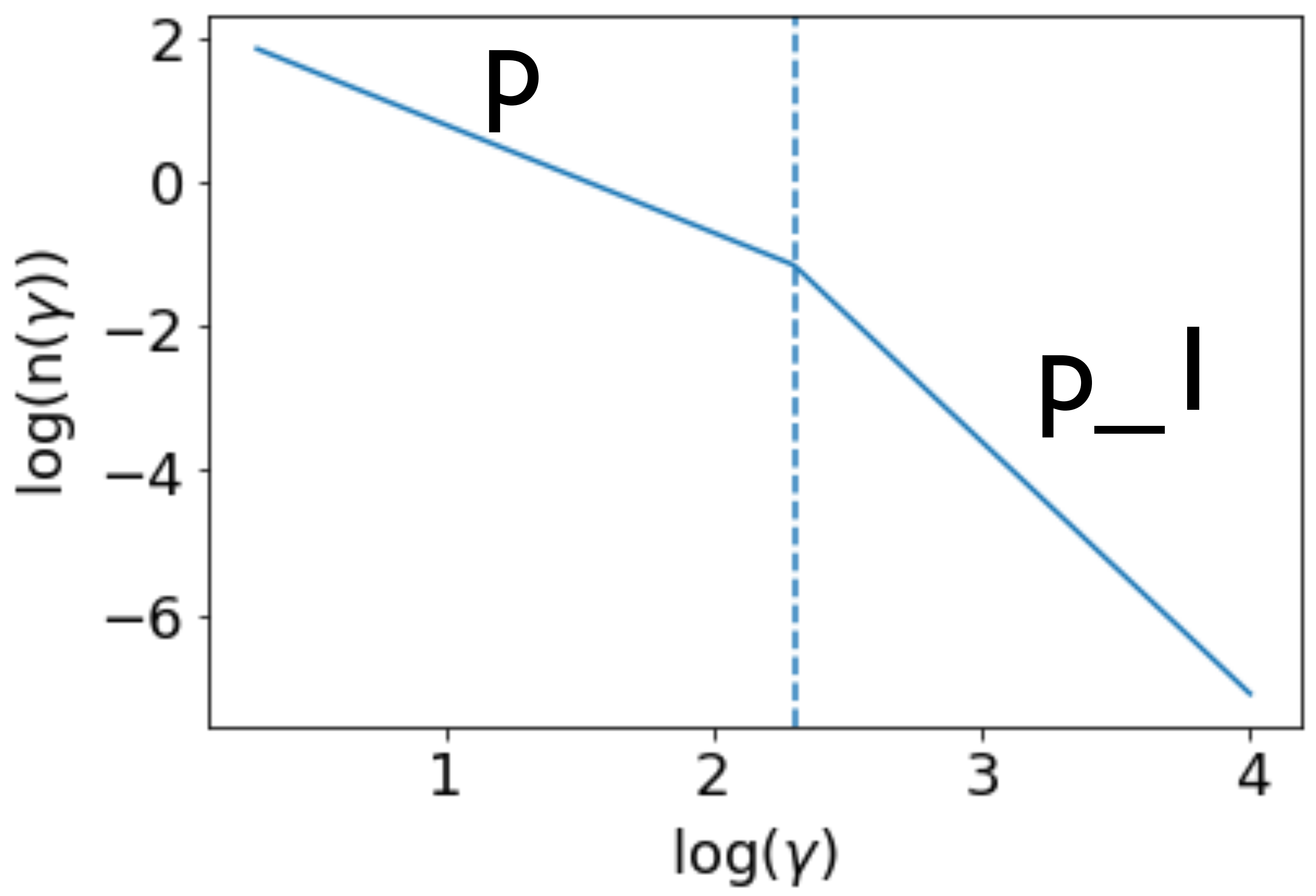
constant within the sphere

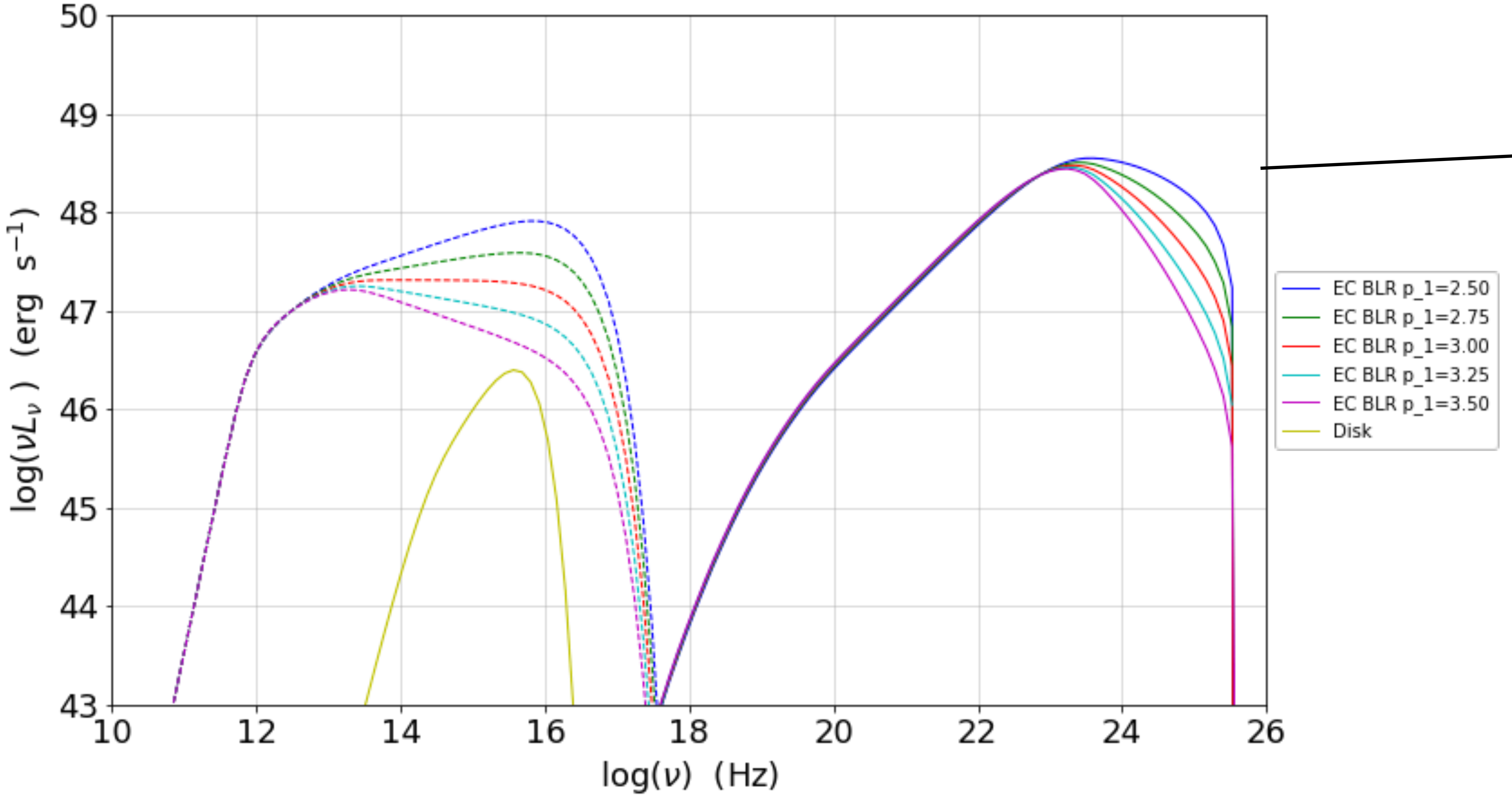
Tutorial 3

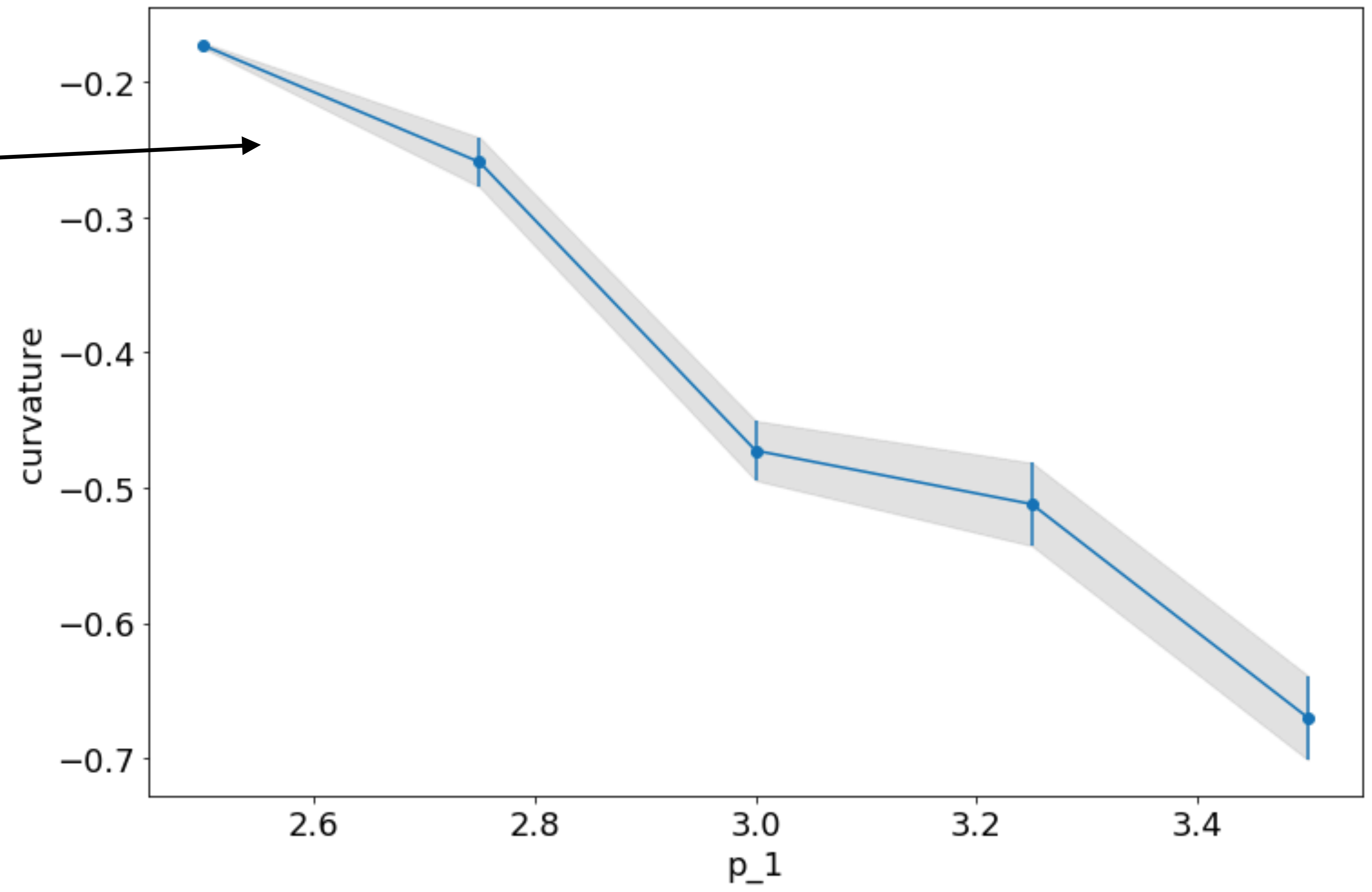
External Compton Scenario and TH/KN



Tutorial 3



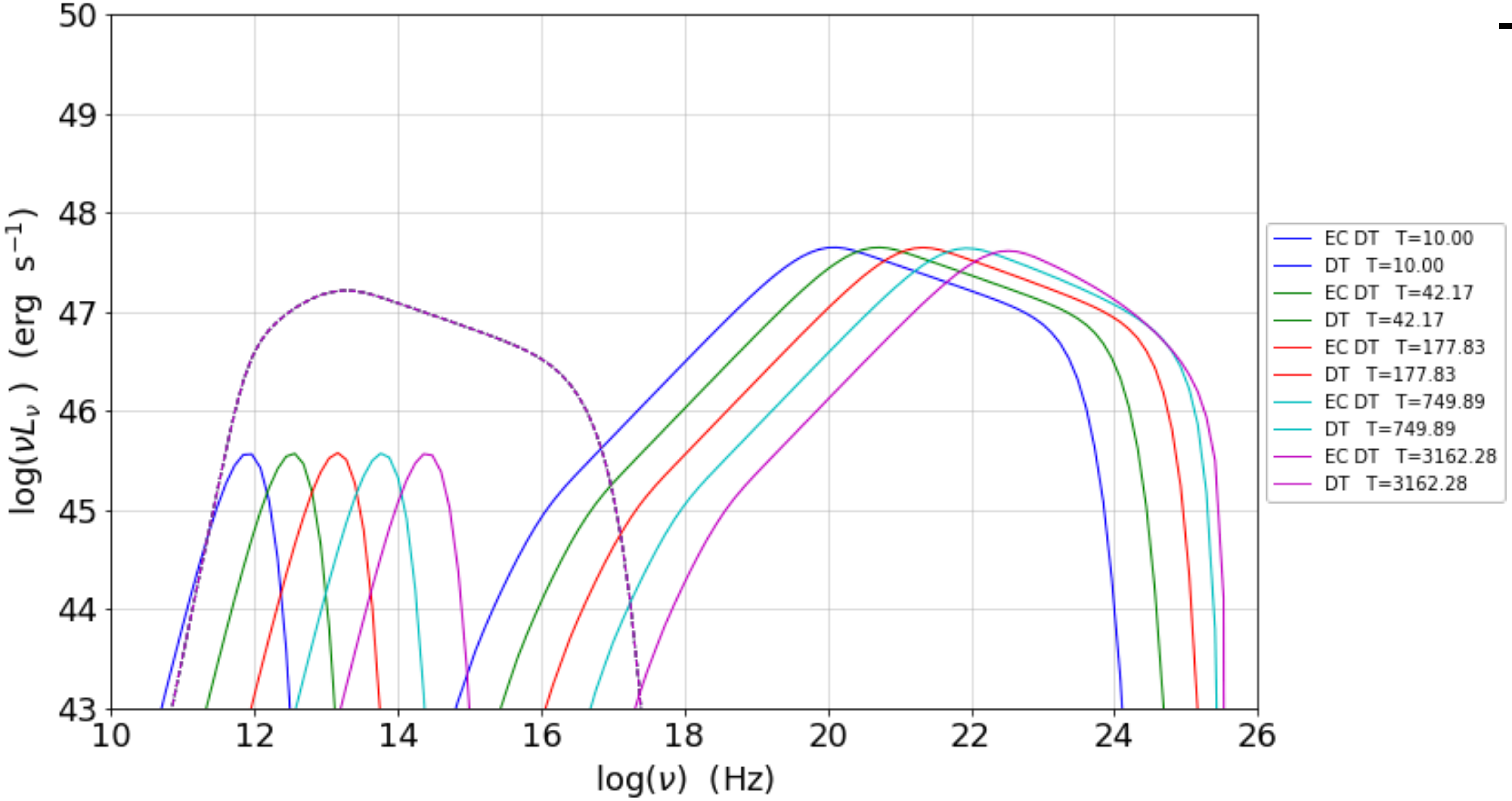




External Compton Scenario and external seed photons energy

$\nu_{p\,EC} \sim (4/3)\,\gamma^2\,\nu''_{p\,ext}\delta\Gamma/(1+z)$ $\quad\quad$ $\nu'_{seed-IC} = \nu''_{p\,ext}\Gamma$

Tutorial 3

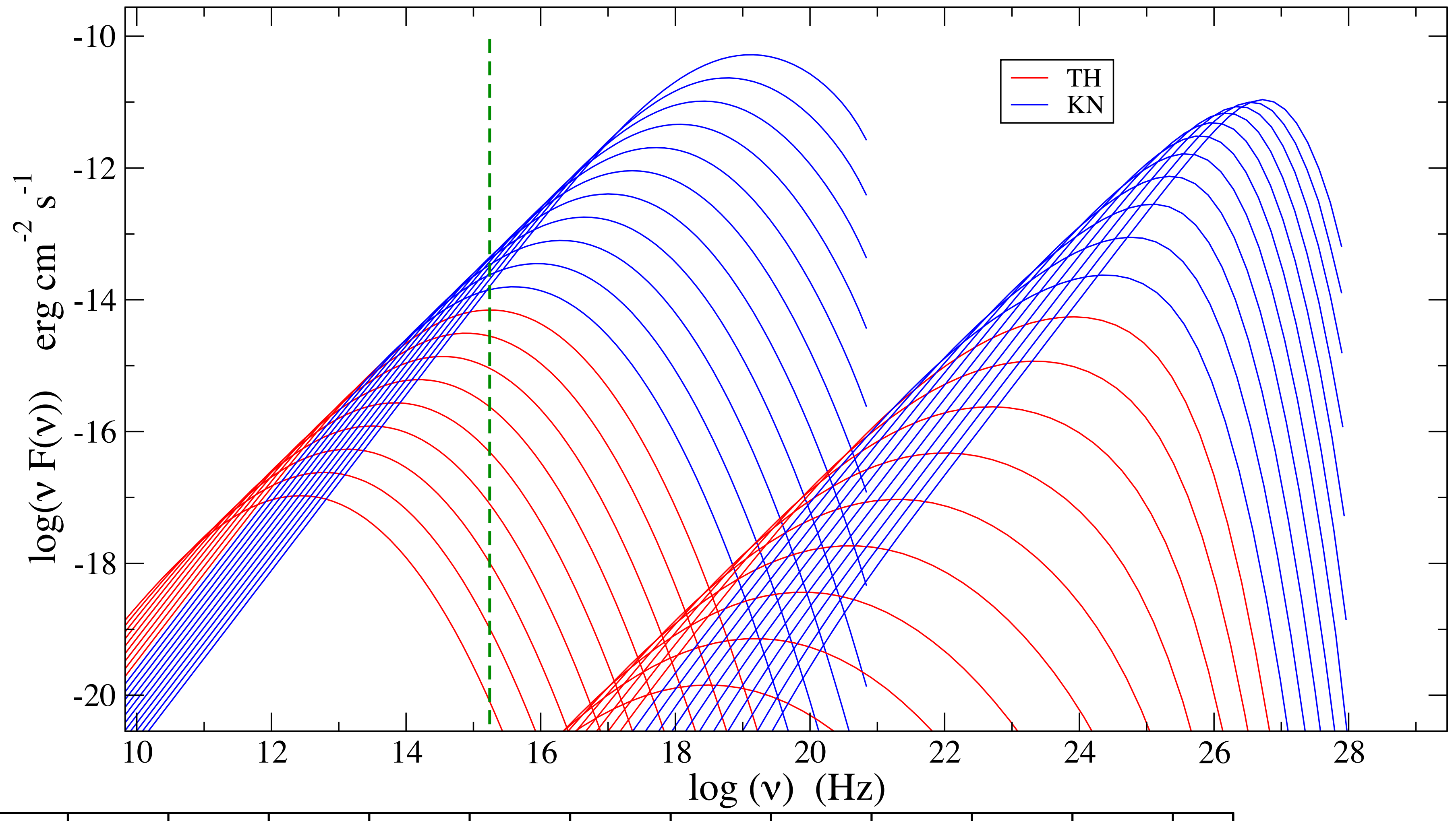


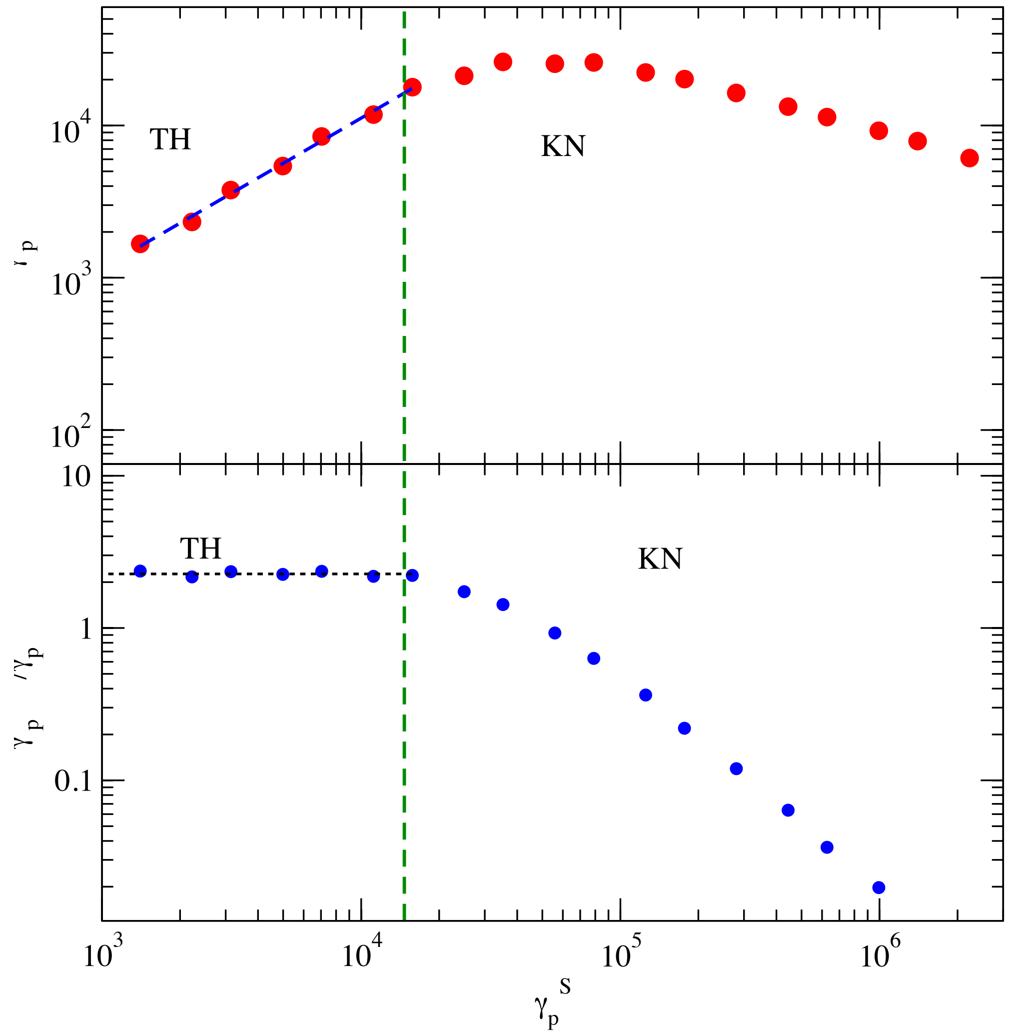
obs. data → model

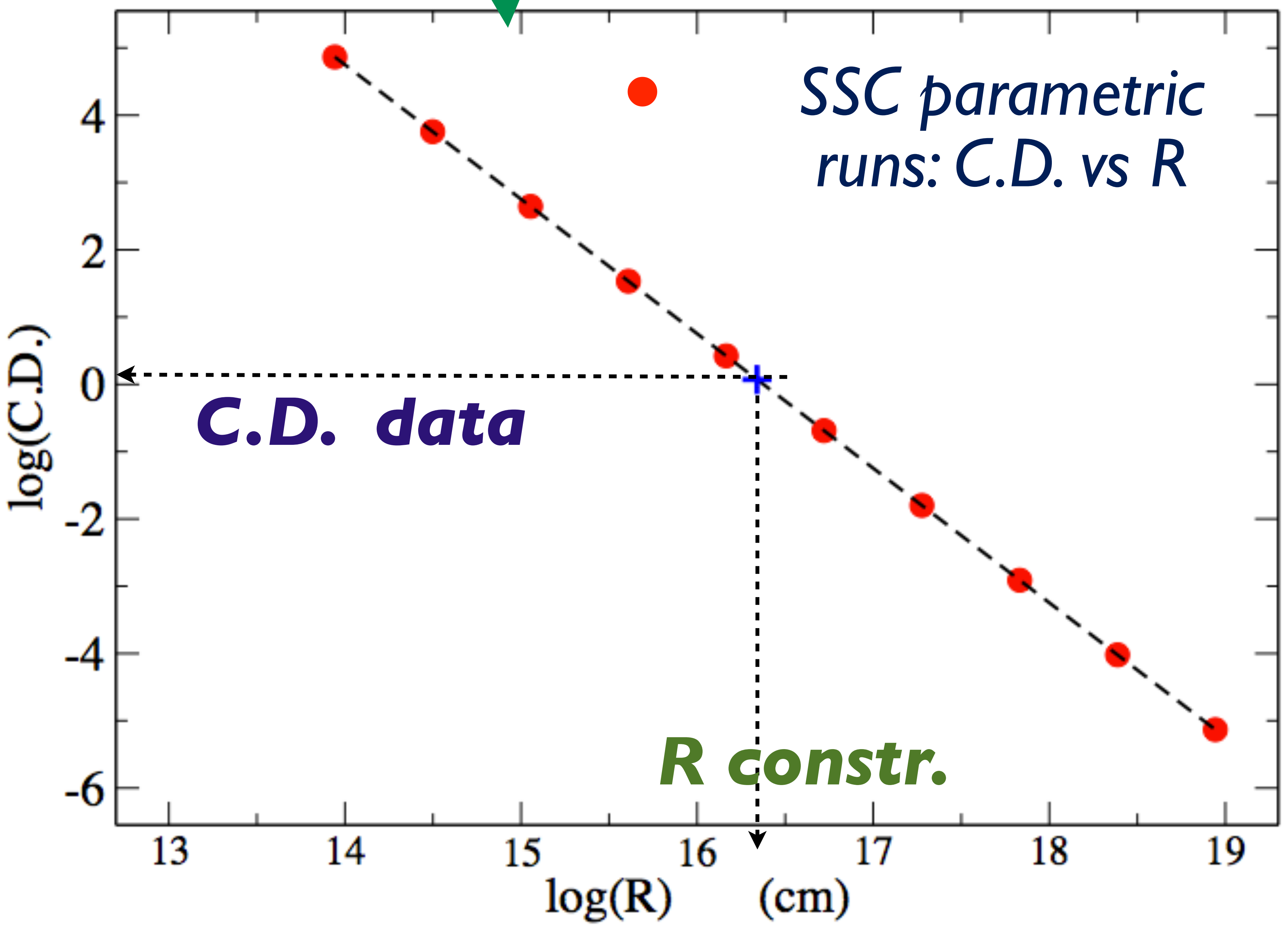
- peak freq. → • T seed ext.

