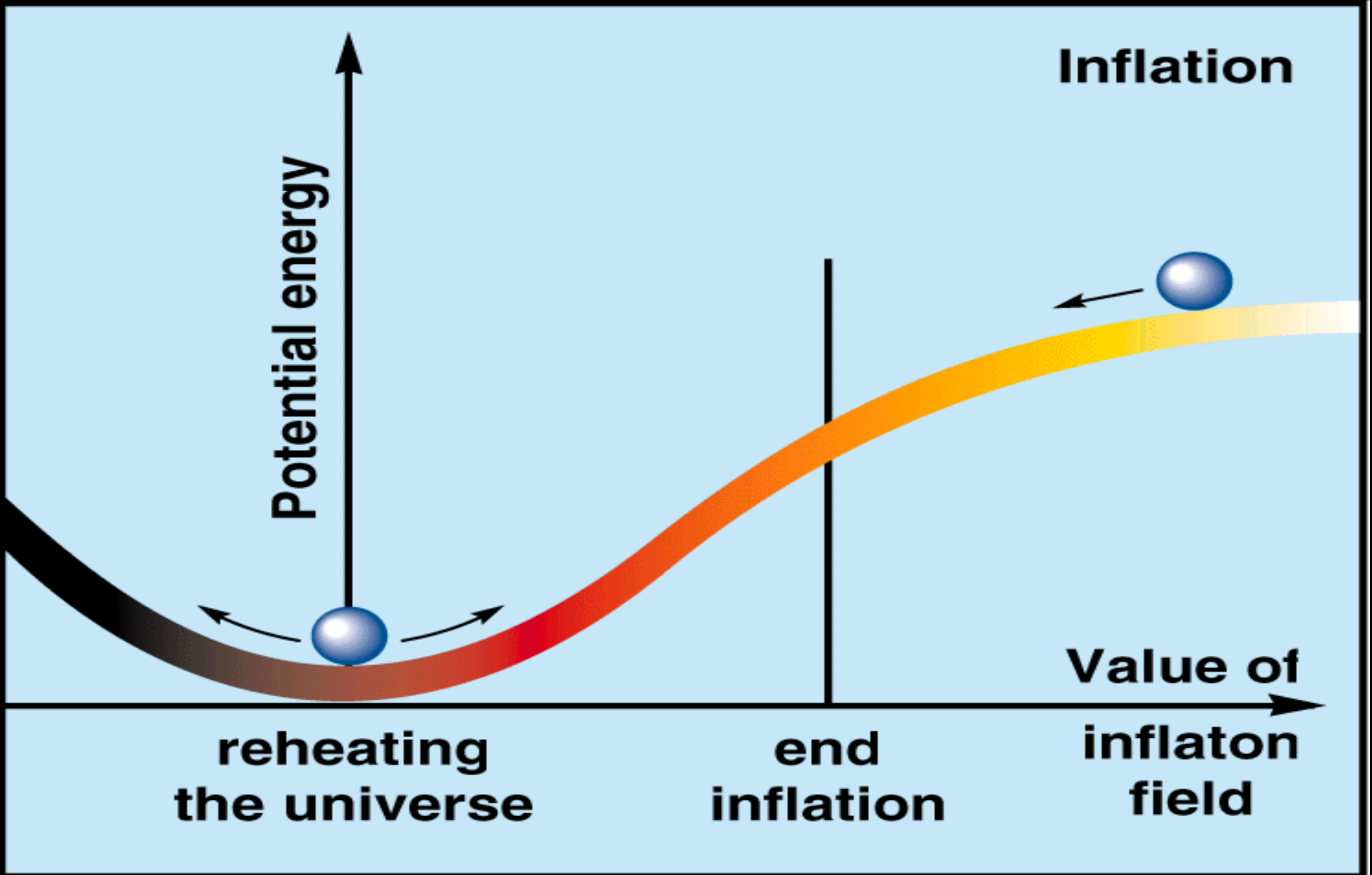
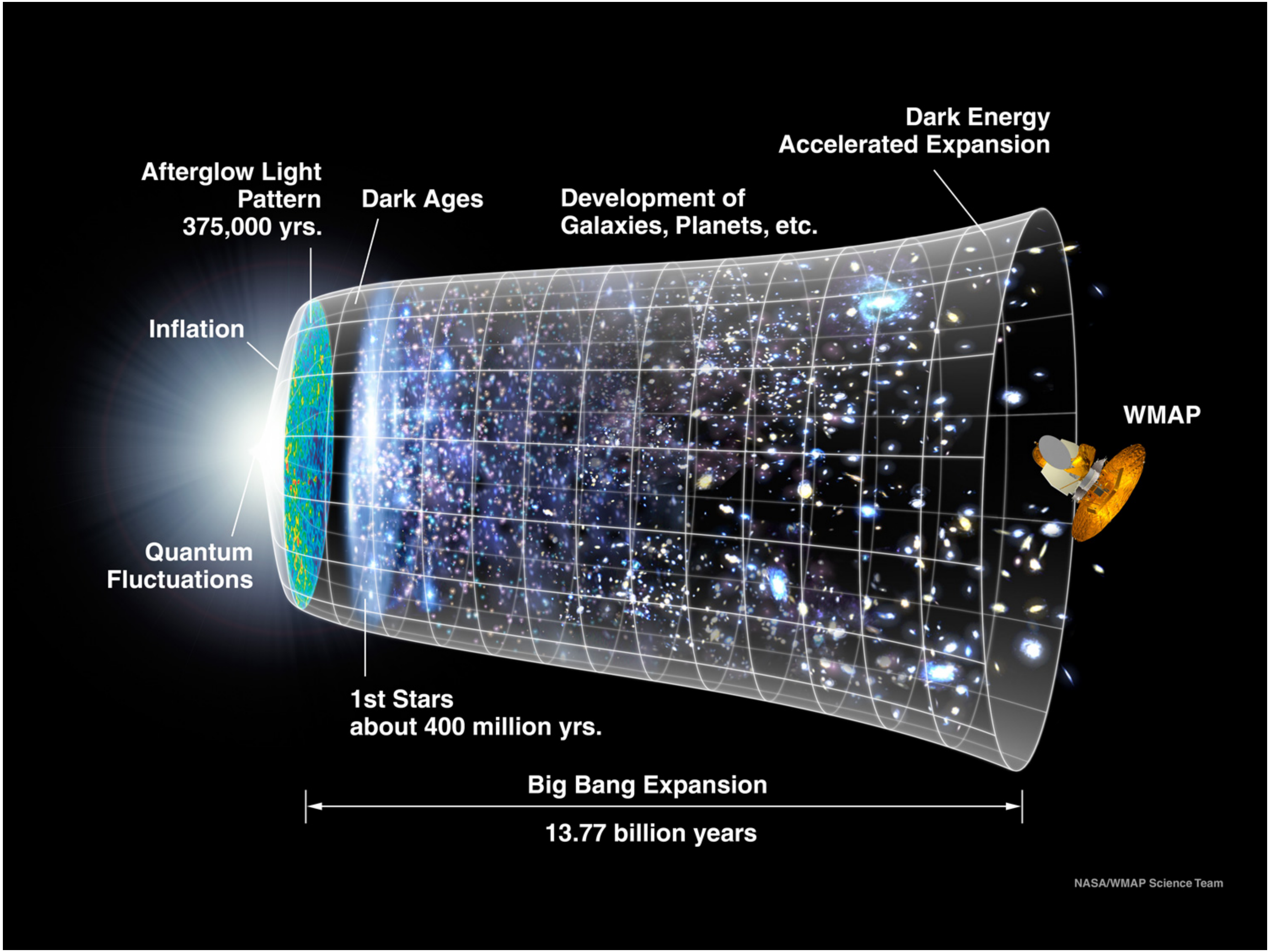


School Observational Cosmology
Angra – Terceira – Açores
3rd June 2014

Juan García-Bellido
Física Teórica UAM
Madrid, Spain


Afterglow Light Pattern 375,000 yrs.
Dark Ages
Development of Galaxies, Planets, etc.
Dark Energy Accelerated Expansion
Inflation
Quantum Fluctuations
WMAP
1st Stars about 400 million yrs.
Big Bang Expansion
13.77 billion years
NASA/WMAP Science Team

Outline

Lecture 1

- Shortcomings of the Hot Big Bang
- The Inflationary Paradigm
- Homogeneous Scalar Field Dynamics
- Slow roll approximation
- Quantum Fluctuations in de Sitter

Shortcomings of the Hot Big Bang

- The space-time structure of the observable Universe
  - Why is the Universe so close to spatial flatness?
  - Why is matter so homogeneously distributed on large scales?
- The origin of structures in the Universe
  - How did primordial spectrum of density perturbations originate?
- The origin of matter and radiation
  - Where does all the energy in the Universe come from?
  - How did the matter-antimatter asymmetry arise?
- The initial singularity
  - Did the Universe have a beginning?
  - What is the global structure of the Universe beyond our observable patch?

Einstein-Friedmann equations

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\rho - \frac{K}{a^2} \qquad ij + 00$$

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}(\rho + 3p) \qquad 00$$

Energy density conservation:

$$D_\mu T^\mu{}_\nu = 0 \Rightarrow \dot{\rho}(t) + 3\frac{\dot{a}}{a}(\rho(t) + p(t)) = 0$$

$$p(t) = w\,\rho(t) \qquad \text{barotropic fluid}$$

Time evolution of density params

$$x \equiv \Omega_M(a) = \frac{8\pi G\,\rho_M(a)}{3H^2(a)} = \frac{\Omega_M}{\Omega_M + \Omega_K a + \Omega_\Lambda a^3}$$

$$y \equiv \Omega_\Lambda(a) = \frac{\Lambda}{3H^2(a)} = \frac{\Omega_\Lambda a^3}{\Omega_M + \Omega_K a + \Omega_\Lambda a^3}$$

Homogeneous system of eqs.

$$x' \equiv \frac{dx}{dN} = -x(1 - x + 2y)$$

$$y' \equiv \frac{dy}{dN} = +y(x + 2(1 - y))$$

$$N = \ln a$$

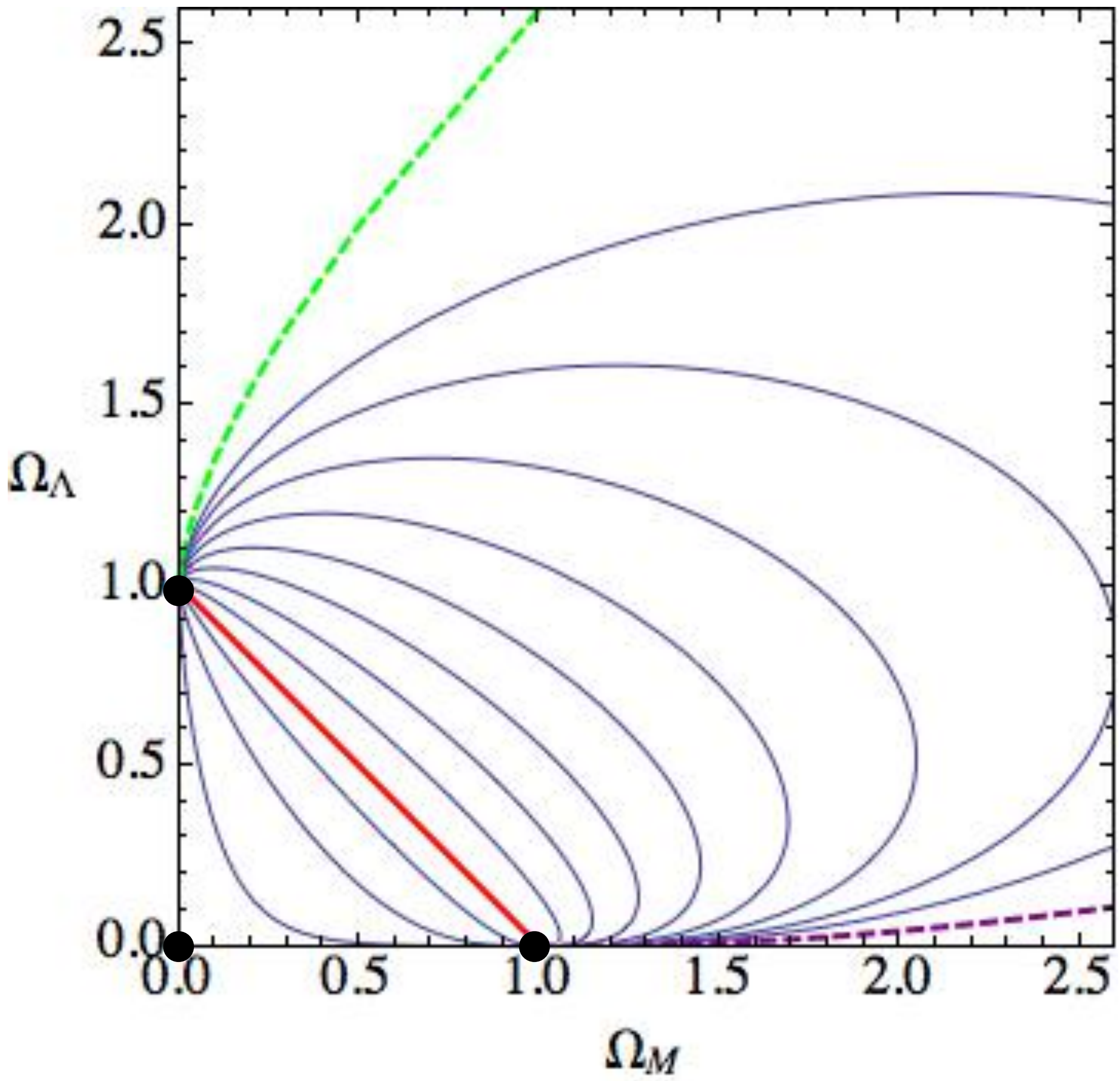
critical points

$$(x = 0, y = 0)$$

$$(x = 1, y = 0)$$

$$(x = 0, y = 1)$$

Flatness is unstable



critical points

$$(x = 0, y = 0)$$

$$(x = 1, y = 0)$$

$$(x = 0, y = 1)$$

$$\Omega_K = 0,$$

$$\Omega_M + \Omega_\Lambda = 1$$

Flatness

$$H^2 = \frac{8\pi G}{3}\rho - \frac{K}{a^2} \quad , \quad \Omega = \frac{8\pi G}{3H^2}\rho \quad , \quad x \equiv \frac{\Omega - 1}{\Omega} = \frac{3K/8\pi G}{\rho a^2}$$

