Title: The World is Discrete

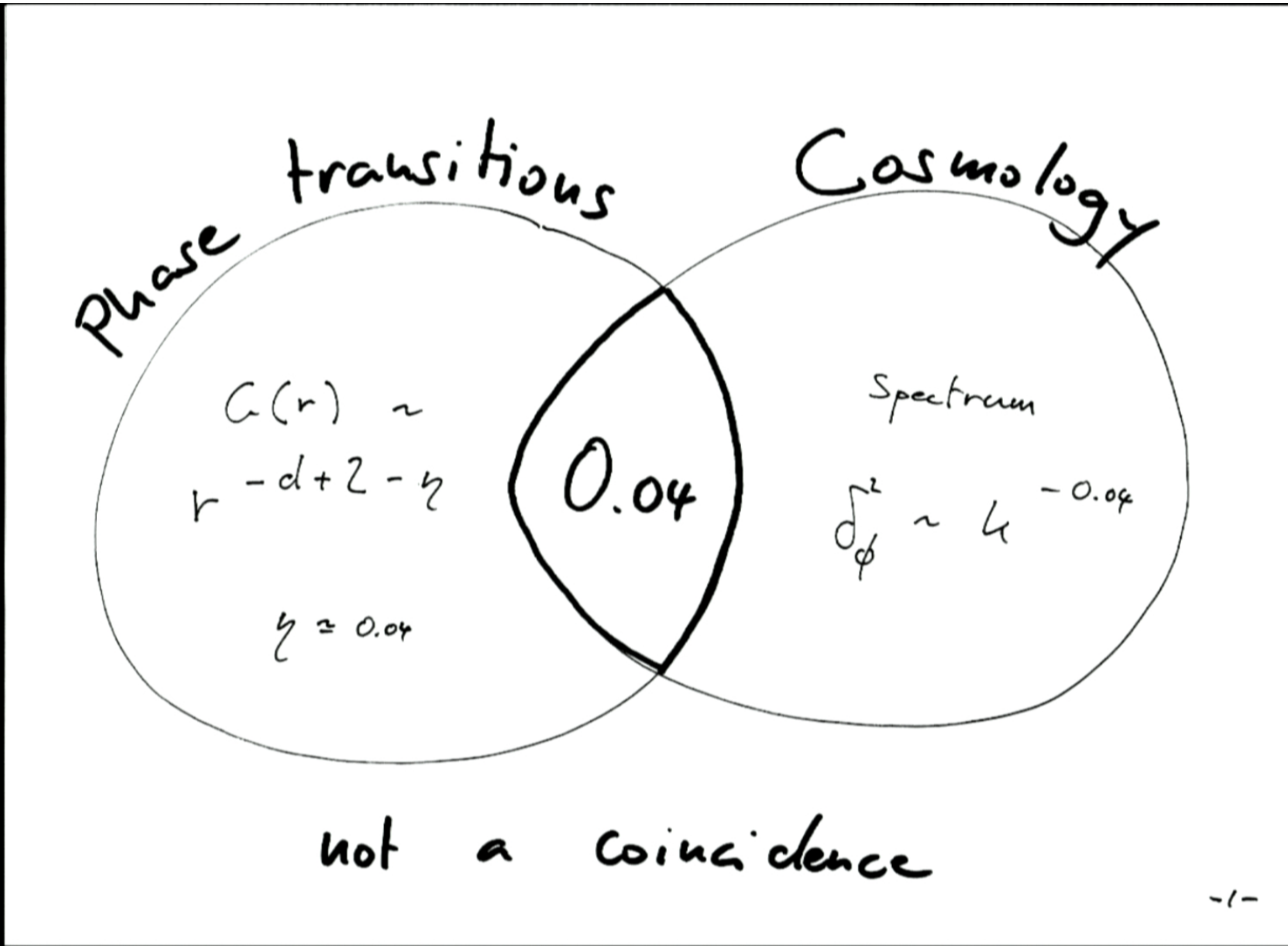
Date: Sep 19, 2013 02:30 PM

URL: http://pirsa.org/13090073

Abstract: We argue that the scale-free spectrum that is observed in the cosmic microwave background is the result of a phase transition in the early universe. The observed tilt of the spectrum, which has been measured to be 0.04, is shown to be equal to the anomalous scaling dimension of the correlation function. The phase transition replaces inflation as the mechanism that produces this spectrum. The tilt further indicates that there is a fundamental small length scale in nature that we have not yet observed in any other way.

