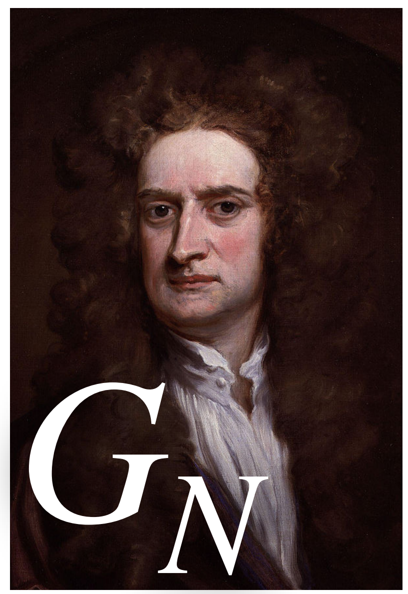
The BRITISH UNIVERSITY IN EGYPT
CENTRE FOR THEORETICAL PHYSICS

Frozen Axions & Global Dynamics



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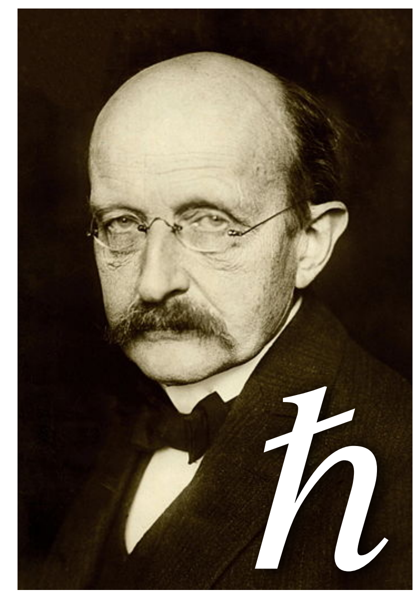

Alexander Vikman

07.02.2023

FZU Institute of Physics of the Czech Academy of Sciences

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Journal of Cosmology and Astroparticle Physics
An IOP and SISSA journal

Losing the trace to find dynamical Newton or Planck constants

Pavel Jiroušek,[a,b] Keigo Shimada,[c] Alexander Vikman[a] and Masahide Yamaguchi[c]

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JCAP04(2021)028 arXiv 2011.07055

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Global Dynamics for Newton and Planck

arXiv 2107.09601

Message to take home

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- There are *local, general-covariant field theories* where the dynamical degrees of freedom are *global,* e.g. given by integrals over the whole Cauchy hypersurface. This is a field theory cover-up of the usual "high school" mechanics.

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- Λ, G_N and even $\hbar$ as global degrees of freedom can be *frozen* axions for a confined Yang-Mills / QCD.

- The origin of the values of these global degrees of freedom should be in quantum cosmology - they are remnants of the BIG BANG - ideal "Landscape" for poor people

What a Strange Theory!

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Λ as a global dynamical degree of freedom

first way to lose the trace

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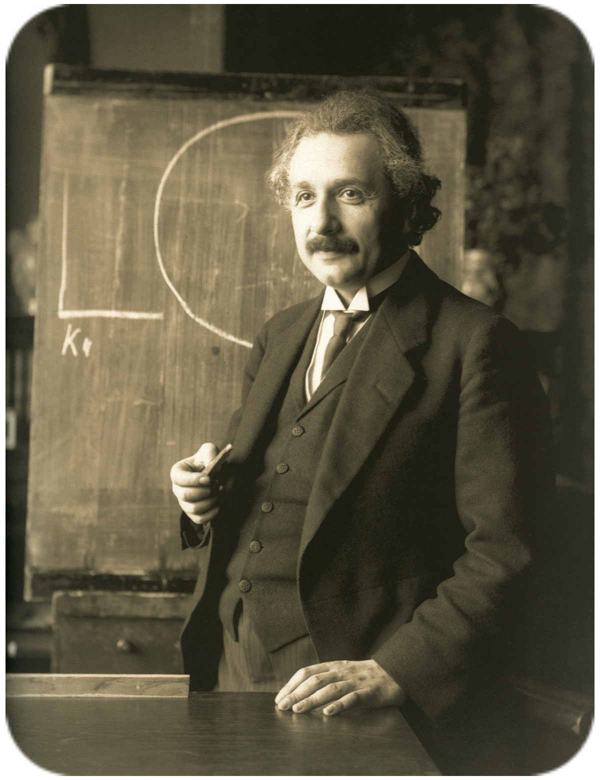

