Based on work in collaboration with Daniel Sudarsky

Dark Energy, IAP

Alejandro Perez Centre de Physique Théorique, Marseille, France.

A possible microscopic source of the accelerating expansion of the universe

October, 2018

e leakage of energy from macroscopic degrees of leties evoked above) diffusive effects are expected al degrees of the company of fluids

m conservation invariance. Therefore, (in presence f making legrees of freedom (suitable probes of tion is the emergence of a cosine of the constant of the presence of a non trivial scalar curvature R. will enter the quantitative estimates that follow.

arising from such hypothesis (from the phenomenological point of view) is that low ical excitations of massive fields could interact with the underlying quantum gravity 4energy" with it. From the point of view of the continuous mathematical description energies, such phenomenon would be characterized as a 'leakage' of energy to degrees ounted for in the field equations and, therefore, would lead to the apparent violation rresponding energy-momentum tensor. This is a well known phenomenon in the more fluid by where viscosity accounts for the leakage of energy from macroscopic degrees of aos. Similarly (although with the subtleties evoked above) diffusive effects are expected it in the discrete underlying fandamental idegrees of freedom of quantum gravity. It most depution of energy-momentum conservation.

the striking consequence of such violation is the emergence of a cosmological-constantodified Einstein's equations [1]. This can be seen from the traceless field equations of

ther our proposal pust, the previous equations iption breaks the identities imply that rary *J* the possibility scales. requir ---- nts allowing of Giolations 27 6nergy stion of homogeneity and isotropy of the a because in this setting Tonly depends on 'time' the unimated by the spatially flat on the module integrability $d\mathcal{N} \ Q$ [11], one can integrate the previous the module functions equations integrated by empirical evidence), $\mathbf{Ffective violation} \ \mathbf{Ffective violati$ to the transfer of energy from the ext dyin, diserene substratum of quantum

spacetime foam leads to a violation ibute. ional socitemust be controlled by the Planck scale

Mathematical description of gravity **General Relativity**



(1)The continuum spacetime description breaks down at the Planck scale.



The cosmological constant problem

 $\mathbf{R}_{ab} - \frac{1}{2}g_{ab}\mathbf{R} = 8\pi\mathbf{T}_{ab} - \Lambda g_{ab}$

How does the vacuum gravitate?

 $\langle \mathbf{T}_{ab} \rangle =$

 $\rho_{vac} \equiv$

 $\rho_{\Lambda_{obs}} \approx 10^{-120} m_p^4 \approx (10^{-2} eV)^4$

Tuesday 23 October 18

 $\Lambda_{\rm obs} \approx 1.19 \ 10^{-52} \ {\rm m}^{-2}$

$$=\frac{\Lambda_{vac}}{8\pi G}\ g_{ab}$$

$$\frac{\Lambda_{vac}}{8\pi G} \approx m_p^4$$

Three related ideas by Einstein on gravity

 \mathbf{R}_{ab} –

1) General Relativity (1916)

2) The cosmological constant (1917)

3) Unimodular Gravity

(1919)

$$\mathbf{R}_{ab} - \frac{1}{4}g_{ab}\mathbf{R} = 8\pi \left(\mathbf{T}_{ab} - \frac{1}{4}g_{ab}\mathbf{T}\right) \quad \text{with} \quad \nabla^{a}\mathbf{T}_{ab} = 0 \qquad \longleftrightarrow \qquad \begin{array}{l} \text{Weinberg 1987} \\ \langle \mathbf{T}_{ab} \rangle = \frac{\Lambda_{vac}}{8\pi G} \ g_{ab} \\ \text{The vacuum does n} \\ \text{gravitate in UG} \end{array}$$

$$\mathbf{R}_{ab} - \frac{1}{2}g_{ab}\mathbf{R} = 8\pi\mathbf{T}_{ab}$$
ant
$$\nabla^{a}\mathbf{T}_{ab} = 0$$

$$\mathbf{R}_{ab} - \frac{1}{2}g_{ab}\mathbf{R} = 8\pi\mathbf{T}_{ab} - \Lambda g_{ab}$$

$$\nabla^{a}\mathbf{T}_{ab} = 0$$



Unimodular Gravity:

Equivalent to General Relativity: with a cosmological constant as a constant of integration!

$$\langle \mathbf{T}_{ab}
angle = rac{\Lambda_{vac}}{8\pi G} g_{ab}$$

The vacuum does not gravitate in UG

Traceless Einstein's Equations:

$$\mathbf{R}_{ab} - \frac{1}{4}g_{ab}\mathbf{R} = 8\pi \left(\mathbf{T}_{ab} - \frac{1}{4}g_{ab}\mathbf{T}\right)$$

Conservation of Energy: symmetries of tangent space

Granted by field equations due to symmetries of the tangent space.



