INFLATION WITHOUT SINGULARITY

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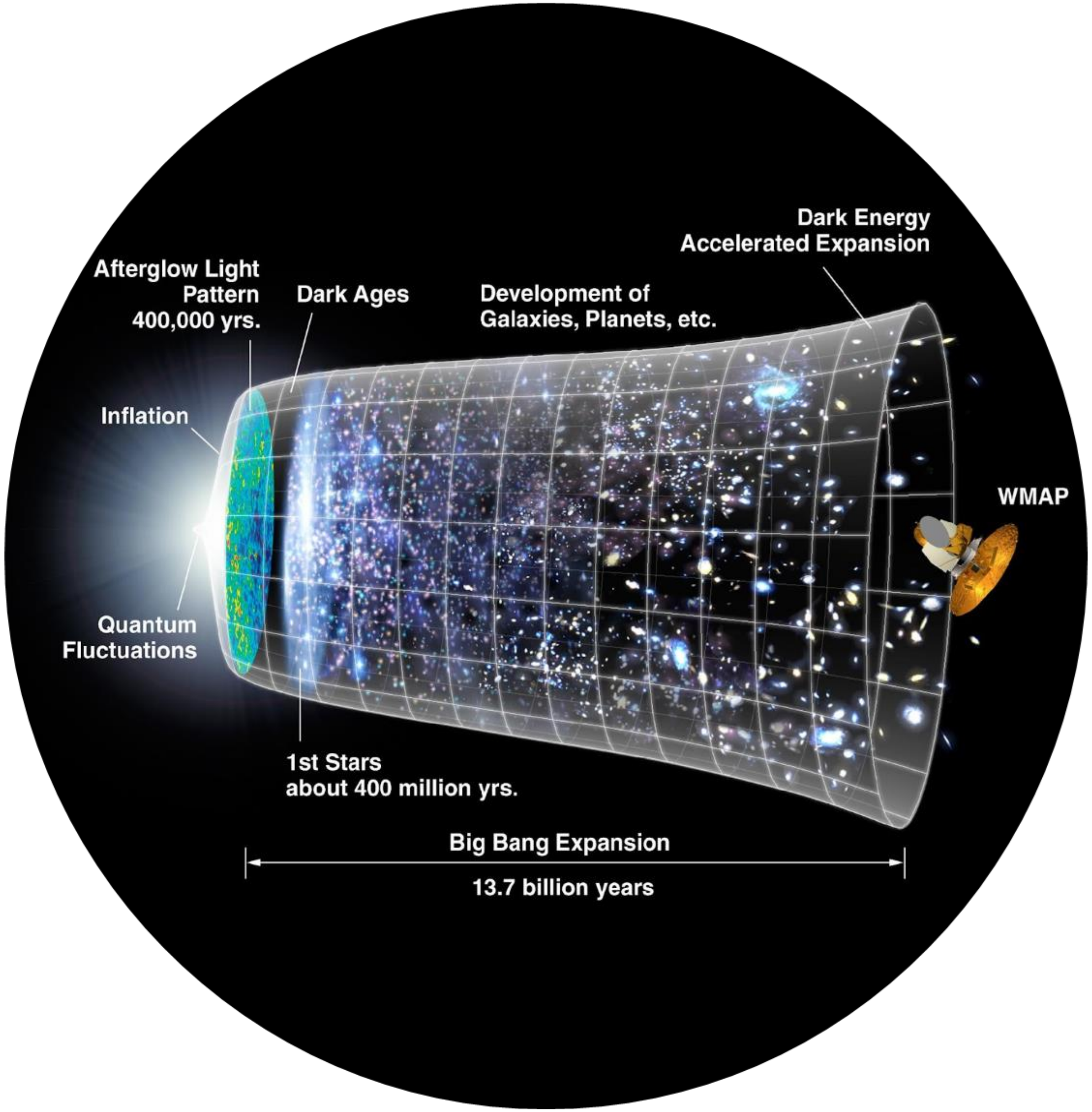

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OUTLINE

- Classic Inflation
- Inflation in closed Universe
- Horndesky theories
- Examples of stable solution
- Construction of our model
- Spectrum of scalar perturbation

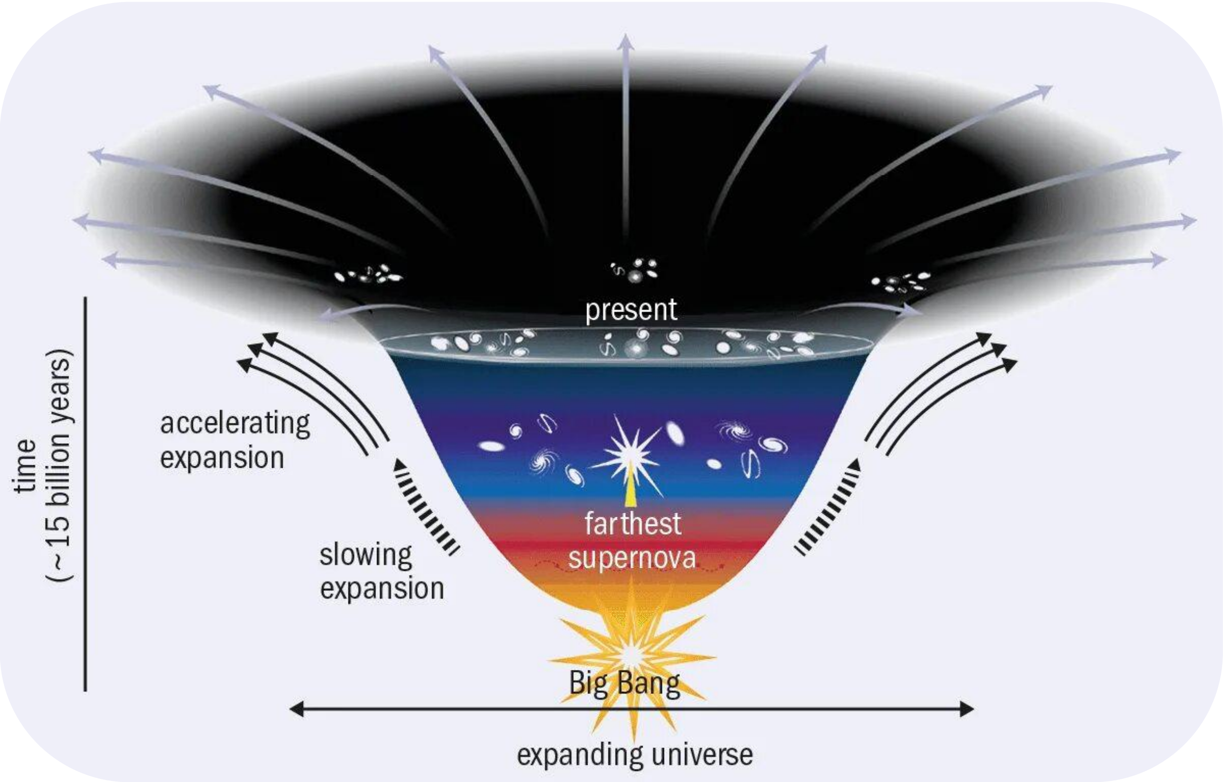
CLASSIC INFLATION

Explains:

