

Announcements

- Spacetime Team Project: due today at 11:59pm
 - Please return experiment materials when you are finished!
- Exploration paper 1 due Feb 09 at 11:59pm
- Problem 3 available now, due Feb 14 at 11:59pm
- Quiz 2 on Feb 12 (100pts)
 - 1 hr, available from 11am-11:59pm
 - See study goals on Canvas; chapter 2 and lecture material

Newton & classical physics

Space & time are *independent* from each other

Time passes continuously from past to future

Gravity acts instantaneously over arbitrary distance

Works to describe *almost* all of everyday life here on Earth

Einstein & modern physics

Spacetime is a 4D quantity; perception of space and time depend on relative motion

Clocks run slow at high speed —
Clocks run slow near large masses

The speed of light is constant and the speed limit of the Universe

Gravity is the manifestation of spacetime curvature induced by mass

Newton & classical physics

Space & time are *independent* from each other

Time passes continuously from past to future

Gravity acts instantaneously over arbitrary distance

Works to describe *almost* all of everyday life here on Earth

Einstein & modern physics

Mass and energy are equivalent through the speed of light as: $E=mc^2$

Time travel is possible, but only in the **future direction**

Gravitational waves can probe the Universe in different ways than light

- initially believed to be undetectable
- discovered in 2015 (almost exactly 100 years after prediction!)

Future physics

Beyond Newton & Einstein

quantum gravity

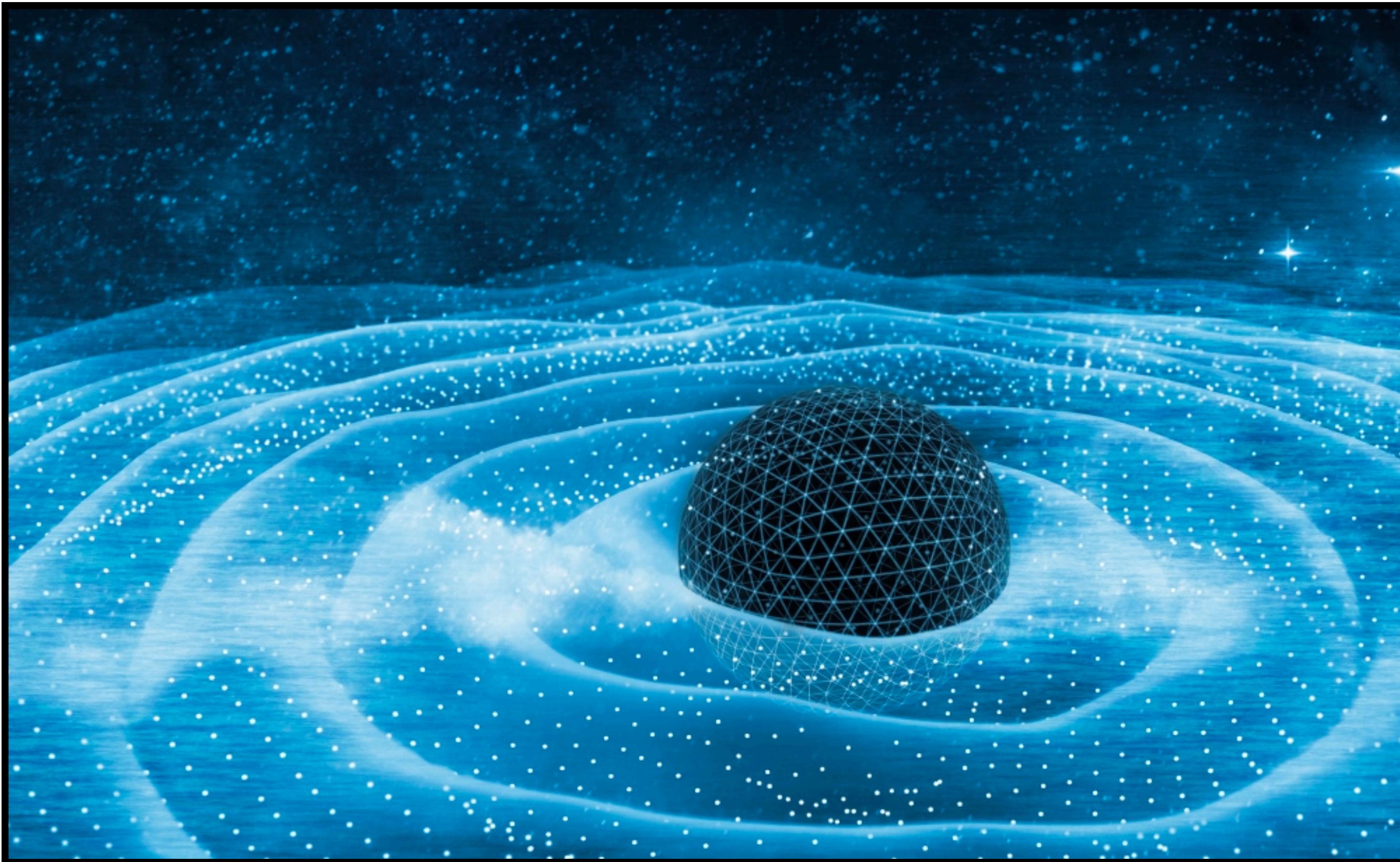
worm holes

time travel to the past?

