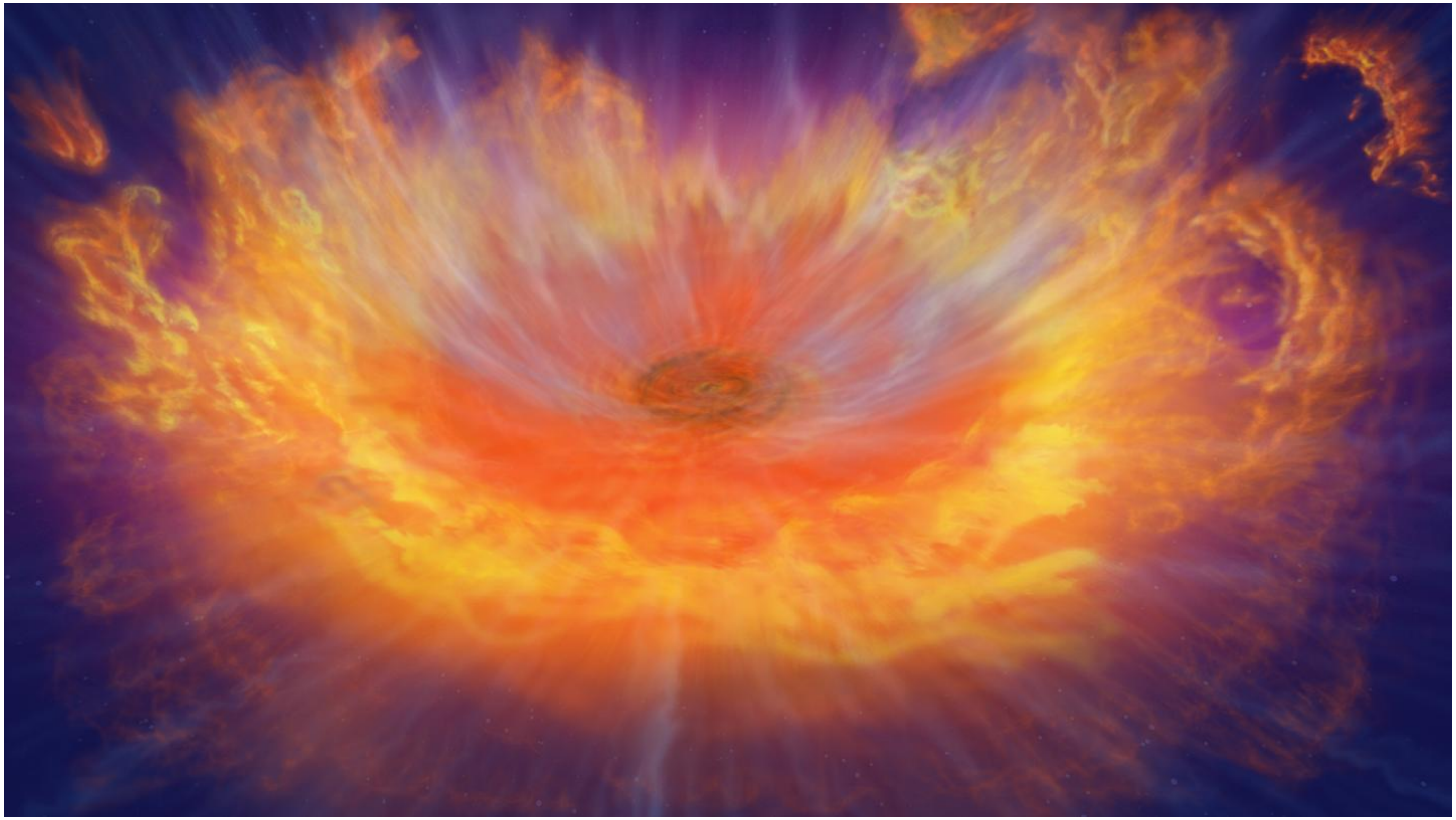
Multi-Messenger Astronomy Journal Club - IAP/APC

High energy neutrino from neutron stars merger : Kilo-Novae emissions



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Neutron star mergers are promising events for multi-messenger astronomy

Highly energetic $L \approx 10^{52}\ \mathrm{erg.s}^{-1}$

Compact object precursor

Full of baryons

→

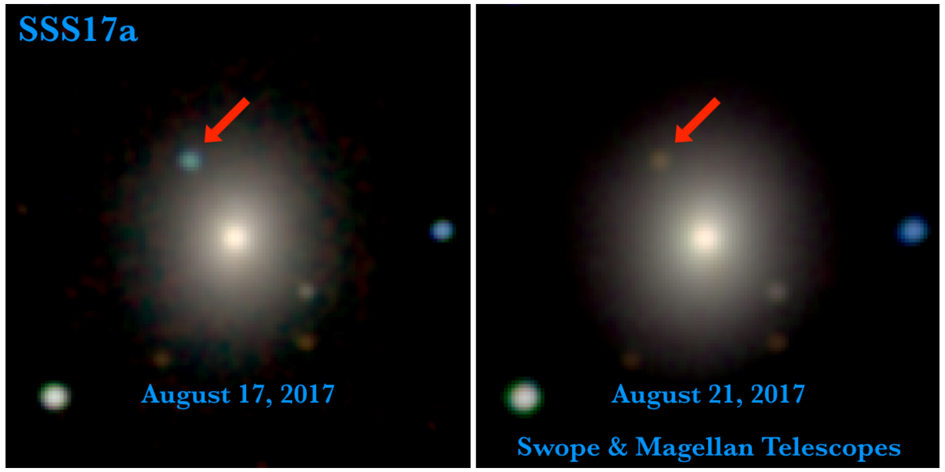
Photons (EM)

