Nonviolent unitarization:

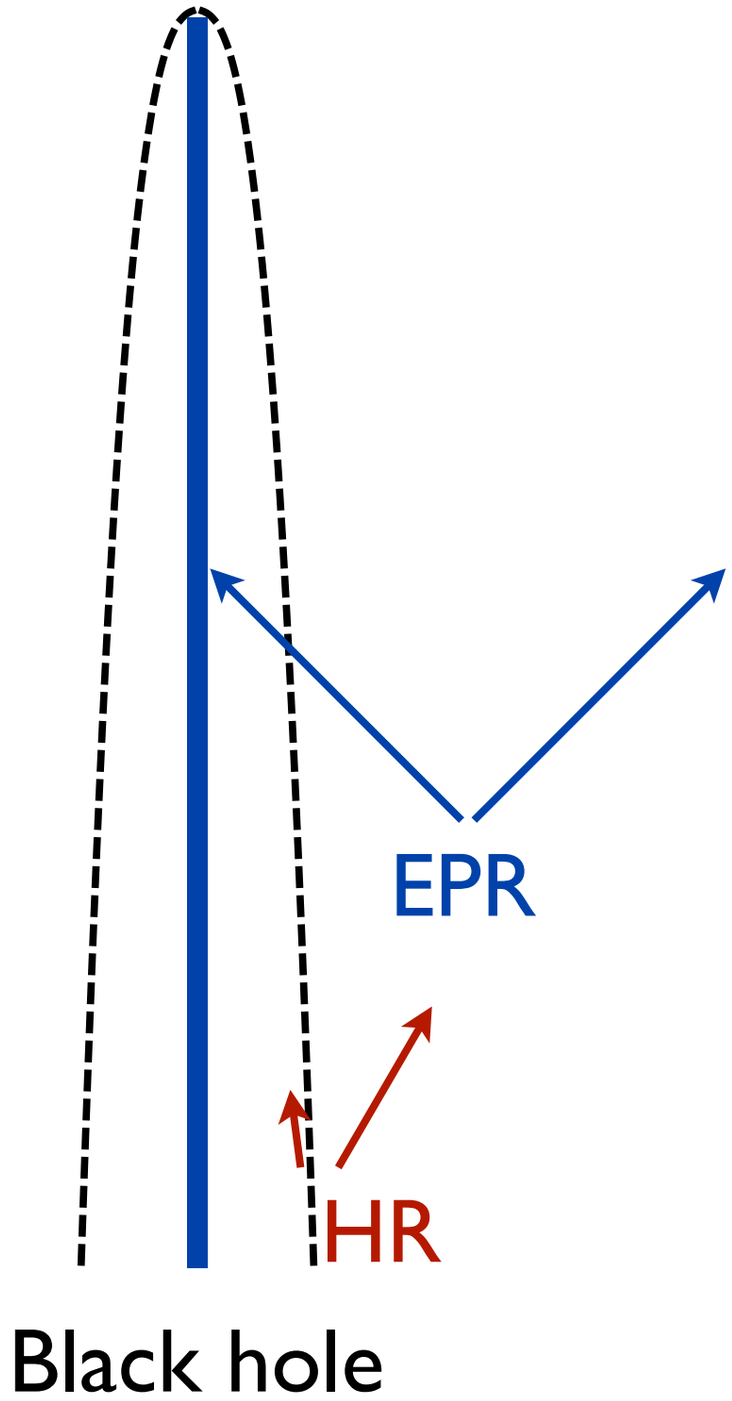
overview, questions, opportunities

Steve Giddings

Quantum Gravity Foundations: UV to IR

Starting point - physics we know and love:

Semiclassical spacetime + local QFT



- Entanglement between BH and environment grows: monotonic

- If BH disappears, unitarity violated

To save unitarity/QM:

Need to transfer entanglement (info) from BH to environment.

LQFT doesn't do this (*locality*)

How is SCST + LQFT modified?

A goal:

Find more basic physics that:

- Matches LQFT in "ordinary circumstances"
  E.g. doesn't violate locality, etc.

