

# HOLOGRAPHIC COSMOLOGY

Holographic Entropy Bound on Finite Causal Diamonds

Basic Postulate:  $4A = \text{Indim}\mathcal{H}$

QM Measurement Theory  $\Rightarrow H(t)$  Ambiguous

For Finite Causal Diamond

QM Origin of General Covariance?

Gauge Fixed Formalism in General Physical Gauge

Hilbert Space of a Time-like Observer

Sequence of Causal Diamonds

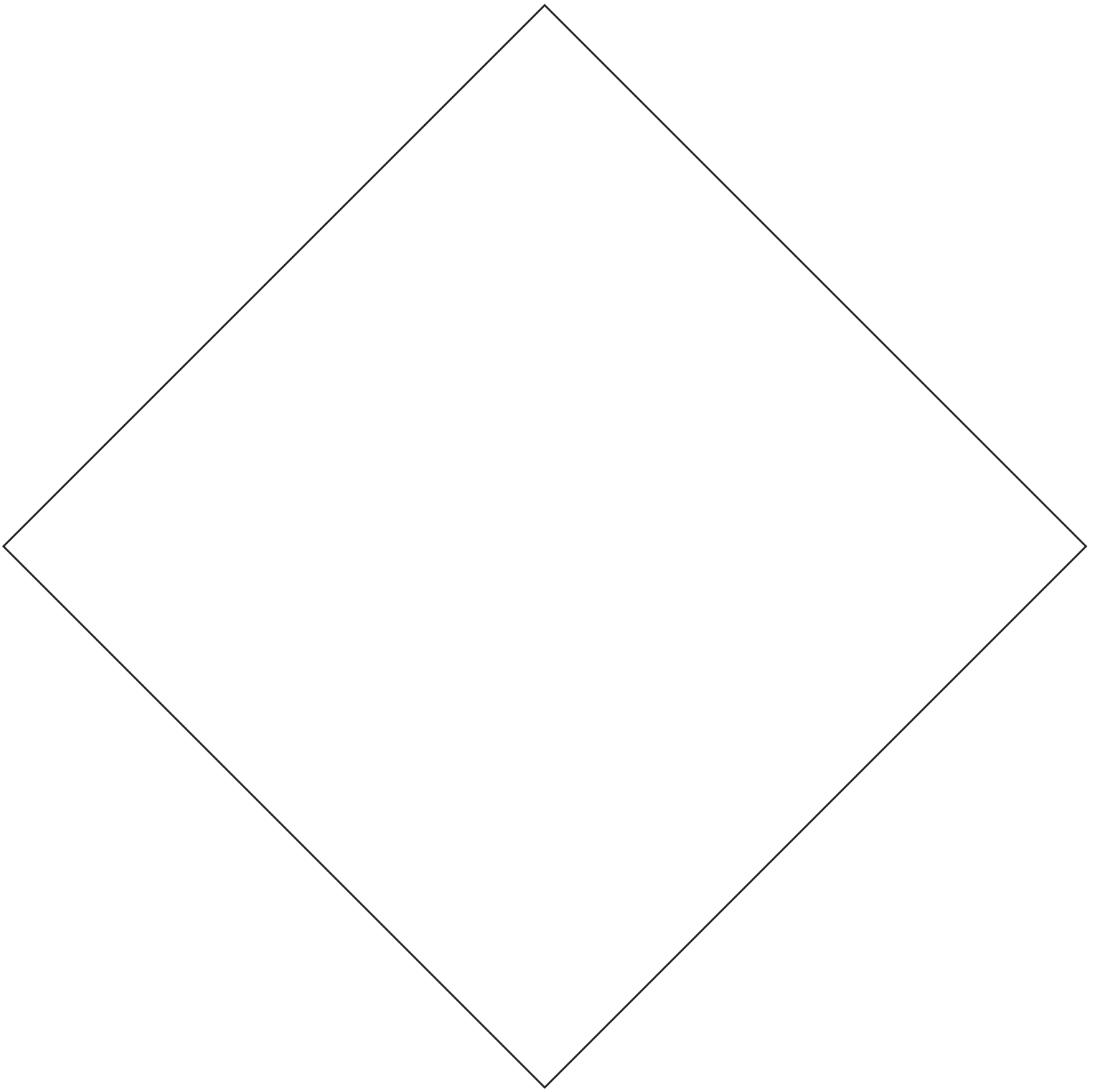
$$\mathcal{H}_N = \mathcal{K} \otimes \mathcal{H}_{N-1}$$

