

Spectral Treatment of Cosmic Ray Electrons

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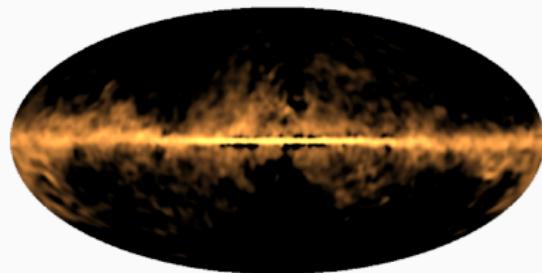
Leibniz Institut für Astrophysik Potsdam (AIP)

Motivation

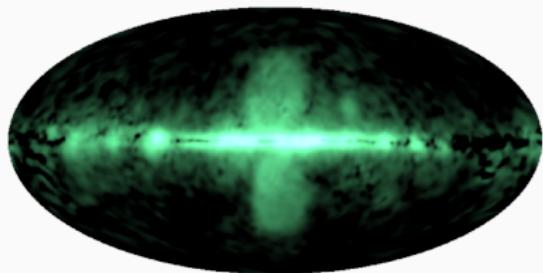
- cosmic ray electrons (CRe) link observations
- Fermi bubbles: γ -ray structures

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cloud-like
hadronic
 $\pi^0 \rightarrow \gamma\gamma$



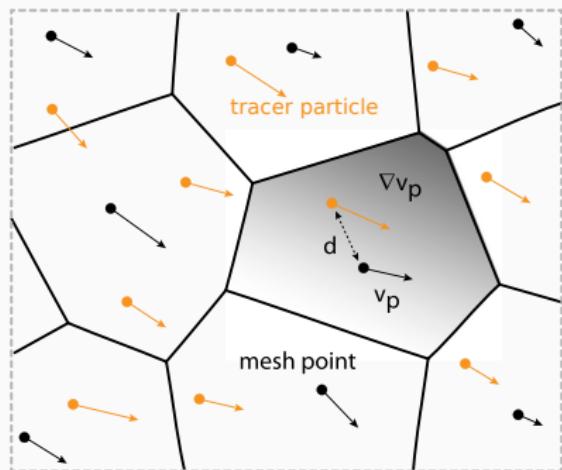
bubble-like
leptonic
IC emission

Selig+ (2015)

Simulation Setup with CRe

- cosmological simulation with moving mesh code AREPO
- CRp - fluid
- CRe - passive Lagrangian tracer particles

- spectrum on every particle
- sampling of the field
- post-processing code



Genel+ (2013)

CRe Spectral Evolution

Fokker-Planck equation (w/o spatial diffusion, streaming)

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$$+ \frac{\partial}{\partial p} \left(\frac{p f}{3} (\nabla \cdot \mathbf{v}) \right) - (\nabla \cdot \mathbf{v}) f \quad \text{Fermi I / adiabatic}$$

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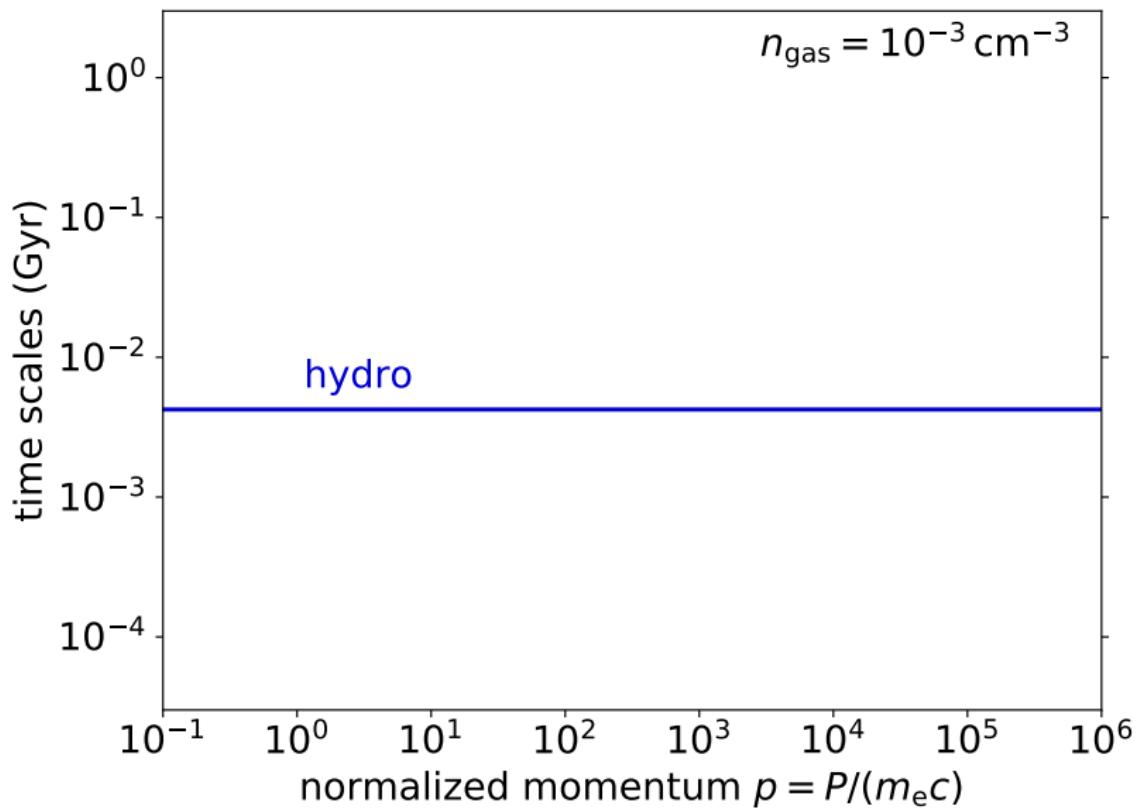
$$- \frac{\partial}{\partial p} \left(\frac{f}{p^2} \frac{\partial}{\partial p} (p^2 D_{pp}) \right) + \frac{\partial^2}{\partial p^2} (D_{pp} f) \quad \text{Fermi II / diffusion}$$

CRe Spectral Evolution

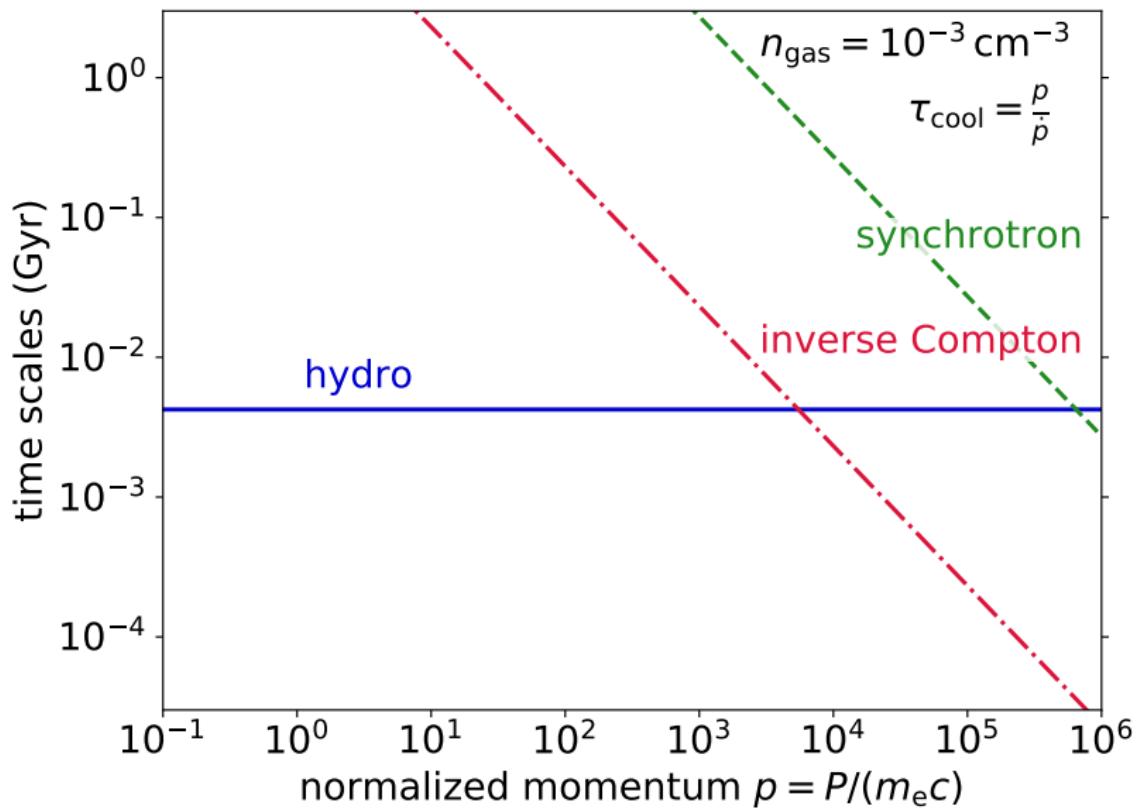
Fokker-Planck equation (w/o spatial diffusion, streaming)

$$\begin{aligned}\frac{df}{dt} = & + \frac{\partial}{\partial p} (f |\dot{p}|) + Q(p, t) && \text{cooling, injection} \\ & + \frac{\partial}{\partial p} \left(\frac{p f}{3} (\nabla \cdot \mathbf{v}) \right) - (\nabla \cdot \mathbf{v}) f && \text{Fermi I / adiabatic} \\ & - \frac{\partial}{\partial p} \left(\frac{f}{p^2} \frac{\partial}{\partial p} (p^2 D_{pp}) \right) + \frac{\partial^2}{\partial p^2} (D_{pp} f) && \text{Fermi II / diffusion}\end{aligned}$$