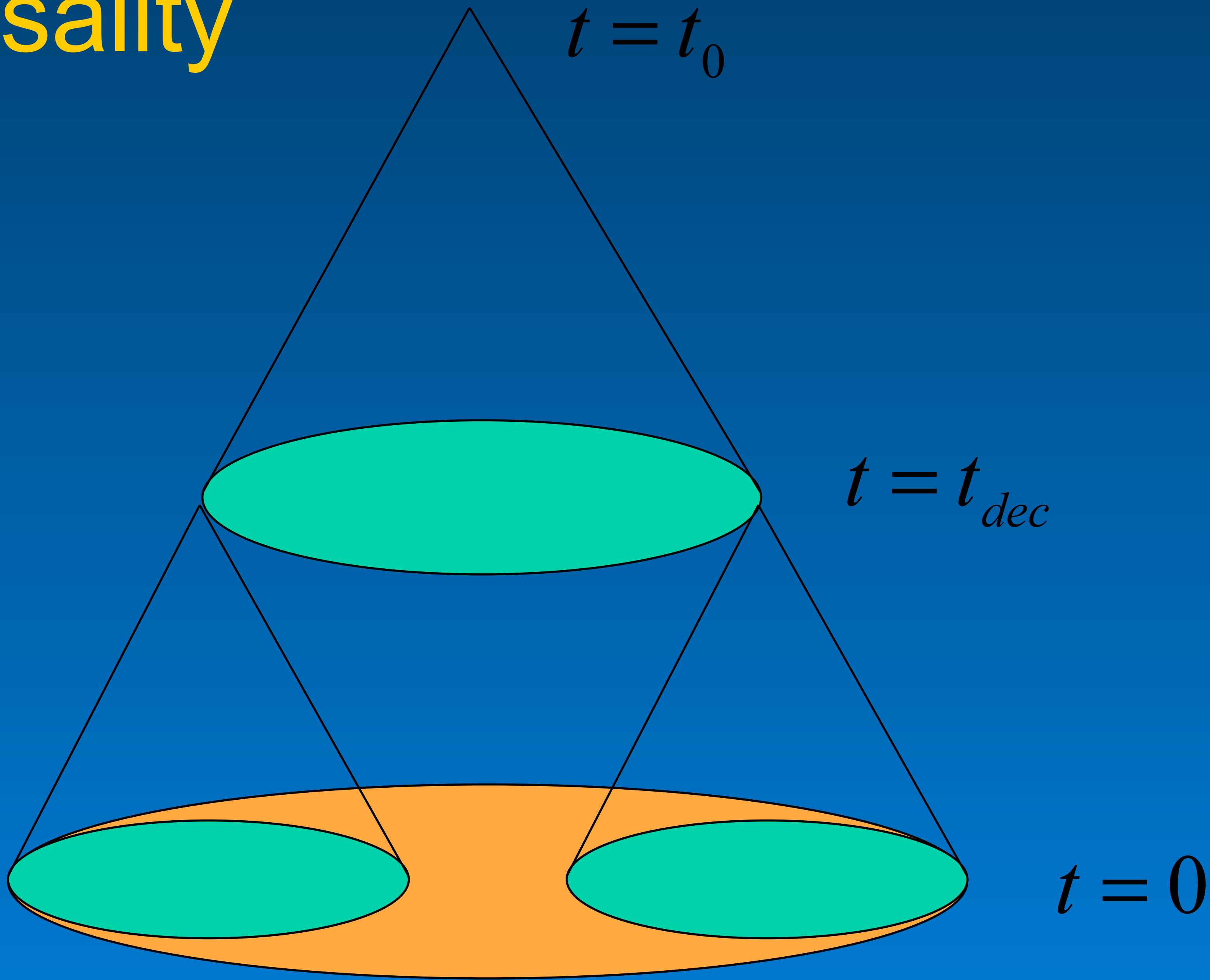
$$\frac{d\ln\rho}{d\ln a} = \frac{\rho'}{\rho} = -3(1+w) \quad \Rightarrow \quad x' = (1+3w)x$$

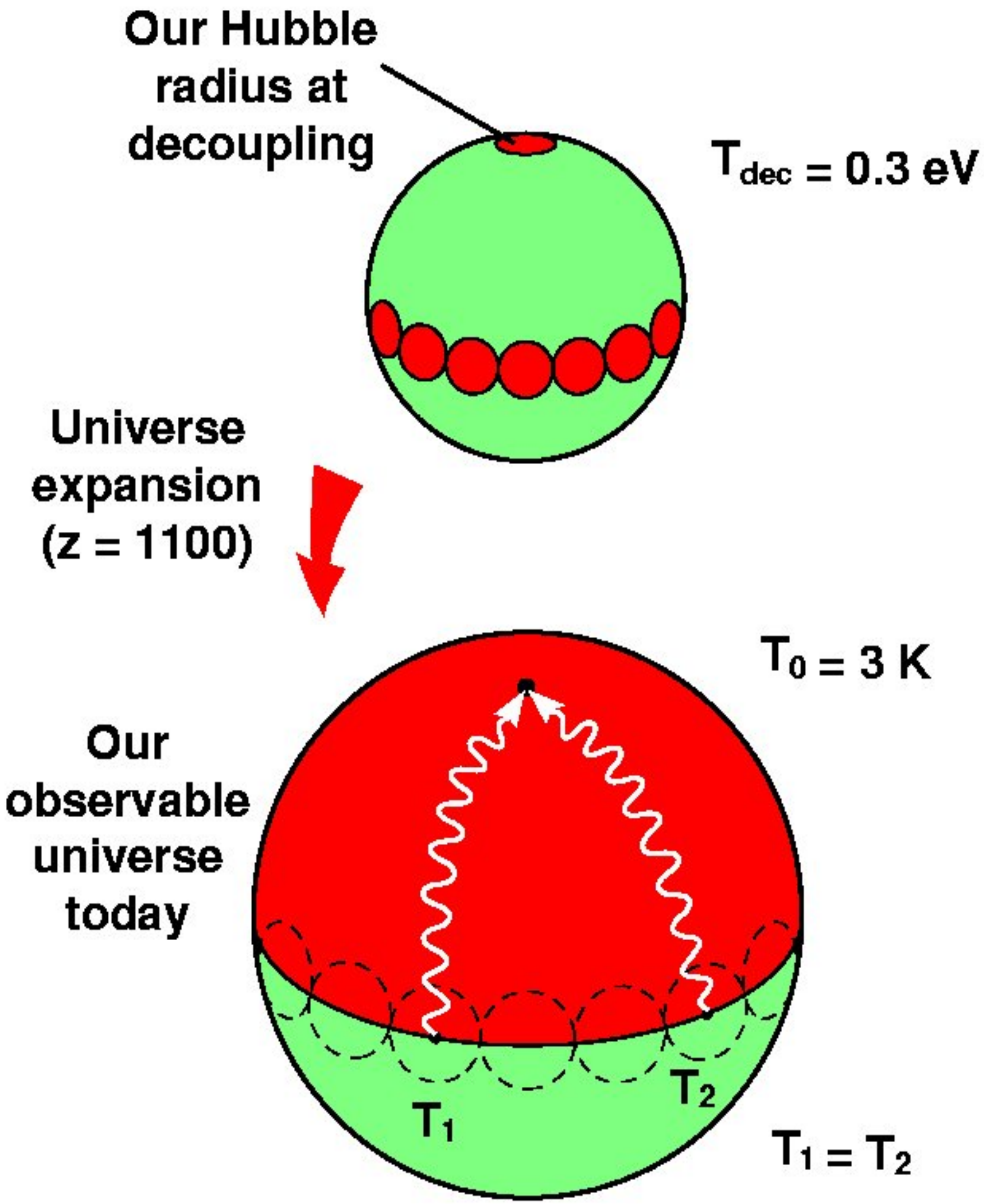
Matter & Radiation $x = 0$ unstable $x \propto a^2,\ a$

Vacuum energy $x = 0$ stable $x \propto a^{-2}$

$$x_0 = x_{in}\left(\frac{T_{in}}{T_{eq}}\right)^2 (1+z_{eq}) < 10^{-3} \quad \text{e.g.} \quad x_{BBN} < 10^{-18}$$

