ASYMPTOTIC DARKNESS, THEORIES OF QUANTUM GRAVITY, AND SUPERSYMMETRY

Conventional Wisdom: String/M-theory Unique Theory
With Many Vacua
All "Connected on the Configuration Space"
Phenomenology: Search for Poincare Invariant SUSY Violating "Vacuum"

Motivated by QFT and by Moduli Spaces

Simple Semiclassical Arguments That This is Wrong

Many Consistent Theories of QG in Various Dimensions

Will Conjecture That All Poincare Invariant QG's Are Susic

A Critique of Pure String Theory

M-theory: A Set of Moduli Spaces of (Mostly) SUSic
Poincare or AdS Invariant Theories of QG
SUSY + Gravity ⇒ (BPS) Strings

Our Conventional Wisdom: All Vacua of One Hamiltonian

I Will Challenge This View

C(osmological) C(onstant) Discrete Label, Partially Classifying

Different Theories - HE Input, Not LE Output

Theory With Positive C.C. As Yet Unknown

Has Finite Number of States - Intrinsic Ambiguities

Our World Described by Theory With Small Positive C.C.

With $m_{3/2} \sim \Lambda^{1/4}$

Possibly Unique Small C.C. Limit, Up to Order

$e^{-(\Lambda M_P^4)^{-\frac{3}{4}}}$

WHY GENERAL RELATIVITY IS NOT A FIELD THEORY

Phase Space: Space of Solutions Given B.C.

In Field Theory Parametrized By Initial Data (Cauchy-Kowalevska)

But in GR Generic Sol'n Singular

Often (Cosmic Censorship) Hidden Behind Black Hole Horizon

Scattering B.C.: $b < E_{cm}^{\frac{1}{(d-3)}}$, BH Forms

Penrose, Matschull, d'Eath and Payne, Giddings and Eardley

UV/IR Connection, Holographic Principle

Collision of Aichelberg-Sexl Waves

$$ds^2 = -dudv + (\nabla_i\nabla_k\Phi(x - X_+)\nabla_j\nabla_k\Phi(x - X_+)u\theta(u) +$$

$$\nabla_i\nabla_k\Phi(x - X_-)\nabla_i\nabla_k\Phi(x - X_-)v\theta(v) + \delta_{ij})dx^i dx^j$$

$$\Phi(x) = \frac{8\pi G\mu}{\Omega_{d-3}(d-4)|x|^{\frac{d-4}{2}}}$$

$$X_\pm = (\pm\tfrac{b}{2}, 0, \dots, 0)$$

This is Solution Before Collision $u \leq 0 \quad v \leq 0$

Find Trapped Surface In This Region

$\rightarrow$ Singularity $\rightarrow$ Black Hole

Assumes Cosmic Censorship for Scattering Sol'ns

Math Problem 1: Prove Cosmic Censorship

For Scattering Solutions With Arbitrary Number
Of Low Amplitude Incoming Waves

Arbitrary Kinematics

SHORT TIMES AT ENERGY HIGH

Feynman: $e^{-iHt} \sim e^{-iH_0 t} e^{-iVt}$, H_0 Gaussian

$\rightarrow$: Path Integral, Schrodinger Quantization *etc.*

HE Theory Defines Hilbert Space

Wilson: More Generally, HE Theory is a CFT

Theory Defined By OPE: $O_I(x) O_J(0) = \sum x^{d_K - d_I - d_J} C_{IJ:K} O_K(0)$

Perturbation by Relevant Op. Gives Non-leading Terms in OPE

Two Kinds of Hilbert Space Realizations: $\mathcal{H}_P : \mathbf{R}^{1,d}$, $\mathcal{H}_S : \mathbf{R} \times S^d$

Full $SO(2, d+1)$ Unitarily Implemented Only in $\mathcal{H}_S$

Relevant Op. Preserves $ISO(1, d)$ or $R \times SO(d+1)$ in $SO(2, d+1)$

There Can Be Many Inequivalent $\mathcal{H}_{P_i}$: Vacua
Sometimes Continuous Moduli Spaces of Vacua

This Is An IR Phenomenon
All Vacua Have Same HE Behavior
Quantum Analog of Degenerate Minima of Potential

At Finite Energy, Configurations in $\mathcal{H}_{P_1}$
Identical to $\mathcal{H}_{P_2}$ Over Volume V
Consequence of Locality and Identical HE Behavior

