Topological Gravity as the Early Phase of our Universe

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String Pheno Seminar

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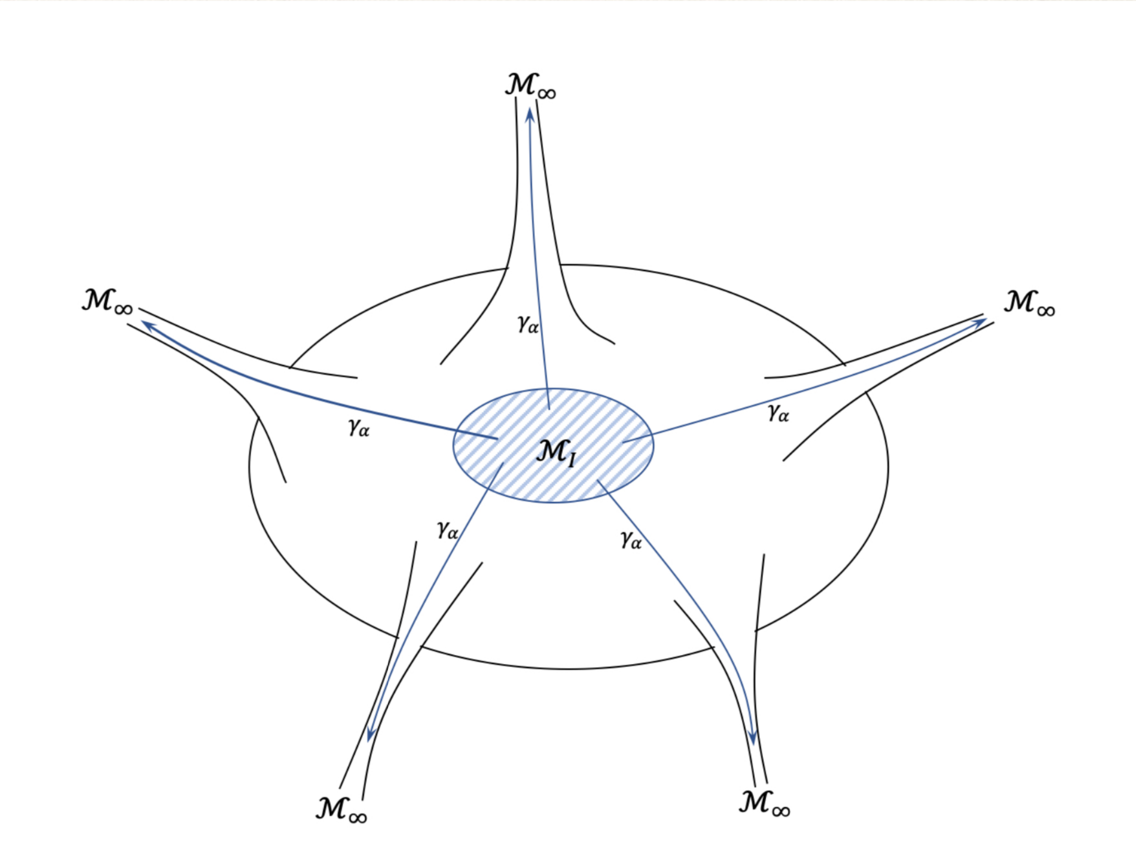
Based on arXiv: 2009.10077 [hep-th]
with Agrawal, Gukov and Vafa

Outline

- Motivation
  - Dualities
  - Observations
  - String Gas Cosmology
- Topological Scenario
- Phenomenology: comparison with inflation
- An Analogy with particle physics

Motivation: Dualities

- Ubiquitous in string theory
- Essential when parameters are taken to extreme limits
- No effective theory is valid in all of parameter space
- New light modes appear in extreme limits (e.g. distance conjecture)



[Ooguri, Vafa ’06]

Early Universe is an extreme limit

$$T \to \infty, \quad a \to 0$$

Therefore, it is natural to expect that there is a dual description for the early universe.

