HOLOGRAPHIC COSMOLOGY

KNOWN FORMULATIONS OF QG
HOLOGRAPHIC ON BOUNDARY

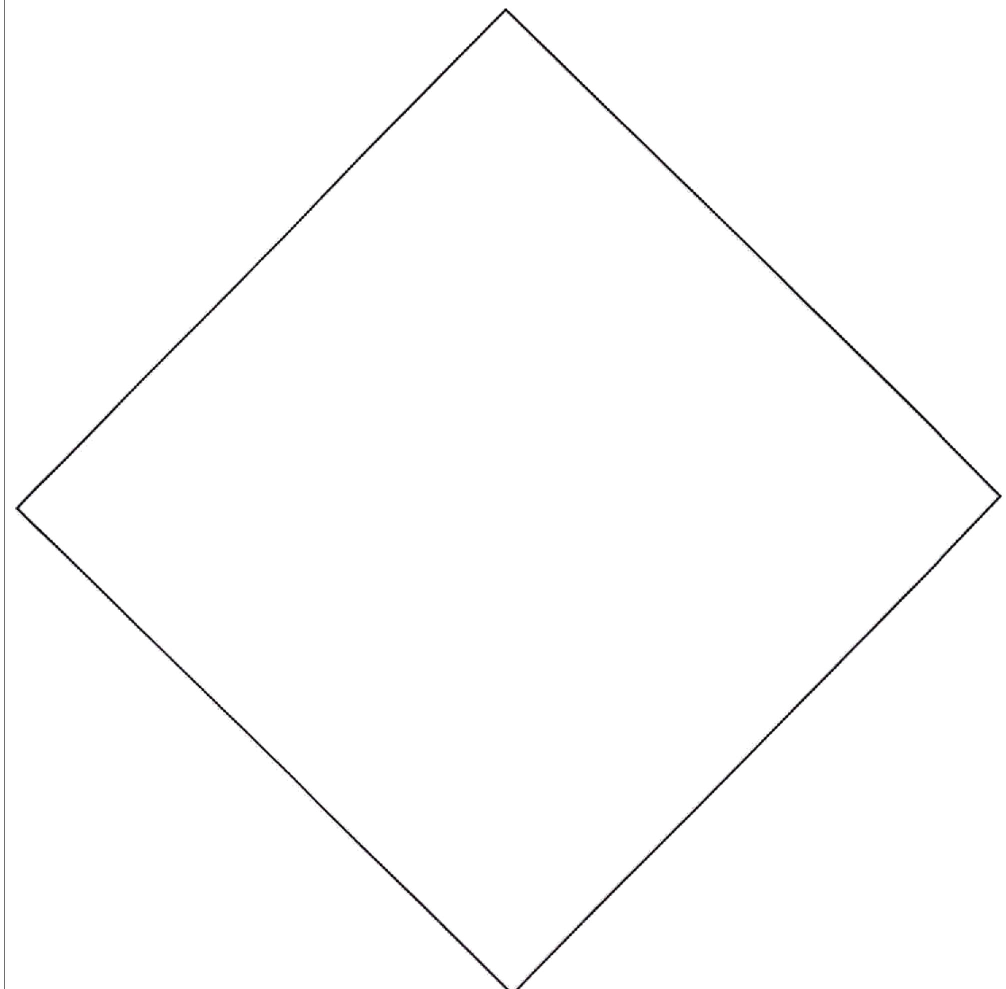
MEASUREMENT THEORY + GRAVITY →
LOCAL PHYSICS **MUST** BE AMBIGUOUS/GAUGE VARIANT

CONNECTION TO PROBLEM OF TIME:
$U(t, t_0)$ NOT UNIQUELY SPECIFIED

HOLOPRINZIP: SMALL CAUSAL DIAMOND HAS FINITE ENTROPY
INTERPRET AS FINITE ln dim$\mathcal{H}$

BOUNDARIES ENTER IN FATE OF LARGE CAUSAL DIAMONDS

ASY FLAT: N GOES TO INFINITY WITH TIMELIKE SEPARATION
ASY ADS: N GOES TO INFINITY
AT FINITE TIMELIKE SEPARATION
ASY DS: N STAYS FINITE FOR ∞ TIMELIKE SEPARATION
BANG OR CRUNCH: DIAMONDS → CONES