Isolated Poincare Invariant Vacua: The Trouble With Bubbles

In FT Two Ways to Show Isolated Vacua Are Different Sup. Sectors of the Same Hamiltonian

I. Show HE Behavior (=SD Behavior) Identical

II. Create Large Bubble of V_1 in V_2

I. Fails Because HE Scattering Produces BHs

$$E \to \infty : \ T_H \to 0$$

HE Scattering Sensitive to LE Spectrum

Regge Region "Eats" SD Regime

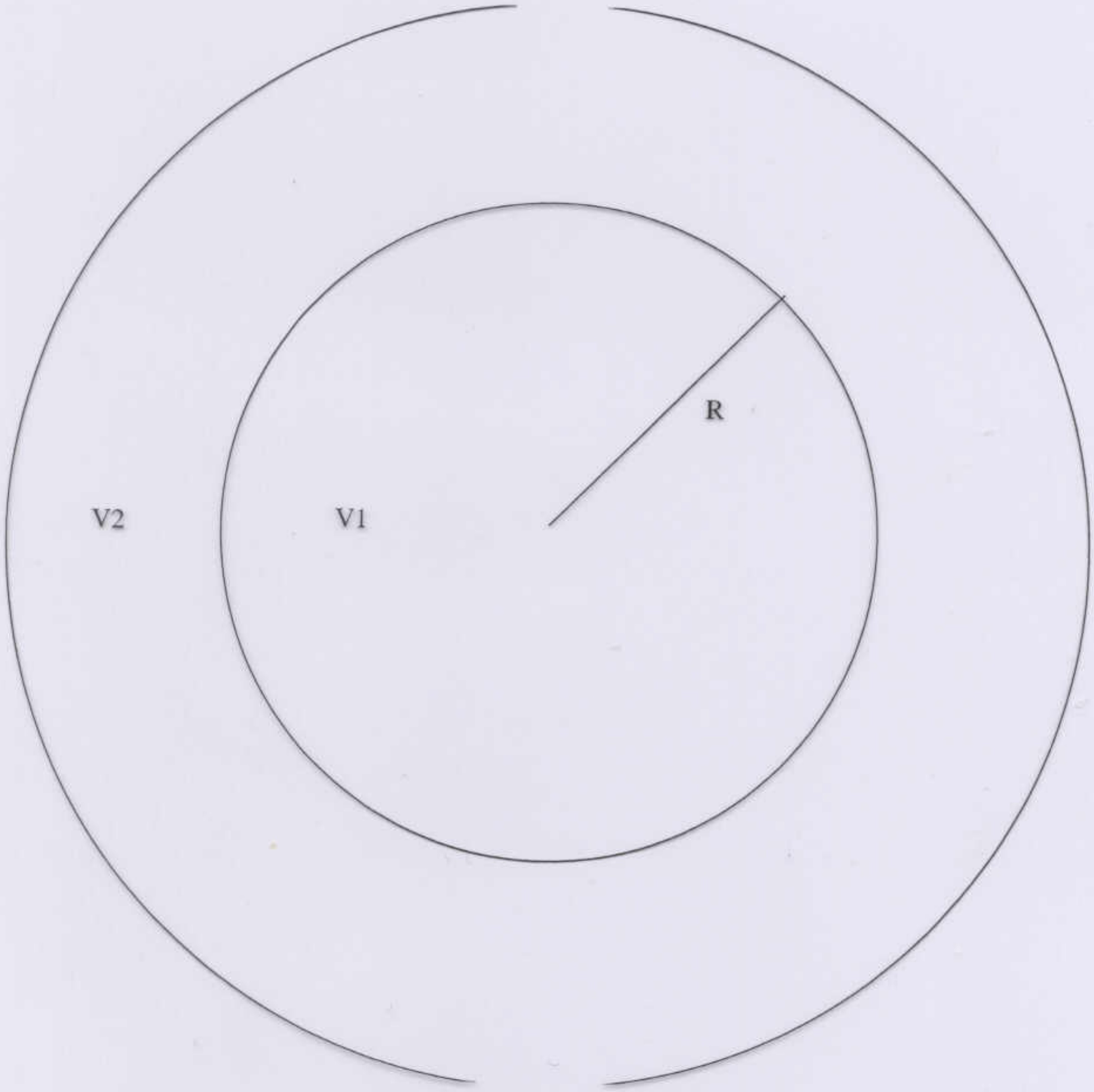
II. Fails Because Can't Make Large Bubble of V_1