Causality





Homogeneity

Scale Factor

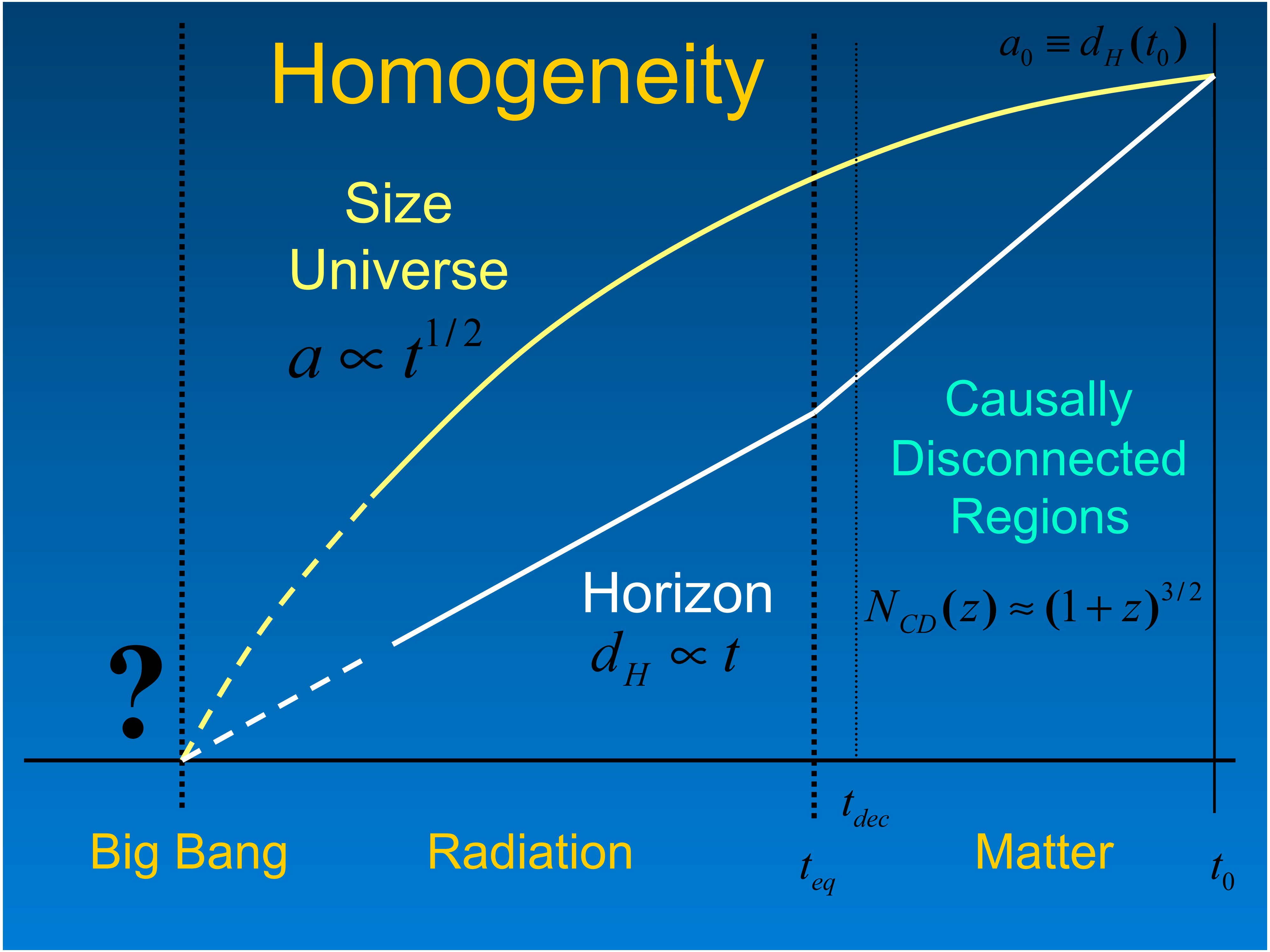
$$a(t) \propto t^p \quad p < 1$$

Particle Horizon

$$d_H(t) = a(t)\int_0^t \frac{dt'}{a(t')} \propto t$$

Causally Disconnected

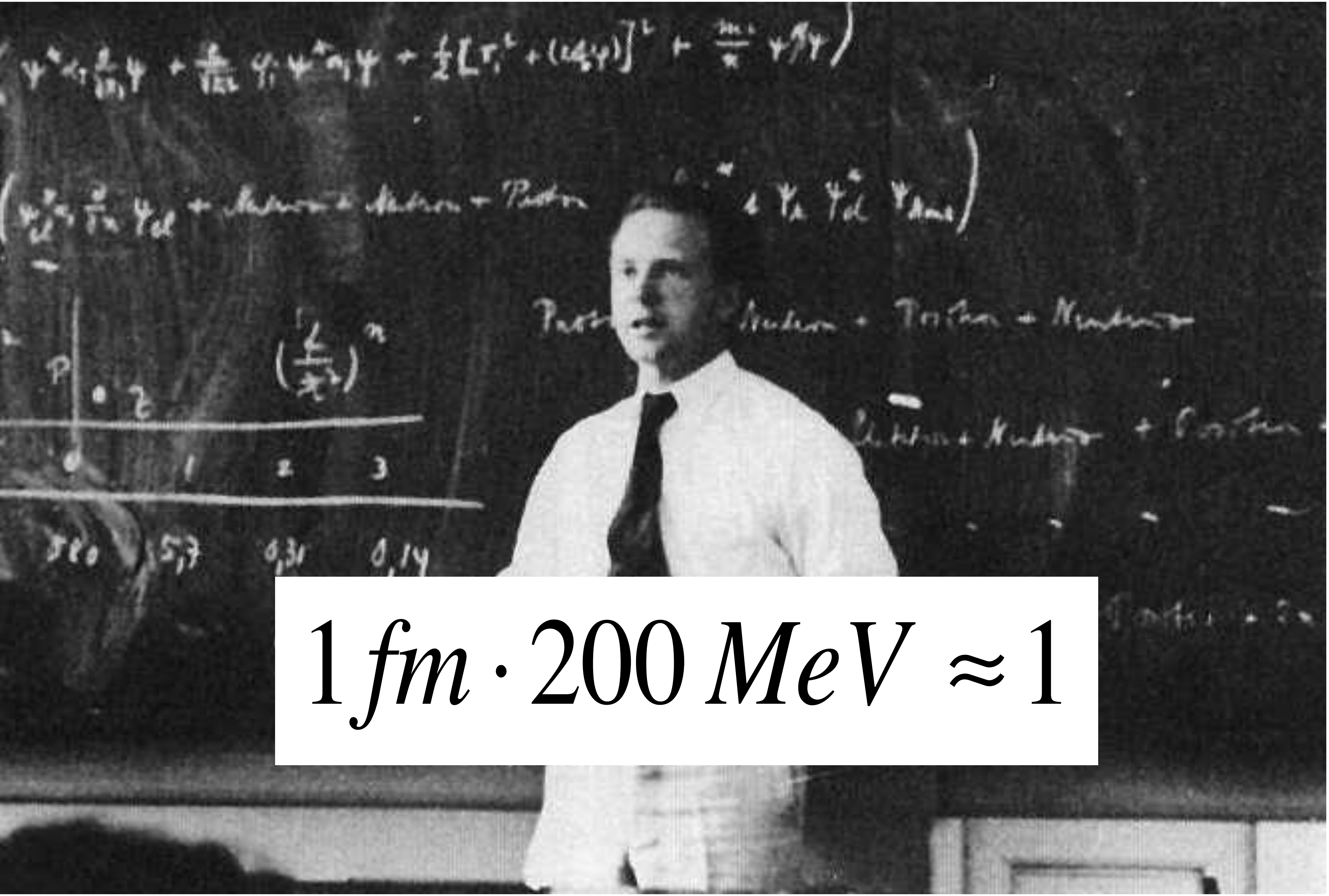
$$N_{CD}(z) \approx \left(\frac{a}{d_H}\right)^3 \approx (1+z)^{3/2}$$



Homogeneity
$a_0 \equiv d_H(t_0)$
Size
Universe
$a \propto t^{1/2}$
Causally
Disconnected
Regions
$N_{CD}(z) \approx (1+z)^{3/2}$
Horizon
$d_H \propto t$
?
t_{dec}
Big Bang
Radiation
t_{eq}
Matter
t_0

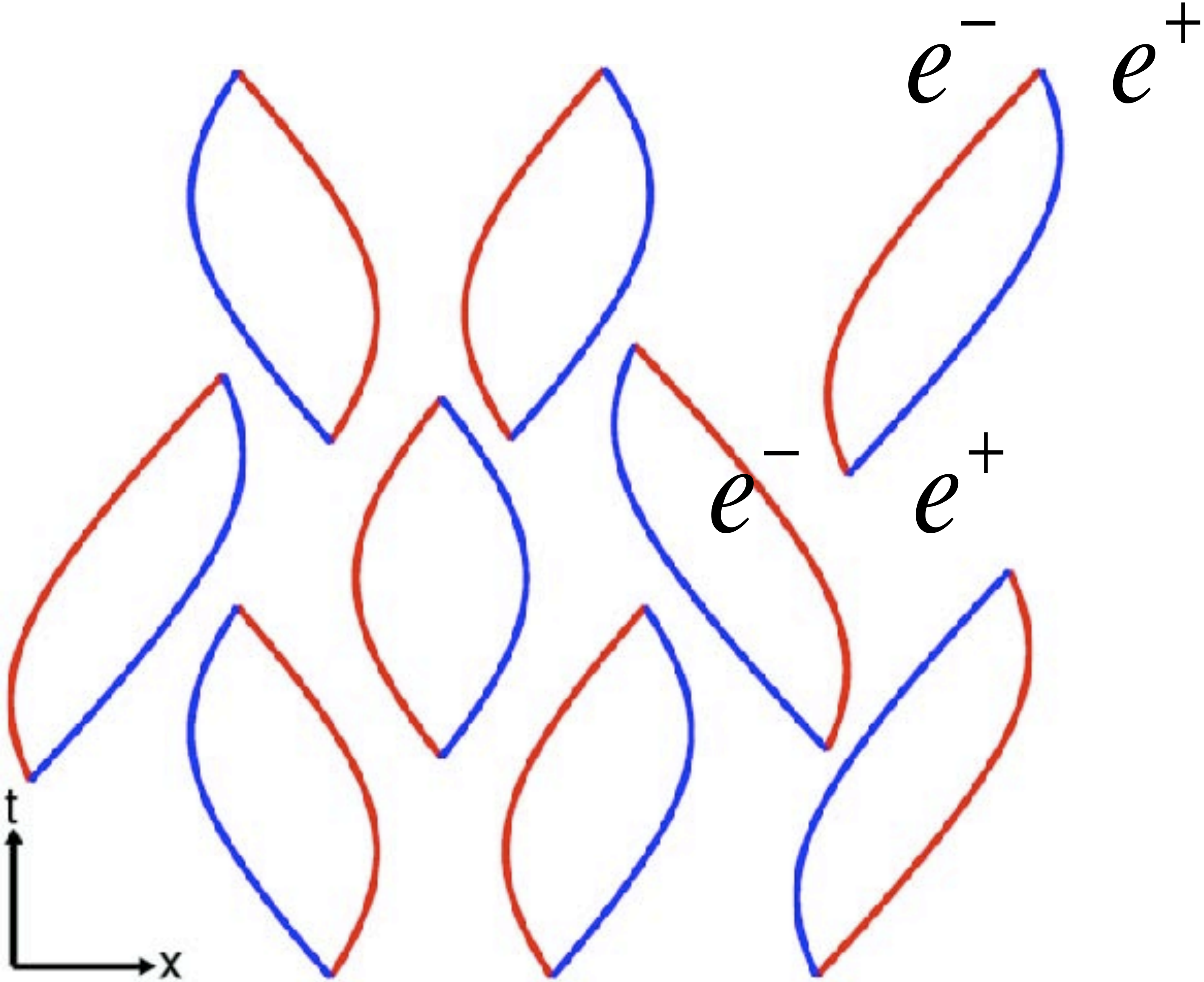
A very elegant solution:

INFLATION



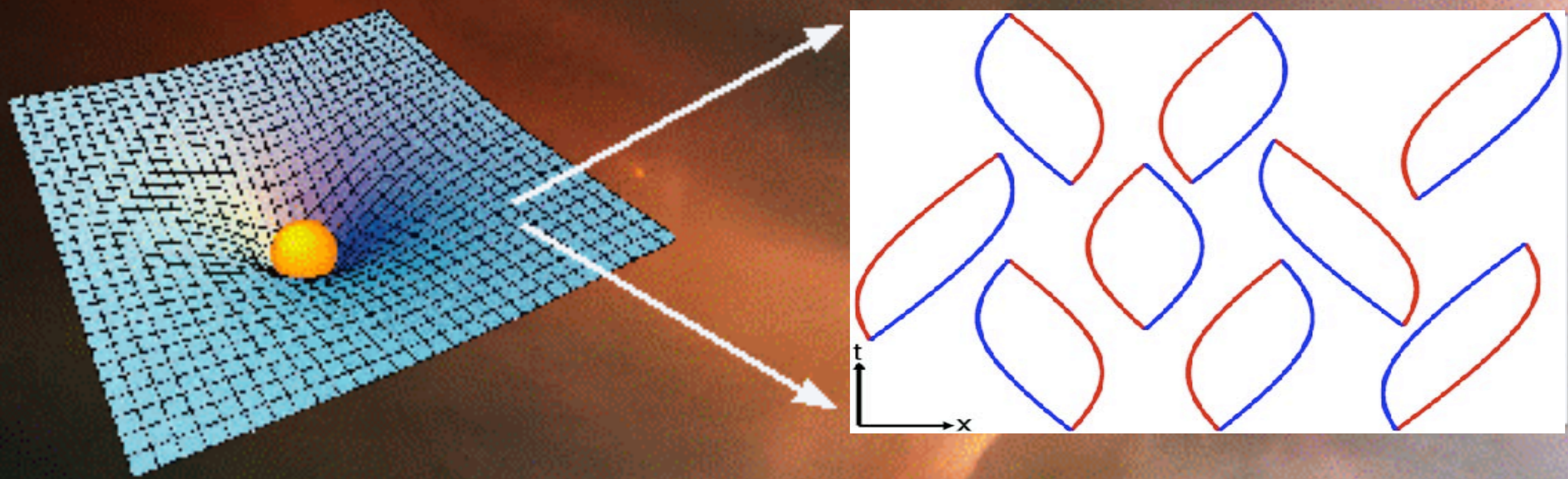
$$1\,fm \cdot 200\,MeV \approx 1$$

Vacuum fluctuations



The universe itself could be a product of quantum uncertainty.

"empty space" is a sea of virtual particles winking in and out of existence:



Inflation

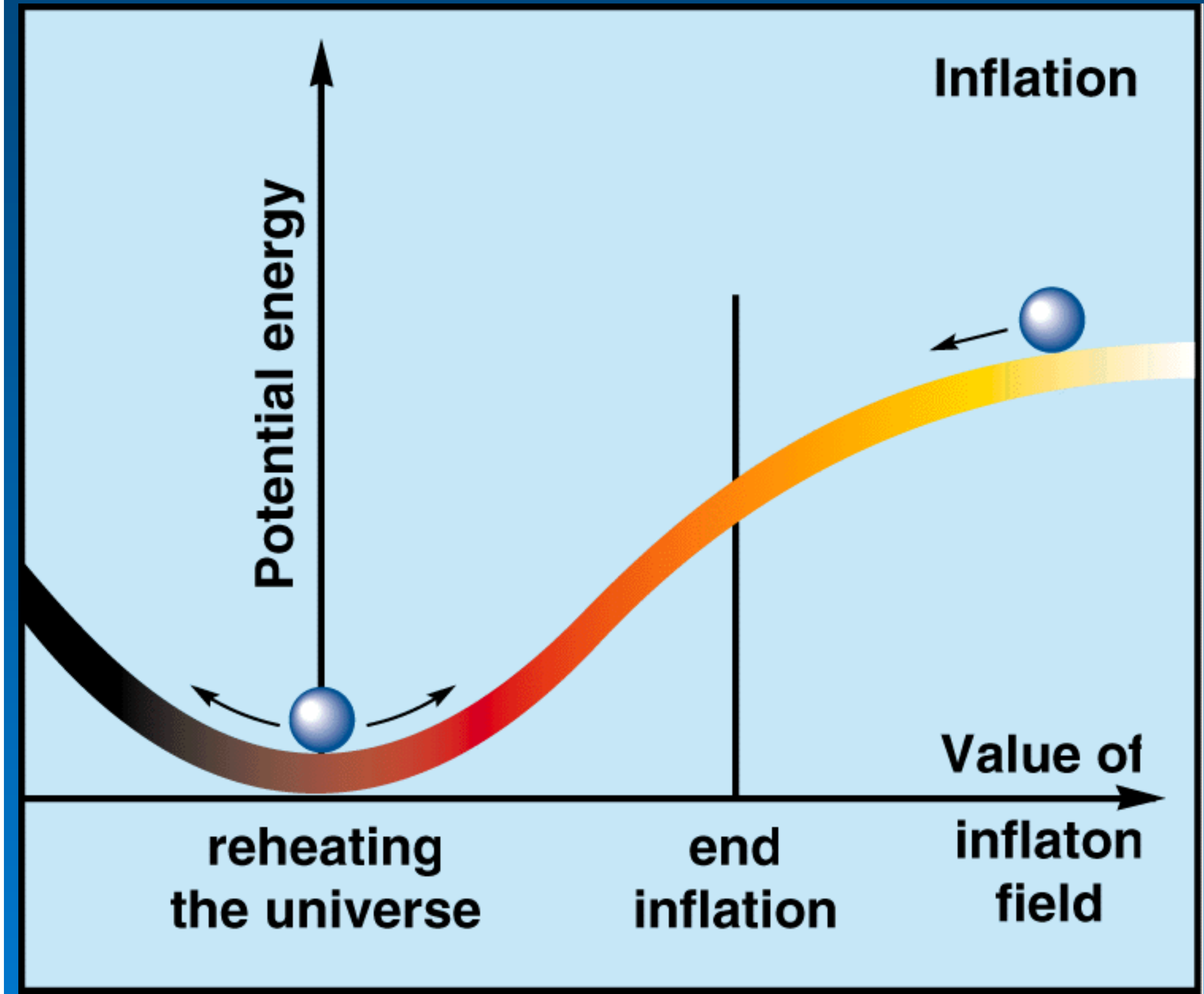
Our Universe could be the result of a quantum fluctuation

