De Sitter Space and the Swampland

Navigating the Swampland: Madrid Sept. 26, 2019

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Is dS Space part of the swamp?

- It doesn't matter as long as dS space is meta-stable with a lifetime much longer than its Hubble scale.

- Properties of meta-stable asymptotically dS cosmology are all we will measure.

- I'll review evidence that meta-stable dS is a finite dimensional system with most of its states having $E < T_{dS}$

- Implies (Page) that if it is a subsystem of a larger system its generic state is the same density matrix assumed in the Banks-Fischler model of stable dS.

Evidence

- Covariant Entropy Principle: A/4 in Planck units is the maximal entropy of any quantum state in a causal diamond. (Jacobson 95, Bousso 99, TB,Fischler (2000 et. seq.)

- CDL tunneling between dS and dS or Big Crunch (above the Great Divide) satisfies principle of detailed balance for systems with finite Hilbert space and entropy given by CEP applied to maximal diamond. Assumes most states in dS below dS temperature. Models below Great Divide are probably in the Swampland.

Most States ARE Below the dS Temperature because:

1.Localized States in dS are constrained states of low entropy

$$ds^2 = -f(r)dt^2 + \frac{dr^2}{f(r)} + r^2 d\Omega^2$$

$$-r f(r) R^2 = (r - R_+)(r - R_-)(r + R_+ + R_-)$$

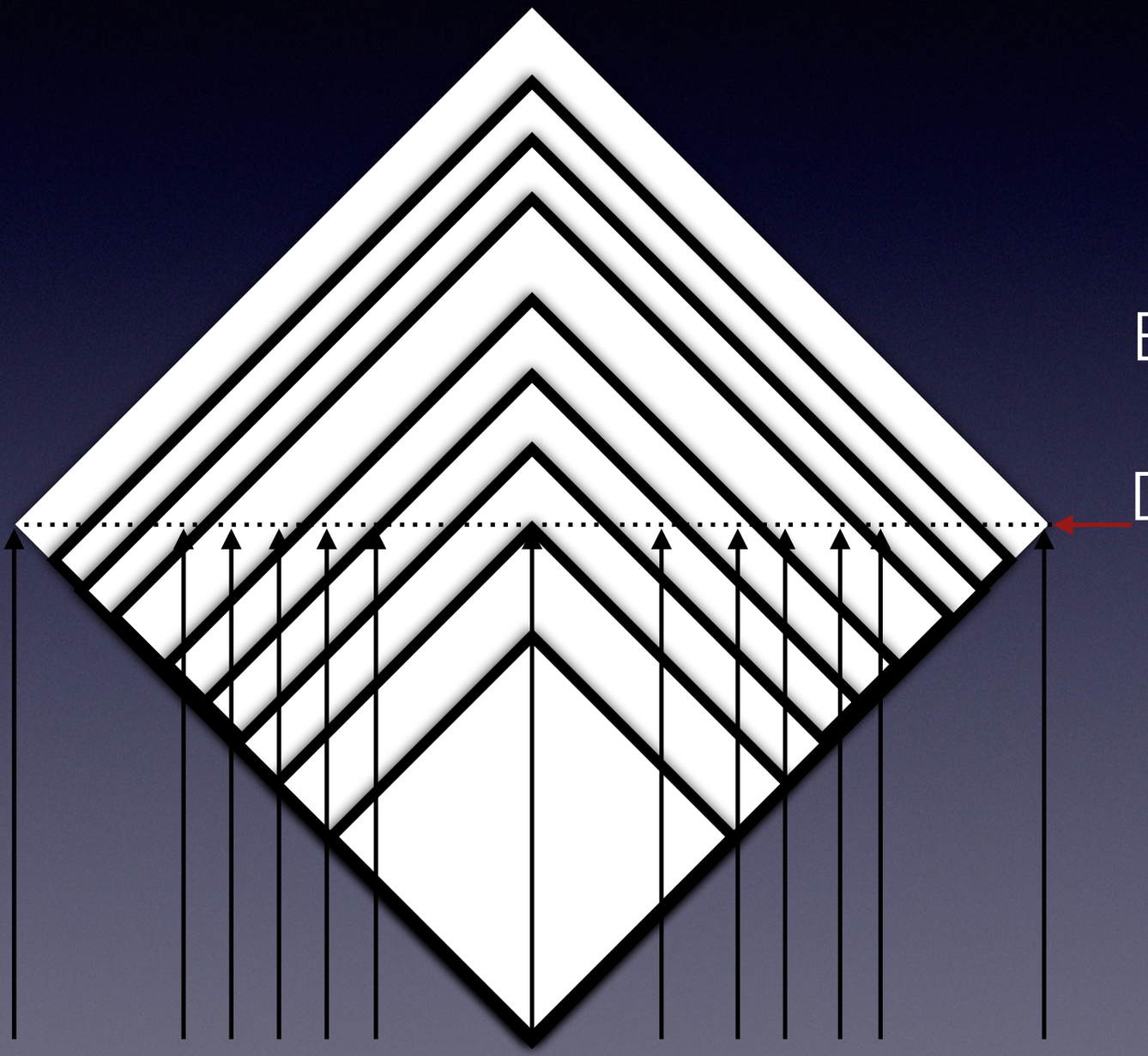
$$R^2 = R_+^2 + R_-^2 + R_+ R_- \quad R_+ R_- (R_+ + R_-) = 2M R^2$$

