Black Holes are True Vacuum Nurseries

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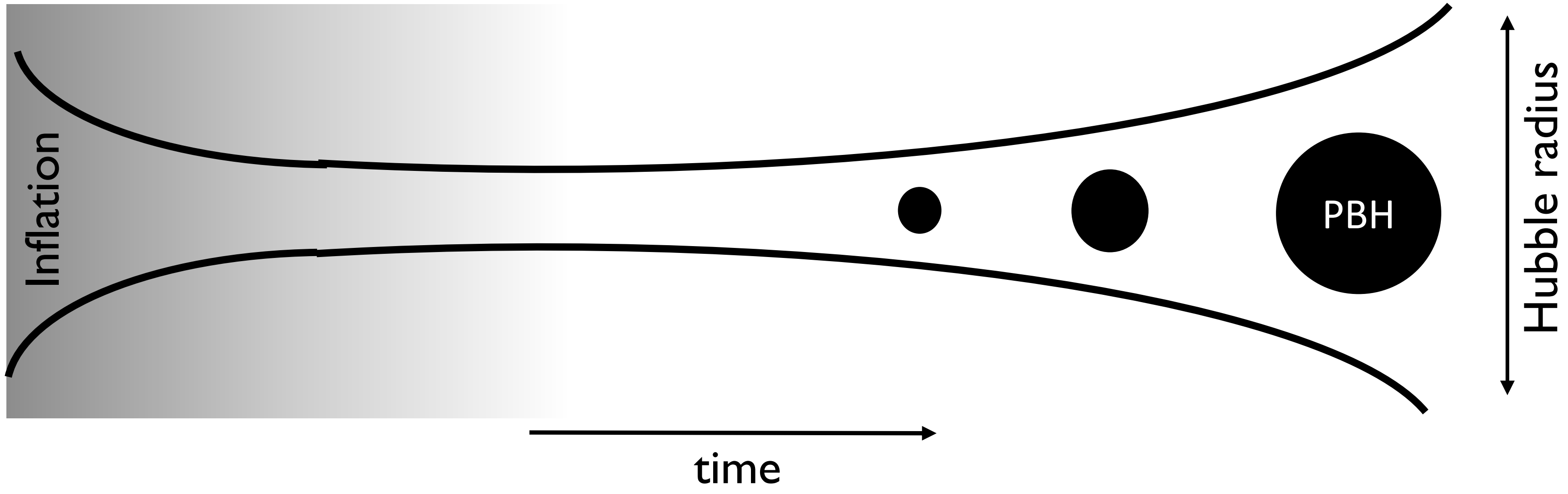
Based on *arxiv 2311.01869*

Introduction to light PBHs (1/2)

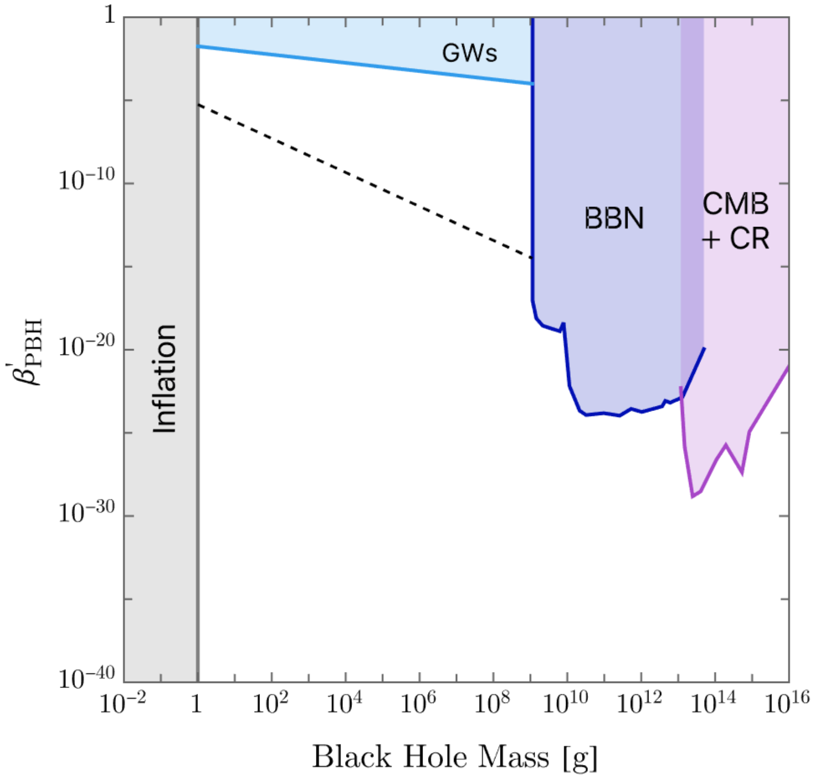
- PBHs arise from large overdensity containing of most of the mass in the Hubble horizon collapse in the early universe
- BHs (or their decay product) formed after inflation are visible to us



