8th Jan. 2023 @ Rencontres du Vietnam

Inflation Theory

— D'où venons-nous? Que sommes-nous? Où allons-nous? —

Yuichiro TADA Nagoya U.

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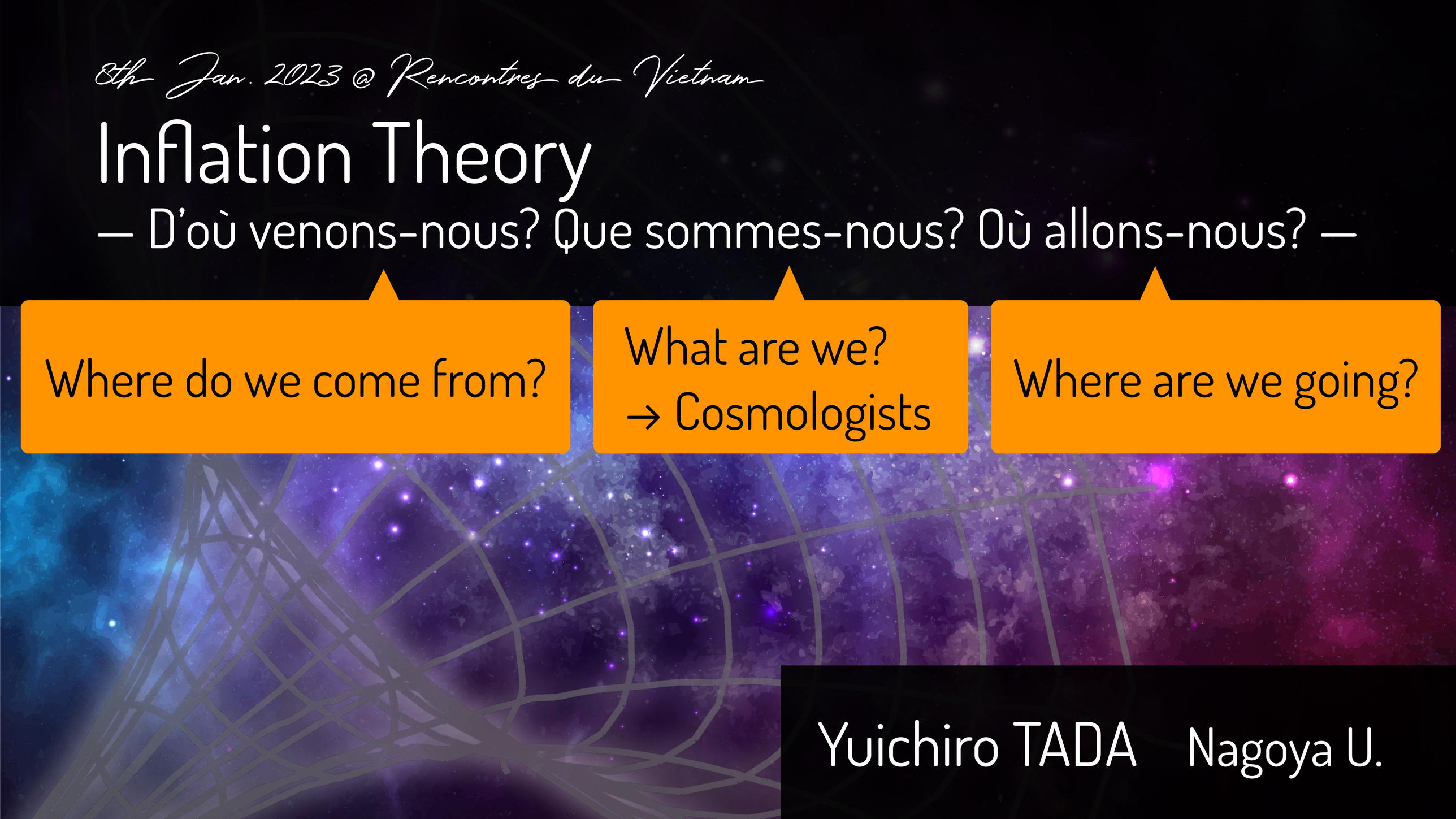
Inflation Theory

— D'où venons-nous? Que sommes-nous? Où allons-nous? —

Where do we come from?

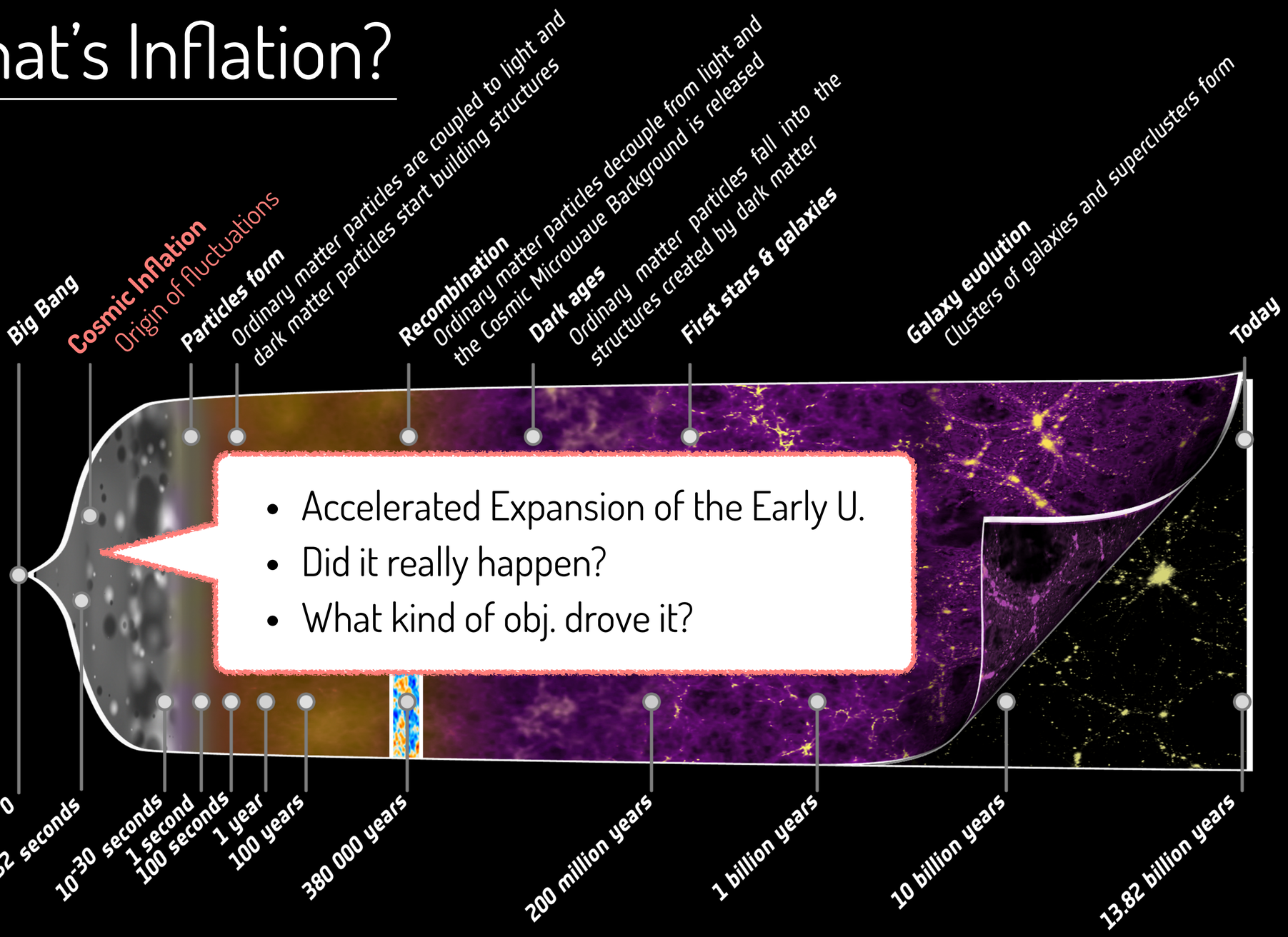
What are we?
→ Cosmologists

Where are we going?



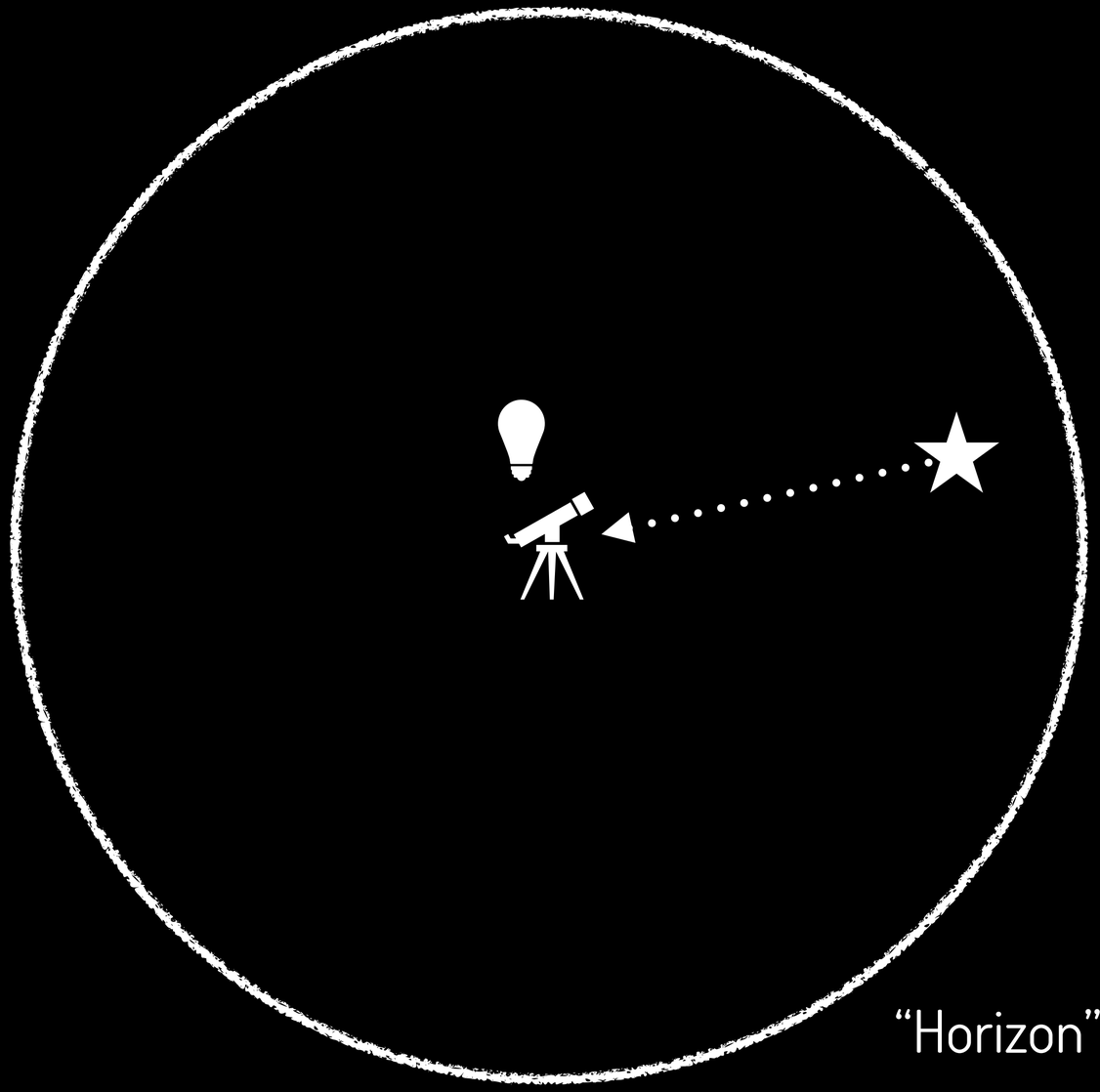
Yuichiro TADA Nagoya U.

