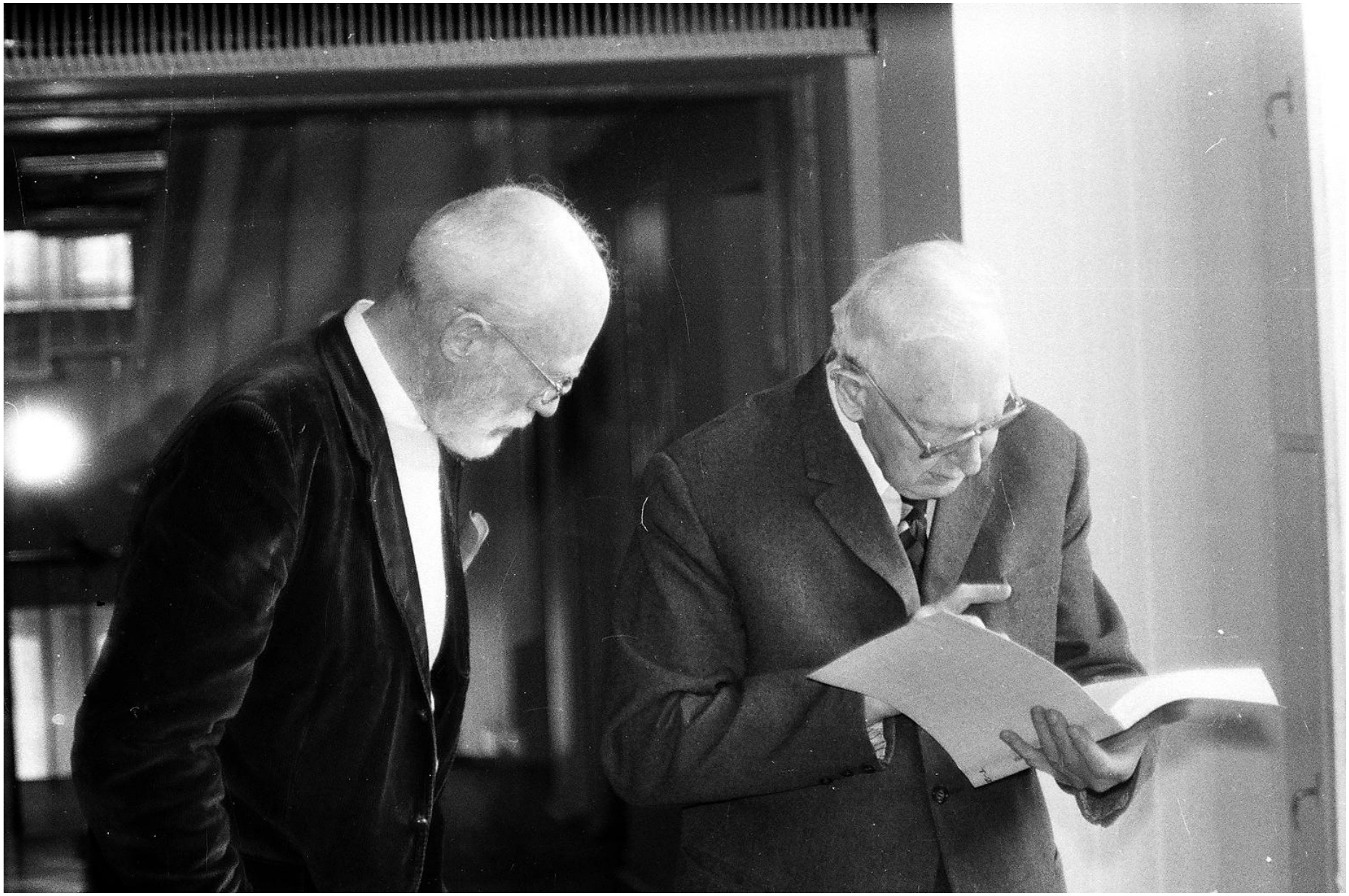
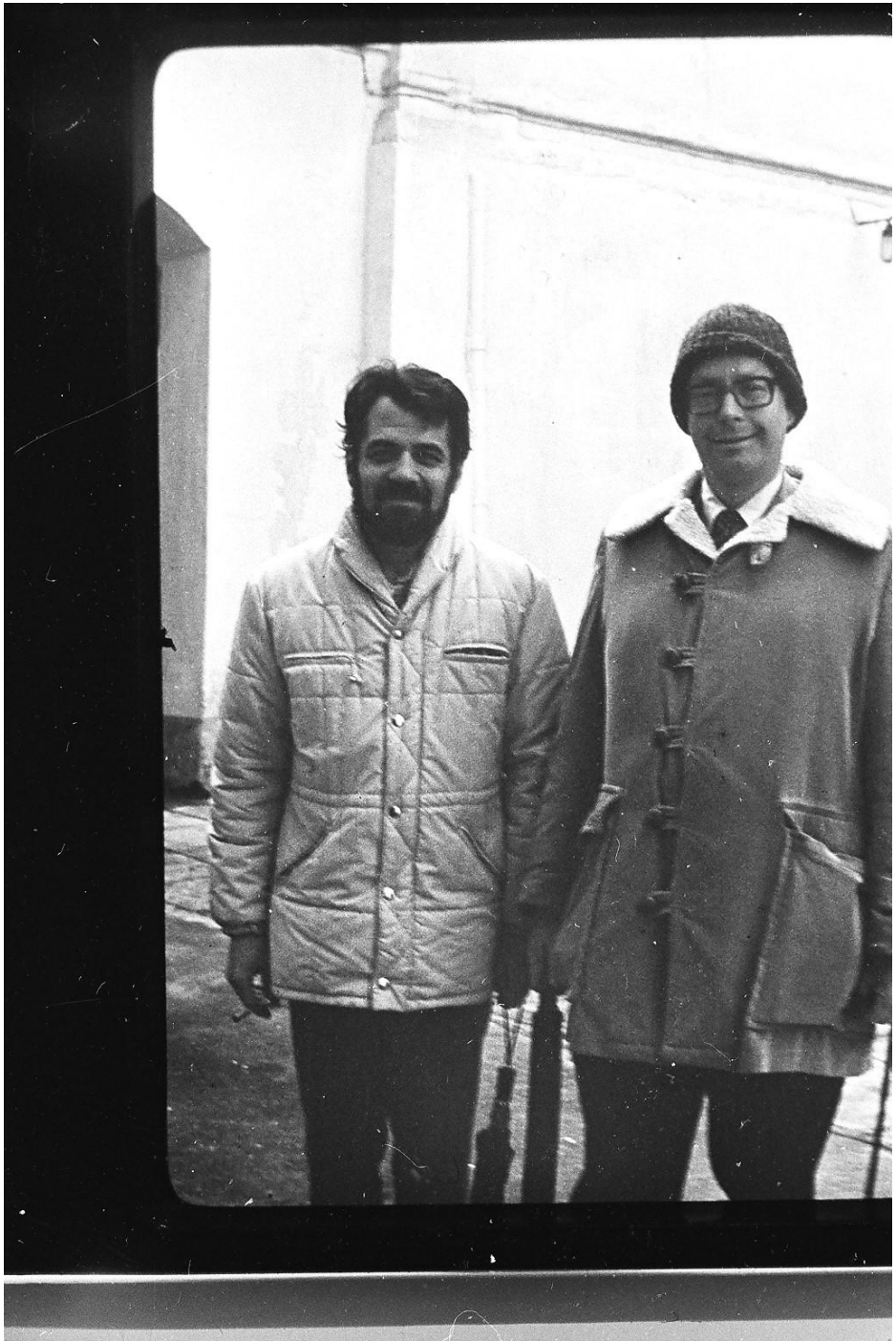
Квантовая космология, SdS/CFT дуальность и происхождение инфляции

