Feedback in the dark: a critical examination of CMB bounds on primordial black holes

(2403.18895)

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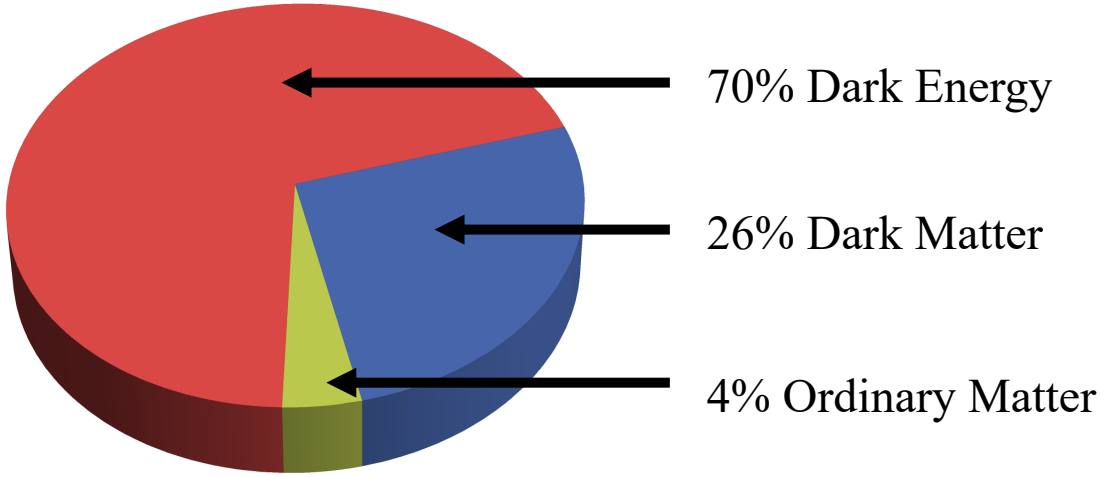
OUTLINE

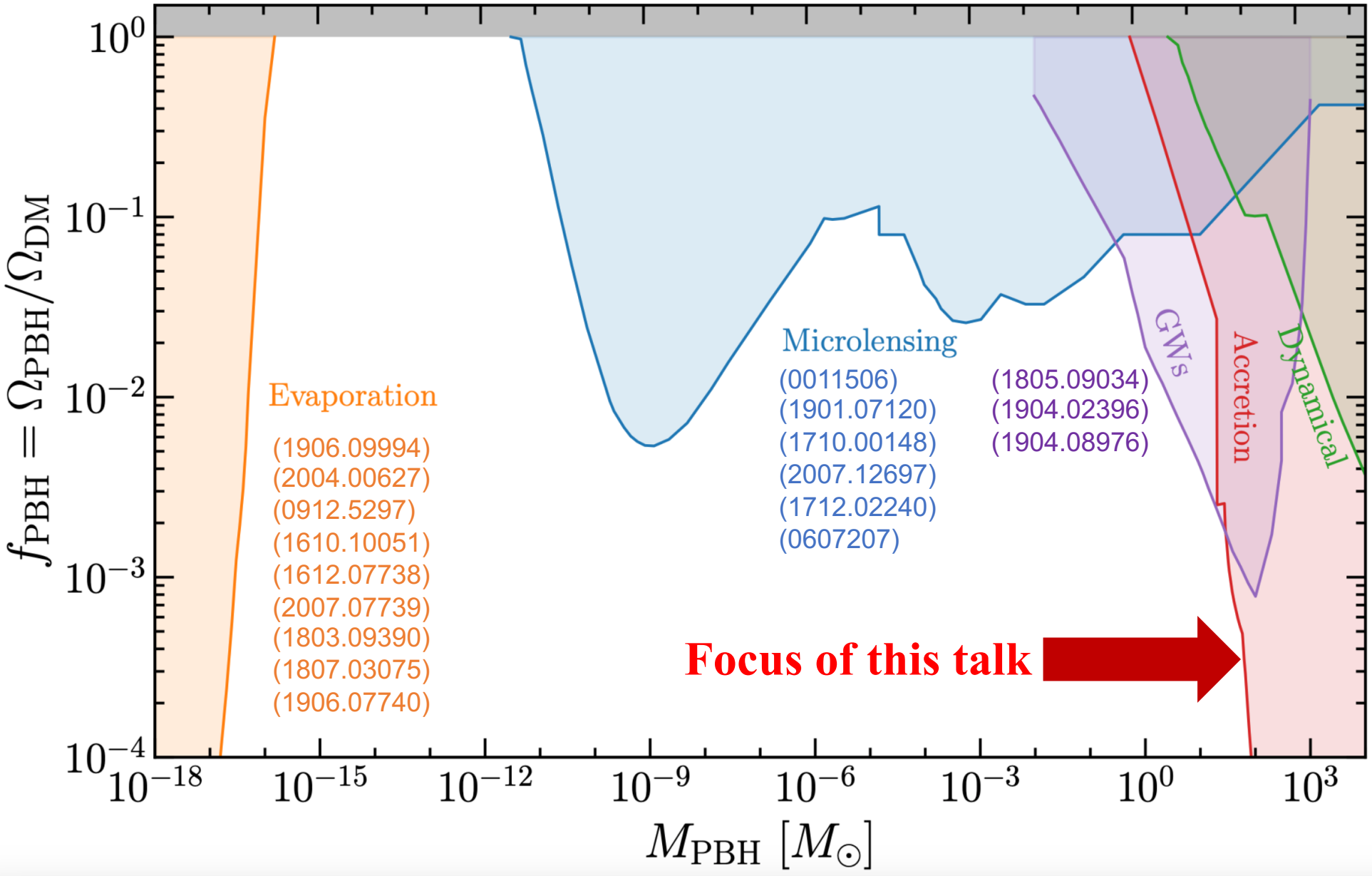
1. Motivation for Primordial Black Holes (PBHs)
2. Impact of PBHs on CMB
3. Comparison of Accretion Models
4. Role of Dark Matter Mini-halos

Motivation for PBHs



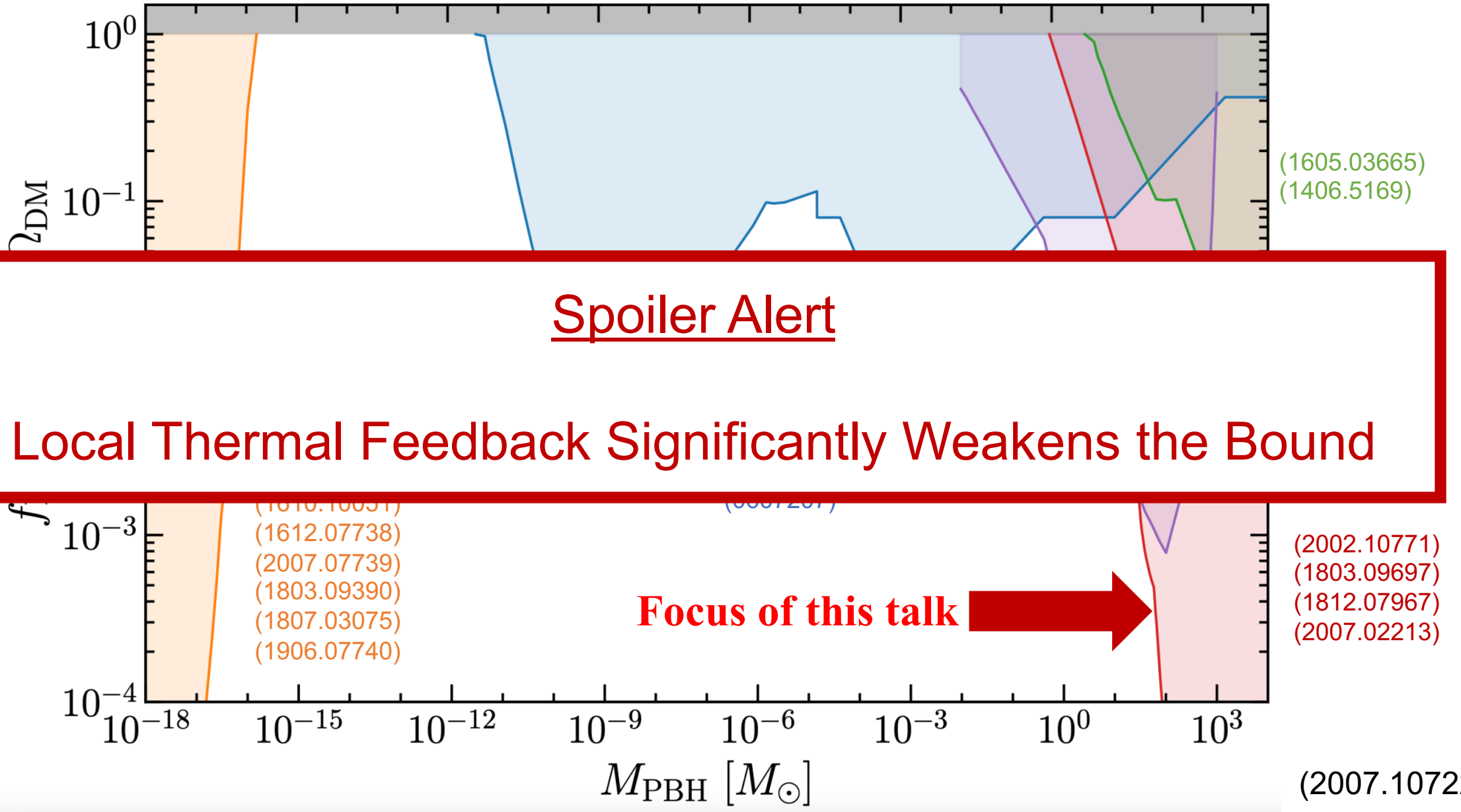
1. PBHs are a macroscopic alternative to particle dark matter
2. PBHs might act as seeds for the formation of super-massive black holes
3. PBHs might explain recent gravitational wave detections of black hole mergers

