ICE CSIC IEEC

Quantum Vacuum Fluctuations & the Cosmological Constant

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Outline of the talk

- On the Zero Point Energy & the Casimir Effect

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- Conclusions

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Even then: Has the final value real sense ?

The Casimir Effect

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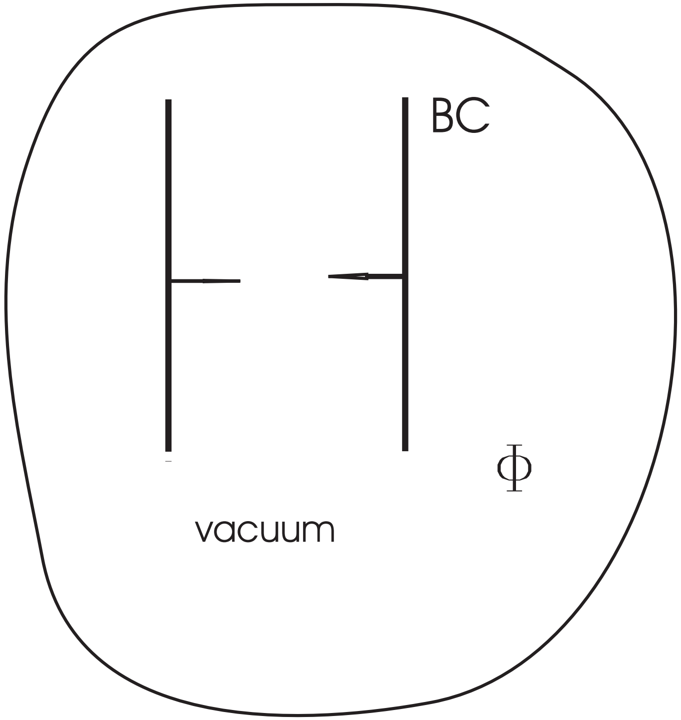
BC e.g. periodic



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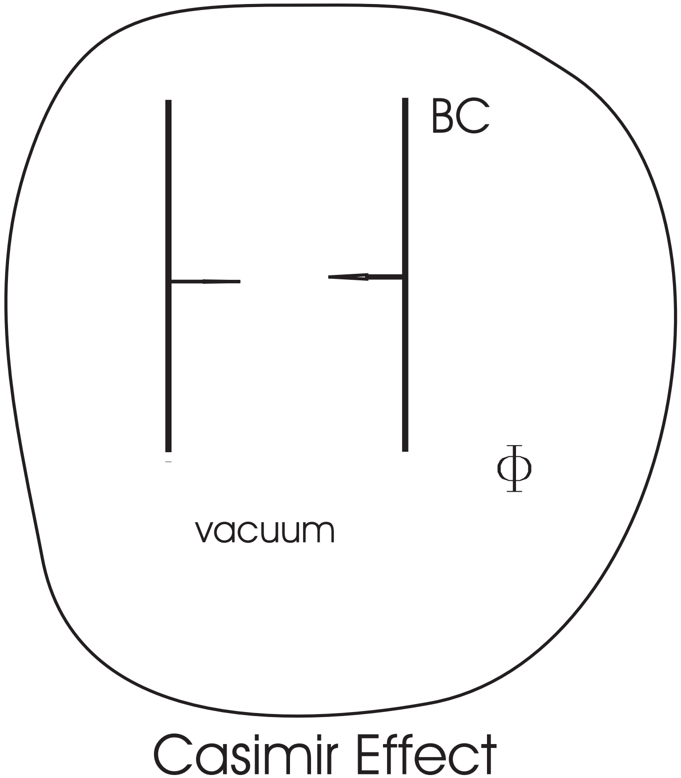

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$\Longrightarrow$ all kind of fields

