Einstein's Relativity

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Early Life

Born in 1879 in Germany, Einstein enrolls in the Zurich Polytechnic Institute in Switzerland in 1896.

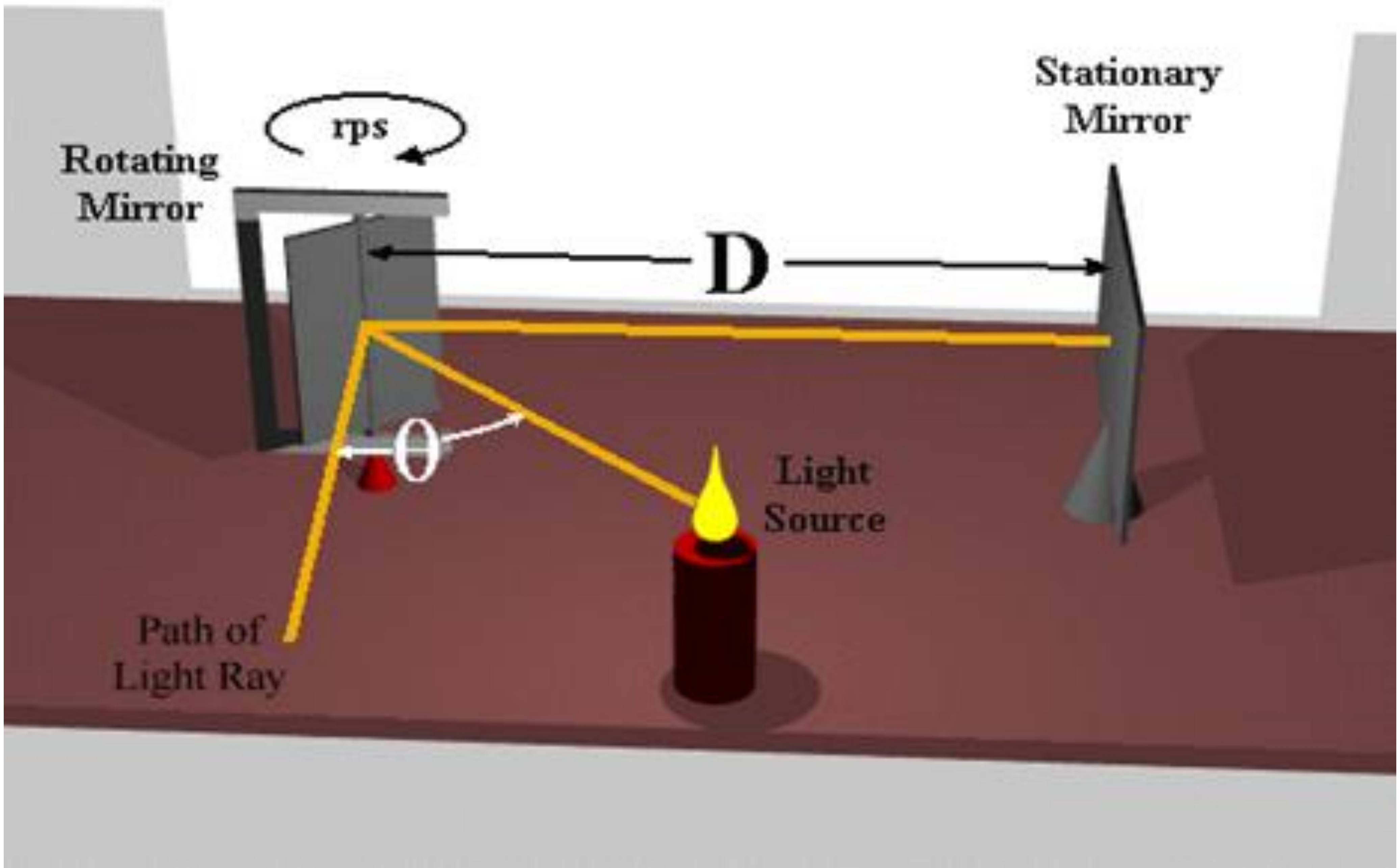
He gets a job in a Swiss patent office in 1902 and publishes 4 seminal papers in 1905 including a paper proposing special relativity.

Why did Einstein make special relativity?

The speed of light had been measured

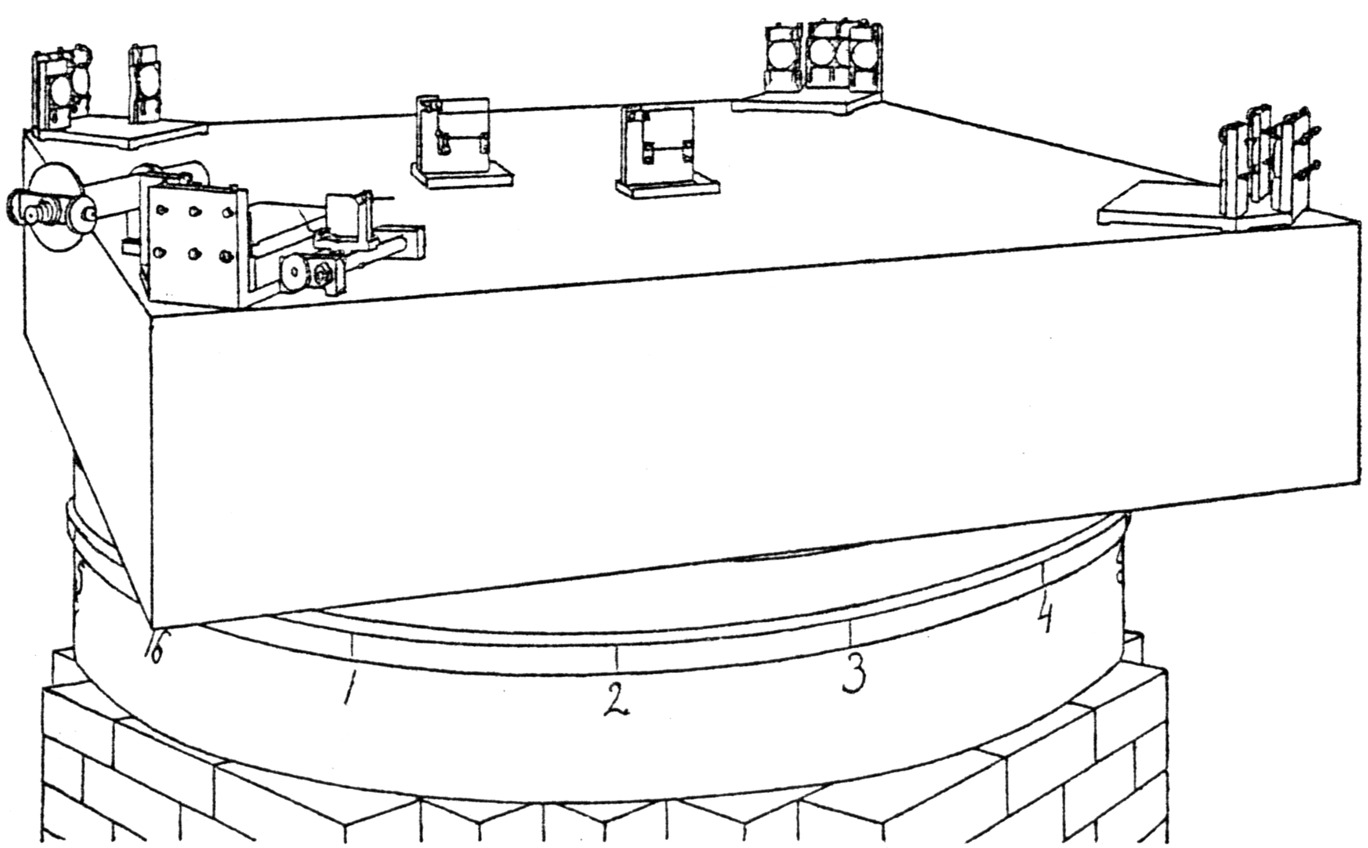
Galileo tried to measure it in 1638
"at least 10 times the speed of sound"

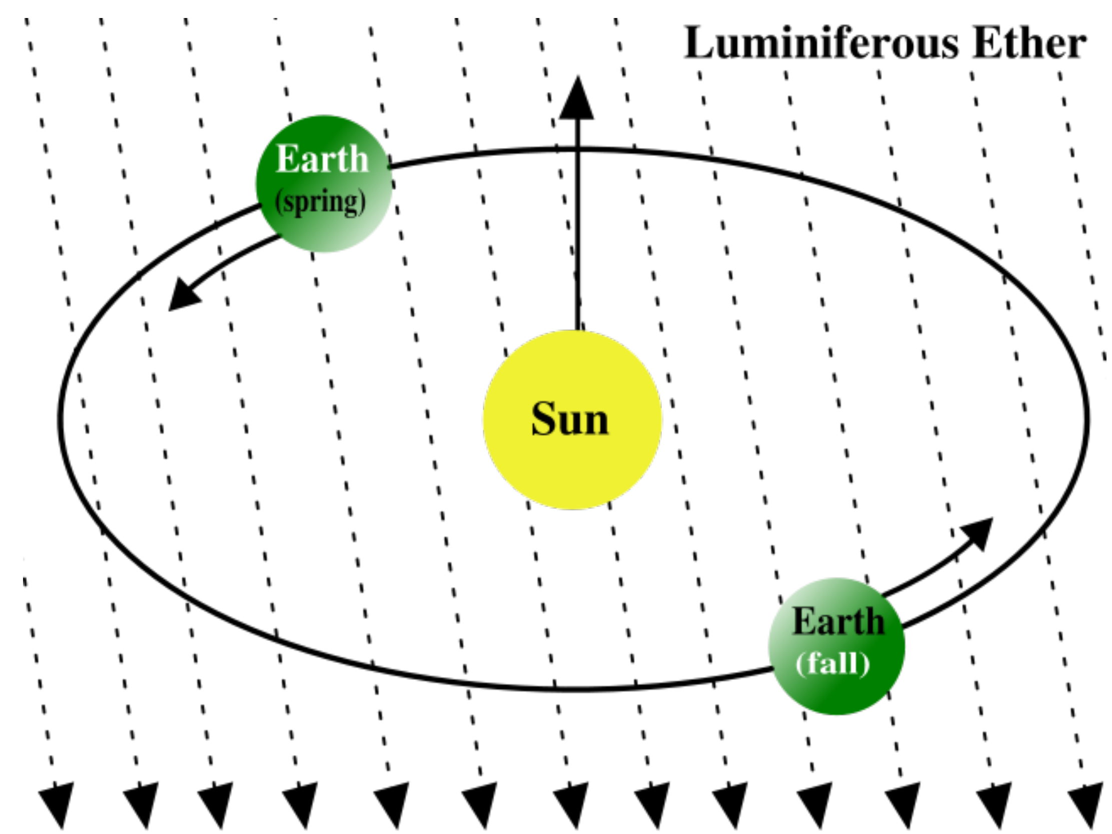
1862 Foucalt gets within 0.0002% of the modern value



Michelson and Morley Experiment

In 1887 Michelson and Morley tried to see if the speed of light was different in different directions





After all, the earth travels around the sun so we should be able to detect this motion

How could these two observations be resolved?

