How Colliding Black Holes Can Help Us Predict Volcanic Eruptions

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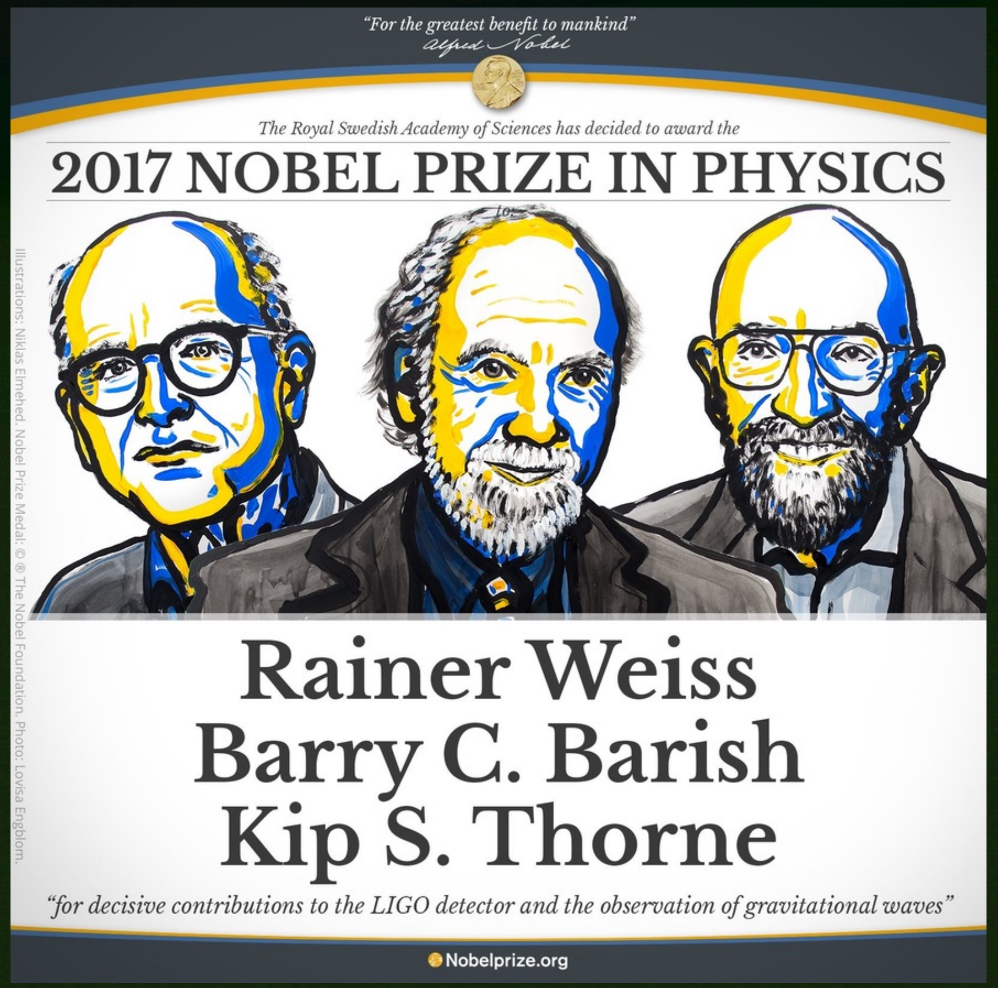
Overview

My story as a physicist

- How my degree in (astro)physics created paths for me to work in:
  - Astronomy
  - Mechanical Engineering
  - Data Analysis
  - Electrical Engineering
  - Nobel Prize winning collaboration
  - Volcanology



Overview

My story as a physicist

- How my degree in (astro)physics created paths for me to work in:
  - Fields of cow dung in Ireland
  - Groundwater monitoring
  - Geophysics
  - TV appearances

Overview

My story as a physicist

- How my degree in (astro)physics created paths for me to work in:
  - Building sites
  - Geology
  - Back to astronomy
  - Teaching

Overview

My story as a physicist

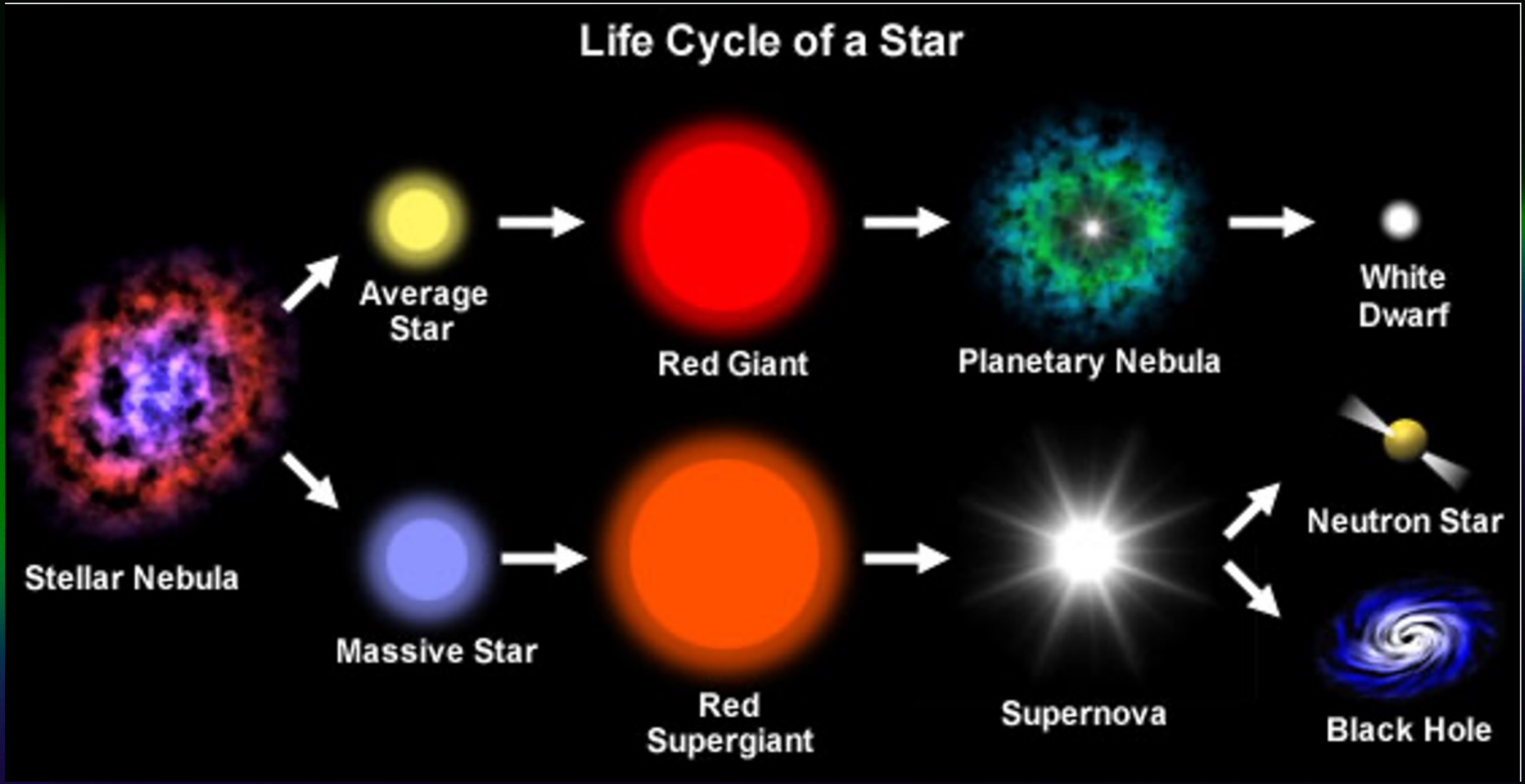
  - And many many more…
- Basically, how studying physics opens endless number of avenues for you to pursue

How do colliding black holes help us predict volcanic eruptions?

