The Quantum Theory of Stable de Sitter Space

Physics With a Positive Cosmological Constant

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The Takeaway

- We DON’T know the general recipe for deriving Effective FT from QG

- Jacobson (95): Einstein eqs, thermo/hydrodynamics for system whose entropy is area of local Rindler horizons. Not nec. quantized fields.

- String theory in AdS and flat space: “particles” --> quantized fields.
This talk: general holographic theory of space-time, based on the fact that holographic principle + (locality = commutativity) completely specifies Lorentzian geometry, which is not a fluctuating q variable. Understand particles as special excitations of the true variables, in situations where CEB far from saturation. Particles in dS space an approximate emergent and evanescent concept.

SUSY broken and gravitino mass proportional to fourth root of c.c.
$H_N(x)$, $H_N(y)$

$H_{N-s}(y)$, $H_{N-s}(x)$

steps

$X \ldots S \ldots Y$
accelerated observers in finite causal diamond of Minkowski space. Variables satisfy

\[ [\psi_i^A P, \psi_{iQ}^B] + = \delta_i^j \delta_A^B Z_{PQ} \]

Q label basis of spinor bundle over compact dimensions, with Dirac eigenvalue cutoff. Z in corresponding cutoff bundle of forms. Superalgebra with finite dimensional unitary rep, irreducible w.r.t. fermions. If covariantly constant spinor, Z has unit matrix piece
Block diagonal $\psi_i^A \sigma_i^P$ at large block size leads to set of massless superparticles. SUSY generators come from smearing with conformal Killing spinors on the sphere. Momentum defined by SUSY. Block size is longitudinal momentum as in matrix theory, but also limits angular localization.

Field theory limit, lots of particles with good angular localization. Maximize field theory entropy with sizes $\propto \sqrt{N}$. Entropy $N^{3/2}$ momentum cutoff same as field theory estimate of particle states which are not horizon filling black holes.
Particle Decomposition of Variables in Diamond

\[
\begin{pmatrix}
1 & 2 & 3 & \ldots & \ldots & \sqrt{N} \\
\sqrt{N} & 1 & 2 & 3 & \ldots & \sqrt{N} - 1 \\
\ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\
\ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\
3 & 4 & 5 & \ldots & 1 & 2 \\
2 & 3 & 4 & \ldots & \sqrt{N} & 1 
\end{pmatrix}
\]
HST formalism can accommodate (fewer) particles of higher momentum. Momentum unit is minimum $1/N$ in Planck units.

The SUSic/Poincare Hamiltonian is bilinear trace in fermion variables. Decouples bands in fermionic matrix. All observers have higher traces in their Hamiltonian, with acceleration dependent coefficient of SUSY term (goes to zero as $a$ increases).

Sekino–Susskind fast scrambling conjecture says these will thermalize, with acceleration dependent temperature. “Maximally accelerated observer” (c.f. Jacobson) will see full complement of states.
Horizon Decomposition of dS Variables

\[
\begin{pmatrix}
1 & 2 & 3 & \ldots & \ldots & \sqrt{N} \\
\sqrt{N} & 1 & 2 & 3 & \ldots & \sqrt{N} - 1 \\
\ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\
\ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\
3 & 4 & 5 & \ldots & 1 & 2 \\
2 & 3 & 4 & \ldots & \sqrt{N} & 1 \\
\end{pmatrix}
\]
Basic idea of dS model: N stays finite. Even the geodesic observer’s Hamiltonian has smaller multi-linear piece, giving rise to thermalization at dS temperature. dS temperature fixed by entropy deficit of P eigenstates in the full Hilbert space.

Can also incorporate dS black holes. In fact all qualitative properties of QFT in dS are reproduced in this model. Number of independent horizon volumes $\sqrt{N}$. No time for details here.
Localized excitations defined by

\[ \psi_i^A(P)|L\rangle = 0 \]

For o(N) matrix elements. Take these to be an N X K + K X N block. SUSY Hamiltonian gives decoupled K X K block a mass of order K. Entropy deficit of order N X K. Probability of such states in maximally uncertain density matrix e^{-NK}, Boltzmann law at dS temperature.
$H = P_0 + \frac{1}{N^2} \text{Tr} \sum_{k=2}^\infty a_k (\psi \psi^\dagger)^k$

- First term SUSY Hamiltonian. It's bilinear in pixel variables and gives no interaction between particles in different horizons.

- Second term is fast scrambler but with 't Hooft coupling $1/N$. Thermalizes system in time $N$.

- Accelerated observers at fixed $r$ have first term multiplied by $(1 - \frac{r^2}{R^2})^{1/2}$
SUSY and The Holographic Screens

- SUSY restored as $N$ gets large. Gravitino mass energy of smallest particle-like excitation. Breaking goes like $N^{-1/2}$ which is the c.c. energy scale, 10
There is a rigorous mathematical model, whose coarse grained description is a black hole, with dS interior (arbitrary c.c.) embedded in a flat FRW with $w = 1$. QFT not a good description of this model (Jacobson) but THEFT describes its "hydrodynamics"

Einstein’s equations suggest there should be models with multiple such black holes. This has two consequences:
Connection between SUSY breaking and c.c. means c.c. selection is “atomothropic”, “starthropic” etc.

Depending on initial conditions, dS-black holes can collide on time scales << dS recurrence time for environmentally selected dS. One such collision makes Boltzmann brains impossible.
Particular illustration of why BB is a non-problem: Given any model with a BB problem there are an infinite number of ways to modify it on a time scale $\gg$ age of the universe and $\ll$ recurrence time, which eliminate BBs with no effect on physics we can conceivably observe.
Stable dS space with a fixed c.c. is a good model for particle physics, valid for times after inflation and of order a few orders of magnitude times the age of the universe. After that all particles thermalize with the horizon and localized objects are just thermal fluctuations. Cosmological model has collisions between dS islands on time scales $\ll$ recurrence time. Even if the post-collision island re-thermalizes to dS with a smaller c.c. microphysics is changed so no BBs possible (connection between c.c. and SUSY)
Conclusions

- Real quantum model of stable dS space. Observables matrix elements of evolution operator over time scales $\ll$ recurrence time and of order lifetimes of localized states.
- Reproduces thermal nature of dS, approximate particle physics and dS black hole statistics. Local physics emergent and evanescent, but VERY robust.
SUSY breaking connected with c.c. by

\[ m_{3/2} = 10K \Lambda^{1/4} = K \times 10^{-2} \text{eV} \]

Cosmological models, not discussed here, allow for environmental (stars, atoms) selection of c.c. and resolution of Boltzmann brain problem. Also show inflation is NOT dS space.

C.C. and primordial DM density determined anthropically/mathematically w/o reference to galaxy formation. Weinberg bound lower bound on fluctuation amplitude.


T. Banks, Cosmological breaking of supersymmetry?. Published in Int.J.Mod.Phys. A16 (2001) 910-921 (Published version of the lennyfest talk - Given at Strings in Michigan).

T. Banks, Cosmological Breaking of Supersymmetry, talk at the Celebration of the 60th birthday of L. Susskind, Stanford University, June(?) 2000.

W. Fischler, Taking de Sitter Seriously, Talk at the Festschrift for G. West, Los Alamos, ???


Holographic Space-time from the Big Bang to the de Sitter era, T. Banks (UC, Santa Cruz