Primordial Black Holes from Domain Wall Relics

an update

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work in progress

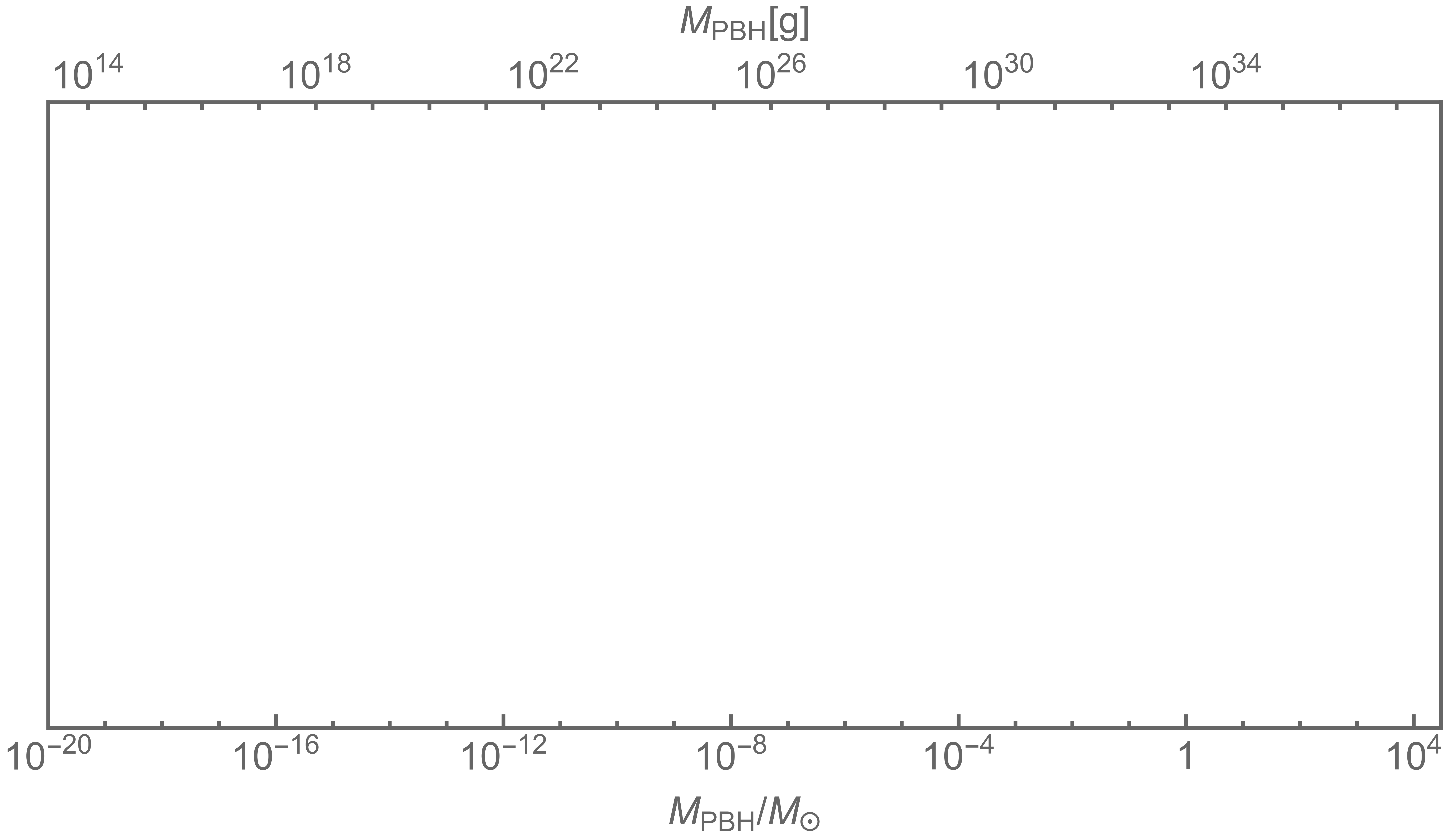
with Peisi Huang, Yuxin Liu & Wei Xue

McMaster University

PERIMETER INSTITUTE

Light Dark World, 30 Jul 2026

Light is a relative notion…



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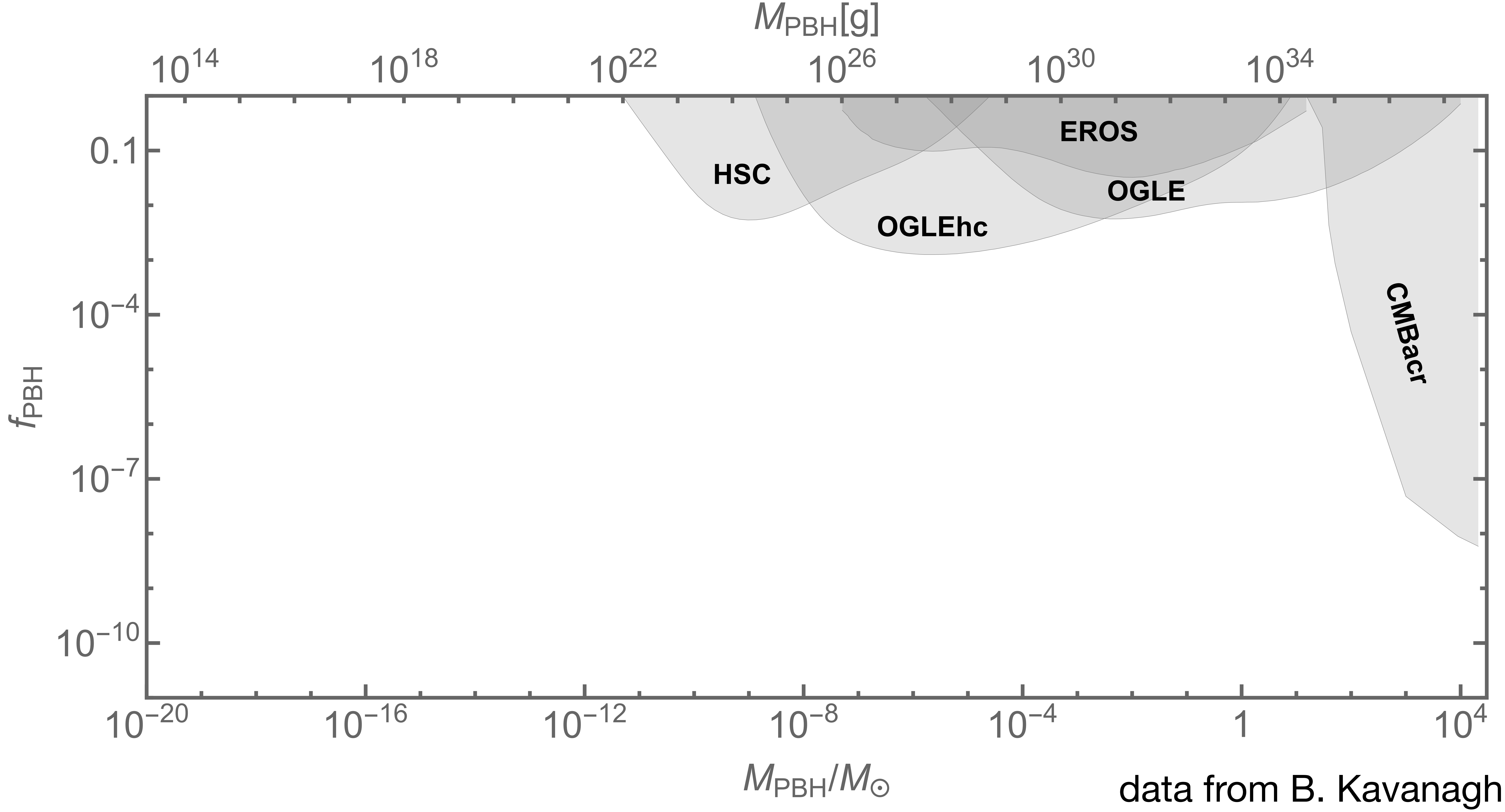

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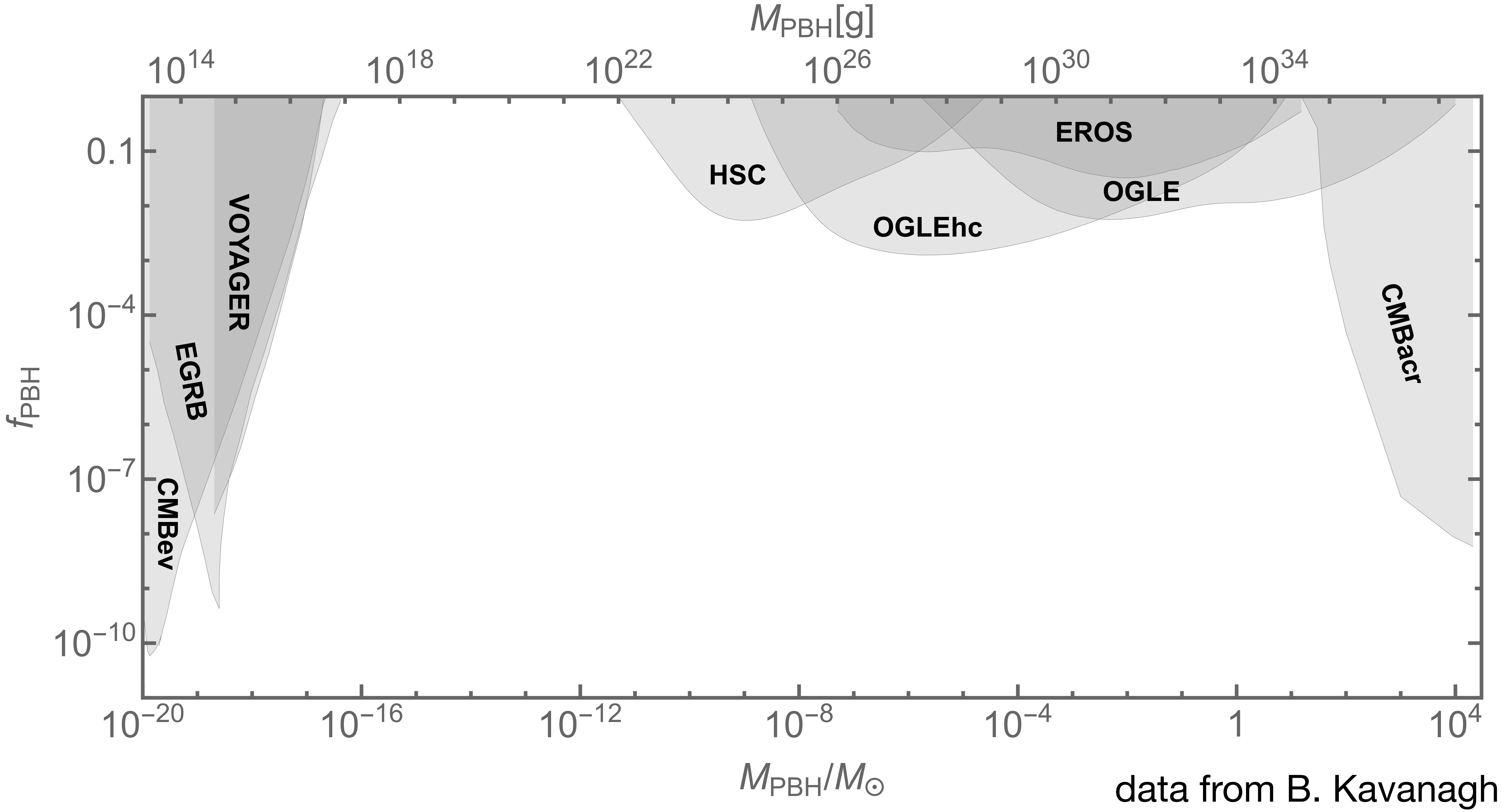

