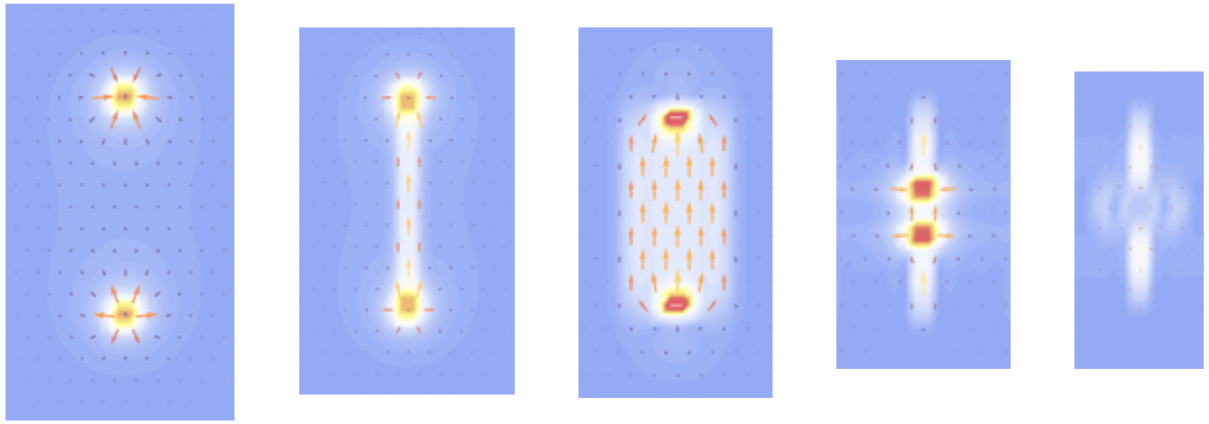

*Primordial Black Holes from Confinement**

EuCAPT Symposium, 6 May 2021

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Why Primordial Black Holes?

- Black Holes formed in the early Universe (primordial) are natural Dark Matter candidate, a priori no new physics required.

- Current/future GW detection experiment as a natural laboratory to study/constrain them.

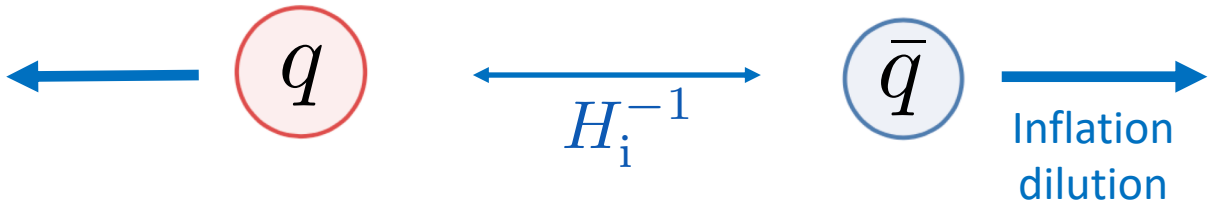
- Different mechanisms could be at work to produce them:
  - Super horizon fluctuations re-entering above certain critical threshold
  - First order phase transitions
  - Many others…

!!! Exponential fine tuning normally required.

!!! Needs to boost power spectrum dramatically.

Formation Mechanism:

Step 1: Production of heavy quarks during inflation (then diluted) $M_{\mathrm{q}} \gtrsim H_{\mathrm{i}}$