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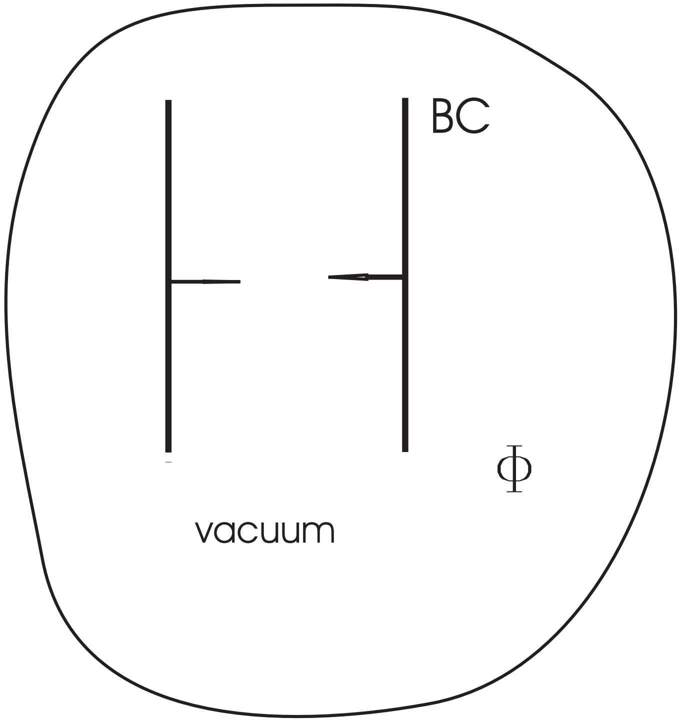

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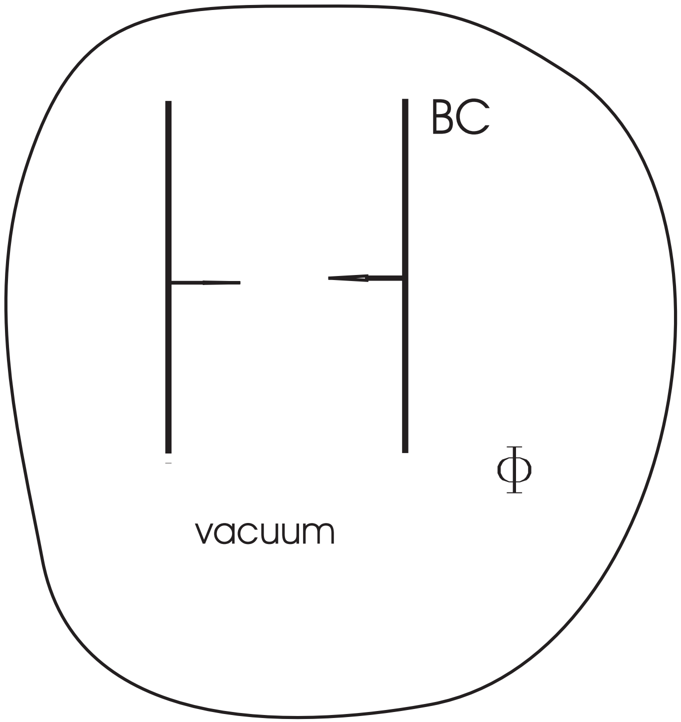

