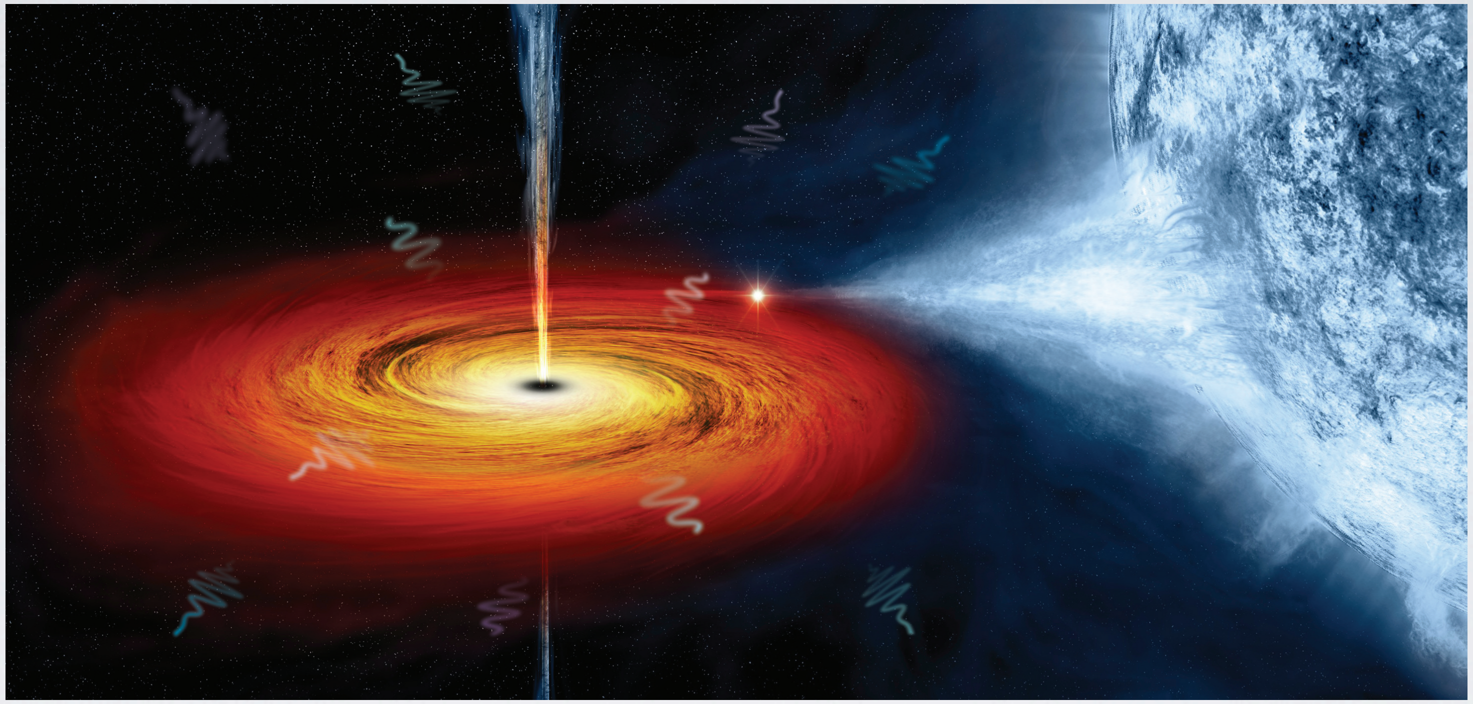
RESCUING QUANTUM MECHANICS AND (APPROXIMATE) SPACETIME



Based on an image from NASA/CXC/M.Weiss

Physics Today April 2013

S.B. Giddings, UC Santa Barbara

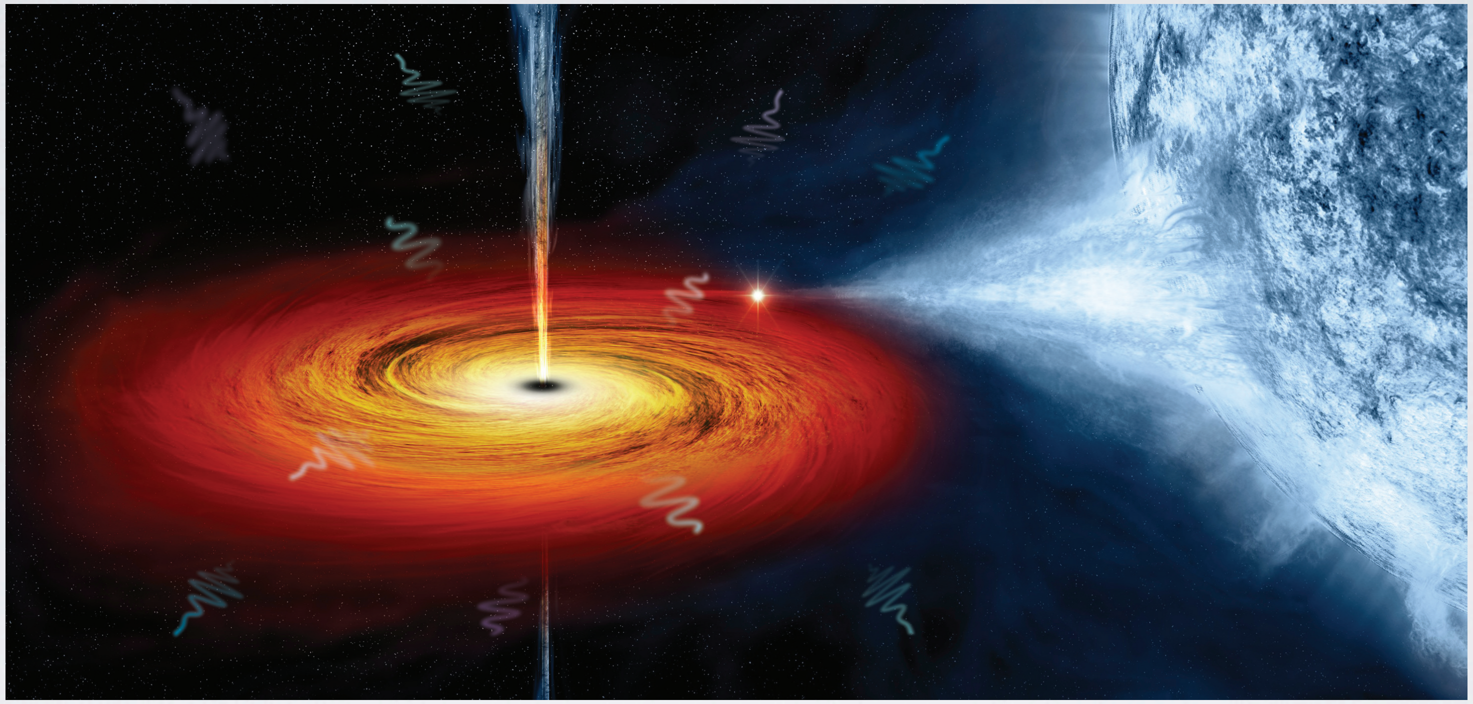
Black Holes: Complementarity, Fuzz, or Fire?

