

IRN Terascale @ LPC-Clermont

The cosmic coincidence of Primordial black holes

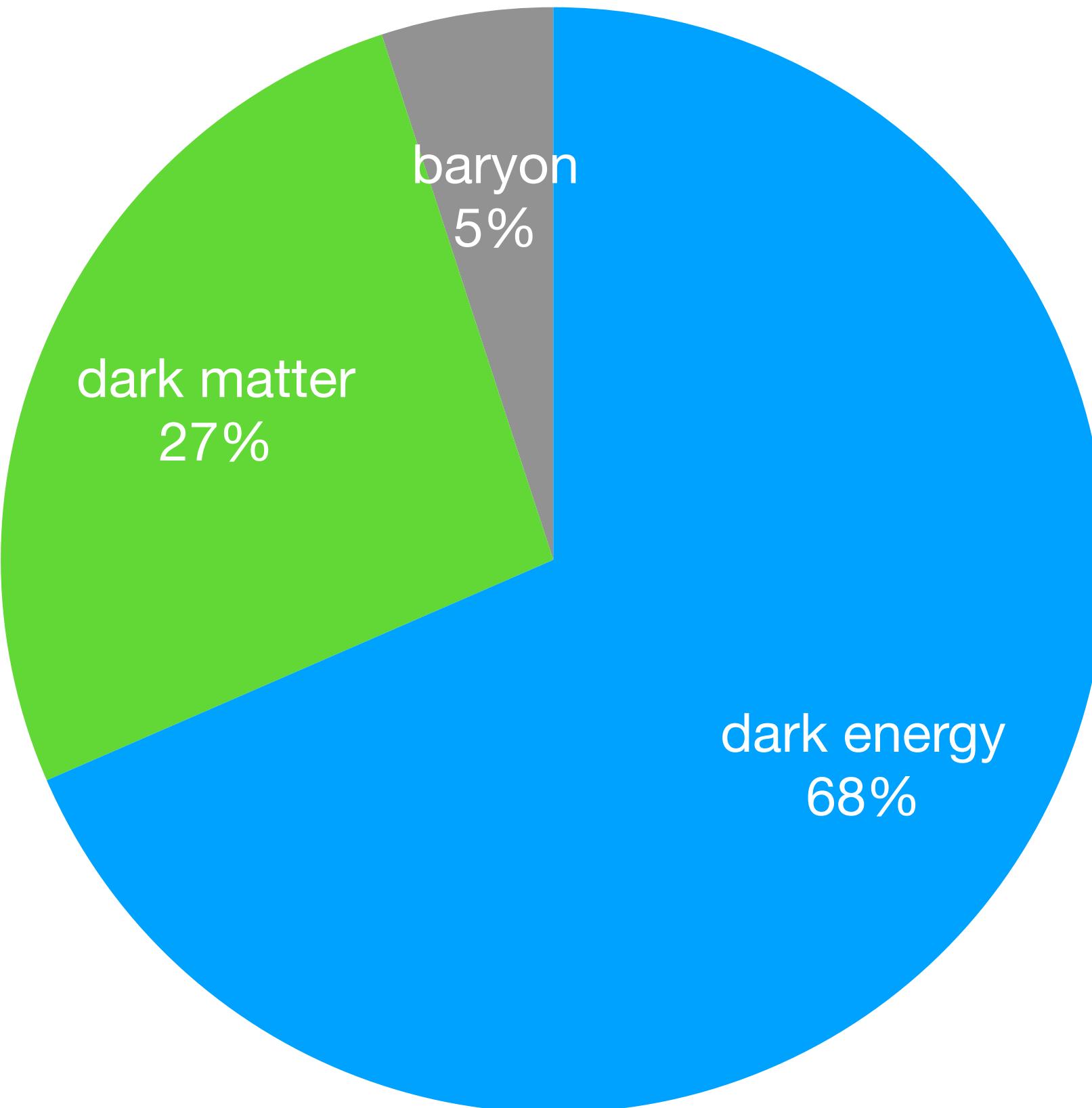
with Elena Pinetti (U. Torino & LPTHE), Kalliopi Petraki (LPTHE & Nikhef)
and Joseph Silk (IAP & JHU & BICPA, Oxford)

Yi-Peng Wu, LPTHE & Sorbonne Université, 23/11/2021

Based on [2109.00118] & [2109.09875]



The cosmic coincidence (in this talk)



$$\frac{\Omega_{\text{DM}}}{\Omega_B} \approx 5$$

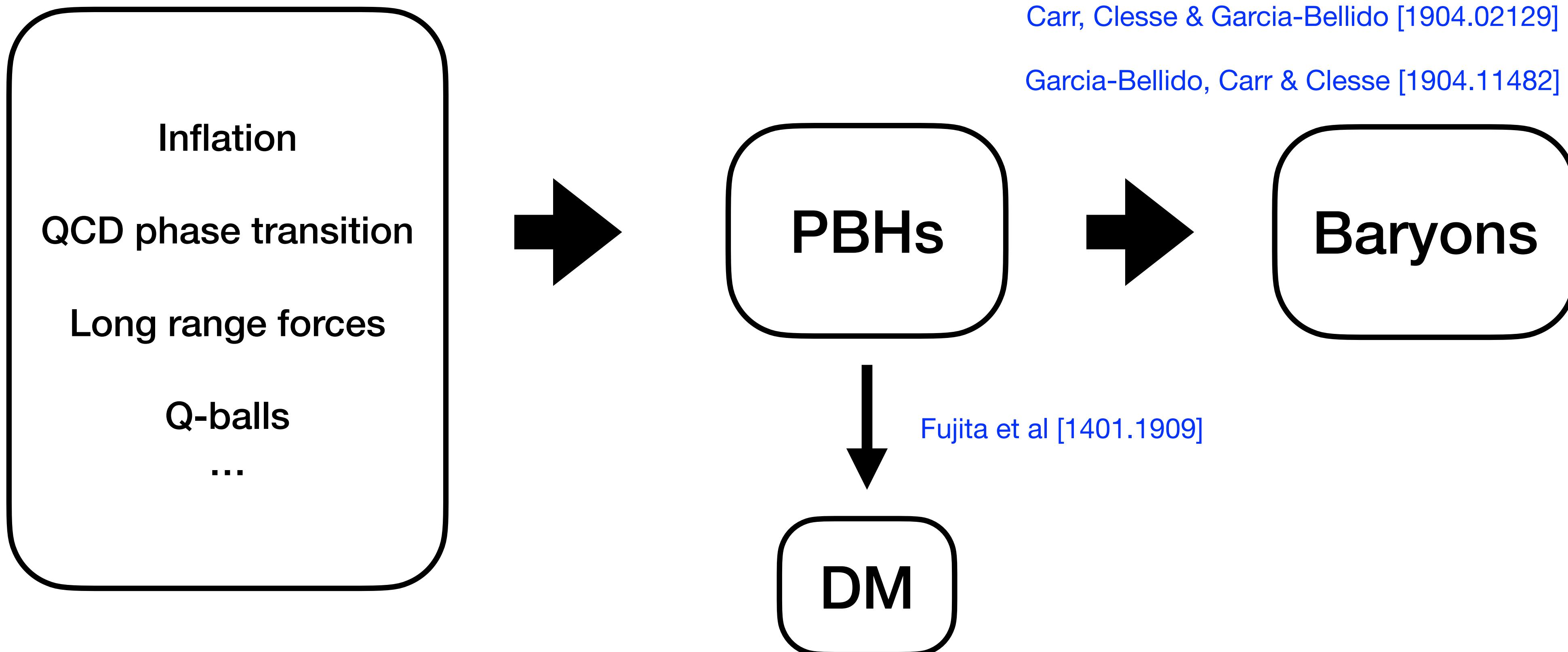
An answer from particle physics: asymmetry dark matter

[Bell, Petraki, Shoemaker & Volkas \[1105.3730\]](#)

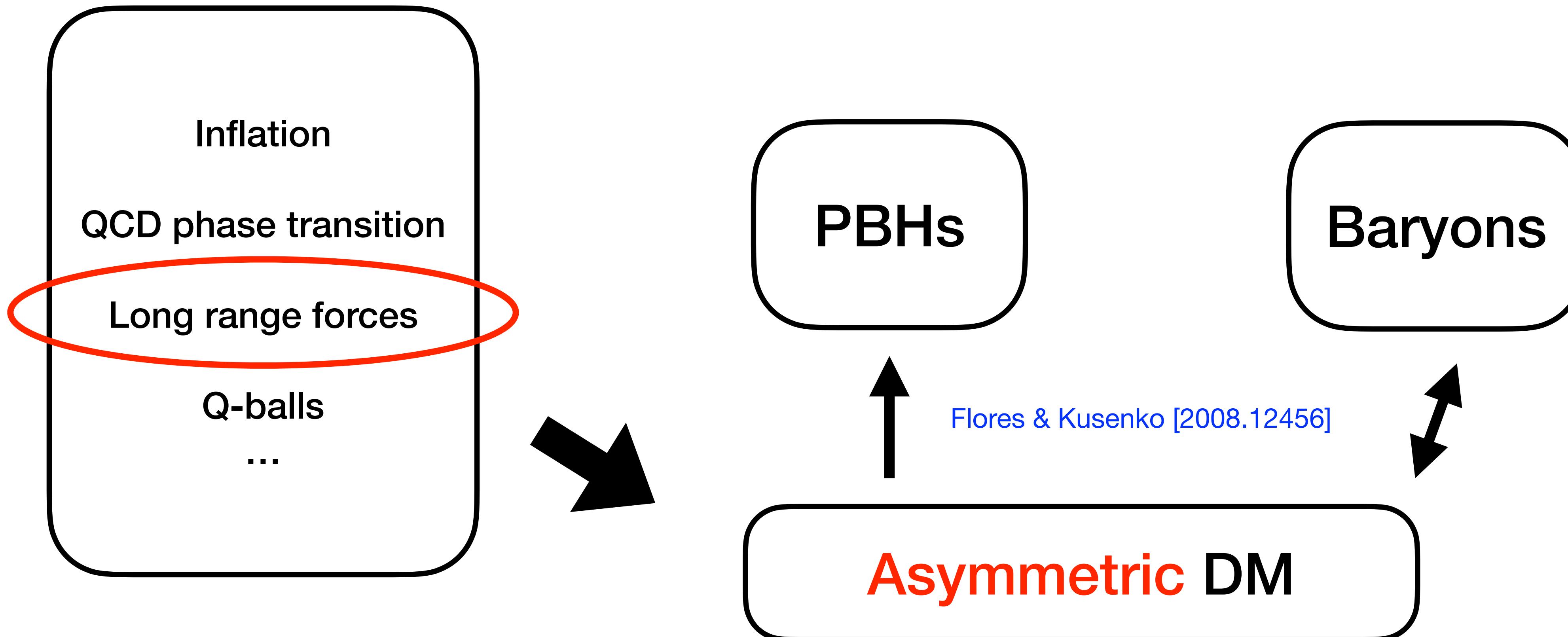
[von Harling, Petraki & Volkas \[1201.2200\]](#)

