Universe without Expansion

NATURE | NEWS

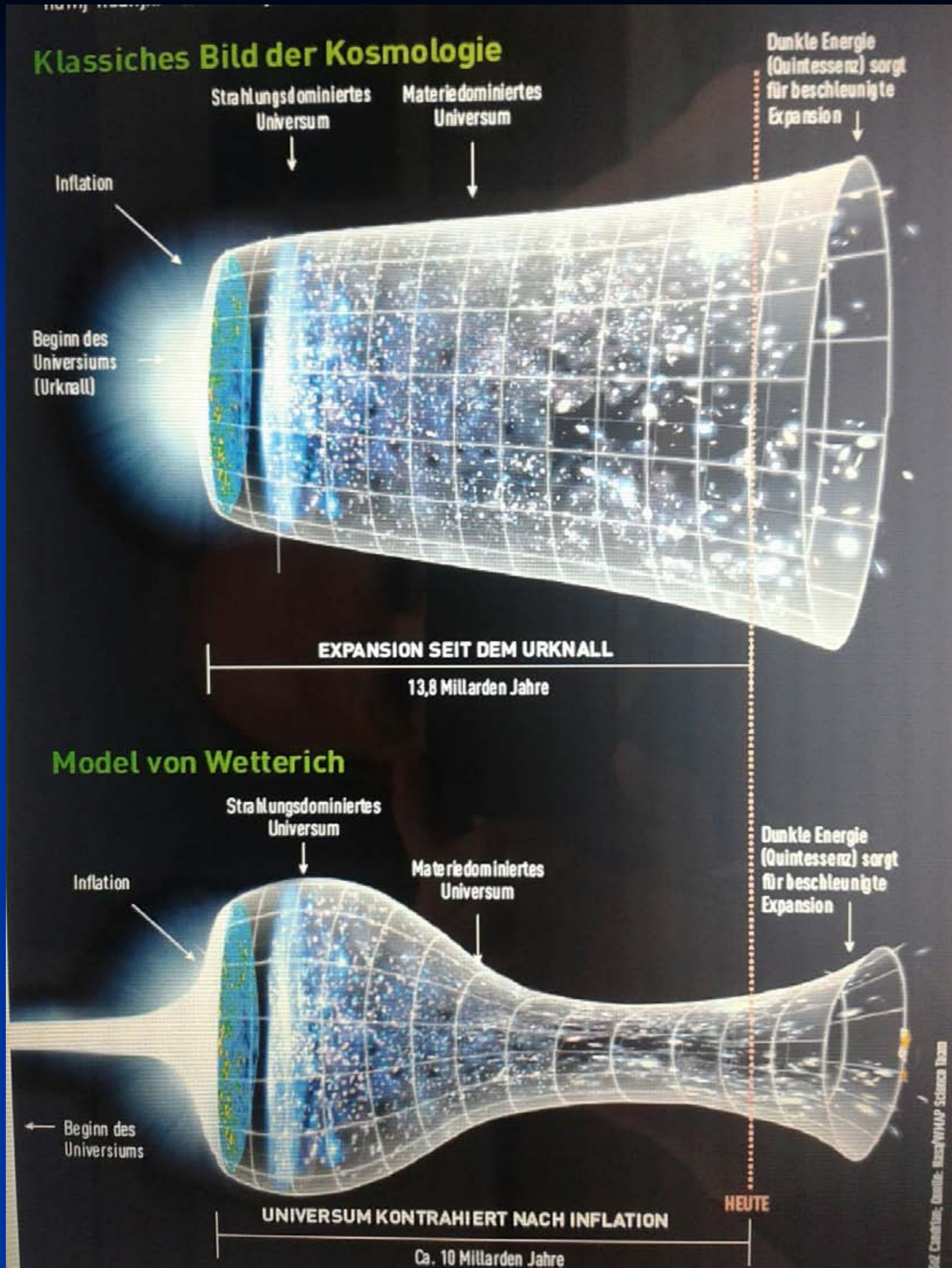
Cosmologist claims Universe may not be expanding

Particles' changing masses could explain why distant galaxies appear to be rushing away.

Jon Cartwright 16 July 2013

German physicist stops Universe

25.07.2013



Sonntagszeitung
Zuerich
Laukenmann

The Universe is shrinking

The Universe is shrinking …

while Planck mass and particle masses are increasing

Redshift

instead of redshift due to expansion :

smaller frequencies have been emitted in the past, because electron mass was smaller !

What is increasing ?

Ratio of distance between galaxies
over size of atoms !

atom size constant : expanding geometry

alternative : shrinking size of atoms

general idea not new : Hoyle, Narlikar,…

Different pictures of cosmology

- same physical content can be described by different pictures
- related by field – redefinitions ,
  e.g. Weyl scaling , conformal scaling of metric
- which picture is usefull ?

Two models of “ Variable Gravity Universe “

- Scalar field coupled to gravity
- Effective Planck mass depends on scalar field
- Simple scalar potential :

  quadratic potential (model A)

  cosmological constant (model B)
- Nucleon and electron mass proportional to Planck mass
- Neutrino mass has different dependence on scalar field

cosmological scalar field (cosmon)

- scalar field is crucial ingredient
- particle masses proportional to scalar field – similar to Higgs field
- particle masses increase because value of scalar field increases
- scalar field plays important role in cosmology

Simplicity

simple description of all cosmological epochs

natural incorporation of Dark Energy :

- inflation
- Early Dark Energy
- present Dark Energy dominated epoch

Cosmon inflation

Unified picture of inflation and dynamical dark energy

Cosmon and inflaton are the same scalar field

Quintessence

Dynamical dark energy ,

generated by scalar field (cosmon)

C.Wetterich,Nucl.Phys.B302(1988)668, 24.9.87
P.J.E.Peebles,B.Ratra,ApJ.Lett.325(1988)L17, 20.10.87

Prediction :

homogeneous dark energy influences recent cosmology

- of same order as dark matter -

Original models do not fit the present observations

…. modifications

(different growth of neutrino mass)

Model A

- Inflation : Universe expands
- Radiation : Universe shrinks
- Matter : Universe shrinks
- Dark Energy : Universe expands

Model B

- Inflation : Universe expands
- Radiation : Static Minkowski space
- Matter : Universe expands
- Dark Energy : Universe expands

Varying particle masses

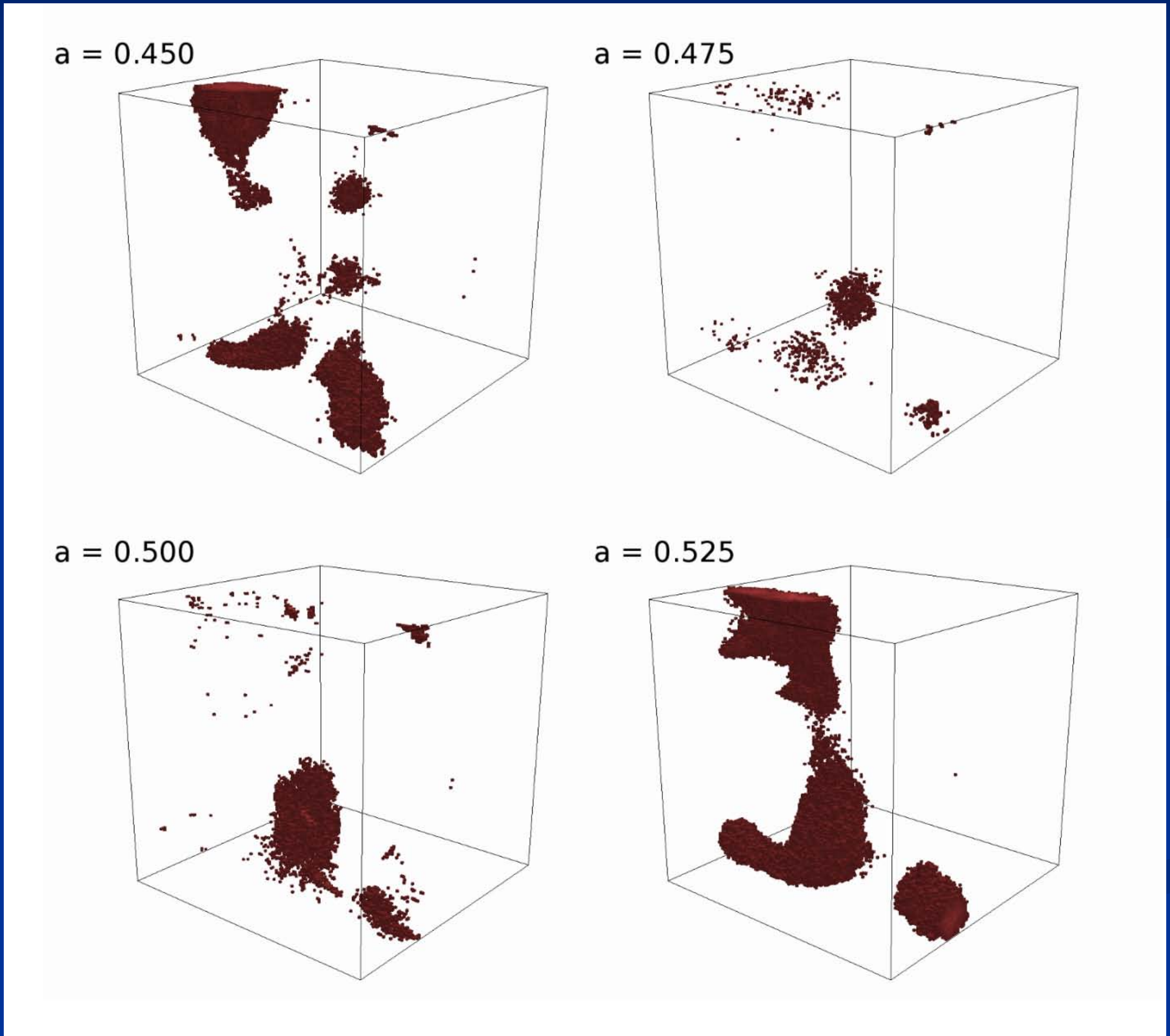
- For both models all particle masses (except for neutrinos) are proportional to χ .
- Ratios of particle masses remain constant.
- Compatibility with observational bounds on time dependence of particle mass ratios.
- Neutrino masses show stronger increase with χ , such that ratio neutrino mass over electron mass grows .

