



Temporal evolution of high energy radiation in type II_n Supernovae

Kantzas K. Dimitrios¹

in collaboration with:

Dr. Petropoulou Maria² &
Prof. Mastichiadis Apostolos¹

1



HELLENIC REPUBLIC
National and Kapodistrian
University of Athens

2

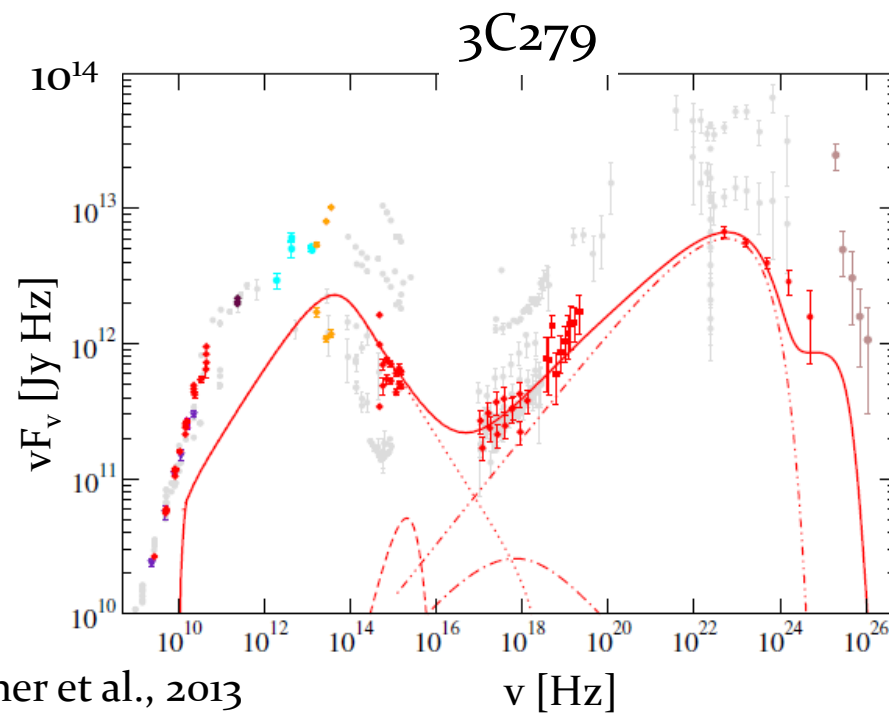
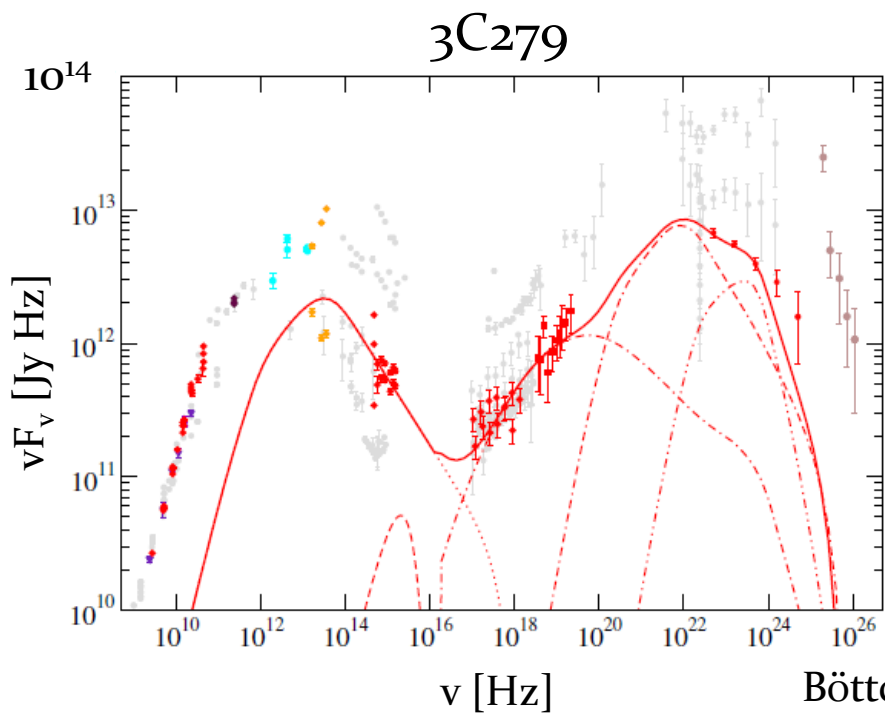




