Asymptotic Safety

(Martin Reuter)

(I) The Effective Average Action approach to quantum gravity and Asymptotic Safety

(II) The importance of "Background Independence" for Asymptotic Safety

(or: What is the physical meaning of a coarse graining scale when the metric is quantized?)

Standard quantization of gravity $\hat{=}$

degrees of freedom carried by:	$g_{\mu\nu}(x)$
bare action:	$\int d^4x \sqrt{-g}\, R$
calculational method:	$g_{\mu\nu} = \eta_{\mu\nu} + \sqrt{8\pi G}\, h_{\mu\nu}$, perturbative quantization, renormalization

What should be given up in order to arrive at a "fundamental" or "microscopic" quantum theory of gravity?

String Theory: d.o.f., action, calc. meth.

Loop Quantum Gravity: d.o.f., calc. meth.

Asymptotic Safety: calc. meth., action

Asymptotic Safety Approach:

- degrees of freedom carried by $g_{\mu\nu}$
- quantization / renormalization is non-perturbative in an essential way
- bare action Γ_* is not an ad hoc assumption, but a prediction:

  $\Gamma_* \sim \int d^4x \sqrt{-g}\, R$ + "more" is a non-Gaussian fixed point of the (∞-dimensional, non-pert.) Wilsonian renormalization group flow
- fixed point "controls" UV divergences

The Effective Average Action $\Gamma_k[g_{\mu\nu}, \cdots]$

M.R. '96

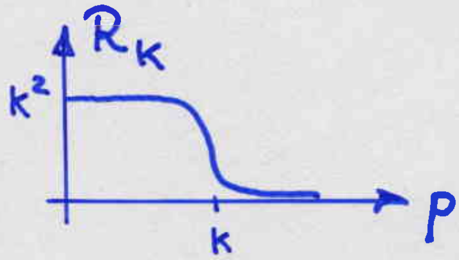
- Scale-dependent (coarse grained) effective action functional for the metric

- Defines family of effective field theories:
  $\{\Gamma_k \mid 0 \leq k < \infty\}$

- Built-in IR cutoff: Only metric fluctuations with cov. momentum $p > k$ are integrated out fully.

  Modes with $p < k$ are suppressed by "mass" term added to the bare action:

  $$(\text{mass})^2 = R_k(p^2)$$



- $\Gamma_{k\to\infty}$ = S = bare action

  $\Gamma_{k\to 0}$ = Γ = standard eff. action

- Γ_k satisfies a FRGE; symbolically:

  $$k\partial_k \Gamma_k = \frac{1}{2}\,\mathrm{STr}\left[\left(\Gamma_k^{(2)} + R_k\right)^{-1} k\partial_k R_k\right]$$

- Natural (nonperturbative) approximation scheme: project RG flow onto truncated theory space

Construction of Γ_k for Gravity

- starting point: $\int \mathcal{D}\gamma_{\mu\nu}\, e^{-S[\gamma_{\mu\nu}]}$
- decompose $\gamma_{\mu\nu} = \bar{g}_{\mu\nu} + h_{\mu\nu}$

  $\bar{g}_{\mu\nu}$: arbitrary backgrd. metric
- add background gauge fixing $S_{gf}[h;\bar{g}]$ + ghost terms
- expand $h_{\mu\nu}$ in $\bar{D}^2$-eigenmodes, and introduce IR cutoff k^2: only modes with generalized momenta ($\bar{D}^2$-eigenvalues) $> k$ are integrated out.
- add sources: generating fctl. $W_k[\text{sources}; \bar{g}]$

$$W_k[\text{sources};\bar{g}] \xrightarrow{\text{Legendre transf.}} \Gamma_k[g_{\mu\nu}, \bar{g}_{\mu\nu}, \text{ghosts}]$$

$g_{\mu\nu} \equiv \langle \gamma_{\mu\nu} \rangle$

- derive exact RG equation from path integral:

$$k\frac{\partial}{\partial k}\Gamma_k[g,\bar{g},\cdots] = \mathrm{Tr}(\cdots)$$

- "Ordinary" diffeomorphism invariant action:

$$\Gamma_k[g] = \Gamma_k[g, \bar{g}=g, \text{ghosts}=0]$$

Taking the UV-limit in QEG

If there exists a non-Gaussian Fixed Point Γ_*, $\beta_i(\Gamma_*) = 0$, Quantum Einstein Gravity is nonperturbatively renormalizable ("asymptotically safe").