What's Inflation?



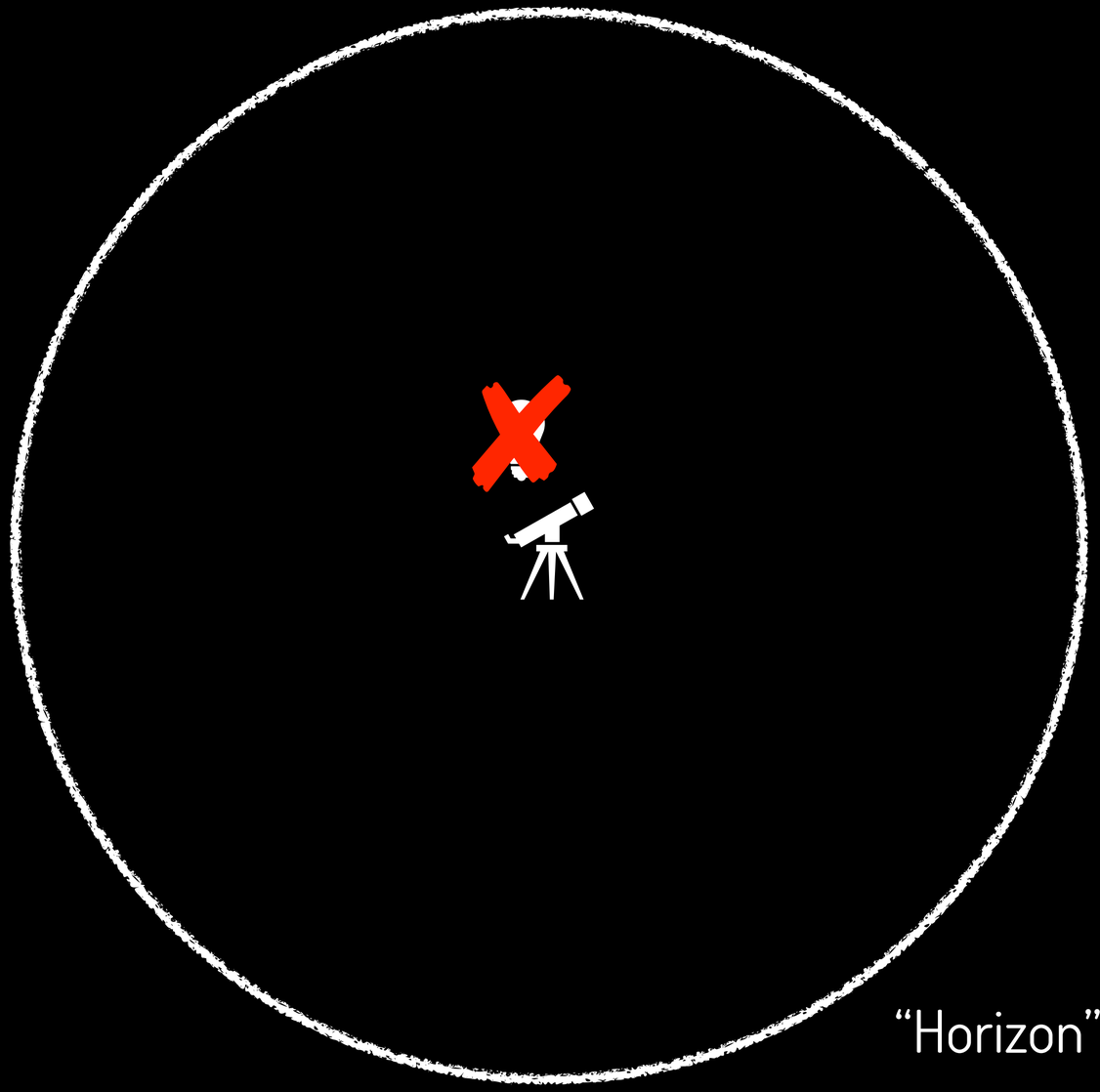
- Accelerated Expansion of the Early U.
- Did it really happen?
- What kind of obj. drove it?

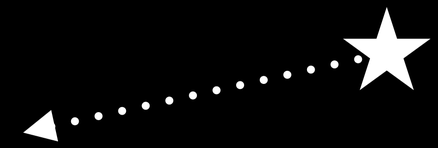
Generation of PTB



"Horizon" of the expanding U.

Generation of PTB





“Horizon” of the expanding U.

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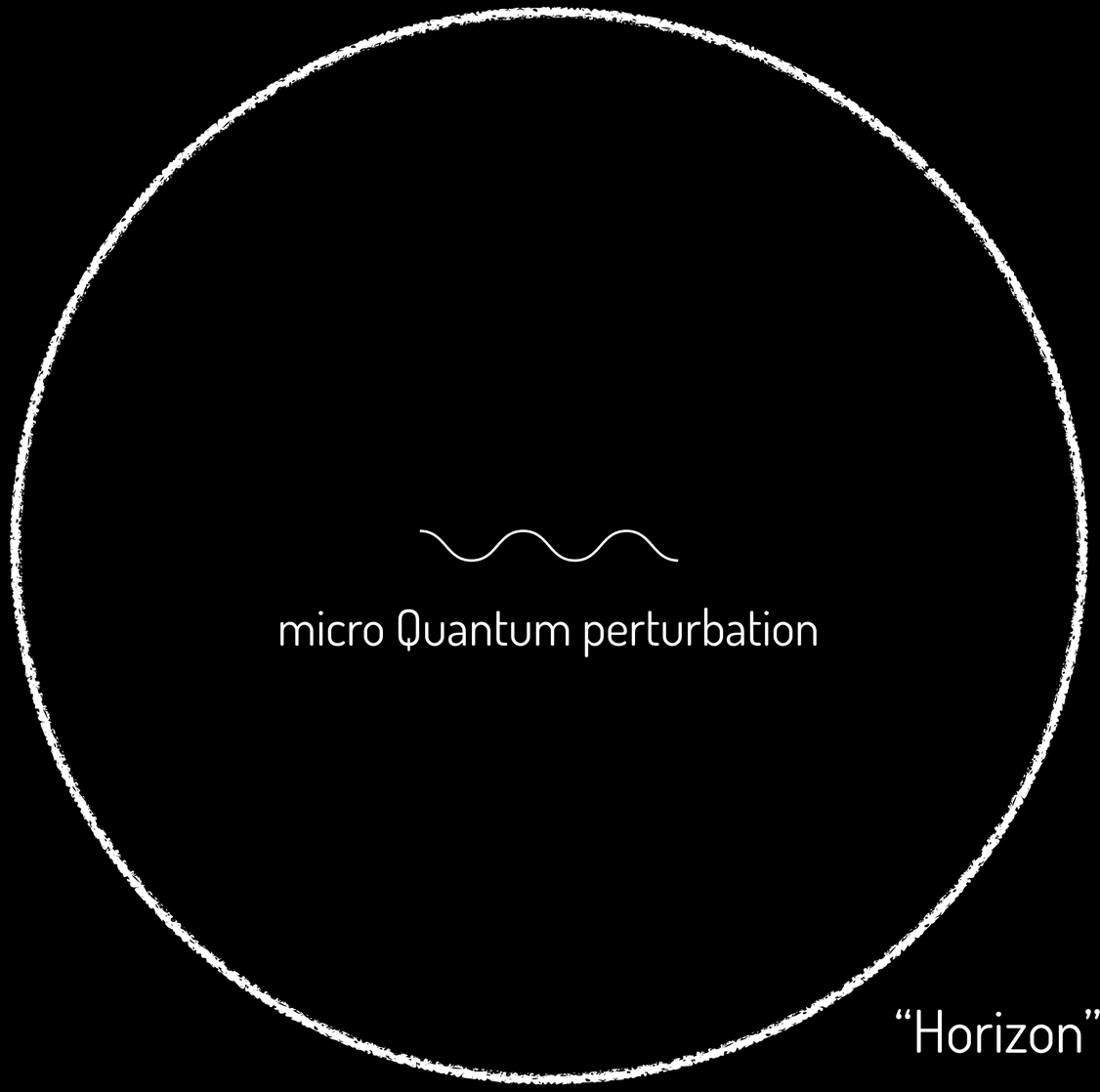