PBH Abundance Constraints



(2007.10722)

PBH Abundance Constraints



Spoiler Alert

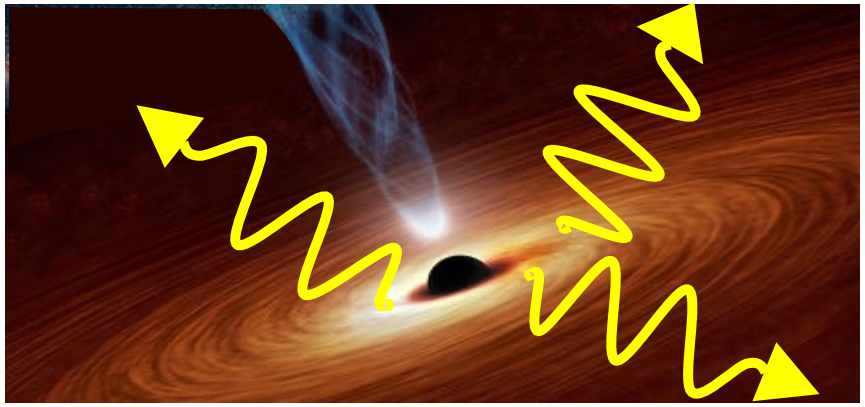
Local Thermal Feedback Significantly Weakens the Bound

(2007.10722)

