Title: Holographic Cosmology Inflation and Entropy

Date: Jul 15, 2011 11:20 AM

URL: http://pirsa.org/11070007

Abstract: I provide a mathematical model of holographic cosmology whose coarse grained description is that of a homogeneous isotropic, flat universe, which makes a transitions from an FRW to an eternal de Sitter regime. Based on this model, I suggest some heuristic ideas which explain the low initial entropy of the universe and may provide a description of an inflationary era with small fluctuations.

Holographic Models of Inflation and Fluctuations

Perimeter Institute, July 15, 2011

The Takeaway

- We DON'T know the general recipe for deriving Effective FT from QG
- Jacobson (95): Einstein eqs, thermo/hydro-dynamics for system whose entropy is area of local Rindler horizons. Not nec. quantized fields.
- String theory in AdS and flat space: "particles" --> quantized fields.

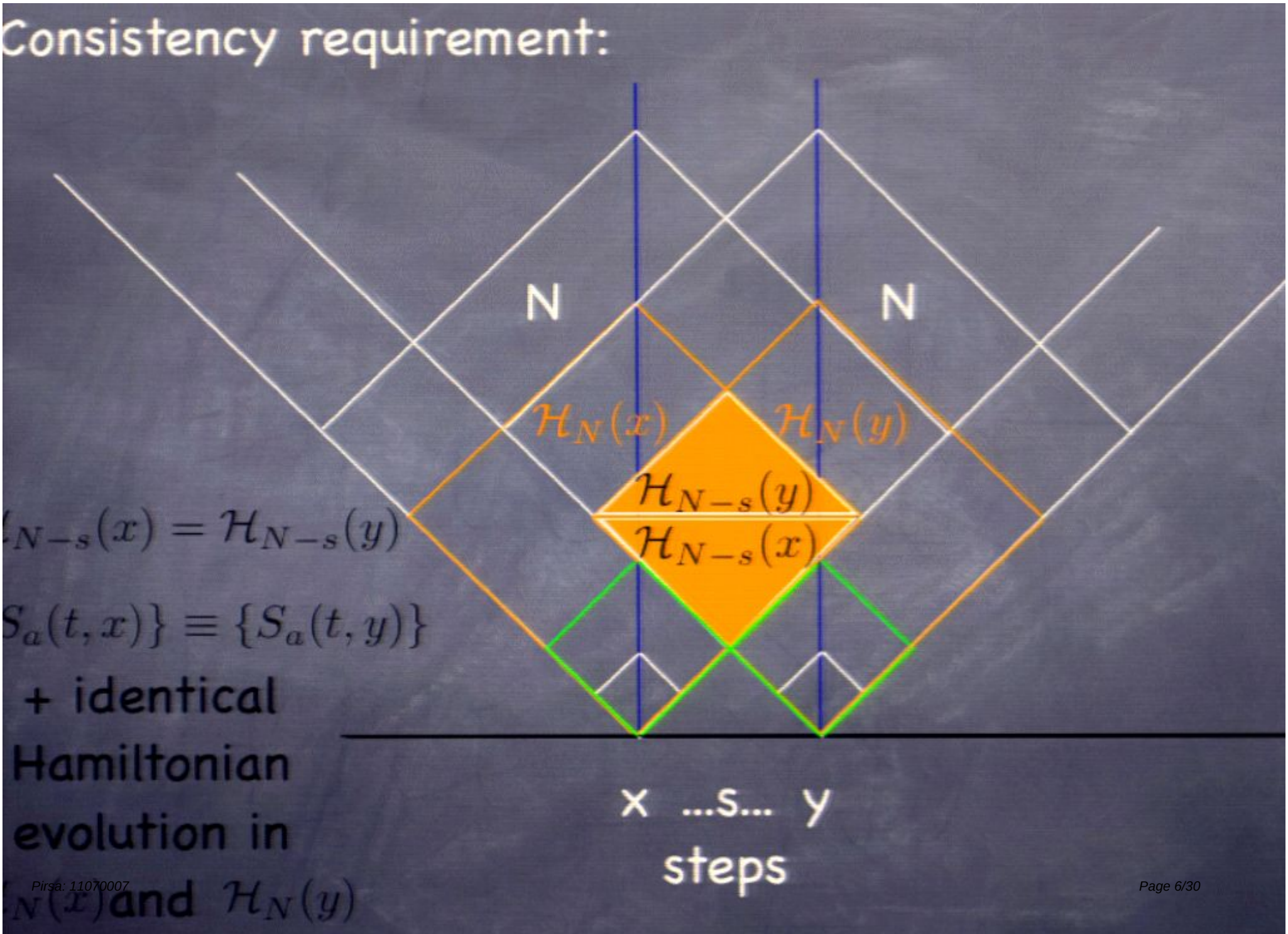
- This talk: general holographic theory of space-time, based on the fact that holographic principle + (locality = commutativity) completely specifies Lorentzian geometry, which is not a fluctuating q variable. Understand particles as special excitations of the true variables, in situations where CEB far from saturation. Inflaton will be an emergent field, like the metric, during an era where CEB almost saturated.

