

A multi-wavelength and multi-messenger spectral model for astrophysical jets

S. Drappeau¹, S. Markoff²,

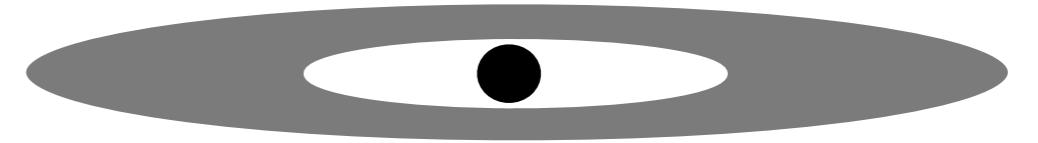
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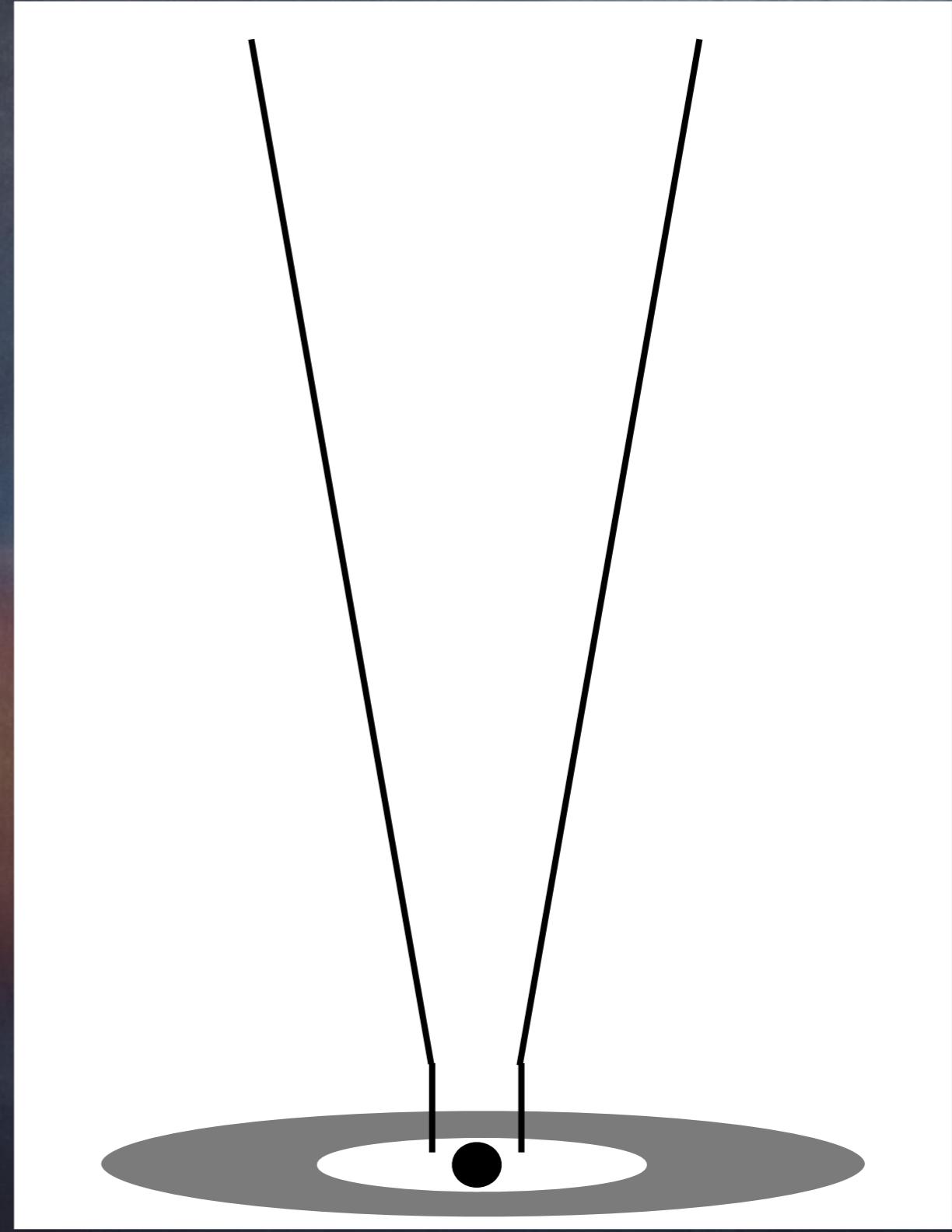
Design of the model

Lepto-hadronic jet model



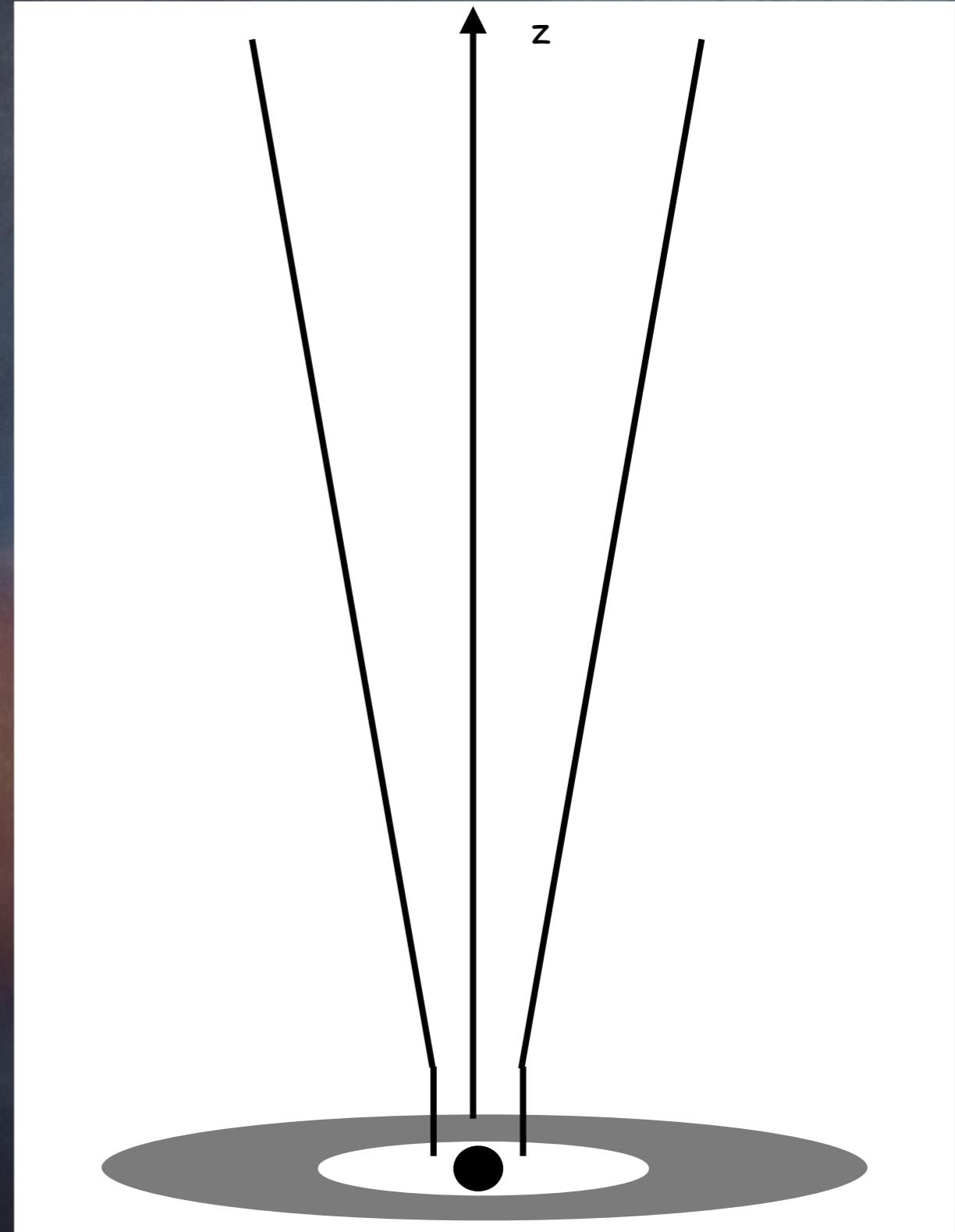
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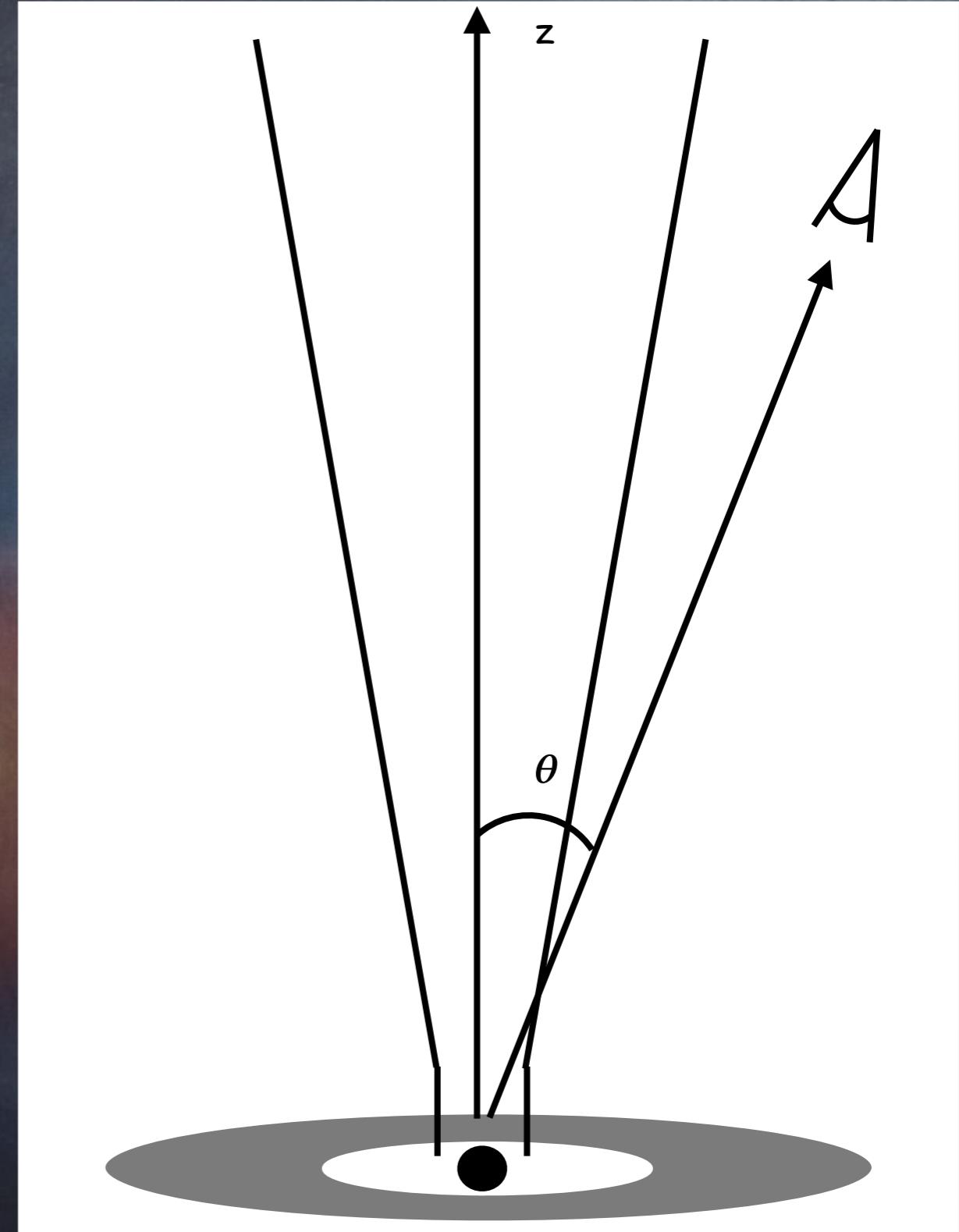
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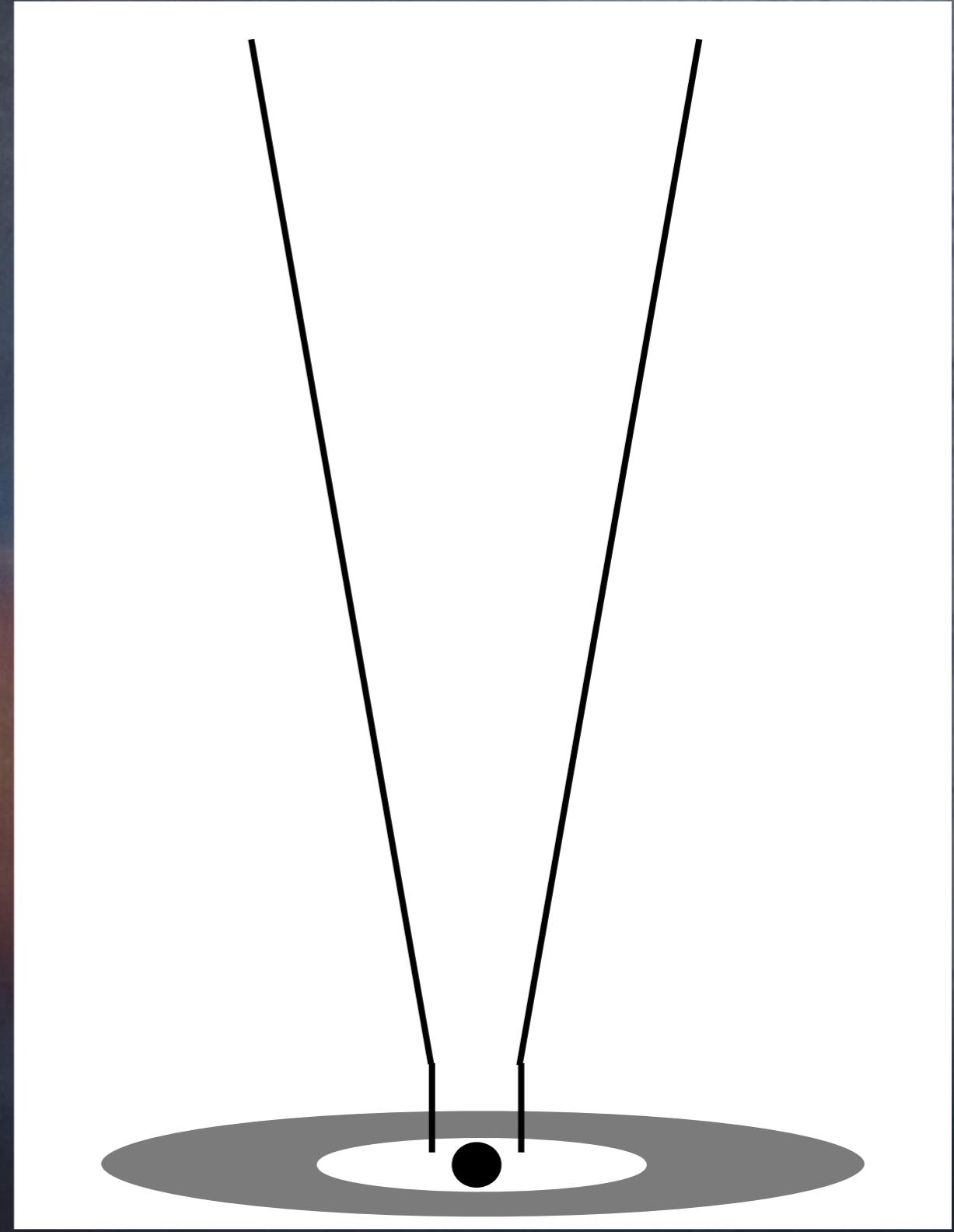
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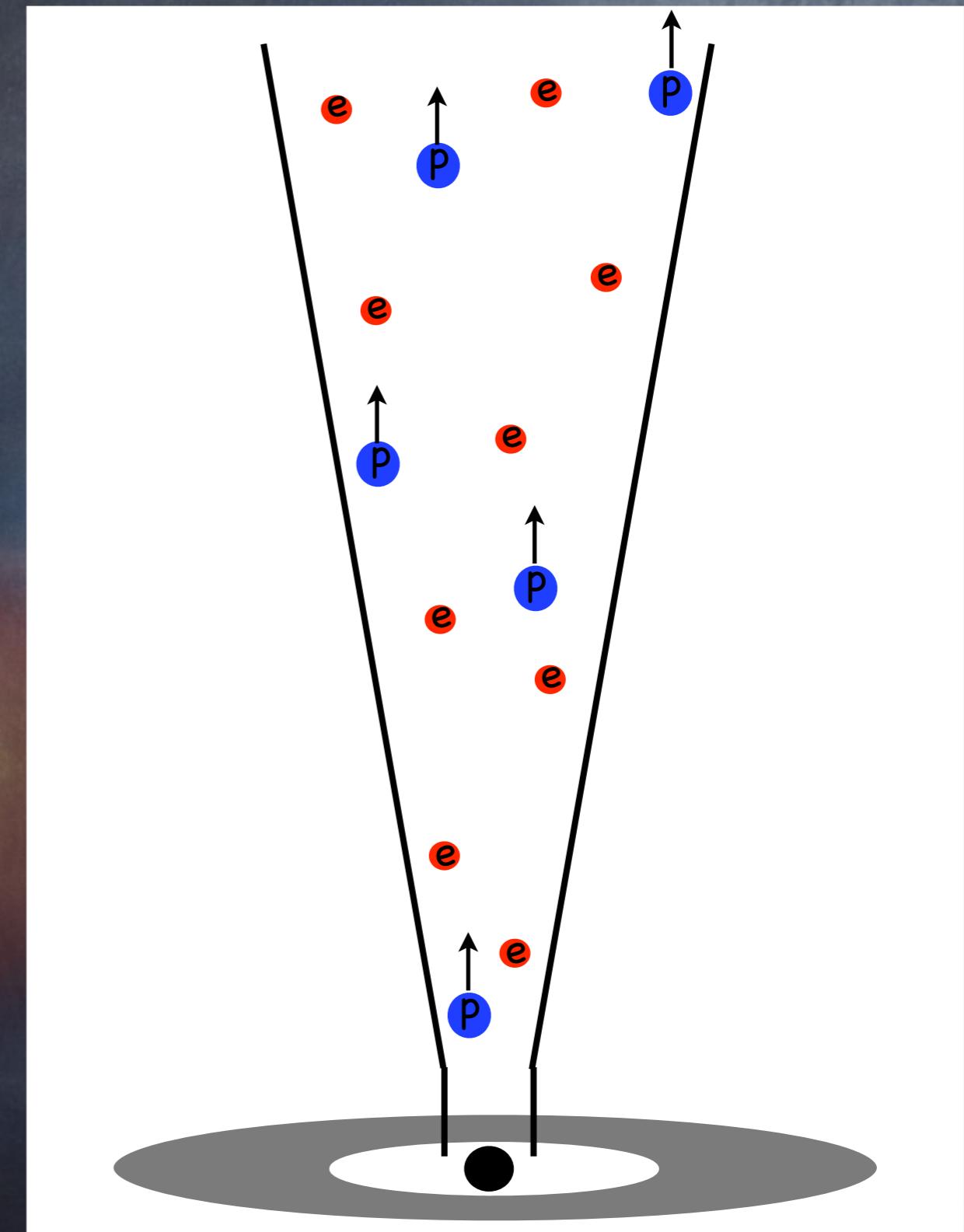
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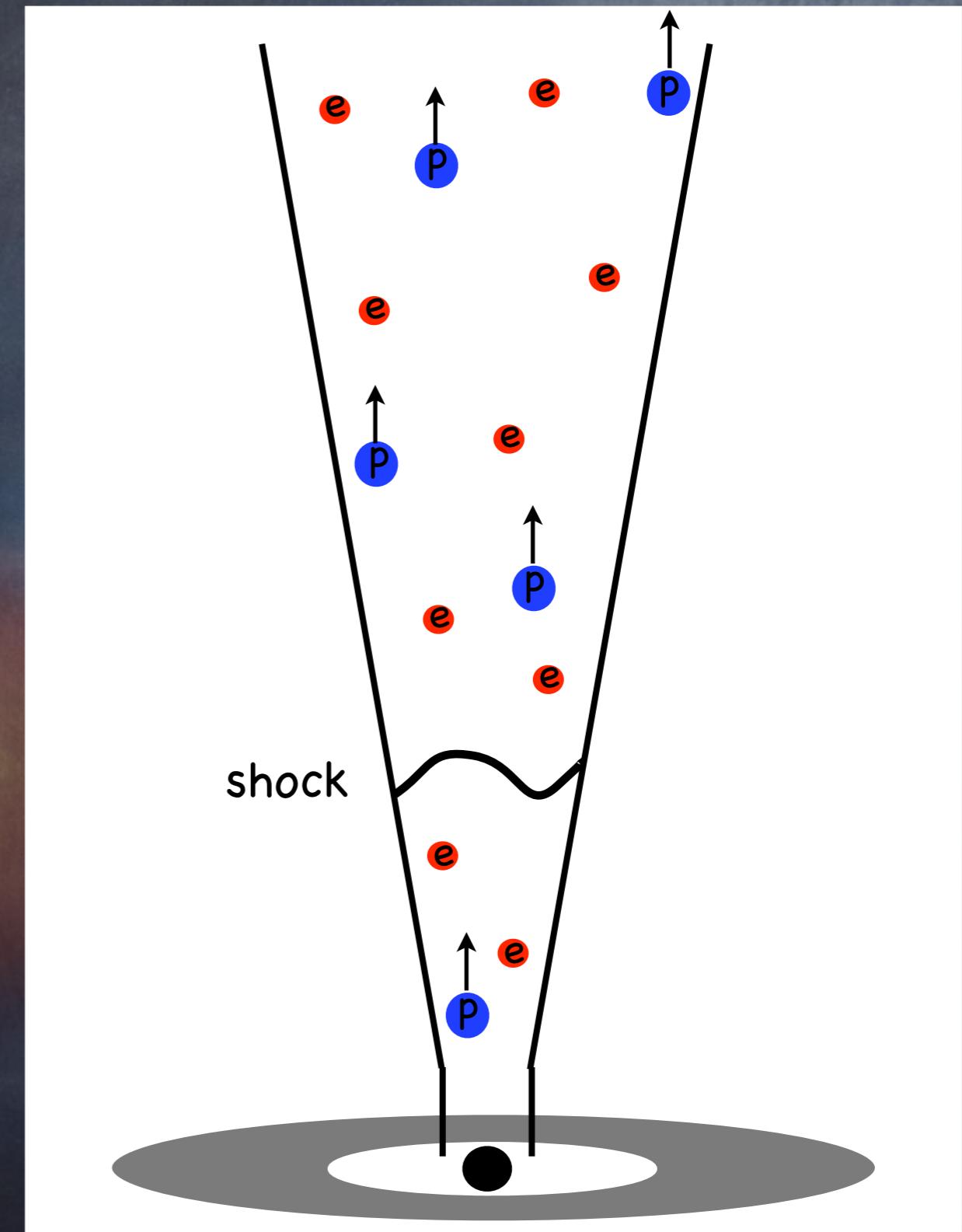
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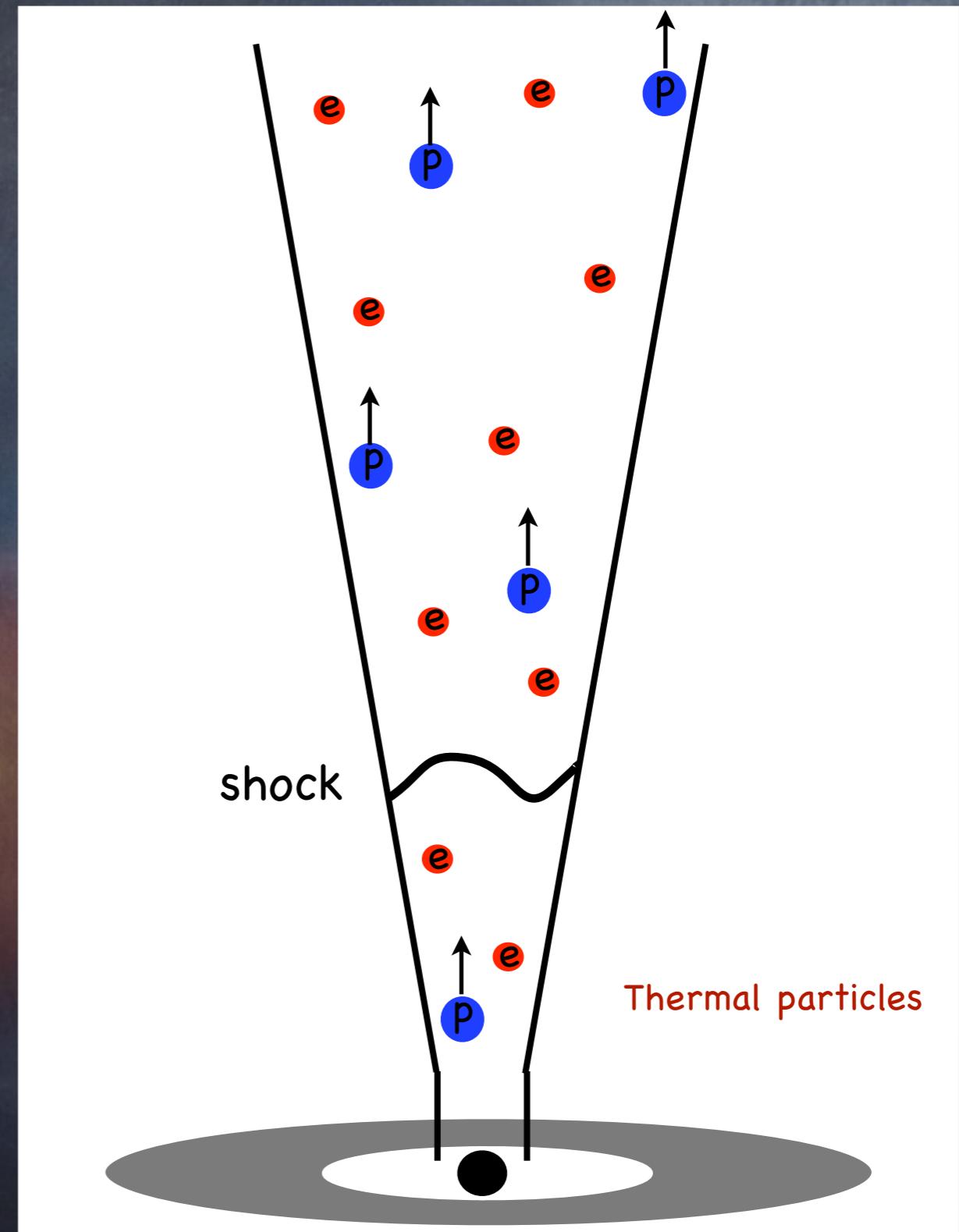
Lepto-hadronic jet model



