

# **Karl Schwarzschild Meeting 2015**

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and Institute for Quantum Computing**

**University of Waterloo  
Perimeter Institute**

# It's been 100 years

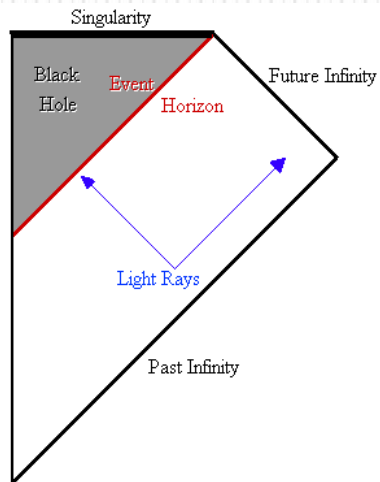


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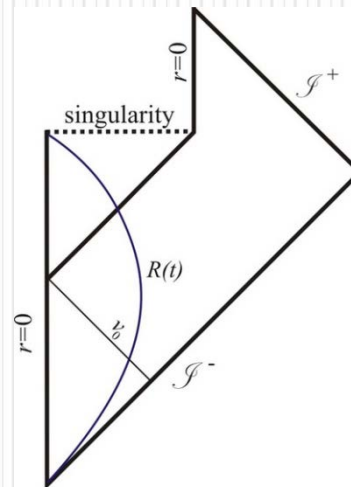
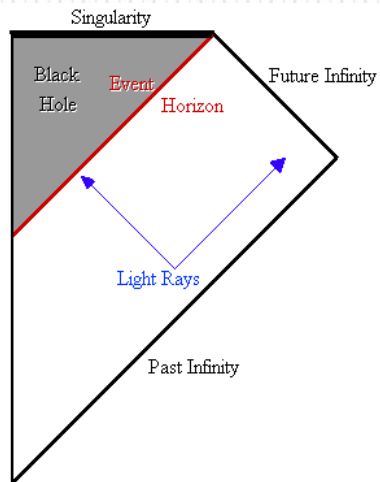
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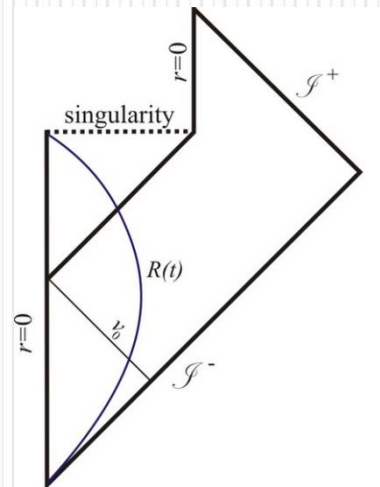
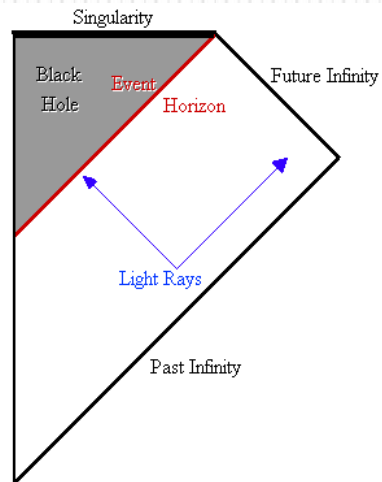
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# Today: BHs are real !

Strong evidence for stellar and supermassive black holes.