- Several rigorous models, fantasy about how to put them together to make real cosmology

The DBHF - c.f. Fischler

- Random Hamiltonians converging to 1+1 CFT with central charge N^2 and UV cutoff N on interval 1/N. N proportional to cosmological time
- Variables form superalgebra generated by N (N+1) D operators. D is dimension of cutoff spinor bundle over compact dimensions.
- Coarse grained (c.f. Jacobson) description as flat $p=\rho$ FRW, for generic initial state.

Consistency requirement:



$\mathcal{H}_{N-s}(x) = \mathcal{H}_{N-s}(y)$

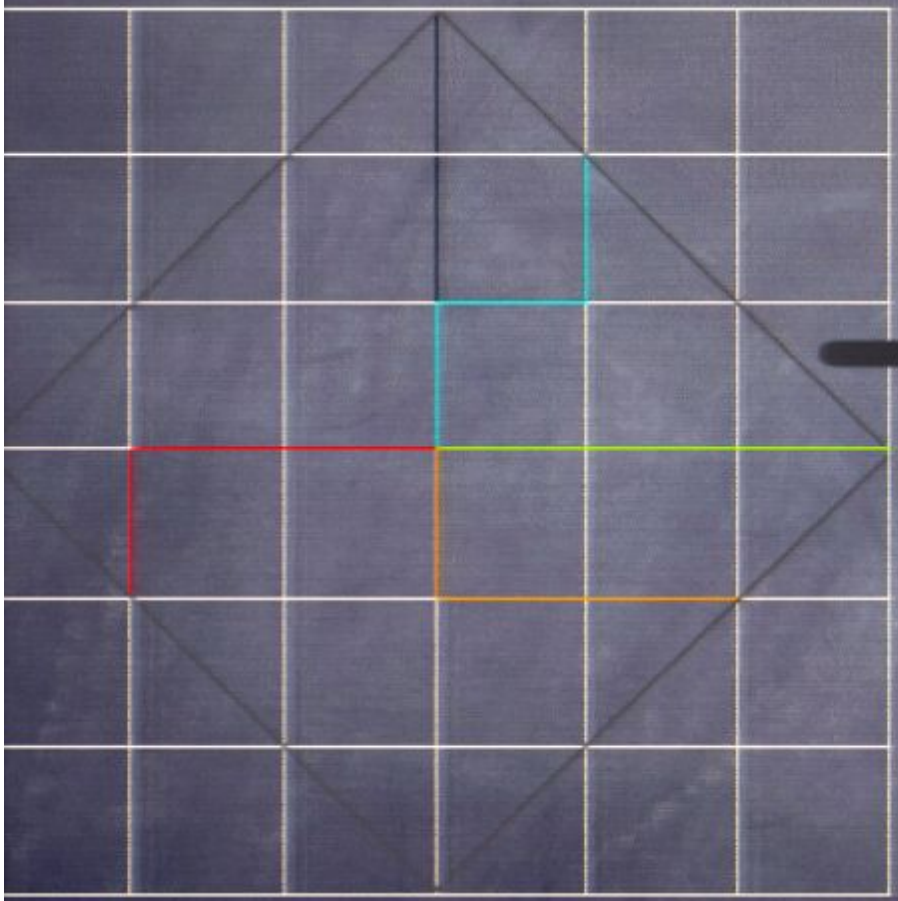
$\{S_a(t,x)\} \equiv \{S_a(t,y)\}$

+ identical Hamiltonian evolution in

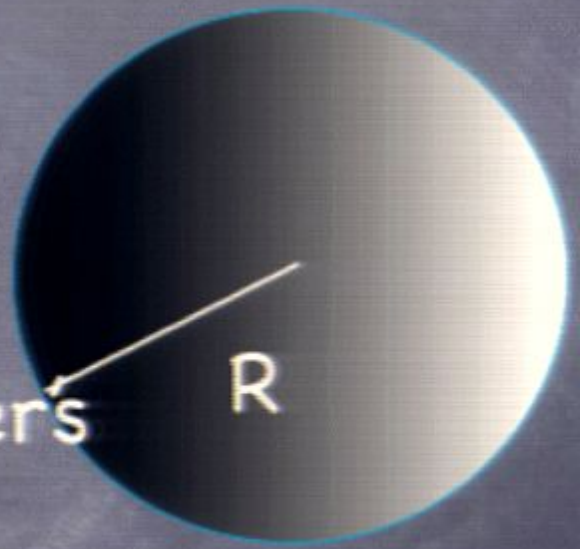
$\mathcal{H}_N(x)$ and $\mathcal{H}_N(y)$

K steps in spatial directions,

each step reduces overlap area by N units



The "Carpenter's ruler" map



no backtracking, no closed loops

opology of a hypercube

ISOTROPY

$p = \rho \rightarrow p = -\rho$ FRW

- Stop evolution of DBHF at n and modify overlap rules so no overlap for d(**x**,**y**) > n
- Rescale H (cutoff, and interval) so ||H|| o(1/n). Interpret this as change of coordinates to static dS time from FRW time.
- Find P such that [H,P] = f(P/n) ||P|| = n, and entropy deficit of eigenspace P= e is $2\pi n e$. f(x) linear for small x.

- To understand theory of dS space, start with accelerated observers in finite causal diamond of Minkowski space. Variables satisfy

$$[\psi_i^A{}_P, \psi_B^\dagger{}^j{}_Q]_+ = \delta_i^j \delta_B^A Z_{PQ}$$

