Title: Galileon dualities and superluminality

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Abstract:

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Galileon dualities and superluminality

with M. Serone and E. Trincherini: 1306.2946 (JHEP)
with M. Serone, G. Trevisan and E. Trincherini, 1403.3095 (JHEP)
with P. Baratella, M. Serone and G. Trevisan, in progress

Outline

- Non-linear representations of the conformal group: Weyl and DBI
- Maps of conformal Galileons. Reduces to Galileon duality.
- Superluminality constraints are different!
- Coupling with gravity

Coset construction

Bellucci, Ivanov, Krivonos, 02

Weyl

$$g = e^{y^\mu P_\mu} e^{\pi D} e^{\Omega^\mu K_\mu}$$

~ CCWZ

DBI

$$g = e^{x^\mu P_\mu} e^{q \hat{D}} e^{\Lambda^\mu \hat{K}_\mu}$$

$$\hat{K}_\mu \equiv \frac{1}{\sqrt{2}L} K_\mu + \frac{L}{\sqrt{2}} P_\mu \,, \quad \hat{D} \equiv \frac{1}{\sqrt{2}L} D$$

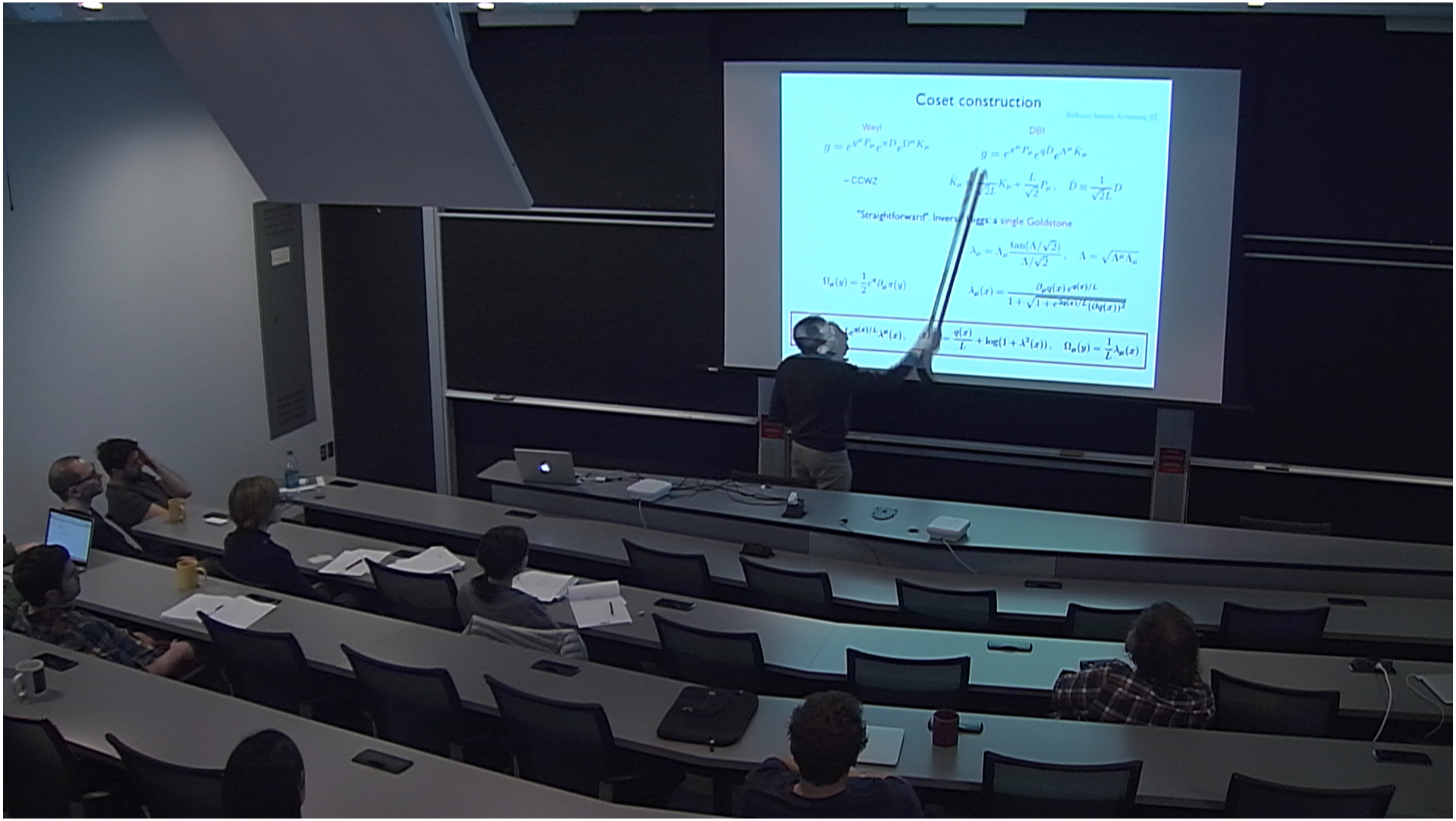
"Straightforward". Inverse Higgs: a single Goldstone

