

Cosmological cancellation of the vacuum energy density

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1- MOTIVATION

- Dark Energy or Modified-Gravity are motivated by the current acceleration of the Universe.

Apart from its current value, the main clue we have is that it is so small:

"OLD COSMOLOGICAL CONSTANT PROBLEM"

This could point to the solution !

- Many DE or MG models have been ruled out. The remaining ones do not match data much better than LCDM.

It would be good if they could be at least useful for something:

solve/address the cosmological constant problem !

"Old cosmological constant problem": it is very sensitive to details of UV physics and gets huge contributions that arise during the radiation era:

The problem of the vacuum energy should always have been at the fore of cosmological research. Indeed one can learn a great deal from its examination:

- \checkmark The result seems to depend on an arbitrary UV cut off.
- \checkmark The result should take into account not only the electron but all the known particles.
- \checkmark The sole contribution from the proton is larger than the energy at the formation of the elements (Big Bang Nucleosynthesis) preventing one from understanding the Universe's dynamics since then.

The first two points have been gradually understood since the 1950's with the advent of modern Quantum
Finiti Ti Field Theory: a more detailed discussion of the issues relation of the issues relation of the cosmological constant problem to unit \mathcal{L}

"Self-tuning": add extra fields that cancel the vacuum energy. $v_{\text{min}} = v_{\text{min}}$ t_{c} argument. Let us the use α in the case of α is to "eat up" the large vacuum energy, protecting the spacetime curvature accordingly. Weinberg's var are go the vacuum crici ζ .

Weinberg's theorem: this is impossible without fine tuning, under general assumptions ! We begin by assuming the following field content: a spacetime metric, *gµ*⌫, and self adjusting

- Lagrangian: $\mathcal{L}[g, \varphi_i].$ matter fields, '*i*, with the tensor structure suppressed. The dynamics is described by a general

on-shell we have *gµ*⌫*,* '*ⁱ* = constant. This leaves a residual GL(4) symmetry, given by a coordinate **- translationally invariant vacuum:** $y_{\mu\nu}, \varphi_i = \text{constant}$. - translationally invariant vacuum: $g_{\mu\nu}, \varphi_i = \text{constant}$. Lagrangian density *L*[*g,* '*i*]. We further assume that the vacuum is *translationally invariant*, so that c_h_n^{*x*} *x*_{*x*} *<i>x <i>x <i>x <i>x <i>x <i>x <i>x <i>x <i>x <i>x <i>x* *****<i>x <i>x <i>x <i>x <i>x <i>x <i>x*

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SUSY Large extra dimensions

string-theory scenarios

degravitation

superfluid, Lorentz-violating theory

self-tuning scalar-tensor models

mirror universe

sequestering

II- DEFINITION OF THE MODEL <u>SI-DERINITOR OF</u> II. DEFINITION OF THE MODEL <u>m DLINNINONVON IIIE</u> $E = \frac{1}{2}$ *^T*(m)*µ*⌫ ⁼ ²

A) Action S density of nonrelativistic matter. This is not surprising, the surprising, $\frac{1}{\sqrt{2}}$ define by the conformal rescaling *g*˜*µ*⌫ = *A*²(')*gµ*⌫*, A*(') *>* 0*.* (6)

We wish to recover GR We wish to resource CD **duced a second scalar fields** a second scalar field of \blacksquare

Reep standard L.m. and mat Keep standard E.H. and matter actions, but with a conformal coupling between Jordan and Einstein metrics ³ $\sum_{i=1}^{\infty}$ on monds tween lordan an In fact, because the matter action couples the matter action couples the scalar $\mathcal{O}(\mathcal{O})$ \overline{G} General meatten eatiene but with a conformed **ultric tensor actions, but with a conformal tensor of the matter second tensor** second tensor and matter a confor een jordan and Einstein metrics actions, but with a conform enter the new term *S*'*,*. Here *M* is a mass parameter ep standard E.H. and matter actions, but with a conformal *etween Jordan and Einstein metrics* on the value of *M*. Indeed, for any constant rescaling fac-

$$
S=S_{\rm EH}+S_{\rm m}+S_{\varphi,\lambda}
$$

$$
S_{\rm EH} = \int d^4x \sqrt{-g} \frac{M_{\rm Pl}^2}{2} R, \qquad S_{\rm m} = \int d^4x \sqrt{-\tilde{g}} \tilde{\mathcal{L}}_{\rm m}(\psi_{\rm m}^{(i)}, \tilde{g}_{\mu\nu}), \qquad \tilde{g}_{\mu\nu} = A^2(\varphi) g_{\mu\nu}, \quad A(\varphi) > 0.
$$

$$
S_{\varphi,\lambda} = \int d^4x \sqrt{-g} \left[\mathcal{M}^3 A^4(\varphi)\lambda + \mathcal{M}^4 K(\varphi; X, Y, Z) \right], \qquad X = -\frac{\partial^{\mu} \lambda \partial_{\mu} \lambda}{2\mathcal{M}^4}, \quad Y = -\frac{\partial^{\mu} \varphi \partial_{\mu} \lambda}{\mathcal{M}^4}, \quad Z = -\frac{\partial^{\mu} \varphi \partial_{\mu} \varphi}{2\mathcal{M}^4}.
$$

energy arising from the mat the role of a Lagrange multiplier that enforces the cancellation of the vacuum dea. γ plus the role of a Lagrange mater enter enter ces the cancellation of the vacuum
energy arising from the matter sector by the second field λ $\frac{1}{\sqrt{1-\frac{1$ energy arising from the matter sector by the second field $\,\lambda$ Idea: φ plays the role of a Lagrange multiplier that enforces the cancellation of the vacuum The idea leading to the idea leading to the action (1) is that ' plays the role of μ second field . This can be expected by noticing the expected by noticing that the expected by noticing that the T is the action (1) is that if the action (1) is that ' plays the role of \mathcal{L} idea: φ plays the role of a Lagrang second field . This can be expected by noticing that the multiplier that enforces the cancellation of t constant which we can be not constant which we have not constant which we have an interesting \sim

This may be guessed from the symmetry: the Einstein-frame metric tensor q^2 and q^2 and q^2 is the matter action of matter action term is the matter action of matter action of q^2 and q^2 an ²*M*⁴ *, Y* ⁼ @*^µ*'@*µ* \mathcal{L}_{m} is the usual Einstein-Hilbert action of \mathcal{L}_{m} is the usual Einstein-Hilbert action of \mathcal{L}_{m} is the usual Einstein-Hilbert action of \mathcal{L}_{m} is the usual Einstein-Hilbert and Einstein-Hi $-g$. using $\sqrt{-\tilde{g}} = A^4 \sqrt{-g}$ shift of the matter-sector vacuum energy. This cancella-sector vacuum energy. This cancella-sector vacuum energy of the sector vacuum energy of the sector vacuum energy. The sector vacuum energy of the sector vacuum energy

$$
\tilde{\mathcal{L}}_{\mathrm{m}} \rightarrow \tilde{\mathcal{L}}_{\mathrm{m}} - \tilde{V}_{\mathrm{vac}}, \ \ \, \lambda \rightarrow \lambda + \tilde{V}_{\mathrm{vac}}/\mathcal{M}^3, \ \ \, S \rightarrow S,
$$

