Instability of de Sitter space and Corpuscular Nature of Gravity

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TFI 2017 — Parma

40 years of research (very small selection)

Gibbons, Hawking 1977

any geodesic observer in dS feels an isotropic heat bath of particles, $T = \frac{H}{2\pi}$,
horizon is thermodynamically stable

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Perlmutter, Riess, Schmidt 1998-99

accelerated expansion of the universe,
$\sim 68\%$ dark energy,
$\Lambda \Rightarrow$ late–time cosmology is asymptotically dS

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Padmanabhan 2002

physical dS vacuum should be time–asymmetric,
cosmological constant evaporates

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IR divergences in dS lead to large loop corrections,
IR regime requires non–perturbative treatment
(similarity with information paradox in BHs)

Polyakov 2012

IR divergences in dS lead to catastrophic particle
production and breaking of dS symmetry

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Dvali Gomez 2014

constant $\Lambda > 0$ is incompatible with corpuscular picture of dS (“quantum N–portrait”), decay of coherent graviton state by condensate depletion

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Rajamaran 2016

IR divergence in graviton propagator is removed by *spontaneous deformation* of dS background

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cosmological expansion in dS produces soft gravitons, which change the vacuum,
dS Page time $t_{dS} \sim M_p^2 H^{-3}$ is the relevant time scale

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dS is a classical approximation (coherent state) of some quantum evolution,
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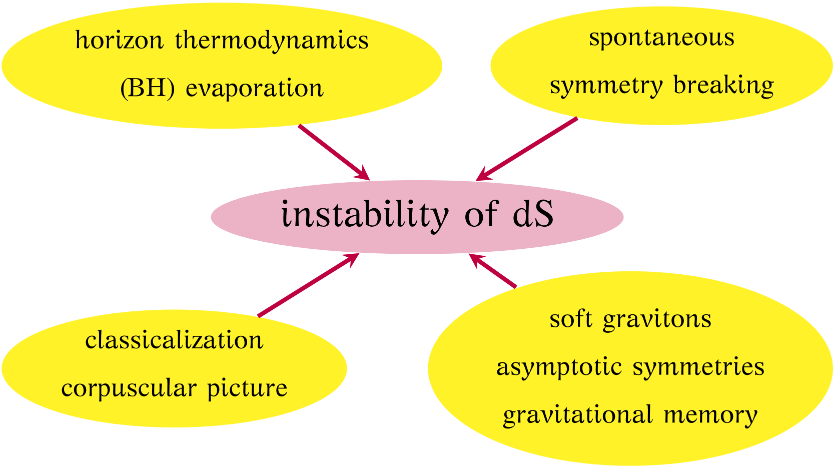
Markkanen 2017

renormalized stress energy tensor for conformally coupled scalar in dS implies

$$\dot{H} \sim H^4 M_p^{-2} \qquad \Rightarrow \qquad t_{dS} \sim M_p^2 H^{-3}$$


horizon thermodynamics
(BH) evaporation
spontaneous
symmetry breaking
instability of dS
classicalization
corpuscular picture
soft gravitons
asymptotic symmetries
gravitational memory

Outline

1. peculiar things we know
   - Unruh effect, BH evaporation
2. de Sitter instability
   - review of two approaches
3. corpuscular picture of gravity
   - BHs, dS space, some speculations about Dark Matter

peculiarities

- notions of particles and the vaccum are observer dependent
  - Unruh effect
  - cosmological particle production
- presence of horizons
  - entanglement, mixed states, open quantum systems
  - thermodynamics, Hawking radiation
  - information paradox, firewall argument

QFT IN CURVED SPACE–TIME

peculiarities

notions of particles and the vaccum are observer dependent

Unruh effect

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It's not Quantum Gravity

QFT in curved space–time

"failure" of QFT at horizons

↓

BHs: classical background = coarse grained picture

breaks down at the horizon

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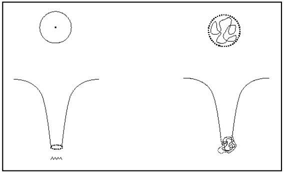
fuzzballs

