Emission processes in blazars

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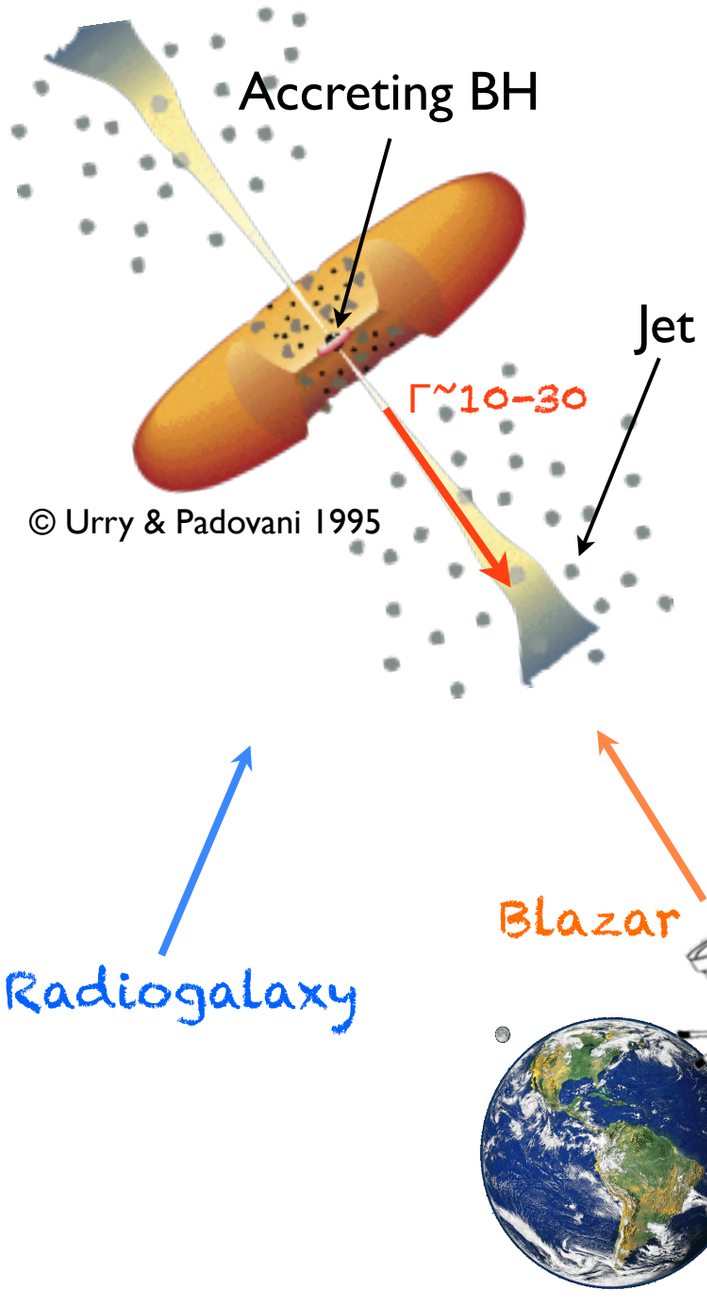
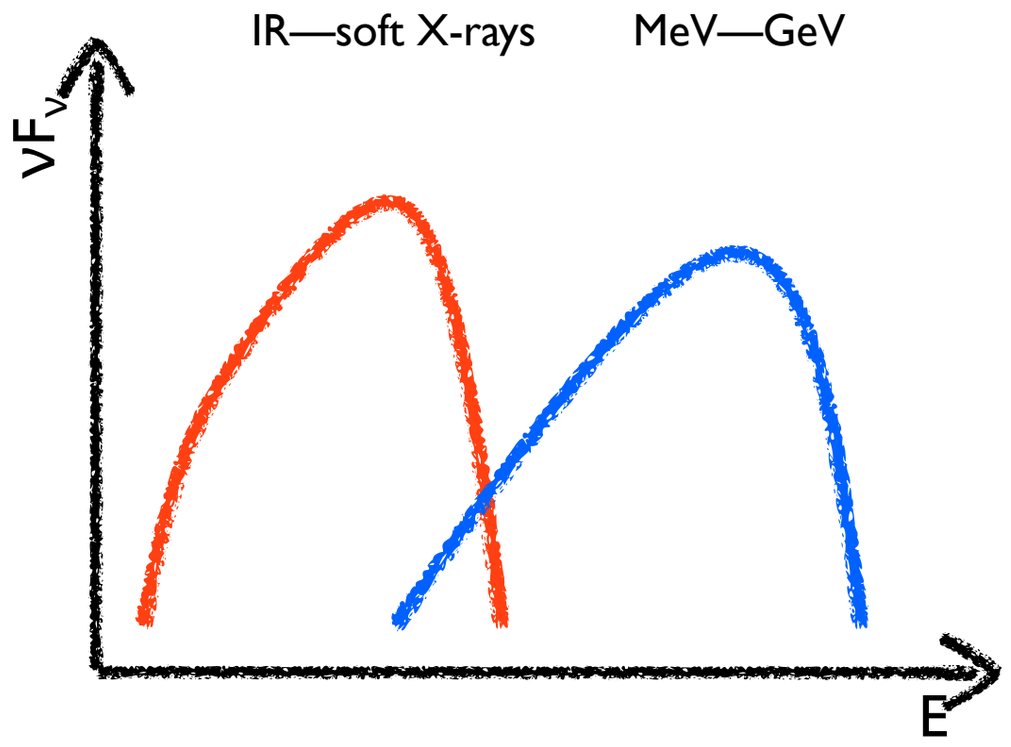
INAF-OABrera

Sexten2022

Sexten - 19/7/2019

Blazars in a nutshell

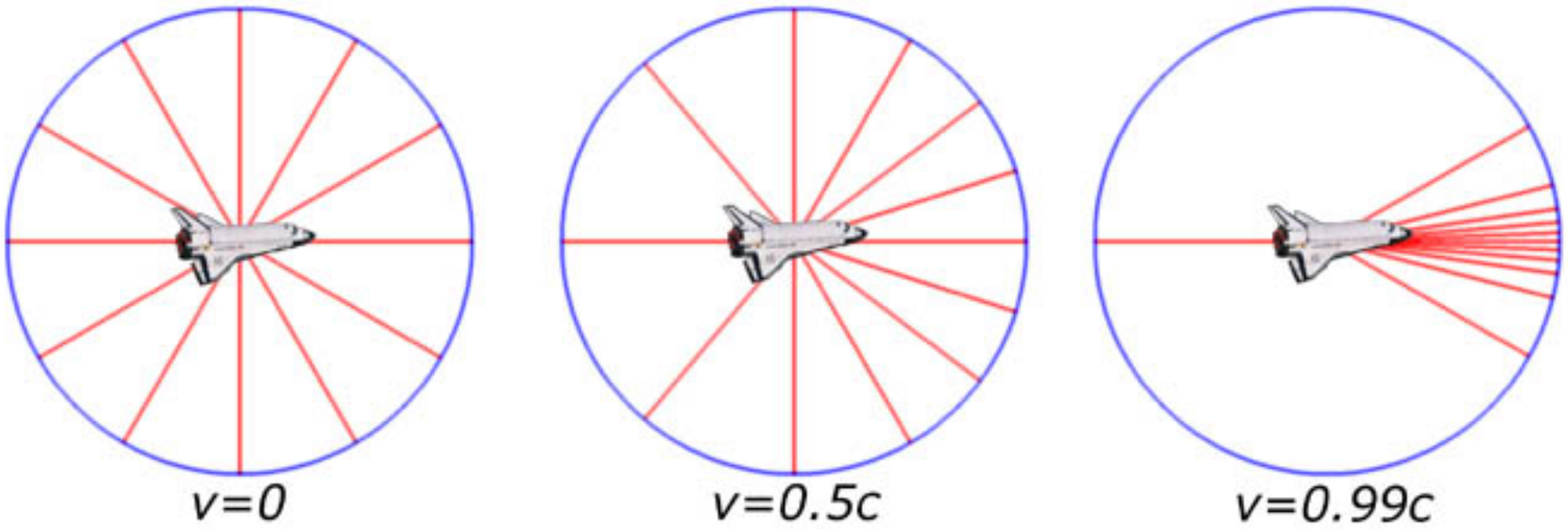




SED dominated by the relativistically boosted non-thermal continuum emission of the jet.

Special relativity at work

Doppler beaming



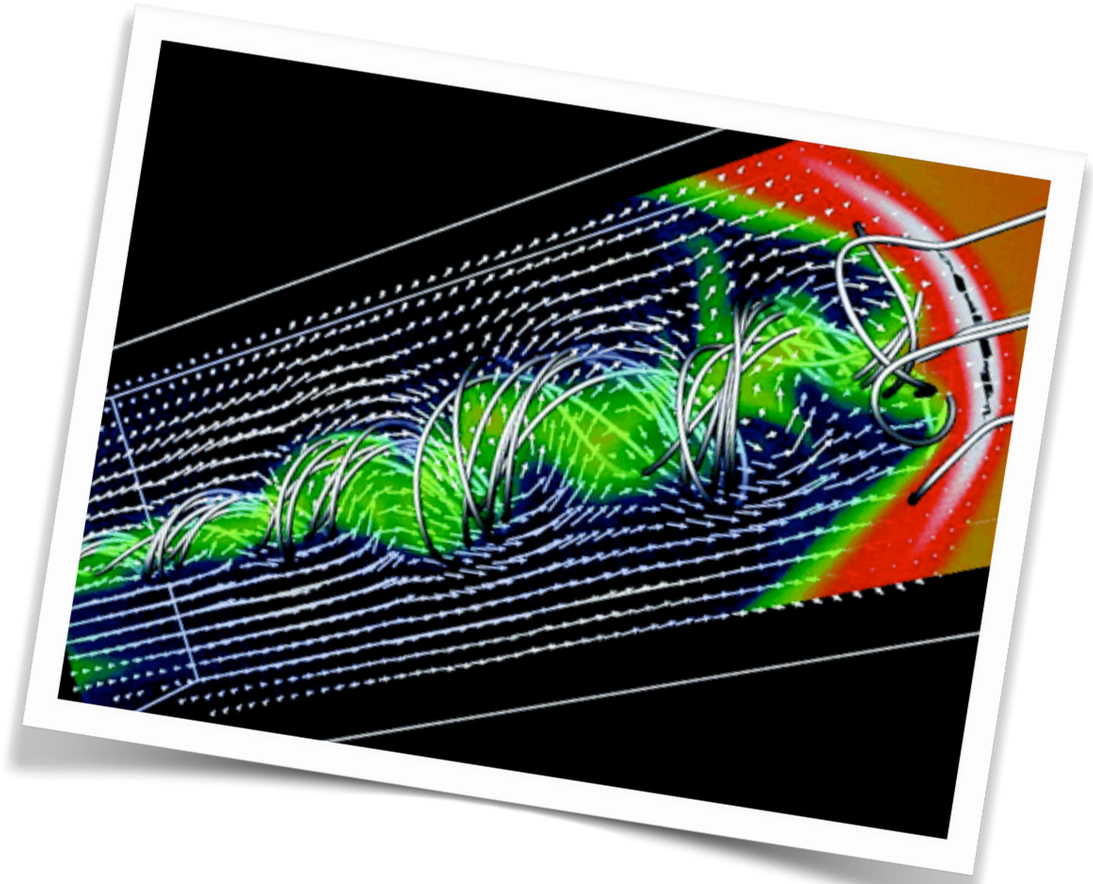
$$\delta = \frac{1}{\Gamma(1 - \beta \cos\theta_{\rm v})}$$

Amplification	$L_{\rm obs} = L' \delta^4$
Blueshift	$\nu_{obs} = \nu' \delta$
Shortening of timescales	$t_{\rm obs} = t'/\delta$

$$\delta \approx 10 - 20$$

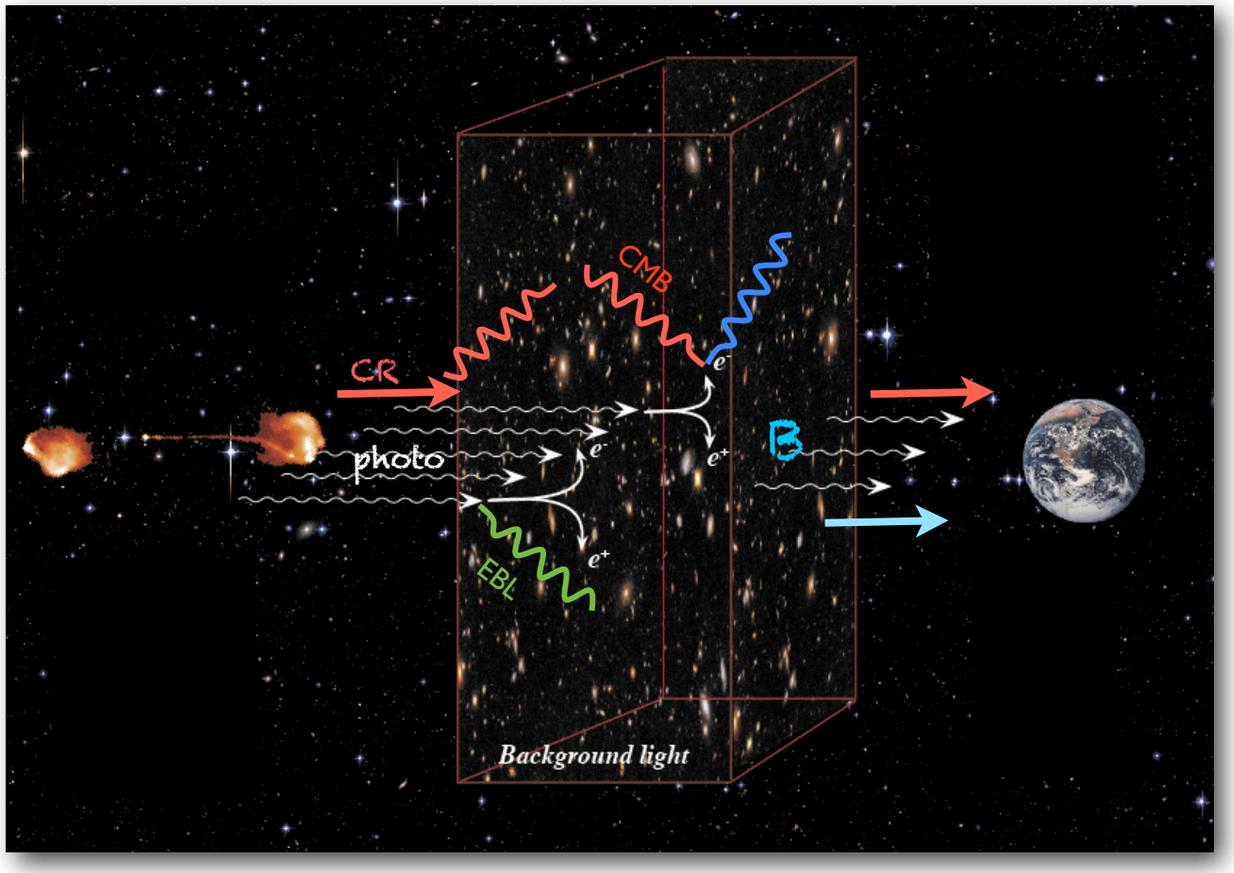
Jet physics

Particle acceleration
Plasma and B-field physics
Reconnection vs shock
Hadronic vs leptonic emission
Location of emission region
...



Propagation effects

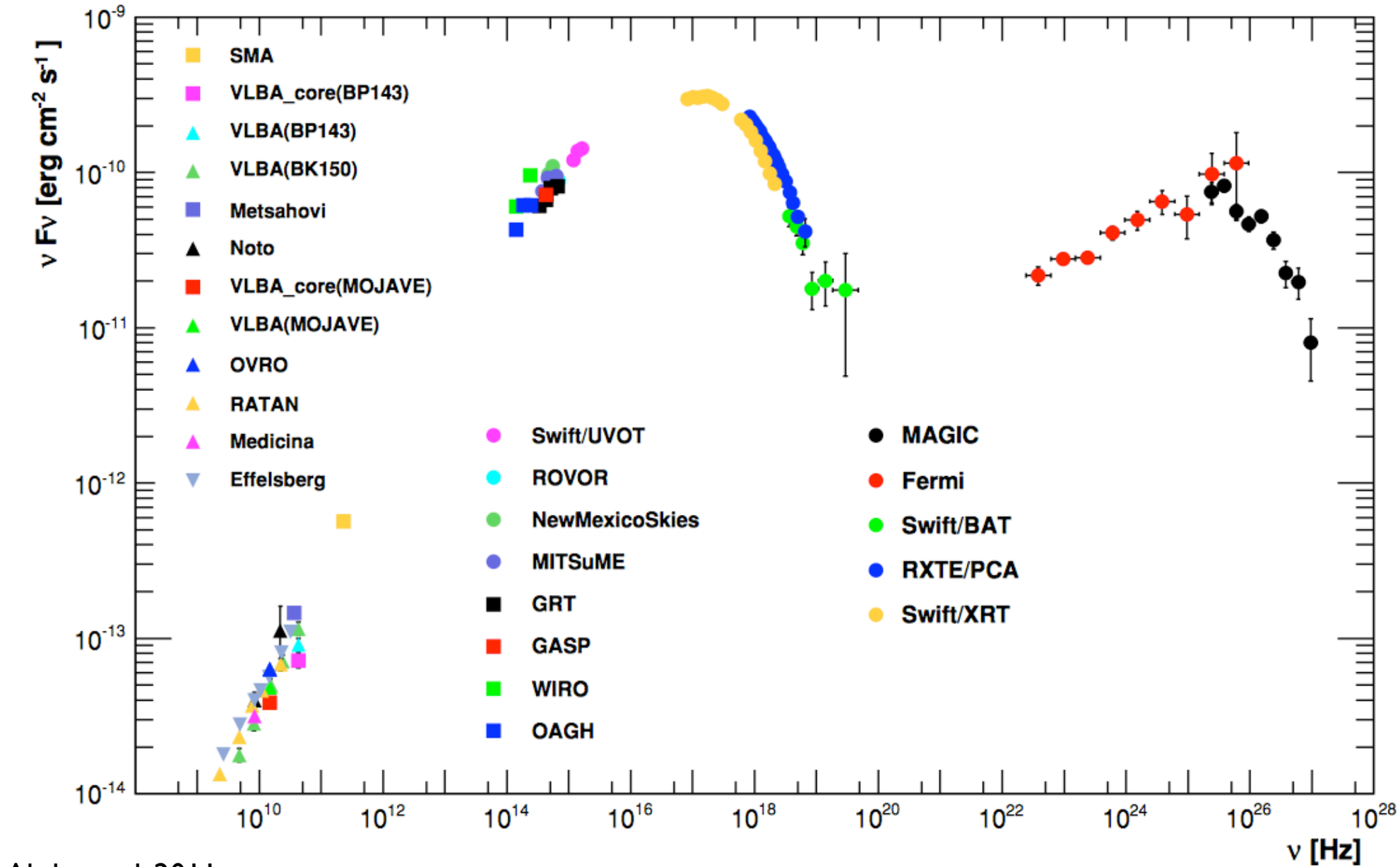
Extragalactic background light
Intergalactic magnetic field
Hadronic beams
LIV and ALPs-induced effects and other anomalies



The spectral energy distribution

Extended over the whole EM spectrum
Extremely variable

Important observational effort



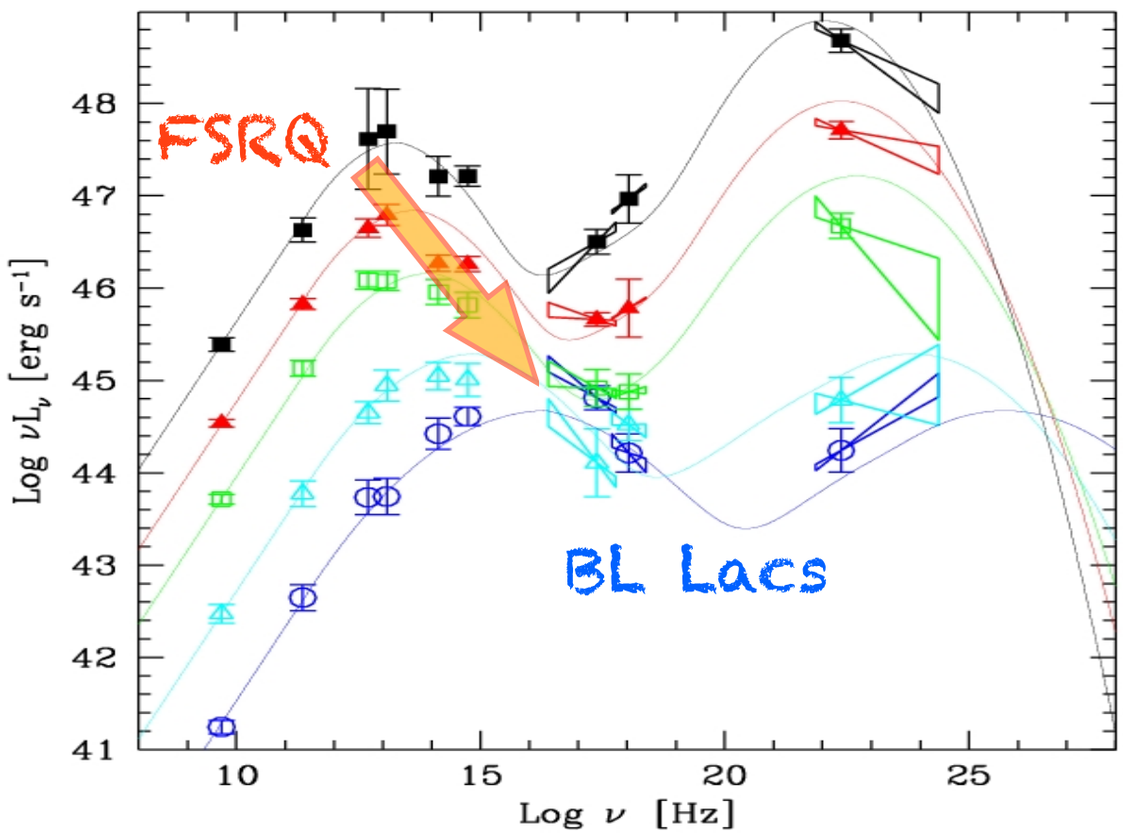
Abdo et al. 2011

Blazars: basic phenomenology

Blazars occur in two flavors:

FSRQ: high power, thermal optical components (broad lines)