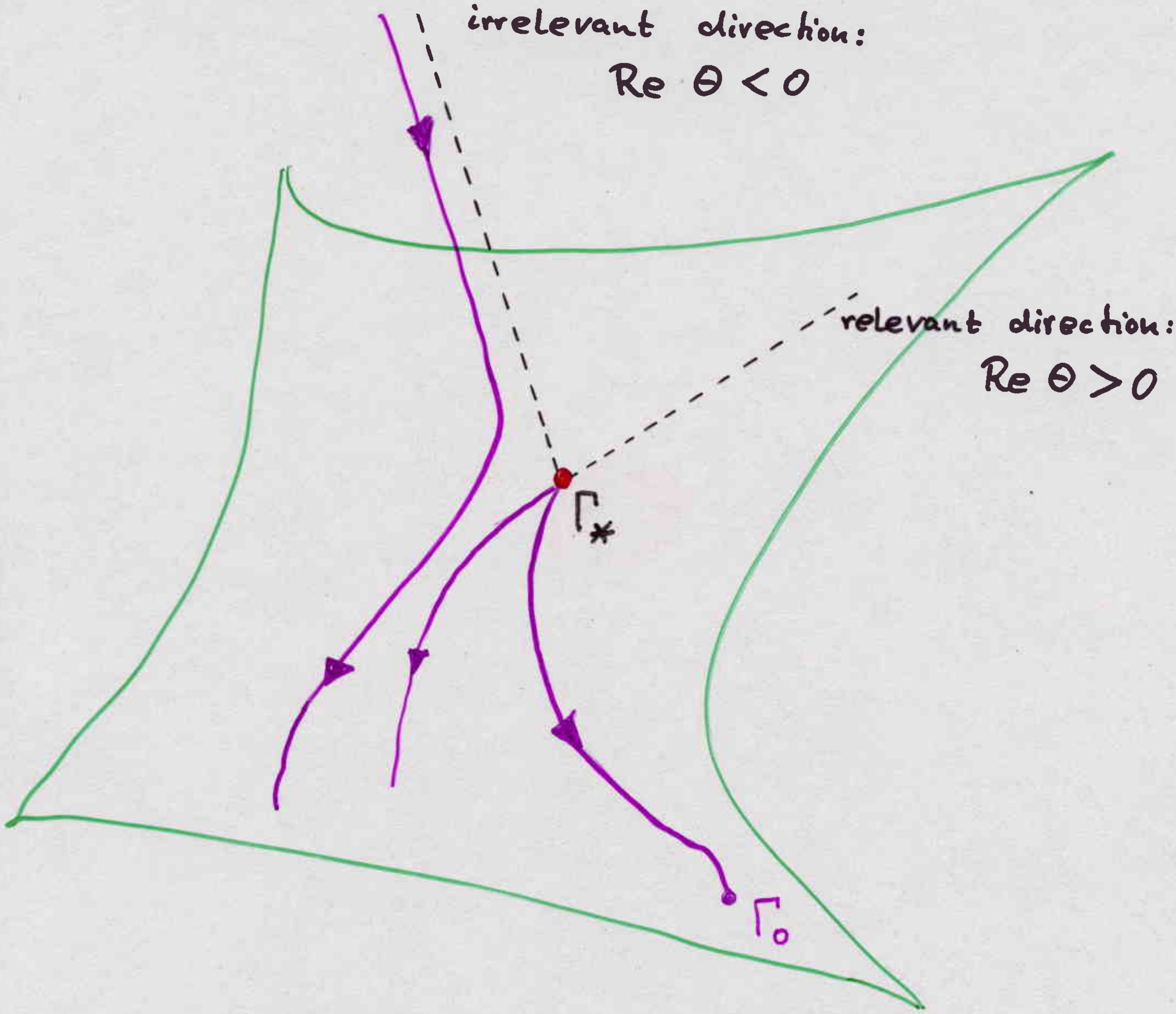
Weinberg 1979

Quantum theory is defined by a RG trajectory running inside the UV-critical hypersurface of the FP, with

initial point $= \Gamma_{k\to\infty} \equiv S$ = action infinitesimally close to Γ_*

end point $= \Gamma_0 \equiv \Gamma$

The UV-critical hypersurface $\mathcal{S}_{UV}$:



$\Delta_{UV} \equiv \dim \mathcal{S}_{UV}$ = # relevant directions

= # free parameters in the a.s. quantum field theory

UV → IR

Θ : critical exponent (neg. eigenvalue of lin. flow)

Properties of QEG

- Background-independent quantization scheme:

No special <u>metric</u> plays any distinguished role!

<u>The background field method</u>:

a) Fix arbitrary $\bar{g}_{\mu\nu}$

b) Quantize (nonlinear) fluctuations $h_{\mu\nu} \equiv \gamma_{\mu\nu} - \bar{g}_{\mu\nu}$ in the backgrd. of $\bar{g}_{\mu\nu}$

c) Adjust $\bar{g}_{\mu\nu}$ such that $\langle h_{\mu\nu} \rangle = 0$

$$\rightsquigarrow \quad g_{\mu\nu} \equiv \langle \gamma_{\mu\nu} \rangle = \bar{g}_{\mu\nu}$$

- Fundamental action $S \approx \Gamma_*$ is a prediction:

No special <u>action</u> plays any distinguished role!

<u>The only input</u>: field contents + symmetries

$\qquad\qquad\qquad\quad \widehat{=}$ theory space

<u>The output</u>: $\Gamma_* = S_{\text{Einstein-Hilbert}} +$ "more"

Einstein-Hilbert action is often a reliable approximation, but not distinguished conceptually.

- Combination average action + background method successfully tested in QED and Yang-Mills theory.

- QEG reproduces successes of classical General Relativity:
$\exists$ trajectories with long classical regime ($G = \text{const}$, $\Lambda = \text{const}$)

- QEG reproduces results of "QFTh. in curved spacetimes" in the classical regime:
Hawking radiation, cosmological particle creation, ...

- Coexistence Asymptotic Safety $\leftrightarrow$ perturbative non-renormalizability well understood;
A.S. tested in models (Gross-Neveu, ...)

- Consistent quantization of gravity seems not to require "fine tuning" of matter system, special symmetries (SUSY, etc.), or unification with the other fundamental forces of Nature.

The Einstein-Hilbert Truncation

(M.R., 1996)

$\Lambda_k \equiv \bar{\lambda}_k$

ansatz:

$$\Gamma_k = -\frac{1}{16\pi G_k} \int d^d x \sqrt{g} \left\{ R - 2\Lambda_k \right\}$$

+ classical gauge fixing and ghost terms

two running parameters:

Newton constant G_k, dimensionless: $g(k) = k^{d-2} G_k$

cosmological constant Λ_k, dimensionless: $\lambda(k) = \Lambda_k / k^2$

insert ansatz into flow equation, expand

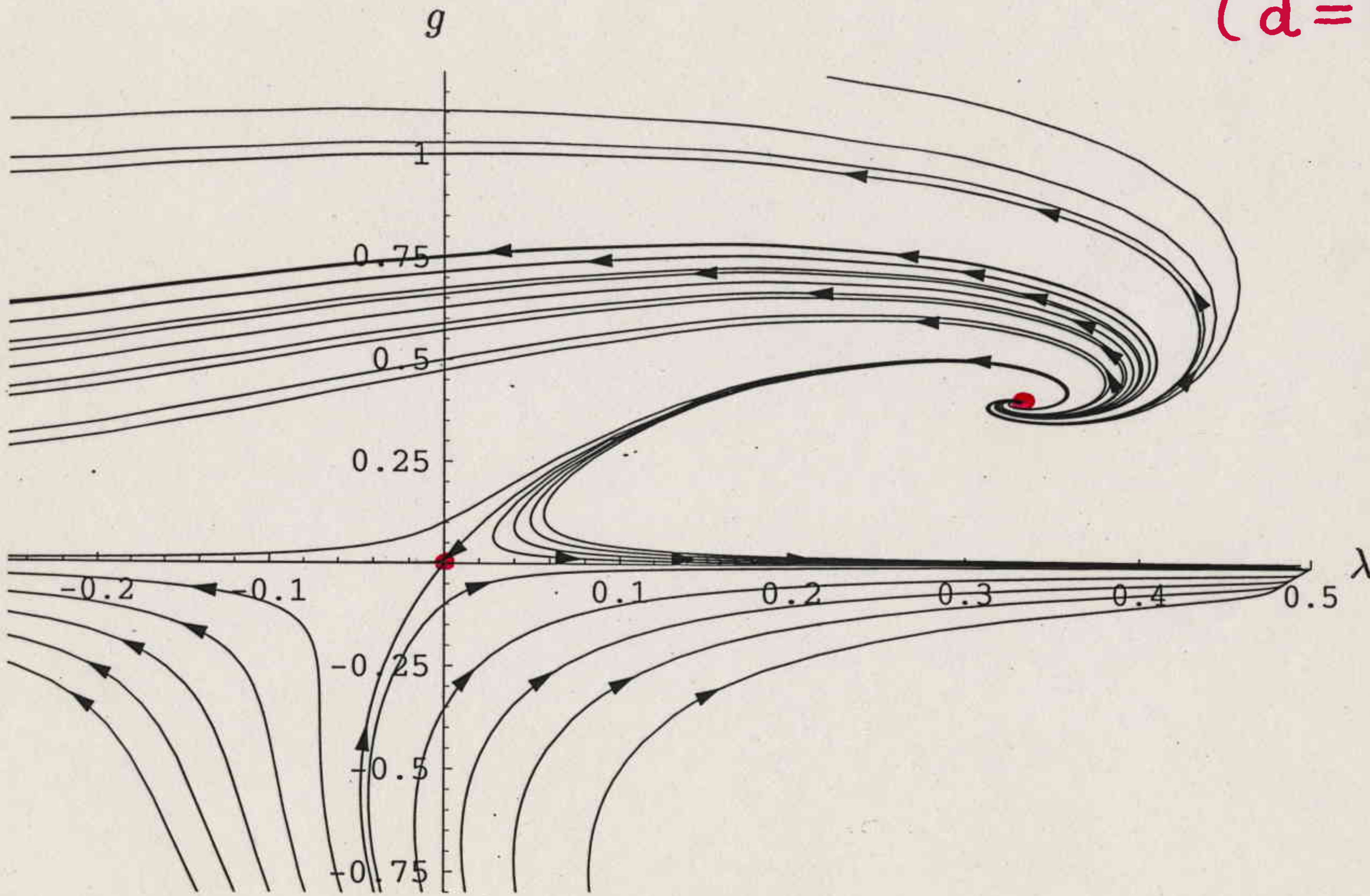
$$\mathrm{Tr}[\cdots] = (\cdots) \int \sqrt{g} + (\cdots) \int \sqrt{g} R + \cdots$$