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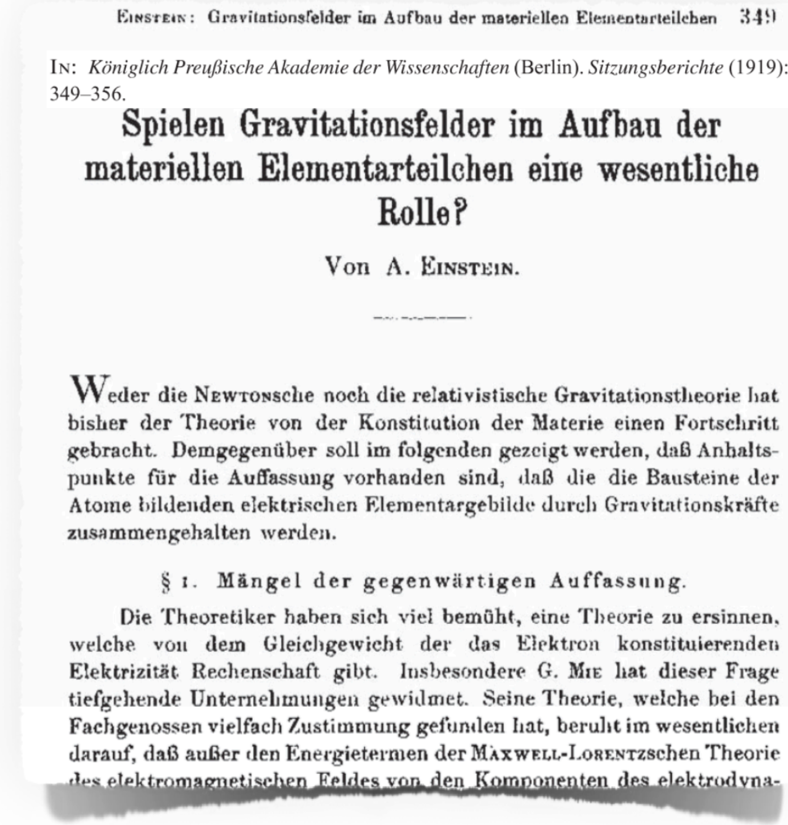

EINSTEIN: Gravitationsfelder im Aufbau der materiellen Elementarteilchen 349

IN: *Königlich Preußische Akademie der Wissenschaften* (Berlin). *Sitzungsberichte* (1919): 349–356.

Spielen Gravitationsfelder im Aufbau der materiellen Elementarteilchen eine wesentliche Rolle?

Von A. EINSTEIN.

Weder die NEWTONsche noch die relativistische Gravitationstheorie hat bisher der Theorie von der Konstitution der Materie einen Fortschritt gebracht. Demgegenüber soll im folgenden gezeigt werden, daß Anhaltspunkte für die Auffassung vorhanden sind, daß die die Bausteine der Atome bildenden elektrischen Elementargebilde durch Gravitationskräfte zusammengehalten werden.

§ 1. Mängel der gegenwärtigen Auffassung.

Die Theoretiker haben sich viel bemüht, eine Theorie zu ersinnen, welche von dem Gleichgewicht der das Elektron konstituierenden Elektrizität Rechenschaft gibt. Insbesondere G. MIE hat dieser Frage tiefgehende Unternehmungen gewidmet. Seine Theorie, welche bei den Fachgenossen vielfach Zustimmung gefunden hat, beruht im wesentlichen darauf, daß außer den Energietermen der MAXWELL-LORENTZschen Theorie des elektromagnetischen Feldes von den Komponenten des elektrodyna-

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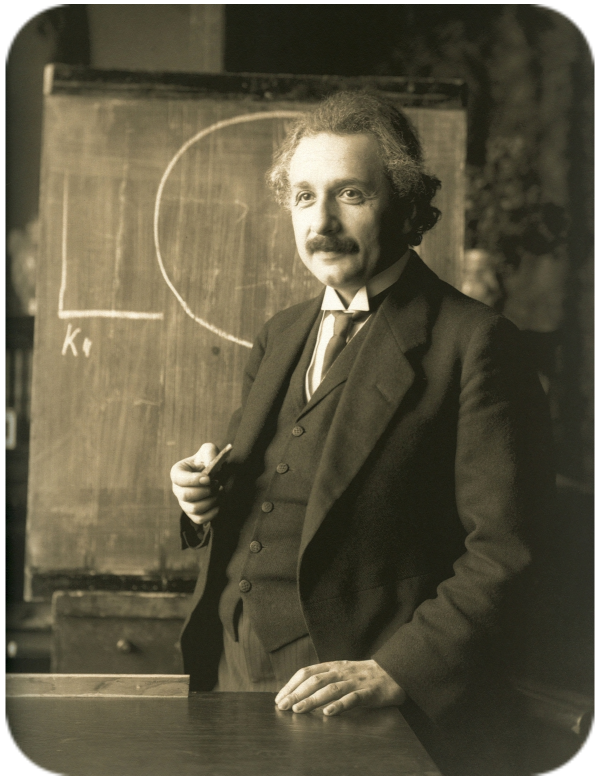