E.g.: Sagittarius A\*

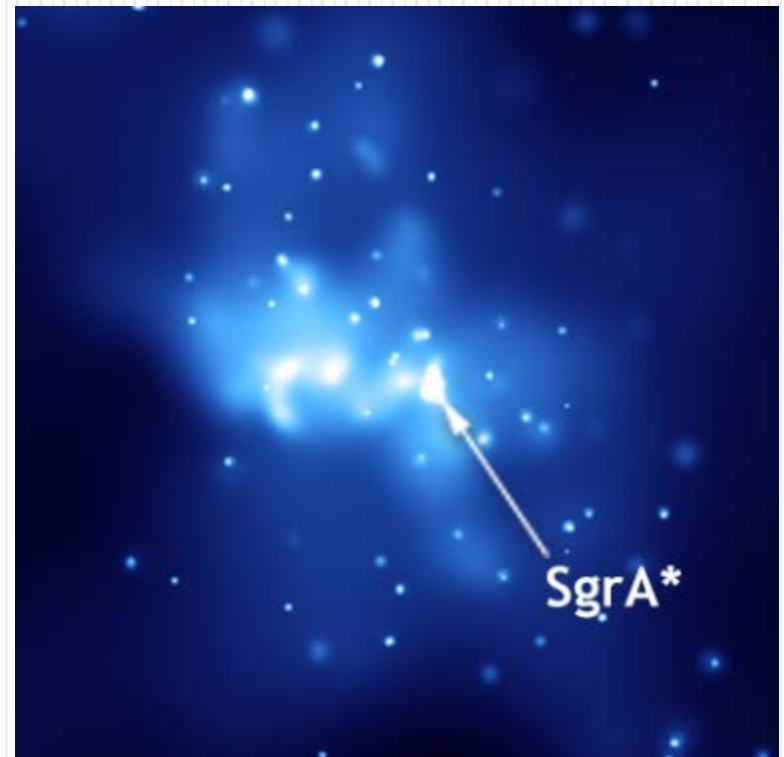
- 4 Mio stellar masses
- Diameter 44 Mio km
- 26000 lightyears away

Exciting prospects:

E.g. Event Horizon

Telescope array (in mm band)

See talk by Silke Britzen.



# Role of BHs in astro and cosmology

We will discuss at this meeting, e.g.:

- Under which realistic conditions do BHs or BH binaries form?
- Experimental signatures of BH formation?
- How do BHs (and neutron stars?) lose their hair?
- BH's roles in formation and dynamics of galaxies?
- Will BHs completely evaporate in the late universe?

Talks, e.g., by Luciano, Laemmerzahl, Pretorius, Ferrari, Ellis

# BHs and generalized gravity theories

Generalize GR:  $f(R)$ , higher dim., Lovelock theories etc:

- How stable is physics of BHs when generalizing GR?
- How to obtain regularisations of the BH singularity?
- Origins of cosmic censorship?
- Stabilization of wormholes?
- Can known BH physics put bounds on generalizations of GR?
- SSB of local scale invariance

Talks, e.g., by Rovelli, 't Hooft

This also leads to ...



# Black holes: GR & QFT & Q. Info

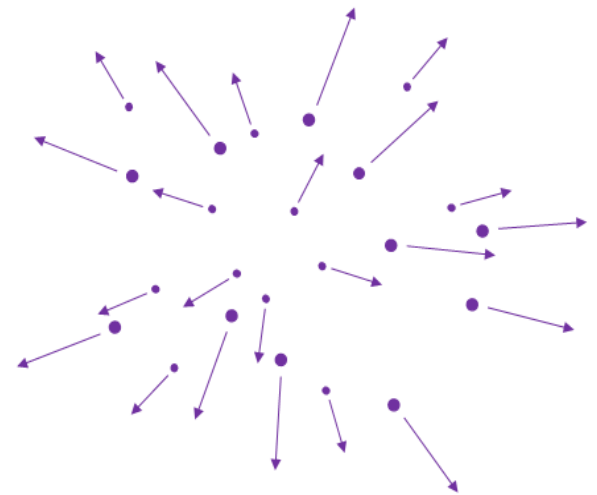
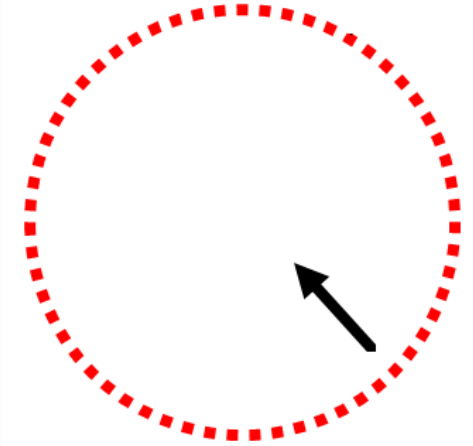
- What BH microstates account for BH entropy?  
Is Black hole entropy entanglement entropy?
- How could Planck scale render entanglement entropy finite?  
Is spacetime discrete & continuous, similarly to information?
- Black hole complementarity, AdS/CFT conjecture?  
Is bulk redundancy same as quantum error correction redundancy?

