Inflationary Ramifications of a Meta-Stable Higgs Vacuum

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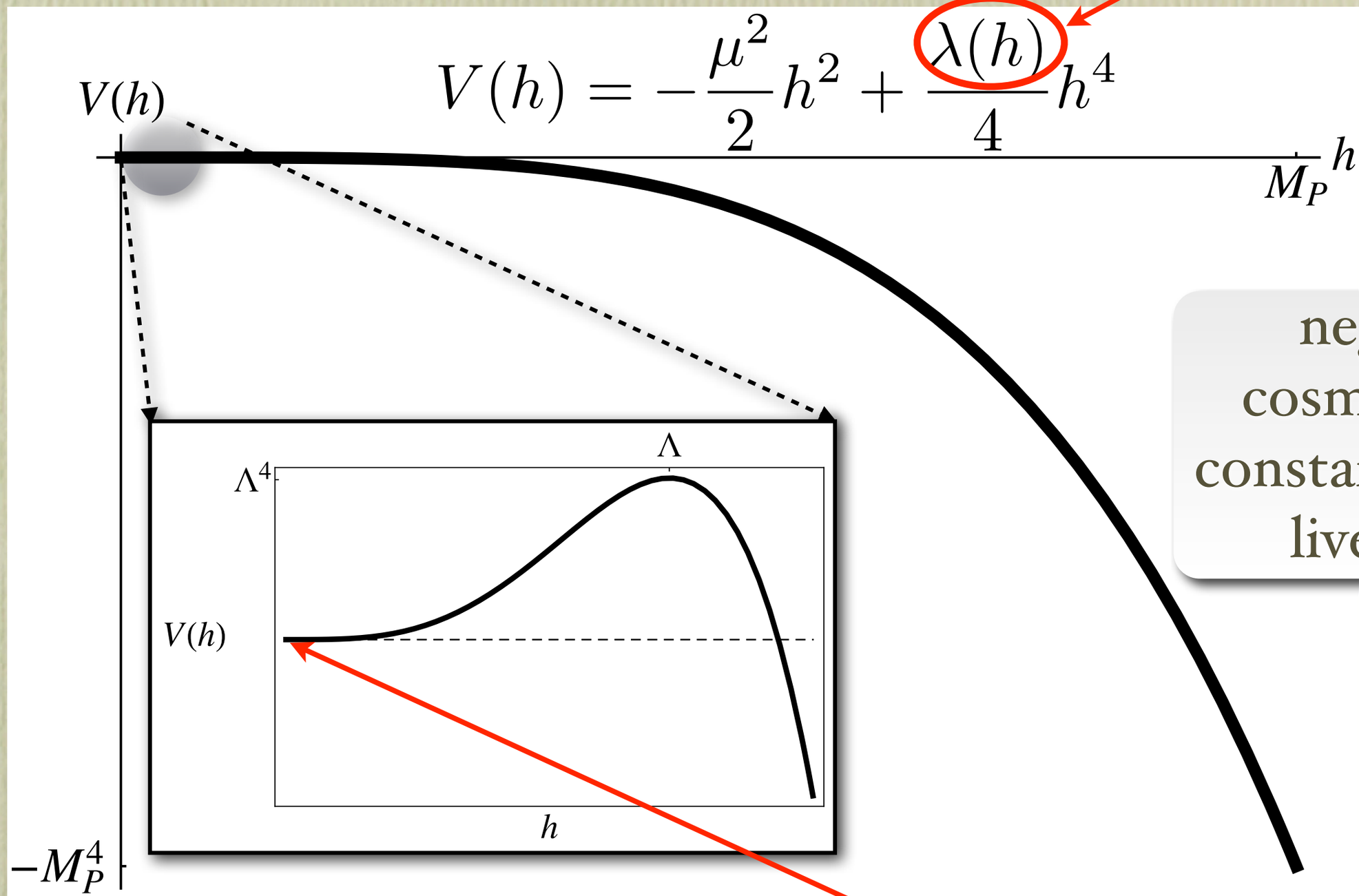
DESY Hamburg

the Higgs scalar potential ... if the coupling runs negative!

$$V(h) = -\frac{\mu^2}{2}h^2 + \frac{\lambda(h)}{4}h^4$$



negative cosmological constant: cannot live here!

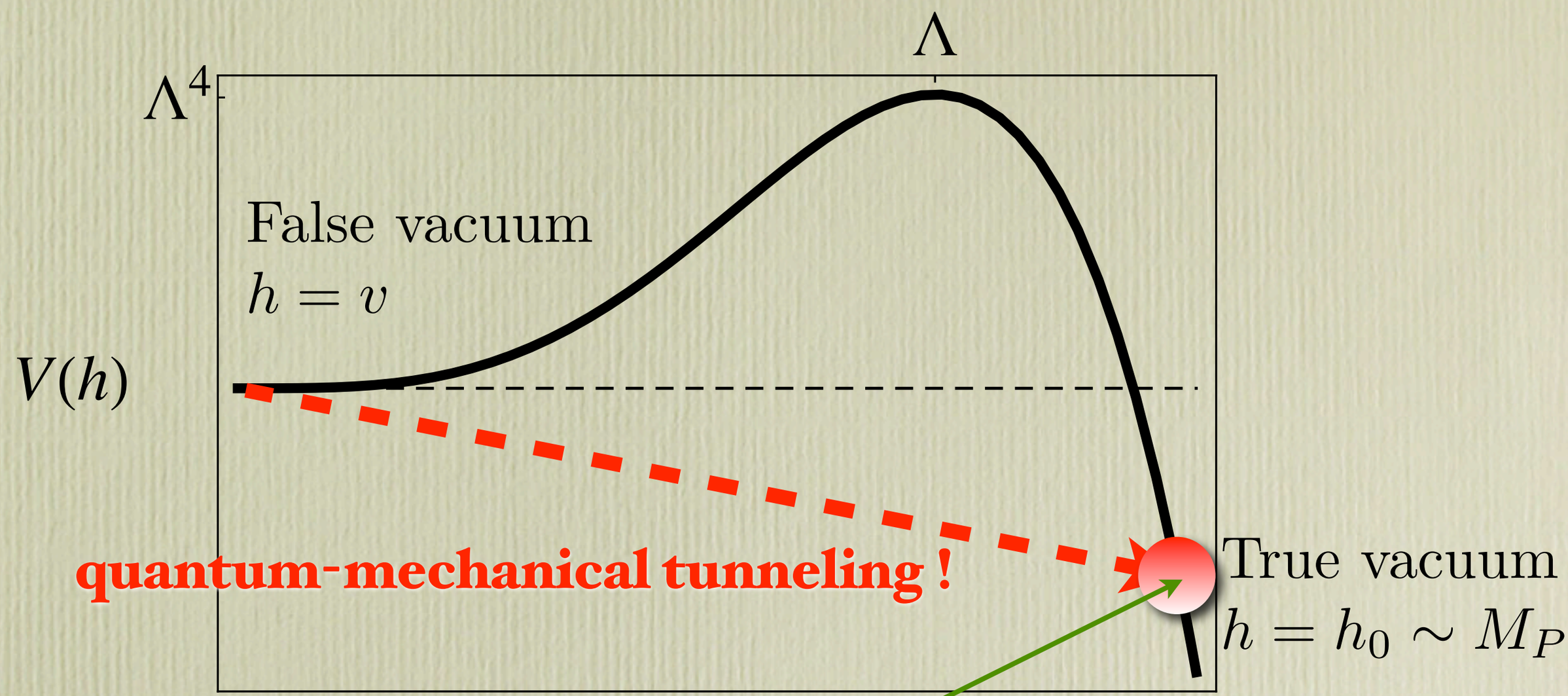
$$\Lambda \sim 10^{10}\,\mathrm{GeV} \sim 10^{-8} M_P$$

