n-DBI gravity

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gravitation.web.ua.pt

Outline

Scale Invariance and Inflation

- Observations suggest that the Universe is nearly scale invariant at early and late times, when it is believed to be approximately de Sitter space.
- At the present epoch, the accelerating expansion is thought to be driven by a nearly constant vacuum energy.
- To explain the inflation phase after the Big Bang, most current models involve a scalar field, the *inflaton*, which acts as the agent of the nearly exponential expansion of the Universe.
- However, the nature of such a field is far from clear from the Particle Physics point of view.

A new model of Gravity

Action for n-DBI Gravity

$$S = -\frac{3\lambda}{4\pi G_N^2}\int d^4x\sqrt{-g}\left\{\sqrt{1+\frac{G_N}{6\lambda}\left({}^{(4)}R+\mathcal{K}\right)}-q\right\}$$

- λ, q are dimensionless constants that set the scale of inflation and the cosmological constant.
- $\mathcal{K} = -2(K^2 + n^\alpha \partial_\alpha K)$, where K is the extrinsic curvature of hypersurfaces orthogonal to n^α.

A new model of Gravity

This model:

- yields the Dirac-Born-Infeld type conformal scalar theory when the Universe is conformally flat.
- reduces to Einstein's gravity with the Gibbons-Hawking-York boundary term in weakly curved spacetimes.

Moreover,

- it breaks Lorentz invariance by introducing a preferred time-like vector field (albeit recovering it the weak curvature limit).
- resembles Hořava-Lifshitz gravity in the sense that we treat time as distinct from space.

The conformally flat Universe

If we consider conformally flat universes, with metric

Friedmann-Robertson-Walker Ansatz

$$ds^2 = \ell_P^2 \phi(\tau)^2(-d\tau^2 + dx^2),$$

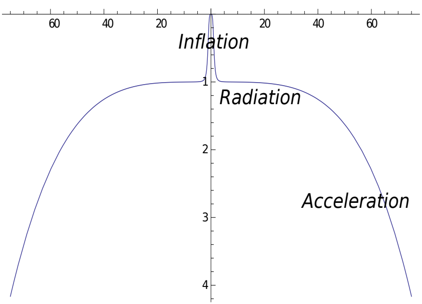
we get a conformal scalar theory with equation of motion

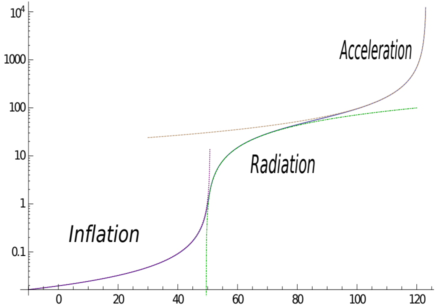
Effective Potential for the Scalar Field

$$\frac{1}{2}\dot{\phi}^2 + V(\phi) = 0,\ V(\phi) = -\frac{1}{2}\lambda\phi^4 \left[1 - \left(q + \frac{\epsilon}{\lambda\phi^4}\right)^{-2}\right].$$

- ℓ_P is the Planck lenght; ϵ is the radiation energy.

The conformally flat Universe





- The model naturally results in inflation at early times, followed by radiation- (and matter-) dominated epochs and subsequent acceleration at late times.

The Universe with a Perfect Fluid

Energy-Momentum Conservation

$$\dot{\rho} + 3H(\rho + p) = 0.$$

Friedmann Equation

$$H^2 = \frac{\lambda}{G_N}\left[1 - \left(q + \frac{4\pi G_N^2}{3\lambda}\rho\right)^{-2}\right].$$

Raychaudhury Equation

$$\partial_t \left[H\left(q + \frac{4\pi G_N^2}{3\lambda}\rho\right)\right] = -4\pi G_N(\rho + p).$$

Inflation and the Cosmological Constant Problem

- Taking the energy scale of inflation to be $E_{inf} = \sqrt{\lambda}\ell_P^{-1} \sim 10^{15}$ GeV,
- and the current CC $\sim 10^{-12}$ GeV, implying $E_\Lambda = \sqrt{\lambda(1-q^{-2})}\ell_P^{-1} \sim 10^{-60} M_P$,
- to generate such a large hierarchy, we need $\lambda \sim 10^{-8}$ and $q \sim 1 + 10^{-110}$.