Distance > Hubble radius

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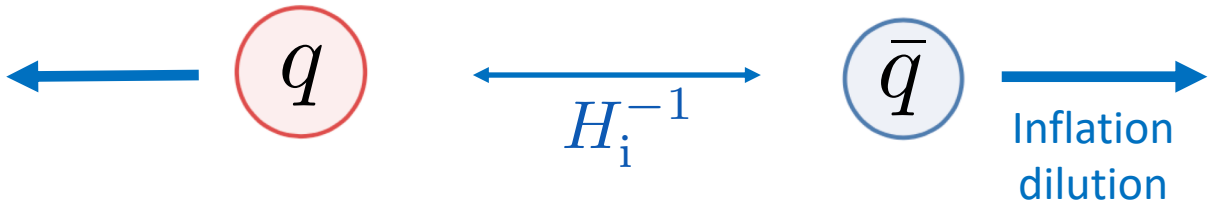
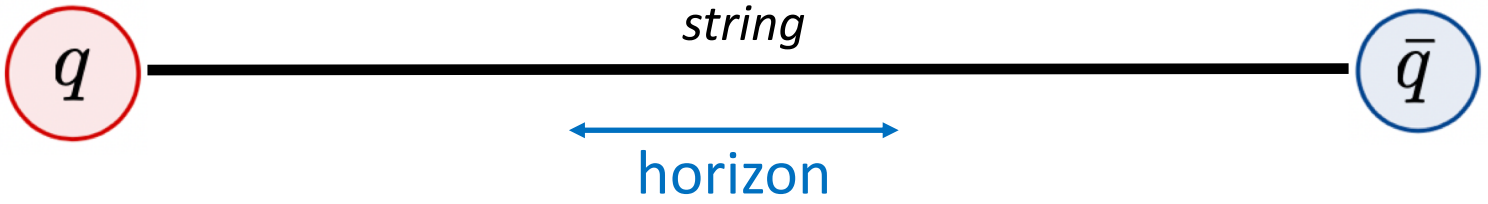


Distance > Hubble radius

Step 2: Confine them at energy scale $\Lambda_{\rm c}$, $\Lambda_{\rm c} < M_{\rm q}$



Distance > horizon

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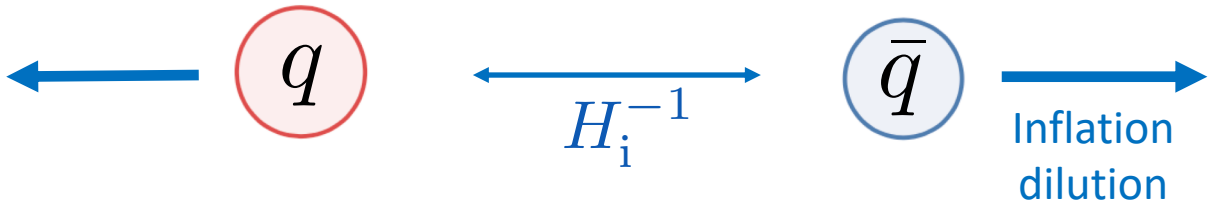

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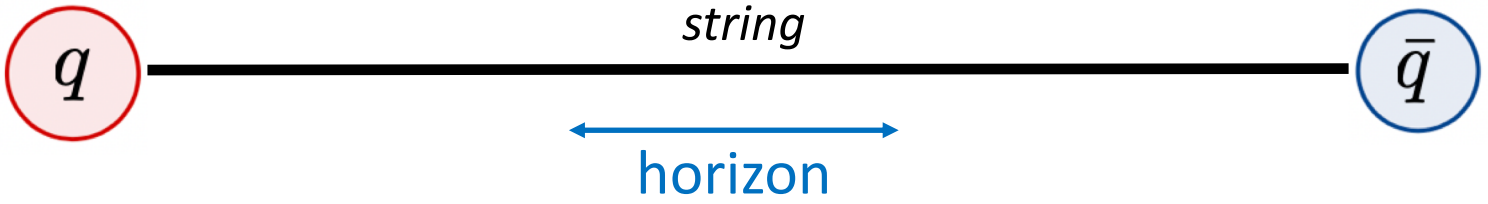


