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III

SUMMER SCHOOL IN HIGH ENERGY PHYSICS AND COSMOLOGY

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QUANTUM MECHANICS OF BLACK HOLES

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Please note: These are preliminary notes intended for internal distribution only.

Info problem

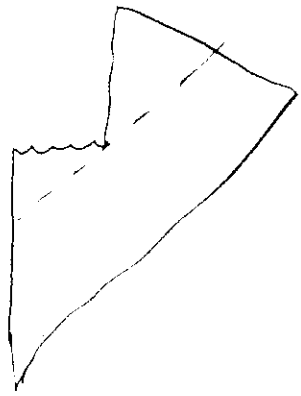
what happens to info ?

1. Lost (Hawking ...)

conservative

but radical :

- QM breaks down



2. Returned (in HR) ('t Hooft, Verlinde, Susskind)

- mistake ? (unlikely ?)
- violate locality/causality ?

Return after $M \sim m_{pl}$:

4d: $S \sim M^2$, $E \sim m_{pl}$

state @ ∞ :

soft γ : 1 bit / photon $\Rightarrow$ M^2 photons;

$$E_\gamma \sim \frac{1}{M^2}$$

decay time : 1 photon $\Gamma_\gamma \sim \frac{1}{E_\gamma} \sim M^2$

$$\Rightarrow \quad \tau \sim \left(\frac{M}{m_{pl}}\right)^4 t_{pl}$$

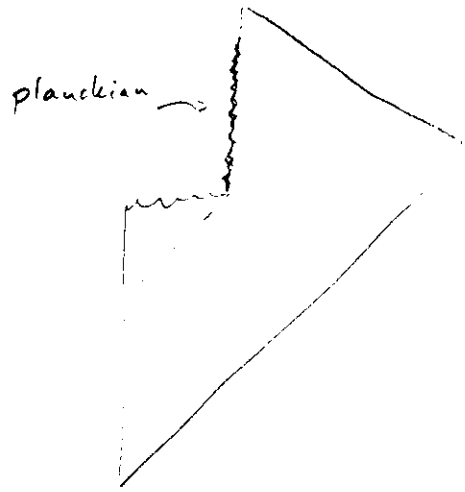
$\tau = T_{univ}$

[→ $(10m)^3$ of $\rho = 10\ H_2O$]

$\sim T_{univ}$ for $M = M_{building}$

⇒

3. <u>Remnants</u> — stable or long lived (Banks ?, SG, ...)



In Research Plot !)

Each stridently advocated

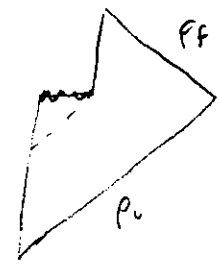
Each seems to violate sacred low energy principles

1. Info loss – violates qm

also <u>energy conservation</u>

(we're very attached to this!)

information $\longleftrightarrow$ energy



want Effective description of BH evap: $\rho_i \rightarrow \rho_f$

useful model: Two Hilbert spaces, $\mathcal{H}_o$, $\mathcal{H}_h$ – exchange info

$$H = H_o + H_i + H_h$$

$$\{ \text{interaction}$$

BH: $\mathcal{H}_o$ = exterior

$\mathcal{H}_i$ = interior

(other types of info loss possible, but this = good enough for BH ?)

Note: info loss repeatable:

n experiments, $\Delta t \geq \tau_{evap} \Rightarrow \Delta S_n = n \Delta S_0$

$\rightsquigarrow$ energy violations, expect $\Delta E \sim 1/\tau_{evap}$.

reason: assume <u>not</u>, ie $H_h = 0$

e.g. $\mathcal{H}_h = \{ |x\rangle \}$

$H_i = \sigma \hat{x}$

σ: ext.

Then solve

$$i\dot{\Psi} = (H_0 + H_i)\Psi,$$

define $\rho = tr_i\, |\Psi\rangle\langle\Psi|$

$\Delta S_0 \downarrow$ (pf.: Coleman – appendix: Black holes as red herrings)

reason: (familiar from wormholes)

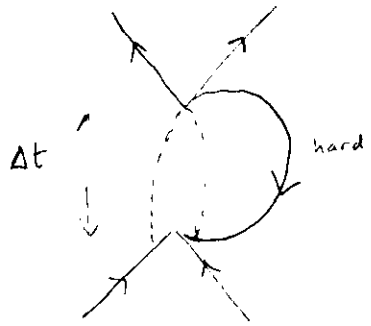
if initially $|\psi_0\rangle\,|x\rangle$, $H = H_0 + \mathcal{O}x$ (coupling const)

if not: distribution for coupling consts, measurements ⇝ determination

similarly for $H = \sum_\alpha \mathcal{O}_\alpha \mathcal{L}_\alpha$ ⇒ $H_h \neq 0$, energy loss.

Worse: quantum principles ⇒ {info / energy} loss in virtual processes

e.g.



$\Delta E \sim 1/\Delta t$

probability $\sim \frac{1}{V_{pe}\, t_{pe}}$; $\Delta E \sim m_{pe}$

$\sim$ thermal dist. w/ $T = T_{pe}$!

Not our world

Indeed : Hawking $\rho \not\to \$\rho$ ~~$\rho \to \$\rho$~~

$\$$ linear, ...