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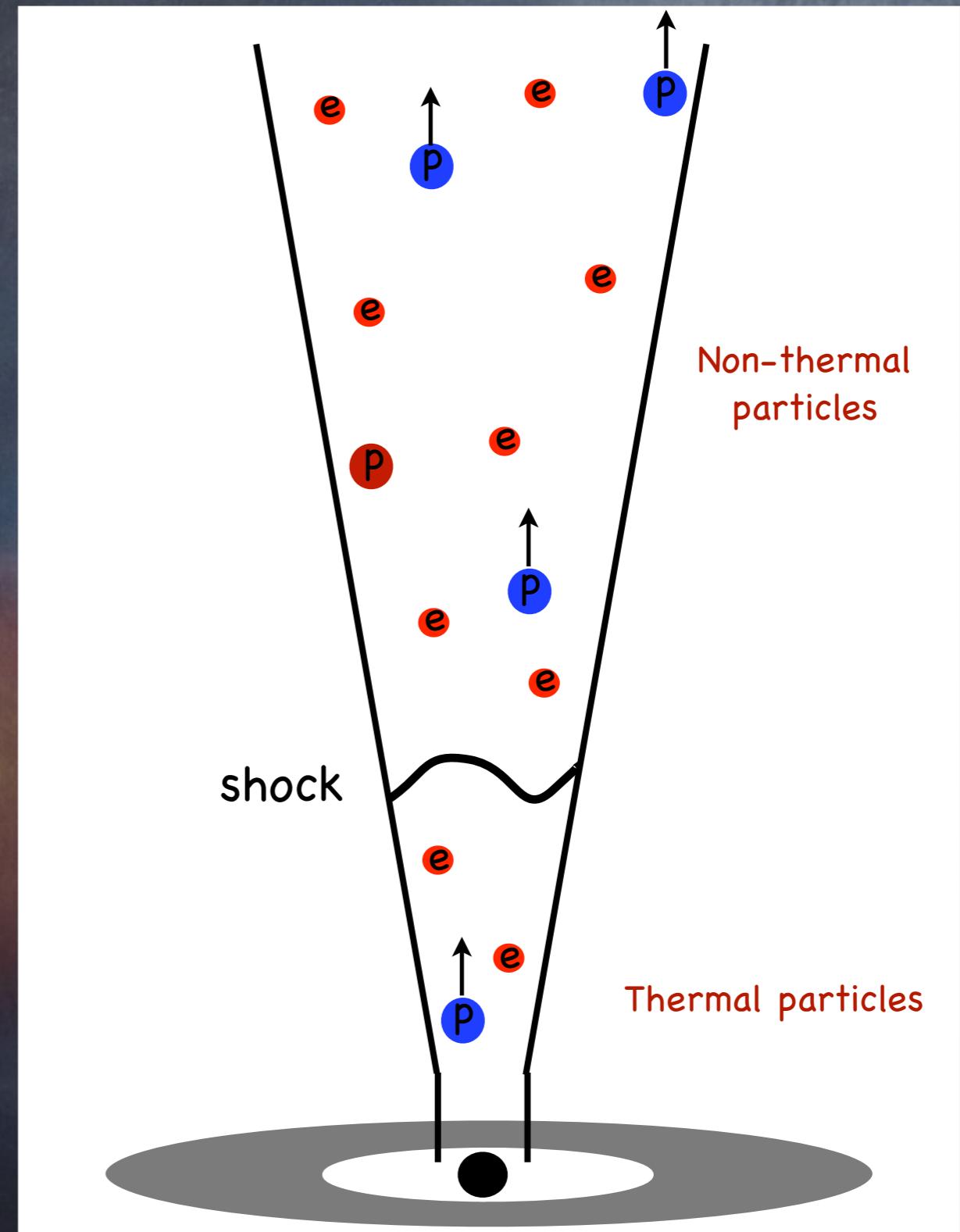
- Maxwellian distribution below shock



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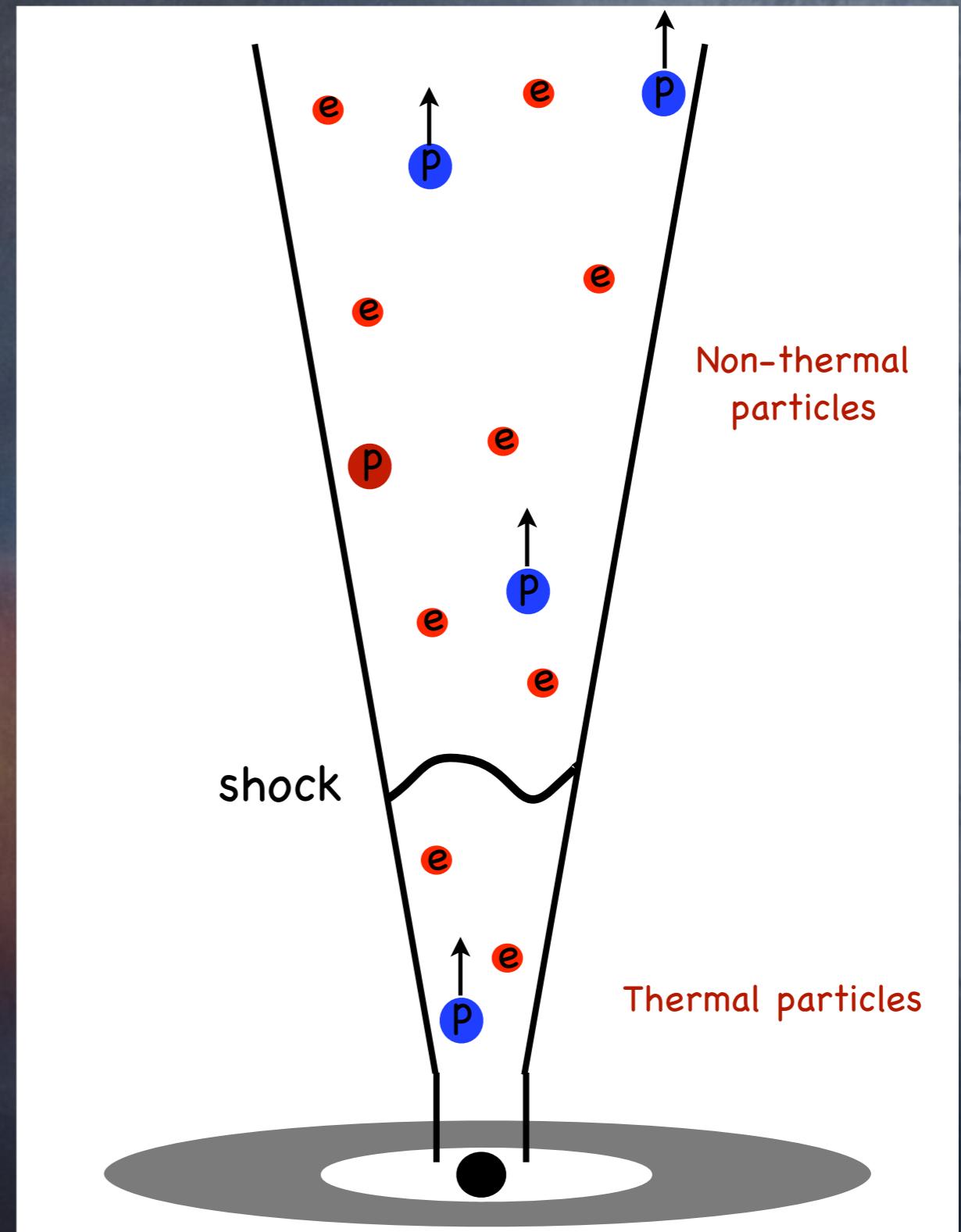
- Maxwellian distribution below shock
- Maxwellian + power-law distribution above shock



