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Te Whare Wānanga
o te Ūpoko o te Ika a Māui

School of Mathematical and Computing Sciences
Te Kura Pangarau, Rorohiko

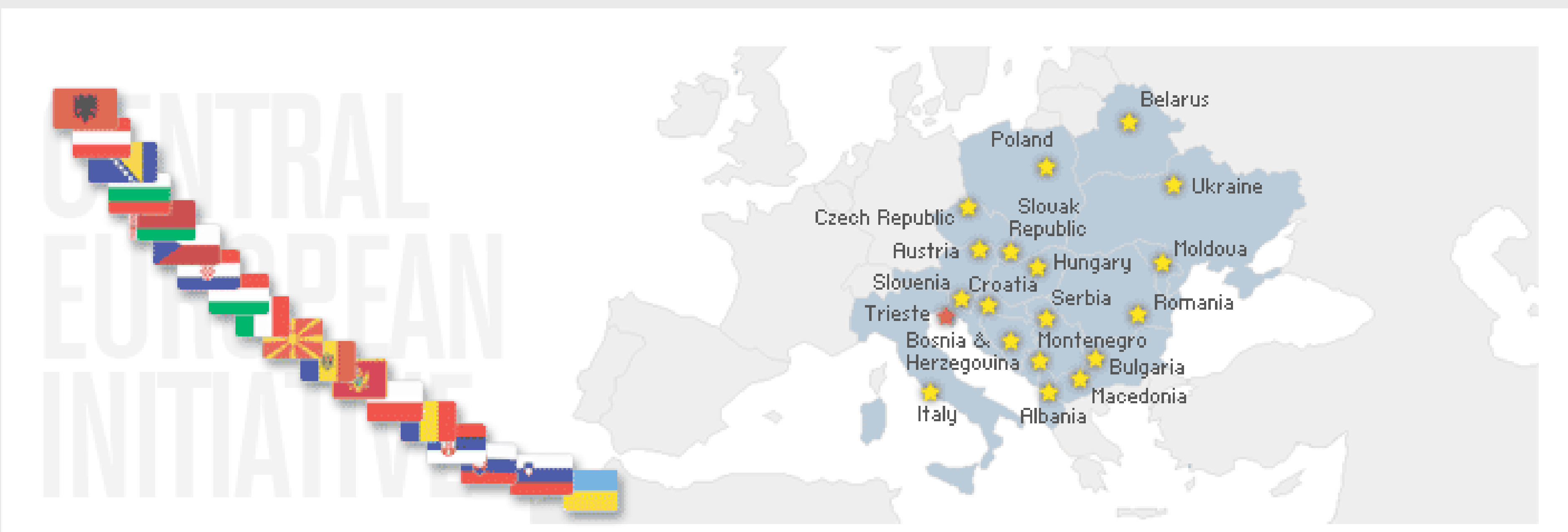
Brief survey of black hole physics

Matt Visser

Veli Losinj, Croatia
August 2008

BLACK HOLES IN GENERAL RELATIVITY AND STRING THEORY

24th – 30th August, 2008
Veli Lošinj, Croatia



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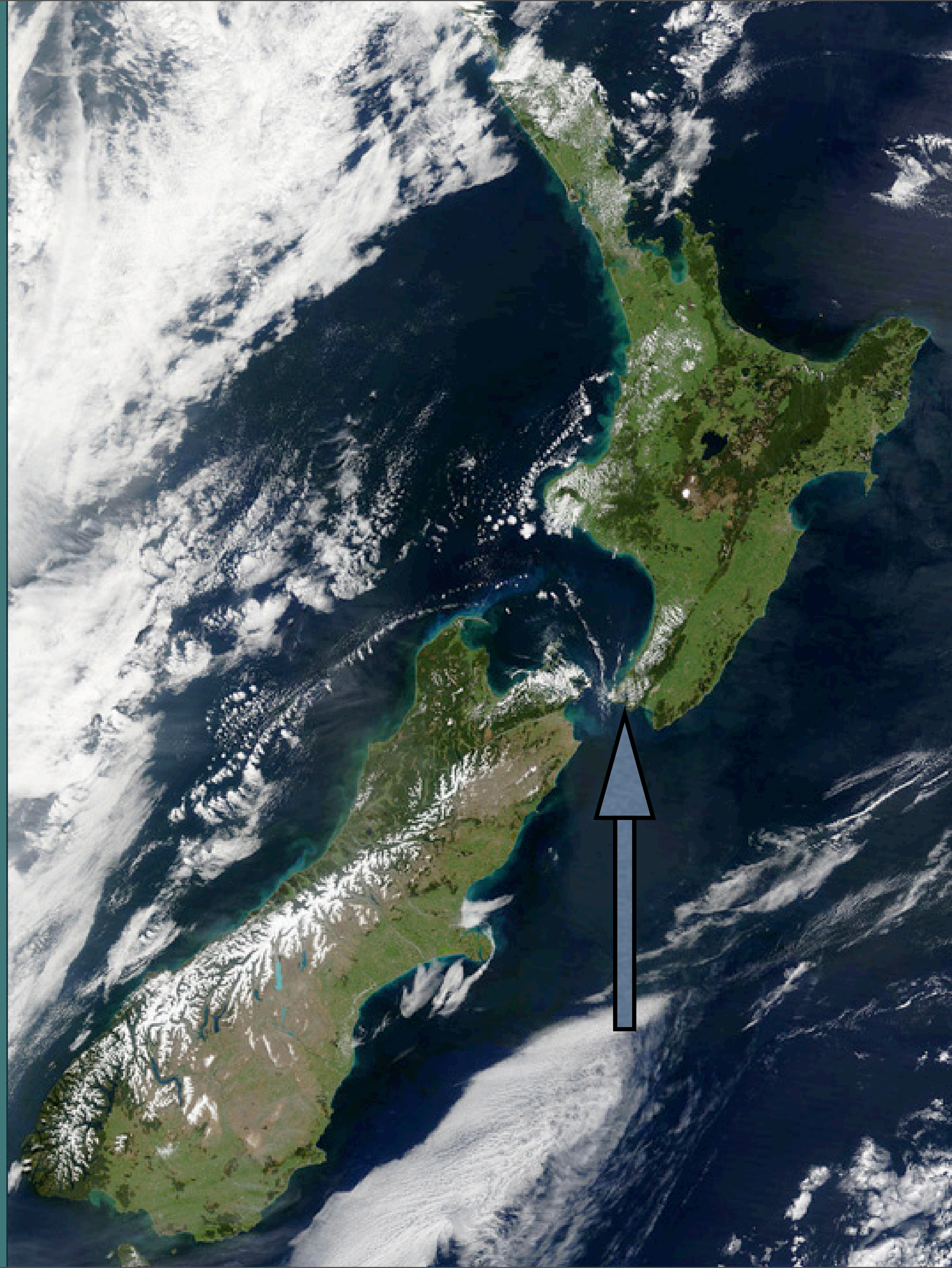