HILBERT SPACE OF AN OBSERVER

AND IT'S NEIGHBORS

$$\mathcal{H}_N(\mathbf{x}) = \mathcal{K} \otimes \mathcal{H}_{N-1}(|\mathbf{x})$$

$$\text{Dim } \mathcal{K} = e^{A_0}$$

IN $\mathcal{H}_N(\mathbf{x})$: $U_N(k)$ $0 \leq k \leq N$

$k < N$, $U_N(k) = U_k(k) \otimes V_N(k)$

NEAREST NEIGHBORS: $\mathbf{x}$ CUBIC SPATIAL LATTICE (TOPOLOGY)

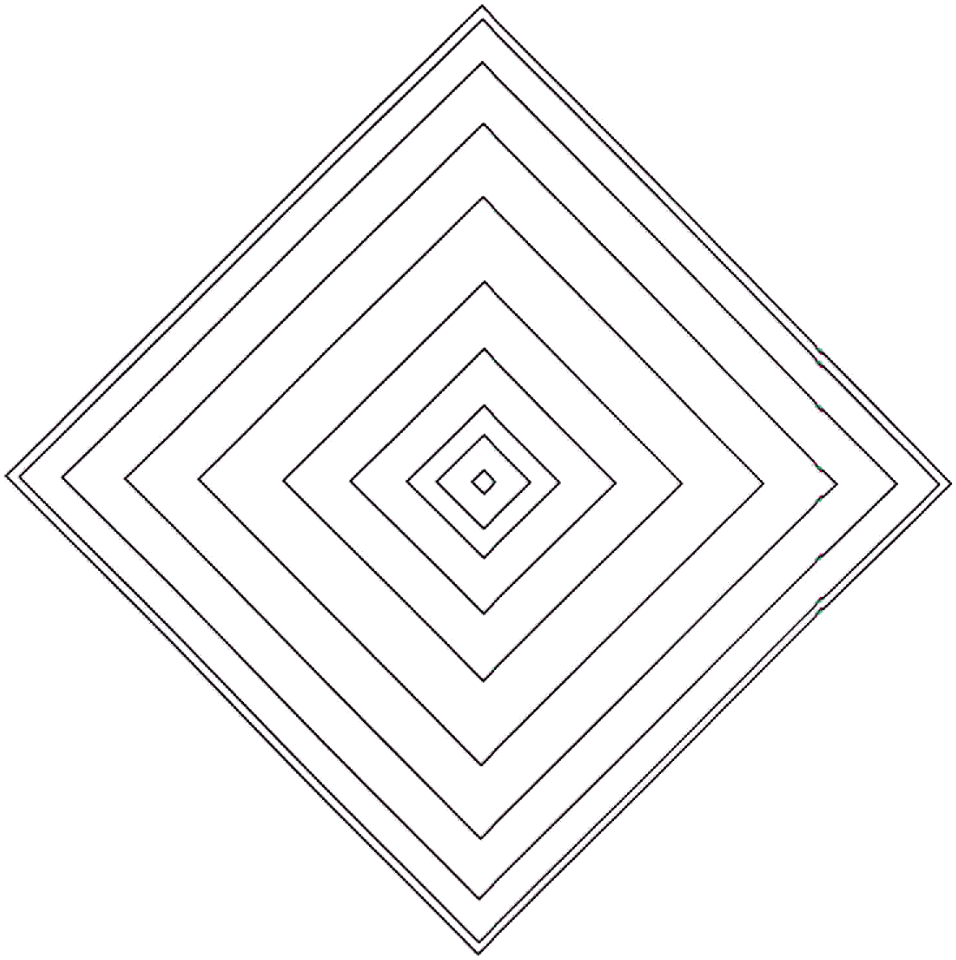
TIPS OF CAUSAL DIAMONDS ON LATTICE POINTS