$$\Lambda^4 \sim (10^{10}\,\mathrm{GeV})^4 \sim 10^{-32} M_P^4$$

SM Higgs vacuum

$$v \sim 10^2\,\mathrm{GeV} \sim 10^{-16} M_P$$

vacuum instability ...



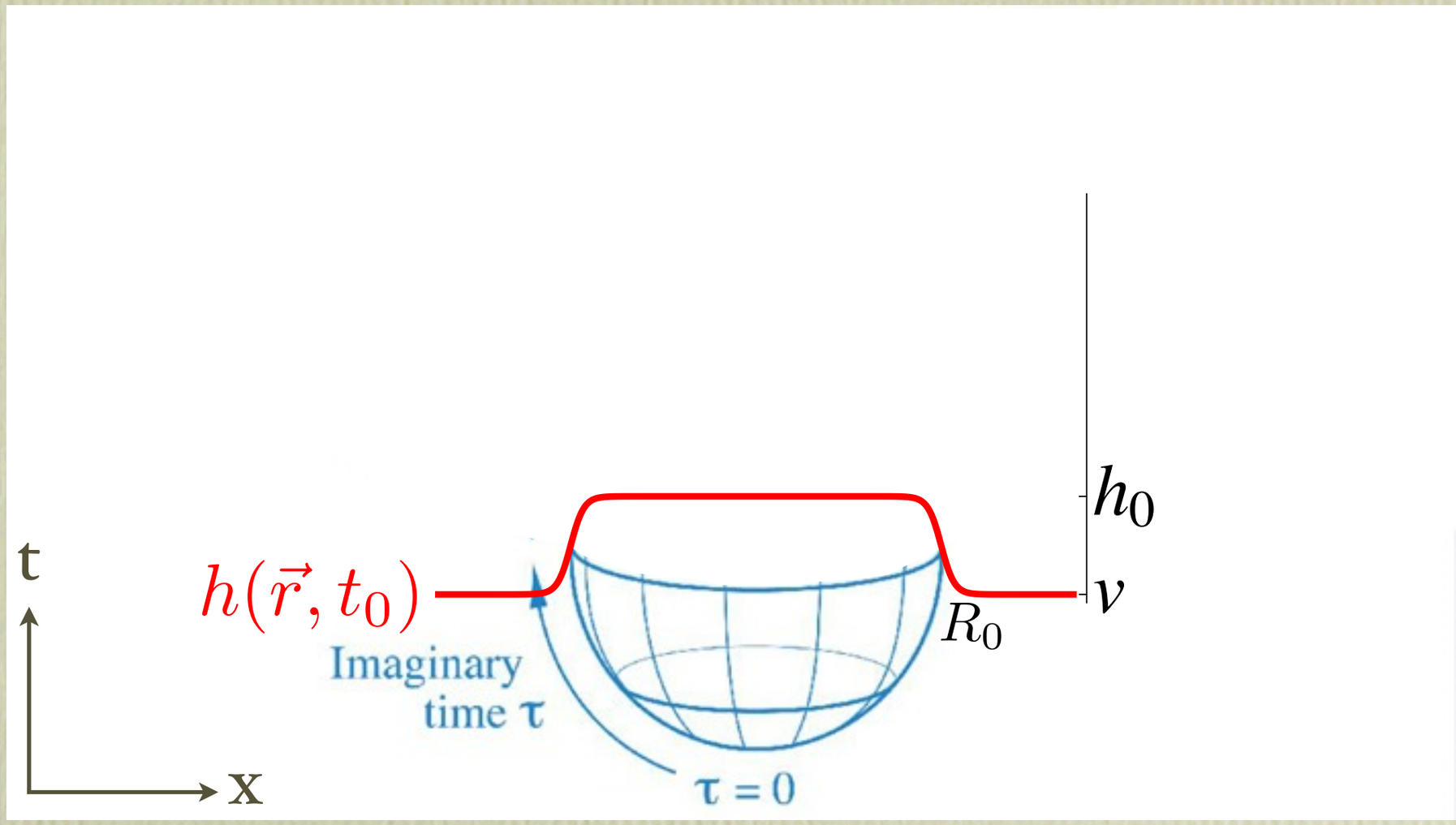
a bubble of true vacuum forms !

[Coleman & de Luccia '77; Arnold '89]
[Isidori, Rychkov, Strumia & Tetradis '07]
[Arkani-Hamed, Dubovsky, Senatore & Villadoro '08]