- Light PBHs ($<10^{10}$g) have been proposed as a DM production mechanism

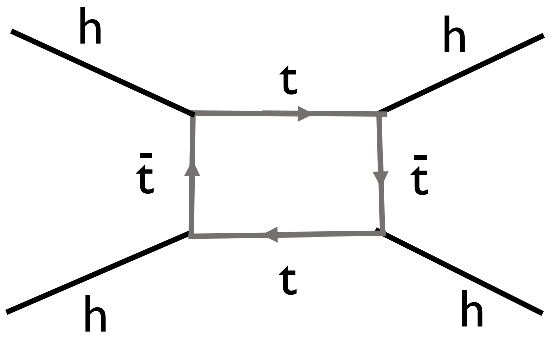
Introduction to light PBHs (2/2)

- PBHs can be light and have evaporated in the past if $<10^{15}$g
- Bounds exist already in this region, although the region 1-10^9 are more difficult to probe

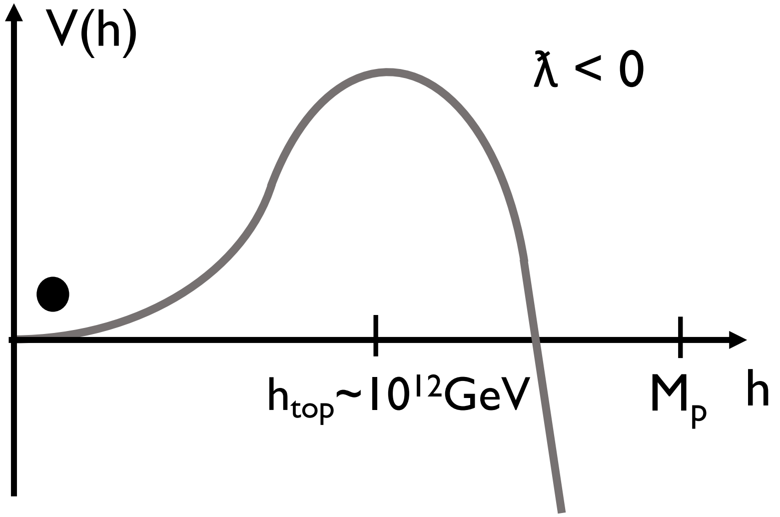


Introduction to Higgs Metastability

- Higgs potential at large energies receives largest (loop renormalization) corrections from Yukawa interactions with top quark
- We can use latest LHC values of SM constants to find metastability (@ 2 sigma)