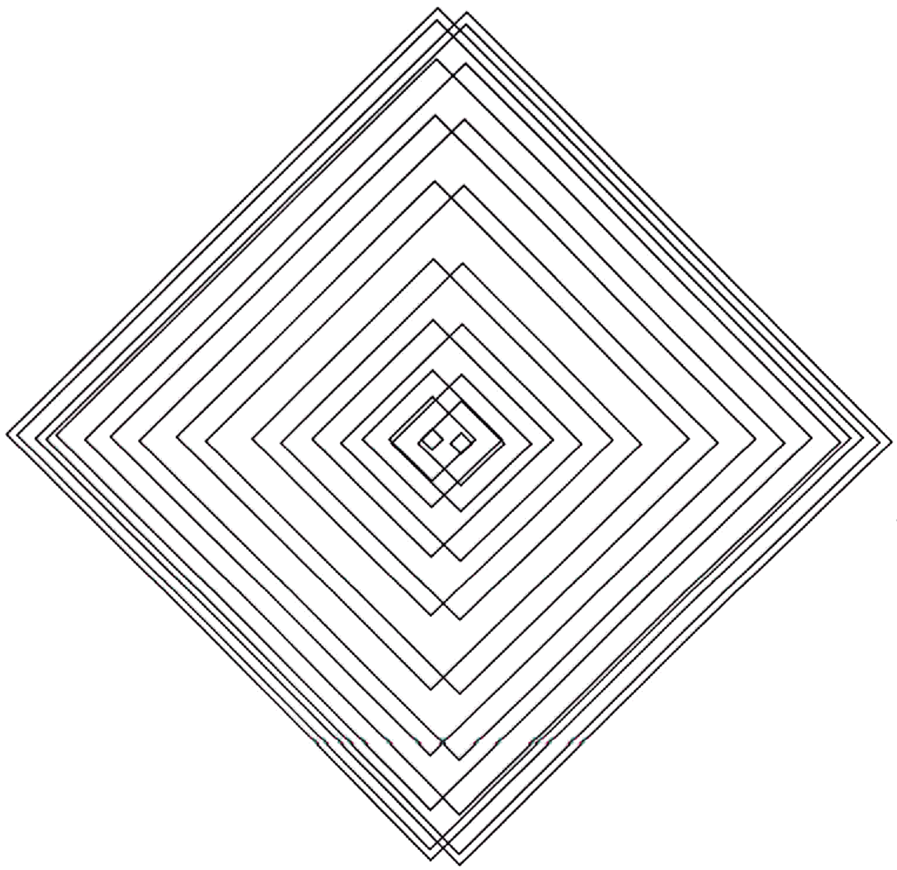
FOR EACH N AND μ MAP $C(N, \mathbf{x}, \mu)$ FROM

$e^{(N-1)A_0}$ DIM'L FACTOR OF $\mathcal{H}_N(\mathbf{x}) \rightarrow \mathcal{H}_N(\mathbf{x} + \mu)$

$C's$ AND $U_N(k, \mathbf{y})$ MUST BE COMPATIBLE

UV CUTOFF BUT GROWS WITH AREA $A \sim L^{D-2}$





VARIABLES: SUSY AND THE HOLOSCREENS

CARTAN PENROSE RELATION: $\bar{\psi}\gamma^N\psi\gamma_N\psi = 0$

DEFINES NULL VECTOR $\bar{\psi}\gamma^M\psi$ AND TRANSVERSE PLANE $\bar{\psi}\gamma^{M_1\ldots M_k}\psi$

CLASSICAL PROJECTIVE GAUGE INVARIANCE: $\psi \to \lambda\psi$

QUANTUM MECHANICS: BHFSB ENTROPY RELATION

BREAKS CONFORMAL INV.

INTRODUCES SPACETIME METRIC

E.G. 11D: $[\hat{S}_a, \hat{S}_b]_+ = \delta_{ab}$ $S_a \in \mathbf{16}$ OF $SO(9)$