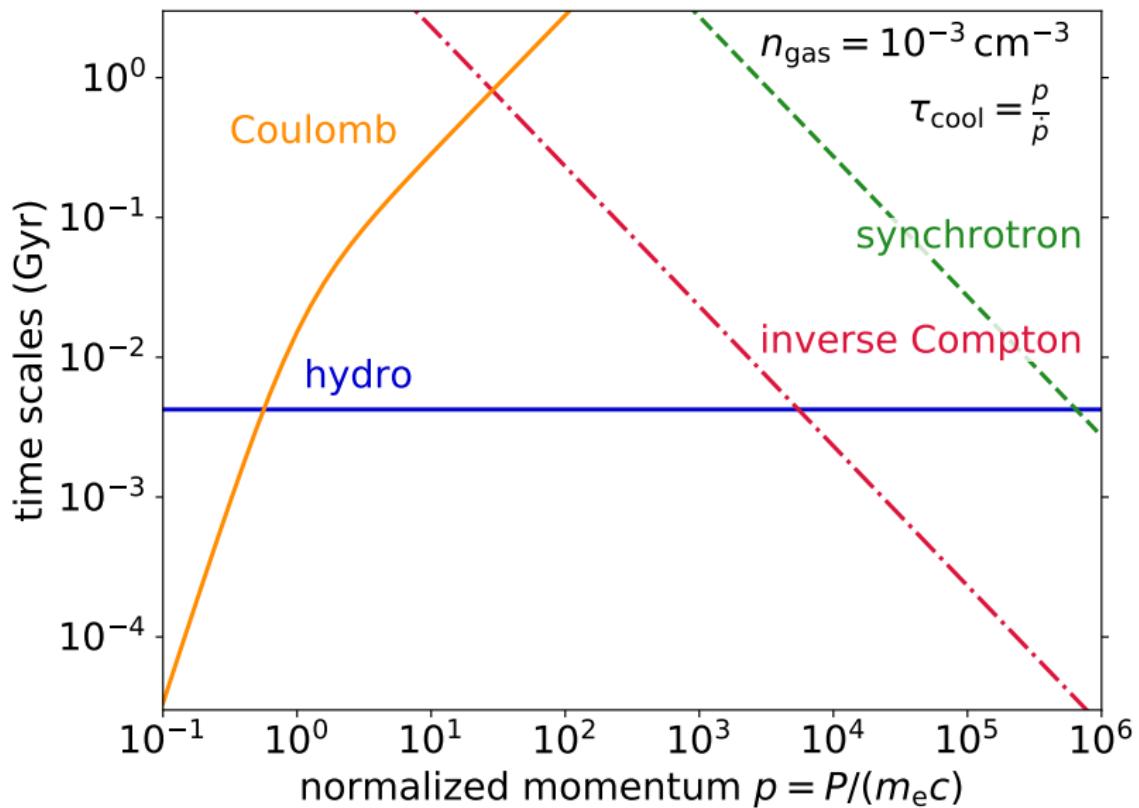
Cooling Time Scales



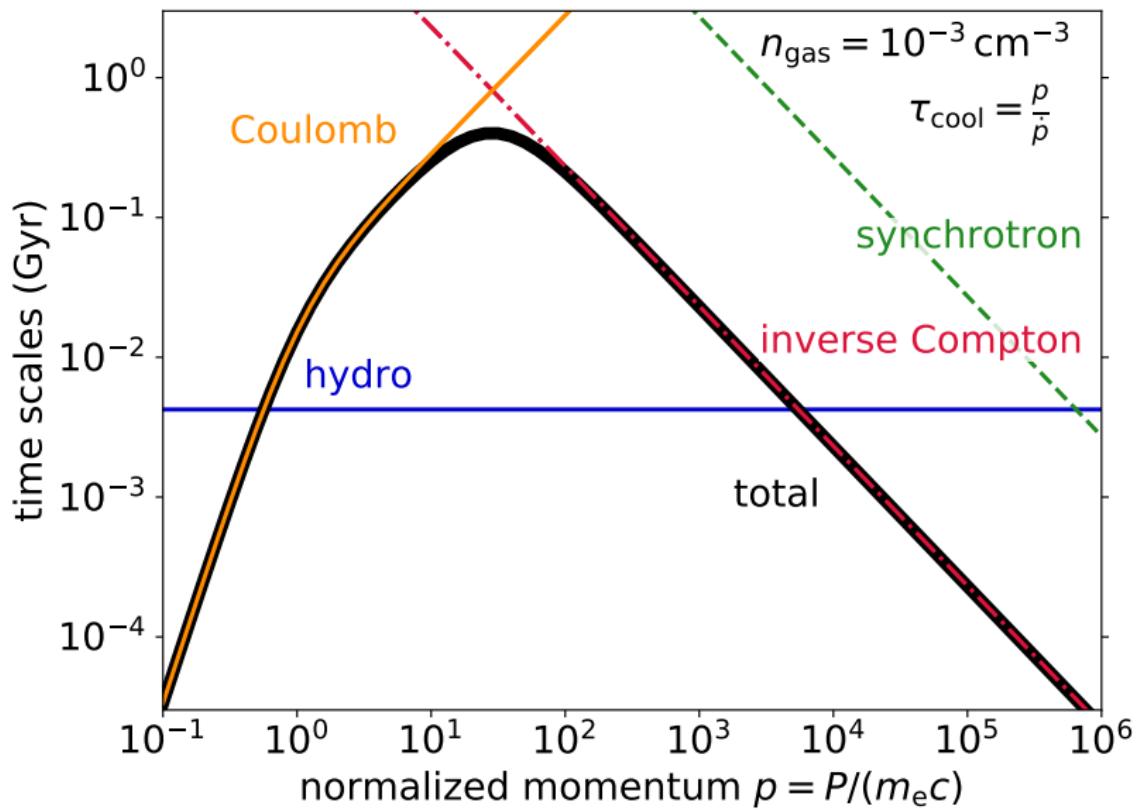
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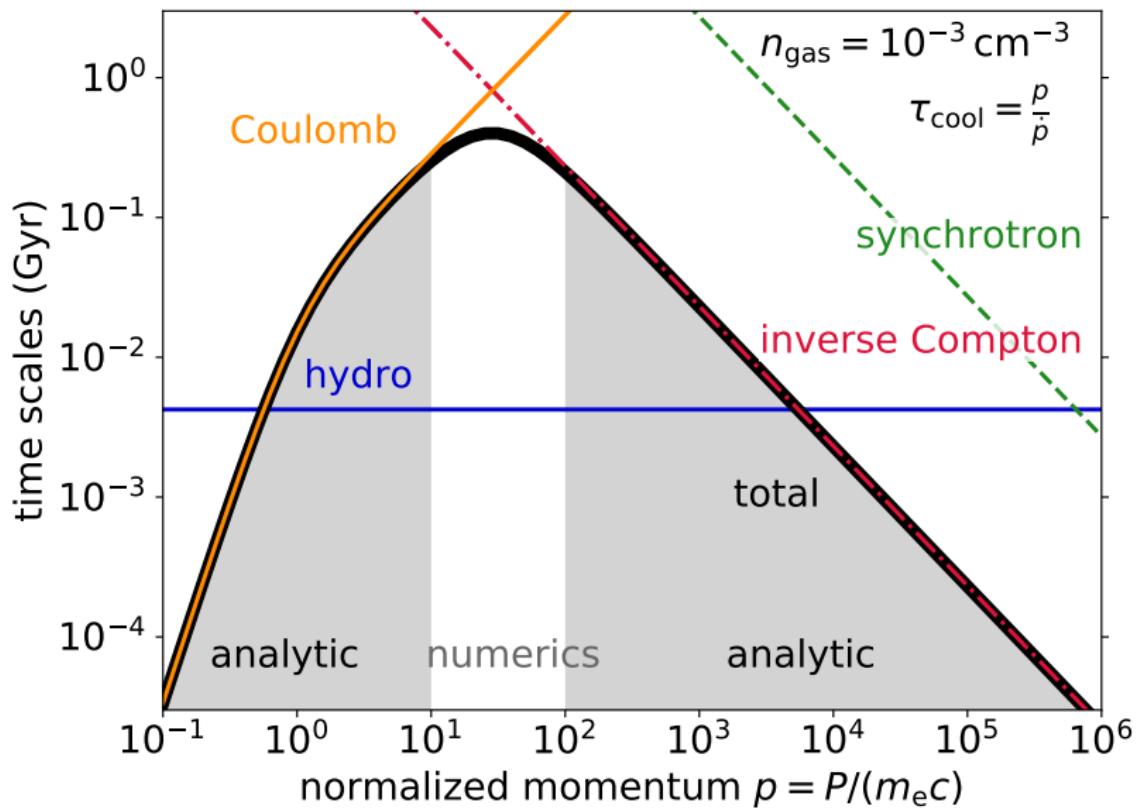
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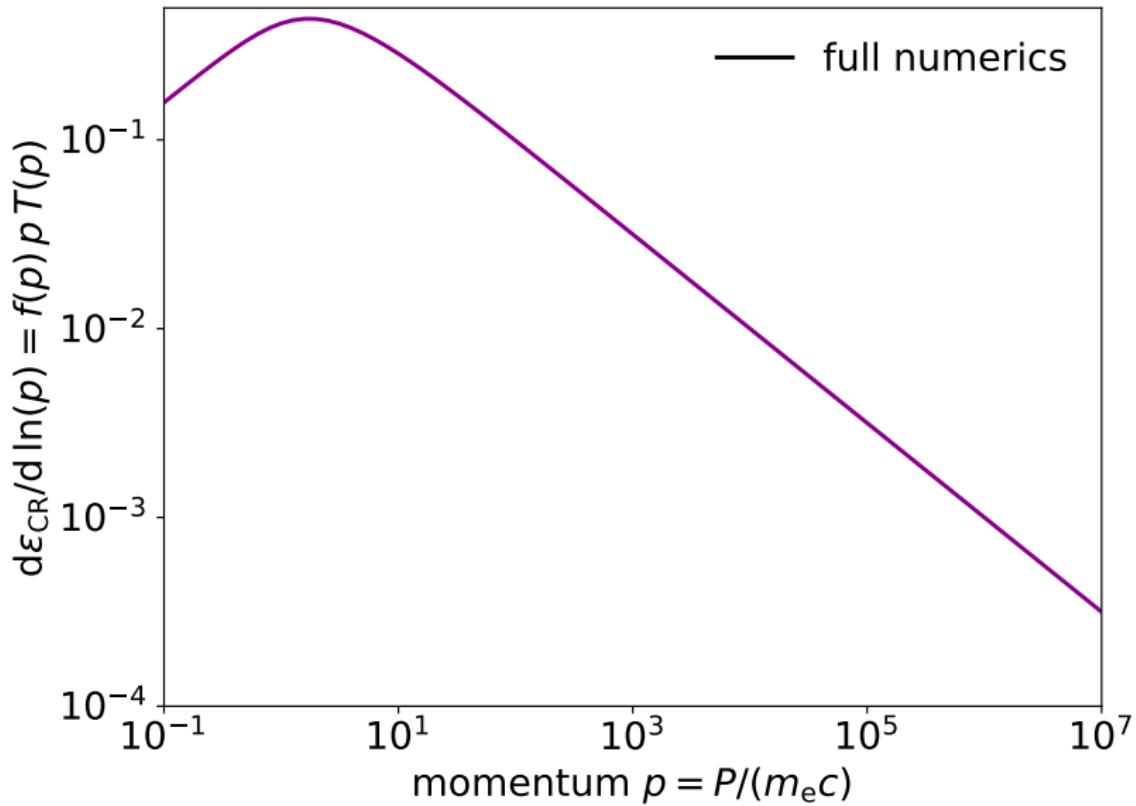
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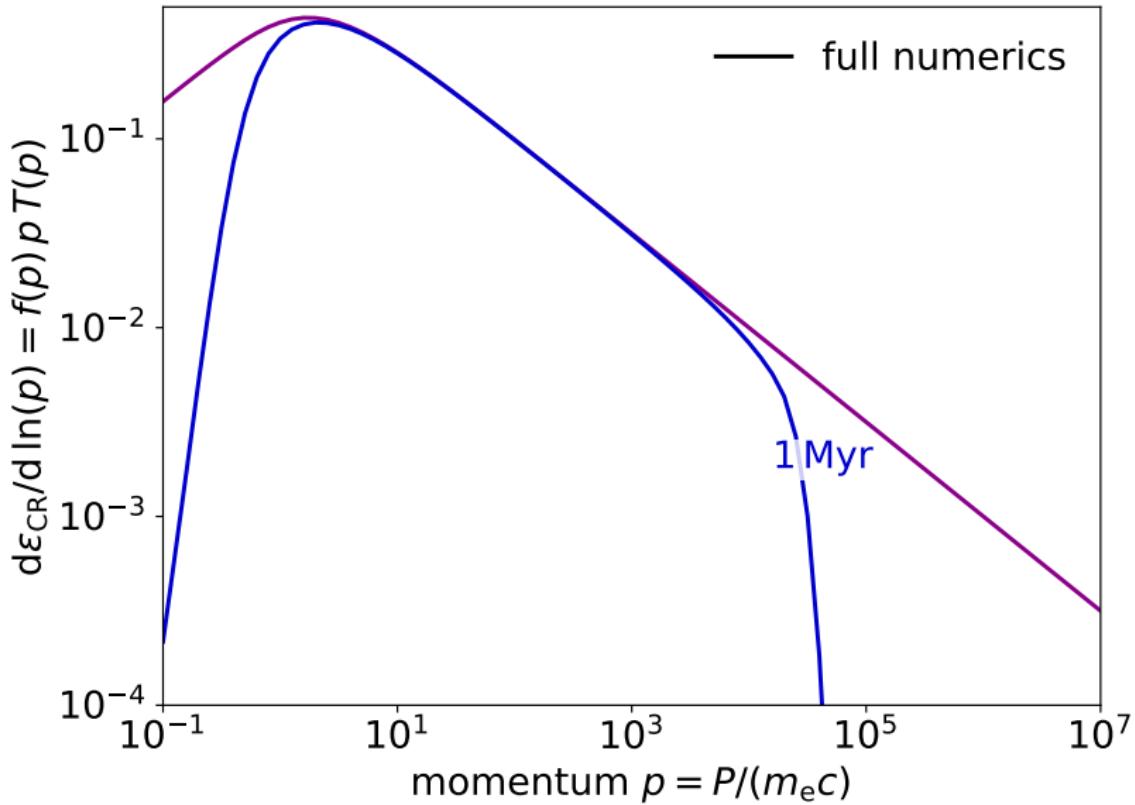
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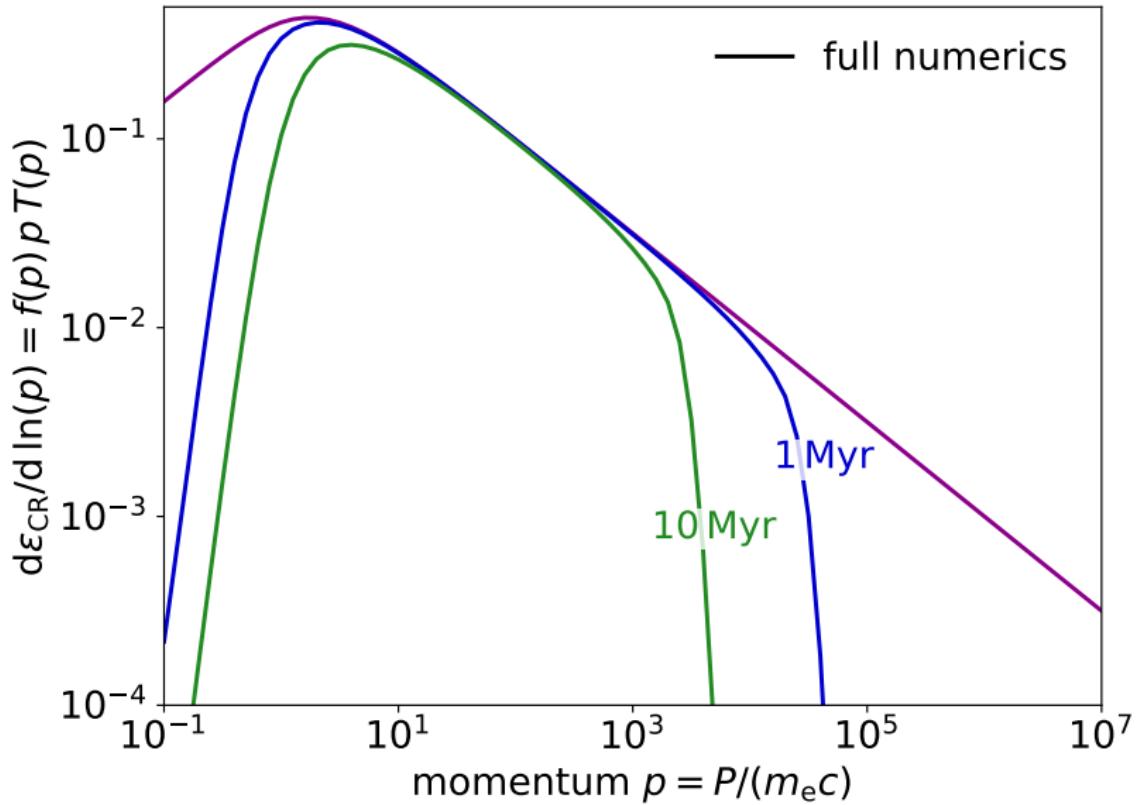
Freely Cooling