$\rightsquigarrow$

$$\boxed{\begin{aligned} k\,\partial_k\, g(k) &= \beta_g(g,\lambda) \\ k\,\partial_k\, \lambda(k) &= \beta_\lambda(g,\lambda) \end{aligned}}$$

RG-Flow in the Einstein-Hilbert Truncation

(d=4)



M.R., F. Saueressig, hep-th/0110054

Conformally Reduced QEG

(M.R., H. Weyer, 2008)

- Simplified version of full QEG:
  only the conformal factor is quantized

- The same approach as in full QEG is used:
  effective average action,
  background field method

- Disentangles conceptual / technical problems

- Illustrates importance of "background independence" for the RG flow:

  scalar-like theory, but with RG behavior <u>very</u> <u>different</u> from that of a scalar matter field on a rigid spacetime

- Disentangles role of backgrd. field method for gauge invariance / "backgrd. independence"

- Has the same qualitative features as full QEG

  ⇝ play ground for gaining new conceptual insights

Conformally Reduced QEG

- quantize only the conformal factor:

$$\underbrace{\gamma_{\mu\nu}}_{\text{integration variable}} = \chi^2 \underbrace{\hat{g}_{\mu\nu}}_{\text{class. reference metric, } \neq \text{ backgrd. metric !}}$$

- treat scalar-like theory $\int \mathcal{D}\chi \, e^{-S[\chi]}$ in the same way as full QEG:
effective average action $\oplus$ backgrd. field method

- introduce background conf. factor:

$$\bar{g}_{\mu\nu} = \chi_B^2 \, \hat{g}_{\mu\nu}$$

- decompose quantum field:

$$\chi = \chi_B + \underbrace{f}_{\text{"fluctuation"}}$$

- expectation values:

$$\phi \equiv \langle \chi \rangle = \chi_B + \bar{f} \, , \quad \bar{f} \equiv \langle f \rangle$$

$$g_{\mu\nu} \equiv \langle \gamma_{\mu\nu} \rangle = \langle \chi^2 \rangle \, \hat{g}_{\mu\nu} = \langle (\chi_B + f)^2 \rangle \, \hat{g}_{\mu\nu}$$

The innocent first steps :

- define, formally,
$$e^{W_k[J;\chi_B]} =$$
$$= \int \mathcal{D}f \; e^{-S[\chi_B+f]-\Delta_k S[f;\chi_B] + \int d^4_x \sqrt{\hat{g}} \; J \; f}$$

with $$\Delta_k S[f;\chi_B] = \frac{1}{2} \int d^4_x \sqrt{\hat{g}} \; f(x) \, \mathcal{R}_k[\chi_B] \, f(x)$$

- define $$\bar{f} \equiv \langle f \rangle_k = \frac{1}{\sqrt{\hat{g}}} \frac{\delta W_k}{\delta J}$$

$$\rightsquigarrow \quad J = \mathcal{J}_k[\bar{f};\chi_B]$$

- define effective average action:

$$\Gamma_k[\bar{f};\chi_B] = \int d^4_x \sqrt{\hat{g}} \; \bar{f} \, \mathcal{J}_k - W_k[\mathcal{J}_k;\chi_B] - \Delta_k S[\bar{f};\chi_B]$$
$$\equiv \Gamma_k[\phi, \chi_B] \qquad \phi \equiv \chi_B + \bar{f}$$

- derive FRGE :

$$\boxed{k\partial_k \Gamma_k[\bar{f};\chi_B] = \frac{1}{2} \mathrm{Tr}\left[\left(\Gamma_k^{(2)}[\bar{f};\chi_B] + \mathcal{R}_k[\chi_B]\right)^{-1} k\partial_k \mathcal{R}_k[\chi_B]\right]}$$

Truncations employed :

- Conformally Reduced Einstein-Hilbert ("CREH") truncation :

$$\Gamma_k[\bar{f};\chi_B] \equiv \Gamma_k[\phi, \chi_B]$$

$$= -\frac{1}{16\pi G_k}\int d^4x \sqrt{g}\left(R(g) - 2\Lambda_k\right)\Big|_{g_{\mu\nu} = \phi^2 \hat{g}_{\mu\nu}}$$

$$= \frac{3}{4\pi G_k}\int d^4x \sqrt{\hat{g}}\left\{\frac{1}{2}\phi\hat{\Box}\phi - \frac{1}{12}\hat{R}\phi^2 + \frac{1}{6}\Lambda_k\phi^4\right\}$$

depends only on the combination $\phi \equiv \chi_B + \bar{f}$;

2-dimensional theory space : $\{g, \lambda\}$

- Local Potential Approximation (LPA):

$$\Gamma_k[\phi, \chi_B] = \frac{3}{4\pi G_k}\int d^4x \sqrt{\hat{g}}\left\{\frac{1}{2}\phi\hat{\Box}\phi - F_k(\phi)\right\}$$

infinite dimensional theory space :

$$\{G, F(\cdot)\} \sim \{g, Y(\cdot)\}$$

Project flow on truncated theory space:

$$k\partial_k \Gamma_k[\bar{f};\chi_B]$$

$$= \frac{3}{4\pi}\int d_x^4 \sqrt{\hat{g}} \left\{ \frac{1}{2}\, k\partial_k\left(\frac{1}{G_k}\right)\phi\,\hat{\Box}\,\phi - k\partial_k\left(\frac{F_k(\phi)}{G_k}\right)\right\}$$

$\phi = \chi_B + \bar{f}$

$$= \frac{1}{2}\mathrm{Tr}\left[\left(\cdots \frac{\delta^2}{\delta \bar{f}^2}\Gamma_k[\bar{f};\chi_B] + \cdots\right)^{-1} \cdots\right]$$

- perform $\bar{f}$-derivatives ($\bar{f}$ arb.)
- set $\bar{f}=0$, $\chi_B = \phi$
- equate coeffs. of equal terms with 0 and 2 deriv.'s

$$\Longrightarrow \beta_G, \beta_F$$

$$\Gamma_k^{(2)}\Big|_{\bar{f}=0} = -\frac{3}{4\pi G_k}\left[-\hat{\Box} + F_k''(\phi)\right]$$

Constructing $\mathcal{R}_k$:

"backgrd. independence" vs. rigid backgrd.