²*M*⁴ *, Y* ⁼ @*^µ*'@*µ ^M*⁴ *, Z* ⁼ @*^µ*'@*µ*' ²*M*⁴ *.* י
(only on its derivatives. General Relativity, written in terms of the Einstein-frame $\sum_{i=1}^{n}$ signal rescaling such that $\sum_{i=1}^{n}$ respectively. tion (associated with all particles, including photons and \sim ellation apply for any $\ V_{\rm vac}$ the action does not dep **g** is the α is the Jordan-frame metric, seen by matter, which we have metric, which we have α $\mathsf{on} \lambda$. α is the Jordan-frame metric, seen by matter, which we matter, wh To make the cancellation apply for any $\tilde{V}_{\rm vac}$ the action does not d *g*˜*µ*⌫ = *A*²(')*gµ*⌫*, A*(') *>* 0*.* (6) pt de *g^µ*⌫ *, ^T*˜ Ind on \land , Pl*/A*(') on the value of *M*. Indeed, for any constant rescaling fac- $\mathop{\mathsf{es}}\nolimits$ not depend on λ , ! ↵³. This also requires appropriate changes to r action does not depend on r *S* action does not depend on λ , *S*'*,*. The second term is introduced to enlarge the space To make the cancellation apply for any the matter components. However, in this section, we for the matter components, we for this section, we for To make the cancellation apply for any $\,\tilde{V}_{\mathrm{vac}}\;$ the action does not depend on $\,\lambda$, only on its derivatives.

B) Equations of motion 139 <u>notion</u> <u>B) Equations of motion</u> @*^Y* (@*^µ*'@⌫ ⁺ @*^µ*@⌫') + @*^K Z* (*R*) Equations of motion <u>otion</u>

Friedmann equations: erefore, the Einstein equations: the Eincludes a possible cosmological constantine equations: Therefore, the Einstein equations read $3M_{\rm Pl}^2 \mathcal{H}^2 \; = \; a^2 A^4 (\tilde{V}_{\rm vac} + \tilde{\rho} + \tilde{\rho}_{\gamma} - \mathcal{M}^3 \lambda) - a^2 \mathcal{M}^4 K$ \mathbb{R}^2 $\hat{a} = a^2 A^4 (\tilde{V}_{\text{me}} - \tilde{a}_2 / 3 - M^3 \lambda) - a^2 M$ ∂K recover the standard Friedmann equations of ∂K standard Friedmann equations of ∂K $+\frac{\partial R}{\partial x}\lambda^{\prime 2}+2\frac{\partial R}{\partial y}\lambda^{\prime}\varphi^{\prime}+\frac{\partial R}{\partial y}$ The vacuum energy *^V*˜vac has been cancelled by *^M*³, \mathcal{L} the scalar field ' acts as a Lagrange multiplier that the scalar field \mathcal{L} $\ddot{}$ $\frac{\partial K}{\partial X} \lambda'^2 + 2 \frac{\partial K}{\partial Y} \lambda' \varphi' +$ ∂K $\frac{\partial K}{\partial Z} \varphi'^2$ *M*² Pl(*H*² + 2*H*⁰) = *^a*²*A*⁴(*V*˜vac ⇢˜*/*³ *^M*³) *^a*²*M*⁴*K,* 3*M*² Pl*H*² @*K* @*^X* 0² + 2@*^K* @*^Y* ⁰ @*^Z* '0² (14) $M_{\rm Pl}^2({\cal H}^2+2{\cal H}')=a^2A^4(\tilde{V}_{\rm vac}-\tilde{\rho}_\gamma/3-{\cal M}^3\lambda)-a^2{\cal M}^4K,$ $\frac{1}{2}$ s a possible cosmological constant ∂K and ∂K $\frac{\partial \mathbf{r}}{\partial \mathbf{v}} \lambda' \varphi' + \frac{\partial \mathbf{r}}{\partial \mathbf{z}} \varphi'^2$ \overline{b} *A* \rightarrow *Z* ∂^{2} ∂^{2} @*K* (15) the radiation era. $e^2\mathcal{M}^*K + \frac{1}{\partial Y}\lambda^2 + 2\frac{1}{\partial Y}\lambda^2\varphi^2 + \frac{1}{\partial Z}\varphi^2$ provides the evolution of '. At this stage, the role of the k_1 is only the scalar field action (4) is only to make $\frac{1}{2}$ is only to make $\frac{1}{2}$ λ) - a⁻NI⁻K, $\frac{1}{\sqrt{2}}$ $\overline{\mathbf{x}}$ a possible cosmolog
 $\overline{\mathbf{x}}$ @*K* α ² CONStant ∂X ² + 2³ ∂Y ² + 3² ∂Z ^{*w*} $m = \tilde{a}$ $(3 - M^3 \lambda) = a^2 M^4 K$ $f''(1)$ $\frac{d}{dx}$ $\frac{d}{dx}$ $\frac{d}{dx}$ $\frac{d}{dx}$ $\frac{d}{dx}$ ∂K $_{12}$ $\overline{\partial Z}^{\varphi}$ @' *^a*⁴@⌧ @*^Y* ⁰ ⁺ @*^Z* '⁰ ◆ ⁼ *M*, which disappears from the Friedmann equations. ⁴*A*³ *dA ^d*' (*V*˜vac + ˜⇢*/*⁴ *^M*³) (16) $M_{\rm Pl}^z(7)$ $\overline{2}$ *a*2 $2\mathcal{H}'$ \mathcal{H}^{\prime} $=$ a $^{2}A^{4}$ $\mathcal{A}^4(\tilde{V}_{\rm vac}-\tilde{\rho}_\gamma/3-\mathcal{M}^3\lambda)-a^2\mathcal{M}^4K,$ α manner the manner the manner the well-known no-good α well-known no-good α $+\frac{\partial K}{\partial t}$ $\chi^2 + 2\frac{\partial K}{\partial t}$ χ^{\prime} $\phi^{\prime} + \frac{\partial K}{\partial t}$ $\phi^{\prime 2}$ ∂X is a set of ∂Y is a set of ∂Z is a set of ∂Z left-hand side. This is because we solve the cosmological $\ddot{}$ *a*⁴@⌧ $\partial K_{y} = \partial K_{y} + \partial K_{z}$ while the kinetic factors are ²*M*⁴*a*² *, Y* ⁼ ⁴A³ dA ^d^ϕ (V˜vac + ˜ρ/⁴ [−] ^M³λ) (16) includes a possible cosmological constant ∂X ² + ∂Y ² + ∂Z ² θ

*M*² Pl(*H*² + 2*H*⁰) = *^a*²*A*⁴(*V*˜vac ⇢˜*/*³ *^M*³) *^a*²*M*⁴*K,* the conformal time α and α is the conformal time α Julie Rolles. Fauations of motion of the two scalar fields: Equations of motion Equations of motion of the two scalar fields: Equations of inotion of the two scal $\mathsf{fields:}\quad$ fields the equations of \mathbf{r} Equations of motion of the two \overline{C} + \overline{C}

$$
\mathcal{M}^4 \frac{\partial K}{\partial \varphi} - a^{-4} \partial_\tau \left[a^2 \left(\frac{\partial K}{\partial Y} \lambda' + \frac{\partial K}{\partial Z} \varphi' \right) \right] = 4A^3 \frac{dA}{d\varphi} (\tilde{V}_{\text{vac}} + \tilde{\rho}/4 - \mathcal{M}^3 \lambda) \qquad a^{-4} \partial_\tau \left[a^2 \left(\frac{\partial K}{\partial X} \lambda' + \frac{\partial K}{\partial Y} \varphi' \right) \right] = \mathcal{M}^3 A^4
$$