Alan Guth

Andrei Linde

A small bubble of quantum vacuum expands very rapidly until it encompasses all our Universe

Effective description (scalar field)

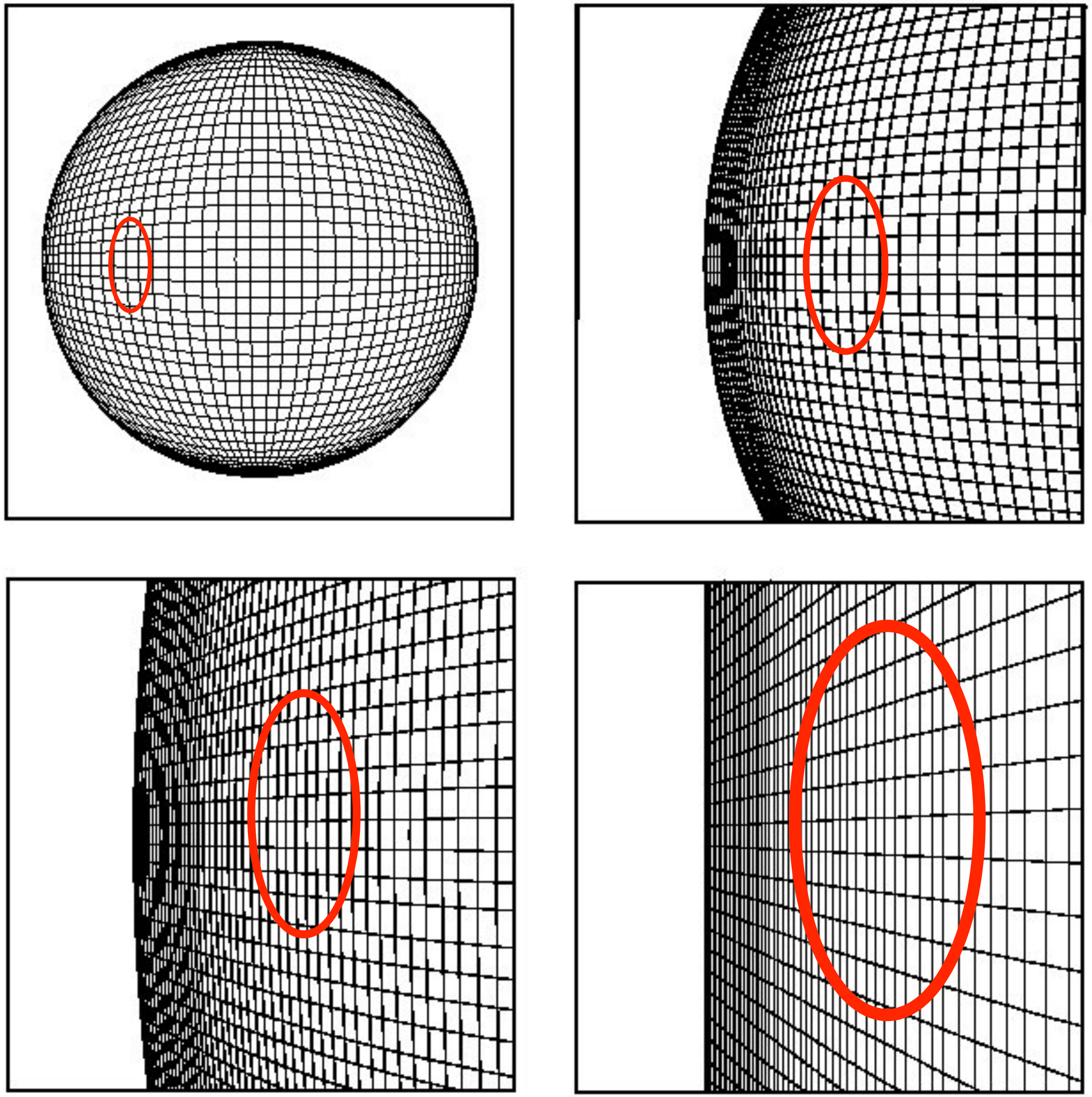


Constant density

GR

Exponential Growth

Flat spatial homogeneous sections



SCALAR FIELD DYNAMICS

$$\mathcal{S} = \int d^4x\sqrt{-g}\Big[\frac{1}{2\kappa^2}R - \frac{1}{2}(\partial\phi)^2 - V(\phi)\Big]$$

Hamiltonian and momentum constraint equations

$$H^2 = \frac{\kappa^2}{3}\left[\frac{1}{2}(\Pi^\phi)^2 + V(\phi)\right],$$

$$H_{|i} = -\frac{\kappa^2}{2}\Pi^\phi\phi_{|i},$$

Evolution equations

$$\dot{H} = -\frac{\kappa^2}{2}(\Pi^\phi)^2,$$

$$\dot{\Pi}^\phi + 3H\Pi^\phi + \frac{\partial V}{\partial\phi} = 0.$$

HAMILTON-JACOBI EQUATION

Constraint equations
$$\left(\frac{\partial H}{\partial t}\right)_{\phi} = 0, \quad \left(\frac{\partial \Pi^{\phi}}{\partial t}\right)_{\phi} = 0.$$

Then
$$H \equiv H(\phi(t, x^i)),$$

$$3H^2(\phi) = \frac{2}{\kappa^2}\left(\frac{\partial H}{\partial \phi}\right)^2 + \kappa^2 V(\phi)\,,$$

$$\dot{\phi} = -\frac{2}{\kappa^2}\left(\frac{\partial H}{\partial \phi}\right) = \Pi^{\phi}\,, \qquad \frac{\dot{a}}{a} = H(\phi)\,,$$

$$\dot{H} = -\frac{2}{\kappa^2}\left(\frac{\partial H}{\partial \phi}\right)^2 = -\frac{\kappa^2}{2}(\Pi^{\phi})^2\,,$$

SLOW-ROLL PARAMETERS

$$\epsilon \equiv -\frac{\dot{H}}{H^2} = \frac{2}{\kappa^2}\left(\frac{H'(\phi)}{H(\phi)}\right)^2 = -\frac{\partial \ln H}{\partial \ln a},$$

$$\delta \equiv -\frac{\ddot{\phi}}{H\dot{\phi}} = \frac{2}{\kappa^2}\left(\frac{H''(\phi)}{H(\phi)}\right) = -\frac{\partial \ln H'}{\partial \ln a},$$

The scalar field φ acts as a new "time"

$$N_e \equiv \ln \frac{a_{\rm end}}{a(t)} = \int_t^{t_{\rm end}} H dt = -\frac{\kappa^2}{2}\int_\phi^{\phi_{\rm end}} \frac{H(\phi)d\phi}{H'(\phi)}$$

The number of "e"-folds N_e to the end inflation

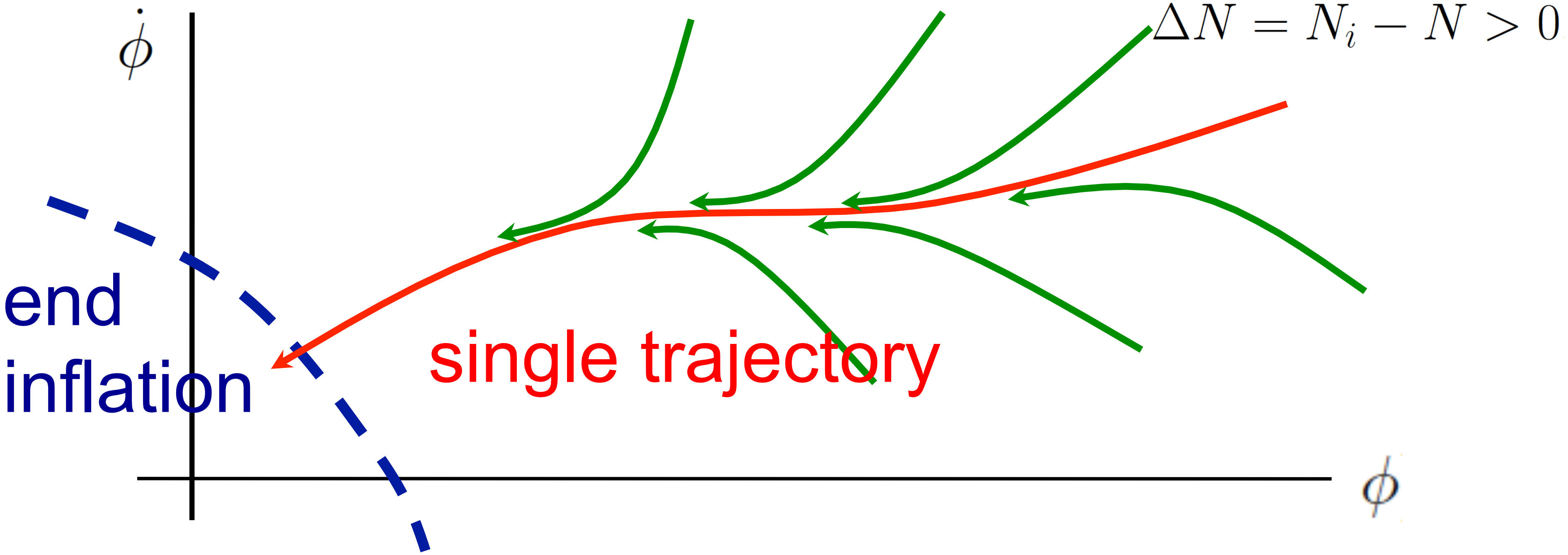
SLOW-ROLL ATTRACTOR

$H_0(\phi)$ exact particular solution

$H(\phi) = H_0(\phi) + \delta H(\phi)$ linear perturbation

Then $H_0'(\phi)\,\delta H'(\phi) = (3\kappa^2/2)\,H_0\delta H$ with solution:

$$\delta H(\phi) = \delta H(\phi_i)\,\exp\left(\frac{3\kappa^2}{2}\int_{\phi_i}^{\phi}\frac{H_0(\phi)d\phi}{H_0'(\phi)}\right) = \delta H(\phi_i)\,\exp(-3\Delta N)$$



SLOW-ROLL APPROXIMATION

$$H^2\left(1-\frac{\epsilon}{3}\right) \;\simeq\; H^2 \;=\; \frac{\kappa^2}{3}V(\phi)\,,$$

$$3H\dot{\phi}\left(1-\frac{\delta}{3}\right) \;\simeq\; 3H\dot{\phi} \;=\; -V'(\phi)$$

just dynamics

$$\epsilon \;=\; \frac{2}{\kappa^2}\left(\frac{H'(\phi)}{H(\phi)}\right)^2 \;\simeq\; \frac{1}{2\kappa^2}\left(\frac{V'(\phi)}{V(\phi)}\right)^2 \;\equiv\; \epsilon_V \ll\; 1\,,$$

$$\delta \;=\; \frac{2}{\kappa^2}\frac{H''(\phi)}{H(\phi)} \;\simeq\; \frac{1}{\kappa^2}\frac{V''(\phi)}{V(\phi)} - \frac{1}{2\kappa^2}\left(\frac{V'(\phi)}{V(\phi)}\right)^2 \;\equiv\; \eta_V - \epsilon_V \;\ll\; 1\,,$$

$$\xi \;=\; \frac{4}{\kappa^4}\frac{H'(\phi)H'''(\phi)}{H^2(\phi)} \;\simeq\; \frac{1}{\kappa^4}\frac{V'(\phi)V'''(\phi)}{V^2(\phi)} - \frac{3}{2\kappa^4}\frac{V''(\phi)}{V(\phi)}\left(\frac{V'(\phi)}{V(\phi)}\right)^2$$

$$+\; \frac{3}{4\kappa^4}\left(\frac{V'(\phi)}{V(\phi)}\right)^4 \;\equiv\; \xi_V - 3\eta_V\epsilon_V + 3\epsilon_V^2 \;\ll\; 1\,.$$

$$N \;\simeq\; \int_{\phi_i}^{\phi_e}\frac{\kappa\, d\phi}{\sqrt{2\epsilon_V(\phi)}} \;=\; \kappa^2\int_{\phi_i}^{\phi_e}\frac{V(\phi)\,d\phi}{V'(\phi)}\,,$$