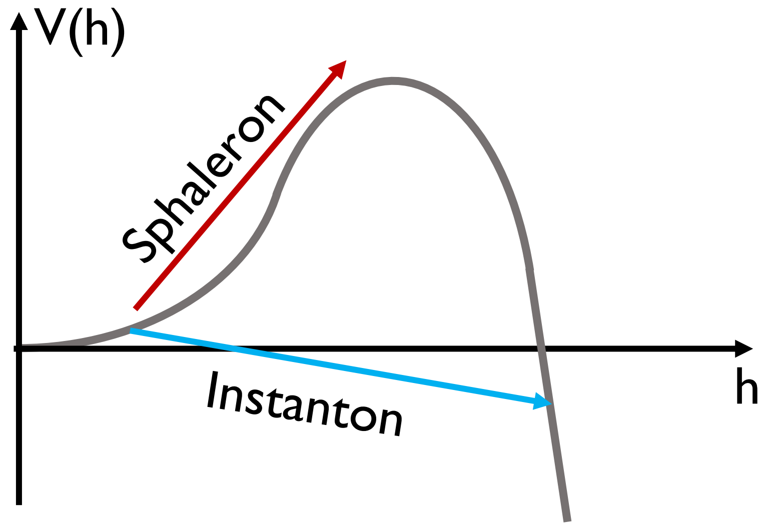
$V(h) = \tilde{\lambda}(h)\, h^4$



Introduction to FVDs

- Taking t → $i\tau$ in the path integral from FV to TV gives $e^{-\beta H}$ for τ-independent solutions and L_E=H
- Notice τ is periodic in the complex plane with period β=1/T. Two options for tunnelling appear

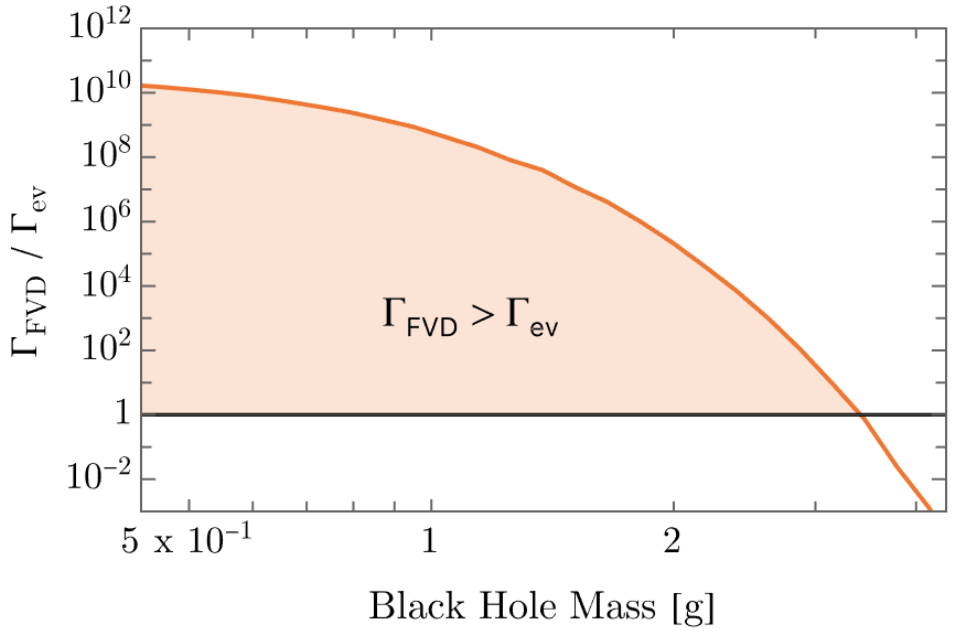
Tunnelling	Fluctuations
h is τ-dependent & β periodic	h is τ-independent
4d action minimized	3d action (i.e. energy) minimized
Solution is O(3) symmetric	Solution is O(4) symmetric