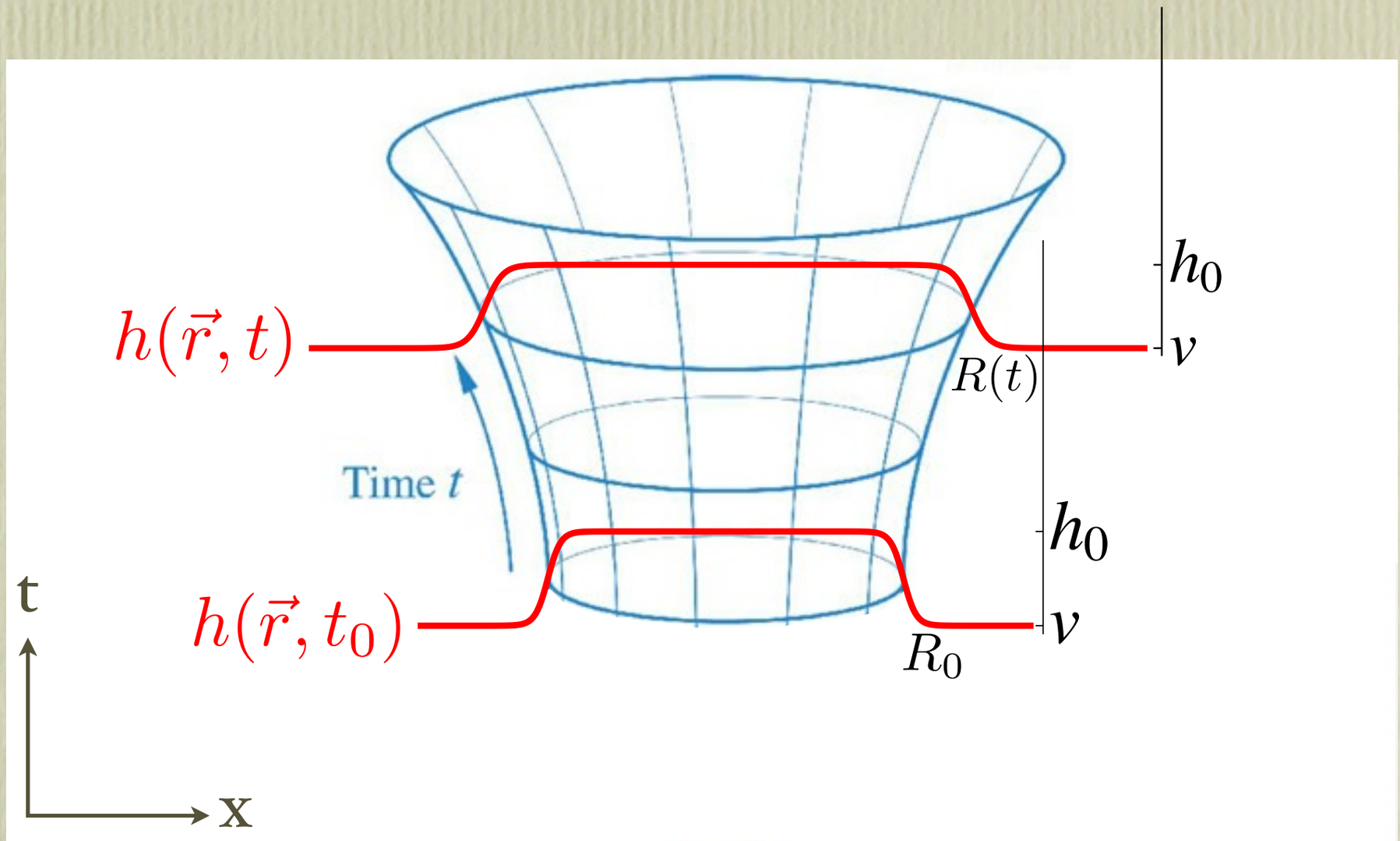
decay rate:

$$\Gamma \sim e^{-S_E} \ll \frac{1}{\text{age of Universe}}$$

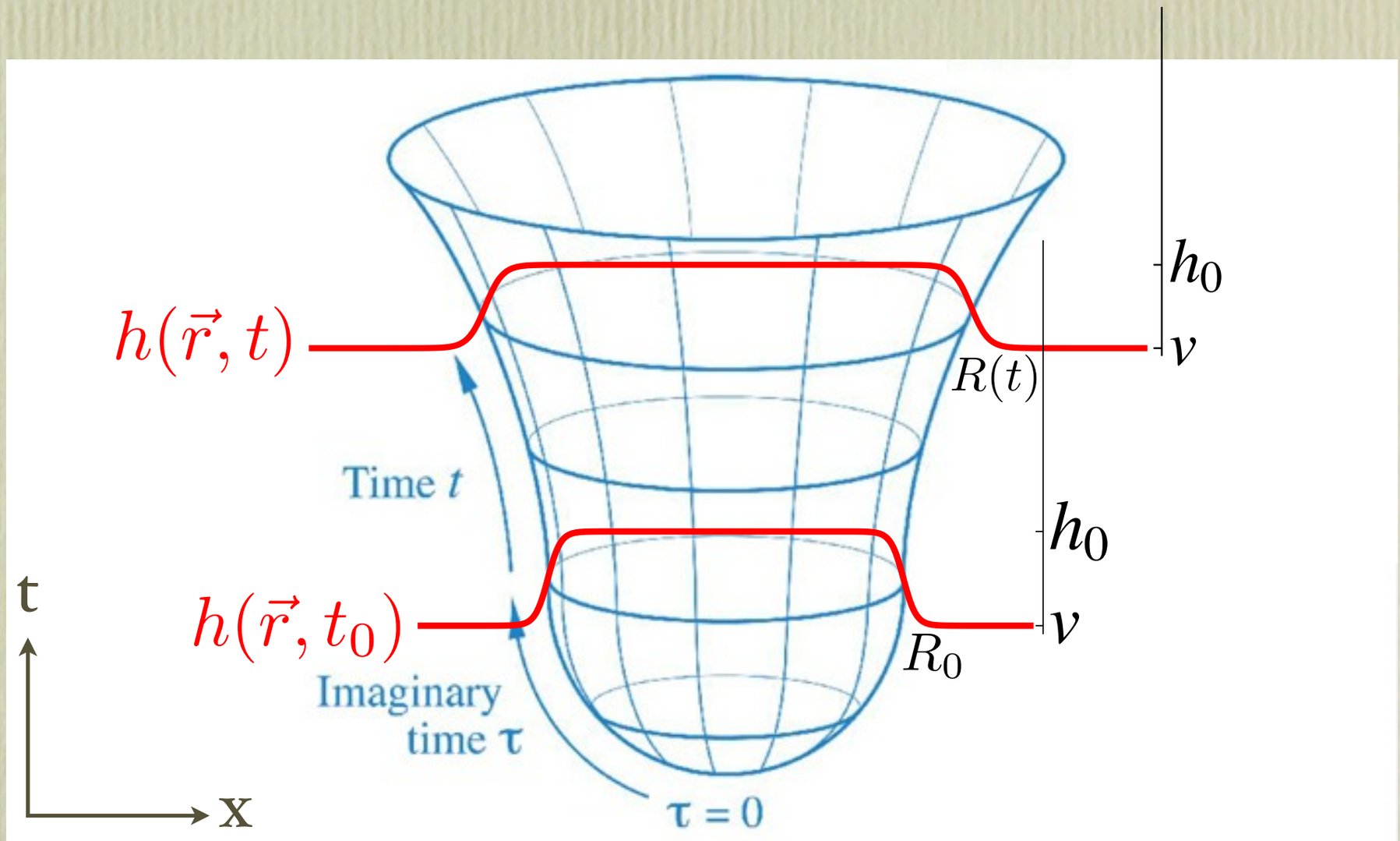
geometry of tunneling - bubble nucleation II



