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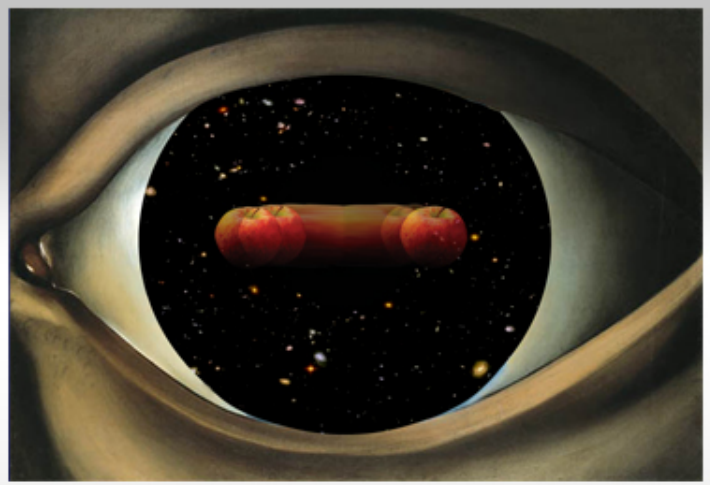


SANTA BARBARA GRAVITY WORKSHOP

May 23-25

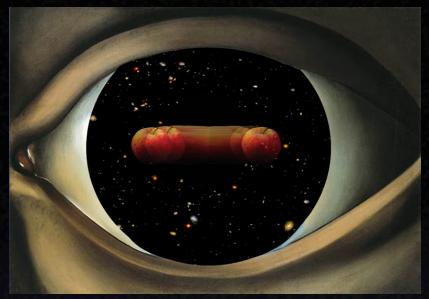
NONLOCALITY, OBSERVABLES,
BLACK HOLES and COSMOLOGY

Overview: questions and issues

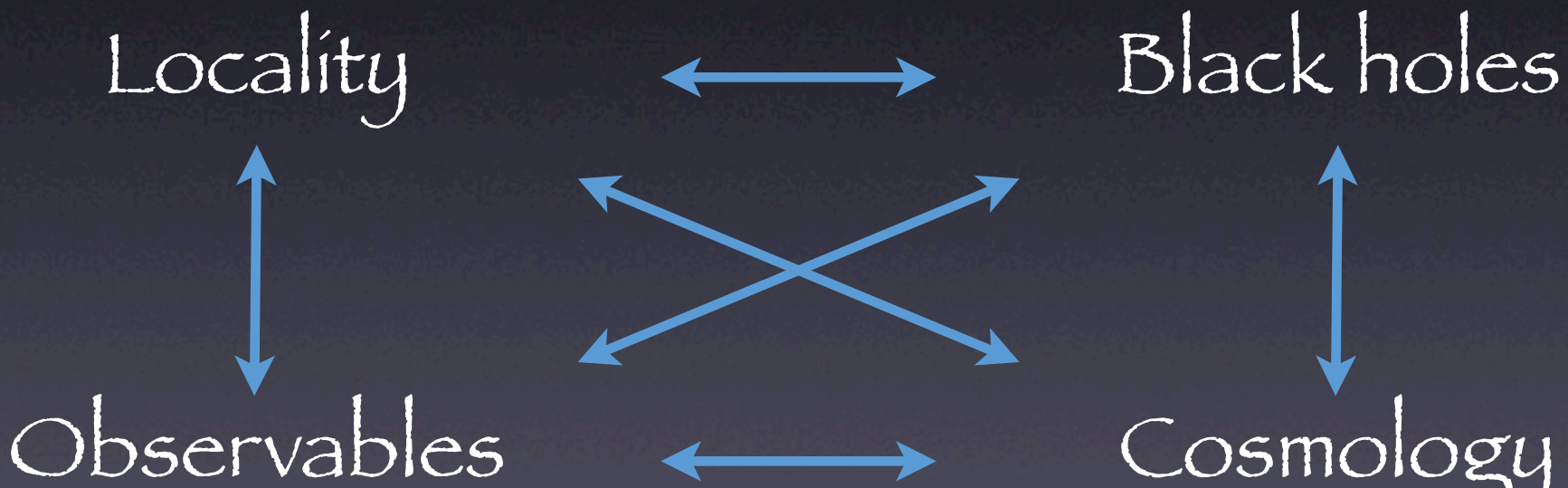
Steven B. Giddings

Santa Barbara Gravity Workshop

May 23, 2007



Many profound puzzles:



Nonlocality - regime and dynamics

How do we parametrize the regime where local QFT plus GR breaks down?