- P,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, irredl. w.r.t. fermions. If covariantly constant spinor, Z has unit matrix piece

- Block diagonal $\psi_i^A{}_P$ at large block size leads to set of massless superparticles. SUSY generators come from smearing $\psi_i^A{}_P$ 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 $N^{3/2}$ and momentum cutoff same as field theory estimate of particle states which are not horizon filling black holes.

Particle Decomposition of Variables in Diamond

$$\begin{pmatrix} 1 & 2 & 3 & \dots & \dots & \sqrt{N} \\ \sqrt{N} & 1 & 2 & 3 & \dots & \sqrt{N}-1 \\ \dots & \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots & \dots \\ 3 & 4 & 5 & \dots & 1 & 2 \\ 2 & 3 & 4 & \dots & \sqrt{N} & 1 \end{pmatrix}$$

- HST formalism can accomodate (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. Accelerated observers have higher traces in their Hamiltonian, with acceleration dependent coefficient.
- Susskind fast scrambling conjecture says these will thermalize, with acceleration dependent temperature. "Maximally accelerated observer" (c.f. Jacobson) will see full N^2 complement of states.

Horizon Decomposition of dS Variables

$$\begin{pmatrix} 1 & 2 & 3 & \dots & \dots & \sqrt{N} \\ \sqrt{N} & 1 & 2 & 3 & \dots & \sqrt{N}-1 \\ \dots & \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots & \dots \\ 3 & 4 & 5 & \dots & 1 & 2 \\ 2 & 3 & 4 & \dots & \sqrt{N} & 1 \end{pmatrix}$$

- 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.