- require coarse graining scale k^{-1} of $\Gamma_k[g, \bar{g}]$ to be a <u>proper</u> (rather than coordinate) length

- "proper" w.r.t. which metric ?

- "backgrd. independence" $\Longrightarrow$ k^{-1} can be proper only w.r.t. metric given by the arguments $[g, \bar{g}]$, but not w.r.t. any rigid metric (such as $\hat{g}_{\mu\nu}$ in CR-QEG)

- <u>Our choice :</u> k^{-1} is proper w.r.t. $\bar{g}_{\mu\nu}$

  more precisely :
$$\boxed{\begin{array}{l} -k^2 \text{ is a cutoff in} \\ \text{the spectrum of} \\ \quad \bar{\Box} \equiv (D^\mu D_\mu)(\bar{g}) \end{array}}$$

  $\Longrightarrow$ Typical structures (periods, $\cdots$) of $\bar{\Box}$ - eigenfunction with eigenvalue $-k^2$ have $\bar{g}$ - proper size of the order k^{-1} .

  $\Longrightarrow$ $\Gamma_k \;\hat{=}$ "effective field theory valid near k"

- <u>Cf. rigid backgrd.</u> : $-k^2$ cutoff in $\hat{\Box}$ - spectrum

Implementation (LPA):

- $\mathcal{R}_k$ must be such that $\Gamma_k^{(2)} \longrightarrow \Gamma_k^{(2)} + \mathcal{R}_k$ entails the replacement

$$(-\bar{\Box}) \longrightarrow (-\bar{\Box}) + \underbrace{k^2 R^{(0)}\left(\frac{-\bar{\Box}}{k^2}\right)}_{\stackrel{!}{=} \begin{cases} 0 & \text{if } -\bar{\Box} \gg k^2 \\ 1 & \text{if } -\bar{\Box} \ll k^2 \end{cases}}$$

- Since $\bar{\Box} = \chi_B^{-2} \hat{\Box}$ when $\bar{g}_{\mu\nu} = \chi_B^2 \, \hat{g}_{\mu\nu}$ with $\chi_B = \text{const}$, this is equivalent to:

$$(-\hat{\Box}) \longrightarrow (-\hat{\Box}) + \chi_B^2 \, k^2 R^{(0)}\left(\frac{-\hat{\Box}}{\chi_B^2 k^2}\right)$$

absent when k is proper w.r.t. $\hat{g}_{\mu\nu}$!

- "Backgrd. independent" choice of $\mathcal{R}_k$ contains additional factors of χ_B compared to standard quantization of scalar matter field on rigid backgrd.:

$$\boxed{\mathcal{R}_k = -\frac{3}{4\pi G_k} \chi_B^2 \, k^2 R^{(0)}\left(\frac{-\hat{\Box}}{\chi_B^2 k^2}\right)}$$

Flow equations and β-functions

$$Y_k(\varphi) \equiv k^2 \, F_k\left(\frac{\varphi}{k}\right), \quad \varphi \equiv k\phi$$ dim. less

$$g_k \equiv k^2 G_k, \quad \lambda_k \equiv \Lambda_k / k^2$$

$$k\partial_k g_k = \left[2 + \eta_N\left(g_k, [Y_k]\right)\right] g_k$$

$$k\partial_k Y_k(\varphi) = (2+\eta_N) Y_k - \varphi Y_k' - \frac{g_k}{24\pi}\left(1 - \frac{1}{6}\eta_N\right) \frac{\varphi^6}{\varphi^2 + Y_k''(\varphi)}$$

anomalous dimension:

$$\eta_N(g, [Y]) = -\frac{g}{24\pi} \frac{\left[\varphi_1^3 \, Y'''(\varphi_1)\right]^2}{\left[\varphi_1^2 + Y''(\varphi_1)\right]^4}$$

(R^4 topology)

φ_1 : normalization point ($\varphi_1 \to \infty$).

Compare to standard scalar on rigid backgrd.:

$$\frac{\phi^6 k^6}{\phi^2 k^2 + F_k''(\phi)} \longrightarrow \frac{k^6}{k^2 + F_k''(\phi)}$$

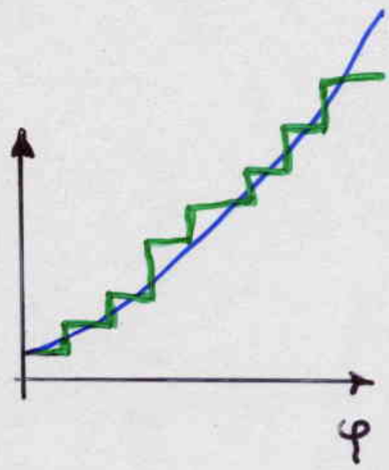
β_Υ for any topology:

$$k\partial_k \Upsilon_k(\varphi) = (2+\eta_N)\Upsilon_k - \varphi\Upsilon_k' - \frac{g_k}{4\pi}\frac{(2-\eta_N)\varphi^2\,\varrho(\varphi) + \eta_N\,\tilde{\varrho}(\varphi)}{\varphi^2 + \Upsilon_k''(\varphi)}$$

$$\begin{cases} \varrho(\varphi) \equiv \mathrm{Tr}\left[\Theta(\varphi^2 + \hat{\Box})\right] \\ \tilde{\varrho}(\varphi) \equiv \mathrm{Tr}\left[(-\hat{\Box})\,\Theta(\varphi^2 + \hat{\Box})\right] \end{cases}$$