Overview of PBH Accretion

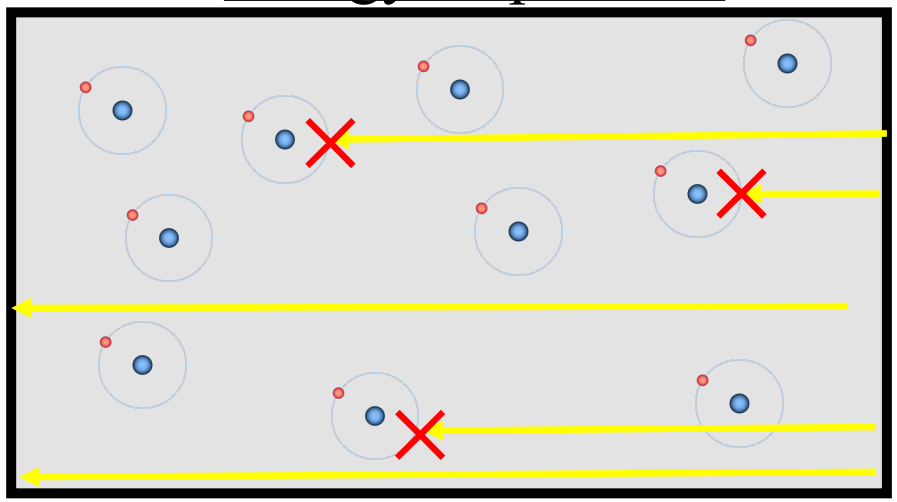
Accretion Rate

Accretion Luminosity



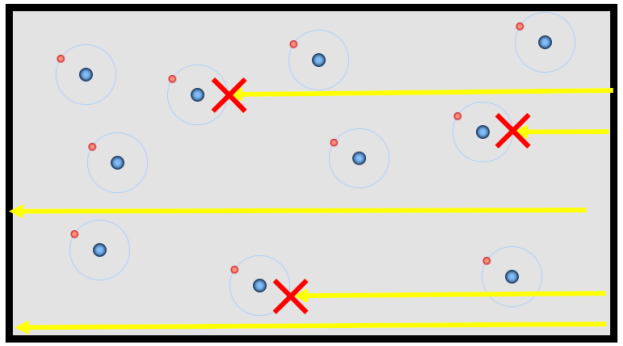
Energy Injection

Energy Deposition



Deriving the CMB Bound

Energy Deposition

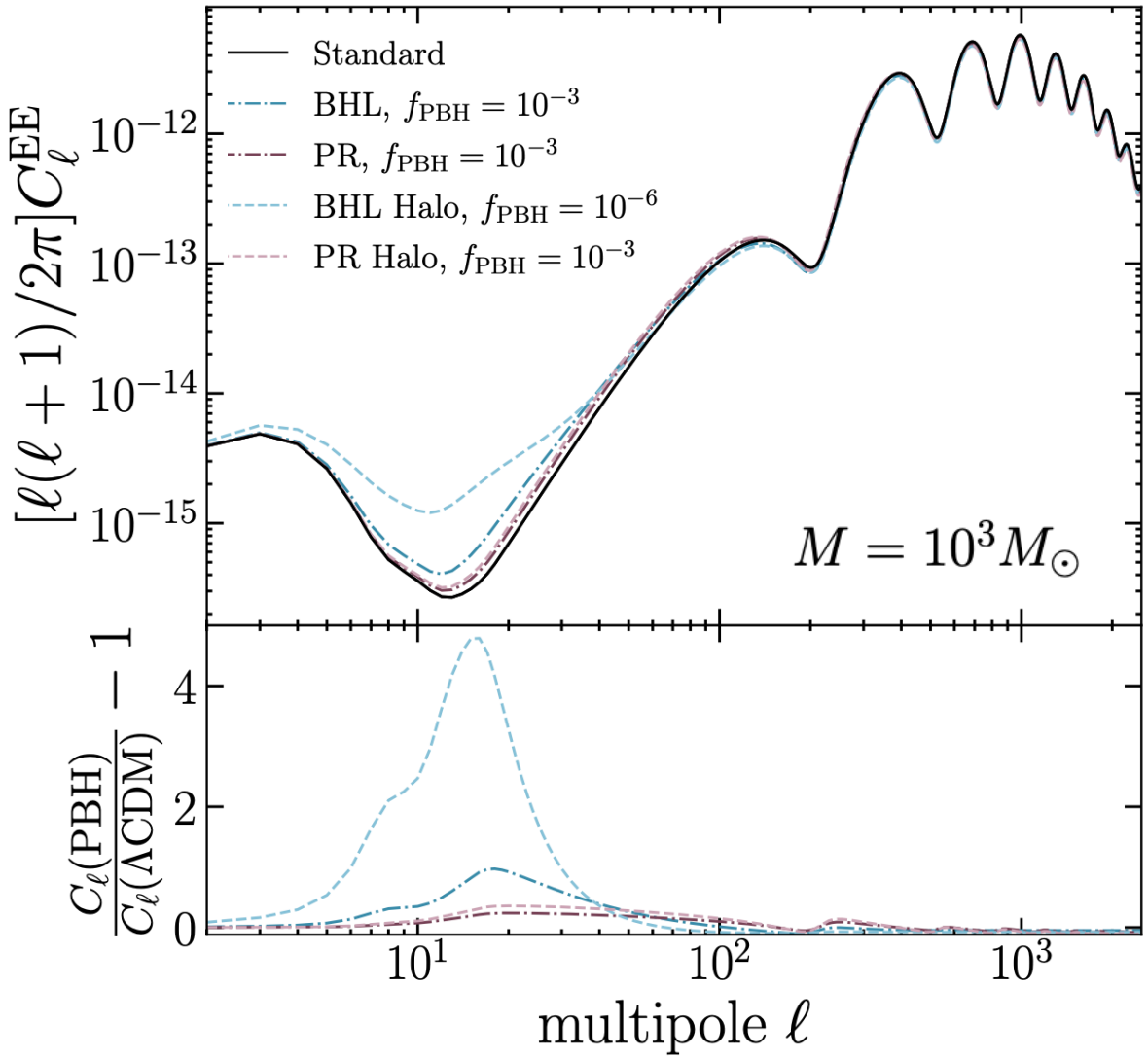


Ionization History

x_e

T_m

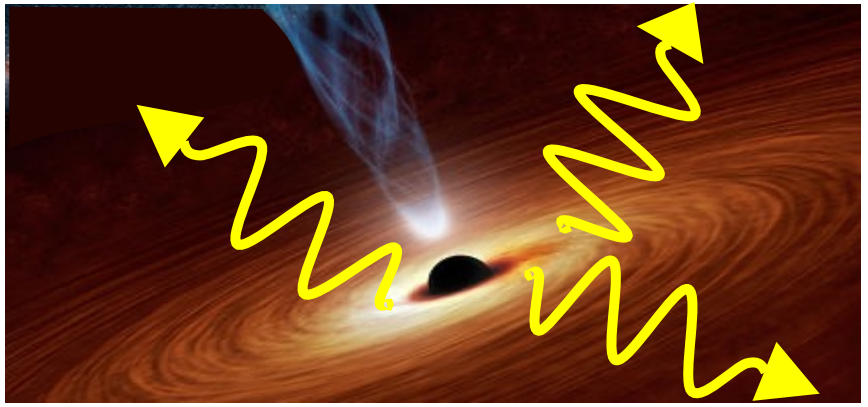
Thermal History



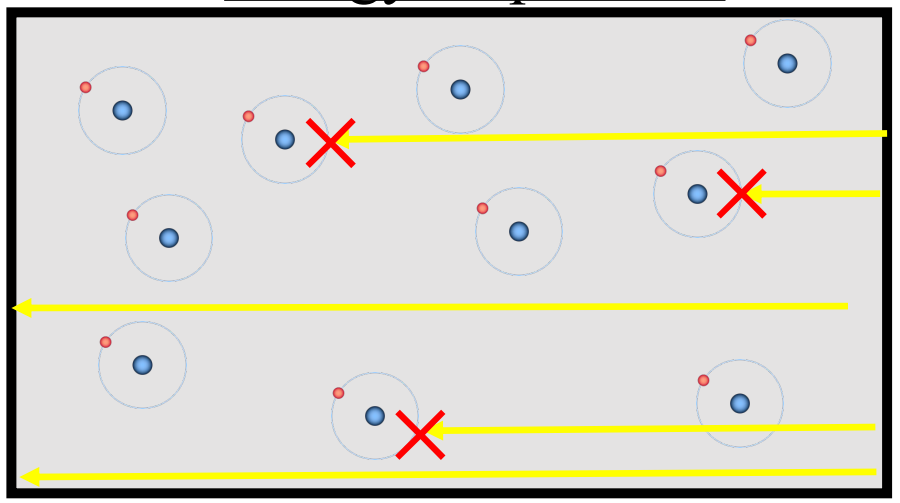
Key Ingredients/Uncertainties

Accretion Rate

Accretion Luminosity



Energy Deposition



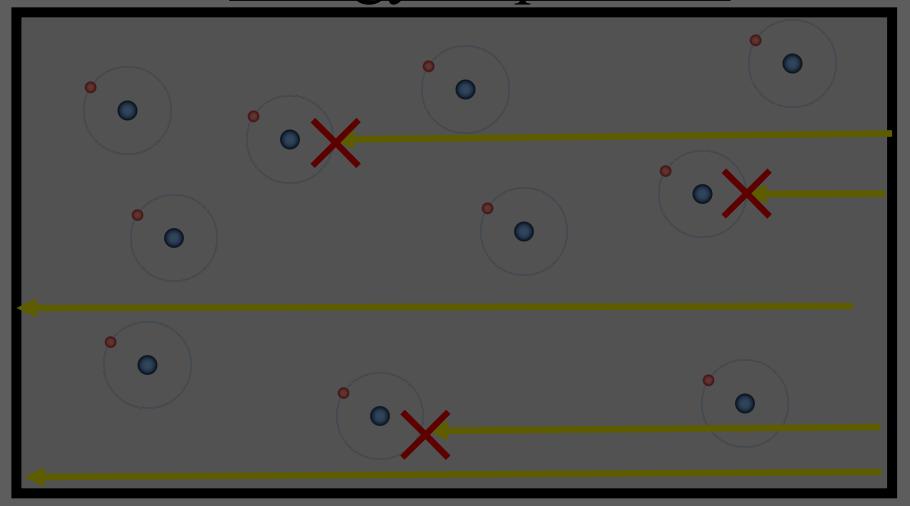
Key Ingredients/Uncertainties

Accretion Rate

Focus of this talk

Accretion Luminosity

Energy Deposition

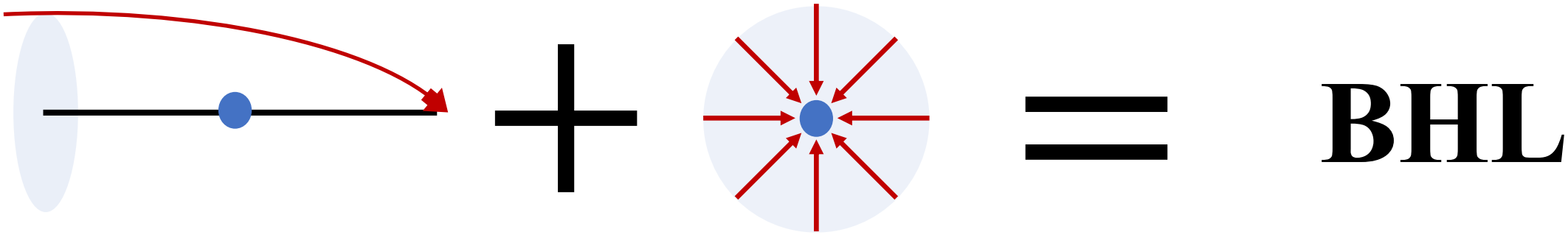


Bondi-Hoyle-Lyttleton Accretion Model

- Bondi-Hoyle-Lyttleton (BHL) is the "standard" PBH accretion model

Hoyle-Lyttleton Accretion (1939)

Bondi Accretion (1952)



BHL

$$\dot{M}_{\mathrm{BHL}} = 4\pi\rho\lambda \frac{G^2 M^2}{(v^2 + c_s^2)^{\frac{3}{2}}}$$

Park-Ricotti (PR) Accretion Model

(2003.05625)

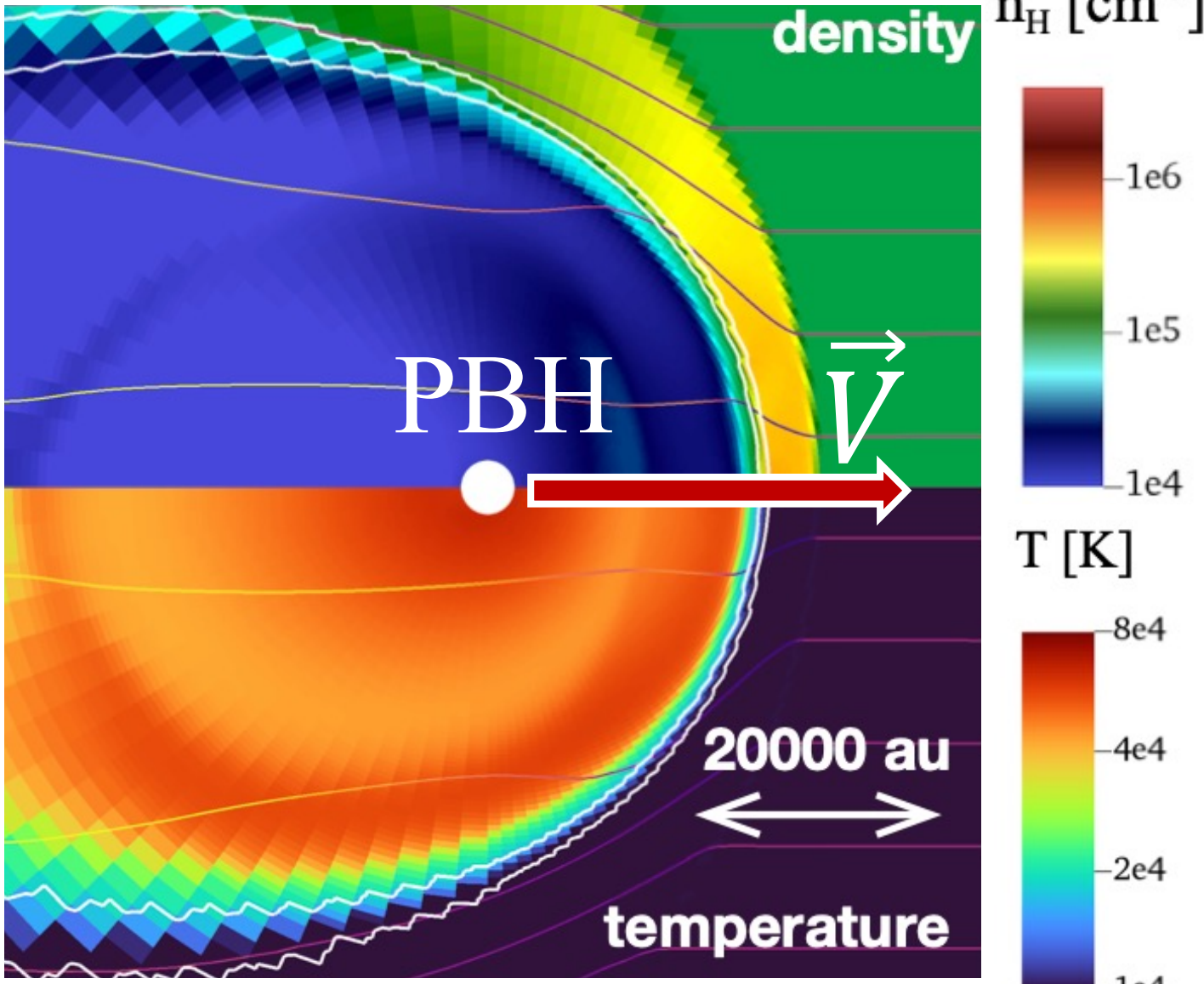
- PBHs can form ionization fronts
  (1211.0542)

