Holographic Cosmology

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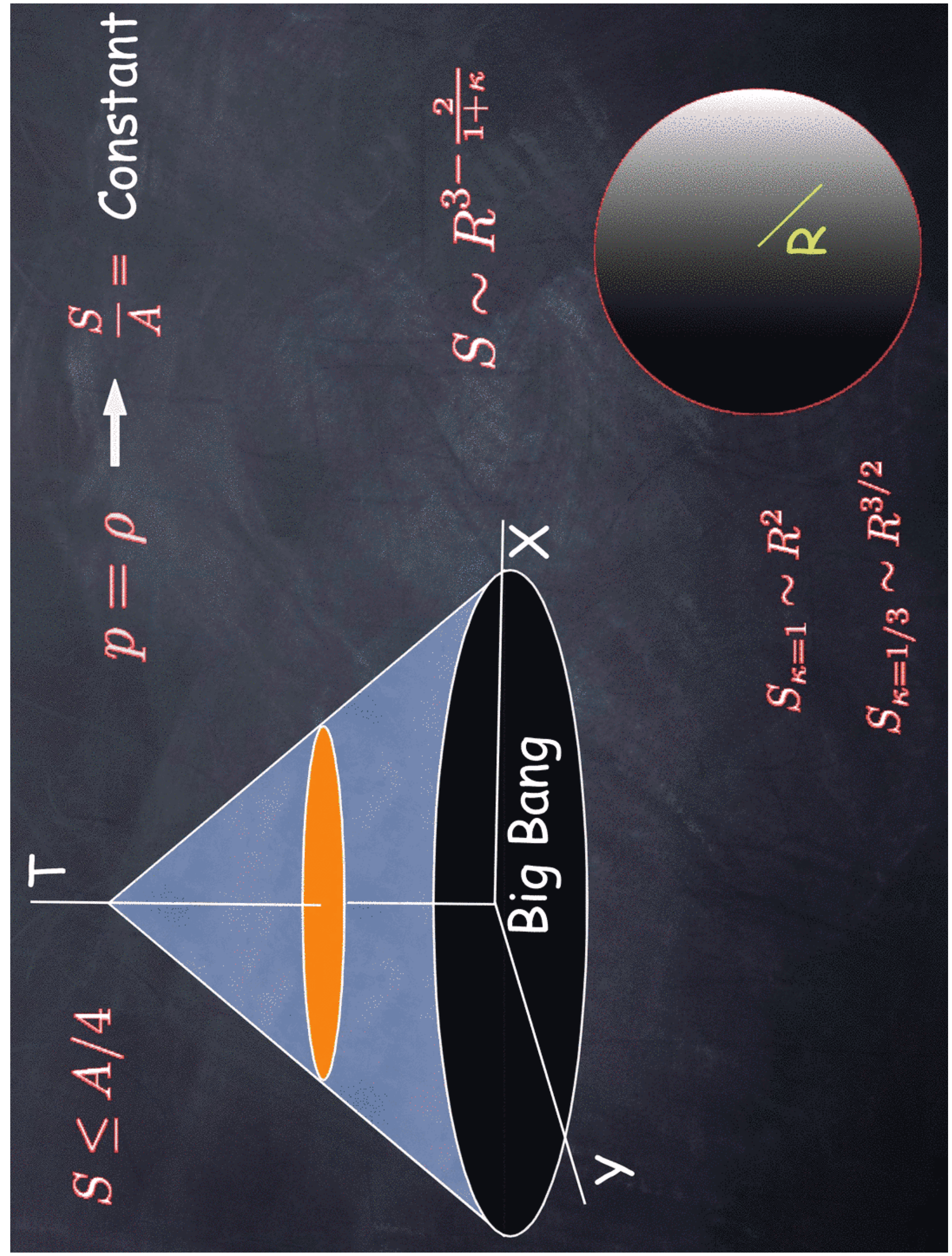