Example: S^4

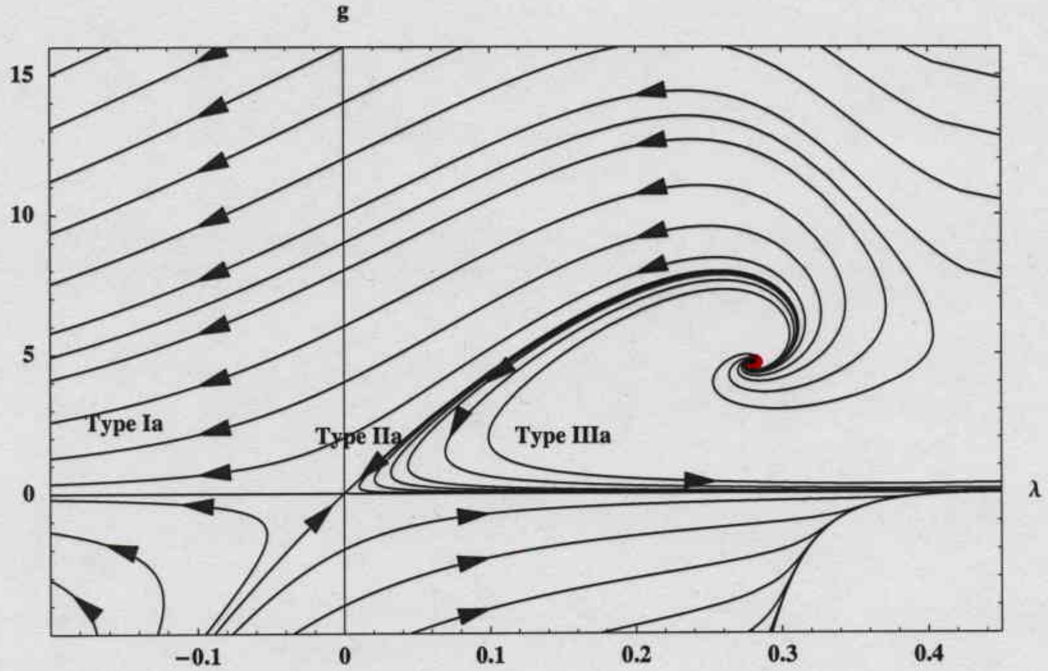
$$\begin{cases} \varrho(\varphi) = \sum_{n=0}^{\infty} D_n\,\Theta(\varphi^2 - \mathcal{E}_n) \\ \tilde{\varrho}(\varphi) = \sum_{n=0}^{\infty} \mathcal{E}_n D_n\,\Theta(\varphi^2 - \mathcal{E}_n) \end{cases}$$



$$\mathcal{E}_n \equiv n(n+3)$$

$$D_n \equiv \frac{1}{6}(n+1)(n+2)(2n+3)$$

The CREH flow: $Y_k(\varphi) = -\frac{1}{6}\lambda_k \varphi^4$



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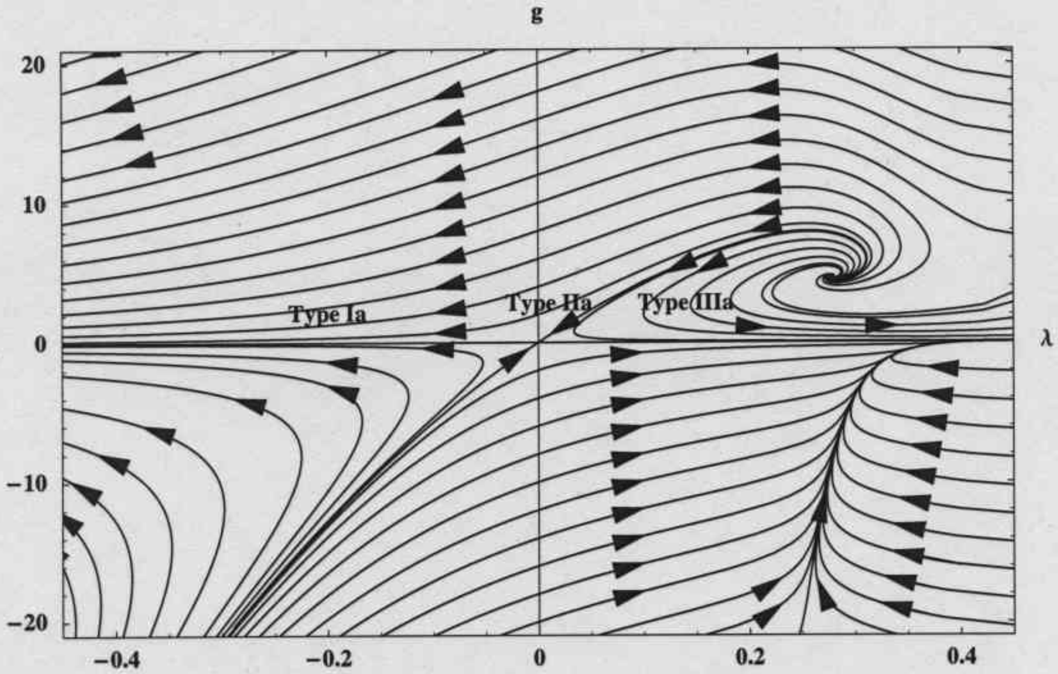


(b)

Figure 1: The figures show the RG flow on the (g, λ)-plane which is obtained from the CREH truncation with $\eta_N^{(\mathrm{kin})}$. The arrows point in the direction of decreasing k.

M.R., H.Weyer, arXiv: 0801.3287

Example: Running of the cosmological constant near the GFP

obtains from interaction term $\Lambda_k \phi^4$

- rigid background quantization:

standard ϕ^4-theory $\Longrightarrow$ $\boxed{\Lambda_k \sim \log(k)}$

Polyakov (2001)
Jackiw et al. (2005)

- "background independent" quantization:

$$\boxed{\Lambda_k \sim G_0 k^4}$$

consistent with full QEG

and sum over zero-point energy approach

Gaussian Fixed Point (LPA)

$$g_*^{GFP} = 0 \;, \quad \Upsilon_*^{GFP}(\varphi) = c\,\varphi^2$$

Linearization:

$$\delta g_k \sim y_g \, k^{-\Theta}$$

$$\delta \Upsilon_k(\varphi) \sim v(\varphi)\, k^{-\Theta}$$

Scaling fields $(y_g, v(\cdot))$ and dimensions Θ:

(i) $\exists$ scaling field $(y_g \neq 0, \; v = \hat{v})$ with $\Theta = -2$;

$$\hat{v} = -\frac{y_g}{96\pi}\varphi^4 + O(\varphi^3)$$

(ii) $\forall\, \Theta \in \mathbb{R}$ $\exists$ scaling field $(y_g = 0, \; v = \varphi^{2+\Theta})$,

i.e. φ^n has dimension $\Theta = n-2$!

