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**Title:** Why We Need (But Don't have) Quantum Gravity

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**Intended for:** Guest lecture in continuing education class, future science outreach projects

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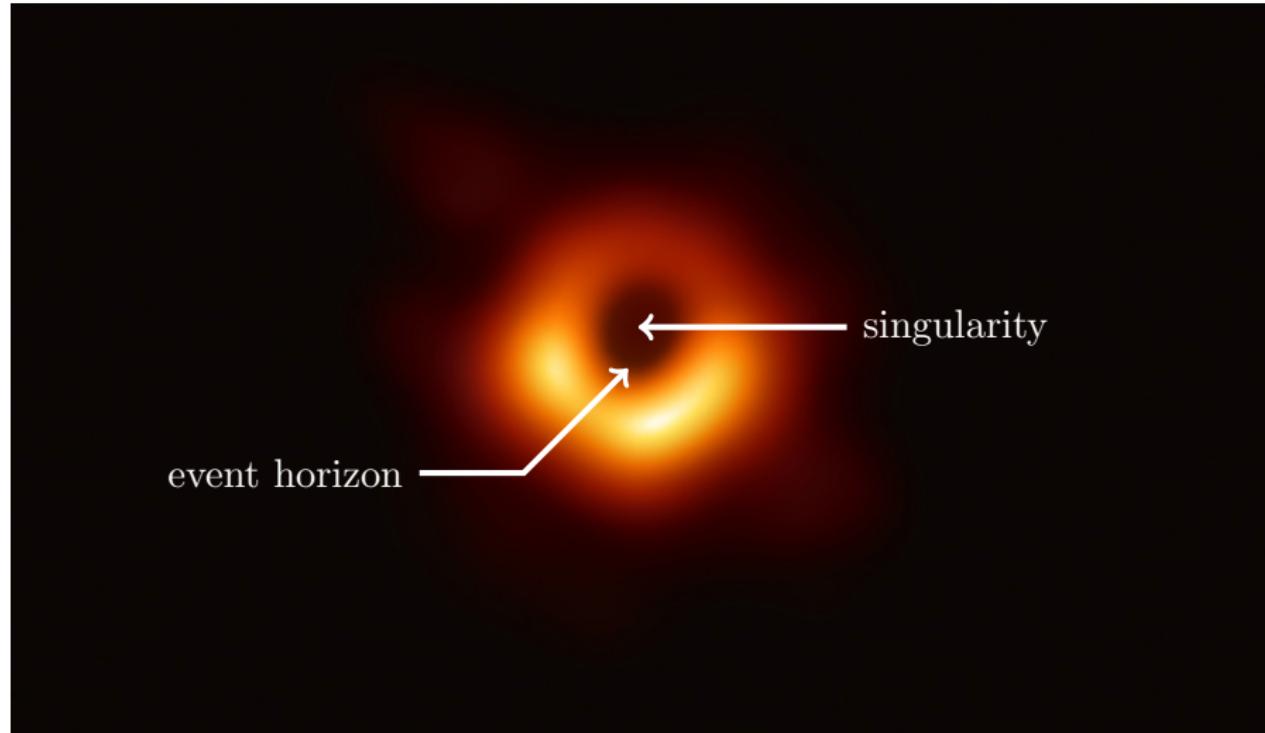
# Why we Need (But Don't Have) Quantum Gravity