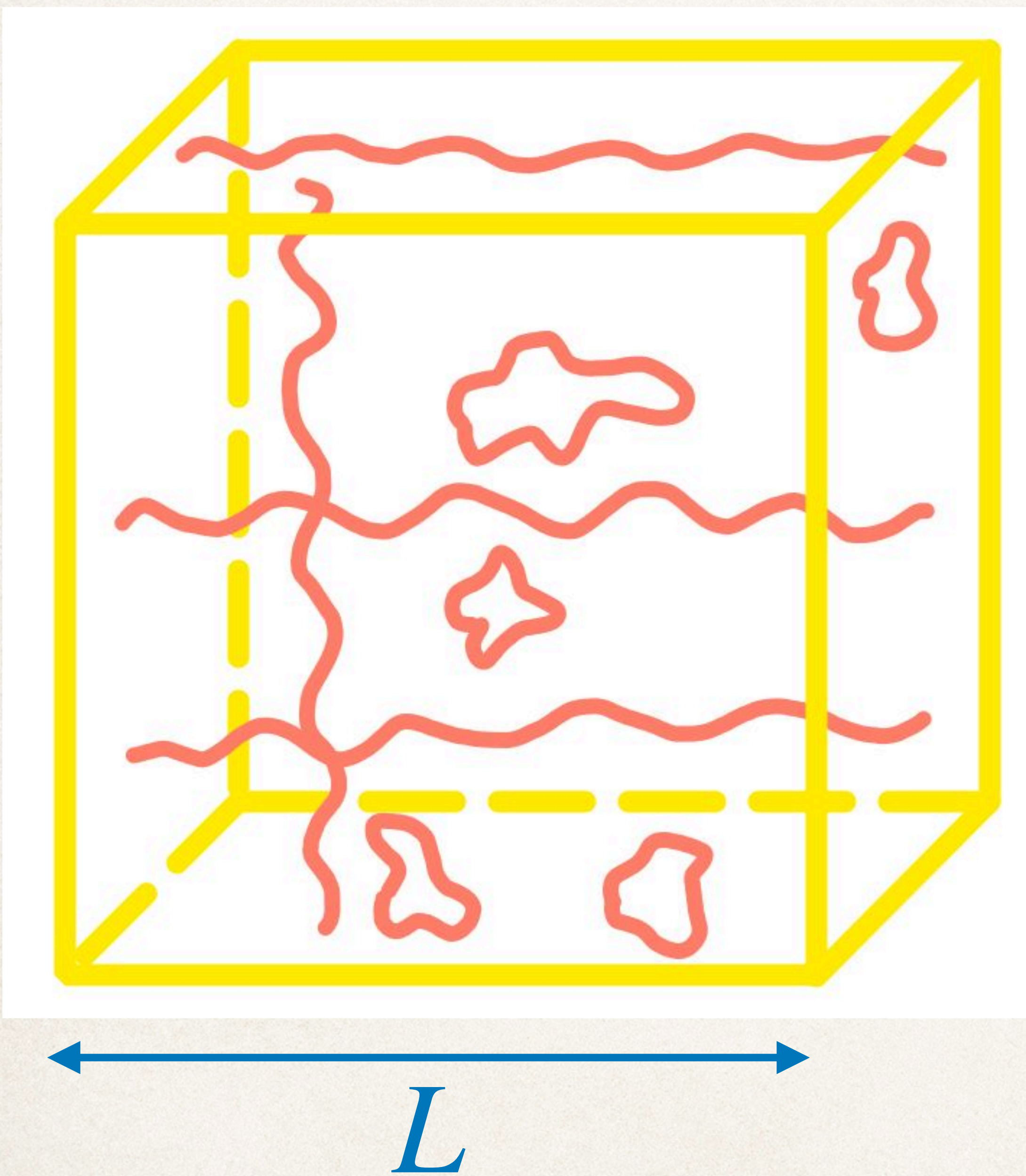
Observations: Cosmological puzzles

- Can be rephrased as certain vanishing statements:
    - Horizon problem (homogeneity): $\partial_i \rho(x) = 0$
    - Flatness: $[D_i, D_j] = 0$
    - Nearly scale invariant fluctuations:

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

- Hint at an early universe that is independent of position

Motivation: String gas cosmology



[Brandenberger, Vafa ’89]
[Tseytlin, Vafa ’92] …

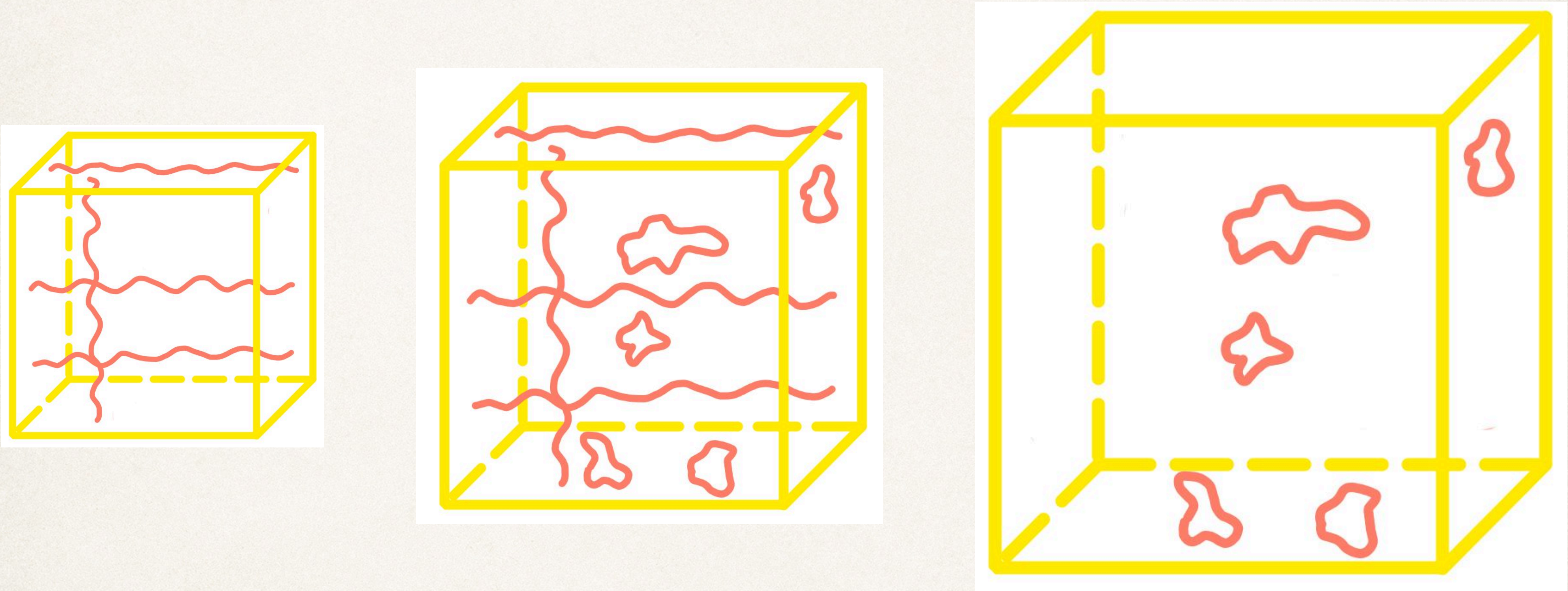
Motivated by T-duality:

$$p = n/L,\ w = mL$$

$$L \leftrightarrow 1/L,\ n \leftrightarrow m$$

$$|\tilde{x}\rangle = \sum_w e^{iw\tilde{x}} |w\rangle, \qquad |x\rangle = \sum_p e^{ipx} |p\rangle$$