А.О.Барвинский
Теоретическое отделение ФИАН

Москва, 12 мая, 2016





План

Волновая функция и матрица плотности черной дыры

Космология: волновая функция Хартла-Хокинга (no-boundary) и космологическая матрица плотности

Микроканоническая матрица плотности Вселенной и ее статсумма в модели конформной космологии

Космологические инстантоны как начальные данные для инфляционной Вселенной

Квантовое происхождение R^2 модели Старобинского и неминимальной хиггсовской инфляции

Конформные поля высших спинов и решение проблем иерархии и стабильности квантовых эффектов (гравитационное обрезание)

Шварцшильд-де Ситтер/CFT duality: динамика тонких оболочек в ОТО

Black hole wavefunction and density matrix

Einstein-Rosen bridge

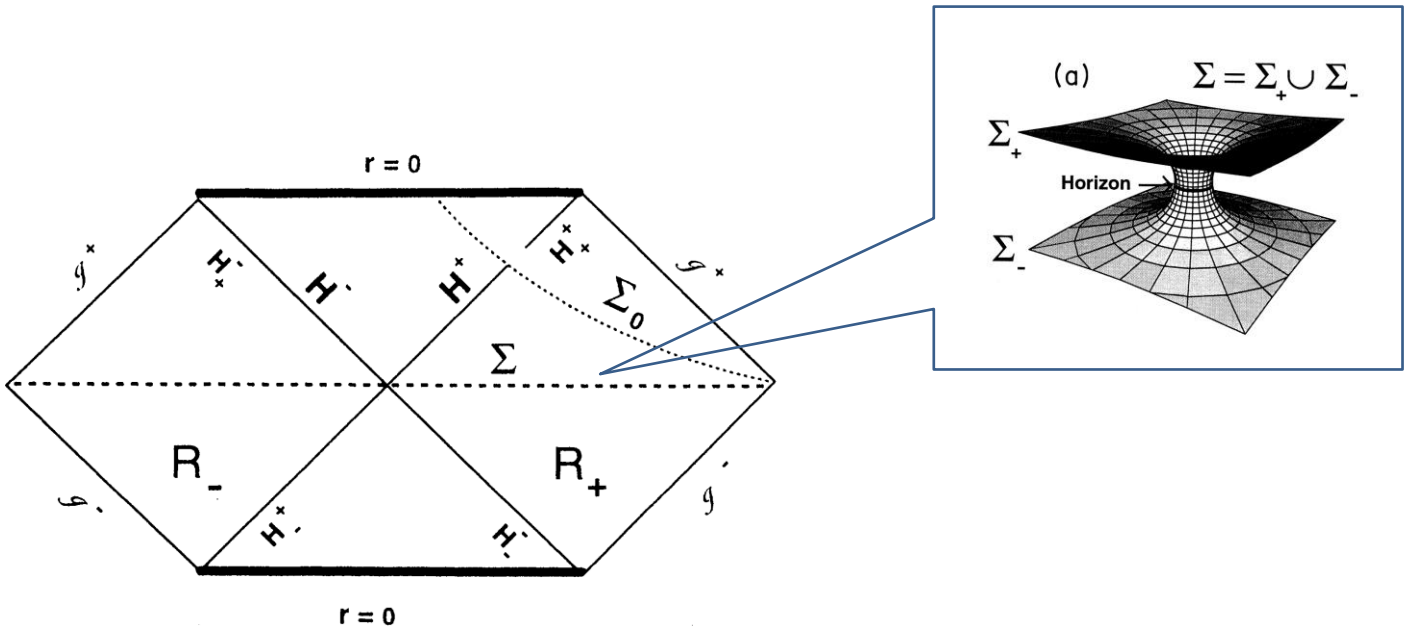
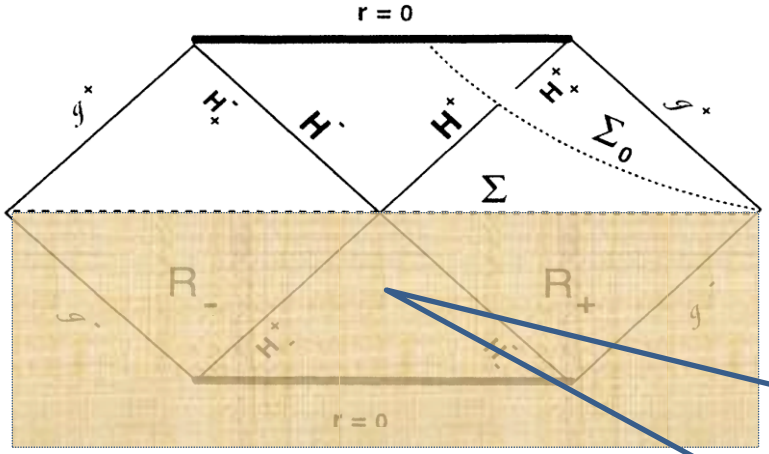
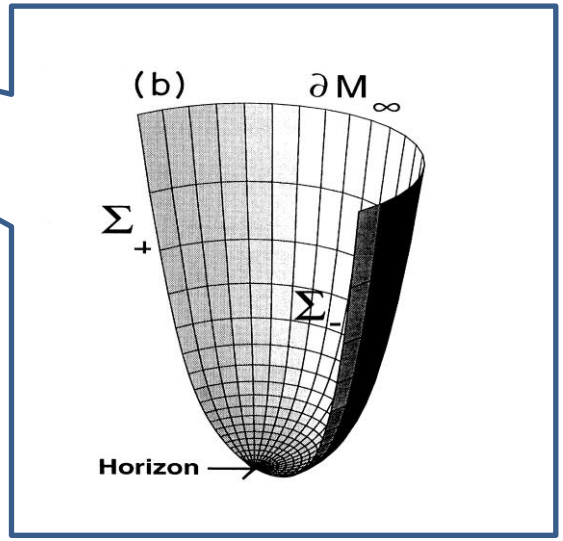