Bubble Wall Tension T: $M_{bubble} \geq TR^{d-2}$

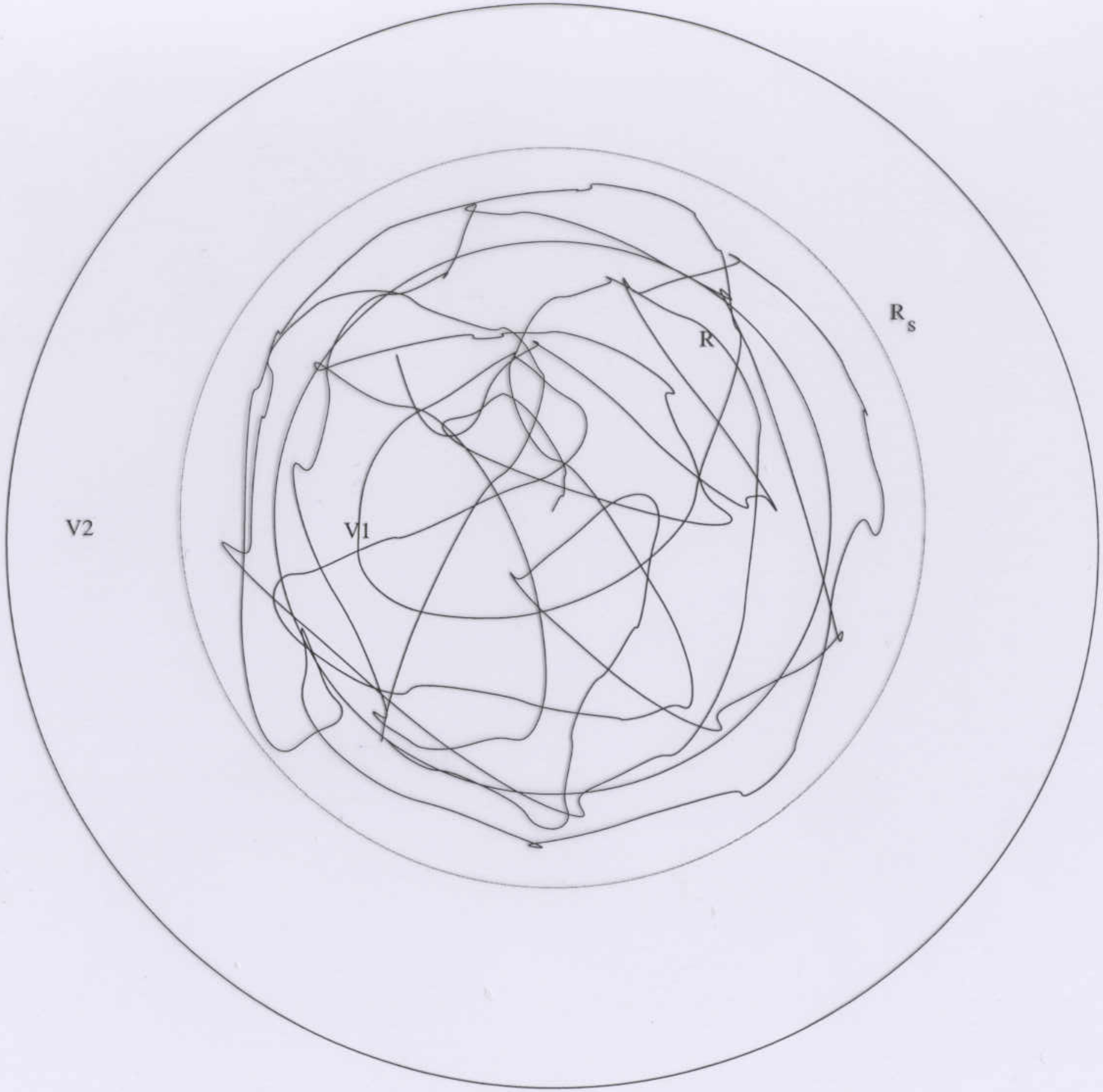
$$R_S \sim \left(\frac{M}{M_P^{d-2}}\right)^{\frac{1}{d-3}} = \left(\frac{R}{M_P}\right)^{\frac{d-2}{d-3}} T^{\frac{1}{d-3}}$$