*^M*⁴ @*^K* **Cancellation mechanism in the radiation era** *a*2 $\frac{1}{2}$ ⁴*A*³ *dA* **Cancellation mechanism in the radiation era**
 discretively ⁴*A*³ *dA* so that time derivatives vanish, Eq.(17) implies at once @*K* ◆ ⁼ *^M*³*A*⁴ ✓@*K A* = 0, and hence the matter action vanishes. This corranism in the radiation era C) Cancellation mechanism in the radiation era constant problem with a cosmological setting, which with a cosmological setting, which with α of the vacuum energy density in the radiation era. Thus, consider a constant vacuum energy density *V*˜vac, <u>when the radiation era</u> nism in the radiation before taking the local Minkowski limit. This way out of \mathbf{u} is shared by other self-tuning by other self-tuning \mathbf{u}

^d' (*V*˜vac + ˜⇢*/*⁴ *^M*³) (16) *a*⁴@⌧ *a*2 ✓@*K* the cor stant cancellation solution: $\lambda = \tilde{V}_{\text{vac}}/\mathcal{M}^3, \quad \lambda' = 0,$ $\partial K = 0$ and $\partial K = 0$ when $\lambda' = 0$ $\partial \varphi$ = 0, and ∂Z = 0 when λ = 0. Then we have the constant cancellation solution: $\lambda = \tilde{V}_{\text{vac}}/M^3$, $\lambda' = 0$, $K = 0$, $\frac{\partial K}{\partial t} = 0$, and $\frac{\partial K}{\partial t} = 0$ when λ' . ✓@*K* $\mu_c = \text{constant}$. and *,* (17) 0. and $\frac{\partial K}{\partial n} = 0$ when $\lambda' = 0$. **and** $\mu = 0$, $v_{\text{vac}} = \text{constant}$. **and** $\mu = 0$, $\frac{\partial \varphi}{\partial \varphi} = 0$, and $\frac{\partial Z}{\partial Z} = 0$ when $\lambda = 0$. $\lambda = V_{\rm vac}/{\cal M}^3, \;\;\; \lambda'=0,$ \mathbf{t} Then we have the constant cancellation solution: $\lambda = \tilde{V}_{\text{vac}}/M^3$, $\lambda' = 0$, ΩV sinds ΩV $K=0, \frac{\partial K}{\partial t}=0, \text{ and } \frac{\partial K}{\partial t}=0 \text{ when } \lambda'=0.$ implies $\partial \varphi$ is the scale factor ∂Z $\lambda = v_{\text{vac}} / \nu t$, $\lambda = 0,$ and $K = 0$, $\frac{\partial K}{\partial \varphi} = 0$, and $\frac{\partial K}{\partial Z} = 0$ cancellation solution $\lambda = \tilde{V}_{\text{res}}/M^3$ $\lambda' = 0$ the Universe is expanding. Moreover, the background for $\lambda' = 0$. is related to the cosmological framework of our Universe. $\tilde{\rho} = 0$, $\tilde{V}_{\text{vac}} = \text{constant}$. and $K = 0$, $\frac{\partial K}{\partial \rho} = 0$, and $\frac{\partial K}{\partial \rho} = 0$ when $\lambda' = 0$. $\text{cl}(V^{\bullet} \cdot \cdot \cdot)$ ΩV be the exact ΩV $b=0, \frac{\partial K}{\partial t}=0, \text{ and } \frac{\partial K}{\partial t}=0 \text{ when } \lambda'=0.$ $\partial \varphi$ and $\partial \varphi$ tion: $\lambda = V_{\rm vac}/{\cal M}^3$, $\lambda' = 0$, dependence for some background fields \mathcal{S}_1 and \mathcal{S}_2 and \mathcal{S}_3 are Lorentz-Lorentz-Lorentz-Lorentz-Lorentz-Lorentz-Lorentz-Lorentz-Lorentz-Lorentz-Lorentz-Lorentz-Lorentz-Lorentz-Lorentz-Lorentz-Lorentz-Lorent Take $\tilde{\rho} = 0$, $\tilde{V}_{\text{vac}} = \text{constant}$. and $K = 0$, $\frac{\partial K}{\partial \rho} = 0$, and $\frac{\partial K}{\partial \rho} = 0$ when $\lambda' = 0$. Then we have the constant cancellation solution: $\lambda = \tilde{V}_\text{vac}/\mathcal{M}^3, \;\;\lambda'=0,$ provided the kinetic function *K* satisfies $K=0,$ $\frac{\partial K}{\partial \varphi} = 0$, and $\frac{\partial K}{\partial Z} = 0$ when $\lambda' = 0$. $\partial \varphi$, $\lim_{N \to \infty} \partial Z$ $\frac{1}{2}$ = 0 $\frac{1}{2}$ $\overline{}$. \overline{a} $= 0.$

and we recover the usual radiation-era Friedmann equations[.] t_{t} the Universe is expanding. Moreover, the background θ **d** we recover the usual radiation-era Friedmann equations: $\overline{}$ *r*ecover the u $\overline{1}$ *x*ual radiatior \sim $\overline{ }$ ²*M*⁴*a*² *.* (18) field time. Note that in a cosmologie with time. Note that in a cosmologie with the cosmologi-C. Cancellation mechanism in the radiation era spect, our solution of the cosmological constant problem a rriedmann equations. radiation-era Friedmann equations; and we recover the asaar radiation-era infledmann equations. and we recover the usual radiation-era Friedmann equations: Then, then,

 $3M_{\rm Pl}^2{\cal H}^2=a^2\rho_\gamma,\;\;\; M_{\rm Pl}^2({\cal H}^2+2{\cal H}')=-a^2\rho_\gamma/3,$ field time. Note that in a cosmological time. Note of the vacuum energy density in the radiation era. Thus, let us neglect the nonrelativistic matter density ˜⇢ and α μ γ , μ μ μ is the small length small lengths. $-\alpha$ ρ_{γ} , $w_{\text{Pl}}(t + \epsilon) = -\alpha \rho_{\gamma}/\sigma$, σ^2 α /3 \mathbf{r} $3M_\mathrm{Pl}^2\mathcal{H}^2=a^2\rho_\gamma, \quad M_\mathrm{Pl}^2(\mathcal{H}^2+2\mathcal{H}')=-a^2\rho_\gamma/3,$ $a^2 \rho_\gamma/3,$

Thus, φ $\,$ acts as a Lagrange multiplier, which enforces the cancellation by $\, \lambda$ $T_{\rm g}$ and $T_{\rm r}$ and $T_{\rm r}$ are the scalar commutatives to the scalar scal \mathbf{a} λ

> dynamical cancellation mechanism. *Mamical cancellation mechanism* @' *^a*⁴@⌧

D) How did we evade Weinberg's no-go theorem ? *^d*' (*V*˜vac + ˜⇢*/*⁴ *^M*³) (16) and $\mathbf n$ time derivatives vanish, Eq.(17) implies at once **A** \overline{A} and \overline{A} a

$$
\lambda \text{ - eq. of motion was:} \qquad a^{-4} \partial_{\tau} \left[a^2 \left(\frac{\partial K}{\partial X} \lambda' + \frac{\partial K}{\partial Y} \varphi' \right) \right] = \mathcal{M}^3 A^4
$$

If we look for static solutions in Minkowski: $\qquad \qquad A=0$

$$
\qquad \qquad \Longrightarrow \qquad A =
$$

$$
\qquad \qquad \longrightarrow \qquad \begin{array}{c} \text{t} \\ \text{t} \end{array}
$$

the matter
2°Weinberg، $t_{\rm{H}}$ is expanding. Moreover, the background \mathbf{H} the matter action vanishes ! $\mathsf{sub}(t)$ no reason to require static background fields. In this re-(Weinberg's result)

This is avoided by a time-dependent background φ that evolves on cosmological timescale. \sim

let us neglect the neglect the neglect the nonrelativistic matter density $\mathcal{L}_{\mathcal{A}}$ Thus, this solution of the cosmological constant/vacuum energy problem is tied to ⇢˜ = 0*, V*˜vac = constant*.* (19) $\mathsf{Id}\mathsf{e}$ \mathbf{b} taking the local Minkowski limit. This way out of \mathbf{b} the cosmological framework: time-dependent FLRW and background fields (instead of static Minkowski and backgrounds).