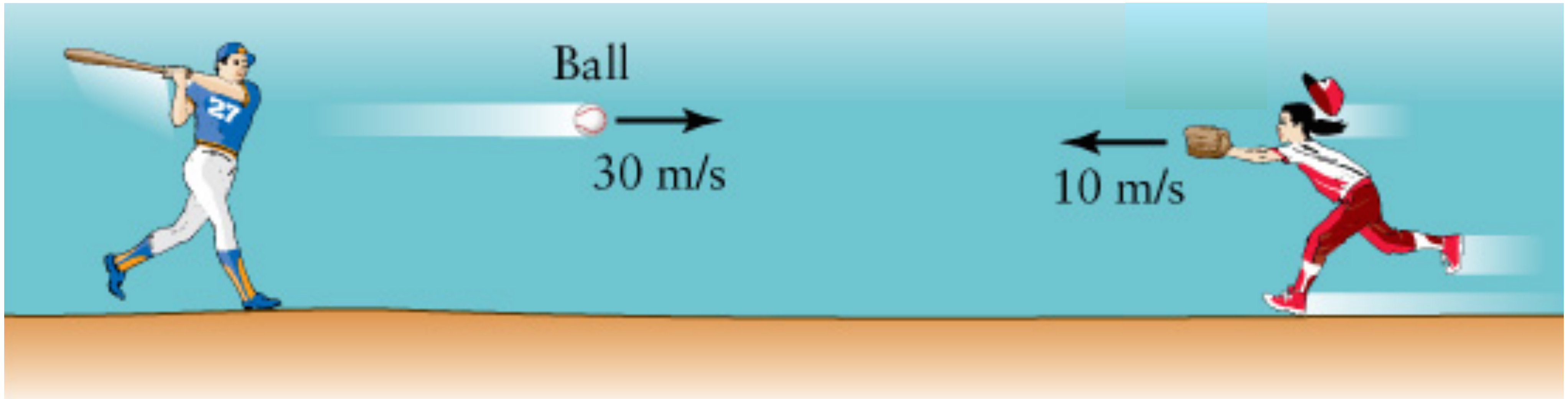
In 1905 Einstein simply said both were right. He made two statements

1. The speed of light is finite and measured.
2. All experiments carried out at constant velocity get the same answers to to measurements.

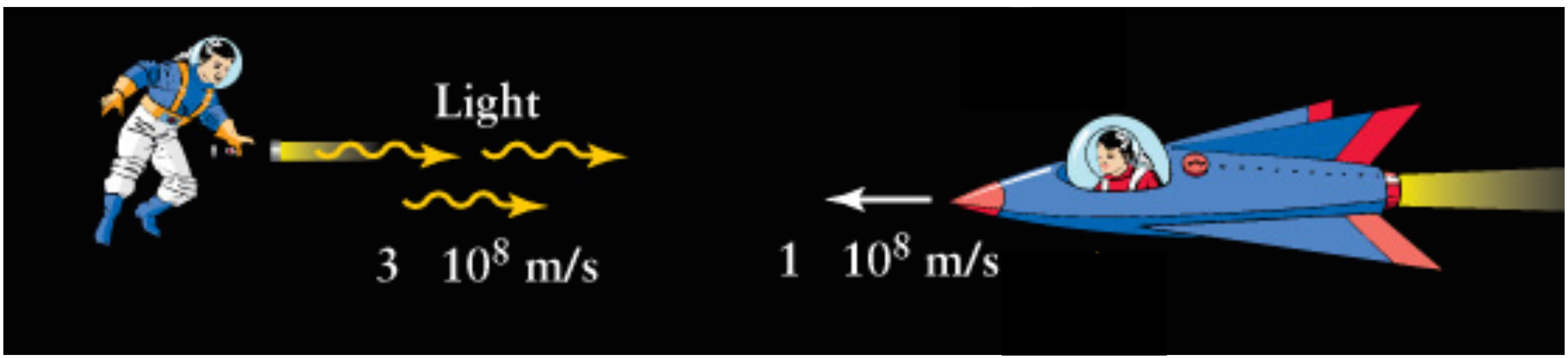
Pouring drinks in an airplane

The flight attendant is going to pour the red wine from the bottle to the glass. Both the bottle and the glass are going 550 MPH to the left. The glass will have moved 800 feet to the left by the time the wine gets down to the glass. The wine will end up on the guy's shirt??

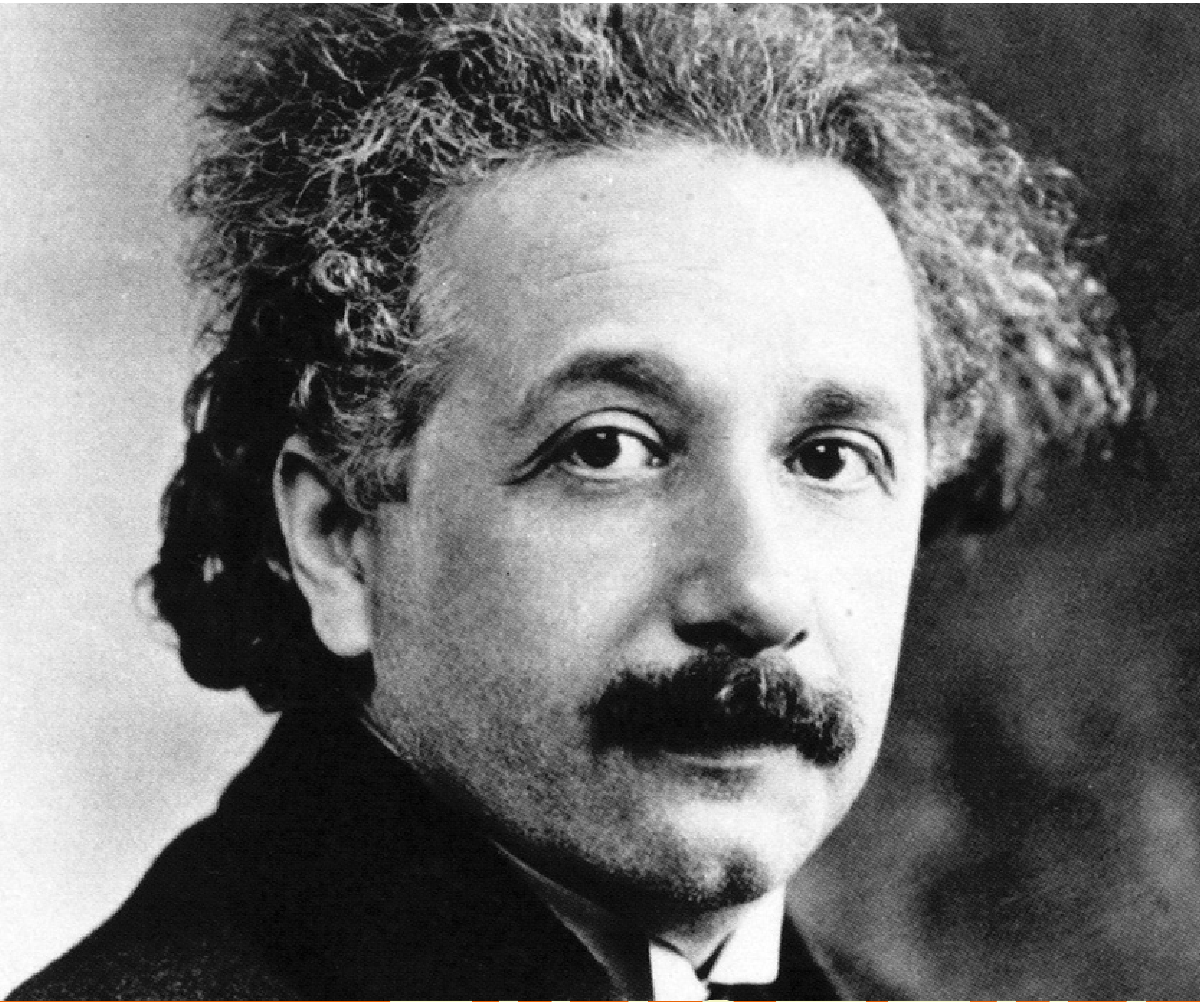
Wait, what?



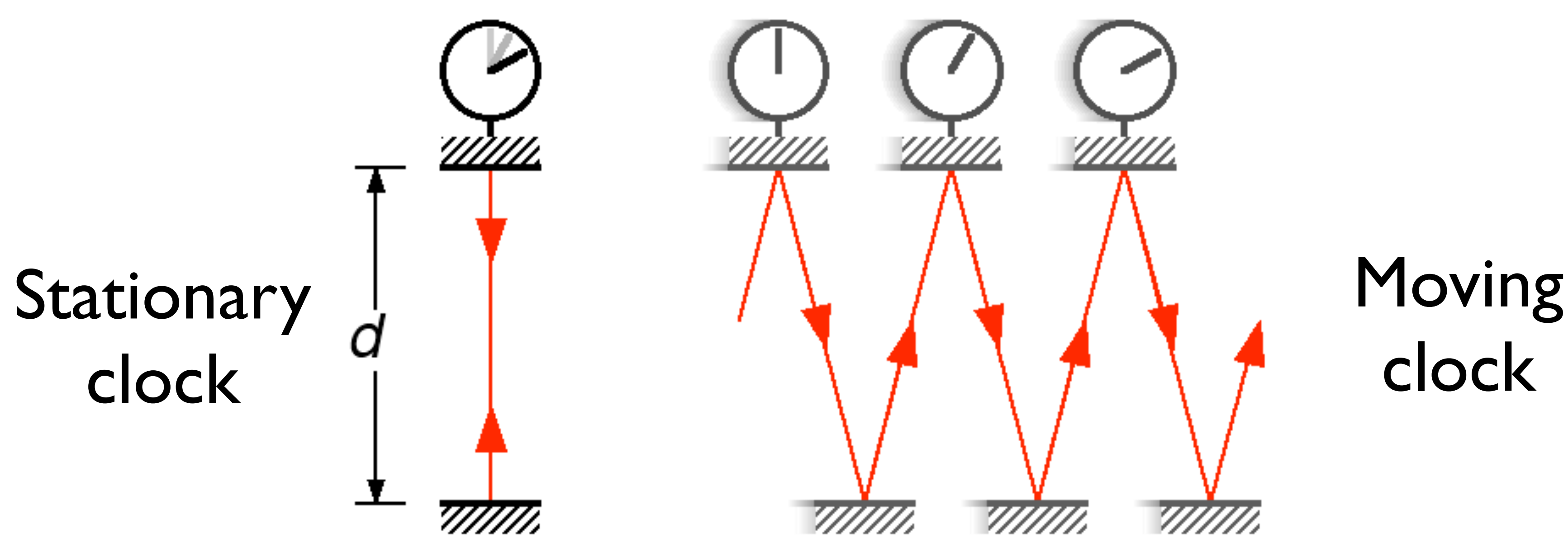
If the fielder runs towards the batter, he should see the ball approaching him faster, right? Right!



For things moving very fast, the normal rules do not hold. The speed of the light the pilot sees is the speed of light.



Einstein explained this apparent impossibility but thinking very carefully about what it meant to measure time and length. He realized that the astronaut and pilot will not measure time the same way.

