Ultralight black holes as astrophysical accelerators

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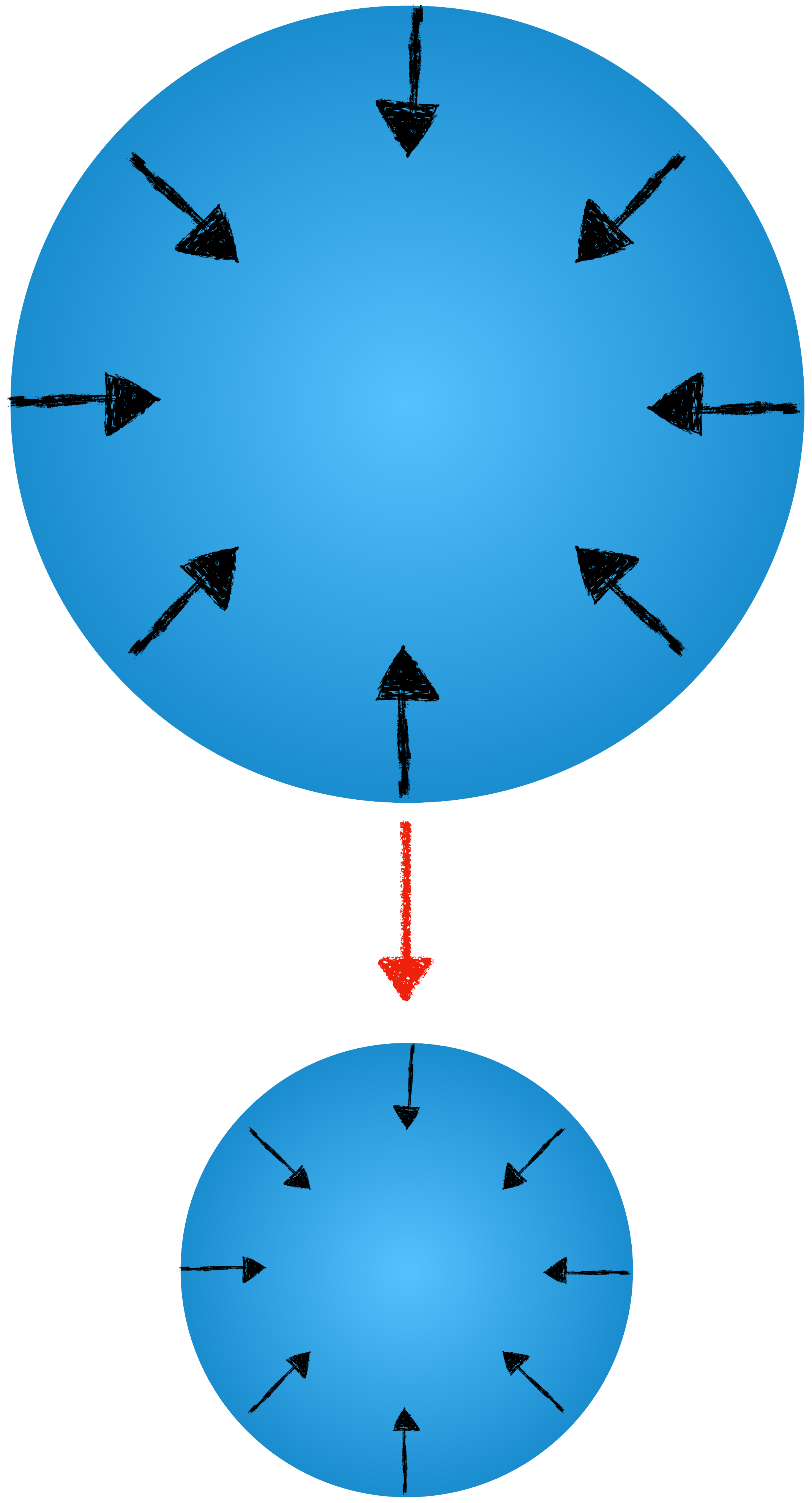
Based on Zantedeschi, LV 2410.07037

Evaporating black holes



Black holes emit thermally: $\Gamma = \frac{1}{r_{\rm BH}} = T$

Leading to a naive semiclassical lifetime

$$\tau_{\rm sc} \simeq r_{\rm BH}\, S = \left(\frac{r_{\rm BH}}{l_{\rm Pl}}\right)^2 r_{\rm BH}$$