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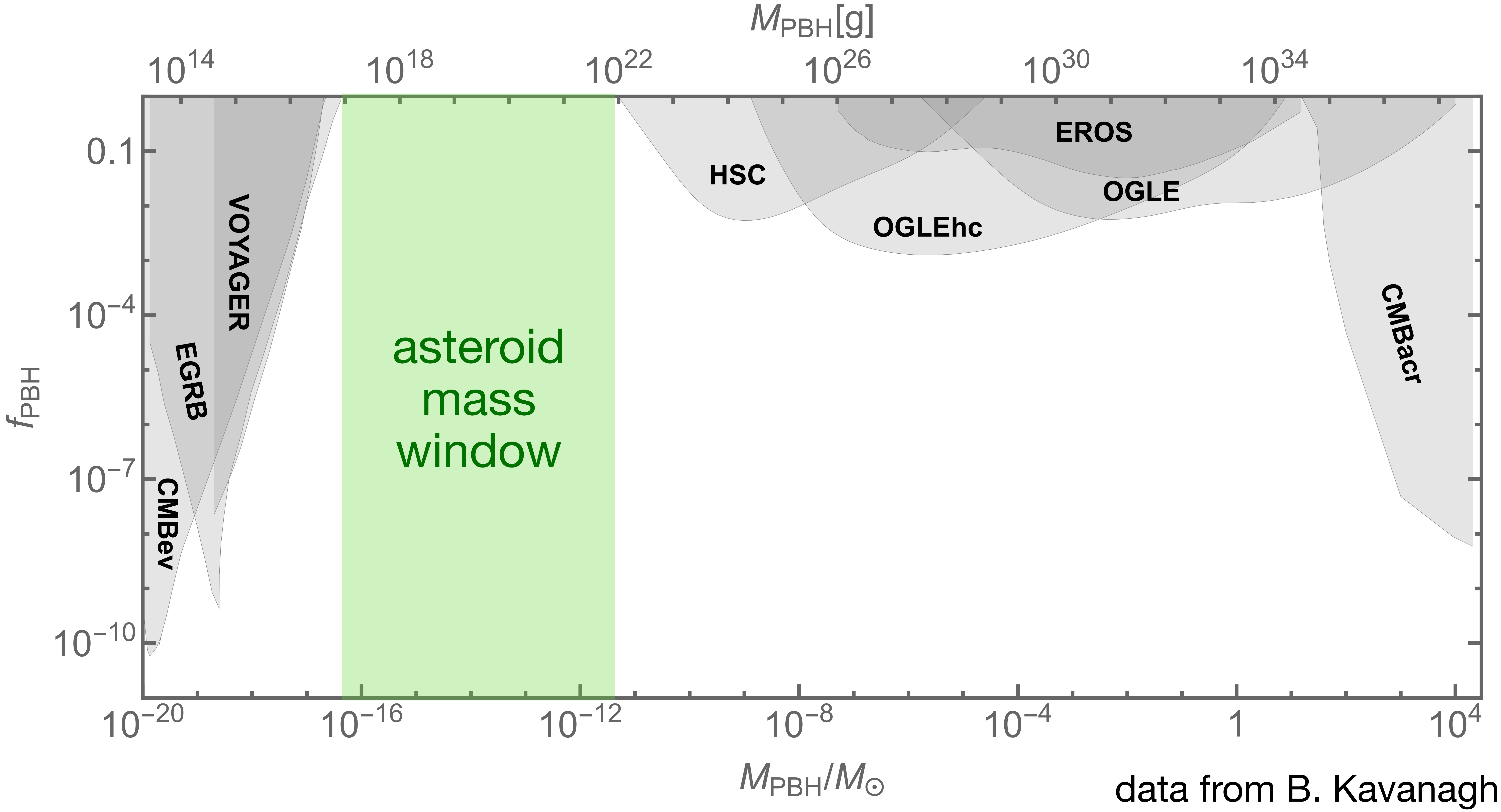

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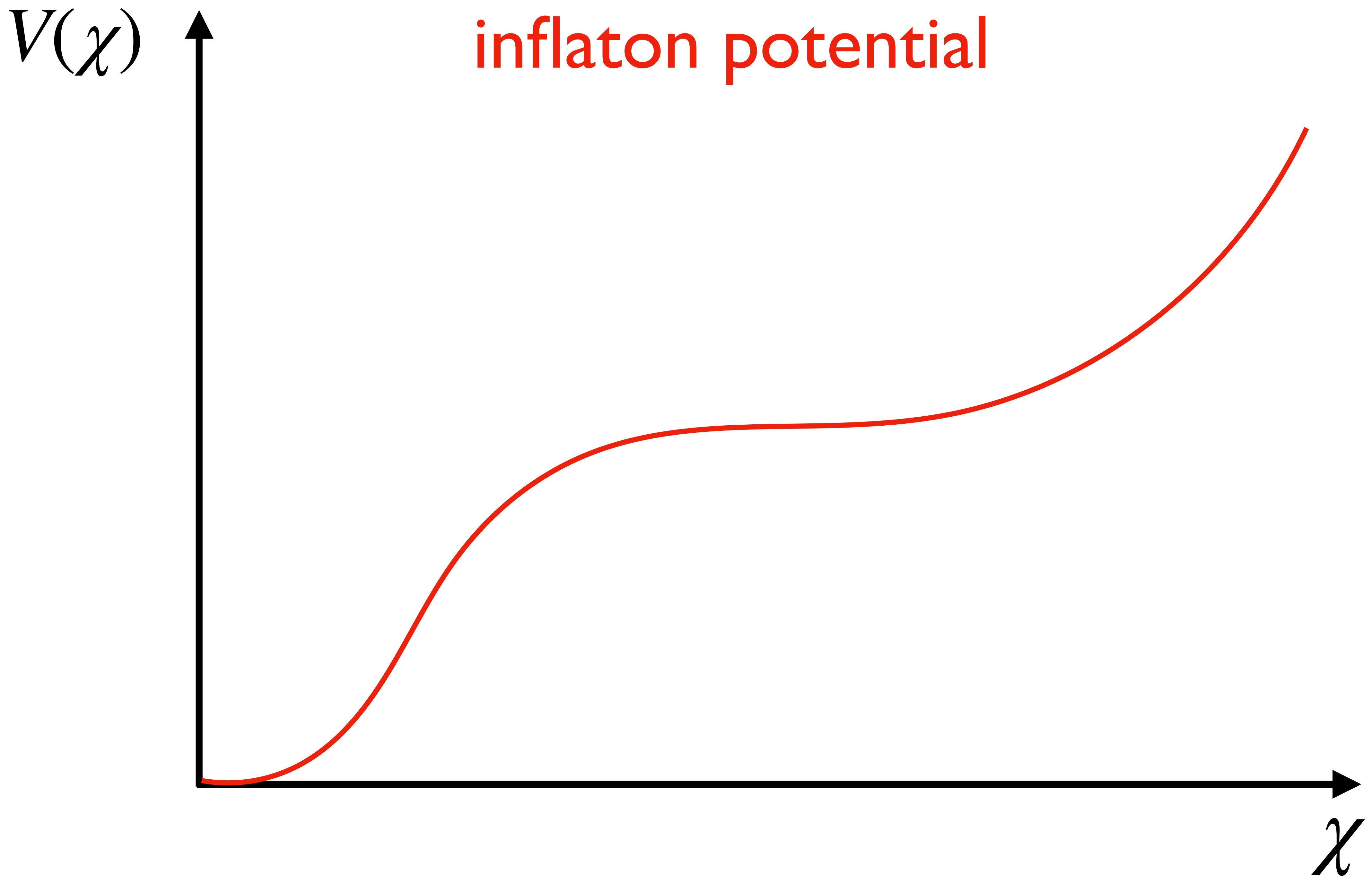
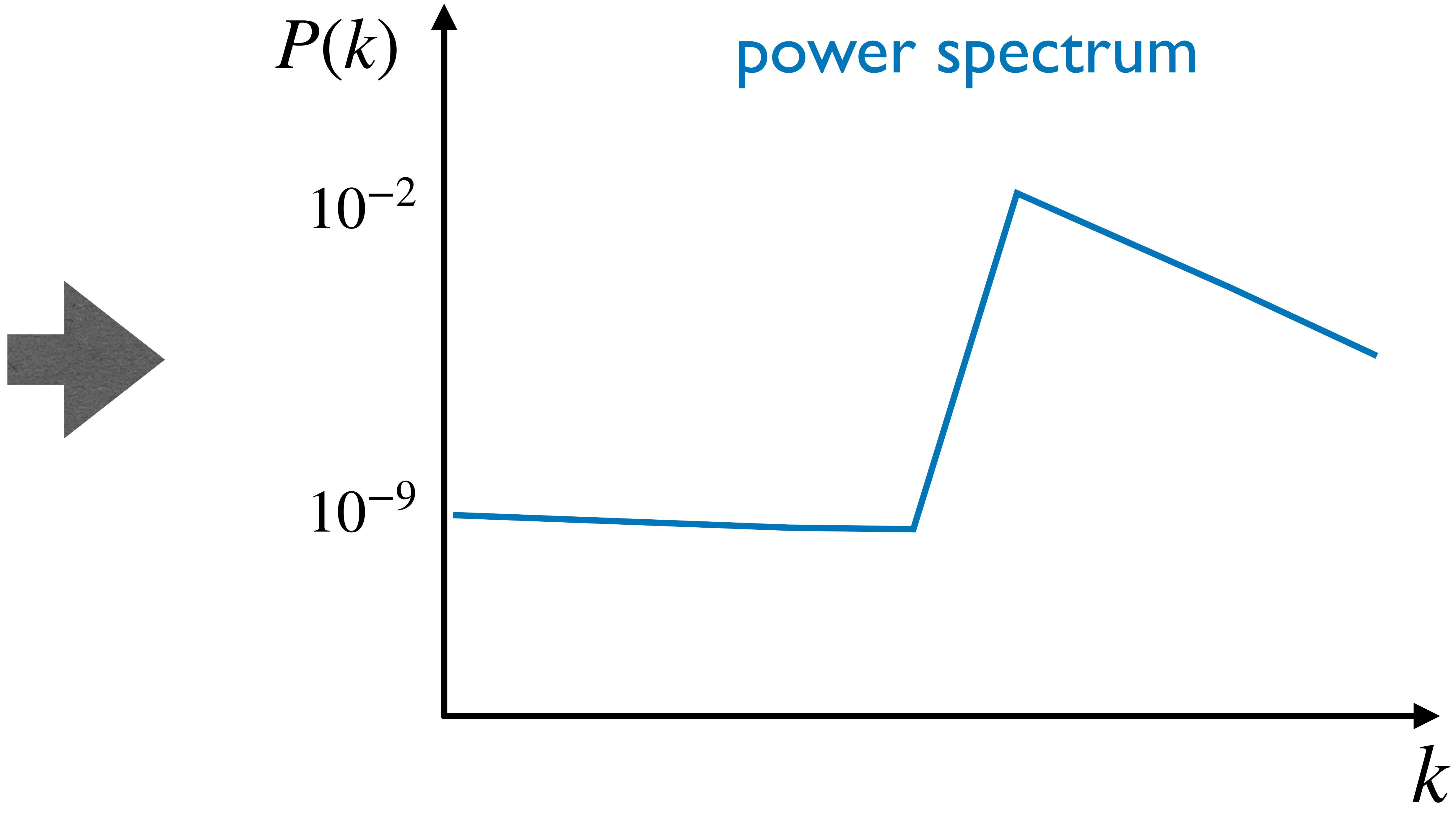
How are PBHs produced?

- most popular scenario: production from enhanced primordial perturbations





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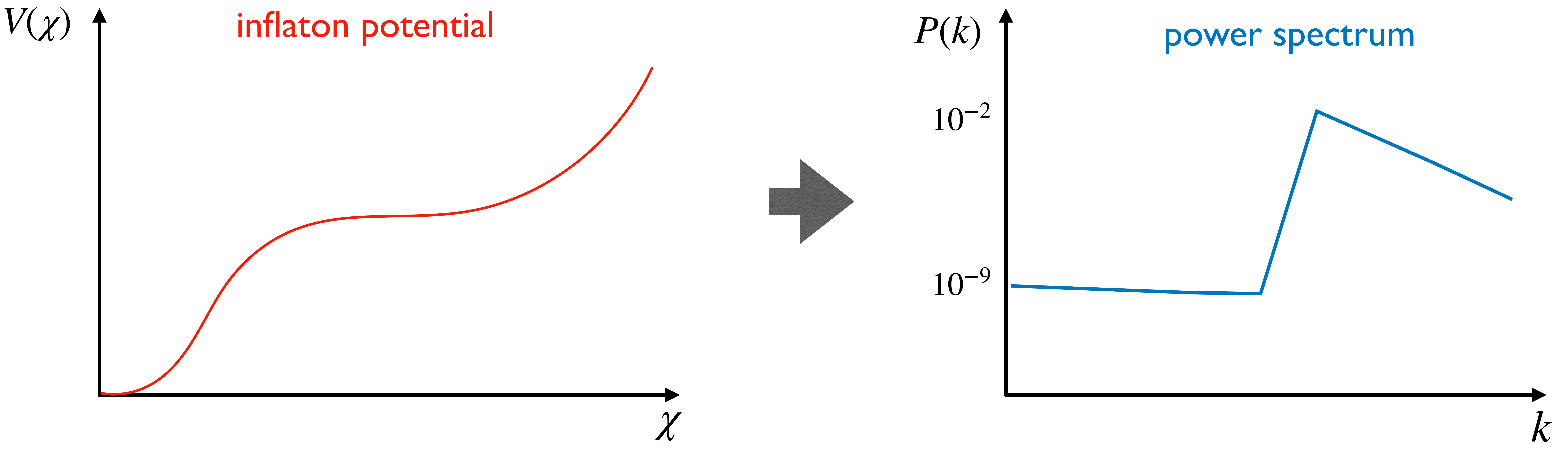


