An Aperitivo of Evolutions, Primo Piatto of Information-Loss Paradoxes, Holographic Proofs of Unitarity for Secondo Piatto with a Contorno of Causal Structure, Effective Field Theory for Formaggi e Frutta and a Digestivo of Epistemological Ruminations

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Outline

'Information Loss' Is Said in Many Ways

Marolf's Boundary Unitarity Argument

Yet More Causality Conditions and a Theorem on Causal Structure

SCG Is an Effective Field Theory—Deal with It

Concluding Unscientific Postscript

two notions of evolution

QFT

1. quantum state ψ_t defined on a Cauchy slice Σ_t
2. evolution between surfaces governed by standard Schrödinger unitary evolution:
$$|\psi_t\rangle = \hat{U}_t|\psi_0\rangle$$
where "$\hat{U}_t = \exp(-it\hat{H})$"

GR

1. (h_{ab}, K_{ab}) on Cauchy slice Σ
2. evolution into domain of dependence governed by "Cauchy development" induced by EFE

one might have thought the central issue of the Information-Loss Paradox would standardly be posed as something like:

are these 2 notions of evolution in an appropriate sense consistent?

in fact, it is not, because to address that question would require being able to solve the SCEFE in some generality, which we most assuredly cannot do there are rather 4 questions commonly posed, not always clearly distinguished from each other, and none clearly equivalent to—or even clearly related to—the question about consistency of evolutions or, indeed, to each other:

Hawking problem is there a unitary scattering matrix from $\mathscr{I}^-$ to $\mathscr{I}^+$?

Page-curve problem does the entropy of Hawking radiation decrease at late times during evaporation?

final-state problem is Hawking radiation in a pure state after evaporation ends?

recovery problem can the "information" encoded in a physical system be recovered after it enters a black hole?

they all have more or less vaguely to do with the idea of unitarity, whether one can hold on to the principle of unitary evolution in QFT for systems that include an evaporating black hole

this is all complicated by the fact that in scattering theory the word 'unitarity' has 2 completely different meanings: (1) conservation of probability; (2) evolution from pure states to pure states

this ambiguity comes out most clearly in the "standard" argument about the Hawking problem, and its relative the final-state problem

let's focus for the moment on the final-state problem

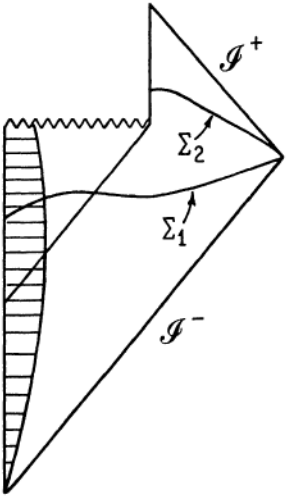


Figure 7.3. A conformal diagram illustrating the phenomenon of loss of quantum coherence in a spacetime in which black hole evaporation occurs.

(taken from Wald 1994)

summary

1. by Cauchy evolution, a pure state on Σ_1 develops into a mixed state on Σ_2
2. by Schrödinger evolution, this cannot happen
3. the root of the conflict lies in the pathology of the causal structure of the spacetime:
    i. Σ_1 is a Cauchy surface for that part of the spacetime lying beneath the null surface "connecting the evaporation point to $\mathscr{I}^+$"
    ii. Σ_2 is not
4. $\Rightarrow$ Σ_2 can, at most, "know" about the information encoded in the mixed state defined on Σ_1 by tracing out that part of the state associated with the part of Σ_1 lying behind the event horizon

Marolf (2009) proposed a novel form of argument, which has become widely influential, that black hole evaporation is fundamentally a unitary process

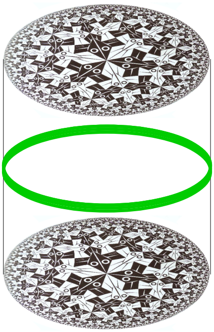
I think it is excruciatingly clever and delivers real insight on a number of issues but I also think it begs a fundamental question, in the same way that all holographic arguments I know of for unitarity do, and it does so in a way that brings out the problem with clarity (because the argument itself is so crisp and clear)

to prove my *bona fides*, I will present the argument using the slides of a talk by Aron Wall from 2019, who vigorously defends the validity of the argument

Argument #2: Boundary Unitarity (Marolf)

assume asymptotically AdS, but do *NOT* assume AdS/CFT
(instead we will be *proving* that something like it must hold)

[a asymptotically flat argument exists, but is more subtle.]



argument concerns the set of all quantities that are measurable on the boundary at a given time t:

$$\mathcal{A}_{t,\Delta t}$$

allow a small "thickness" Δt to avoid worries about smearing operators in time...

basic principles of physics will now imply that the info that falls into a black hole remains accessible on the boundary...