A large hierarchy is generated between the two effective CC's, $1/\sqrt{1-q^{-2}}$. The required fine-tuning is of the same order as the traditional description.

The vector field n^α

- The introduction of the everywhere time-like vector field n^α yields equations which are at most second order in time, albeit higher order in spatial derivatives.
- This is a desirable property to avoid *ghosts* in the quantum theory.
- n^α defines a natural foliation of space-time by (constant time) hypersurfaces orthogonal to n^α.

ADM decomposition

$$ds^2 = -N^2 dt^2 + h_{ij}(dx^i + N^i dt)(dx^j + N^j dt), \qquad n = -N dt.$$

The gauge group of *n*-DBI gravity

The general diffeomorphism group of General Relativity is broken down into:

Foliation-Preserving Diffeomorphisms

$$t \to t + \xi^0(t), \qquad x^i \to x^i + \xi^i(t, x^j).$$

- Quantities such as the shear σ_{ij} and the expansion θ of a congruence of time-like curves with tangent n^α acquire an invariant geometric meaning:

$$\sigma_{ij} = K_{ij} - \frac{1}{3}Kh_{ij}, \qquad \theta = K.$$

Einstein's Gravity limit

Einstein's equations can be recovered by taking the limit

$$\lambda \to \infty, \qquad q \to 1,$$

with the product $\lambda(q-1)$ kept fixed.

- We get a CC term
$$\Lambda = \frac{6\lambda(q-1)}{G_N^2}.$$
- Full Lorentz invariance is restored.

Solutions with constant $\mathcal{R}$

The study of solutions with constant $\mathcal{R} = {}^{(4)}R + \mathcal{K}$ establishes the following theorem

Theorem

Any solution of Einstein's gravity with cosmological constant plus matter, admitting a foliation with constant $\mathcal{R}$, is a solution of n-DBI gravity.

Corollary (maximal slicing)

Any Einstein space admitting a foliation with constant $R - N^{-1}\Delta N$ (hypersurface metric and Ricci scalar), is a solution of n-DBI gravity.
E.g. Kerr metric in Boyer-Lindquist coordinates.

Black Hole Solutions

If we require spherical symmetry and include a Maxwell field, we get the RN-(A)dS black hole metric, albeit in an unusual set of coordinates. The cosmological constant is an integration constant

$$\Lambda_C = \frac{3\lambda}{G_N^2}(2qC - 1 - C^2), \qquad C \equiv \sqrt{1 + \frac{G_N}{6\lambda}\mathcal{R}}.$$

Thus, asymptotically ($r \to \infty$), we can get either de Sitter, Anti-de Sitter or Minkowski space, depending on the value of C.

What are the degrees of freedom of *n*-DBI gravity?

- The breaking of Lorentz invariance down to FPD's should give rise to extra degrees of freedom.
- Local degrees of freedom can be computed using Dirac's theory of constraints.
- In addition to the 2 graviton polarizations of General Relativity, *n*-DBI has an extra *scalar* mode.

The dynamics of the scalar graviton

- In the $3+1$ formulation of General Relativity, the Hamiltonian constraint is automatically preserved by the evolution equations.
- In n-DBI, its time evolution gives an equation for the scalar mode

$$\Delta\dot{\chi} - KN\Delta\chi - \left(N\partial^i K + 2K\partial^i N\right)\partial_i\chi - N^{-1}\Delta N\dot{\chi} = 0\,,$$

where

$$\chi \equiv \left(1 + \frac{G_N}{6\lambda}\mathcal{R}\right)^{-1/2}.$$

Taming the scalar mode

- Extensions of original HL model [BPS 2009] have improved the behaviour by the addition of $N^{-1}\partial_i N$ terms.
- This appears *naturally* in *n*-DBI

$$\mathcal{R} = R + K_{ij}K^{ij} - K^2 - 2N^{-1}\Delta N \,.$$

- HL has the combination $K_{ij}K^{ij} - \lambda K^2$ and the GR limit $\lambda \to 1$ is usually ill-defined.
- *n*-DBI has $\lambda = 1$.