BL Lacs: low power, almost purely non-thermal components



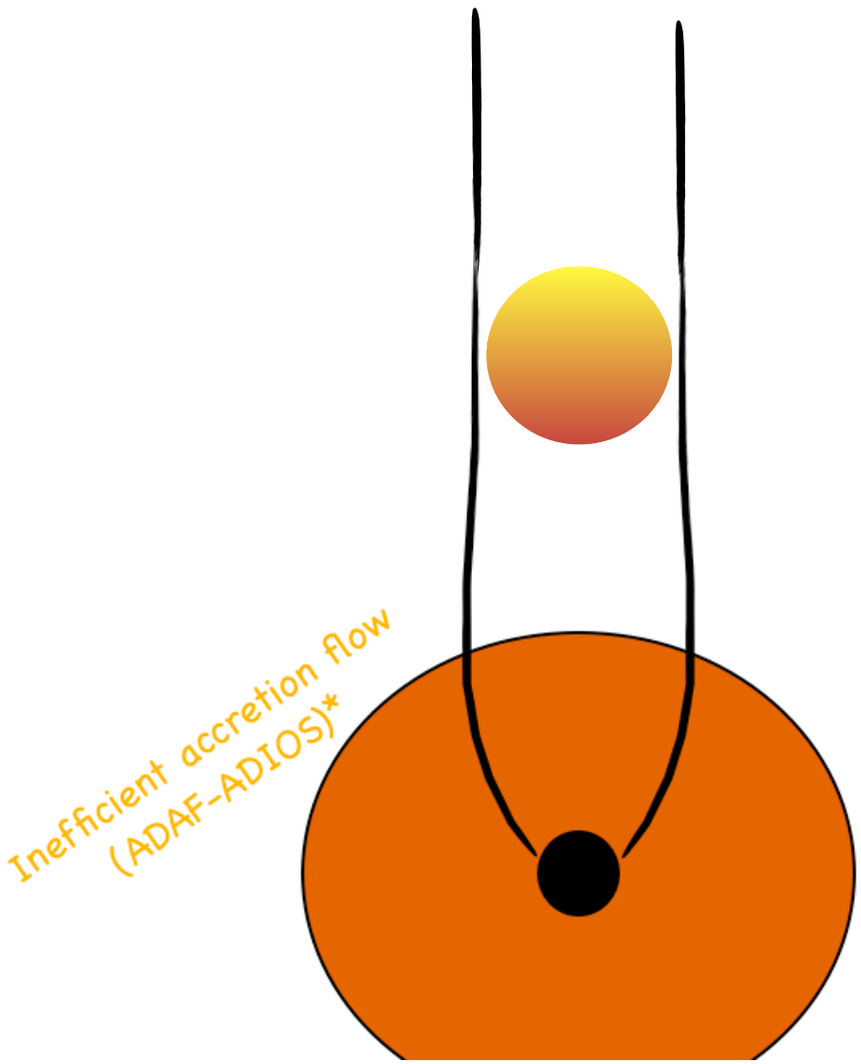
The "blazar sequence"

Fossati et al. 1998
Donato et al. 2002
Ghisellini et al. 2009

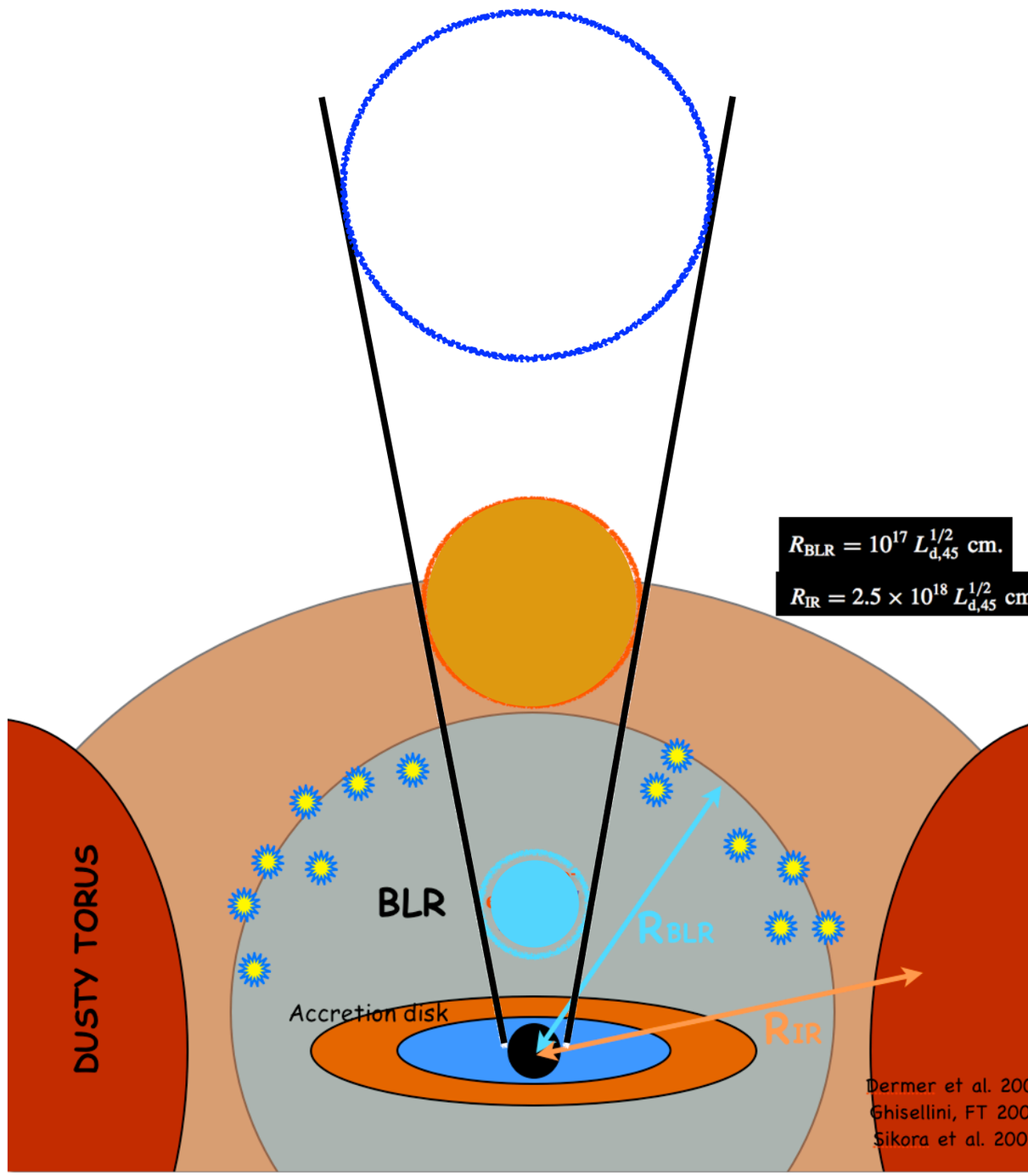
But see several papers by Giommi & Padovani

Blazars in a nutshell

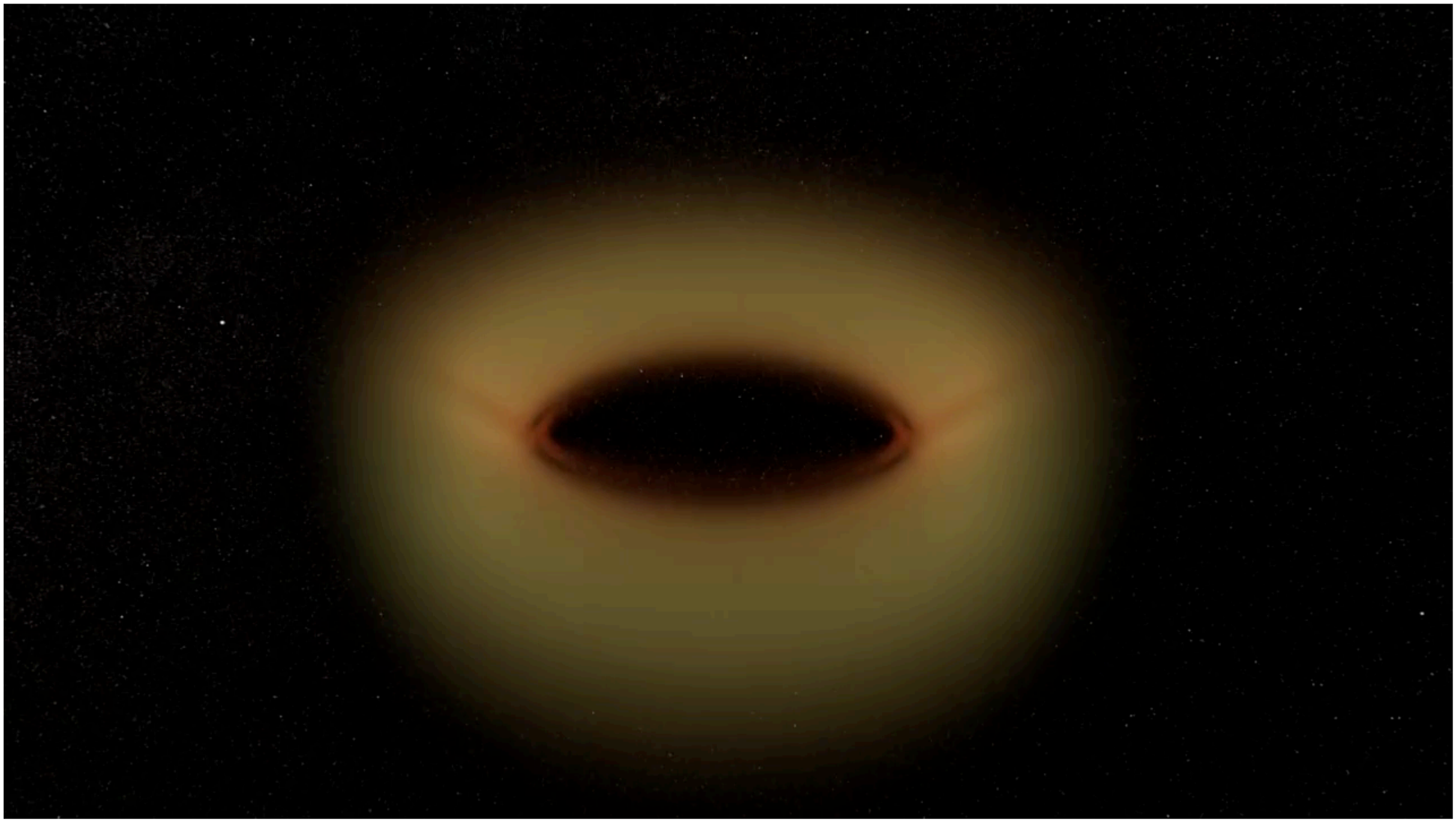
BL Lacs: “naked” jets



FSRQ: “dressed” jets

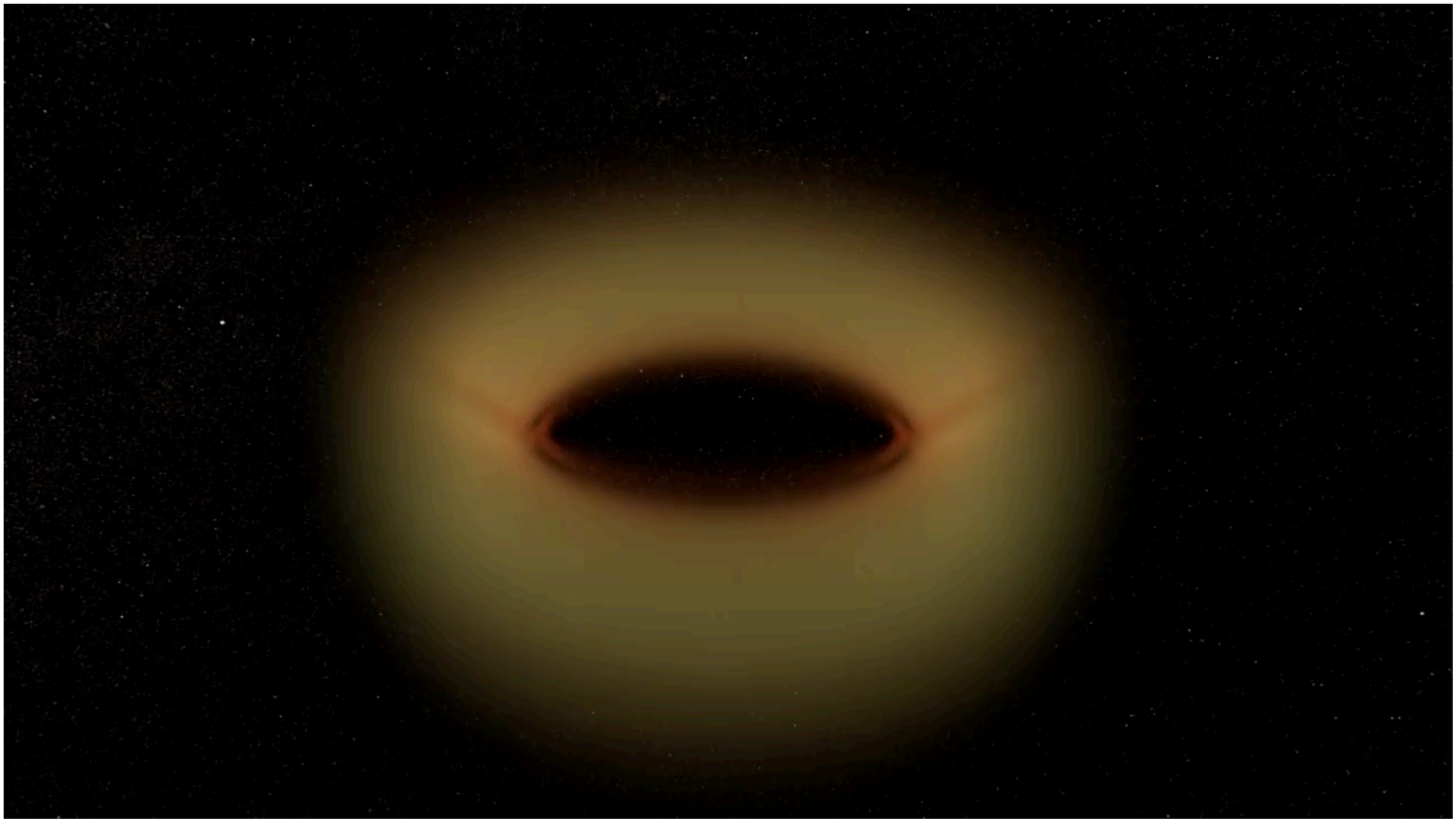


Producing the jet



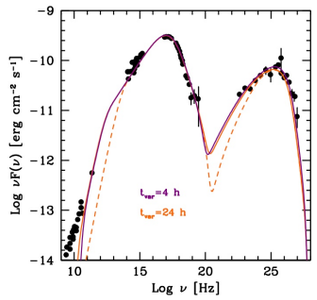
McKinney, Tchekhovskoy, and Blandford 2012

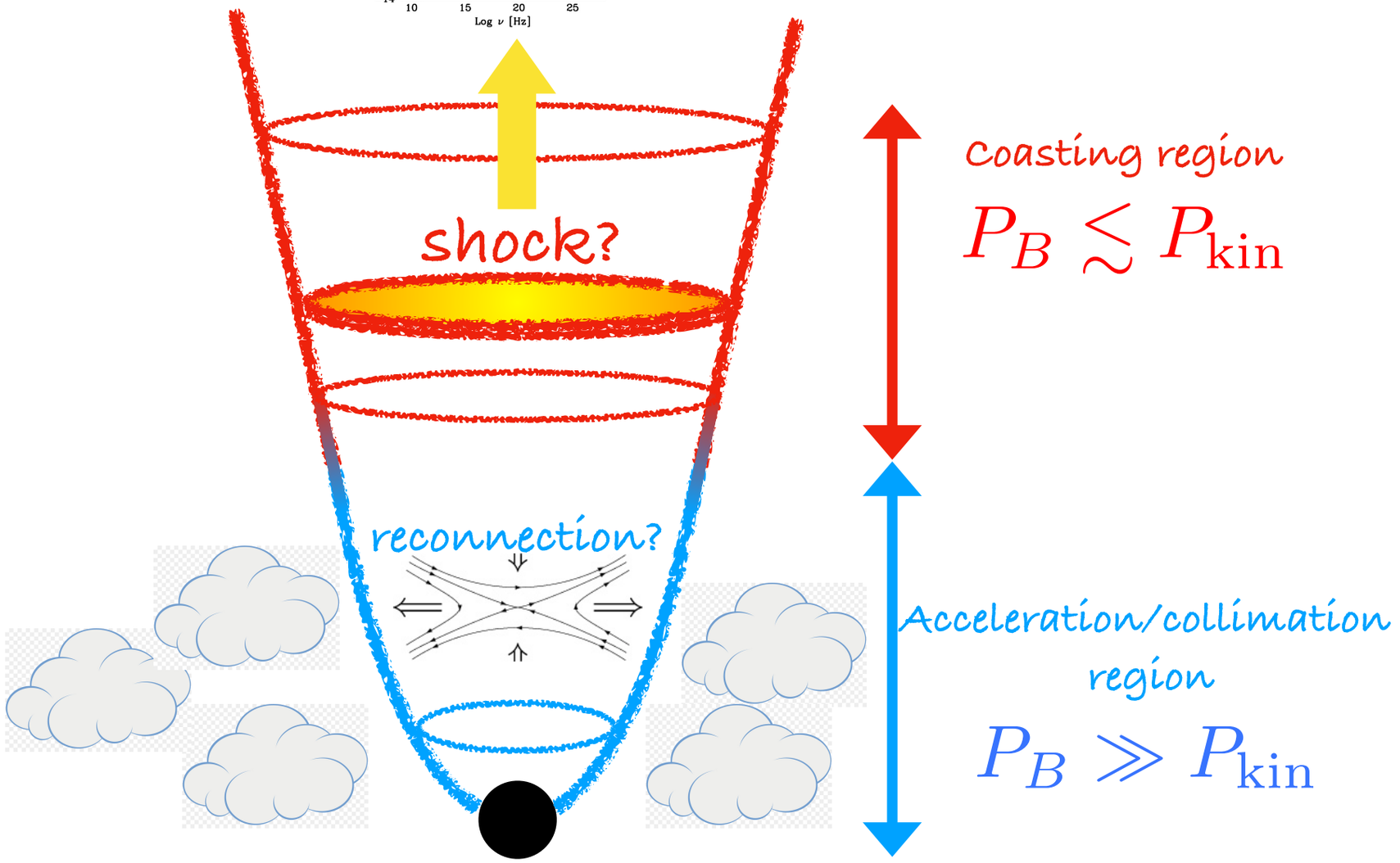
Producing the jet



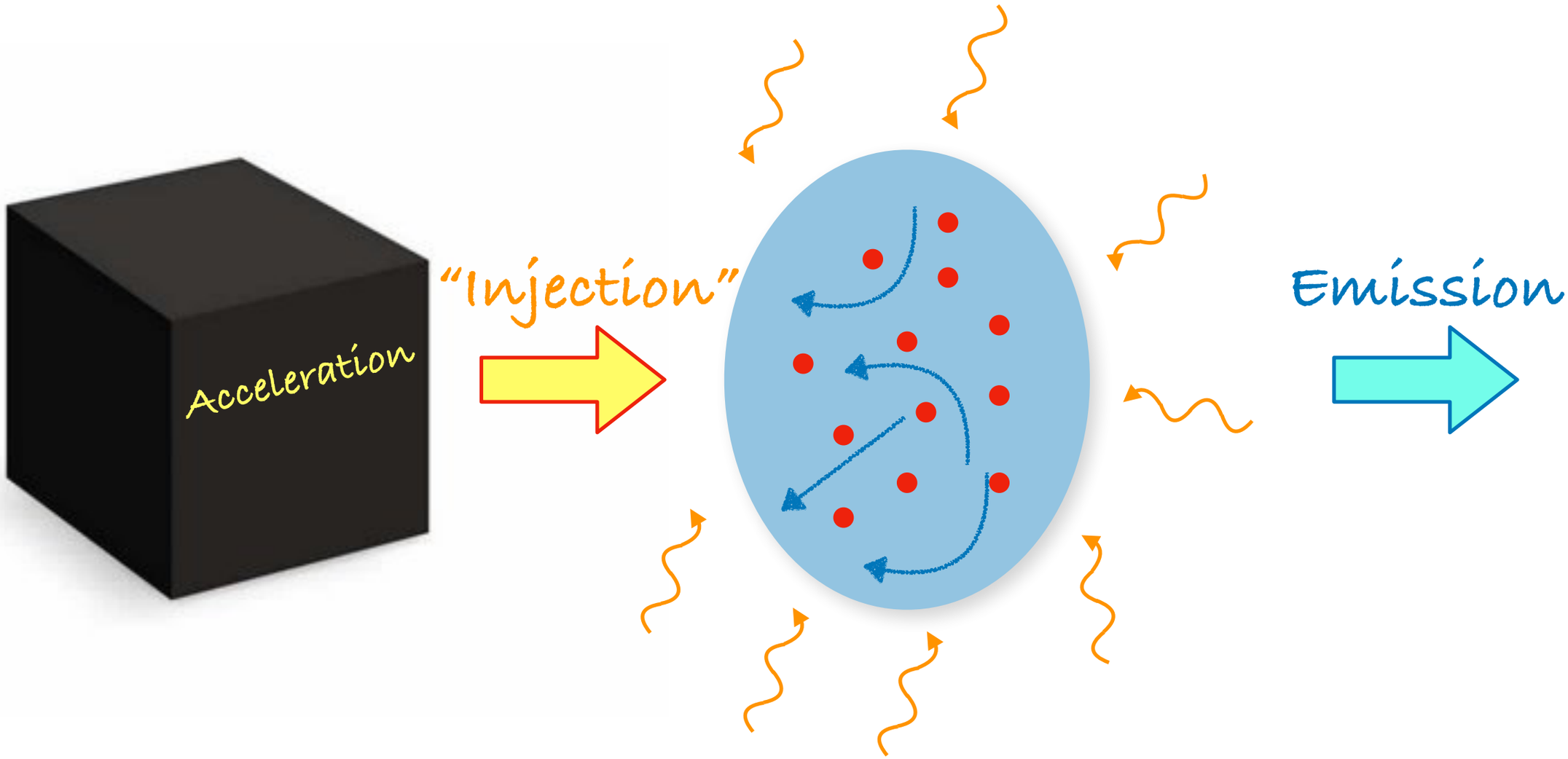
McKinney, Tchekhovskoy, and Blandford 2012