This way out (time dependence) is shared by other self-tuning models. Alternatives can be to introduce spatial dependence for backgrounds, provided the kinetic function *K* satisfies or Lorentz-violating theories.

III- RADIATION ERA $\overline{\mathcal{L}}$ recover interesting cosmological behaviors in the subclass **III- RADIATION ERA** simplest choice that choice that can reproduce all cosmological eras, which cosmological eras, which cosmologi
The cosmological eras, which cosmological eras, which cosmological eras, which cosmological eras, which cosmol K^Z = 0. It appears that the kinetic functions (34) are the \mathbf{y} and \mathbf{y} and \mathbf{y} and \mathbf{y} and \mathbf{y} and include include \mathbf{y} <u>III- KADIATION EKA</u> \overline{a} $\frac{1}{1-\Delta}$ stronger condition that λ − Ωvac0 decay faster than ˜ρ^γ ∝ $\frac{1}{4}$ <u>ροφορίζοντα</u> $\mathsf A$

A) Explicit model simple exponential for A(ϕ), dη $\overline{}$ ∂Kˆ ∂Yˆ **A)** Explicit model dη from the inflationary stage to the current dark-energy recover interesting cosmological behaviors in the subclass <u>K_D Explicit filouer</u> \blacksquare lutions where the scalar fields are subdominant in the A) Explicit model H

 $A(\varphi) = A_{\star}e^{\nu_A\varphi}, \quad A_{\star} > 0, \qquad K(\varphi; X, Y, Z) = K_{X}e^{\nu_{X}\varphi}X^{\gamma}, \quad \gamma > 0,$ $\sum_{i=1}^{n}$ $\Lambda(a) = A e^{\nu_A \varphi}$ $A > 0$ $K(a; V, V, Z) = K_{ab} \nu_X \varphi V \gamma$ $a > 0$ $\sigma = \frac{\nu_X}{\gamma}$ τ , the scalar field $4\nu_A$ $\mathbf{H}(\varphi, \mathbf{A}, \mathbf{I}, \mathbf{Z}) = \mathbf{H}_X \mathbf{C}$ $s(t) = 1/t^2$ can reproduce all cosmological eras, $\frac{1}{2}$ $\$ $f_{\mathbf{A}}(\varphi) = A_\star e^{-\epsilon}, \quad A_\star > 0, \qquad \qquad \mathbf{A}(\varphi, \mathbf{A}, \mathbf{I}, \mathbf{Z}) = \mathbf{A} X e^{-\epsilon} \mathbf{A}^{-1}, \quad \gamma > 0.$ $K(\varphi;X,Y,Z)=K_{X}e^{\nu_{X}\varphi}X^{\gamma},\quad \gamma>0,$ $\sigma \equiv$ ν_X $4\nu_A$

which for \mathbf{R} we take the separable form \mathbf{R} and (21) and (21) and (21) and (24). They do not constraints (21). They do not constraints (21) and (21). They do not constraint (21) and (21). They do not constraint \mathbf{F} exponential conformal ifference $\lambda = \lambda - \Omega_{\text{vac0}}$, enters. $\mathsf{tders.}$ By symmetry, only the difference $\lambda = \lambda - \Omega_{\rm vac0},$ enters. A s the kinetic function \mathcal{A} does not depend on \mathcal{A} does not depend on \mathcal{A} does not depend on \mathcal{A} By symmetry, only the difference $\lambda = \lambda - \Omega_{\rm vac0}, \;$ enters. By symmetry, only the difference $\lambda = \lambda - \Omega_{\text{vac0}}$, enters. symmetry, only the difference $\| \lambda \| = \lambda - \Omega_{\rm V\zeta}$ By symmetry, onl

 $\frac{1}{2}$ $\frac{1}{2}$ Eqs. of motion are nonlinear but we can obtain simple solutions: $\varphi = \varphi_\star + \mu_\varphi \eta, \quad \lambda = \lambda_\star e^{\mu_\lambda \eta}.$ Eqs. of motion are $\frac{1}{2}$ t_{t} but we can obtain simple solutions. Eas of motion are nonlinear but we can obtain Eqs. of motion are nonlinear but we can obtain simple solutions: aan simple solutions. but we can obtain simple solutions: $\varphi = \varphi_{+} + \mu_{\varphi} \eta$, $\lambda = \lambda_{+} e^{\mu_{\lambda} \eta}$. but we can d equation (31). The junction condition condition condition condition condition \mathcal{H} Eqs. of motion are nonlinear but we can obtain simple solutions: $\varphi = \varphi_{*} + \mu_{\varphi} \eta$,

constant for most of the expansion history of the \mathcal{L} vve require: $\quad \ast \quad \lambda \quad$ decays (so that We require: $\forall x \in \mathcal{X}$ decomposition λ decays (so that cancellation occurs) \ast λ decays (so that cancellation occurs) tween λ and the vacuum energy density, De vote romane for ∪onstraint en *v*oe romane en *v*onstraint en *i* T_{max} and T_{max} rays (so that cancellation occurs) $\frac{1}{2}$ efficients that provide a provide approximations that provide a provide approximations of the kinetic function
The kinetic functions of the kinetic functions of the kinetic functions of the kinetic functions of the kineti

 $m_{\rm e}$ scenarios, they would only be effective co-second only be effective co-second only be effective co-second efficients that \ast λ and K decay factors of the kinetic function over limited ranges, and smoothly vary with the area \sim sity \mathcal{L} to be constant. Then, it will be constant. Then, it will be convenient to be convenient λ and K decay faster than radiation density \ldots \ldots and π decay has contain radiation density \ast λ and K decay faster than radiation density radiation era. We also require that the Jordan-frame $\mathsf{I} \, K$ decay faster than radiation density

 $\ddot{a} = Aa$ lordan-fr a component of the form $\mathcal{L}_\mathcal{L}$ because we can already we can al the discussions below will use ¯λ. $\ast \quad \tilde a = A a \quad \quad$ Jordan-frame scale factor grows w $\frac{1}{2}$ can be checked in Eqs.(29). This is the property in Eqs.(29). This is the property is the property of $\frac{1}{2}$ $*\quad \tilde{a} = A a \quad$ Jordan-frame scale factor grows with time and a 5 $\frac{1}{\sqrt{2}}$ ame scale factor grows wit h time and $\,a$ \overline{v} $\mathbf{y} = \mathbf{y} - \mathbf$ a component of the scale factor grows with time and a

 \ast the solution is stable. II. IS SURFICE the solution is stable * 2011 an with a with a with a with a
with a with α on is sta \mathbf{r} a the solution is stat $\overline{}$ e recover interesting cosmological behaviors in the subclass in