What is the mechanism for its failure?
(Is it stringy, gravitational, a combination, or something else?)

Is the physics of high-energy scattering indeed an accurate guide to this breakdown?

Observables

Are there other approaches to physically realizable local observation besides relational observables?

What are the basic limits on local observation?

Do such limitations on local observation imply restrictions on the states and/or dynamics of the theory? What elements of current theory are in principle unobservable, and can/should we formulate a theory that doesn't predict such unobservable quantities?

Black holes and information

By what mechanism is the black hole information paradox avoided?

Are there any viable alternatives to a non-local resolution of the paradox?

How are singularities resolved?

Cosmology

Does de Sitter space have a finite-dimensional Hilbert space?

What is the analogous statement for more general states such as those of an eternally inflating multiverse?
What implications does this have for measures in eternal inflation?

How is local observation described in such a context?

AdS/CFT

Can AdS/CFT directly address the preceding questions?

Can one recover a local description of physics on scales small as compared to the AdS radius?

Does AdS/CFT clearly resolve the information paradox? How?

Fundamental theory

What implications do limitations on locality and observation have for the structure of a more fundamental theory?

What other properties are expected to characterize such a theory?

How can a fundamentally nonlocal theory reduce to local QFT plus GR in the appropriate limit?

Can see some answers...? (though not uncontroversial?)

Some remain glaringly unanswered

Black holes and information

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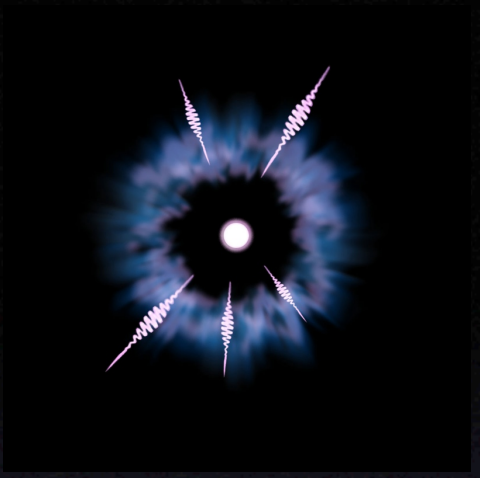

Plausible viewpoint: comparable importance to the paradox of classical instability of matter

Abandon: unitarity and energy conservation
stability
locality

(to be discussed)

Various evidence: abandon locality

But: where is the flaw in Hawking's argument?

Two possibilities:

A. local QFT + GR is simply invalid, just as classical physics becomes invalid at the atomic radius

B. there is a manifest failure of the local QFT+GR (semiclassical) description of a black hole

will provide evidence supporting B ...

(also Nima + Sergei)

Either way, nonlocality at horizon scale needed.

Two further comments:

1. No paradox without a description of local observation?
2. could the singularity be a red herring? (Planck scale irrelevant?)

Nonlocality - regime and dynamics

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What is the mechanism for its failure?
(Is it stringy, gravitational, a combination, or something else?)

Is the physics of high-energy scattering indeed an accurate guide to this breakdown?

What is the evidence for locality?

1. Local observables.

none in gravity.

relational observables

locality only recovered in limiting cases

Don, M. Gary, Jim, Tom?

2. High-energy scattering

plausibly a good guide;

(assume on-shell lessons extend off shell?)

what does it say?

In string theory, many have had the feeling that nonlocality is related to "extendedness" of strings ...

Will present evidence:

no apparent role for string extendedness

intrinsically gravitational effects -- breakdown of grav. pert thy -- nonlocality? (also Nima)

(Indeed, unitarity of gravity may be a deeper issue than renormalizability ? -- cf electroweak physics; suggestion: resolved by nonlocal physics)

Other suggestive evidence for nonlocality: AdS/CFT, ideas of holography, conundrums of cosmology (landscape, BBs, etc.)

What is the correspondence limit?

Classical -- QM:

Phase space —(uncertainty principle)→ Hilbert space

QFT+GR -- "Full quantum dynamics"

Classical geom.+ Fock space —(????)→ ????

Some existing proposals

planckian curvature: $\mathcal{R} < M_P^2$

string uncertainty principle: $\Delta X \geq \frac{1}{\Delta p} + \alpha' \Delta p$

modified dispersion: $p < M_p$

} 1 particle

holographic (information) bounds: $S \leq A/4G_N$

multiparticle

Conjecture: strong (non-perturbative) gravitational physics

Parametrize?

two particle states in Fock space:

$$\phi_{x,p}\phi_{y,q}|0\rangle$$ (x,p -- wavepacket)

good description for ...

$$|x-y|^{D-3} > G|p+q|$$

"locality bound"

One conjectured parametrization of correspondence limit.