- Colliding black holes help us predict volcanic eruptions… really?
- Well, through the magic of engineering, they can
- Lets take a step back and take a crash course in some astronomy

What are black holes?

- Black holes are one of the possible end stages of a massive star’s life cycle

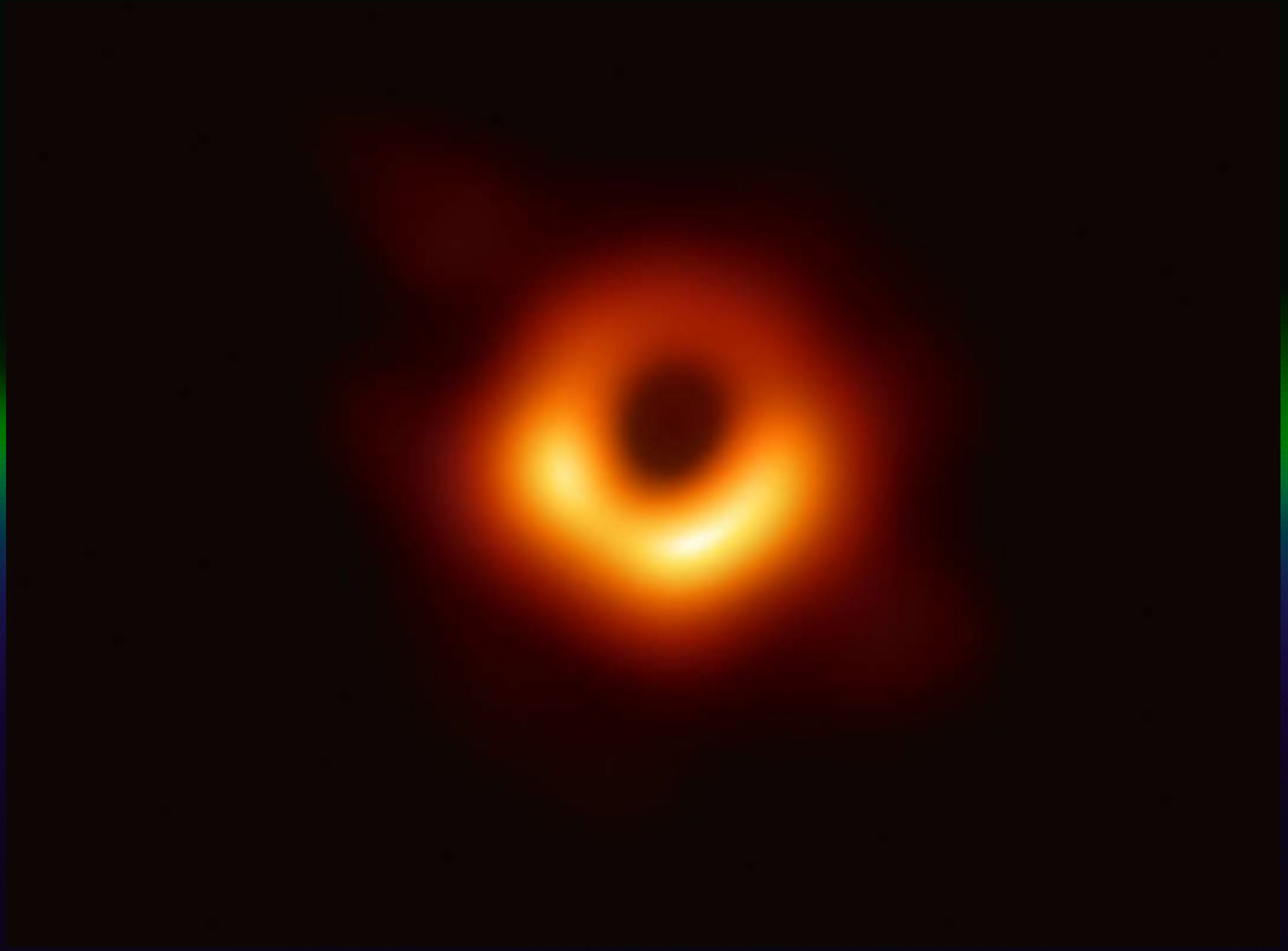


What are black holes?

- When massive stars run out of fuel to burn, they explode in what is known as a supernova
- These explosions can temporarily outshine a galaxy
- For massive stars, one potential object that is left after this explosion is a black hole

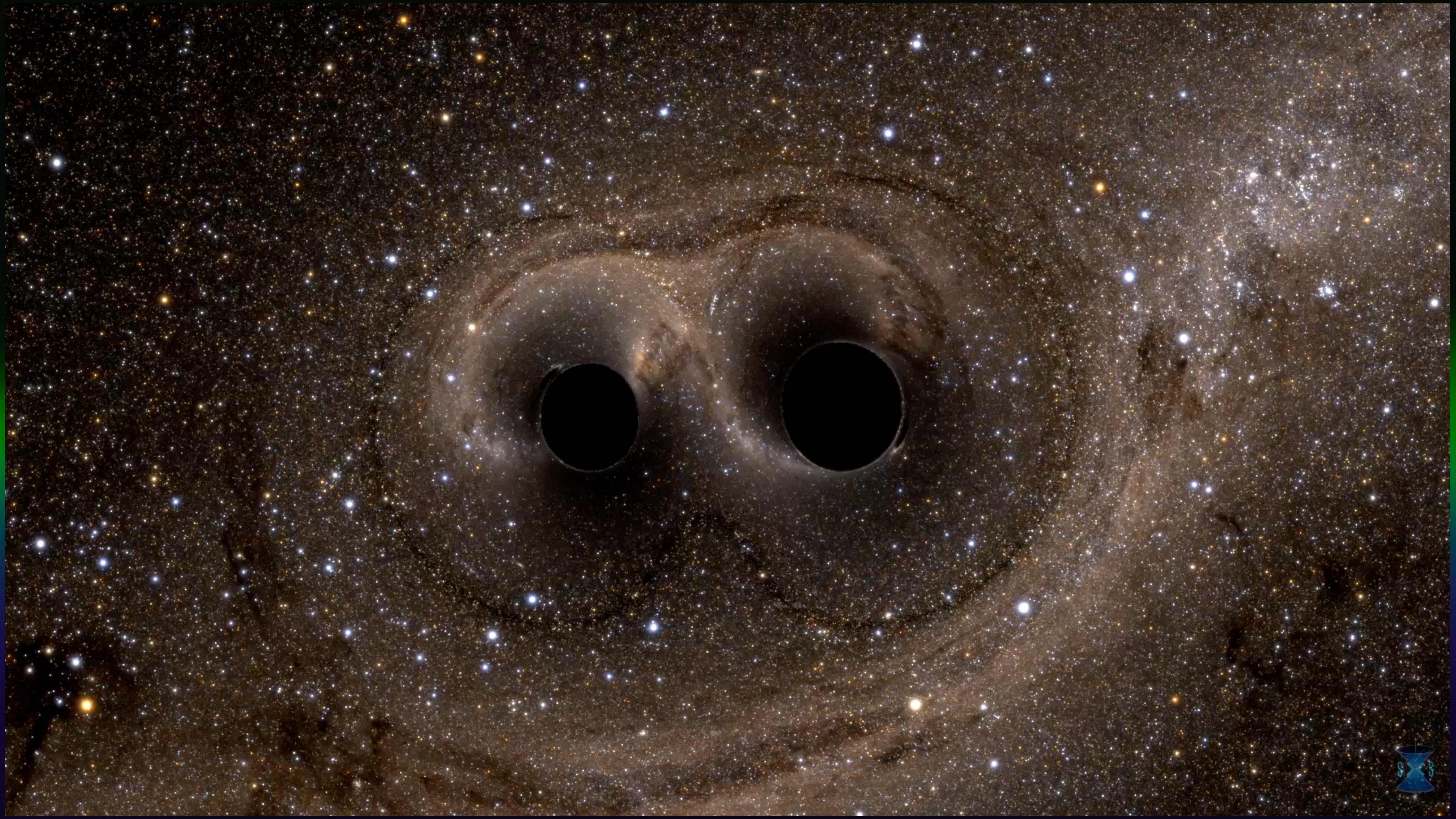
What are black holes?