Instead of Large Bubble of V_1 Get Large BH Which Decays Back To V_2

An Alternative Way of Finding One Vac. in Another



Make Bubbles of V_1 in V_2



R
R_s
V1
V2

There is an Analogous Problem With Decay

to $\Lambda < 0$ Vacuum

Interior of Coleman De Luccia Bubble is Always

Singular Big Crunch Rather Than AdS

Should Be Viewed As Evidence That Effective Potential

Picture of Different Vacua as States of Same Theory

Is Completely Wrong

This is The Implication of Asymptotic Darkness and UV/IR

Note No Problem Along Moduli Space

For $\Lambda < 0$ We Can Investigate This

Using Maldacena's AdS/CFT Correspondence

The Wisdom of Don Juan:

An AdS/CFT Way of Knowledge

Maldacena, Gubser-Klebanov-Polyakov, Witten

Quantum Gravity on $AdS_d \times K(ompact)$

$\equiv$ CFT on Conformal Bdry of AdS_d

$$ds^2 = -(1 + \tfrac{r^2}{l^2})dt^2 + \frac{dr^2}{(1+\frac{r^2}{l^2})} + r^2 d\Omega_{d-2}^2.$$
$$\to \tfrac{r^2}{l^2}(-dt^2 + l^2 d\Omega_{d-2}^2)$$

$$\phi_c(t, r, \Omega) \to r^{\Delta_+}\phi_+(t, \Omega) + r^{\Delta_-}\phi_-(t, \Omega)$$

$\Delta_\pm$ Sol'ns Of $\Delta(\Delta + d) = m^2$

ϕ_c Solution of Bulk Eff. Field Eqns.

$$S_{eff}[\phi_c] = \ln < e^{\int \phi_+ O} >$$

O is An Operator of Dim $d + \Delta_+$

Non-leading Term in ϕ_c is Its VEV

High Energy Thermodynamics: Asymptotic Darkness

AdS-Schw: $(1 + \frac{r^2}{l^2}) \to (1 - \frac{M}{M_P (r M_P)^{d-3}} + \frac{r^2}{l^2})$

If $R_{Sch} \gg l, R_{Sch} \sim (\frac{Ml^2}{M_P^{d-3}})^{\frac{1}{d-1}}$

Black Hole Entropy: $S \sim \epsilon^{\frac{d-2}{d-1}} l^{d-2} (\frac{l}{l_P})^{\frac{d-2}{d-1}}$

Like CFT in Finite Vol. $\sim l^{d-2}$

Large $l/l_P \sim$ Large No. DOF

BH Dominance of HE Scattering $\equiv$ Thermalization

Stable Canonical Ensemble: Eternal Black Holes

l Parameter Fixing HE Spectrum

In Known Examples, Always Discrete *e.g.* $N^{1/4}$ of $SU(N)$ Gauge Theory

Shouldn't Be Determined in LE Eff. Theory

Must Tune S_{eff} To Get Right HE l

Relevant Perturbations of CFT Define
QG in Almost AAdS Space-Times

No Degenerate Vacua Because Finite Volume

May Be Metastable FT Vacua, But Same Bulk Asymptotics
Decay of False FT Vac Does Not Change C.C.
Even W/O SUSY No Coleman De Lucia
Tunnelling From Higher to Lower C.C.
Consistent with CDL

Paradigm of Off Shell Eff. Potential Does Not Work
In AdS, Even For Large Radius

To Use LE Eff. Action in AdS Must Tune C.C.
To Agree With High Energy Behavior

l/l_S and SUSY Breaking

CFT Which Is Finite Pert of Free FT Has Exponentially Growing Spectrum Of Ops. As Fcn of Δ_O

Cannot Be Accounted For by Kaluza-Klein Towers

$$l_S \sim l$$

Bulk Local Field Theory is Never a Good Approx.

Gorbatov: In This Regime Polchinski Horowitz Corr. Princ. Implies All Black Holes Have $R_{Sch} \gg l$

All Known SUSY Violating CFT's Have $l \leq l_S$

SUSY Violating Relevant Pert. of Large Radius SUSic CFT

Inhomogeneous Defect in SUSic AdS

Silverstein, Giddings *et. al.* and Kachru *et. al.*

Claim Large Radius, Weak Coupling SUSY Violating AdS

What is the CFT Dual To These?

