

Asymmetric Reheating by Primordial Black Holes

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DPF21, Florida State University

July 14, 2021

DM exists (Gravitational Evidence):

Rotation curves, CMB, Structure formation, Gravitational lensing

null result of search for possible **non-gravitational interactions of DM**:
motivates idea of dark sectors coupled only **gravitationally** to visible sector.

challenge: populating the dark sector

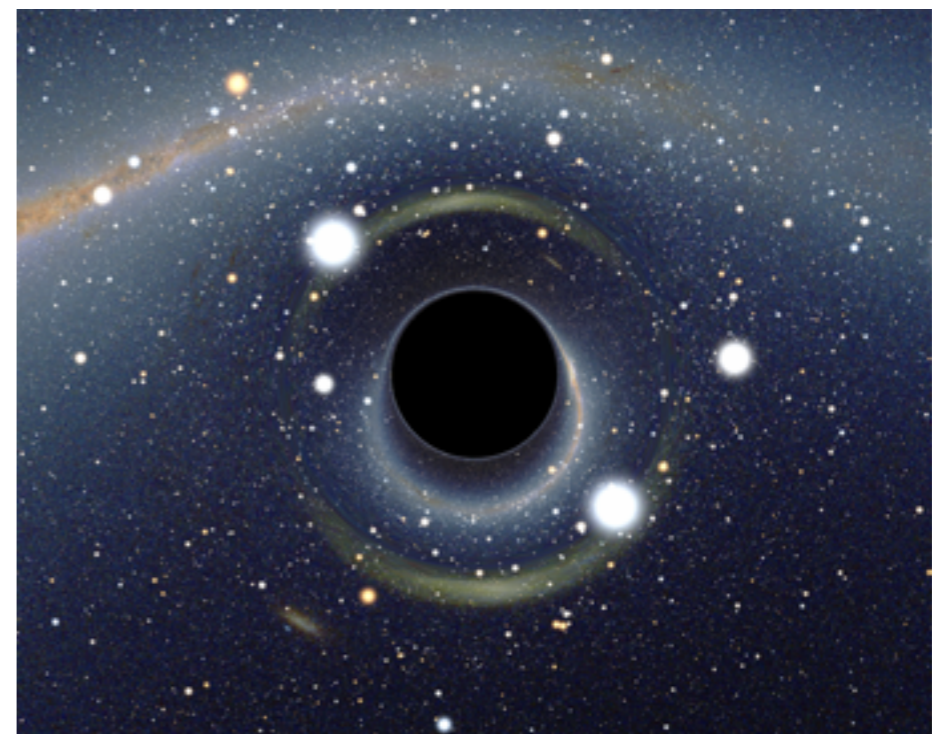
Example:

reheating by inflaton, populating both dark and visible sectors.

but two sectors can communicate by exchanging inflaton, possibility of thermalization, washes out initial asymmetry in temperatures.

Novel mechanism:

Hawking evaporation of PBHs!



Populating a self-interacting dark sector by relativistic and far from equilibrium particles:

$$\mathcal{L} = \frac{1}{2} \partial_\mu \chi \partial^\mu \chi - \frac{1}{2} m_\chi \chi^2 - \frac{m_\chi \lambda}{3!} \chi^3 - \frac{\lambda^2}{4!} \chi^4 \quad 1 \lesssim \lambda \lesssim 4\pi$$

populating: $t = \tau : n_\chi(\tau), \rho_\chi(\tau)$

particles become non-relativistic: $t = t_m : \bar{E}_\chi \sim m_\chi$

toward equilibrium:

$$\frac{\Gamma_{\chi,2 \rightarrow 2}(t)}{H(t)} \sim \frac{n_\chi(t) / \bar{E}_\chi(t)^2}{H(t)} \propto a(t), \quad \tau \lesssim t \lesssim t_m$$

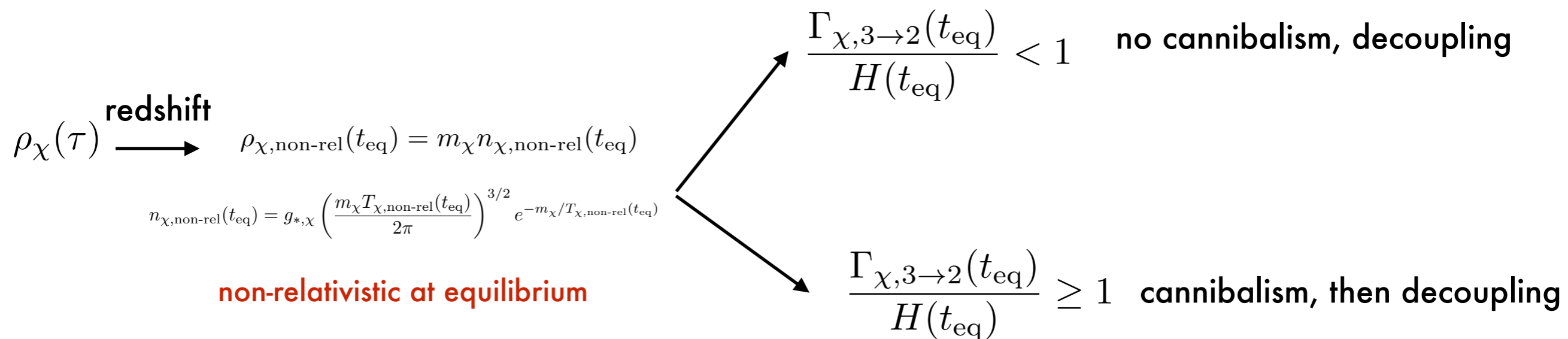
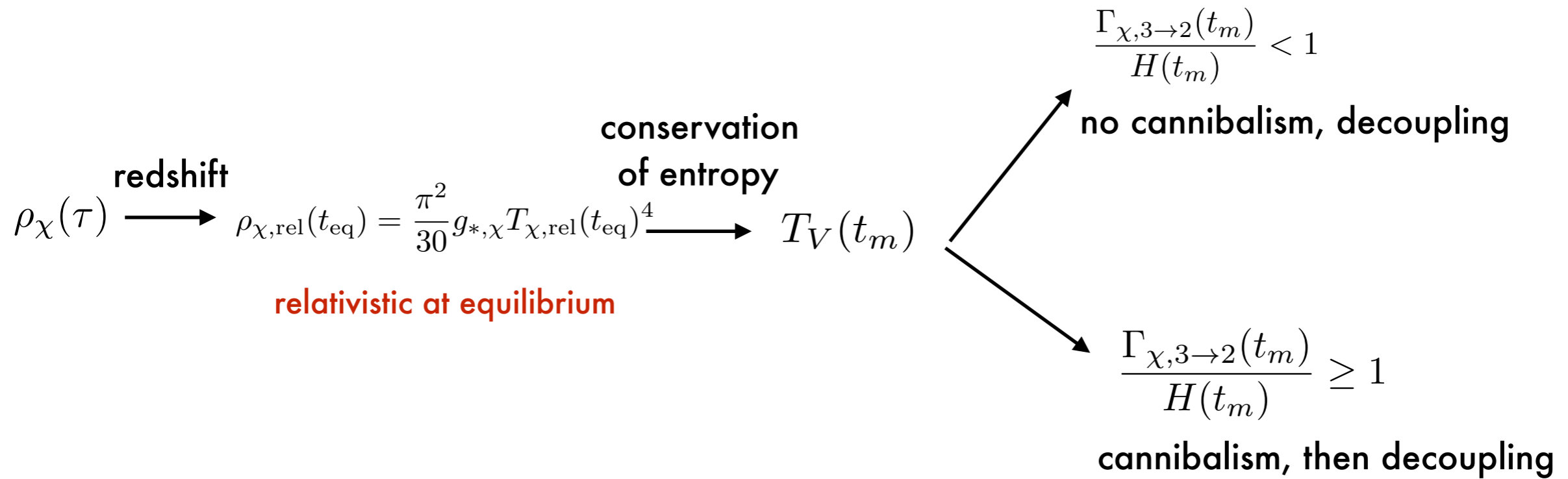
kinetic equilibrium: elastic scattering processes, lead to a temperature and non-zero chemical potential