Unimodular Gravity UG is a natural generalization of GR as an open system



Ingredient 1

$$\mathbf{R}_{ab} - \frac{1}{4}g_{ab}\mathbf{R} = 8\pi \left(\mathbf{T}_{ab} - \frac{1}{4}g_{ab}\mathbf{T}\right)$$



Unimodular Gravity UG is a natural generalization of GR as an open system



Ingredient 1

$$\mathbf{R}_{ab} - \frac{1}{4}g_{ab}\mathbf{R} = 8\pi \left(\mathbf{T}_{ab} - \frac{1}{4}g_{ab}\mathbf{T}\right)$$



Unimodular Gravity UG is a natural generalization of GR as an open system



Ingredient 1

$$\mathbf{R}_{ab} - \frac{1}{4}g_{ab}\mathbf{R} = 8\pi \left(\mathbf{T}_{ab} - \frac{1}{4}g_{ab}\mathbf{T}\right)$$



Unimodular Gravity UG is a natural generalization of GR as an open system



Ingredient 1

$$\mathbf{R}_{ab} - \frac{1}{4}g_{ab}\mathbf{R} = 8\pi \left(\mathbf{T}_{ab} - \frac{1}{4}g_{ab}\mathbf{T}\right)$$



Unimodular Gravity UG is a natural generalization of GR as an open system



Ingredient 1

$$\mathbf{R}_{ab} - \frac{1}{4}g_{ab}\mathbf{R} = 8\pi \left(\mathbf{T}_{ab} - \frac{1}{4}g_{ab}\mathbf{T}\right)$$



Violations of energy conservation in the effective smooth semiclassical stant of integration and we see that the therefore the stand of the expected the sequece of a term T_{ab} Einstern ng the dark energy equation of state. s the general framework where we will develop further our proposal. First, the previous equation the energy-moment in the state of the many J the possibility of t gravitational dynamics in terms of a metric theory is compromised: unimodular gravity is, as fa only relaxation of the standard general covariance requirements allowing $\frac{8}{6}$ (violations $\frac{3}{6}$) (mathematical standard general covariance requirements) allowing $\frac{8}{6}$ (violations) $\frac{3}{6}$ rvation. Fortunately, in applications to cosmology the a stion of homogeneity and isotropy of scales of interest, implies integrability of J (this is because in this setting J only depends on 'tim a comoving coordinates) ing $J_a \equiv (8\pi G/c^4) \nabla^b T_{ba}$, and assuming the unimodular integrabili will assume that the spacetime metric at large scales is well approximated by the spatially fla re-Robertson-Walker (FLRW) metric (an assumption very well supported by empirical evidence), the amount of energy-momentum violation experienced due to the transfer of energy. s of freedom of massive matter for the anticking manoscopled districter substratum = of that according to our rationale only ρ_m contributes, thus simple dimensional analysis to be a violatic determined on the spacetime formulation of the spacetime formulatin of the spacetime formulation of the spacetim tum conservation. The process is quantum gravitational so it must be contreal phintage planck sca (as argued before) by the presence of a non trivial scalar curvature or Ricci scalar which (from and we **recent the scalar which (from and we recent ance is to start the** tion and we **recent ance is to start the** tion and we recent the scalar which (from and we recent ance is the scalar which (from ance is the scalar which (from an constraint ance is the scalar which (from ance is the scalar which (from an constant ance The previous the deneral manademork where we will develop further Tuesday 23 October 18



Unimodular Gravity without energy conservation

 $\mathbf{R}_{ab} - \frac{1}{4}$



 $\frac{1}{4}\nabla b$



Trace free Einstein's equations

$$\frac{1}{4}\mathbf{R}g_{ab} = 8\pi\left(\mathbf{T}_{ab} - \frac{1}{4}\mathbf{T}g_{ab}\right)$$

$$\frac{1}{4}\mathbf{R}g_{ab} = 8\pi\left(\mathbf{T}_{ab} - \frac{1}{4}\mathbf{T}g_{ab}\right)$$

$$\mathbf{J}_b \equiv 8\pi \nabla^a \mathbf{T}_{ab}$$

 $\mathbf{J}_b \equiv 8\pi \nabla^a \mathbf{T}_{ab}$

Need to satisfy the integrability condition $d\mathbf{J} = 0$

$$g_{ab} = 8\pi \mathbf{T}_{ab} - \left[\Lambda_0 + \int_{\ell} \mathbf{J}\right] g_{ab}$$

Dark Energy Λ



Need a phenomenological model which:

• Only depends on fundamental constants.