Perturbations around flat space

Consider scalar perturbations around Minkowski space-time

$$N = 1 + \phi \; , \qquad N_i = \nabla_i B ,$$
$$h_{ij} = \delta_{ij} - 2\left(\delta_{ij} - \frac{\nabla_i \nabla_j}{\triangle}\right)\psi - 2\frac{\nabla_i \nabla_j}{\triangle} E \; ,$$

In GR, we can gauge-fix $B = \phi = 0$, and the equations of motion yield

$$\ddot{E} = \ddot{\psi} = \triangle \psi = 0 \; .$$

Thus there is no propagating degree of freedom.

Perturbations around flat space

In n-DBI, we can gauge-fix $E = 0$. The scalar mode is manifest in the general solution

$$
\begin{aligned}
B(t,x) &= B_0(x) + B_1(x)t\,, \\
\phi(t,x) &= -B_1(x) - \psi_0(x)\,, \\
\psi(t,x) &= \psi_0(x)\,, \\
\psi_0(x) &= -\frac{G_N}{6\lambda}\left(\Delta B_1 + \frac{3}{2}\Delta\psi_0\right)\,.
\end{aligned}
$$

The pair of free functions $\{B_0(x), B_1(x)\}$ represents 1 degree of freedom in the Hamiltonian formalism.

Vanishing Lapse

- In HL gravity, it was found [Henneaux 2010] that in asymptotically flat space-times, the lapse must vanish: the time flow of the hamiltonian constraint yields a new constraint.
- In n-DBI, due to its non-linear lapse dependence, the time flow of the hamiltonian constrain determines a Lagrange multiplier instead.
- No additional constraint is imposed on the lapse.

Strong Coupling

- Naively, *n*-DBI admits the GR limit $\lambda \to \infty$ and $q \to 1$ with $\lambda(q-1)$ fixed.
- It is subtle whether the scalar couple decouples in the IR (eg. vDVZ discontinuity).
- HL suffers from a similar strong coupling problem: the scalar mode becomes strongly coupled at $\Lambda_s = \sqrt{\lambda_{HL} - 1} M_P$.

Strong Coupling in *n*-DBI

- In *n*-DBI, the scalar mode action in flat space (to third order) is

$$S = \frac{1}{192\pi\lambda} \int d^4x \left[\frac{1}{2}(\Delta\dot{\varphi})^2 - (\dot{\varphi}\Delta\ddot{\varphi} - \partial_i\varphi\Delta\partial^i\dot{\varphi})\Delta\varphi + \frac{5(\Delta\dot{\varphi})^3}{12\lambda M_P^2} \right] .$$

- The most *relevant* terms are of the middle type and actually (classically) *marginal*.

Strong Coupling in n-DBI

For the cubic terms with coupling $g = \sqrt{\lambda}$, the beta function is $\beta(g) = -cg^3$ from which

$$g^2 = g_0^2 \left(1 + 2cg_0^2 \ln \frac{\Lambda}{M_P}\right)^{-1} .$$

- Strong coupling scale: $\Lambda_s \sim M_P \exp\left(-\frac{1}{2c\lambda}\right)$.
- If $c < 0$, then for $\lambda \to \infty$, $\Lambda_s \sim M_P$.