Effective Field Theory and the dS black hole in the DBHF

- DBHF --> dS thermodynamics, described by effective field theory with constraint $(\nabla\phi)^2 < 0$. FRW symmetries imposed. No inhomogeneous field fluctuations. Field parametrizes deviation of emergent HST geometry from vacuum Einstein solution. Micro DOF not related to the field. $\mathcal{L} = \sqrt{-g}[-\frac{1}{2}(\nabla\phi)^2 - V_0 + R]$
- Morally equivalent to extraction of field theory Lagrangian from String S-matrix

The ds - DBHF black hole

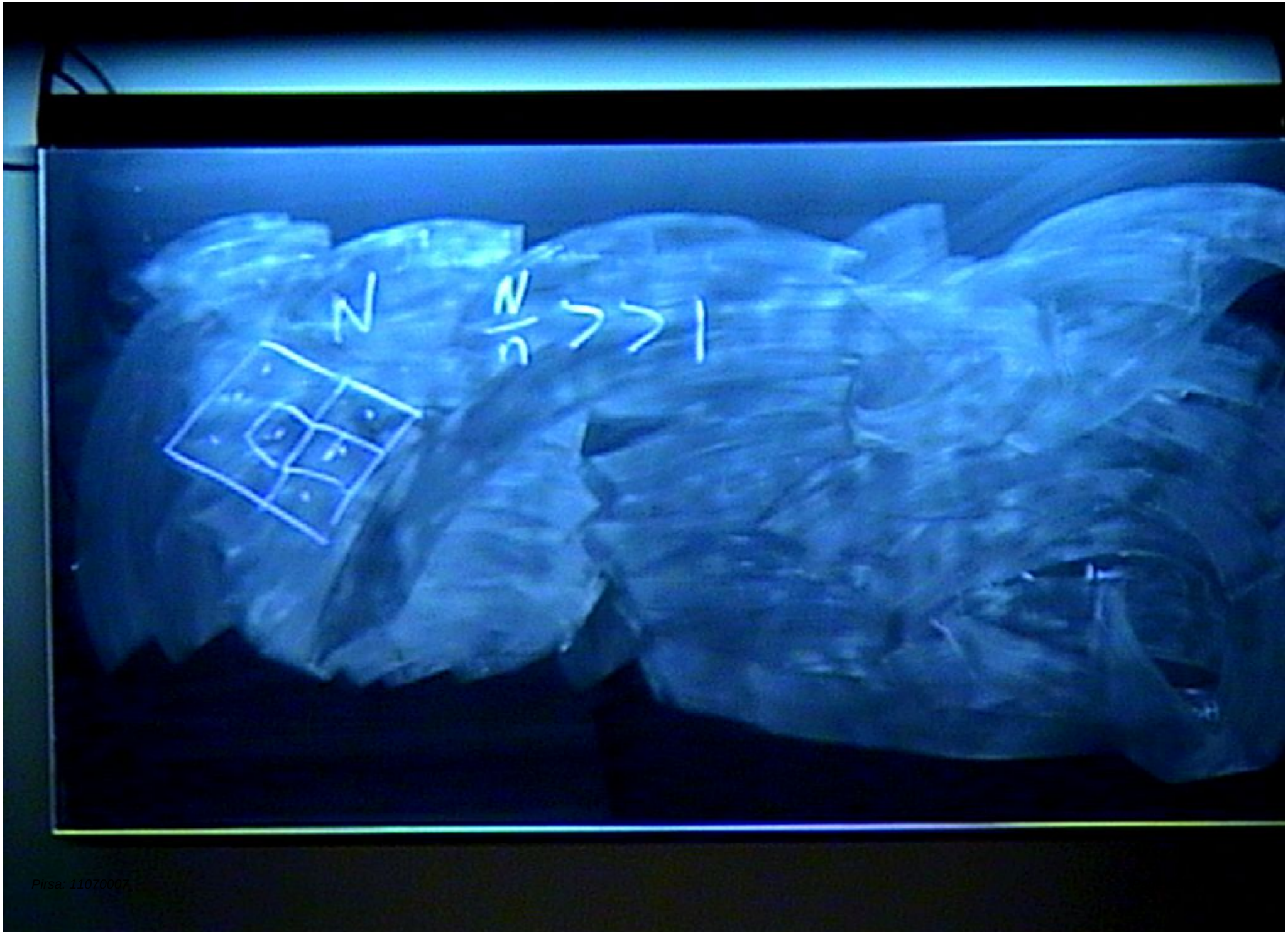
- dS interior, Schwarzschild outside, $p = \rho$ on the horizon, satisfies Israel junction condition (limit of Mazur-Mottola solutions)
- Quantum model, of which, these solutions give coarse grained thermodynamics, exists.