The world is discrete

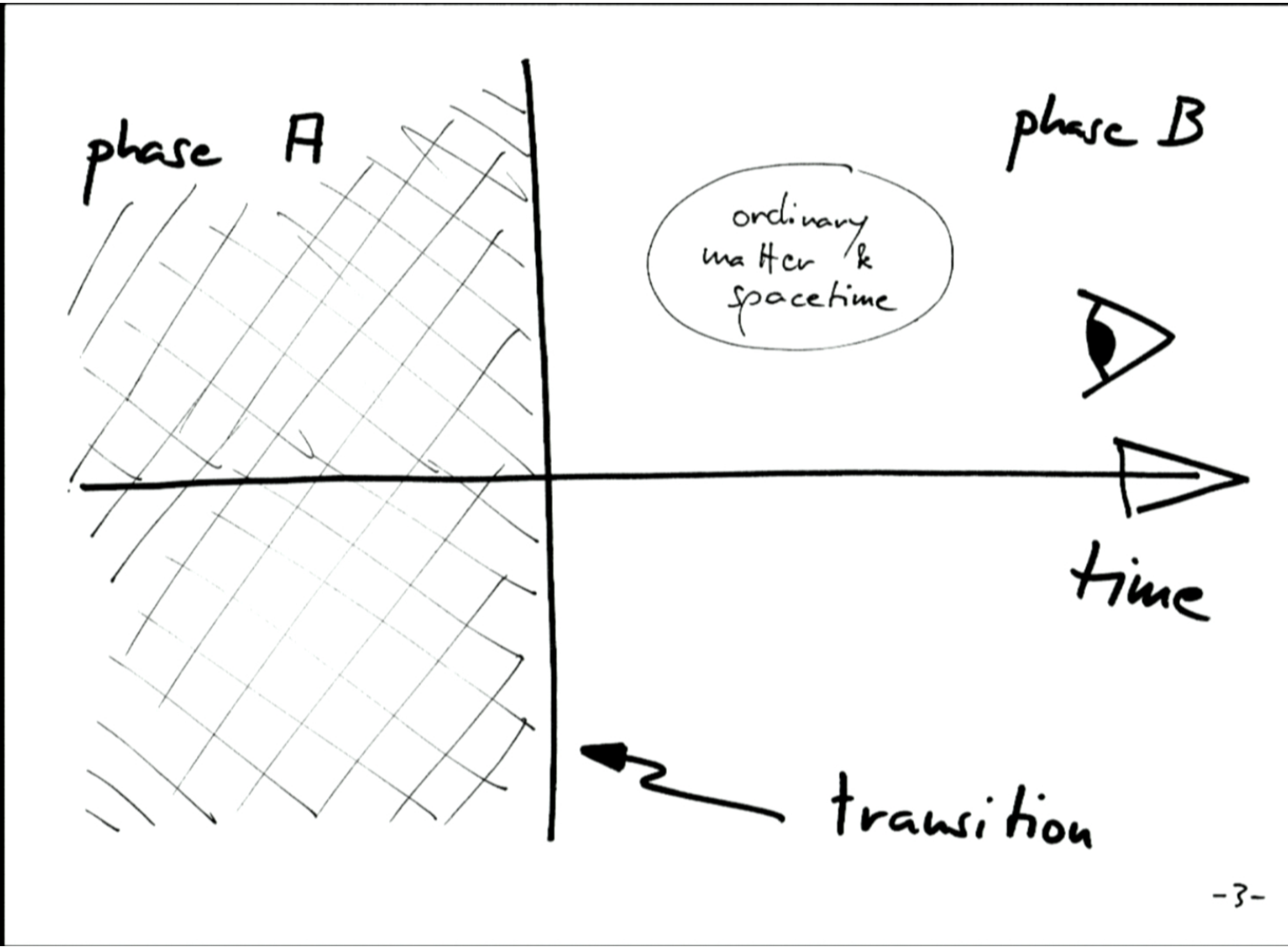
Olaf DREYER


Phase transitions
Cosmology
$G(r) \sim$
$r^{-d+2-\eta}$
$\eta \simeq 0.04$
0.04
Spectrum
$\delta_\phi^2 \sim k^{-0.04}$
not a coincidence
-1-