Short distance instability

- In HL, the scalar graviton develops an exponential short distance instability in generic spacetimes.
- No such solution, of the type

$$(\phi, \gamma) \sim (\phi(\omega, p), \gamma(\omega, p)) e^{i\omega t + i p \cdot x} \,,$$

  is found in n-DBI, except for $\omega = 0$.
- The scalar mode is neither oscillating nor exponentially growing (to linear order).

Non-linear (in)stability?

To study the fully non-linear stability of the scalar mode, it is useful to work in the Einstein frame, in which the action becomes

$$S \sim \int d^4x\sqrt{-g}\left[{}^{(4)}R - 6(n^\alpha n^\beta + h^{\alpha\beta})\partial_\alpha\chi\partial_\beta\chi + 2\mathcal{K}\chi + V(\chi)\right] ,$$

$$V(\chi) = \frac{6\lambda}{G_N}\frac{(e^\chi - e^{-\chi})^2 + 2(1-q)}{e^{4\chi}} .$$

- The auxiliary field χ is *not* the scalar mode, but a linear analysis around flat space shows that it is essentially its time derivative, i.e $\chi \sim \dot{\phi}$.

Non-linear (in)stability?

The equation of motion for χ in the gauge $N^i = 0$ is

$$\partial_t(N^{-2}\dot{\chi}) + \Delta\chi - \frac{1}{3}\partial_t(N^{-1}K) - \frac{1}{12}V'(\chi) = 0\,.$$

For curvature length scale L,

- Repulsive force $-N^2\Delta\chi = N^2 p^2 \chi$.
- Friction $\partial_t \ln N^2 \dot{\chi} = L^{-1}\dot{\chi}$.
- External force $\frac{1}{3}N^2\partial_t(N^{-1}K) \sim L^{-2}$.

These are dominant for small χ and may work against stability. However, we've seen that to linear order the scalar mode is stable.

Non-linear (in)stability?

For larger χ, the dominant term is the strongly attractive force $\frac{1}{12}N^2V'(\chi)$. Hence it seems plausible that the solution oscillates around $\chi = 0$.

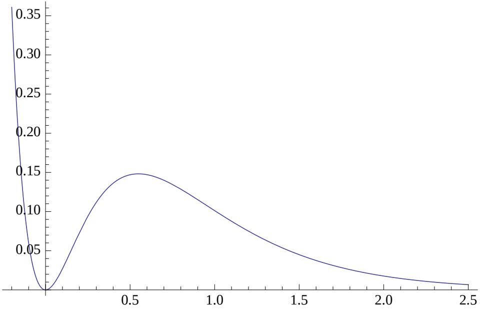


Figure : $V(\chi)$ for $q = 1$.

Parameterized Post-Newtonian Formalism

$$U \sim v^2 \sim p/\rho \sim \Pi \sim O(2)\,, \qquad \frac{\partial/\partial t}{\partial/\partial x} \sim O(1)\,, \tag{1}$$

- U: Newtonian potential
- v: 3-velocity of fluid element
- p: pressure
- ρ: rest-mass density
- Π: energy density / rest-mass density

Parameterized Post-Newtonian Formalism

- Expand field equations around background cosmological solution.
- Expand any additional gravitational fields (scalar, vector, tensor...).
- Find g_{00} to $O(4)$, g_{0i} to $O(3)$ and g_{ij} to $O(2)$.

Metric in PPN gauge

$$
\begin{aligned}
g_{00} &= -1 + 2U - 2\beta U^2 - 2\xi \Phi_W + (2\gamma + 2 + \alpha_3 + \zeta_1 - 2\xi)\Phi_1 \\
&+ 2(3\gamma - 2\beta + 1 + \zeta_2 + \xi)\Phi_2 + 2(1 + \zeta_3)\Phi_3 \\
&+ 2(3\gamma + 3\zeta_4 - 2\xi)\Phi_4 - (\zeta_1 - 2\xi)A - (\alpha_1 - \alpha_2 - \alpha_3)w^2 U \\
&- \alpha_2 w^i w^j U_{ij} + (2\alpha_3 - \alpha_1)w^i V_i \,, \qquad (2) \\
g_{0i} &= (\ldots) \qquad (3) \\
g_{ij} &= (1 + 2\gamma U)\delta_{ij} \qquad (4)
\end{aligned}
$$