Compatibility with observations

- Both models lead to same predictions for radiation, matter , and Dark Energy domination, despite the very different expansion history
- Different inflation models:

  A: n=0.97, r=0.13   B: n=0.95, r=0.04
- Almost same prediction for radiation, matter, and Dark Energy domination as ΛCDM
- Presence of small fraction of Early Dark Energy
- Large neutrino lumps

oscillating neutrino lumps



Einstein frame

- Weyl scaling maps variable gravity model to Universe with fixed masses and standard expansion history.
- Standard gravity coupled to scalar field.
- Only neutrino masses are growing.

Model A

$$S = \int_x \sqrt{g}\left\{-\frac{1}{2}\chi^2 R + \frac{1}{2}K(\chi)\partial^\mu\chi\partial_\mu\chi + V(\chi)\right\}$$

$$V(\chi) = \mu^2\chi^2$$

$\mu = 2 \cdot 10^{-33}$ eV

$$K(\chi) = \frac{4}{\tilde{\alpha}^2}\frac{m^2}{m^2+\chi^2} + \frac{4}{\alpha^2}\frac{\chi^2}{m^2+\chi^2} - 6$$

K interpolates between two different constants for small and large χ .

No tiny dimensionless parameters
(except gauge hierarchy)

- one mass scale $\mu = 2 \cdot 10^{-33}$ eV
- Planck mass does not appear
- **m/μ** around 100 -1000
- Planck mass grows large dynamically

variable gravity

$$S = \int_x \sqrt{g} \left\{ -\frac{1}{2}\chi^2 R + \frac{1}{2} K(\chi) \partial^\mu \chi \partial_\mu \chi + V(\chi) \right\}$$

Scalar field χ plays role of the Planck mass.
Its value increases with time.
Gravitational (Newton's) "constant" decreases with time : "gravity gets weaker" .
With increasing particle masses : gravitational attraction between massive particles remains constant.

Scaling solutions

(for constant K)

$$H = b\mu \ , \ \chi = \chi_0 \exp(c\mu t).$$

Four different scaling solutions for inflation, radiation domination, matter domination and Dark Energy domination

Slow Universe

$$H = b\mu \ , \ \chi = \chi_0 \exp(c\mu t).$$

$$\mu = 2 \cdot 10^{-33} \text{ eV}$$

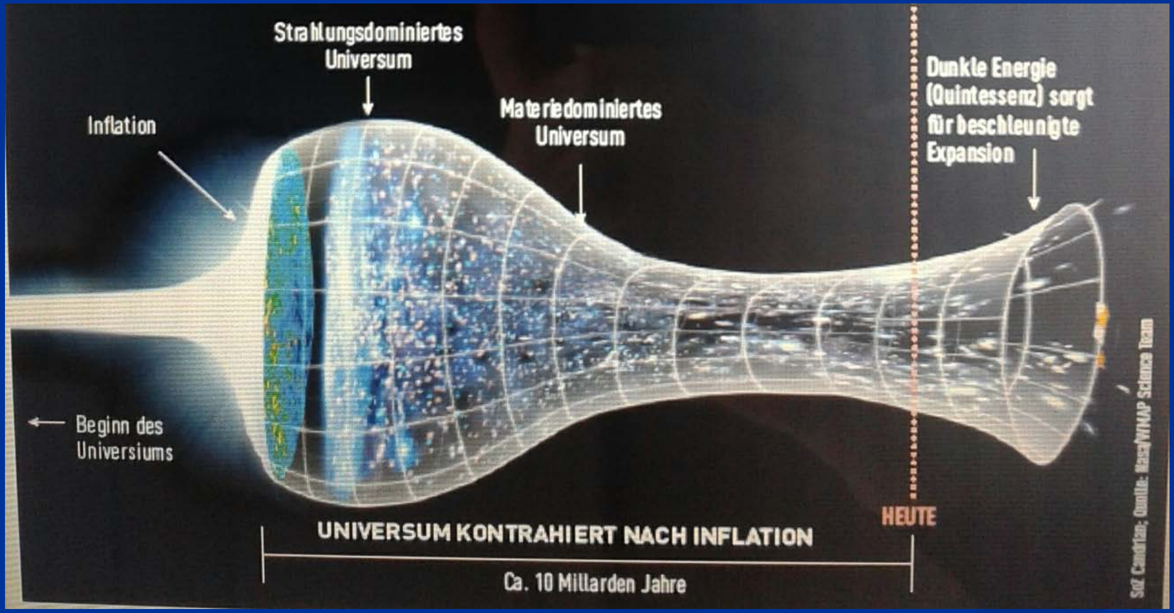
Expansion or shrinking always slow , characteristic time scale of the order of the age of the Universe : $t_{ch} \sim \mu^{-1} \sim$ 10 billion years !

Hubble parameter of the order of present Hubble parameter for all times , including inflation and big bang !

Slow increase of particle masses !

Slow Universe

$$H = b\mu \ , \ \chi = \chi_0 \exp(c\mu t).$$



Hot plasma ?

- Temperature in radiation dominated Universe : $T \sim \chi^{1/2}$ smaller than today
- Ratio temperature / particle mass : $T / m_p \sim \chi^{-1/2}$ larger than today
- T/m_p counts ! This ratio decreases with time.

- Nucleosynthesis , CMB emission as in standard cosmology !

Scalar field equation:

additional force from R counteracts potential gradient : increasing χ !

$$\Gamma = \int d^4x \sqrt{g} \left\{ -\frac{1}{2} F(\chi) R + \frac{1}{2} K(\chi) \partial^\mu \chi \partial_\mu \chi + V(\chi) \right\}$$

$$-D_\mu (K \partial^\mu \chi) + \frac{1}{2} \frac{\partial K}{\partial \chi} \partial^\mu \chi \partial_\mu \chi = -\frac{\partial V}{\partial \chi} + \frac{1}{2} \frac{\partial F}{\partial \chi} R + q_\chi$$

$$K(\ddot{\chi} + 3H\dot{\chi}) + \frac{1}{2} \frac{\partial K}{\partial \chi} \dot{\chi}^2 = -\frac{\partial V}{\partial \chi} + \frac{1}{2} \frac{\partial F}{\partial \chi} R + q_\chi$$

Incoherent contribution to scalar field equation

$$K(\ddot{\chi} + 3H\dot{\chi}) + \frac{1}{2}\frac{\partial K}{\partial \chi}\dot{\chi}^2 = -\frac{\partial V}{\partial \chi} + \frac{1}{2}\frac{\partial F}{\partial \chi}R + q_\chi$$

$$q_\chi = -\frac{\partial \ln m_p}{\partial \chi}(\rho - 3p)$$

if particle mass proportional to χ :

$$q_\chi = -\frac{\rho - 3p}{\chi} = -\frac{m_p}{\chi}n_p$$

Incoherent contribution to scalar field equation

$$K(\ddot{\chi} \; + \; 3H\dot{\chi}) + \frac{1}{2}\frac{\partial K}{\partial \chi}\dot{\chi}^2 = -\frac{\partial V}{\partial \chi} + \frac{1}{2}\frac{\partial F}{\partial \chi}R + q_\chi$$

$$q_\chi = -\frac{\partial \ln m_p}{\partial \chi}(\rho - 3p)$$

particles couple to metric :
energy momentum tensor
massive particles couple to χ :
incoherent term q_χ