At Any Rate, In These Models, SUSY Breaking Vanishes

As AdS Radius Goes To Infinity

Consistent With Conjecture: *Poincare* $\rightarrow$ *Super-Poincare*

The High Energy Behavior of QG: Asymptotic Darkness

TBOAH/hep-th/9812237 ; TBWF/9906038 ; TB, Davidfest 2001

HE Dominated By Black Holes: IR Sensitive

The Ultimate UV/IR Connection

As A Consequence, The Choice of Vacuum and Hamiltonian

Are Harder to Disentangle

cf Def. of H by Surface Integral at ∞ in GR

Scattering at Large Mandelstam Invariants Produces Black Holes

Amplitudes are IR Sensitive, "Vacuum "Dependent

Example: "Derivation "of AdS/CFT

General Principles + Asymptotic Darkness $\Rightarrow$

QM of AdS_d is Conformally Inv. on $R \times S^{(d-2)}$

And Has HE Spectrum of CFT_{d-1}

Energy Not Extensive in $d-1$ Space Dimensions

In AF Spacetime Asymptotic Darkness

$$\rho(E) \sim e^{E^{\frac{(d-2)}{(d-3)}}}$$

$\Rightarrow < 0|O(t_1) \ldots O(t_n)|0 >$ Are Not Distributions

On Space of Functions W/ Compact Support

M^d, $d > 4$ Light Cone QM in Better Shape

$P^- = M^2/P^+$

M^4 Hagedorn in Light Cone

Connected(?) With IR Divergences, Nonexistence of

S-Matrix, BMS Group and All That

Note: Even in LCFT, Change of Vac. Is Change of Hamiltonian

Summary

1) QM Defined by HE behavior

2) Asymptotic Darkness: HE of QG → Black Holes
   ⇒ Holography UV/IR

3) ⇒ Long Distance Eff. C.C. is
   HE input parameter

4) Many math QG's Λ_{eff} one
   of discrete params characterizing
   H

5) Evidence : Semiclassical
   + AdS/CFT

Asymptotically de Sitter Spaces

$$ds^2 = -dt^2 + R^2 Cosh^2(t/R) d\Omega^2$$
$$\mathcal{I}_{\pm} : \ t \to \pm\infty$$

Most "Scattering Data" on $\mathcal{I}_{\pm}$ Lead To
(Come From) Big Crunch (Big Bang) Singularities
Phase Space of Time Symmetric AsdS Sol'ns Compact?
Implies Finite Number of States in Quantum Theory

Time-like Observer: Static Patch

$$ds^2 = -(1 - (r^2/R^2))dt^2 + \frac{dr^2}{(1 - r^2/R^2)} + r^2 d\Omega_{d-2}^2$$