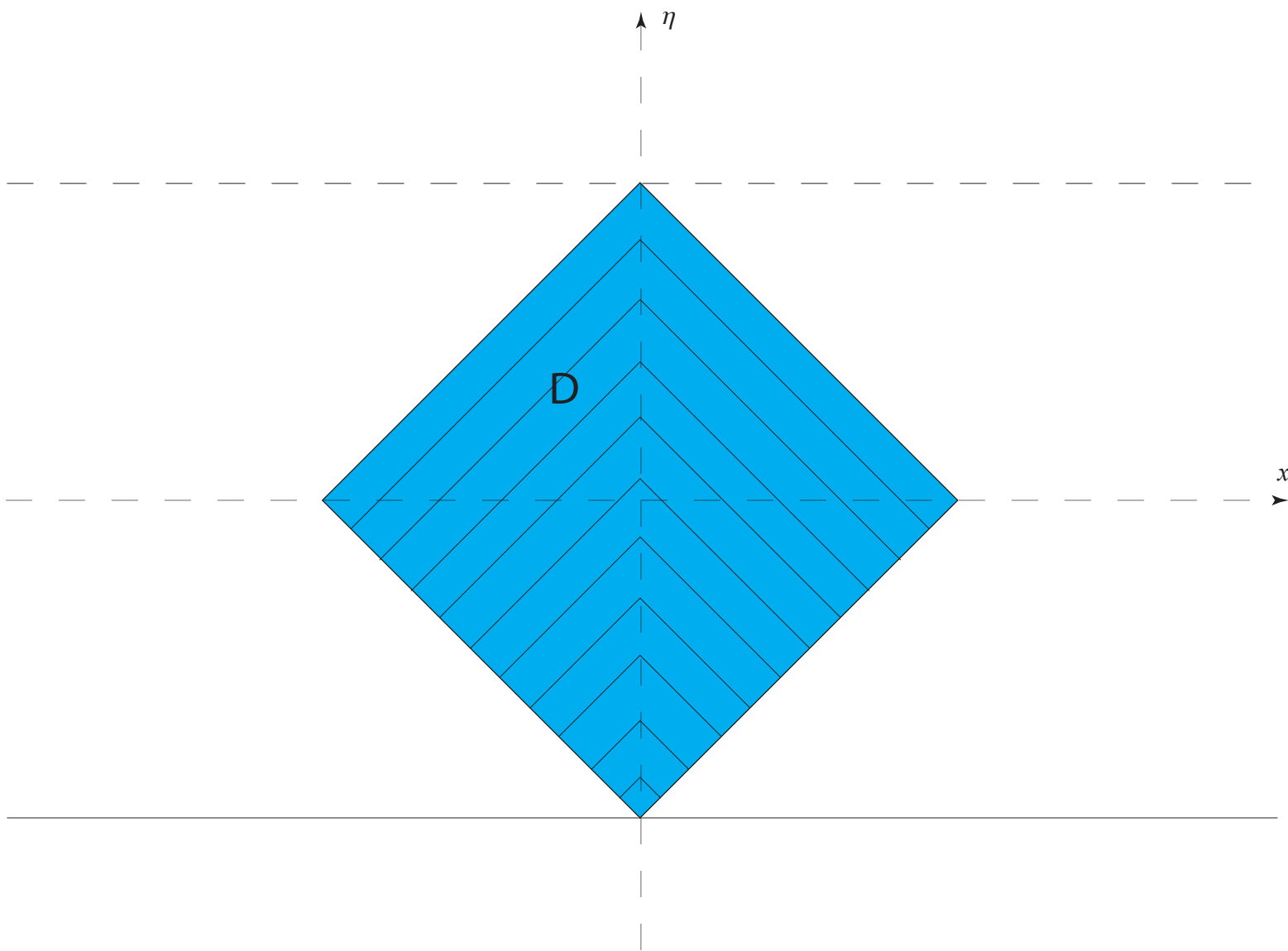
$\mathcal{K}$  Basic Rep of  $[S_a, S_b]_+ = \delta_{ab}$