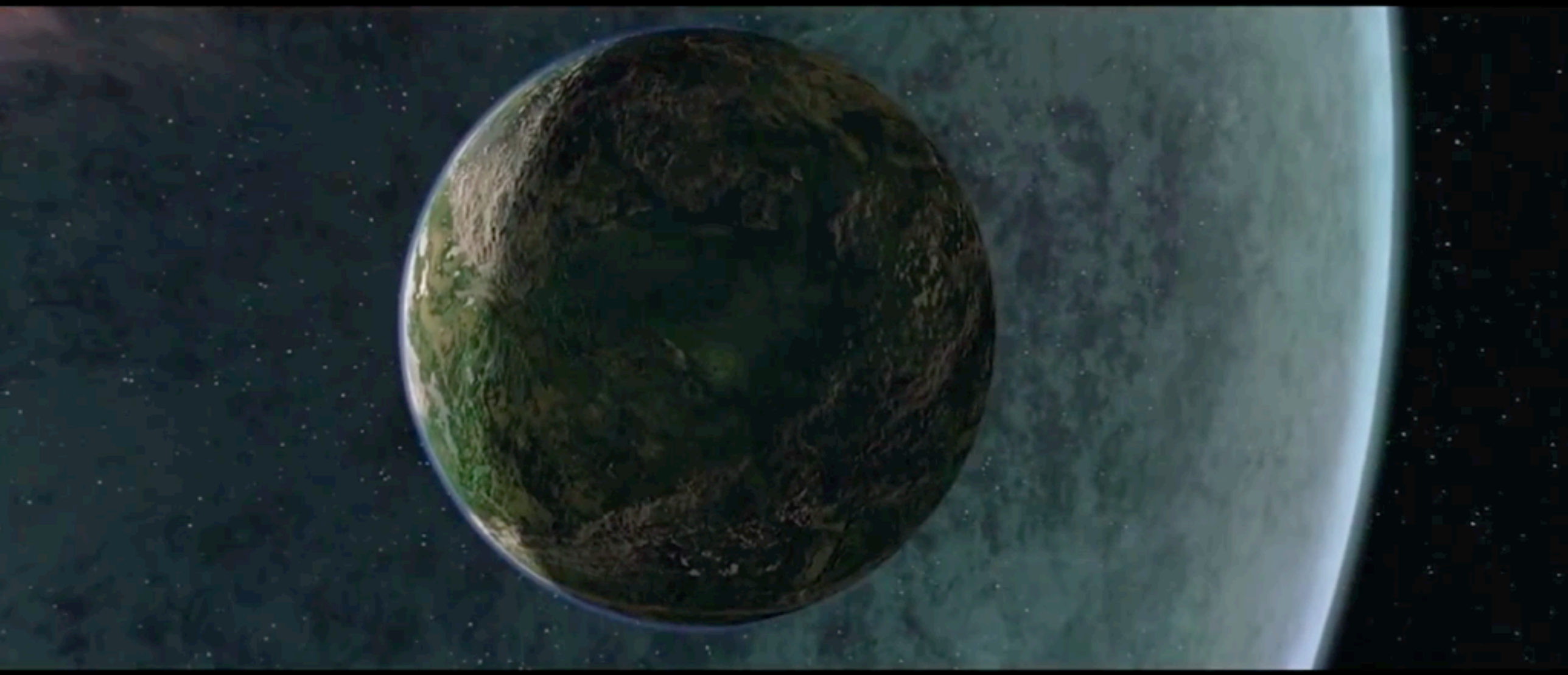
geometry of tunneling - bubble nucleation II



geometry of tunneling - bubble nucleation II



geometry of tunneling - bubble nucleation III



how do we avoid that fate ...

we either hope to be in one of the few Universes,
where the Higgs does not jump over the barrier ...

[Espinosa, Giudice & Riotto '08]

or

we have a tiny coupling to a heavy singlet scalar:
threshold effect stabilizes the Higgs potential

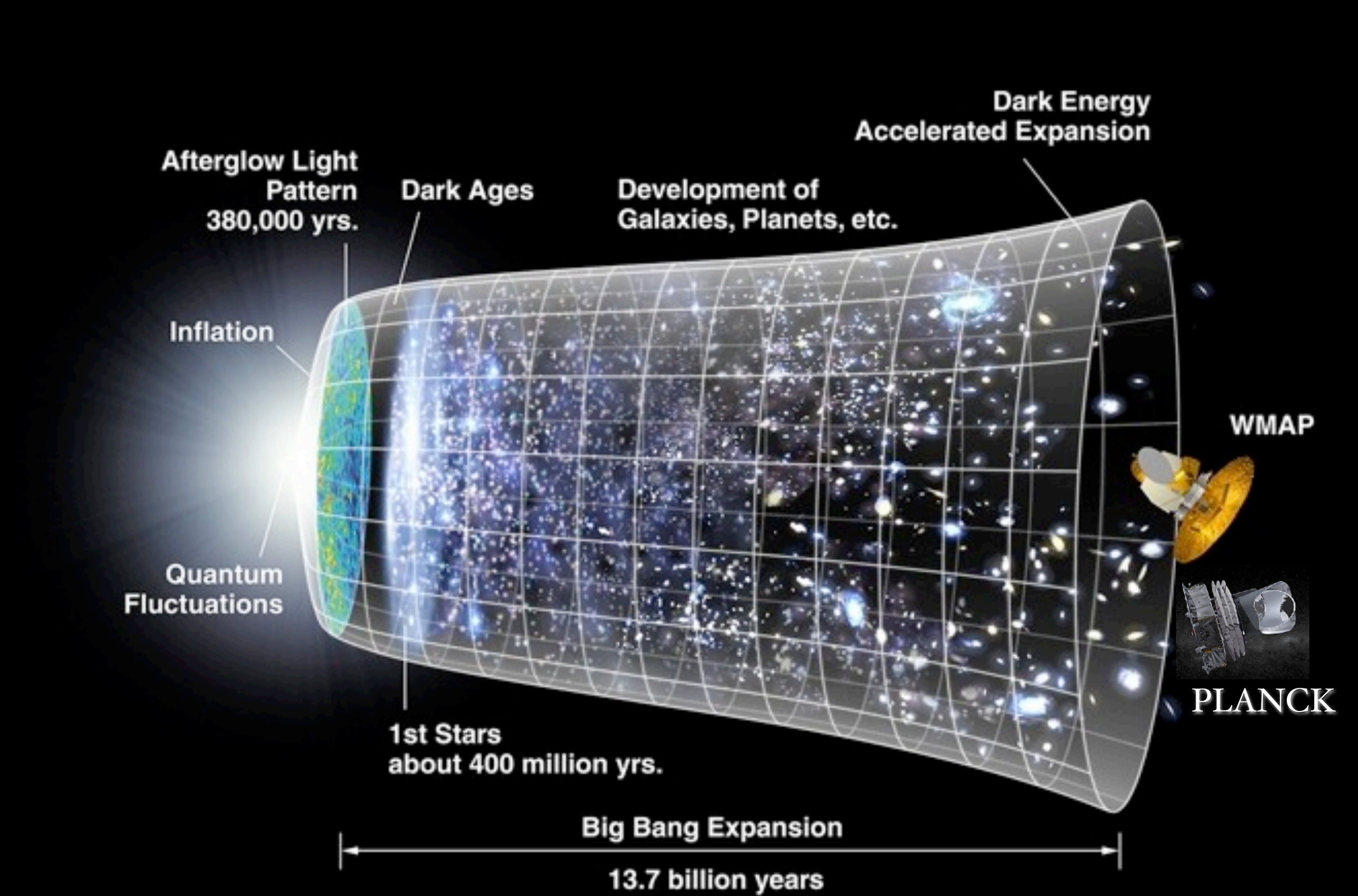
(cf. see-saw for neutrino masses;
Peccei-Quinn axion for theta-angle ...)