Axiom #1: $\mathcal{A}_{t,\Delta t}$ is an *algebra of operators* [QFT]

- vector subset of operators A, B... in global Hilbert space

- closed under addition (vector space): A + B

- closed under multiplication (algebra): AB

- and reasonable limits thereof (C* algebra)

These assumptions are totally standard in AQFT when describing the set of all measurable quantities in a region

Axiom #2: the Hamiltonian is measurable at boundary [GR]

$$H \in \mathcal{A}_{t,\Delta t}$$

In ANY **diffeomorphism-invariant** *theory of gravity (not just GR), the total energy is a pure boundary term (the ADM energy).*

Gauge symmetry implies that H = 0 locally, up to a total derivative that arises when the diffeo vector ξ *does not vanish on the boundary.*

The ADM energy is obtained from the case where ξ *limits to a time translation on the boundary.*

Axiom #3: The Hamiltonian generates time translations [QM]

a) H is a self adjoint operator

b) for all $\mathcal{O}$, $[H, \mathcal{O}] = i\frac{d\mathcal{O}}{dt}$ (Heisenberg picture)

These rules are simply the **definition** *of the Hamiltonian in QM, which always exists if there is a time-translation symmetry acting on the complete Hilbert space.*

(the identification of this with the previous H is related to the exact equivalence of gravitational and inertial energy in GR.)

Axioms 1-3 imply that the boundary evolves unitarily!

If $\mathcal{O}(t)$ is a family of operators related by time translation symmetry, then you can solve for one time in terms of other times:

$$\mathcal{O}(t_1) = e^{iH(t_1 - t_2)}\mathcal{O}(t_2)e^{-iH(t_1 - t_2)}$$

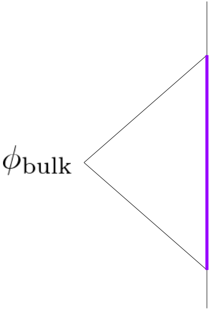
anything that can be measured at t_1
can also be measured at t_2,

because H and $\mathcal{O}(t_2)$ are in the algebra and the r.h.s. is just a limit of sums & products of those...

hence no info can be lost from the boundary (unless it was *never* on the boundary)

Axiom #4: There are other nontrivial operators in the algebra that can be excited to form a black hole [AdS QFT]

e.g. the boundary value of a scalar field $\phi(t) \in \mathcal{A}_{t,\Delta t}$



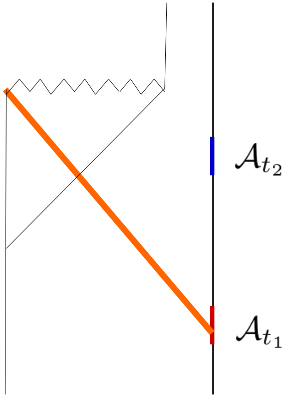
it is known how to solve for a field (outside of any horizons) in terms of integrals of boundary limiting values $\phi_{\rm bulk}$

sideways Cauchy problem subtle but basically OK

Hamilton-Kabat-Lifschytz-Lowe (free fields)
interacting case done perturbatively in 1/N
(should be good near infinity)

note we just need ***some*** *nontrivial field operator,*
(other than vacuum symmetry generators like H)
on a small boundary interval

Information is not lost into the black hole



excite fields at t_1 to form BH,
these fields carry info to the inside

at any later moment of time t_2
(even before the BH evaporates)
the information is still available
in principle, and can be measured
by a complicated experiment

Summary of Assumptions

#1: exists an *algebra of operators* $\mathcal{A}_{t,\Delta t}$. [QFT]

#2: $H \in \mathcal{A}_{t,\Delta t}$ [GR]

#3: a) H is a self adjoint operator

b) for all $\mathcal{O}$, $[H, \mathcal{O}] = i\frac{d\mathcal{O}}{dt}$ [QM]

