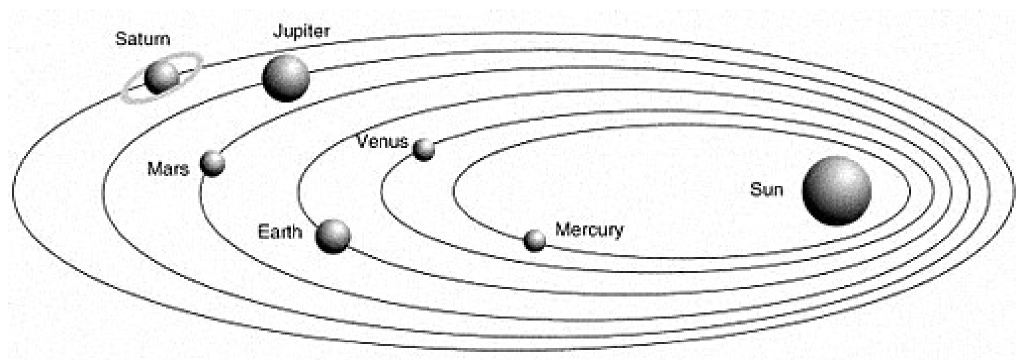
Topological Gravity as the Early Phase of Our Universe

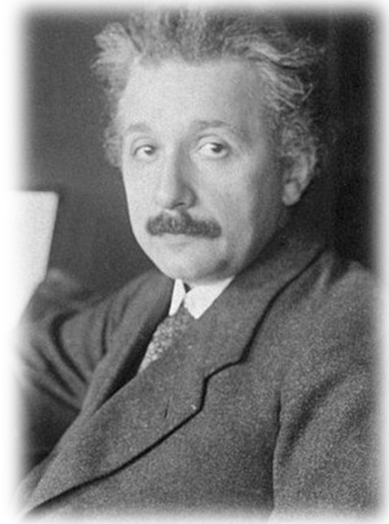
Prateek Agrawal[1], Sergei Gukov[2], Georges Obied[3] and Cumrun Vafa[3]

arXiv:2009.10077v2

see also:
R.Blumenhagen, C.Kneissl, A.Makridou
A.Kehagias, A.Riotto

talk by Ralph Blumenhagen



"His life work was possible only when he succeeded in freeing himself to a large extent from the intellectual tradition in which he was born."
-- Albert Einstein on work of Johannes Kepler

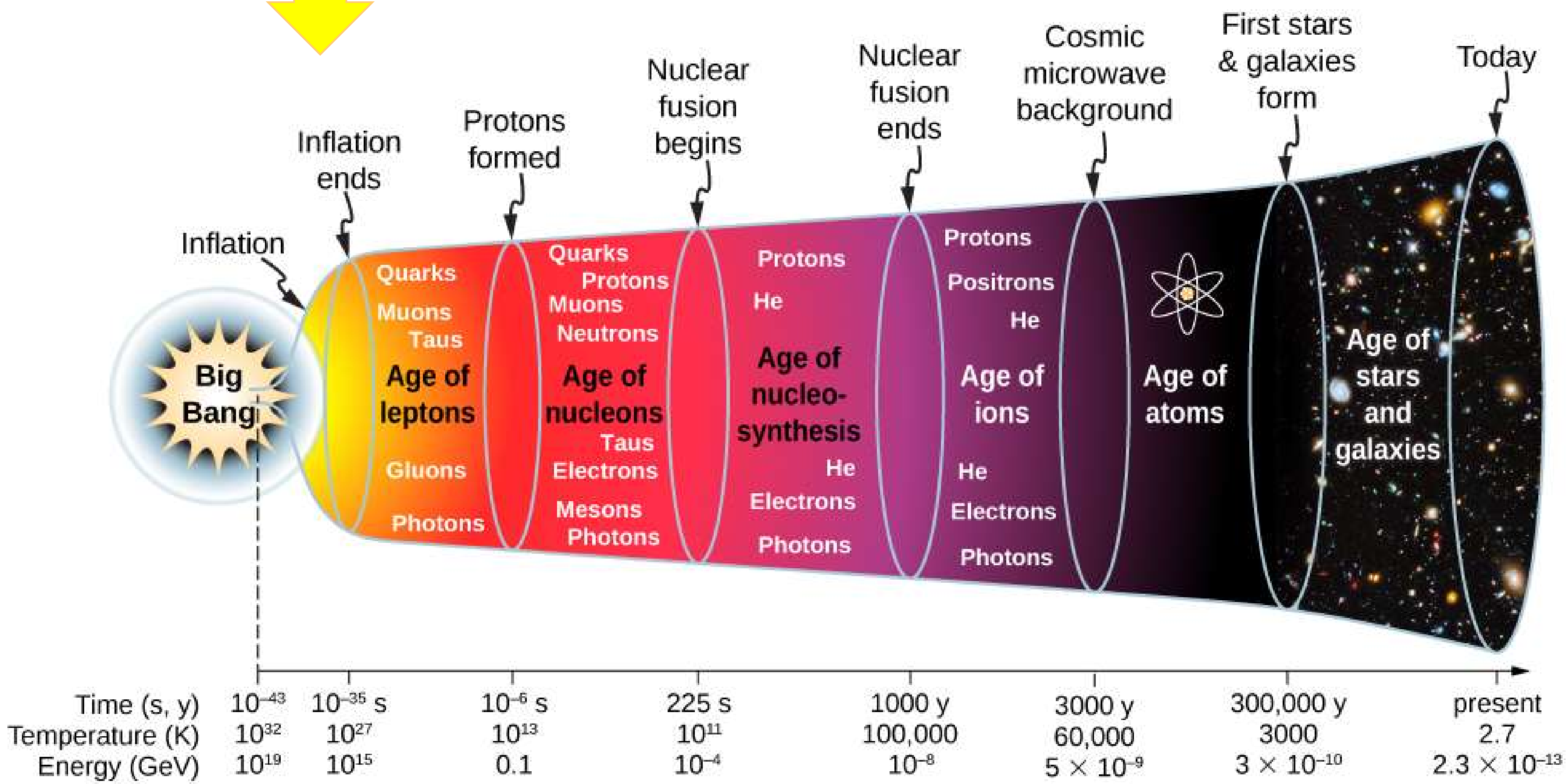
Motivation:

- New mathematical descriptions of cosmological physics?
- Do exotic smooth structures play a role in gravity? cosmology?
- Is physics of the early universe well described by the same degrees of freedom (fields) we see now?
- Is Einstein gravity the right framework to describe the early universe?

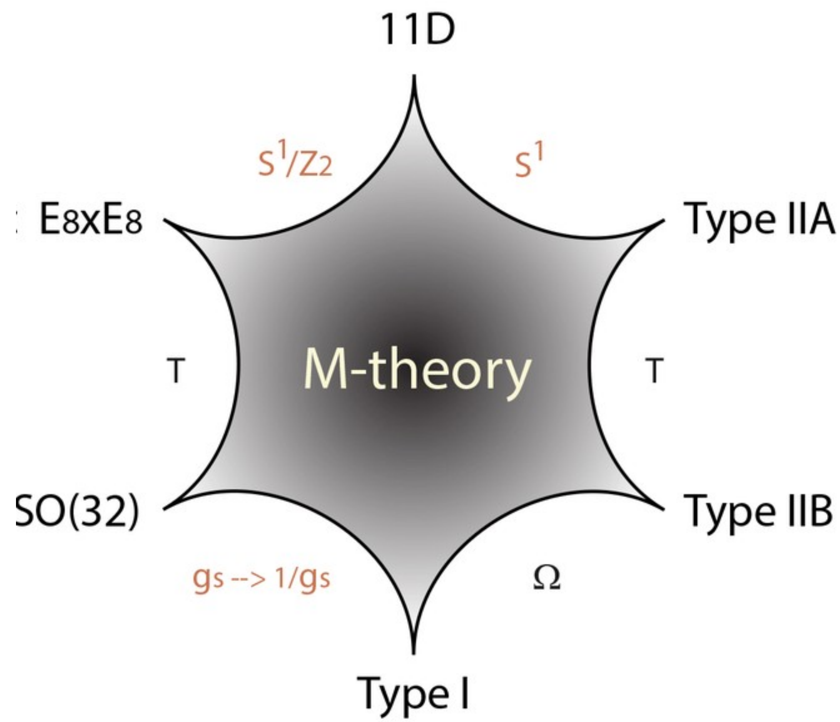
Strong gravitational interactions,
Strong time-dependence
(derivatives of all orders)

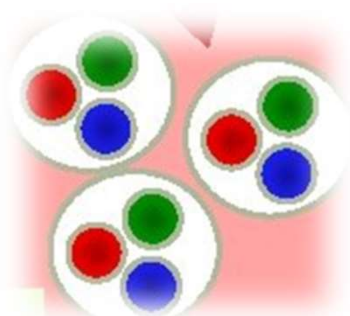
Non-local physics
(no local excitations?)