$S \leq A/4$
$p = \rho$ → $\frac{S}{A}$ = Constant
$S \sim R^{3-\frac{2}{1+\kappa}}$
R
T
X
Y
Big Bang
$S_{\kappa=1} \sim R^2$
$S_{\kappa=1/3} \sim R^{3/2}$

The thermodynamics of the equation of state: $p = \rho$

$$dE = TdS - pdV$$

locally:

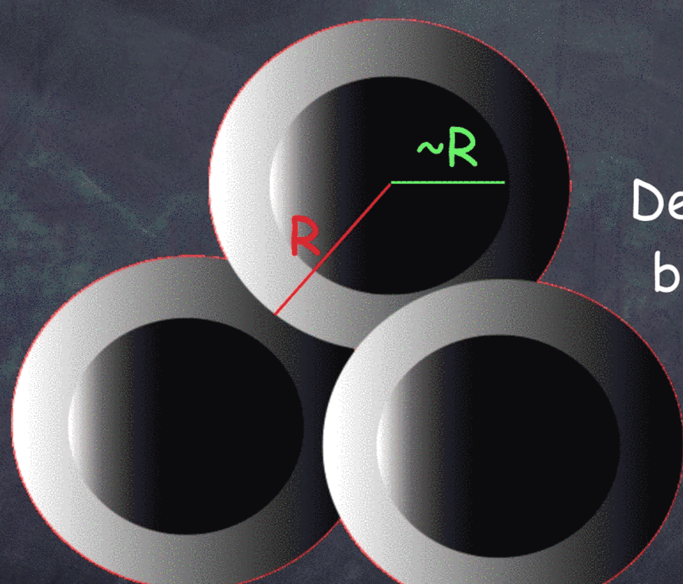
$$p + \rho = T\sigma$$

$$d\rho = Td\sigma$$

$$\sigma \sim \rho^{1/2}$$

This is the statistical mechanics of a 1+1 dim. CFT (not a homogeneous scalar field)

Mechanical picture of $p = \rho$



Dense gas of black holes

$$\sigma \sim \frac{R^{D-2}}{R^{D-1}} \sim R^{-1} \qquad \rho \sim \frac{R^{D-3}}{R^{D-1}} \sim R^{-2}$$

$$\sigma \sim \rho^{1/2}$$

The storage of information requires space

The merger of black holes leads to bigger black holes

$\longrightarrow$ pressure in the dense gas of black holes

Most entropic and robust initial state

The dense $p = \rho$ gas of black holes

has a conformal Killing symmetry:

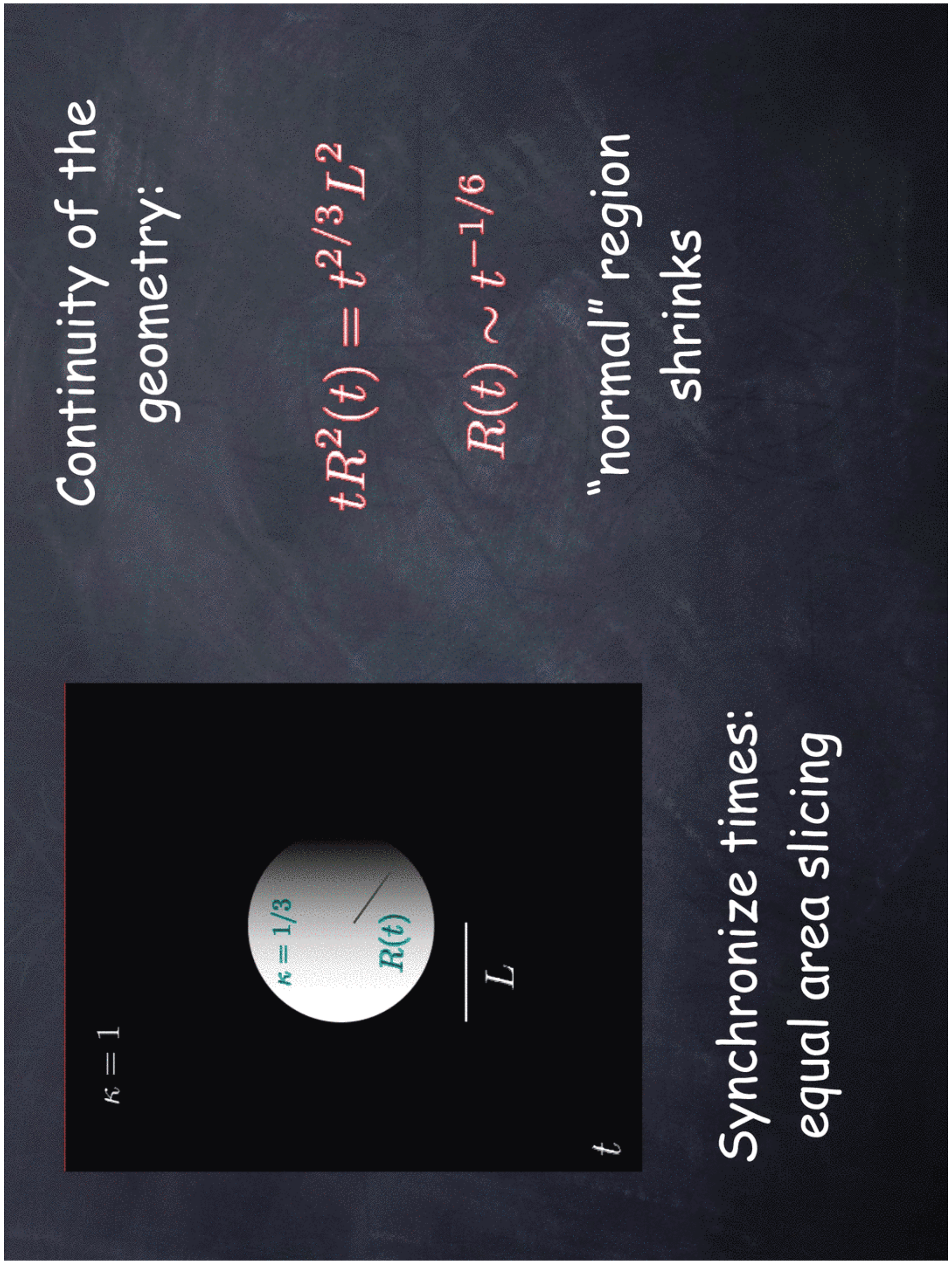
$$ds^2 = dt^2 - t^{2/3} dx_i dx^i$$

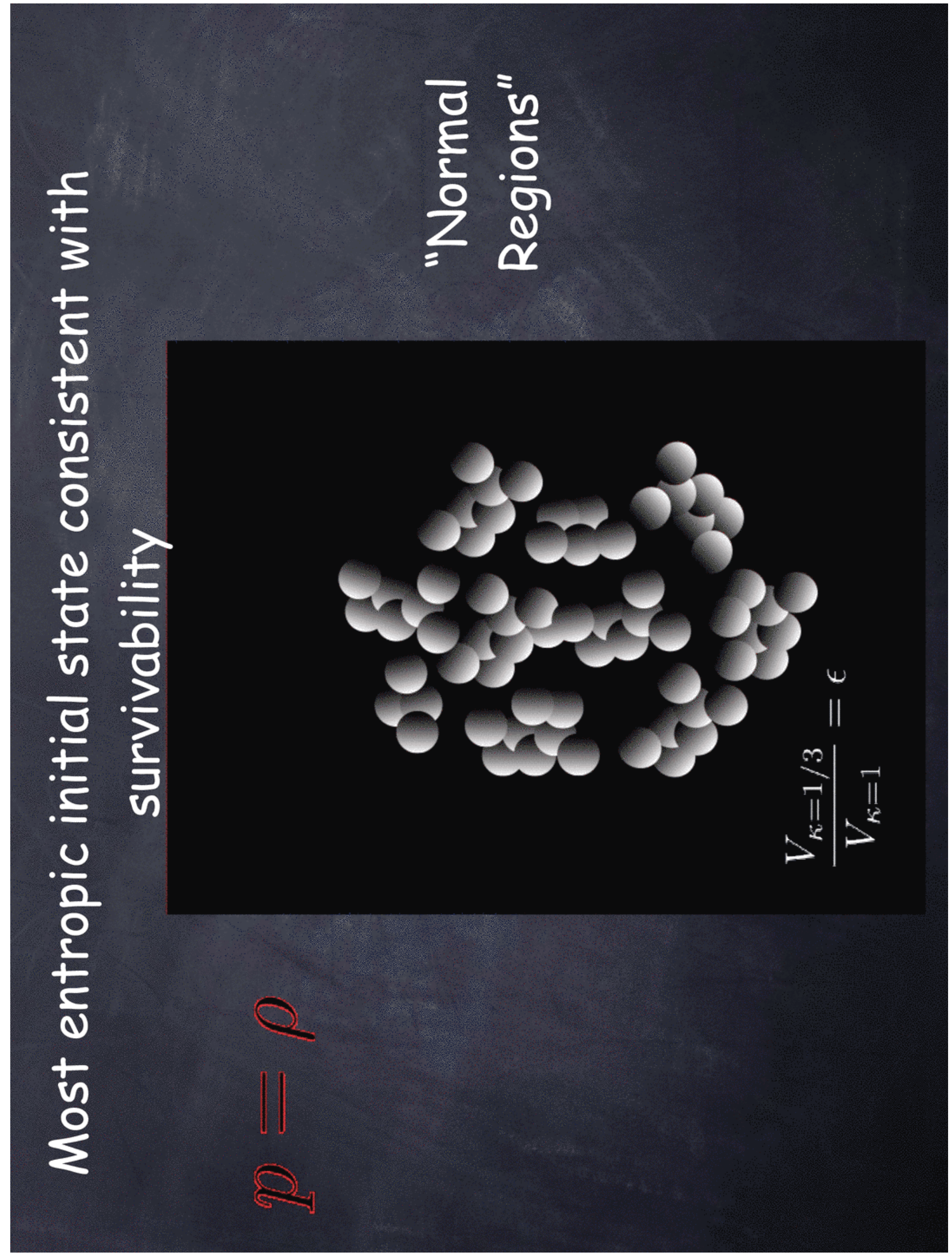
$$t \to \lambda t$$

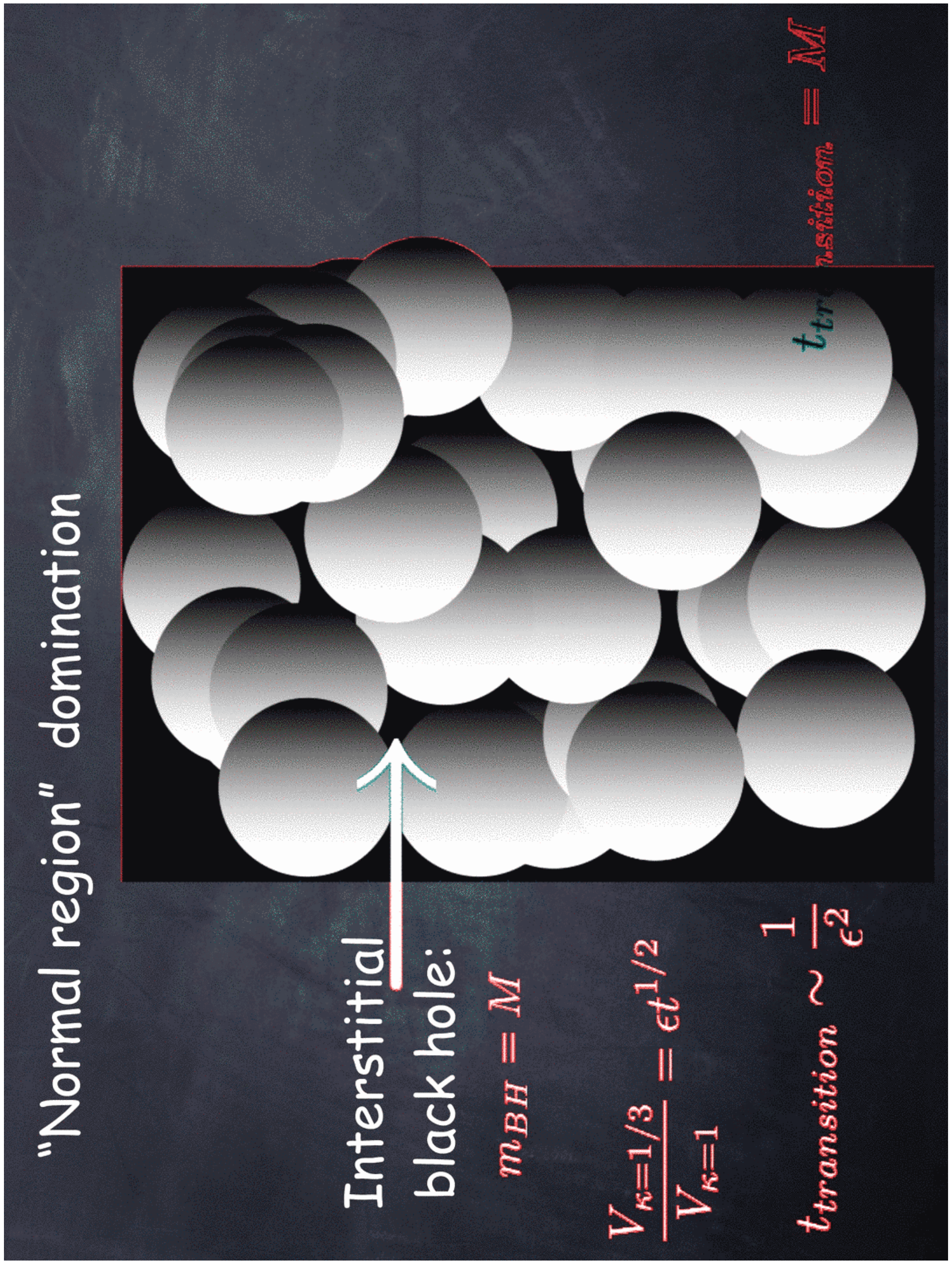
$$x_i \to \lambda^{2/3} x_i$$

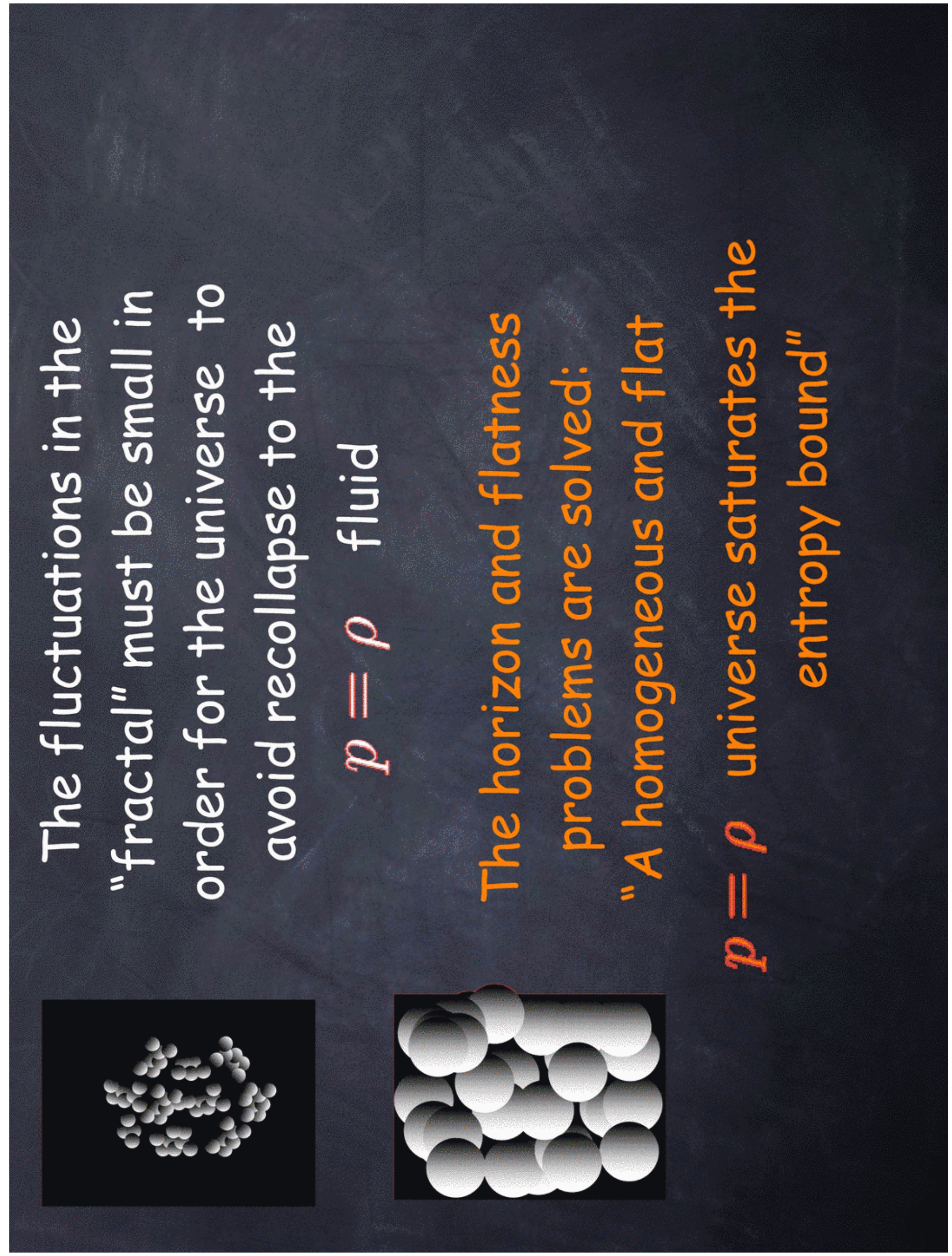
Unlike other fluids, $p = \rho$ has no observable that can detect changes in scale

The dynamics of this fluid is conformally invariant.