multiverse hypotheses



quantum gravity



4 fundamental
forces in nature

Described by quantum mechanics

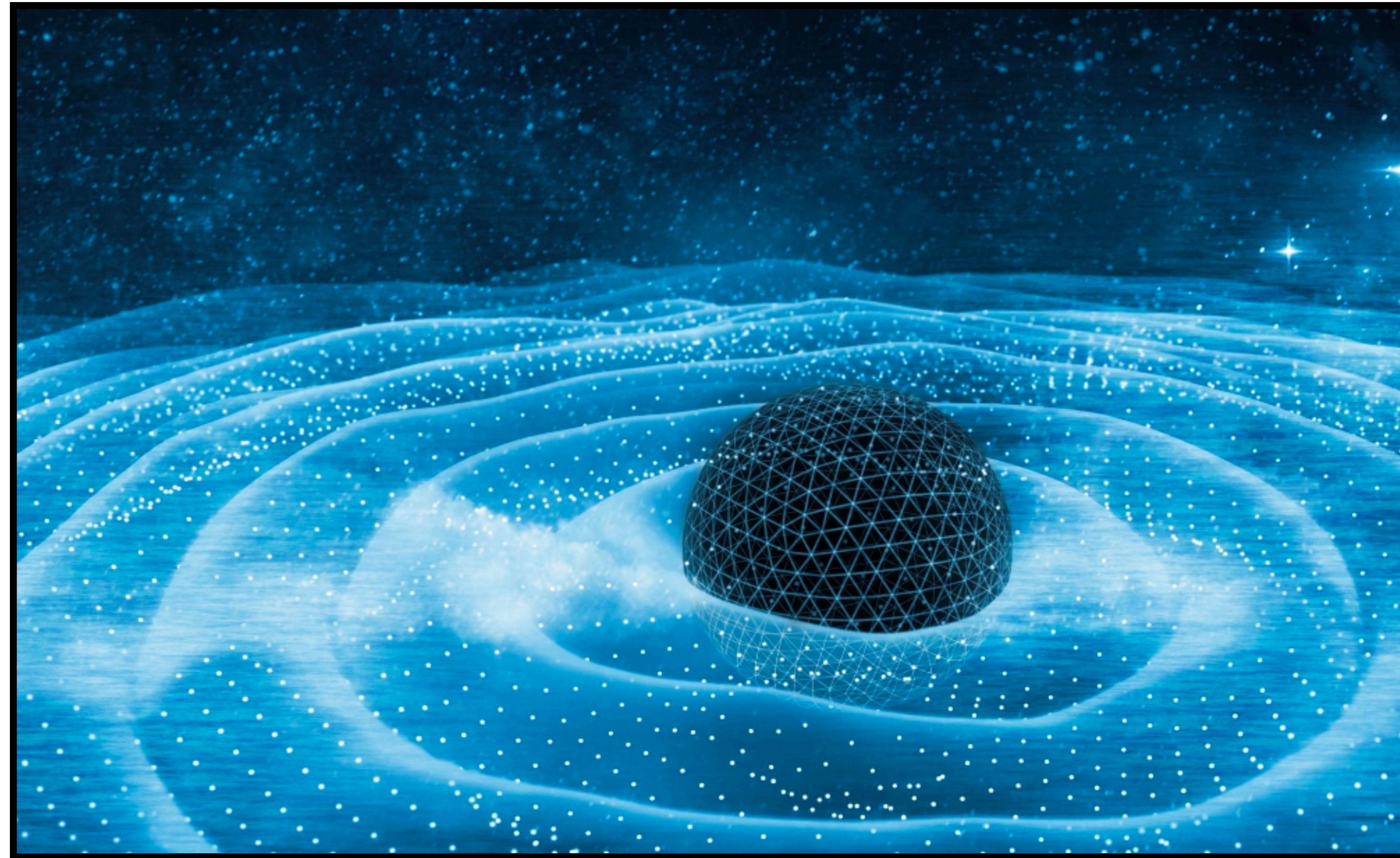
electromagnetic force

strong force

weak force

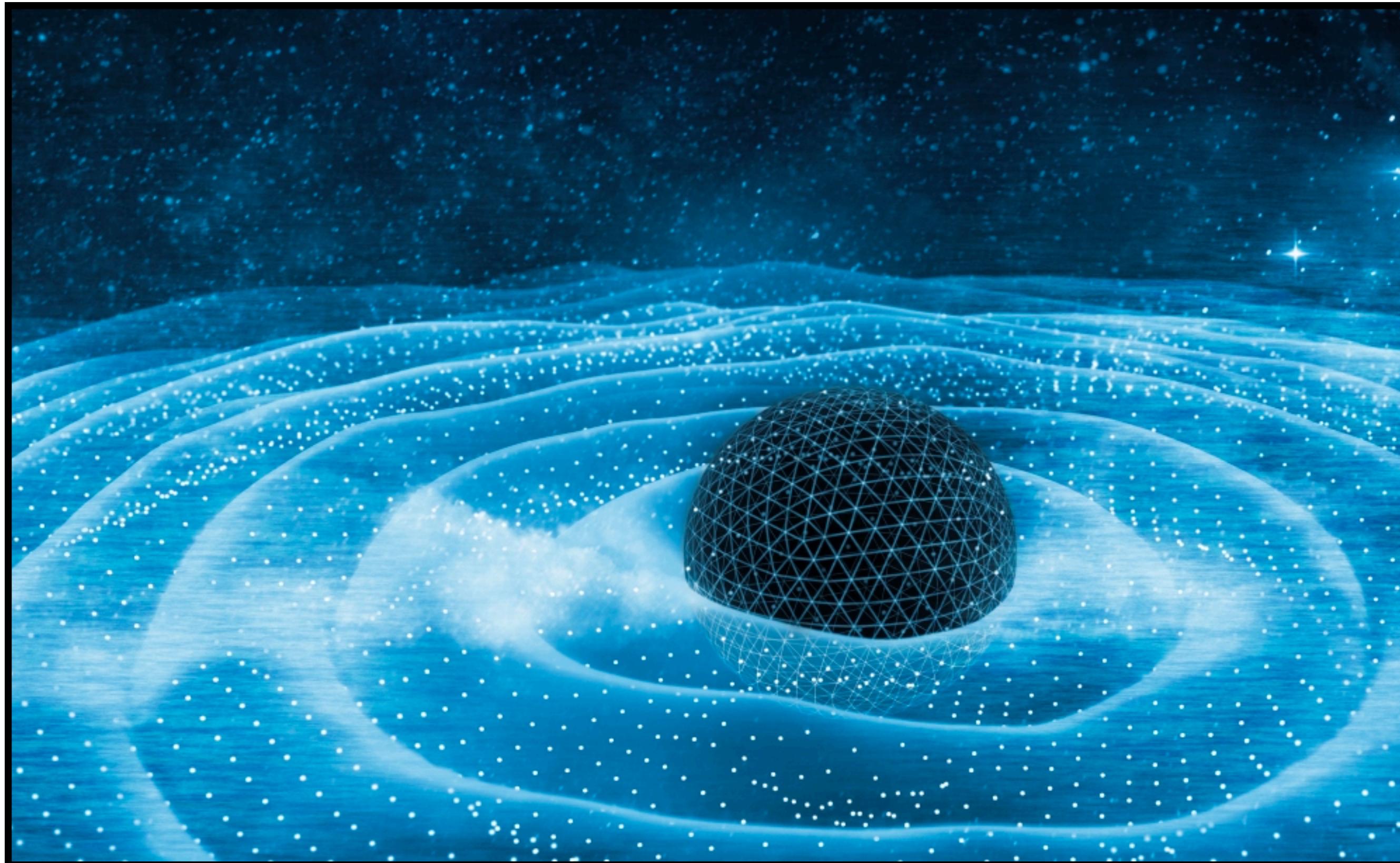
force due to gravity

quantum gravity



quantum gravity seeks
