Title: Fluctuations and reheating after Inflation

Date: Apr 25, 2006 11:00 AM

URL: http://pirsa.org/06040022

Abstract:

Fluctuations and Reheating after Inflation

Top-down approach to inflation:
seeks to embed it in fundamental theory

Bottom-up approach to inflation:
reconstruction of acceleration trajectories

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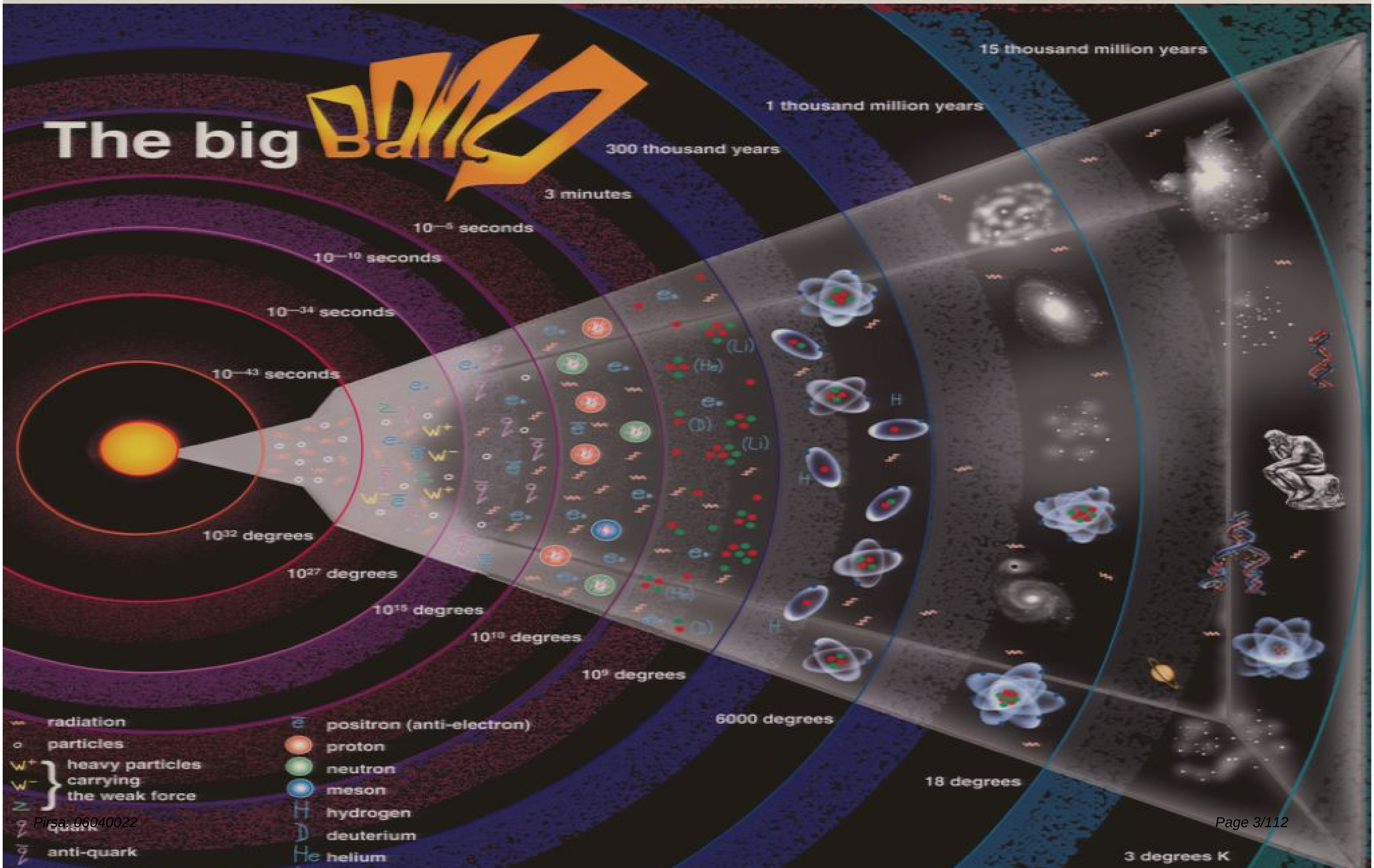
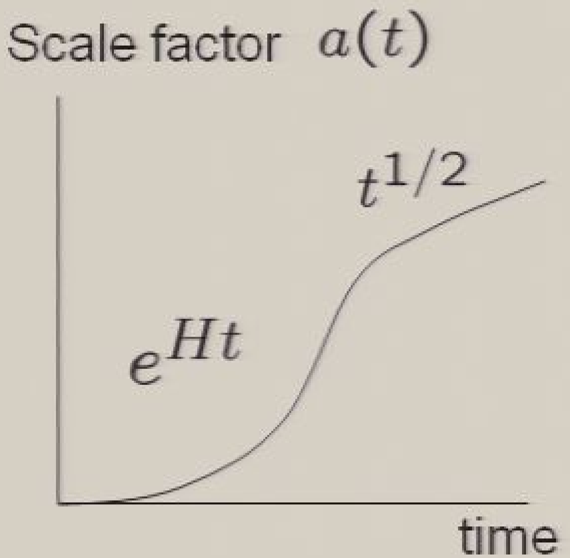
CITA ICAT
Canadian Institute for Theoretical Astrophysics
L'institut canadien d'astrophysique theorique

PI April 25, 2006

Early Universe



Early Universe Inflation



Equation of State $t \leq 10^{-35}$ sec

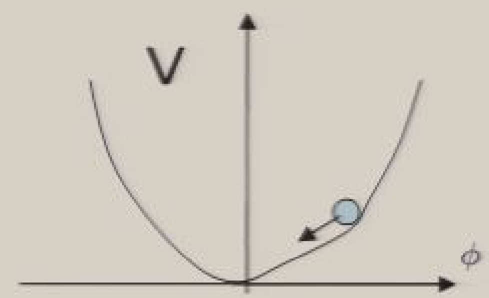
$$p \approx -\epsilon$$

Inflation $a(t) \approx e^{Ht}$

Realization of Inflation

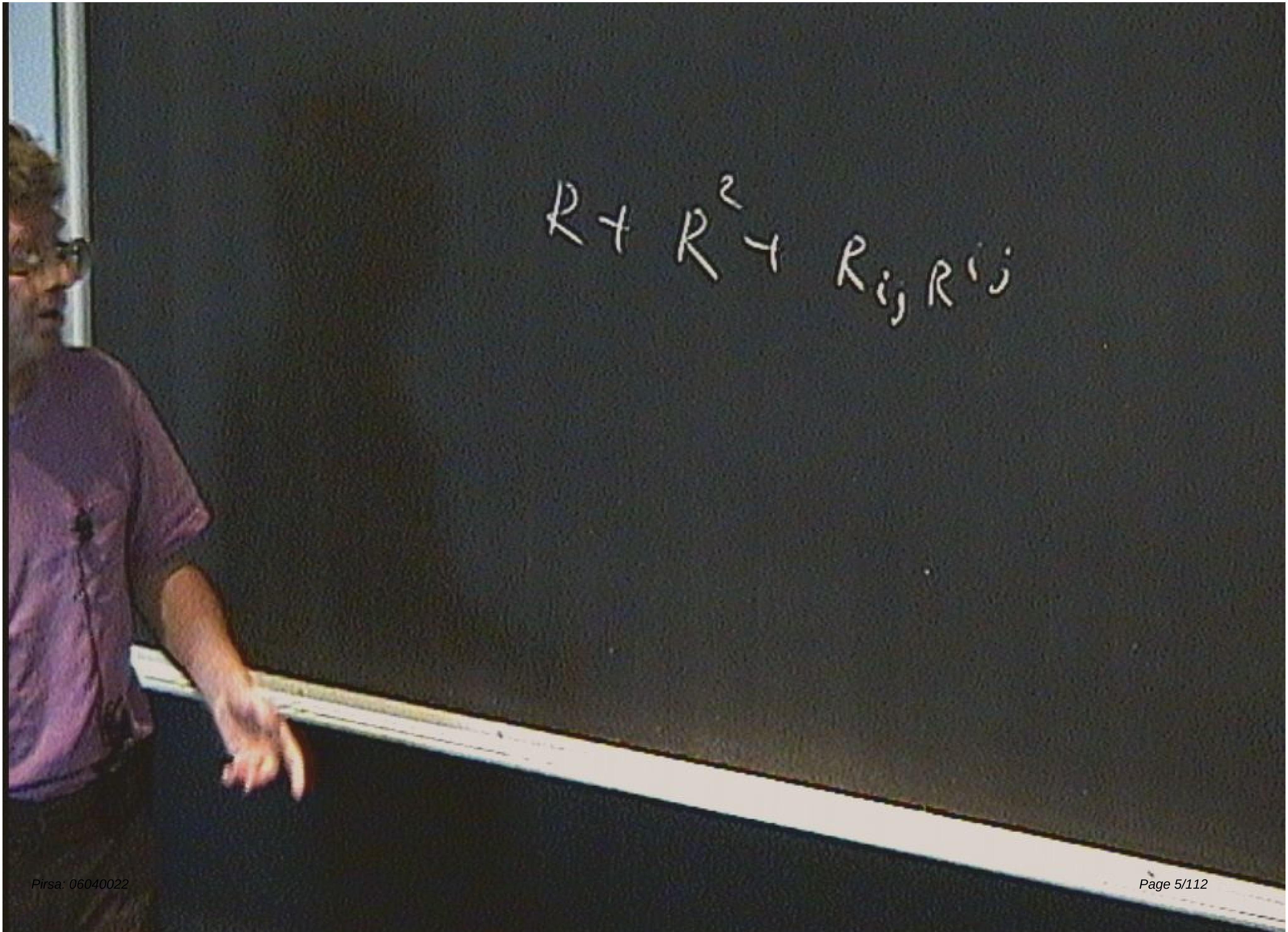
Scalar field

$$\ddot{\phi} + 3H\dot{\phi} + V_{,\phi} = 0$$

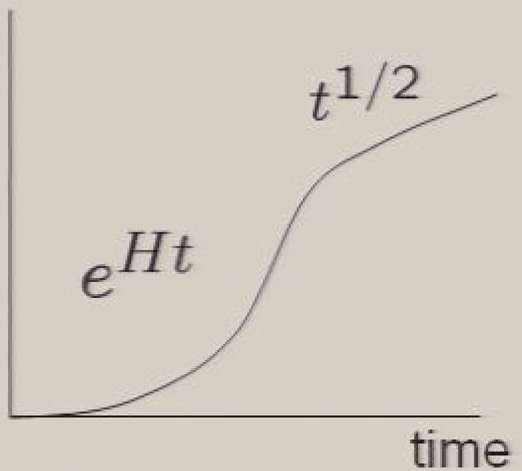


$$p = \frac{1}{2}\dot{\phi}^2 - V$$

$$\epsilon = \frac{1}{2}\dot{\phi}^2 + V$$


$R + R^2 + R_{ij} R^{ij}$

Early Universe Inflation



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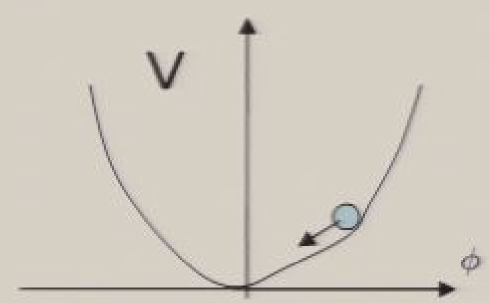

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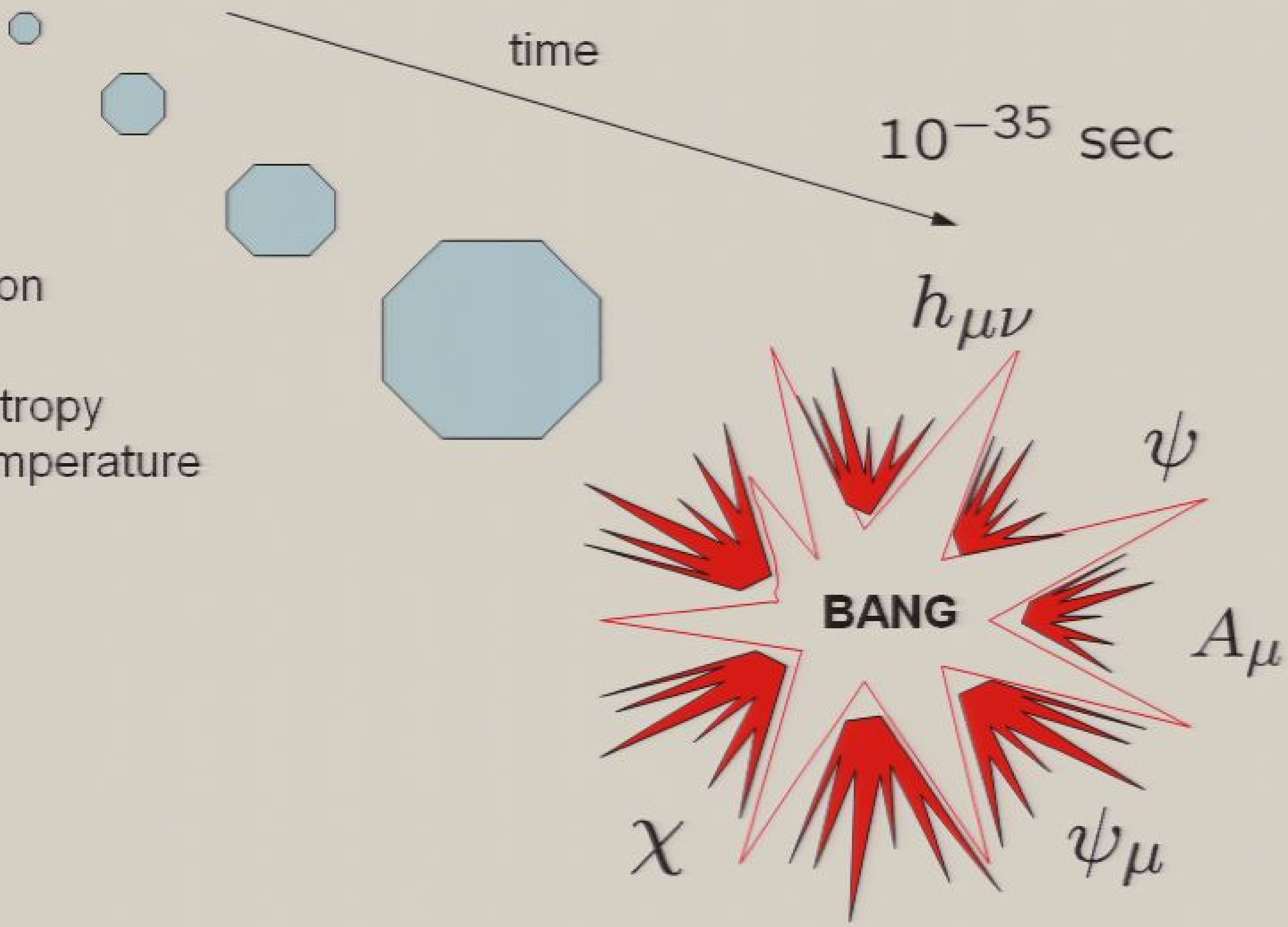
Particlegenesis

10^{-43} sec



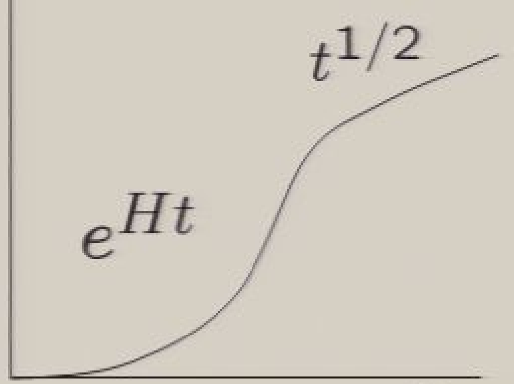
Inflation

no entropy
no temperature

$$\mathcal{L}(\phi, \chi, \psi, A_\mu, \psi_\mu, h_{\mu\nu})$$

Early Universe Inflation

Scale factor $a(t)$



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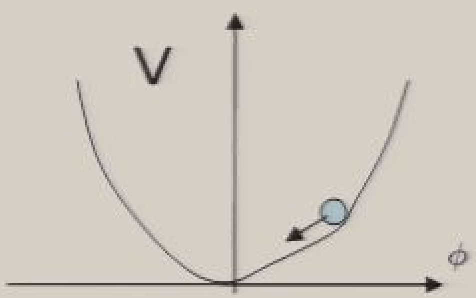

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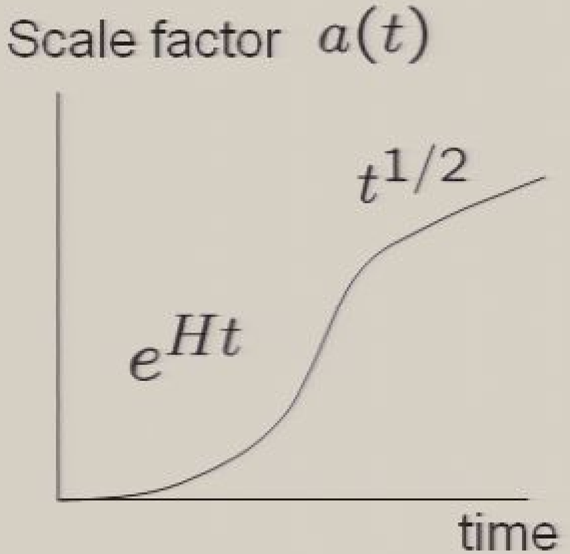
Early Universe Inflation



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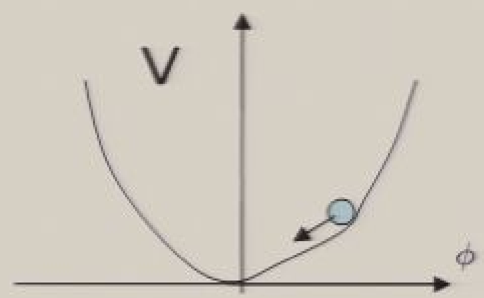

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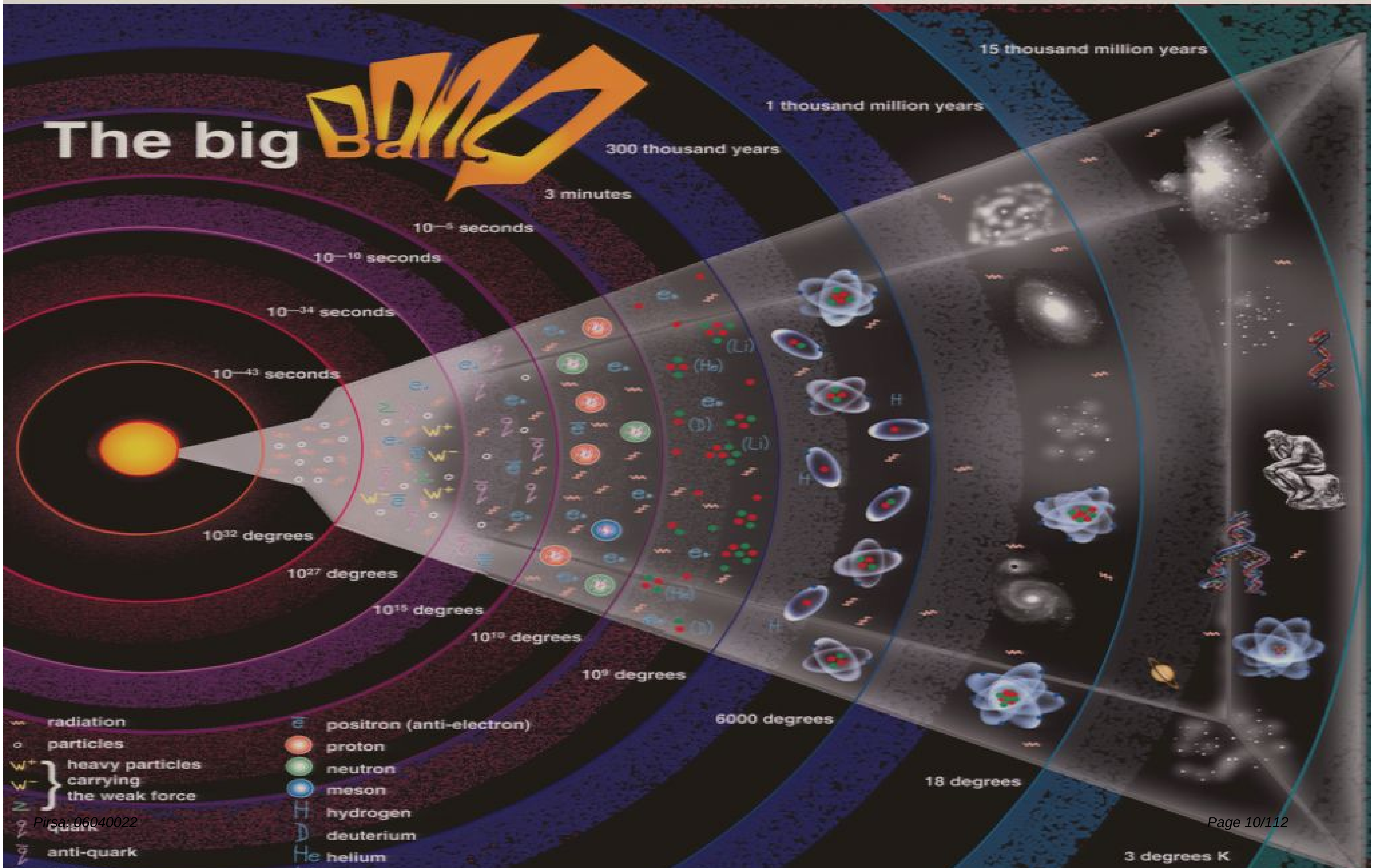
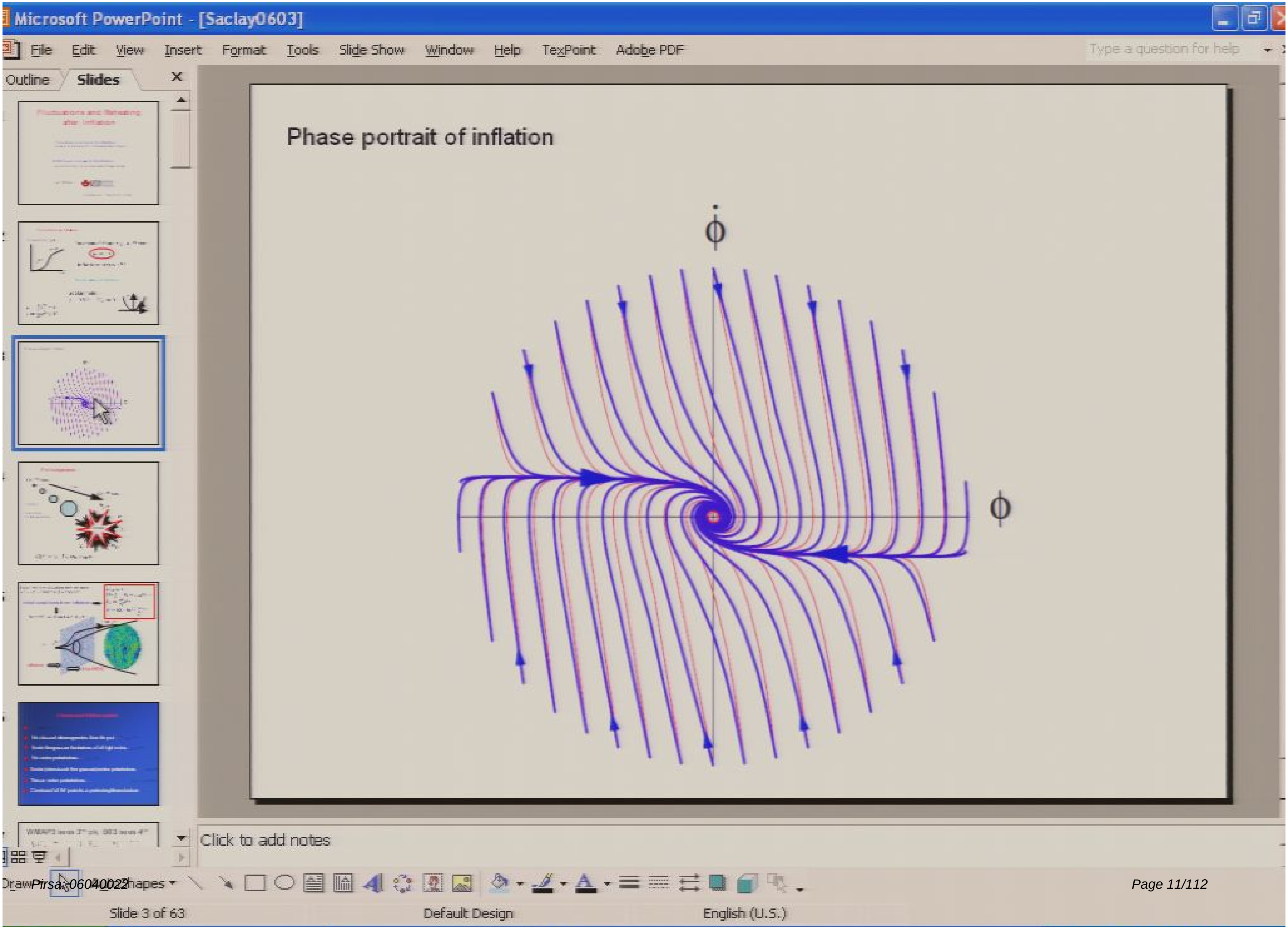
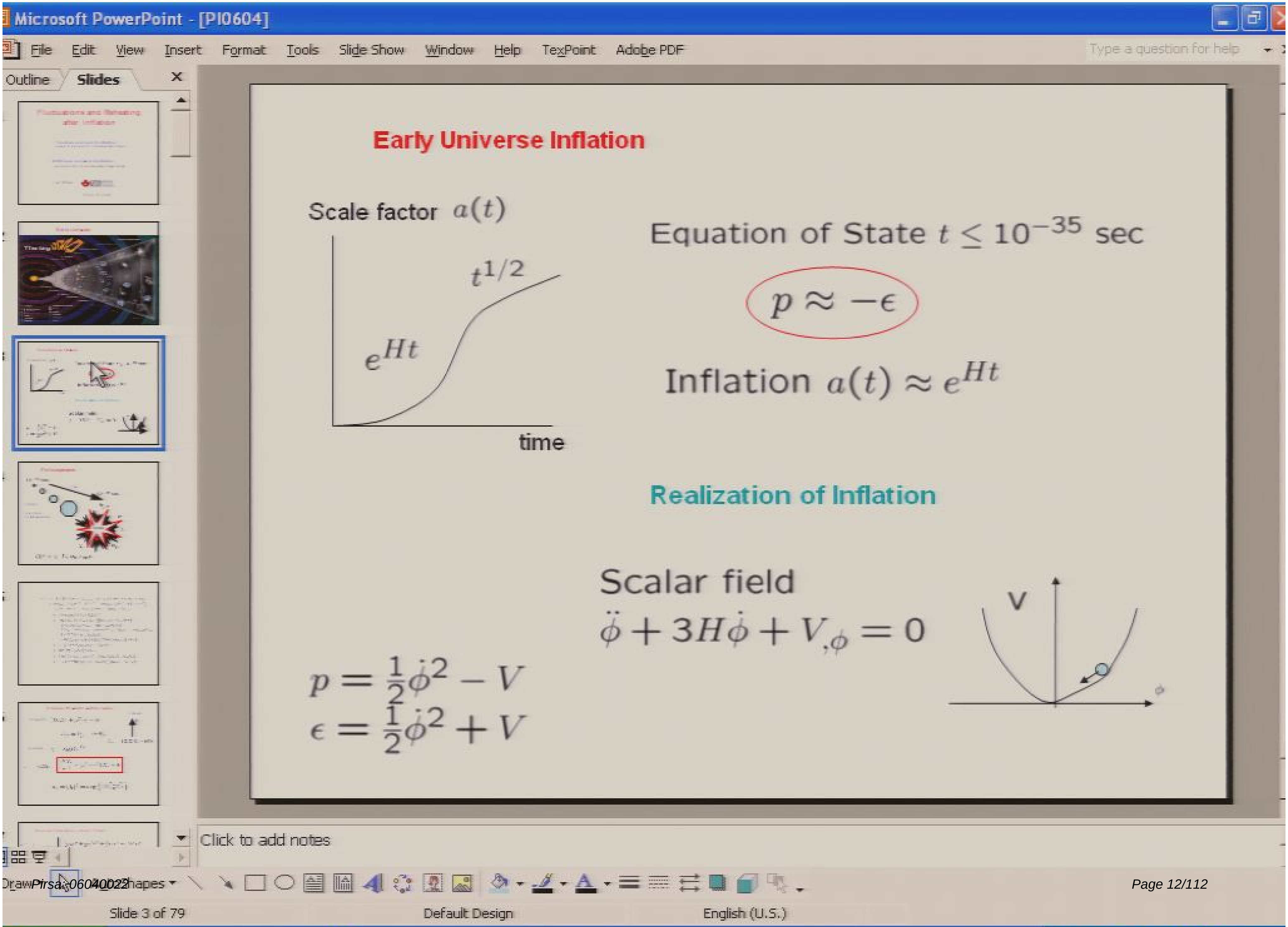
Early Universe




Microsoft PowerPoint - [Saclay0603]
File Edit View Insert Format Tools Slide Show Window Help TexPoint Adobe PDF
Type a question for help
Outline Slides
Phase portrait of inflation
$\dot{\phi}$
ϕ
Click to add notes
Slide 3 of 63
Default Design
English (U.S.)


Microsoft PowerPoint - [PI0604]
Early Universe Inflation
Scale factor $a(t)$
$t^{1/2}$
e^{Ht}
time
Equation of State $t \leq 10^{-35}$ sec
$p \approx -\epsilon$
Inflation $a(t) \approx e^{Ht}$
Realization of Inflation
Scalar field
$\ddot{\phi} + 3H\dot{\phi} + V_{,\phi} = 0$
V
ϕ
$p = \frac{1}{2}\dot{\phi}^2 - V$
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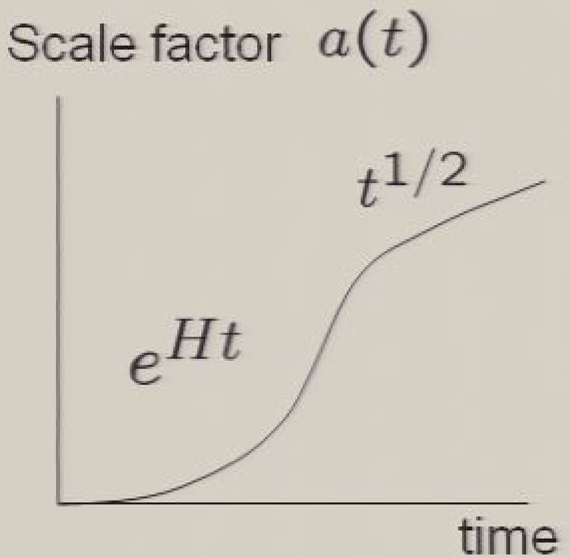
Click to add notes
Slide 3 of 79
Default Design
English (U.S.)

Early Universe Inflation



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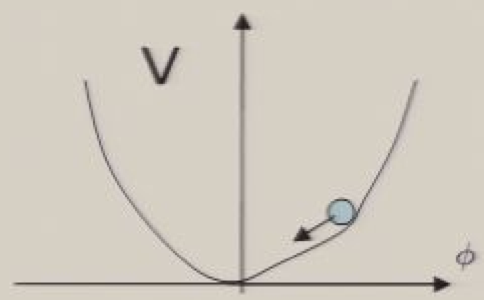

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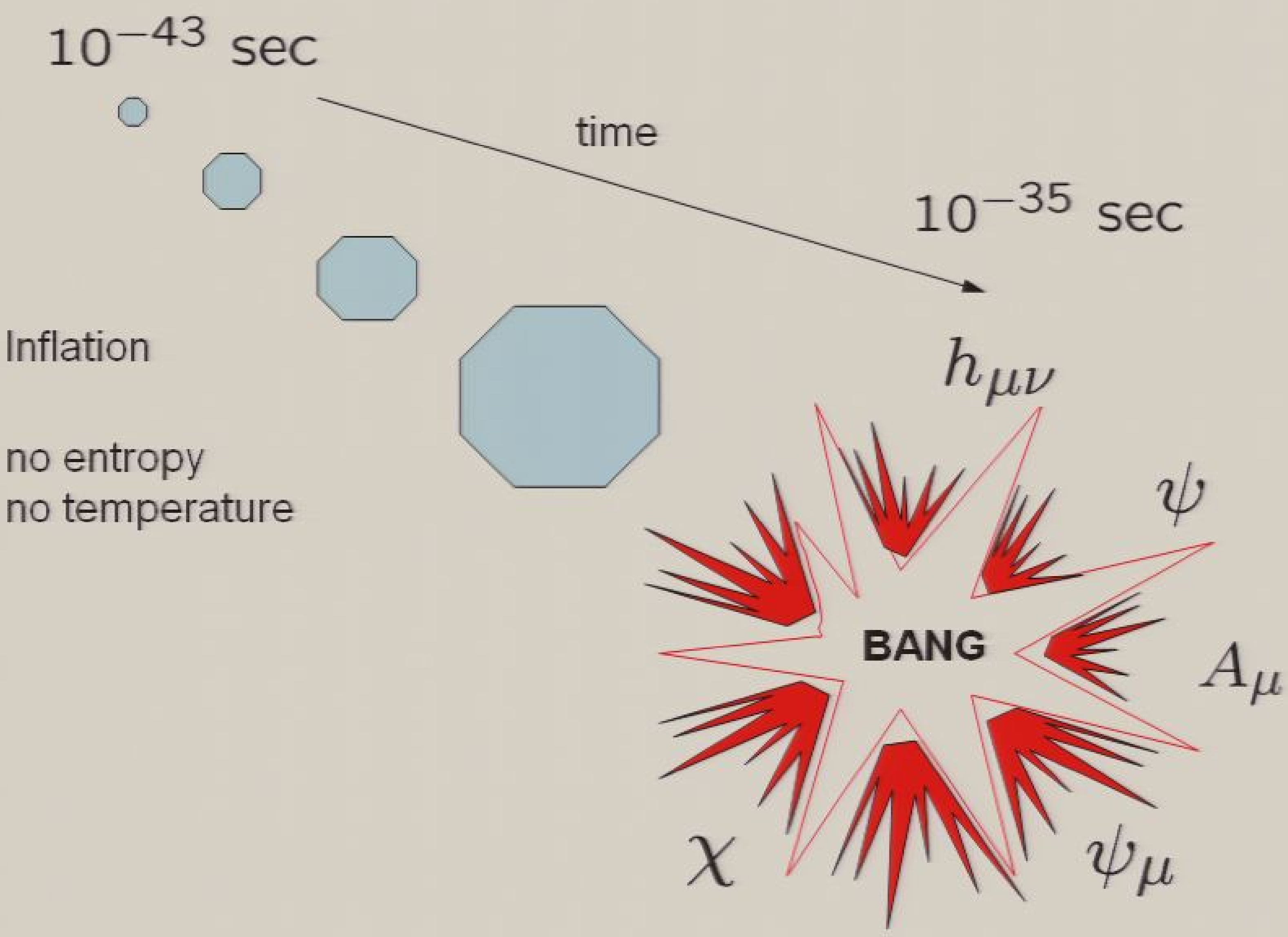
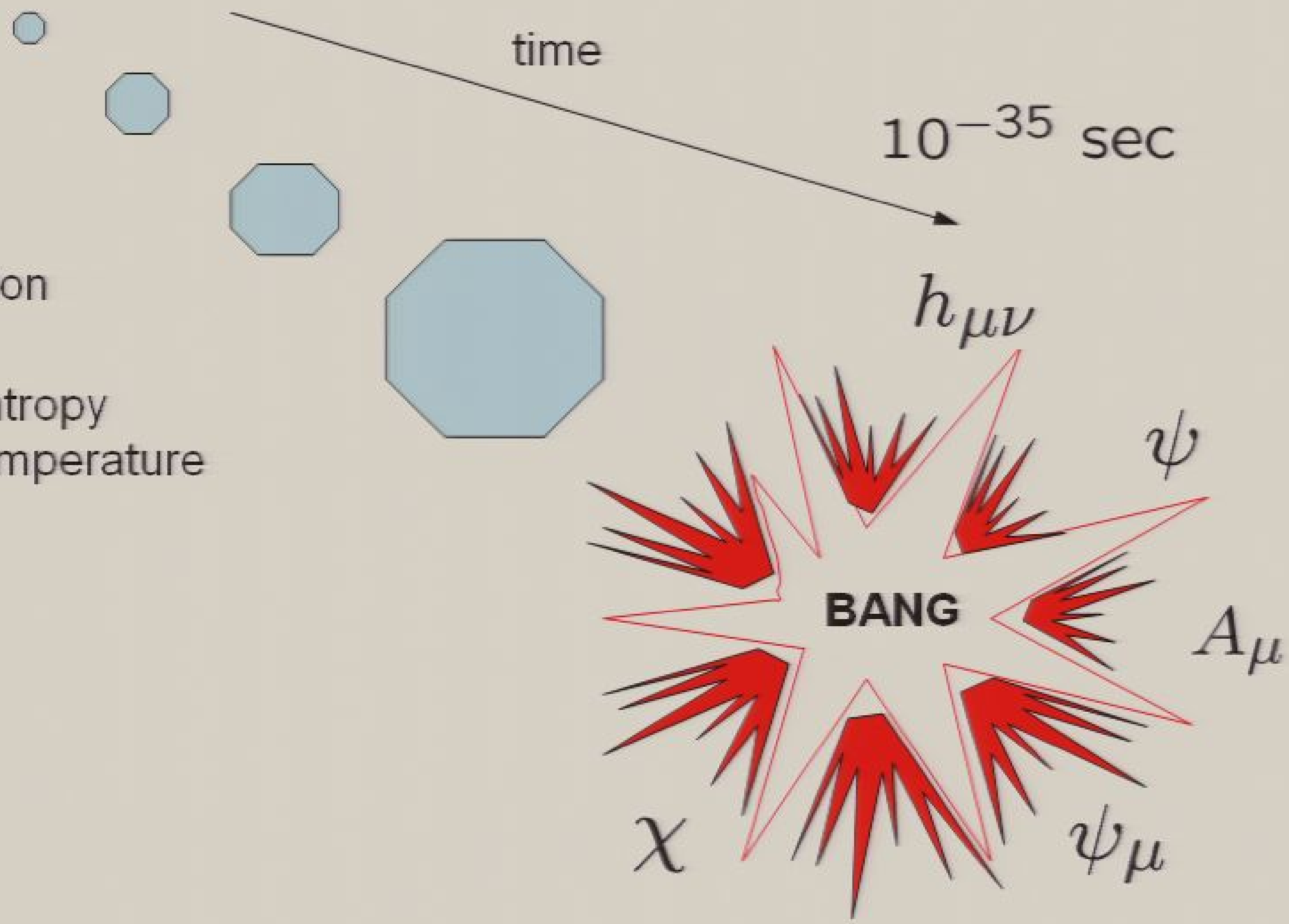
Particlegenesis



$$\mathcal{L}(\phi, \chi, \psi, A_\mu, \psi_\mu, h_{\mu\nu})$$

Particlegenesis

10^{-43} sec



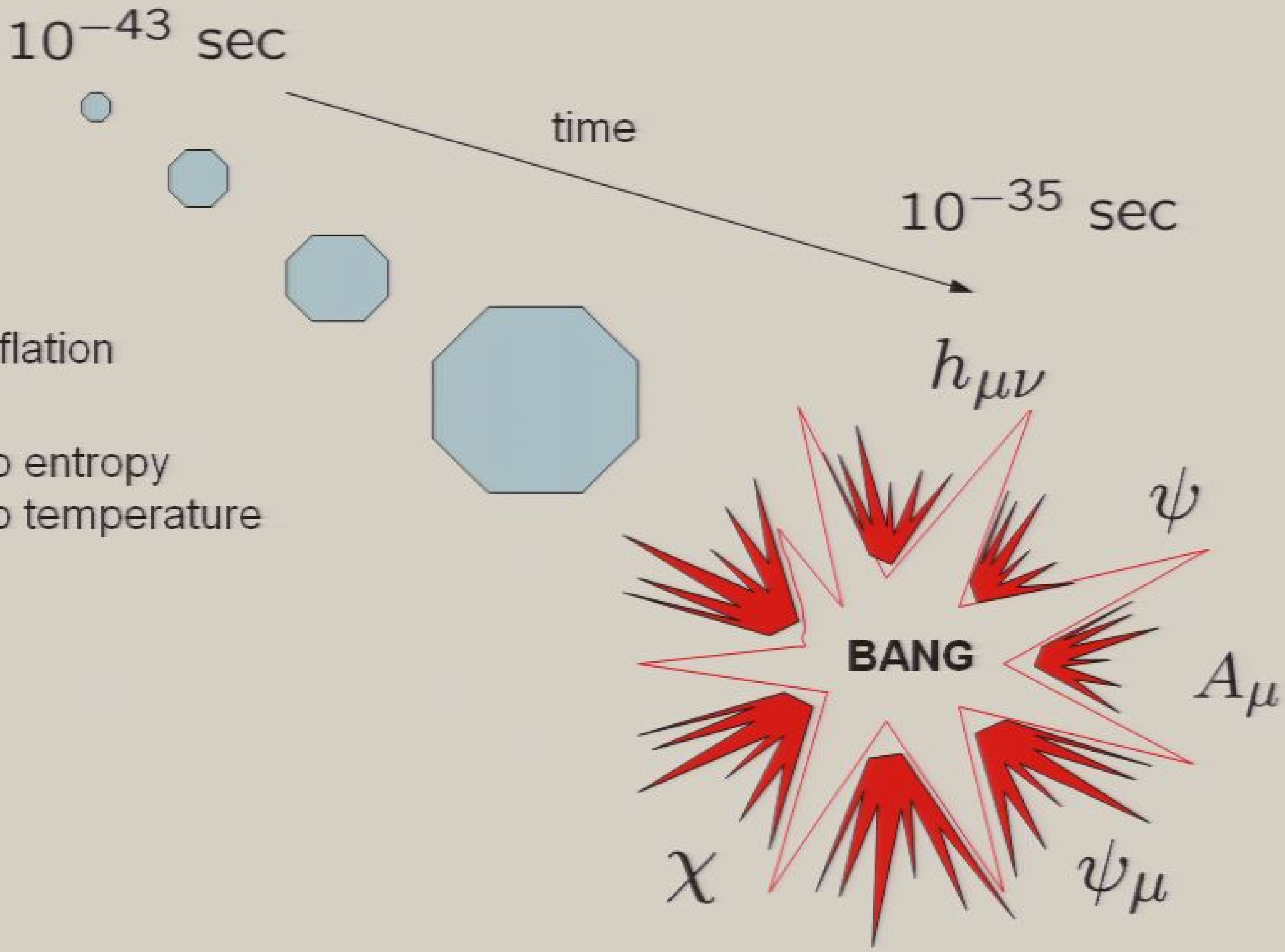
Inflation

no entropy
no temperature

$$\mathcal{L}(\phi, \chi, \psi, A_\mu, \psi_\mu, h_{\mu\nu})$$

$$
\begin{aligned}
e^{-1}\mathcal{L} \;=\; & -\tfrac{1}{2}M_P^2\left[R+\bar{\psi}_\mu R^\mu+\mathcal{L}_{SG,torsion}\right]-g_i{}^j\left[M_P^2(\hat{\partial}_\mu z^i)(\hat{\partial}^\mu z_j)+\bar{\chi}_j\,\not{\mathcal{D}}\chi^i+\bar{\chi}^i\,\not{\mathcal{D}}\chi_j\right] \\
+ & \;(\mathrm{Re}\,f_{\alpha\beta})\left[-\tfrac{1}{4}F^\alpha_{\mu\nu}F^{\mu\nu\,\beta}-\tfrac{1}{2}\bar{\lambda}^\alpha\,\hat{\not{\mathcal{D}}}\lambda^\beta\right]+\tfrac{1}{4}\mathrm{i}(\mathrm{Im}\,f_{\alpha\beta})\left[F^\alpha_{\mu\nu}\tilde{F}^{\mu\nu\,\beta}-\hat{\partial}_\mu\left(\bar{\lambda}^\alpha\gamma_5\gamma^\mu\lambda^\beta\right)\right] \\
- & \;M_P^{-2}\mathrm{e}^{\mathcal{K}}\left[-3WW^*+(\mathcal{D}^iW)g^{-1}{}_i{}^j(\mathcal{D}_jW^*)\right]-\tfrac{1}{2}(\mathrm{Re}\,f)^{-1\,\alpha\beta}\mathcal{P}_\alpha\mathcal{P}_\beta \\
+ & \;\tfrac{1}{8}(\mathrm{Re}\,f_{\alpha\beta})\bar{\psi}_\mu\gamma^{\nu\rho}\left(F^\alpha_{\nu\rho}+\hat{F}^\alpha_{\nu\rho}\right)\gamma^\mu\lambda^\beta \\
+ & \;\Big\{M_P g_j{}^i\bar{\psi}_{\mu L}(\hat{\not{\partial}}z^j)\gamma^\mu\chi_i+\bar{\psi}_R\cdot\gamma\left[\tfrac{1}{2}\mathrm{i}\lambda^\alpha_L\mathcal{P}_\alpha+\chi_iY^3M_P^{-4}\mathcal{D}^iW\right] \\
& +\tfrac{1}{2}Y^3M_P^{-3}W\bar{\psi}_{\mu R}\gamma^{\mu\nu}\psi_{\nu R}-\tfrac{1}{4}M_P^{-1}f^i_{\alpha\beta}\bar{\chi}_i\gamma^{\mu\nu}\hat{F}^{-\alpha}_{\mu\nu}\lambda^\beta_L \\
& -Y^3M_P^{-5}(\mathcal{D}^i\mathcal{D}^jW)\bar{\chi}_i\chi_j+\tfrac{1}{2}\mathrm{i}(\mathrm{Re}\,f)^{-1\,\alpha\beta}\mathcal{P}_\alpha M_P^{-1}f^i_{\beta\gamma}\bar{\chi}_i\lambda^\gamma-2M_P\xi_\alpha{}^ig_i{}^j\bar{\lambda}^\alpha\chi_j \\
& +\tfrac{1}{4}M_P^{-5}Y^3(\mathcal{D}^jW)g^{-1}{}_j{}^if_{\alpha\beta i}\bar{\lambda}^\alpha_R\lambda^\beta_R \\
& -\tfrac{1}{4}M_P^{-1}f^i_{\alpha\beta}\bar{\psi}_R\cdot\gamma\chi_i\bar{\lambda}^\alpha_L\lambda^\beta_L+\tfrac{1}{4}M_P^{-2}(\mathcal{D}^i\partial^jf_{\alpha\beta})\bar{\chi}_i\chi_j\bar{\lambda}^\alpha_L\lambda^\beta_L+\mathrm{h.c.}\Big\} \\
+ & \;g_j{}^i\left(\tfrac{1}{8}e^{-1}\varepsilon^{\mu\nu\rho\sigma}\bar{\psi}_\mu\gamma_\nu\psi_\rho\bar{\chi}^j\gamma_\sigma\chi_i-\bar{\psi}_\mu\chi^j\,\bar{\psi}^\mu\chi_i\right) \\
+ & \;M_P^{-2}\left(R^{k\ell}_{ij}-\tfrac{1}{2}g_i{}^kg_j{}^\ell\right)\bar{\chi}^i\chi^j\bar{\chi}_k\chi_\ell \\
+ & \;\tfrac{3}{64}M_P^{-2}\left((\mathrm{Re}\,f_{\alpha\beta})\bar{\lambda}^\alpha\gamma_\mu\gamma_5\lambda^\beta\right)^2-\tfrac{1}{16}M_P^{-2}f^i_{\alpha\beta}\bar{\lambda}^\alpha_L\lambda^\beta_Lg^{-1}{}_i{}^jf_{\gamma\delta j}\bar{\lambda}^\gamma_R\lambda^\delta_R \\
+ & \;\tfrac{1}{8}(\mathrm{Re}\,f)^{-1\,\alpha\beta}M_P^{-2}\left(f^i_{\alpha\gamma}\bar{\chi}_i\lambda^\gamma-f_{\alpha\gamma i}\bar{\chi}^i\lambda^\gamma\right)\left(f^j_{\beta\delta}\bar{\chi}_j\lambda^\delta-f_{\beta\delta j}\bar{\chi}^j\lambda^\delta\right).
\end{aligned}
$$