Finite Area Horizon: Finite Entropy $\sim (\frac{R}{l_P})^{d-2}$

Thermal Density Matrix For Static H

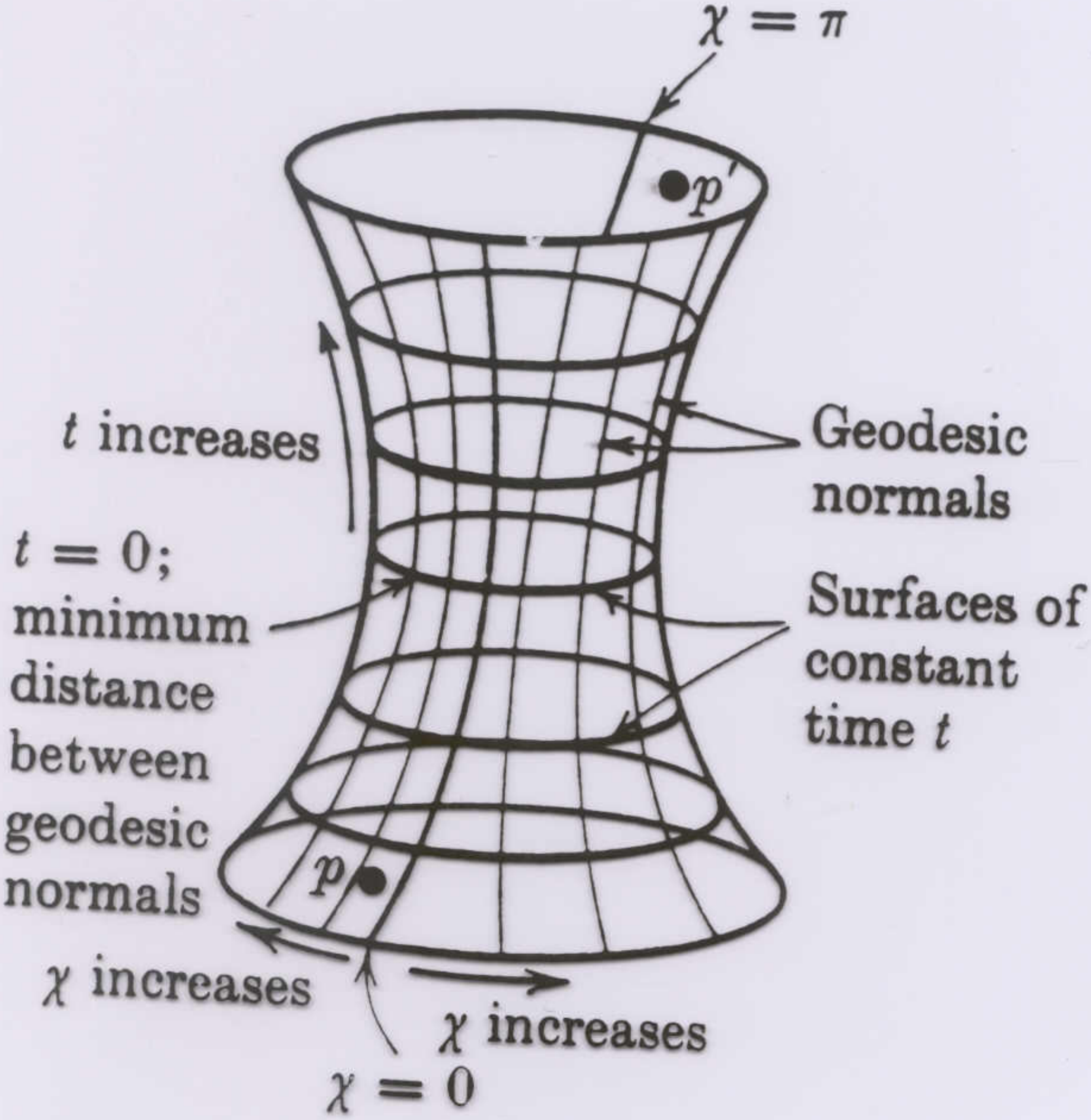
$$T_{GH} \sim \frac{l_P^2}{R}$$

$$ds^2 = -(1 - \frac{M}{M_P^{d-2} r^{d-3}} - (r^2/R^2) dt^2 + \frac{dr^2}{(1 - \frac{M}{M_P^{d-2} r^{d-3}} - r^2/R^2)} + r^2 d\Omega_{d-2}^2$$

Maximal (Nariai) BH: Entropy of BH + Cosm Horizons $< S_{ds}$

Maximal Energy Thermal Density Matrix: Finite No. States

Entropy Not Dominated By Localized Configurations



$\chi = \pi$
p'
Geodesic normals
t increases
$t = 0$; minimum distance between geodesic normals
Surfaces of constant time t
p
χ increases
χ increases
$\chi = 0$

Implies Very Low Energy Horizon States $E \leq T_{GH}$ $\rho(E) \sim e^{-S_{dS}}$