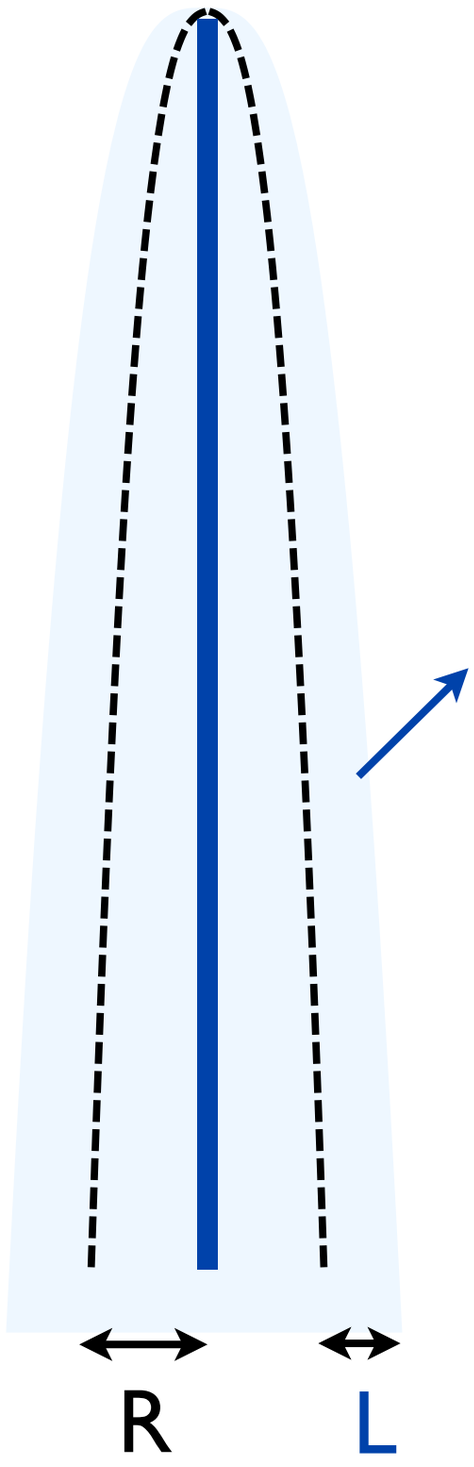
correspondence principle

- Saves quantum mechanics

- Minimal disruption to semiclassical picture

Possible general properties of that, in BH context:

Nonviolent nonlocality -- basic picture



Characteristics:

1) Information transfer from "internal" DOF to BH exterior.

Locality w.r.t. SC geom forbids: "nonlocal"

2) Characteristic scales

$L \gg l_{Pl}$ e.g. $L \sim R^p$, p>0

(horizon separation, wavelengths)

"Soft," or nonviolent

(see e.g. arXiv:0911.3395, 1108.2015, 1201.1037, 1211.7070; Dodelson/Silverstein?)

Another way to state:

Complementarity/AMPS postulates

[hep-th/9306069; 1207.3123]

I) Unitary QM / S-matrix

II) Semiclassical field eqns outside stretched horizon

III) BH is Q. system with no. states given by S_{BH}

IV) Free-faller sees nothing unusual crossing horizon

Violate postulate II

specifically: info transfer allowed, over characteristic scale L

How does this arise from a fundamental theory?

Don't yet have complete picture.

Dovetails w/understanding: *locality not sharp in QG*

Maybe comes out of AdS/CFT, somehow.
(If/when we understand what AdS/CFT tells us.)

Or: key *guide* to principles? (cf: atom/QM)

A possible approach:

If "small" corrections near BH: can model as *modification to LQFT?*

[arXiv:1211.7070, 1302.2613, 1310.5700]

Can begin to test:

What sharp constraints?
(firewall, or more radical, necessary?)

What do we have to give up?
(we know something!)

Are there observational consequences?

Let's avoid double standards:

Objection: no fundamental theory, or complete model

E.g. "I can find problem X in your model. Therefore, there must be a firewall."

Well, one doesn't have a fundamental theory or complete model of firewalls either, and if people started to write them down I expect there would be various serious objections.

