Title: Creation of Space, Field Energy and Modes

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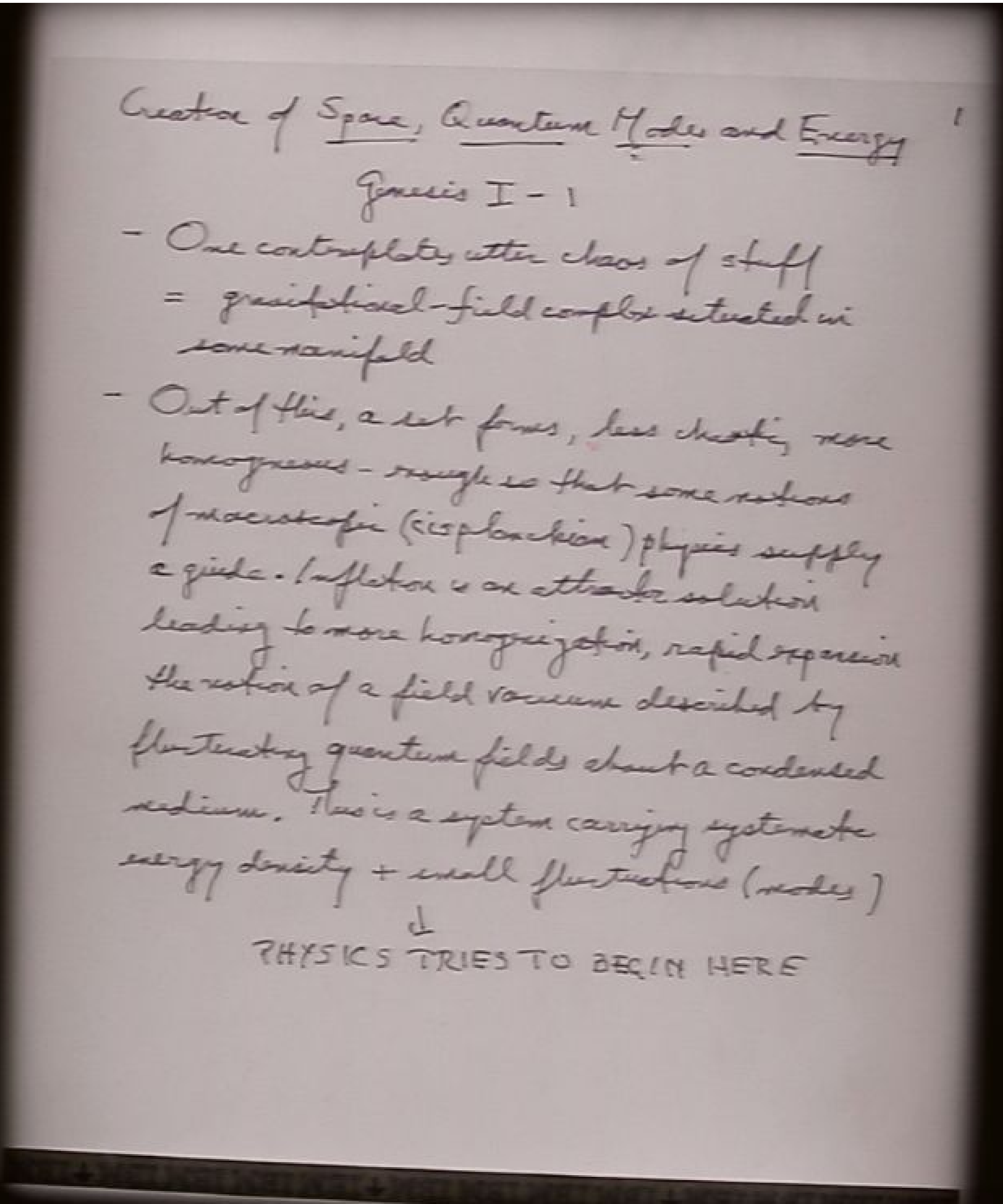
Abstract:



Creation of Space, Quantum Modes and Energy

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Genesis I - 1

- One contemplates utter chaos of stuff
  = gravitational-field complex situated in some manifold
- Out of this, a set forms, less chaotic, more homogeneous - enough so that some notions of macroscopic (cisplanckian) physics supply a guide. Inflation is an attractor solution leading to more homogenization, rapid expansion the notion of a field vacuum described by fluctuating quantum fields about a condensed medium. This is a system carrying systematic energy density + small fluctuations (modes)

↓

PHYSICS TRIES TO BEGIN HERE

been created.