Particlegenesis



Inflation

no entropy
no temperature

$$\mathcal{L}(\phi, \chi, \psi, A_\mu, \psi_\mu, h_{\mu\nu})$$

Schwinger formula for particle creation

classical

Scalar ED $\left(D_\mu D^\mu + \mu^2\right)\chi = 0$

$\vec{E}$

$$D_\mu = \partial_\mu + ieA_\mu$$

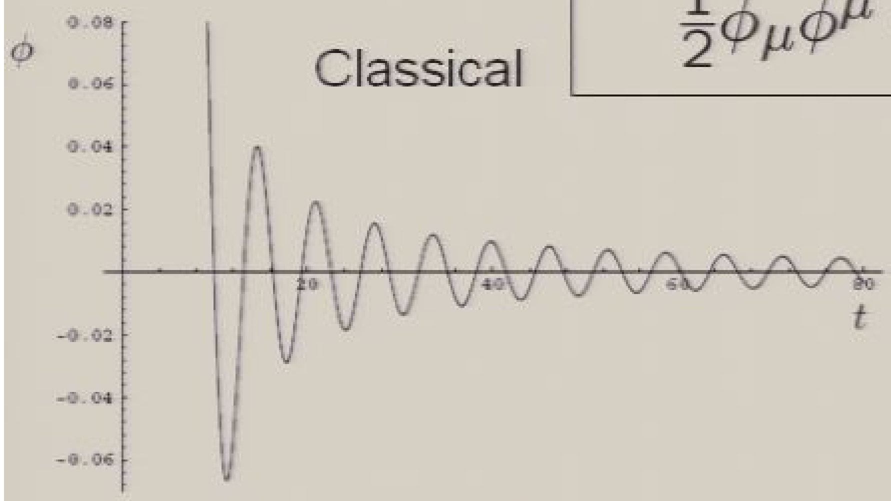
$$A_\mu = (0,0,0,-Et)$$

Quantum $\chi = X_k(t)e^{i\vec{k}\vec{x}}$

$$\tau = eEt \qquad \boxed{\frac{d^2 X_k}{d\tau^2} + \left(\kappa^2 + \tau^2\right) X_k = 0}$$

$$n_k = |\beta_k|^2 = \exp\left(\frac{\pi(k^2+\mu^2)}{eE}\right)$$

Resonant Preheating in Chaotic Inflation



Classical

$$\frac{1}{2}\phi_\mu\phi^\mu + \frac{1}{2}m^2\phi^2 + \frac{1}{2}\chi_\mu\chi^\mu + g^2\phi^2\chi 2$$

Quantum

$$\ddot{\chi}_k + 3\frac{\dot{a}}{a}\dot{\chi}_k + \left(\frac{\mathbf{k^2}}{a^2} + m_\chi^2(0) - \xi R + g^2\phi^2\right)\chi_k = ($$

$$\tau = mt$$

$$\ddot{X}_k + \left(\frac{k^2}{m^2} + q\sin^2\tau\right)X_k = 0$$

parameter $q = \frac{g^2\phi_0^2}{m^2} \sim g^2 10^{10}$

Occupation number

$$n_k = \frac{\omega_k}{2}\left(\frac{|\dot{\chi}_k|^2}{\omega_k^2} + |\chi_k|^2\right) - \frac{1}{2}$$

$$n_k \sim e^{\mu t}$$

$$\kappa^2 = \frac{k^2}{gm\phi_0}$$

Method od successive scatterings

$$n_k^{j+1} = e^{-\pi\kappa^2} + \left(1 + 2e^{-\pi\kappa^2}\right) n_k^j - 2e^{-\frac{\pi}{2}\kappa^2}\sqrt{1+e^{-\pi\kappa^2}}\sqrt{n_k^j(1+n_k^j)}\sin\theta_{tot}^j$$

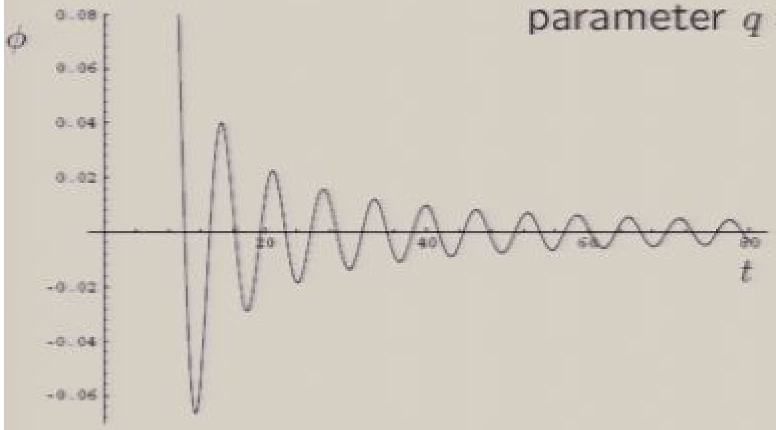
$$n_k^{j+1} \approx \left(1 + 2e^{-\pi\kappa^2} - 2\sin\theta_{tot}^j\, e^{-\frac{\pi}{2}\kappa^2}\, \sqrt{1+e^{-\pi\kappa^2}}\right) n_k^j$$

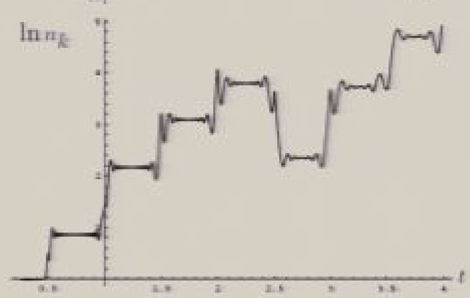
$$n_{j+1} \approx e^{4\pi j\mu_k} = e^{2\mu_k mt}$$

Resonant Preheating in Chaotic Inflation

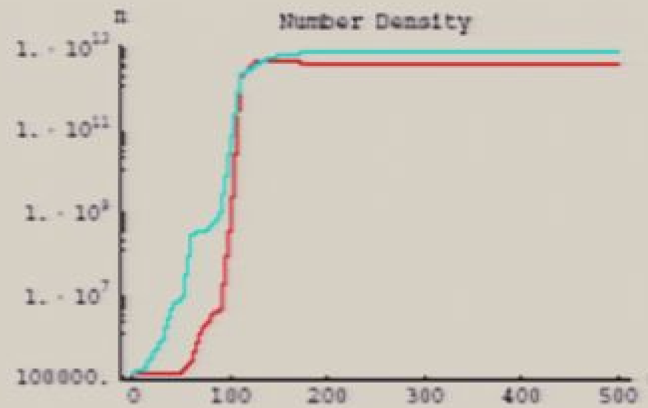
$$g^2\phi^2\chi^2$$

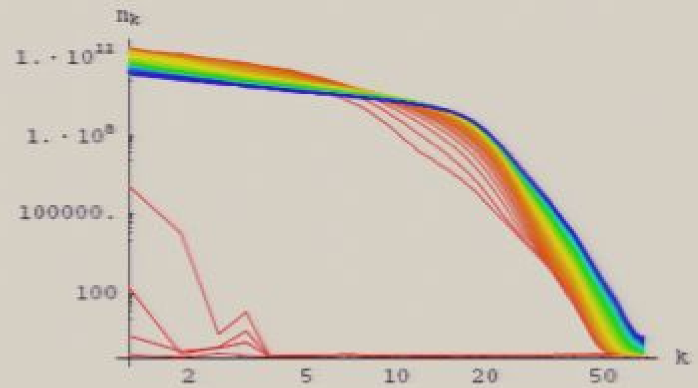
parameter $q = \frac{g^2\phi_0^2}{m^2} \sim g^2 10^{10} \gg 1$





$$\delta\chi$$





$$D(t)^2 \equiv \sum_A (|f'_A - f_A|)^2 + (|\dot{f}'_A - \dot{f}_A|)^2$$

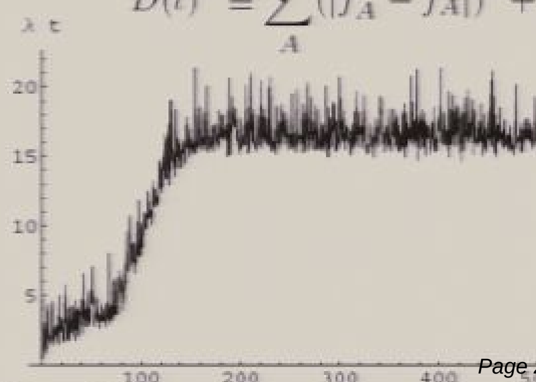
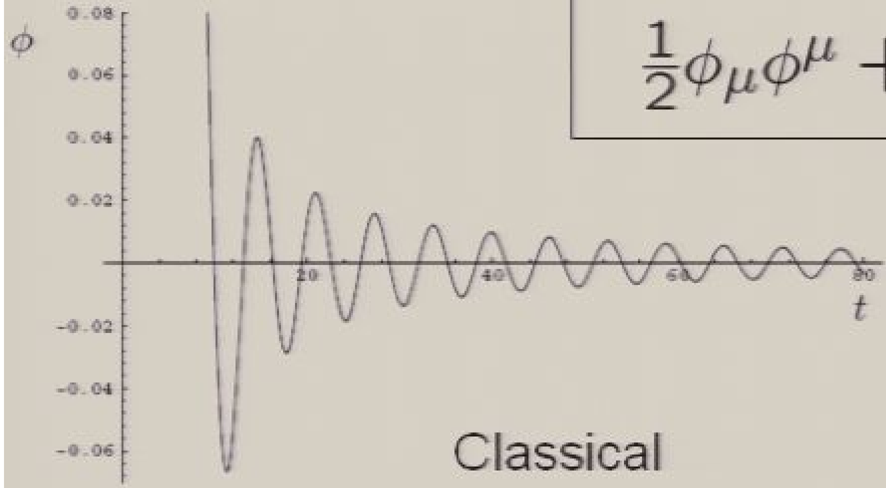


FIG. 8. The Lyapunov exponent λ' for the fields ϕ and

$$\frac{1}{2}\phi_\mu\phi^\mu + \frac{1}{2}m^2\phi^2 + \frac{1}{2}\chi_\mu\chi^\mu + g^2\phi^2\chi 2$$



Decay of inflaton and preheating after inflation

Classical

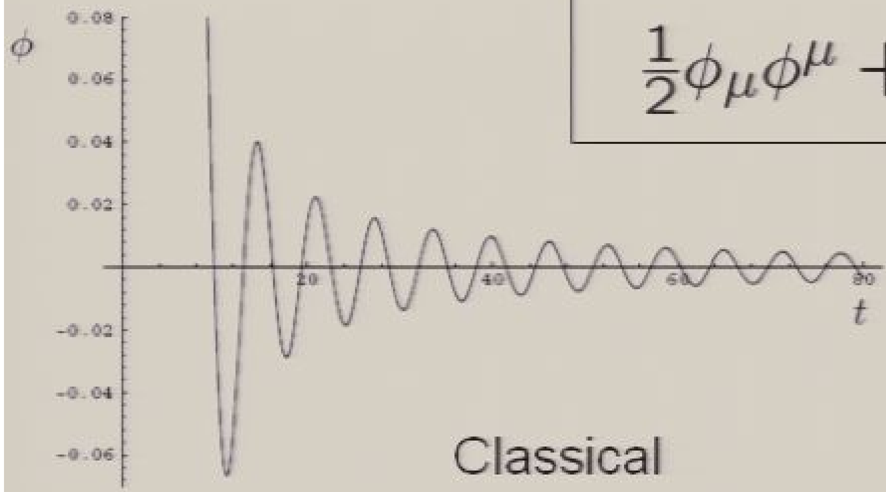
$$\phi_0 + \phi$$

Quantum

$$\chi$$

Felder, LK, Peloso,06

movie



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Decay of inflaton and preheating after inflation

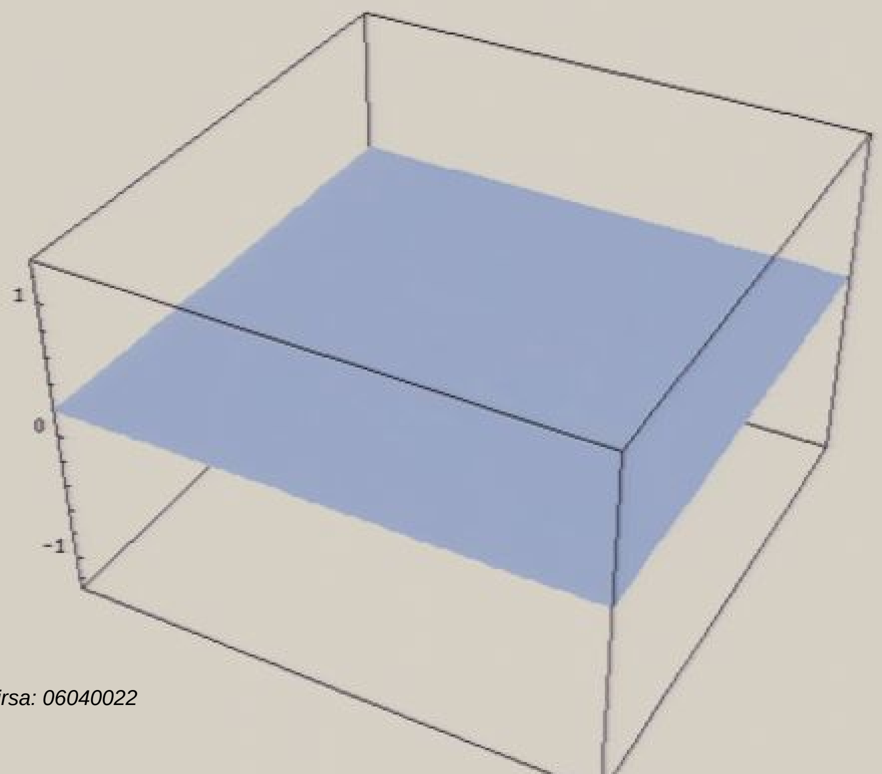
Classical

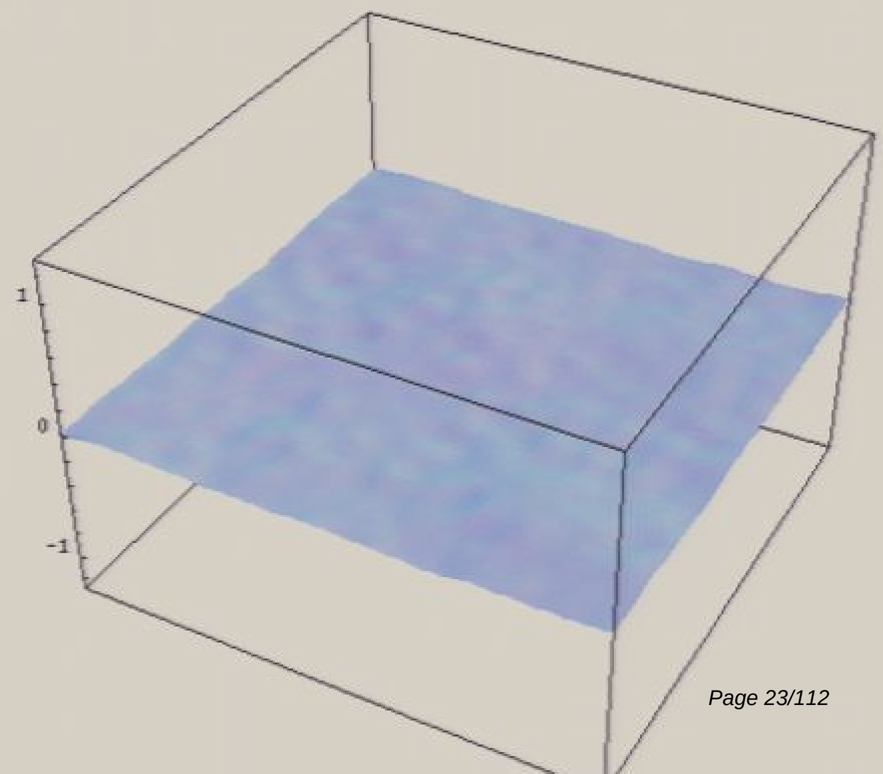
Quantum

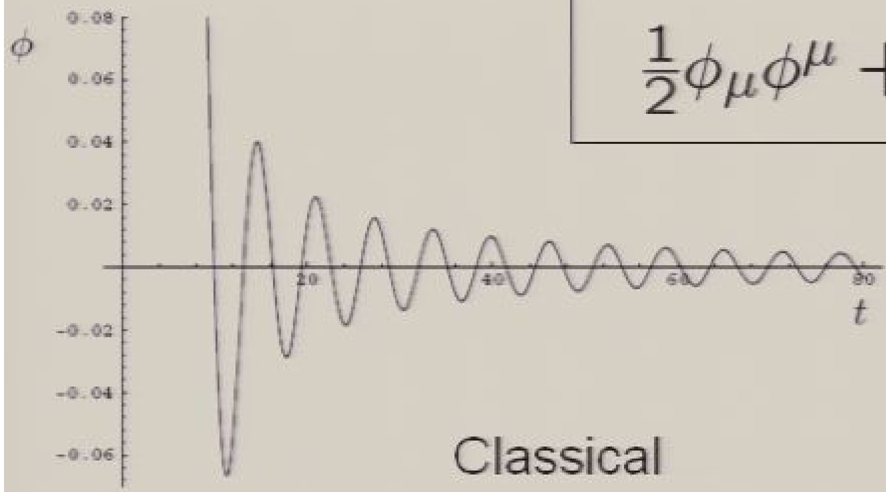
$\phi_0 + \phi$

χ

Slices for t=95.702







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Decay of inflaton and preheating after inflation

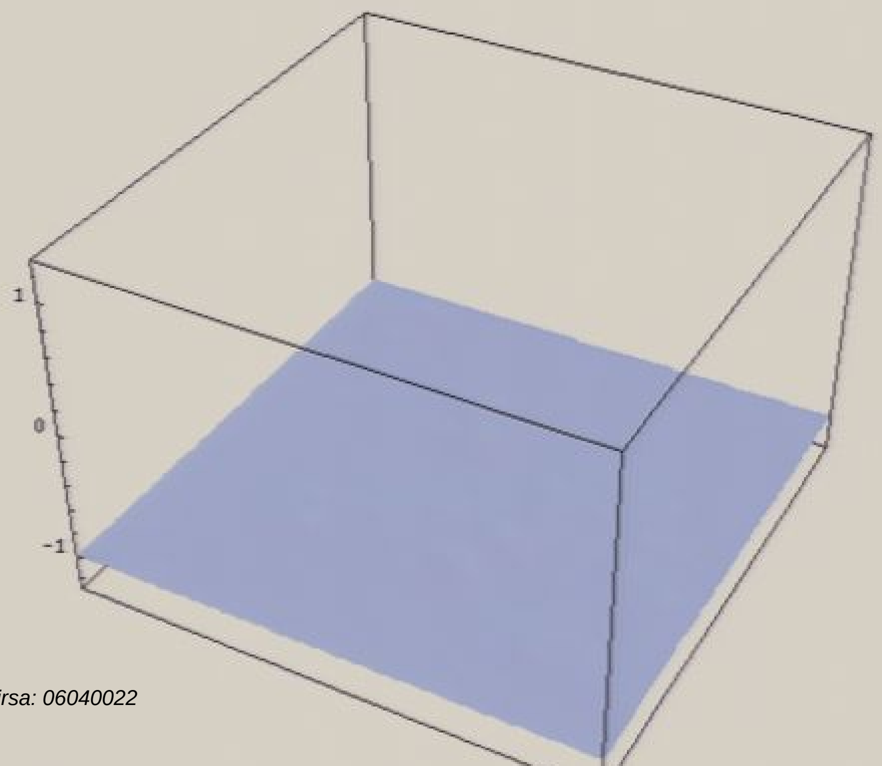
Classical

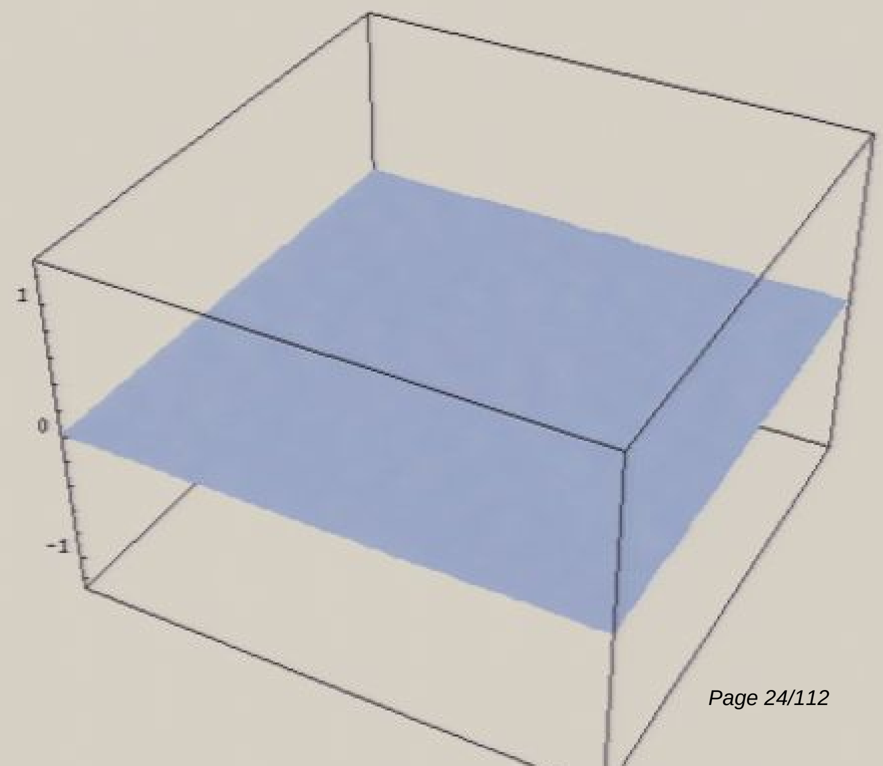
$\phi_0 + \phi$

Quantum

χ

Slices for t=97.7025





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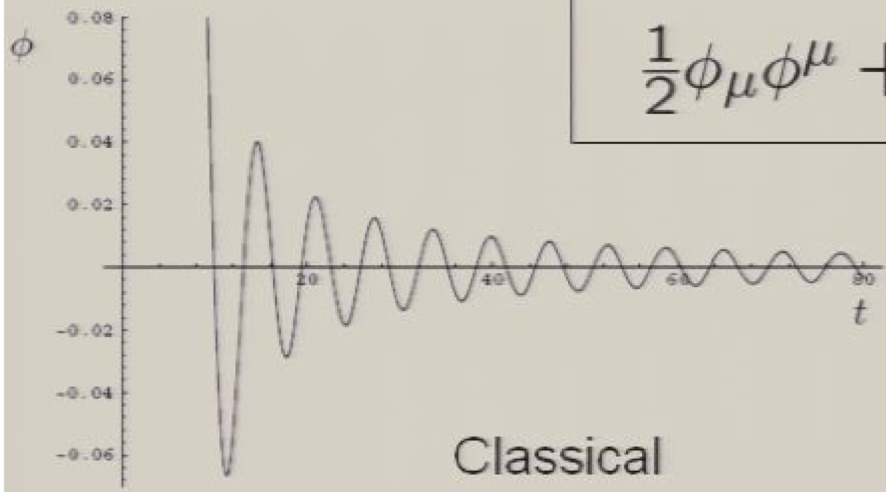


Decay of inflaton and preheating after inflation

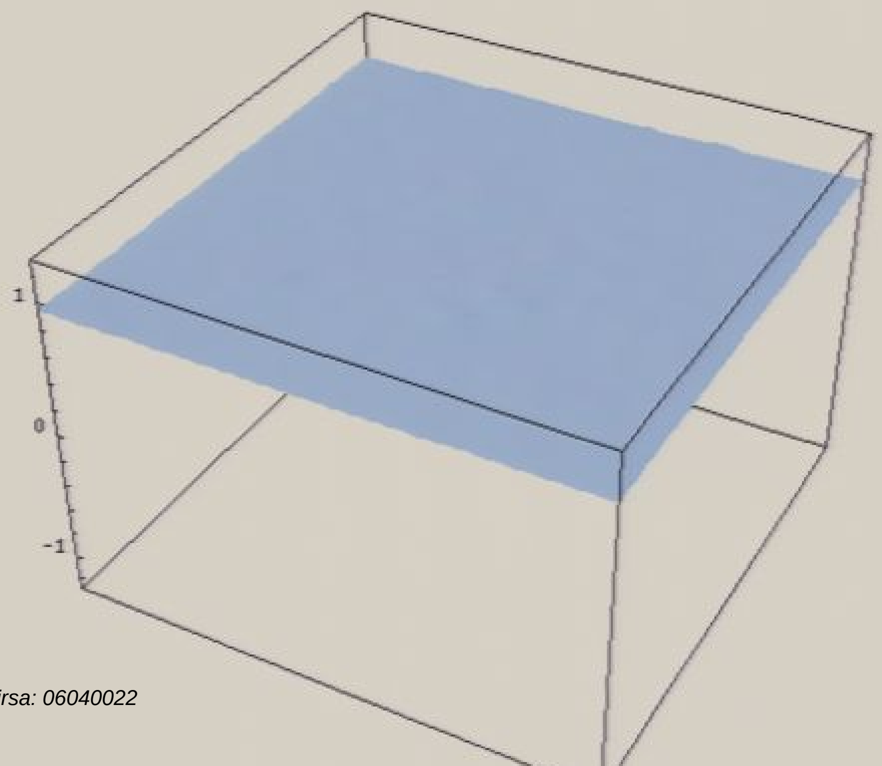
Classical

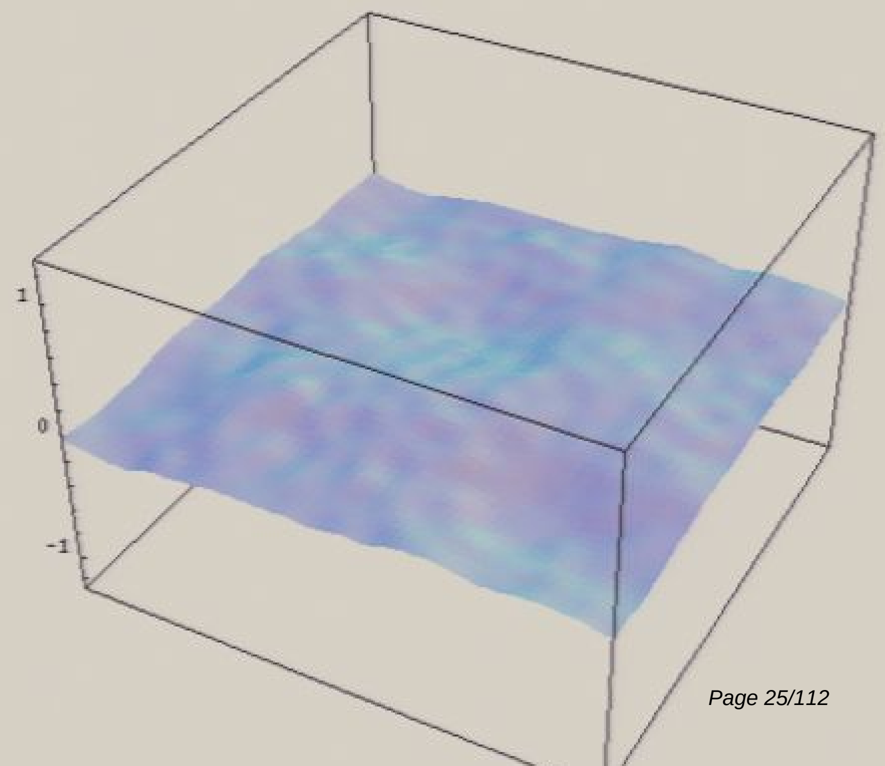
Quantum

$\phi_0 + \phi$

χ

Slices for t=100.203





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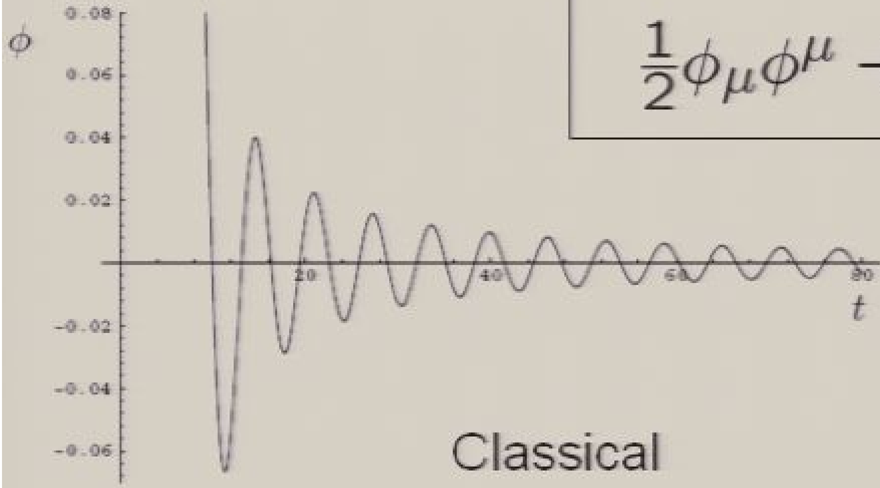


Decay of inflaton and preheating after inflation

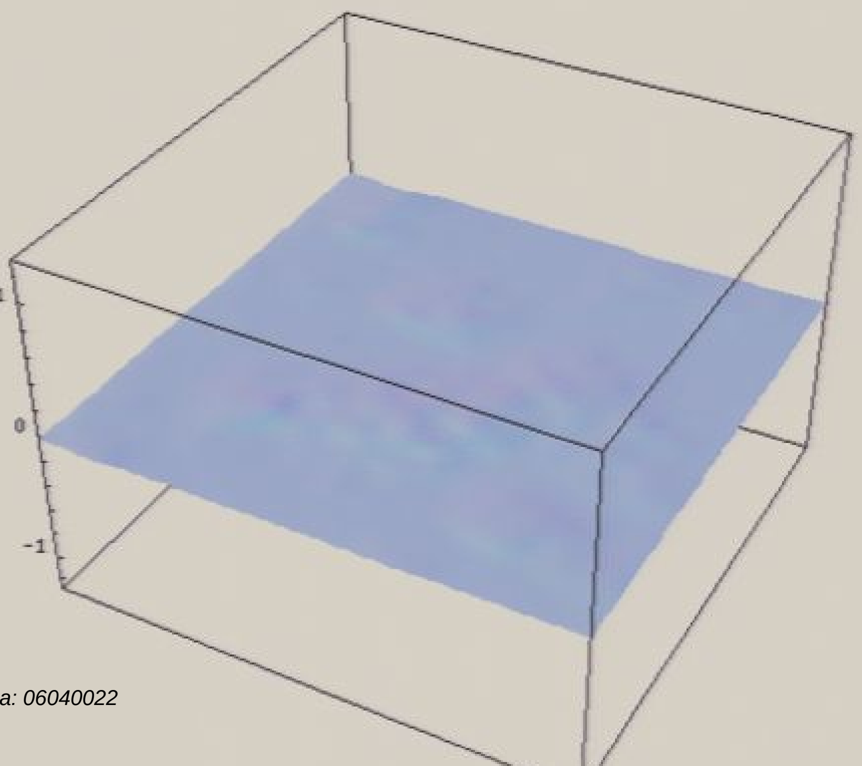
Classical

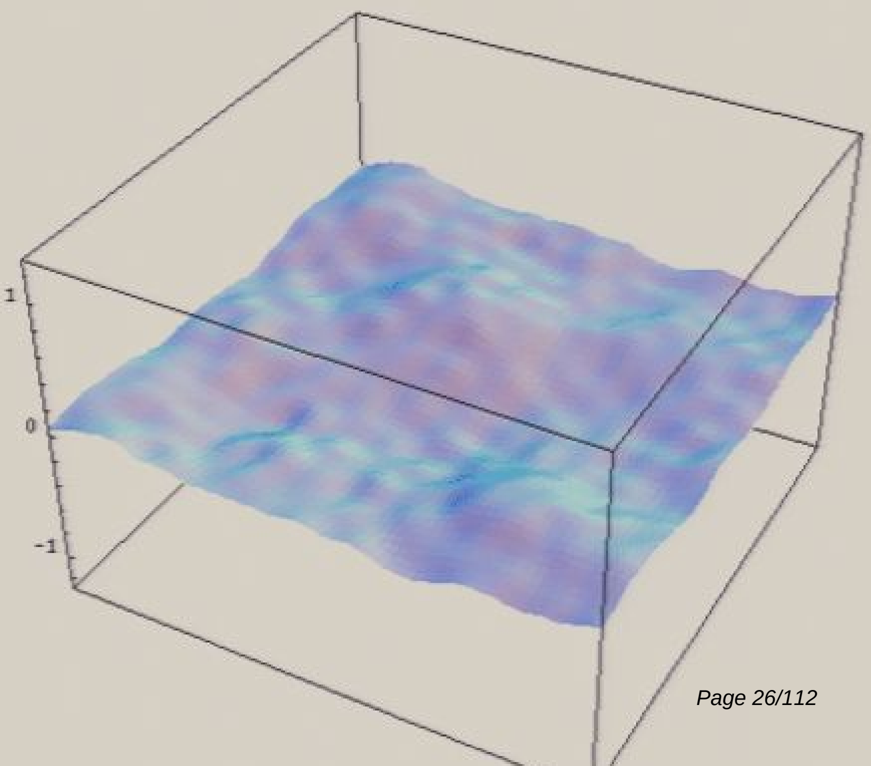
$\phi_0 + \phi$

Quantum

χ

Slices for t=102.203





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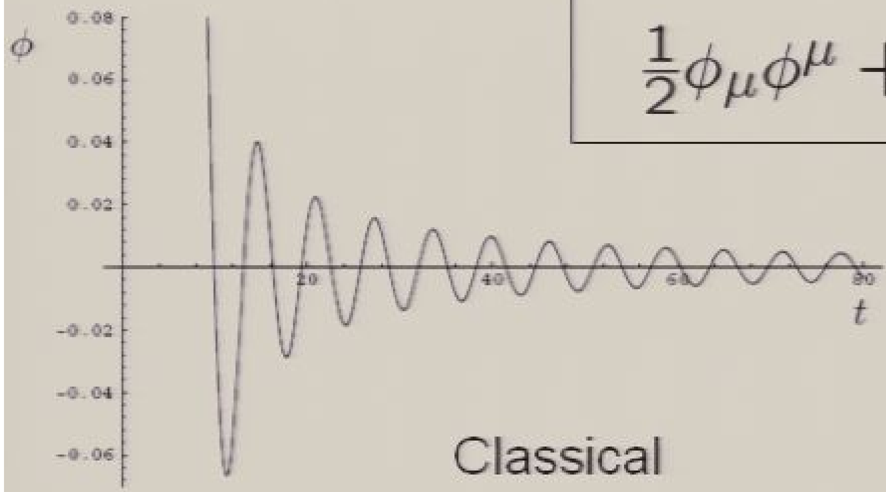


Decay of inflaton and preheating after inflation

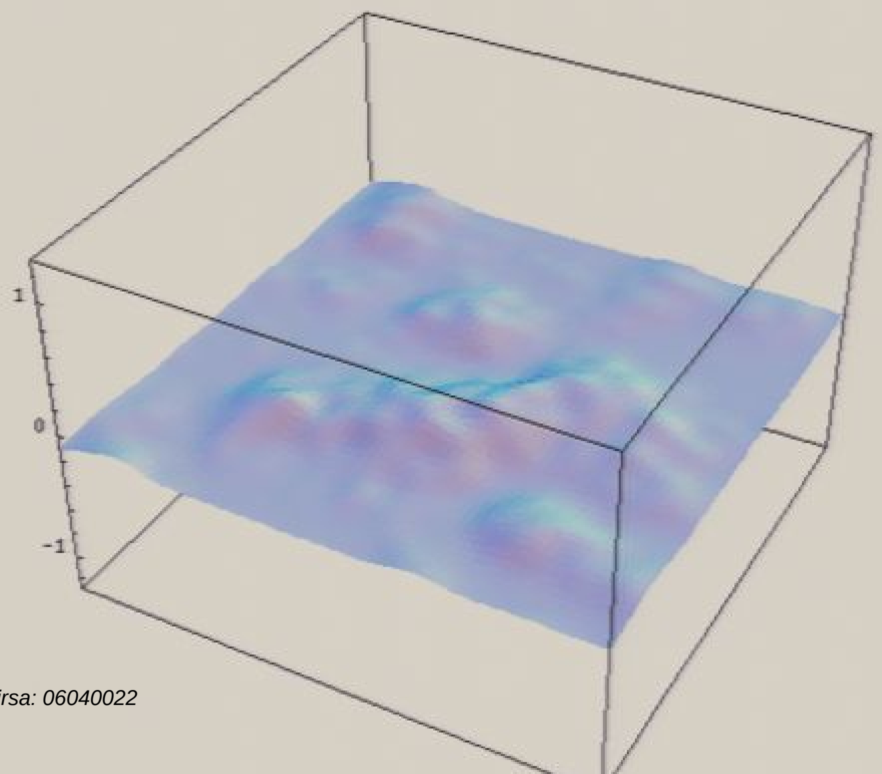
Classical

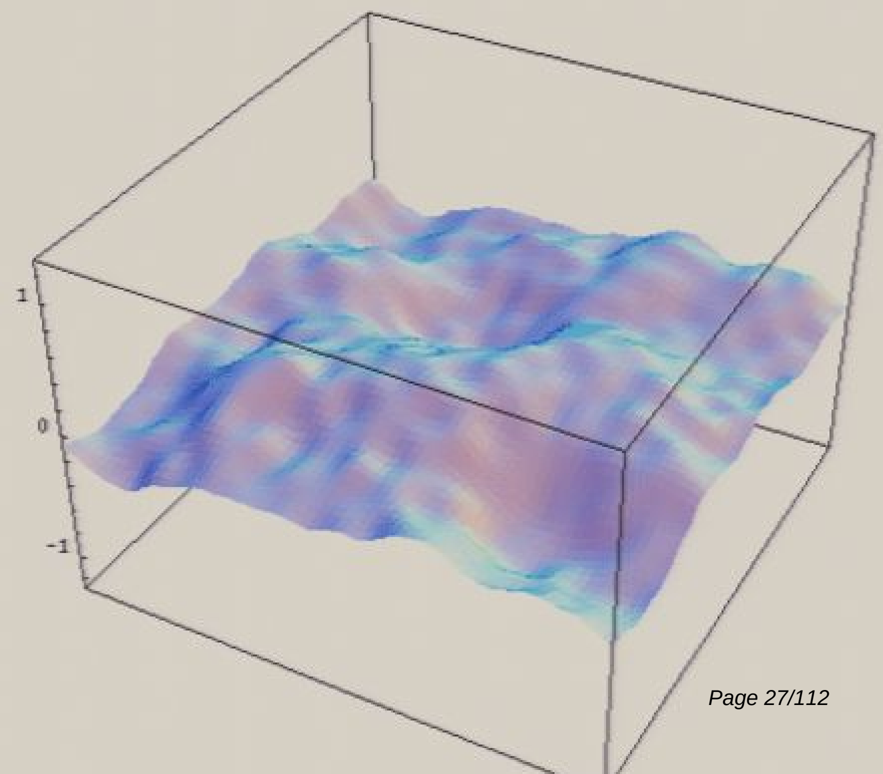
Quantum

$\phi_0 + \phi$

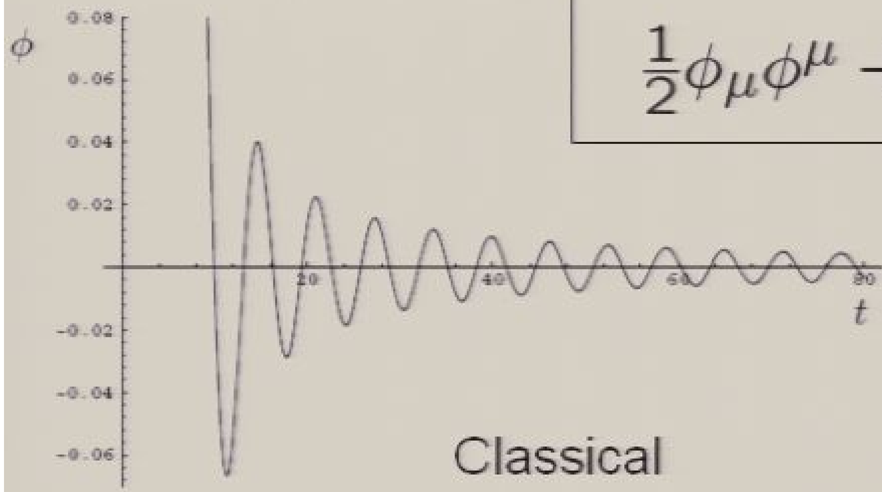
χ

Slices for t=104.704





$$\frac{1}{2}\phi_\mu\phi^\mu + \frac{1}{2}m^2\phi^2 + \frac{1}{2}\chi_\mu\chi^\mu + g^2\phi^2\chi 2$$



Decay of inflaton and preheating after inflation

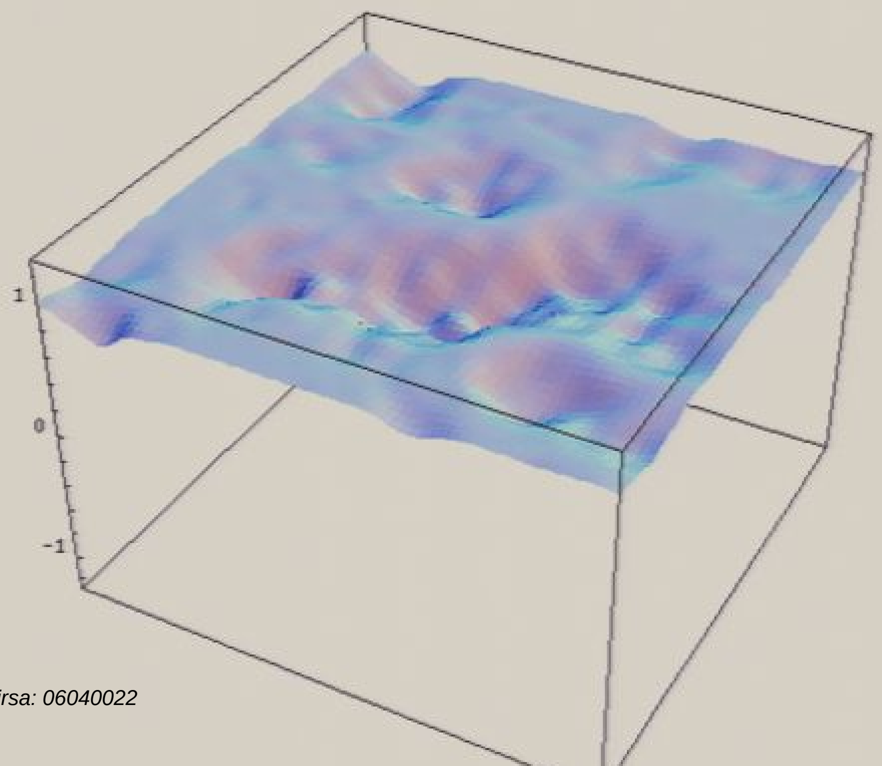
Classical

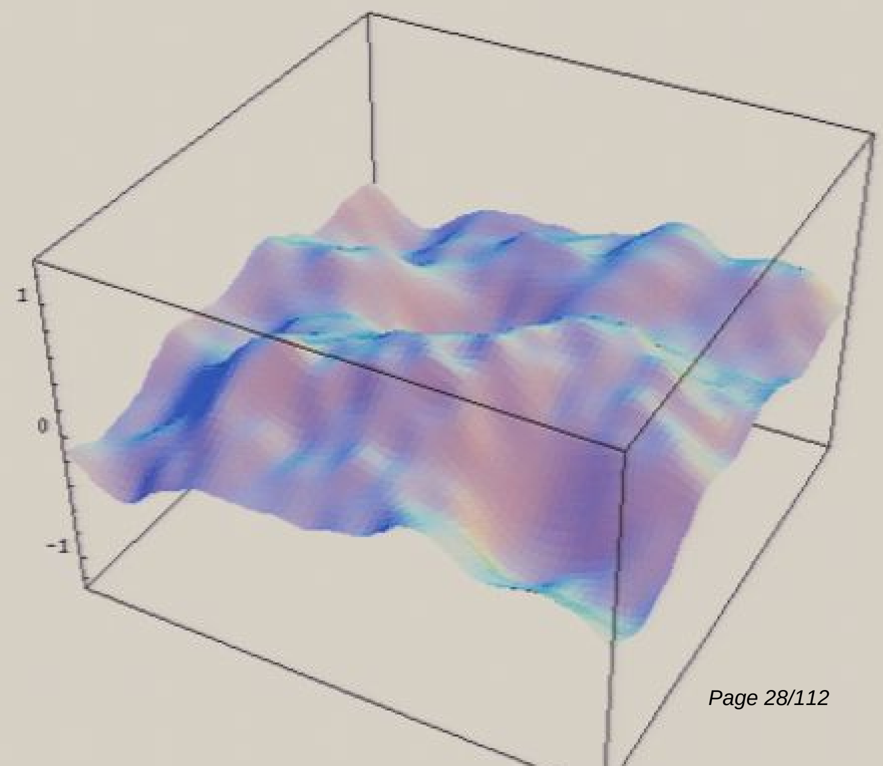
Quantum

$\phi_0 + \phi$

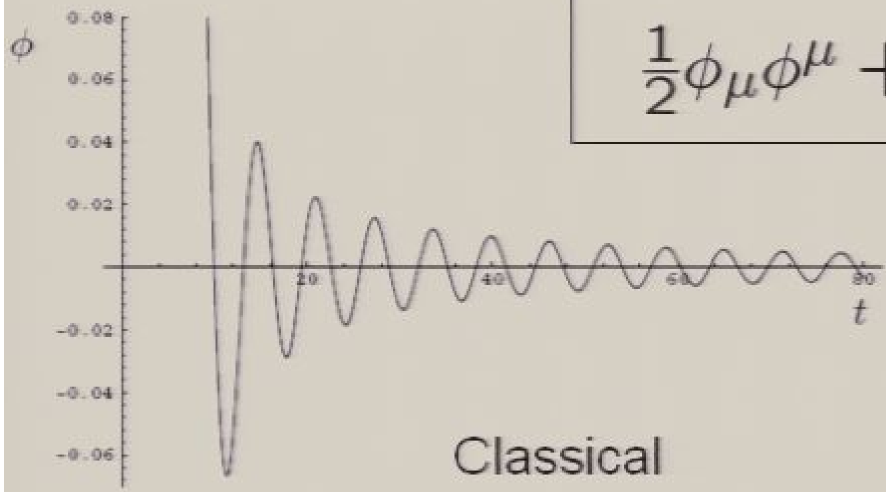
χ

Slices for t=106.704





$$\frac{1}{2}\phi_\mu\phi^\mu + \frac{1}{2}m^2\phi^2 + \frac{1}{2}\chi_\mu\chi^\mu + g^2\phi^2\chi 2$$



