Non-cold dark matter from primordial black hole evaporation

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*Based on Baldes, Decant, **DCH**, Lopez-Honorez (2004.14773)*

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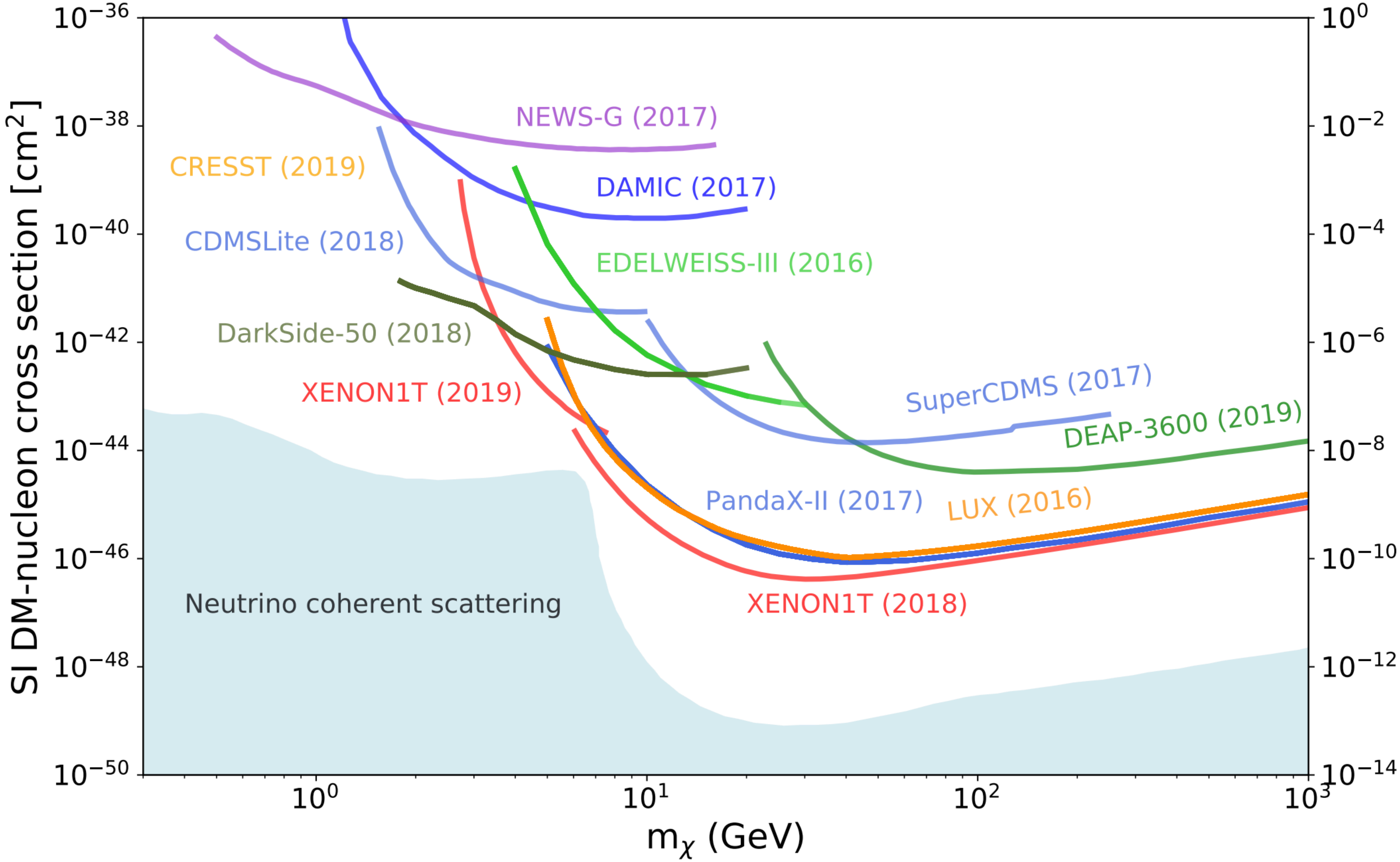
Elusive dark matter



M. Tanabashi et al. (Particle Data Group) 2018

PBH evaporation

- If DM does not interact weekly, we can no longer rely on freeze-out → new production mechanism