Abstract:

What is going on at the interface between theoretical general relativity, string-inspired models, and observational astrophysics ?

Let's take a broad overview of the situation...

This workshop:

- Astrophysical Black Holes (from super-massive to stellar)
- Primordial and Mini Black Holes
- Black Hole Entropy
- Information Paradox
- Asymptotic Symmetries
- Anomalies
- Attractor Mechanism
- Holography
- ADS/CFT correspondence

Do black holes “exist” ?

Observational astronomy:

Astronomers have certainly seen things that are small, dark, and heavy...

But are these small, dark, heavy objects really black holes in the sense of general relativity ?

Do black holes “exist” **?**

Observational astronomy:

Small, dark, and heavy...

Accretion disks probe down to the ISCO:

2m/r ~ **1/3 !**

ADAFs probe down to 2m/r ~ **1 ?**

Everything so far compatible with Schwarzschild/ Kerr.

Do black holes "exist"?

General relativity (theory):

(Eternal) black holes certainly exist mathematically, as stationary vacuum solutions in general relativity...

Classical black holes (future event horizons) certainly exist mathematically as the end result of classical collapse based on certain physically plausible equations of state.

BUT... (insert favourite "problem" here...)


Mirror Lakes, New Zealand
travelblog.org

Information "problem" ?

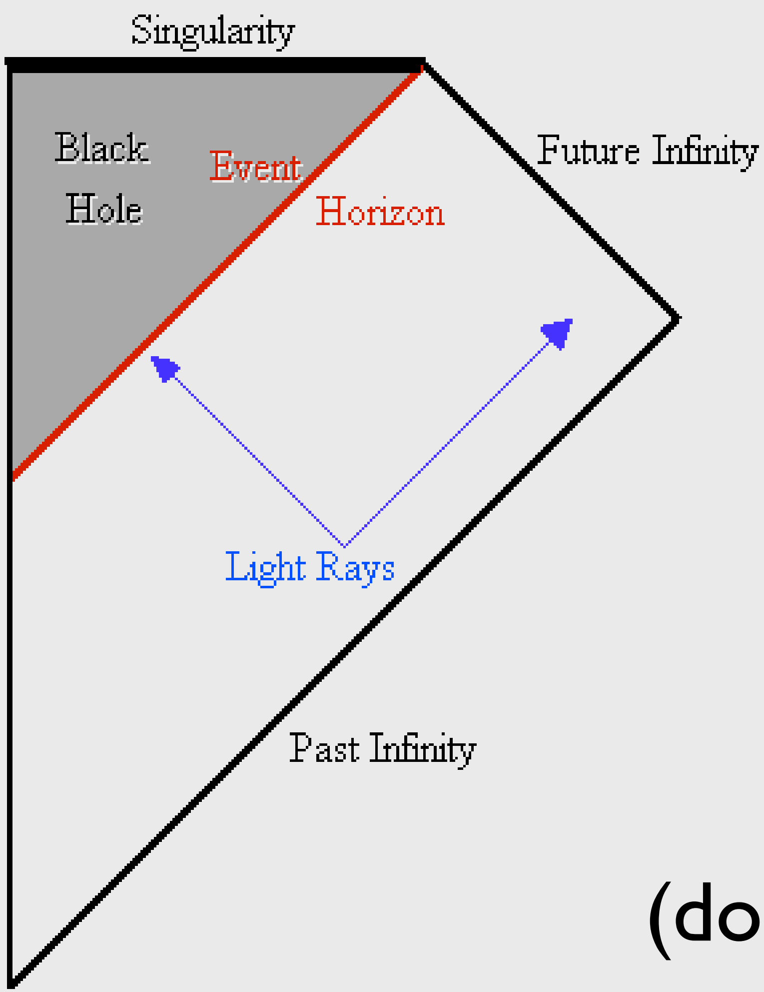
The information "problem" is more of an "issue" than a "problem"...