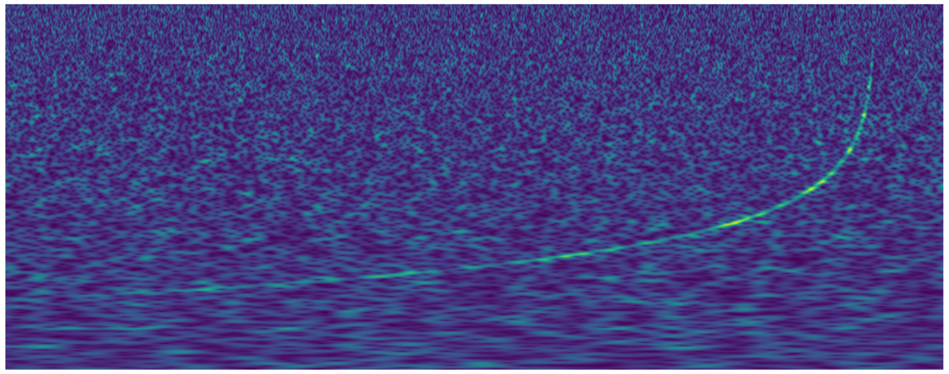
Gravitational waves (GW)

Ultra High Energy Cosmic-rays (UHECR)

Neutrinos

The GW170817/GRB170817 event





First multi-messenger observation consistent with binary neutron star merger and sGRB

EM ✓

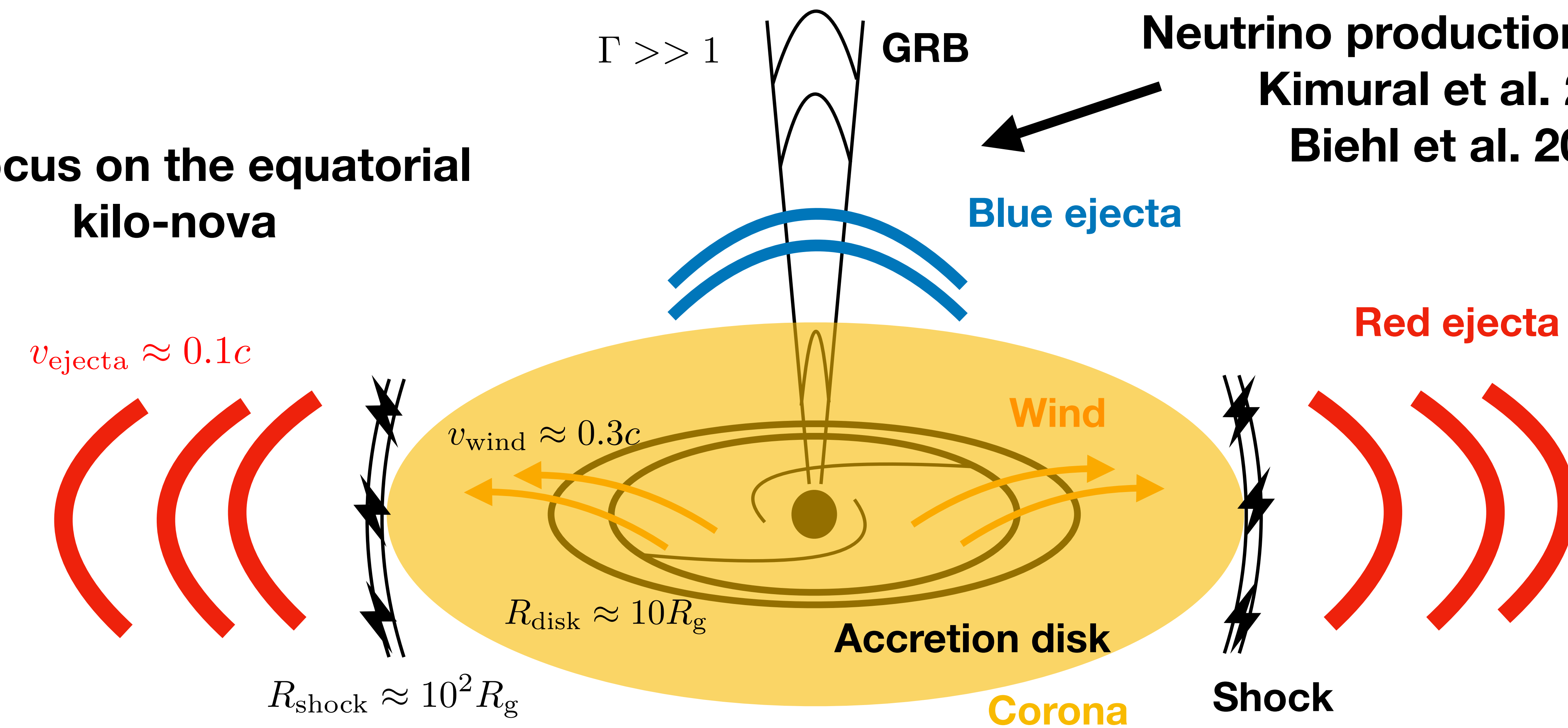
GW ✓

What about UHECR and Neutrinos ?

How to produce high energy neutrino in neutron stars mergers ?