FIG. 2. This is a Penrose diagram of the eternal black hole. In Kruskal coordinates the global Cauchy surface $\boldsymbol{\Sigma}$ is defined by the equation $U + V = 0$. It has a wormhole topology $\boldsymbol{R} \times \boldsymbol{S^2}$. Both (future H^+ and past H^-) horizons consist of two parts $H^+_\pm$ and $H^-_\pm$, the boundaries of $R_\pm$.



Half of BH "cigar" instanton:



Einstein-Rosen bridge

$$\Sigma = \Sigma_+ \cup \Sigma_-$$

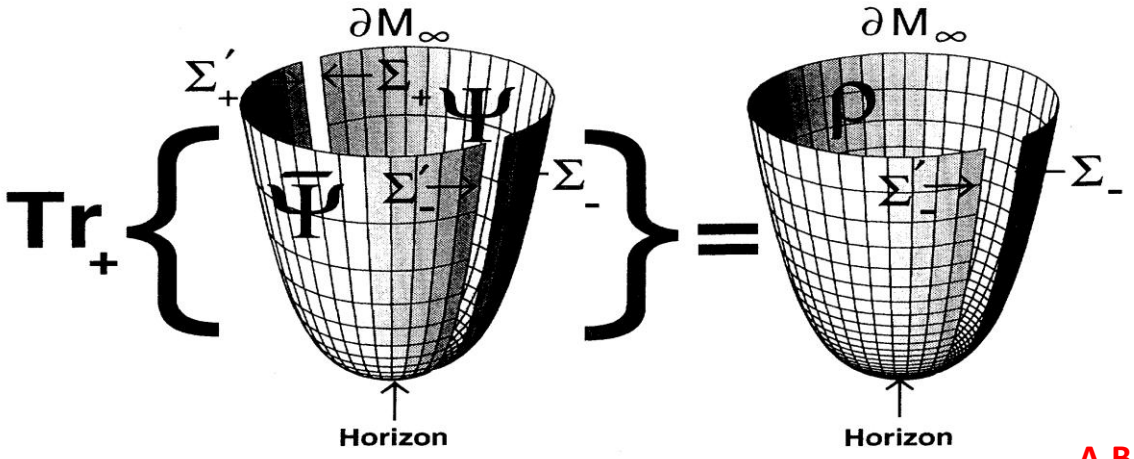
No-boundary wavefunction of BH:

$$\Psi_\Sigma(\varphi_+, \varphi_-) = \int\limits_{\phi_\Sigma = \varphi_\pm} d\phi\, e^{-S[\phi]}$$

A.B.,V.P.Frolov and A.I.Zelnikov, Wavefunction of a Black Hole and The Dynamical Origin of Entropy, Phys. Rev. D51 (1995) 1741

Reduced density matrix of a black hole: tracing out and glueing

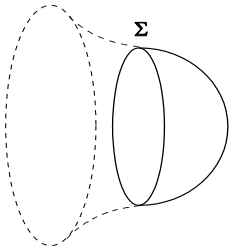
$$\rho(\varphi,\varphi') = \mathrm{Tr}_+ |\Psi\rangle\langle\Psi| = \int D\varphi_+ \, \Psi(\varphi_+,\varphi)\,\Psi^*(\varphi_+,\varphi')$$