Modified Einstein equation

New term with derivatives of scalar field

gravitational field eq.

$$\chi^2\left(R_{\mu\nu}-\frac{1}{2}Rg_{\mu\nu}\right)+(\chi^2)_{;\rho}^{;\rho}g_{\mu\nu}-(\chi^2)_{;\mu\nu}$$

$$+\frac{1}{2}K\partial^\rho\chi\partial_\rho\chi g_{\mu\nu}-K\partial_\mu\chi\partial_\nu\chi+Vg_{\mu\nu}=T_{\mu\nu}$$

$\Rightarrow$

$$\chi^2R=3(\chi^2)_{;\mu}^{;\mu}+K\partial^\mu\chi\partial_\mu\chi+4V-T_\mu^\mu$$

Curvature scalar and Hubble parameter

Robertson Walker metric

$$\chi^2 R = 4V - (K+6)\dot{\chi}^2 - 6\chi\ddot{\chi} - 18H\chi\dot{\chi} - T^{\mu}_{\mu}$$

$$(\chi^2)_{;\rho}^{;\rho} = -2\dot{\chi}^2 - 2\chi\ddot{\chi} - 6H\chi\dot{\chi}$$

0-0-component

$$3\chi^2 H^2 + 6H\chi\dot{\chi} = \frac{1}{2}K\dot{\chi}^2 + V + T_{00}$$

Scaling solutions

(for constant K)

$$H = b\mu \;,\; \chi = \chi_0 \exp(c\mu t).$$

Four different scaling solutions for inflation, radiation domination, matter domination and Dark Energy domination

Scalar dominated epoch, inflation

$$c = \pm \frac{2}{\sqrt{(K+6)(3K+16)}}$$

$$K > -\frac{16}{3}.$$

$$\begin{aligned} b &= \pm\sqrt{\frac{1}{3} + \frac{K+6}{6}c^2} - c \\ &= \pm\frac{K+4}{\sqrt{(K+6)(3K+16)}} = \frac{K+4}{2}c. \end{aligned}$$

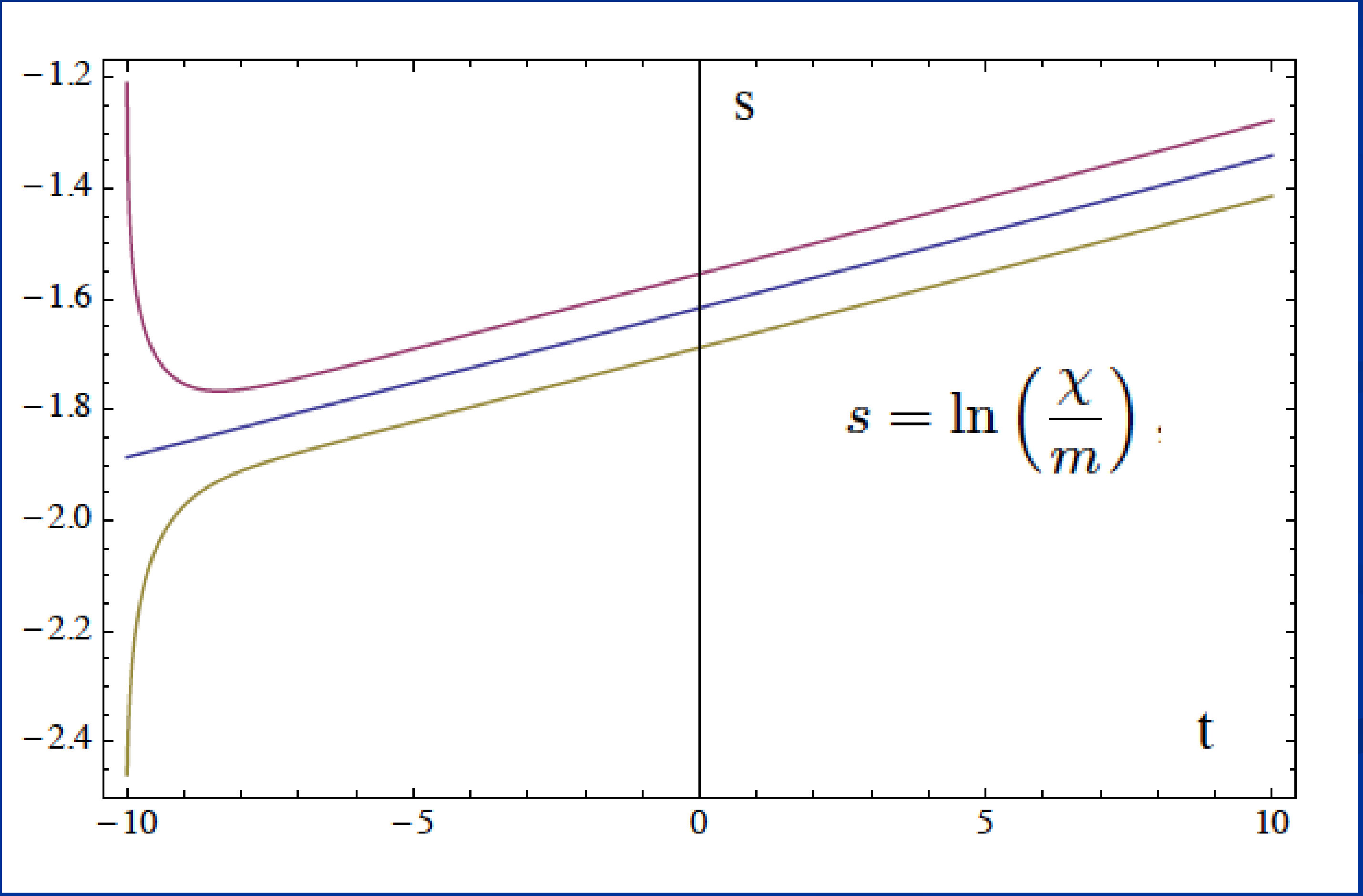
Universe expands for K > -4, shrinks for K < -4.

No big bang singularity

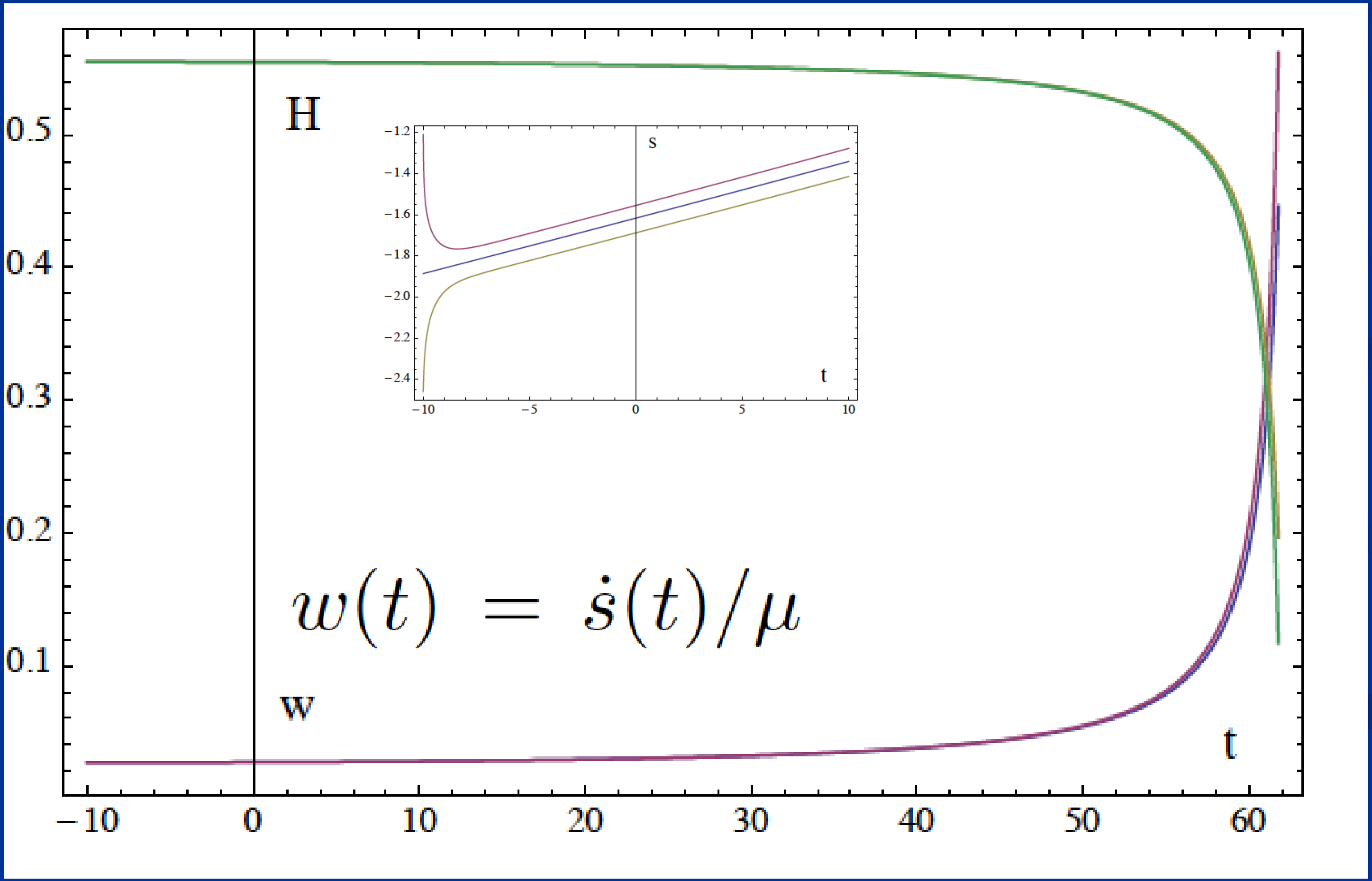
$$H = b\mu \ , \ \chi = \chi_0 \exp(c\mu t).$$