$S_a$  in Spinor of  $SO(d-2)$

Full Algebra in  $\mathcal{H}_N : [S_a(n), S_b(m)] = \delta_{ab}\delta_{mn}$

In Isotropic Geometries  $S_a(n) \in$  Spinor Bundle Over Fuzzy Sphere





## Time Evolution

Sequence of Unitaries  $U_N(k) = e^{iH_N(k)}$  in Each  $\mathcal{H}_N$

In Cosmology  $U_N(k)$  Evolves From Future Tip of  $D_{k-1}$   
To Future Tip of  $D_k$

$$U_N(k) = U_l(k) \otimes V_{Nl}(k) \quad \text{if } l \geq k$$

$V_{Nl}(k)$  Commutes With Op. Alg. of  $\mathcal{H}_l$

Other People's Observations

Spatial Lattice of Observers With Topology of  $R^{d-1}$

$$\mathcal{H}_N(\mathbf{x}), U_N(k, \mathbf{x}), S_a(n, \mathbf{x})$$

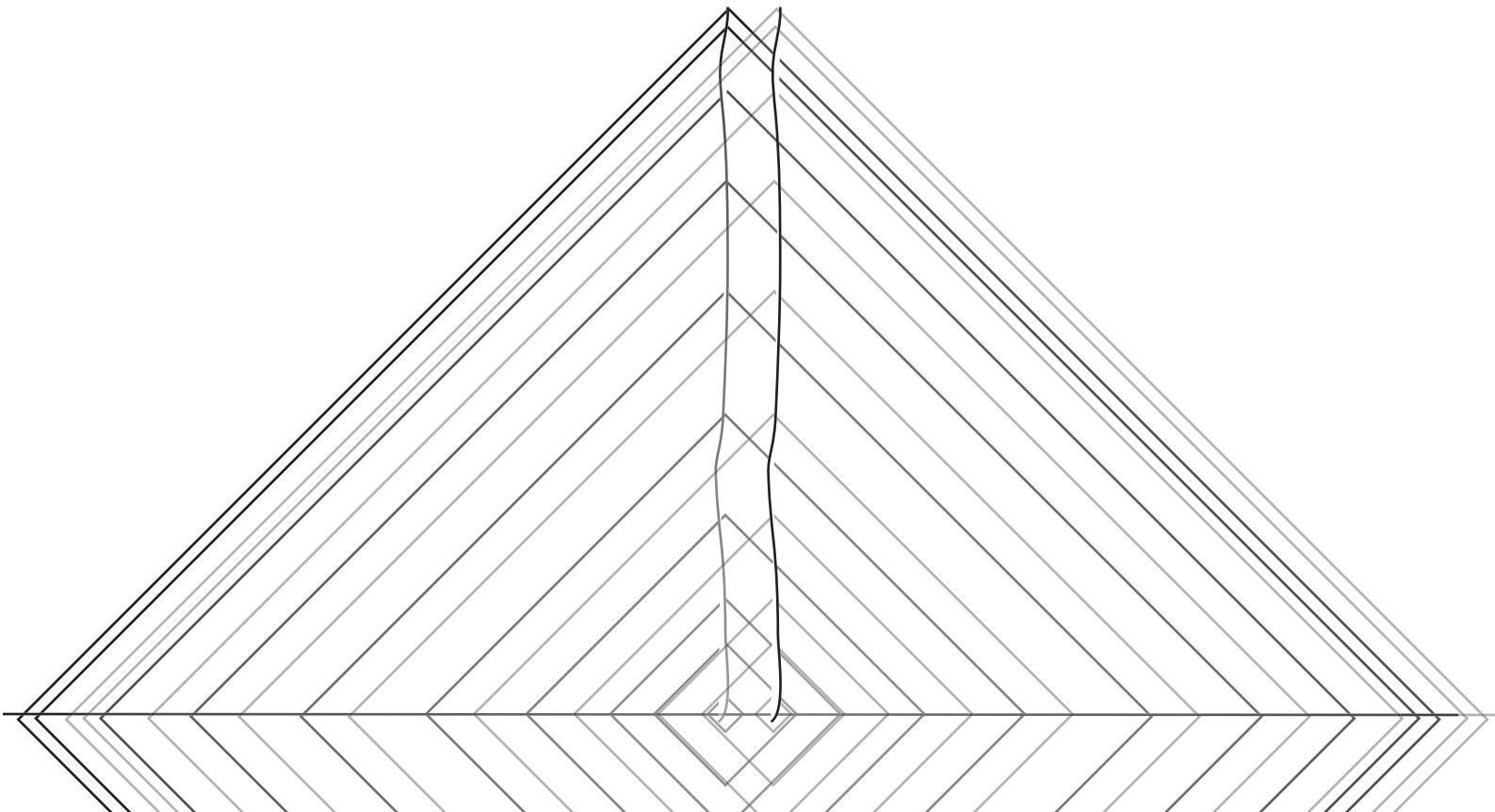
$\mathcal{O}_N(\mathbf{x}, \mathbf{y})$  Tensor Factor of Both  $\mathcal{H}_N(\mathbf{x})$  and  $\mathcal{H}_N(\mathbf{y})$