- The gravitational pull of a black hole is so strong, that matter or energy can only escape by travelling faster than the speed of light
- The distance from the black hole at which light can not escape is called the event horizon
- Supermassive (millions to billions of times the mass of our sun) black holes exist at the centre of galaxies
- But we're not interested in those…



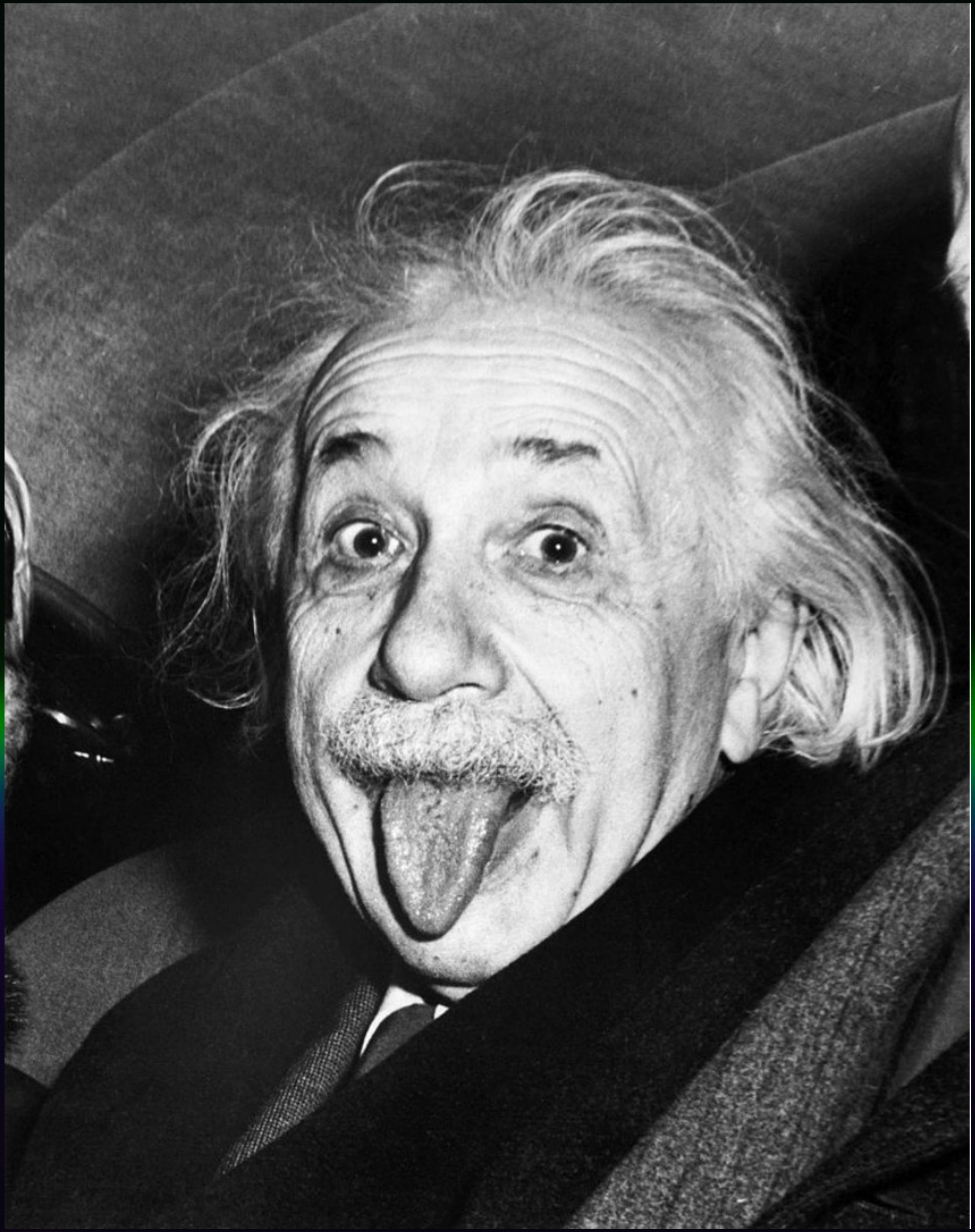
Inspiraling black hole pairs

- What we're interested in here are pairs of black holes that orbit each other
- These black holes will get closer and closer together before merging (crashing together)
- So, why these black holes in particular?
- Well, we need to visit some previous research by a smart guy…