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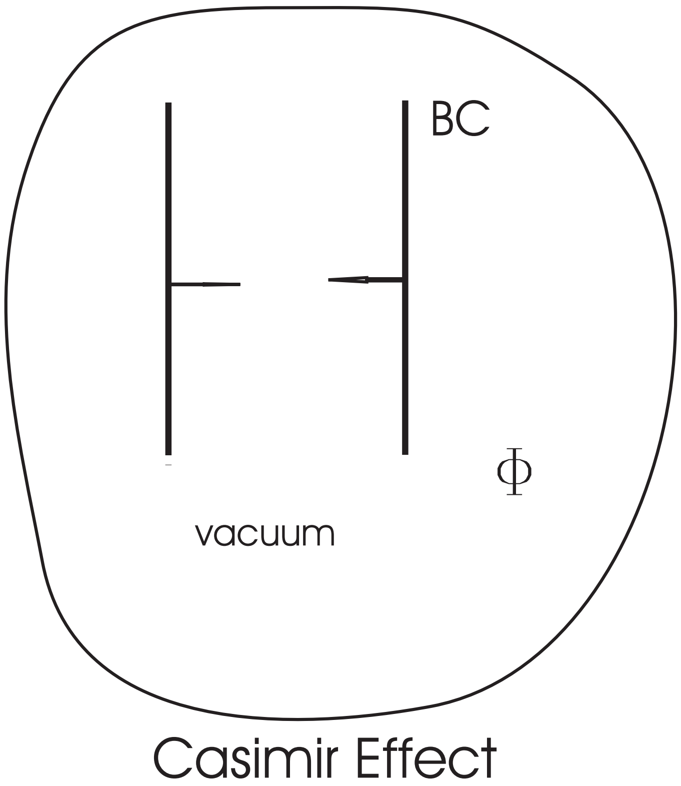

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- Sonoluminiscence (Schwinger)
- Cond. matter (wetting ^{3}He alc.)
- Optical cavities
- Direct experim. confirmation

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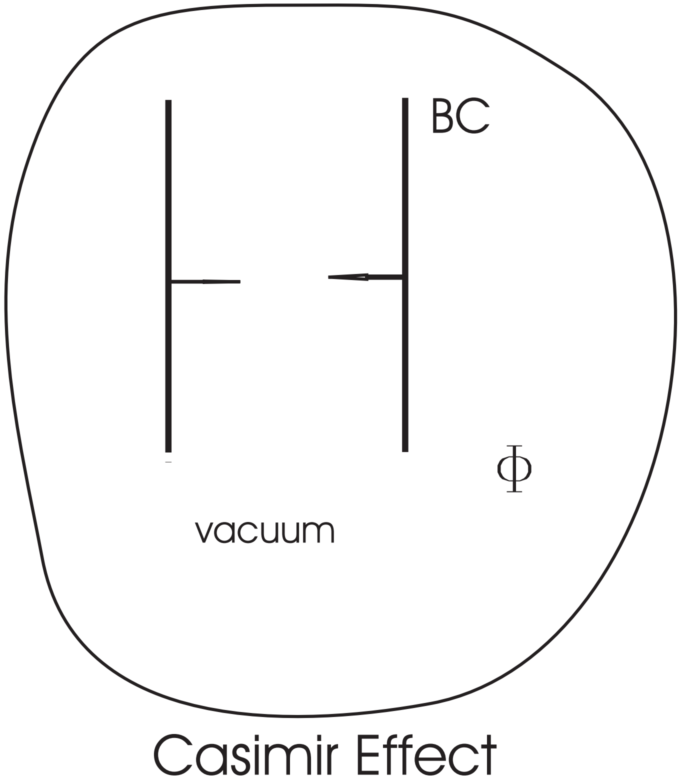

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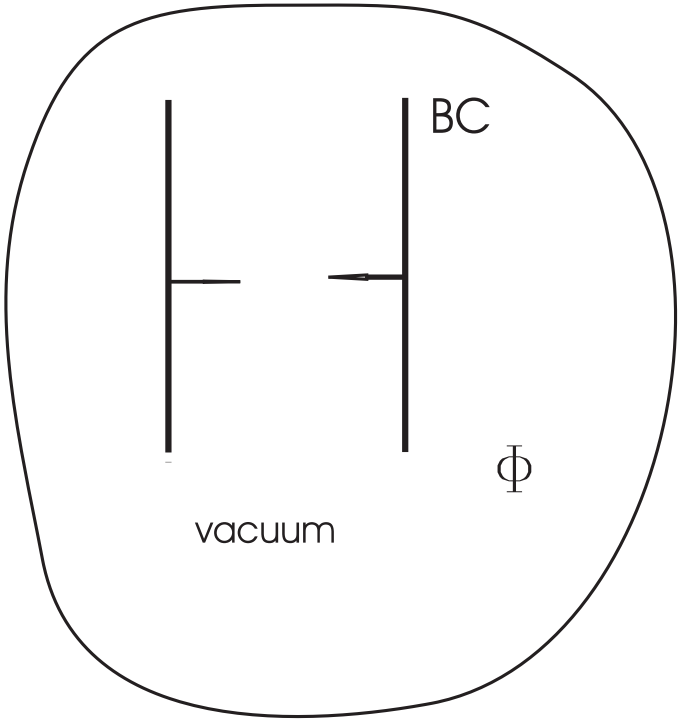