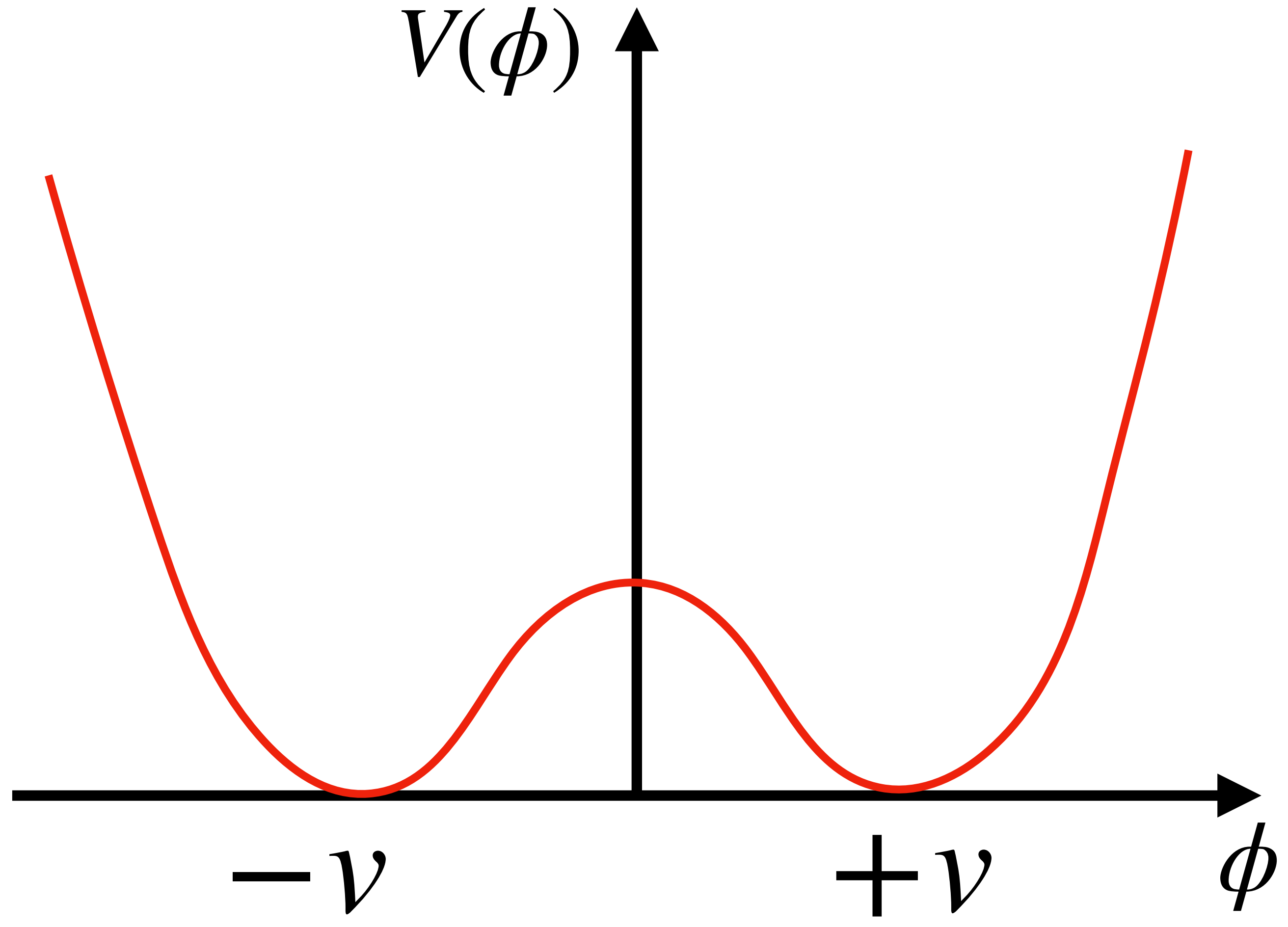
- problem: need tuning of the inflaton potential

There is another inflationary mechanism for PBH production

- consider a spectator scalar with spontaneously broken Z_2-symmetry

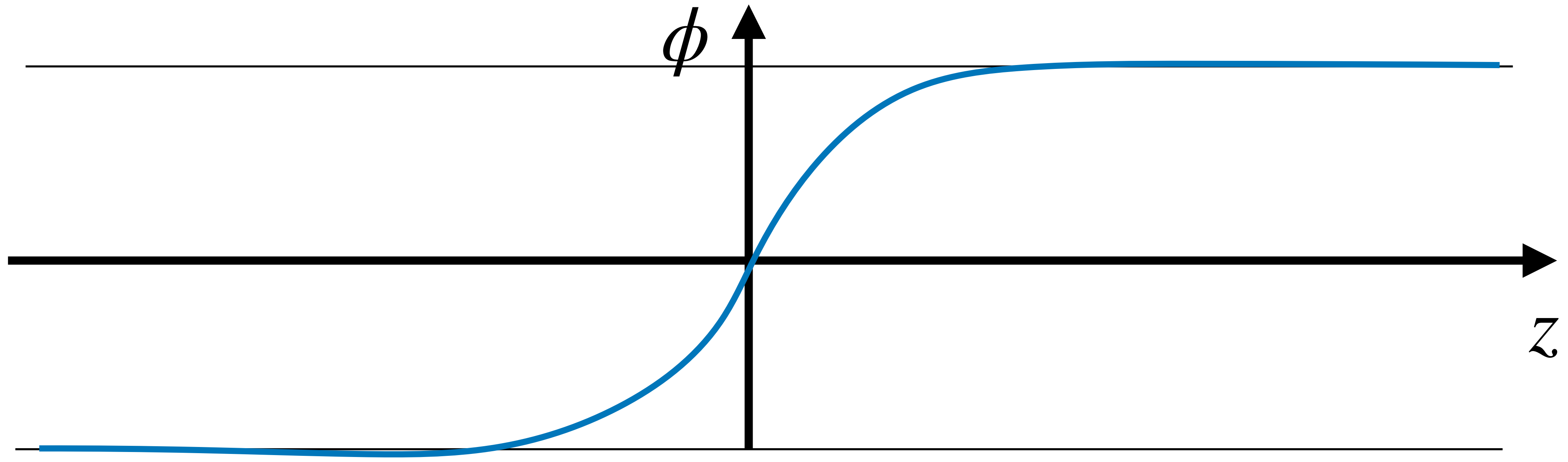
Garriga, Vilenkin, Zhang (2015)
Deng, Garriga, Vilenkin (2016)
Basu, Guth, Vilenkin (1991)

$$\mathscr{L} = \frac{(\partial\phi)^2}{2} - \frac{\lambda}{4}(\phi^2 - v^2)^2$$



$$\mu = \sqrt{\lambda} v$$

- it forms domain walls (DW): $\phi = v \tanh\left(\sqrt{\mu/2}\, z\right)$ with tension: $\sigma = \dfrac{2\sqrt{2}\mu^3}{3\lambda}$

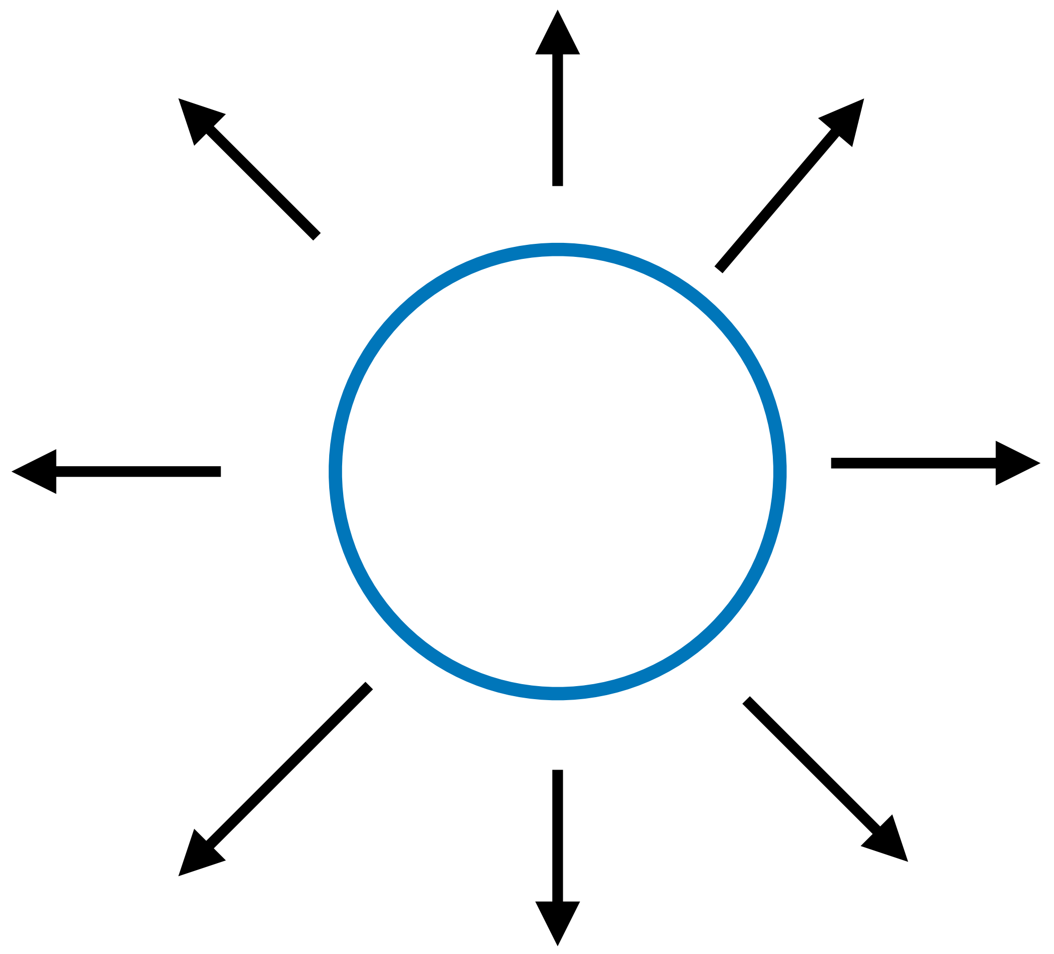


- spherical domain walls are nucleated during inflation by quantum tunneling (which can also be thought as thermal excitation)

$$a = e^{H_I t}$$

$$T_{\mathrm{dS}} \sim H_I$$

probability per Hubble time per Hubble volume: $p \sim S_E^2 \exp(-S_E)$



Euclidean instanton action $S_E = \dfrac{2\pi^2 \sigma}{H_I^3}$

- at nucleation, DWs have horizon size, then they are frozen in comoving coordinares

- DW nucleation is a continuous process, lasting over the whole duration of inflation

- by the end of inflation: population of superhorizon domain walls with broad distribution of comoving radii:

$$\frac{dN}{dVdR} \simeq p\frac{dR}{R^4}$$

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$$M_{\rm re} \sim \frac{4\pi\sigma}{H_{\rm re}^2} \sim M_{\rm horizon} \sim \frac{4\pi\rho_{\rm rad}}{3H_{\rm re}^3}$$

➡

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$$\rho_{\rm rad} = \frac{3M_{pl}^2H^2}{8\pi}$$

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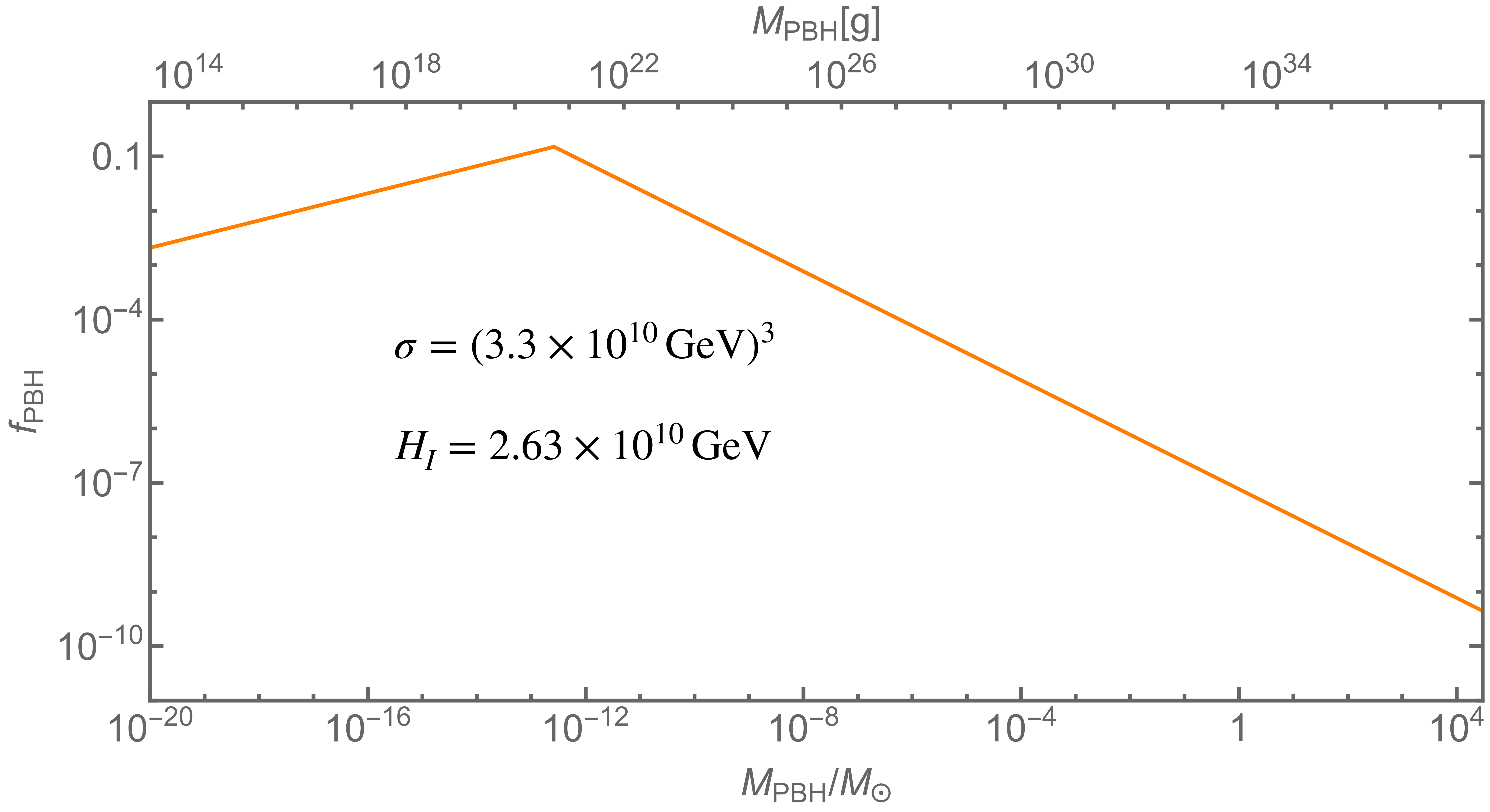
independent of anything, but σ !