PBHs with $\tau_{\rm sc} \lesssim t_0$ are generally discarded as potential dark matter candidates, since they have long evaporated. This corresponds to

$$m_{\rm BH} \gtrsim 10^{15}\,{\rm g}$$

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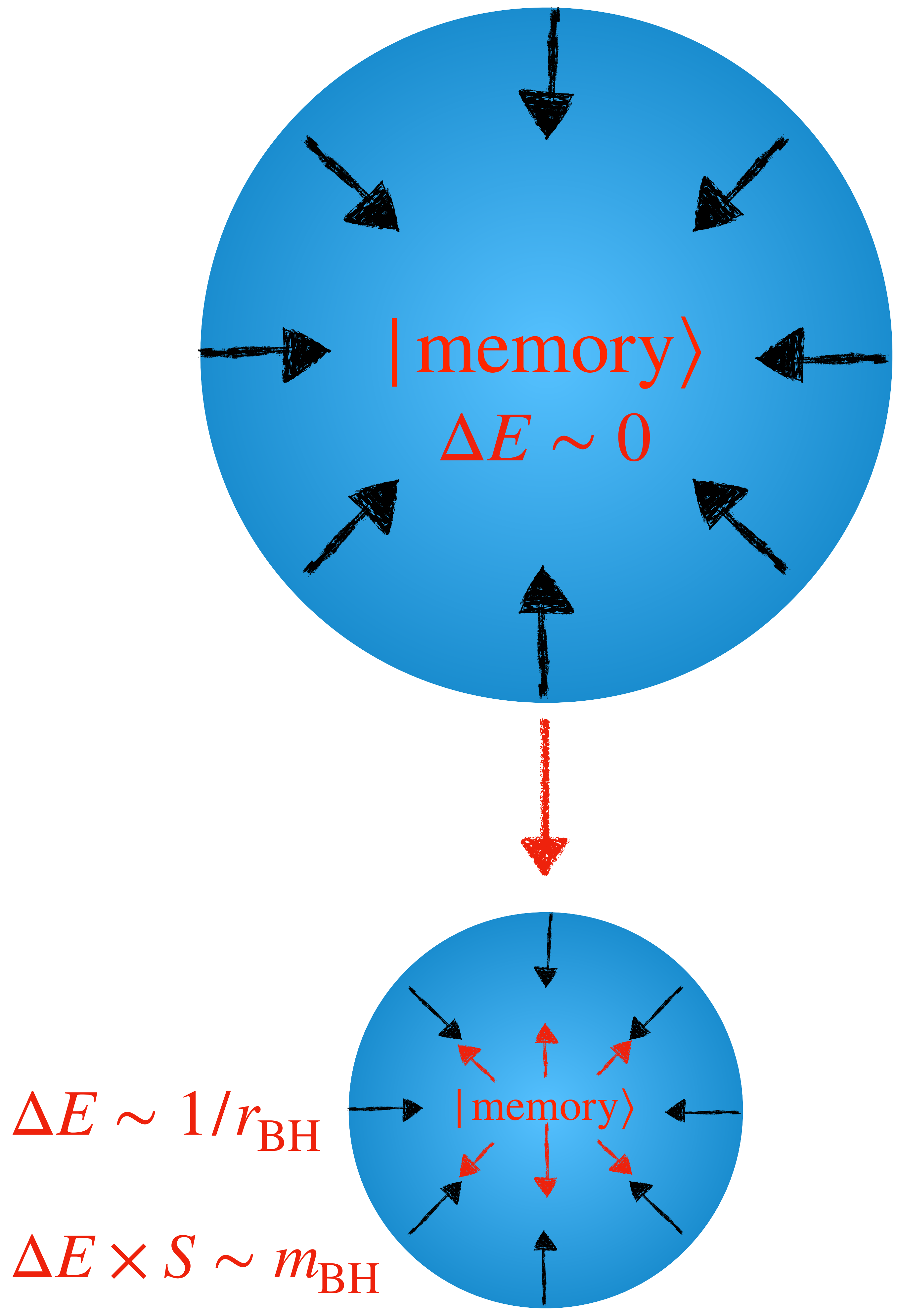

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The memory burden effect slows down the evaporation, latest by $\tau_{\rm sc}$

$$\tau \simeq S^{1+k} \tau_{\rm sc}$$

with $k \geq 1$. This opens a new mass window for dark matter [Dvali+ 2006.00011]

Motivation

The memory burden effect can be summarized in a single statement:

The memory carried by an object resists its decay. Dvali 1810.02336

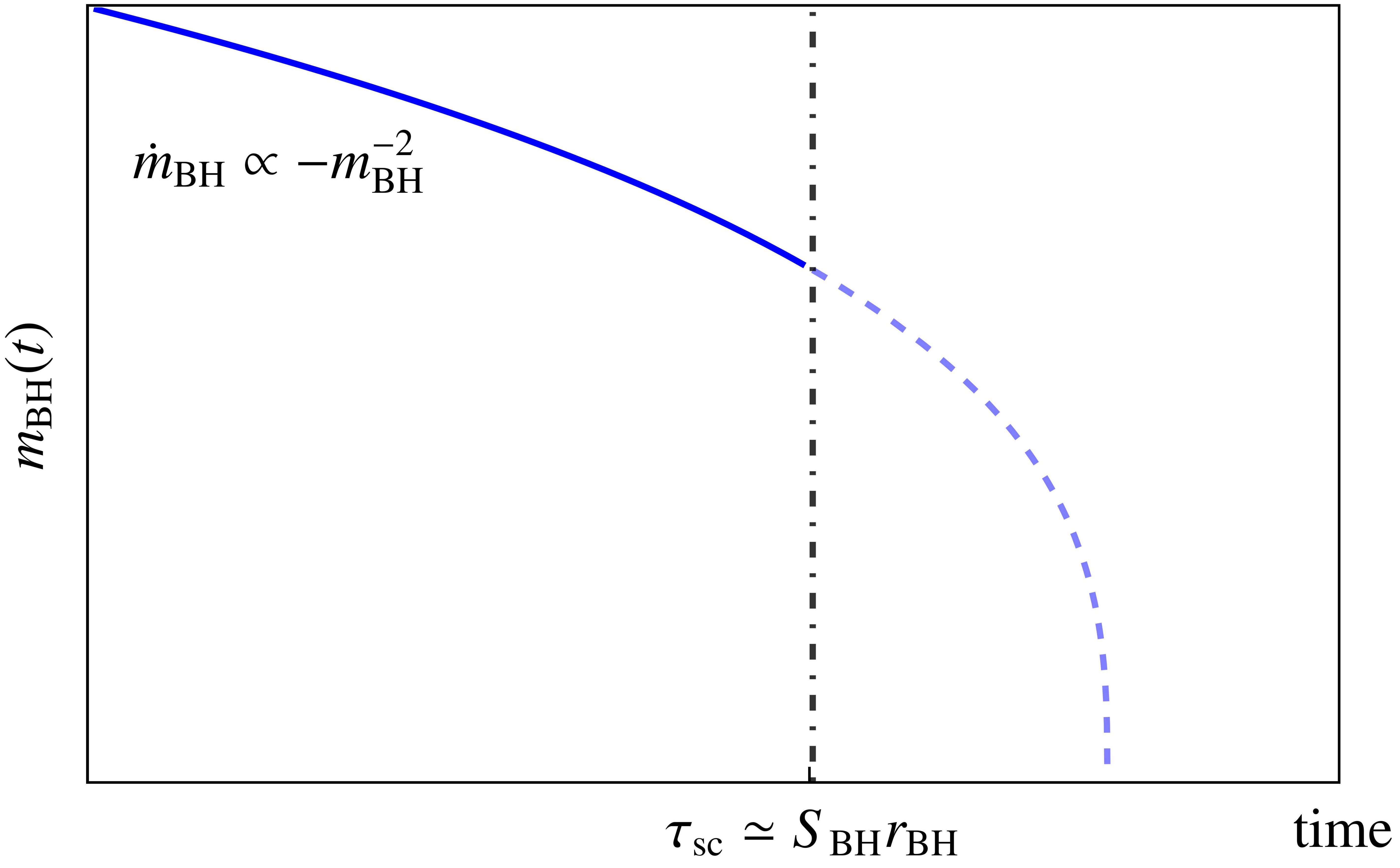
- Leads to stabilization of evaporating black holes $\rightarrow$ new mass window of light black holes as dark matter B.Carr, S. Hawking '74, Zel'dovich '74

- Predicts unique spread of the mass function distribution of primordial black hole Dvali+ 2405.13117

- Memory-burdened black holes in the form of dark matter are accelerators sourcing astrophysical high-energy particles comparable to present day measurement [Zantedeschi, **LV** 2410.07037]

