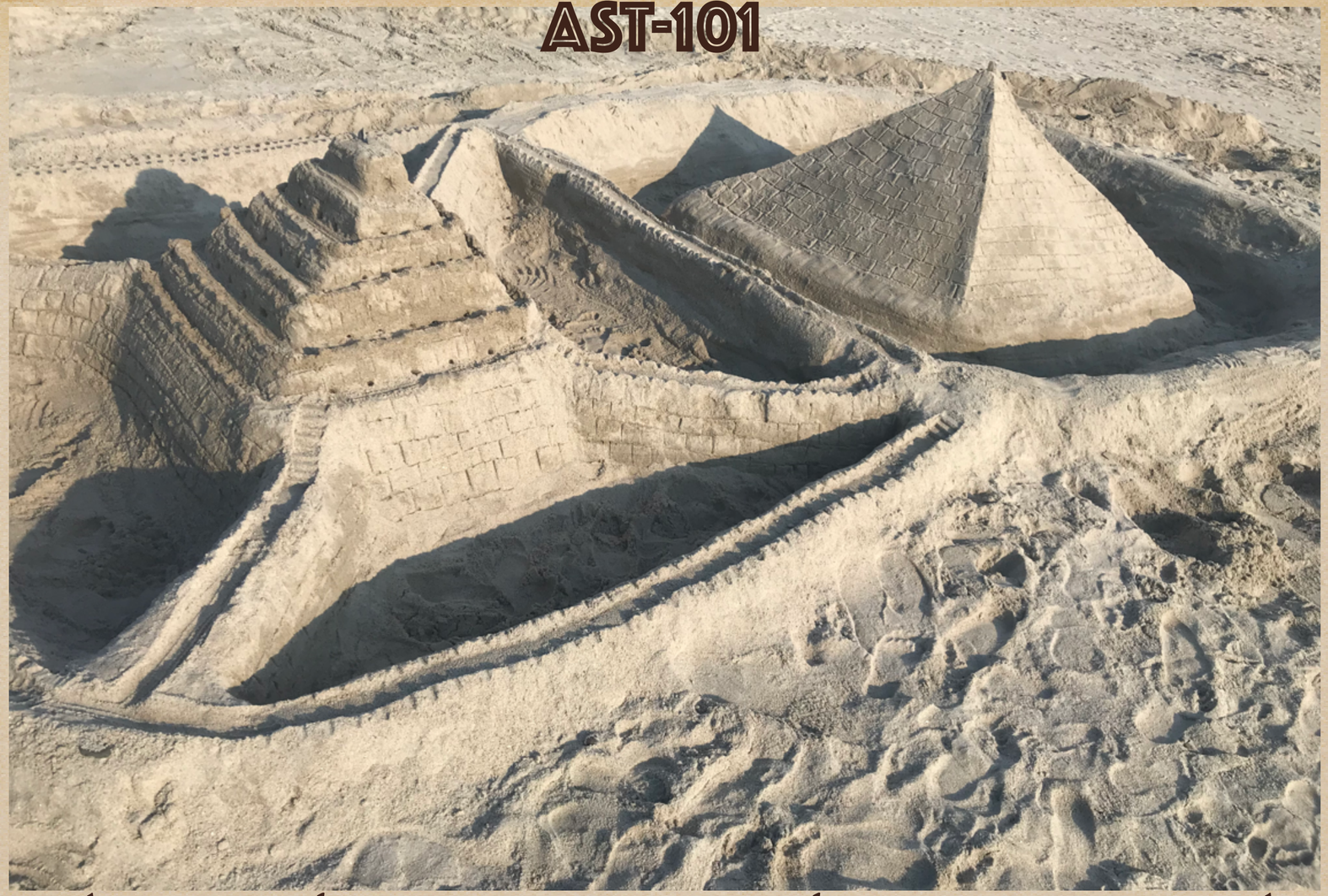
AST-101

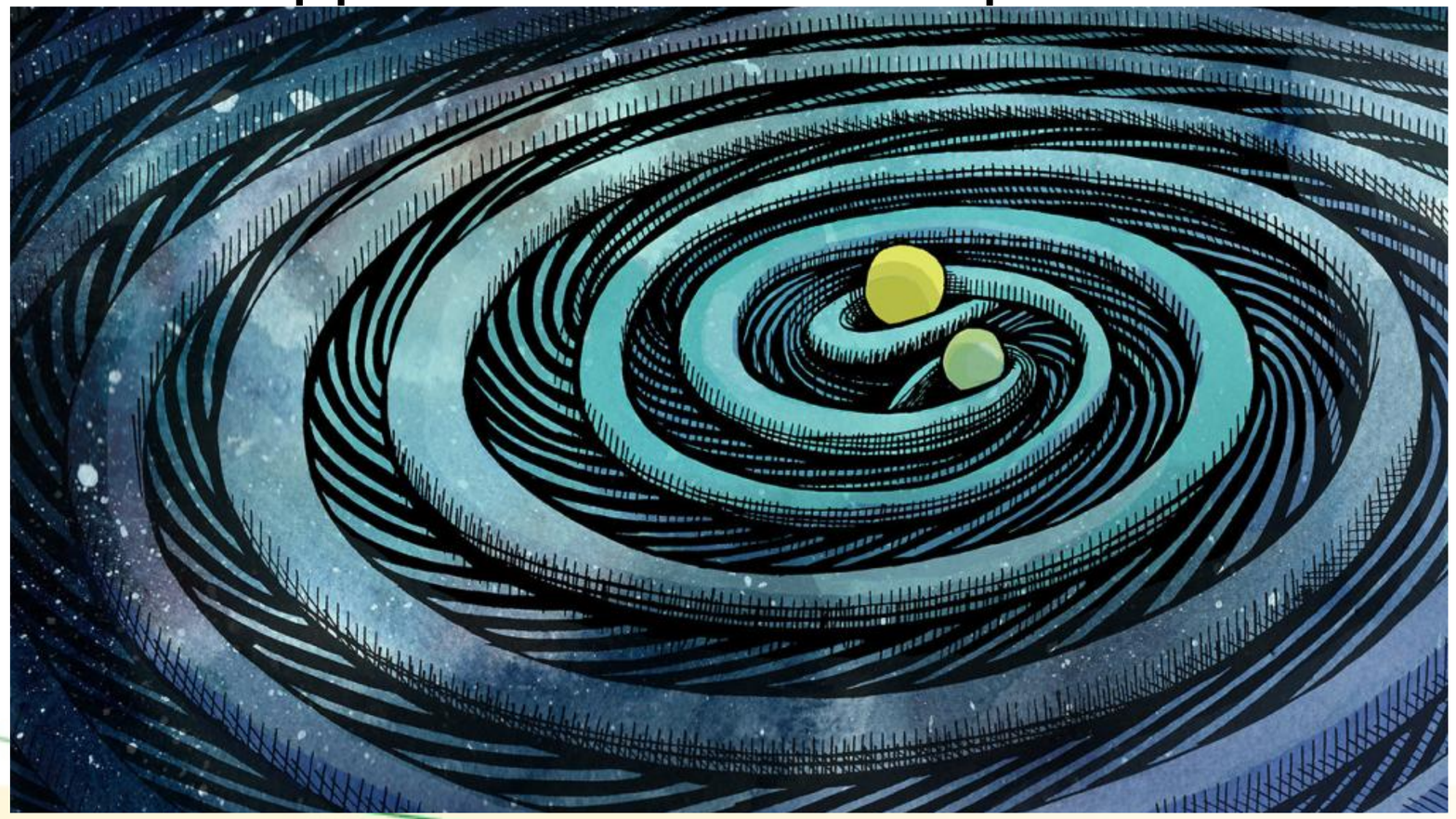


Exploring the Universe with gravitational waves

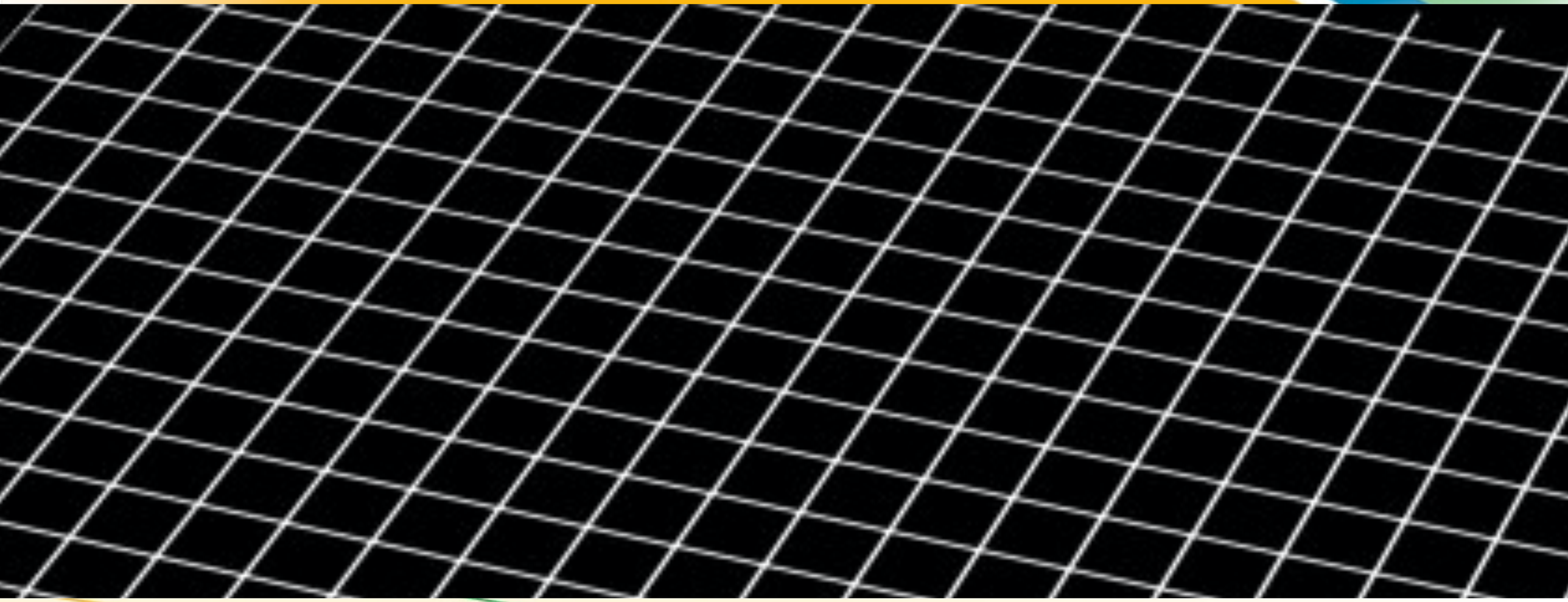
Luis Anchordoqui

What is a gravitational wave?

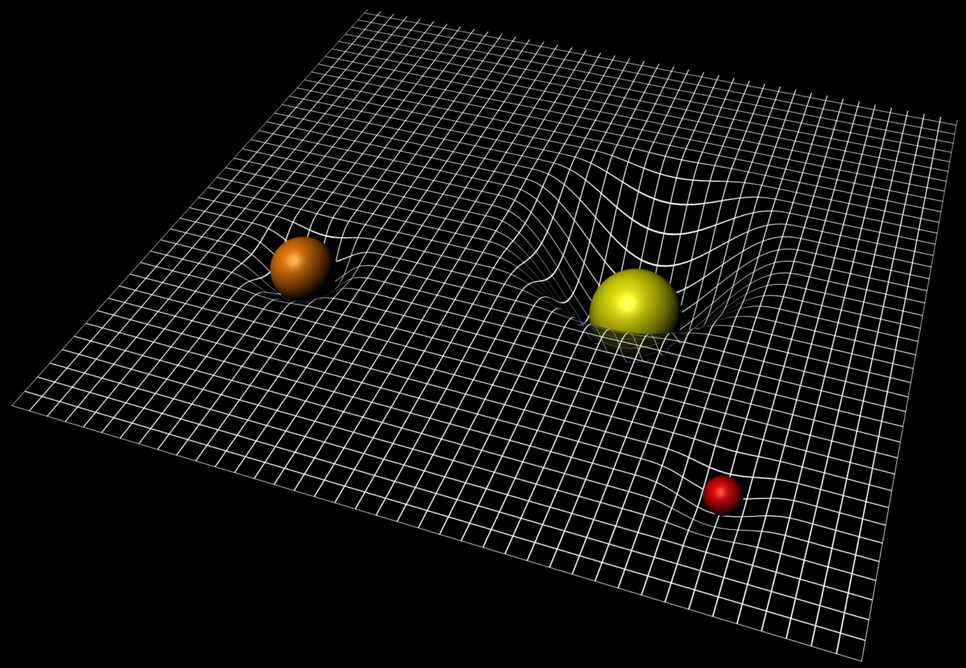
It is a ripple in the fabric of spacetime



Imagine space is a giant sheet of rubber



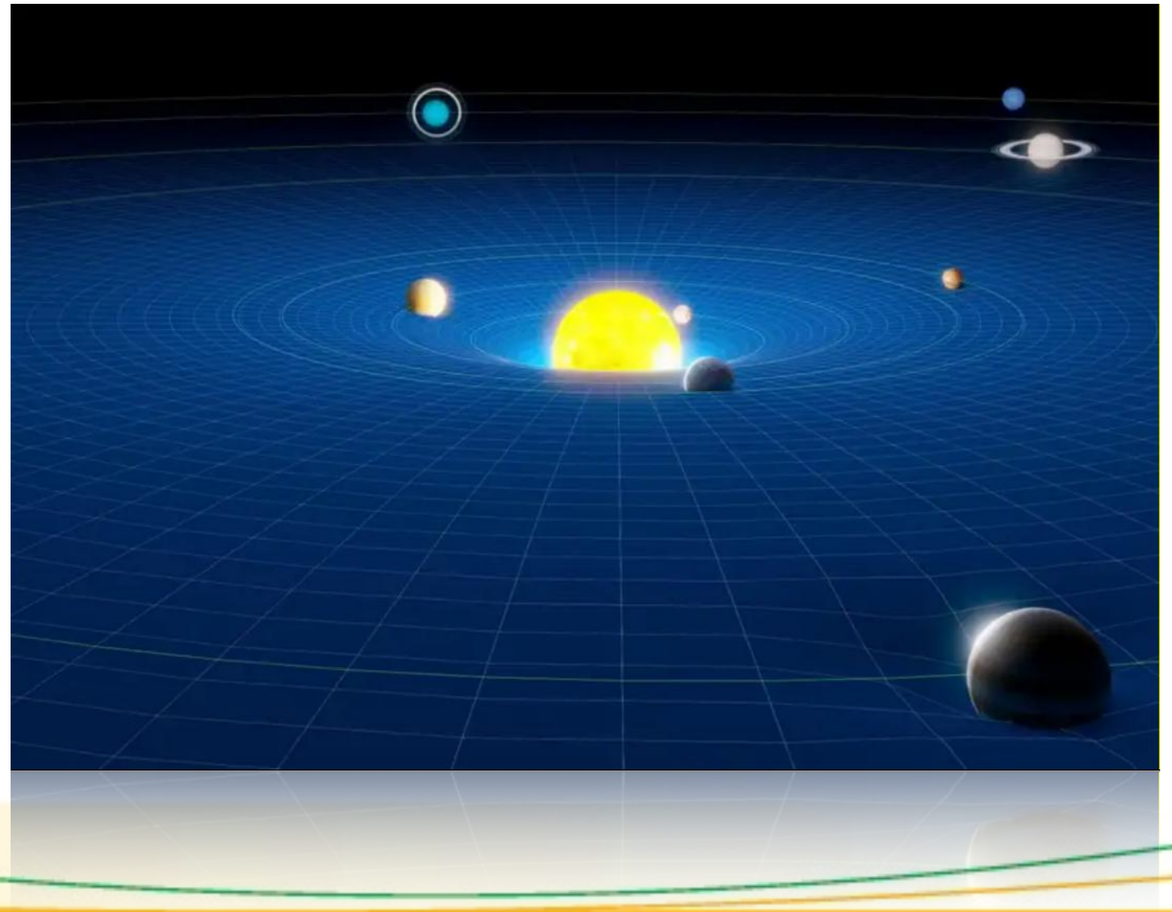
Anything that have mass caused this rubber sheet to bend



The more mass ☛ the more that space gets bent and distorted by gravity

Example

The reason the Earth goes around the Sun is that the sun is very massive causing a big distortion of the space around it

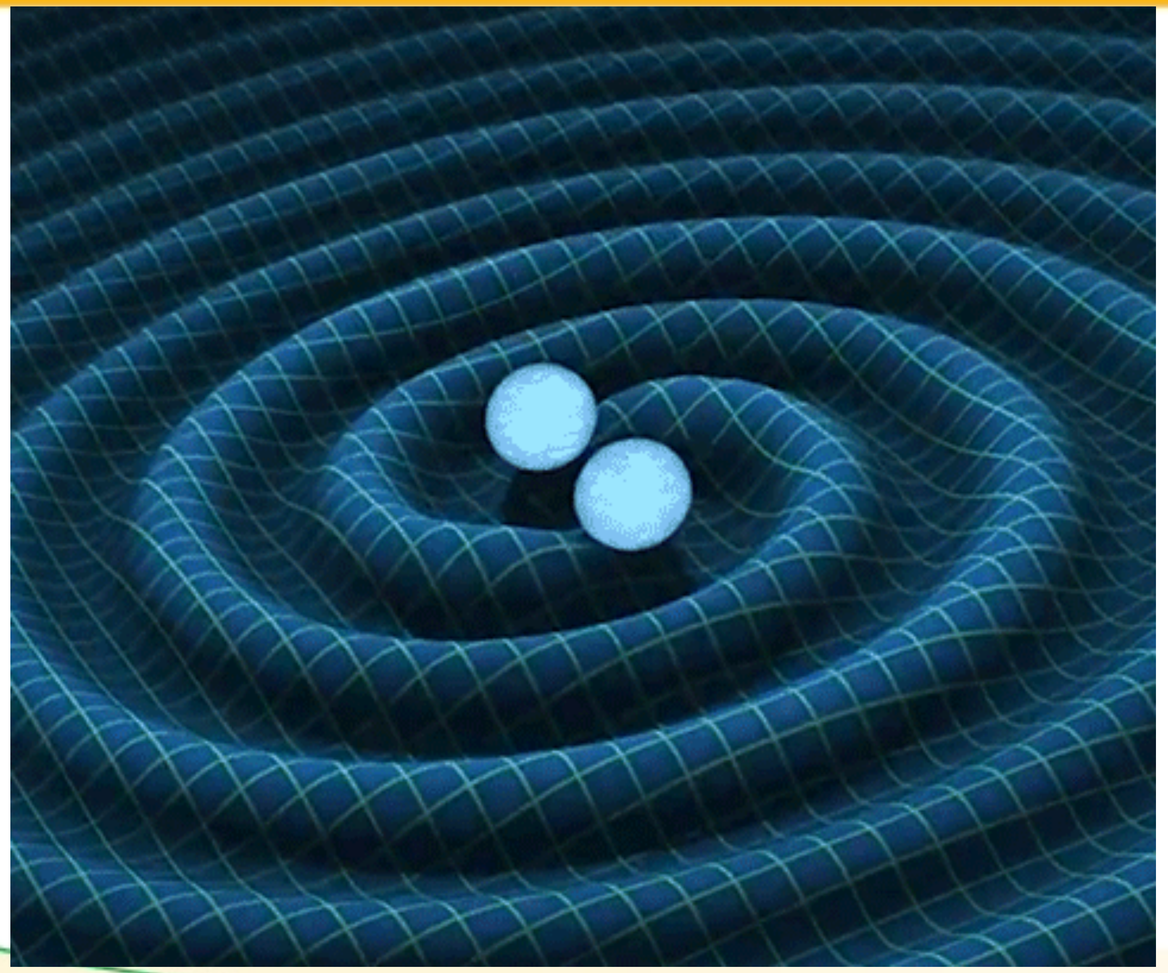


If you try to move in straight line in such a big distortion you will find yourself actually moving in a circle

That's is how orbits work:

there is not an actual force pulling the planets around just the bending of space

Gravitational waves are produced whenever masses accelerate changing the distortion of space



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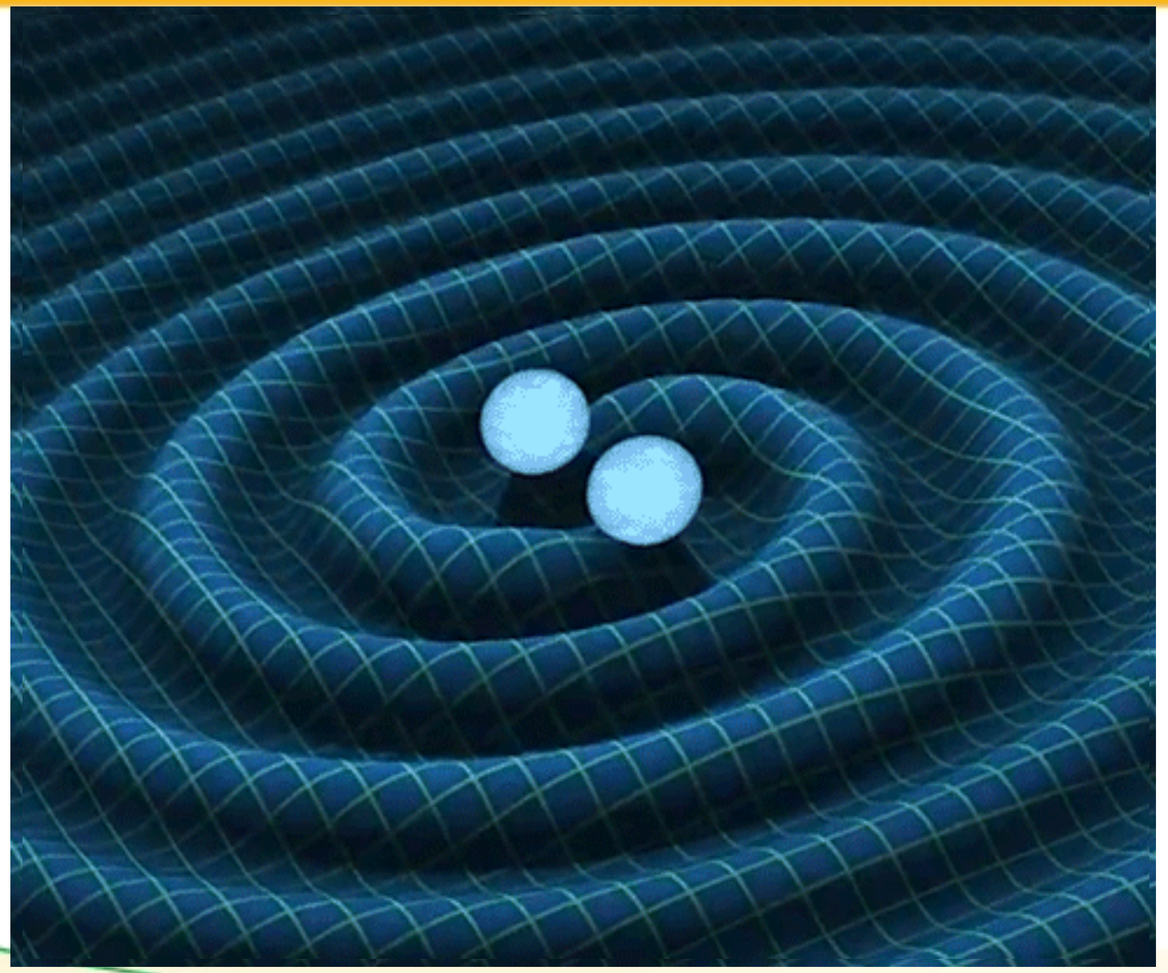

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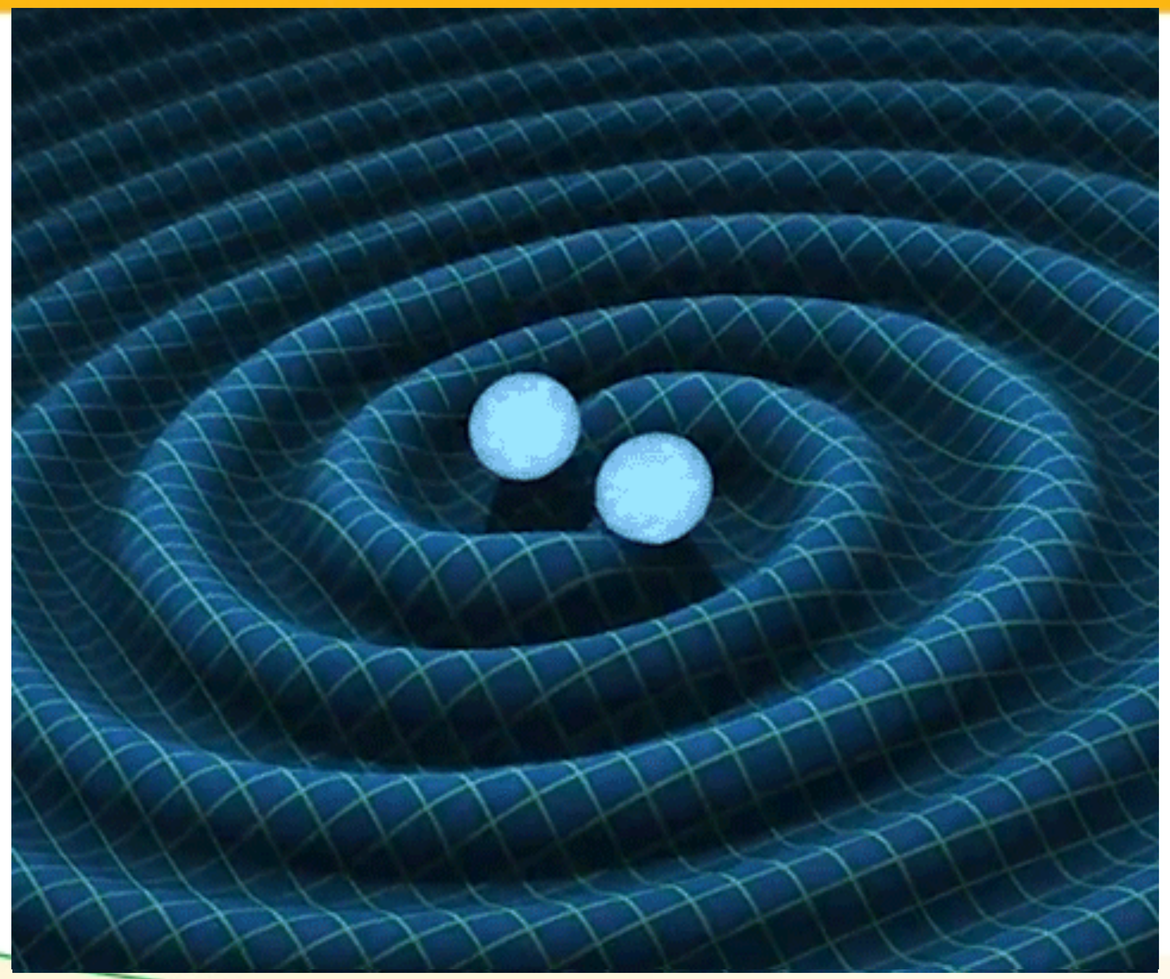

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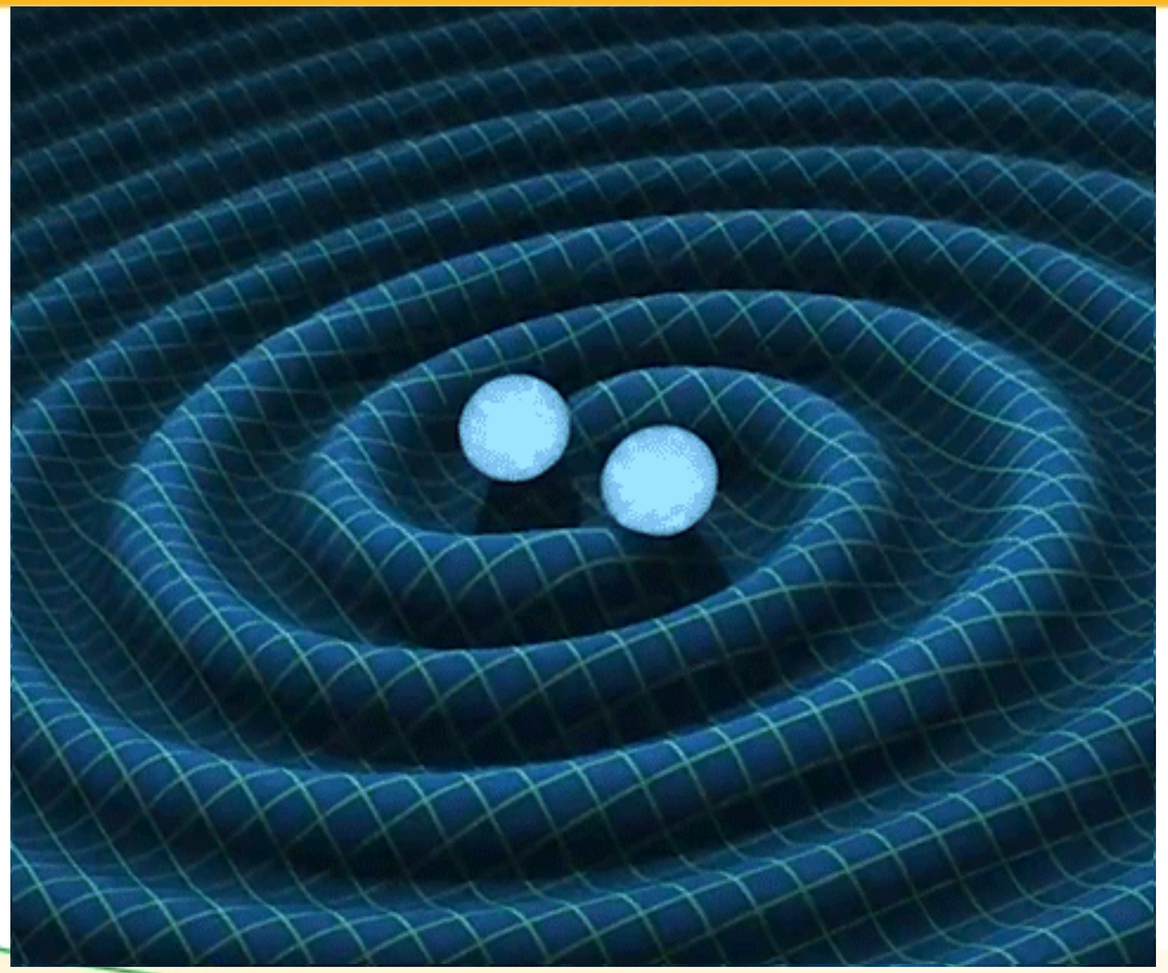

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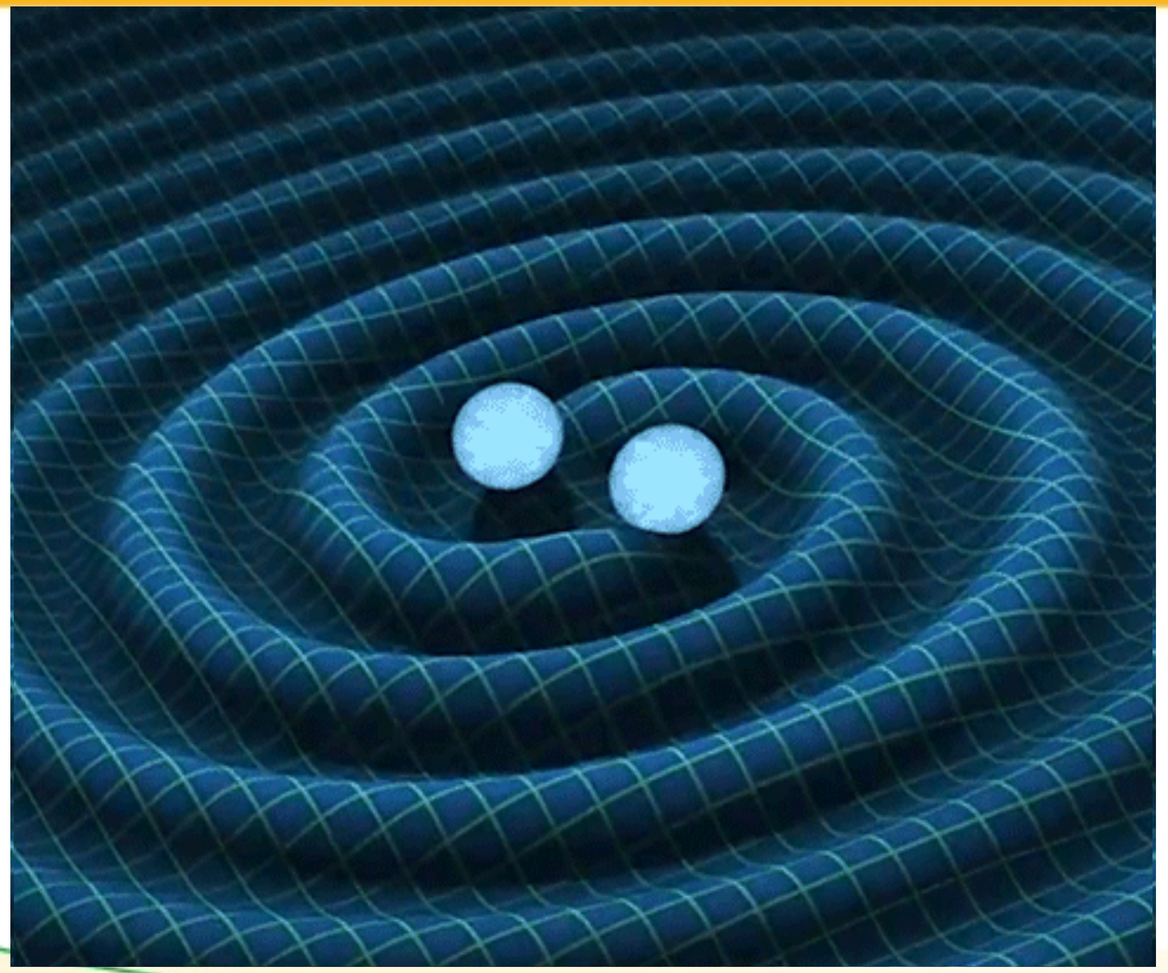

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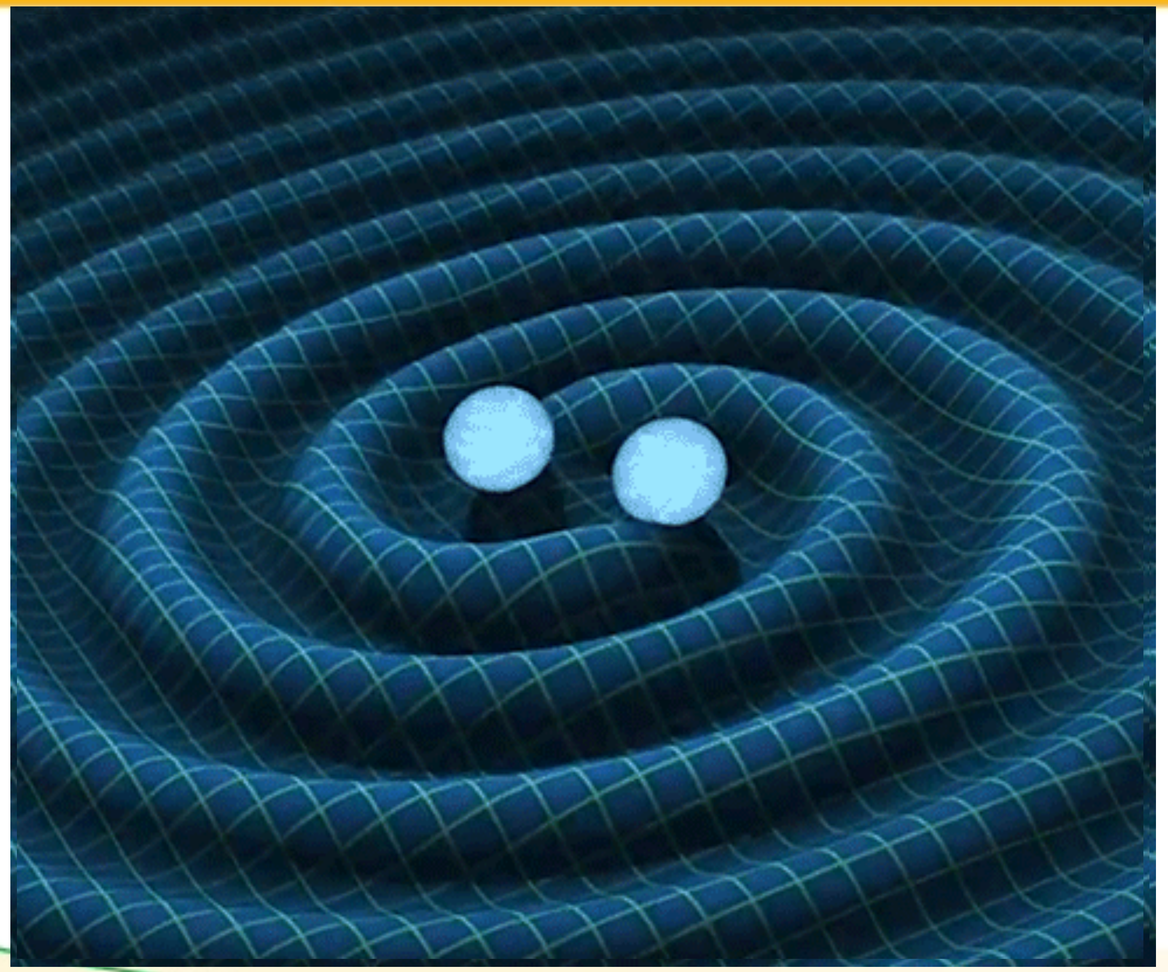