We focus on the equatorial kilo-nova

Neutrino production from jet:
Kimural et al. 2017
Biehl et al. 2018



Remnant central black-hole → Accretion disk → Corona → Shocks

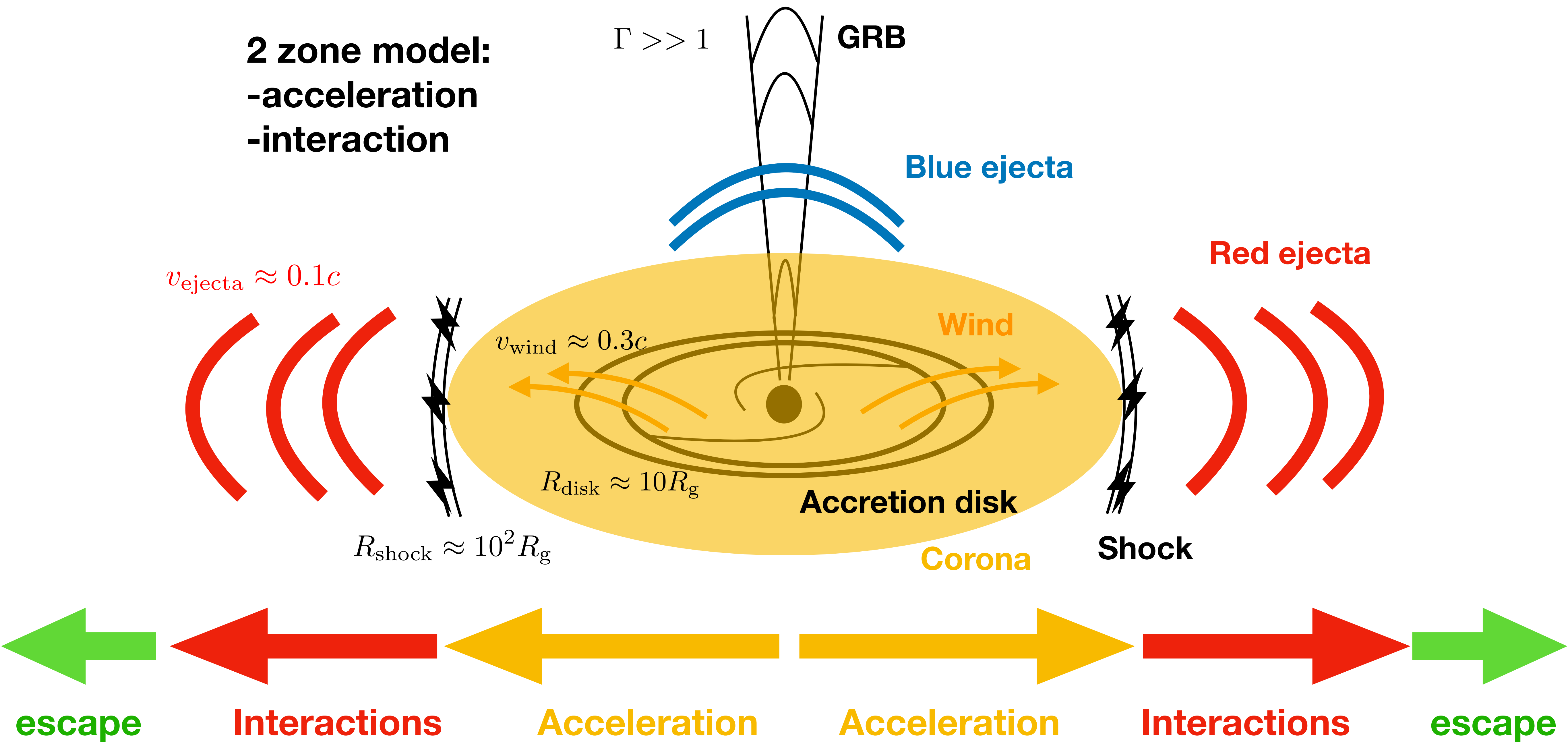
Particles Acceleration

Tidal ejecta from the neutron stars → r-processes → Photon background

→ Hadronic background

Particles Interactions

How to produce High energy neutrino in neutron stars mergers ?



Processes for acceleration ? → **Fermi in shocks, stochastic processes, …**

Processes for interactions ? → **Photonuclear/Hadronic** → **Kilo-Novae model**

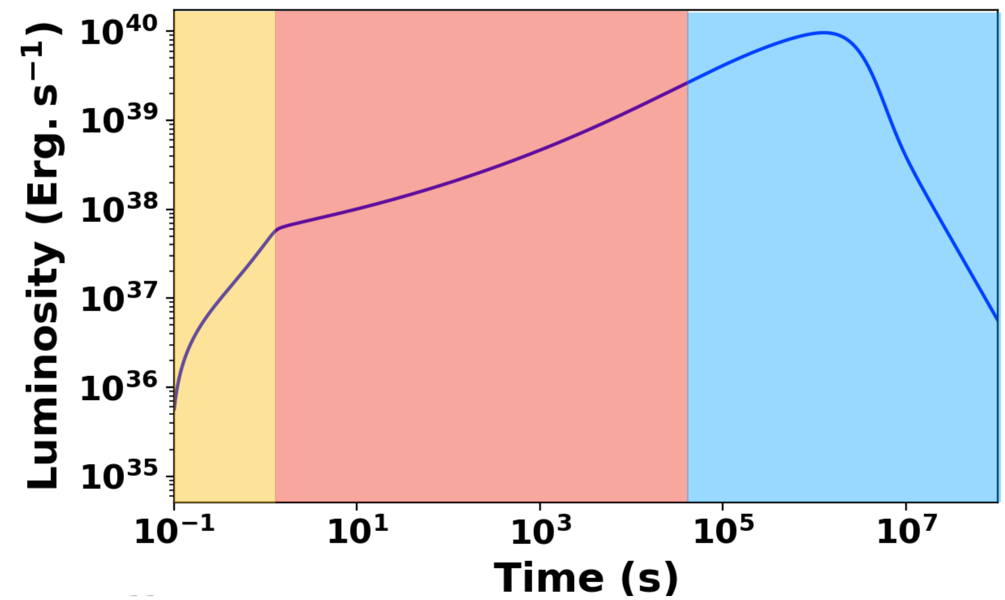
Thermodynamical equilibrium *Metzger et al. 2011*

$$\frac{d\mathcal{E}}{dt} = -\frac{\mathcal{E}}{R}\frac{dR}{dt} - \frac{\mathcal{E}}{t_{\rm esc}} + \dot{Q}_{\rm r} + \dot{Q}_{\rm fb}$$

