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Hadronic Supercriticality and its application to Extreme Blazars

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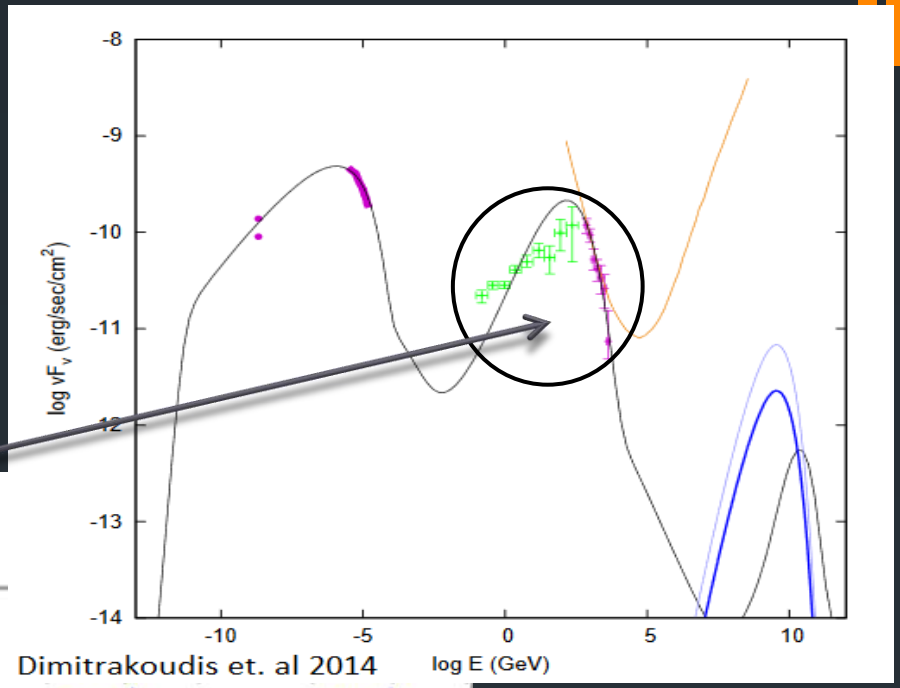
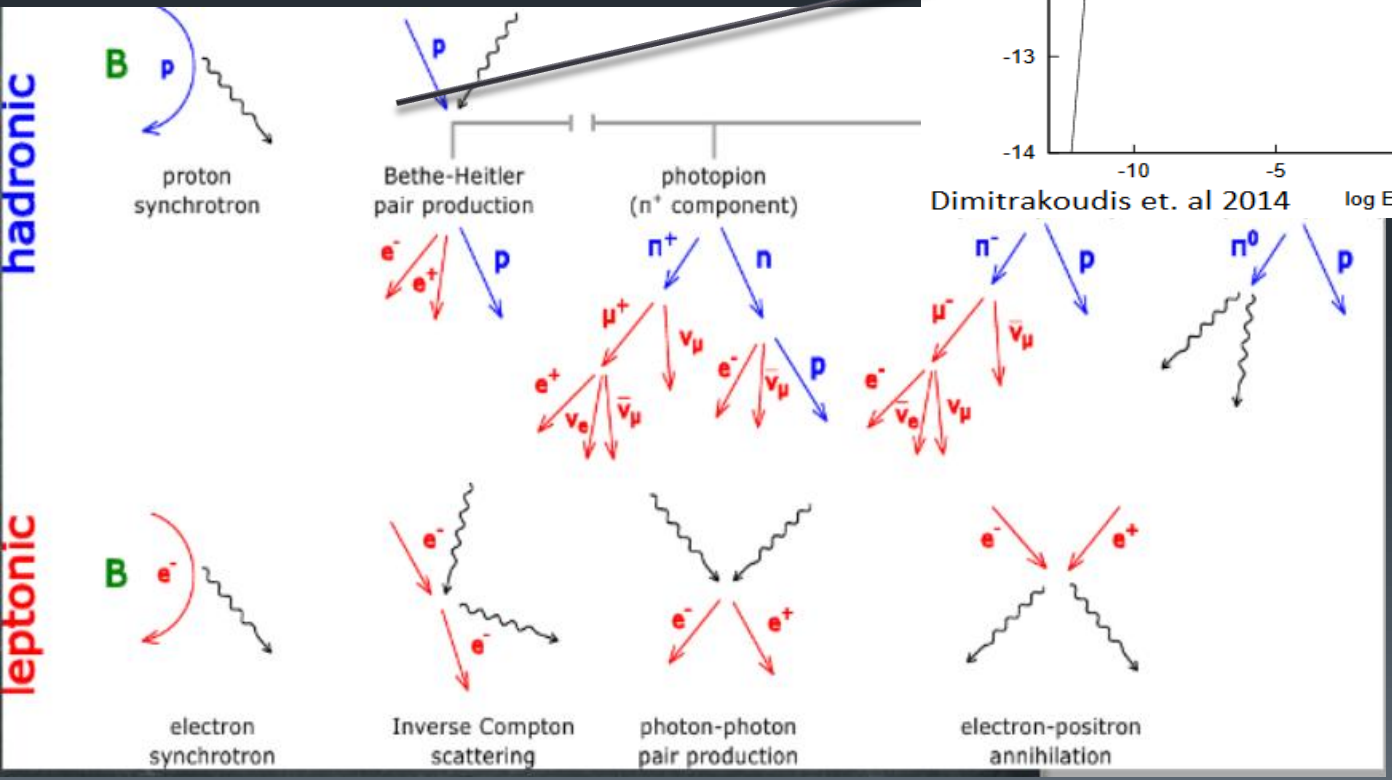
Physical Processes for spectral formation

