Sequestering the Sp Vacuum Energy

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Messages:

1) What it is not: solution of CC problem (yet!)
2) What it is: a way around Weinberg no-go
3) Mechanism
   a) Cancelling vacuum energy loops
   b) Keeping monter mass gap in naive QFT
   c) Symmetries & projection mechanism

4) Comments on features and predictions
5) Questions & future directions

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Cosmological Constant problem

You hear:
1) "Why is it not $M_p^4$?"
2) "Why is it not 0?"
3) "Why is it $10^{-120} M_p^4$?"

THIS IS ALL NONSENSE!!!

We do not yet have a fully consistent UV complete algorithm for computing vacuum energy; maybe we do not even have a unique vacuum. The best we CAN do: compute in QFT coupled to gravity + see what happens.

SO DO IT, BUT DO IT "RIGHT": IE USE THE RULES OF QFT TO THE LETTER (AND SPIRIT...!)
Cosmological constant - aka vacuum energy diverges:

\[ \Lambda_{\text{vac}} = \square + \square + \square + \ldots \quad \text{matter loops} \]

\[ + (\square + \square + \ldots) \quad \text{gravity + matter loops} \]

Must be renormalized! Finite part NOT calculable but MUST be measured!

But: if determined at N-loop level and fitted to observations (like Higgs mass!) it needs to be completely refitted - from scratch - at N+1 loops

Just like the Higgs mass...
MEASURED CC IS BADLY RADIATIVELY UNSTABLE!

This is the ONLY meaningful formulation of CC problem in QFT of matter + gravity

The problem is very serious due to the famous Weinberg no-go theorem! (1989)

(Alternative philosophy: forget naturality & use anthropic arguments - giving up ?!)
Weinberg no-go: prohibits dynamical adjustment in EFT+gravity to a non-zero mass gap

Adjustment + radiative stability \iff \text{Conformal symmetry}

\lambda_{\text{eff}} = \left( \lambda_{\text{vac}} + \lambda_{\text{classical}} \right)^4 \ell^2

either of the two options is bad:

1) \lambda_{\text{vac}} + \lambda_{\text{classical}} \ll (\text{cutoff})^4: \text{TUNING}

2) \phi \rightarrow -\infty: \text{"ADJUSTMENT"}?

But then, since \( M_{\text{phys}} = M e^\phi \),

\[ M_{\text{phys}} \rightarrow 0! \]

\textbf{NOT OUR WORLD!}
$S = \int d^4x \sqrt{g} \left\{ \frac{M_{pl}^2}{2} R - \Lambda - \lambda \Lambda \left( \frac{\phi}{\Lambda} \right) \right\} + \sigma \left( \frac{\Lambda}{\lambda^{\frac{1}{4}} M^4} \right)$

Postulate: $\Lambda$, $\lambda$ dynamical GLOBAL variables

:: LAGRANGE MULTIPLIERS JUST LIKE IN THE ISOPERIMETRIC PROBLEM

\[ \int d^4x \sqrt{g} \Lambda : \text{Legendre transformation: } \text{trades } \int d^4x \sqrt{g} \]

for new INDEPENDENT VARIABLES $\Lambda$

Variational eqs fix $\Lambda + \sigma \frac{1}{4} \langle T^{\text{const}} \rangle_{\text{vac}}$

because $\lambda$ is just the engineering scale

:: $\frac{1}{4} \langle T^{\text{const}} \rangle_{\text{vac}} = \Lambda_{\text{vac}} = \mathcal{O} + \mathcal{O} + \mathcal{O} + \ldots$

NO INTERNAL GRAVITON LINES !!!
We work @ QFT of matter @ (semi)classical gravity: gravity is a spectator, a probe only.

OK: this is the original version of the problem recognized by Pauli & by Zeldovich.
The Weinberg NO GO prevents a dynamical field even in this restricted setup.

NOTE: can define $\bar{g}_{\mu\nu} = \lambda^2 g_{\mu\nu}$ to rewrite the QFT of matter as

$$S_{\text{matter}} = -\int d^4x \sqrt{|g|} \mathcal{L} \left( \bar{g}^{\mu\nu}, \phi \right)$$

Since the theory is Poincare INV & DIFF INV -- as long as we insist that the UV regulator is also included in $\mathcal{L}_{\text{matter}}$ -- the form of the matter action is PRESERVED by all loop corrections.

So:

$$\Lambda_{\text{vac}} = \Lambda + \Omega + \Theta + \ldots = \lambda^4 \left( \text{dimensionful factor} \right)$$

Thus:

$$\Lambda_{\text{vac}} \langle 0 | \mathcal{L}_{\text{matter}} | 0 \rangle = \frac{1}{4} \langle 0 | T^n | 0 \rangle$$
Variational Eqs

$$M_p^2 G^\mu_\nu = T^\mu_\nu - \Lambda d^\mu_\nu$$

$$\frac{\sigma^i}{\lambda^i \mu^i} = \int d^4x \, \Gamma g \quad \Lambda \frac{\sigma^i}{\lambda^i \mu^i} = \frac{1}{4} \int d^4x \, T^\mu_\nu$$

In the vacuum, $T^\mu_\nu \rightarrow \langle 0 | T^\mu_\nu | 0 \rangle$ regularized; so elimination of $\sigma^i$ gives

$$\Lambda = \frac{1}{4} \frac{\int d^4x \, \Gamma g \langle 0 | T^\mu_\nu | 0 \rangle}{\int d^4x \, \Gamma g} = \frac{1}{4} \langle T^\mu_\nu \rangle$$