 A the kinetic function \mathcal{A} does not depend on \mathcal{A} does not depend on \mathcal{A} \overline{t} his giv $^{\bullet}$ This gives the allowed range of parameters: $\frac{5}{14} \leq \gamma < \frac{2}{5}$: $2\gamma < \sigma$ This gives the allowed range of parameters: $\frac{0 \le \gamma \le \frac{11}{14}}{5}$ $\overline{}$ This gives the allowed range of parameters: $\frac{5}{2} < \frac{14}{2}$. $\frac{2}{2} < \frac{2}{2}$. $\frac{2}{2} < \frac{2}{2}$ ζ

This gives the allowed range of parameters:
$$
0 < \gamma \leq \frac{5}{14} : \frac{1 - \gamma + \sqrt{1 - 3\gamma^2}}{2} < \sigma < 1 - \frac{\gamma}{2},
$$

. (a) $\frac{1}{2}$, $\frac{1}{2}$,

are constant for: $\mu_{\varphi} = 0$ with $5 \t 1 \t 5$ φ and A are constant for: $\mu_{\varphi} = 0$ when $\sigma = \frac{5}{2} - 5\gamma$, $\frac{1}{3} < \gamma < \frac{5}{14}$. $\mathcal{L} = \mathcal{L} = \mathcal{L} = \mathcal{L}$ re constant for: $\mu_{\varphi} = 0$ when $\sigma = \frac{5}{2} - 5\gamma$, $\frac{1}{3} < \gamma < \frac{5}{14}$. φ and *A* are constant for: $\mu_{\varphi} = 0$ when $\sigma = \frac{5}{2} - 5\gamma$, $\frac{1}{3} < \gamma < \frac{5}{14}$. $\frac{3}{2} - 5\gamma,$ 1 $\frac{1}{3} < \gamma <$ 5 **or:** $\mu_{\varphi} = 0$ when $\sigma = \frac{5}{2} - 5\gamma$, $\frac{1}{3} < \gamma < \frac{5}{14}$.

(Weinberg: there is a nonzero running of λ) "& ⁼ ^A4. (32) $t \in \mathbb{R}$ and $t \in \mathbb{R}$ is taken by \mathbb{R} . Then, \mathbb{R} is \mathbb{R} is \mathbb{R} if \mathbb{R} is \mathbb{R} (Weinberg: there is a nonzero running of $\bar{\lambda}$) λ)

B) Matter phase transitions <u>die motion of motion in the motion of motion in the set of motion in the set of motion in the set of motion in </u> \mathbf{P} <u>bj r</u> <u>latter p</u> 3M² PlH² <u>r pi</u> $s_n = \frac{1}{\sqrt{2}} \int_{-\infty}^{\infty} \frac{1}{\sqrt{2}} \, e^{-\frac{1}{2} \left(\frac{1}{2} \right)} \, e^{-\frac{1}{2} \left(\frac{1}{2} \right)}$

The vacuum energy density is expected to jump at phase transitions during the radiation era: The vacuum energy density is expected to jump at phase transitions during the radiation era: nergy density is expected to <mark>jump at phase transitions</mark> during **f**

$$
T_{\rm EW} = 100\,{\rm GeV}\ \ \, {\rm and}\ \ \, T_{\rm QCD} = 200\,{\rm MeV}.\qquad \qquad \ \ \Delta \tilde{V}_{\rm vac} = -\alpha_{\rm pt} \tilde{\rho}_{\gamma},
$$

 \mathcal{M} model them as instantaneous, with a sudden jump of \mathcal{M} We take: $\alpha_{\text{EW}} = 0.1$ and $\alpha_{\text{QCD}} = 0.1$. tions. We also define the dimensionless scalar fields **The take:** $\alpha_{\text{EW}} = 0.1$ and $\alpha_{\text{QCD}} = 0.1$. Ω 1

dη

,

smoother phase transitions.

This is a simple and some and some that is a simple some that is a simple structure of $\frac{1}{2}$ an checeive cosmological constant that is i Thus, even if the total vacuum energy density is zero at very early times, these jumps generate an effective cosmological constant that is much greater than the observed value at $z=0$: , the scalar field λ and the product ∂K and the p the vacuum energy density. We can expect the vacuum energy density. We can expect that if the vacuum energy density. the Jordan frame must follow the standard radiation era \mathbf{r} more complex scenarios, they would only be effective conergy density is zero at very early times, these ji: int that is much greater than the observed value $\mathcal{L}_{\mathcal{A}}$, $\mathcal{L}_{\mathcal{A}}$ and $\mathcal{L}_{\mathcal{A}}$ and $\mathcal{L}_{\mathcal{A}}$ and $\mathcal{L}_{\mathcal{A}}$ and include include

dle such phase transitions and restore the cancellation of standard cosmological constant problem standard cosmological constant problem

The cancellation mechanism must respond to these jumps and adjust to the new vacuum ences densities and the radiation of the radiation o $\frac{1}{3}$ densities. energy densities.
To make sure that standard predictions are not model in the standard predictions are not model in the standard \mathbf{b} $\frac{1}{2}$ ncellation mechanism $U₁$ from the inflationary state to the inflationary stage to the current dark-energy stage to the current dark-energy I st I

We take:
$$
\gamma \simeq \frac{1}{3}
$$
 and $\sigma \simeq \frac{5}{6}$, λ decays only slightly faster than radiation

 φ and *A* are almost constant that ensures the cancellation of the vacuum energy den- φ and A are all lost constant

and the $\mathbf{L}(\mathbf{r})$ is not to success the difficultion of DDN. so that H(z) is not too much modified at BBN $\frac{1}{d \ln a} \left| \frac{1}{\infty} \right| \frac{1}{\infty}$ at $T_{\rm BBN} \sim 1 \text{ MeV}$

$$
\text{1:} \quad \text{1:} \quad \text{1:} \quad \text{1:} \quad \left| \frac{d \ln A}{d \ln a} \right| \lesssim 10^{-2} \quad \text{at} \quad T_{\text{BBN}} \sim 1 \text{ MeV},
$$

 a choice of normalization for b . However, more generalization for b . $\mathbf{y} \times \mathbf{y}$ and \mathbf{y} and \mathbf{y} and t : \ldots and λ -jump. At each phase transition, φ and λ jump. αν το Ωvac2 ατ το τραγουσία του αποτελεί του από το από το αναφέρει το αναφέρει το από το από το από το από το
Στην επίσης το από το απ TEW T and TQCD T and TQCD T and TQCD T and TQCD T At each phase transition, φ and λ jump. λ t each phase transition, φ and λ -jump.