Model Universes

- It's clear there are multiple black hole solutions. Depending on initial black hole positions and velocities, black holes will merge or live in stable isolation.
- The latter situation gives rise to a distribution of "universes" with different values of the c.c. - ripe for anthropic selection

The most entropic universe

- Consistent with asymptotic dS, is the dS-DBHF black hole. Always in equilibrium at maximal entropy. No organized activity "= life" except Boltzmann brains.
- Instead put many horizon volumes of DBHF--> dS_n FRW model inside tilted cube on lattice of observers. Put Hilbert space with entropy $N^2 >> n^2$ on the boundary.



- Allow Hilbert space to grow by local interaction of different inflationary horizon volumes --> some local deformation of dS_N
- Note number of e-folds fixed by N/n
- Large perturbations of dS_n are LOW entropy fluctuations of dS_N "vacuum". Highest entropy from small localized fluctuations.
- Natural origin: tensor product of time avg. dS-n density matrices is dS-N vacuum, but fine grained tensor product states are special

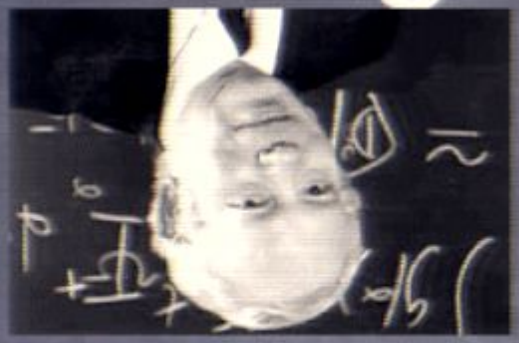
- Statistical fluctuations o(1/n) of local quantities away from coarse grained density matrix average gives spectrum of perturbations around dS space. Gaussian by central limit thm if (N/n) large.
- Multiple, initially non-interacting horizons with identical dynamics lead to emergence of spatial locality when new overlap rules imposed (a guess)

- dS with radius n, plus small local fluctuations evolving to dS with radius N "follows" from underlying theory.
- EFT, scalar with slow roll potential. Size of fluctuations and number of e-folds fixed by quantum model, N and n. Scalar is emergent description of hydrodynamics of this model. It is not obviously related to any particle degree of freedom in asymptotic dS universe.

Anthropic Constraints

- As $\Lambda \to 0$, SUSY restored, QCD scale goes to zero, as does electroweak scale. Conventional particles physics requires observed value of the c.c. Dark matter is Pyramid sector baryon, density determined by same particle physics, also depends on c.c.
- Q, the initial fluctuation amplitude is determined by initial configuration of fluctuations. Entropy considerations push it to zero (DBHF --> dS BH is homogeneous, and maximal entropy).

Turning Weinberg on his head



- Anthropic constraints want Q nonzero. In particular, Weinberg bound is a Lower bound on Q, given values of c.c. and DM density, which are "determined by microphysics"
- $Q > (\Lambda/\rho_0)^{\frac{1}{3}}$, Famous "discrepancy" of factor of 100 in c.c. becomes a factor of 4.6 in Q. Recalling only entropy constraints want small Q, this is not that improbable.