- We consider PBHs evaporating via Hawking radiation and producing the SM particles and the DM → the resulting DM might only interact gravitationally

- We assume the population of PBHs has **completely decayed** before BBN → very small PBH masses ($10^{-3} - 10^{9}$ g) avoids existing bounds

- If the dark matter is lighter than the initial BH temperature, it can constitute non-cold dark matter and affect structure formation

- Despite only interacting gravitationally, we can constrain the resulting DM

Phase-space distribution

- The relevant information of the produced dark matter is encoded in the phase-space distribution

- PSD will depend on

$$M_{\rm F} \longrightarrow \text{black hole mass at formation time}$$

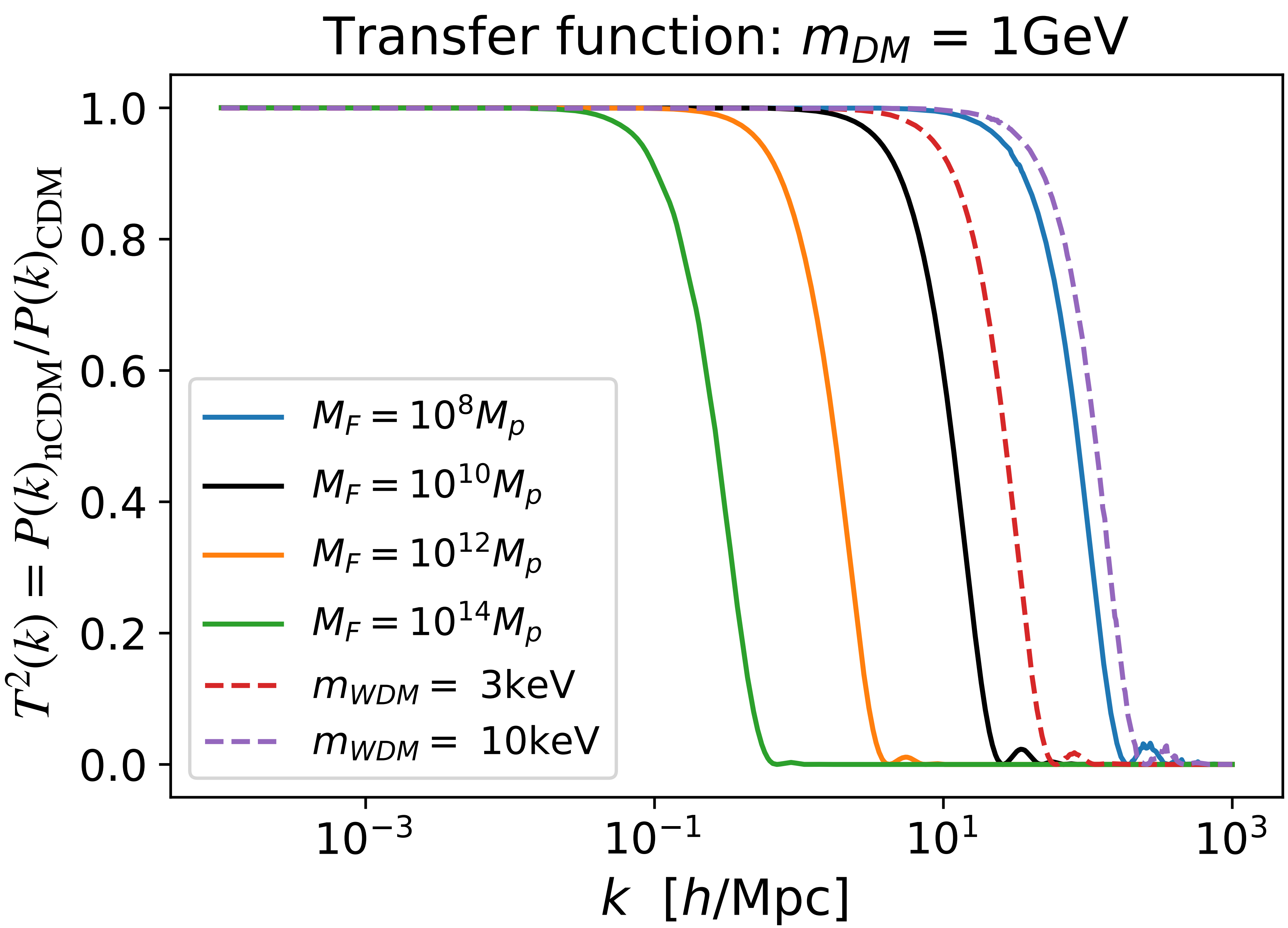
$$\beta \longrightarrow \text{initial PBH abundance}$$

$$+\, M_{\rm DM} \longrightarrow \text{dark matter mass}$$

- We use the PSD as a starting point for the cosmology code `CLASS`

- `CLASS` uses this and the Boltzmann equations for NCDM to compute the resulting matter power spectrum

