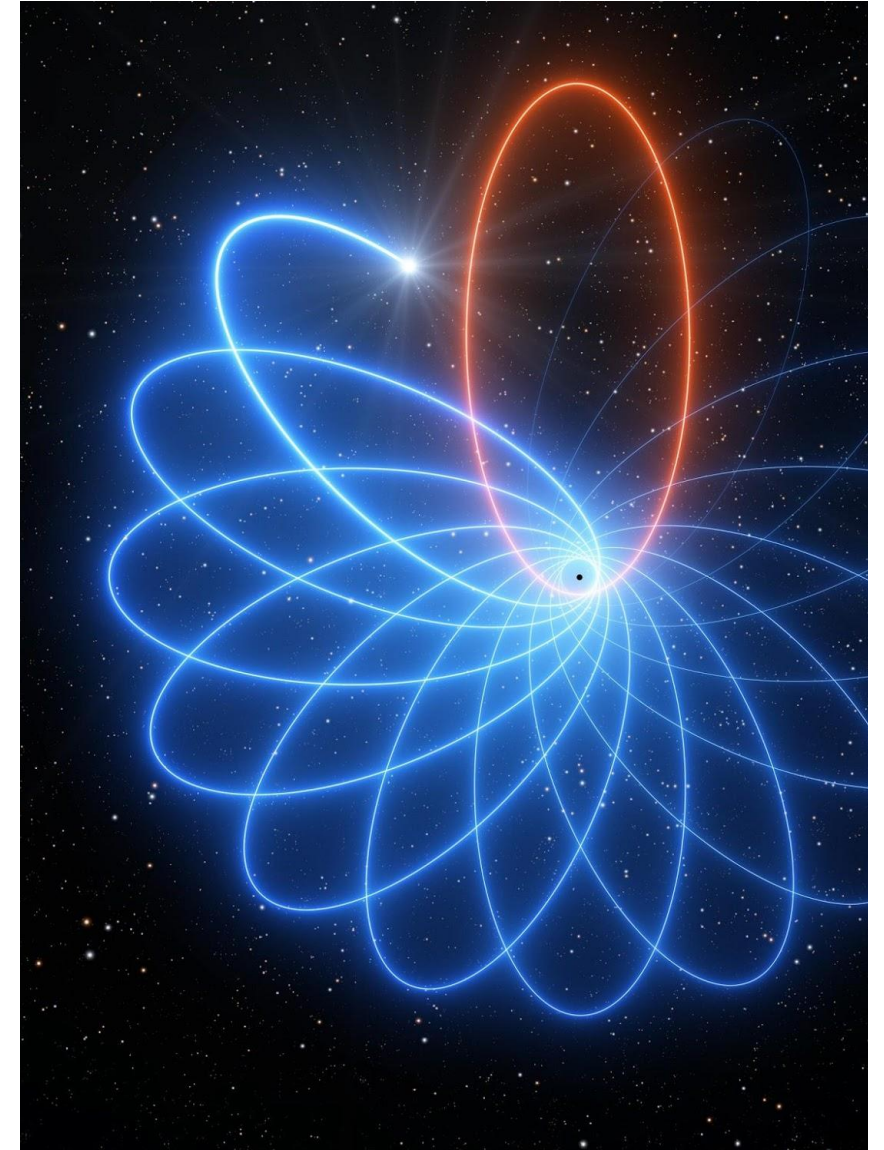


# RELATIVITY

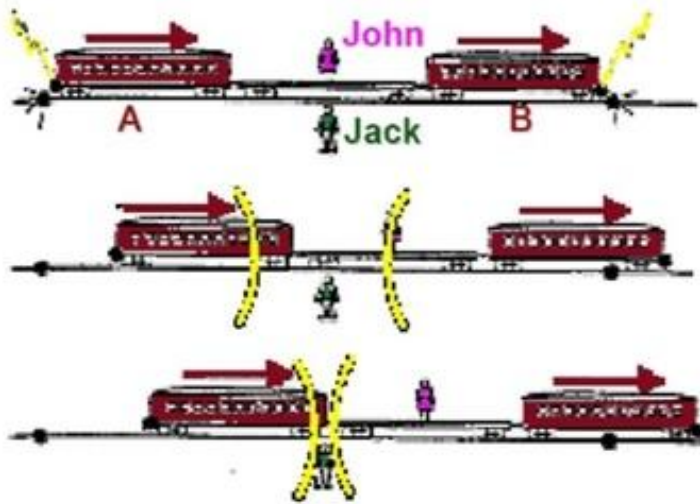
<https://lab.nstmf.org/gravity>

# INTRODUCTION

- In 1905, Albert Einstein determined that the laws of physics are the same for all non-accelerating observers, and that the speed of light in a vacuum was independent of the motion of all observers. This was the theory of special relativity. It introduced a new framework for all of physics and proposed new concepts of space and time.
- Einstein then spent 10 years trying to include acceleration in the theory and published his theory of general relativity in 1915. In it, he determined that massive objects cause a distortion in space-time, which is felt as gravity.