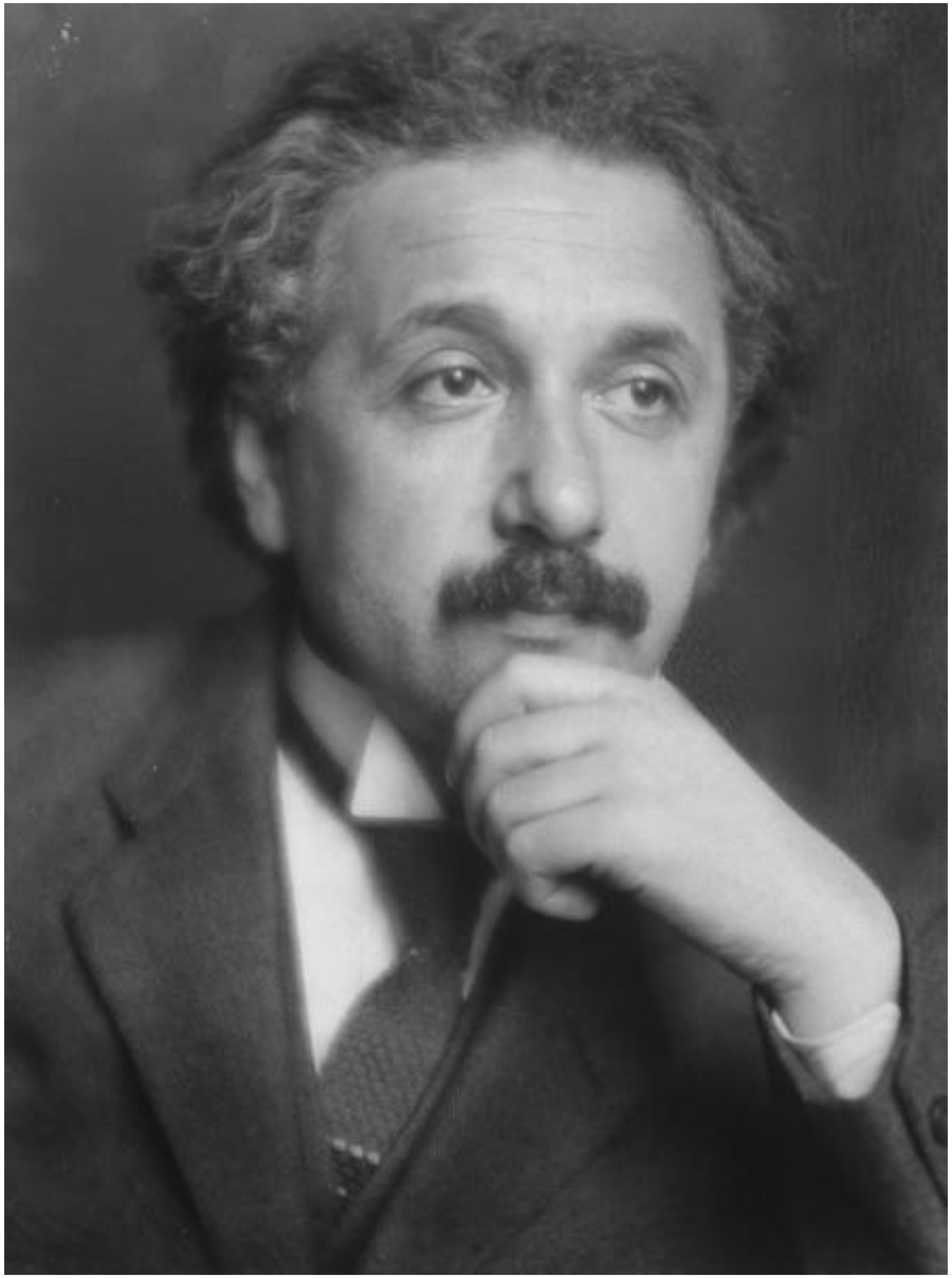


This results in a self-consistant theory that explains all experiments we have done so far.

- Time dilation has been measured, clocks work the way Einstein said.
- Another prediction is that the masses appear larger for systems moving fast relative to us. This has also been confirmed experimentally.

Scientists are always looking for experimental evidence that relativity is wrong or has a problem. None found so far!

Einstein's next years



Einstein in 1921

In 1915, Einstein publishes his work on General Relativity.

In 1919 Sir Arthur Eddington confirms Einstein's prediction that light should be bent by a gravitational field.

1921 Einstein get the Nobel Prize - but not for relativity!

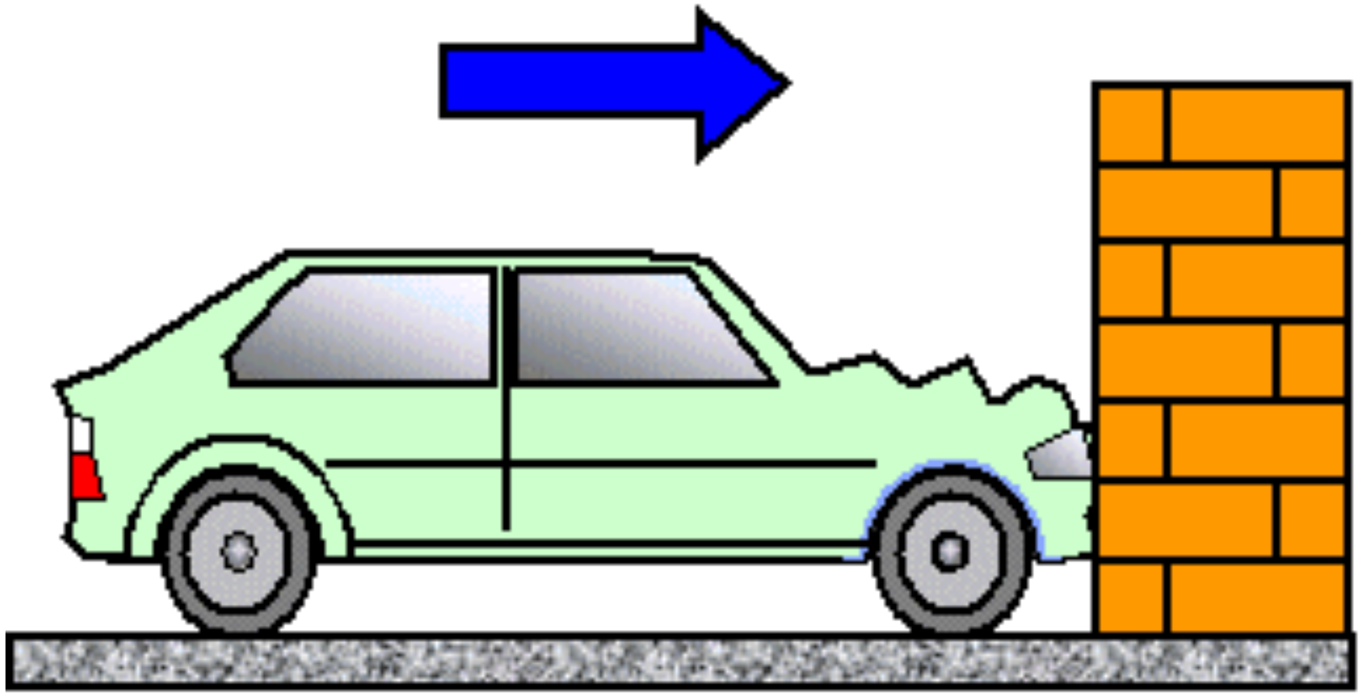
How did Einstein predict the bending of light?

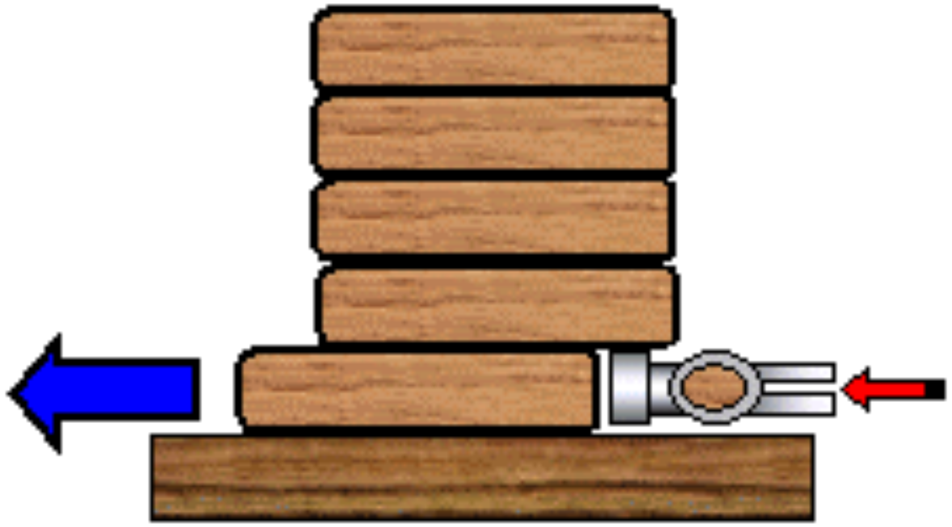
Again, he worked with a curious fact that many had puzzeled over but no one had been able to explain.

There are two very different places where the concept of mass is used:

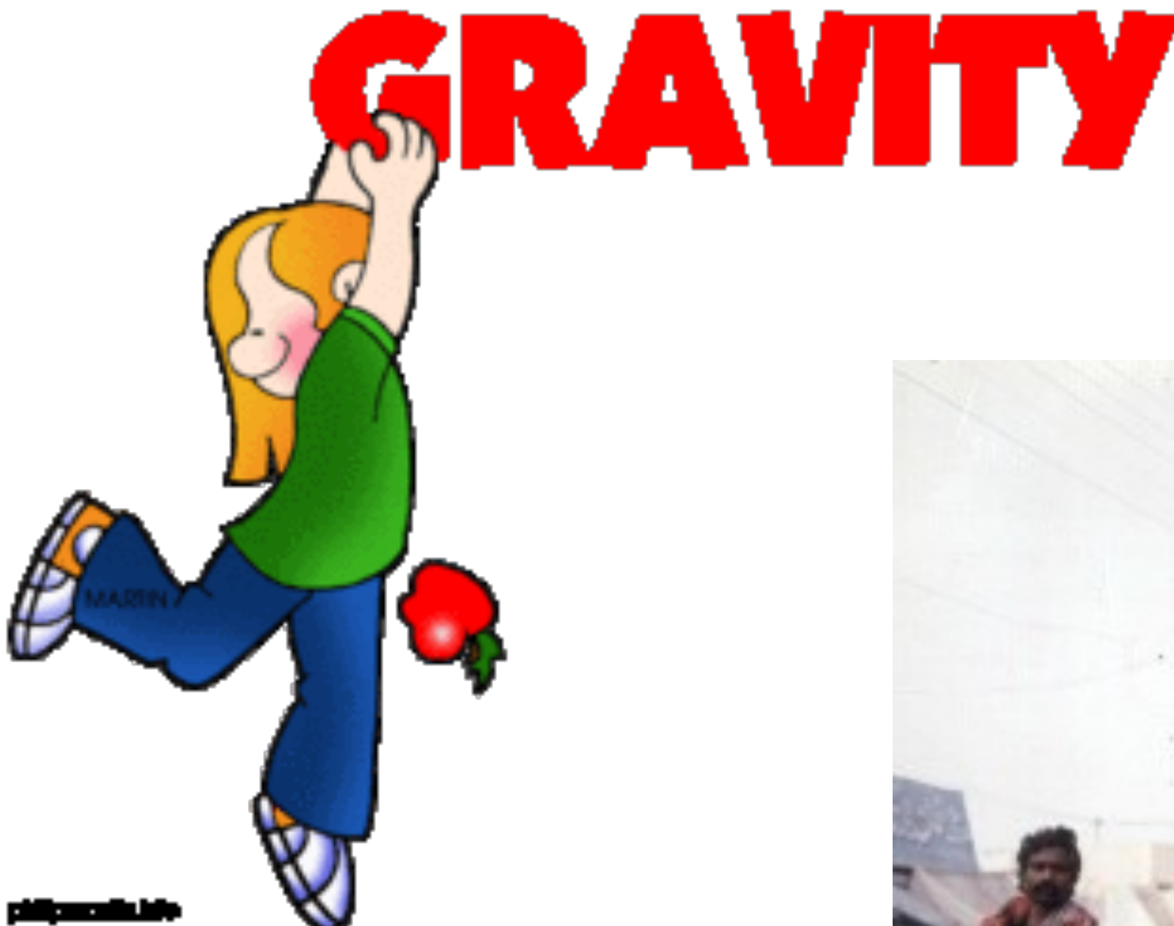
1. Inertial mass. How hard is it to get something moving or slowed down once it is moving.
2. Gravitational mass. How hard does the earth pull on something.