[Lebedev; Elias-Miro, Espinosa, Giudice, Lee & Strumia '12]

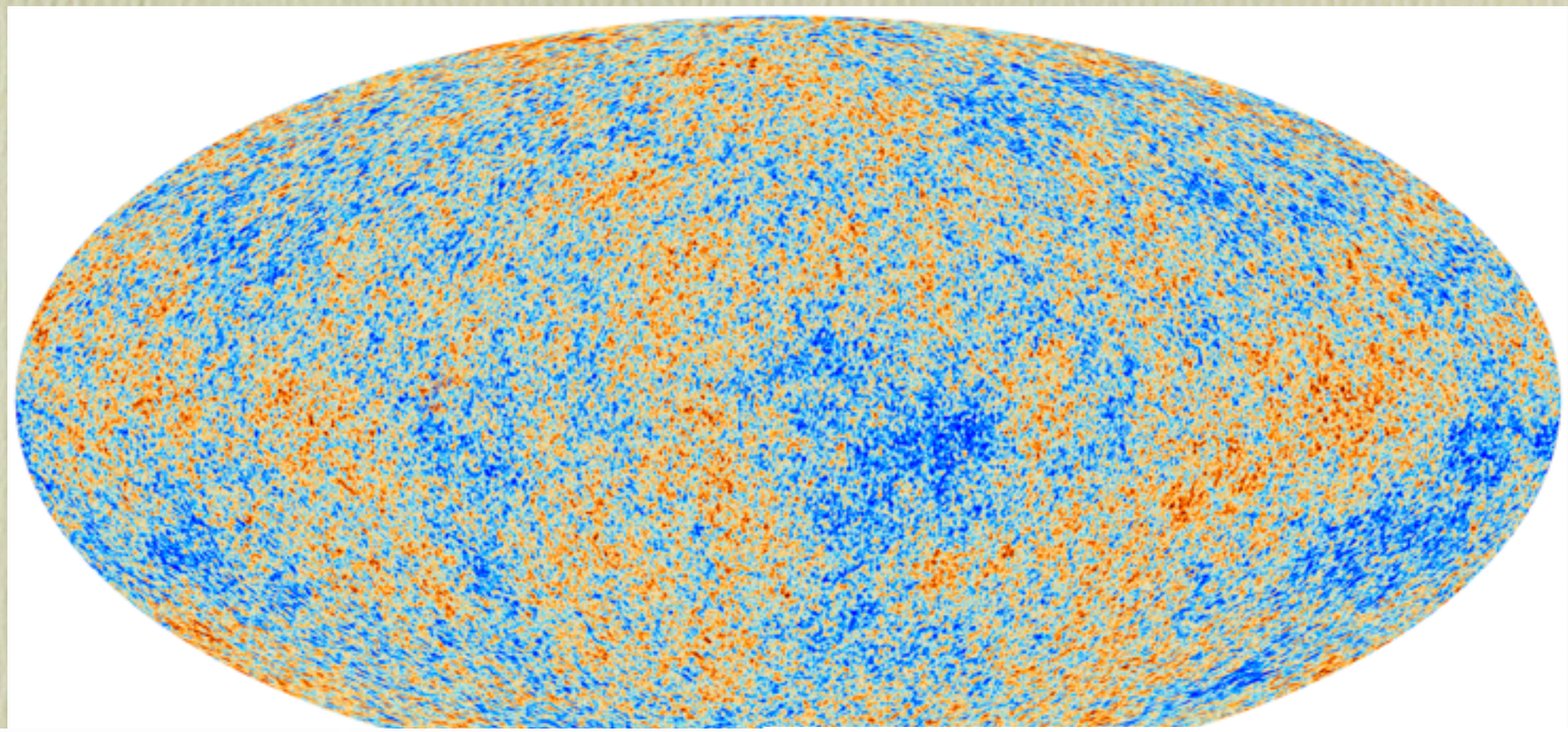
or

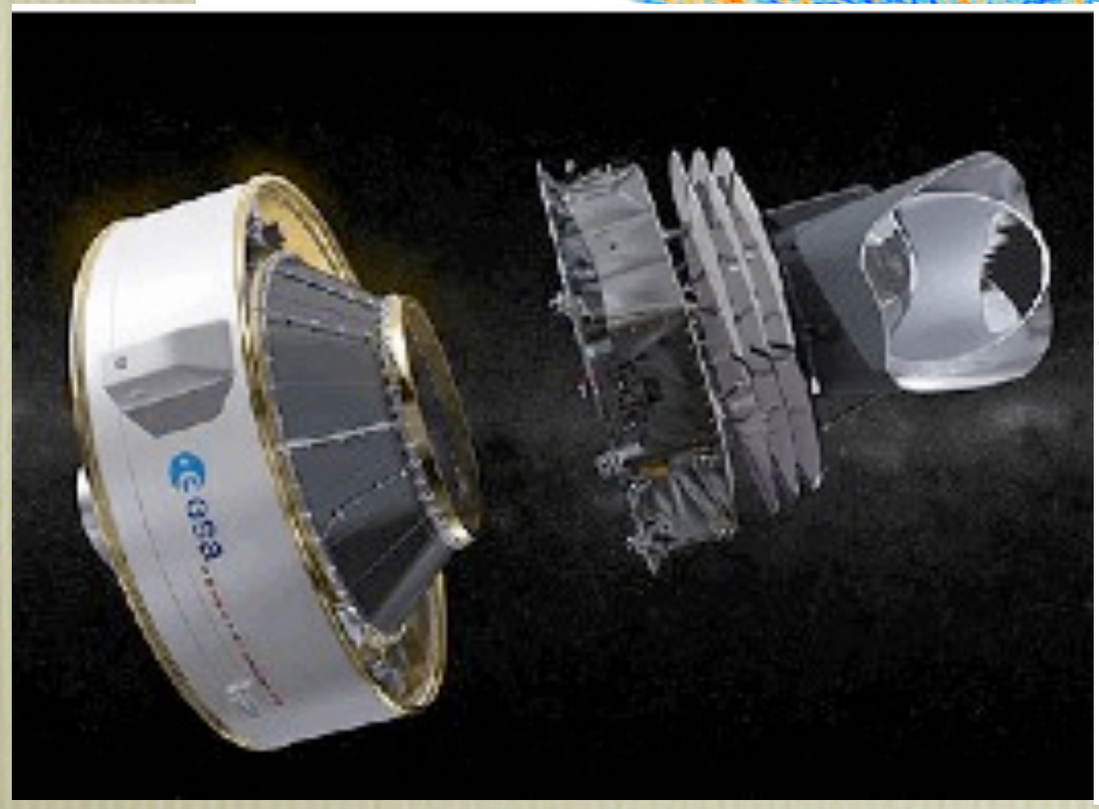
we use inflation in our past ....