- $\vec{w}$ is the velocity of PPN coordinate system w.r.t. Universe rest frame.
- $\vec{w} = 0$ frame suited to compute PPN parameters:

$$\beta, \gamma, \xi, \alpha_1, \alpha_2, \alpha_3, \zeta_1, \zeta_2, \zeta_3, \zeta_4 \,. \qquad (5)$$

Preferred-Frame Effects

- GR: $\beta = \gamma = 1$, others vanish.
- $\alpha_1, \alpha_2, \alpha_3$ measure PFE's.

1. Perihelion-Shift:

$$\Delta\omega \sim \frac{1}{3}(2 + 2\gamma - \beta) + \frac{1}{6}(2\alpha_1 - \alpha_2 + \alpha_3 + 2\zeta_2)\frac{\mu}{M} + \frac{J_2 r^2}{2Mp}$$

2. Nordtvedt effect:

$$\begin{aligned} \eta_N &\equiv 4\beta - \gamma - 3 - \frac{10}{3}\xi - \alpha_1 + \frac{2}{3}\alpha_2 - \frac{2}{3}\zeta_1 - \frac{1}{3}\zeta_2 \\ &= (4.4 \pm 4.5) \times 10^{-4} \end{aligned}$$

Preferred-Frame Effects

1. Geophysical Tests of Preferred-frame/location effects: "Cavendish"-like experiments with Earth, measure variations of G_L (a.k.a. solid-Earth tides);
2. Orbital tests for n-bodies.

Significance of PPN parameters

Parameter	What it measures relative to GR	Value in GR	Value in semi-conservative theories	Value in fully-conservative theories
γ	How much space-curvature produced by unit rest mass?	1	γ	γ
β	How much "nonlinearity" in the superposition law for gravity?	1	β	β
ξ	Preferred-location effects?	0	ξ	ξ
α_1	Preferred-frame effects?	0	α_1	0
α_2		0	α_2	0
α_3		0	0	0
α_3	Violation of conservation of total momentum?	0	0	0
ζ_1		0	0	0
ζ_2		0	0	0

Current limits on PPN parameters

Parameter	Effect	Limit	Remarks
$\gamma - 1$	time delay	2×10^{-3}	Viking ranging
	light deflection	3×10^{-4}	VLBI
$\beta - 1$	perihelion shift	3×10^{-3}	$J_2 = 10^{-7}$ from helioseismology
	Nordtvedt effect	6×10^{-4}	$\eta = 4\beta - \gamma - 3$ assumed
ξ	Earth tides	10^{-3}	gravimeter data
α_1	orbital polarization	10^{-4}	Lunar laser ranging
		2×10^{-4}	PSR J2317+1439
α_2	spin precession	4×10^{-7}	solar alignment with ecliptic
α_3	pulsar acceleration	2×10^{-20}	pulsar $\dot{P}$ statistics
η[1]	Nordtvedt effect	10^{-3}	lunar laser ranging
ζ_1	–	2×10^{-2}	combined PPN bounds
ζ_2	binary acceleration	4×10^{-5}	$\ddot{P}_p$ for PSR 1913+16
ζ_3	Newton's 3rd law	10^{-8}	Lunar acceleration
ζ_4	–	–	not independent

[1]Here $\eta = 4\beta - \gamma - 3 - 10\xi/3 - \alpha_1 - 2\alpha_2/3 - 2\zeta_1/3 - \zeta_2/3$

Solar System Planetary Precessions

Constraints on the Preferred-Frame α_1, α_2 parameters from Solar System planetary precessions, L. Iorio, [arXiv:1210.3026], October 2012

- $\alpha_1 = (-1 \pm 6) \times 10^{-6}$
- $\alpha_2 = (-0.9 \pm 3.5) \times 10^{-5}$

Expect improvement from Messenger spacecraft (orbiting Mercury), and Bepi Colombo Mission (2015-2022).