Decay of inflaton and preheating after inflation

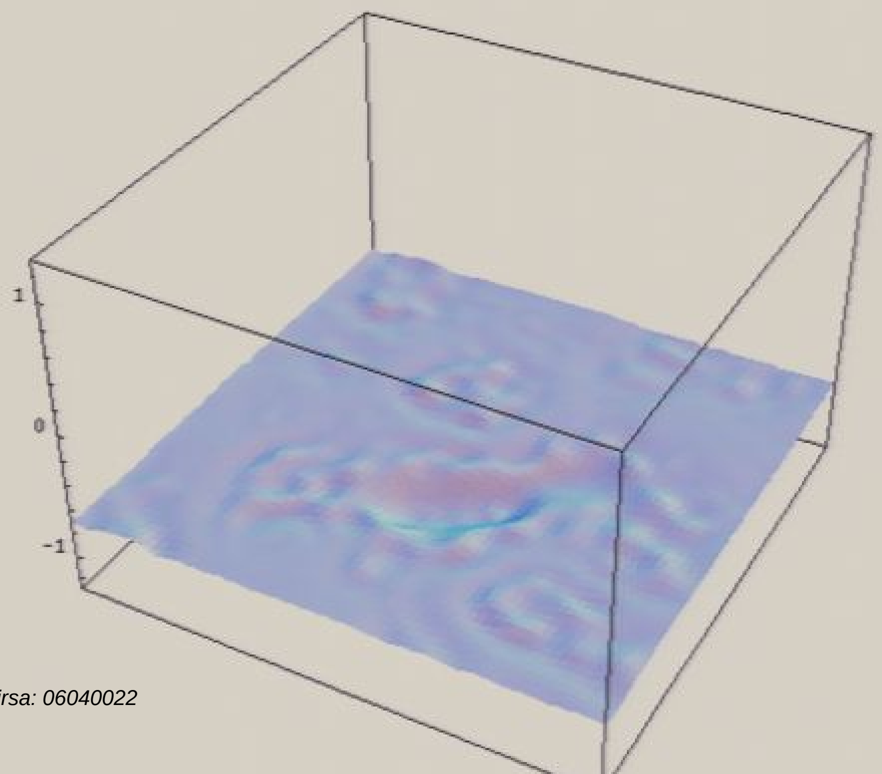
Classical

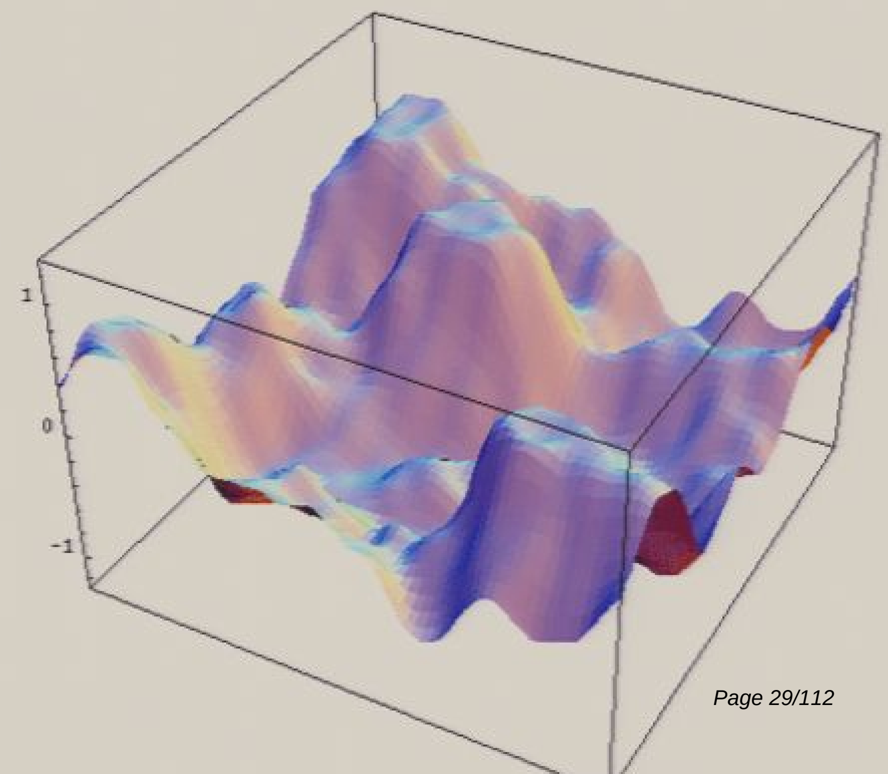
Quantum

$\phi_0 + \phi$

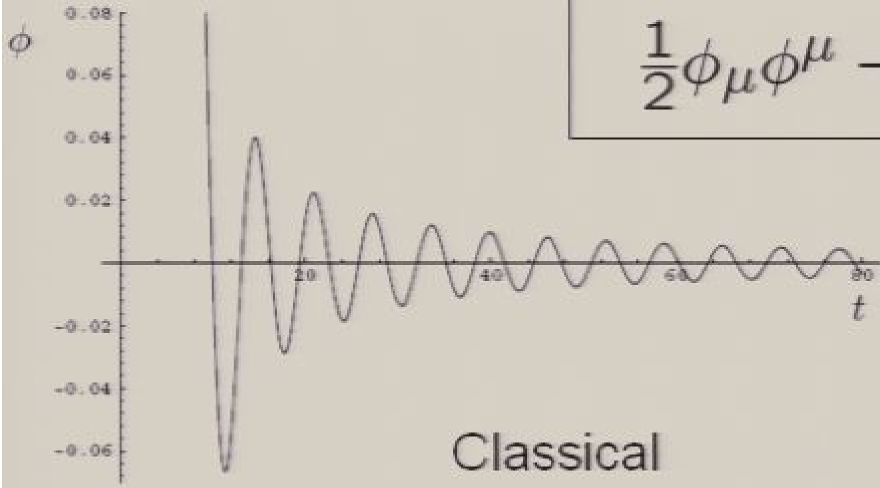
χ

Slices for t=109.205





$$\frac{1}{2}\phi_\mu\phi^\mu + \frac{1}{2}m^2\phi^2 + \frac{1}{2}\chi_\mu\chi^\mu + g^2\phi^2\chi 2$$



Decay of inflaton and preheating after inflation

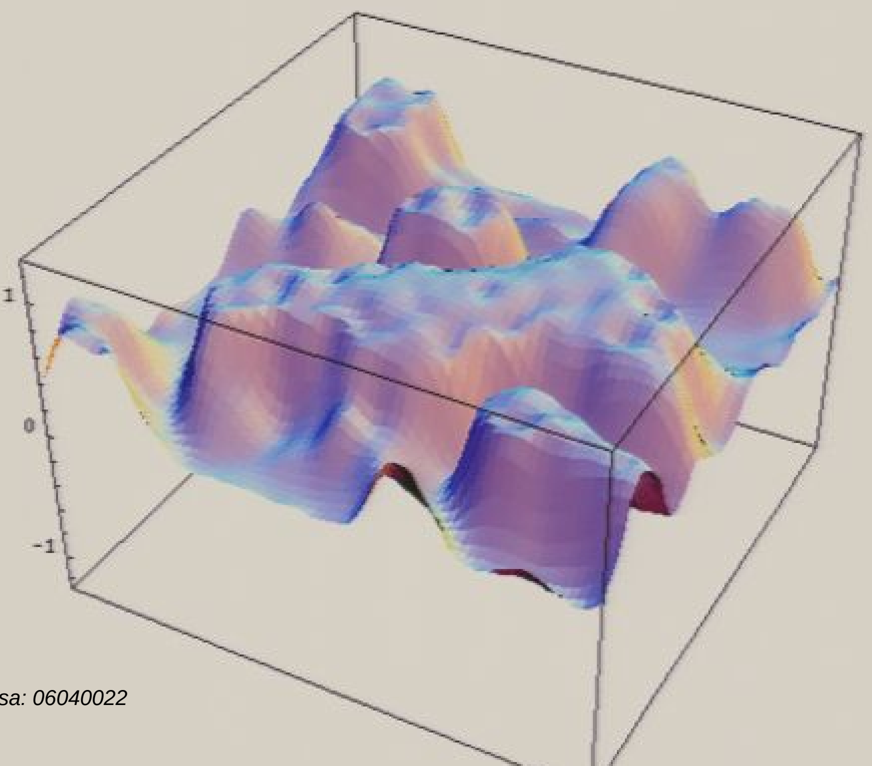
Classical

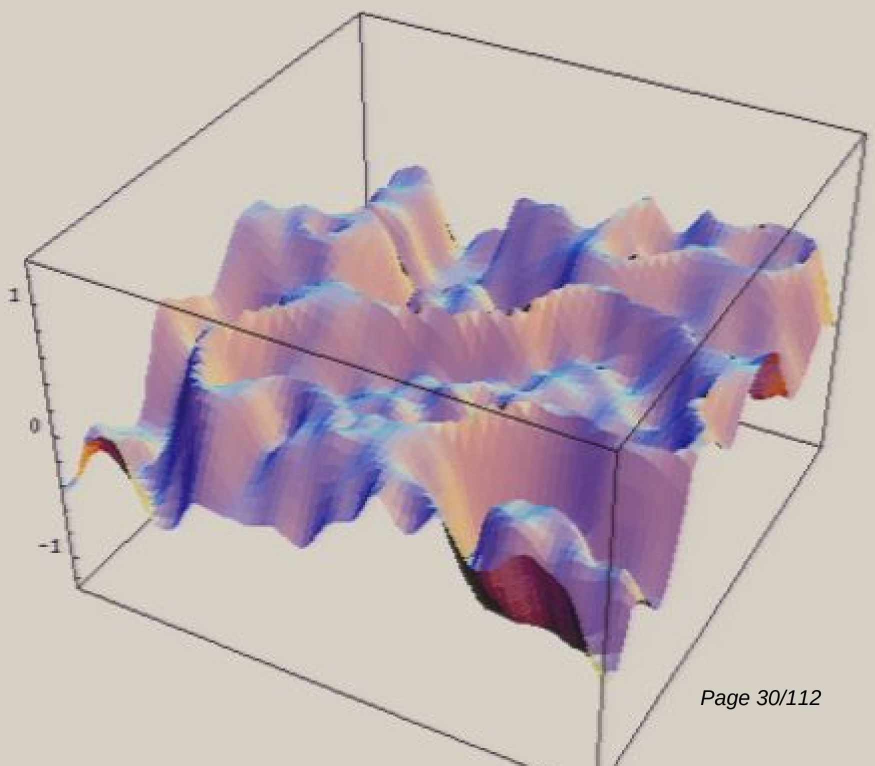
Quantum

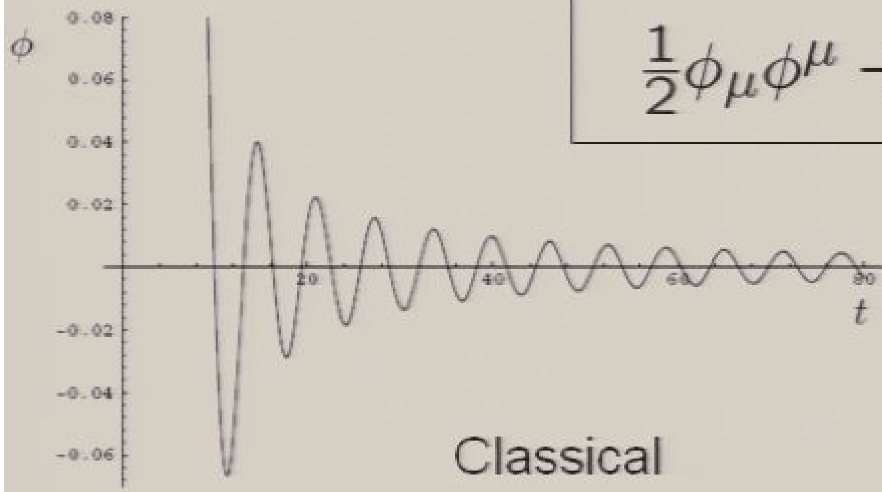
$\phi_0 + \phi$

χ

Slices for t=111.705







$$\frac{1}{2}\phi_\mu\phi^\mu + \frac{1}{2}m^2\phi^2 + \frac{1}{2}\chi_\mu\chi^\mu + g^2\phi^2\chi 2$$

Decay of inflaton and preheating after inflation

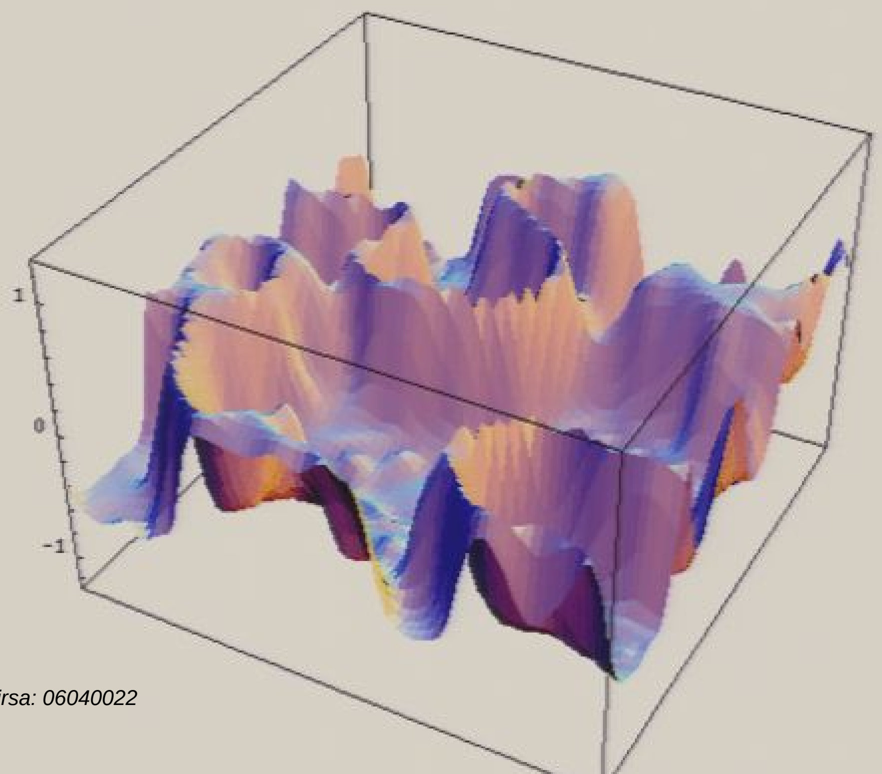
Classical

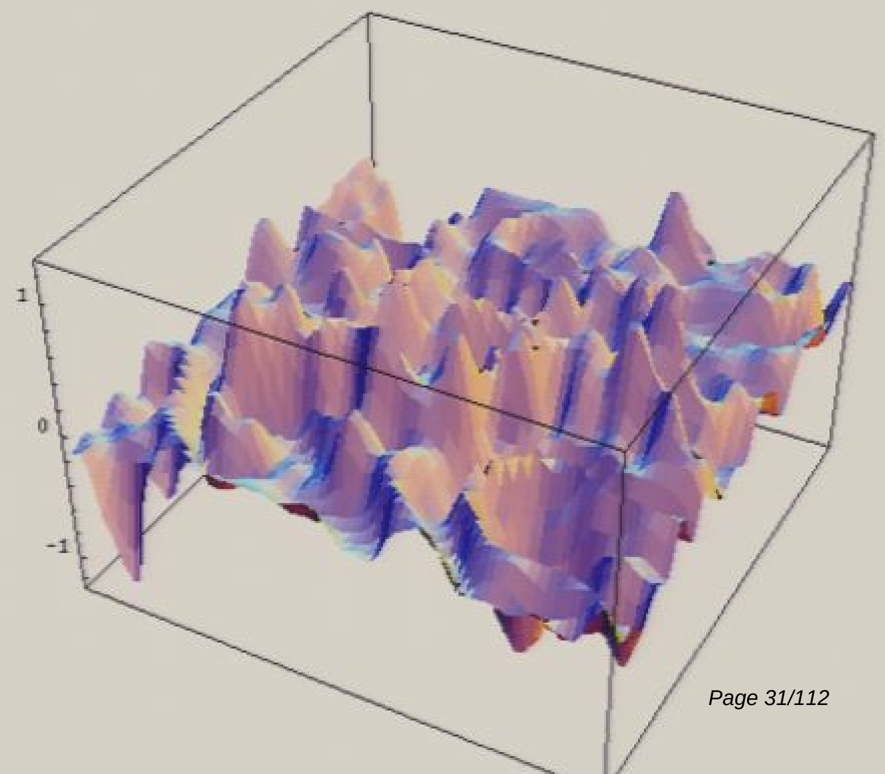
Quantum

$\phi_0 + \phi$

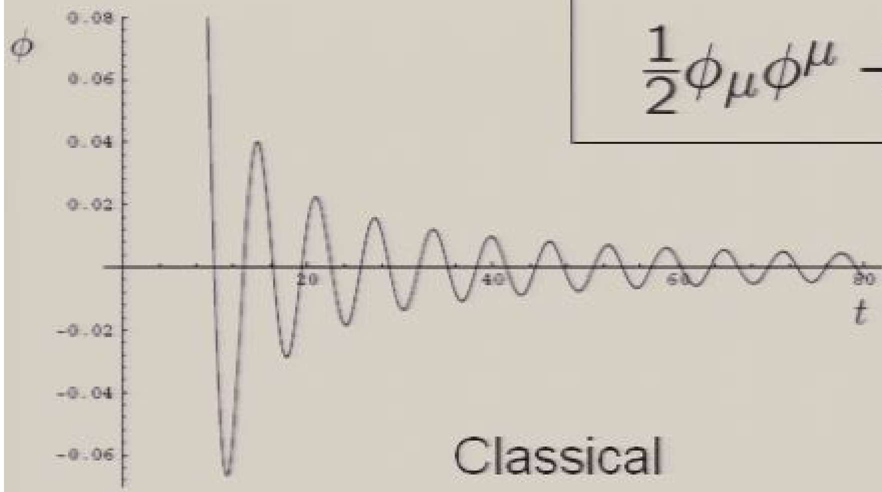
χ

Slices for t=114.206





$$\frac{1}{2}\phi_\mu\phi^\mu + \frac{1}{2}m^2\phi^2 + \frac{1}{2}\chi_\mu\chi^\mu + g^2\phi^2\chi 2$$



Decay of inflaton and preheating after inflation

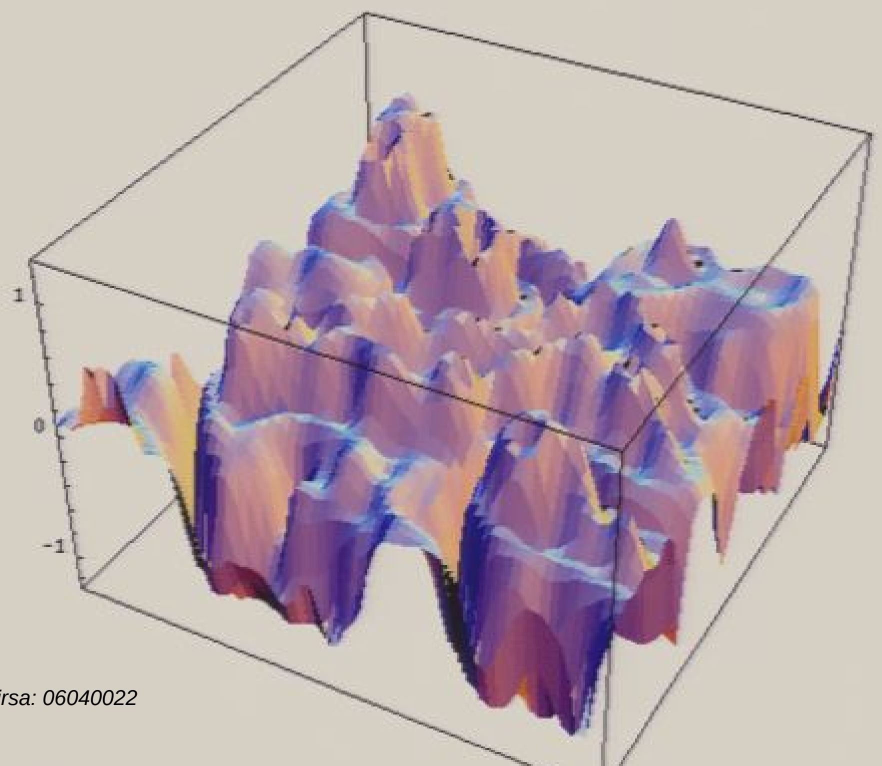
Classical

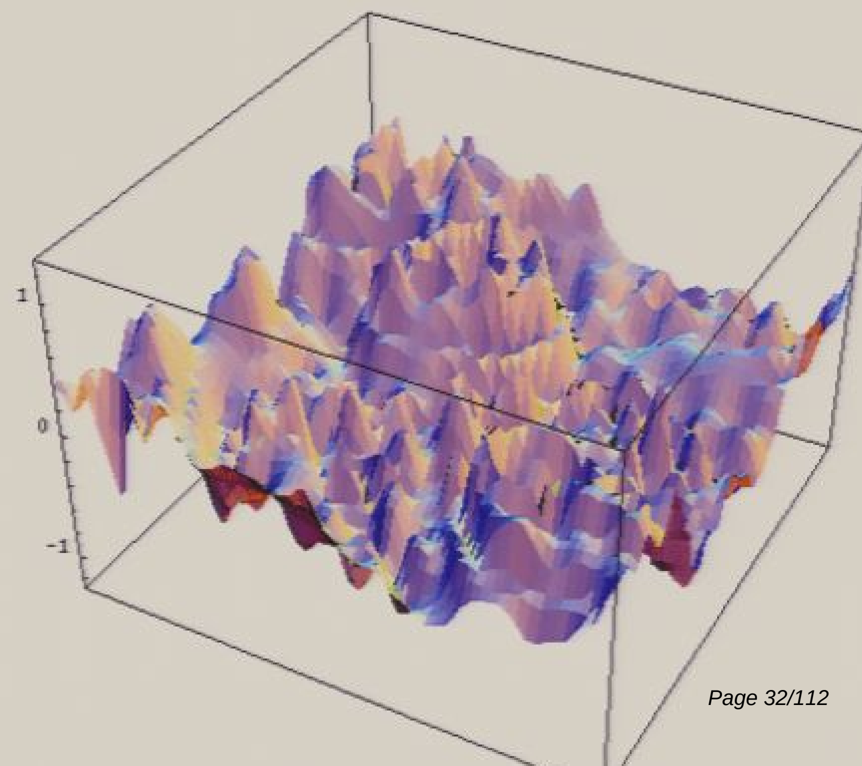
$\phi_0 + \phi$

Quantum

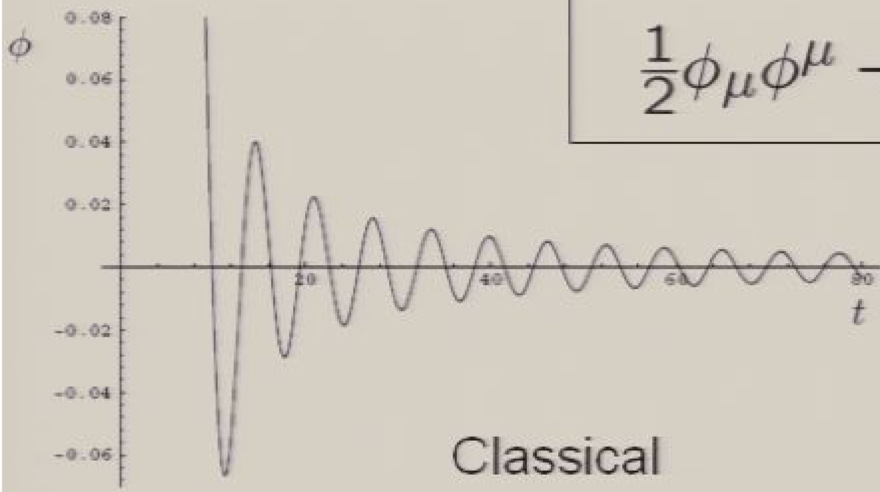
χ

Slices for t=116.707





$$\frac{1}{2}\phi_\mu\phi^\mu + \frac{1}{2}m^2\phi^2 + \frac{1}{2}\chi_\mu\chi^\mu + g^2\phi^2\chi 2$$



Decay of inflaton and preheating after inflation

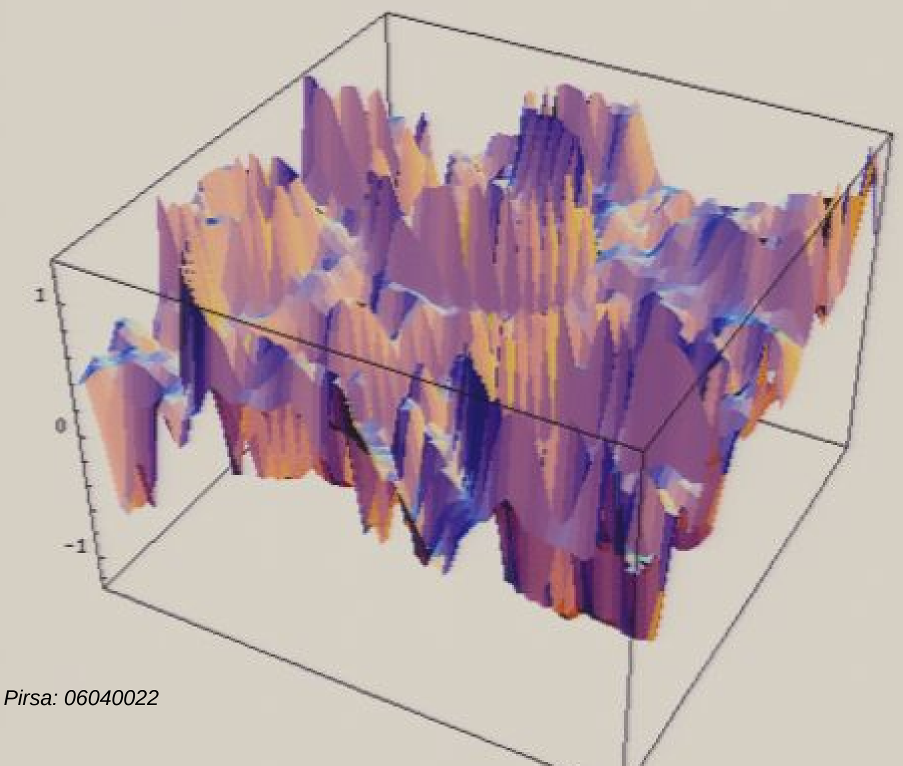
Classical

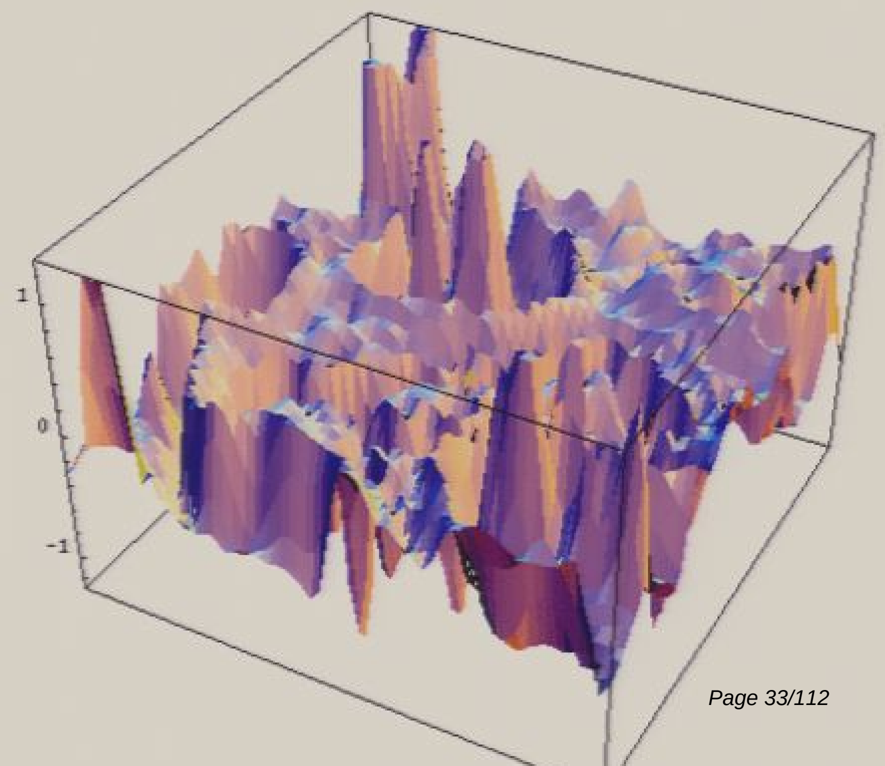
Quantum

$\phi_0 + \phi$

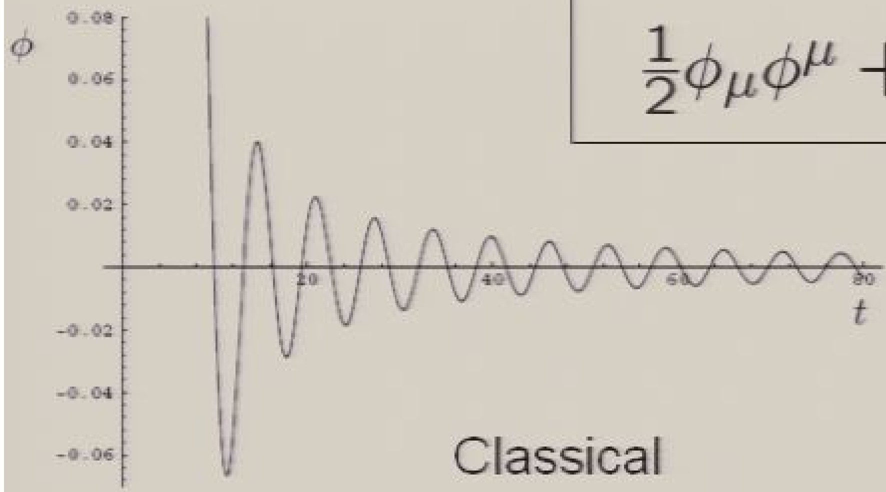
χ

Slices for t=119.207





$$\frac{1}{2}\phi_\mu\phi^\mu + \frac{1}{2}m^2\phi^2 + \frac{1}{2}\chi_\mu\chi^\mu + g^2\phi^2\chi 2$$



Decay of inflaton and preheating after inflation

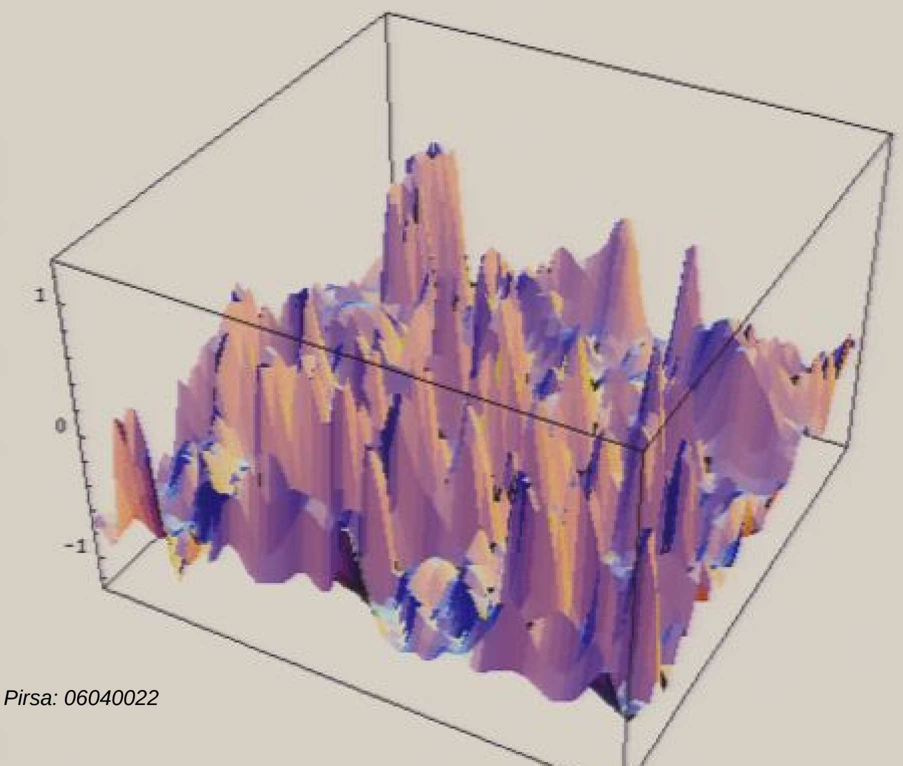
Classical

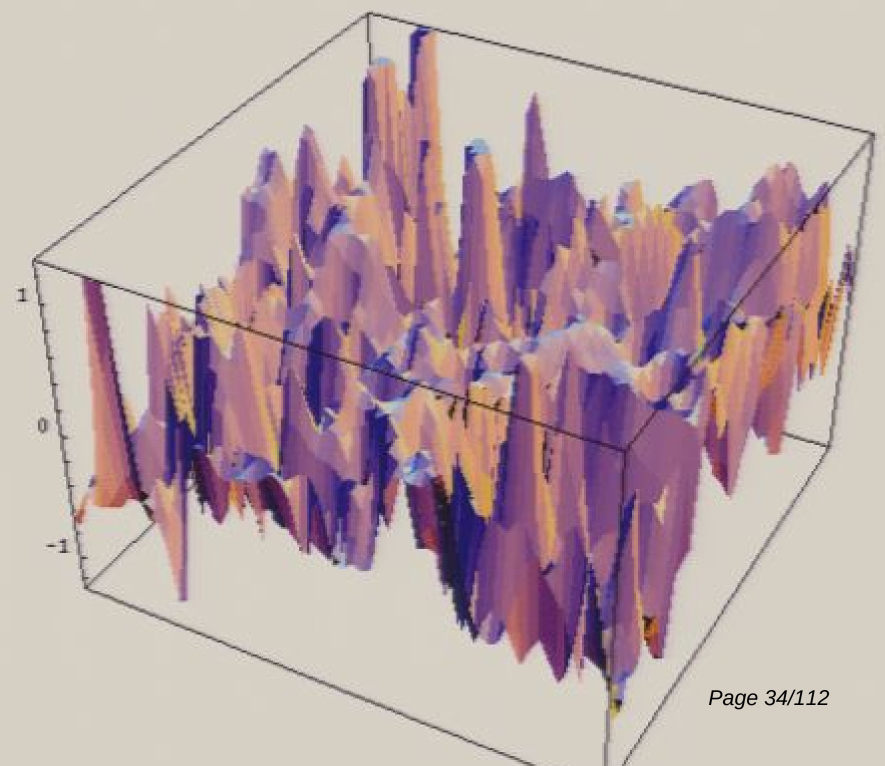
Quantum

$\phi_0 + \phi$

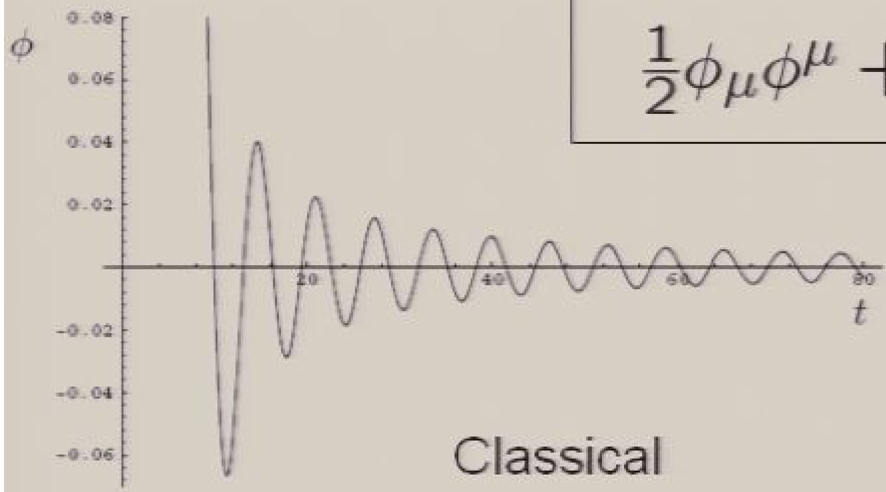
χ

Slices for t=120.707





$$\frac{1}{2}\phi_\mu\phi^\mu + \frac{1}{2}m^2\phi^2 + \frac{1}{2}\chi_\mu\chi^\mu + g^2\phi^2\chi 2$$



Decay of inflaton and preheating after inflation

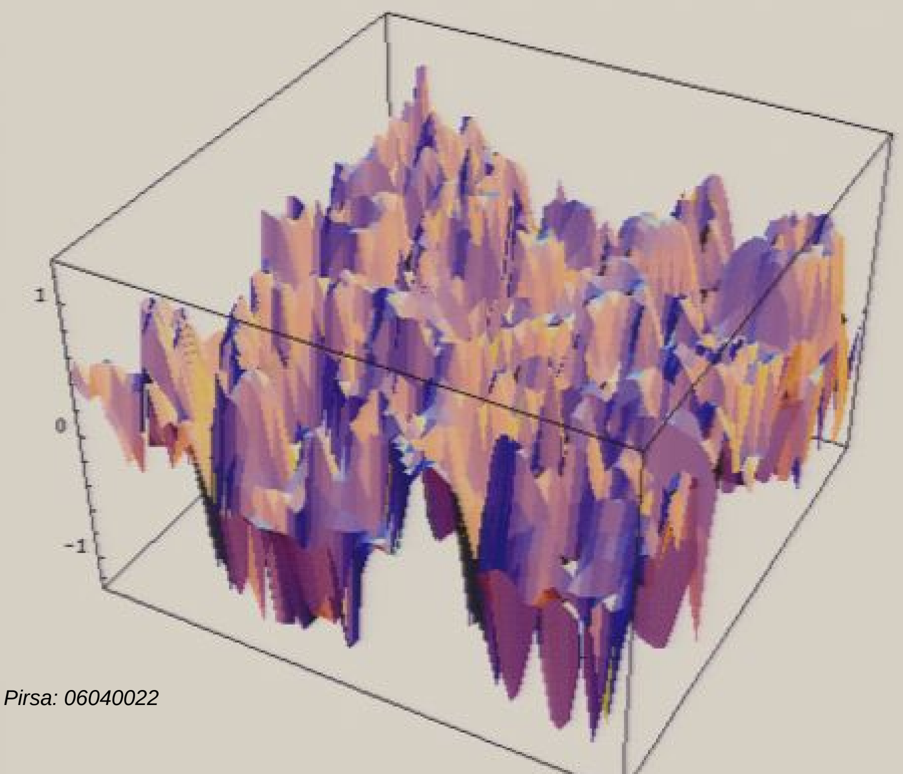
Classical

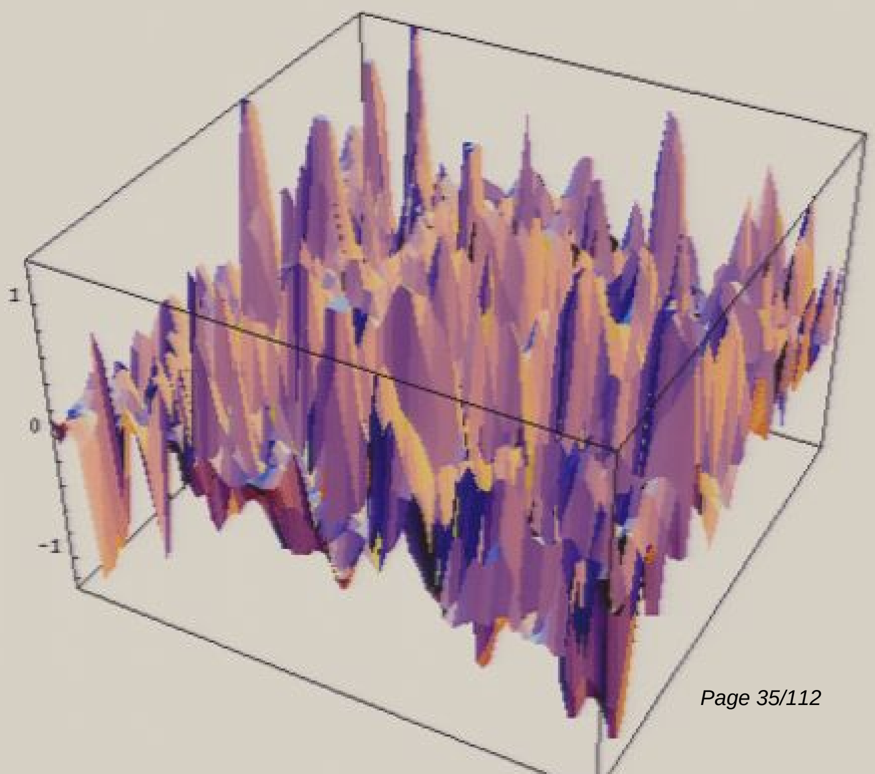
Quantum

$\phi_0 + \phi$

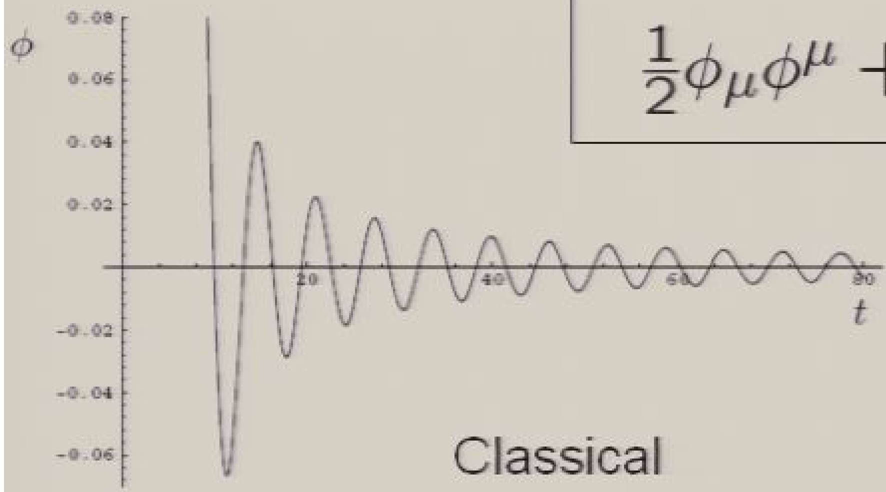
χ

Slices for t=122.708





$$\frac{1}{2}\phi_\mu\phi^\mu + \frac{1}{2}m^2\phi^2 + \frac{1}{2}\chi_\mu\chi^\mu + g^2\phi^2\chi 2$$



Decay of inflaton and preheating after inflation

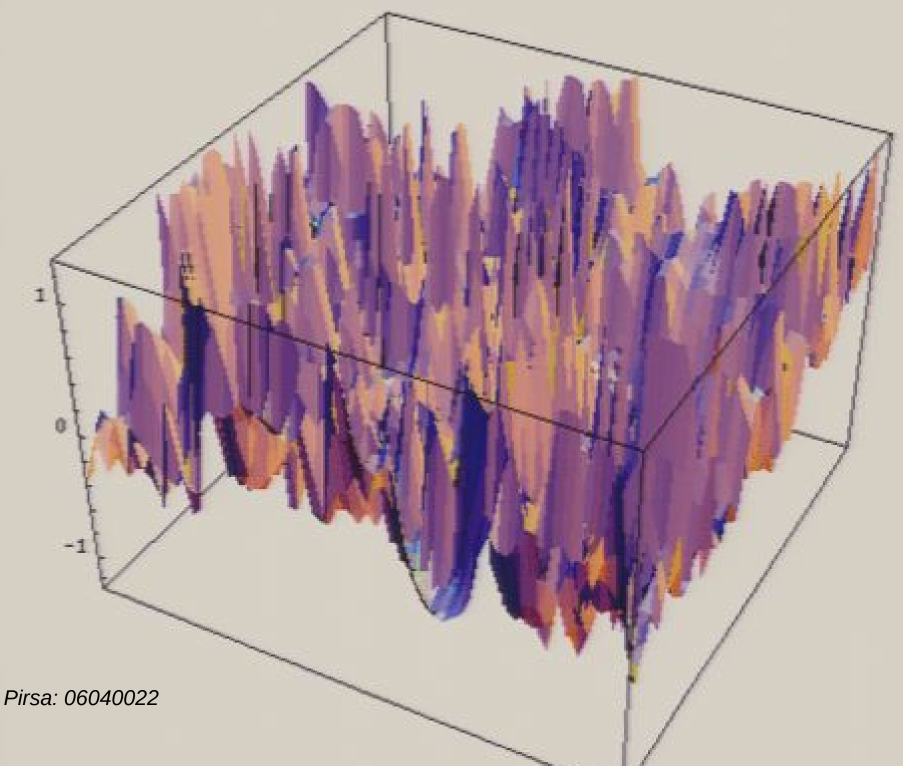
Classical

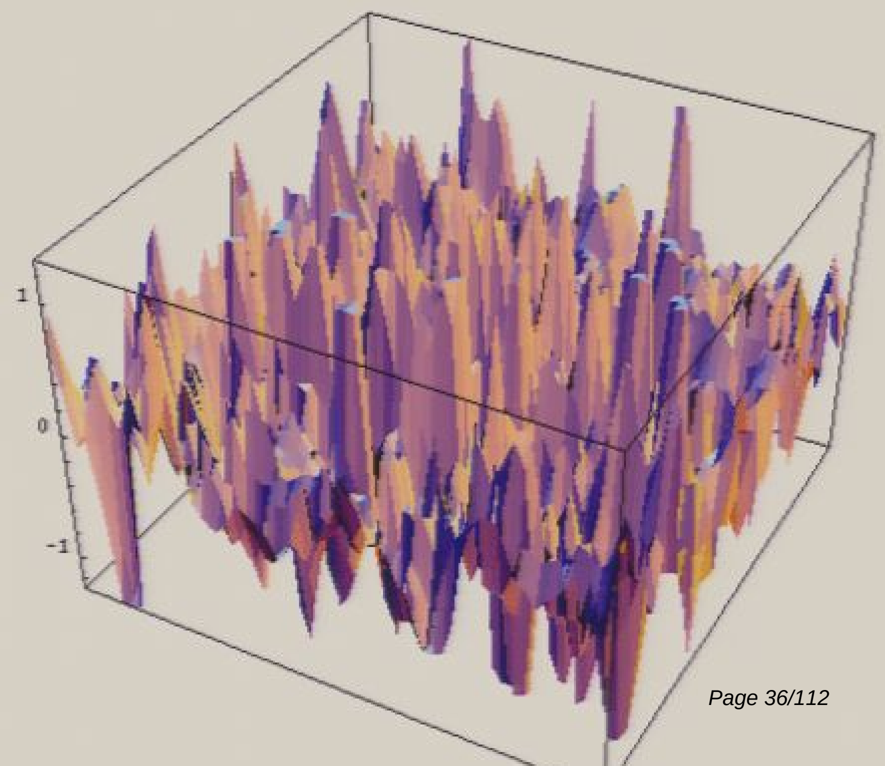
$\phi_0 + \phi$

Quantum

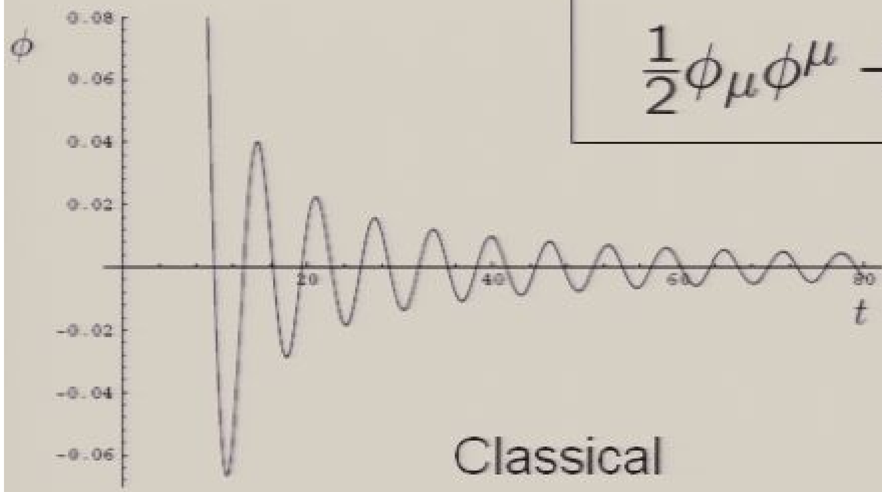
χ

Slices for t=125.208





$$\frac{1}{2}\phi_\mu\phi^\mu + \frac{1}{2}m^2\phi^2 + \frac{1}{2}\chi_\mu\chi^\mu + g^2\phi^2\chi2$$