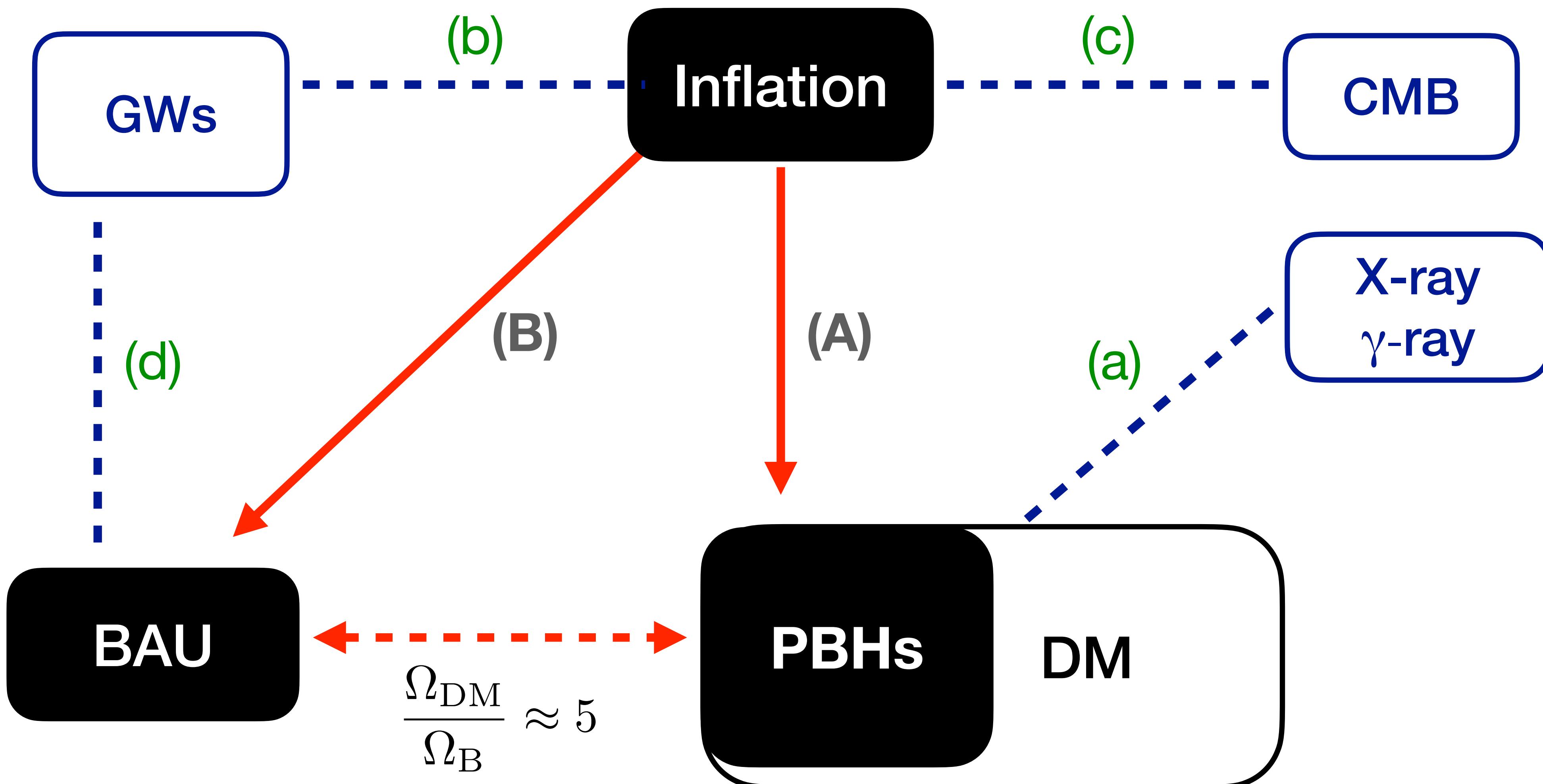
[Petraki & Volkas \[1305.4939\]](#)

The cosmic coincidence via PBHs

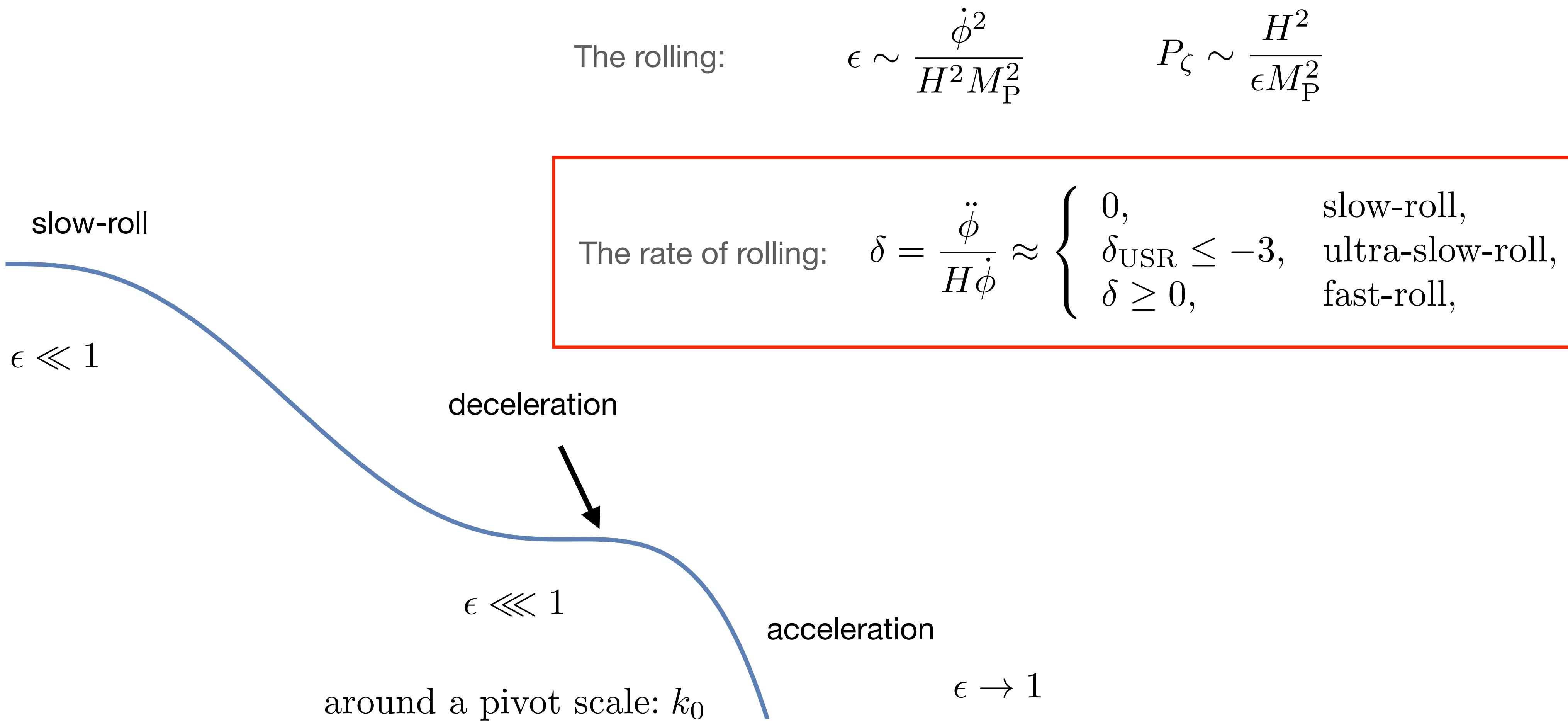


The cosmic coincidence via PBHs





A. PBHs from (ultra-slow-roll) inflation



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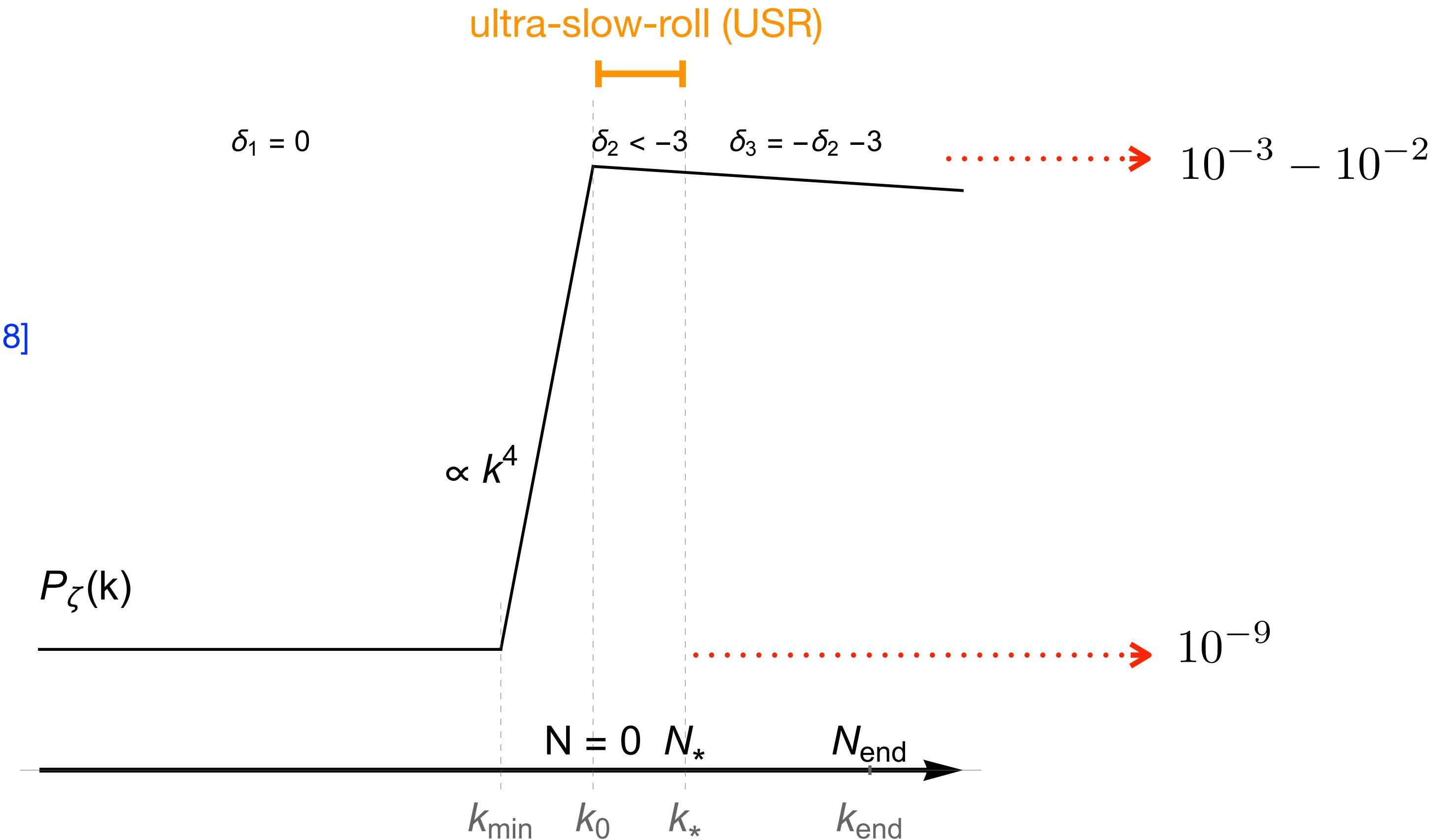
Analytic templates:

Liu, Guo & Cai [2003.02075]

Ng & YPW [2102.05620]

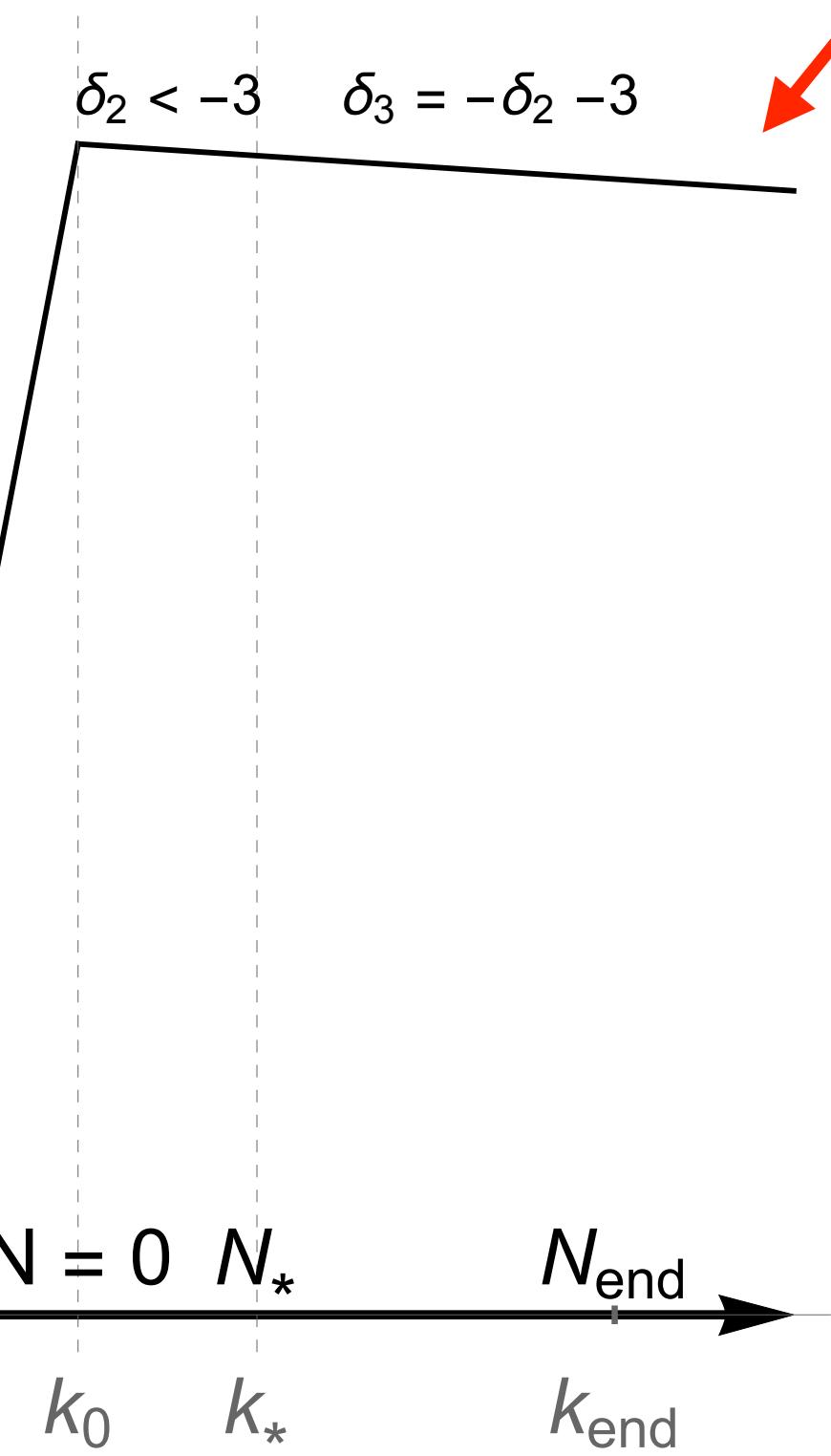
YPW, Pinetti, Petraki & Silk [2109.00118]

ζ : curvature perturbation



A. PBHs from (ultra-slow-roll) inflation

adiabatic condition (conformal weight continuity)



The Leach-Sasaki-Wands-Liddle mechanism:

Leach et al [astro-ph/0101406]

(also called the steepest growth)

Byrnes, Cole & Patil [1811.11158]

Carrilho, Malik & Mulryne [1907.05237]

Ng & YPW [2102.05620]

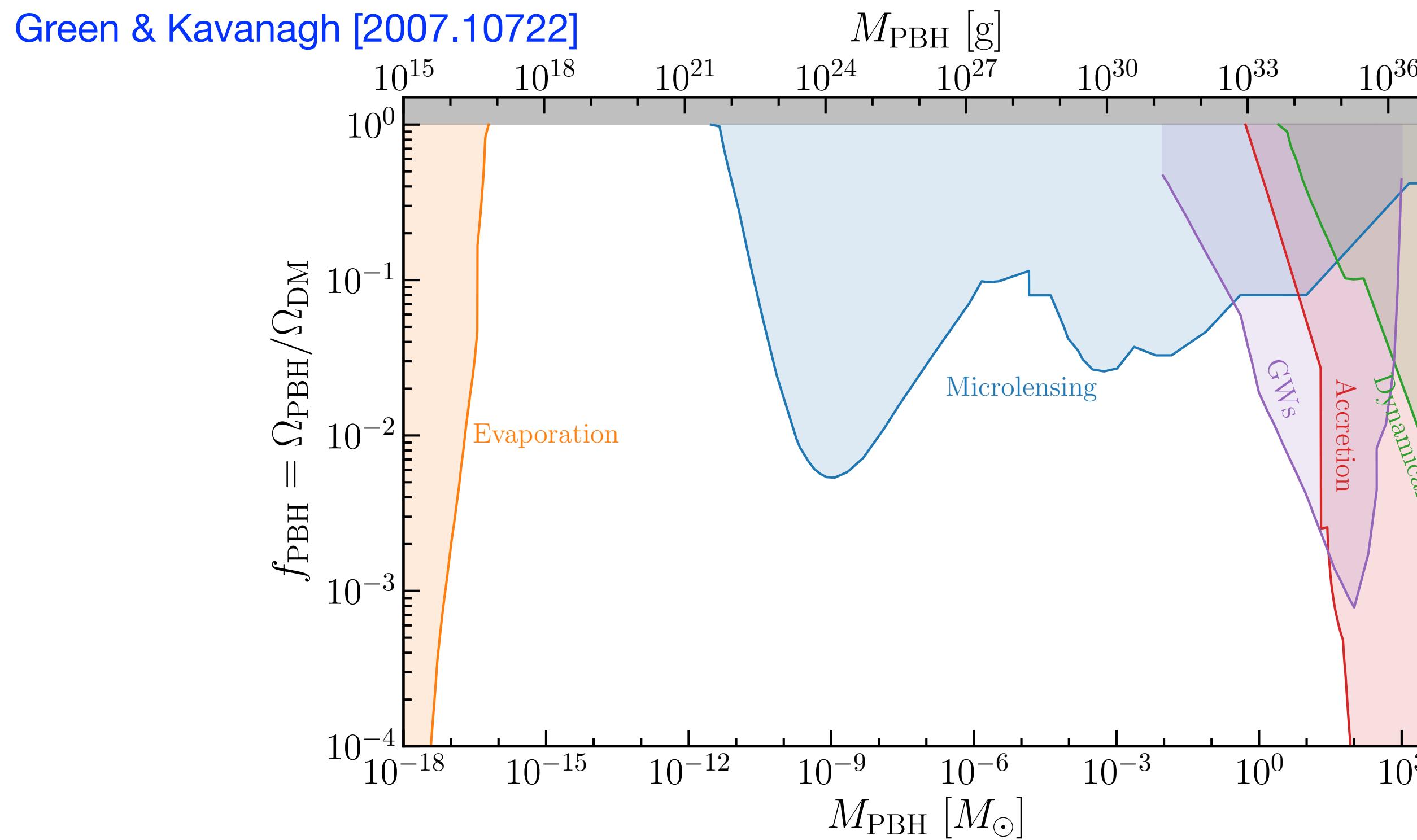
A. PBHs from (ultra-slow-roll) inflation

Enhanced curvature perturbation → large density contrast → collapse to PBHs

(inflation)

(reheating)

(radiation domination)