$$R_{\mu\nu\rho\sigma} = b^2\mu^2(g_{\mu\rho}g_{\nu\sigma} - g_{\mu\sigma}g_{\nu\rho})$$

Scaling solution is attractive



Scaling solution ends when K gets closer to -6



Radiation domination

$$c = \frac{2}{\sqrt{K+6}}$$

$$b = -\frac{c}{2}.$$

Universe shrinks !

$$T_{00} = \rho = \bar{\rho}\mu^2\chi^2,$$

$$\bar{\rho}_r = -3\frac{K+5}{K+6}.$$

$$K < -5$$

$$H = b\mu \ , \ \chi = \chi_0 \exp(c\mu t).$$

Early Dark Energy

Energy density in radiation increases , proportional to cosmon potential

$$T_{00} = \rho = \bar{\rho}\mu^2\chi^2$$

$$V(\chi) = \mu^2\chi^2$$

fraction in early dark energy

$$\Omega_h = \frac{\rho_h}{\rho_r + \rho_h} = \frac{1}{K+6} = \frac{4}{\alpha^2}$$

requires large α >10

$$K(\chi) = \frac{4}{\tilde{\alpha}^2}\frac{m^2}{m^2+\chi^2} + \frac{4}{\alpha^2}\frac{\chi^2}{m^2+\chi^2} - 6$$

scaling of particle masses

mass of electron or nucleon is proportional to variable Planck mass χ !

effective potential for Higgs doublet h

$$\tilde{V}_h = \frac{1}{2}\lambda_h(\tilde{h}^\dagger\tilde{h} - \epsilon_h\chi^2)^2$$

cosmon coupling to matter

$$K(\ddot{\chi} + 3H\dot{\chi}) + \frac{1}{2}\frac{\partial K}{\partial \chi}\dot{\chi}^2 = -\frac{\partial V}{\partial \chi} + \frac{1}{2}\frac{\partial F}{\partial \chi}R + q_\chi$$

$q_\chi = -(\rho - 3p)/\chi$

Matter domination

$$c = \sqrt{\frac{2}{K+6}},$$

$$b = -\frac{1}{3}\sqrt{\frac{2}{K+6}} = -\frac{1}{3}c,$$

$$T_{00} = \rho = \bar{\rho}\mu^2\chi^2,$$

$$\bar{\rho}_m = -\frac{2(3K+14)}{3(K+6)}$$

Universe shrinks !

$$K < -14/3$$

Neutrino mass

$$M_\nu = M_D M_R^{-1} M_D^T + M_L$$

$$M_L = h_L \gamma \frac{d^2}{M_t^2}$$

seesaw and cascade mechanism

triplet expectation value ~ doublet squared

$$m_\nu = \frac{h_\nu^2 d^2}{m_R} + \frac{h_L \gamma d^2}{M_t^2}$$

omit generation structure

Neutrino mass

assume that singlet scale has not yet reached scaling limit $\sim \chi$

$$\frac{M_{B-L}(\chi)}{\chi} = F_{B-L} - G_{B-L} \ln\left(\frac{\chi^2}{\mu^2}\right)$$

$$m_\nu \sim \frac{\tilde{h}^2}{M_{B-L}} \sim \frac{\epsilon_h \chi^2}{M_{B-L}(\chi)}$$

Dark Energy domination

neutrino masses scale differently from electron mass

$$m_\nu = \bar{c}_\nu \chi^{2\tilde{\gamma}+1}$$

$$\chi q_\chi = -(2\tilde{\gamma}+1)(\rho_\nu - 3p_\nu)$$

$$\frac{\rho_\nu}{\chi^2} = \bar{\rho}_\nu \mu^2$$

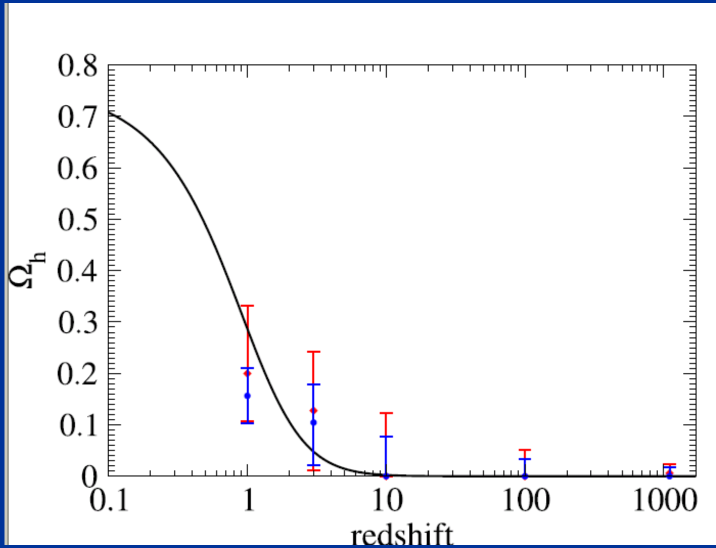
$$b = \frac{1}{3}(2\tilde{\gamma}-1)c.$$

new scaling solution. not yet reached.

at present : transition period

Why now problem

Why does fraction in Dark Energy increase in present cosmological epoch ,
and not much earlier or much later ?



neutrinos become non-relativistic at $z = 5$

connection between dark energy and neutrino properties

$$[\rho_h(t_0)]^{\frac{1}{4}} = 1.27 \left(\frac{\gamma m_\nu(t_0)}{eV} \right)^{\frac{1}{4}} 10^{-3} eV$$

present dark energy density given by neutrino mass

present equation of state given by neutrino mass !

$$w_0 \approx -1 + \frac{m_\nu(t_0)}{12\text{eV}}$$

Model B

$$\Gamma = \int d^4x\sqrt{g}\left\{-\frac{1}{2}F(\chi)R + \frac{1}{2}K(\chi)\partial^\mu\chi\partial_\mu\chi + V(\chi)\right\}$$

$$F(\chi) = \chi^2 + m^2\ ,\ V(\chi) = \bar{\lambda}_c$$

$$\frac{\bar{\lambda}_c}{M^4} \approx 7\cdot 10^{-121}\ ,\ (\bar{\lambda}_c)^{1/4} = 2\cdot 10^{-3}eV$$

$$K + 6 = \frac{16}{\tilde{\alpha}^2}\frac{m^2}{m^2+\chi^2} + \frac{16}{\alpha^2}\frac{\chi^2}{m^2+\chi^2}$$

Radiation domination

Flat static Minkowski space ! H=0 !

$$\chi = 2\sqrt{\frac{\lambda_c}{K+6}}(t+t_0).$$

exact regular solution ! (constant K)

constant energy density

$$\frac{\bar{\rho}}{\bar{\lambda}_c} = -\frac{3(K+2)}{K+6}.$$

$$K < -2.$$

Matter domination

$$H = \frac{1}{3}\dot{s}.$$

$$\dot{\chi}^2 = \frac{2}{K+6}\bar{\lambda}_c,$$

$$\frac{14-3K}{6}\dot{\chi}^2 = \bar{\lambda}_c + \bar{\rho}$$

$$\frac{\bar{\rho}}{\lambda_c} = -\frac{2(2+3K)}{3(K+6)}$$

$$K < -\frac{2}{3}$$

Observations

simplest description in Einstein frame

Weyl scaling

$$g_{\mu\nu} = \frac{M^2}{F(\chi)} g'_{\mu\nu}.$$

$$\Gamma = \int d^4x \sqrt{g} \left\{ -\frac{M^2}{2} R + \frac{k^2}{2} \partial^\mu \varphi \partial_\mu \varphi + M^4 \exp\left(-\frac{\alpha\varphi}{M}\right) \right\}$$

$$k^2 = \frac{\alpha^2 (K+6)}{4}.$$

$$\varphi = \frac{2M}{\alpha} \ln\left(\frac{\chi}{\mu}\right)$$

(A)