Motivation: String gas cosmology

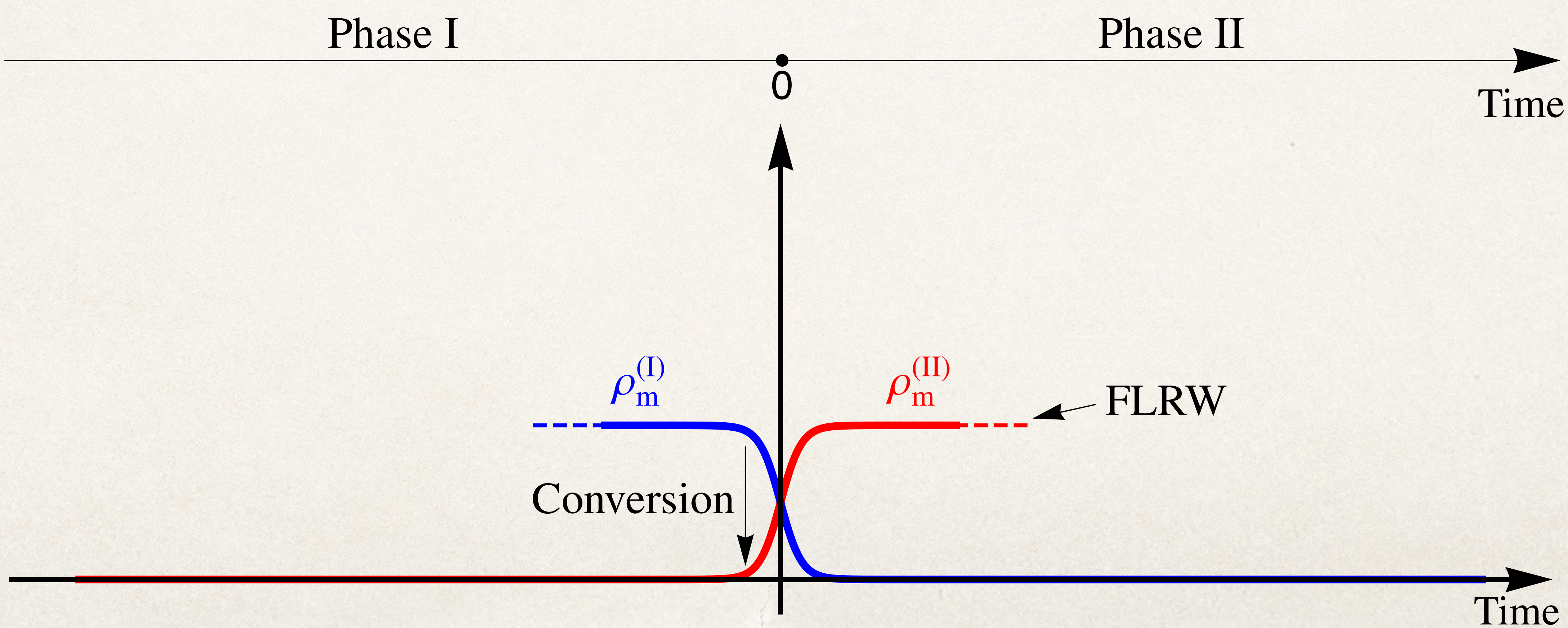


$$|\tilde{x}\rangle = \sum_w e^{iw\tilde{x}}|w\rangle, \qquad |x\rangle = \sum_p e^{ipx}|p\rangle$$