#4: exist nontrivial operators in $\mathcal{A}_{t,\Delta t}$ that can be used to form black hole [AdS QFT]

the nub of my problem with Marolf's argument is that it implicitly assumes the interior of spacetime is causally well behaved (all required actions on the boundary can propagate in a determinable way anywhere into the interior of spacetime I want)—but the final-state problem strongly suggests that that is exactly what is up for grabs

to make the claim precise, I will introduce a few more causality conditions and a theorem by Lesourd (2018), and show where in Marolf's argument the implicit assumption is made without justification for $\mathcal{M} = (M,\, g_{ab})$:

distinguishing $\forall p, q \in M$, $I^{-}(p) = I^{-}(q)$ or $I^{+}(p) = I^{+}(q)$ implies $p = q$

reflecting $\forall p, q \in M$, $I^{-}(p) \subseteq I^{-}(q)$ iff $I^{+}(q) \subseteq I^{+}(p)$

causally continuous $\mathcal{M}$ is both distinguishing and reflecting

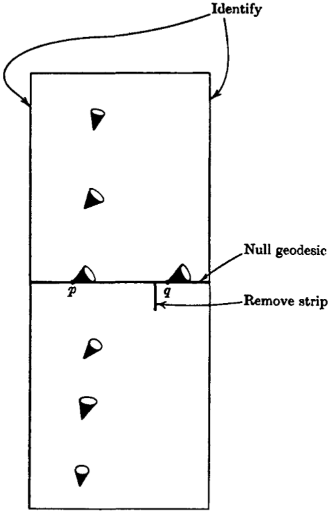


Figure 37. A space in which the causality and past distinguishing conditions hold everywhere, but the future distinguishing condition does not hold at p or q (in fact, $I^+(p) = I^+(q)$). The light cones on the cylinder tip over until one null direction is horizontal, and then tip back up; a strip has been removed, thus breaking the closed null geodesic that would otherwise occur.

(taken from Hawking and Ellis 1973)

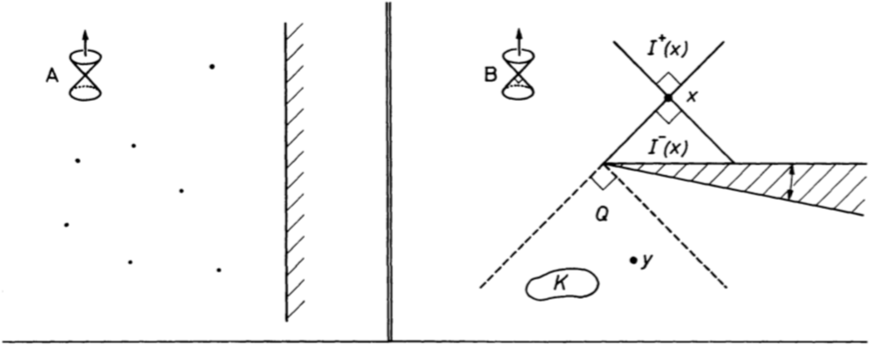


Fig. 1.2. The spacetime A is reflecting; the spacetime B is not

(taken from Hawking and Sachs 1974)

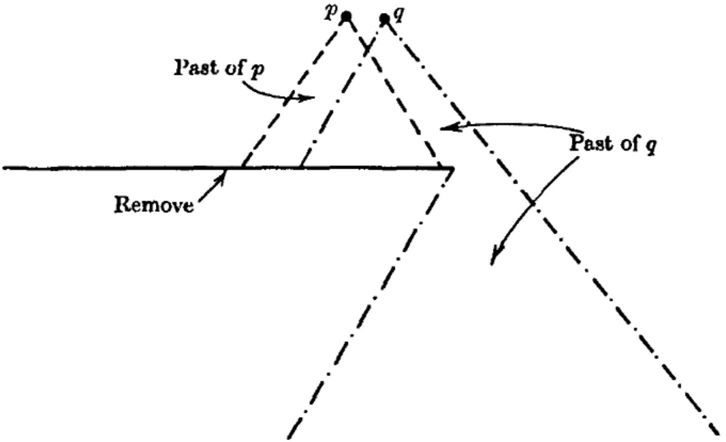


FIGURE 42. A small displacement of a point from p to q results in a large ohange in the volume of the past of the point. Light cones are at $\pm 45°$ and a strip has been removed as shown.