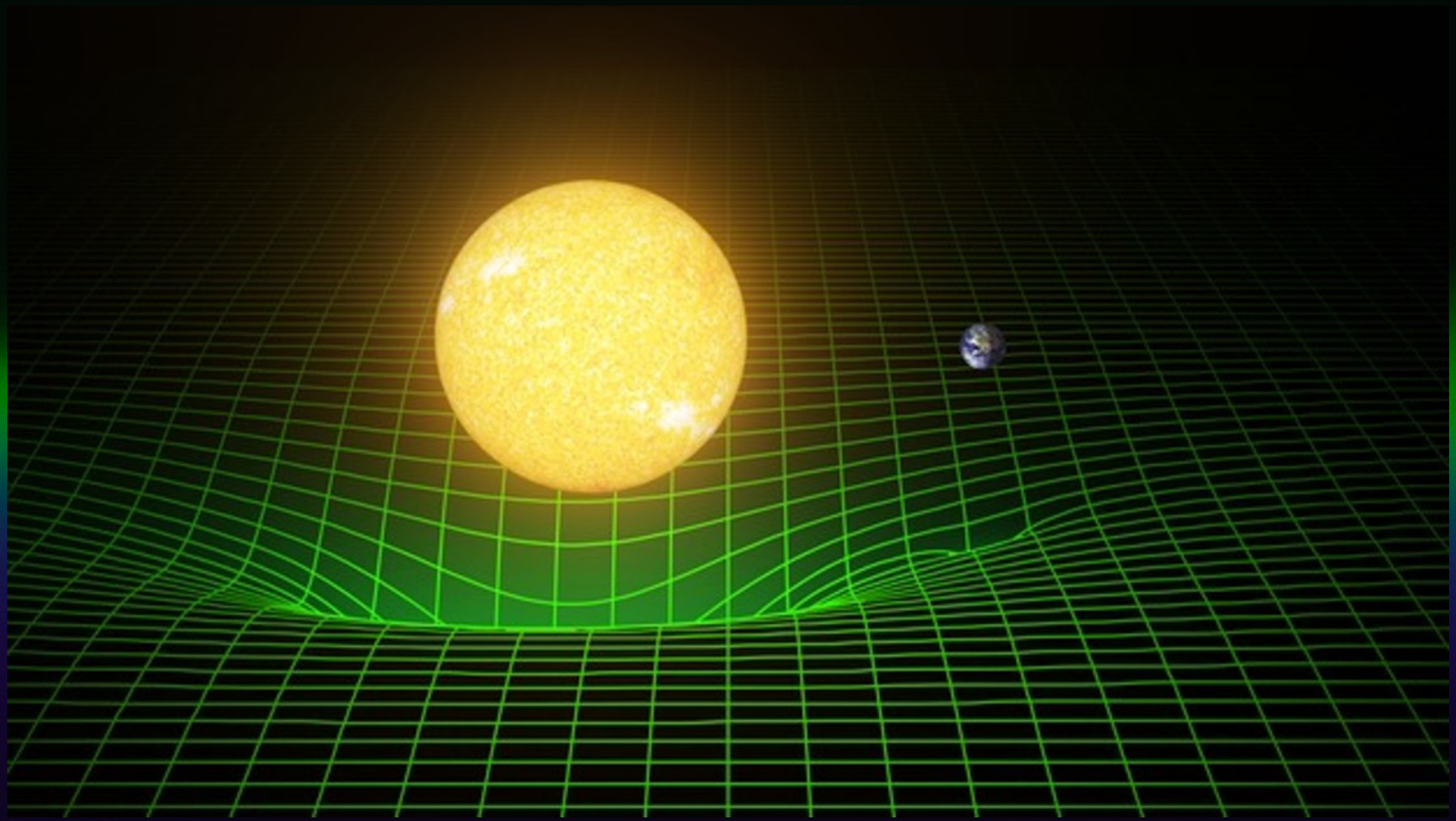
Albert Einstein

- This is smart guy



General Relativity

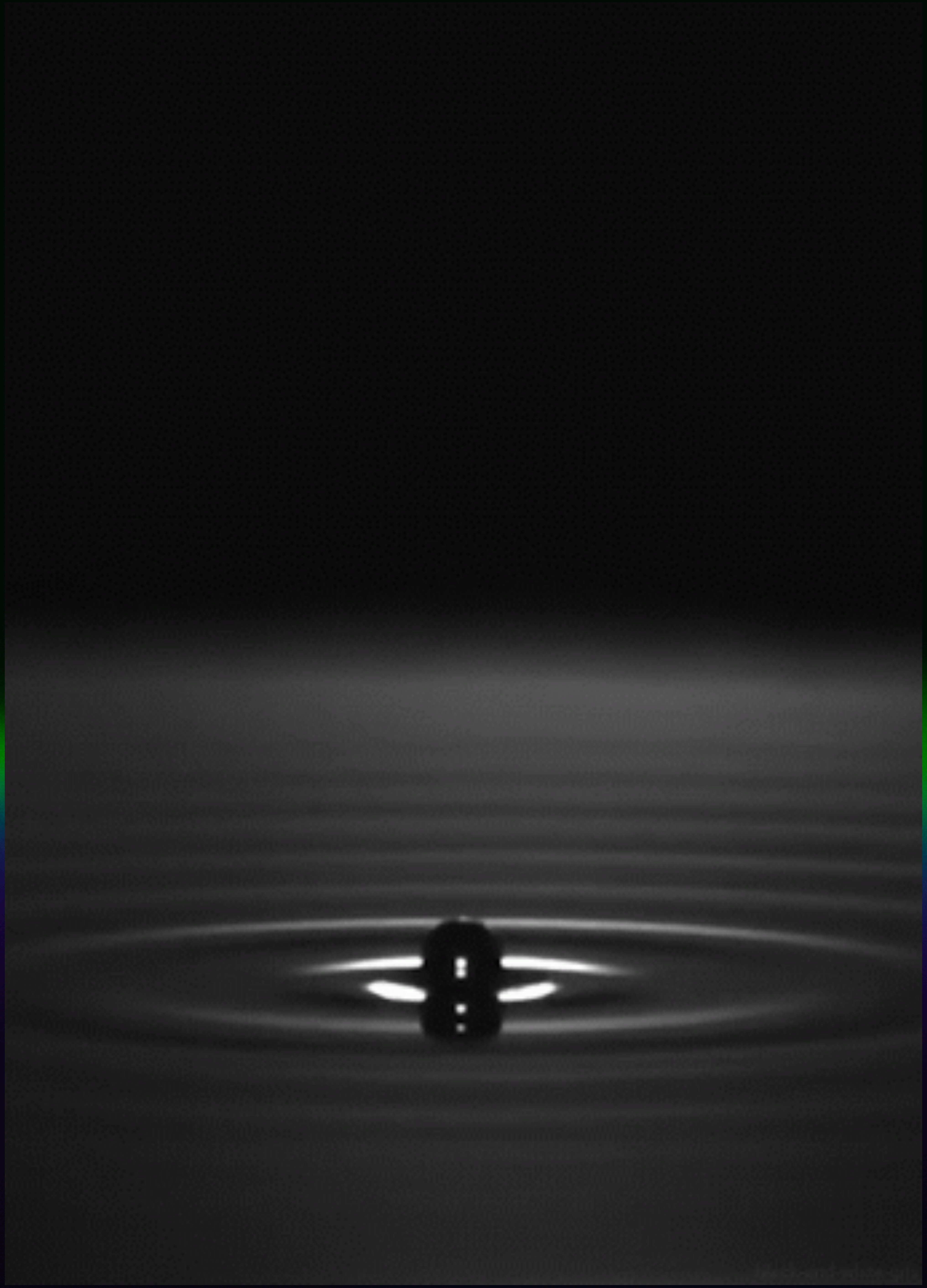
- Over 100 years ago, Einstein came up with his Theory of General Relativity
  - Basically, how things move through the universe
- He said that objects will create a curvature in the spacetime it occupies, which will influence any movement of another object that passes by it
- Bigger the object, bigger the curvature