(Mathur)



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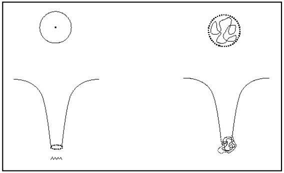
quantum N–portrait

(Dvali, Gomez)



BH = BEC of gravitons

$$N \sim (M/M_p)^2$$

$$\lambda \sim r_s$$

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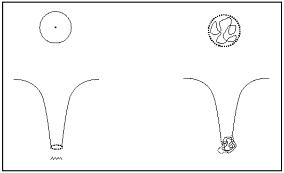


quantum N–portrait
(Dvali, Gomez)

BH = BEC of gravitons

$$N \sim (M/M_p)^2$$

$$\lambda \sim r_s$$

cosmological
(apparent)
horizons
?

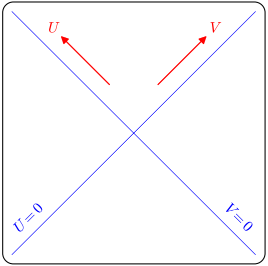
massless scalar in $2d$ Minkowski space

$$ds^2 = -\,dU\,dV$$

$$U = T - X \qquad V = T + X$$

positive frequency modes ($\omega > 0$)

$$u^M_{in,\omega} \sim e^{-i\omega U} \qquad u^M_{out,\omega} \sim e^{-i\omega V}$$



$$\phi^M = \sum_{\omega>0} \left(u^M_{in,\omega} a_{in,\omega} + \overline{u^M_{in,\omega}} a^\dagger_{in,\omega} + u^M_{out,\omega} a_{out,\omega} + \overline{u^M_{out,\omega}} a^\dagger_{out,\omega} \right)$$

Minkowski vacuum $\qquad a_{in,\omega}|M\rangle = a_{out,\omega}|M\rangle = 0$

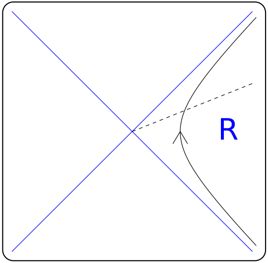
massless scalar in a Rindler wedge (R)

$$U = -\frac{1}{a}\,\mathrm{e}^{-au} < 0 \qquad V = \frac{1}{a}\,\mathrm{e}^{av} > 0$$

$$\mathrm{d}s^2 = -\,\mathrm{e}^{a(v-u)}\,\mathrm{d}u\,\mathrm{d}v$$

positive frequency modes ($\sigma > 0$)

$$u^R_{in,\sigma} \sim \mathrm{e}^{-i\sigma u} \qquad u^R_{out,\sigma} \sim \mathrm{e}^{-i\sigma v}$$



$$\phi^R = \sum_{\sigma>0} \left(u^R_{in,\sigma} b^R_{in,\sigma} + u^R_{out,\sigma} b^R_{out,\sigma} + c.c.\right)$$

Rindler (R) vacuum $\qquad b^R_{in,\sigma}|R\rangle = b^R_{out,\sigma}|R\rangle = 0$

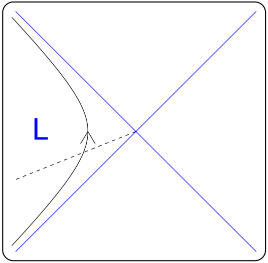
massless scalar in a Rindler wedge (L)

$$U = \frac{1}{a}\,\mathrm{e}^{av} > 0 \qquad V = -\frac{1}{a}\,\mathrm{e}^{au} < 0$$

$$\mathrm{d}s^2 = -\,\mathrm{e}^{a(v-u)}\;\mathrm{d}u\,\mathrm{d}v$$

positive frequency modes ($\sigma > 0$)

$$u^L_{in,\sigma} \sim \mathrm{e}^{-i\sigma u} \qquad u^L_{out,\sigma} \sim \mathrm{e}^{-i\sigma v}$$



$$\phi^L = \sum_{\sigma>0}\left(u^L_{in,\sigma}b^L_{in,\sigma} + u^L_{out,\sigma}b^L_{out,\sigma} + c.c.\right)$$