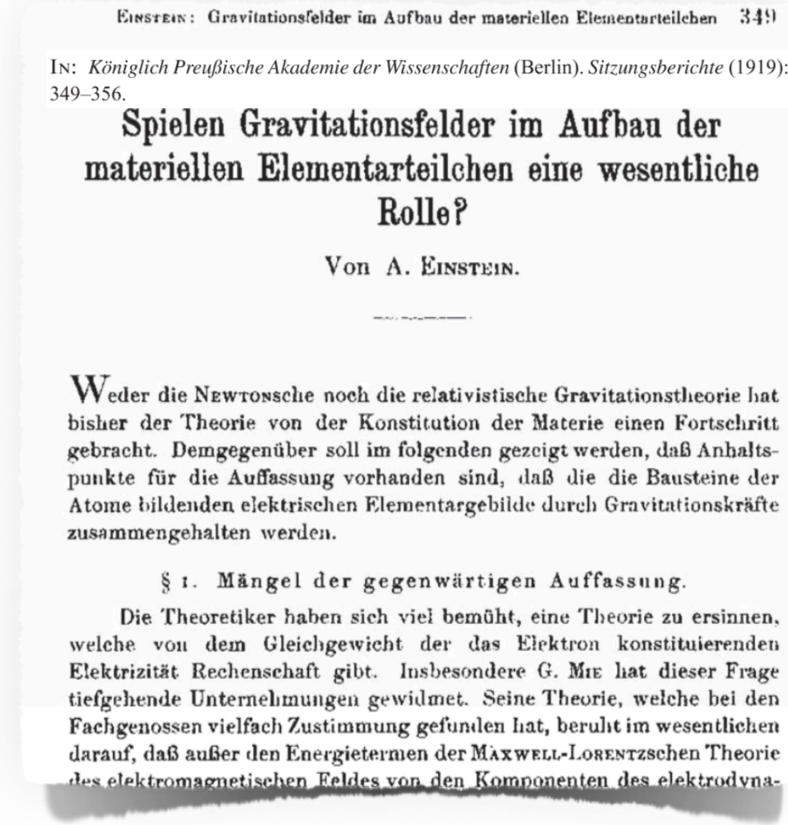

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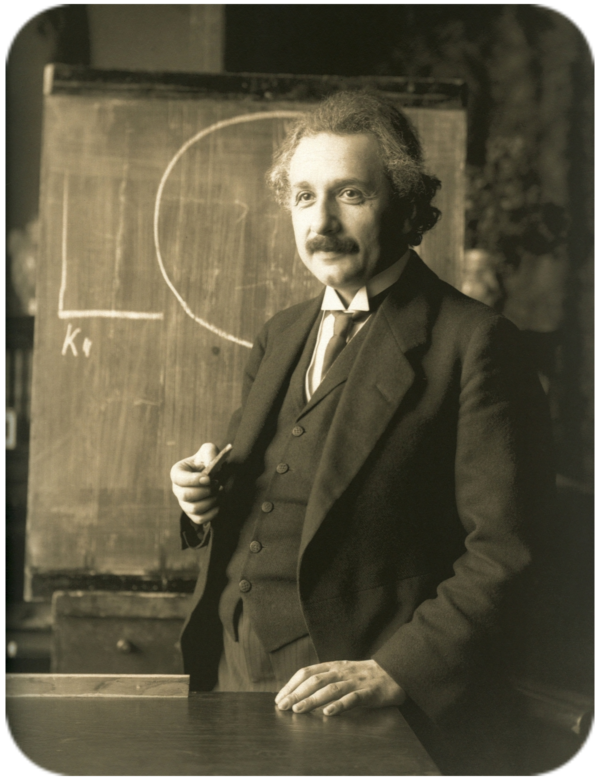

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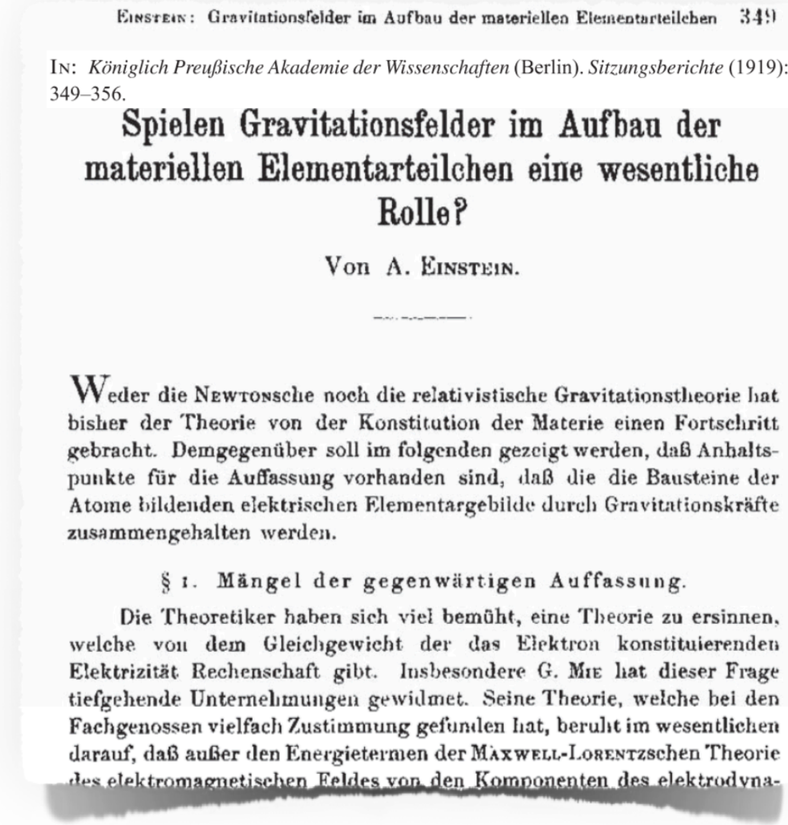