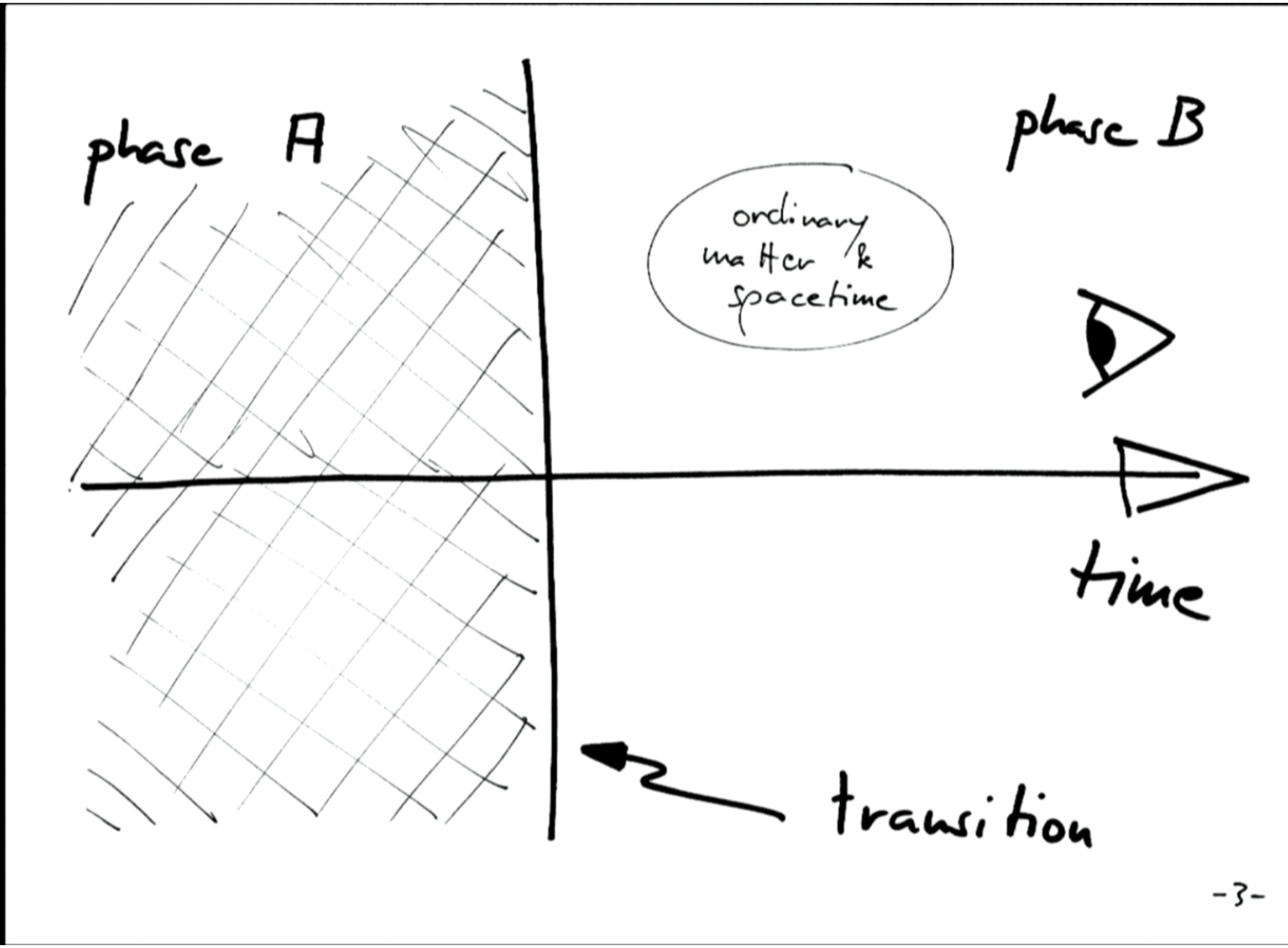
~~Inflation~~

Phase transition

-2-



phase A
phase B
ordinary
matter &
spacetime
time
transition
-3-


phase A
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-3-

The transition

(Zurek, Kibble)

$$\varepsilon = \frac{T - T_c}{T_c}$$

correlation length $\quad \xi \xrightarrow{\varepsilon \to 0} |\varepsilon|^{-\nu}$

relaxation time $\quad \tau \xrightarrow{\varepsilon \to 0} |\varepsilon|^{-\nu z}$