INFLATIONARY SOLUTIONS OF HBBP

$$\rho = \frac{1}{2}\dot{\phi}^2 + V(\phi)\,,$$
$$p = \frac{1}{2}\dot{\phi}^2 - V(\phi)\,.$$

$$\dot{\rho} + 3H(\rho + p) = 0$$

$$V(\phi) \gg \dot{\phi}^2 \quad \Rightarrow \quad p \simeq -\rho \quad \Rightarrow \quad \rho \simeq \text{const.} \quad \Rightarrow \quad H(\phi) \simeq \text{const.}$$

$$a(t) \sim \exp(Ht) \quad \Rightarrow \quad \frac{\ddot{a}}{a} > 0 \quad \text{accelerated expansion}$$

$$x_0 = x_{\text{in}}\, e^{-2N}\, \frac{a_{\text{rh}}^2 \rho_{\text{rh}}}{a_{\text{end}}^2 \rho_{\text{end}}}\, \frac{T_{\text{rh}}^2}{T_{\text{eq}}^2} (1 + z_{\text{eq}}) \;\simeq\; e^{-2N}\, 10^{56} \le 1 \quad \Rightarrow \quad N \ge 65$$

$${}^{(3)}R = \frac{6K}{a^2} = {}^{(3)}R_{\text{in}}\, e^{-2N} \;\longrightarrow\; 0\,, \quad \rho_{\text{M}} \propto a^{-3} \sim e^{-3N} \;\longrightarrow\; 0\,,$$

$$\delta_k \sim \left(\frac{k}{aH}\right)^2 \Phi_k \propto e^{-2N} \;\longrightarrow\; 0\,, \quad \rho_{\text{R}} \propto a^{-4} \sim e^{-4N} \;\longrightarrow\; 0\,,$$

curvature matter

LINEAR METRIC PERTURBATIONS

$$ds^2 = a(\eta)^2 \left[-(1+2\Phi)d\eta^2 + (1-2\Phi)d\mathbf{x}^2 + h_{ij}\, dx^i dx^j\right]$$

linear pert. eqs.

$$\begin{aligned}
\Phi'' + 3\mathcal{H}\Phi' + (\mathcal{H}' + 2\mathcal{H}^2)\Phi &= \frac{\kappa^2}{2}[\phi'\delta\phi' - a^2V'(\phi)\delta\phi]\,,\\
-\nabla^2\Phi + 3\mathcal{H}\Phi' + (\mathcal{H}' + 2\mathcal{H}^2)\Phi &= -\frac{\kappa^2}{2}[\phi'\delta\phi' + a^2V'(\phi)\delta\phi]\,,\\
\Phi' + \mathcal{H}\Phi &= \frac{\kappa^2}{2}\phi'\delta\phi\,,\\
\delta\phi'' + 2\mathcal{H}\delta\phi' - \nabla^2\delta\phi + a^2V''(\phi)\delta\phi &= 4\phi'\Phi' - 2a^2V'(\phi)\Phi\,.
\end{aligned}$$

$$\begin{aligned}
u'' - \nabla^2 u - \frac{z''}{z}u &= 0\,,\\
\nabla^2\Phi &= \frac{\kappa^2}{2}\frac{\mathcal{H}}{a^2}(zu' - z'u)\,,\\
\left(\frac{a^2\Phi}{\mathcal{H}}\right)' &= \frac{\kappa^2}{2}zu\,.
\end{aligned}$$

Mukhanov variables

$$\begin{aligned}
u &\equiv a\delta\phi + z\Phi\,,\\
z &\equiv a\frac{\phi'}{\mathcal{H}}\,.
\end{aligned}$$

QUANTUM FLUCTUATIONS IN dS

$$\delta S = \frac{1}{2}\int d^3x\, d\eta \left[(u')^2 - (\nabla u)^2 + \frac{z''}{z}u^2\right]$$

$$\hat{u}(\eta, \mathbf{x}) = \int \frac{d^3\mathbf{k}}{(2\pi)^{3/2}}\left[u_k(\eta)\, \hat{a}_\mathbf{k}\, e^{i\mathbf{k}\cdot\mathbf{x}} + u_k^*(\eta)\, \hat{a}_\mathbf{k}^\dagger\, e^{-i\mathbf{k}\cdot\mathbf{x}}\right],$$

scalar field's Fock space

$$[\hat{a}_\mathbf{k}, \hat{a}_{\mathbf{k}'}^\dagger] = \delta^3(\mathbf{k} - \mathbf{k}'),$$
$$\hat{a}_\mathbf{k}|0\rangle = 0.$$

equal-time commutation relations

$$[\hat{u}(\eta, \mathbf{x}), \hat{\Pi}_u^\dagger(\eta, \mathbf{x}')] = i\hbar\delta^3(\mathbf{x} - \mathbf{x}')$$

QUANTUM FLUCTUATIONS IN dS

normalization condition on the modes u_k

$$u_k\, u_k^{*\prime} - u_k^{\prime}\, u_k^{*} = i$$

the Wronskian of the mode equation

$$u_k^{\prime\prime} + \left(k^2 - \frac{z^{\prime\prime}}{z}\right) u_k = 0$$

Schrödinger like equation

$$-u_k^{\prime\prime} + U(\eta)\, u_k = k^2\, u_k$$

time-dependent potential

$$U(\eta) \;=\; z^{\prime\prime}/z$$

SOLUTIONS OF MODE EQUATIONS

slow-roll parameters

$$\epsilon = 1 - \frac{\mathcal{H}'}{\mathcal{H}^2} = \frac{\kappa^2}{2}\frac{z^2}{a^2},$$

$$\delta = 1 - \frac{\phi''}{\mathcal{H}\phi'} = 1 + \epsilon - \frac{z'}{\mathcal{H}z},$$

$$\xi = -\left(2 - \epsilon - 3\delta + \delta^2 - \frac{\phi'''}{\mathcal{H}^2\phi'}\right)$$

approx. constant

$$\epsilon' = 2\mathcal{H}\left(\epsilon^2 - \epsilon\delta\right) = \mathcal{O}(\epsilon^2),$$

$$\delta' = \mathcal{H}\left(\epsilon\delta - \xi\right) = \mathcal{O}(\epsilon^2).$$

for constant slow-roll parameters, we can write

$$\eta = \frac{-1}{\mathcal{H}} + \int \frac{\epsilon da}{a\mathcal{H}} \simeq \frac{-1}{\mathcal{H}}\frac{1}{1-\epsilon},$$

$$\frac{z''}{z} = \mathcal{H}^2\left[(1+\epsilon-\delta)(2-\delta) + \mathcal{H}^{-1}(\epsilon' - \delta')\right] \simeq \frac{1}{\eta^2}\left(\nu^2 - \frac{1}{4}\right),$$

where $\nu = \dfrac{1+\epsilon-\delta}{1-\epsilon} + \dfrac{1}{2}$

EXACT SOLUTIONS OF MODE EQS.

two asymptotic regimes,

$$u_k = \frac{1}{\sqrt{2k}} e^{-ik\eta} \qquad k \gg aH \qquad \text{Minkowsky}$$

$$u_k = C_1(k)\, z \qquad k \ll aH \qquad \text{superhorizon}$$

exact solution that connects the two regimes

$$u_k(\eta) = \frac{\sqrt{\pi}}{2} e^{i(\nu+\frac{1}{2})\frac{\pi}{2}} (-\eta)^{1/2} H_\nu^{(1)}(-k\eta)$$

where $H_\nu^{(1)}(z)$ is the Hankel function of the first kind

$$\text{e.g. } H_{3/2}^{(1)}(x) = -e^{ix}\sqrt{2/\pi x}(1 + i/x),$$

and ν is given by $\quad \nu = \dfrac{1+\epsilon-\delta}{1-\epsilon} + \dfrac{1}{2}$

EXACT SOLUTIONS OF MODE EQS.

limit $k\eta \to 0$, the solution becomes

$$|u_k| = \frac{2^{\nu-\frac{3}{2}}}{\sqrt{2k}} \frac{\Gamma(\nu)}{\Gamma(\frac{3}{2})} (-k\eta)^{\frac{1}{2}-\nu} \equiv \frac{C(\nu)}{\sqrt{2k}} \left(\frac{k}{aH}\right)^{\frac{1}{2}-\nu},$$

$$C(\nu) = 2^{\nu-\frac{3}{2}} \frac{\Gamma(\nu)}{\Gamma(\frac{3}{2})} (1-\epsilon)^{\nu-\frac{1}{2}} \simeq 1 \qquad \text{for} \quad \epsilon, \delta \ll 1$$

compute Φ and $\delta\phi$ from the super-Hubble-scale mode

$$\Phi = C_1 \left(1 - \frac{\mathcal{H}}{a^2} \int a^2 d\eta\right) + C_2 \frac{\mathcal{H}}{a^2},$$

$$\frac{\delta\phi}{\phi'} = \frac{C_1}{a^2} \int a^2 d\eta - \frac{C_2}{a^2}.$$

C_1 growing mode

C_2 decaying mode

SCALAR CURVATURE PERTURBATIONS

gauge invariant quantity *constant* for superhorizon modes of adiabatic perturbations,

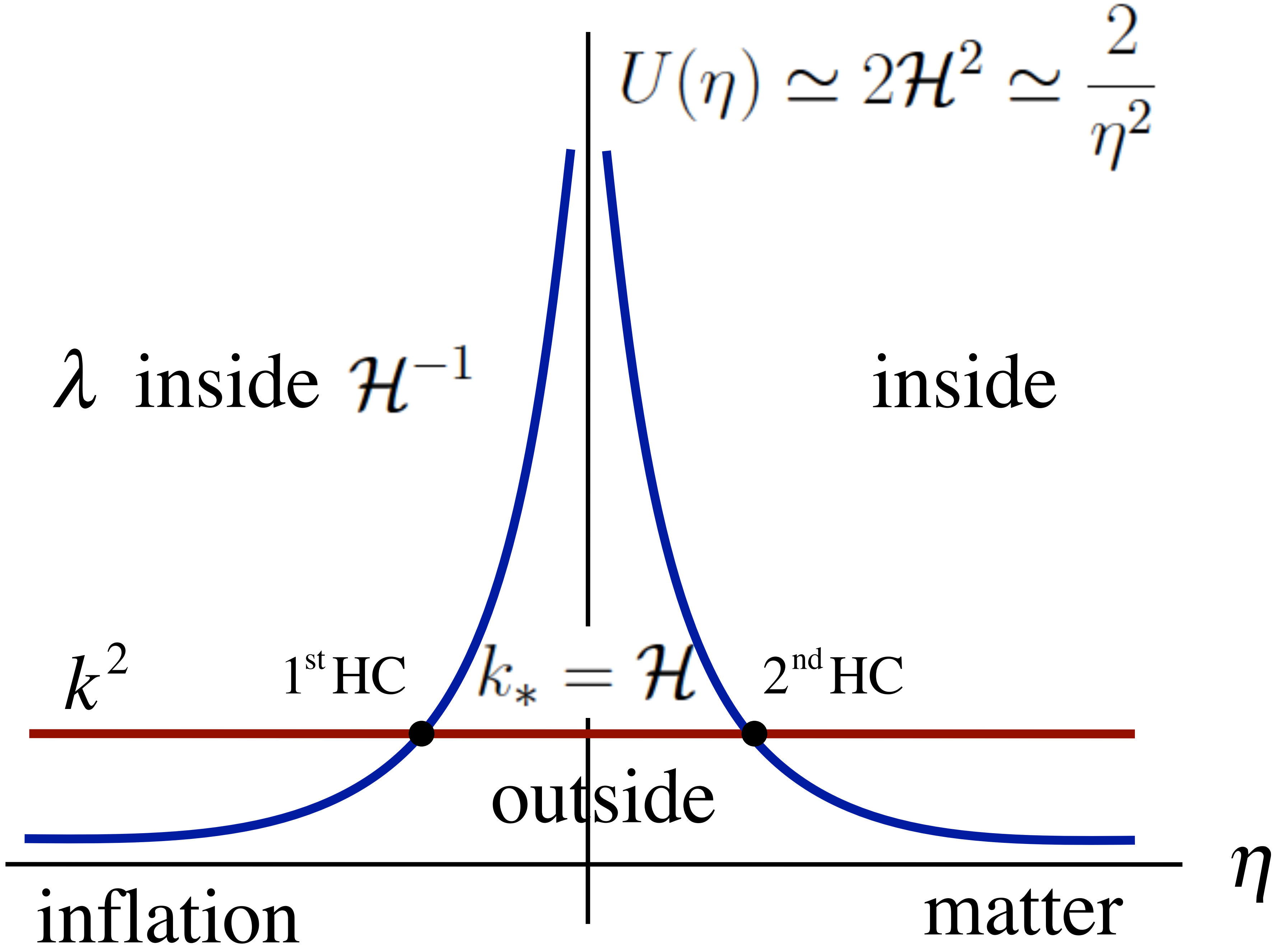
$$\zeta \equiv \Phi + \frac{1}{\epsilon \mathcal{H}} \left(\Phi' + \mathcal{H}\Phi \right) = \frac{u}{z} \,,$$