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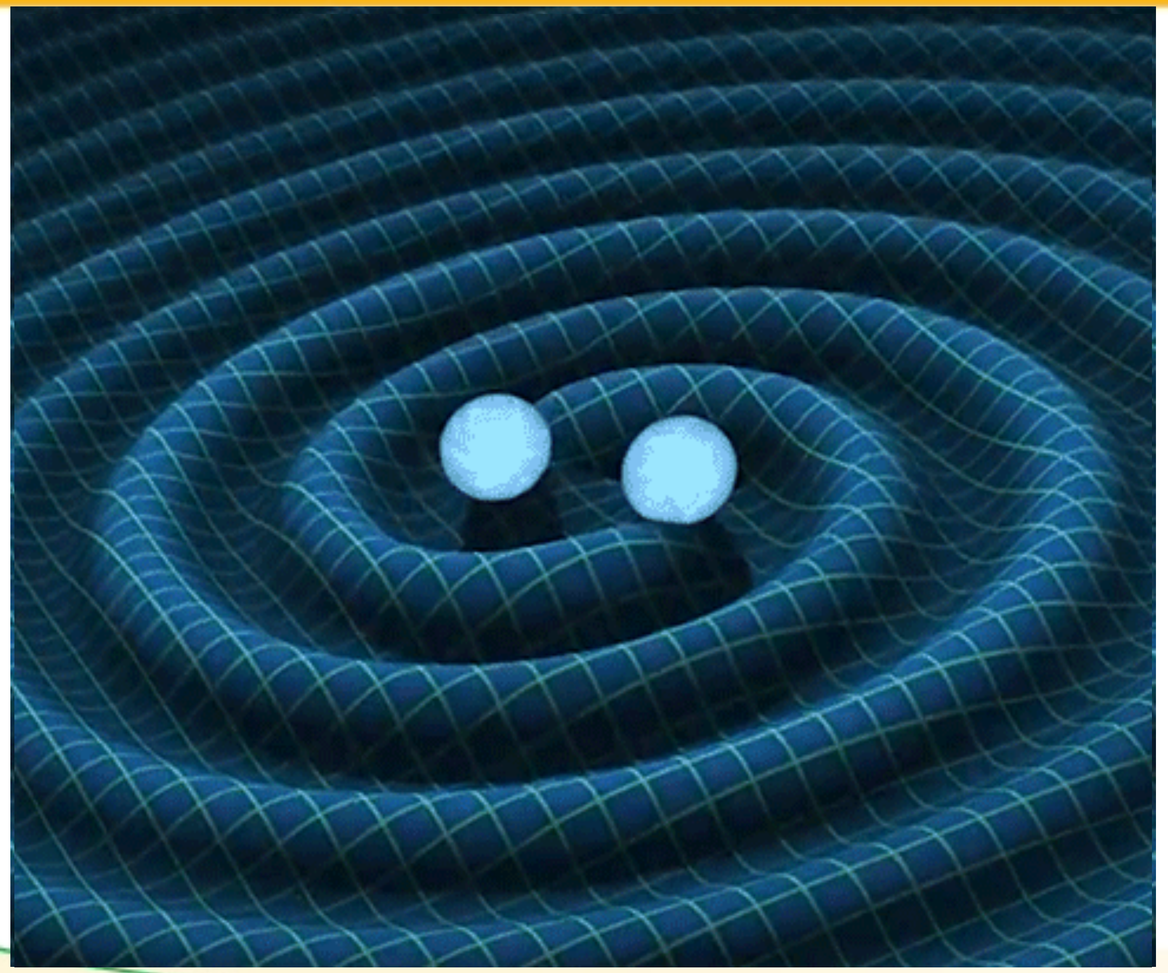

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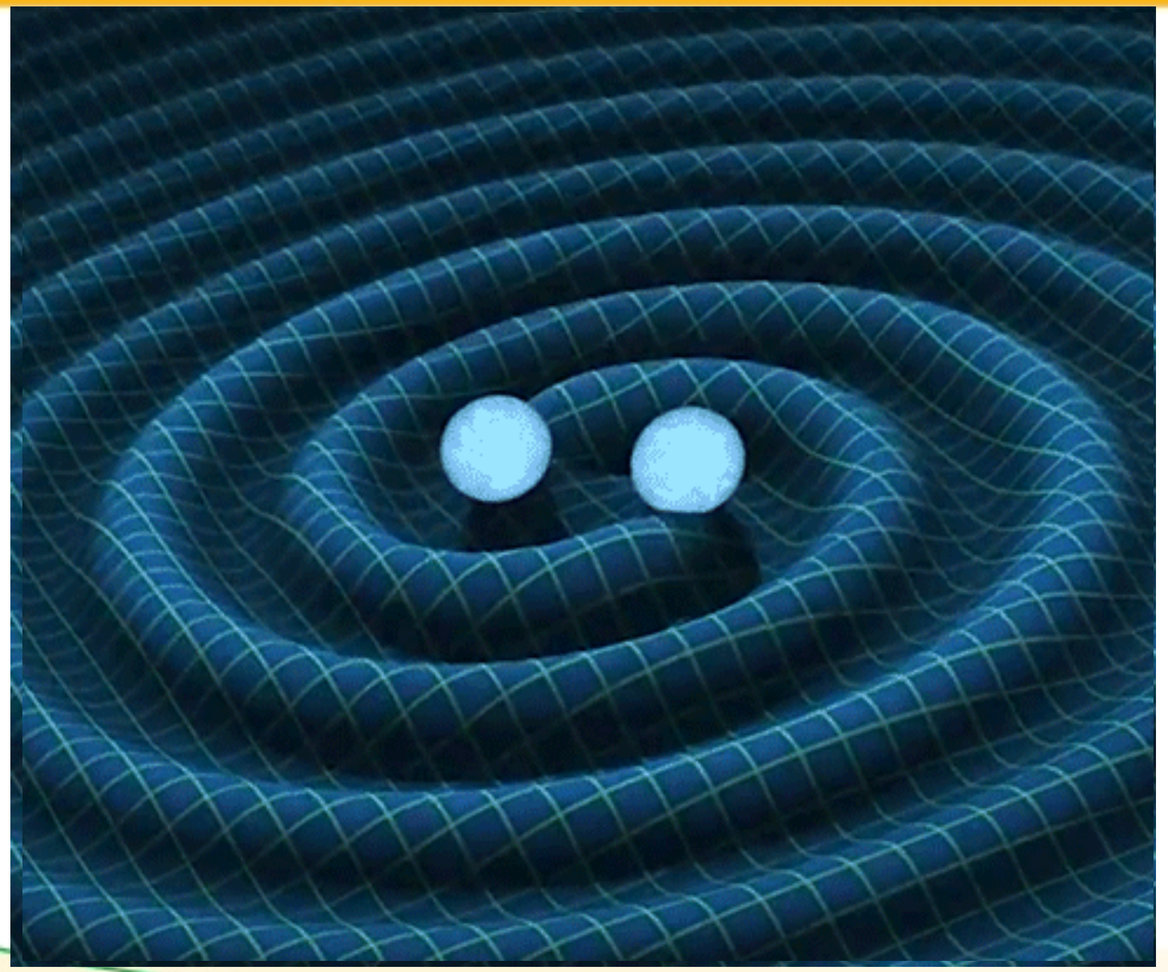

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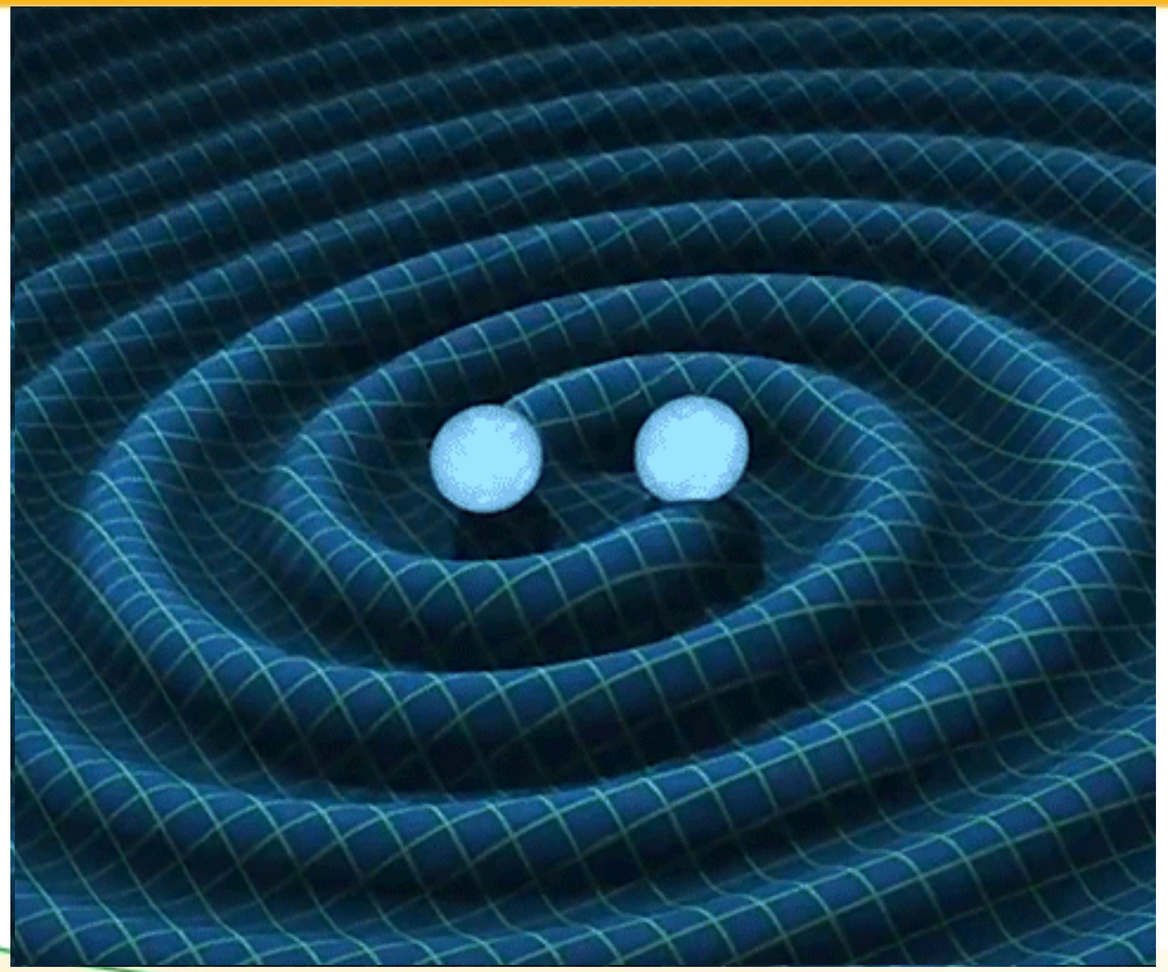

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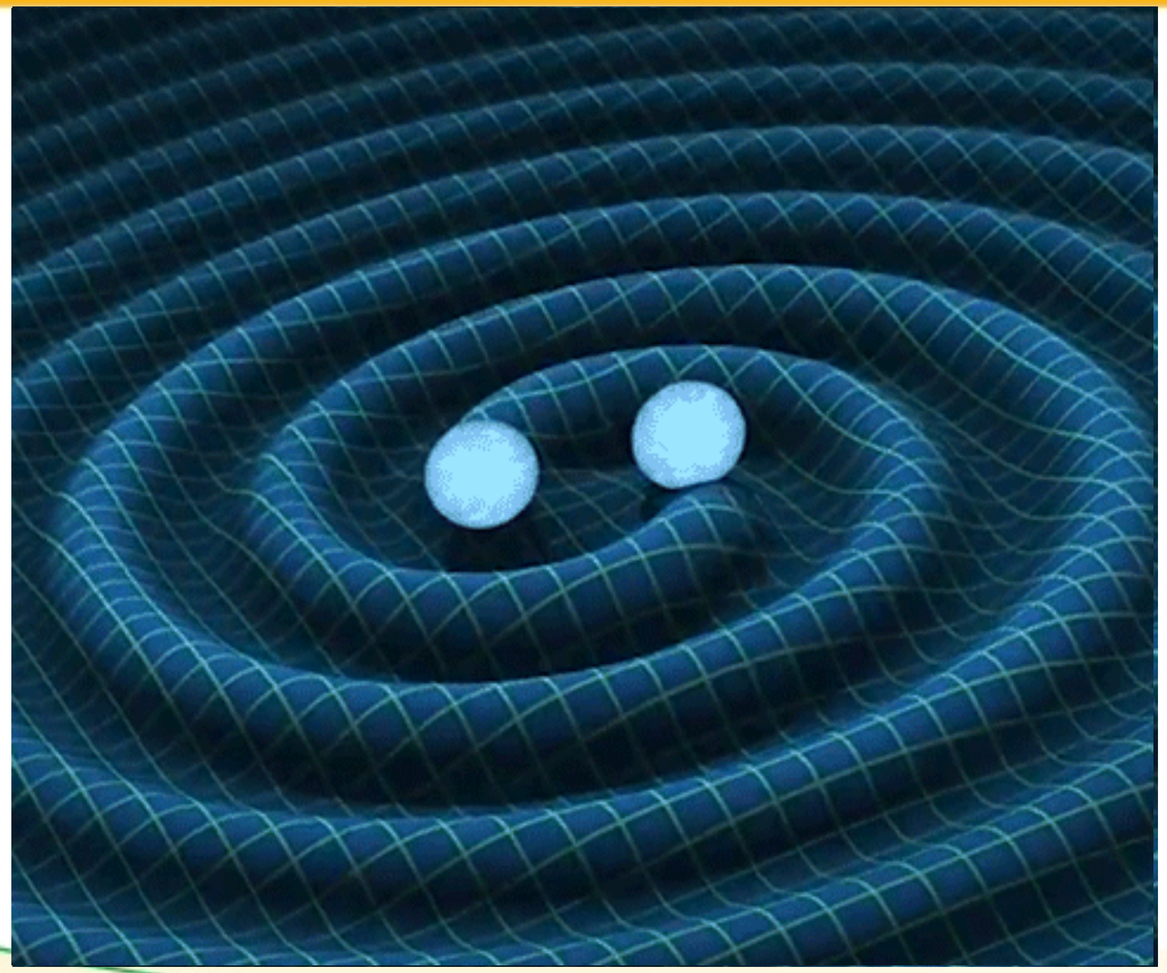

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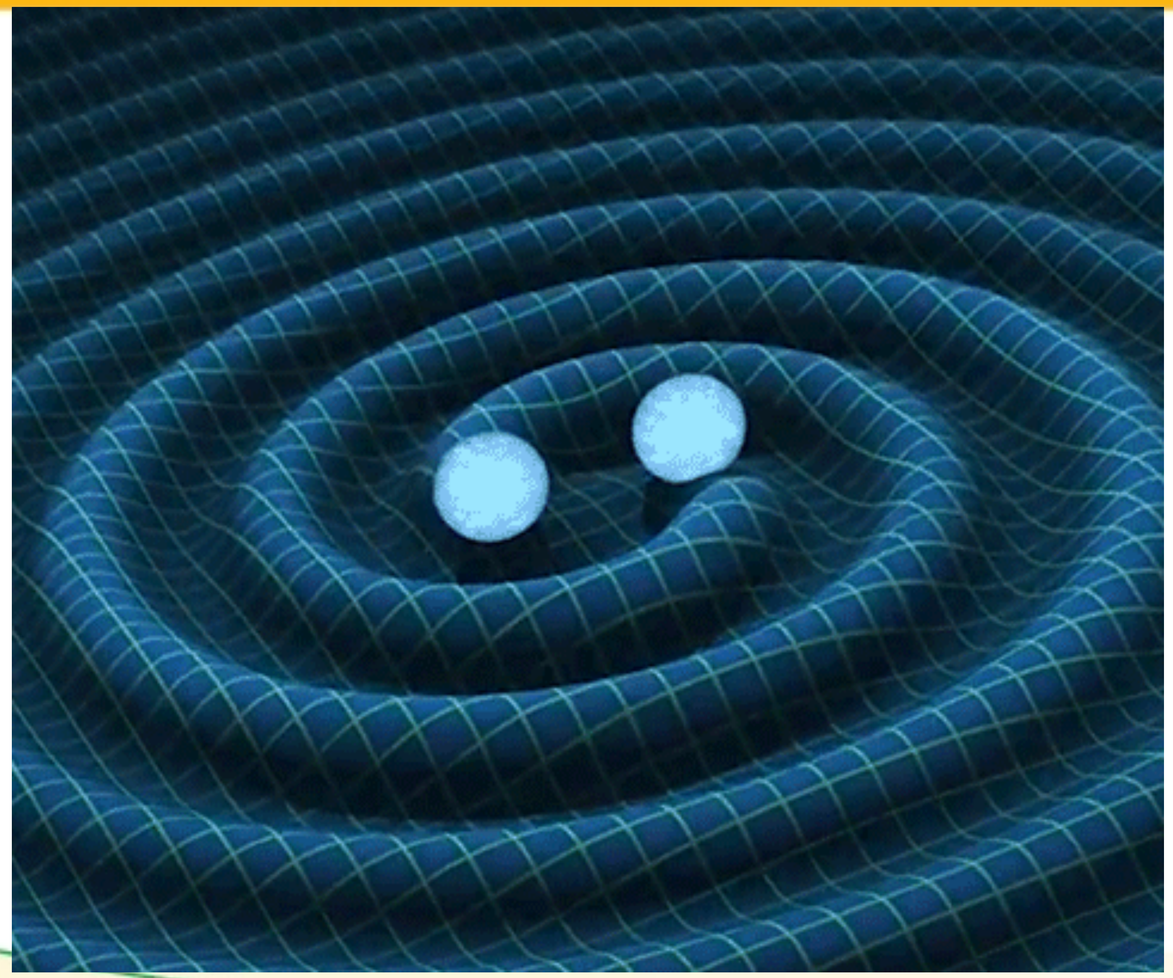

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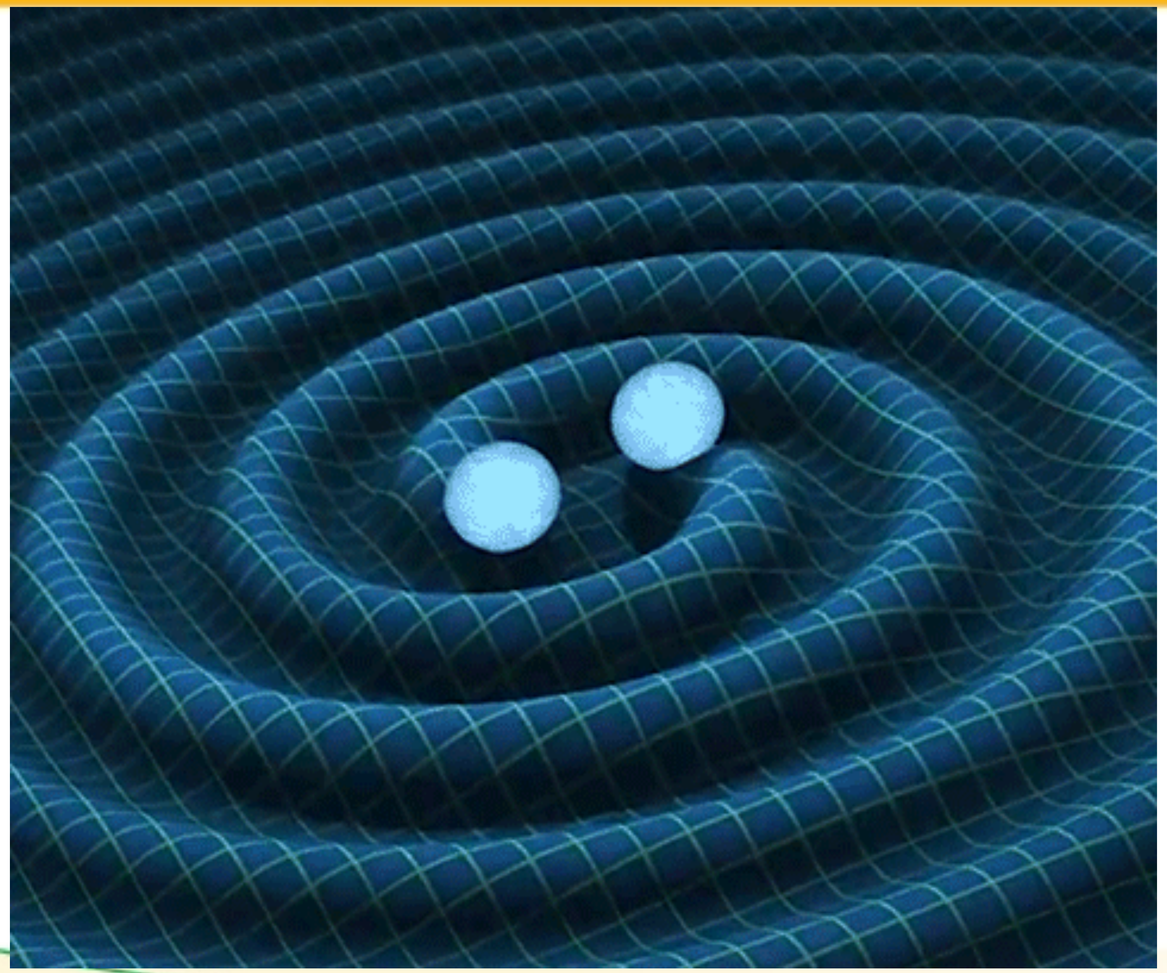

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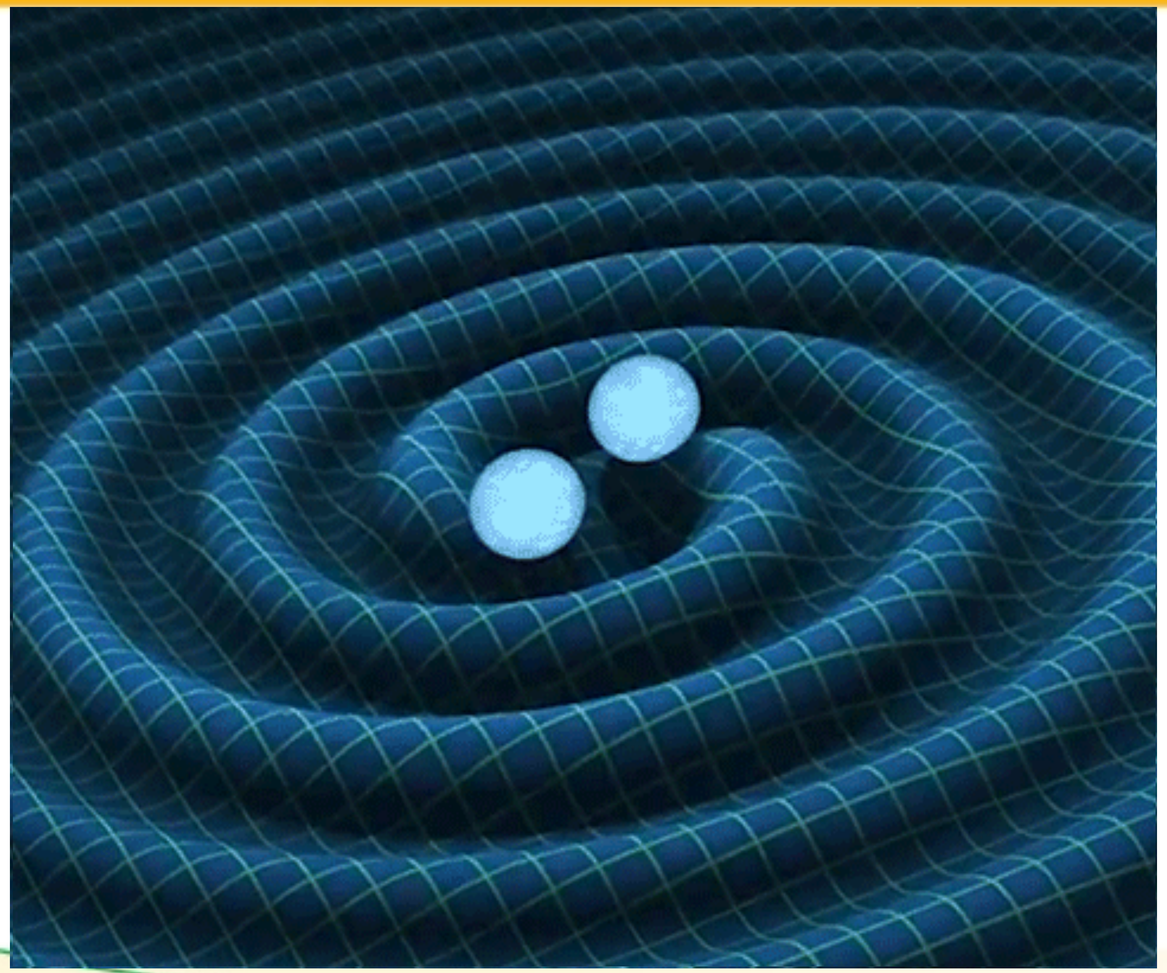

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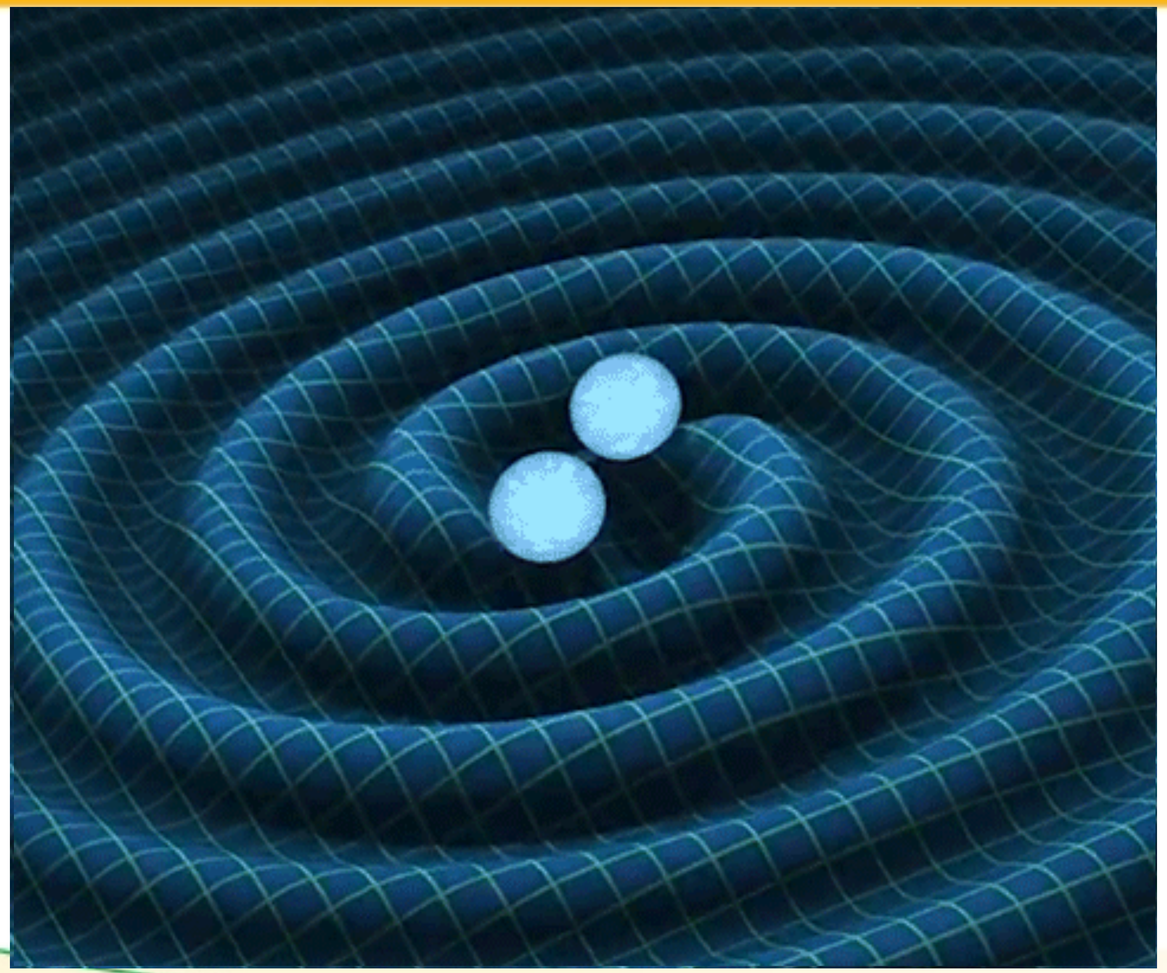

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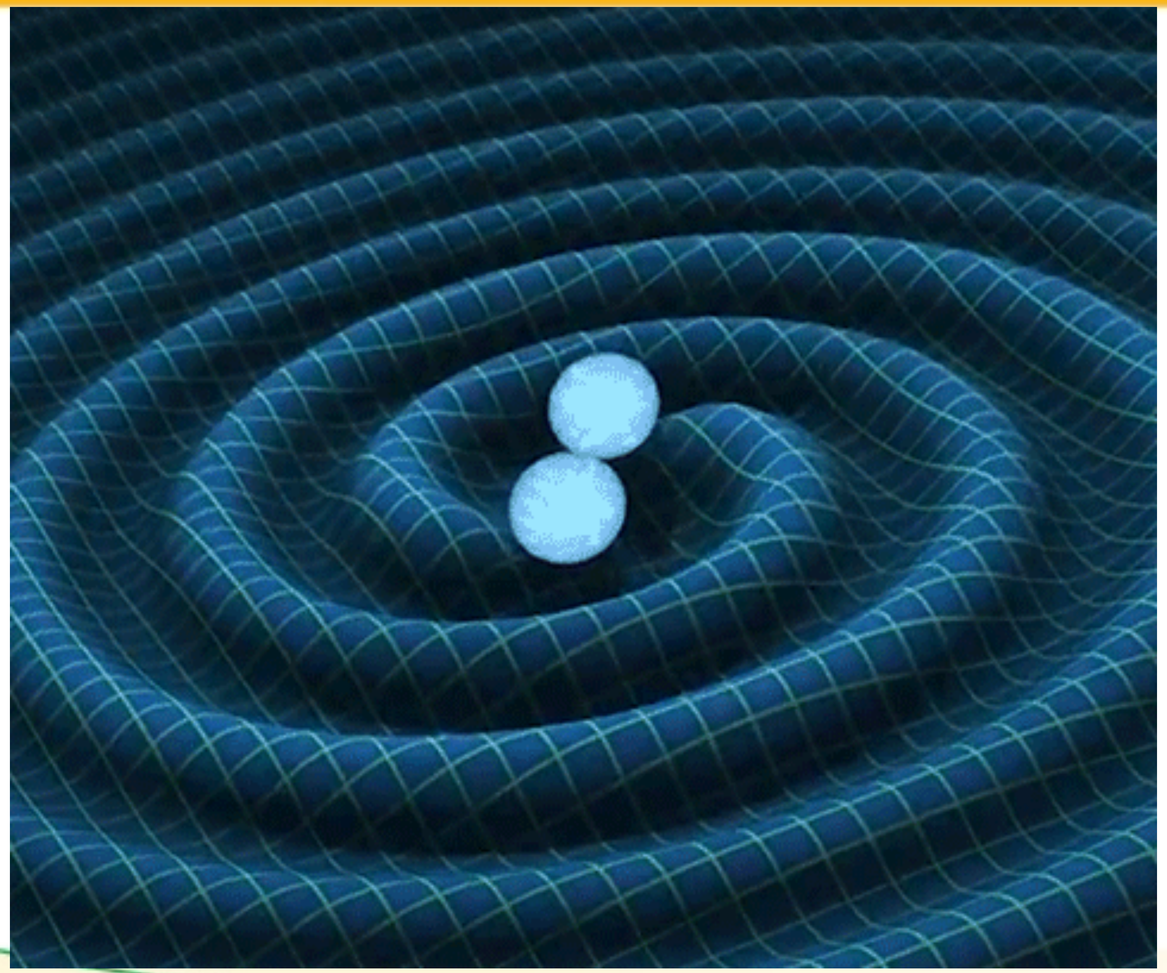

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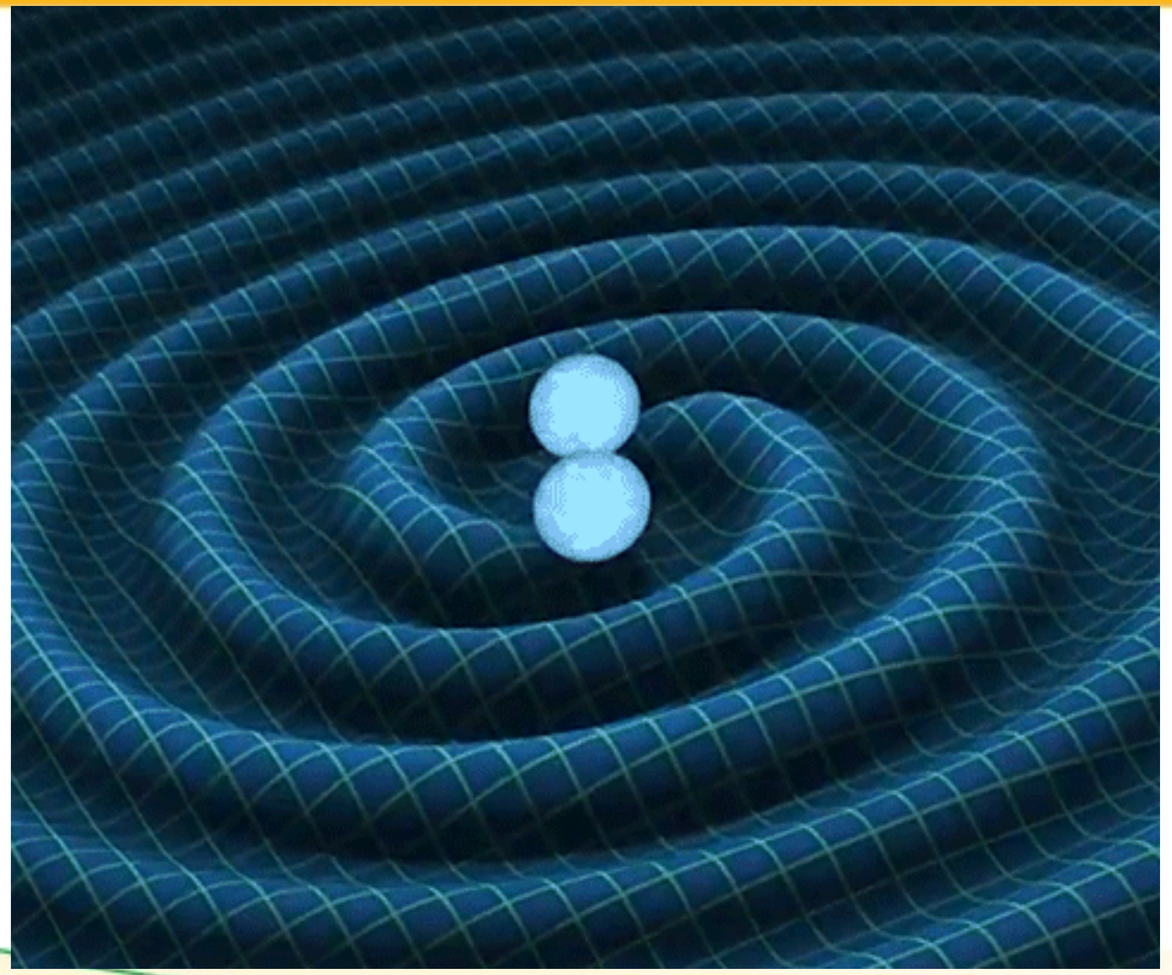