- distribution of BH masses:

$$\frac{df_{\rm PBH}}{d\log M_{\rm PBH}} \propto \begin{cases} M_{\rm PBH}^{1/4}\,, & M_{\rm PBH} < M_{\rm PBH,peak} \quad \text{(light)} \\ M_{\rm PBH}^{-1/2}\,, & M_{\rm PBH} > M_{\rm PBH,peak} \quad \text{(heavy)} \end{cases}$$



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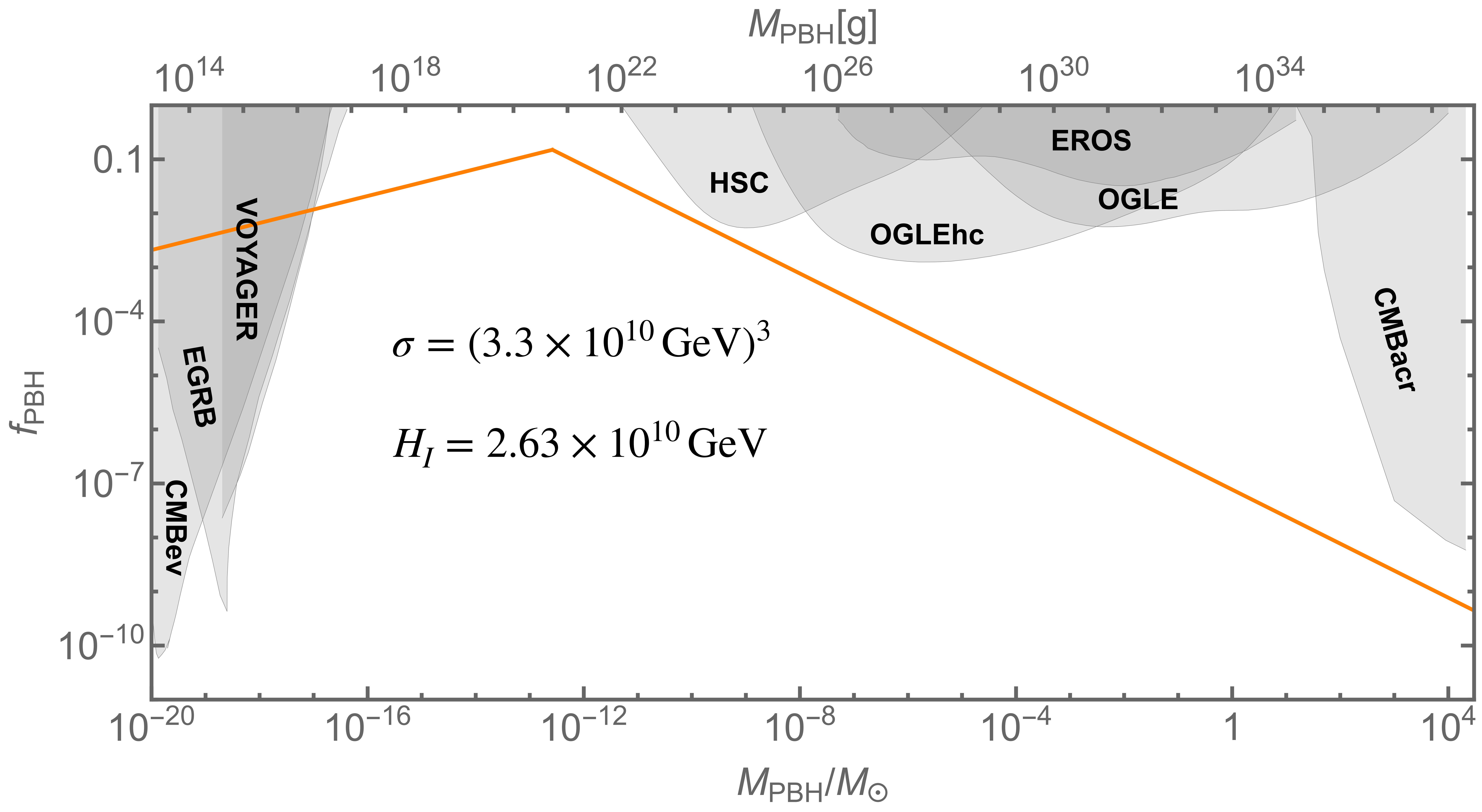

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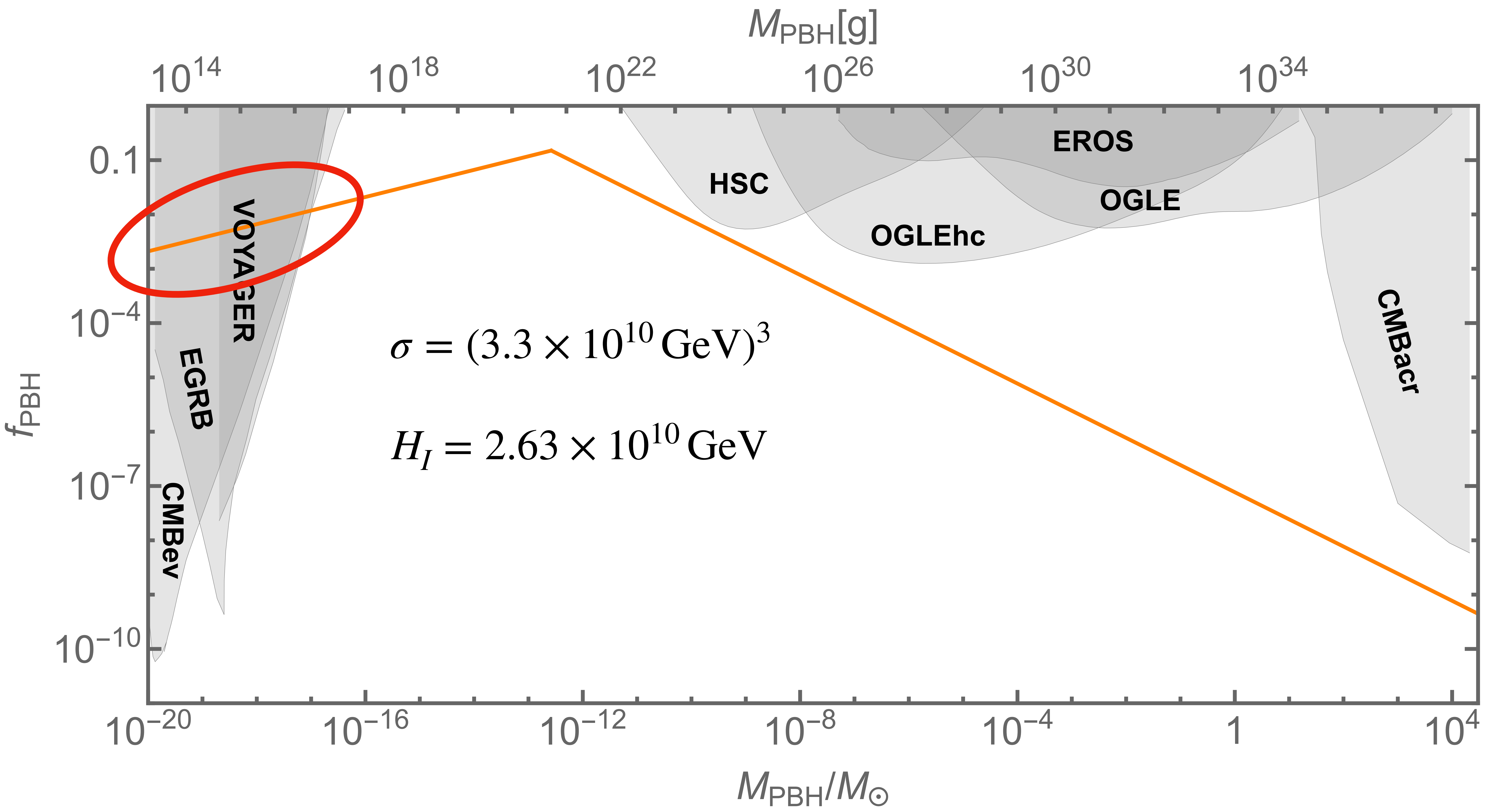

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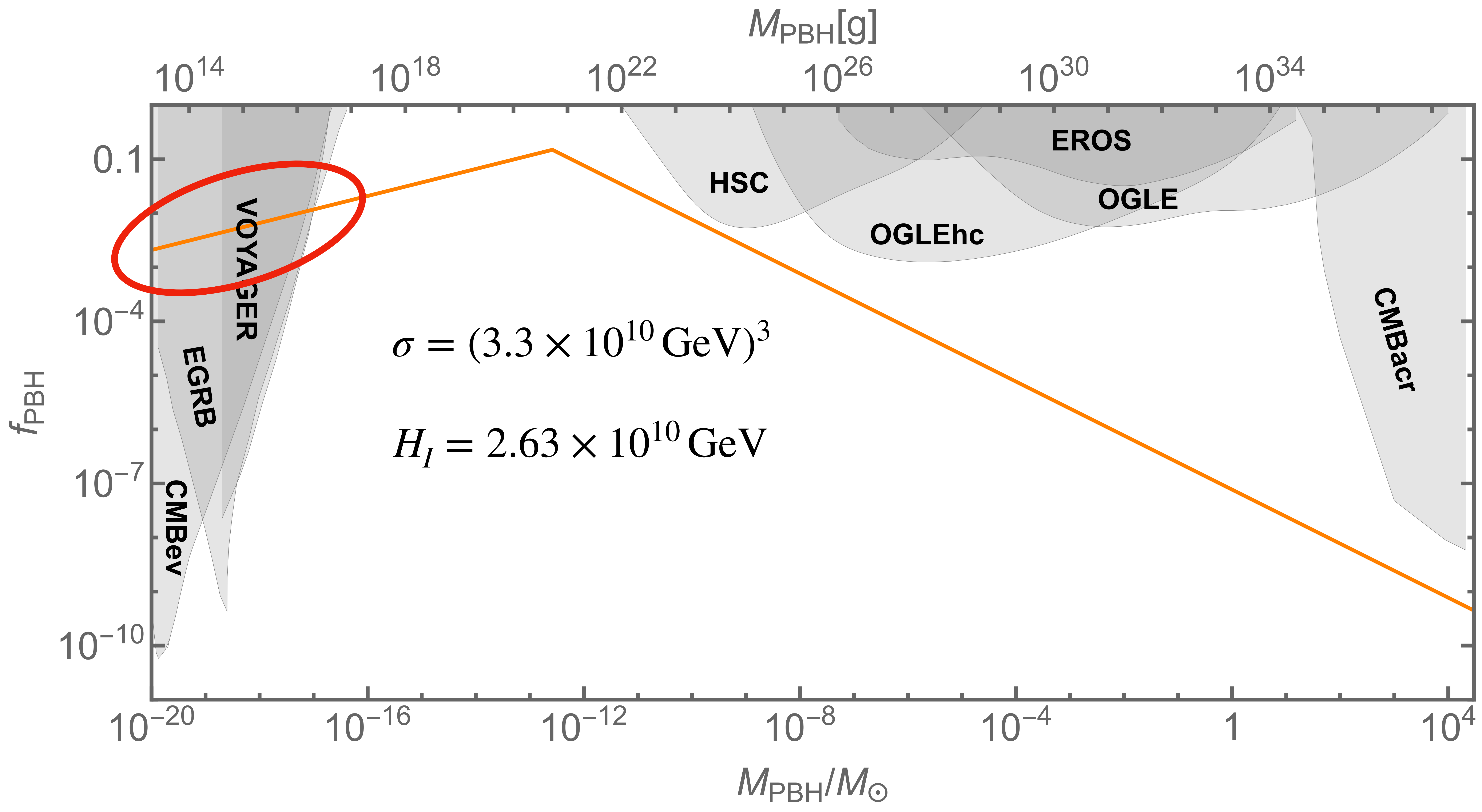