A.B.,V.P.Frolov and A.I.Zelnikov, Wavefunction of a Black Hole and The Dynamical Origin of Entropy, Phys. Rev. D51 (1995) 1741

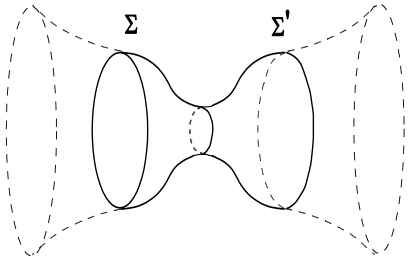
Cosmology: no-boundary wavefunction and cosmological density matrix

$$\Psi(\varphi) \sim$$



$$\Psi(\varphi) = \int_{\phi|_\Sigma = \varphi} d\phi\, e^{-S[\phi]}$$

$$\rho(\varphi, \varphi') \sim$$



$$\rho(\varphi, \varphi') = \int d\phi\, e^{-S[\phi]}\Big|_{\phi|_\Sigma = \varphi,\, \phi|_{\Sigma'} = \varphi'}$$

Cosmological initial conditions – microcanonical density matrix of the Universe and its statistical sum

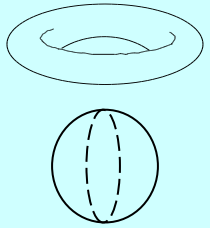
Microcanonical density matrix – projector onto subspace of quantum gravitational constraints

A.B., Phys. Rev. Lett. 99, 071301 (2007)

Statistical sum

$$e^{-\Gamma} = \int_{\text{periodic}} D[\, g_{\mu\nu}, \Phi\,]\; e^{-S[\, g_{\mu\nu}, \Phi\,]}$$

- on $S^3 \times S^1$ (thermal)
- including as a limiting (vacuum) case S^4

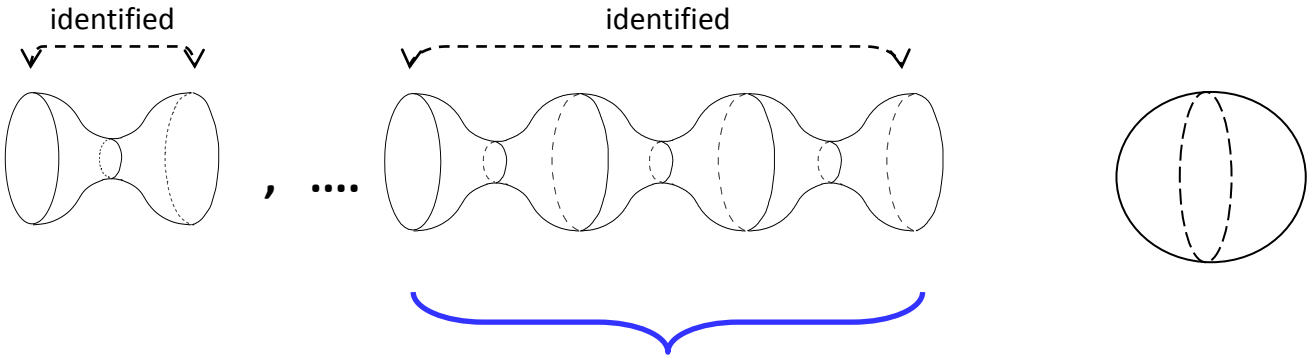


Application to CFT driven cosmology -- Universe dominated by quantum matter conformally coupled to gravity (CFT) :

$$S[\, g_{\mu\nu}, \Phi\,] = -\frac{M_P^2}{2} \int d^4x\, g^{1/2}\, (R - 2\Lambda) + S_{CFT}[\, g_{\mu\nu}, \Phi\,]$$

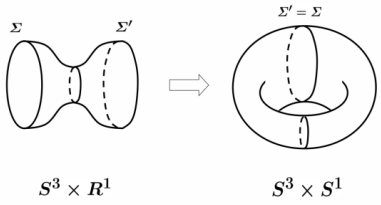
Λ -- primordial cosmological constant

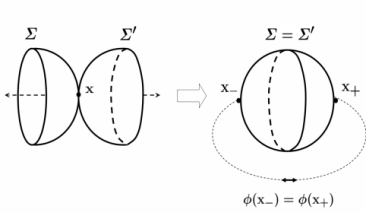
Saddle point solutions for $S_{eff}[\,g_{\mu\nu}\,]$ with Friedmann-Robertson-Walker geometry --- set of periodic – thermal -- garland-type instantons with oscillating scale factor ($S^1 \times S^3$) and the vacuum Hartle-Hawking instantons (S^4)