Motivation

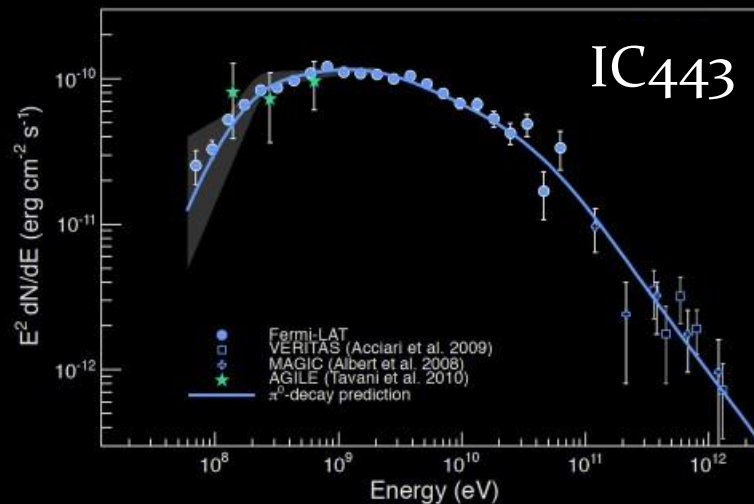
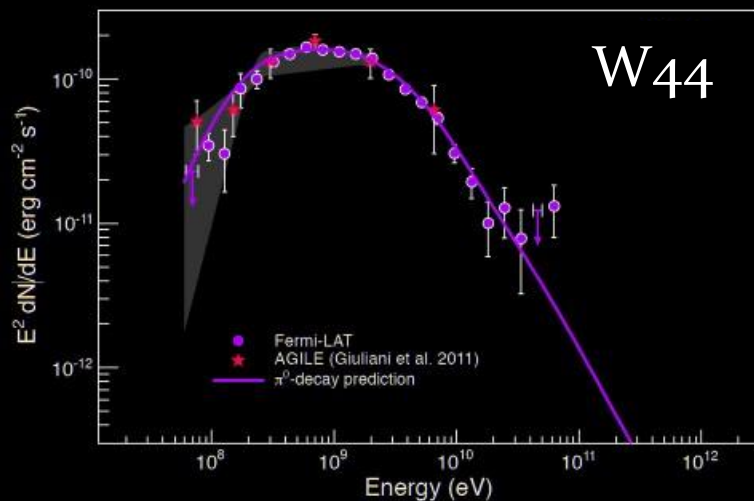
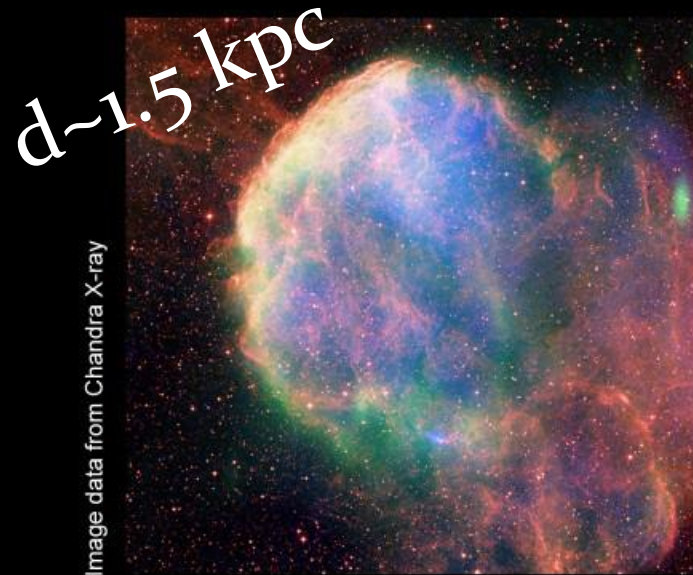
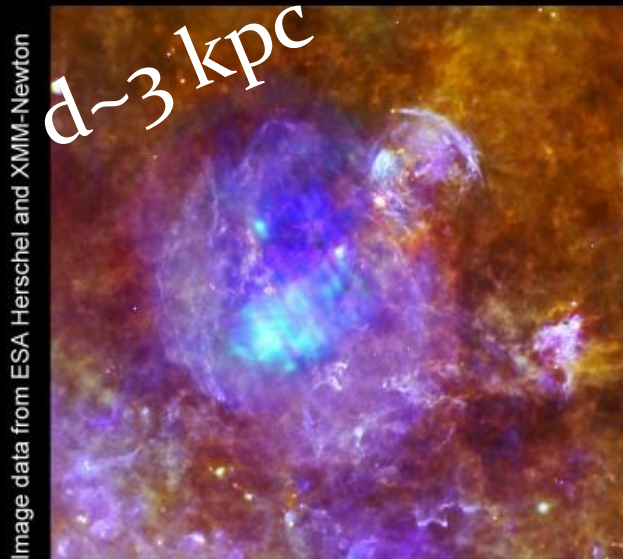
Leptonic Model

Hadronic Model



Also: On the flaring γ -ray activity of quasar 3c279, *A. Mastichiadis et al.*

Supernova W44 & IC 443 Neutral Pion Decay Spectral Fit



Leptonic Model

- electrons
- ICS
- low B
- See poster: On the connection of radio and γ -ray emission of blazars, *S. Boula et al.*

On the connection of radio and gamma-ray emission of blazars
 Stella Boula¹, Maria Petropoulou², Apostolos Mastichiadis¹
¹ National and Kapodistrian University of Athens, ² Purdue University

Abstract
 Blazars are a sub-category of radio-loud Active Galactic Nuclei which is characterized by some cases a correlation between gamma-ray and radio emission. These sources exhibit a correlation. In this work we construct a one-zone leptonic model in order to explain this correlation. Adopting the hypothesis that high energy photons are produced by flaring particles close to the central black hole, we study the evolution of the population of particles as it moves down the jet and hence energy loss produced by relativistic Inverse Compton (IC) scattering and synchrotron emission. We consider the evolution of the electron population which can be tracked into a time coordinate once as a function of the radial distance which is known. In the specific gamma-ray emission at a later time when the electrons have cooled and the emission region becomes optically thin to synchrotron self-absorption. We will discuss the parameters entering our calculations (like the magnetic field strength, the density of relativistic electrons, etc.) in connection to the observations data.

Adiabatic Expansion
 In this work we construct a simple leptonic model in order to study in the steady state as flaring emission of blazars by taking into account radiative and adiabatic losses [1]. The emitting region is assumed to be spherical with initial radius R_0 in its rest-frame, to move with a Lorentz factor $\Gamma = [1 - \beta^2]^{-1/2}$ and at the same time to expand with a velocity βc . The jet Doppler factor is $\delta = [\Gamma(1 - \beta \cos \theta)]^{-1}$ is the viewing angle of the blazar. The characteristic timescale of the problem is $\tau_{obs} = R_0/c$ in its rest position. Utilizing the numerical code of [2] we solve the integro-differential equations of the electrons and photons and we produce the SED of BL Lac objects. These kinetic equations have the form

$$\frac{dn_e}{dt} + \frac{dn_e}{dr} = -L_e + Q_e \quad (1)$$

where n_e is the differential number density of electrons and photons, L_e the terms of the loss of electrons, Q_e the injection term. In the case of adiabatic expansion, we have

$$L_e = L_{syn} + L_{IC} + L_{ad} \quad (2)$$

where L_{syn} , L_{IC} and L_{ad} are the losses due to synchrotron radiation, inverse Compton scattering and adiabatic expansion, respectively.

We assume that the electron injection rate has the form of a power law

$$Q_e(\gamma) = A_e \gamma^{-p} \quad \text{for } \gamma > \gamma_{min}$$

where A_e is the normalization factor, p is the slope of the power law. γ_{min} and γ_{max} are the minimum and maximum electron Lorentz factor, respectively.

Figure 1: Sketch of the adiabatic expansion of a relativistic radiative blob of plasma. High energy electrons are produced close to the central region, as the jet expands it becomes optically thin to synchrotron self-absorption and radio photons are emitted.