N-particle generalization: $\phi_{x_1,p_1}\cdots\phi_{x_N,p_N}|0\rangle$

de Sitter generalization (Formulate in terms of $\langle T_{\mu\nu}\rangle$)

Comments:

if one bit of information = one quantum of energy:

locality bounds $\Rightarrow$ holographic bounds ?

Conjecture "nonlocality principle:"

"the nonperturbative physics that unitarizes gravity in domains where gravitational perturbation theory fails is nonlocal"

Observables

Are there other approaches to physically realizable local observation besides relational observables?

What are the basic limits on local observation?

Do such limitations on local observation imply restrictions on the states and/or dynamics of the theory? What elements of current theory are in principle unobservable, and can/should we formulate a theory that doesn't predict such unobservable quantities?

#1: guess no.

will discuss further (Don, M. Gary, Jim ...)

any alternatives?

#2: locality bound considerations

"ultimate detector"

large gravitational fluctuations (BH, dS)

Boltzmann brains

unified picture?

Do such limitations on local observation imply restrictions on the states and/or dynamics of the theory? What elements of current theory are in principle unobservable, and can/should we formulate a theory that doesn't predict such unobservable quantities?

Wheeler's paraphrase of Bohr's dictum: "no phenomenon is a real phenomenon until it is an observed phenomenon."

Too strong by today's standards?

More minimal: "Theory should not predict quantities whose observation would not make sense"

(Maybe still too strong ...)

Humble suggestion: perhaps we should really take such considerations to heart in formulation of theories ...

Cosmology

Does de Sitter space have a finite-dimensional Hilbert space?

What is the analogous statement for more general states such as those of an eternally inflating multiverse?

What implications does this have for measures in eternal inflation?

How is local observation described in such a context?

Does nonperturbative gravitational physics permit a landscape and transitions between its vacua?

#1: Tom -- yes . Don -- yes, but possibly not a finite number of DOF

reconcile? recovery of local QFT?

#2, 3: discuss. Hints from Rafael, Ben, Mark, Matt J., Matt K.

#4: relationally or ...? Or globally (Alex)

#5: so far? Discussion: Tom, Matt J., ...

AdS/CFT

Can AdS/CFT directly address the preceding questions?

Can one recover a local description of physics on scales small as compared to the AdS radius?

Does AdS/CFT clearly resolve the information paradox? How?

If string theory directly addresses these questions (by no means clear), the lessons of HE scattering tell us it should do so through a nonperturbative framework. "AdS-CFT," or matrix ...

Notoriously hard to unravel

~ Issue of "decoding hologram;" issue of extracting flat space limit not settled.

Definite challenges: extract expected behavior (more to be described) for

$$p \gg 1/R_{AdS}$$

While AdS/CFT hints at a resolution of the information paradox, in a sense it doesn't address the information paradox

(need ~local observation -- relational? "inside matrix")

Gary and Joe -- comments about beliefs and expectations on these issues?

Fundamental theory

What implications do limitations on locality and observation have for the structure of a more fundamental theory?

What other properties are expected to characterize such a theory?

How can a fundamentally nonlocal theory reduce to local QFT plus GR in the appropriate limit?

Is it string theory?

Accumulated evidence suggests locality at macroscopic scales is in serious question

Think (or at least observe) relationally

Proposal: we should eliminate from the theory elements whose observation wouldn't make sense

Role of string dynamics unclear

#3 seems particularly non-trivial -- strong constraint?

Tom: proposal for such a theory of dS space

would like to better understand:

1) Explanation of basic building blocks and rules

2) how to match to local QFT in the correspondence limit?

Constraints from dS dynamics (Don);

role of time (Nima); discussion

Other comments???

Analogy to emergence of quantum mechanics, pre 1925

QM	? (NLM)
$\hbar$	G
Hydrogen atom	Black hole
UV catastrophes	Information paradox, ...
Old quantization rules	Holographic princ; I=A/4
Uncertainty principle	Nonlocality principle (locality bound, ...)
(Noble gases)	(Extremal black holes)
Wave function	?
Schrodinger eqn	?

What is this "nonlocal mechanics"?

If you're with me so far, the real questions:

What regime?
(correspondence)

What properties
should it have?

How/what does
it predict?

How does it
explain black holes?

What is the underlying dynamics
("Nonlocal mechanics")

Is it strings?
"AdS/CFT"

How does it
explain cosmology,
inflation, etc.

Does it predict
a landscape?

Are there observational
consequences?