1- fold, k=1 **k- folded garland, k=1,2,3,…** **S^4**

Examples of identification





Properties and implications of cosmological instantons

1) Limited range of Λ – subplanckian domain (limiting the string vacua landscape?):

$$\Lambda_{\min} \leq \Lambda \leq \Lambda_{\max} = \frac{12\pi^2 M_P^2}{\beta}$$

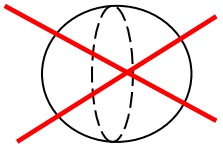
$$\beta = \sum_s \beta_s \, \mathbb{N}_s$$

N_s # of fields of spin s

Conformal anomaly coefficient

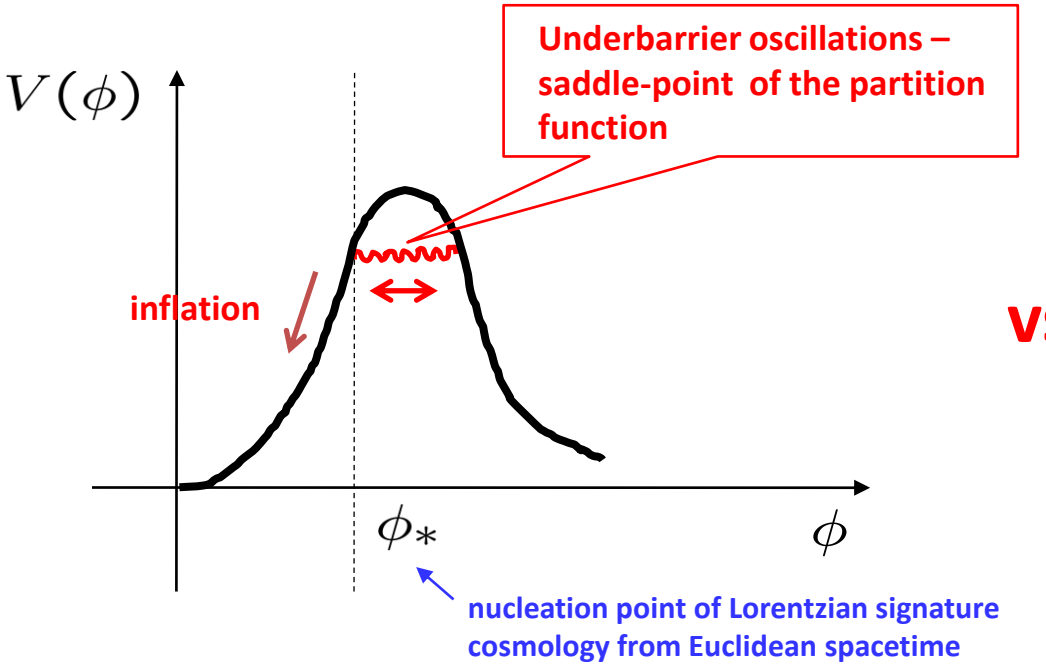
$$g_{\mu\nu}\frac{\delta \Gamma_{CFT}}{\delta g_{\mu\nu}} = \frac{1}{64\pi^2} g^{1/2}\left(\beta E + \alpha \Box R + \gamma C^2_{\mu\nu\alpha\beta}\right)$$

2) No-boundary instantons S^4 are ruled out by *infinite positive* Euclidean action – elimination of infrared catastrophe

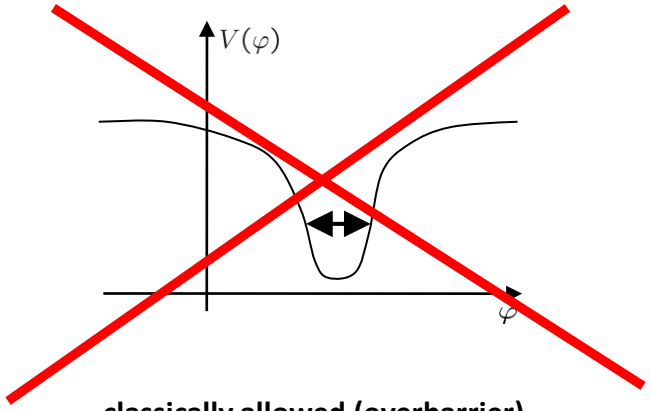


3) Generalization to inflationary model, $\Lambda \rightarrow V(\phi)$ – selection of inflaton potential $V(\phi)$ maxima (new type of hill-top inflation) – quantum origin of the Starobinsky model and Higgs inflation model with a primordial radiation at $V(\phi) \sim \Lambda_{max}$