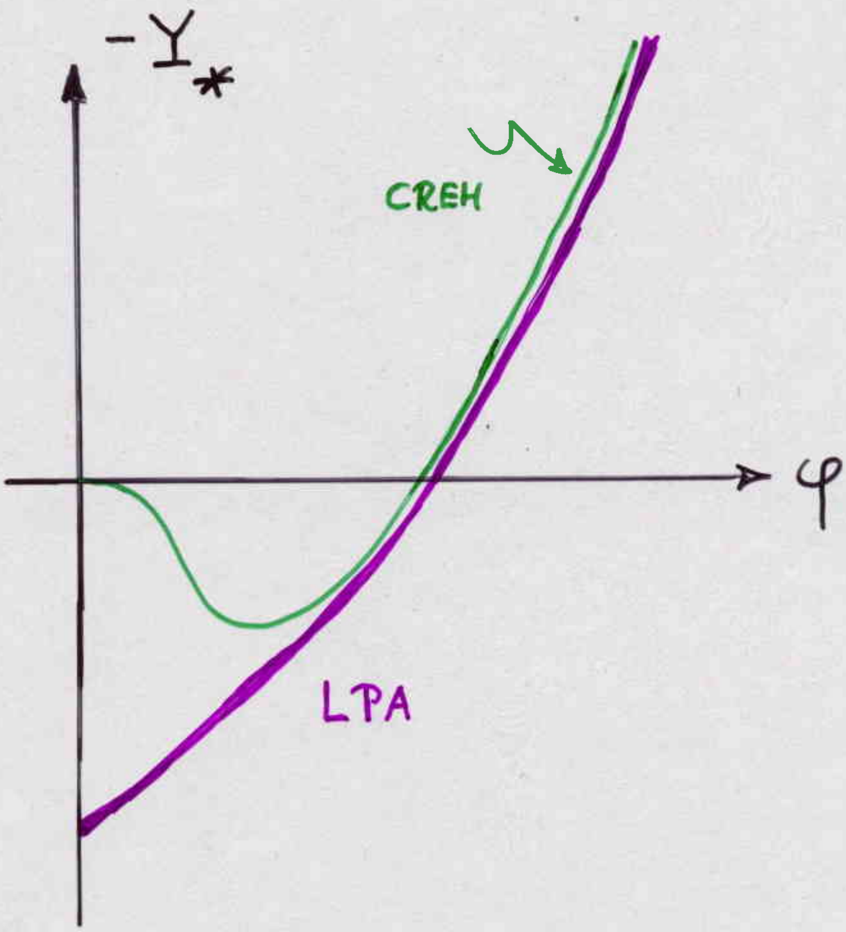
cf. standard scalar: $\Theta = n-4$

Θ	...	-3	-2	-1	0	$+1$	$+2$	$+3$	...
	irrelevant				marg.	relevant			
$y_g = 0,\; v =$	...	φ^{-1}	φ^0	φ^1	φ^2	φ^3	φ^4	φ^5	...
$y_g \neq 0,\; v =$			$\hat{v}$						

Non-Gaussian Fixed Point (LPA)

$$\begin{cases} g_*^{NGFP} = g_*^{CREH} \\ \Upsilon_*^{NGFP}(\varphi) = y_* - \frac{1}{6}\lambda_*^{CREH}\varphi^4 \end{cases} \qquad (R^4)$$

Numerical solution for S^4 topology :



Corresponds to non-trivial fixed points of infinitely many couplings !

Scaling fields / dimensions (R^4) :

(i) $\exists$ two scaling fields $(y_g \neq 0,\ \Upsilon = \varphi^4)$

with $\Theta = \Theta^{\text{CREH}}$.

(ii) $\exists$ infinitely many scaling fields $(y_g = 0,\ \Upsilon)$:

- $\Upsilon = \varphi^n$, $n \in \mathbb{C}$, $\Theta(n) = (1+\alpha)n - \alpha n^2 \in \mathbb{C}$
- $\Upsilon = \varphi^{\frac{1+\alpha}{2}}, \varphi^{\frac{1+\alpha}{2}} \ln\varphi$, $\Theta = (1+\alpha)^2/4\alpha$ $\qquad \alpha \equiv \frac{2^{1/3}}{3}$

Eigenvalue problem well defined if $\mathrm{Re}\, n \leq 4$

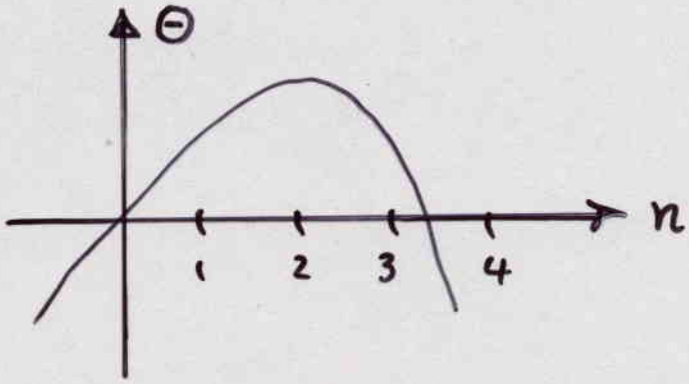
- Number of relevant / irrelevant directions depends on the precise definition of theory space, i.e. of $\{Y(\cdot)\}$ and its tangent space at the NGFP, $\{\Upsilon(\cdot)\}$.

- Choice of $\{\Upsilon(\cdot)\}$ determines set of allowed

$$n \equiv n' + i\, n'' \longleftrightarrow \Theta \equiv \Theta' + i\, \Theta''$$

- **Example:** $n \in \mathbb{Z}$ or $n \in \mathbb{N}$

$\rightsquigarrow$ Θ real



$\varphi, \varphi^2, \varphi^3$ relevant, φ^0 marginal,

all other φ^n irrelevant

- **Example:** $n \in \mathbb{C}$

infinitely many relevant and irrelevant directions; generic scaling field is non-polynomial oscillatory function of φ:

$$\mathrm{Re}\ \delta Y_k(\varphi) \sim \varphi^{n'}\, e^{-\Theta' t} \cos\left(n'' \ln\varphi - \Theta'' t\right)$$

Similar to Halpern-Huang directions of standard scalar at its GFP.

- Correct / optimal choice of theory space unknown:
  should mimic full QEG as well as possible

Phase Transitions to a new phase of gravity: Unbroken Diffeomorphism Invariance

- Solve full nonlinear PDE for Y_k numerically, search for trajectories inside $\mathcal{S}_{UV}$.