$$\lambda_\mu = \Lambda_\mu \frac{\tan(\Lambda/\sqrt{2})}{\Lambda/\sqrt{2}} \,, \quad \Lambda = \sqrt{\Lambda^\mu \Lambda_\mu}$$

$$\Omega_\mu(y) = \frac{1}{2} e^{\pi} \partial_\mu \pi(y)$$

$$\lambda_\mu(x) = \frac{\partial_\mu q(x)\, e^{q(x)/L}}{1 + \sqrt{1 + e^{2q(x)/L} (\partial q(x))^2}}$$

$$y^\mu = x^\mu + L e^{q(x)/L} \lambda^\mu(x) \,, \qquad \pi(y) = \frac{q(x)}{L} + \log(1 + \lambda^2(x)) \,, \quad \Omega_\mu(y) = \frac{1}{L} \lambda_\mu(x)$$


Coset construction
Weyl
DBI
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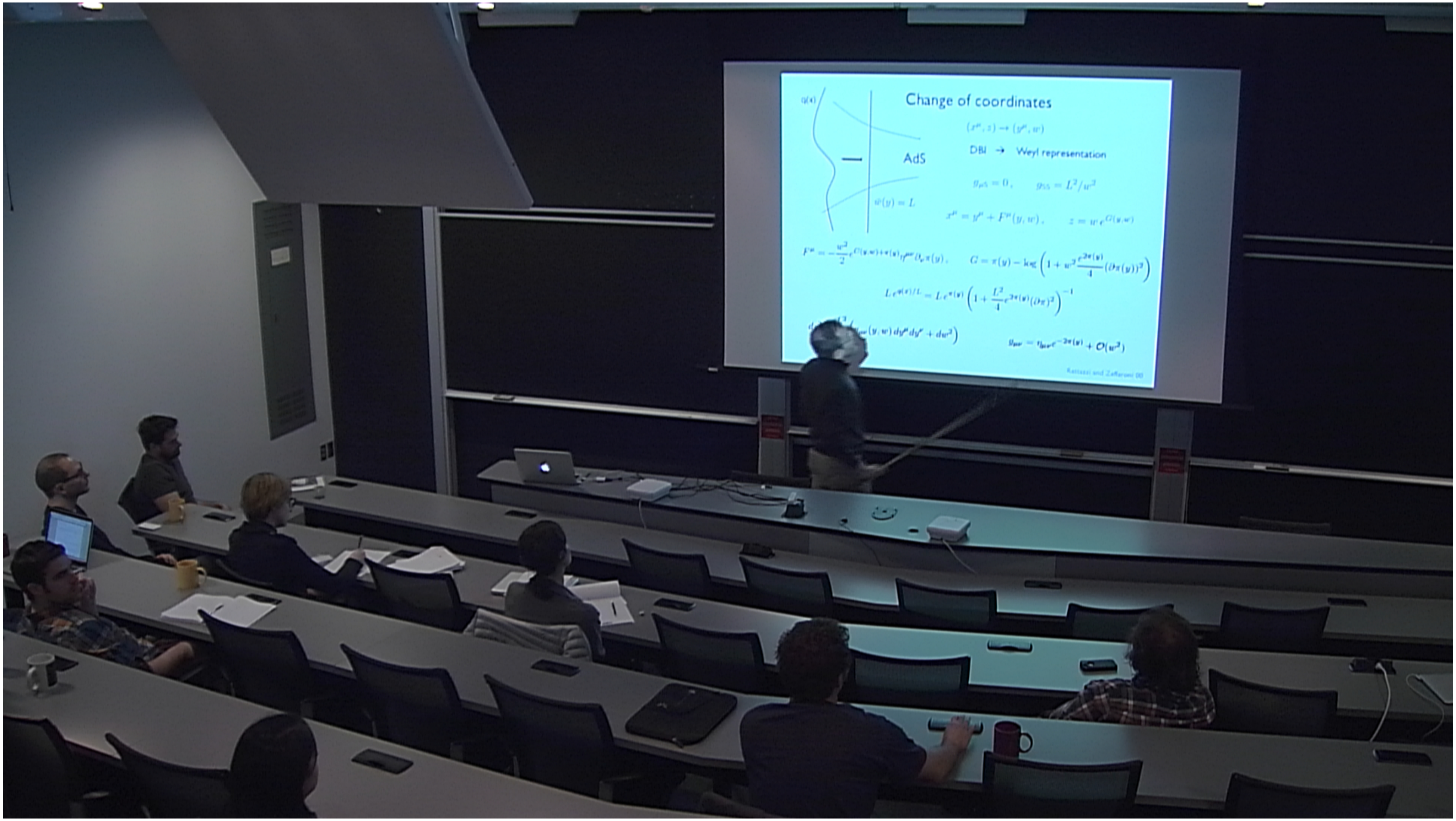
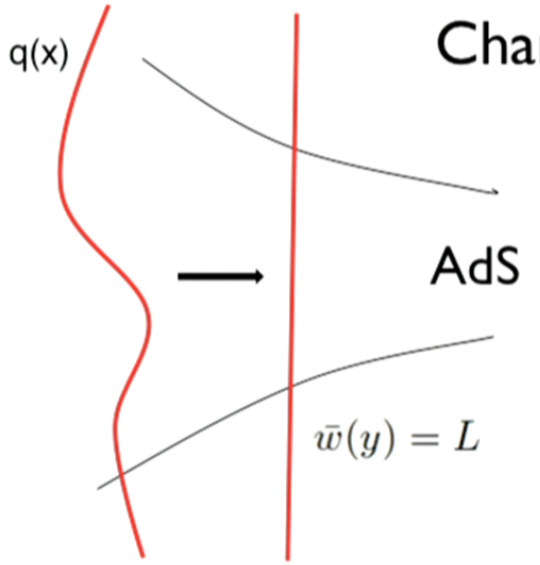


Change of coordinates
AdS
DBI → Weyl representation



Change of coordinates

$$(x^\mu, z) \to (y^\mu, w)$$

DBI → Weyl representation

$$g_{\mu 5} = 0\,, \qquad g_{55} = L^2/w^2$$

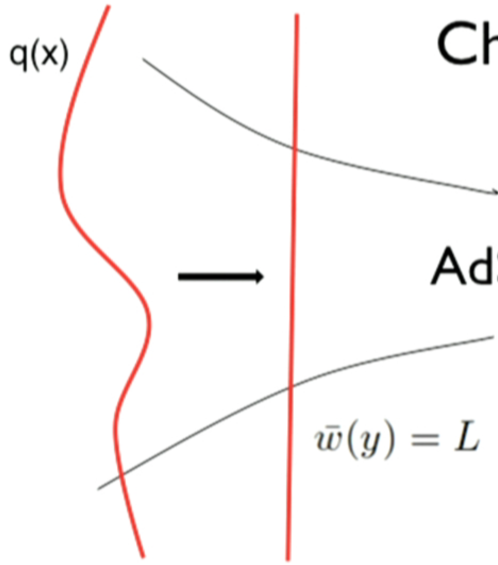
$$x^\mu = y^\mu + F^\mu(y,w)\,, \qquad z = w\,e^{G(y,w)}$$