D.Gross
E.Witten

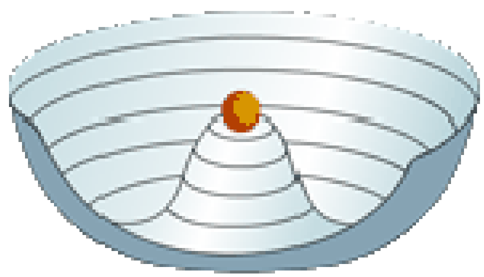


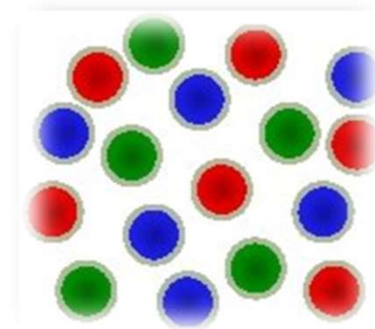
Lessons from dualities:





chiral symmetry
breaking

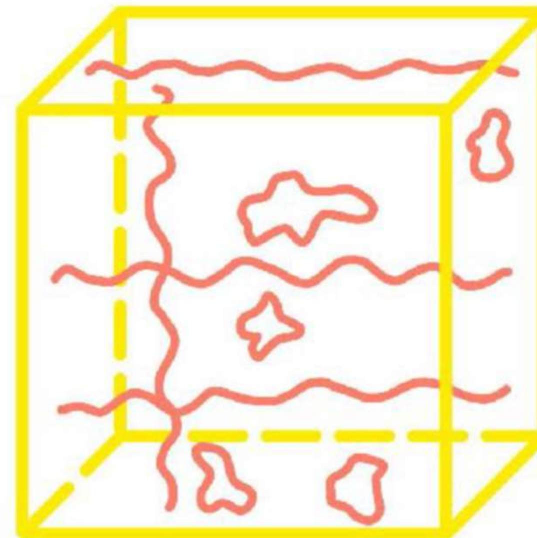




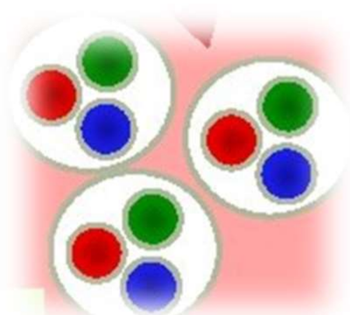
RG time

QCD

Lessons from dualities:



R.Brandenberger, C.Vafa
A.Tseytlin, C.Vafa
:



chiral symmetry
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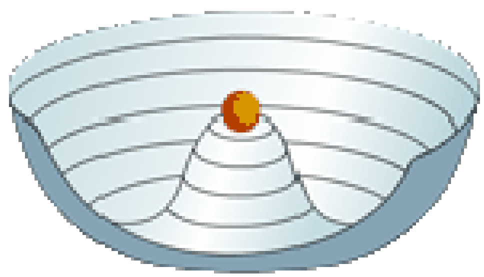