Figure 2: Sketch of photon spectra at various radii in the case where magnetic field and electron density decrease as R^{-1} as the source expands.

Figure 3: The same as Figure 2, but in the case where magnetic field and electron density are assumed to decrease as R^{-2} .

Mk 421 - Preliminary Results
 Figure 4 depicts the evolution of Mk421 SED in time. The dependence of physical quantities (such as magnetic field and electron luminosity) on R has the functional form $\propto R^{-1}$.

Time	B [G]	L_e [erg/s]
Day 1	0.1	10 ⁴²
Day 2	0.1	10 ⁴²
Day 3	0.1	10 ⁴²
Day 4	0.1	10 ⁴²
Day 5	0.1	10 ⁴²
Day 6	0.1	10 ⁴²
Day 7	0.1	10 ⁴²
Day 8	0.1	10 ⁴²
Day 9	0.1	10 ⁴²
Day 10	0.1	10 ⁴²

Figure 4: Time dependent SED of Mk 421.

Figure 5: Time evolution of SED in the case of a flaring episode in the source or lower energy is emitted.

Gamma ray and radio lightcurve for the produced flux in figure 5.

Future Work
 Although this work is at a preliminary stage, it shows that radio emission can be produced related to the blob's energy. In principal the parameters of the problem can be searched the parameter space to produce enough SED of BL Lac objects in the possibility and with observations along both steady state conditions and flaring episodes.

References
 [1] H. van der Laan, *Model for Variable Extragalactic Radio Sources*, *Astron. J.* 70, 1023 (1972).
 [2] I. Hovatta, M. Petropoulou, J. L. Richards, D. Giannou, K. Wai, M. Bakhshif, A. Ghisellini, B. Liu, W. Mao, Mastichiadis, V. Bamford, and A. C. S. Readhead, *Simultaneous radio and GeV γ -ray view of the 2012 and 2013 flares of Mrk 421*, *MNRAS*, 444, 2028-2040 (2014).
 [3] A. Mastichiadis and J. G. Kirk, *Self-consistent particle acceleration in active galactic nuclei*, *MNRAS*, 306, 1069 (1999).

1837 2017

ATHENS UNIVERSITY OF ECONOMICS AND BUSINESS

15th Hellenic Astrophysics Conference

stboula@phys.uoa.gr

THINK LIKE A PROTON



AND STAY POSITIVE

Hadronic Model

- protons/nuclei
- π^0 decay
- CR acceleration +
- high energy -
- neutrinos ...
- See poster: Modeling the rapid flare of 3C279 June 2015, I. Florou et al.

Modelling the June 2015 rapid flare of 3C279
 Ioella Florou¹, Maria Petropoulou² & Apostolos Mastichakidis¹
¹ Department of Physics, National & Kapodistrian University of Athens, 15701 Zografos, Greece
² Department of Physics and Astronomy, Pomona University, Claremont, CA 91738, USA

Abstract
 The Spectrum Radio Quasar (SRQs), a sub class of blazars, are strong emitters of electromagnetic radiation with an emitting region as strong as several hours. Quasar 3C279 is one of the most extensively studied SRQs. In June 2015 the source underwent a giant outburst with a minute scale variability that was observed by Fermi Large Area Telescope. In this paper we investigate whether a one-zone proton synchrotron model could describe the origin of the observed γ -ray emission. We examined whether a Log Parabolic distribution of relativistic protons and pions could provide a better fit to the observational data of this flare and also minimize the total power of the jet.

Model Assumptions
 • We adopt the standard picture of the one-zone hadronic radiation model, according to which a spherical emitting region of radius R_s containing a randomly oriented magnetic field of strength B_s is swirling with a Lorentz factor Γ . We assume that in this region relativistic protons and pions are injected with a Log Parabolic distribution

$$Q_{inj} = Q_{inj} \left(\frac{\gamma}{\gamma_{min}} \right)^{-\alpha} \exp\left(-\frac{\gamma}{\gamma_{max}}\right) \quad (1)$$

instead of the usual power-law.

• Gamma rays are produced via proton synchrotron as well as via radiative losses for photopion production (pp) collisions. Target photons from synchrotron emission of co-accelerated electrons are those produced in the same region.

• A flow is simulated from some low flux steady-state through a variation of proton and electron injection function in the form of a luminosity

$$L_{p,e}(\beta) = L_{p,e} (1 + \beta^2)^{-\beta^2} \quad (2)$$

where β is the Doppler factor of the source

$$\beta = \frac{\beta_s}{1 + \beta_s \cos \theta} \quad (3)$$

where θ is the angle with our line of sight and β_s is the orbital velocity of the emitting source.

• Motivated by the idea of [1] we try to fit the data of [2] and minimize the total jet power

$$P_j = 2\pi R_s^2 \Gamma^4 (U_p + U_e) \quad (4)$$

where U_p is the proton energy density and U_e is the magnetic energy density in the hadronic zone.

• We take into account absorption of gamma rays both on soft synchrotron photons inside the emitting region and on photons outside of it coming from the Broad Line Region. For the latter we assume that the Broad Line Region is spherical with radius $R_{BLR} = 27.15 \text{ pc}$ [3] and density

Numerical Results
 We calculate the time dependent spectra by using the numerical code of Mastichakidis & KIK [4]. The results, using the parameters from Tables 1 and 2 are shown in Figure 1, 2.

Table 1: Particle injection parameters derived from the numerical modeling (see equations (1), (2)).