$$\rho_\Lambda\Big|_{\text{Classical}} \rightarrow \underset{\text{(reheating)}}{\rho_{rad}} + \rho_M \xrightarrow[a\to\infty]{} 0 \qquad \text{I}$$

There also remains

$$\rho_\Lambda\Big|_{\text{vacuum}} = \text{Dark Energy} = O(10)\rho_M \qquad \text{II}$$

At present

$$\rho_{Tot} = \rho_{rad} + \rho_M + \rho_\Lambda = O(10^{-100})\rho_\Lambda\Big|_{\text{inflation}} \qquad \text{III}$$

Neither the former, (I), nor the remnant vacuum energy (II) are understood in the sense of a consensus

In this talk, I is assumed, and the point of view of Ahmed, Greene, Dodelson, Sorkin on Dark Energy will be pursued.

It will be proposed that

— Dark Energy = Fluctuating Remnant of Inflation

— The nature of the inflaton mass partic

Mode Depletion Problem

- The quantum field theoretic mode loses its significance for $k > 1$; its zero point energy, naively calculated is < gravitational interaction energy with everything in sight (other modes, "space-time" foam? --) It is part of ~~of~~ a strongly interacting system and field configurations can no more be described in terms of modes with $k > 1$ than can a liquid be described in terms of the independent momenta of its constituent molecules

- If the modes cut off at $k = 1$, then their number will dilute like a^{-3}, so we require a mode reservoir

- Some inspiration derived from Sorkin's causet generation of Dark Energy in the adiabatic era. A somewhat modified version is thus:
- Expanding space is delivered in lumps planckian in dimension, at random at planckian densities.
- An observer sees their creation sequentially as ~~the~~ his horizon increases

Hence ~~that~~ he sees a causet, the elements that cause sequential events in his world.

- A causet in the adiabatic era exchanges "vacuum energy" with the space that has been laid down, (in the planckian region that surrounds it)

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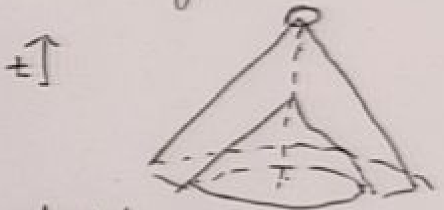

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- A causet in the adiabatic era exchanges "vacuum energy" with the space that has been laid down, (in the planckian region that surrounds it)

- The macroscopic response (H) is due to the "vacuum energy" as it varies due to its exchange with the causets
- Implication: the stuff sequestered in causet elements does not directly elicit a macroscopic response, but only indirectly due its exchange with the "cisplanckian" vacuum. that is "vacuum energy".
- Further implication: The stuff attached to causets leaks out a little (its cisplanckian cloud) Overlap of leakages is a good candidate for mode creation

As space is made by causet proliferation, modes and cisplanckian vacuum energy are made concommittantly. The causet scenario of space creation eliminates the hiatus of mode dilution

– First estimate of magnitude of Dark Energy in the Adiabatic Era

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$N(t_i)$ = number of causet elements laid down up to time slice i in an observer's light cone,

$= V(t_i)$ = space-time volume containing $N(t_i)$

(V is dominated by the immediate).

$$V(t_i) \sim \mathcal{O}(H^{-4}(t_i))$$

Each element exchanges a unit of energy with the vacuum

$$\rho_\Lambda(t) \sim \pm\sqrt{N(t)}\,/N(t)$$

$$= \pm H^{-2}(t)/H^{-4}(t)$$

$$= \pm H^{2}(t)$$

$$\therefore \rho_\Lambda = O(\rho_{rad}+\rho_{m}) = O(H^2)$$

We are in a region of a positive fluctuation of vacuum energy.

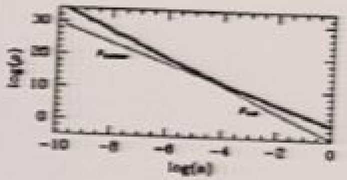


FIG. 2. Evolution of the energy densities in the Universe. The thick curve is the absolute value of the energy density in the cosmological constant. The fluctuating ρ_Λ is always of order the ambient density, be it radiation (early on) or matter (later). Here the dimensionless parameter α which governs the amplitude of the fluctuations has been set to 0.01.

III. SIMULATIONS

We take as the spacetime volume

$$V(t)=\frac{4\pi}{3}\int_0^t dt' a(t')^3\left[\int_{t'}^t dt''/a(t'')\right]^3 \qquad (3)$$

where $a(t)$ is the scale factor of the Universe at proper time t. Note from this formula that the backward light-cones depicted in Fig. 1 are quite deceptive: because $a(t)$ was much smaller in the past and vanishes at the big bang, most of the four-volume V of these light cones accumulates recently. One consequence of this is that $V \sim H^{-4}$ recently, even if there was a period of cosmic inflation in the early Universe.