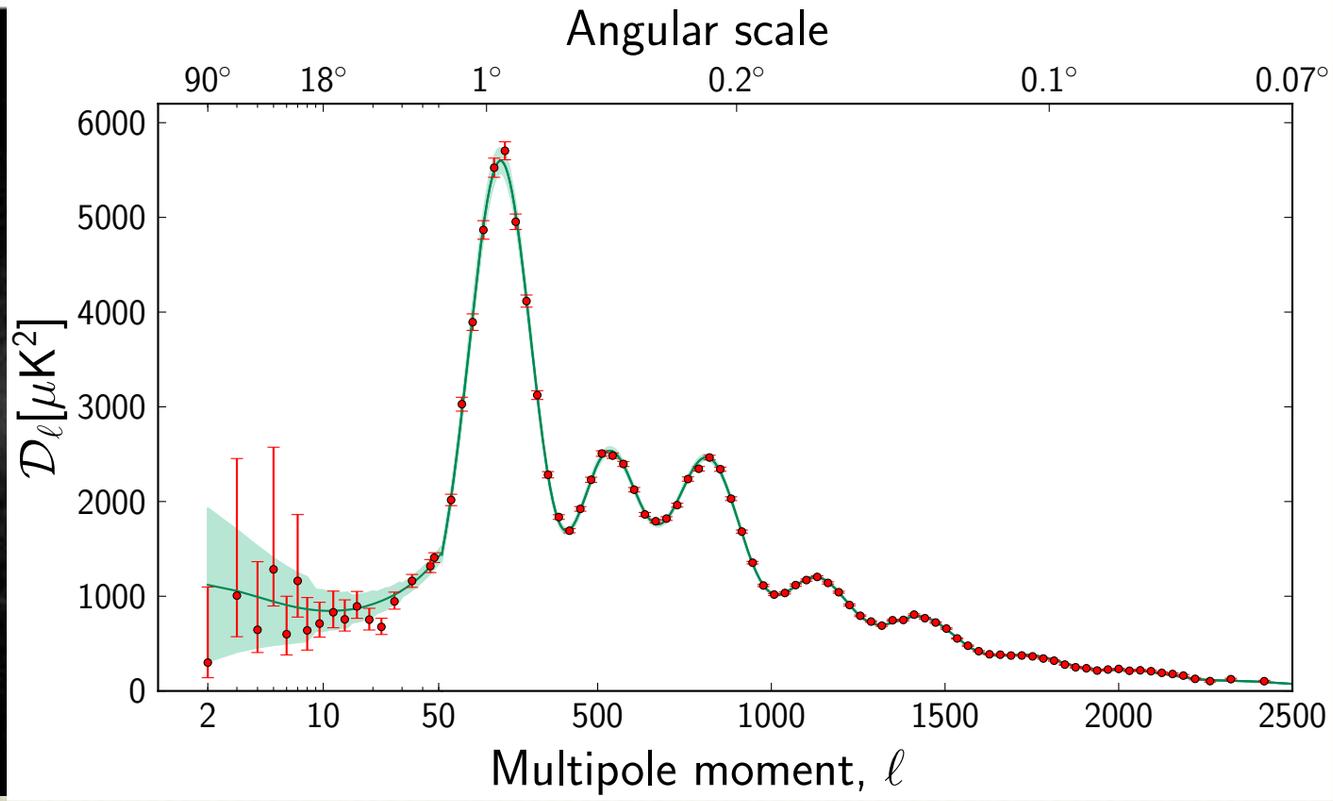
[Lebedev & Lee '12]
[Lebedev & AW '12]


Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
380,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
WMAP
Quantum
Fluctuations
PLANCK
1st Stars
about 400 million yrs.
Big Bang Expansion
13.7 billion years

Cosmic Microwave Background: PLANCK cosmology results 2013!







what we know so far ...

- The initial fluctuations are plasma sound waves seeded by perturbations in energy density with very peculiar properties:

  - near uniform distribution of power ('scale invariance')

  - coherence (have the same initial phase)

  - correlations which have been out of causal contact at 370.000 yrs, if the Universe expanded always driven by matter or radiation

➥ mounting evidence for a very early phase of hyperfast ***exponential expansion*** of the Universe - ***Inflation***

horizon problem of the hot Big Bang

time t

why so many causally disconnected regions with $\Delta T/T \sim 10^{-5}$?

today: 13.7 billion years

CMB: 370,000 years

Big Bang: $t = 0$

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Inflation

equations of motion:

$$\ddot{\phi} + 3H\dot{\phi} = -V' =: \frac{dV}{d\phi}$$

scalar field equation

scale factor:
size of the Universe

$$\frac{1}{2}\dot{\phi}^2 + V = H^2 =: \frac{\dot{a}^2}{a^2}$$

Friedmann (Einstein) equation

slow-roll:

$$|\ddot{\phi}| \ll 3H|\dot{\phi}| \quad \text{and} \quad \dot{\phi}^2 \ll V \quad \Rightarrow \quad H \simeq const.$$