Parameter	Value
γ_{min}	10^7
γ_{max}	10^{11}
β_s	0.5
n	1.4
α	1.2
α_p	0.6
α_e	0.6
β	100 Γ_{BLR}

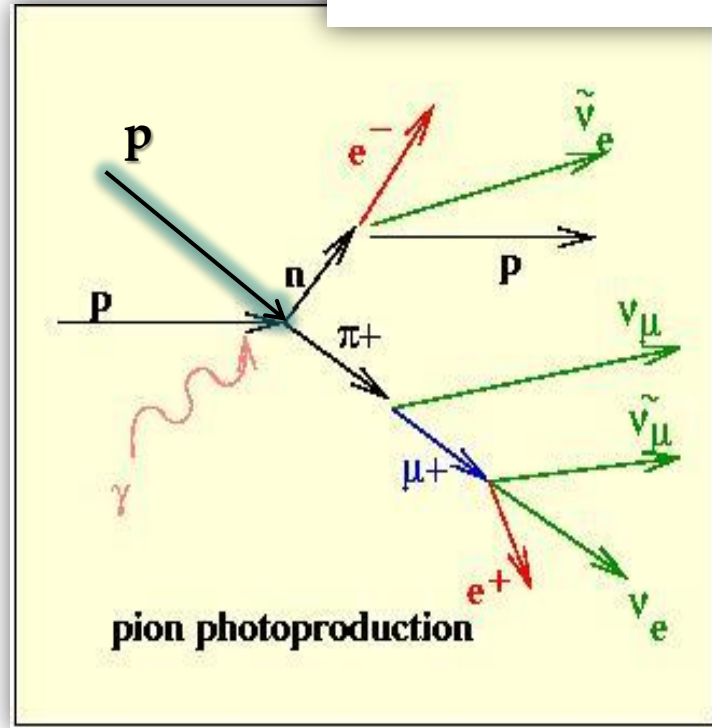
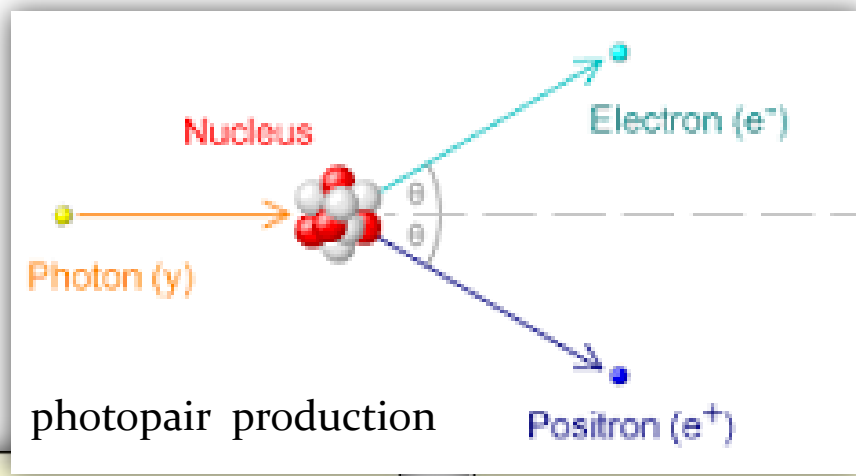
Table 2: Spectral fitting parameters determined after the injection rate Log Parabolic function distribution with the source. The value of total jet power was calculated from eq. (4).

Parameter	Value
Doppler factor β	300
Magnetic field B_s (G)	30
Source Radius R_s (pc)	$4.4 \cdot 10^{14}$
Proton energy density U_p (eV cm ⁻³)	$9 \cdot 10^{11}$
Magnetic energy density U_e (eV cm ⁻³)	$3.5 \cdot 10^{11}$
Total jet power P_j (erg s ⁻¹)	$3.8 \cdot 10^{47}$

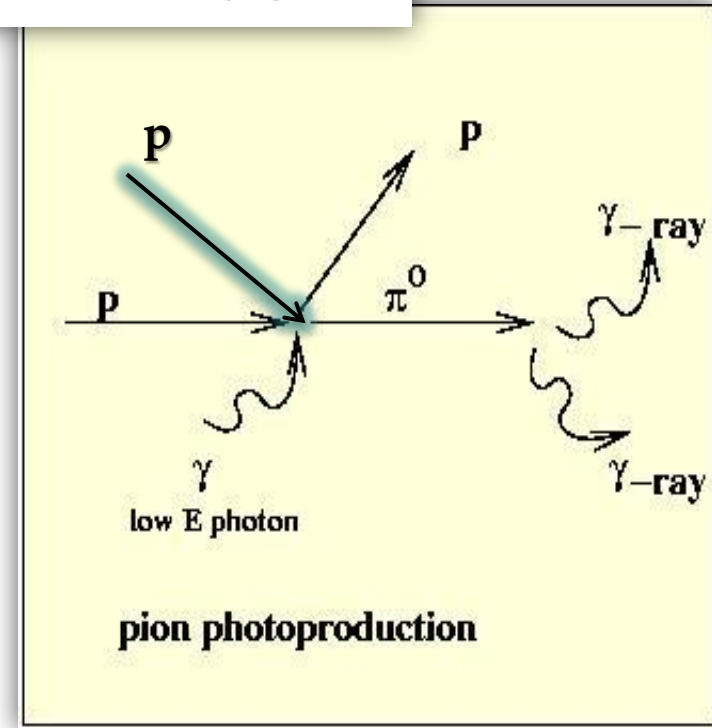
Conclusions
 We find that a Log Parabolic distribution is preferred in this case over a Power Law as it produces a better fit to the observational data and it minimizes the total jet power. The gamma rays are assumed to be produced on soft photons. Finally, the total jet power is calculated to be about one order of magnitude greater than the Hadronic luminosity of the source while the particle and magnetic fields are found to be in rough equipartition.

References
 [1] M. Abramson et al. *AJ*, 88, L20, 1984.
 [2] A. Cohen, P. Padovani, and G. Chiodella *MNRAS* 465, 2415, April 2017.
 [3] G. Chiodella and P. Padovani *MNRAS* 387, 3669, July 2008.
 [4] I. Florou, M. Petropoulou, K. Nisimos, A. Mastichakidis, and A. Mastichakidis *MNRAS* 467, 267, May 2017.

Figure 1: The top left plot shows the γ -ray lightcurve calculated from our model (red line). The blue points represent the observed data from Fermi LAT [1]. The other three plots show different components of the total emission: synchrotron (green), pp collisions (purple), and π^0 decay (blue). The total fit is shown in black.



