Memory burdened black holes as astro-particle accelerators

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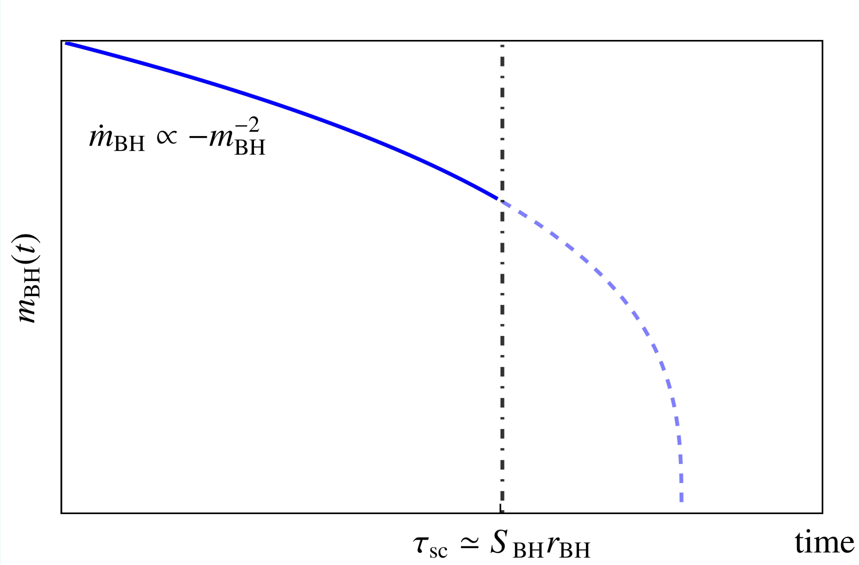
Key: Evaporating black holes in the form of dark matter can source ultra high-energy cosmic rays, gamma-rays and neutrinos comparable to current measurements

Memory Burden

Semiclassical black holes emit thermally $T = 1/r_{\rm BH}$ [1].
If $m_{\rm PBH} \lesssim 10^{15}$ g, the semiclassical lifetime is shorter than the age of the Universe, $\tau_{\rm sc} \simeq S_{\rm BH}\, r_{\rm BH} \lesssim t_0$.
Therefore, these objects are traditionally discarded as viable dark matter candidates.

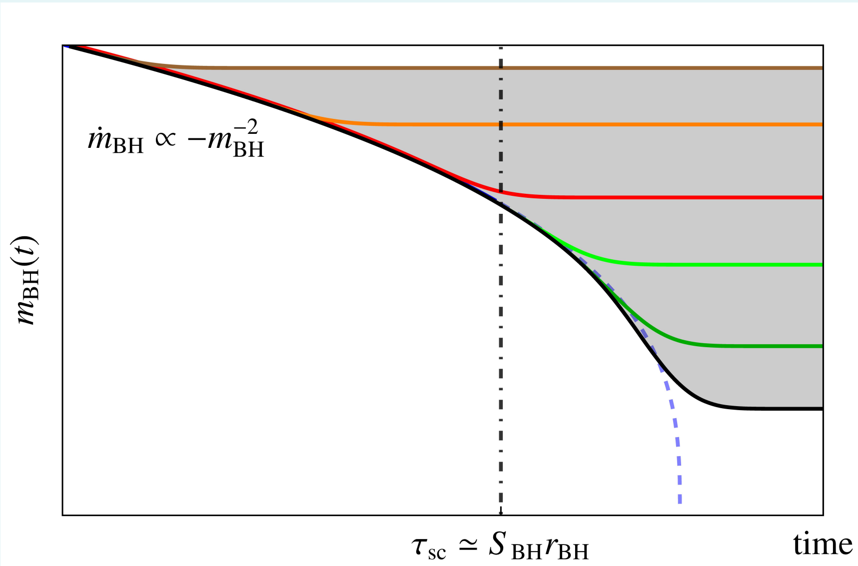


Semiclassical description should, however, eventually break down due to the quantum backreaction on the dynamics. The memory burden is summarized as

The memory stored in a configurations halts its decay [2]

$$\tau \simeq \tau_{\rm sc}\,\left(S_{\rm BH}\right)^{1+k}\,,\quad k \in \mathbb{N}$$

Black holes of mass $m_{\rm PBH} \lesssim 10^{15}\, g$ are viable dark matter.