$S_{dS} \sim \ln \dim \mathcal{H}$

If H_{hor} Random, May Account for T_{dS}

Complementary Picture in Global Coordinates

Static Observers Horizon States Are Localized

States in Many Horizon Volumes

Finite Entropy Implies IR Cutoff in Global Picture

$(RM_P)^{(d-2)/d}$ Disjoint Horizon Volumes Rather Than ∞

Indeed FT States $\mu^d R^{d-1} \equiv M$

$$R_S \equiv (M/M_P)^{\frac{1}{d-3}} M_P^{-1} : \; R > R_S \rightarrow$$

$$1 > \mu^{d-1} R^{2\frac{d-1}{d}} M_P^{-\frac{(d-1)(d-2)}{d}}$$

$$S_{FT} < (RM_P)^{\frac{(d-1)(d-2)}{d}} \ll S_{GH}$$

Measurement Theory in dS Space

IMHO: Measurement Theory Based On Approx SuperSelection Sectors

Pointers Are Like Degenerate Vacua of Finite Vol. FT

Tunnelling Amps. Between Pointer Positions

$\sim e^{-b\text{Entropy}}$

Limits Utility of Measuring Device

Bound on Accuracy

Bound on Time Over Which Measurement is Meaningful

In AsdS Space Tunnelling Time of FT Devices

Always $\ll$ Poincare Recurrence Time

Not Physically Meaningful To Follow System For Recurrence Time

Hamiltonian Not Unique: Universality Class

Imprecision for LE Local Measurements $o(e^{-k(\Lambda L_P^4)^{-3/4}})$

Probably Imprecision Mostly for Horizon States

Best Classical Detectors: Free Falling Devices Near Horizon

Become S-Matrix Meters as $\Lambda \to 0$

Decouple From Horizon States

Group Theory

Witten: dS Group Gauge Transfs. No Timelike or Null Boundary

But Taking Into Account Mass of Observer

$dS = M \to 0$ Limit of Black Hole

Gomberoff and Teitelboim: Euclidean Boundary

Boundary Can Be Cosmological Horizon of Lorentzian

Manifold And Gens. Which Preserve it Are Global Symms.

$H_{static} \oplus so(d-2)$

Near Horizon: $ds^2 = R^2(dudv + d\Omega_{d-2}^2)$

Horizon is $v \to 0$

cf. Minkowski: $ds^s = \frac{(dudv + d\Omega_{d-2}^2)}{v^2}$

H_{static} Inf'l Boost On u, v

Not a Symm. of Minkowski

Poincare is Semi-direct of Conformal Group of S^{d-2} and $f_\mu(\Omega)\partial_u$

Only $SO(d-1$ Shared

H_{static} Describes Physics of Static Observer

Poincare, That of S-Matrix Meters

Which Decouple From Horizon States as $\Lambda \to 0$

Breaking SUSY on the Horizon

No Unitary Super-dS Group Because
$SO(1, d)$ Has No Highest Weight Generators

Classical SUGRA (4d) $V = e^K [F_i \bar{F}_{\bar{i}} K^{i\bar{i}} - (3/M_P^2)|W|^2]$
$e^{K/2} F_i = e^{K/2} D_i W$ Order Parameter for SUSY
W Order Parameter for Complex R-symmetry
Near $\Lambda = 0$, $\Delta M_{SUSY}^2 \sim e^{K/2} F$, $m_{3/2} \sim \Delta M_{SUSY}^2 / M_P$
With No Fine Tuning $m_{3/2} \sim \Lambda^{1/2} / M_P$

New Insight Λ HE Parameter: LE Must Be Tuned
Can We Understand Size of SUSY Breaking Given Λ?

Hypotheses: SUSY Breaking Due to Horizon
$\Lambda \to 0$ Theory, SUSic, R-symmetric
(Note Only Works for 4D $N = 1$)
SUSY Breaking Tunable to Zero, Must Be Dynamical in LEL
Horizon Provides R Breaking Terms, In Whose Presence
LEL Spontaneously Breaks SUSY
$m_{3/2}$ Lightest R Charged Particle

R Breaking Comes From Graphs With Virtual Gravitino

Bouncing Off Horizon $e^{-m_{3/2}R}$ Suppression

Gravitino Propagates Prop Dist. $1/m_{3/2}$ Near Horizon

Accelerated Gravitino Feels Random Forces, Random Walks

Covers Area $1/m_{3/2}$ in Planck Units

Samples $e^{1/m_{3/2}}$ Degenerate States

$$\delta\mathcal{L} \sim e^{-m_{3/2}R+b/m_{3/2}}$$

If $m_{3/2} < R^{-\frac{1}{2}}$, Exponentially Large

If $m_{3/2} > R^{-\frac{1}{2}}$, Exponentially Small

Self Consistent Scaling $m_{3/2} \sim R^{-\frac{1}{2}} \sim \Lambda^{1/4}$

$$\Delta M_{SUSY} \sim TeV$$

Alternate Calculation in Complementary Global Picture

Conjecture $m_{3/2}$ IR Divergent in Field Theory

Cutoff at $L_{IR} \sim R^{3/2}$ in Planck Units as Above

Leads to Anomalous $\ln\Lambda$? Dependence

In Loops. Resum to Anomalous Exponent.