General Relativity

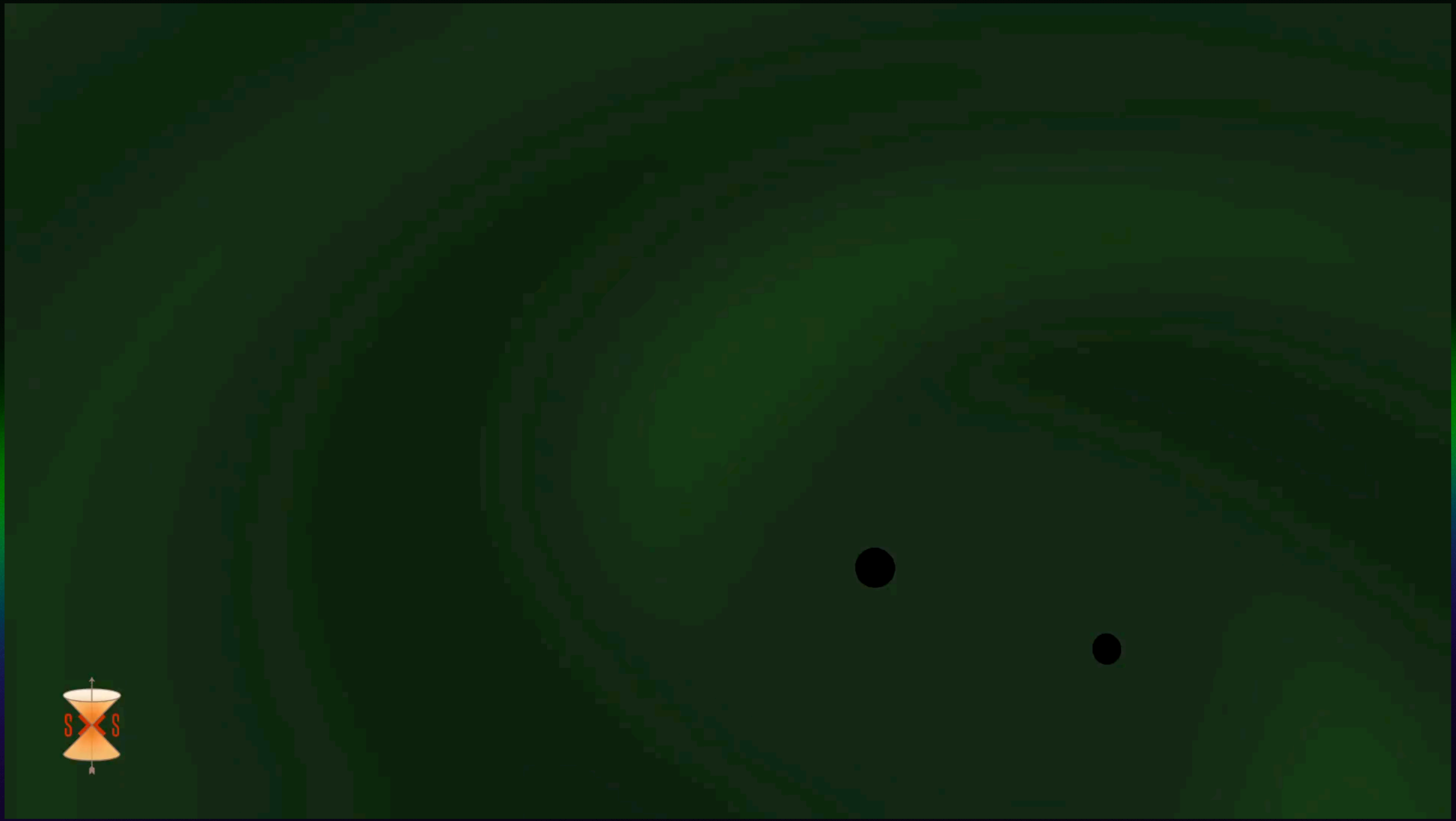
- Einstein in his theory also said that any object that goes under an acceleration (moves faster) will create ripples in spacetime

- Think like ripples in water travelling through the ocean, but don't slow down or get obstructed



General Relativity

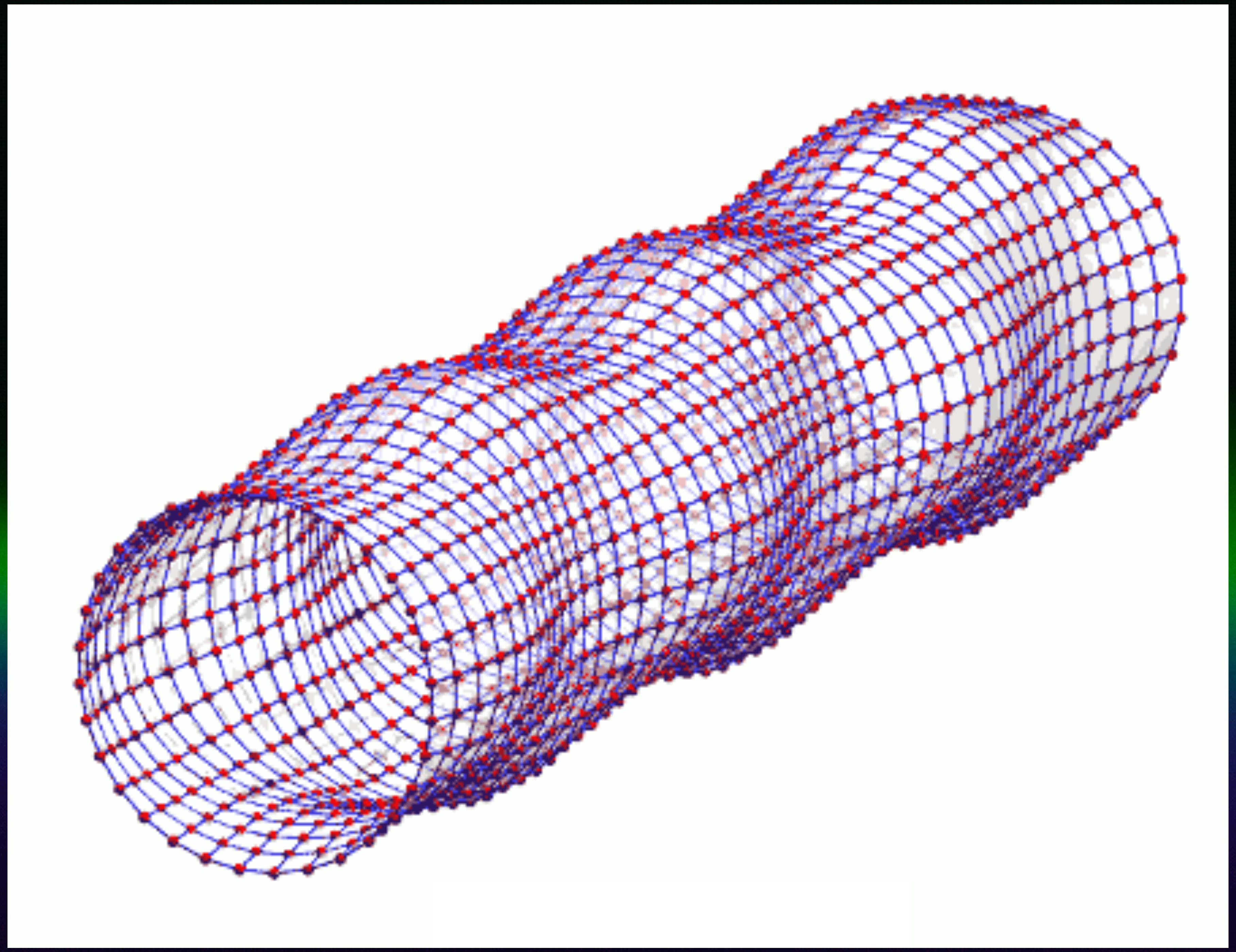
- So, if our orbiting black holes are creating a curvature in spacetime, and getting faster and faster before crashing into each other, they will create ripples in spacetime
- These ripples are called Gravitational Waves
  - Detection of these waves in 2015 was awarded the 2017 Nobel Prize



