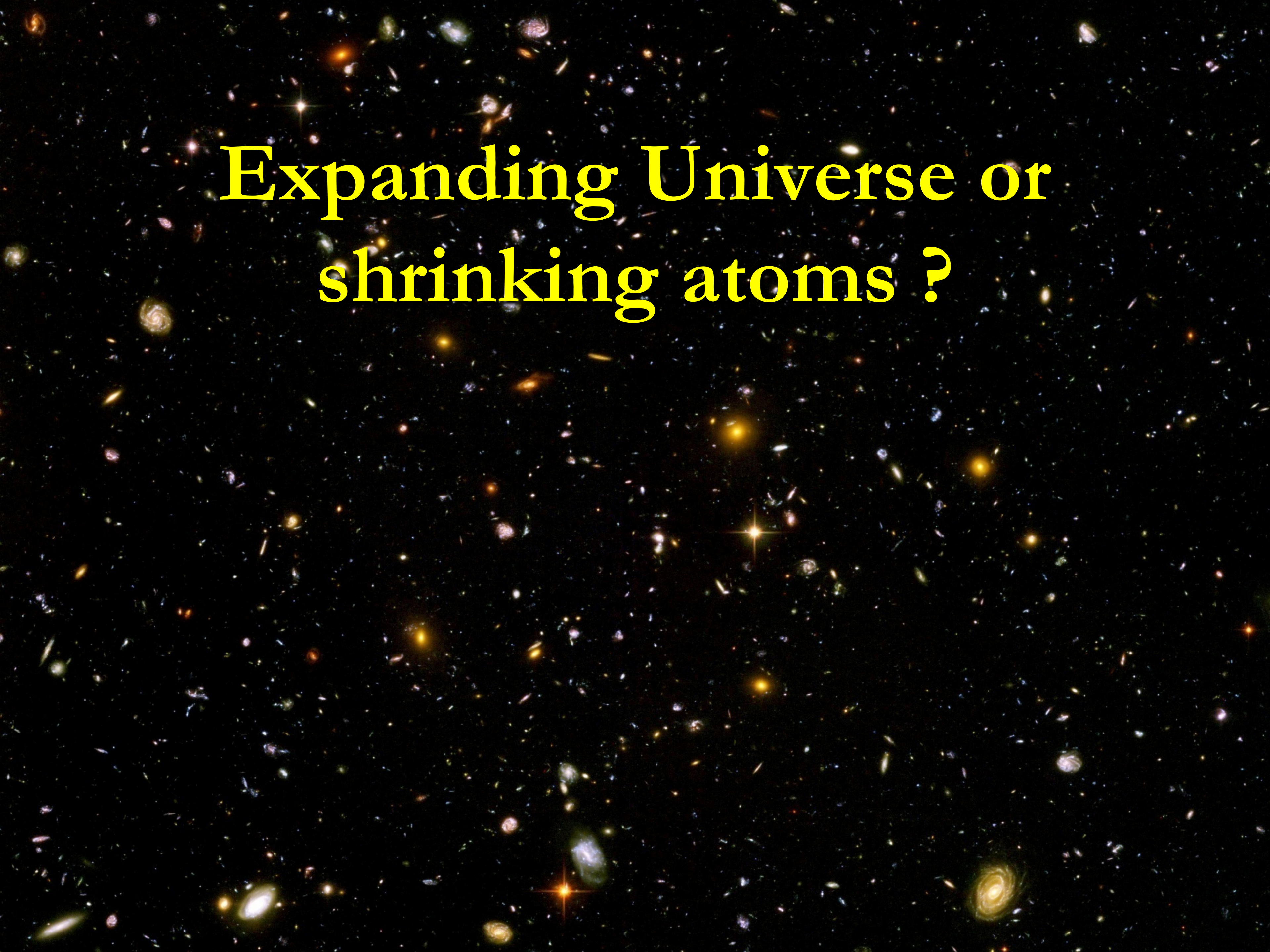
Expanding Universe or shrinking atoms ?

A new view on dynamical Dark Energy, and the Origin of the Universe

Expanding Universe or shrinking atoms ?

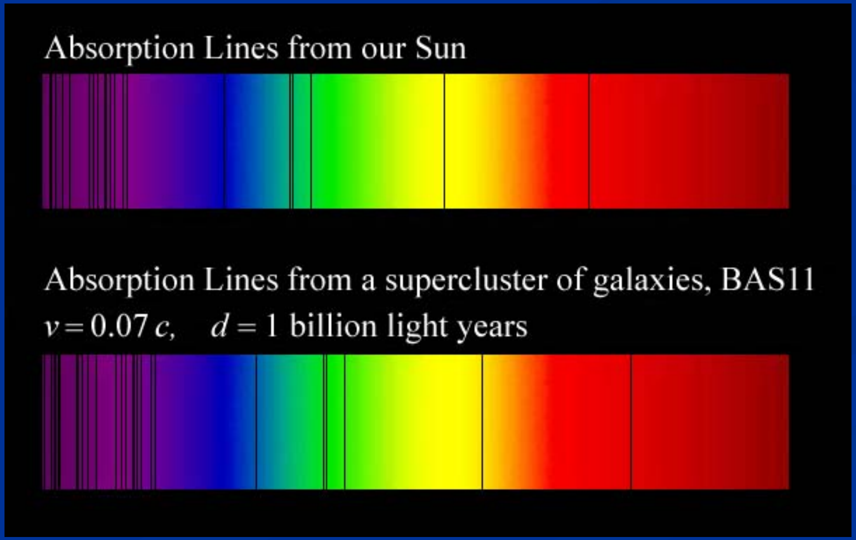


Hot big bang or freeze ?

Do we know that the Universe expands ?

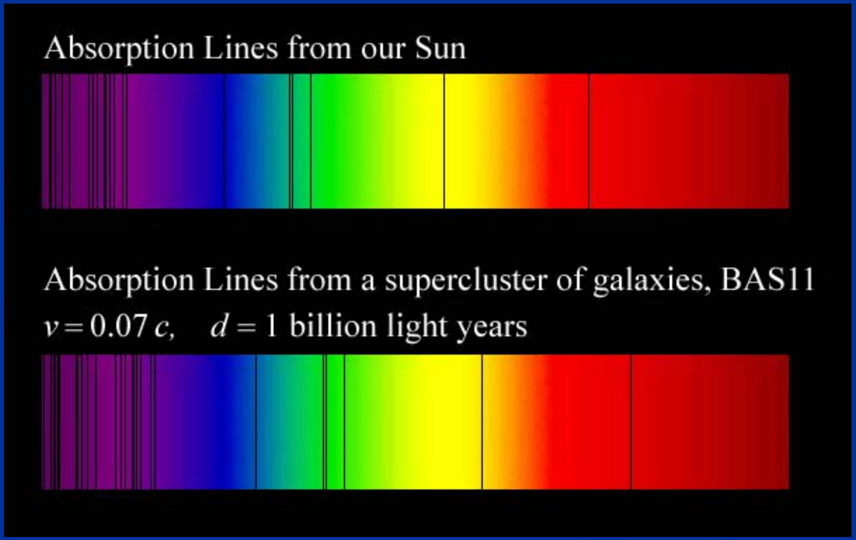
instead of redshift due to expansion :

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



Why do we see redshift of photons emitted in the distant past ?

photons are more red because they have been emitted with longer wavelength



frequency ~ mass

wavelength ~ atomsize

What is increasing ?

Ratio of distance between galaxies
over size of atoms !

atom size constant : expanding geometry

alternative : shrinking size of atoms

Only dimensionless ratios of length or mass scales are observable

How can particle masses change with time ?

- Particle masses are proportional to scalar field χ . Similar to Higgs field.
- Scalar field varies with time.
- Ratios of particle masses are independent of χ and therefore remain constant.
- Compatibility with observational bounds on time dependence of particle mass ratios.
- Dimensionless couplings are independent of χ .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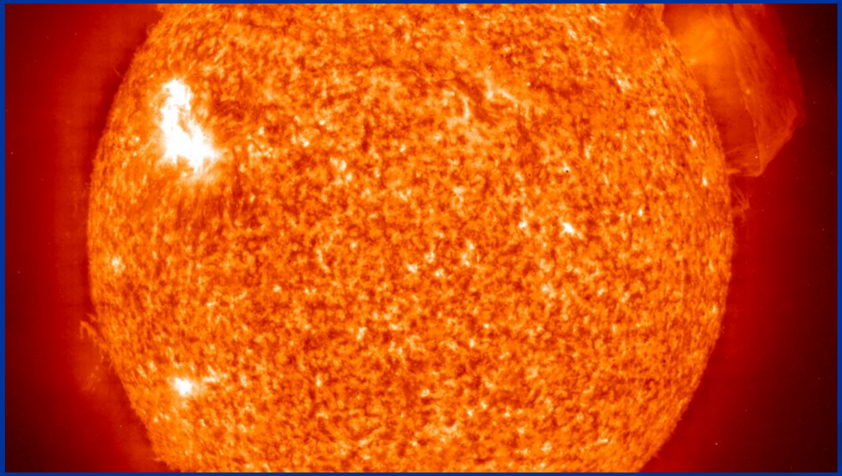
Do we know that the temperature was higher in the early Universe than now ?

Cosmic microwave radiation , nucleosynthesis

instead of

higher temperature :

smaller particle masses



Hot plasma ?

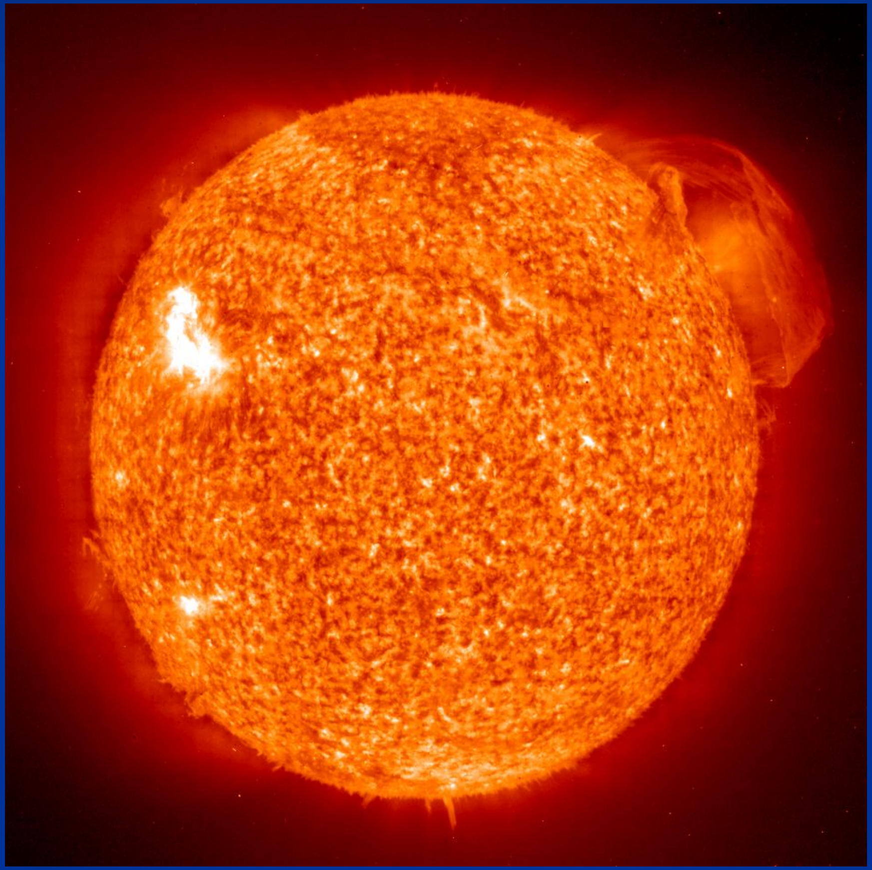
- Temperature in radiation dominated Universe : $T \sim \chi^{1/2}$ smaller than today
- Particle masses : $m_p \sim \chi$ smaller than today
- Ratio temperature / particle mass : $T / m_p \sim \chi^{-1/2}$ larger than today
- T/m_p counts ! This ratio decreases with time.
- Nucleosynthesis , CMB emission as in standard cosmology !