Design of the model

Lepto-hadronic jet model

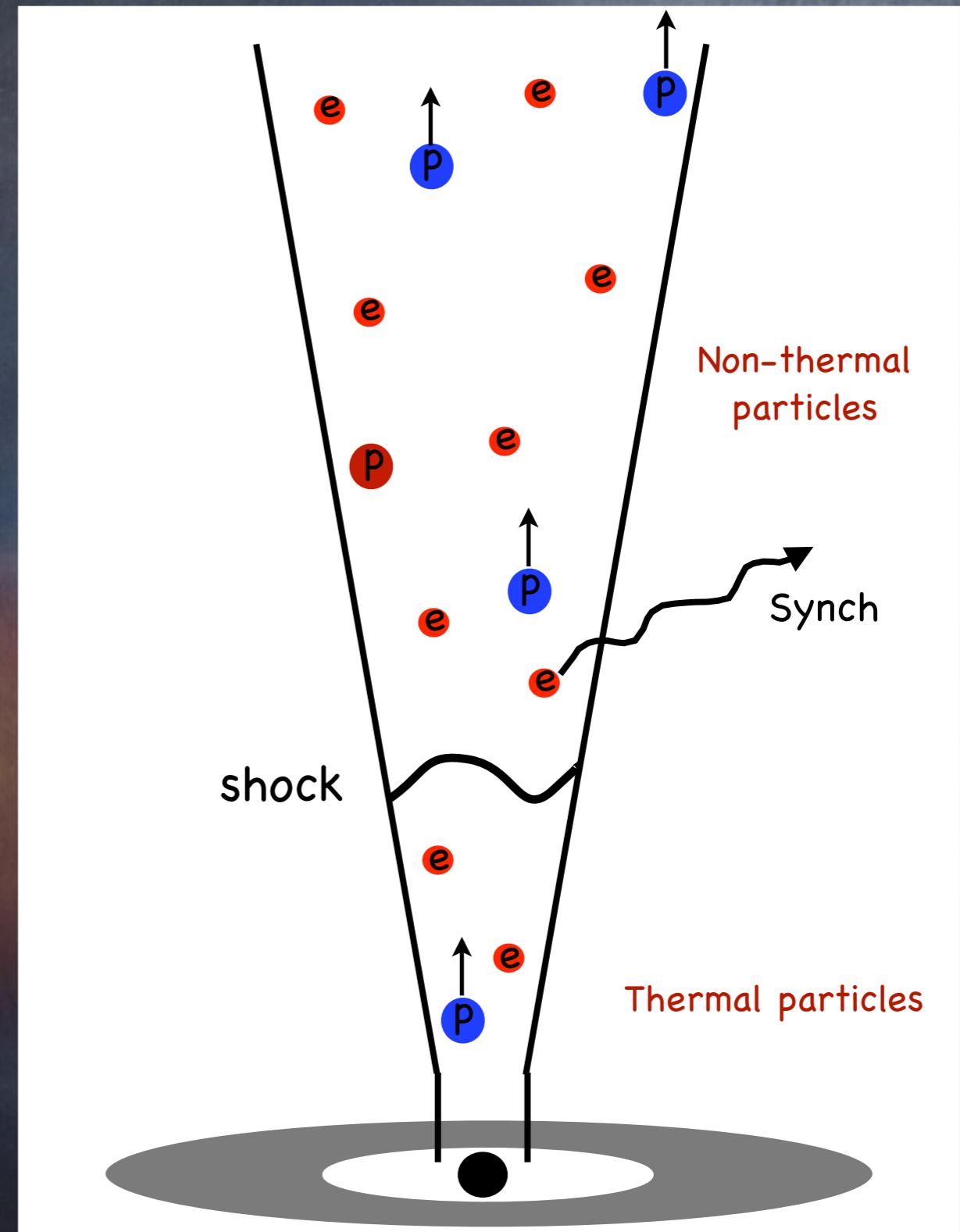
- Maxwellian distribution below shock
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- Leptonic radiative processes includes:



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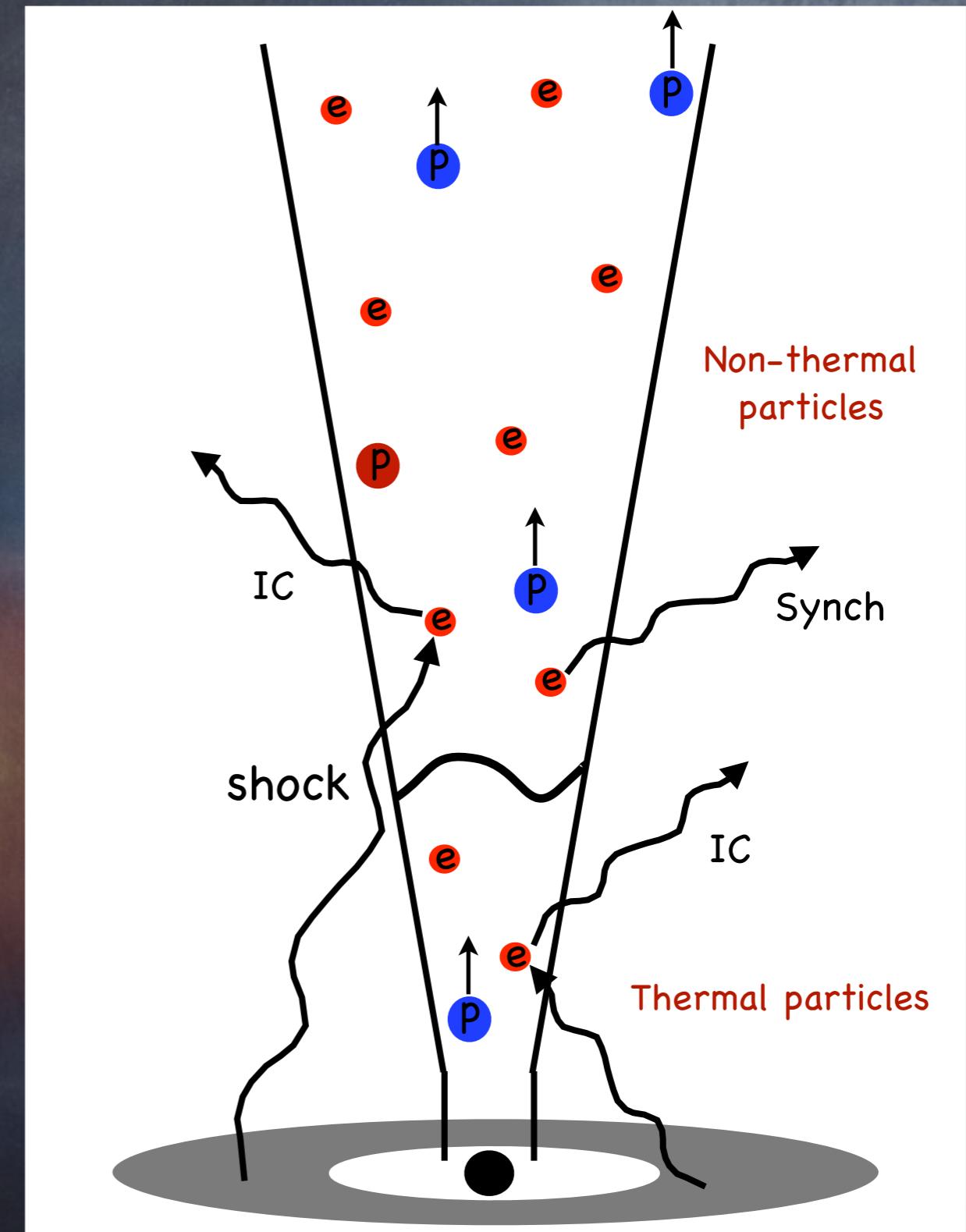
- Maxwellian distribution below shock
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- Leptonic radiative processes includes:
 - > synchrotron self-absorbed



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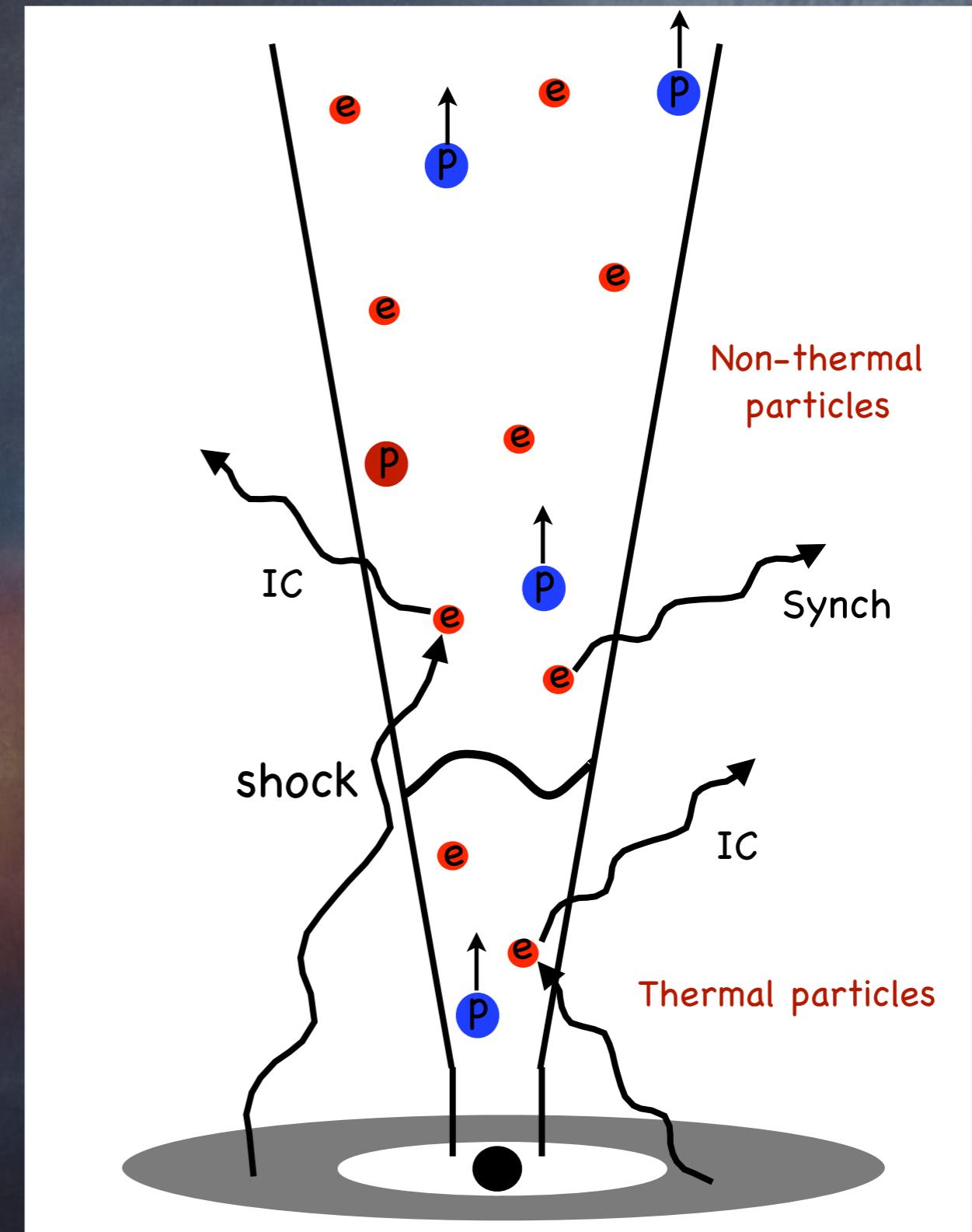
Lepto-hadronic jet model

- Maxwellian distribution below shock
- Maxwellian + power-law distribution above shock
- Leptonic radiative processes includes:
 - > synchrotron self-absorbed
 - > synchrotron self- & external- Compton



Design of the model

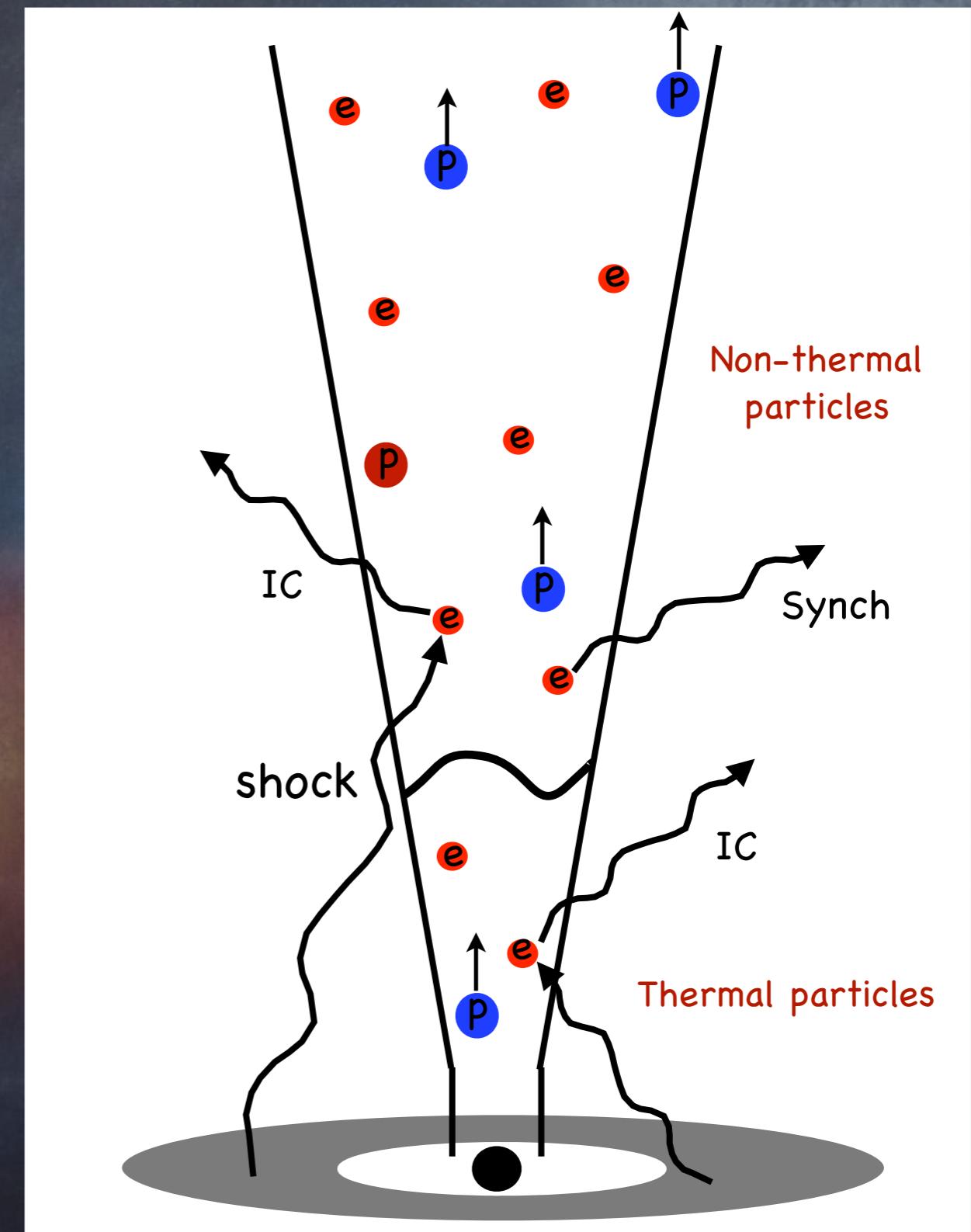
Lepto-hadronic jet model



Design of the model

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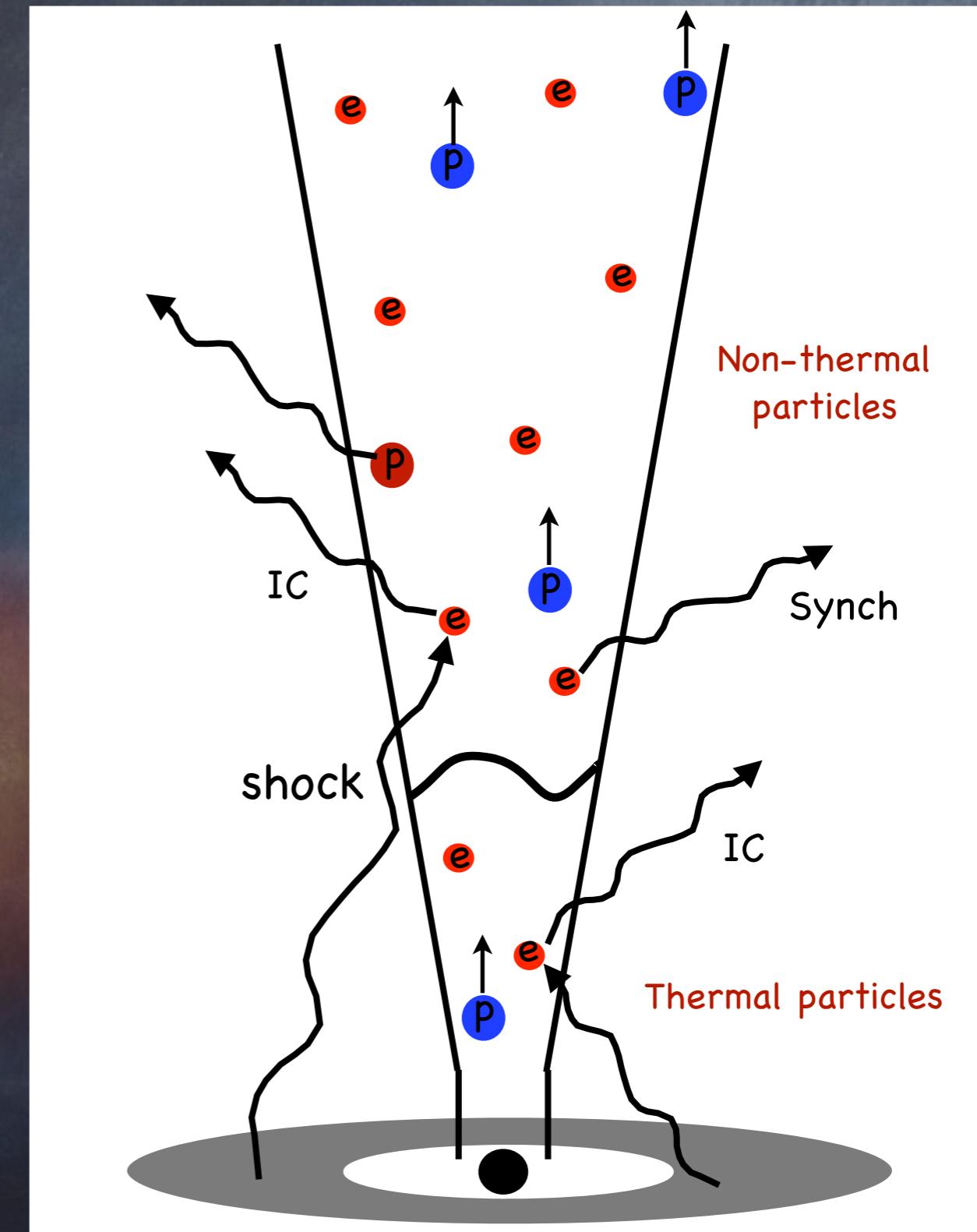
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Design of the model