# HISTORY



From the point of view of Jack, lightning struck both train cars at the same time

From the point of view of John, lightning struck car B first and then car A later

Simultaneity is relative - things occurring at the same time at one

- Objects in motion (or at rest) remain in motion (or at rest) unless an external force imposes change.
- Force is equal to the change in momentum per change of time. For a constant mass, force equals mass times acceleration.
- For every action, there is an equal and opposite reaction.

# FAMOUS EQUATION

One of the most famous equations in mathematics comes from special relativity. The equation —  $E = mc^2$  — means "energy equals mass times the speed of light squared." It shows that energy (E) and mass (m) are interchangeable; they are different forms of the same thing.

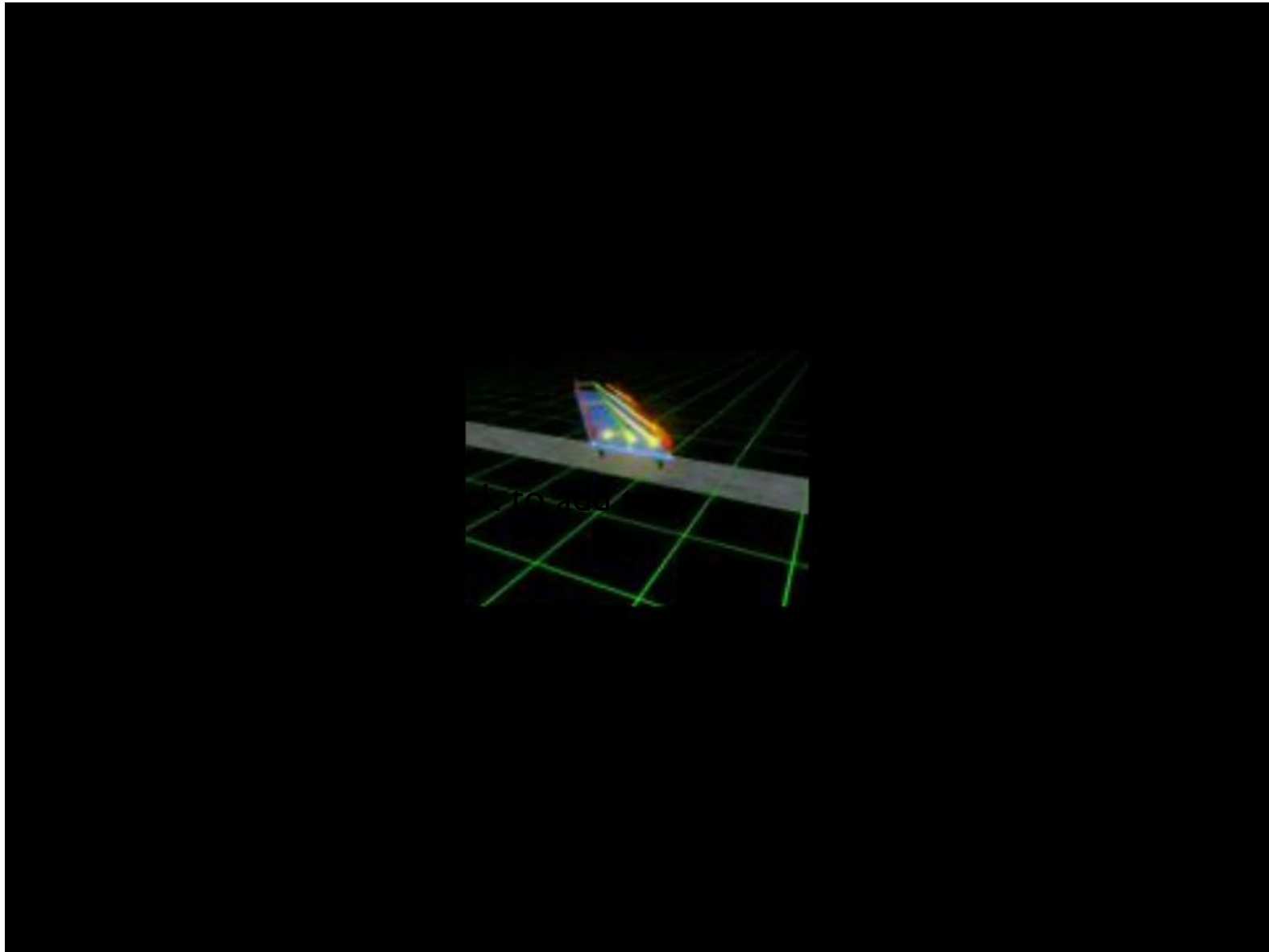
As an object moves, its mass also increases. Near the speed of light, the mass is so high that it reaches infinity, and would require infinite energy to move it, thus capping how fast an object can move. The only reason light moves at the speed it does is because photons, the quantum particles that make up light, have a mass of zero.