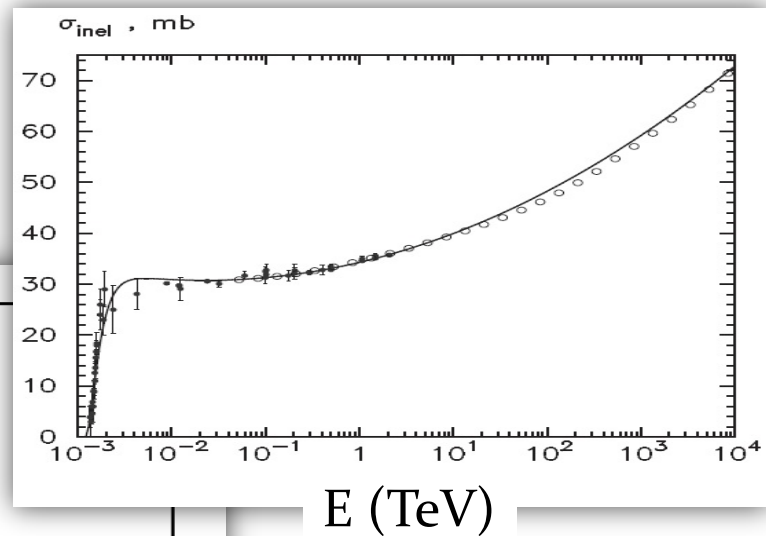
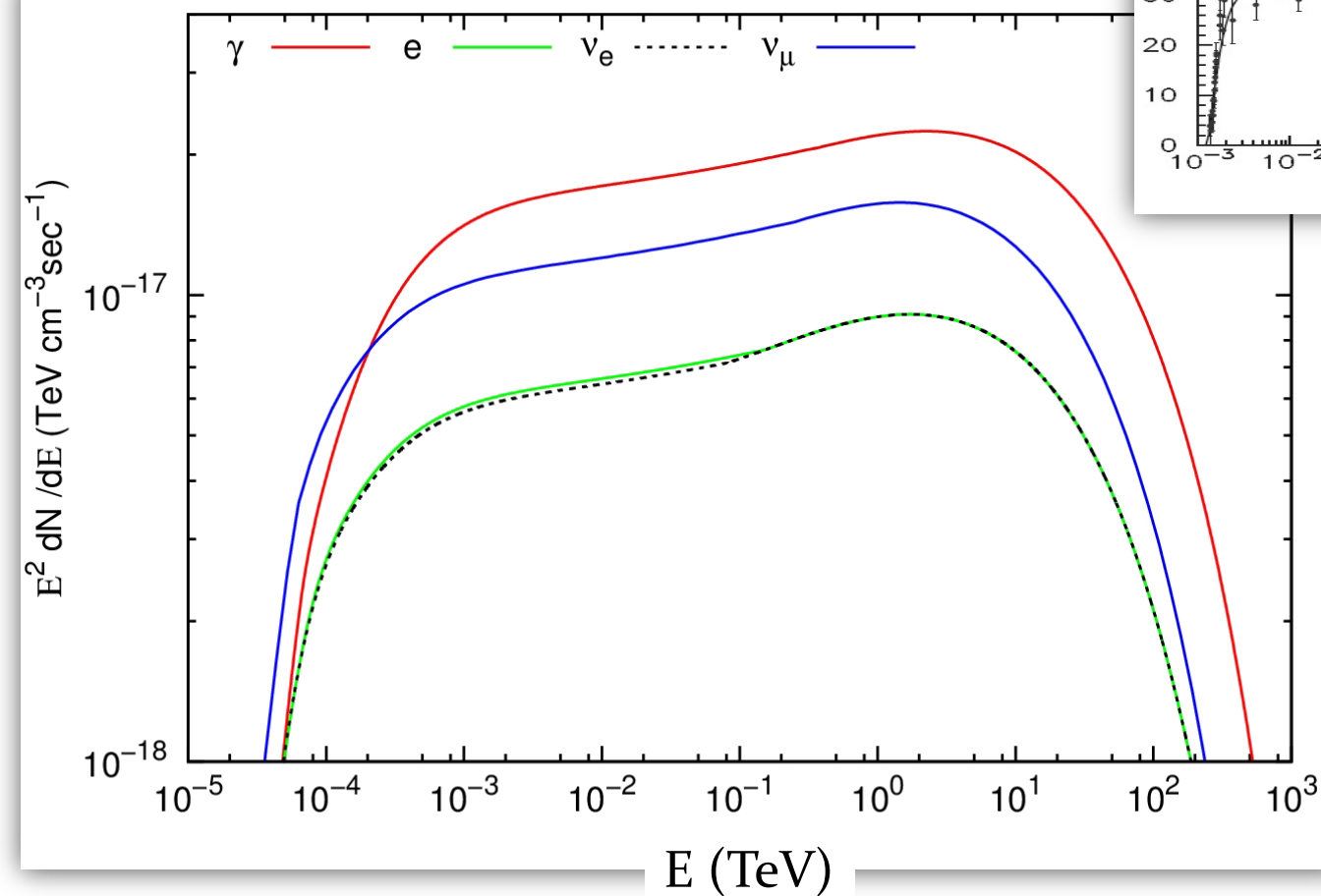
$2.6 \times 10^{-8} \text{ sec} \ \& \ 2.2 \times 10^{-6} \text{ sec}$



$9 \times 10^{-17} \text{ sec}$

Kelner et al., 2006

pp collisions



Protons:

The kinetic equation approach

$$\frac{\partial n_p}{\partial t} + L_p^{\text{BH}} + L_p^{\text{photonion}} + L_p^{\text{psyn}} + L_p^{pp} + \frac{n_p}{t_{p,\text{esc}}} = Q_p^{\text{inj}} + Q_p^{\text{photonion}}$$

Electrons:

$$\frac{\partial n_e}{\partial t} + L_e^{\text{syn}} + L_e^{\text{ics}} + L_e^{\text{ann}} + L_e^{\text{tpp}} + \frac{n_e}{t_{e,\text{esc}}} = Q_e^{\text{ext}} + Q_e^{\text{BH}} + Q_e^{\gamma\gamma} + Q_e^{\text{photonion}} + Q_e^{\text{tpp}} + Q_e^{pp}$$

Photons:

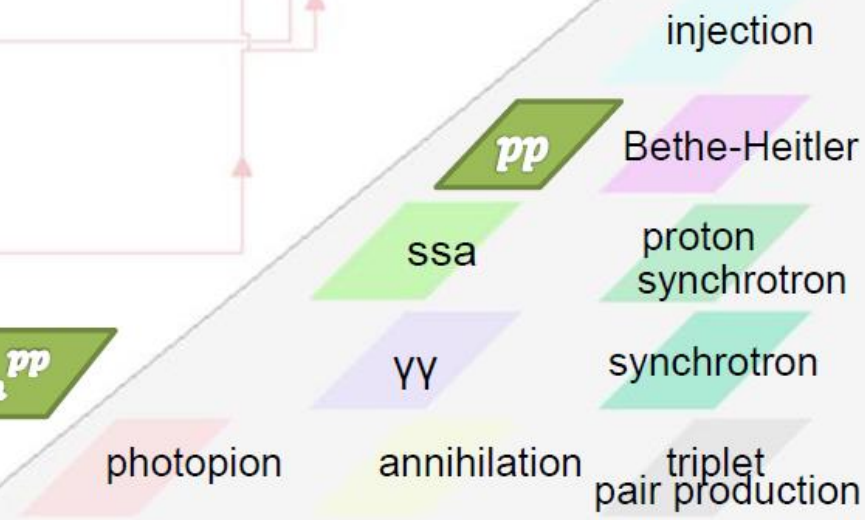
$$\frac{\partial n_\gamma}{\partial t} + \frac{n_\gamma}{t_{\gamma,\text{esc}}} + L_\gamma^{\gamma\gamma} + L_\gamma^{\text{ssa}} = Q_\gamma^{\text{syn}} + Q_\gamma^{\text{psyn}} + Q_\gamma^{\text{ics}} + Q_\gamma^{\text{ann}} + Q_\gamma^{\text{photonion}} + Q_\gamma^{pp}$$

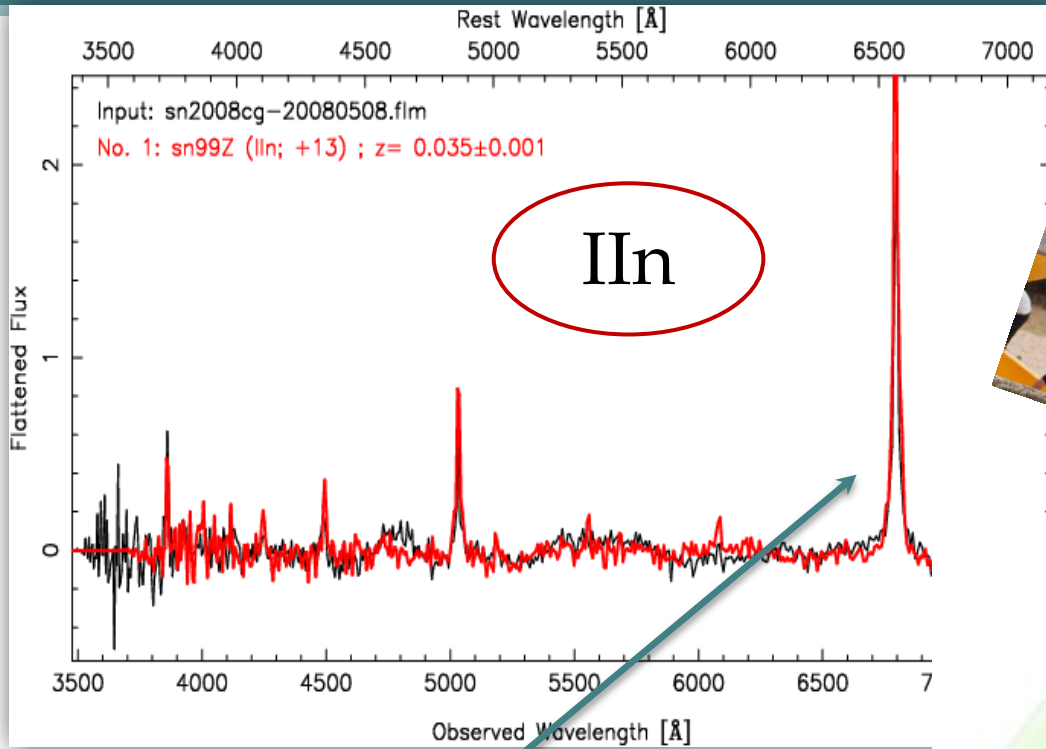
Neutrinos:

$$\frac{\partial n_\nu}{\partial t} + \frac{n_\nu}{t_{\text{esc}}} = Q_\nu^{\text{photonion}} + Q_\nu^{pp}$$

Neutrons:

$$\frac{\partial n_n}{\partial t} + L_n^{\text{photonion}} + \frac{n_n}{t_{\text{esc}}} = Q_n^{\text{photonion}} + Q_n^{pp}$$





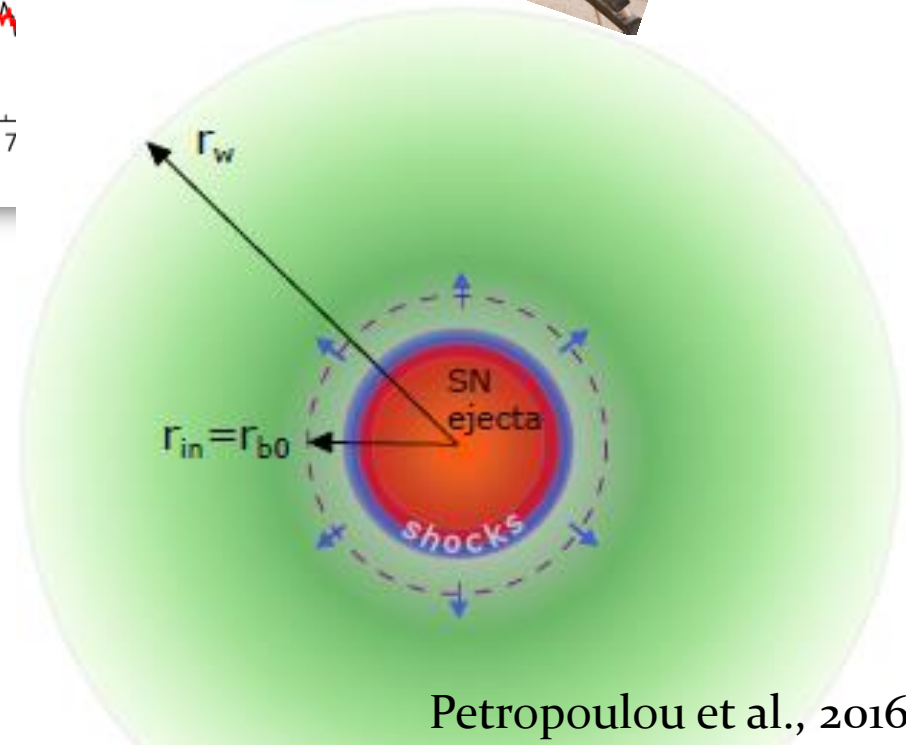
$$\dot{M} \geq 0.1 M_{\odot}/\text{yr}^{(1)}$$