Jonah M. Miller

UNM Continuing Education Class

Why we need quantum gravity

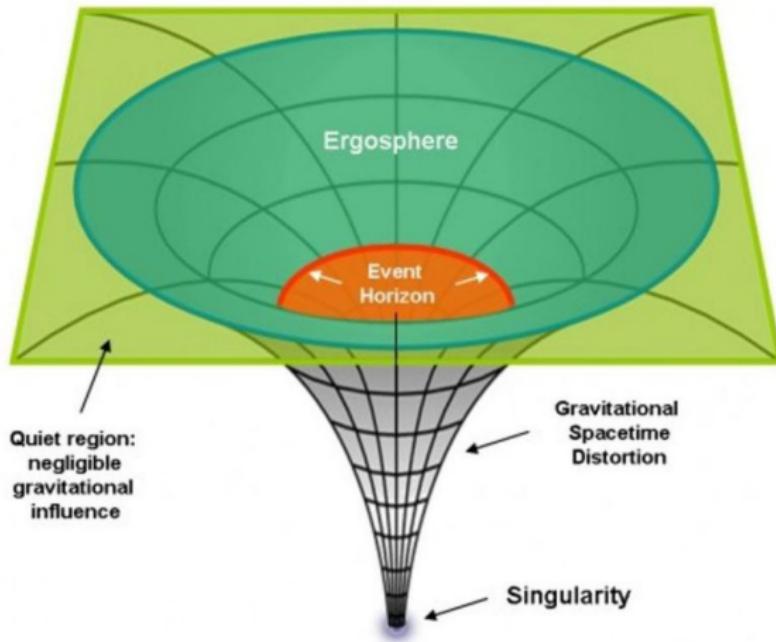
# Black Holes



EHT Collaboration

# The Singularity: A Point of Infinite Density?

## Black Hole Regions

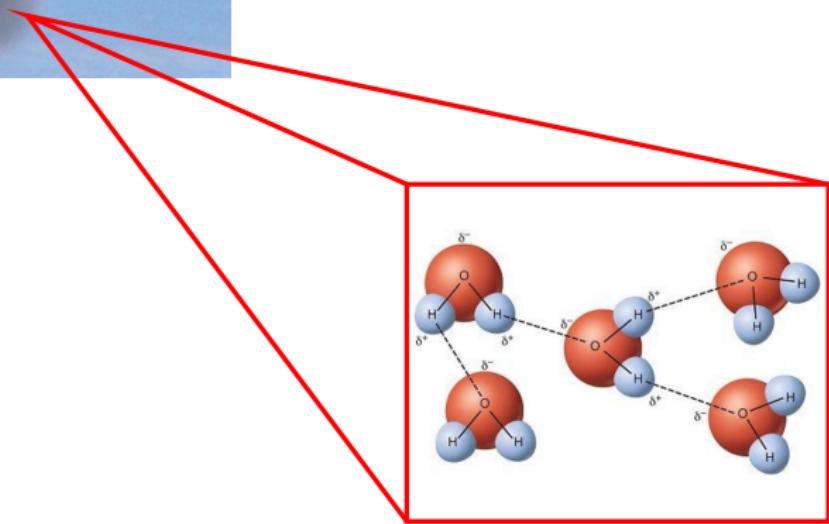


We've seen this before...



Ensign John Gay, USS Constellation, US Navy/USGS

We've seen this before...



Ensign John Gay, USS Constellation, US Navy/USGS

# Why we need quantum gravity

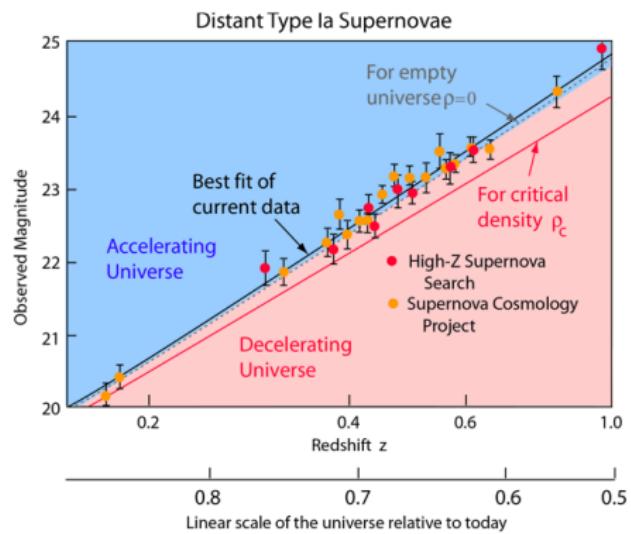
- When the fluid approximation for air breaks down...
  - We must understand it as a collection of molecules...
  - which are quantum
- When the continuum approximation for spacetime breaks down...
  - We must understand it as...?
  - Which is quantum?