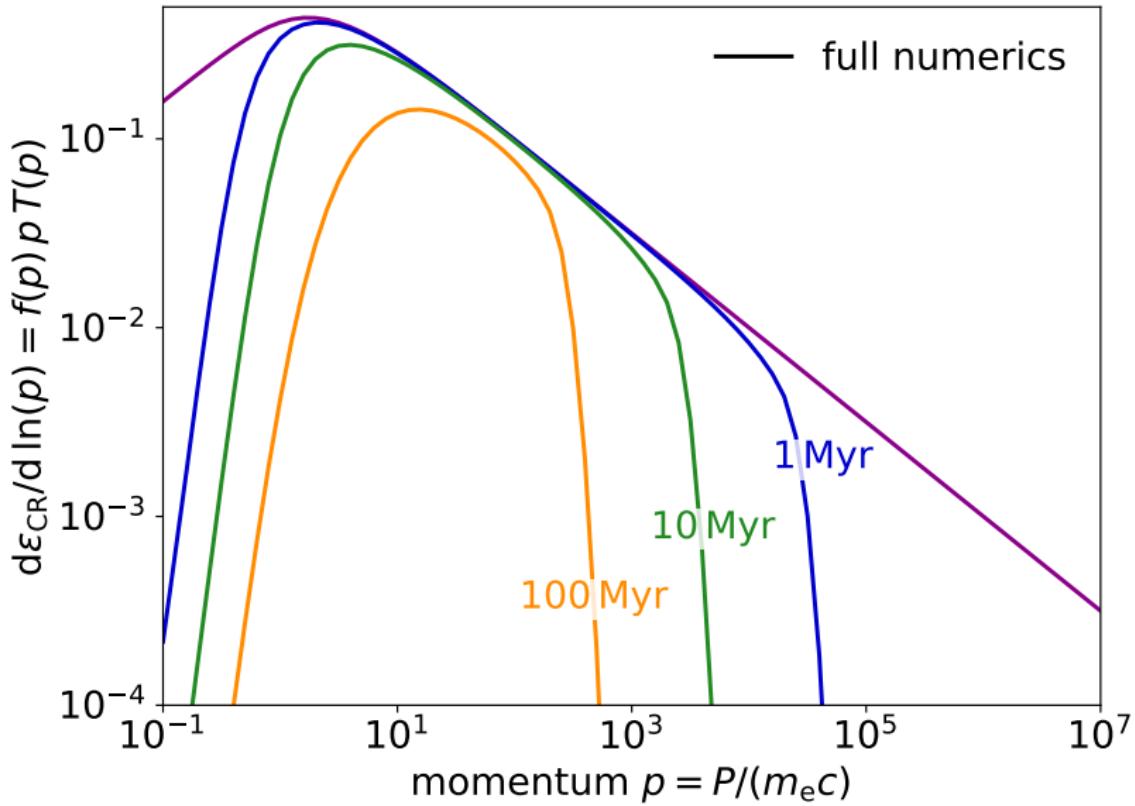
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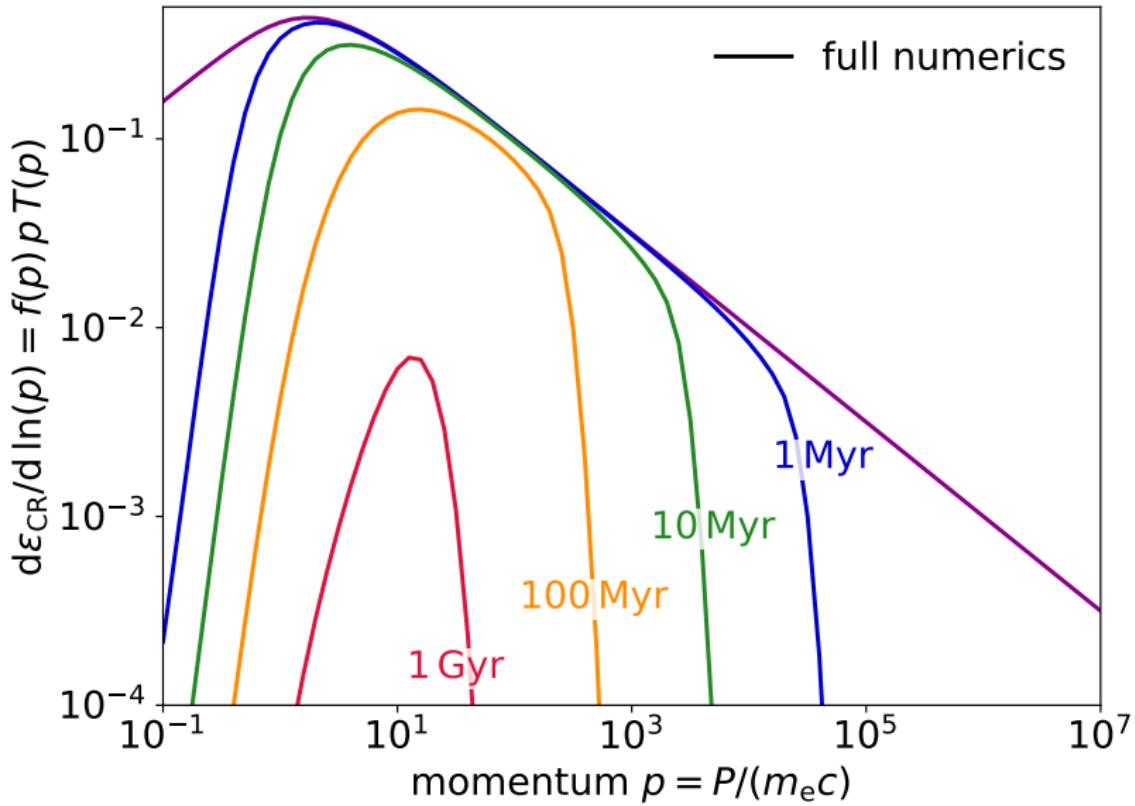
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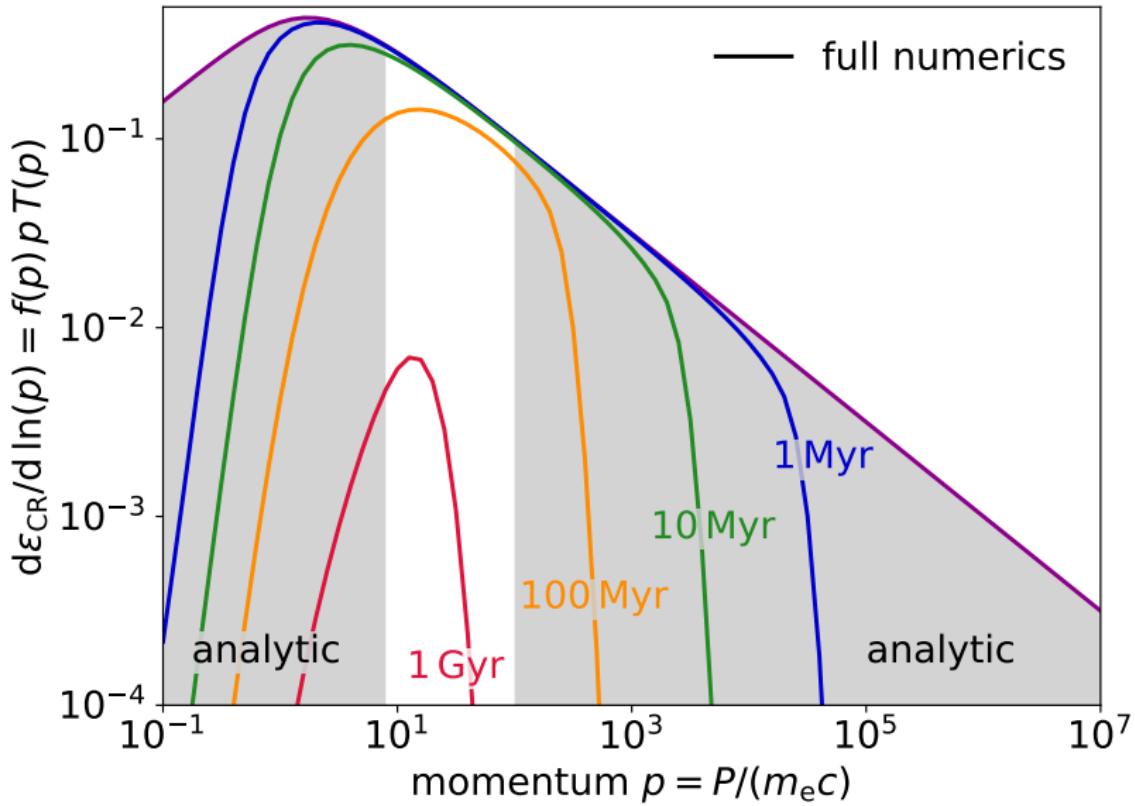
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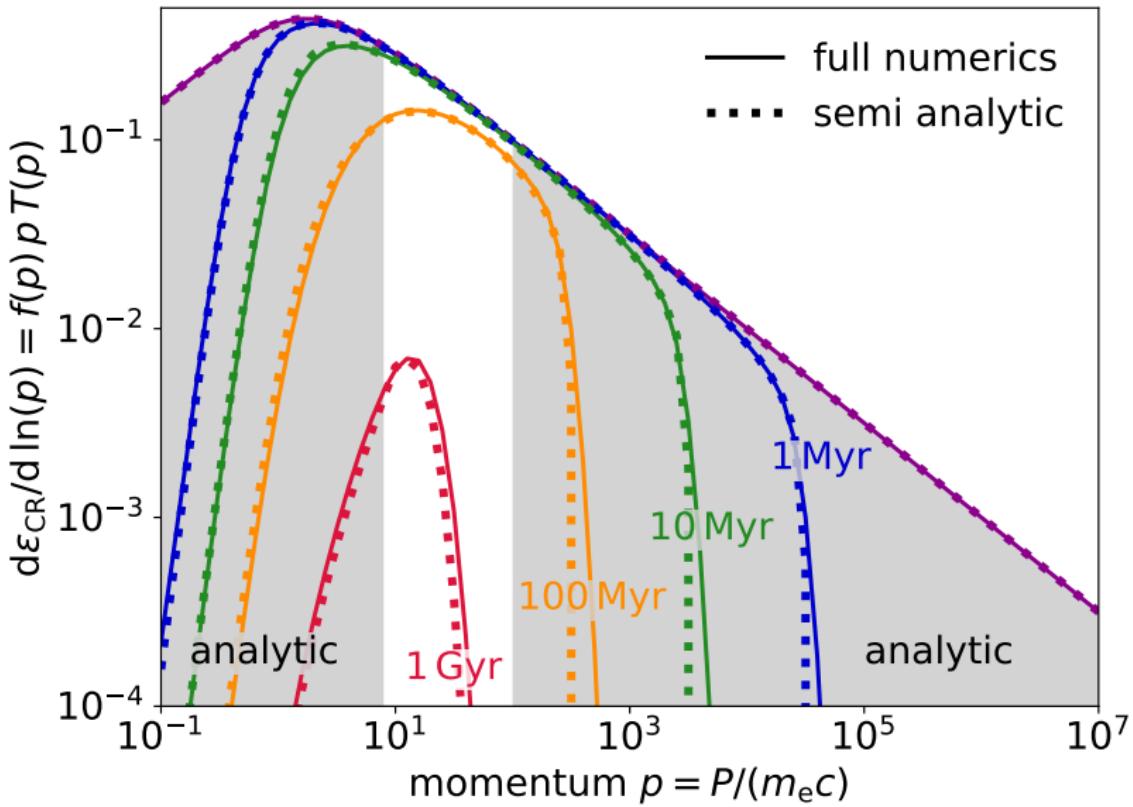
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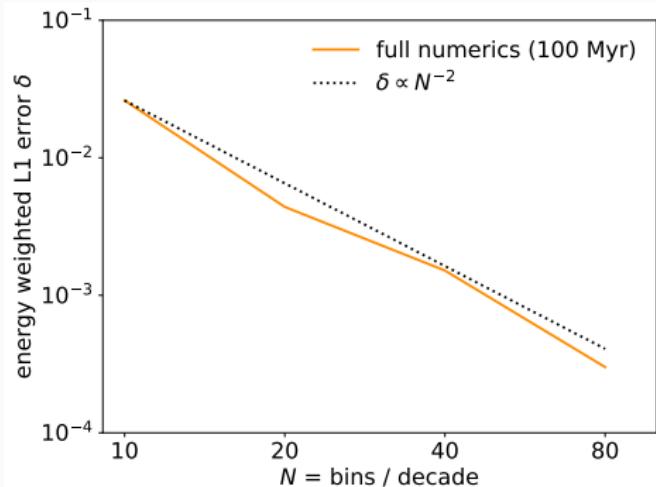