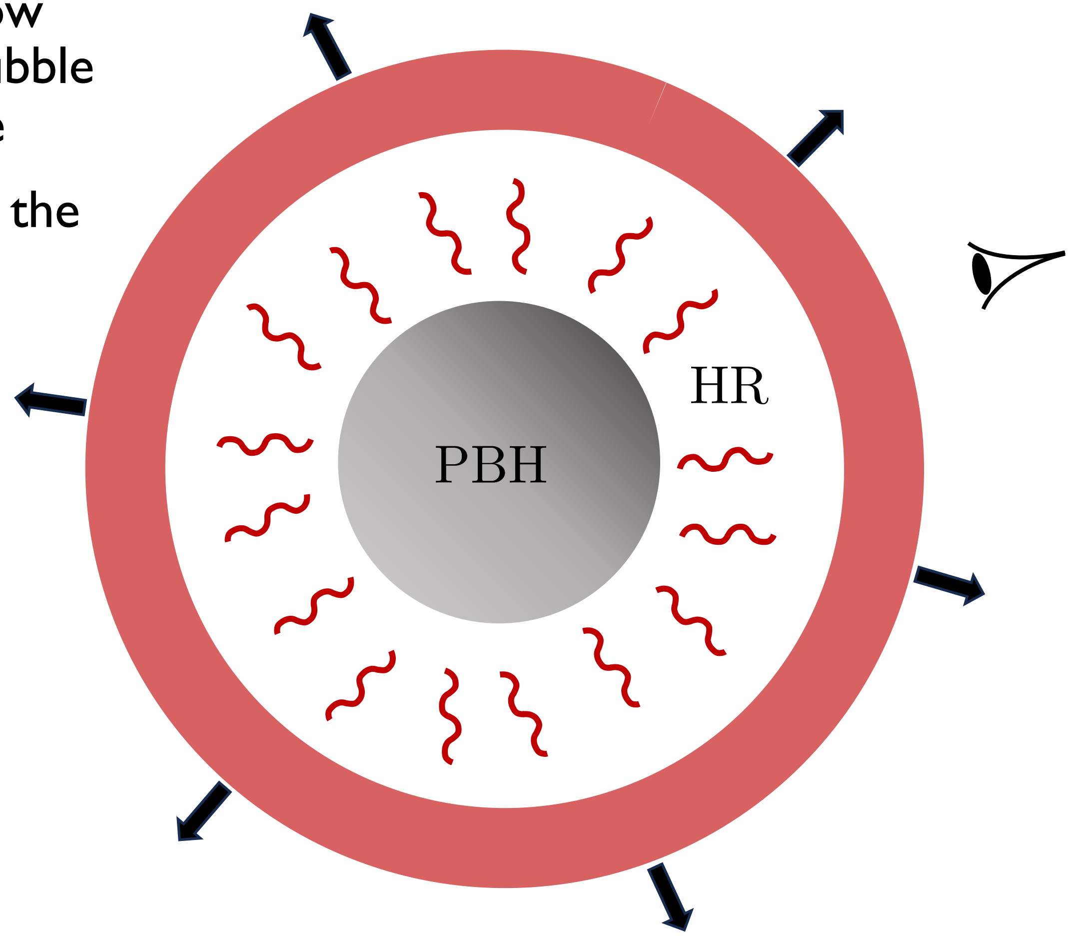


- Coleman and de Lucia found decay rate of FV. It is $\Gamma \propto I^{1/2} e^{I}$ for decays with 1D symmetry

Black Holes as Bubble Nucleators (1/3)

- Although Higgs vacuum has been found to be stable at low energies (today), decay rate would increase for lower bubble energies → inhomogeneities considered for this purpose
- Black holes evaporate and thus can contribute energy to the bubble if high enough temperature





Black Holes as Bubble Nucleators (2/3)

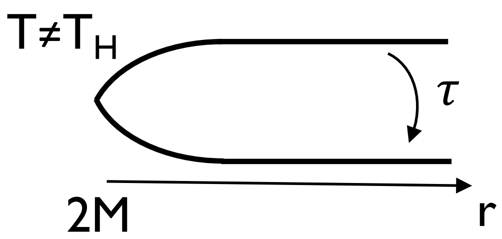
- Gregory & Moss have calculated the action of a Higgs decay in the presence of a black hole, using the high temperature sphalerons, to be:

$$I_{\rm b}[T] = \frac{\mathcal{A}_+}{4G} - \frac{\mathcal{A}_-}{4G}$$

using the Euclidean β = 8∏M , i.e. the black hole temperature.