It's just one of those things you have to live with if you accept the standard Carter-Penrose diagram for stellar collapse...

For all practical purposes:

Information loss <==> non-unitary evolution in the domain of outer communication...

Information “problem” ?



An event horizon
automatically
leads to non-unitary
evolution ---
at least as seen
from the outside...

(domain of outer communication)

Information "problem" ?

But is "event horizon" the right concept to be using ?

Especially once you add semiclassical quantum physics, specifically Hawking evaporation...

There are other possible definitions of horizon: apparent, dynamical, trapping horizons that may make more physical sense...

(For instance, in numerical general relativity, event horizons are seriously diseased.)

Information “problem” ?

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If you believe that Hawking evaporation is unitary:

(as seen from our own asymptotically flat region...)

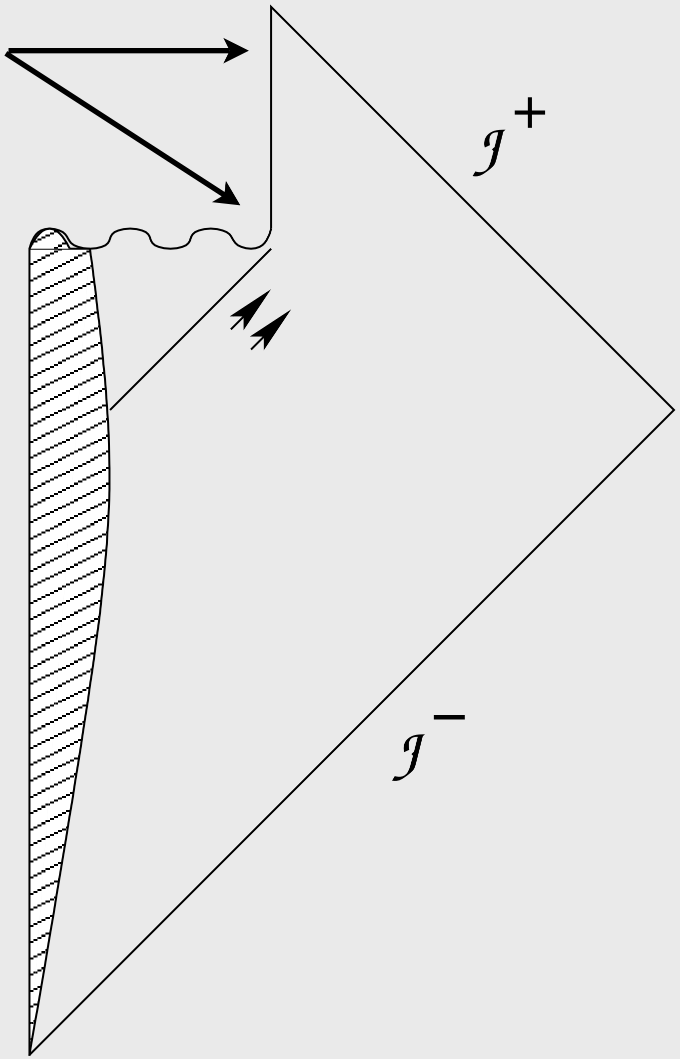
“The way the information gets out seems to be that a true event horizon never forms, just an apparent horizon.”

(Stephen Hawking in the abstract to his GR17 talk.)

The event/ absolute/ apparent/ trapping/ horizon distinction may be critically important...

Information "problem" ?