Inertial mass





Gravitational mass



The mystery is that these two kinds of mass are *EXACTLY* the same

In 1589 Galileo (again) famously measured the speed of two different masses getting dropped from the leaning tower of Pisa.

This went counter to Aristotle's idea that the heaver should fall faster.

August 2, 1971

The fact that all objects fall at the same speed is due to the fact that the gravitational mass and the inertial mass are the same. This experiment has now been done with enourmous precision: Better than 1 part in 10^{17}.

So what did Einstein say?

He simply stated that they *ARE* the same thing. Gravity is acceleration.

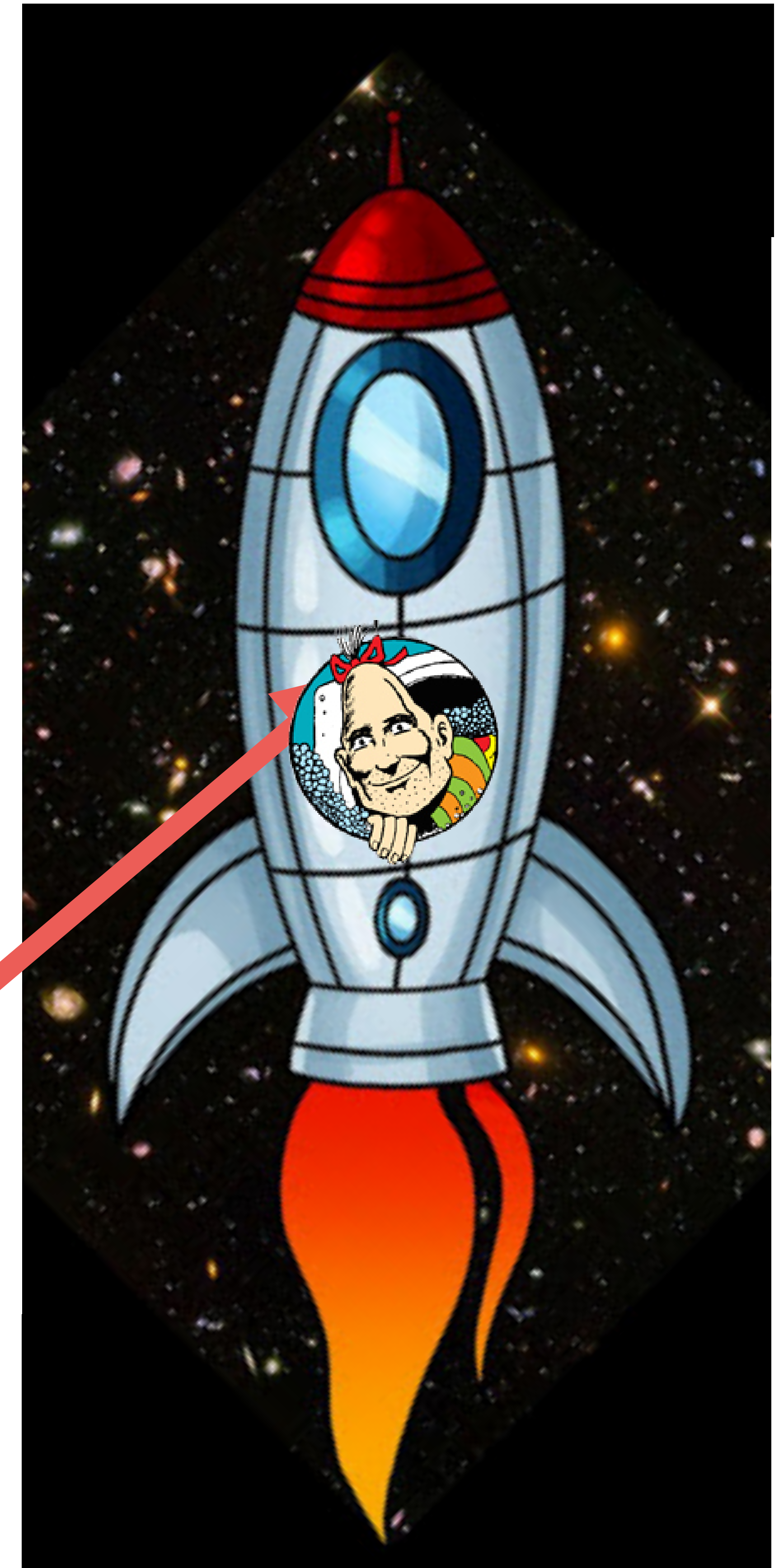
This is pretty similar to what he did to come up with special relativity. This one resulted in even more apparent contradictions. Again he just thought them through.

What is he talking about?

Einstein did what is called a thought experiment.

He imagined a person in an enclosed lab who could not look out through a window but could do any imaginable internal experiment.

How could they figure out if the lab were sitting on the earth or accelerating in space?

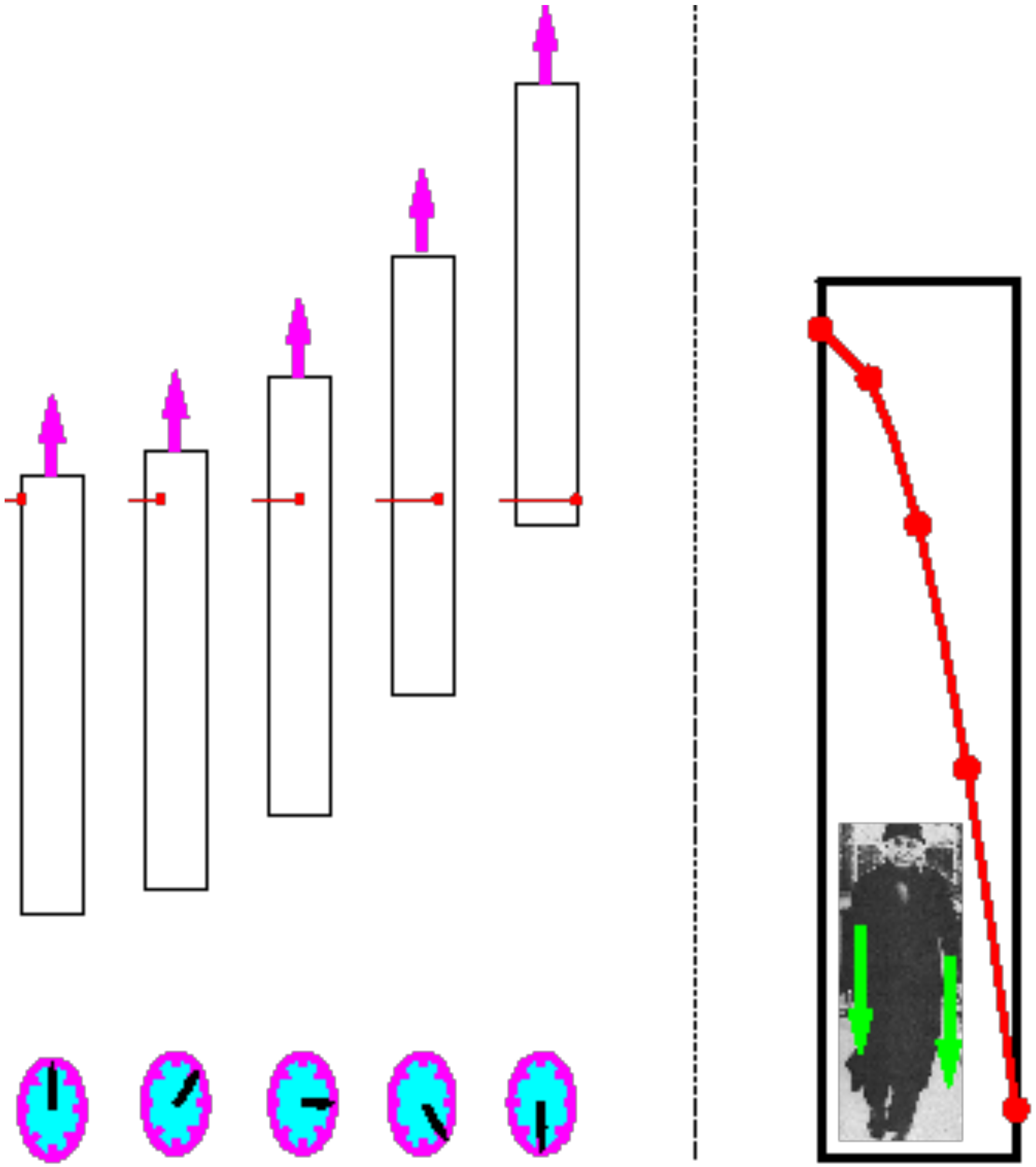


Both feel the push downward

The Little Prince is being held to the planet by his gravitational mass, just like we are held down to the earth.

But for Zippy, it is clearly "inertial mass" that is pushing him down.