- Critically the calculation is independent of ambient temperature and cosmological constants, thanks to conical deficits:

$$I_{\rm b}[T] = I_{\rm b}[T_H]$$

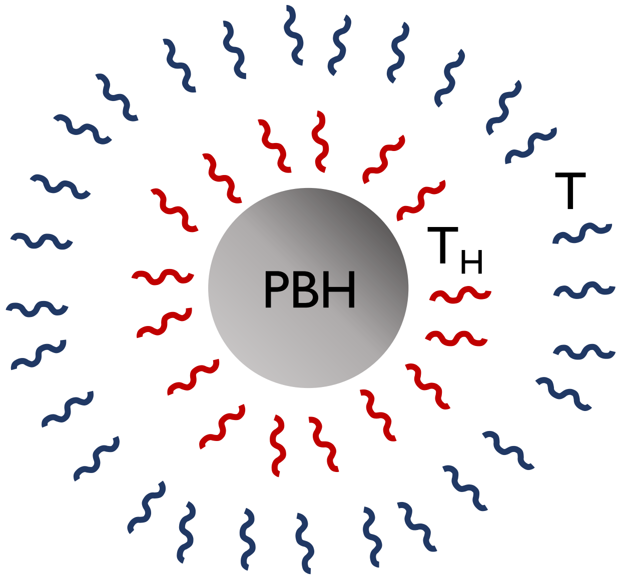


- However the temperature appears in the decay rate:

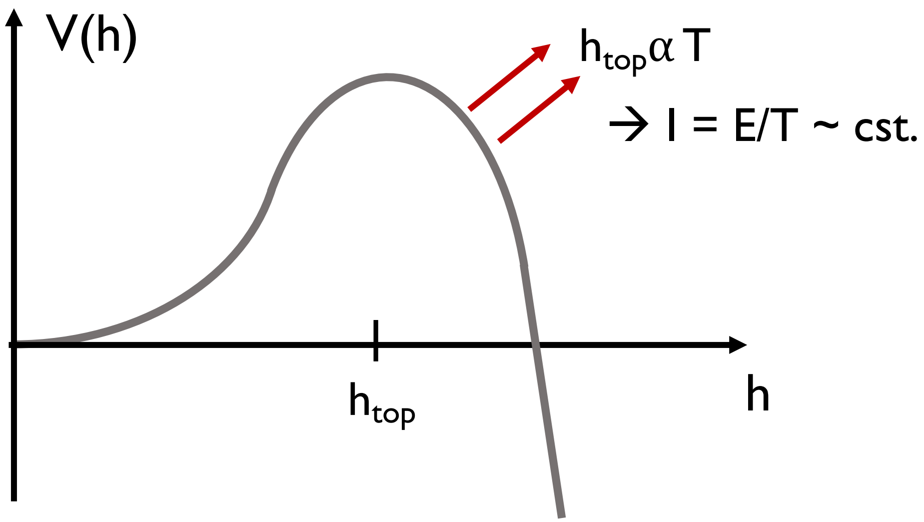
$$\Gamma_{\rm FVD}(T) \;\approx\; T\left(\frac{I_{\rm b}[T_H]}{2\pi}\right)^{1/2} \exp\left(-I_{\rm b}[T_H]\right)$$

Black Holes as Bubble Nucleators (3/3)

- These results require thermalized plasma around the black hole, however evaporating black holes are not in equilibrium
- Note results were calculated for Hartle-Hawking vacuum, but expected to be too short lived to allow FVD. Alternatively, lower temperatures would be suppressed due to determinant



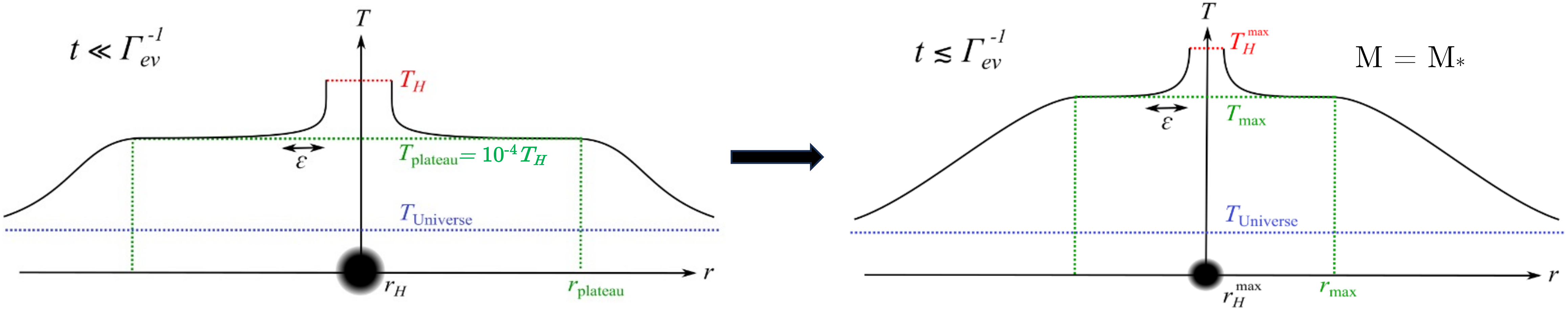
- Strumia noted thermal loop corrections to the Higgs potential must also be taken into account which increase the action (i.e. suppress the decay rate) at high temperature