CHOOSE $\mathcal{K}$ IRREP OF $\hat{S}_a$: QUANTIZED HOLOPIXEL

PROJECTIVE INVARIANCE BROKEN TO Z_2

Z_2 GAUGE (KLEIN) TRANSFORMATION

MAKES $S_a(N, \mathbf{x})$ FERMIONS

APPLICATION TO COSMOLOGY

DIAMONDS $\rightarrow$ CONES, INITIAL STATE PURE

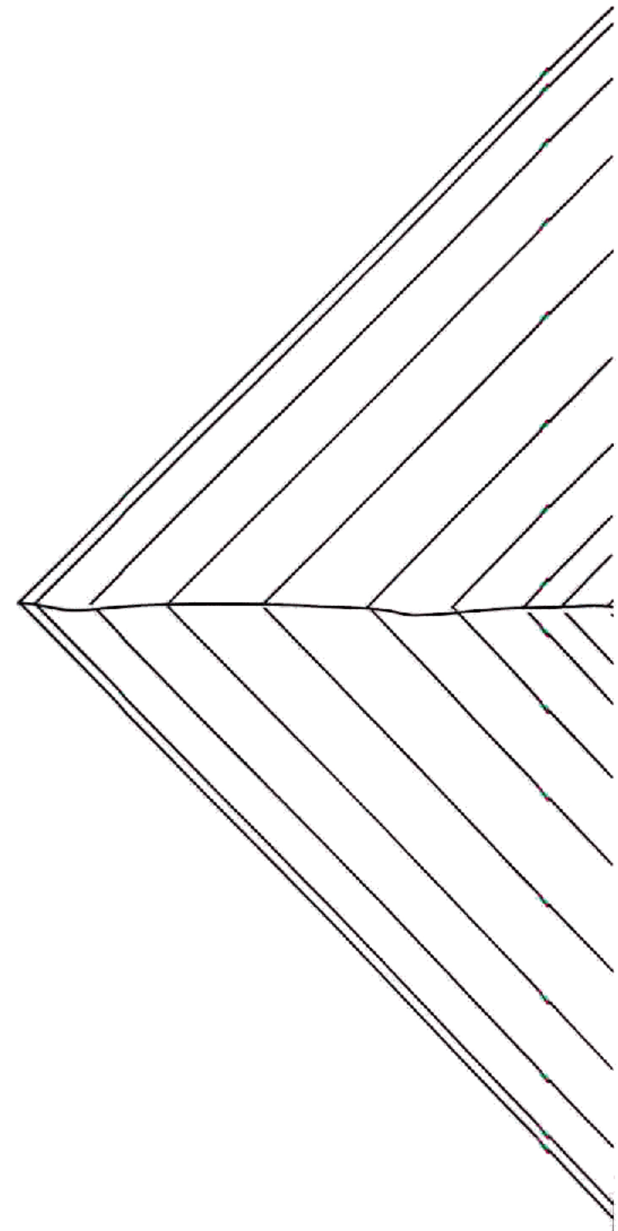
CLASSICAL CLUES: $p = \rho$ DOMINATES NEAR SING IF IT EXISTS
$p = \rho$ CAN SATURATE COVARIANT ENTROPY
BOUND AT ALL TIMES
BKL CHAOS NEAR SINGULARITY
MISNER MIXMASTER, DAMOUR ET. AL. BILLIARDS
PROBLEM OF TIME SUGGESTS RANDOM $H(t)$

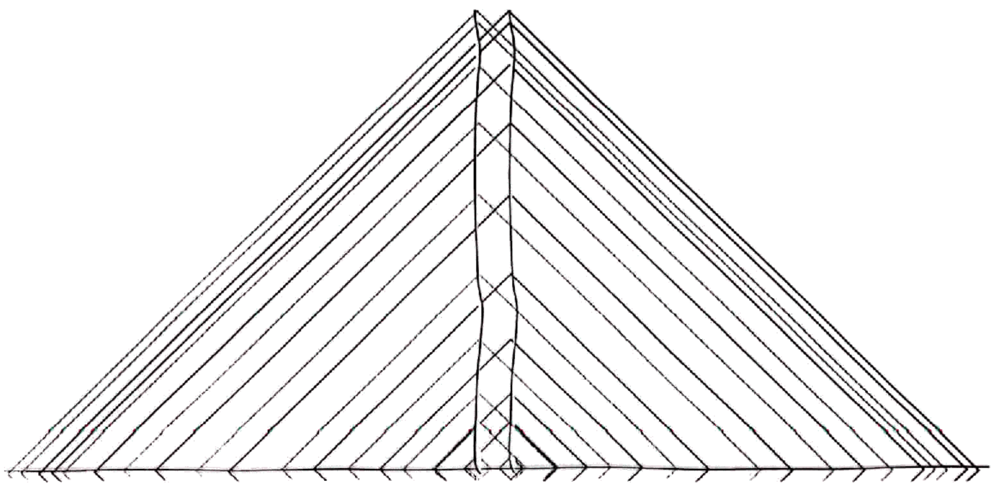
FIXED $\mathbf{x}$, $U_N(k) = e^{-iH_N(k)}$
$H_N(N) = \frac{1}{N}[S^T h_N S + I\{S\}]$
$h_N = -h_N^T$: GAUSSIAN RANDOM $2^{[\frac{d-2}{2}]}N \times 2^{[\frac{d-2}{2}]}N$ MATRIX