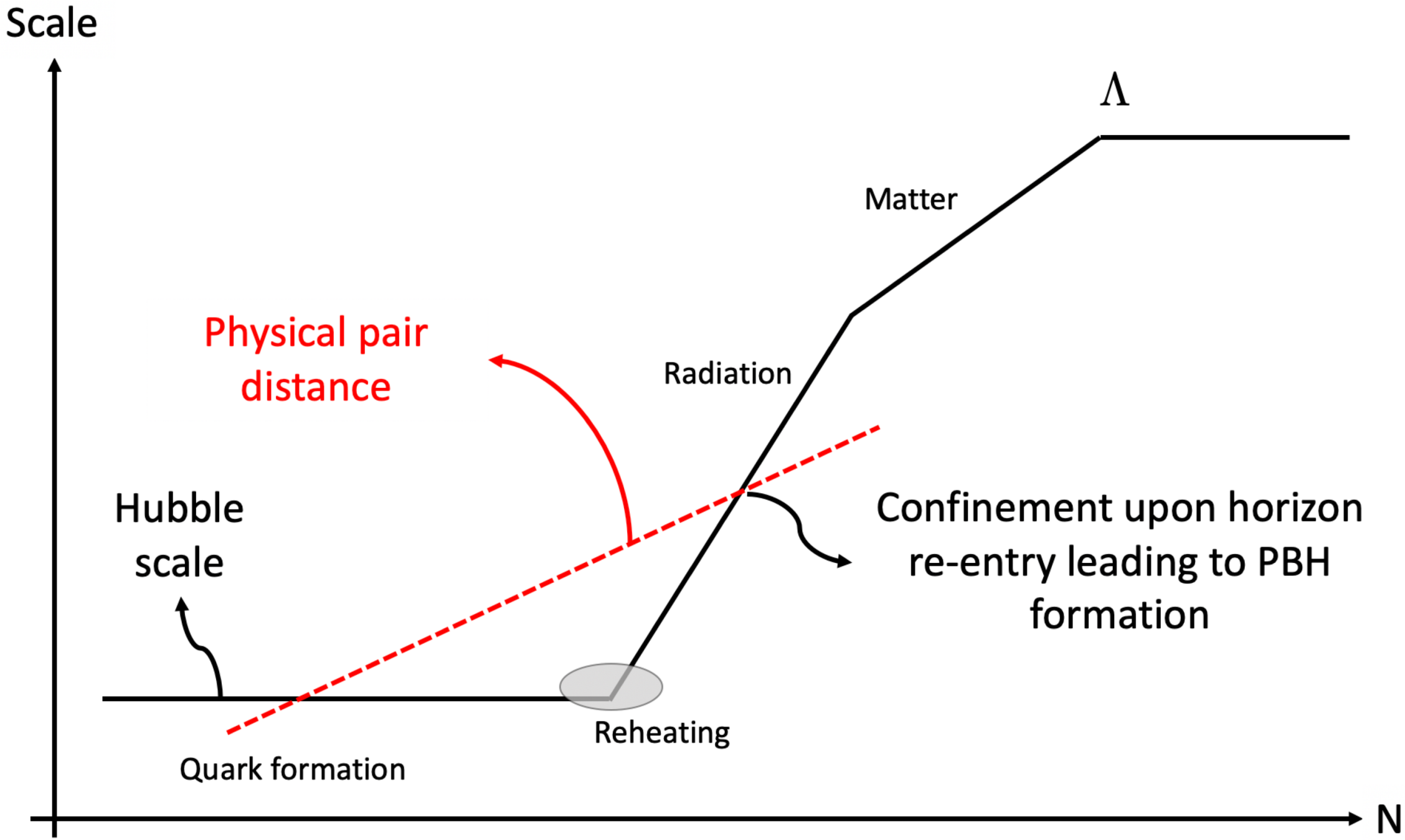
Distance > horizon

Step 3: During radiation dominated universe, as they re-enter horizon, collapse leads to BH formation