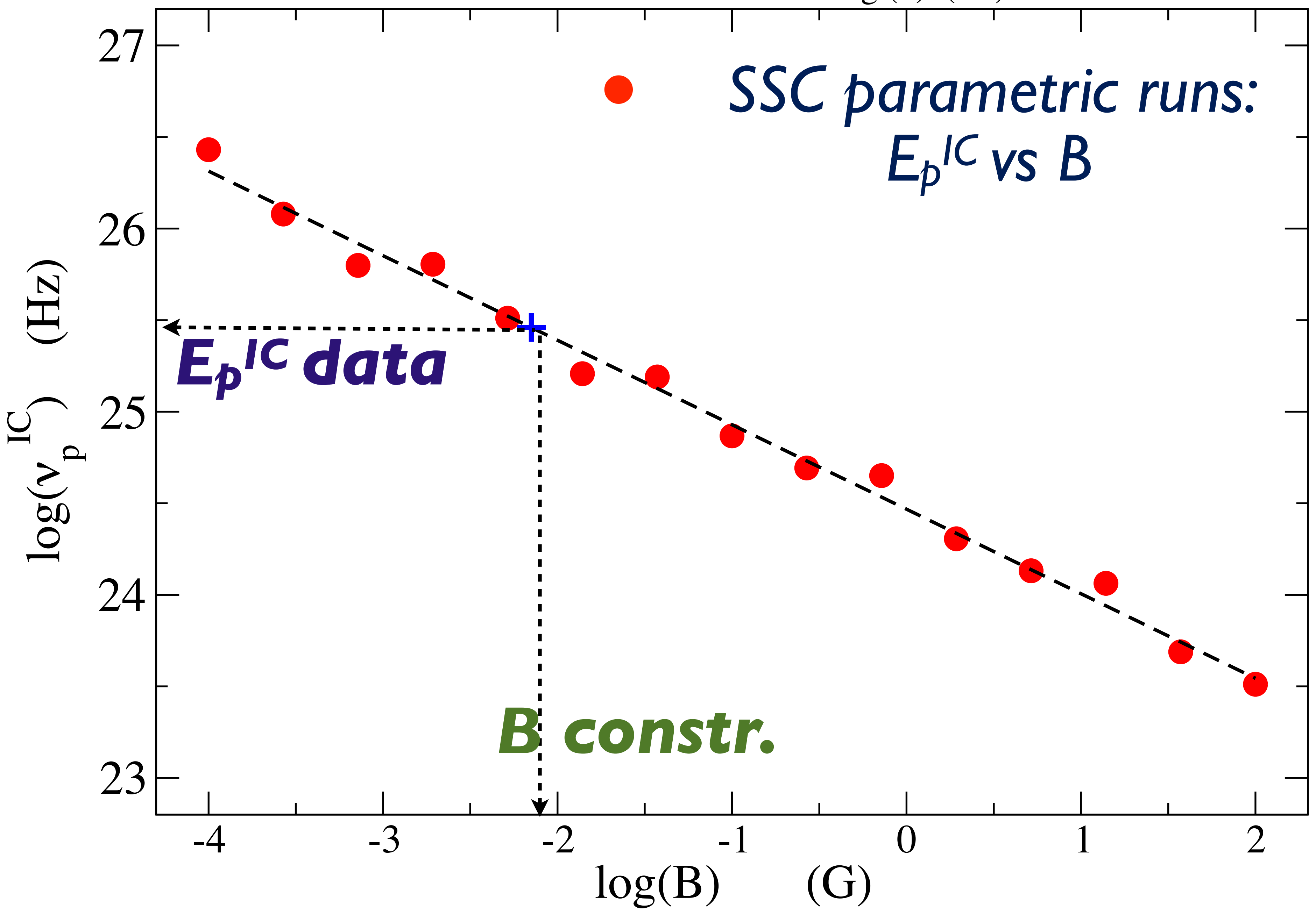
SED shaping and model constraining

- ✓ Γ=> s
- ✓ b=>r
- ✓ E_p^S,r,s=> γ_0
- ✓ t_{var},δ=> R u.l.
- ✓ N=> best S_p^S match
- B-> best E_p^{IC},S_p^{IC} match
- R -> CD



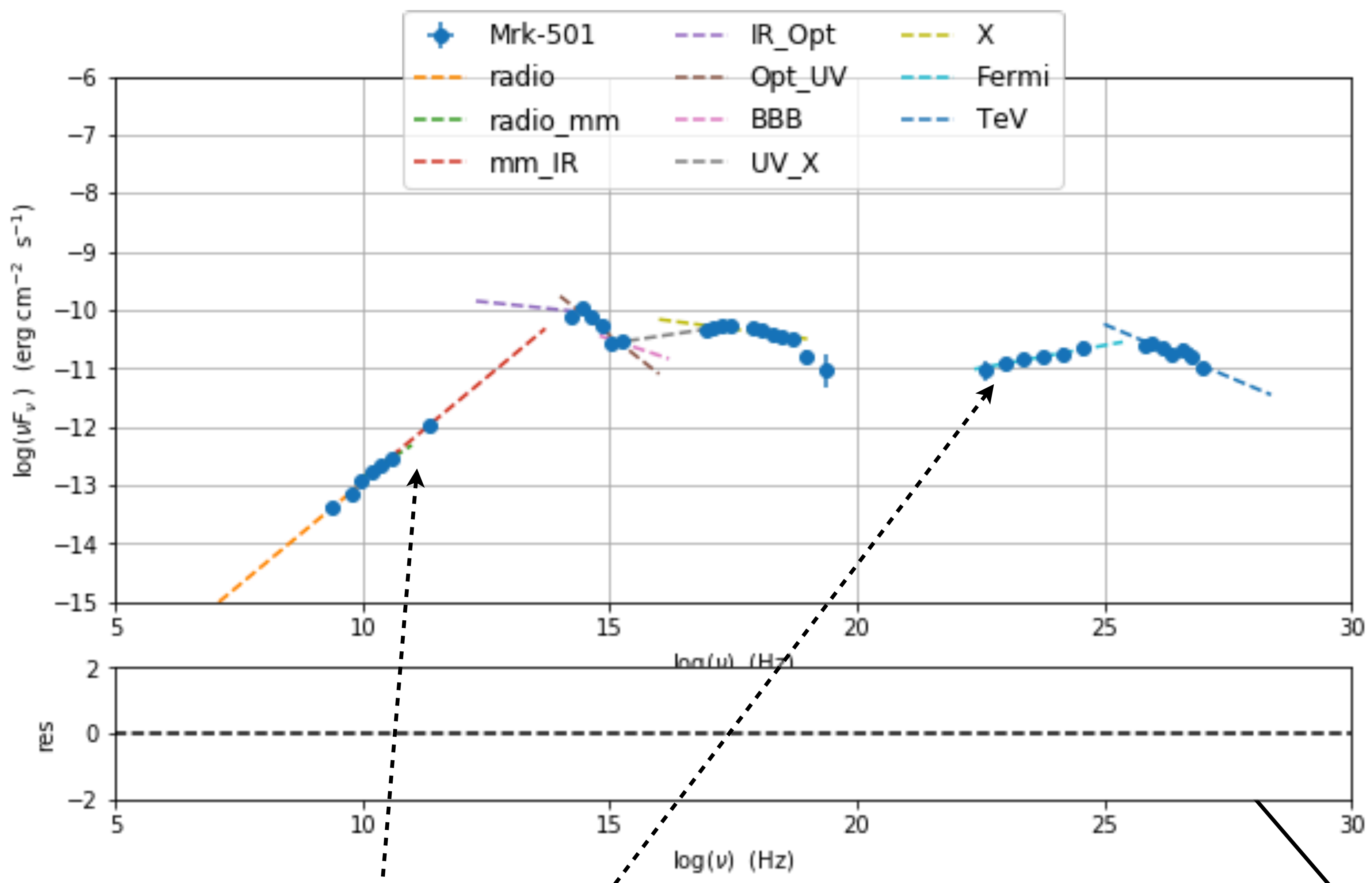


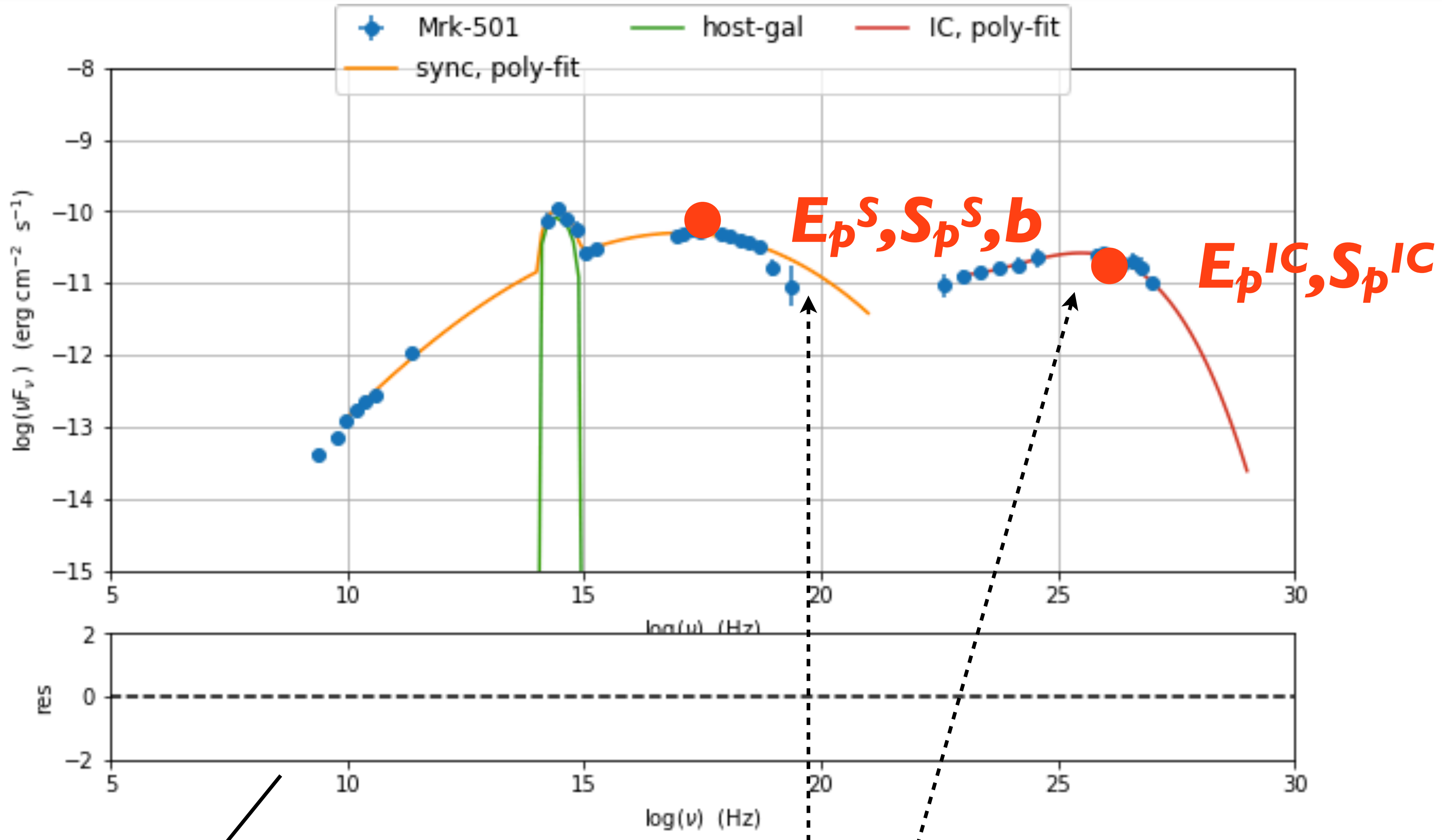


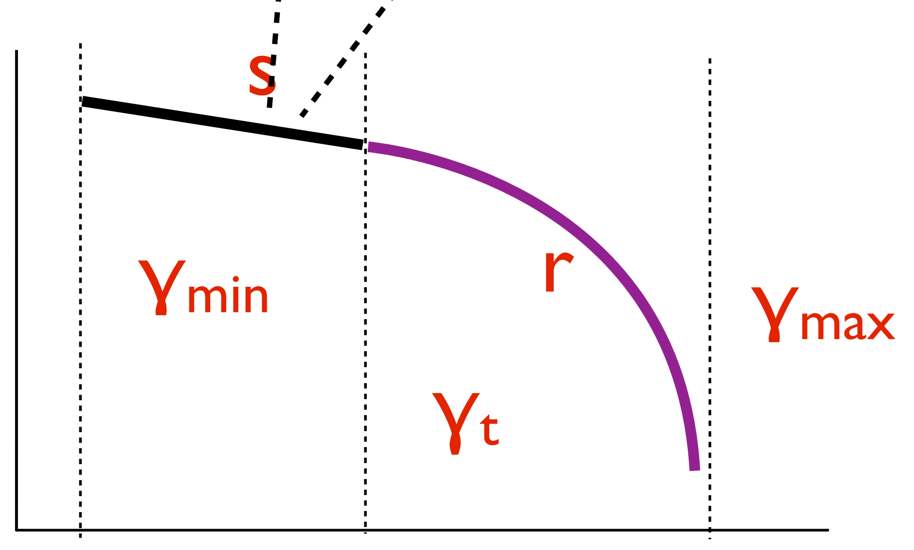


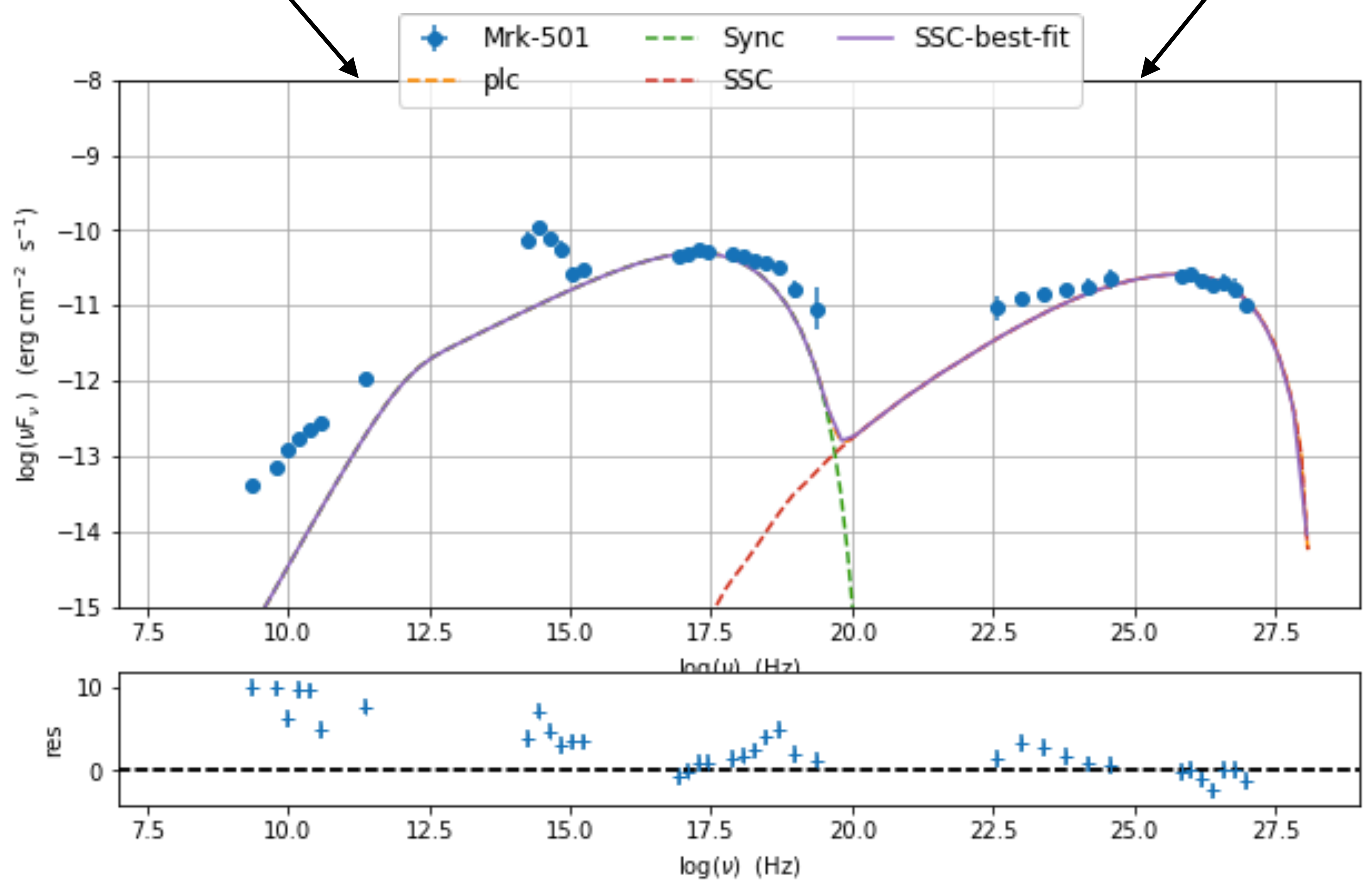
SED shaping and model constraining (Mrk 501)

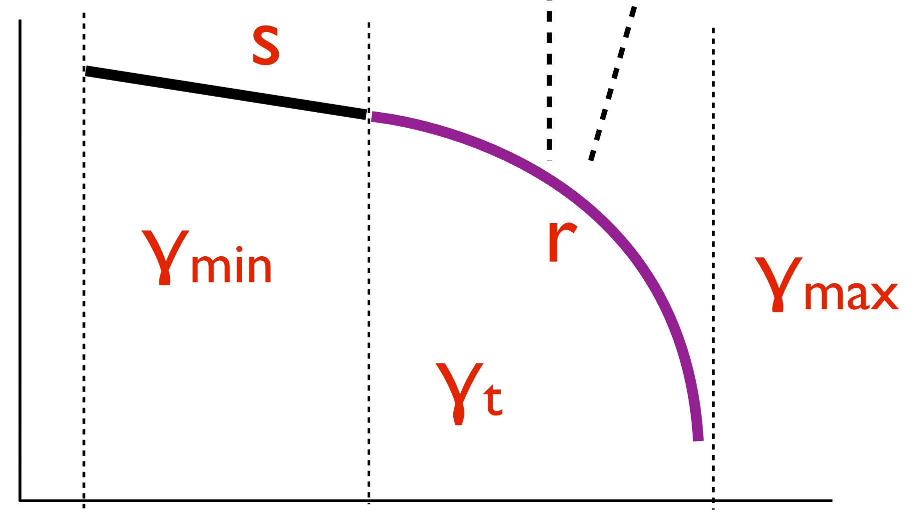
Tutorial 5



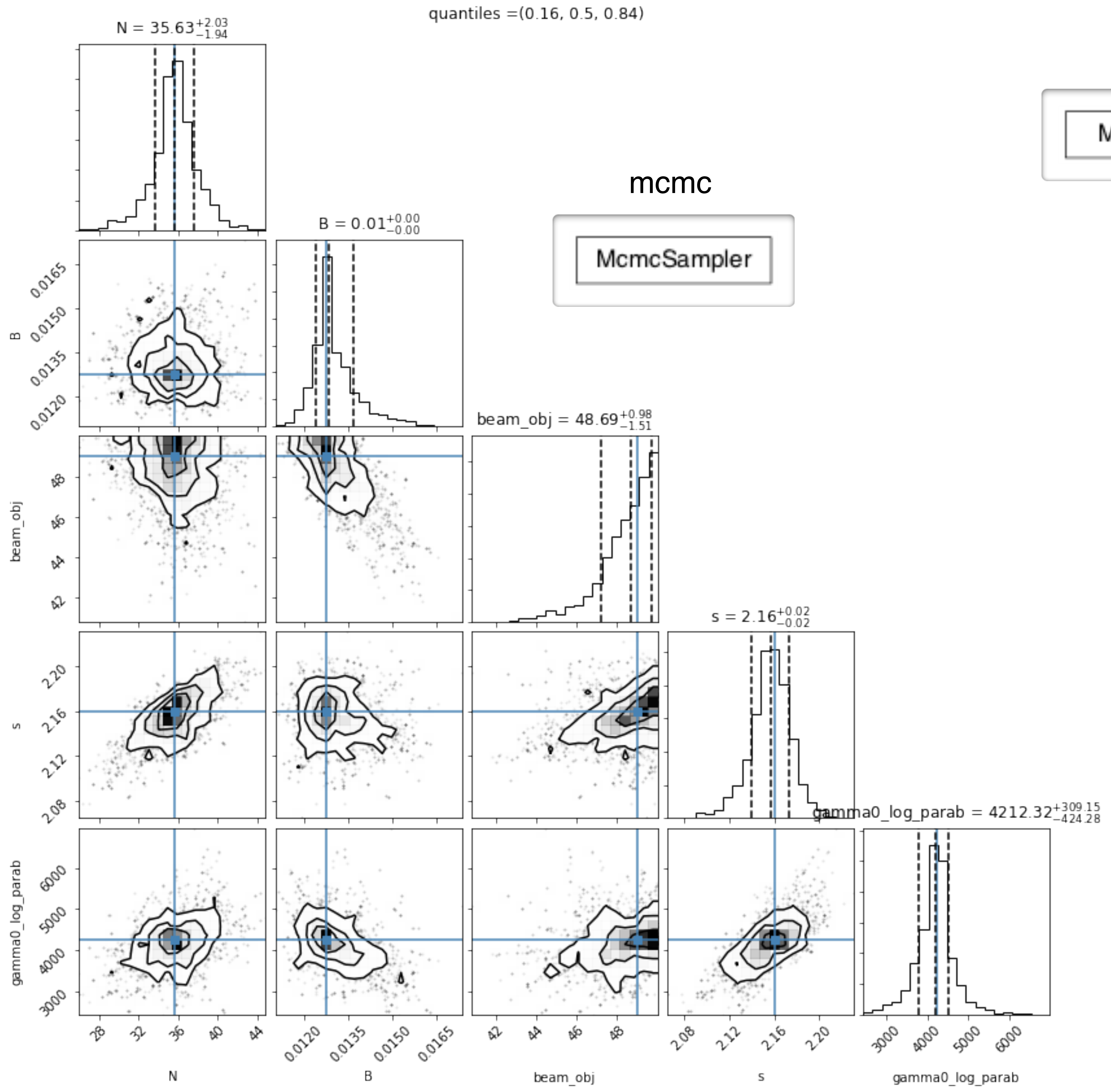




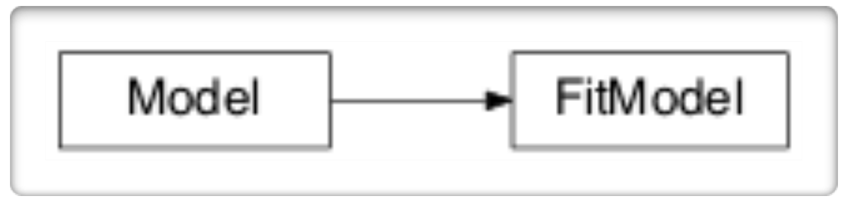




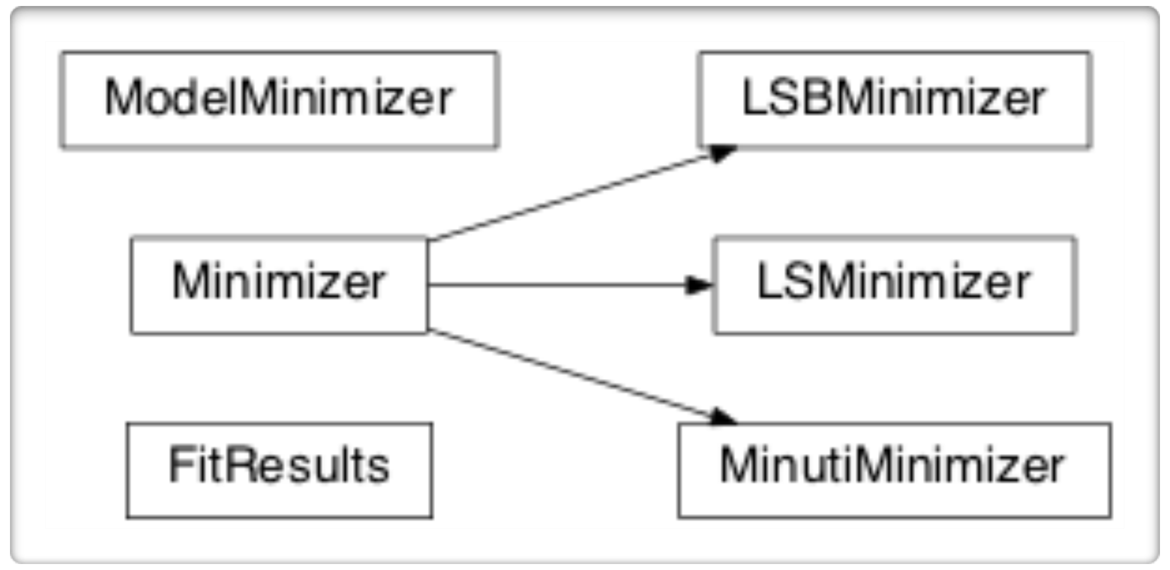
model fitting MCMC

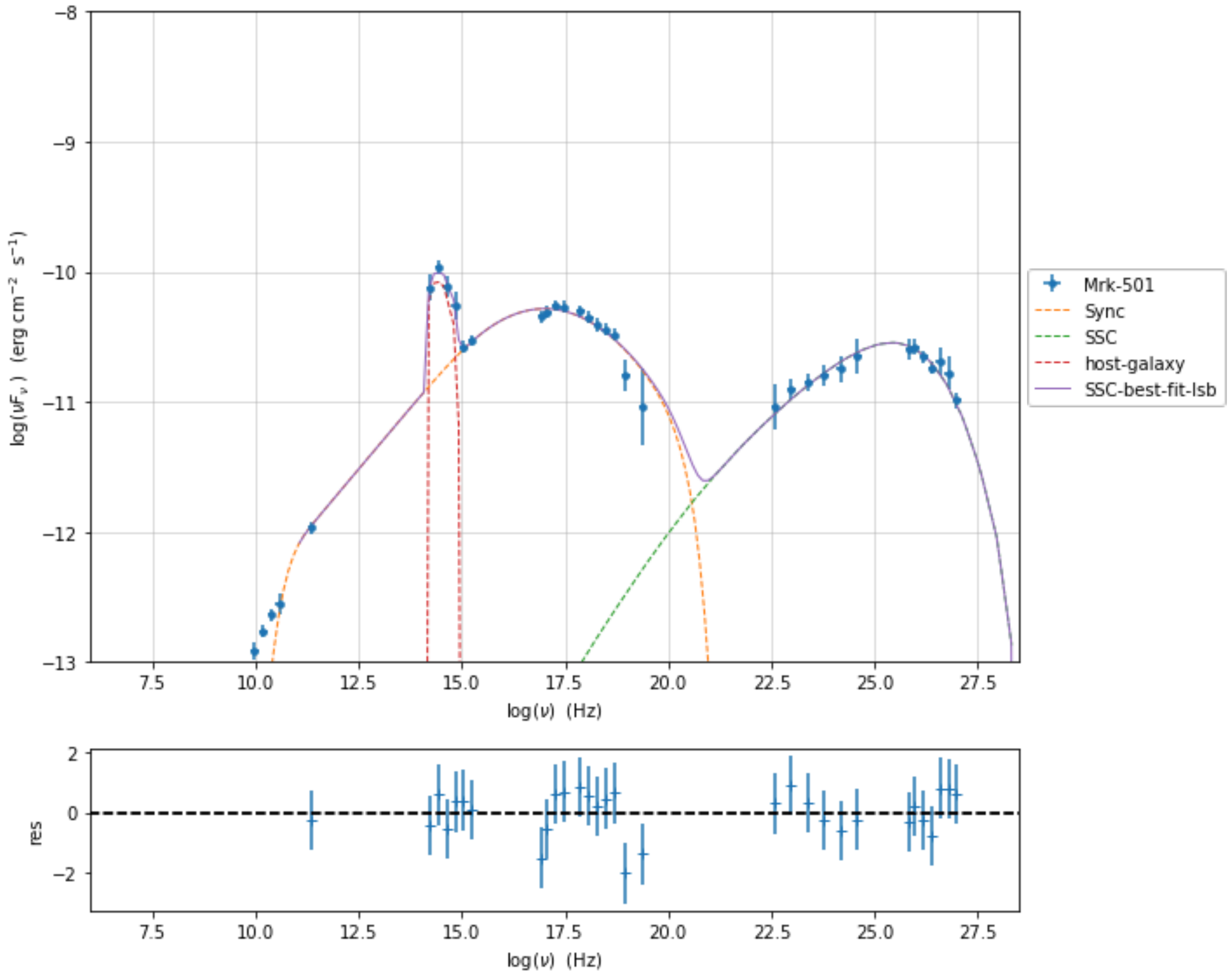


model_manager



minimizer





p(parameters given data) ∝ p(data given parameters)× (parameters)