Effects on cosmology



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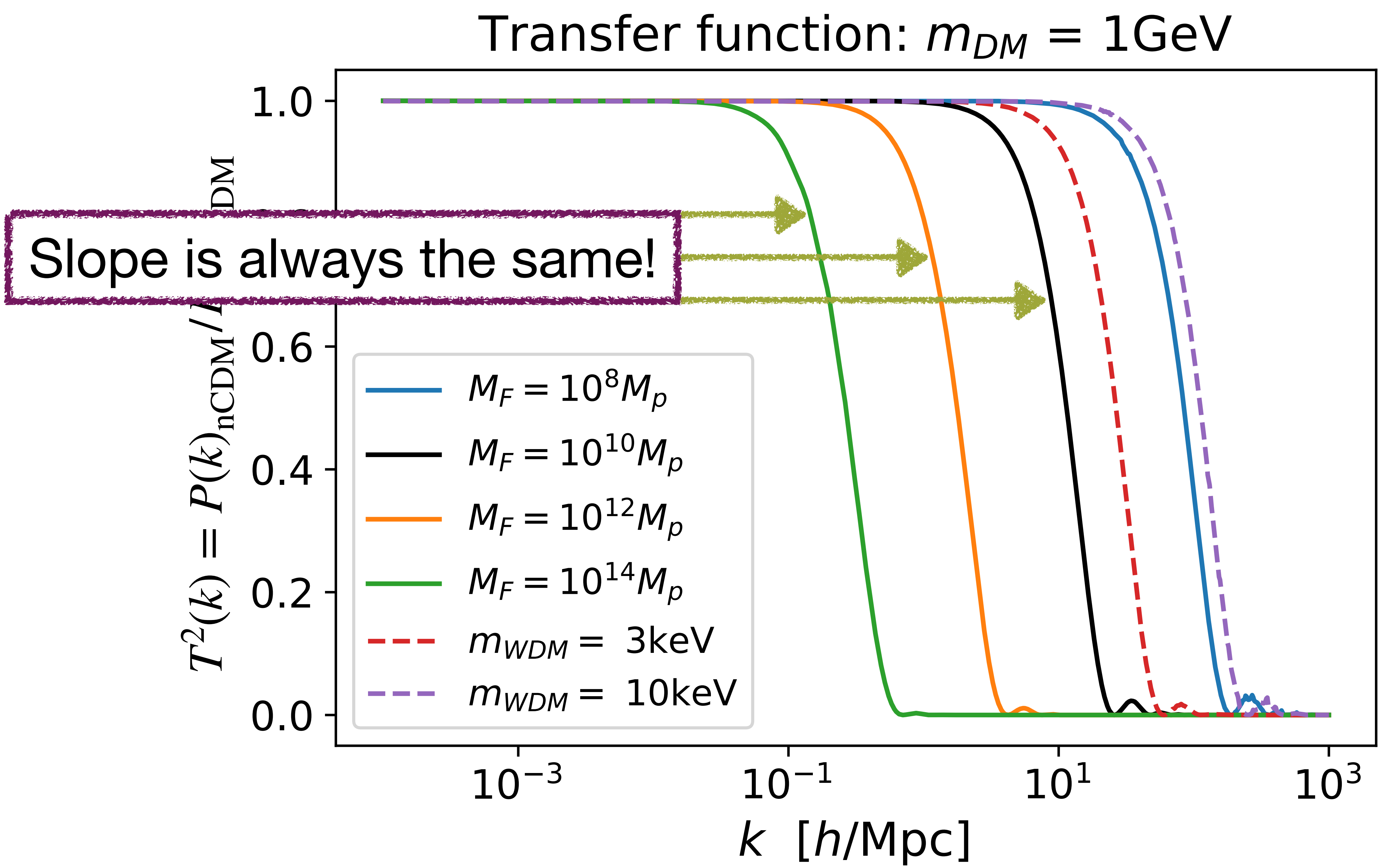
Effects on cosmology