to describe gravity
according to the
principles of quantum
mechanics

quantum gravity

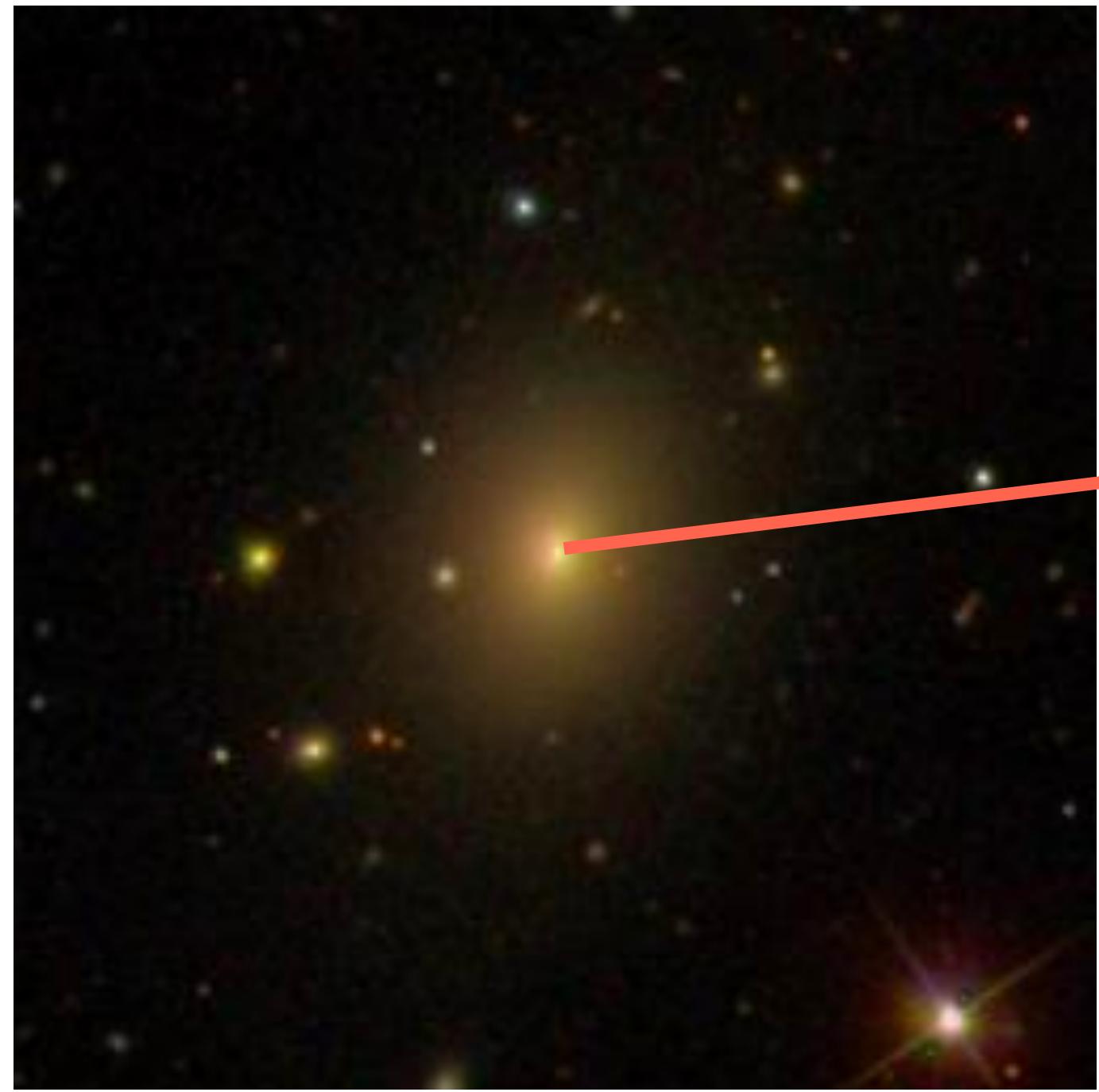


important near the very center of black holes where curvature is ~infinite
(very small scales!)

Virtual particles pop in/out of existence on these small scales — Planck length 10^{-35} m