Continuity of the geometry:
$tR^2(t) = t^{2/3}L^2$
$R(t) \sim t^{-1/6}$
"normal" region shrinks
$\kappa = 1$
$\kappa = 1/3$
$R(t)$
L
t
Synchronize times: equal area slicing


Most entropic initial state consistent with survivability
"Normal Regions"
$\frac{V_{\kappa=1/3}}{V_{\kappa=1}} = \epsilon$
$p = \rho$


"Normal region" domination
Interstitial black hole:
$m_{BH} = M$
$\frac{V_{\kappa=1/3}}{V_{\kappa=1}} = \epsilon t^{1/2}$
$t_{transition} \sim \frac{1}{\epsilon^2}$
$= M$


The fluctuations in the "fractal" must be small in order for the universe to avoid recollapse to the
$p = \rho$ fluid
The horizon and flatness problems are solved:
"A homogeneous and flat
$p = \rho$ universe saturates the entropy bound"

Fluctuations, $\delta\rho_F$, in the "fractal" get transferred to fluctuations, $\delta\rho_{BH}$ in the

positions and sizes of the

interstitial black holes

Assuming the probability distribution for $\delta\rho_F$ is invariant under the conformal symmetry:

$$< \delta\rho_{BH}(k,T)\delta\rho_{BH}(-k,T) > \sim \frac{1}{k^3}$$

$\longrightarrow$ Scale invariant spectrum

The physical size of the horizon, during the $p=0$ black hole era, grows like $Ma^{3/2}$