The pivot scale:

$$k_0 \sim 10^{12} - 10^{15} \text{Mpc}^{-1}$$

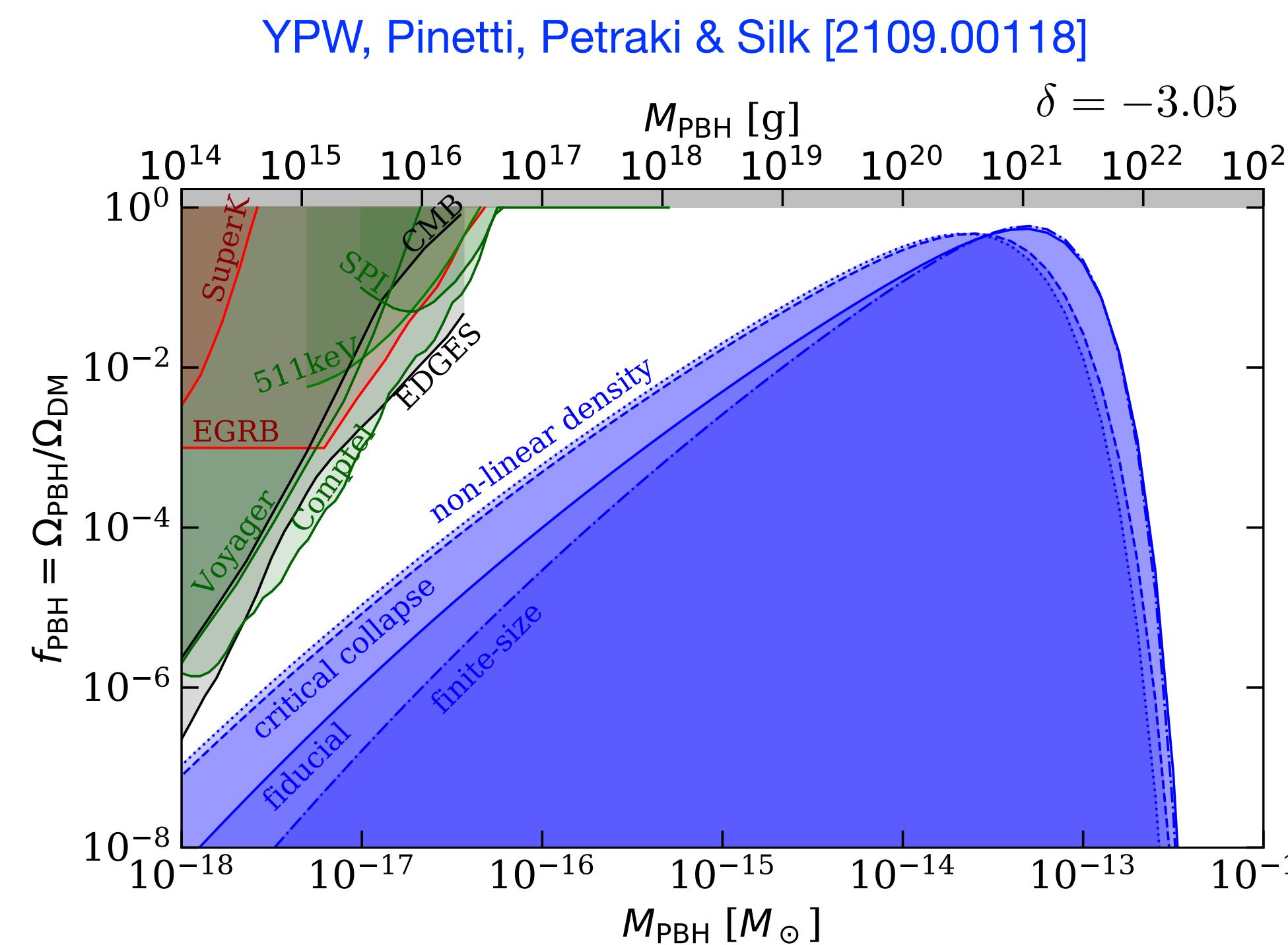
Schwarzschild radius:

$$10^{-9} - 10^{-13} \text{m}$$

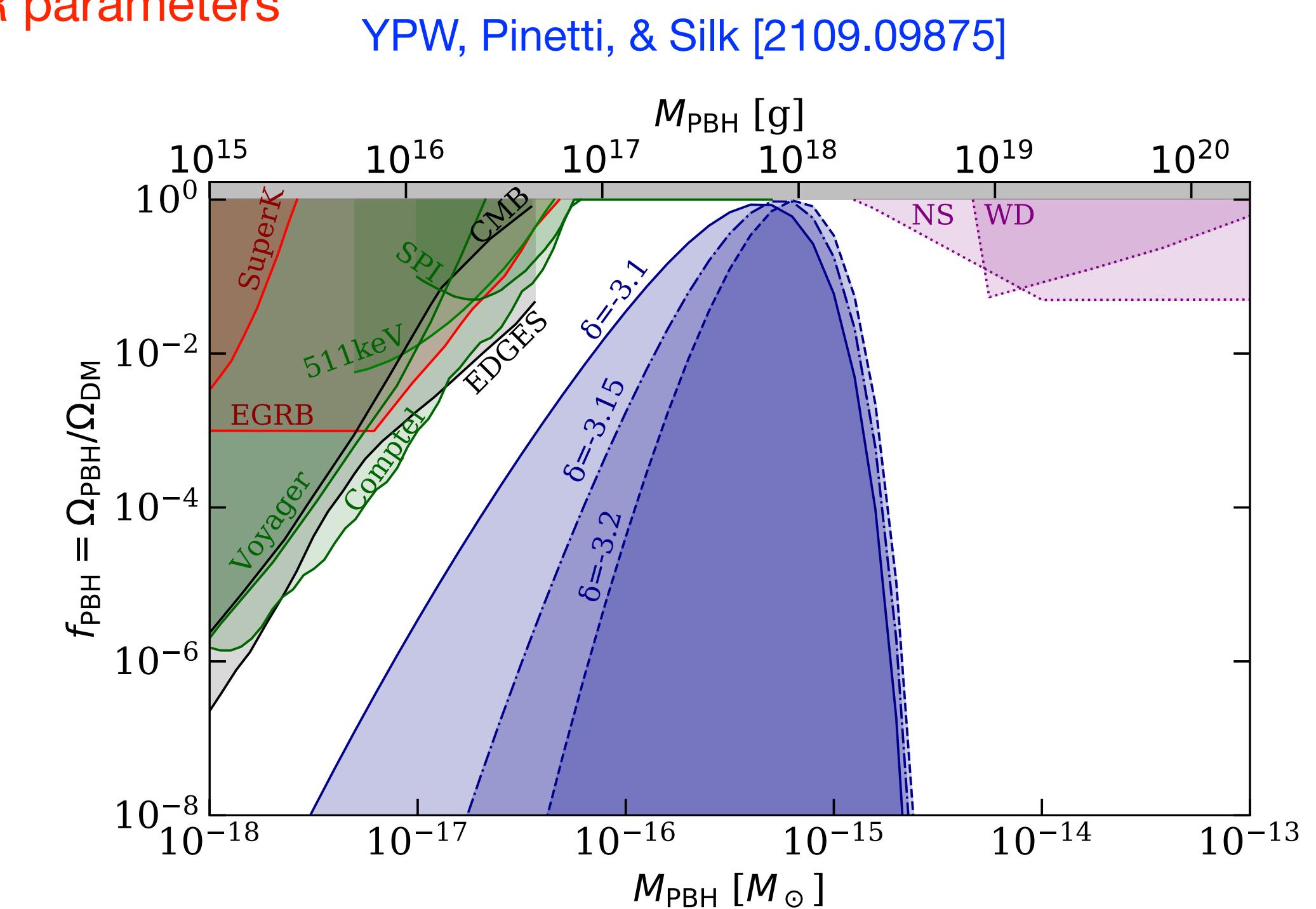
A. PBHs from (ultra-slow-roll) inflation

...as all dark matter

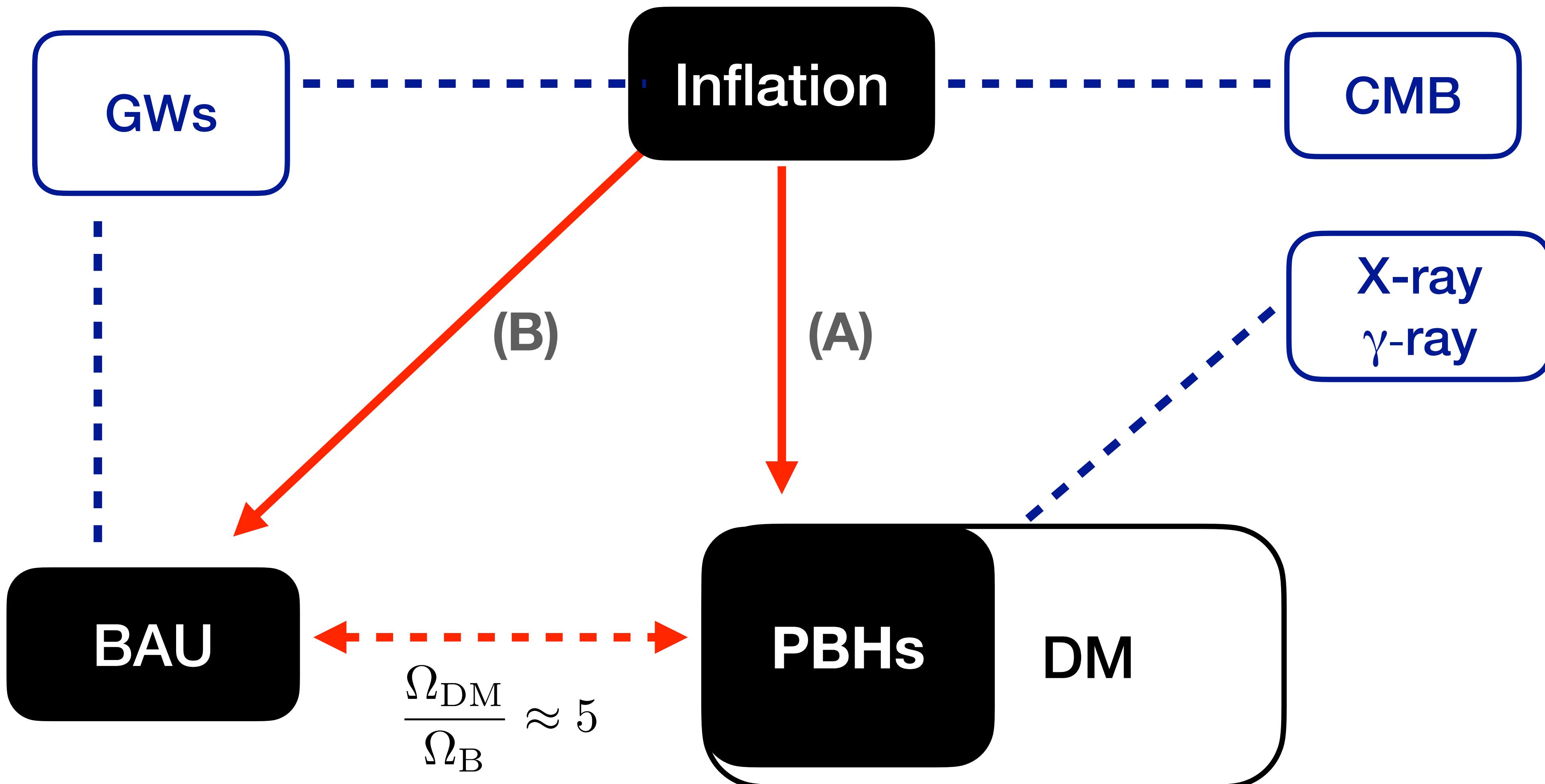
$$f_{\text{PBH}} = f_{\text{PBH}}(\delta, N_*) = 1$$