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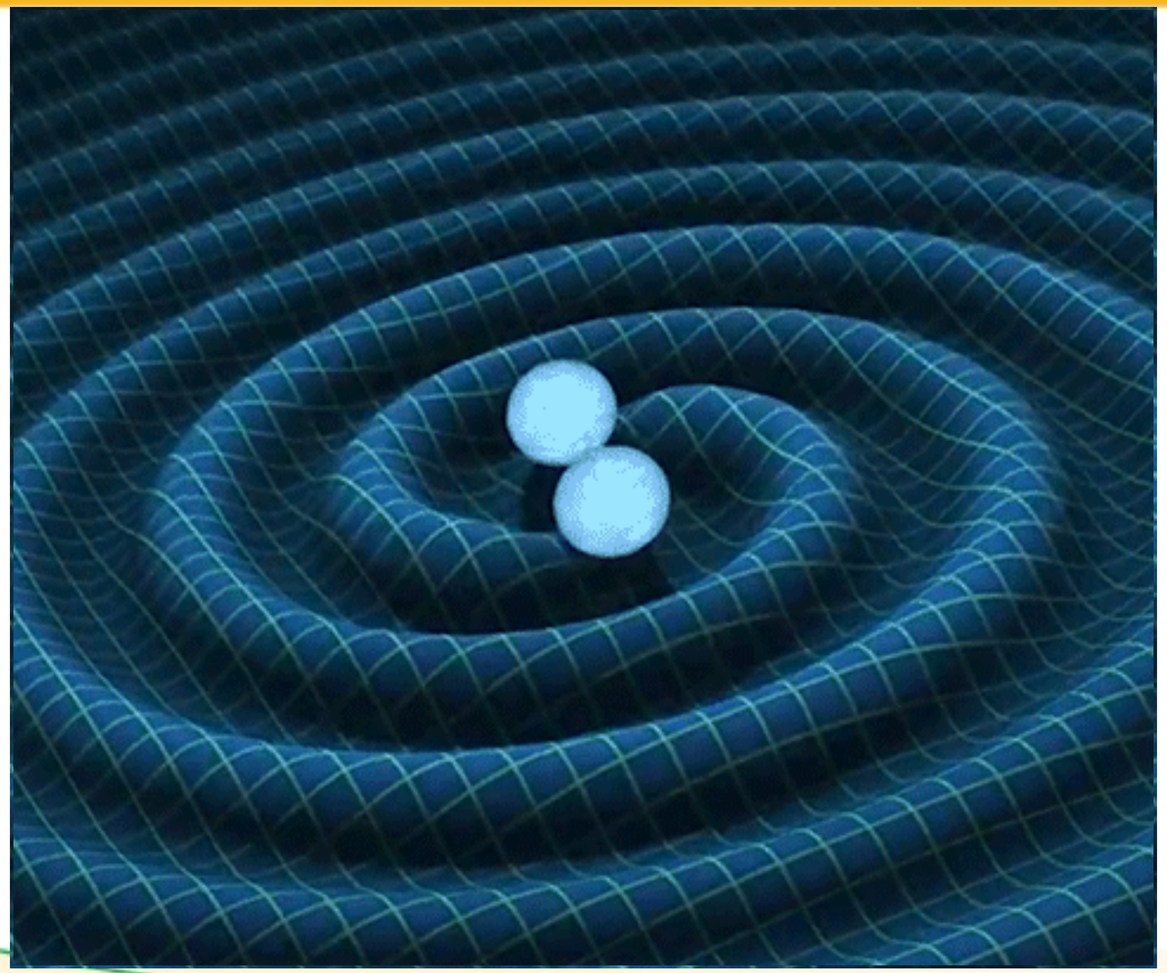

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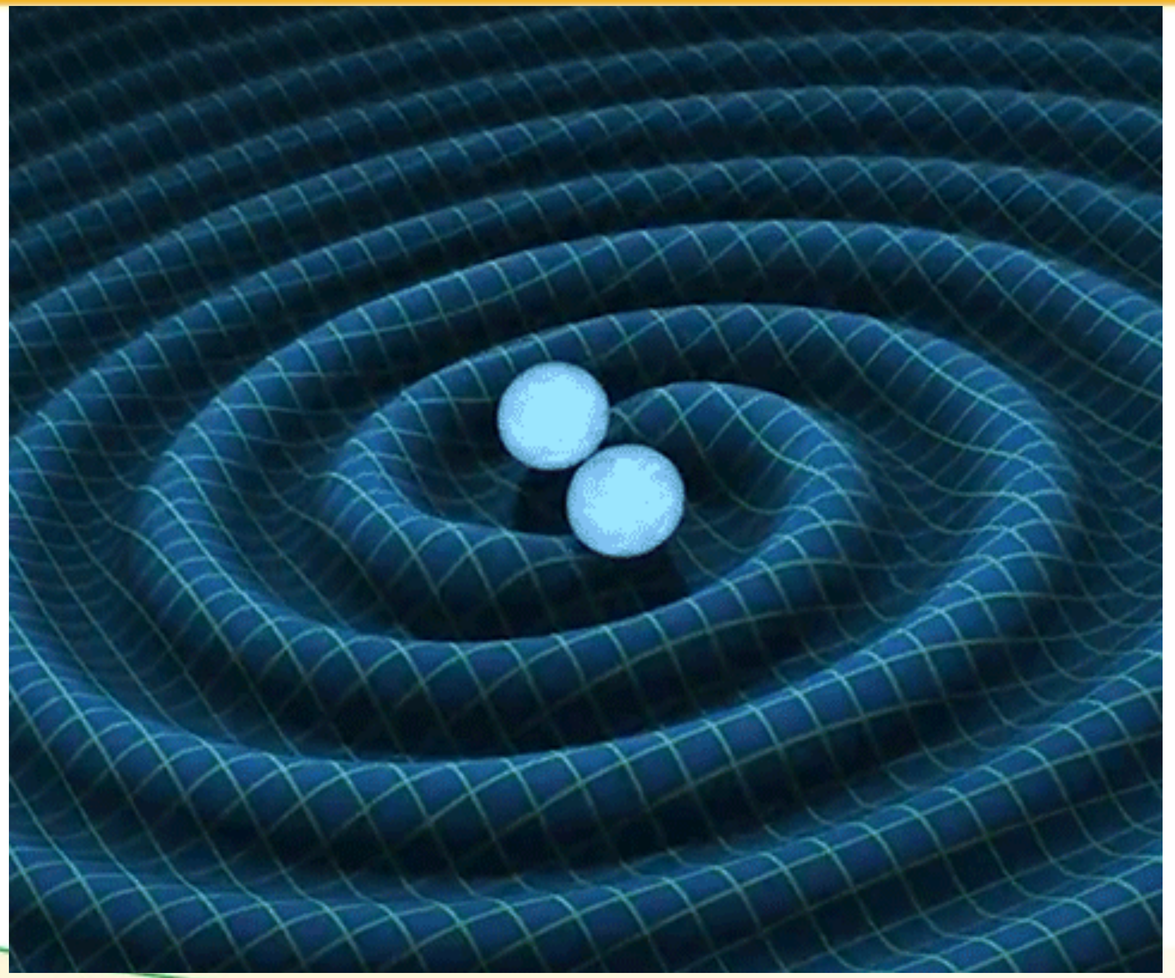
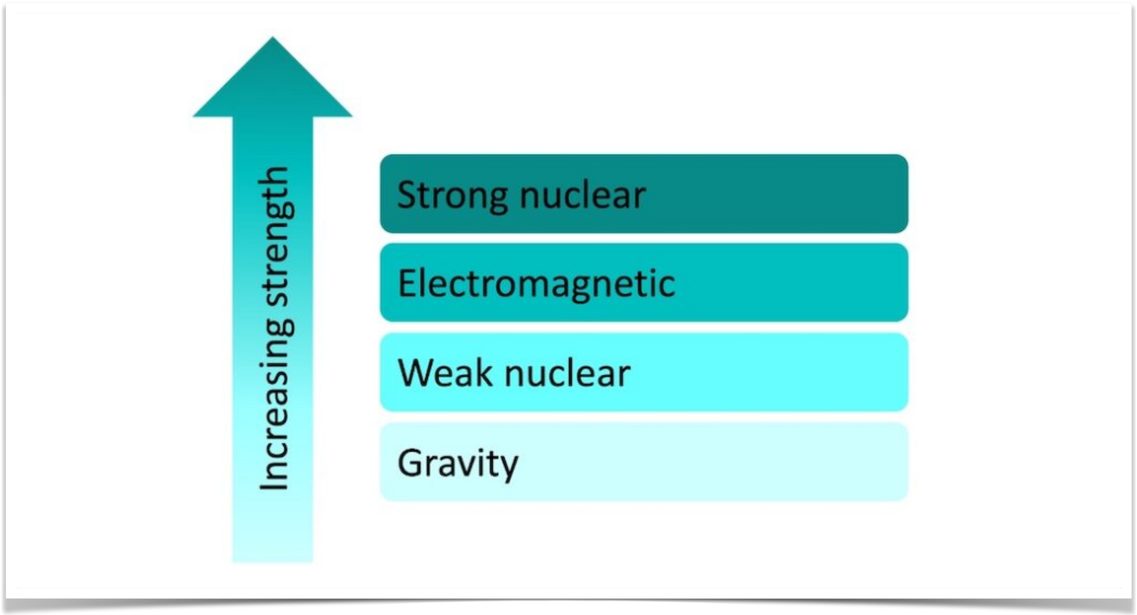


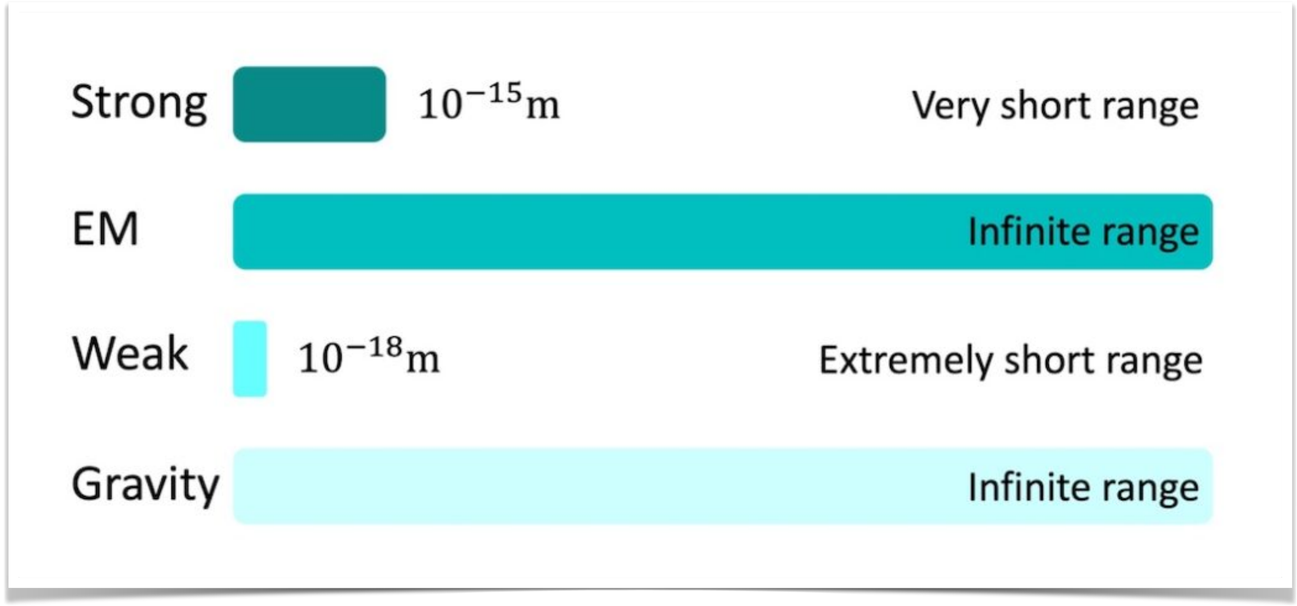
Everything with mass and energy can make gravitational waves

If you and I started dancing around each other we would cause ripples in the fabric of space and time

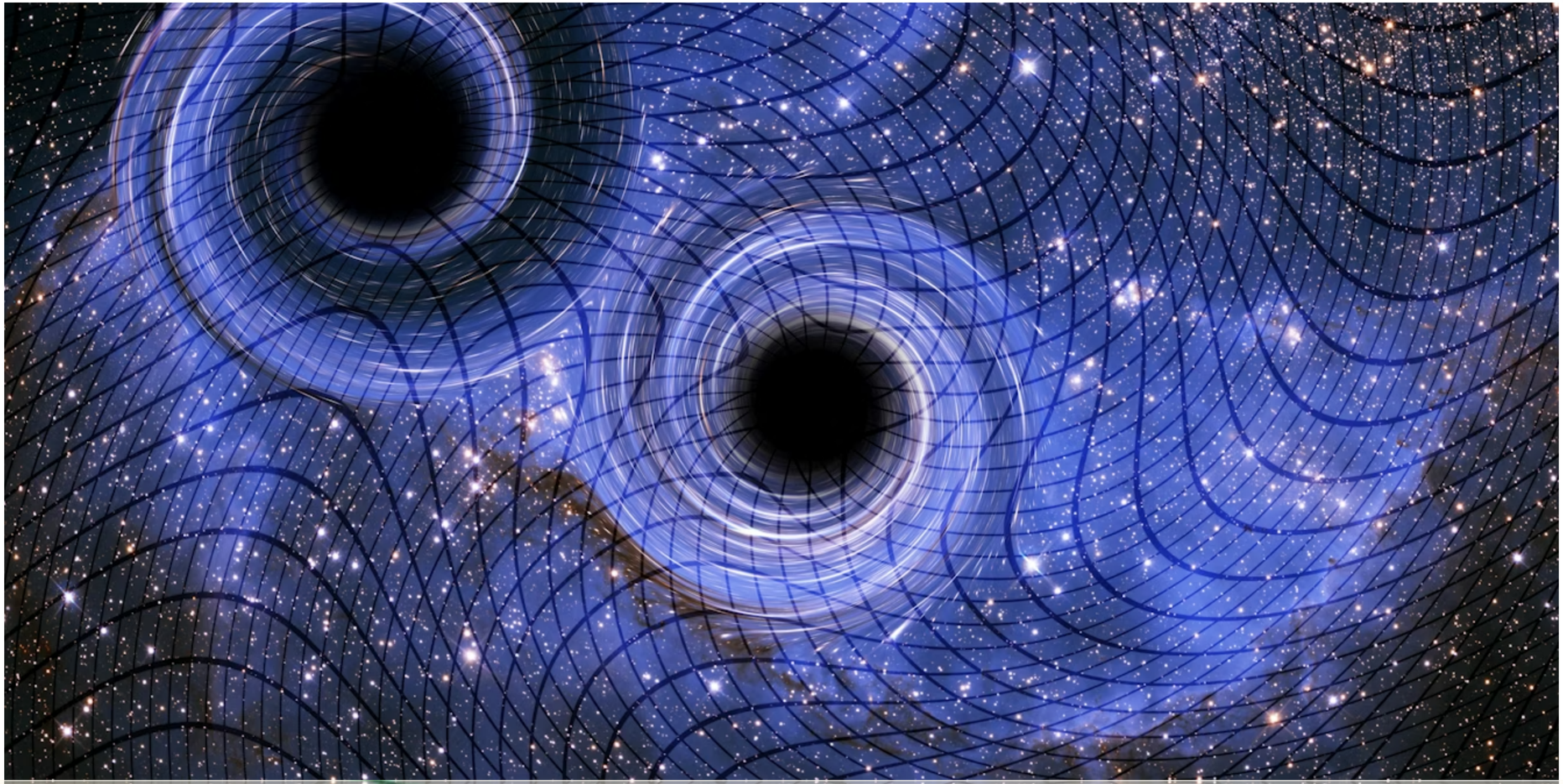
But these would be extremely small ☛ practically undetectable

Gravity is very weak in the scale of other forces in the universe

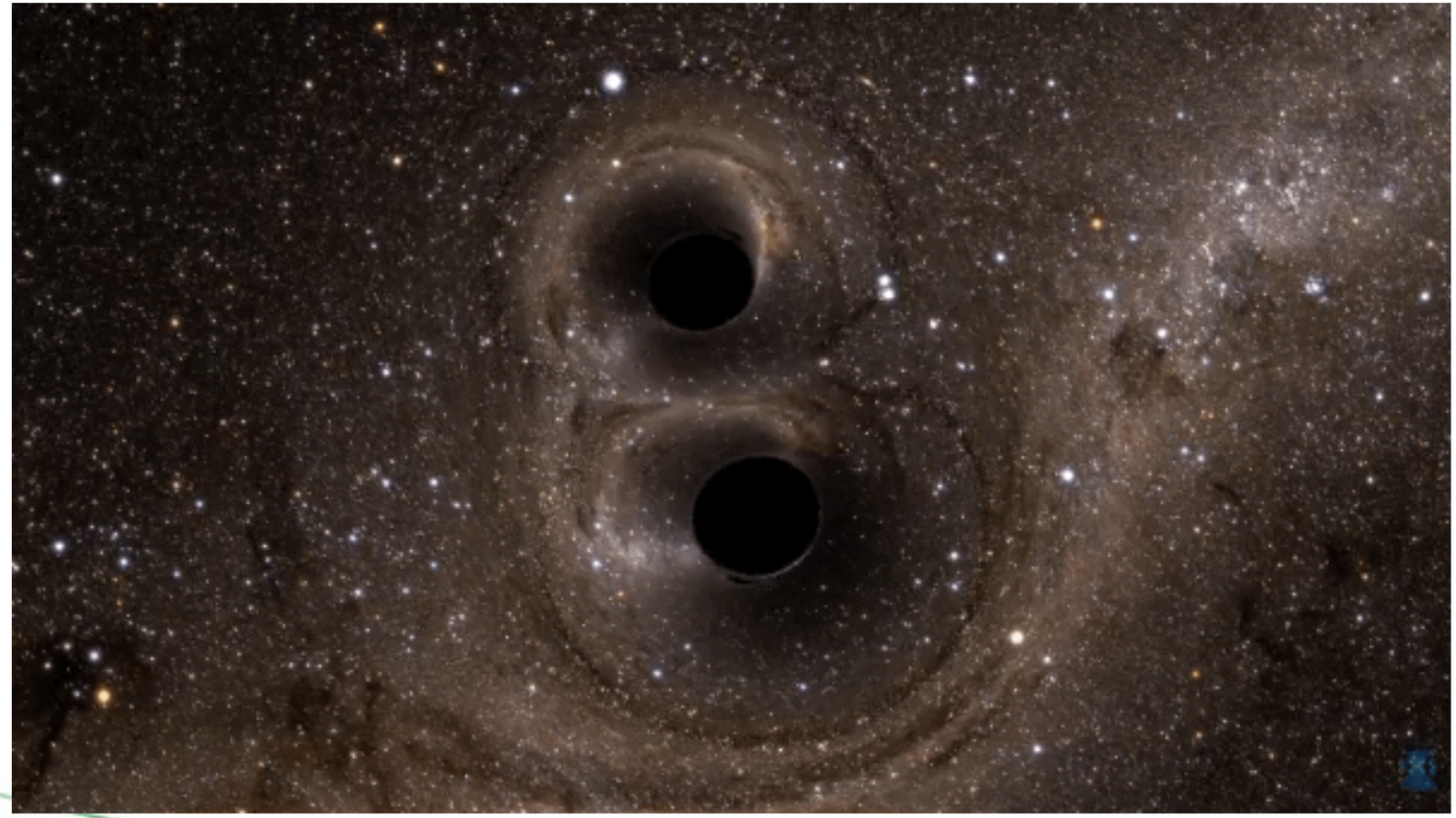




So you need something really really massive moving very fast to make the big ripples that we can detect



When black holes merge



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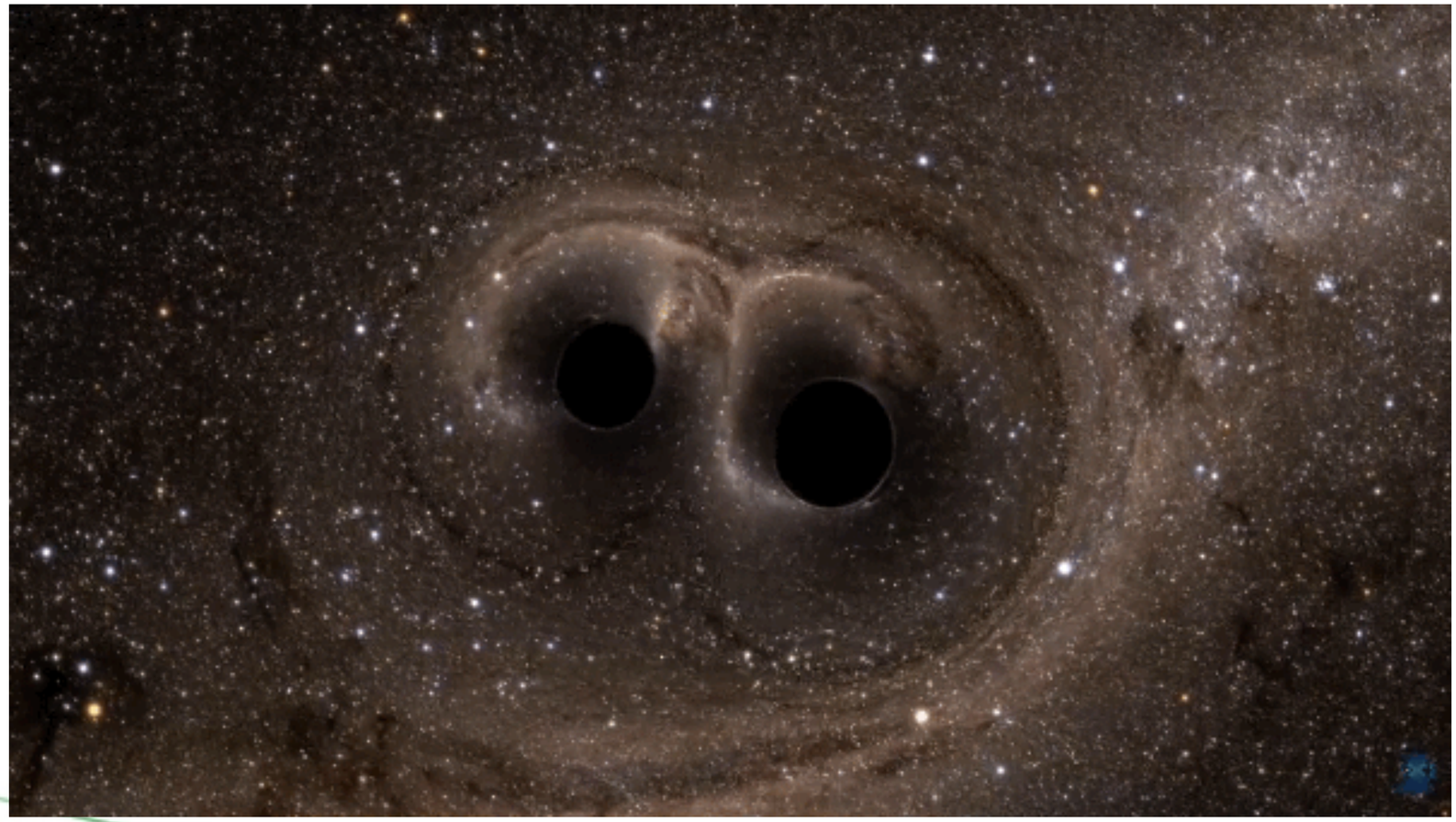

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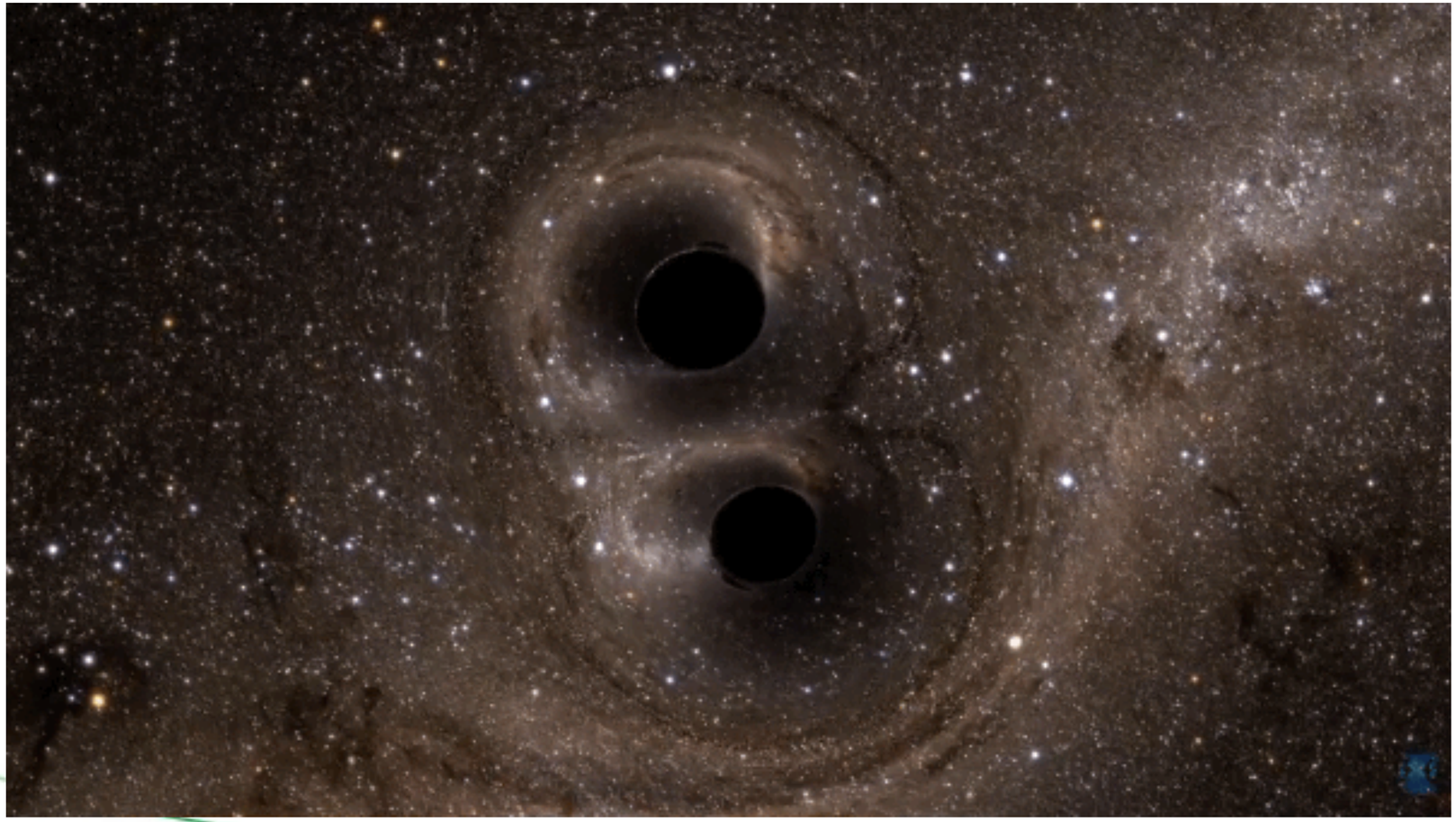

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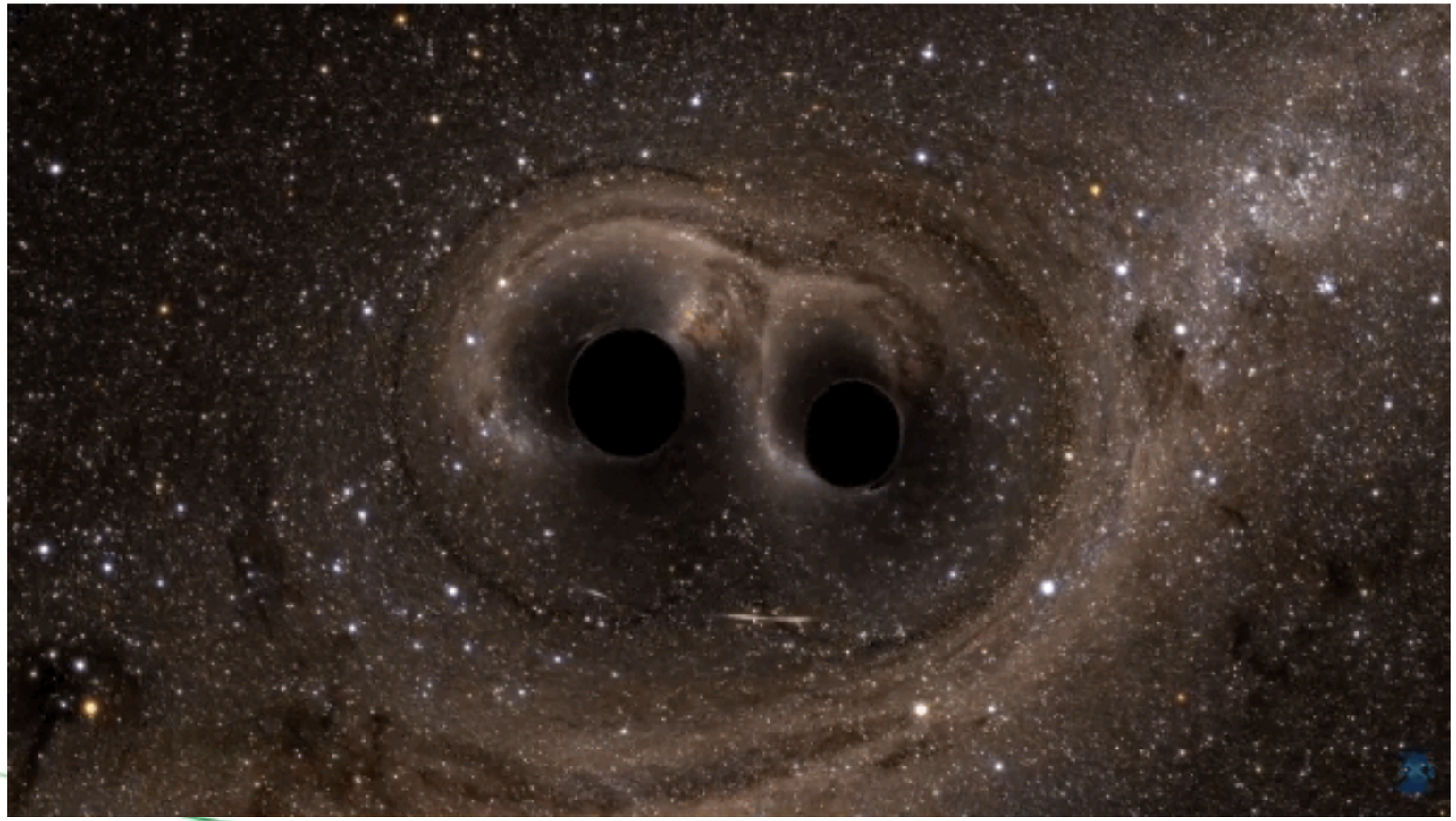

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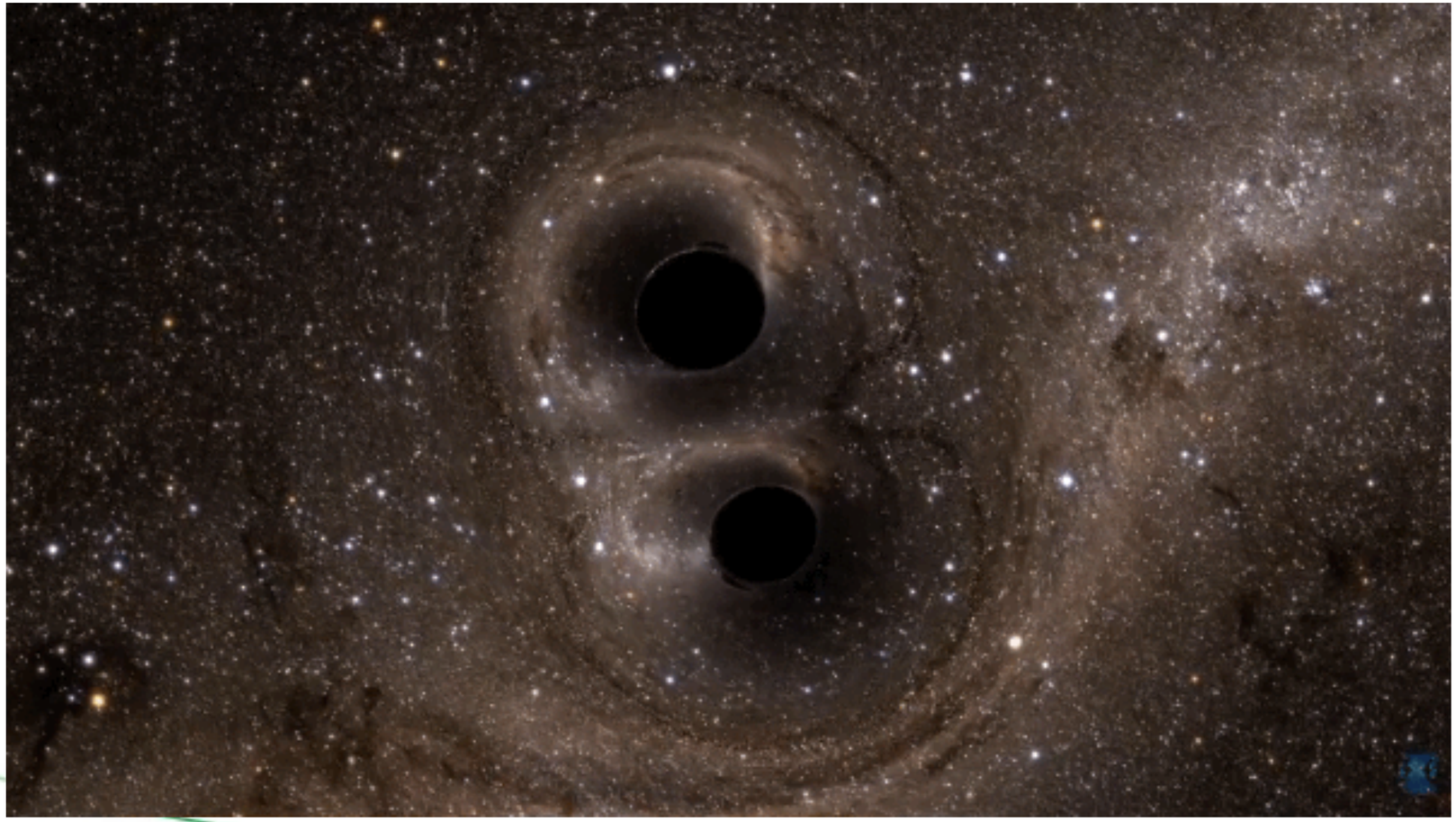