Kinetial

$$k^2(\varphi) = \left(\frac{\alpha^2}{\tilde{\alpha}^2} - 1\right) \frac{m^2}{m^2 + \mu^2 \exp(\alpha\varphi/M)} + 1.$$

scalar σ with
standard normalization

$$\frac{d\sigma}{d\varphi} = k(\varphi).$$

$$\Gamma = \int d^4x \sqrt{g} \left\{ -\frac{M^2}{2} R + \frac{k^2}{2} \partial^\mu \varphi \partial_\mu \varphi + M^4 \exp\left(-\frac{\alpha\varphi}{M}\right) \right\}$$

$$k^2 = \frac{\alpha^2(K+6)}{4}.$$

Cosmon inflation

Properties of density fluctuations model A

$\tilde{\alpha}$	0.001	0.02	0.1
n	0.975 (0.97)	0.975 (0.97)	0.972 (0.967)
r	0.13 (0.16)	0.13 (0.16)	0.18 (0.2)
$\frac{m}{\mu}$	120 (100)	2400 (2000)	12 000(10 000)

Properties of density fluctuations, model B

$\tilde{\alpha}$	0.24	0.28	0.325
n	0.954 (0.95)	0.95 (0.944)	0.94 (0.936)
r	0.08 (0.12)	0.054 (0.085)	0.027 (0.049)
$\frac{m}{(\bar{\lambda}_c)^{1/4}}$	129 (114)	150 (131)	182 (156)

Growing neutrino quintessence

connection between dark energy and neutrino properties

$$[\rho_h(t_0)]^{\frac{1}{4}} = 1.27 \left(\frac{\gamma m_\nu(t_0)}{eV}\right)^{\frac{1}{4}} 10^{-3} eV$$

present dark energy density given by neutrino mass

present equation of state given by neutrino mass !

$$w_0 \approx -1 + \frac{m_\nu(t_0)}{12\mathrm{eV}}$$

Neutrino cosmon coupling

- realized by dependence of neutrino mass on value of cosmon field

$$\beta(\varphi) = -M \frac{\partial}{\partial \varphi} \ln m_\nu(\varphi)$$

- $\beta \approx 1$: cosmon mediated attractive force between neutrinos has similar strength as gravity

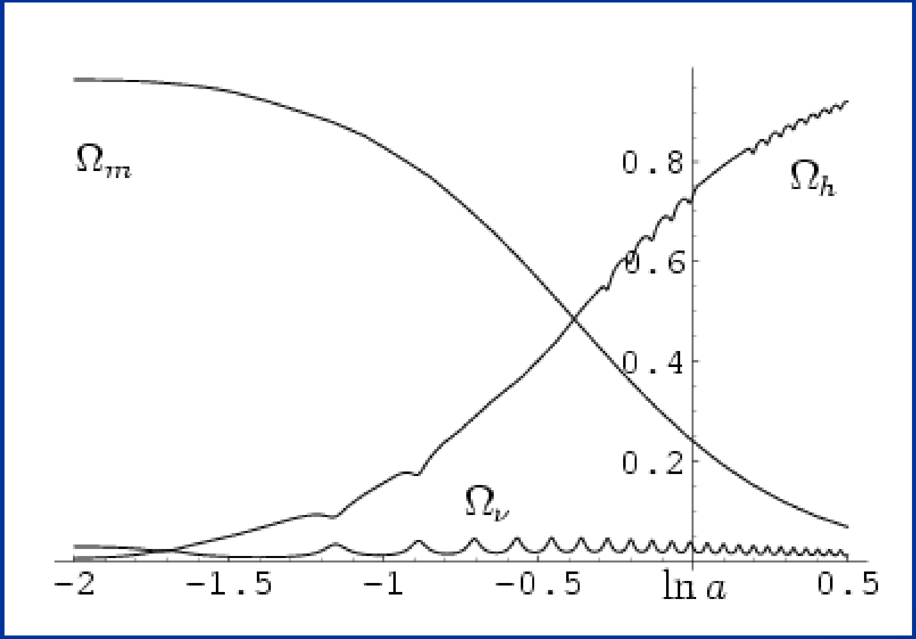
growing neutrinos change cosmon evolution

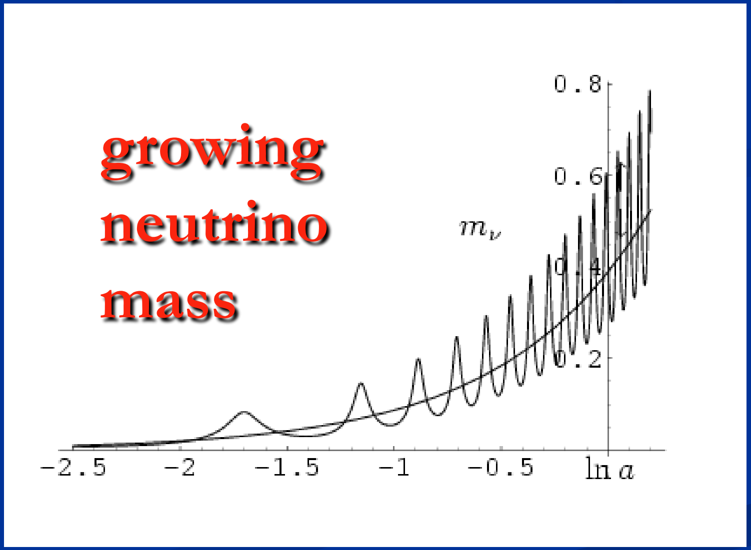
$$\ddot{\varphi} + 3H\dot{\varphi} = -\frac{\partial V}{\partial \varphi} + \frac{\beta(\varphi)}{M}(\rho_\nu - 3p_\nu),$$
$$\beta(\varphi) = -M\frac{\partial}{\partial \varphi}\ln m_\nu(\varphi) = \frac{M}{\varphi - \varphi_t}$$

modification of conservation equation for neutrinos

$$\dot{\rho}_\nu + 3H(\rho_\nu + p_\nu) = -\frac{\beta(\varphi)}{M}(\rho_\nu - 3p_\nu)\dot{\varphi}$$
$$= -\frac{\dot{\varphi}}{\varphi - \varphi_t}(\rho_\nu - 3p_\nu)$$