$\dim \mathcal{O}_N(\mathbf{x}, \mathbf{y})$  Decreases Along SA Lattice Walks

$\dim \mathcal{O}_N(\mathbf{x}, \mathbf{y}) = (\dim \mathcal{K})^{N-1}$  For Nearest Neighbors

Dynamical Consistency Condition:  $U_N(k, \mathbf{x}) = U_N(k, \mathbf{y})$  On  $\mathcal{O}_N(\mathbf{x}, \mathbf{y})$

Analog of Closure of Wheeler DeWitt Constraint Algebra



## The Dense Black Hole Fluid Phase of the Early Universe

Big Bang:  $\mathcal{H}_0(\mathbf{x}) = \mathcal{K}$

BKL: *et. seq.*: Dynamics Near **BB** Chaotic

BFM:  $H_N(N, \mathbf{x})$  is Random Hermitian Operator  
Chosen From the Following Distribution

$$H_N^{(2)}(N, \mathbf{x}) = \frac{1}{N} \sum S_a(n) S_a(m) h_N^{mn}$$

With  $h$  a Gaussian Random  $N \times N$  Anti-symmetric Matrix

For Large  $N$  This Gives a Free 1 + 1 Fermion With  
Cut-off of Order 1 on Interval of Length  $N$

Add Random RG-Irrelevant Perturbations

$h_N$  Chosen Ind. at Each  $N$ : Dynamics Random Though Spectrum Universal

Choose  $\mathcal{O}_N(\mathbf{x}, \mathbf{y}) = \mathcal{H}_{N-k}$

$k$  is Minimum SA Lattice Walk Length Between  $\mathbf{x}, \mathbf{y}$

If We Choose Same Sequence of Hamiltonians at Each  $\mathbf{x}$   
Dynamical Consistency Conditions Are Satisfied

Homogeneous, Isotropic, Flat Universe With an Exact Scaling Symmetry as  $N \rightarrow \infty$