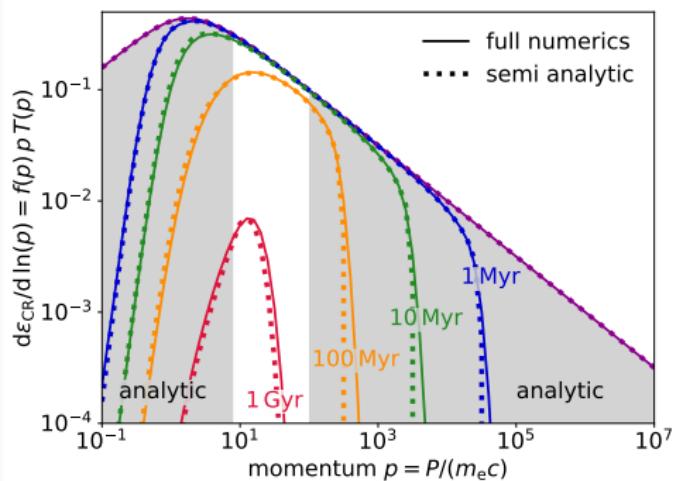
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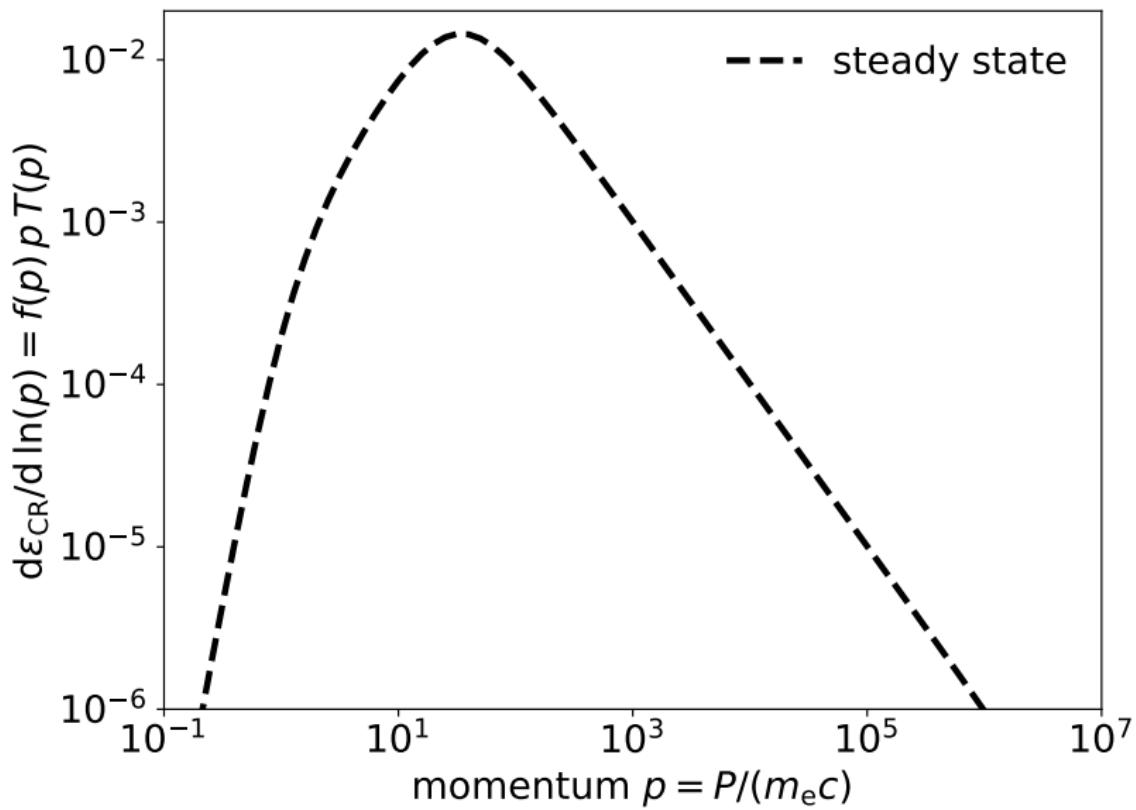
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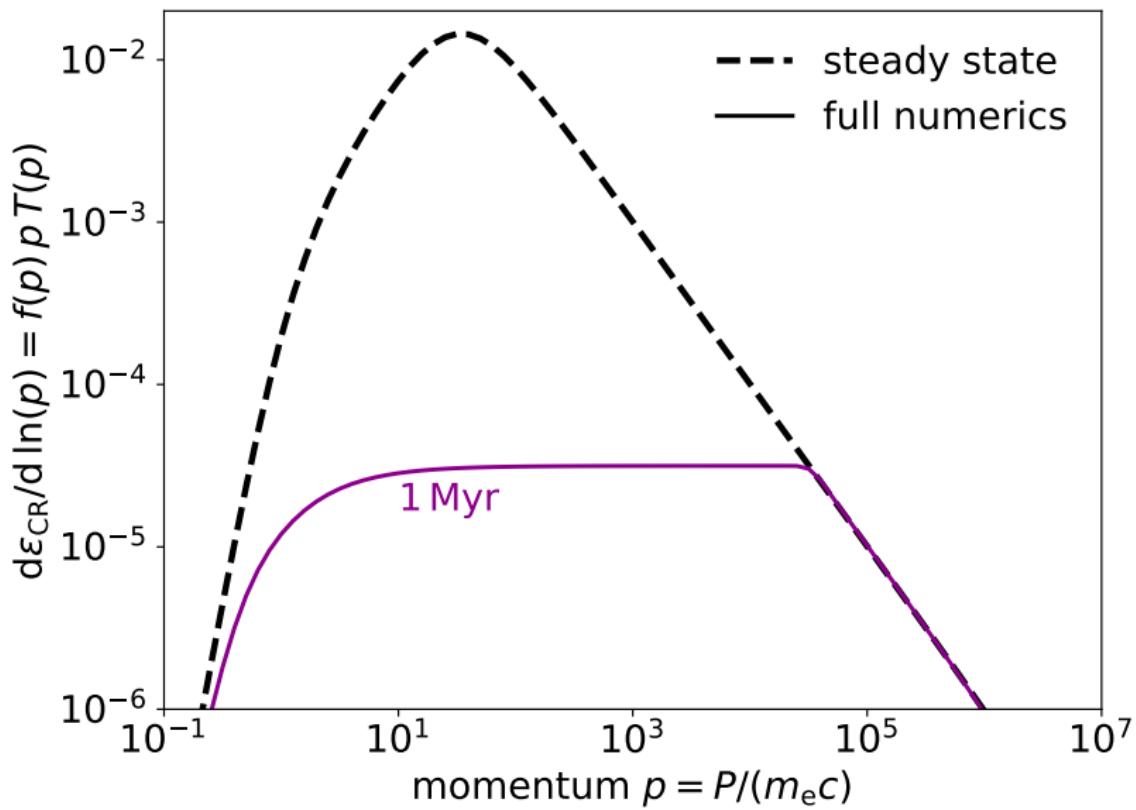
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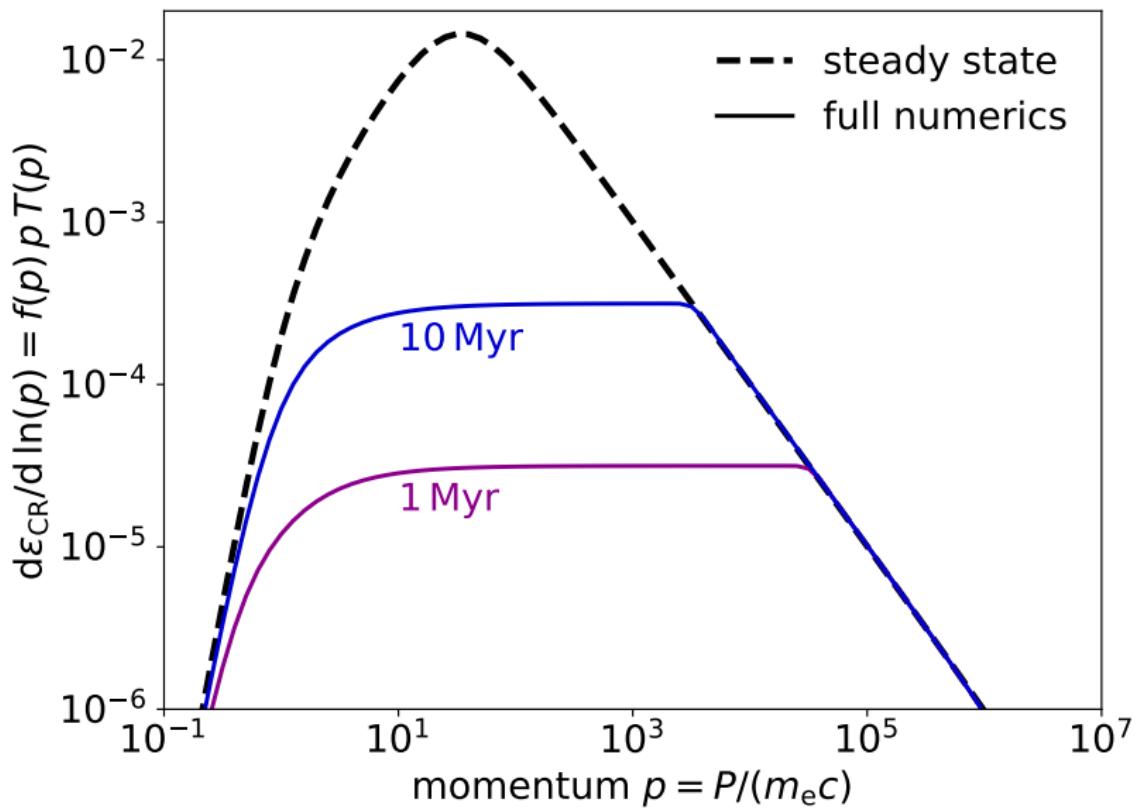
Steady State: Cooling + Continuous Injection