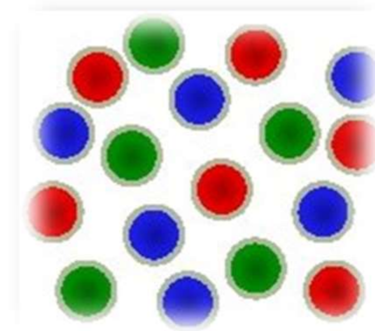

RG time

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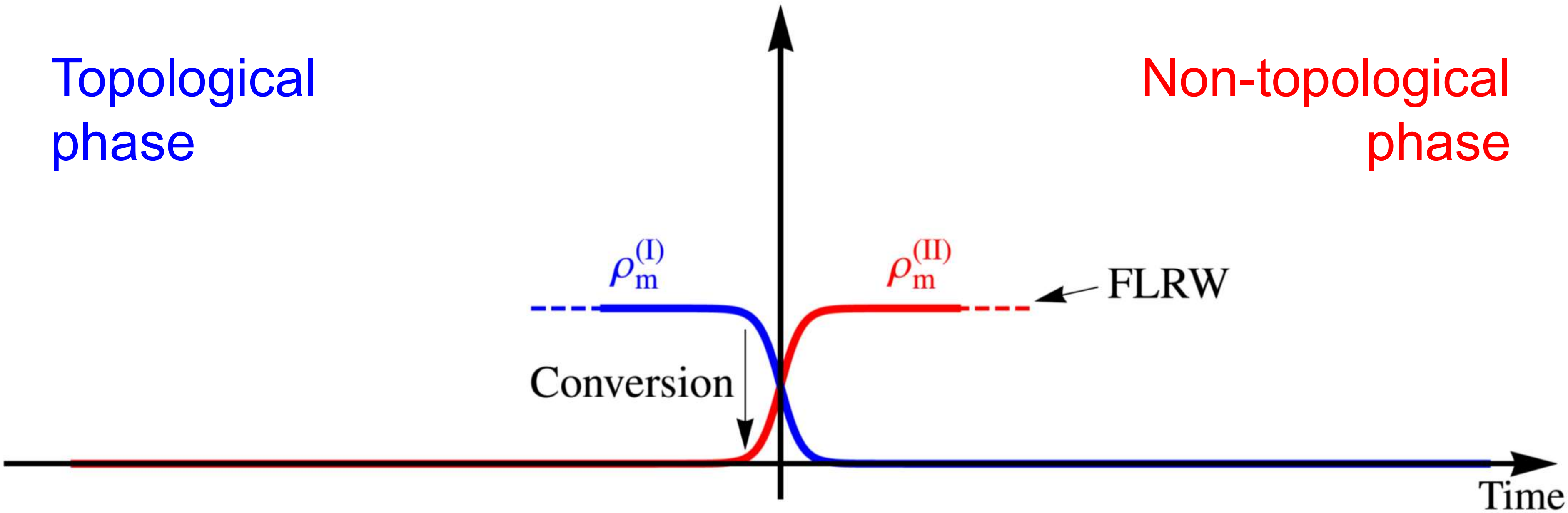
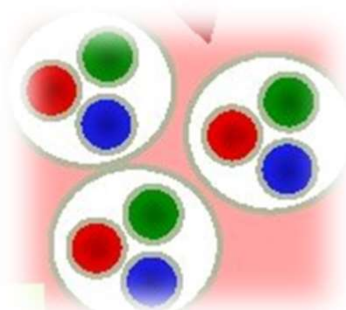
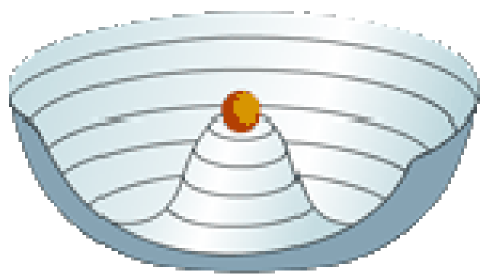


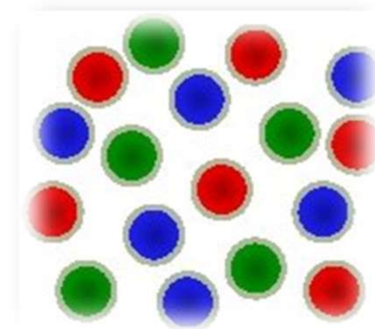
Breaking of topological invariance vs. breaking of chiral symmetry