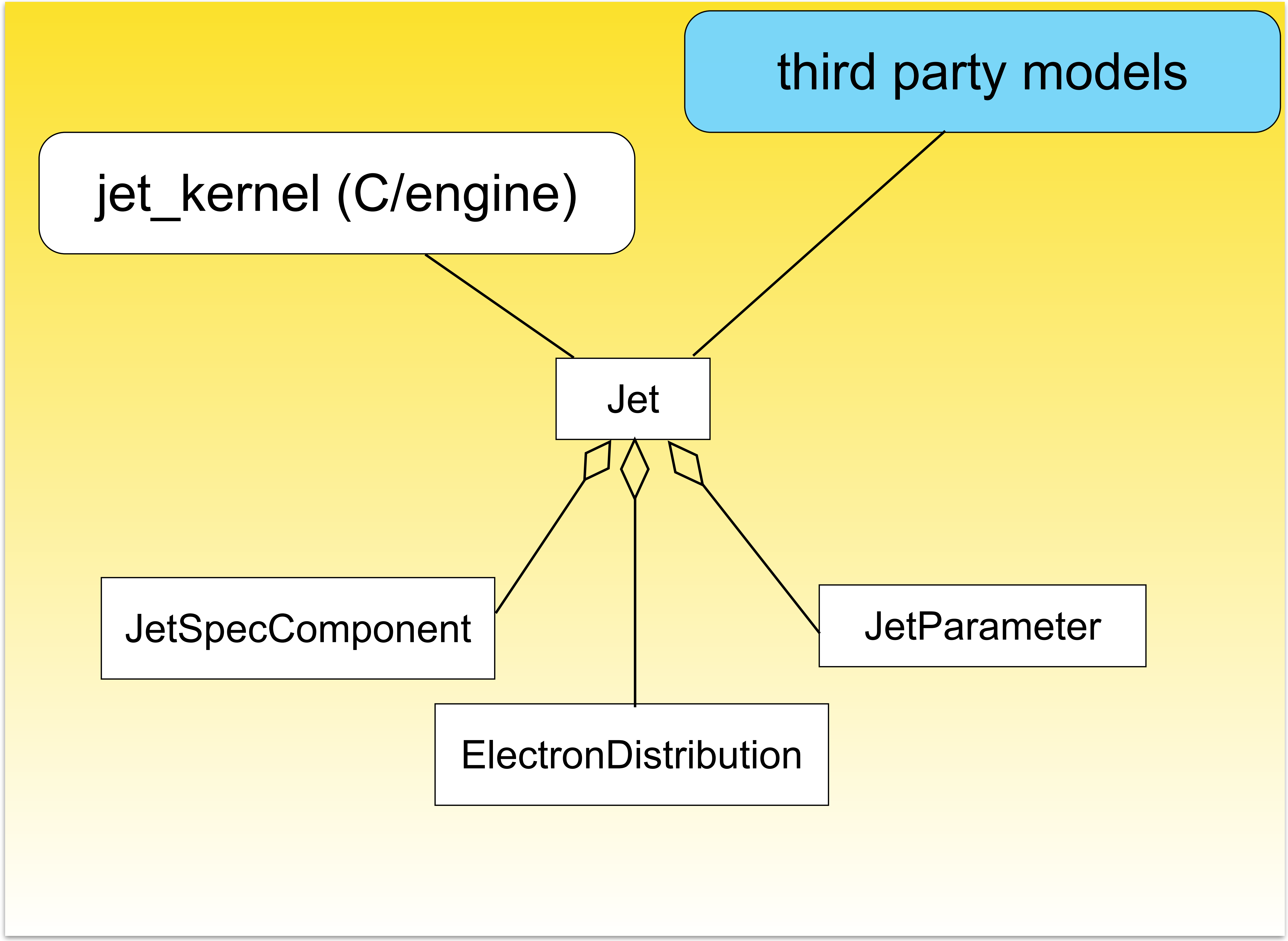
Posterior = Likelihood × Prior

backup slides

models

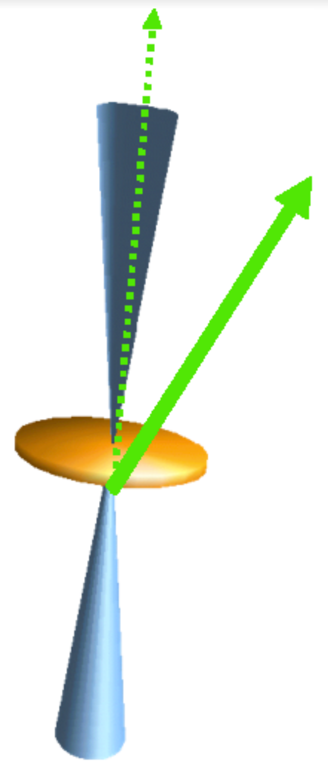

base_model
Model
base model
parameter
Value
ModelParameterArray
ModelParameter
jet_model
JetSpecComponent
ModelParameter
JetParameter
Model
Jet
ElectronDistribution
numerical
log_log_poly_model
ModelParameter
PolyParameter
Model
LogLogModel
LogCubic
LogLinear
LogParabolaEp
LogParabolaPL
analytical
template_model
ModelParameter
TemplateParameter
Model
Template
template

jet model definition



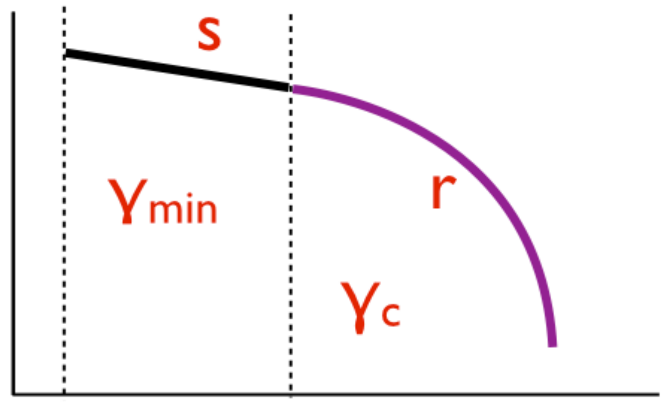
model

jet/disk



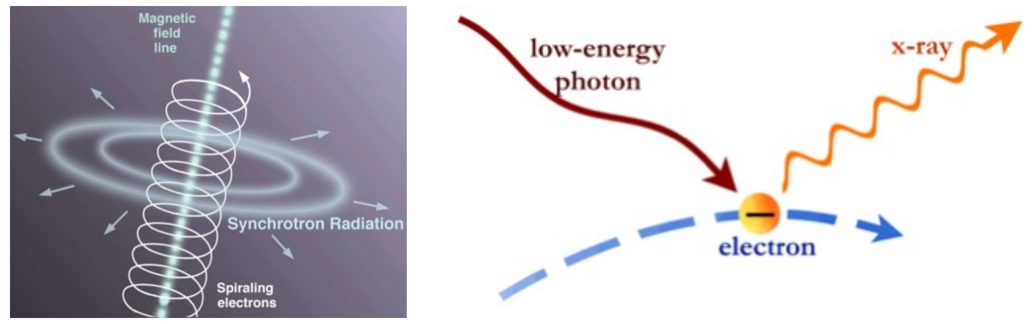
+

acc.



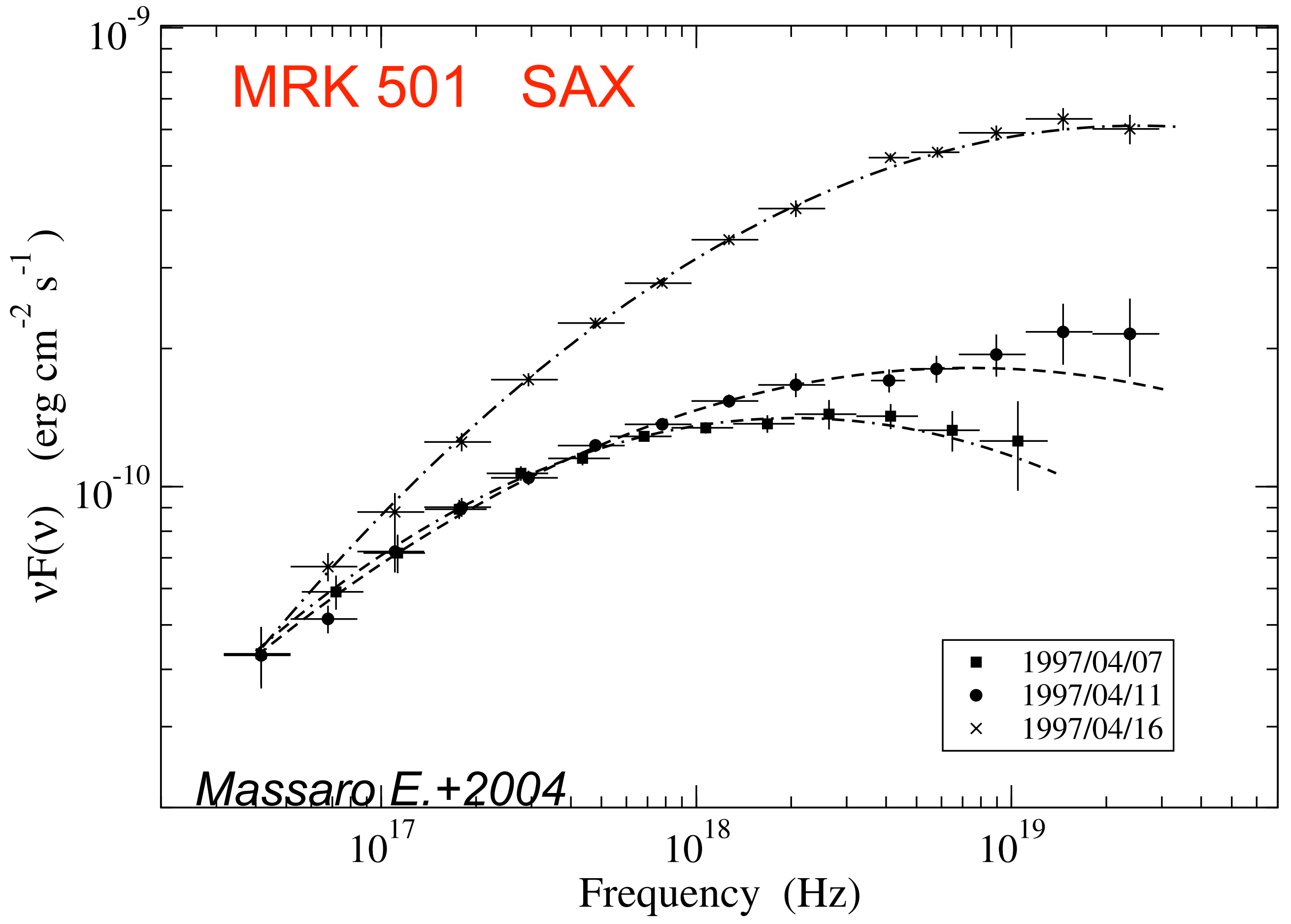
+

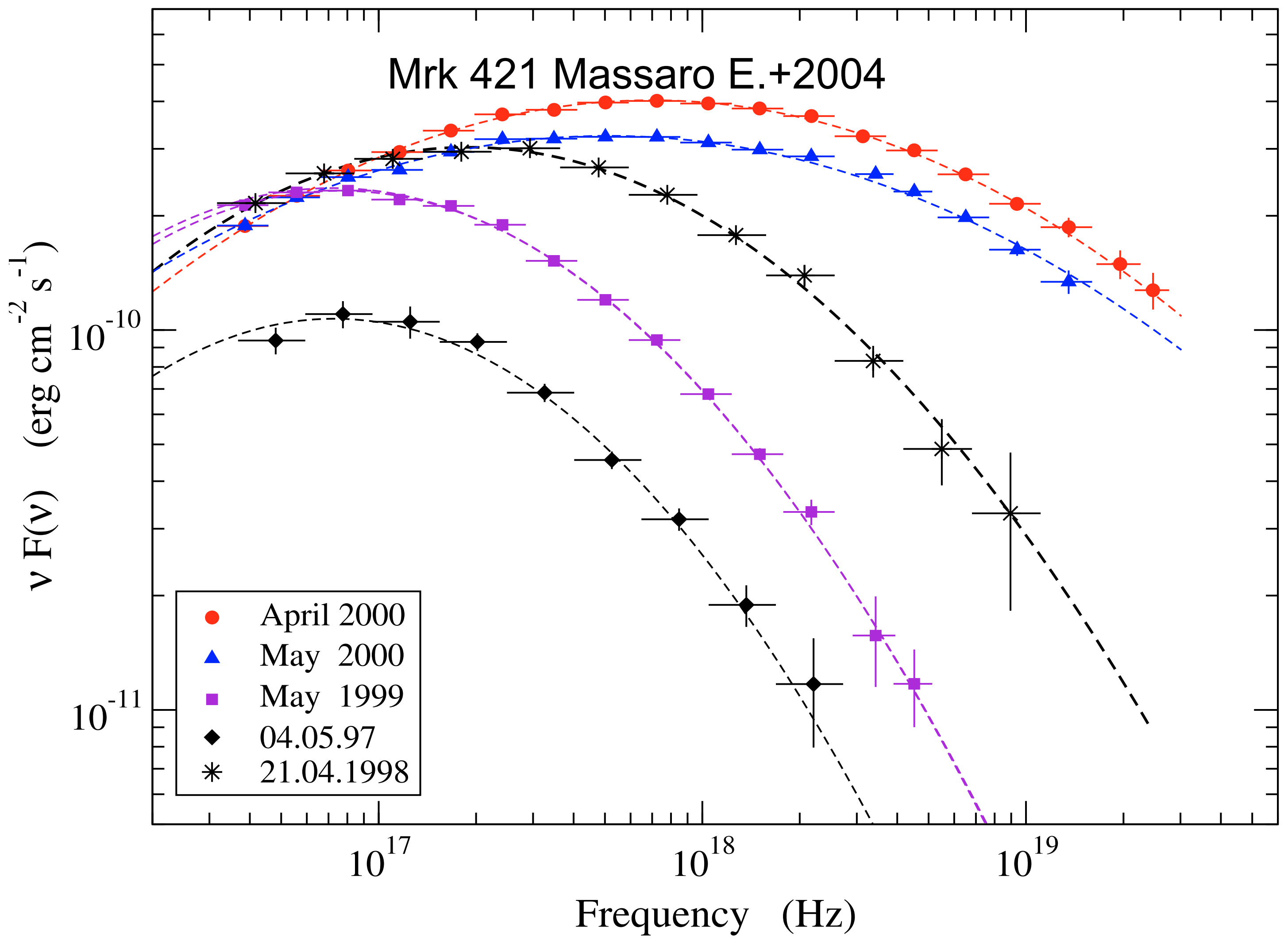
em.

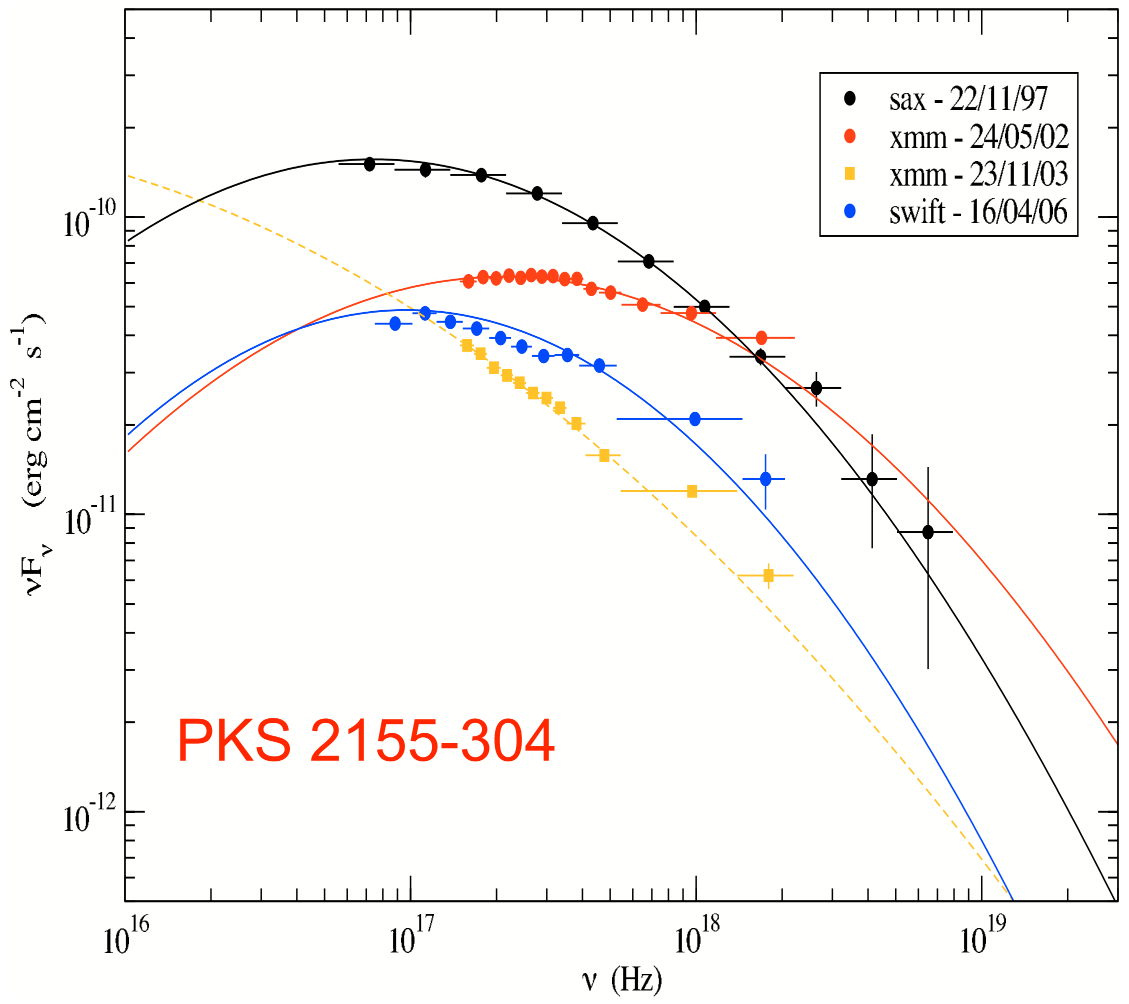


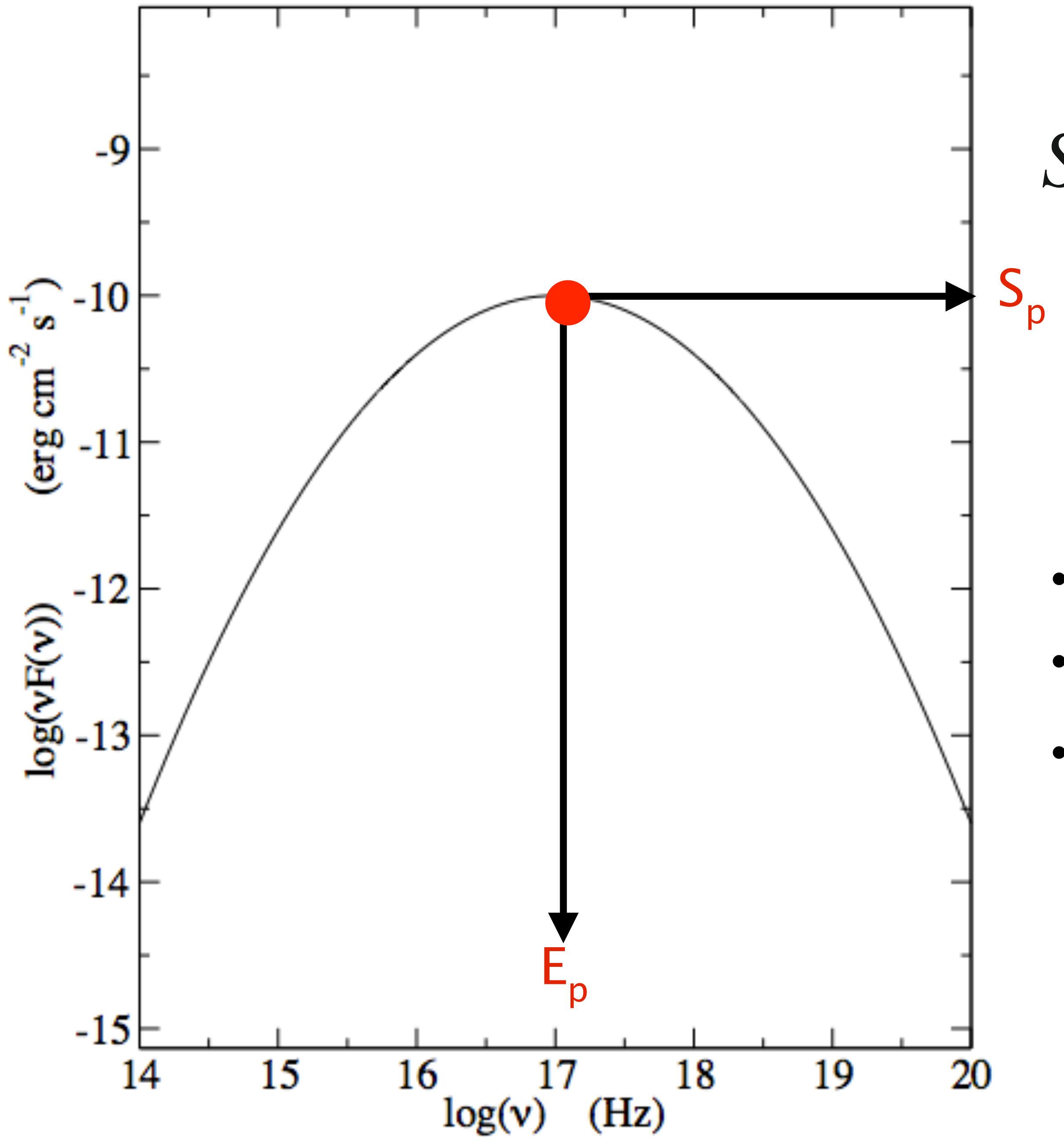
JetSeT

X-ray SPECTRAL DISTRIBUTION OF HBLs (stochastic acceleration)