Several Calculations Show Friedmann Eqn Is Satisfied and  $p = \rho$

Energy in Given Horizon Volume Scales Like Mass of  
Horizon Filling Black Hole

Volume of Causal Diamond, Volume of Overlap of Two Diamonds

Most Constants are Definitions, But Overlap Calculation  
Predicts a Pure Number

Wrong By a Factor of  $d - 2$

Hope Small Modification of Overlap Rule Fixes This

## Heuristic Treatment of Real Cosmology

$p = \rho$  Exact But Boring Solution of Quantum Gravity

It Has Highest Entropy Initial Conditions

Want Highest Entropy Initial Conditions With  
Large “Normal” Space-time Region

Israel Condition For Sphere of  $p = w\rho$  Embedded in  $p = \rho$

Coordinate Volume of Sphere Shrinks Unless  $w = \pm 1$

Also Follows From Entropy Maximization

Max. Entropy Initial Conditions in Small Horizon Volumes  
Near Big Bang

“Tinkertoy” Embedded in  $p = \rho$

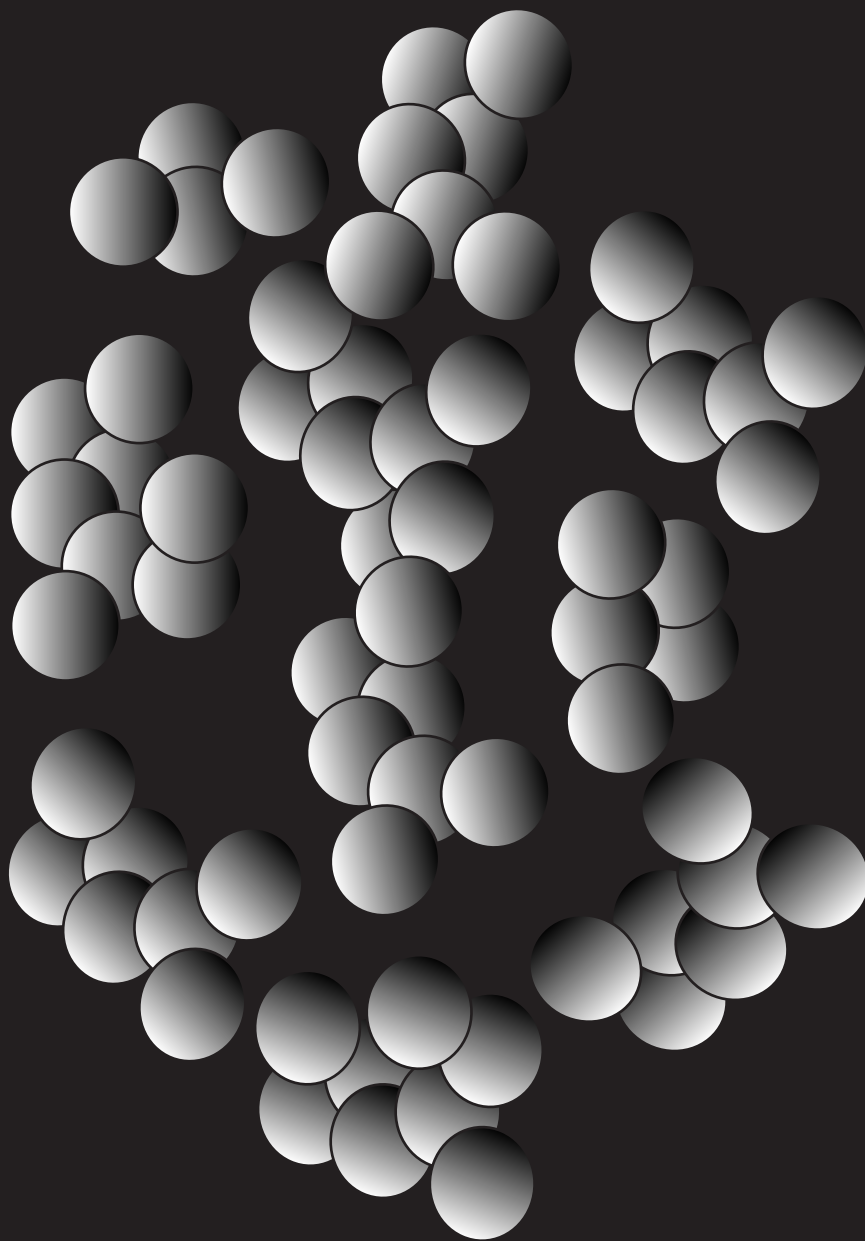
Tinker-toy Components Filled With Sub-Max Black Holes  
Which Quickly Decay Leaving Radiation Dominated Universe