Refs:

SBG: 0911.3395, 1108.2015, 1201.1037, 1211.7070,1302.2613, 1308.3488, WIP

SBG & Y. Shi: 1205.4732, and in preparation

RESCUING QUANTUM MECHANICS AND (APPROXIMATE) SPACETIME



Based on an image from NASA/CXC/M.Weiss

Physics Today April 2013

S.B. Giddings, UC Santa Barbara

Black Holes: ~~Complementarity, Fuzz, or Fire?~~

Alternative title: None of the above

Refs:

SBG: 0911.3395, 1108.2015, 1201.1037, 1211.7070,1302.2613, 1308.3488, WIP

SBG & Y. Shi: 1205.4732, and in preparation

Things I choose to believe in:

Quantum mechanics

Robust; hard to sensibly modify

Spacetime (approximate)

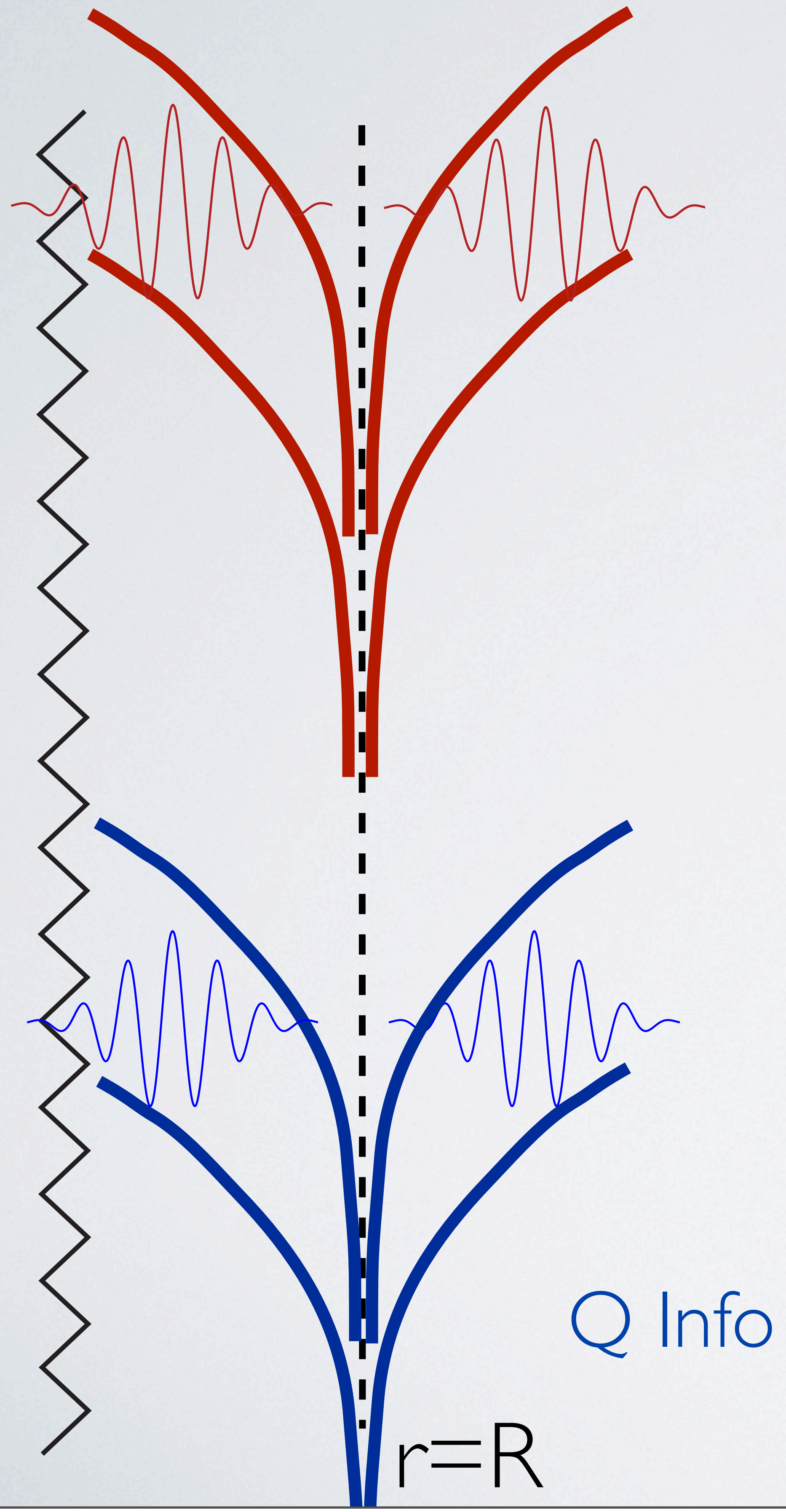
Ultimately likely arises from deeper quantum structure

Good approximation -- with limitations -- for big black holes and cosmologies

LQFT as an approximate description of dynamics

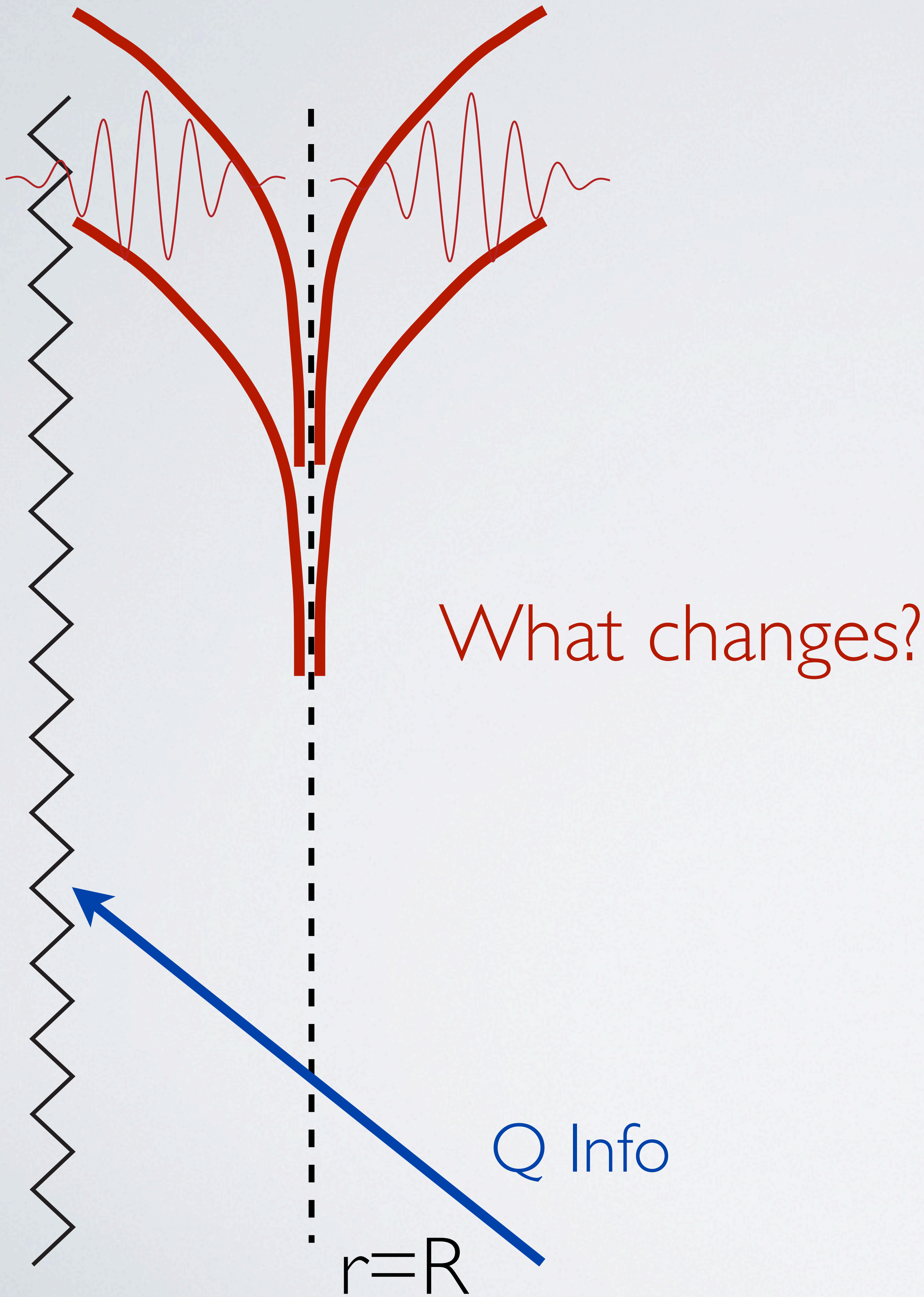
Can these be reconciled with black hole evolution?