\( \Lambda \) is SPACETIME average of the $T^\mu_\nu$ - integrated over all times, past & future! (GLOBAL CONSTRAINT!)

$$M_p^2 G^\mu_\nu = T^\mu_\nu - \frac{1}{4} \langle T^\alpha \_\alpha \rangle \, d^\mu_\nu$$

Define now $T^\mu_\nu = -\Lambda_{vac} \, \delta^\mu_\nu + \Box T^\mu_\nu$ \( \text{(non-const part)} \)

Since $\langle \Lambda_{vac} \rangle = \Lambda_{vac} = -\frac{1}{4} \langle T^\alpha \_\alpha \rangle$ (const). :
\[ M_{\text{pl}}^2 G^m_\nu = \nabla^m \nu - \frac{1}{4} \left< \frac{\partial}{\partial \nu} \right> \delta^m_\nu \]

\( \Lambda_{\text{vac}} \) completely cancelled from the source at the curvatures irrespective of the loop order

**In this theory vacuum energy invisible to \( G^m_\nu \)**

**Trick:** global variable \( \Lambda \) is tied to \( \Lambda_{\text{vac}} \) and always exactly cancels it; the residual finite part is \( -\frac{1}{4} \left< \frac{\partial}{\partial \nu} \right> \) - historic average of energy density of all **nonconstant sources** (\( f, B, D, M, \ldots \))

**Note:** canonically normalizing all matter fields shows that physical dimensionless parameters are

\[
\frac{M_{\text{phys}}}{M_{\text{pl}}} = \lambda \quad \frac{M_{\text{bare}}}{M_{\text{pl}}}
\]

So \( M_{\text{phys}} \neq 0 \iff \lambda \neq 0 \); but by

\[
\lambda q \mu^4 = \frac{\sigma'}{\int d^4 x \sqrt{g}} \Rightarrow \int d^4 x \sqrt{g} < \infty \quad \text{finite! universe!}
\]
Recapitulate:

1) Vacuum energy completely cancelled!  
2) Residual "c.c." determined by the historic average of all nonconstant matter:

$$\Lambda_{\text{eff}} = \frac{1}{4} \langle T^\nu_{\alpha\gamma} \rangle$$

This is NONLOCAL IN TIME! — but: NO PATHOLOGIES in (semi) classical gravity.  
Recall QFT: if $\Omega$ is divergent, $\Omega$ CANNOT be predicted: one regulates it ($\Lambda_{\text{vac}}$), picks the constant term ($\Lambda$), cancels the divergent part and MEASURES the finite remainder!

$\Lambda$: codimension-0 parameter — need cod. 0 detector to measure:  
THE WHOLE UNIVERSE IS THE ONLY DETECTOR

3) Need $\int d^4x \sqrt{g} < \infty$ to keep nonren QFT mass gap  
UNIVERSE LARGE BUT FINITE IN SPACE-TIME!

Predictions:  
1) will collapse  
2) finite spatial sections (CMB?)  
3) cannot accelerate forever!
Symmetries & Naturalness

Whenever Δ mass does cancelation look for symmetries

there are 2 approx sym entries

1) approx scaling sym

\[ \lambda \rightarrow \frac{\lambda}{\Lambda^4} \]

\[ g_{\mu\nu} \rightarrow g_{\mu\nu}/\Lambda^2 \]

2) approx shift sym

\[ \Lambda \rightarrow \Lambda + \alpha \Lambda^9 \]

\[ \ell \rightarrow \ell - \alpha \]

Weakly broken by

\[ \Delta S \sim \alpha^4 \int d^4x \sqrt{g} \rho_n d \left( \frac{\rho_n}{M_{O_3}} \right)^4 \]

\[ \ll \]

Scaling ensures cancellation happens at all scales

Shift performs the cancellation

Since symmetric are approx, \[ \alpha \ll M^{-1} \]

It is naturally small since in the conformal limit \[ M_{O_3} \rightarrow 0 \] symmetries enhanced!

PROTECTION MECHANISM!
Further properties & consequences

1) Consistent @ inflation - can make a big old universe @ slowly rolling $\Phi$

2) Phase transition contributions to $\Lambda_{\text{eff}}$ automatically small! (Reason: PT takes only a fraction of universes lifetime and its correction to $\Lambda_{\text{eff}}$ is weighted by $\int dt^4 \sqrt{g}$.)

3) $\Lambda_{\text{eff}} = \frac{1}{4} \langle \xi^2 \rangle \leq M_{Pl}^2 H_*^2$ where $H_*$ is Hubble at the onset of collapse $H_* \leq H_{\text{now}}$

$$\Lambda_{\text{eff}} \leq 10^{12} \text{eV}^4$$

as long as we live in a big old universe (we do!)

4) Offers a new perspective on the cosmic coincidence "problem": can we explain cosmic acceleration NOW? (Work in progress, it seems YES!)


SUMMARY

1. Found a way around Weinberg no-go
   a. Cancels all loop corrections to $\Lambda$
   b. Maintains $\text{Mphys} \neq 0$
   c. Radiatively stable - aka technically natural
   d. Maximally minimal modification of GR+QFT
      * Pomare & diff. invariant
      * No new local DOFs
      * Locally theory behaves the same as usual
      * Cosmological predictions differ: $\Lambda \neq -1$, universe finite, will collapse

2. Phase transitions tamed
3. Inflation OK!

4. Microscopic origin & UV completion?
5. Protection from gravity loops?
6. Uniqueness? Or not? Further predictions?

"The End"