Black holes of the same mass, will in general have different memories, and therefore asymptotically evolve to different burdened remnants [3]. The number of gravitons N_G responsible for the memory - and therefore the back reaction - is governed by the probability distribution:

$$\mathscr{P}_{N_{\rm G}} = 2^{-S}\frac{S!}{(S-N_{\rm G})!N_{\rm G}!}\,,$$

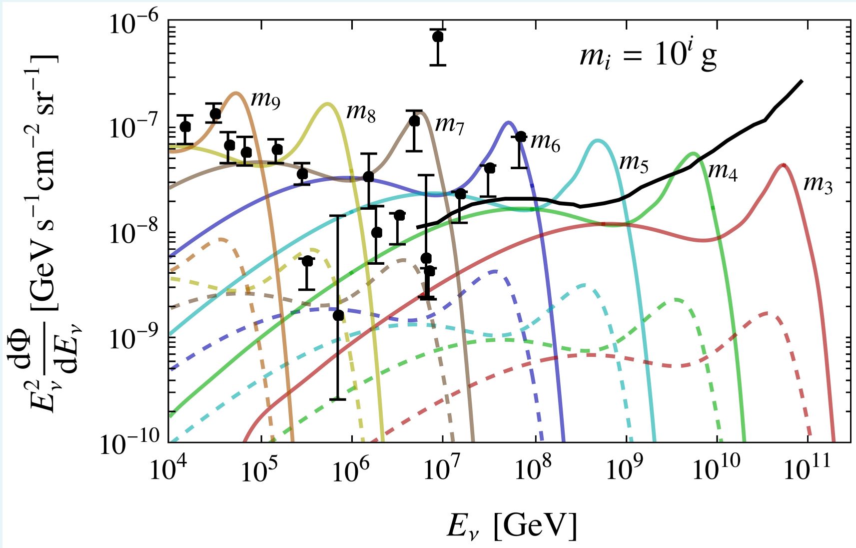
Notice $\overline{N_{\rm G}} = S/2$ and width $\sqrt{S}$.
This leads to a natural spread of the primordial black hole asymptotic mass distribution [3] schematically shown above.

Result

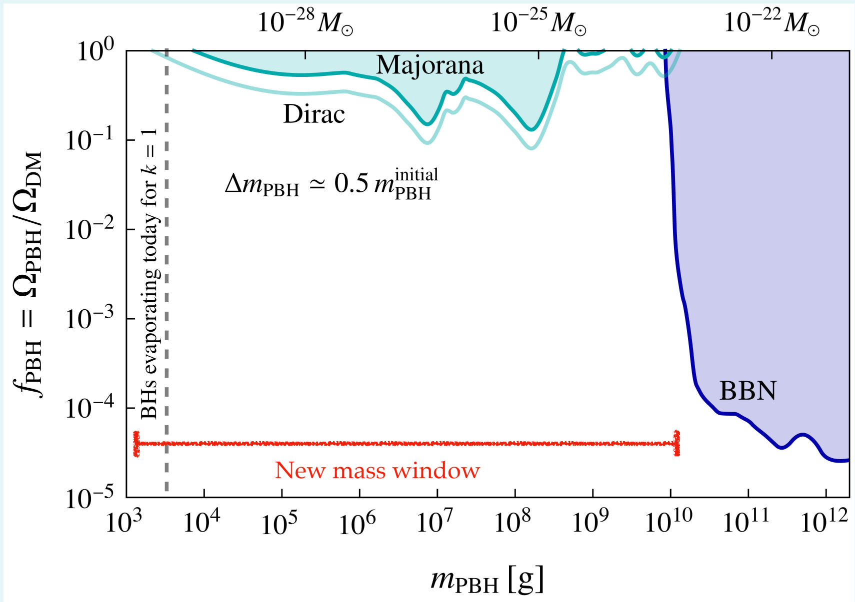
If these objects compose the dark matter, they will merge today, leading to new ``young'' semiclassical black holes [4].
Therefore, they will emit again for a timescale $\tau_{\rm sc}$.

We can obtain the galactic and extragalactic fluxes from their low-redshift evaporation as

$$\left.\frac{{\rm d}\Phi_i}{{\rm d}E}\right|_{\rm gal} \simeq \frac{\tau_{\rm sc}}{4\pi}\int_{s,\theta} R_{\rm PBH}\,\delta(r(s,\theta))\,\frac{{\rm d}^2N_i(E)}{{\rm d}E\,{\rm d}t}\,,\qquad \left.\frac{{\rm d}\Phi_i}{{\rm d}E}\right|_{\rm eg} \simeq \frac{\tau_{\rm sc}}{4\pi}\int_0^{z_f}{\rm d}z\left|\frac{{\rm d}t}{{\rm d}z}\right| R_{\rm PBH}(t(z))\frac{{\rm d}^2N_i(E(z))}{{\rm d}E\,{\rm d}t}e^{-\eta_i(z)}\,.$$



- The resulting theoretical flux is comparable to present day measurements of high energy neutrino data measured by IceCube as shown above.
- Remarkably, analogous comparable fluxes are obtained for high-energy and ultra high energy gamma-rays and cosmic rays.
- The signal is independent of the actual modelling of the burdened phase.



References.
[1] Hawking, Commun. Math. Phys. 43, 199, (1975)
[2] Dvali, arXiv:1810.02336, (2018); Dvali, Michel, Zell, Phys. Rev. D 102, 103523 ,(2020)
[3] Dvali, Bermudez, **MZ**, Phys. Rev. D 110, 056029, (2024)
[4] **MZ**, Visinelli, arXiv:2410.07037, (2024)