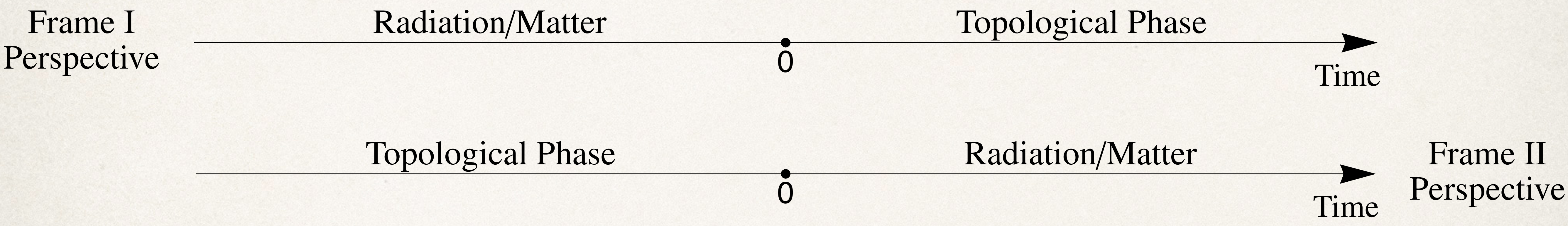
The early universe is x-independent (i.e. topological) from the point of view of the operators relevant today.

Duality in the Early Universe

- Proposal: this holds more generally than T-duality/SGC
- Suppose we have two phases/frames (call them I & II)
- We do not know the nature of phase I but we know it is topological from our perspective



Topological Theory



- Even gravity is topological since the graviton of phase I is different from the graviton of phase II

- Horizon problem (homogeneity) is automatically solved because the topological theory is not sensitive to positions

- For other aspects we need to know more about the topological phase

- Consider Witten’s 4d topological gravity as one realization

[Witten ’88]

Witten's 4d topological gravity

- Gravity action contains a scale-invariant term:

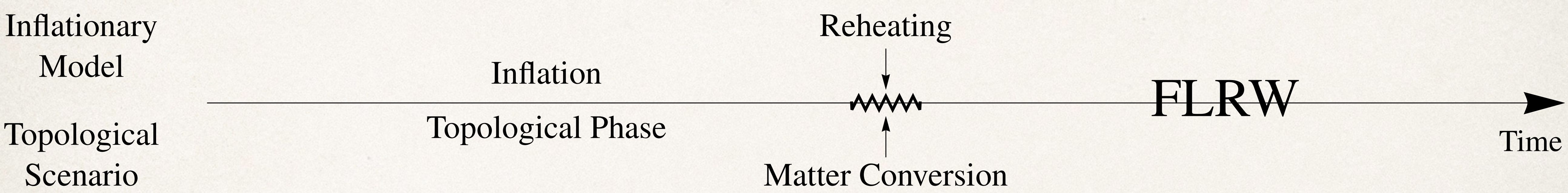
$$S \supset \int \frac{1}{g^2} W^2$$

- Backgrounds that preserve topological invariance have:

$$W = 0$$

- Additional sector that contains a BRST-invariant massless field Φ

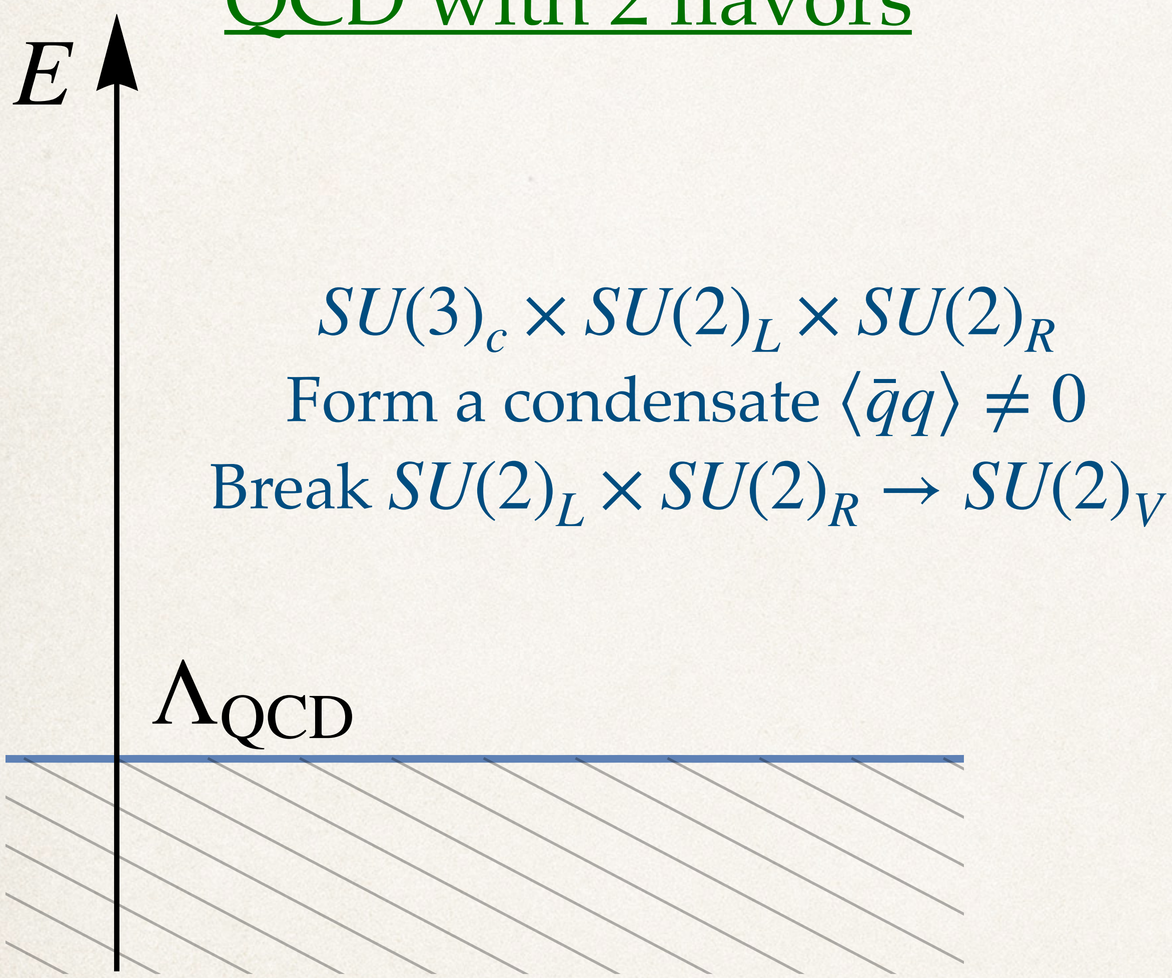
Phenomenology



	Inflation	Topological Scenario
Homogeneity/Isotropy/ Flatness	dS bkg	Topological phase
(Near) Scale-inv.	(quasi-)dS bkg	(Weakly-broken) Topological phase
Red Tilt	Decreasing Hubble parameter	Positivity of conformal anomaly coefficient c (due to unitarity)
Non-Gauss.	$O(\epsilon)$ in simple models*	$O(1)$ for four- and higher-point functions*
Tensor modes	Present due to massless graviton	Absent since graviton is not dynamical in topological phase