$$v_w \sim 100 \text{ km/sec}^{(2)}$$

$$R_w \sim 10^{16} \text{ cm}^{(2)}$$

$$v_{sh} \sim 10000 \text{ km/sec}^{(3)}$$

$$n \sim 10^7 - 10^{12} \text{ cm}^{-3} \text{ }^{(2),(3)}$$

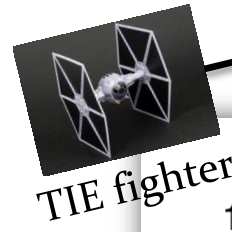
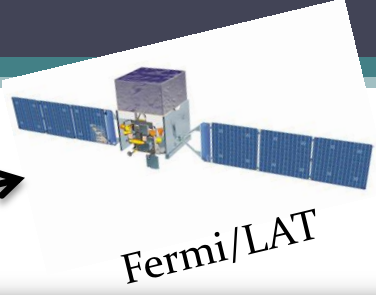


Petropoulou et al., 2016

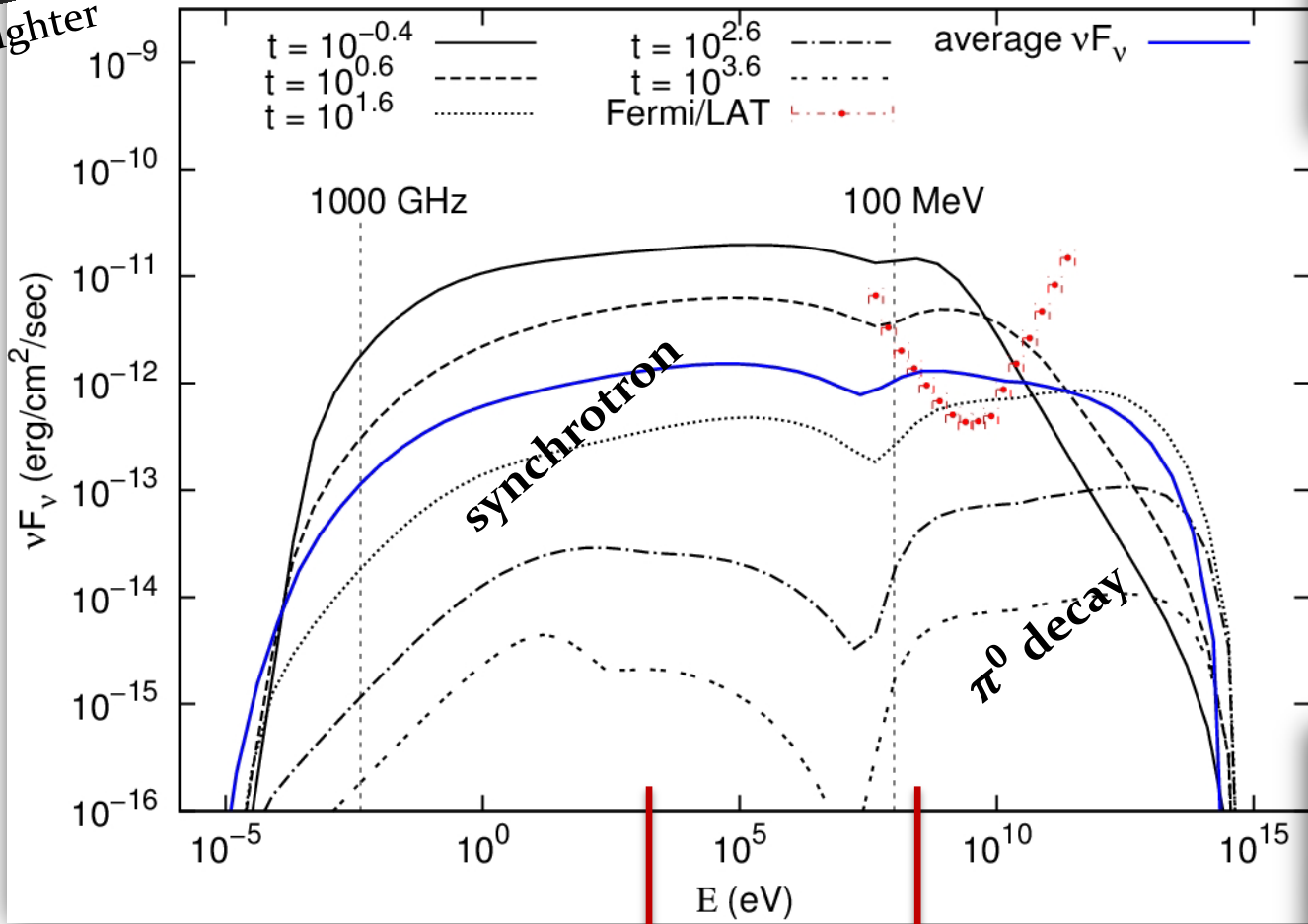
⁽¹⁾Smith et al., 2008, ⁽²⁾Fasia et al., 2000, ⁽³⁾Murase et al., 2014

Application to SN IIn

- $n(R) = n_0 \left(\frac{R_0}{R}\right)^2$
 - $n_0 \approx 2 \times 10^{12} \left(\frac{R_0}{10^{14} \text{ cm}}\right)^{-1} \left(\frac{v_s}{0.03 \text{ c}}\right)^{-1} \text{ cm}^{-3}$
- $B(R) = B_0 \left(\frac{R_0}{R}\right)^{a_B}$
 - $B_0 \approx 460 \left(\frac{\varepsilon_B}{0.01}\right)^{1/2} \left(\frac{v_s}{0.03 \text{ c}}\right)^{1/2} \left(\frac{R_0}{10^{14} \text{ cm}}\right)^{-1/2} \text{ G}$