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The transition II

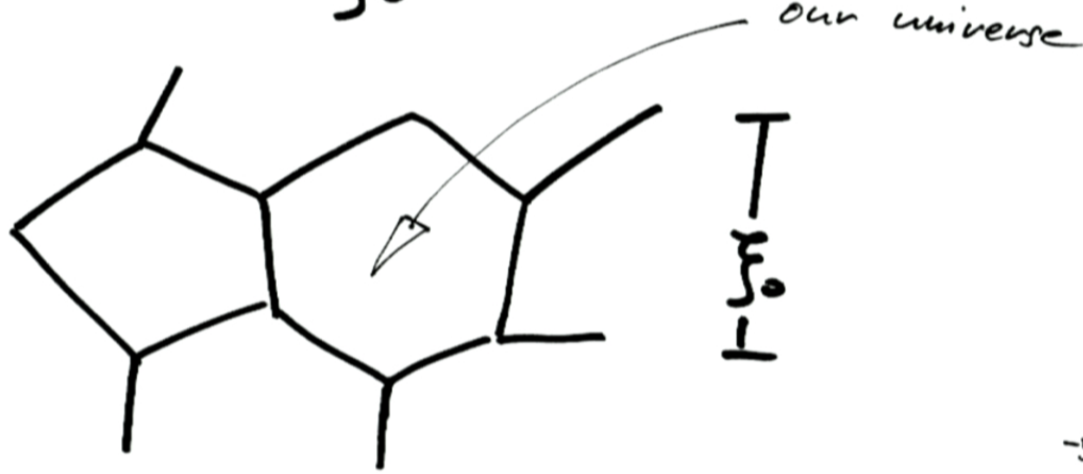
When

$$\dot{\varepsilon}/\varepsilon > J$$

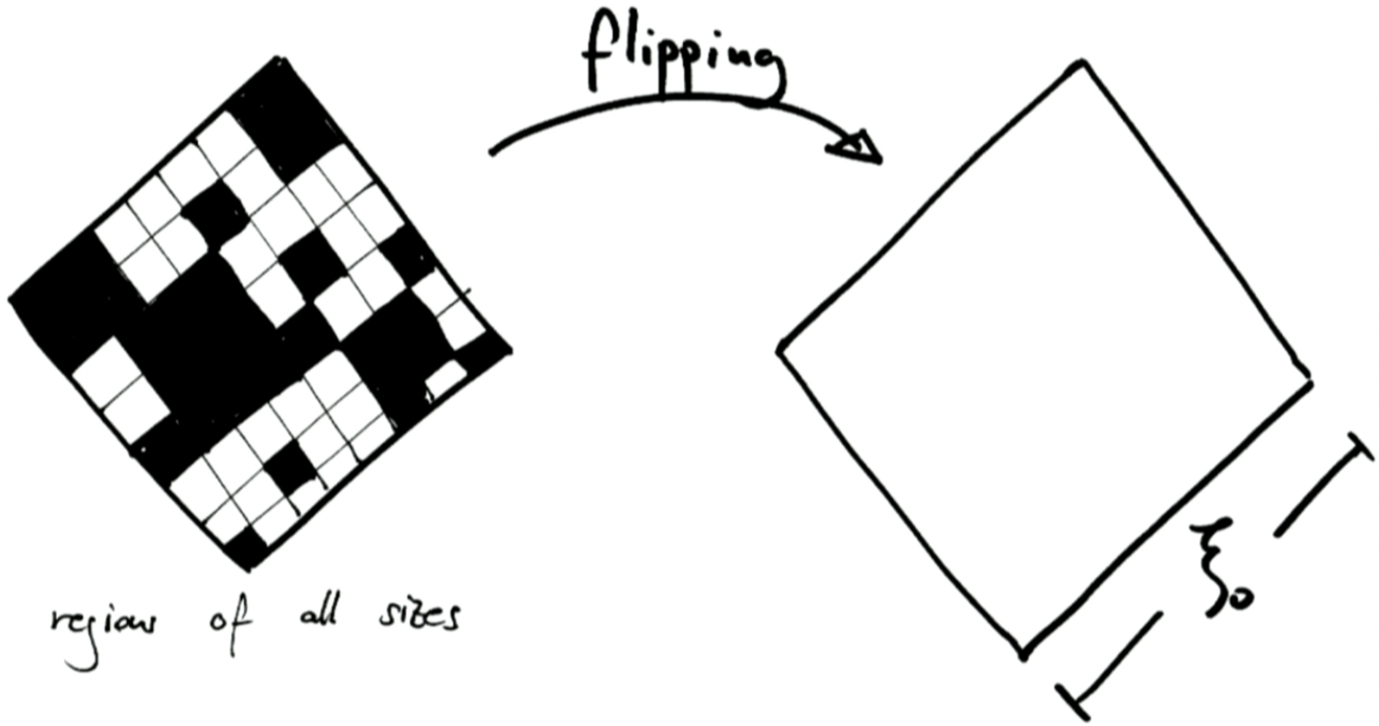
the evolution freezes. Correlation length

$$\xi_0$$

Result:



The crucial step:



Claim: This flipping gives the spectrum.

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The spectrum

$$\delta_\theta^2 = k^3 \lim_{V\to\infty} \frac{|\Theta_V(k)|^2}{V}$$

$$\Theta(x) = \sum_{i\in I} \Theta^i(x)$$

I = set of regions that need to flip.

$$|\Theta_V(k)|^2 = \sum_{i\in I} |\Theta_V^i(k)|^2$$

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The spectrum II

Let

$$V \nu(l) dl = $$ number of regions of size L with $l \le L \le l + dl$ in the volume V.