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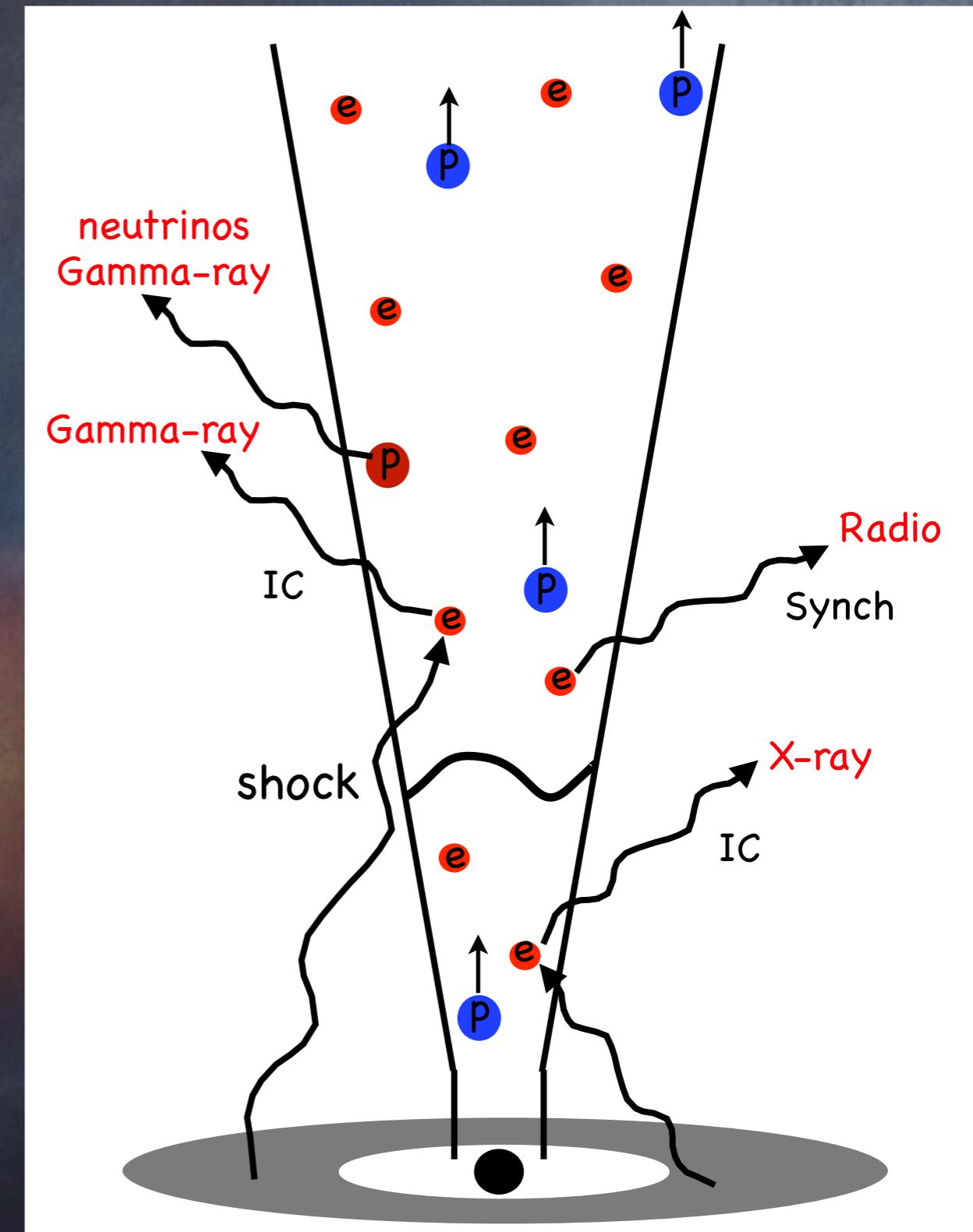
- Hadronic radiative processes includes:
 - > proton-proton
 - > proton-photon



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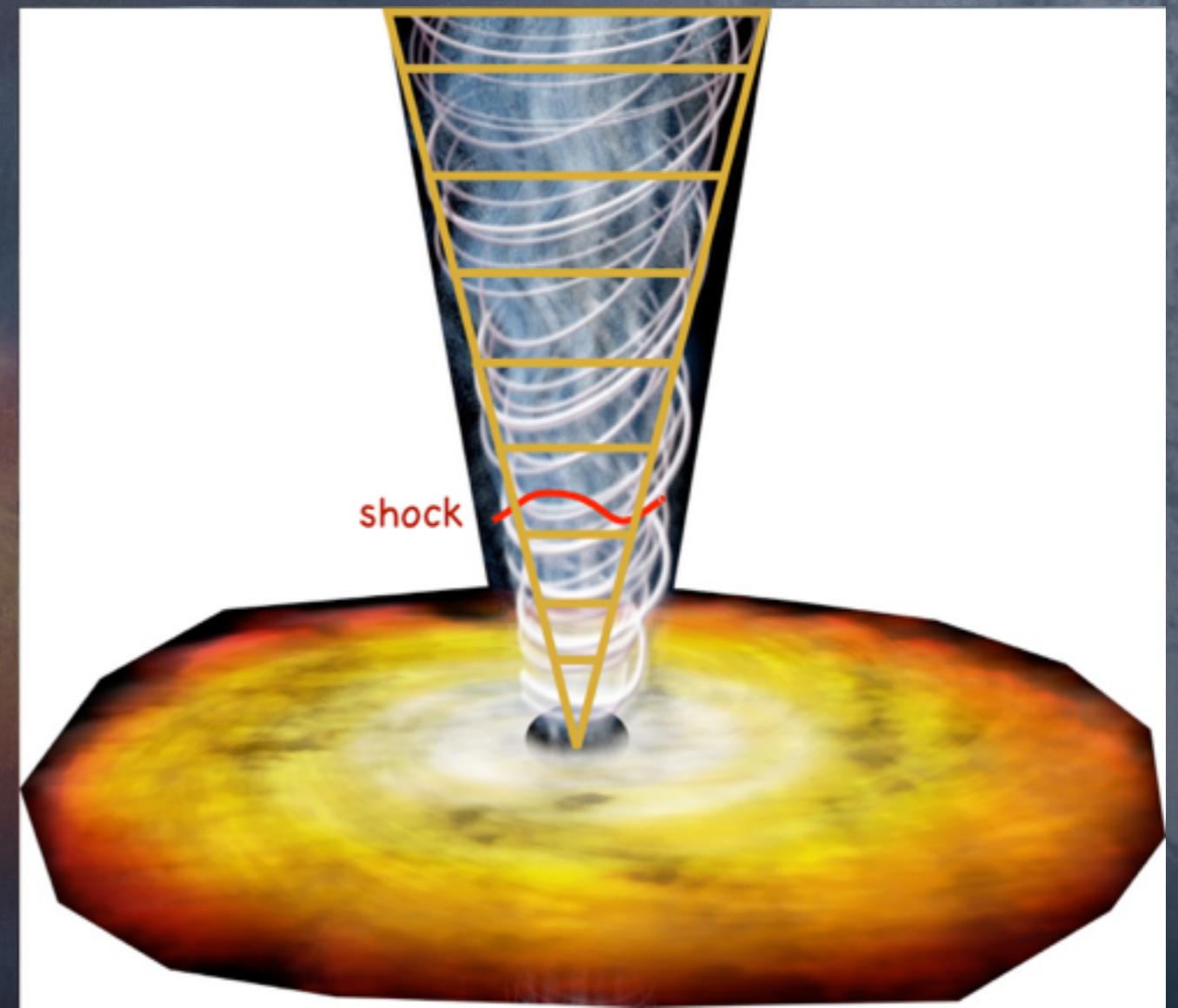
Lepto-hadronic jet model

- Hadronic radiative processes includes:
 - > proton-proton
 - > proton-photon
- Models emission from Radio to Gamma-ray & neutrinos



Assumption of the model

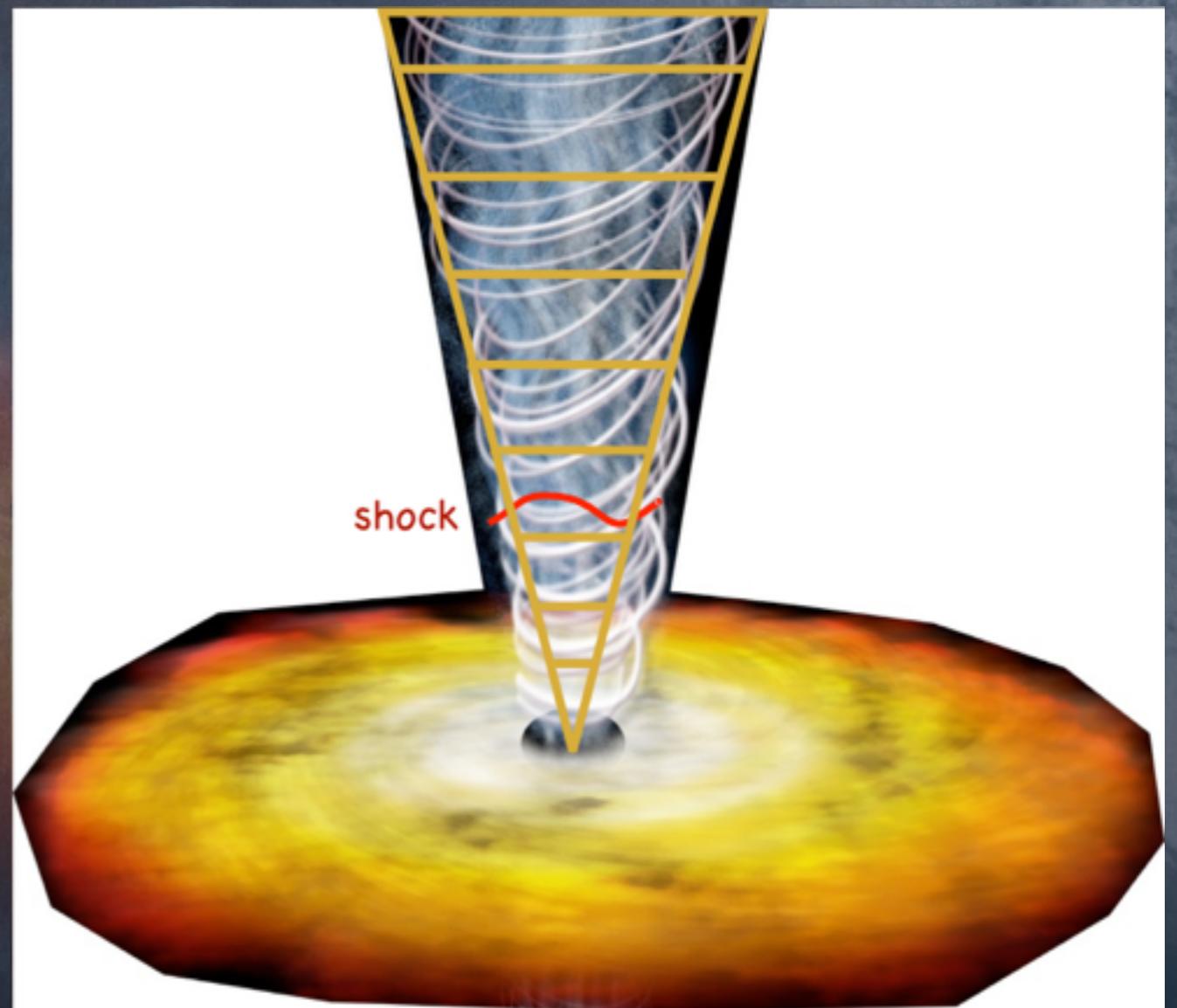
Lepto-hadronic jet model



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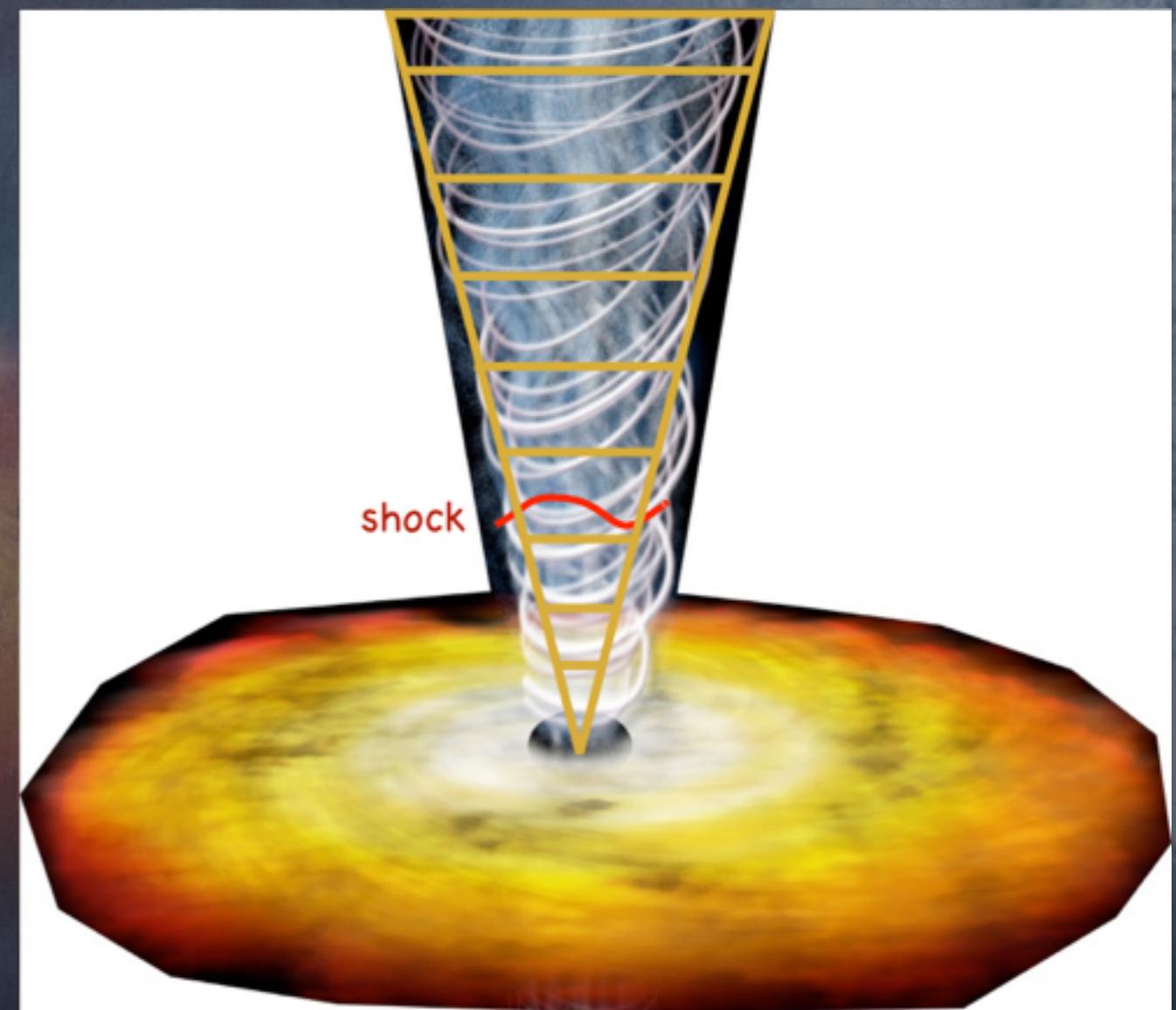
- Multi-zone jet



Assumption of the model

Lepto-hadronic jet model

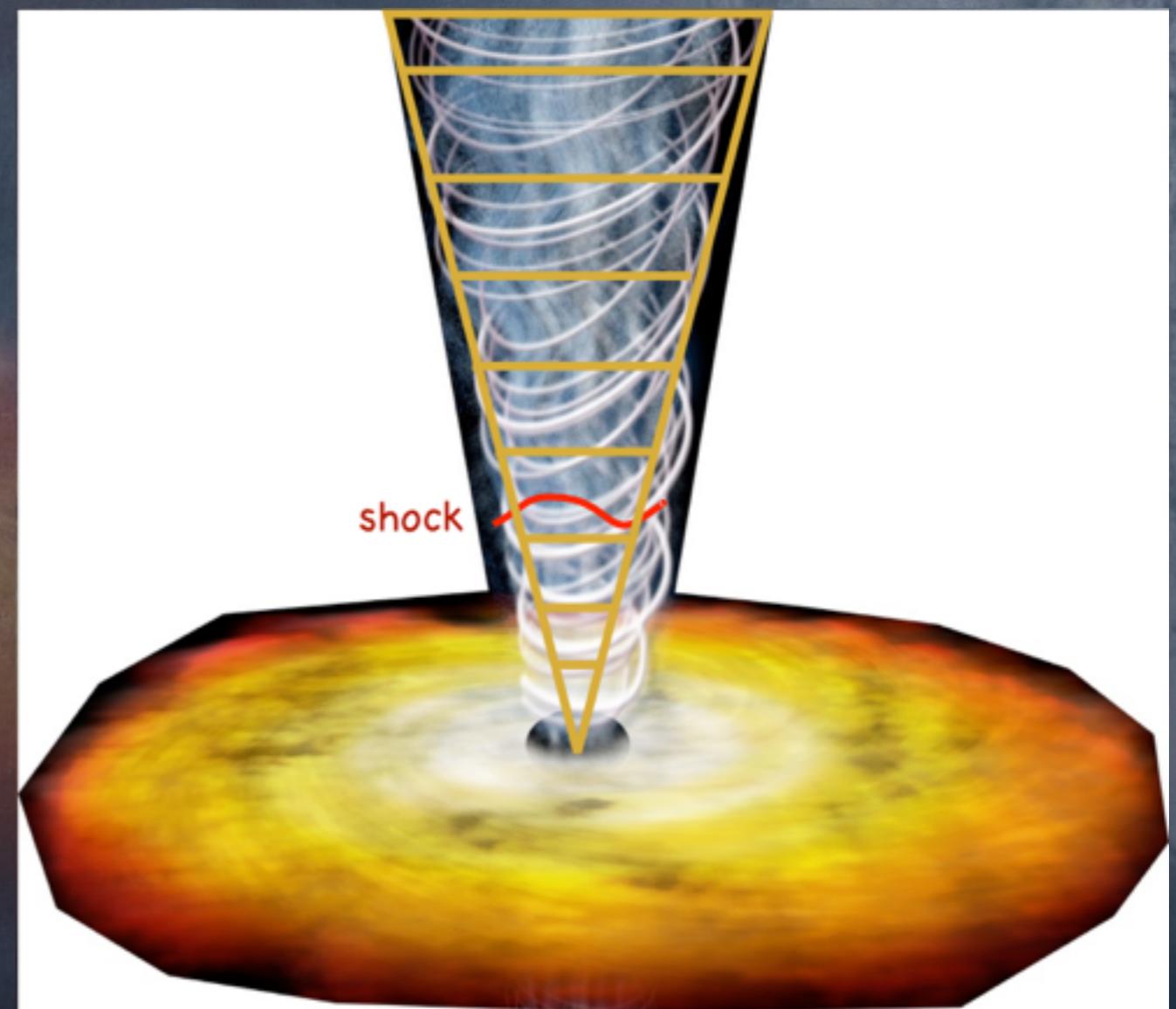
- Multi-zone jet
- Steady-state treatment of the particle distributions