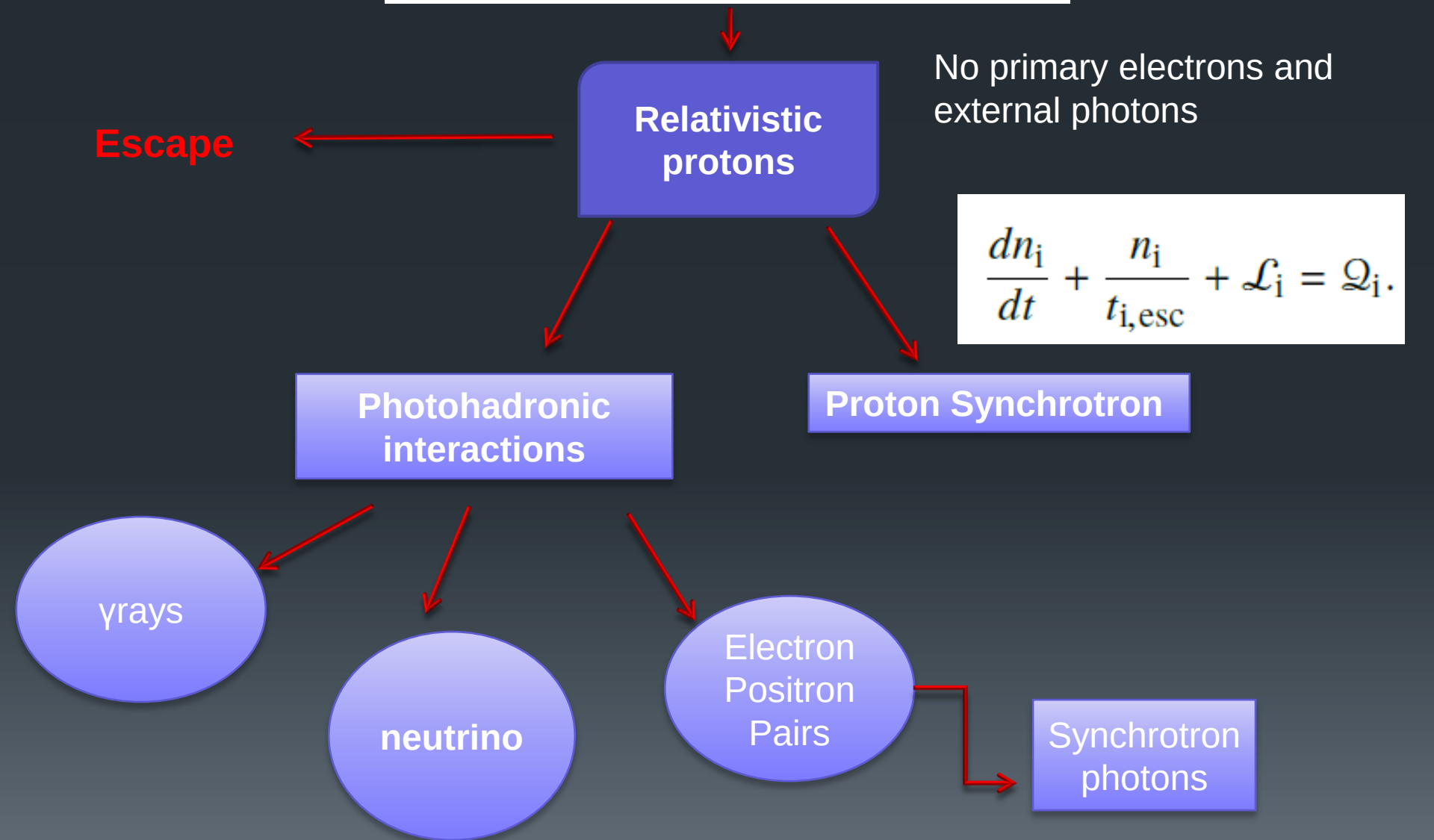




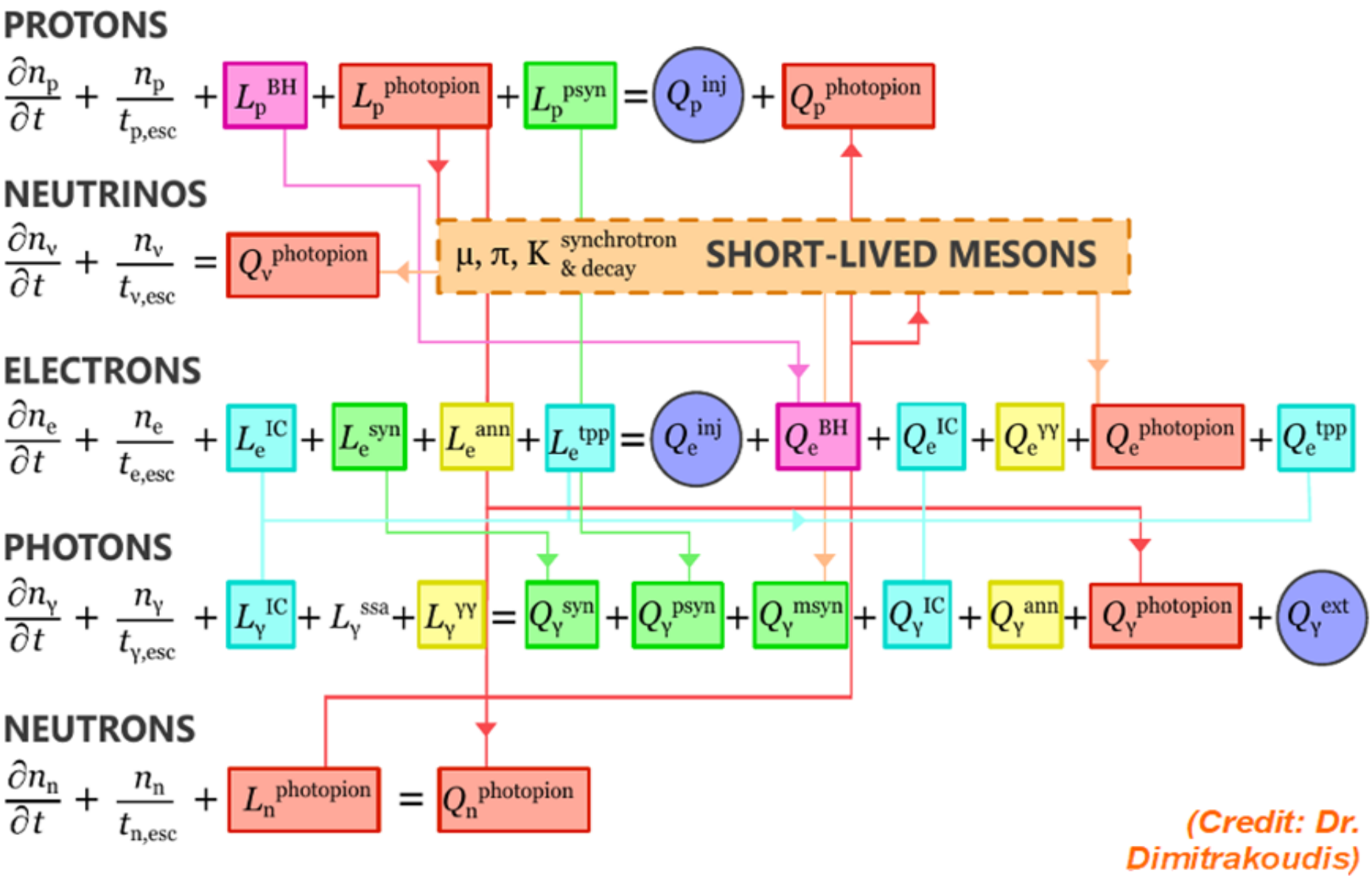
One zone model
Relativistic proton injection in a spherical volume of Radius R and Magnetic Field B, inside the jet

The distribution function

$$Q_{\rm p}(\gamma_{\rm p},t) = Q_{\rm p_0}\gamma_{\rm p}^{-s}H(\gamma_{\rm p}-\gamma_{\rm p,min})H(\gamma_{\rm p,max}-\gamma_{\rm p})H(t)$$



Solving the energy conserving time dependent kinetic equations...