LARGE N: H_N APPROACHES $1+1$ CFT (I CHOSEN IRRELEVANT
COEFFS OF I RANDOM ORDER ONE,
SIGN OF S^4 TERMS REPULSIVE
$1+1$ UV CUTOFF $o(1)$, SPACING $o(1/N)$
$\sigma \propto \sqrt{\rho}$: IDENTIFY WITH
SPACE-TIME ENTROPY AND ENERGY DENSITIES

TOTAL ENERGY ~ 1

4





IN ANY FLAT FRW : AREA $\sim t^{d-2}$

$\Delta N H_N \sim dt N^{\frac{d-3}{d-2}} H(t)$ IF $H_N \sim o(1)$,

$H(t)$ MASS OF BLACK HOLE OF ENTROPY N

OVERLAP CONDITIONS SATISFIED BY TAKING

OVERLAP TO BE $\mathcal{H}_{N-1}(\mathbf{x})$

PROBLEM WITH INHOMOGENEOUS INITIAL CONDITIONS, BUT THIS IS ERASED

BY RANDOM EVOLUTION ??????

HEURISTIC PICTURE: THE DENSE BLACK HOLE FLUID

$$n \sim \frac{1}{R_S^{d-1}}$$
$$\rho \sim R_S^{(d-3)-(d-1)} = R_S^{-2}$$
$$\sigma \sim R_S^{(d-2)-(d-1)} \sim \sqrt{\rho}$$

EQN OF STATE IF BLACK HOLES CONSTANTLY MERGE

PREVIOUS AS MOTIVATION FOR

EARLIER HEURISTIC PICTURE OF $p = \rho$

“SOLVES HORIZON AND FLATNESS PROBLEMS”

EQUAL AREA SLICING: SLICES ARE HOMOGENEOUS

BECAUSE HOMOGENEOUS FLUID SATURATES ENTROPY

BUT IT ONLY WORKS FOR FLAT FRW

FLAT $p = \rho$ UNIVERSE STABLE QUANTUM COSMOLOGY

MOST ENTROPIC INITIAL CONDITIONS

BUT BORING !!!!!!

WHAT ARE THE MOST ENTROPIC

“INTERESTING” INITIAL CONDITIONS?

HEURISTIC: ISRAEL COND’N FOR SPHERE OF “NORMAL” FRW

$-1 < w$: $L(t) \sim Lt^{\frac{1-w}{3(1+w)}}$

MUST CHOOSE INITIAL COORD SPHERE >> CURRENT HORIZON

MORE ENTROPIC TO CHOOSE “FRACTAL”