Mechanical losses | Radiative losses | Radioactive source | Fall-back source

$$t_{\rm esc} \approx (\tau + 1)\frac{R}{c} = \left(\frac{3M\kappa}{4\pi R^2} + 1\right)\frac{R}{c}$$

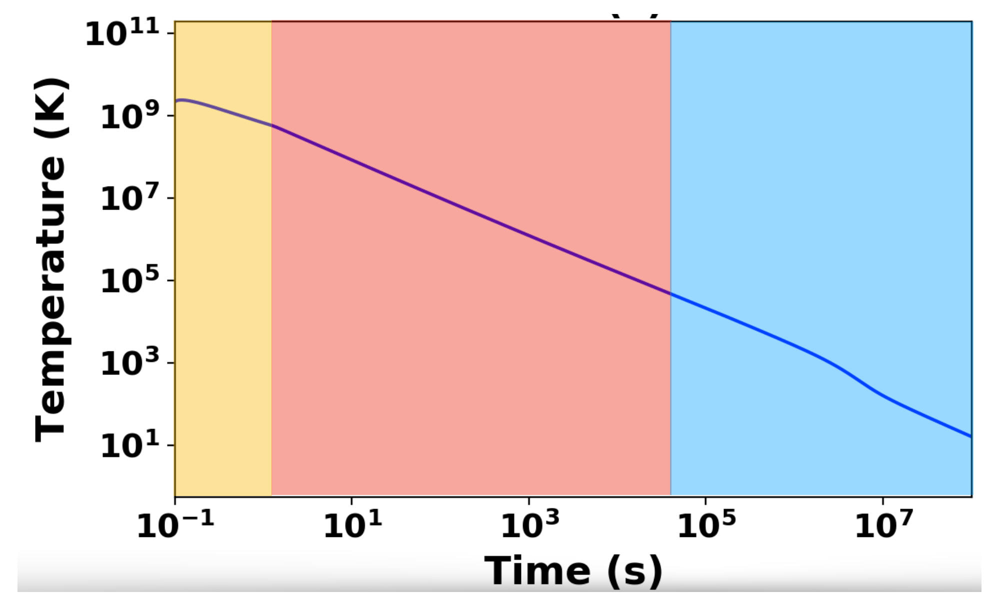
Opacity (lanthanides)



Fall-back

Mass accretion rate

$$\dot{Q}_{\rm fb} = \epsilon_{\rm fb}\dot{M}_{\rm fb}c^2$$
$$= 2\times 10^{51}\ {\rm Erg.s^{-1}}\ \epsilon_{\rm fb,0.1}\dot{M}_{\rm fb,-3}(0.1{\rm s})\, t_{0.1}^{-5/3}$$



Nuclear reaction *Barnes et al. 2016, M. R. Drout et al, 2017*

$$\dot{Q}_{\rm r} = M\, X_{\rm r}\, \dot{e}_{\rm r}(t)$$

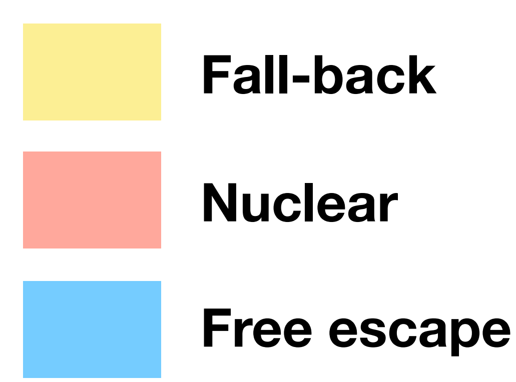
Nuclear mass energy

Mass fraction of lanthanides

$$\dot{e}_{\rm r}(t) = 4\times 10^{18}\ {\rm Erg.s^{-1}.g^{-1}}\ \epsilon_{\rm th}(t)\, f(t; t_0, \sigma)$$

$$t_0 = 1.3 \text{ and } \sigma = 0.11$$

Thermal efficiency



How particles propagates and interacts in the kilo-nova ?

Cosmic-ray interactions in the kilo-nova:

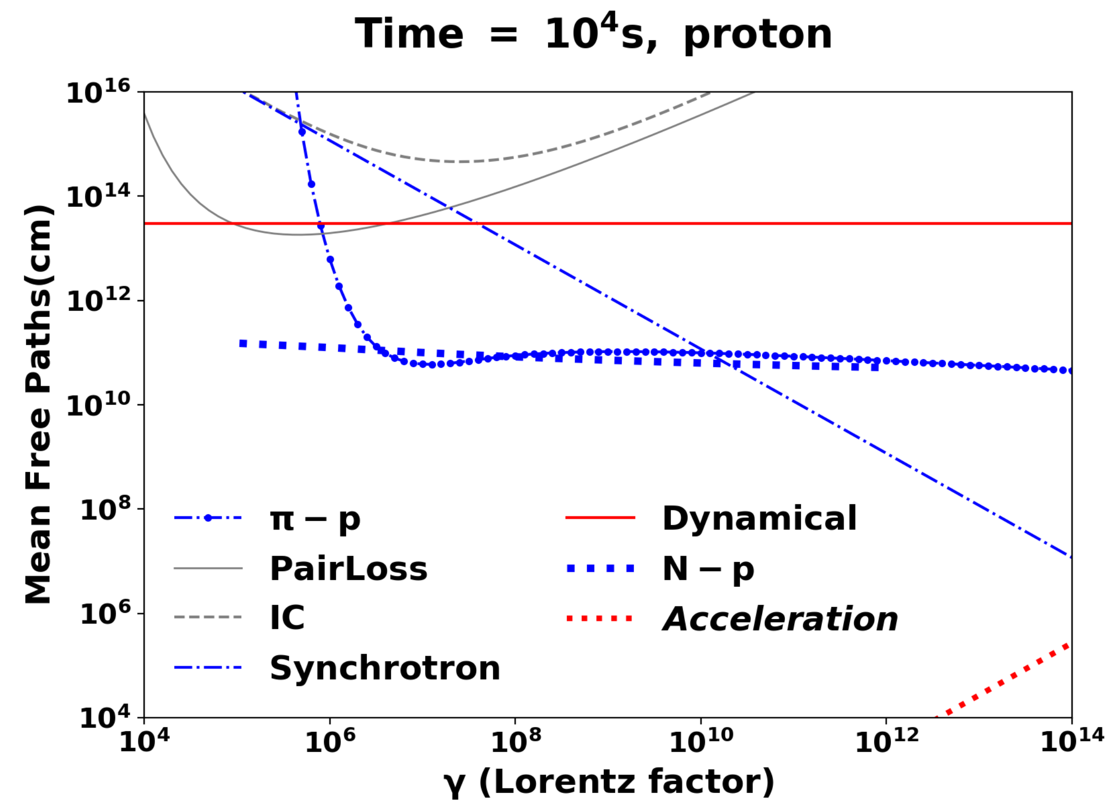
- Photo-nuclear
- Hadronic
- Synchrotron
- Inverse Compton
- Pair creation

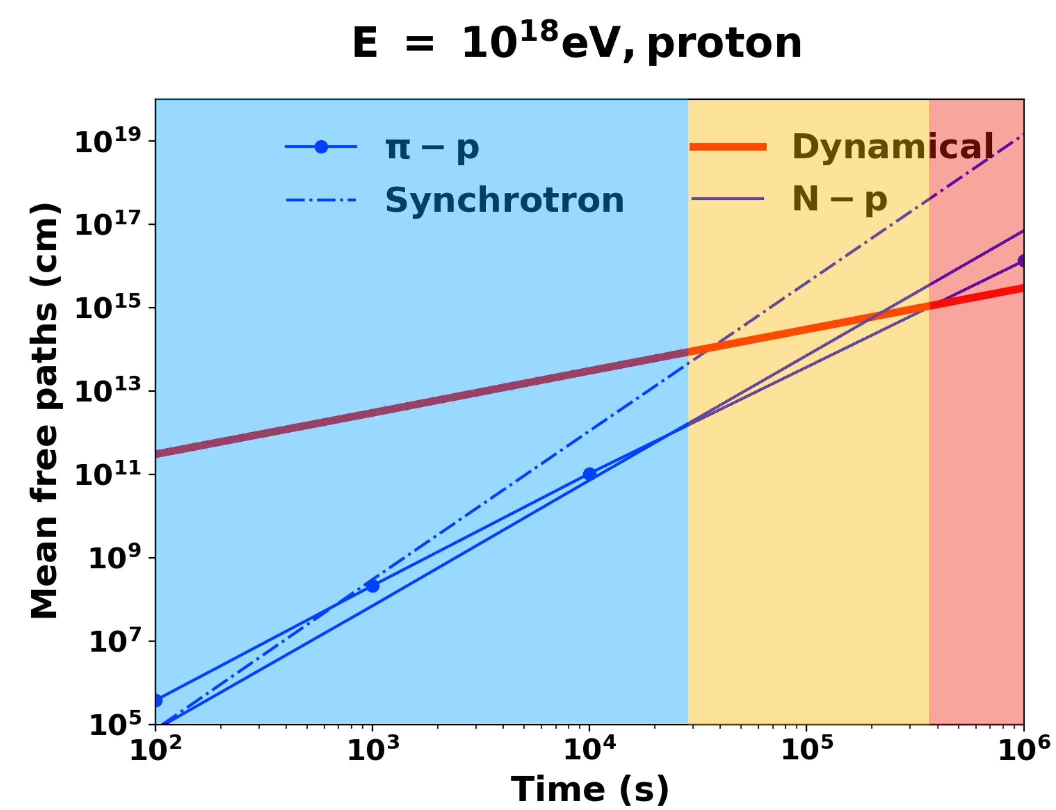
Neutrino production

Energy losses

UHECR production efficiency :
Background Density (escape rate 👍)
VS
Dynamical Expansion (lower energy 👎)

Neutrino production efficiency :
Interactions Efficiencies (👍)
VS
Mesons Cascades (suppression factor 👎)