(taken from Hawking and Ellis 1973)

Theorem (Lesourd 2018)

Let $\mathcal{M} = (M, g_{ab})$ be a chronological spacetime with timelike asymptotic boundary $\mathscr{I}^+$ as in Marolf's argument having topology $V \times \mathbb{R}$, such that:

1. *there is a non-trivial black hole region and event horizon;*
2. *$\dot{I}^-(\mathscr{I}^+) \subset \overline{I^-(\Sigma)}$, where Σ is a complete cross-section of $\mathscr{I}^+$, i.e., a spacelike submanifold of $\mathscr{I}^+$ with topology V.*

Then $\mathcal{M}$ is causally discontinuous.

Condition 2 captures the idea that the event horizon persists only up to a finite "moment of time" in the interior of the spacetime, *i.e.*, that the black hole evaporates.

(I slightly alter the phrasing, but the original statement of the theorem implies this one.)

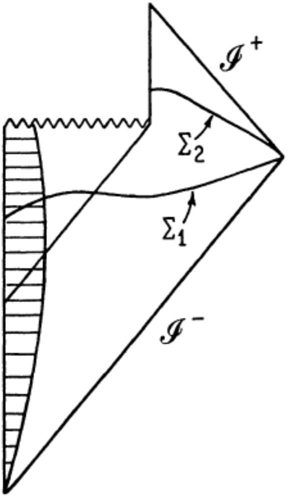


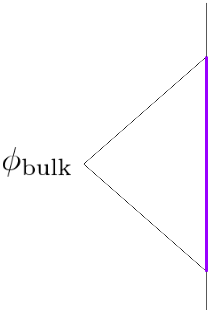
Figure 7.3. A conformal diagram illustrating the phenomenon of loss of quantum coherence in a spacetime in which black hole evaporation occurs.

(taken from Wald 1994)

now, recall this crucial step in Marolf's argument:

Axiom #4: There are other nontrivial operators in the algebra that can be excited to form a black hole [AdS QFT]

e.g. the boundary value of a scalar field $\phi(t) \in \mathcal{A}_{t,\Delta t}$



it is known how to solve for a field (outside of any horizons) in terms of integrals of boundary limiting values ϕ_{bulk}

sideways Cauchy problem subtle but basically OK

Hamilton-Kabat-Lifschytz-Lowe (free fields)
interacting case done perturbatively in 1/N
(should be good near infinity)

note we just need ***some*** *nontrivial field operator,*
(other than vacuum symmetry generators like H)
on a small boundary interval

"sideways Cauchy problem subtle but basically OK"—*only assuming that the interior of the spacetime is causally well behaved!!!* – that is to say, assuming that the interior is not, *e.g.*, causally discontinuous because a black hole has badly evaporated one cannot reject this problem by claiming that we need a full theory of QG to know what happens around "the evaporation point":

Lesourd's theorem shows the causal discontinuity to occur arbitrarily far from *any* neighborhood of "the evaporation point"

in particular, the spacetime is causally discontinuous in regions asymptotically far from any neighborhood of "the evaporation point", in a way completely independent of the details of the geometry in the neighborhood of the evaporation point

Conjecture

Schrödinger evolution is impossible in a causally discontinuous spacetime.

recall: Hawking radiation is not generated by micro-degrees of freedom of the event horizon...

Hawking radiation is not blackbody radiation!

The Temperature Decoupling Problem

Why should we believe the thermal temperature of Hawking radiation is the temperature of the black hole, when it is not generated by micro-degrees of freedom of the event horizon?

- one needs further assumptions to bring these two *prima facie* disparate phenomena—the (presumed) micro-dynamics of the horizon on the one hand, and those of the external quantum field on the other—into explicit and harmonious relation with each other
- only then can one conclude that the temperature of the thermalized quantum radiation is a sound proxy for the temperature of the black hole itself as determined by the dynamics of (presumably) its very own micro-degrees of freedom
- but it is exactly the lack of such bridging principles that, as we will see, calls into question the importance of the information-loss paradox
- so perhaps the derivations of Hawking radiation themselves, which don't depend on a coupling of the quantum field with the classical geometry, are already trying to tell us not to take any of this terribly seriously, with regard to fundamental issues...

information-loss paradox (final-state)

quantum field in curved spacetime with black hole:

- dynamical evolution from pure state to mixed ("thermal") state
- $\Rightarrow$ violation of unitarity

information-loss paradox (Page-curve)

- treat black hole as statistical-mechanical system of quantum degrees of freedom
- then emitted blackbody radiation will eventually no longer be thermal—must be entanglement between early- and late-time quanta
- but SCG says Hawking radiation is thermal
- $\Rightarrow$ contradiction between SM and QFT treatments of black hole
- *pace* Wallace, this is still fundamentally about failure of unitarity

The arguments in favor of loss of unitarity in black-hole evaporation are strong—why all the fuss about it in the case of black-hole evaporation, but not in standard treatments of other quantum fields in an effective field theory formalism (and, for that matter, in the case of measurements in standard quantum theory)?