The full problem

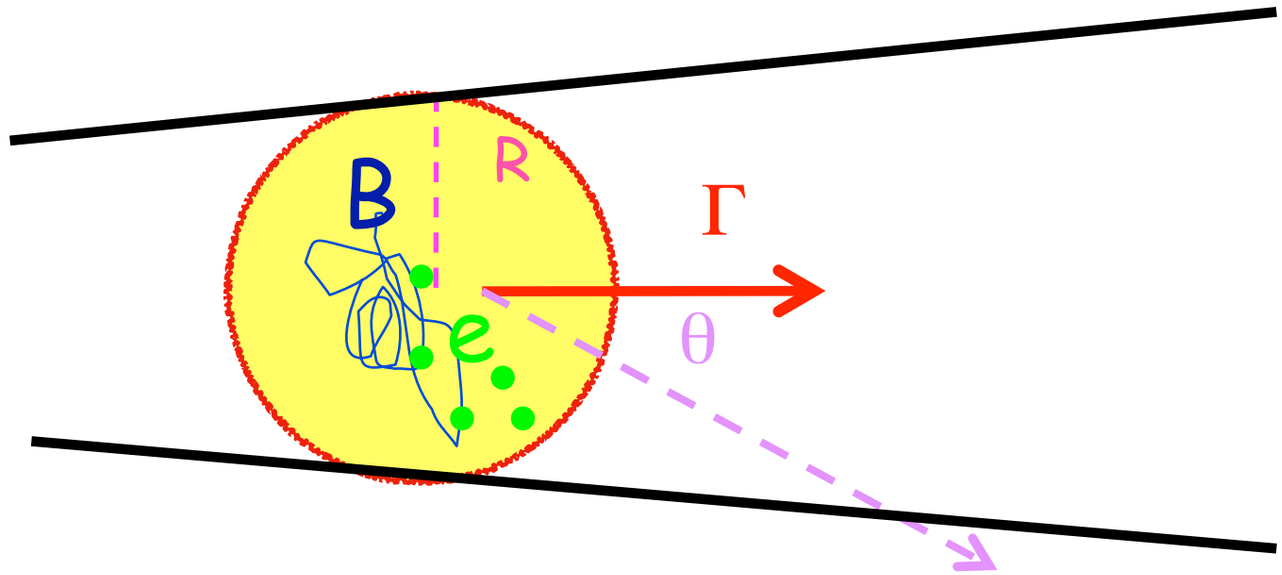




A (very) simple model

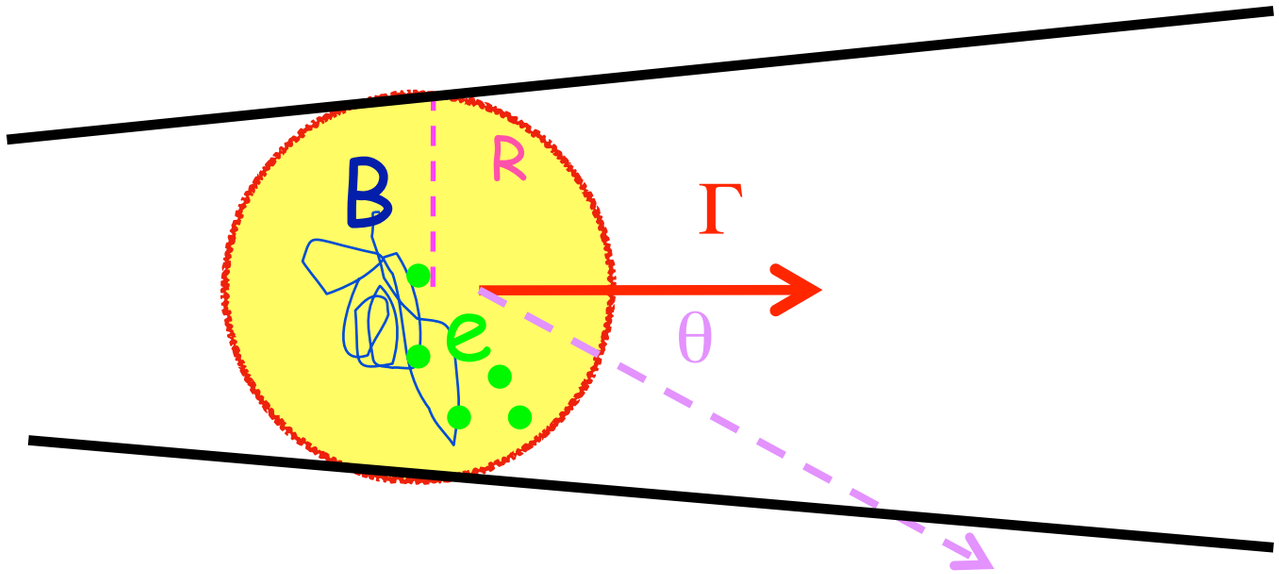


A modest model - 1

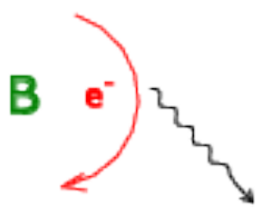


"One zone"

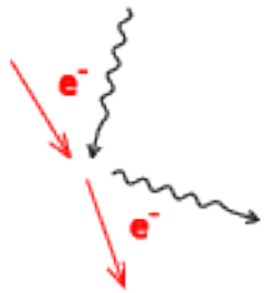
A modest model - 1



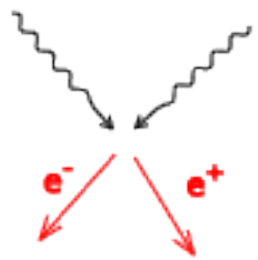
leptonic



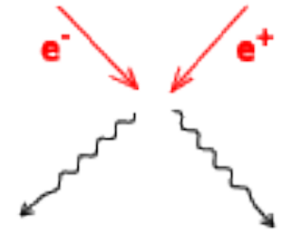
electron synchrotron



Inverse Compton scattering



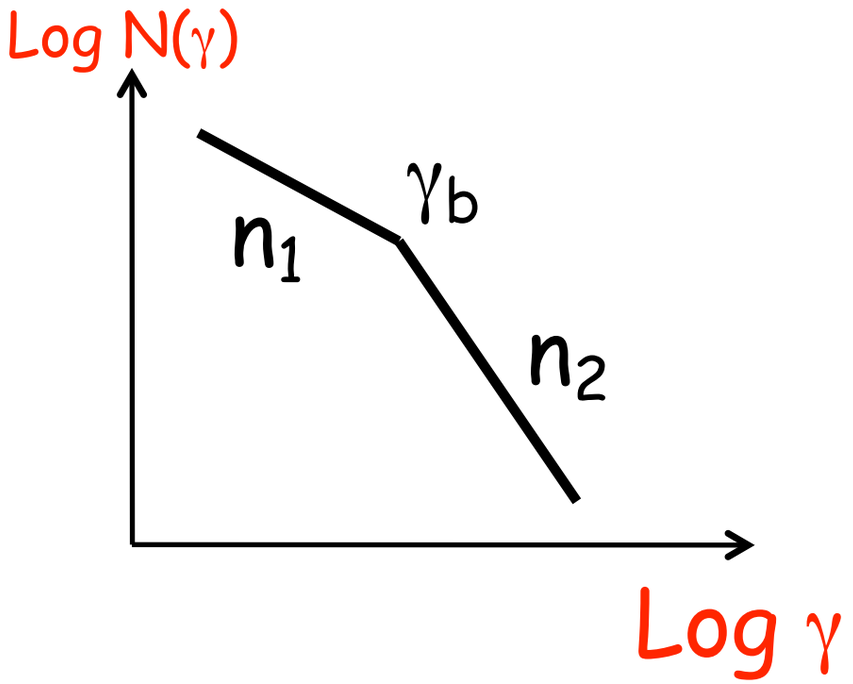
photon-photon pair production

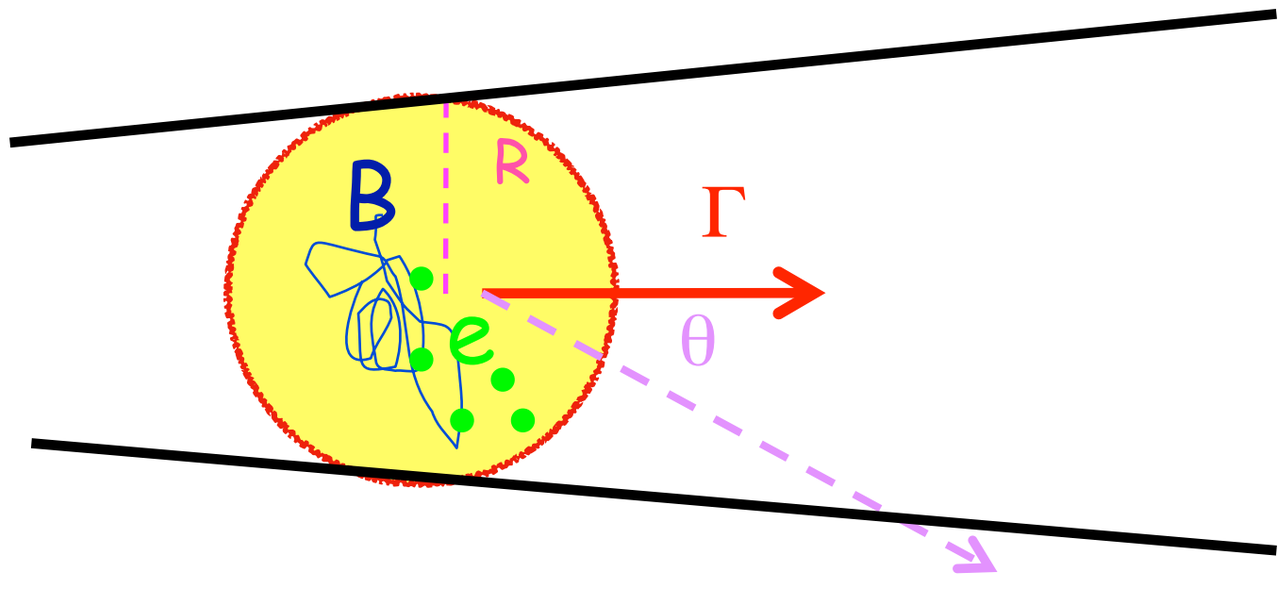


electron-positron annihilation

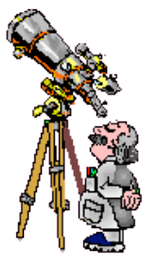
Hadron not important for the emission (but not for energetics!)

A modest model - 1

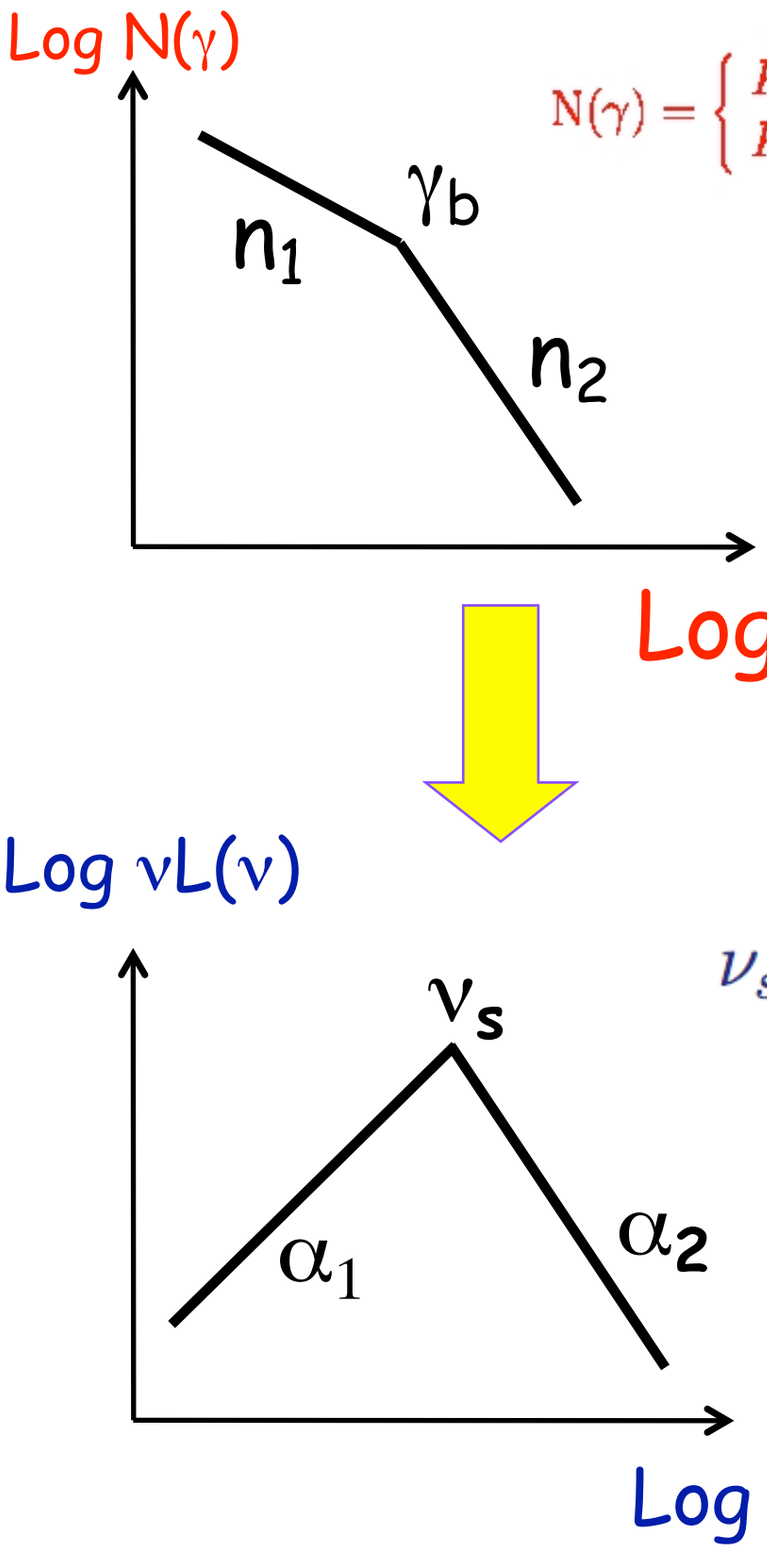




$$\mathrm{N}(\gamma) = \begin{cases} K_1 \gamma^{-n_1} & \gamma < \gamma_b \\ K_2 \gamma^{-n_2} & \gamma > \gamma_b \end{cases}$$



A modest model - 1



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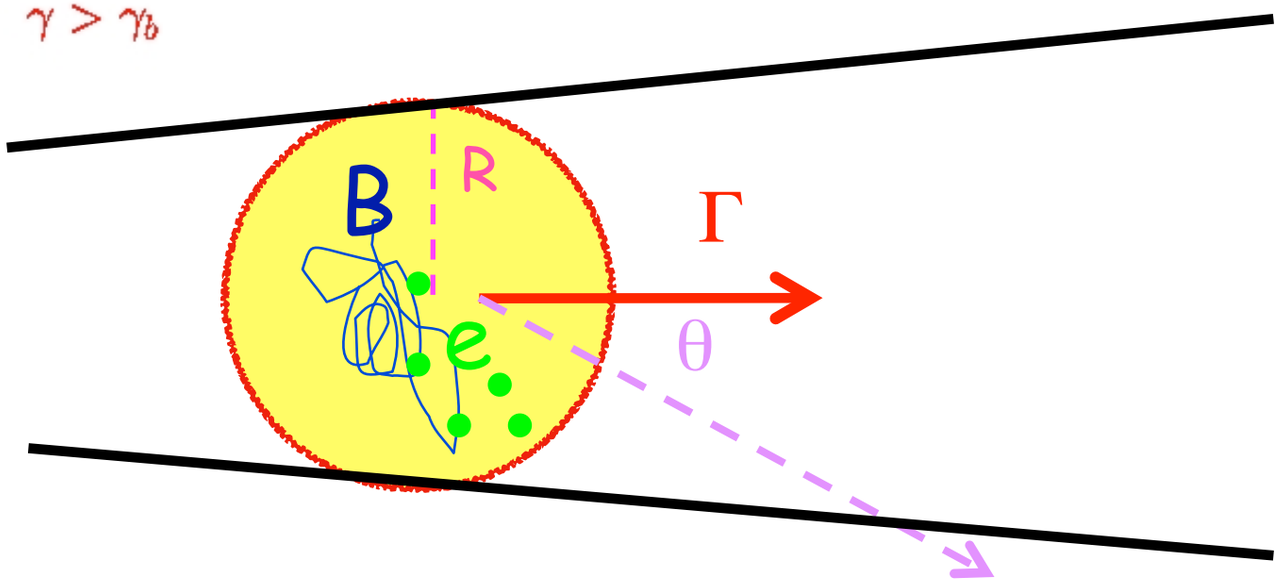
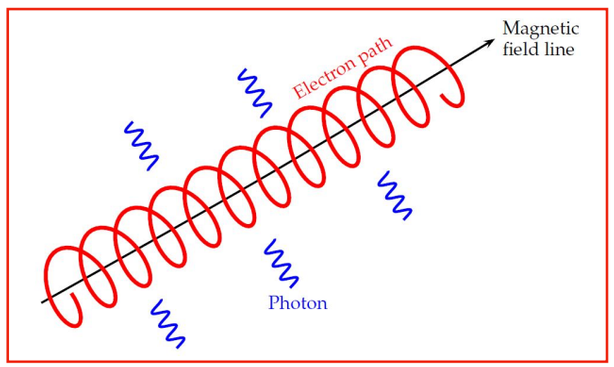


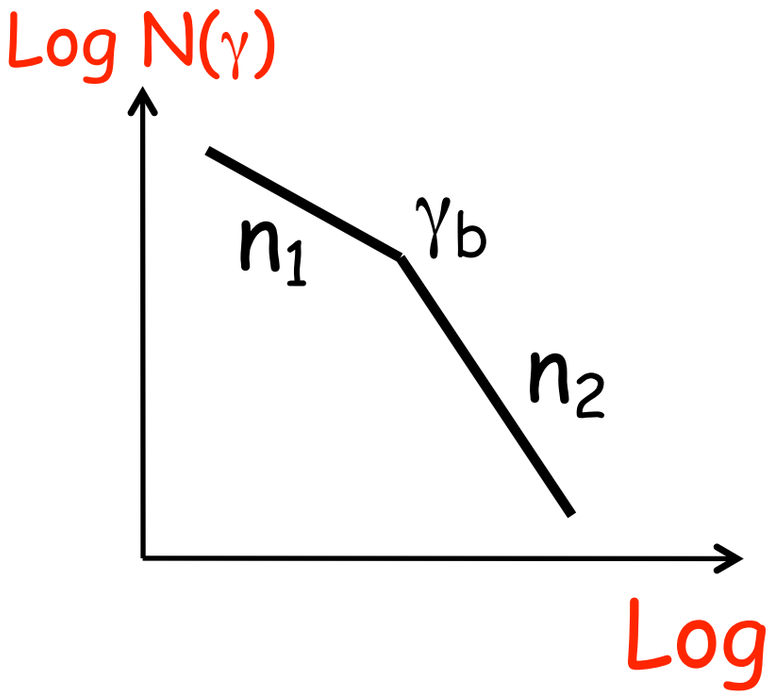
$$\nu_s = 3 \times 10^6 B \gamma_b^2 \delta$$

$$\alpha_i = \frac{n_i - 1}{2}$$

Synchrotron emission



A modest model - 1



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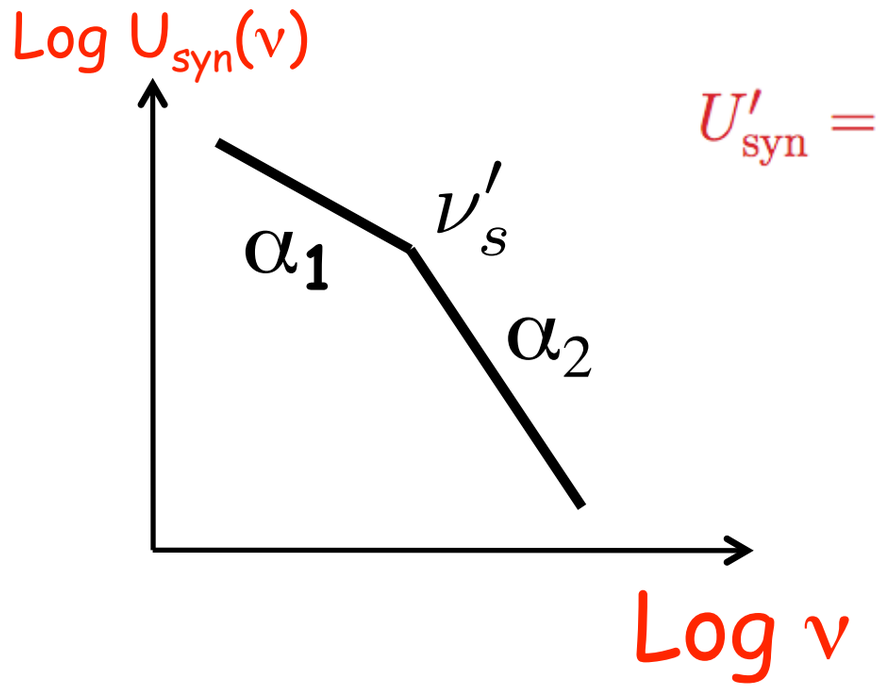
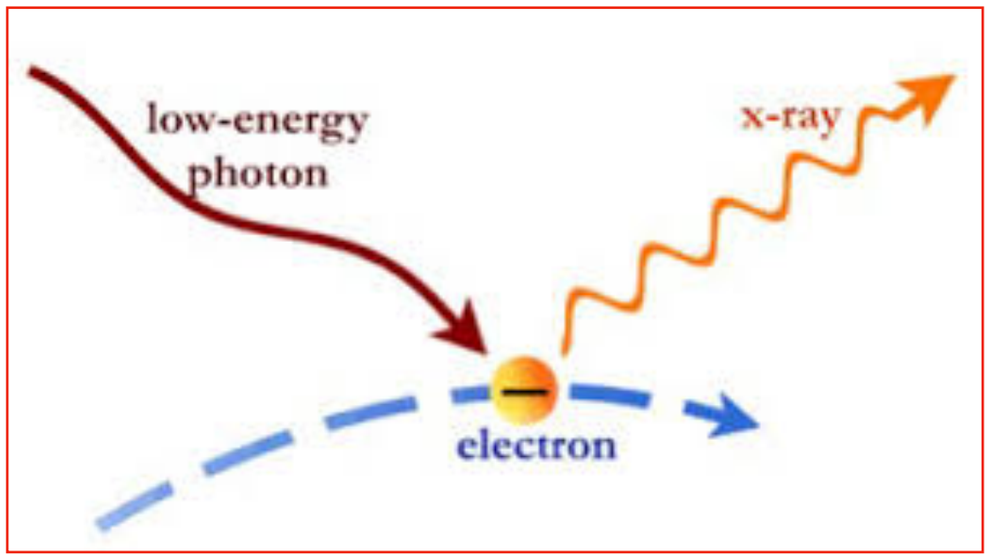
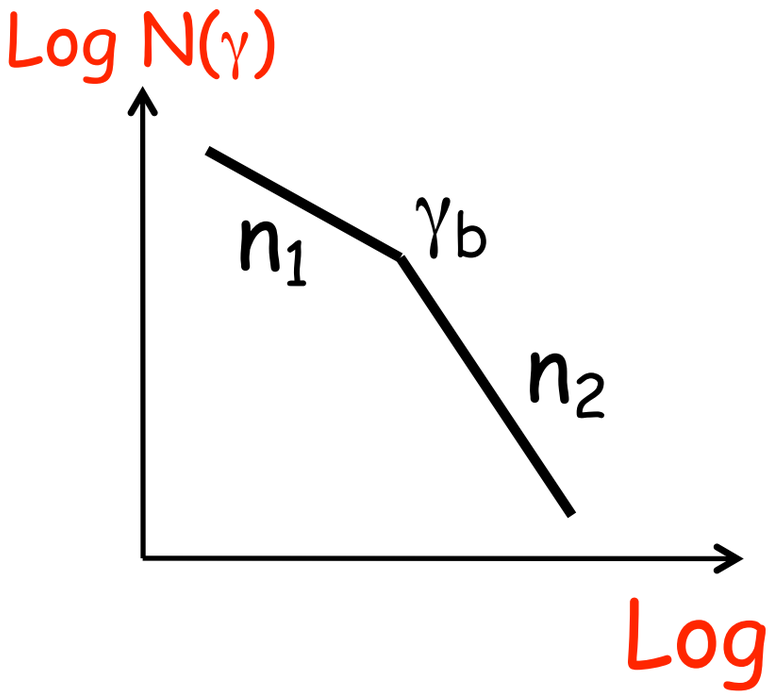


$$U'_{\rm syn} = \frac{\nu_s L(\nu_s)}{4\pi R^2 c \delta^4}$$



Inverse Compton

A modest model - 1



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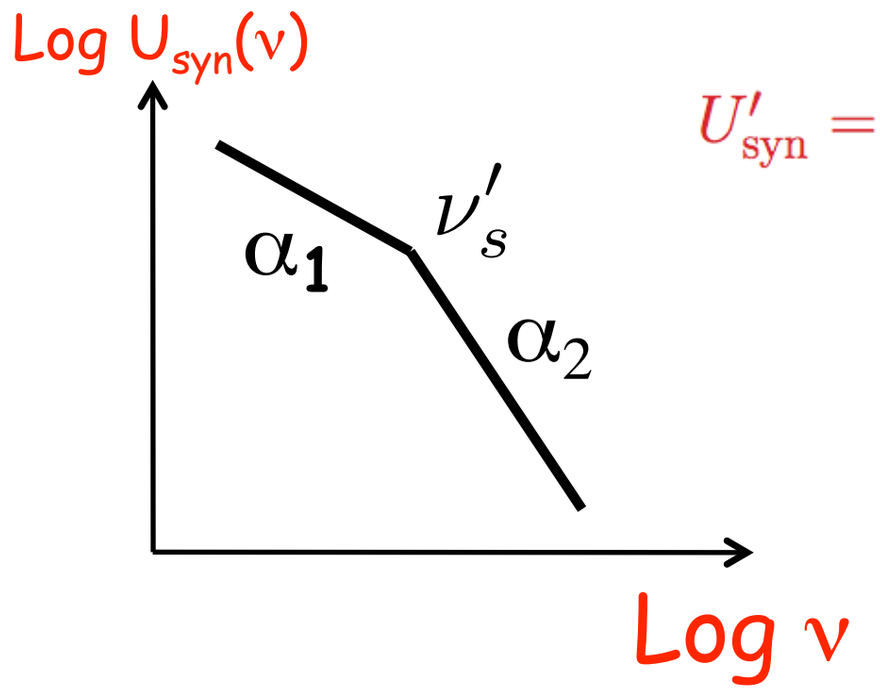