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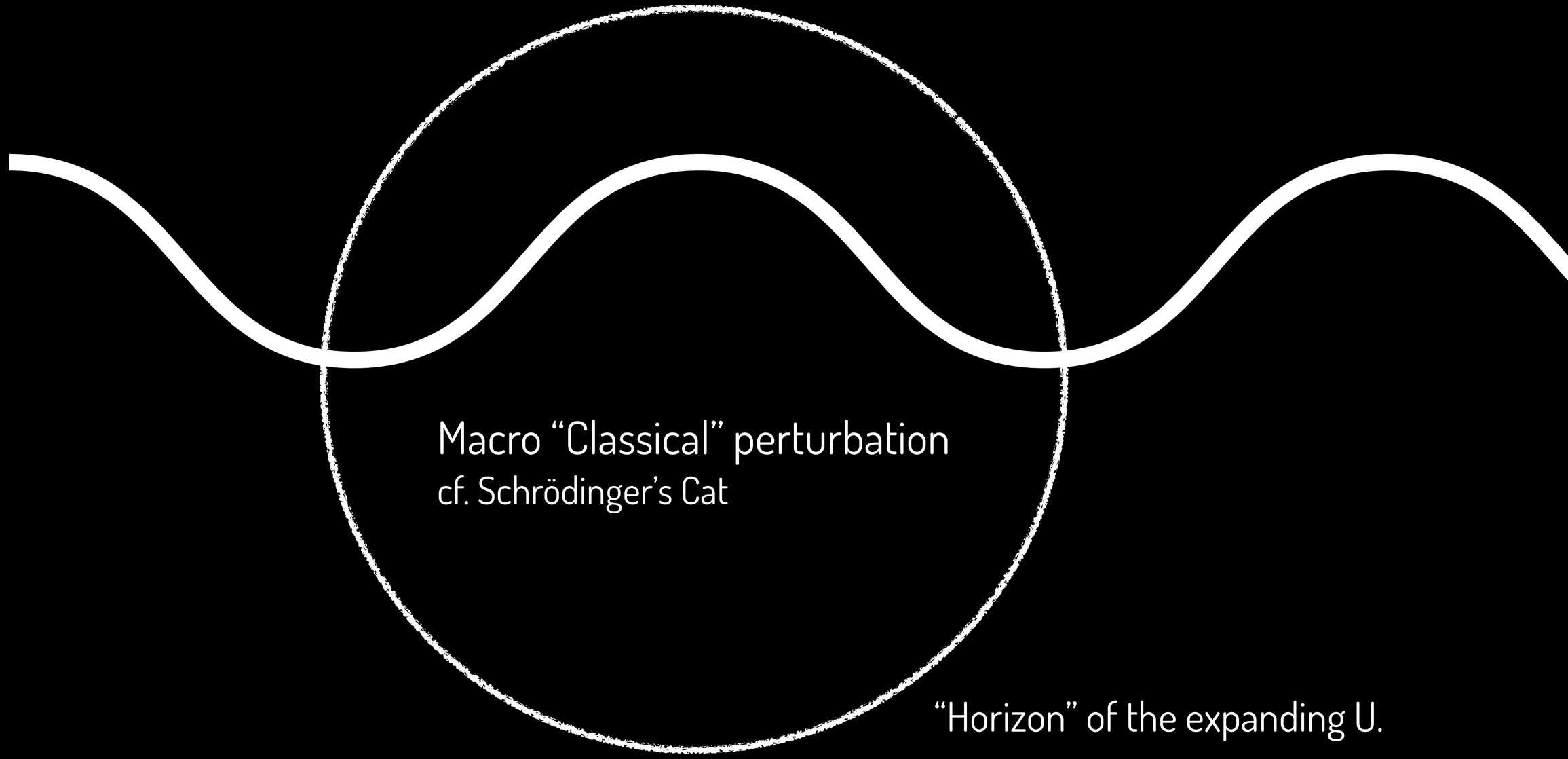
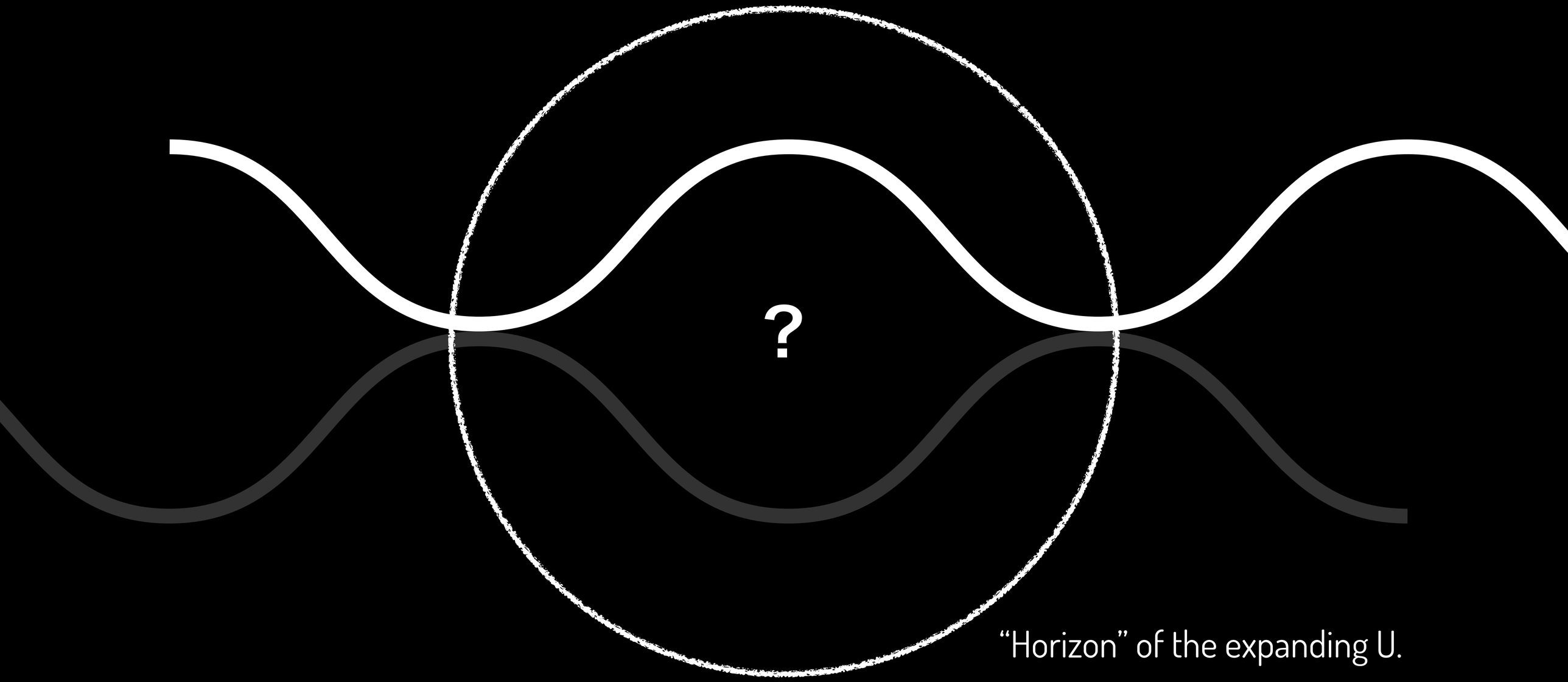
Generation of PTB