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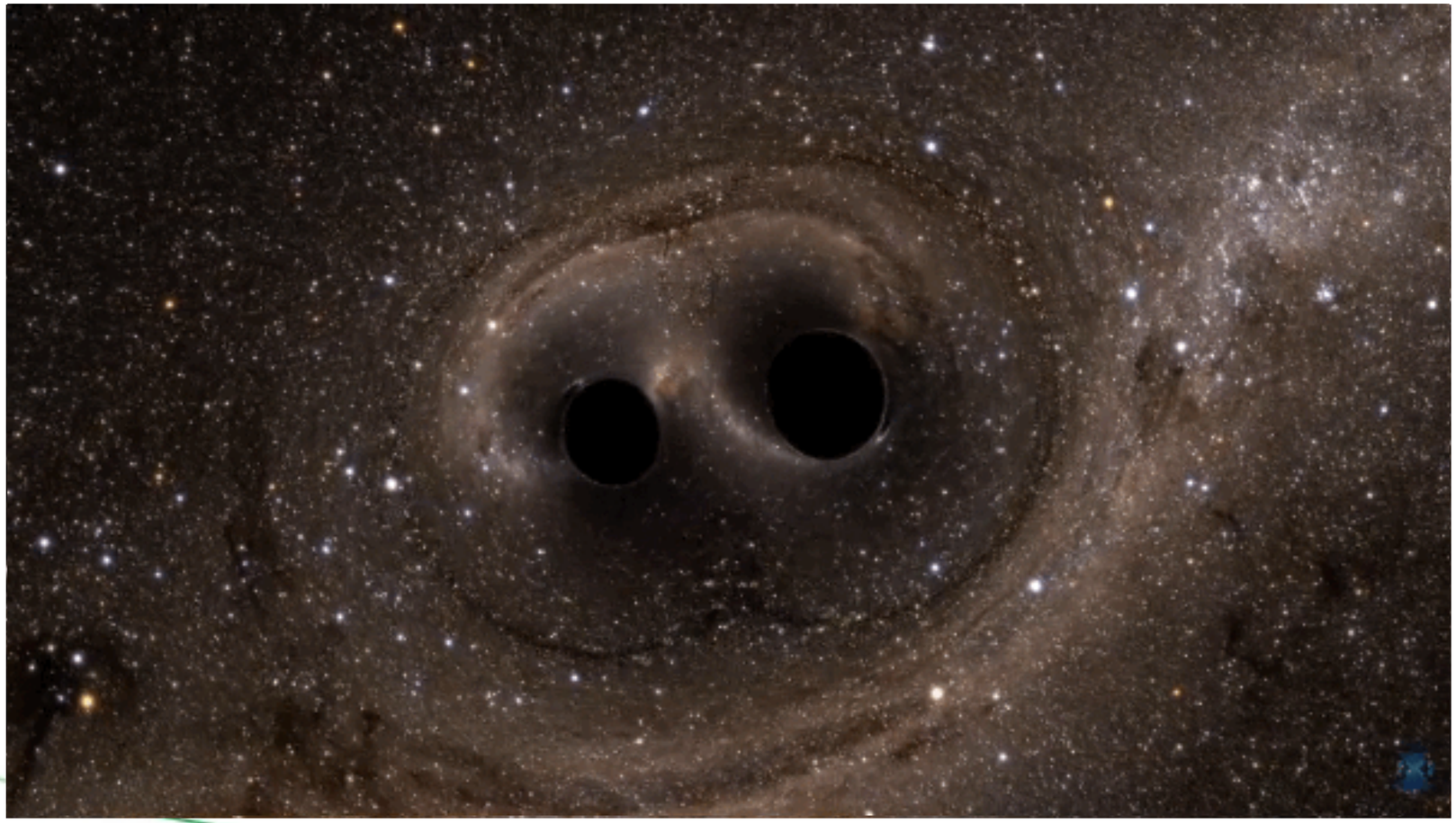

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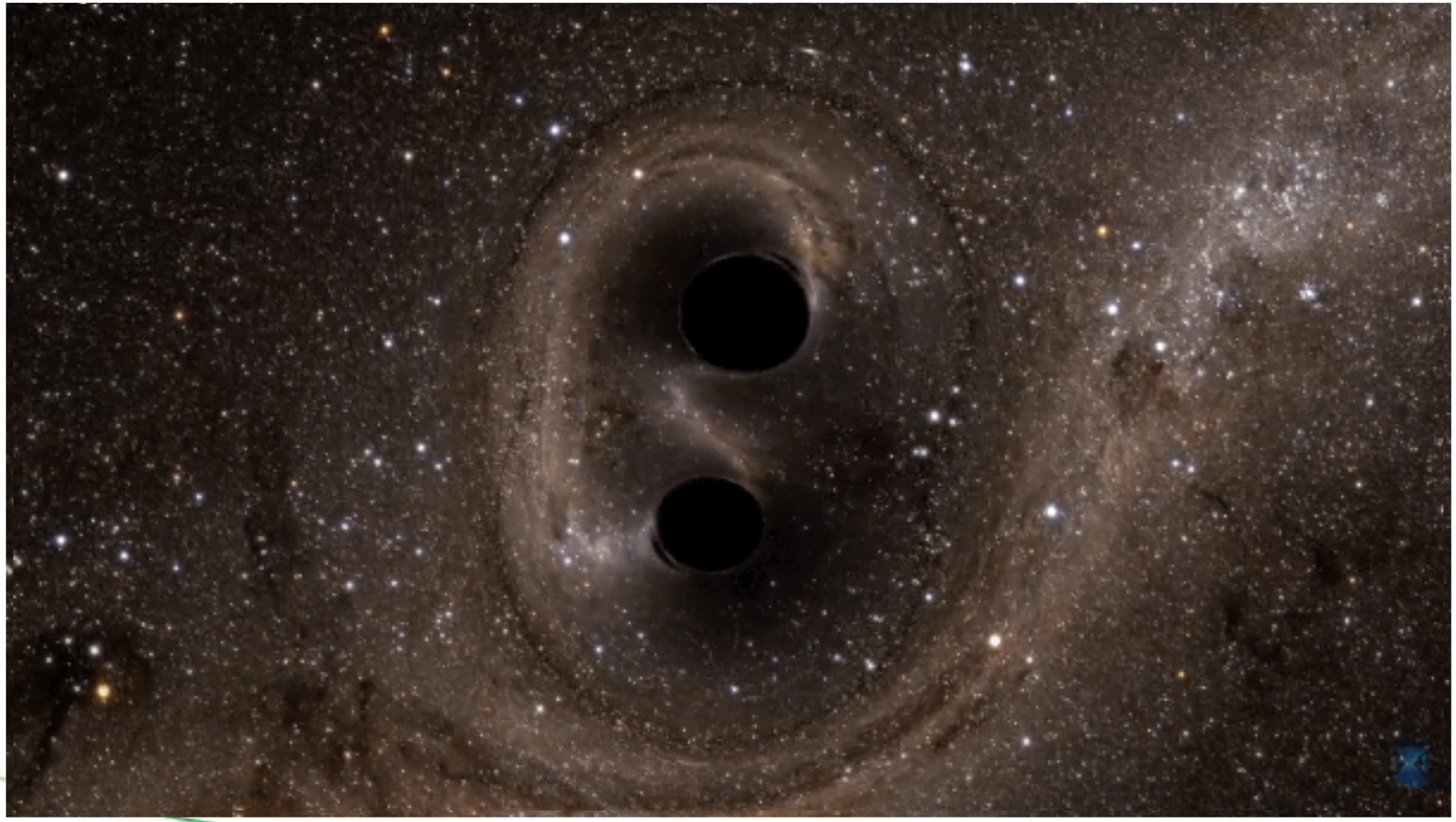

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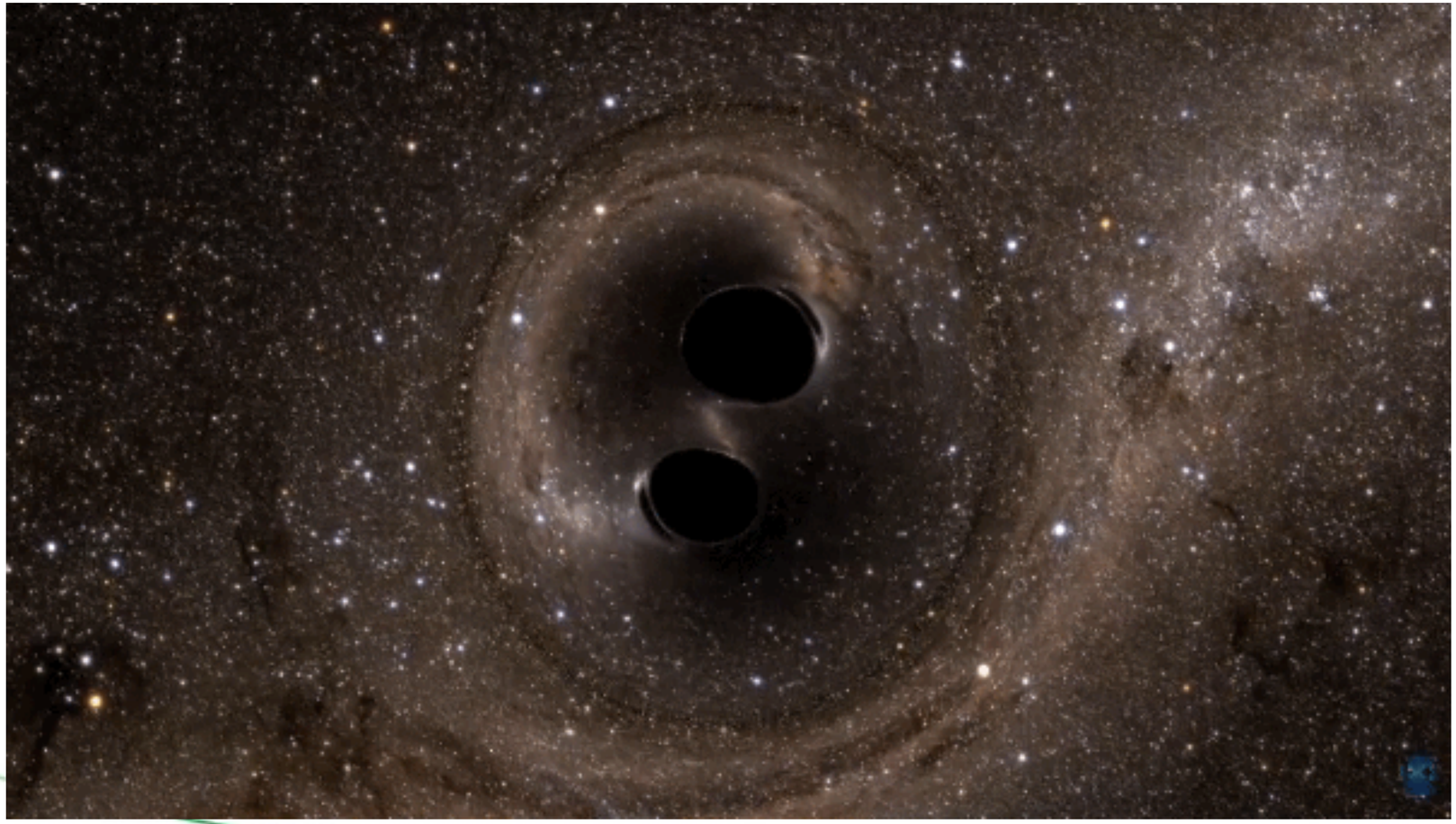

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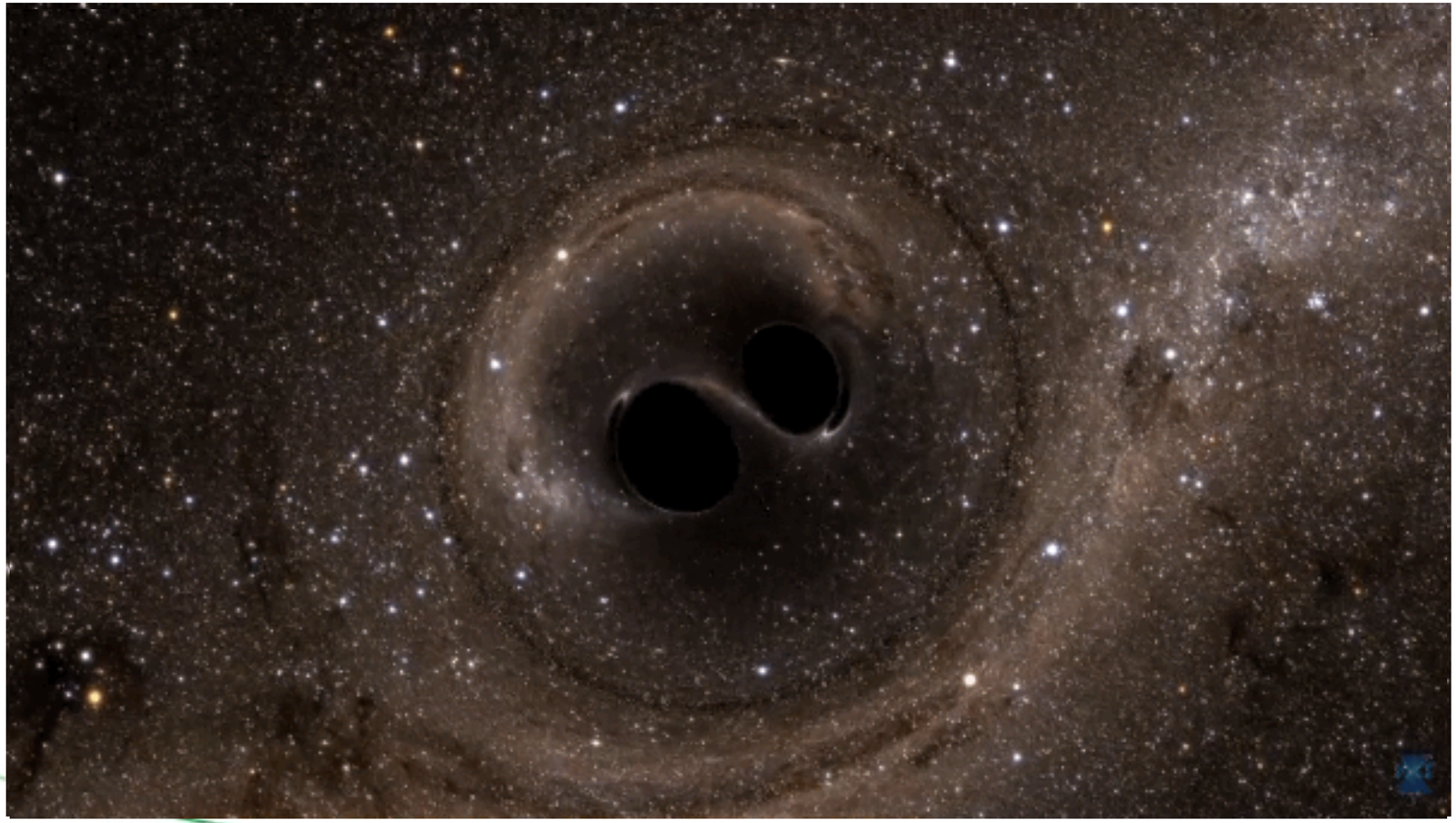

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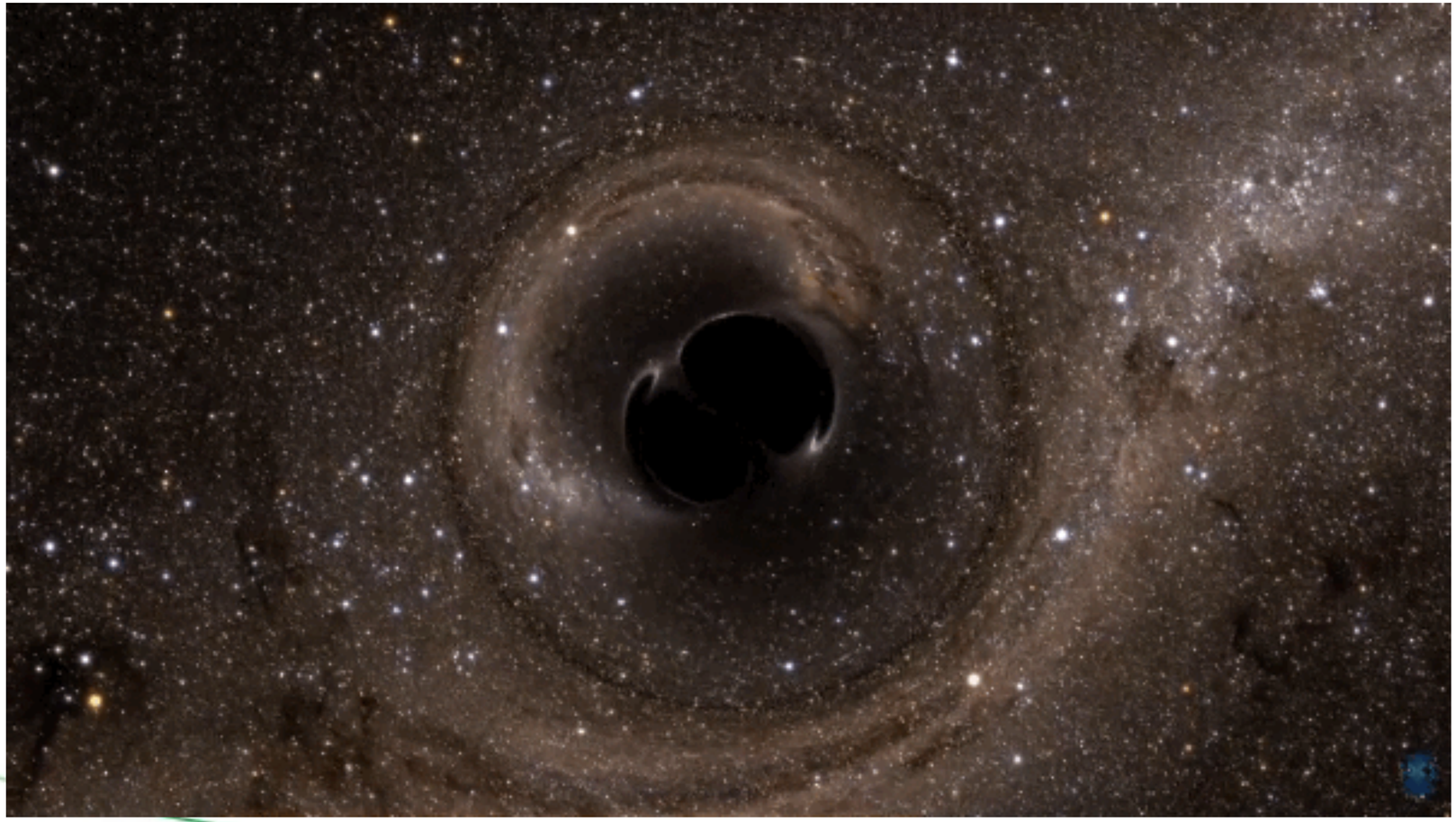

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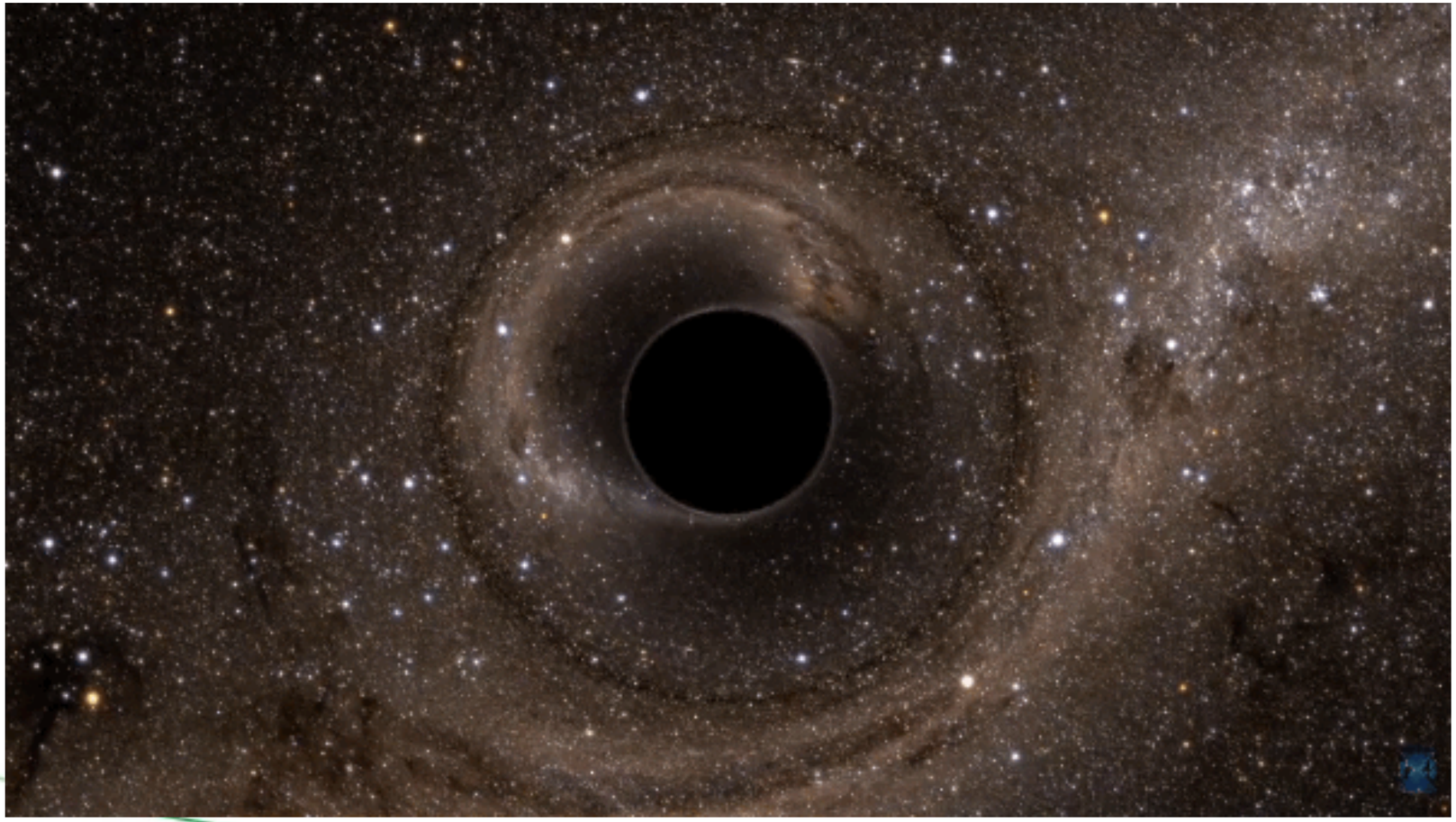

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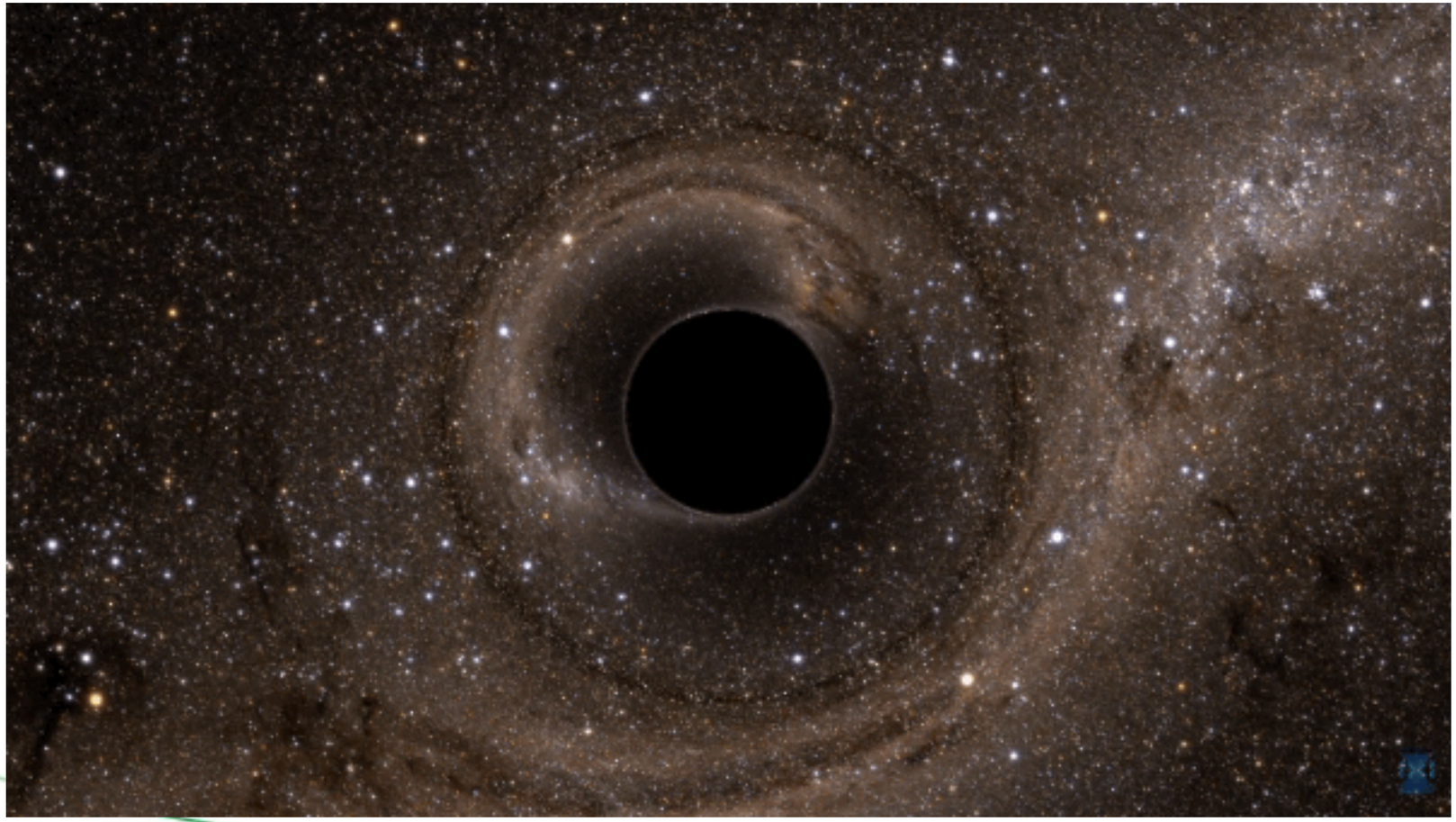

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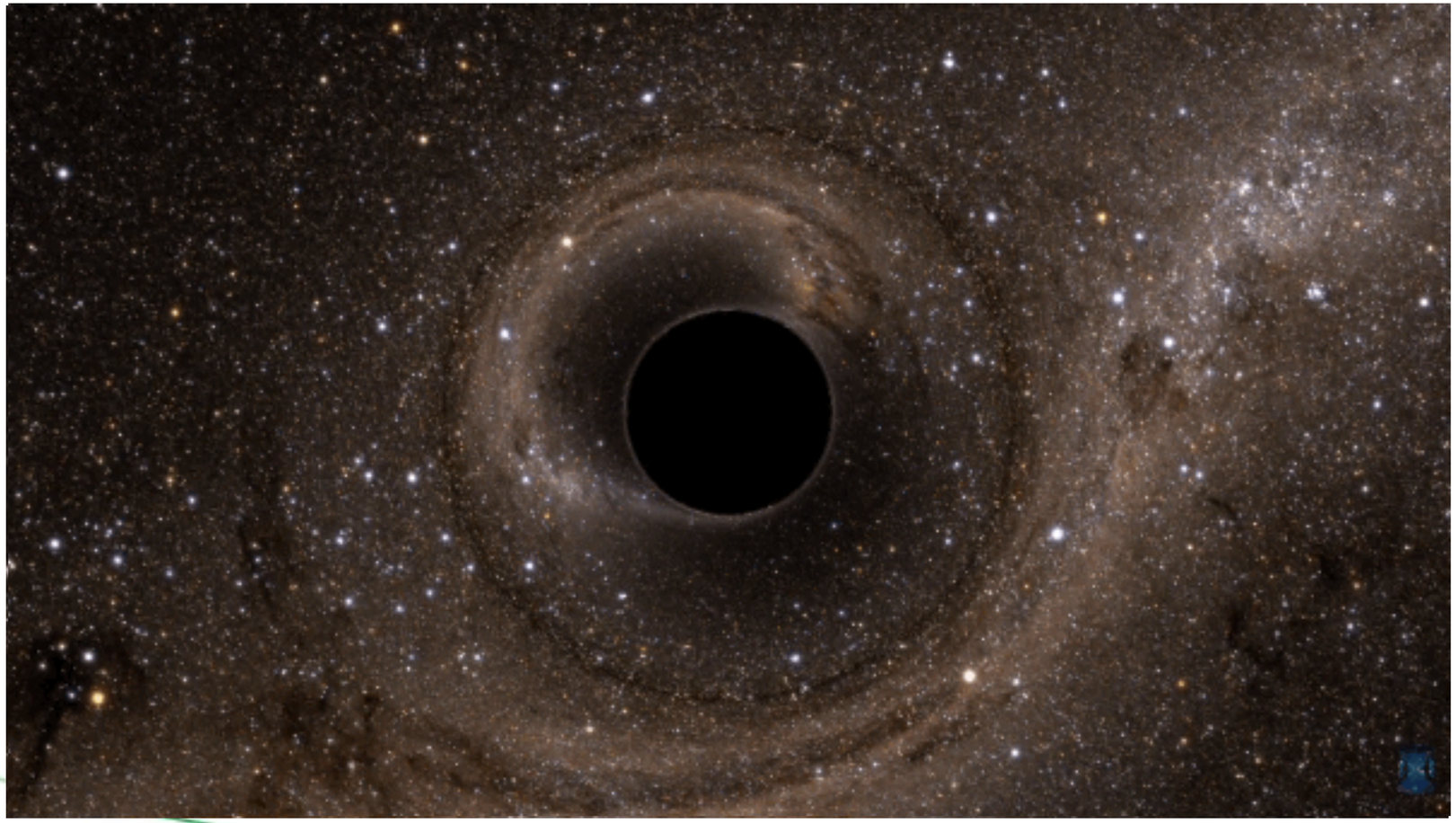
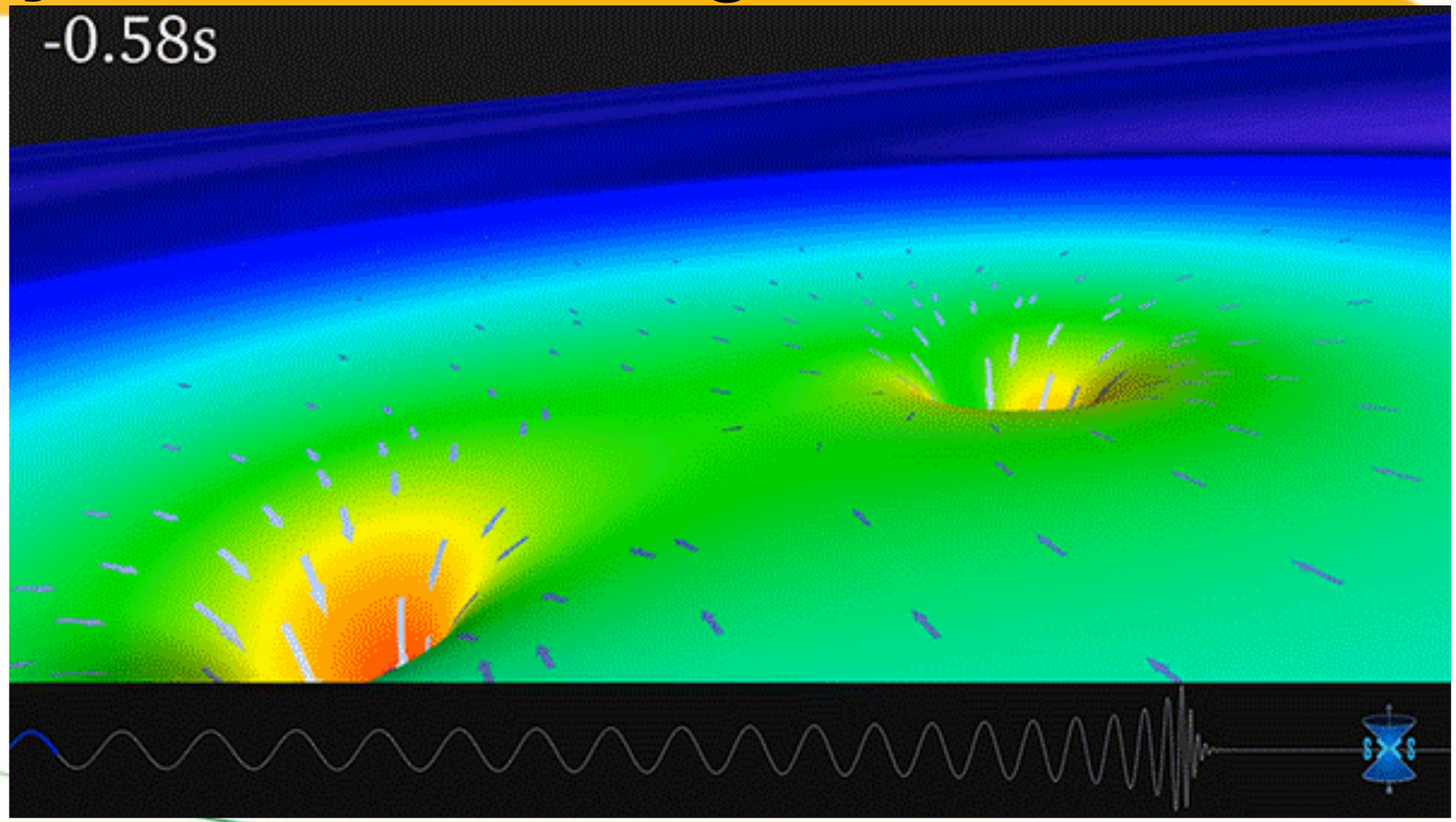


First observation of gravitational waves: binary black hole merger



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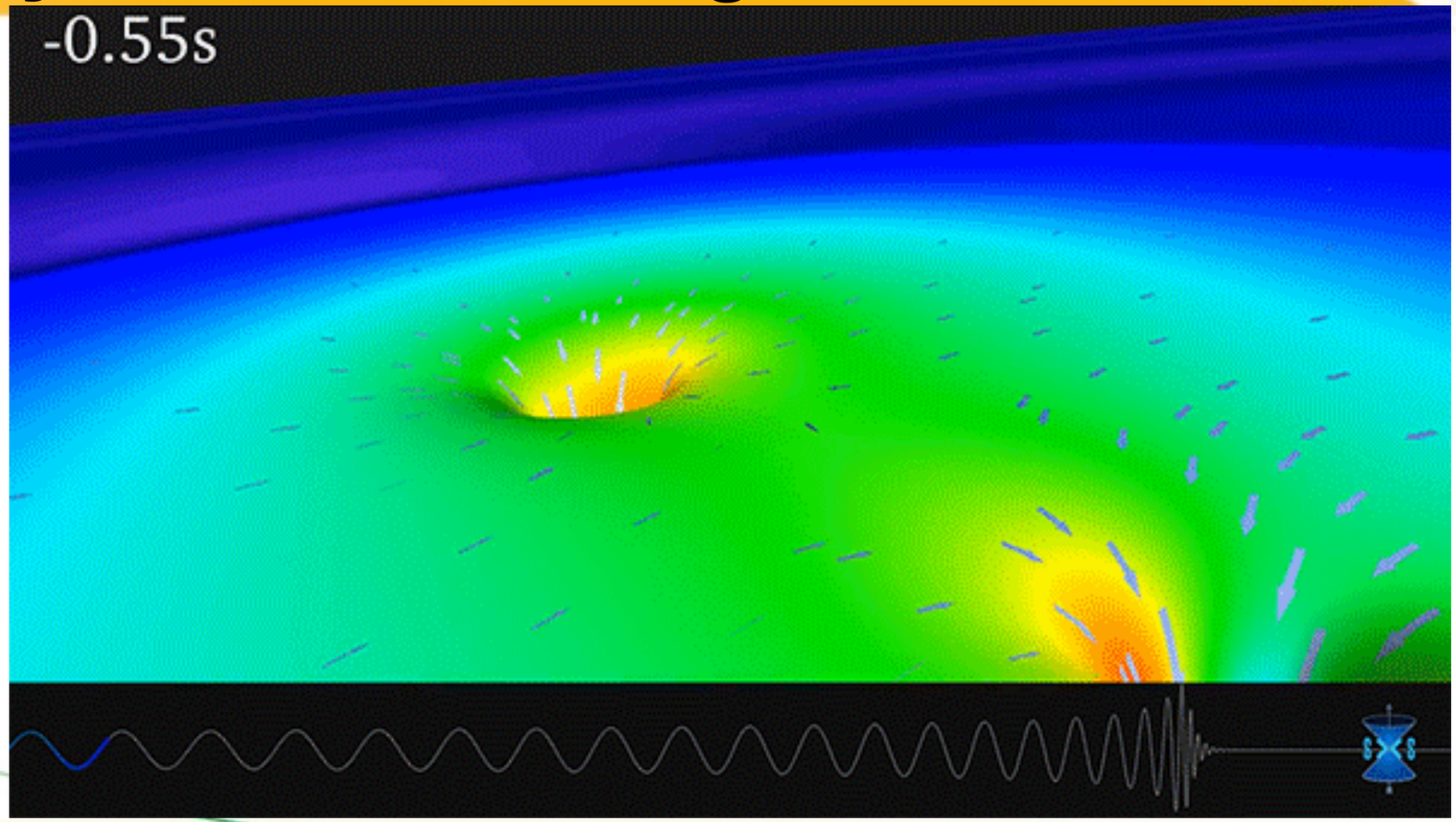