PR = BHL + Ionization Front

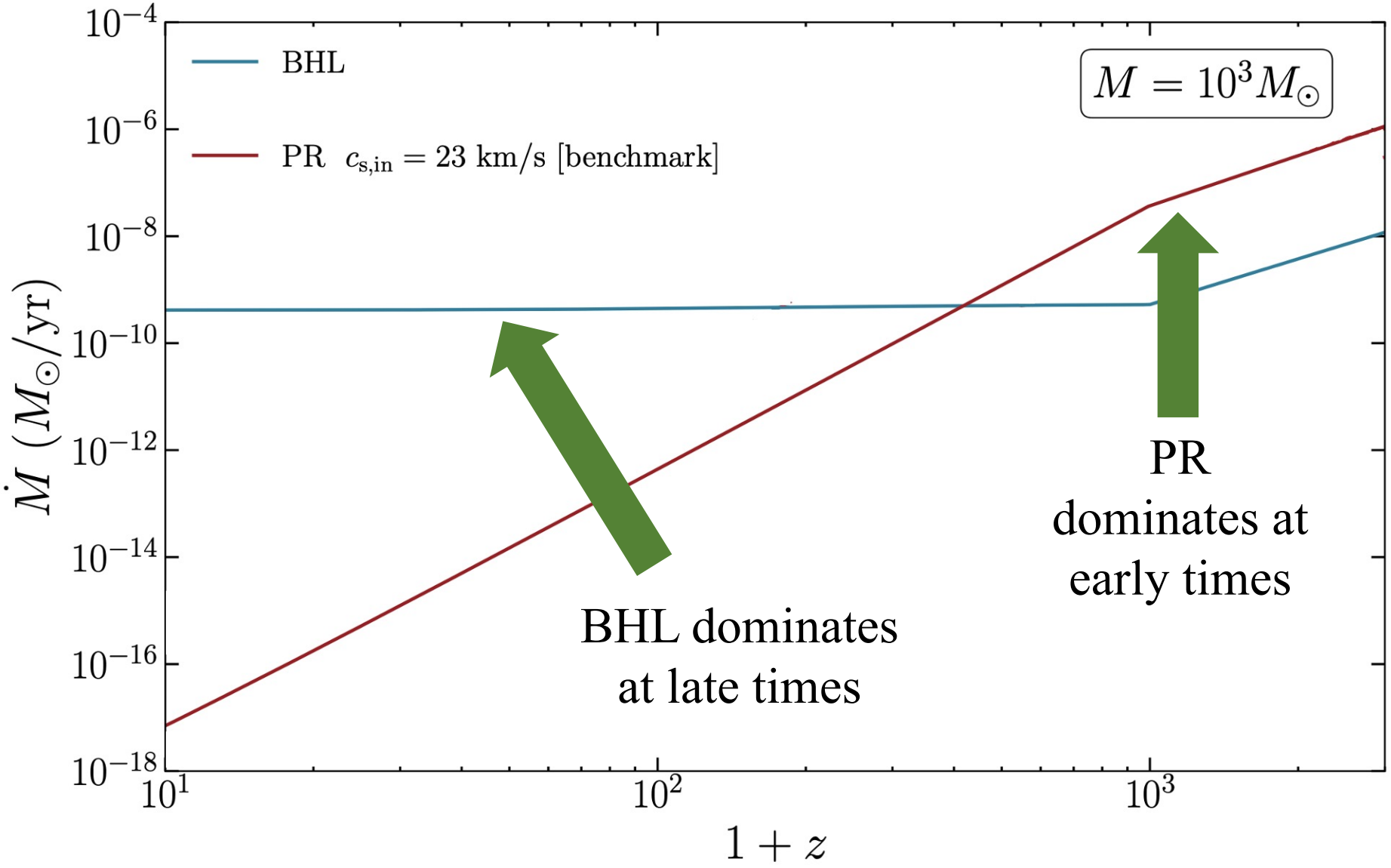
$$\dot{M}_{\rm PR} = 4\pi\rho_{\rm in}\frac{G^2M^2}{\left(v_{\rm in}^2 + \left(c_{\rm s}^{\rm in}\right)^2\right)^{3/2}}$$