- Large-scale structure
- CMB spectrum
- Isotropic of the Universe

But

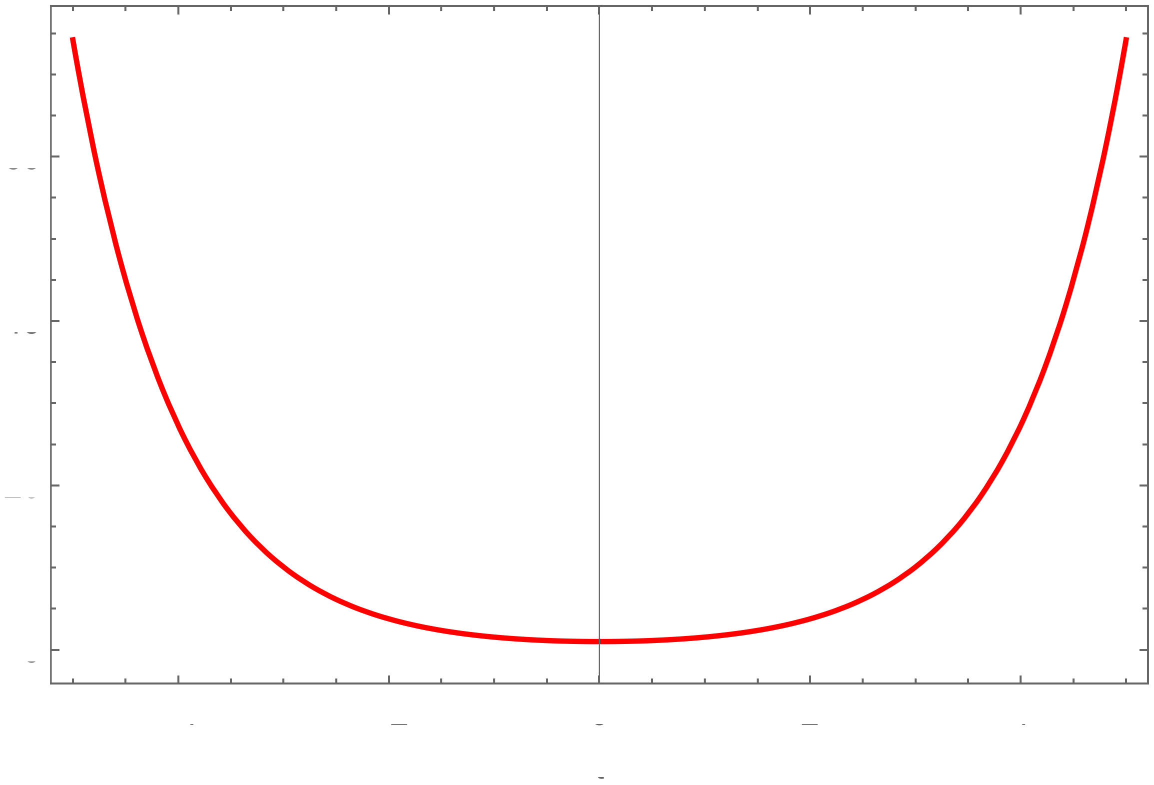
Initial singularity



GEOGRE ELLIS AND ROY MAARTENS MODEL

Features:

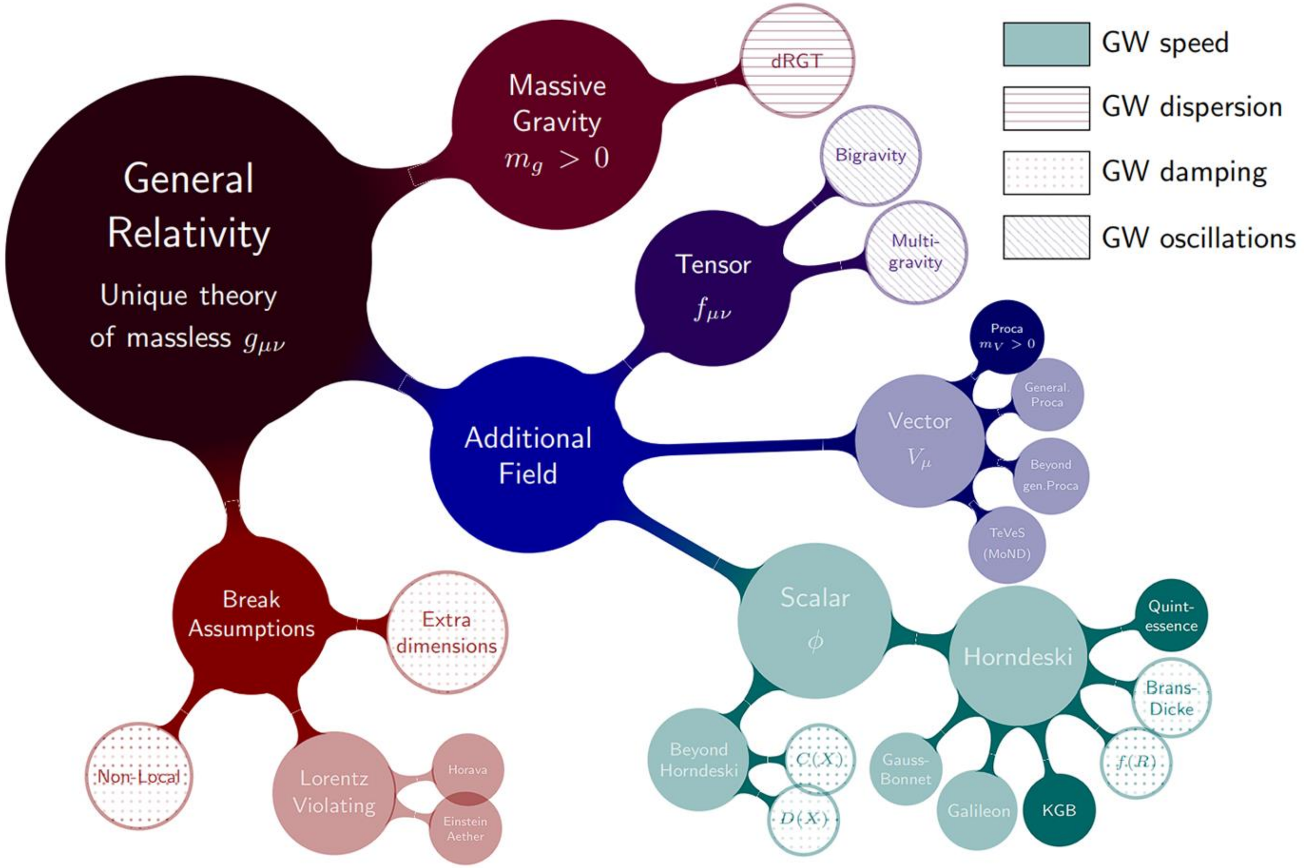
- Closed Universe
- Observation do not rule out a closed universe
- no singularity, no "beginning of time" and no horizon problem
- no quantum gravity era if initial radia is big
- Bounce solution



HOW AND WHY TO MODIFY GRAVITY?