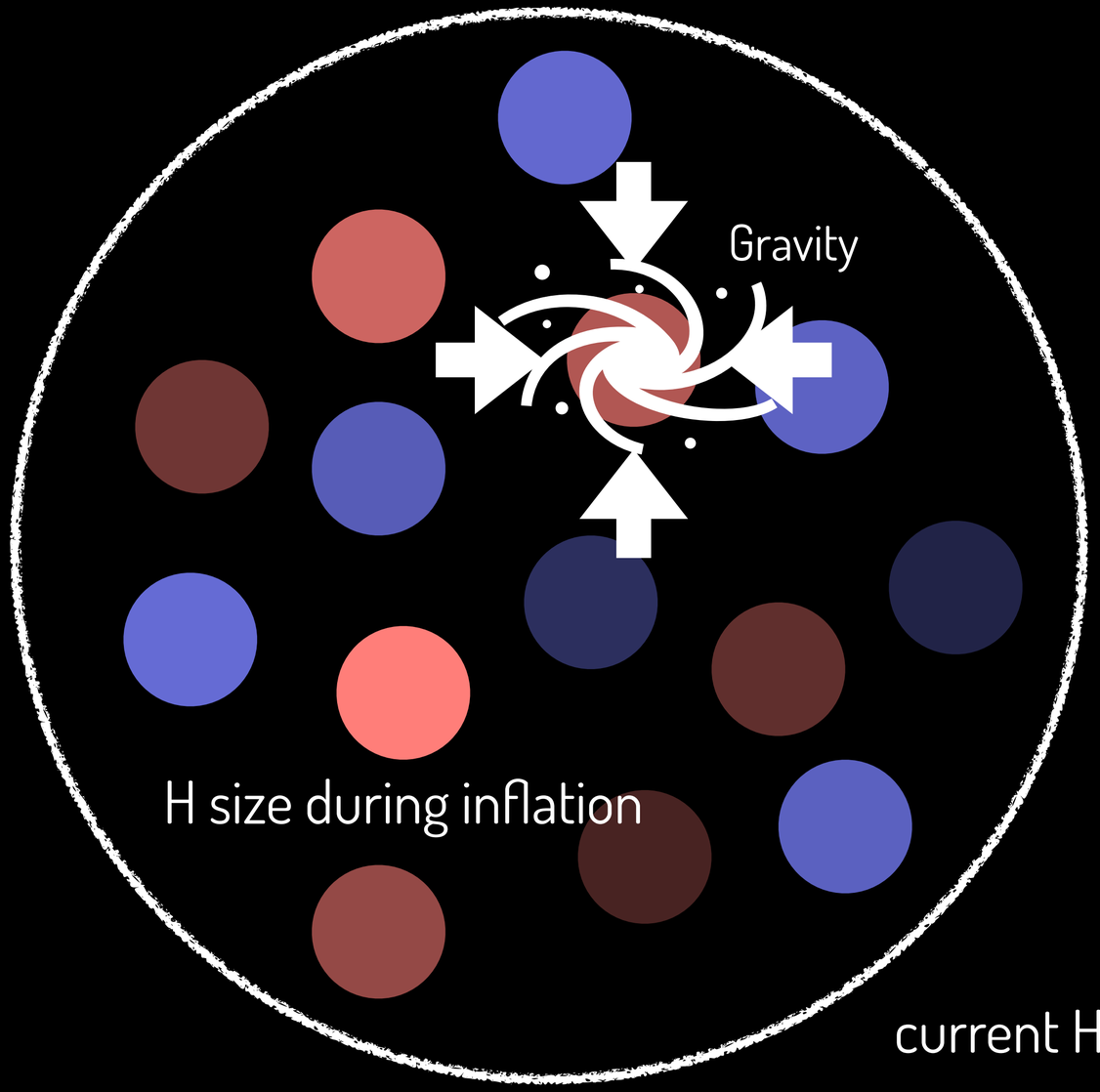


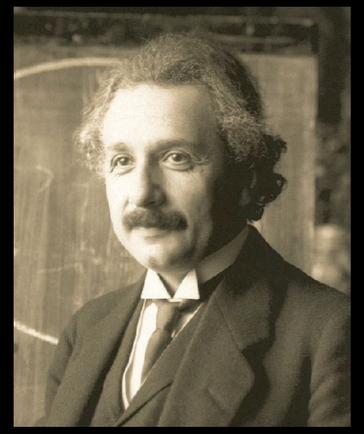
Generation of PTB



“Horizon” of the expanding U.

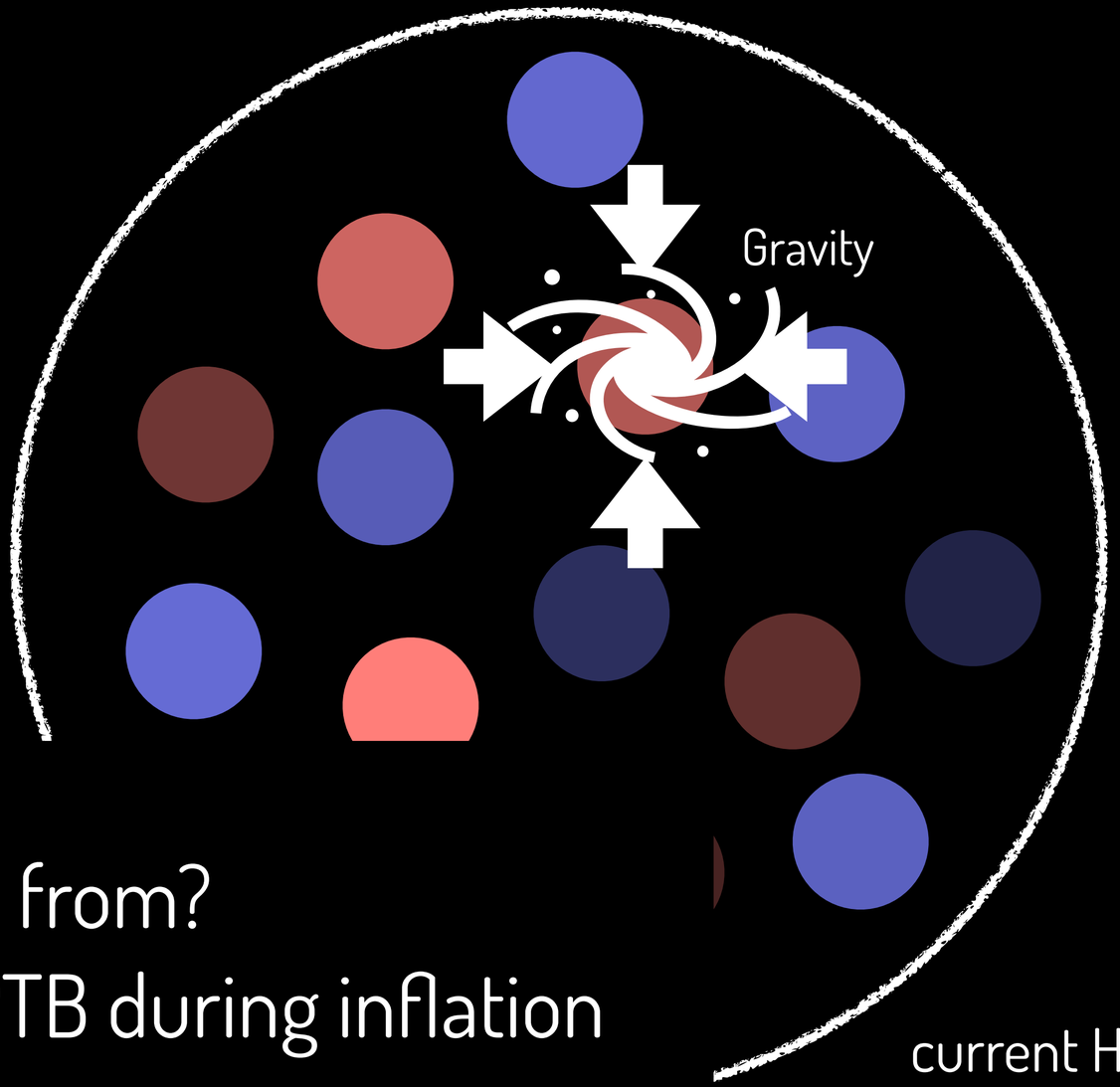
Generation of PTB

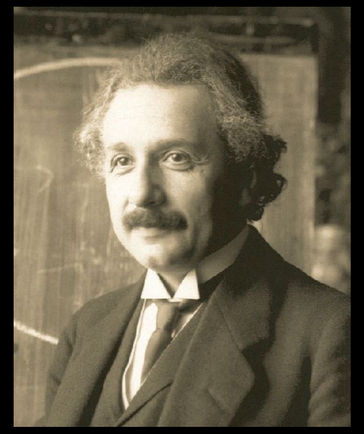




Energy = Mass

Generation of PTB





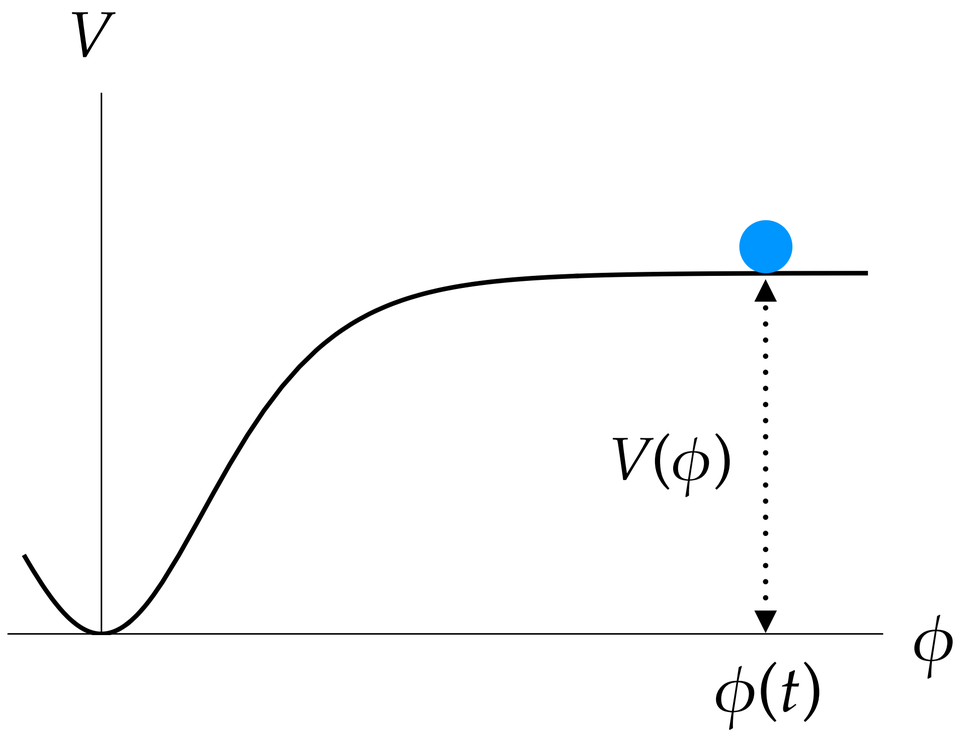
Energy = Mass

Where do we come from?