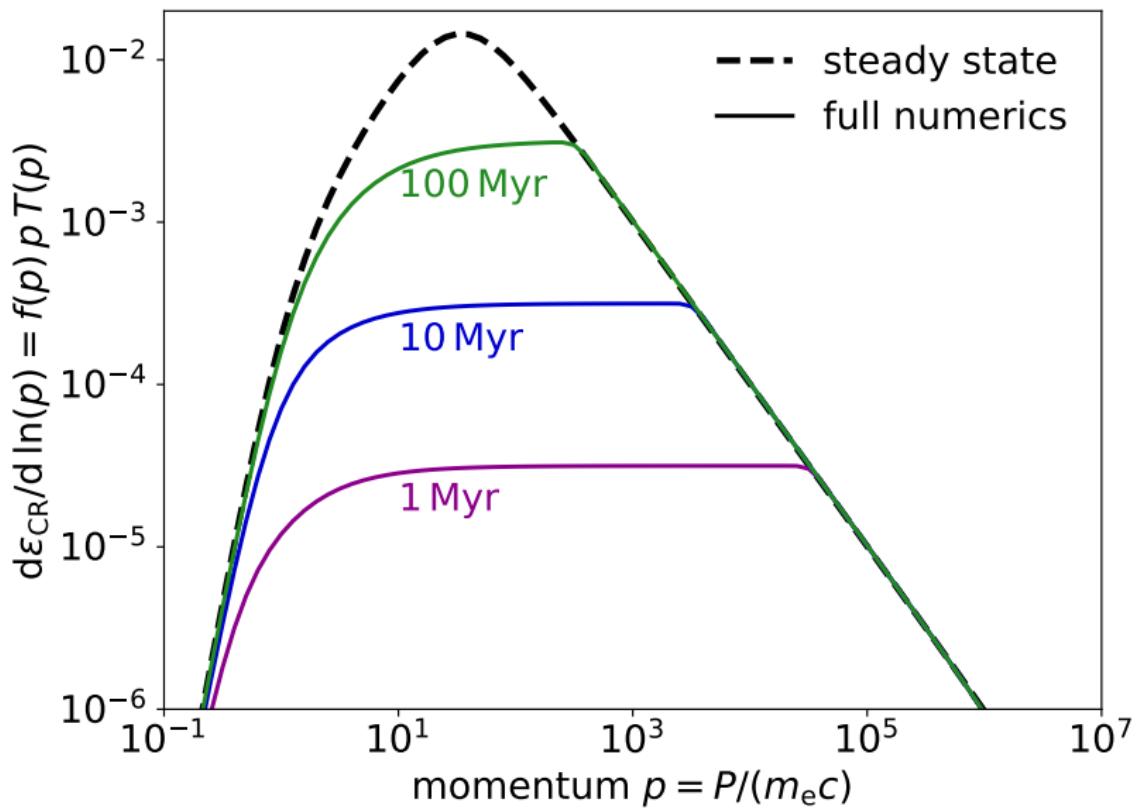
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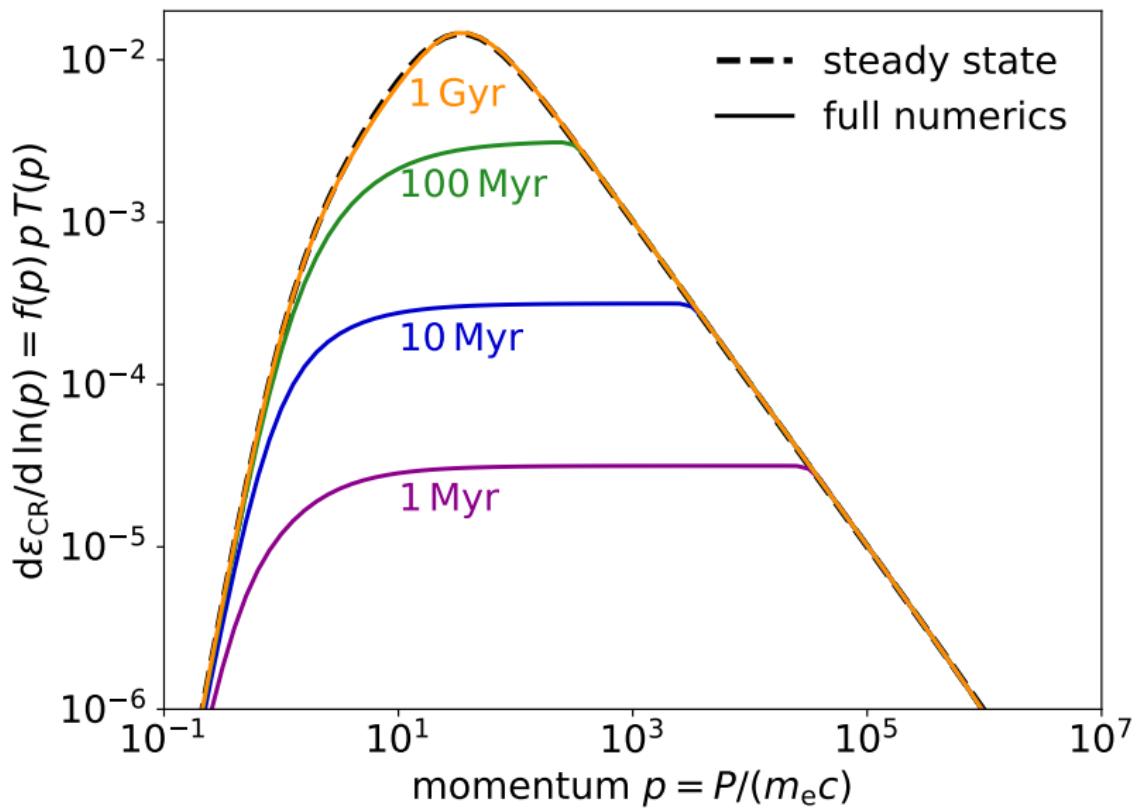
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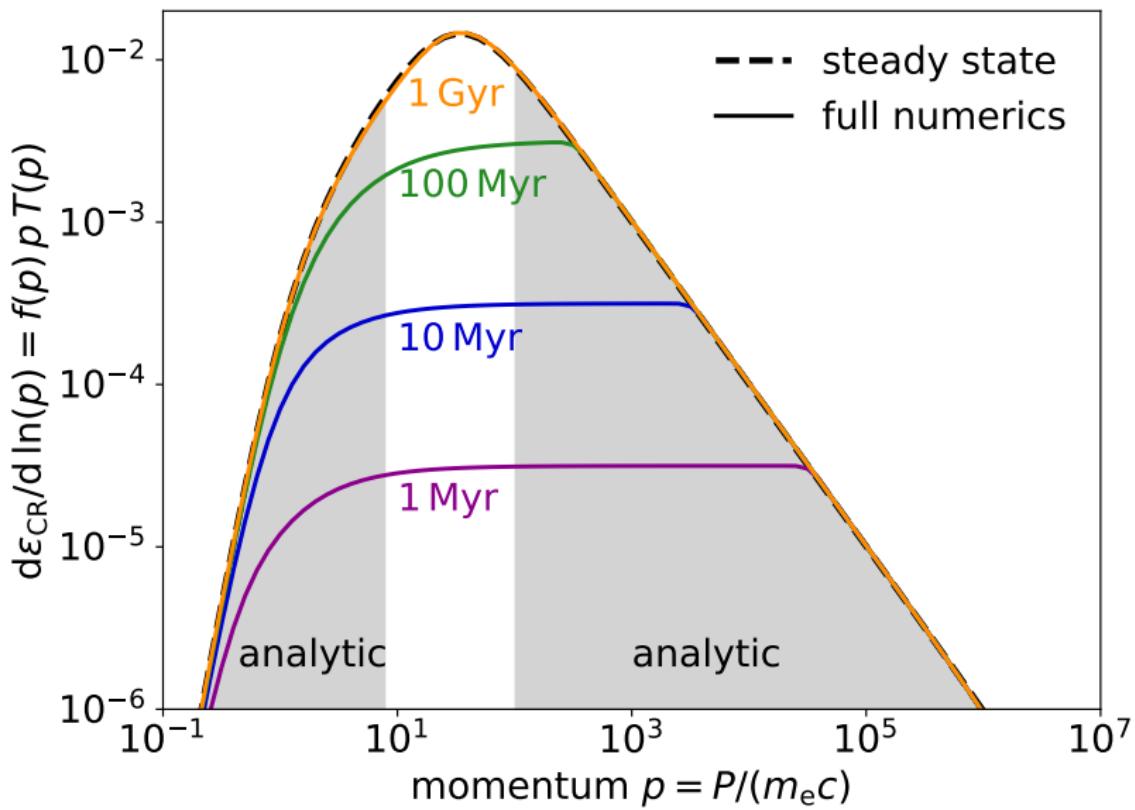
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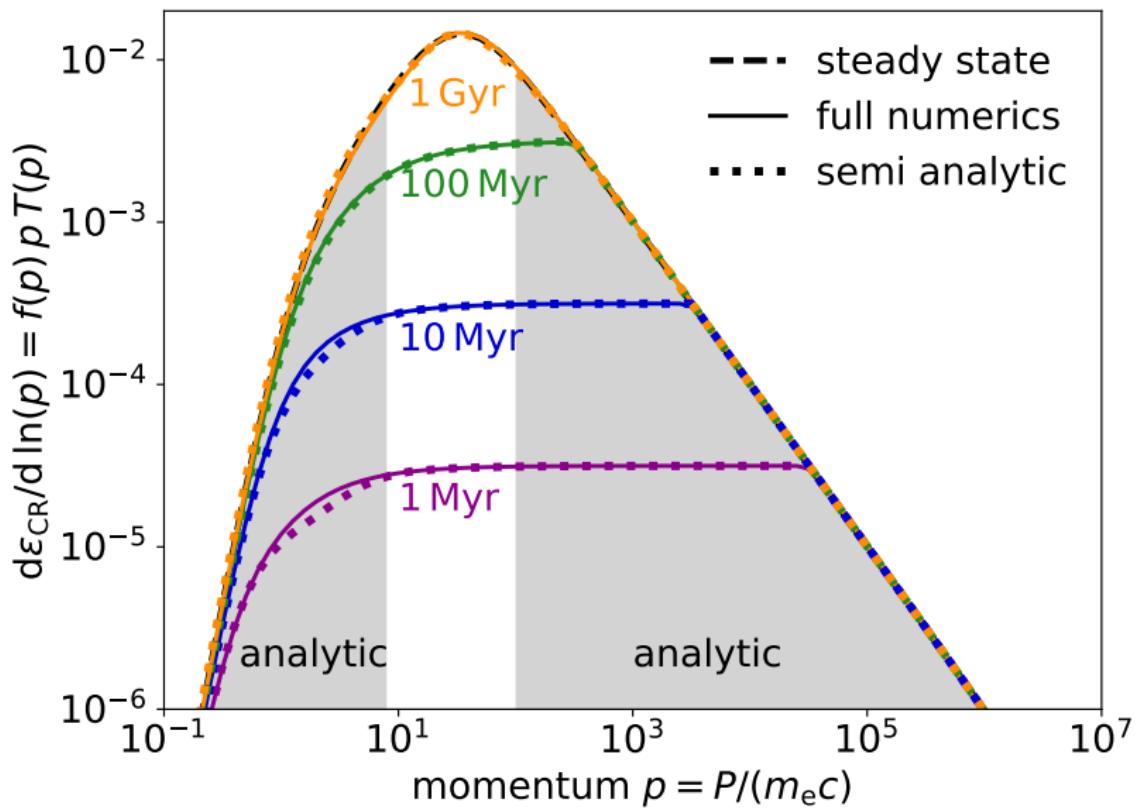
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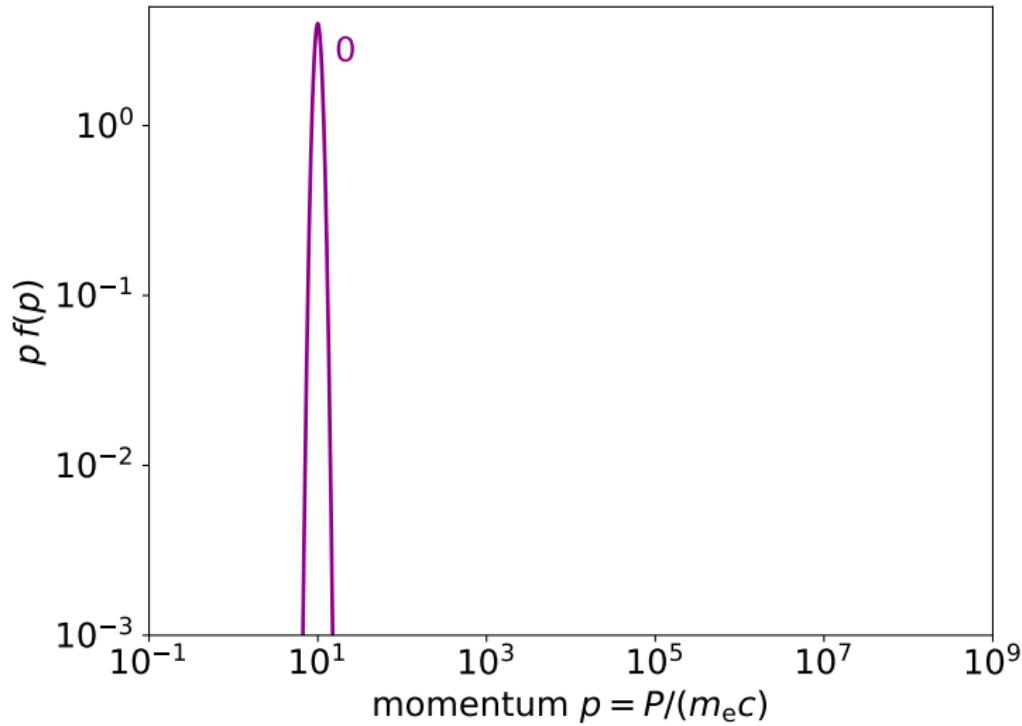