Decay of inflaton and preheating after inflation

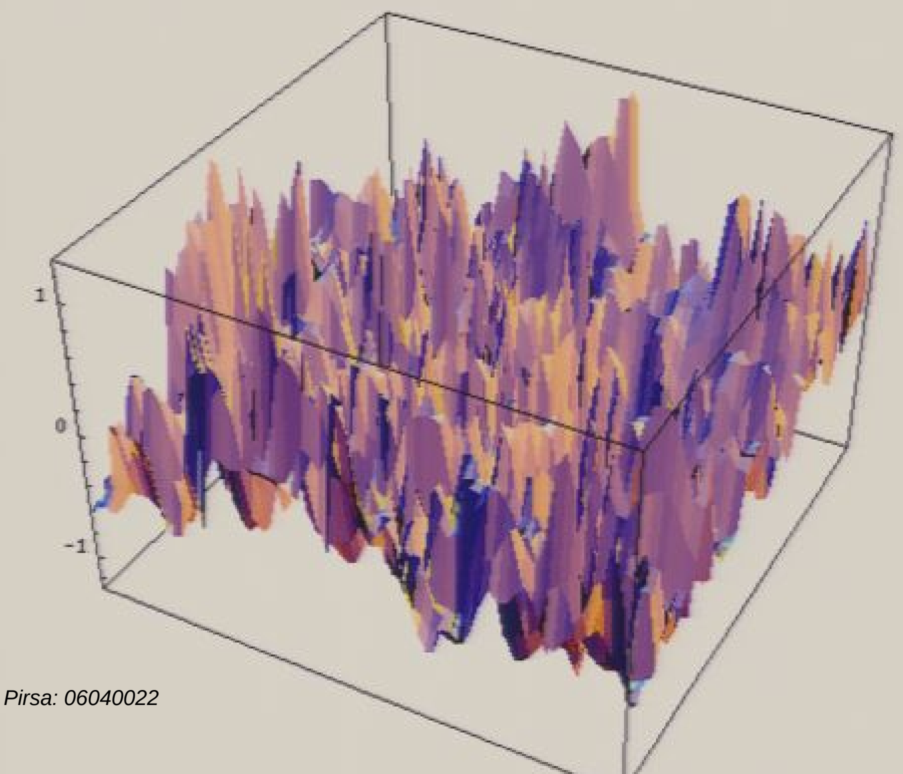
Classical

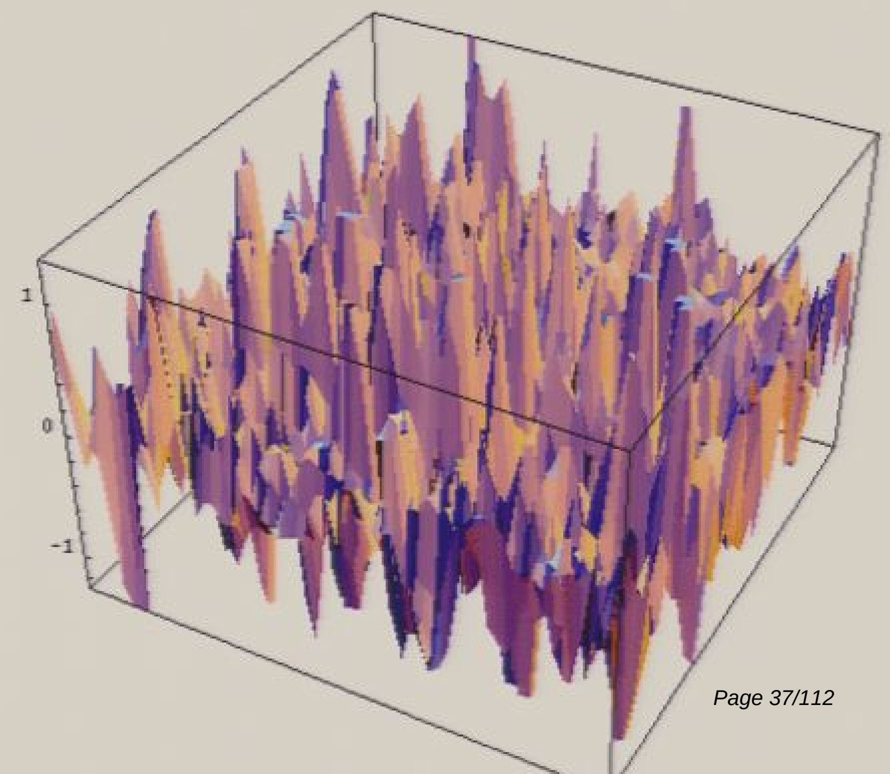
Quantum

$\phi_0 + \phi$

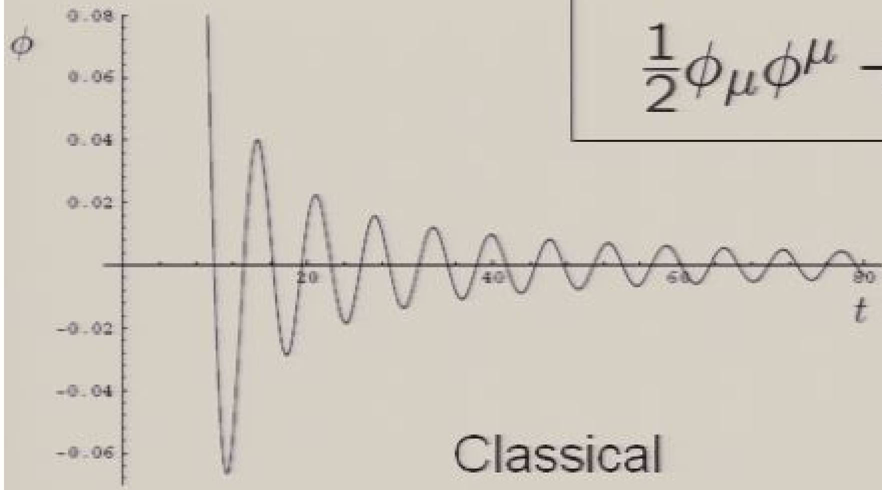
χ

Slices for t=125.708





$$\frac{1}{2}\phi_\mu\phi^\mu + \frac{1}{2}m^2\phi^2 + \frac{1}{2}\chi_\mu\chi^\mu + g^2\phi^2\chi2$$



Decay of inflaton and preheating after inflation

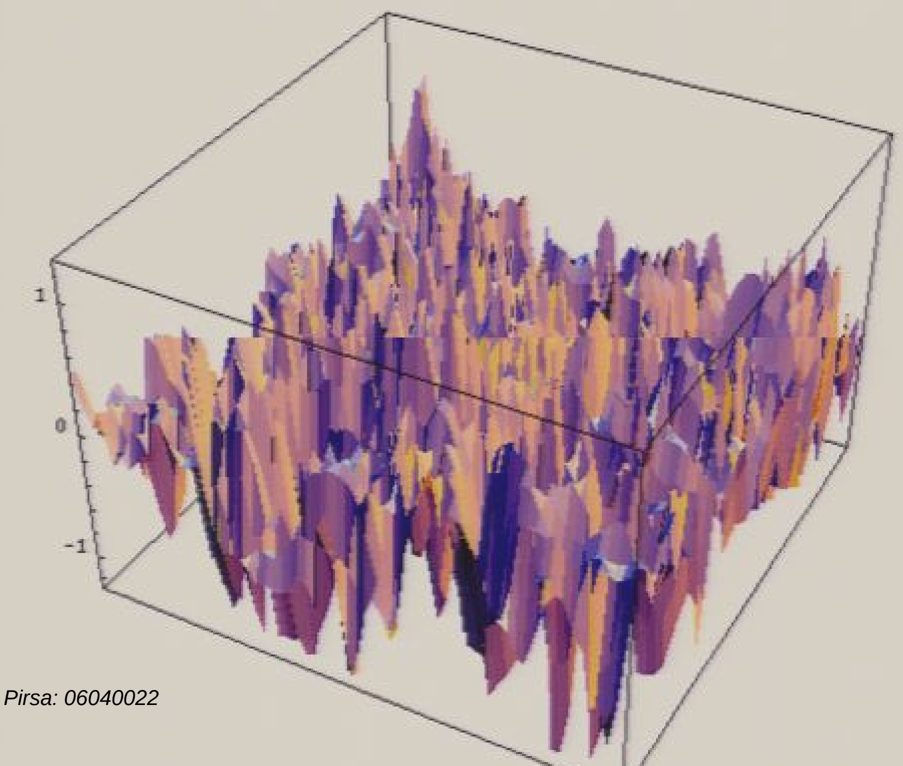
Classical

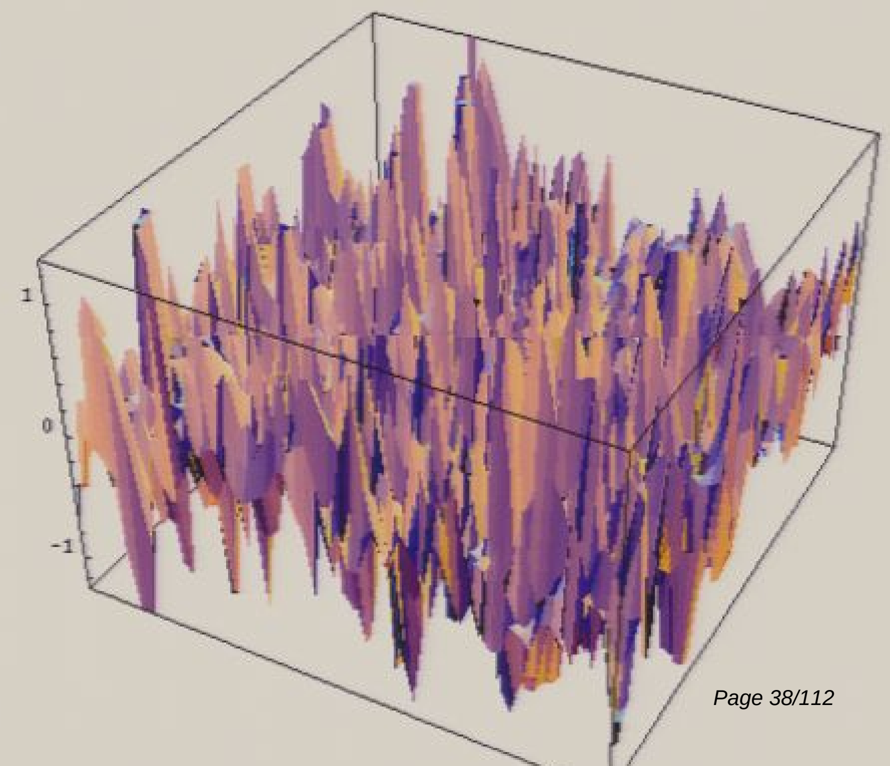
$\phi_0 + \phi$

Quantum

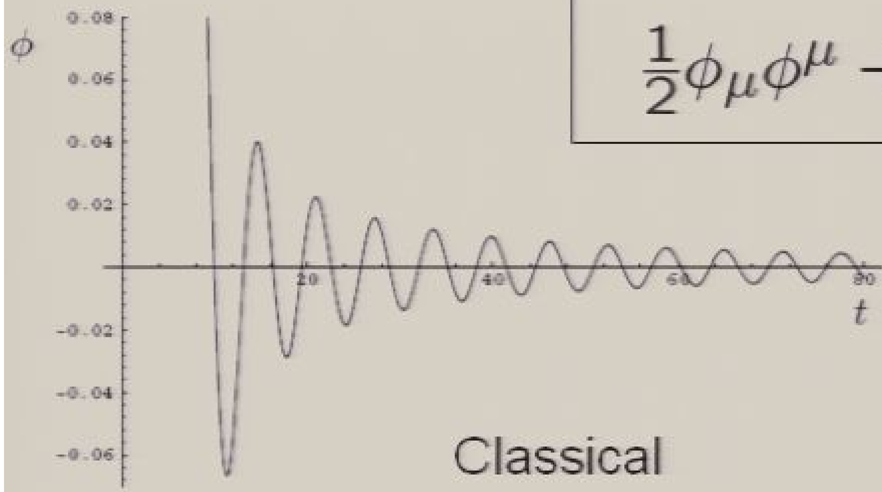
χ

Slices for t=127.709





$$\frac{1}{2}\phi_\mu\phi^\mu + \frac{1}{2}m^2\phi^2 + \frac{1}{2}\chi_\mu\chi^\mu + g^2\phi^2\chi 2$$



Decay of inflaton and preheating after inflation

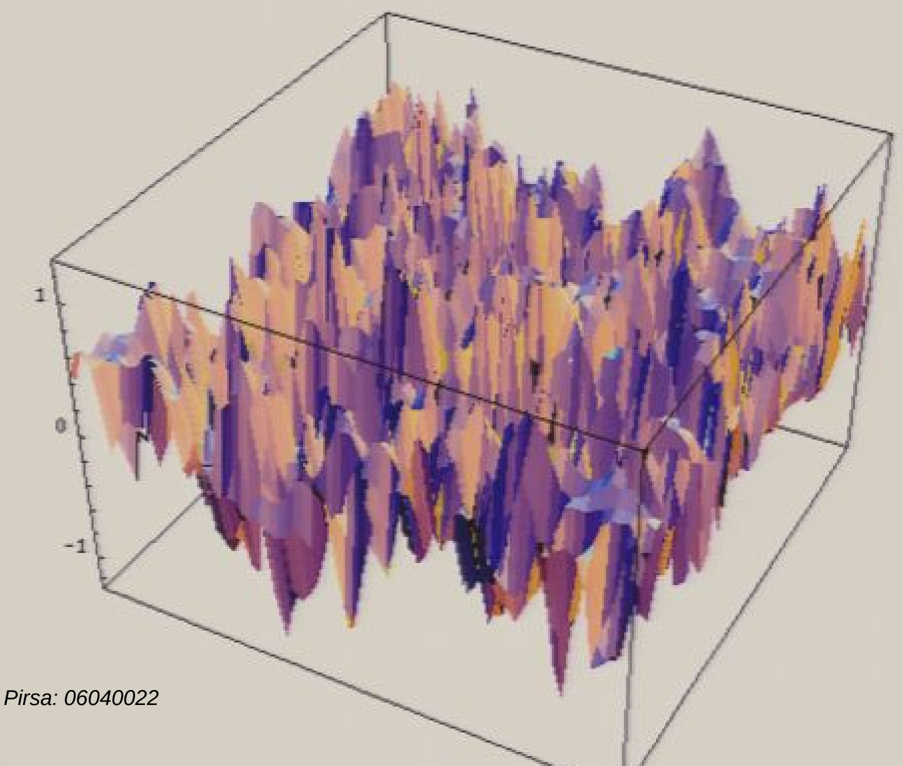
Classical

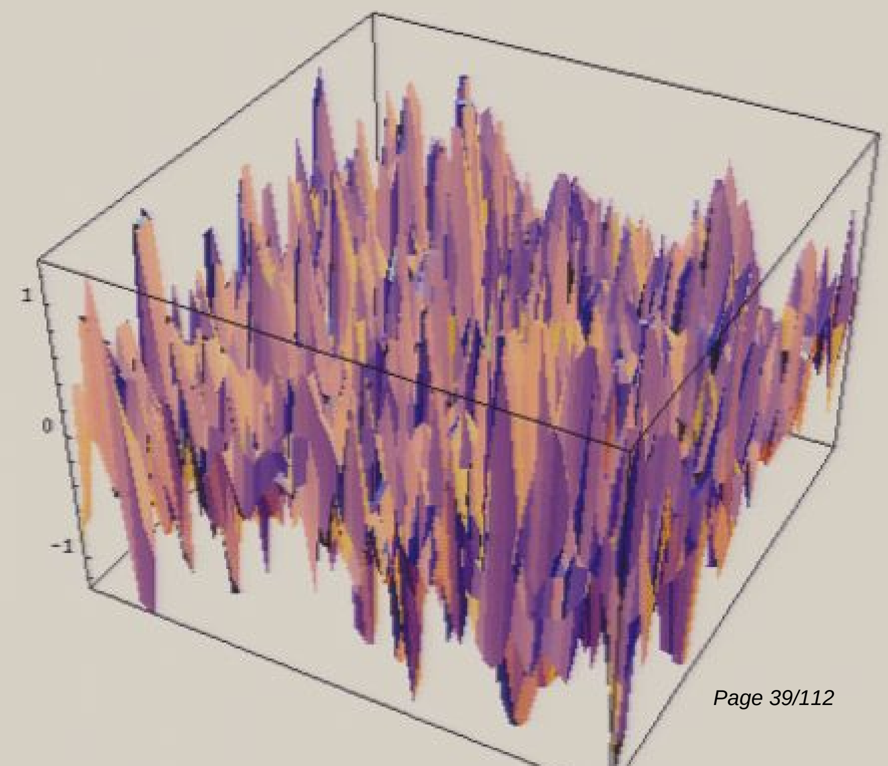
Quantum

$\phi_0 + \phi$

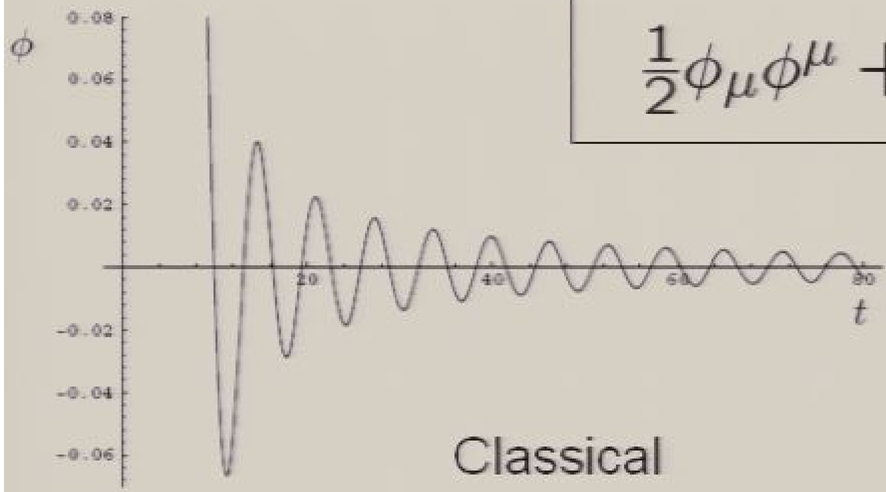
χ

Slices for t=128.729





$$\frac{1}{2}\phi_\mu\phi^\mu + \frac{1}{2}m^2\phi^2 + \frac{1}{2}\chi_\mu\chi^\mu + g^2\phi^2\chi 2$$



Decay of inflaton and preheating after inflation

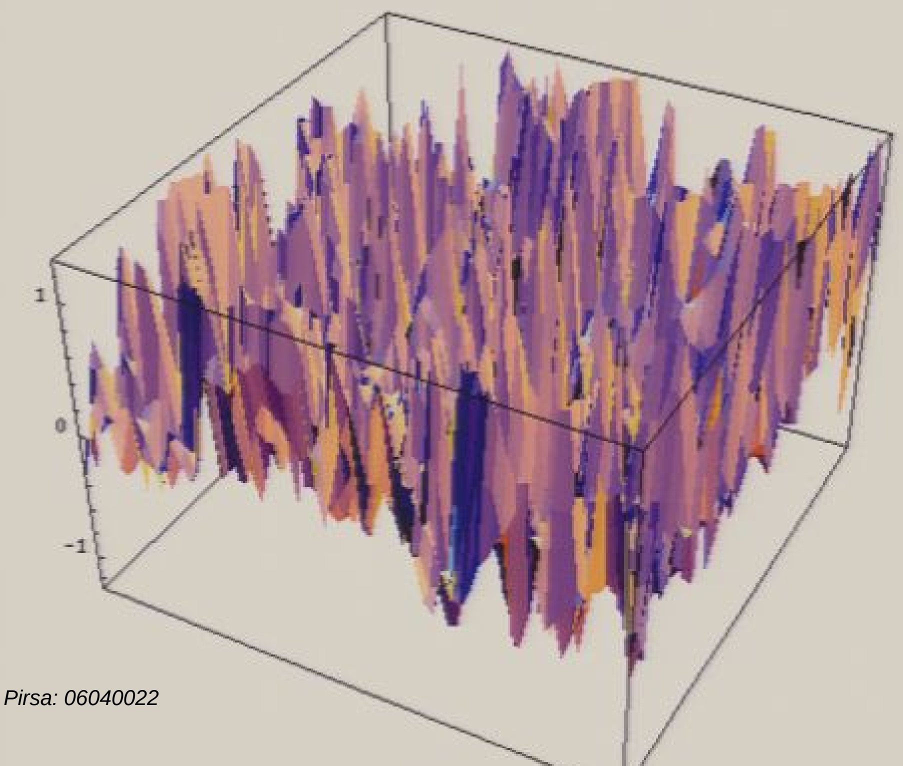
Classical

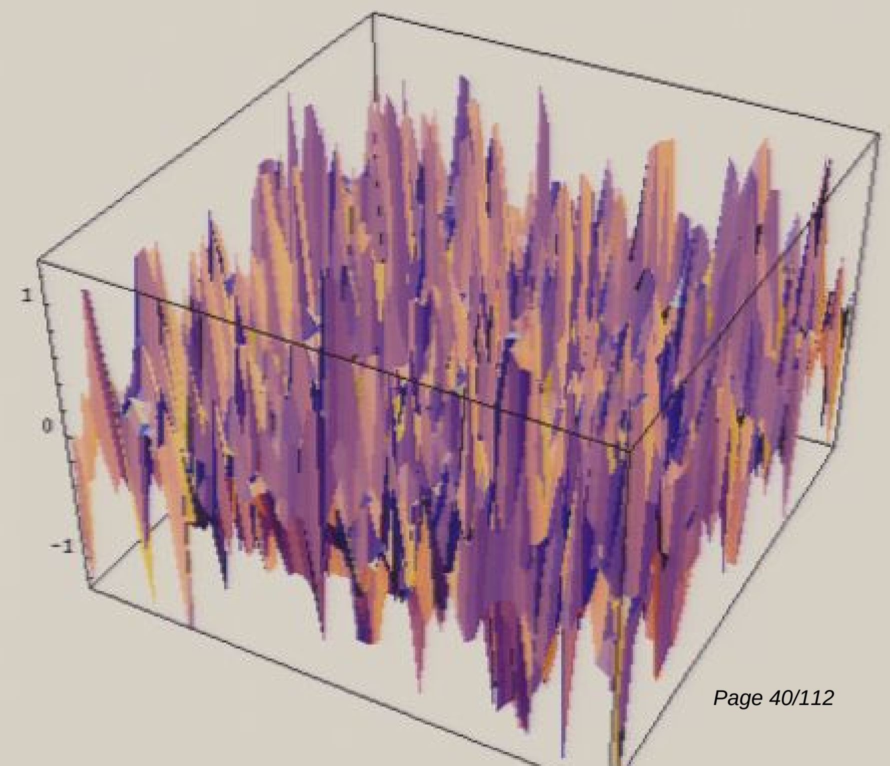
$\phi_0 + \phi$

Quantum

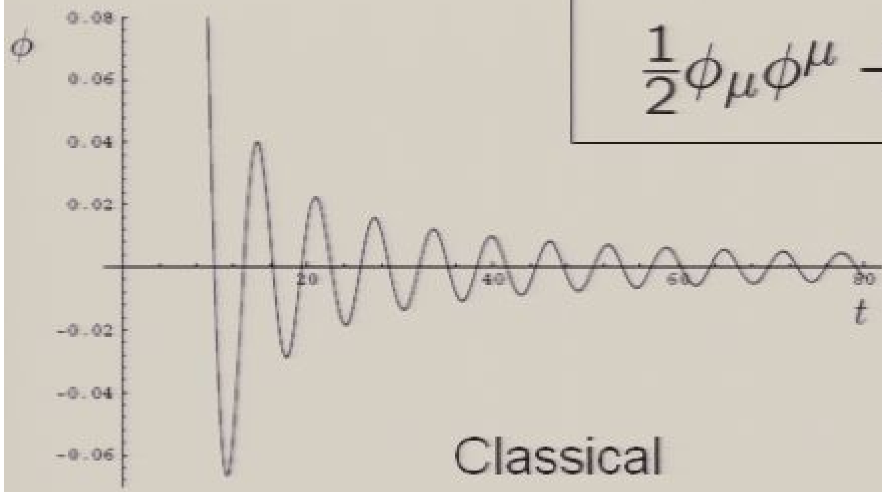
χ

Slices for t=130.767





$$\frac{1}{2}\phi_\mu\phi^\mu + \frac{1}{2}m^2\phi^2 + \frac{1}{2}\chi_\mu\chi^\mu + g^2\phi^2\chi 2$$



Decay of inflaton and preheating after inflation

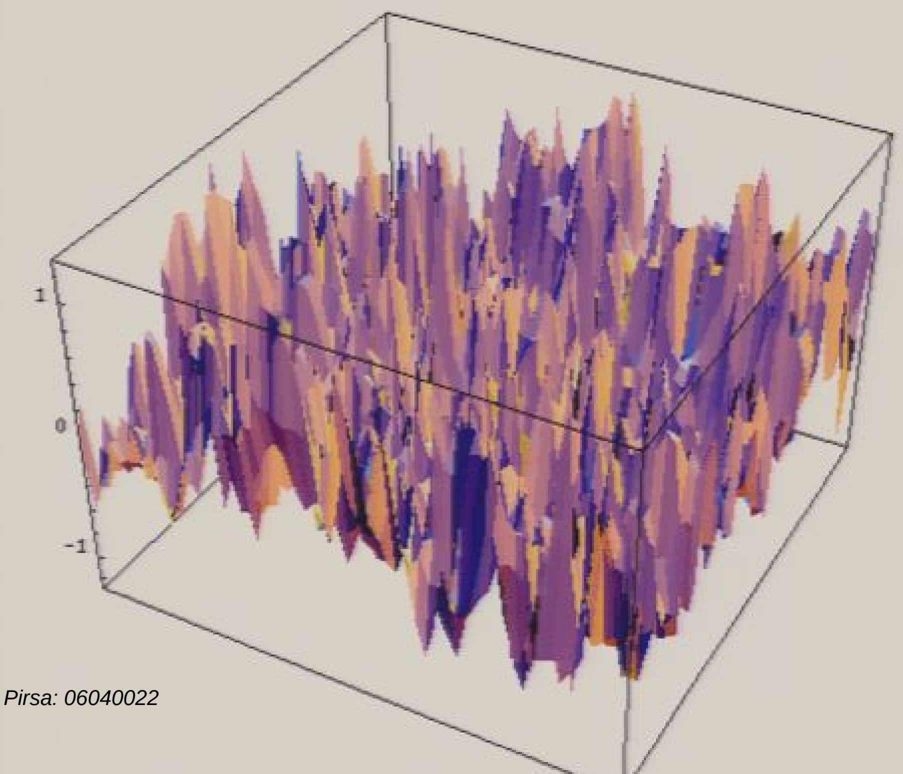
Classical

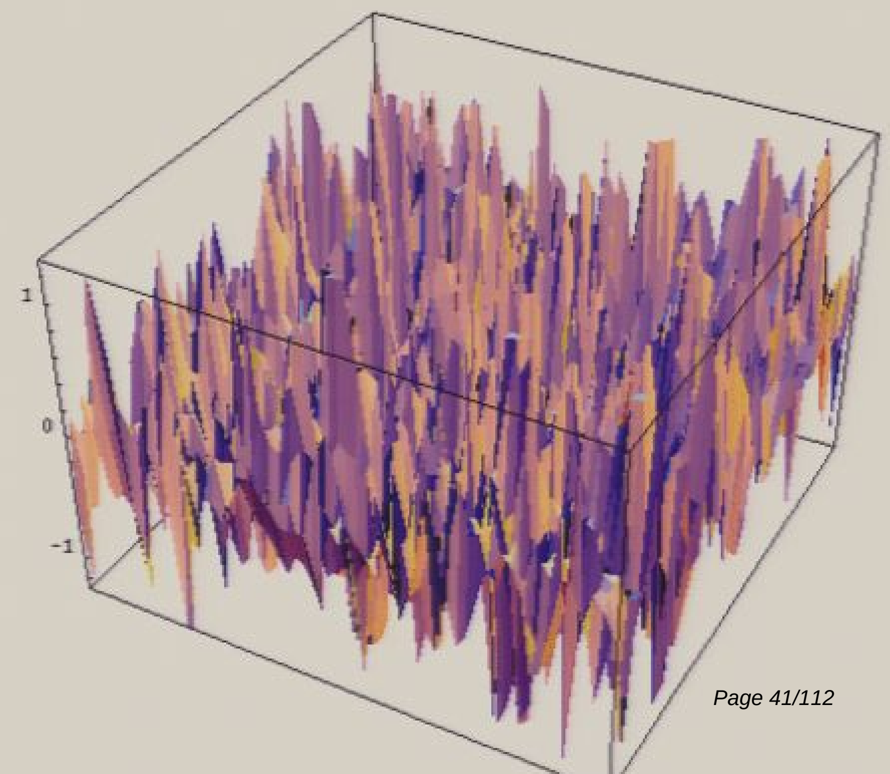
$\phi_0 + \phi$

Quantum

χ

Slices for t=131.277

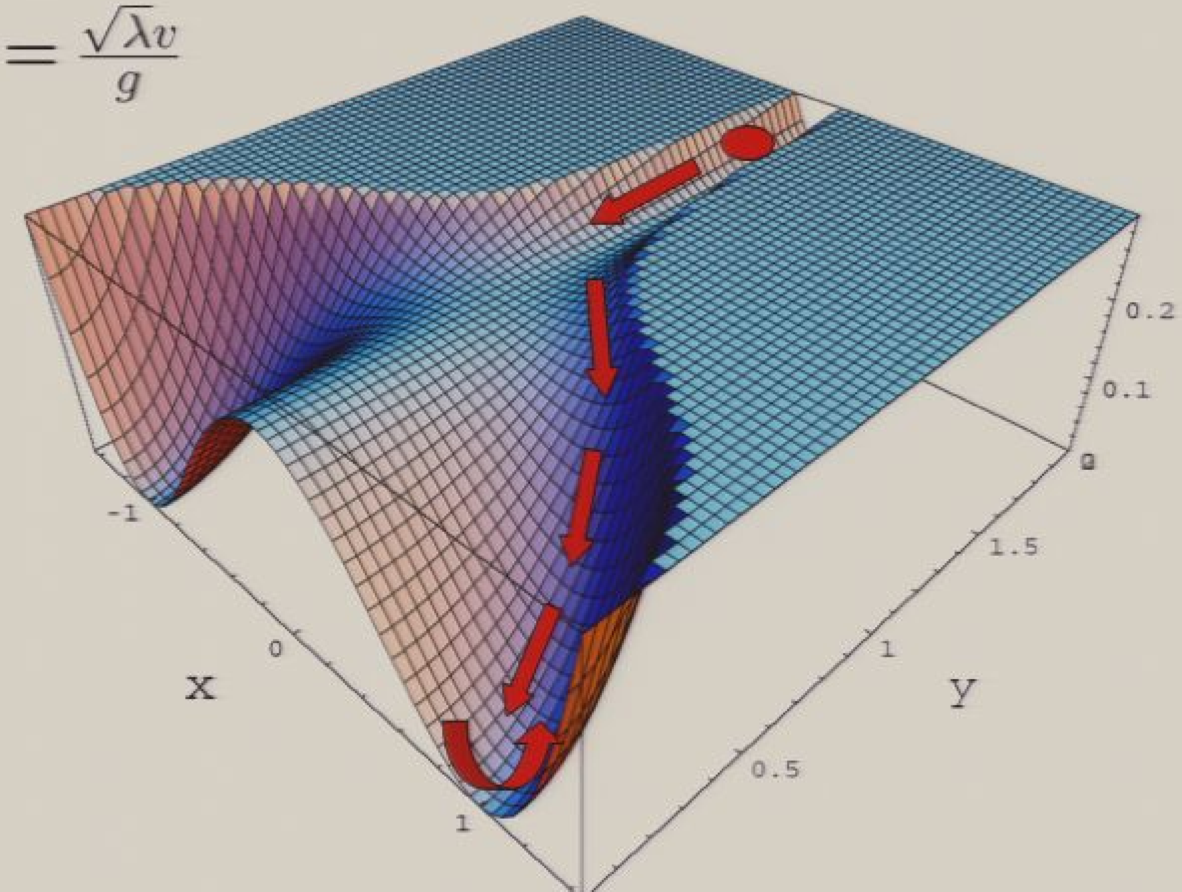




Tachyonic Preheating in Hybrid Inflation

$$V(\phi,\sigma) = \frac{\lambda}{4}(\sigma^2 - v^2)^2 + \frac{g^2}{2}\phi^2\sigma^2$$

bifurcation point $\phi_c = \frac{\sqrt{\lambda} v}{g}$

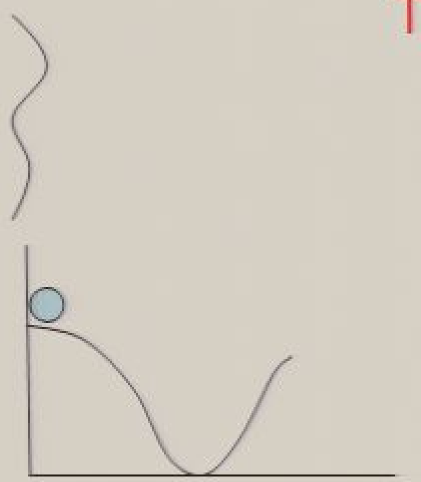


Felder, LK, Linde,01

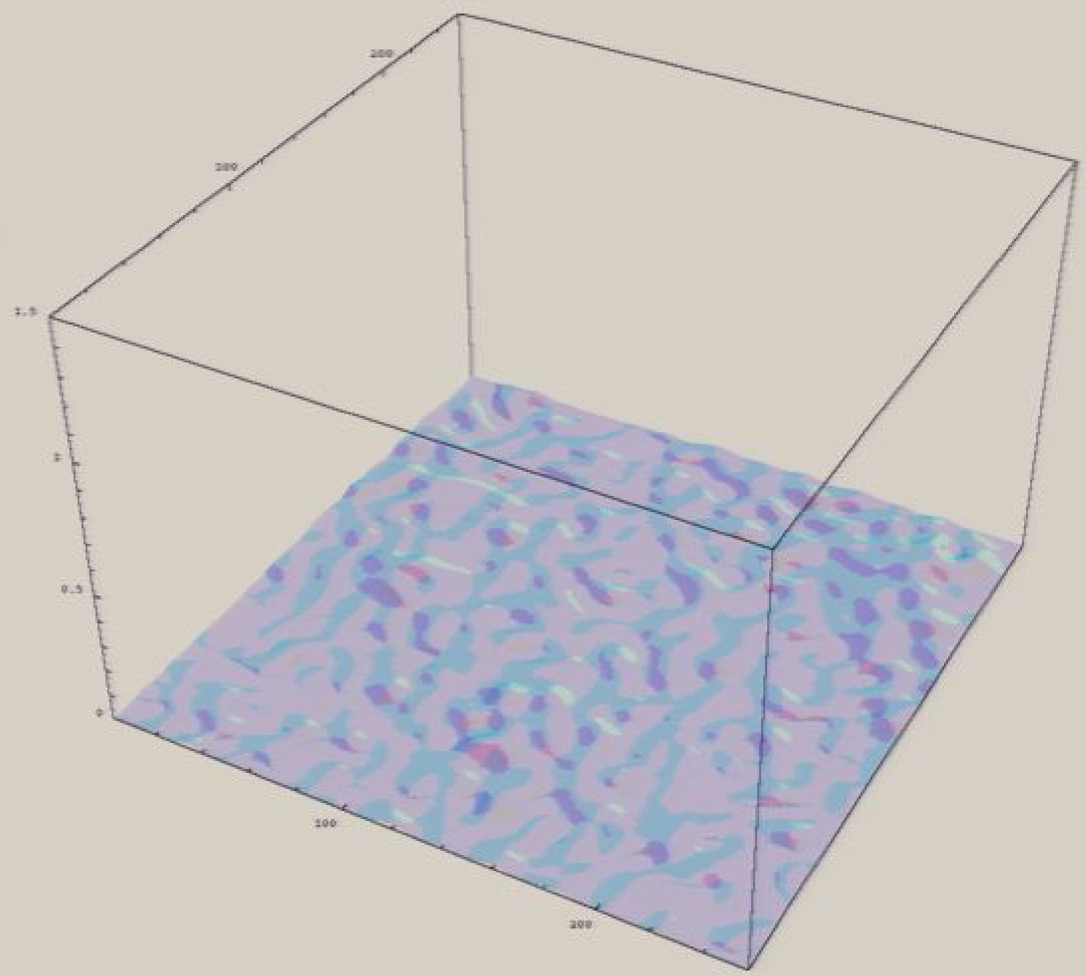
movie

Tachyonic Preheating

$$V_F = V_0 + \frac{\lambda}{4}\sigma^4 - \frac{\lambda^3}{4}\sigma^3 + \lambda\sigma^2$$

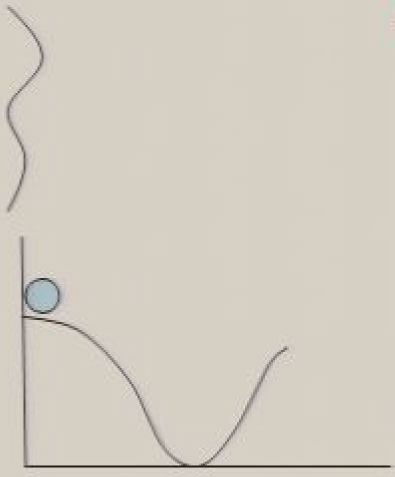


$\sigma(t, \vec{x})$

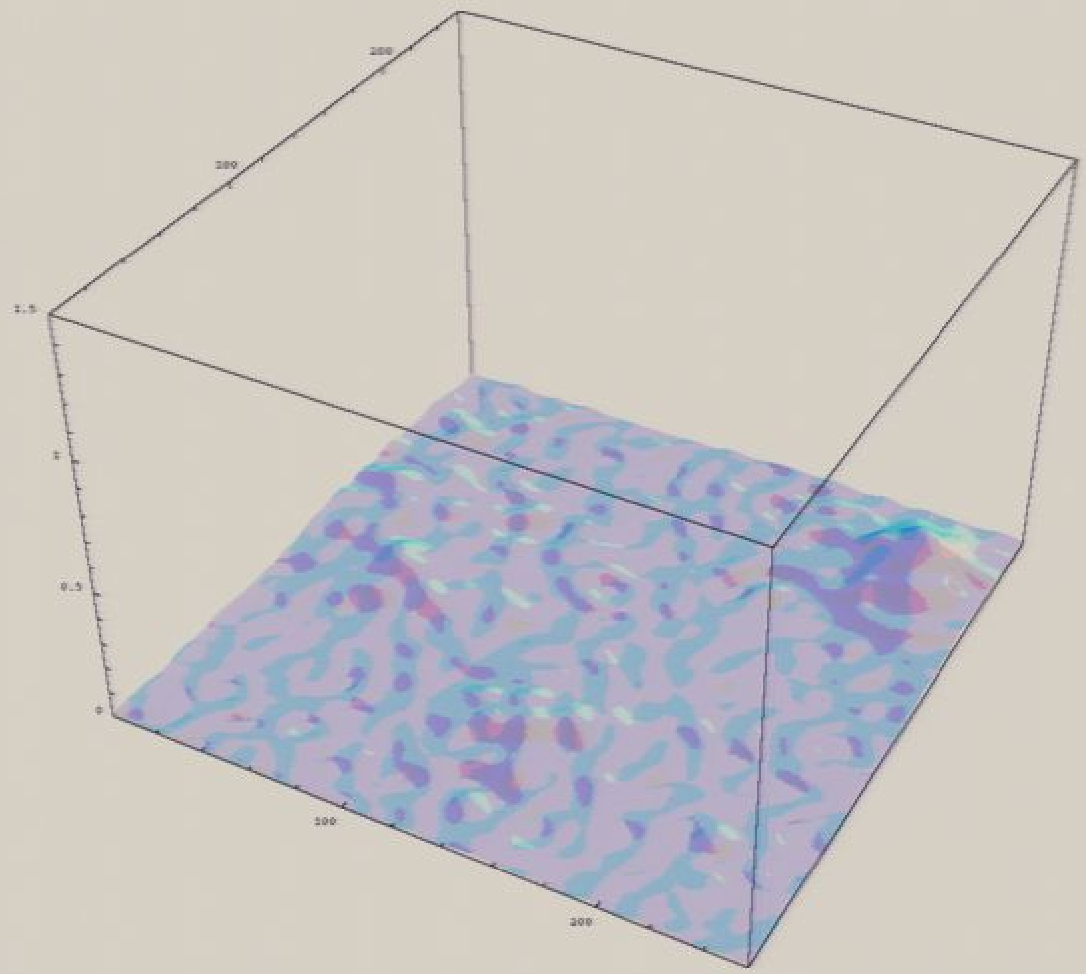


Tachyonic Preheating

$$V_F = V_0 + \frac{\lambda}{4}\sigma^4 - \frac{\lambda^3}{4}\sigma^3 + \lambda\sigma^2$$

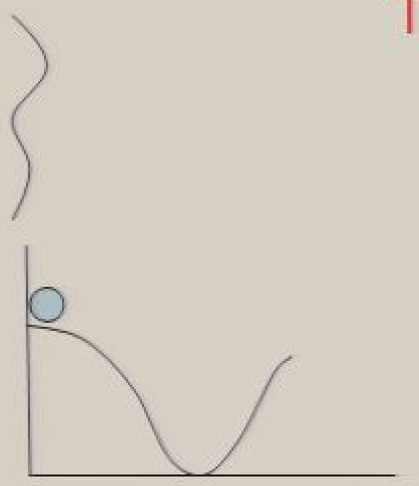


$\sigma(t, \vec{x})$

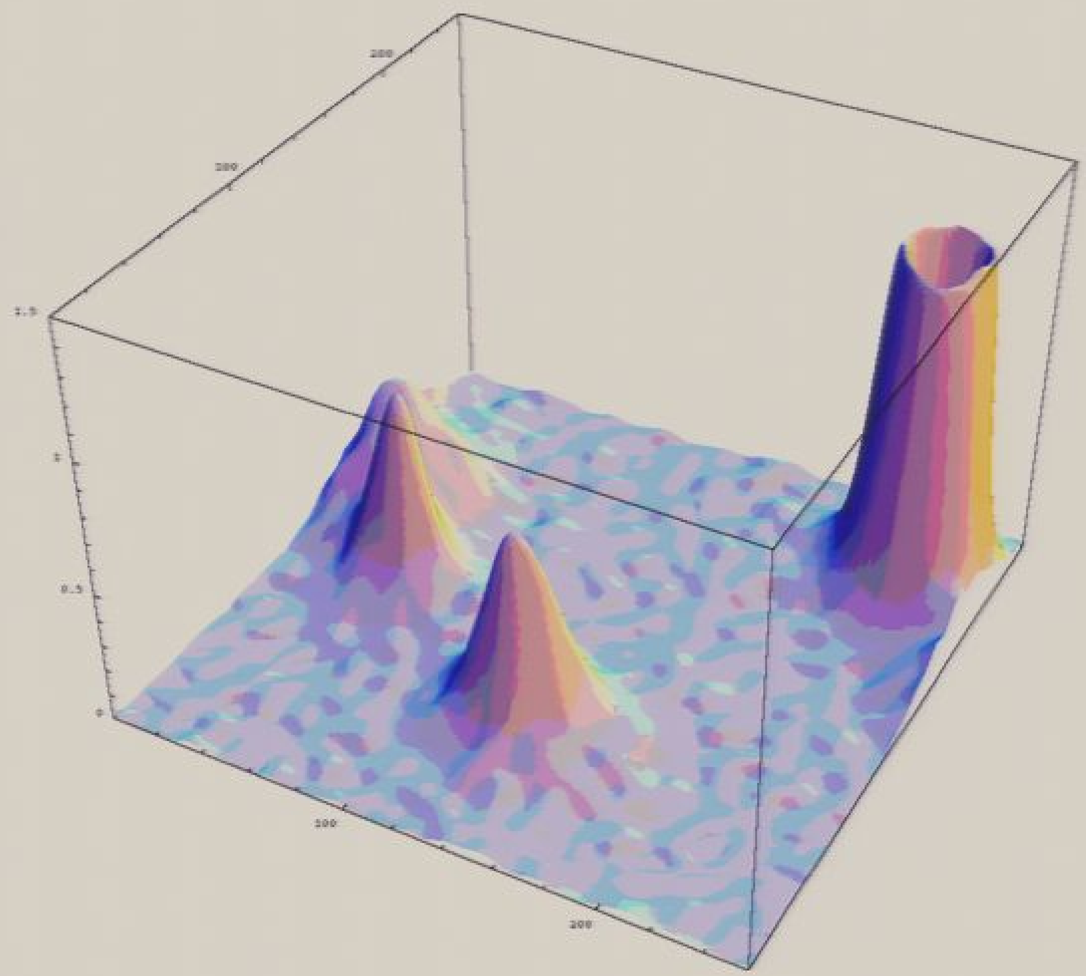


Tachyonic Preheating

$$V_F = V_0 + \frac{\lambda}{4}\sigma^4 - \frac{\lambda^3}{4}\sigma^3 + \lambda\sigma^2$$

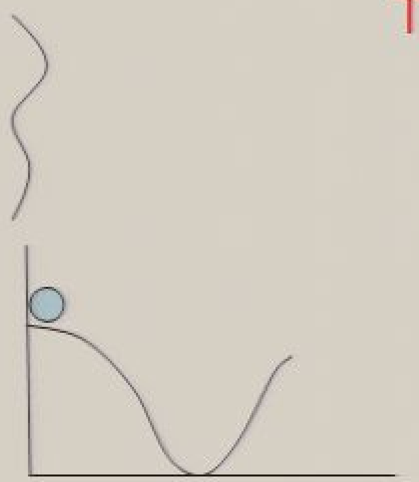


$\sigma(t, \vec{x})$

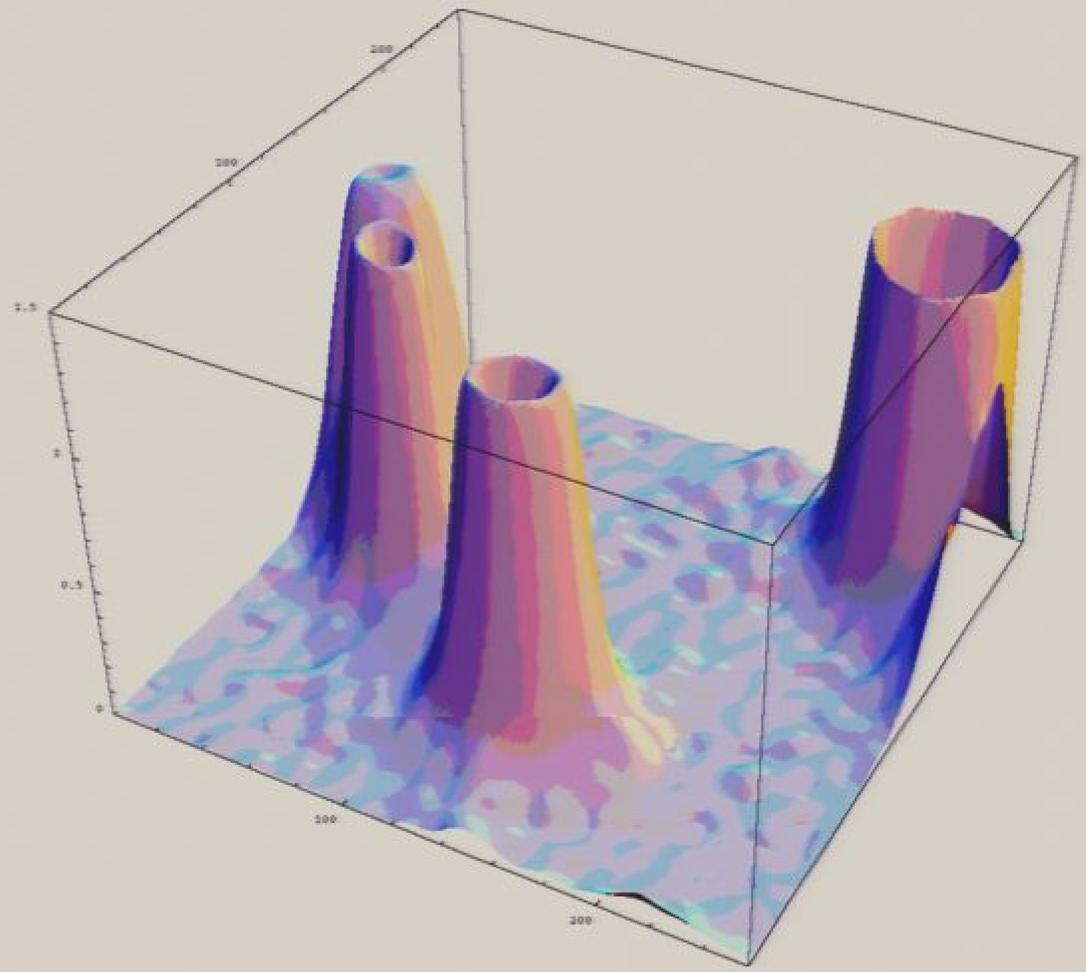


Tachyonic Preheating

$$V_F = V_0 + \frac{\lambda}{4}\sigma^4 - \frac{\lambda^3}{4}\sigma^3 + \lambda\sigma^2$$