→ from Quantum PTB during inflation

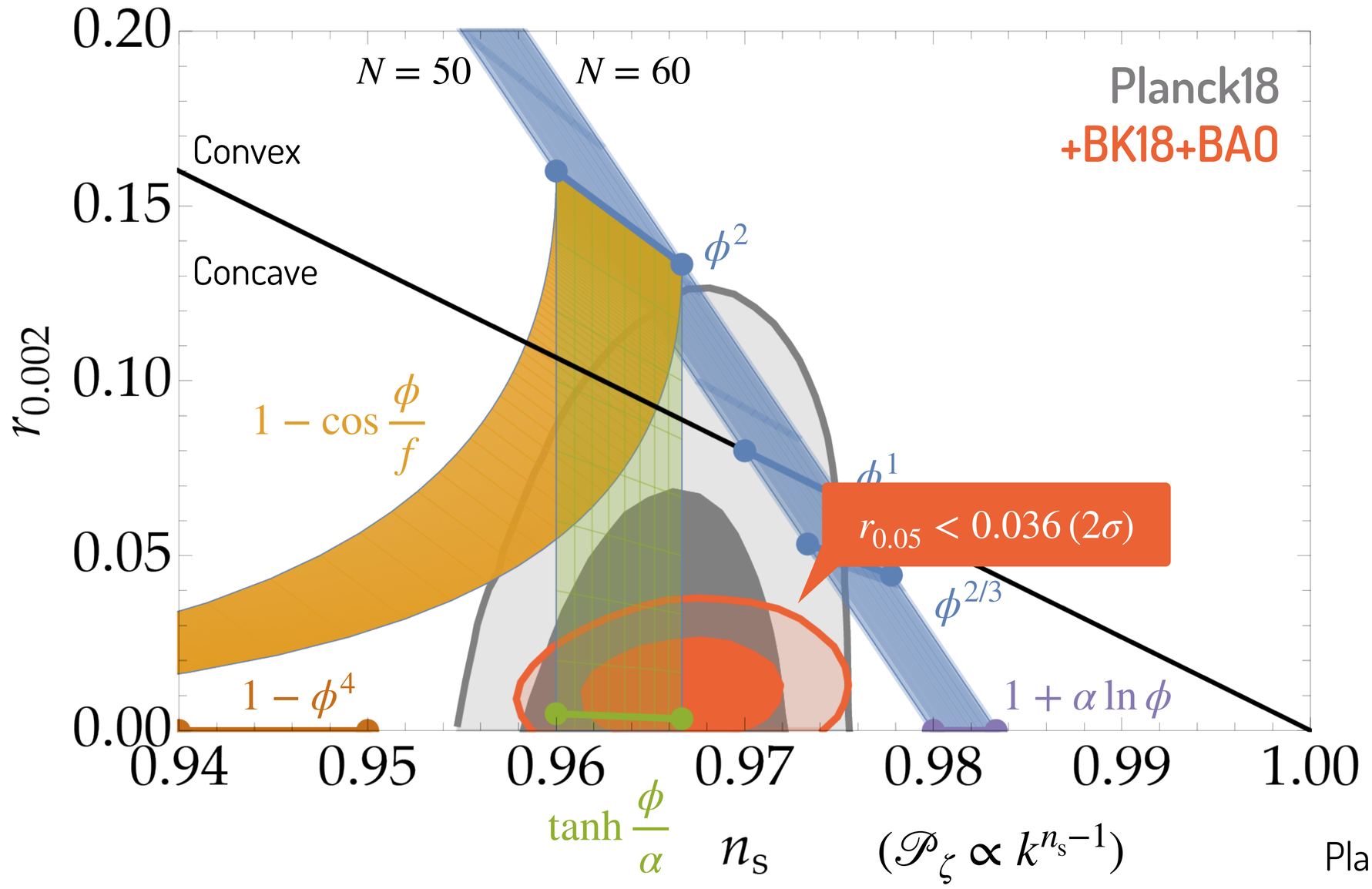
Inflation Theories

Just to realise an Accelerated Expansion (= Dark Energy = almost const. energy), you only need homogeneous VEV of some scalar $\phi(t)$ with the potential $V(\phi)$.



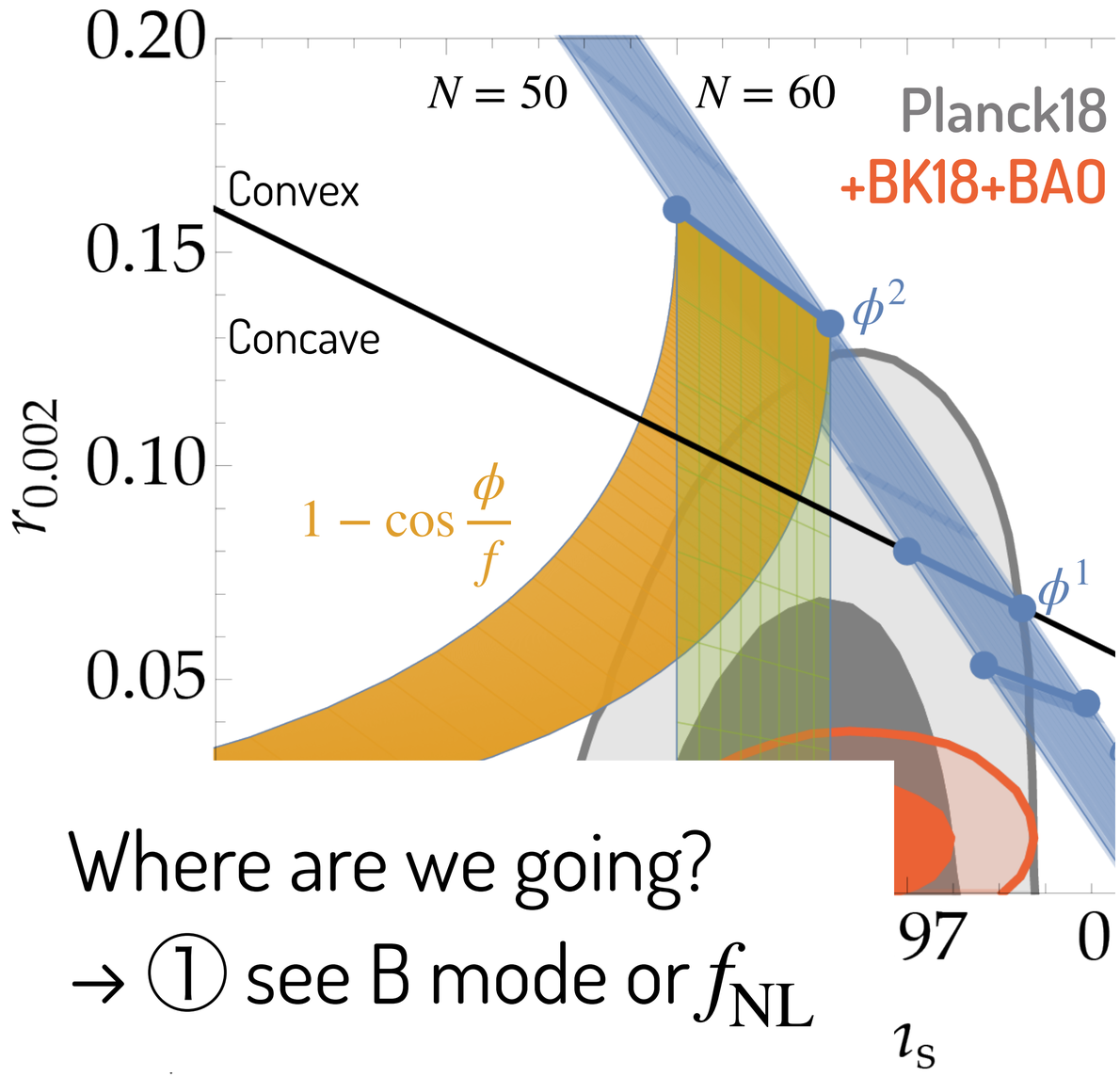
"Inflation of the # of inflation theories"
by T. Matsubara

Latest CMB const.



Planck '18, BK '21

Latest CMB const.



Where are we going?

→ ① see B mode or $f_{\rm NL}$

✗

- Large-field $r \sim \mathcal{O}(0.1)$
  - chaotic
  - natural

✓

- Plateau-type $r \sim \mathcal{O}(10^{-3})$
  - Starobinsky (cf. LiteBIRD...)

$$\mathscr{L} = \frac{1}{16\pi G}R + \alpha R^2$$

  - Higgs

$$\mathscr{L} = \left(\frac{1}{16\pi G} + \xi\mathscr{H}^2\right)R + \mathscr{L}_{\rm SM}$$

▲

- Small-field $r \ll 1$
  - hilltop

    c.f. $1 - \phi^4 - \phi - \cdots$

(✓ - curvaton

check nonGauss $f_{\rm NL} \sim \mathcal{O}(1)$

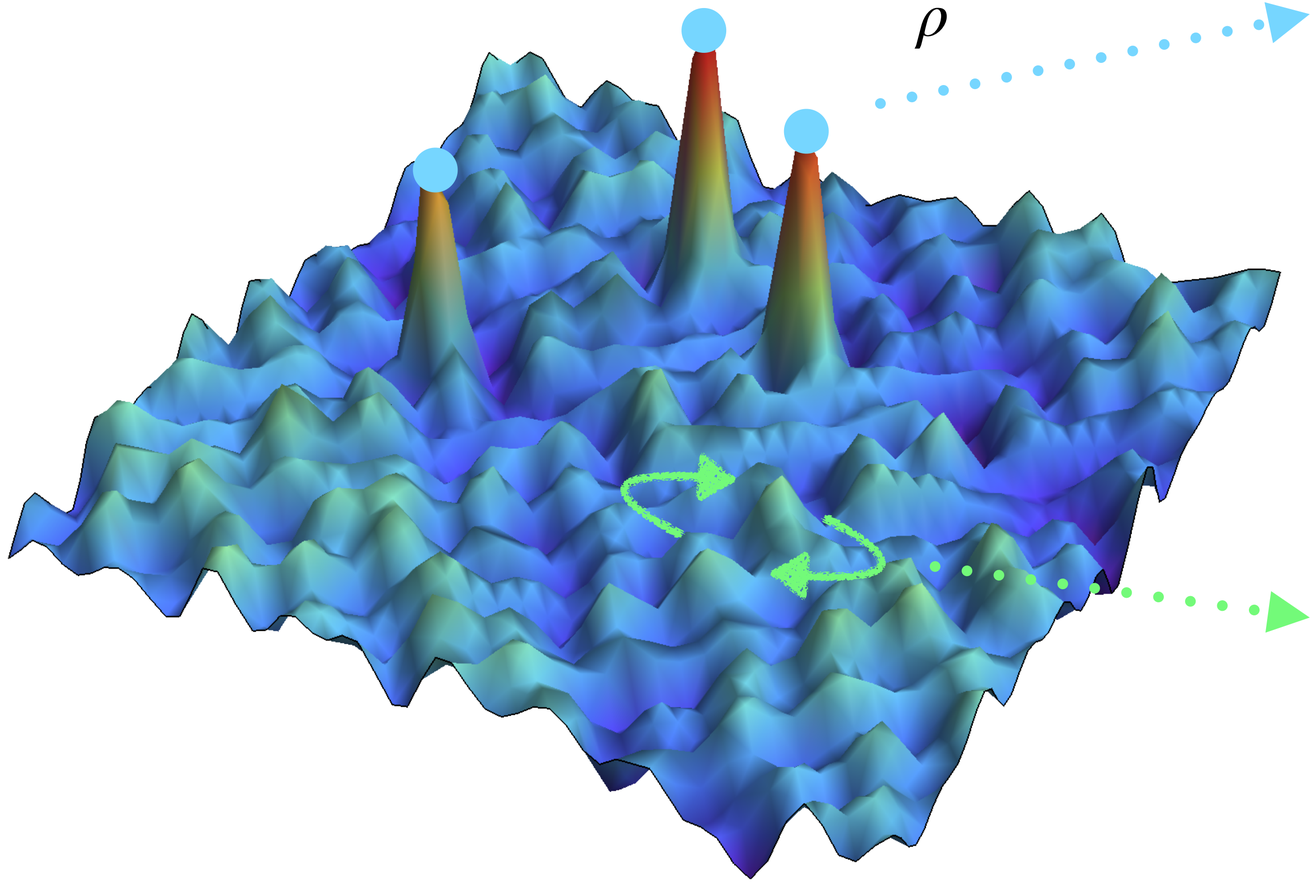
Other Info?