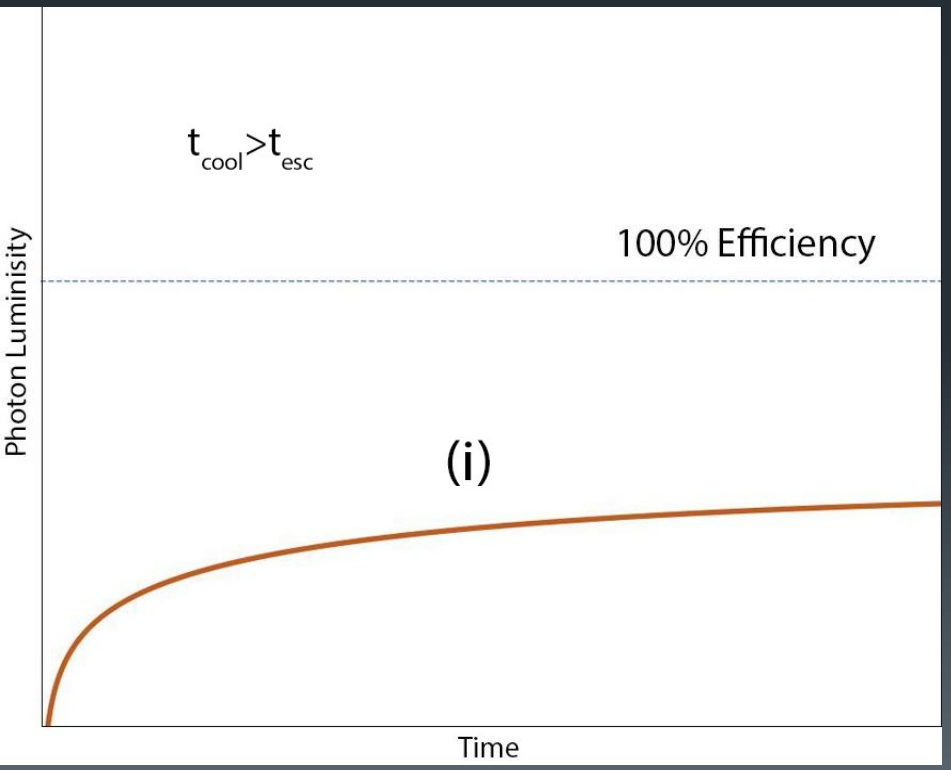
(Credit: Dr. Dimitrakoudis)