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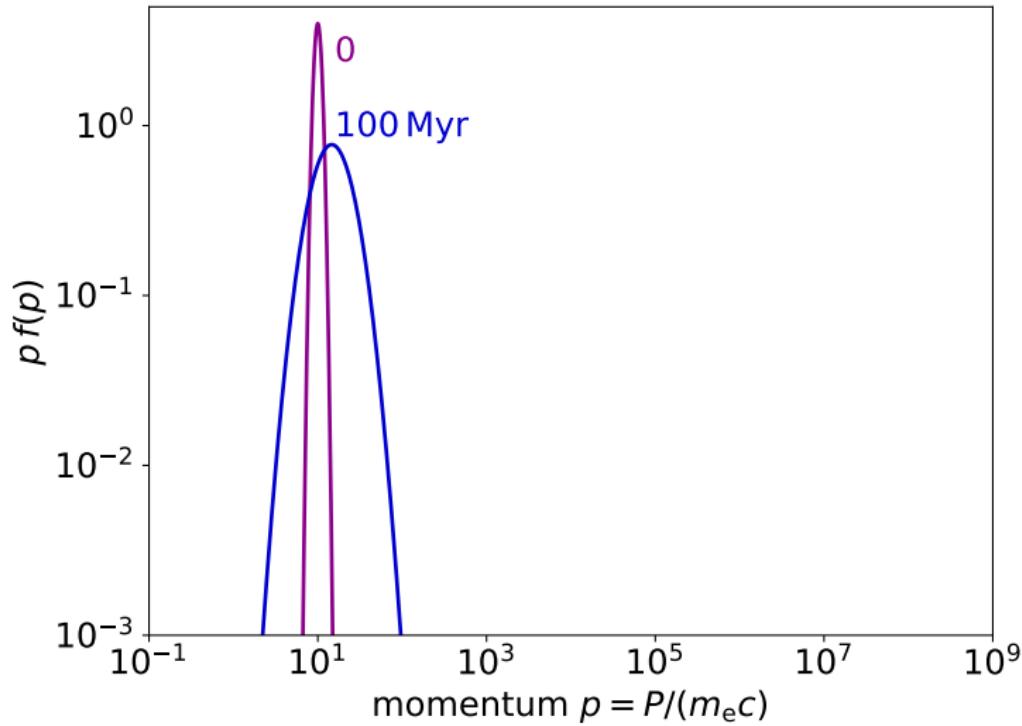
Fermi II Reacceleration