USR parameters



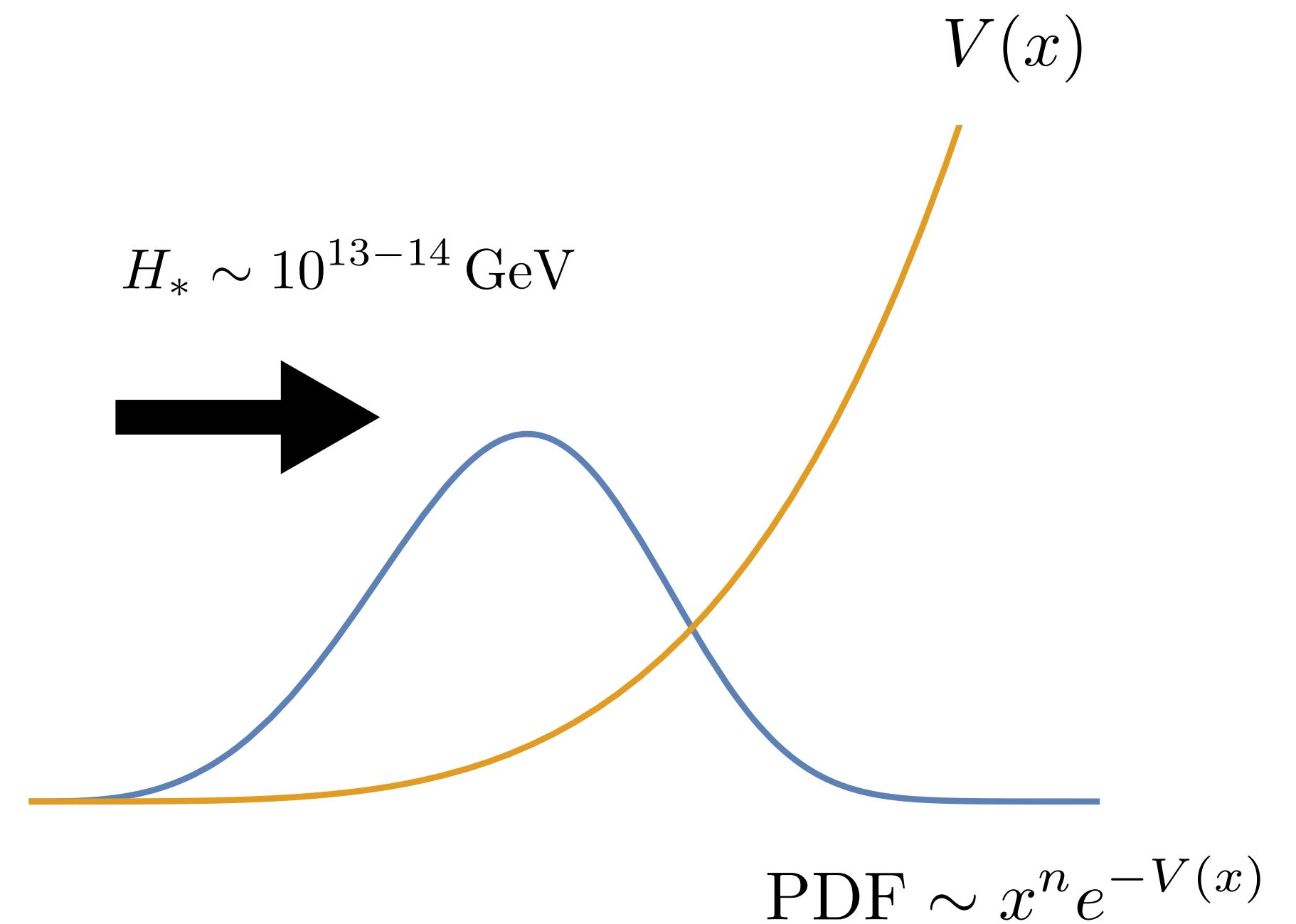
Fiducial: the Press-Schechter method (Carr 1975)



B. Baryogenesis from USR inflation

The Affleck-Dine mechanism:

1. Scalar fields develop large VEVs during inflation.
2. The relaxation of scalar VEVs after inflation end is out-of-equilibrium.



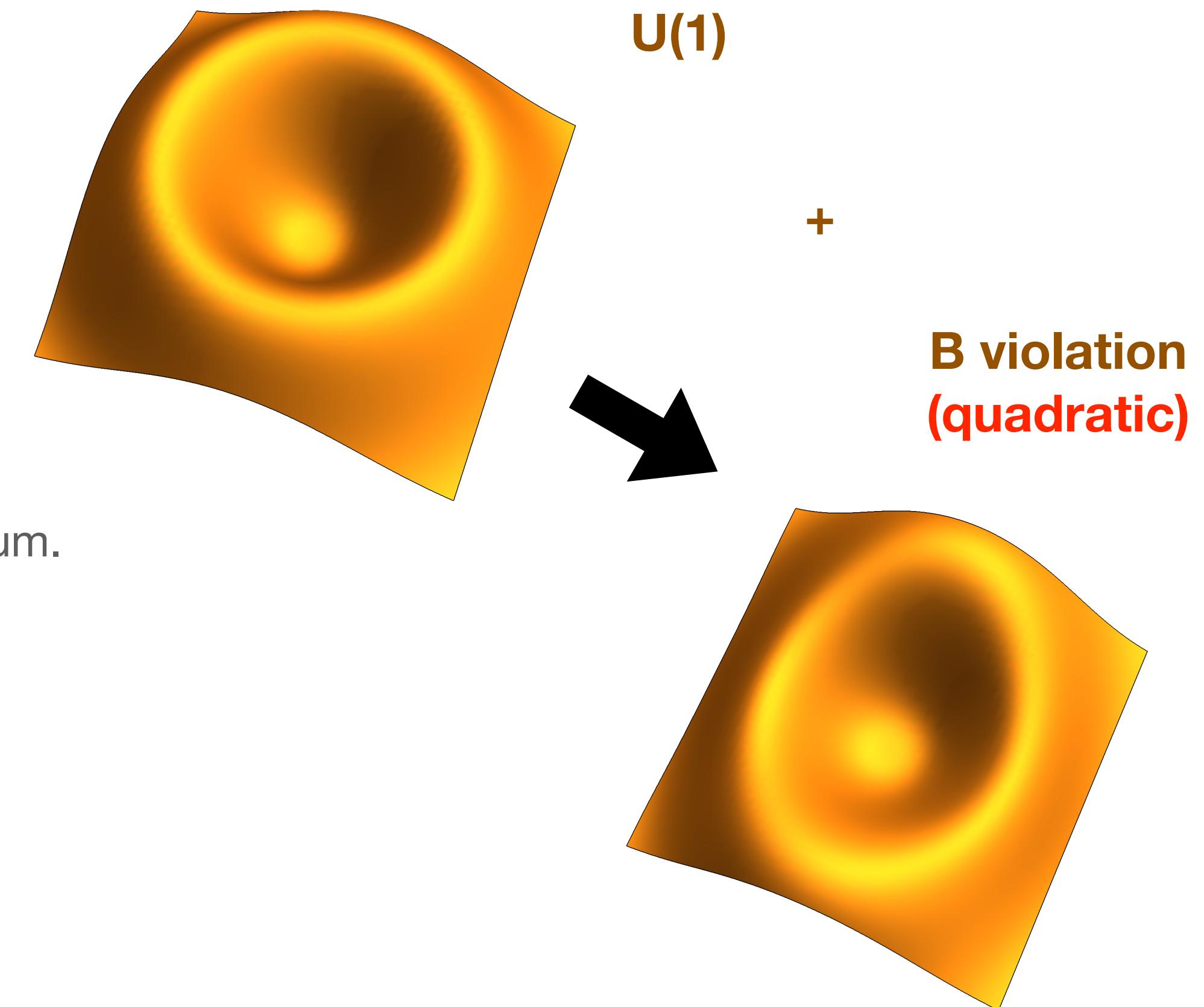
B. Baryogenesis from USR inflation

The Affleck-Dine mechanism:

1. Scalar fields develop large VEVs during inflation.
2. The relaxation of scalar VEVs after inflation end is out-of-equilibrium.
3. The presence of B / L / B-L number violating interactions.
4. Spontaneous CP violation at the beginning of relaxation!

Dine, Randall & Thomas [9507453]

YPW & Petraki [2008.08549]



B. Baryogenesis from USR inflation

If the USR transition runs into the effective mass of the AD field:

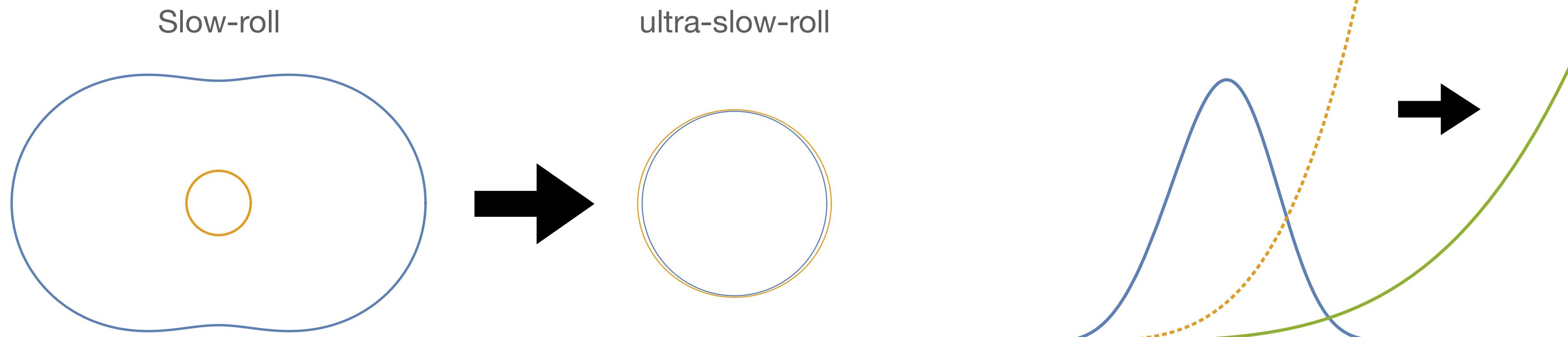
$$m_{\text{AD}}^2 \sim \square\phi/\Lambda$$

[YPW, Pinetti, Petraki & Silk \[2109.00118\]](#)

$$\square\phi = -\ddot{\phi} - 3H\dot{\phi} = -(\delta + 3)$$

[YPW, Pinetti, & Silk \[2109.09875\]](#)

δ : rate of rolling



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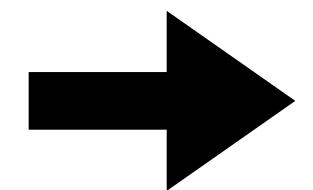
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YPW, Pinetti, & Silk [2109.09875]