COVERING FRACTION ϵ OF THIS VOLUME

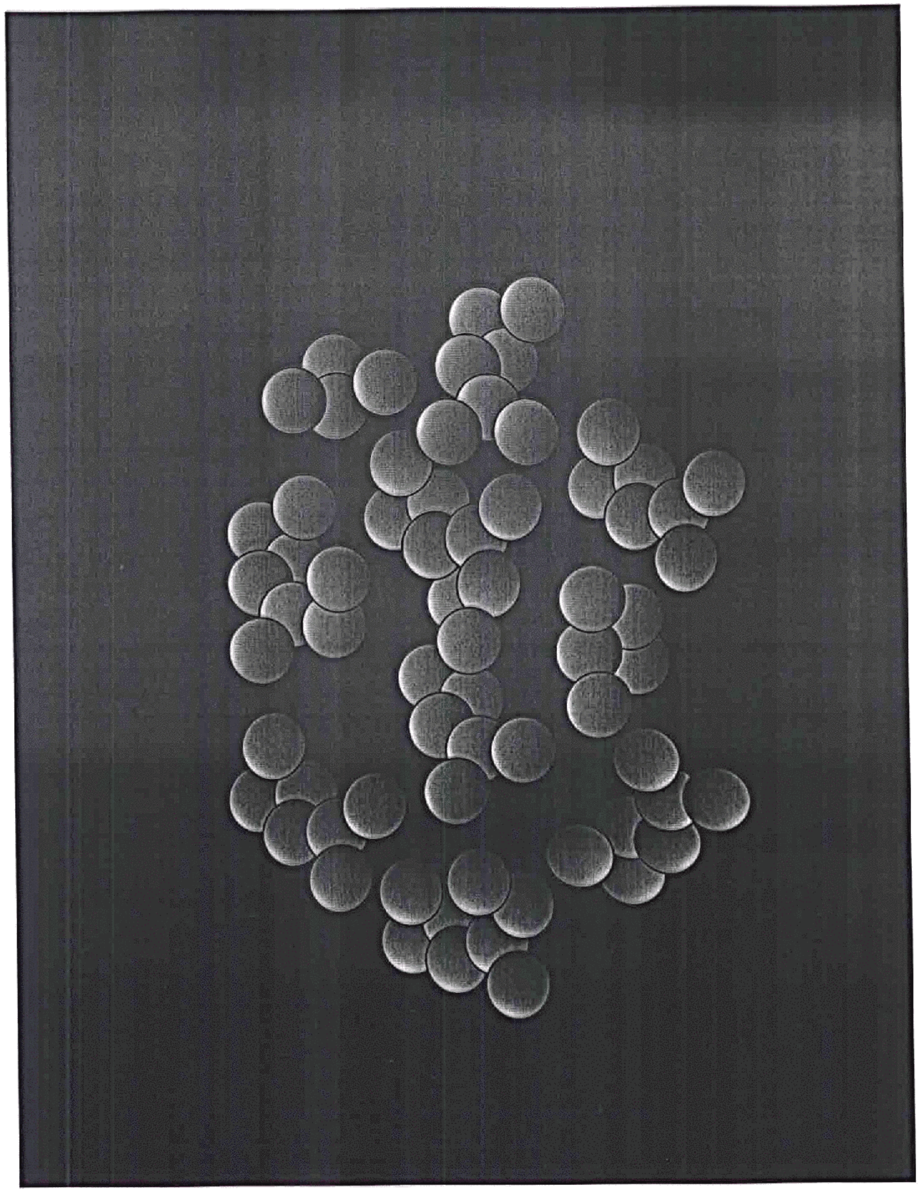
IN EQ AREA SLICING “NORMAL” VOLUME

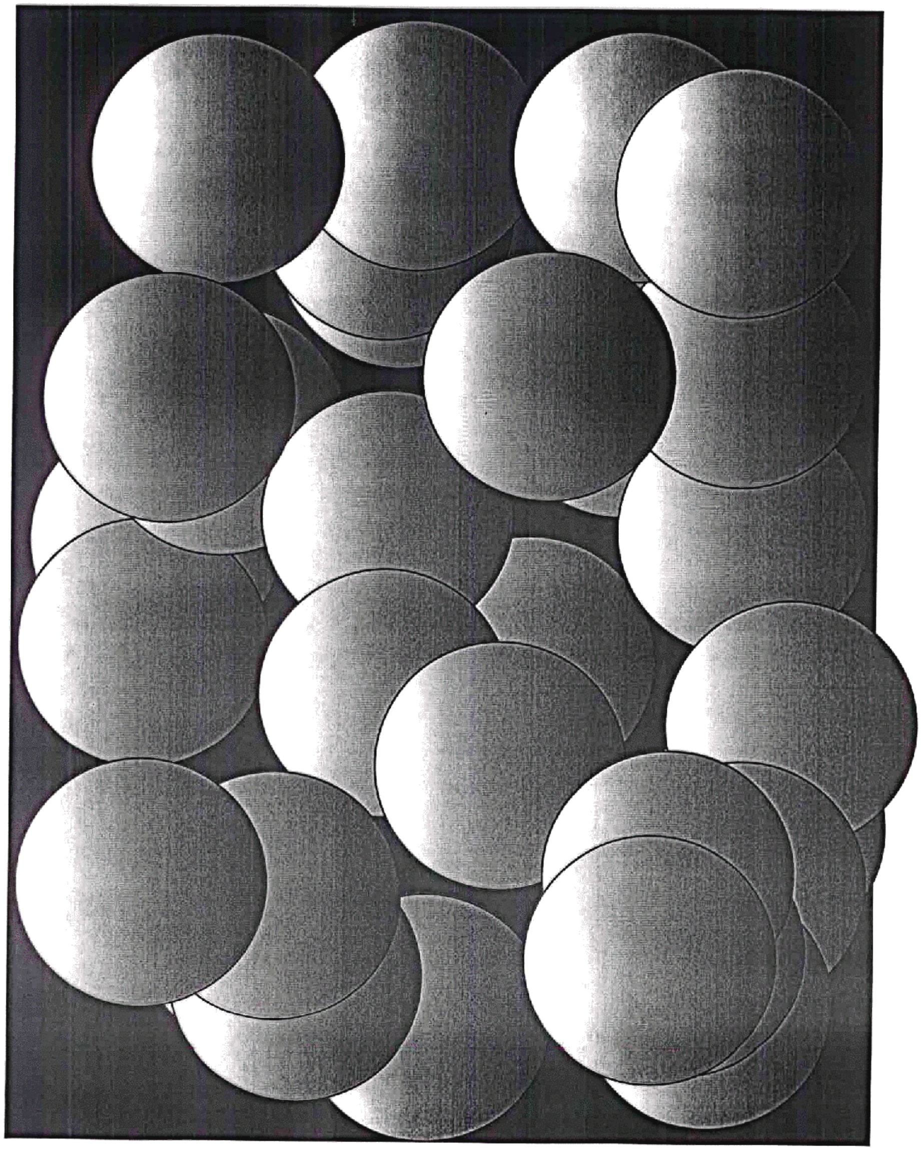
GROWS FASTER THAN $p = \rho$

→ NORMAL UNIVERSE WITH INTERSTITIAL BLACK HOLES

DILUTE BLACK HOLE GAS

$\frac{M \sim 1}{\epsilon^2}$ AVG. BH MASS AT END OF $p = \rho$





FLUCTUATIONS

IN HOLOGRAPHIC COSMOLOGY PRIMORDIAL FLUCTUATIONS ARE FLUCTUATIONS IN THE DENSITY OF BLACK HOLES JUST AFTER THE PHASE TRANSITION TO DILUTE BLACK HOLE GAS - BOTH POSITION AND SIZE FLUCTUATIONS

CALCULATED IN TERMS OF DENSITY FLUCTUATIONS $P(\mathbf{x}, t, t')$ OF NORMAL REGIONS DURING $p = \rho$ PHASE

$$< \delta(k, T)\delta(-k, T) >= \int_{t_0}^{T} ds \int_{t_0}^{T} ds' f(k, s) f(-k, s') P(k, s, s')$$

f SHORT RANGE, GIVES INTERSTICE DENSITY
IN TERMS OF FRACTAL DENSITY
TRANSLATION INVARIANCE: FROM $p = \rho$ BACKGROUND

$$ds^2 = -dt^2 + t^{2/3} d\mathbf{x}^2 \quad t \rightarrow at;\ \mathbf{x} \rightarrow a^{2/3}\mathbf{x}$$