10⁷⁰

10⁵⁰ ncellation mechanism cancels the n α cancenation meenamsiti cancels to stant between transitions and jumping at the phase trannew vacuum energy density. This gives a th of the order of 1 in the smooth regime, with regime, with regime, with regime, with regime, with α of these contributions is negative; this implies a small umes its decay: the cancellation mechanism cancels the new vacuum energy density. $d_{\rm{max}}$ much below α smaller jump for a smaller jump for a smaller jump for a smaller jump for a smaller jump for ∆Ωvac = Ωvac2 − Ωvac1 = −αpt But $\,\lambda$ resumes its decay: the cancellation mechanism cancels the new vacuum energy density.
 But λ resumes its decay: the cancellation mechanism cancels the new ut $\,\bar{\lambda}$ resumes its decay: the cancellation

IV- MATTER ERA R FRA the derivative with respect to the derivative with respect to R the conformal time ⌧ and *H* = *d* ln *a/d*⌧ is the conformal \blacksquare $\overline{ }$ **MATTER ERA**

A) Difficulties with the coupling to matter **A) Difficulties with the coupling to matter**
 M following the conditions (21) and (24). The cancellation works for any value of the vacuum energy density *V*˜vac @' *^a*⁴@⌧

✓@*K*

$$
\varphi \text{ -eq.:} \qquad \qquad \mathcal{M}^4 \frac{\partial K}{\partial \varphi} - a^{-4} \partial_\tau \left[a^2 \left(\frac{\partial K}{\partial Y} \lambda' + \frac{\partial K}{\partial Z} \varphi' \right) \right] = 4A^3 \frac{dA}{d\varphi} (\tilde{V}_{\text{vac}} + \tilde{\rho}/4 - \mathcal{M}^3 \lambda)
$$

⁴*A*³ *dA ^d*' (*V*˜vac + ˜⇢*/*⁴ *^M*³) (16) we look for static solutions in the Minkowski background, a coupled to T^{μ} However we should not cancel $\tilde{\rho}/4$ during the matter era $!$ λ) cancels both the vacuum energy and 1/4 of the non-relativistic matter density \mathcal{L} responds to we avoid \mathcal{L} result. In our case, we are \mathcal{L} λ cancels bout the vacuum energy and 174 or the non-relativistic matter density
because it is coupled to T^{μ}_{μ} . However, we should not cancel $\tilde{\rho}/4$ during the matter era ! because it is coupled to T^{μ}_{μ} . However, we should not cancel $\tilde{\rho}/4$ during the matter era !

gome other solf tuning models It origon from the difficulty ◆ ⁼ *^M*³*A*⁴ This difficulty is common to some other self-tuning models. It arises from the difficulty
to <mark>distinguish between the vacuum and matter densities</mark> at a given time. **ig models. It arises from the difficulty
<mark>nsities</mark> at a given time.** This difficulty is common to some other self-tuning models. It arises from the difficulty

cal framework, because the Universe is not static there is del by the use of global variables: $\hphantom{\big(}\hphantom{\big)}$ This is solved in an elegant manner in the sequestering model by the use of global variables: \mathbf{I} $\frac{1}{2}$ menner in the sequestering model by the use of global veriables: $\sum_{i=1}^{\infty}$ and the sequestering moder by the use or grobal variables.

$$
\Lambda = \frac{\int d^4x \sqrt{-g} \, T_\mu^\mu/4}{\int d^4x \sqrt{-g}}
$$

 $\frac{y + \mu}{7}$ can density left is the lo $\frac{1}{x}\sqrt{-q}$ only density iera. The radiation era $\mu v = g$ and $\mu v = g$ and μ and μ and μ and μ are μ and μ are iminated by late times, where the $\frac{1}{\sqrt{1-\frac{1$ energy vacuum energy density. \mathbf{S}_t of the vacuum energy density in the radiation era. Thus, The spacetime integral is dominated by late times, where the only density left is the low-energy vacuum energy density. Figure show \mathbf{e}

the Universe is expanding. Universe is expanding. $\mathcal{M}(\mathcal{M})$

⇢˜ = 0*, V*˜vac = constant*.* (19) Then, the equation of motion (16) has the constant so-L_{ut} before taking the local Minkowski limit. This way out of e only know about T^w_μ models [37–40], which also require time-dependent back-This is not possible in our dynamical framework, where we only know about $\,T^{\mu}_{\mu}\,$ at each time-step, not about the distant future. This is not possible in our dynamical framework, where we only know about T^{μ}_{μ}

> To face this coupling we consider solutions where λ scales as a constant fraction of the matter density. T_{α} To face this coupling we consider solutions where $\,\lambda\,$ scales as a constant fraction
of the matter density

\bullet constant to a constant \bullet solution, which will eventually ev **B) Explicit implementation**

We look for stable solutions: $\varphi = \varphi_\star, \quad \lambda = \lambda_\star e^{-3\eta}.$ ($\gamma = \frac{1}{2},$ $\beta_1 - \sqrt{145}$ 5 $\frac{1}{\sqrt{110}}$ < σ < $\frac{3}{6}$ $\mathcal{L}_{\mathbf{1}}$ and start somewhat be- $1 - \sqrt{145}$ $\frac{\sqrt{110}}{24} < \sigma <$ 5 6 $-3n$ $1 \t 1 - \sqrt{145} \t 5$ This gives two decay in 3^{7} $\gamma = \frac{1}{2}$ $\frac{1}{3}$, $\frac{1-\sqrt{145}}{24} < \sigma$ $\frac{6}{9}$, \mathcal{L} t_1 over limited ranges, and smoothly variable ranges, and smoothly vary with the architecture t_1 **lutions:** $\varphi = \varphi_\star, \quad \lambda = \lambda_\star e^{-\omega t}$. $\gamma = \frac{1}{3}, \quad \frac{1 - \sqrt{110}}{24}$

recover interesting contract abendo $* \;\; \gamma \,$ does not change $\left(\begin{matrix} \bullet \\ \bullet \end{matrix}\right)$ R^2 = 0. It and the kinetic functions (34) are the kinetic f

 \mathbb{C}

- $\frac{1}{2}$ m 5/6 to -0.4 \ast σ goes down from 5/6 to -0.4 from the inflationary state to the inflationary state to the current data \mathcal{A}
- $*$ the scalar relative density is 13% k the scalar re

$$
X_{\lambda} + X_K = \frac{1}{6\sigma - 5},
$$

V- DARK ENERGY ERA verse, but allow them to vary between different eras. In

 $\mathbf{Q} = \mathbf{Q} \cdot \mathbf{Q} \cdot \mathbf{Q}$

The end of the cancellation mechanism provides in a natural fashion a dark energy era. stant, we need ∂K/∂Y and down to be need ∂X/∂Y and down to be nonzero. This is in this is in this is in this i <u>, і</u> guments of the cancellation mechanism provides in a natural fashion a dark \overline{P} can condition modificity \overline{P} , on the first we have already we can be

Because the cancellation mechanism arises from the conformal coupling $\;A(\varphi)\;$ it naturally stops when: *dA* p can be the surfact of the section \mathbf{r} is not used by a to be a time dependent back- $\frac{1}{\sqrt{1-\frac{1}{c}}}\int_0^c f(x) \, dx$ $\overline{6}$ use the cancellation mechanism arises from the c stand that $A(\varphi)$ is constant or $\frac{dA}{d\varphi} \simeq 0$ ancellation mechanism arises from the conformal coupling $\,$ $\,$ $\,$ $\,$ The state of the kinetic functions (34) and the kinetic functions (34) and the kinetic functions (34) are the $\frac{1}{2}$

 $A(\varphi)$ is constant or $\frac{d\Omega}{d\varphi} \simeq 0$ $\frac{1}{2}$ relations to the new term as the new term as $a\varphi$ from the inflationary state to the current data of $a\varphi$

This is possible because φ plays the role of a clock. This is possible because φ plays the role of a clock. e role of a clock. To have simply consider the \sim case where the kinetic function becomes the kinetic function becomes the kinetic function becomes the contract of the contract This is possible because $K_{\rm{max}}$ + $K_{\rm{max}}$ + $K_{\rm{max}}$ + $K_{\rm{max}}$ + $K_{\rm{max}}$ $+1$ era. because φ plays the role of a clock.