Rindler (L) vacuum $\qquad b^L_{in,\sigma}|L\rangle = b^L_{out,\sigma}|L\rangle = 0$

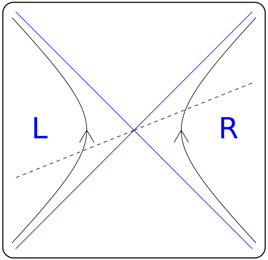
Minkowski Hilbert space in terms of Rindler modes

R–out, L–in sector

$$u^R_{out,\sigma} \sim \begin{cases} e^{-\frac{i\sigma}{a}\ln(aV)} & V > 0 \\ 0 & V < 0 \end{cases}$$

$$u^L_{in,\sigma} \sim \begin{cases} 0 & V > 0 \\ e^{\frac{i\sigma}{a}\ln(-aV)} & V < 0 \end{cases}$$

$$\overline{u^R_{out,\sigma}} \quad , \quad \overline{u^L_{in,\sigma}}$$

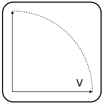


$$\phi^M = \sum_{\sigma>0} \left(u^R_{in,\sigma} b^R_{in,\sigma} + u^L_{out,\sigma} b^L_{out,\sigma} + c.c. \right)$$

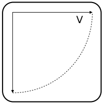
Fourier components with respect to V

$$u^R_{out,\sigma}(\pm\omega) \sim \int_0^\infty \mathrm{e}^{\pm i\omega V}\,\mathrm{e}^{-\frac{i\sigma}{a}\ln(aV)}\,\mathrm{d}V$$

$$u^R_{out,\sigma}(\omega) \sim i\,\mathrm{e}^{\frac{\pi\sigma}{2a}}\int_0^\infty \mathrm{d}y\,\mathrm{e}^{-\omega y}\,\mathrm{e}^{-\frac{i\sigma}{a}\ln(ay)}$$



$$u^R_{out,\sigma}(-\omega) \sim -i\,\mathrm{e}^{-\frac{\pi\sigma}{2a}}\int_0^\infty \mathrm{d}y\,\mathrm{e}^{-\omega y}\,\mathrm{e}^{-\frac{i\sigma}{a}\ln(ay)}$$



Fourier components with respect to V

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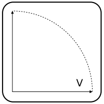

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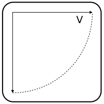


repeat for

$u^L_{in,\sigma}$, $\overline{u^R_{out,\sigma}}$, $\overline{u^L_{in,\sigma}}$

→

positive frequency combinations

$u^R_{out,\sigma} + e^{-\frac{\pi\sigma}{a}}\, \overline{u^L_{in,\sigma}}$ $\qquad$ $u^L_{in,\sigma} + e^{-\frac{\pi\sigma}{a}}\, \overline{u^R_{out,\sigma}}$

Bogoliubov transformation

$$d^1_\sigma = \left(1 - e^{-\frac{2\pi\sigma}{a}}\right)^{-1/2} \left(b^R_{out,\sigma} - e^{-\frac{\pi\sigma}{a}}\, b^L_{in,\sigma}{}^\dagger\right)$$
$$d^2_\sigma = \left(1 - e^{-\frac{2\pi\sigma}{a}}\right)^{-1/2} \left(b^L_{in,\sigma} - e^{-\frac{\pi\sigma}{a}}\, b^R_{out,\sigma}{}^\dagger\right)$$

$|M\rangle$ is entangled state in $|R\rangle \times |L\rangle$ Fock space

$$d^1_\sigma |M\rangle = d^2_\sigma |M\rangle = 0 \qquad \Rightarrow \qquad |M_{out,\sigma}\rangle = \sum_n p_n(\sigma)\, |n^R_{out,\sigma}\rangle \times |n^L_{in,\sigma}\rangle$$

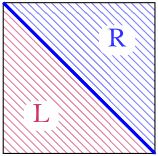
$$p_n(\sigma) = \left(1 - e^{-\frac{\sigma}{T}}\right)^{-1/2} e^{-\frac{n\sigma}{2T}} \qquad T = \frac{a}{2\pi}$$