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- Dynamical CE
- Lateral CE
- Extract energy from vacuum
- CE and the cosmological constant

Vacuum energy density and the CC

- The main issue:

  energy ALWAYS gravitates, therefore the energy density of the vacuum, more precisely, the vacuum expectation value of the stress-energy tensor $\langle T_{\mu\nu} \rangle \equiv -\mathcal{E} g_{\mu\nu}$

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$$\lambda \;=\; (2.14 \pm 0.13 \times 10^{-3}\ \text{eV})^4 \quad \sim\; 4.32 \times 10^{-9}\ \text{erg/cm}^3$$

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- Idea: zero point fluctuations can contribute to the cosmological constant Ya.B. Zeldovich '68

- Relativistic field: collection of harmonic oscill's (scalar field)

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- Evaluating in a box and putting a cut-off at maximum k_{max} corresp'ng to QFT physics (e.g., Planck energy)

$$\rho \sim \frac{\hbar k_{Planck}^4}{16\pi^2} \sim 10^{123} \rho_{obs}$$

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- What we do consider —with relative success in some different approaches— is the additional contribution to the cc coming from the non-trivial topology of space or from specific boundary conditions imposed on braneworld models:

  $\Longrightarrow$ kind of cosmological Casimir effect

Cosmo-Topological Casimir Effect

- Assuming one will be able to prove (in the future) that the ground value of the cc is zero (as many had suspected until recently), we will be left with this incremental value coming from the topology or BCs

  * L. Parker & A. Raval, VCDM, vacuum energy density
  * C.P. Burgess et al., hep-th/0606020 & 0510123: Susy Large Extra Dims (SLED), two $10^2 \mu$m dims, bulk vs brane Susy breaking scales
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  - (c) supergraviton theories (discret dims, deconstr)

A. Simple model: large & small dim's

- Space-time: $\mathbb{R}^{d+1} \times \mathbb{T}^p \times \mathbb{T}^q, \qquad \mathbb{R}^{d+1} \times \mathbb{T}^p \times \mathbb{S}^q, \quad \cdots$

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- M effective mass term, m arbitrarily small
  (a tiny mass for the field cannot be excluded, and fits well)

* L. Parker & A. Raval, PRL86 749 (2001); PRD62, 083503 (2000)
* V.G. Gurzadyan & S.-S. Xue, Mod Phys Lett A18, 561 (2003)

- For d–open, (p, q)–toroidal universe:

$$\rho_\phi = \frac{\pi^{-d/2}}{2^d\Gamma(d/2)\prod_{j=1}^{p} a_j \prod_{h=1}^{q} b_h}\int_0^\infty dk\, k^{d-1}$$

$$\sum_{\mathbf{n}_p=-\infty}^{\infty}\sum_{\mathbf{m}_q=-\infty}^{\infty}\left[\sum_{j=1}^{p}\left(\frac{2\pi n_j}{a_j}\right)^2+\sum_{h=1}^{q}\left(\frac{2\pi m_h}{b_h}\right)^2+\mathbf{k}_d^2+M^2\right]^{1/2}$$

$$\simeq \frac{1}{a^p b^q}\sum_{\mathbf{n}_p,\mathbf{m}_q=-\infty}^{\infty}\left(\frac{1}{a^2}\sum_{j=1}^{p} n_j^2+\frac{1}{b^2}\sum_{h=1}^{q} m_h^2+M^2\right)^{\frac{d+1}{2}+1}$$