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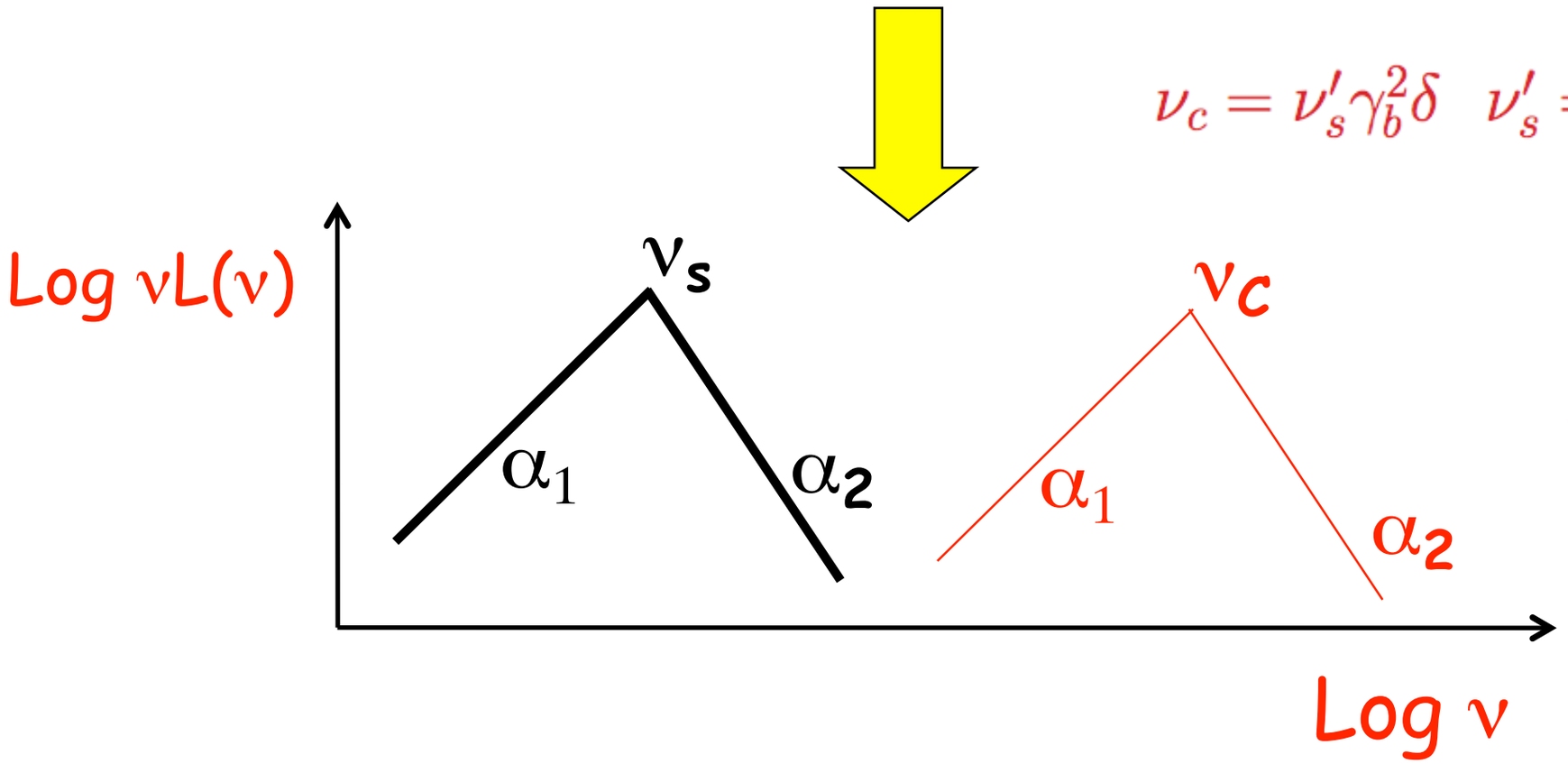
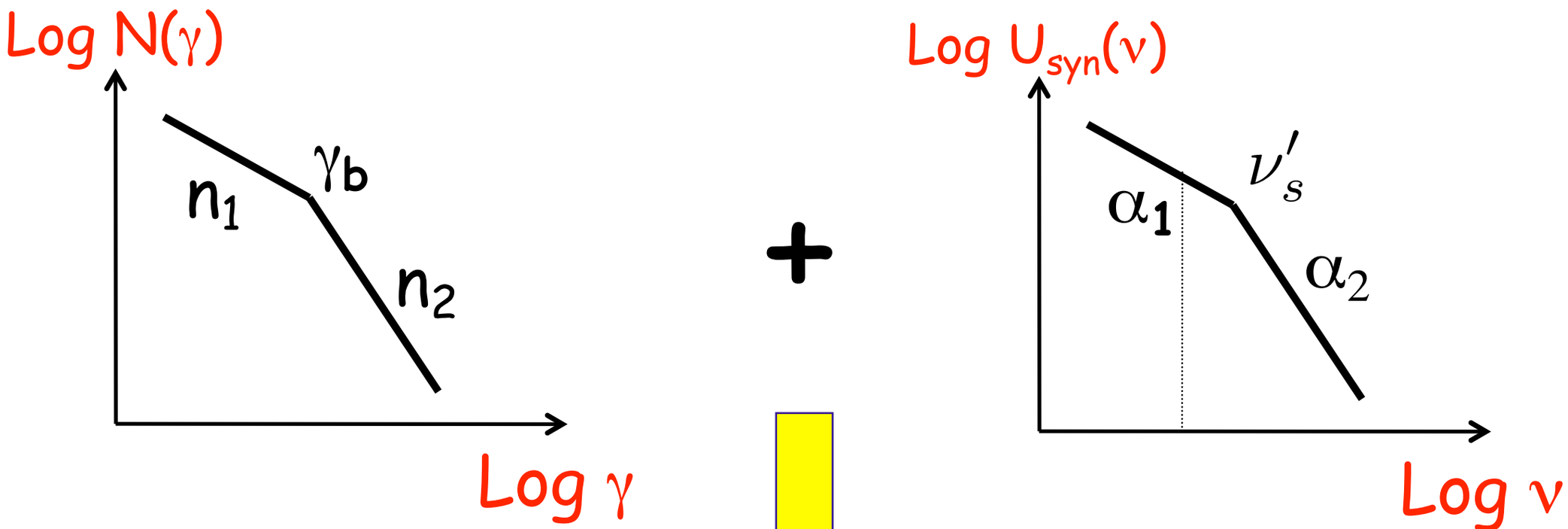


$$\nu_c = \nu'_s \gamma_b^2 \delta \quad \nu'_s = \nu_s/\delta$$

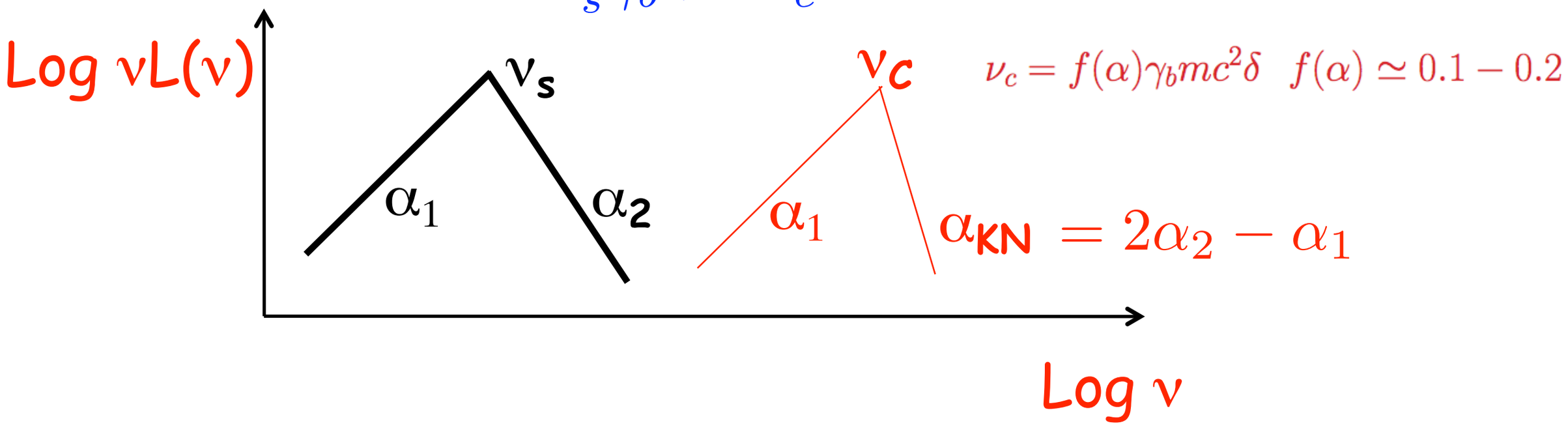
$$\frac{\nu_c L(\nu_c)}{\nu_s L(\nu_s)} = \frac{U'_{\rm syn}}{U_B}$$

A modest model - 1



"Klein-Nishina regime"

$$h\nu'_s\gamma_b > m_e c^2$$



$$\nu_c = f(\alpha)\gamma_b mc^2\delta \quad f(\alpha) \simeq 0.1 - 0.2$$

In principle, in this simple version of the Synchrotron-Self Compton (SSC) model, all parameters can be constrained by quantities available from observations:

7 free parameters

R B N_o γ_b n_1 n_2 δ

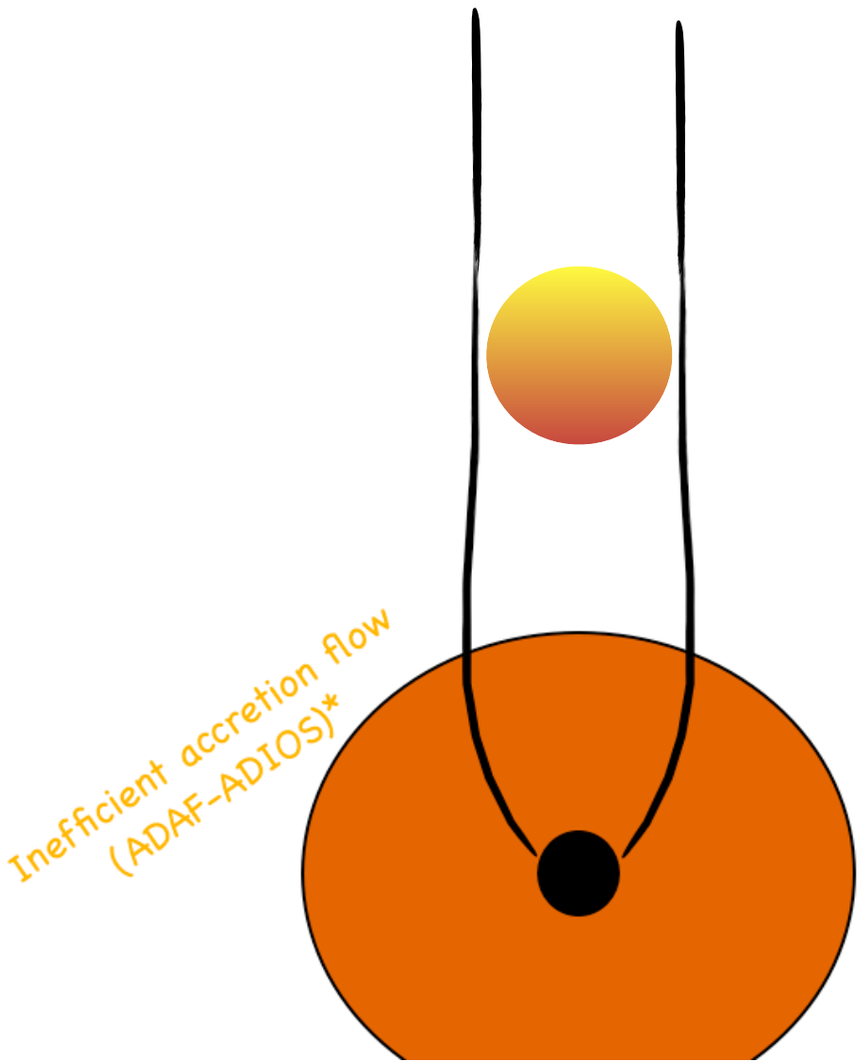
7 observational quantities

ν_s L_s ν_C L_C t_{var} α_1 α_2

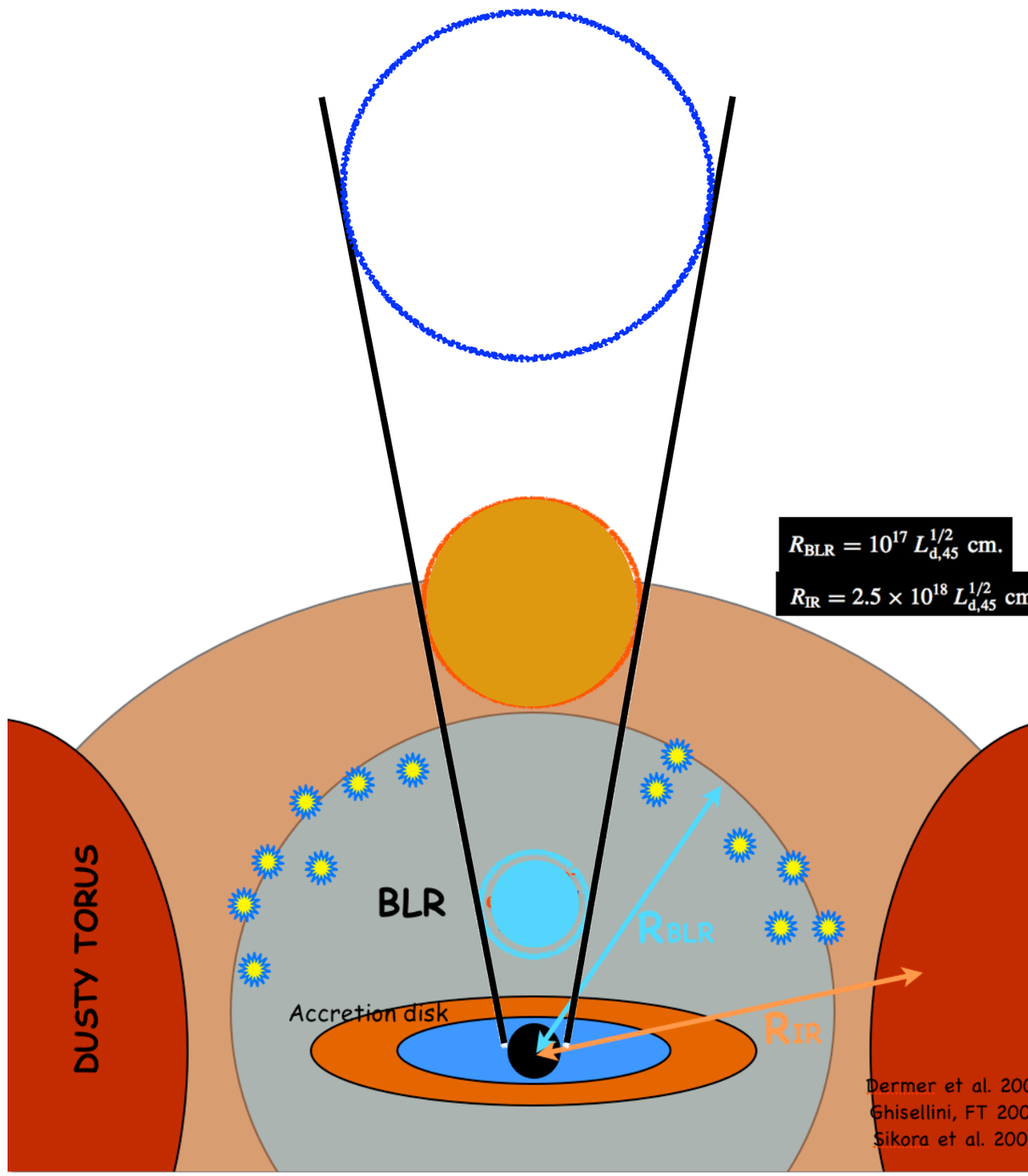
Tavecchio, Maraschi & Ghisellini 1998

Blazars in a nutshell

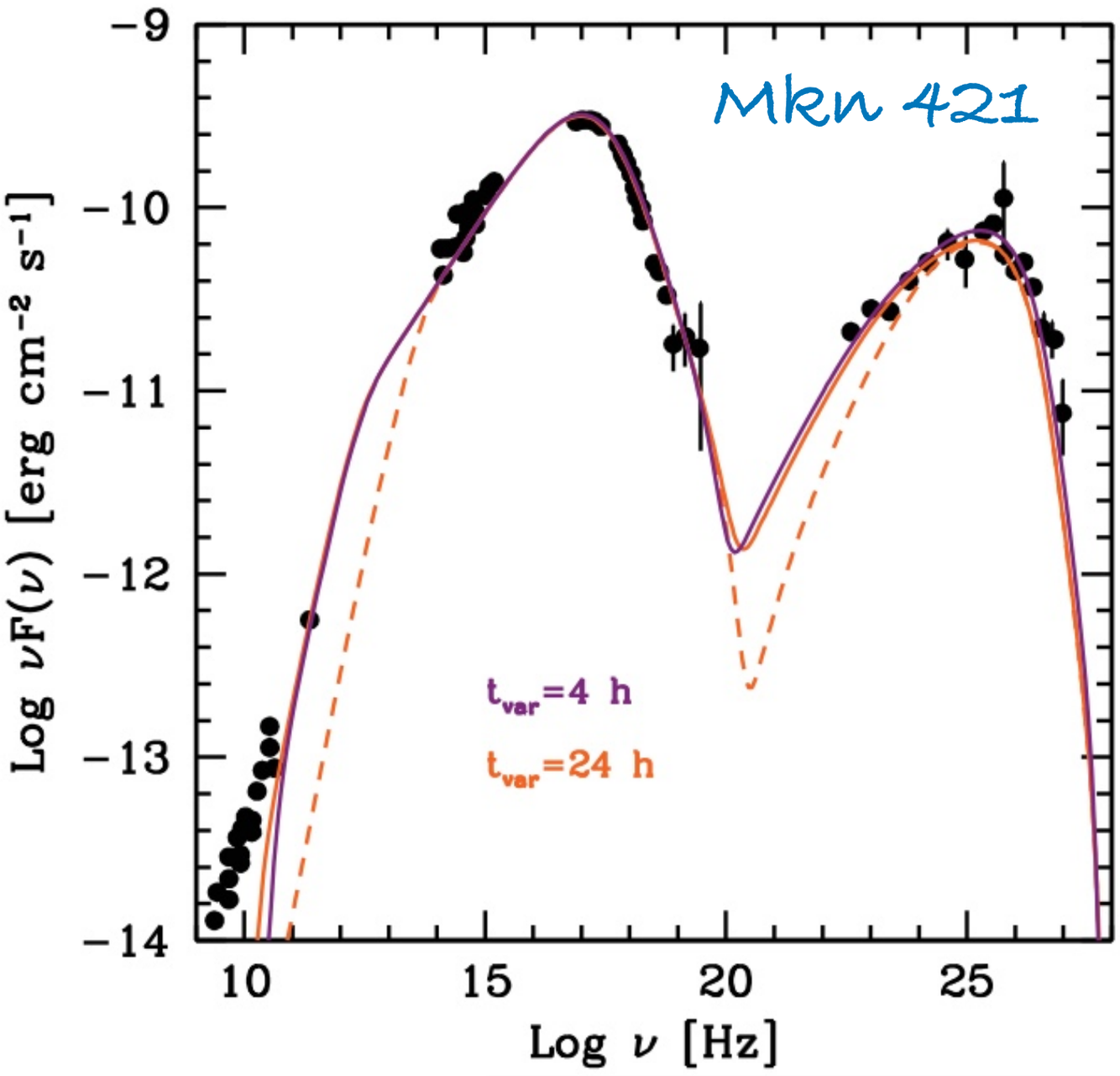
BL Lacs: “naked” jets



FSRQ: “dressed” jets



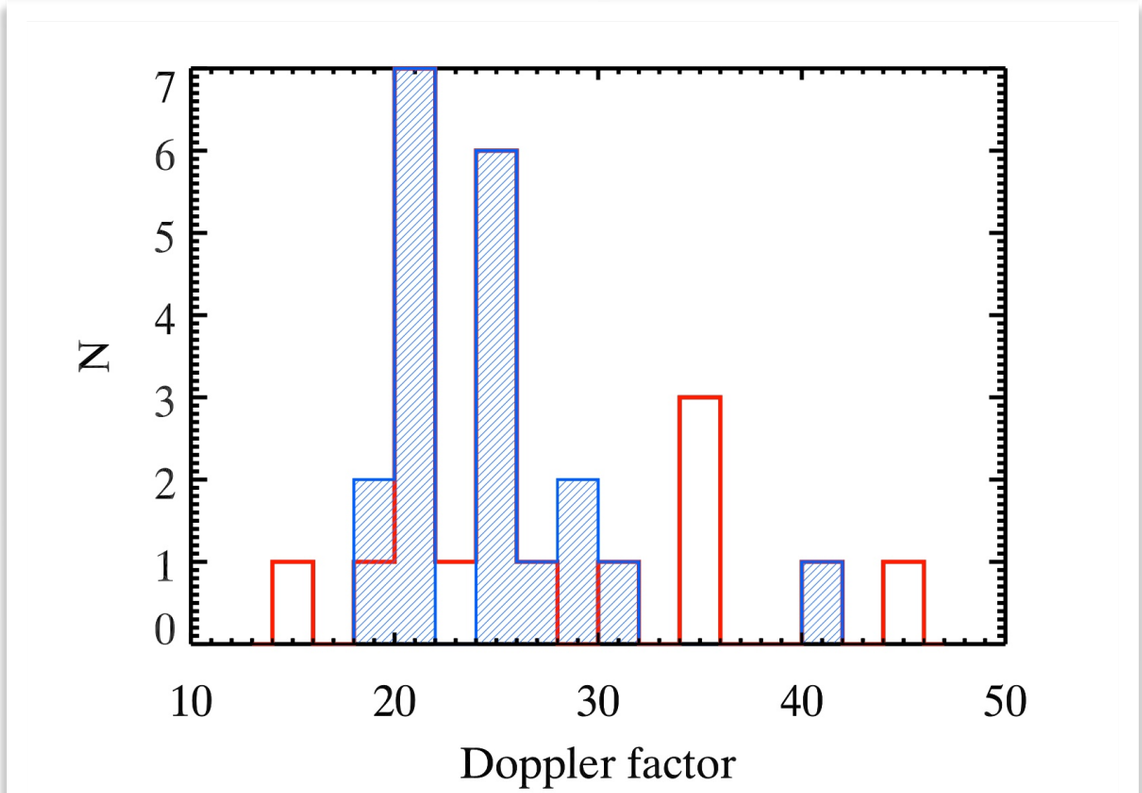
Application: BL Lacs

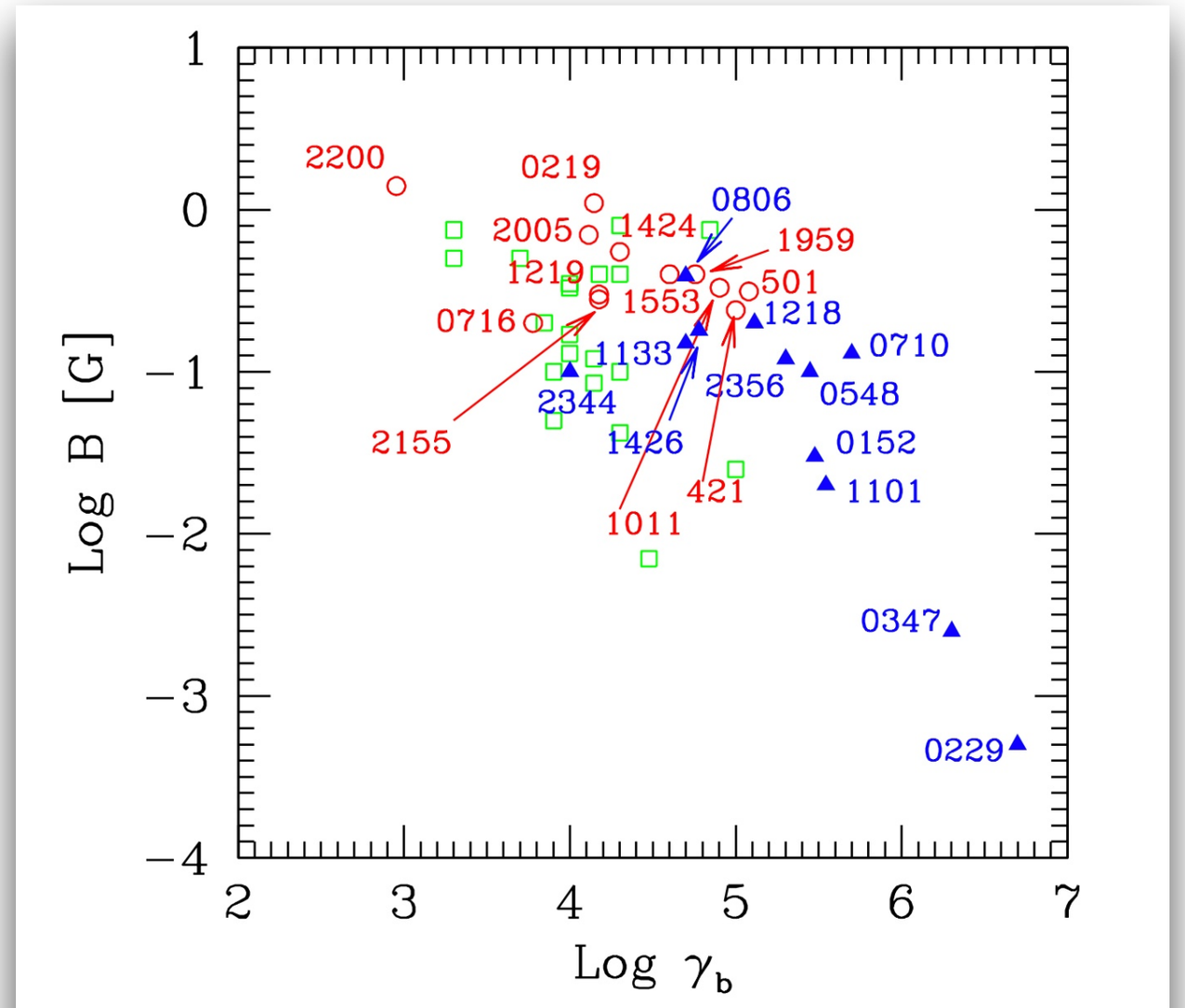


Tavecchio and Ghisellini 2016

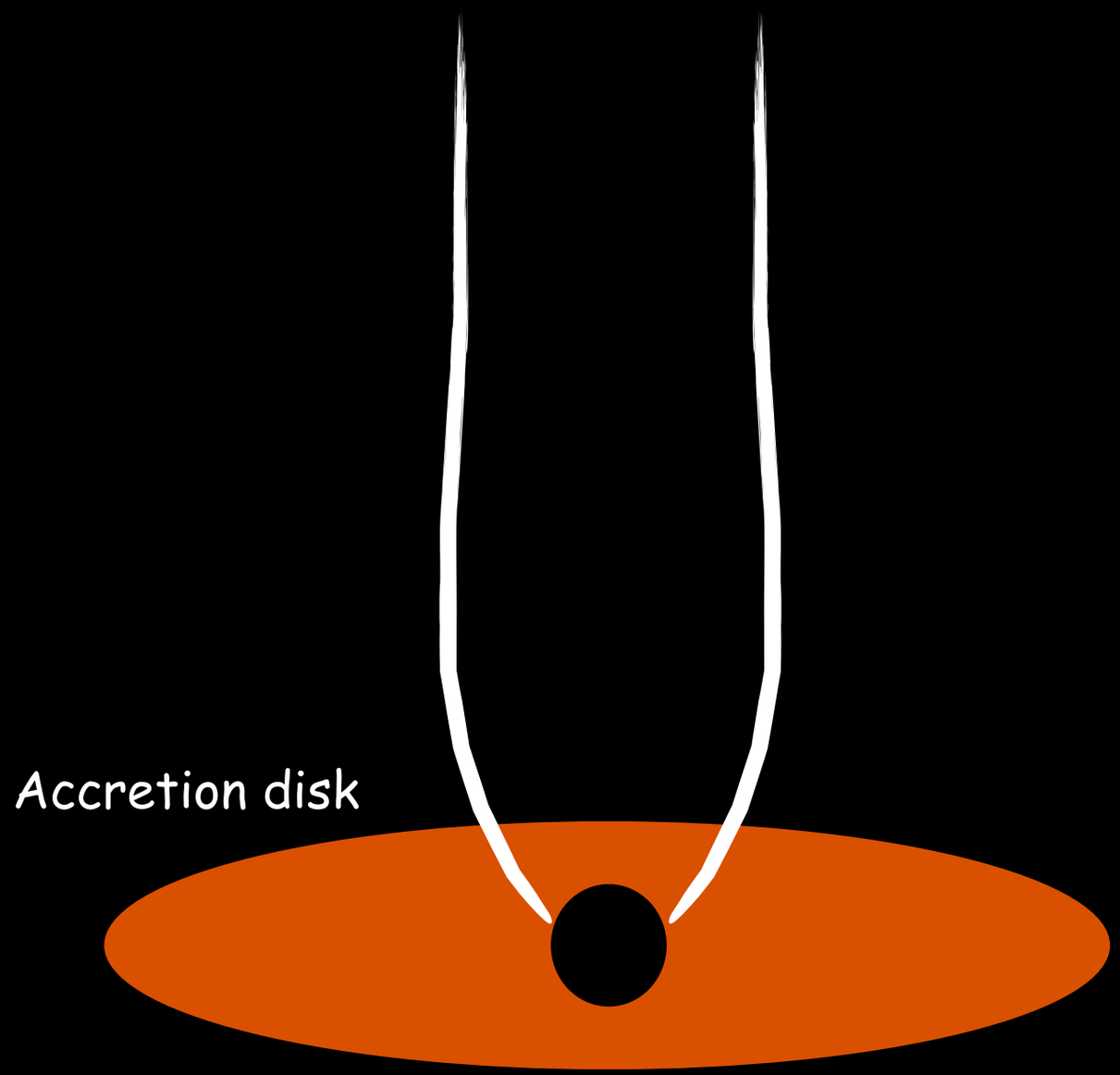
Model (1)	γ_{min} (2)	γ_b (3)	γ_{max} (4)	n_1 (5)	n_2 (6)	B (7)	K (8)	R (9)	δ (10)
1	500	1.7×10^5	2×10^6	2.2	4.8	0.075	1.3×10^4	1	25
2	700	2.5×10^5	4×10^6	2.2	4.8	0.06	3.2×10^3	3.6	14

Application: BL Lacs

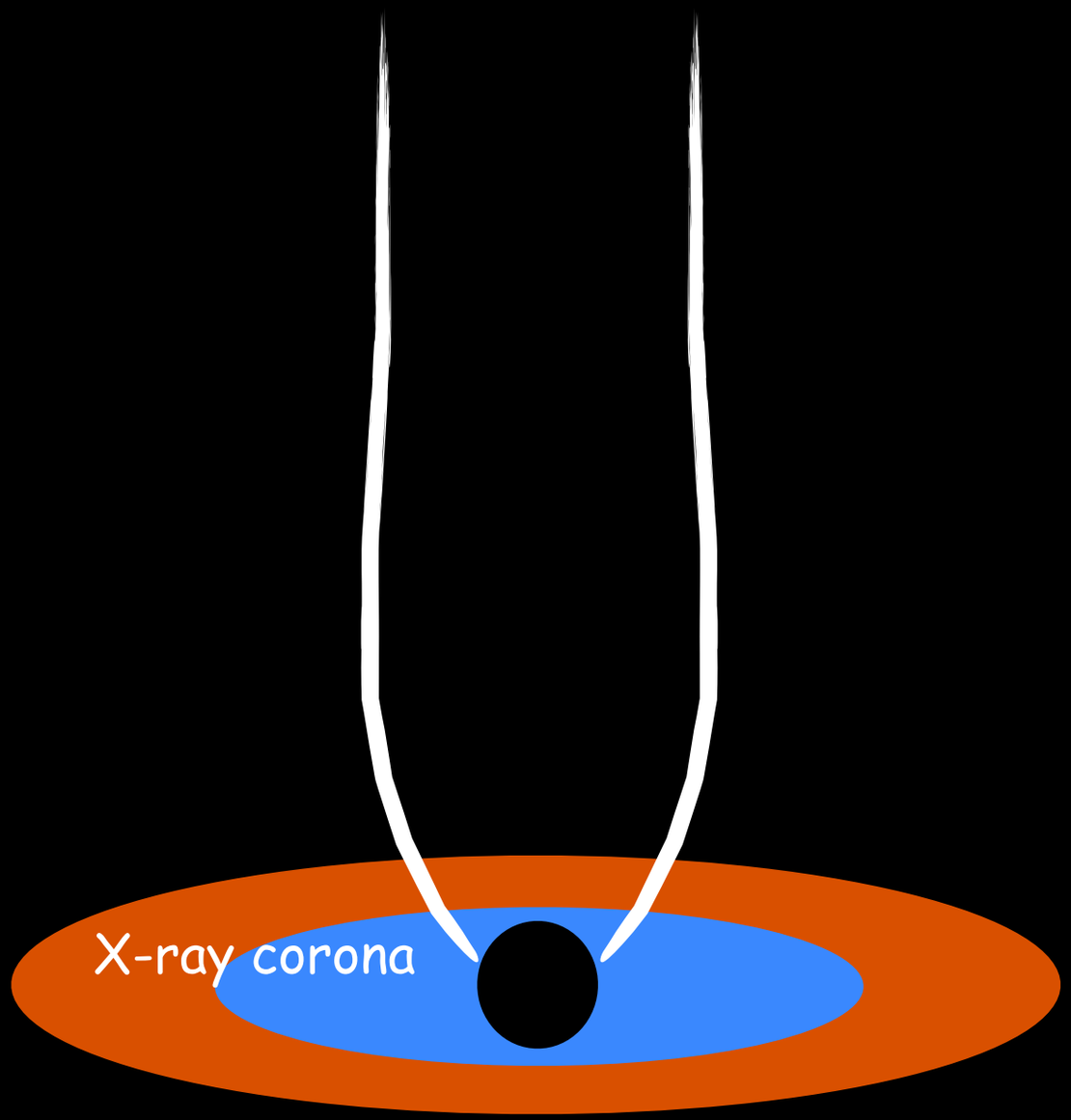




FSRQs: the general scenario



FSRQs: the general scenario



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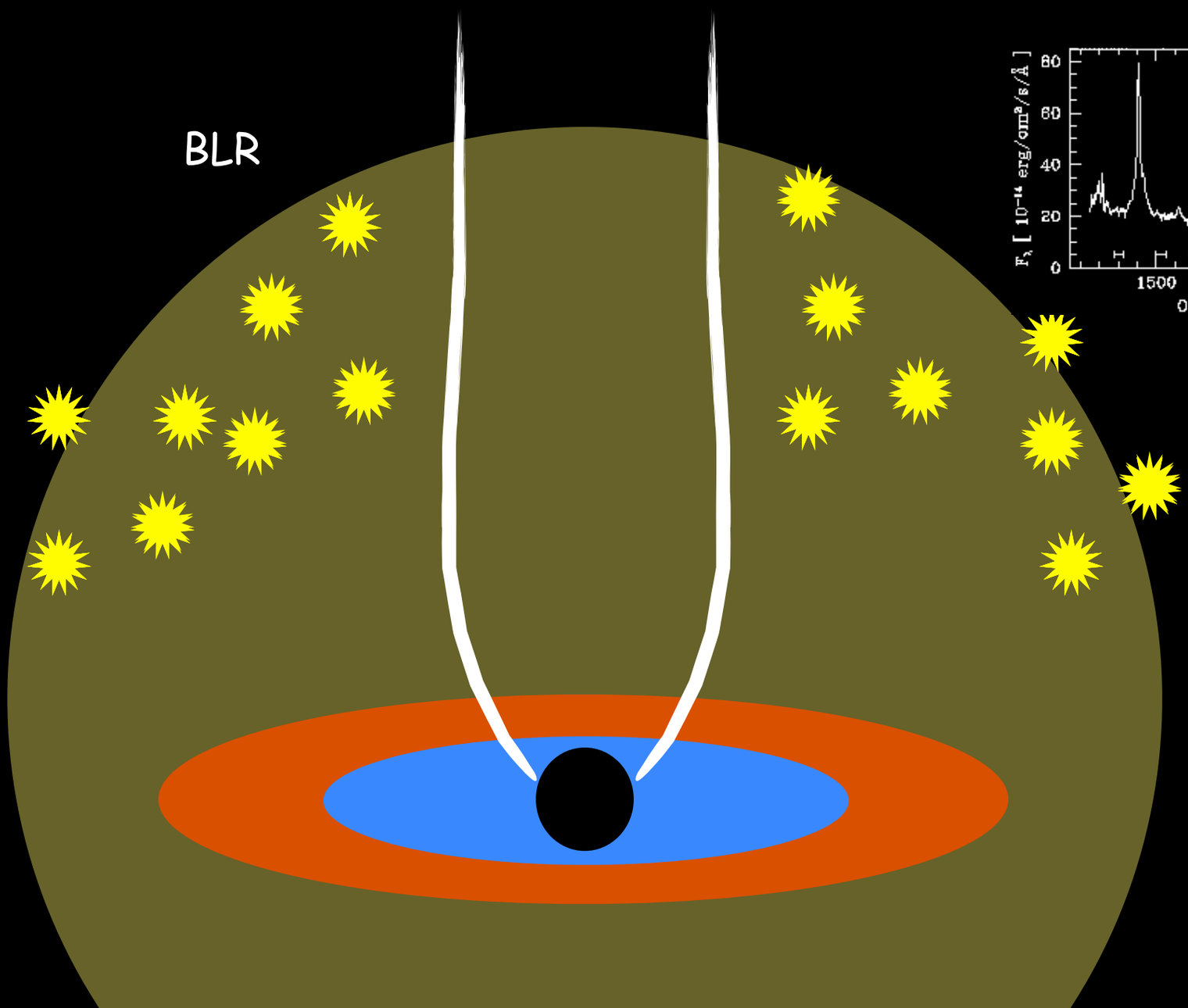
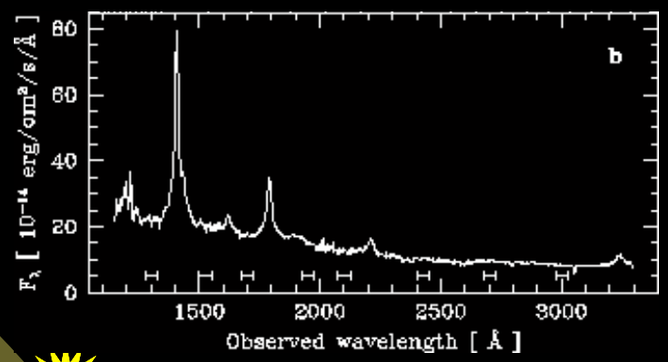
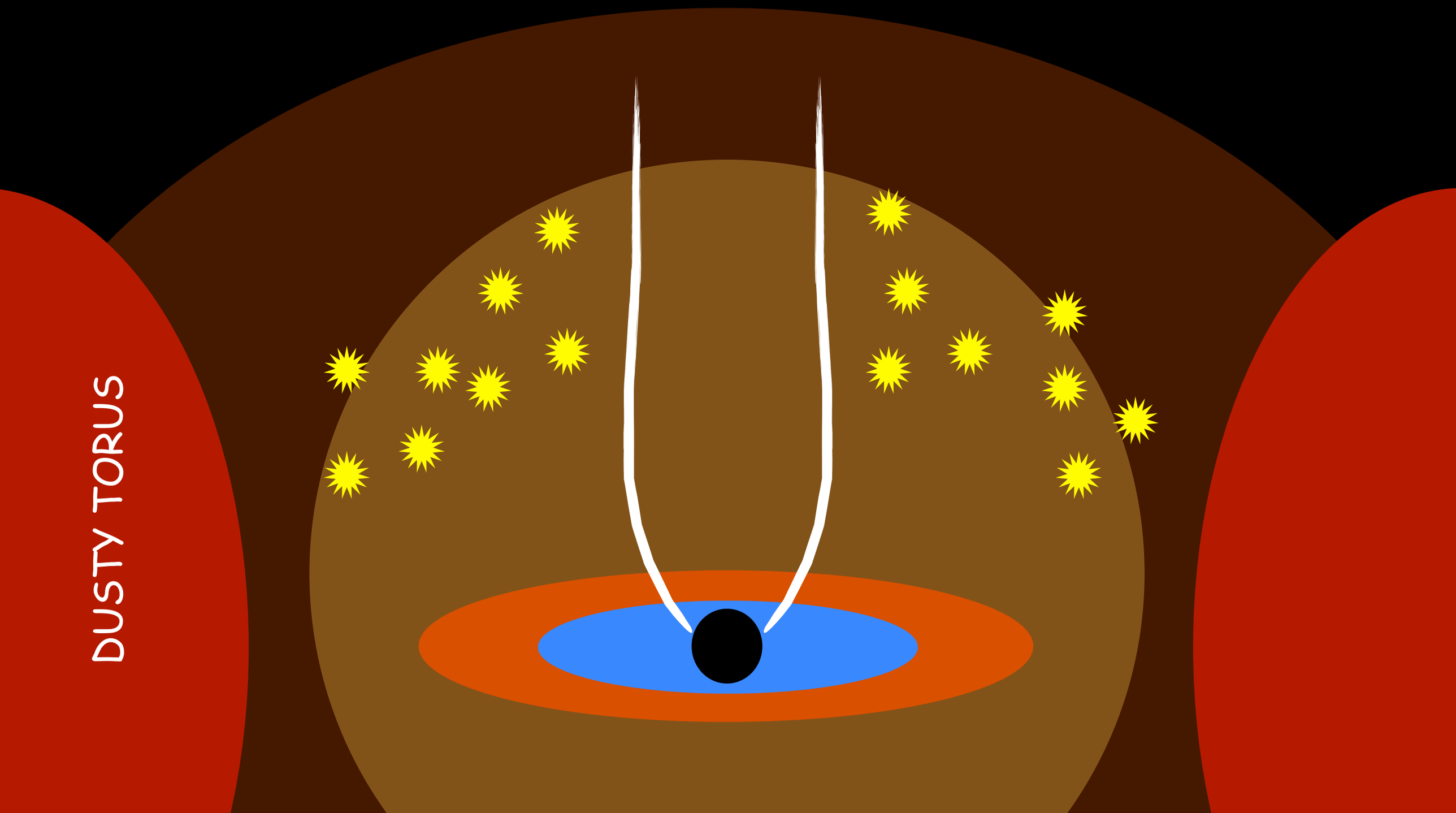