Fluctuations

- Small in order to avoid evolution to empty dS plus a few huge black holes and no local physics. Static by usual dS argument. Gaussian by central limit theorem.
- Nonzero in order to have local physics, galaxies
-

Conclusions

- Real quantum model which is DBHF evolving to dS black hole embedded in DBHF, for any dS radius. Maximal entropy always FRW.
- Incomplete model: multiple horizons of DBHF-->dS FRW evolving to DBHF-dS BH with much smaller c.c. Ratio of c.c.'s controls number of e-folds, Gaussian nature of fluctuations. Inflationary c.c. in Planck units controls size of fluctuations.

- Inflaton field emergent. Not connected to particle physics of late time universe.
- Local space emergent from independent inflationary horizon volumes.?????
- C.C. and primordial DM density determined anthropically/mathematically w/o reference to galaxy formation. Weinberg bound lower bound on fluctuation amplitude.

References for Holographic Space-time

M theory observables for cosmological space-times. Tom Banks (UC, Santa Cruz), W. Fischler (Texas U.). RUNHETC-2001-5, SCIPP-01-2, UTTG-02-01. Feb 2001. 29 pp. e-Print: hep-th/0102077

Recurrent nightmares? Measurement theory in de Sitter space. T. Banks (Rutgers U., Piscataway & UC, Santa Cruz), W. Fischler, S. Paban (Texas U.). RUNHETC-2002-35, SCIPP-02/25, UTTG-11-02. Oct 2002. 19 pp. Published in JHEP 0212 (2002) 062 e-Print: hep-th/0210160

T. Banks (Rutgers U., Piscataway & UC, Santa Cruz), W. Fischler (Texas U.), L. Mannelli (UC, Santa Cruz). *Microscopic quantum mechanics of the p = rho universe*. SCIPP-04/12, UTTG-08-04. Aug 2004. 45 pp. Published in Phys.Rev. D71 (2005) 123514 e-Print: hep-th/0408076

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.

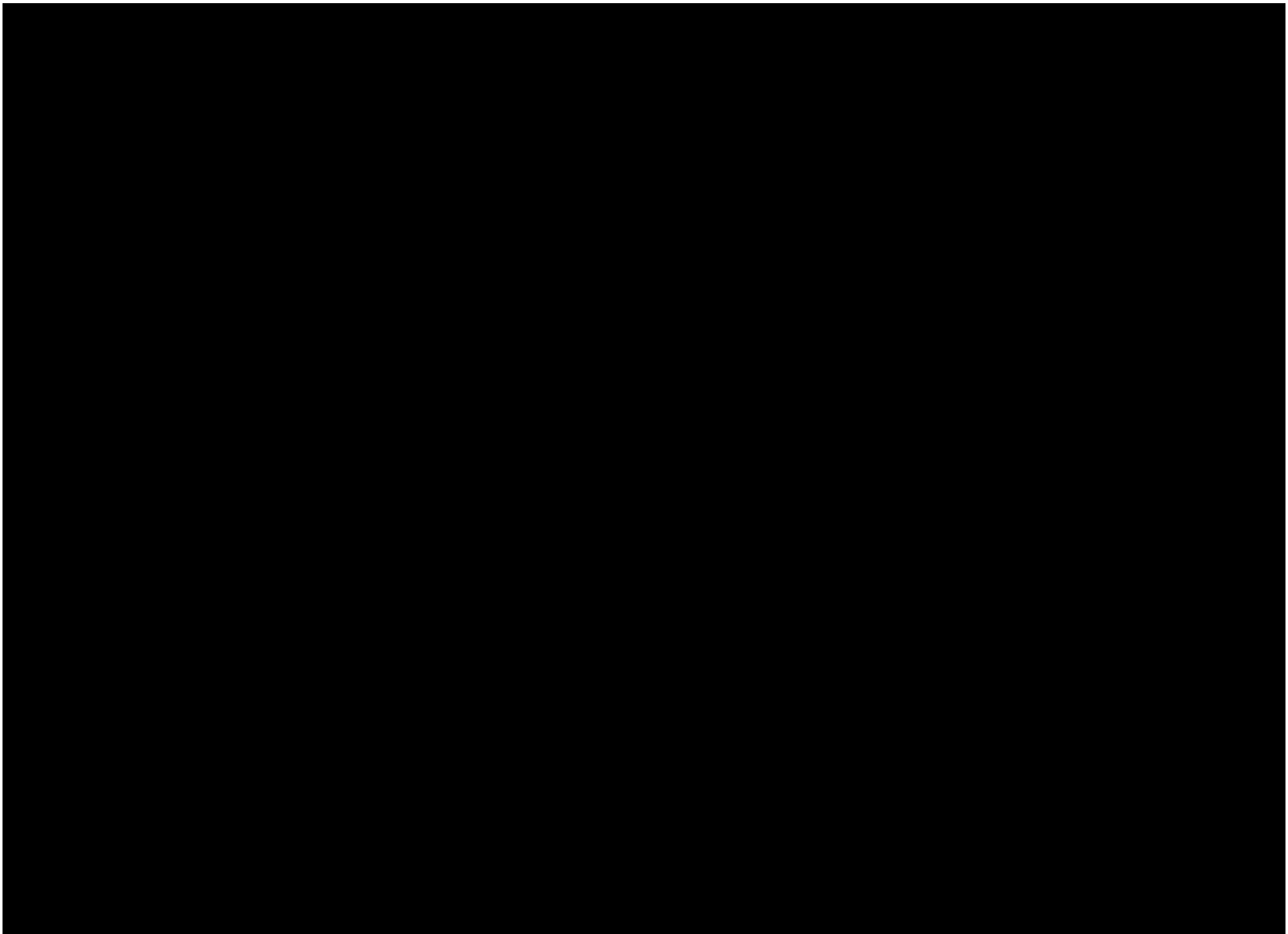
W. Fischler, *Taking de Sitter Seriously*, Talk at the Festschrift for G. West, Los Alamos, ???