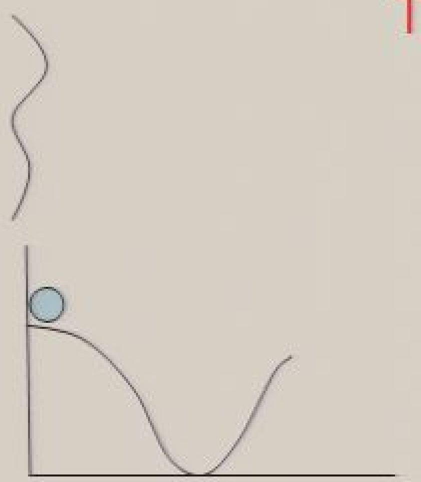


$\sigma(t, \vec{x})$

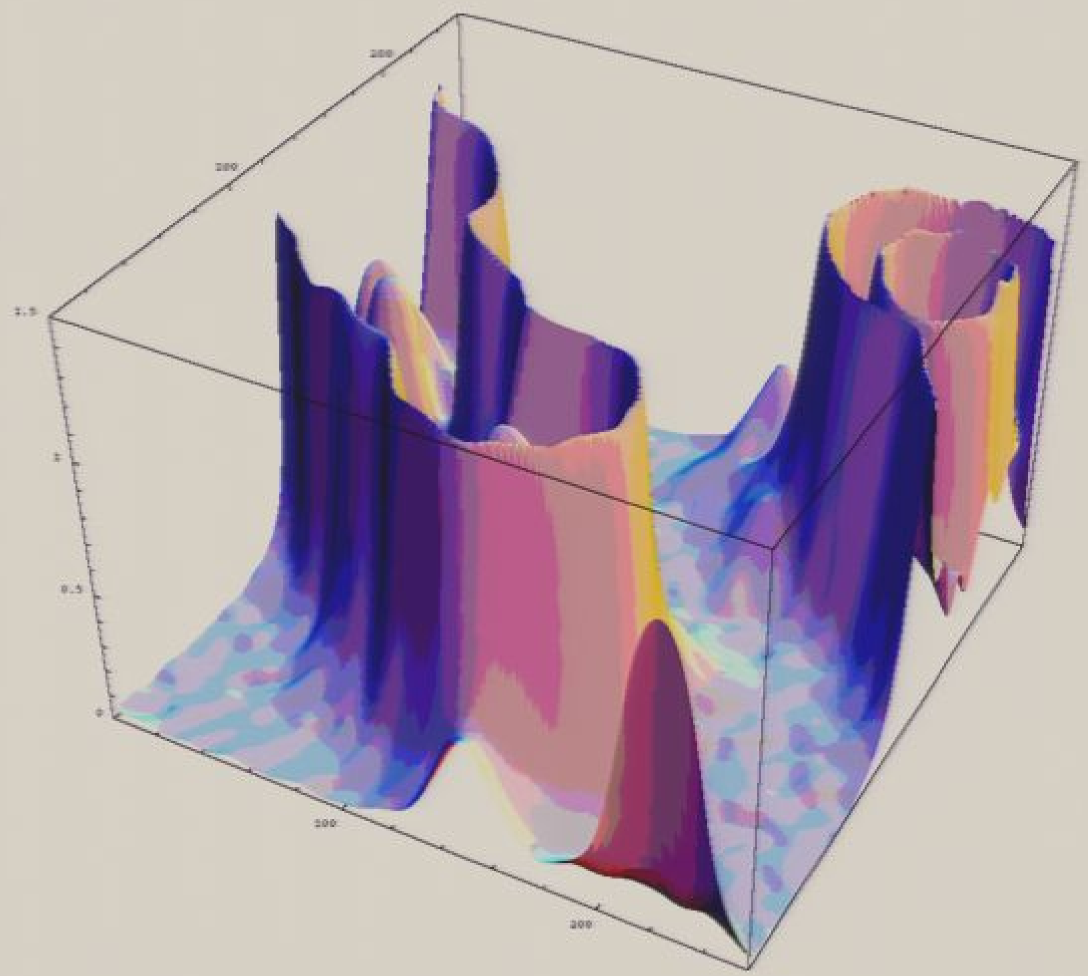


Tachyonic Preheating

$$V_F = V_0 + \frac{\lambda}{4}\sigma^4 - \frac{\lambda^3}{4}\sigma^3 + \lambda\sigma^2$$

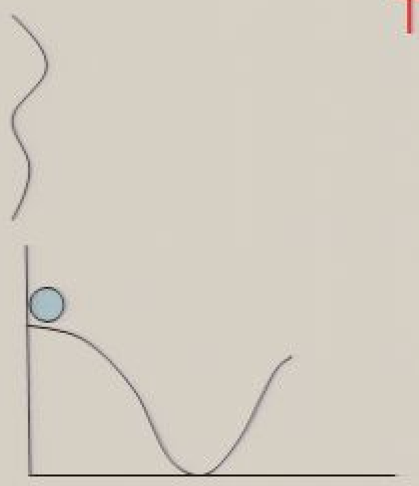


$\sigma(t, \vec{x})$

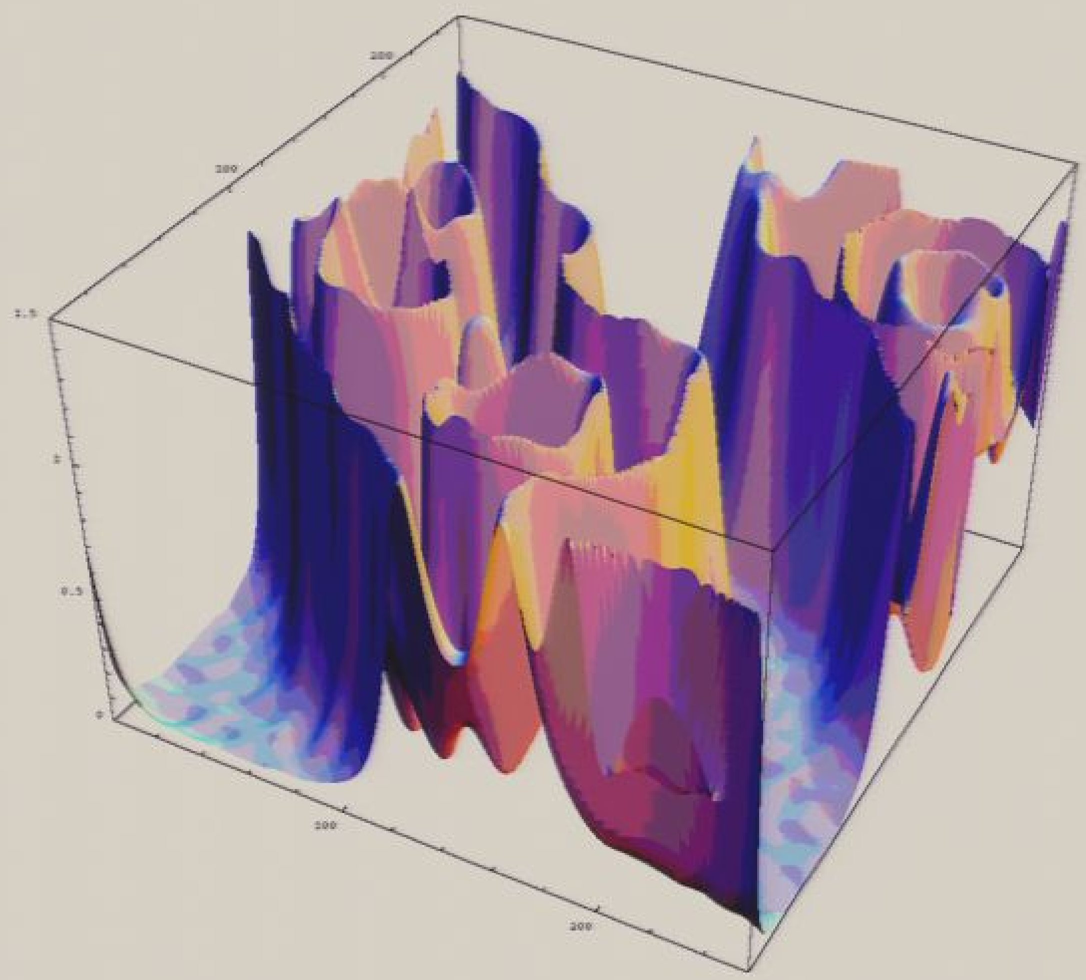


Tachyonic Preheating

$$V_F = V_0 + \frac{\lambda}{4}\sigma^4 - \frac{\lambda^3}{4}\sigma^3 + \lambda\sigma^2$$

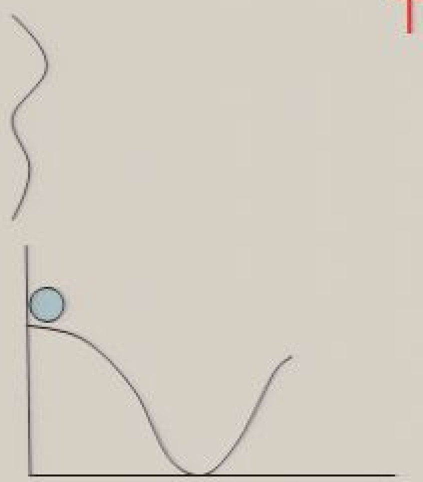


$\sigma(t, \vec{x})$

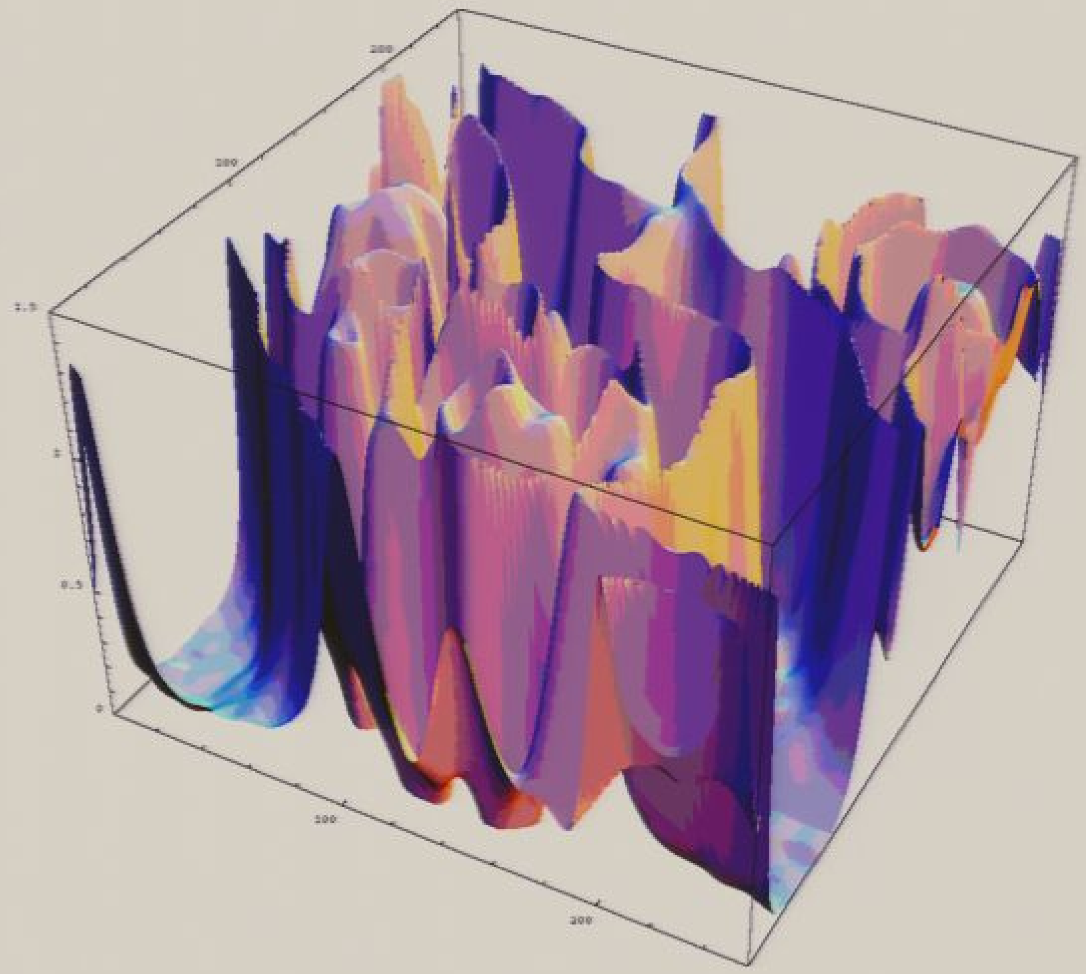


Tachyonic Preheating

$$V_F = V_0 + \frac{\lambda}{4}\sigma^4 - \frac{\lambda^3}{4}\sigma^3 + \lambda\sigma^2$$

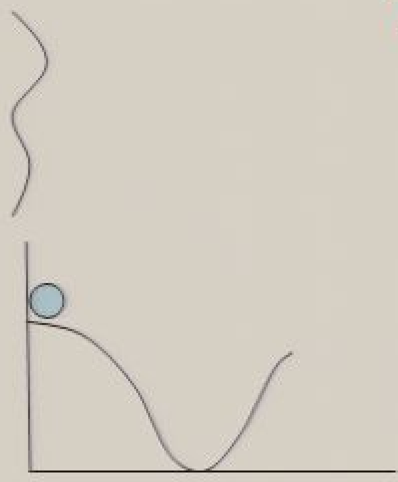


$\sigma(t, \vec{x})$

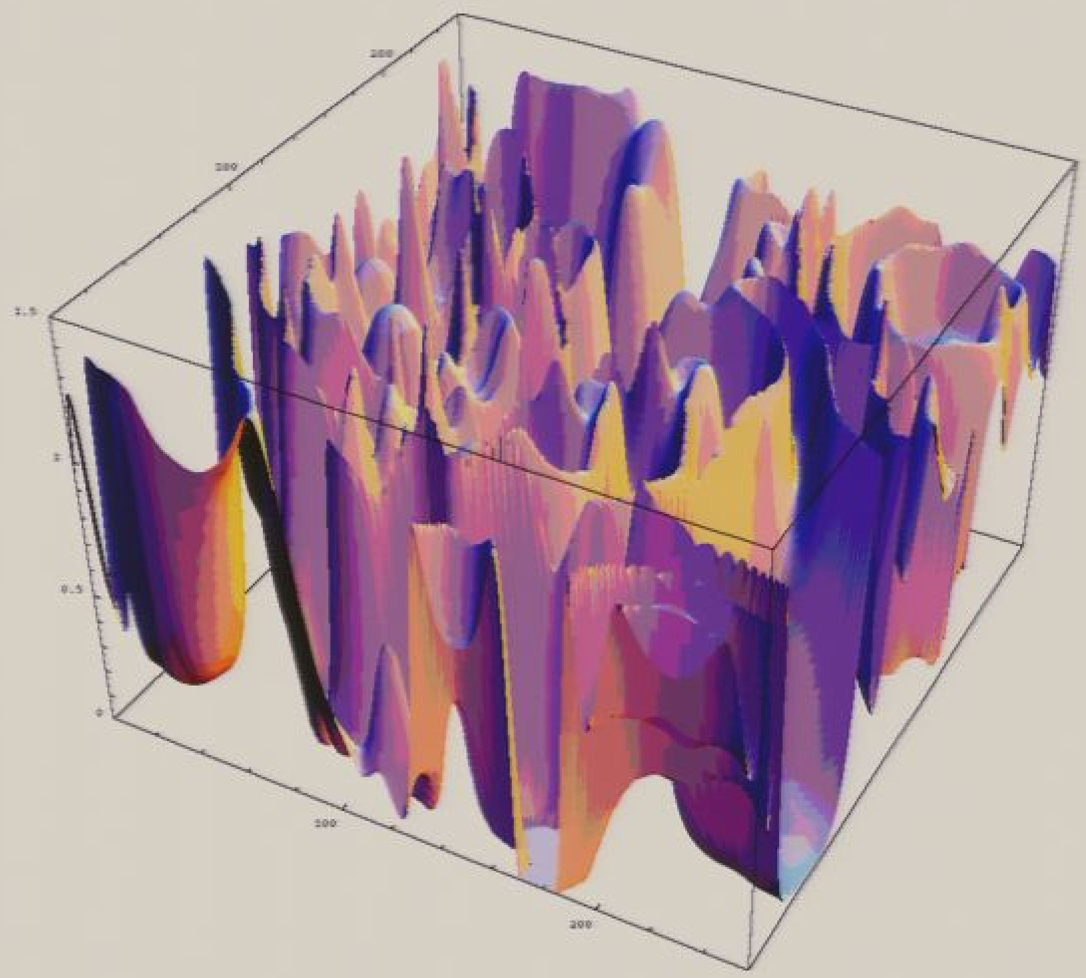


Tachyonic Preheating

$$V_F = V_0 + \frac{\lambda}{4}\sigma^4 - \frac{\lambda^3}{4}\sigma^3 + \lambda\sigma^2$$



$\sigma(t, \vec{x})$



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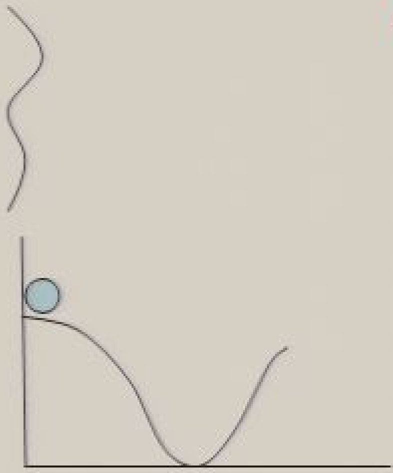

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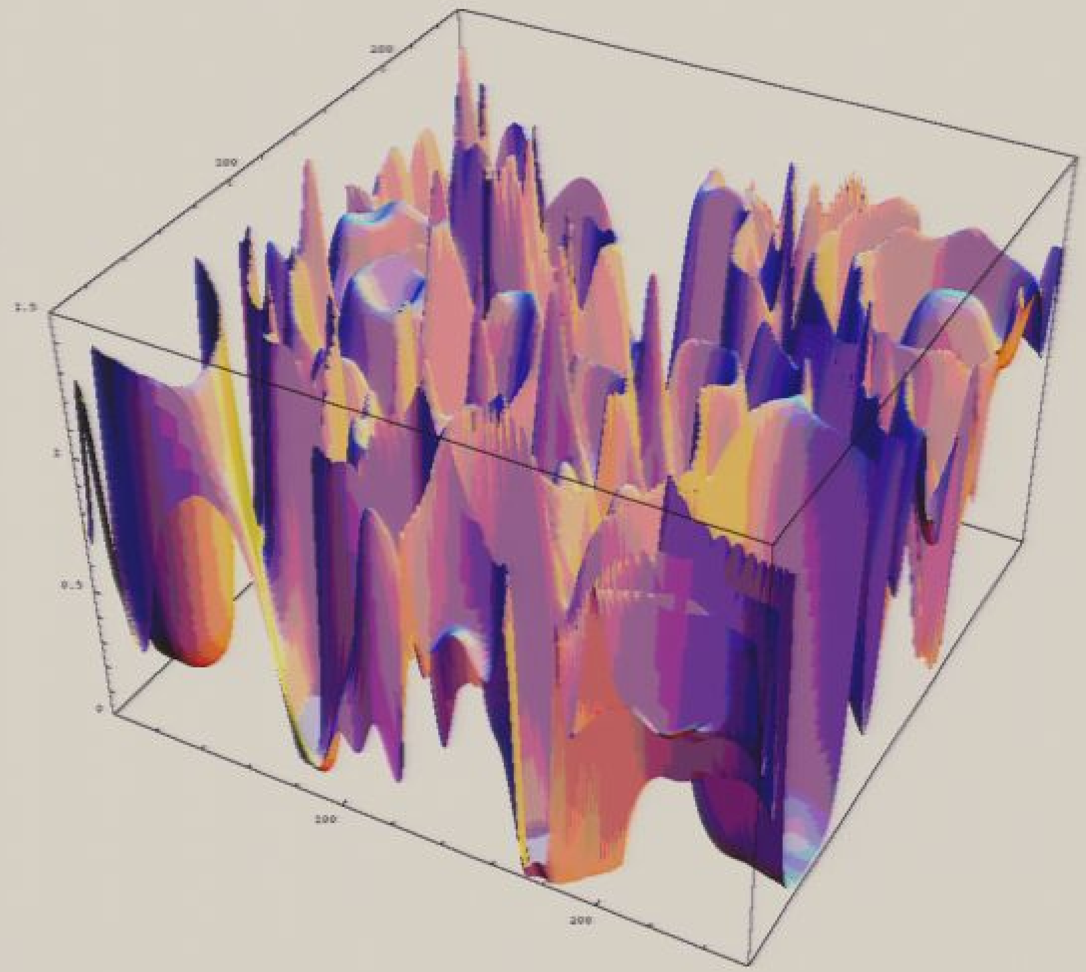
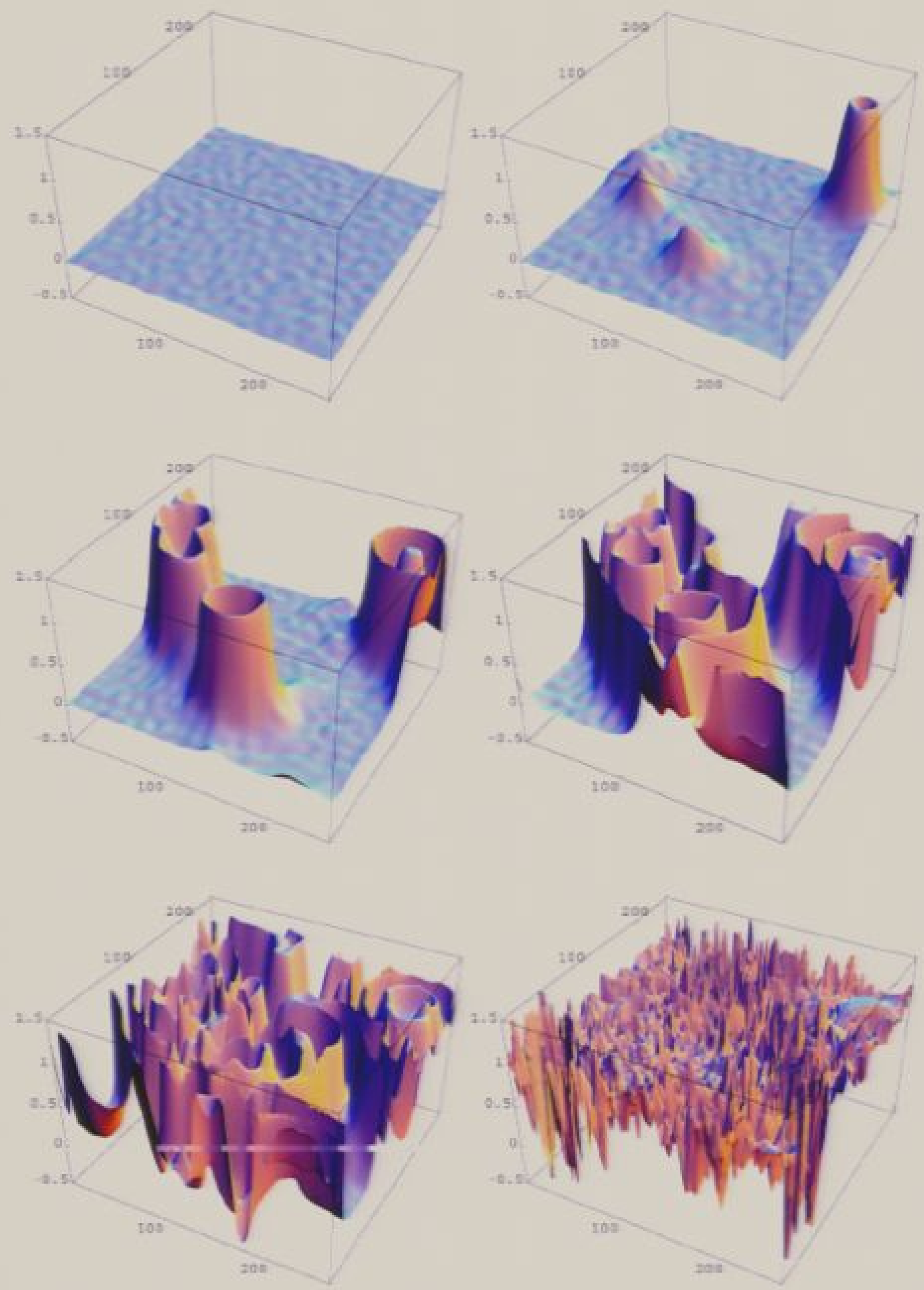
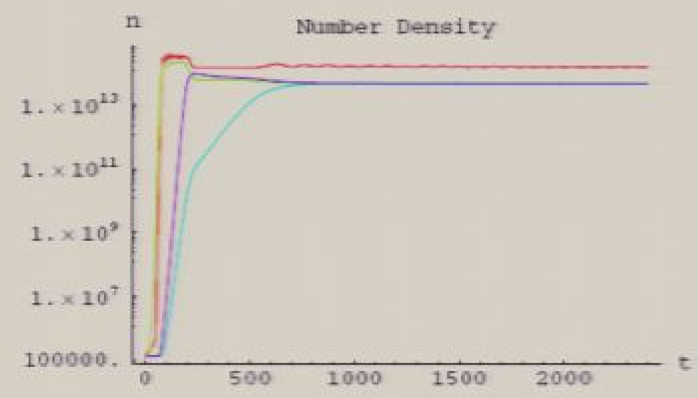






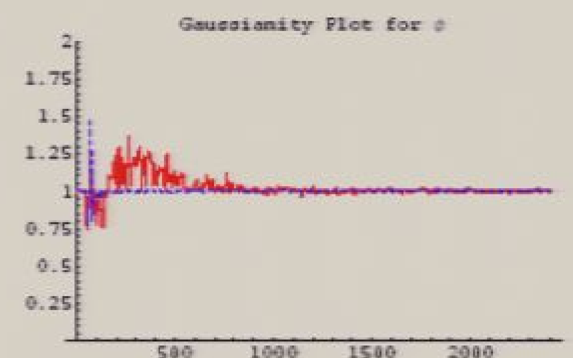


FIG. 10. Deviations from Gaussianity for the field ϕ as a function of time. The solid, red line shows $3\langle\delta\phi^2\rangle^2/\langle\delta\phi^4\rangle$ and the dashed, blue line shows $3\langle\delta\dot{\phi}^2\rangle^2/\langle\delta\dot{\phi}^4\rangle$.

Probing preheating with stochastic background gravitational radiation

$$\Omega_{gw} h^2 = \Omega_r h^2 \frac{d\rho_{gw}(a_e)}{d \ln \omega} \left(\frac{g_0}{g_*} \right)^{1/3}$$

estimation

$$\frac{\rho_{gw}}{\rho_r} \sim (RH)^2$$

$$f \sim \frac{M}{10^{15} Gev} 10^8 \text{ Hz}$$

numerics

$$\frac{dE}{d\Omega} = 2G\Lambda_{ij,lm}\omega^2 T^{ij*}(\vec{\mathrm{k}},\omega) T^{lm}(\vec{\mathrm{k}},\omega) d\omega$$

$$\Lambda_{ij,lm}(\hat{k}) = \delta_{ij}\delta_{lm} - 2\hat{k}_j\hat{k}_m\delta_{il} + \frac{1}{2}\hat{k}_i\hat{k}_j\hat{k}_l\hat{k}_m - \frac{1}{2}\delta_{ij}\delta_{lm} + \frac{1}{2}\delta_{ij}\hat{k}_l\hat{k}_m + \frac{1}{2}\delta_{jl}\hat{k}_i\hat{k}_m$$

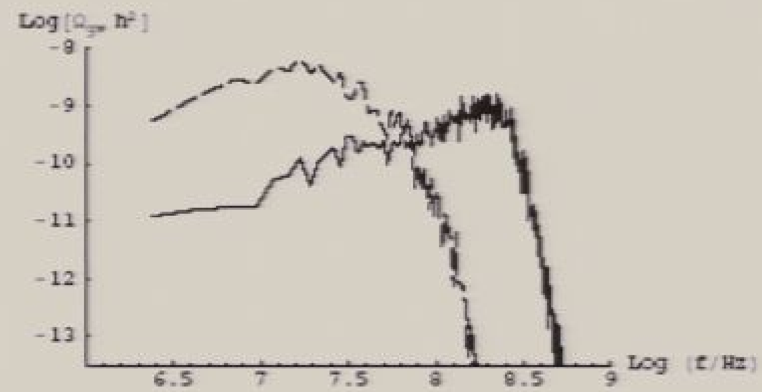
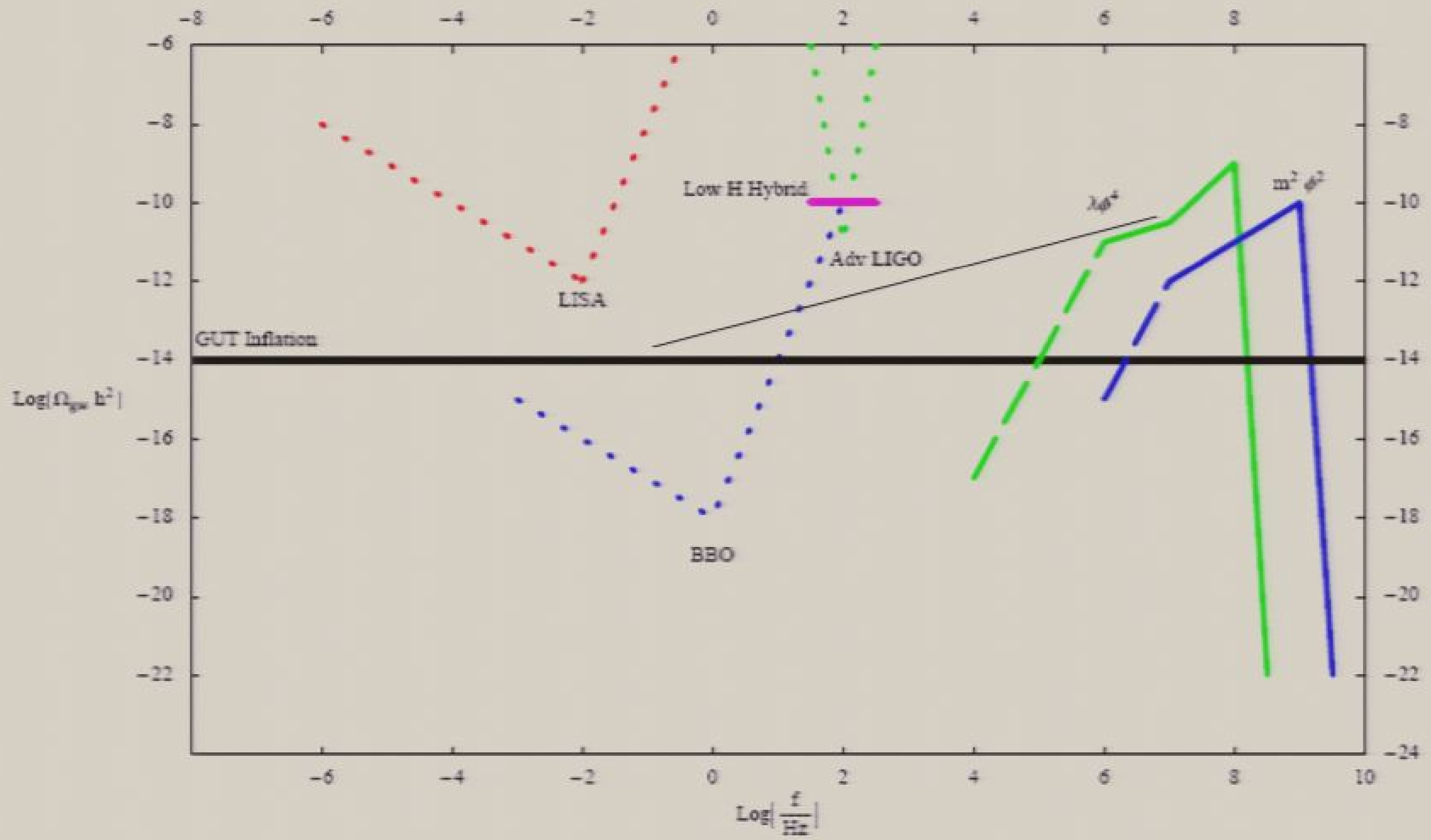


FIG. 1: The gravitational spectrum for the $\lambda\phi^4$ model with $\lambda = 10^{-14}$ and $g^2/\lambda = 1.2$ (dash line) and 120 (full line) respectively . As expected, it is peaked around $10^7 \sim 10^8$ Hz and spans about 2 decades. The horizon size at the time of preheating imposes the low frequency cut-off, while the high frequency cut-off is due to the fact that high momentum χ particles are energetically too expensive to be created. Notice



Low H Hybrid
Adv LIGO
LISA
GUT Inflation
BBO
$\lambda\phi^4$
$m^2\phi^2$
$\mathrm{Log}[\Omega_{gw} h^2]$
$\mathrm{Log}[\frac{f}{Hz}]$

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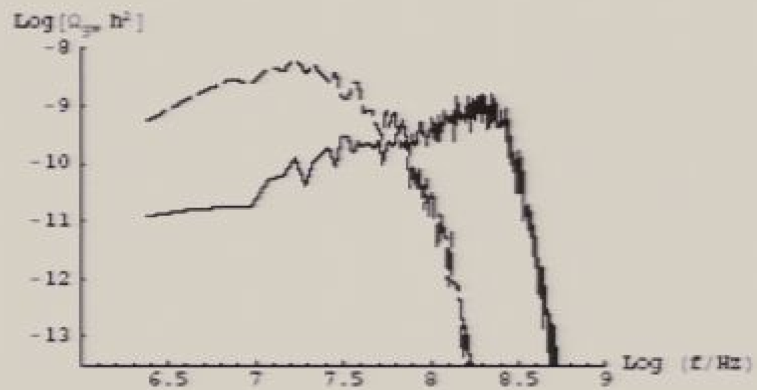

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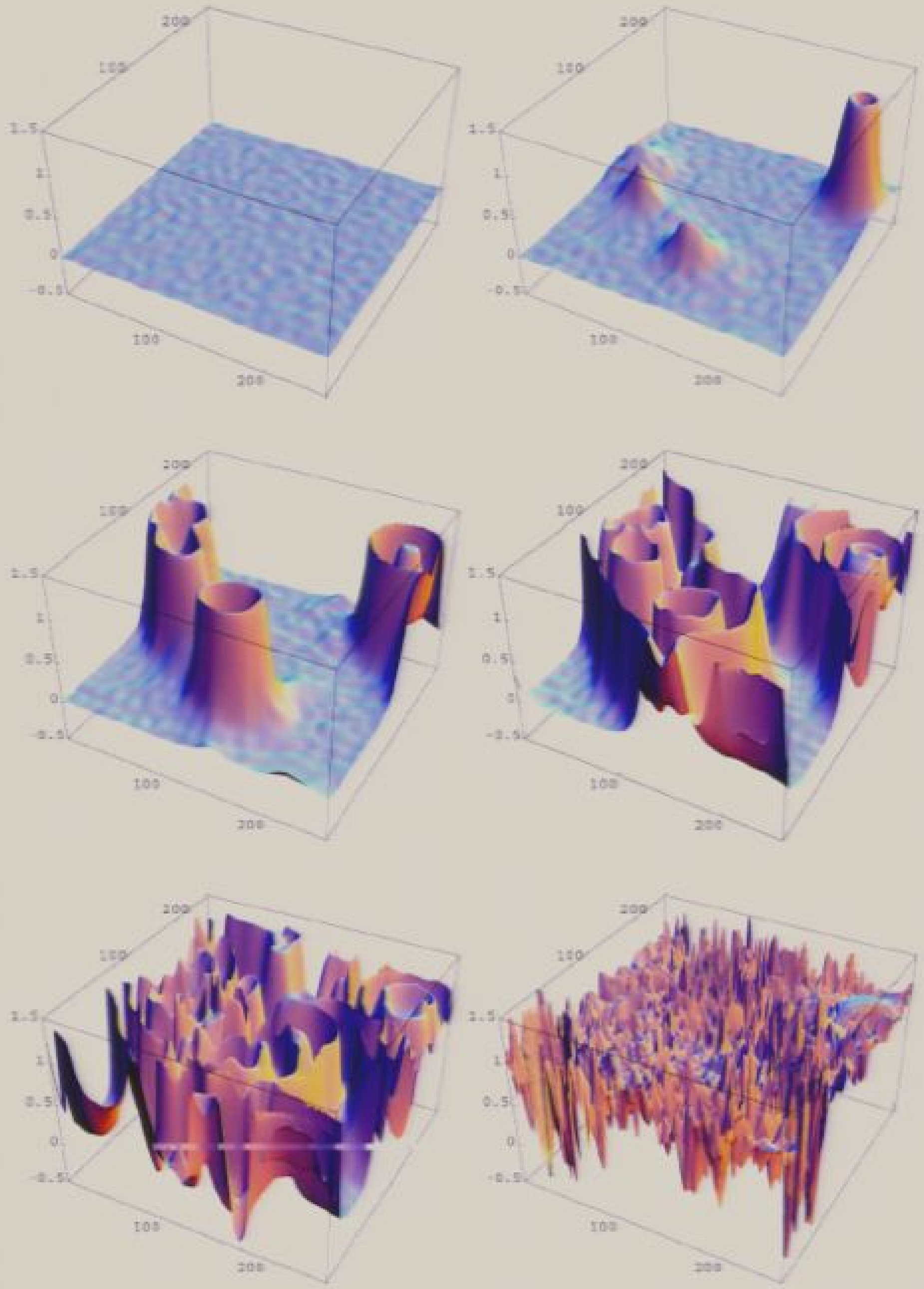

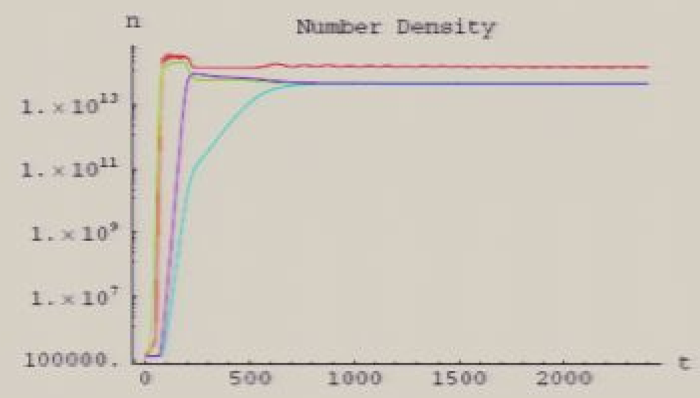

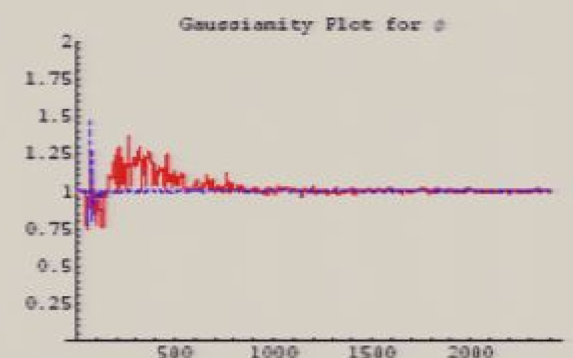

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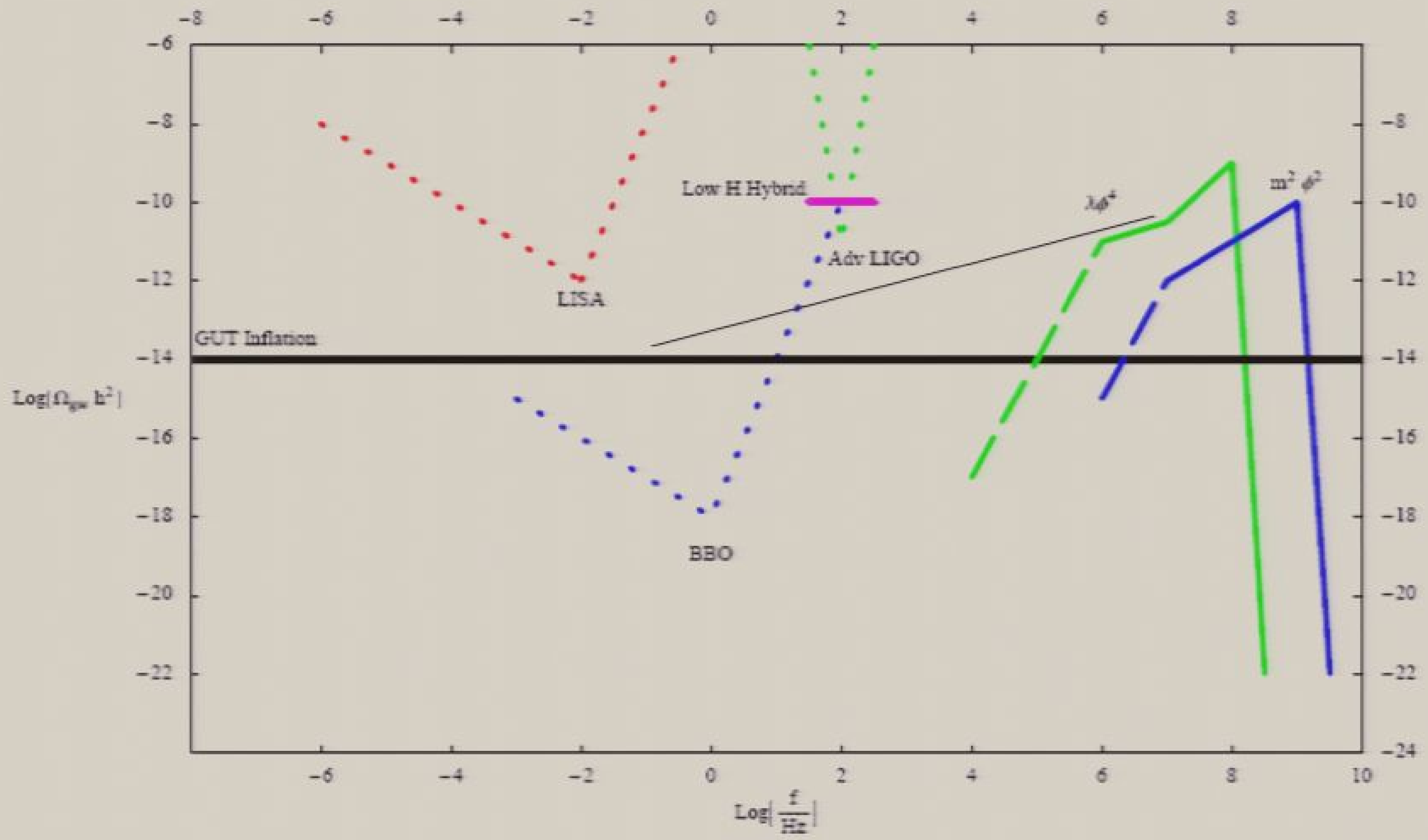

Low H Hybrid
Adv LIGO
LISA
GUT Inflation
BBO
λφ⁴
m² φ²
Log[Ω_gw h²]
Log[f/Hz]

Three-linear interaction

In expanding universe complete inflaton decay requires 3-legs interactions

$$V = \frac{m^2}{2}\phi^2 + \frac{\sigma}{2}\phi\chi^2 + \frac{g^2}{2}\phi^2\chi^2 + \frac{\lambda}{4}\chi^4 \quad \Longleftarrow \quad W = \frac{m}{2\sqrt{2}}\phi^2 + \frac{g}{2\sqrt{2}}\phi\chi^2$$

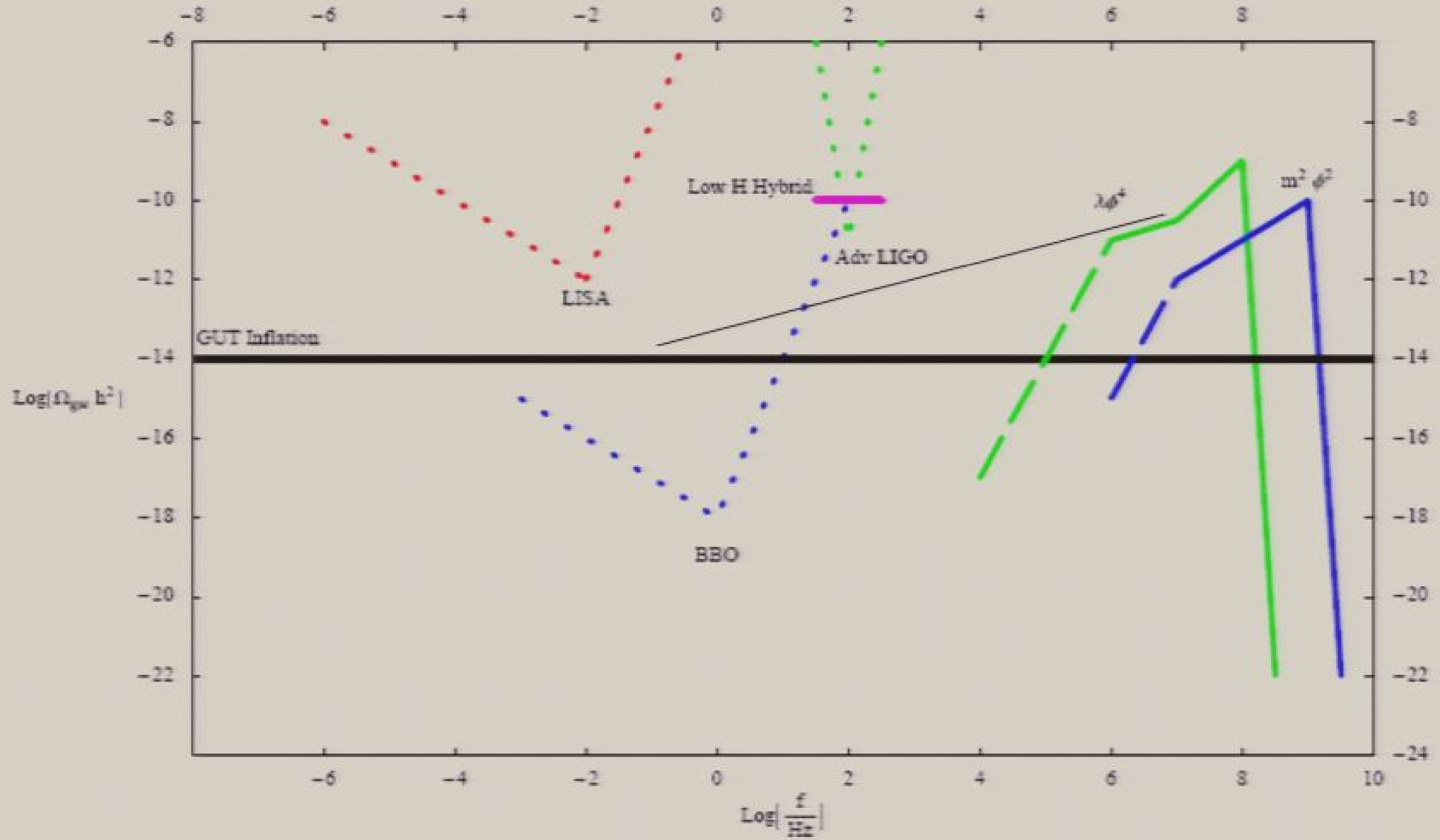
$$\lambda = g^2/2 \text{ and } \sigma = gm$$

$$\chi_k'' + (A_k - 2q\cos 2z)\chi_k = 0$$

$mt = 2z - \frac{\pi}{2}$, $A_k = \frac{4k^2}{m^2}$ and $q = \frac{2\sigma\Phi}{m^2}$

$A_k \geq 2q$ **Broad Parametric Resonance**

$0 < A_k < 2q$ **Tachyonic Resonance** Dufaux et al 06



Low H Hybrid
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$\lambda\phi^4$
$m^2\phi^2$
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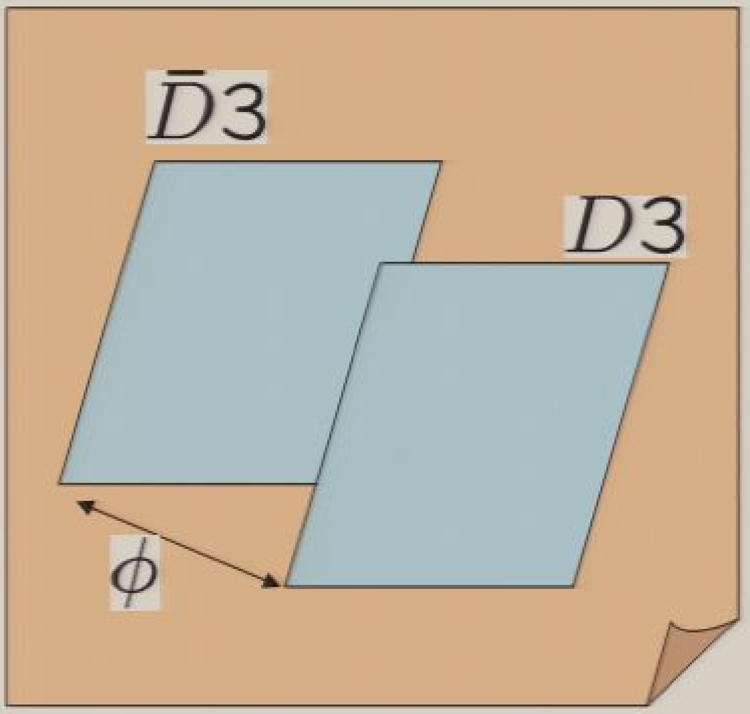
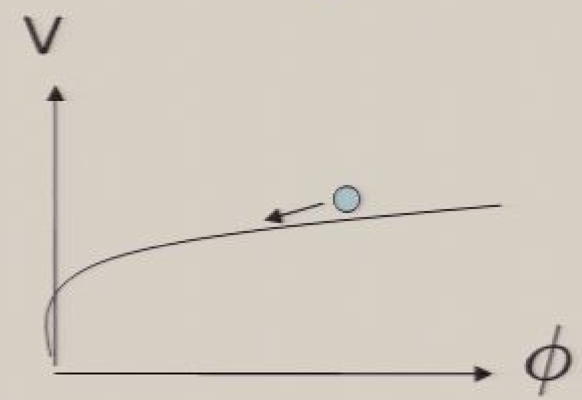
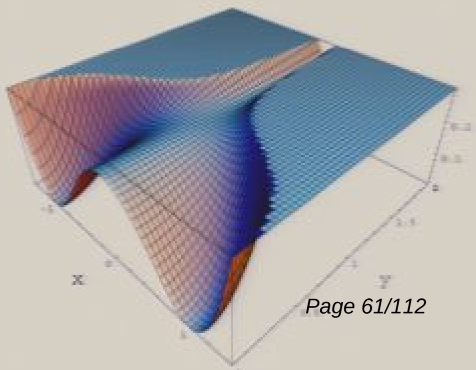
Inflaton with branes in String Theory