ζ is the gauge invariant curvature perturbation $\mathcal{R}_c$ on constant energy density hypersurfaces,

$$\zeta = \mathcal{R}_c + \frac{1}{\epsilon \mathcal{H}^2} \nabla^2 \Phi$$

$$\zeta' = \frac{1}{\epsilon \mathcal{H}} \nabla^2 \Phi \simeq 0 \qquad \text{constant}$$

for (adiabatic) superhorizon modes, $k \ll aH$

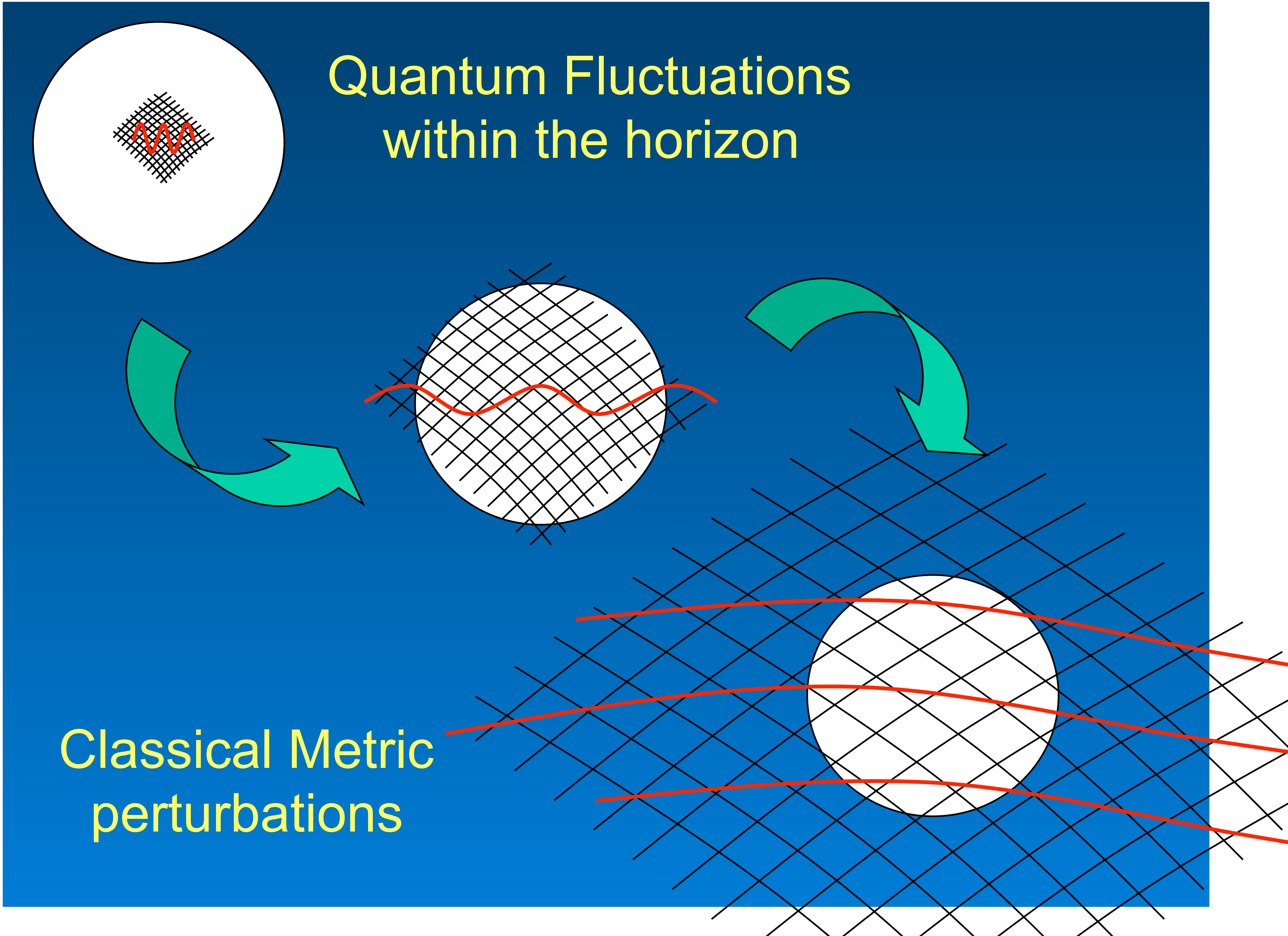

$U(\eta) \simeq 2\mathcal{H}^2 \simeq \frac{2}{\eta^2}$
λ inside $\mathcal{H}^{-1}$
inside
k^2
1st HC
$k_* = \mathcal{H}$
2nd HC
outside
η
inflation
matter

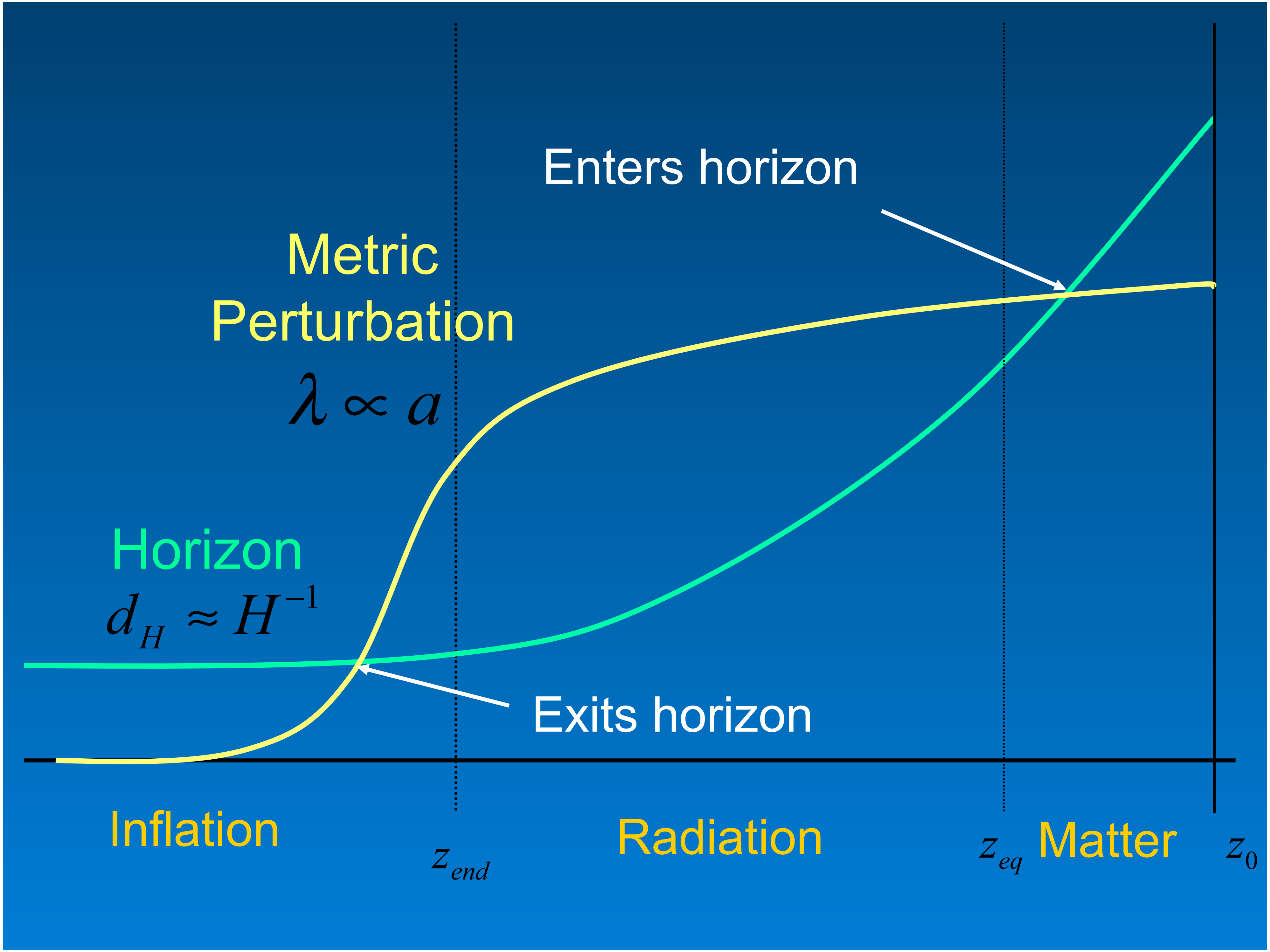
SCALAR CURVATURE PERTURBATIONS

Therefore, we can evaluate the Newtonian potential Φ_k when the perturbation reenters the horizon during radiation/matter eras in terms of the curvature perturbation $\mathcal{R}_k$ when it left the Hubble scale during inflation,

$$\Phi_k = \left(1 - \frac{\mathcal{H}}{a^2} \int a^2 d\eta\right) \mathcal{R}_k = \frac{3+3\omega}{5+3\omega} \mathcal{R}_k = \begin{cases} \frac{2}{3} \mathcal{R}_k & \text{radiation era}\,, \\ \frac{3}{5} \mathcal{R}_k & \text{matter era}\,. \end{cases}$$

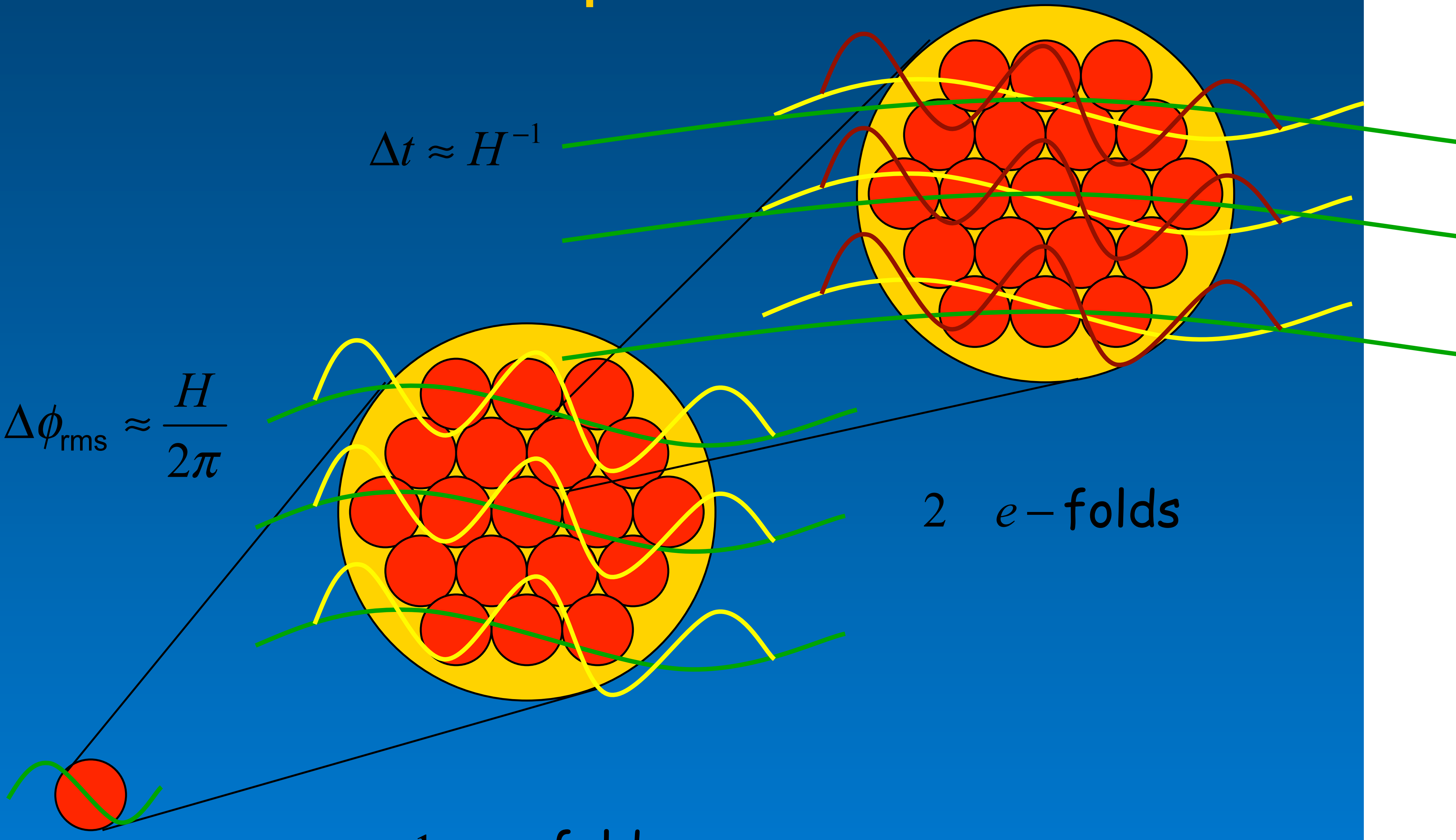
These expressions will be of special importance later.