• Does not require one to arbitrarily set an initial time for diffusion.



Discreteness manifest itself via interactions with the matter that probes it.

To probe **Planck scale** we need a breaking of scale invariance (need a ruler!)

Scalar curvature is the natural "order parameter"

$R = 8\pi GT$

This notion encodes in a MEAN FIELD manner the interaction of the matter degrees of freedom with fundamental discreteness



$$= 8\pi G(\rho - 3P) \quad R = 8\pi G$$

Tuesday 23 October 18



A mesoscopic model for Planckian friction:

The effect on a test particle



constant

A mesoscopic model for Planckian friction:



Relational nature of discreteness in quantum gravity

$$a^{b} = u^{a} \nabla_{a} u^{b} = \alpha \operatorname{sign}(s \cdot \xi) \frac{m \mathbf{R}}{m_{p}^{2}} s^{b}$$



Langevin-like equation

Tuesday 23 October 18

Scale invariant matter does not **suffer** nor **sources** friction force



$$\dot{E} \equiv -mu^{\mu}
abla_{\mu} (u^{
u} \xi_{
u}) = -lpha rac{m^2}{m_p^2} |(s \cdot \xi)| \mathbf{R} - mu^{\mu} u^{
u}
abla_{(\mu} \xi_{
u})$$



Other similar looking equations

$$a^b = u^a \nabla_a u^b = \alpha \operatorname{sign}(s \cdot \xi) \frac{m\mathbf{R}}{m_p^2} s^b$$

$$u^{\nu} \nabla_{\nu} P_{\mu} = -\frac{1}{2} \mathbf{R}_{\mu\nu\rho\sigma} u^{\nu} S^{\rho\sigma}$$

Papapetrou-Dixon equation: motion of a spinning body in curved spacetimes

Achille Papapetrou, Proc. Roy. Soc. Lond., A209:248–258, 1951.



Other similar looking equations

$$a^b = u^a \nabla_a u^b = \alpha \operatorname{sign}(s \cdot \xi) \frac{m\mathbf{R}}{m_p^2} s^b$$

$$u^{\nu}\nabla_{\nu}(mu_{\mu}) = -\frac{1}{2}\tilde{\mathbf{R}}_{\mu\nu\rho\sigma}u^{\nu}\langle S^{\rho\sigma}\rangle + \mathscr{O}(\hbar^2)$$

WKB trajectories: fermions in curved spacetimes with torsion

J. Audretsch, Phys. Rev., D24:1470–1477, 1981.



Other similar looking equations

$$a^{b} = u^{a} \nabla_{a} u^{b} = \alpha \operatorname{sign}(s \cdot \xi) \frac{m\mathbf{R}}{m_{p}^{2}} s^{b}$$



Langevin Equation

$$\dot{K} + \xi(t)$$

From simple rel

stic kinetic theory

$$\mathbf{T}^{i}_{\mu\nu}(x) \equiv \int p_{\mu}p_{\nu} f^{i}(x, p, s_{r})\mathbf{D}p$$

$$a^{b} = u^{a}\nabla_{a}u^{b} = \alpha \operatorname{sign}(s \cdot \xi) \frac{m\mathbf{R}}{m_{p}^{2}} s^{b}$$

$$\frac{T^{i}_{\mu\nu}}{i} = -\frac{\int m_{i}F_{\nu}f^{i}(x, p, s_{r})\mathbf{D}p\mathbf{D}s_{r}}{m_{i}^{2}\int f^{i}(x, p, s_{r})\mathbf{D}p\mathbf{D}s_{r}}$$

$$= -\alpha \frac{m_{i}}{m_{p}^{2}}\mathbf{R} \frac{\int \left[\frac{s_{\nu}s_{0}}{|s_{0}|}\right]f^{i}(x, p, s_{r})\mathbf{D}p\mathbf{D}s_{r}}{\int f^{i}(x, p, s_{r})\mathbf{D}p\mathbf{D}s_{r}}$$

$$\int |s_{0}|\mathbf{D}s_{r} = \frac{2\pi\mathbf{p}|s|}{m} \int |\cos(\theta)|\sin(\theta)d\theta = \frac{2\pi\mathbf{p}|s|}{m}$$