E.Witten



chiral symmetry breaking





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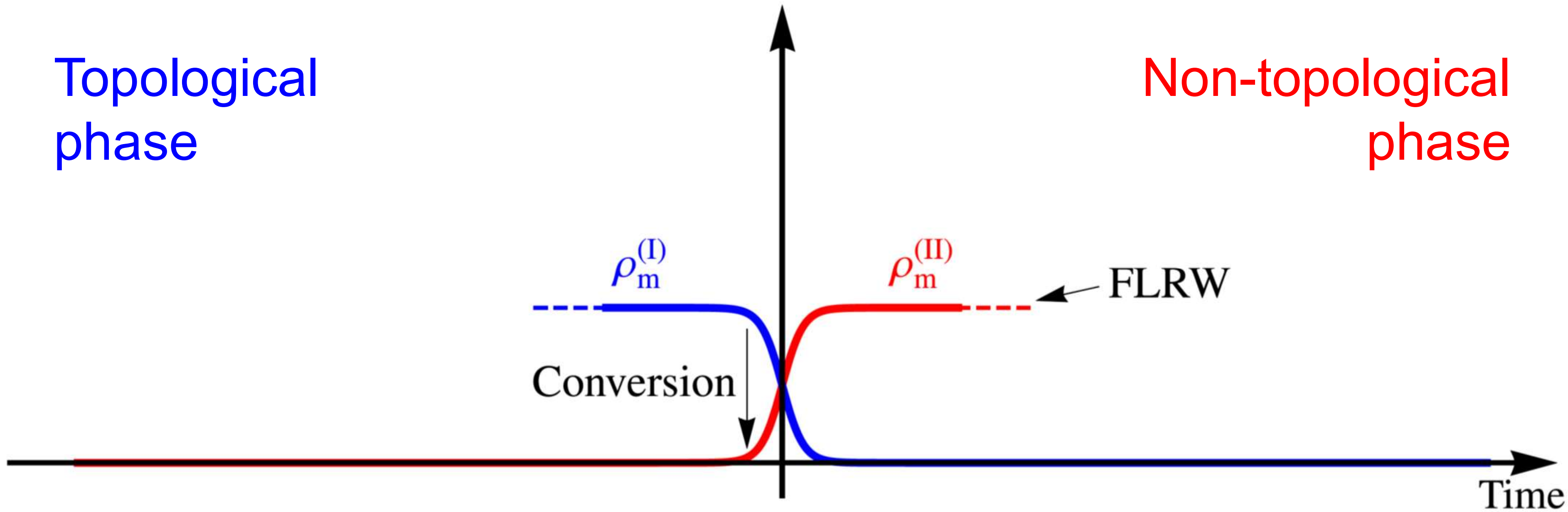
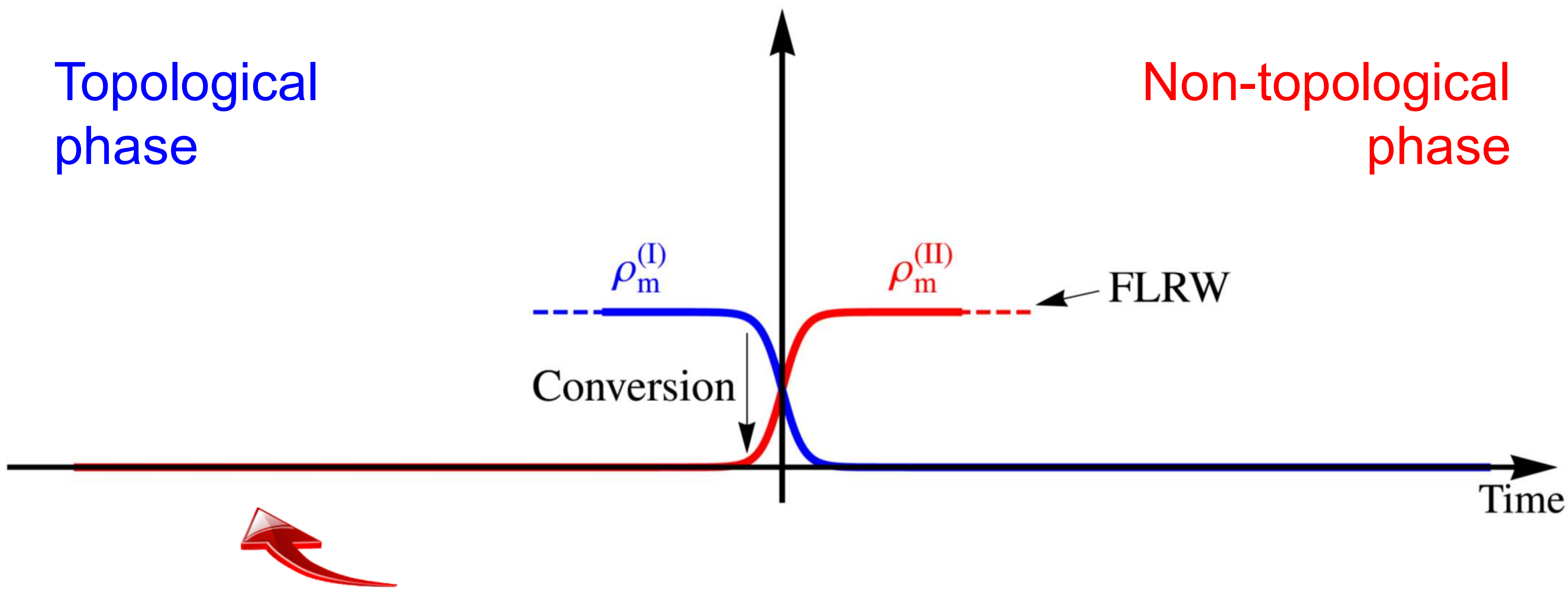