**Are there firewalls?**

Talks, e.g., by Giddings, Verlinde, Mann, Dvali, ...

# Firewalls ?

- Pure initial state: Infalling matter
- A black hole forms and evaporates.
- Finally: no BH and lots of radiation:  
Unitarity demands it is a pure state!



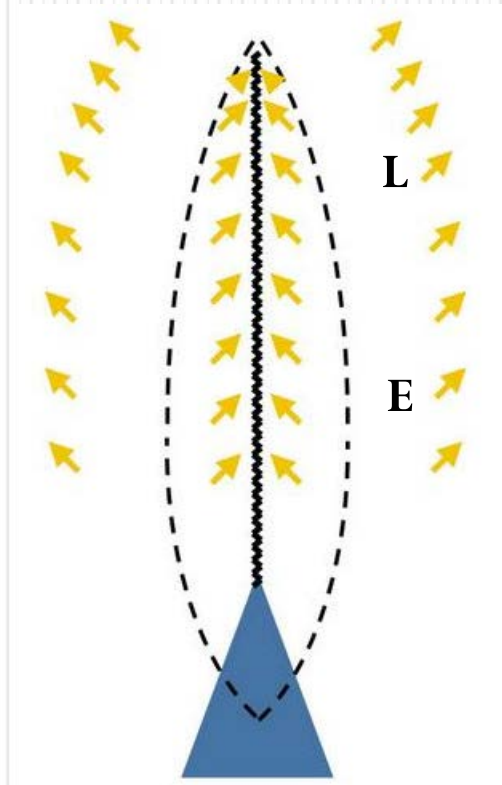
Therefore: Entanglement btw early and late Hawking radiation

# Firewalls ?

Late radiation has entropy  $S(\mathbf{L})$

Early radiation has entropy  $S(\mathbf{E})$

**Unitarity:** total radiation has entropy  $S(\mathbf{L}, \mathbf{E}) = 0$



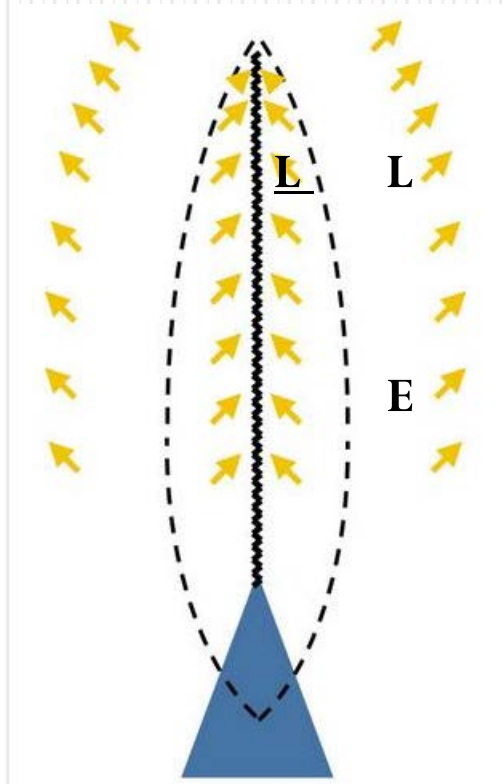
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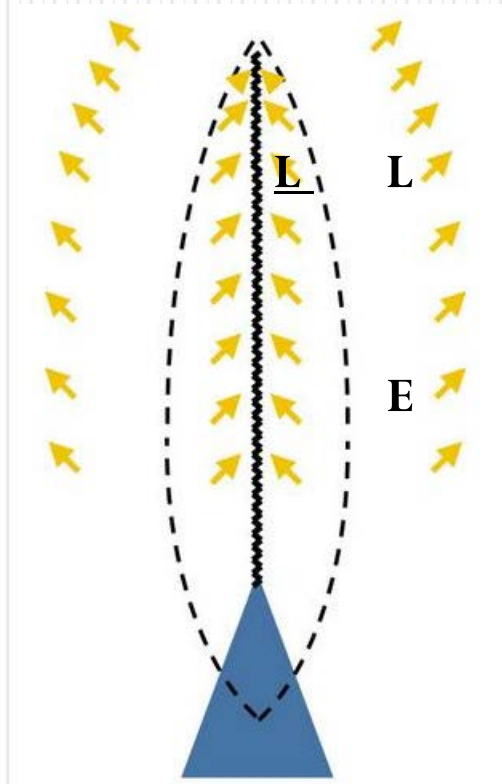
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**Strong subadditivity:**  $S(\underline{L}, \mathbf{L}) + S(\underline{L}, \mathbf{E}) > S(\underline{L}) + S(\mathbf{E})$