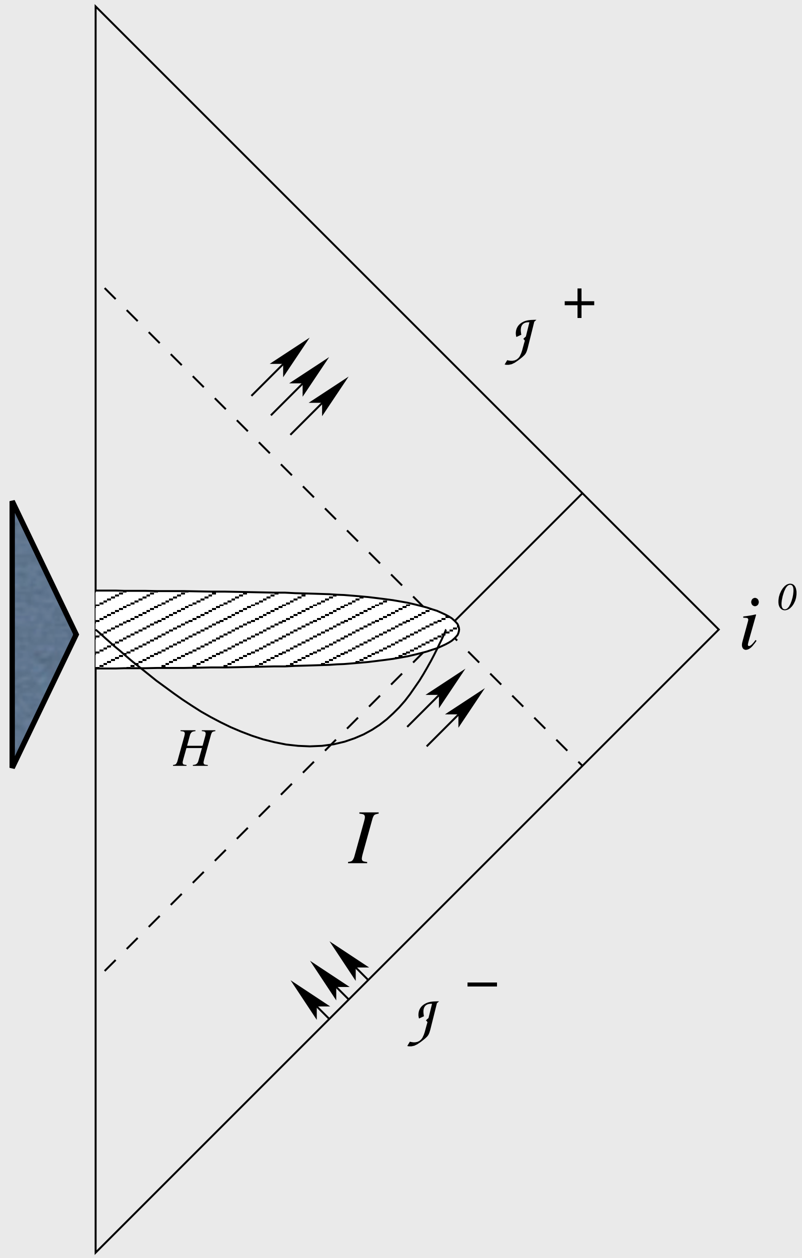
don't ask,
don't tell



"Standard" Carter-Penrose diagram for an evaporating black hole...

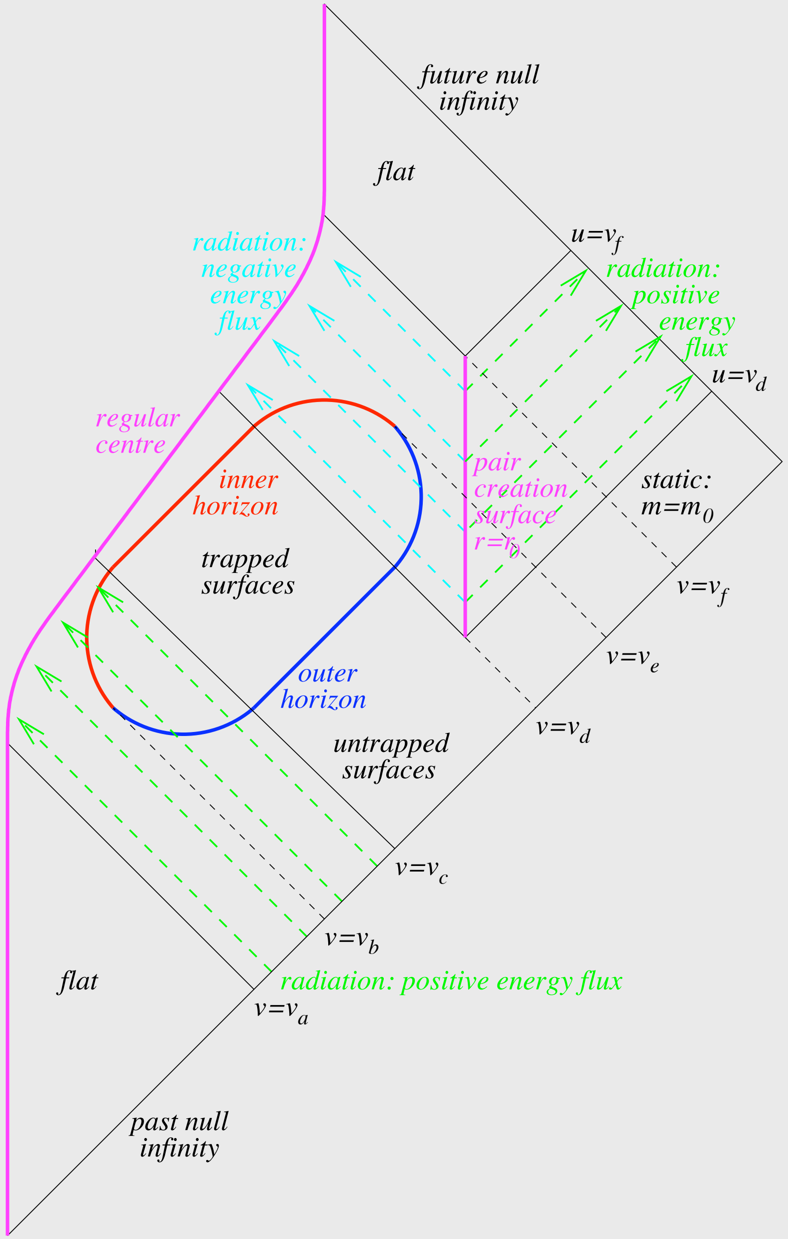
Information "problem" ?