Motivation:

- Inflanton field
- Initial singularity
- Dark matter and energy
- Comparing with GR



Article: 1807.09241

HORNDESKY THEORIES

- Even 2nd derivatives doesn't lead to 3rd order PDE in EOM
- The most general scalar-tensor theory of gravity
- Simplest
- Reducing other modifications

$$S = \int d^4x \sqrt{-g} \left(\mathcal{L}_2 + \mathcal{L}_3 + \mathcal{L}_4 + \mathcal{L}_5 + \mathcal{L}_{\mathcal{BH}} \right)$$

$$\mathcal{L}_2 = F(\pi, X),$$

$$\mathcal{L}_3 = K(\pi, X)\Box\pi$$

$$\mathcal{L}_4 = -G_4(\pi, X)R + 2G_{4X}(\pi, X)\left[(\Box\pi)^2 - \pi_{;\mu\nu}\pi^{;\mu\nu}\right]$$

$$\mathcal{L}_5 = G_5(\pi, X)G^{\mu\nu}\pi_{;\mu\nu} + \frac{1}{3}G_{5X}\left[(\Box\pi)^3 - 3\Box\pi\pi_{;\mu\nu}\pi^{;\mu\nu} + 2\pi_{;\mu\nu}\pi^{;\mu\rho}\pi^{\nu}_{;\rho}\right]$$

$$X = g^{\mu\nu}\pi_{,\mu}\pi_{,\nu}$$

HORNDESKY THEORIES

Conditions:

- Speed of sound for tensor and scalar perturbation
- NEC
- No ghosts, tachyons and exponential modes

$$\mathcal{G}_\mathcal{T} \geq \mathcal{F}_\mathcal{T} > \epsilon > 0, \quad \mathcal{G}_\mathcal{S} \geq \mathcal{F}_\mathcal{S} > \epsilon > 0.$$

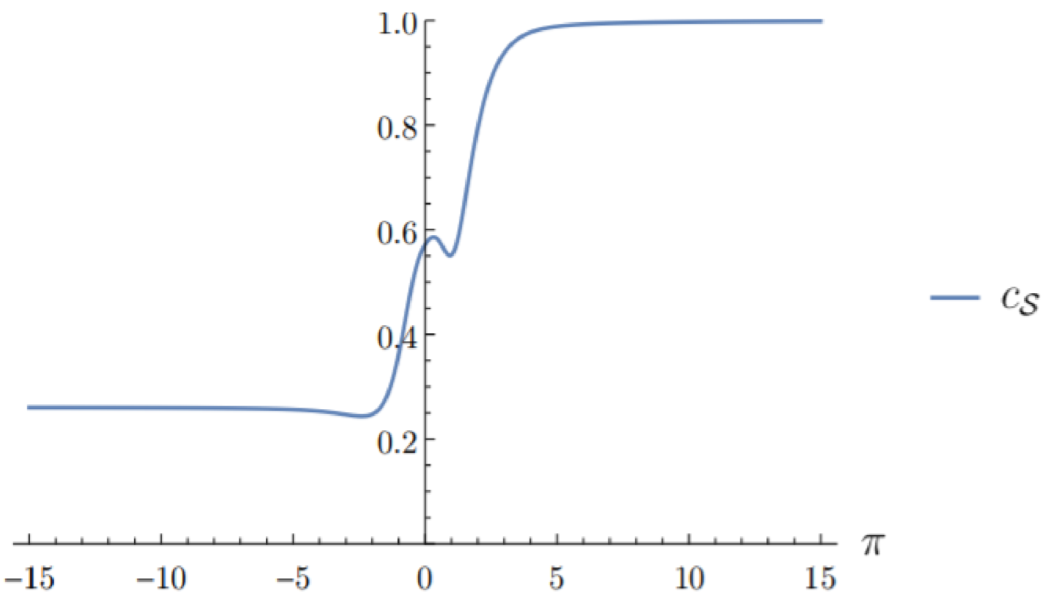
$$S = \int \mathrm{d}t\, \mathrm{d}^3x a^3 \left[\frac{\mathcal{G}_\mathcal{T}}{8}\left(\dot{h}^T_{ij}\right)^2 - \frac{\mathcal{F}_\mathcal{T}}{8a^2}\left(\partial_k h^T_{ij}\right)^2 + \right. \\ \left. +\mathcal{G}_\mathcal{S}\dot{\zeta}^2 - \mathcal{F}_\mathcal{S}\frac{(\nabla\zeta)^2}{a^2}\right]$$

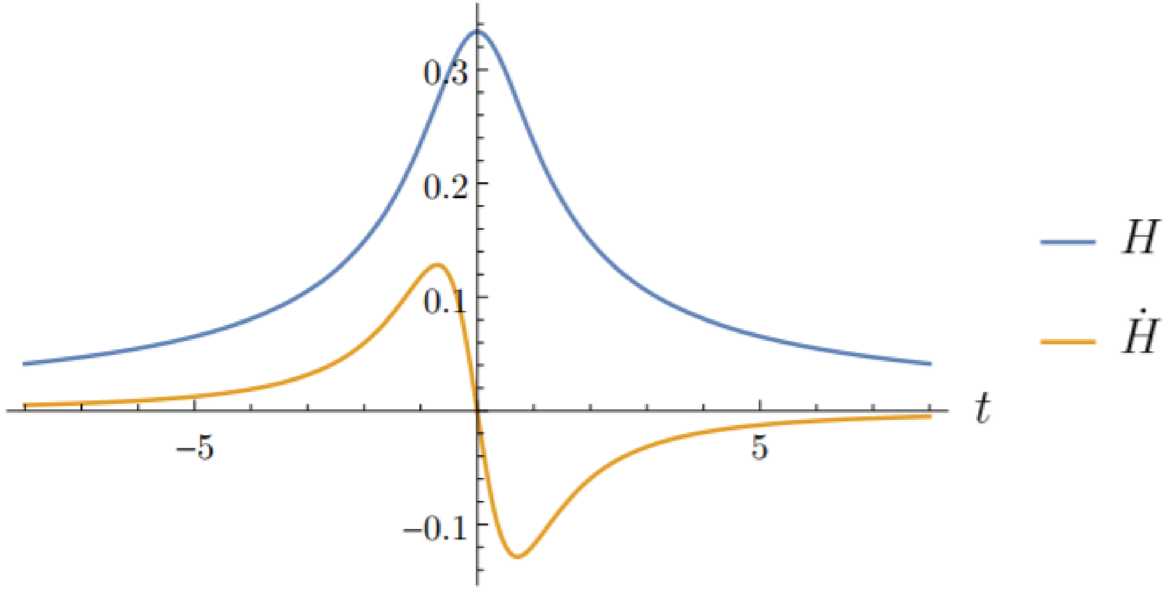
$$\delta g^{00}: \quad F - 2F_X X - 6HK_X X\dot{\pi} + K_\pi X + 6H^2 G_4 + \\ +6HG_{4\pi}\dot{\pi} - 24H^2 X\left(G_{4X} + G_{4XX}X\right) + 12HG_{4\pi X}X\dot{\pi} - \\ -6H^2X^2\left(5F_4 + 2F_{4X}X\right) = 0$$