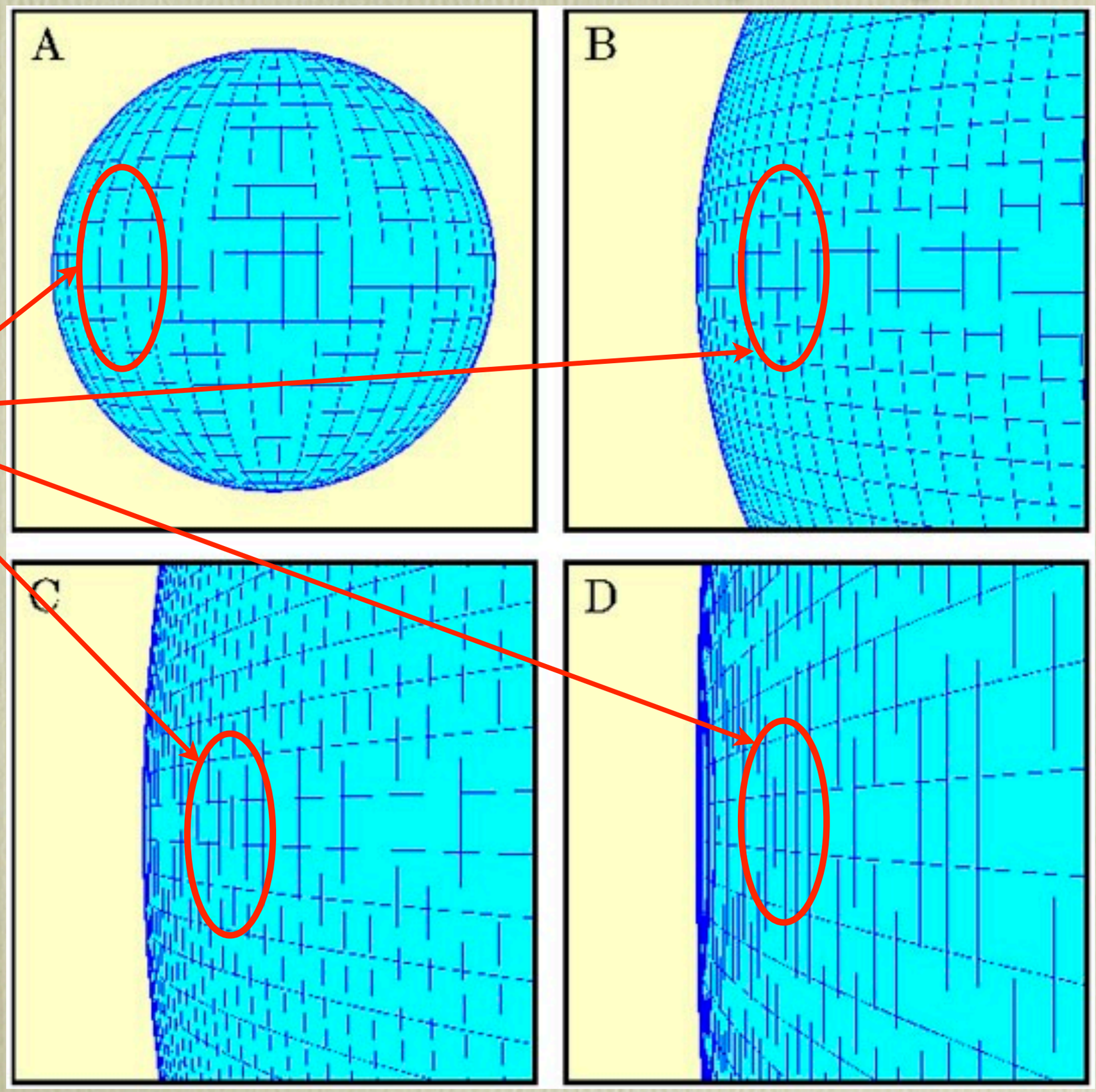
$$\Rightarrow \quad a = e^{H\,t} \quad \text{for many e-folds} \quad N = H\,\Delta t \quad , \quad \text{need:} \quad N > 60$$

exponential expansion:
inflation

slow-roll conditions on the scalar potential:

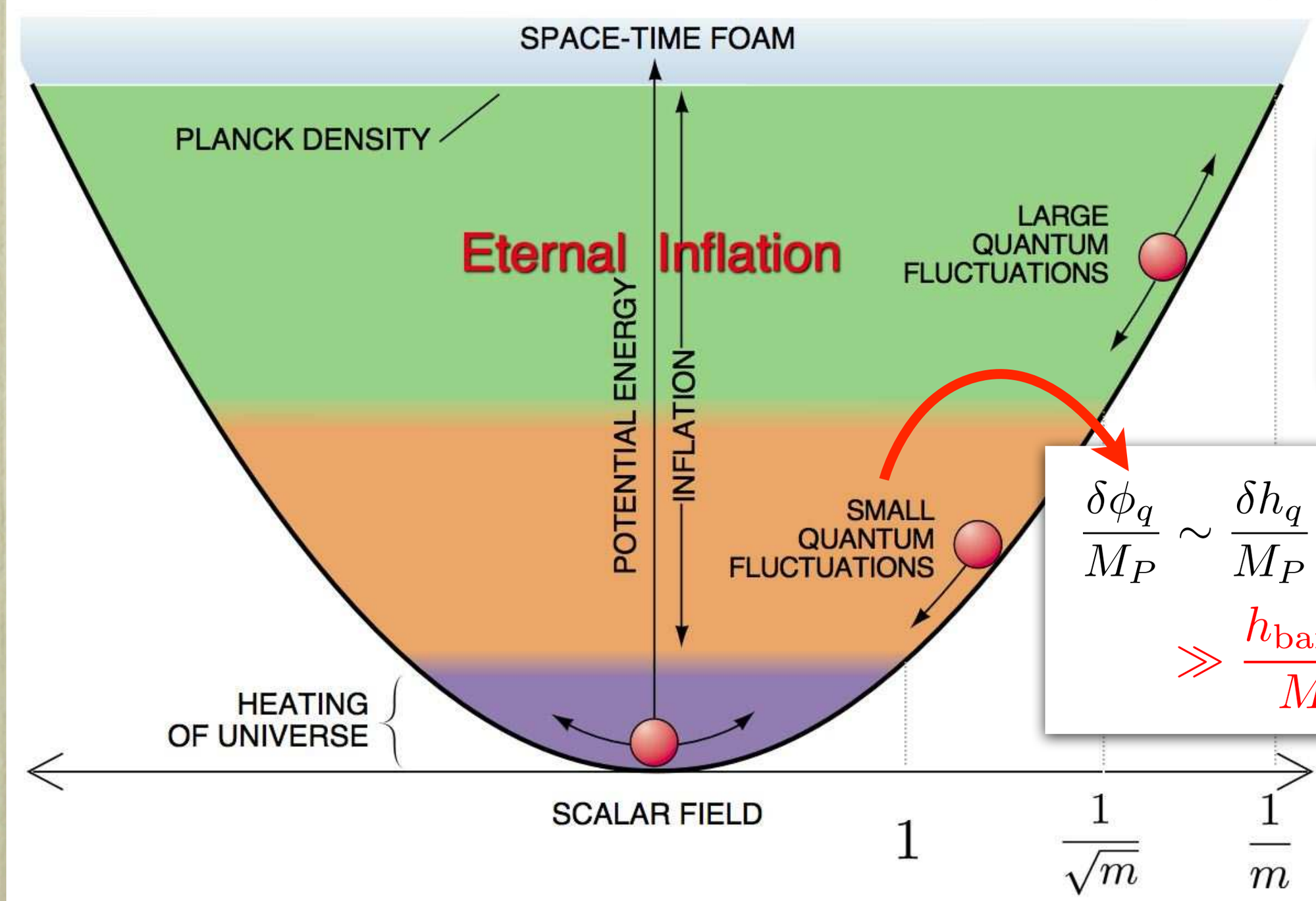
$$\Rightarrow \quad \epsilon \equiv -\frac{\dot{H}}{H^2} \simeq \frac{1}{2}\left(\frac{V'}{V}\right)^2 \ll 1 \quad , \quad \eta \equiv \frac{\dot{\epsilon}}{\epsilon H} \simeq \frac{V''}{V} \ll 1$$