δ : rate of rolling

$$Y_B = \frac{n_B}{s} = \frac{i(\sigma^* \dot{\sigma} - \sigma \dot{\sigma}^*)}{s}$$

$$\sigma(t_0) = \sigma(t_0; \delta, N_*, N_{\text{end}})$$



$$Y_B = Y_B(\underline{\delta, N_*, N_{\text{end}}})$$

USR parameters

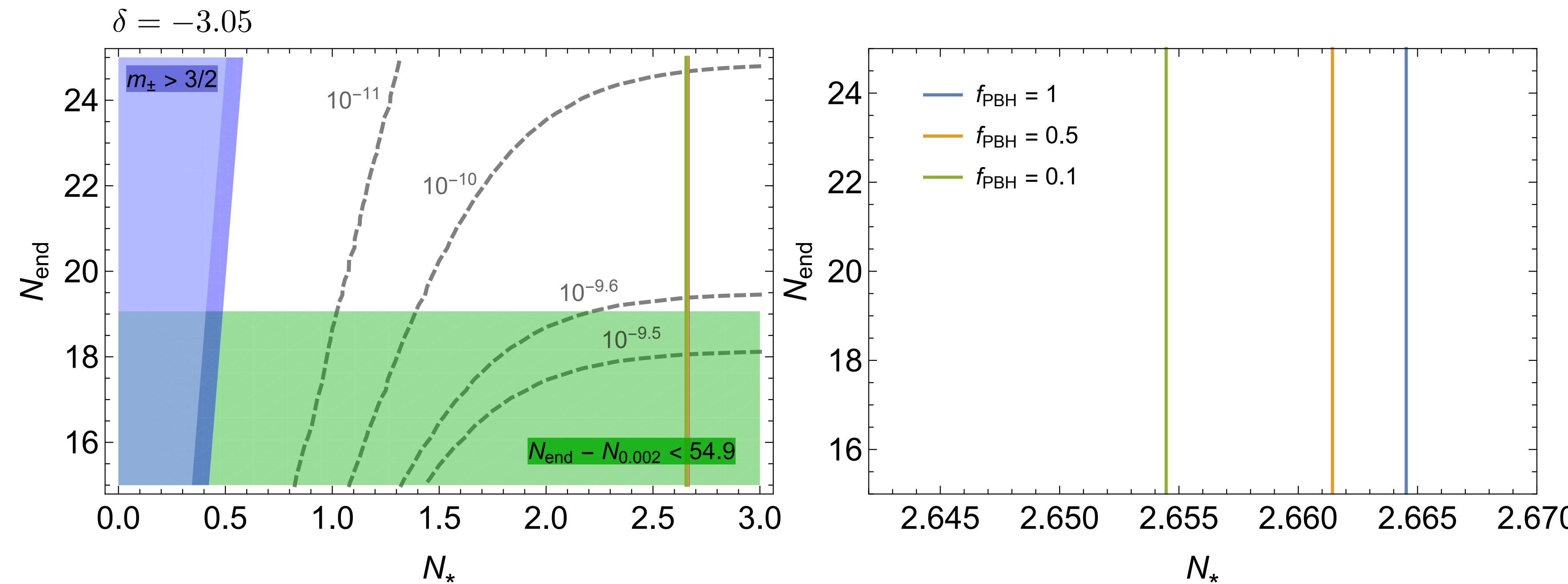
The cosmic coincidence from inflation

YPW, Pinetti, Petraki & Silk [2109.00118]