Planckian curvature



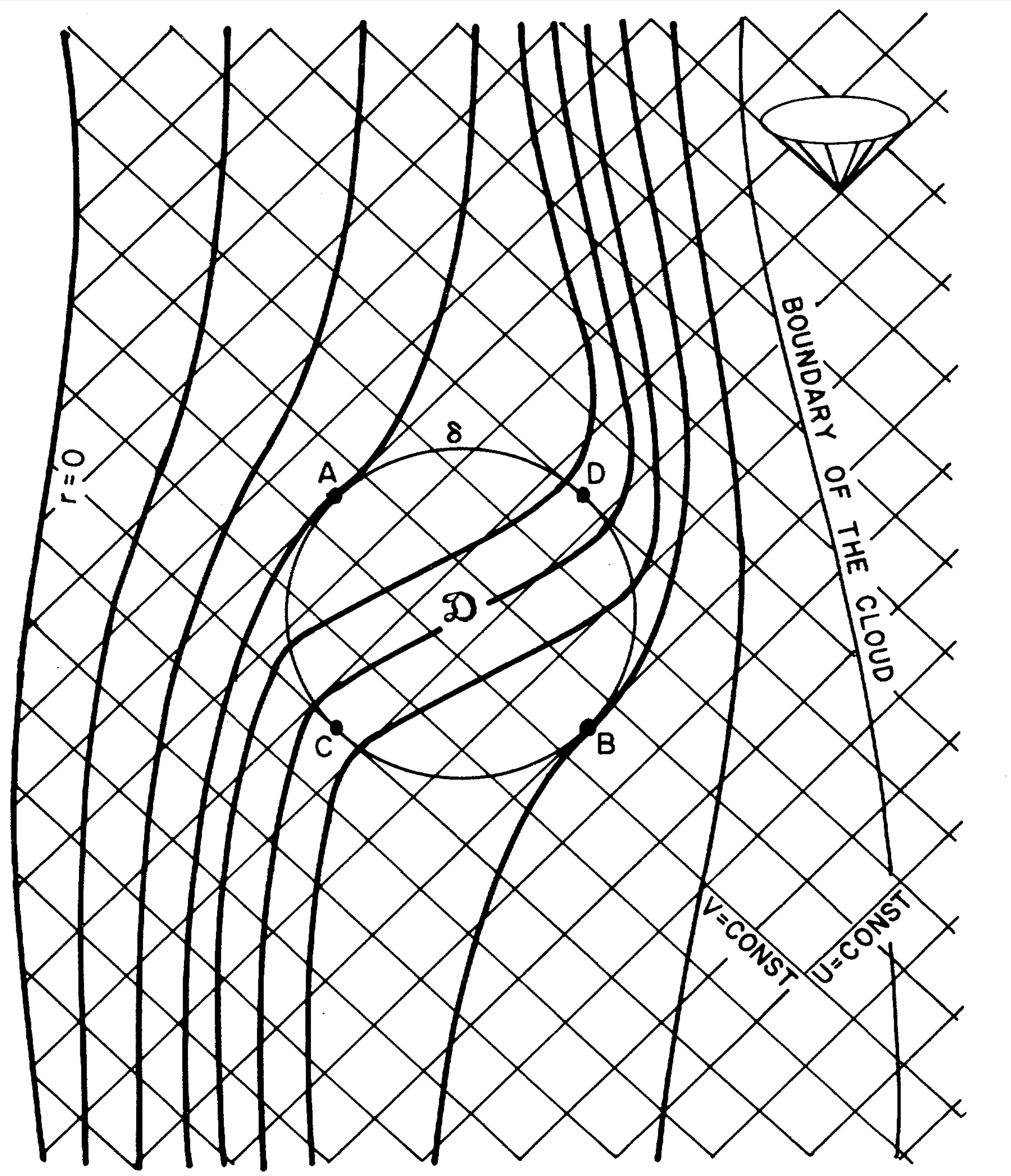
Ashtekar-Bojowald version of the Carter-Penrose diagram for an evaporating black hole...

Information “problem” ?