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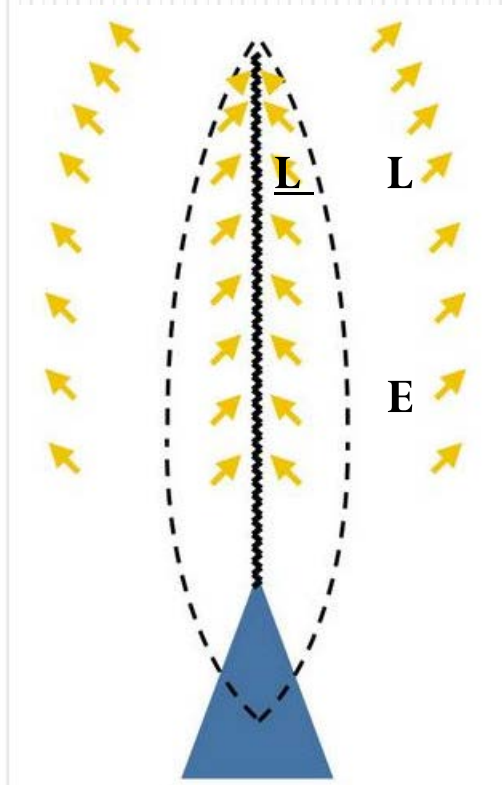
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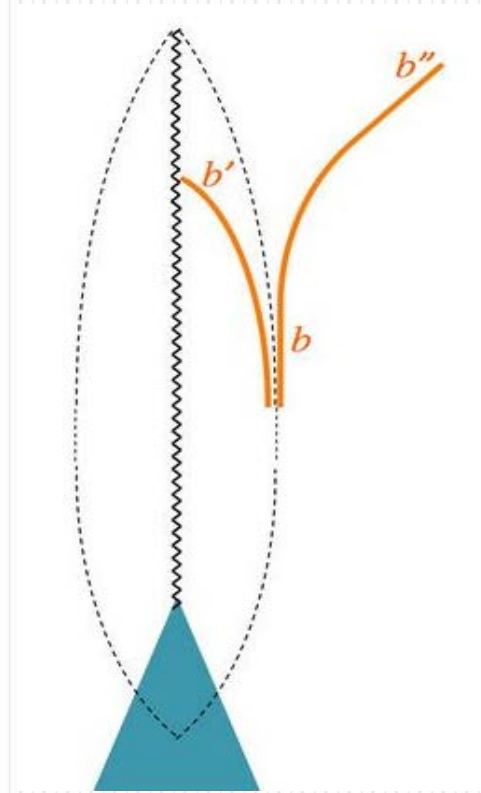
**Also:**  $\underline{\mathbf{L}}$  and  $\mathbf{L}$  are entangled

**Strong subadditivity:**  $S(\underline{\mathbf{L}},\mathbf{L}) + S(\mathbf{L},\mathbf{E}) > S(\underline{\mathbf{L}}) + S(\mathbf{E})$

**Therefore**  $S(\underline{\mathbf{L}},\mathbf{L}) > 0$  and therefore  $(\underline{\mathbf{L}},\mathbf{L})$  non-pure!