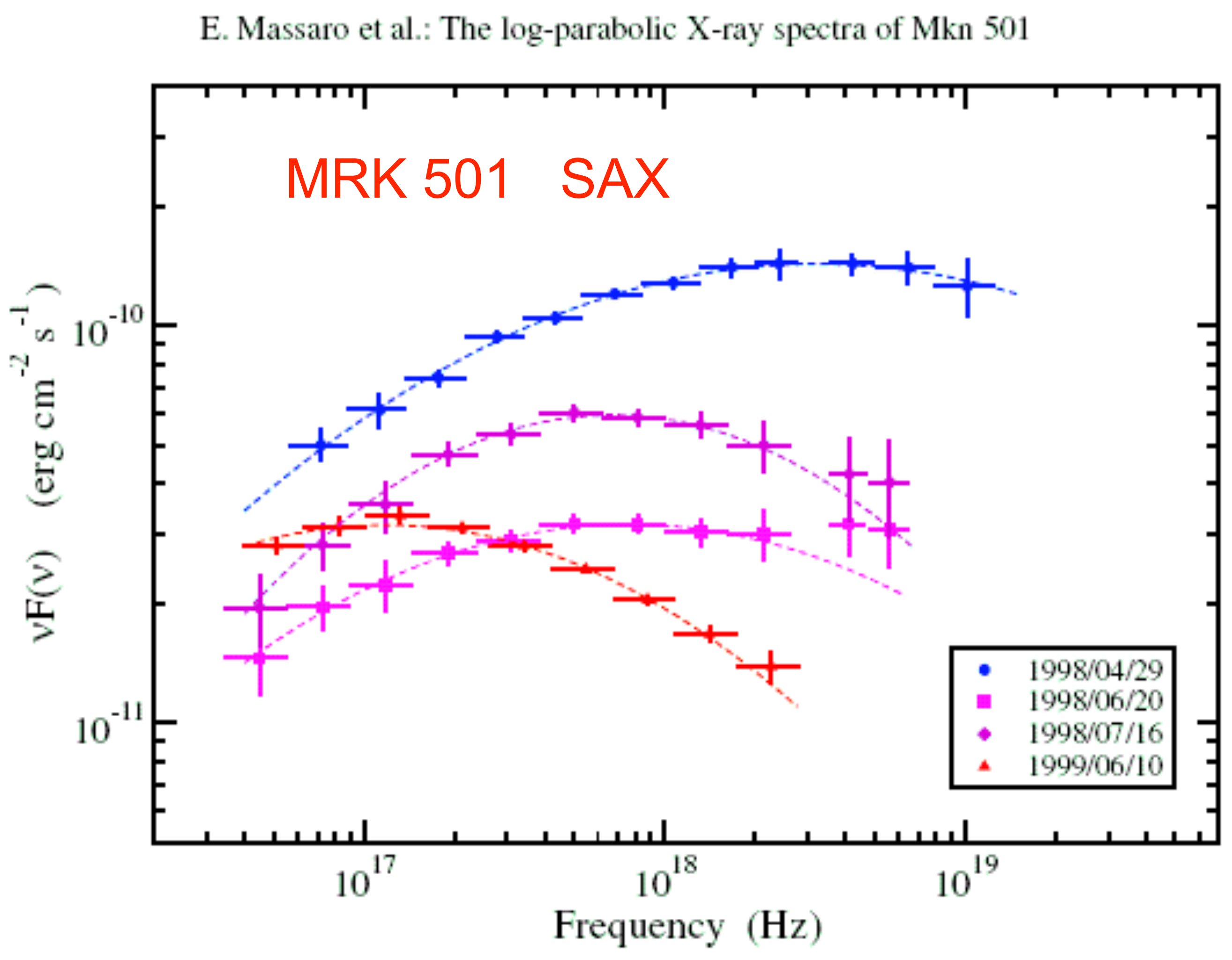


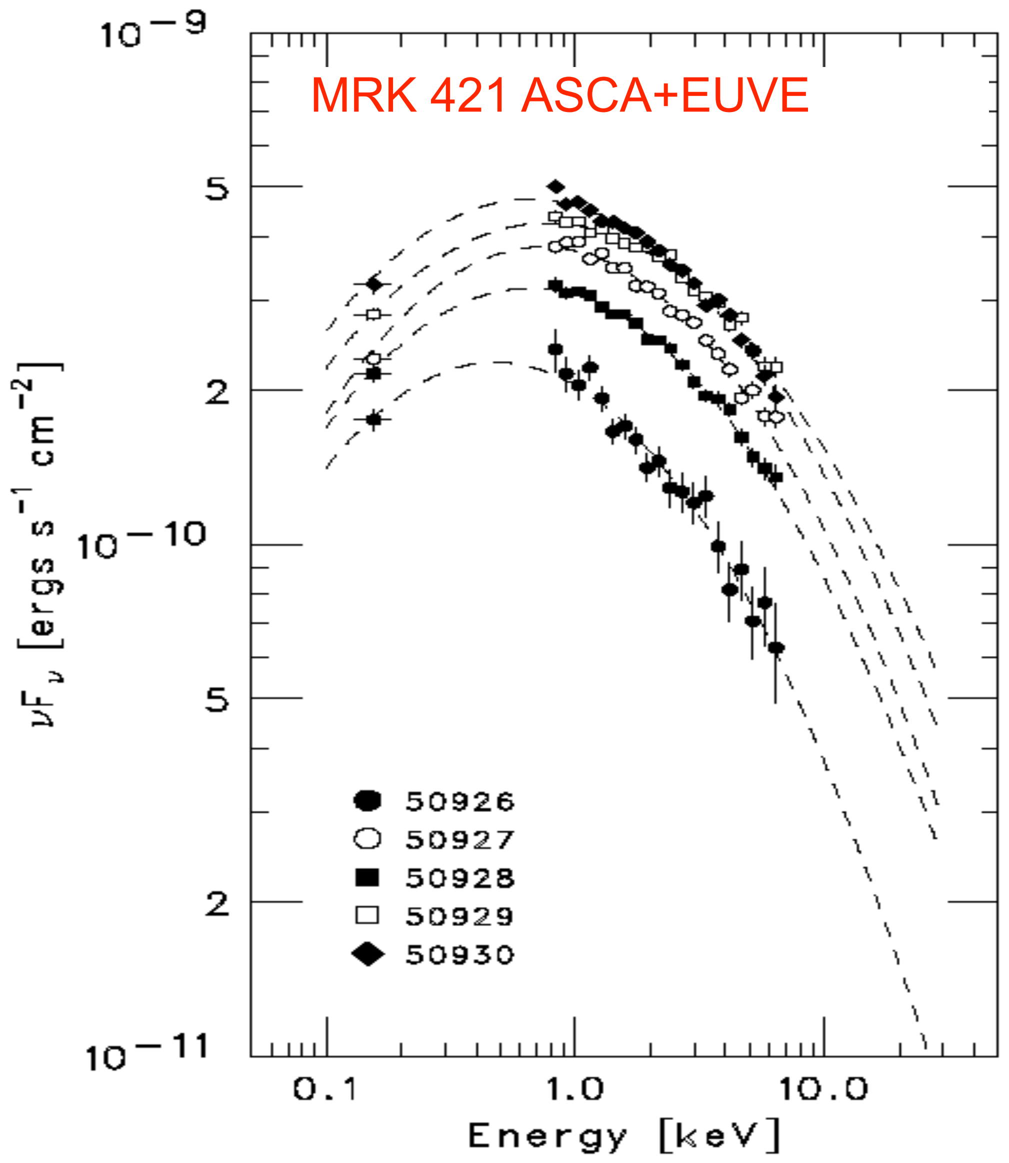




$$S(E) = S_{\rm p}\, 10^{-b\,(\log(E/E_{\rm p}))^2}$$

- b: curvature at peak
- E_p: peak energy
- S_p: SED height @ E_p





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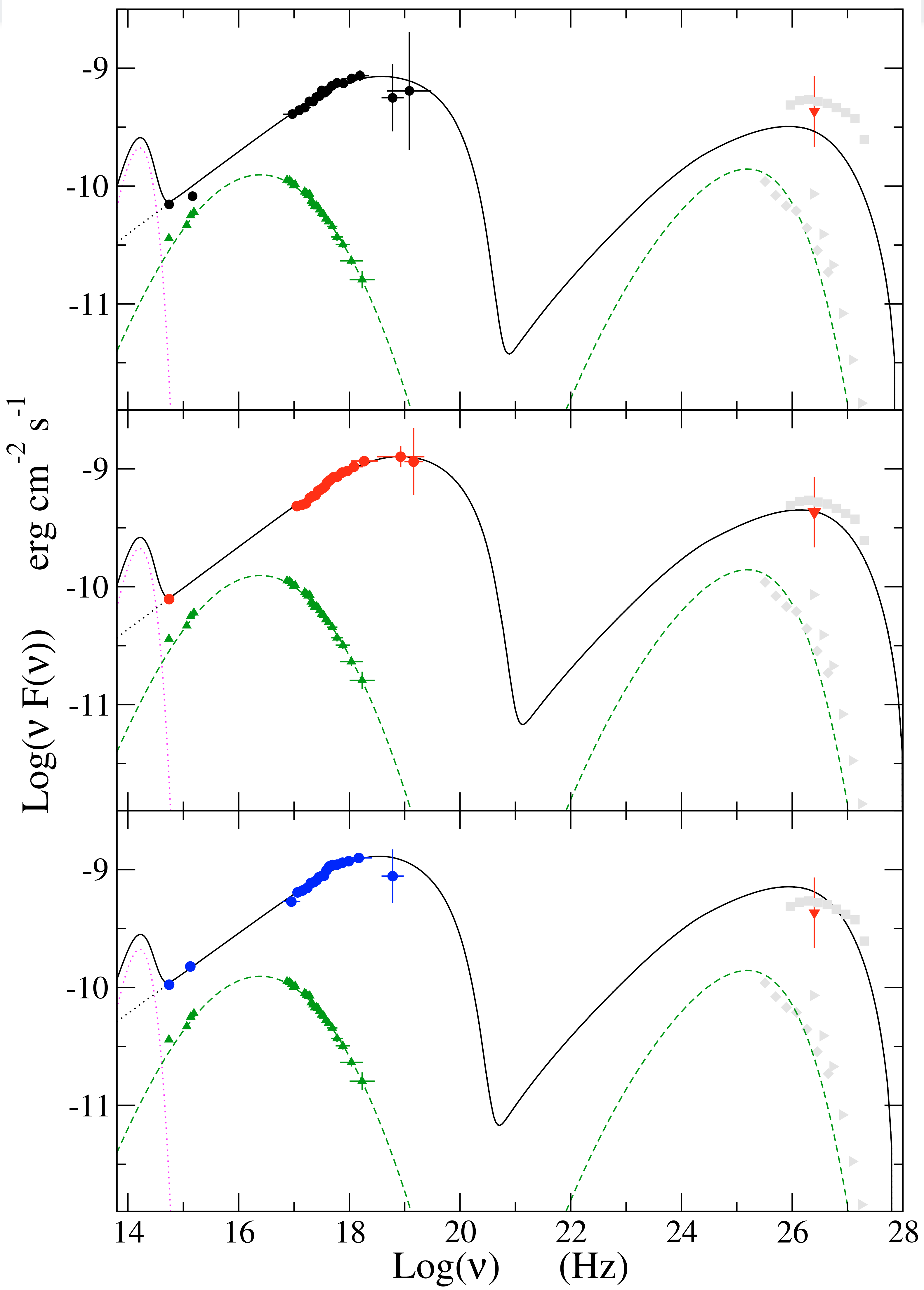
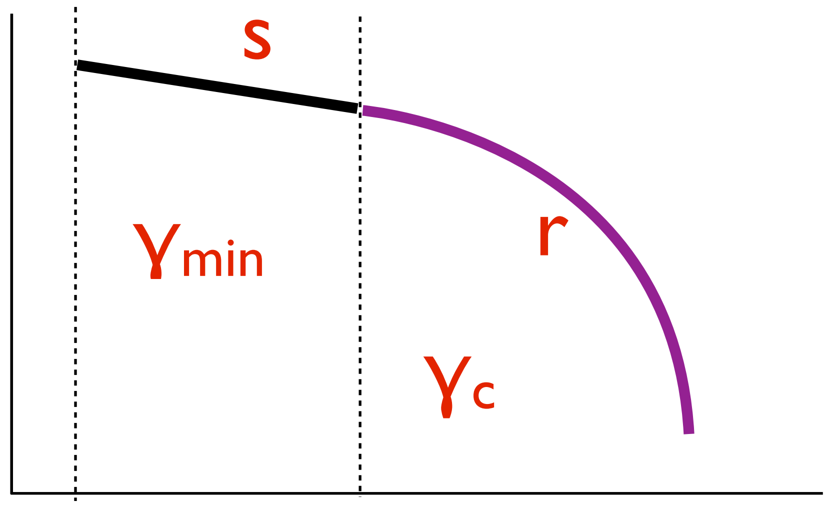
HBL: Fermi I+Fermi II Mrk 421 2006

Tramacere +2009/2011

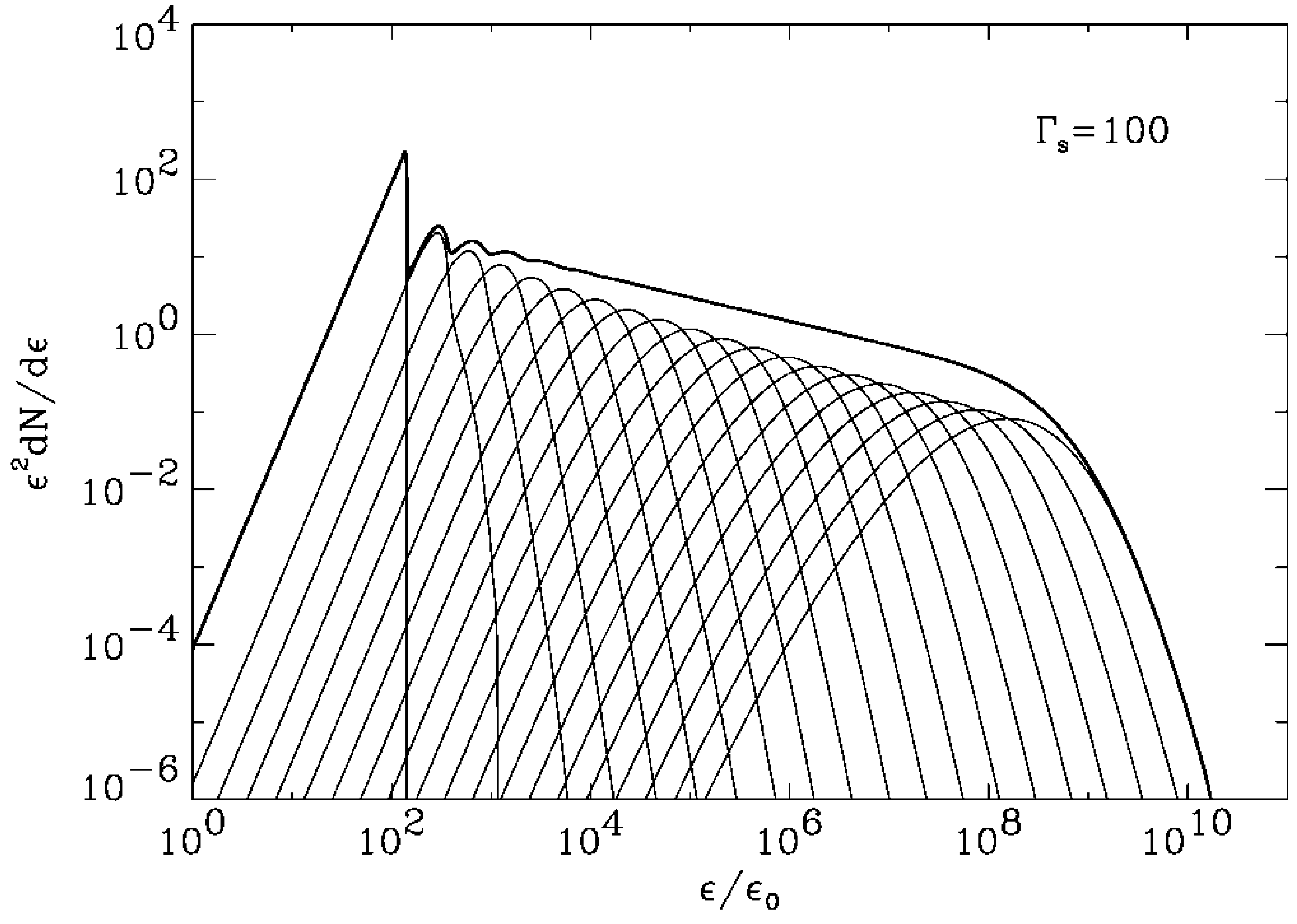


LP+PL spectra

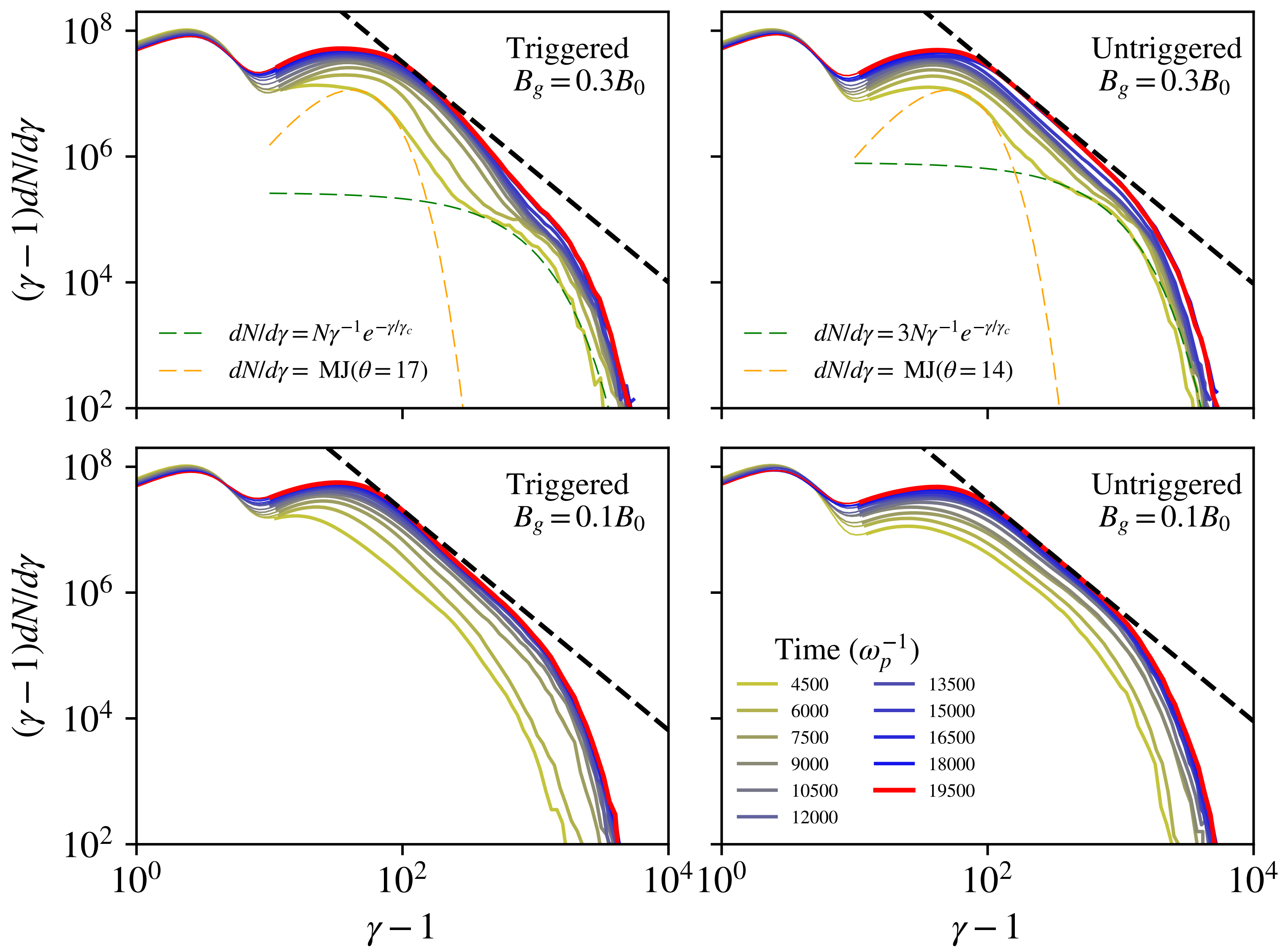
Synch index~[1.6-1.7]=>s~[2.2-2.4]



Lemoine,Pelletier 2003 F1 multip.



Ball+ 2019 magnetic reconnection (PIC)