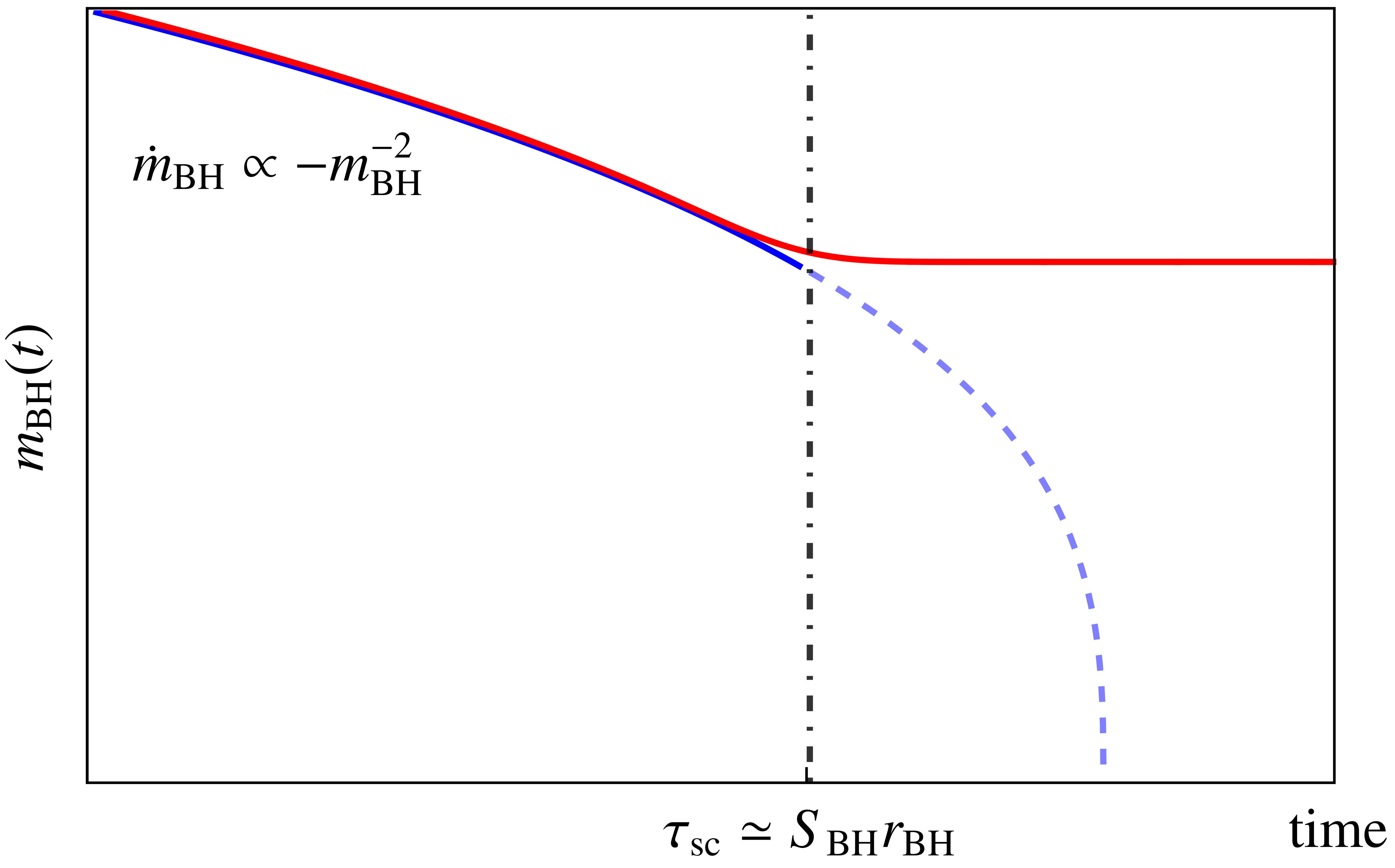
Memory burden

Emitting thermally beyond τ_{sc} leads to a violation of unitarity. The trajectory below is based on semiclassical calculation. Is an old black hole the same as a young black hole?