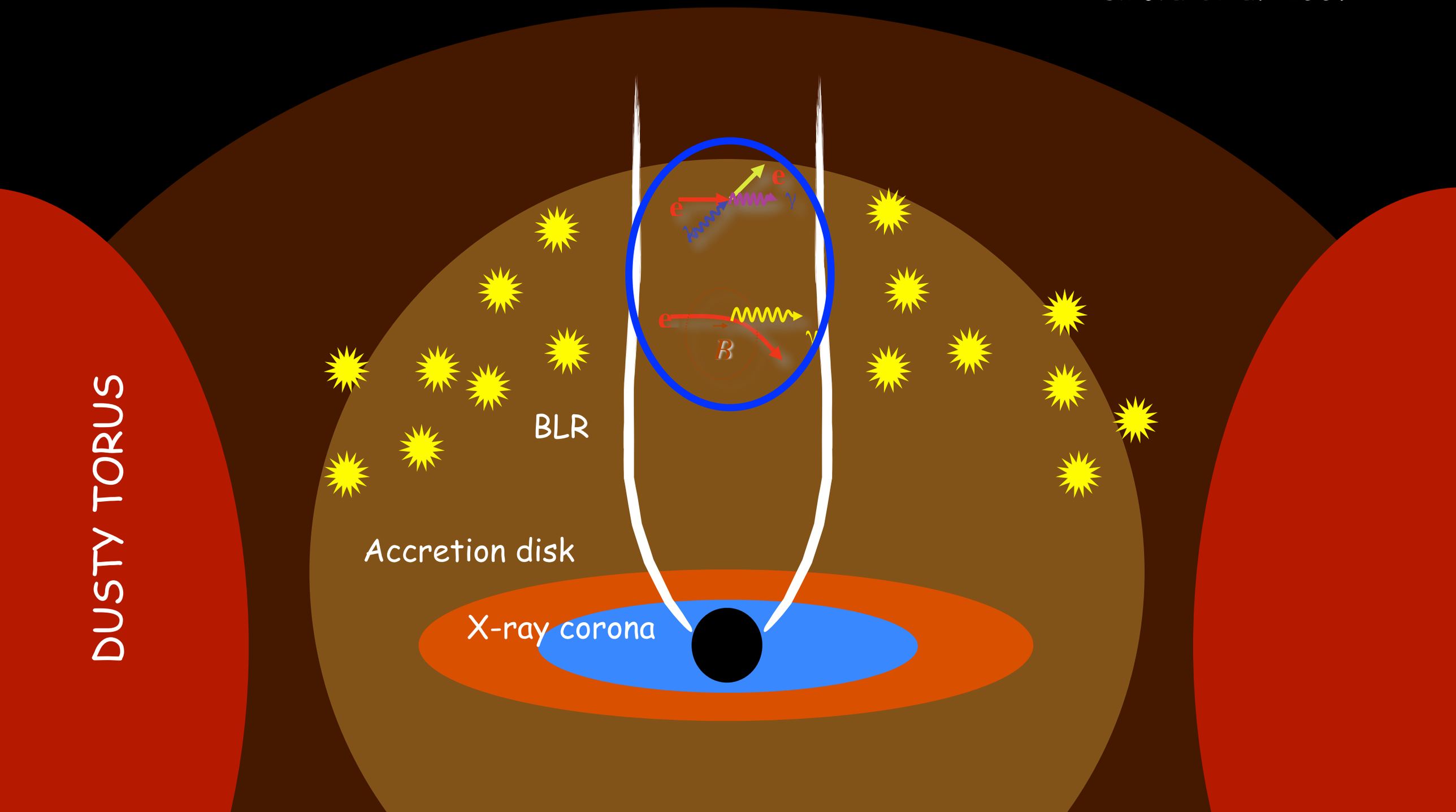


FSRQs: the general scenario

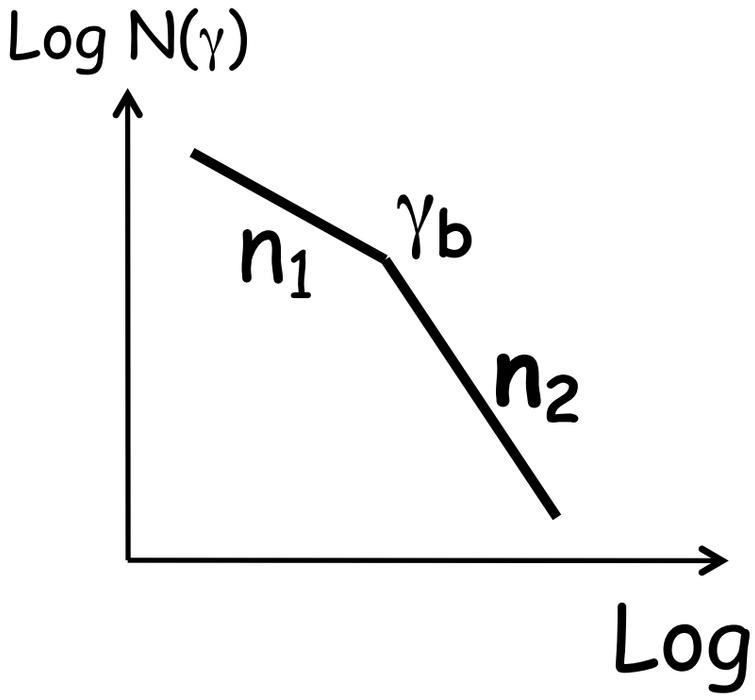


FSRQs: the “canonical” scenario

Dermer et al. 2009
Ghisellini, FT 2009
Sikora et al. 2009



A more modest model - 2



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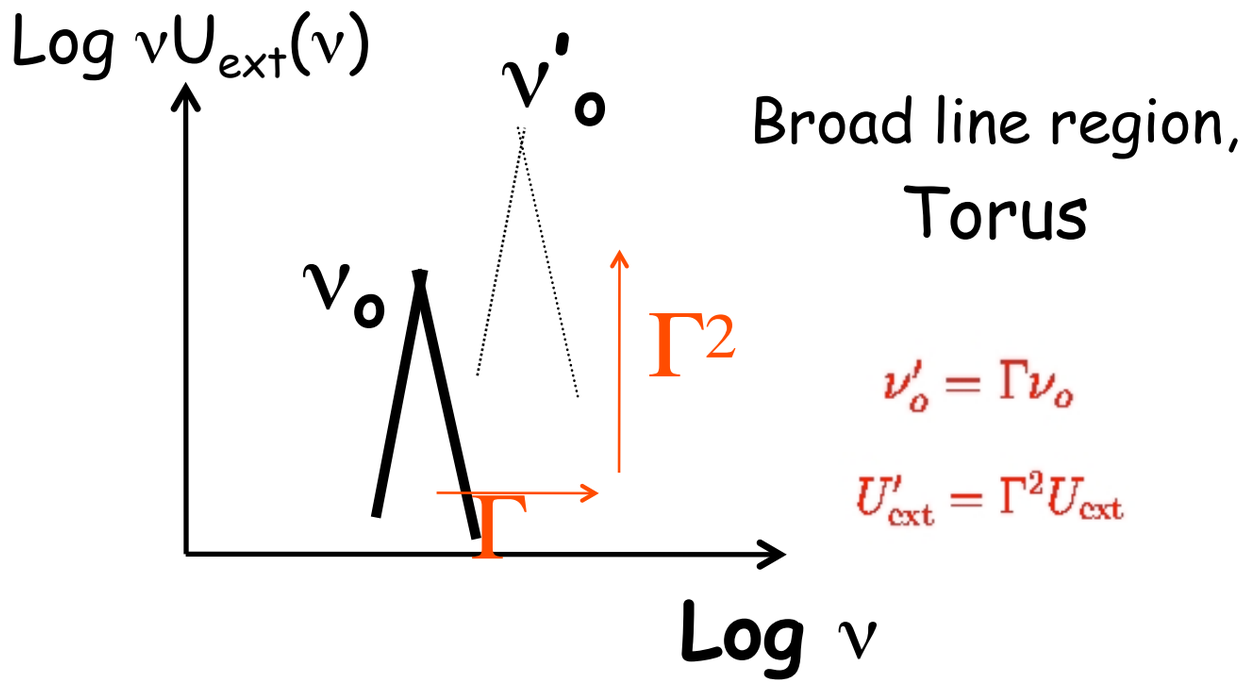
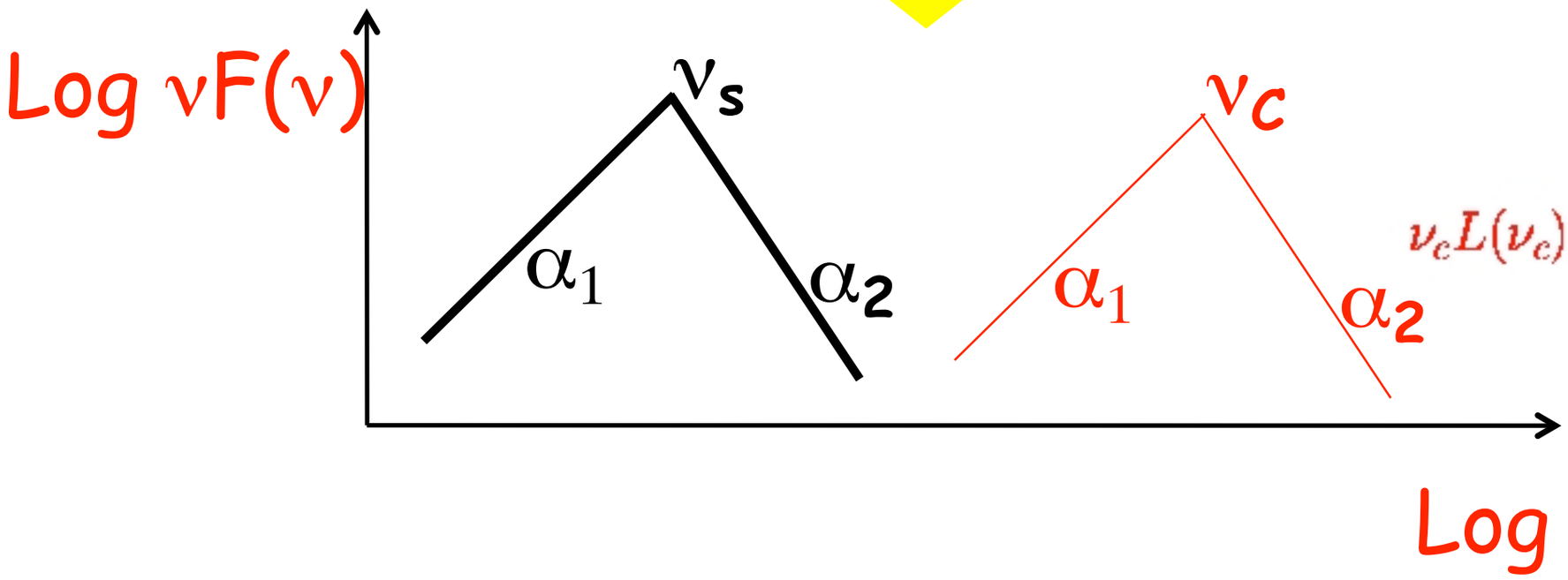


Broad line region,
Torus

$$\nu'_o = \Gamma \nu_o$$

$$U'_{\rm cxt} = \Gamma^2 U_{\rm cxt}$$

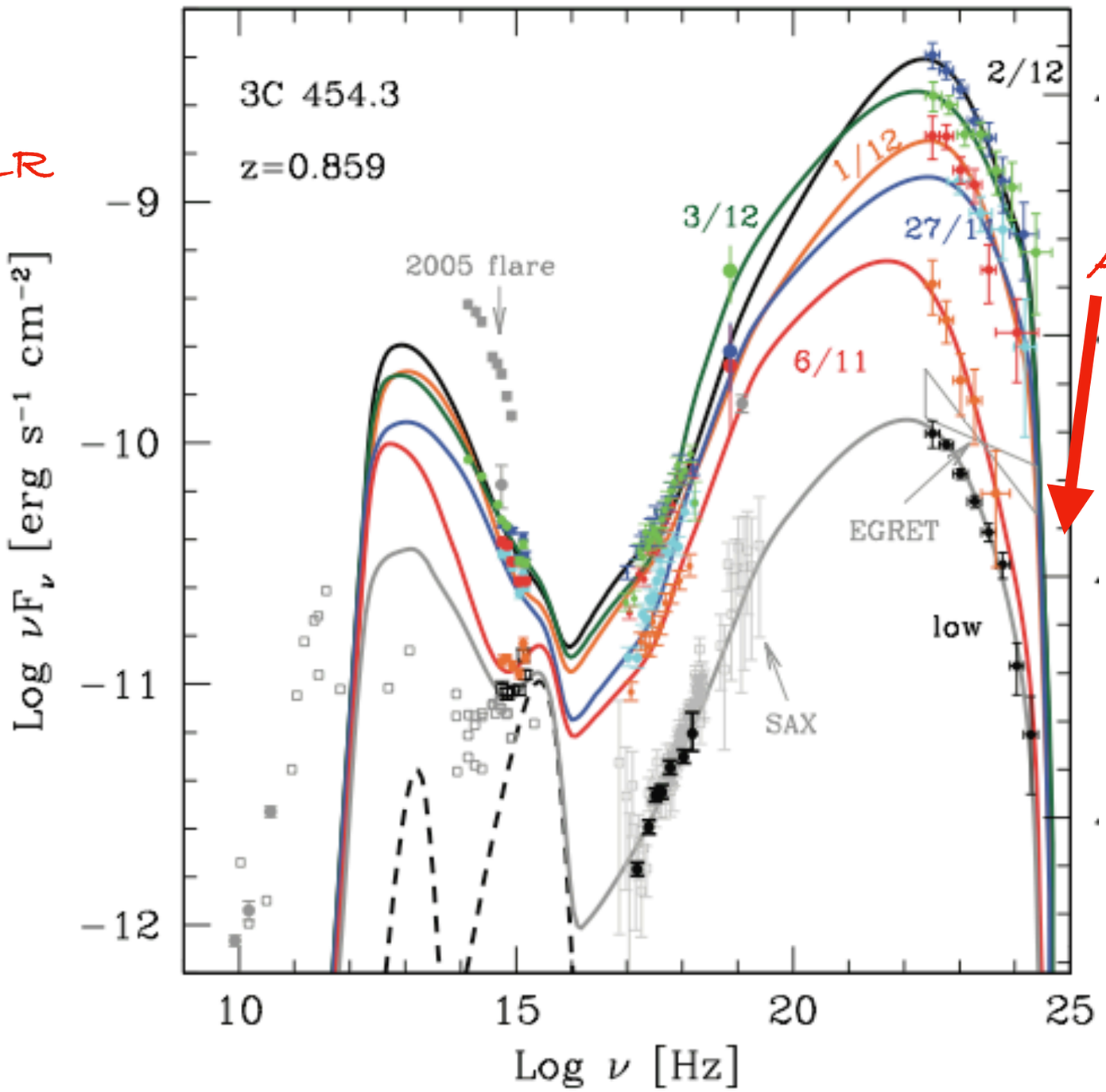


$$\nu_c = \nu'_o \gamma_b^2 \delta = \nu_o \gamma_b^2 \Gamma \delta$$

$$\nu_c L(\nu_c) \propto \sigma_T c U'_{\rm cxt} N(\gamma_b) \gamma_b \gamma_b^2 V \delta^4$$

4C454.3

Within the BLR



Absorption (20 GeV)

Bonnnoli et al. 2011

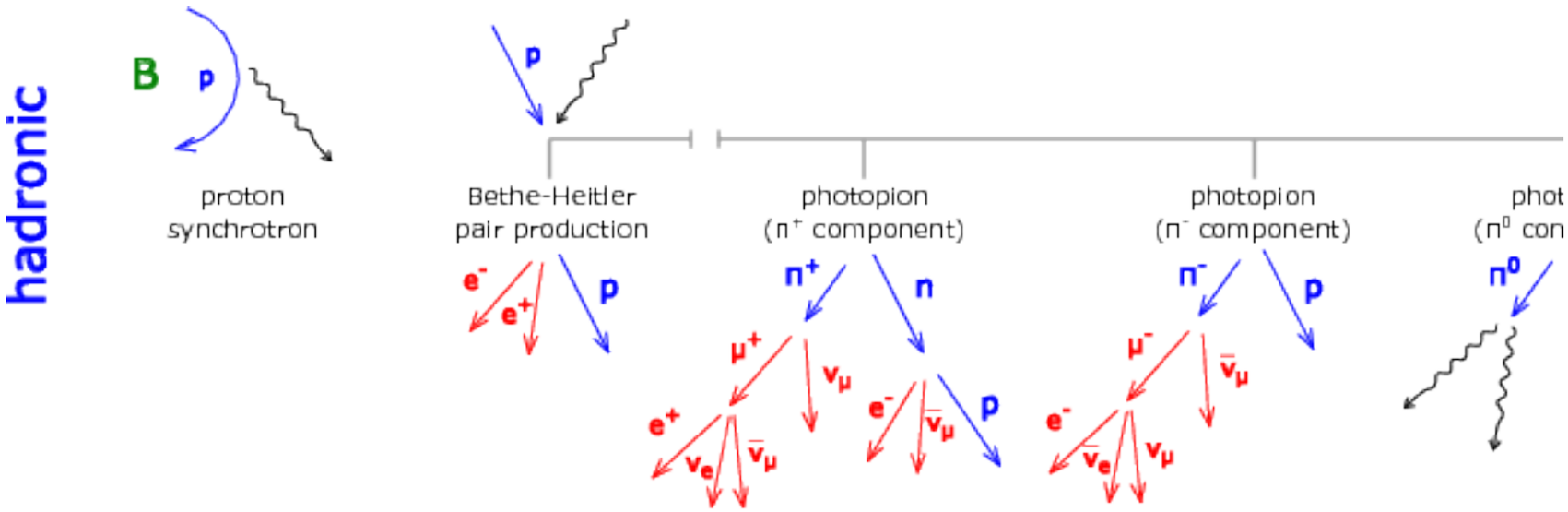
Leptons or hadrons?

UHECR
IceCube Neutrinos

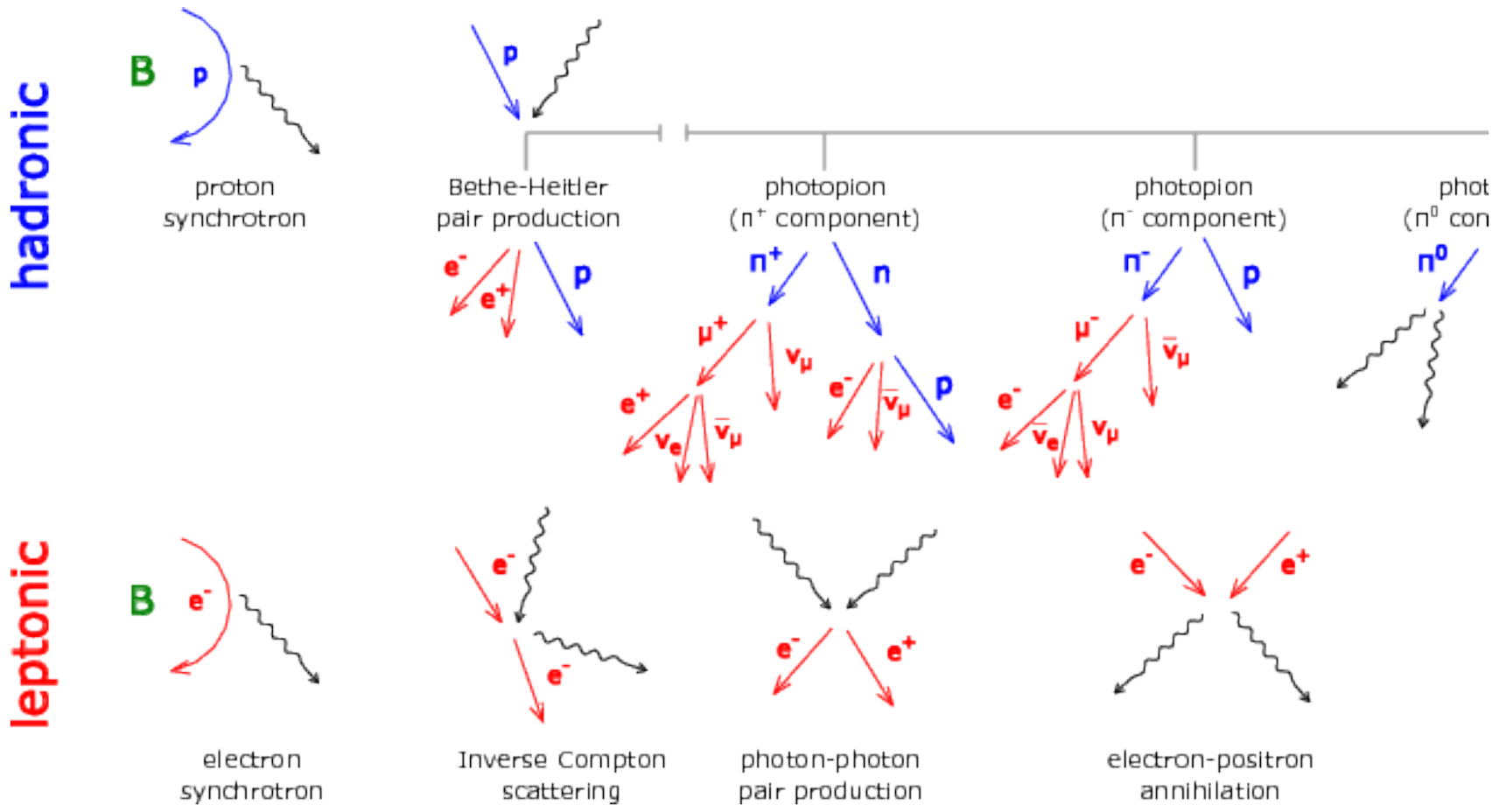
Hadrons are accelerated to very-high and ultra-high energy somewhere in the extragalactic space

Jets offer ideal conditions (B, radius,power)