- Global minimum $\phi_0(k) \equiv k\,\varphi_0(k)$ of $F_k(\phi) \sim -Y_k(\varphi)$ determines expectation value

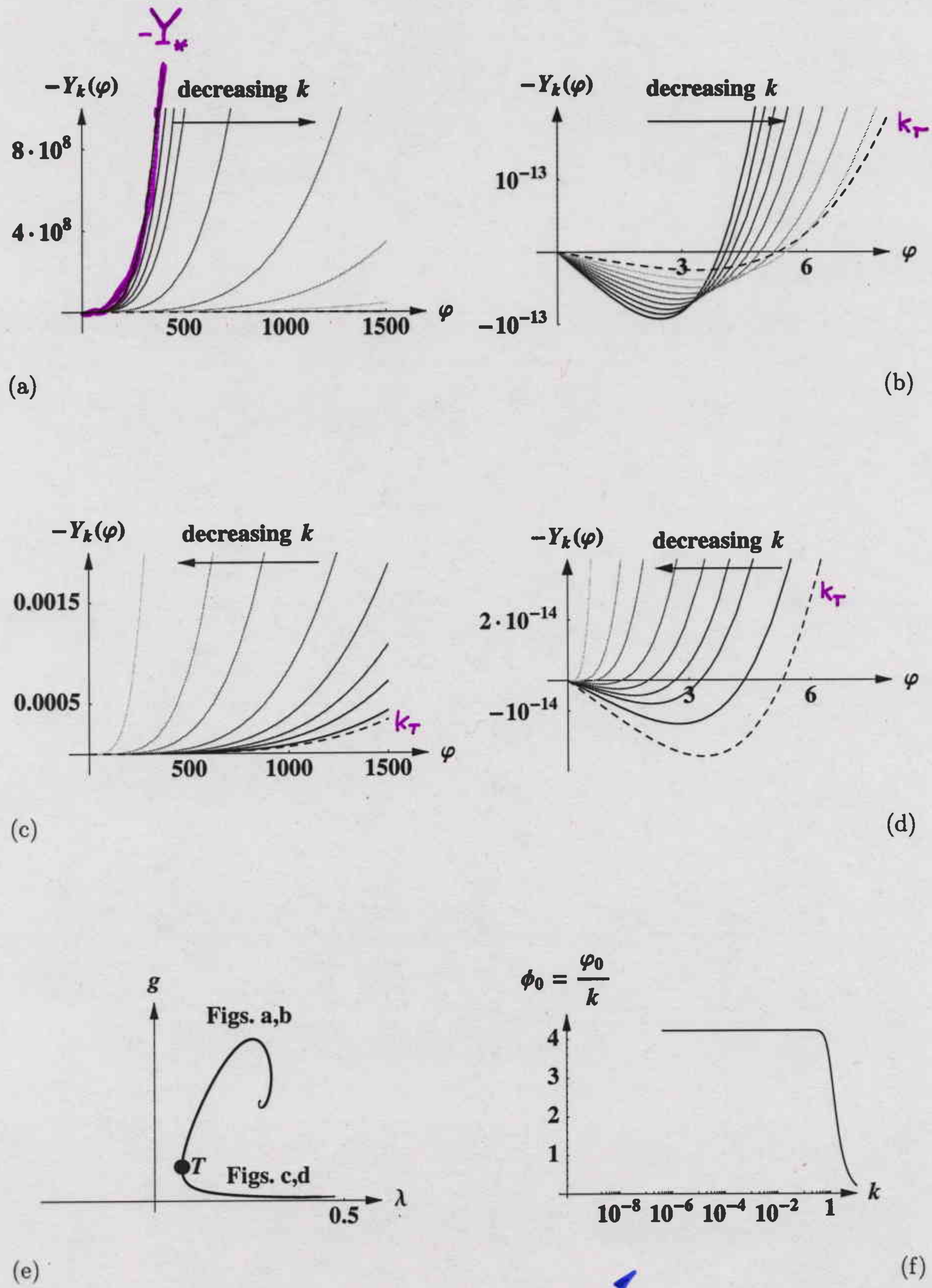
$$\langle \gamma_{\mu\nu} \rangle \equiv \langle g_{\mu\nu} \rangle_k = \phi_0^2(k)\ \hat{g}_{\mu\nu}$$

- $\phi_0 = 0$: phase with vanishing exp. val. of the metric (vielbein)

  $\phi_0 \neq 0$: exp. val. $\neq 0$, spontaneously breaks group of diffeo.'s to stability group of $\langle g_{\mu\nu} \rangle_k$

- Forms of phase transitions (w.r.t. scale k):
  - "1^{st} order" $\longleftrightarrow$ "2^{nd} order"
    (φ_0 discontinuous) (φ_0 continuous)
  - at k "$=$" ∞ $\longleftrightarrow$ at $k = k_c < \infty$

2^{nd} order transition at k "=" ∞ (R^4)