$$\frac{\Gamma_{\chi,2 \rightarrow 3}(t)}{H(t)} \sim \frac{n_\chi(t) m_\chi^2 / T_\chi^4(t)}{H(t)} \propto a^3(t), \quad t_{\text{kin-eq}} \lesssim t \lesssim t_m$$

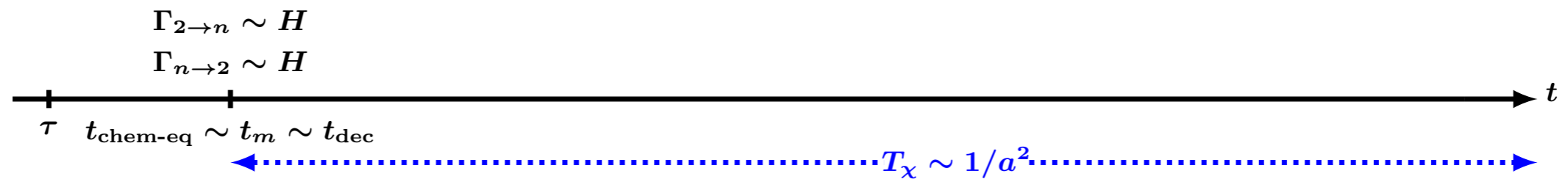
Chemical equilibrium: number changing processes, give rise to a temperature and zero chemical potential

decoupling:

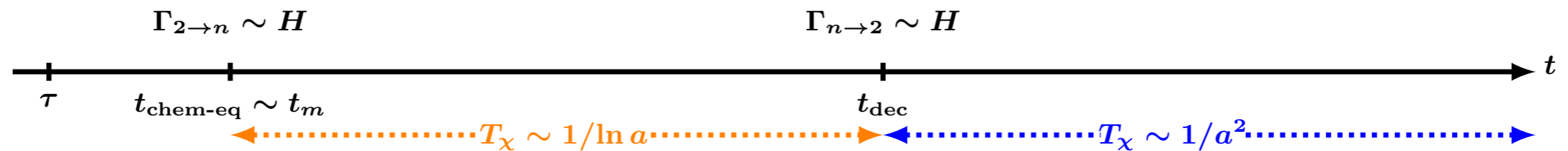
$$\frac{\Gamma_{\chi,3 \rightarrow 2}(t)}{H(t)} \sim \frac{n_\chi^2(t) / m_\chi^5}{H(t)}, \quad t_m \lesssim t \lesssim t_{\text{dec}}$$



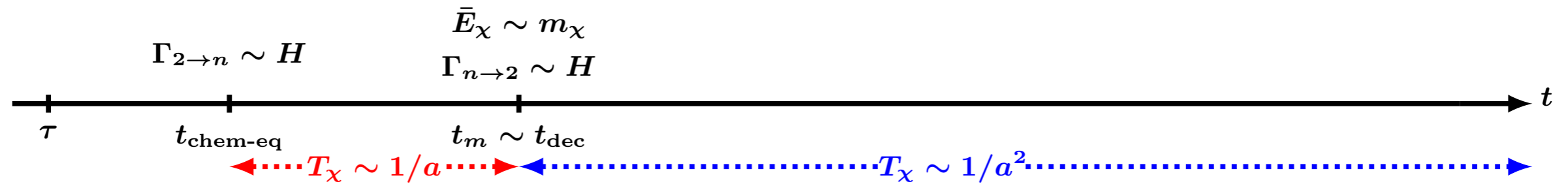
non-relativistic, no cannibalism (NRNC):



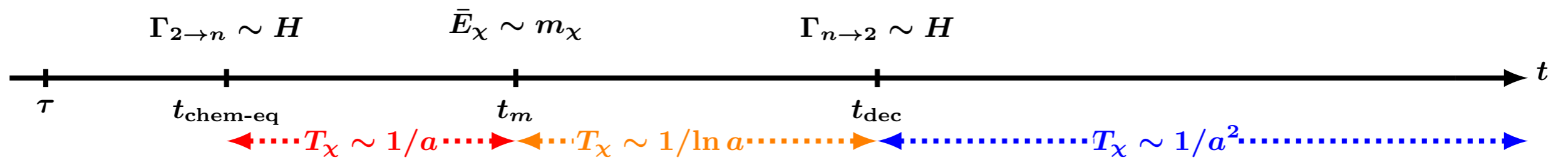
non-relativistic, with cannibalism (NRC):



relativistic, no cannibalism (RNC):



relativistic, with cannibalism (RC):



Populating a self-interacting dark sector by Hawking evaporation of PBHs:

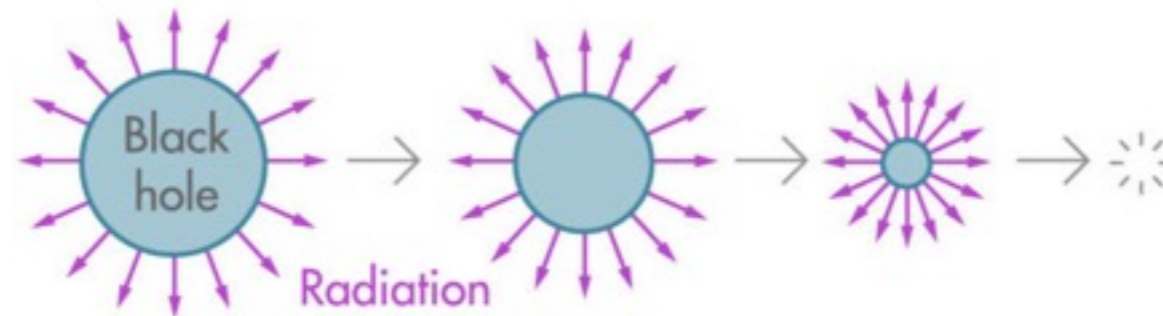
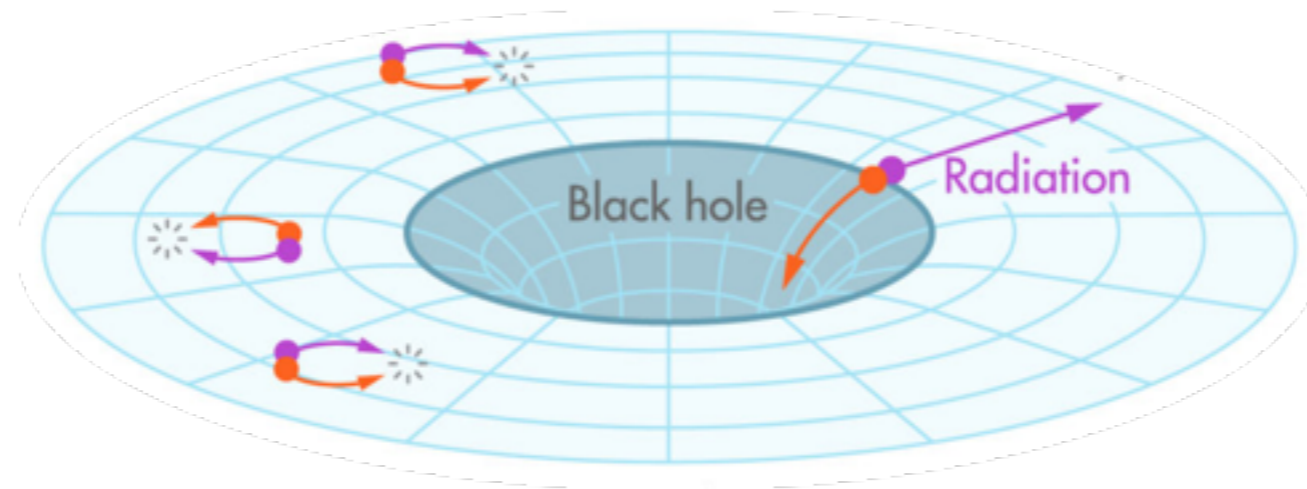
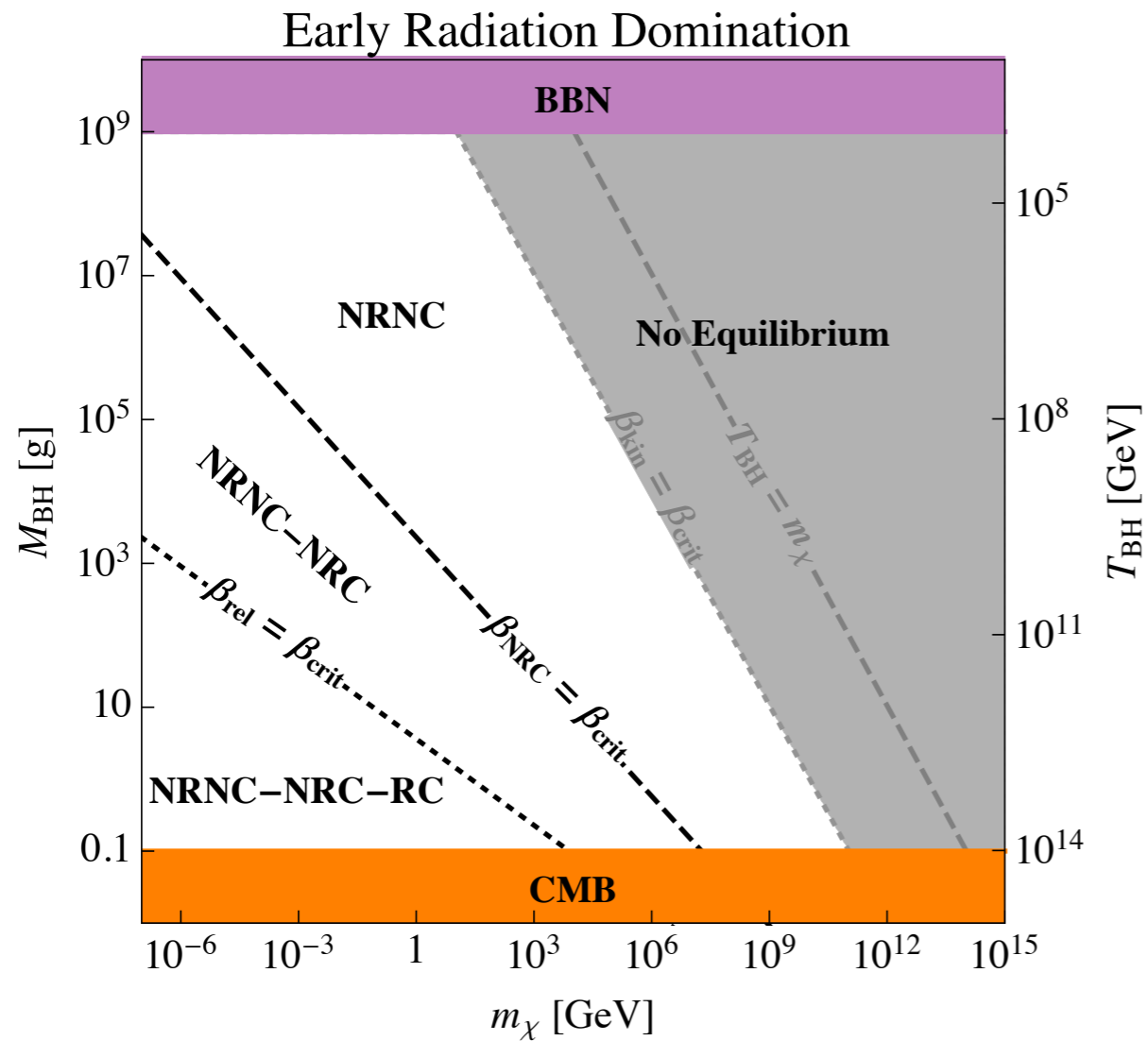
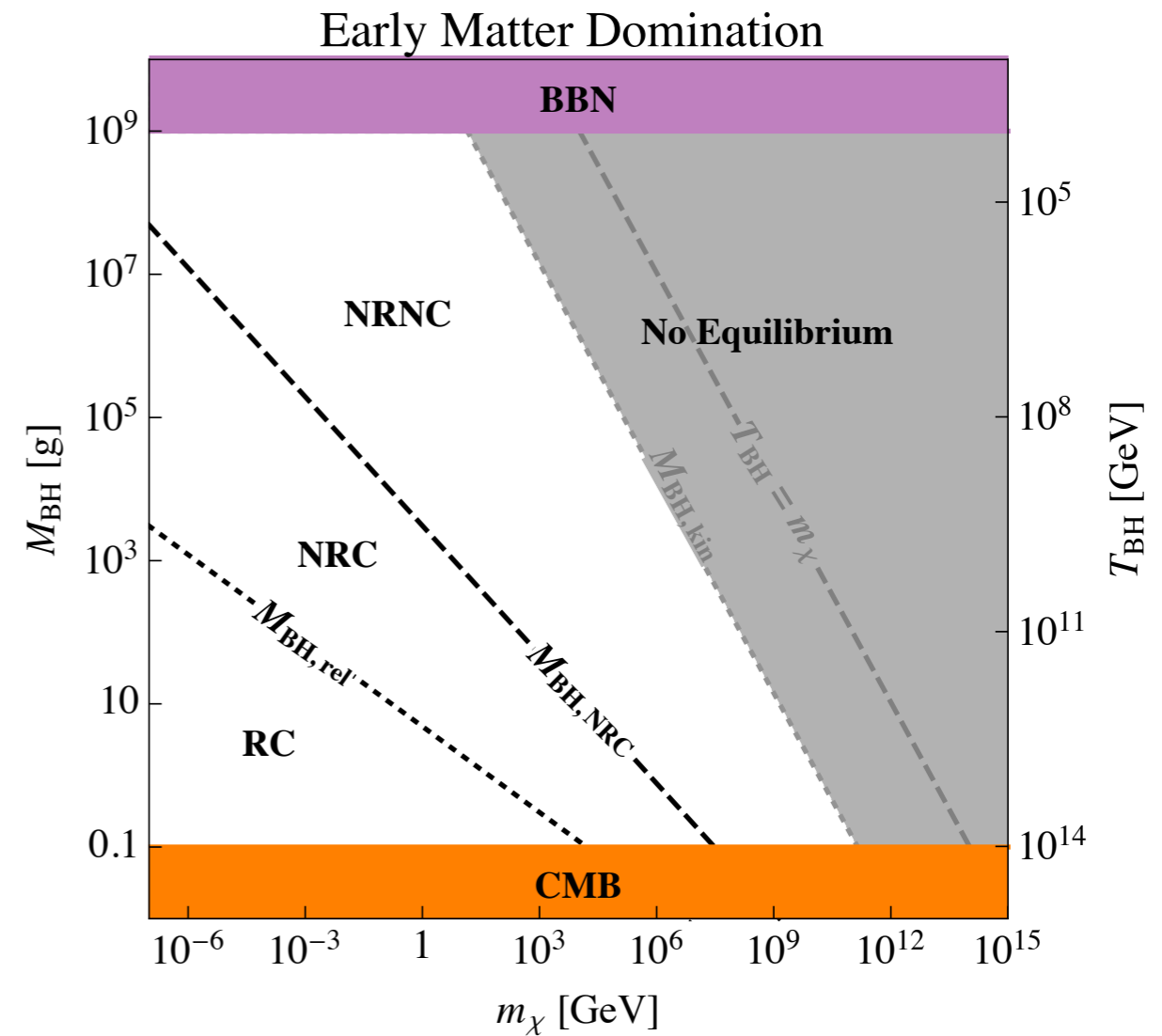