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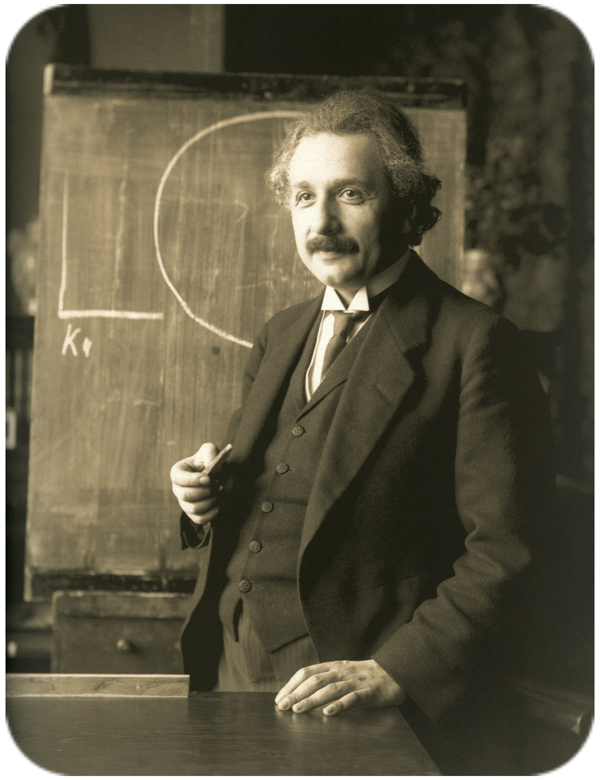

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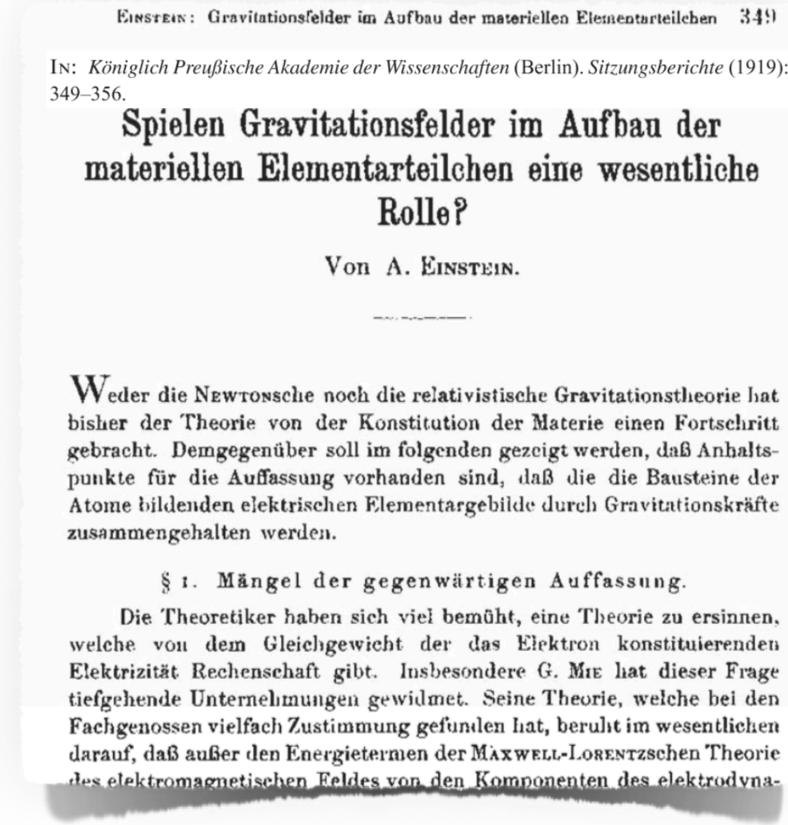
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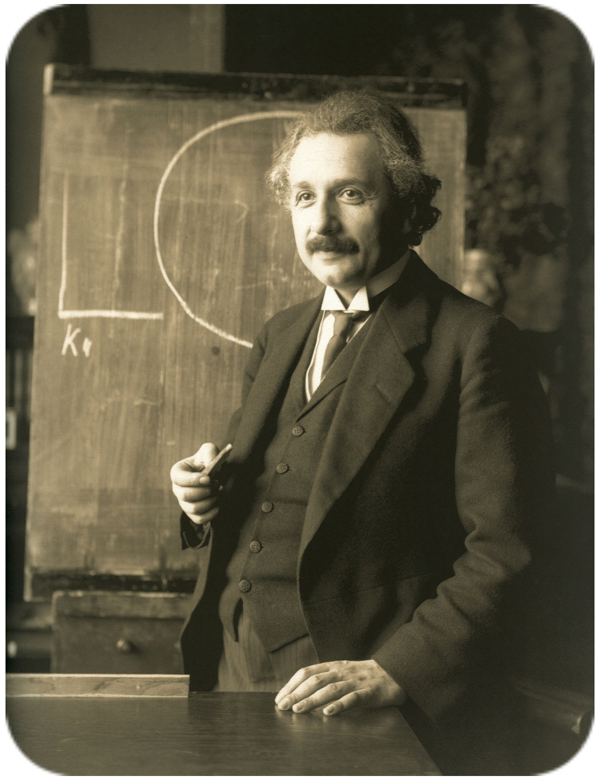