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Warm dark matter

- Parameterise the suppression of the matter power spectrum with transfer function

$$T^2(k) = \frac{P(k)_{\rm nCDM}}{P(k)_{\rm CDM}}$$

- For WDM models, $T(k)$ is well described by

$$T(k) = \left[1 + (\alpha k)^{2\nu}\right]^{-5/\nu} \quad \text{with} \quad \nu = 1.12$$

$$\Downarrow$$

$$\alpha_{\rm WDM} = 0.049 \left(\frac{m_{\rm WDM}}{1\rm keV}\right)^{-1.11} \left(\frac{\Omega_{\rm WDM}}{0.25}\right)^{0.11} \left(\frac{h}{0.7}\right)^{1.22} h^{-1}{\rm Mpc}$$

- One-to-one correspondence between $\alpha_{\rm WDM} \leftrightarrow m_{\rm WDM}$ (breaking scale - mass)

- Bounds on α can be translated into bounds on $m_{\rm WDM} \rightarrow$ WDM can be constrained with small scale observations (e.g. Lyman-α data)

Mapping to WDM

- We found that this also provides a very good fit for PBH. With the same slope $\nu = 1.12$ and assuming $\Omega_{\rm DM}h^2 = 0.12$ we find

$$T(k) = \left[1 + (\alpha k)^{2\nu}\right]^{-5/\nu} \quad \text{with} \quad \nu = 1.12$$

$$\Downarrow$$

$$\alpha_{\rm PBH} = \left(\frac{m_{\rm DM}}{1\rm eV}\right)^{-0.83}\left(\frac{M_{\rm F}}{M_p}\right)^{0.42} \times \begin{cases} 60.4\,{\rm Mpc}h^{-1} & \text{if } \beta < \beta_c \\ 53.2\,{\rm Mpc}h^{-1} & \text{if } \beta > \beta_c \end{cases}$$

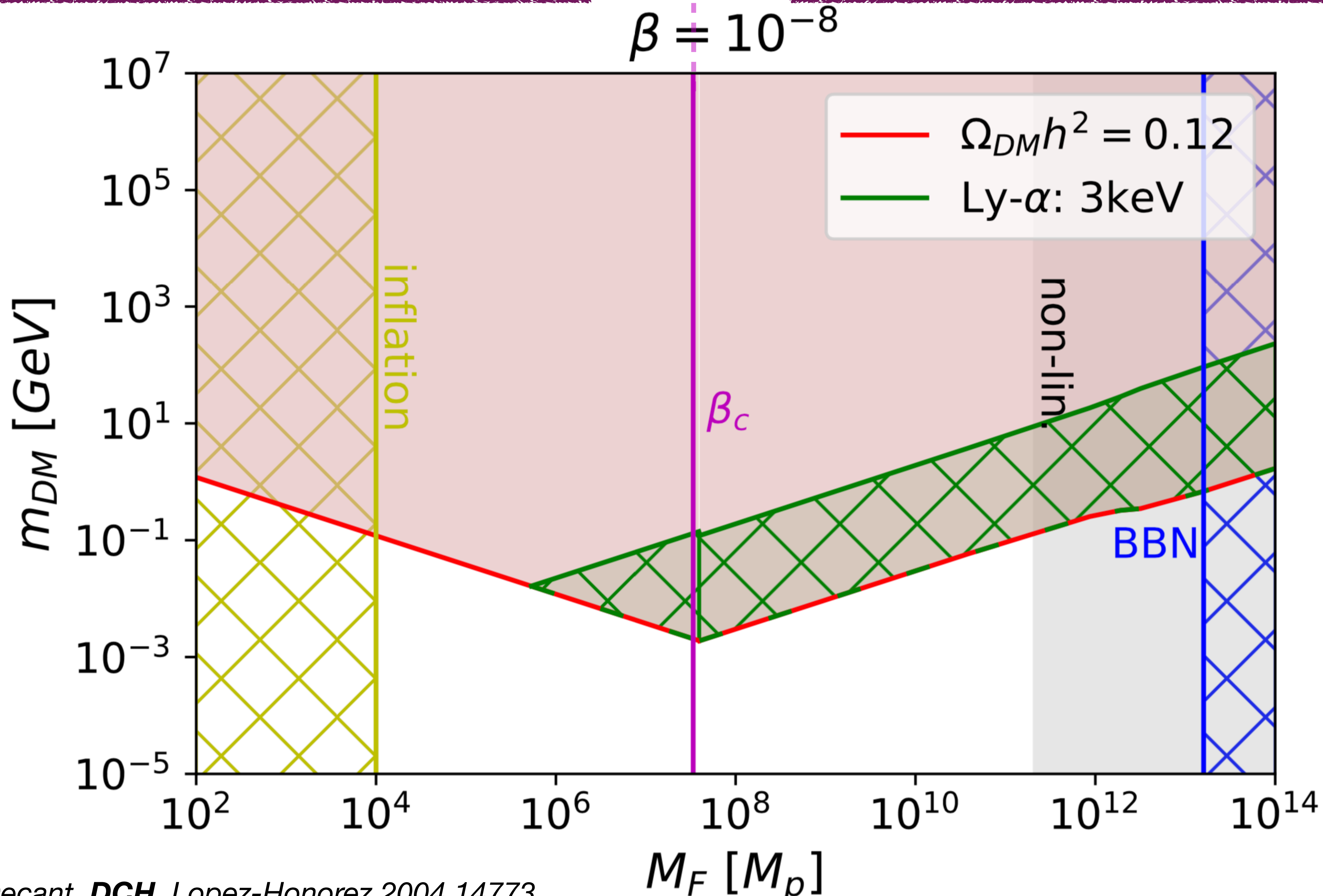
- Bounds on $\alpha_{\rm WDM}$ (and therefore $m_{\rm WDM}$) can be remapped into bounds on $\alpha_{\rm PBH}$ (and therefore $m_{\rm DM}$)