4-dim picture

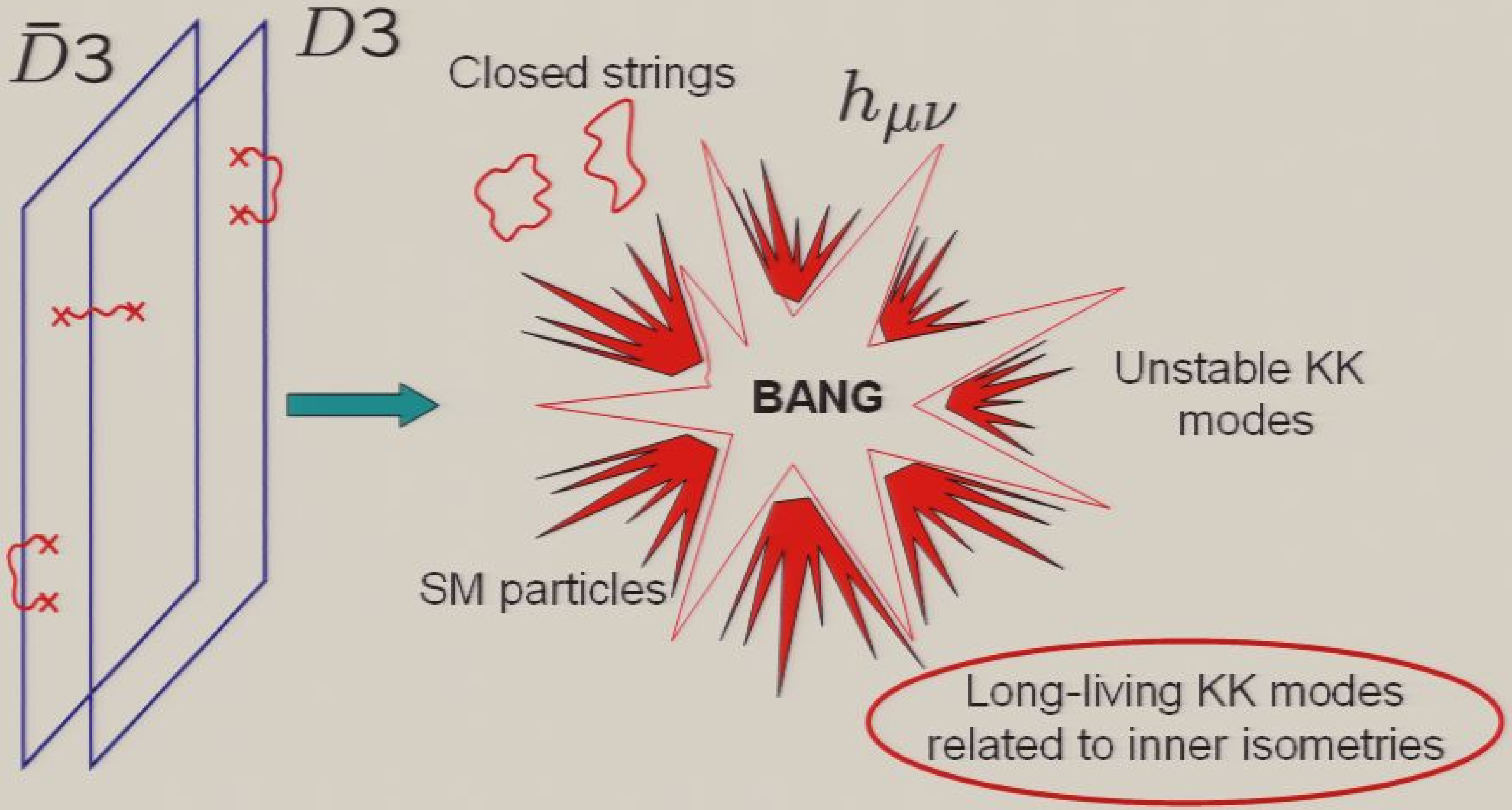


Prototype of
hybrid inflation



End point of inflation

LK, Yi 05



Open strings ×~× between branes are unstable

Cascading Energy from Inflaton to Radiation

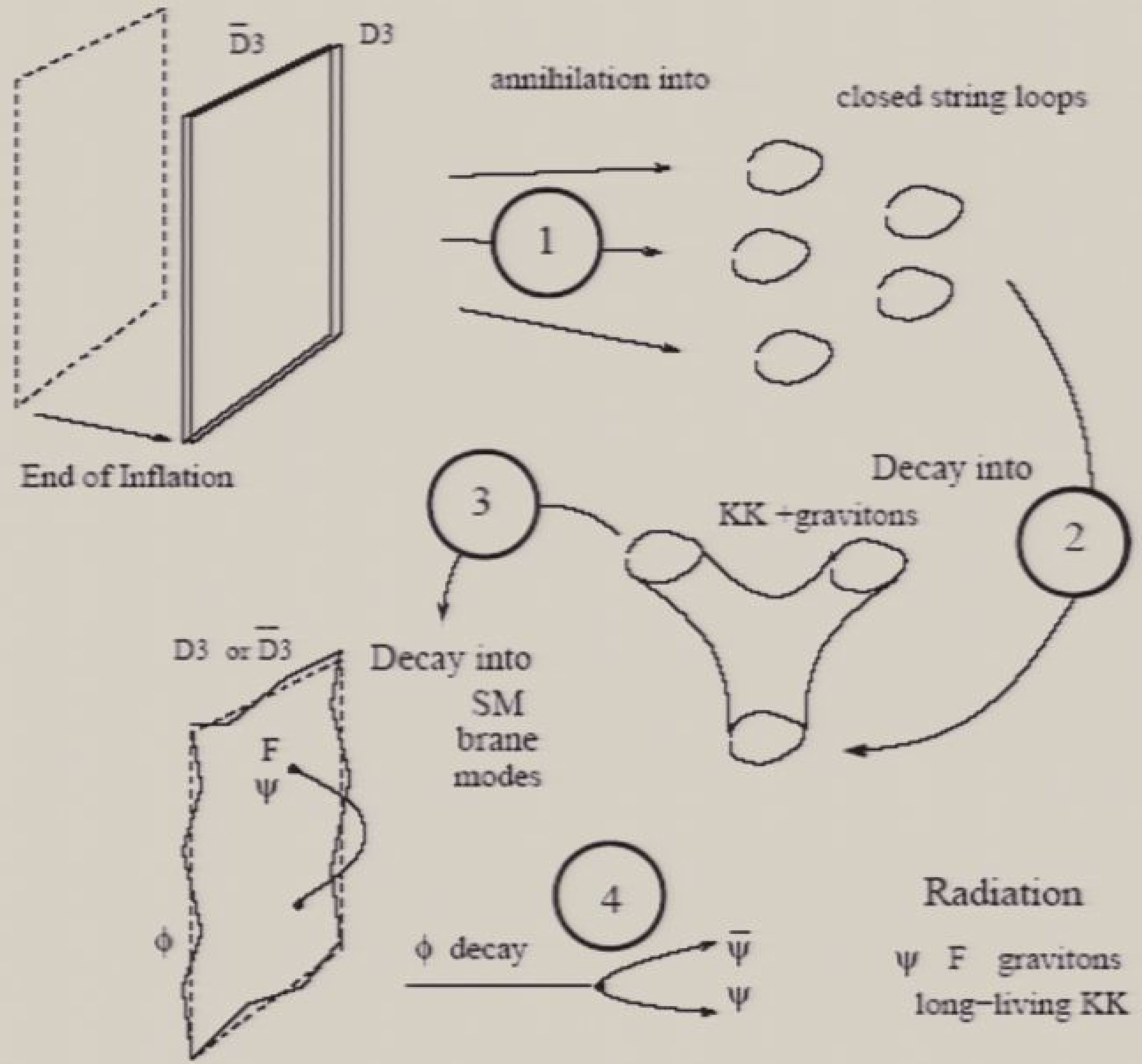
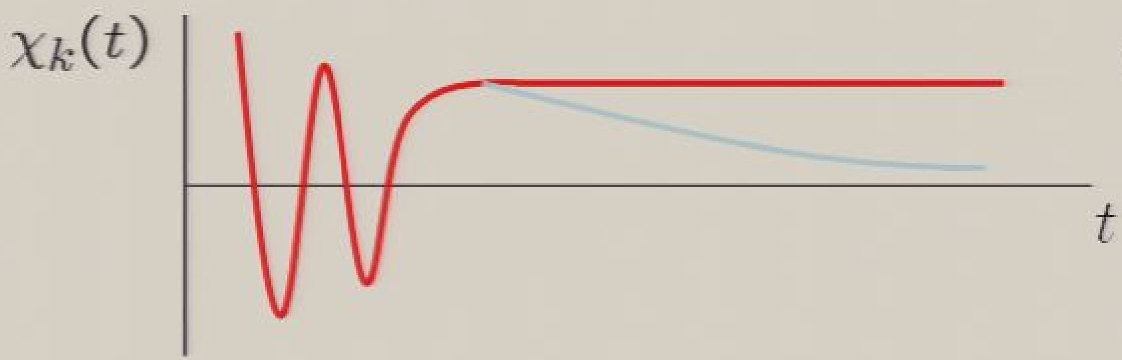


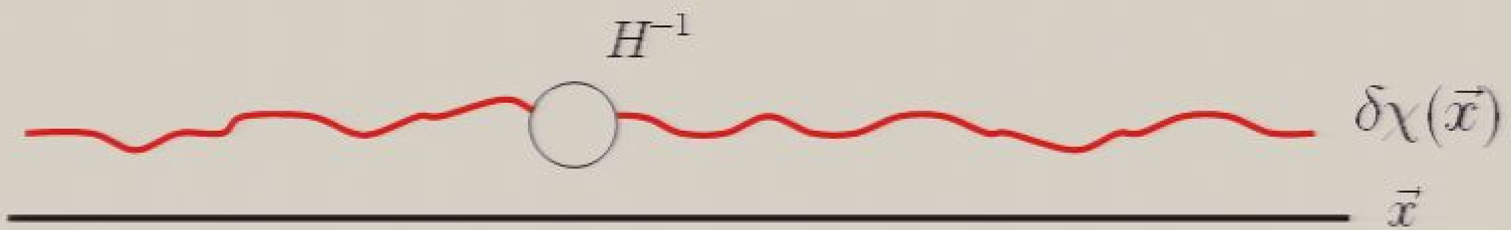
Figure 2: Identifying the channels of D-brane decay

Light field at inflation

$$\delta\chi = \int d^3k (a_k \chi_k(t) e^{i\vec{k}\vec{x}} + h.c.)$$



$$\chi_k \simeq \frac{H}{\sqrt{2} k^{3/2}}$$



Scalar metric Fluctuations from Inflation

$$ds^2 = -(1-2\Phi)dt^2 + (1+2\Phi)a^2 d\vec{x}^2$$

$$\Omega_{tot} = 1$$

$$k^3 \Phi_k^2 \rightarrow P_s = A_s k^{n_s - 1}$$

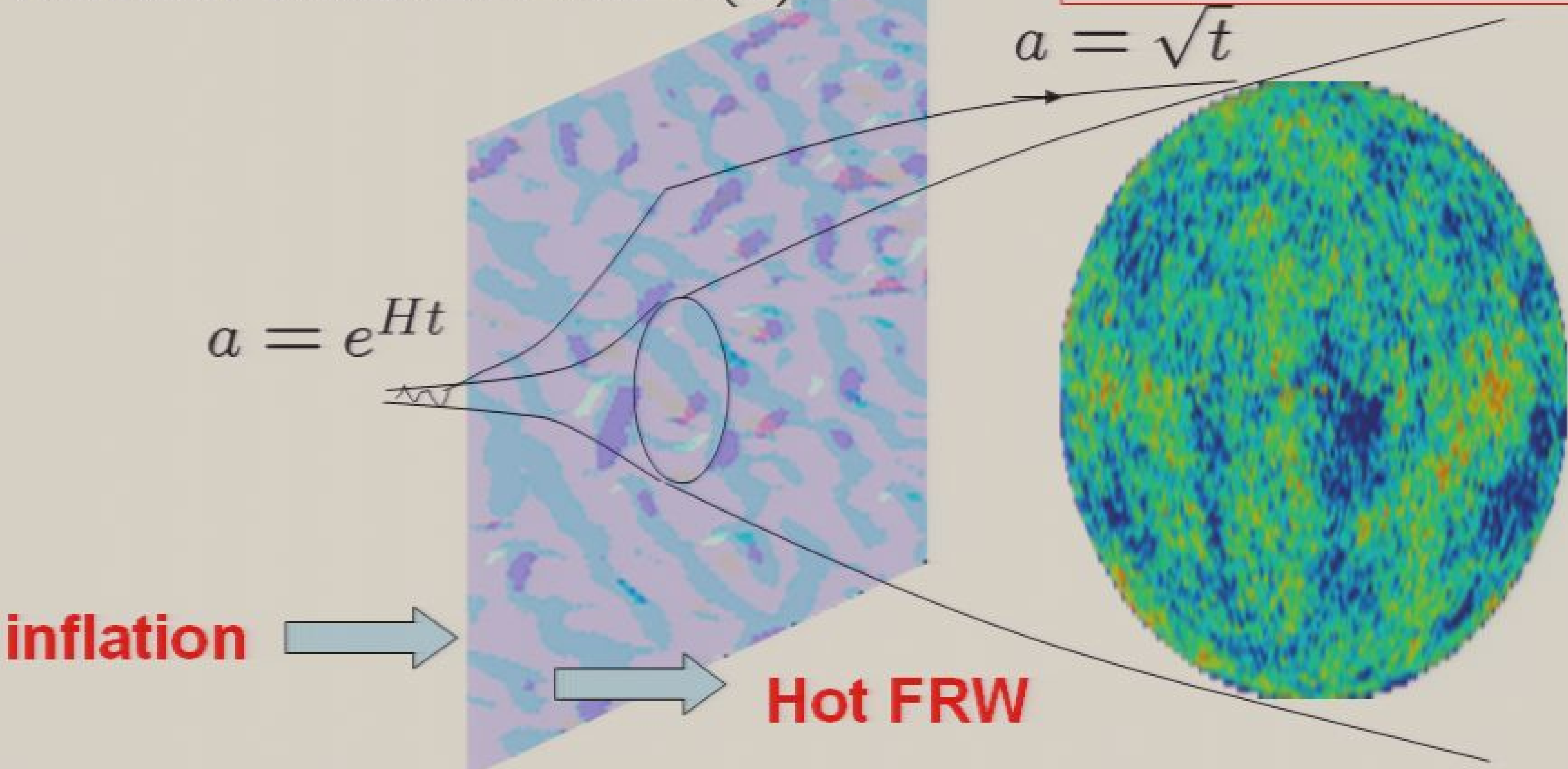
$$P_T = \frac{H^2}{M_p^2} k^{n_T}$$

$$N = 62 - \ln \frac{10^{16} Gev}{V_{inf}^{1/4}}$$

Initial conditions from Inflation ⇒

⇓

Random Gaussian Field $\Phi(\vec{x})$



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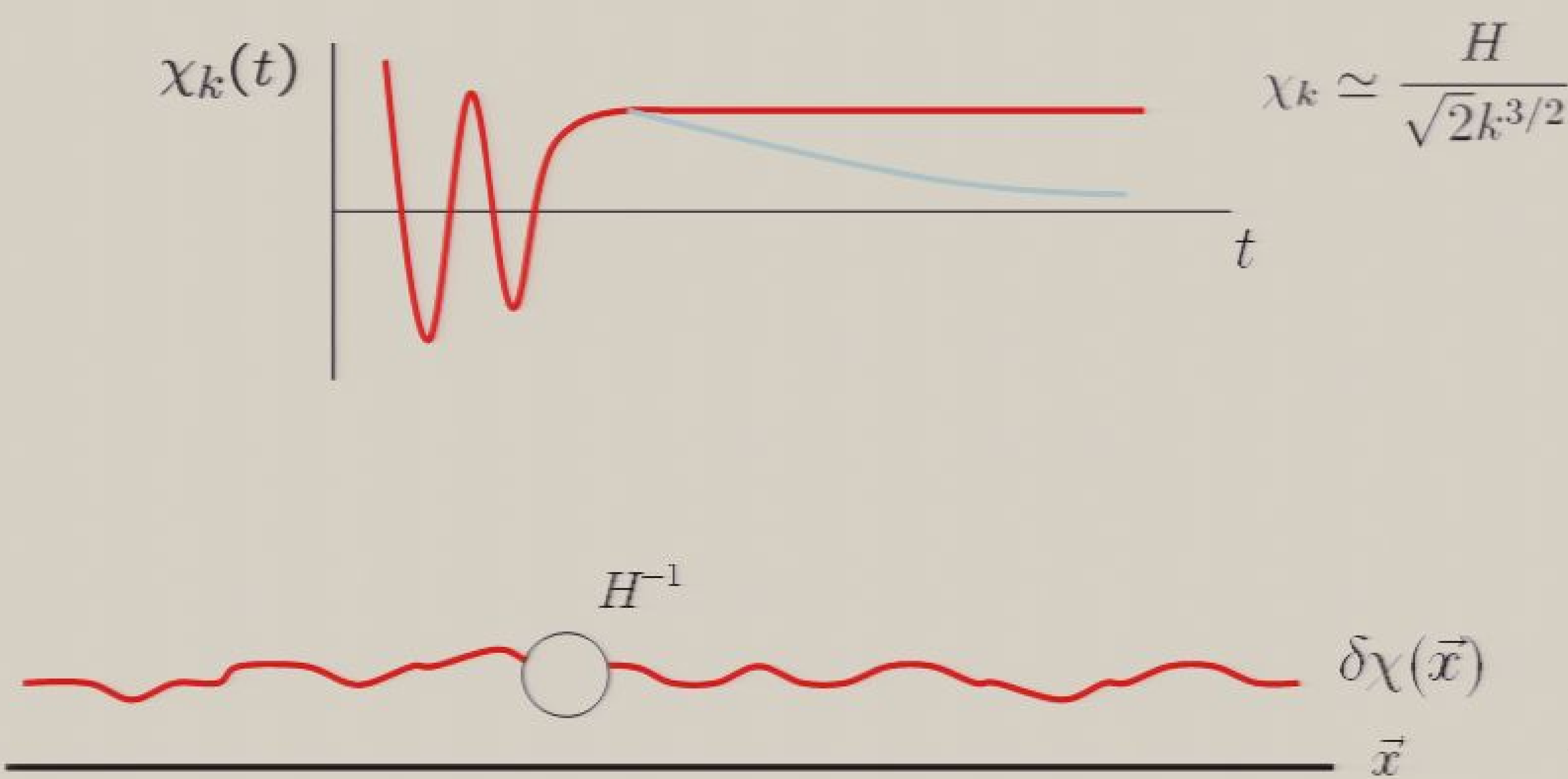

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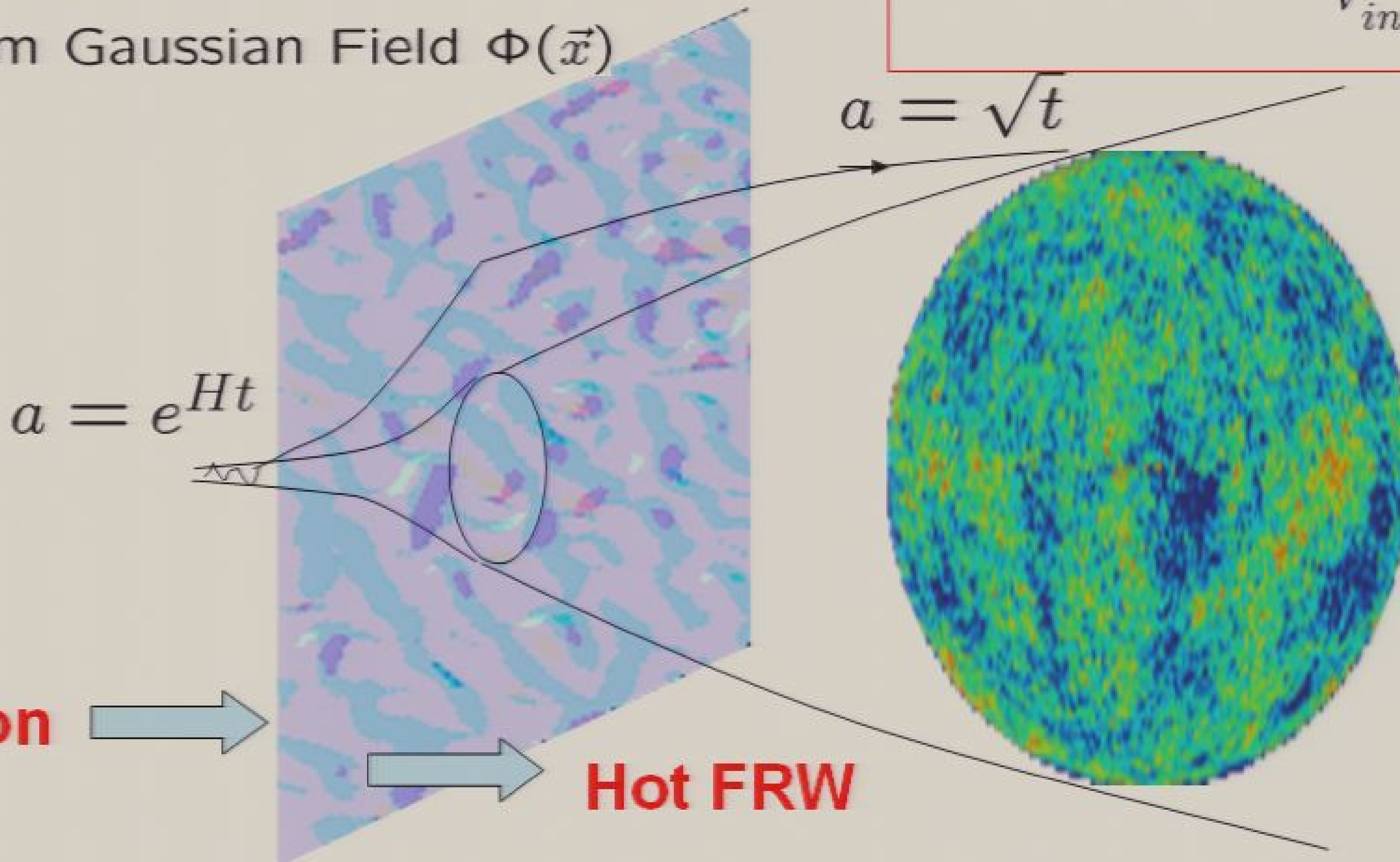

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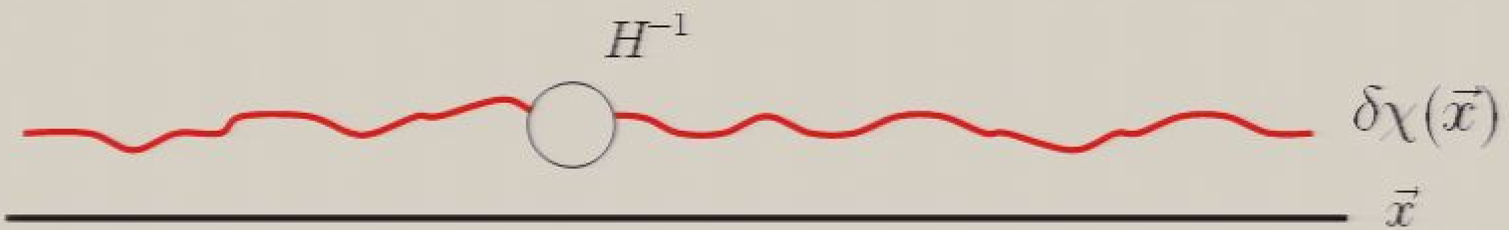

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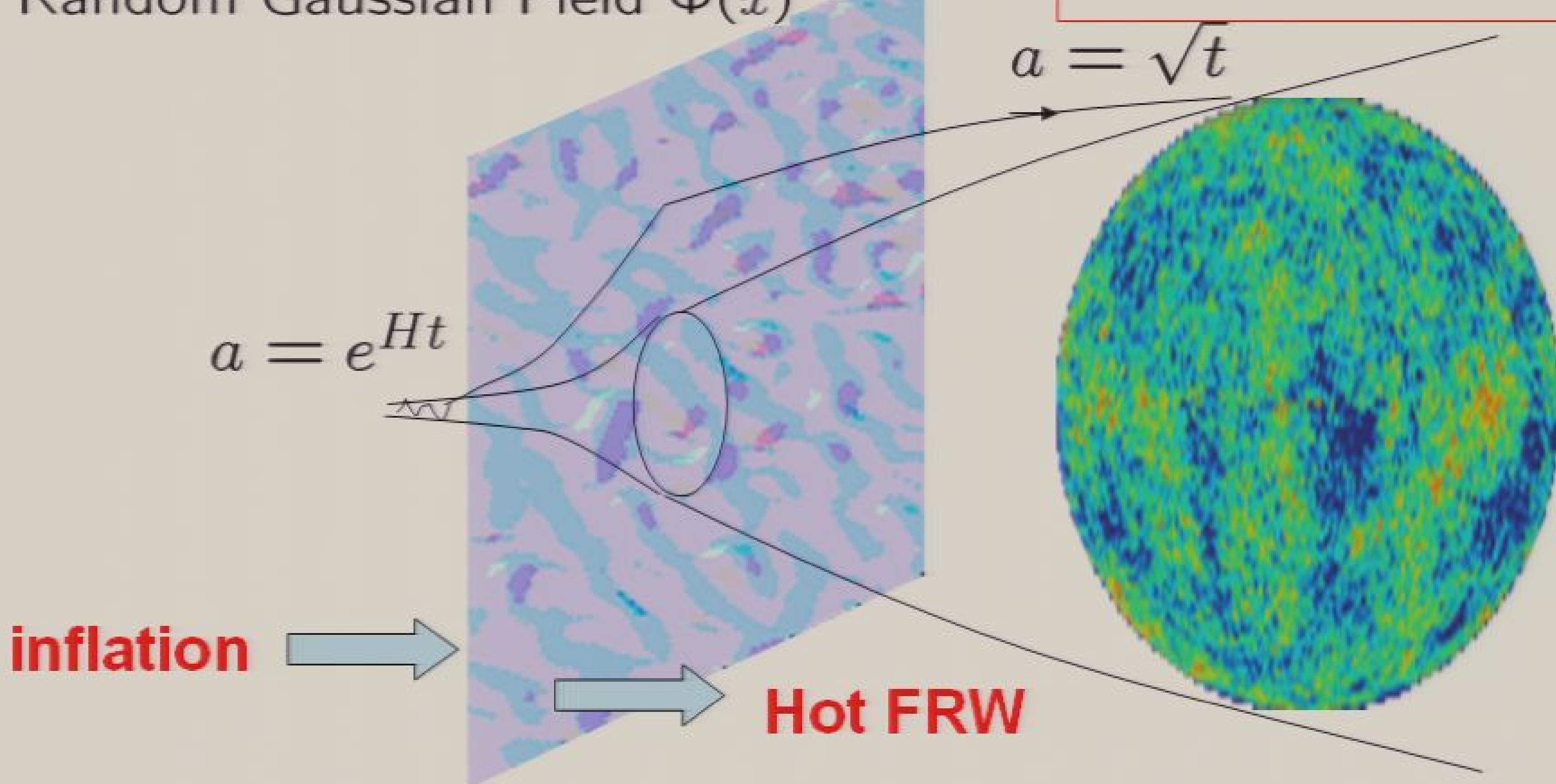
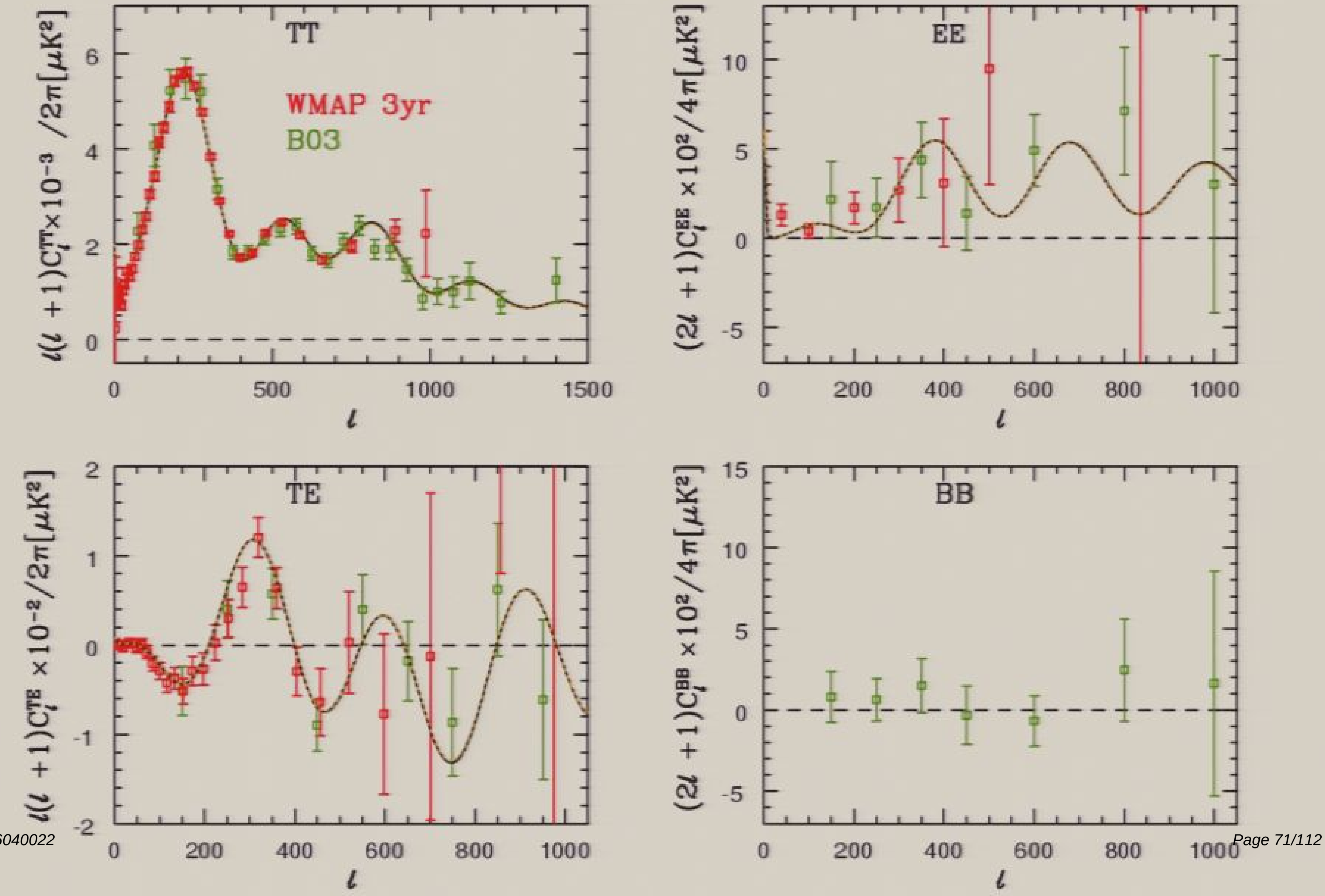


WMAP3 sees 3rd pk, B03 sees 4th



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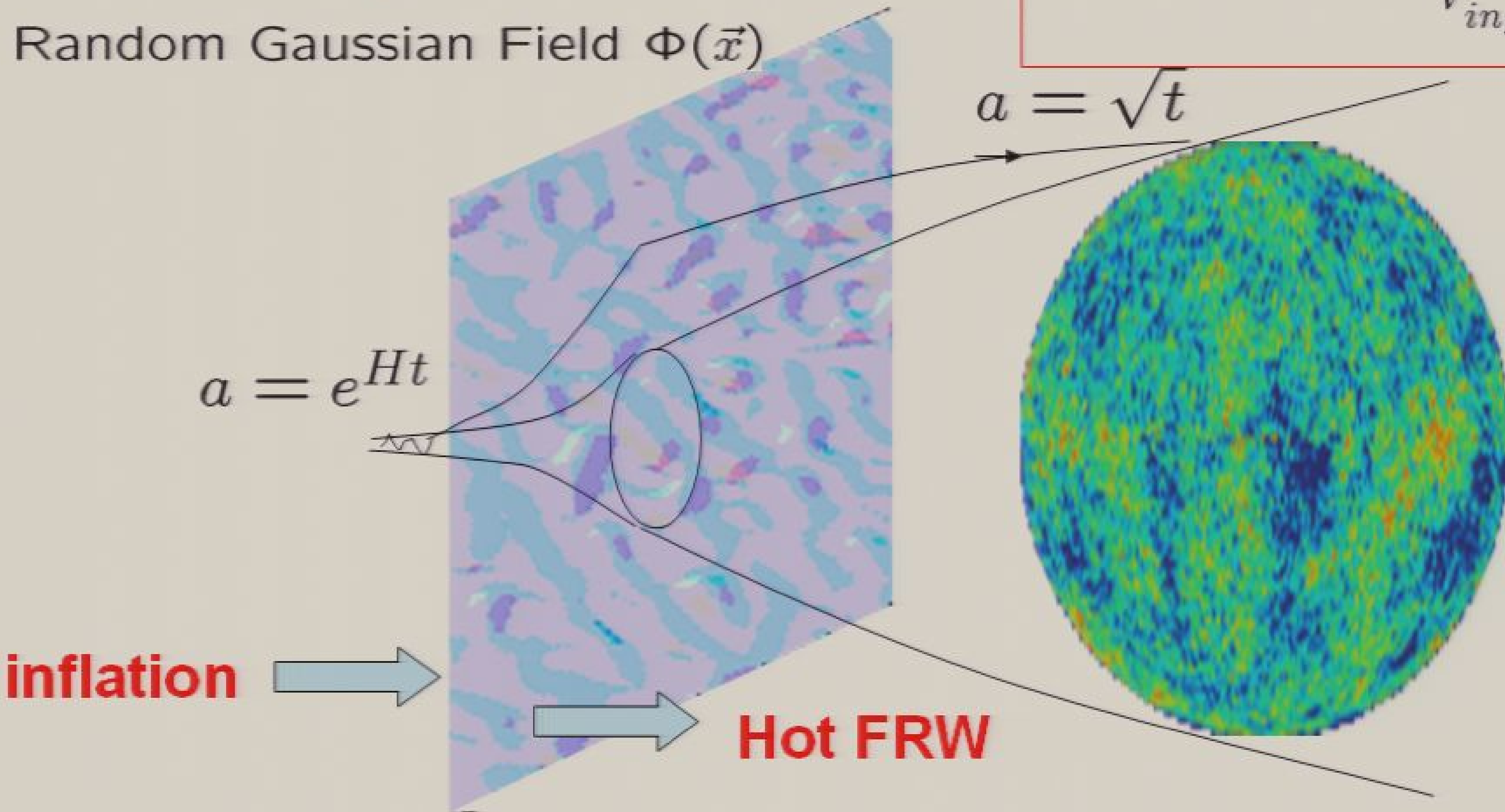

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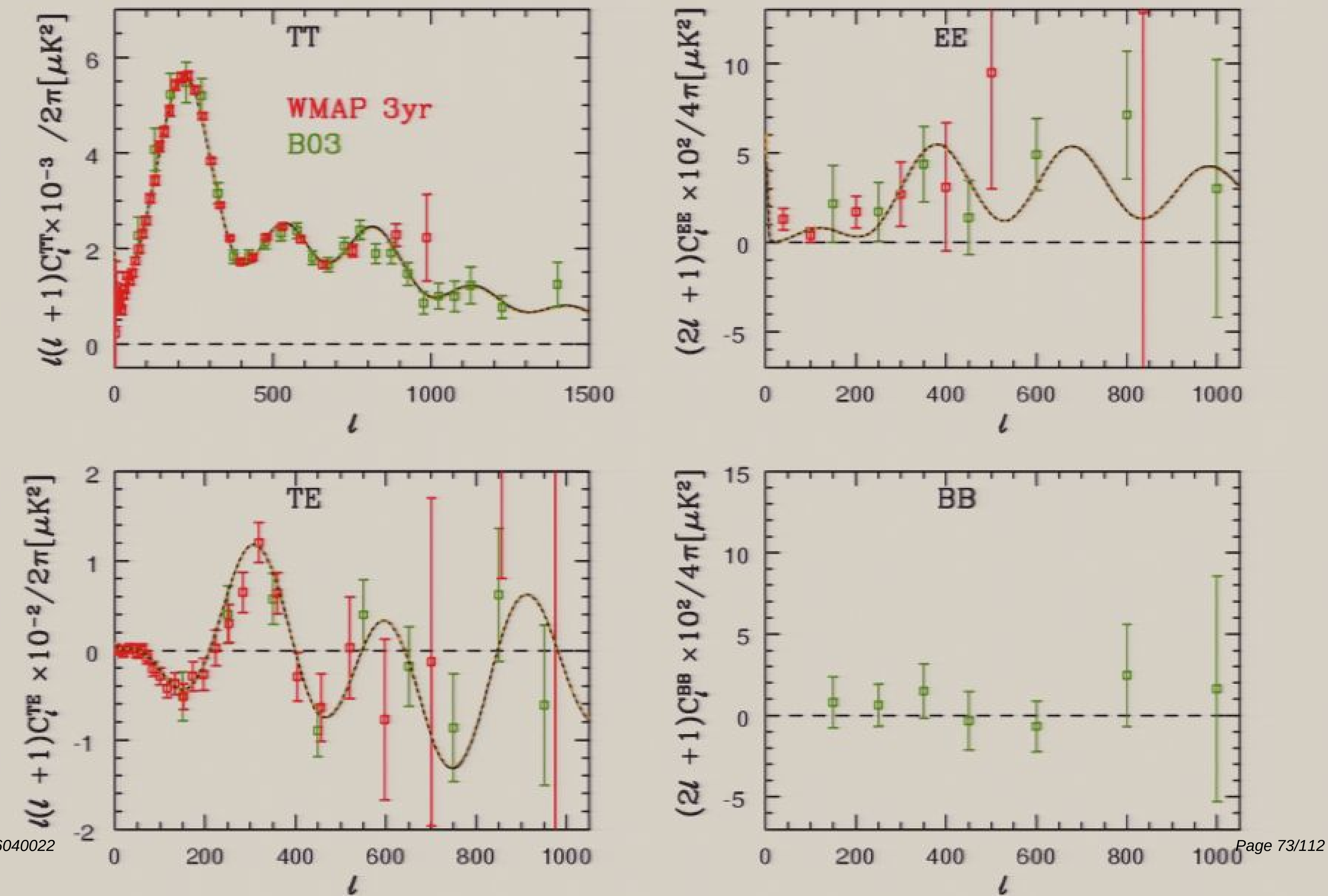
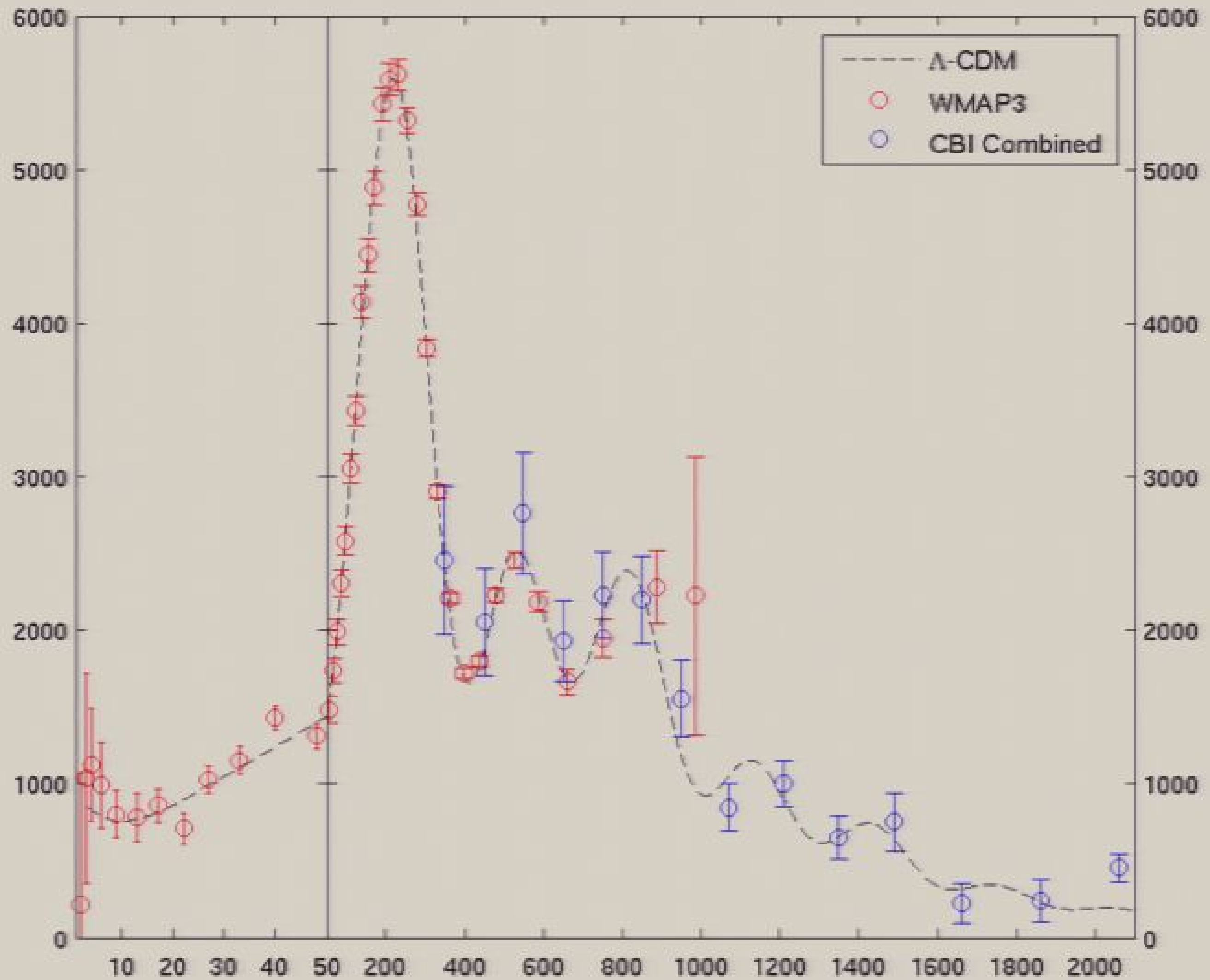


CBI combined TT sees 5th pk



Inflation in the context of ever changing fundamental theory

1980

R^2-inflation

Old Inflation

New Inflation

Chaotic inflation

SUGRA inflation

Double Inflation

Power-law inflation

Extended inflation

1990

Hybrid inflation

Assisted inflation

SUSY F-term inflation

SUSY D-term inflation

Brane inflation

2000

SUSY P-term inflation

Super-natural Inflation

K-flation

N-flation

DBI inflation

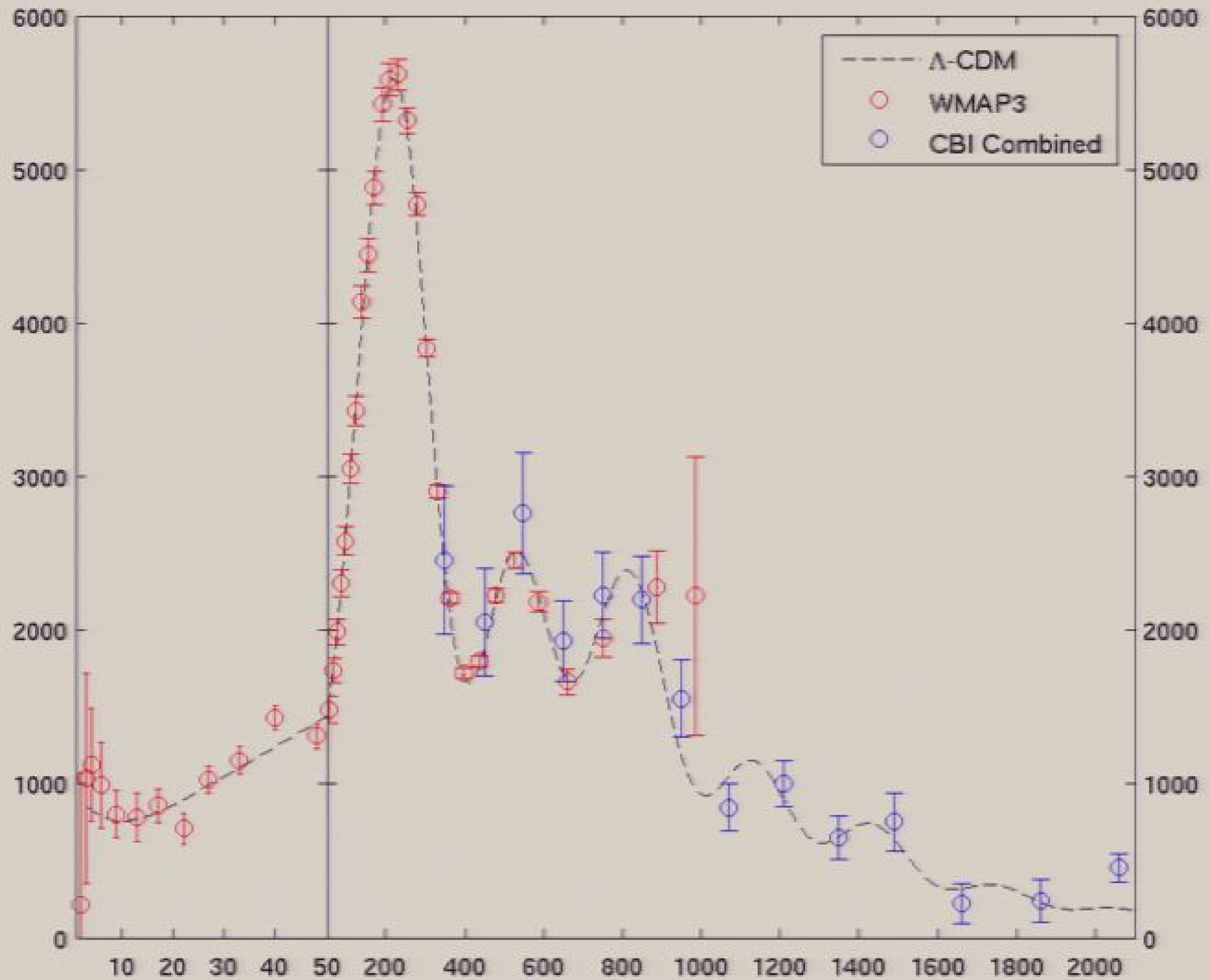
$D3-D7$ inflation

Warped Brane inflation

Tachyon inflation

Racetrack inflation

CBI combined TT sees 5th pk



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N-flation

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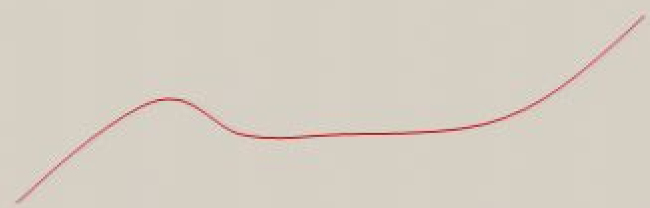
Tachyon inflation