diffusion $D_{pp} \propto p^2$, $\tau_D = 200$ Myr



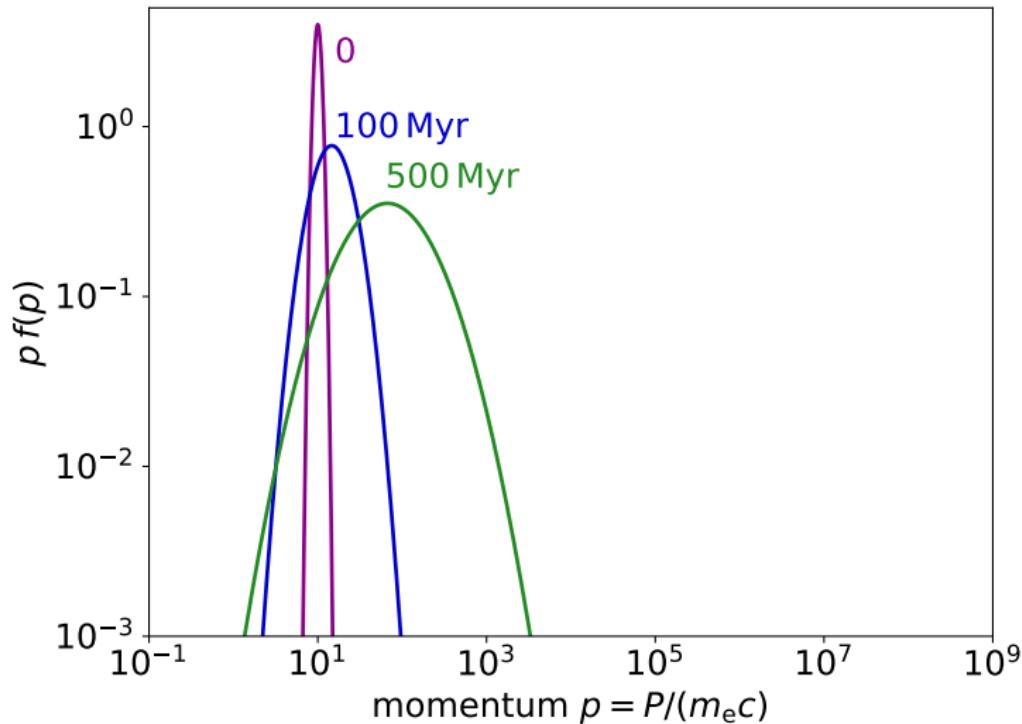
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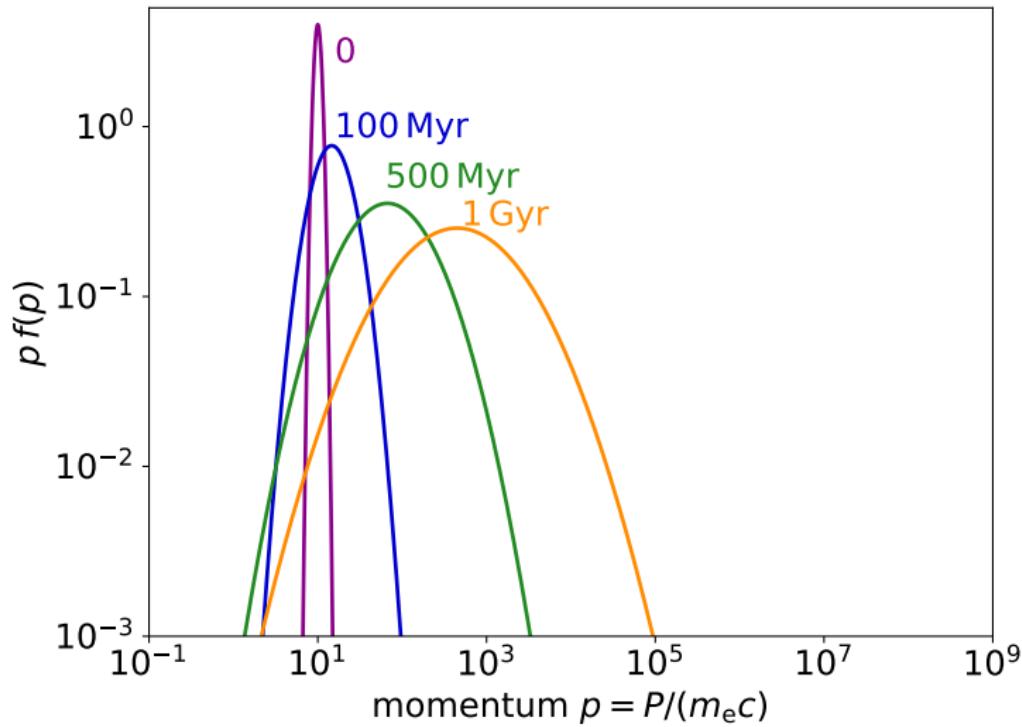
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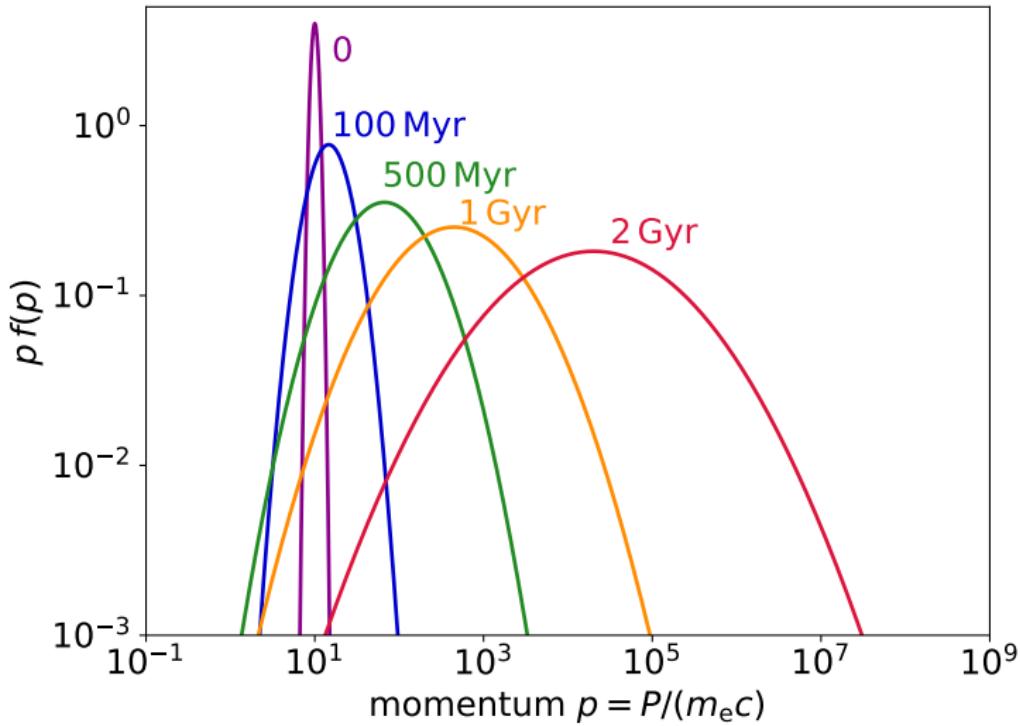
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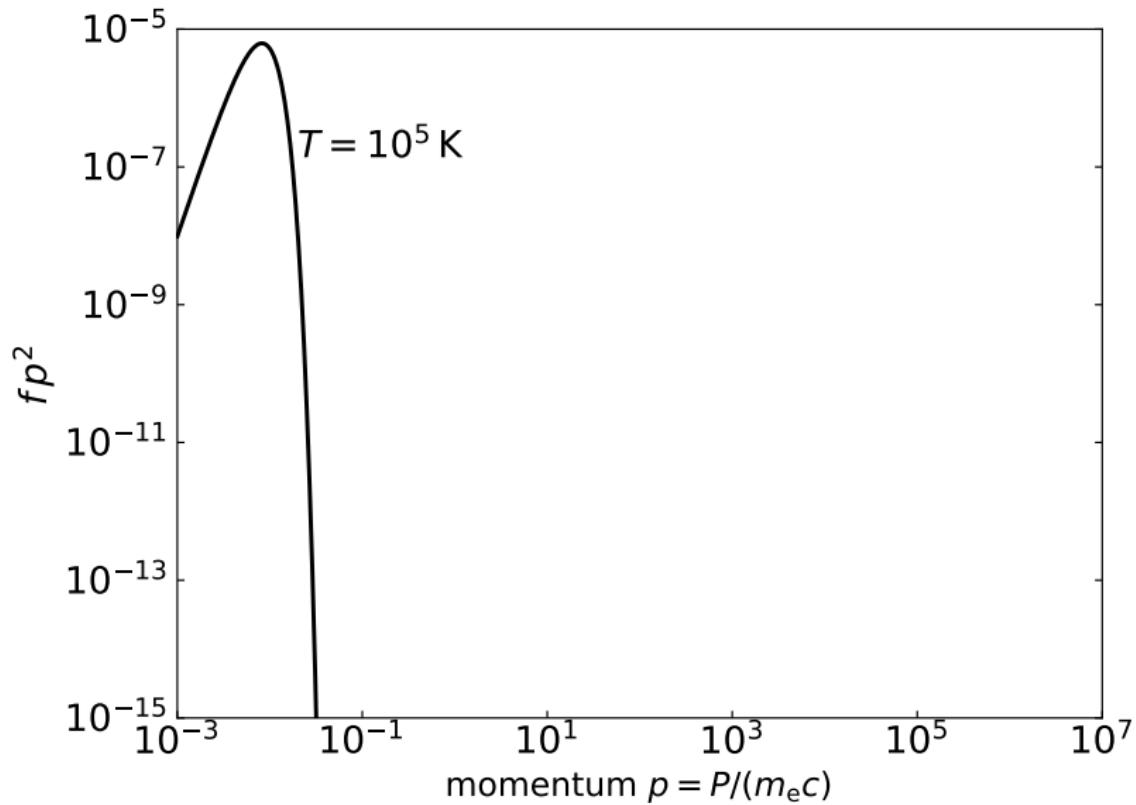