Unruh temperature

thermal density matrix

$$\rho_R = \mathrm{tr}_L\, |M_{out,\sigma}\rangle\langle M_{out,\sigma}| = \sum_n |p_n(\sigma)|^2\, |n^R_{out,\sigma}\rangle\langle n^R_{out,\sigma}|$$

Unruh effect



R: $\mathrm{d}s^2 = -\,\mathrm{e}^{av}\,\mathrm{d}v\,\mathrm{d}U$

$|M\rangle$ → thermal for R–out modes
→ vacuum for R–in modes

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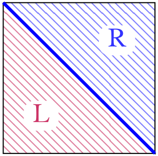

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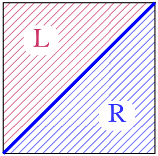

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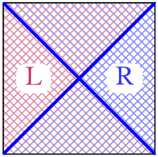

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Effective CFT on the horizon

[Padmanabhan]

generic metric with horizon

$$\mathrm{d}s^2 = -f(r)\,\mathrm{d}t^2 + \frac{f'(r)^2}{4a^2 f(r)}\,\mathrm{d}r^2 + g_{ab}(r,x)\,\mathrm{d}x^a\,\mathrm{d}x^b$$

horizon

$$f(r_h) = 0$$

interacting scalar field

$$\nabla^2\phi - V'(\phi) = 0$$

$\xi = \frac{1}{2a}\ln f(r)$

$f(r) > 0$

$r \longrightarrow r_h$

$$\left(-\partial_t^2 + \partial_\xi^2\right)\phi = 0$$

2d massless scalar

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[Padmanabhan]

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CFT know–how:

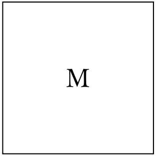
$$\mathrm{d}s^2 = C(x^+, x^-)\,\mathrm{d}x^+\,\mathrm{d}x^-$$

EM tensor

$$\langle T_{\pm\pm}\rangle = -\frac{1}{12\pi} C^{1/2}\partial_\pm^2 C^{-1/2}$$

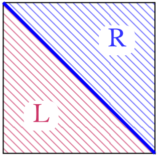
$$\langle T_{+-}\rangle = \frac{1}{24\pi}\partial_+\partial_- \ln C$$

BHs: Three vacua



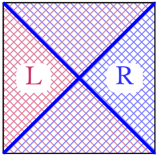
$\langle T_{\mu\nu} \rangle = 0$

Hartle–Hawking vacuum, time–symmetric



$\langle T_{Uv} \rangle = \langle T_{UU} \rangle = 0, \quad \langle T_{vv} \rangle = -\frac{a^2}{48\pi}$

Unruh vacuum, time–asymmetric, evaporation



$\langle T_{uv} \rangle = 0, \quad \langle T_{vv} \rangle = \langle T_{uu} \rangle = -\frac{a^2}{48\pi}$

Boulware vacuum, time–symmetric, singular

BH evaporation: Page time and emitted quanta

Schwarzschild BH emits Hawking quanta with thermal spectrum

$$T = (8\pi M)^{-1} \qquad A = 16\pi M^2 \sim S \qquad (\hbar = G = 1)$$

Planck's formula

$$\frac{\mathrm{d}L}{\mathrm{d}\omega} = \frac{\#A}{8\pi^2}\frac{\omega^3}{\mathrm{e}^{\omega/T}-1}$$

$$L = \frac{\#\pi^2}{120} A T^4$$

$$L = -\frac{dM}{dt} = \frac{\#}{15 \cdot 2^{11}\pi} M^{-2}$$

Page time

$$t_{\mathrm{Page}} = 5 \cdot 2^{11}\pi\#^{-1} M^3$$

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Page time

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number flux $\quad \frac{\mathrm{d}\Gamma}{\mathrm{d}\omega} = \frac{1}{\omega} \frac{\mathrm{d}L}{\mathrm{d}\omega}$