Freeze Universe

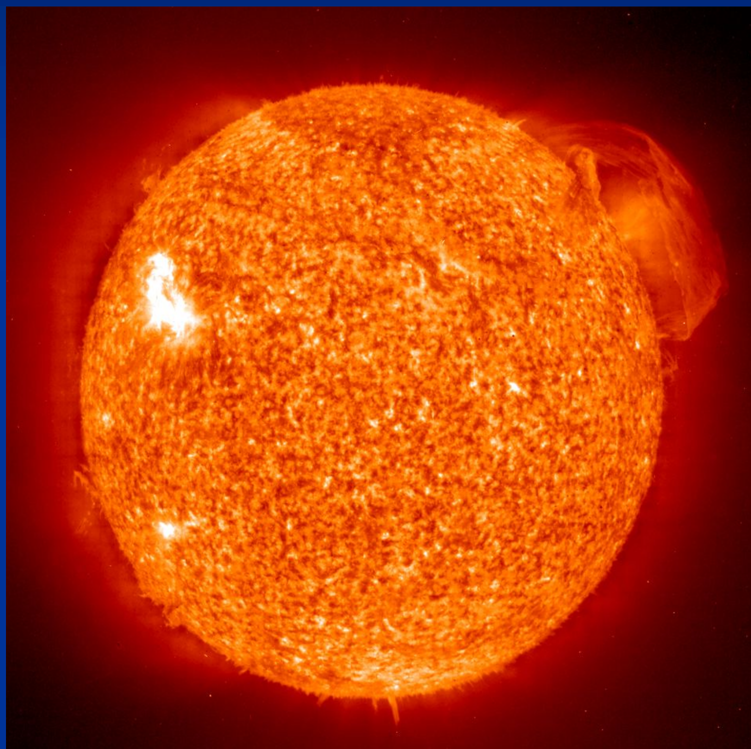
The Universe may have started very cold, and only later heat up.

Freeze picture of the Universe

Hot big bang or freeze ?



Big bang or freeze ?



freeze picture :
only rods for measurements
(masses) are different !

Big bang is not wrong ,

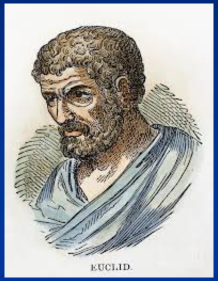
but alternative pictures exist !

Field relativity :
different pictures of cosmology

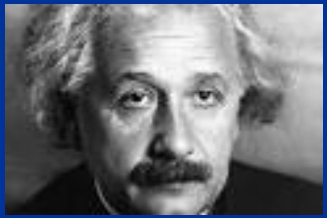
- same physical content can be described by different pictures
- related by field – redefinitions ,
  e.g. Weyl scaling , conformal scaling of metric
- observables cannot depend on choice of fields
- metric is one of the fields
- which picture is useful ?

Relativity of geometry

- Euclid … Newton : space and time are absolute



- Special relativity : space and time depend on observer
- General relativity : space-time is influenced by matter (including radiation)



geometry is independent of coordinates

geometry is observable

- Field relativity : geometry is relative

Space-time is a description
of correlations between "matter".

Observables cannot depend on choice of
fields used to describe them.

Different pictures for geometry exist.

Why should you care about the freeze picture of the Universe ?

Some aspects are understood easier :

- Beginning of Universe
- Role of scale symmetry
- Range of impact of quantum gravity

preview

- Big bang singularity is artefact
  of inappropriate choice of field variables –
  no physical singularity

- Quantum gravity may be observable in
  dynamics of present Universe :
  Dynamical Dark Energy

Quantum Gravity

Quantum Gravity is a renormalisable quantum field theory

Asymptotic safety

Quantum scale symmetry

- quantum fluctuations violate scale symmetry
- running dimensionless couplings
- at fixed points , scale symmetry is exact !
- quantum fluctuations can generate scale symmetry !
- at UV- fixed point for renormalizable quantum gravity : quantum scale symmetry is exact

Quantum scale symmetry

No parameter with dimension of length or mass is present in the quantum effective action.

Then invariance under dilatations or global scale transformations is realized.

Continuous global symmetry

quantum gravity with scalar field – the role of scale symmetry for cosmology

Spontaneous breaking of scale symmetry

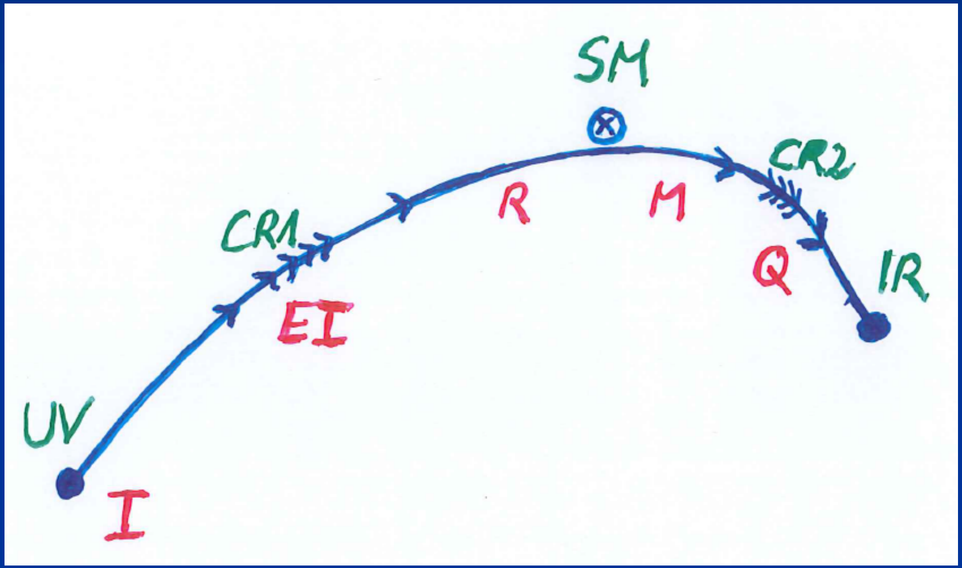
- expectation value of scalar field breaks scale symmetry spontaneously
- massive particles are compatible with scale symmetry
- in presence of massive particles : sign of exact scale symmetry is exactly massless Goldstone boson – the dilaton

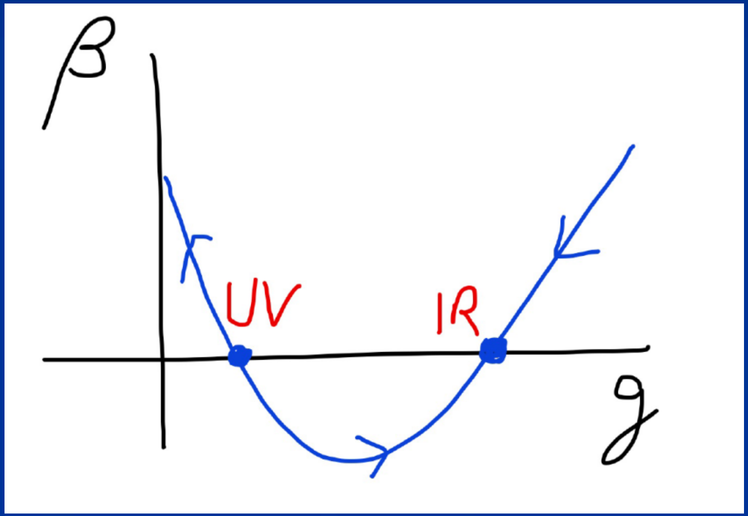
Approximate scale symmetry near fixed points

- UV : approximate scale invariance of primordial fluctuation spectrum from inflation

- IR : cosmon is pseudo Goldstone boson of
  spontaneously broken scale symmetry,
  tiny mass,
  responsible for dynamical Dark Energy

Possible consequences of crossover in quantum gravity





Realistic model for inflation and dark energy with single scalar field

variable gravity

"Newton's constant is not constant –
and particle masses are not constant"

Variable Gravity

$$\Gamma = \int_x \sqrt{g}\left\{-\frac{1}{2}\chi^2 R + \mu^2\chi^2 + \frac{1}{2}\left(B(\chi/\mu) - 6\right)\partial^\mu\chi\partial_\mu\chi\right\}$$

quantum effective action,
variation yields field equations

Einstein gravity : $\Gamma = \int_x \sqrt{g}\left\{-\frac{1}{2} M^2 R\right\}$

Scale symmetry in variable gravity (IR – fixed point)

$$\Gamma = \int_x \sqrt{g} \left\{ -\frac{1}{2}\chi^2 R + \mu^2\chi^2 + \frac{1}{2}\left(B(\chi/\mu) - 6\right)\partial^\mu\chi\partial_\mu\chi \right\}$$

quantum effective action,
variation yields field equations

Einstein gravity : $\Gamma = \int_x \sqrt{g} \left\{ -\frac{1}{2} M^2 R \right\}$

Variable Gravity

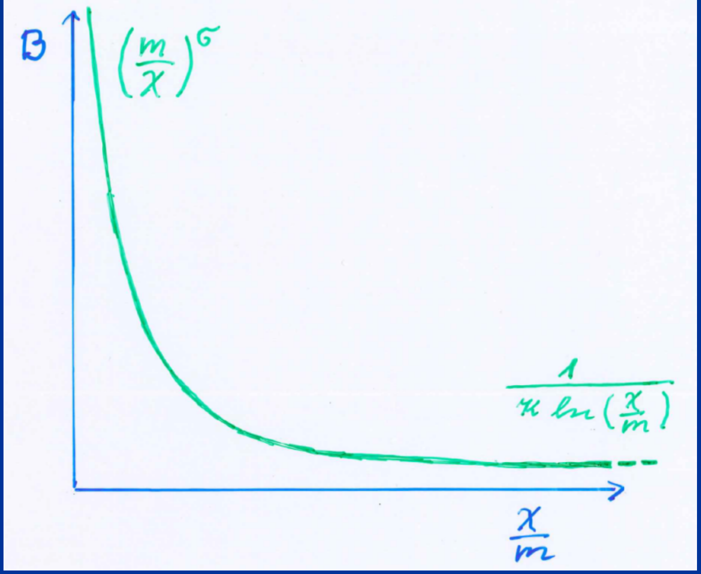
- Scalar field coupled to gravity
- Effective Planck mass depends on scalar field
- Simple quadratic scalar potential involves intrinsic mass μ
- Nucleon and electron mass proportional to dynamical Planck mass

$$\Gamma = \int_x \sqrt{g} \left\{ -\frac{1}{2}\chi^2 R + \mu^2 \chi^2 + \frac{1}{2}\left(B(\chi/\mu) - 6\right)\partial^\mu \chi \partial_\mu \chi \right\}$$

Crossover

- Possible description of crossover between two fixed points by scale dependence of "kinetial" B
- Not the only possible description of crossover
- Advantage : only one quantity, few parameters

Kinetial B :
Crossover between two fixed points



assumption:
running coupling obeys flow equation

$$\mu \frac{\partial B}{\partial \mu} = \frac{\kappa \sigma B^2}{\sigma + \kappa B}$$

$$B^{-1} - \frac{\kappa}{\sigma} \ln B = \kappa \left[\ln \left(\frac{\chi}{\mu} \right) - c_t \right] = \kappa \ln \left(\frac{\chi}{m} \right)$$

m : scale of crossover
can be exponentially larger than intrinsic scale μ

Four-parameter model

- model has four dimensionless parameters
- three in kinetial :