Our algorithm for calculating the cosmological constant at time step $i+1$ is then to set

$$\delta N_i \equiv N_{i+1}-N_i = V(t_{i+1})-V(t_i) \qquad (4)$$

and then write

$$\Lambda_{i+1}=\frac{S_{i+1}}{N_{i+1}}=\frac{S_i+\alpha\xi_{i+1}\sqrt{\delta N_i}}{N_i+\delta N_i} \qquad (5)$$

Here α is an

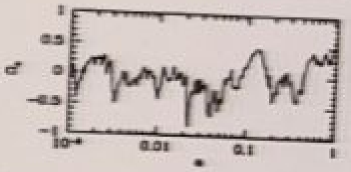


FIG. 3. The ratio of the energy density in cosmological constant to the total density as a function of scale factor. Here $\alpha = 0.02$.

Hidden in the gross structure of Fig. 2 are the fluctuations about this average scaling. These fluctuations are crucial if the theory is to describe the real Universe for two reasons: First, there cannot be too much excess energy at $a \sim 10^{-9}$ or else the successful predictions of big bang nucleosynthesis (BBN) will be destroyed. Second, if ρ_Λ scales exactly as matter today, it will not have the correct equation of state to account for the cosmological observations. Figure 3 shows the ratio of the energy density in Λ to the total energy density as a function of the scale factor for another realization, this time with a slightly larger value of α. This ratio, Ω_Λ, fluctuates about zero with an amplitude of order 0.5 (as we will shortly see, this amplitude is a function of α). In this particular realization, Λ accounts for over 50% of the energy density today and changes very little going back to redshift $z = 1$ ($a = 0.5$); thus it behaves recently as a true cosmological constant, and therefore satisfies the observed cosmological constraints.

In half the realizations, Λ will be positive today. Whether or not it is positive enough to explain the observations then becomes a question of probability. For $\alpha = 0.02$, it clearly is not that improbable (indeed, in the same run, we see another spike in the energy density at $a \sim 0.1$).

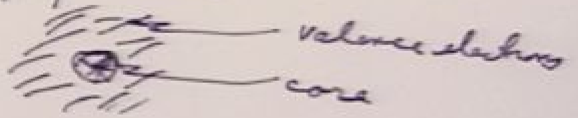
The same qualitative argument applies to the BBN and CMB constraints. Consider first BBN where the situation appears even a little better. Half of the time the extra energy density from the fluctuating Λ will be

Sounds like the right track

There is an example in matter physics which helps to fix the imagination

Tight binding theory of metals

- An isolated atom



- A metal seeks a density of atoms to give a minimum of energy (zero external pressure)
- In an alkali metal it looks like

- Overlap of the valence electrons delocalizes them. They appear in the spectrum as bands. The band width ~ overlap

The same stuff exists as $\begin{cases}\text{localized cores}\\ \text{delocalized modes of momentum } k\end{cases}$

The attraction to the cores keeps the cores tight ~~and~~ but the bands are only macroscopically confined to a finite total volume (= N/ρ)

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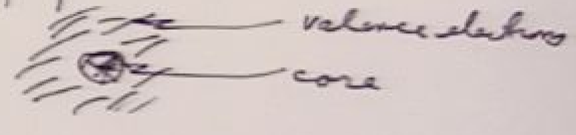

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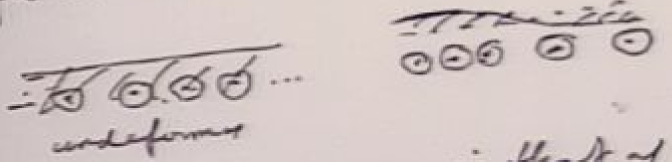
- In an alkali metal (Na), the measured speed of sound is $c^2 = B_{band}/M_{ion}$ the pressure response to deformation is <u>only</u> from the bands not the cores



Macroscopic response is that of the delocalized degrees of freedom

$\rightarrow \rho_\Lambda$ in $H^2 = \rho_{rad} + \rho_m + \rho_\Lambda$

is due to delocalized degrees of freedom

The concert idea accommodates well to the concepts we seek

∴ Try to go quantitative

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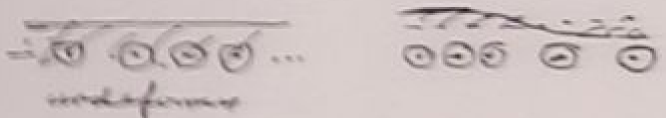