Binary Pulsars

New tests of local Lorentz invariance of gravity with small-eccentricity binary pulsars, L. Shao, N. Wex, [arXiv:1209.4503], September 2012

New Constraints on Preferred Frame Effects from Binary Pulsars, L. Shao, N. Wex, M. Kramer, [arXiv:1209.5171], September 2012

- PSR's J1012+5307, J1738+0333
- $\hat{\alpha}_1 = -0.4^{+3.7}_{-3.1} \times 10^{-5}$ at 95% C.L.
- $|\hat{\alpha}_2| = 1.8 \times 10^{-4}$ at 95% C.L.

Expect improvement with next generation of radio telescopes (FAST, SKA).

Horava-Lifshitz gravity

- D. Blas, O. Pujolas, S. Sibiryakov, JHEP 1104:018 (2011)
- D. Blas, H. Sanctuary, Phys.Rev.D 84:064004 (2011)
- Preferred time coordinate $\Rightarrow$ Preferred Frame.
- Extra scalar (spin-0) mode: excitations of foliation structure.

$$ds^2 = -N^2 dt^2 + h_{ij}(dx^i + N^i dt)(dx^j + n^j dt)$$

- Restore general covariance:
  $n_\mu = -Ndt \Rightarrow n_\mu = -\partial_\mu \phi / \sqrt{-X}, \qquad X = g^{\mu\nu}\partial_\mu\phi\partial_\nu\phi$
- Stückelberg field $\phi(x)$, dubbed *khronon*.
- Symmetry: $\phi \to f(\phi)$.
- Preferred frame (unitary gauge): $\phi = t$.

Low energy limit: khronometric theory

$$S = -\frac{M_b^2}{2}\int d^4x\sqrt{-g}\left(R + K^{\mu\nu}{}_{\sigma\rho}\nabla_\mu u^\sigma \nabla_\nu u^\rho\right) + S_m$$

- $K^{\mu\nu}{}_{\sigma\rho} = \beta\delta^\mu_\rho\delta^\nu_\sigma + \lambda\delta^\mu_\sigma\delta^\nu{}\rho + \alpha u^\mu u^\nu g_{\sigma\rho}$
- Same form has Einstein-Aether, but no vector (spin-1) mode.

$$c_t^2 = \frac{1}{1-\beta}\,, \qquad c_s^2 = \frac{(\alpha-2)(\beta+\lambda)}{\alpha(\beta-1)(2+\beta+3\lambda)}$$

- Avoid Cerenkov radiation: $c_t^2 \geq 1, c_s^2 \geq 1$.
- $\beta^{PPN} = \gamma^{PPN} = 1, \xi^{PPN} = 0$ (as GR and AE).

- BUT $\alpha_1^{PPN} \neq 0, \alpha_2^{PPN} \neq 0$.
- Also $G_N \neq G_{cosm}$; restricted by $|G_N/G_{cosm} - 1| \leq 0.13$ by BB nucleosynthesis.

For a point source of mass *in its rest frame*, $(g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu})$

$$
\begin{aligned}
h_{00} &= -\frac{2G_N m}{r}\left(1 - \frac{\alpha_1 - \alpha_2}{2} v^2 - \frac{\alpha_2}{2}\frac{(\vec{x}\cdot\vec{v})^2}{r^2}\right) \\
h_{0i} &= \frac{\alpha_1}{2}\frac{G_N m}{r} v^i \\
h_{ij} &= -\frac{2G_N m}{r}\delta_{ij}
\end{aligned}
$$

Gravitational Radiation

In GR, only 2 polarizations $\Rightarrow$ quadrupole formula.
Khronometric theory:

$$< \dot{\varepsilon} >= -\frac{M_b^2}{4}\int_{S^2_\infty} d\Omega r^2 \left\langle \frac{1}{c_t}\dot{t}_{ij}\dot{t}^{ij} - \frac{8(\alpha-2)}{\alpha c_s}\dot{\psi}^2 \right\rangle$$