This is possible because
$$
\varphi
$$
 plays the role of a clock.
\n $\varphi > \varphi_{\text{DE}}$: $A(\varphi) = A_{\star} = 1$.
\n $K(\varphi; X, Y, Z) = K_X X^{\gamma} + K_Y Y$, $\gamma = 1/4$

VI- INFLATION ERA longer systematically runs towards Ωvac and compensates VI- INFLATION ERA <u>VE HALLAHUM LIVE</u> M_{\odot} in $ONFRA$ constant for most of the expansion history of the expansion history of the Uni-

A) Accelerated expansion 3 2.5 2 1.5 1 0.5 0 τ motions of motion (31)-(32) only depend on τ longer systematically runs towards Ωvac and compensates to zero. We also set the initial radiation of the initial radiation density to zero. We also set the initial r
The initial radiation density to zero. We also set the initial radiation of the initial radiation of the initi only relate the end of the inflationary stage to the change $\frac{1}{\sqrt{1-\frac{1$ $\overline{\mathbf{A}}$ more complex scenarios, they would only be effective co-

As for DE, accelerated expansion occurs for constant $\ A(\varphi)$ \sim \sim \sim \sim \sim \sim \sim \sim on occurs for constant $A(\varphi)$ \mathcal{L} of the kinetic and coupling functions. The term [∂]^K As for DE, accelerated expansion occurs for constant $\,A(\varphi)\,$ efficients that provide a provide approximations of the kinetic functions of the kinetic functio t ated expansion occurs for constant $A(\varphi)$

 $\varphi < \varphi_\mathrm{I}: \quad A(\varphi) = A_\mathrm{I}.$ $\frac{1}{\sqrt{2}}$ $K(\varphi;X,Y,Z)=K_XX+K_YY, \qquad$ (standard (standard kinetic function) \cdot ic fur \overline{h} $\mathbb{E}(\omega \times \nabla Z) = \mathbb{E} \cdot \nabla \cdot \cdot \nab$ $T(\varphi, \Lambda, I, \varphi) = T\Lambda \Lambda I + T\Gamma I,$ (see the second constraint) φ φ φ :
.
. A_1 . A_2 (φ , A , I , Z) Λ _{X} A $+$ Λ _{Y} I , φ (because λ and

 σ in the kinetic function (σ) has a standard form, in the sta **CONSTANT-** λ solution: $\lambda = \lambda_I, \lambda = \lambda$ In this paper, we do not try to match the expansion $3K_{Y}h_{\text{I}}^{2}$ Constant- λ solution: $\lambda = \lambda_I$, $\lambda = \lambda_I - \Omega_{\text{vacI}}$, $\varphi = \varphi_I +$ $A_{\rm I}^4$ $\overline{3K_Y\hslash_{\rm I}^2}$ Constant- λ solution: $\lambda = \lambda_I$, $\lambda = \lambda_I - \Omega_{\text{vacI}}$, $\varphi = \varphi_I + \frac{\lambda_I}{3K_V\hbar^2}(\eta - \eta_I)$, .
. (!
! λ solution:
 λ solution: λ ! ! λ_1, λ_2 $\overline{14}$ $\Omega_{\text{vac},I}$, $\varphi = \varphi_I + \frac{I_{II}}{2.55 \times 10^9} (\eta - \eta_I),$ $\delta R Y h_{\rm I}^2$ າt- λ recover interesting cosmological behaviors in the subclass $A^4_{\rm I}$ **KION:** $\lambda = \lambda_I$, $\lambda = \lambda_I - \Omega_{\text{vacI}}$, $\varphi = \varphi_I + \frac{1}{3K_Y \hbar_I^2} (\eta - \eta_I)$,

plays no role and a faith and any value of the angular can take and the series of <u>Equation the acce</u> kinetic and coupling function, the sound so as the so-<u>the observed Hubble diagram</u>. Better still, one should be the still, one should be the still, one should be the sense that it is in the industrian in only a quadratic polynomial in ∂⊿. <u>Ford after the put the term can </u> where we assume that the decay in the decay in
The decay in the d the accelerated expansion and ea Hubble expansion rate is **B) End of the accelerated expansion and early radiation era** continuous at the transition. Because the transition of the vacuum energy of the vacuum energy of the vacuum e meant as an example for a transition from the inflation-<u>ated expansion and early radiatio</u> connected to the later radiation era. B) End of the accelerated expansion and ear equations of motion (31)-(31)-(31)-(32) gives of motion (31)-(32) gives $\overline{}$ $\mathbf{B}(\mathbf{y})$. (28). (d of the esseleveted evrespeier and conly -<u>u u</u>

We assume a transition with \mathcal{L} $\Delta Q = e^{-\hbar_{I}^{2}}$ while the conform: $\Delta v_{\text{vac}} = \alpha_1 A_1^4$, will energy densitive \hbar^2 is a constant the transition to a constant \hbar^2 $\Delta \Omega_{\rm vac} = -\alpha_{\rm I} \frac{1}{44}, \quad$ while the co $A_{\rm I}^$ rop of the vacuum energy and a transfer t ϵ \mathbf{v} disappears from the scalar field equations of motion, \mathbf{v} and it gives a vanishing contribution to the Friedmann prmal coupling and $\overline{}$ We assume a transition with a drop of the vacuum energy and a transfer to the radiation density: the conformal coupling and kinetic function take are comormal coupling and issiect function take eir radiation-era form \mathcal{L}_{II} radiation or a form. $\Delta\Omega_{\rm vac}=-\alpha_{\rm I}\frac{n_{\rm I}}{A^4},~\;$ while the conformal coupling and kinetic function take their radiation-era form. $\Delta \Lambda / \Omega$ assumes a two notion by Ω \hbar^2 I $A_{\rm I}^4$ $,$ while the conforma isume a transition with a drop of the vacuum energy and a transfer to the radiatior T this is only one of the possible scenarios, and it should scenarios, and it should scenarios, and it should be pupling and kinetic function take their radiation-energy baphig and through and through the transition to a change of the theory of the theory of the theory of the the sun; ! \overline{e} : \mathbf{d} <u>u</u> " d
" dan d cı tion with a $_{\rm ac}$ = $-\alpha_{\text{I}} \frac{n_{\text{I}}}{44}$ A_{1}^{\prime} $,$ while lile the conformal -0.6 p or the vacuum energy and a transier while the conformal coupling and kinetic function take the $\bf v \bf v \bf c$ assume coordinate $\bf c$ $\frac{1}{2}$ tion with a drop of the vacuum energy and a transfer to the $\frac{1}{2}$ and the difference of the difference $\frac{1}{2}$ and $\frac{1}{2}$ changed to the difference $\frac{1}{2}$

VII- CONCLUSION

- It is possible to build simple self-tuning models that provide a dynamical cancellation of the vacuum energy density

- This does not "explain" the value of the observed cosmological constant, but it can solve the "old cosmological constant problem".

- For these dynamical models, a delicate issue is to cancel the vacuum and only the vacuum ! (How to distinguish it from the matter density ?)

- An interesting feature is to link together: - "old cosmological constant problem"

-
- DE
- Inflation

hope to see something in cosmological data !