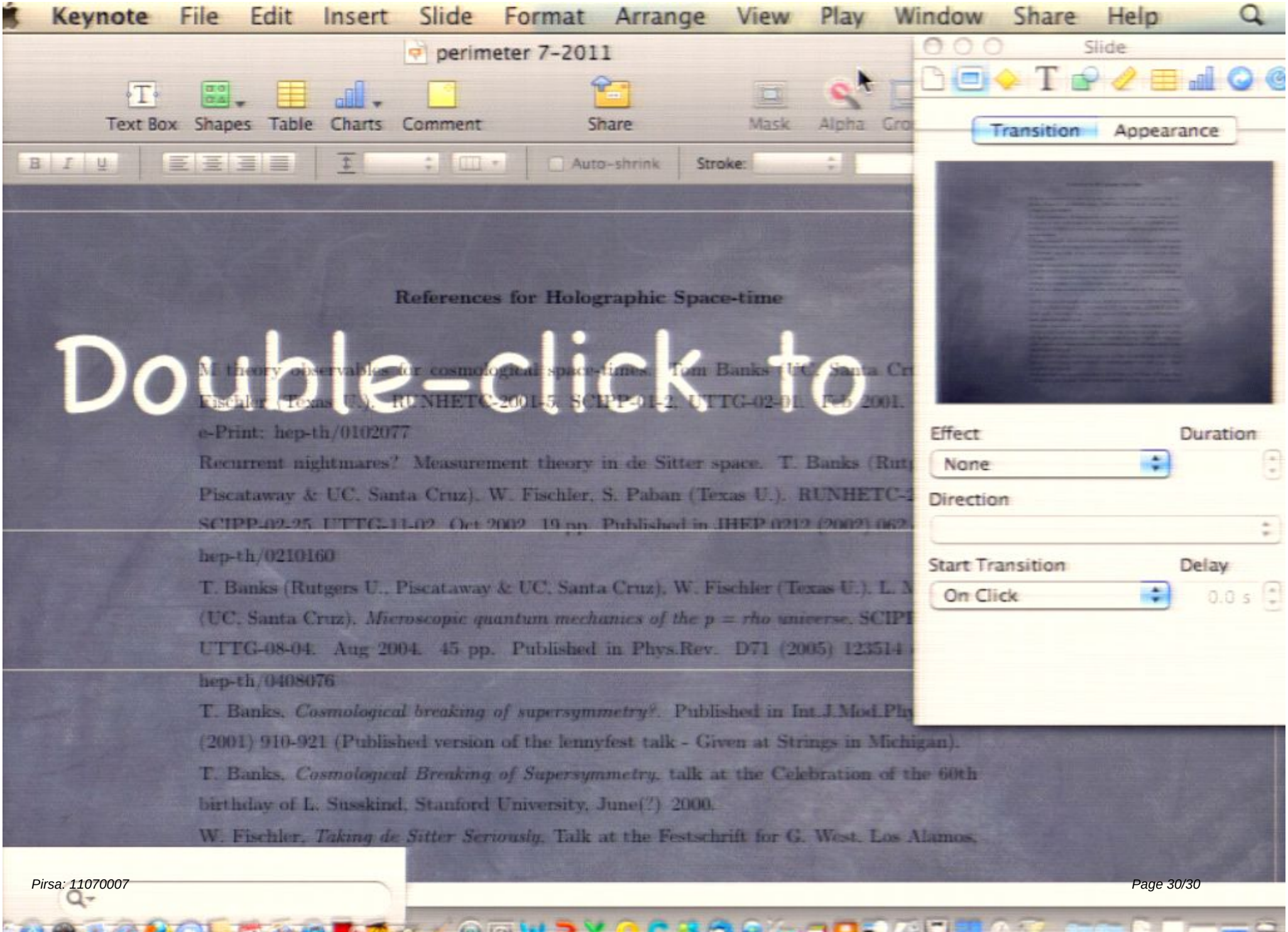
TASI Lectures on Holographic Space-Time, SUSY and Gravitational Effective Field Theory. Tom Banks (Rutgers U., Piscataway & UC, Santa Cruz). RUNHETC-2010-16, SCIPP-10/11. Jul 2010. 58 pp. Lectures given at SPIRES Conference C10/06/01.1 e-Print: arXiv:1007.4001 [hep-th]