- Waveforms $\dot{t}_{ij}, \dot{\psi}$ depend on $\alpha_1^{PPN}, \alpha_2^{PPN}$.
- Binary system $\Rightarrow \alpha \sim \beta \sim \lambda \leq 10^{-2}$.
- PPN bounds give $\alpha \sim \beta \sim \lambda \sim 10^{-6}$.

n-DBI gravity

$$S = -\frac{3\lambda}{4\pi G_N^2}\int d^4x\sqrt{-g}\left(\sqrt{1+\frac{G_N}{6\lambda}\left(R-2\nabla_\mu(n^\mu\nabla_\nu n^\nu)\right)}-q\right)+S_m$$

- khronon field as in HL or khronometric theory
- 2+1 degrees of freedom; scalar free of pathologies (non-propagating?)
- interesting cosmology (vacuum+radiation fluid: inflation, radiation epoch, accelerated expansion)
- $q \sim 1 + 10^{-110}, \qquad \lambda \sim 10^{-8}$
- BUT GR limit is $\lambda \to \infty$!

- $\lambda > \lambda_{PPN}\,, \qquad \lambda < \lambda_{inflation}$
- $\lambda_{PPN} < \lambda < \lambda_{inflation} \qquad ??$

Result

n-DBI is indistinguishable from GR at post-Newtonian level: can always choose khronon field χ to enforce $\mathcal{R} = 0\,.$ True to first order, likely to higher orders.

Scalar Perturbations of FRW

$$ds^2 = \phi^2(\tau)\left[-(1+2A)d\tau^2 + 2\partial_i B dx^i d\tau + (1-2\psi)\delta_{ij}dx^i dx^j\right]$$

Constraints:

$$a_1 A + b_1 \Delta B = c_1 \dot{\psi} + d_1 \psi \,,$$
$$a_2 A + b_2 \Delta B = c_2 \dot{\psi} + d_2 \psi \,,$$

If $a_1 b_2 - a_2 b_1 \neq 0$, get canonical action for $\Psi = \sqrt{\alpha(\tau, \Delta)}\psi$,

$$S = \int d^4x \dot{\Psi}^2 - \omega^2(\tau, \Delta)\Psi^2 \,.$$

Flat space limit

$a_1 b_2 - a_2 b_1 \propto H$. Take the limit $\Lambda \to 0$ (well defined everywhere):

- Ψ remains, is independent of Λ.
- $\alpha \propto \Lambda^{-1} \Rightarrow \psi \to 0$.

Is this in disagreement with flat space perturbations??

Flat space limit

$$ds^2 = -dt^2 + \phi^2 \delta_{ij} dx^i dx^j \,, \qquad \phi(t) = \phi_0 + \phi_1 t + \frac{1}{2}\phi_2 t^2 + \dots$$

Make coordinate transformation $x^\mu \to x^\mu + \xi^\mu$,

$$g_{ij} \to g_{ij} + 2\xi_{(i,j)} \,, \qquad g_{0i} \to g_{0i} + \xi_{i,0} + \xi_{0,i} \,, \qquad g_{00} \to g_{00} \to g_{00} + 2\xi_{0,0}$$

- choose $\xi_i = \frac{1}{2}\phi_1 t x_i$ to eliminate first derivative of g_{ij};
- choose $\xi_{0,i}$ to cancel the previous contribution in g_{0i};
- not possible in theories invariant under FPD's only, since $\xi_0 = \xi_0(t)$!

For Further Reading

- C. Herdeiro, S. Hirano, "Scale invariance and a gravitational model with non-eternal inflation," JCAP 05 (2012) 031.
- C. Herdeiro, S. Hirano, Y. Sato, "*n*-DBI gravity," Phys. Rev. D 84 124048 (2011).
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