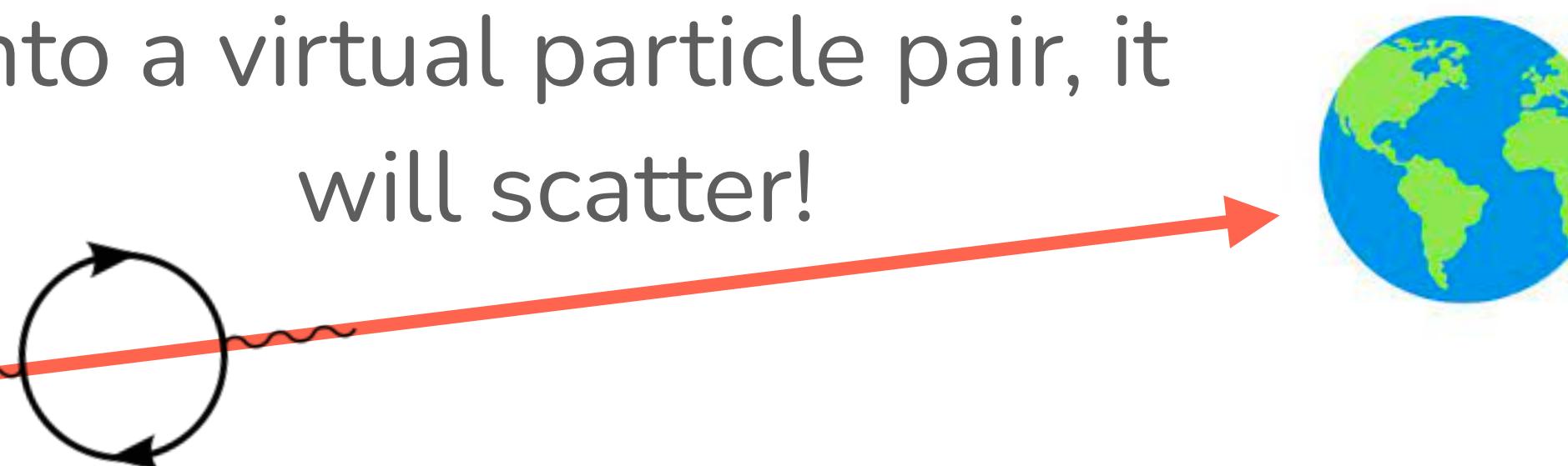
“Quantum foam”

Tests of quantum foam



γ -ray photons are emitted by disks around massive black holes millions of lightyears away and observed by telescopes in Earth's orbit

If the γ -ray photon crashes into a virtual particle pair, it will scatter!



By observing γ -rays from massive black hole disks, we can confirm that the size of these quantum fluctuations are smaller than 1/1000th the width of a proton!



Contact

Directed:
Robert Zemeckis

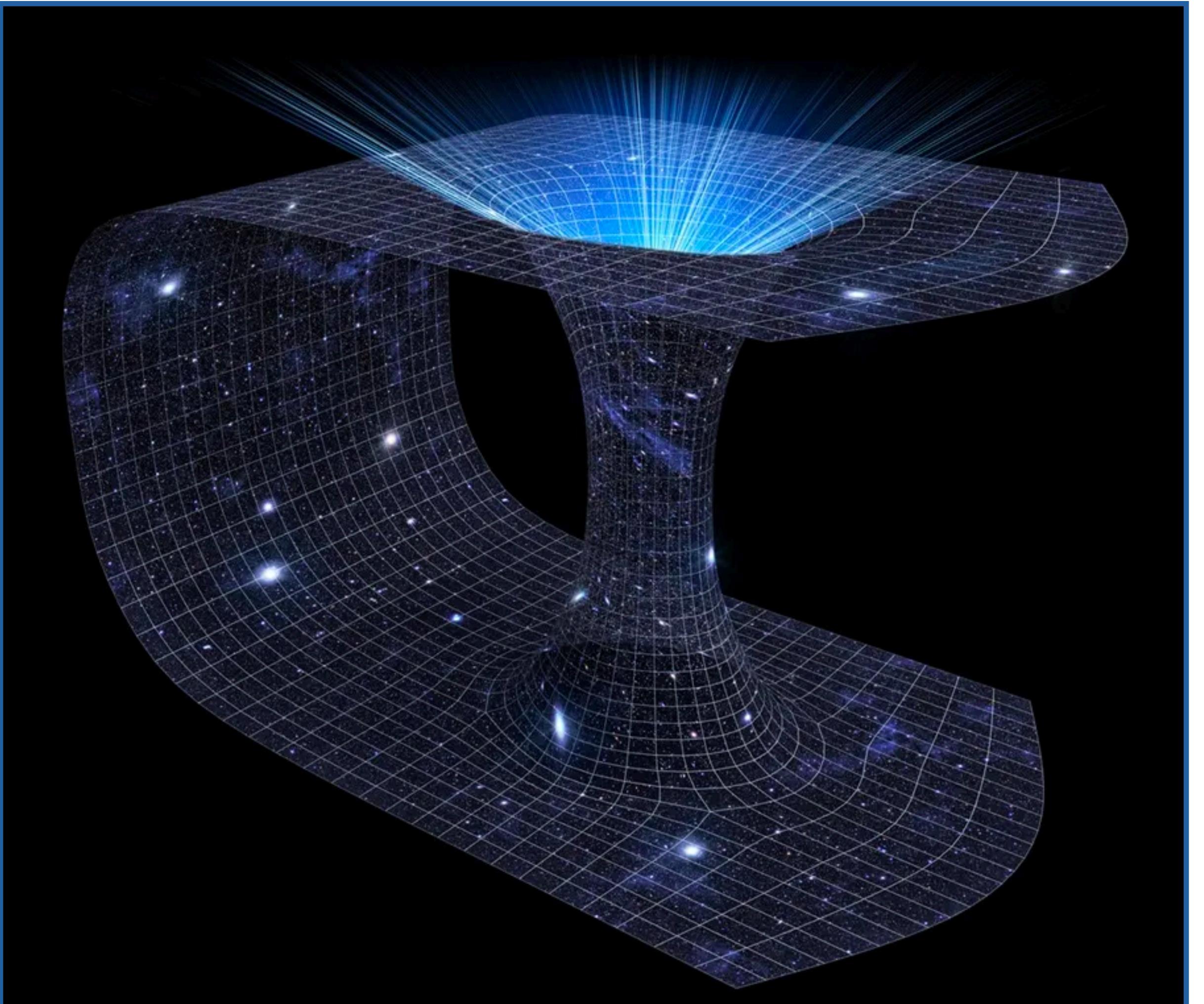
Warner Brothers (1997)

Based on novel by Carl Sagan — initially wanted to use a black hole for faster than light travel — Kip Thorne suggested a wormhole instead!