growing neutrino mass triggers transition to almost static dark energy



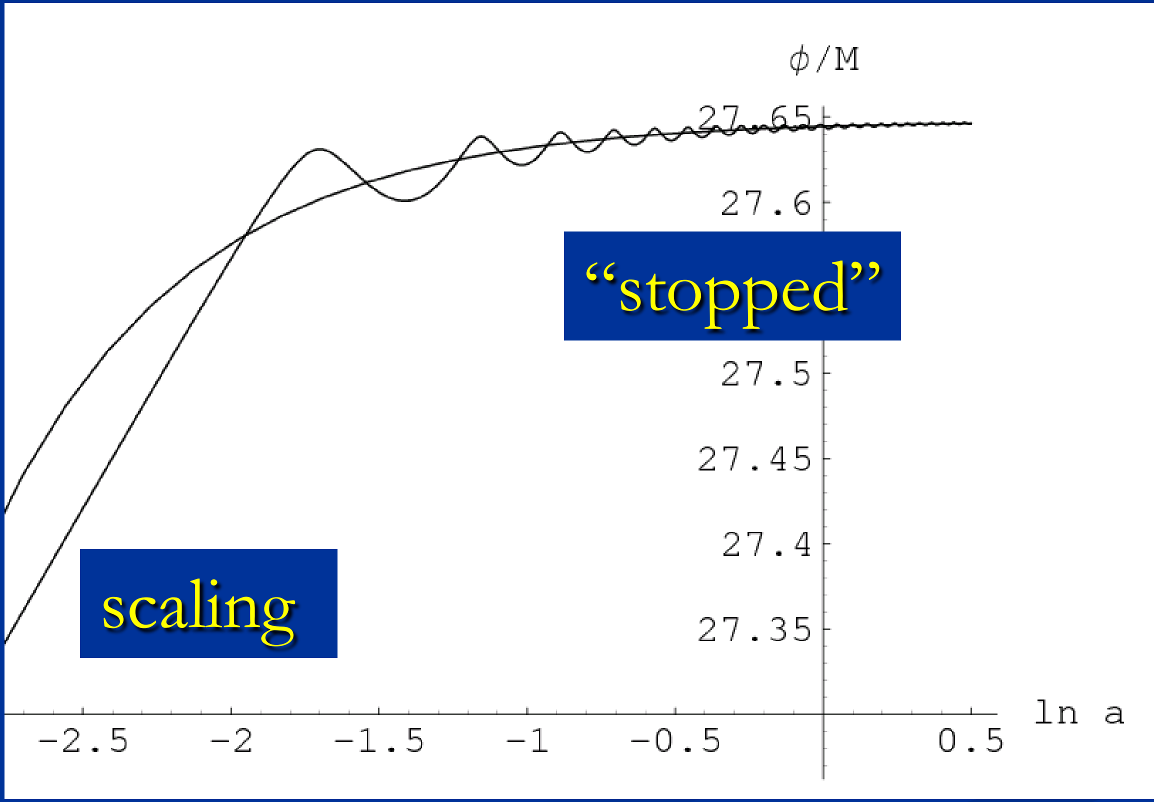


L.Amendola, M.Baldi,…

effective cosmological trigger for stop of cosmon evolution : neutrinos get non-relativistic

- this has happened recently !
- sets scales for dark energy !

cosmon evolution

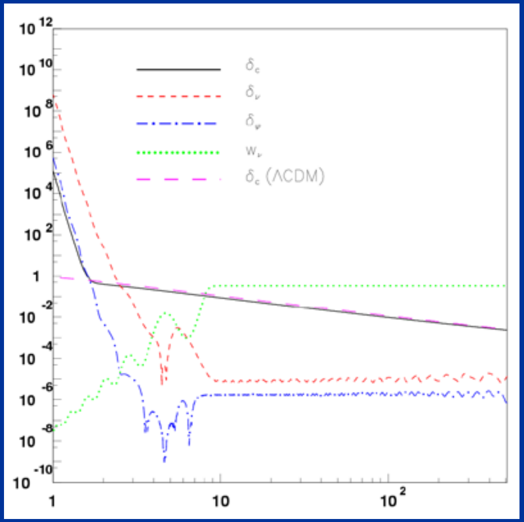


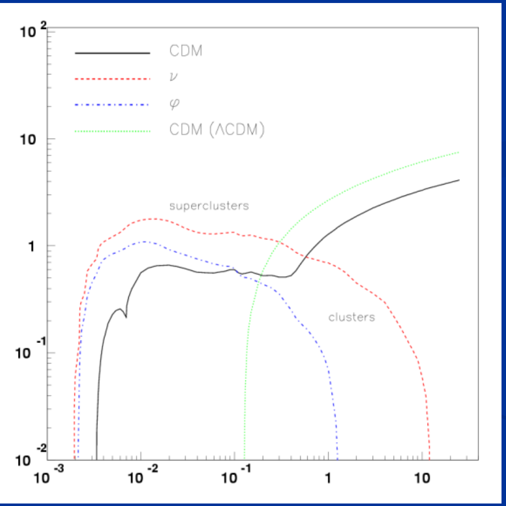
neutrino lumps

neutrino fluctuations

neutrino structures become nonlinear at z~1 for supercluster scales

D.Mota , G.Robbers , V.Pettorino , …





stable neutrino-cosmon lumps exist

N.Brouzakis , N.Tetradis ,… ; O.Bertolami ; Y.Ayaita , M.Weber,…

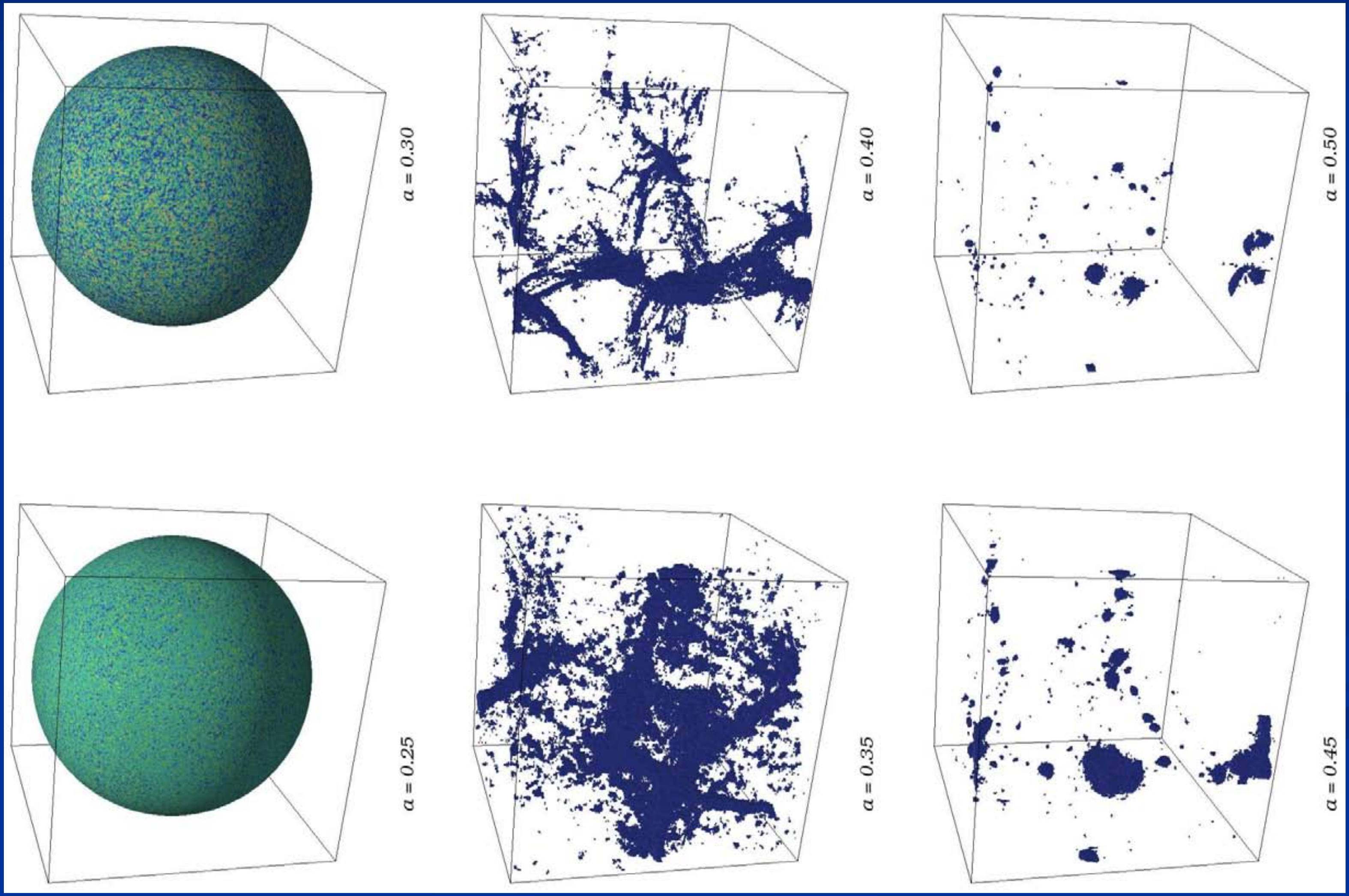
N-body code with fully relativistic neutrinos and backreaction

one has to resolve local value of cosmon field and then form cosmological average;
similar for neutrino density, dark matter and gravitational field