Assumption of the model

Lepto-hadronic jet model

- Multi-zone jet
- Steady-state treatment of the particle distributions
- Leptonic part based on Markoff+2005 & Maitra +2009



Assumption of the model

Lepto-hadronic jet model

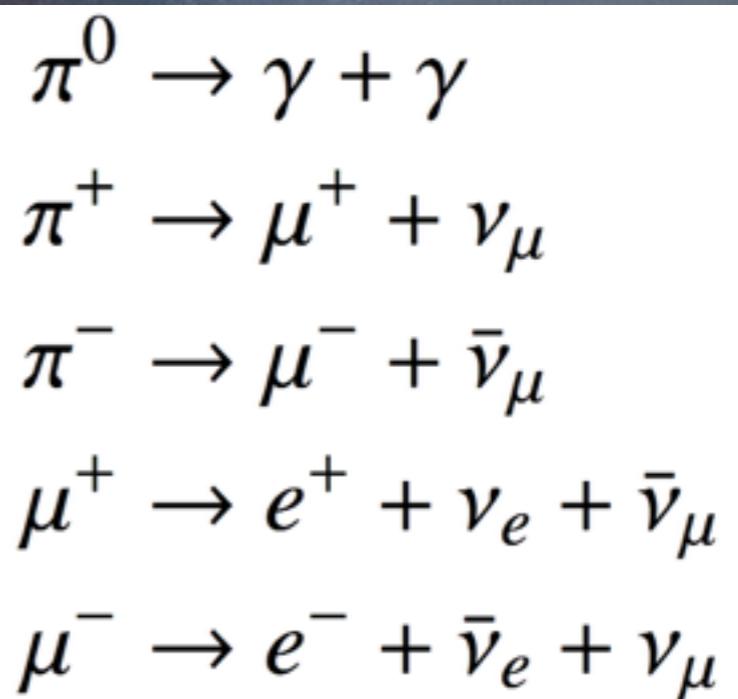
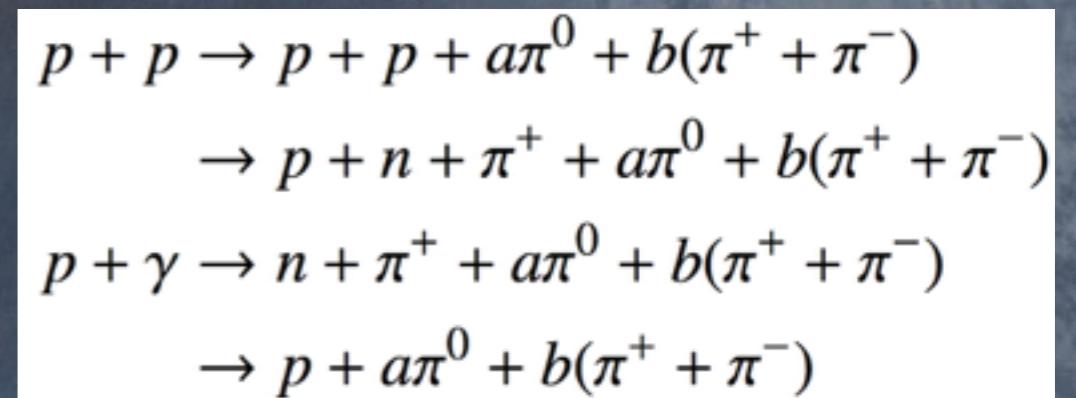
$$\begin{aligned} p + p &\rightarrow p + p + a\pi^0 + b(\pi^+ + \pi^-) \\ &\rightarrow p + n + \pi^+ + a\pi^0 + b(\pi^+ + \pi^-) \\ p + \gamma &\rightarrow n + \pi^+ + a\pi^0 + b(\pi^+ + \pi^-) \\ &\rightarrow p + a\pi^0 + b(\pi^+ + \pi^-) \end{aligned}$$

$$\begin{aligned} \pi^0 &\rightarrow \gamma + \gamma \\ \pi^+ &\rightarrow \mu^+ + \nu_\mu \\ \pi^- &\rightarrow \mu^- + \bar{\nu}_\mu \\ \mu^+ &\rightarrow e^+ + \nu_e + \bar{\nu}_\mu \\ \mu^- &\rightarrow e^- + \bar{\nu}_e + \nu_\mu \end{aligned}$$

Assumption of the model

Lepto-hadronic jet model

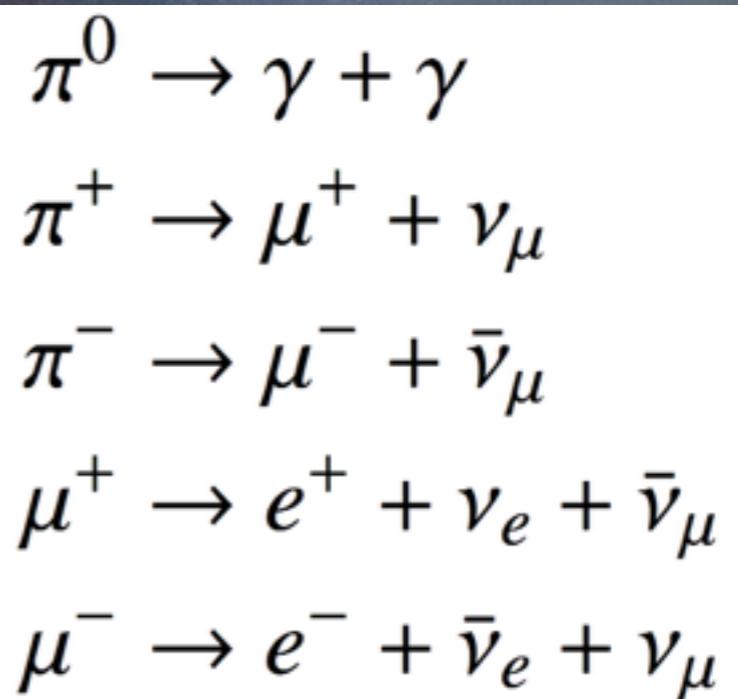
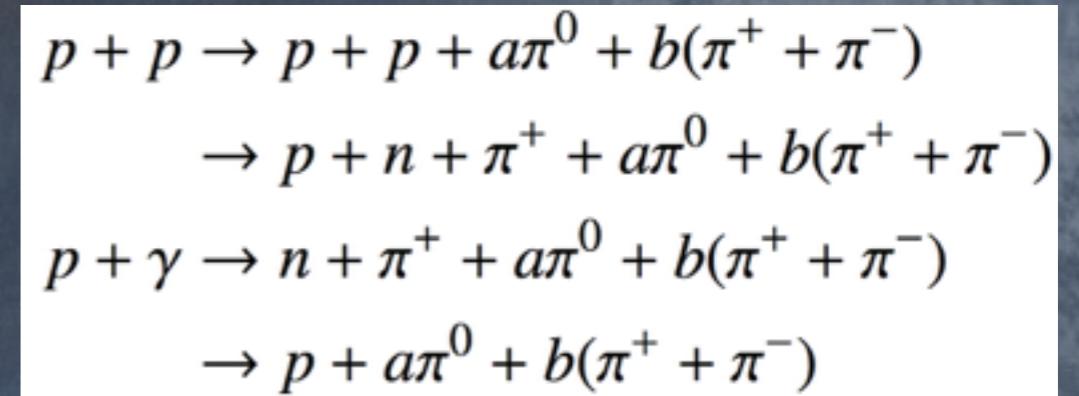
• Proton-proton interaction:



Assumption of the model

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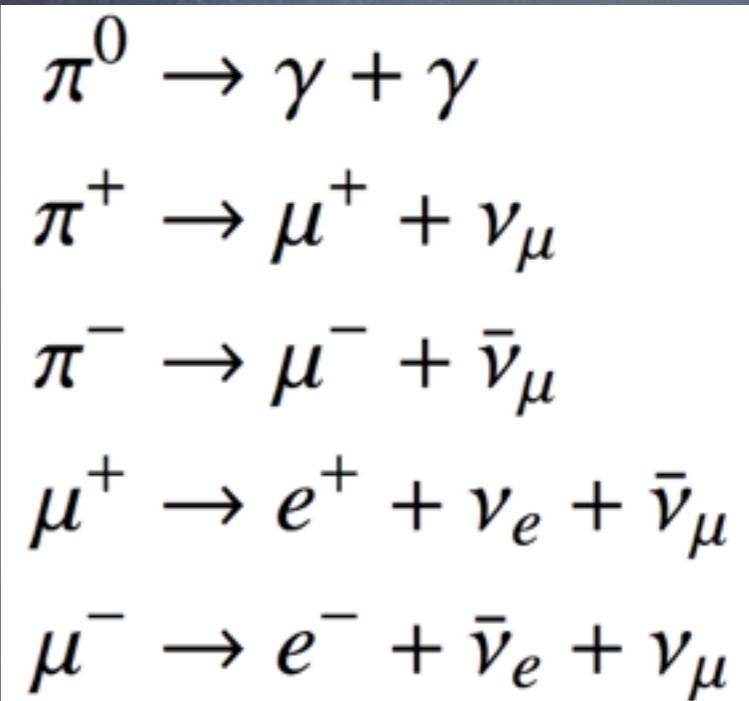
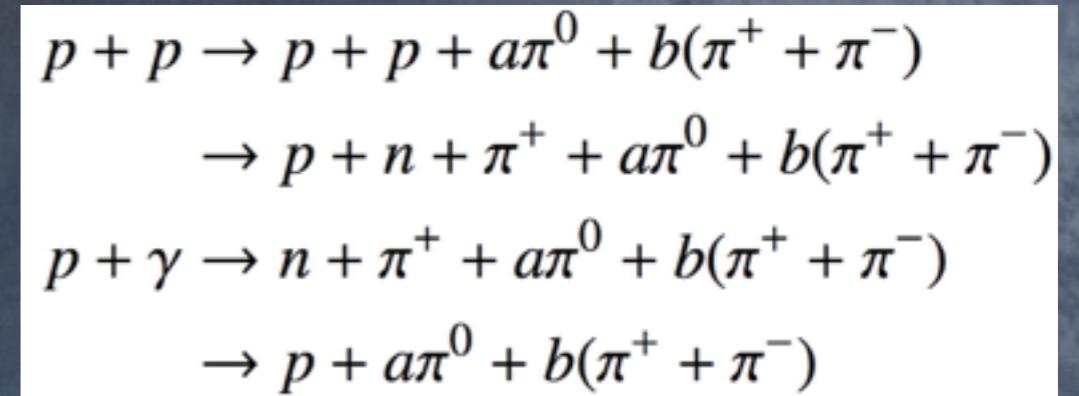
- ⦿ Proton-proton interaction:
 - > Kamae+2006,
 - > Karlsson&Kamae 2008



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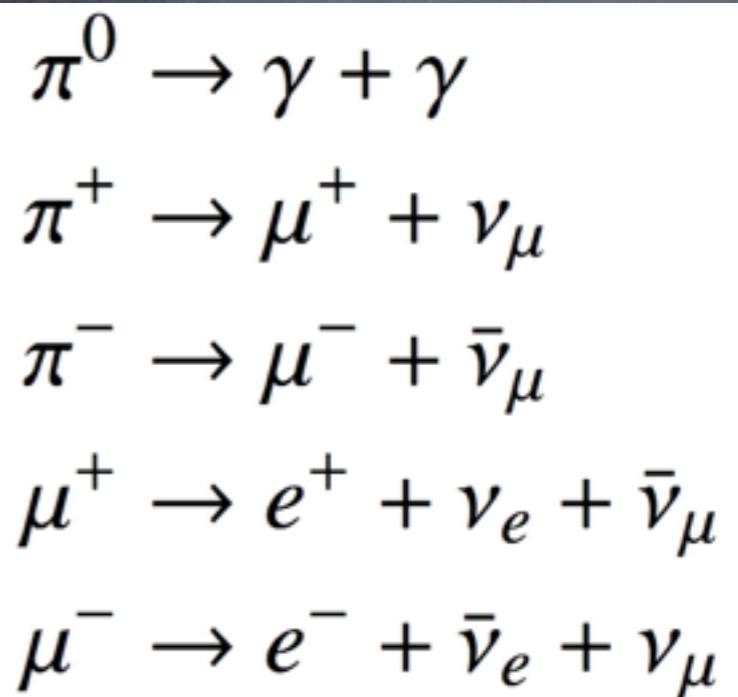
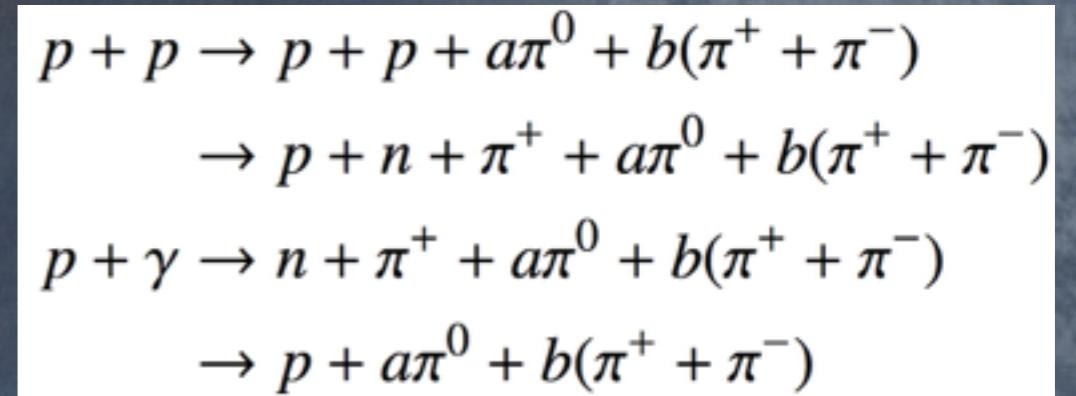
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- ⦿ Proton-photon interation:



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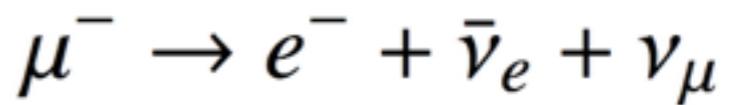
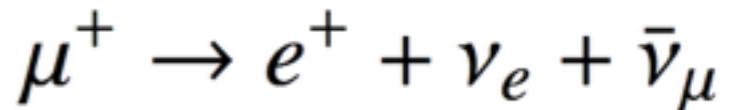
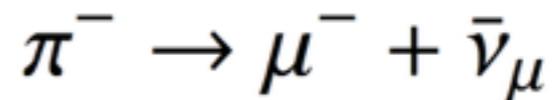
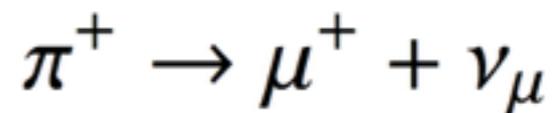
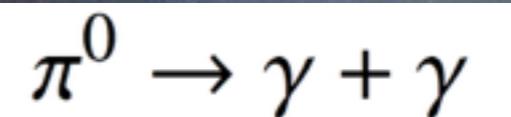
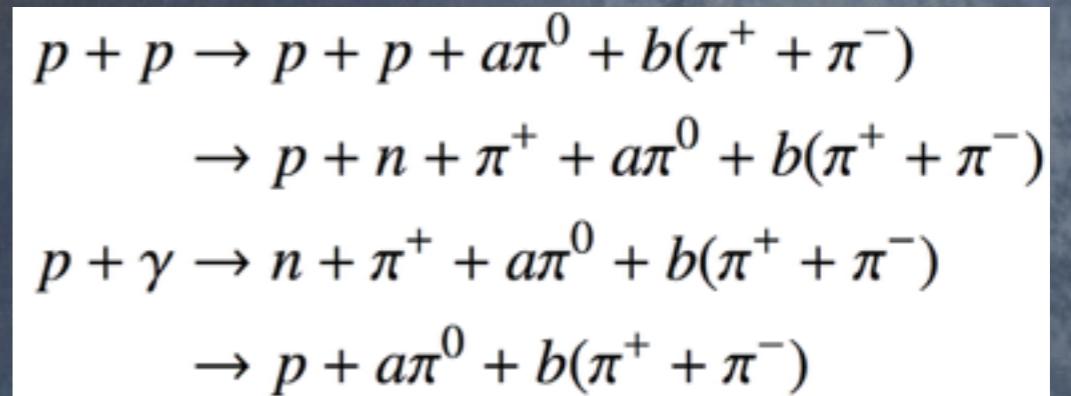
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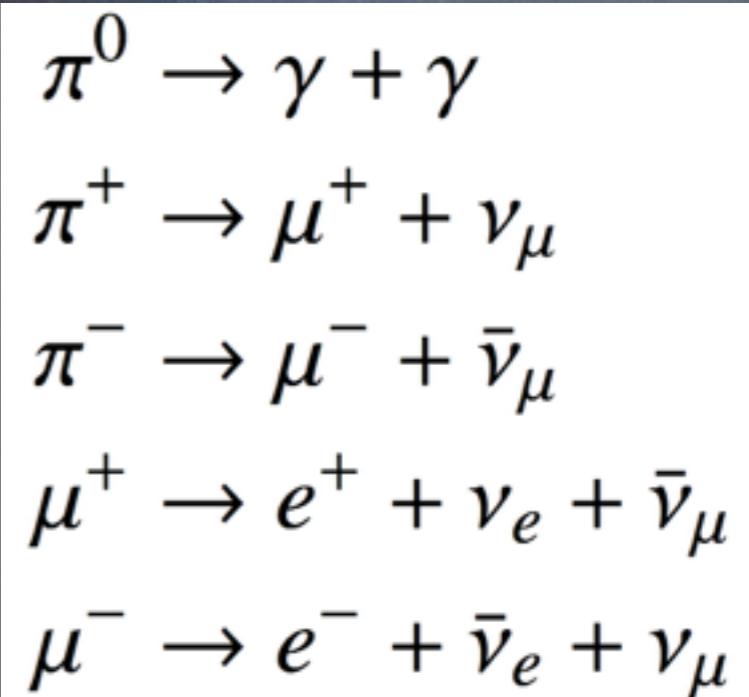
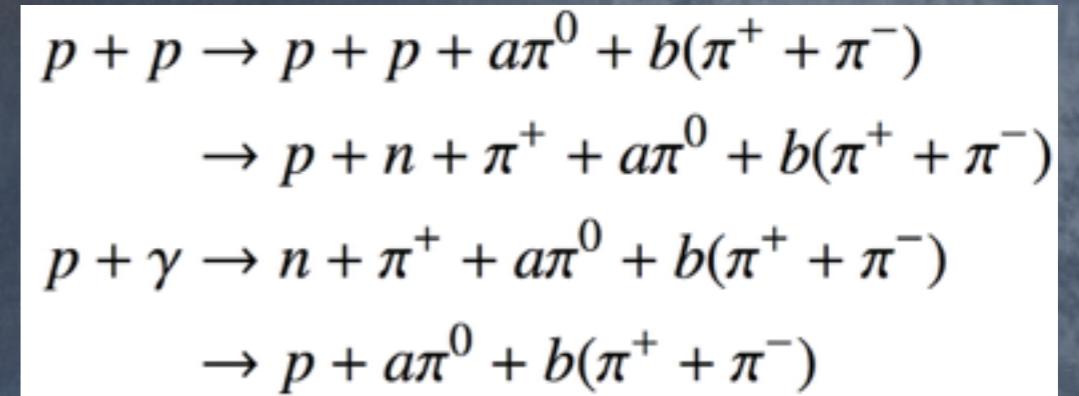
$$\bullet t_{acc}^{-1}(pc_{max}) = t_{cool}^{-1}(pc_{max})$$