Hypothetically possible
shortcuts through
spacetime

worm holes

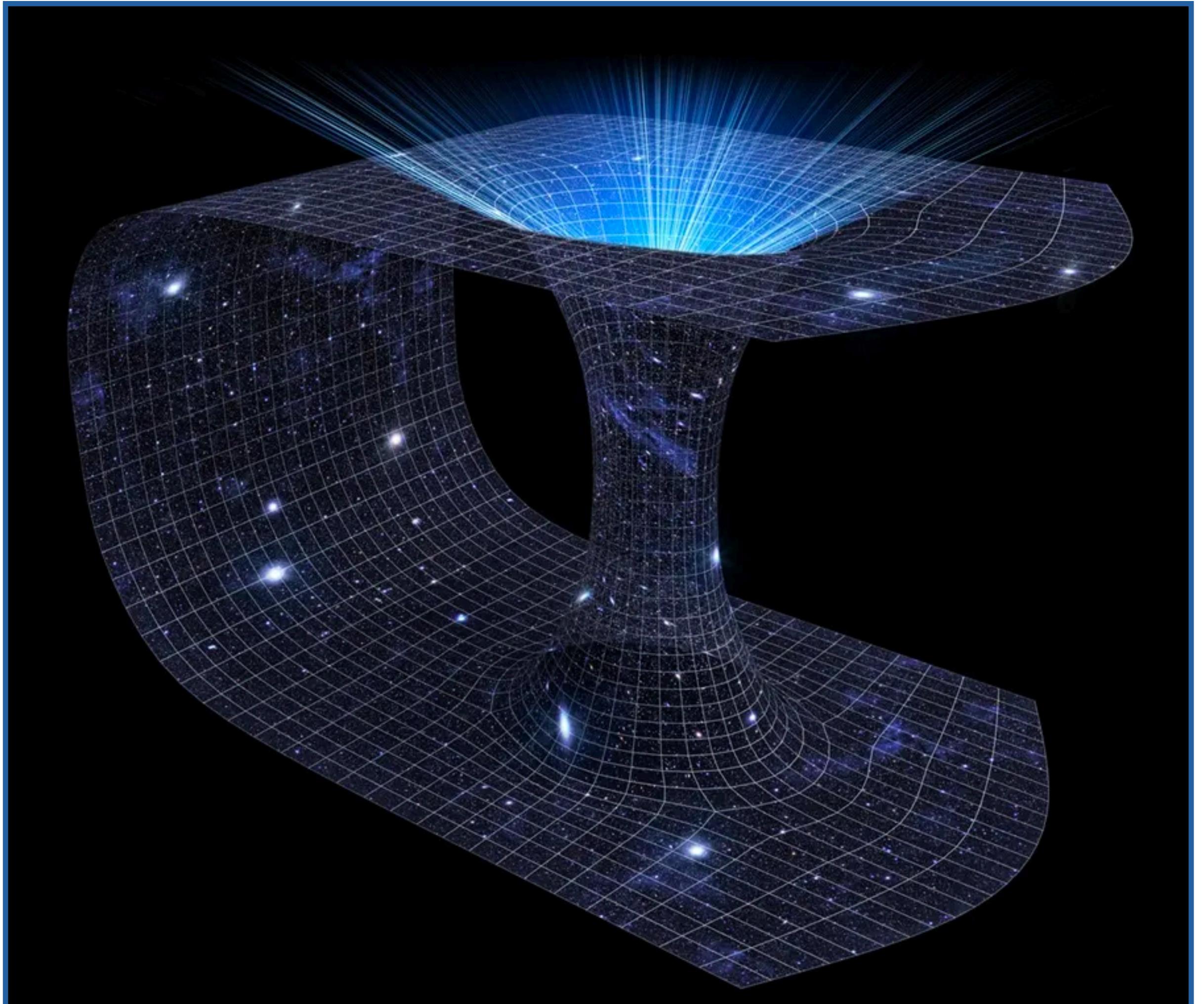
Requires an **enormous**
amount of energy to
keep open and so are
thought to only occur
at near quantum
scales in nature