So: can we infer reasonable physical behavior by making more detailed models,

Or is there a sharp argument against such models on reliable physical grounds?

Put differently: since the unitarity crises tells us we have to give up something, assess: what could it plausibly be?

Phenomenological *models* (not yet theories)

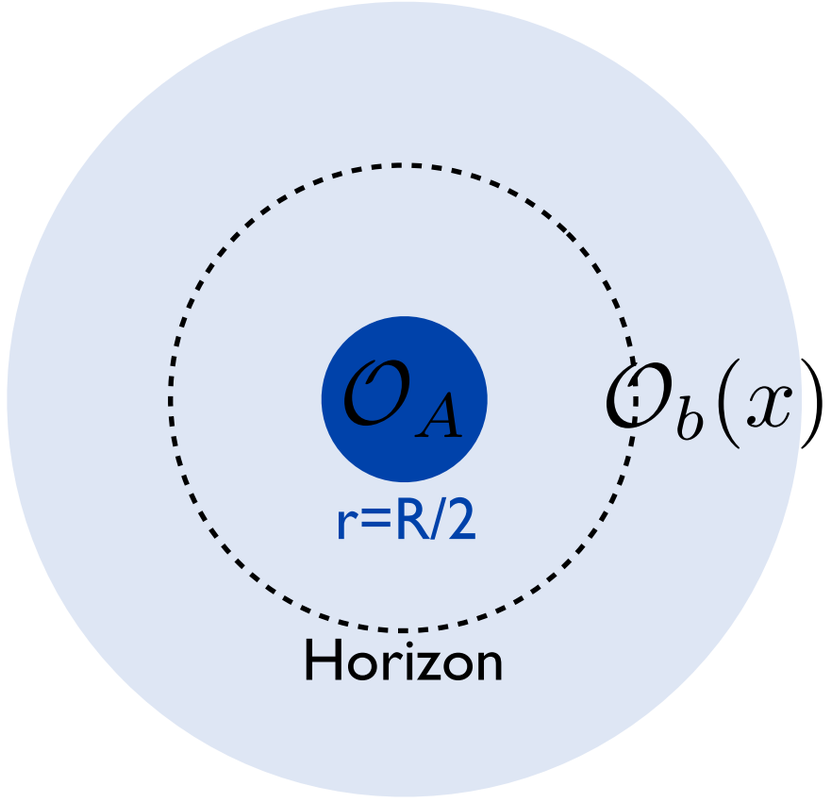
Assume SCST, LQFT, +corrections, for r>R/2

$$\int dt \Delta H \sim -\Delta S \sim \sum_{Ab} \int_{r>R/2} dV_4 \, \mathcal{O}_A \, G_{Ab}(x) \, \mathcal{O}_b(x)$$

acts on "$\mathcal{H}_{r<R/2}$"

coupling functions

acts on "$\mathcal{H}_{r>R/2}$"



Simple examples:

[arXiv:1302.2613, 1310.5700, 1401.5804]

$$\int dV_4 J(x) \Phi(x)$$

$$\int dV_4 J^{\mu\nu}(x) T_{\mu\nu}(x)$$

J's: quantum sources; ~classical

These interactions transfer information (entanglement) from BH to its atmosphere; it then escapes.

A challenge:

Generically, unless disrupt Hawking process, these yield

$$\frac{dE}{dt} > \frac{dE}{dt}\Big|_{\rm Hawk}$$

[arXiv:1201.1037, 1205.4732, 1211.7070]

So $S_{bh} < S_{BH}$ by detailed balance

[arXiv:1211.7070, AMPSS, 1308.3488]

So, either:

1) Find special evolution w/ Hawking flux (or, no go)

2) Make peace w/ $S_{bh} < S_{BH}$

3) Firewall, or more radical ...

$$S_{bh} < S_{BH}$$

Do we know BH density of states $\sim e^{S_{BH}}$?

Alternative: S_{BH} characterizes semiclassical near-horizon geometry

(which we know doesn't give exact physics - extreme case FW)

Any incontrovertible evidence for S_{BH} ?