Then

$$\delta_\Theta^2 = k^3 \int dl \ \nu(l) \ \left| \Theta_v^{(l)}(k) \right|^2$$

$\nu(l)$: number of regions

$\Theta_v^{(l)}(k)$: contribution from one region

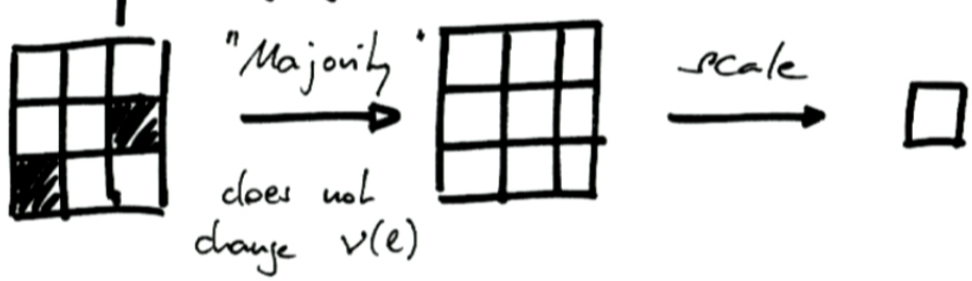
The number of regions $\nu(\ell)$

For a critical configuration $\{s\}$

$$\nu(\ell)\left[R\{s\}\right] = \nu(\ell)\left[\{s\}\right]$$

R ↑ renormalization group transformation

Action of R



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Scaling

$$\nu(\ell)[R\{s\}] = \lambda^d \lambda \; \nu(\lambda \ell) \; [\{s\}]$$

$$= \nu(\ell)[\{s\}]$$

$$\boxed{\nu(\ell) \sim \ell^{-d-1}}$$

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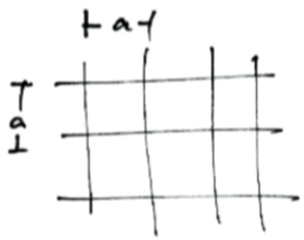
The effect of a small length scale

$$C(r) \sim r^{-d+2-\eta}$$

slightly **more** correlation at small length scales

Consistent:
more correlation
⇕
fewer regions



perfect correlation for scales smaller than a

$$V(\ell) \sim \ell^{-d-1+\eta}$$

slightly **fewer** regions of small size
(no regions smaller than a)

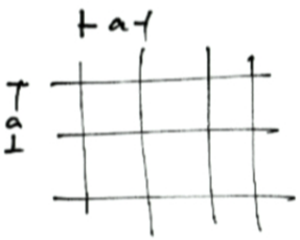
-11-

The effect of a small length scale

$$C(r) \sim r^{-d+2-\eta}$$

↖ slightly more correlation at small length scales

Consistent: more correlation ⇕ fewer regions



← perfect correlation for scales smaller than a

$$V(\ell) \sim \ell^{-d-1+\eta}$$

↖ slightly fewer regions of small size
(no regions smaller than a)

-11-

Contribution from one region

Parseval's identity

$$\ell^3 |\Theta^{(\ell)}(x)|^2 = \ell^3 \cdot \text{const.}$$

$$= \frac{1}{\ell^3} |\Theta^{(\ell)}(k)|^2$$

$$\Rightarrow \quad |\Theta^{(\ell)}(k)|^2 \sim \begin{cases} \ell^6 & k < \frac{1}{\ell} \\ 0 & \text{else} \end{cases}$$

Result

$$\delta_\Theta^2 \sim k^3 \int_0^{1/k} dl\, l^{-4+\eta}\, l^6$$

$$\sim k^3 \left(\frac{1}{k}\right)^{3+\eta}$$

$$\sim k^{-\eta}$$

Identify Θ and ϕ

Main points:

1. Our world originated in a phase transition.

2. There is a small length scale.

3. Gravity is emergent.

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1. Our world originated in a phase transition.

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Remarks on inflation

1. We do not need a new particle

2. No fine-tuned potential to get 0.04

3. Don't have to think about

"Everything that can happen has happened an infinite number of times"
(Guth)

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Remarks on Quantum Gravity

1. Numerology

2. This is the

fuzzy quantum stuff
→ smooth spacetime

transition (LQG, spinfoams, CDT, GS, ...)

→ 3. Real emergence ←

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Discreteness

The CMB is showing us a small length scale!

(Planck scale?)