$$\Gamma = \frac{\mathrm{d}N}{\mathrm{d}t} = \frac{\#\zeta(3)}{4\pi^2} A T^3 = \frac{\#\zeta(3)}{128\pi^4} M^{-1}$$

number of emitted quanta

$$N = \int_0^{t_{\text{Page}}} \Gamma \, \mathrm{d}t = \frac{120\zeta(3)}{\pi^3} M^2 \sim S$$

dS in comoving coordinates

$$ds^2 = -(1 - H^2 r^2)\, dt^2 + (1 - H^2 r^2)^{-1}\, dr^2 + r^2\, d\Omega^2$$

ideal fluid: $-p = \varepsilon = \dfrac{3H^2}{8\pi G}$ apparent horizon $r_h = H^{-1}$

horizon thermodynamics

$$M_h = V_h \varepsilon \quad V_h = \frac{4}{3}\pi r_h^3$$

$$S_h = \frac{A_h}{4\hbar G} \quad A_h = 4\pi r_h^2$$

$$dM_h = T_h\, dS_h - p\, dV_h$$

$$T_h = -\frac{\hbar}{2\pi} H$$

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horizon evaporation

$$-T_h \frac{dS_h}{dt} = \frac{\#\pi^2}{120\hbar^3} A_h T_h^4$$

$$\Rightarrow \quad r_h^3(t) = r_h^3(0) + \frac{\# L_P^2}{160\pi} t$$

dS Page time

$$t_{dS} \sim L_P^{-2} H^{-3}$$

physical graviton modes propagate like a minimally coupled massless scalar field

Spontaneous deformation of de Sitter

[Rajamaran]

physical graviton modes propagate like a minimally coupled massless scalar field

massive scalar in dS

$$(\Box - m^2)\,\phi = 0 \qquad \mathrm{d}s^2 = \frac{1}{H^2\tau^2}\left(-\,\mathrm{d}\tau^2 + \mathrm{d}\mathbf{x}^2\right) \qquad \tau \in (-\infty, 0)$$

mode expansion $\phi(x) = \sum_k \left[u_k(x) a_k + \overline{u_k(x)} a_k^\dagger\right]$

positive frequency modes $u_k(\tau, \mathbf{x}) \sim (-\tau)^{3/2}\, \mathrm{e}^{-i\mathbf{k}\cdot\mathbf{x}}\, H_\nu^{(1)}(-k\tau)$

with $\nu^2 = \frac{9}{4} - m^2 H^{-2}$

scalar propagator in dS is IR divergent for $m = 0$

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Schwinger–Keldysh formalism (CTP)

$$G_{SK}(x,y) = \begin{pmatrix} iF(x,y) & G^R(x,y) \\ G^A(x,y) & 0 \end{pmatrix}$$

$$\left(\Box - m^2\right) F(x,y) = 0$$

$$\left(\Box - m^2\right) G^{R,A}(x,y) = \delta(x,y)$$

$$F(x,y) = \frac{1}{2}\left[\langle \phi(x)\phi(y)\rangle + \langle \phi(y)\phi(x)\rangle\right]$$

Spontaneous deformation of de Sitter

scalar propagator in dS is IR divergent for $m = 0$

Schwinger–Keldysh formalism (CTP)

$$G_{SK}(x,y) = \begin{pmatrix} iF(x,y) & G^R(x,y) \\ G^A(x,y) & 0 \end{pmatrix}$$

$$\left(\Box - m^2\right) F(x,y) = 0$$

$$\left(\Box - m^2\right) G^{R,A}(x,y) = \delta(x,y)$$

$$F(x,y) = \frac{1}{2}\left[\langle\phi(x)\phi(y)\rangle + \langle\phi(y)\phi(x)\rangle\right]$$

$$k \to 0 : \qquad F(\mathbf{k};\tau_1,\tau_2) \sim \begin{cases} \frac{H^2}{2k^3} & m = 0 \\ \frac{H^2}{2k^3}\left(k^2\tau_1\tau_2\right)^{\frac{m^2}{3H^2}} & m \neq 0 \end{cases}$$

$F(x,y)$ is ill–defined for $m = 0$!