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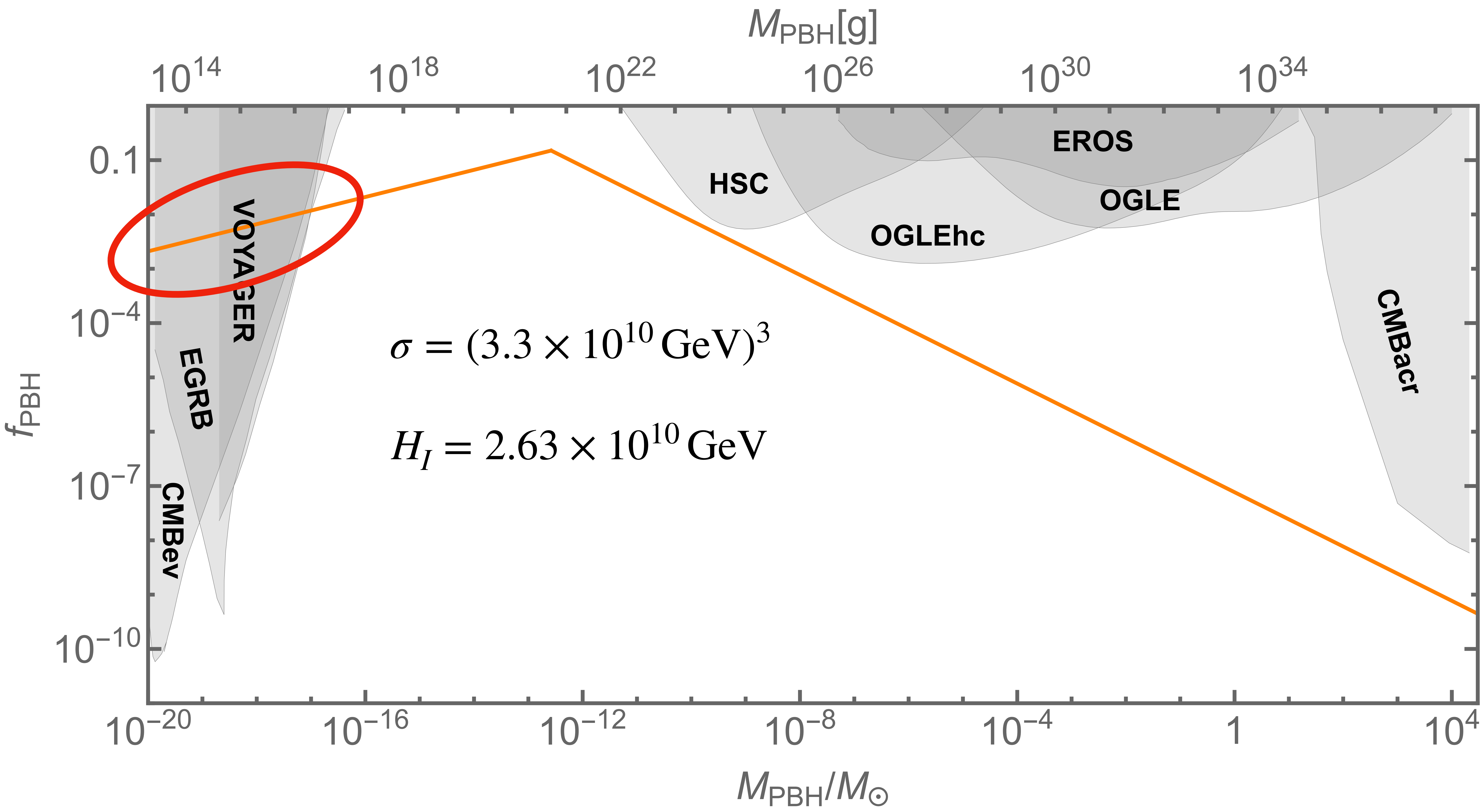

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include it back!

We missed something important: Shape perturbations of the domain walls

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- Domain walls are not born exactly spherical. *Garriga, Vilenkin (1992)*

  Their shape is perturbed by quantum fluctuations, which become classical and freeze out when the wall is superhorizon

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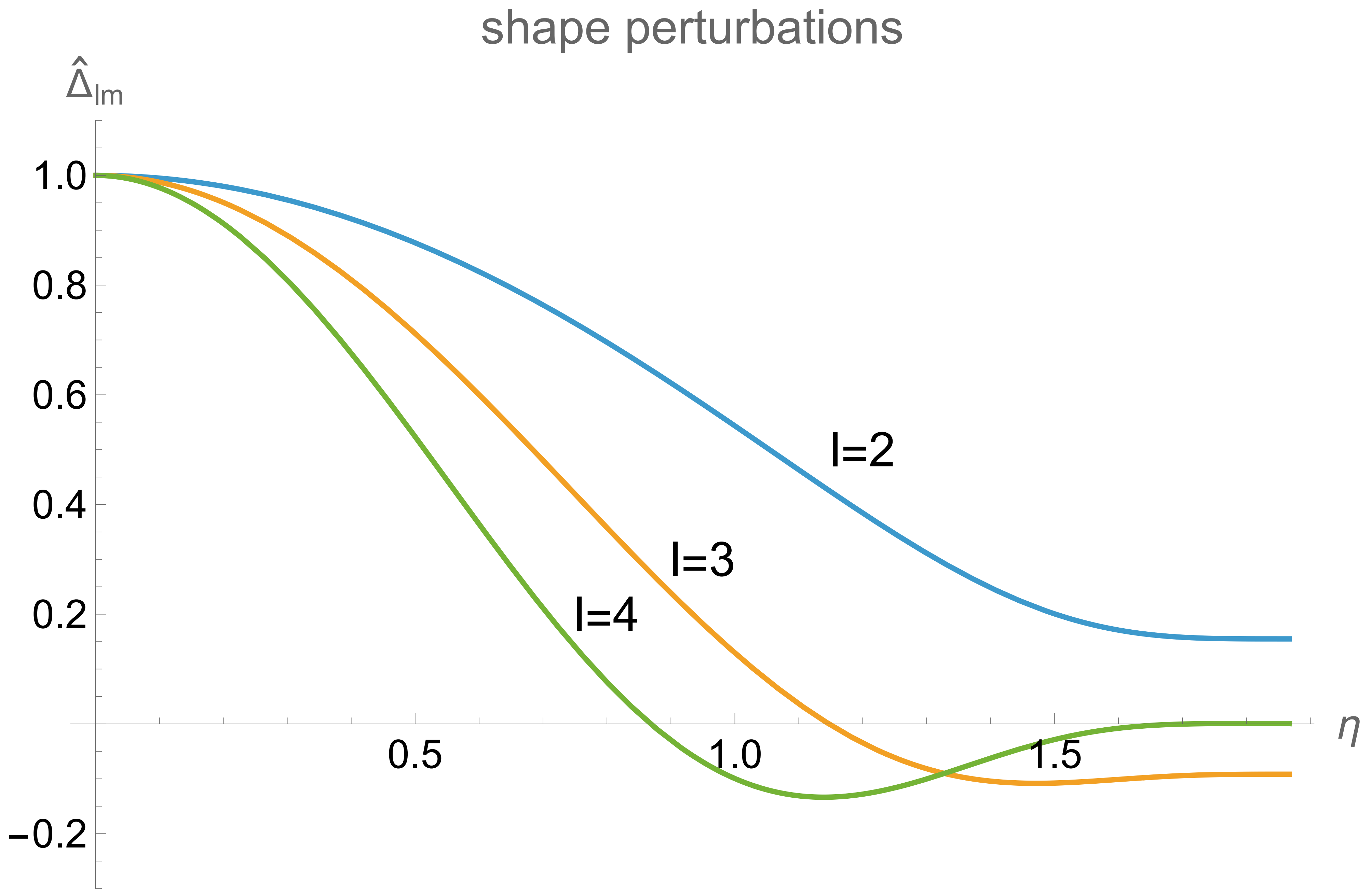

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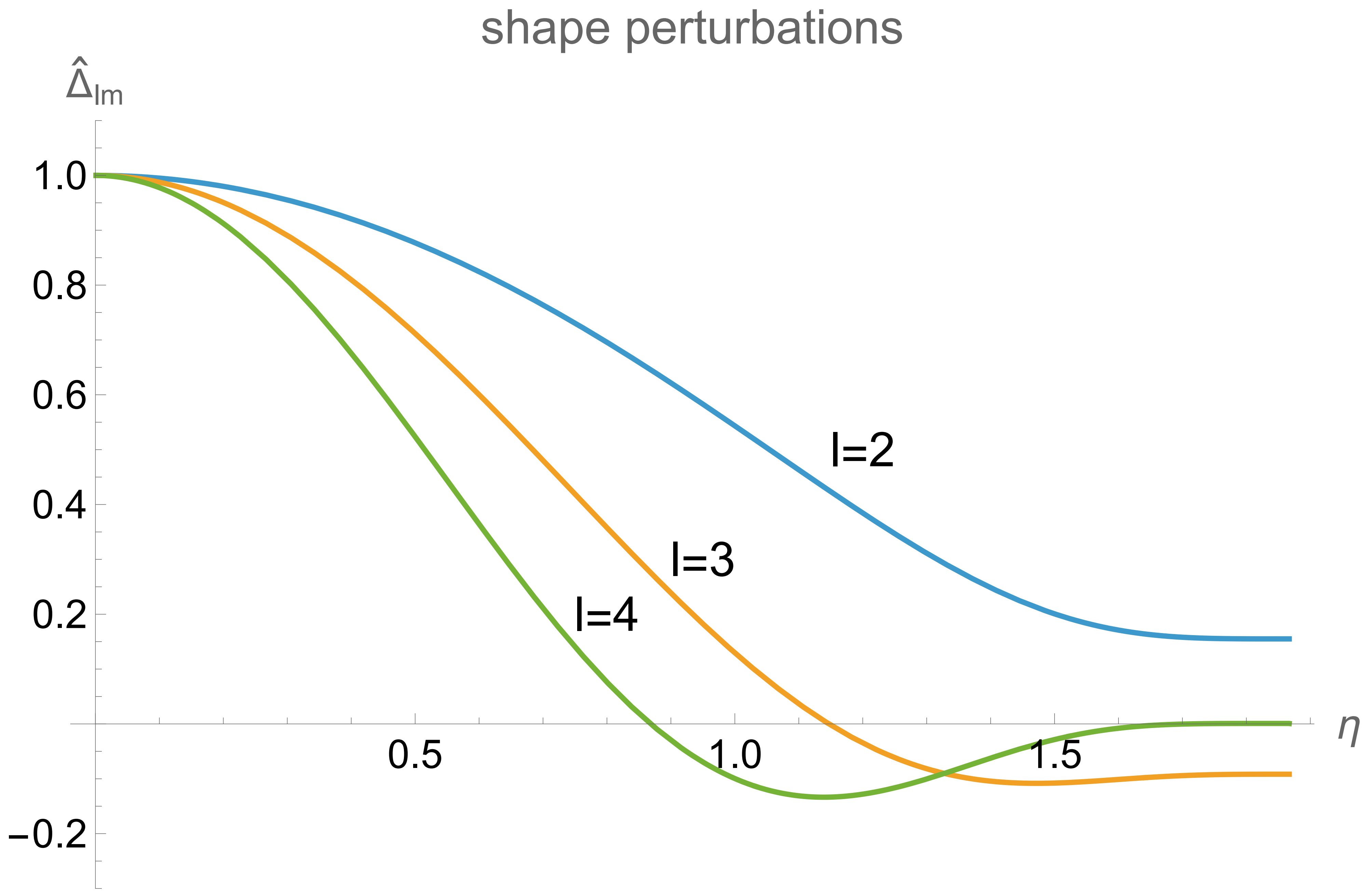
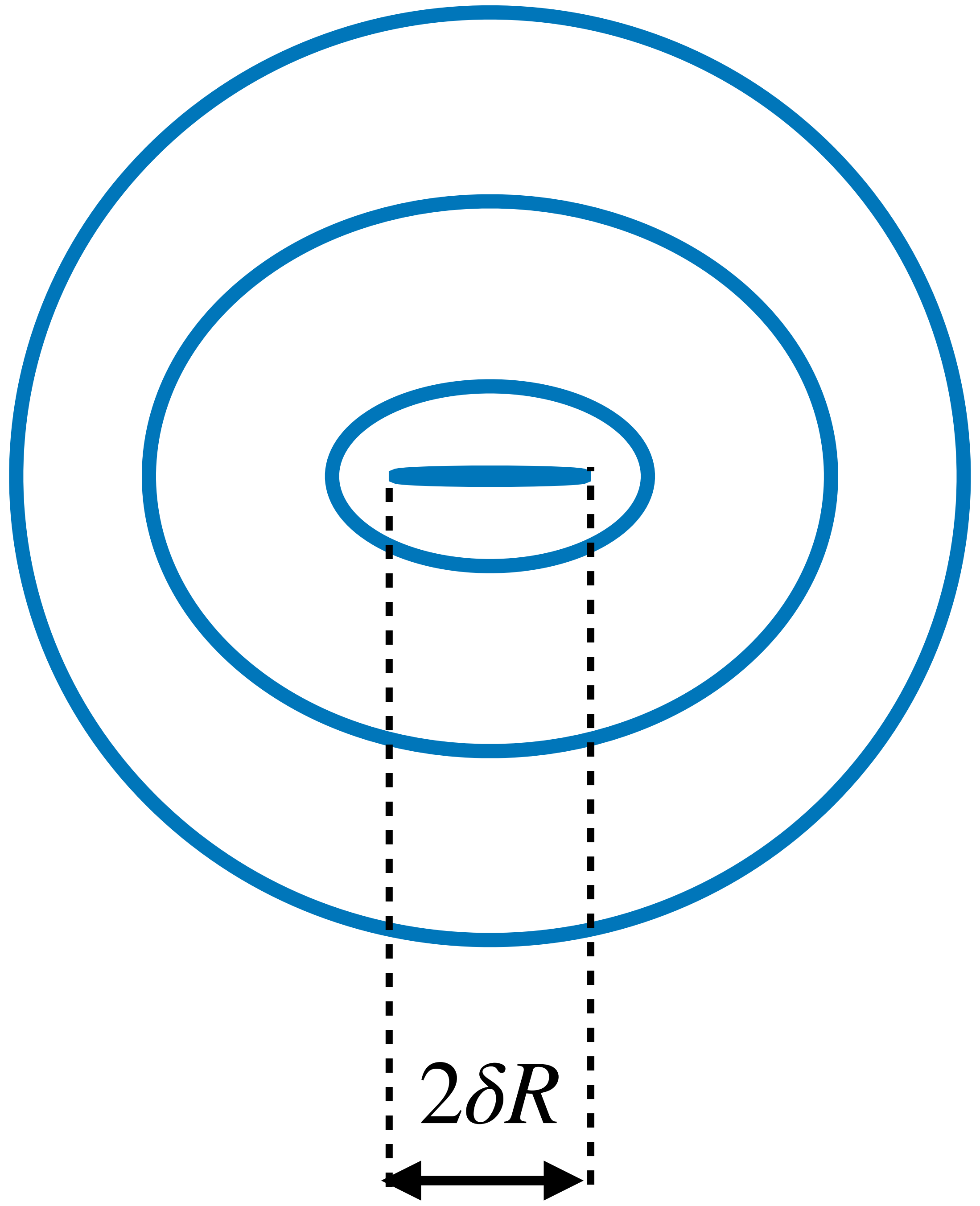
- Shortly after re-entry, the DW becomes ultra-relativistic and δR remains constant