From probability distribution evolution

Isotropy in the spin distribution

$$\begin{aligned} \text{lativistic kinetic theory} \qquad \mathbf{T}_{\mu\nu}^{i}(x) &\equiv \int p_{\mu}p_{\nu} f^{i}(x, p, s_{r})\mathbf{D} \mathbf{D} \\ a^{b} &= u^{a} \nabla_{a} u^{b} = \alpha \operatorname{sign}(s \cdot \xi) \frac{m\mathbf{R}}{m_{p}^{2}} s^{b} \\ \frac{\nabla^{\mu} \mathbf{T}_{\mu\nu}^{i}}{\mathbf{T}^{i}} &= -\frac{\int m_{i} F_{\nu} f^{i}(x, p, s_{r}) \mathbf{D} p \mathbf{D} s_{r}}{m_{i}^{2} \int f^{i}(x, p, s_{r}) \mathbf{D} p \mathbf{D} s_{r}} \\ &= -\alpha \frac{m_{i}}{m_{p}^{2}} \mathbf{R} \frac{\int \left[\frac{s_{\nu} s_{0}}{|s_{0}|}\right] f^{i}(x, p, s_{r}) \mathbf{D} p \mathbf{D} s_{r}}{\int f^{i}(x, p, s_{r}) \mathbf{D} p \mathbf{D} s_{r}} \\ &\int |s_{0}| \mathbf{D} s_{r} = \frac{2\pi \mathbf{p} |s|}{m} \int |\cos(\theta)| \sin(\theta) d\theta = \frac{2\pi \mathbf{p} |s|}{m} \\ &\frac{\int \left[\frac{2\pi \mathbf{p} |s|}{m}\right] f_{T}(p) \mathbf{D} p}{\int f_{T}(p) \mathbf{D} p} = 4\pi |s| \frac{T}{m} \left[1 + \mathcal{O}\left(\log\left(\frac{m}{T}\right) \frac{m^{2}}{T^{2}}\right)\right] \end{aligned}$$

Thermal average



From simple relativistic kinetic theory

$$a^b = u^a \nabla_a u^b = \alpha$$







Unimodular Gravity:







$$\Lambda \approx \frac{\overline{m}_t^4 T_{ew}^3}{m_p^7} m_p^2 \approx \underbrace{\left(\frac{T_{ew}}{m_p}\right)^7}_{10^{-120}} m_p^2$$

- discrete (quantum gravity).
- nent.
- standard model particles (analogy with Brownian motion).
- a negligible way.
- sufficiently diluted.
- from quantum gravity.

Discussion

• Violations of energy momentum conservation are natural in an effective **description** in terms of smooth fields of a physics that is **fundamentally**

• When they satisfy suitable integrability conditions they can be described in terms of **unimodular gravity** and they feed a **dark energy compo**-

• In absence of a fundamental theory a phenomenological approach is justified. The constraints from low energy Lorentz invariance determined an essentially **unique leading contribution** to the nosy diffusion on

• The effects are tiny in laboratory experiments. They are also tiny (when maximal) in cosmology: they affect the cosmological dynamics in

• Such tiny effect produces the cosmological constant during the electroweak transition. It becomes dominant today once the universe has

• If all this is correct, the cosmological constant would be the first observable manifestation of Planckian discreteness expected

Possible independent signals: radiative corrections in QFT

Radiative corrections make Lorentz violation percolate to low energies

$$\mathcal{L} = \frac{1}{2} (\partial \phi)^2 - \frac{m_0^2}{2} \phi^2 + \bar{\psi} (i \gamma^{\mu} \partial_{\mu} - M_0) \psi + g_0 \phi \bar{\psi} \psi.$$
$$\frac{i}{\gamma^{\mu} p_{\mu} - m_0 + i\epsilon} \rightarrow \frac{i f(|\mathbf{p}|/\Lambda)}{\gamma^{\mu} p_{\mu} - m_0 + \Delta(|\mathbf{p}|/\lambda) + i\epsilon},$$
$$\frac{i}{p^2 - M_0^2 + i\epsilon} \rightarrow \frac{i \tilde{f}(|\mathbf{p}|/\Lambda)}{p^2 - M_0^2 + \tilde{\Delta}(|\mathbf{p}|/\lambda) + i\epsilon}.$$



Collins, AP, Sudarsky, Urrutia, Vusetich; Phys. Rev. Letters. 93 (2004).