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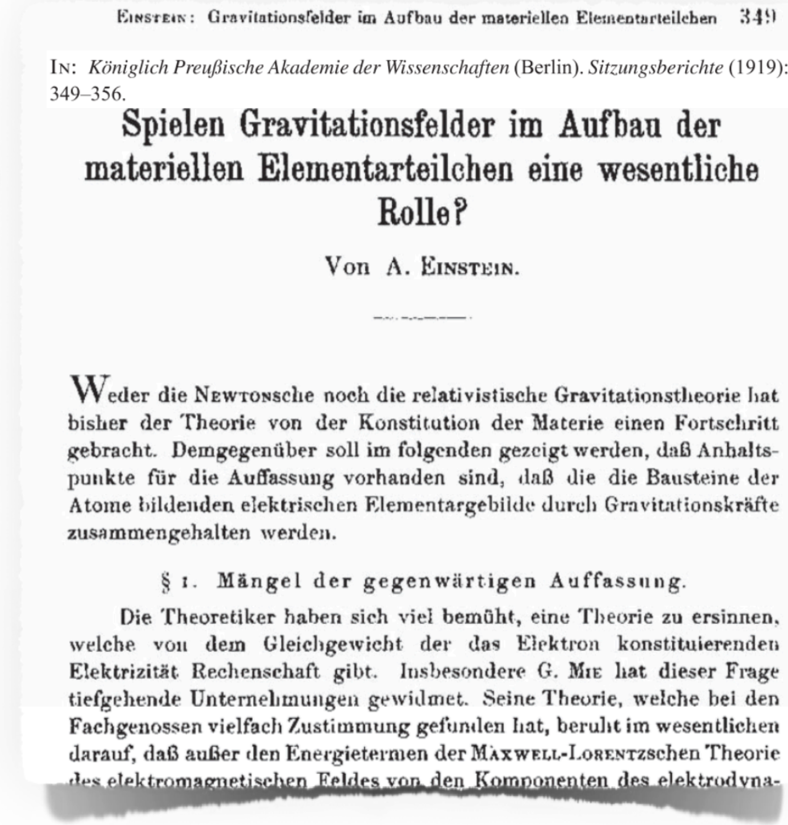

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Λ is merely an integration constant!

Decoupling vacuum energy from spacetime curvature

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known under the name "unimodular" gravity

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Let's make $f(x)$ internal / dynamical function, which would still be irrelevant, but save general covariance!

Henneaux, Teitelboim(Bunster)(1989)

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$$\pi = \frac{\delta L}{\delta \dot{W}^t} = \sqrt{-g}\,\Lambda$$

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- Similarly to the Ostrogradsky Hamiltonian, the system is *linear* in canonical momentum π, i.e. in energy density of DE, Λ

$$\pi = \frac{\delta L}{\delta \dot{W}^t} = \sqrt{-g}\,\Lambda$$

However, $\partial_\mu \Lambda = 0$

Theory of *all* (a)dS

$$S_{dS}\left[g, W, \Lambda\right] = \int d^4x\sqrt{-g}\,\Lambda\left[\nabla_\mu W^\mu - 1\right]$$

$$T_{\mu\nu} = \Lambda g_{\mu\nu}$$

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Henneaux–Teitelboim "unimodular" gravity (1989)

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four volume of space time $\quad \mathcal{T}(t_2) - \mathcal{T}(t_1) = \int_{t_1}^{t_2} dt\int d^3\mathbf{x}\sqrt{-g}$

Four-volume of spacetime is canonically conjugated to the cosmological constant

Heisenberg uncertainty relation

$$\delta\Lambda \times \delta \int_{\Omega} d^4x\sqrt{-g} \geq 4\pi\,\ell_{Pl}^2$$

Energy-Time Uncertainty Relation

$$\delta\varepsilon_{\lambda} \times \delta\mathscr{V} \geq \frac{\hbar}{2}$$

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Global Solution to Global Problem!

actually $\delta\varepsilon_\lambda \simeq \varepsilon_r$ close to final singularity,
dS avoids "end of time"!