- A domain wall collapses into a pancake, not a point!



If $\delta R > R_{\rm sch}$, no black hole forms

The wall sloshes around and annihilates into radiation

$$\delta R_{l=2} \sim \frac{0.3}{\sqrt{S_E}} \cdot \frac{1}{H_{\rm re}} \qquad R_{\rm sch} = \frac{2M}{M_{pl}^2}$$

$$M_{\rm PBH,cr} = M_{\rm PBH,peak} \cdot \frac{0.1}{S_E} \simeq 2.5 \times 10^{-3} M_{\rm PBH,peak}$$

~ 40

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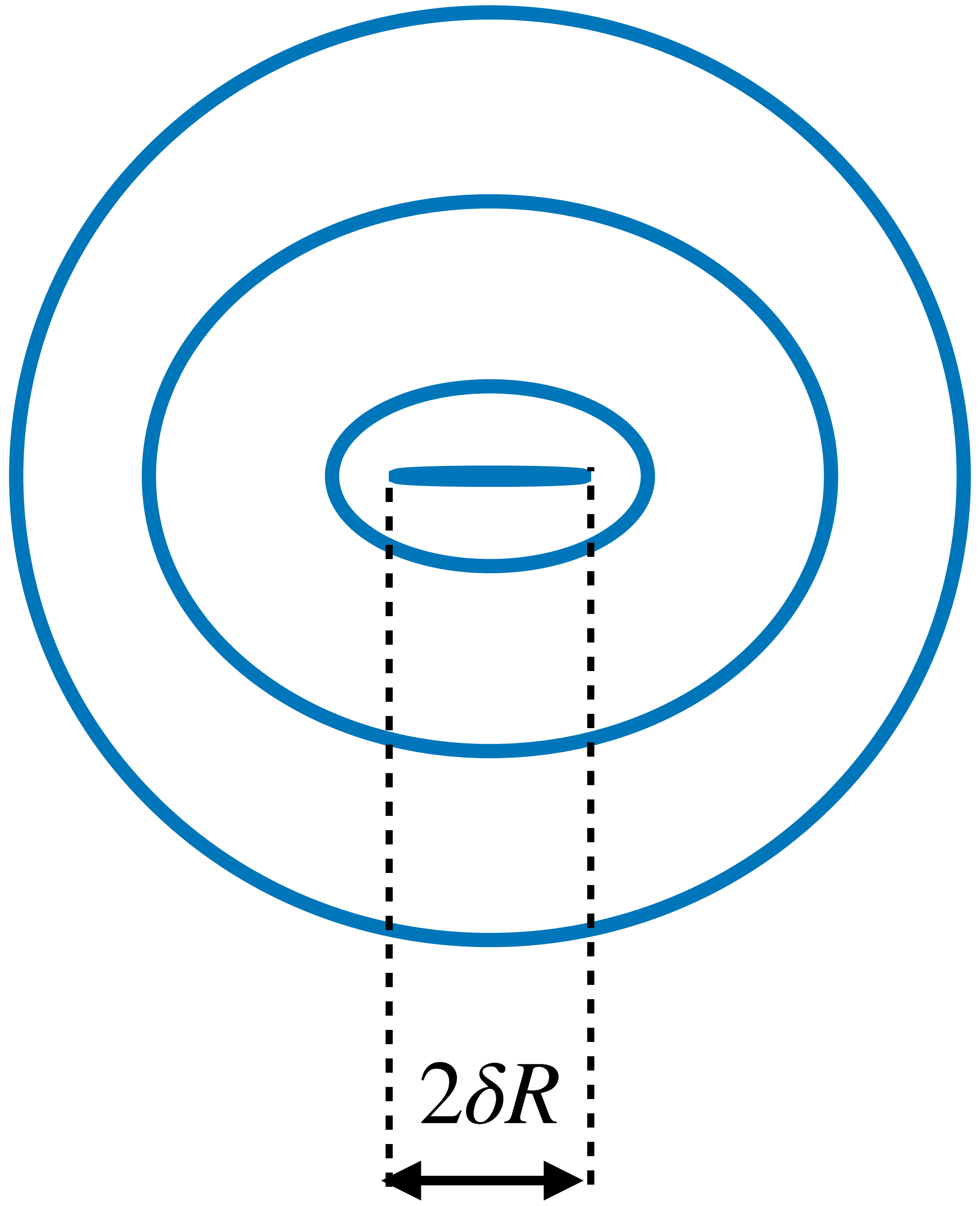

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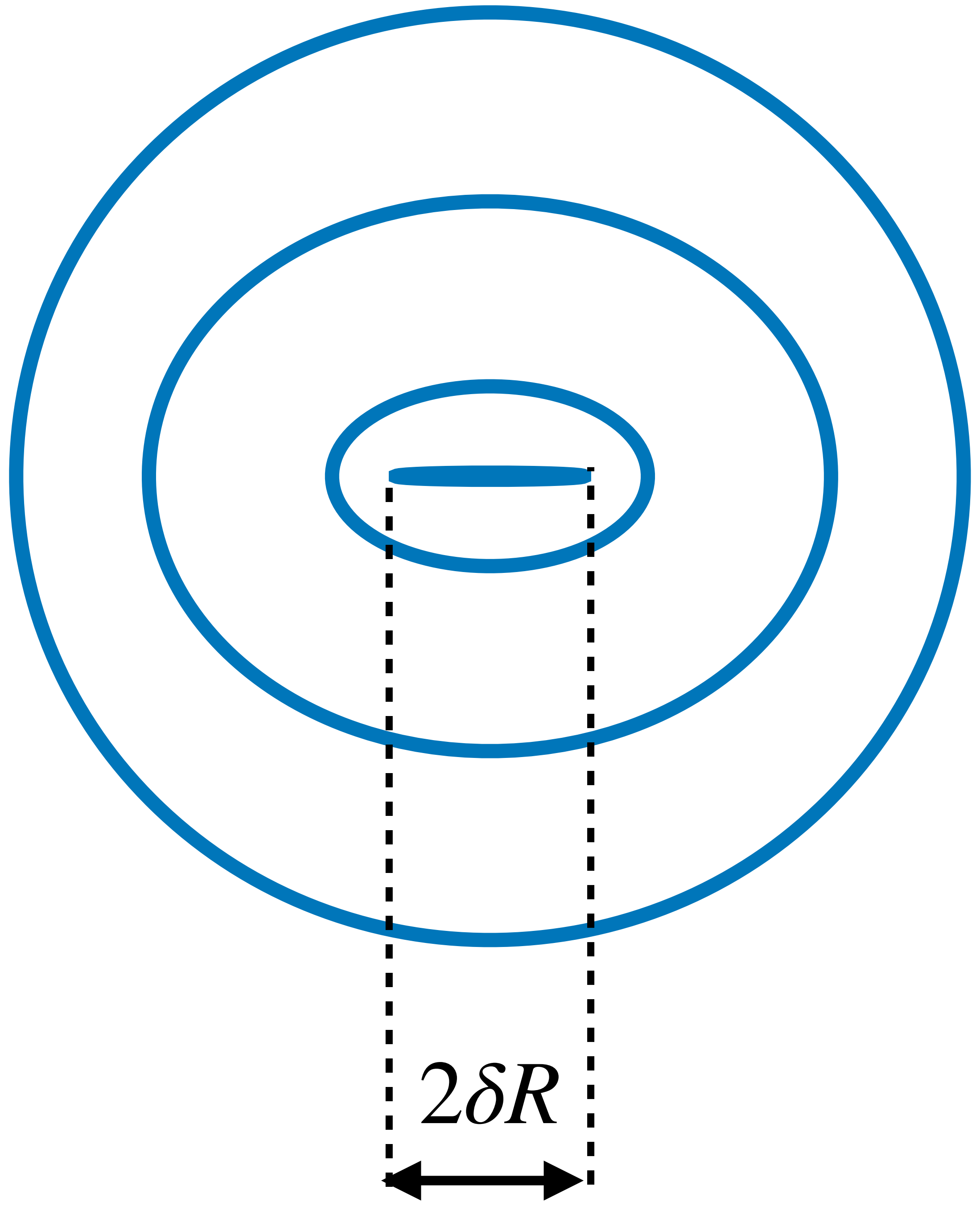

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The light PBHs are cut away; the dynamics of heavy domain walls is not modified

- probability to have small shape asymmetry to form a BH

  for a single quadrupole mode: $P(\delta R_{l=2} < R_{\rm sch}) \propto R_{\rm sch}/\delta R_{l=2,\rm rms} \propto (M_{\rm PBH}/M_{\rm PBH,cr})^{1/2}$