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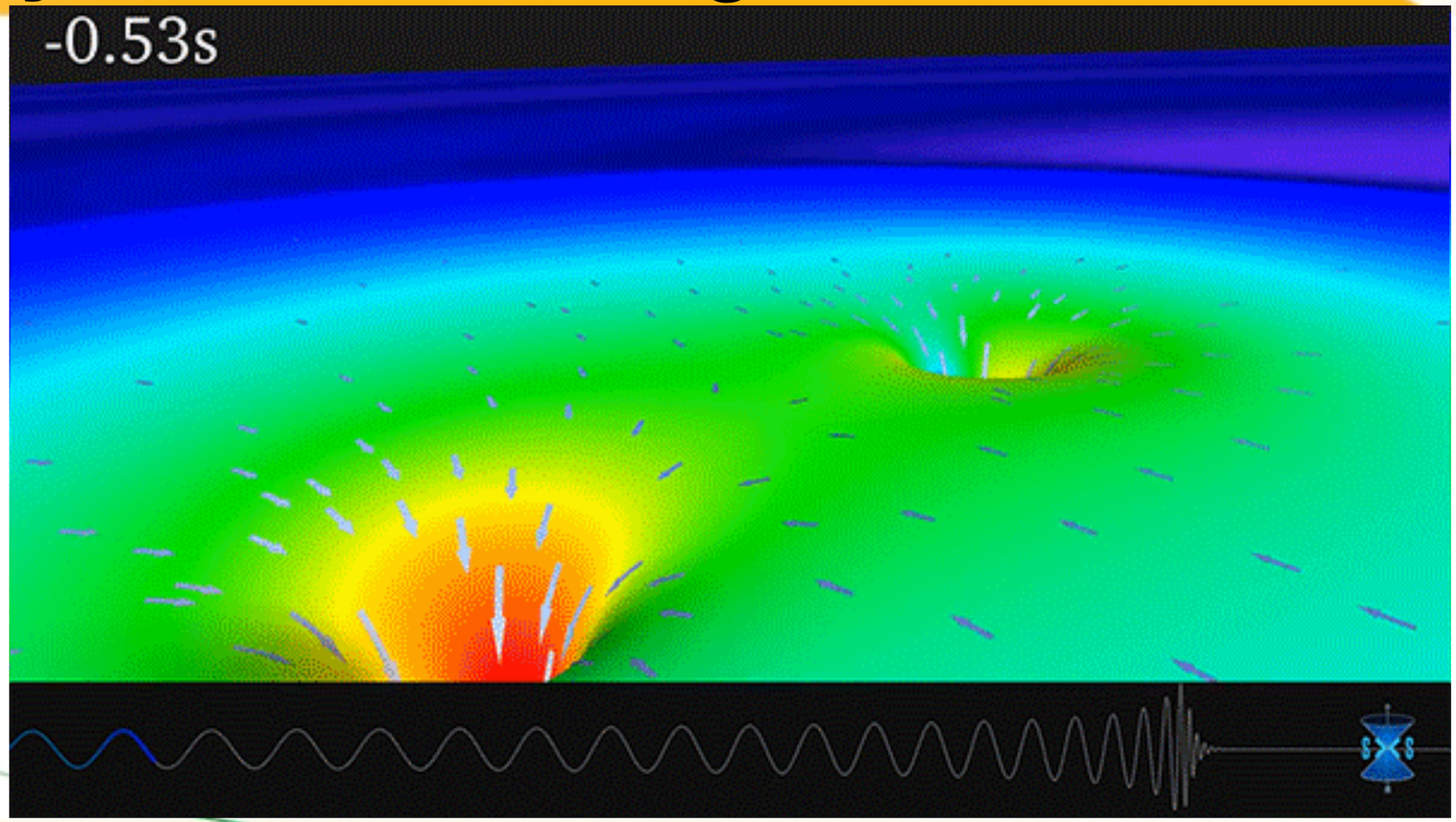

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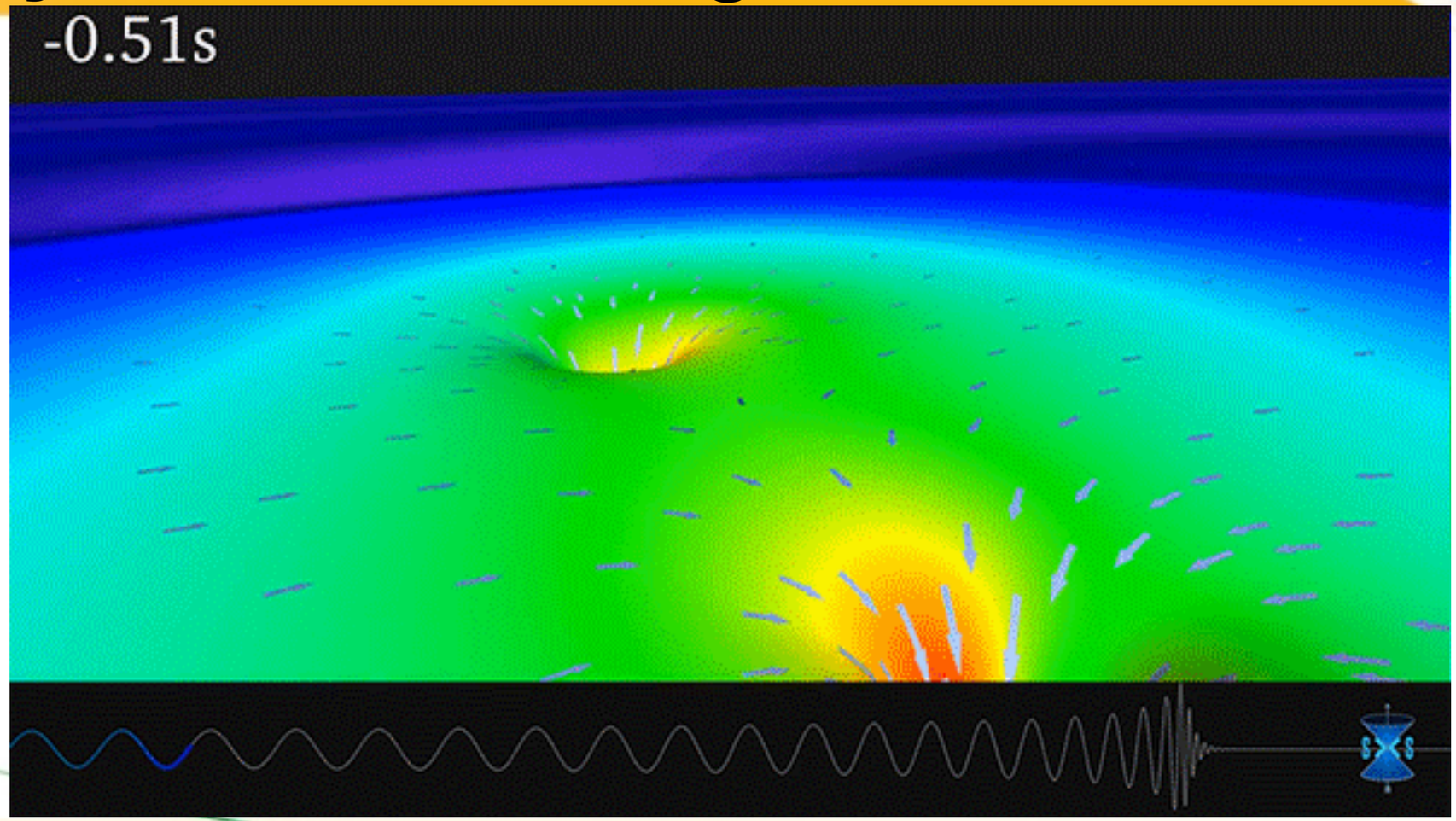

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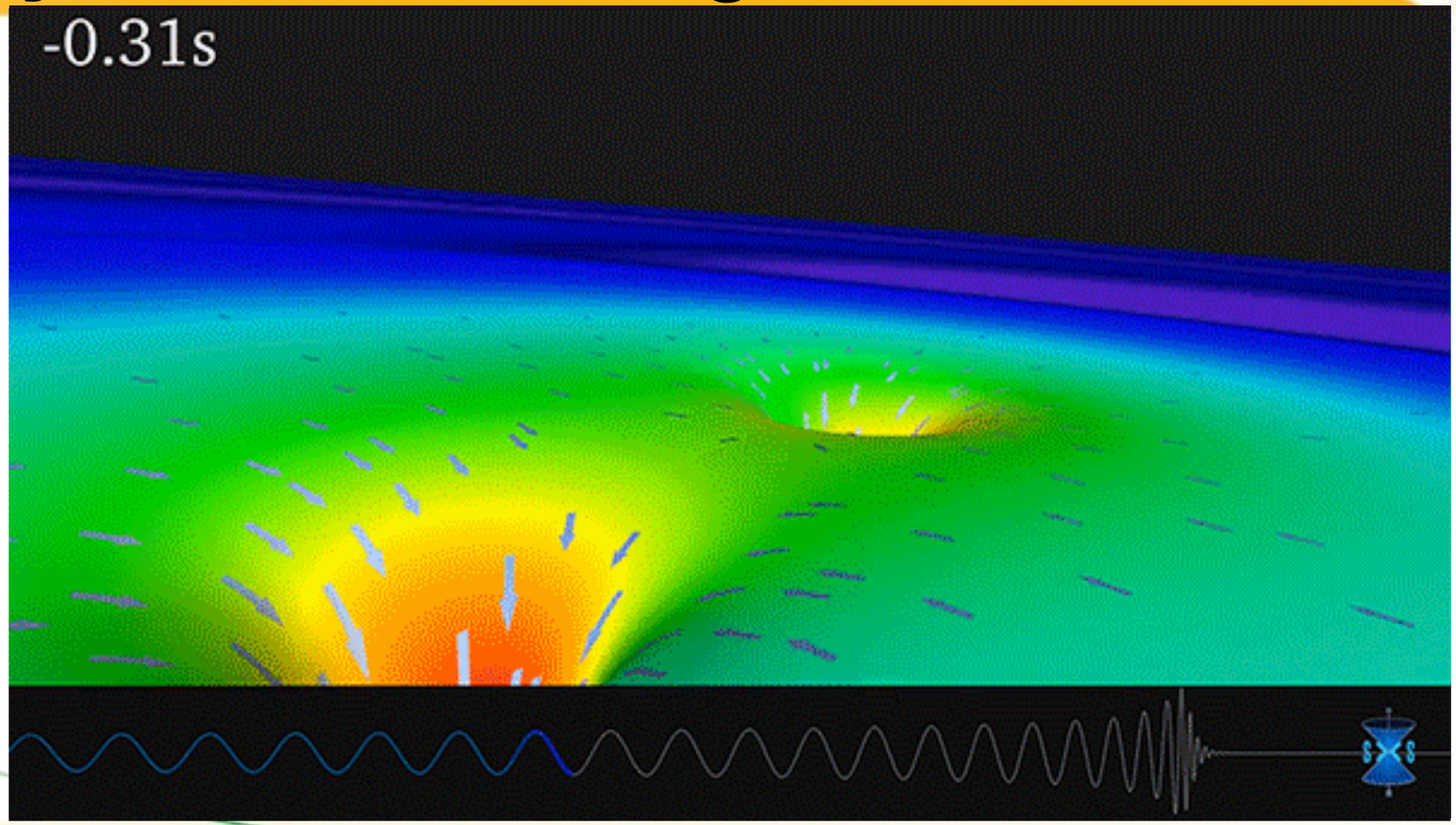

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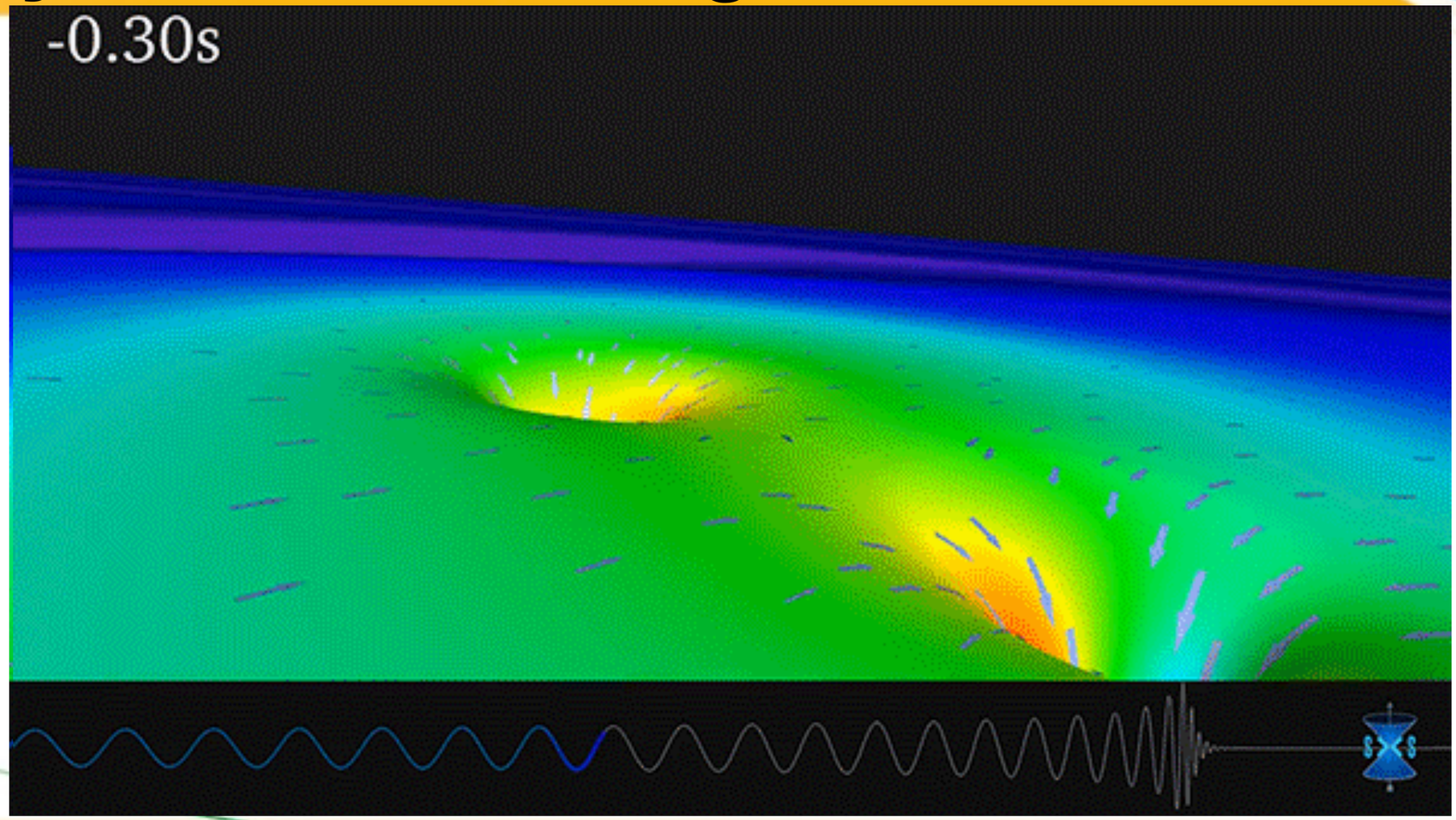

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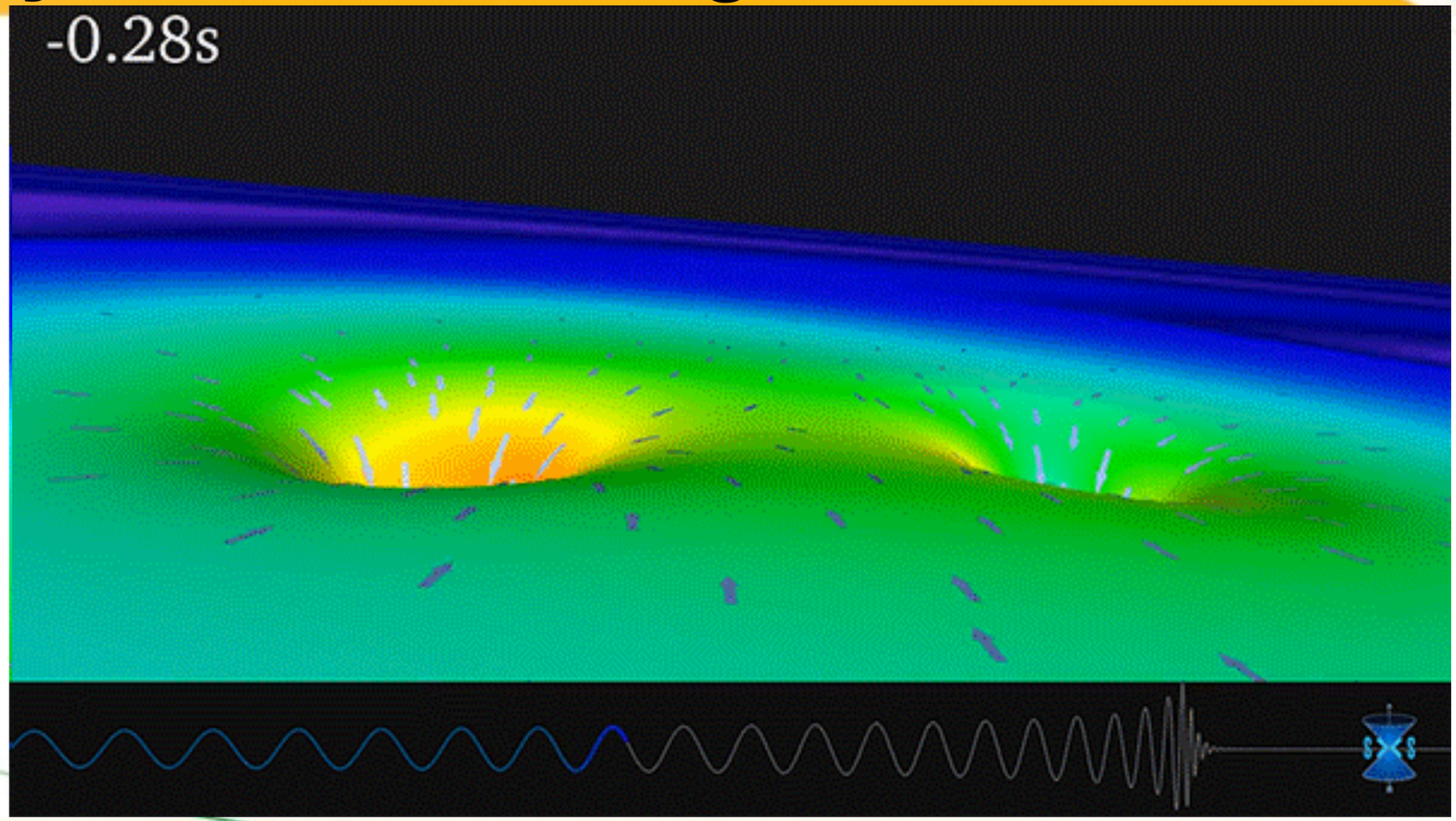

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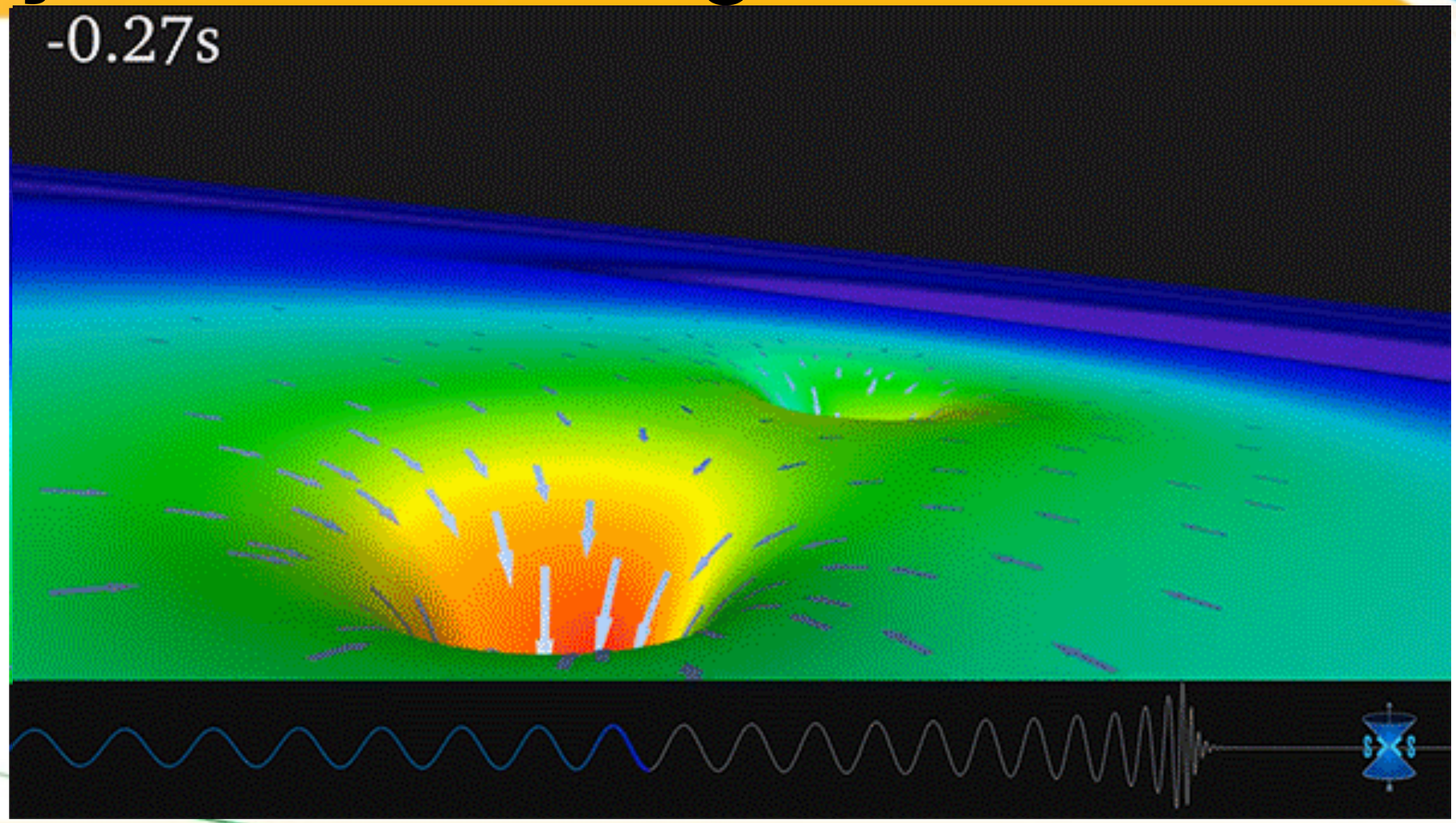

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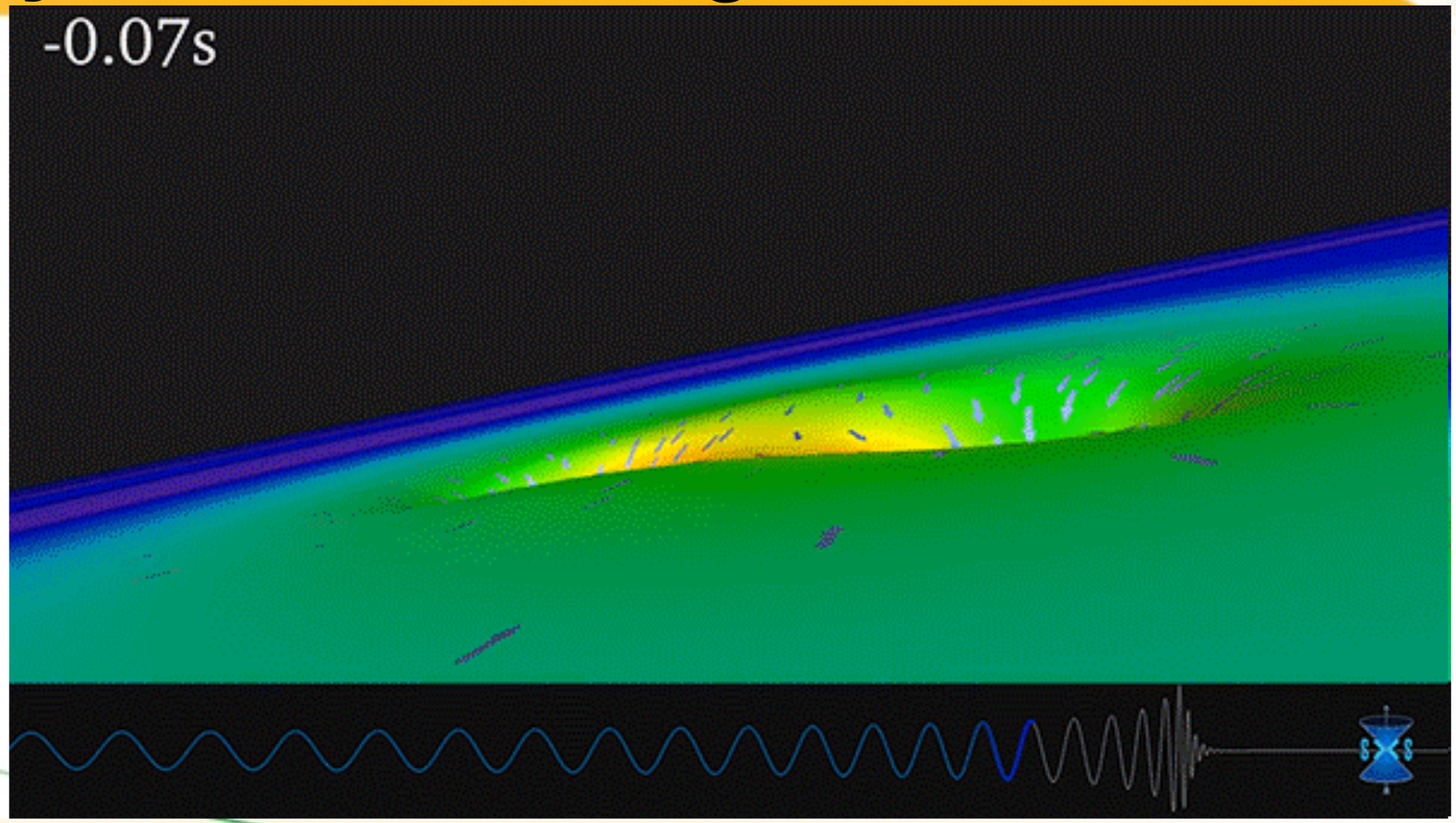

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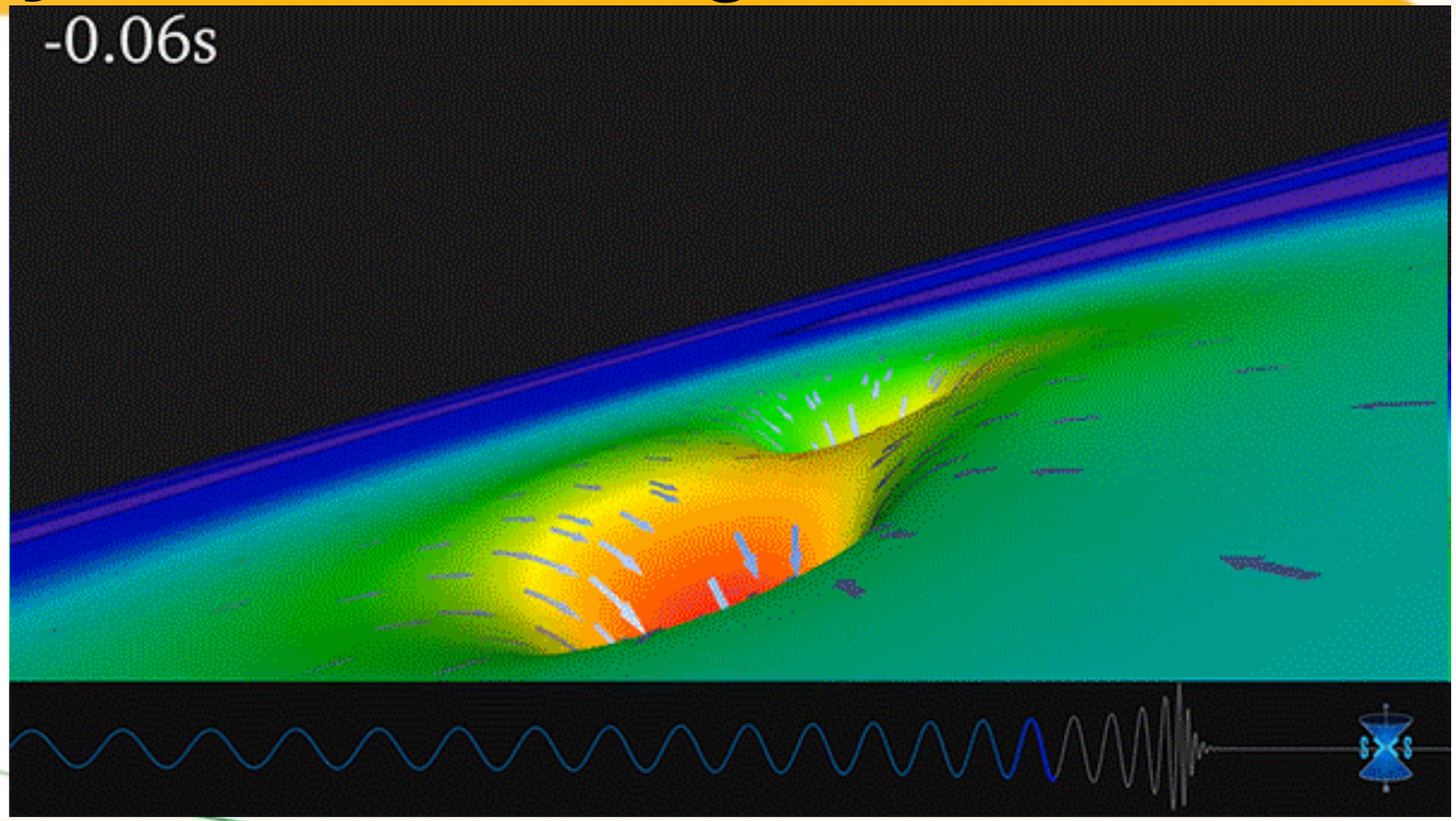

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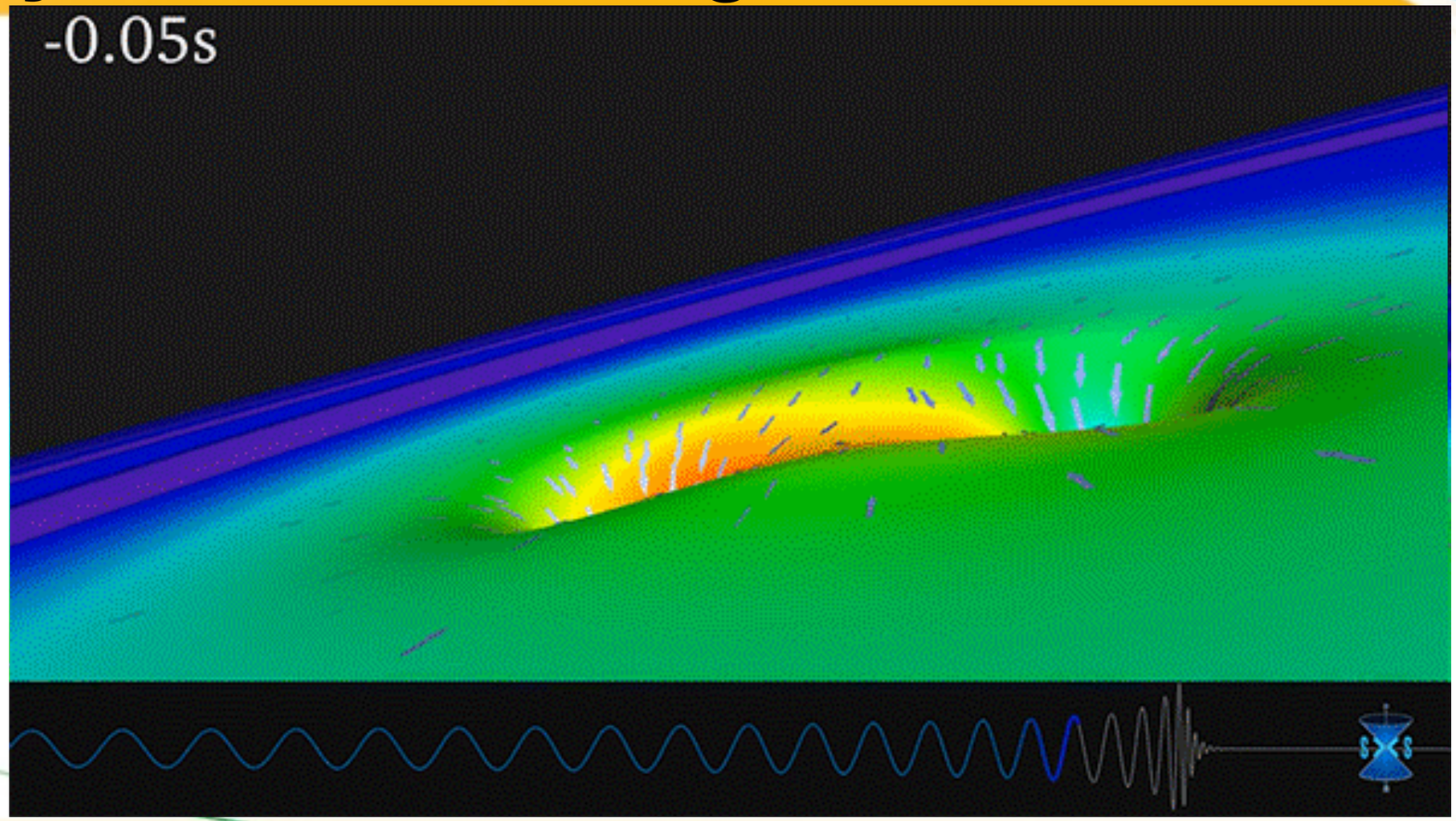