image credit: [Quantamagazine](#)

	Thermal History	Early Radiation Domination	Early Matter Domination
$\beta \equiv \frac{\rho_{\text{BH}}(t_f)}{\rho_{\text{R}}(t_f)}$	NRNC (non-relativistic, no cannibalism)	$\beta_{\text{kin}} \lesssim \beta \lesssim \beta_{\text{NRC}}$	$M_{\text{BH, NRC}} \lesssim M_{\text{BH}} \lesssim M_{\text{BH, kin}}$
	NRC (non-relativistic, cannibalism)	$\beta_{\text{NRC}} \lesssim \beta \lesssim \beta_{\text{rel}}$	$M_{\text{BH, rel}} \lesssim M_{\text{BH}} \lesssim M_{\text{BH, NRC}}$
	RNC (relativistic, no cannibalism)	$\beta_{\text{rel}} \lesssim \beta \lesssim \beta_{\text{RC}}$	$M_{\text{BH, RC}} \lesssim M_{\text{BH}} \lesssim M_{\text{BH, rel}}$
	RC (relativistic, cannibalism)	$\beta_{\text{RC}} \lesssim \beta \lesssim \beta_{\text{crit}}$	$M_{\text{BH}} \lesssim M_{\text{BH, RC}}$



$$\beta < \beta_{\text{crit}}$$

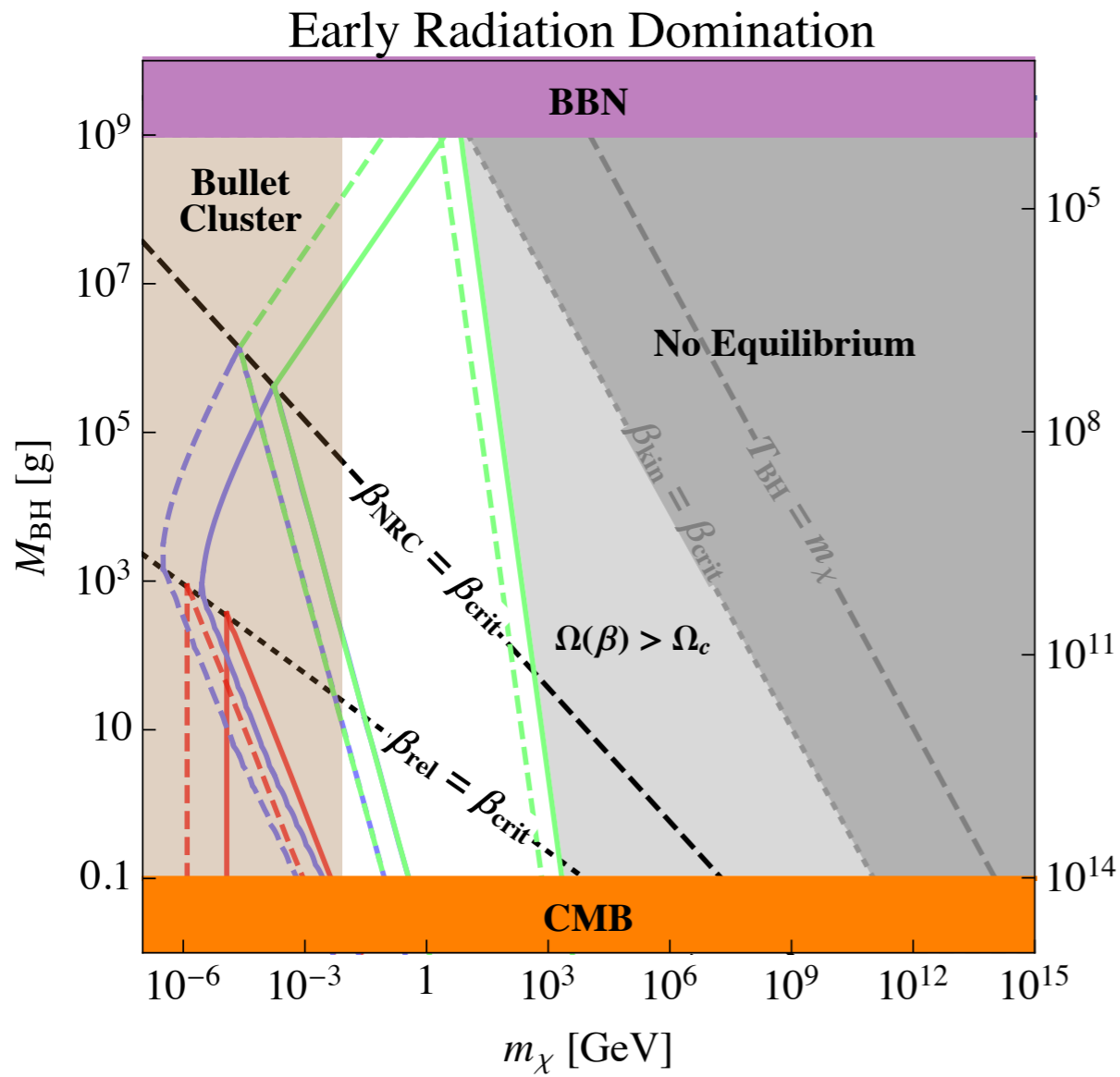


$$\beta \geq \beta_{\text{crit}}$$

$T_{\text{BH}} < m_\chi$ no equilibrium

relativistic: cannibalism is inevitable

constraints: relic abundance, Bullet Cluster



$$\beta < \beta_{\text{crit}}$$

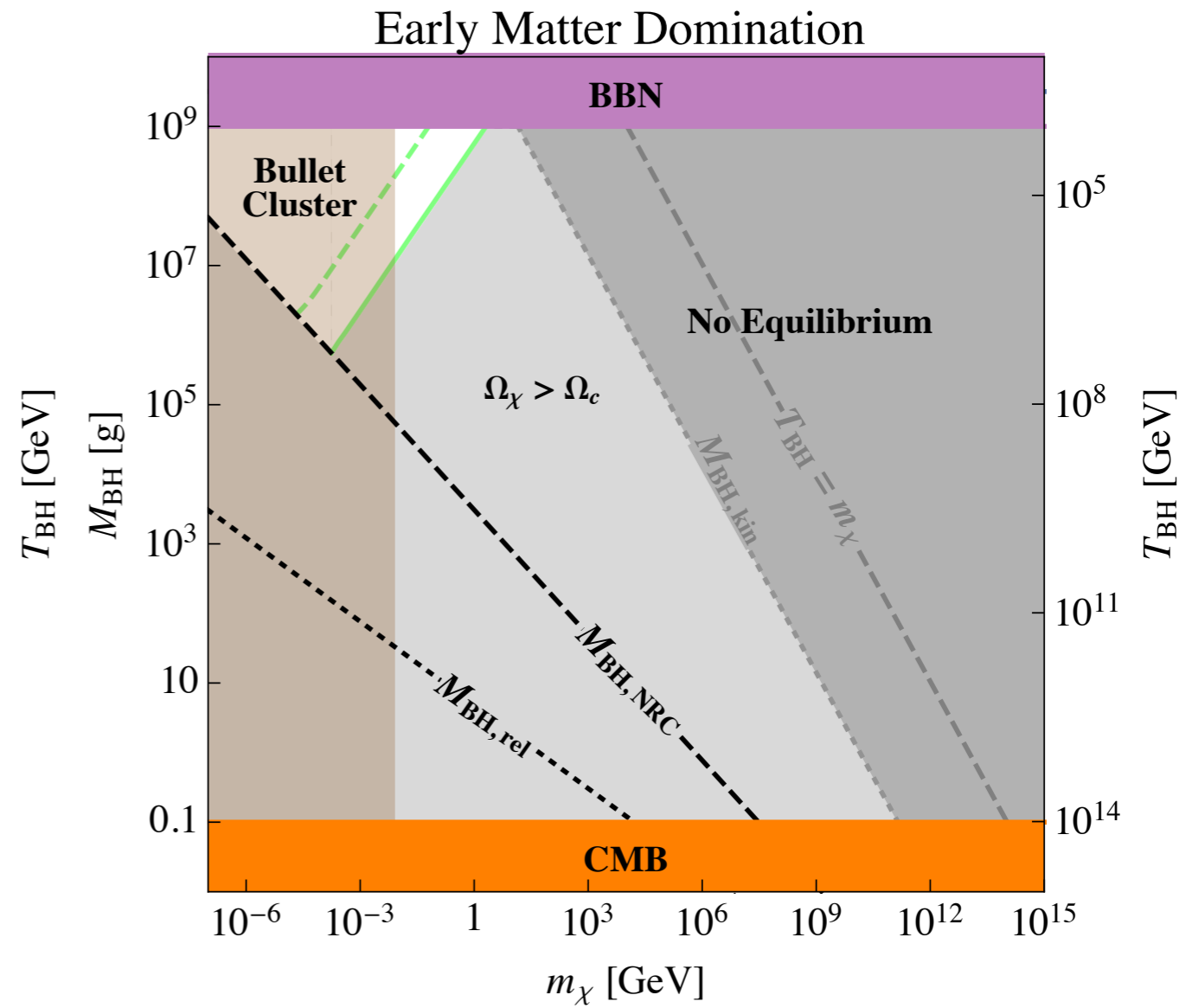