In an accelerating rocket we expect light to bend



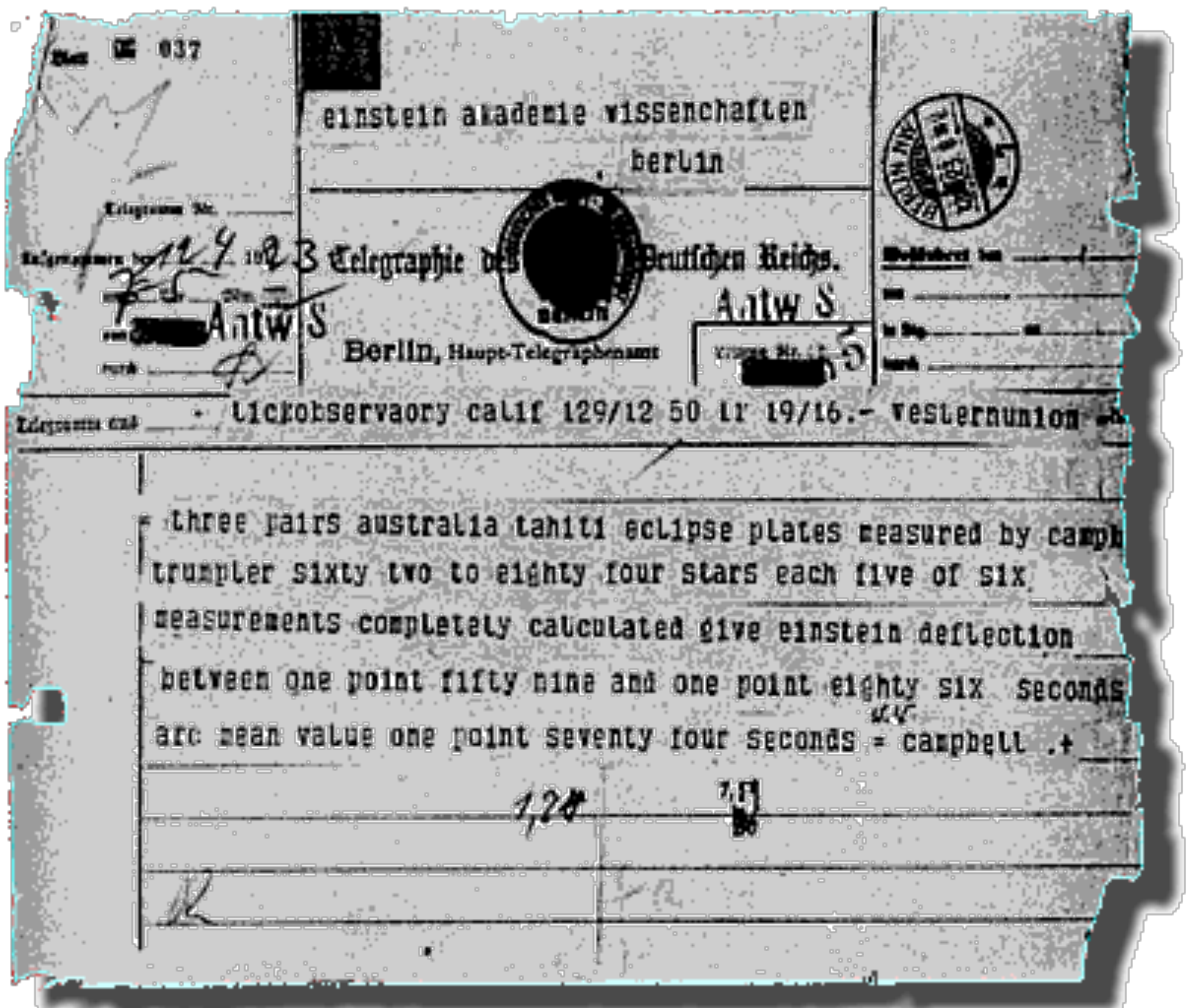
Viewed by stationary observer

viewed from inside the rocket

As the rocket accelerates upward, the guy inside the rocket lab sees he light deflect to the floor.

Because Einstein said that the rocket lab was EXACTLY the same as standing on the planet, light must bend when going around the planet.

This was his prediction and in 1919, Eddington measured the effect.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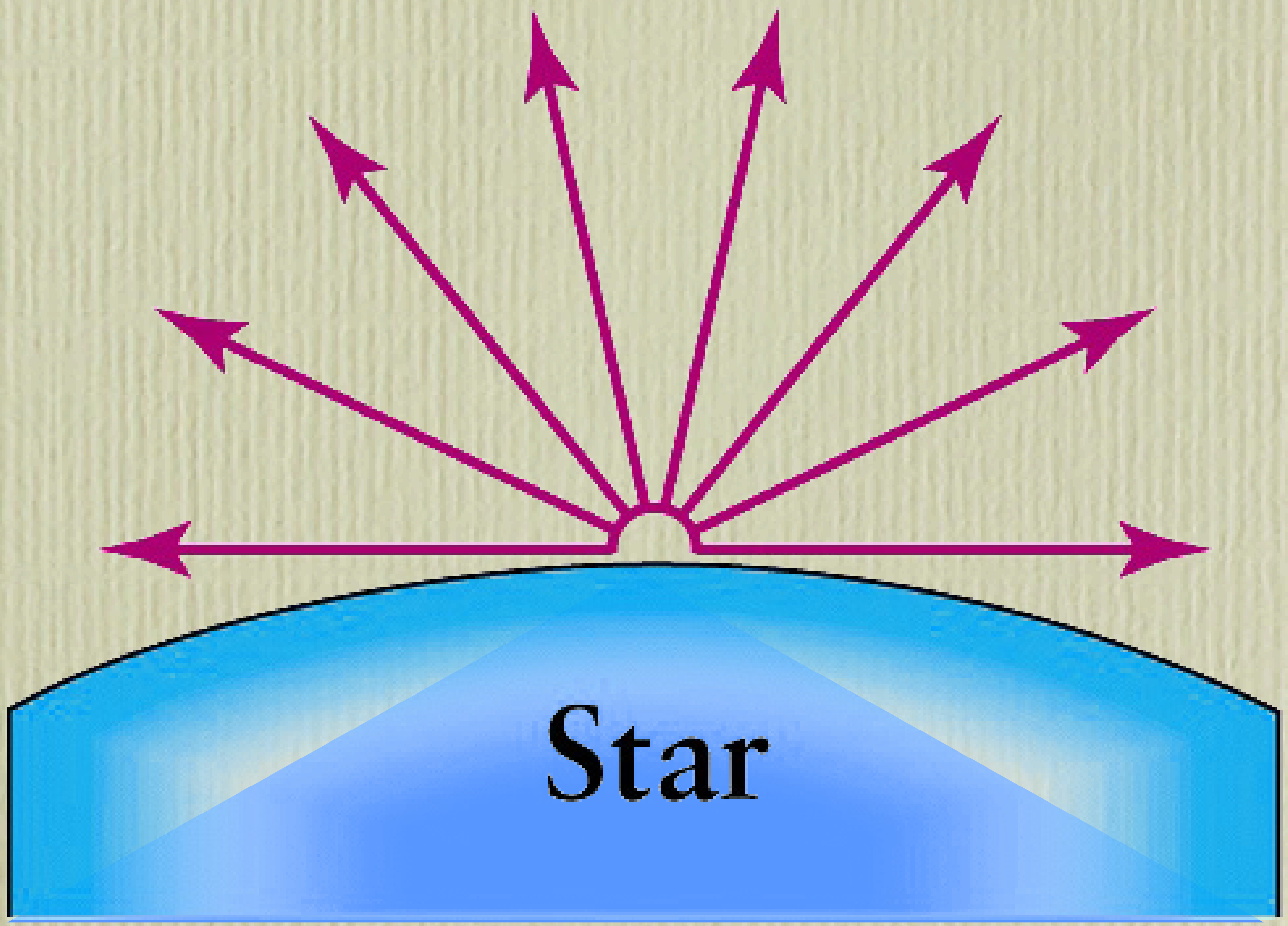
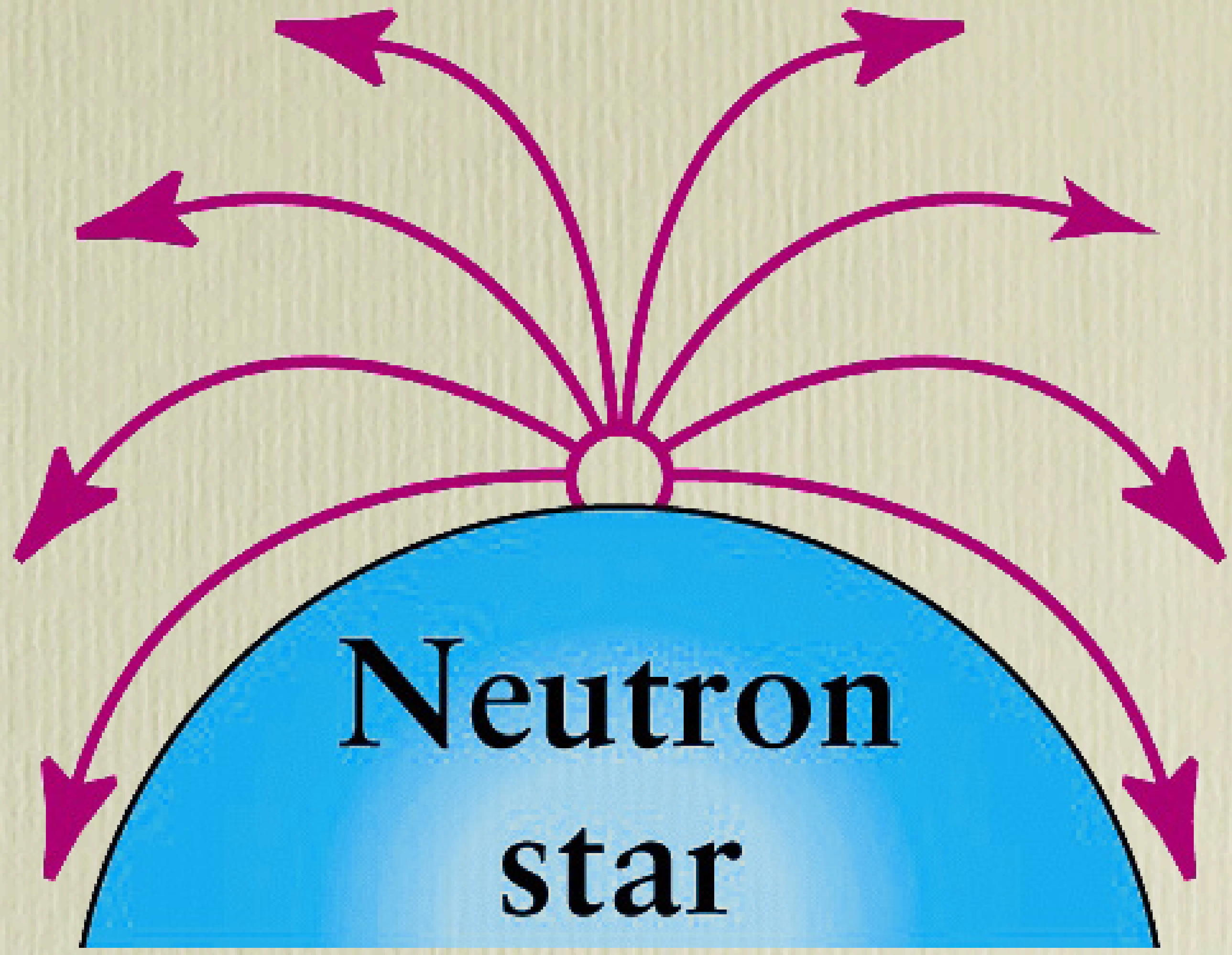
berlin
Telegraphie des Deutschen Reichs.
Antw S
Berlin, Haupt-Telegraphenamt
lickobservaory calif 129/12 50 lr 19/16.- westernunion
three pairs australia tahiti eclipse plates measured by camp
trumpler sixty two to eighty four stars each five of six
measurements completely calculated give einstein deflection
between one point fifty nine and one point eighty six seconds
arc mean value one point seventy four seconds = campbell .+

Telegram from Eddington to Einstein telling him that the bending of light had been measured.