- We can use existing constraints on WDM to constrain this DM scenario

PBH NCDM new constraints

$\beta < \beta_c \rightarrow$ radiation dominated before evap

$\beta > \beta_c \rightarrow$ early matter dominated epoch



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Summary

- The lack of detection of WIMPs calls for new DM scenarios, including new production mechanisms

- PBHs can produce the DM via Hawking radiation

- Even if it only interacts gravitationally, the resulting DM is subject to cosmological constraints

- Due to similar effects, we can remap WDM bounds

- We have excluded a large region of parameter space for NCDM produced by PBH evaporation

- We showed that if the PBHs dominated the universe before BBN, they cannot produce all of the DM

Thank you for your attention

PBH Formulas

Black Hole Temperature: $T_{\rm BH} = \dfrac{M_p^2}{8\pi M_{\rm BH}}$

Lifetime: $\tau = \dfrac{1}{3e_T}\dfrac{M_F^3}{M_p^4}$ with $e_T = \dfrac{27}{4}\dfrac{g_{*\rm BH}}{30720\pi}$

Beta_critical: $\beta_c = \sqrt{\dfrac{3e_T}{\gamma}\dfrac{M_p}{M_F}}$

DM density: $\Omega_{\rm DM}\left(t_0\right) = \dfrac{m_{\rm DM} n_{\rm DM}\left(t_{\rm ev}\right)}{\rho_c} \times \left(\dfrac{a_{\rm ev}}{a_0}\right)^3$