NRNC



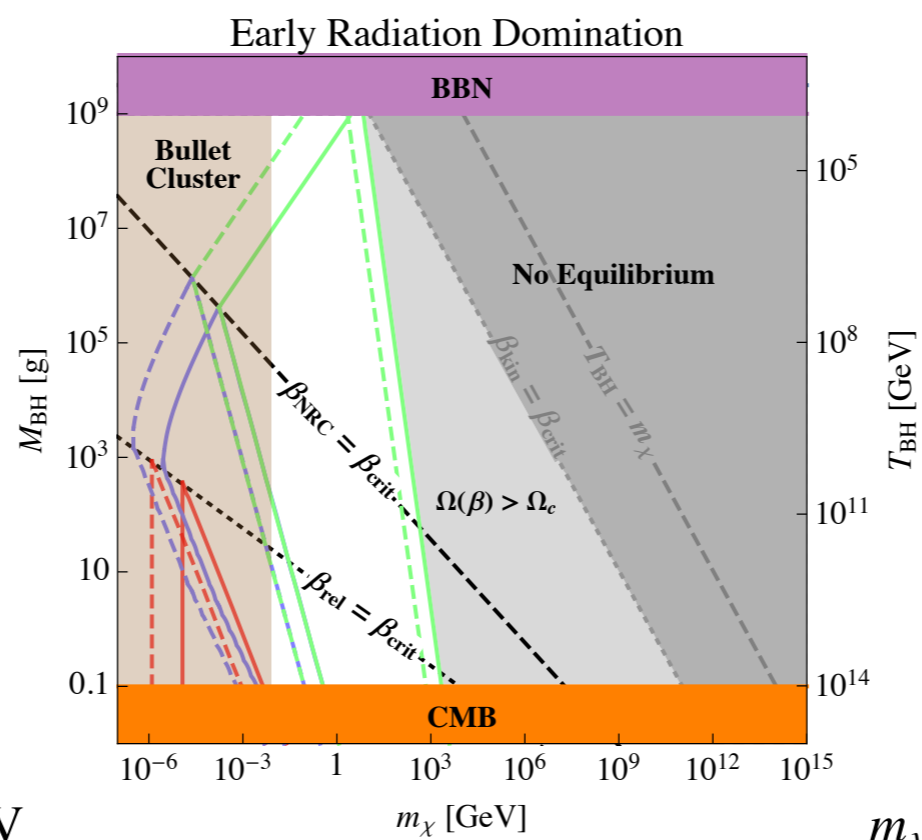
NRC



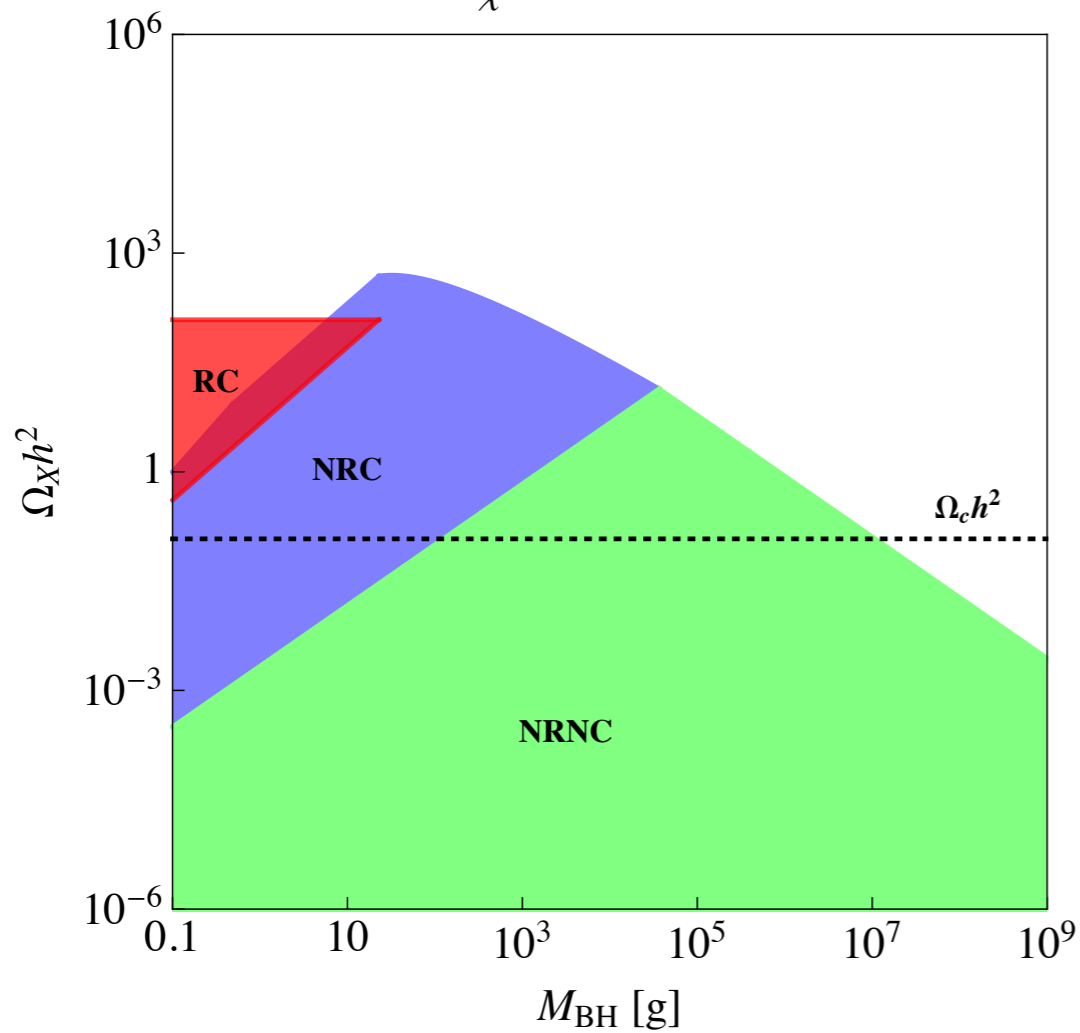
RC



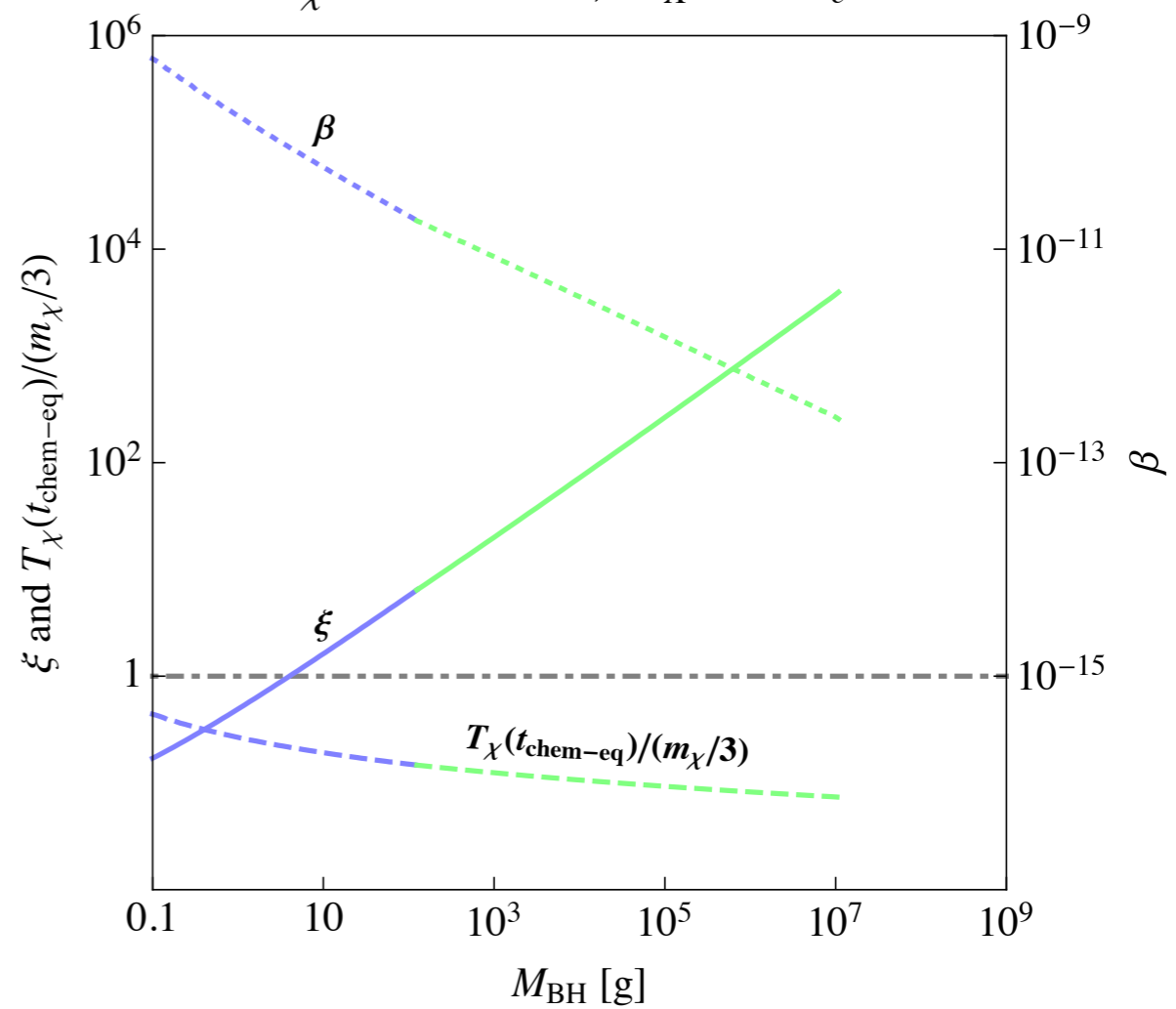
$$\beta \geq \beta_{\text{crit}}$$



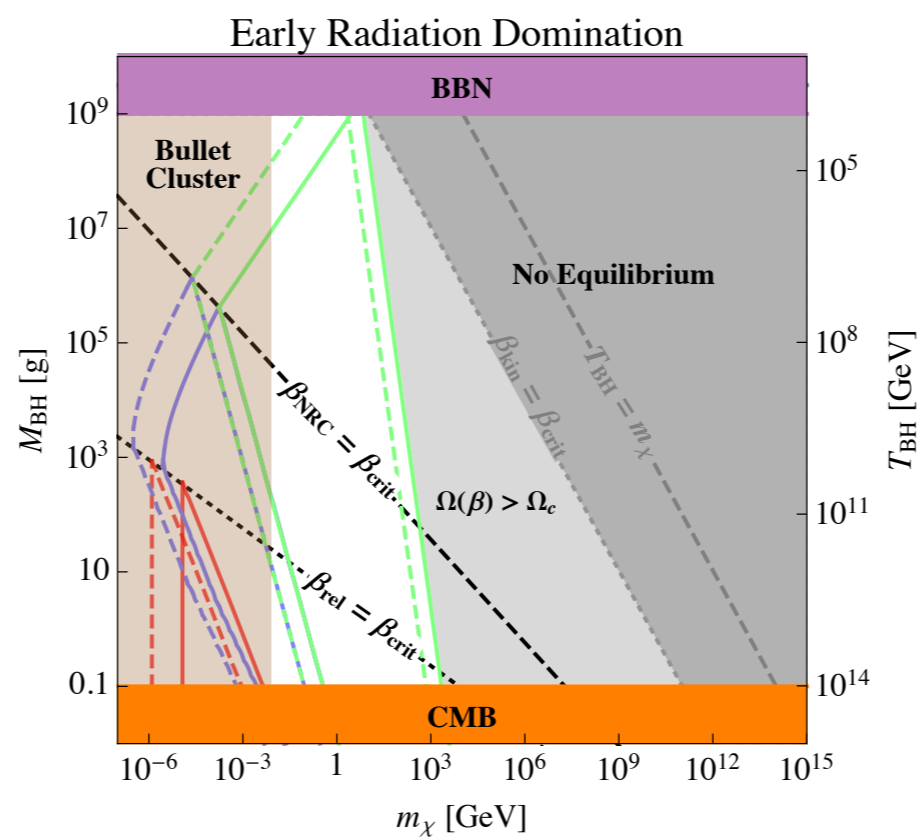
$m_{\chi} = 10^{-2} \text{ GeV}$



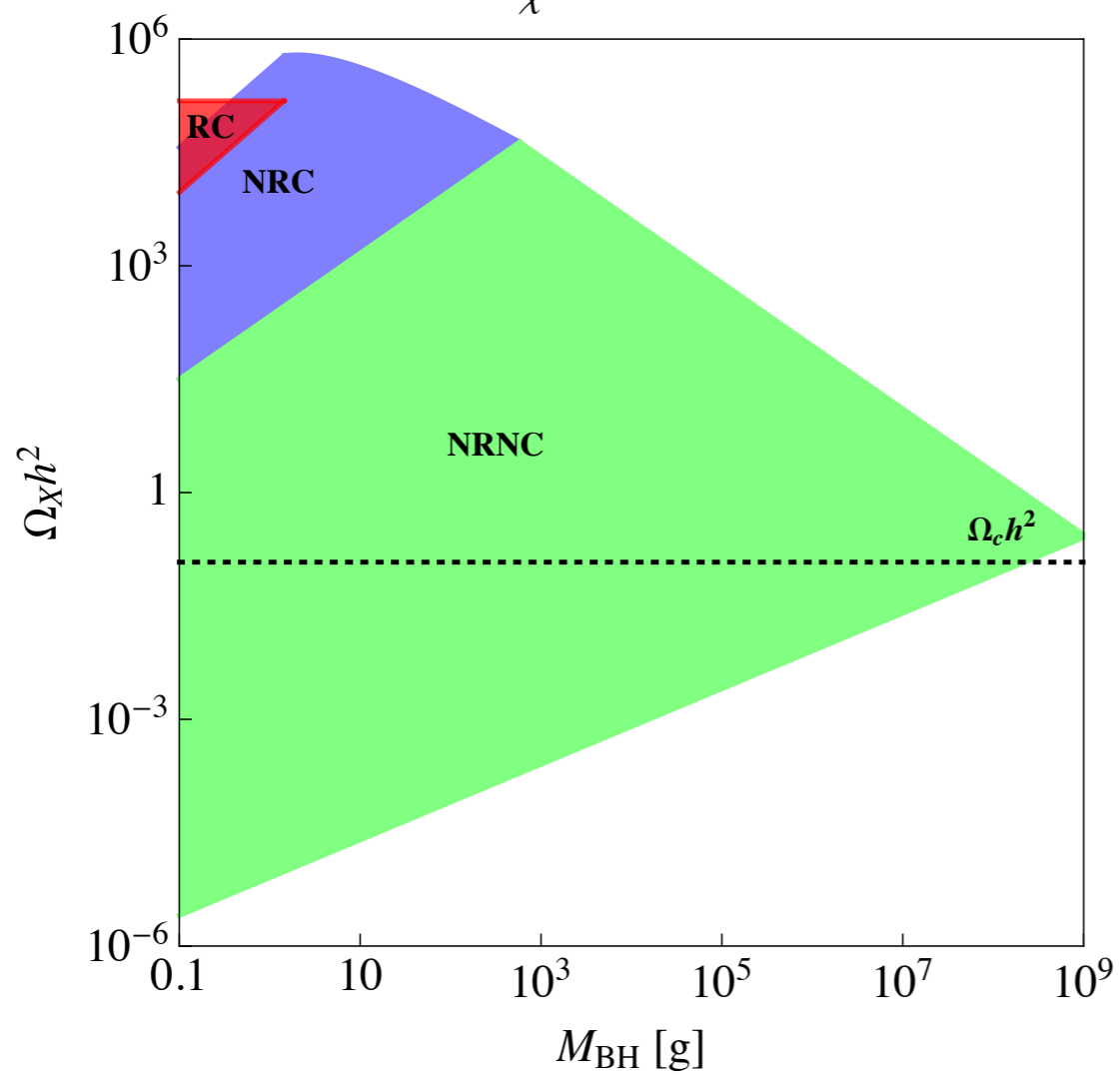
$m_{\chi} = 10^{-2} \text{ GeV}, \Omega_{\chi} h^2 = \Omega_c h^2$