Period of accelerated expansion is replaced by a topological phase to address

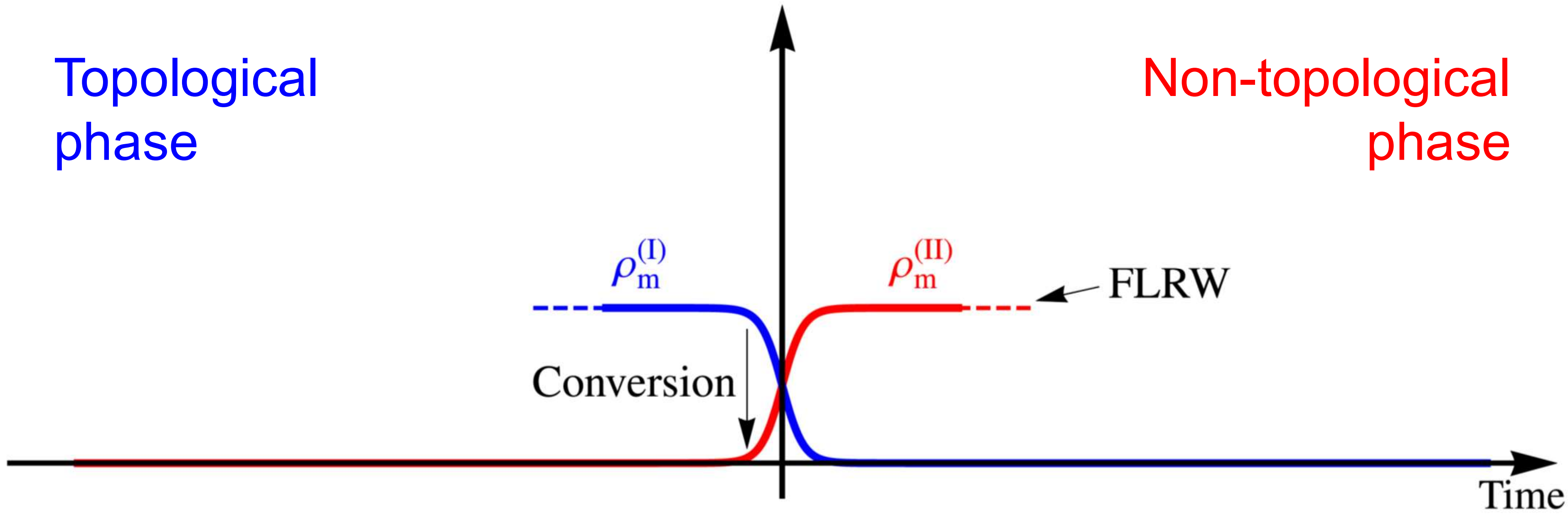
- Horizon problem (homogeneity, isotropy) $\partial_i \rho(x) = 0$
- Flatness problem $[D_i, D_j] = 0$
- Nearly scale-invariant power-spectrum

$$\langle \delta(x)\delta(y) \rangle \sim 10^{-10}|x-y|^{0.03}$$



$$\langle \mathcal{O}^{i_1}(x_1)\ldots\mathcal{O}^{i_n}(x_n)\rangle = A^{i_1,\ldots,i_n}$$