# TIME DILATION

- An object in motion experiences time dilation, meaning that time moves more slowly when one is moving, than when one is standing still. Therefore, a person moving ages more slowly than a person at rest
- This becomes extremely apparent at speeds approaching the speed of light. Imagine a 15-year-old traveling at 99.5 percent the speed of light for five years (from the astronaut's perspective). When the 15-year-old gets back to Earth, according to NASA, he would be only 20 years old. His classmates, however, would be 65 years old.

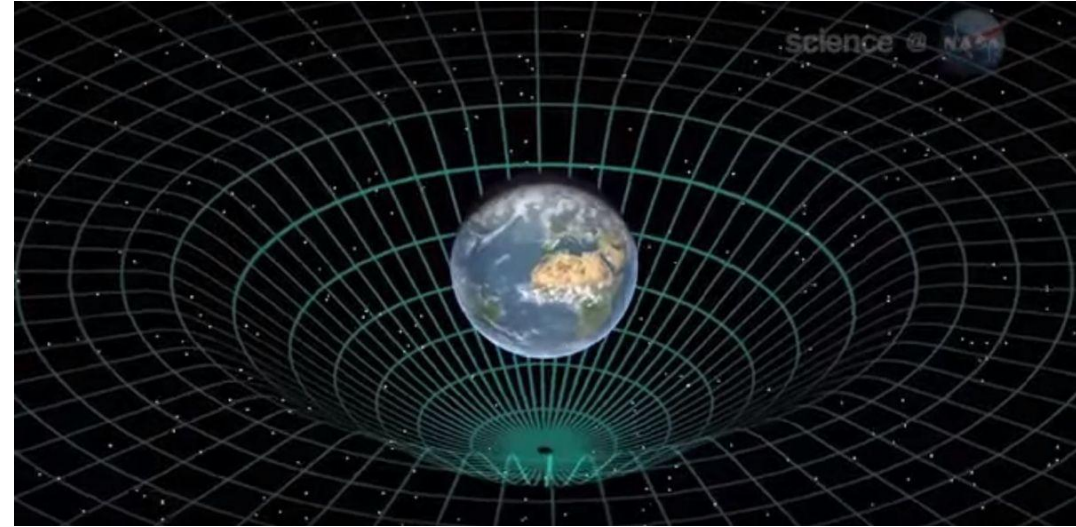
# SPECIAL RELATIVITY AND QUANTUM MECHANICS

- As our knowledge of physics has advanced, scientists have run into more counterintuitive situations. One is trying to reconcile general relativity — which describes well what's going on with large objects — with quantum mechanics, which is best used for very small things (such as uranium atom decay). The two fields, which excellently describe their individual fields, are incompatible with one another — which frustrated Einstein and generations of scientists after him.
- Relativity gives nonsensical answers when you try to scale it down to quantum size, eventually descending to infinite values in its description of gravity. Likewise, Quantum mechanics runs into serious trouble.
- Quantum fields carry a certain amount of energy, even in seemingly empty space, and the amount of energy gets bigger as the fields get bigger. According to Einstein, energy and mass are equivalent (that's the message of  $E=mc^2$ ), so piling up energy is exactly like piling up mass. Go big enough, and the amount of energy in the quantum fields becomes so great that it creates a black hole that causes the universe to fold in on itself.
- There are several ideas to overcome this. One approach is to imagine a quantum theory that would have a massless particle (called the graviton) to generate the force. But as physicist Dave Goldberg pointed out in 2013, there are problems with that. At the smallest scales, gravitons would have infinite energy density, creating an unimaginably powerful gravity field. More study will be required to see if this is possible.