$$\delta g^{ii}: \quad F - X\left(2K_X\ddot{\pi} + K_\pi\right) + 2\left(3H^2 + 2\dot{H}\right)G_4 - \\ -12H^2 G_{4X}X - 8\dot{H}G_{4X}X - 8HG_{4X}\ddot{\pi}\dot{\pi} - \\ -16HG_{4XX}X\ddot{\pi}\dot{\pi} + 2(\ddot{\pi} + 2H\dot{\pi})G_{4\pi} + \\ +4XG_{4\pi X}(\ddot{\pi} - 2H\dot{\pi}) + 2XG_{4\pi\pi} - 2F_4 X\left(3H^2 X + \right. \\ \left. +2\dot{H}X + 8H\ddot{\pi}\dot{\pi}\right) - 8HF_{4X}X^2\ddot{\pi}\dot{\pi} - \\ -4HF_{4\pi}X^2\dot{\pi} = 0$$

Article: 1705.06626

BOUNCING COSMOLOGY





$$c_{\mathcal{T}}^2 = \frac{\mathcal{F}_{\mathcal{T}}}{\mathcal{G}_{\mathcal{T}}}, \quad c_{\mathcal{S}}^2 = \frac{\mathcal{F}_{\mathcal{S}}}{\mathcal{G}_{\mathcal{S}}}.$$

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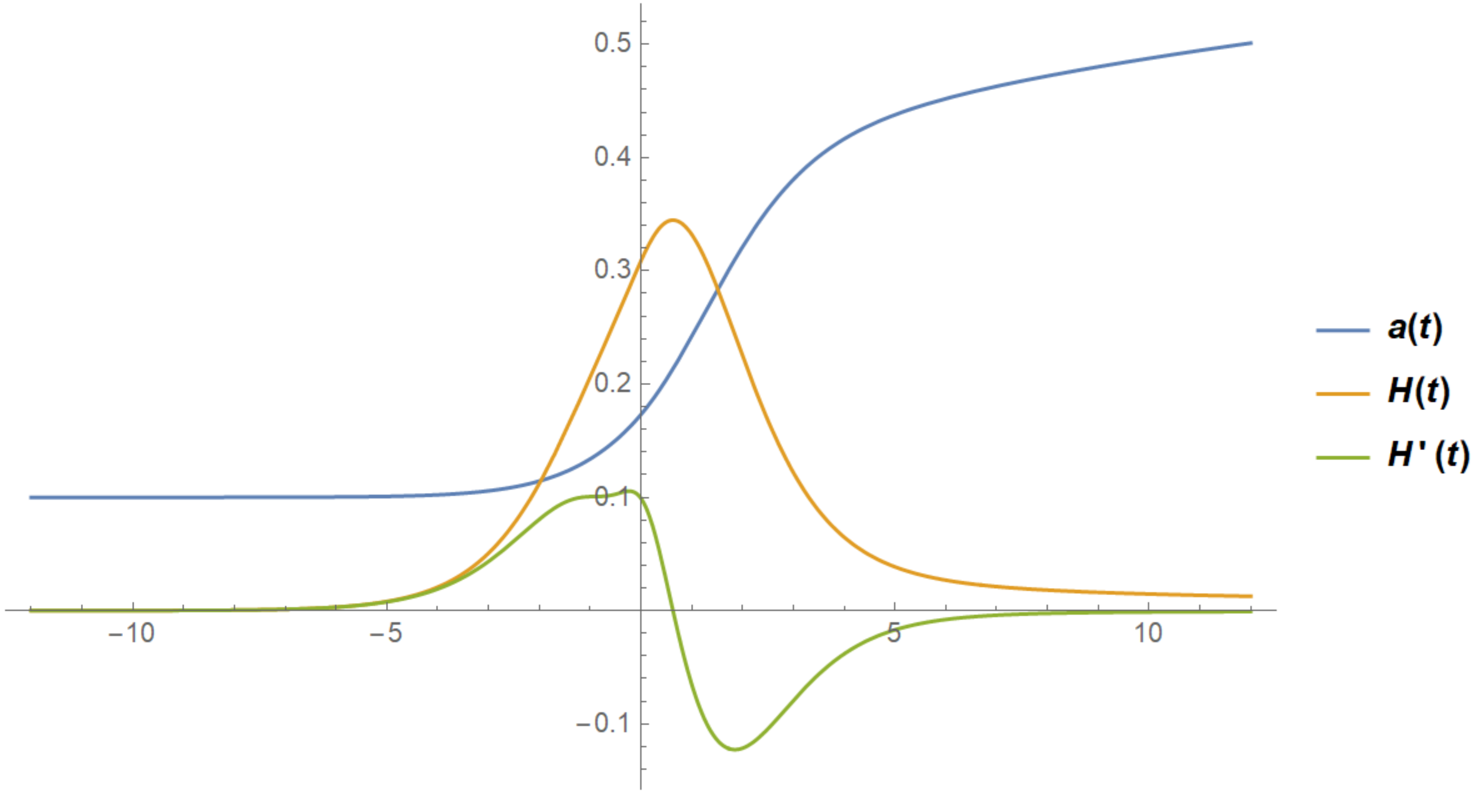
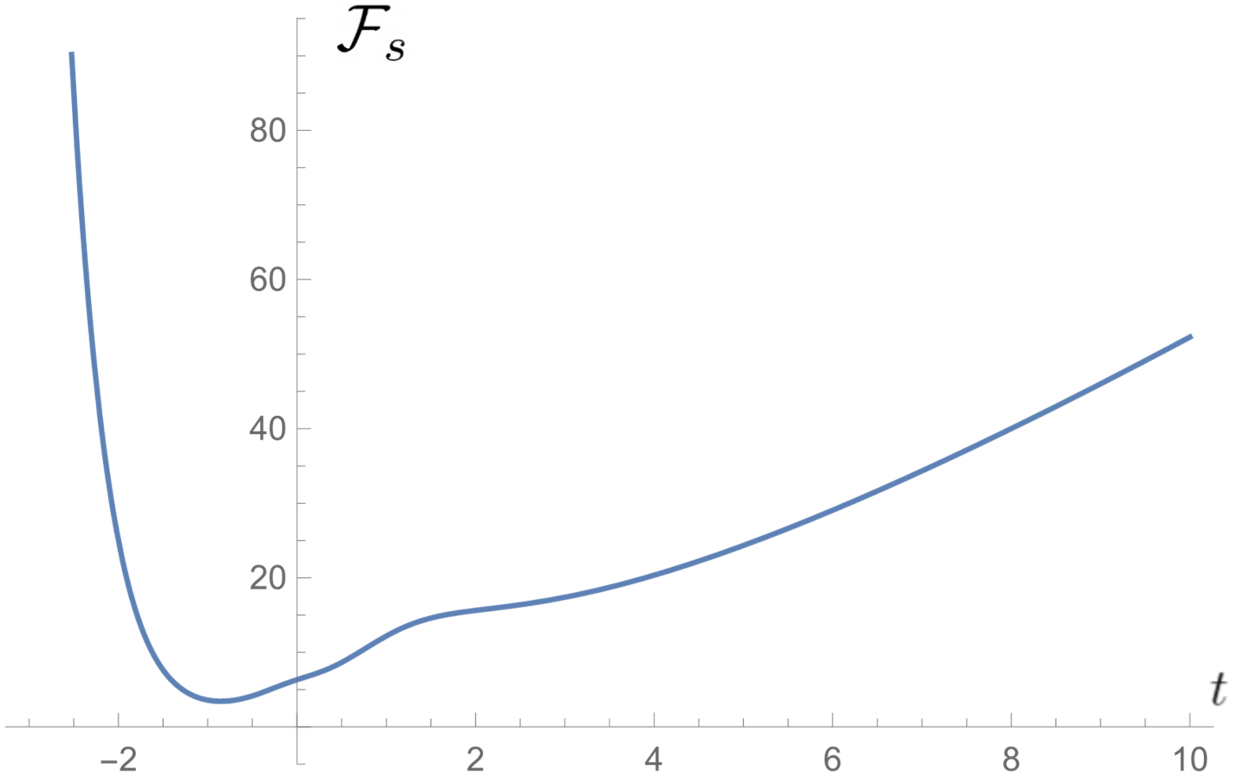
GENESIS TO KINATION THROUGH INFLATION