1) BTZ/Cardy formula — 2+1 special; assumes AdS=CFT

2) Strominger/Vafa — weak coupling; ~BPS

3) Hanada et al — ?

These are strongly suggestive.

Are they incontrovertible?

If $S_{bh} = S_{BH}$ implies firewalls, do we believe it?

(If AdS/CFT implies firewalls, do we believe AdS=CFT?)

$\therefore$ perhaps $S_{bh} < S_{BH}$ consistent.

[arXiv:1308.3488]

But this is a little inelegant, and we might explore whether we can avoid it.

An interesting prospect, with some intriguing features:

$$G^{\mu\nu}(x)$$

$$\int dV_4 J^{\mu\nu}(x) T_{\mu\nu}(x)$$

I.e. e*ffective* description: BH state-dependent metric fluctuations

(think of as ~ inaccuracy of classical geometry)

universality ~ gravity

(helps address mining)

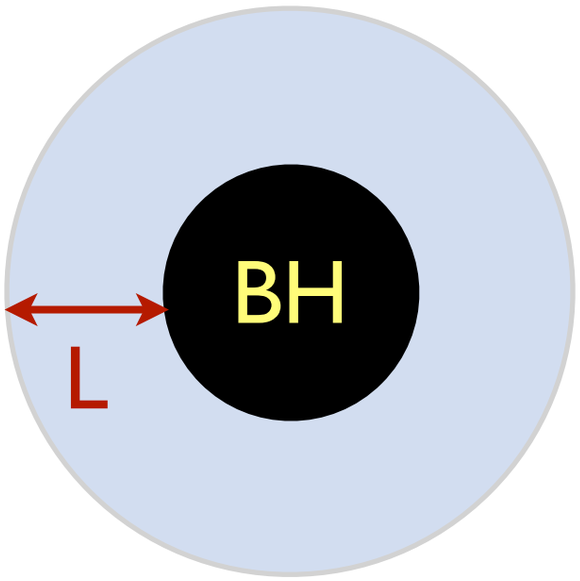
These can "modulate" Hawking radiation; possibility of small (vanishing?) increase of energy flux.

[arXiv:1401.5804]

2d model: $\delta P_-(x^-) = \int dx^- \langle \delta T_{--} \rangle_G = 0$

to linear order in G

How large are these effective fluctuations?



Constraint: $\frac{dS_{\rm vN}}{dt} \sim -\frac{1}{R}$

Suppose (e.g.) $L \sim 1/\omega \sim R$

$\Longrightarrow$ **e.g.** $\langle I|G^{\mu\nu}(x)|J\rangle \sim e^{-i\omega v + ikr} \; f_L(r)$

$\mathcal{O}(1)$

restricts to $r \lesssim R + L$

$\therefore$ Strong, soft effective metric fluctuations

A "new" firewall alternative

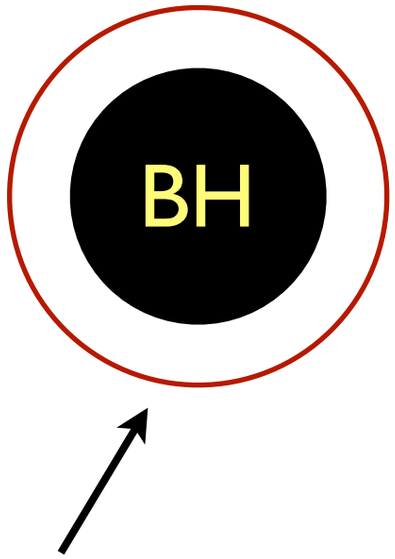
[arXiv:1401.5804]

(significant mods. to HR...)