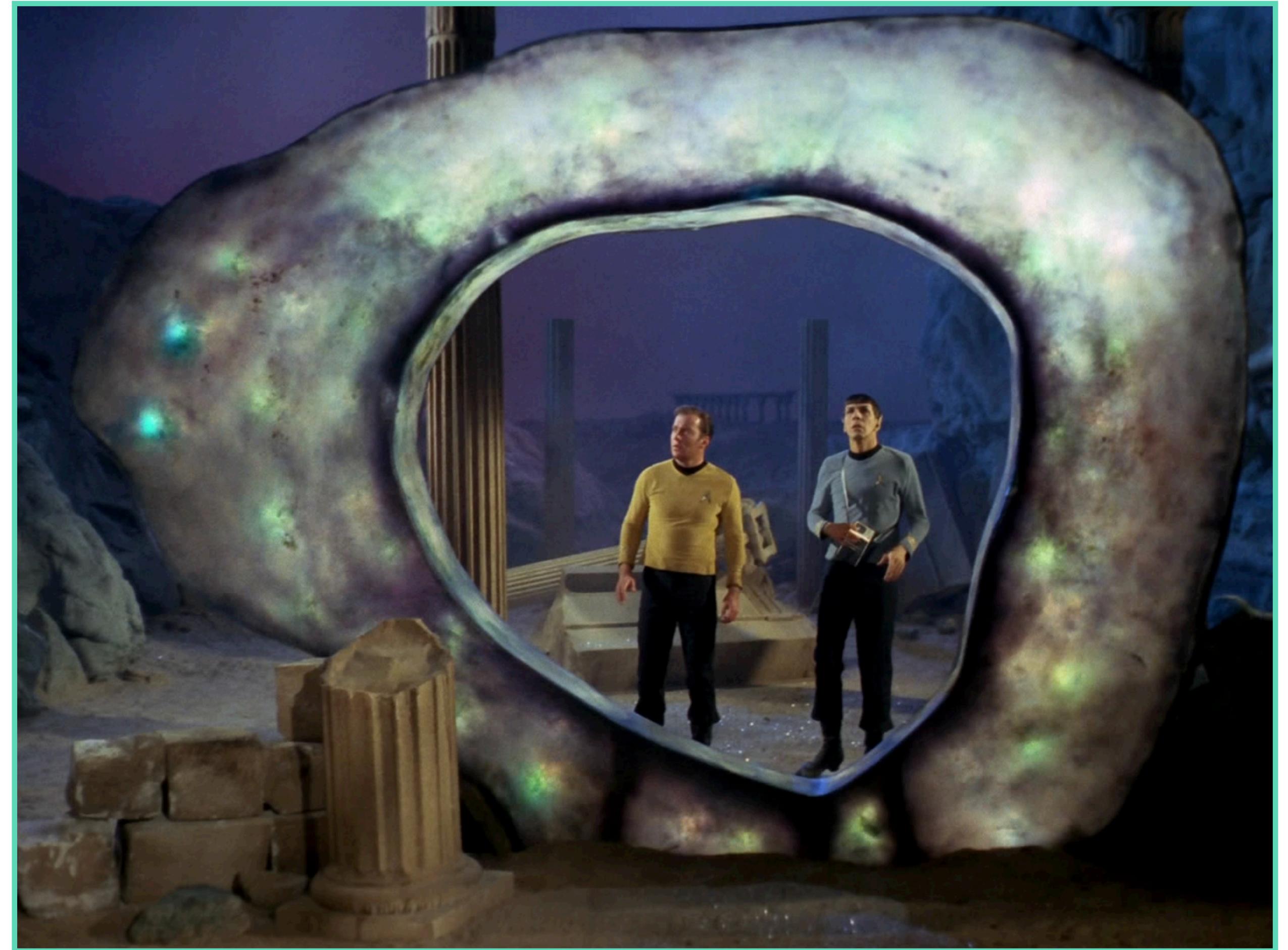


Could a worm hole be
used to travel
back in time?

Yes! But we currently
are not able to harness
enough energy to
create and maintain
one that we could
send humans or
spacecraft through