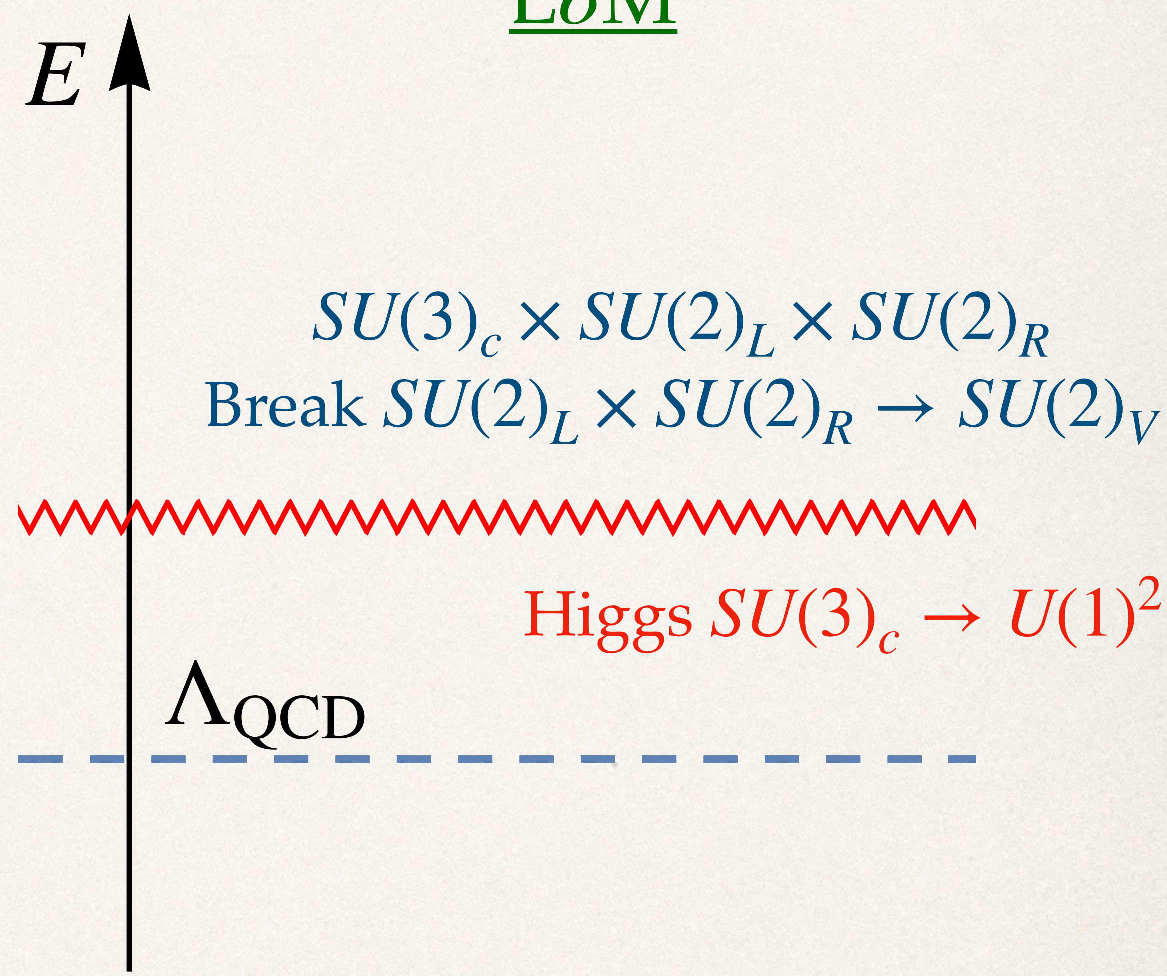
Analogy with QCD: Particle Physics

<u>QCD with 2 flavors</u>



Low energy spectrum contains pions
No spin-1 gauge bosons

<u>LσM</u>



Low energy spectrum contains pions
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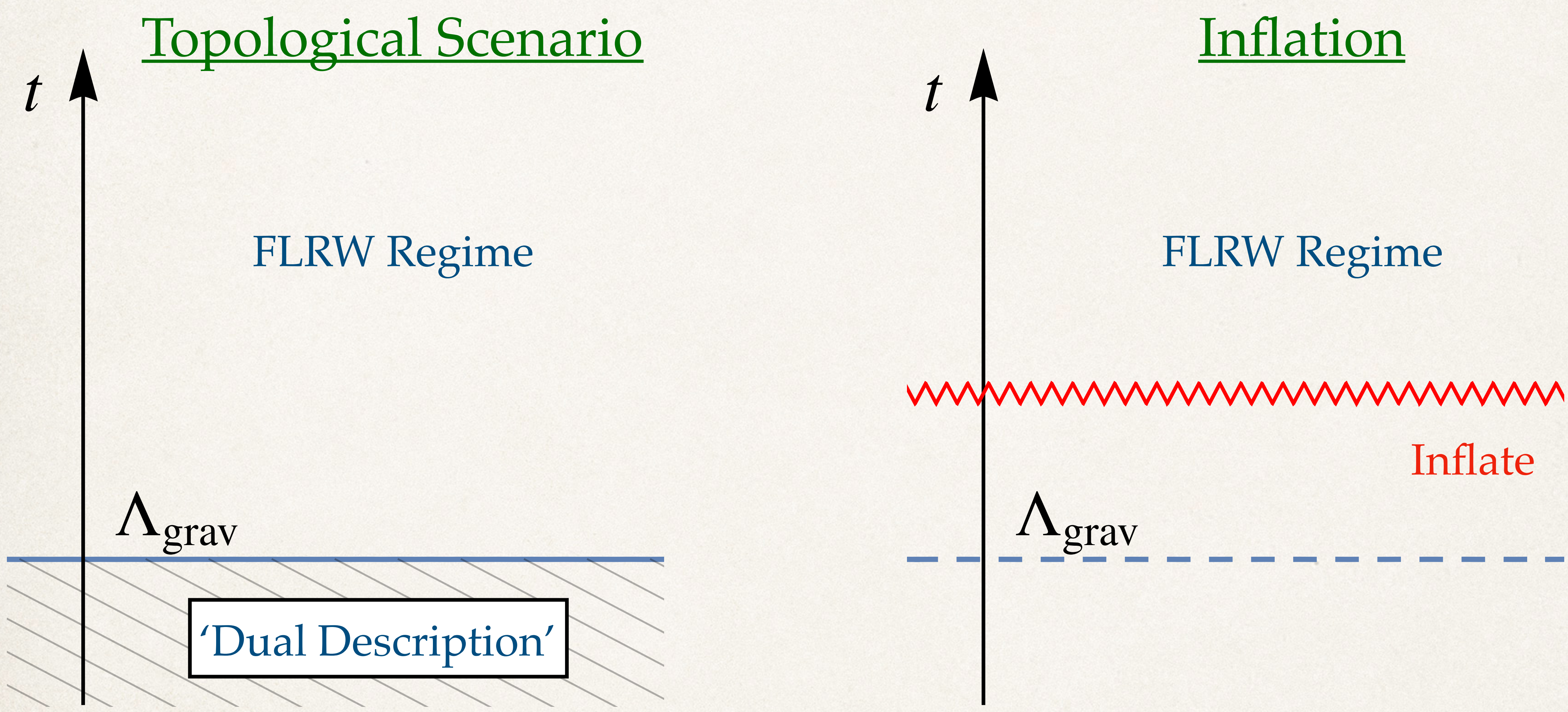
Analogy with QCD: Cosmology



Additional sector gives a scalar mode
No graviton (no tensor modes)

Inflaton gives scalar mode
Graviton present (tensor modes)

Symmetry breaking pattern dictates behavior of the scalar mode.
(cf. EFT of inflation)

[Cheung *et al.* '08]

Conclusions

- String theory dualities lead us to believe that the early universe is described by a dual theory
- Early universe looks topological from our perspective; in particular it is not sensitive to our position variable
- Study cosmology in Witten's 4d topological gravity as an example
- Future directions:
  - Other realizations of topological gravity in 4d
  - Deeper understanding of the breaking of topological invariance
  - Develop tools to systematically compute observables such as non-Gaussianities

Thank you!

Analogy: Scalar gravity

- Consider a spontaneously broken CFT ($\langle\phi\rangle = M$)
- Goldstone boson: the dilaton
- We can define a `metric' $g_{\mu\nu} \equiv \phi^2\eta_{\mu\nu}$ and write the dilaton action in generally covariant form:

$$S \sim \int d^4x\sqrt{-g}\left(M^2R + \mathcal{L}_m + \dots\right)$$

See e.g. [Sundrum '03] and references therein