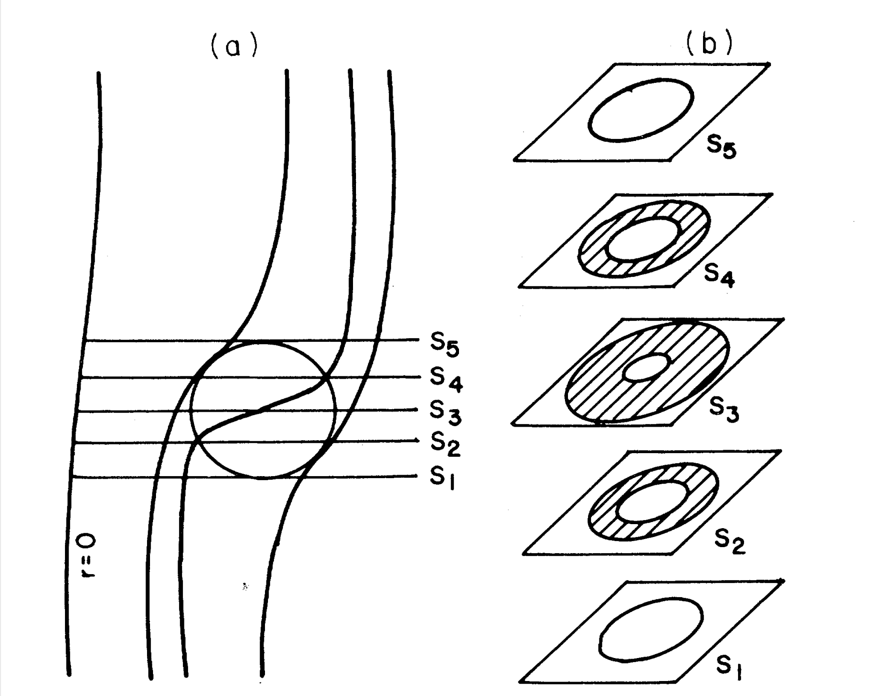
Hayward version of the Carter-Penrose diagram for an evaporating black hole...

Information "problem" ?



Apparent horizons without an event horizon

Bergmann-Roman



Information “problem” ?

You do not need an event horizon to get Hawking radiation...

(e.g., Hajicek, plus many others...)

You do not even need apparent/ dynamical/ trapping horizons to get a Hawking-like flux...

(Barcelo, Liberati, Sonego, Visser)

So do we actually need “black holes” to do “black hole physics” ?

[Not Veli Lossinj]

Do black holes "exist" ?

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Can one avoid black hole formation with a suitably weird equation of state ?

Can one avoid black hole formation with semi-classical quantum effects ?

Can one avoid black hole formation with "quantum gravity" ?

The possibilities are rather tightly constrained.

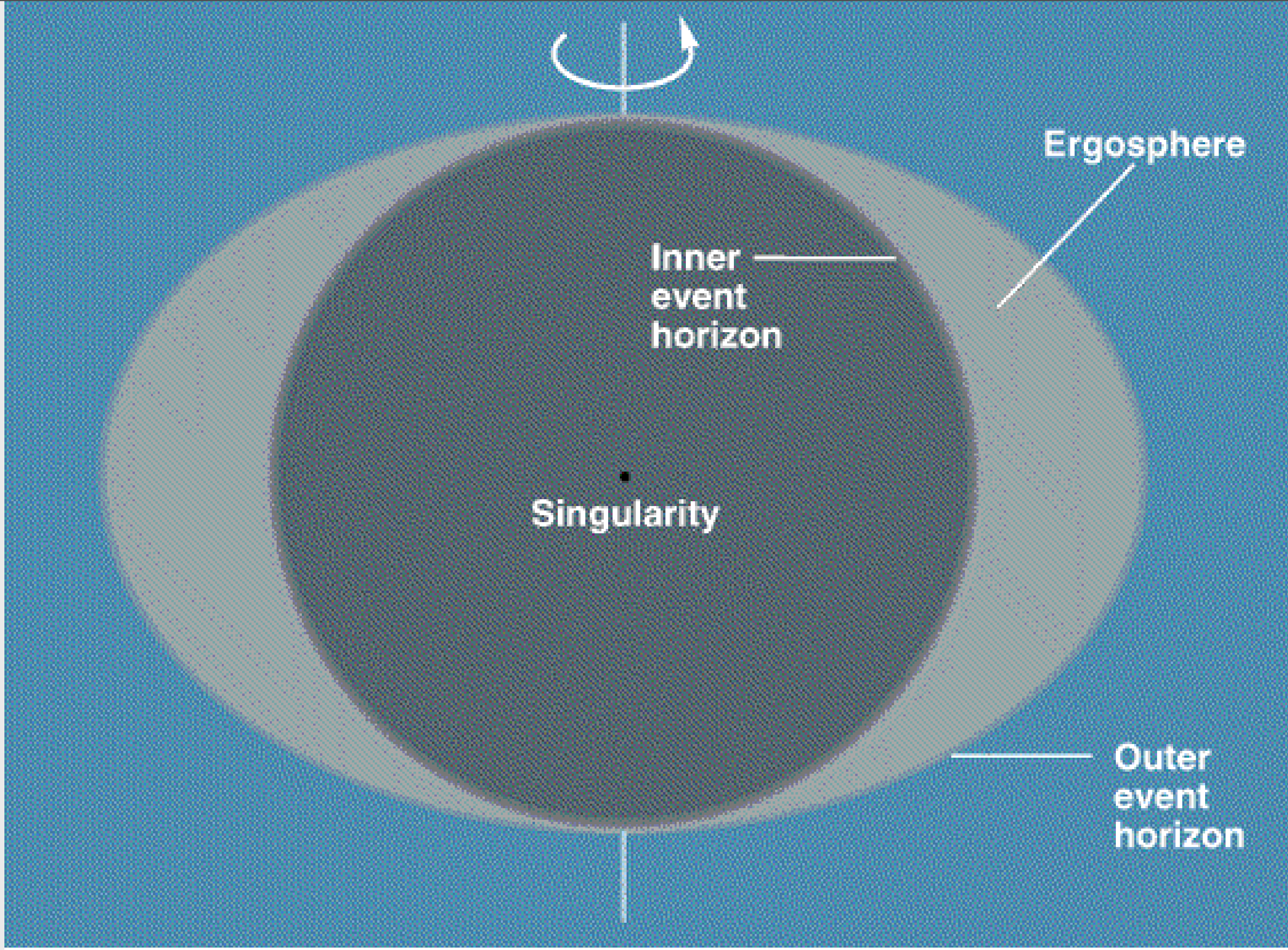
Do black holes “exist” ?