Correlatively, why do physicists feel confident that an effect predicted by what is manifestly an effective-field theoretic calculation—evaporation due to emission of Hawking radiation—can be trusted to reveal features of an underlying fundamental theory of quantum gravity?

The Cascade Problem

Why assume failure of unitarity at semi-classical level automatically cascades down to failure of unitarity at level of more fundamental theory of quantum gravity?

here is one plausible answer:

- in the case of black-hole evaporation, there is an articulated dynamical mechanism that directly yields violation of unitarity
- this is in clear opposition to the case of standard effective-field theoretic calculations, in which violation of unitarity is manifestly an artifact of the mathematical manipulations used to make calculations tractable, not reflecting or representing anything physical (also: in clear opposition to "measurement collapse")
- also, it happens at arbitrarily low energies (large black holes), where one *expects* the "high-energy gravitational modes" one ignores in SCG (whatever they may be) to be essentially non-existent

moreover. . .

- the failure of unitarity follows from the geometry of the classical spacetime background rather than the dynamics of the quantum field itself
- in particular, it is global features of the large-scale structure of such spacetimes that are responsible for the failure of unitarity
- one can plausibly expect, moreover, that such global features should be insensitive to any effects due to a theory of quantum gravity near the evaporation point, since those effects are appropiately localized in a small spacetime region (as Lesourd's theorem makes precise)

THUS: the onset of "new physics" here (as one expects from a breakdown of an EFT) is heralded by complexity in the causal structure of spacetime—high *entropy*—not by the *energy* of "gravitational phenomena"

So, again: SCG is just an EFT—why get fussed about problems in an EFT?

EFT:

- an explicitly approximative representation of phenomena using only degrees of freedom relevant for its characteristic scales (energy, length, time, ...—generically "IR modes")
- UV modes "integrated out"—-*e.g.*, incorporated into "coupling constants" mediating effective interactions at the relevant scale
- example: coefficient of friction in treatment of dissipative motion in Newtonian mechanics, encoding "averaged effect of intermolecular electrostatic interactions"
- breakdown is expected to herald "new physics"

so let's look more closely at how treating SCG as EFT may bear on the problems I've raised

SCG as EFT

that the geometry is treated classically, *viz.*, with no internal or micro (quantum?) degrees of freedom, suggests (at least) 2 ways to treat as EFT:

1. classical geometry is a coarse-grained environment that quantum field couples to $\Rightarrow$ *prima facie* can reasonably expect Lindblad-evolution (non-unitary) for the quantum field characteristic of an open system, from other standard cases

2. $\mathcal{TBD}$ gravitational degrees of freedom "integrated out" of coupling with quantum field $\Rightarrow$ *prima facie* can reasonably expect (for the most part) unitary evolution, from other standard cases

coarse-graining

- treat "gravity" as free statistical-mechanical system (with micro-degrees of freedom presumably properties of some possibly perturbative quantum gravitational states), then coarse-grain
- curvature is then macro-property that external systems couple with (like temperature and pressure for gases)
- loss of unitarity comes about for reasons similar to why we expect loss of retrodictability for classical systems interacting with dissipative coarse-grained or effectively integrated systems—they wipe out information about initial conditions (*e.g.*, box sliding down incline with friction coming to a stop)

(possible relation to "gravity from thermodynamics" programs of Jacobson and Padmanabhan?)

coarse-graining virtues (clarifying conceptual muddles?) and demerits (raising new difficulties):

1. hints for origin of thermodynamical character of BHs (and more general pure gravitational systems) when external quantum effects taken into account?