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- ⦿ $t_{acc}^{-1}(pc_{max}) = t_{cool}^{-1}(pc_{max})$
- ⦿ Acceleration & cooling rates from Begelman+1990



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- $t_{acc}^{-1}(pc_{max}) = t_{cool}^{-1}(pc_{max})$
- Acceleration & cooling rates from Begelman+1990
 - One major modification:
steady-state distribution of secondaries e^\pm to calculate their synchrotron and IC scattering radiation
(Ginzburg&Syrovatskii 1964)

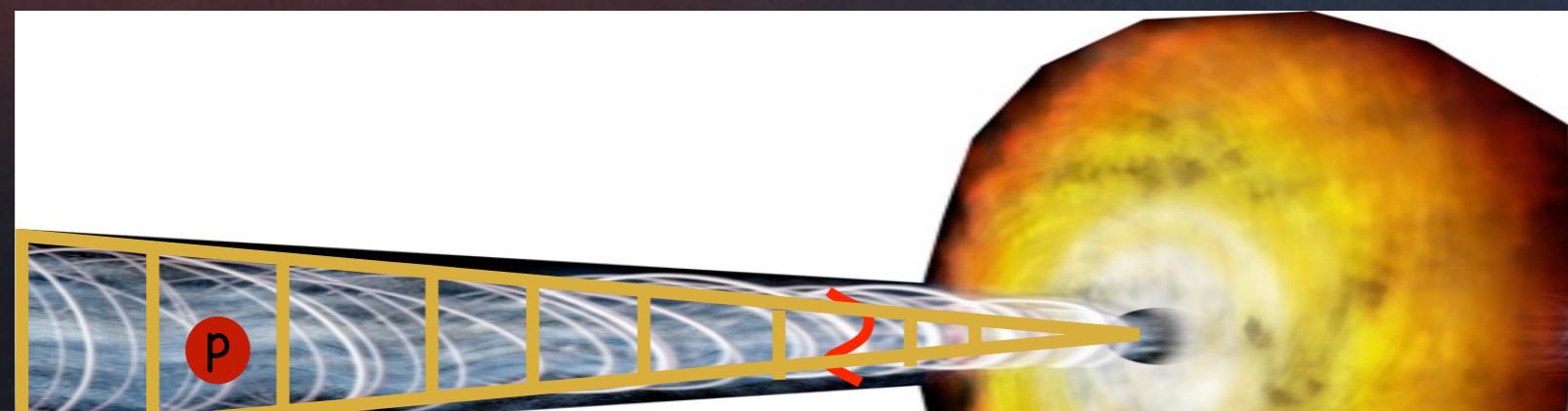
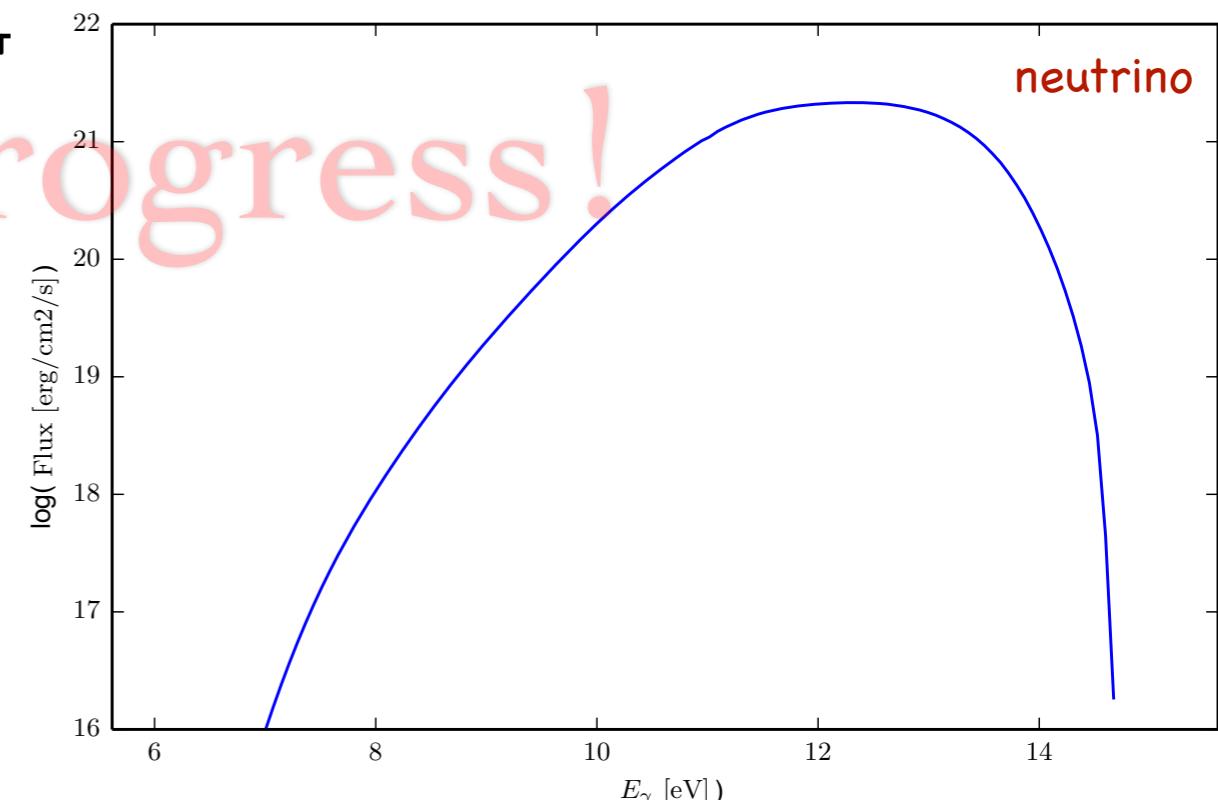
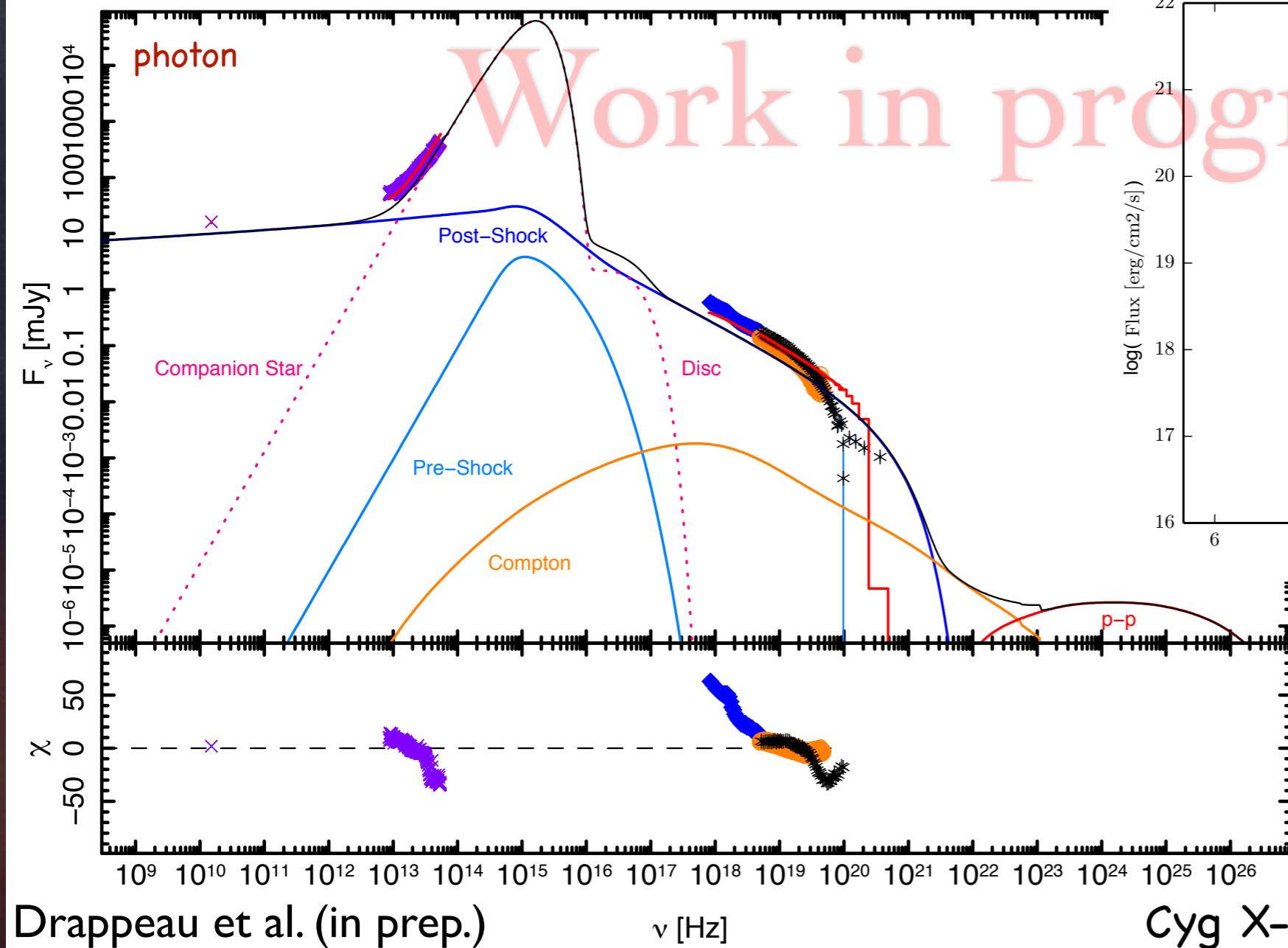
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- ⦿ $t_{acc}^{-1}(pc_{max}) = t_{cool}^{-1}(pc_{max})$
- ⦿ Acceleration & cooling rates from Begelman+1990
 - ⦿ One major modification: steady-state distribution of secondaries e^\pm to calculate their synchrotron and IC scattering radiation (Ginzburg&Syrovatskii 1964)
 - ⦿ Model of stellar wind (Lamers&Cassinelli 1999)

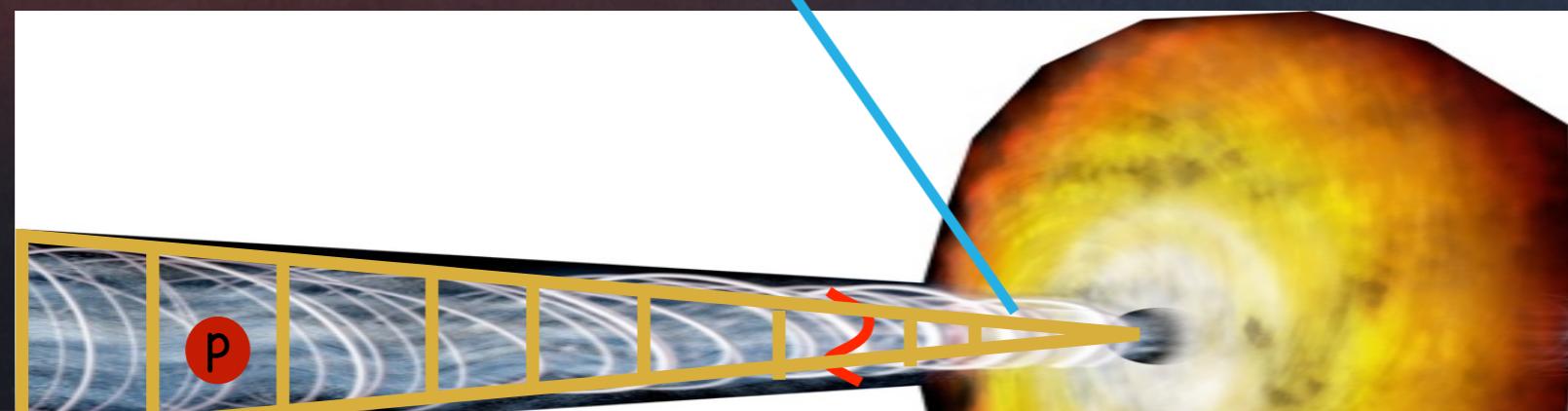
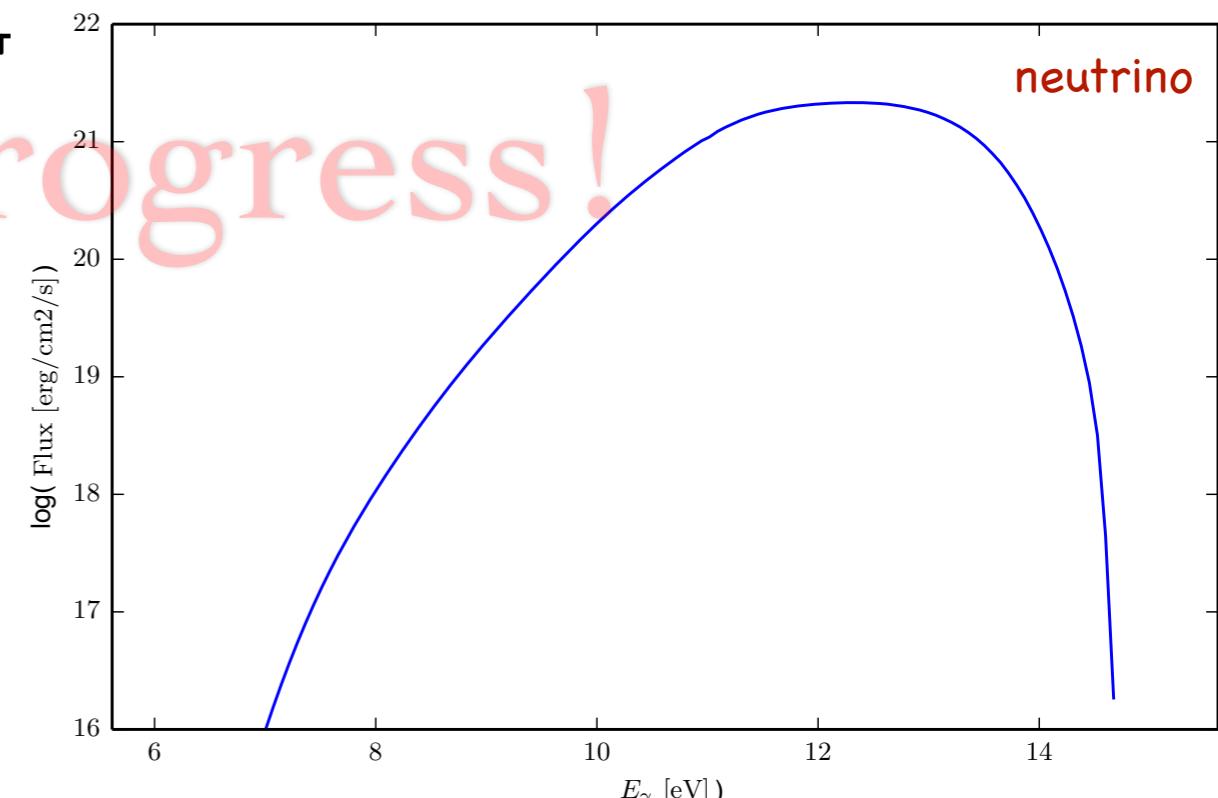
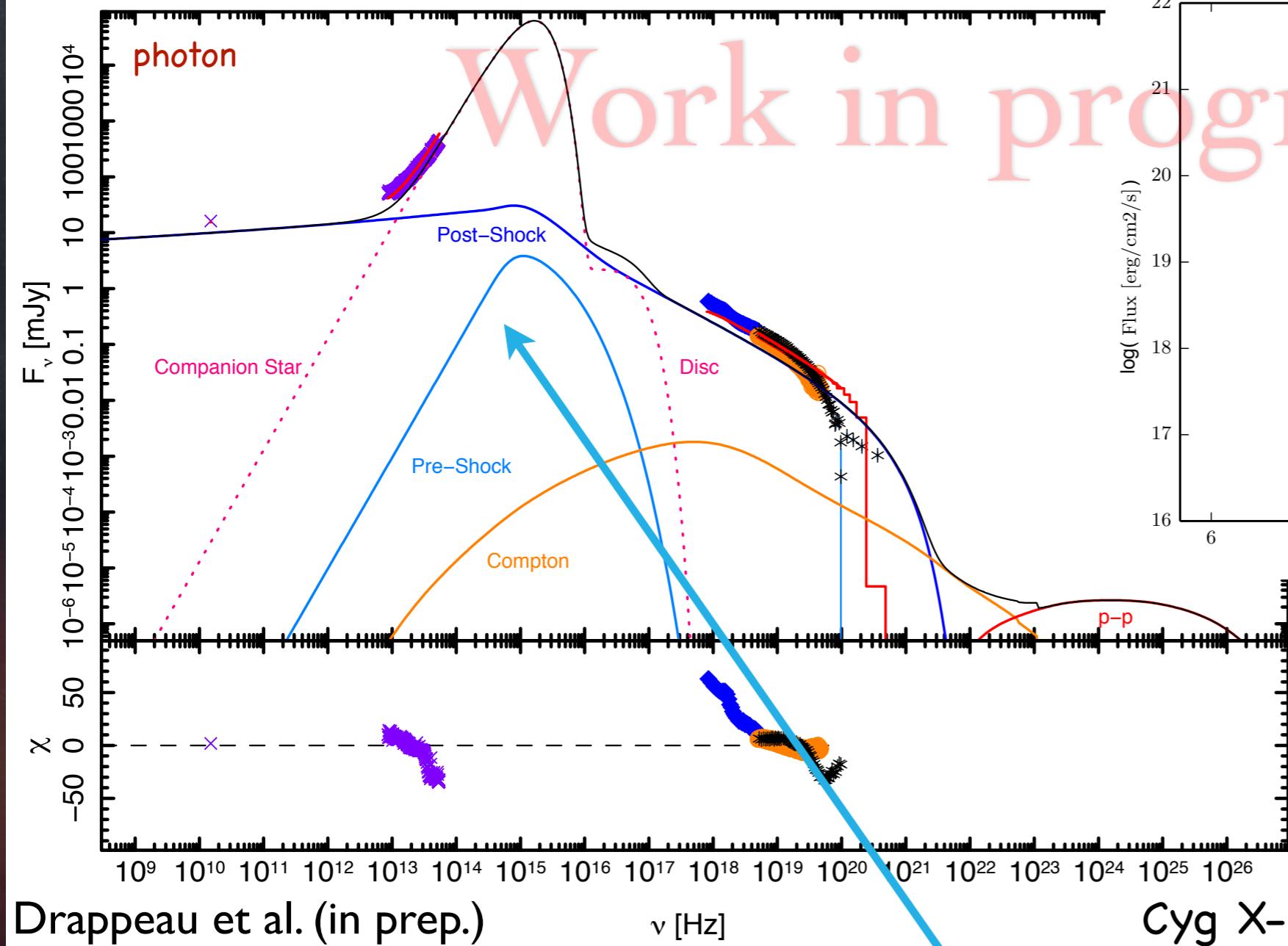
Preliminary results

Work in progress!