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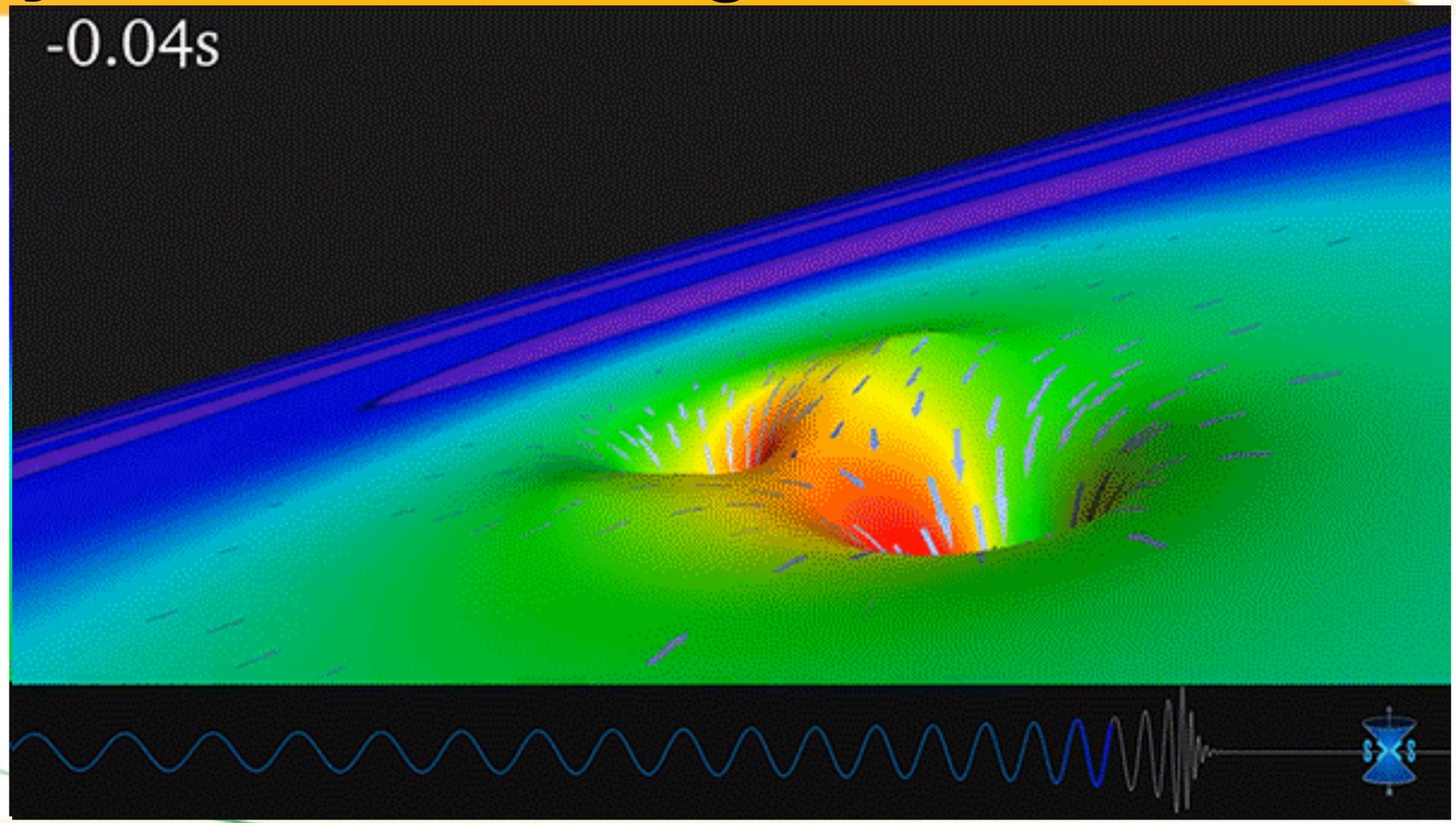

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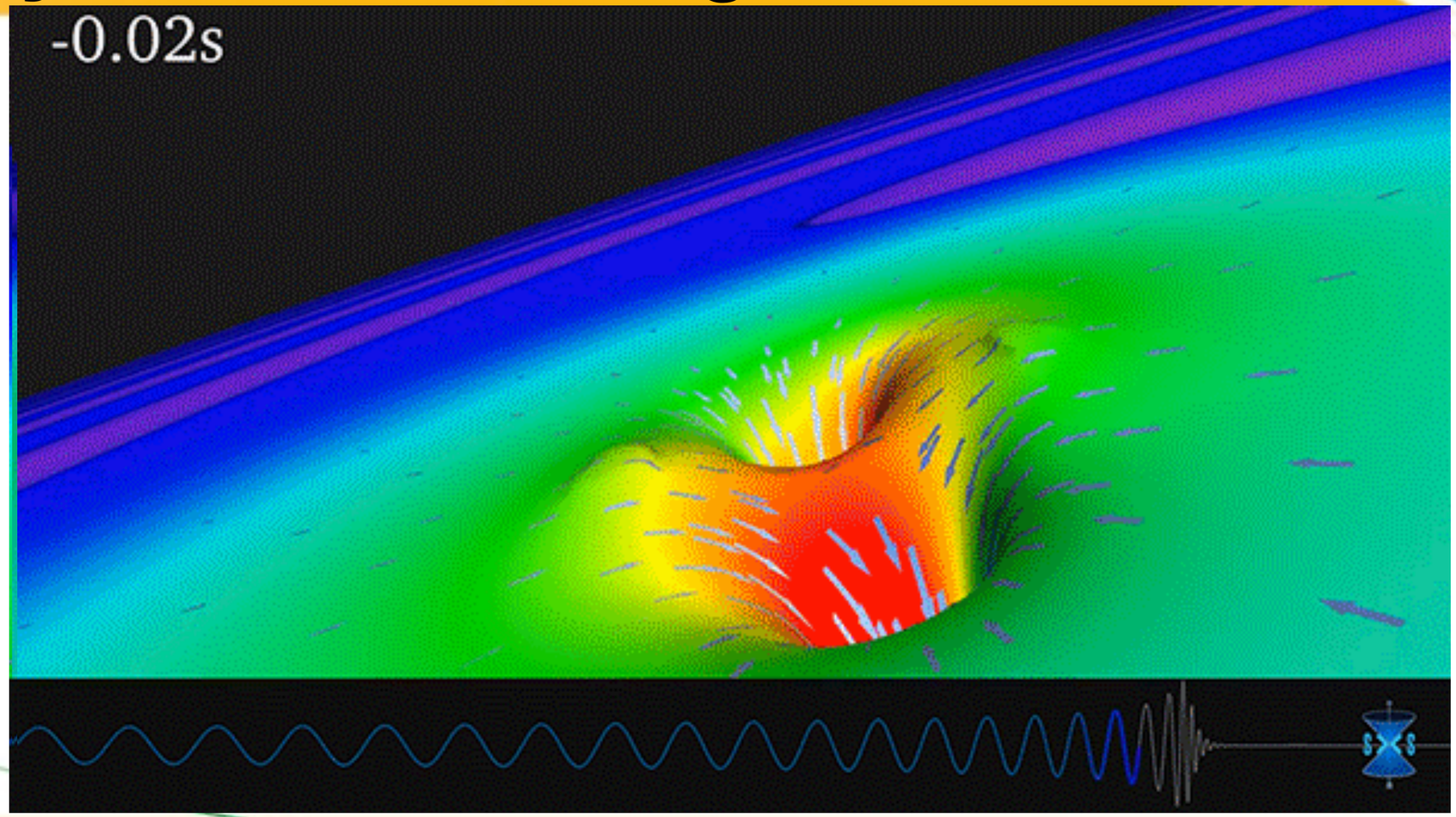

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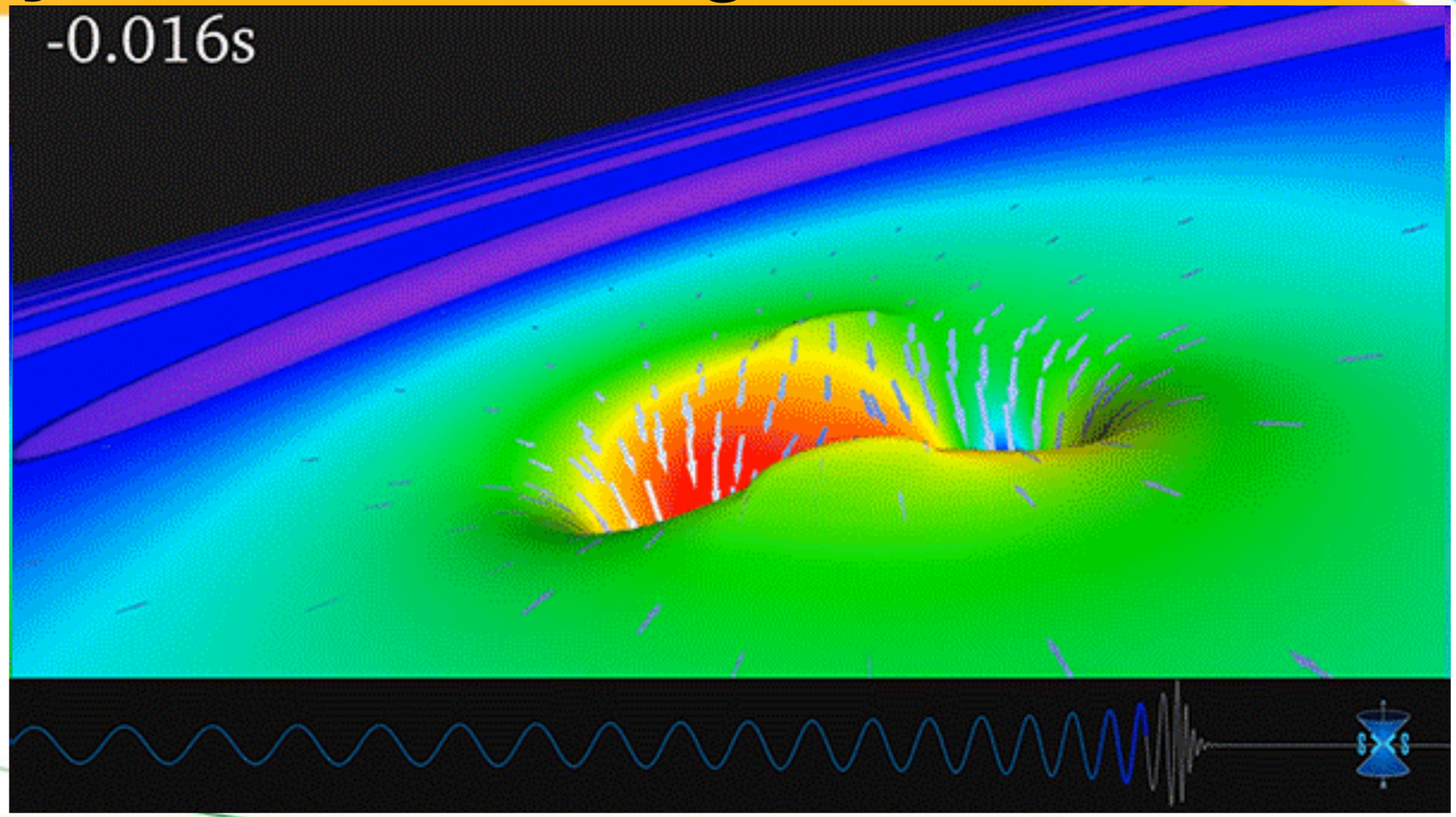

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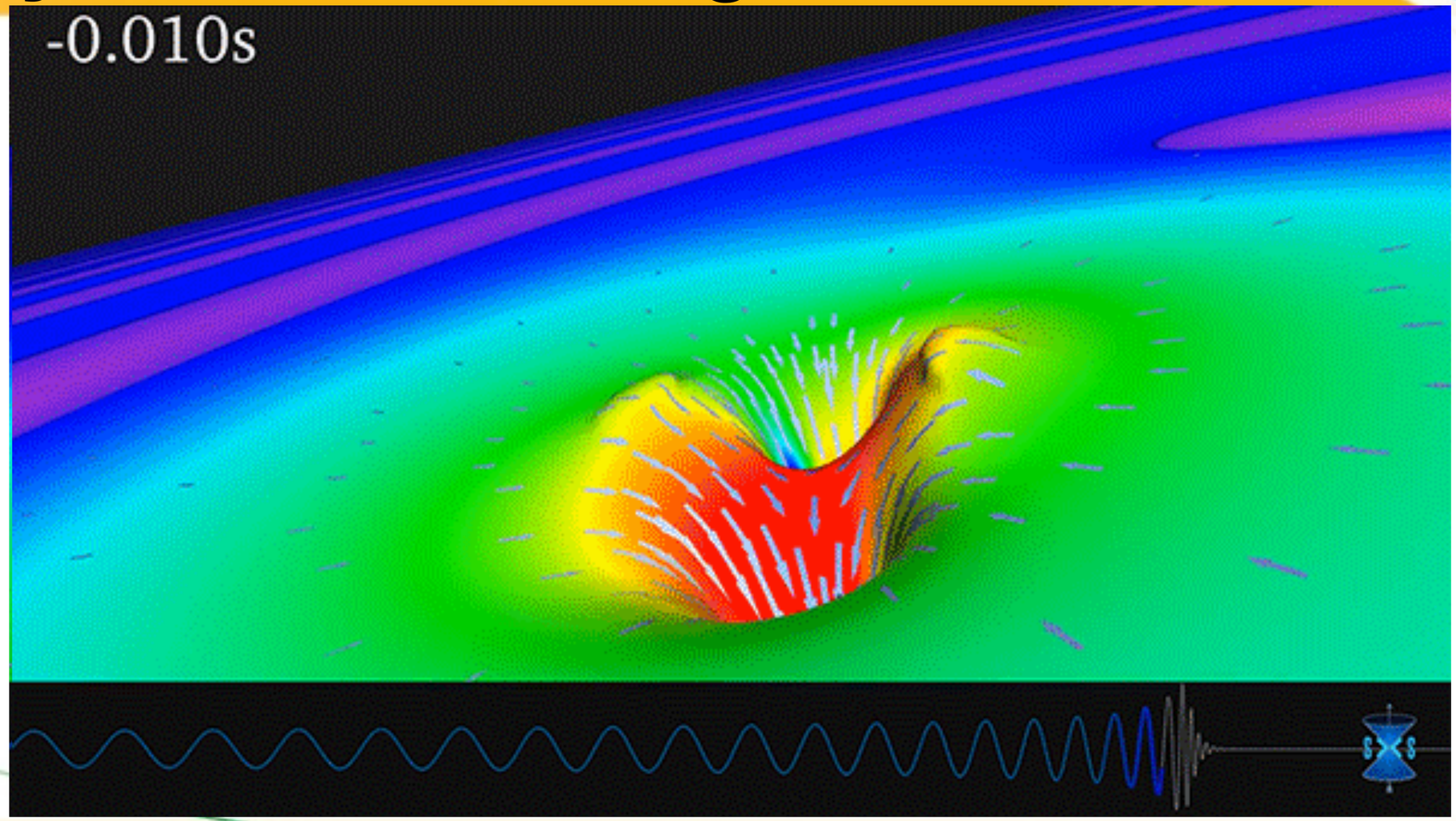

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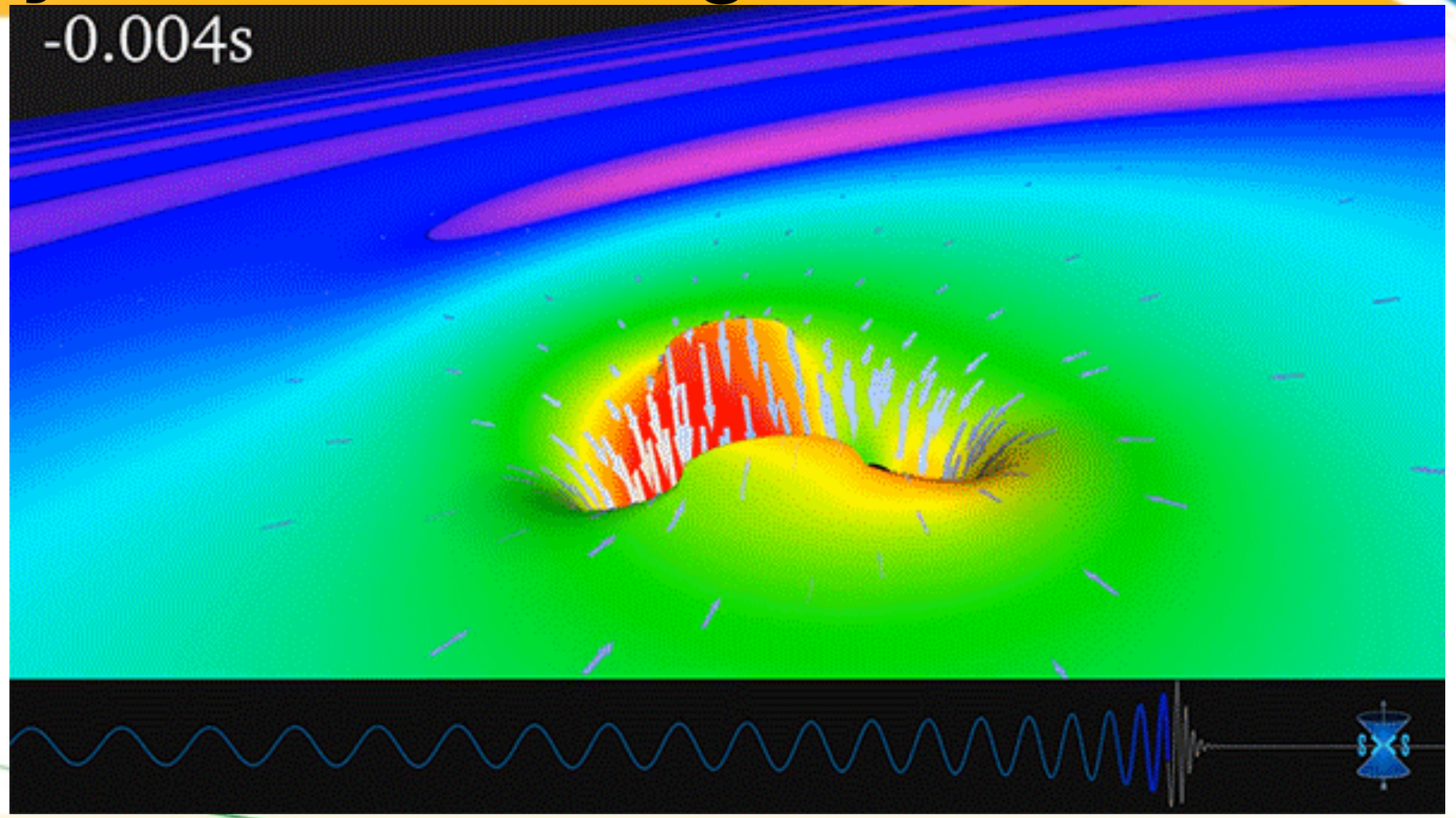

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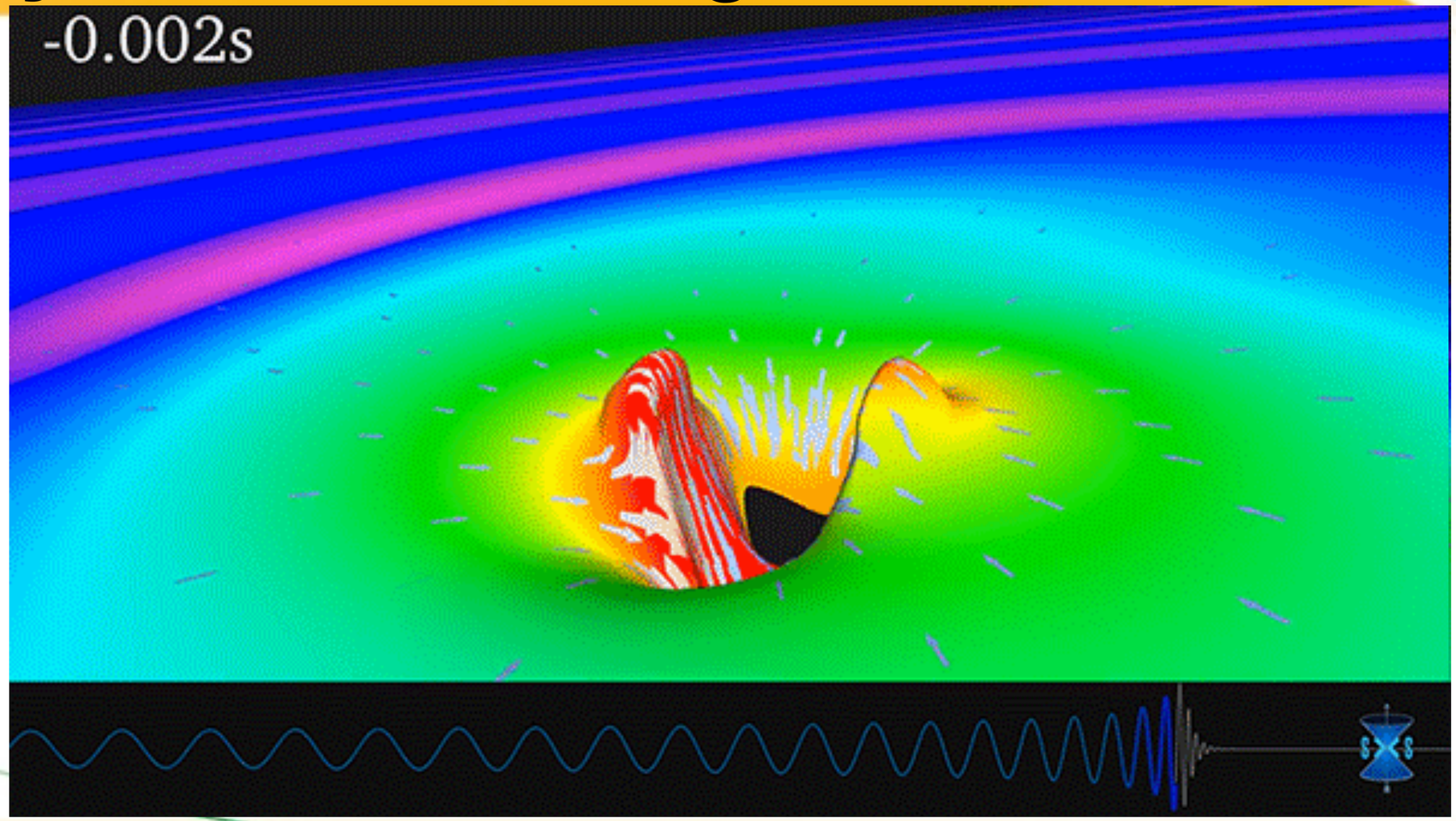

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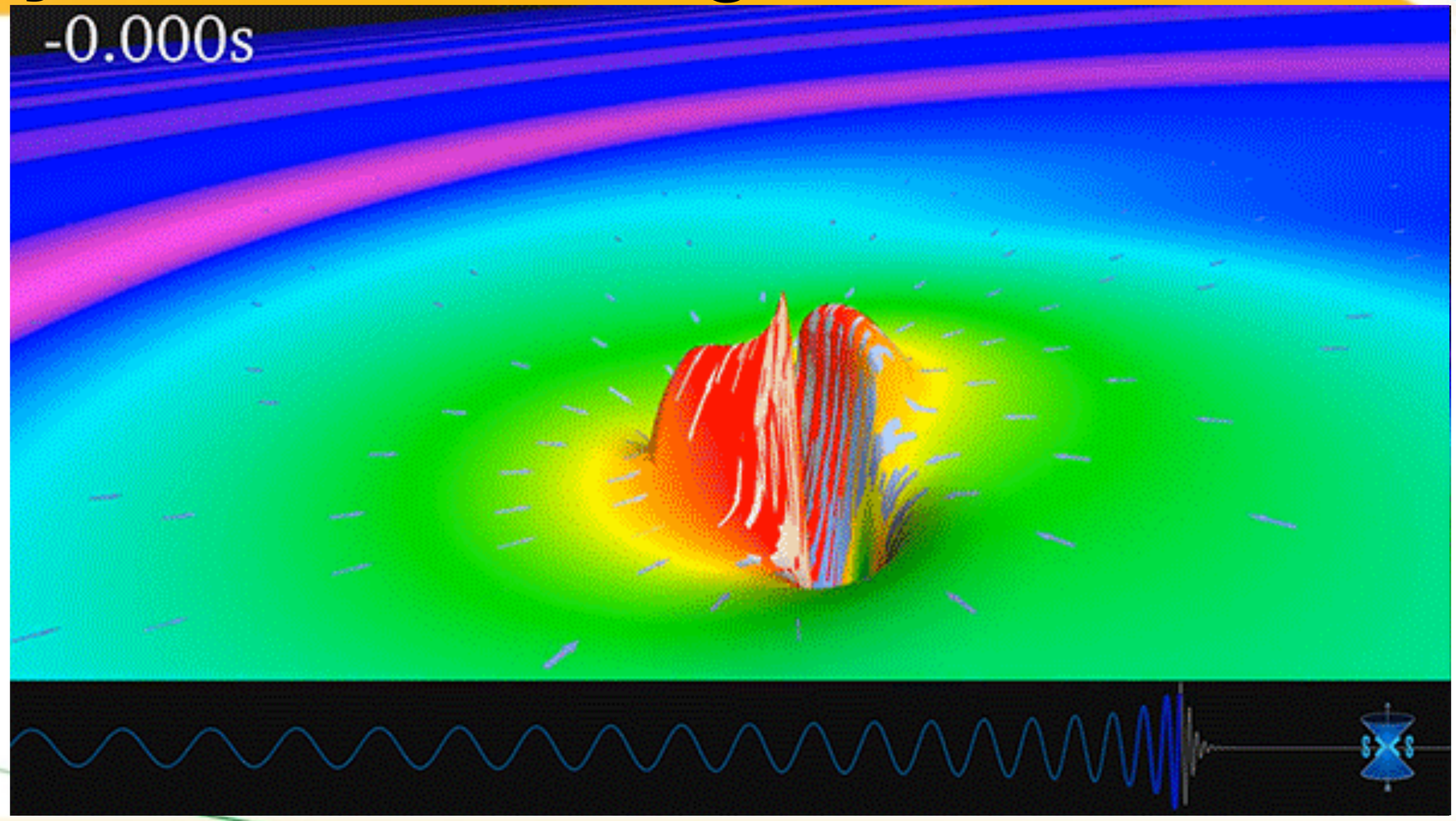
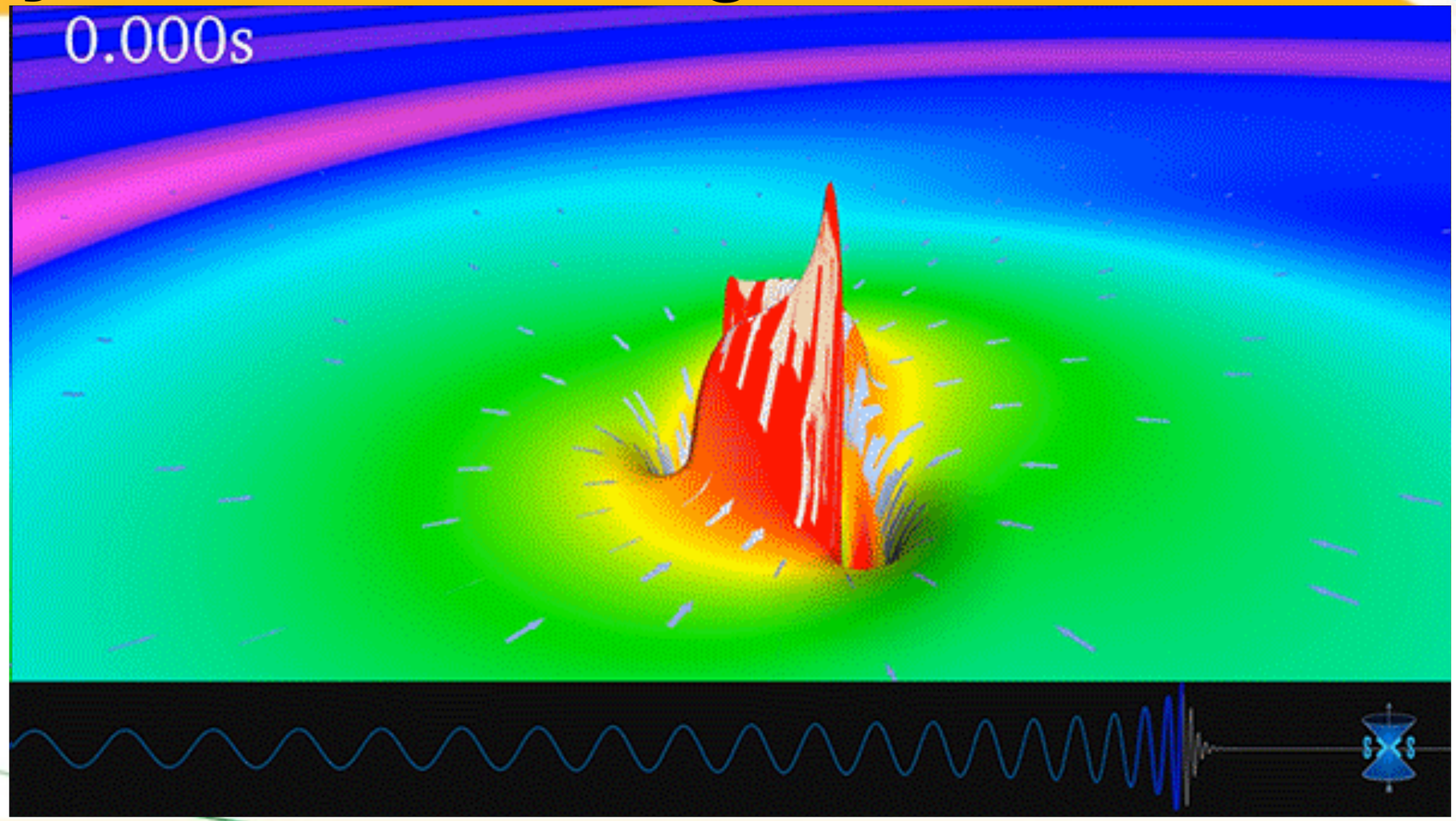


First observation of gravitational waves: binary black hole merger



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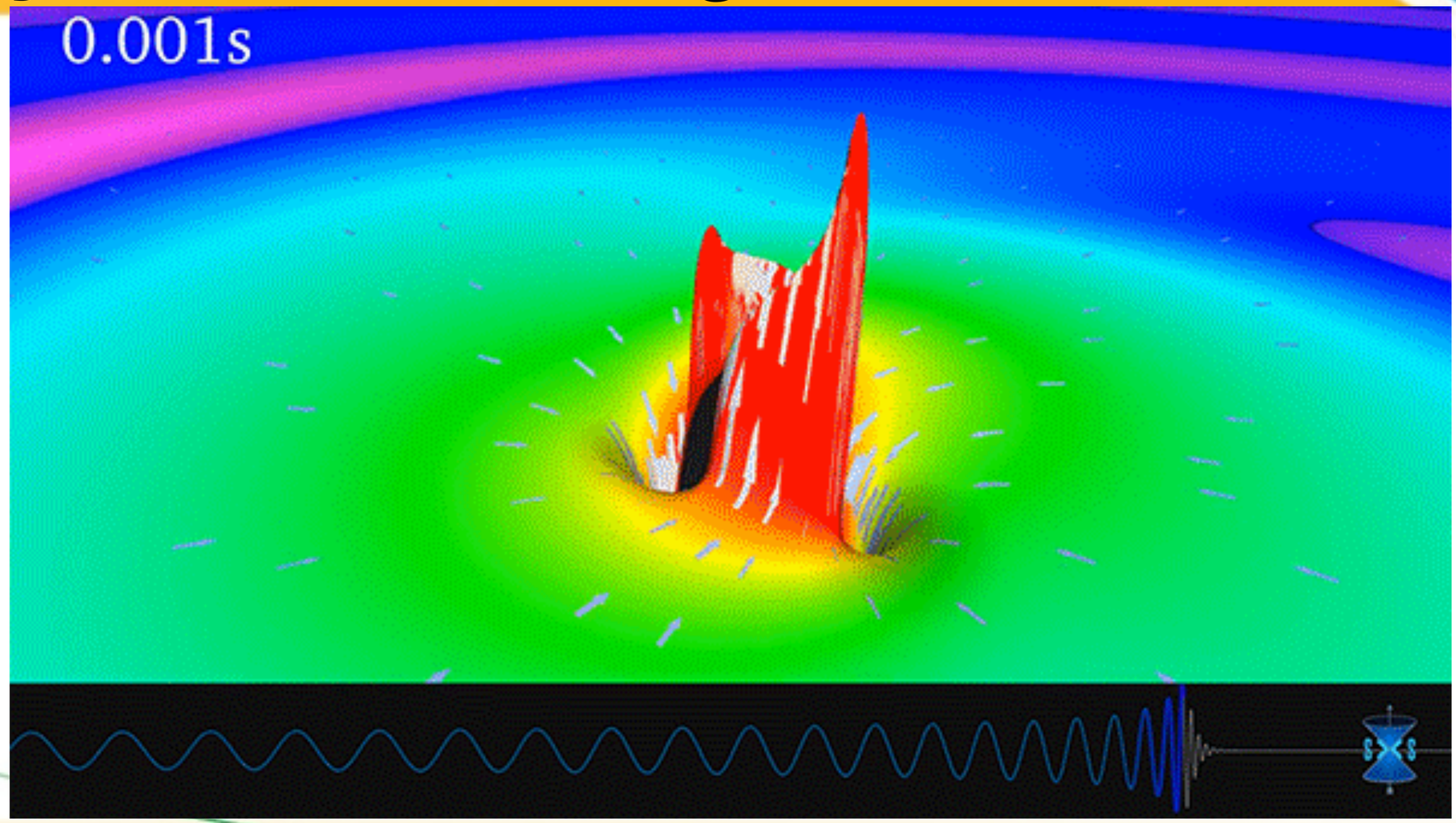

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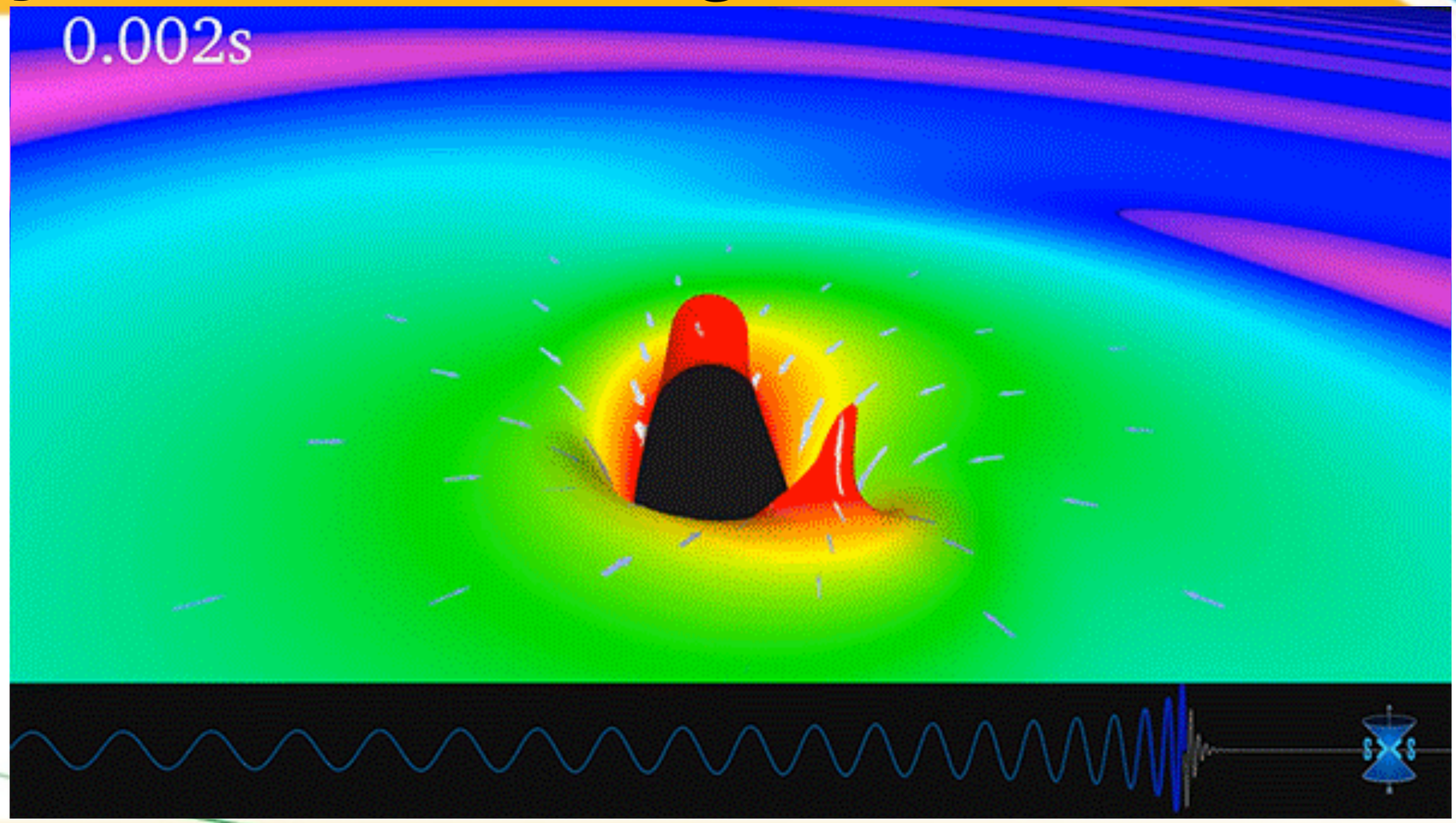