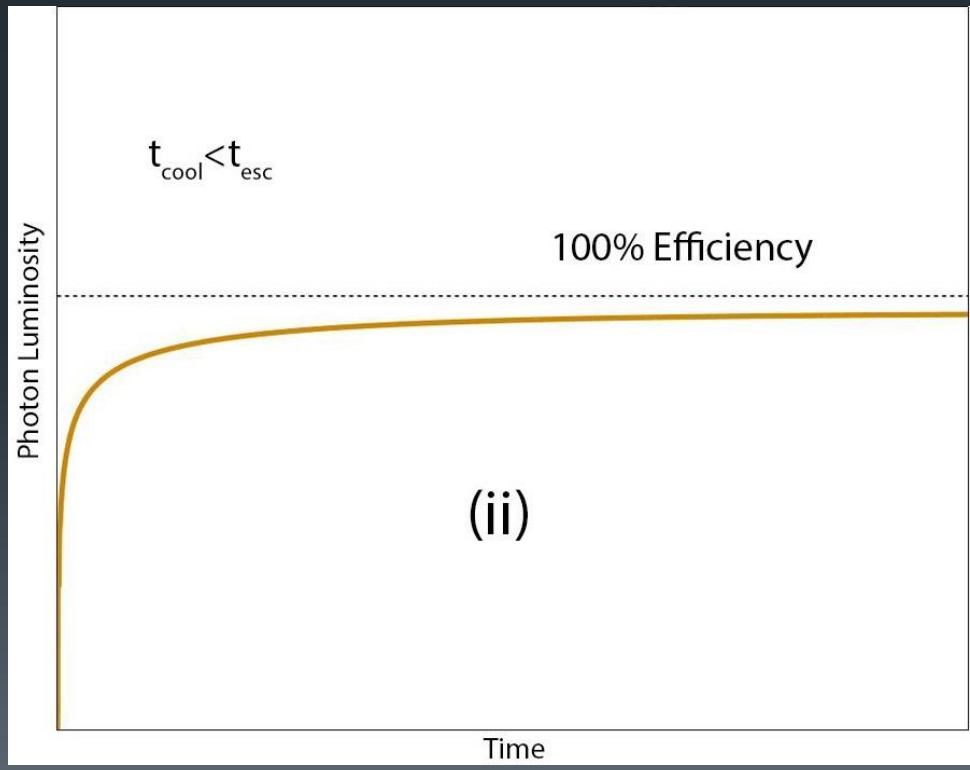
AM & Kirk 1995

Parameters that make the system operate linearly

Excessively used approach

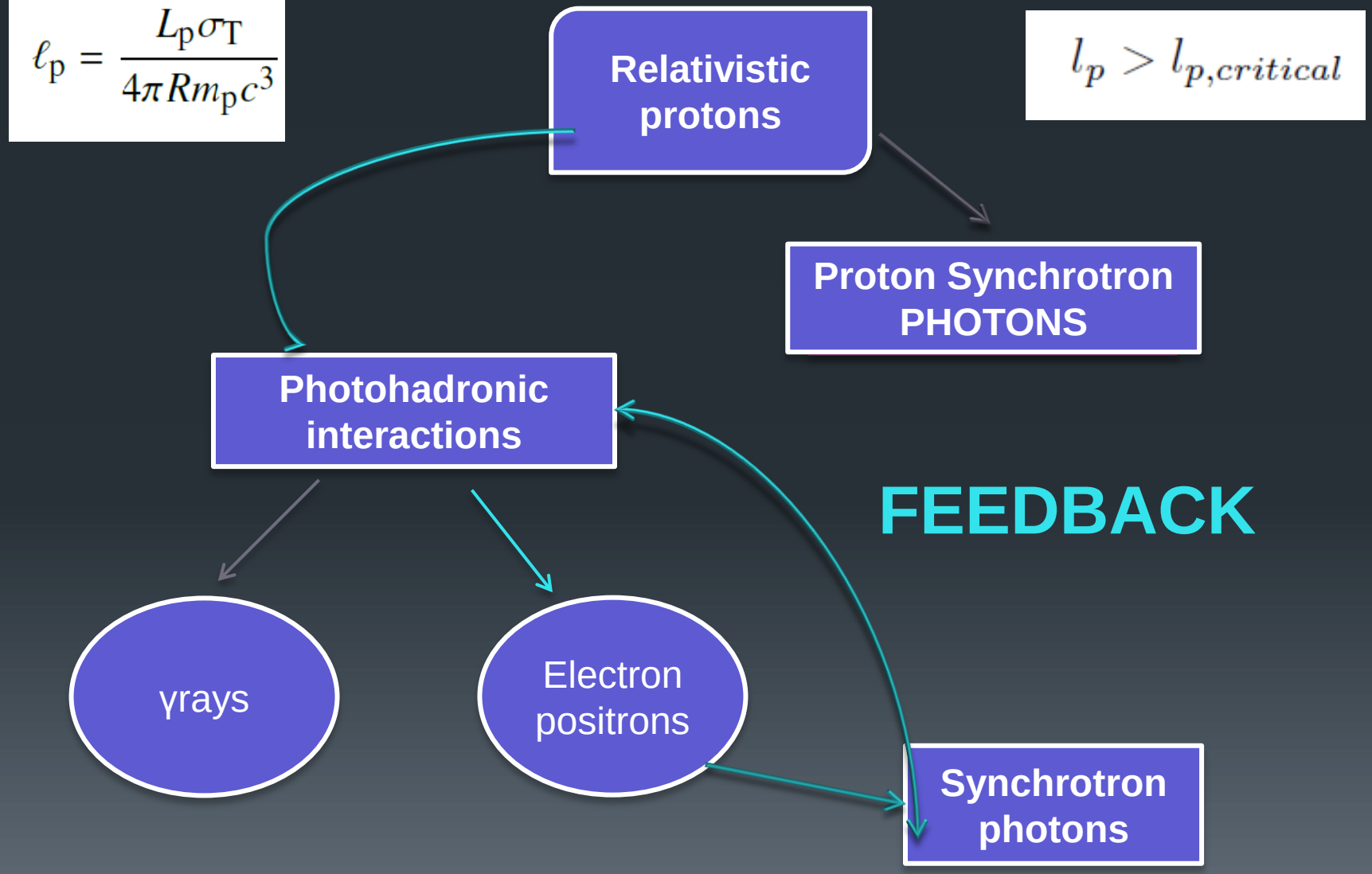
The system is regulated by proton synchrotron.



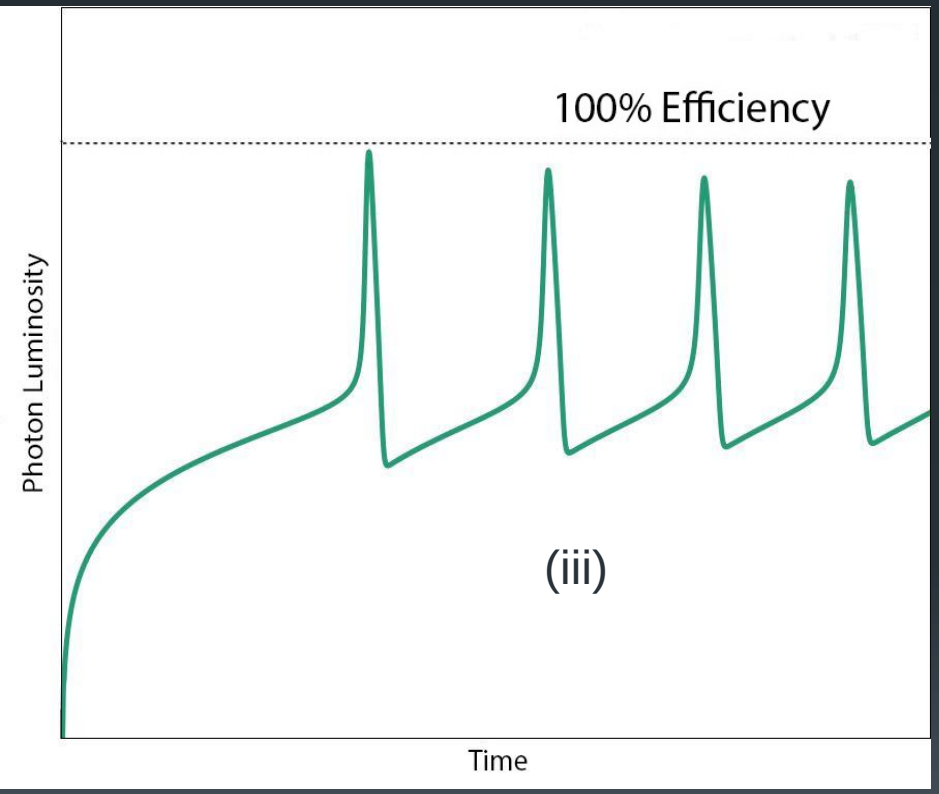


This problem can become non-linear

$$\ell_{\rm p} = \frac{L_{\rm p}\sigma_{\rm T}}{4\pi R m_{\rm p} c^3}$$



Hadronic Supercriticality
Unique and Overlooked property of hadronic models



- ❖Threshold conditions for proton compactness
- ❖Protons release energy with high radiative output in small timescales
- ❖Lightcurves that might be associated with flares from compact astrophysical objects

Stern & Svensson 1991
Stern et. al 1992
Mastichiadis & Kirk 1992,1995
Petropoulou & Mastichiadis 2012,2018

Present work: explore the parameter space of Hadronic Supercriticality

Physical quantity	Minimum value	Maximum value
R (cm)	10^{11}	10^{16}
B (G)	10^{0}	$10^{4.5}$
γ_{max}	10^{3}	10^{9}

Relevance with the flaring events of compact Astrophysical Sources?