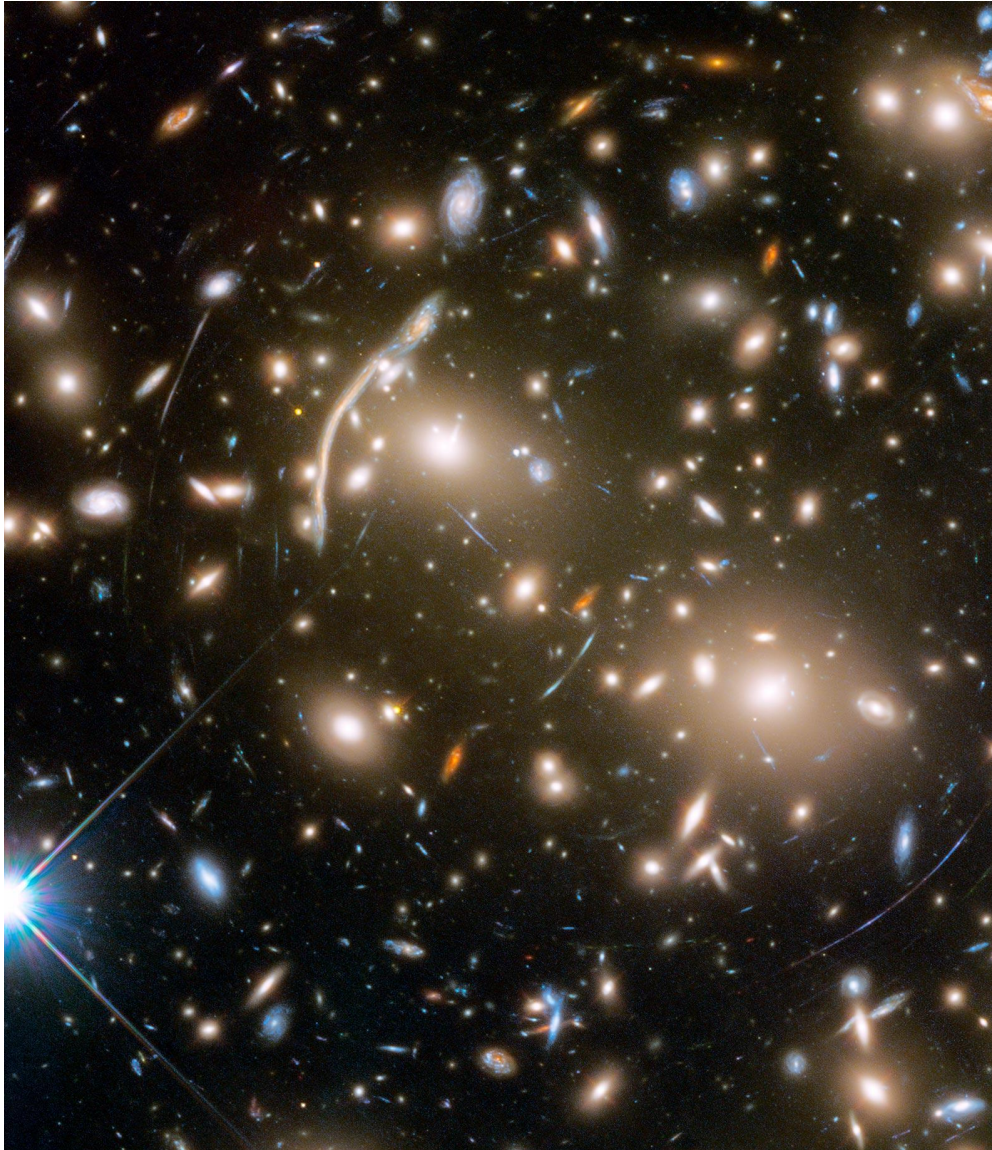


<https://www.youtube.com/watch?v=C2VMO7pcWhg>

# GENERAL RELATIVITY



- Einstein realized that massive objects caused a distortion in space-time. Imagine setting a large body in the center of a trampoline. The body would press down into the fabric, causing it to dimple. A marble rolled around the edge would spiral inward toward the body, pulled in much the same way that the gravity of a planet pulls at rocks in space.



Gravitational lensing

## EXPERIMENTAL EVIDENCE

- Gravitational lensing: Light around a massive object, such as a black hole, is bent, causing it to act as a lens for the things that lie behind it. Astronomers routinely use this method to study stars and galaxies behind massive objects.
- Changes in the orbit of Mercury: The orbit of Mercury is shifting very gradually over time, due to the curvature of space-time around the massive sun. In a few billion years, it could even collide with Earth.
- Frame-dragging of space-time around rotating bodies: The spin of a heavy object, such as Earth, should twist and distort the space-time around it.
- Gravitational redshift: The electromagnetic radiation of an object is stretched out slightly inside a gravitational field. Think of the sound waves that emanate from a siren on an emergency vehicle; as the vehicle moves toward an observer, sound waves are compressed, but as it moves away, they are stretched out, or redshifted
- Gravitational waves: Violent events, such as the collision of two black holes, are thought to be able to create ripples in space-time known as gravitational waves.