An opportunity:

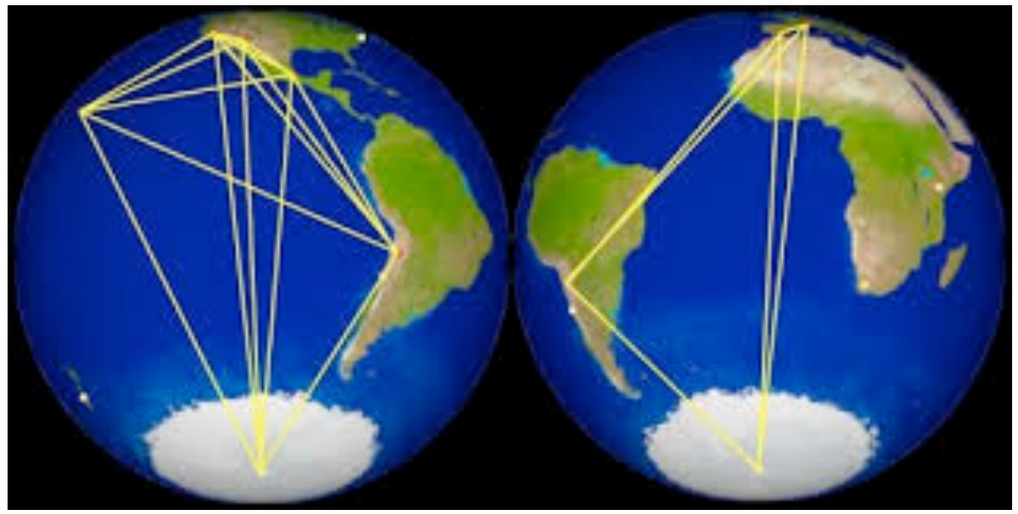
Event horizon telescope:

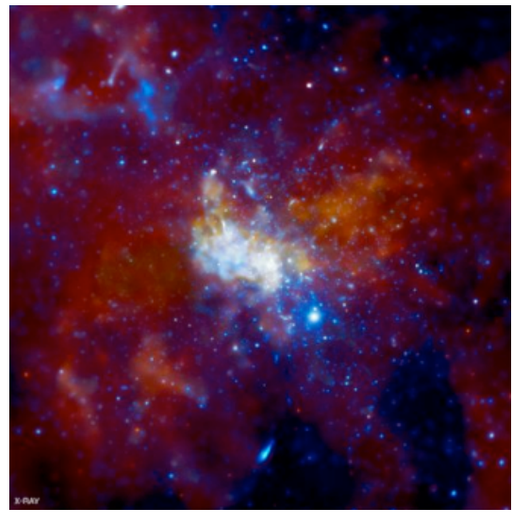
arXiv:1406.7001



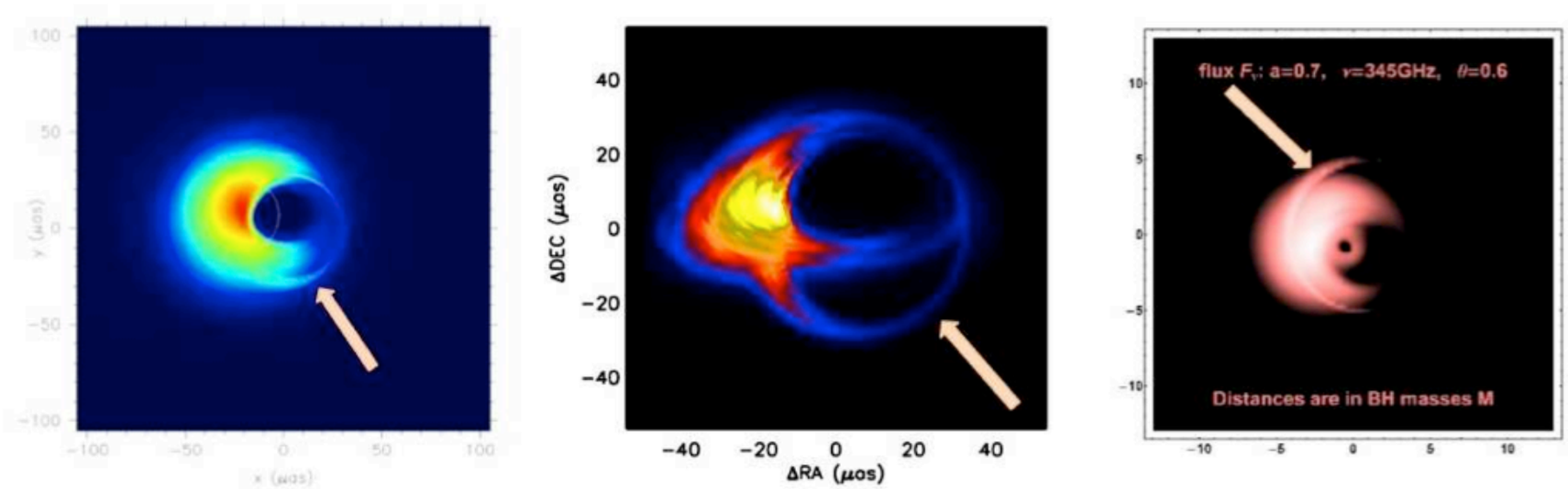
r=3R/2

(Schwarzschild)





Sgr A*



Psaltis/Johannsen

BH shadow, photon ring

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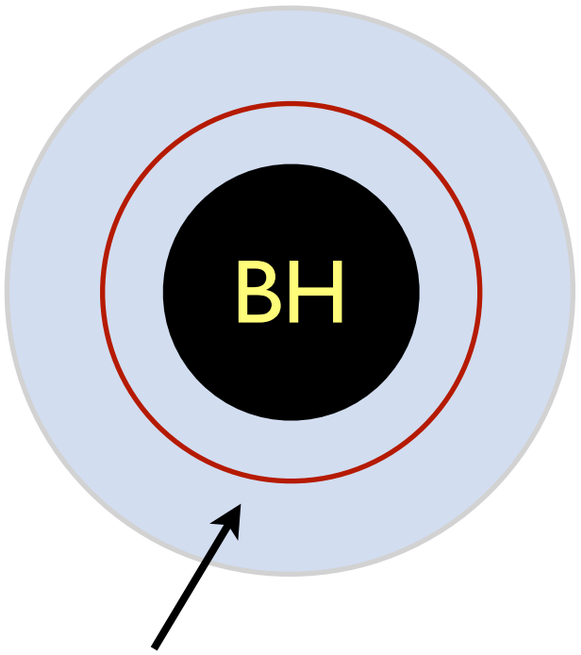
arXiv:1406.7001



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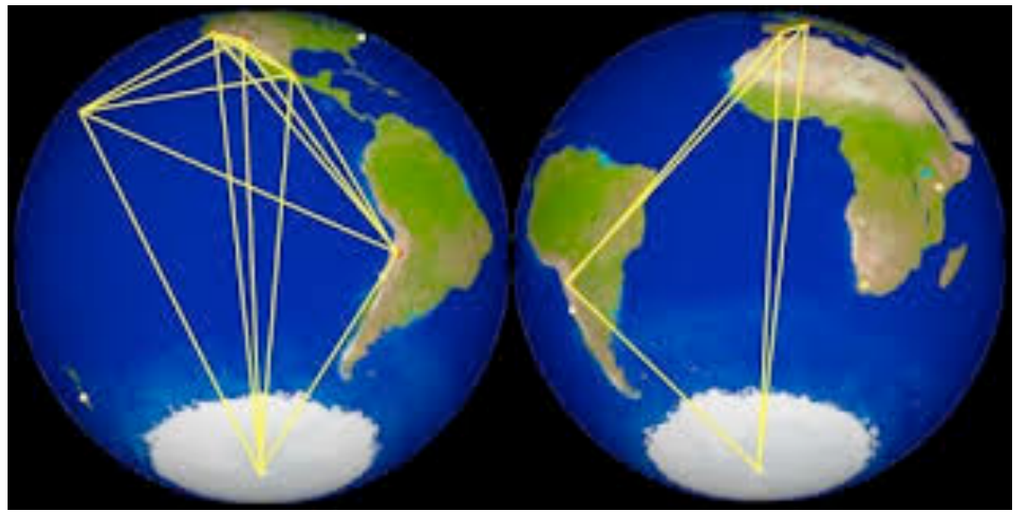