A proposed picture:



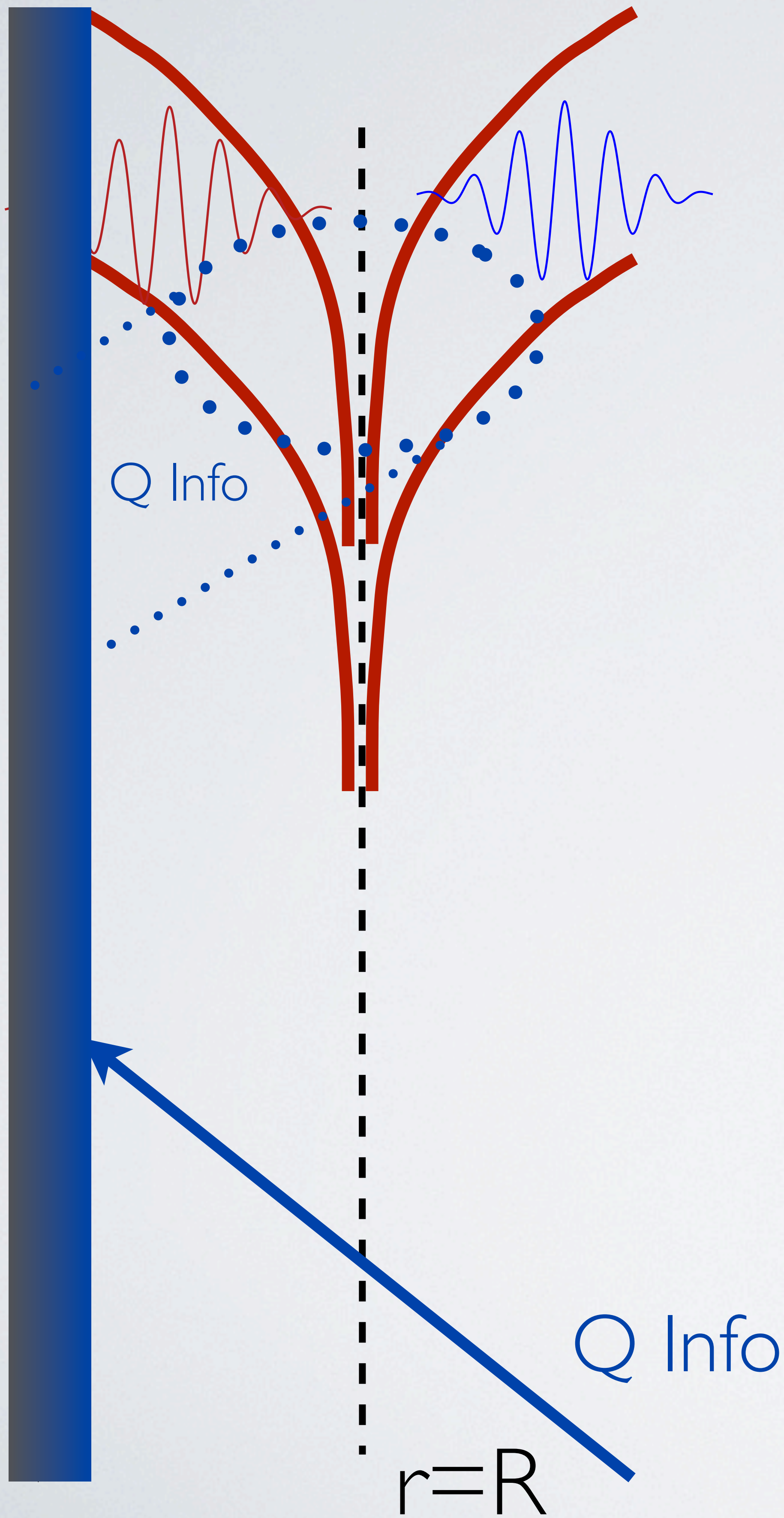
Stuff goes into singularity
(Stuff = Q Info)

A proposed picture:



Stuff goes into singularity
(Stuff = Q Info)

A proposed picture:



Stuff goes into singularity
(Stuff = Q Info)

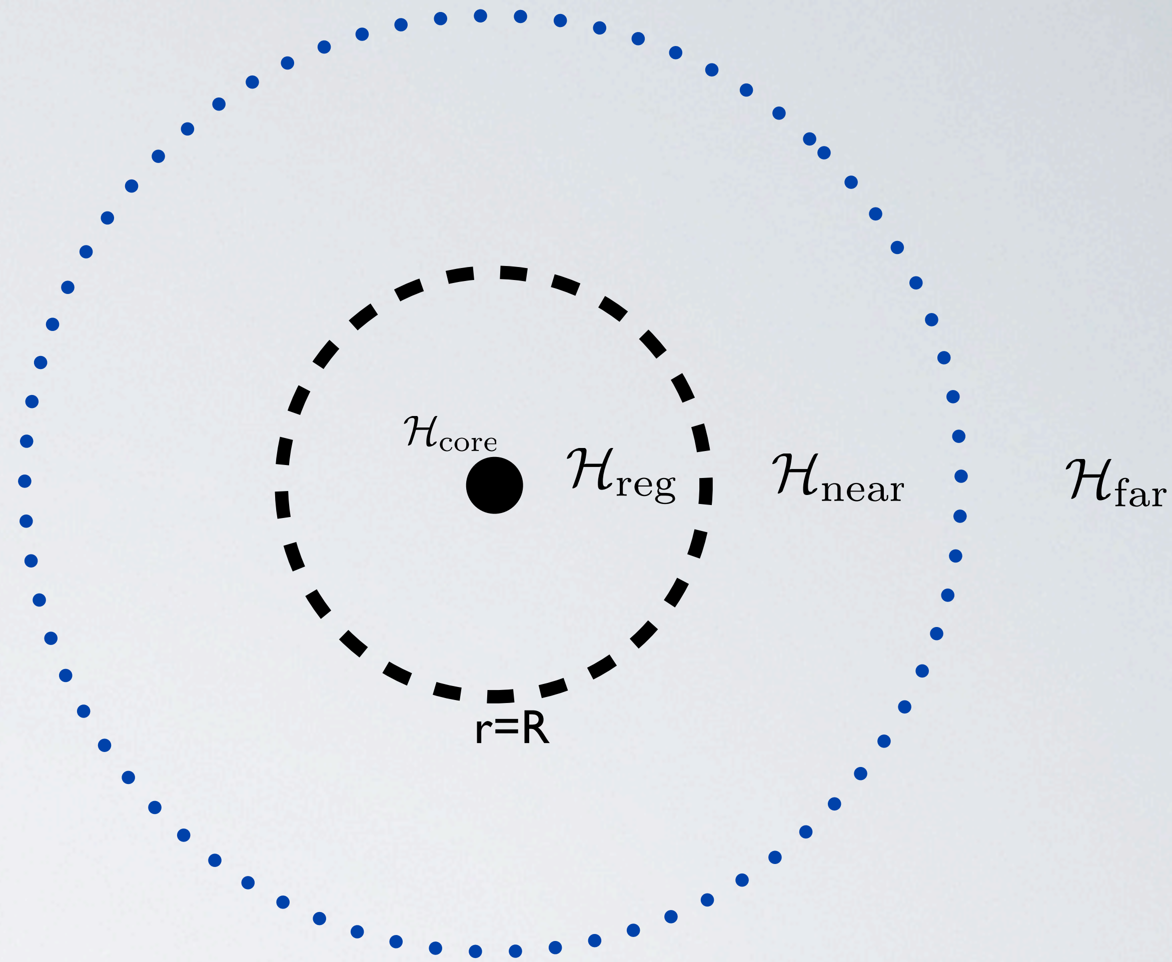
QM: Stuff comes out -
black holes leak information

Nonlocal or superluminal
(w.r.t. semiclass. geometry)

(like massive remnants:
fuzzballs, firewalls, etc.)