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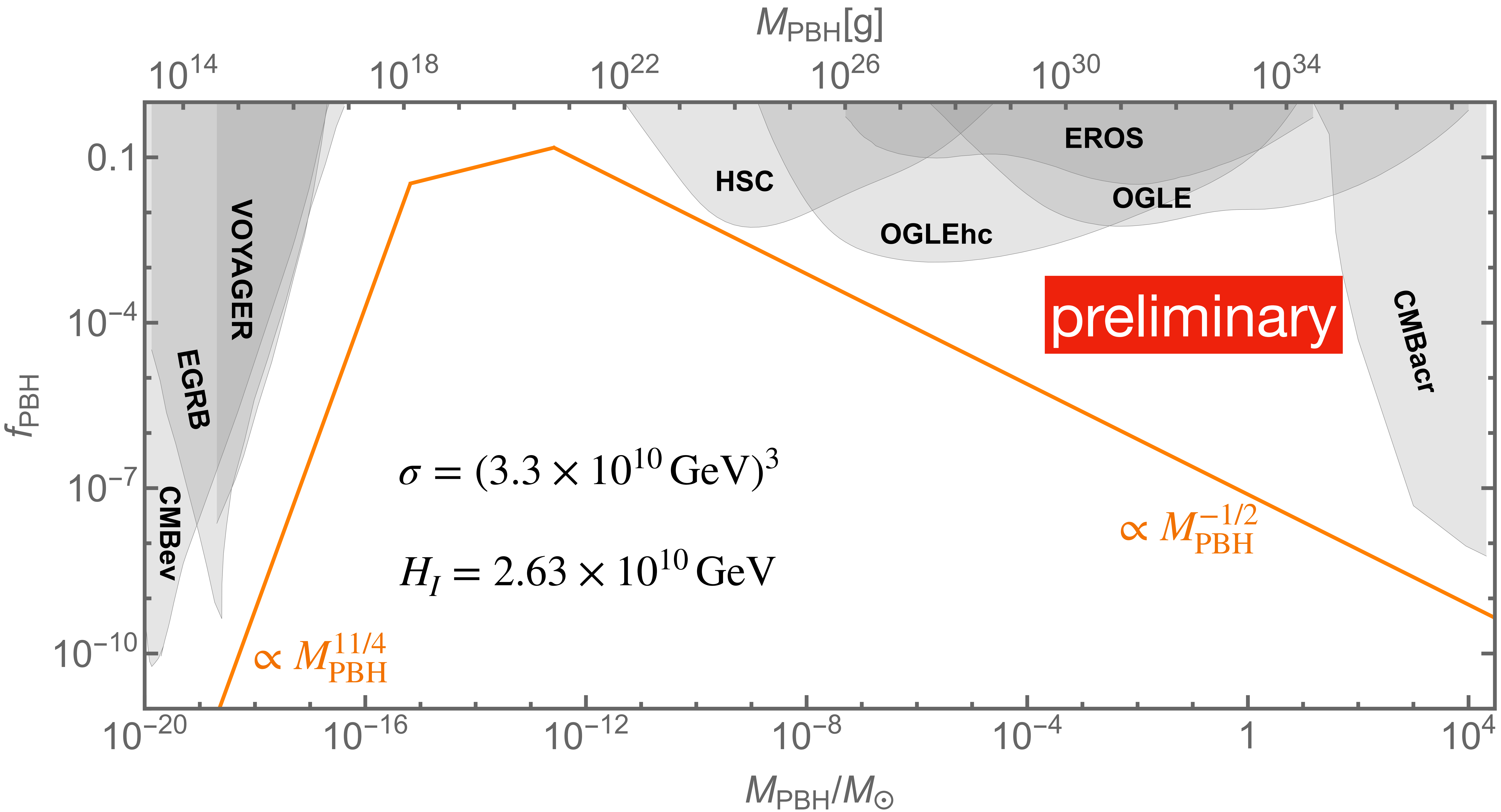

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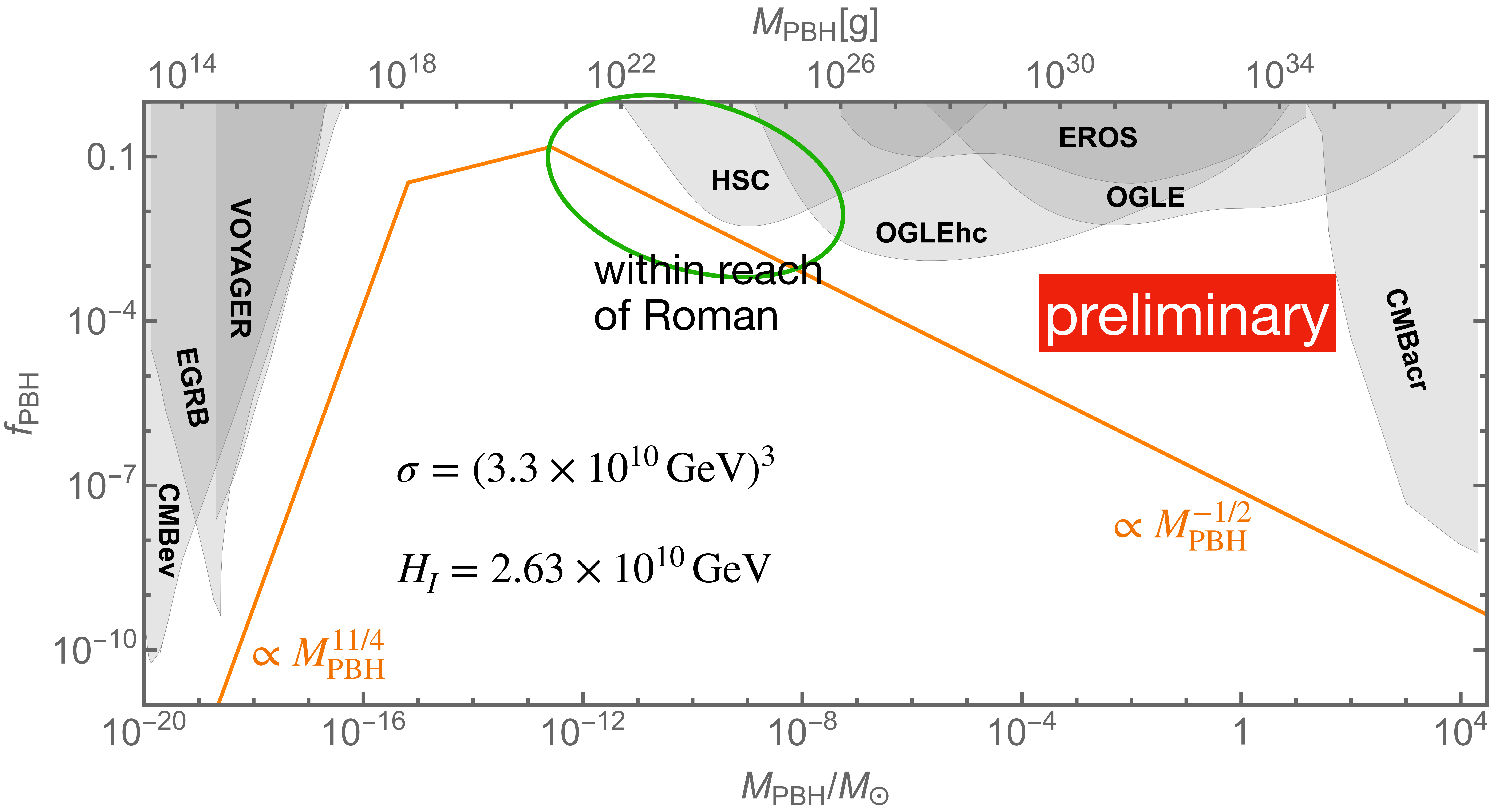

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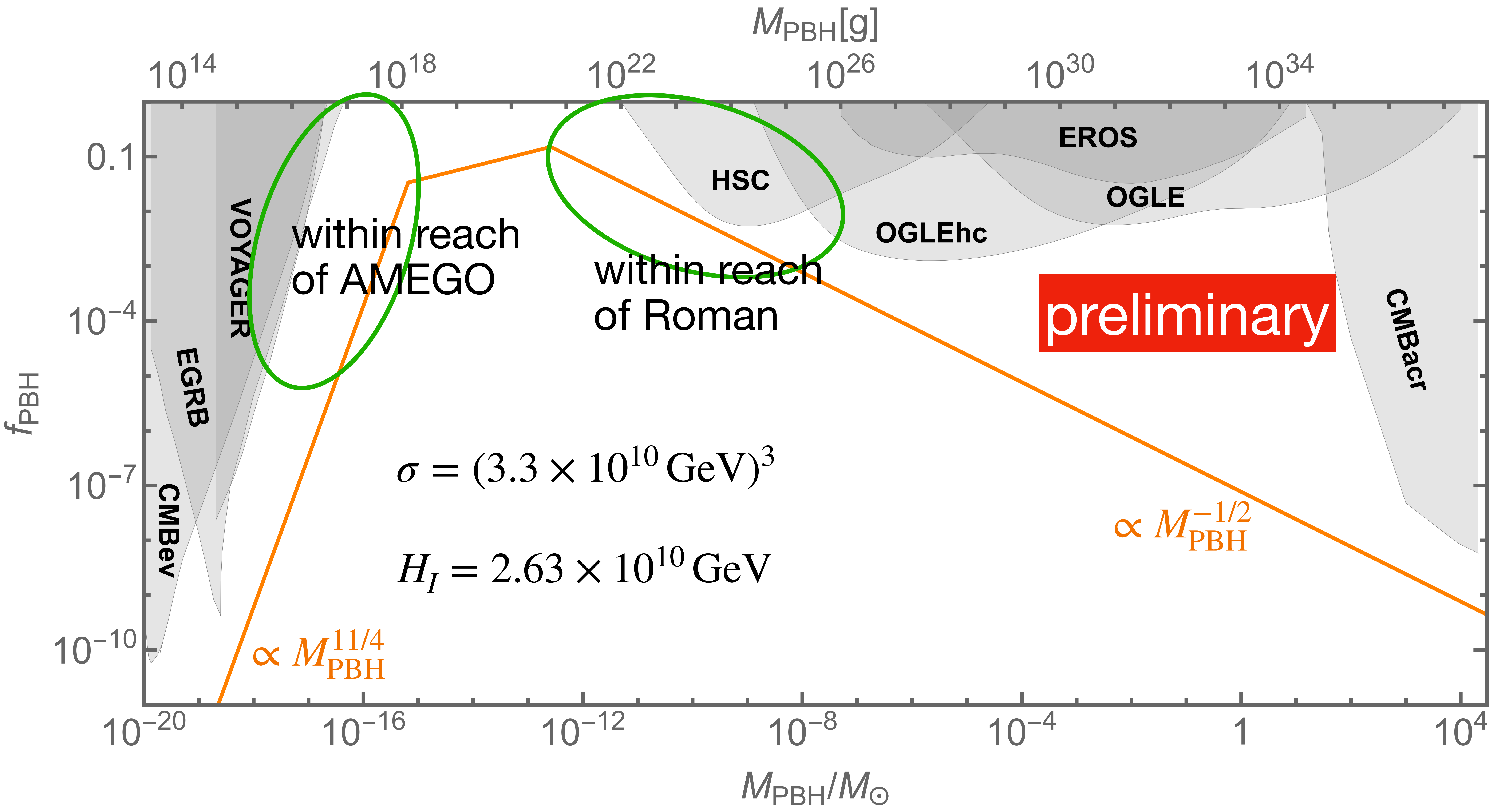

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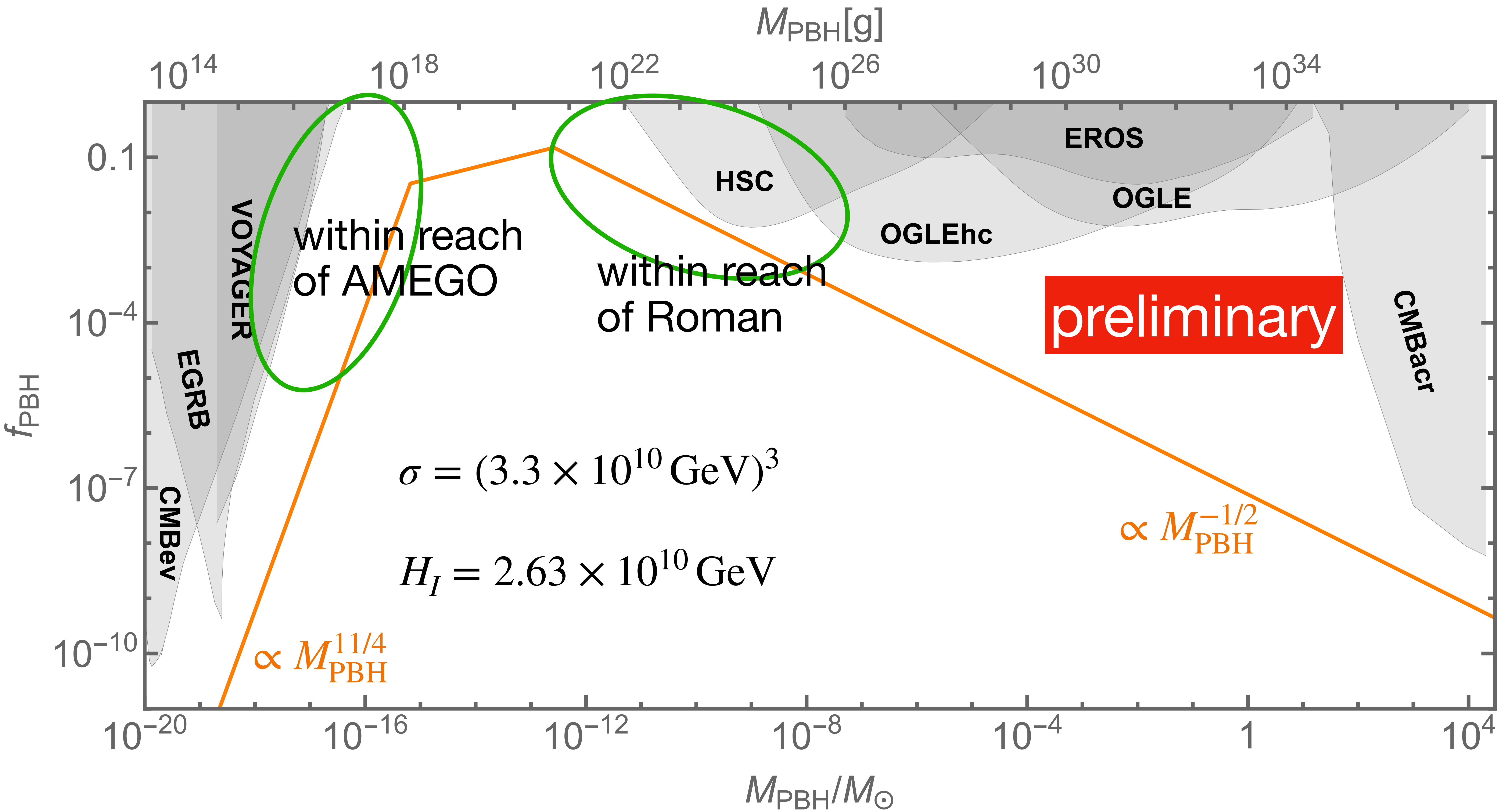

if we see this PBH spectrum, we will:

✓ discover dark matter

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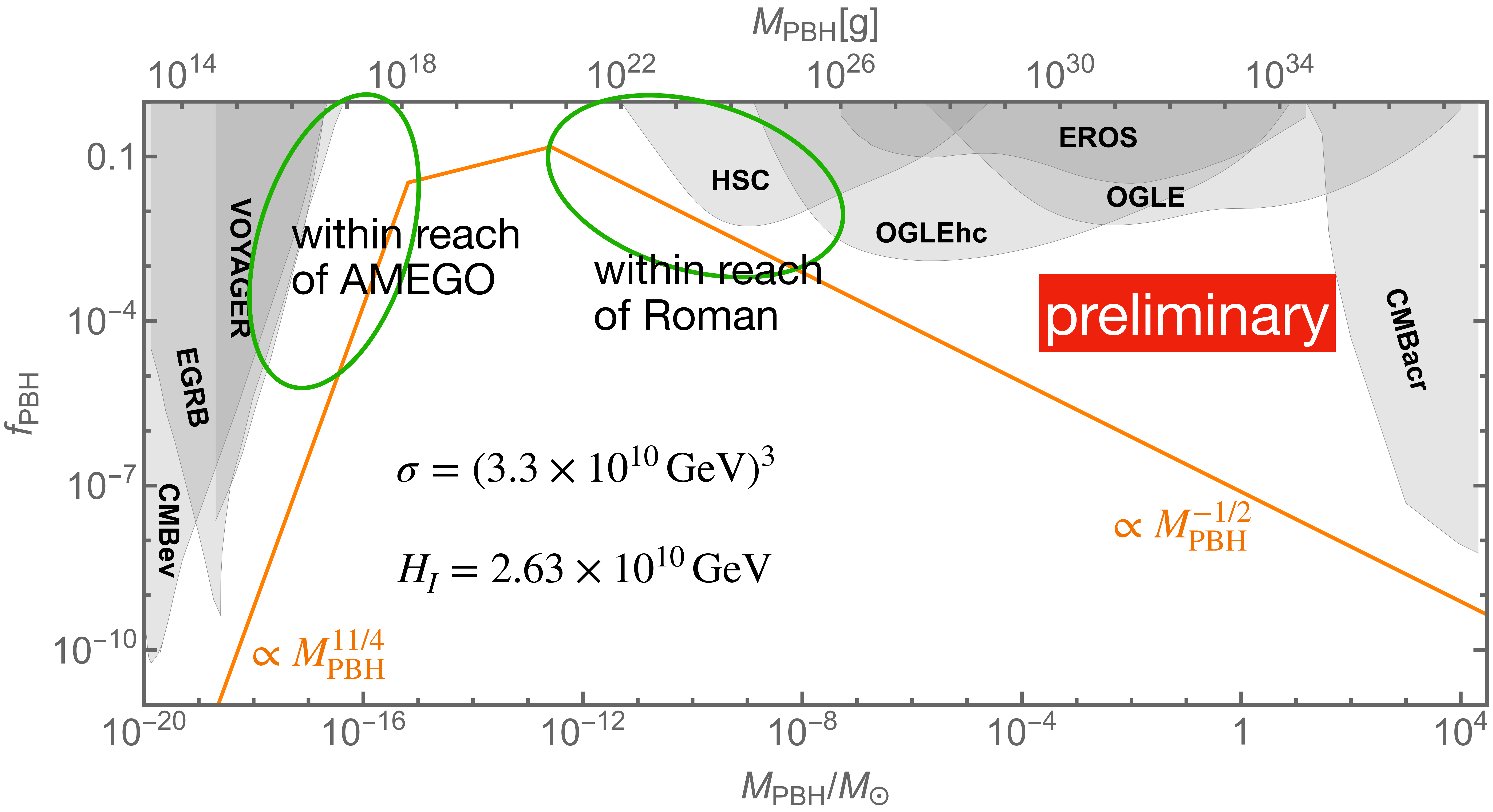

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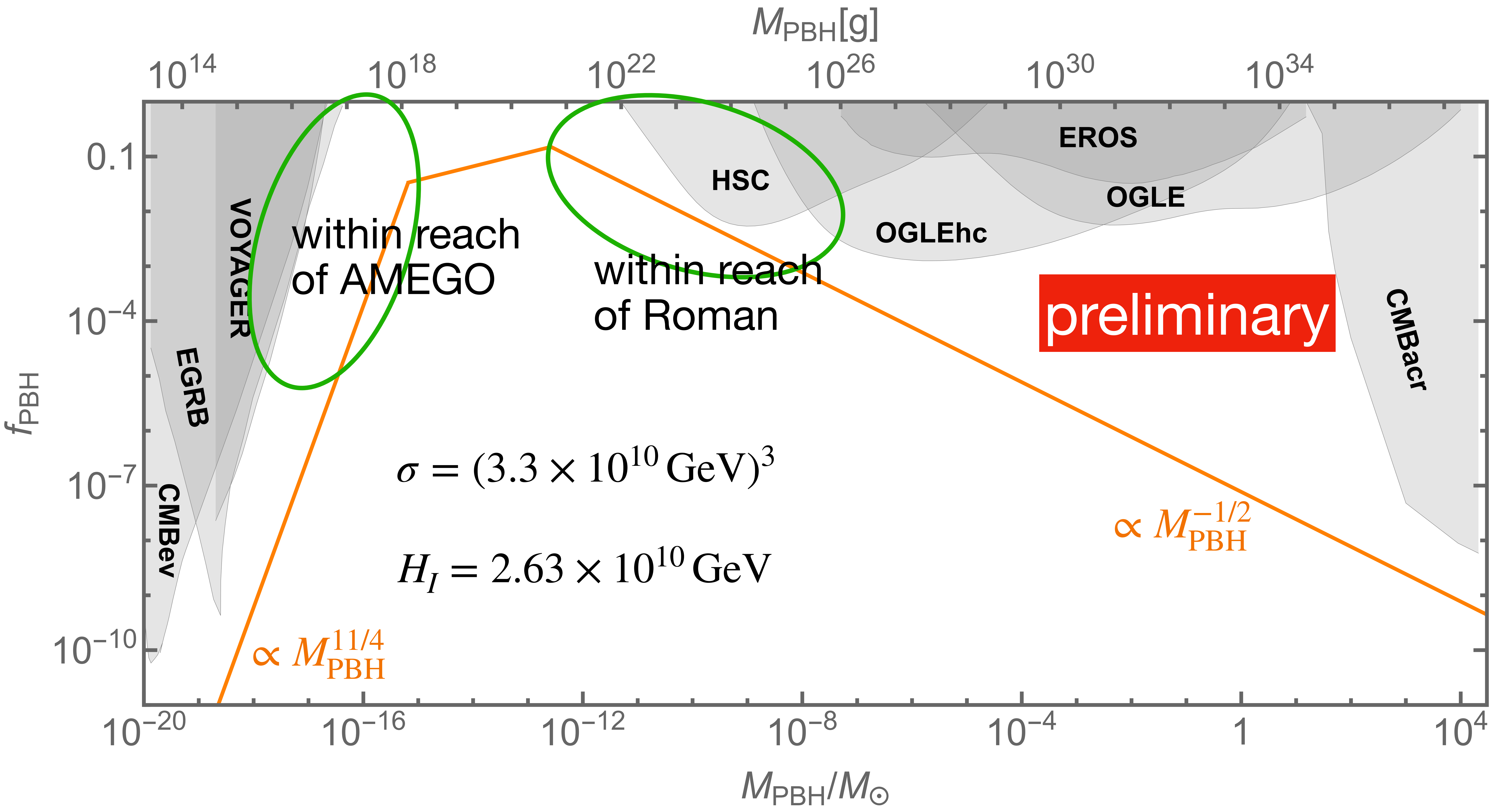

if we see this PBH spectrum, we will:

✓ discover dark matter

✓ measure σ from the position of the peak

✓ measure H_I from DM abundance

✓ We will even discover multiverse

each heavy black hole
contains a **baby universe**

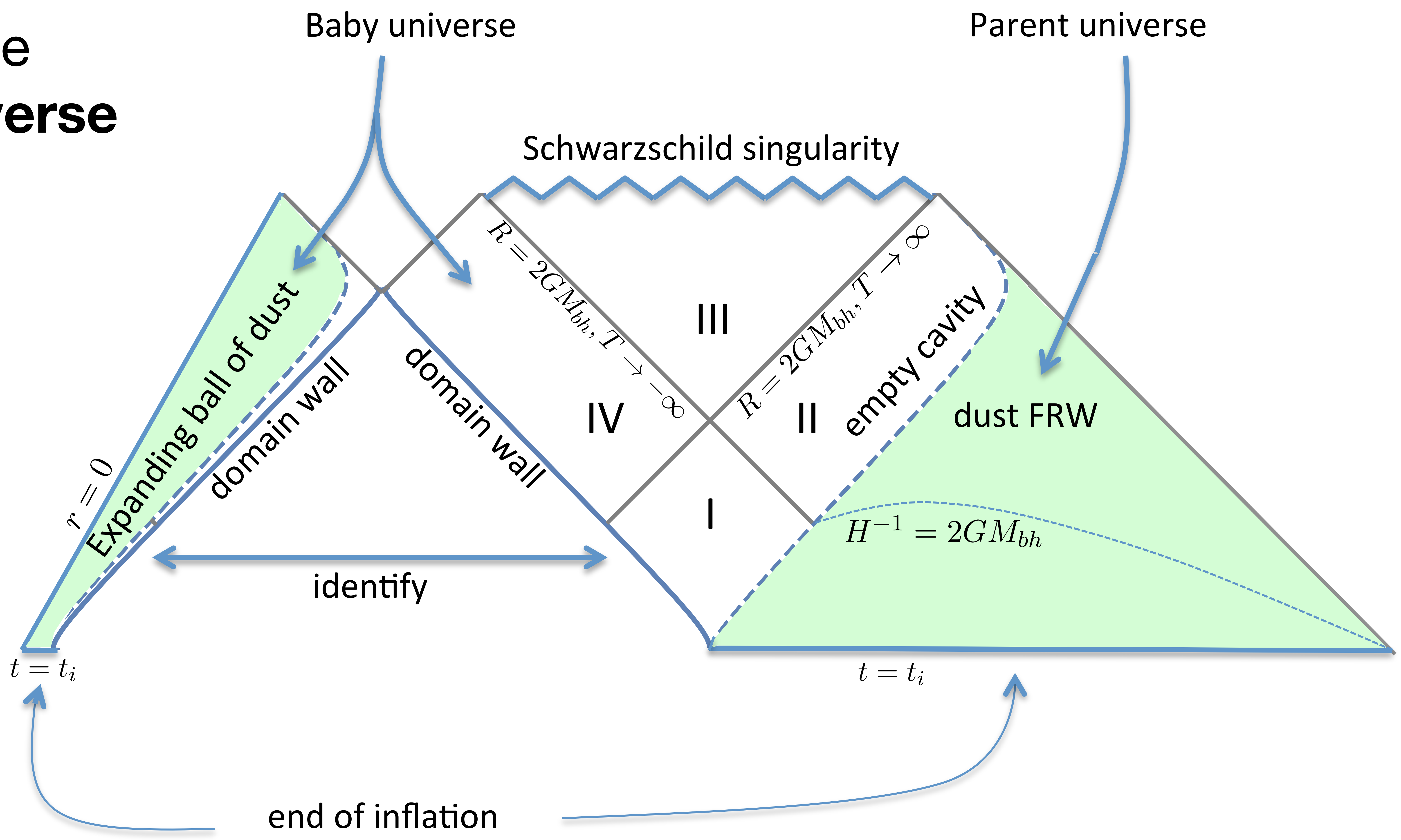

FIG. 6: A large domain wall causing the birth of a baby universe.

figure from Garriga, Vilenkin, Zhang, arXiv:1512.01819

Conclusions:

- The scenario with PBH production by relic domain walls has been *included*
- It produces a broad spectrum of PBH from $10^{-16}M_\odot$ to $10^4 M_\odot$, without fine-tuning of inflationary potential
- The shape of the spectrum is the smoking gun of the scenario
- The norm of the spectrum is directly related to inflationary physics
- $10^{-16}M_\odot \div 10^{-11}M_\odot$ PBHs can constitute all of DM
- $10^4 M_\odot$ PBHs can be seeds for supermassive black holes