$$F^\mu = -\frac{w^2}{2} e^{G(y,w)+\pi(y)} \eta^{\mu\nu}\partial_\nu \pi(y)\,, \qquad G = \pi(y) - \log\left(1 + w^2 \frac{e^{2\pi(y)}}{4}(\partial\pi(y))^2\right)$$

$$L\,e^{q(x)/L} = L\,e^{\pi(y)}\left(1 + \frac{L^2}{4} e^{2\pi(y)}(\partial\pi)^2\right)^{-1}$$

$$ds^2 = \frac{L^2}{w^2}\Big(g_{\mu\nu}(y,w)\,dy^\mu dy^\nu + dw^2\Big) \qquad g_{\mu\nu} = \eta_{\mu\nu} e^{-2\pi(y)} + \mathcal{O}(w^2)$$

Rattazzi and Zaffaroni 00



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Galileon map

What happens to Galileons? They are mapped into each other since they give 2[nd] order EOM and this does not depend on the gauge

$$\begin{pmatrix} \mathcal{L}_{\pi 1} \\ \mathcal{L}_{\pi 2} \\ \mathcal{L}_{\pi 3} \\ \mathcal{L}_{\pi 4} \\ \mathcal{L}_{\pi 5} \end{pmatrix} = \begin{pmatrix} 0 & \frac{1}{2} & \frac{7}{64} & -\frac{1}{24} & -\frac{1}{192} \\ 0 & 0 & -\frac{1}{16} & -\frac{1}{12} & -\frac{1}{48} \\ 4 & 0 & -\frac{11}{8} & 0 & -\frac{1}{8} \\ 0 & 0 & -\frac{3}{2} & 2 & -\frac{1}{2} \\ 0 & -96 & 21 & 8 & -1 \end{pmatrix} \begin{pmatrix} \mathcal{L}_{q1} \\ \mathcal{L}_{q2} \\ \mathcal{L}_{q3} \\ \mathcal{L}_{q4} \\ \mathcal{L}_{q5} \end{pmatrix}$$

Invertible

- Weyl kinetic term into a q3, q4 and q5
- Nambu-Goto into all πs
- WZW only contributes to WZW. (Why?)

Galileons less "exotic"?

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The other dualities

Another independent duality of Galileons:

Kampf Novotny 14

$$P + \beta B \equiv P_\beta \qquad \pi = \frac{1}{4}H^2x^2 + \pi'$$

in total GL(2,R)

Expansion around a "dS" solution

Nicolis, Rattazzi, Trincherini, 08

Back to conformal:

$$SO(4,2)/ISO(3,1) \longrightarrow SO(4,2)/SO(4,1)$$

The two cosets are related by a reparametrization

$$g = e^{y^\mu (P_\mu + \frac{1}{4}H^2 K_\mu)} e^{\pi D} e^{\Omega^\mu K_\mu}$$

Hinterbichler, Joyce, Khoury 12

Turning on background is a reparametrization

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Hinterbichler, Joyce, Khoury 12

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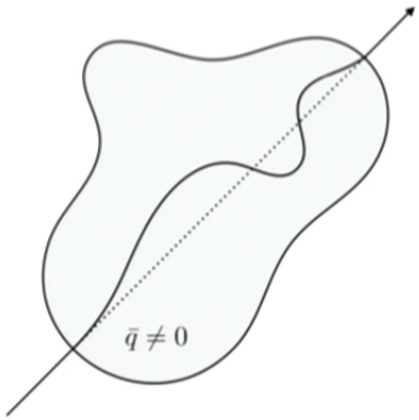
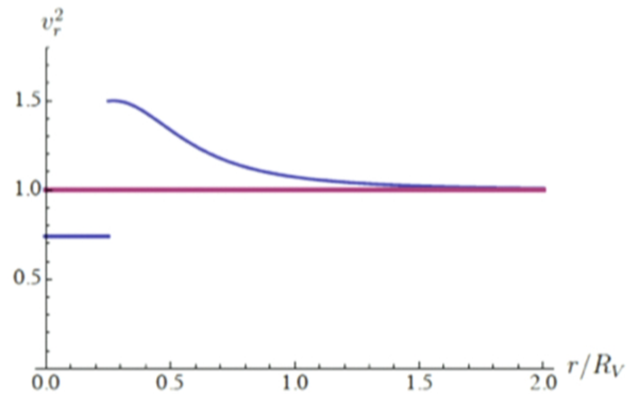
Asymptotic superluminality