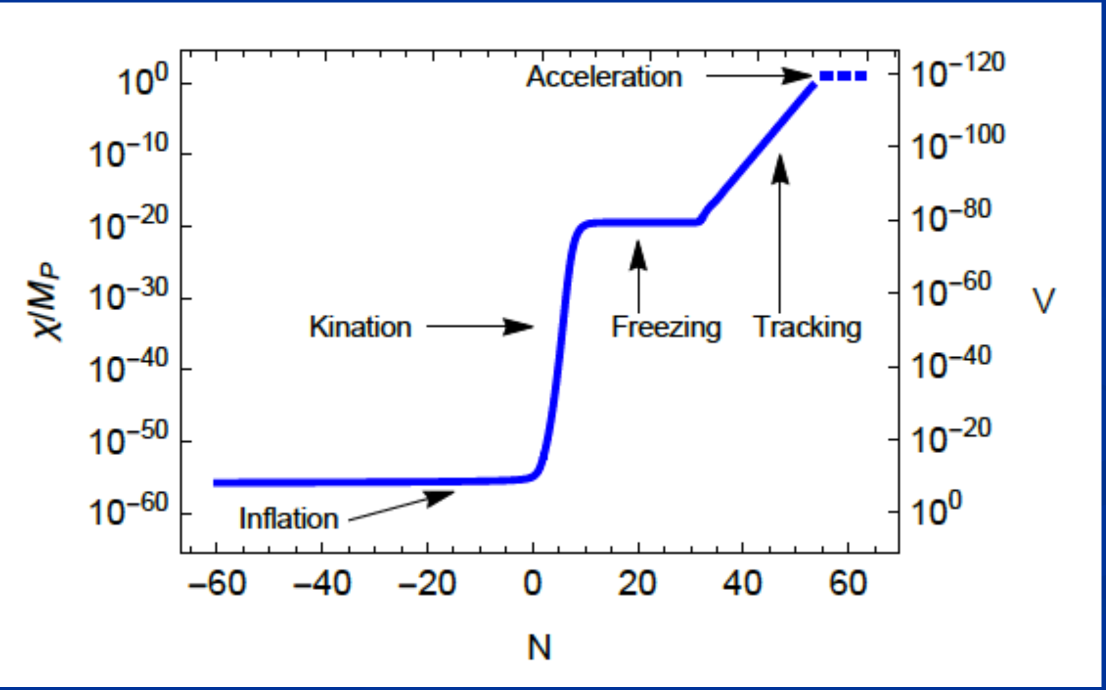
  $\sigma \sim 2.5$

  $\varkappa \sim 0.5$

  $c_t \sim 14$ (or m/μ)
- one parameter for growth rate of neutrino mass over electron mass : $\gamma \sim 8$
- + standard model particles and dark matter : sufficient for realistic cosmology from inflation to dark energy
- no more free parameters than ΛCDM

Cosmological solution

- scalar field χ vanishes in the infinite past
- scalar field χ diverges in the infinite future



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Model is compatible with present observations

Together with variation of neutrino mass over electron mass in present cosmological epoch :

model is compatible with all present observations, including inflation and dark energy

$$\Gamma = \int_x \sqrt{g}\left\{-\frac{1}{2}\chi^2 R + \mu^2\chi^2 + \frac{1}{2}\left(B(\chi/\mu) - 6\right)\partial^\mu\chi\partial_\mu\chi\right\}$$

$$B^{-1} - \frac{\kappa}{\sigma}\ln B = \kappa\left[\ln\left(\frac{\chi}{\mu}\right) - c_t\right] = \kappa\ln\left(\frac{\chi}{m}\right)$$

No tiny dimensionless parameters
(except gauge hierarchy)

- one mass scale $\mu = 2 \cdot 10^{-33}$ eV
- one time scale $\mu^{-1} = 10^{10}$ yr
- Planck mass does not appear as parameter
- Planck mass grows large dynamically

Slow Universe

Asymptotic solution in freeze frame :

$$H = \frac{\mu}{\sqrt{3}} \; , \; \chi = \frac{3^{\frac{1}{4}} m}{2\sqrt{\mu}} (t_c - t)^{-\frac{1}{2}}$$

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

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 !

Cosmic time is relative

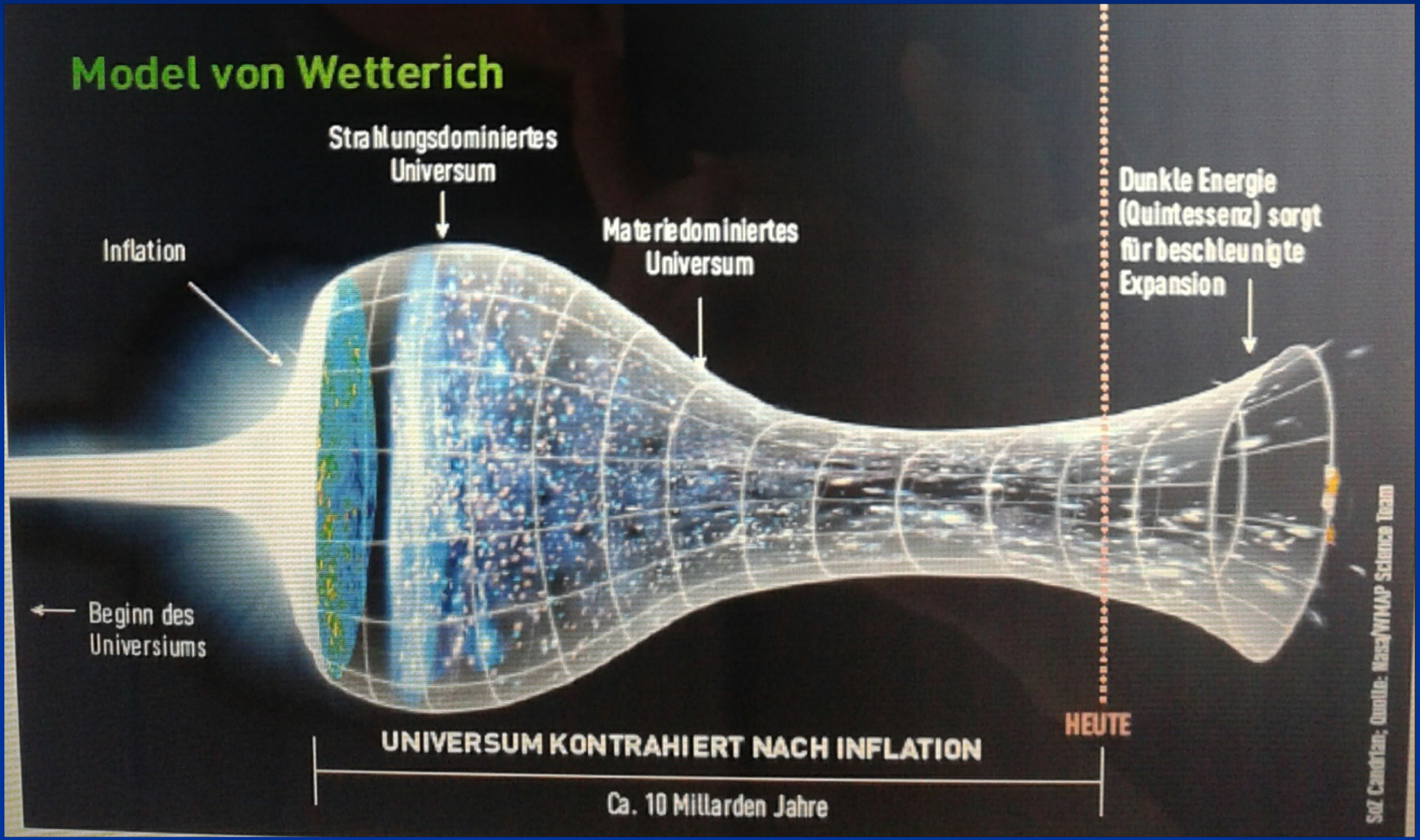
Observable fluctuations,

that form later galaxies and other cosmic structures,

freeze 5000 billion years ago,

not 13.7 billion years ago

Strange evolution of Universe



Sonntagszeitung Zürich , Laukenmann

Einstein frame

- "Weyl scaling" maps variable gravity model to Universe with fixed masses and standard expansion history.

- Exact equivalence of different frames !

  " different pictures"

- Standard gravity coupled to scalar field.

Einstein frame

Weyl scaling :

$$g'_{\mu\nu} = \frac{\chi^2}{M^2} g_{\mu\nu} \ , \ \varphi = \frac{2M}{\alpha} \ln\left(\frac{\chi}{\mu}\right)$$

effective action in Einstein frame :

$$\Gamma = \int_x \sqrt{g'} \left\{ -\frac{1}{2} M^2 R' + V'(\varphi) + \frac{1}{2} k^2(\varphi) \partial^\mu \varphi \partial_\mu \varphi \right\}$$

$$V'(\varphi) = M^4 \exp\left(-\frac{\alpha\varphi}{M}\right)$$

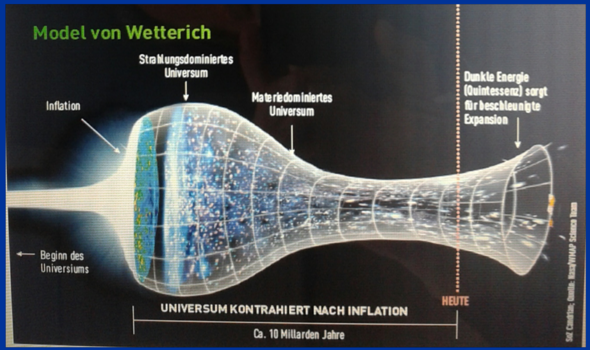
$$k^2 = \frac{\alpha^2 B}{4}$$

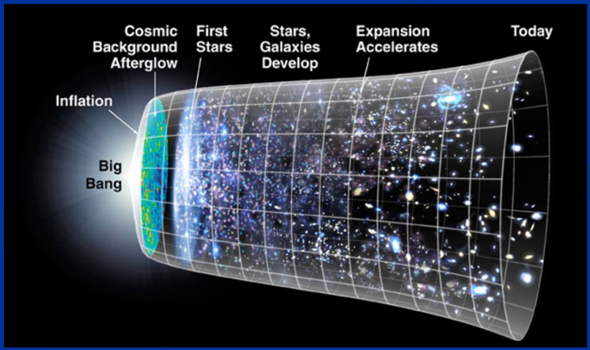
Field relativity

Weyl scaling :

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

changes geometry,
not a coordinate transformation





infinite past

Infinite past : slow inflation

$\sigma = 2$: field equations

$$\ddot{\chi} + \left(3H + \frac{1}{2}\frac{\dot{\chi}}{\chi}\right)\dot{\chi} = \frac{2\mu^2\chi^2}{m}$$

$$H = \sqrt{\frac{\mu^2}{3} + \frac{m\dot{\chi}^2}{6\chi^3}} - \frac{\dot{\chi}}{\chi}$$

approximative solution

$$H = \frac{\mu}{\sqrt{3}}\ ,\ \chi = \frac{3^{\frac{1}{4}}m}{2\sqrt{\mu}}(t_c - t)^{-\frac{1}{2}}$$

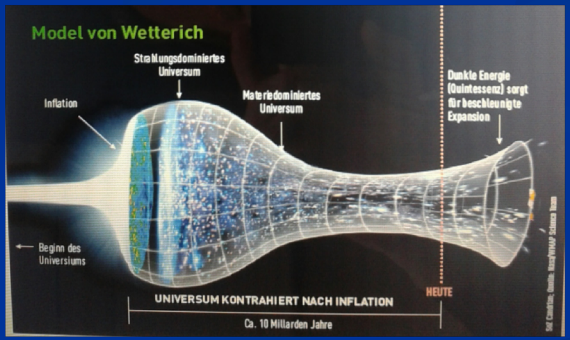
particles become massless in infinite past !