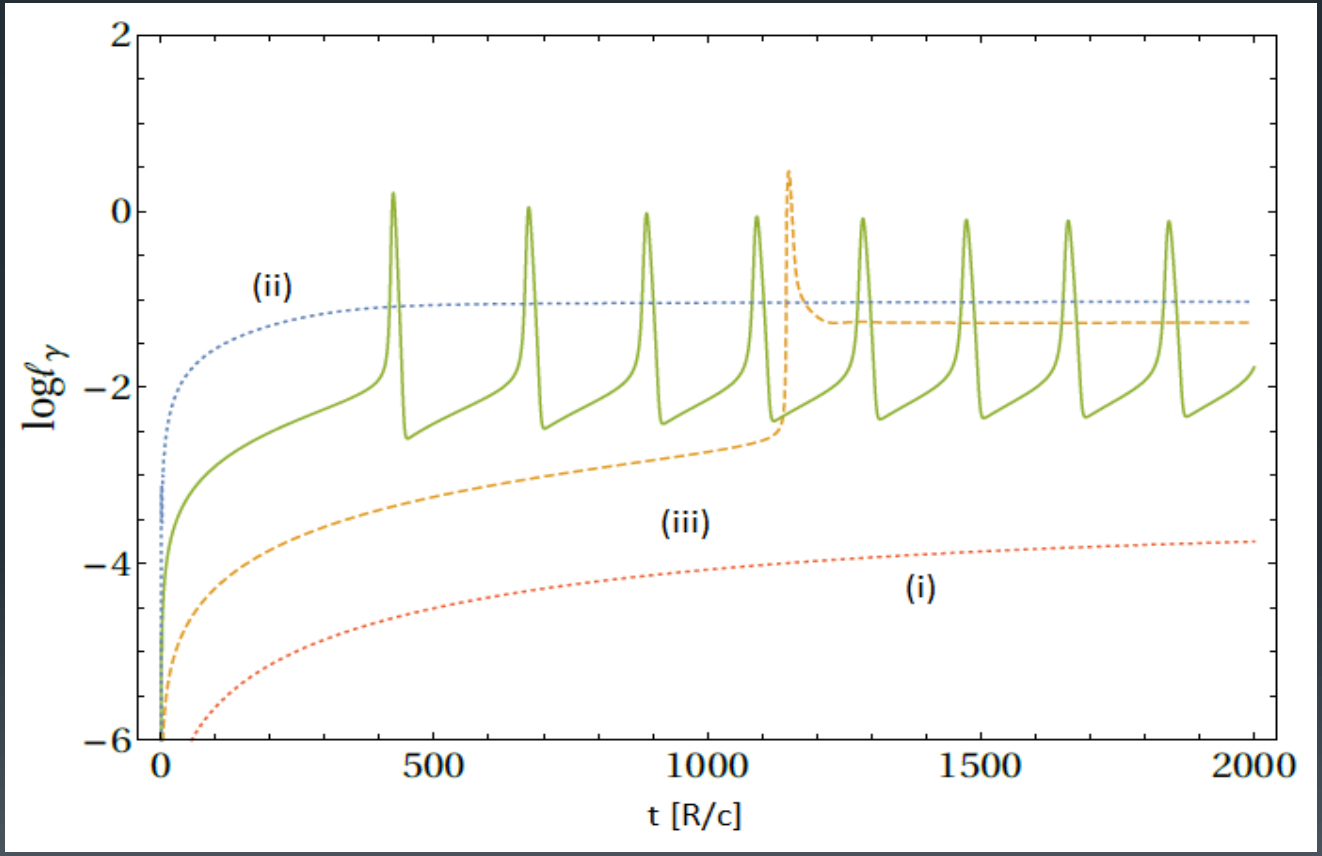
The parameters are

- ✓ The proton compactness lp
- ✓ The source radius R
- ✓ The magnetic field strength B
- ✓ The maximum proton energy
- ✓ The slope of the proton distribution $s = 2$
- ✓ The proton escape time scale

$$t_{\mathrm{p,esc}} = 1000 t_{\mathrm{cr}}, \text{ where } t_{\mathrm{cr}} = R/c$$

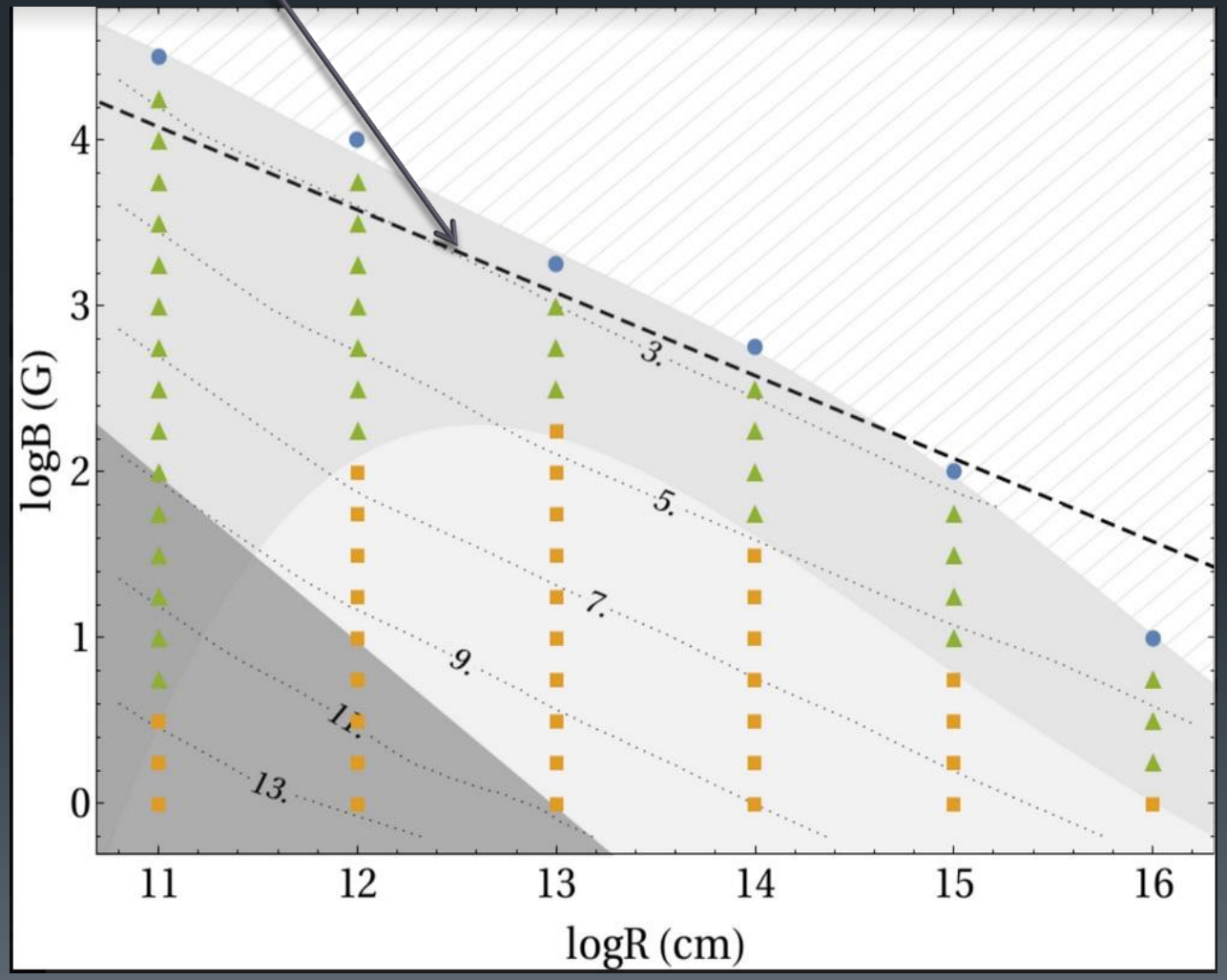
The behaviour of Hadronic Supercriticality