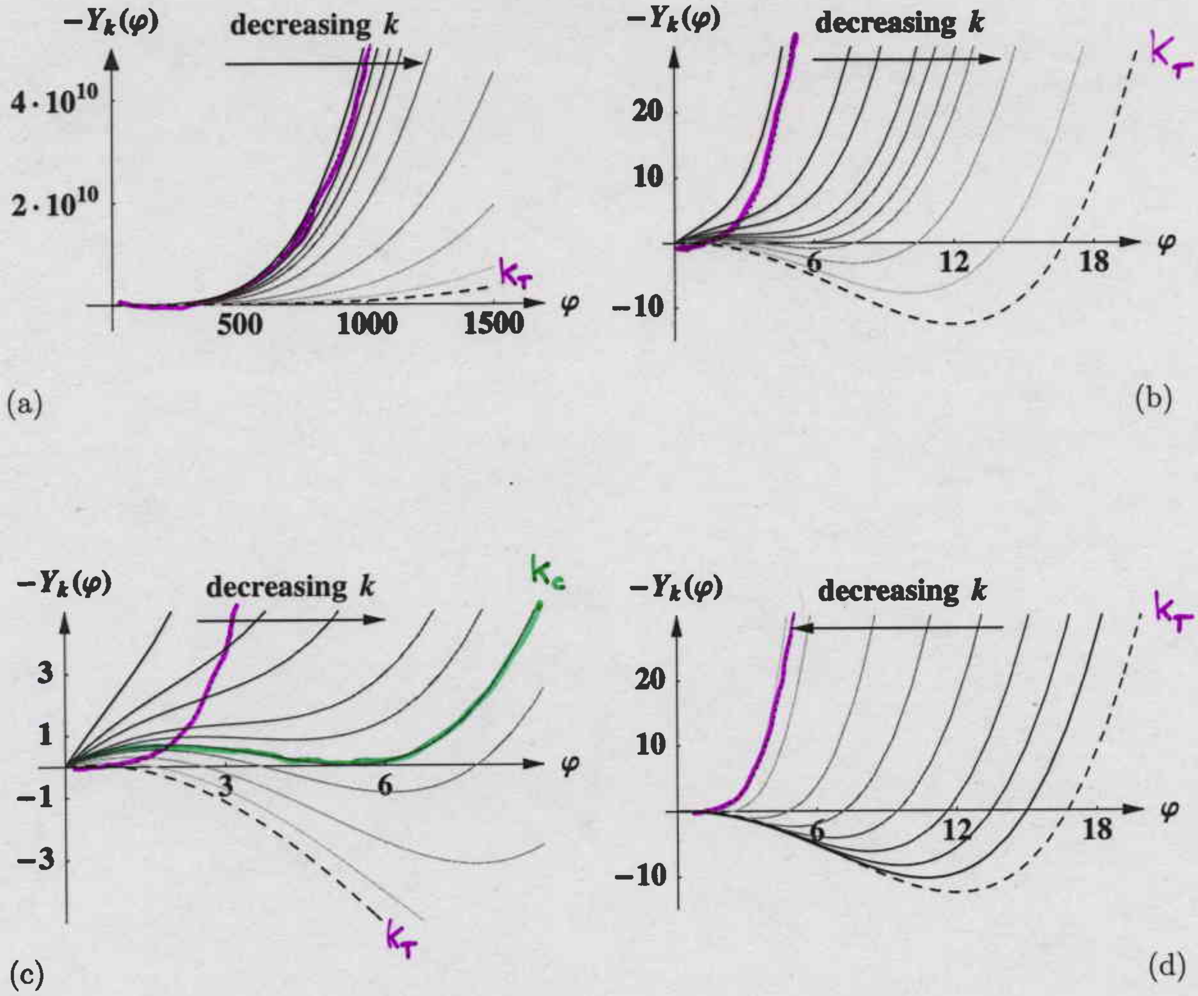


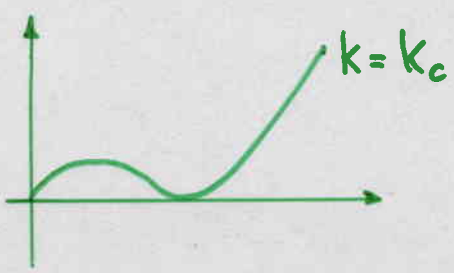
classical spacetime emerges:

$\phi_0 \approx \text{const} \neq 0$

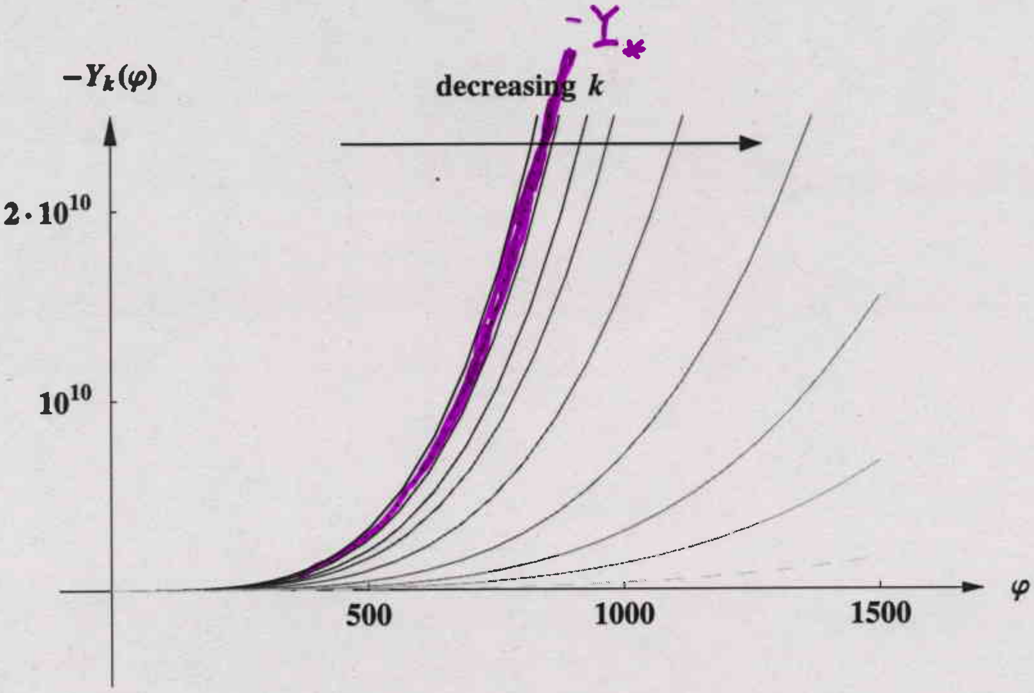
M. R., H. Weyer, arXiv: 0804.1475

1^{st} order transition at $k_c < \infty$ (R^4)

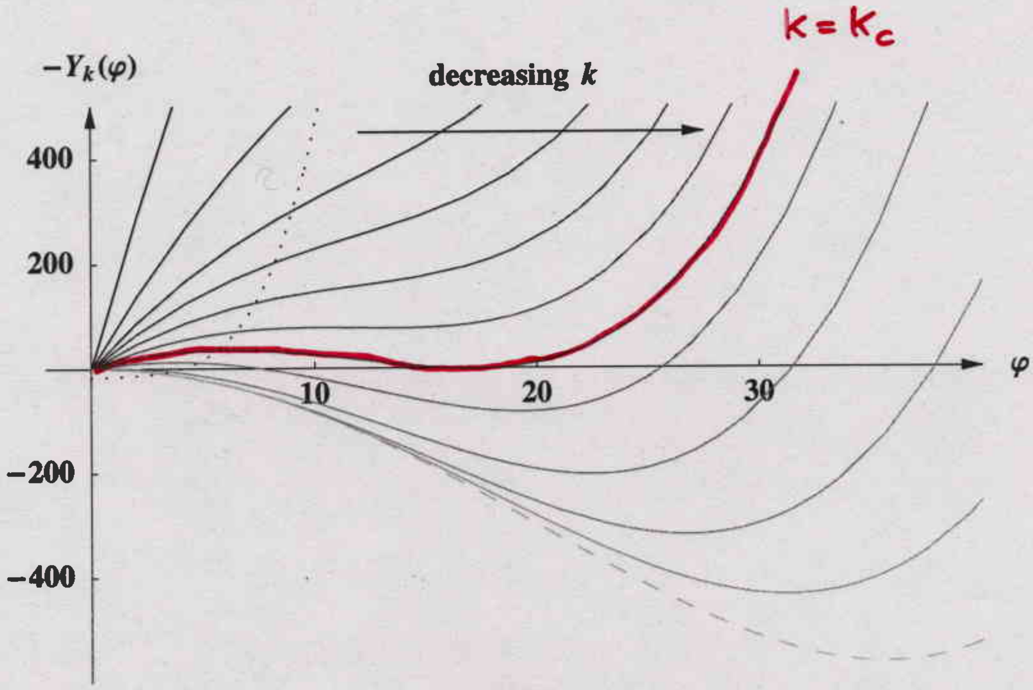




1^{st} order transition at $k_c < \infty$ (S^4)



(a)



(b)

Summary

- "Backgrd. independence" has a crucial impact on the RG flow of the eff. average action:

  - rigid backgrd: standard $-\phi^4$ theory (asymptotically free: Symanzik '73)

  - "backgrd. indep.": NGFP forms $\Rightarrow$ A. S.

- RG flow due to the conformal factor is <u>typical</u> of the full set of metric degrees of freedom:

  "backgrd. indep." seems to be more important to A. S. than spin-2 excitations, their complicated self-interactions, etc. !