Eternal Universe

Asymptotic solution in freeze frame :

$$H = \frac{\mu}{\sqrt{3}} \; , \; \chi = \frac{3^{\frac{1}{4}} m}{2\sqrt{\mu}} (t_c - t)^{-\frac{1}{2}}$$

- solution valid back to the infinite past in physical time
- no singularity



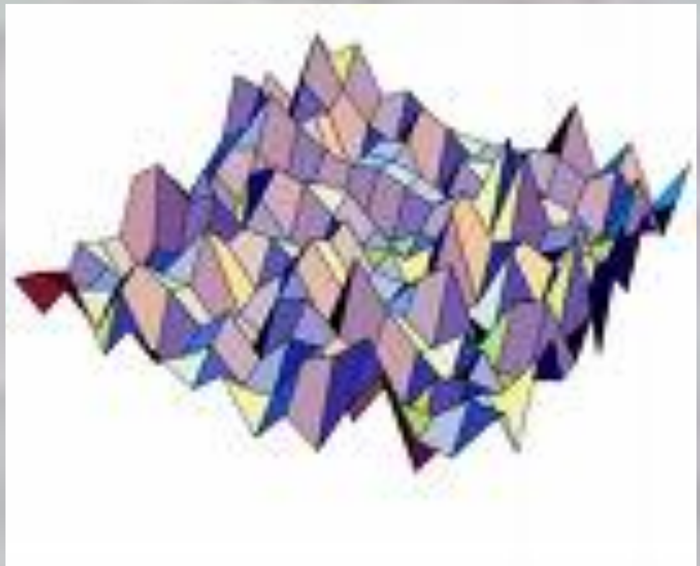
- physical time to infinite past is infinite

Eternal light-vacuum

Everywhere almost nothing
only fluctuations

All particles move
with light velocity,
similar to photons

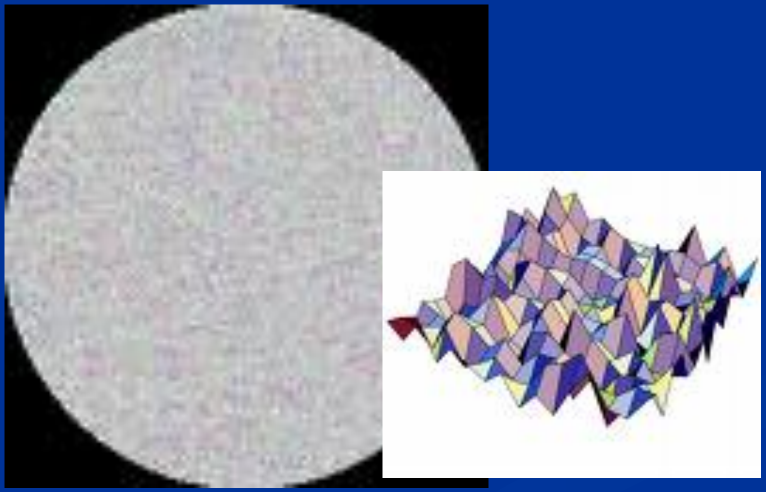
strength of gravity
much stronger than today

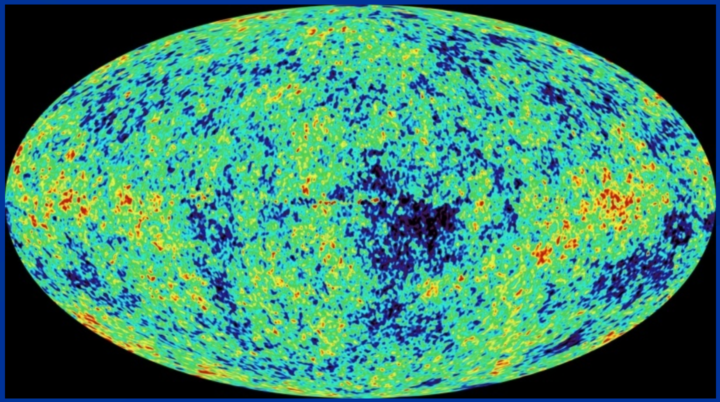


In the beginning was light-like emptiness.

Eternal light-vacuum is unstable

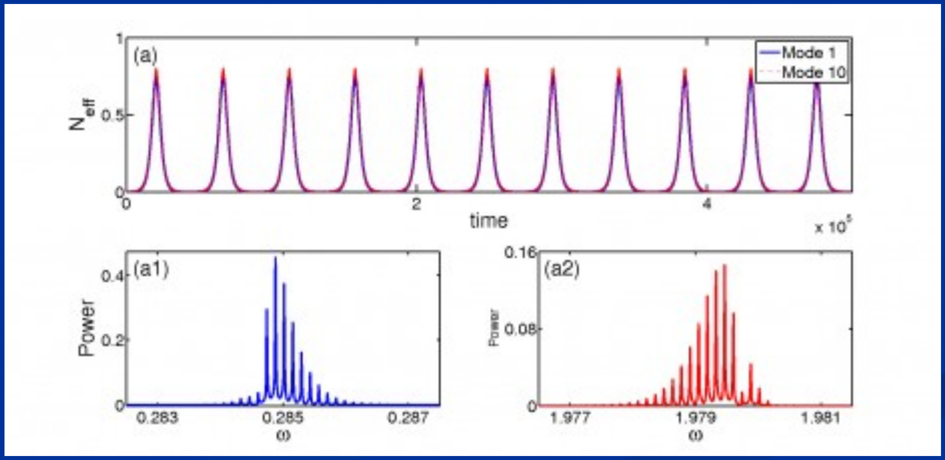
- Slow increase of particle masses and weakening of gravity
- Only slow change of space-time geometry
- Consequence for observation : primordial fluctuations become visible in cosmic background radiation
- We see fluctuations in a stage 5000 billion years ago.





Physical time

count oscillations ….



Physical time

field equation for scalar field mode

$$(\partial_\eta^2 + 2Ha\partial_\eta + k^2 + a^2m^2)\varphi_k = 0$$

$$\varphi_k = \frac{\tilde{\varphi}_k}{a} \qquad \left\{\partial_\eta^2 + k^2 + a^2\left(m^2 - \frac{R}{6}\right)\right\}\tilde{\varphi}_k = 0$$

determine physical time by counting number of oscillations

$$\tilde{t}_p = n_k$$

$$n_k = \frac{k\eta}{\pi}$$

(m=0)

Physical time

- counting : discrete
- invariant under field transformations
- same in all frames

Big bang singularity in Einstein frame is field singularity !

$$g'_{\mu\nu} = \frac{\chi^2}{M^2} g_{\mu\nu} \ , \ \varphi = \frac{2M}{\alpha} \ln\left(\frac{\chi}{\mu}\right)$$

choice of frame with constant particle masses is not well suited if physical masses go to zero !

Field - singularity

- Big Bang is field - singularity
- similar (but not identical with) coordinate - singularity

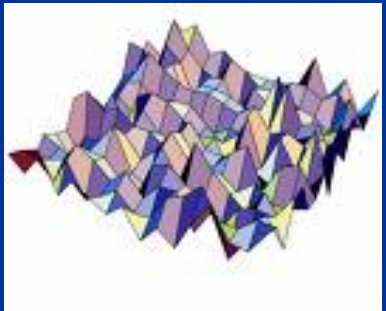
$$g'_{\mu\nu} = \frac{\chi^2}{M^2} g_{\mu\nu}$$

Looking closer at the big bang picture

- Same physical situation as in freeze picture
- Infinite number of oscillations before big bang singularity is reached - infinite physical time !
- At the beginning was light-like vacuum:

  All particles effectively massless

  Ratio mass over momentum counts, and all momenta diverge in big bang picture as singularity is approached



Looking closer at the big bang picture

- Singular field choice shrinks the infinite duration of beginning epoch to extremely short time interval for inflation
- Proper time not a valid physical time for massless particles! (frame – dependent)
- Singularity theorems based on proper time being finite for approach to big bang : not valid !

Inflation

Beginning epoch : slow inflation

approximative solution

$$H = \frac{\mu}{\sqrt{3}} ,$$

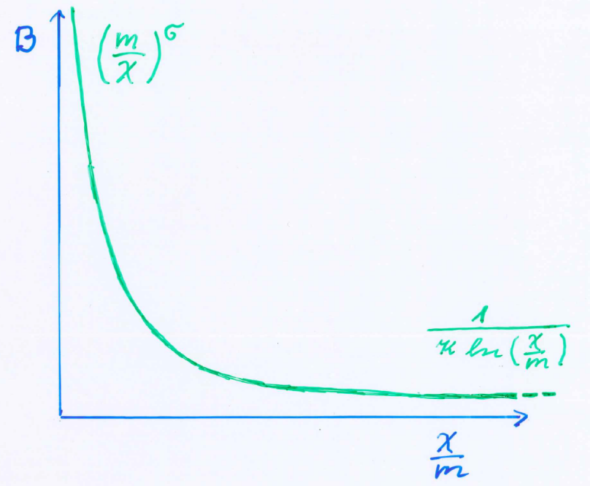
Masses increase slowly with time

particles become massless in infinite past !

Particular model predicts properties of primordial fluctuation spectrum

$$\Gamma = \int_x \sqrt{g}\left\{-\frac{1}{2}\chi^2 R + \mu^2\chi^2 + \frac{1}{2}\left(B(\chi/\mu) - 6\right)\partial^\mu\chi\partial_\mu\chi\right\}$$

$$B^{-1} - \frac{\kappa}{\sigma}\ln B = \kappa\left[\ln\left(\frac{\chi}{\mu}\right) - c_t\right] = \kappa\ln\left(\frac{\chi}{m}\right)$$



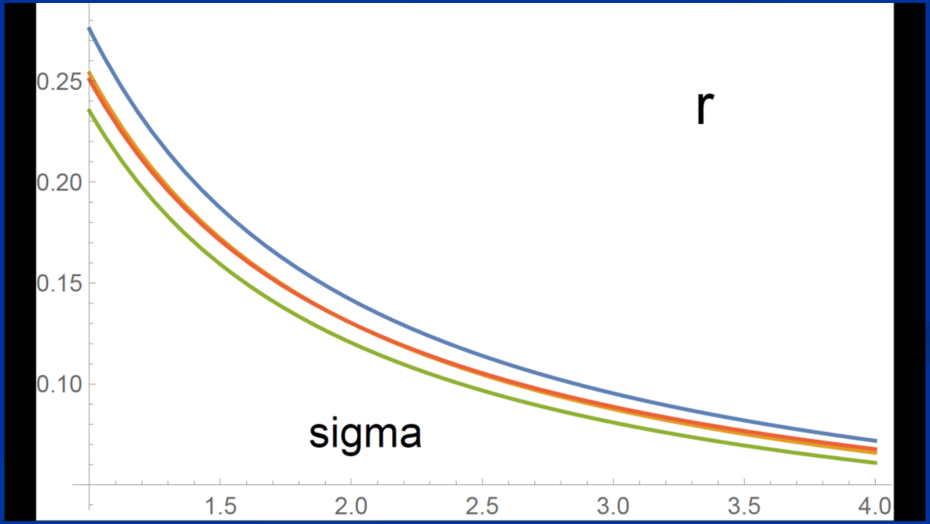
Anomalous dimension determines spectrum of primordial fluctuations

$$r = \frac{0.26}{\sigma}$$

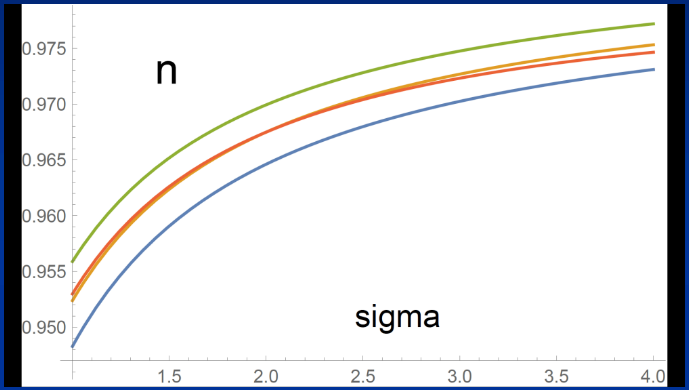
$$n = 1 - \frac{0.065}{\sigma} \cdot \left(1 + \frac{\sigma - 2}{4}\right)$$

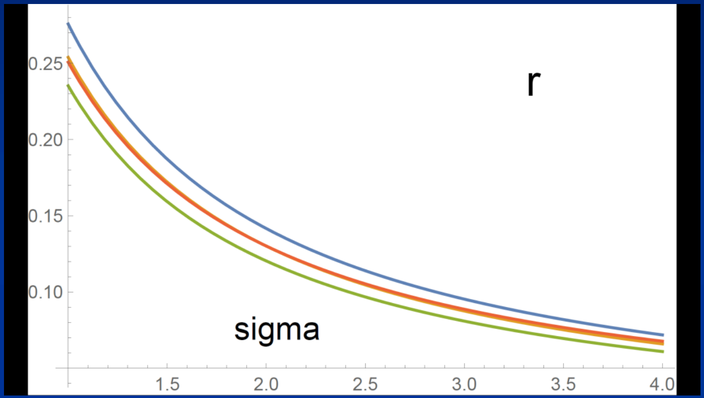
spectral index n

tensor amplitude r

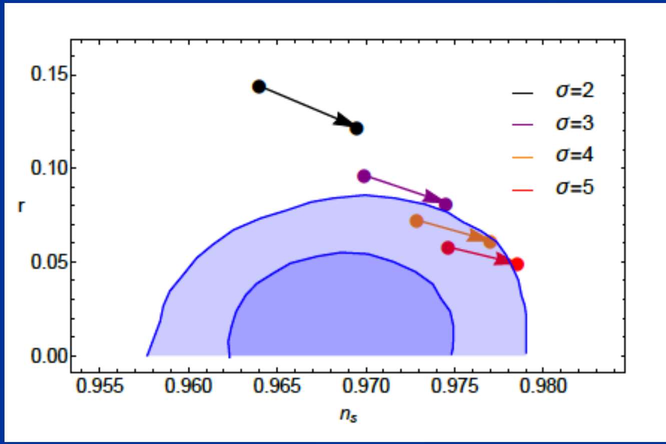


relation between n and r





$$r = 8.19\,(1 - n) - 0.1365$$



Amplitude of density fluctuations

small because of logarithmic running near UV fixed point !