- CMB $\gtrsim 1\,\mathrm{Mpc}$

  → How about smaller scales?

If perturbations get enhanced on small scales...

Large P on small scale



$$\frac{\delta\rho}{\rho} \sim 1$$

❖ Primordial Black Holes

- Large PTB directly form BHs in RD era before star formation
- Candidate of Dark Matter

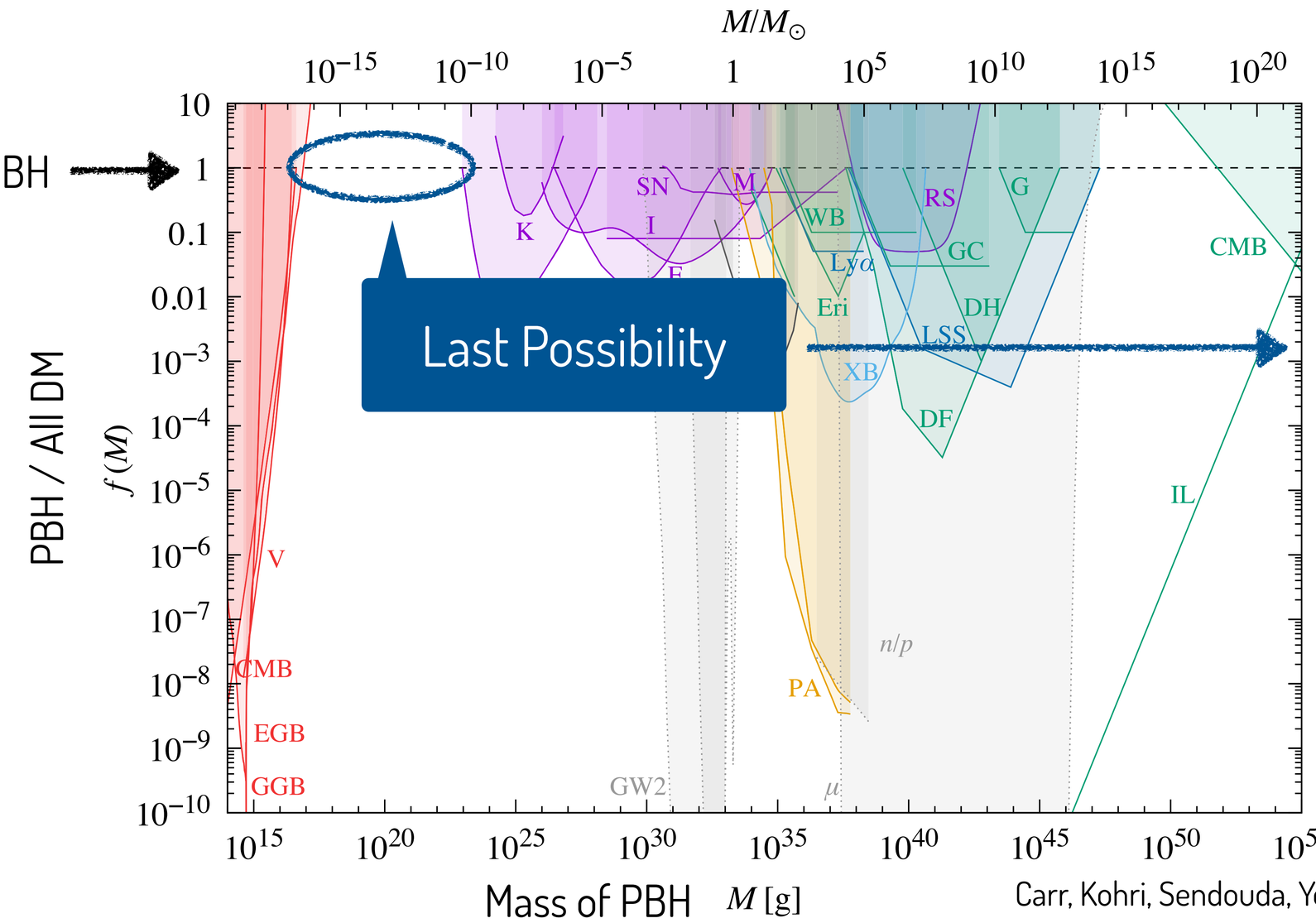
⬆ Indirect Evidence

❖ Induced Gravitational Waves

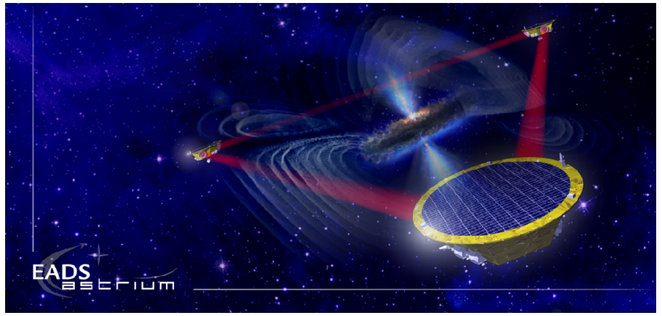
Stochastic GW b.g. from insufficient PTB for PBH

Obs. Const. on PBH

All DM = PBH



Carr, Kohri, Sendouda, Yokoyama '20



Freq. of corresponding GWs are at the sweet spot of LISA (2037—)!

prove PBH to be / not to be all DM?

How to enhance PTB?