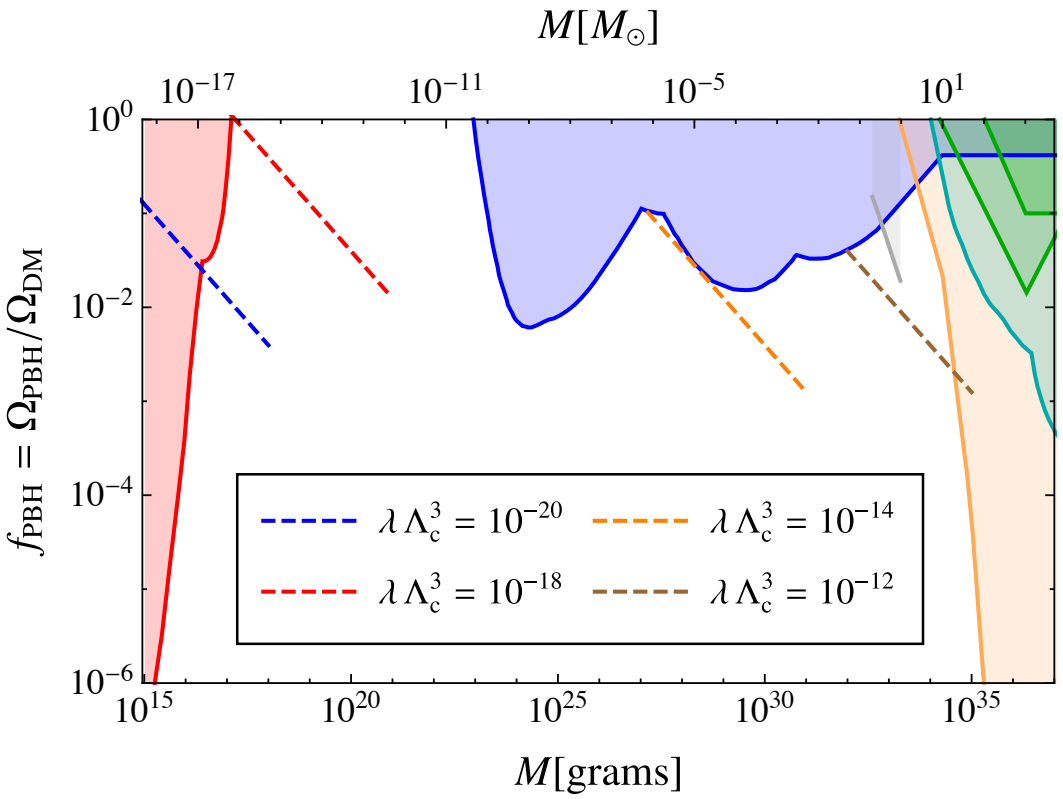
Distance < horizon

Collapse due to string tension takes place.

$$E \approx E_{\rm string} = \Lambda_{\rm c}^2 t \approx M_{\rm PBH}$$


Scale
Λ
Matter
Physical pair distance
Radiation
Hubble scale
Confinement upon horizon re-entry leading to PBH formation
Reheating
Quark formation
N

Features



Spectrum with monochromatic constraints:

$$f_{\rm PBH} \equiv \frac{\rho_{\rm PBH}(t)}{\rho_{\rm CDM}(t)} = \frac{32\pi}{3}\,\lambda\Lambda_{\rm c}^3\left(\frac{M_{\rm PBH}}{M_{\rm eq}}\right)^{-1/2}$$

Generalization to extended case:

$$\int_{M_1}^{M_2} {\rm d}\ln M_{\rm PBH}\,\frac{{\rm d}f_{\rm PBH}(M_{\rm PBH})}{{\rm d}\ln M_{\rm PBH}}\,\frac{1}{f_{\rm max}(M_{\rm PBH})} \overset{!}{\leq} 1$$

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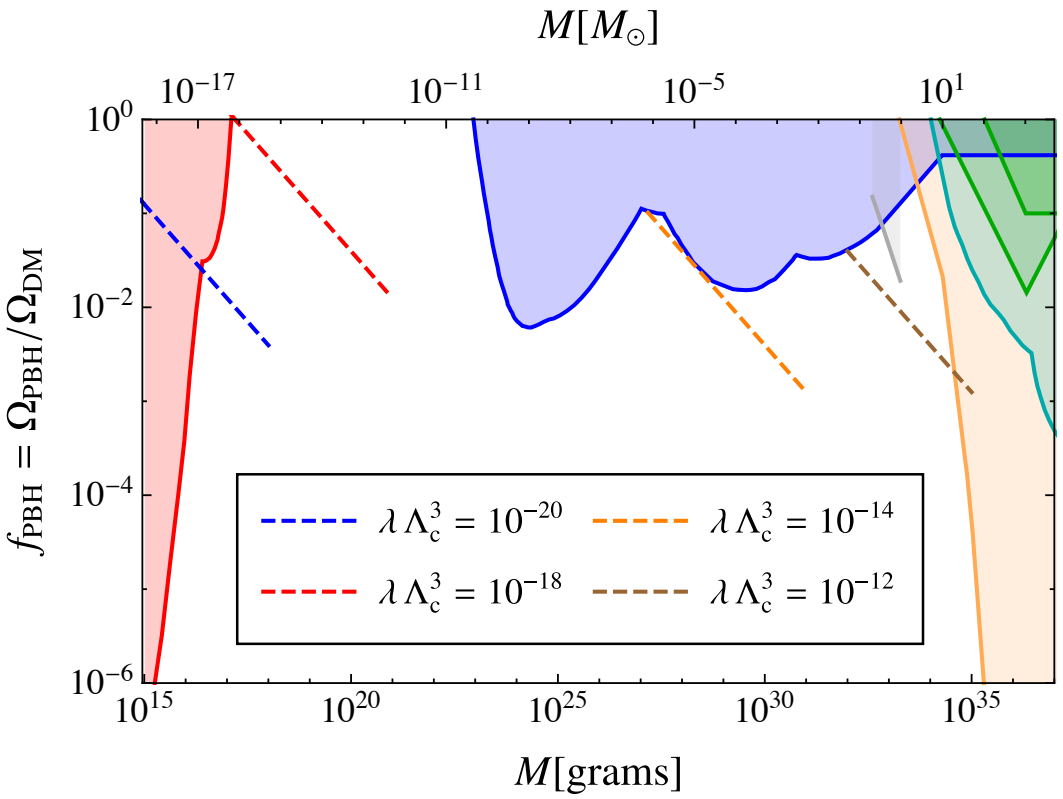