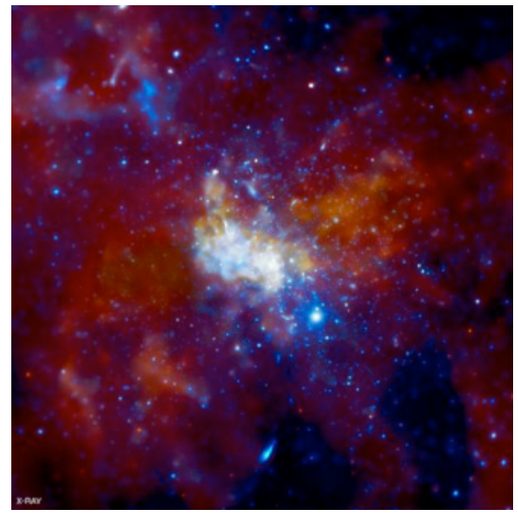

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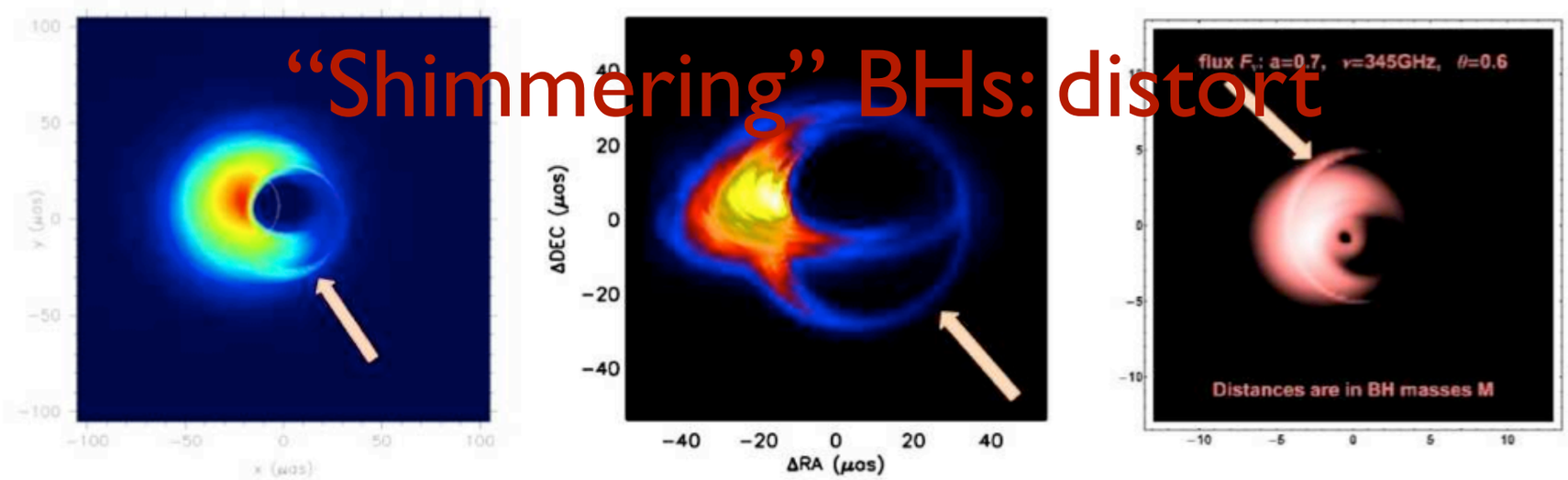

"Shimmering" BHs: distort

SBG/Psaltis, WIP

Theoretical uncertainty:

$$t_{qn} \sim t_{\text{Fast Sc}} \sim R \log R \sim 8 \text{ hr}$$

$$t_{1/2} \sim R^3 \sim 10^{74}\, t_{\text{Universe}}$$

} bounds

Summary:

"Unitarity crisis" for BHs represents a conflict among fundamental principles ... something has to give

"NVNL" proposes "soft" information transfer to the "atmosphere" of a BH; violates macro. SC locality

[hep-th/9203059]

Typical models give $S_{bh} < S_{BH}$; special models $S_{bh} \approx S_{BH}$?

Effective metric fluctuations: a natural, universal alternative

Necessary info transfer: strong, soft fluctuations

These present observational opportunity as we image BHs (EHT, etc.)