2. hints for way to explain that BHs (and more general pure gravitational systems) obey thermodynamical relations in *classical* GR, at least formally: any theory of gravity at the classical level *must* recapitulate (at least formally) such thermodynamical behavior as a minimal criterion of adequacy

3. seems to dissolve the Information-Loss Paradox: shows why loss of unitarity at semi-classical level need not imply anything about dynamics at more fundamental levels

4. indeed, retaining of predictability with loss of retrodictability is exactly what one has in BH evaporation (I can tell you exactly what mixed state this pure state will evolve into, but not what pure state it came from once it's there), and exactly what one expects from such coarse-graining (*cf*. the box sliding down the frictional slope come to rest)

coarse-graining virtues and demerits, cont.:

5. may still provide guidance to quantum gravity: look for gravitational micro-degrees of freedom whose statistics give the kind of coarse-grained environment required, both for manifesting thermodynamical behavior of BHs and for coupling to $\langle \hat{T}_{ab} \rangle$
6. possible problem—not clear why following seems to be ruled out: that general relativity could be adequate in some regimes in which seeming thermodynamical nature of gravity is irrelevant (*e.g.*, Solar System, gravitational waves, cosmology), and yet still be inadequate in those regimes in which thermodynamical character of gravity *is* relevant (*e.g.*, BHs)
7. problem: *really* hard to see how this could *explain* coupling to $\langle \hat{T}_{ab} \rangle$
8. problem: *really* hard to see how this could explain coherence of quantum-field state as condition on adequacy of approximation

integrating out

- we treat quantum field's degrees of freedom as coupling with something like "perturbative quantum gravitational degrees of freedom"
- then integrate out from the interaction the $\mathfrak{TBD}$ gravitational degrees of freedom as in the standard EFT framework in particle physics
- coupling can't be with "fundamental quantum gravity" degrees of freedom, because we don't expect those to couple with gross macroscopic (relatively speaking) matter—the quantum fields whose excitations constitute Hawking radiation

integrating-out virtues (clarifying conceptual muddles?) and demerits (raising new difficulties):

1. hard to see how to characterize "$\mathfrak{TBD}$":
    i. can't be "UV" because gravitational field *has no* high-energy modes in relevant cases (at least as compared to energies of possible modes of quantum field)
    ii. can't be "IR", because we want "arbitrarily close to" Minkowski spacetime as a possibility
    iii. only possibility left seems to be something like "low entropy" modes (compared to characteristic entropy of the standard quantum field states), since it is effectively high gravitational entropy that characterizes the relevant cases
    iv. but this is severely non-standard form of EFT, and difficult to see how to implement—not even clear whether "low entropy mode" makes sense!

2. *prima facie*, no relief from Information-Loss Paradox: standard EFTs can in principle violate unitarity, but only when dynamics "tries to probe integrated-out phase space regions" (*i.e.*, when coupling energies become large); but that is not BH evaporation, at least not for big BHs with effectively flat curvature and infinitesimal Hawking temperature

integrating-out virtues and demerits, cont.:

3. if we can figure out how to integrate out "low entropy modes", there may be relief: it is exactly those modes that quantum field degrees of freedom are trying to probe, if one assumes a form of coupling in which mode-by-mode interaction is governed by respective entropies, not respective energies
4. but no such coupling is known for any other types of field, and it would seem impossible to govern such a coupling with a Hamiltonian (energy wouldn't govern dynamics, and quantum entropy is not a self-adjoint operator nor is it obvious how to make it one)
5. because $\mathfrak{TBD}$ modes are integrated out from the *interaction*, there is some hope of explaining the coupling of G_{ab} to $\langle \hat{T}_{ab} \rangle$
6. difficult to see why coherence of quantum-field state should be restriction on adequacy of semi-classical approximation

with particular regard to the Page-curve problem:

- argument assumes BH micro-degrees of freedom in statistical-mechanical treatment are entangled with Hawking radiation
- Hawking radiation is a "macroscopic" phenomenon (relative, presumably, to fundamental QG)
- $\Rightarrow$ BH micro-degrees of freedom, presumably, are of the form that the EFT integrates out or coarse-grains over (otherwise, it's hard to understand how SCG can be framework for BHT)
- $\Rightarrow$ one may be justified in treating Page-curve problem as no more nor less paradoxical, with regard to fundamental theory, as the standard Information-Loss Paradox (*pace* Wallace), since those degrees of freedom are *ex hypothesi* not fundamental

my sense is that, at this level of discussion, coarse-graining wins on virtues and demerits—but one really needs to construct concrete models of each type and work through all the virtues and demerits in detail to verify them as such (which I have not done)

if one were decisively argued to be superior, what would it tell us about conceptual structure of SCG, and its standing as a viable, possibly fruitful physical framework?