There is of course the utter gibbering crackpot fringe...

(Names suppressed to protect the guilty.)

“Physically reasonable” alternatives to black hole formation are counted on the fingers of one (severely mutilated) hand...

(For selected values of “physically reasonable”.)



(even the physics-challenged have access to graphics software...)

Do alternatives "exist" ?

Quark stars, Q-balls, boson-stars?

Gravastars: Mazur--Mottola variants.

Gravastars: Laughlin-et-al variants.

Fuzz-balls: Mathur-et-al variant.

Fuzz-balls: Amati variant.

Vachaspati & Krauss... Hajicek...

Boulware... Marek Abramowicz...

Q-balls ?

Quark stars, Q-balls, boson-stars?

(Change EOS: Star/white dwarf/ neutron star/ etc...)

Questionable justification for EOS...

Still have Buchdahl-Bondi bound:
$2m/r <= 8/9$ for any
isotropic pressure profile.

So you cannot get "close" to $2m/r \sim$ **1**,
unless you have anisotropic stresses.

Gravastars ?

Gravastars:

Core: de Sitter like....

Exterior: Schwarzschild like...

Where the horizon would have formed: $2m/r \sim 1$

1) don't ask...

2) anisotropies guaranteed...

3) breakdown of spacetime manifold ? [Laughlin]

4) one-loop action ? [Mazur--Mottola]

Fuzz balls ?

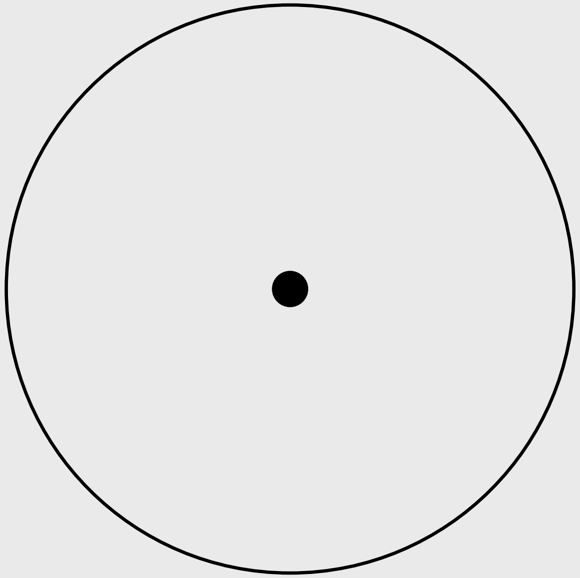
Fuzz balls:

Explicit calculations appear to be limited to extremal/ near-extremal regime...

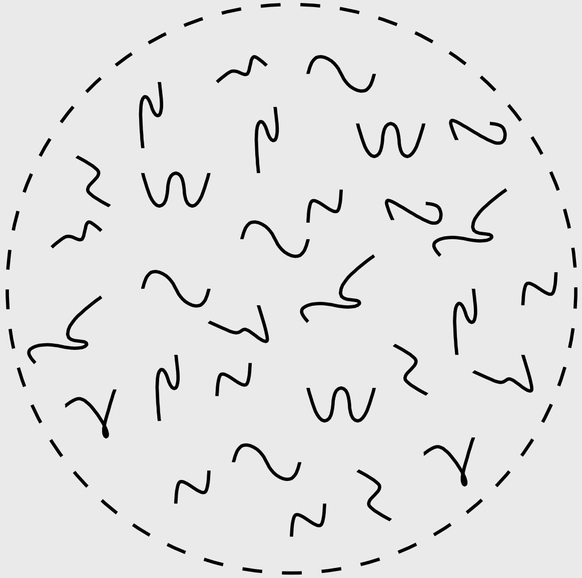
Black hole "interior" = "string muck"?

Not *a* spacetime, a *superposition* of "spacetimes"?

(And none of the individual "spacetimes" in the superposition has a horizon?)



GR



Fuzz ball

Our proposal:

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Fate of gravitational collapse in semiclassical gravity.