Y.Ayaita,M.Weber,…

Formation of neutrino lumps

Y.Ayaita,M.Weber,…



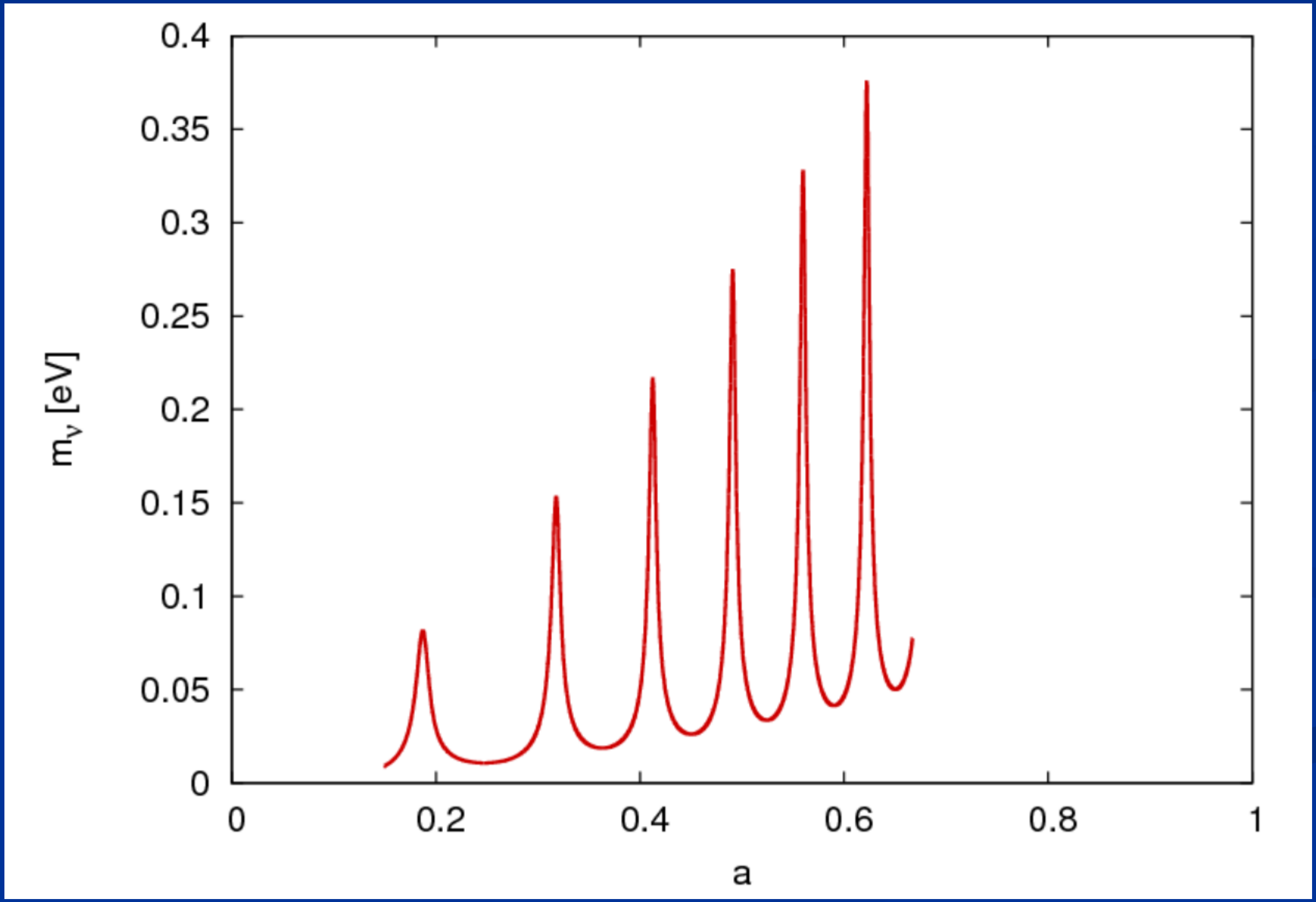
φ - dependent neutrino – cosmon coupling

$$\beta(\varphi) = -M\frac{\partial}{\partial\varphi}\ln m_\nu(\varphi) = \frac{M}{\varphi - \varphi_t}$$

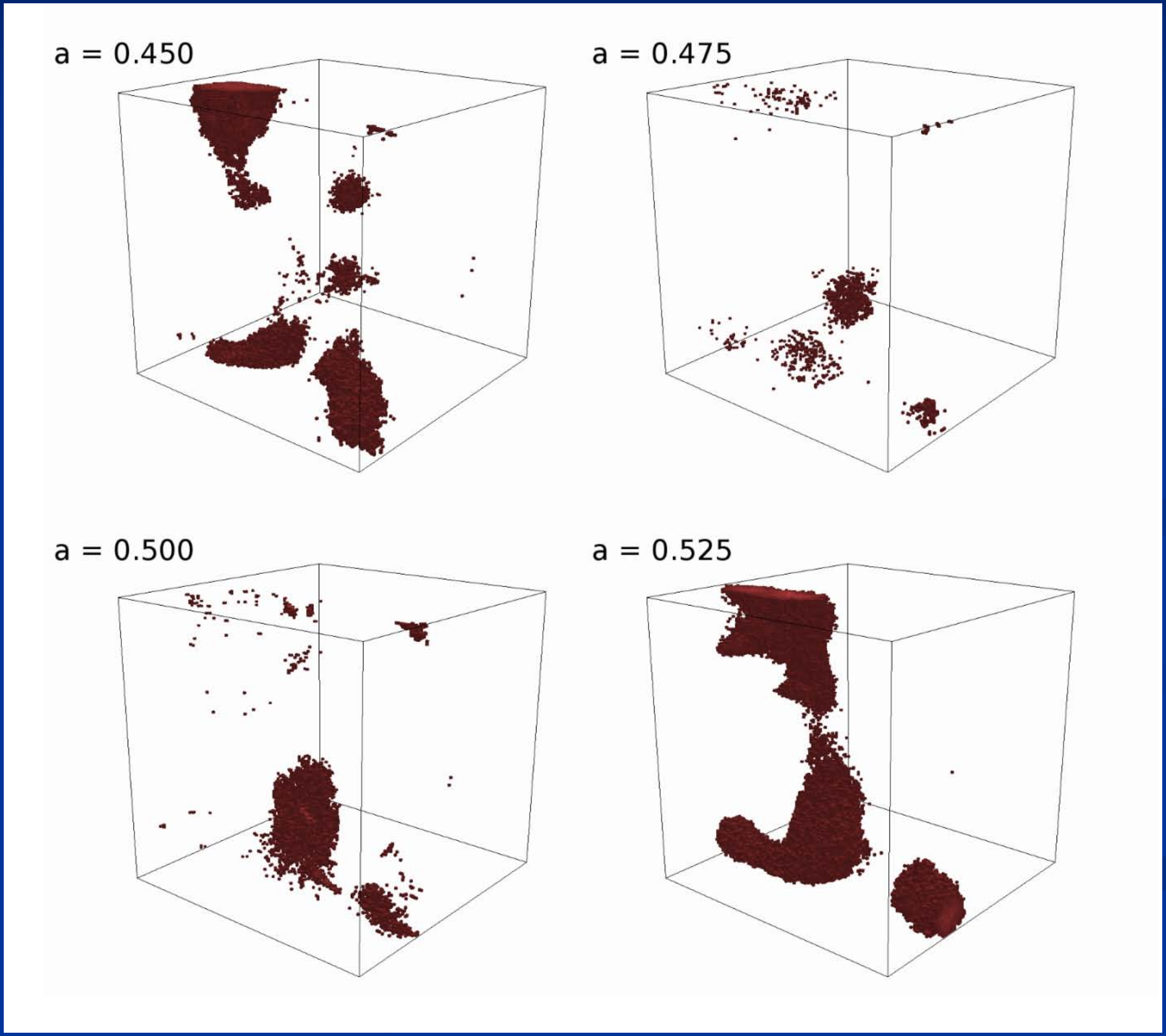
neutrino lumps form and are disrupted by oscillations in neutrino mass