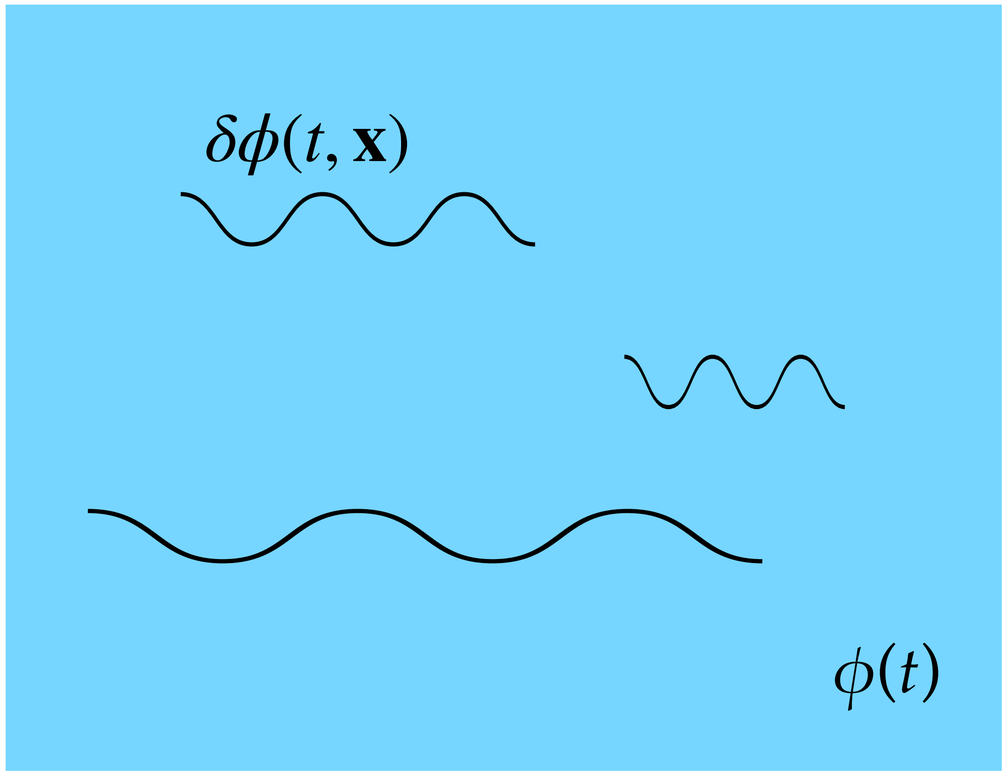
curv. PTB & δN formalism

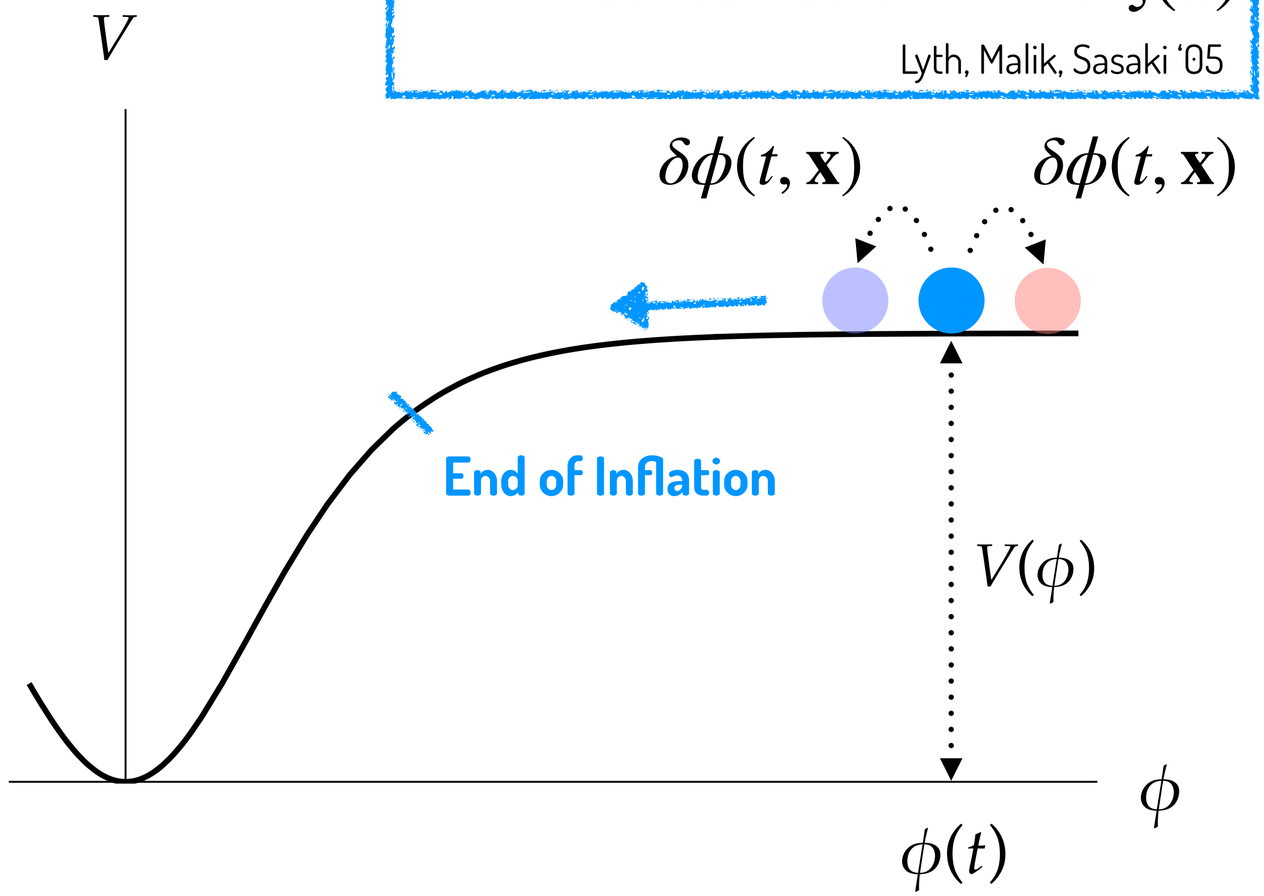
PTB in duration of inflation

$$\delta N = H\delta t \simeq -H\frac{\delta\phi(t,\mathbf{x})}{\dot{\phi}(t)}$$

$=$ conserved curv. PTB $\zeta(\mathbf{x})$

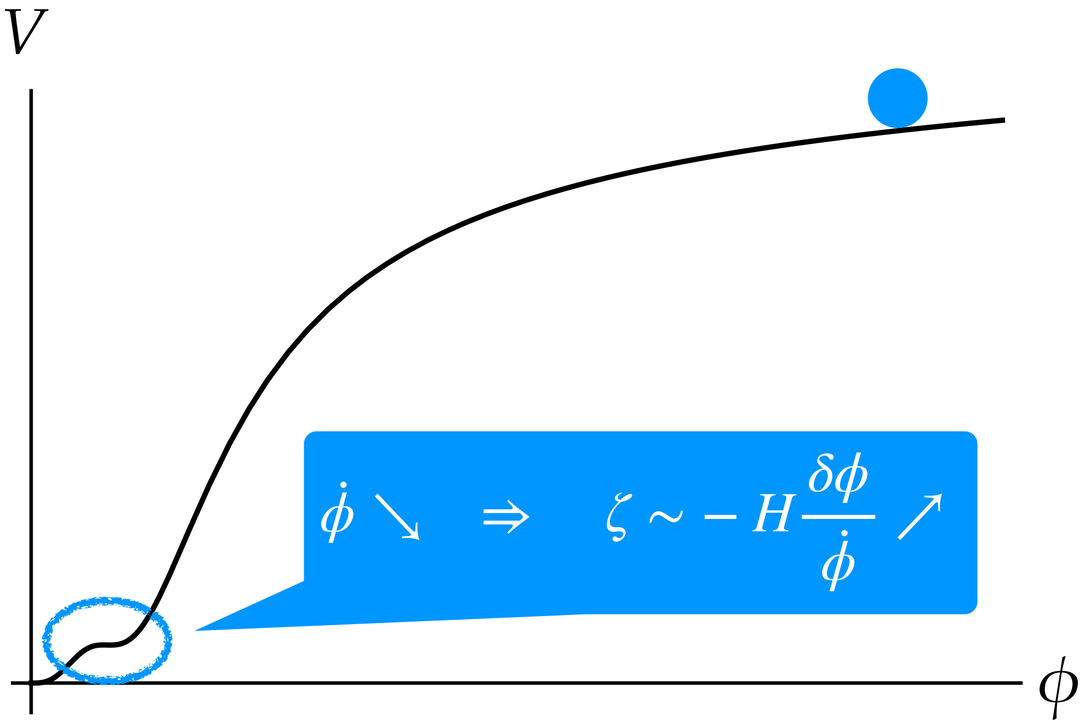
Lyth, Malik, Sasaki '05





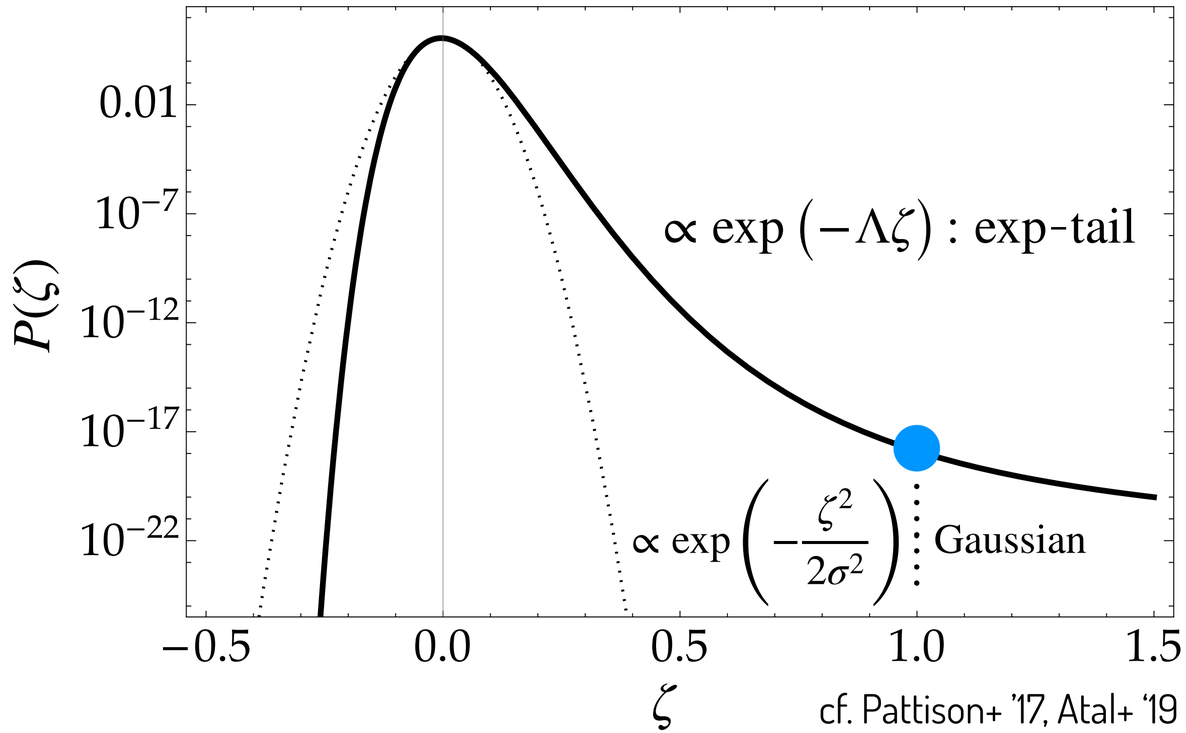
How to enhance PTB?

inflection model & exp-tail



cf. Ezquiaga, Garcia-Bellido, Morales '17

$\dot{\phi}$ is reducing → $\delta\phi$'s effect is asymmetric!



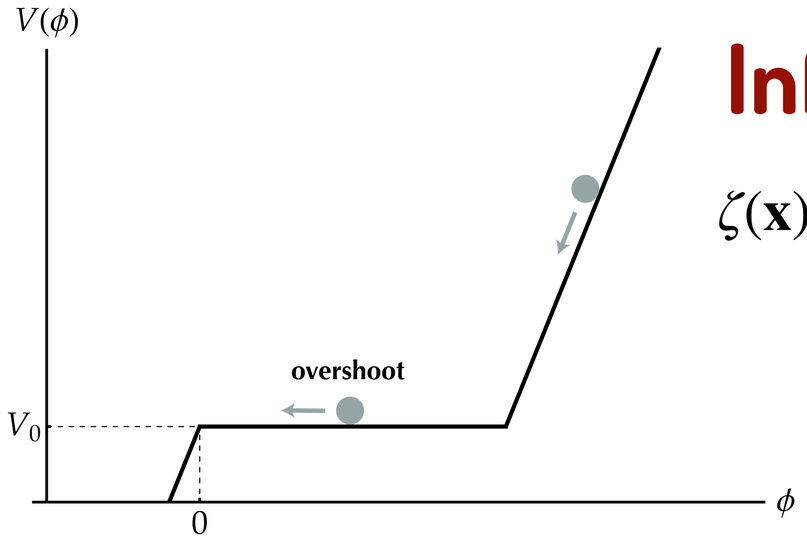
cf. Pattison+ '17, Atal+ '19

$\delta\phi \to \zeta = \delta N$: non-linear relation

Triangle Study

"Peak Theory"
Statistical Estimation
Yoo+ '18, '19, '20
Kitajima, YT, Yokoyama, Yoo '21