# Firewalls ?



( $\underline{L}, L$ ) non-pure, i.e.,  $b'$  and  $b''$  created at horizon not out of vacuum but out of an excited state.

**Blueshift:**  $b'$  and  $b''$  were created at a **firewall at the horizon.**

# Firewalls:

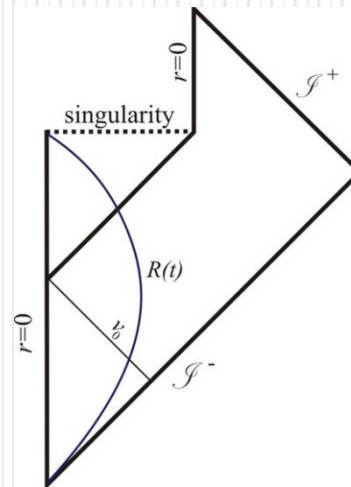
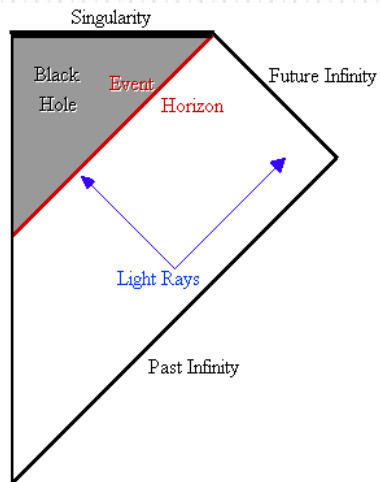
- **Would violate equivalence principle !**
- Resolution suggestions? E.g.:
  - Quantum gravity not unitary
  - Remnants
  - Stringy fuzzballs
  - Wormholes
  - Gradual breaking of pair entanglement
  - Scrambling, Page time questioned (e.g., M. Hotta)
  - Firewalls not efficient at necessary breaking of entanglement (Louko, Martin-Martinez, PRL of July 2015)



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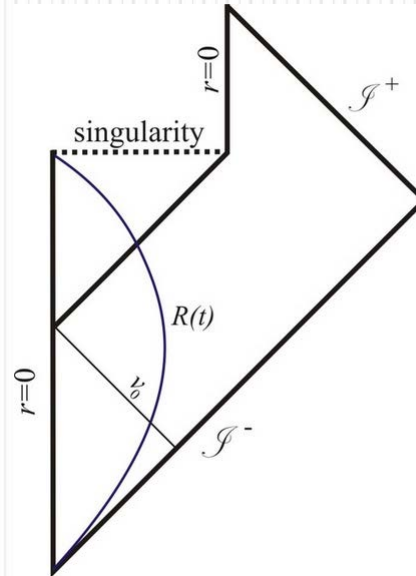
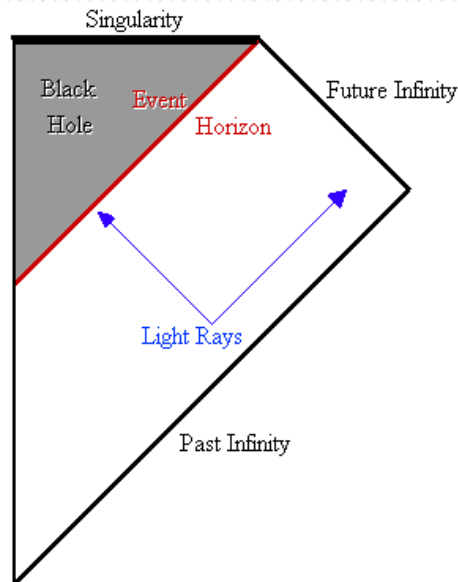
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## Firewalls:

All is on the line:

Equivalence principle violated?

Unitarity violated?

Or what else gives?

Thank you !