independent of positions $\partial_j A^{i_1,\ldots,i_n} = 0$



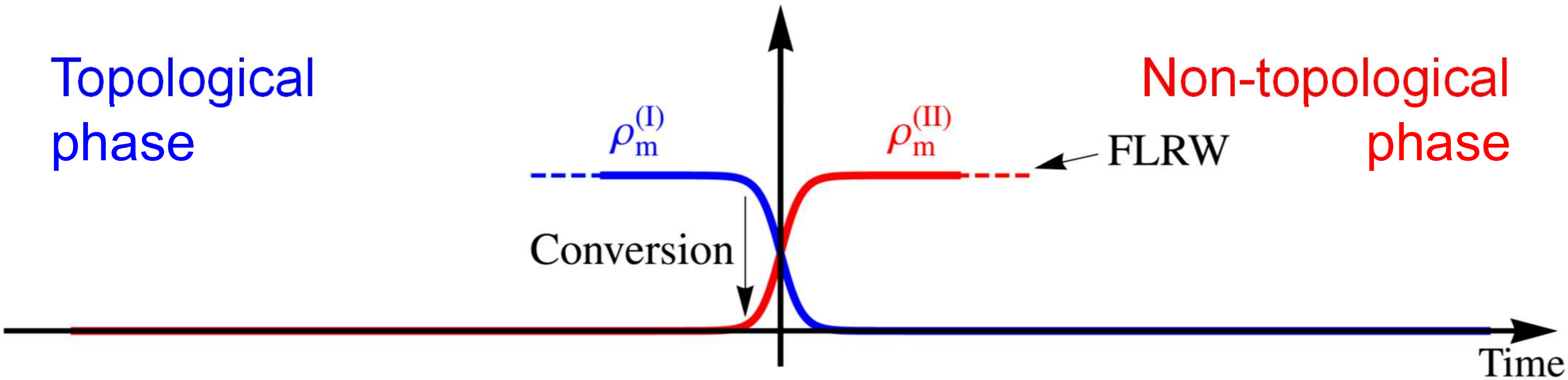
Fits in with the distance conjecture

talks by: Dieter Lust
Timo Weigand
Ralph Blumenhagen
Irene Valenzuela
Angel Uranga
Anthony Ashmore
Tom Rudelius
:

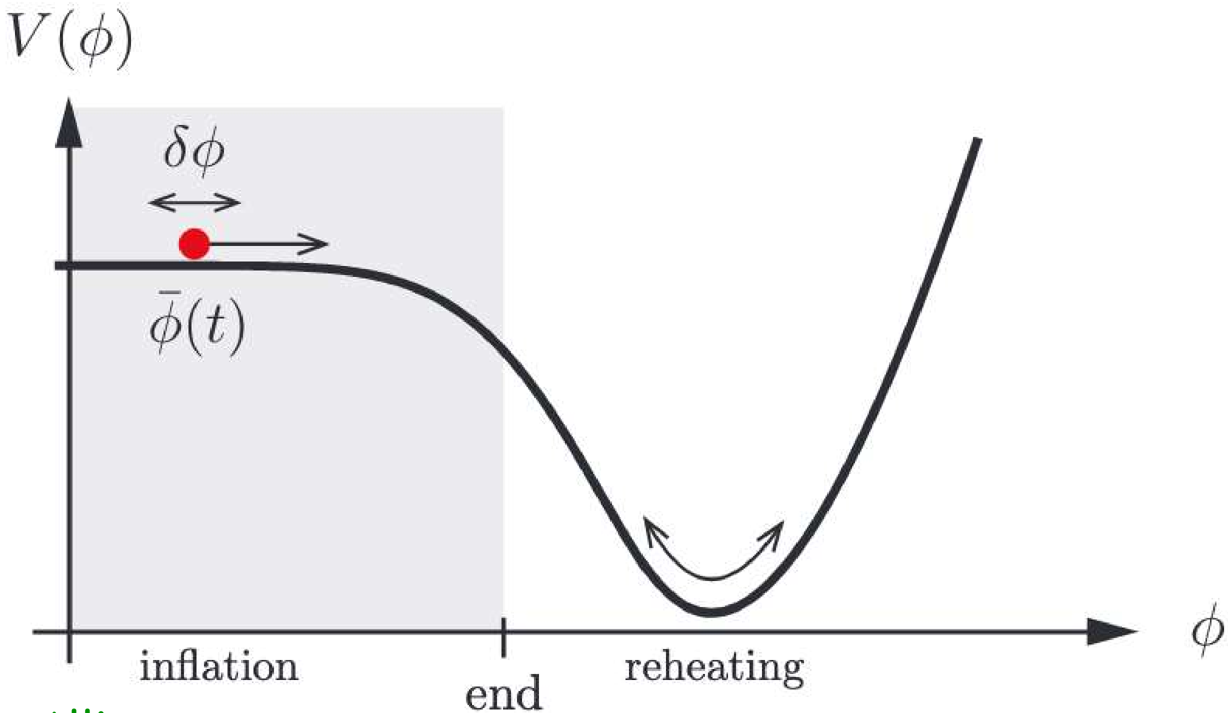
Falsifiable:

- no tensor mode fluctuations (no propagating graviton)
- O(1) non-Gaussianities

cf. A.Kehagias, A.Riotto



Reheating at the end of inflation $\rightsquigarrow$ phase transition (a lot of complicated physics)