$p = \rho$ PHYSICS INVARIANT UNDER THIS CKV

$P(\mathbf{x}, t, t') d^3 x$ INVARIANT

$$< \delta(k, T)\delta(-k, T) >= \frac{1}{k^3} |f|^2 \int_{k^{3/2} t_0}^{k^{3/2} T} ds \int_{k^{3/2} t_0}^{k^{3/2} T} ds' f(k, s) f(-k, s') P(1, s, s')$$

SCALE INV SPECTRUM FOR $T^{-2/3} \leq k \leq .1(?)$

.1 UV CUTOFF BELOW WHICH $p = \rho$ DESCRIPTION FAILS

MAX CORRELATION LENGTH: HORIZON SIZE AT END OF $p = \rho$
NEED A BIT OF INFLATION TO STRETCH
TO CURRENT PARTICLE HORIZON

FLUCTUATIONS MUST BE SMALL FOR SURVIVAL
DILUTE BH GAS AT END OF $p = \rho$ AT THE EDGE OF PHASE TRANSITION TO DENSE BLACK HOLE FLUID. LARGE FLUCTUATIONS DRIVE IT BACK TO $p = \rho$

WHY ARE FLUCTUATIONS GAUSSIAN?
CAN WE CALCULATE 10^{-5} FROM FIRST PRINCIPLES?

CRITICAL PARAMETER M: BH MASS AT END OF $p = \rho$
TYPICALLY NEED LOW SCALE INFLATION MODEL WITH $N_e < 30$
T_{RH} NOT FAR FROM NUCLEOSYNTHESIS
IMPLICATIONS FOR BARYOGENESIS, DARK MATTER
SUSY BREAKING