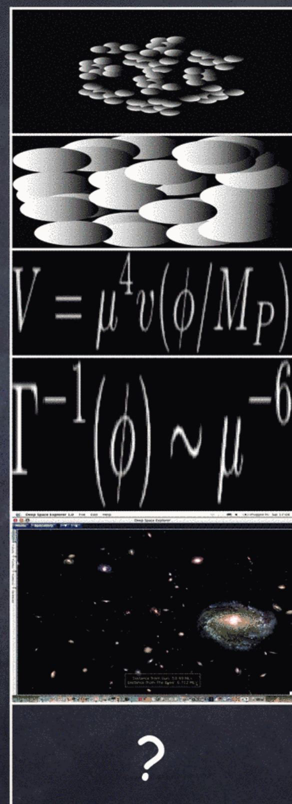
The energy density drops like $\frac{1}{M^2a^3}$

The "normal regions" has all the low energy degrees of freedom, moduli...

$$\mathcal{L} = \frac{1}{2}G_{ij}(\phi)\nabla\phi^i\nabla\phi^j - \mu^4 V(\phi)$$

When $Ma^{3/2} \geq \mu^{-2}$ it is possible to enter a period of slow roll inflation followed by reheating to:

$$T_R \sim \mu^3$$

$t = 1$		$\frac{R_{Planck}}{R_{now}} = 10^{-61}$
M		$10^{-61} M = \frac{R_{corr}}{R_{now}}$
$M a^{1/2}$		$10^{-61} M a$
oscillations		$10^{-61} M a e^{N_e}$
reheating		$\frac{10^{-61} M a e^{N_e}}{\Gamma^{2/3}(\phi)}$
today		$\frac{10^{-29} M a e^{N_e}}{\Gamma^{1/6}(\phi)}$

The parameters of the model: M, a, μ and N_e

1) $M^{2/3} \geq 10^{4(6)}$ — scale invariance should extend over three (five) decades

2) $\mu^4 = \frac{1}{M^2 a^3}$ — Inflation starts at the end of the black hole dominated era

3) $10^{29} M^{-1/3} \mu^{7/3} \leq e^{N_e} \leq 10^{25(23)} M^{1/3} \mu^{7/3}$

$R_{corr} \geq R_{now}$ $\quad$ $10 M^{-2/3} R_{corr} \leq 10^{-3(5)} R_{now}$

Scale invariance ranging from the present horizon down to 100(1) x galactic scale

Parameters of the cosmological model

$$T_R \sim \mu^3 \qquad M^2 a^3 = \frac{1}{\mu^4}$$

$a = 10$

μ	T_R	M	N_e
$10^{-22/3}$	$1 MeV$	10^{13}	$17 \le N_e \le 31$ $17 \le N_e \le (22)$
$10^{-15/4}$ $10^{(-21/4)}$	$10^{5(0)} TeV$	$10^{6(9)}$	$41(39)$

$$M^{2/3} \ge 10^{4(6)}$$

scale invariance over at least 3(5) decades

Relative probability of the initial conditions for our model versus models of inflation

Take an equal area slice where the area of the horizon is A

The entropy of the initial conditions that lead to the "fractal" ~ A

For inflation, the entropy of the initial conditions $\le A^{3/4}$

"This is not an apple"
Magritte

$$< \delta\rho_{BH}(k,T)\delta\rho_{BH}(-k,T) >\sim \int_1^T dsds' < \rho_F(k,s)\rho_F(-k,s') >\equiv \int_1^T dsds' G(k,s,s')$$

$$\delta\rho_{BH}(\mathbf{x},T) = \int_1^T ds \int d^3y f(T,s,\mathbf{x}-\mathbf{y})\rho_F(s,\mathbf{y})$$

where $\int d^3x\rho_F$ is invariant.

f falls off at large separation in a time independent way

$$G(\lambda^{-2/3}\mathbf{k},\lambda s,\lambda s') = G(\mathbf{k},s,s')$$

$$< \delta\rho_{BH}(k,T)\delta\rho_{BH}(-k,T) >\sim \frac{1}{k^3}\int_{k^{3/2}}^{k^{3/2}T} dsds' G(1,s,s')$$