The system is sensitive to the change of the parameter values



The parameter space of hadronic supercriticality

$t_{p,esc} = t_{p,cool}$

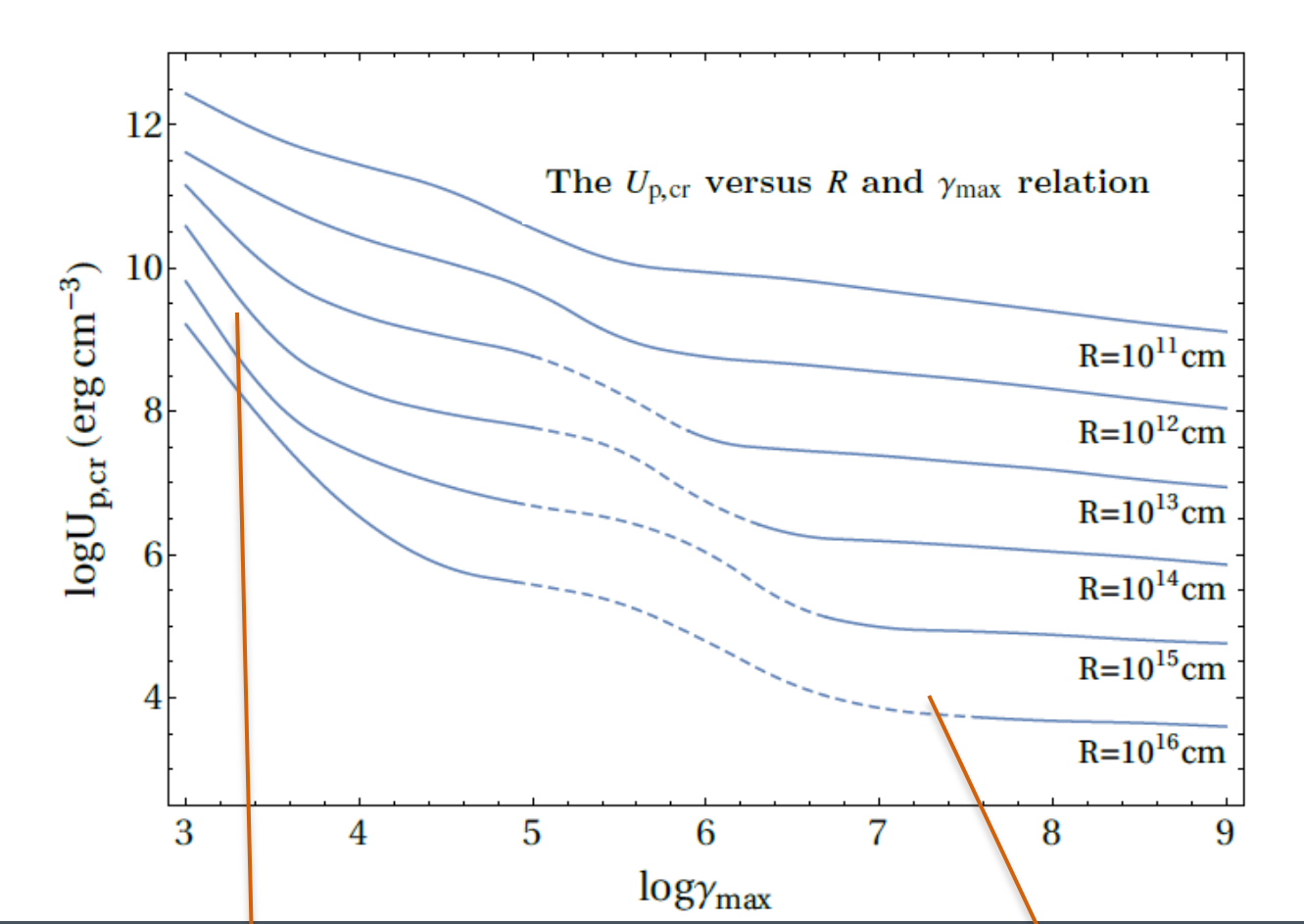


$\gamma_{max} = constant$

$t_{app} = t_{esc}$

✓Search for the proton compactness for which the first flare appears at a timescale equal to the escape proton timescale