In Progress With L. Mannelli

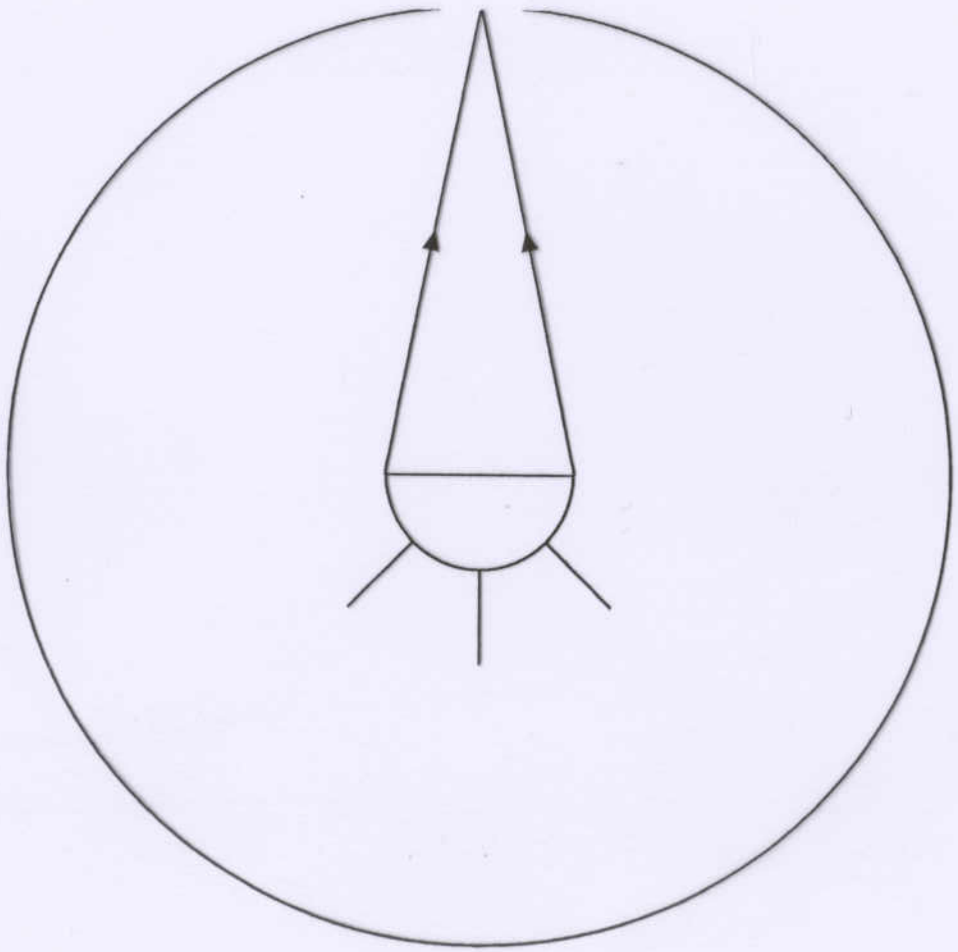


Fig. 1 Effective Vertex Induced by Gravitino Exchange With the Horizon

Isolated SUSic, R-Symmetric $d = 4$ Vacua

Perturbative Analysis Suggests Convergent Instanton Series for W, not K

Eqns. $D_i W = W = 0$ Independent of K

Conjecture "Topological $N = 1, d = 4$ QG" Computes Sol'ns

In BOAPW TN1D4QG Also Gives Algorithm for Physical Theory
At Each Solution

First Step: Computation of W On D-branes in $N = 2$ Compactifications
Douglas, Vafa, *et. al.*
Or Computation of W on $R^{1,3}$ Filling Branes
In *e.g.* $R^{1,3} \otimes N(\text{on})K(\text{ompact})$ G2?
Can This Program Be Extended to $R^{1,3} \otimes K$?
What About SUSic AdS_4 Vacua?

Conclusions

1. Many Math'l Theories of QG Depending on Boundary Conditions

2. Λ Discrete Tunable HE Parameter

3. SUSY Breaking in AdS Goes Away in Flat Limit ?

4. Poincare QG $\rightarrow$ Super-Poincare ??

5. Consistent(?) Theories of Stable dS With Finite $\mathcal{H}$

6. In dS $m_{3/2} \sim \Lambda^{1/4}$???

7. Constructive Algorithm for Isolated $N = 1, d = 4$ S-matrices????