Fixed by Mass Conservation and Force Equilibrium across ionization front

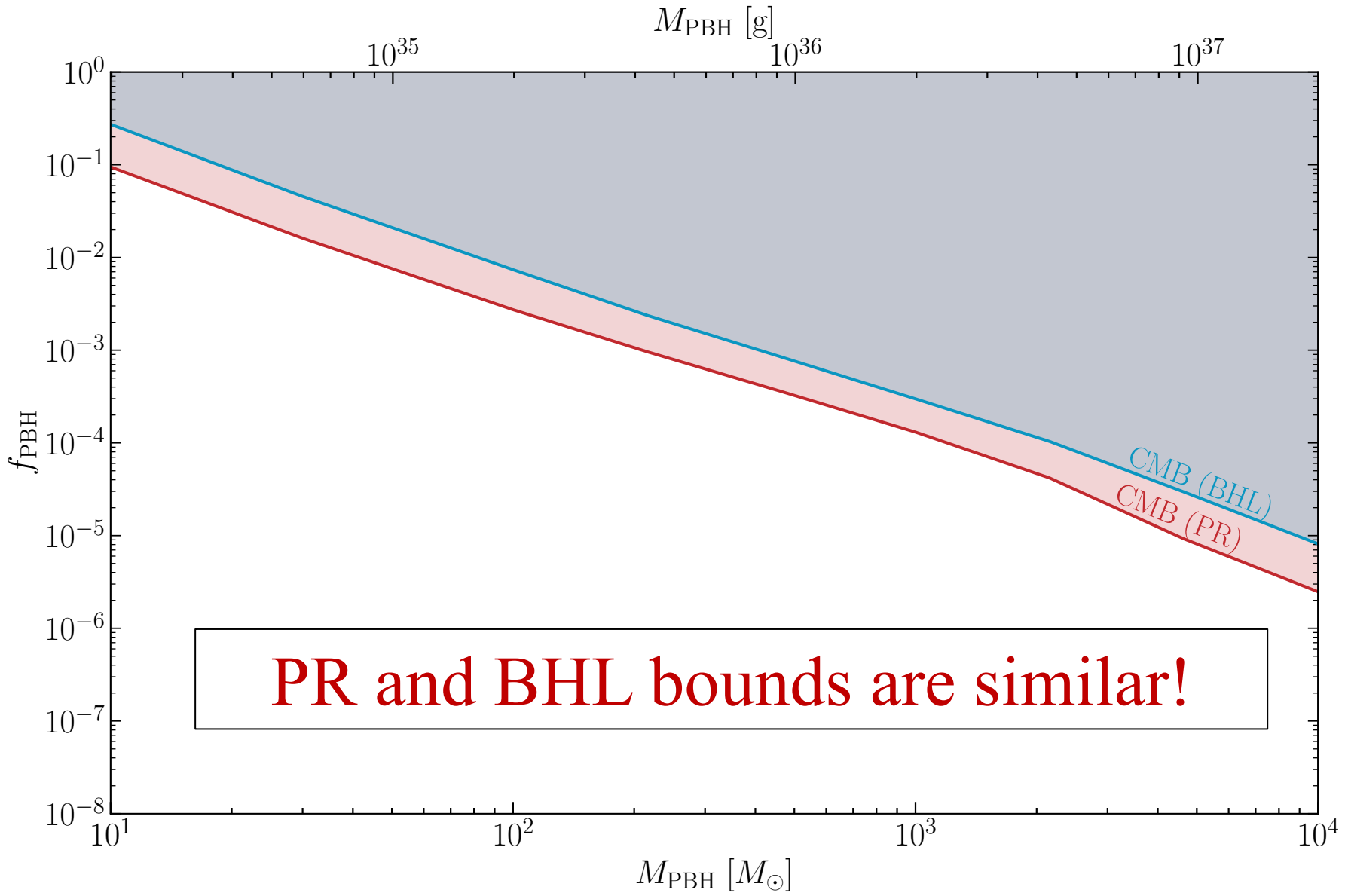
Free Parameter



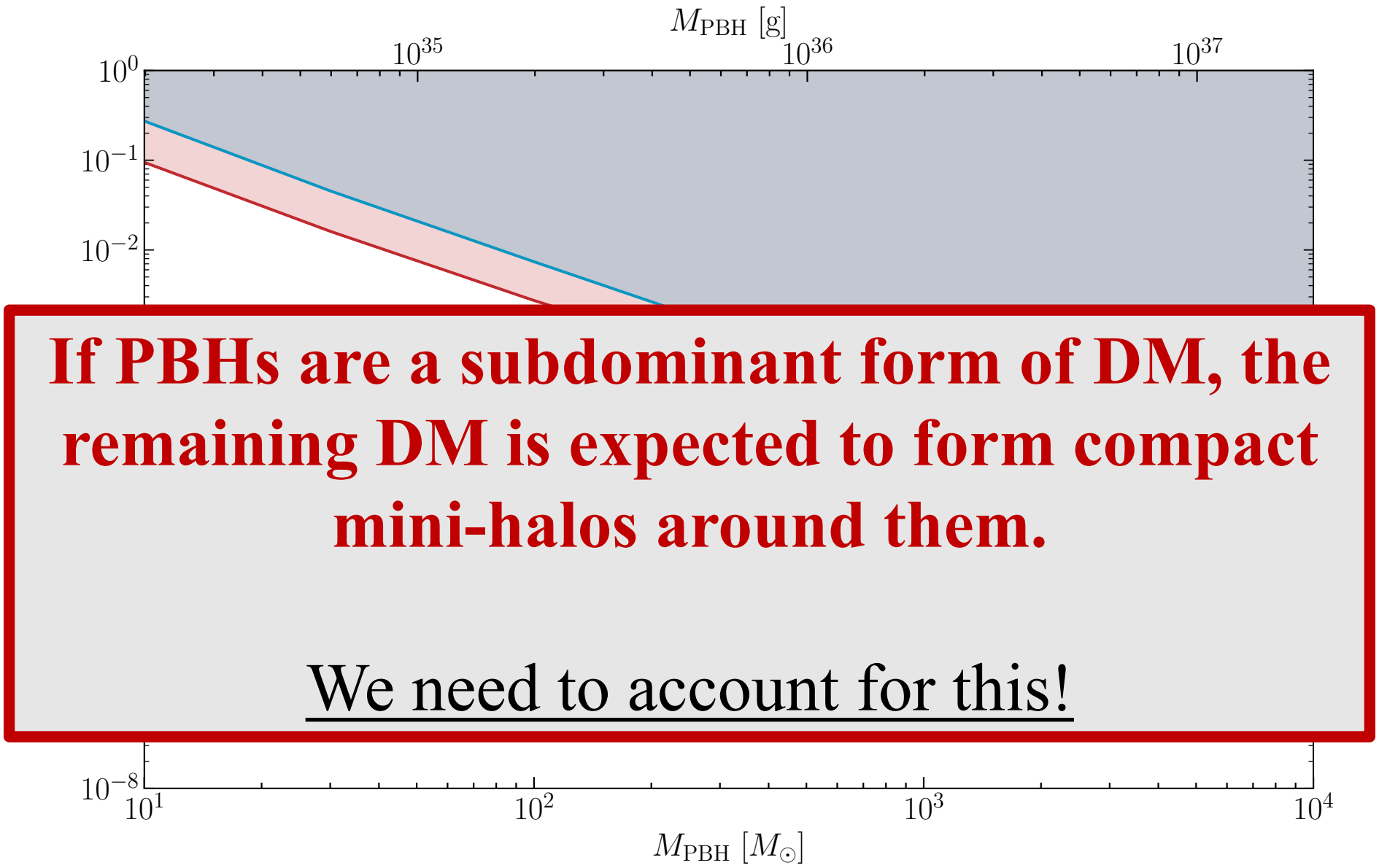
PR vs. BHL Accretion Rates



PR vs. BHL Bound



PR vs. BHL Bound

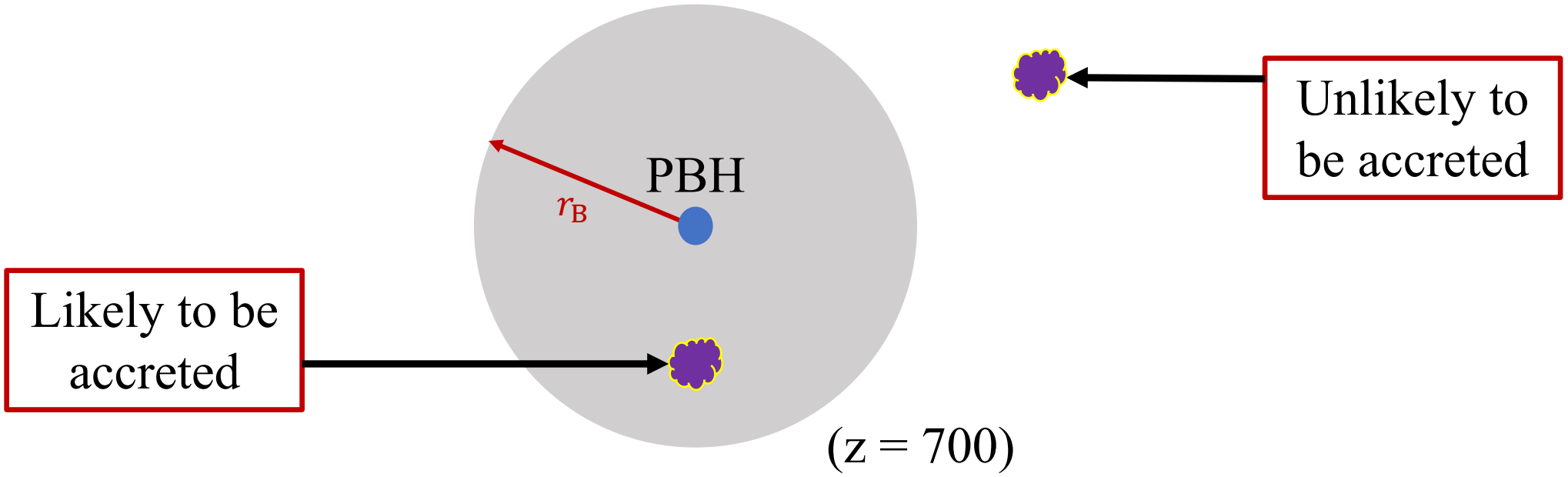


If PBHs are a subdominant form of DM, the remaining DM is expected to form compact mini-halos around them.

We need to account for this!