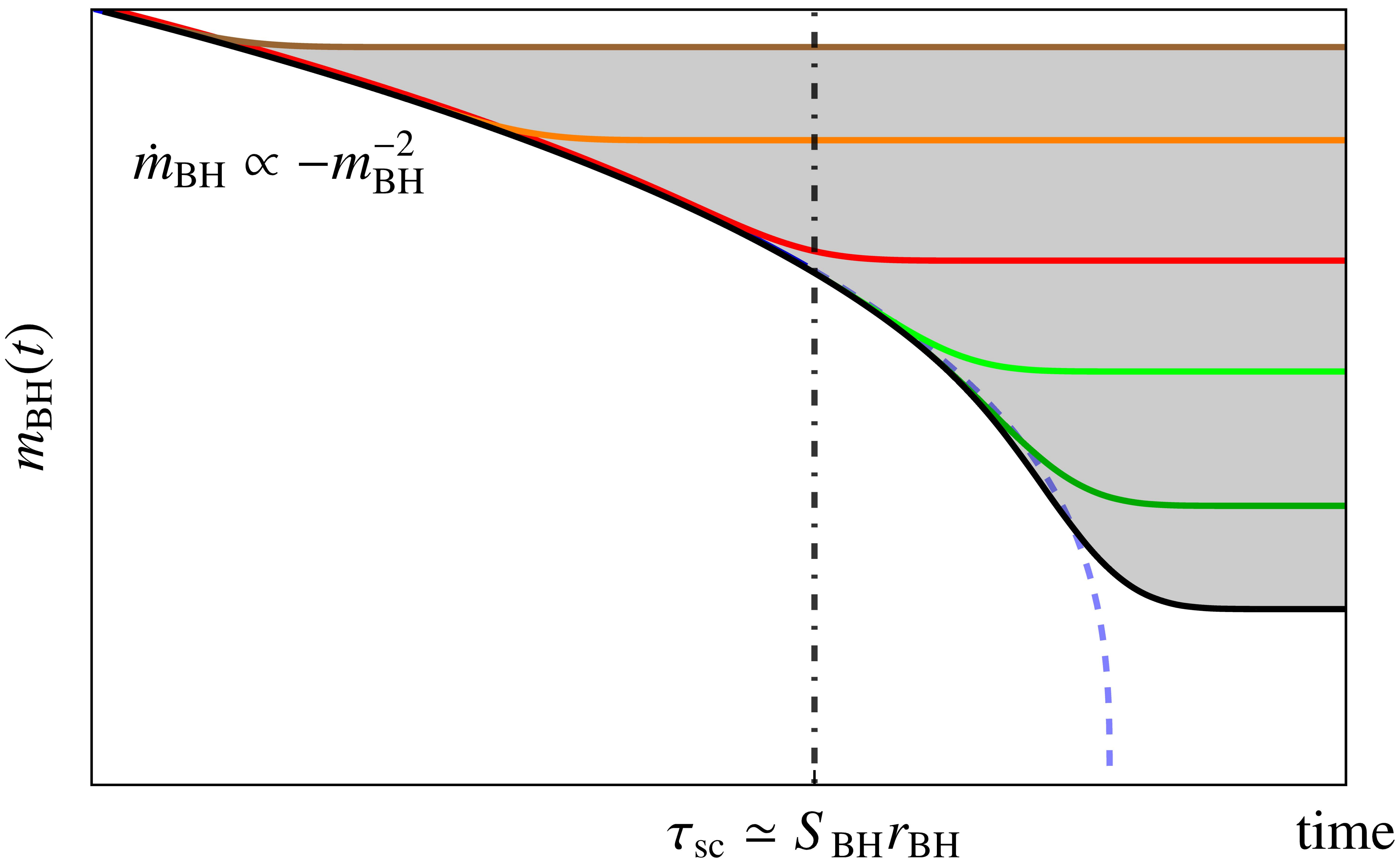
Memory burden

Memory burden informs us that, in reality, semiclassical description is broken and the black hole is likely stabilized Dvali 1810.02336

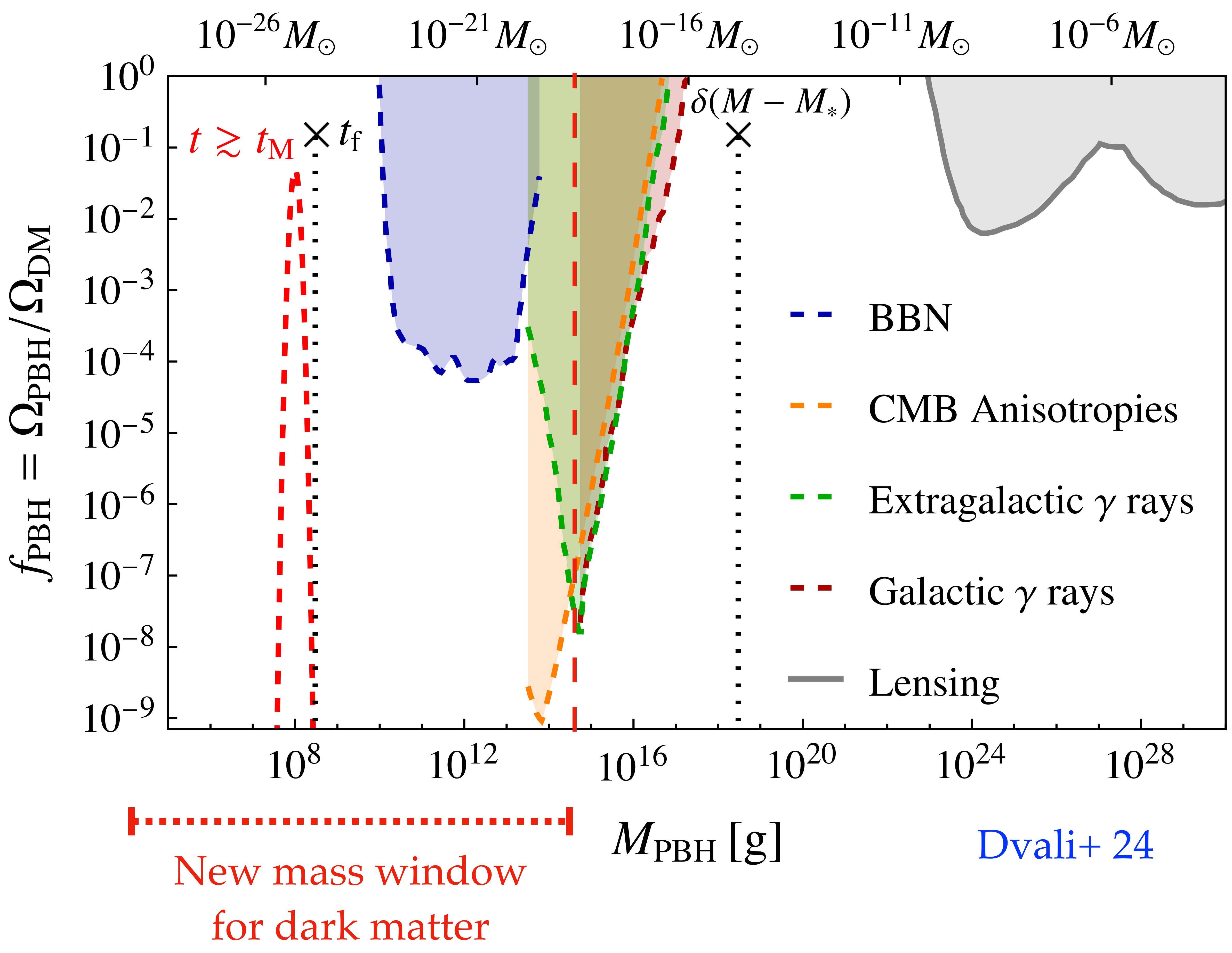


Memory burden

Black holes with initially the same mass, will have different memories, leading to an asymptotic spread in the asymptotic masses Dvali+ 2405.13117



Consequences for black holes as dark matter



Any initial distribution in the light mass region will observe a natural spread for timescales longer than τ_{sc}.