$$\Pi(p) = A + p^2 B + p^{\mu} p^{\nu} W_{\mu} W_{\nu} \tilde{\xi} + \Pi^{(\text{LI})}(p^2) + \mathcal{O}(p^4/A)$$

$$\tilde{\xi} = \frac{g^2}{6\pi^2} \left[1 + 2 \int_{0}^{\infty} dx x f'(x)^2 \right]$$

WAY OUT: Observables in QG are relational, discreteness must be relational



$\Lambda^2)$

 $O_1 = \lambda_1 \, \xi^\mu \nabla_\mu \phi \mathbf{R} = \lambda_1 \phi \mathbf{R}$

 $O_2 = \lambda_2 \, \xi^\mu \bar{\psi} \gamma_\mu \psi \frac{\mathbf{R}}{m}$

Constraints from present experiments and observations

 $\mathbf{T} = \frac{\mathbf{R}}{8\pi G} > 10 \,\mathrm{GeV}^4$

$$a \approx 10^{-2} \mathbf{T}_{ew}$$

V. Alan Kostelecky and Neil Russell. Data Tables for Lorentz and CPT Violation. Rev. Mod. Phys., 2011.



Lack of energy conservation has a negligible effect on the dynamics of the background

(語)(題)



Lack of energy conservation has a negligible effect on the dynamics of the background



Lack of energy conservation has a negligible effect on the dynamics of the background

Other formal implications

Tuesday 23 October 18

Entropy production in FLRW cosmology:

$$abla^a T_{ab}$$
 =

$$\dot{\rho} + 3\frac{\dot{a}}{a}(\rho + P) = \frac{J_0}{8\pi G}$$

 $Td(sa^3) = d(\rho a^3)$

$$d(sa^{3}) = \frac{J_{0}a^{3}}{8\pi GT}dt - \frac{\mu}{T}d(na^{3})$$



 $= J_b/(8\pi G)$

$$d(\rho a^3) + Pd(a^3) = \frac{J_0 a^3}{8\pi G} dt$$

$$) + Pd(a^3) - \mu d(na^3)$$

$$\approx 10^{-116}$$

Other formal implications Unitarity loss in the QFT effective description

decoherence with the environment

Entropy production in general: decoherence in a Planckian discrete environment

$$a^b = u^a \nabla_a u^b = \alpha \operatorname{sign}(s \cdot \xi) \frac{m\mathbf{R}}{m_p^2} s^b$$

Hongguang Liu, work in progress $i\hbar\gamma^{\mu}\partial_{\mu}\Psi(x) - m\Psi(x)$

 $i\hbar\gamma^{\mu}\partial_{\mu}\Psi(x) - m\Psi(x) = F(x)\Psi(x)$

$$= \int d^4 y D(x,y) \Psi(y)$$

Bei-Lok Hu, Esteban Calzetta, Nonequilibrium QFT.



Black Holes: Their thermal properties suggest micro-structure



Collapsing Matter

$$\delta E = \mathcal{I}\delta S - P\delta V$$

Heat: Energy in molecular chaos

1st law:
$$\delta M = \frac{\kappa}{8\pi} \delta a + \Omega \delta J + \Phi \delta Q$$

heat?

$$S_{BH} = \frac{a}{4}$$

2nd law: $\delta a \ge 0$

New perspective on the information paradox



Collapsing Matter

 t_{W}

 \Box

AP, Class. Quant. Grav. 32, 2015.





CPT violation in the smooth QFT effective description!

Wald 1980,

New perspective on the information paradox



Collapsing Matter

 $t^{\text{Tuesday}_{23}}$ octobe H⁸ awking particle b and its partner a

INFORMATION RETRIEVED AP, Class. Quant. Grav. IN PLANCKIAN 32, 2015. D.O.F. HAWKING RADIATION

Decoherence with discrete micro-structure imply violations of energy conservation in the smooth effective description!

Banks, Peskin, Susskind (1984) - Unruh, Wald (1995)





Outlook: Lambda, okay. But what else?



- 1. Violations of energy conservation in local experiments (too tiny!)
- 2. Violations of the equivalence principle in local experiments (too tiny) 3. Violations of Lorentz invariance of the week type we propose (too tiny)
- 4. Violations of unitarity: nice perspective for the information paradox.
- 5. Early cosmology is the natural arena where to test additional effects (baryogengesis, leptogenesis, structure formation, etc)



NGC 4526 with SN 1994D

Thank you!



Conditions for Baryogenesis: A.D. Sakharov 1967

- 1. Baryon number is not conserved.
- 2. CP violation
- undo what was built by (1) and (2)).