D.Baumann, L.McAllister

Topological gravity:

$$S = \int d^4x \sqrt{g}\,(W_+)^2 + \ldots$$

E.Witten

unitary, BRST, and scale-invariant

field	ghost number	$[Q, \text{field}\}$
$C_{A\dot{A}}$	2	$\psi_{AB,\dot{A}\dot{B}}C^{B\dot{B}}$
$\psi_{AB,\dot{A}\dot{B}}$	1	$-\frac{i}{4}(e^{\alpha}_{A\dot{A}}D_\alpha C_{B\dot{B}} + e^{\alpha}_{B\dot{A}}D_\alpha C_{A\dot{B}} + e^{\alpha}_{A\dot{B}}D_\alpha C_{B\dot{A}} + e^{\alpha}_{B\dot{B}}D_\alpha C_{A\dot{A}})$
$e_{\alpha A\dot{A}}$	0	$e^{B\dot{B}}_{\alpha}\psi_{AB,\dot{A}\dot{B}}$
W_{ABCD}	0	$\frac{1}{6}(\psi_{AB,}{}^{\dot{A}\dot{B}}R_{CD,\dot{A}\dot{B}} - e^{\alpha}_{C\dot{C}}e^{\beta}_{D\dot{D}}D_\alpha D_\beta \psi_{AB,}{}^{\dot{C}\dot{D}})$ $+\ 5$ permutations of A, B, C, D
χ_{ABCD}	-1	$-iW_{ABCD}$
$\lambda_{A\dot{A}}$	-1	$-iC^{\alpha}D_\alpha B_{A\dot{A}} +$ "$(\psi\psi + eDC)B$" $- \frac{i}{4}B_{A\dot{A}}e^{\beta}_{X\dot{X}}D_\beta C^{X\dot{X}}$
$B_{A\dot{A}}$	-2	$\lambda_{A\dot{A}}$

Topological gravity:

$$S = \int d^4x \sqrt{g}\, (W_+)^2 + \dots$$

E.Witten

unitary, BRST, and scale-invariant

- Einstein-Hilbert term not generated

- Conformal anomaly at the quantum level

S_{anomaly}

- Witten adds a massless BRST singlet to produce non-degenerate kinetic terms

Topological gravity:

E.Witten

$$S = \int d^4x \sqrt{g}\,(W_+)^2 + \ldots$$

Critical points: "gravitational instantons"

$$W_+ \;=\; 0$$

self-dual (a.k.a. conformally half-flat) metrics

Natural to assume that conformal factor depends only on time (shared by the two phases)

$$\Rightarrow \quad ds^2 = -dt^2 + a^2(t)\left[\frac{dr^2}{(1-kr^2)} + r^2 d\Omega^2\right] \quad \text{with } k = 0$$

The tilt is due to the Weyl anomaly:

$$\langle T_\mu{}^\mu \rangle = \frac{1}{16\pi^2}\left(cW^2 - a \cdot \mathrm{Euler}\right)$$

D.Capper, M.Duff
E.Fradkin, A.Tseytlin
Z.Komargodski, A.Schwimmer
:

$$S_{\mathrm{anomaly}} = \frac{1}{16\pi^2}\int \Big[-\tau\left(cW^2 - aE_4\right)$$

$$+ a\left(4(R^{\mu\nu} - \frac{1}{2}g^{\mu\nu}R)\partial_\mu\tau\partial_\nu\tau - 4(\partial\tau)^2\Box\tau + 2(\partial\tau)^4\right)\Big]$$

dilatation mode (cf. gauge-invariant scalar perturbation in the FLRW phase)

cf. C.Cheung, P.Creminelli, A.Fitzpatrick, J.Kaplan, L.Senatore

$$\Delta^2(k) = \frac{k^3}{2\pi^2}\langle \tau(\vec{k})\tau(-\vec{k})\rangle \simeq \frac{1}{a}\left(\frac{k}{k_0}\right)^{-cg^2/16\pi^2}$$

Primordial power-spectrum and the spectral index:

$$\Delta^2(k) = \frac{k^3}{2\pi^2}\langle\tau(\vec{k})\tau(-\vec{k})\rangle \simeq \frac{1}{a}\left(\frac{k}{k_0}\right)^{-cg^2/16\pi^2}$$

PLANCK data: $a \sim c \sim 10^{10}$ cf. D.Hofman, J.Maldacena

$cg^2/16\pi^2 \simeq 0.03$ ➡ $g \sim 10^{-5}$

cf. the eta-problem

Unitarity ($c > 0$) ➡ red tilt of the spectrum

Future directions:

- Exotic relic problem? (monopoles)
- Realizations of the topological scenario?
- String models of topological gravity / cosmology?
- Other topological gravity theories?
- Brane world realization?
- Celestial dual for topological gravity?
- "Spontaneous breaking" of topological invariance? (initial conditions for FLRW cosmology)

G.Horowitz
R.Myers
A.Nakamichi, A.Sugamoto, I.Oda
H.Kunitomo
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