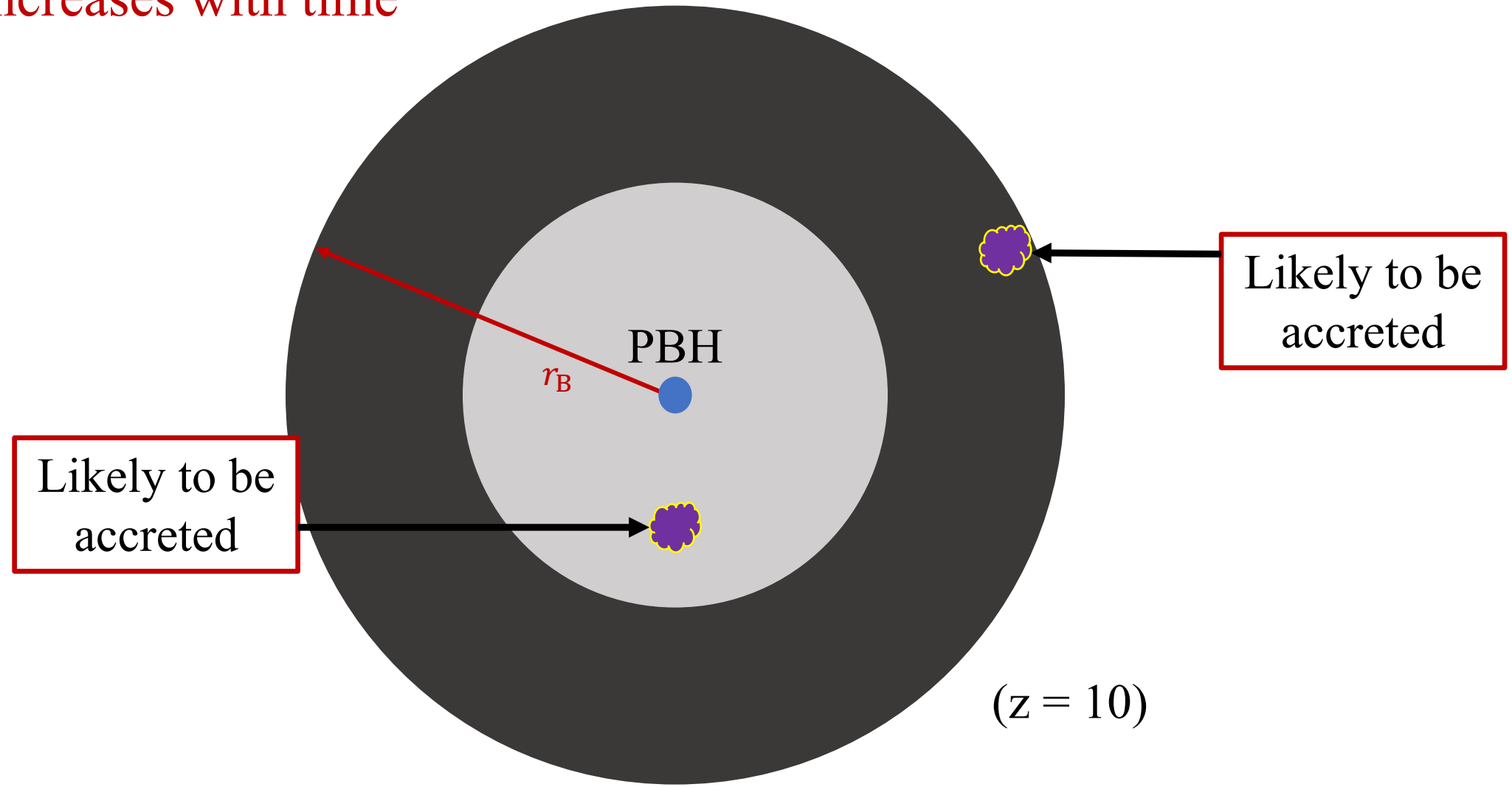
Bondi Radius

- Bondi radius (r_{B}) sets the scale of the radius of accretion



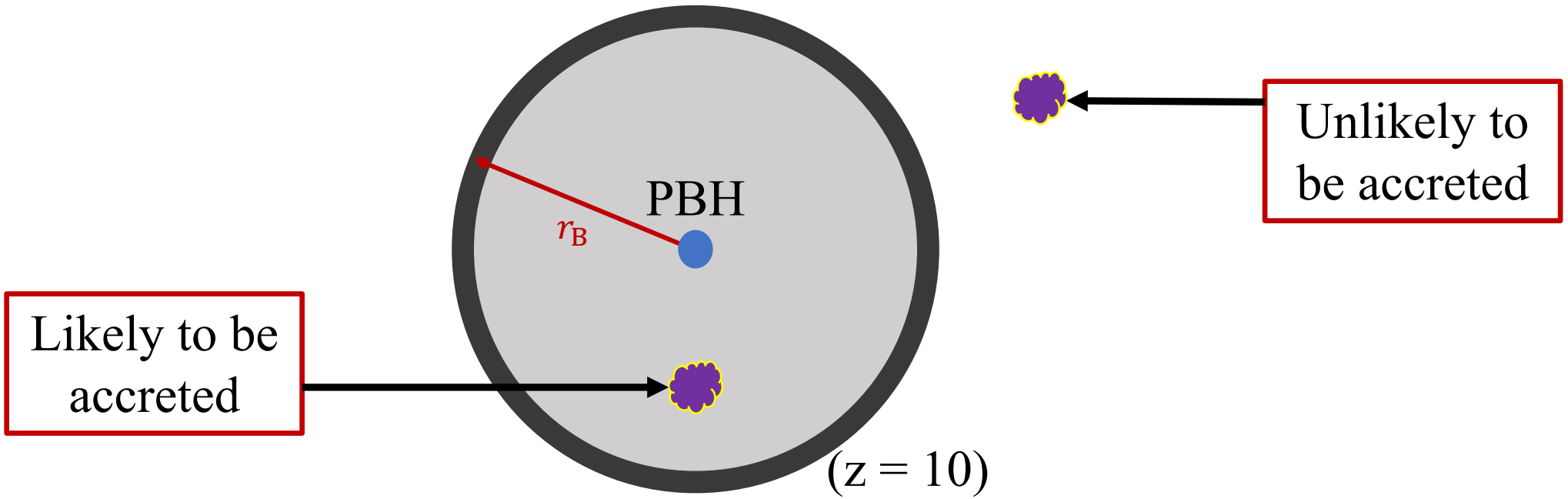
Bondi Radius in BHL Model

- r_{B} depends on the **background cosmology**
- r_{B} increases with time



Bondi Radius in PR Model

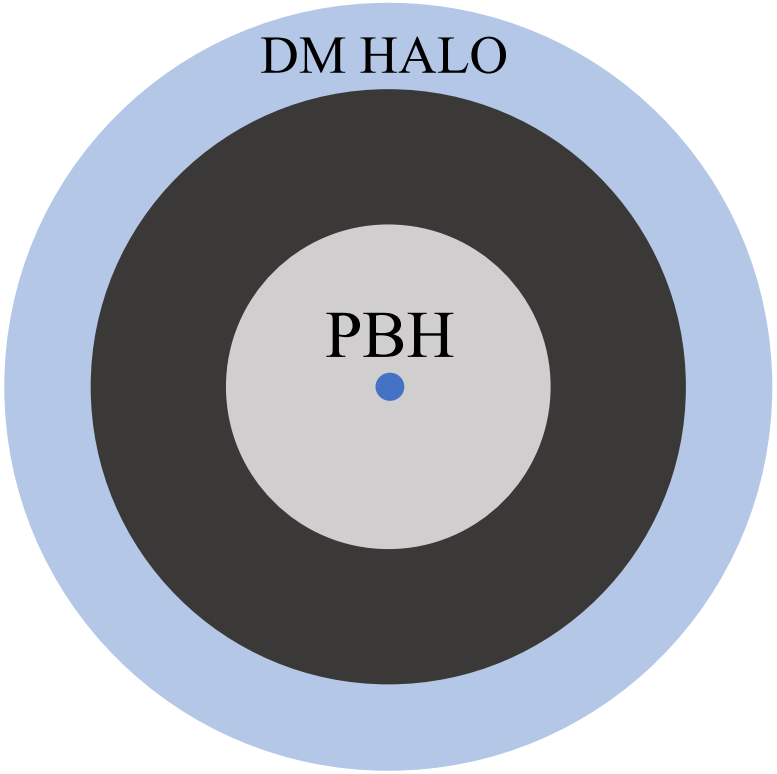
- r_{B} depends on the **local, ionized region** around PBH
- Due to local thermal feedback, r_{B} is roughly constant with time



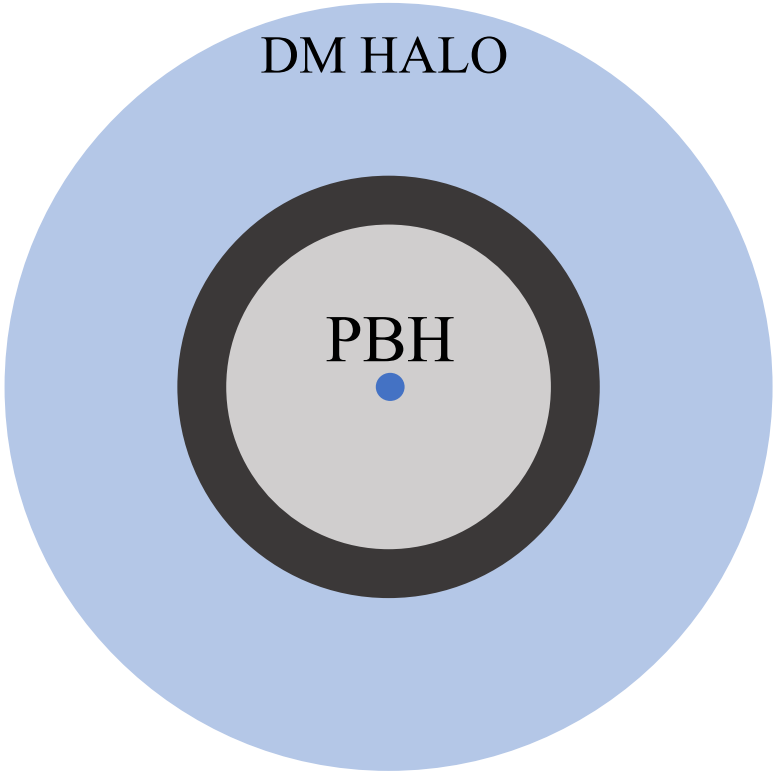
Role of DM Mini-halos

- DM pools around PBHs, increasing the gravitational potential at large radius
- **BHL gets a large enhancement due to the increase in the Bondi Radius**
- **PR does not get an enhancement since the Bondi radius is constant**