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$$\left[\sum_{j=1}^{p}\left(\frac{2\pi n_j}{a_j}\right)^2+\frac{Q_2(l)}{b^2}+\mathbf{k}_d^2+M^2\right]^{1/2}$$

$[P_{q-1}(l)$ poly in l deg $q-1]$

$$\simeq \frac{1}{a^p b^q}\sum_{\mathbf{n}_p=-\infty}^{\infty}\sum_{l=1}^{\infty}P_{q-1}(l)\left(\frac{4\pi^2}{a^2}\sum_{j=1}^{p} n_j^2+\frac{l(l+q)}{b^2}+\frac{M^2}{4\pi^2}\right)^{\frac{d+1}{2}+1}$$

- Regularize: zeta function

$$\zeta(s) = \frac{1}{2}\sum_i \lambda_i^{-s} = \frac{1}{2}\sum_{\mathbf{k}} \left(\frac{k^2 + M^2}{\mu^2}\right)^{-s/2} \Longrightarrow \rho_\phi = \zeta(-1)$$

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- For the zeta function (Re $s > p/2$):

$$\zeta_{A,\vec{c},q}(s) = \sum_{\vec{n}\in\mathbb{Z}^p}{}' \left[\frac{1}{2}(\vec{n}+\vec{c})^T A(\vec{n}+\vec{c}) + q\right]^{-s}$$

$$\equiv \sum_{\vec{n}\in\mathbb{Z}^p}{}' \left[Q(\vec{n}+\vec{c}) + q\right]^{-s}$$

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- Exhibits singularities (simple poles) of meromorphic continuation —with corresponding residua— explicitly
- Only condition on matrix A: corresponds to (non negative) quadratic form, Q. Vector $\vec{c}$ arbitrary, while q (for the moment) positive constant

$$\zeta_{A,\vec{c},q}(s) = \frac{(2\pi)^{p/2} q^{p/2-s}}{\sqrt{\det A}} \frac{\Gamma(s-p/2)}{\Gamma(s)} + \frac{2^{s/2+p/4+2} \pi^s q^{-s/2+p/4}}{\sqrt{\det A}\, \Gamma(s)}$$

$$\sum_{\vec{m} \in \mathbb{Z}^p_{1/2}}{}' \cos(2\pi \vec{m} \cdot \vec{c}) \left(\vec{m}^T A^{-1} \vec{m}\right)^{s/2-p/4} K_{p/2-s}\left(2\pi \sqrt{2q\, \vec{m}^T A^{-1} \vec{m}}\right)$$

- Prime means that point $\vec{n} = \vec{0}$ is excluded from sum (not important)
- Gives (analyt cont of) multidim zeta function in terms of an exponentially convergent multiseries, valid in the whole complex plane
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- K_ν modified Bessel function of the second kind and the subindex 1/2 in $\mathbb{Z}^p_{1/2}$ means that only half of the vectors $\vec{m} \in \mathbb{Z}^p$ are summed over. That is, if we take an $\vec{m} \in \mathbb{Z}^p$ we must then exclude $-\vec{m}$ (as simple criterion one can, for instance, select those vectors in $\mathbb{Z}^p \backslash \{\vec{0}\}$ whose first non-zero component is positive).