Spontaneous deformation of de Sitter

deformed dS

$$ds^2 = \frac{1}{H^2\tau^2}\left[-\,d\tau^2 + f(\tau)\,d\mathbf{x}^2\right]$$

spontaneous deformation

$$f(\tau) \approx 1$$

for example,

$$f(\tau) = \left(\frac{\tau}{\tau_0}\right)^{\varepsilon} \qquad \varepsilon \ll 1$$

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for example,

$$f(\tau) = \left(\frac{\tau}{\tau_0}\right)^{\varepsilon} \qquad \varepsilon \ll 1$$

$$\Box^{(ddS)}\phi = 0 \qquad \Rightarrow \qquad (\Box^{(dS)} - m^2)\phi = 0 \qquad m^2 \sim \varepsilon H^2$$

background deformation acts as IR regulator in graviton propagator

Consider pure trace components

$$8h - 8\tau h' - 4\tau^2 h'' = \frac{8f' - 4\tau f''}{H^2\sqrt{\kappa}\tau}$$

classical source

Spontaneous deformation of de Sitter

Consider pure trace components

$$8h - 8\tau h' - 4\tau^2 h'' = \underbrace{\frac{8f' - 4\tau f''}{H^2\sqrt{\kappa}\tau}}_{\text{classical source}} + \underbrace{2\sqrt{\kappa}H^2 h_{ij}^2 \tau^2}_{\text{tadpole}} \stackrel{!}{=} 0$$

$$\langle h_{ij}(x) h_{ij}(x) \rangle \sim F(x,x) \sim \frac{1}{H^2\tau^4\varepsilon}$$

tadpole cancellation fixes

$$\varepsilon^2 + \frac{2\kappa H^2}{15\pi^2} = 0$$

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Nice idea, but needs more study

linearize gravity (with Λ)

around Minkowski

$$\epsilon_{\mu\nu}^{\alpha\beta} h_{\alpha\beta} = -2\Lambda\eta_{\mu\nu}$$

→

metric =

approximation of dS

for $t_{cl} \ll \Lambda^{-1/2}$

Quantum break time of de Sitter

[Dvali, Gomez, Zell]

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gravitons with Fierz–Pauli mass

$$\epsilon_{\mu\nu}^{\alpha\beta} h_{\alpha\beta} + m^2 \left(h_{\mu\nu} - \eta_{\mu\nu} h\right) = 0$$

→ graviton dynamics valid for $t_{cl} \ll m^{-1}$

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$$\epsilon_{\mu\nu}^{\alpha\beta} h_{\alpha\beta} = -2\Lambda\eta_{\mu\nu}$$

metric = approximation of dS for $t_{cl} \ll \Lambda^{-1/2}$

They agree up to an additive constant! $m = \sqrt{\Lambda}$

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graviton dynamics valid for $t_{cl} \ll m^{-1}$

Quantum resolution of dS

trace component of Fierz–Pauli graviton

$$\Phi_{cl} = \frac{\Lambda}{\sqrt{4\pi} m^2} \cos(mt)$$

$(\hbar = G = 1)$

$$\langle N|\Phi|N\rangle = \Phi_{cl}$$

$$\Phi = \sum_{\mathbf{k}} \frac{1}{\sqrt{2V\omega_k}} \left(a_k\, e^{-ikx} + a_k^\dagger\, e^{ikx}\right)$$

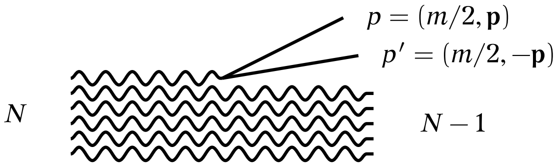
coherent state $|N\rangle = e^{\sqrt{N}(a_0 - a_0^\dagger)}\,|0\rangle$

$$N = \frac{V\Lambda^2}{8\pi m^3} \quad \text{with} \quad m = \sqrt{\Lambda}, \quad V \sim \Lambda^{-3/2}$$