Summery of model:

- Closed Universe
- No NEC violating
- Analog of Genesis
- Initial radius more than Planck scale
- About 25 e-foldings
- leading to a Universe dominated by a massless scalar field

CLOSED UNIVERSE. STABILITY

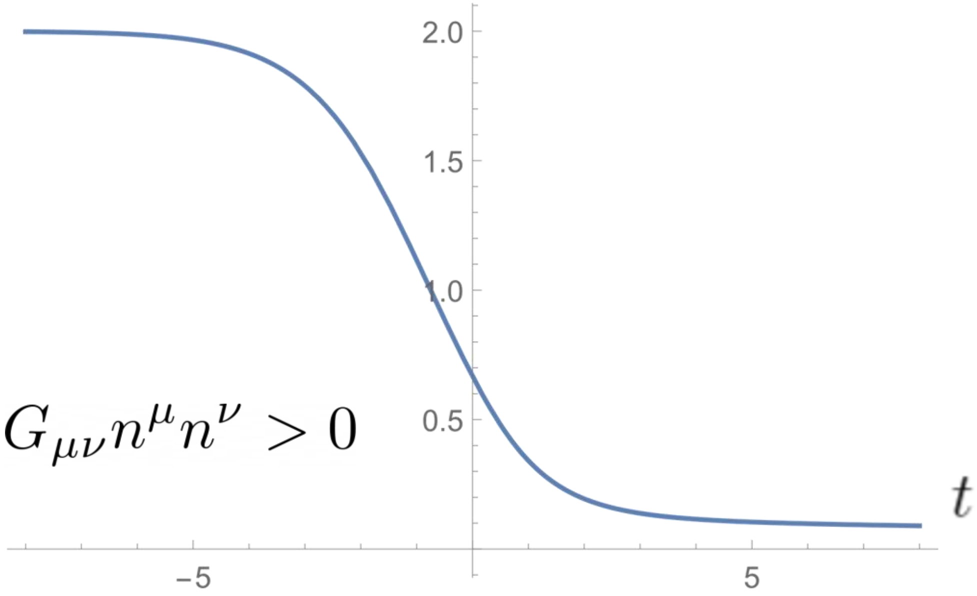


$$\mathcal{F}_s = -\frac{H'}{H^2} + \frac{1}{H^2 a^2}$$

$$c_{\mathcal{T}}^2 = \frac{\mathcal{F}_{\mathcal{T}}}{\mathcal{G}_{\mathcal{T}}} = 1, \quad c_{\mathcal{S}}^2 = \frac{\mathcal{F}_{\mathcal{S}}}{\mathcal{G}_{\mathcal{S}}} = 1$$

NULL ENERGY CONDITION

$$G_{\mu\nu} = \begin{pmatrix} \frac{3(e+e^x)^2}{\left(e+e^{1+x}+e^x(1+x^2)^{1/6}\right)^2} & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & -\sin(\chi)^2 & 0 \\ 0 & 0 & 0 & -\sin(\chi)^2\sin(\tau)^2 \end{pmatrix}$$



$$G_{\mu\nu}n^\mu n^\nu > 0$$

LAGRANGIAN RECONSTRUCTION

- Selection of coefficients in the Lagrangian from stability conditions
- EOM
- Ansatz for function F
- kinetic term and General Relativity

$$S = \int d^4x\sqrt{-g}(\mathcal{L}_4 + \mathcal{L}_2) = \int d^4x\sqrt{-g}(R + F(\pi, X))$$