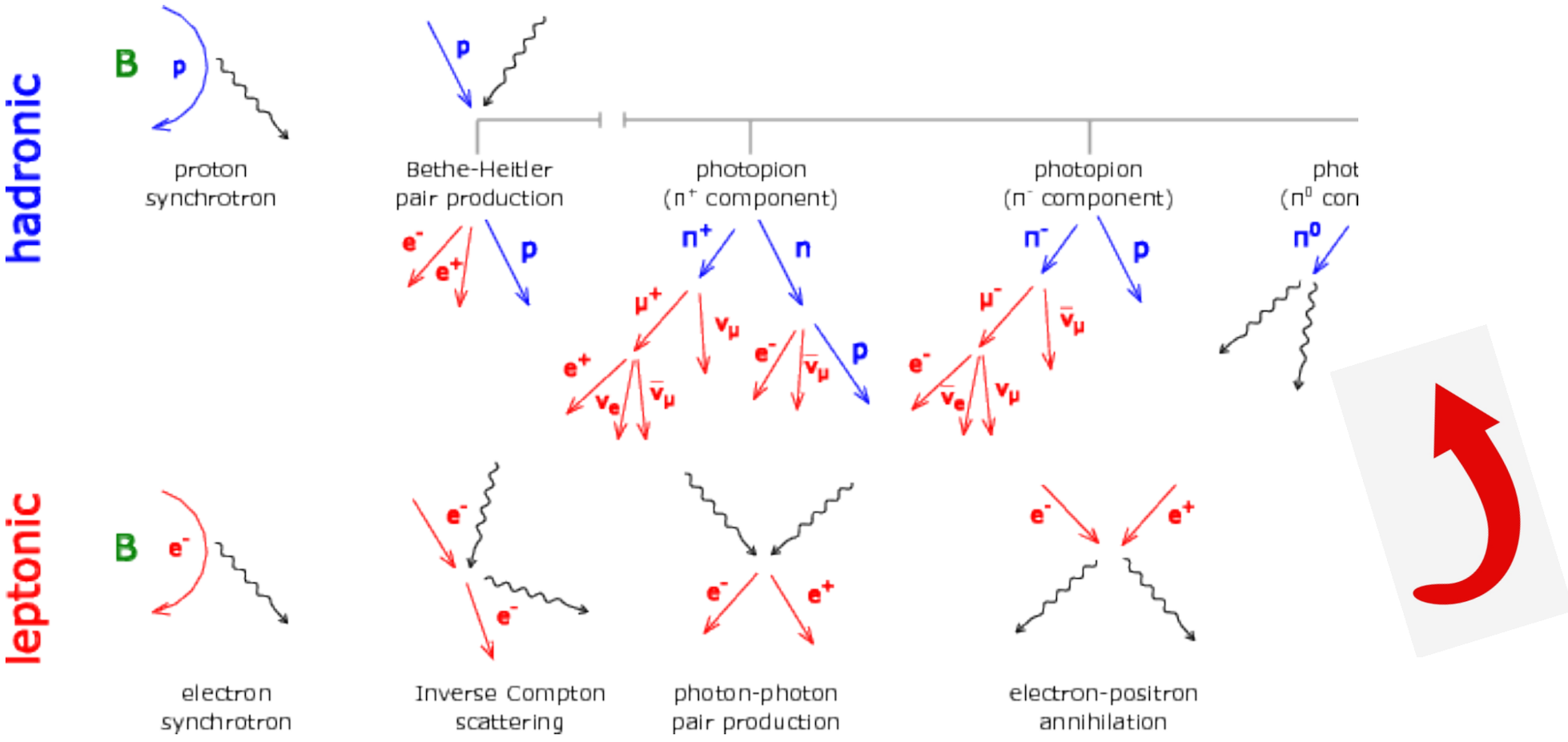
Leptons or hadrons?



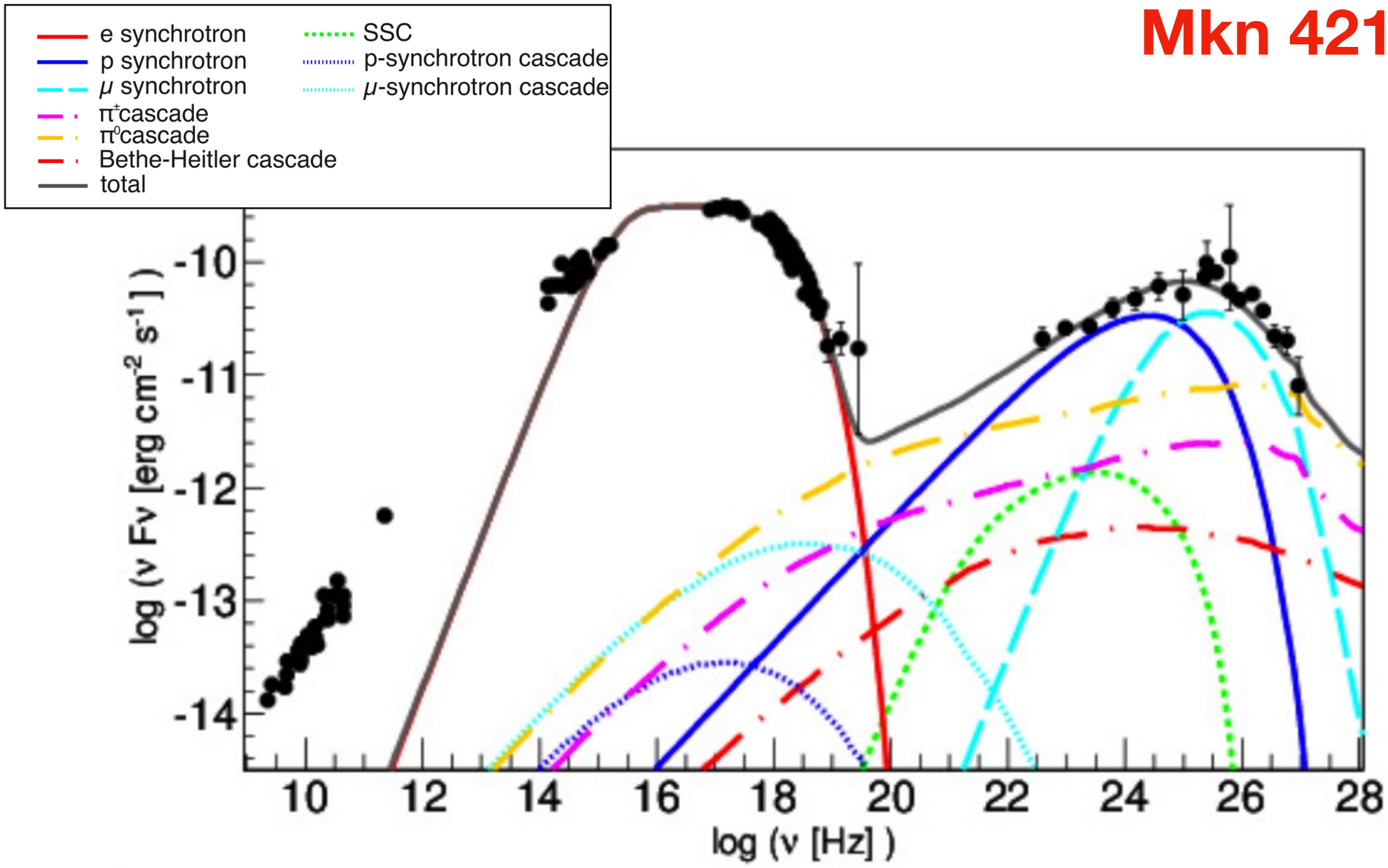
Leptons or hadrons?



Leptons or hadrons?



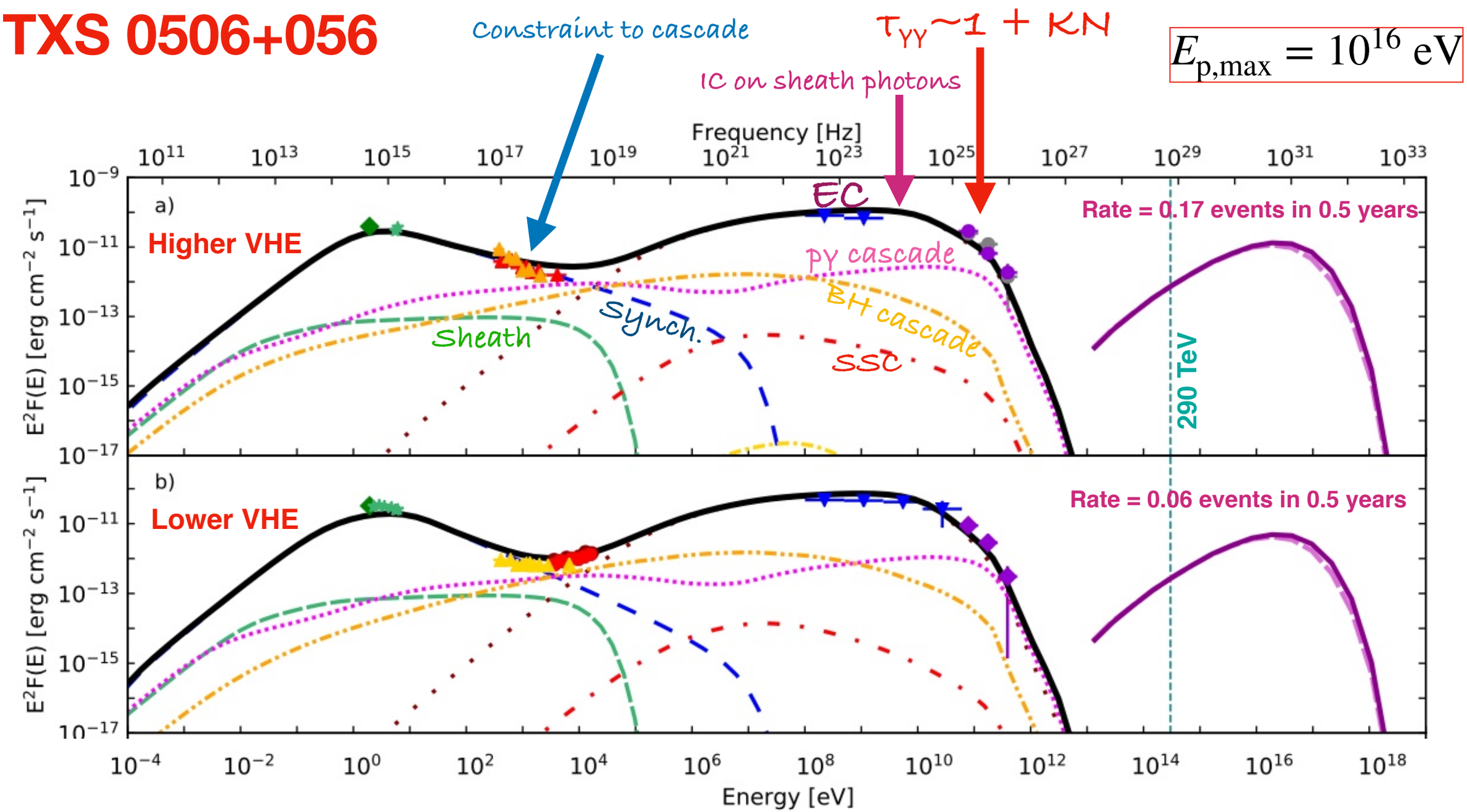
Lepto-hadronic models



Cerruti et al. 2015

Lepto-hadronic models

TXS 0506+056

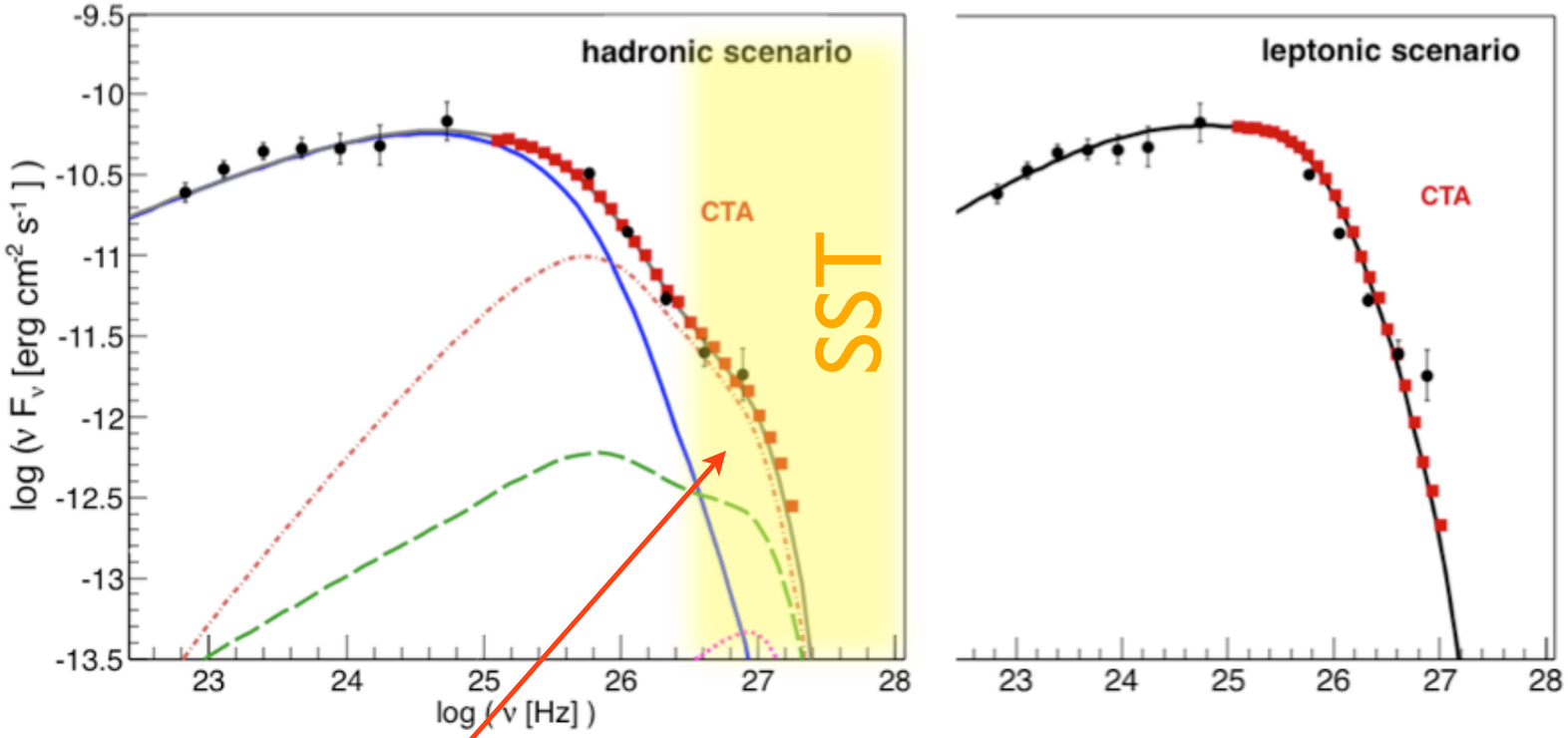


MAGIC Coll. 2018

Lepto-hadronic models

Zech et al. 2017

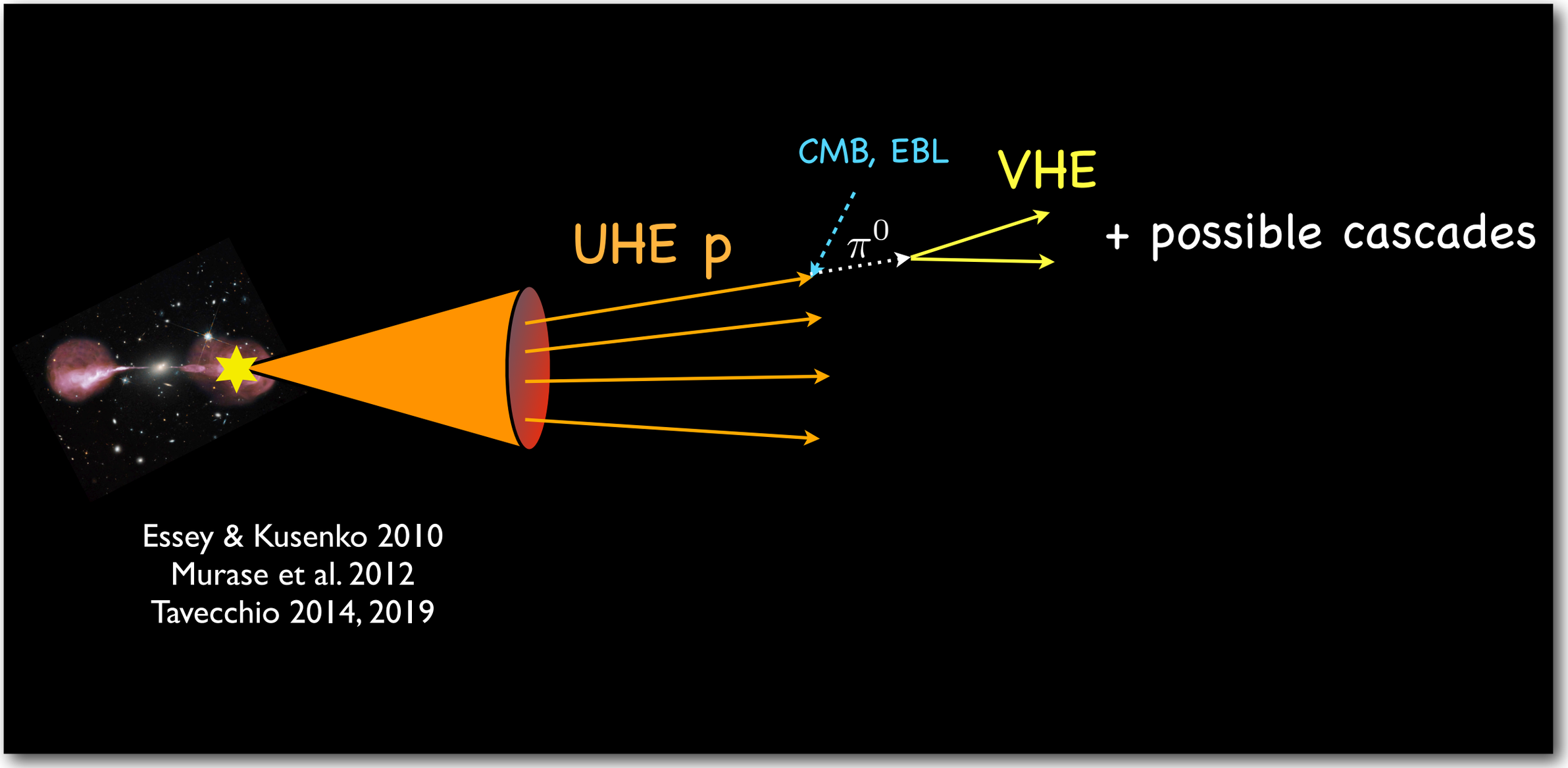
PKS 2155-304



Hard tail

Prospects for CTA

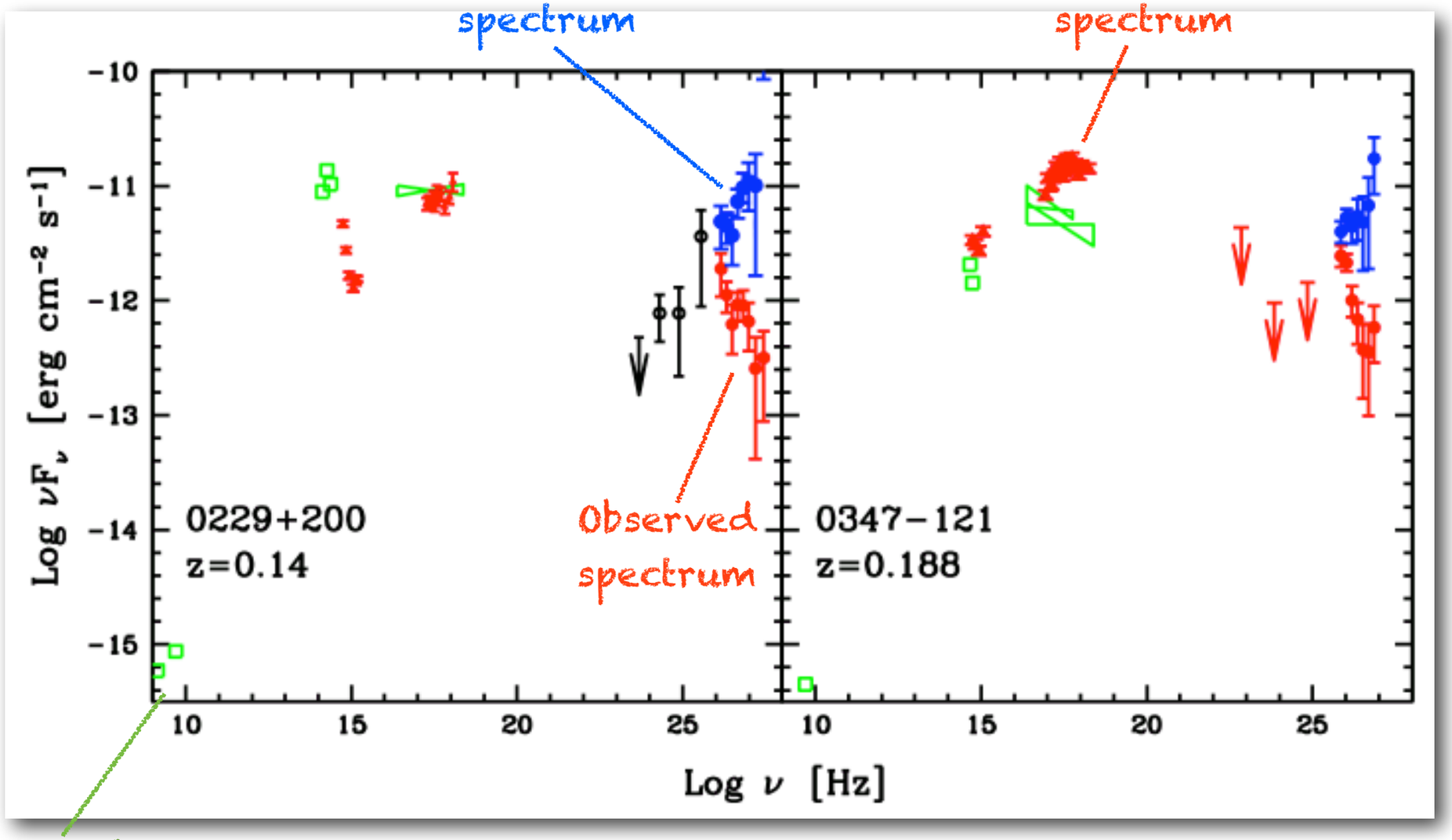
Hadron beams?