Why we won't get it

# The Accelerating Universe

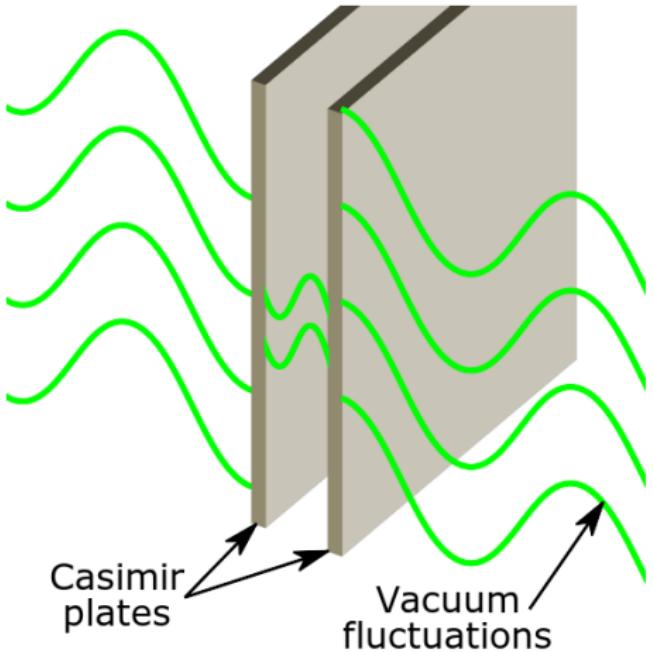


2006 Shaw Prize, Wikimedia Commons



Carroll and Ostlie

# The Cassimir Effect



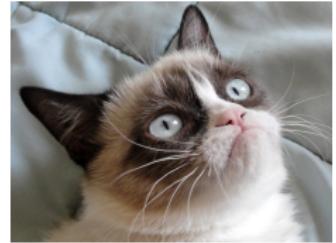
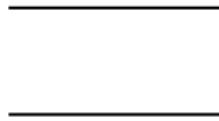
Wikimedia Commons

The Royal Dutch Academy of Sciences

# The Vacuum Catastrophe: wrong by $10^{120} \times$

$$E [\Lambda]$$

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Images: Hubble Deep Field, NASA, Grumpy Cat

# The varied approaches to quantum gravity

- Start from quantum field theory, and try to add gravity (string theory)
- Start from general relativity and attempt to quantize it (loop quantum gravity)
- Start from discrete building blocks (causal sets, causal dynamical triangulations)

# Guidance?

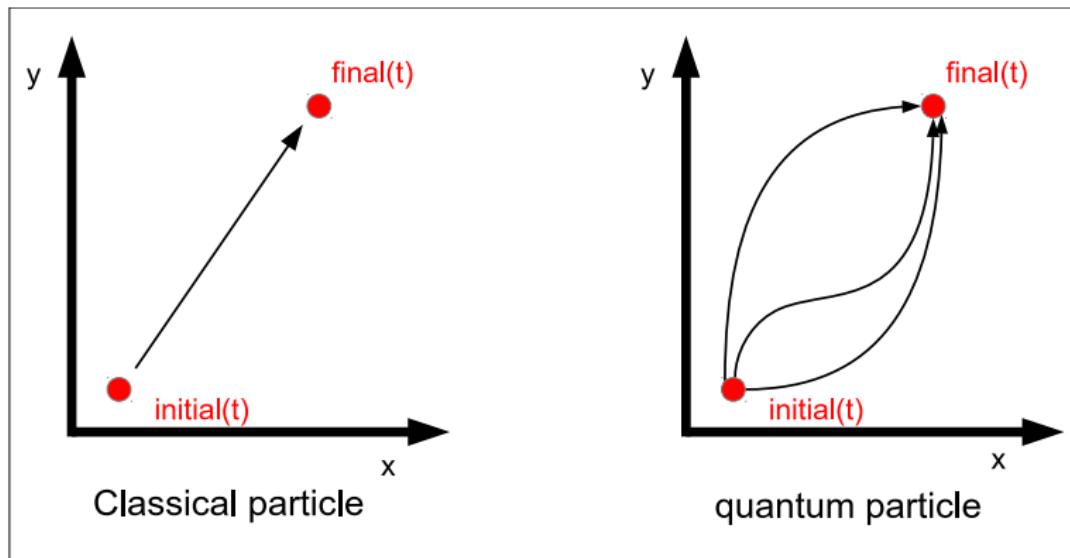
- Essentially no measurements
- Black holes could offer clues
- So could the early universe