New possible mechanism

- 1. Baryon number is not conserved.
- 2. CP violation

3. CPT is violated by QG discreteness.

Outlook

3. Out of equilibrium process (thermal equilibrium makes CPT symmetry

The EW transition triggers CP violation as well as the QG effect presented here!



GR Symmetry: General Diffeo.

$$\mathscr{L}_{\xi}g_{ab} = 2\nabla_{(a}\xi_{b)}$$

$$\nabla_{(a}\xi_{b)} = \frac{\theta}{4}g_{ab} + \sigma_{ab}$$

We relax diff-invariance to accommodate violations of energy conservation

Order parameter for discreteness probes: scalar curvature $R = 8\pi T \neq 0$

UG Symmetry: Volume preserving Diffeo.

Broken Diffeos

The same as Weyl transformations on shell

$$g_{ab} \to (1 + \frac{\theta}{4})g_{ab}$$



degrees of freedom to the degrees of the degrees of the degrees of the degree of the d

GR Symmetry: General Diffeo.

$$\mathscr{L}_{\xi}g_{ab} = 2\nabla_{(a}\xi_{b)}$$
$$\nabla_{(a}\xi_{b)} = \frac{\theta}{4}g_{ab} + \sigma_{ab}$$

$$g_{ab} \rightarrow D_{gab} \rightarrow D_{ga$$

Order parameter for discreteness probes: scalar curvature $R = 8\pi T \neq 0$

where A is a constant of integration and we see that the energy violation current J is t equations at is fringet built runney of the constant of integration and we see The previous is the sequent framework, where set will develop it the dark energy of the sec

Modeling the diffusion the transferrence of the providence of the gramogical context the striking consequence of fravity modified $\frac{1}{q}$ are gravity en Diffeos $R_{ab} - \frac{F}{A}Rg_a$ tions do not while same as we lanch which together with the Bianchi identifies the start transformations on shell ∇_{a} ($R_{a} + \frac{87}{87}$ with Hev Baanchi Mehrities imply

 $\nabla^{\sigma} F_{\beta d}$, and assuming the unimodular integrability $dJ \equiv 0$ [11] is very semaind respectively of the unimodular integrability $dJ \equiv 0$ [11] is the very semaind respectively of the unimodular integrability $dJ \equiv 0$ [11]. on and re-write the system in terma of the model of iEinthinsy stationsterms of th

$$R_{ab} = \frac{1}{2} R_{ab} + \left[A_{*} + \int J \right]_{ab} = \frac{8\pi G}{c^4} \frac{1}{c^4} \frac{1}{c^4}$$



GR Symmetry: General Diffeo.

$$\mathscr{L}_{\xi}g_{ab} = 2\nabla_{(a}\xi_{b)}$$
$$\nabla_{(a}\xi_{b)} = \frac{\theta}{4}g_{ab} + \sigma_{ab}$$



Broken Diffeos The same as Weyl transformations on shell $g_{ab} \rightarrow (1 + \frac{\theta}{4})g_{ab}$

Order parameter for discreteness probes: scalar curvature $R = 8\pi T \neq 0$

UG Symmetry: Volume preserving Diffeo. $\nabla_a \xi^a = 0 \iff \theta = 0$



GR Symmetry: General Diffeo.

$$\mathscr{L}_{\xi}g_{ab} = 2\nabla_{(a}\xi_{b)}$$
$$\nabla_{(a}\xi_{b)} = \frac{\theta}{4}g_{ab} + \sigma_{ab}$$

Order parameter for
discreteness probes:
scalar curvature
$$R = 8\pi T \neq 0$$



UG Symmetry: Volume preserving Diffeo.

Broken Diffeos The same as Weyl transformations on shell $g_{ab} \to (1 + \frac{\theta}{4})g_{ab}$



GR Symmetry: General Diffeo.

$$\mathscr{L}_{\xi}g_{ab} = 2\nabla_{(a}\xi_{b)}$$
$$\nabla_{(a}\xi_{b)} = \frac{\theta}{4}g_{ab} + \sigma_{ab}$$

The same as Weyl transformations on shell

 $g_{ab} \rightarrow$

Both **R** the preferred volume structure are natural ingredients of the **Planckian** phenomenology we are exploring

Order parameter for discreteness probes: scalar curvature $R = 8\pi T \neq 0$

Broken Diffeos

$$(1+\frac{\theta}{4})g_{ab}$$

UG Symmetry: Volume preserving Diffeo.

 $\nabla_a \xi^a = 0 \iff \theta = 0$