"nonviolent:" saves approx
spacetime, equiv. principle?

How to describe?

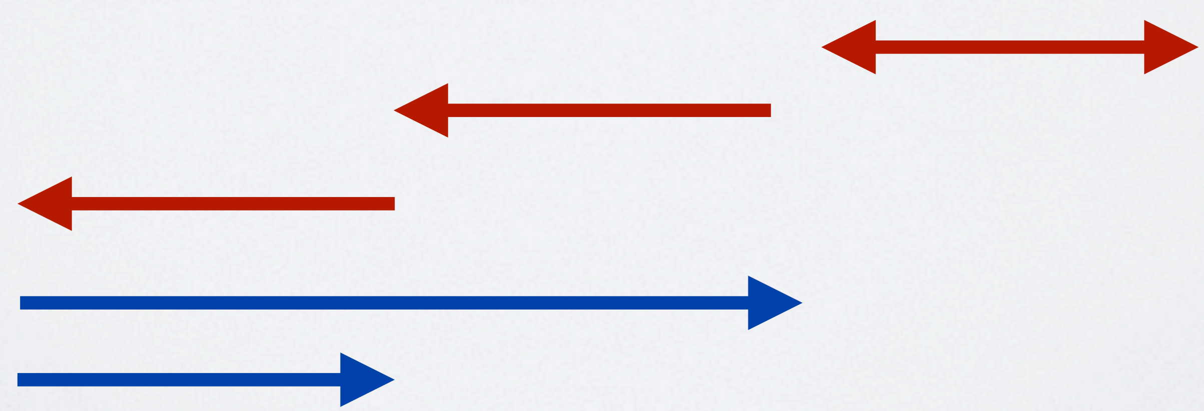


Possible fundamental picture ~

Unitary evolution: U

- rearranges excitations/degrees of freedom (+creates)

$$\mathcal{H} \subset \mathcal{H}_{\rm core} \otimes \mathcal{H}_{\rm reg} \otimes \mathcal{H}_{\rm near} \otimes \mathcal{H}_{\rm far}$$

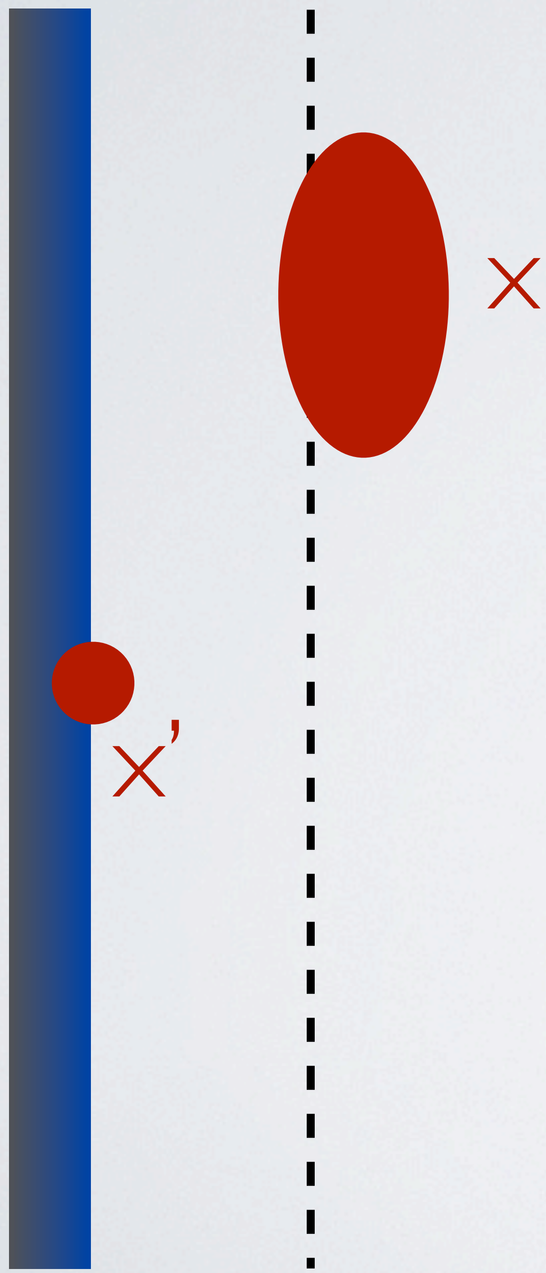


LQFT

"Extra"

Approximate description: deviation from local QFT

(*Not yet* a complete picture)



$$\int dt H_{NL} = \int dV_4 dV_4' \mathcal{O}_A(x) G_{AB}(x, x') \mathcal{O}_B(x')$$

local operators

(compare G=const. : ~wormholes)

E.g. $\mathcal{O}_A = \phi^I$

$= T_{\mu\nu}$

...

A main question of workshop:
Can information get out w/out destroying horizon?

The *effective source approximation*

Focus on outside: $$\int dV_4 \mathcal{O}_A(x) \underbrace{\int dV_4' G_{AB}(x,x') \mathcal{O}_B(x')}_{J_A(x)}$$

E.g. $$\int dV_4 J^I(x) \Phi^I(x) \ , \qquad \int dV_4 J^{\mu\nu}(x) T_{\mu\nu}(x) \quad \ldots$$

(~"horizon fluctuations")

For purposes of near-horizon dynamics: can such effective sources 1) get needed info out 2) not have unacceptable ("violent") consequences

Toy model: [1302.2613, +w/ Y. Shi, in preparation]

$\phi =$ free scalar

$$\int dV_4 J(x)\phi(x) \qquad J(x) = \sum_{lm} \int d\omega\ j_{\omega l}(r) e^{-i\omega t} Y_{lm}$$

(e.g. t= Schw. time)

Properties of J:

- e.g. $\omega \sim 1/R$ (can generalize $1/R^p$)
- $j_{\omega l}(r)$ smooth at r=R; vanishes at r>>R
- required size: $\frac{dS_{\rm vN}}{dt} \lesssim -\frac{1}{R} \longleftrightarrow \frac{dE}{dt} \gtrsim \frac{1}{R^2}$

$\Rightarrow$ minimal: $J \sim 1/R^3 \qquad j_{\omega l} \sim 1/R^2$

(take for all $l < l_{max}$)

Possible concerns:

Singular at horizon?

J ~ smooth $\Rightarrow$ don't excite planckian wavelengths

$\langle T^{\rm Krusk}_{--}\rangle_J \xrightarrow[\text{horizon}]{}$ finite

$a_p^{\rm Kruskal}|\Psi_J\rangle = 0$ for p~Planckian: "no firewall condition"

Provides a way to avoid firewall problem

Other checks:

$R \to \infty$ limit: effects turn off, $\longrightarrow$ Rindler

Mining $\longrightarrow$ "overfull" black holes? $(S_{\rm vN} > S_{\rm BH})$

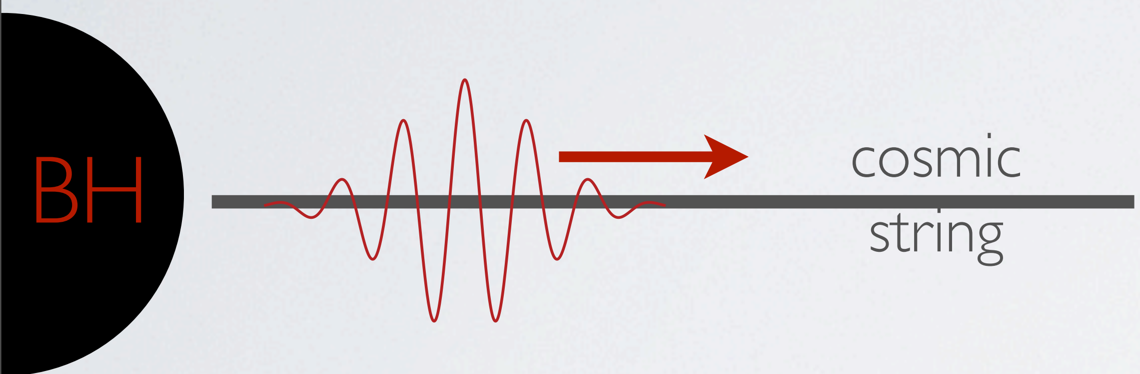
Effects of higher-l modes

No mining:

- suppressed contribution at $\mathcal{I}^+$ $\qquad |T_{\omega l}|^2 \sim (R\omega/l)^{2l}$
- small energy density near H $\qquad \langle T^{\rm Krusk}_{\mu\nu} \rangle \sim l^2_{max}/R^4$

... little effect

Mining: (e.g. cosmic string)



open extra channel for Hawking
+ "new" excitations

$$\frac{dE_i}{dt} \sim \frac{1}{R^2} \qquad \frac{dS_{{\rm vN},i}}{dt} \sim -\frac{1}{R}$$

Extra information-carrying excitations present only when mining

Avoid AMPS "implausible conspiracy"

No:
- Word bag
- Photon bag
- Mineable mode bag

Another possible objection:

Generically predict extra flux [1201.1037, 1205.4732, 1211.7070, 1302.2613]

Hawking + "information carrying"

Deviation from expected thermodynamics [1308.3488]

Quick argument:

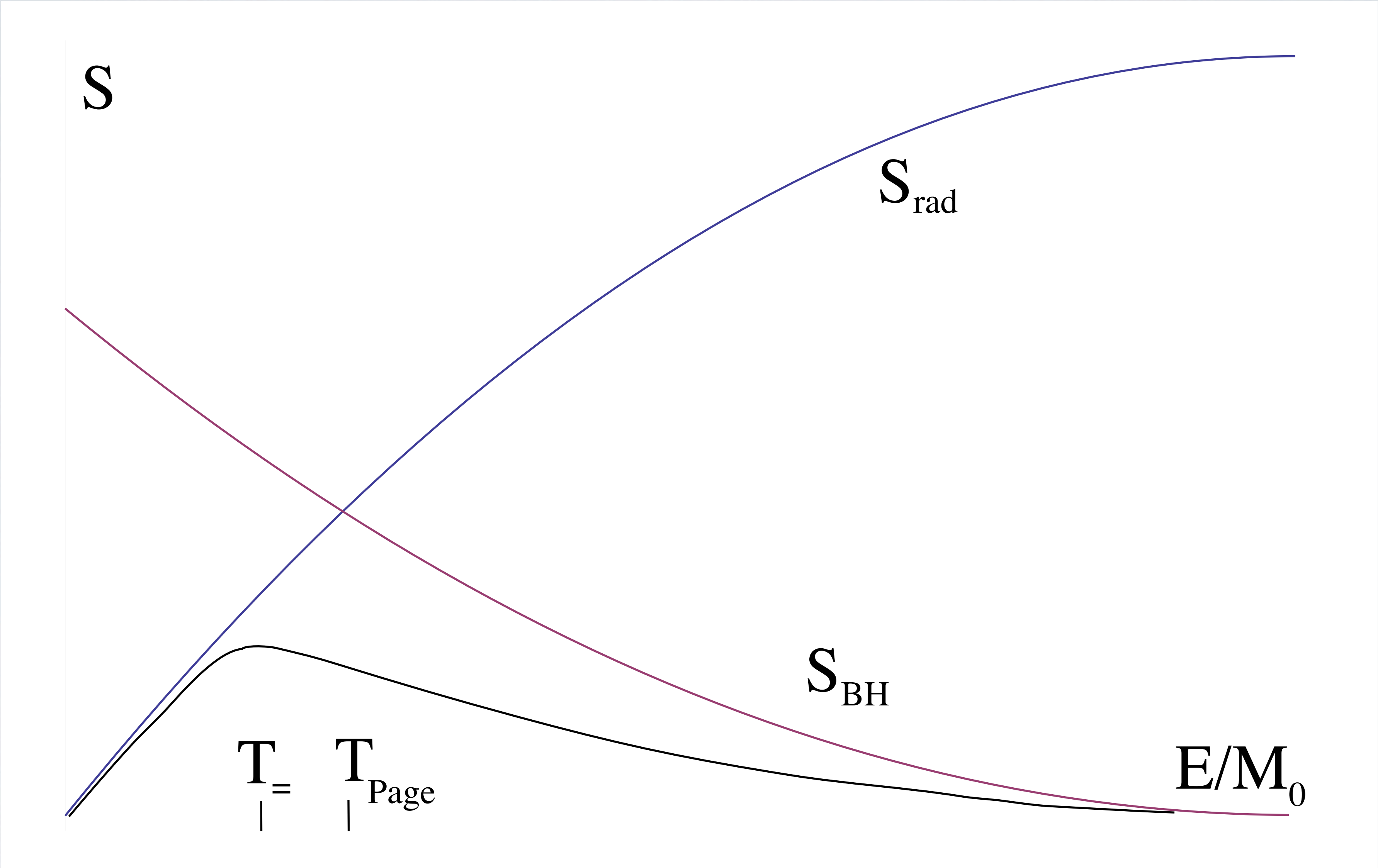
$$\frac{dE}{dt} > \frac{dE}{dt}\Big|_{\rm Hawk} \quad \to \quad T_{\rm equilib} > T_H \quad \to \quad \frac{dS_{\rm bh}}{dM} < \frac{dS_{\rm BH}}{dM}$$

Interesting question: models without extra flux?

Yes -- at infinite temp [1108.2015, 1201.1037]

No in simple models at finite temp [1308.3488 + WIP]

Page curve vs. new curve:



Important question: does this present a contradiction with anything we really know?

Further comments:

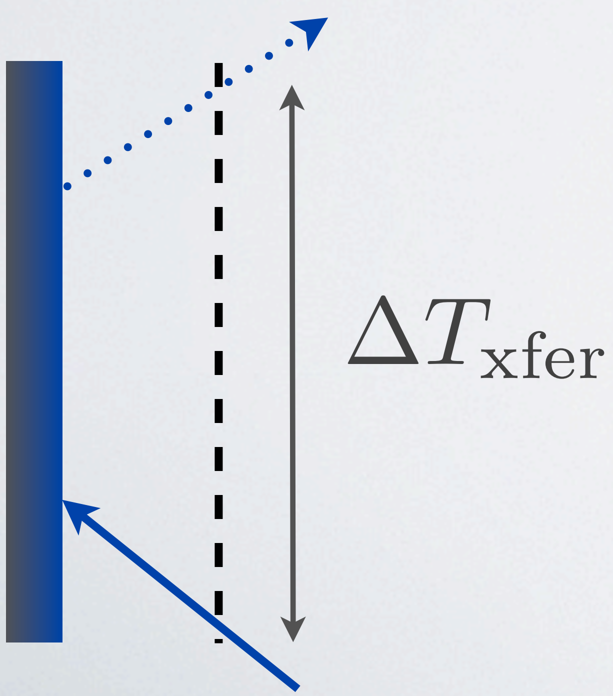
- Horizon is special
- "Violate" equivalence principle

(really: generalize?)

} small for big BH

not sharp:
e.g. scales ~ R

- Nonlocality $\not\Rightarrow$ acausality



$\Delta T_{\rm xfer} >> R$

asymptotic causal ordering "from background"

no observable violation of causality?

(conjecture: also inside)

From: Steve Giddings
Subject: **complementarity**
Date: November 22, 2009 11:47:38 AM PST
To: Leonard Susskind

Show in Mailbox

Dear Lenny,

I hope you'll forgive me, but I always had trouble understanding complementarity! Of course, if you have any further comments to sort out my confusions, I'd be interested! (http://arxiv.org/abs/0911.3395).