Gravitational Waves

- These ripples will travel through the universe at the speed of light passing through any object it comes across (including Earth)

- As it passes through the universe, the ripples will stretch and squeeze the spacetime it passes through by a very very very very very very small amount

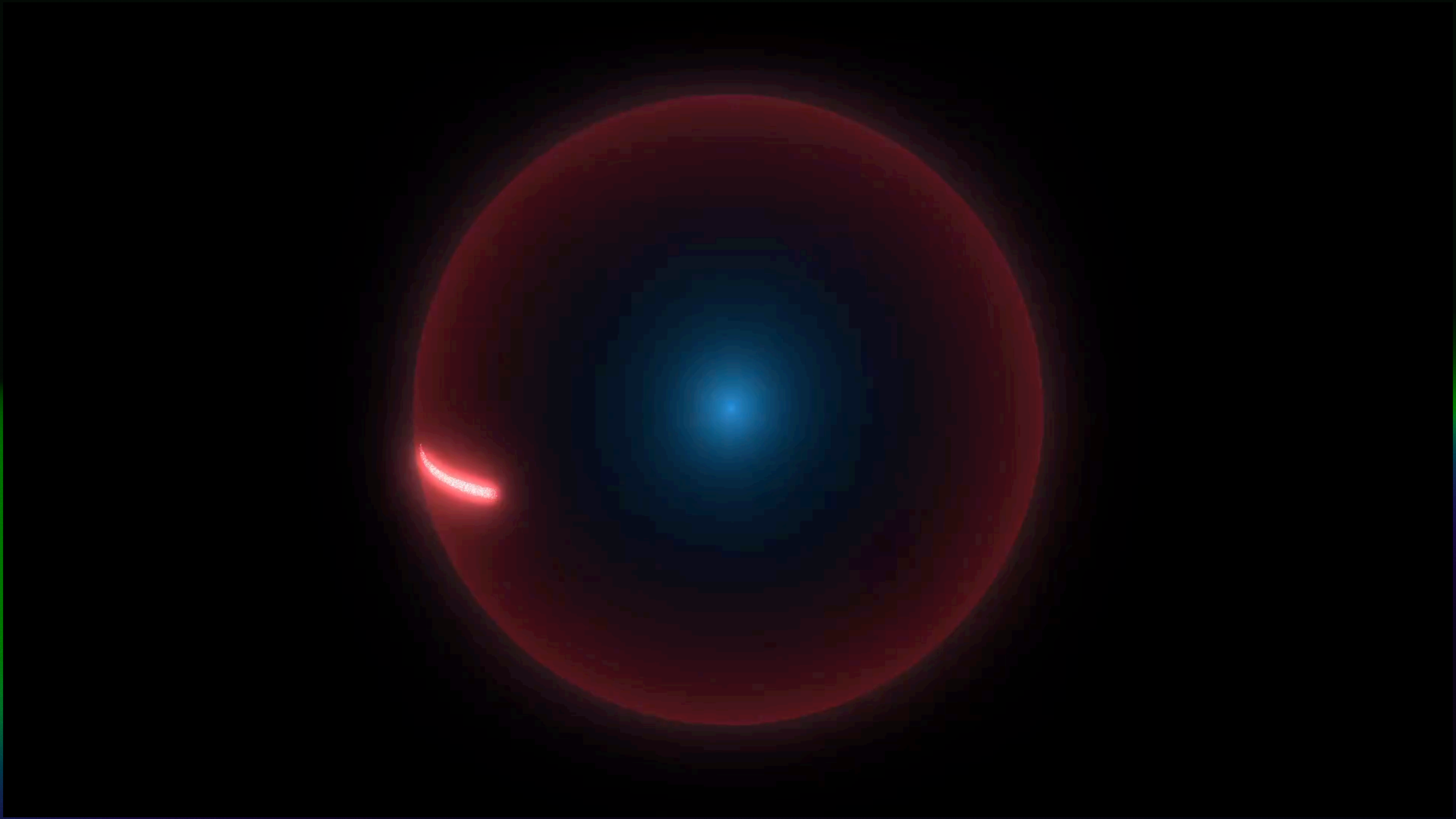


*exaggerated stretching and squeezing

How much does it stretch and squeeze?

- For reference, the thickness of an iPad is around 0.007m
- The average thickness of a human hair is 0.0001m
- A grain of salt has a diameter of 0.00006m
- A dust particle has a diameter of 0.000002m
- A hydrogen atom has approximate diameter of 0.0000000001m
- These are all still larger than how much the Earth would be squeezed by a gravitational waves

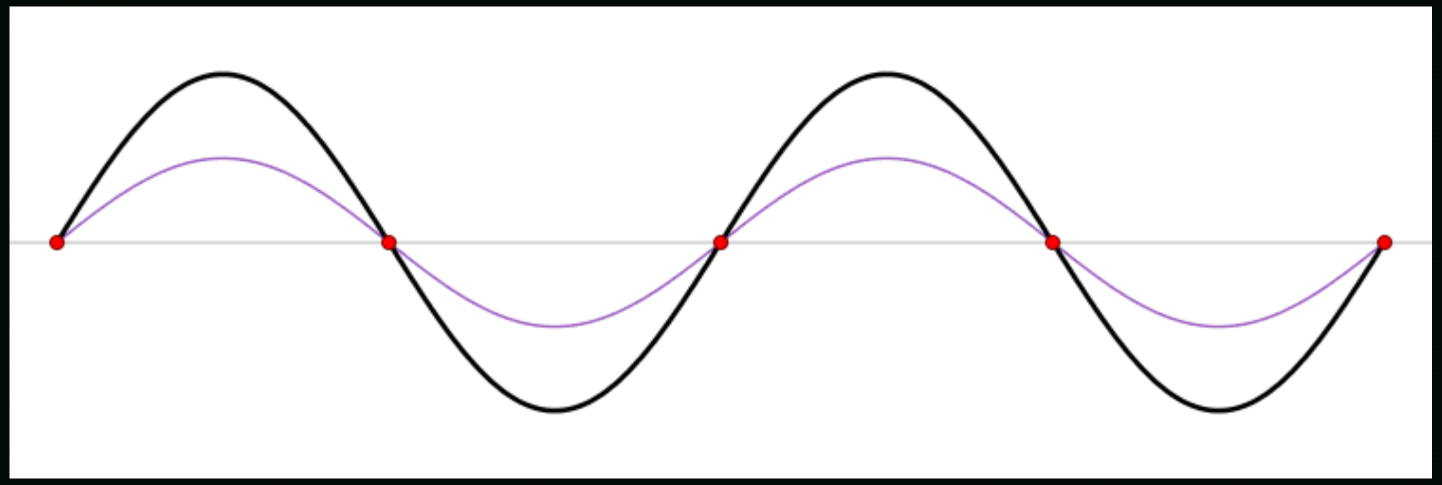
How much does it stretch and squeeze?