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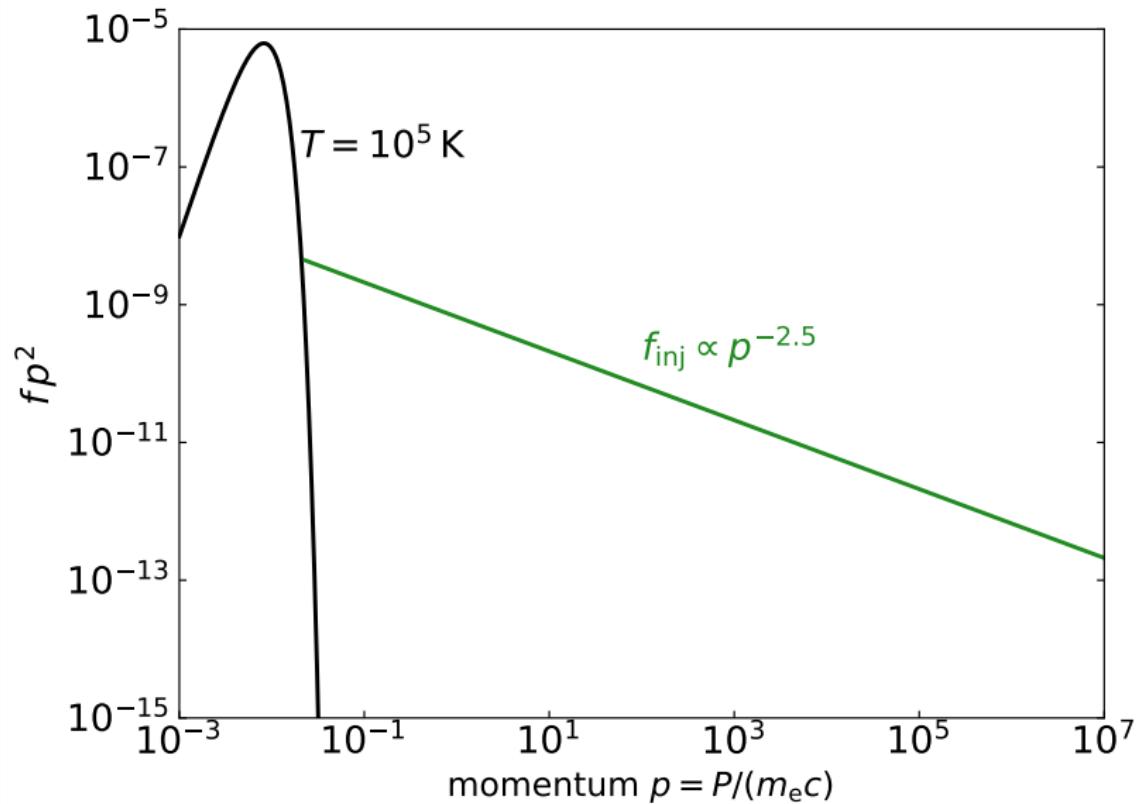
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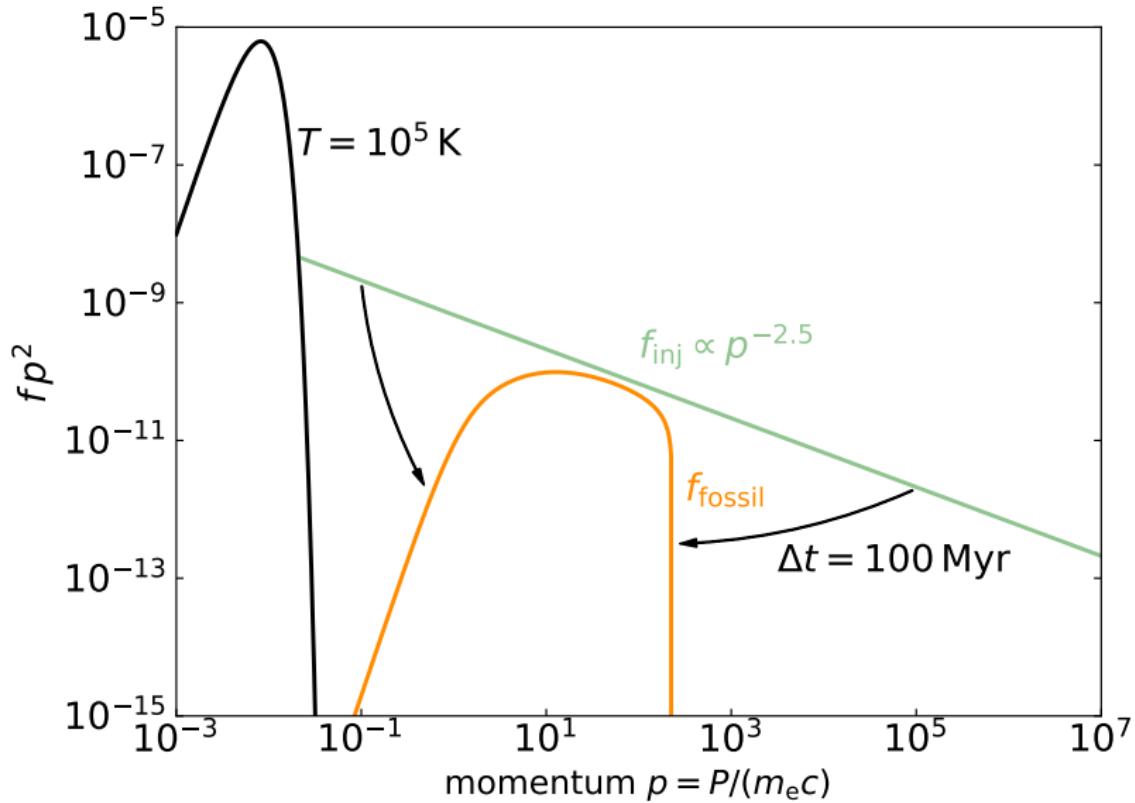
Fermi I / Diffusive Shock Acceleration



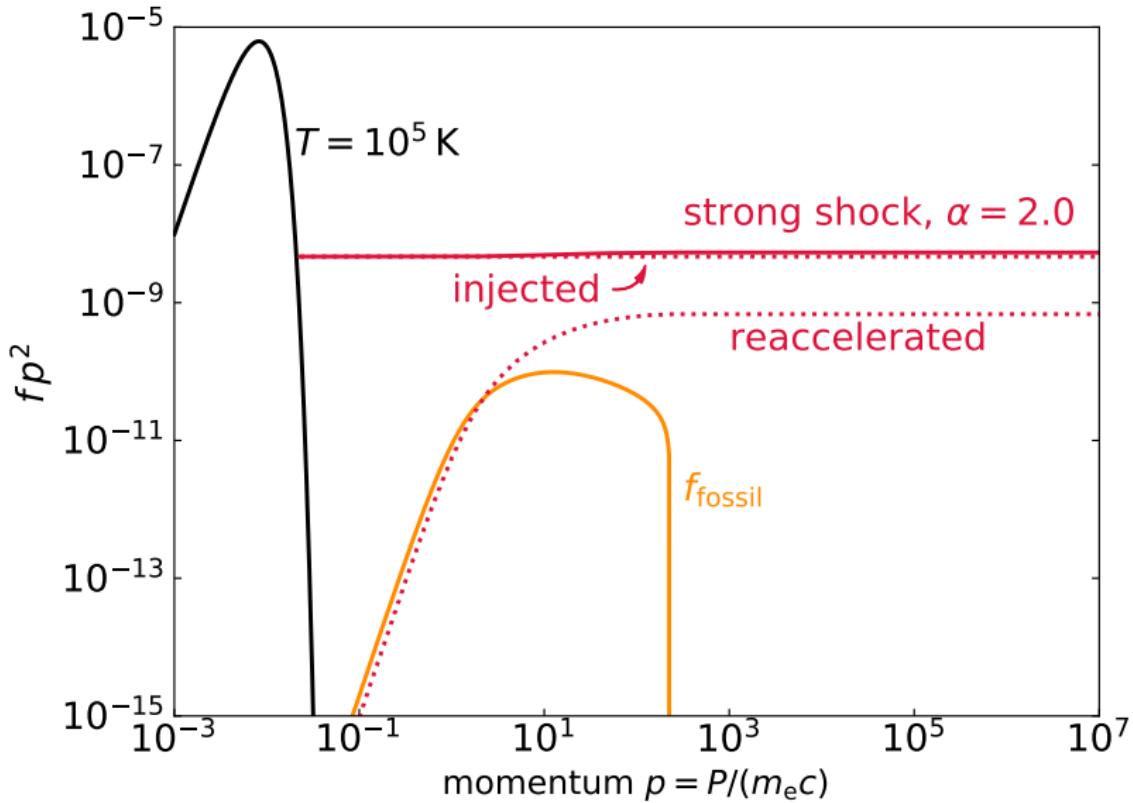
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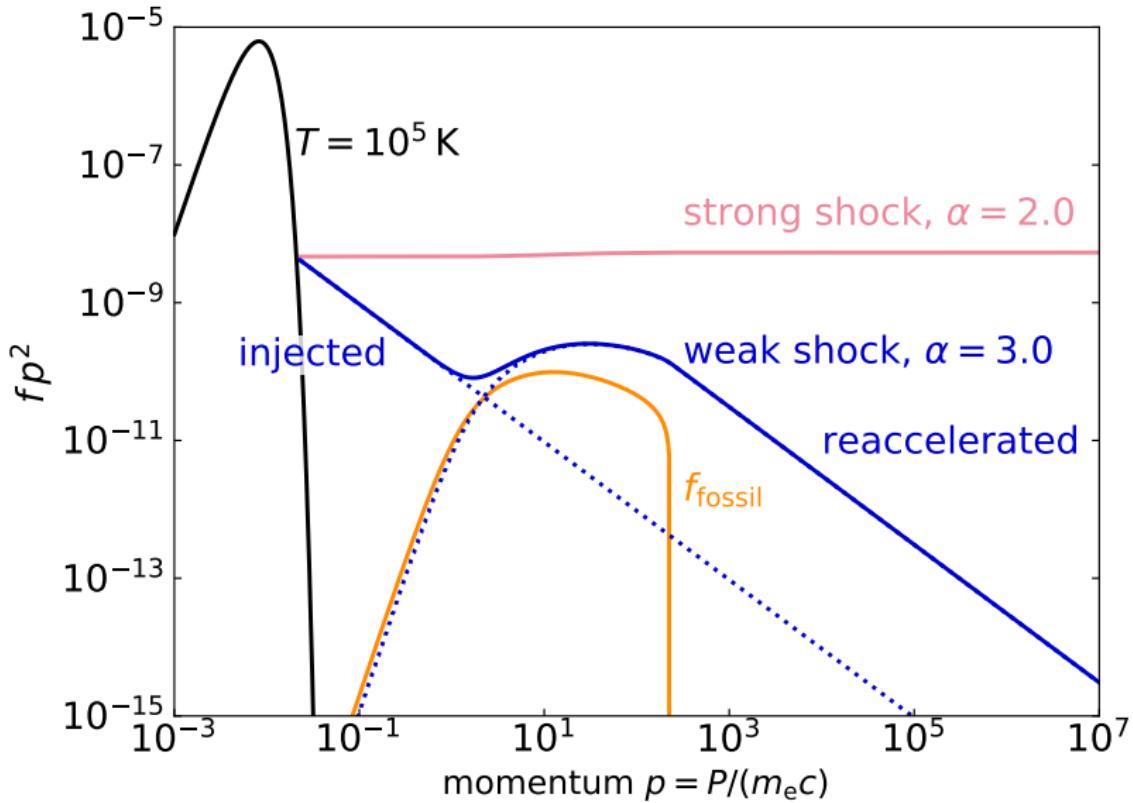
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Fermi I / Diffusive Shock Acceleration



Outlook & Applications

- cosmological hydrodynamical simulations with CRe
- CRe emission from supernova remnants
- CRe model for Fermi bubbles

References

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