worm holes

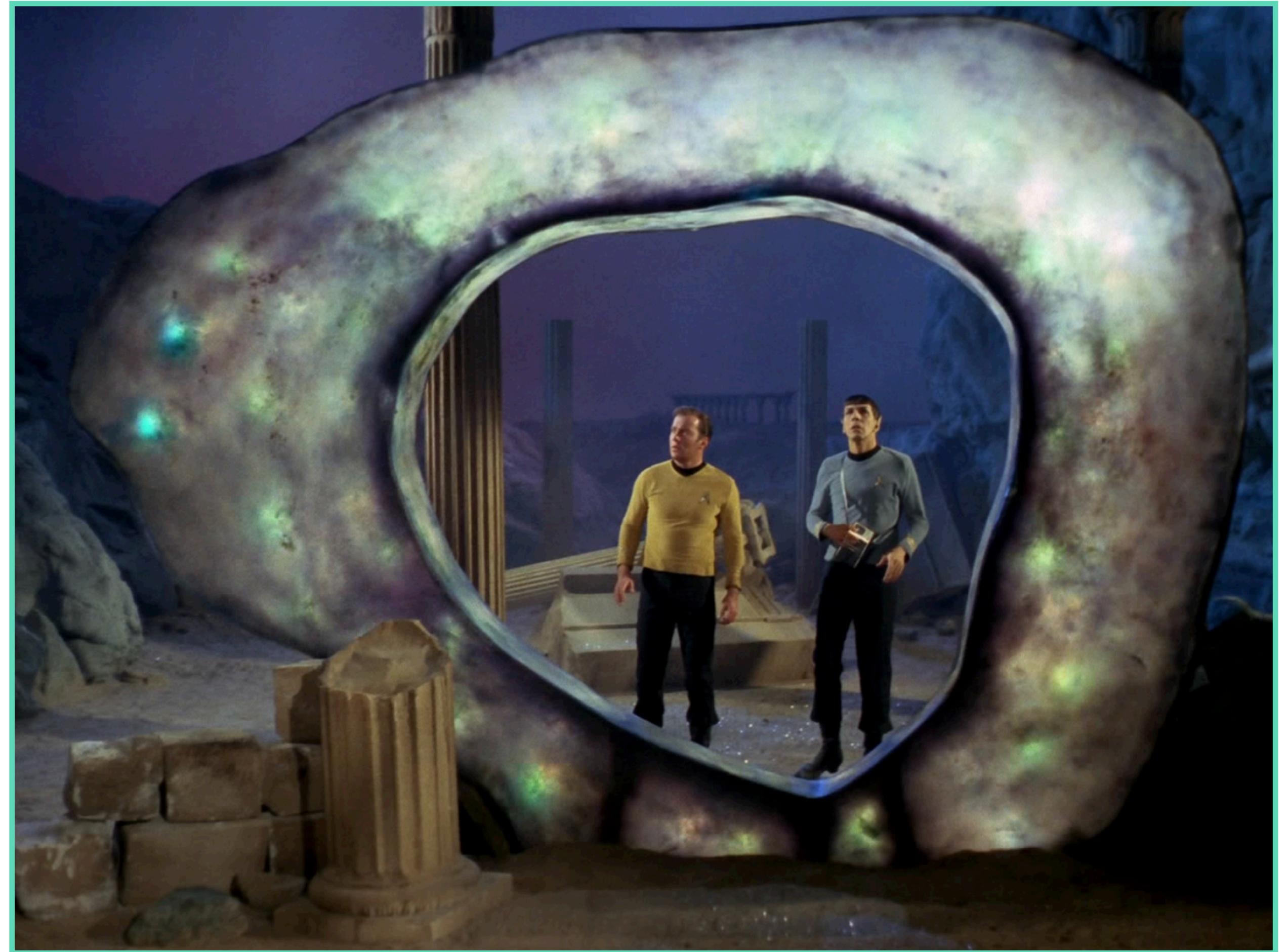




Star Trek
*The City on the Edge
of Forever*

Written:
Harlan Ellis

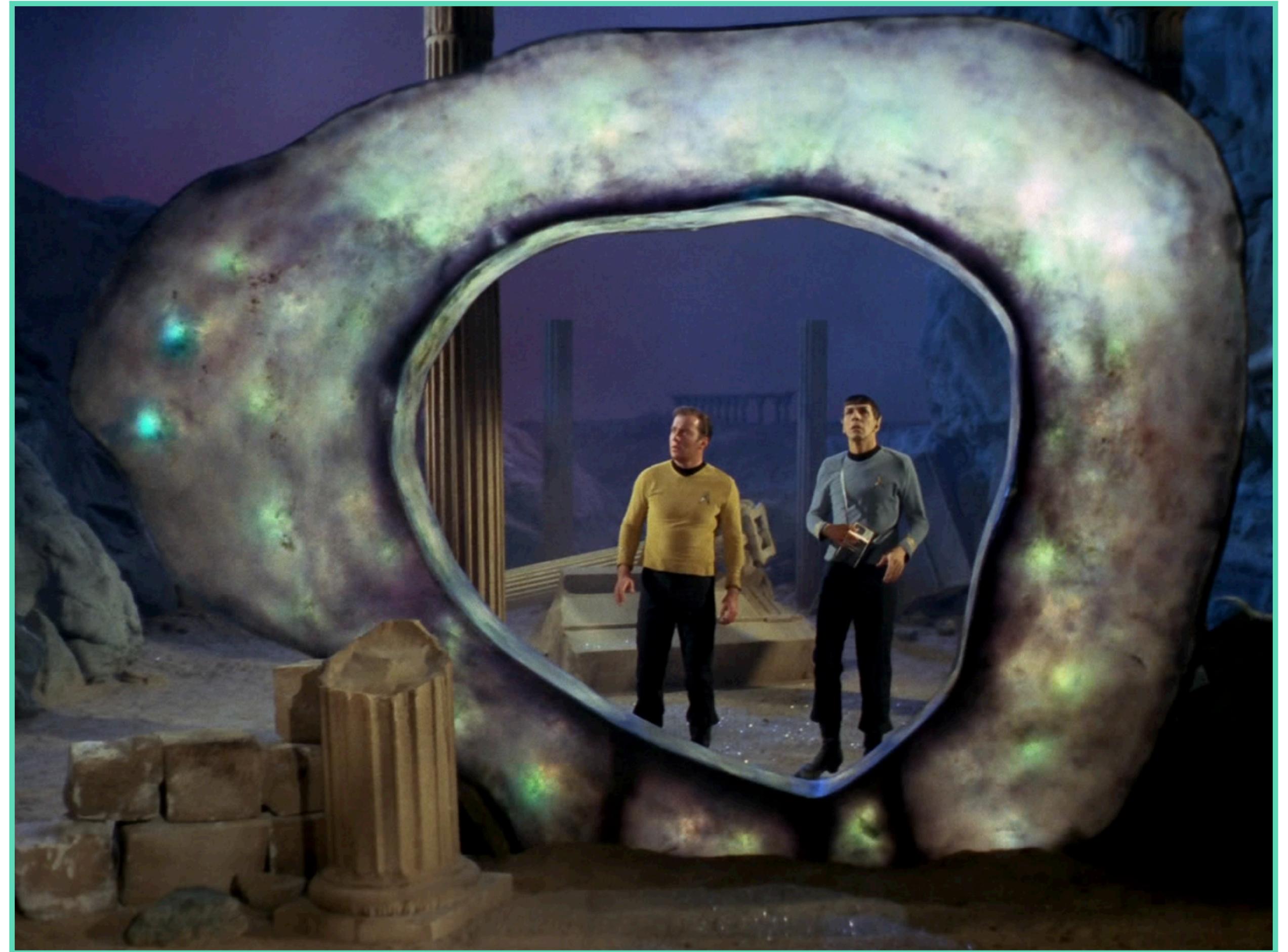
Paramount (1967)



What is the Guardian of Forever?

“A time portal, Captain. A gateway to other times and dimensions, if I’m correct.”