Racetrack inflation

String theory lanscape

10^{500} vacua



$$V(\phi_1, ..., \phi_{1000}, ...)$$

String theory lanscape

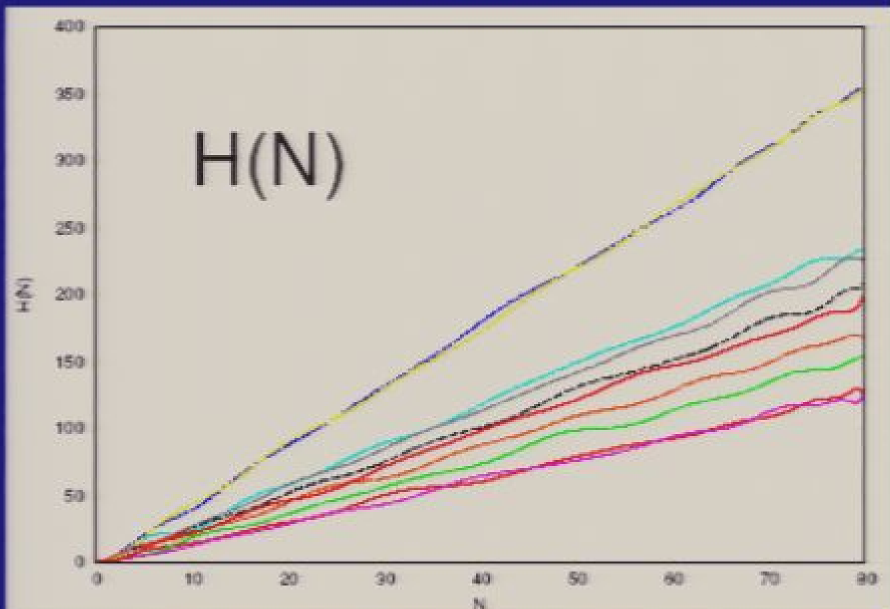
10^{500} vacua

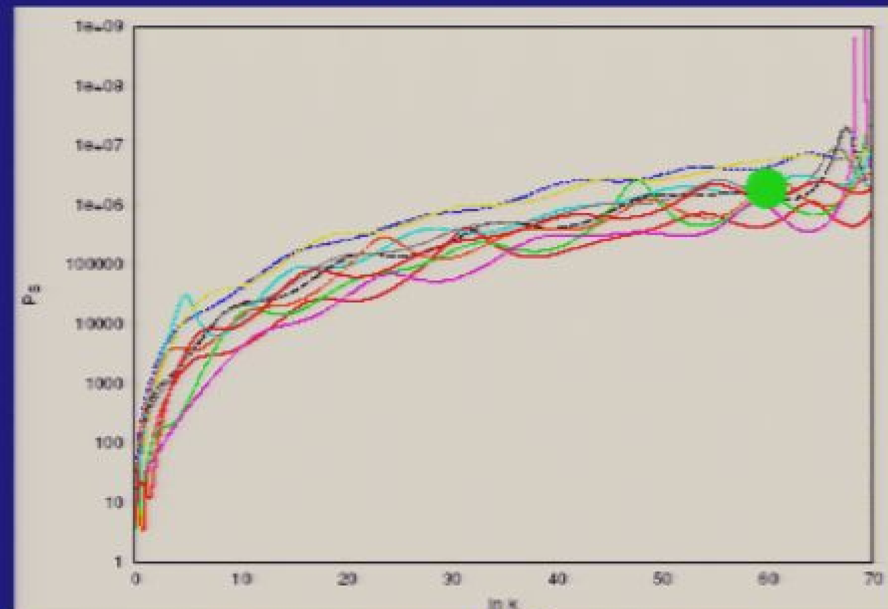
$$V(\phi_1, ..., \phi_{1000}, ...)$$

The Eye Of The Needle

reconstruction ⟵

Acceleration | **Powerspectrum**





trajectory $H(N)$ $\xrightarrow{\text{map}}$ $P_S = \frac{H^2}{\epsilon}$

(natural object from Hamilton-Jacobi formalism)

(mildly broken scale invariance)

Scanning inflation

Bond, LK, Contaldi, Vandrevange 06

String theory lanscape

10^{500} vacua

$$V(\phi_1, ..., \phi_{1000}, ...)$$

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DBI inflation

$D3-D7$ inflation

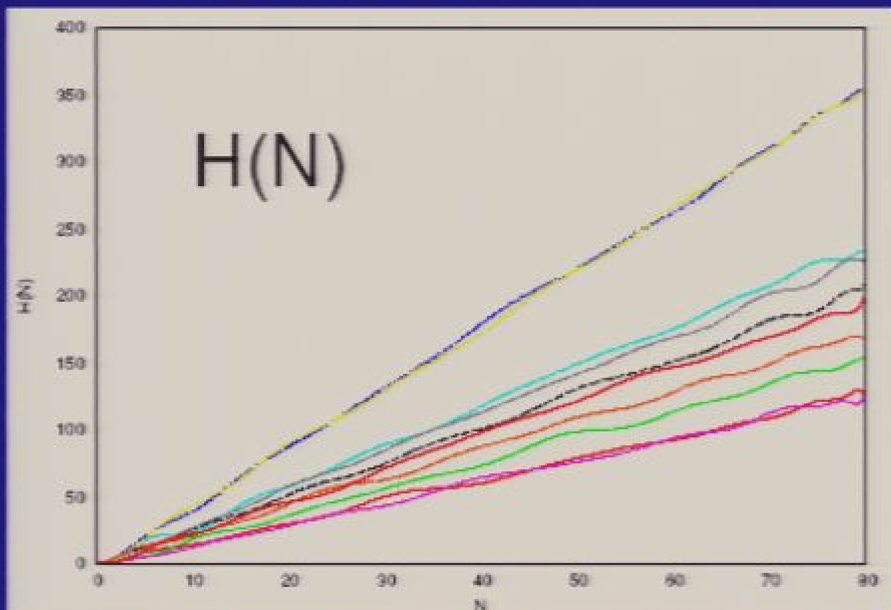
Warped Brane inflation

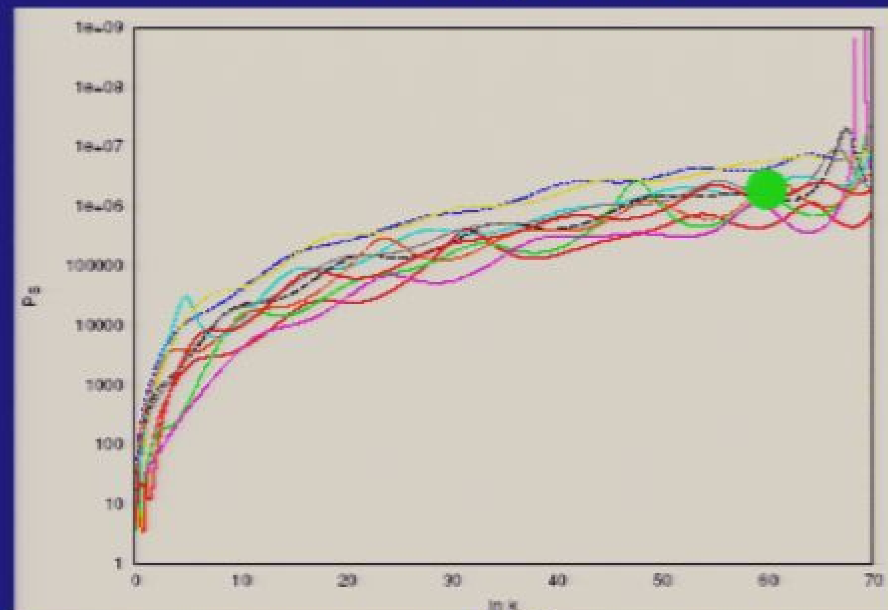
Tachyon inflation

Racetrack inflation

The Eye Of The Needle

Acceleration — reconstruction ⟵ — **Powerspectrum**





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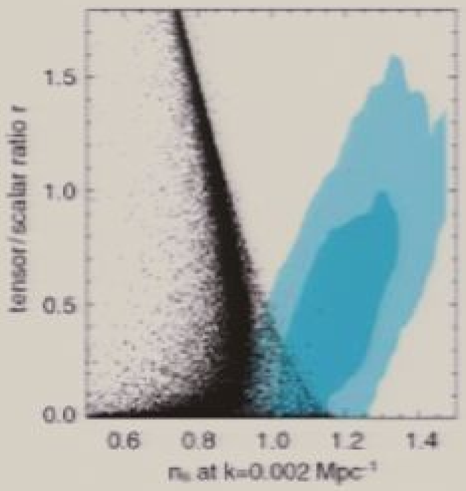
Scanning inflation

Bond, LK, Contaldi, Vandrevange 06

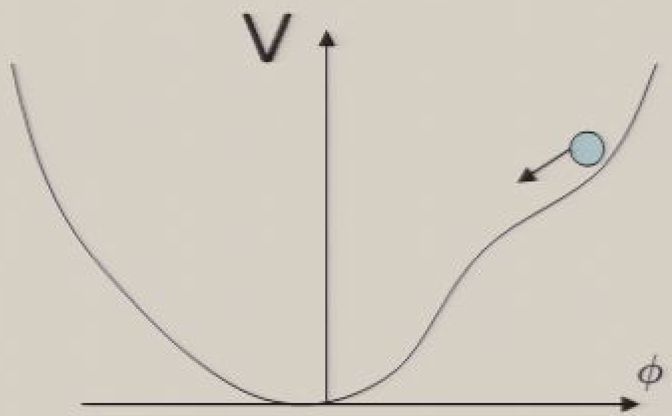
Bottom-up

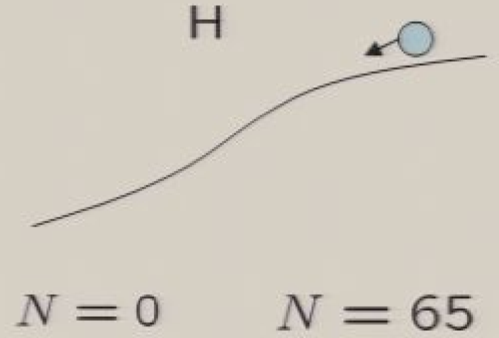
Scanning Inflation



$P_s(k) = A_s k^{n_s - 1}$, $r = P_{GW}/P_s$
RG flow method

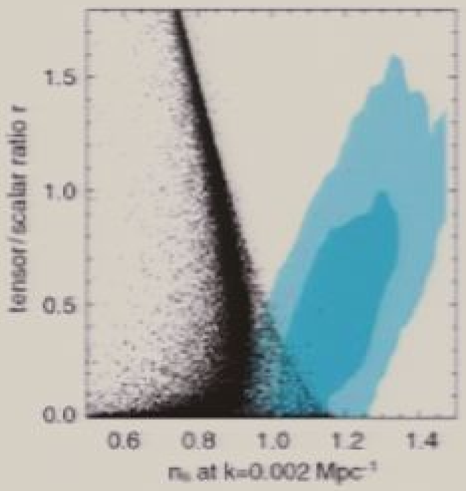
Small slow roll parameters
$\epsilon = \frac{M_p^2}{4\pi}\frac{H'^2}{H^2}$, $\eta = \frac{M_p^2}{4\pi}\frac{H''}{H^2}$, $\xi \sim H'''$ etc.
Flow eqs.
$\frac{d\epsilon}{dN} = \epsilon(\sigma + 2\epsilon)$
$\frac{d\sigma}{dN} = -5\sigma\epsilon - 12\epsilon^2 + 2\xi$
$\frac{d\xi}{dN} \sim$ cubic in $\epsilon, \sigma, \xi + \lambda$
etc





Bottom-up

Scanning Inflation



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RG flow method

Small slow roll parameters

$\epsilon = \frac{M_p^2}{4\pi}\frac{H'^2}{H^2}$, $\eta = \frac{M_p^2}{4\pi}\frac{H''}{H^2}$, $\xi \sim H'''$ etc.

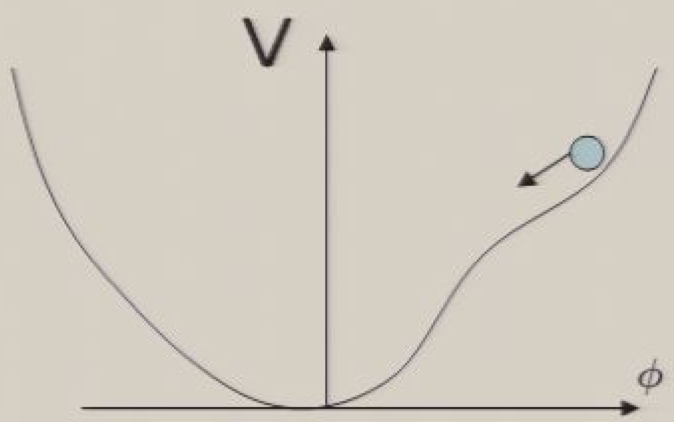
Flow eqs.

$\frac{d\epsilon}{dN} = \epsilon(\sigma + 2\epsilon)$

$\frac{d\sigma}{dN} = -5\sigma\epsilon - 12\epsilon^2 + 2\xi$

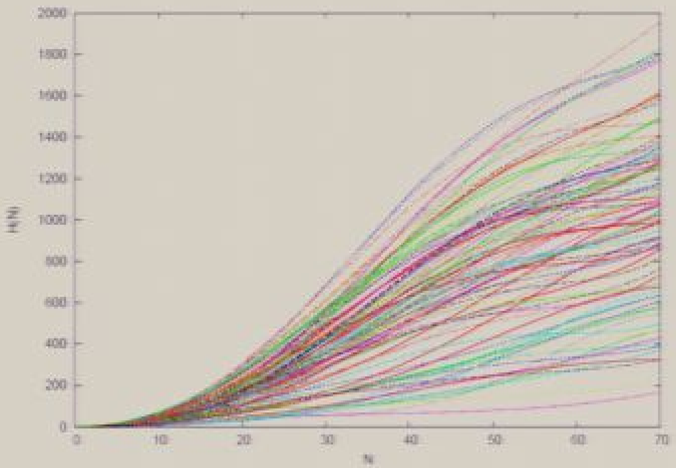
$\frac{d\xi}{dN} \sim$ cubic in $\epsilon, \sigma, \xi + \lambda$

etc



$N = 0$ $N = 65$

Ensemble of Inflationary trajectories



Chebyshev decomposition

$$H(x) = \sum c_n T_n(x) \;,\; x = \frac{2N - N_{\max}}{N_{\max}}$$

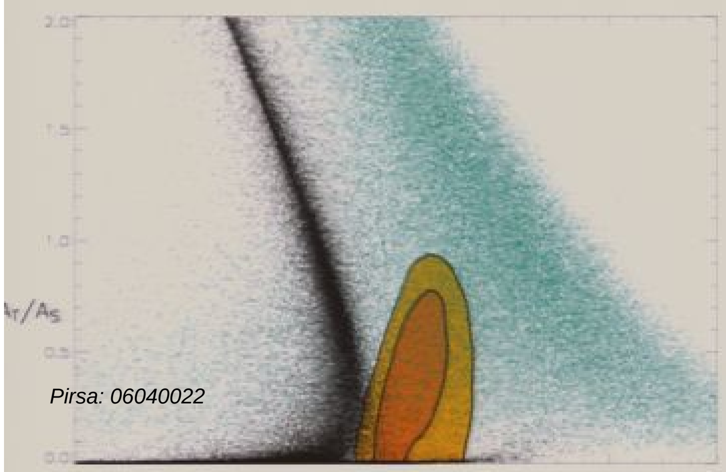
$$\|H(x) - \sum^{M} c_n T_n(x)\| = min \;.$$

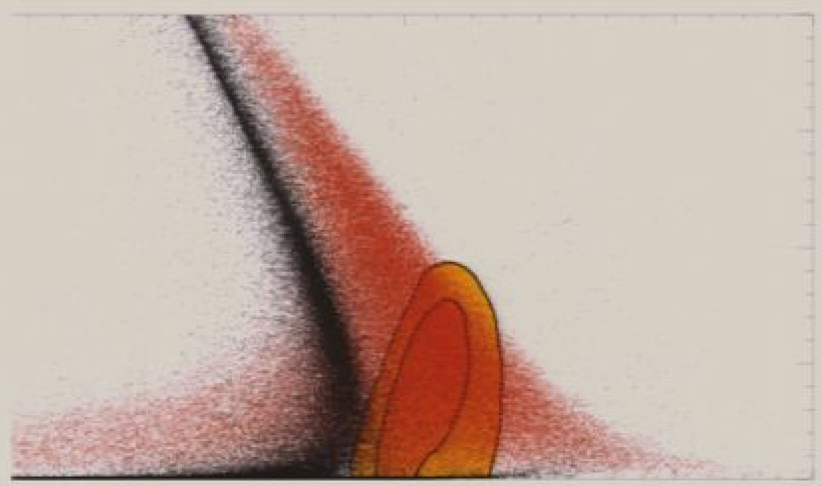
$0 < \frac{dH}{dN} < H$ $\qquad$ $\frac{dH}{dN} = H$ at $N = 65$

Related methods of trajectory generation

speed 10^5 up vs RGF

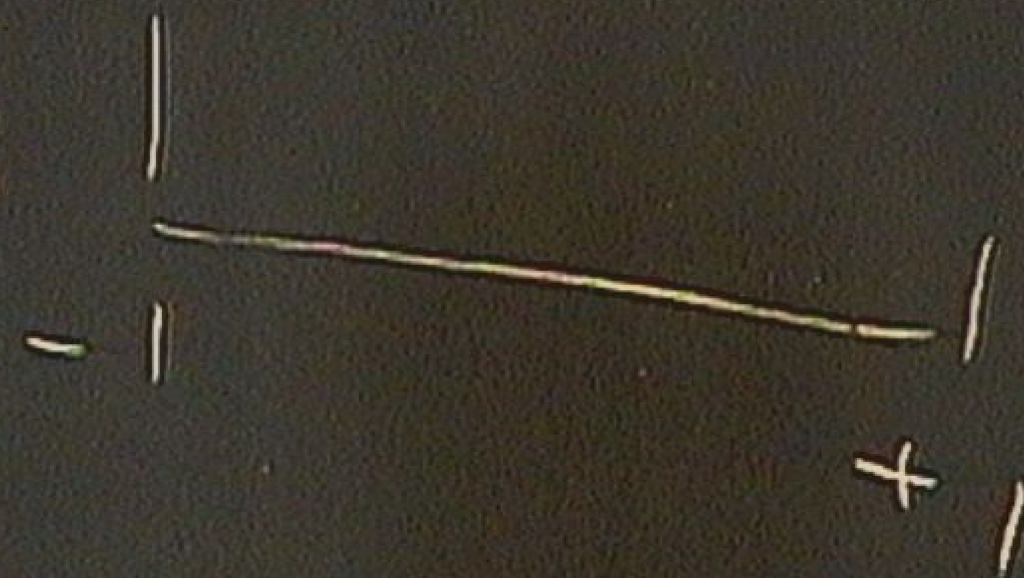
Space of models opens wide





$f(x)$

$R^2 + a R_{ij} R^{ij}$



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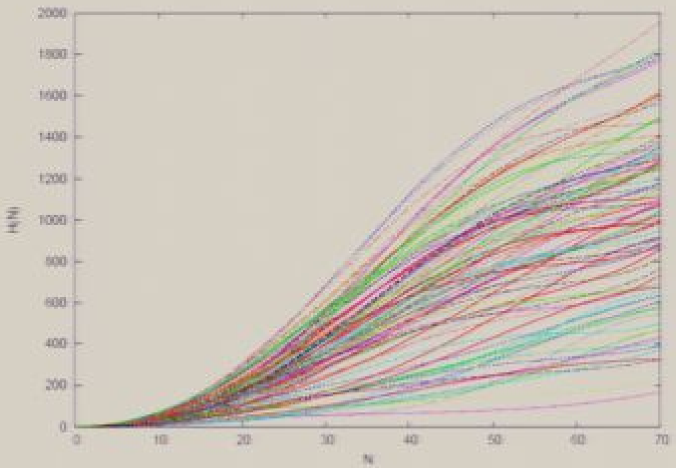

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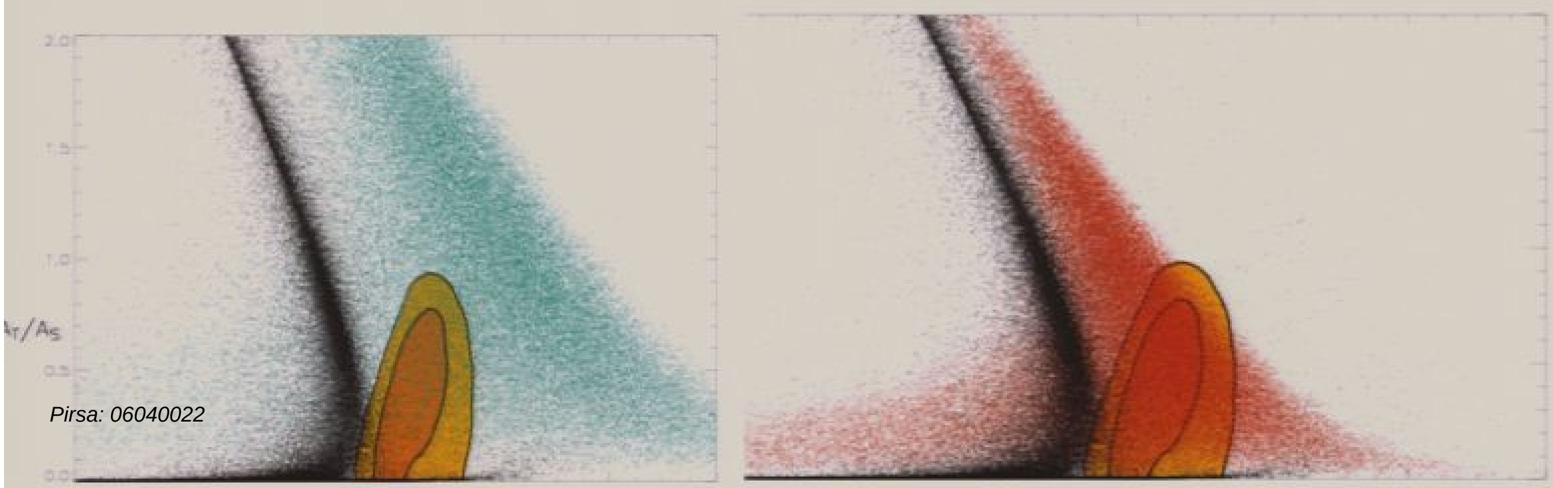
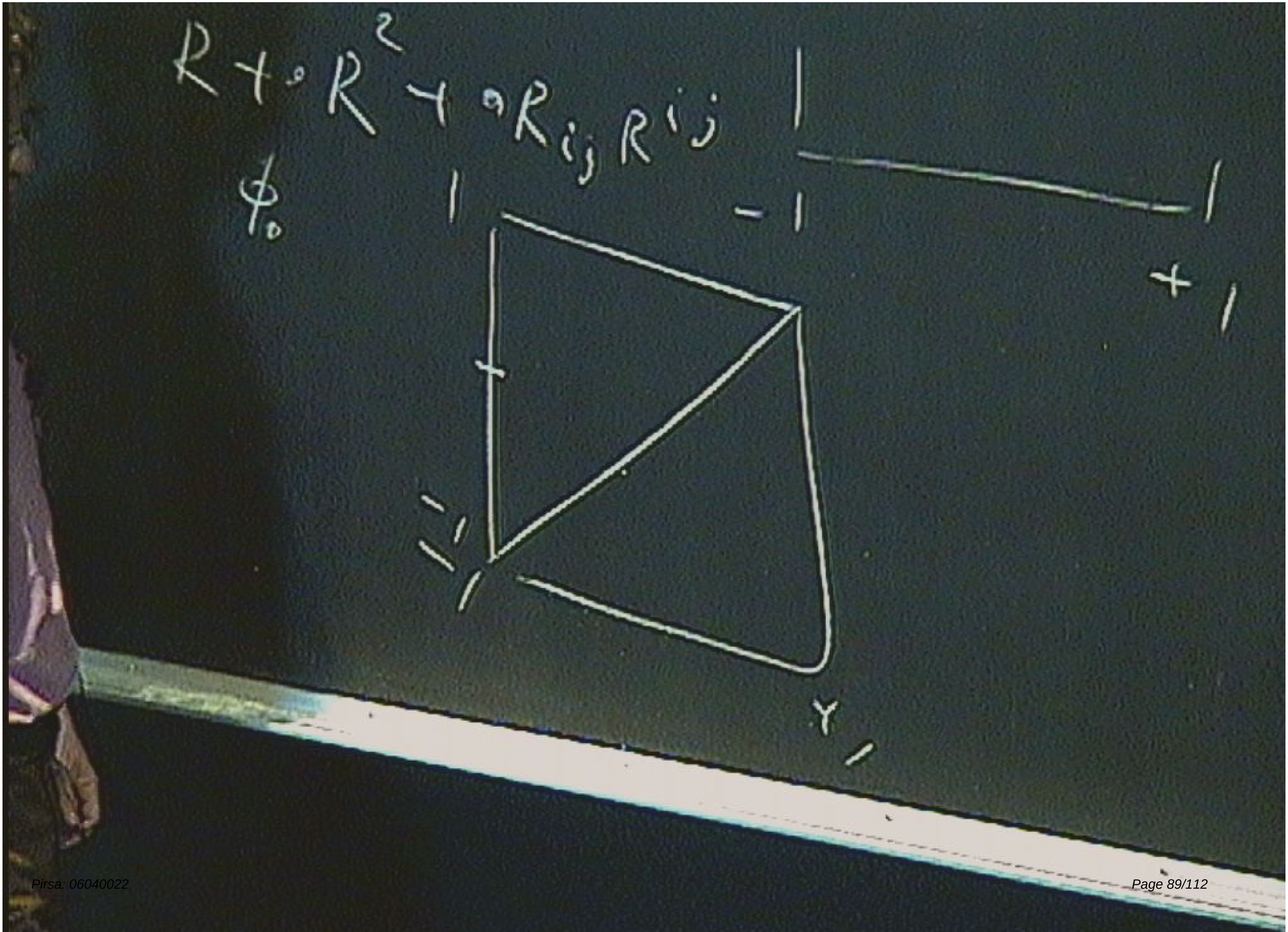
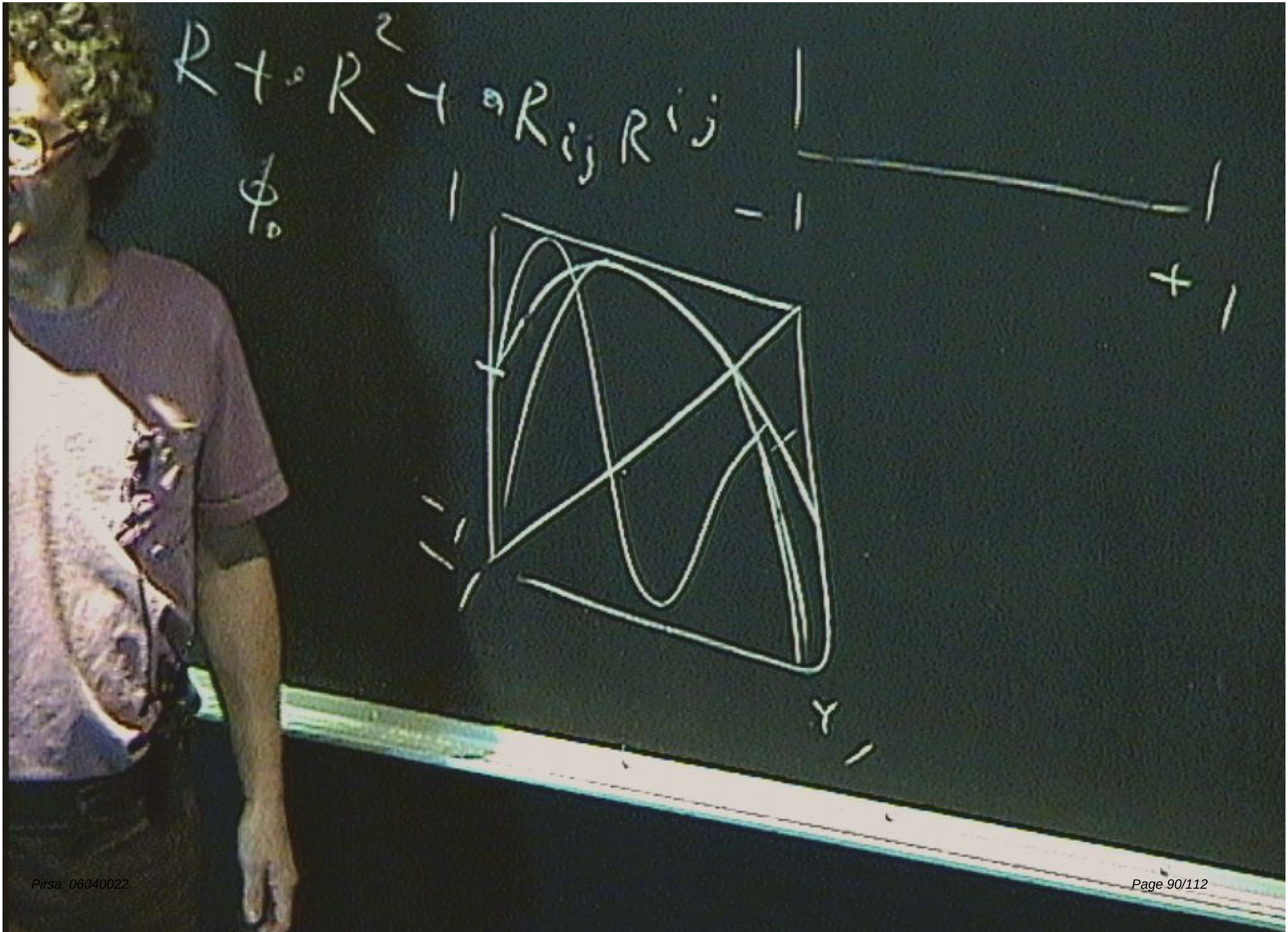



R + a R^2 + a R_ij R^ij
φ_0
1
-1
+1
-1
Y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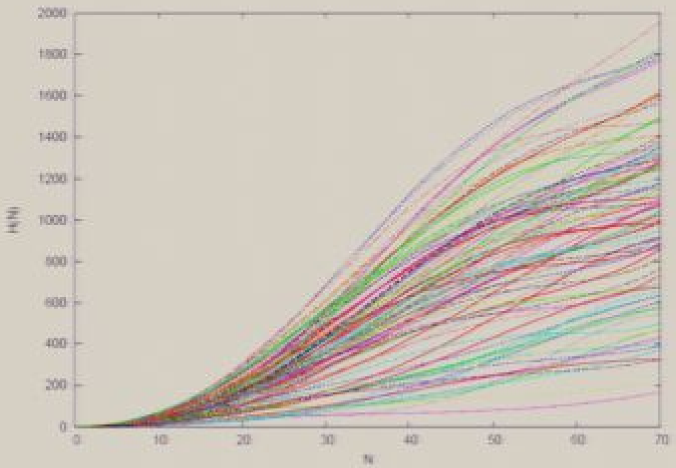
ϕ_0
-1
$+1$
Y

Ensemble of Inflationary trajectories



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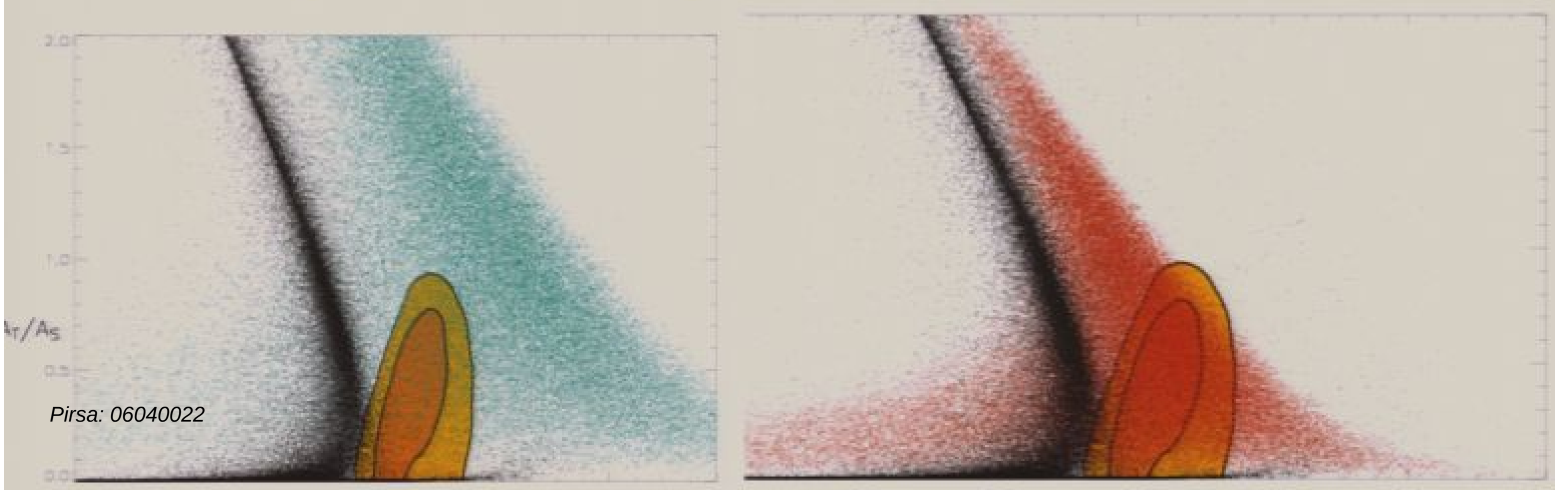
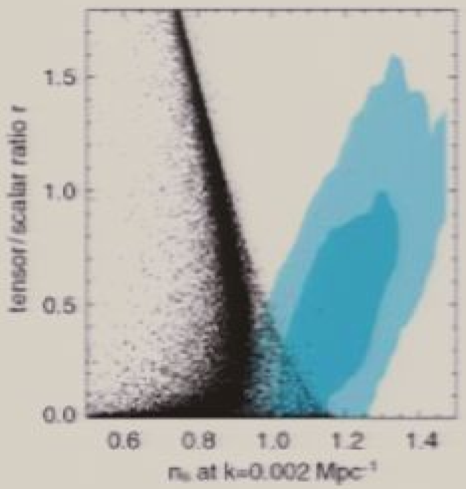


Bottom-up Scanning Inflation



$P_s(k) = A_s k^{n_s - 1}$, $r = P_{GW}/P_s$

RG flow method

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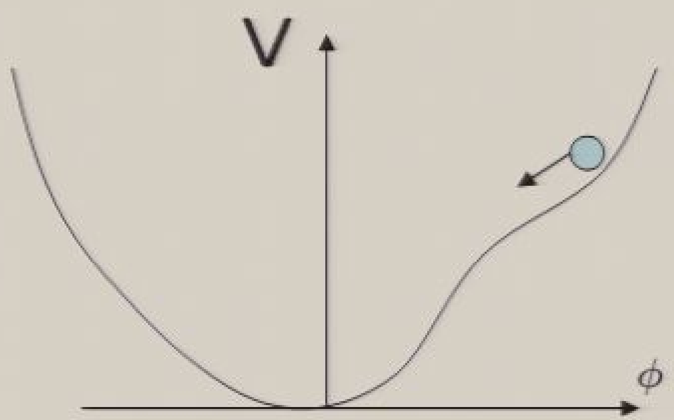
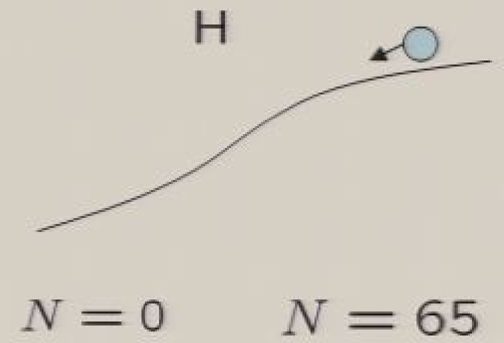
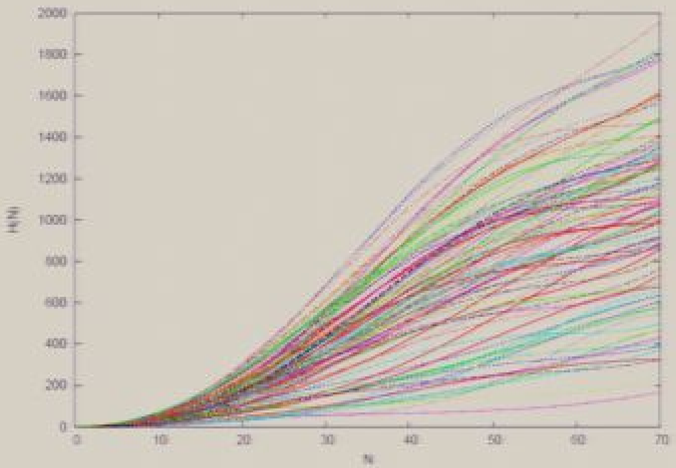




Ensemble of Inflationary trajectories



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Related methods of trajectory generation

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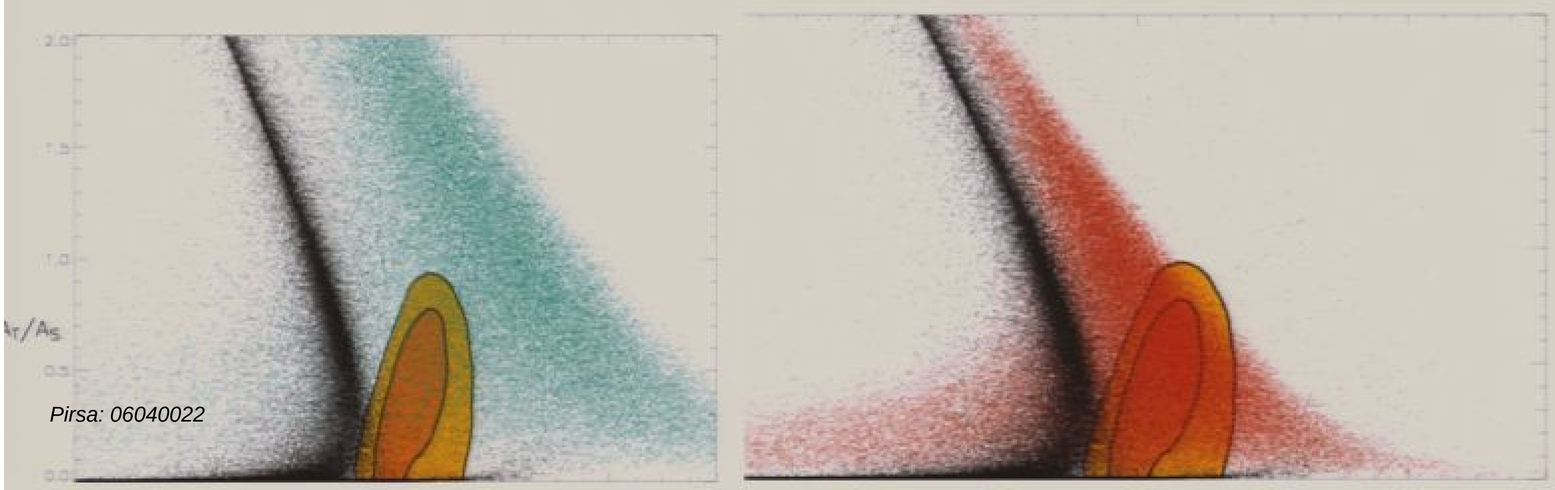
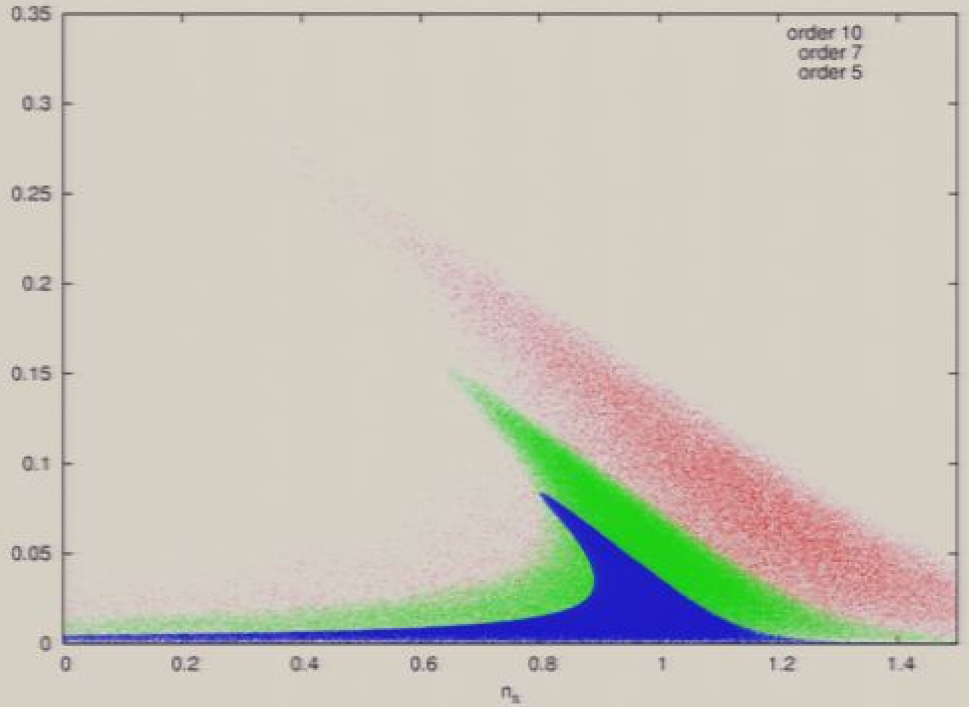
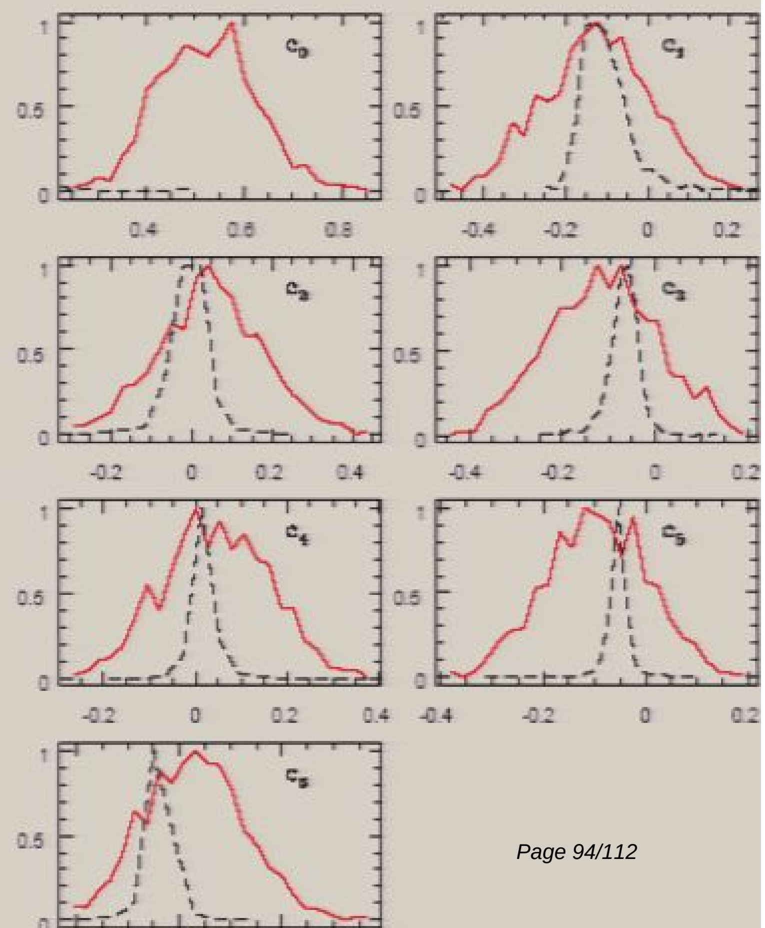
Space of models opens wide

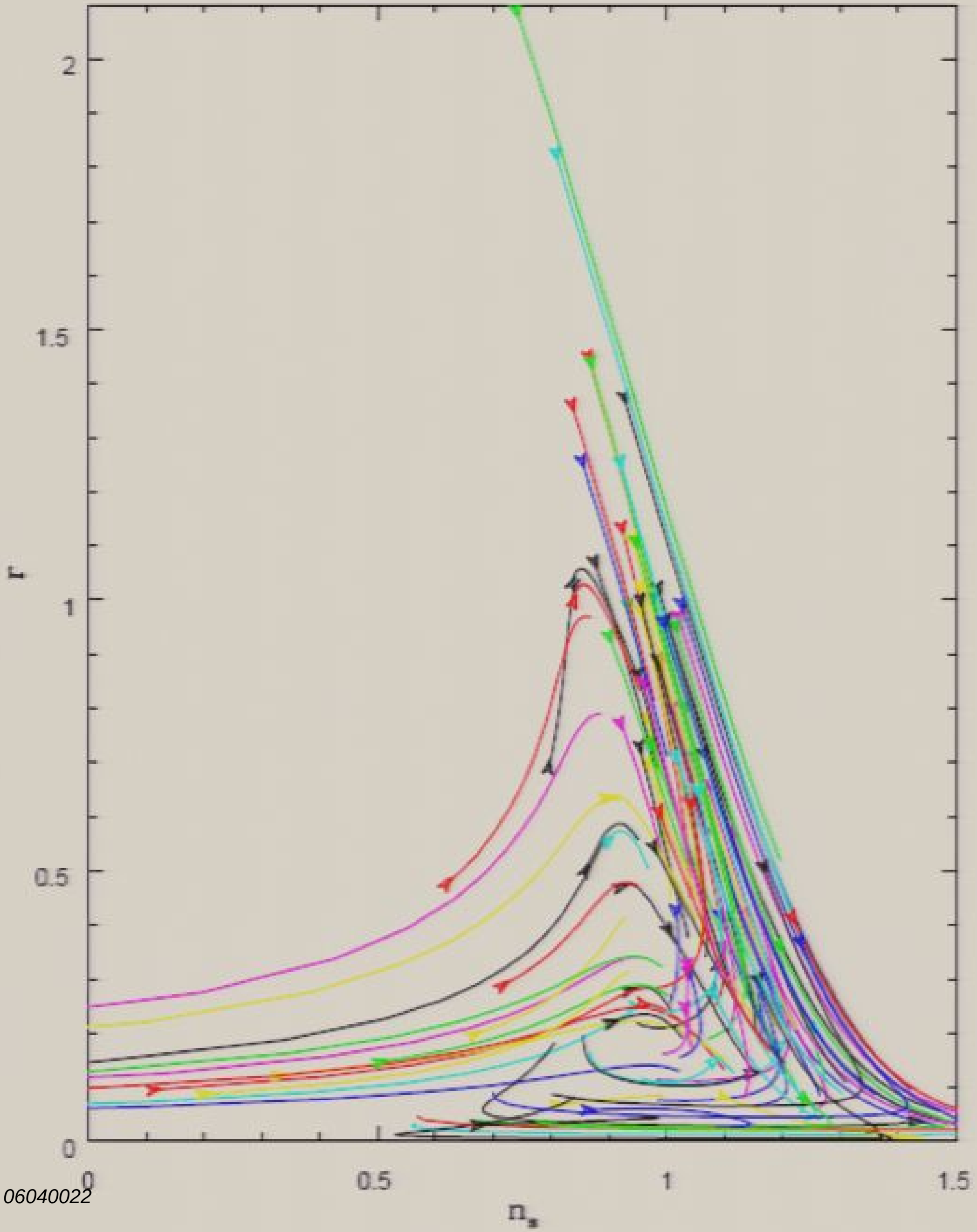




space opens more with higher order polynoms

comparison of c_n (red) in our method vs c_n (black) of Chebyshev transform of trajectories generated with RG flow