$$\delta y^i = \frac{1}{\Lambda^3}\int \mathrm{d}t \int \mathrm{d}t\ \partial_y \partial_y \partial^i \bar{q}(y=t) = \frac{1}{\Lambda^3}\partial^i \bar{q}\Big|_{y_i}^{y_f}$$



No asymptotic effect

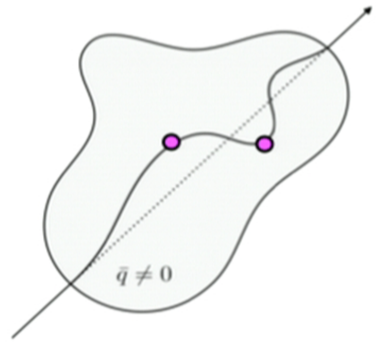
This holds at any order in the background, if the coefficients are "dual" to free theory



Compare with radial motion in DGP

Non-local field redefinition

What forbids to measure superluminality locally?



Measurable superluminality: $\frac{\partial^2 \bar{q}}{\Lambda^3} L \gtrsim \frac{1}{\omega} \quad \Rightarrow \quad \frac{\omega \partial \bar{q}}{\Lambda^3} \gtrsim 1$

$$\mathcal{L}_{G\pi} = \mathcal{L}_{G\pi 2} + \mathcal{L}_J = -\frac{1}{2}(\partial\pi)^2 + \pi(y)J(y)$$

$$\pi(q(y))J(y) = \left(q(y) + \frac{1}{2\Lambda^3}(\partial q(y))^2 + \frac{1}{2\Lambda^6}\partial^\mu\partial^\nu q(y)\partial_\mu q(y)\partial_\nu q(y) + \dots \right) J(y)$$

$$\partial^n q \cdot \left(\frac{\partial\bar{q}}{\Lambda^3}\right)^n \simeq \left(\frac{\omega\partial\bar{q}}{\Lambda^3}\right)^n q$$

Field redefinition cannot be truncated!

$$\mathcal{L}_{source} = q\left(y^\mu + \frac{1}{\Lambda^3}\partial^\mu \bar{q}(y)\right) J(y)$$

The two theories are not equivalent. Different local operators.

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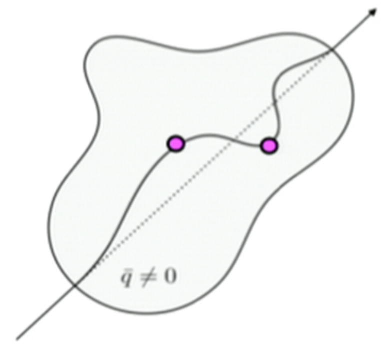

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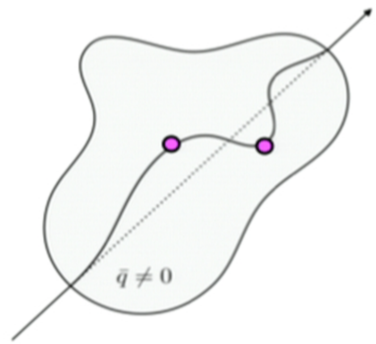