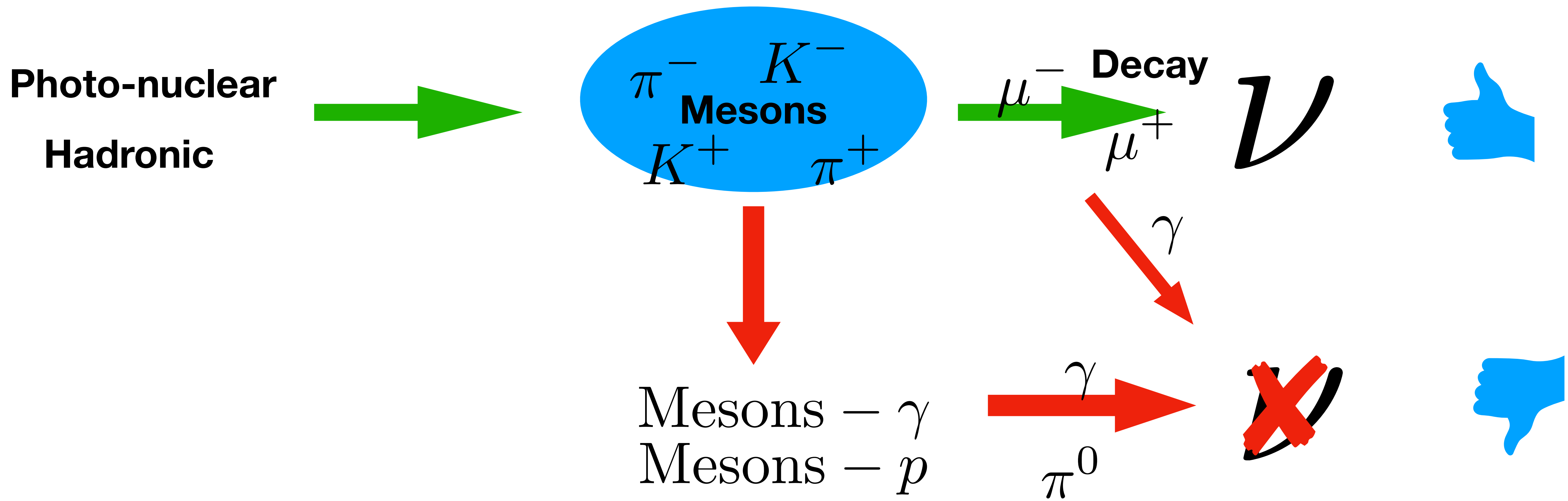


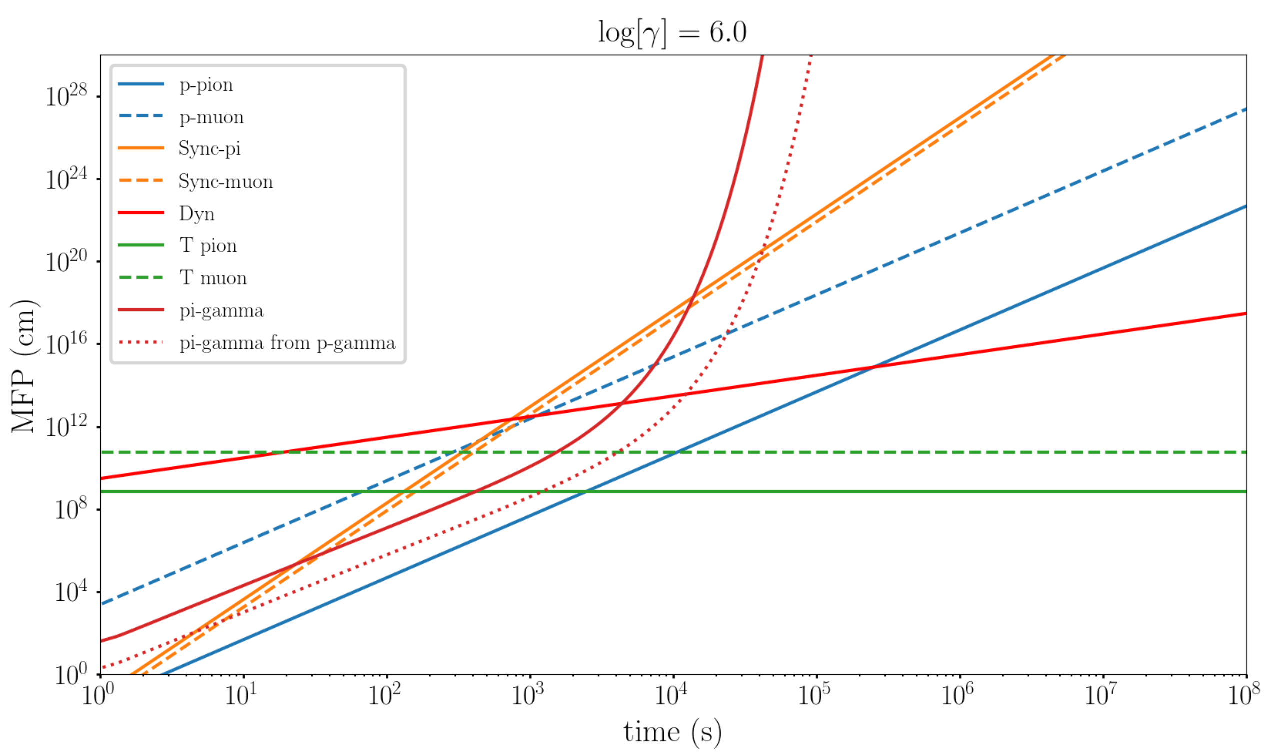
proton-proton dominant

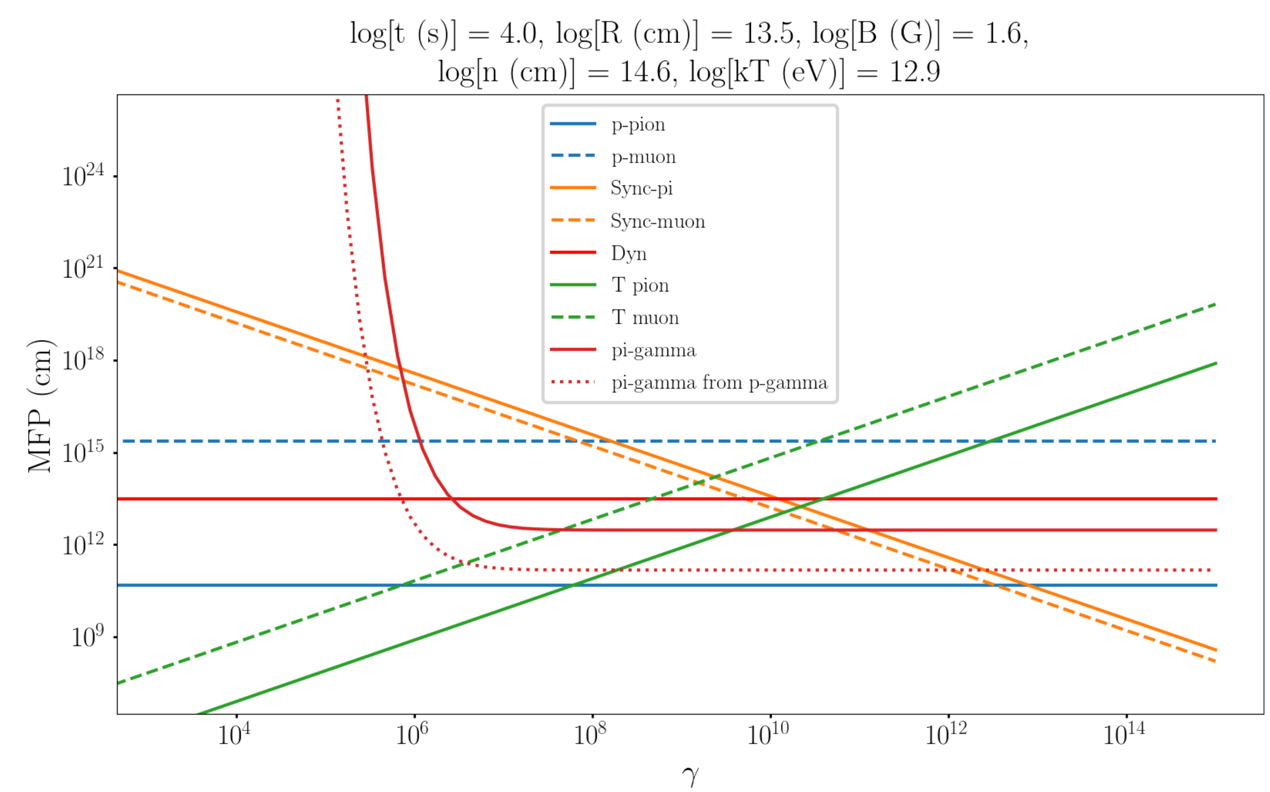