BPS : violates E conserv.

these arguments : $\sim$ thermal bath, $T = \infty$!

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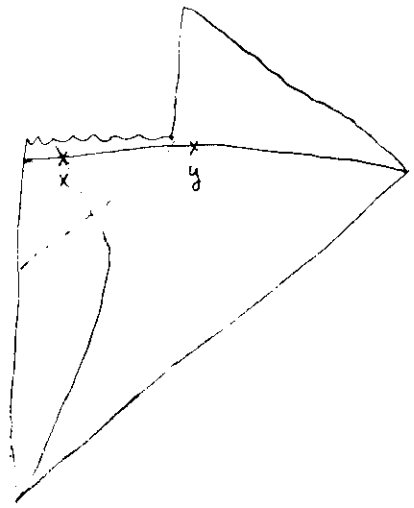
2. Info return - violates locality/causality



mistake?

$\frac{dE}{dt} \sim N$

also want $\frac{dI}{dt} \sim N$ after $\sim \frac{M}{2}$ (Page)

no obvious evidence?

also if state not Hawking state, trace back, difficult to see something that looks like vac.

1) $[\theta_{(x)}, \theta_{(y)}] = 0 \Rightarrow \psi = \sum_\alpha |\psi_\alpha\rangle_{in} |\psi_\alpha\rangle_{out}$

2) Infalling guy carries info, no trouble @ horizon
$\Rightarrow$ non-trivial correlations

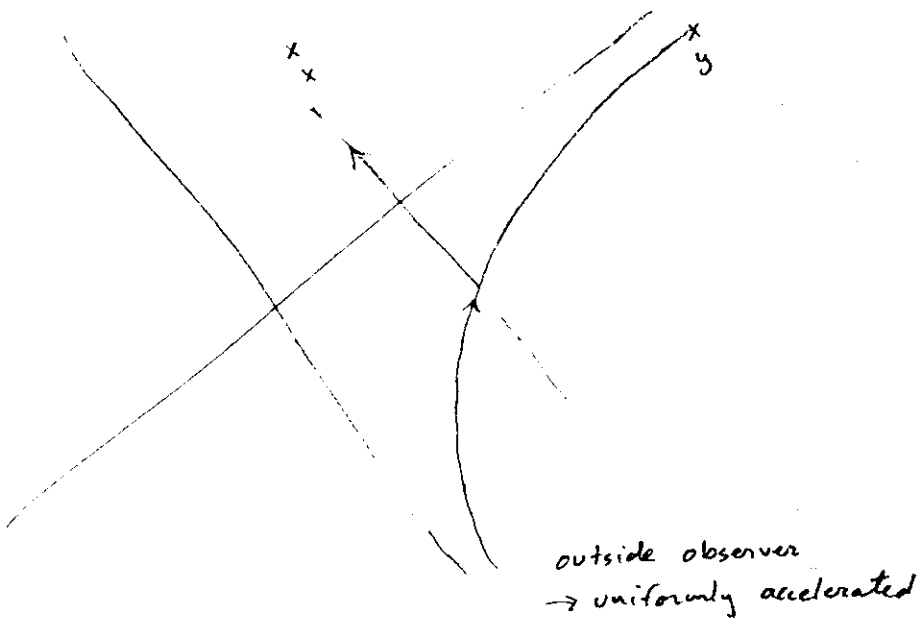
$\Rightarrow \Delta I \neq 0, \quad \sim M^2$

defining observables notoriously difficult in QG

(cf Hermann)

maybe nonlocal ?

extreme case: $M \to \infty$: Rindler space



all info in left half of universe is actually on or to R of horizon; $[\mathcal{O}(x), \mathcal{O}(y)] \neq 0$.

't Hooft, Susskind } new physics responsible

't Hooft : cellular automata (can't assess)

Susskind : strings — are nonlocal

(non-perturb.

String thy: R_1 R_2

$$[\mathcal{O}(R_1), \mathcal{O}(R_2)] \sim e^{-|R_1 - R_2|^2/\ell_{st}^2}$$ ordinary measurement

$$\sim 1$$ high energy measurement

(Lowe, Susskind, Uglum)

$\Rightarrow$ maybe all info is in state on R half of world!

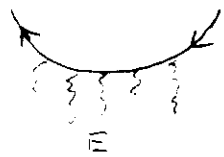
Problem: transfer to HR? (no demonstrated mechanism)

(indeed, could stay @ horizon $\rightsquigarrow$ remnant!)

3. Remnants violate naive crossing

E.g. if charged

$\rightarrow$



: Schwinger production

$$\Gamma_{vac} \propto \mathcal{N} e^{-\frac{\pi m^2}{qE}} = \infty$$

$\mathcal{N} \rightarrow \infty$

likewise: Hawking: $\frac{dM}{dt} \propto \mathcal{N} \cdot \frac{1}{M^2} = \infty$ ($\mathcal{N} \rightarrow \infty$) (is self consistent)

Thermal: $n \sim \mathcal{N} \cdot e^{-m/T} = \infty$

(can't really make)

Summary:

proposal	violates
Info loss	energy conservation
Info return	locality / causality
Remnants	naïve crossing

- each objection phrased in terms of low E physics

⇝ Information "paradox"

Relevance of planck scale ⇝ problem

(Hermann; next time)