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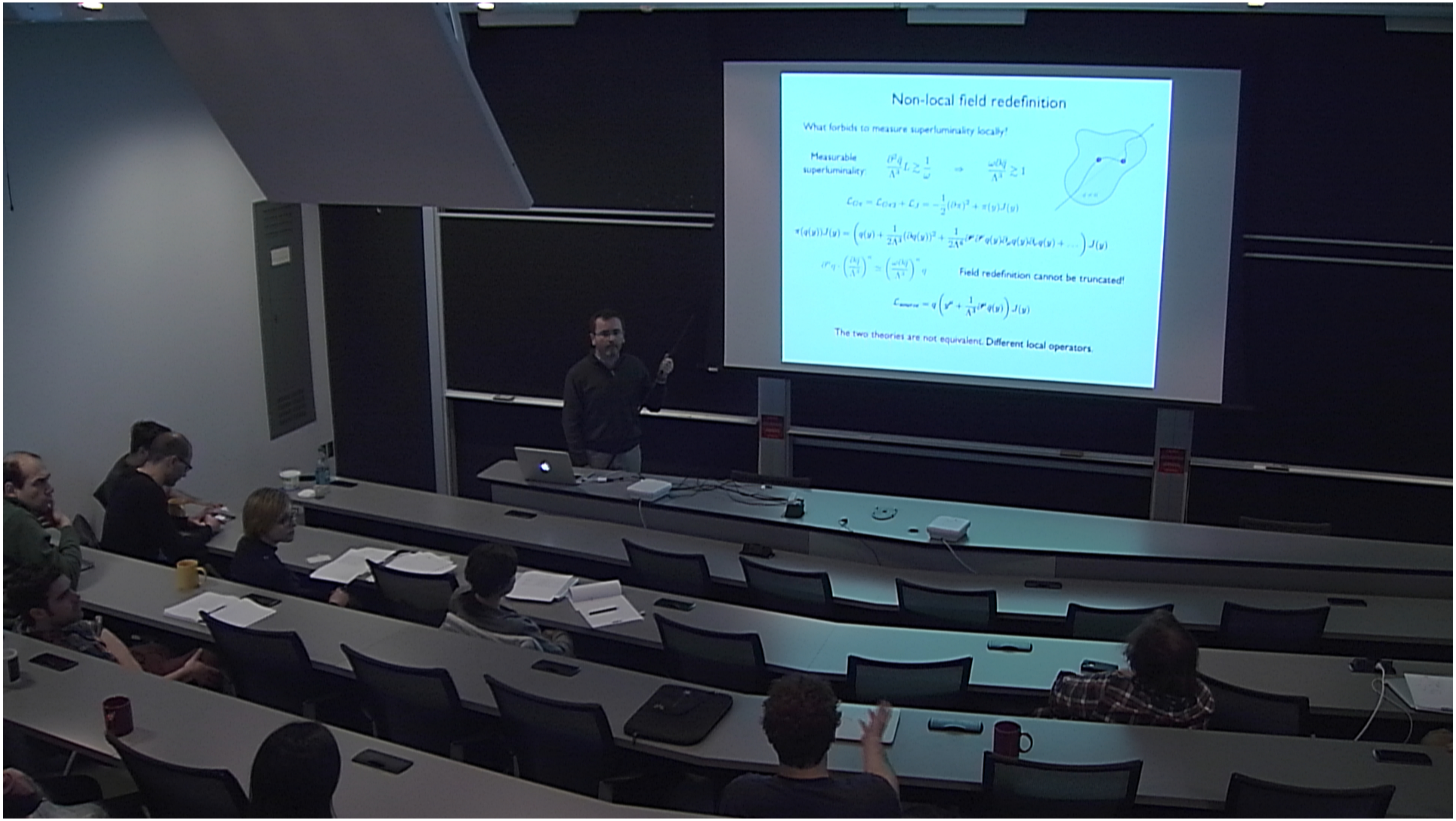
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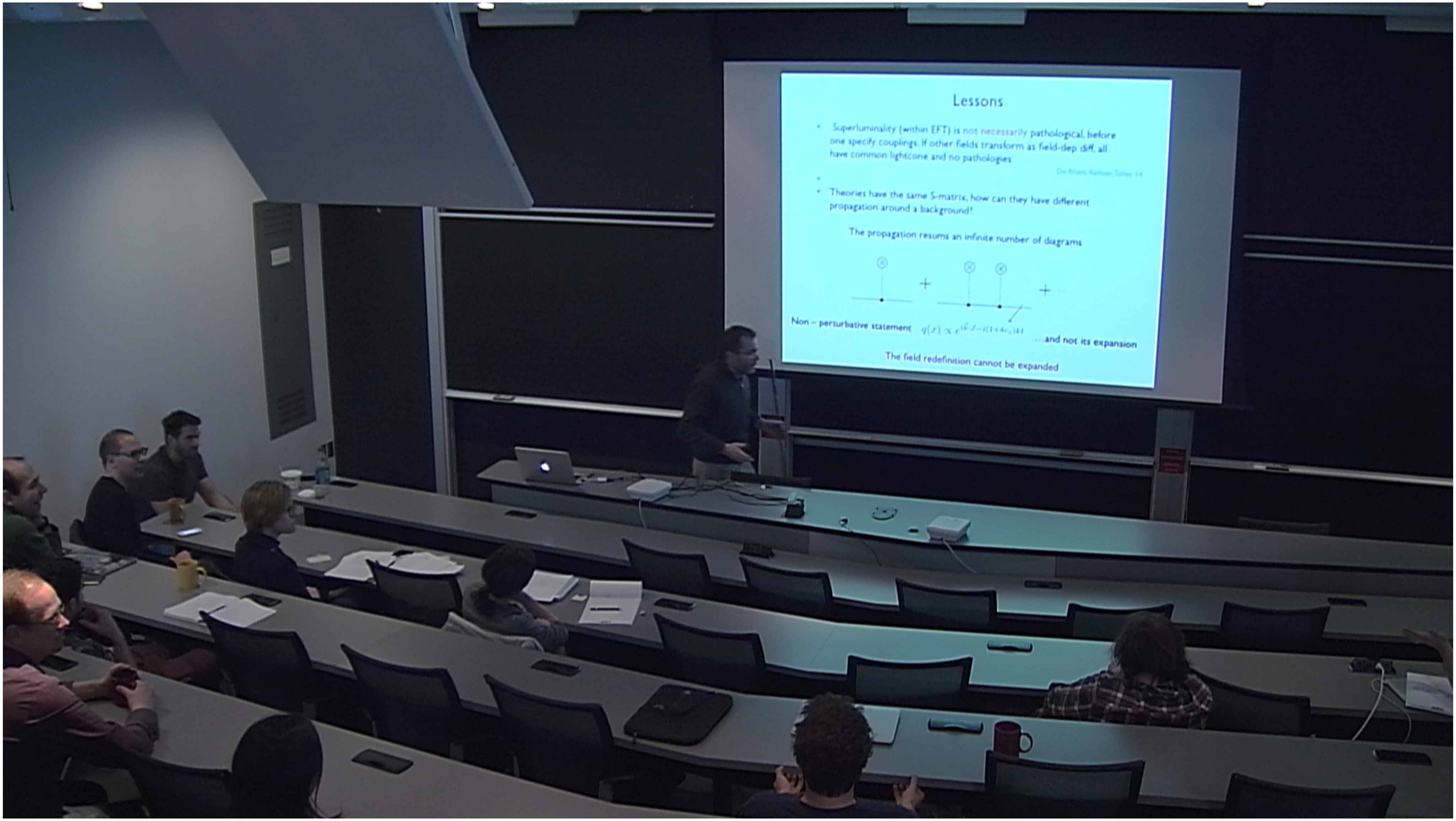
Lessons
Superluminality (within EFT) is not necessarily pathological, before one specify couplings. If other fields transform as field-dep diff, all have common lightcone and no pathologies
Theories have the same S-matrix, how can they have different propagation around a background?
The propagation resums an infinite number of diagrams
Non – perturbative statement
...and not its expansion
The field redefinition cannot be expanded