Holographic space-time and its phenomenological implications T. Banks (Rutgers U., Piscataway & UC, Santa Cruz). Apr 2010. 15 pp. Published in Int.J.Mod.Phys. A25 (2010) 4875-4887 Prepared for Conference in Honor of SPIRES Conference C10/02/21 (Talk given at the conference for Murray GellMann's 80th birthday, Singapore, February 2010) e-Print: arXiv:1004.2736 [hep-th]

Deriving particle physics from quantum gravity: A Plan. Tom Banks (UC, Santa Cruz & Rutgers U., Piscataway). SCIPP-2009/14, RUNHETC-2009-19. Sep 2009. 34 pp. e-Print: arXiv:0909.3223 [hep-th]

Holographic Space-time from the Big Bang to the de Sitter era. T. Banks (UC, Santa Cruz & Rutgers U., Piscataway). SCIPP-2008-RUNHETC. Sep 2008. 31 pp. Published in




Keynote File Edit Insert Slide Format Arrange View Play Window Share Help
perimeter 7-2011
Text Box Shapes Table Charts Comment Share Mask Alpha
Auto-shrink Stroke:
Slide
Transition Appearance
Effect Duration
None
Direction
Start Transition Delay
On Click
0.0 s
References for Holographic Space-time
Double-click to
e-Print: hep-th/0102077
Recurrent nightmares? Measurement theory in de Sitter space. T. Banks (Rut
Piscataway & UC. Santa Cruz). W. Fischler, S. Paban (Texas U.). RUNHETC-
hep-th/0210160
T. Banks (Rutgers U., Piscataway & UC. Santa Cruz). W. Fischler (Texas U.). L.
(UC. Santa Cruz). Microscopic quantum mechanics of the p = rho universe. SCIP
UTTG-08-04. Aug 2004. 45 pp. Published in Phys.Rev. D71 (2005) 123514
hep-th/0408076
T. Banks, Cosmological breaking of supersymmetry?. Published in Int.J.Mod.Ph
(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,