BHL

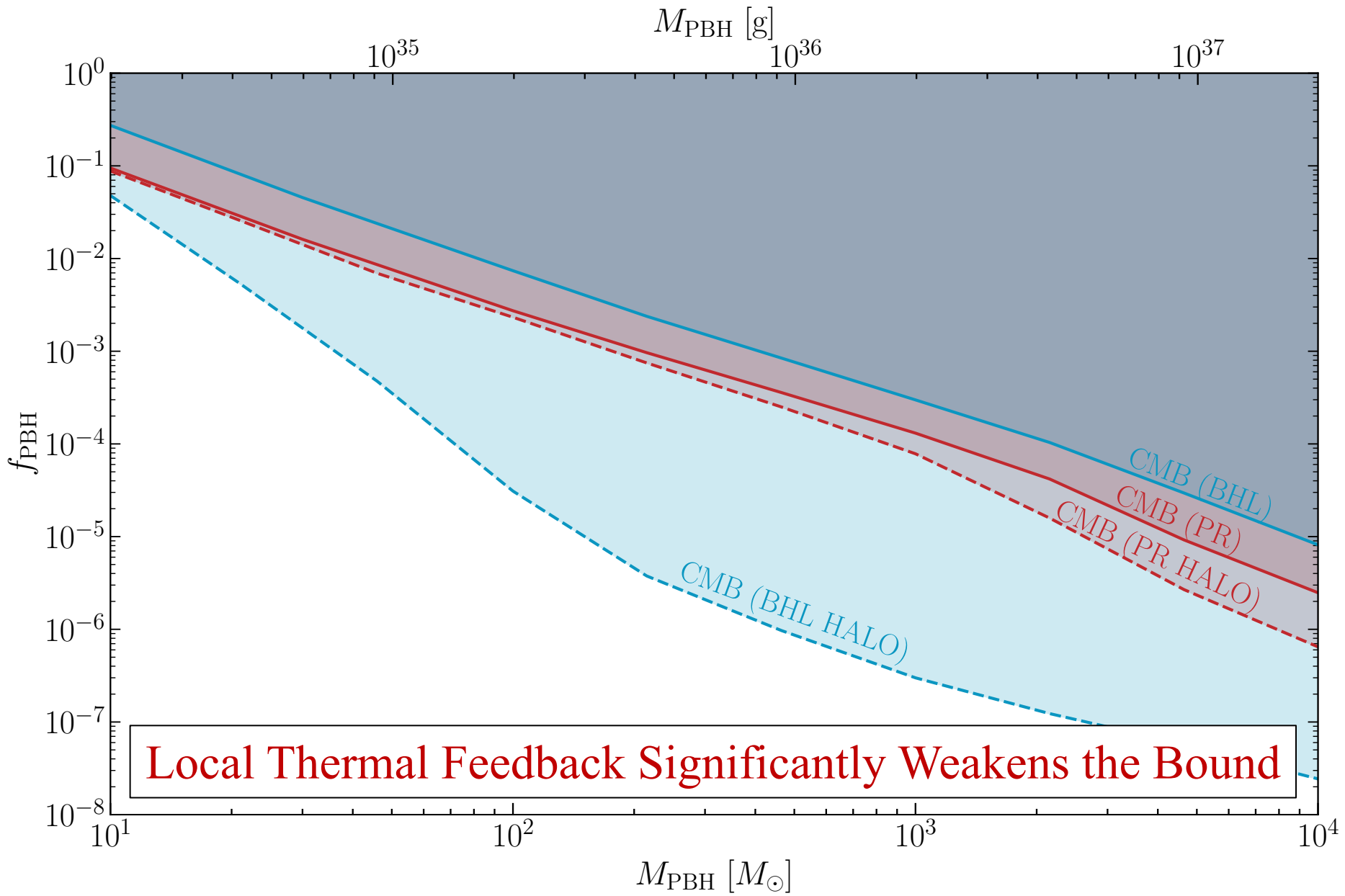


PR



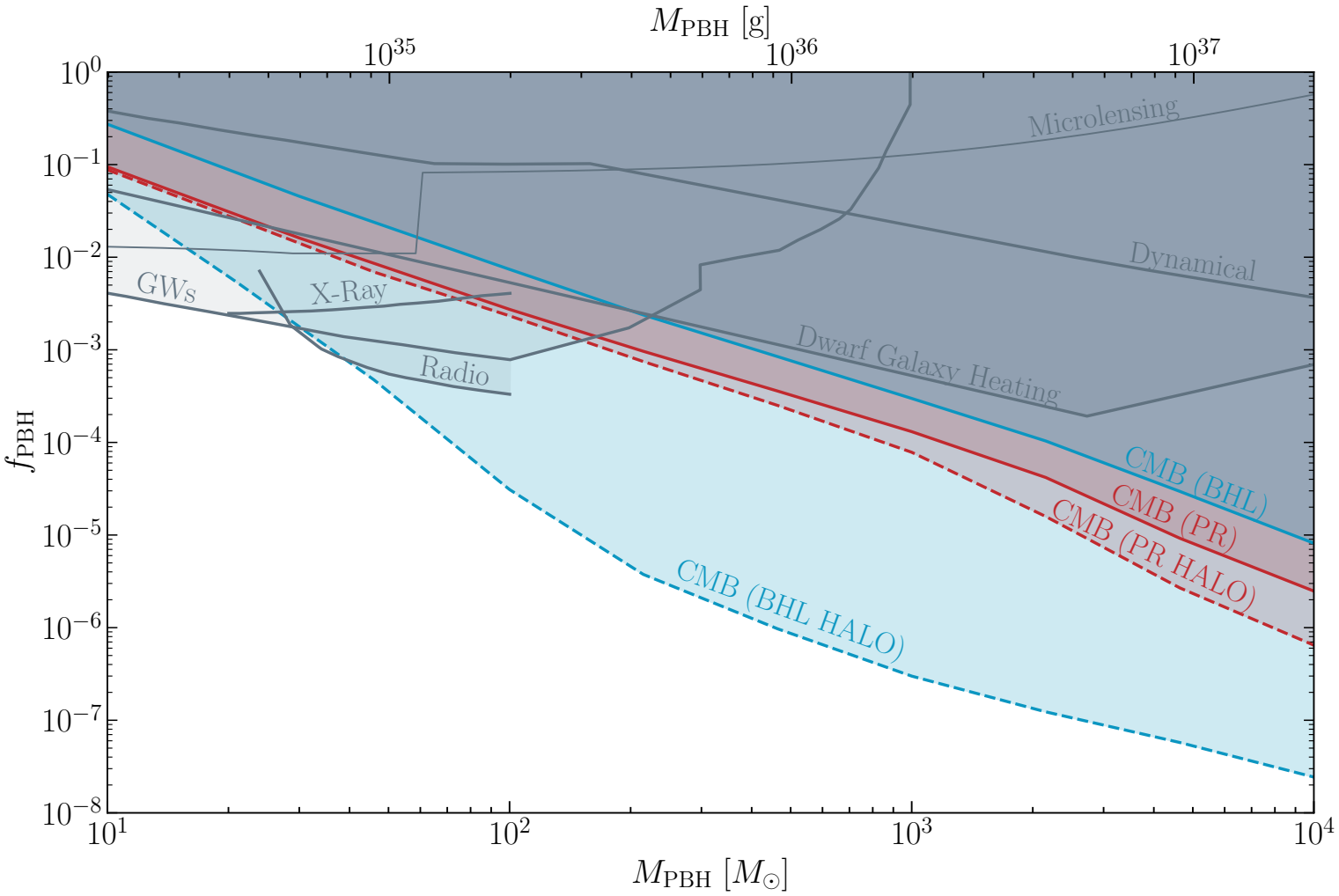
Local thermal feedback confines accretion to a small region around the PBH, which is dominated by the PBH gravitational potential, not the halo

CMB Bound


$M_{\rm PBH}$ [g]
10^{35}
10^{36}
10^{37}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
$f_{\rm PBH}$
CMB (BHL)
CMB (PR)
CMB (PR HALO)
CMB (BHL HALO)
Local Thermal Feedback Significantly Weakens the Bound
10^{1}
10^{2}
10^{3}
10^{4}
$M_{\rm PBH}$ $[M_\odot]$

Summary

- PBHs can impact the CMB power spectra
- Many astrophysical uncertainties were investigated and quantified (**accretion rate was highlighted in this talk**)
- Local Thermal Feedback significantly weakens the bound
  - ➢ Shown explicitly for PR scenario



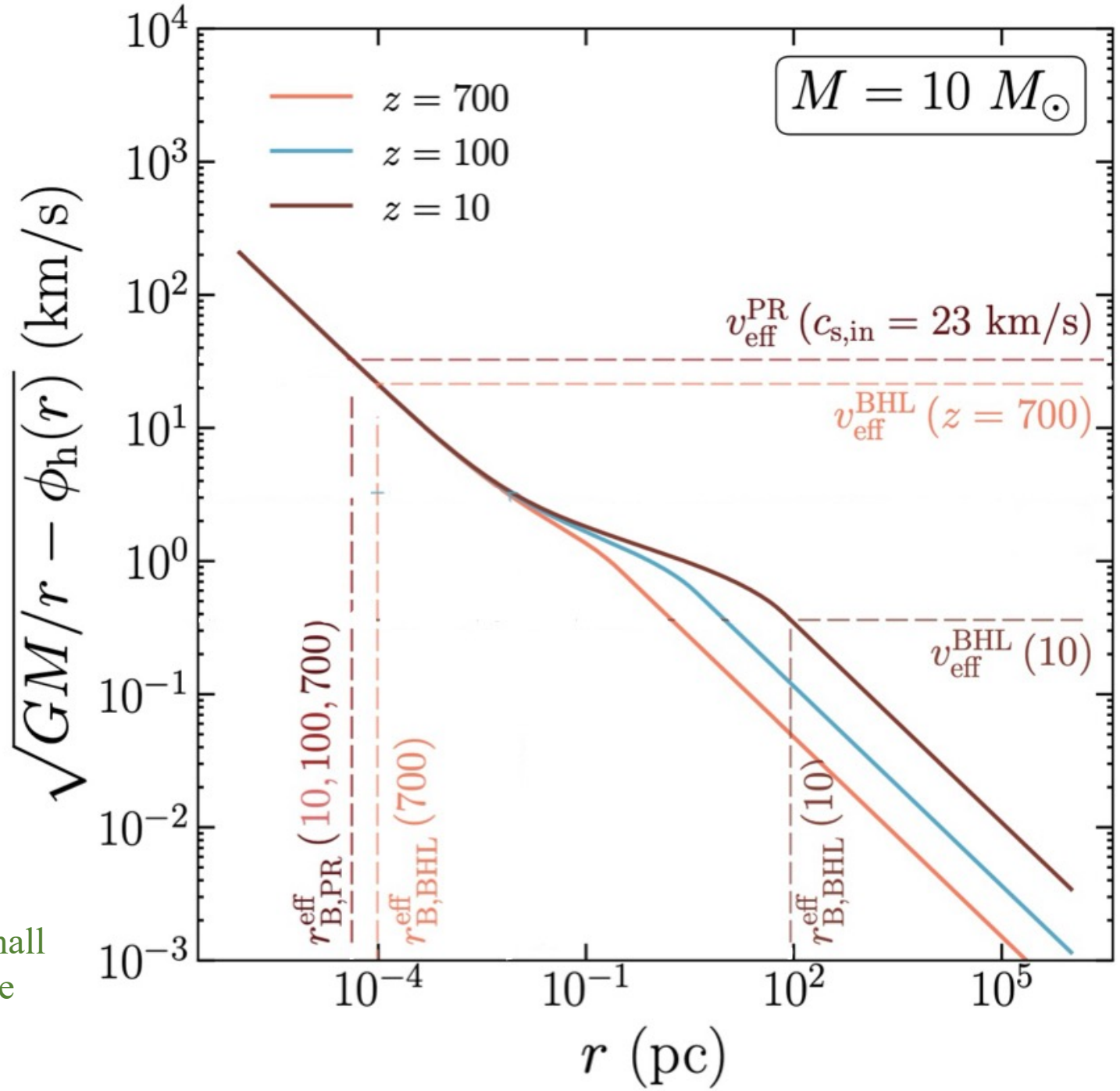
$$v_{\rm eff} = \sqrt{\frac{GM}{r_{\rm B}^{\rm eff}} + \phi_{\rm halo}(r_{\rm B}^{\rm eff})}$$