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De Rham, Keltner, Tolley 14

-
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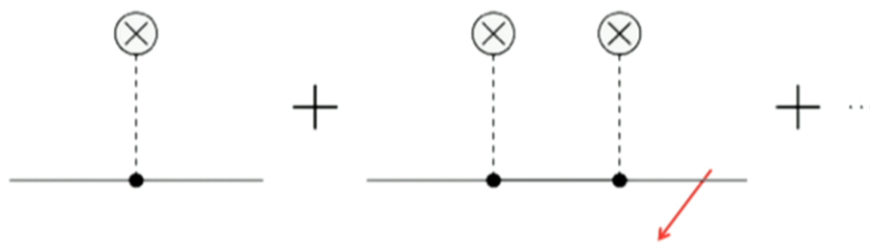

Non – perturbative statement $q(x) \propto e^{i\vec{k}\cdot\vec{x} - i(1+\delta c_s)kt}$ …and not its expansion

The field redefinition cannot be expanded

Galileons and gravitons

Minkowski lightcone is different. What happens to gravitons?

Gravity can be included in coset construction:
gauge translations and boosts

Ivanov, Niederle 82
Delacretaz, Endlich, Monin, Penco, Riva 14

$$\Omega^{-1}D_\mu\Omega \equiv e^{-iy^a(x)P_a}\left(\partial_\mu + i\tilde{e}_\mu{}^a P_a + \frac{i}{2}\omega_\mu^{ab}J_{ab}\right)e^{iy^a(x)P_a} = ie_\mu{}^a P_a + \frac{i}{2}\omega_\mu^{ab}J_{ab}$$

Spin connection not dynamical and solved in terms of vierbein (no torsion)

$$\omega_\mu^{ab}(e) = \frac{1}{2}\left[e^{\nu a}(\partial_\mu e_\nu{}^b - \partial_\nu e_\mu{}^b) + e_{\mu c}e^{\nu a}e^{\lambda b}\partial_\lambda e_\nu{}^c - (a \leftrightarrow b)\right]$$

Galileons coupled to gravity

$$g(x,\pi,\Omega) = e^{x\cdot P}e^{\pi C}e^{\Omega\cdot B}$$

$$[M_{ab}, B_c] = \eta_{ac}B_b - \eta_{bc}B_a$$

$$[P_a, B_b] = \eta_{ab}C$$

Goon, Hinterbichler, Joyce, Trodden 12

Mapping

The mapping is (decevingly) simple: $E^a_\mu = \tilde{E}^a_\mu + \alpha \tilde{D}_\mu \tilde{\Omega}^a$

$$\Omega^a = \tilde{\Omega}^a$$

$$\omega^{ab}_\mu = \tilde{\omega}^{ab}_\mu$$

Inverse Higgs

$$E^{\mu a}\partial_\mu \pi = -\Omega^a$$

$$E^{\mu a}\partial_\mu \pi = \tilde{E}^{\mu a}\partial_\mu q$$

$$\tilde{\omega} = \omega_{\rm LC}(\tilde{E} + \alpha \tilde{D}\Omega)$$

We generate torsion $T^a = dE^a + \omega^a{}_b \wedge E^b \; = \tilde{T}^a + \alpha \tilde{R}^a{}_b \tilde{\Omega}^b$

The mapping contains effectively a infinite number of derivatives $g \supset \partial^n \tilde{R} (\partial q)^n$

Mapping the action

$$S = \frac{1}{16\pi G}\int d^4x |E| E^\mu_a E^\nu_b R_{\mu\nu}{}^{ab}(\omega) + \frac{1}{2\kappa}\int d^4x |E| E^\mu_a E^{\nu a}\partial_\mu\pi\partial_\nu\pi =$$

$$= \frac{1}{16\pi G}\int d^4x\sqrt{-g}\bar{R} + \frac{1}{2\kappa}\int d^4x\sqrt{-g}g^{\mu\nu}\partial_\mu\pi\partial_\nu\pi$$

EH invariant

$$S = \frac{1}{16\pi G}\int d^4x\sqrt{-\tilde{g}}\bar{R} + \frac{1}{2\kappa}\int d^4x\sqrt{-\tilde{g}}\left(1+\alpha\tilde{\tilde{\nabla}}^2 q\right)\tilde{g}^{\mu\nu}\partial_\mu q\partial_\nu q \quad \ldots$$

$$T \sim R\partial q \supset \partial(T\partial q)\partial q \ldots \supset \partial^n R(\partial q)^n$$

- Graviton standard lightcone
- Galileon superluminal
- Coupling with gravity becomes non-local when measureable superl.

Conclusions

1. Mapping among different Galileon theories
2. Local superluminality is not necessarily pathological
3. Asymptotic superluminality
4. Coupling with gravity: change of representation is non-local