- Filled areas correspond to known existing constraints for PBHs.

- BBN and EG gamma-ray searches further constraints PBHs up to about 10^5 g for $k = 1$ (Alexandre+24, Thoss+24, Chianese+24). These constraints are absent for $k > 1$.

For formation mechanism in the light mass window, see Dvali+ 2108.09471

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IDEA: Light BH newly formed resume semiclassical emission upon mergers for a period τ_{sc}

Effectively, these are ultralight black holes evaporating today.

Source of high-energy particles - neutrinos, gamma and cosmic rays easily above PeV energies.

The merger rate of black holes in the form of dark matter is given by

$$R_{PBH}(t) \simeq \frac{0.03}{\mathrm{kpc}^3\,\mathrm{yr}} f_{PBH}^{\frac{53}{37}} \left(\frac{t_0}{t}\right)^{\frac{34}{37}} \left(\frac{m_{PBH}}{10^{-12} M_\odot}\right)^{-\frac{32}{37}}$$

Ali-Haïmoud+17, Sasaki+ 18, Raidal+ 19

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From the merger rate, we compute the galactic and extragalactic fluxes:

$$\left.\frac{\mathrm{d}\Phi_i}{\mathrm{d}E}\right|_{\mathrm{gal}} \simeq \frac{\tau_{\mathrm{sc}}}{4\pi}\int_{s,\theta} R_{\mathrm{PBH}}\,\delta(r(s,\theta))\,\frac{\mathrm{d}^2N_i(E)}{\mathrm{d}E\,\mathrm{d}t}$$

$\delta(r)$: NFW Galaxy enhancement

$$\left.\frac{\mathrm{d}\Phi_i}{\mathrm{d}E}\right|_{\mathrm{eg}} \simeq \frac{\tau_{\mathrm{sc}}}{4\pi}\int_0^{z_f}\mathrm{d}z\left|\frac{\mathrm{d}t}{\mathrm{d}z}\right| R_{\mathrm{PBH}}(t(z))\frac{\mathrm{d}^2N_i(E(z))}{\mathrm{d}E\,\mathrm{d}t}e^{-\eta_i(z)}$$

This works for any species *i* in the Standard Model of particles and beyond

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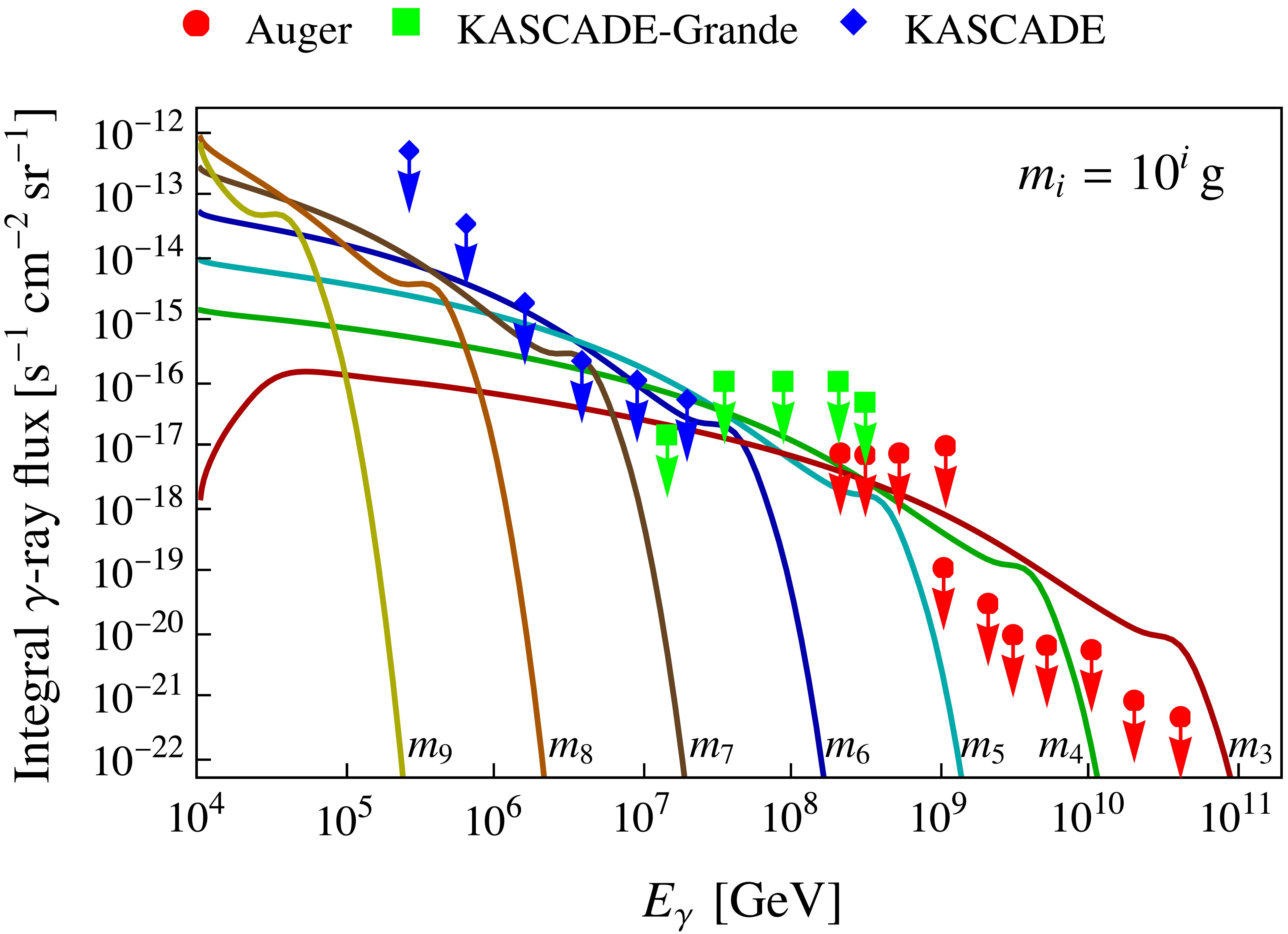