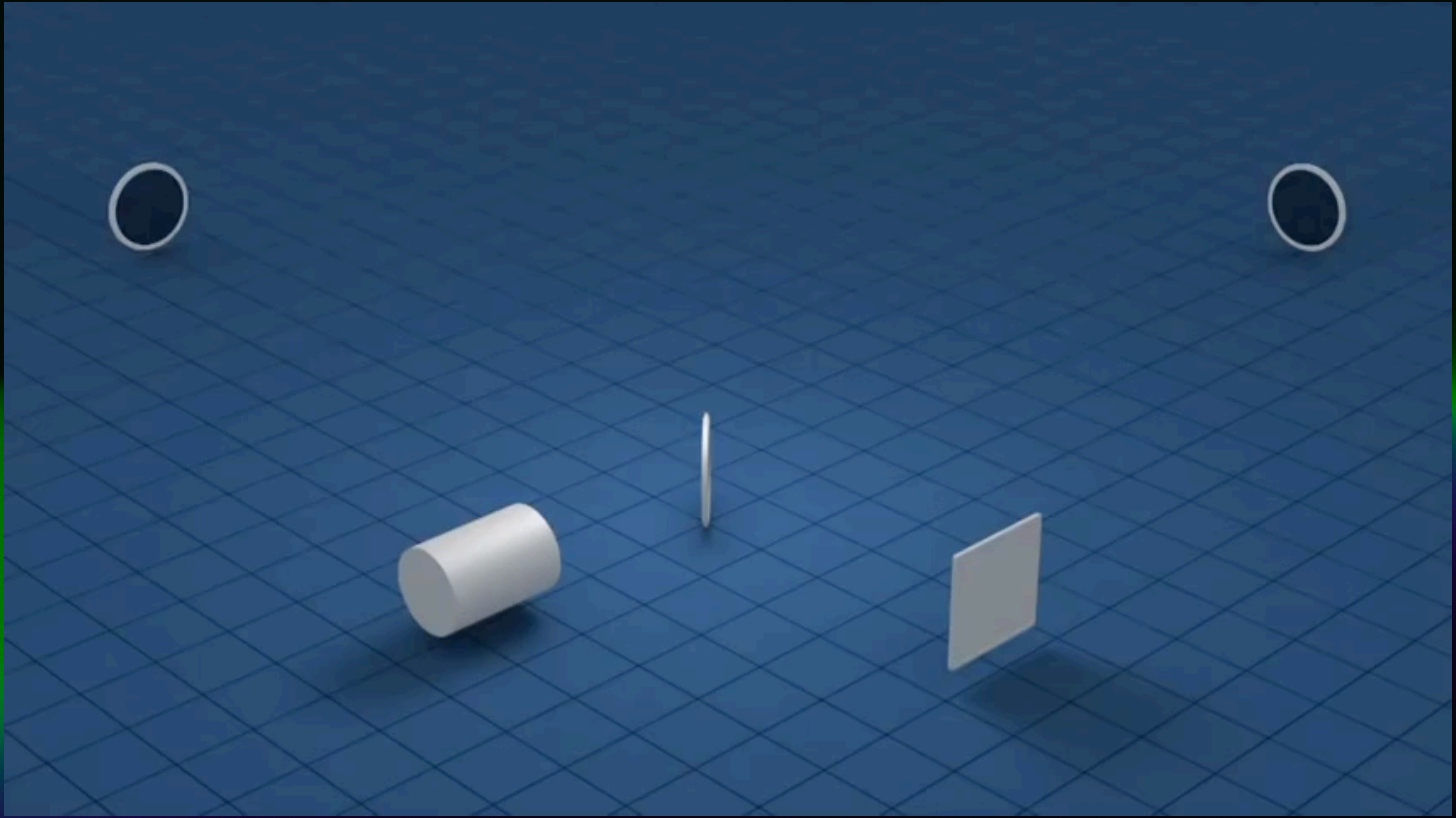


How much does it stretch and squeeze?

- So, as a gravitational wave passes through Earth, it squeezes and stretches the Earth such that the distance between Glasgow and Edinburgh changes by 0.0000000000000001m
- That's all cool and all, but how can we link this to predicting when volcanos erupt?
- This is where the engineering magic happens