$$F(\pi, X) = f_0(\pi) + f_1(\pi)X + f_2(\pi)X^2$$

On shell: $$F_X = f_1(t) + 2f_2(t), \quad F_{XX} = 2f_2(t)$$

SCALAR PERTURBATIONS

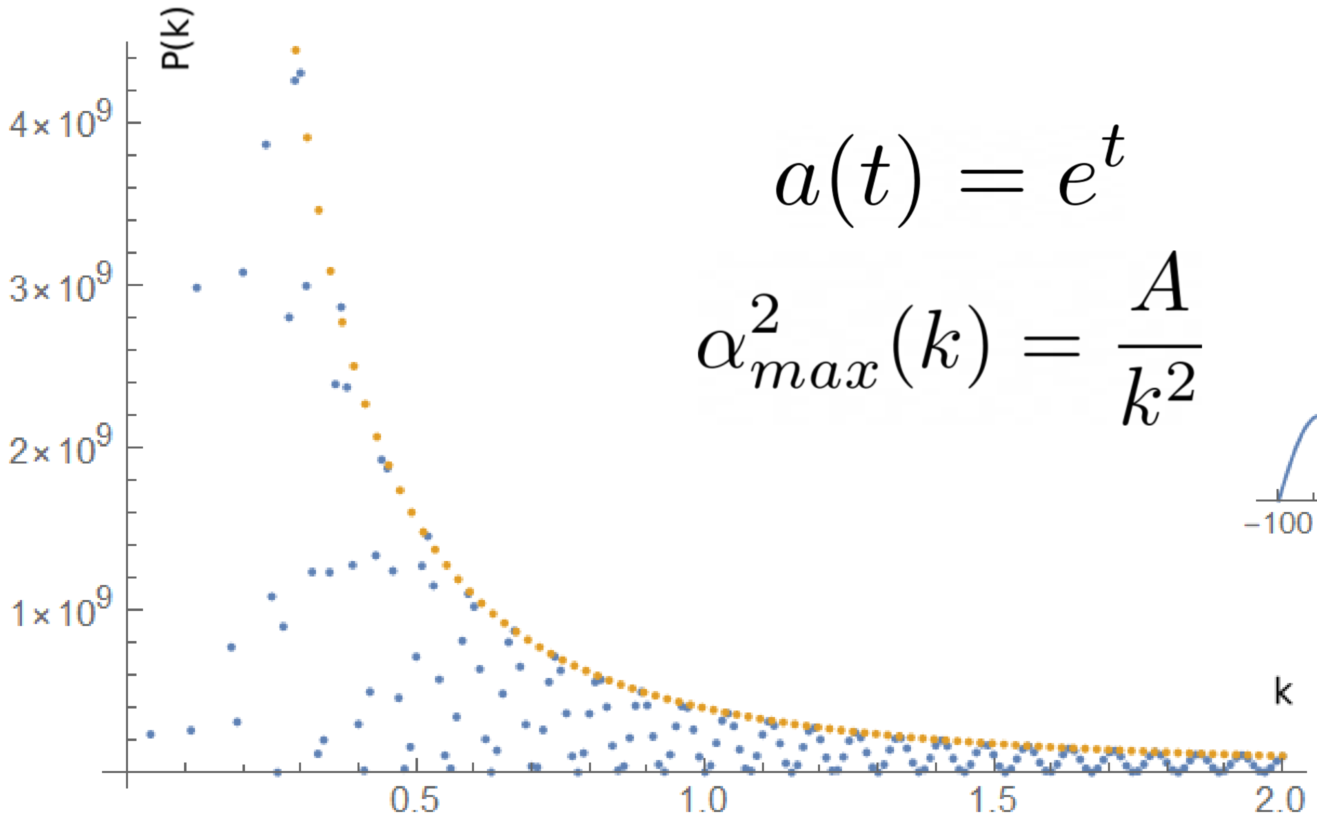
$$S_s = \int \mathrm{d}t\ \mathrm{d}^3 x a^3 \left[\mathcal{G}_\mathcal{S}\dot{\alpha}^2 - \mathcal{F}_\mathcal{S}\frac{(k\alpha)^2}{a^2}\right]$$

canonically normalized: $\alpha \to \dfrac{\alpha}{\sqrt{2a^3\mathcal{G}_\mathcal{S}}}$

$$B = \frac{(a^3\mathcal{G}_\mathcal{S})'}{a^3\mathcal{G}_\mathcal{S}} \qquad w(t) = \frac{k^2}{a^2} - \left(\frac{B}{2}\right)^2 - \frac{B'}{2}$$