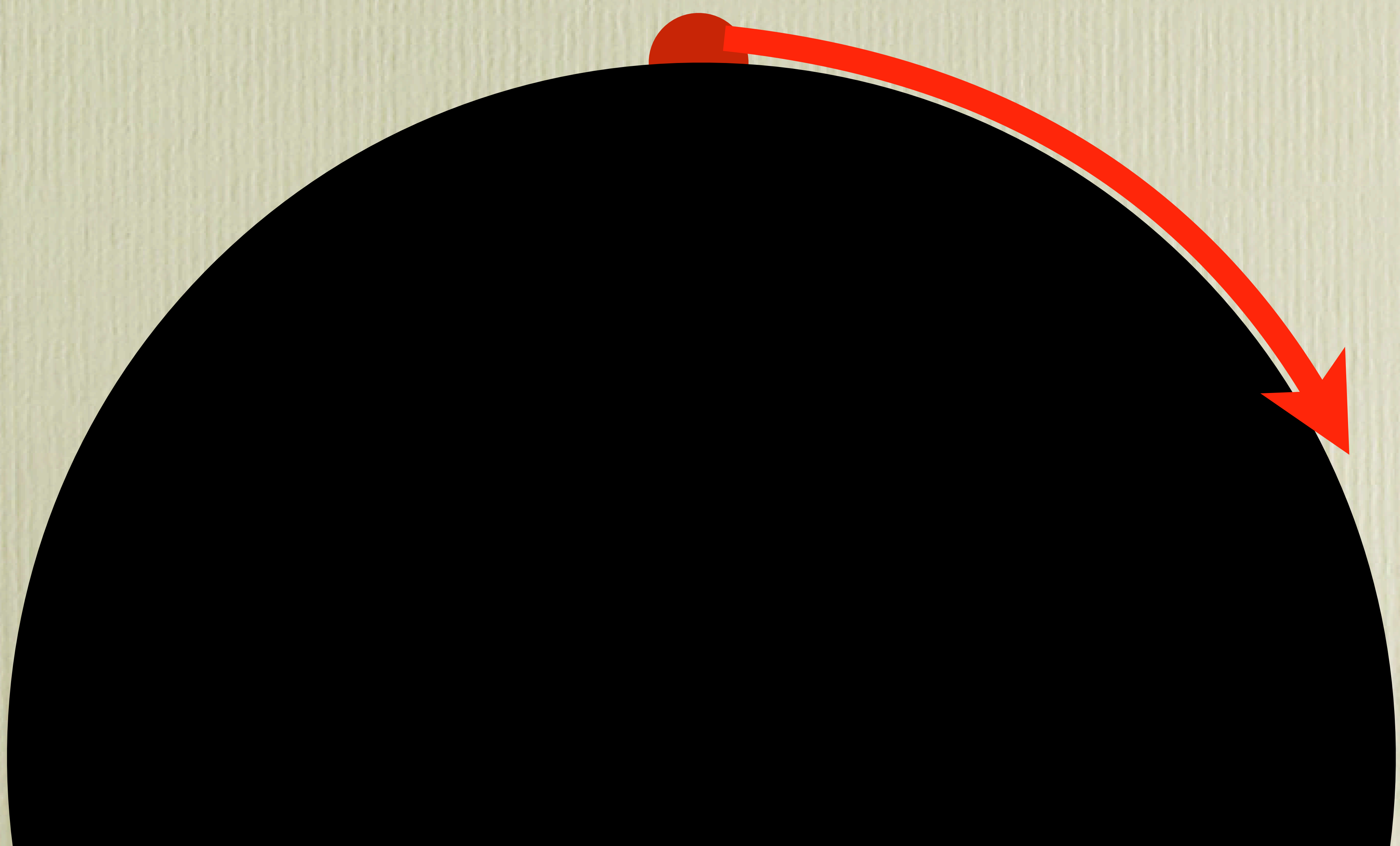


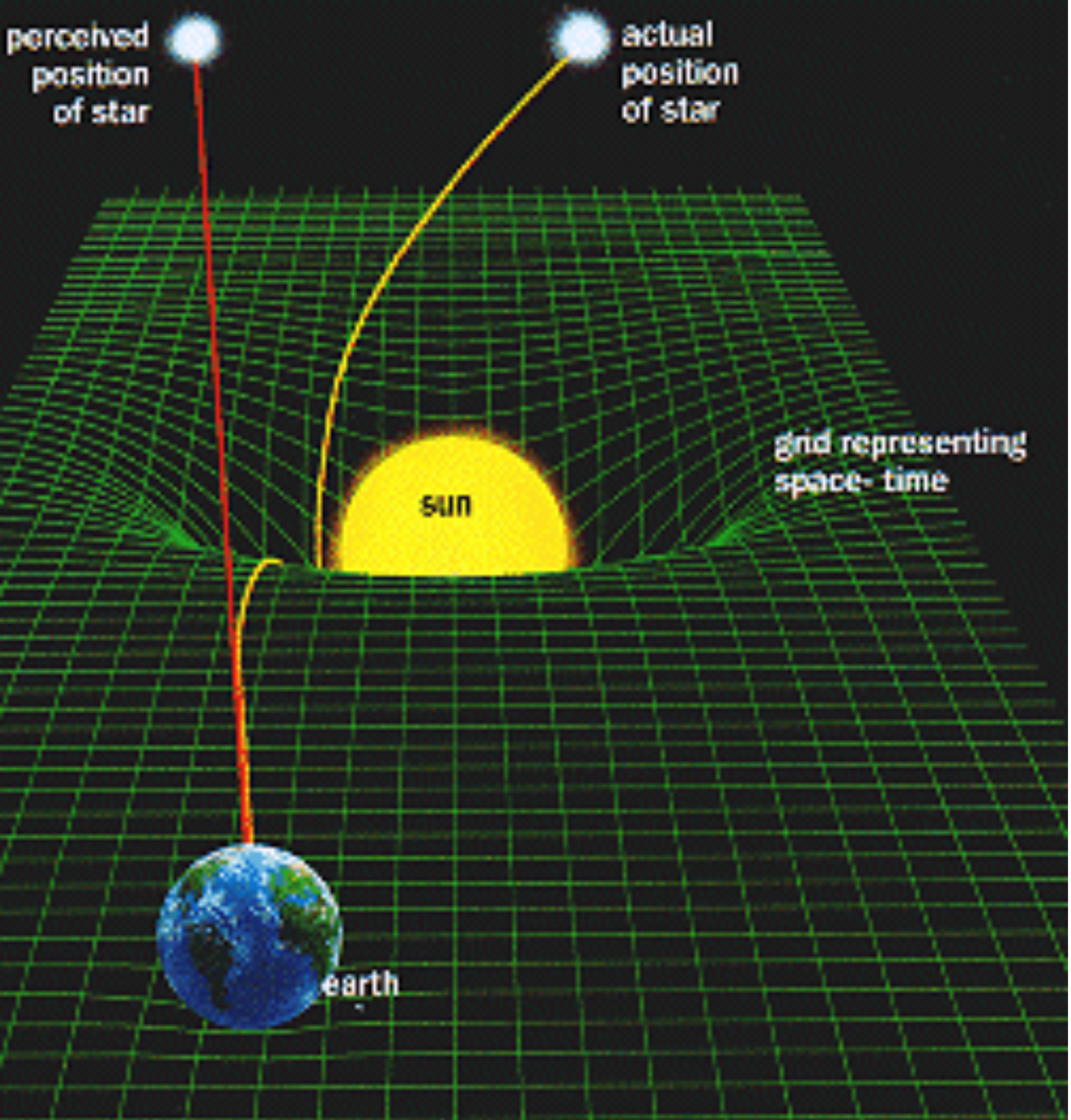
A star bends the light a little.



A neutron star bends the light a little more.

For a black hole, the light orbits right at the surface.

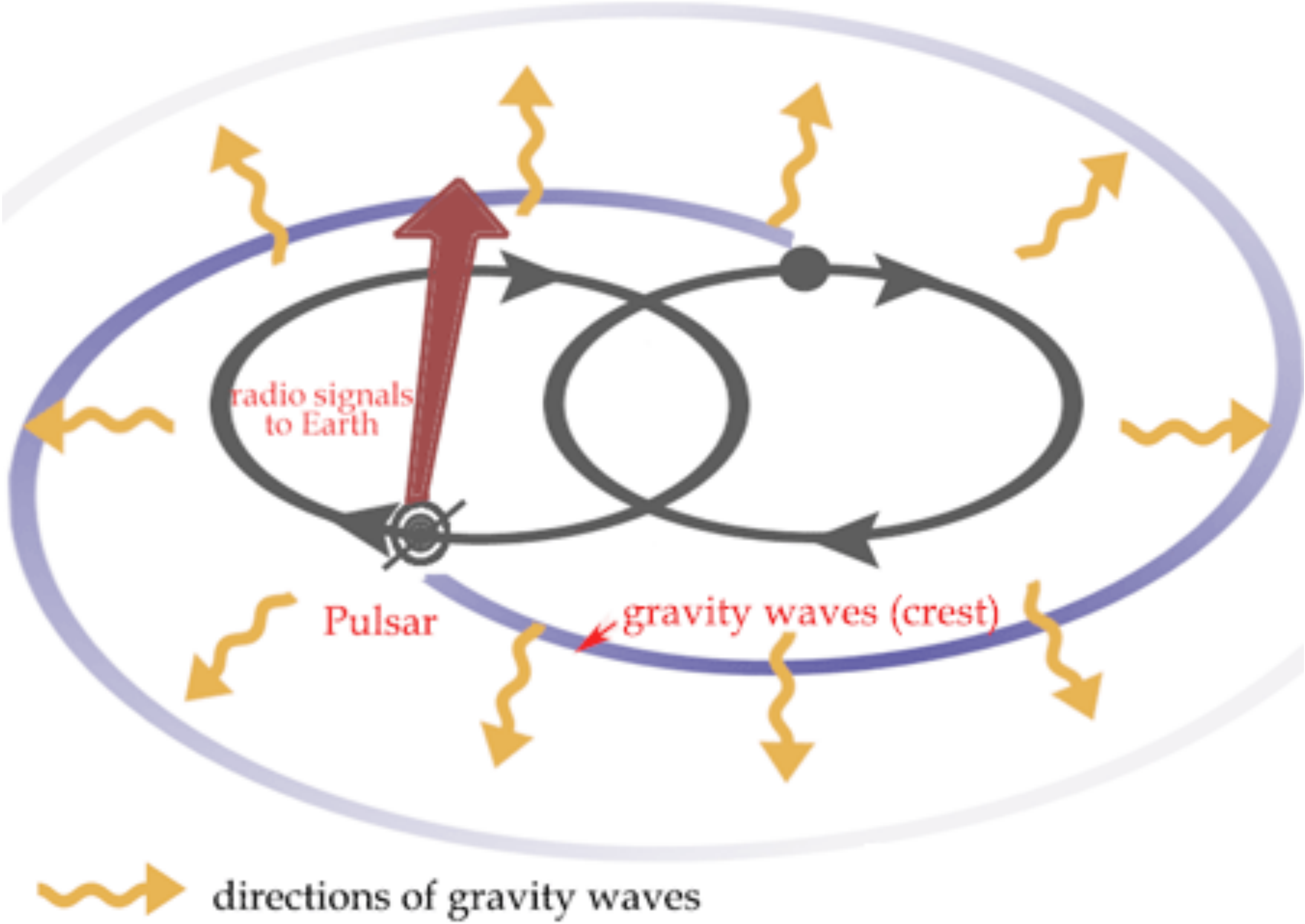




As shown here the idea is that it is space itself that is bent by the presence of the sun and the light follows a straight path in the curved space.

The next step

The idea of a curved, dynamical space (reacts to the things in it) opens the door to the possibility of waves in the spacetime itself - gravitational waves.