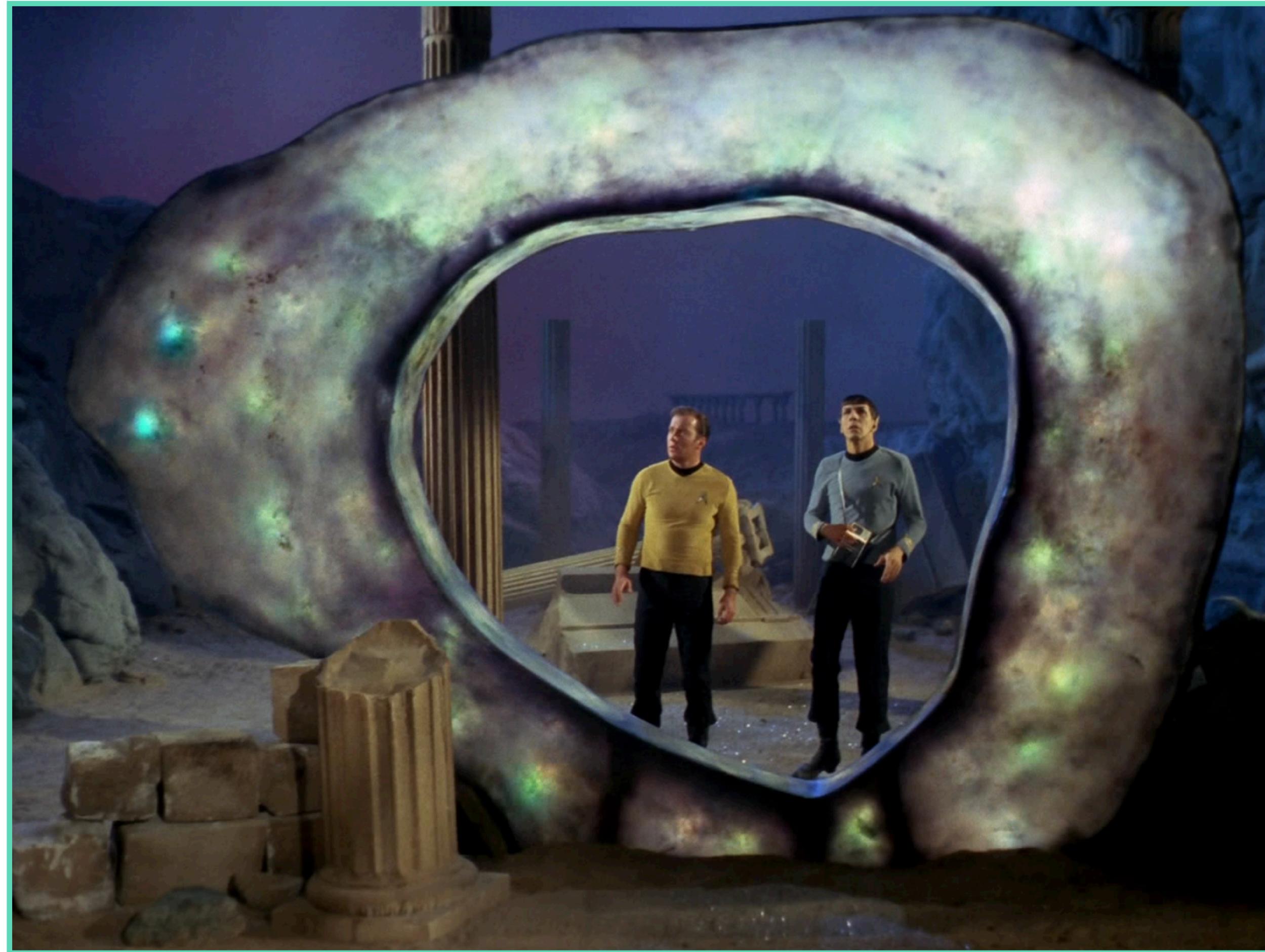
- Spock



Could something like
the Guardian of
Forever actually exist?

*"For this to do what it
does is impossible, by any
science I understand."*

- Spock



“As correct as possible for you. Your knowledge of science is obviously primitive”

- Guardian of Forever

Maybe there is a breakthrough we are really missing!

Principle of Consistent Causality

*“...the only solutions to the laws of physics that can occur **locally** in the real Universe are those which are **globally self-consistent**.”*

- Igor Novikov

See section 2.5 of the book!

Attempting to change the past through time travel is like trying to defy the law of gravity



The idea that you could go into the past and make your self disappear like Marty McFly is *unphysical* as far as the laws of nature are concerned



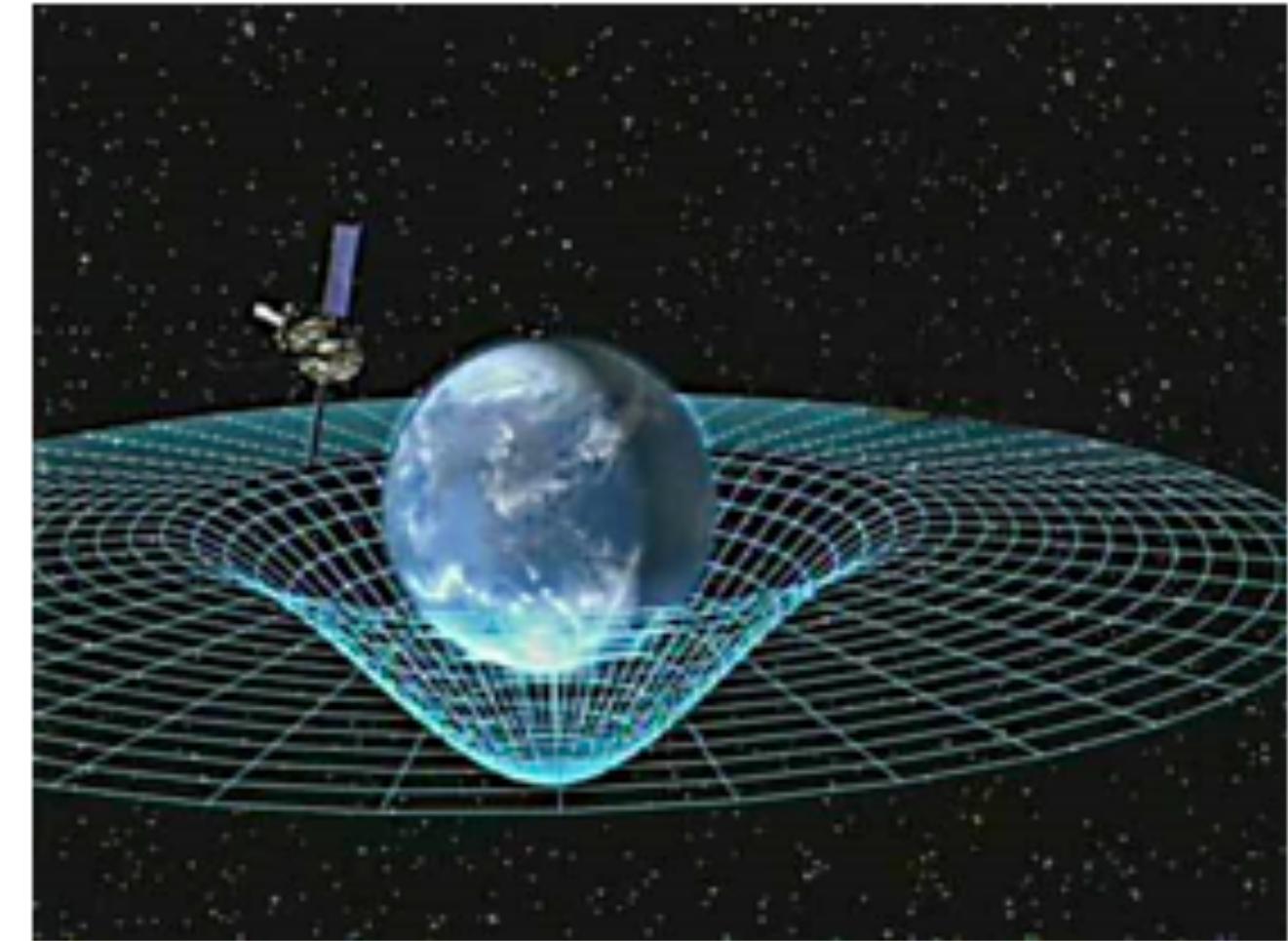
Star Trek IV:
The Voyage Home

Directed:
Leonard Nimoy

Paramount (1986)

Next time:

- ▶ Finish up future physics
- ▶ Multiverse hypotheses



What is the nature of space and time?