Selection of inflaton potential *maxima* as initial conditions for inflation – new paradigm of HILL-TOP INFLATION

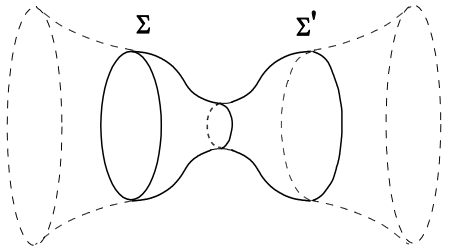


VS



classically allowed (overbarrier) oscillation --- ruled out because of *underbarrier* oscillations of scale factor

Lorentzian Universe with initial conditions set by the instanton -- analytic continuation of the instanton solutions.
Expansion and quick dilution of primordial radiation decay of a composite Λ, exit from inflation and particle creation of conformally non-invariant matter and its thermalization



4) Origin of Starobinsky R^2 model and non-minimal Higgs inflation: slow roll smallness parameters + thermal imprint on primordial power spectrum

$$\eta = -\frac{\beta\mu^2}{12\pi^2 M_P^2} < 0$$

$$\epsilon = \frac{1}{2}\left(\frac{\Delta_\phi}{M_P}\right)^2 \eta^2 \sim \eta_*^2 \ll |\eta|$$

$$n_s = 1 - 6\epsilon + 2\eta \simeq 0.96$$

$$r = 16\epsilon \ll 1$$

Main observable CMB parameters (WMAP, Planck,...):

$$\frac{\Delta T}{T} \sim 10^{-5},\ n_s \simeq 0.96,\ r \simeq 0.003$$

relation of CMB data to the Higgs mass
A.Kamenshchik, A.Starobinsky & A.B. (2008)
Bezrukov,Shaposhnikov (2008);

$$M_{\text{Higgs}} \simeq 126 GeV$$

5) Hidden sector of conformal higher spin fields (CHS): solution of hierarchy problem and stabilization of graviton loop corrections below the gravitational cutoff

$$\Lambda \sim 10^{-11} M_P^4 \ll \Lambda_{\text{cutoff}}$$

A.Barvinsky (2016)

Schwarzschild-de Sitter/CFT duality

The analogue of the thermal version of AdS/CFT correspondence: duality of the 4D finite temperature boundary CFT to 5D black hole thermodynamics in AdS spacetime with a boundary

Witten (1998)

VS

4D CFT cosmology: Einstein theory sourced by quantum conformal matter with conformal anomaly at finite temperature

$$\Longleftrightarrow$$

Brane induced gravity in 5D Schwarzschild-deSitter bulk (5D black hole in dS_5)

$$G_4,\ \Lambda_4,\ \mathcal{C} \qquad\qquad G_5,\ \Lambda_5,\ R_S$$

primordial 4D cosmological constant

4D radiation is imitated by the BH mass

$$\mathcal{C} \sim G_5 M = R_S^2$$

Schwarzschild radius of bulk BH

Technique of thin shells in GR:

Einstein equations in the bulk

+

Israel junction conditions on the brane

V.A.Berezin, V.A.Kuzmin and I.I.Tkachev, Thin Wall Vacuum Domains Evolution, Phys.Lett. B120 (1983) 91

Duality of 4D CFT driven cosmology and 5D brane induced gravity

4D side

$$S_E[\,g_{\mu\nu},\phi\,] = -\frac{1}{16\pi G}\int d^4x\, g^{1/2}\left(R - 2\Lambda\right) + S_{CFT}[\,g_{\mu\nu},\phi\,]$$