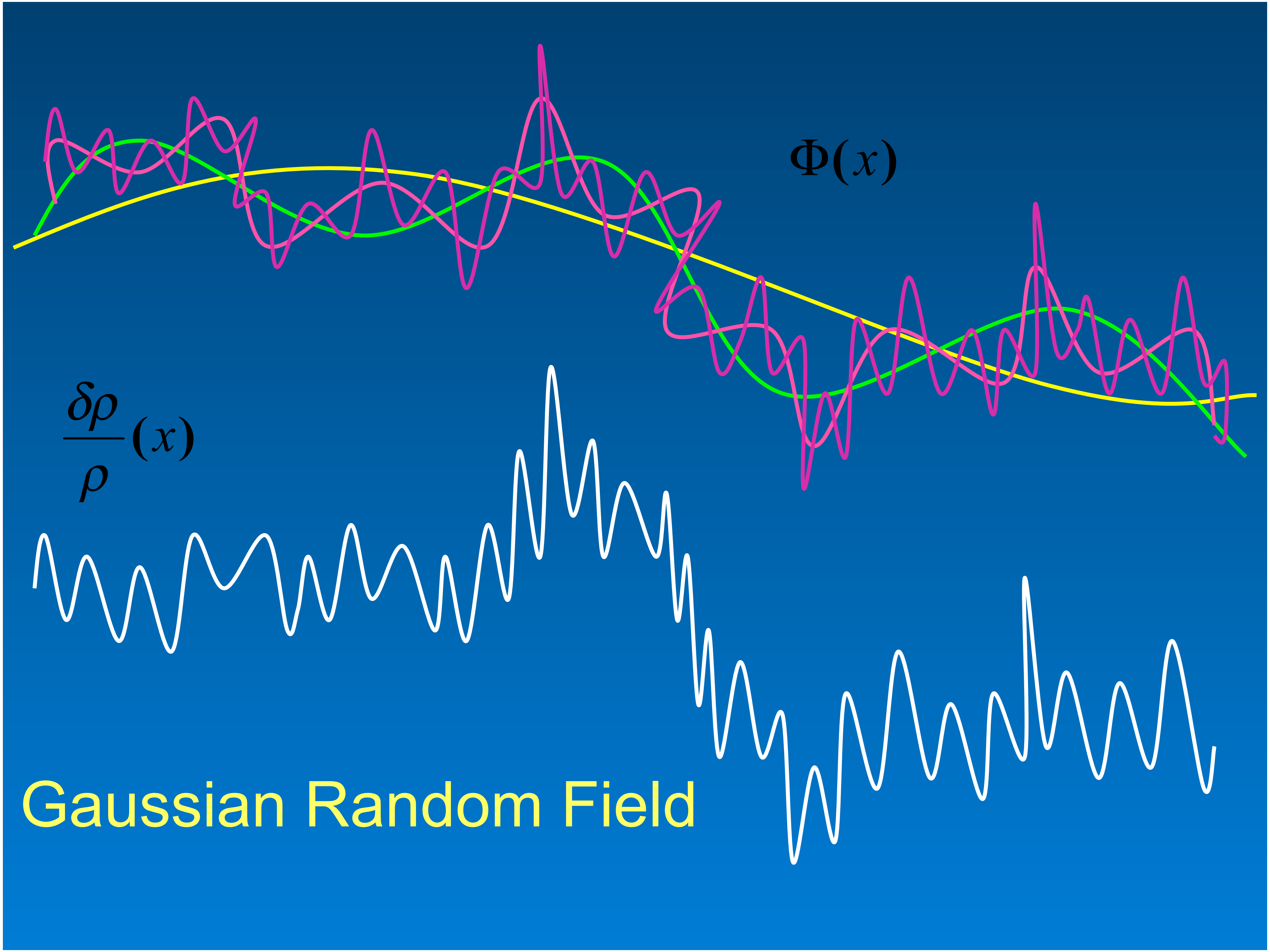

Quantum Fluctuations
within the horizon
Classical Metric
perturbations



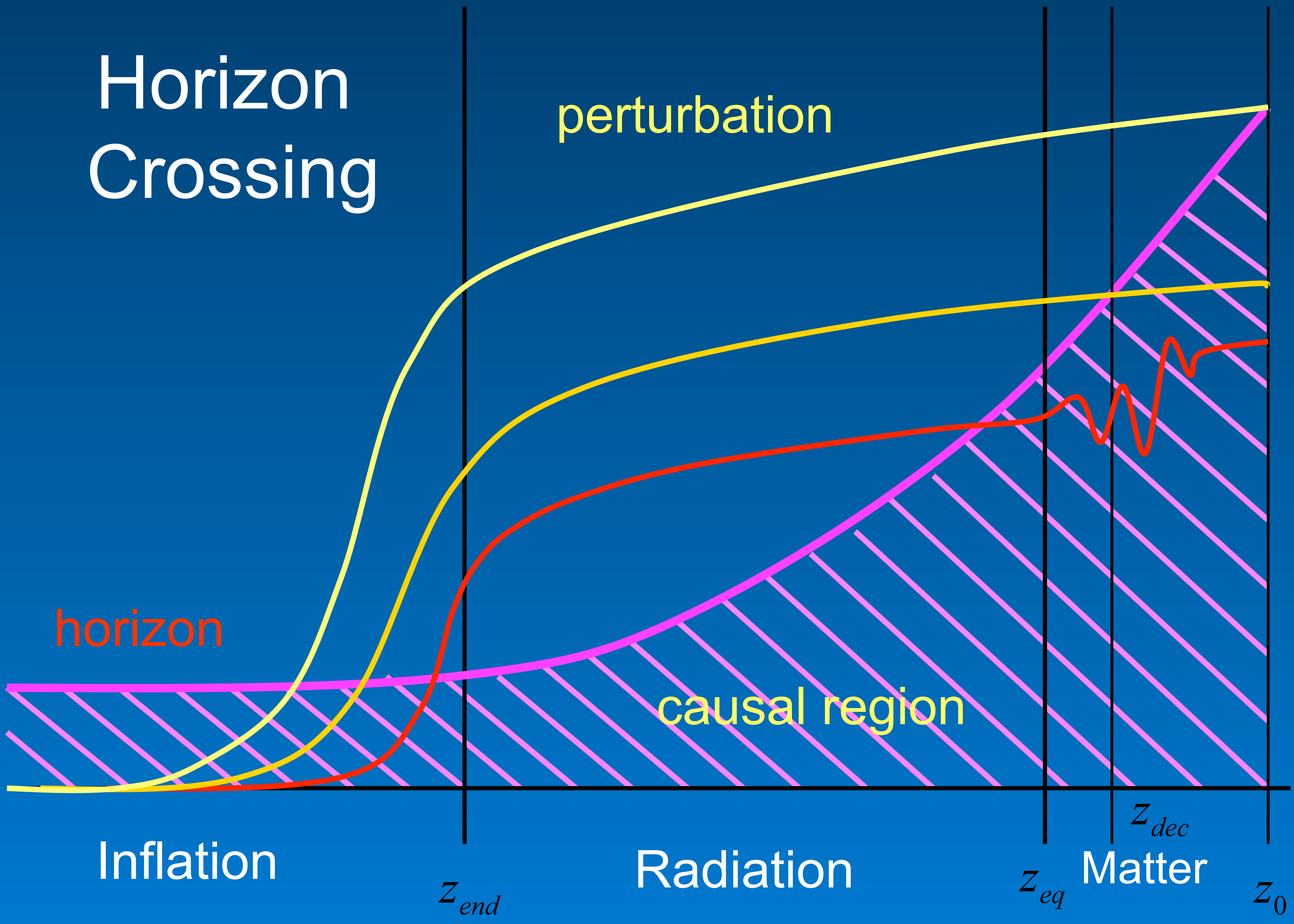
Enters horizon
Metric
Perturbation
$\lambda \propto a$
Horizon
$d_H \approx H^{-1}$
Exits horizon
Inflation
z_{end}
Radiation
z_{eq}
Matter
z_0