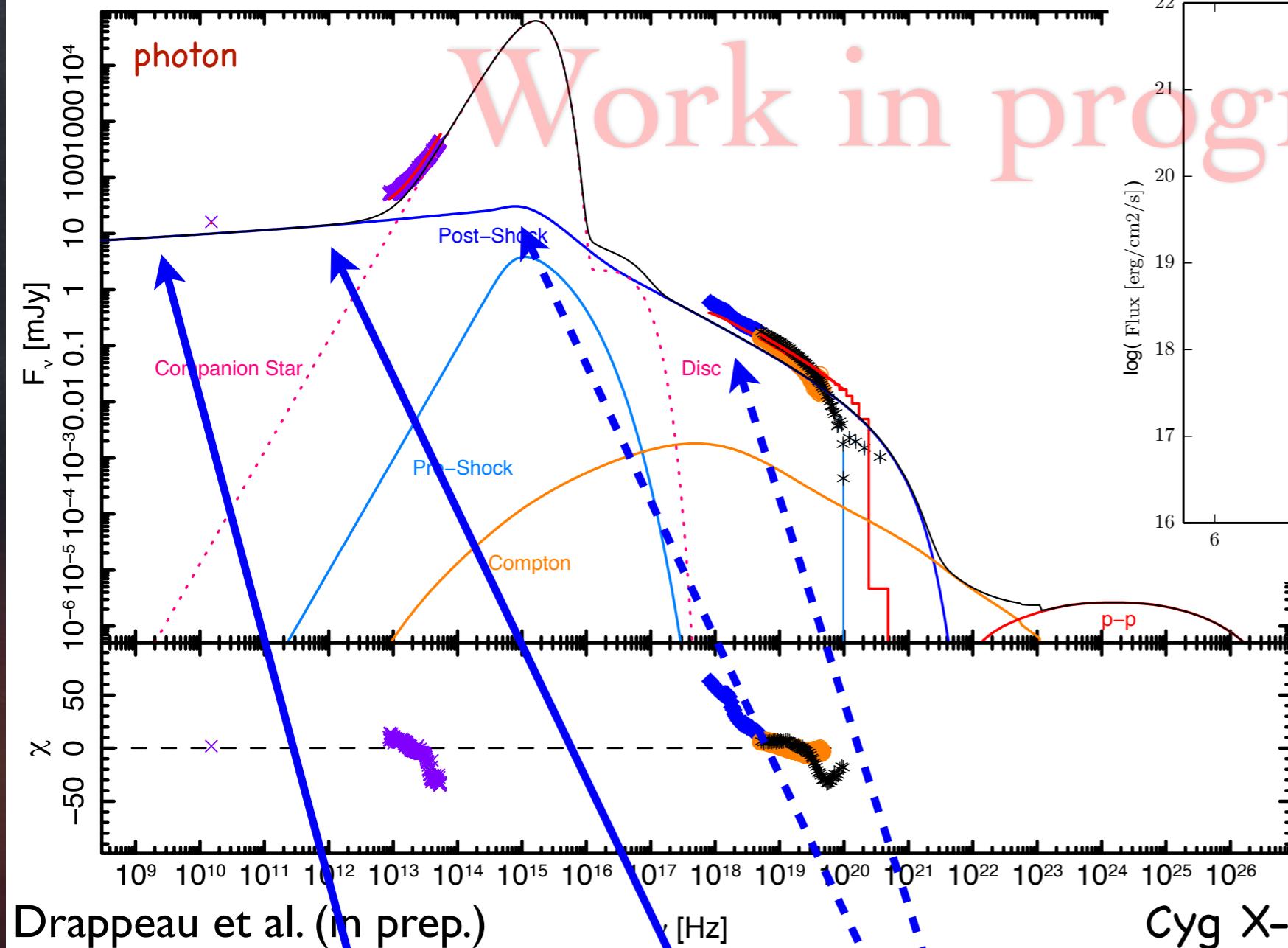
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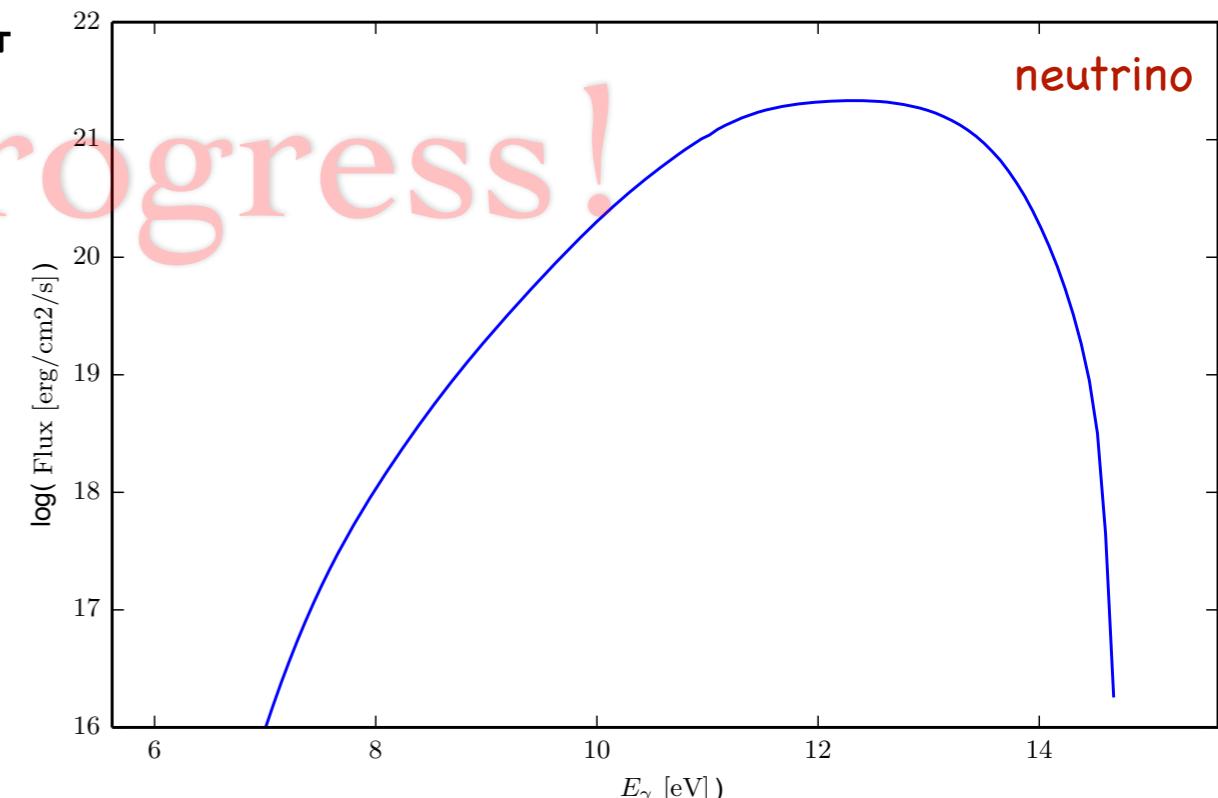


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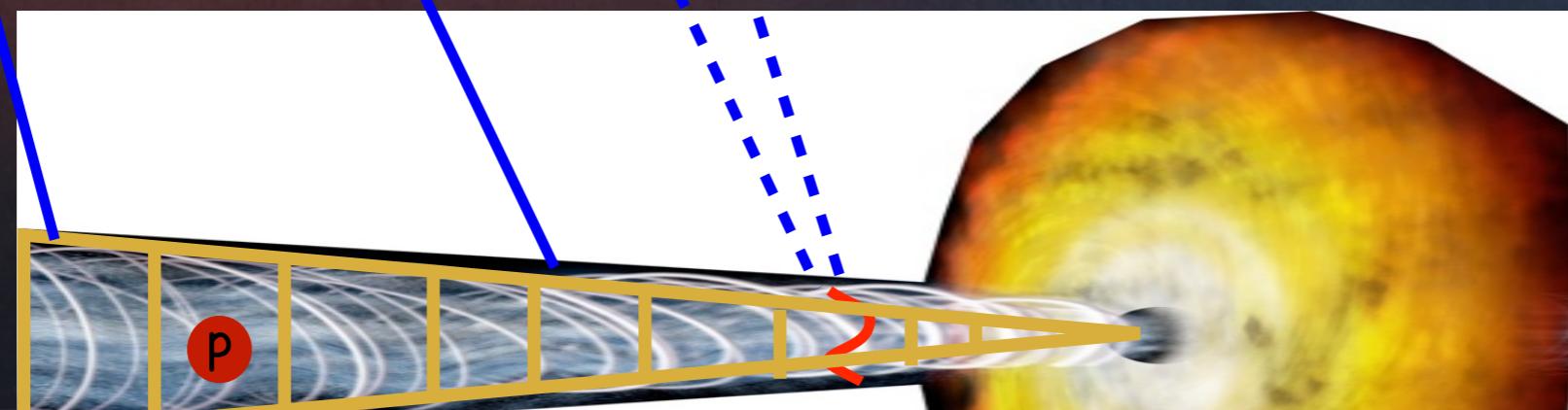
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Drappeau et al. (in prep.)

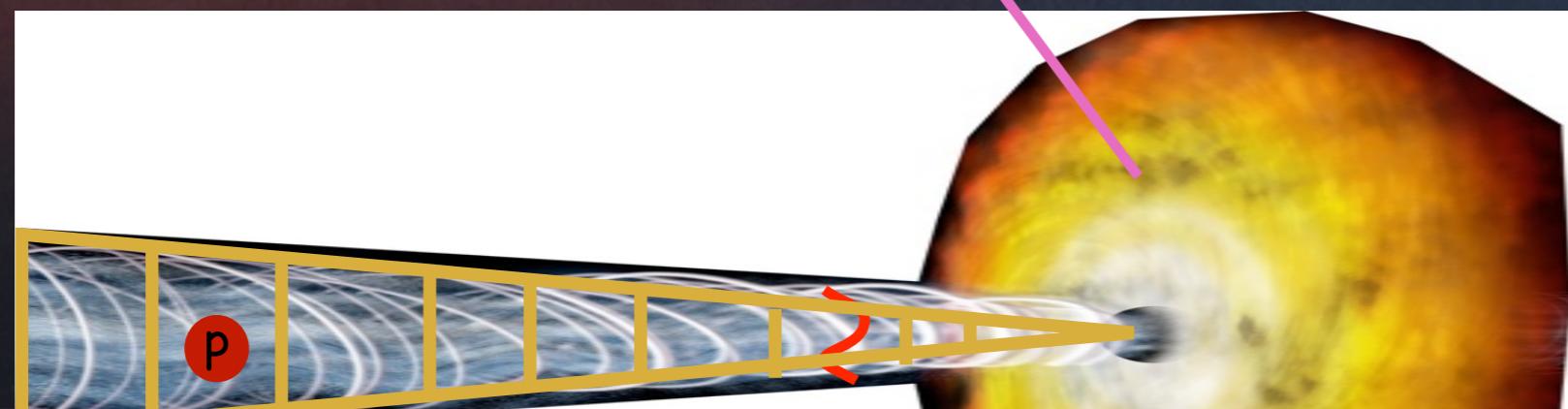
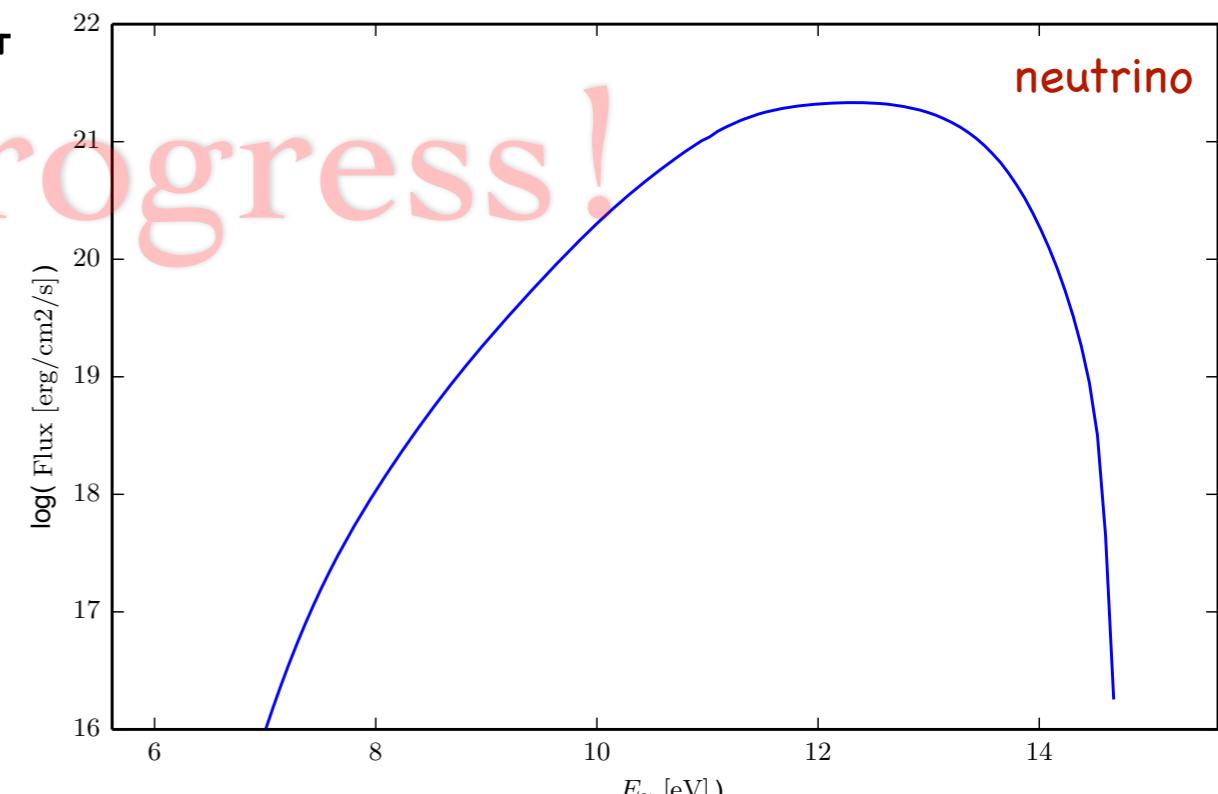
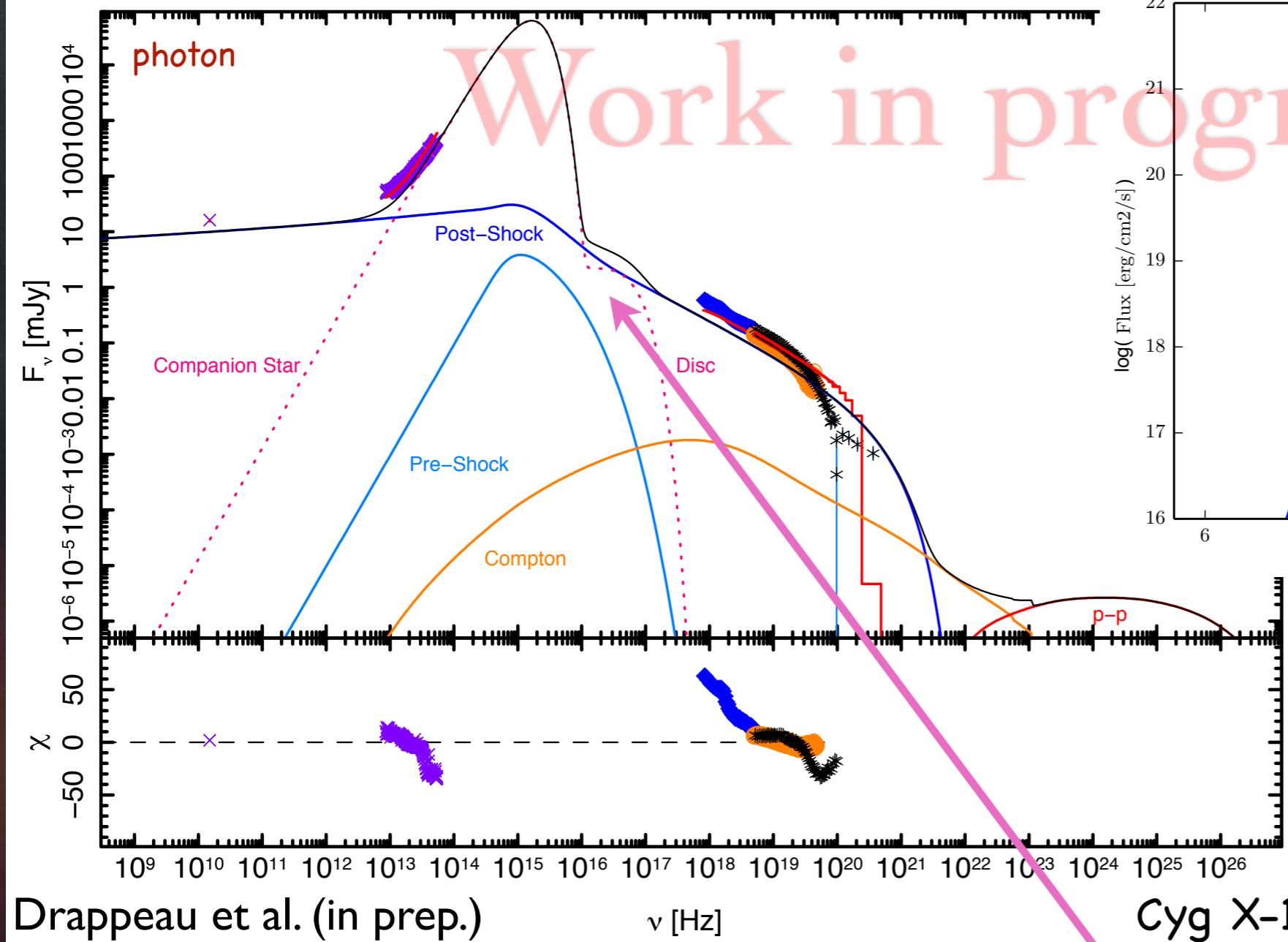