Photomeson dominant

No interactions

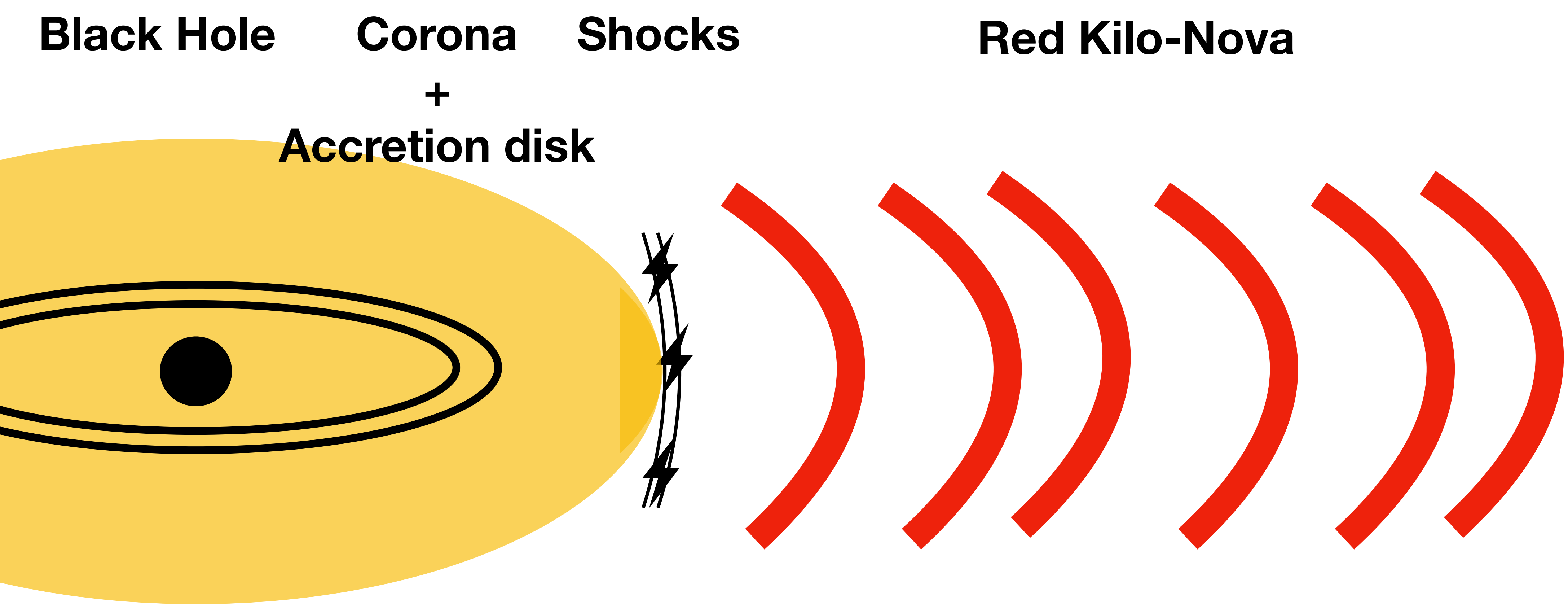
Secondary mesons interactions: neutrino suppression