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∴ Try to go [illegible]

Ahmed, Greene, Dodelson, Sorkin 10

PR D69 103523 (2004)

i labels time slice

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N_i = number of causet elements in backward light cone of t_i

δN_i = number of elements in the slice

$\xi_i = \pm 1$

S_i = action in the cone

α adimensionless parameter 10^{-2} to 10^{-1} is tightly constrained to obtain realistic runs

N_i hence the volume $\underline{V_i}$

obtained from the energy constraint

$$H^2(t_i) = (\rho_\Lambda)_{t_i} + \rho_{rad}(t_i) + \rho_M(t_i)$$

(No acceleration equation is used, it is

Ahmed, Greene, Dodelson, Sorkin 10

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ρ_{rad} and ρ_M are independently conserved

$$\rho_{rad} \sim a^{-4} \, , \; \rho_M \sim a^{-3}$$

ρ_Λ is taken to vary slowly enough · to validate the procedure (homogeneity as well) $^*_*$

There are realistic runs

Some runs give $\rho_{Tot} < 0$. They are stopped

[My opinion – the model breaks down. The ~~the~~ causets then only give energy, there is none to take]

· In like fashion the "target" value of ρ_Λ as $\rho_M = \rho_{rad} \to 0$ is $\rho_\Lambda \to 0$. This is in the the stochastic procedure and is not realistic. The endpoint is a quiescent universe. Once more the model breaks down – such a quiescent state fluctuates and is metastable against formation of a ~~seed~~ seed.

Much [illegible] about Nothing / Full of soun[illegible]ifying nothing

L10'

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Much ado about Nothing / Full of sound & fury - signifying nothing

The Inflaton

As for the metal we may suppose:

Mode density (i.e. cut-off) and causets in equilibrium

- In the metal this leads to an accoustic fluctuation (as well as a massy plasmon; that is irrelevant since it is a manifestation of charge)
- The <u>accoustic fluctuation</u> has its cosmological analogue - <u>the inflaton</u>, essentially due to the fluctuation of mode density. It can propagate and since it is composed of all quantum fields, all fields have a common velocity of propagation ($\equiv c$)
- Unlike in the metal the number of modes is not conserved. Modes can leak out of the causets, changing their number - i.e. their density can change due to compression and rarefaction, but

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- Unlike in the metal the number of modes is not conserved. Modes can leak out of the cavities, changing their number – i.e their density can change due to compression and rarefaction, but

it can also change due to quantum conversion of field configuration sequestered in conseats to modes

- This is the vacuum analog of Hawking evaporation of black holes

Thus the inflaton can (and does have a mass)

- If a mode leaks in or escapes from a conseat element it will cause an oscillation of the vacuum configuration of fields in in its vicinity $= e^{\pm i\mu t}$

i.e. Thus there is a fluctuation around equilibrium described by

$$-\frac{\partial^2\varphi}{\partial t^2} + \underbrace{\nabla^2\varphi}_{\text{due to deformation}} \mp \underbrace{\mu^2\varphi}_{\text{due to mode-conseat exchange}} = 0$$

The seed is when this fluctuation sets up a classical field $\varphi_c = O(1)$ and the

whole system inflates ~~under~~ being driven by the energy constant 113

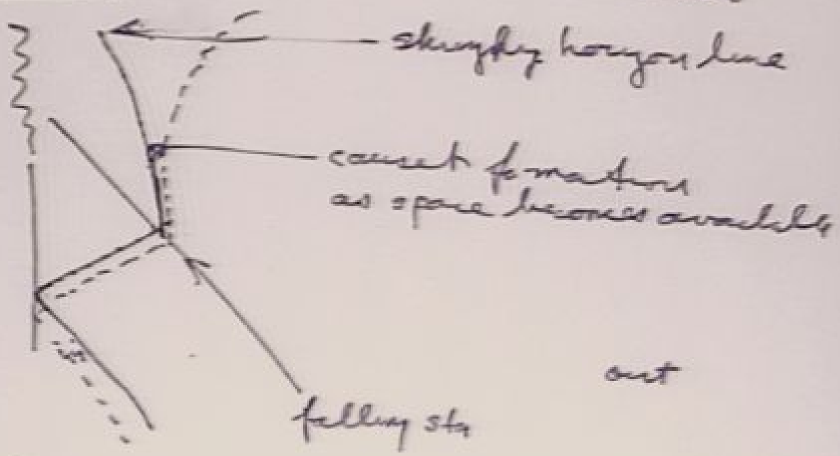
$$H^2 = \mu^2 \phi_c^2 = O(1)$$

- The rate of expansion is planckian as is presumably the rate of exchange
- So during inflation as new causets are created they can only give energy, there no time to take it $\therefore \rho_\Lambda = O(1)$.
- Since inflation is the great homogenizer the ρ_Λ that is made is the uniform vacuum energy encoded in $\mu^2 \phi_c^2$
- To find μ we see in the adiabatic era that in the stochastic exchange α^2 = mass exchanged per exchange event