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100% of DM can be explained by the mechanism.

Features

1) SMBHs are explained (bonus!)

$$f_{\rm PBH}^{\rm heavy} \equiv \int_{10^4\,M_\odot} {\rm d}\ln M_{\rm PBH}\ \frac{{\rm d}f_{\rm PBH}(M_{\rm PBH})}{{\rm d}\ln M_{\rm PBH}} \approx 10^{-10}$$

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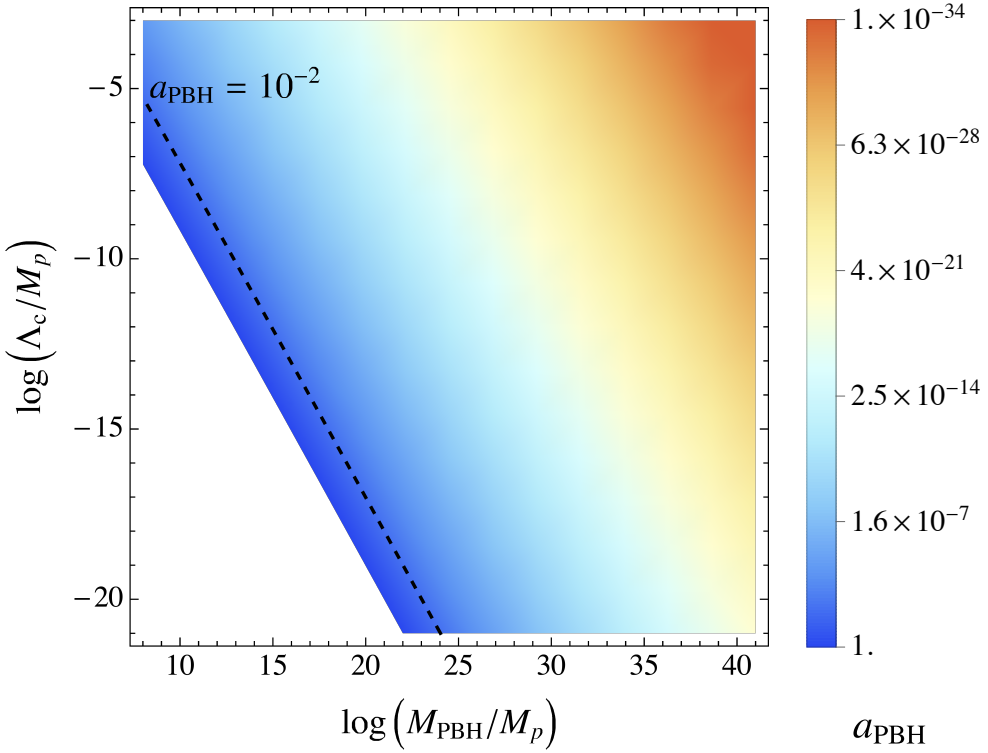
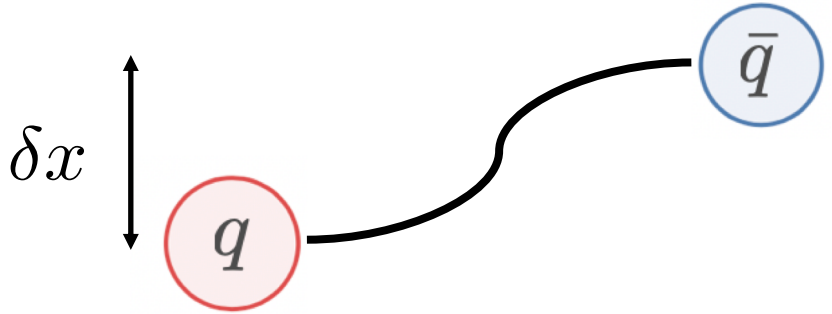
2) High-spin sub-solar mass primordial black holes (Smoking Gun!)