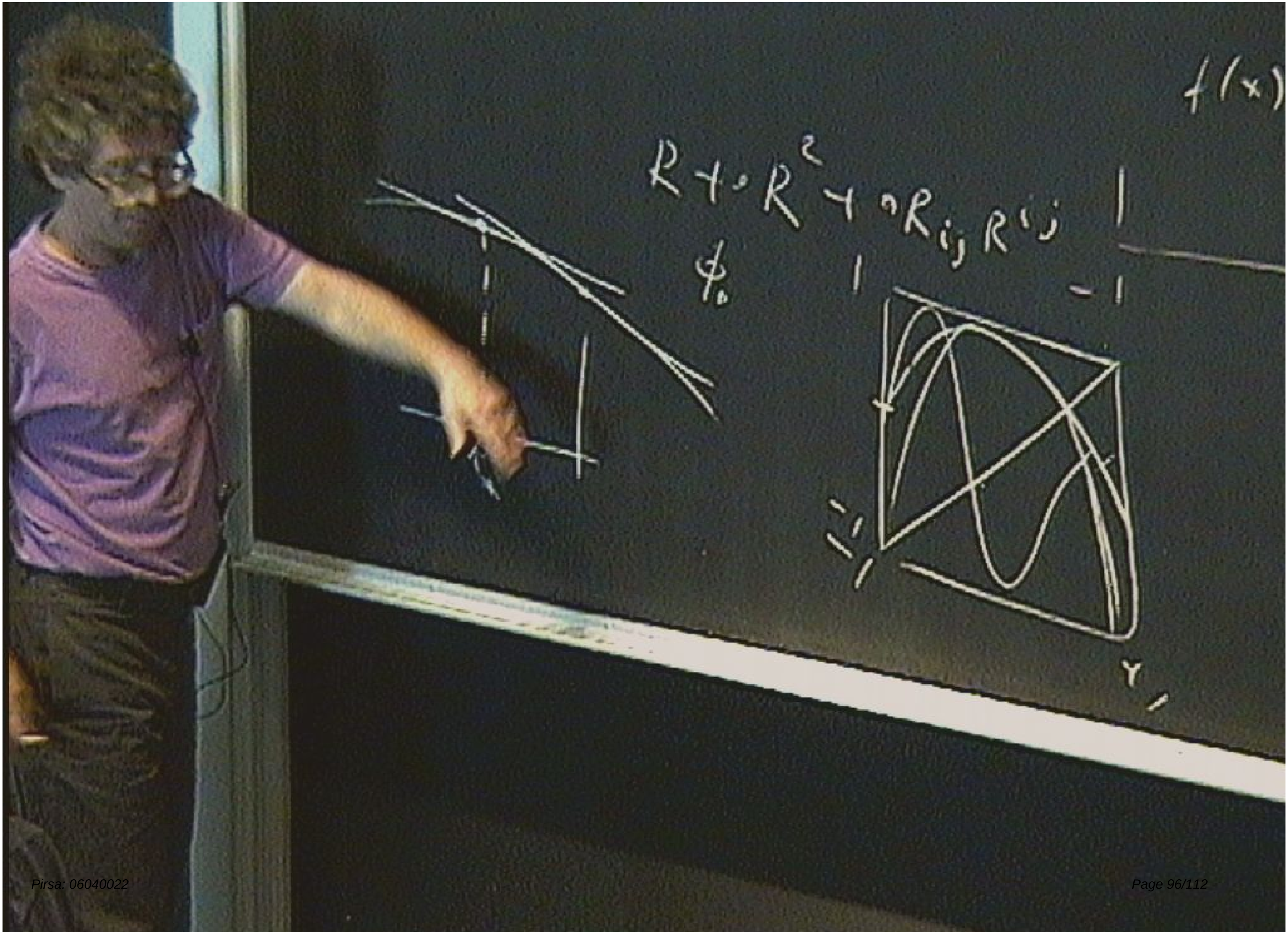


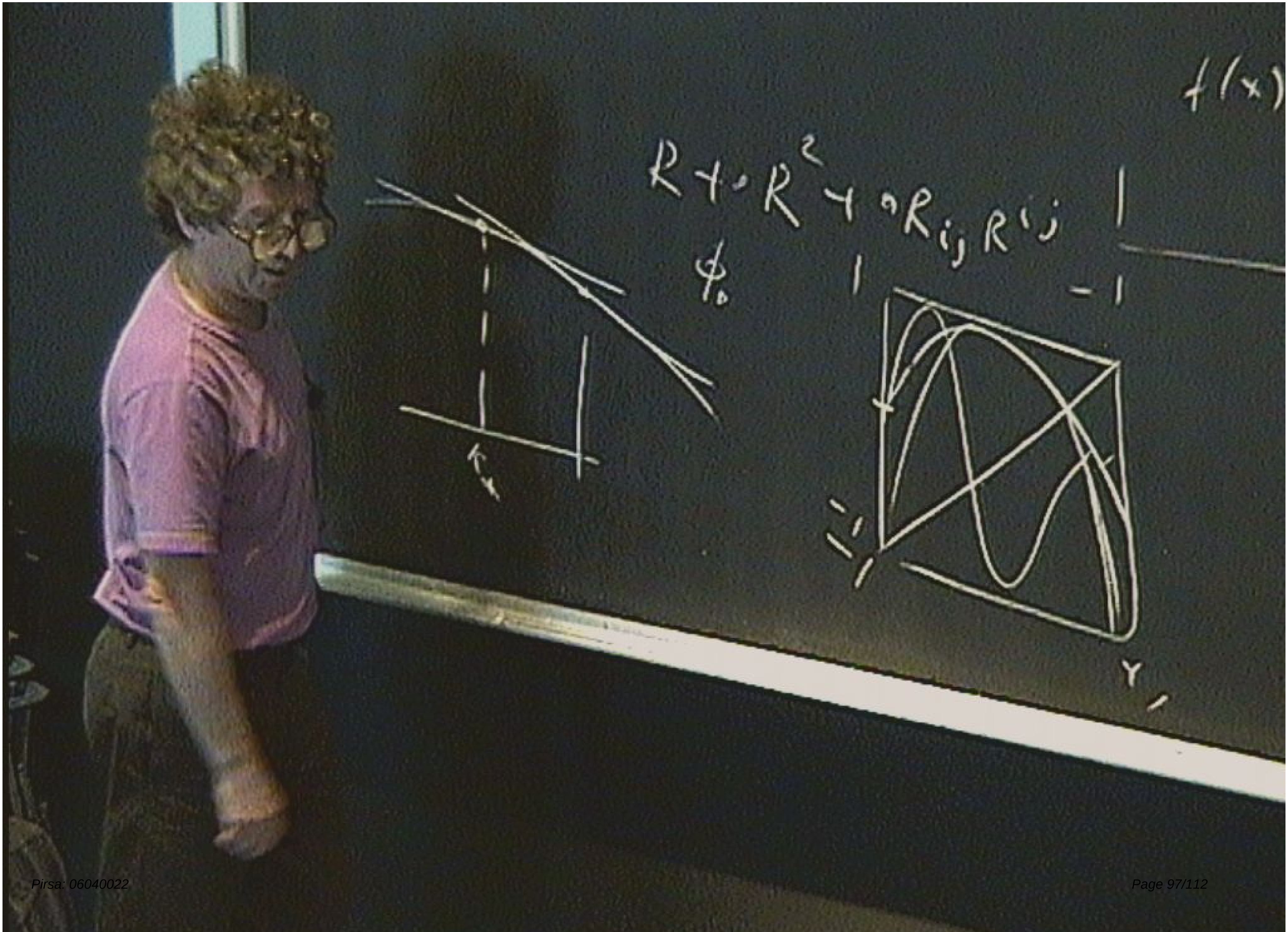


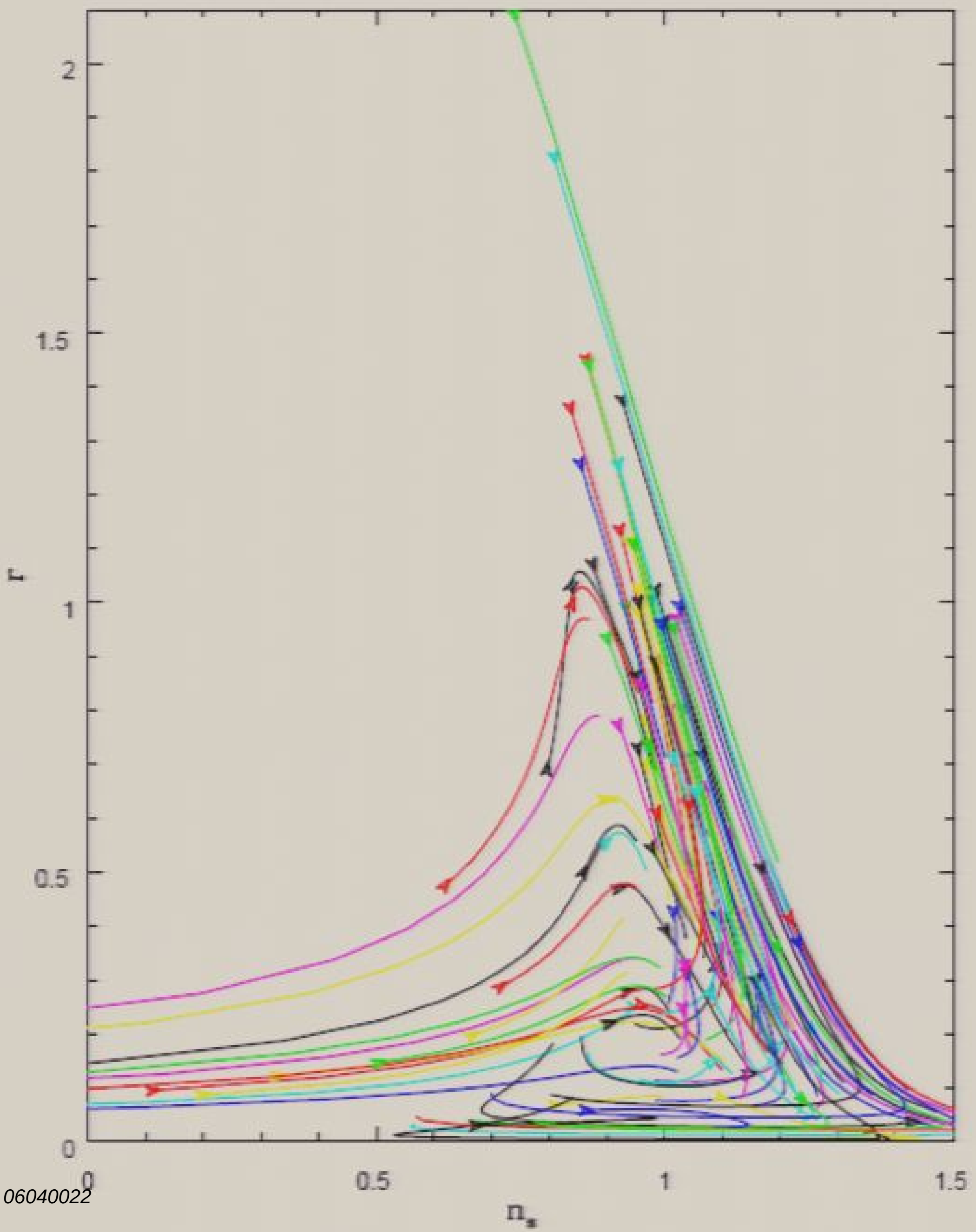
$$\epsilon, \eta \ldots$$

$$H(N) \longrightarrow P(k)$$

$n_s, n_t, r, dn/d\ln k, A_s, \ldots$


f(x)


f(x)
R + R^2 + R_ij R^ij
φ_0



$$\epsilon, \eta \ldots$$

$$H(N) \longrightarrow P(k)$$

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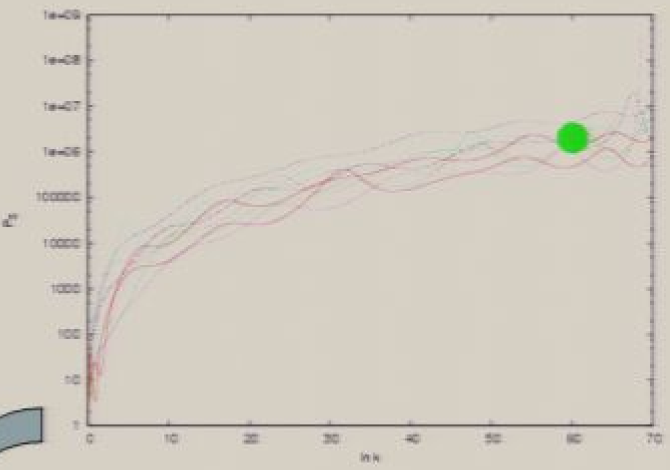
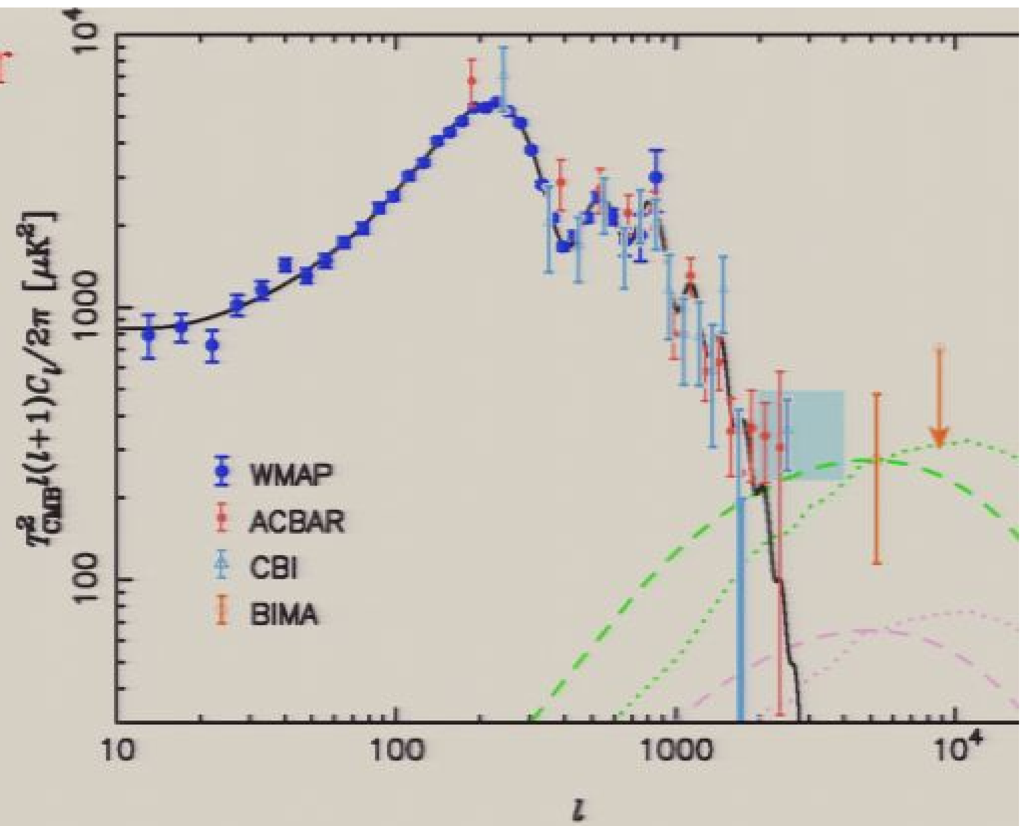
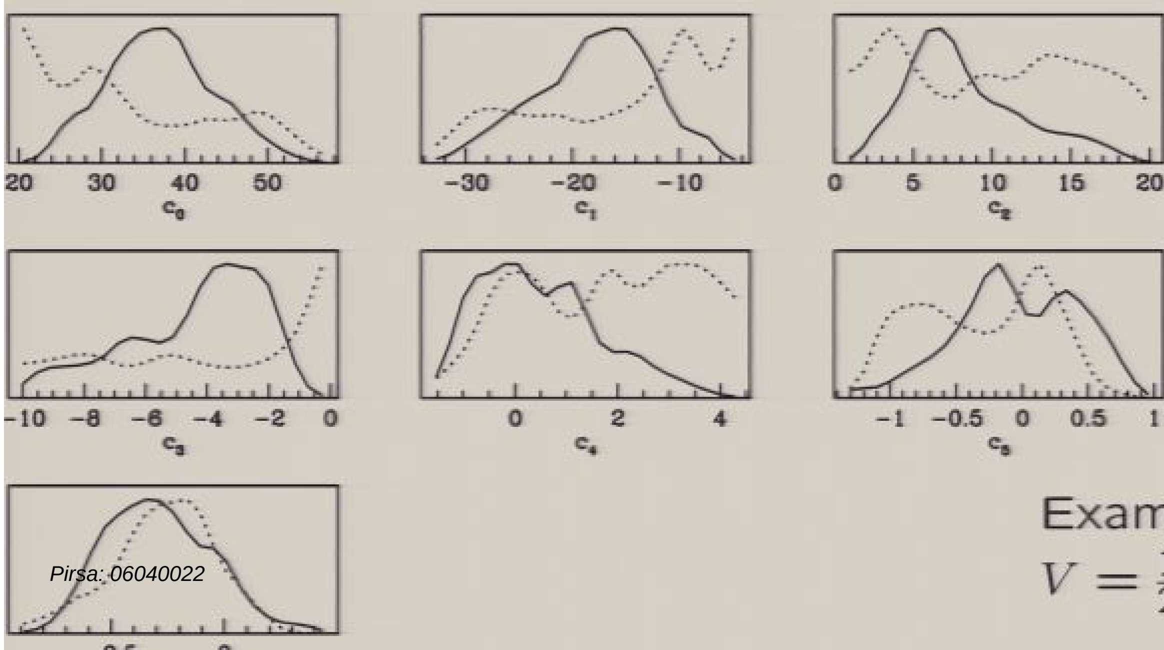
Observational constraints on trajector

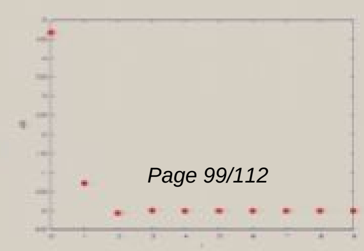


Markov Chain Monte Carlo

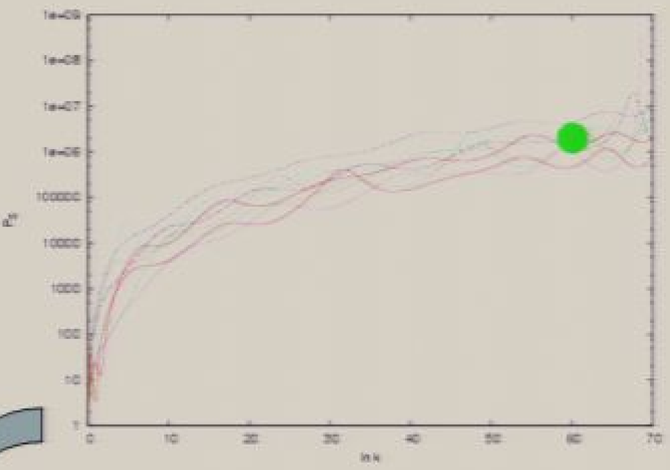


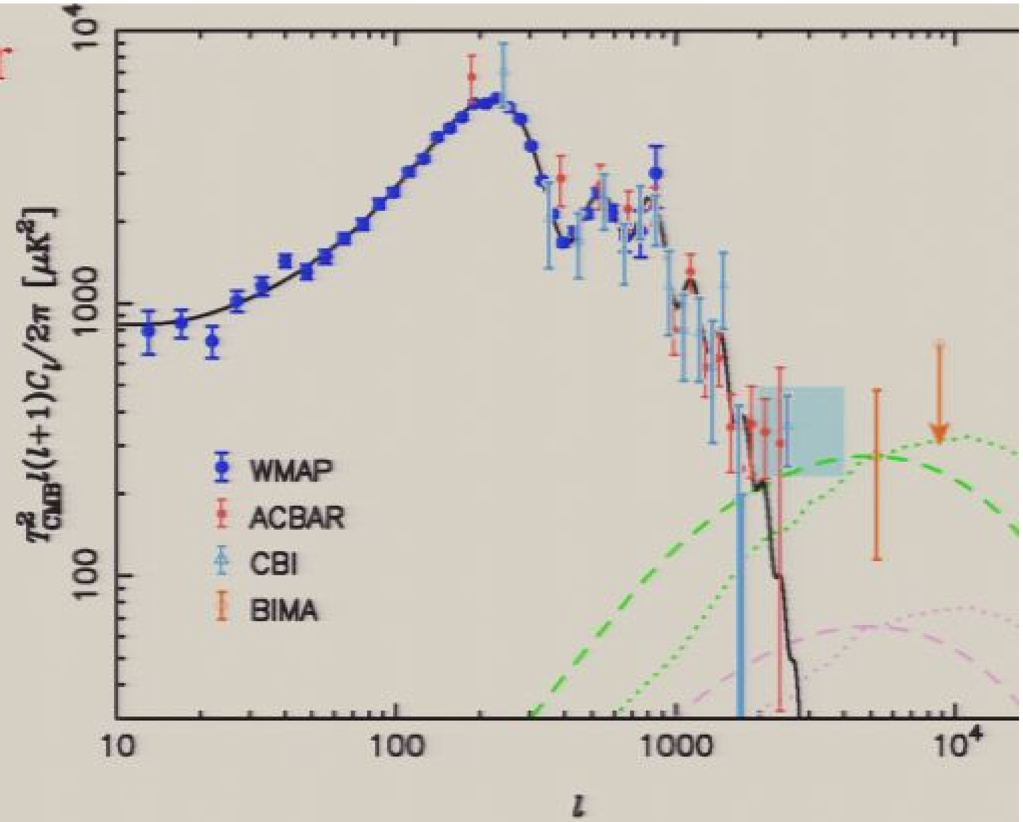


Example of c_n for $V = \frac{1}{2}m^2\phi^2$



Observational constraints on trajector





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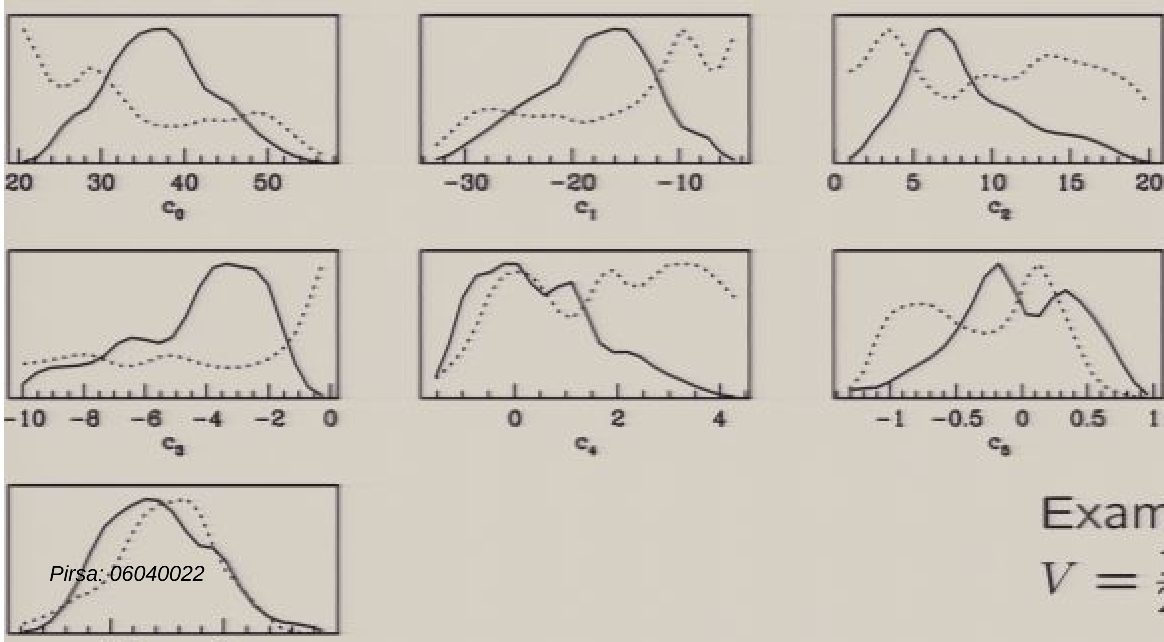

Example of c_n for
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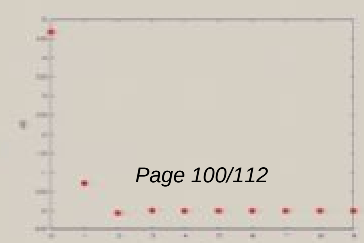
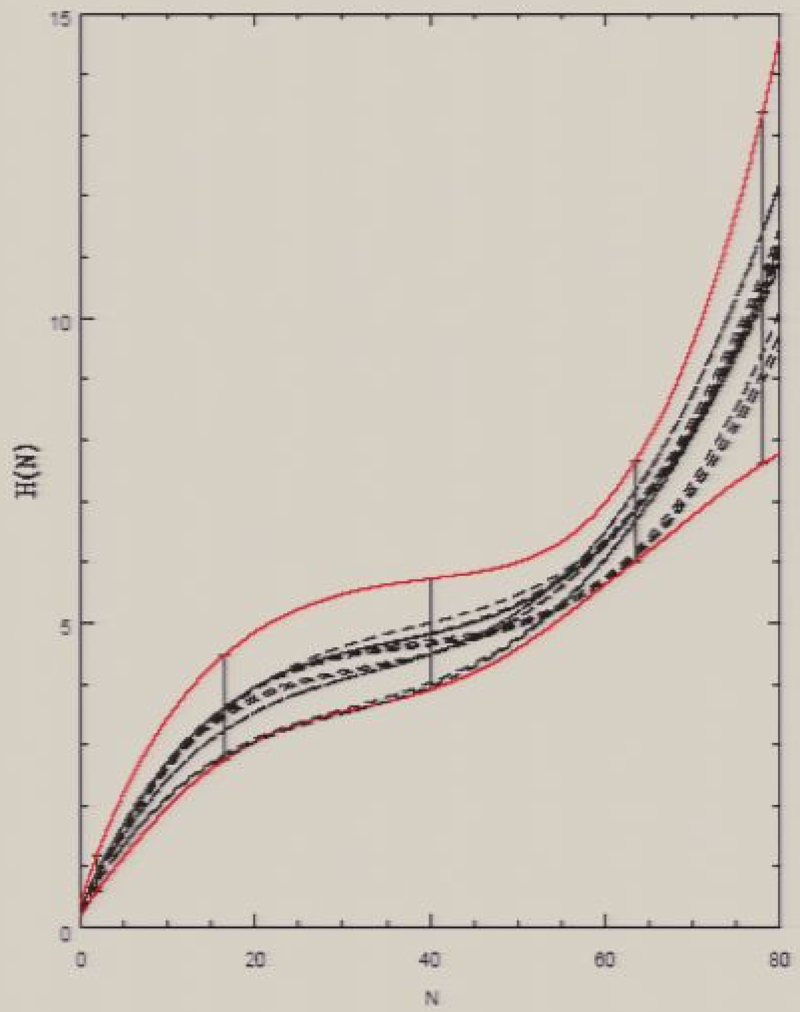


Reconstruction of Inflationary Trajectory



$$f(x) = \sum^{j=n} c_j T_j(x)$$

Chebyshev Polynoms Nodal Points Method

$$f(x) = \sum f(x_j)\phi_j^{(n)}(x)$$

set of nodal points $x_j^{(n)}$

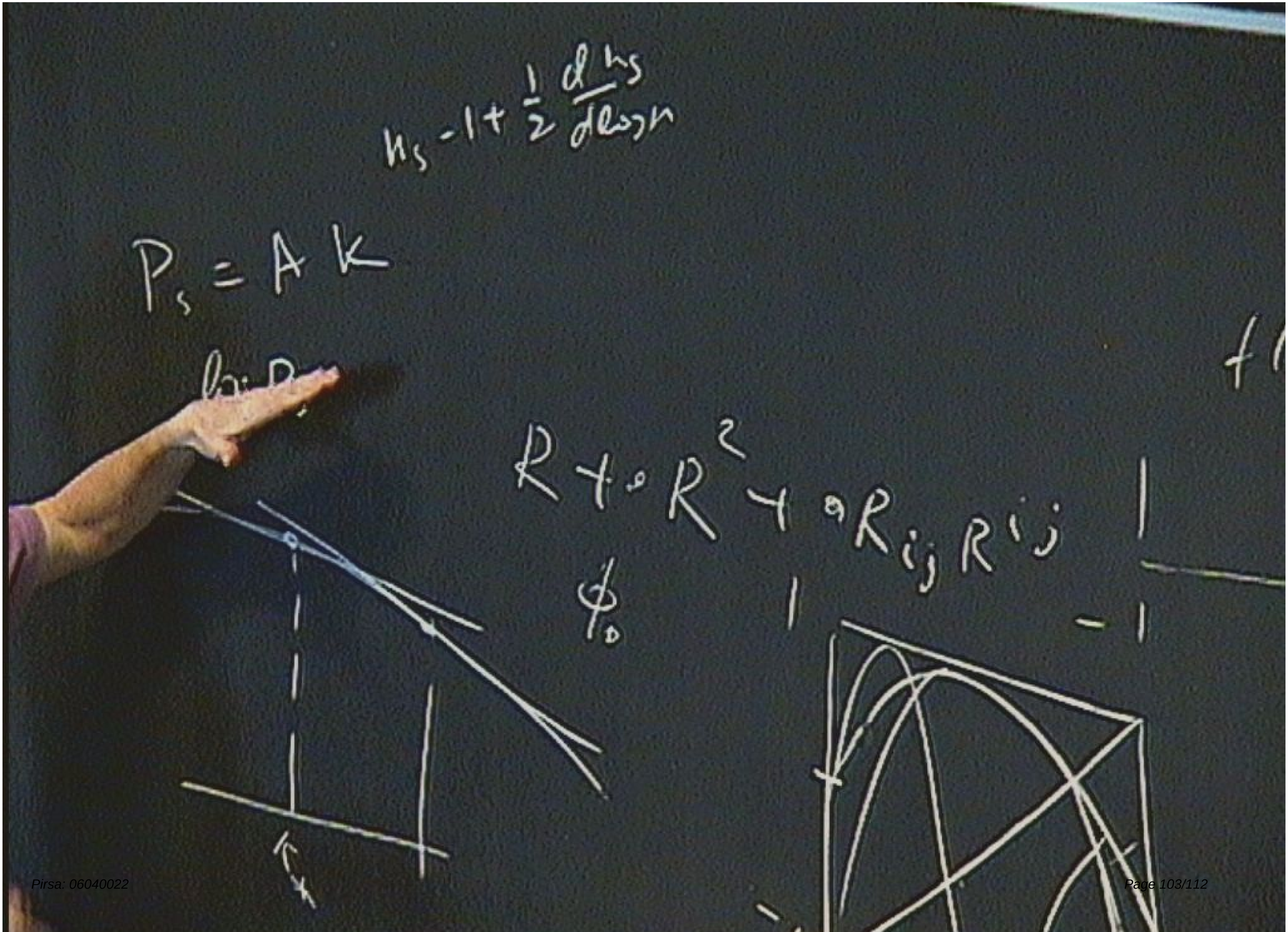
Variations

$$f(x) = H, \log H, \epsilon, \log \epsilon, P_s, P_t$$

$$x = N, \log k$$

Trajectories cf.

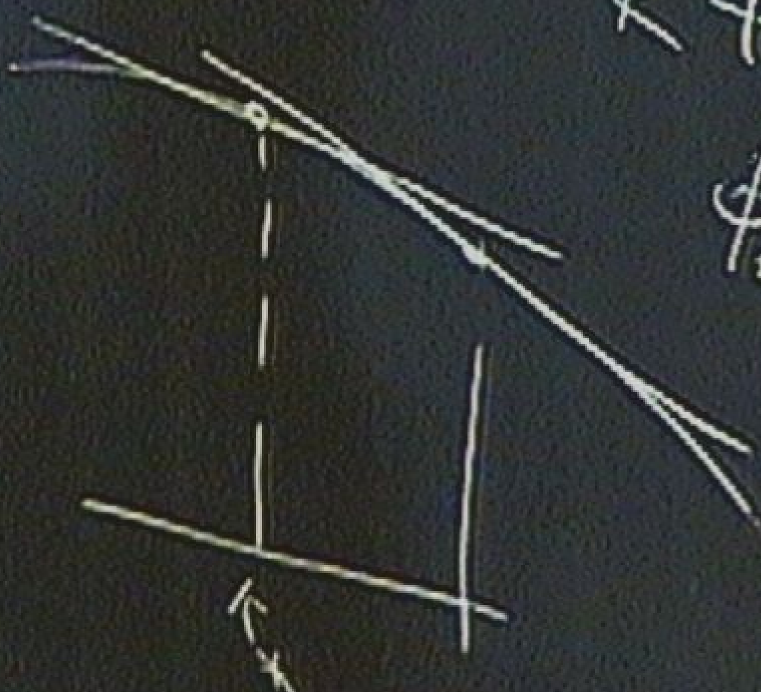
WMAP1+BO3+CBI+DASI+VSA+Acbar+Maxima+SDSS+2dF


$n_s - 1 + \frac{1}{2}\frac{d\, n_s}{d \log n}$
$P_s = A K$
$R + a R^2 + a R_{ij} R^{ij}$
ϕ_0

$n_s - 1 + \frac{1}{2}\frac{d\, n_s}{d\log k}$

$P_s = A k$

$\log P_s$



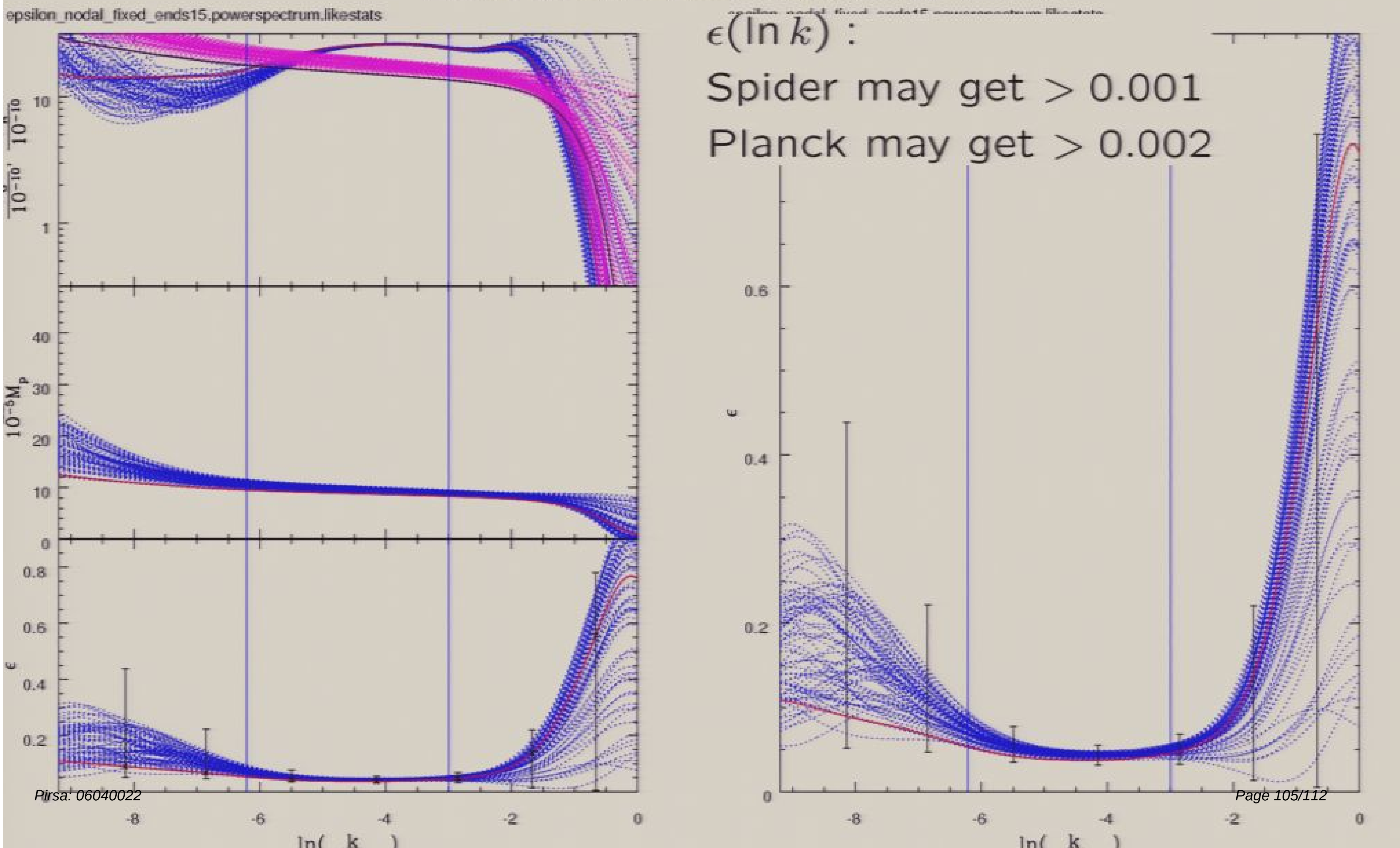
$R + a R^2 + a R_{ij} R^{ij}$

$\phi_0 \qquad 1 \qquad -1$

$f($

$\epsilon(\ln k)$ reconstructed from CMB+LSS data using Chebyshev expansion (order 15 nodal points) and Markov Chain Monte Carlo Method. T/S consistency function is imposed

Probe of CMB+LSS window only 1- folds



Top-down approach:
no priors

"Best fit" model is not usual:

features in the potential
suppression of scalar mode at large scales
large tensor mode
mutually (almost) compensated features in

$$\left(\frac{\Delta T}{T}\right)^2_{tot} = \left(\frac{\Delta T}{T}\right)^2_s + \left(\frac{\Delta T}{T}\right)^2_t$$

Bottom-up:
personal priors

Non-vanishing probability

Top-down approach:
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Bottom-up:
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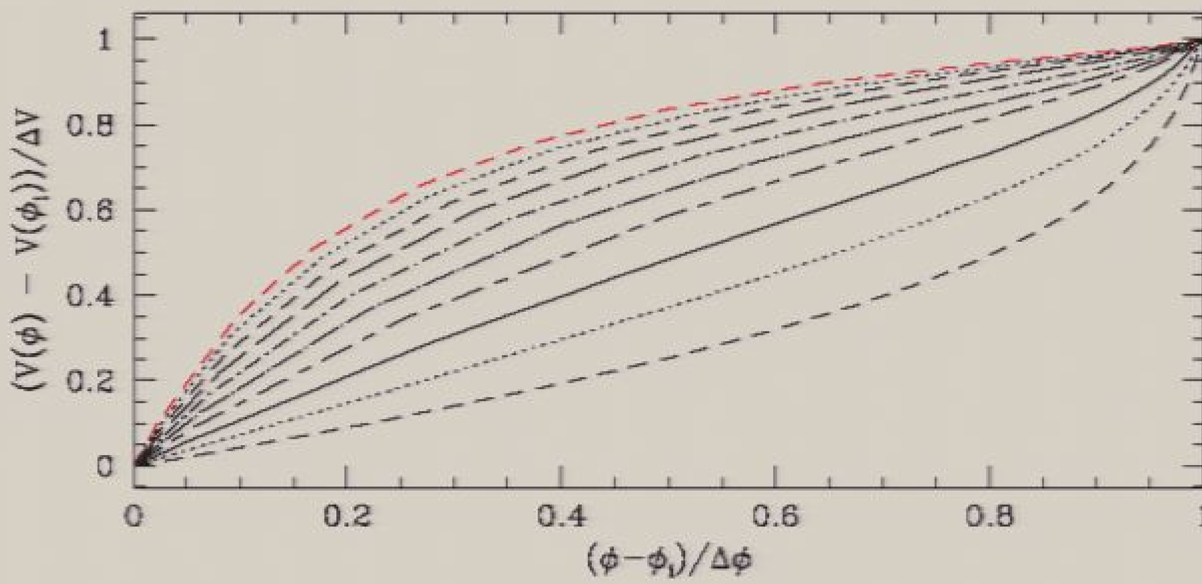
Non-vanishing probability

Degeneracy of the Potential Reconstruction

known $P_s(k) \rightarrow$ reconstruct $V(\phi)$

$$P_s(k) = \frac{8\pi H^4}{M_p^4 H'^2}$$

$$V(\phi) = \frac{M_p^4}{32\pi^2}\left(\frac{12\pi}{M_p^2}H^2 - H'^2\right)$$



$$\phi - \phi_0 = \frac{M_p^2}{2}\int_{\ln k_0}^{\ln k} d\ln k' \frac{\sqrt{P_s(k')}}{H^2(k')}\frac{dH}{d\ln k'}$$

$$\frac{dH}{d\log k} = \frac{H^3}{H^2 - \pi M_p^2 P_s(k)}$$

Degeneracy is lifted by fixing $P_{GW} = \frac{H_*^2}{M_p^2}$

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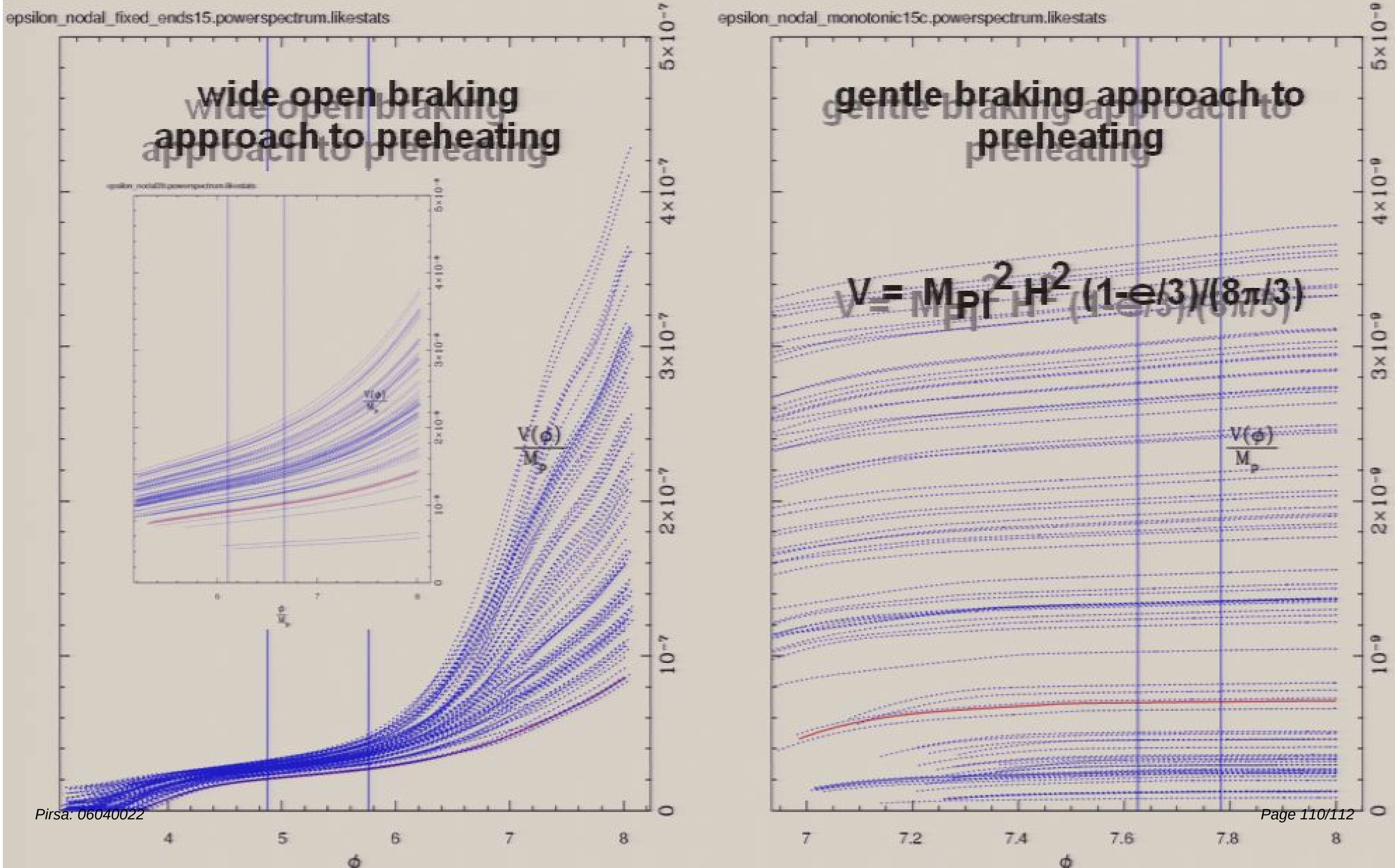
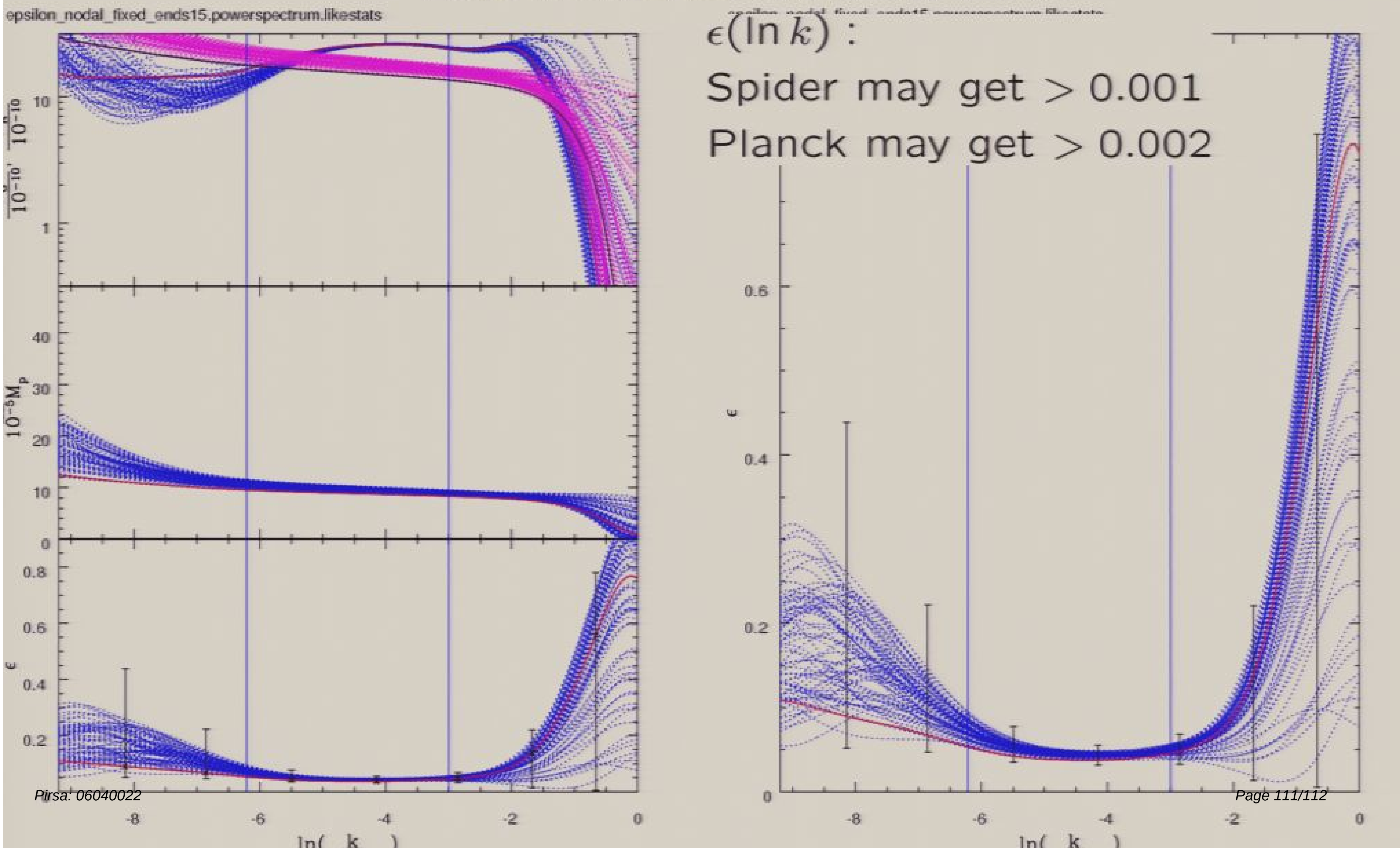
Bottom-up:
personal priors

Non-vanishing probability

V(f) reconstructed from CMB+LSS data using Chebyshev expansions **(uniform order 15 nodal point)** cf. **(uniform order 3 nodal point)** cf. **(monotonic order 15 nodal point)** and Markov Chain Monte Carlo methods...



$\epsilon(\ln k)$ reconstructed from CMB+LSS data using Chebyshev expansion (order 15 nodal points)
and Markov Chain Monte Carlo Method. T/S consistency function is imposed
Probe of CMB+LSS window only 1- folds



$\epsilon(\ln k)$:

Spider may get > 0.001

Planck may get > 0.002

Top-down approach:
no priors

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$$\left(\frac{\Delta T}{T}\right)^2_{tot} = \left(\frac{\Delta T}{T}\right)^2_s + \left(\frac{\Delta T}{T}\right)^2_t$$

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Non-vanishing probability