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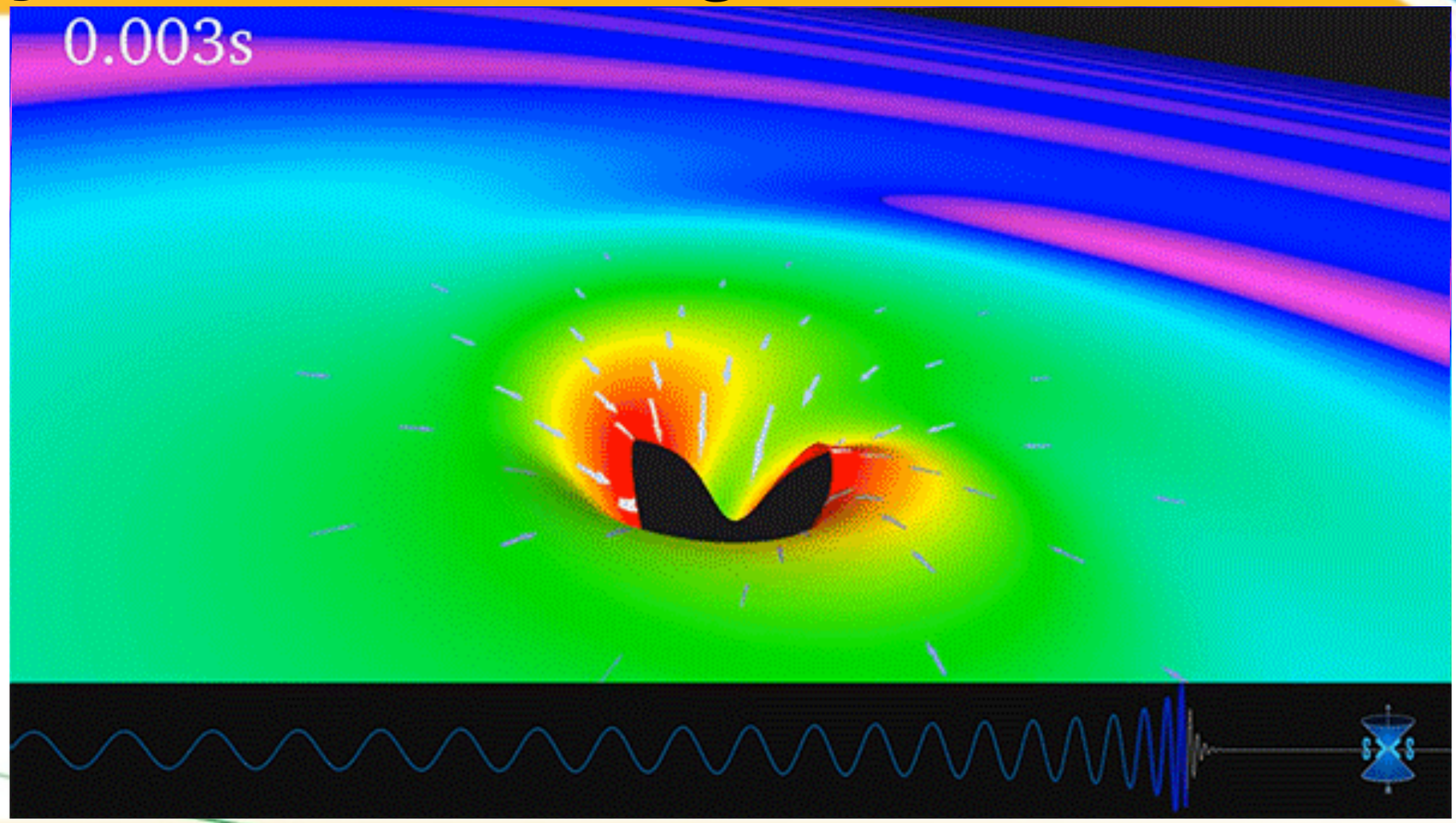

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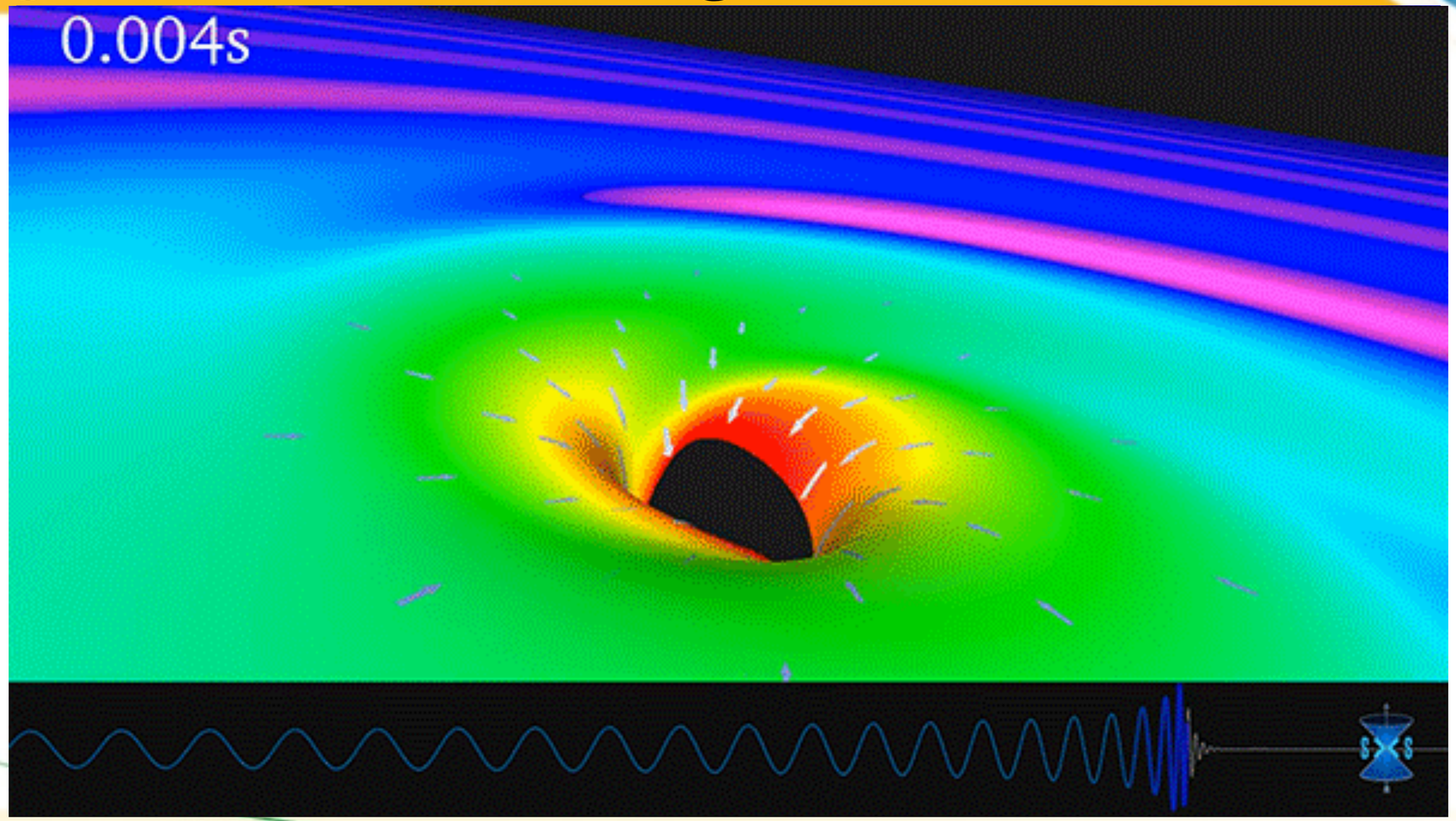

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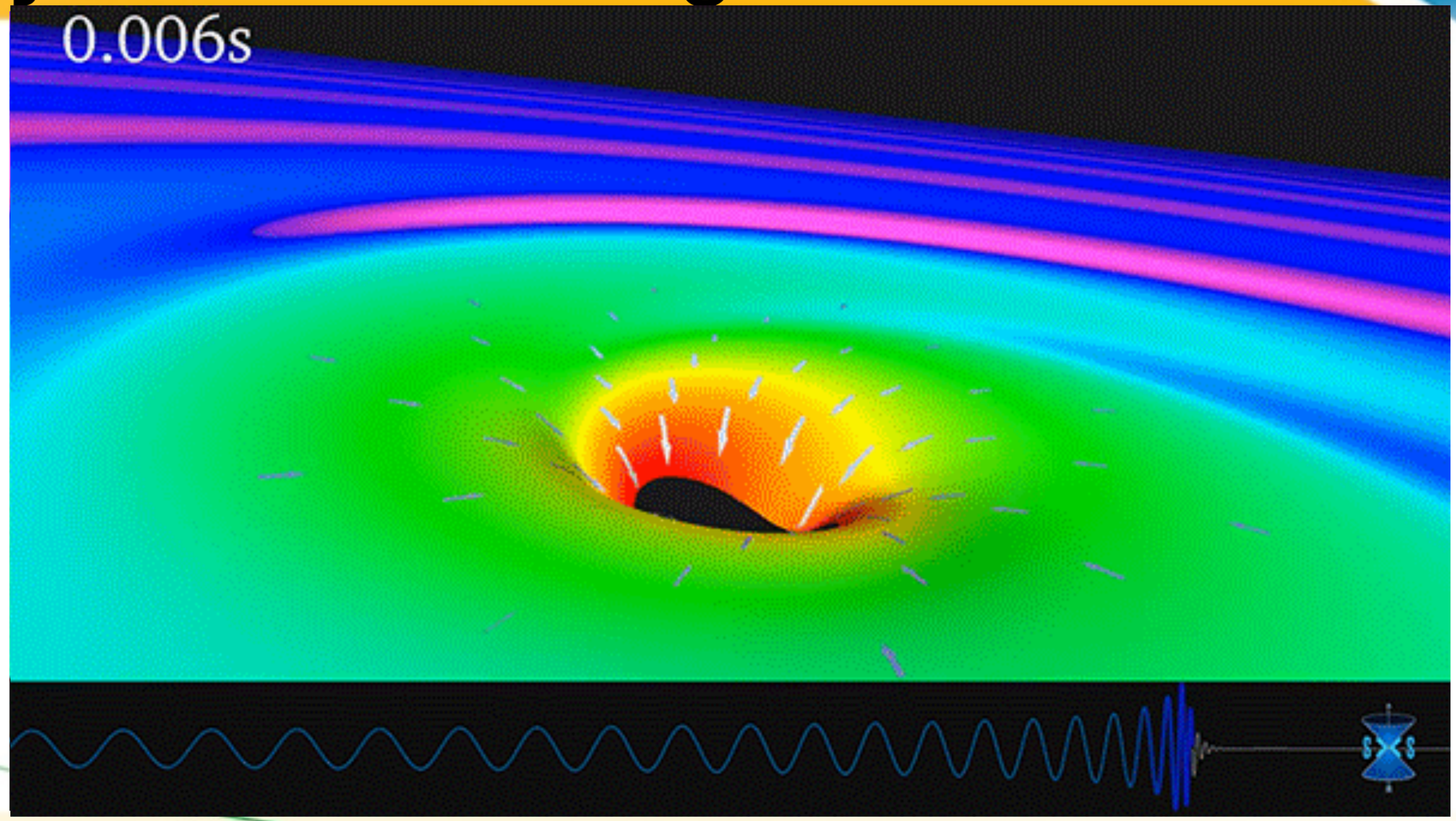

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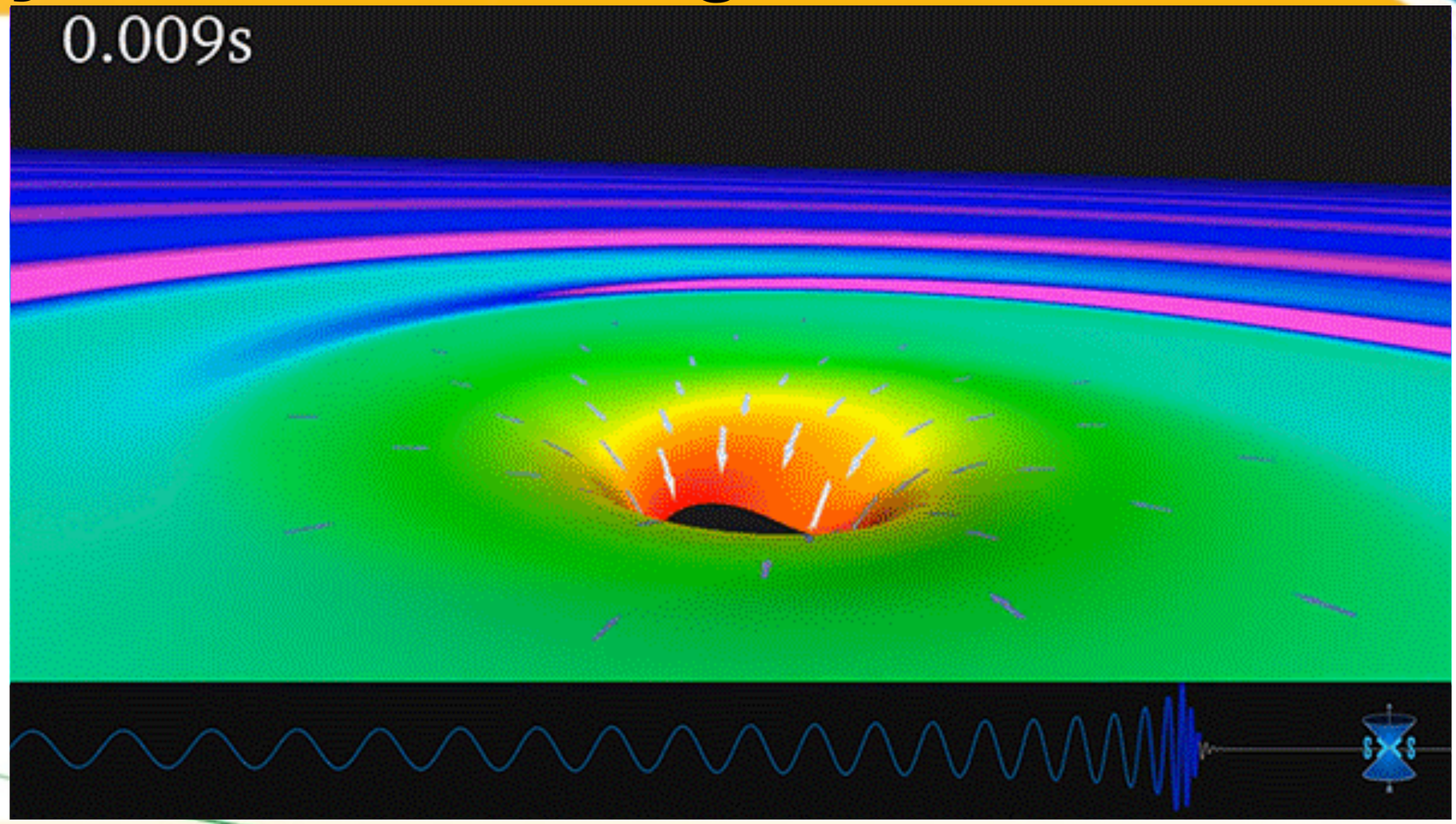

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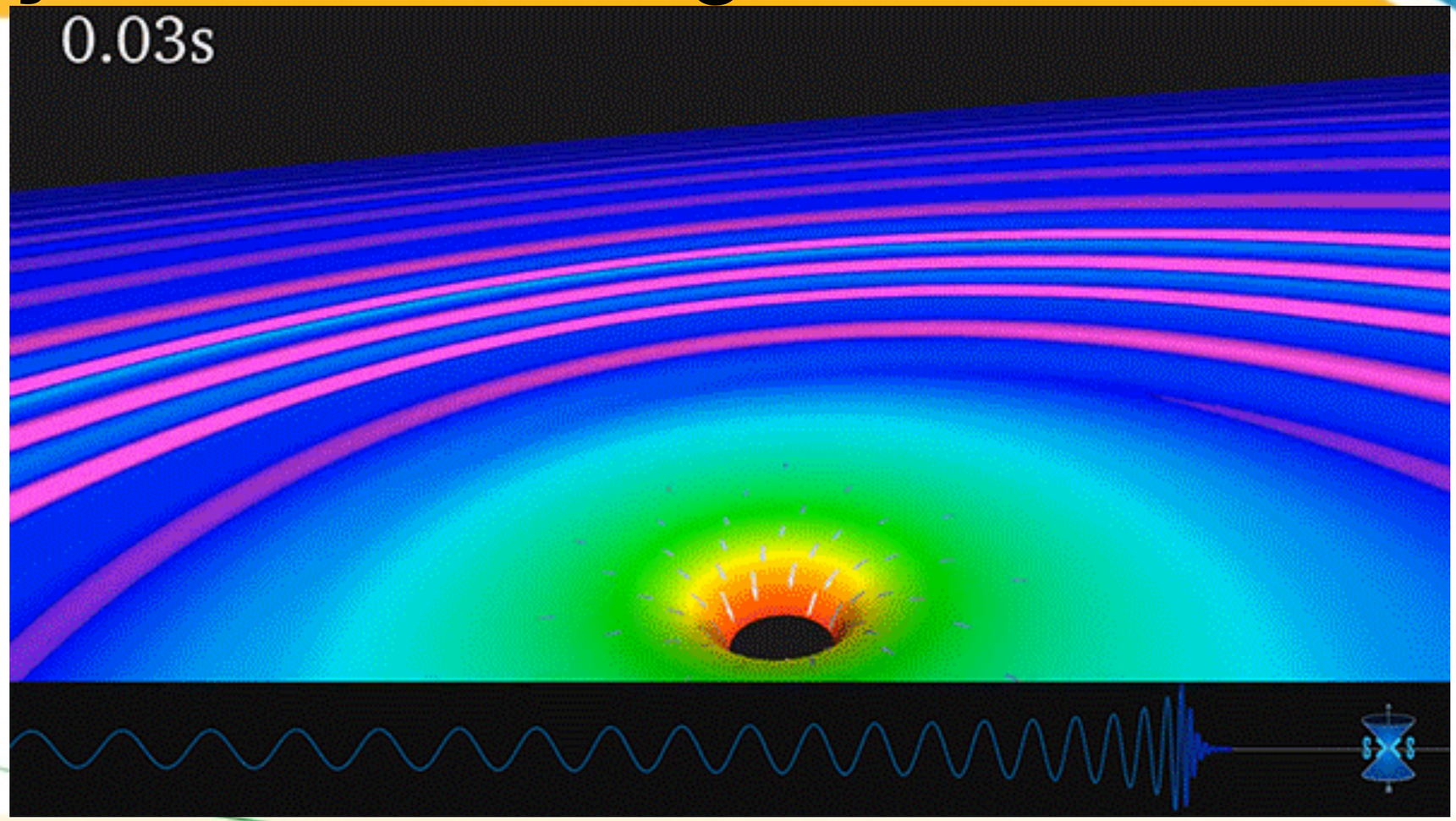

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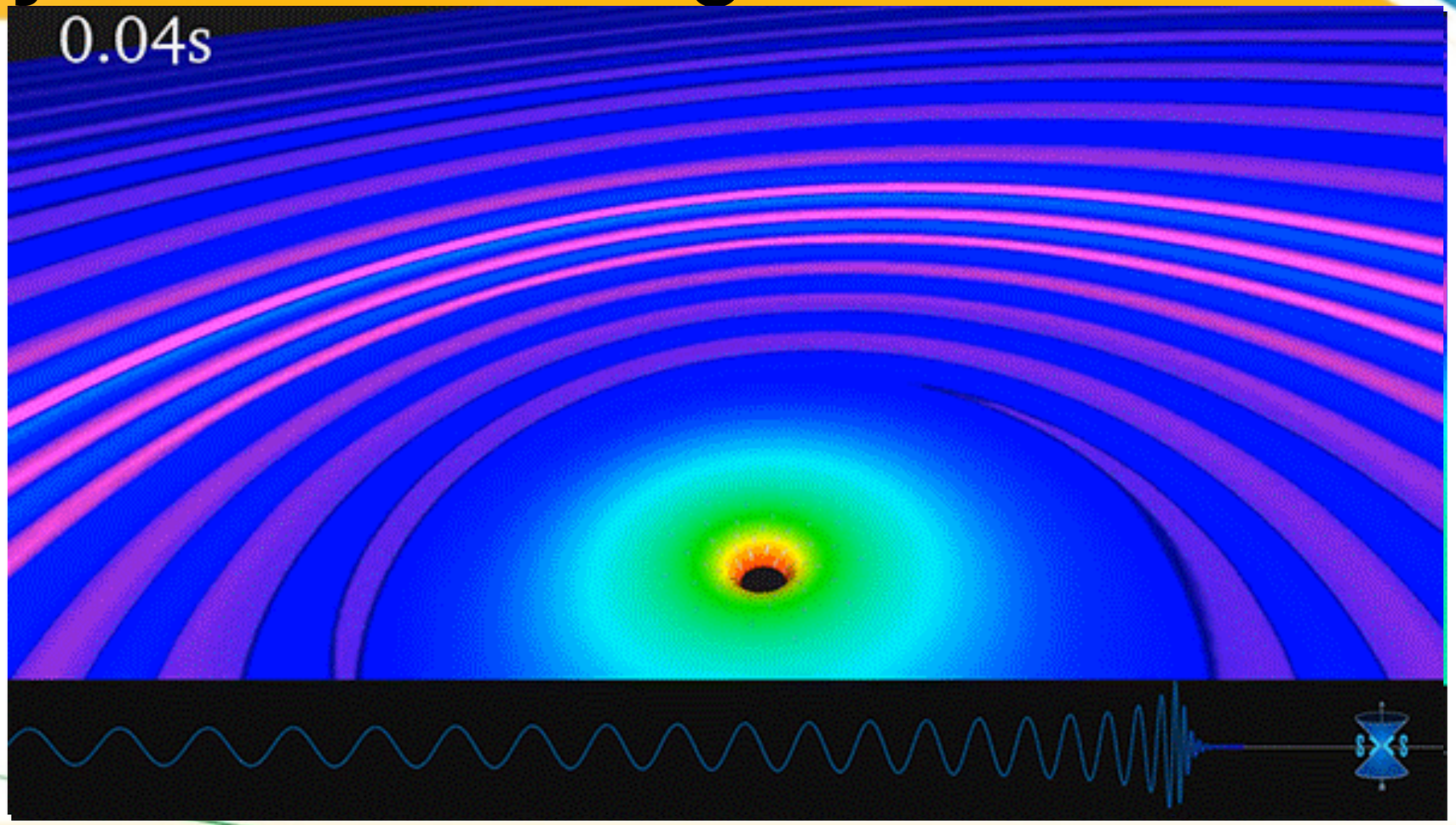

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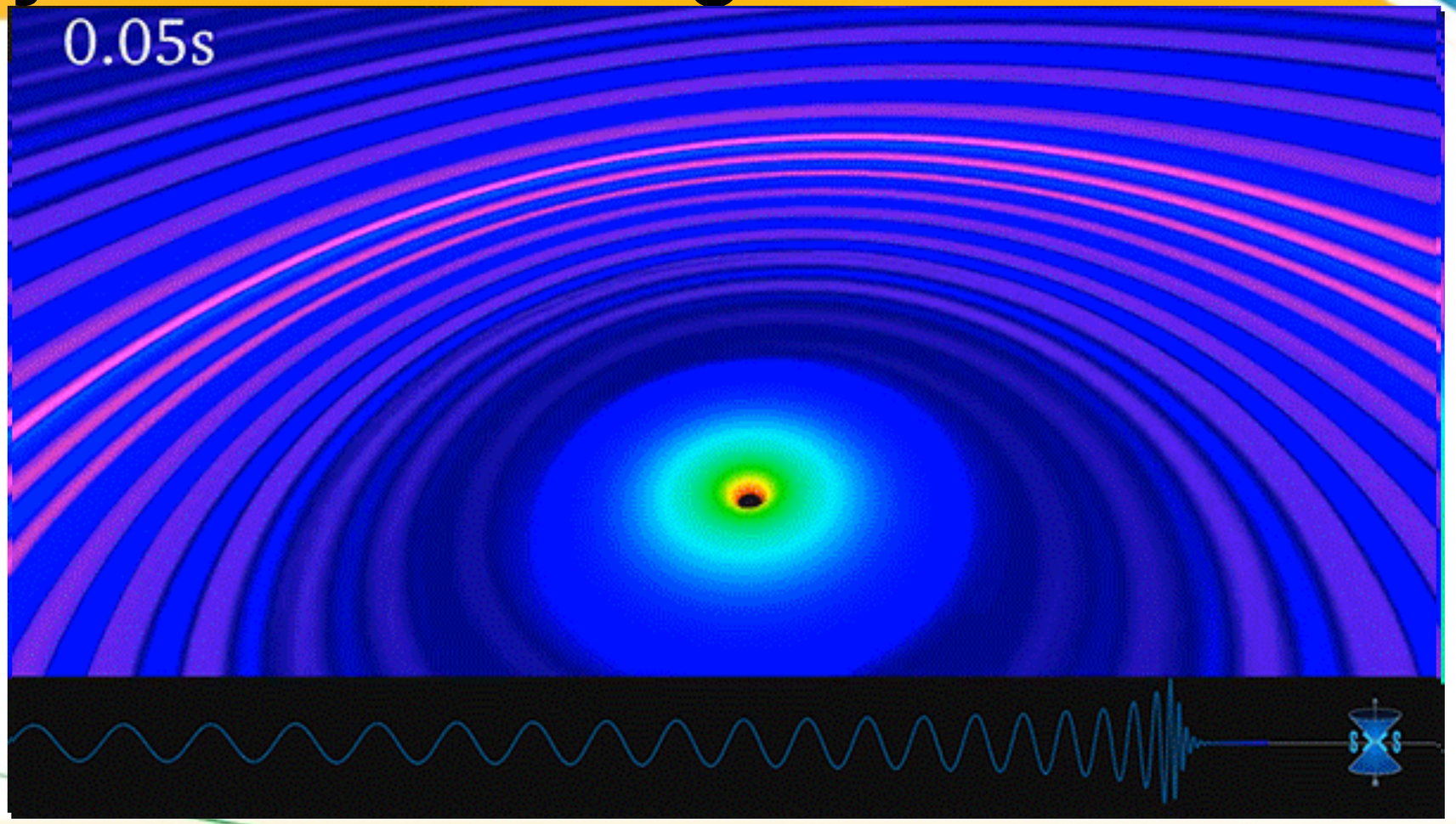

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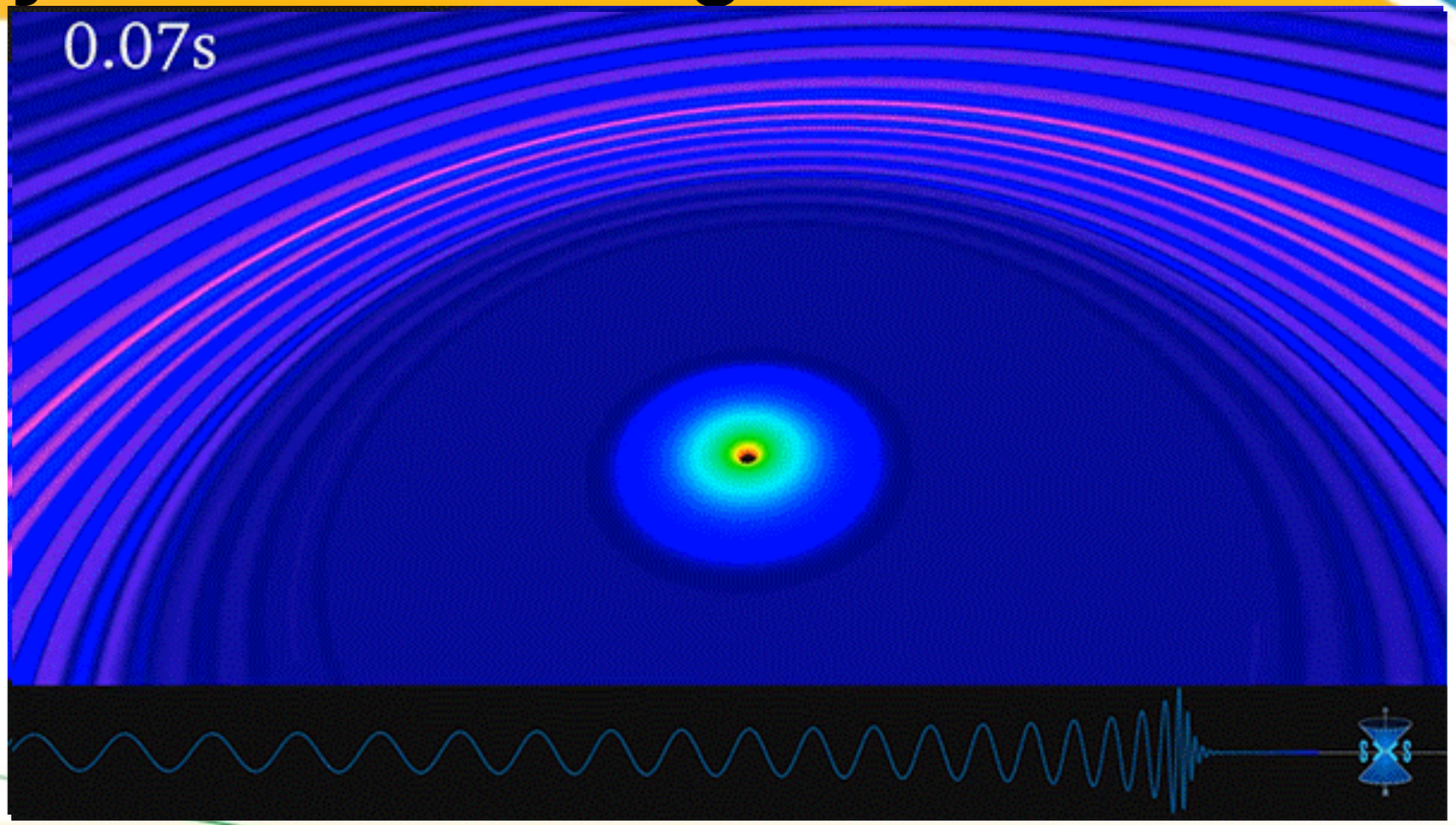


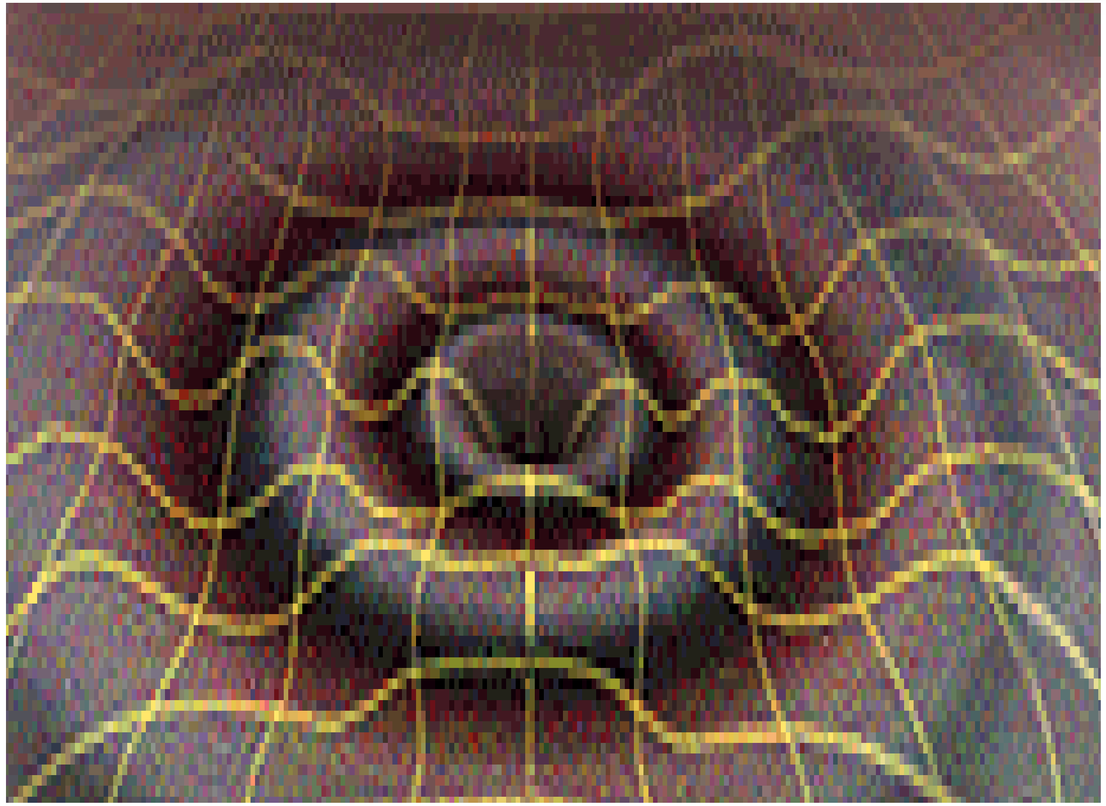
Einstein's Theory of General Relativity

➢ Space-time tells matter how to move

➢ Matter tells space-time how to curve

➢ Gravitational Waves ☛ ripples in fabric of space-time

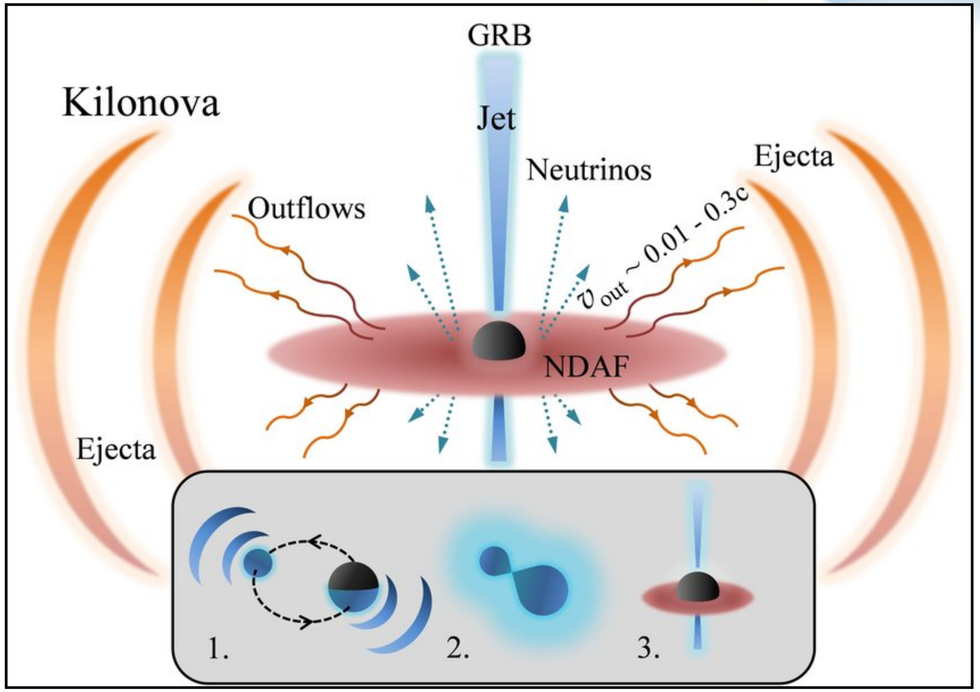
➢ Black Holes ☛ final fase in collapse of matter



Compact (NS-NS) binary merger with strong outflows that powers a kilonova

1. Pre-merger stage ☛ the binary with GW emission

2. The coalescence of the binary



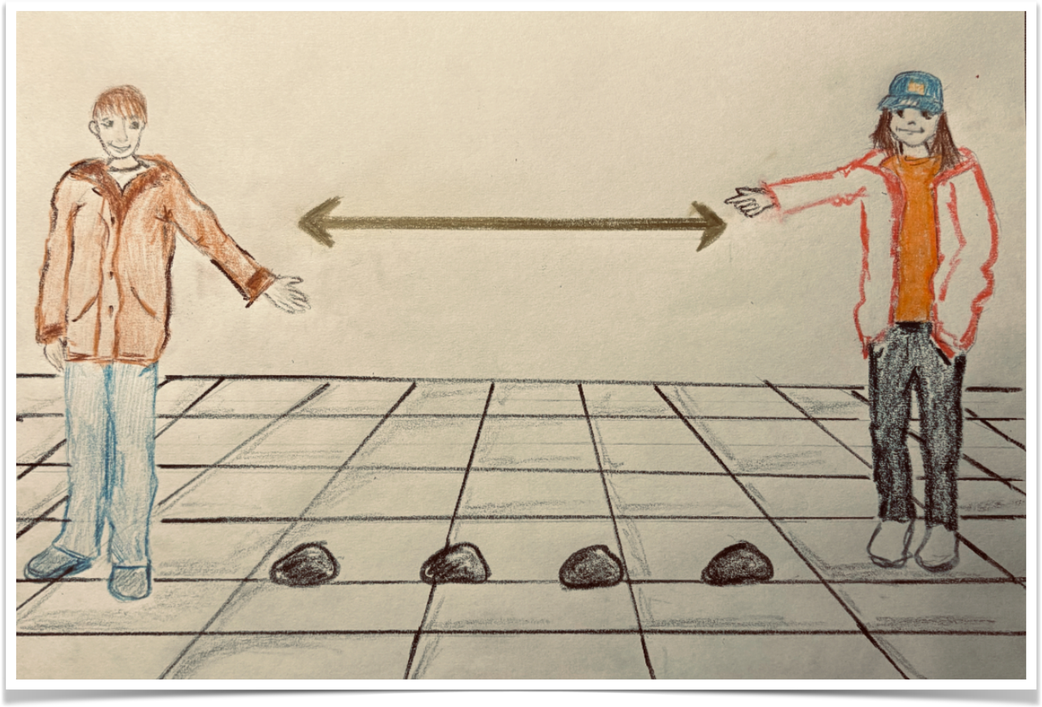
3. The formation of a hyper-accretion disc around the BH after the merger with neutrino-dominated accretion flow (NDAF) and gamma rays

How would you observe ripples in space?