$$\mathcal{A} = \frac{(N+3)^3}{4} e^{-2c_t}$$

$$c_t = \ln\left(\frac{m}{\mu}\right) = 14.1.$$

σ=1

$$\frac{m}{\mu} = \frac{(N+3)^{\frac{3}{2}}}{2\sqrt{\mathcal{A}}} = 1.32 \cdot 10^6 \left(\frac{N}{60}\right)^{\frac{3}{2}}$$

$$B^{-1} - \frac{\kappa}{\sigma} \ln B = \kappa \left[\ln\left(\frac{\chi}{\mu}\right) - c_t\right] = \kappa \ln\left(\frac{\chi}{m}\right)$$

N : number of e – foldings at horizon crossing

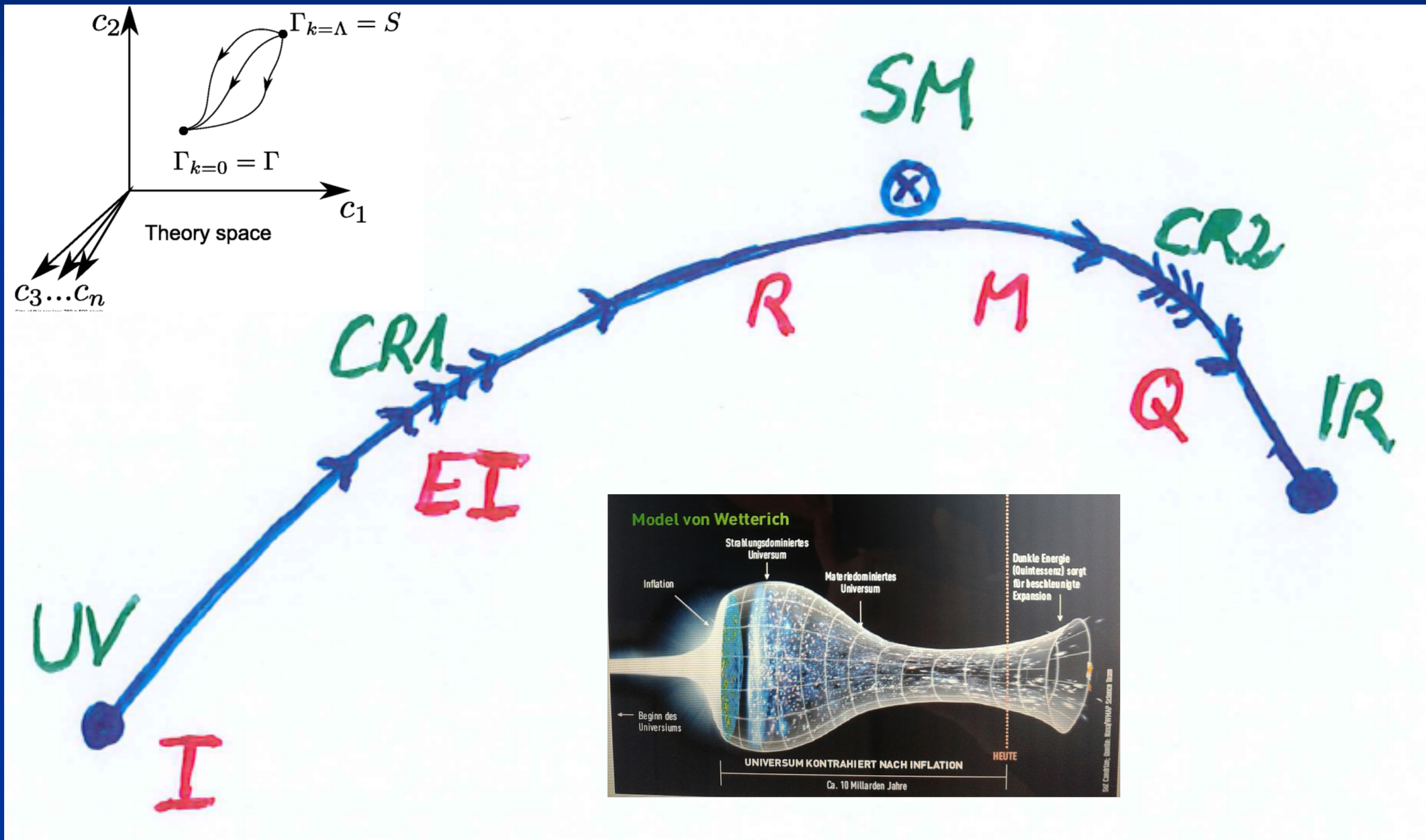
Primordial fluctuation spectrum

- Precise properties change if model is modified
- E.g. different function B

- If UV- fixed point of quantum gravity can be computed reliably : Spectral parameters and amplitude can be predicted !

The Universe after inflation

Crossover in quantum gravity and cosmology

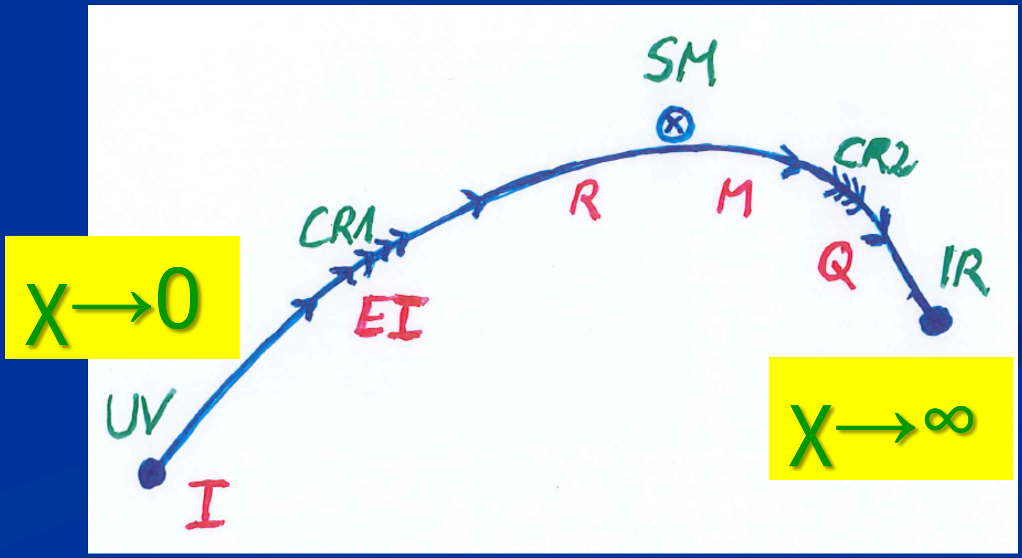


Cosmological solution : crossover from UV to IR fixed point

- Dimensionless functions as B depend only on ratio μ/χ .
- IR: $\mu \rightarrow 0$, $\chi \rightarrow \infty$
- UV: $\mu \rightarrow \infty$, $\chi \rightarrow 0$

$$\Gamma = \int_x \sqrt{g} \left\{ -\frac{1}{2}\chi^2 R + \mu^2\chi^2 + \frac{1}{2}\left(B(\chi/\mu) - 6\right)\partial^\mu\chi\,\partial_\mu\chi \right\}$$

Cosmology makes crossover between fixed points by variation of χ .



Renormalization flow and cosmological evolution

- renormalization flow as function of μ

  is mapped by dimensionless functions to

- field dependence of effective action on scalar field χ

  translates by solution of field equation to

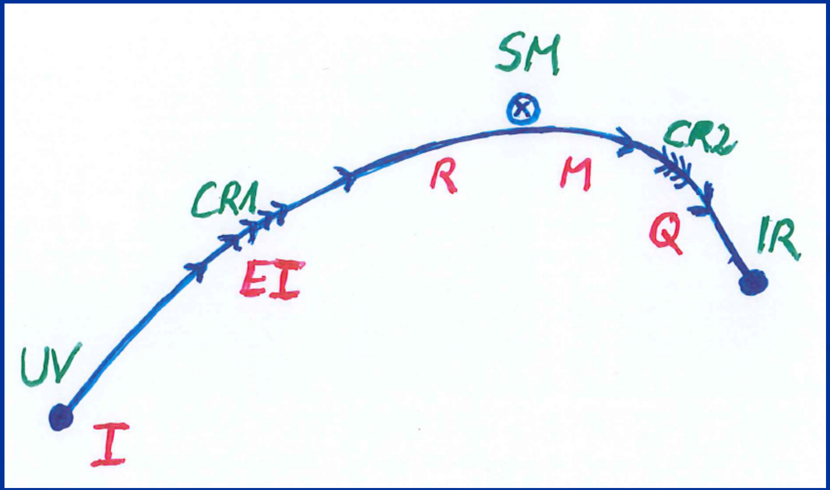
- dependence of cosmology an time t or η

First step of crossover ends inflation

- induced by crossover in B

$$B^{-1} - \frac{\kappa}{\sigma} \ln B = \kappa \left[\ln\left(\frac{\chi}{\mu}\right) - c_t \right] = \kappa \ln\left(\frac{\chi}{m}\right)$$

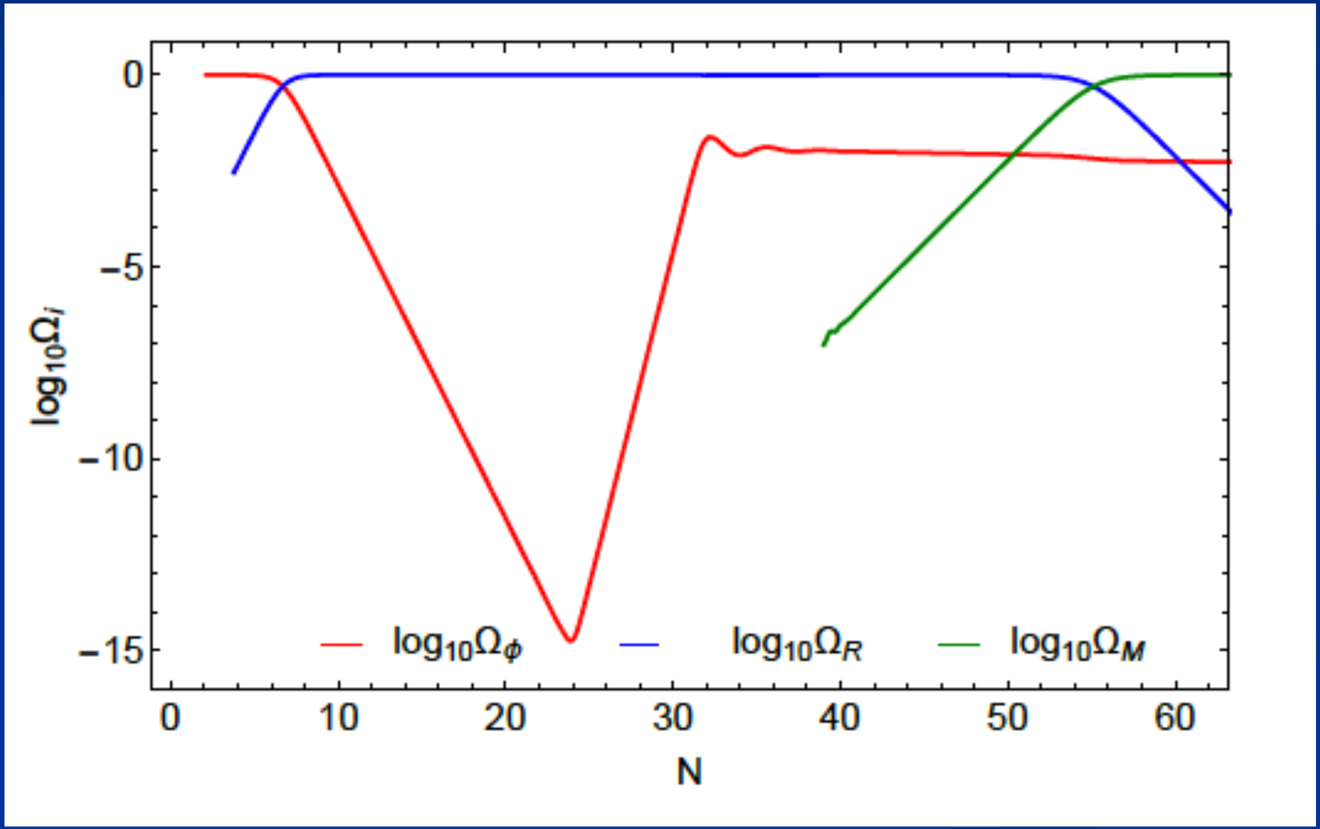
- after crossover B changes only very slowly