$$N \sim \frac{1}{\hbar G \Lambda}$$

Quantum break time of de Sitter

decay of the coherent state



decay rate

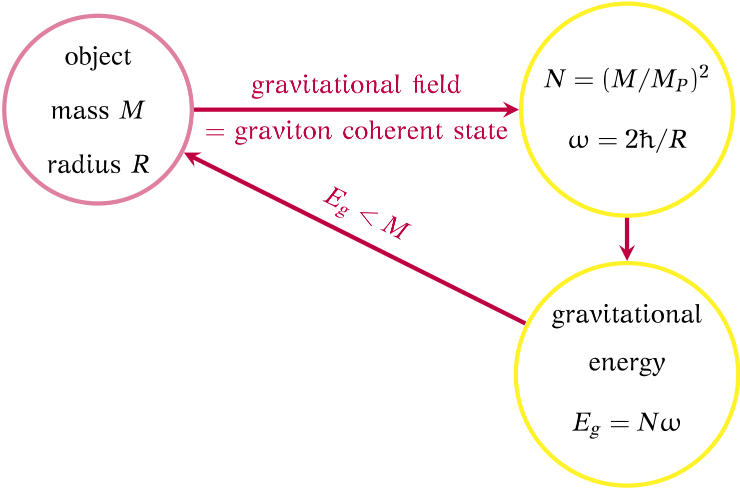
$\Gamma \sim \Lambda^{1/2}$

quantum break time

$$t_q \sim \Gamma^{-1} N \sim N \Lambda^{-1/2} \sim L_P^{-2} H^{-3} \sim t_{dS}$$

Corpuscular picture of Gravity

[Dvali, Gomez]



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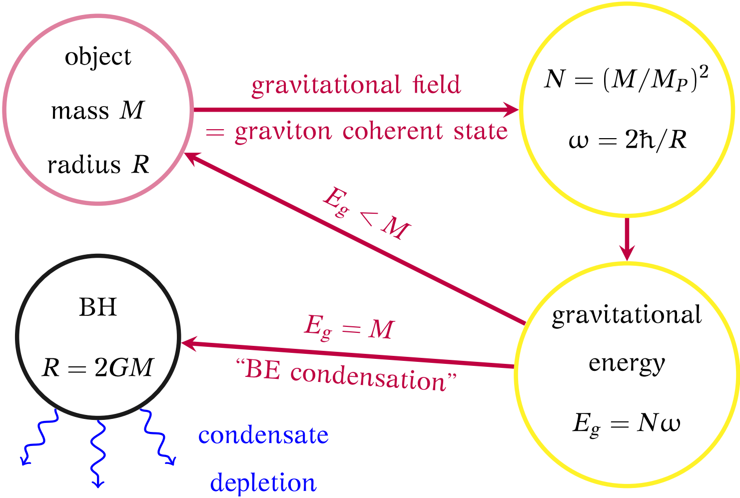

Corpuscular picture of Gravity

static, spherically symmetric metric

Misner–Sharp mass function

$$ds^2 = -f(r)\,dt^2 + f(r)^{-1}\,dr^2 + r^2\,d\Omega^2 \qquad f(r) = 1 - \frac{2G\,m(r)}{r}$$

horizon $\quad f(r_h) = 0 \quad \Rightarrow \quad r_h = 2Gm(r_h)$

Quantum N–portrait

$N = [m(r_h)/M_P]^2$ gravitons with mean energy $\omega = 2\hbar/r_h$

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Quantum N–portrait

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For dS, turn the argument around:

Dark Energy density

$$m = \frac{4\pi}{3}R^3\varepsilon, \qquad N\omega = \frac{m^2}{M_P^2}\frac{2\hbar}{R} = m \quad \Rightarrow \quad \varepsilon = \frac{3}{8\pi G R^2}$$