Effective Bondi Radius grows significantly for BHL

- Effective velocity decreases
- DM halo grows

Effective Bondi Radius is constant for PR

- Effective velocity is constant



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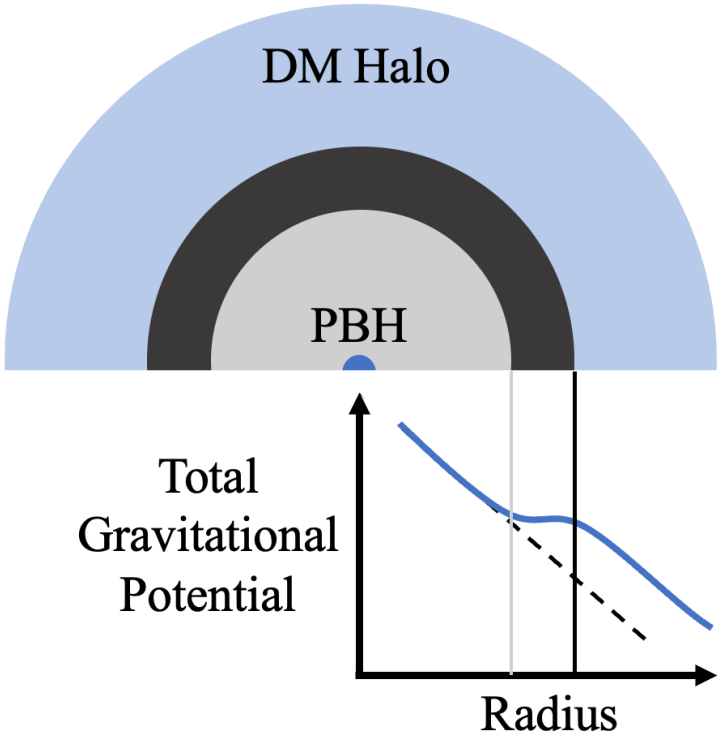
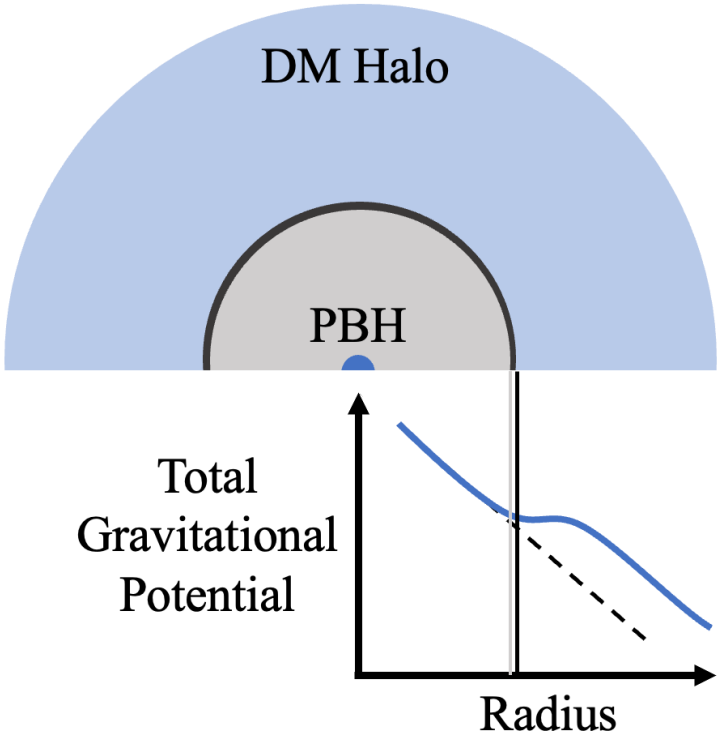


PR



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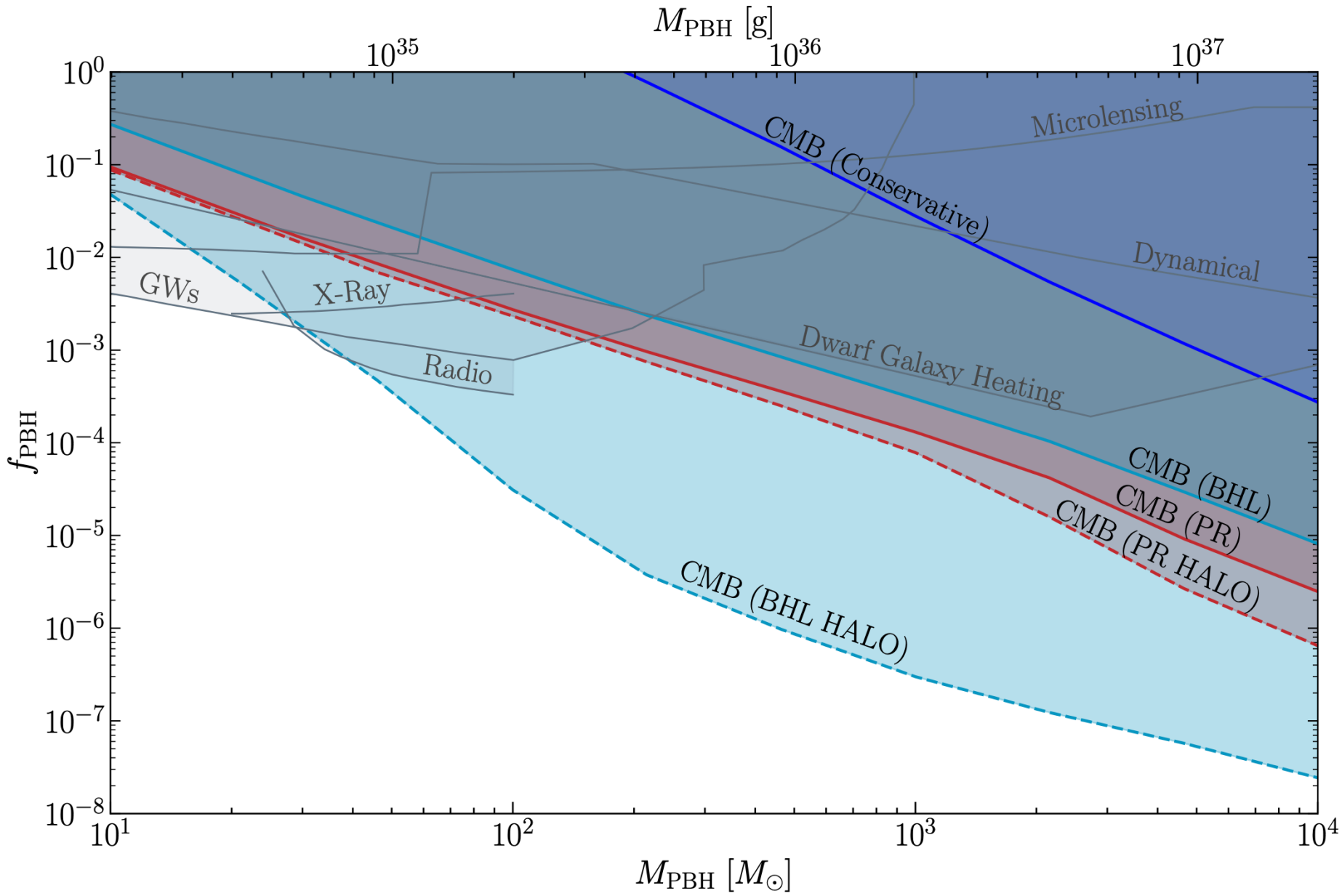
$M_{\rm PBH}$ [g]
10^{35}
10^{36}
10^{37}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
$f_{\rm PBH}$
CMB (Conservative)
Microlensing
Dynamical
GWs
X-Ray
Dwarf Galaxy Heating
Radio
CMB (BHL)
CMB (PR)
CMB (PR HALO)
CMB (BHL HALO)
10^{1}
10^{2}
10^{3}
10^{4}
$M_{\rm PBH}$ [$M_\odot$]