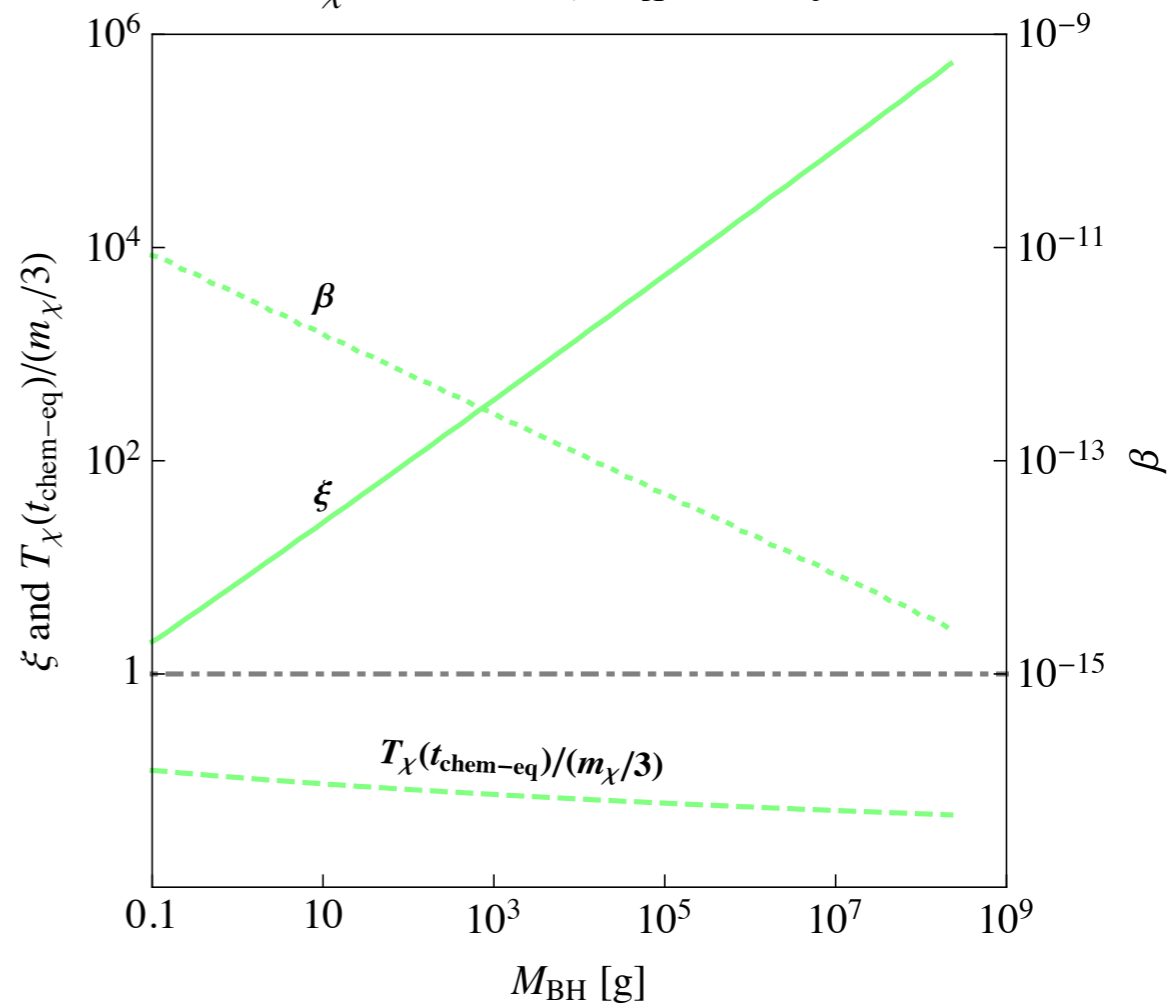
$$\xi = \frac{T_{\chi}(t_{\text{chem-eq}})}{T_V(t_{\text{chem-eq}})}$$



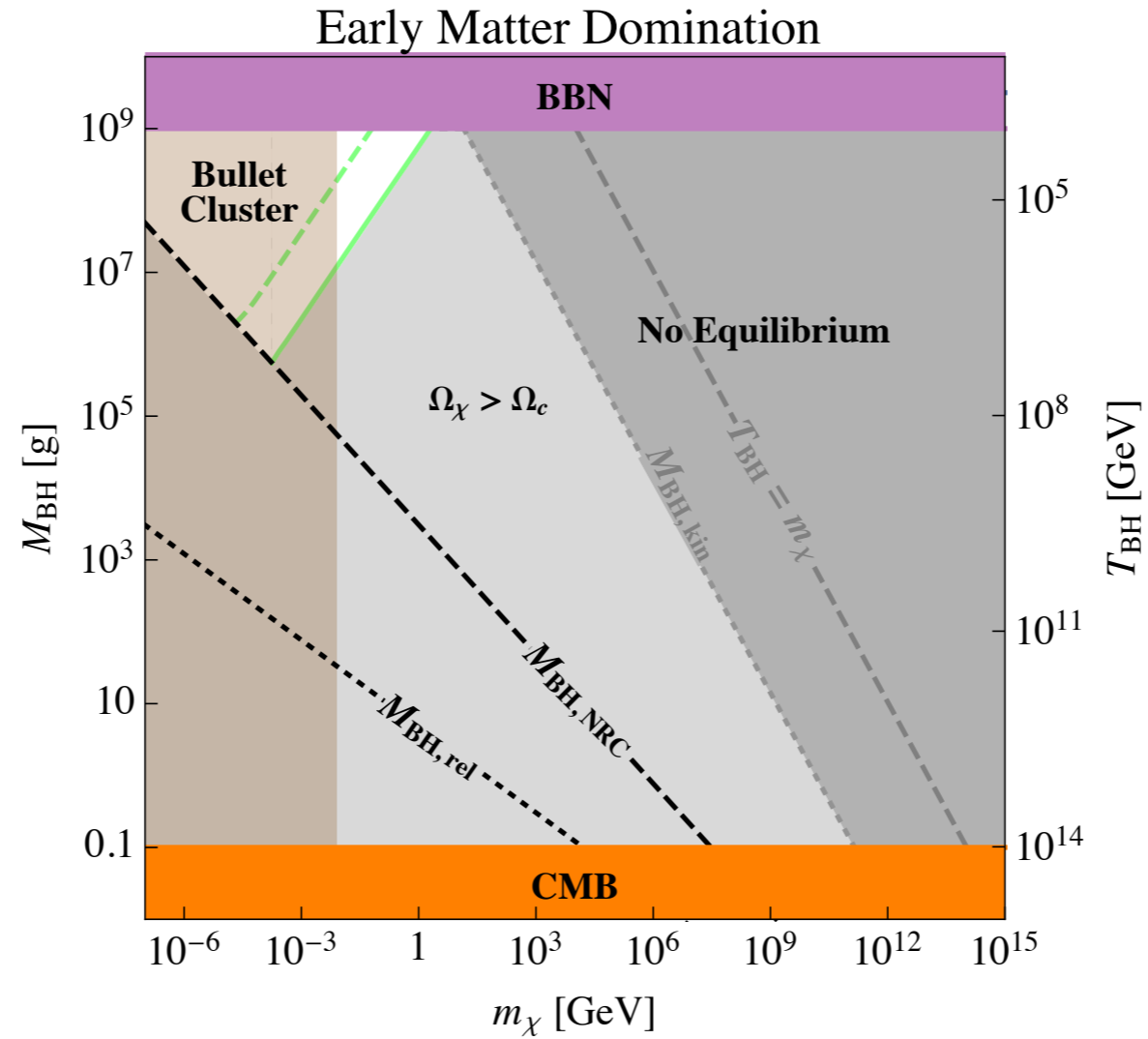
$m_\chi = 10 \text{ GeV}$



$m_\chi = 10 \text{ GeV}, \Omega_\chi h^2 = \Omega_c h^2$



$$\xi = \frac{T_\chi(t_{\text{chem-eq}})}{T_V(t_{\text{chem-eq}})}$$



$$(m_\chi = 8 \text{ MeV}, M_{\text{BH}} = 1.2 \times 10^7 \text{ g}, \xi = 3.3 \times 10^3)$$

$$(m_\chi = 2.1 \text{ GeV}, M_{\text{BH}} = 10^9 \text{ g}, \xi = 5.4 \times 10^5)$$

$$\xi = \frac{T_\chi(t_{\text{chem-eq}})}{T_V(t_{\text{chem-eq}})}$$

Conclusions

- PBHs are motivated by many scenarios.
- Hawking evaporation of PBHs can populate a self-interacting dark sector which is hotter or colder than the visible sector.
- The asymmetry in temperatures of the two sectors is persistent.
- DM with right relic abundance points to MeV-TeV mass range.