Transition to scaling solution

- After end of inflation scalar field changes more rapidly
- Kinetic energy dominated "kination" epoch
- Entropy production, Heating of the Universe
- Scaling solution with almost fixed fraction of Early Dark Energy

Evolution of dark energy fraction



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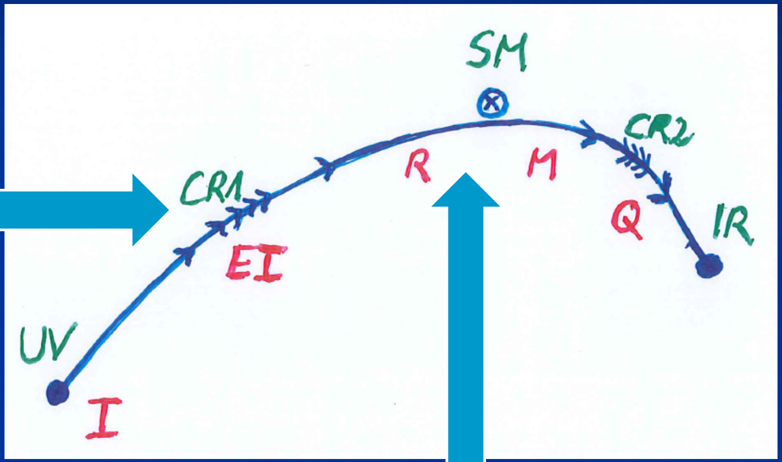
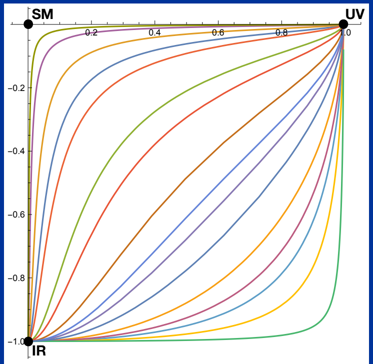
Scaling solution

after end of inflation



scaling solution with
few percent
of Early Dark Energy



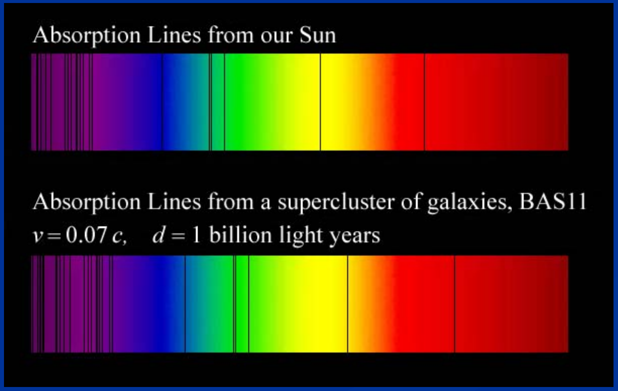
Dark Energy decreases similar to radiation and matter

Freeze picture with shrinking Universe

Constant negative H ~ μ $\mu = 2 \cdot 10^{-33}$ eV

$t_{ch} \sim \mu^{-1} \sim$ 10 billion years

photons are more red because they have been emitted with longer wavelength



frequency ~ mass

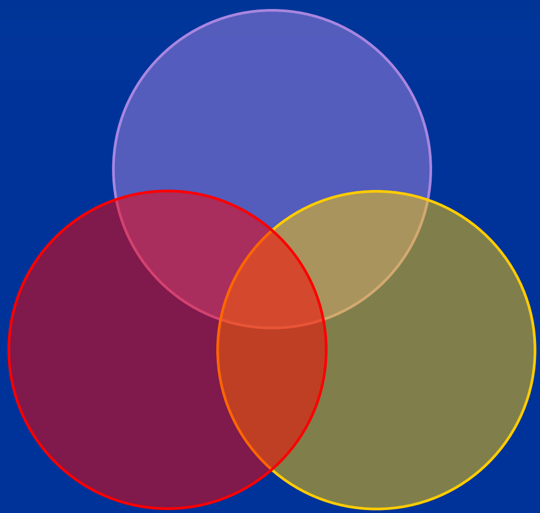
wavelength ~ atomsize

particle masses change with time

- Particle masses are proportional to scalar field χ . Similar to Higgs field.
- Scalar field varies with time.
- Freeze picture possible only if there is a light scalar field that varies in time during radiation and matter domination – prediction !

"Fundamental" Interactions

Strong, electromagnetic, weak interactions



gravitation   cosmodynamics

On astronomical length scales:

graviton

+

cosmon

Dark energy

What is Dark Energy ?

Dark energy is energy density of scalar field χ

$$\rho = V + \text{kinetic term}$$

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

$$p = -V + \text{kinetic term}$$

Dark energy is dynamical if χ changes with time

No small parameter for dark energy

Four-parameter model

- model has four dimensionless parameters
- three in kinetial :

  $\sigma \sim 2.5$

  $\varkappa \sim 0.5$

  $c_t \sim 14$ (or m/μ)
- one parameter for growth rate of neutrino mass over electron mass : $\gamma \sim 8$
- + standard model particles and dark matter : sufficient for realistic cosmology from inflation to dark energy
- no more free parameters than ΛCDM
- no tiny parameter

asymptotically vanishing cosmological „constant“

- What matters : Ratio of potential divided by fourth power of Planck mass

$$\frac{V}{\chi^4} = \frac{\mu^2 \chi^2}{\chi^4} = \frac{\mu^2}{\chi^2}$$

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

- vanishes for $\chi \to \infty$!

small dimensionless number ?

- needs two intrinsic mass scales
- standard approach :V and M (cosmological constant and Planck mass)
- variable gravity : Planck mass moving to infinity , with fixed V ➡ ratio vanishes asymptotically !

Cosmological Constant
- Einstein -

- Constant λ compatible with all symmetries
- No time variation in contribution to energy density

- Why so small ? $\lambda/M^4 = 10^{-120}$

- Why important just today ?

Cosmological mass scales

- Energy density

  $\varrho \sim (2.4 \times 10^{-3} \text{ eV})^{-4}$

- Reduced Planck mass

  $M = 2.44 \times 10^{27}$ eV

- Newton's constant

  $G_N = (8\pi M^2)$

Only ratios of mass scales are observable !

homogeneous dark energy: $\rho_h/M^4 = 7\ 10^{-121}$

matter: $\rho_m/M^4 = 3\ 10^{-121}$

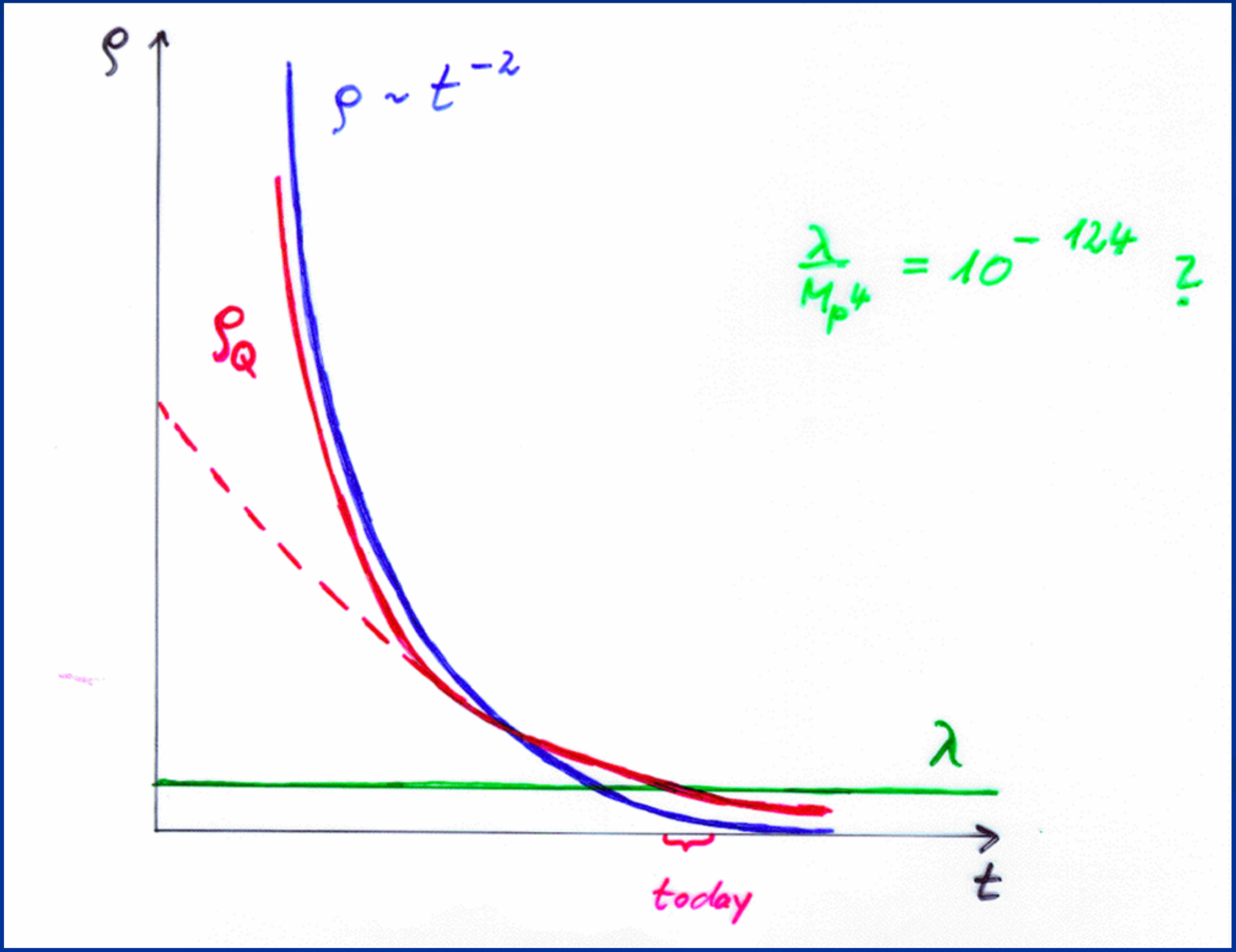
Time evolution

- $\varrho_m/M^4 \sim a^{-3} \sim$
  - t^{-2} matter dominated universe
  - $t^{-3/2}$ radiation dominated universe
- $\varrho_r/M^4 \sim a^{-4} \sim t^{-2}$ radiation dominated universe

Huge age ⇨ small ratio

Same explanation for small dark energy?

Cosm. Const. | Quintessence
static | dynamical



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)

asymptotically vanishing cosmological „constant“

- What matters : Ratio of potential divided by fourth power of Planck mass

$$\frac{V}{\chi^4} = \frac{\mu^2 \chi^2}{\chi^4} = \frac{\mu^2}{\chi^2}$$

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

- vanishes for $\chi \to \infty$!