Hot Spots Around PBHs (1/2)

Is there a path forward ?

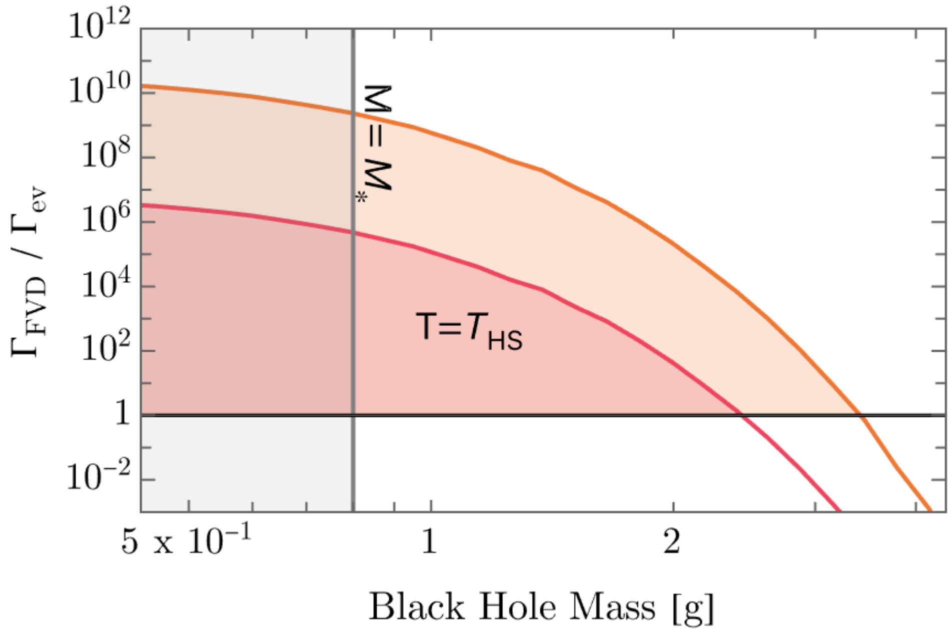
- He, Kohri, Matsui & Yamada recently computed the energy deposition rate of Hawking radiation into the surrounding plasma
- Due to the deposition rates much higher than evaporation rate for masses above $M_* \sim 0.8$g , thermalized "hot spots" can form around black holes (hotter than plasma but **colder** than black hole)