δ : rate of rolling

A. PBHs from USR inflation: $f_{\text{PBH}} = f_{\text{PBH}}(\delta, N_*)$ $\Delta N_{\text{USR}} = N_* - N_0 = N_*$

B. Baryons from USR inflation: $Y_B = Y_B(\delta, N_*, N_{\text{end}})$ N_{end} : end of inflation



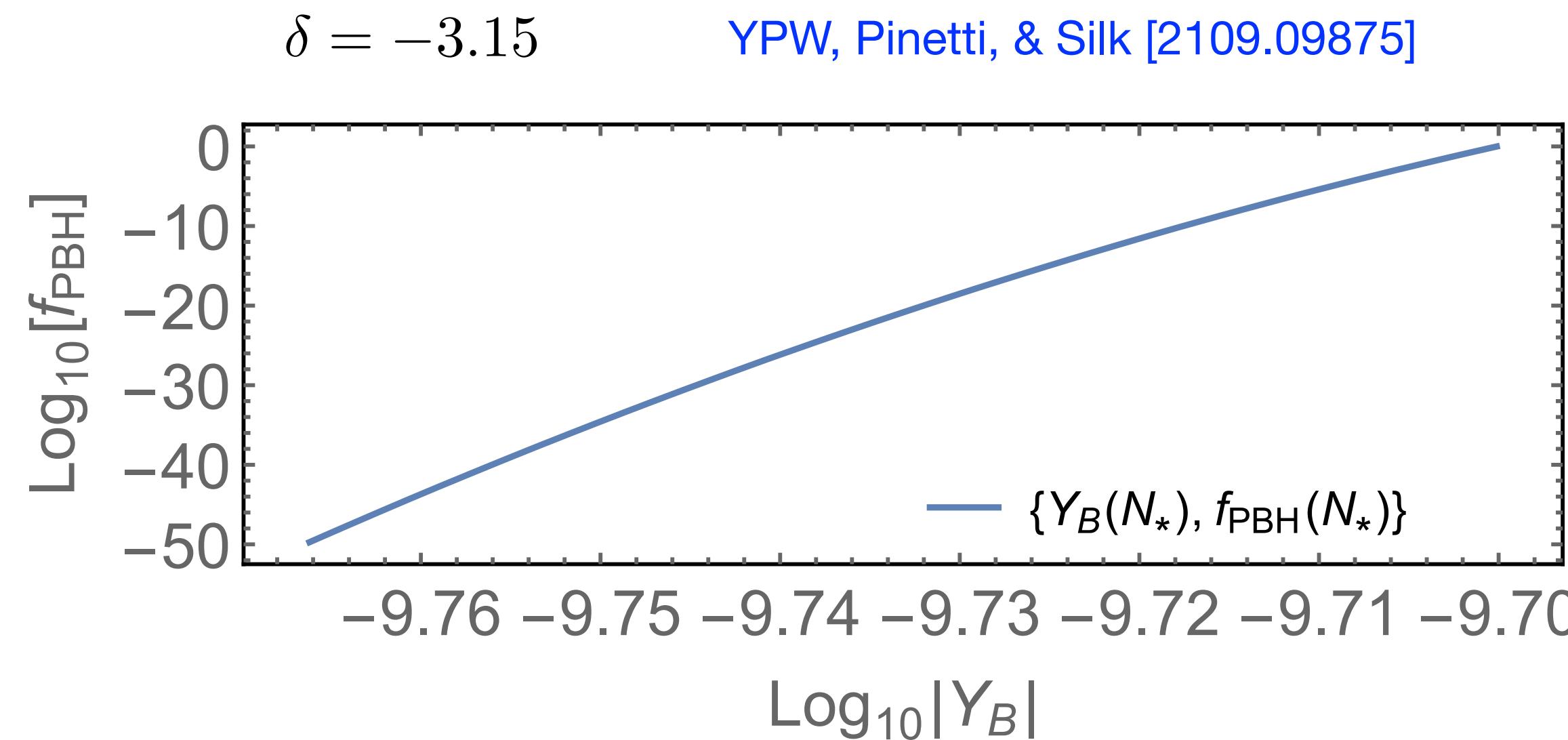
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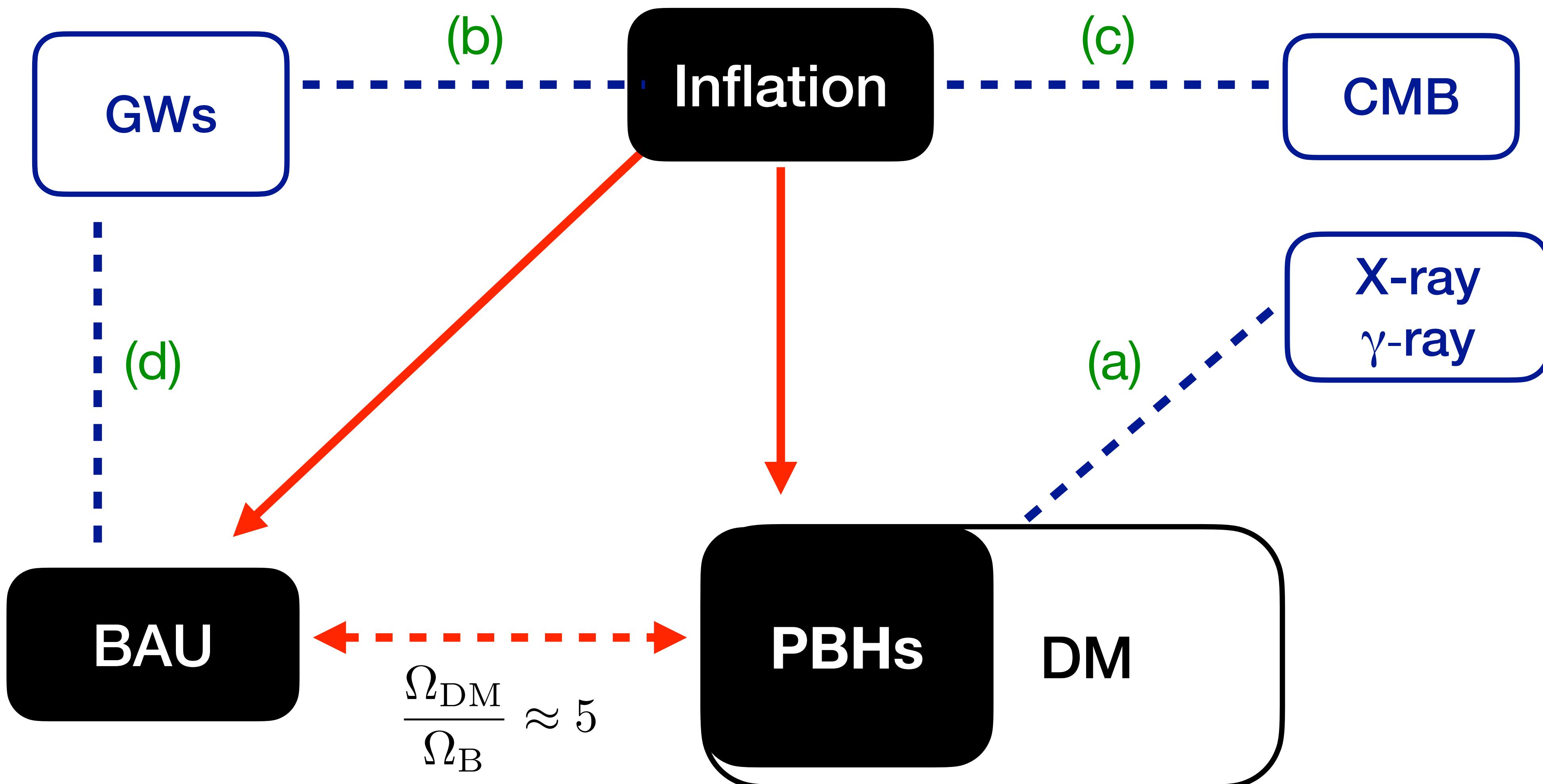
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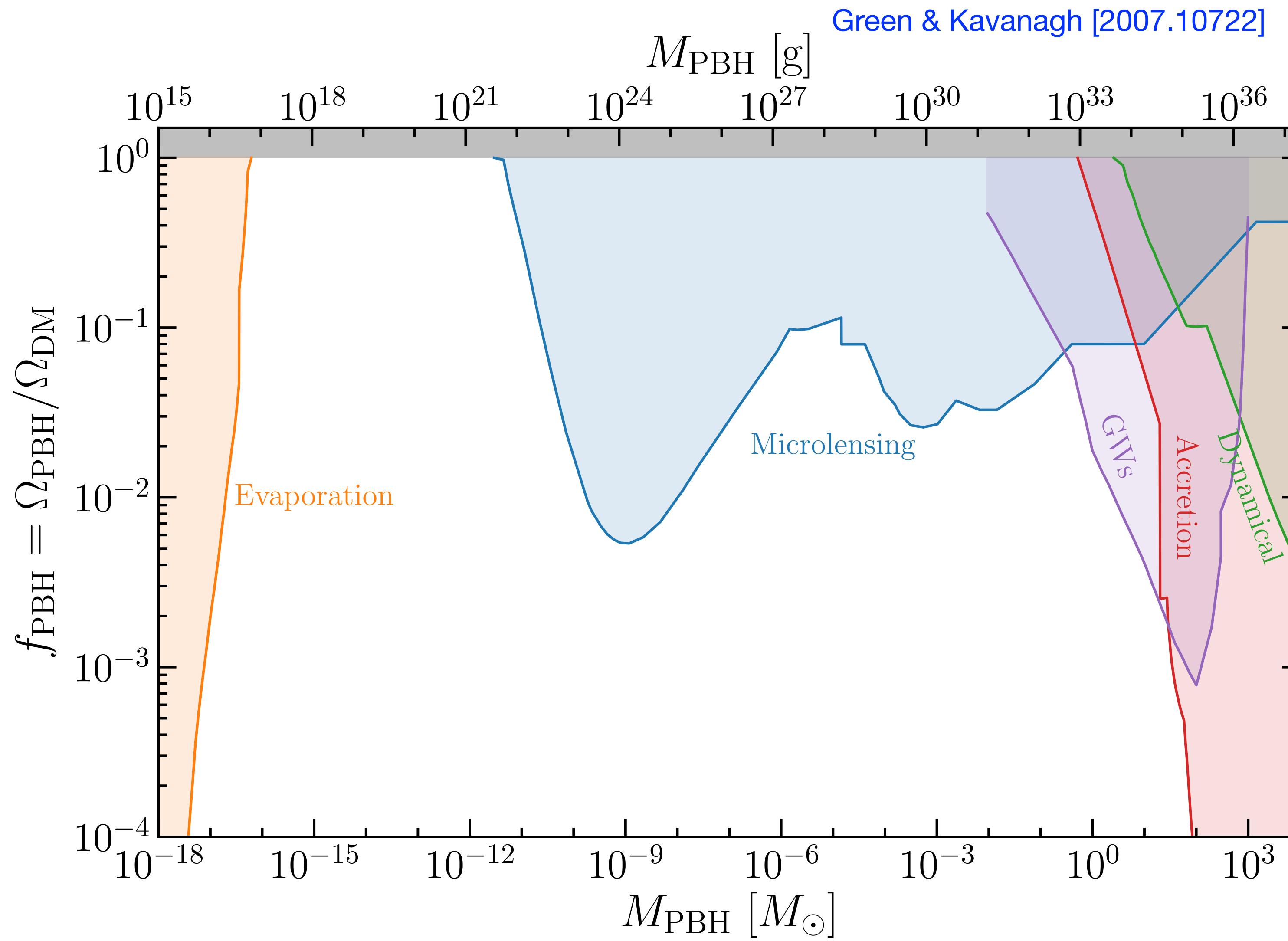
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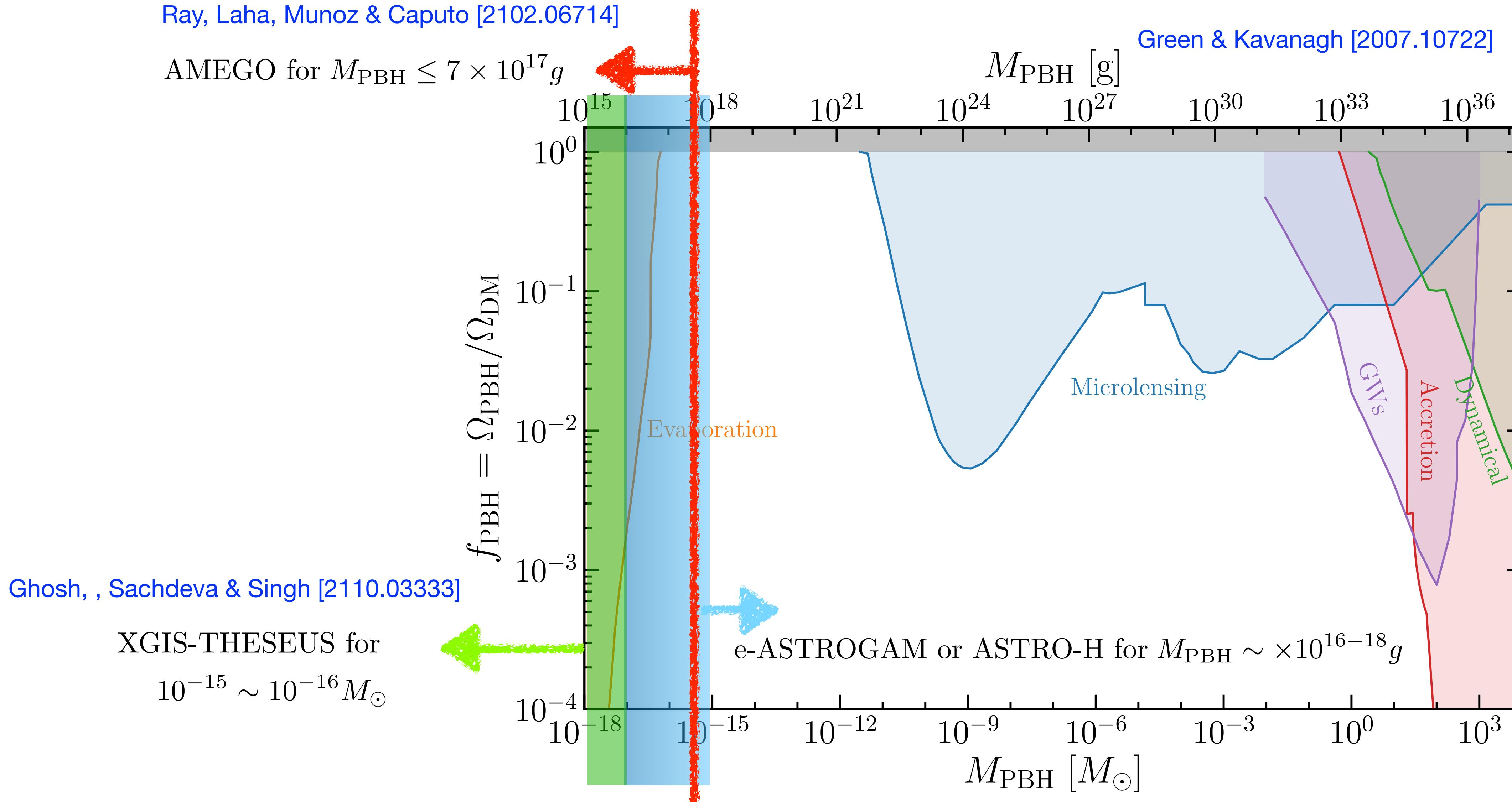




(a) Constraints from evaporation



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(b) Induced gravitational waves

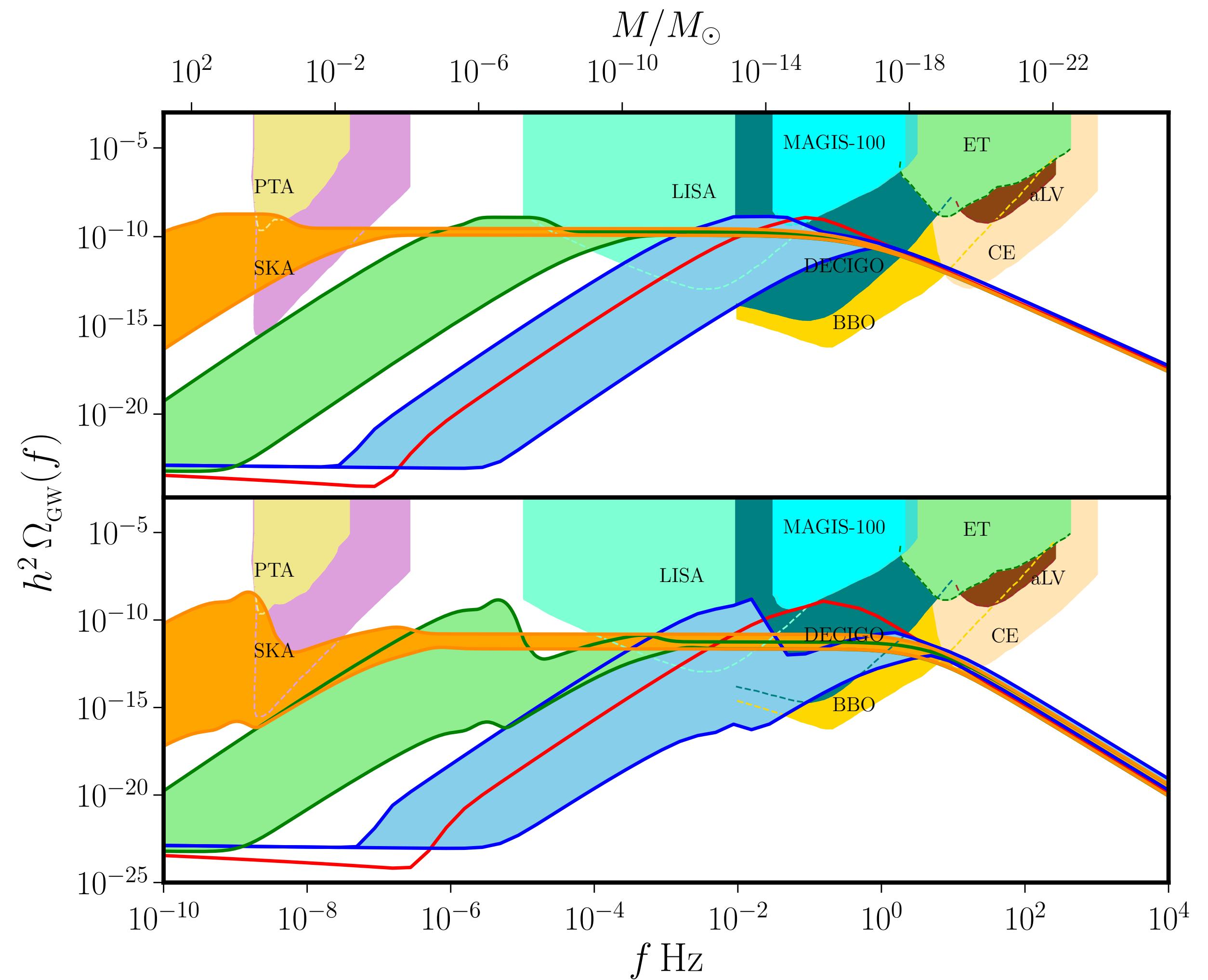
Large scalar perturbations are sources of tensor modes at second order (induced GWs).