Einstein frame

Weyl scaling :

$$g'_{\mu\nu} = \frac{\chi^2}{M^2} g_{\mu\nu} \;,\; \varphi = \frac{2M}{\alpha} \ln\left(\frac{\chi}{\mu}\right)$$

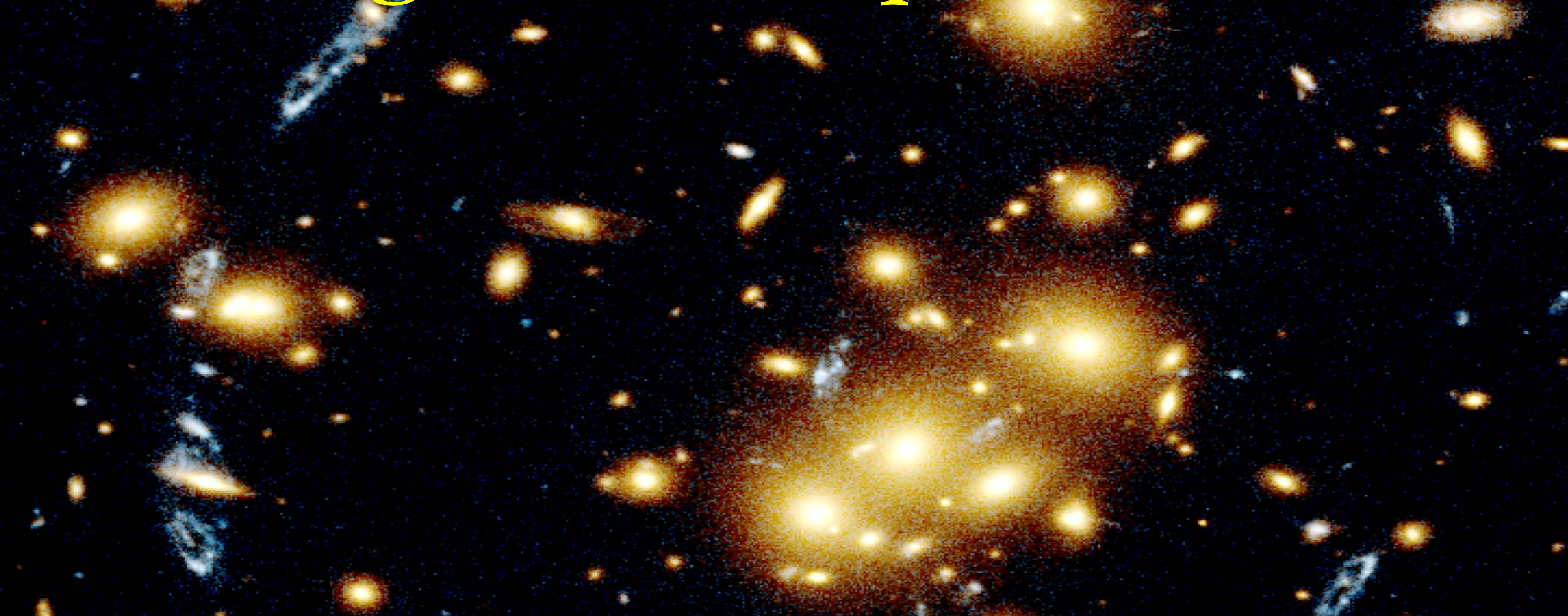
effective action in Einstein frame :

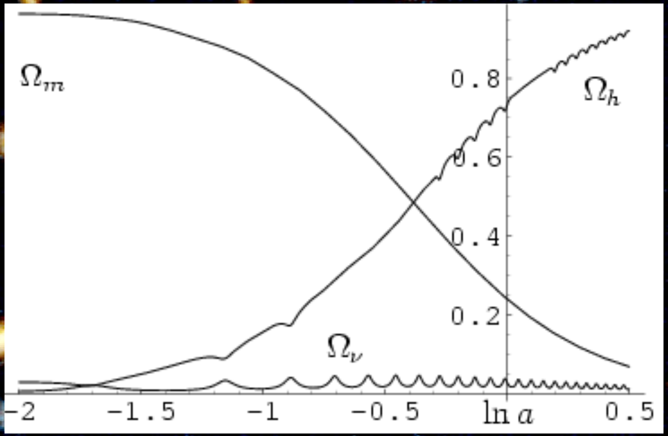
$$\Gamma = \int_x \sqrt{g'} \left\{ -\frac{1}{2} M^2 R' + V'(\varphi) + \frac{1}{2} k^2(\varphi) \partial^\mu \varphi \partial_\mu \varphi \right\}$$

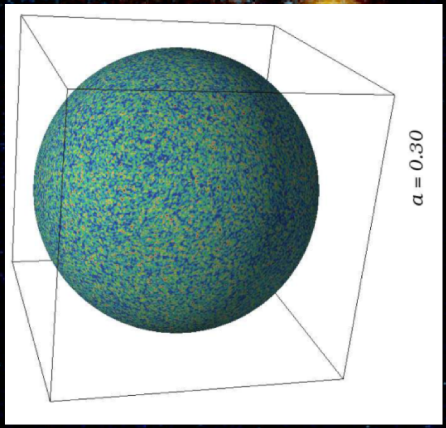
$$V'(\varphi) = M^4 \exp\left(-\frac{\alpha\varphi}{M}\right)$$

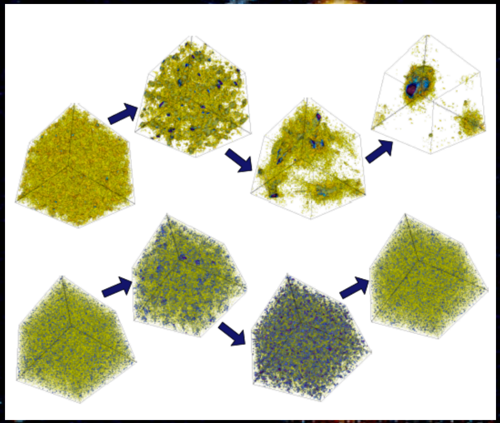
$$k^2 = \frac{\alpha^2 B}{4}$$

Growing neutrino quintessence









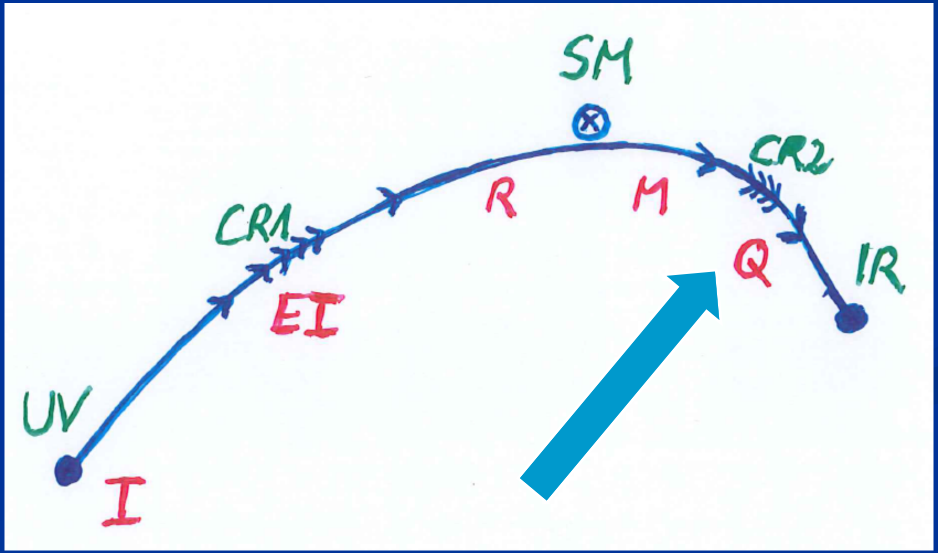
Growing neutrino masses and quintessence

Cosmic trigger can explain why now problem for dynamical dark energy

- Stop of evolution of scalar field when neutrinos become non-relativistic
- Transition from scaling solution to (almost) cosmological constant

Second stage of crossover

- from SM to IR
- in sector Beyond Standard Model
- affects neutrino masses first (seesaw or cascade mechanism)



Varying particle masses at onset of second crossover

- **Except for neutrinos** all particle masses 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 .**

Cosmic trigger

- Stop of evolution of scalar field when neutrinos become non-relativistic
- Transition from scaling solution to (almost) cosmological constant

growing neutrinos change cosmon evolution

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

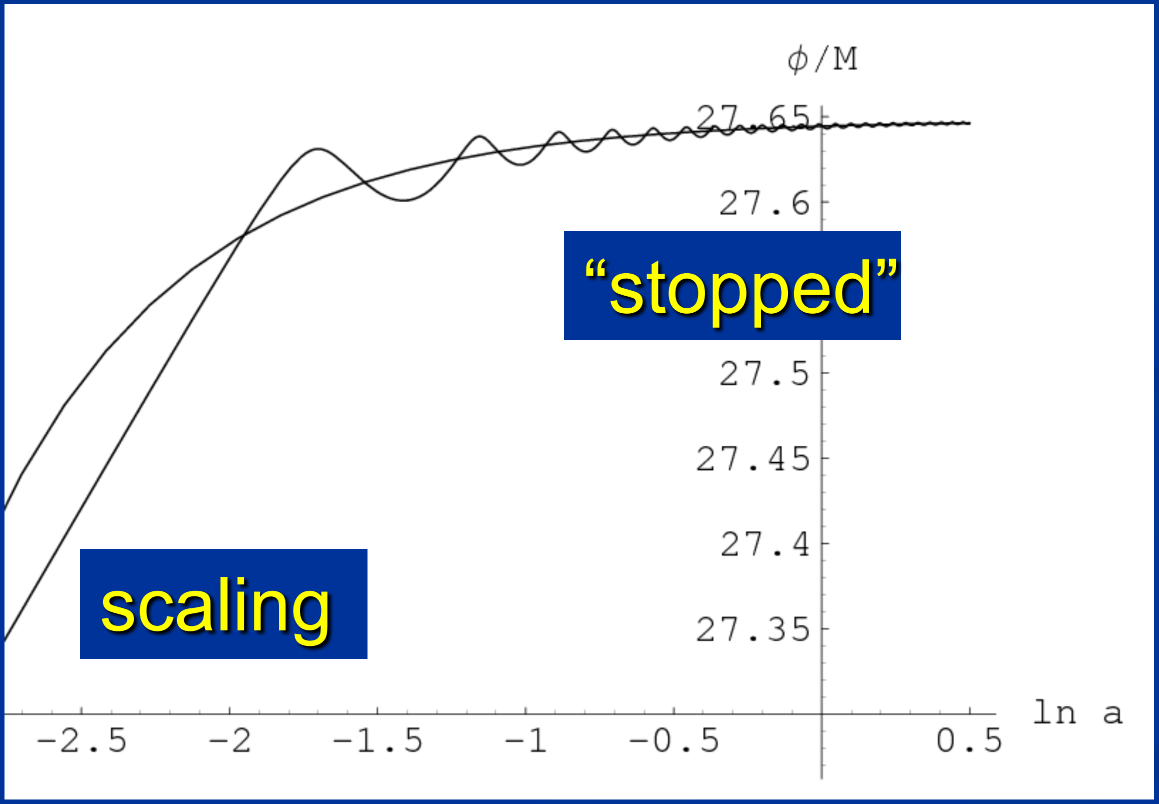
$$\beta(\varphi) = -M\frac{\partial}{\partial \varphi}\ln m_\nu(\varphi) = \frac{M}{\varphi - \varphi_t}$$