Axionic Cosmological Constant

JAMES L. ANDERSON
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(Received 13 January 1971)

Cosmological Constant and Fundamental Length

In usual formulations of general relativity, the cosmological constant Λ appears as an inelegant ambiguity in the fundamental action principle. With a slight reformulation, Λ appears as an unavoidable Lagrange multiplier, belonging to a constraint. The constraint expresses the existence of a fundamental element of space–time hypervolume at every point. The fundamental scale of length in atomic physics provides such a hypervolume element. In this sense, the presence in relativity of an undetermined cosmological length is a direct consequence of the existence of a fundamental atomic length.

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Chern-Simons Current C^{μ}
instead of W^{μ}

$$\nabla_{\alpha} C^{\alpha} = F_{\alpha\beta} \widetilde{F}^{\alpha\beta}$$

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Axionic Cosmological Constant, Comment II

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PHYSICS REPORTS (Review Section of Physics Letters) 104, Nos. 2–4 (1984) 143–157. North-Holland, Amsterdam

Foundations and Working Pictures in Microphysical Cosmology

Frank WILCZEK

I would like to briefly mention one idea in this regard, that I am now exploring. It is to do something for the Λ-parameter very similar to what the axion does for the θ-parameter in QCD, another otherwise mysteriously tiny quantity. The basic idea is to promote these parameters to dynamical variables, and then see if perhaps small values will be chosen dynamically. In the case of the

Chern-Simons Current

$$C^{\alpha} = \mathrm{Tr}\frac{\varepsilon^{\alpha\beta\gamma\delta}}{\sqrt{-g}}\left(\boldsymbol{F}_{\beta\gamma}\boldsymbol{A}_{\delta} - \frac{2}{3}ig\boldsymbol{A}_{\beta}\boldsymbol{A}_{\gamma}\boldsymbol{A}_{\delta}\right)$$

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composite vector variable, yet C^{t} does not depend on $\partial_{t}A_{\mu}$!

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introduce the shifts $\quad C^\mu \to C^\mu + \epsilon^\mu \qquad \nabla_\mu \epsilon^\mu = 0$

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formal limit / “confinement” $\mathbf{g} \rightarrow \infty$

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formal limit / "confinement" $\mathbf{g}\to\infty$

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$$\mathbf{g}^2\left(q\right) = \frac{48\pi^2}{\left(11n-2f\right)\log\left(q^2/\Lambda_{QCD}^2\right)}$$

New vacuum energy density $V_\lambda\left(\theta\right)$

G_N as a global dynamical degree of freedom

Second way to lose the trace

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Side product: $\hbar$ as global dynamical degree of freedom

1=1 instead of 0=0!

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$$\frac{G_{\mu\nu}}{G} = \frac{T_{\mu\nu}}{T}$$

Jiroušek, Shimada, Vikman, Yamaguchi (2020)

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Bianchi identity
+energy-momentum conservation
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$\overline{G}_N$ is merely an integration constant!

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⇒ two distinct ways to write an action

Changing Gravity: Henneaux–Teitelboim analogy for G_N

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$$\dot{\mathscr{R}} = \frac{1}{2}\int_\Sigma d^3\mathbf{x}\partial_t\left(\sqrt{-g}\, C^t(t, \mathbf{x})\right) = \frac{1}{2}\int_\Sigma d^3\mathbf{x}\left[\sqrt{-g}R - \partial_i\left(\sqrt{-g}\, C^i(t, \mathbf{x})\right)\right]$$

Changing Gravity: Henneaux–Teitelboim analogy for G_N

$$S_{G_N}\left[g, C, \alpha\right] = \frac{1}{2}\int d^4x\sqrt{-g}\,\Big(\nabla_\mu C^\mu - R\Big)\,\alpha$$

cf. Kaloper, Padilla, Stefanyszyn, Zahariade (2016)

global shift-symmetric degree of freedom

canonically conjugated to $\alpha = M_{pl}^2$

$$\mathscr{R}\,(t) = \frac{1}{2}\int_\Sigma d^3\mathbf{x}\sqrt{-g}\;C^t\,(t, \mathbf{x})$$

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$$\mathscr{R}\,\big(t_2\big) - \mathscr{R}\,\big(t_1\big) = \frac{1}{2}\int_{\mathscr{V}} d^4x\sqrt{-g}\;R$$

integrated Ricci scalar

Heisenberg uncertainty relation

$$\delta\mathscr{R} \times \delta\alpha \geq \frac{1}{2}\hbar$$

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$$\frac{\delta G_N}{G_N} \times \frac{\delta \int_{\mathscr{V}} d^4x\sqrt{-g}\, R}{\ell_{Pl}^2} \geq 8\pi$$