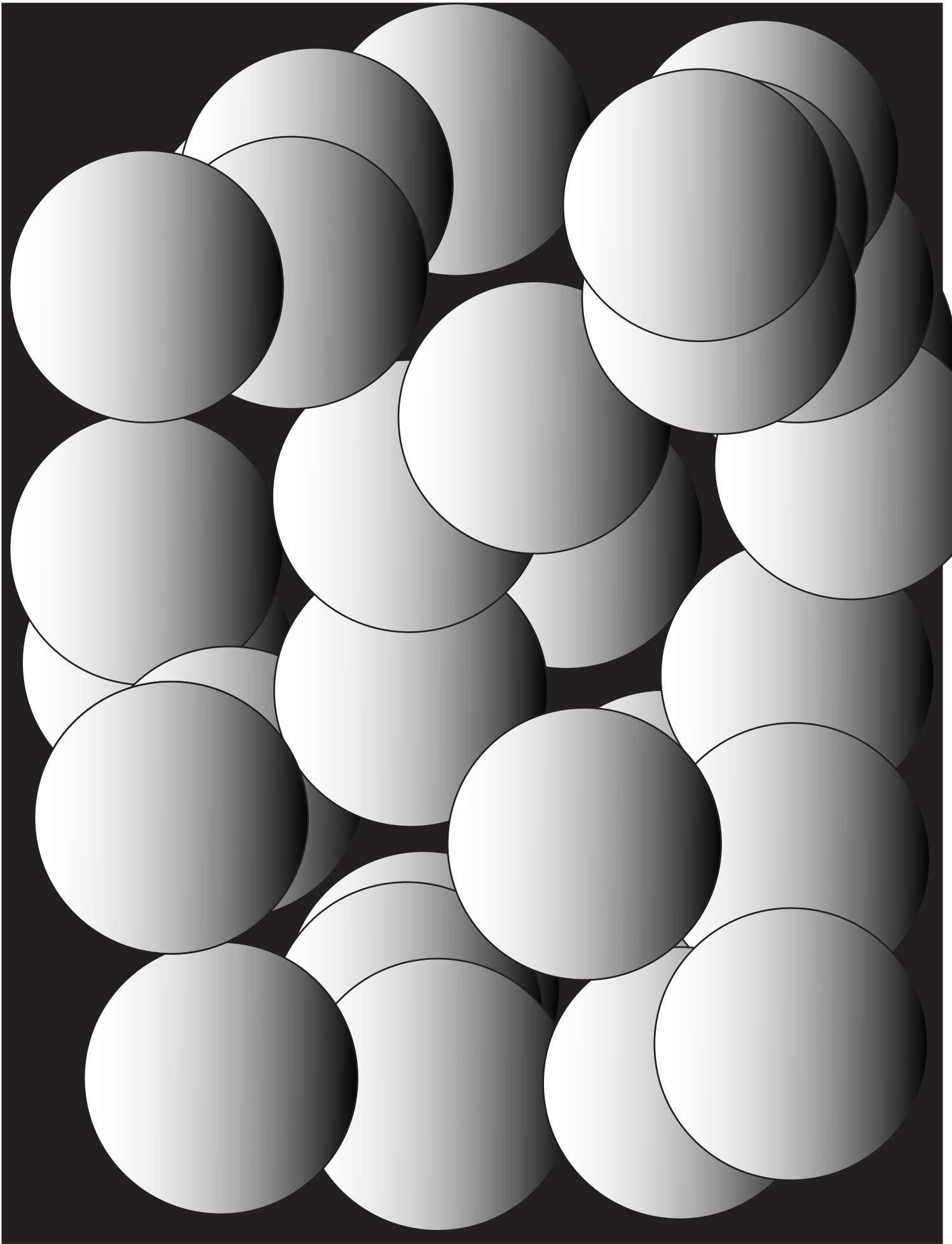
In Equal Area Slicing, Physical Volume of Radiation Region  
Increases Relative To  $p = \rho$  Region

Phase Transition to Dilute Black Hole Gas  
At Critical Horizon Size  $M$

Density Fluctuations in DLBHG Originate As Stat.  
Fluctuations in Tinkertoy Density, Processed Thru  
 $p = \rho$  Evolution

Exact Scale Invariance of Latter Implies HZ Spectrum  
For Scales Ranging From  $M$  to 1 When  $R_H \sim M$





Fluctuations Must Be Small In Order to Avoid Transition  
Back to DSBHF, But Cannot Yet Estimate  
Their Amplitude or Statistics

Scale Factor Increases by  $a > 10$  While DLBHG Phase Lasts  
More or Less Homogeneous Background, in Which Inflation Initiation is Probable

$$V_I = \mu^4 f(\phi/M_P) \text{ With } \mu^4 \sim \frac{1}{a^3 M^2}$$

Expect  $N_e$  e-folds With  $N_e \sim 1 - 100$ .  
With  $1/N_e$  Tuning of Dimensionless Parameters

Nucleosynthesis Bound on Reheat Temp:  $\mu^3 \geq 10^{22}$

For Some Values of  $M, a, N_e$   $p = \rho$  Fluctuations Are Of  
Scale Relevant to CMB

Can Also Have Inflationary Fluctuations, But Large  $M$   
 $\Rightarrow$  Small  $\mu$   
So It Must Be Some Kind of Hybrid Inflation

## Global Meta-Physics

Israel Condition on Big Sphere Enclosing Tinker-toy  
Can Only Be Satisfied if Normal Region Asymptotes to STABLE dS

Global Geometry Flat  $p = \rho$  Universe With dS Bubbles of Various Sizes

C.C. of Our Universe Is a Random Variable in This Larger System

Only Meta-physical If dS Subuniverse Do Not Interact

## Conclusions

Mathematical Quantum Model of  $p = \rho$  Universe  
(Almost) Reproduces Geometrical Properties

Hypothetical Extension With Inhomogeneities  
Provides an Attractive Model of Big Bang Cosmology

Sets Up Conditions for Inflation

Alternative Source of Scale Invariant Fluctuations

Strong Constraints on Inflationary Model - Probably Low Scale

If CMB Comes From Inflationary Fluctuations  
Must Be Hybrid Inflation Model

Probably Requires Low Energy Baryogenesis  
 $T_{RH}$  Might Be Too Low for SUSY Dark Matter