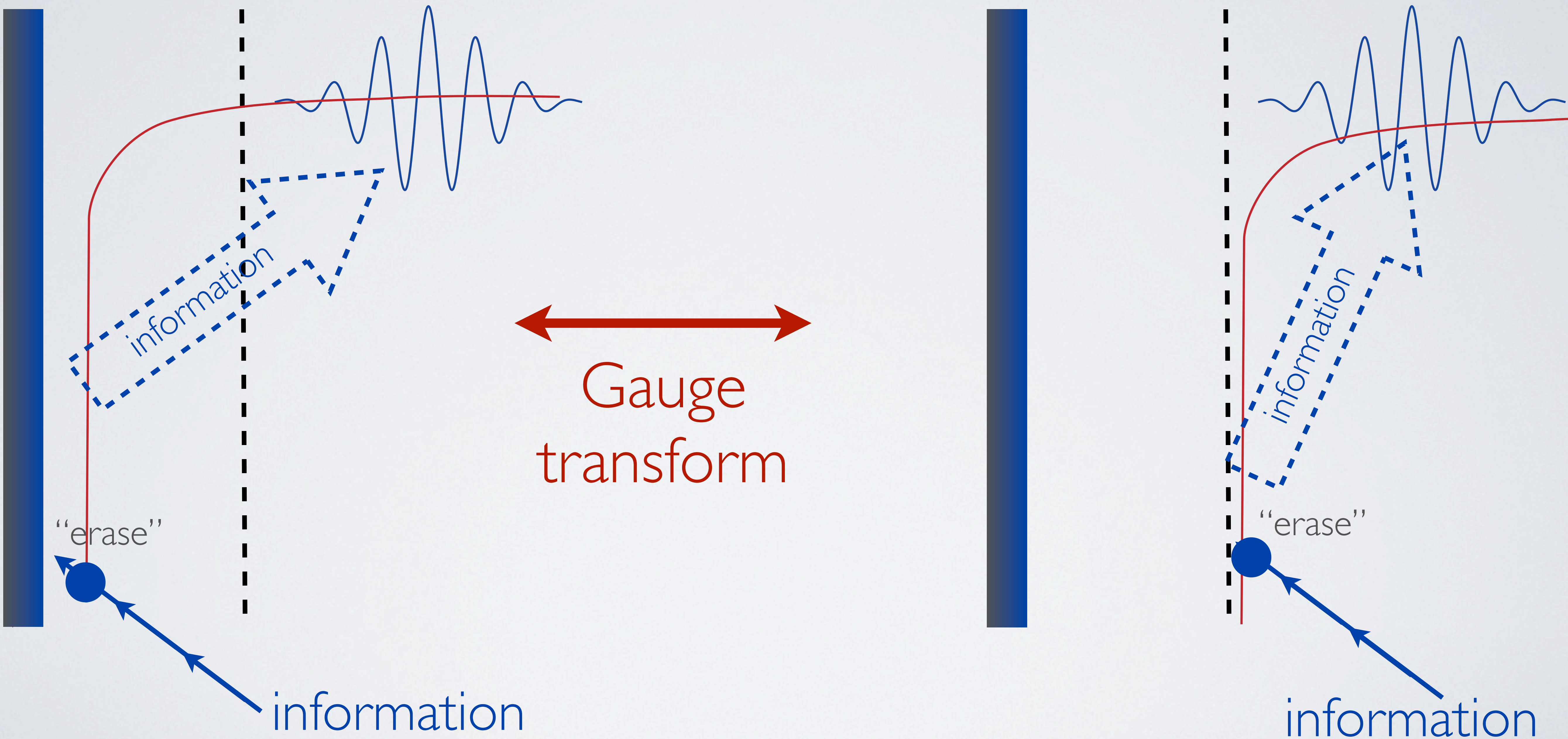
All the best,
Steve

Steve Giddings | Professor, Department of Physics
University of California | Santa Barbara, CA 93106
805-893-4750 | 805-893-8838 (fax) | giddings@physics.ucsb.edu
http://www.physics.ucsb.edu/~giddings/index.html

Nonlocality vs. complementarity: a conservative approach to the information problem

A different way to think about complementarity: Different descriptions from different gauges ~ "slicings"?

[1211.7070]



"Weak complementarity"

"Outside picture;" no interior

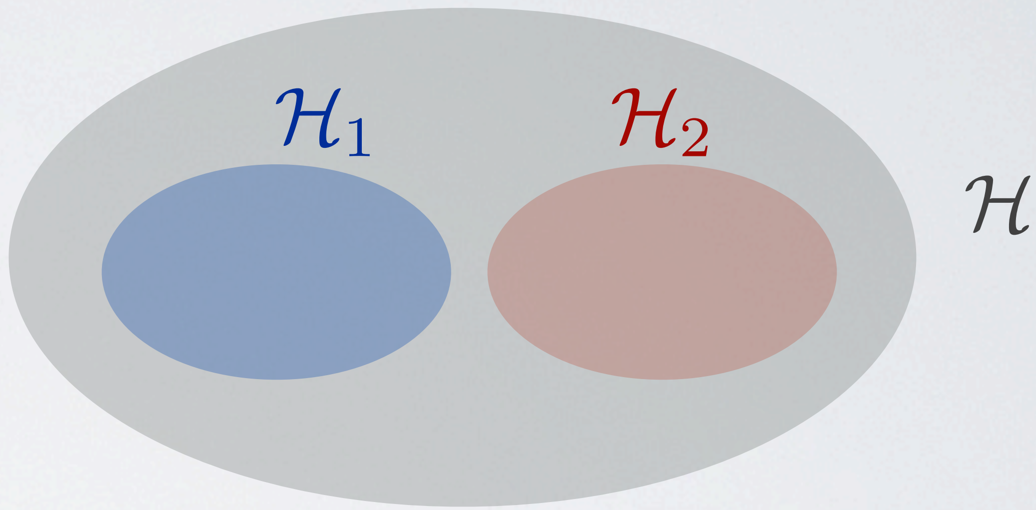
Have only given an approximate, incomplete description, proposed to evade some potential problems

What is the more fundamental story?

1201.1037

QM, ~locality: Hilbert space with networked factor structure:

Subfactor localization



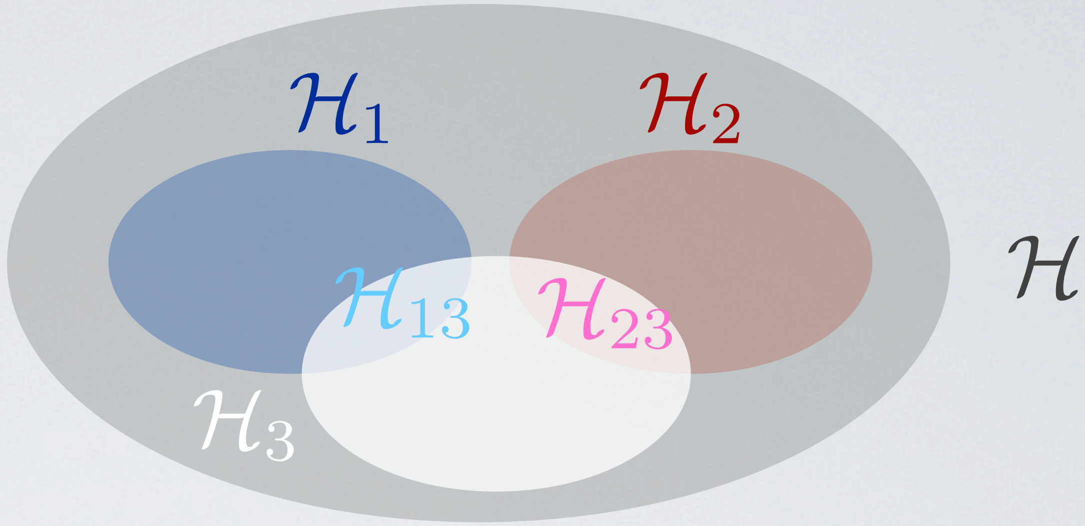
$$\mathcal{H}_1 \otimes \mathcal{H}_2 \subset \mathcal{H}$$