High energy neutrino emissions : summary



Particle acceleration

Interactions

Shocks acceleration

Stochastic acceleration

Photo-nuclear

Hadronic

Synchrotron
Inverse Compton
Pair-creation

Meson cascades

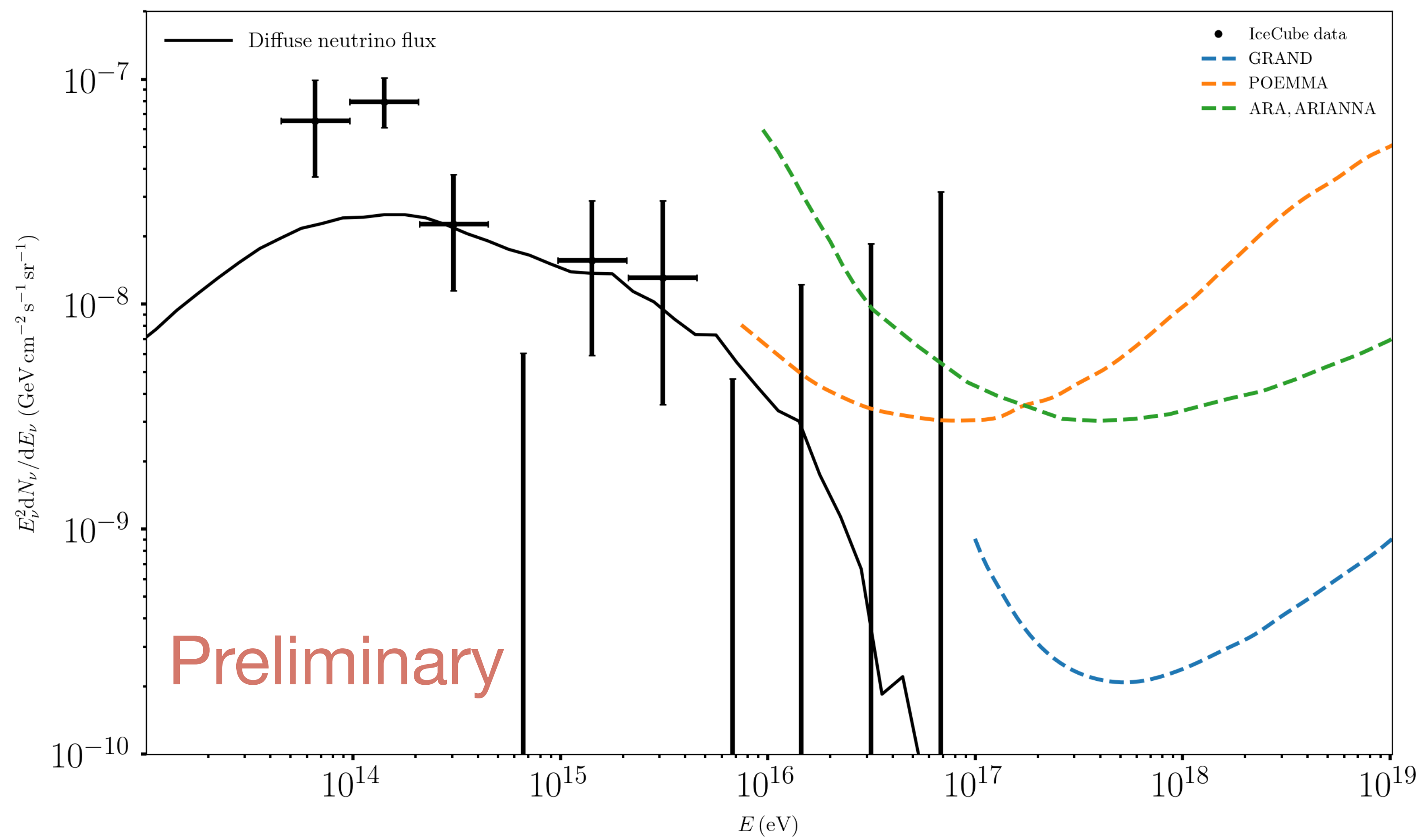
Neutrinos

What is the diffuse neutrino flux from the neutron stars mergers population ?

Neutron star merger population following star formation rate (Beacon and Hopkins 2006)

Injection composition:
10% protons, 20% He, 30% C, 50% Si

Cosmic-rays counter part:
≈10% of observed flux



Neutrino diffuse flux from neutron star mergers is in IceCube energy range

Could explain neutrino flux measured by IceCube ?

IceCube detected fluxes can constrain UHECR production/interactions in NS mergers

Meson production

$$p + \gamma \rightarrow \pi^{\pm}$$
$$p + p \rightarrow \pi^{\pm}$$

Meson cascades

$$\pi^{\pm} + \gamma \rightarrow \pi^{\pm} + \gamma$$
$$\pi^{\pm} + p \rightarrow \pi^{0} + n$$

$$\pi^{\pm} \rightarrow \mu^{\pm} + \bar{\nu_{\mu}}$$

$$\mu^{\pm} + p \rightarrow \mu^{\pm} + p$$
$$\mu^{\pm} + \gamma \rightarrow \mu^{\pm} + \gamma$$

Lepton cascades

$$\mu^{\pm} \rightarrow e^{\pm} + \bar{\nu_{e}}$$

Neutrino production