- This explicit model is probably not the final answer ! Need to overcome some tuning (matter era transition). Also need to check perturbations.

therefore vacuum energy, in a "protected" matter sector taken to include the Standard Model. We the two densities the two dynamical variables to talk the talk to one and the talk to one and the talk to one a form is set by dimensional analysis. What follows is the *sequestering* action [9, 10] Sequestering model Kaloper & Padilla (2014), PRD 90, 084023 (+....) *S* = *d*⁴*x* p*^g* <u>Exering model</u> $Sequence$ </u> <u>uc</u> e Z **dia** *a**z* **(***x**dieperal is defined a <i>kaloper* **state of** *Kaloper g*˜ *g*˜ p*g*˜*Lm*(˜*g^µ*⌫ = ⁴*T*˜*^µ*

where $Padilla$ 1502.05296 م العالم ال
والمسابق العالم الع

$$
S = \int d^4x \sqrt{-g} \left[\frac{M_{pl}^2}{2} R - \lambda^4 \mathcal{L}_m(\lambda^{-2} g^{\mu\nu}, \Psi) - \Lambda \right] + \sigma \left(\frac{\Lambda}{\lambda^4 \mu^4} \right)
$$

 Λ and Λ **exaction** \mathbf{p} form of the sequestering function \mathbf{p} function \mathbf{p} Λ and λ are global variables scales go intervals and the bare mass scale appearing in the matter scale appearing in the matter Lagrangian. No λ , and λ , and the equation is just the equation of motion of μ motion of μ R_{H} and R_{H} and R_{H} variables Λ and λ are global variables forced to vanish. However, since all the physical masses in the matter sector scale with relative to

$$
\sqrt{-g}\lambda^4 \mathcal{L}_m(\lambda^{-2}g^{\mu\nu}, \Psi) = \sqrt{-\tilde{g}}\mathcal{L}_m(\tilde{g}^{\mu\nu}, \Psi) \quad \text{with} \quad \tilde{g}_{\mu\nu} = \lambda^2 g_{\mu\nu}.
$$

e constant conformal mapping between Jordan **g** again to a constant conformal manning hetween **External mapping between Jordan and Einstein metrics**
 External mapping between Jordan and Einstein metrics t conformal manning hetween lordan and Finstein metrics **g** $\frac{1}{2}$ yields the following equations of $\frac{1}{2}$ \sim sonstant conformal mapping forced to vanish. However, since all the physical masses in the matter sector sect In other words, spatial sections must be finite, and the Universe must ultimately end in a crunch.

Equations of motion with respect to Λ , λ and $g_{\mu\nu}$ $\frac{1}{\lambda} \frac{d}{d\mu} \sigma'$ In other words, spatial sections must be finite, and the Universe must ultimately end in a crunch. **Equations of motion with respect to** Λ , λ and $g_{\mu\nu}$ $\frac{1}{\lambda^4 \mu^4} \sigma' \left(\frac{\Lambda}{\lambda^4 \mu^4} \right) = \int d^4x \sqrt{-g}$

Equations of motion with respect to
$$
\Lambda
$$
, λ and $g_{\mu\nu}$
$$
\frac{1}{\lambda^4 \mu^4} \sigma' \left(\frac{\Lambda}{\lambda^4 \mu^4}\right) = \int d^4 x \sqrt{-g}
$$

$$
\frac{4\Lambda}{\lambda^4 \mu^4} \sigma' \left(\frac{\Lambda}{\lambda^4 \mu^4}\right) = \int d^4 x \sqrt{-g} \lambda^4 \tilde{T}_{\alpha}^{\alpha}
$$

$$
M_{pl}^2 G_{\nu}^{\mu} = -\Lambda \delta_{\nu}^{\mu} + \lambda^4 \tilde{T}_{\nu}^{\mu}
$$

This gives:
$$
\Lambda = \frac{1}{4} \langle T_{\alpha}^{\alpha} \rangle = \frac{\int d^4x \sqrt{-g} T_{\alpha}^{\alpha} / 4}{\int d^4x \sqrt{-g}} \quad \text{and hence:}
$$

$$
M_{pl}^2 G_{\nu}^{\mu} = T_{\nu}^{\mu} - \frac{1}{4} \delta_{\nu}^{\mu} \langle T_{\alpha}^{\alpha} \rangle = \tau_{\nu}^{\mu} - \frac{1}{4} \delta_{\nu}^{\mu} \langle \tau_{\alpha}^{\alpha} \rangle \qquad \text{with:} \quad T_{\nu}^{\mu} = -V_{vac} \delta_{\nu}^{\mu} + \tau_{\nu}^{\mu},
$$

 θ = θ excitations showe the *require* $\frac{1}{\sqrt{2}}$ the Planck scale, vanish. We do not live in a Universe in a Universe in a Universe in which all $\frac{1}{\sqrt{2}}$ The energy momentum tensor can be written as *T ^µ* V_V are the local excitations above the vacuum. $-\mu$ - there are no highest in unimodular gravity. The classical dynamics of the classical τ_{ν}^{μ} are the local excitations above the vacuum. τ^{μ}_{ν}

out from the Einstein equations, to all loop orders. calculate the latter to any desired loop order, but it makes no diverse no diverse no diverse no diverse no di Standard Model vacuum energy will *always* drop out of the gravitational dynamics, leaving us with $\overline{\mathbf{r}}$ is calculated. There is a sense in which we have decoupled the zero in which we have decoupled the ze The vacuum endrely drops out from the Linstein equations, to all it Standard Model in the Guit from the Finstein equations to all loop orders the vacuum entirely drops out from the The vacuum entirely drops out from the Einstein equations, to all loop orders.

There remains a small residual cosmological constant, but it is smaller than the current dark energy density: energy conditions (1 **partlers)**, the energy density is the smaller than the current dark energy density. but it is sinalier than the current da $\alpha_{\rm e}$ = *a*₄ *a*₂ *a*₂ *a*₄ *a*₂ *a*₄ *a*₂ *a*₄ max*,* ^h⌧ ↵

⇤e↵ = 1 4 h⌧ ↵ ↵ i (7.11) ↵ i ⇠ ⇢turn (7.12) first ever models of quintessence[61] in which a canonical scalar field, , minimally coupled to gravity *V* = *m*³ (7.24)

$$
\int d^4x \sqrt{-g} = a^4_{\rm max}, \qquad \langle \tau^{\alpha}_{\alpha} \rangle \sim \rho_{\rm turn} \qquad \qquad \rho_{\rm turn} \sim M_{pl}^2 H_{\rm turn}^2 \stackrel{= \text{num}}{\sim} \rho_c \sim \bar{M}_{pl}^2 H_0^2.
$$

characteristic a particular solution. Fixing its value does not lead of all the contract of local dynamics, and does not lead to lead the contract of local dynamics, and does not lead to lead the contract of lead to lead t energy density of matter near the turnaround ⇢turn ⇠ *^M*² *plH*² turn . ⇢*^c* ⇠ *^M*² *plH*² ⁰ . It follows that ⇤e↵ Spacetime volume is finite, Universe is closed k>0. technically natural and do not su↵er from any radiative instabilities. c and c are therefore c

cosmological constant can only be achieved by scanning all of $\overline{M}_{\overline{J}}$ COIIapse: $V = m^{\circ} \phi$ t_{collapse} $\sim \sqrt{\frac{m^3}{m^3}}$ Transient dark energy before collapse: $V\, \equiv m^{\circ}\varphi$ have expected. The first is an approximate scaling symmetry (becoming exact as *Mpl* ! 1), $\frac{1}{2}$ and $\frac{1}{2}$ belong compose. $= m^2 \varphi$ $\sqrt{m^3}$ Transient dark energy before collapse: $V = m^3 \phi$ *t*_{collapse} ~ $\sqrt{\frac{M_{pl}}{m^3}}$ $\sqrt{M_{pl}}$ $\frac{m}{m^3}$