Cyg X-1

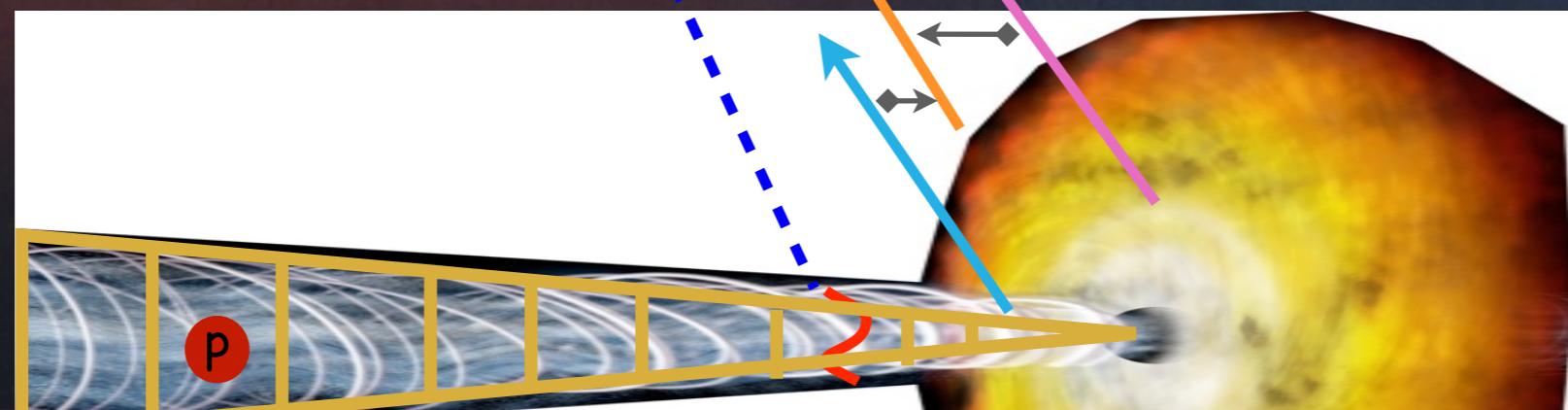
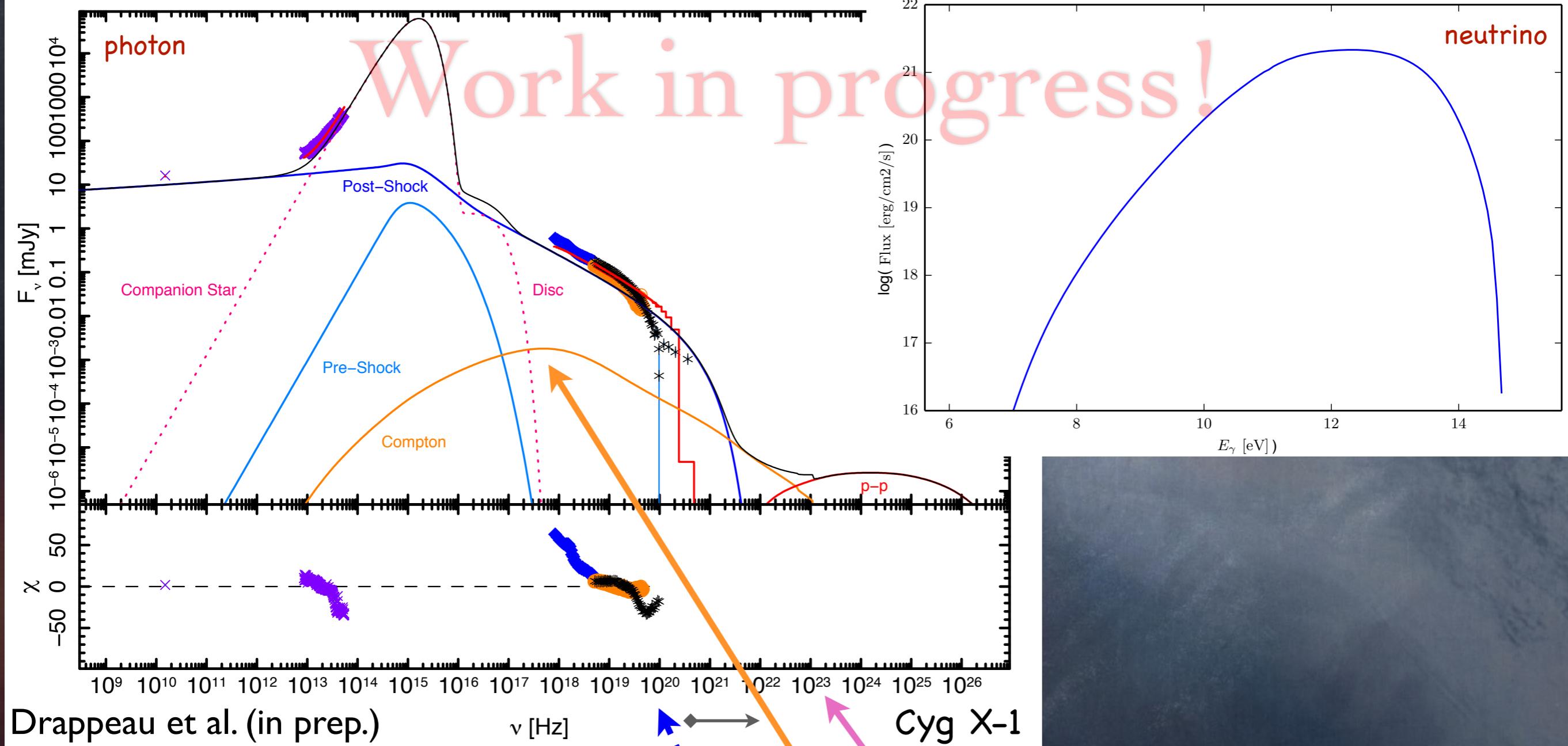


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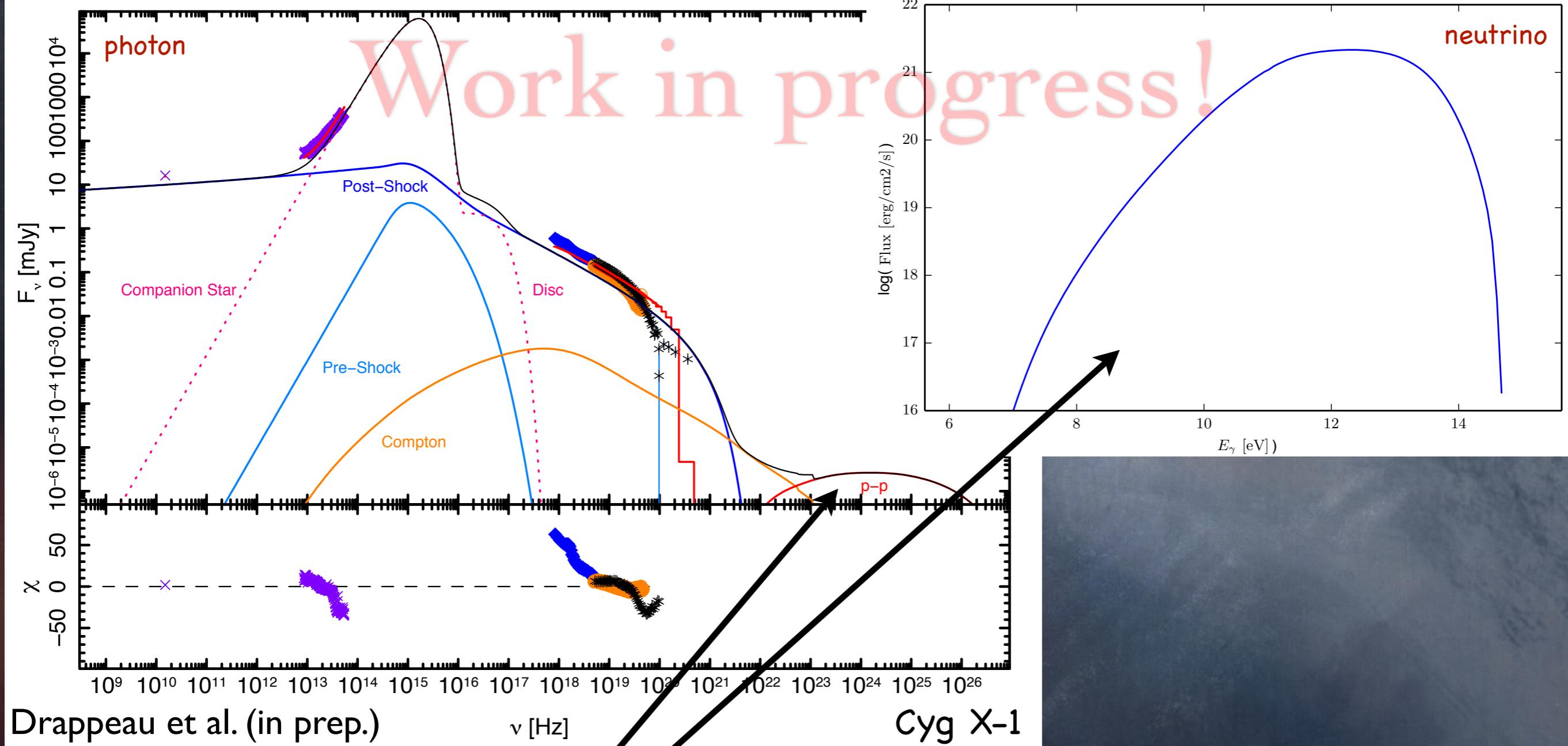
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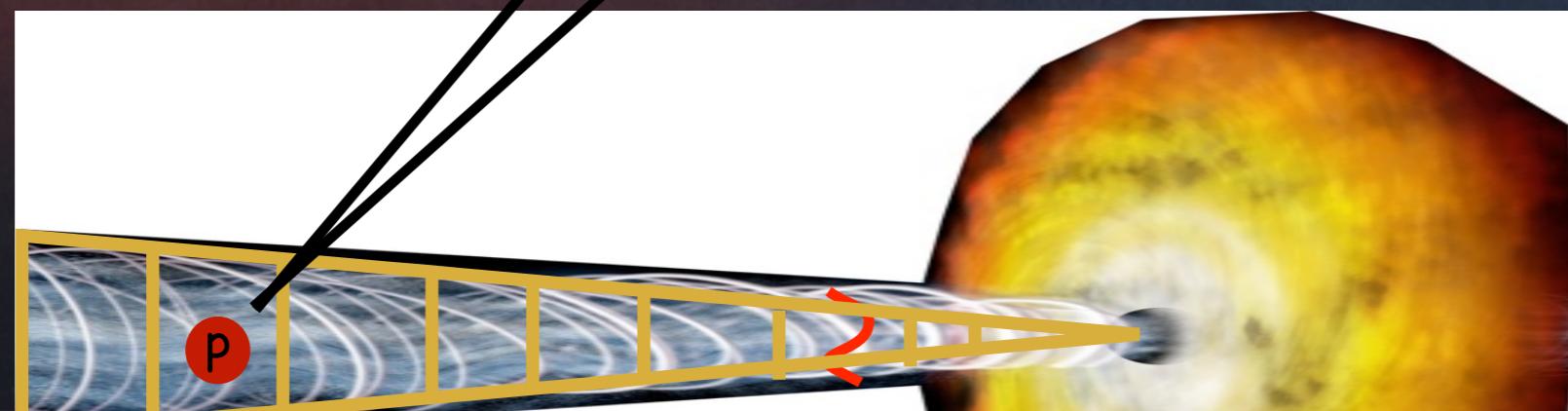
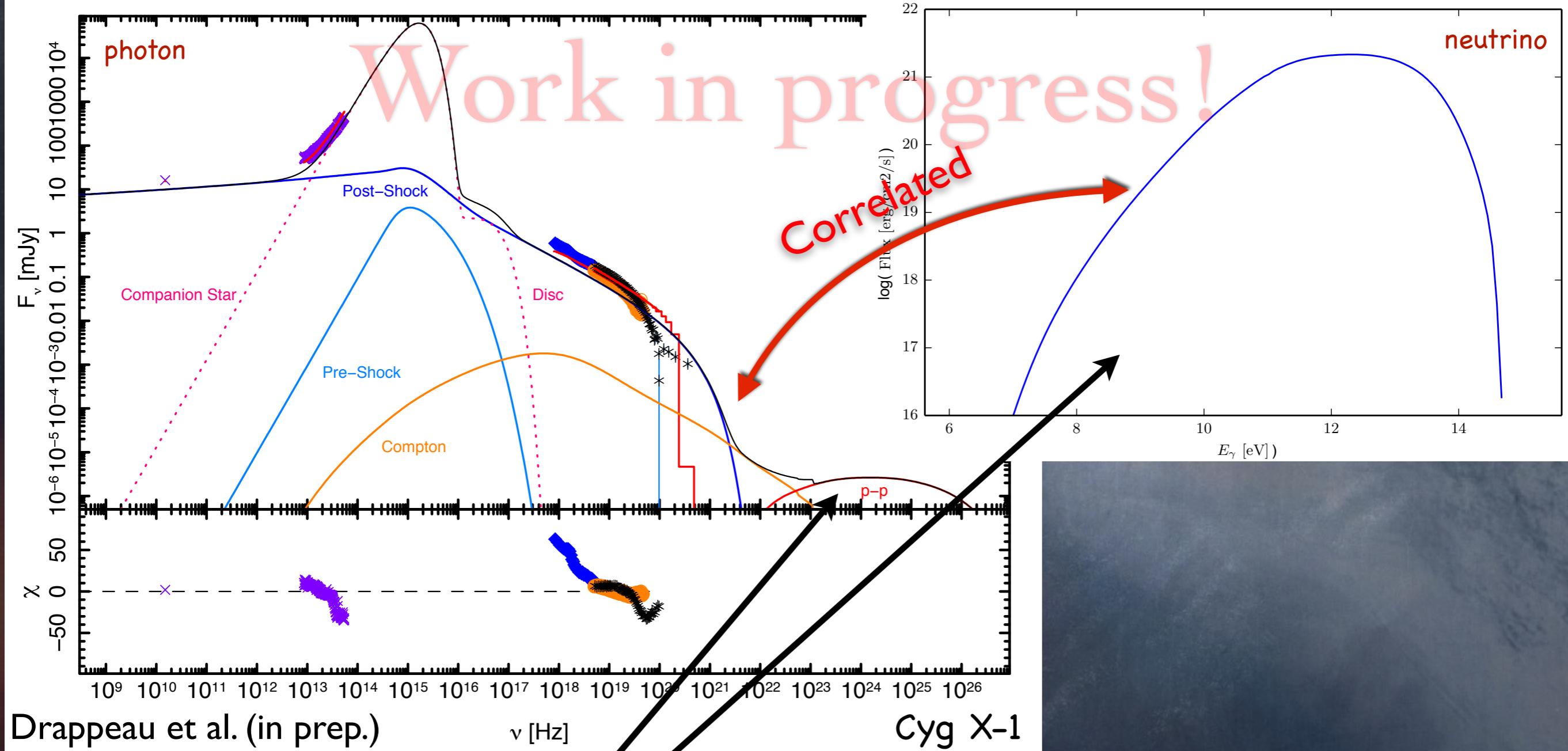
Preliminary results



Preliminary results



Preliminary results



What the model offers

Examples

Help to...

- ...choose promising sources
- ...study recurring flaring events of gamma-rays and neutrinos
- ...better constrain gamma-ray and neutrino background signal from astrophysical sources in the Dark Matter annihilation

Next steps

- Better treatment of the neutrino signal
 - > open to collaboration with the neutrino community!
- Complete the radiative processes modelling
 - > pair production/annihilation, synchrotron from proton and secondaries,...
- Quid of nuclei acceleration in jet? (AUGER results)
- Development of a time-dependant version
 - > variability-triggered internal shocks (see Malzac's talk)

Take-away points

- We propose an **multi-wavelength and multi-messenger spectral jet model**
- Prepare the future of radio to gamma-ray + neutrinos analyses of **accreting black holes at all scales**