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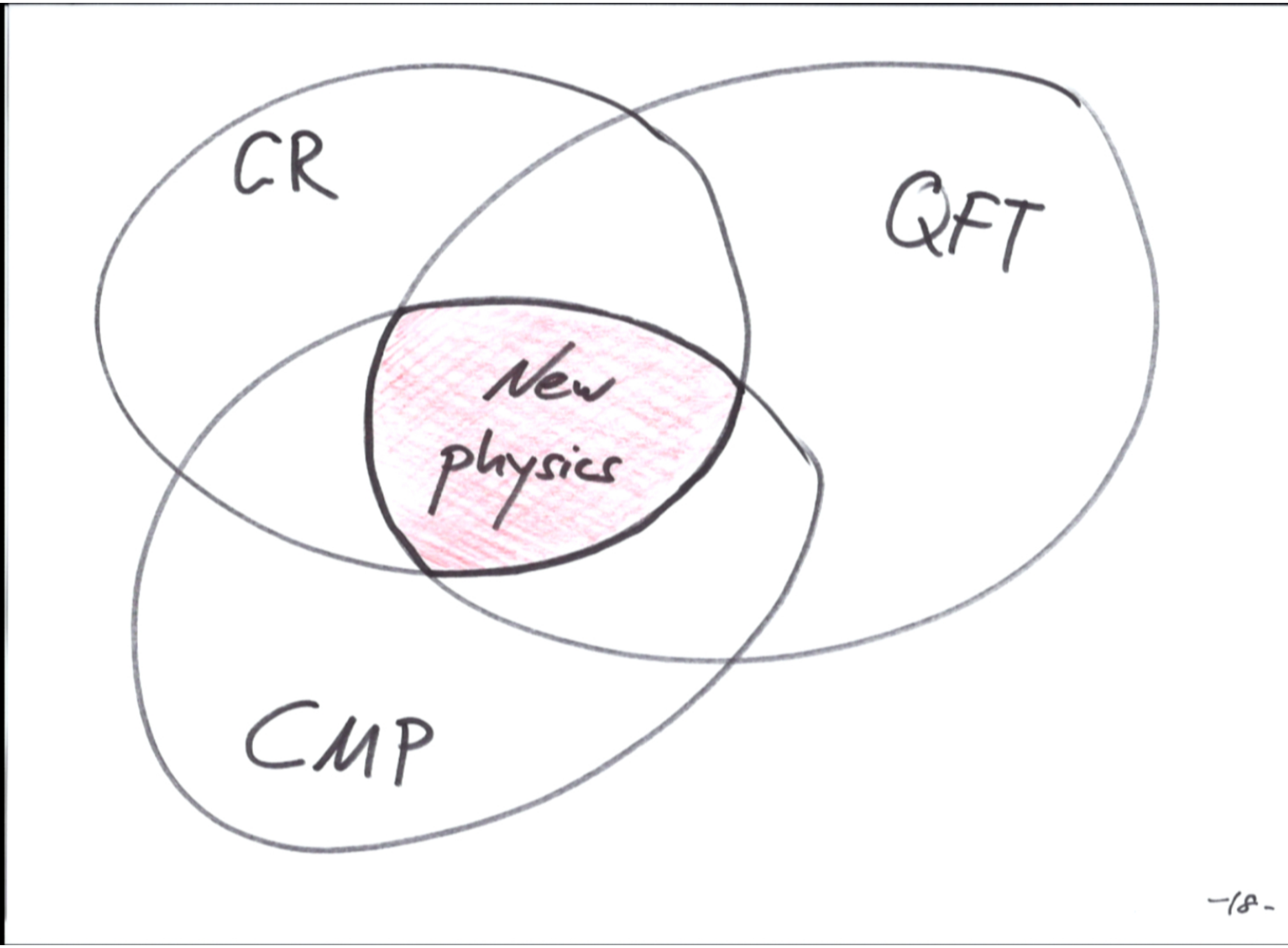
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