Carlos Barcelo, Stefano Liberati,
Sebastiano Sonego, Matt Visser.

e-Print: arXiv:0712.1130 [gr-qc]
Physical Review D77 (2008) 044032

(see tomorrow's talk)

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Detecting horizons:

Common statement:

"Horizons are not detectable with local physics"

This is, of course, *false*.

Though it's *almost* true... True statements are:

"Event horizons are (often) not detectable with local physics"

"Apparent/ dynamical/ trapping horizons are not detectable with ultra-local physics"

Event horizons:

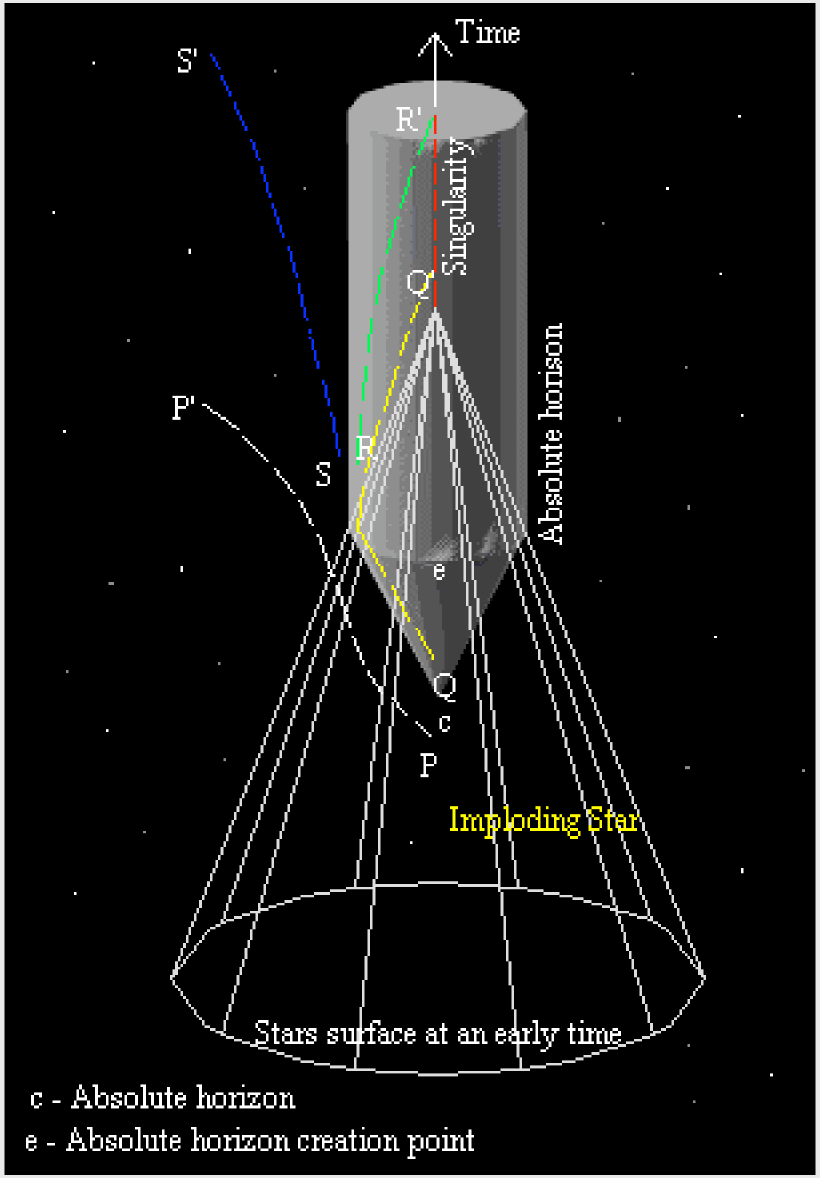
Event horizons can form in locally flat portions of Minkowski spacetime

Just let a dust shell collapse...

Apply Birkhoff's theorem...

Event horizon =/= strong (local) gravity...

This class of event horizons is certainly not detectable by local physics.



Measuring 2m(r)/r:

Apparent/ dynamical/ trapping horizons are typically associated with $2m(r)/r \sim \mathbf{1}$

And $2m(r)/r$ is measurable using local (though not ultra-local) physics.

Proof:

In any finite-size laboratory you can measure the Riemann tensor.

Equivalently, physics with finite-range interactions is sensitive to the Riemann tensor.

In spherical symmetry the orthonormal components of the Riemann tensor are linear combinations of density, radial and transverse pressures, and $2m(r)/r$.

The stress-energy tensor is certainly measurable using local physics.

Combining: $2m(r)/r$ is measurable using local (though not ultra-local) physics.

Apparent/ dynamical/ trapping horizons
are detectable using local
(though not ultra-local) physics.

At the risk of initiating tribal warfare:

The most physically interesting horizons
are detectable using local
(though not ultra-local) physics.

Lot’s of subtle things going on in black hole physics...

Many deep issues of principle remain...

In my more cynical moments...

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“It is important to keep an open mind; just not so open that your brains fall out”

--- Albert Einstein