Relation between critical proton density, source radius and maximum proton energy



$$B^2 R = \text{constant}$$

$$\gamma_{crit} = \left(\frac{2\ B_{critical}}{B}\right)^{1/3}$$

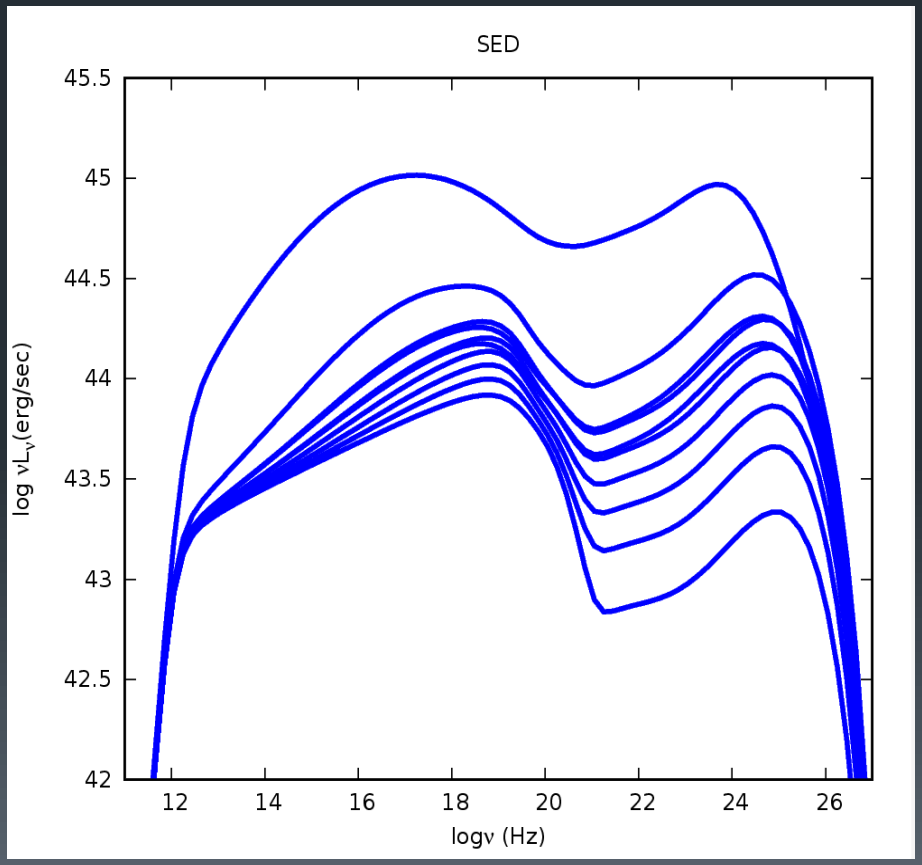
Mastichiadis & Kirk 1992

$$\frac{U_{p,cr}}{U_B} = 10^6 - 10^7$$

$$\frac{U_{p,cr}}{U_B} = 10^2 - 10^3$$

Application to Extreme Blazars

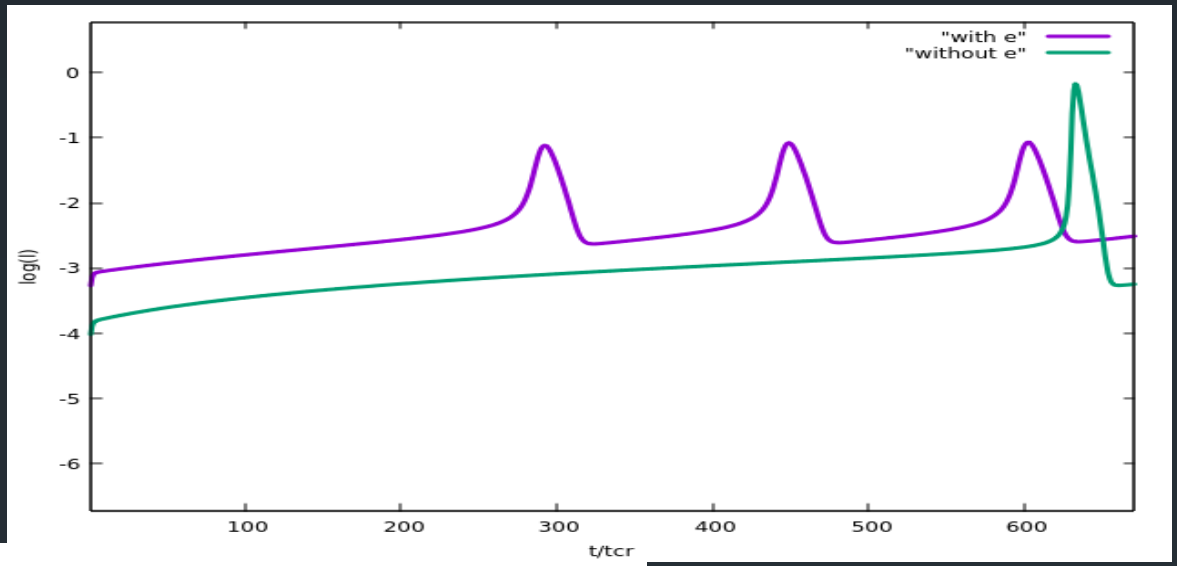
- Ejection of a power law distribution of relativistic electrons and protons