Calcul. of vacuum energy density

Analytic continuation of the zeta function:

$$\zeta(s) = \frac{2\pi^{s/2+1}}{a^{p-(s+1)/2} b^{q-(s-1)/2} \Gamma(s/2)} \sum_{\mathbf{m}_q=-\infty}^{\infty} \sum_{h=0}^{p} \binom{p}{h} 2^h \sum_{\mathbf{n}_h=1}^{\infty} \left(\frac{\sum_{j=1}^{h} n_j^2}{\sum_{k=1}^{q} m_k^2 + M^2} \right)^{\frac{s-1}{4}}$$

$$\times K_{(s-1)/2} \left[\frac{2\pi a}{b} \left(\sum_{j=1}^{h} n_j^2 \right)^{1/2} \left(\sum_{k=1}^{q} m_k^2 + M^2 \right)^{1/2} \right]$$

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Yields the vacuum energy density:

$$\rho_\phi = -\frac{1}{a^p b^{q+1}} \sum_{h=0}^{p} \binom{p}{h} 2^h \sum_{\mathbf{n}_h=1}^{\infty} \sum_{\mathbf{m}_q=-\infty}^{\infty} \sqrt{\frac{\sum_{k=1}^q m_k^2 + M^2}{\sum_{j=1}^h n_j^2}}$$

$$\times K_1 \left[\frac{2\pi a}{b} \left(\sum_{j=1}^{h} n_j^2 \right)^{1/2} \left(\sum_{k=1}^{q} m_k^2 + M^2 \right)^{1/2} \right]$$

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Inserting the $\hbar$ and c factors

$$\rho_\phi = -\frac{\hbar c}{2\pi a^{p+1} b^q}\left[1 + \sum_{h=0}^{p}\binom{p}{h} 2^h \alpha\right] + \mathcal{O}\left[q K_1\left(\frac{2\pi a}{b}\right)\right]$$

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$\Longrightarrow$ Sign may change with BC (e.g., Dirichlet): a problem

Matching the obs. results for the CC

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ρ_ϕ	$p = 0$	$p = 1$	$p = 2$	$p = 3$
$b = l_P$	10^{-13}	10^{-6}	1	10^{5}
$b = 10 l_P$	10^{-14}	$[10^{-8}]$	10^{-3}	10
$b = 10^2 l_P$	10^{-15}	(10^{-10})	10^{-6}	10^{-3}
$b = 10^3 l_P$	10^{-16}	10^{-12}	$[10^{-9}]$	(10^{-7})
$b = 10^4 l_P$	10^{-17}	10^{-14}	10^{-12}	10^{-11}
$b = 10^5 l_P$	10^{-18}	10^{-16}	10^{-15}	10^{-15}

Table 2: Vacuum energy density in units of erg/cm^3, for p large compactified dimensions a, and $q = p + 1$ small compactified dimensions b, $p = 0, \ldots, 3$, for different values of b, proportional to the Planck length l_P

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$\Longrightarrow$ To examine $\rightarrow$ couplings in GR
$\rightarrow$ alternative theories

B. Realistic models: dS & AdS BW

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$\Longrightarrow$ Action for conformally inv massless scalar with scalar-gravit coupling

$$\mathcal{S} = \frac{1}{2}\int d^5x\sqrt{g}\left[-g^{\mu\nu}\partial_\mu\phi\partial_\nu\phi + \xi_5 R^{(5)}\phi^2\right]$$

$\xi_5 = -3/16$ $\qquad R^{(5)}$ 5-dim scalar curvature

$\Longrightarrow$ Euclidean metric of the 5-dim AdS bulk

$$
\begin{aligned}
ds^2 &= g_{\mu\nu} dx^\mu dx^\nu = \frac{\alpha^2}{\sinh^2 z}\left(dz^2 + d\Omega_4^2\right) \\
d\Omega_4^2 &= d\xi^2 + \sin^2 \xi \, d\Omega_3^2
\end{aligned}
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α is the AdS radius, related to cc of AdS bulk

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$$\mathcal{E}_{\text{Cas}} = \frac{\hbar c}{2L\mathcal{R}^4}\zeta\left(-\frac{1}{2}|L_5\right) = -\frac{\hbar c\pi^3}{36L^6}\left[\frac{\pi^2}{315} - \frac{1}{240}\left(\frac{L}{\mathcal{R}}\right)^2 + \mathcal{O}\left(\frac{L}{\mathcal{R}}\right)^4\right]$$