smaller backreaction

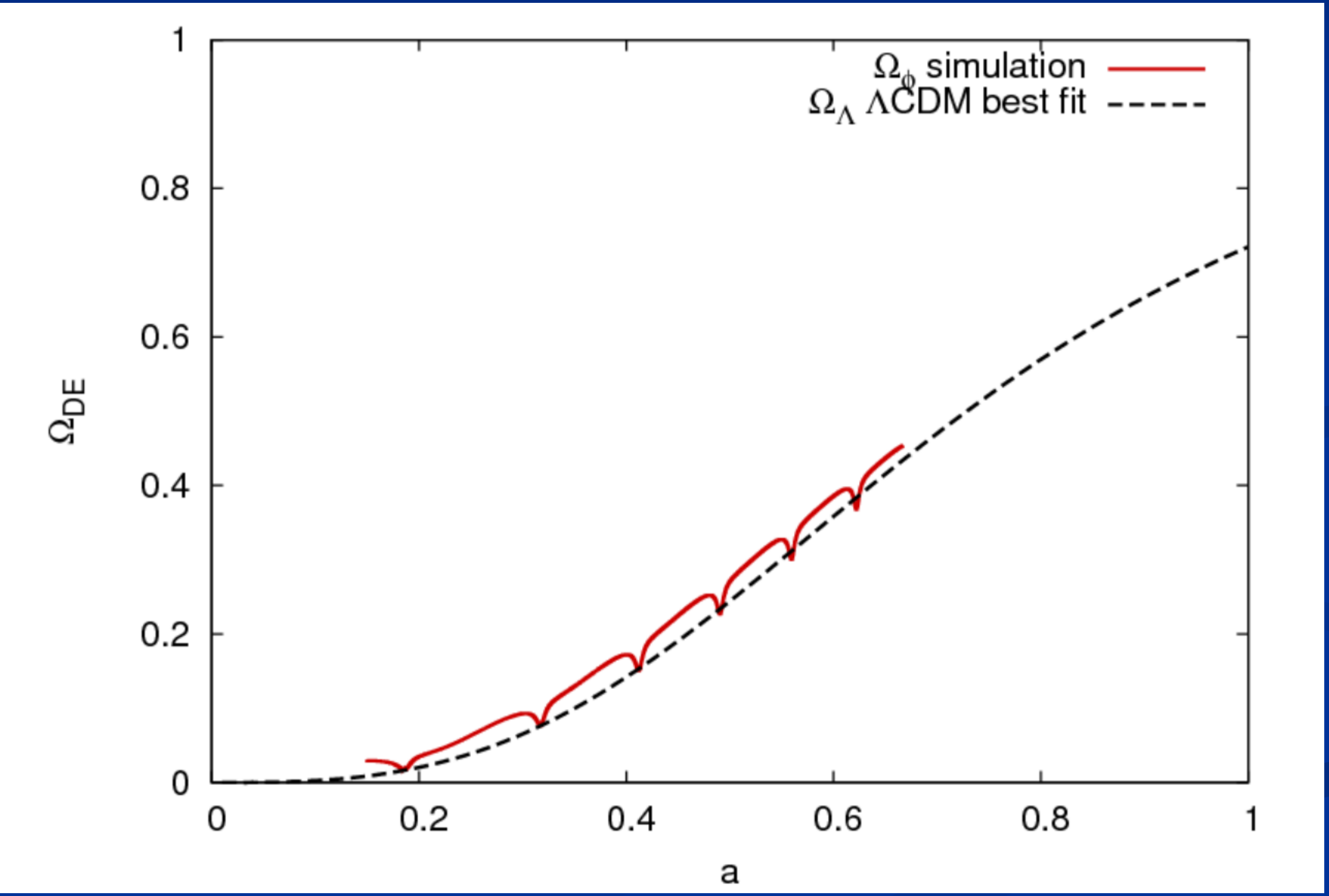
oscillating neutrino mass



oscillating neutrino lumps



small oscillations in dark energy



conclusions

- Variable gravity cosmologies can give a simple and realistic description of Universe
- Compatible with tests of equivalence principle and bounds on variation of fundamental couplings if nucleon and electron masses are proportional to variable Planck mass
- Different cosmon dependence of neutrino mass can explain why Universe makes a transition to Dark Energy domination now
- characteristic signal : neutrino lumps

Cosmon inflation

Kinetial

$$k^2(\varphi) = \left(\frac{\alpha^2}{\tilde{\alpha}^2} - 1\right) \frac{m^2}{m^2 + \mu^2 \exp(\alpha\varphi/M)} + 1.$$

scalar σ with
standard normalization

$$\frac{d\sigma}{d\varphi} = k(\varphi).$$

$$\Gamma = \int d^4x \sqrt{g} \left\{ -\frac{M^2}{2} R + \frac{k^2}{2} \partial^\mu \varphi \partial_\mu \varphi + M^4 \exp\left(-\frac{\alpha\varphi}{M}\right) \right\}$$

$$k^2 = \frac{\alpha^2 (K+6)}{4}.$$

Inflation : Slow roll parameters

$$\epsilon = \frac{M^2}{2}\left(\frac{\partial \ln V}{\partial \sigma}\right)^2 = \frac{M^2}{2k^2}\left(\frac{\partial \ln V}{\partial \varphi}\right)^2 = \frac{\alpha^2}{2k^2}$$

$$\eta = \frac{M^2}{V}\frac{\partial^2 V}{\partial \sigma^2} = 2\epsilon - \frac{M}{\alpha}\frac{\partial \epsilon}{\partial \varphi}$$

For large $\alpha \gg 1$ and small $\tilde{\alpha} \ll 1$ we can approximate

$$\epsilon = \frac{\tilde{\alpha}^2}{2}\left(1 + \frac{\mu^2}{m^2}\exp(\alpha\varphi/M)\right),$$

$$\eta = \epsilon + \frac{\tilde{\alpha}^2}{2}.$$

End of inflation at $\varepsilon = 1$

$$\exp\left(\frac{\alpha\varphi_f}{M}\right) = \frac{2m^2}{\tilde{\alpha}^2\mu^2}$$

Number of e-foldings before end of inflation

$$N(\varphi) = \frac{1}{\alpha M} \int_{\varphi}^{\varphi_f} d\varphi' k^2(\varphi')$$

$$= \frac{\alpha(\varphi_f - \varphi)}{\tilde{\alpha}^2 M} - \left(\frac{1}{\tilde{\alpha}^2} - \frac{1}{\alpha^2}\right) \ln\left(\frac{m^2 + \mu^2 \exp(\alpha\varphi_f/M)}{m^2 + \mu^2 \exp(\alpha\varphi/M)}\right)$$

ε, η, N can all be computed from kinetial alone

Spectral index and tensor to scalar ratio

Model A

$$n = 1 - 6\epsilon + 2\eta = 1 - \frac{2}{N}$$
$$r = 16\epsilon = \frac{8}{N} = 4(1 - n).$$

$$n \approx 0.97 \, , \; r \approx 0.13$$

Amplitude of density fluctuations

$$24\pi^2\Delta^2 = \frac{V}{\epsilon M^4} = 2N\exp\left(-\frac{\alpha\varphi}{M}\right) \approx 5\cdot 10^{-7}.$$

$$\exp\left(-\frac{\alpha\varphi}{M}\right) \approx 4\cdot 10^{-9},$$

$$\frac{\tilde{\alpha}^2\mu^2}{m^2} \approx \frac{2}{3}\cdot 10^{-10}$$

Properties of density fluctuations model A

$\tilde{\alpha}$	0.001	0.02	0.1
n	0.975 (0.97)	0.975 (0.97)	0.972 (0.967)
r	0.13 (0.16)	0.13 (0.16)	0.18 (0.2)
$\frac{m}{\mu}$	120 (100)	2400 (2000)	12 000(10 000)

Einstein frame , model B

$$\varphi = \frac{M}{\alpha} \ln \frac{(\chi^2 + m^2)^2}{\bar{\lambda}_c},$$

$$k^2 = 1 + \alpha^2 \left(\frac{1}{\tilde{\alpha}^2} - \frac{3}{8} \right) \frac{m^2}{\chi^2}$$

for large χ :
no difference to model A

$$\Gamma = \int d^4x \sqrt{g} \left\{ -\frac{M^2}{2} R + \frac{k^2}{2} \partial^\mu \varphi \partial_\mu \varphi + M^4 \exp\left(-\frac{\alpha \varphi}{M} \right) \right\}$$

inflation model B

approximate relation between r and n

$$r = \frac{16(1-n)\exp\big(-N(1-n)\big)}{1-3\big[N(1-n)-1\big]\exp\big(-N(1-n)\big)}$$

n=0.95 , r=0.035

Properties of density fluctuations, model B

$\tilde{\alpha}$	0.24	0.28	0.325
n	0.954 (0.95)	0.95 (0.944)	0.94 (0.936)
r	0.08 (0.12)	0.054 (0.085)	0.027 (0.049)
$\frac{m}{(\bar{\lambda}_c)^{1/4}}$	129 (114)	150 (131)	182 (156)

conclusion

cosmon inflation :

- compatible with observation
- simple
- no big bang singularity
- stability of solution singles out arrow of time
- simple initial conditions

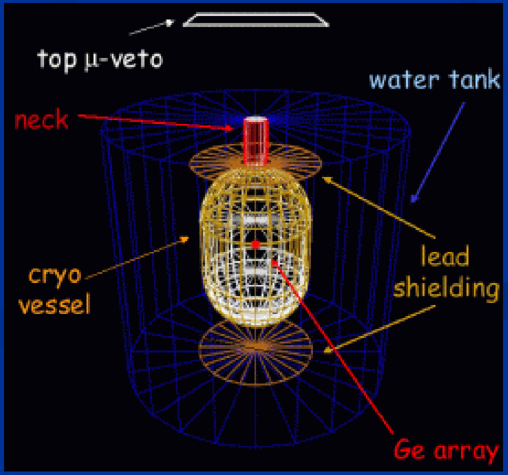
$$\Gamma = \int d^4x \sqrt{g} \left\{ -\frac{1}{2} F(\chi) R + \frac{1}{2} K(\chi) \partial^\mu \chi \partial_\mu \chi + V(\chi) \right\}$$

End

Can time evolution of neutrino mass be observed ?

Experimental determination of neutrino mass may turn out higher than cosmological upper bound in model with constant neutrino mass

(KATRIN, neutrino-less double beta decay)



GERDA

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