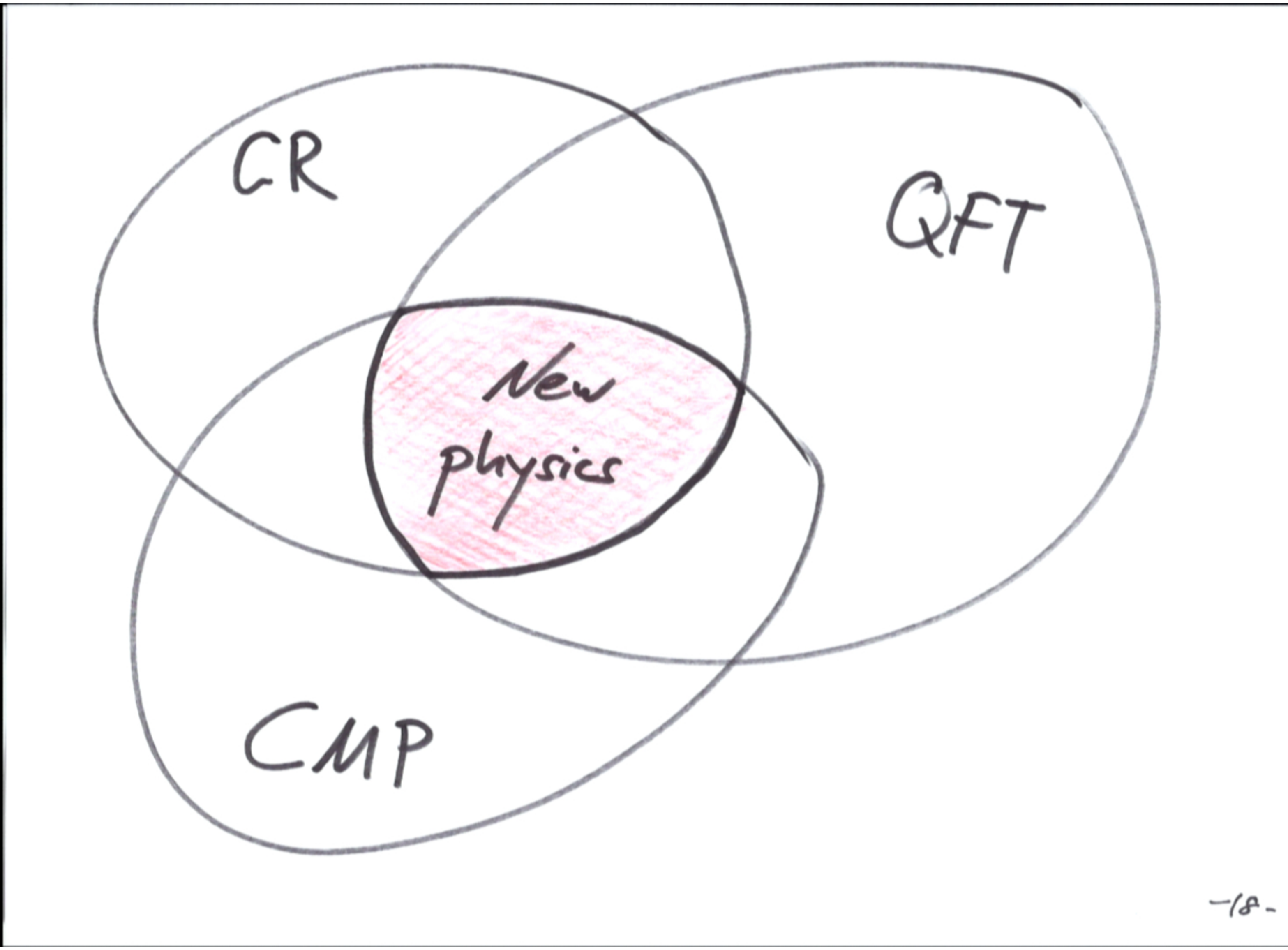
QFT
New physics
CMP
-18-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-18-