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$$\frac{\delta \ell_{Pl}}{\ell_{Pl}} \times \frac{\delta \int_{\mathscr{V}} d^4x \sqrt{-g}\, R}{\ell_{Pl}^2} \geq 4\pi$$

Minimal Quantum Fluctuations of G_N

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$$8\pi G_N \left| \int_{\mathscr{V}} d^4x \sqrt{-g}\, T \right| \gg \delta \int_{\mathscr{V}} d^4x \sqrt{-g}\, R$$

Minimal Quantum Fluctuations of G_N

$$8\pi G_N \left| \int_{\mathscr{V}} d^4x \sqrt{-g}\, T \right| \gg \delta \int_{\mathscr{V}} d^4x \sqrt{-g}\, R$$

$$\Downarrow$$

$$\frac{\delta G_N}{G_N} \gg \hbar \left| \int_{\mathscr{V}} d^4x \sqrt{-g}\, T \right|^{-1}$$

Frozen Axion for G_N

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$$S\left[g,\mathscr{A},\nu\right] = \int d^4x\sqrt{-g}\left[-\frac{1}{2}\nu^2 R + \frac{1}{2}\left(\partial\nu\right)^2 + \frac{\nu}{f_\alpha}\mathscr{F}_{\gamma\sigma}\widetilde{\mathscr{F}}^{\gamma\sigma} - V_\alpha\left(\nu\right)\right.$$

Frozen Axion for G_N

Canonically normalised ν instead of α

$$S\left[g,\mathscr{A},\nu\right] = \int d^4x\sqrt{-g}\left[-\frac{1}{2}\nu^2 R + \frac{1}{2}(\partial\nu)^2 + \frac{\nu}{f_\alpha}\mathscr{F}_{\gamma\sigma}\widetilde{\mathscr{F}}^{\gamma\sigma} - V_\alpha(\nu)\right.$$

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New vacuum energy density $V_\alpha(\nu)$

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Again formal limit / "confinement" $\mathbf{g} \to \infty$

New vacuum energy density $V_\alpha(\nu)$

Changing Matter via Henneaux–Teitelboim

$$S\left[g,\beta,L,\Phi_m\right]=\int d^4x\sqrt{-g}\,\beta\left(\mathscr{L}_m-\nabla_\lambda L^\lambda\right)$$

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$$S\left[g,\beta,L,\Phi_m\right] = \int d^4x\sqrt{-g}\,\beta\left(\mathscr{L}_m - \nabla_\lambda L^\lambda\right)$$

Momentum rescaling $\quad \pi = \beta\pi^{(m)} = \beta\sqrt{-g}\dfrac{\partial\mathscr{L}_m}{\partial\dot{\phi}}$

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Effective Planck Quantum $\quad \bar{\hbar}=\dfrac{\hbar}{\beta}$

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Effective Planck Quantum $\bar{\hbar} = \dfrac{\hbar}{\beta}$ Effective Newton Constant $\overline{G}_N = \beta\,G_N$

Planck length $\ell_{Pl} = \sqrt{\hbar G_N}$ remains invariant!

Action Conjugated!

Effective Planck Quantum $$\bar{\hbar} = \frac{\hbar}{\beta}$$

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$$I\left(t_2\right) - I\left(t_1\right) = -\int_{\mathscr{V}} d^4x\sqrt{-g}\, \mathscr{L}_m$$

Heisenberg uncertainty relation

$$\delta I \times \delta \beta \geq \frac{1}{2}\hbar$$

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Minimal Quantum Fluctuations of $\bar{G}_N$ and $\bar{\hbar}$

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Quasiclassical Regime

$$\int_{\mathscr{V}} d^4x\sqrt{-g}\,\mathscr{L}_m > \delta \int_{\mathscr{V}} d^4x\sqrt{-g}\,\mathscr{L}_m$$

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$$\frac{\delta\bar{G}_N}{\bar{G}_N} \geq \tfrac{1}{2}\bar{\hbar}\left|\int_{\mathscr{V}} d^4x\sqrt{-g}\,\mathscr{L}_m\right|^{-1}$$

Frozen Axion for $\hbar$ and G_N

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$$S\left[g,\eta,A,\Phi_m\right]=\int d^4x\sqrt{-g}\left[-\frac{R}{2\varkappa}+\frac{1}{2}\left(\partial\eta\right)^2-V_\beta\left(\eta\right)+\frac{\eta^2}{M_m^2}\mathscr{L}_m-\frac{\eta}{f_\beta}F_{\mu\nu}\widetilde{F}^{\mu\nu}\right.$$

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$$\varkappa = 8\pi G_N$$

Frozen Axion for $\hbar$ and G_N

Canonically normalised η instead of β universally coupled to all matter

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New vacuum energy density $V_\beta\left(\eta\right)$

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Again formal limit / "confinement" $\mathbf{g} \to \infty$

$\varkappa = 8\pi G_N$

New vacuum energy density $V_\beta\left(\eta\right)$

Unimodular, Unicurvature and Unimatter

for the globally dynamical Λ

Unimodular $$S[g,\Lambda] = \int d^4x\, \Lambda \left(1 - \sqrt{-g}\,\right)$$

Henneaux-Teitelboim construction with fixed $$W^\mu = \delta^\mu_t \frac{t}{\sqrt{-g}}$$

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similarly one can write for the globally dynamical $\hbar$ and G_N

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Can be changed to $\pm$ as in cosmology $R = 3p - \varepsilon$

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each of these three constraints could be a gauge condition… but they yield dynamics!