PTB amp. A_g

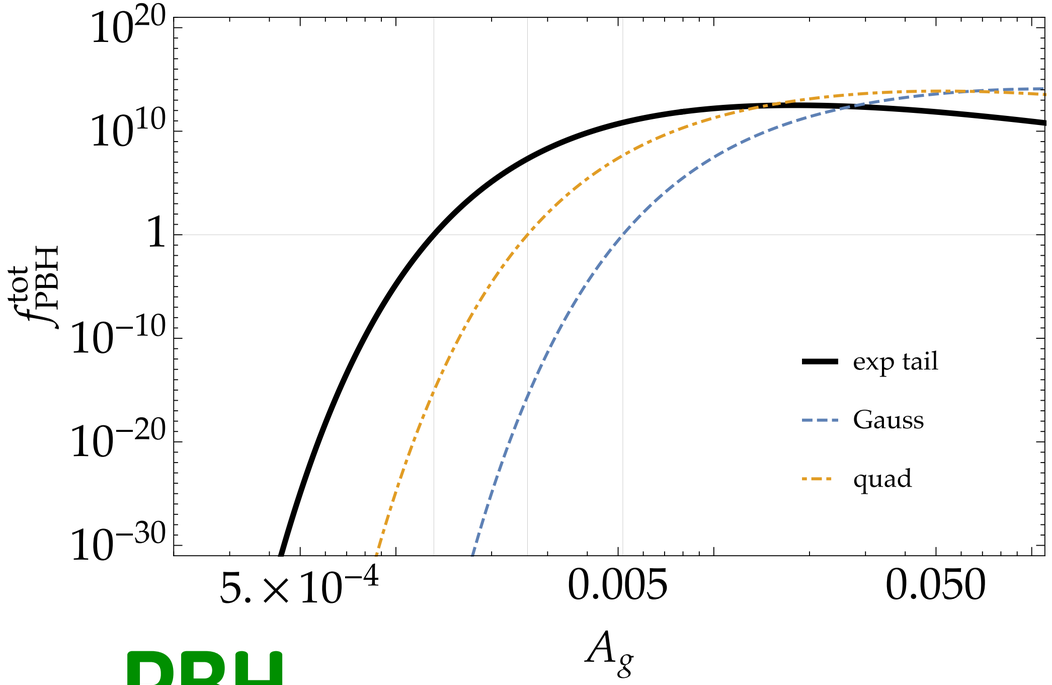


Inflation

$$\zeta(\mathbf{x}) = -\frac{1}{3}\ln(1 - 3\zeta_{\rm G}(\mathbf{x}))$$

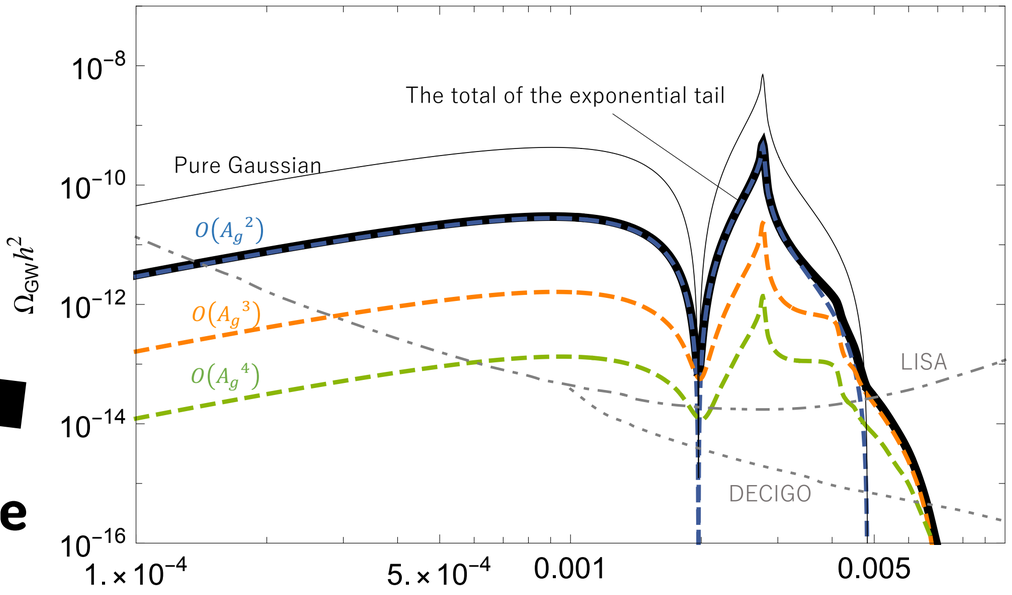
Cai+ '18

perturbative GR



PBH

Evidence



Abe, Inui, YT, Yokoyama '22

GW

Triangle Study

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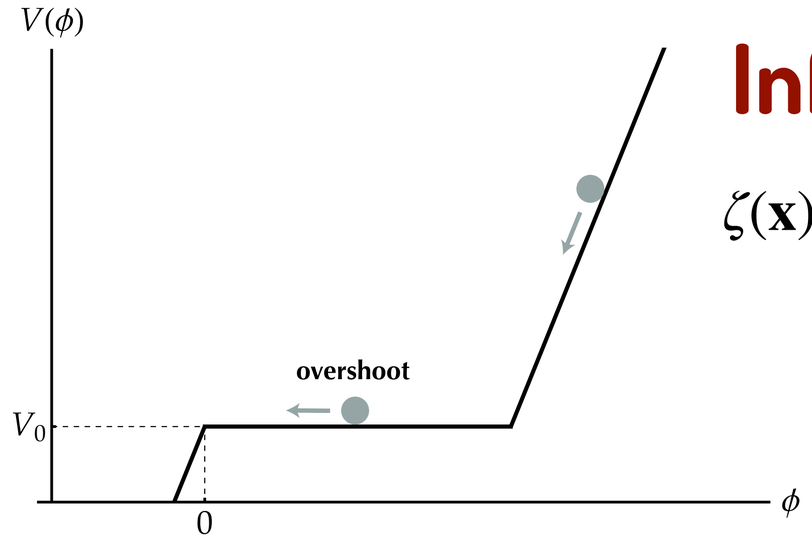

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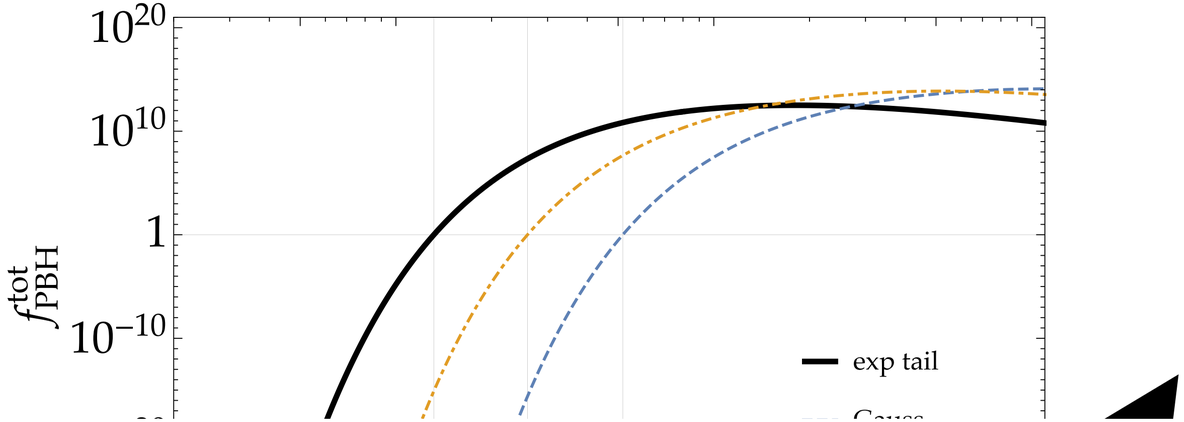

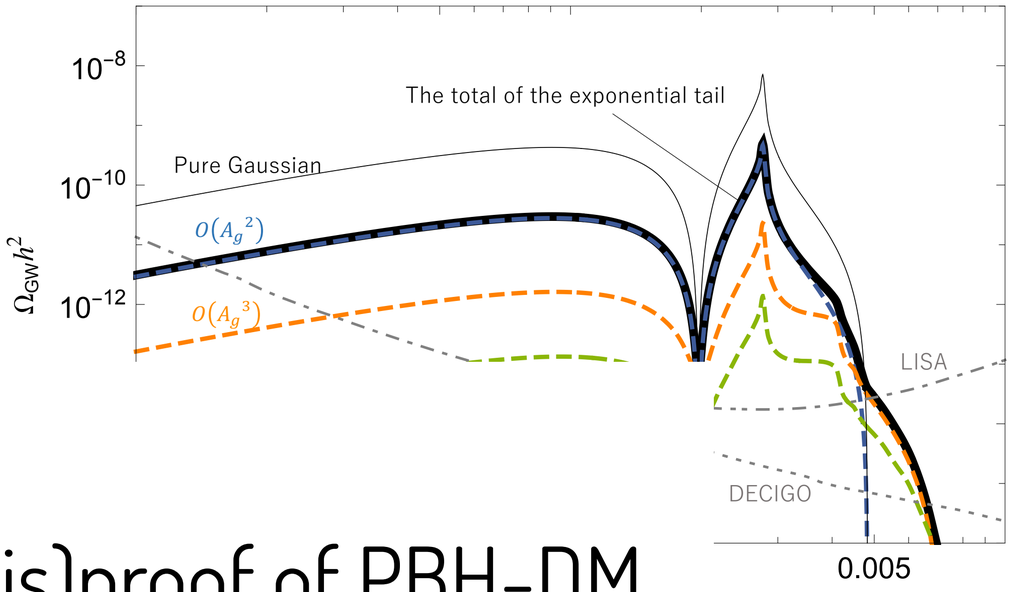

Where are we going?
→ ② triangle study for a rigorous (dis)proof of PBH-DM

Conclusions

Where do we come from?

From quantum perturbations during inflation.

Where are we going?

① see B mode or $f_{\rm NL}$ (after that ... ?)

② triangle analysis (Inflation ↔ PBH ↔ GW) toward PBH-DM

(see our review 2211.05767 Escrivà, Kuhnel, YT as invited book chapter in
"Listening to the dark Universe: black holes in the era of gravitational-wave astronomy")