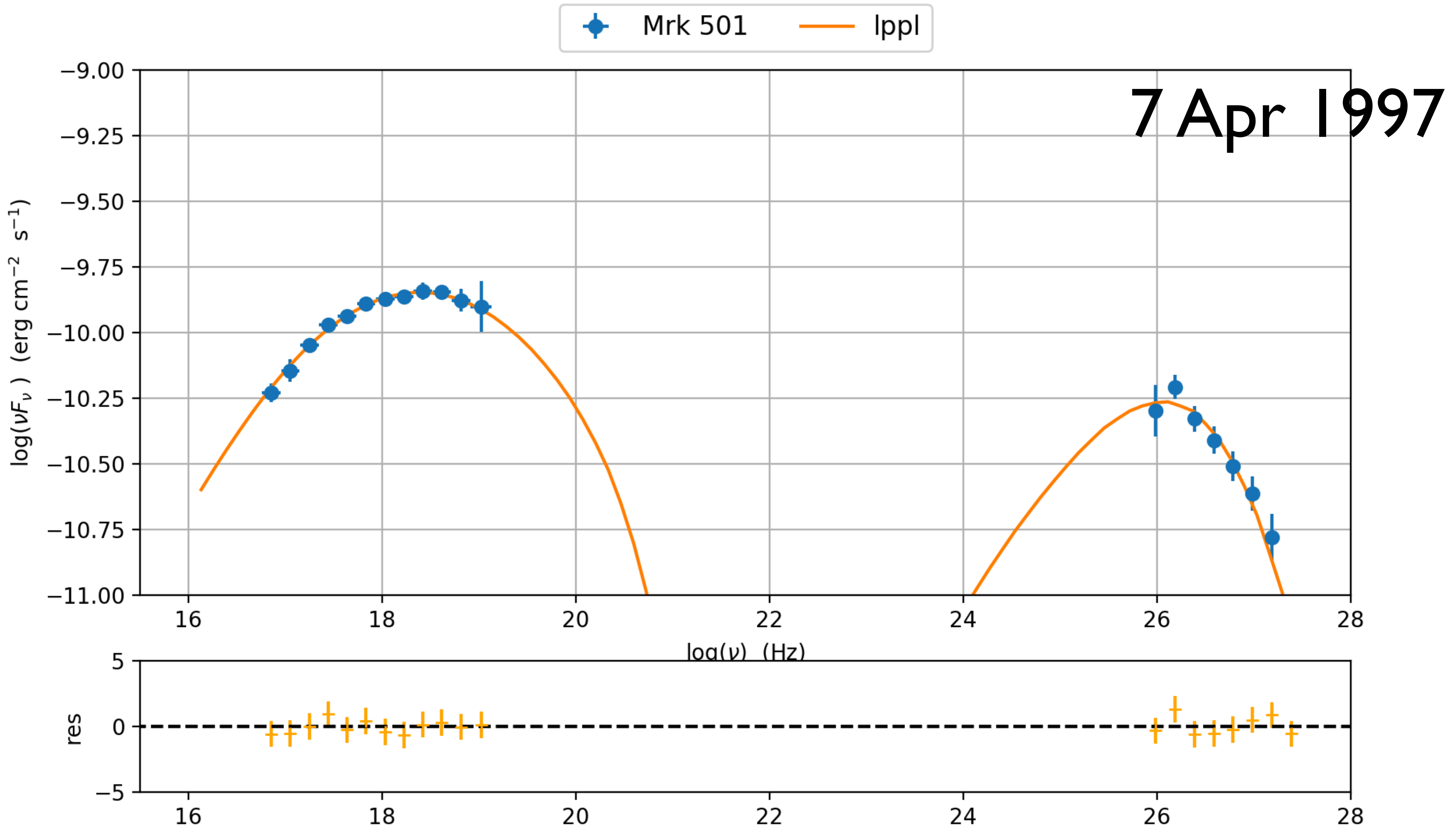


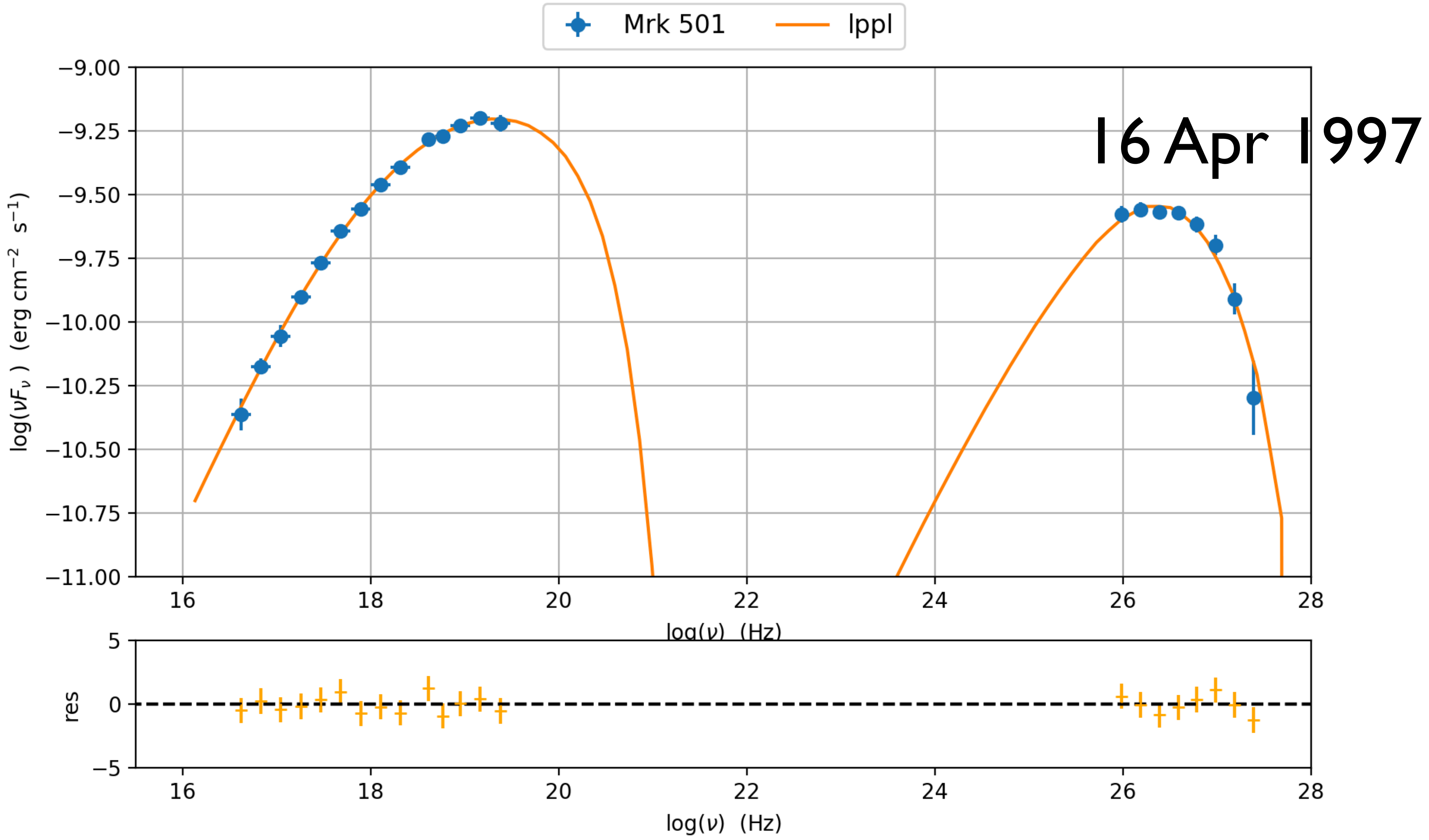
Hard spectra $s << 2.00$

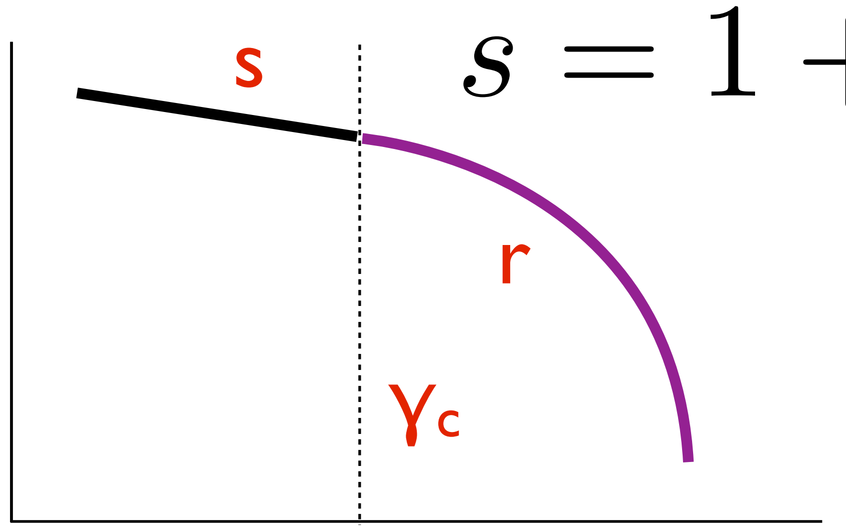
JetSeT

Mrk 501 1997 Flare

Massaro & Tramacere +2006







$$s = 1 + \frac{t_{acc}}{2t_{esc}}$$

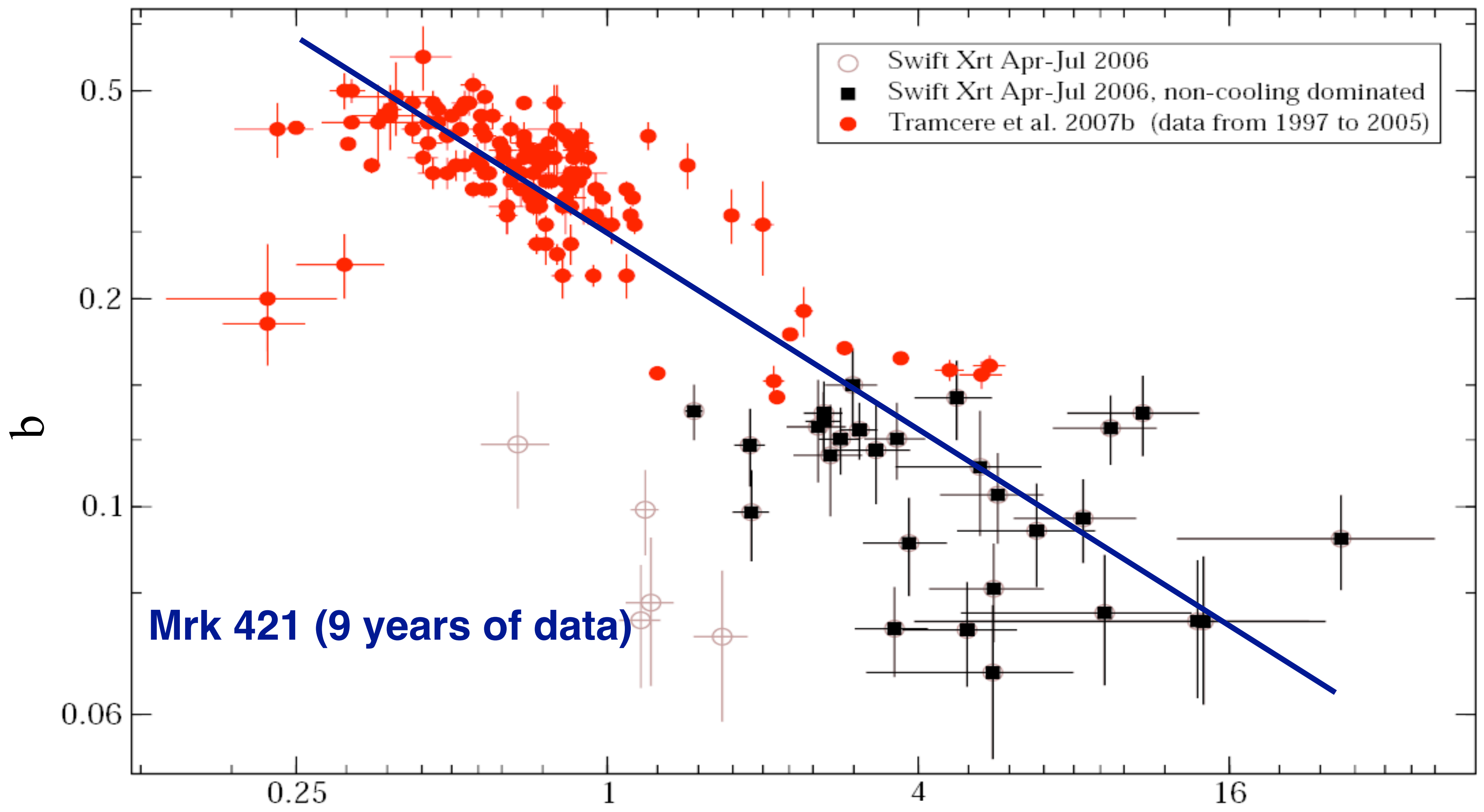
```
best fit pars
-----------------------------------------------------------------
best-fit parameters:
  Name                    | best-fit value| best-fit err +|
-----------------------------------------------------------------
 B                        | +1.072178e-01 | +5.436622e-03 |
 N                        | +4.585348e+00 | +4.756569e-01 |
 R                        | Frozen        | Frozen        |
 beam_obj                 | +2.450884e+01 | +7.642113e-01 |
 gamma0_log_parab         | +6.609649e+04 | +7.427709e+03 |
 gmax                     | +1.860044e+14 | +5.881595e+14 |
 gmin                     | +1.404527e+03 | +2.198648e+02 |
 r                        | +7.513452e-01 | +5.059815e-02 |
 s                        | +1.638026e+00 | +3.170384e-02 |
 z_cosm                   | Frozen        | Frozen        |
-----------------------------------------------------------------
*****************************************************************

=================================================================
```

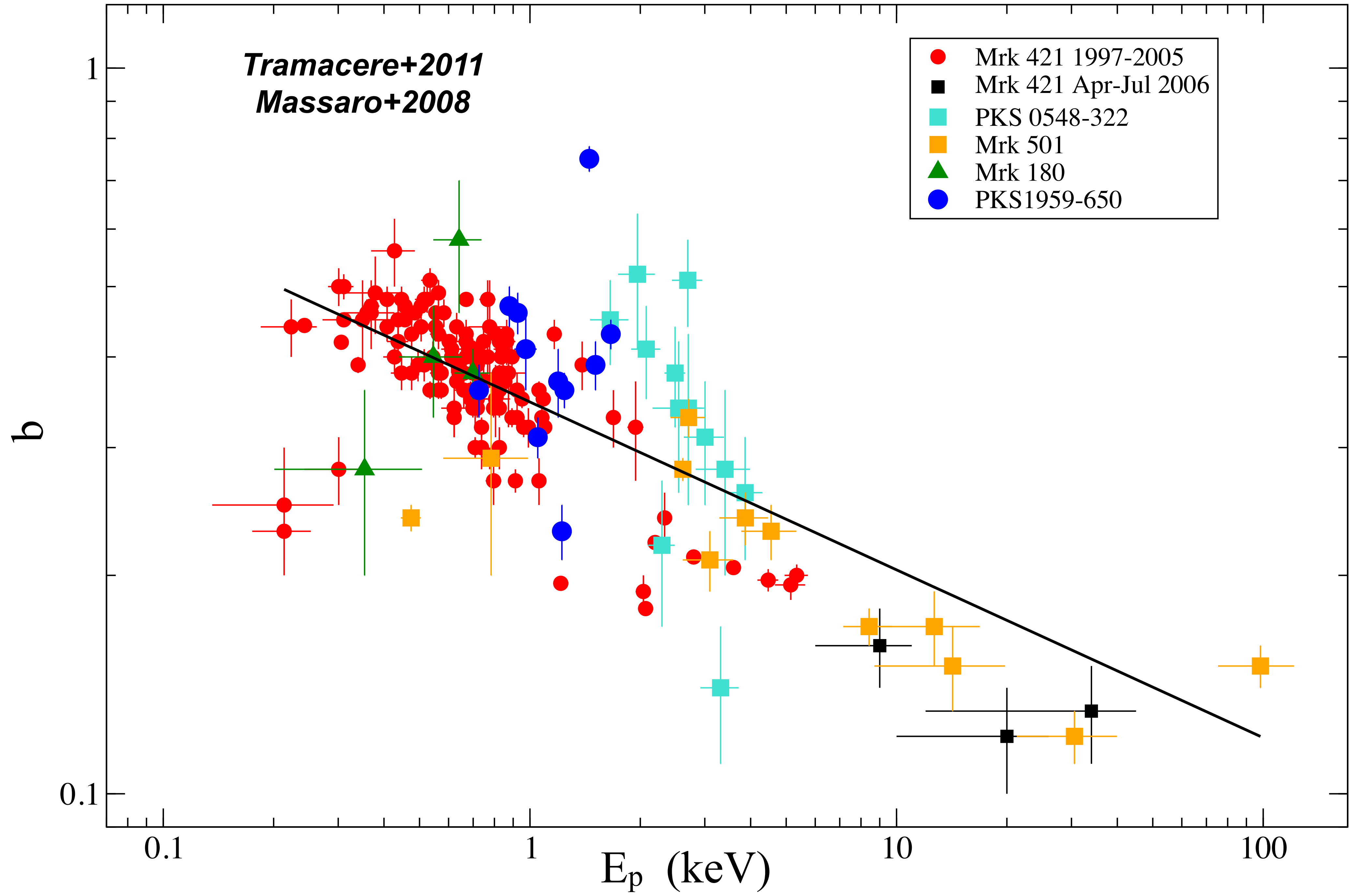
```
-----------------------------------------------------------------
best-fit parameters:
  Name                    | best-fit value| best-fit err +|
-----------------------------------------------------------------
 B                        | +3.065207e-01 | +1.159567e-02 |
 N                        | +1.079944e+02 | +7.375385e+00 |
 R                        | Frozen        | Frozen        |
 beam_obj                 | +2.722013e+01 | +5.889626e-01 |
 gamma0_log_parab         | +6.493888e+04 | +5.410315e+03 |
 gmax                     | +1.902146e+06 | +2.216666e+02 |
 gmin                     | +3.003970e+02 | +5.686711e+01 |
 r                        | +6.778727e-01 | +3.526656e-02 |
 s                        | +1.321307e+00 | +1.844825e-02 |
 z_cosm                   | Frozen        | Frozen        |
-----------------------------------------------------------------
```

JetSeT

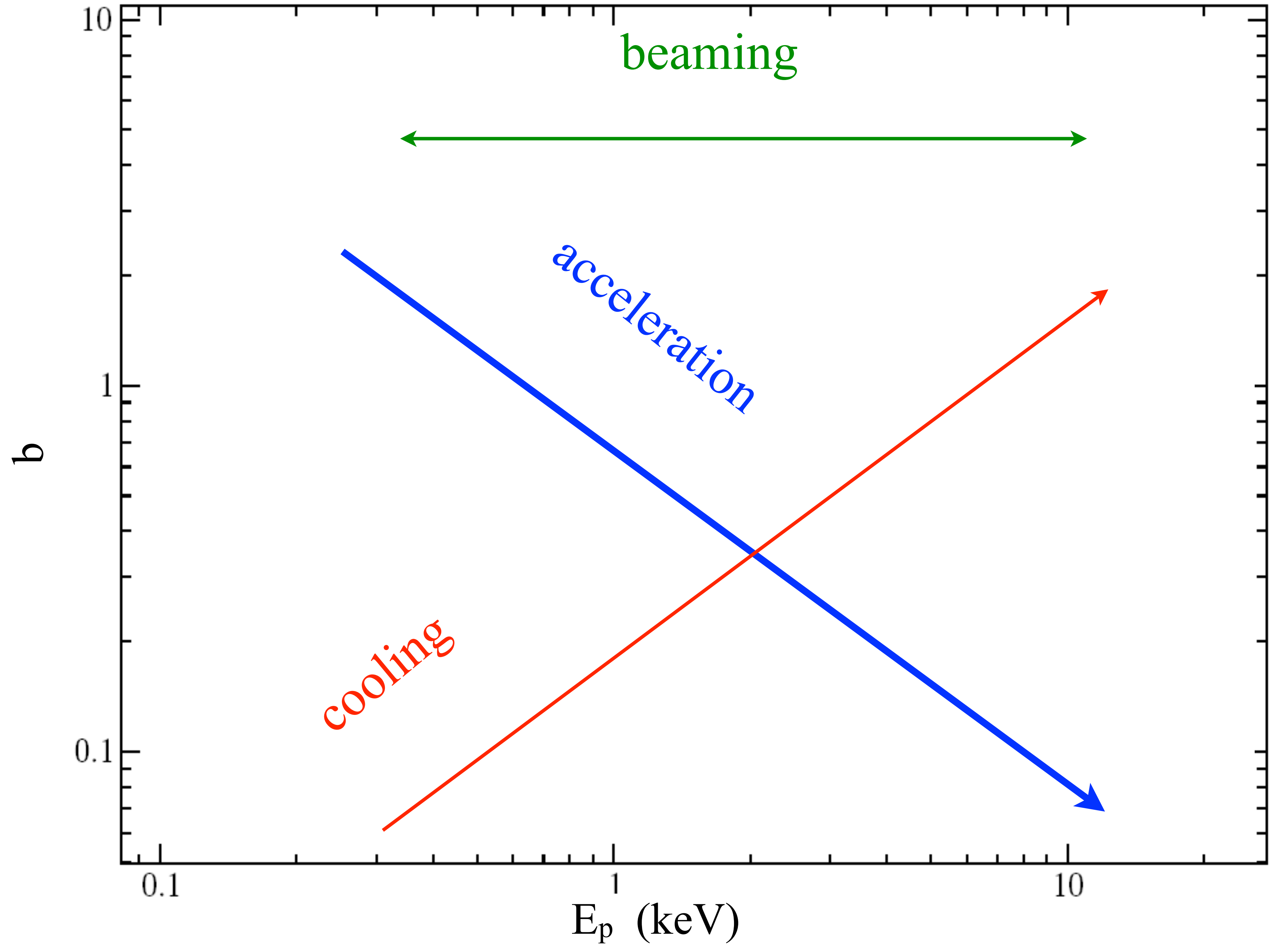
acceleration signature in the E_S-vs-b trend

Tramacere+2007,2009





Ep-vs-b, different scenarios



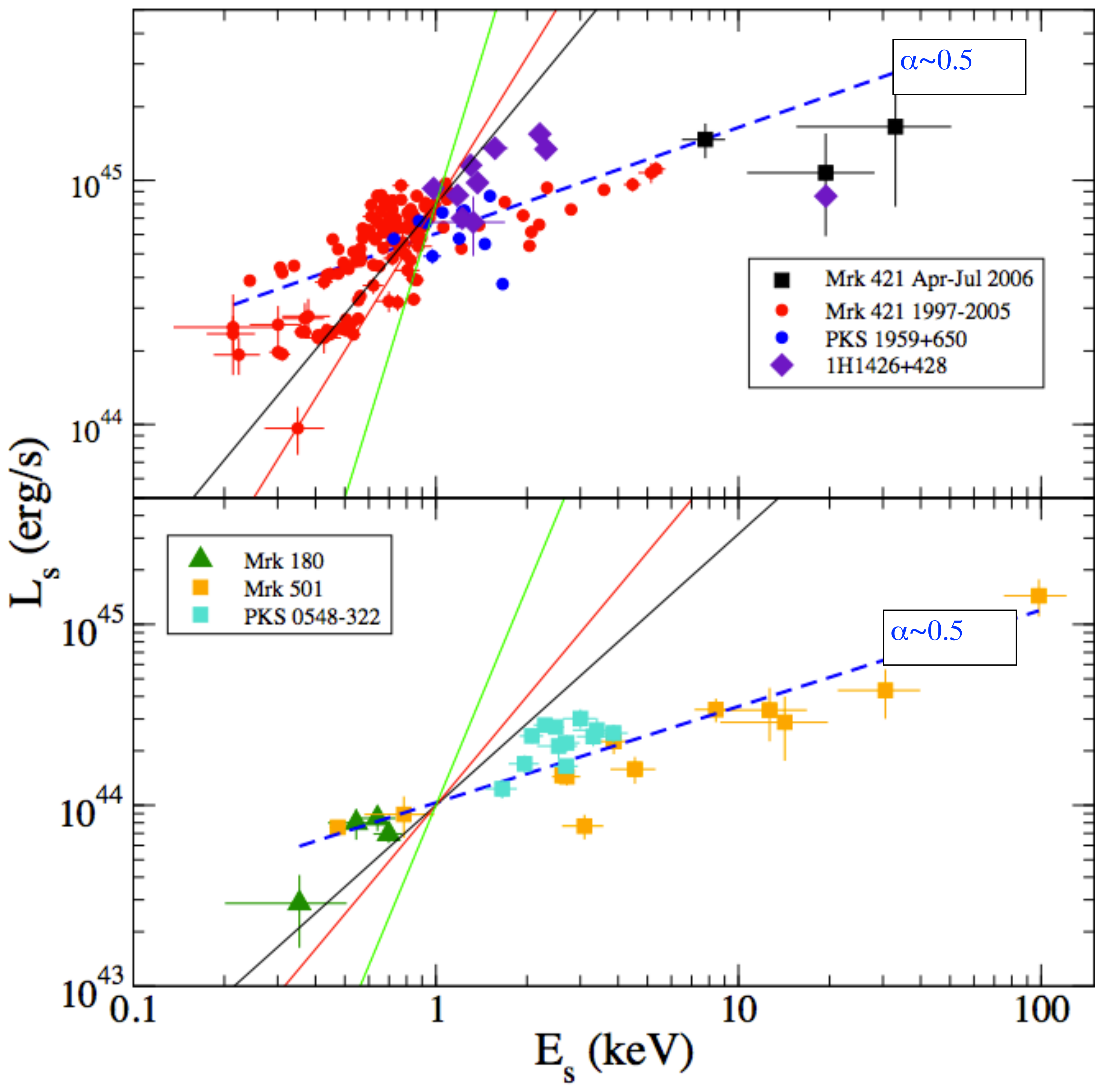
11 years of data:

PKS 0548-322,1H1426+418, Mrk 501 ,1ES1959+650, PKS2155-34

Long term (overall 13 years of data) Ep-vs-b trends hint for an acceleration dominated scenario

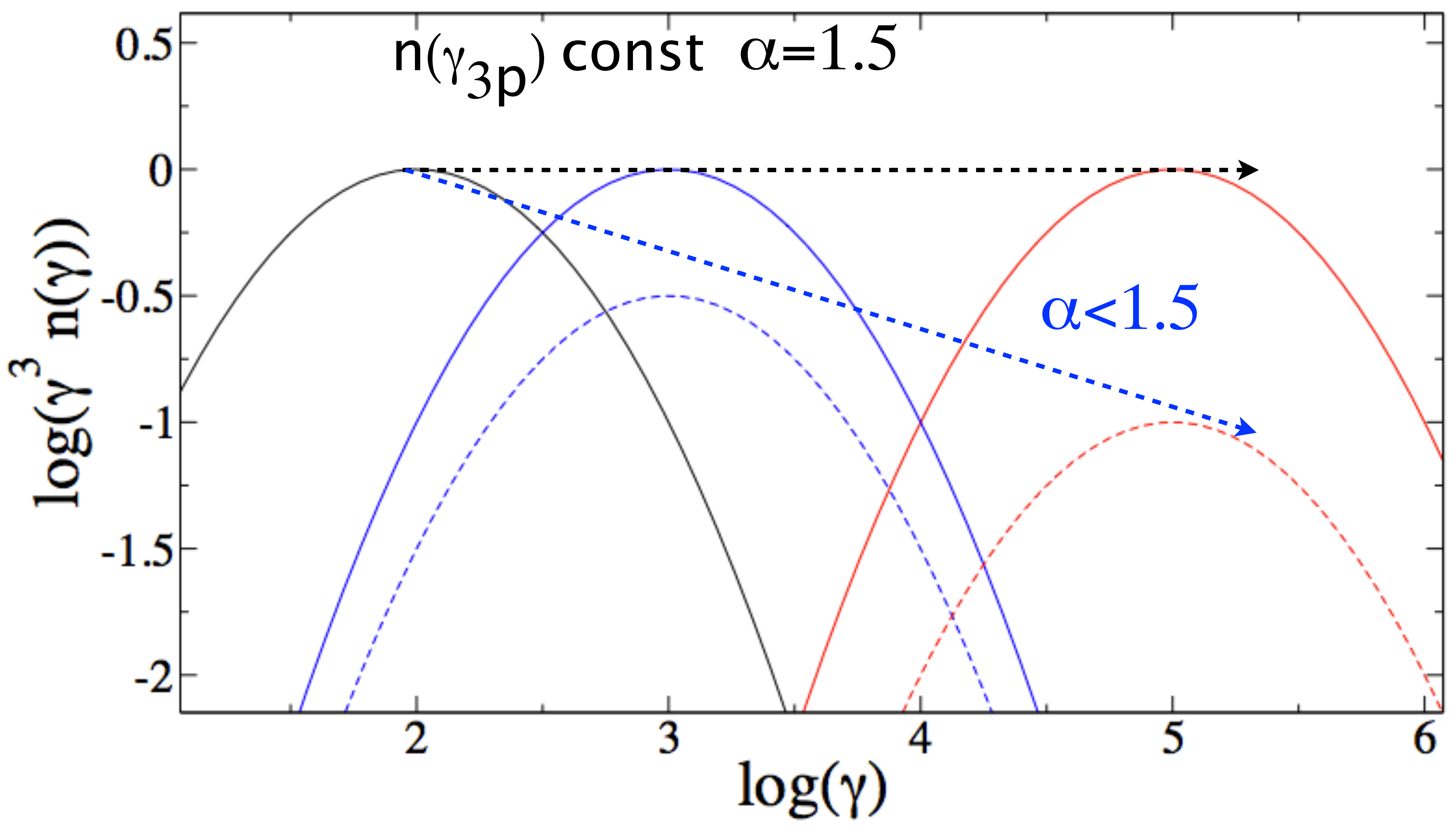
acceleration signature in the E_S-vs-L_s trend

long-trend main drivers



• γ_{3p} ↑ **and n(γ3p)** ↓ **=>** $\alpha<1.5$
acceleration+energy conservation

• B−>α=2.0,
• δ−>α=4
incompatible as long-trend main driver



The origin of the log-parabolic shape: statistical derivation

fluctuation

$$\varepsilon = \bar{\varepsilon} + \chi$$

systematic

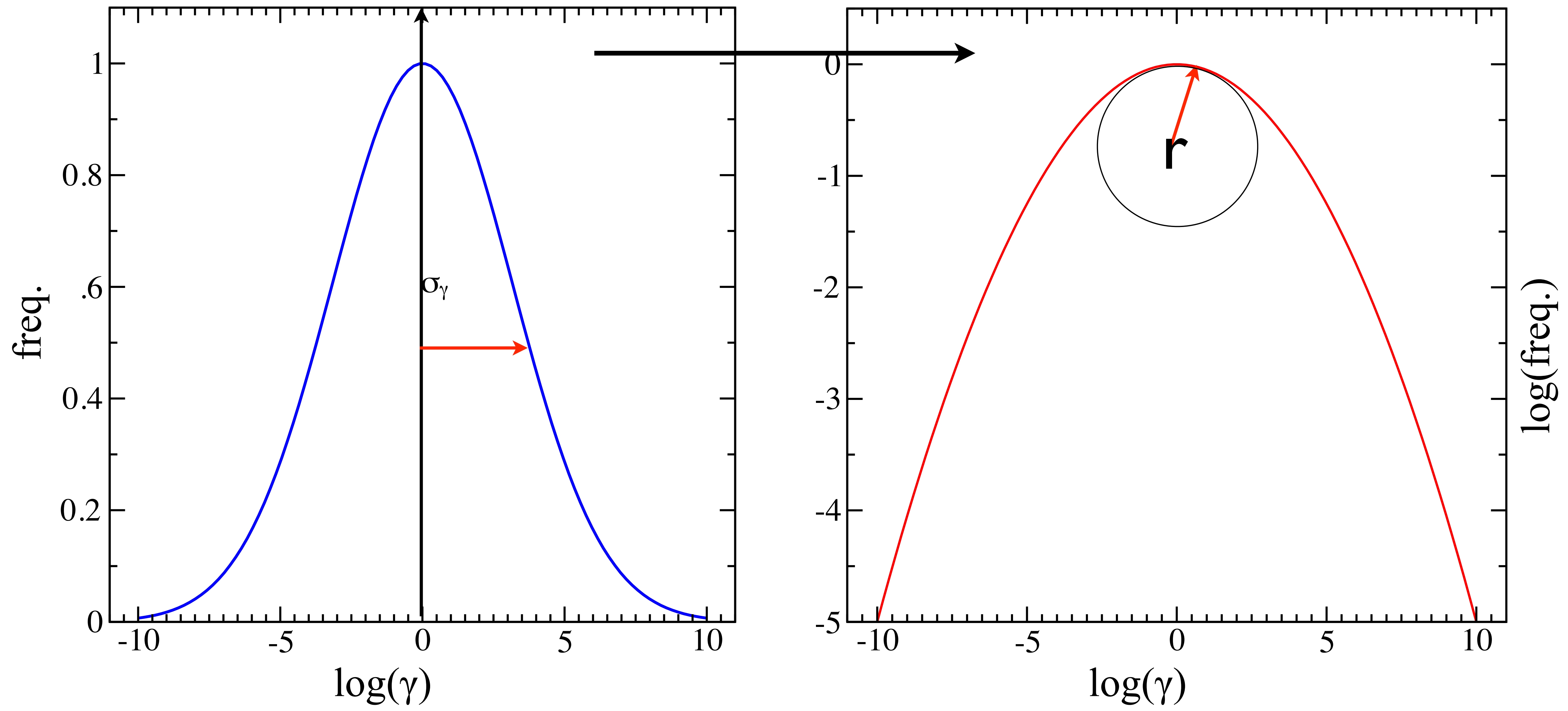
ε_i is a R.V.

$$\gamma_{n_s} = \gamma_0 \Pi_{i=1}^{n_s} \varepsilon_i$$

C.L. Theorem
multipl. case

log-normal distribution

Log-Parabolic representation



$$\log(n(\gamma)) \propto \frac{(\log\gamma - \mu)^2}{2\sigma_\gamma^2} \propto r\ [\log(\gamma) - \mu]^2$$

$$\sigma_y^2 = \sigma^2(\log(\gamma)) \approx n_s \left(\frac{\sigma_\varepsilon}{\bar{\varepsilon}}\right)$$

curvature = $\dfrac{1}{\sigma_\gamma} = 2r$

$$r = \frac{c_e}{2n_s\left(\frac{\sigma_\varepsilon}{\bar{\varepsilon}}\right)^2}$$

JetSeT

The origin of the log-parabolic shape: diffusion equation approach

$$\frac{\partial n(\gamma,t)}{\partial t} = \frac{\partial}{\partial \gamma}\left\{ -\left[S(\gamma,t) + D_A(\gamma,t)\right]n(\gamma,t) + D_p(\gamma,t)\frac{\partial n(\gamma,t)}{\partial \gamma}\right\} - \frac{n(\gamma,t)}{T_{esc}(\gamma)} + Q(\gamma,t)$$