Λ -- primordial cosmological constant

$N_s \gg 1$ conformal fields of spin s=0,1,1/2

5D side

$$S[\,G_{AB}(X)\,] = -\frac{1}{16\pi G_5}\int\limits_{\text{Bulk}} d^5X\, G^{1/2}\left(R^{(5)}(\,G_{AB}\,) - 2\Lambda_5\right)$$
$$- \int\limits_{\text{brane}} d^4x\, g^{1/2}\left(\frac{1}{8\pi G_5}[\,K\,] + \frac{1}{16\pi G_4}R(\,g_{\mu\nu}\,)\right).$$

5D Schwarzschild-dS solution with a bulk black hole of the mass$\sim R_s^2/G_5$ and a spherical 4D shell inhabited by the Einstein term

$$ds^2_{(5)} = f(R)dT^2 + \frac{dR^2}{f(R)} + R^2 d\Omega^2_{(3)}$$

$$f(R) = 1 - \frac{\Lambda_5}{6}R^2 - \frac{R_S^2}{R^2}$$

embedding

$$ds^2_{(4)} = d\tau^2 + a^2(\tau)d\Omega^2_{(3)}$$

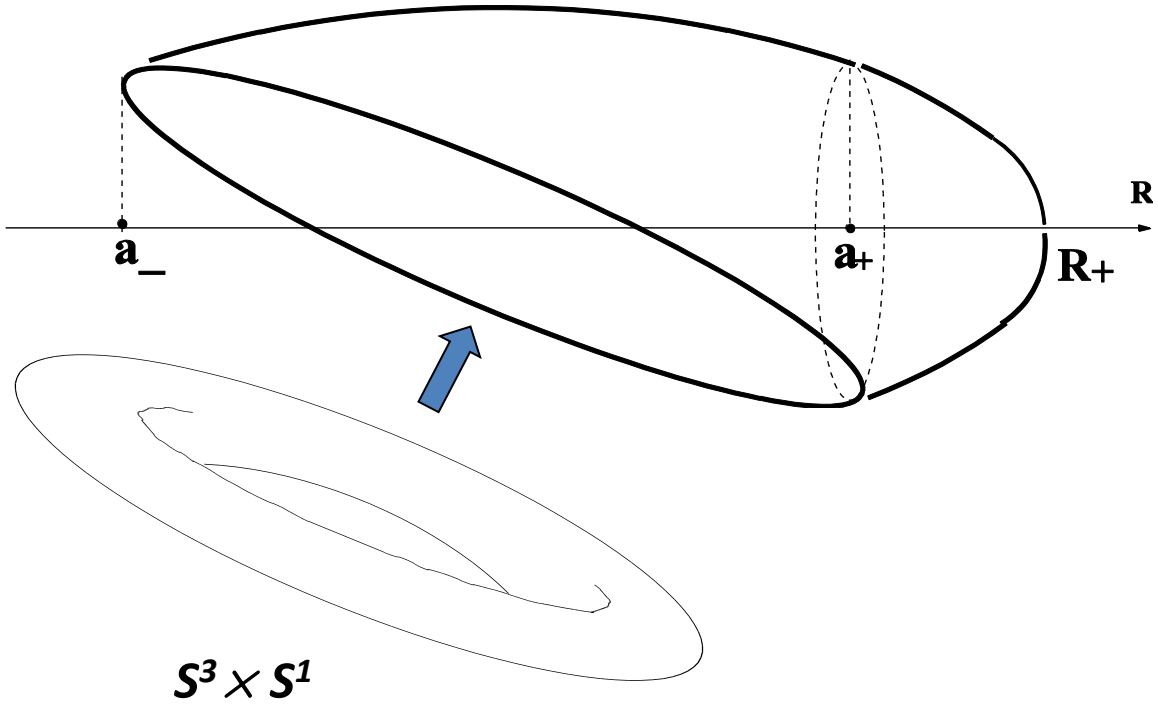
$$R = a(\tau), \quad T = T(\tau), T'(\tau) = \frac{\sqrt{f(a) - a'^2}}{f(a)}$$

Euclidean Schwarzschild-de Sitter "cigar" instanton:

$$f(R) \geq 0, \quad R_- \leq R \leq R_+$$

$$R_\pm^2 = \frac{3}{\Lambda_5}\left(1 \pm \sqrt{1 - 2\Lambda_5 R_S^2/3}\right)$$

$$R_- < \underbrace{a_- \leq a(\tau) \leq a_+}_{\text{4D instanton domain}} < R_+$$



Желаем нашим лауреатам дальнейших успехов, творческих прозрений и талантливых учеников !