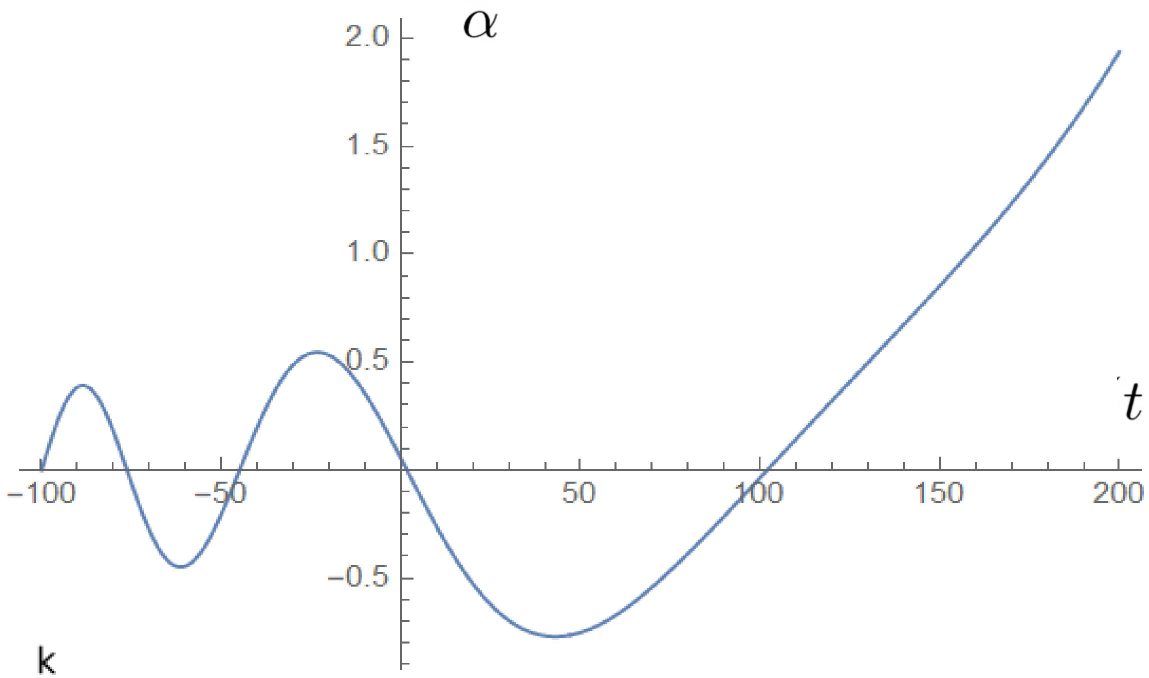
EOM: $\alpha''(t) + \alpha(t)w(t) = 0$

SPECTRUM CHECK FOR ETERNAL INFLATION

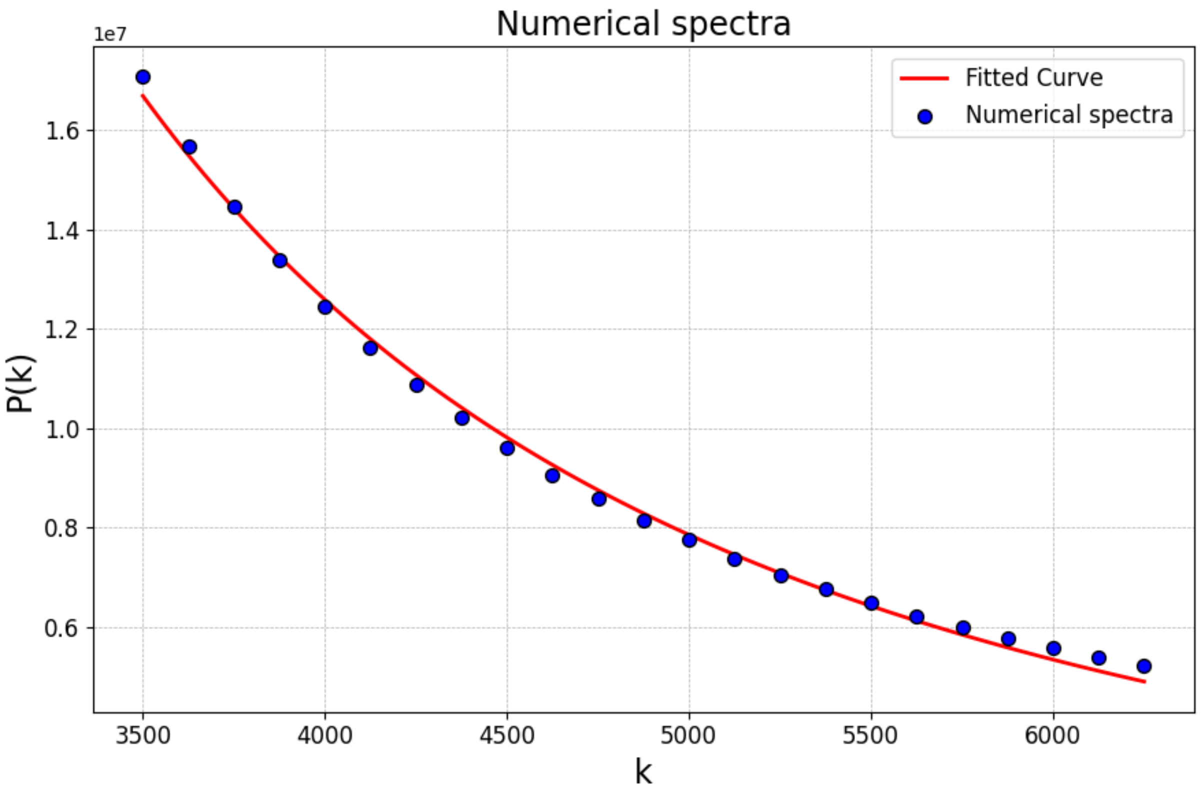


$$a(t) = e^t$$

$$\alpha_{max}^2(k) = \frac{A}{k^2}$$



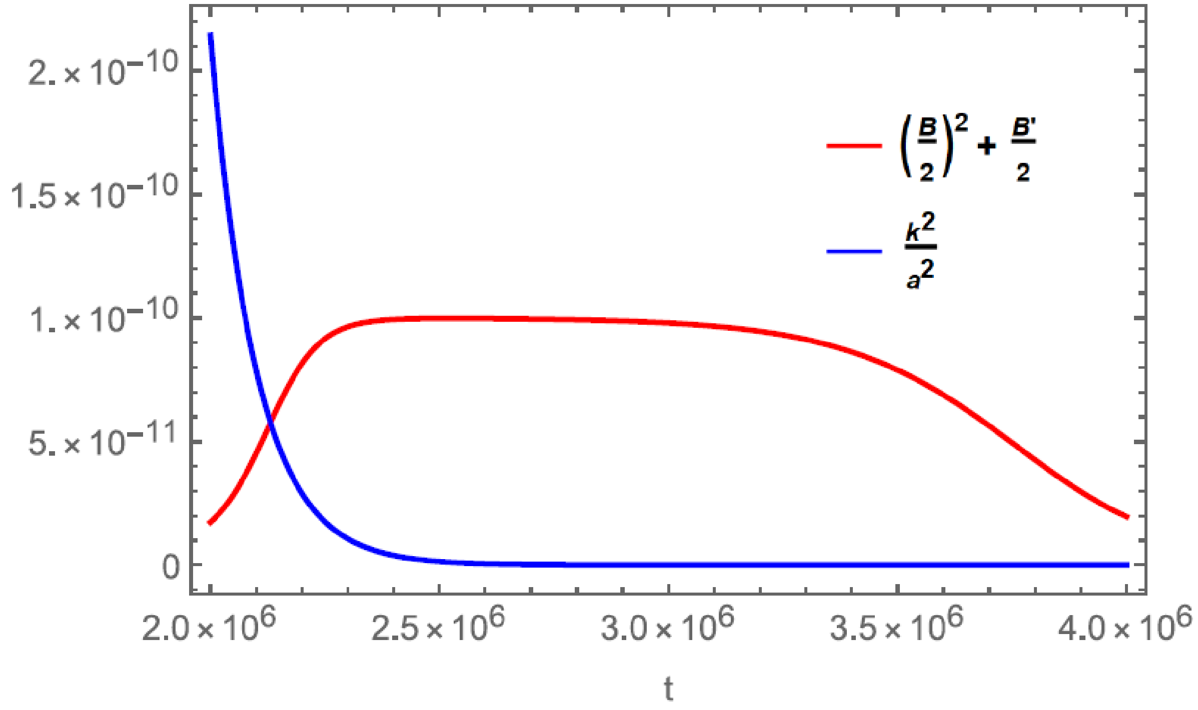
SPECTRUM FOR OUT MODEL



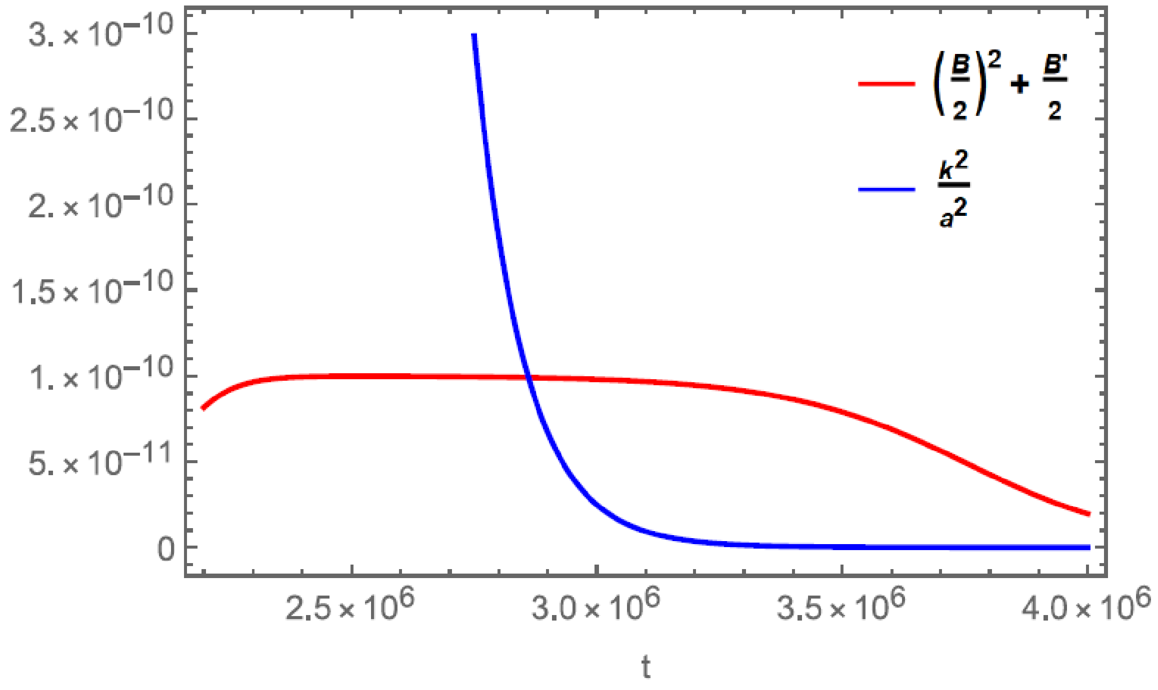
Slope is less than 0

$$P(k) = \frac{5 \cdot 10^{14}}{x^{2.11}}$$

HOW TO CHOOSE MOMENTUM?



k=100

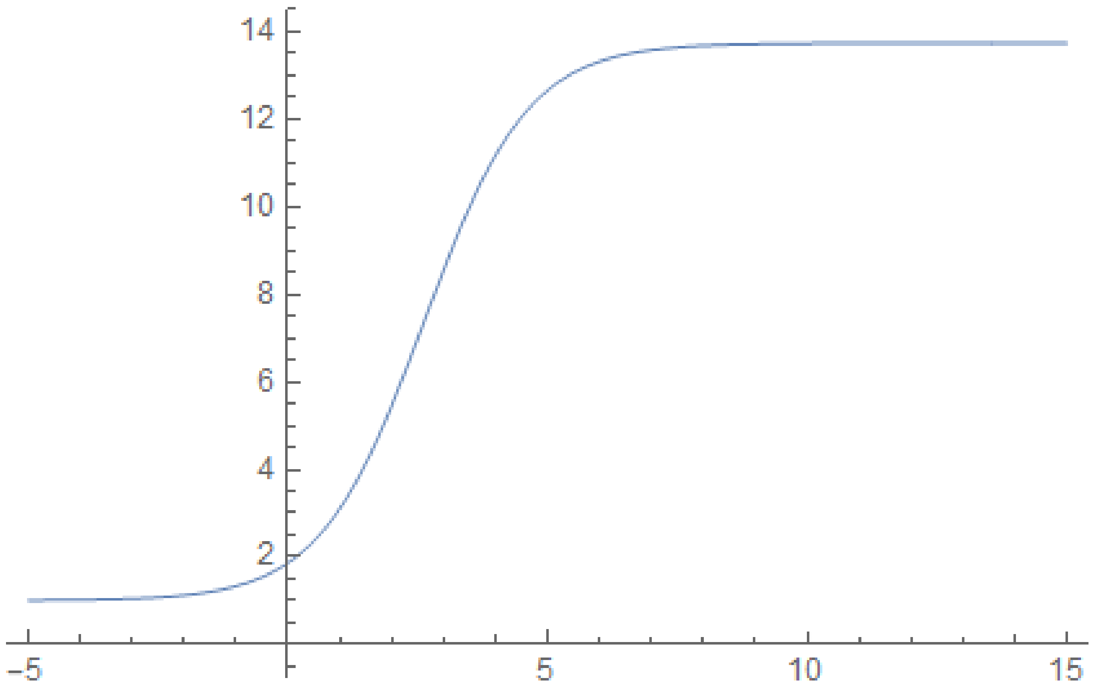