CL theorem

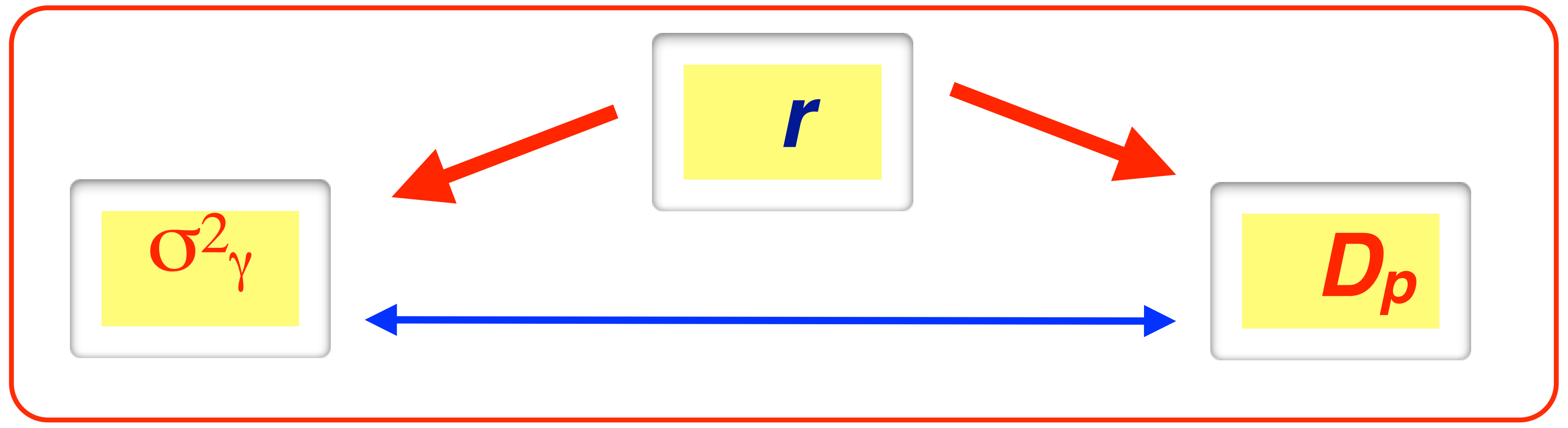
analytical solution for:
$D_p \sim \gamma^q$, q=2
"hard-sphere" case
Melrose 1968, Kardashedv 1962

$$n(\gamma,t) = \frac{N_0}{\gamma\sqrt{4\pi D_{p0} t}} \exp\left\{ - \frac{[\ln(\gamma/\gamma_0) - (A_{p0} - D_{p0})t]^2}{4 D_{p0} t}\right\}$$

$$\log(n(\gamma)) \propto \frac{(\log\gamma - \mu)^2}{2\sigma_\gamma^2} \propto r\ [\log(\gamma) - \mu]^2$$

$$\propto \frac{1}{D_{p0} t} \rightarrow D_{p0} \propto \left(\frac{\sigma_\varepsilon}{\bar{\varepsilon}}\right)^2$$

The curvature r is inversely proportional to ***t*=>*n*$_s$** and ***D*$_p$=>σ_ε**



Temporal evolution

Tramacere +2011

injection term

$$L_{inj} = \frac{4}{3}\pi R^3 \int \gamma_{inj} m_e c^2 Q(\gamma_{inj}, t) d\gamma_{inj} \quad (erg/s)$$

systematic term

$$S(\gamma, t) = -C(\gamma, t) + A(\gamma, t)$$

cooling term

$$C(\gamma) = |\dot{\gamma}_{\rm synch}| + |\dot{\gamma}_{\rm IC}|$$

syst. acc. term

$$A(\gamma) = A_{p0}\gamma, t_A = \frac{1}{A_0}$$

$$\frac{\partial n(\gamma, t)}{\partial t} = \frac{\partial}{\partial \gamma}\left\{ -[S(\gamma, t) + D_A(\gamma, t)]n(\gamma, t) + D_p(\gamma, t)\frac{\partial n(\gamma, t)}{\partial \gamma}\right\} - \frac{n(\gamma, t)}{T_{\rm esc}(\gamma)} + Q(\gamma, t)$$

Turbulent magnetic field $\longrightarrow$ momentum diffusion term

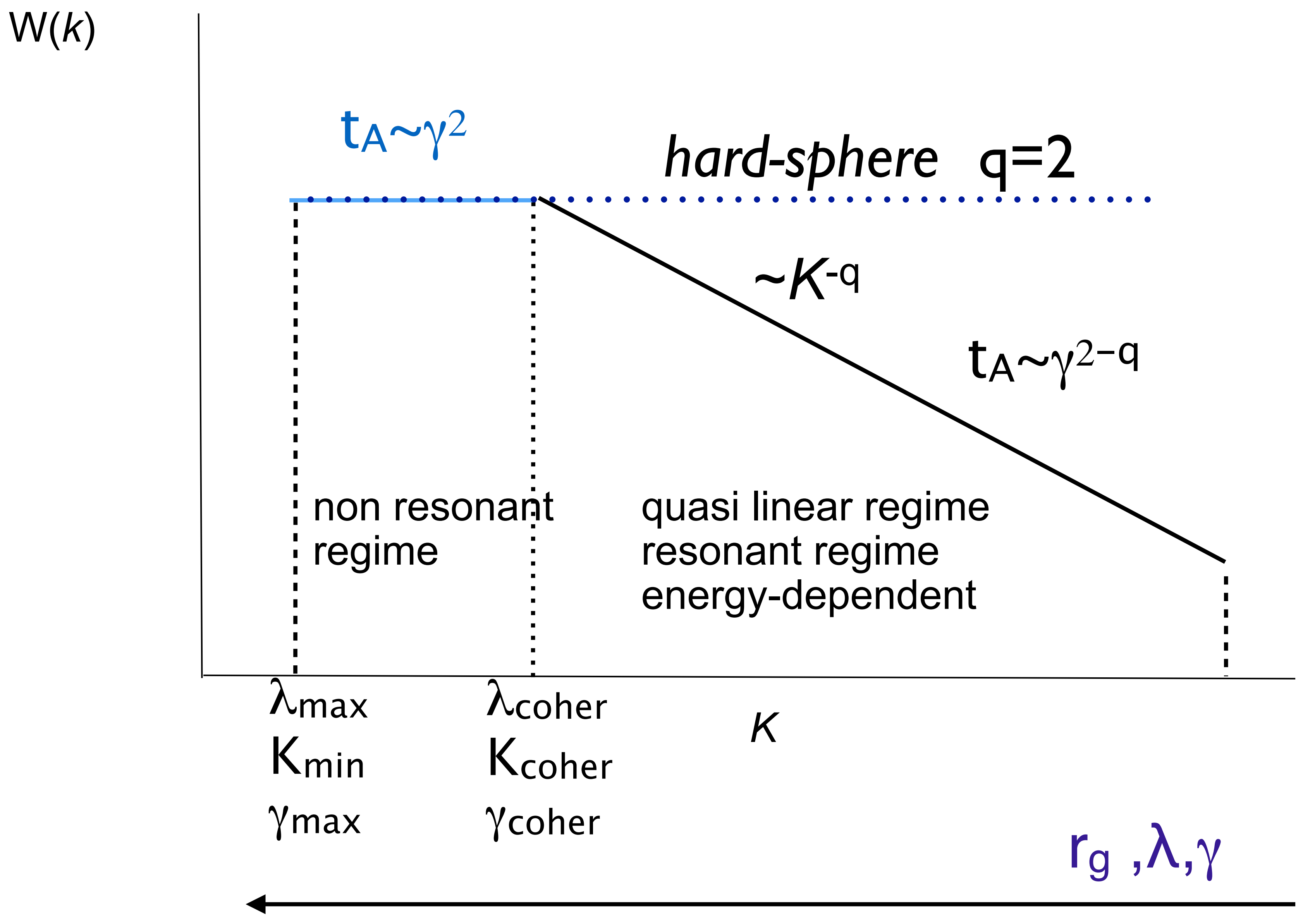
$$W(k) = \frac{\delta B(k_0^2)}{8\pi}\left(\frac{k}{k_0}\right)^{-q}$$

$$D_p \approx \beta_A^2 \left(\frac{\delta B}{B_0}\right)^2 \left(\frac{\rho_g}{\lambda_{\rm max}}\right)^{q-1} \frac{p^2 c^2}{\rho_g c}$$

set-up of the accelerator

$$t_D = \frac{1}{D_{p0}} \left(\frac{\gamma}{\gamma_0}\right)^{2-q}$$

$$t_{DA} = \frac{1}{2D_{p0}} \left(\frac{\gamma}{\gamma_0}\right)^{2-q}$$



$$D_p \approx \beta_A^2 \left(\frac{\delta B}{B_0}\right)^2 \left(\frac{\rho_g}{\lambda_{\max}}\right)^{q-1} \frac{p^2c^2}{\rho_g c}$$

$$\rho_g = pc/qB$$

e-folding time

observed values

$E_{p1}/E_{p2} \sim 5$

$\Delta t \sim$ few ks

→

values compatible with Tammi & Duffy 2009

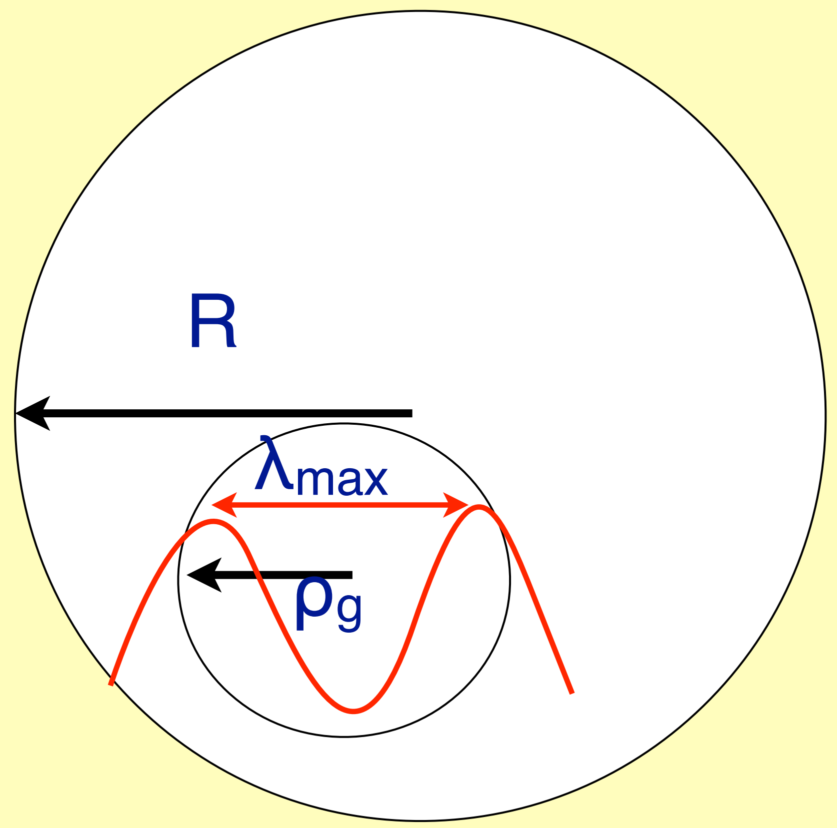
t_{DA} ~< 5 ks

t_D ~< 10 ks

set-up of the accelerator

- $R \sim 10^{13}$-10^{15} cm
- $\delta B/B \ll 1$, $B \sim [0.01$-$1.0]$ G
- $\beta_A \sim 0.1$-0.5
- $\lambda_{max} < R$ => $\sim 10^{[9-15]}$ cm
- $\rho_g < \lambda_{max}$ => $\gamma_{max} \sim 10^{7.5}$

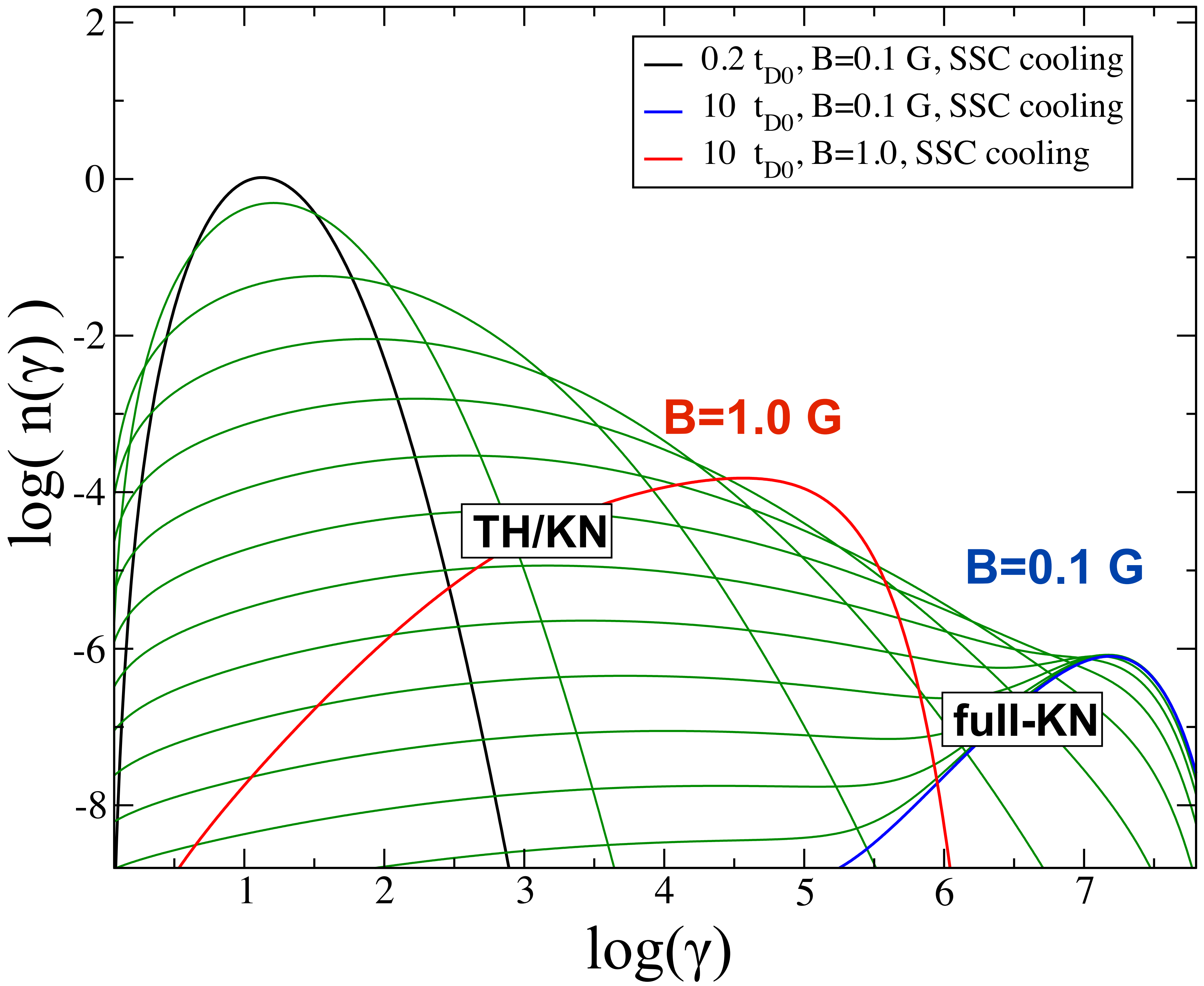
→ **t_D~<10^4 ks**



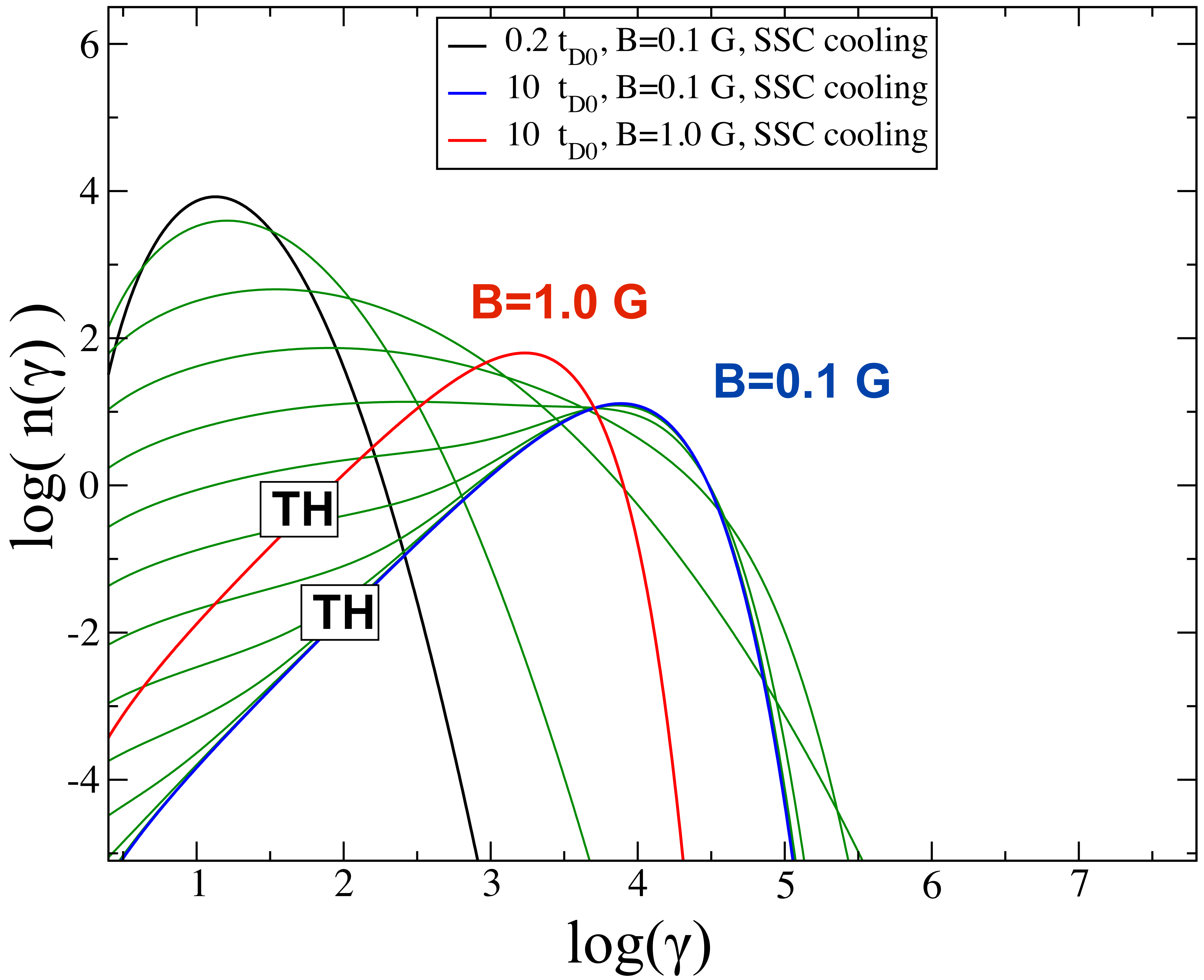
temporal evolution

IC cooling and equilibrium

R= 1x10^15 cm

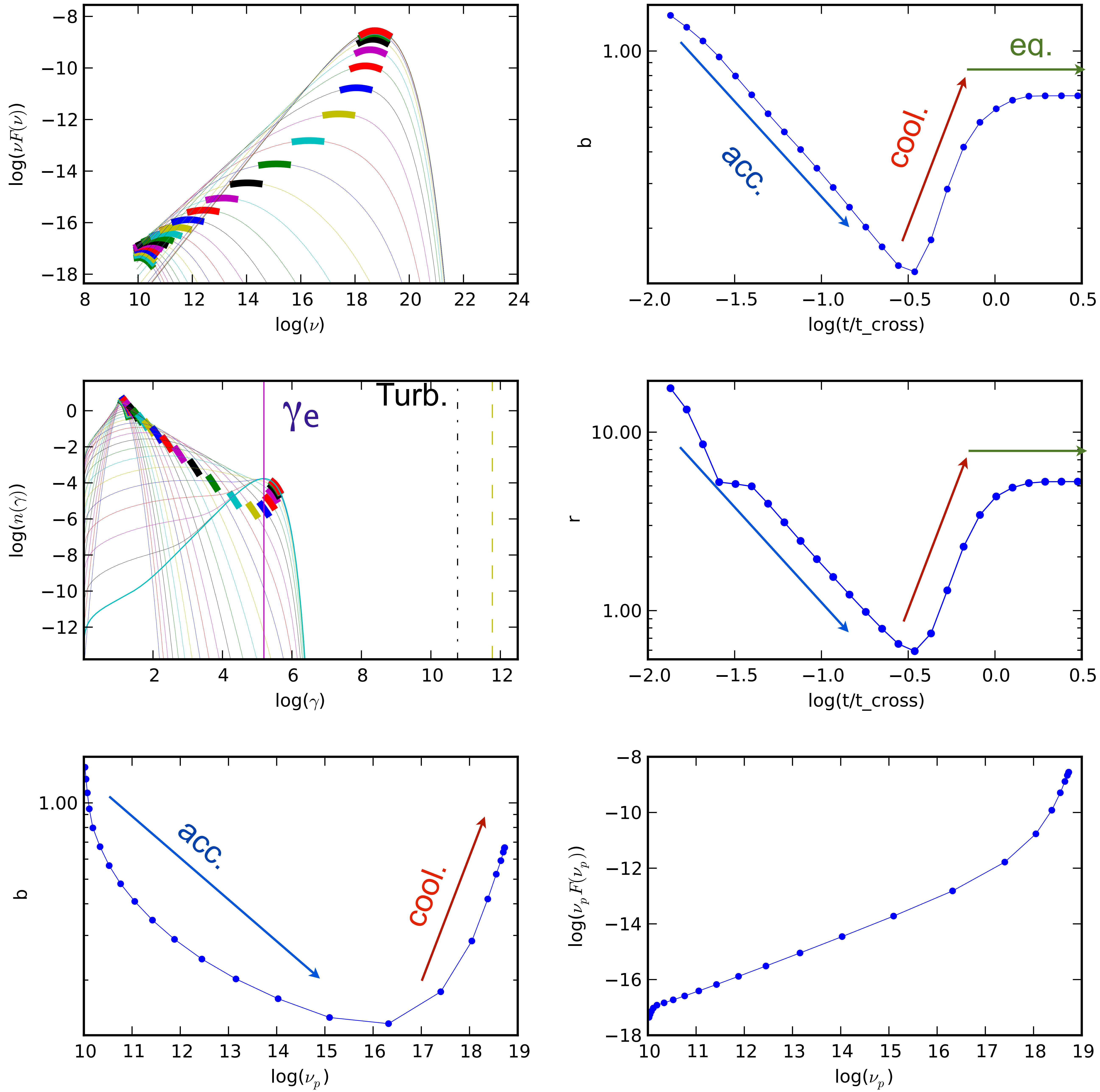


R= 5x10^13 cm



Tramacere +2011

acceleration-vs-equil.