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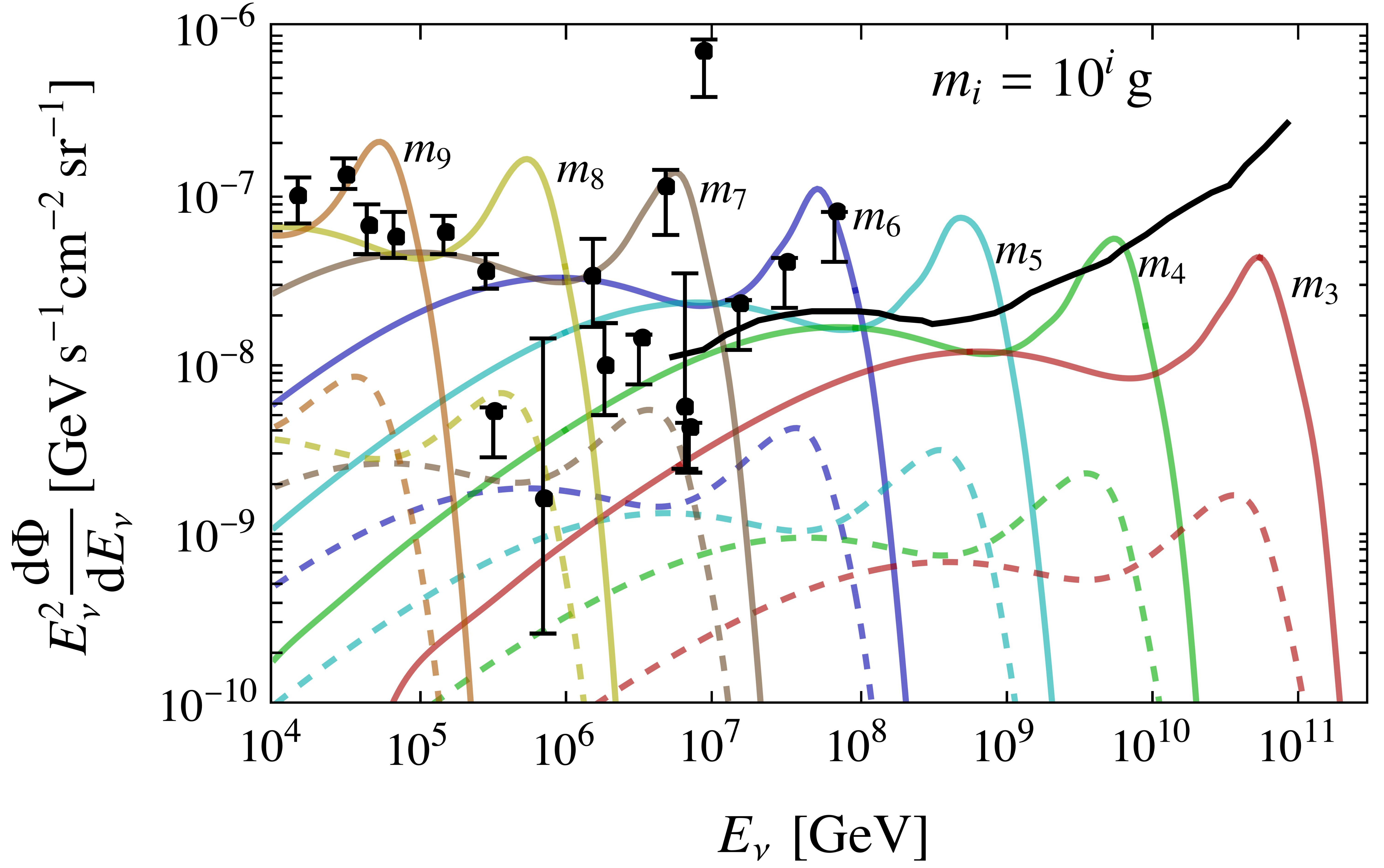