'Information Loss' Is Said in Many Ways

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Yet More Causality Conditions and a Theorem on Causal Structure

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Concluding Unscientific Postscript

The Problem of Semi-Classical Coupling

What justification, if any, can there be for the form of the SCEFE? Why should classical geometry couple to the expectation value of $\hat{T}_{ab}$ in semi-classical approximation?

- expectation values standardly represent averages of possible experimental outcomes
- does the SCEFE assume that classical geometry effectively acts as a "continual measurement probe" of the quantum field?
- Ehrenfest Theorem irrelevant: we're not talking about "classical evolution of expectation value", but rather how the *quantum field operator* evolves *in a quantum way* when coupled to classical geometry

(dynamical collapse interpretations may be able to make sense of this. . .)

mostly, I think, the thought is that this is justified because the same techniques are used to "derive" the SCEFE as, say, to derive the semi-classical treatment of phonons and their coupling to classical fluid "background":

1. expansion in power series of coupling constants
2. saddle-point approximation
3. truncation to first order
4. ...
5. $\Rightarrow$ coupling mediated by expectation values of relevant "thermodynamical" quantum observables

but in the other contexts, because of all the background knowledge we have about the solid-state/fluid systems (*e.g.*), including both theoretical and empirical/experimental justifications, we know:

- what the power series means physically as a whole (including understanding, and having empirical evidence for, its regime of applicability)
- what the individual terms in the power series mean physically
- what the saddle-point approximation means physically (including understanding, and having empirical evidence for, its regime of applicability)
- what truncating to first-order means, including again its regime
- ...

because of all that, we have epistemic warrant for using, *e.g.*, the semi-classical phonon model (both for claiming that we understand it, and for claiming that it is a good model in the circumscribed regime)

we have epistemic warrant for using it as the basis for further knowledge claims that *ipso facto* already have some confirmatory support in virtue of being derived from the well entrenched, well understood semi-classical phonon model to be fair, I must note that there may be some empirical support for QFT-CST: particle-production in early-state cosmology, and it's possible signature in the anisotropies of the cosmic microwave background

but one still has to be careful here: the anisotropies are definitely detected, definitely there—the issue is that the derivation of them is not very convincing

anyway:

- it does not use the SCEFE
- and even if this turns out to be confirmatory, it would not show that QFT-CST, much less SCG, works for BHs

- we want to use the SCEFE as the basis for arguments whose conclusions we want to have confidence in—we want, essentially, to use it as part of an evidential network to buttress the assertability of claims in BHT (*inter alia*)
- but we have none of the entrenched background in SCG
- it can't confer confirmation, because one of the essential elements of confirmation is that anything that gets it can then be used as evidence for other claims, but that is exactly what Hawking radiation, BHT and SCG and such cannot do, at least not in our current epistemic state
- we must be careful in trying to use SCG to draw fundamental lessons!

there is an active danger in assuming that the semi-classical regime is now well understood and that its results may be used as the touchstone for testing programs of QG, that recovering those results acts as a minimal criterion of adequacy, if not something epistemically stronger. . .

if it turns out not to have been right, all of QG has been wasted effort

it makes sense to hedge our bets

- I am not saying that we shouldn't use it as the grounds for *speculative* investigation
- I am rather saying that we should be more critical, more skeptical, and more modest in our understanding of the epistemic warrant we have for it...
- ... both with regard to our understanding of it, and with regard to our confidence in using it as the ground for further investigation
- we should be clearer on our epistemic state with regard to it

A Knight of Faith? Or a Lost Soul?

- Is there a consistent picture of spacetime geometry, matter, and their interaction in this framework?
- Can such a problematic framework give good results, and, if so, how?
- Why have faith in results from a framework with such manifest, serious, unresolved problems?
- How to make progress in important parts of theoretical physics if one doesn't have faith?

Make the Leap of the Absurd?
or
Remain a Skeptic and Be Damned?

I Tentatively Recommend. . .

Socratic Irony

a dialectical process of moving from skepticism to faith, and back again, as our epistemic circumstances evolve under constant questioning, knowing that we do not know

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