Synchrotron

electrons

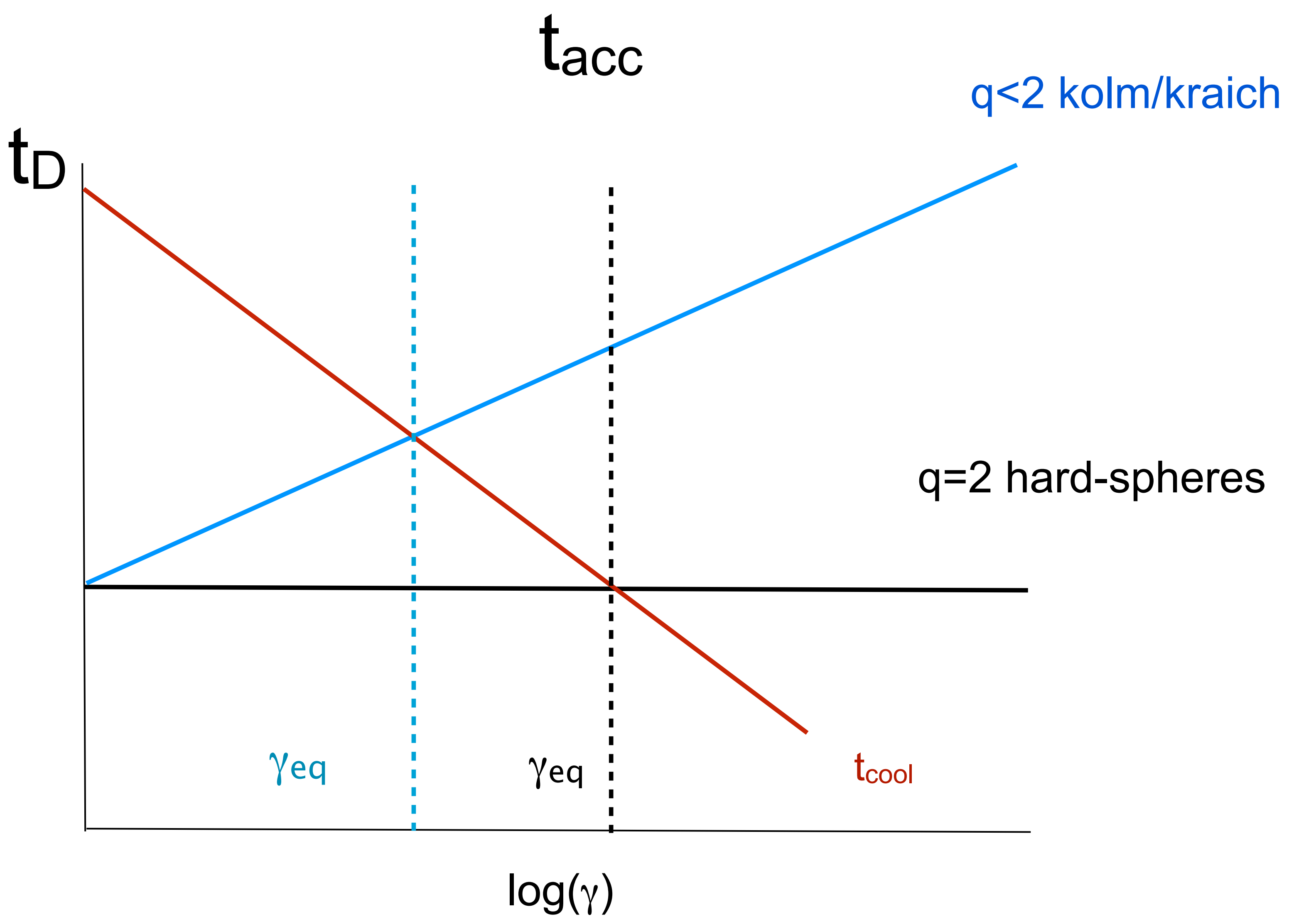
Synchrotron

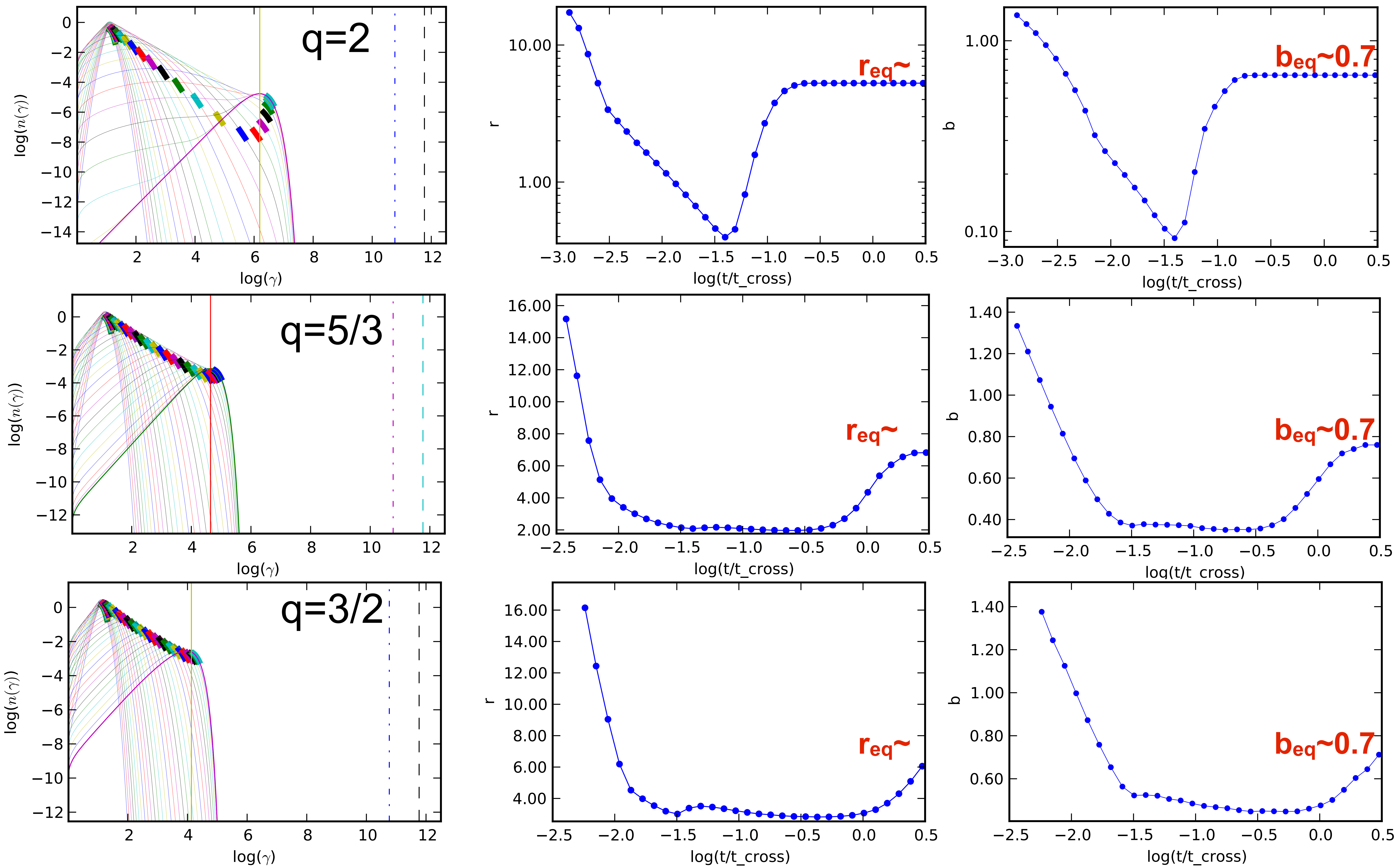
Tramacere +2011

JetSeT

effect of the turbulence index q and cooling

B=1.0 G, $t_{D0}=10^3$, R=5x10^{15} cm

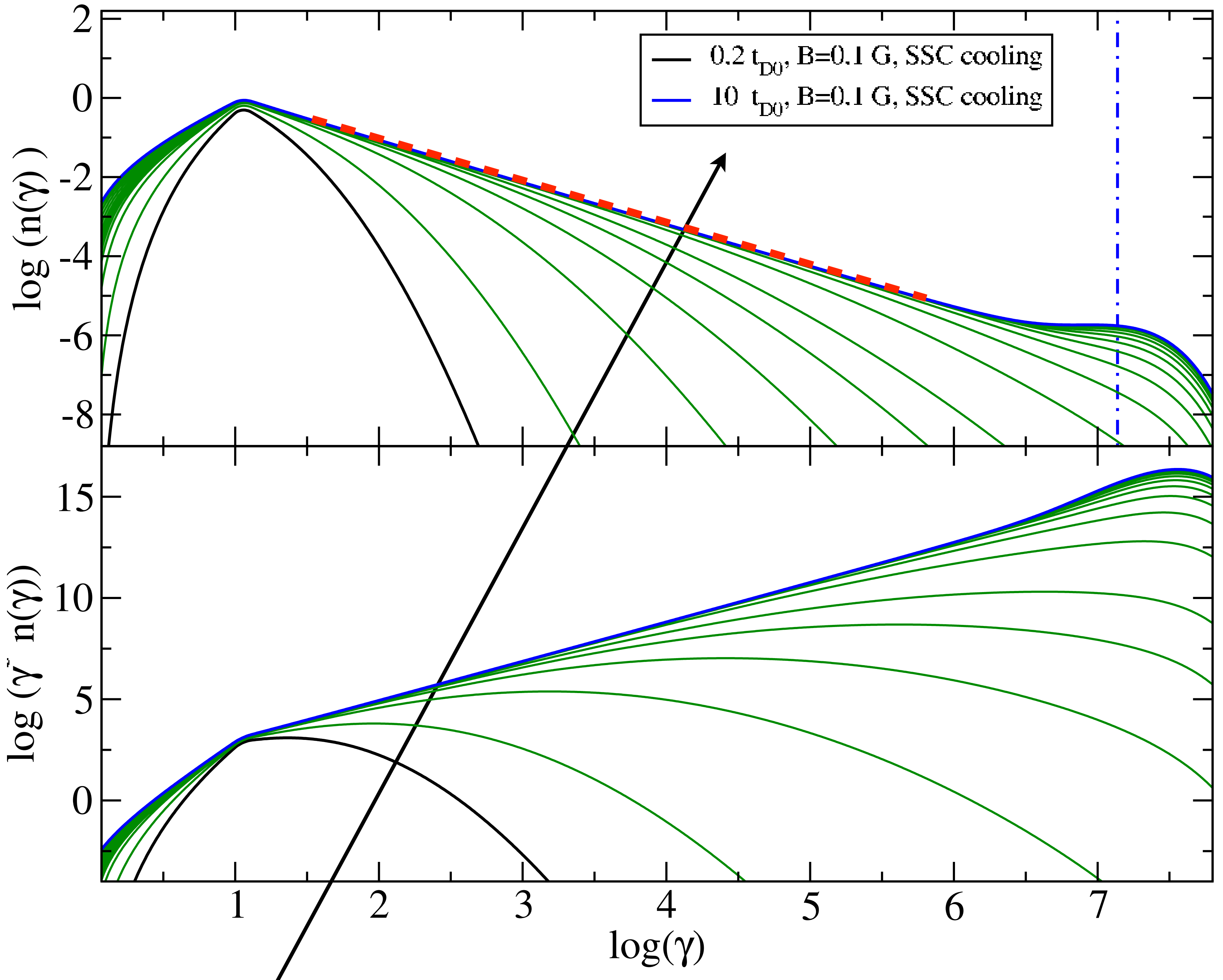




Pile-up and hard spectra

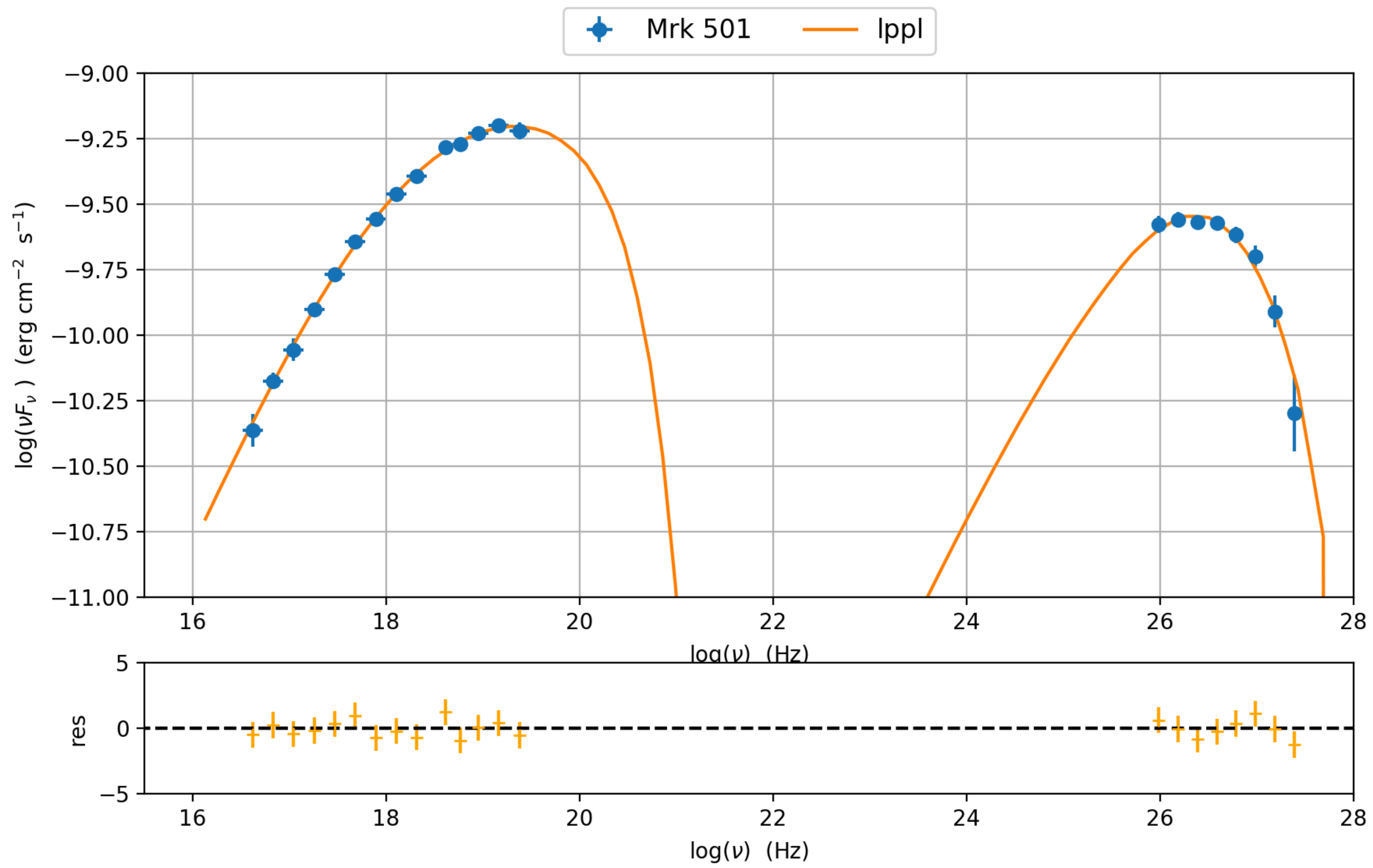
q=2, R=10^{15} cm, B=0.1 G, t_{inj}=t_D=10^4 s

Tramacere +2011



s in agreement with $s = 1 + \frac{t_{acc}}{2t_{esc}}$

Mrk 501 1997



Massaro & Tramacere +2006

s~1.6

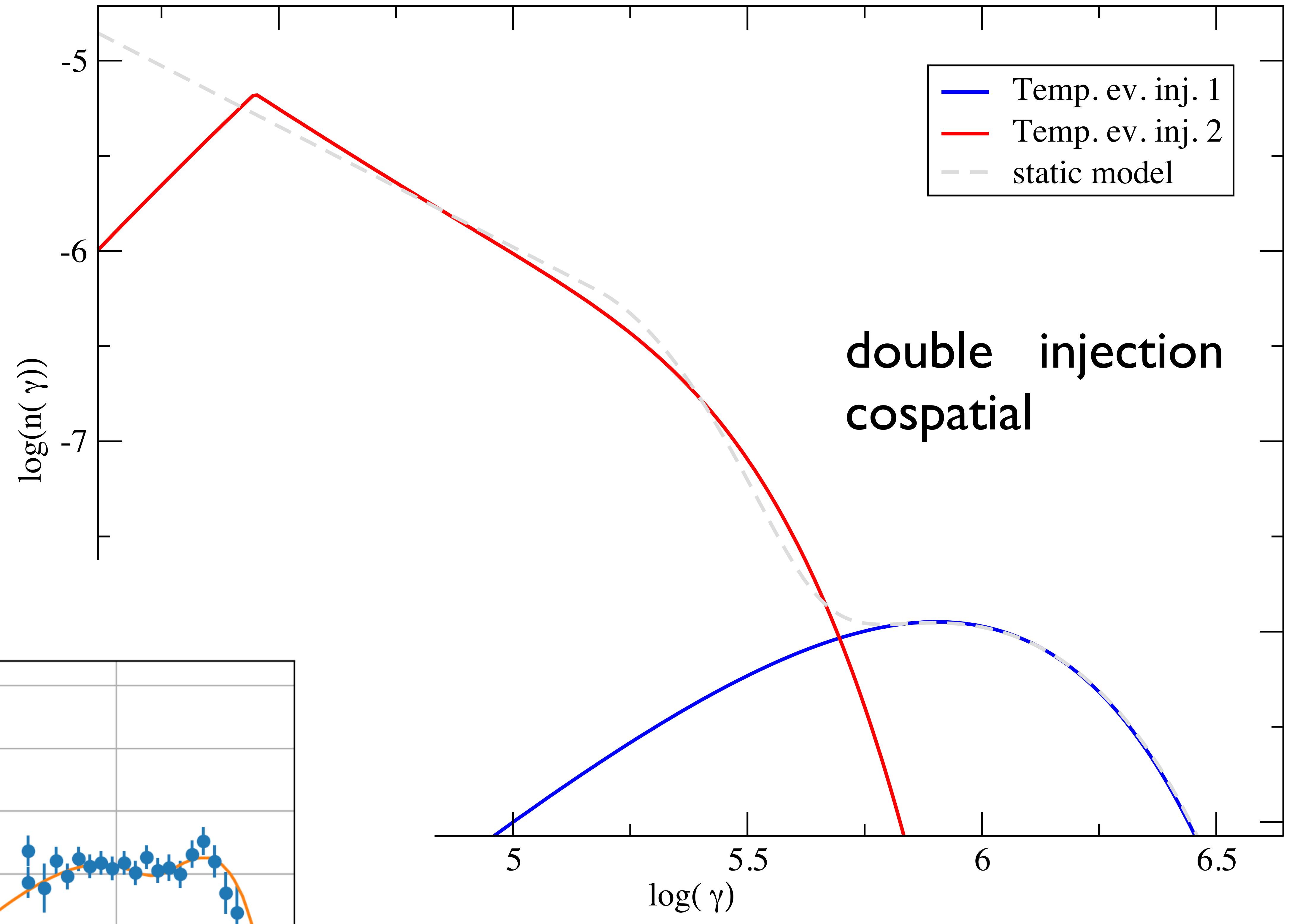
r~0.7-0.8<<r_{eq}~6

s<<s_{FI}~2.3

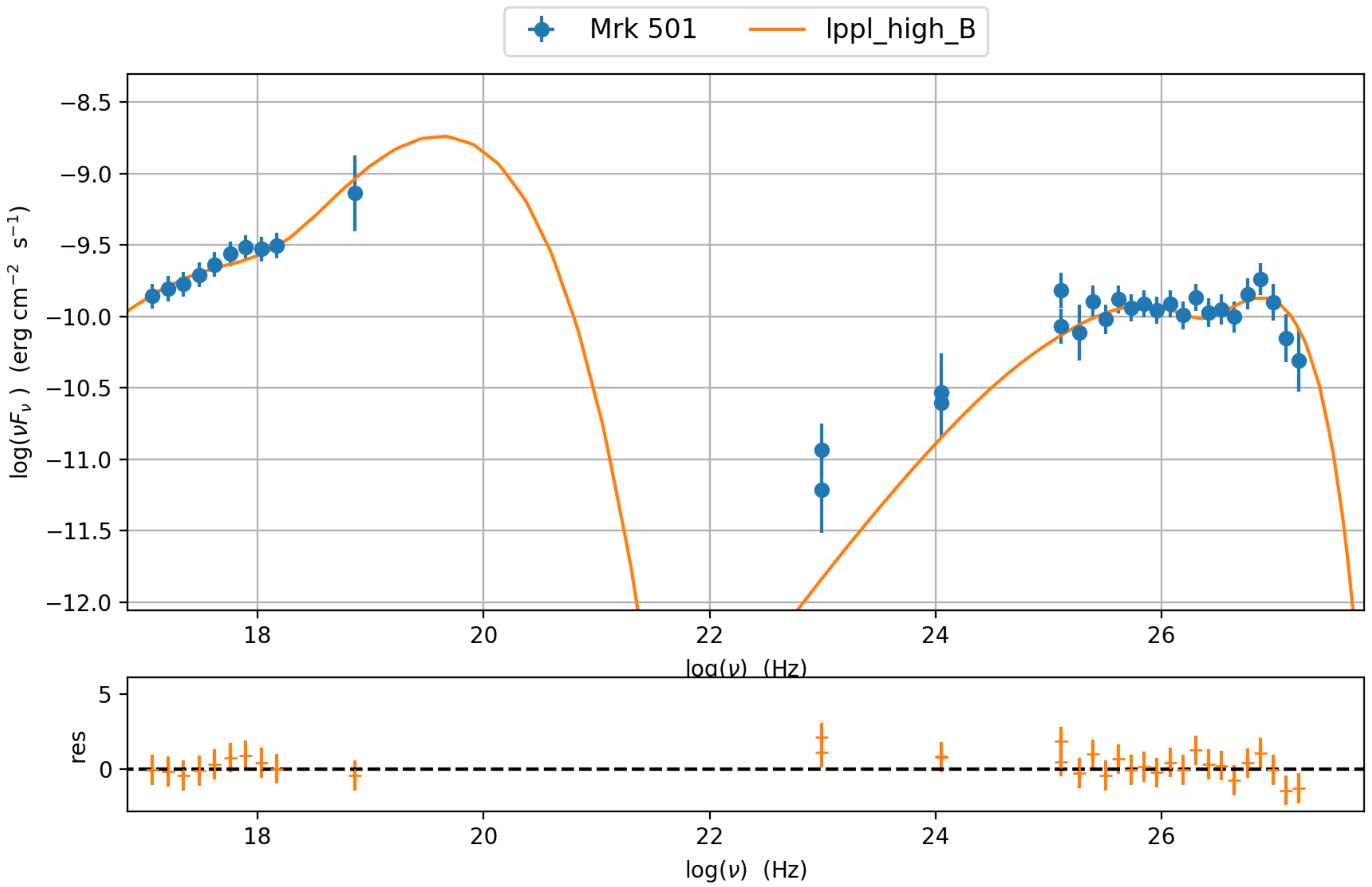
temporal evolution

Pile-up and hard spectra

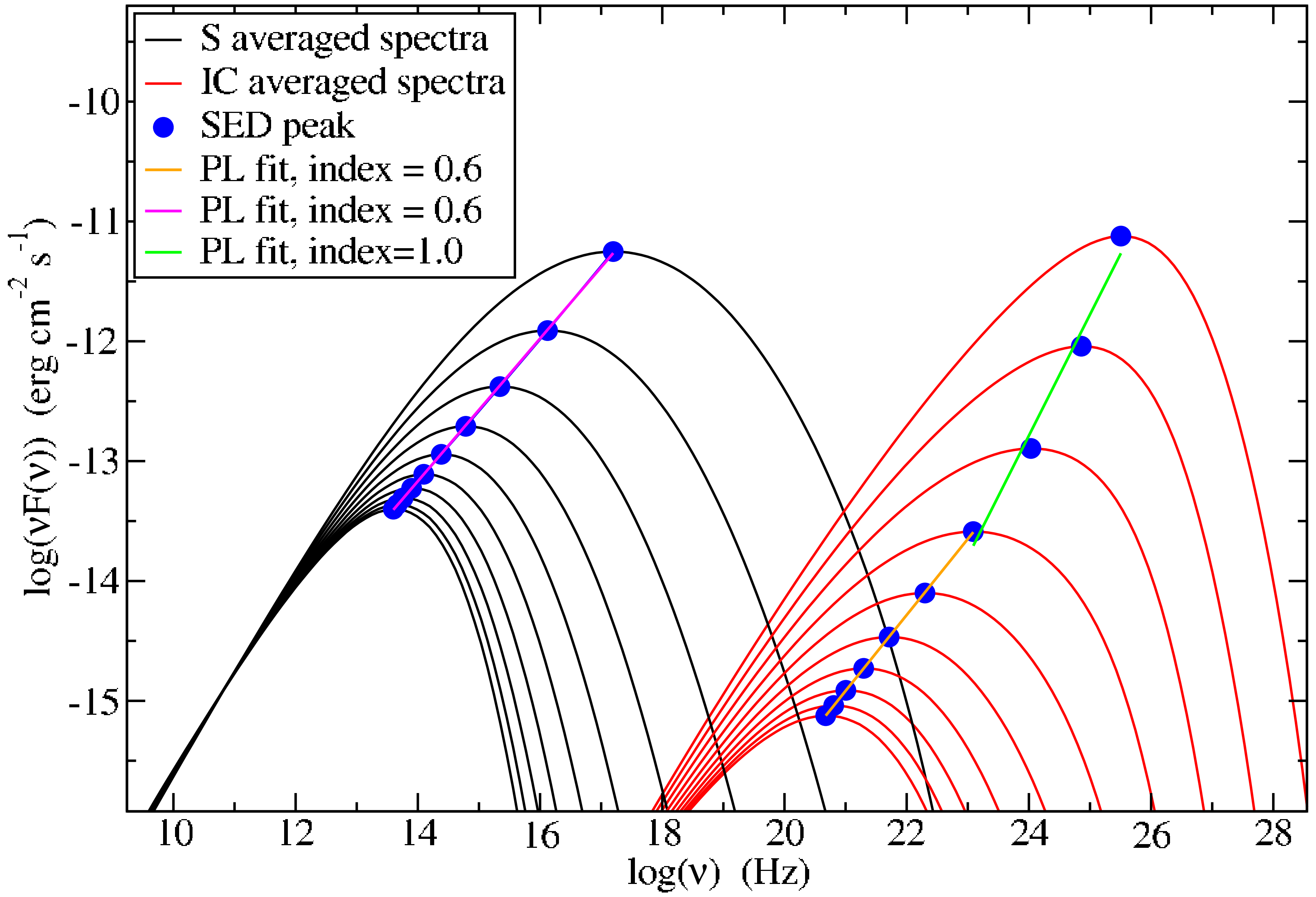
Mrk 501 2014 Flare
MAGIC paper
A&A 637, A86 (2020)