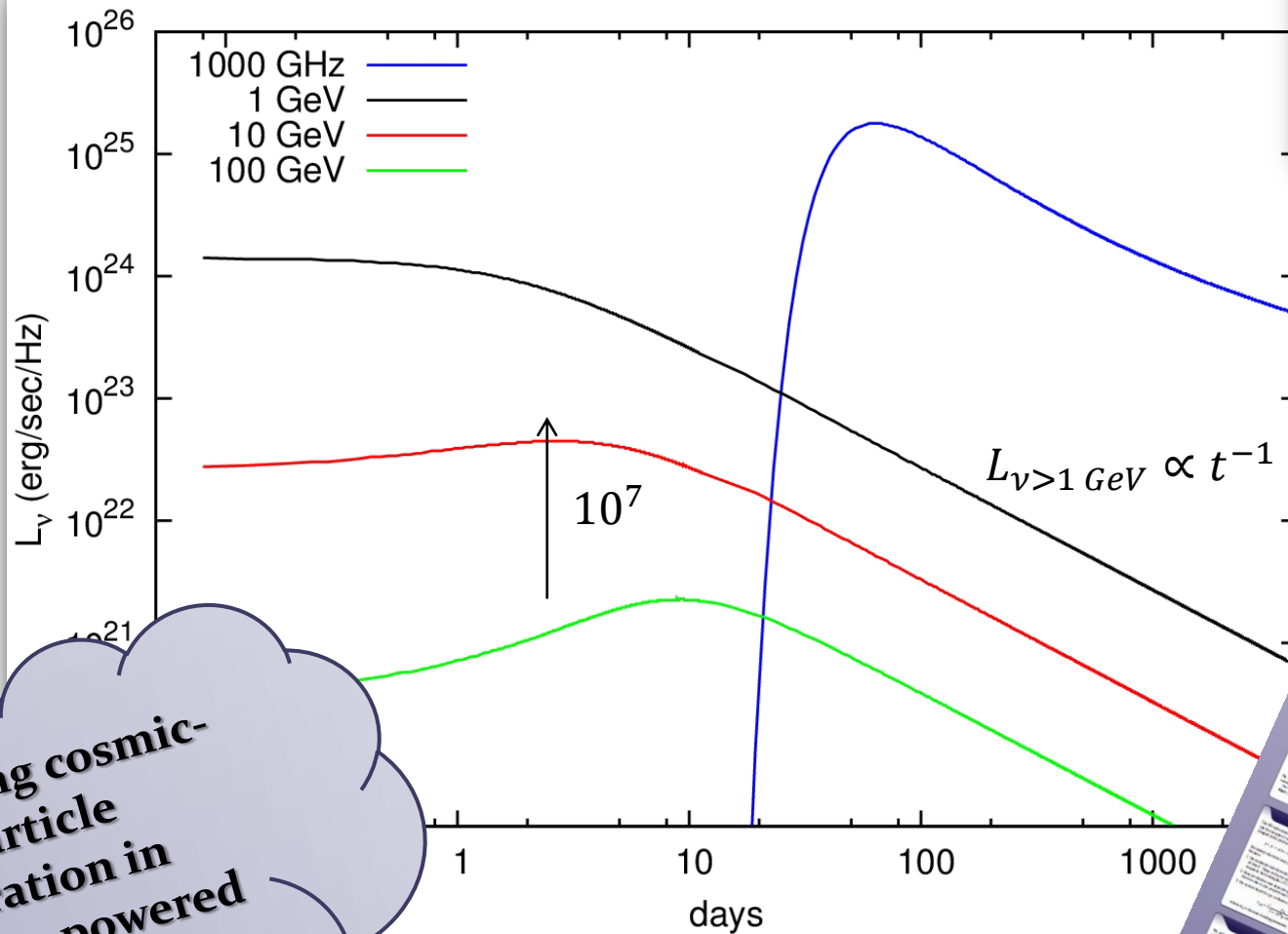
$B_0 = 46 \text{ G}$
 $\alpha_B = 1$
 $v \approx 0.03c$
 $d = 5 \text{ Mpc}$



~ 1 keV ~ 500 MeV

$R_0 = 10^{14} \text{ cm}$
 $p = 2$
 $L_p = 10^{41} \text{ erg/s}$
 $L_e = 0.01 L_p$
 $[t] = \text{days}$

Kantzas et al. 2016 | arXiv:1607.05847



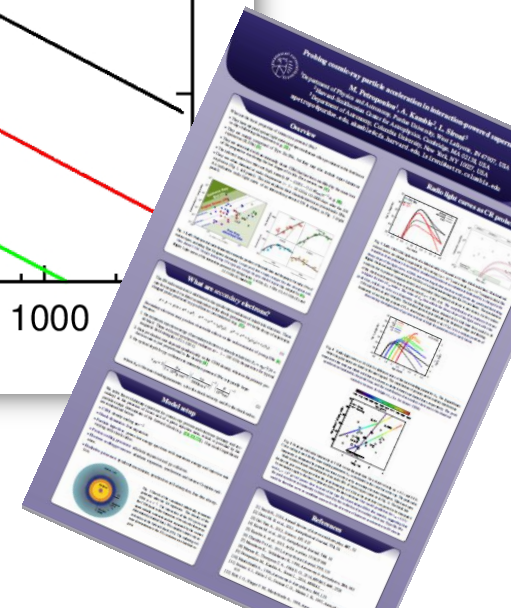
$$B_0 = 46 \text{ G}$$

$$\alpha_B = 1$$

$$v \approx 0.03c$$

$$T = 10^5 \text{ K}$$

Also: Probing cosmic-ray particle acceleration in interaction-powered supernovae, M. Petropoulou et al.



Take Home Note

- $pp \rightarrow \gamma\text{-rays, } e \text{ \& } \nu$
- photon – photon absorption
- $d < 10 \text{ Mpc}$ or $n_0 > 10^{10} \text{ cm}^{-3}$

+

- neutrinos

(e.g. Aartsen et al. 2015 &
Petropoulou et al.,2017)