inflation flattens everything out ...



slow-roll inflation ... [Linde '82]

$$V(\phi) = \frac{m^2}{2}\phi^2 \qquad m \sim 10^{13}\,\mathrm{GeV}$$



CMB:

$$\frac{\Delta T}{T} \sim 10^{-5}$$

$$\frac{\delta\phi_q}{M_P} \sim \frac{\delta h_q}{M_P} \sim \frac{H}{M_P} \sim 10^{-5}$$

$$\gg \frac{h_{\mathrm{barrier}}}{M_P} \sim 10^{-8}$$

instability insurance: couple the Higgs to the inflaton ...

[Lebedev & AW ;12]

a simple example:

$$\mathcal{L} = \frac{1}{2}(\partial\mu h)^2 + \frac{1}{2}(\partial\mu\phi)^2 - V \qquad \text{with: } V = V(h) + \frac{1}{2}m^2\phi^2 + \frac{1}{2}\xi\phi^2\, h^2 \quad \begin{matrix} < 0 & > 0 \end{matrix}$$

radiative stability of inflation: $\xi \lesssim 10^{-6}$

Higgs is stable for: $\phi_0 \gtrsim 20\, M_P$

can start inflaton & Higgs at: $\phi_0 \gtrsim 20\, M_P \quad , \quad h_0 \simeq 0.1\, M_P$

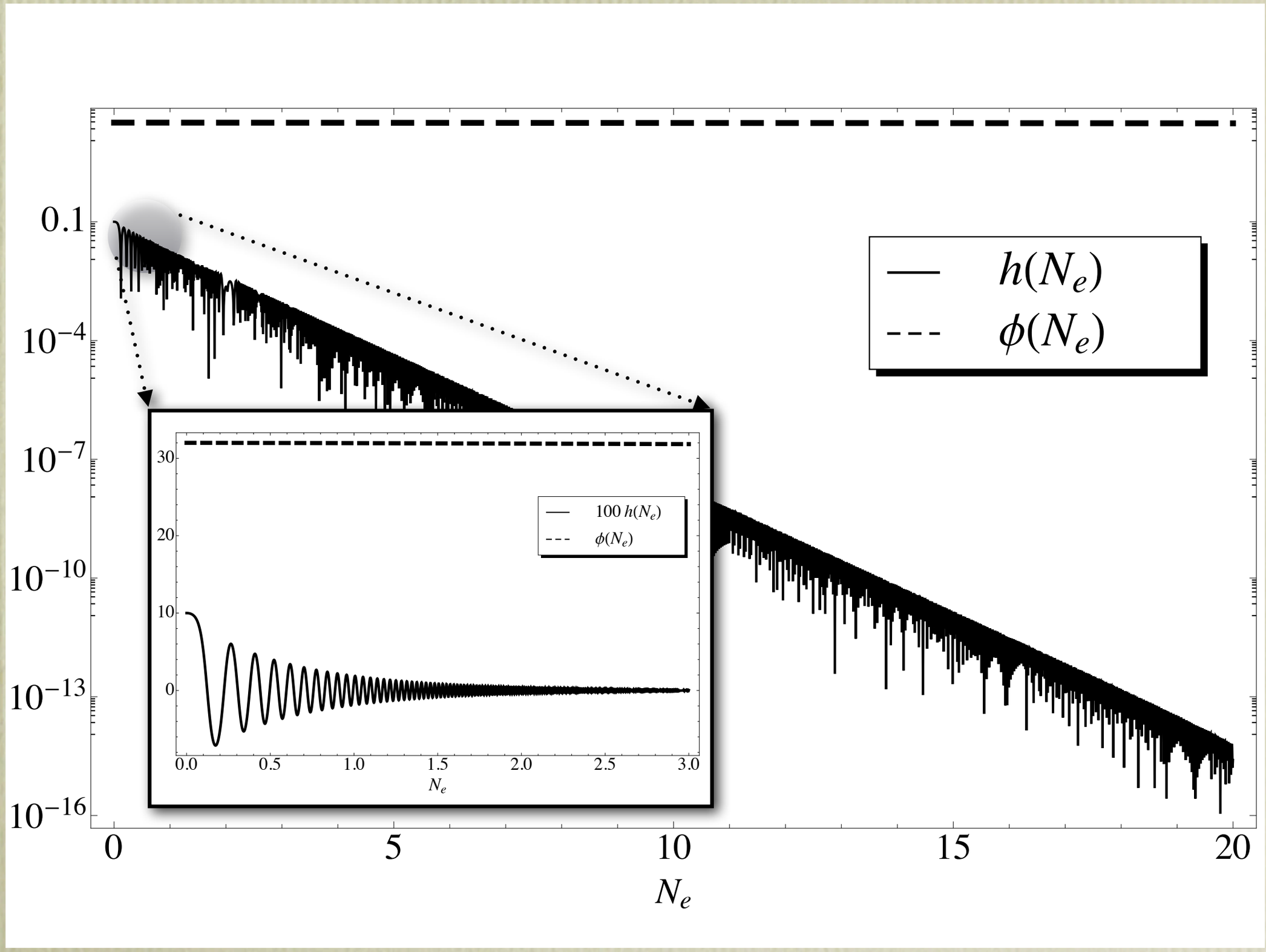
and Higgs will run exponentially fast to $h = v = 10^{-16}\, M_P$ in about 20 e-folds !

→ see also SFB lectures by: Oleg Lebedev

evolution of the Higgs during inflation ...

[Lebedev & AW ;12]

$\frac{h_0}{M_P}$



$\frac{v}{M_P}$

Thanks!