- Summary

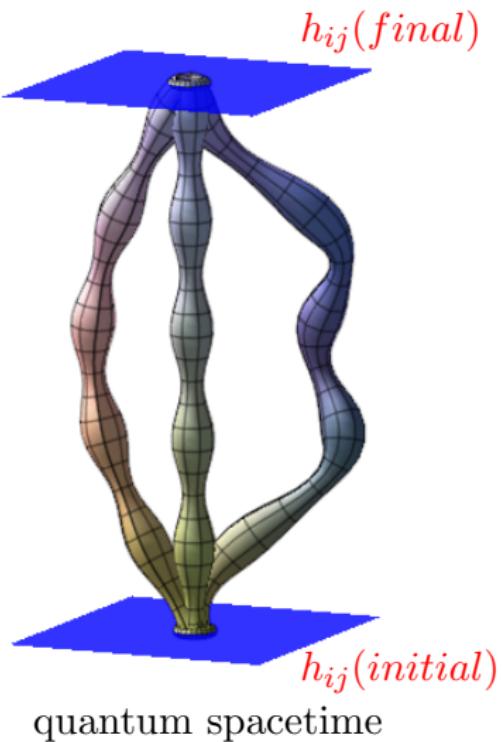
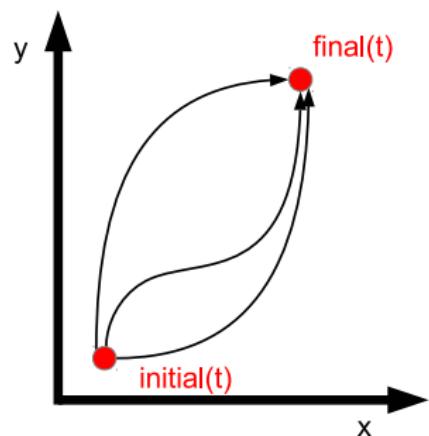
- We need quantum gravity:
  - Just as the fluid approximation sometimes breaks down for air, the continuum approximation breaks down for gravity
- We're not going to get it:
  - This is the hardest problem in physics, with the worst prediction in the history of physics
  - No experimental guidance to send us in the right direction

# The Feynman Path Integral

$$\frac{dL}{dp} = \frac{d}{dx} \frac{dL}{dq} \longrightarrow \mathcal{A} = \int \mathcal{D}g e^{iS}$$

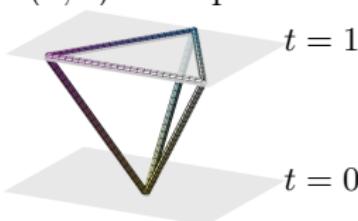


# Sum-Over-Histories

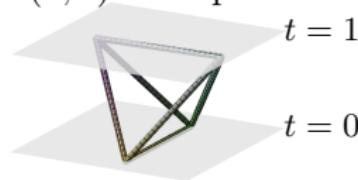


# Causal Triangulations in 2+1 Dimensions

(1, 3) 3-simplex



(2, 2) 3-simplex



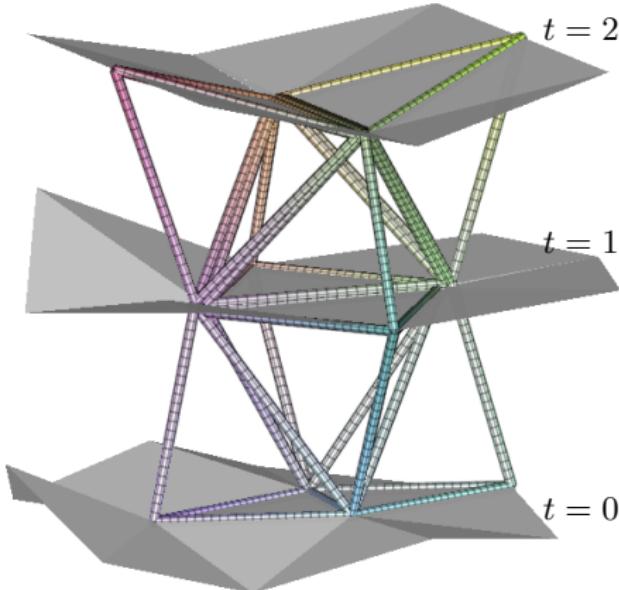
(3, 1) 3-simplex



$$l_{SL}^2 = a^2$$

$$l_{TL}^2 = -\alpha a^2$$

Segment of a causal triangulation



Forbidden  
spacetimes