PBH Lyman-α Bounds

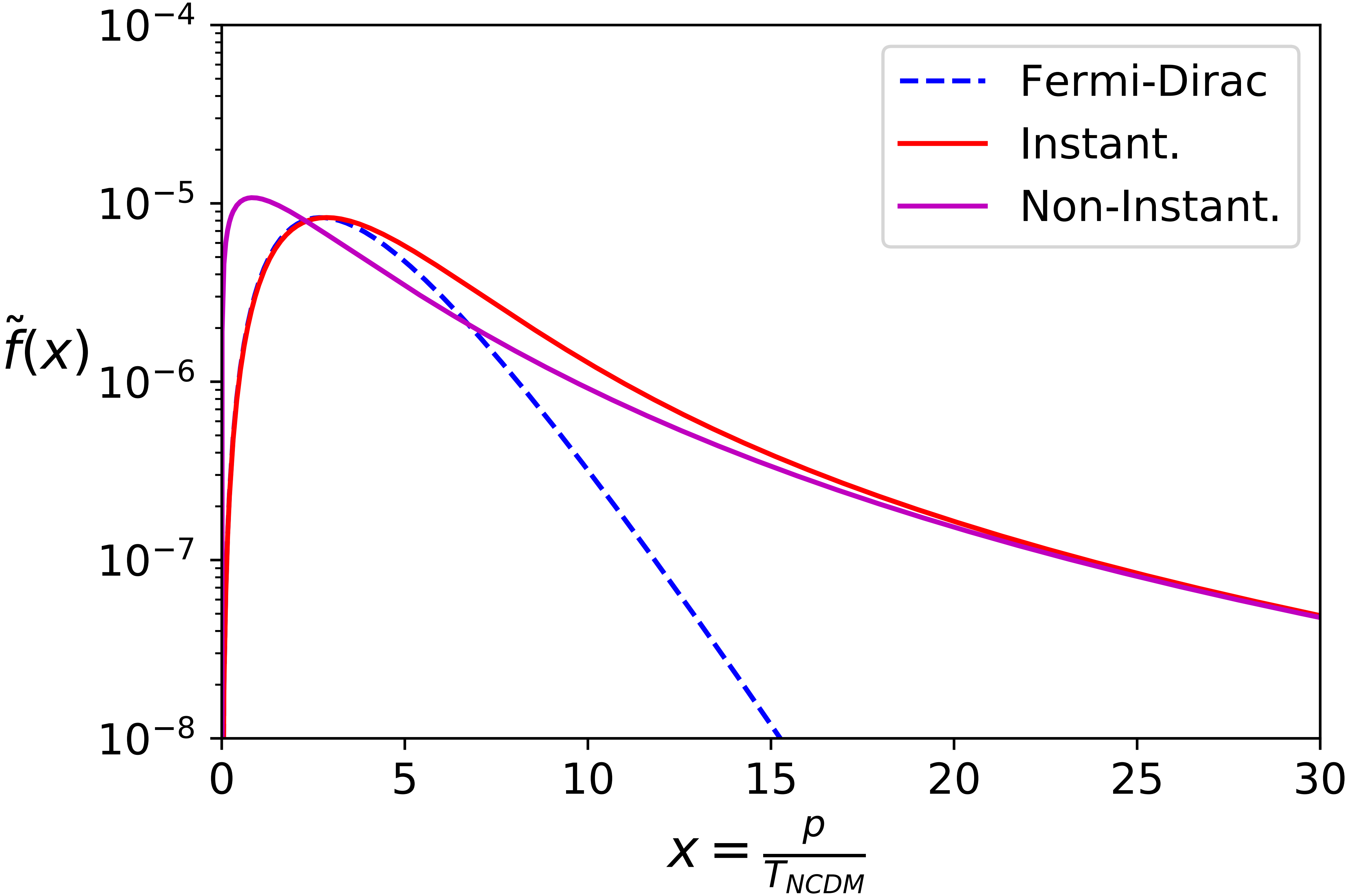
Bound on α_{PBH}

$$\alpha_{\mathrm{PBH}} = \left(\frac{m_{\mathrm{DM}}}{1\mathrm{eV}}\right)^{-0.83} \left(\frac{M_{\mathrm{F}}}{M_p}\right)^{0.42} \times \begin{cases} 60.4\,\mathrm{Mpc}h^{-1} & \text{if } \beta < \beta_c \\ 53.2\,\mathrm{Mpc}h^{-1} & \text{if } \beta > \beta_c \end{cases}$$

Bound on m_{DM}

$$m_{\mathrm{DM}} \geq \left(\frac{m_{\mathrm{WDM}}^{\mathrm{Ly}-\alpha}}{\mathrm{keV}}\right)^{4/3} \left(\frac{M_F}{M_p}\right)^{1/2} \times \begin{cases} 5.2\,\mathrm{keV} & \text{if } \beta < \beta_c \\ 4.4\,\mathrm{keV} & \text{if } \beta > \beta_c \end{cases}$$

Instant vs Non-instant PSD



PBH Leptogenesis