$$\mu \simeq \alpha^2 \;(\underline{10^{-2} \text{ to } 10^{-4}})$$

One quotes $10^{-5} - 10^{-6}$ for the

Black Hole Evaporation - EF coordinates



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is replaced by

$$\frac{dM}{dt} = T_{ox} = \frac{1}{M^2}$$

Black Hole Evaporation - EF coordinates

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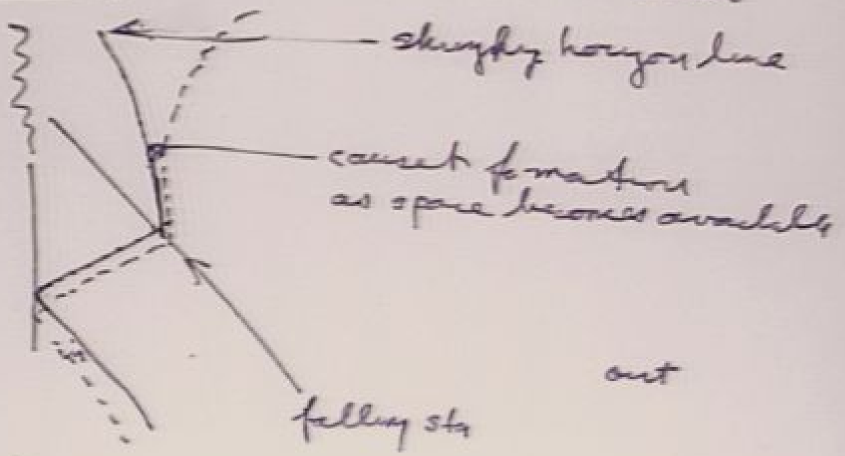
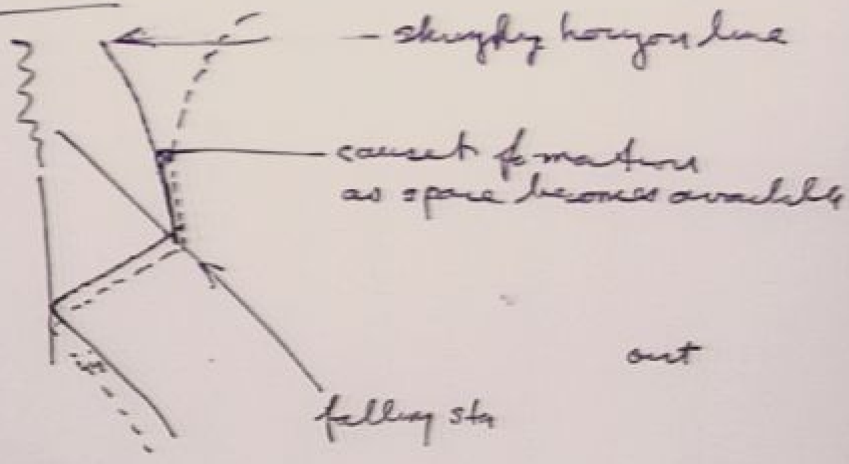


$H^2 = \rho_\Lambda \big|_{inflation}$

unexplained by

$$\frac{dM}{dt} = T_{BH} = \frac{1}{M^2}$$

Black Hole Evaporation – EF coordinates



$$H^2 = \rho_\Lambda \big|_{\text{inflation}}$$

is replaced by

$$\frac{dM}{dt} = T_{0r} = \frac{1}{M^2}$$

– Both become smooth classical descriptions after the hair is smoothed. Then space expands, modes form and QFT can be used

– The Hawking process to convert the vacuum configuration of the Kruskal mode to Schwarzschild heat

The analogies are extremely strong!

— What means space?

— If $k_{\text{Mode}} < 1$, to see planckian space is not possible

— Theoretically if Hilbert space of modes in a finite volume is finite and denumerable so should be the Hilbert space of space ($|x\rangle$)

— The caveat or ~~space~~ foam notion seems to incorporate our inevitable frustration but not in completely unproductive fashion

So

Let our spirits roam fancy free
Ye gods that reign, tell us how the world
might be!