↕

Spacetime localization

Compare LQFT: $[\mathcal{O}(x), \mathcal{O}(y)] = 0 \quad , \quad (x-y)^2 > 0$

~ quantum analog of manifold:



(some common ideas w/ algebraic QFT; also Banks/Fischler "HST" -- though important differences)

- Unitary evolution; ~local, LQFT

- ~Locality: conditions on evolution

- Symmetries $\mathcal{H} \to \mathcal{S}\mathcal{H}$ global

  $\mathcal{H} \to \mathcal{S}_{loc}\mathcal{H} = \mathcal{S}_1\mathcal{H}_1 \otimes \mathcal{S}_2\mathcal{H}_2 \cdots$ local

Hilbert spaces w/ networked factors: a possible fundamental framework for a unitary theory of quantum gravity

Summary:

Have asked question: can we describe the information transfer necessary to save QM without violent departure from semiclassical physics?

Evidence: yes

Deeper question: what does this tell us about the more fundamental framework for quantum gravity?

Hilbert spaces with networked factors, unitary evolution

Scorecard for scenarios preserving QM

	Nonlocality	~Semiclass. Spacetime	Classical BH Thermo
"$A = R_B$" (generalized)	$r >> R$	X	?
Firewall	$r \leq R + l_{Pl}$	X	X(?)
Nonviolent transfer	$r \sim R$ (just right?)	✓	modify(?)

Details with modes

Simple model: free scalar, $\int dt H_{NL} \to \int dV_4 J(x)\phi(x)$

Describe effect in terms of modes created:

$$\phi(x) = \sum_A a_A U_A + h.c.$$

$$U_A \sim Y_{lm}(\Omega)\frac{u_l(r,t)}{r}$$

radial problem: motion in effective potential, in new coordinates

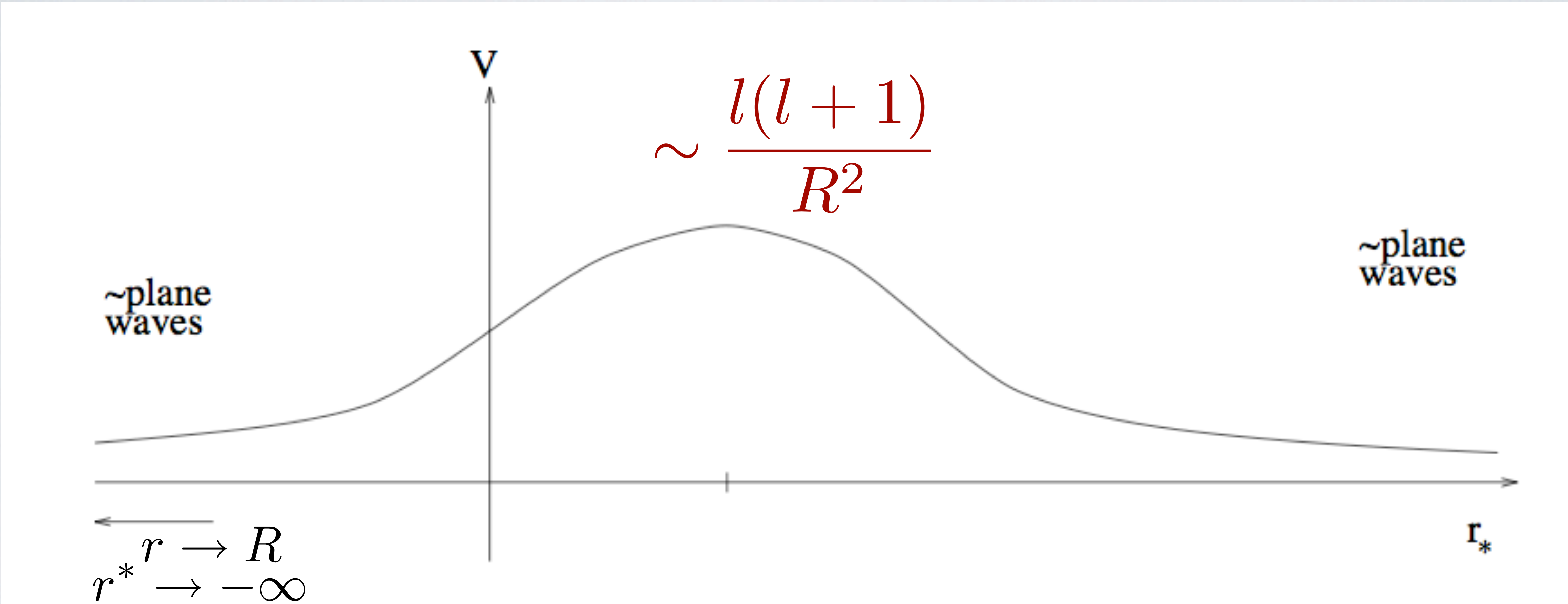
$$ds^2 = -f(r)dt^2 + \frac{dr^2}{f(r)} + r^2 d\Omega^2$$

$$= -f(r)(dt^2 + dr^{*2}) + r^2 d\Omega^2$$

$$f(r) = 1 - \frac{R}{r}$$

"tortoise coordinate"

$$\left(-\frac{\partial^2}{\partial t^2}+\frac{\partial^2}{\partial r^{*2}}\right)u_l = V_l(r^*)u_l$$



Let $$J(x) = j_l(t,r)Y_{lm}(\theta,\phi)$$

$$\Rightarrow \qquad \int dV_4 J\phi \sim a^\dagger_{lm}\int j_l u_l^*$$

Specifically, consider J's that are:

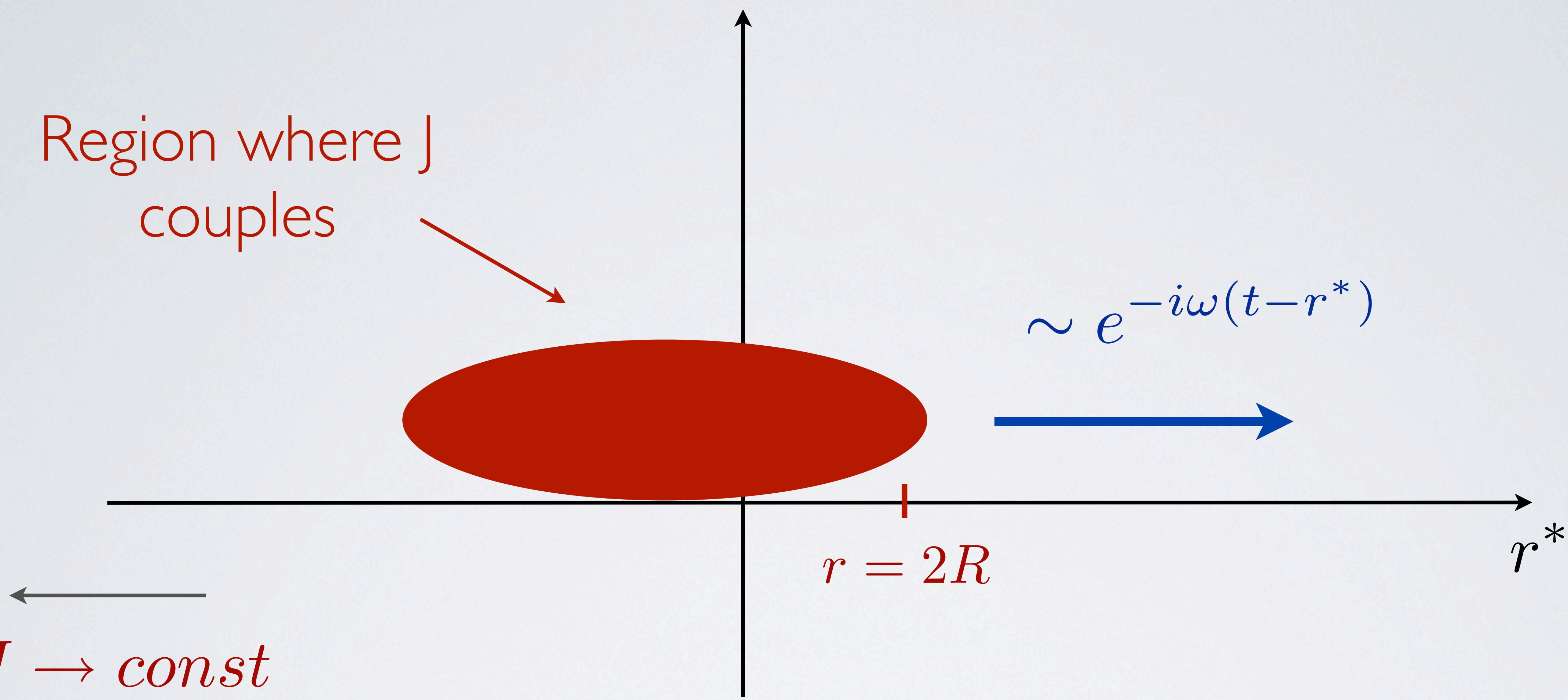
A) smooth at $r=R$ and

B) vanish rapidly for $r>>2R$ (outside "atmosphere")

C) definite Schwarzschild frequency

First, $l = 0, \quad \omega \sim 1/R$

Region where J couples



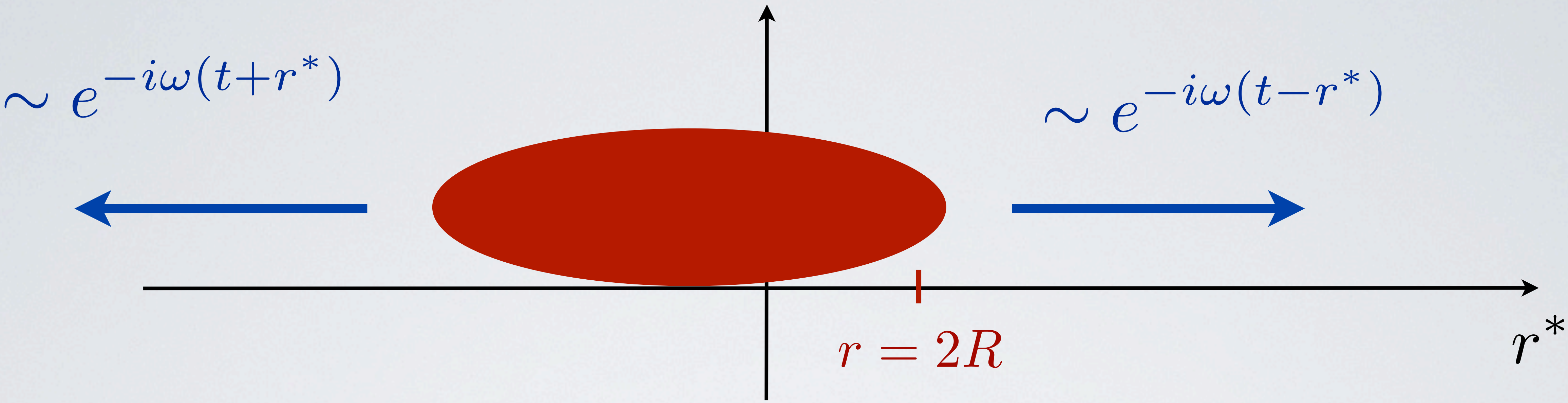
$J \rightarrow const$

$$\int Ju^* \rightarrow 0$$

Can arrange ~ one quantum of energy 1/R per time R: benchmark transfer rate

Outgoing energy density: $\sim 1/R^4$ "tiny"

Singular horizon?



$$T_{++} \not\to 0$$

$$T_{--} \to 0$$

$$x^{\pm} = t \pm r^*$$

$$T^{\text{Krusk}}_{--} = \left(\frac{\partial x^-}{\partial X^-}\right)^2 T_{--}$$

$\to \infty$ at r=R

Good coords, infalling observer:

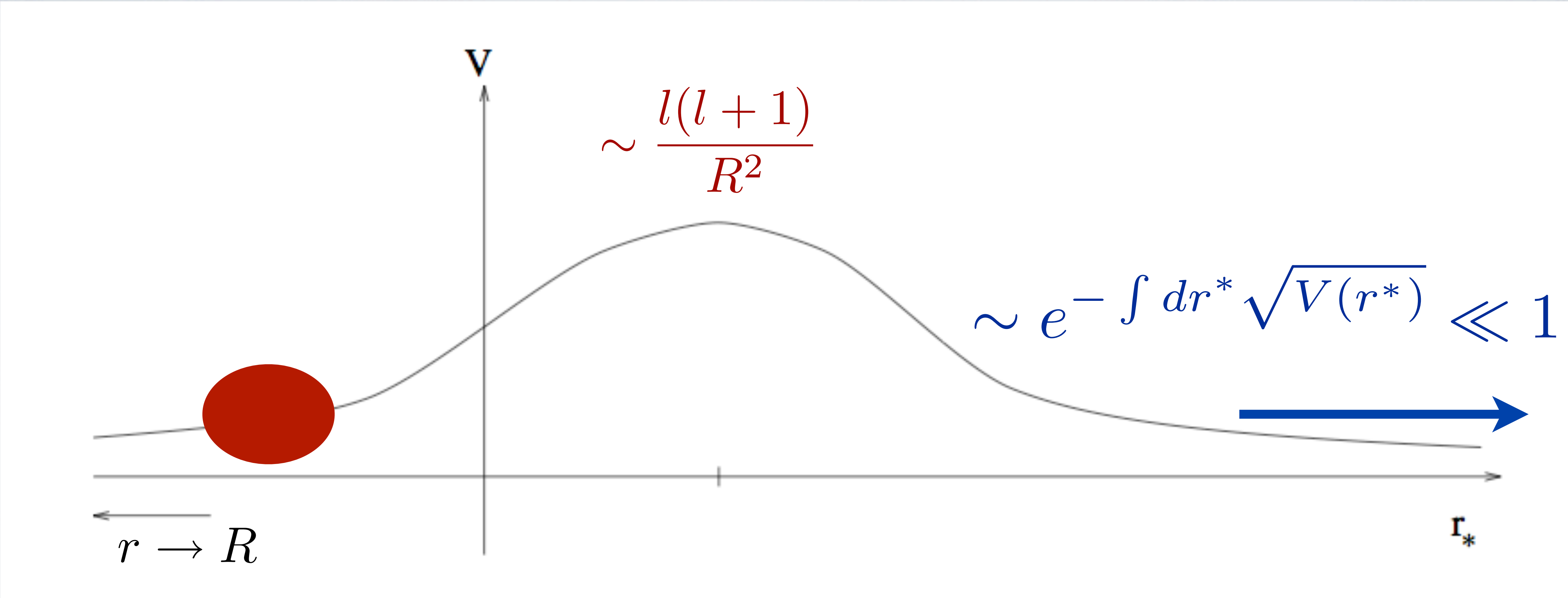
$$X^{\pm} = \pm 2R e^{\pm x^{\pm}/2R}$$

Kruskal

No singularity!

holds for arbit. l

Next, consider $l > 0, \quad \omega \ll l/R$ (e.g. $\omega \sim 1/R$)



So: Effective sources $\sim j_l(t,r) Y_{lm}$ can be present, even with large magnitude compared to s-wave, without significant energy/information flux

This may help address one challenge to the scenario of nonviolent nonlocality