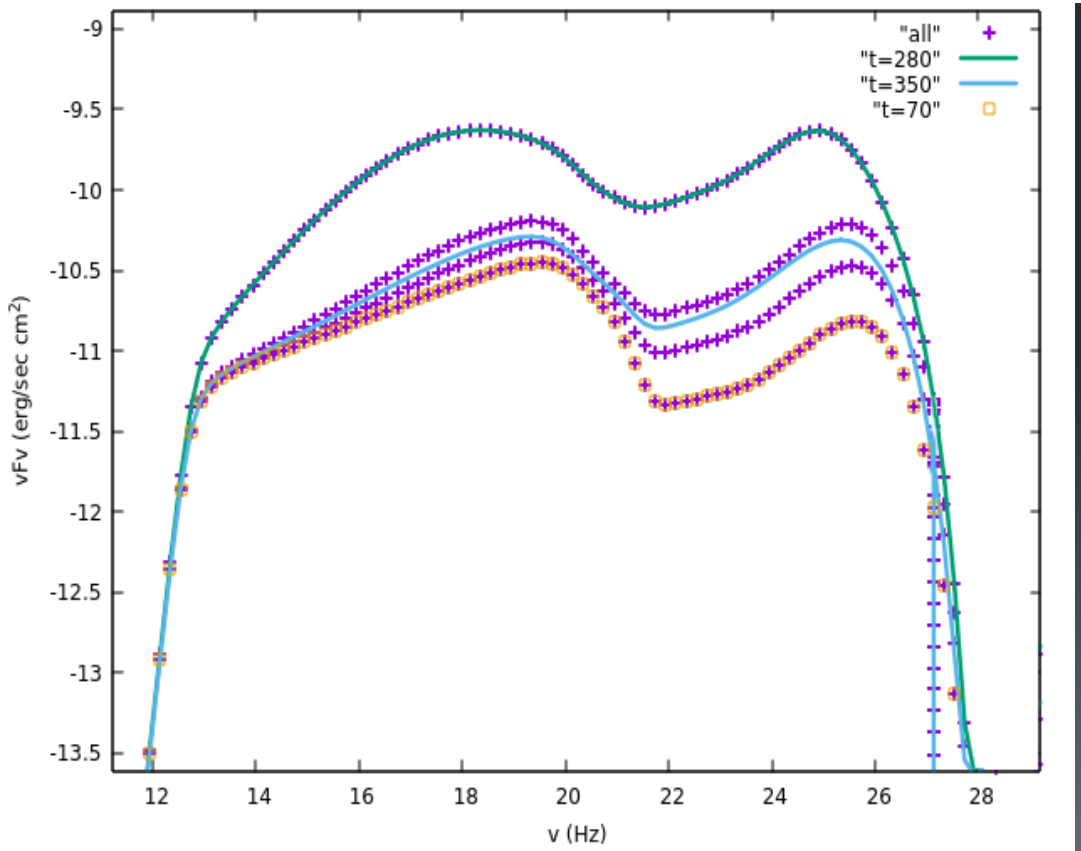


Parameters	Values
Source Radius	10^{15} cm
Magnetic Field	31.4 G
$\gamma_{p,max}$	10^{7}
$\gamma_{e,max}$	10^{6}
l_p	10^{-5}
l_e	$10^{-3.5}$
Proton Slope	1.8
Doppler factor	10

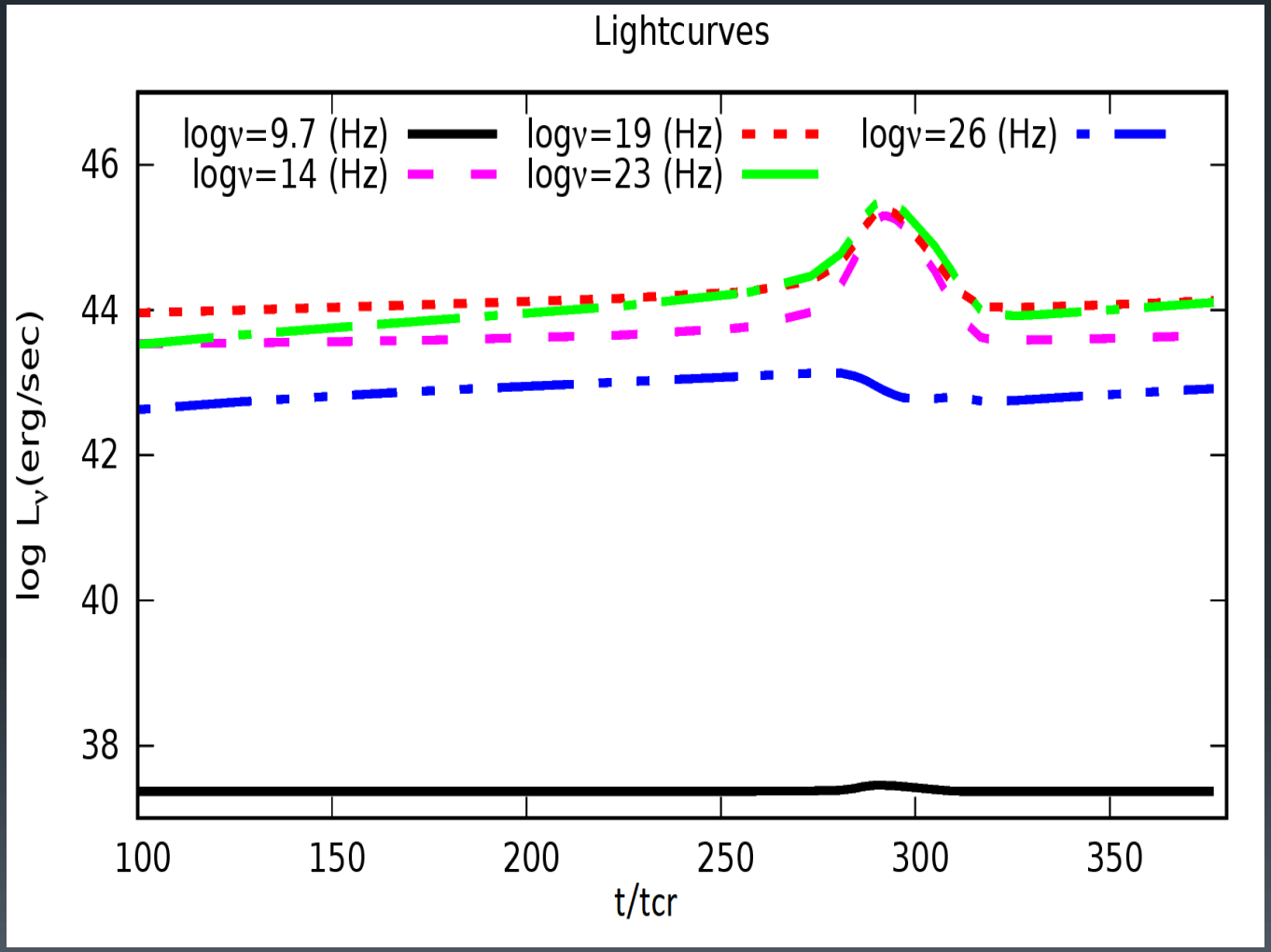
$$L_e = 1.14\ 10^{41}\ erg/sec$$

$$L_p = 5.7\ 10^{43}\ erg/sec$$


"with e"
"without e"
log(I)
t/tcr
0
-1
-2
-3
-4
-5
-6
100
200
300
400
500
600


"all"
"t=280"
"t=350"
"t=70"
vFv (erg/sec cm^2)
v (Hz)
-9
-9.5
-10
-10.5
-11
-11.5
-12
-12.5
-13
-13.5
12
14
16
18
20
22
24
26
28

Application to extreme Blazars



Conclusions

- We perform a study of hadronic supercriticality in the context of a one zone model
- We explored the parameter space of hadronic supercriticality for a constant injection rate and investigate the dependence of the dynamical behaviour of the system to proton compactness, magnetic field, maximum proton energy and radius
- It is possible to apply this model to compact Astrophysical Objects, such as Blazars

Thank you for your attention!