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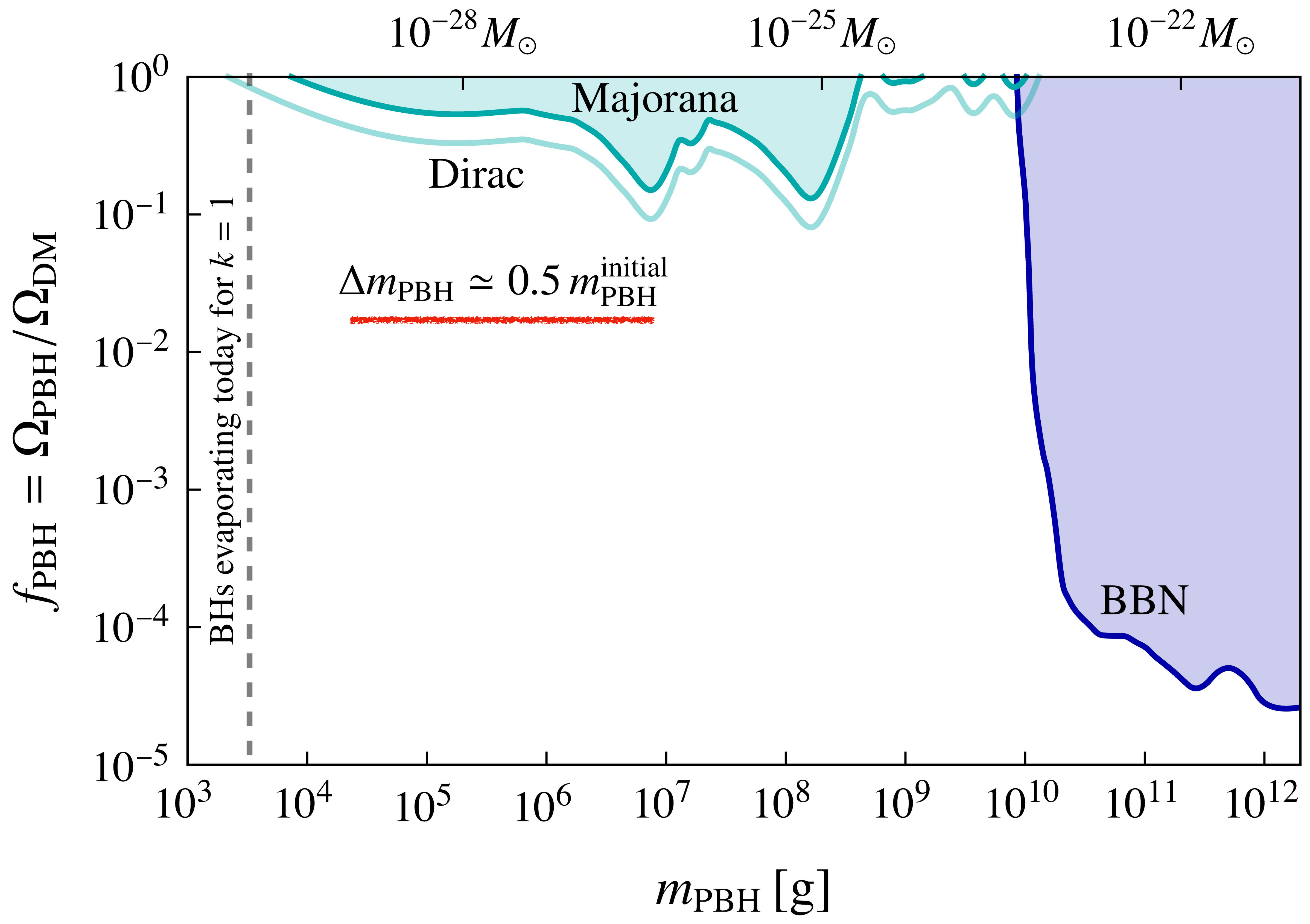

- Burdened black holes in the form of dark matter source high-energy particles in the right ball-park for present-day measurements.
- The results are independent of the modelling of the memory burdened phase. It relies, instead, on the calculability of semiclassical dynamics applied in the realm of its validity.
- Emission thermal in all Standard Model species implying a counterpart in cosmic rays and gamma-rays. Clear correlation.
- Galactic to extragalactic ratio under control.