From the quantum vacuum to the observed acceleration?

Alain Blanchard

Arnaud Dupays (LCAR), Brahim Lamine (LKB)

Quynhon, August 2nd, 2013

Accelerated expansion

There is no FL model that reproduces the present day observations without acceleration...

Nobel Prize in Physics 2011

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S.Perlmuter, A.Riess, B.Schmidt

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So that the gravity strength is repulsive and proportional to R

...

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So is this the origin of the acceleration ?

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The Vacuum catastroph (Weinberg, 1989):

$$\rho_v = \langle 0 | T^{00} | 0 \rangle = \frac{1}{(2\pi)^3} \int_0^{+\infty} \frac{1}{2} \hbar\omega \, \mathrm{d}^3\mathbf{k}$$

with $\omega^2 = k^2 + m^2$

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with $\omega^2 = k^2 + m^2$ highly divergent:

$$\rho_v(k_c) \propto \frac{k_c^4}{16\pi^2}$$

(for $k_c \ll m$).

Equation of state

The pressure (massless field):

$$P_v = (\mathbf{1/3}) \sum_i \langle 0 | T^{ii} | 0 \rangle = \frac{1}{3} \frac{1}{2(2\pi)^3} \int_0^{+\infty} k \, \mathrm{d}^3\mathbf{k}$$

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$\rightarrow$ usual conclusion on zero-point energy contribution (for instance by rgularization).

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cf Review by J.Martin 2012 (astro-ph/1205.3365).

Everything You Always Wanted To Know About
The Cosmological Constant Problem (But Were Afraid To Ask)

Casimir effect

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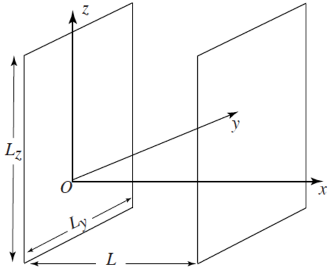

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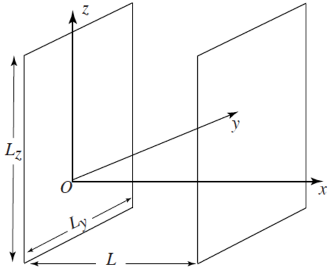

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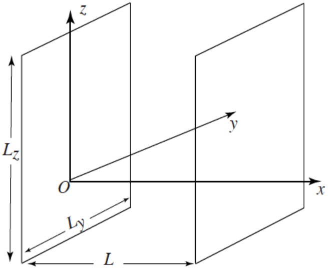

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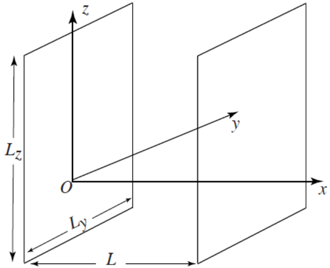

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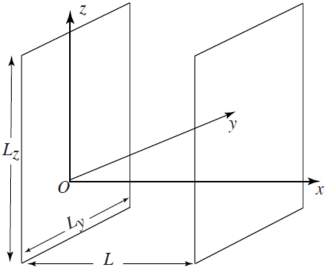

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Brown & Maclay (1968)

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This (permanent) contribution can be evaluated by mean of dimensional regularization.

Casimir effect: the horizon

Assumption 1: At high energy, only modes with λ smaller than ct have to be taken into account i.e.:

$$\rho_v = \frac{5\hbar c}{8\pi^3 R} \int_{\omega>\omega_H}^{\infty} k^2 \mathrm{d}k \left[\sum_{n=-\infty}^{\infty} \left(k^2 + \frac{n^2}{R^2} \right)^{1/2} \right]$$

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Assumption 2: as long as $ct \ll \pi R$ gravitational vacuum should be that of a massless field in a 4+1D space time i.e.:

$$\rho_v = 0$$

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Later, when $ct \gg \pi R$ i.e. $\omega_H \sim 0$

$$\rho_v = \frac{5\hbar c}{8\pi^3 R} \int_0^{\infty} k^2 \mathrm{d}k\,[...] = \frac{5\hbar c}{8\pi^3 R} \int_0^{1/R} k^2 \mathrm{d}k\,[...]$$

with :

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The condition :

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In the brane:

$$\rho_v = \frac{5\hbar c}{16\pi^2 R^4}$$

Dark energy emerges...

Pressure:

$$P_v^{\perp} = 4\rho_0 = \frac{20\hbar c}{32\pi^3 R^5}$$

Along the brane, using the fact that the $T^{\mu\nu}$ is traceless and integrating along the 4th spatial dimension:

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$\Omega_v \sim 0.7 \Rightarrow R \sim 35\mu\mathrm{m}$ fits data. Corresponding to $E \sim 1\,TeV$

Consequences

Acceleration is due to vacuum: GR + $w = -1$

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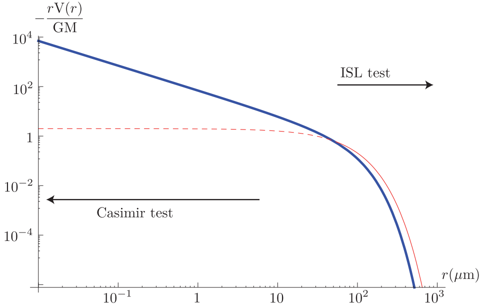
The presence of additional compact "large" dimension ($\sim 35\mu\mathrm{m}$) can be tested by experiment on gravitational inverse square law on short scale. Additional term:



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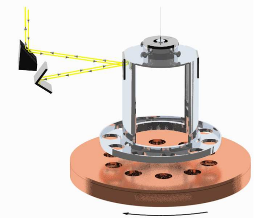

Present day limit (Adelberger et al. 2009) :

$$R < 46\mu\mathrm{m}$$

Conclusion

- Casimir effect from quantized scalar field in additional compact dimension can produce a non-zero vacuum contribution to the density of the universe with the correct equation of state for a cosmological constant. i.e. "usual" physics for DE.
- Acceleration could be the direct manifestation of the quantum gravitational vacuum.
- With $R \sim 35\mu\mathrm{m}$ it produces a cosmological constant as observed.

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- Acceleration could be the direct manifestation of the quantum gravitational vacuum.
- With $R \sim 35\mu\mathrm{m}$ it produces a cosmological constant as observed. $\rightarrow$ gravitation is modified on scales $\leq 45\mu\mathrm{m}$