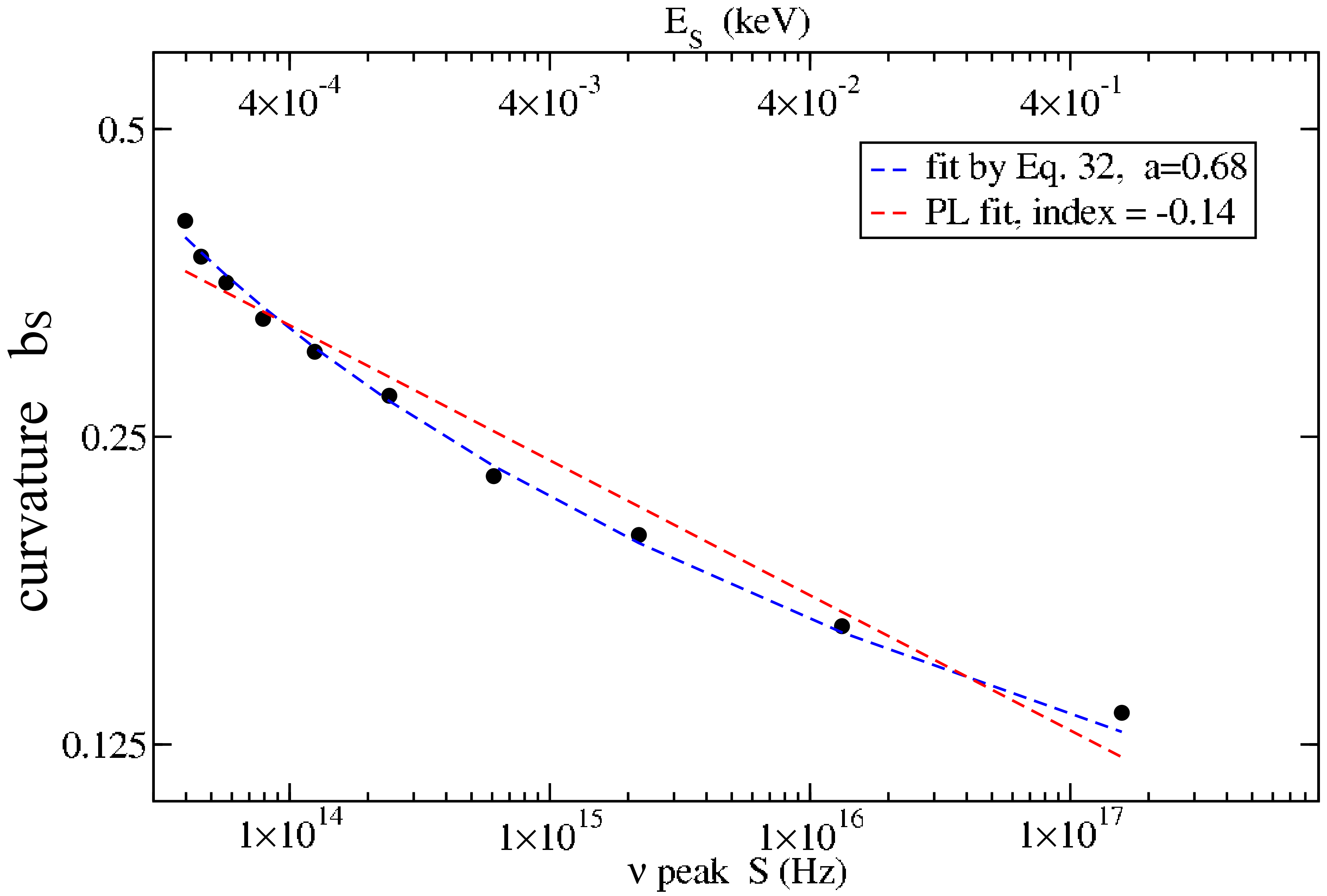
double injection
cospatial

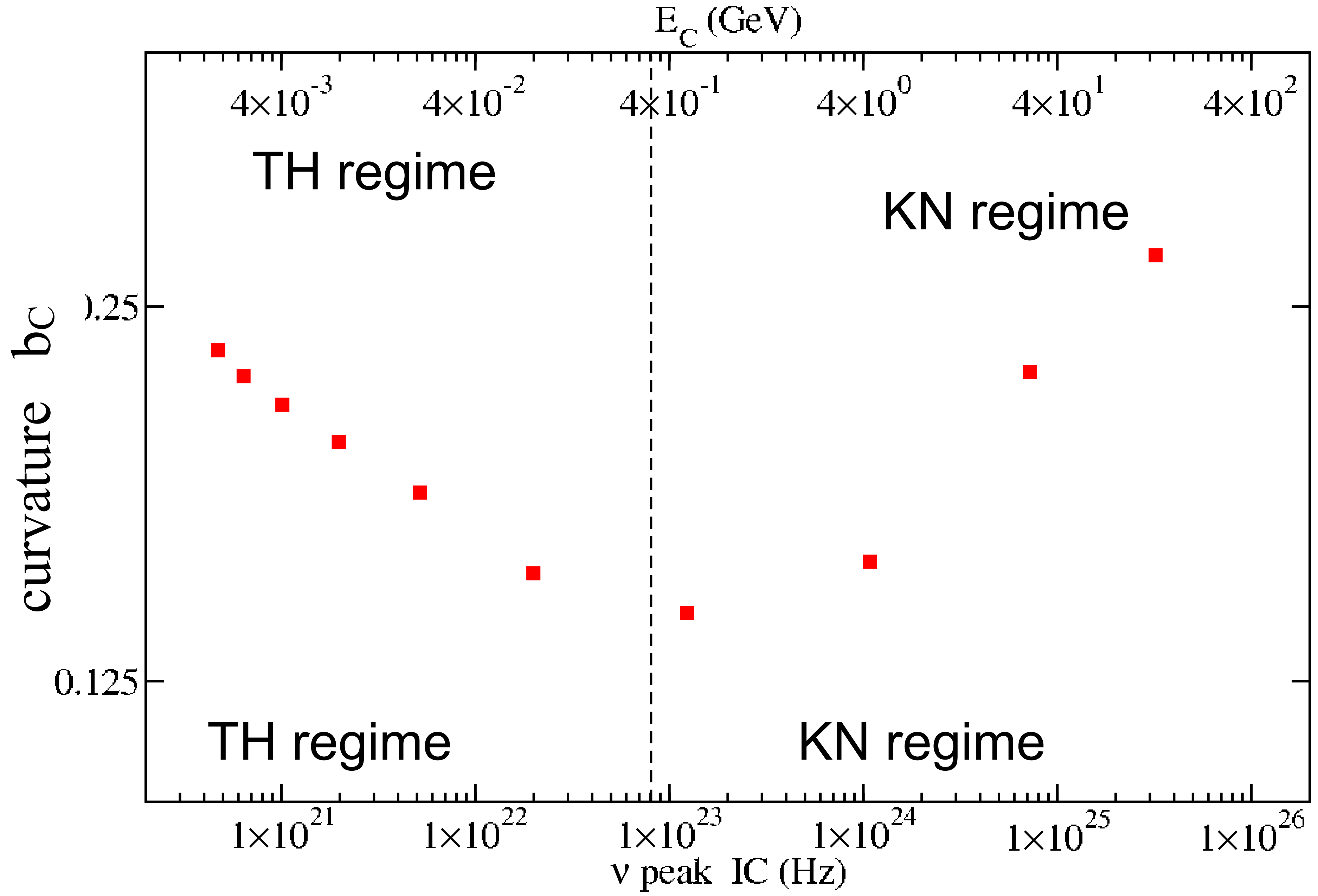


S vs IC



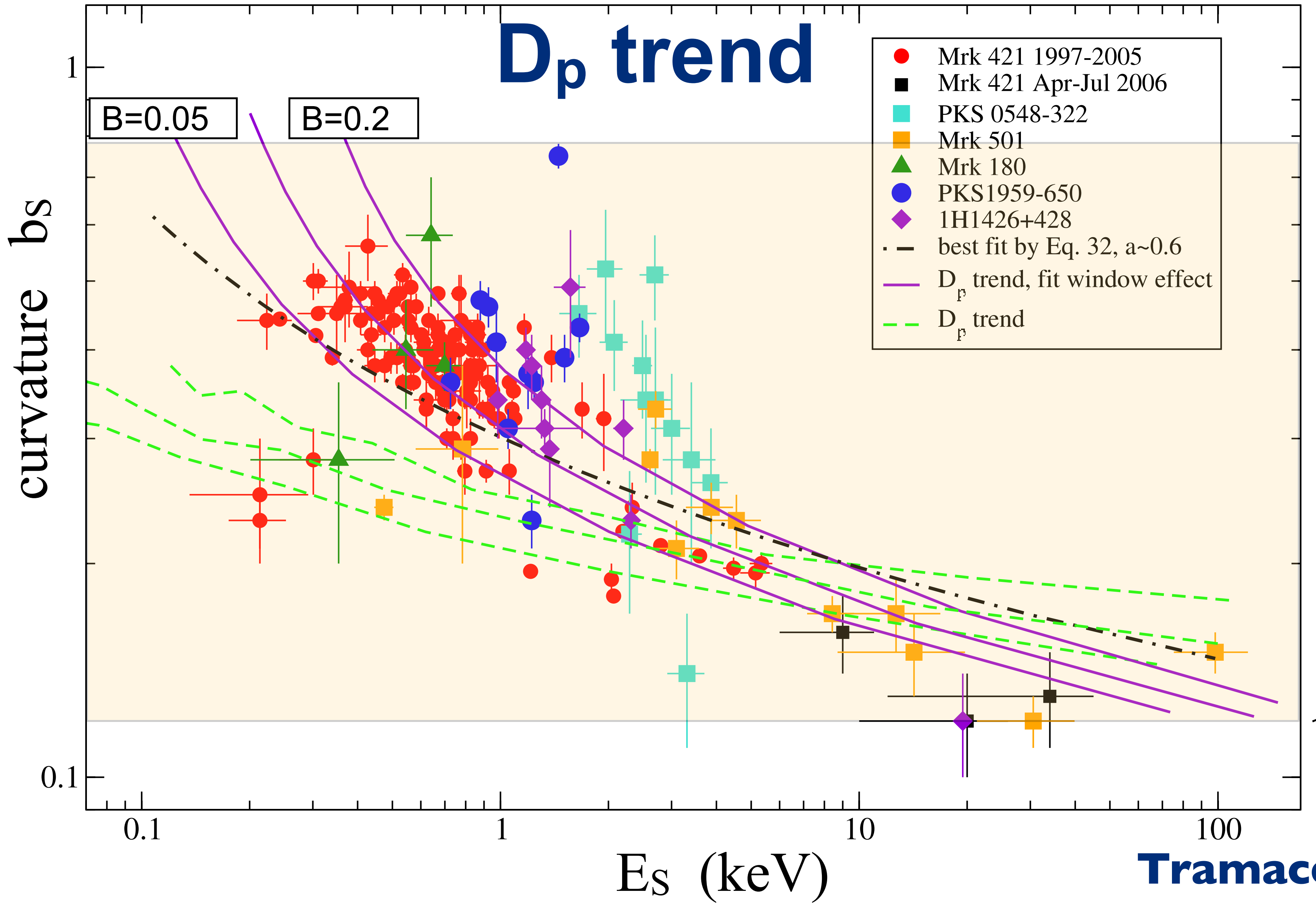
Tramacere +2011



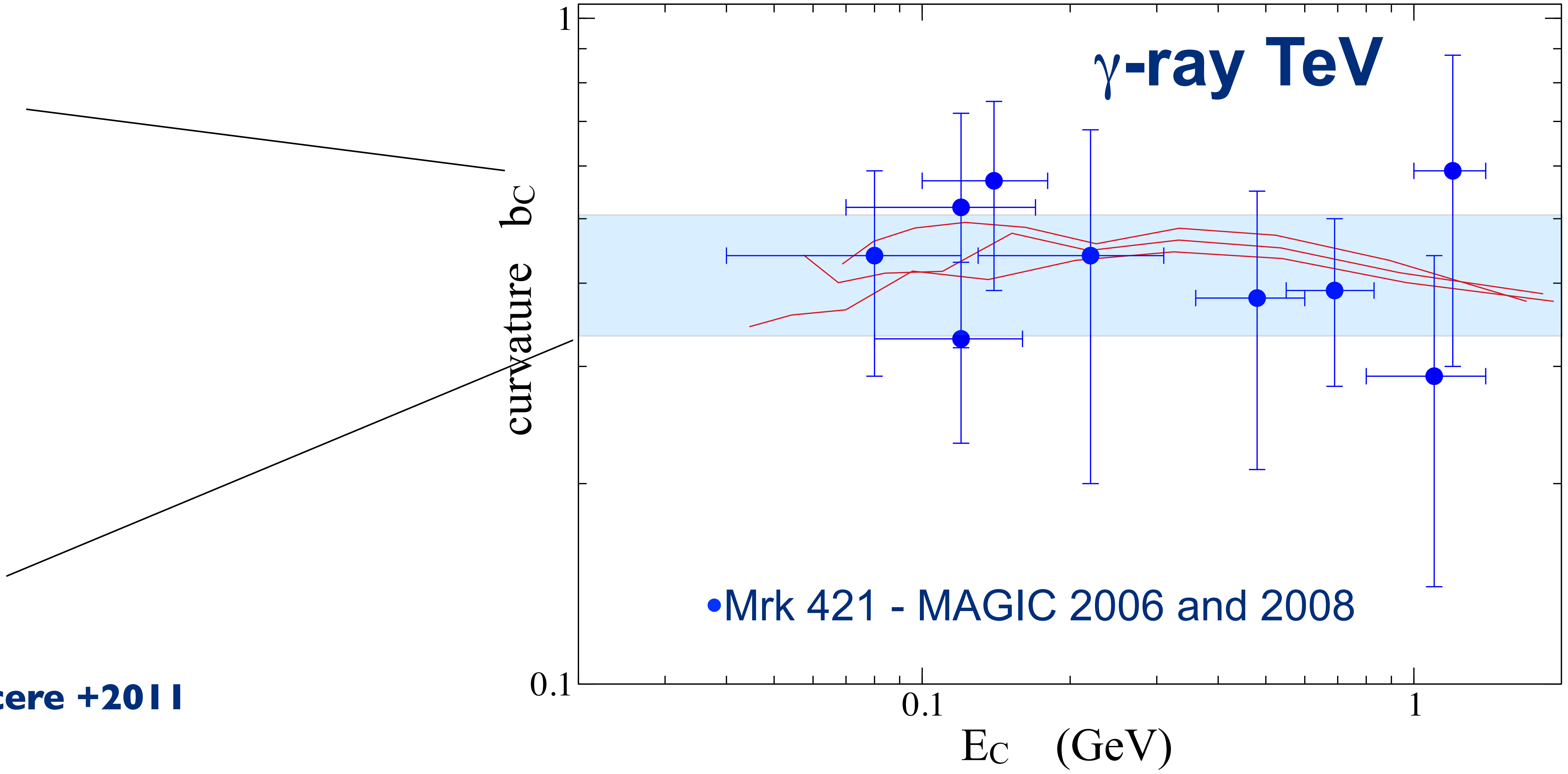


	Acceleration dominated	Equilibrium
curvature trend	curvature decreasing trend *b-Ep*	curvature stable or increasing (r~7,b~1.3)
spectral shape	LPPL or LP	PL+exp-cutoff or Maxwellian

E_S-b_S X-ray trend and γ-ray predictions



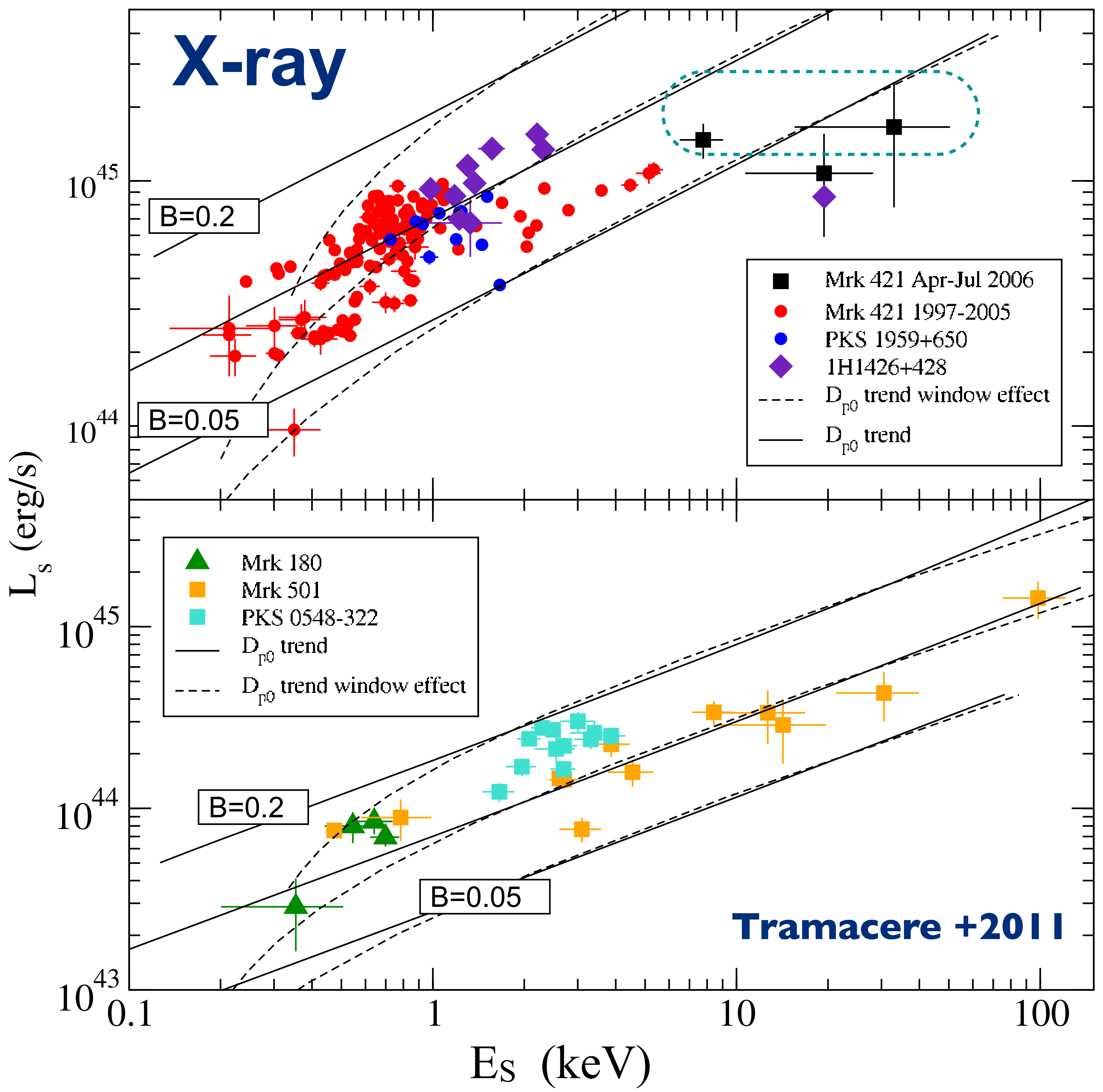
Tramacere +2011

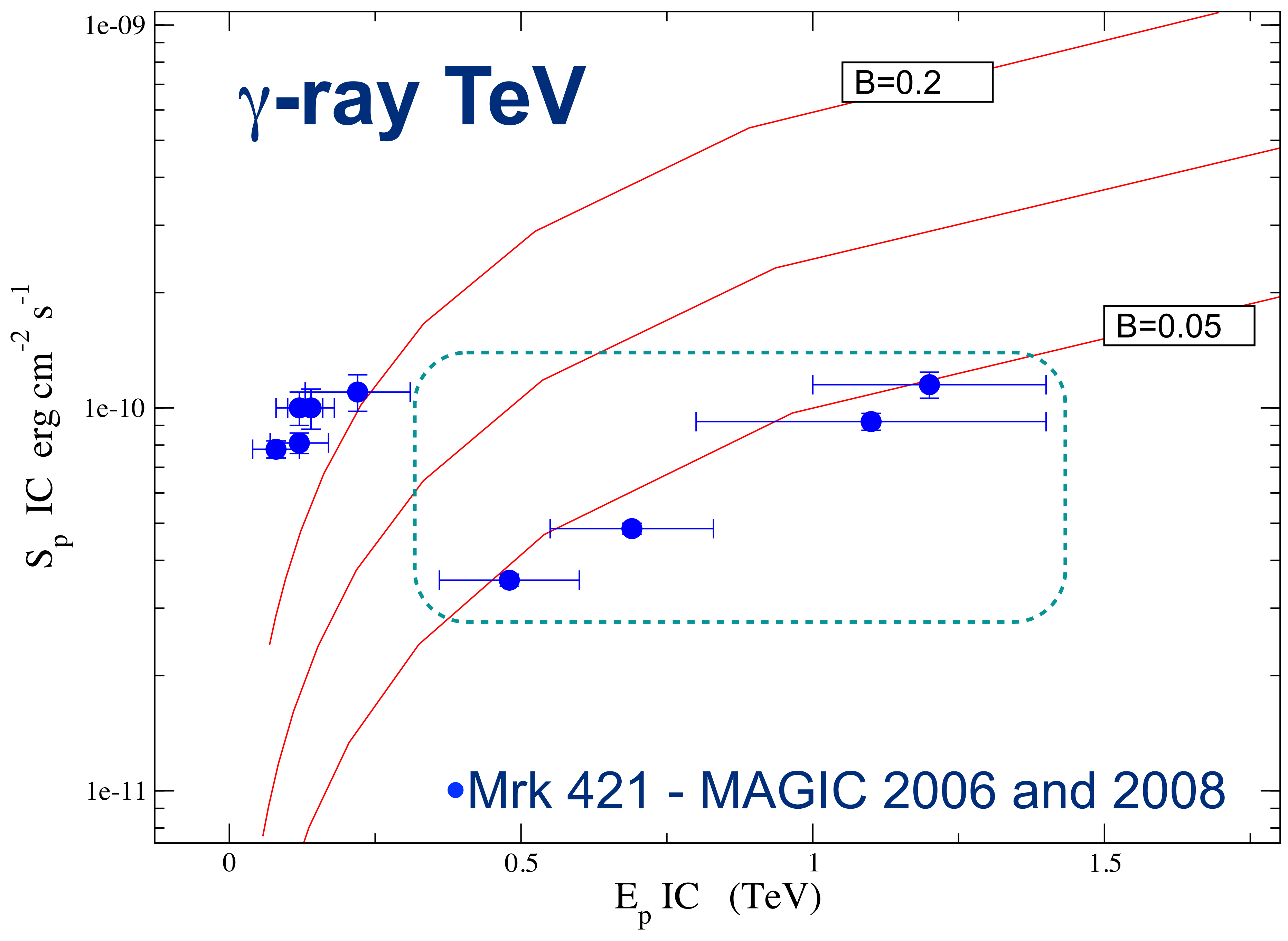


- data span **13 years**, both flaring and quiescent states
- We are able to reproduce these long-term behaviours, by changing the value of only one parameter (D_p)
- for q=2, curvature values imply distribution far from the equilibrium (b~[1.0–0.7])
- More data needed at GeV/TeV, curvature seems to be cooling-dominated
- Similar trend observed in GRBs (Massaro & Grindlay 2001)

$L_{\rm inj}$ (E_s–b_s trend)	(erg s^{-1})	5×10^{39}
$L_{\rm inj}$ (E_s–L_s trend)	(erg s^{-1})	5×10^{38}, 5×10^{39}
q		2
t_A	(s)	1.2×10^3
$t_{D_0} = 1/D_{P0}$	(s)	$[1.5 \times 10^4, 1.5 \times 10^5]$
$T_{\rm inj}$	(s)	10^4
$T_{\rm esc}$	(R/c)	2.0

E_S-L_S X-ray trend and γ-ray predictions





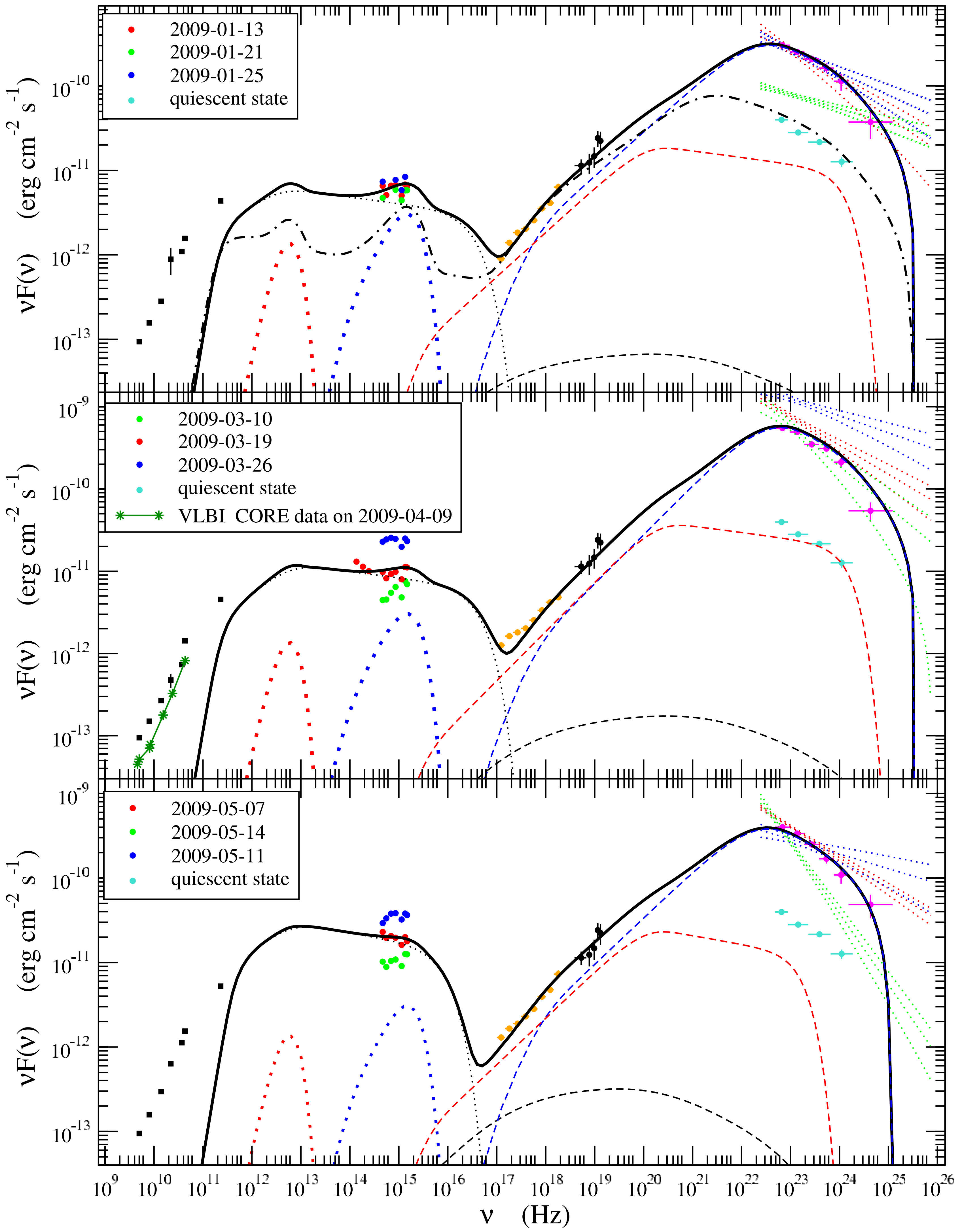
•Mrk 421 - MAGIC 2006 and 2008

- the E_s–S_s (E_s–L_s) relation follows naturally from that between E_s and b_s
- the low L_{inj} objets (Mrk 501 vs Mrk 421) reach a larger E_S, compatibly with larger γ_{eq}
- Mrk 421 MAGIC data on 2006 match very well the Synchrotron prediction with simultaneous X-ray data
- the average index of the trend $L_s \propto E_S^{\alpha}$ with $\alpha \sim 0.6$, is compatible with the data, and with a scenario in which a typical constant energy ($L_{inj}\, xt_{inj}$) is injected for any flare (jet-feeding problem), whilst the peak dynamic is ruled by the turbulence in the magnetic field.

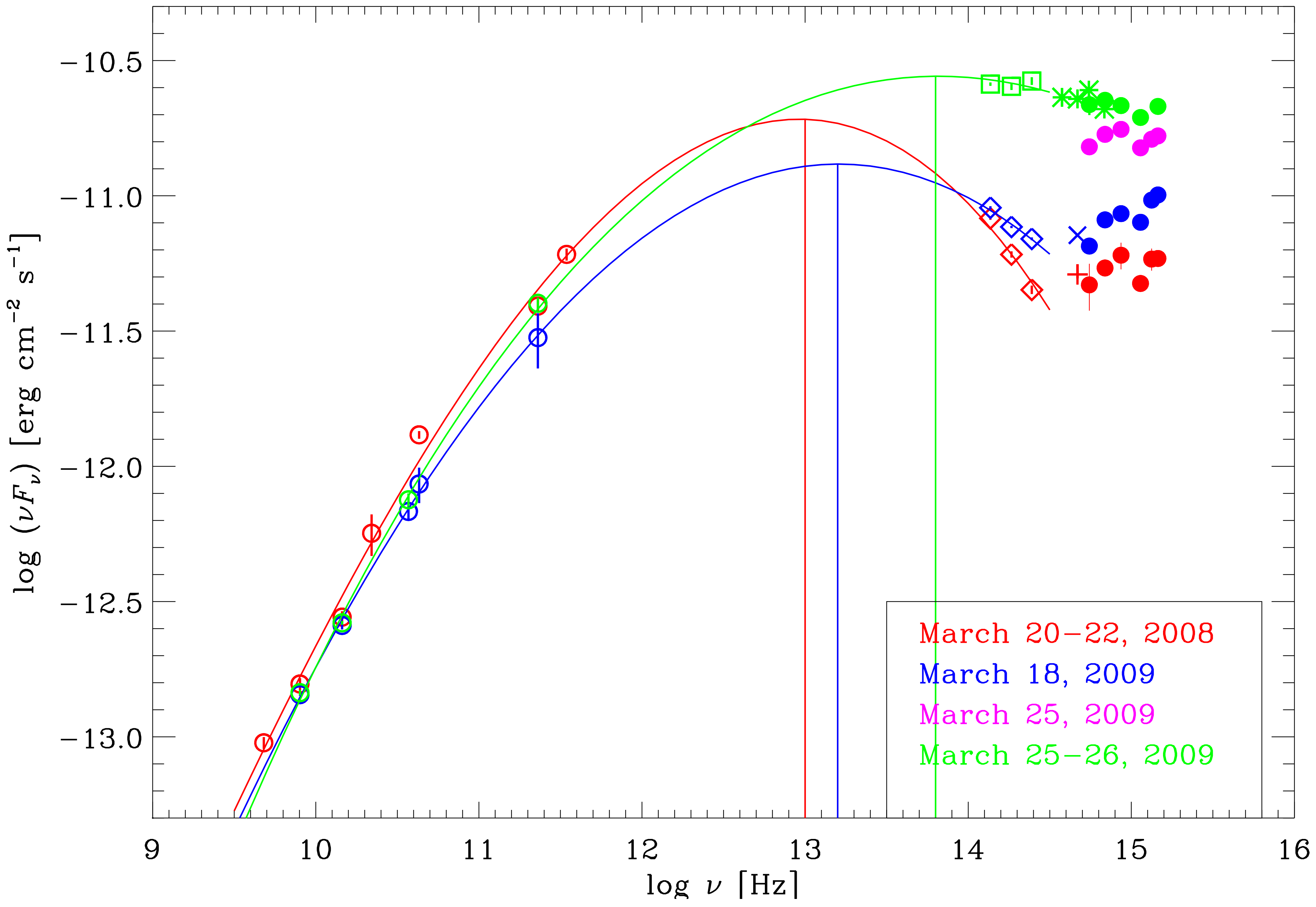
JetSeT

FSRQs

PSK 1510-089 Abdo+ 2010



Dammando+ 2012



JetSeT

JetSeT web interface: https://www.isdc.unige.ch/sedtool