Scale Invariant Spectrum

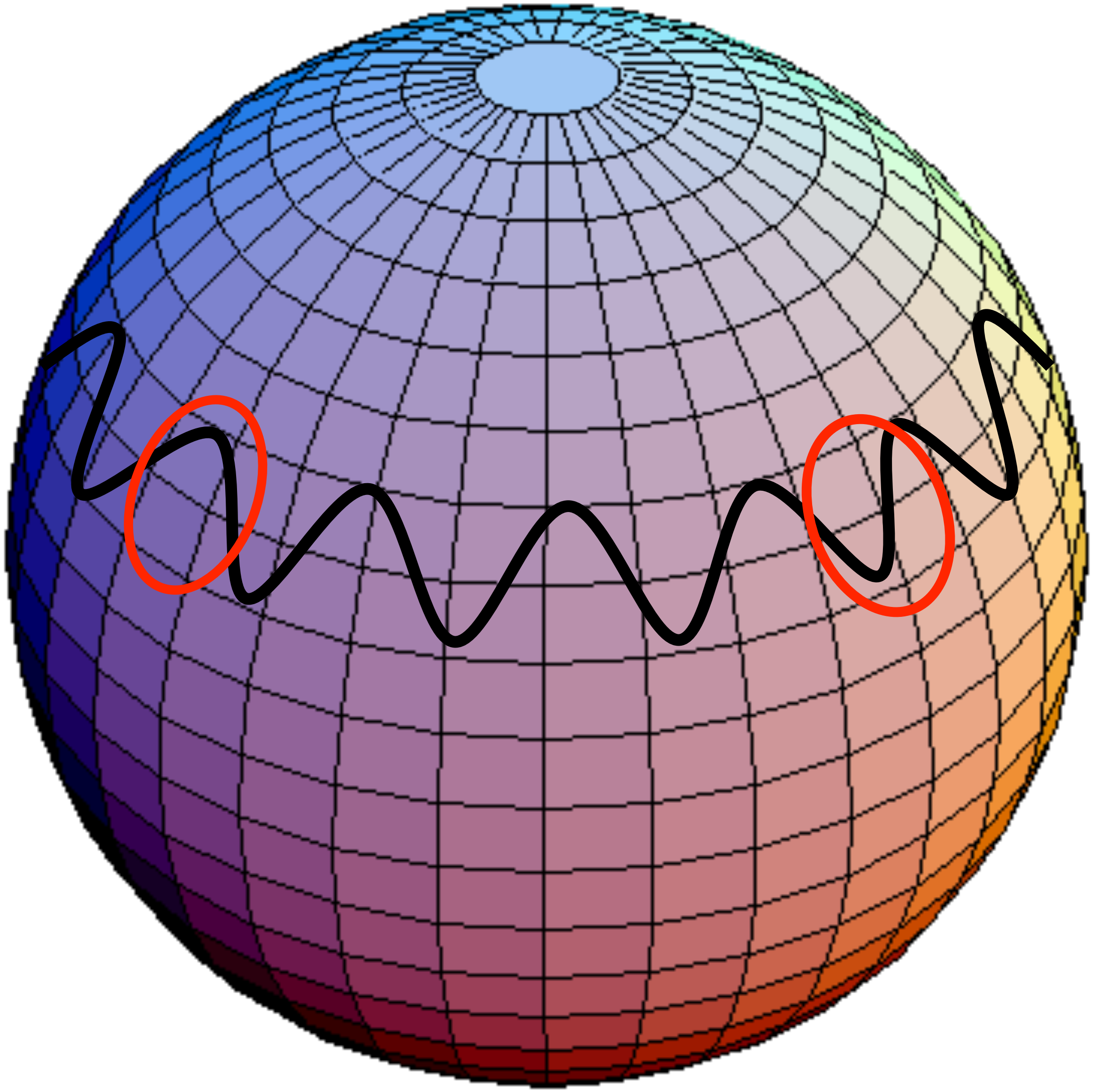


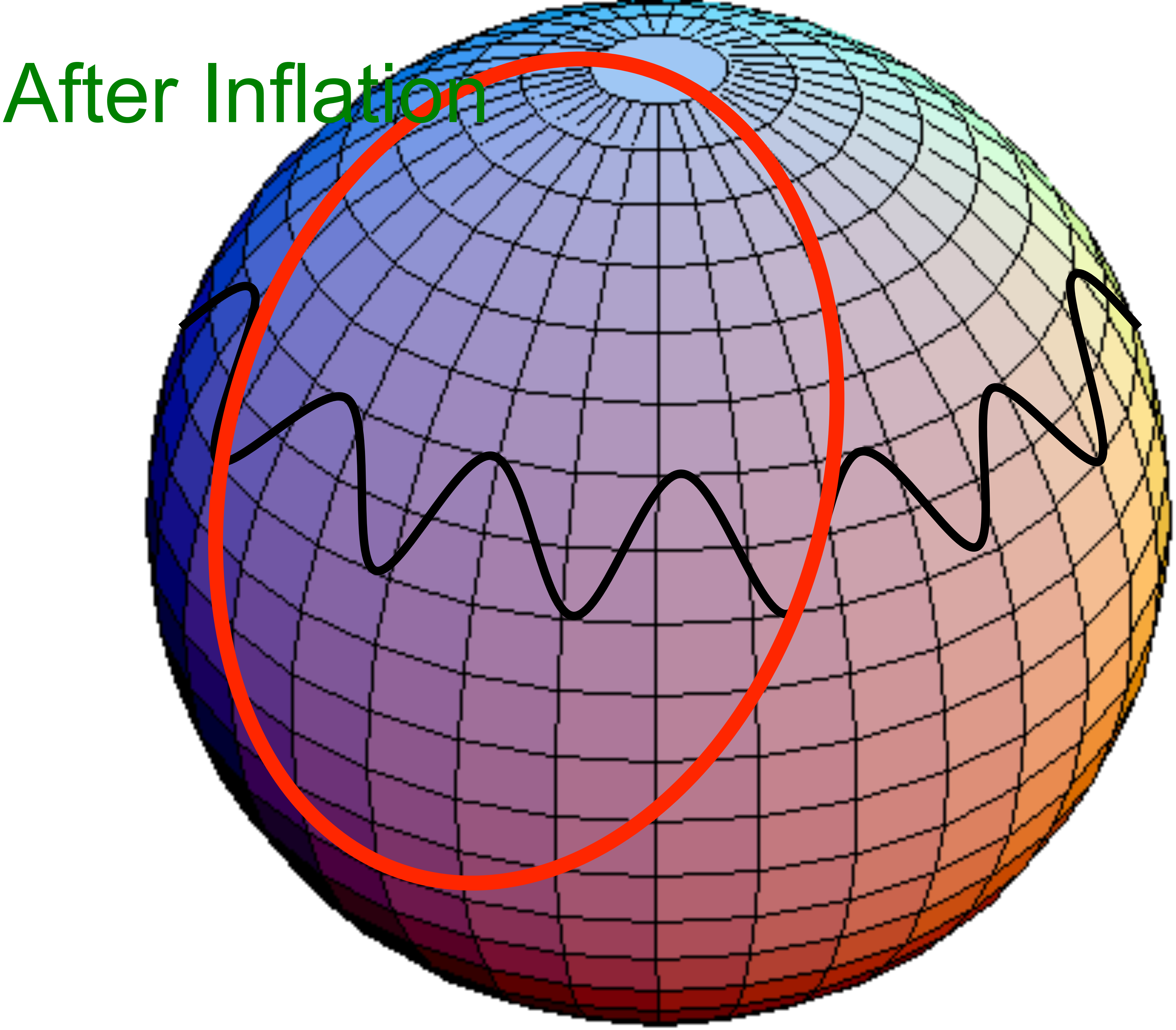

$\Phi(x)$
$\frac{\delta\rho}{\rho}(x)$
Gaussian Random Field

Horizon Crossing

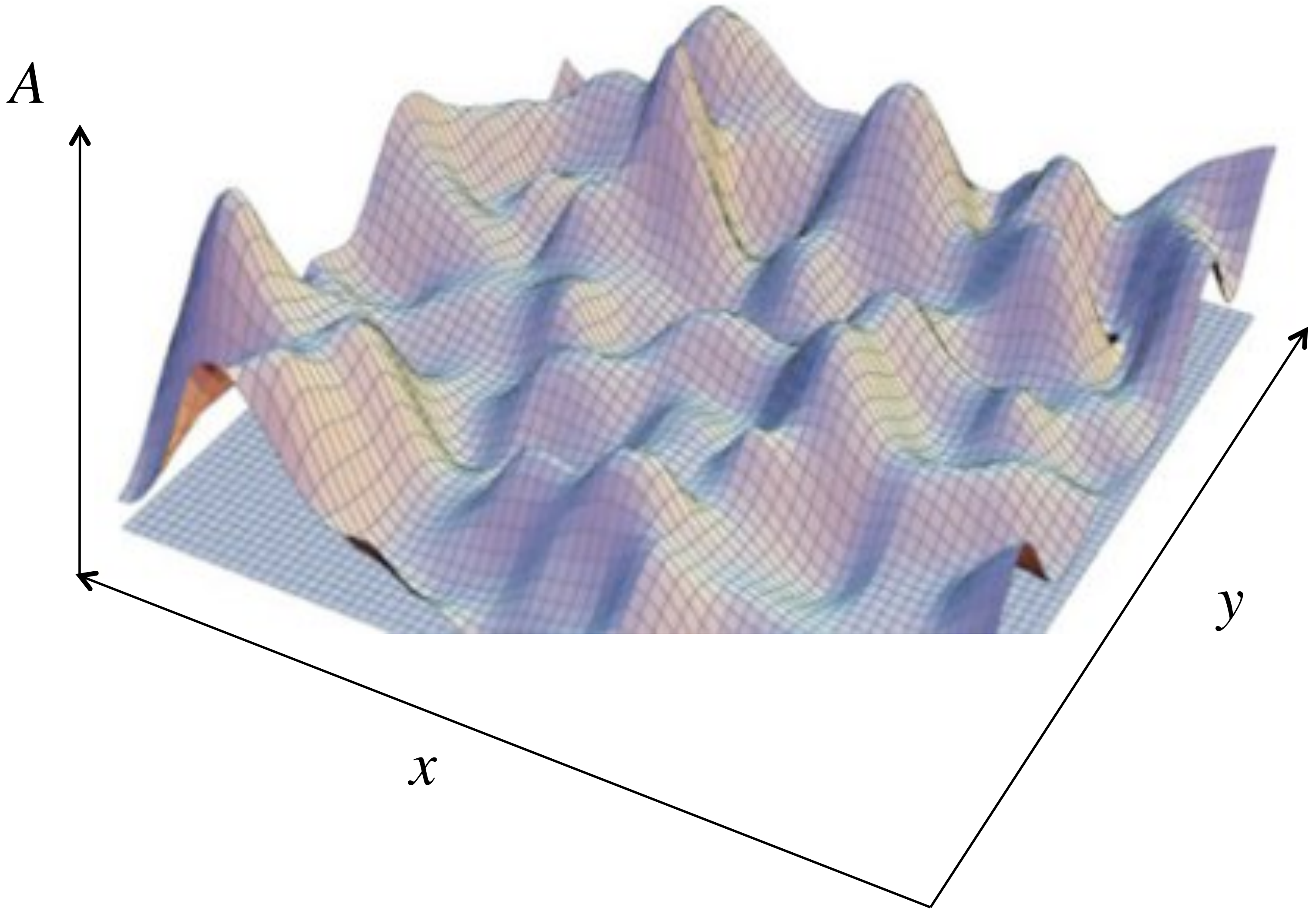


During Inflation




After Inflation

Ripples in Space



Stretched to cosmological distances

GRAVITATIONAL WAVE PERTURBATIONS

$$\delta S = \frac{1}{2}\int d^3x\, d\eta\, \frac{a^2}{2\kappa^2}\Big[(h'_{ij})^2 - (\nabla h_{ij})^2\Big]$$

tensor field h_{ij} considered as a quantum field,

$$\hat{h}_{ij}(\eta, \mathbf{x}) = \int \frac{d^3\mathbf{k}}{(2\pi)^{3/2}} \sum_{\lambda=1,2} \Big[h_k(\eta)\, e_{ij}(\mathbf{k}, \lambda)\, \hat{a}_{\mathbf{k},\lambda}\, e^{i\mathbf{k}\cdot\mathbf{x}} + h.c.\Big]\,,$$

$e_{ij}(\mathbf{k}, \lambda)$ are the two polarization tensors,

satisfying symmetric, transverse and traceless conditions

$$e_{ij} = e_{ji}\,, \quad k^i e_{ij} = 0\,, \quad e_{ii} = 0\,,$$

$$e_{ij}(-\mathbf{k}, \lambda) = e^*_{ij}(\mathbf{k}, \lambda)\,, \quad \sum_{\lambda} e^*_{ij}(\mathbf{k}, \lambda) e^{ij}(\mathbf{k}, \lambda) = 4\,,$$

TENSOR MODE EQUATION

gauge invariant tensor amplitude

$$v_k(\eta) = \frac{a}{\sqrt{2}\kappa} h_k(\eta)$$

decoupled in linear perturbation theory,

$$v_k'' + \left(k^2 - \frac{a''}{a}\right) v_k = 0$$

For constant slow-roll parameters, the potential becomes

$$\frac{a''}{a} = 2\mathcal{H}^2 \left(1 - \frac{\epsilon}{2}\right) = \frac{1}{\eta^2}\left(\mu^2 - \frac{1}{4}\right),$$

$$\mu = \frac{1}{1-\epsilon} + \frac{1}{2}.$$

EXACT SOLUTIONS

in the two asymptotic regimes,

$$v_k = \frac{1}{\sqrt{2k}} e^{-ik\eta} \qquad k \gg aH \qquad \text{Minkowsky}$$

$$v_k = C_3(k)\, a \qquad k \ll aH \qquad \text{superhorizon}$$

exact solutions

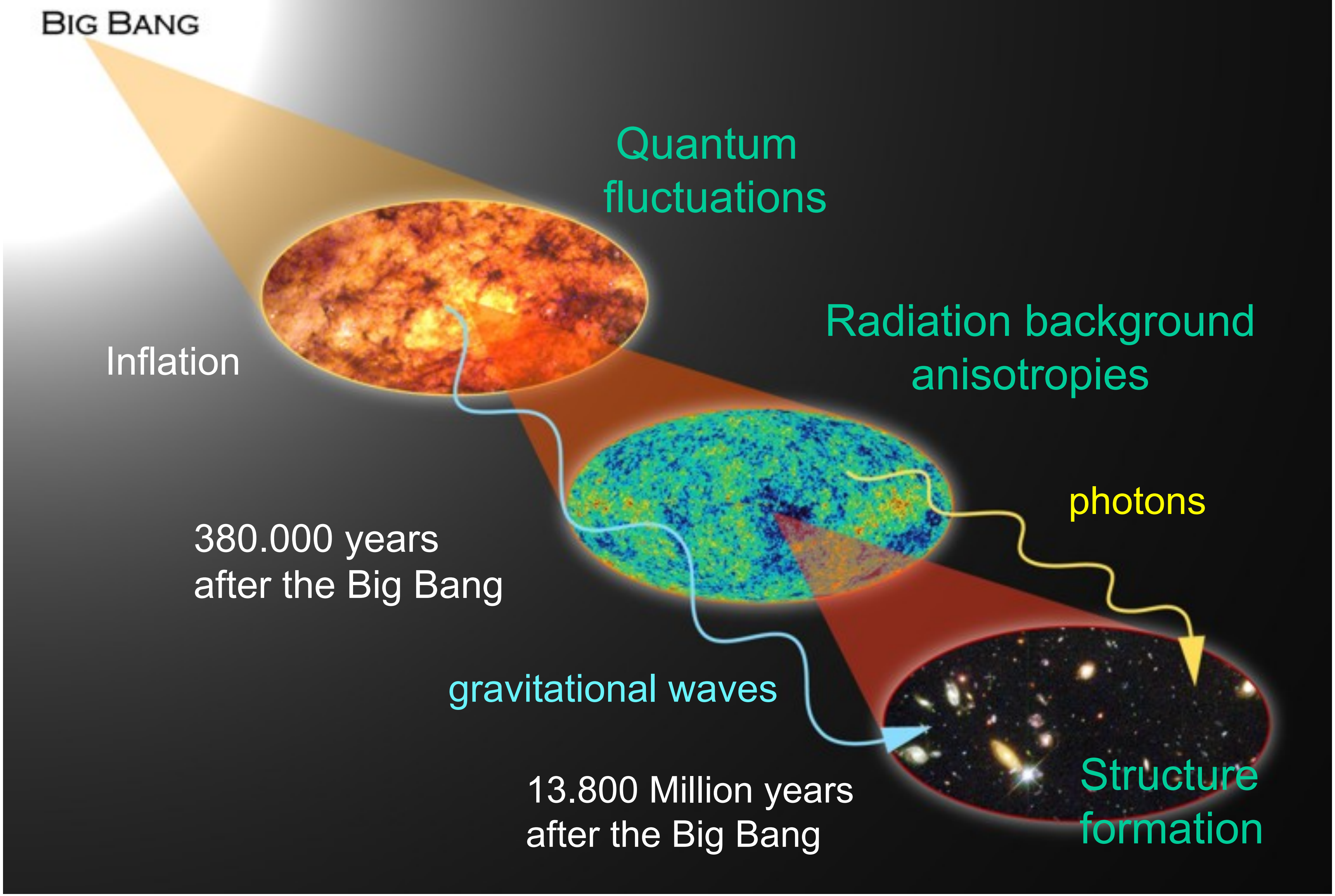
$$v_k(\eta) = \frac{\sqrt{\pi}}{2} e^{i(\mu+\frac{1}{2})\frac{\pi}{2}} (-\eta)^{1/2} H_\mu^{(1)}(-k\eta)$$

In the limit $k\eta \to 0$, $\quad |v_k| = \dfrac{C(\mu)}{\sqrt{2k}} \left(\dfrac{k}{aH}\right)^{\frac{1}{2}-\mu}$

Since h_k becomes constant on superhorizon scales,

evaluate the tensor metric perturbation when it reentered during the radiation or matter era directly in terms of its value during inflation.

Predictions of Inflation



Basic Inflationary Predictions

Geometry and matter:

- Homogeneity (acausal origin)
- Flat spatial sections (exp. growth)
- No appreciable topology (exp.growth)
- Origin matter & radiation (reheating)

Metric Perturbations:

- Gaussian spectrum (ground state)
- Aprox. scale invariant (slow roll cond.)
- Adiabatic density fluctuations (single fluid)
- Gravitational waves (tensor metric pert.)
- No vector perturbations (no defects)

Cosmological Observations

Cosmic Microwave Background:

- Temperature Anisotropies (WMAP9+Planck)
- Polarization Anisotropies (BICEP2+Planck)

Large Scale Structure:

- Matter Power Spectrum (2dFGRS+SDSS)
- Baryon Acoustic Oscillations (BOSS+DES)
- Weak Lensing (KIDS, DES, LSST, Euclid)