- 2. Maximal Black Hole Mass in dS
- 3. Finite mass localized object at rest will be knocked out of causal diamond by Gibbons Hawking radiation and migrate to the horizon in a time of order R
- 4.Quasi-normal modes of dS show horizon is a fast scrambler with ln S ~ ln R. (Simple variation on Hayden Preskill).

Leads to sharp Boltzmann-Penrose conundrum about the early universe: why was it in a constrained state with non-maximal entropy? HST model argues that the highest entropy state consistent with ANY localized excitations is one in which the universe inflates with $H_I >> H_{dS}$, followed by a dilute gas of black holes with $m \sim H_I$ and

$$\frac{\delta H}{H} \sim \frac{M_P}{m}$$

Inflationary Horizon Before Horizon Entry Becomes Black Hole Inside the Horizon



$$\zeta = \epsilon^{-1} \frac{\delta m}{m}$$

- Fixing m in terms of observations leads to Hot Big Bang at T ~ 10^{10} GeV

- Baryon asymmetry $\propto$ dM/dt compatible with observation.

- Fluctuations grow to order 1 long before HBB. Black hole collisions making holes with Hawking temp lower than reheat temp could make primordial holes with observable consequences

All of this is independent of whether and how dS decays, if time scale >> dS Hubble, and the model fits the data.

HST models show no WGC constraints on “flatness of the inflaton potential” i.e. slowness of slow roll, but also no eternal inflation. The only constraint is that the roll should not be sufficiently adiabatic to allow the black holes to come into equilibrium with the horizon, since then the equation of state becomes $p = \rho$ $\rightarrow \epsilon > \frac{c}{\ln H(t)}$

Roll must be faster than scrambling time.

- CEP Implies QFT treatment of inflation is incorrect. QFT valid only when QFT entropy in a diamond is < $A^{d-1/d}$ This is the covariant version of a bound suggested many years ago by Cohen Kaplan and Nelson

- Jacobson tells us CLASSICAL gravity is a good description of high entropy situations in quantum gravity: Hydrodynamics is valid for strongly coupled quantum systems

- IMHO ALL field theory inflation models violate this bound and are in the Swampland

- More general lesson from success of HST model in fitting cosmological 2 pt function data:

- Jacobson tells us GR is hydrodynamics of the area law.

- Derivation of hydro from QM implies it is always a stochastic classical field theory, independent of most micro details.

- Data on CMB fit by stochastic GR plus approximate dS invariance plus general properties of classical cosmological perturbation theory (norm of scalar versus tensor, squeezed limit theorem), plus choice of slow roll metric not tested by other observations

- Validation of particular models must await discovery of non Gaussianity and/or tensor fluctuations

L’Envoi

- HST cosmology gives a finite account of asymptotically dS cosmology, consistent with data, unitarity and causality. It is stable. It is incompatible with eternal inflation, and its constraints on slow roll differ from WGC

- Claimed instabilities of dS space are on time scales >> R, and Page’s theorem tells us coupling to a larger system before it decays would only increase the fine tuning of initial conditions necessary to the existence of localized excitations.