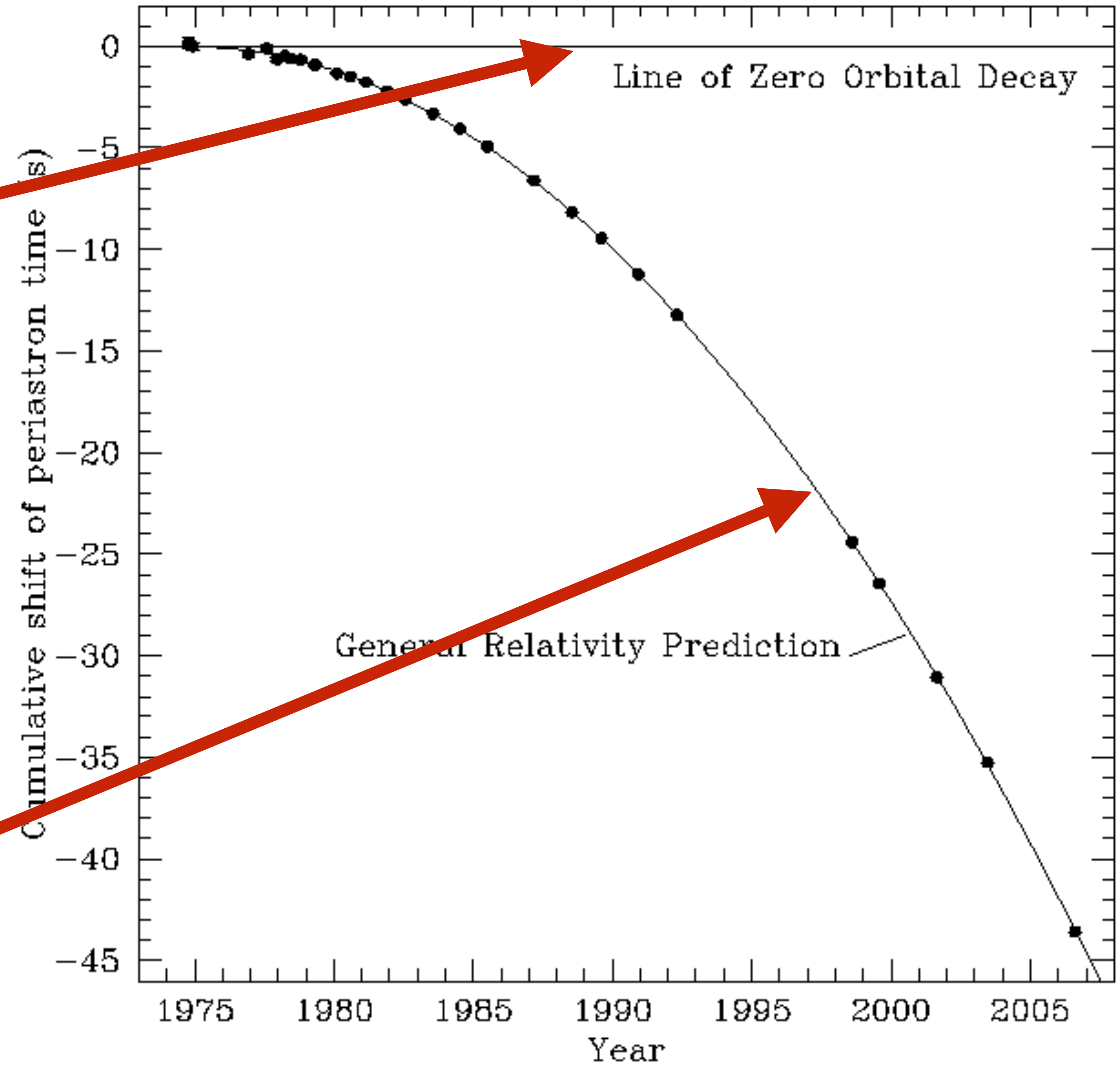

radio signals
to Earth
Pulsar
gravity waves (crest)
directions of gravity waves

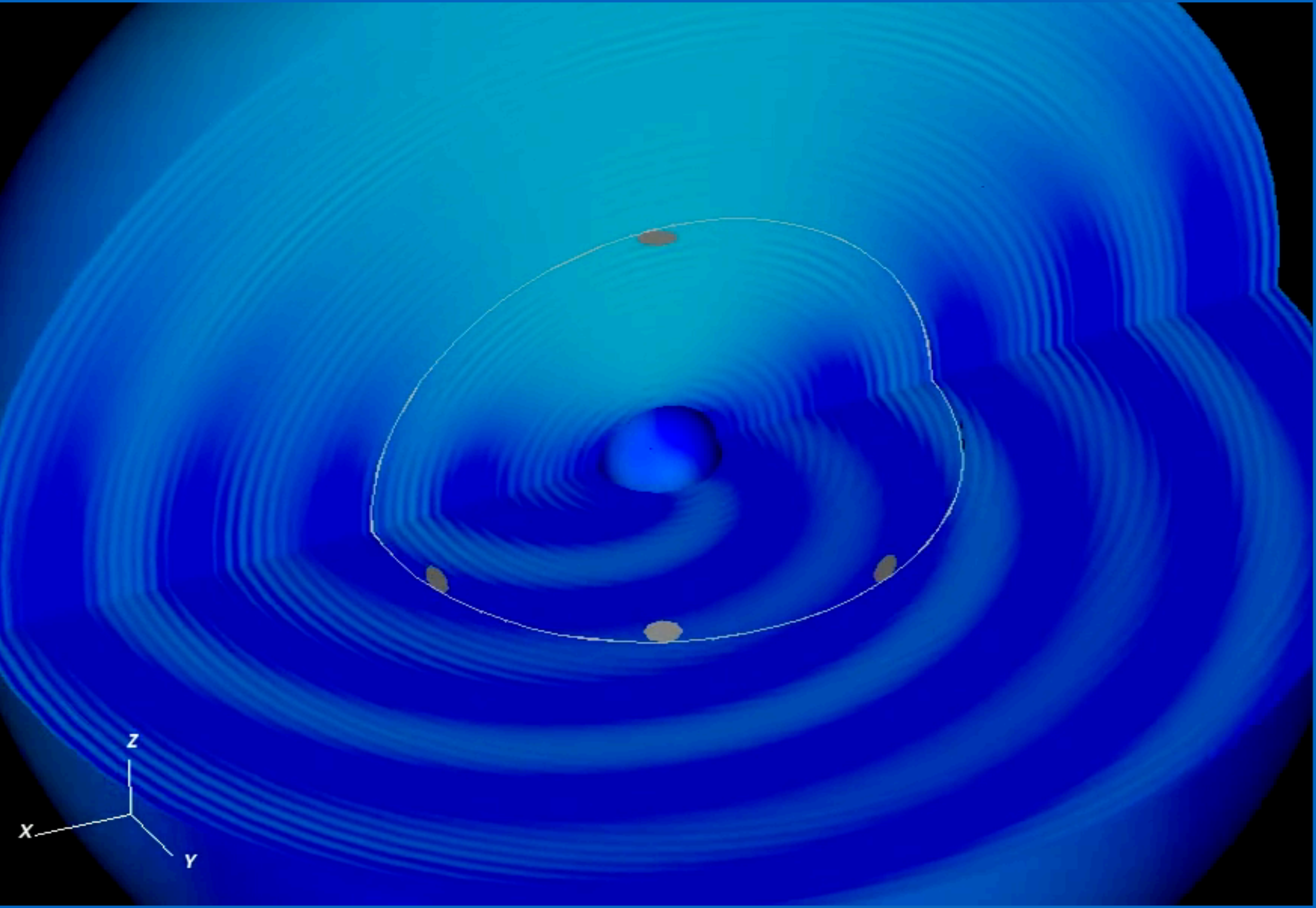
The changing of the period of the Hulse-Taylor pulsar.

When the pulsar was found to be orbiting another object, in 1974, the classic prediction was that the period would stay constant

However, the period keeps getting shorter - indicating that the objects are getting closer together - the system is losing energy.

The data fall exactly on the prediction for gravitational waves.