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Unicurvature $$S[g,\alpha] = \frac{1}{2}\int d^4x\left(1 - \sqrt{-g}R\right)\alpha$$

each of these three constraints could be a gauge condition… but they yield dynamics!

Dynamics is the same as without fixing W^μ, C^μ or L^μ !

Thanks a lot for attention!

Mimetic vector-tensor theory for Λ

Jiroušek, Vikman(2018)

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Ansatz : $$g_{\mu\nu} = h_{\mu\nu} \cdot \left(\nabla^{(h)}_{\alpha} V^{\alpha} \right)^{1/2}$$

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Weyl invariance for the *vector field of conformal weight 4*

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$$h_{\mu\nu} = \Omega^2 (x)\, h'_{\mu\nu}$$

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Weyl invariance for the *vector field of conformal weight 4*

$$h_{\mu\nu} = \Omega^{2}(x)\, h'_{\mu\nu}$$

$$V^{\mu} = \Omega^{-4}(x)\, V'^{\mu}$$

Action

$$S_g\left[h, V\right] = -\frac{1}{2}\int d^4x\sqrt{-h}\left[\left(\nabla^{h)}_{\alpha}V^{\alpha}\right)^{1/2} R\left(h\right) + \frac{3}{8}\cdot\frac{\left(\nabla^{h)}_{\mu}\nabla^{h)}_{\alpha}V^{\alpha}\right)^{2}}{\left(\nabla^{h)}_{\sigma}V^{\sigma}\right)^{3/2}}\right] \; .$$

Action

$$S_g\left[h,V\right] = -\frac{1}{2}\int d^4x\sqrt{-h}\left[\left(\nabla_\alpha^{h)}V^\alpha\right)^{1/2} R\left(h\right) + \frac{3}{8}\cdot\frac{\left(\nabla_\mu^{h)}\nabla_\alpha^{h)}V^\alpha\right)^2}{\left(\nabla_\sigma^{h)}V^\sigma\right)^{3/2}}\right] .$$

Equations of motion

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Equations of motion

$$\frac{1}{\sqrt{-h}}\cdot\frac{\delta S}{\delta V^\mu} = \frac{1}{4}\,\partial_\mu\left(T-G\right) = 0$$

Action

$$S_g\left[h, V\right] = -\frac{1}{2}\int d^4x\sqrt{-h}\left[\left(\nabla^{h)}_{\alpha} V^{\alpha}\right)^{1/2} R\left(h\right) + \frac{3}{8}\cdot\frac{\left(\nabla^{h)}_{\mu}\nabla^{h)}_{\alpha}V^{\alpha}\right)^2}{\left(\nabla^{h)}_{\sigma}V^{\sigma}\right)^{3/2}}\right].$$

Equations of motion

$$\frac{1}{\sqrt{-h}}\cdot\frac{\delta S}{\delta V^{\mu}} = \frac{1}{4}\,\partial_{\mu}\left(T - G\right) = 0$$

$$\frac{1}{\sqrt{-h}}\cdot\frac{\delta S}{\delta h^{\alpha\beta}} = \frac{\sqrt{\nabla^{h)}_{\alpha}V^{\alpha}}}{2}\left[T_{\alpha\beta} - G_{\alpha\beta} - \frac{1}{4}g_{\alpha\beta}\left(T - G - \frac{1}{\nabla^{h)}_{\alpha}V^{\alpha}}V^{\lambda}\partial_{\lambda}\left(T - G\right)\right)\right] = 0$$

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$$S_g\left[h,V\right] = -\frac{1}{2}\int d^4x\sqrt{-h}\left[\left(\nabla^{h)}_{\alpha}V^{\alpha}\right)^{1/2}R\left(h\right) + \frac{3}{8}\cdot\frac{\left(\nabla^{h)}_{\mu}\nabla^{h)}_{\alpha}V^{\alpha}\right)^{2}}{\left(\nabla^{h)}_{\sigma}V^{\sigma}\right)^{3/2}}\right].$$

Equations of motion

$$\frac{1}{\sqrt{-h}}\cdot\frac{\delta S}{\delta V^{\mu}} = \frac{1}{4}\,\partial_{\mu}\left(T-G\right) = 0$$

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$$G_{\mu\nu} - T_{\mu\nu} - \frac{1}{4}g_{\mu\nu}\left(G-T\right) = 0$$