$$\delta x \simeq \sqrt{N_{\rm e}}\, H_{\rm i}^{-1}$$

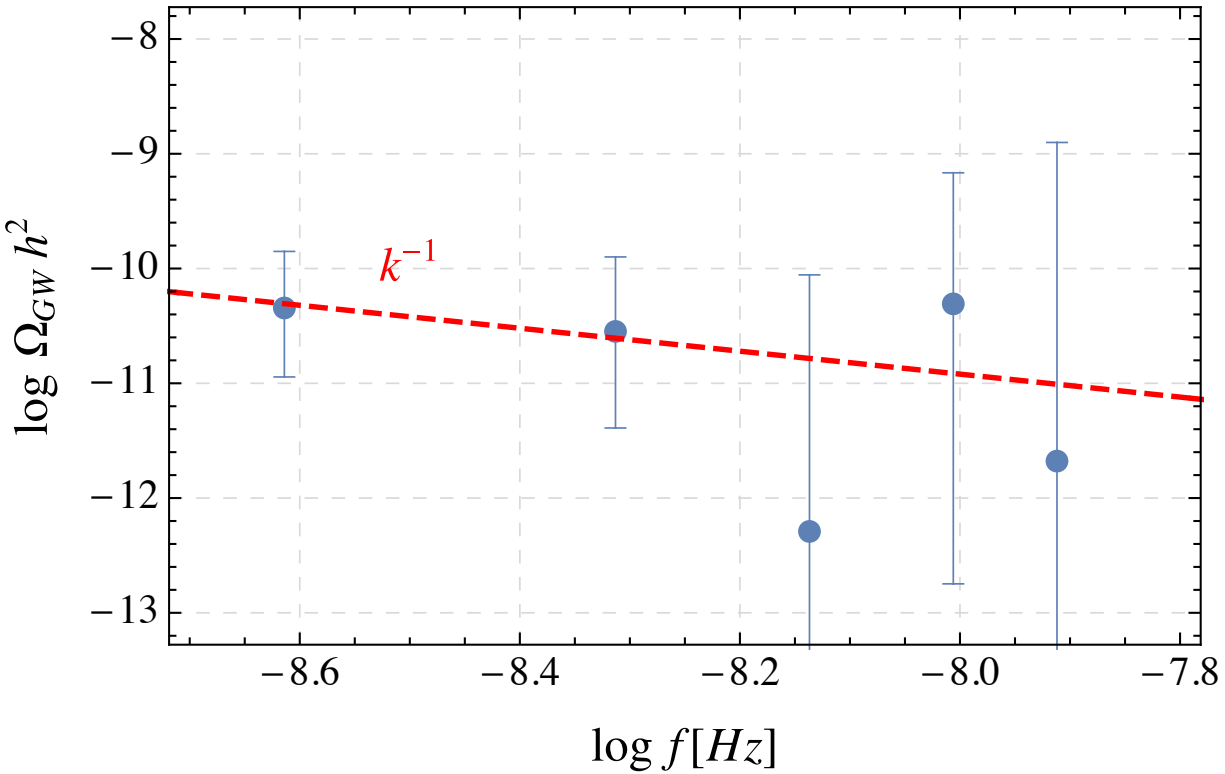
$$a_{\rm PBH} \simeq \frac{\delta x}{R_{\rm g}} \simeq \frac{1}{H_{\rm i} M_{\rm PBH}} \log\left(\frac{H_{\rm i} M_{\rm PBH}}{\Lambda_{\rm c}^2}\right)^{1/2}$$