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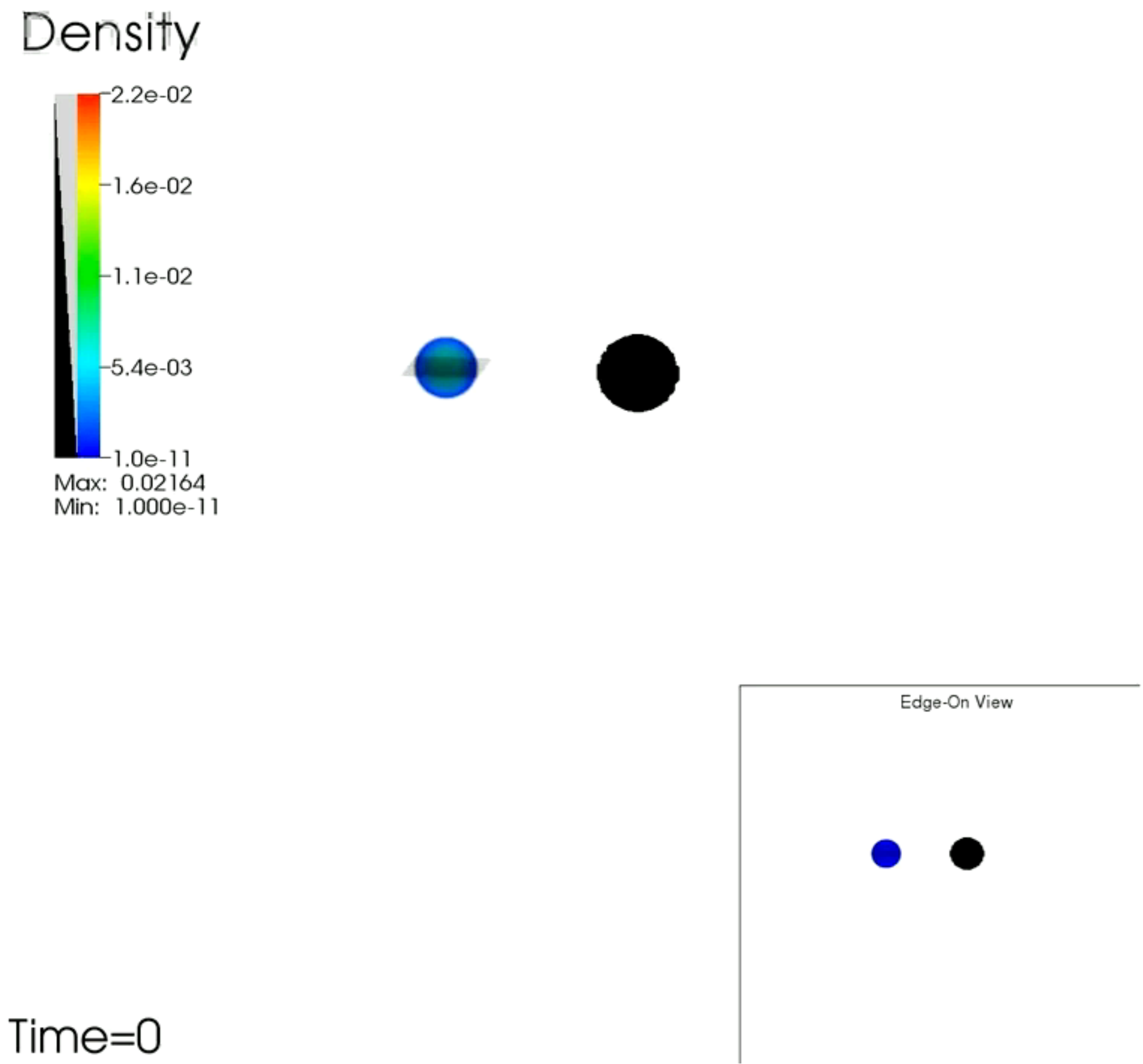
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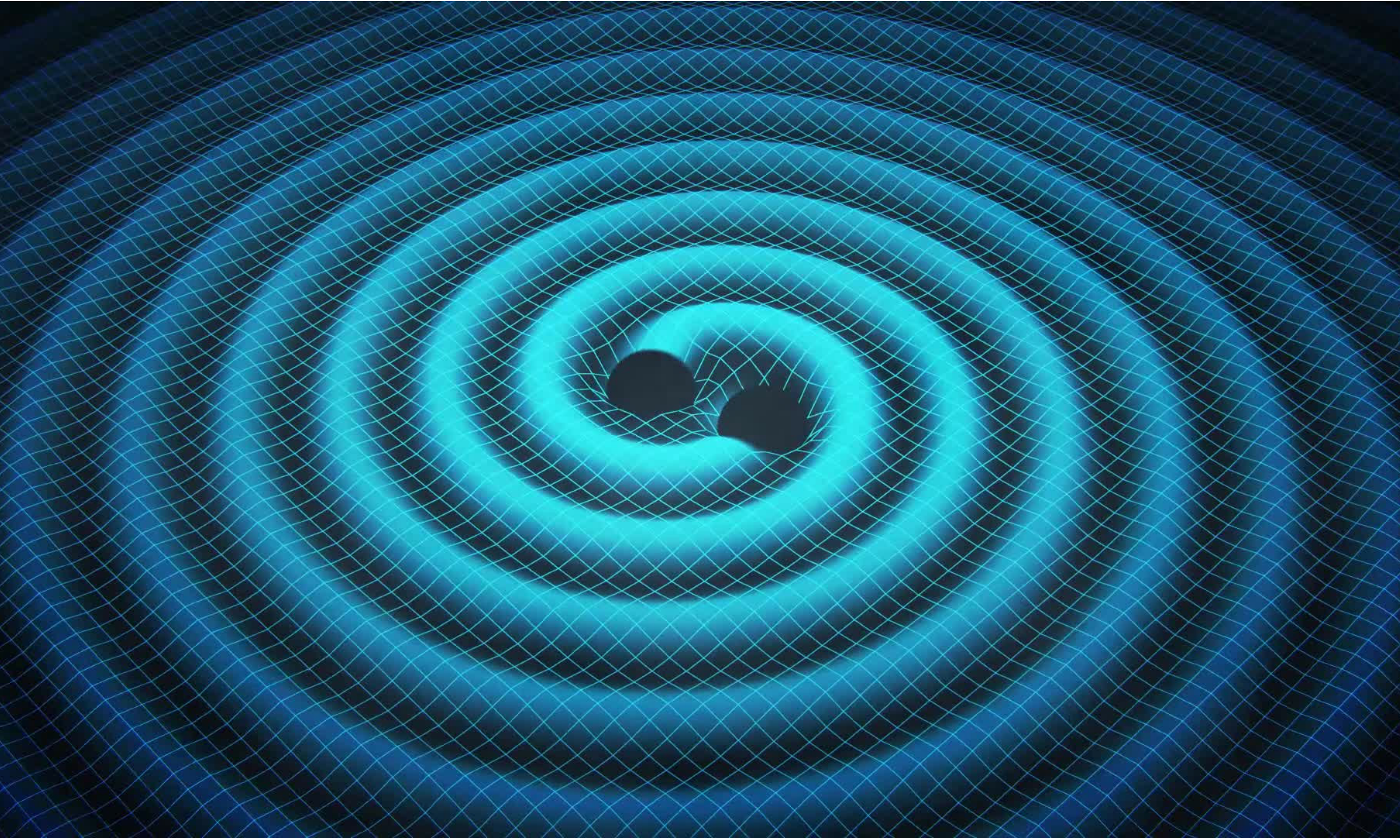
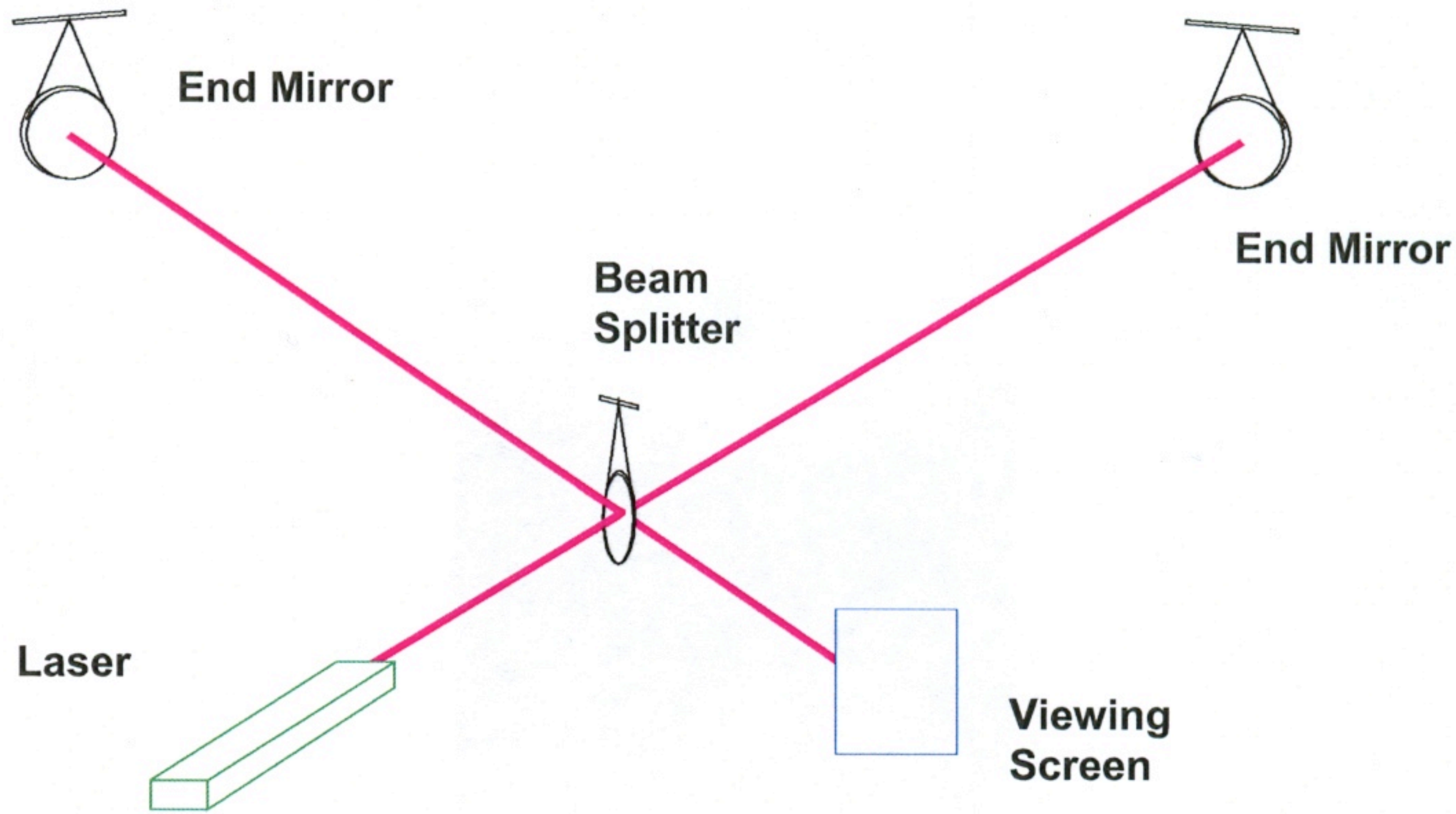


Two massive objects orbiting each other are thought to emit gravitational waves.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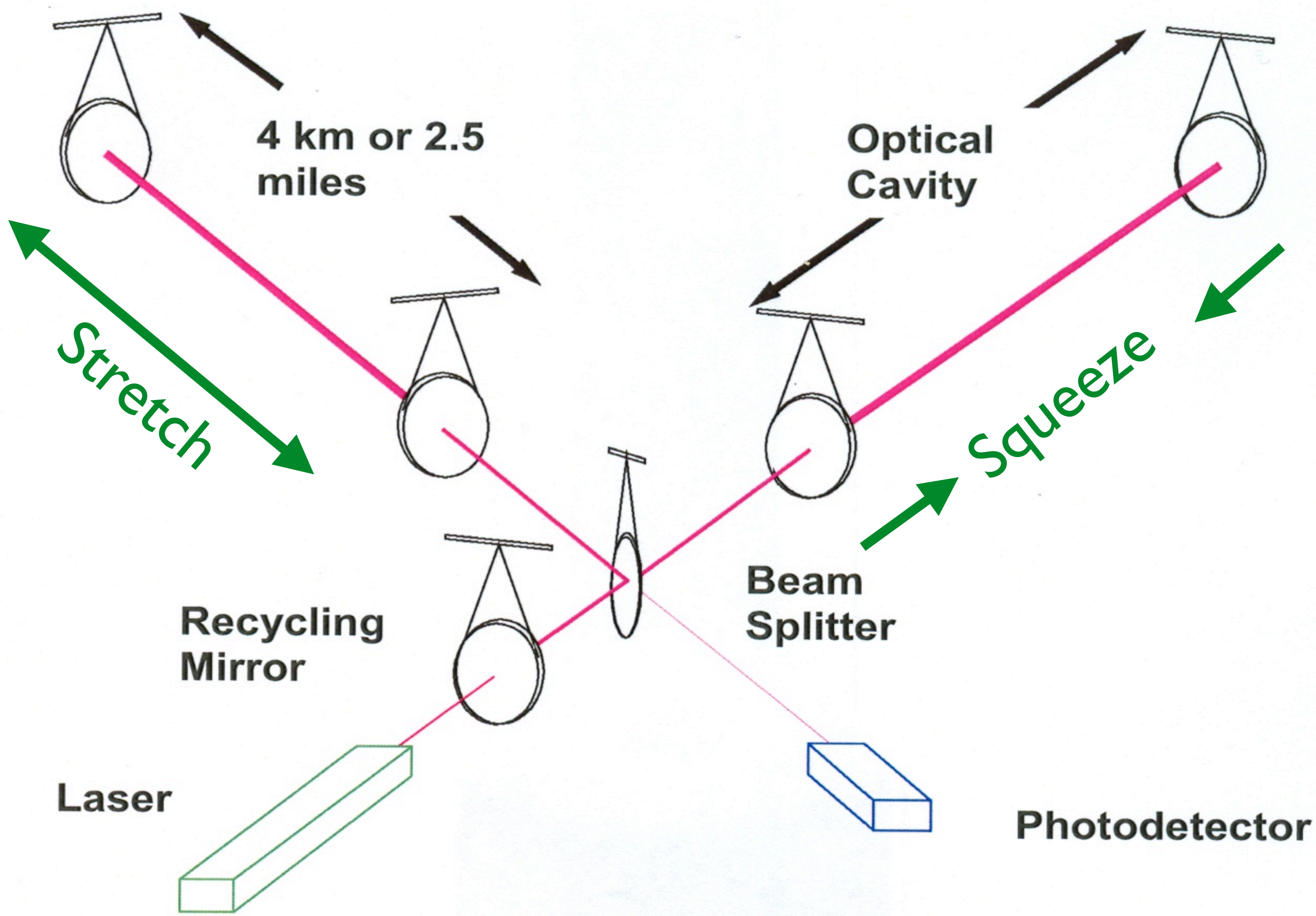
4 km or 2.5 miles
Optical Cavity
Stretch
Squeeze
Beam Splitter
Recycling Mirror
Laser
Photodetector


LIGO