$$h_{ij}^{(2)} \sim \partial_i \Phi \partial_j \Phi$$

Ragavendra, Saha, Sriramkumar & Silk [2008.12202]

$$f_{\text{peak}} \sim 10^{-3} - 1 \text{ Hz}$$

(focus on the red line)



Take home messages

- If “PBHs from USR inflation” contribute more than 10% of the DM density, then “Baryogenesis from USR inflation” admits the cosmic coincidence.
- “Baryogenesis from USR inflation” does not rely on the presence of PBHs.
- The ultralight asteroid-mass window for PBH DM could become narrower (closed?) in the future.

Thank you very much!



This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 101002846 (ERC CoG “CosmoChart”).

Supplement

The correlation length problem:

Baryogenesis from flat directions

Dine, Randall & Thomas [9507453]

$$V(\sigma) = -\xi H^2 |\sigma|^2 + \left(\frac{\lambda H \sigma^n}{n M^{n-3}} + h.c \right) + |\lambda|^2 \frac{|\sigma|^{2n-2}}{M^{2n-6}}$$

$$\sigma = R e^{i\theta} / \sqrt{2}$$

$$n_B = R^2 \dot{\theta}$$

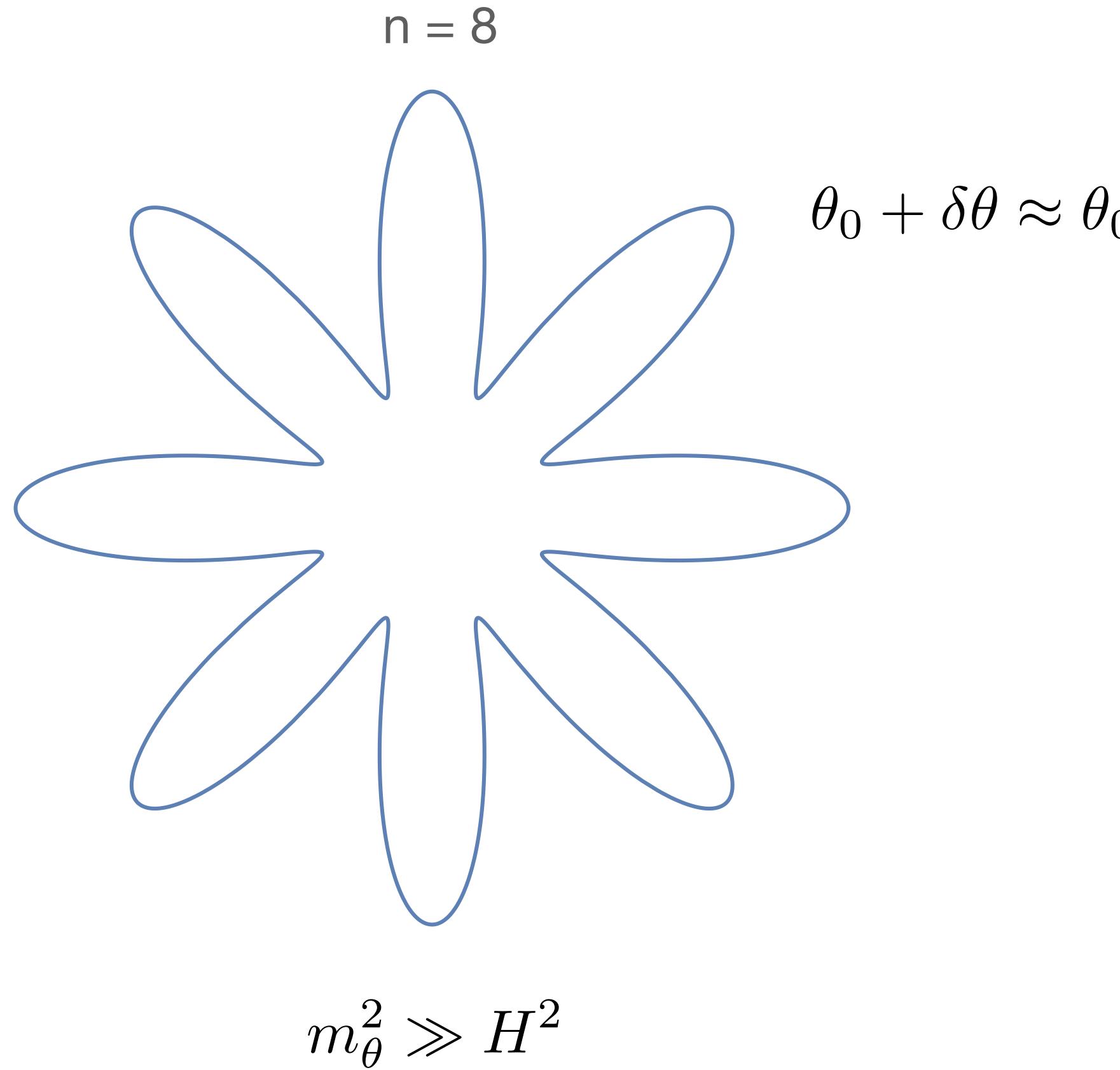
$$\theta \rightarrow (\text{anti})\text{matter}$$

The correlation length problem:

Baryogenesis from flat directions

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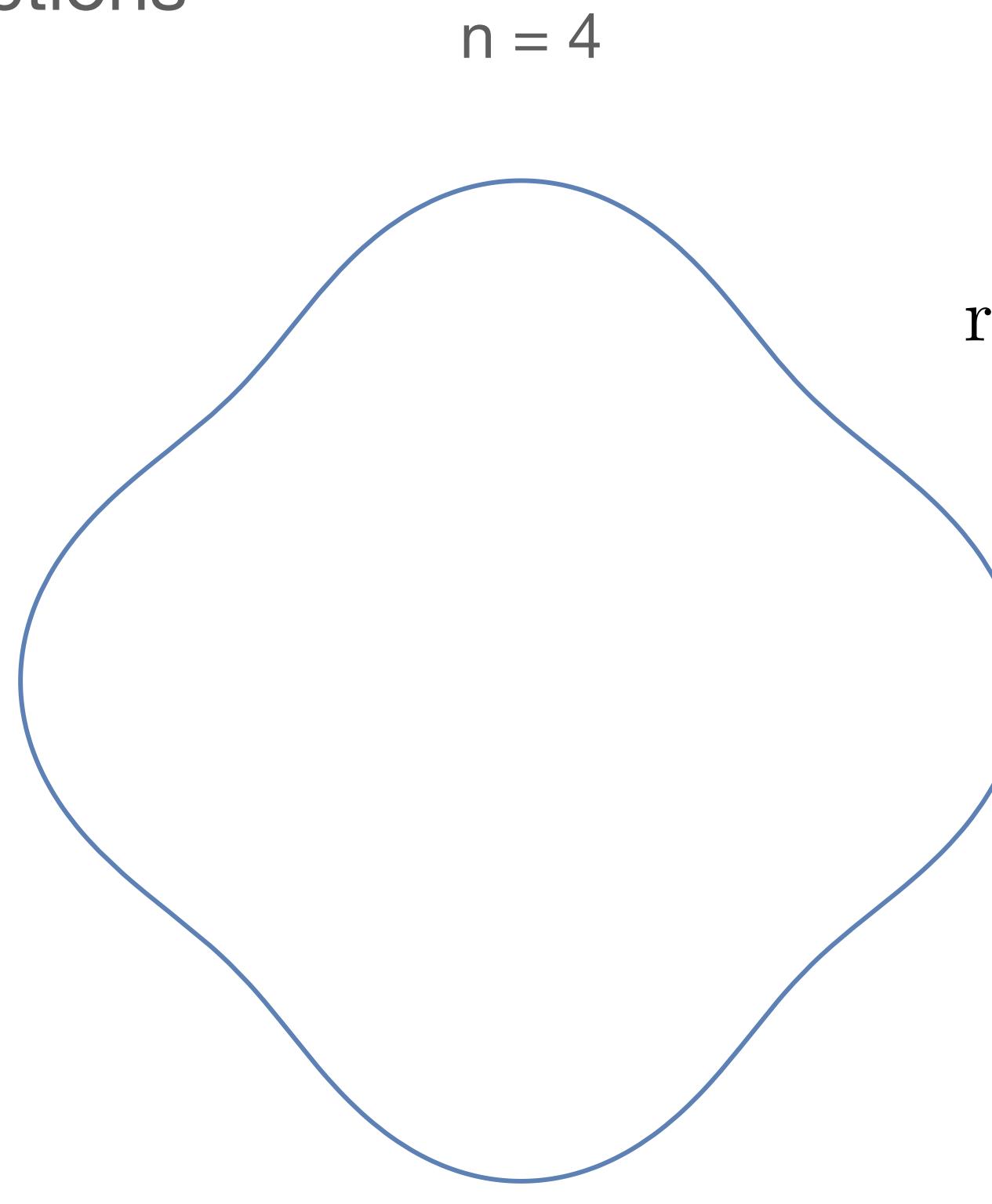
$$V(R, \theta) =$$



The correlation length problem:

Baryogenesis from flat directions

$$V(R, \theta) =$$



$$m_\theta^2 \ll H^2$$

Dine, Randall & Thomas [9507453]

random θ_0

Stochastic initial conditions from small B-violation

YPW & Petraki [2008.08549]