Scenario for "extreme Bl Lacs"

Extreme BL Lacs

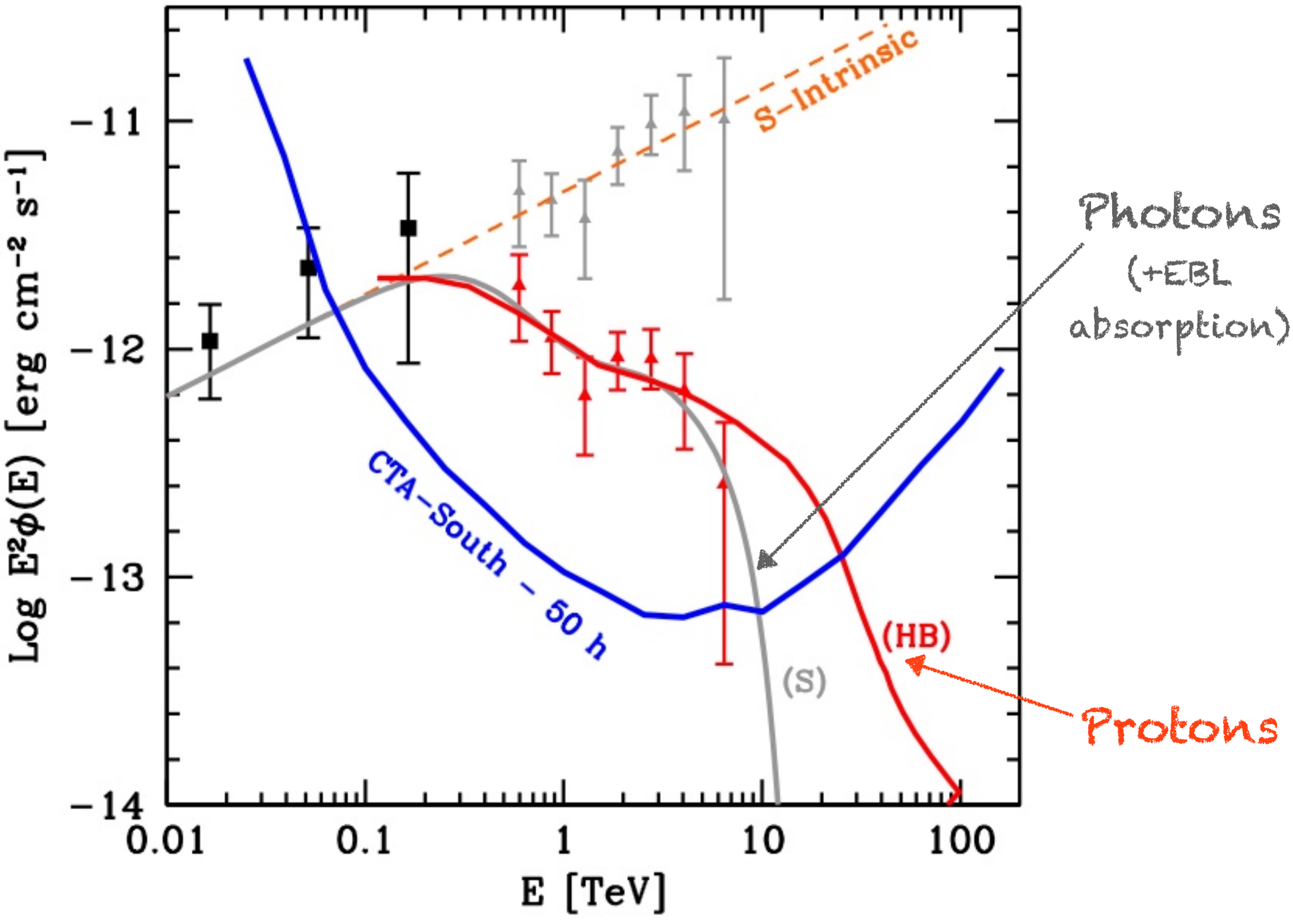
after Costamante et al. 2001



Bonnoli et al. 2015

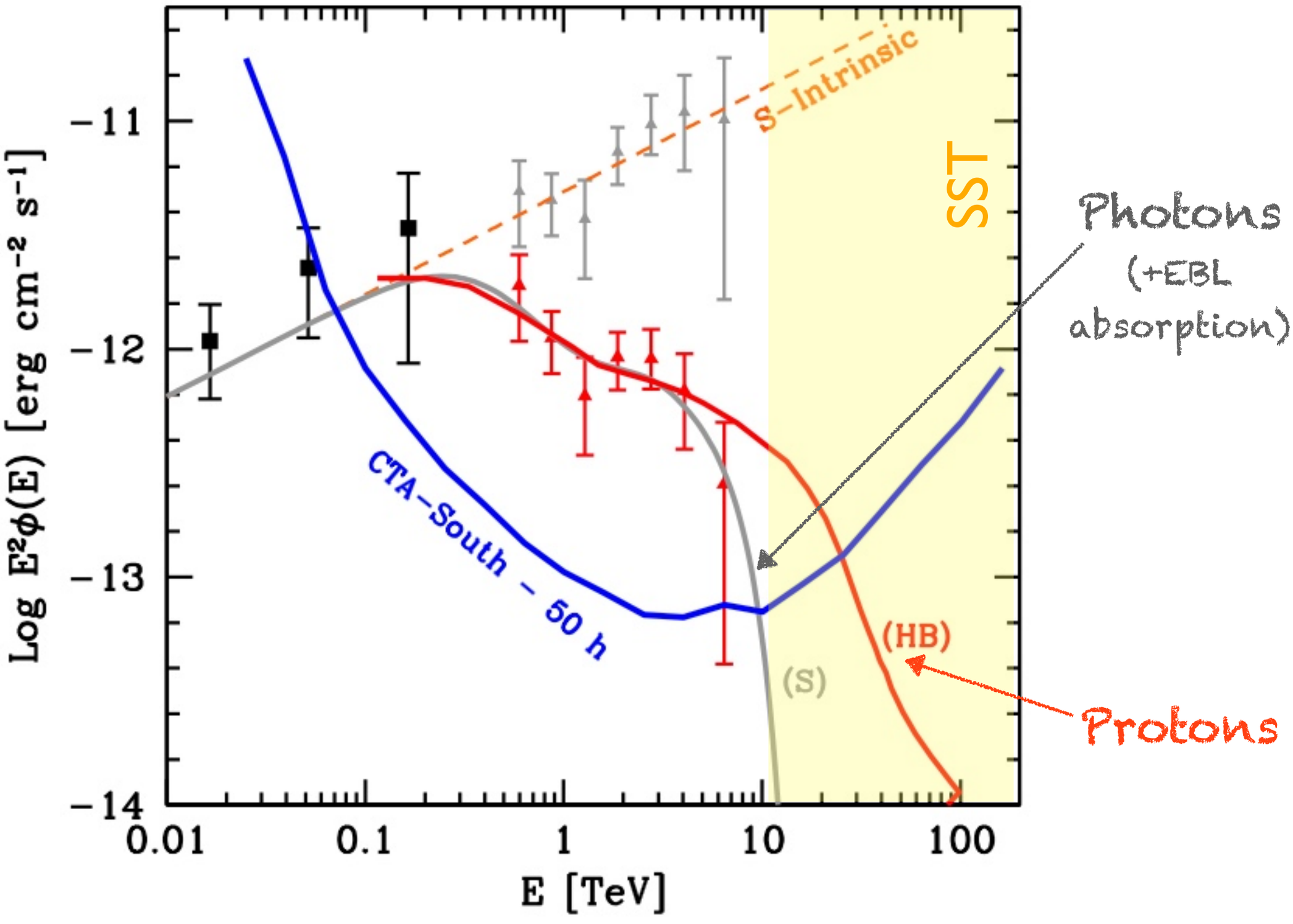
Hadron beams?

Tavecchio et al. 2019



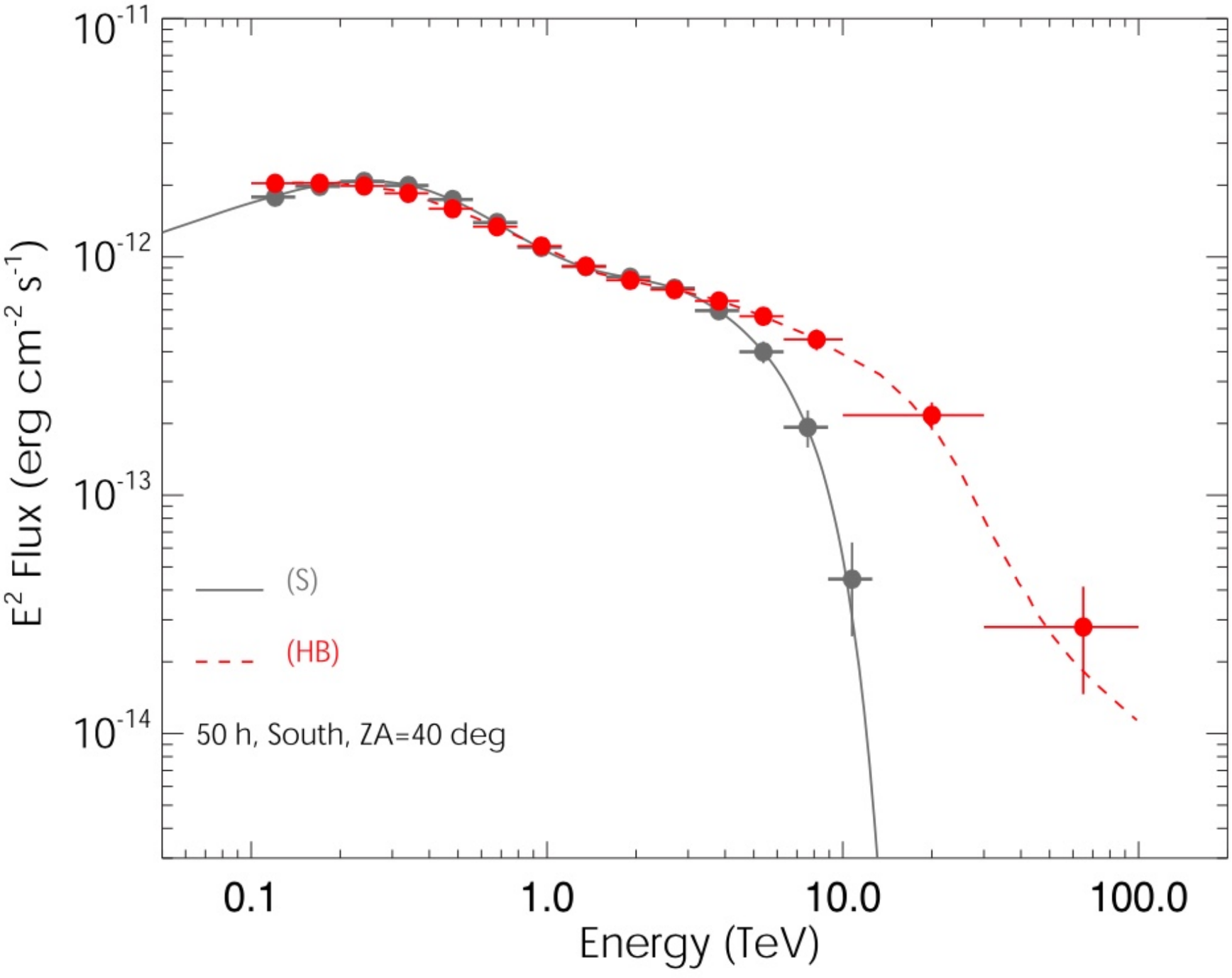
Hadron beams?

Tavecchio et al. 2019



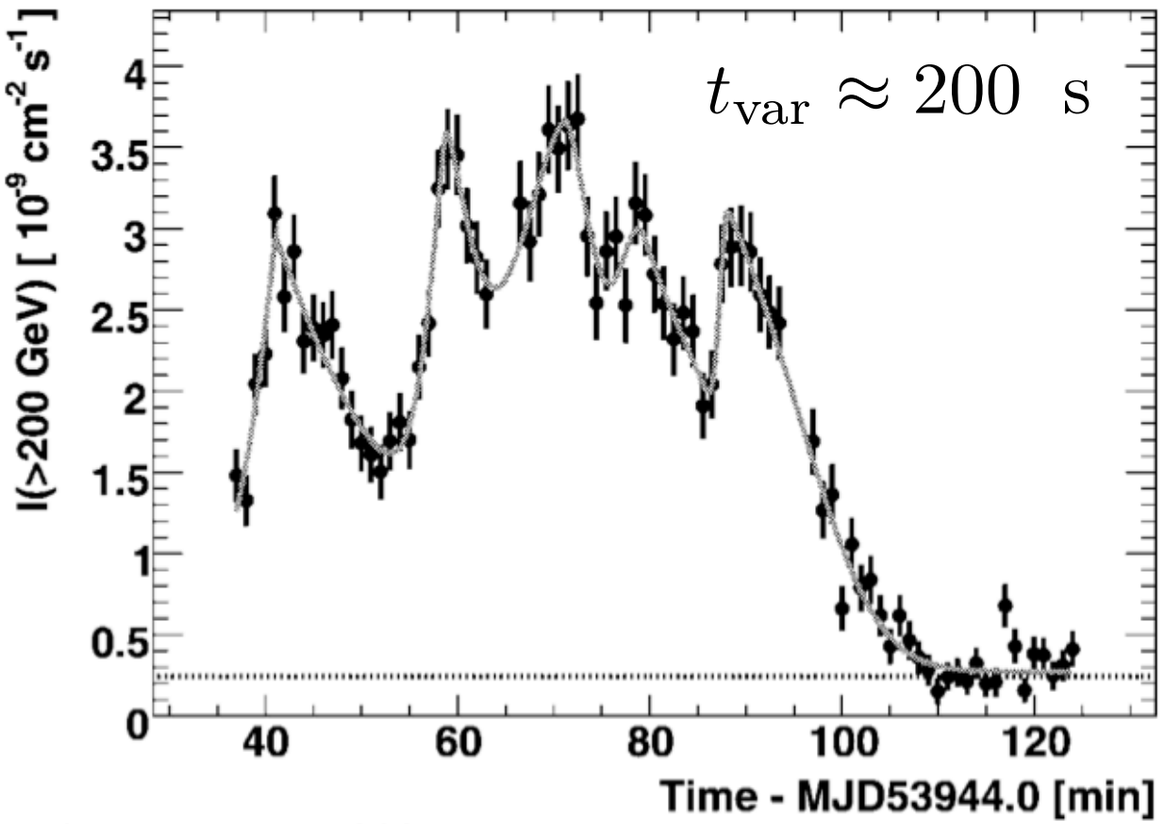
Hadron beams?

Tavecchio et al. 2019



Variability

PKS 2155-304@TeV



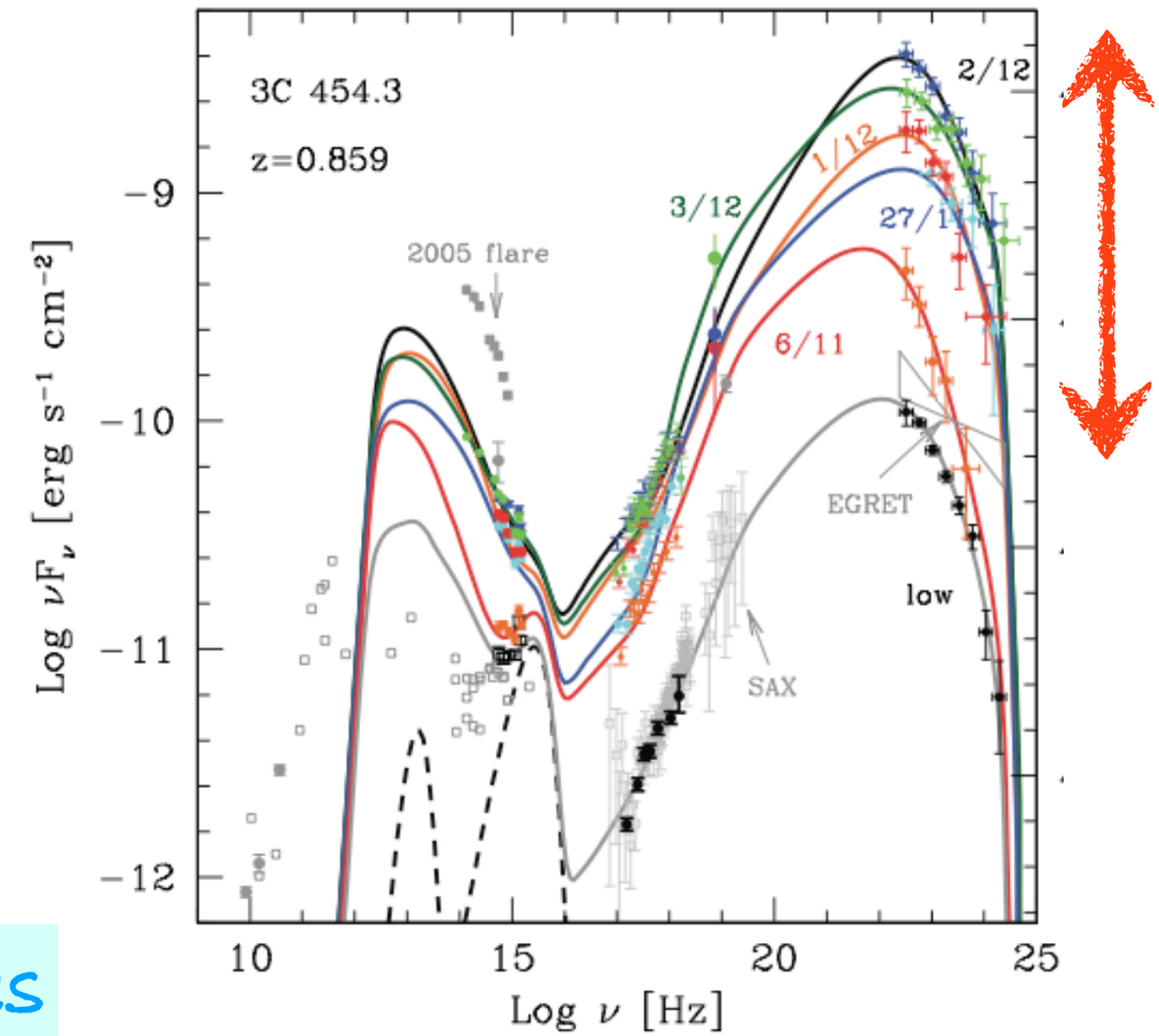
Aharonian et al. 2007

Short time-scales

Small spatial scales
Close to the BH

Large amplitudes

Bonnoli et al. 2011



Time dependent models

Continuity equation

escape

$$\frac{\partial N(\gamma,t)}{\partial t} = \frac{\partial}{\partial \gamma}\left[\dot{\gamma}(\gamma,t)N(\gamma,t)\right] + Q(\gamma,t) - \frac{N(\gamma,t)}{t_{\rm esc}}$$

cooling

injection

$$\dot{\gamma} = \frac{4}{3}\frac{\sigma_{\rm T} c}{m_{\rm e}c^2}\left[U_B + U_{\rm rad}(\gamma,t)\right]\gamma^2$$

Time dependent models

Continuity equation

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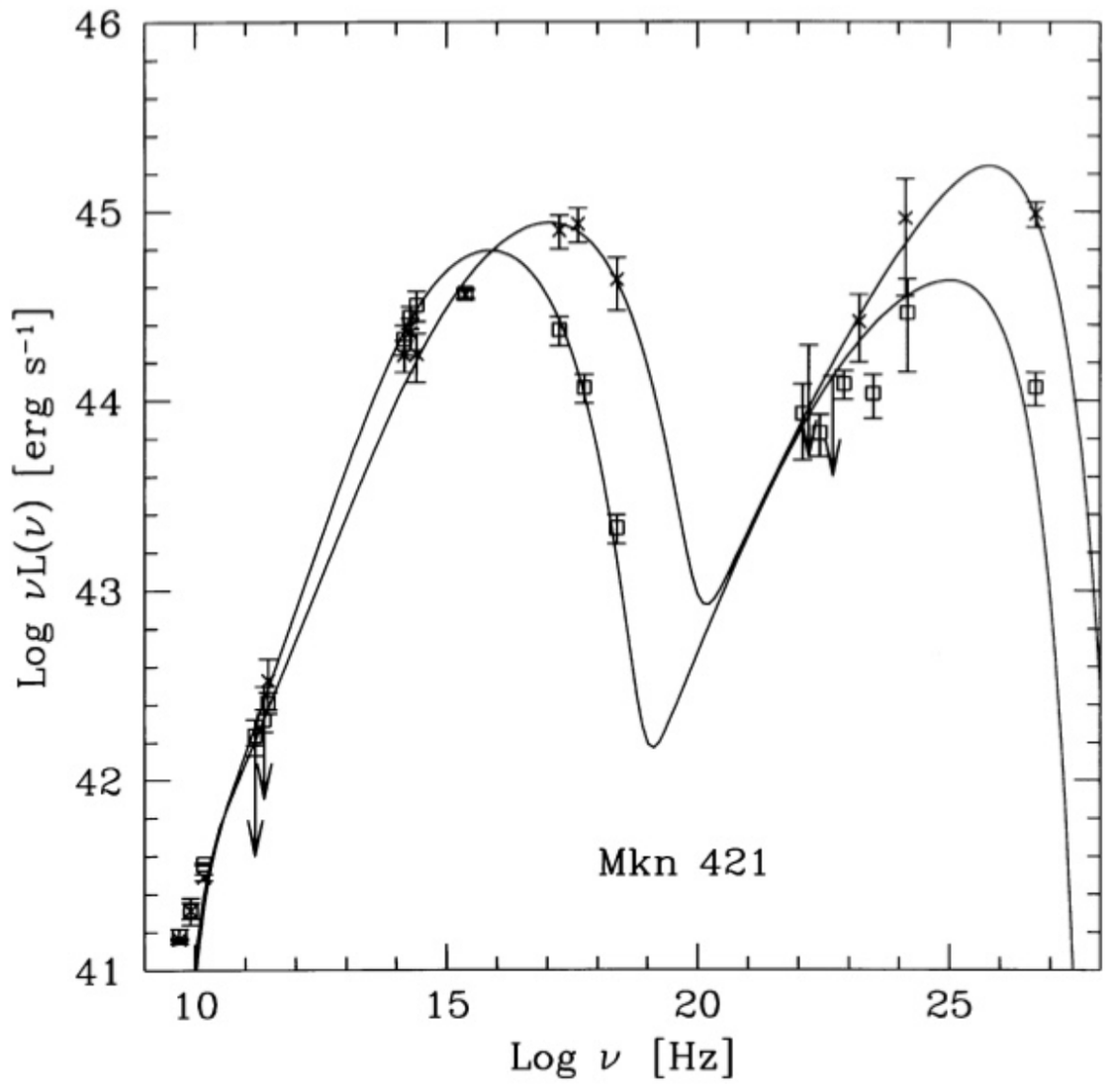
Chiaberge and Ghisellini 1999



Final thoughts

Jets are very complex systems but …

(Leptonic)One zone models are surprisingly successful!

We can obtain rather interesting clues one particle acceleration, evolution etc…

Lepto-Hadronic models suggested by neutrino data but still need improvements