If the space between you and me compressed or stretched ☛ we wouldn't notice it if we had made marks on our metaphorical rubber sheet

(for example using equally space rocks)

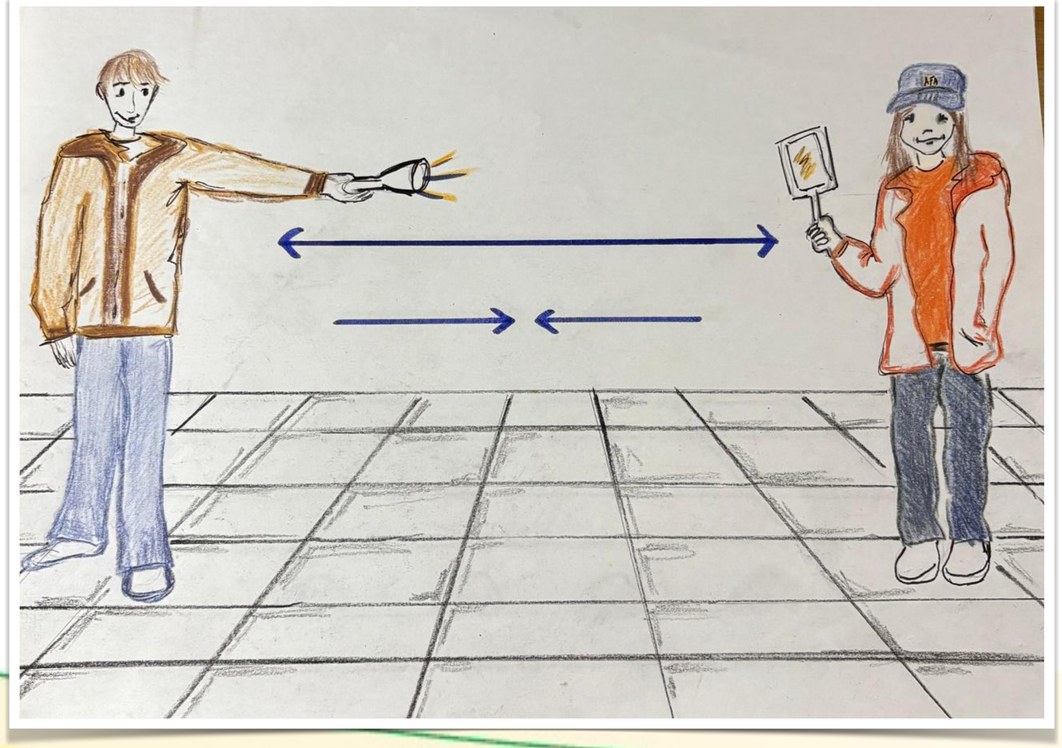
because these marks would also get stretched further apart



However ☛ there is one ruler that doesn't get stretched ☛ one made using the speed of light

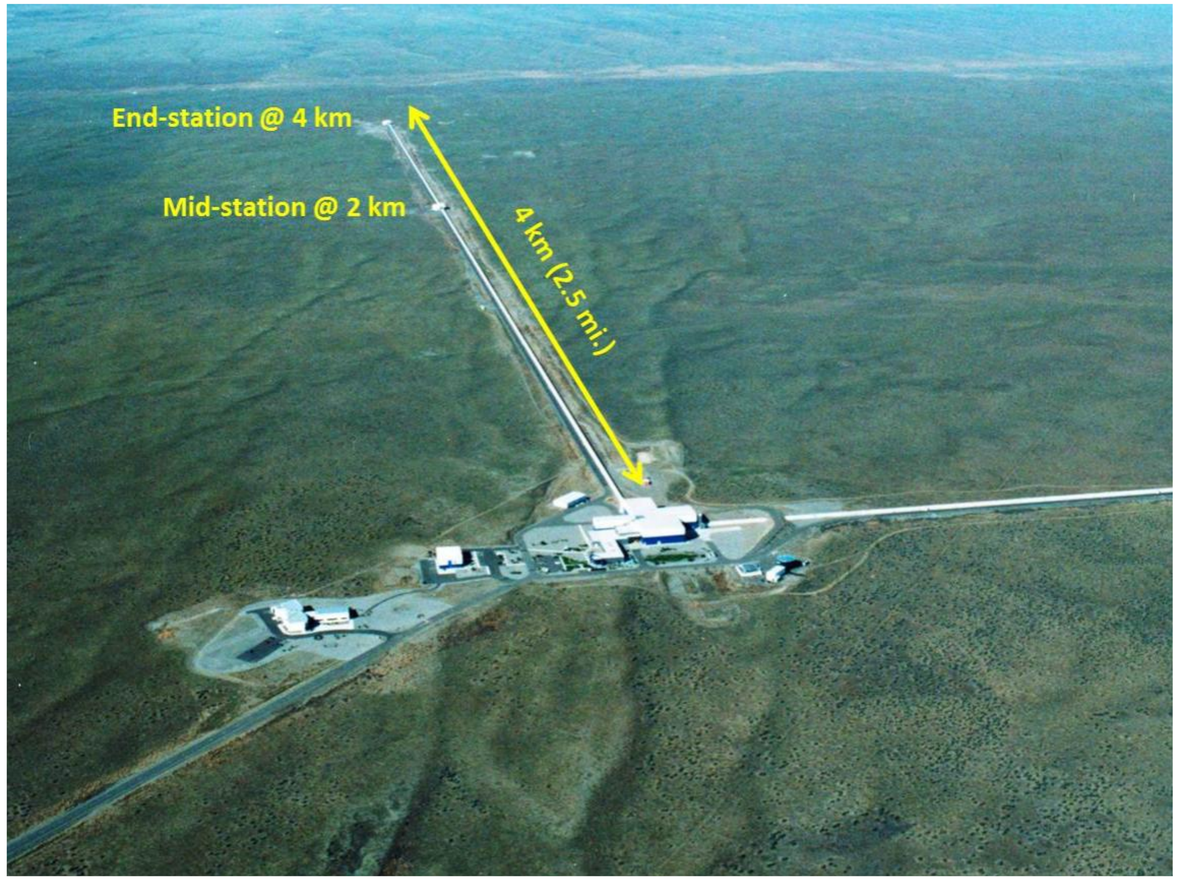
If the space between two points gets stretched ☛ light will take longer to go from one to the other

and if the space gets squeezed ☛ light take less time to cross the two points

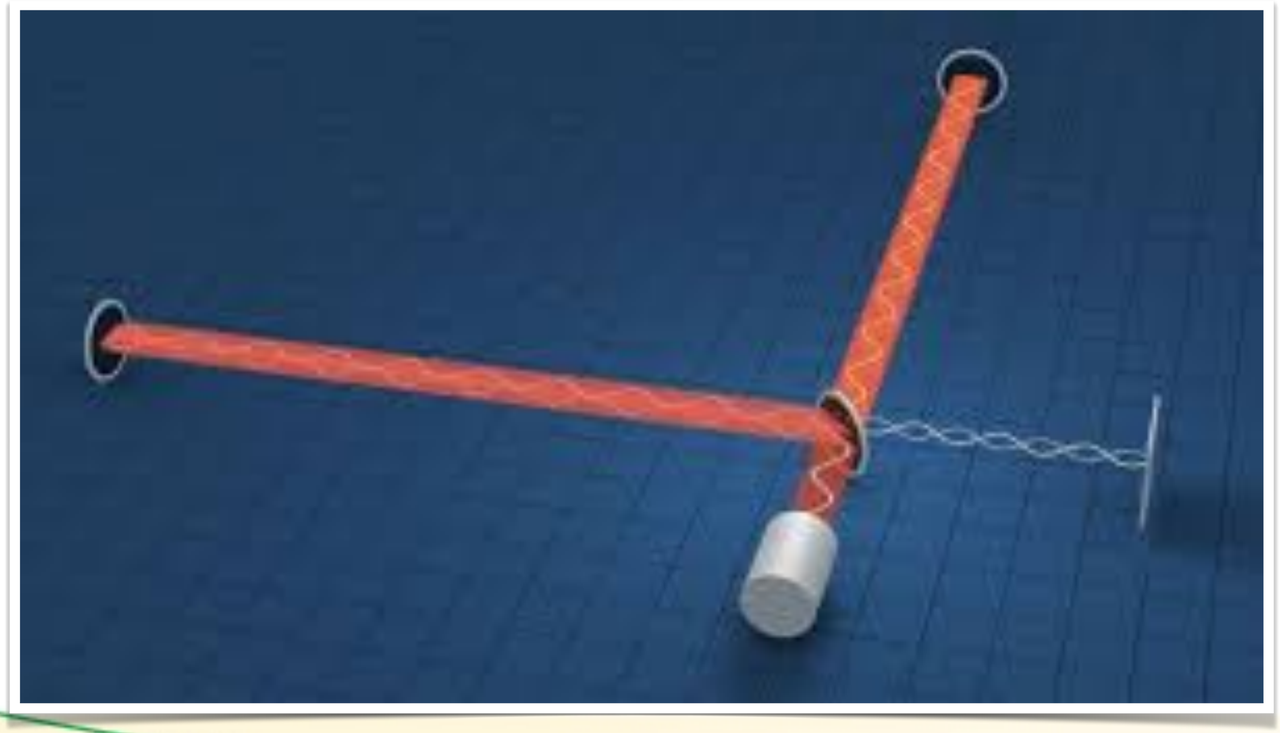


The LIGO experiment has 4 km long tunnels and uses lasers to measure changes in the distance between the ends of the tunnels

When a gravitational waves comes in
stretches the space in one direction
and squeezes space in the other direction

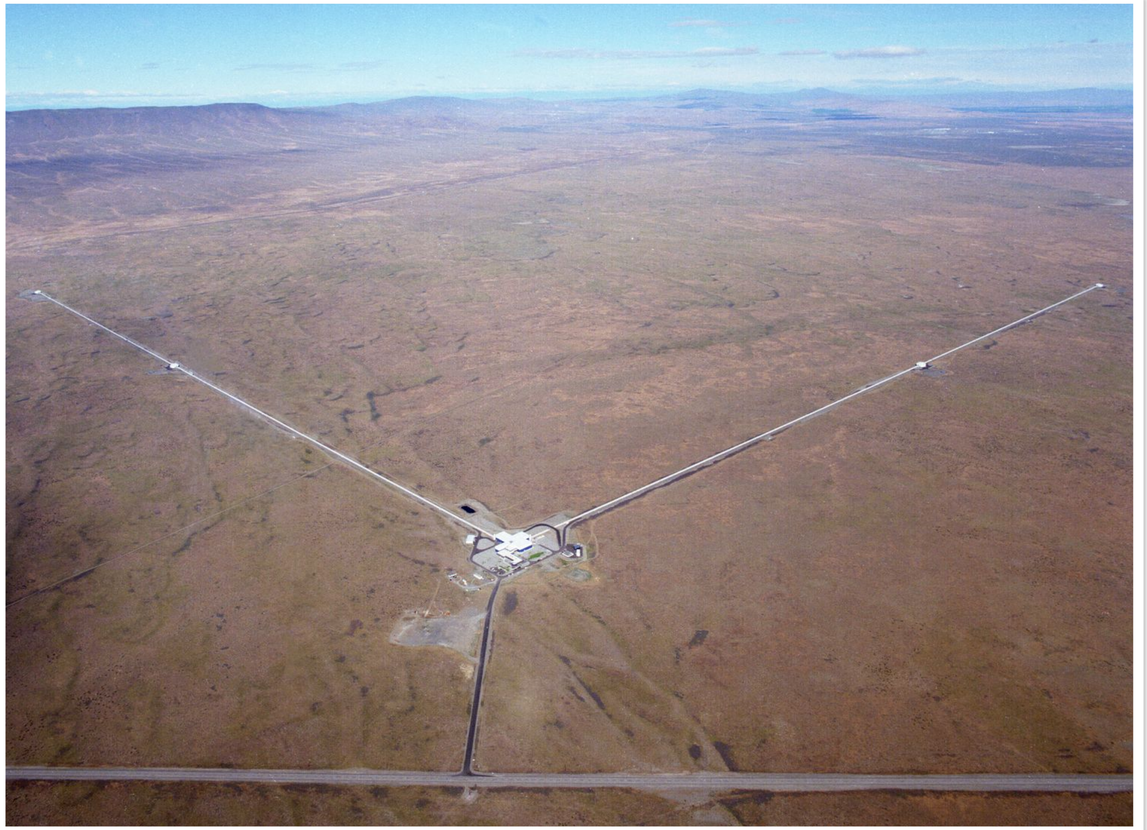


By measuring the interference of the lasers as they bounced between the different points we can measure very precisely whether the space in between has stretched or compressed



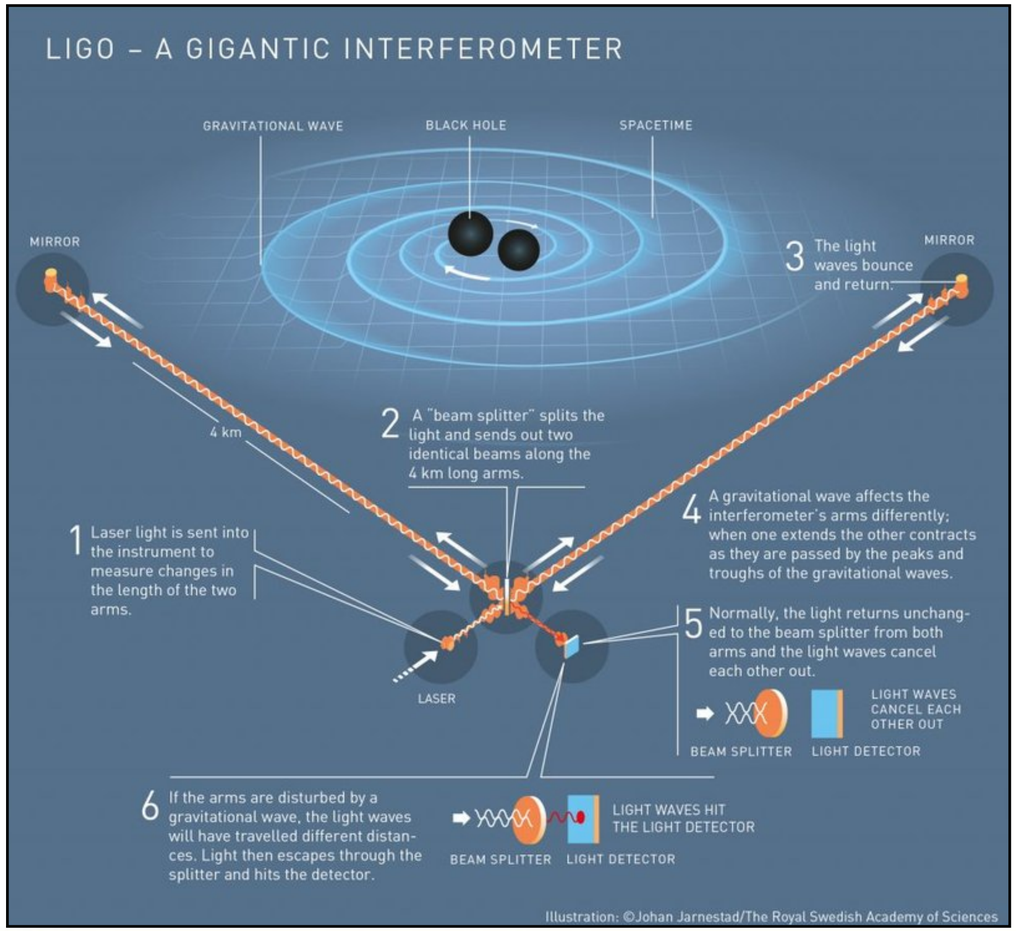
The precision needed is incredible!!!

To detect a gravitational wave you need to be able to tell when something changes in length by a few parts in 10^{23}!!!

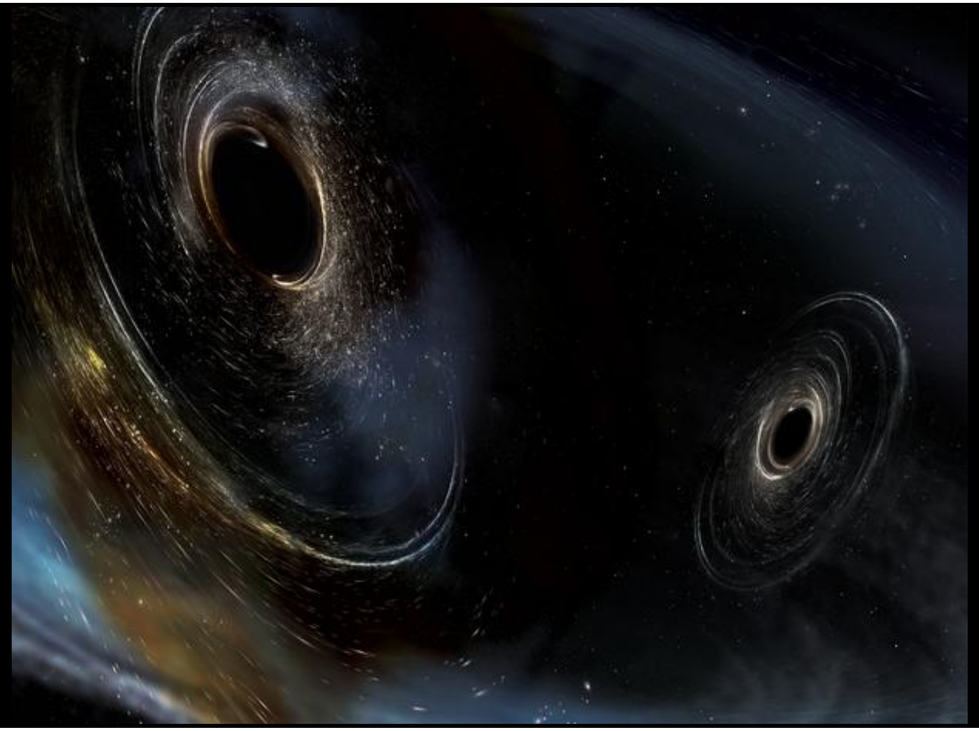


It's like being able to tell that a stick 10^{21} m long has shrunk by 5 mm

Laser Interferometer Gravitational-wave Observatory



Detecting gravitational waves is a completely new way of studying the universe



Any time there is a new way to observe the universe we discover thing that we didn't expect
It's really about looking for new things that we didn't know existed examining the extreme edges of our knowledge of physics and testing theories about how the universe works

Gravitational Wave Standard Sirens

Gravitational waves offer a novel independent way to measure the expansion of the universe ☛ bypassing the assumptions of the traditional cosmic distance ladder

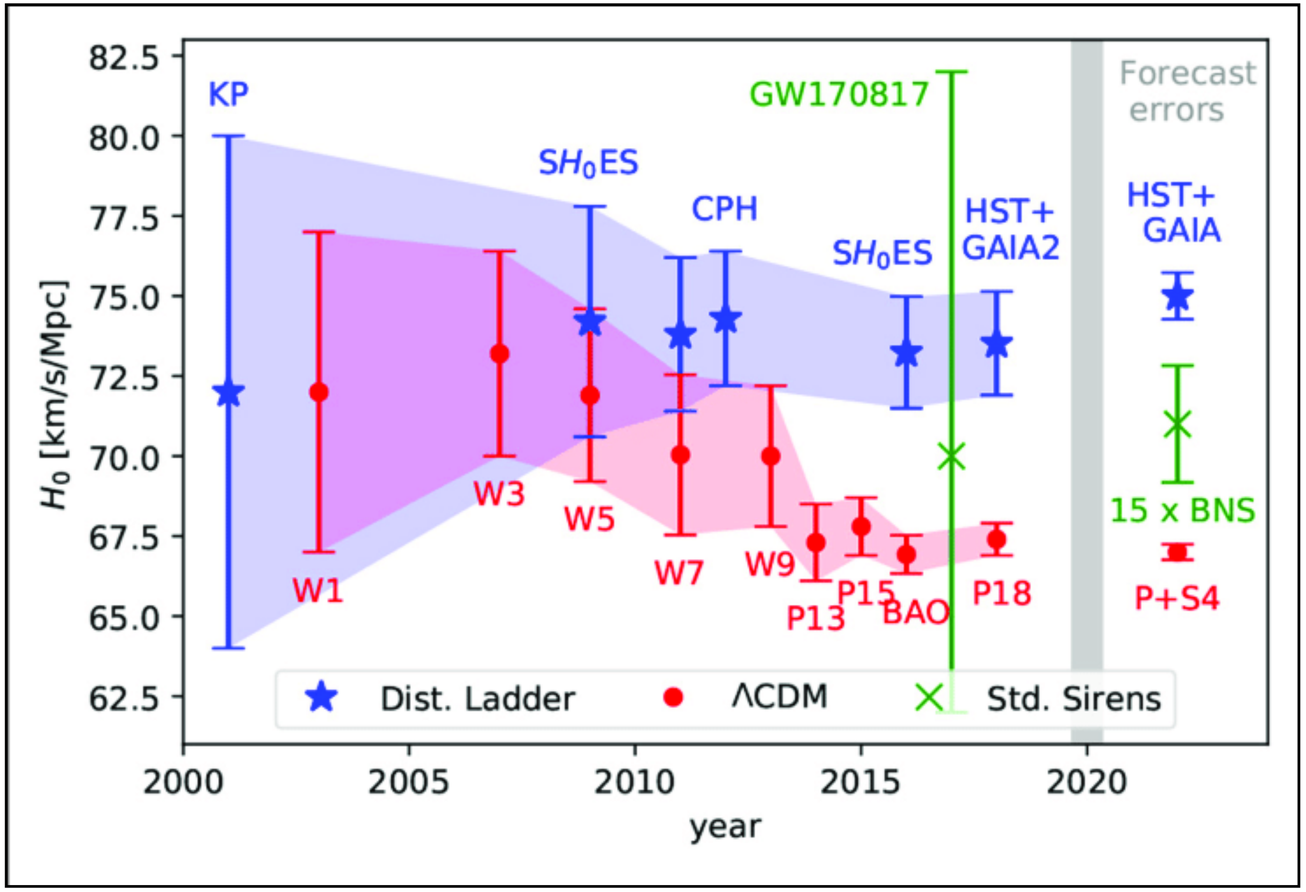
Mechanism:

The amplitude of a gravitational wave signal directly encodes the absolute luminosity distance to its source

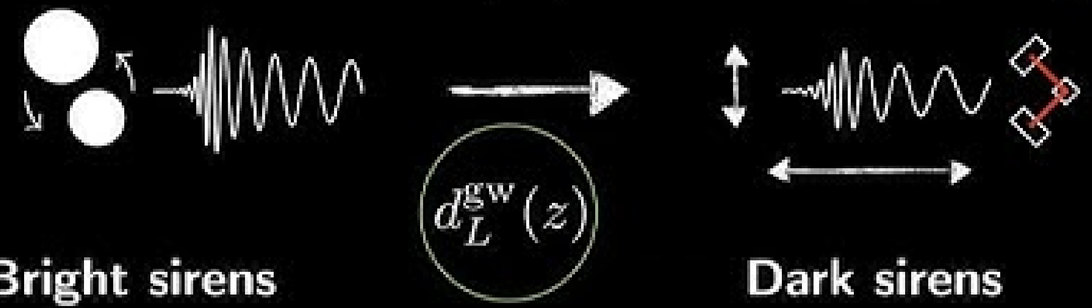
By independently determining the source's redshift (a measure of how fast it is moving away from us), we can plot the distance-redshift relationship and measure the Hubble constant

Sources like merging binary neutron stars are called standard sirens because their gravitational wave signals serve as a standard ruler in the cosmos

A standard siren measurement of Hubble constant



From GWs to astrophysics and cosmology

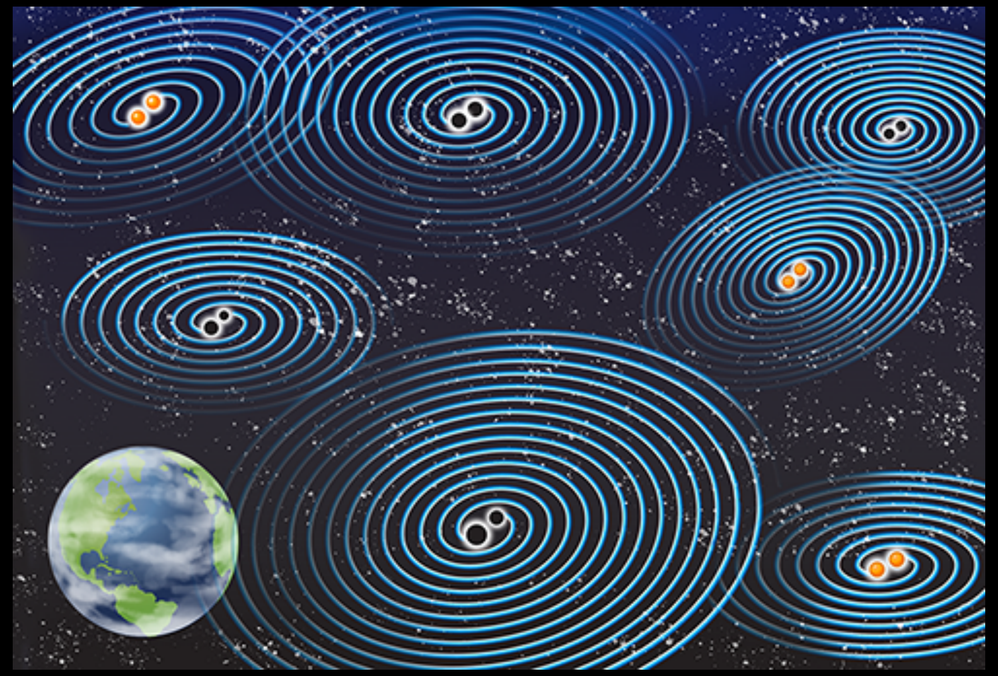


Bright sirens

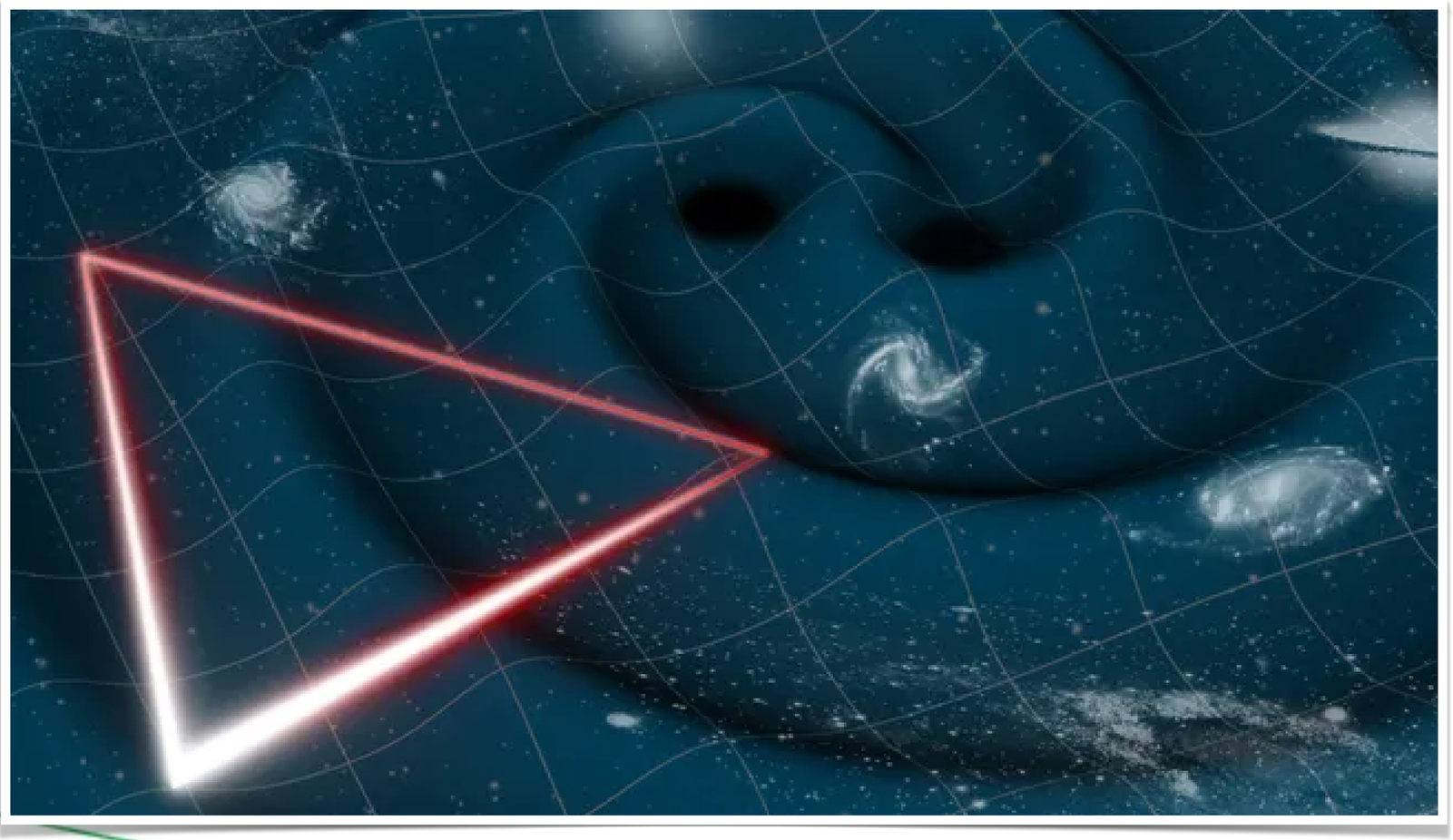
- Redshift from EM counterpart
- E.g. GW170817
- Need **neutron stars**!
- Bright counterpart at high-z?

Dark sirens

- Statistically infer z from galaxies in localization volume
- E.g. GW170814
- Need good localization and **complete** galaxy catalogs!



Space holds the key to future gravitational wave experiments

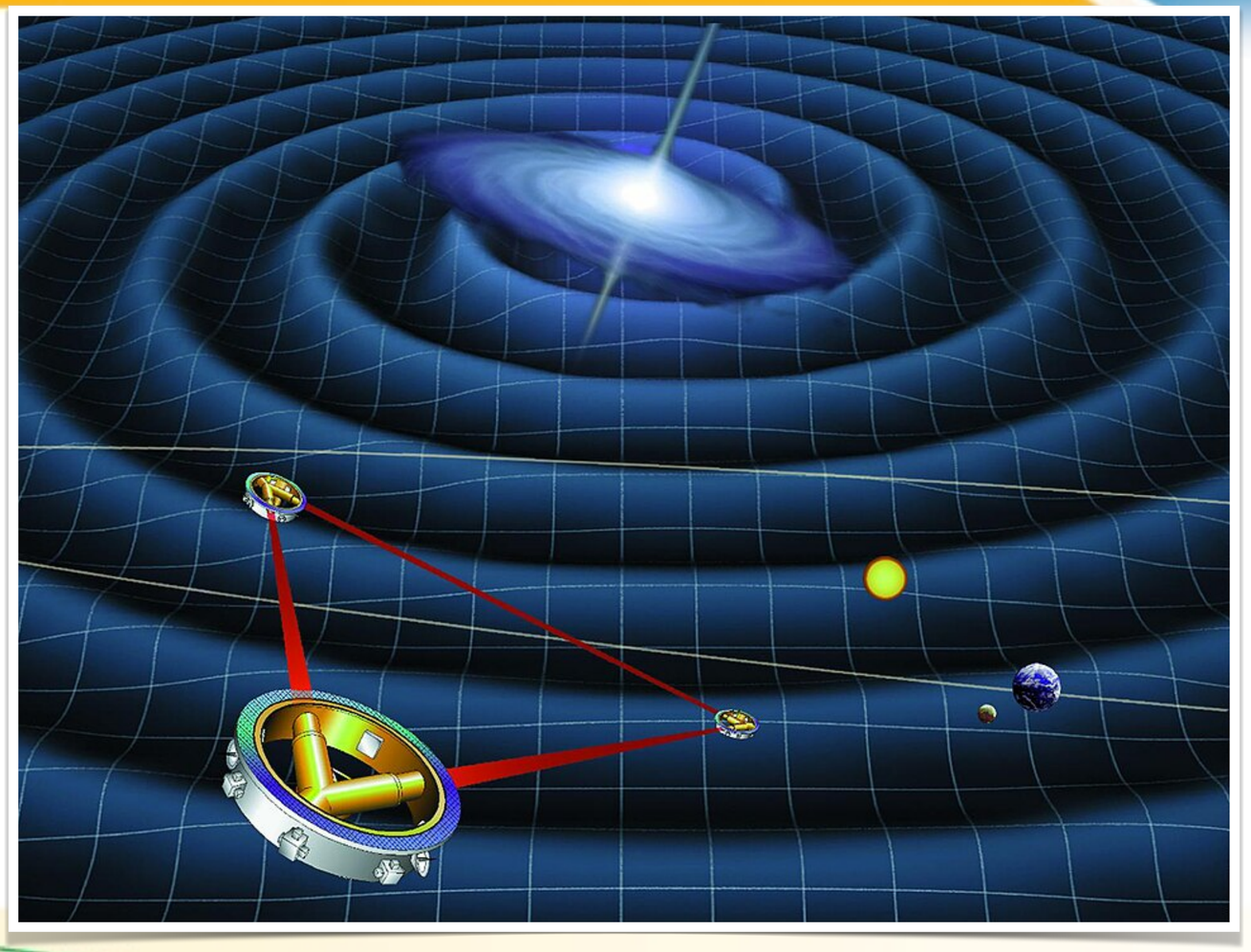


Laser Interferometer Space Antenna (LISA)

3 satellites

2.5 million km arms

50 million km behind Earth



What is the main working principle of LIGO?

A. Electromagnetic radiation

B. Gravitational wave detection

C. Particle acceleration

D. Quantum entanglement

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B. Hubble

C. Spitzer

D. Chandra

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What does LIGO stand for?

A. Light used for gravitational observations

B. Laser interferometric gravitational wave observatory

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D. Luminosity of gravitational objects

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What is the approximate length of LIGO arms?

A. 1 km

B. 4 km

C. 4 m

D. 10 km

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