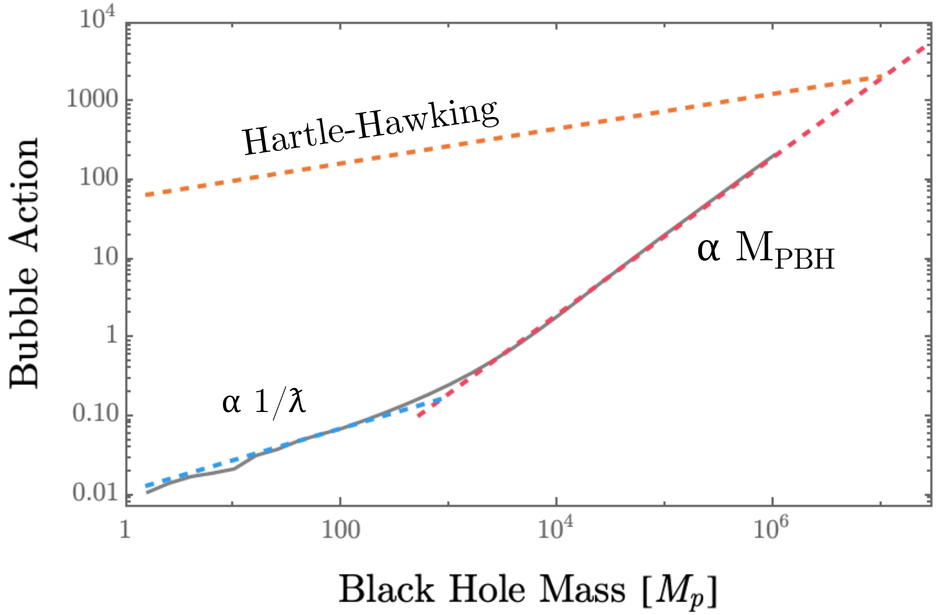


Hot Spots Around PBHs (2/2)

- Vacuum decay can now occur inside hotspots: energy is calculated using thermal fluctuations from (relatively low) T_{HS}, while temperature in front of action is T_H
- Hot spot create ideal conditions: if T_{HS} too low or too high FVD doesn't occur since:

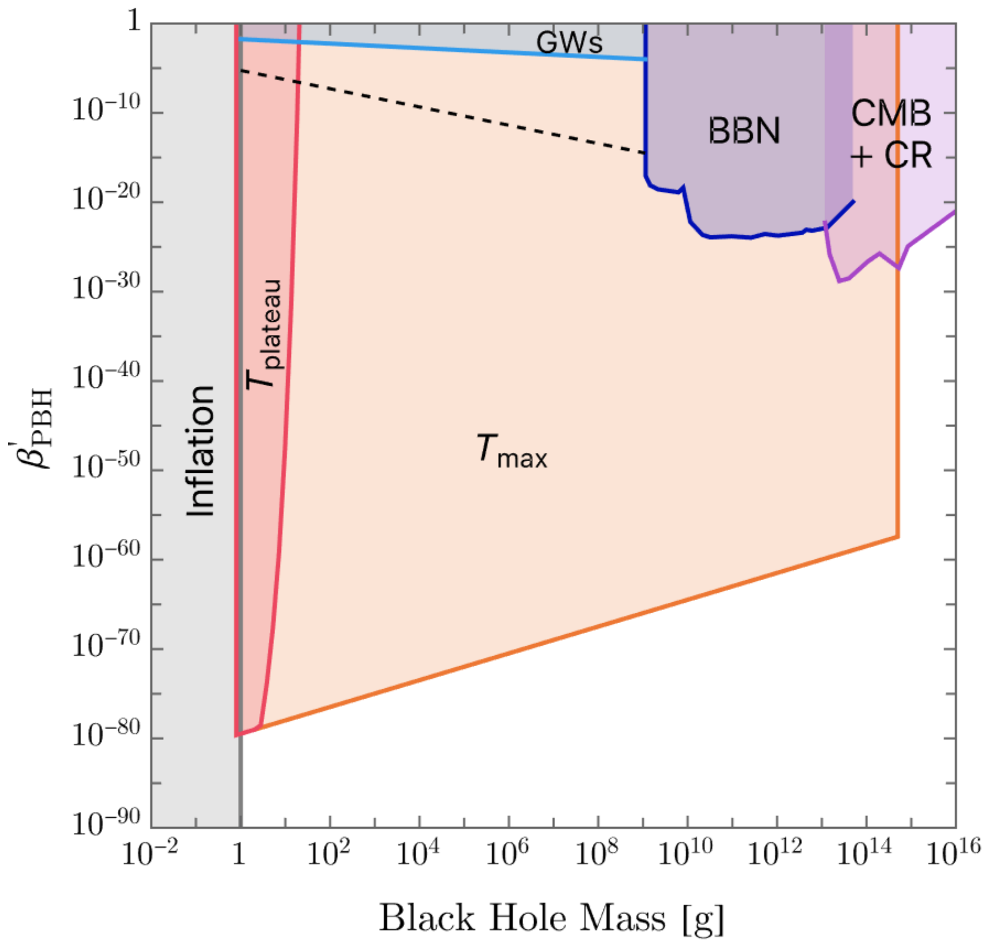
$$\Gamma_{\rm FVD}(T) \approx T \left(\frac{I_{\rm b}[T_H]}{2\pi}\right)^{1/2} \exp\left(-I_{\rm b}[T_H]\right)$$