C. Supergraviton Theories

⟹ Cognola, Elizalde, Zerbini, PLB624 (2005) 70

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⟹ Allow for non-nearest-neighbor couplings

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$\Longrightarrow$ Multi-graviton model defined by taking $N-$copies of fields, with graviton $h_{n\mu\nu}$ and Stückelberg fields $A_{n\mu}$, φ_n

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$\Longrightarrow$ Lagrangian of the theory: a generalization of N. Kan–K. Shiraishi

$$\mathcal{L} = \sum_{n=0}^{N-1} \Big[-\frac{1}{2}\partial_\lambda h_{n\mu\nu}\partial^\lambda h_n^{\mu\nu} + \partial_\lambda h_{n\mu}^\lambda \partial_\nu h_n^{\mu\nu} - \partial_\mu h_n^{\mu\nu}\partial_\nu h_n + \frac{1}{2}\partial_\lambda h_n \partial^\lambda h_n$$
$$-\frac{1}{2}\left(m^2 \Delta h_{n\mu\nu}\Delta h_n^{\mu\nu} - (\Delta h_n)^2\right) - 2\left(m\Delta^\dagger A_n^\mu + \partial^\mu \varphi_n\right)\left(\partial^\nu h_{n\mu\nu} - \partial_\mu h_n\right)$$
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Δ, $\Delta^\dagger$ difference operators

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Δ, $\Delta^\dagger$ difference operators operate on the indices n as

$$\Delta\phi_n \equiv \sum_{k=0}^{N-1} a_k \phi_{n+k},\ \Delta^\dagger \phi_n \equiv \sum_{k=0}^{N-1} a_k \phi_{n-k},\ \sum_{k=0}^{N-1} a_k = 0,$$

a_k are N constants and ϕ_n can be identified with periodic fields on a lattice with N sites if periodic boundary conditions, $\phi_{n+N} = \phi_n$, are imposed

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$\Longrightarrow$ Lagrangian of the theory: a generalization of N. Kan–K. Shiraishi

$$\mathcal{L} = \sum_{n=0}^{N-1} \Big[-\frac{1}{2}\partial_\lambda h_{n\mu\nu}\partial^\lambda h_n^{\mu\nu} + \partial_\lambda h_{n\mu}^\lambda \partial_\nu h_n^{\mu\nu} - \partial_\mu h_n^{\mu\nu}\partial_\nu h_n + \frac{1}{2}\partial_\lambda h_n \partial^\lambda h_n$$
$$-\frac{1}{2}\left(m^2 \Delta h_{n\mu\nu}\Delta h_n^{\mu\nu} - (\Delta h_n)^2\right) - 2\left(m\Delta^\dagger A_n^\mu + \partial^\mu \varphi_n\right)\left(\partial^\nu h_{n\mu\nu} - \partial_\mu h_n\right)$$
$$-\frac{1}{2}\left(\partial_\mu A_{n\nu} - \partial_\nu A_{n\mu}\right)\left(\partial^\mu A_n^\nu - \partial^\nu A_n^\mu\right)\Big]$$

Δ, $\Delta^\dagger$ difference operators operate on the indices n as

$\Delta\phi_n \equiv \sum_{k=0}^{N-1} a_k \phi_{n+k}$, $\Delta^\dagger \phi_n \equiv \sum_{k=0}^{N-1} a_k \phi_{n-k}$, $\sum_{k=0}^{N-1} a_k = 0$,

a_k are N constants and ϕ_n can be identified with periodic fields on a lattice with N sites if periodic boundary conditions, $\phi_{n+N} = \phi_n$, are imposed

(Δ becomes usual differentiation operator in properly defined continuum limit)

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- The value of the cc is regulated by the corresponding size of the torus (one can most naturally use the minimum number, N = 3, of copies of bosons and fermions), and is not far from the observational values

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Thank You !