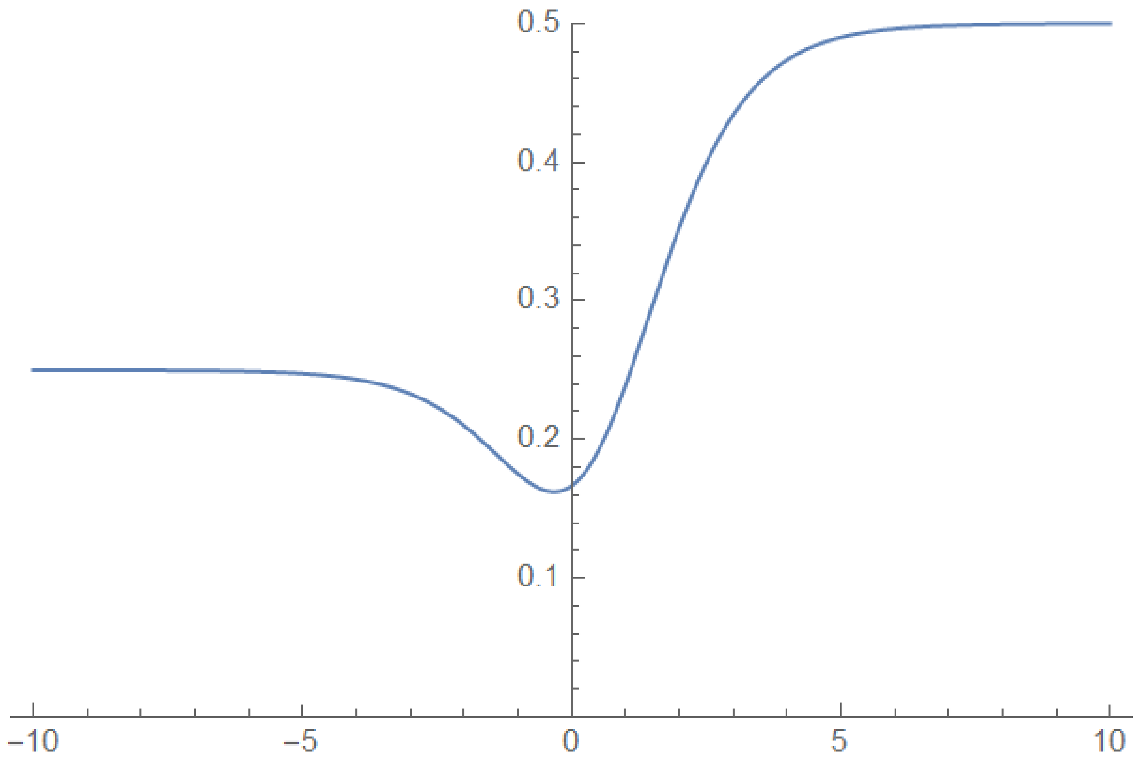
k=1000

CONCLUSIONS

- The possibility of constructing various cosmological models without singularity is shown
- For all models, stability conditions are met, no ghosts, tachyons, NEC is met
- These models are consistent with observed data. The spectrum corresponds to a flat
- It is possible to add additional parameters describing sizes and velocities in cosmology
- Tensor perturbation analysis required

OTHER STABLE MODELS





OSCILLATIONS IN SPECTRUM