More features

3) Gravitational waves emission: $\Omega^0_{\rm GW} = \dfrac{\rho^0_{\rm GW}}{\rho_0} = 2\, f_{\rm PBH}\, \Lambda_{\rm c} \left(\dfrac{M_{\rm PBH}}{M_{\rm eq}} \right)^{1/2} (t_{\rm eq}\, H_0)^{2/3}$

$$f_0 \simeq 3\, T\, g_*(T)^{1/4}\, t_{\rm eq}^{1/6}\, H_0^{2/3}$$

NANOGrav detections



$$\Lambda_{\rm c} \lesssim M_{\rm p}, \qquad P \propto k^{-1}$$

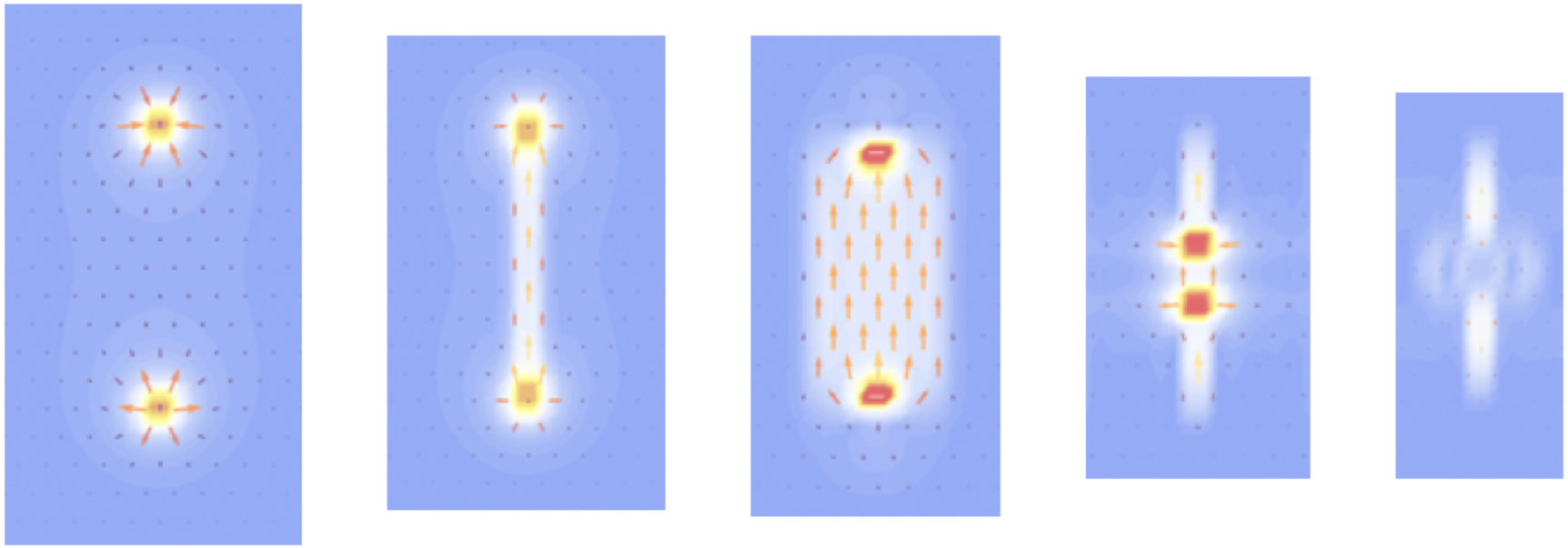
Summary and Conclusions

- Novel mechanism for PBH formation based on the confinement of *some quarks* is introduced.

- 100% of dark matter can be explained within the mechanism with no need to **fine tune exponentially** and no need to **boost the power spectrum**.

- As a bonus SMBHs in the galactic centres are also obtained.

- Possible highly rotating PBHs in the sub-solar mass range are produced, with clear correlation of spin vs mass (smoking gun).

- Gravitational-wave spectrum has very peculiar signatures.

Thank you for your attention!