modification of conservation equation for neutrinos

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

$$= -\frac{\dot{\varphi}}{\varphi - \varphi_t}(\rho_\nu - 3p_\nu)$$

cosmon evolution



connection between dark energy and neutrino properties

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

L.Amendola, M.Baldi, …

present dark energy density given by neutrino mass

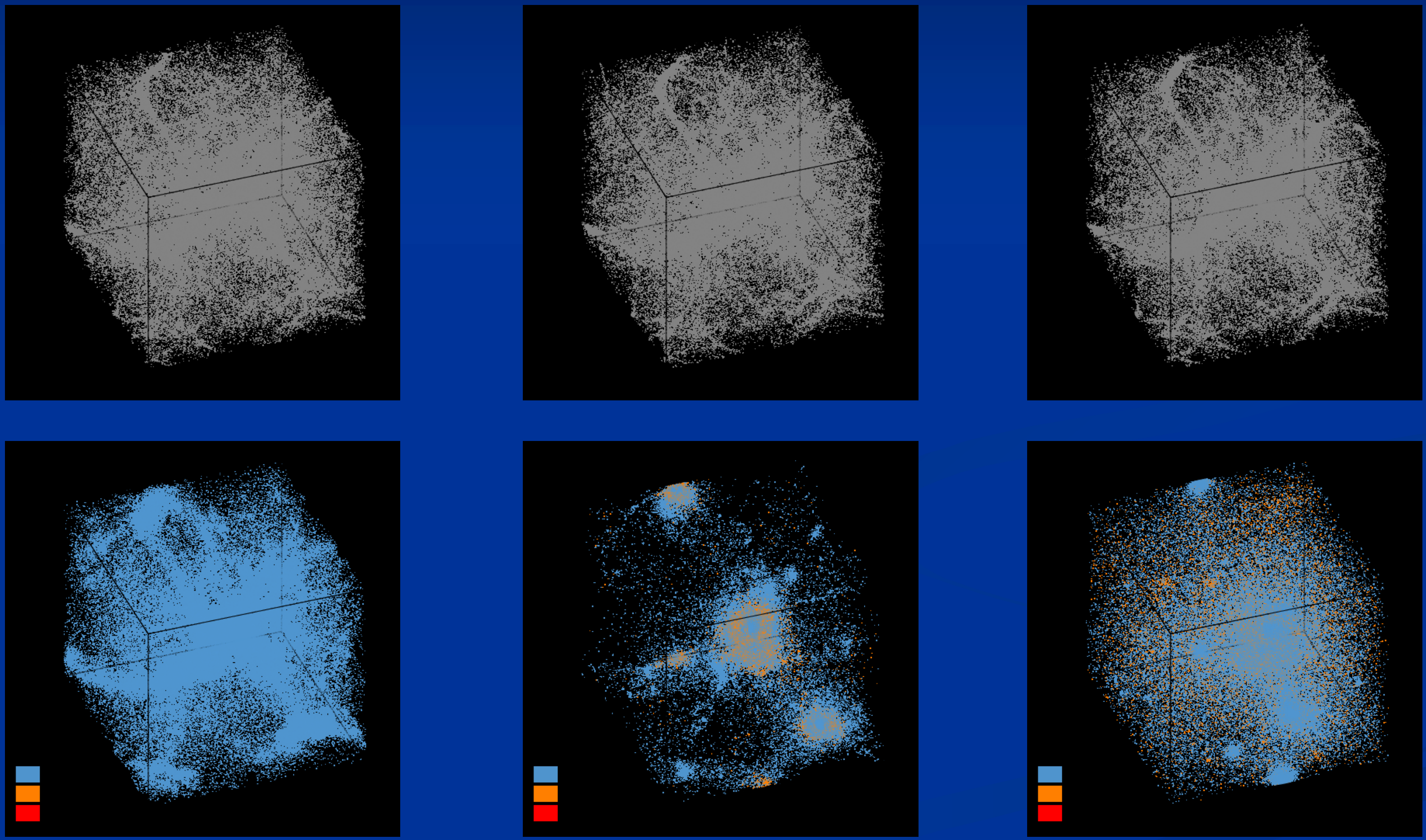
present equation of state given by neutrino mass !

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

Neutrino lumps

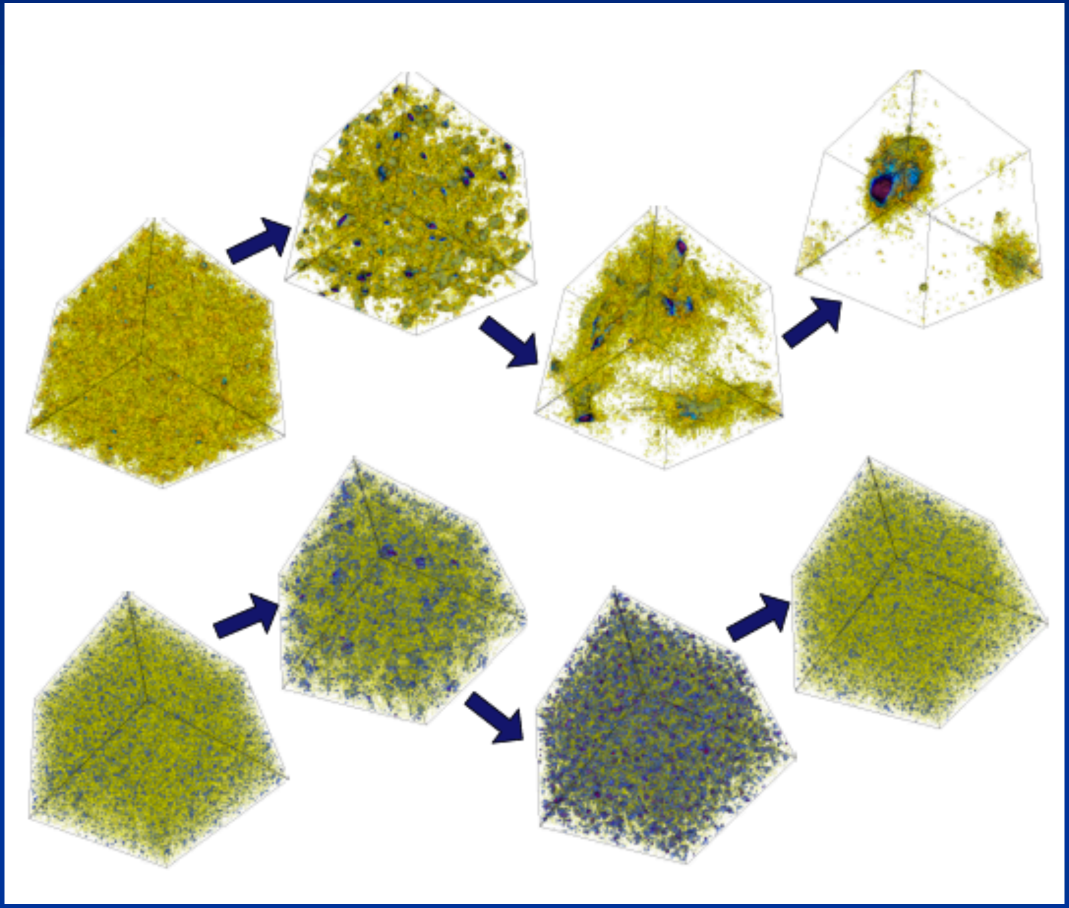
- Scalar- mediated attractive force between neutrinos 1000 times stronger than gravitational attraction
- Clumping of cosmic neutrino background
- Formation of non-linear neutrino lumps

Formation of neutrino lumps



N- body simulation M.Baldi et al

Neutrino lumps

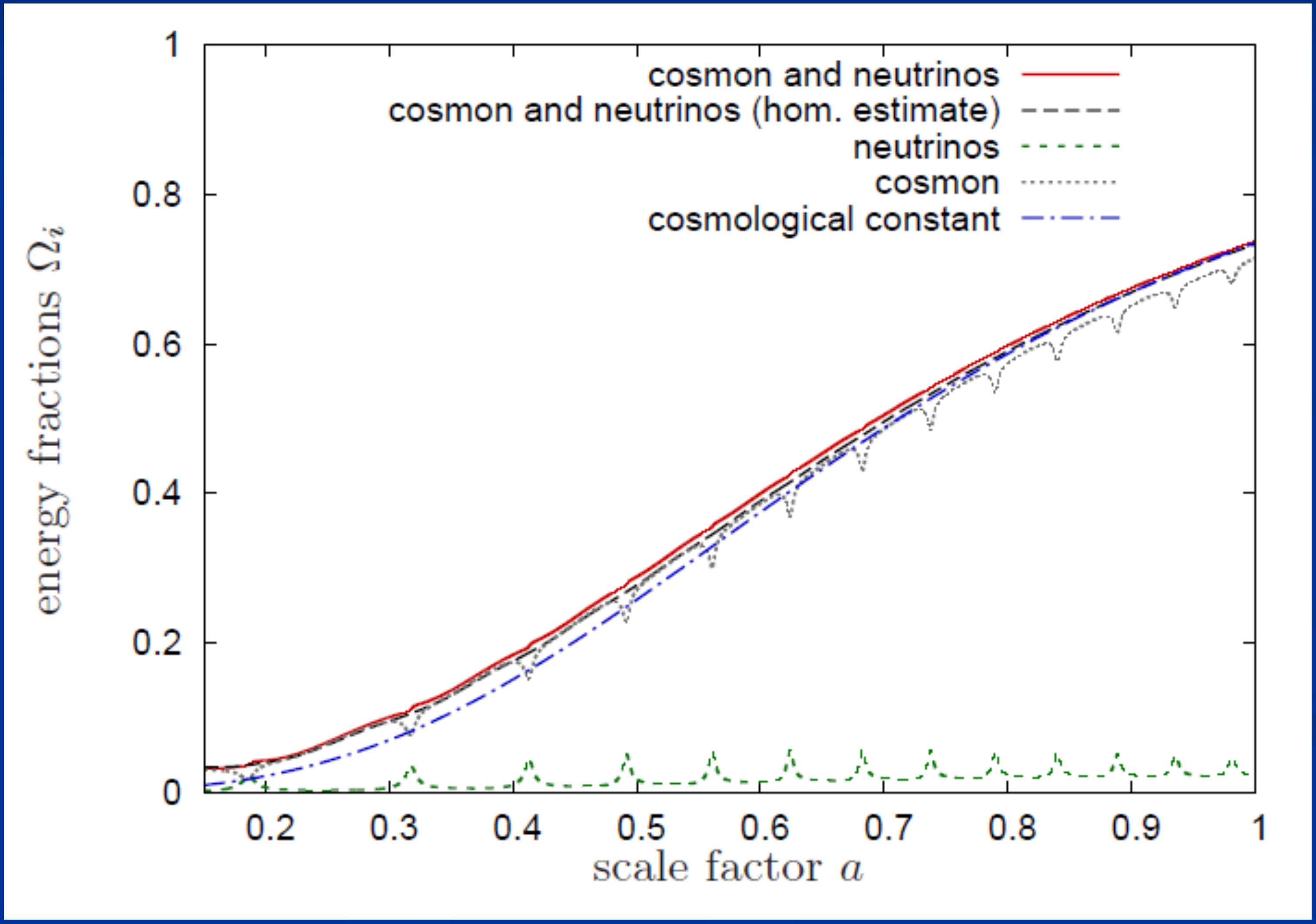


large m_ν

small m_ν

Casas, Pettorino,…

Evolution of dark energy similar to ΛCDM



Compatibility with observations and possible tests

- Realistic inflation model
- Almost same prediction for radiation, matter, and Dark Energy domination as ΛCDM
- Presence of small fraction of Early Dark Energy

  Reduces observed cosmic structures as compared to ΛCDM extrapolation from CMB
- Large neutrino lumps

Conclusions

Quantum gravity may be observable in dynamics of present Universe

Fixed points and scale symmetry crucial

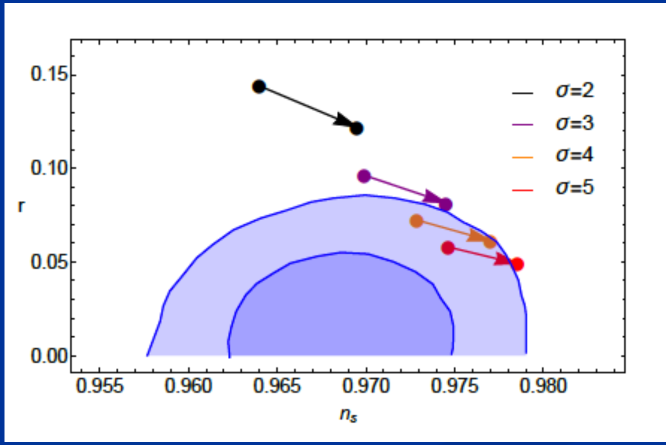
Big bang singularity is artefact of inappropriate choice of field variables – no physical singularity

Simplicity

simple description of all cosmological epochs

natural incorporation of Dark Energy :

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



J.Rubio…

conclusions (2)

- Variable gravity cosmologies can give a simple and realistic description of the 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
- Cosmon dependence of ratio neutrino mass/ electron mass can explain why Universe makes a transition to Dark Energy domination now
- characteristic signal : neutrino lumps

end