2 masses, m_1, m_2, of radii R_1, R_2, distance $r_{12} \gg R_1, R_2$

# of gravitons

$$N = \frac{(m_1 + m_2)^2}{M_P^2} = \frac{m_1^2}{M_P^2} + \frac{m_2^2}{M_P^2} + \frac{2m_1 m_2}{M_P^2}$$

gravitational energy

$$E_g = \frac{m_1^2}{M_P^2} \frac{2\hbar}{R_1} + \frac{m_2^2}{M_P^2} \frac{2\hbar}{R_2} + \frac{2m_1 m_2}{M_P^2} \frac{\hbar}{r_{12}}$$

total mass

Newtonian gravitational potential

$$m_1 + m_2 = \underbrace{\left(m_1 - \frac{m_1^2}{M_P^2} \frac{2\hbar}{R_1} - G\frac{m_1 m_2}{r_{12}}\right)}_{E_1} + \underbrace{\left(m_2 - \frac{m_2^2}{M_P^2} \frac{2\hbar}{R_2} - G\frac{m_1 m_2}{r_{12}}\right)}_{E_2} + E_g$$

Corpuscular speculations on Dark Matter

[Cadoni, Casadio, Giusti, W.M., Tuveri]

"baryonic" mass μ inside a universe filled with dark energy

$$r_h = 2G(m_d + \mu) \qquad N = \frac{m_d^2}{M_P^2} + \frac{2\mu m_d}{M_P^2} + \frac{\mu^2}{M_P^2}$$

dark energy

$$m_d = \frac{m_d^2}{M_P^2}\,\frac{2\hbar}{r_h + \delta} + \frac{2\mu m_d}{M_P^2}\,\frac{\hbar}{\lambda}$$

horizon shift (δ)

new length scale (λ)

$$2\mu G = r_\mu \ll \lambda \ll r_h$$

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new length scale

$$2\mu G = r_\mu \ll \lambda \ll r_h$$

$$\frac{\delta}{r_h}\left(1 - \frac{r_\mu}{\lambda}\right) = \frac{r_\mu}{\lambda} - \frac{r_\mu}{r_h}$$

1 equation, 2 unknowns

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generic solution must satisfy $r_\mu \ll \lambda \ll r_h$

$$\boxed{\frac{\delta}{r_h} = \frac{r_\mu}{\lambda} + (1-\gamma)\frac{r_\mu^2}{\lambda^2}} + \boxed{\gamma\frac{r_\mu^2}{\lambda^2} - \frac{r_\mu}{r_h}} + \mathcal{O}\left(r_\mu^3/\lambda^3\right)$$

γ: $\mathcal{O}(1)$ constant

$$\boxed{\delta \approx \sqrt{\gamma^{-1} r_\mu r_h}}$$

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γ: $\mathcal{O}(1)$ constant

dS horizon shift $\Rightarrow$ total apparent matter in dS universe

$$r_h \approx H^{-1} - GM = H^{-1} - \delta \qquad \Rightarrow \qquad M \approx \sqrt{\frac{2\mu}{\gamma G H}}$$

(one) evidence of DM:

galaxy rotation curves

baryonic Tully–Fisher relation

$$v_f^4(r) \approx a_0 G \mu(r)$$

$$a_0 \approx \frac{1}{6} H$$

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MOND

$$g = \nu(g_N/a_0) g_N$$

$$\begin{cases} \nu(x \ll 1) \sim x^{-1/2} \\ \nu(x \gg 1) \sim 1 \end{cases}$$

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Verlinde 2016

elastic reaction of space–time

to presence of matter

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Verlinde 2016

elastic reaction of space–time

to presence of matter

corpuscular origin ?

Corpuscular speculations on Dark Matter

static, spherically symmetric

anisotropic fluid space–time

match BTF

kinematics

$$p_\parallel \sim \varepsilon \sim \frac{\sqrt{HG\mu}}{4\pi G}\frac{1}{r^2}$$

μ: baryonic mass

dS asymptotics

$$\varepsilon = \frac{3H^2}{8\pi G} + \frac{\sqrt{HG\mu/6}}{4\pi G}\frac{\alpha}{r^2}$$

$$p_\parallel = -\frac{3H^2}{8\pi G} + \frac{\sqrt{HG\mu/6}}{4\pi G}\frac{1-\alpha}{r^2}$$

horizon shift

$$Hr_h \approx 1 - \frac{\sqrt{HG\mu/6}}{1+\alpha}$$