Bounds on PBHs

- Decay ratio >> 1 → $P_d \sim 1$ before end of evaporation
- We can exclude any PBH which evaporated in our current Hubble horizon → very stringent constraints
- Conservative bounds $T_{plateau}$ assume Euclidean formalism only valid at M_i
- Further work must solve exact temperature profile, as action depends strongly on near horizon region
- Higgs stabilization at high energy could allow light PBHs

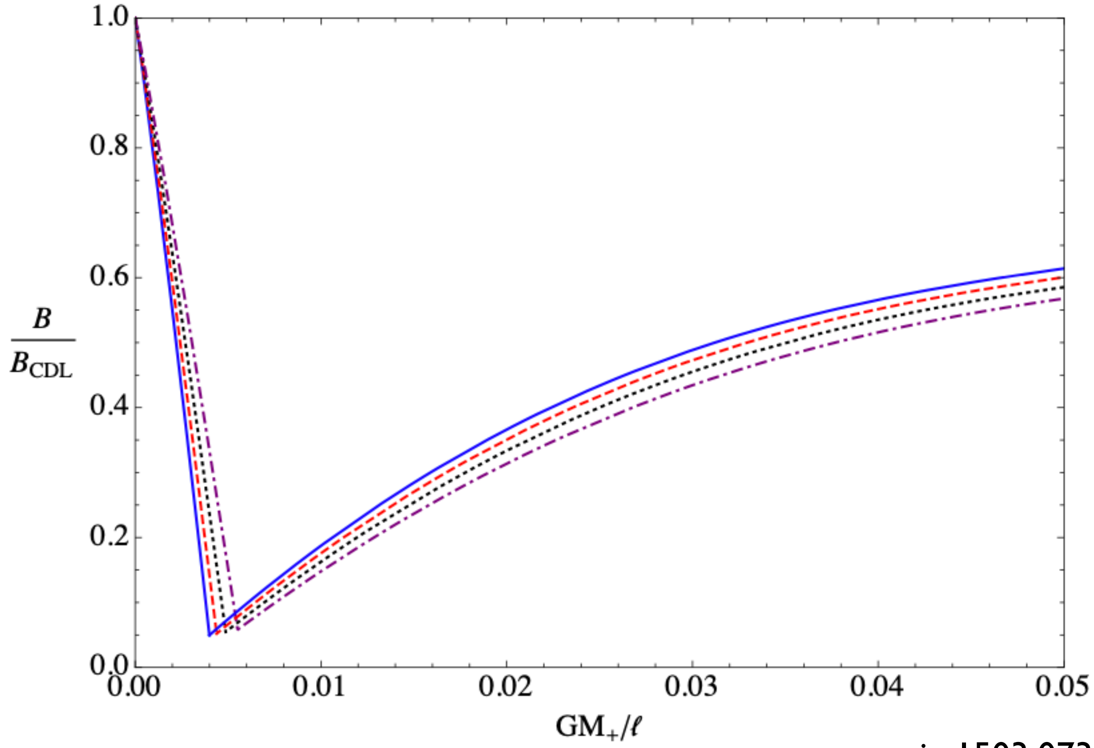


Conclusions

- PBHs are of theoretical interest and not highly constrained below 10^{10}g
- Light PBHs give a mechanism to create FVD of metastable Higgs but difficult to produce without PBHs due to thermal fluctuations
- Hot spots around PBHs provide a path to destabilize the vacuum
- Studying light PBHs means one needs to address metastability first
- We can now apply this to metastability in DM and/or other BSM scenarios!

Thank you!

Back-up



arxiv 1503.07331