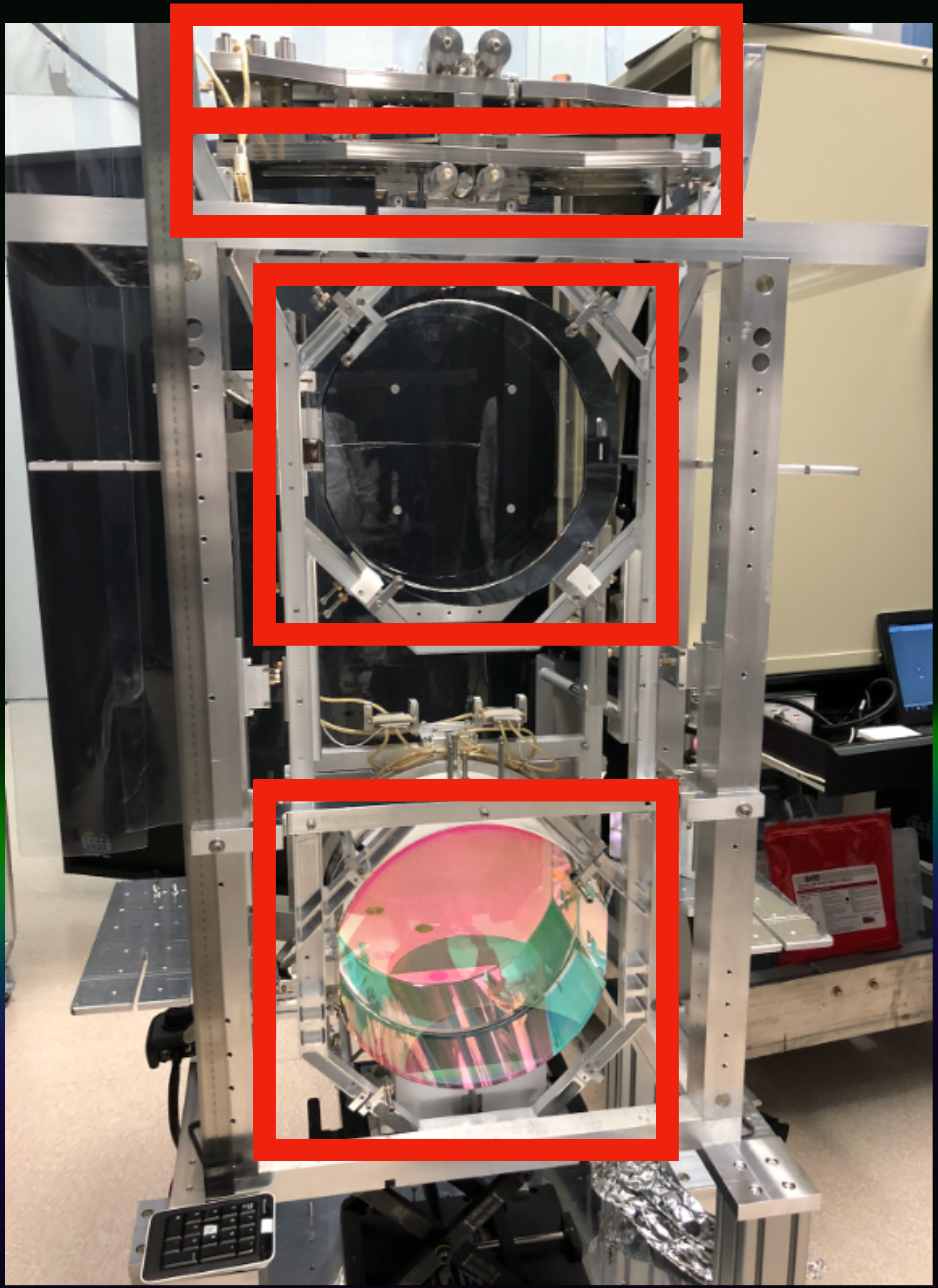
Gravitational Wave Detectors

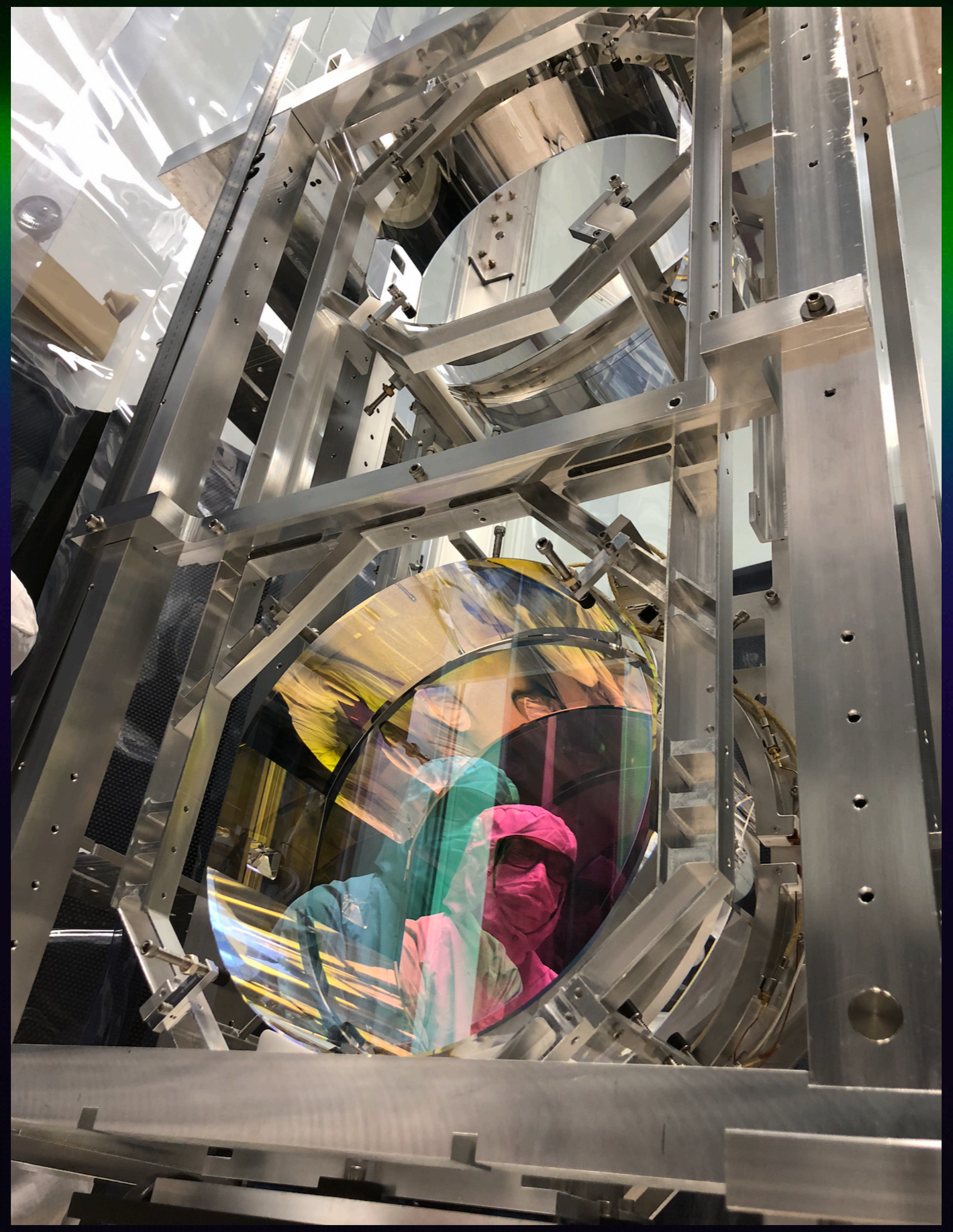




Ultra-still mirrors

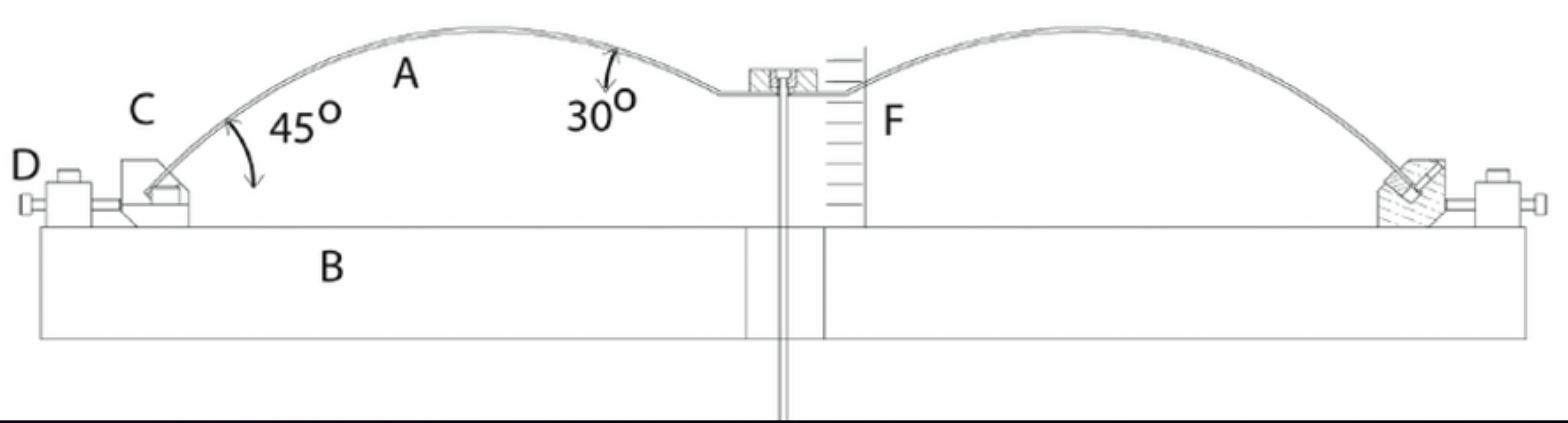
- To make these mirrors ultra-stable and ultra-still, we have to isolate them from any ground motion
- By hanging the mirror from other hanging stages above it, we can isolate them from external ground motion
- We call these suspension systems
- We're almost at the volcanos now…





Geometric Anti-Spring

- One such technique to keep the mirrors ultra-still is to have one of the stages above the mirror a geometric anti-spring
- If you think about springs, for example a slinky, it always wants to return to its original shape when you stretch it out (put it under a load)
- These springs actually get softer when they are under load, allowing for low frequency oscillation and great isolation from ground motion



Now, quick change in scenery

- Volcanos now?

- …not quite, first we need to visit the Sun and Moon

Tidal Forces

- Tidal forces occur due to the interaction between the gravitational pull between the Sun, Earth and the Moon.
- This not only is what causes ocean waves (high/low tides), but also ever so slightly squeezes and stretches the Earth (by around 40cm or so)
- Basically, over the course of 12-13 hours, Glasgow (for example) goes up and down by around 40cm

Tidal Forces

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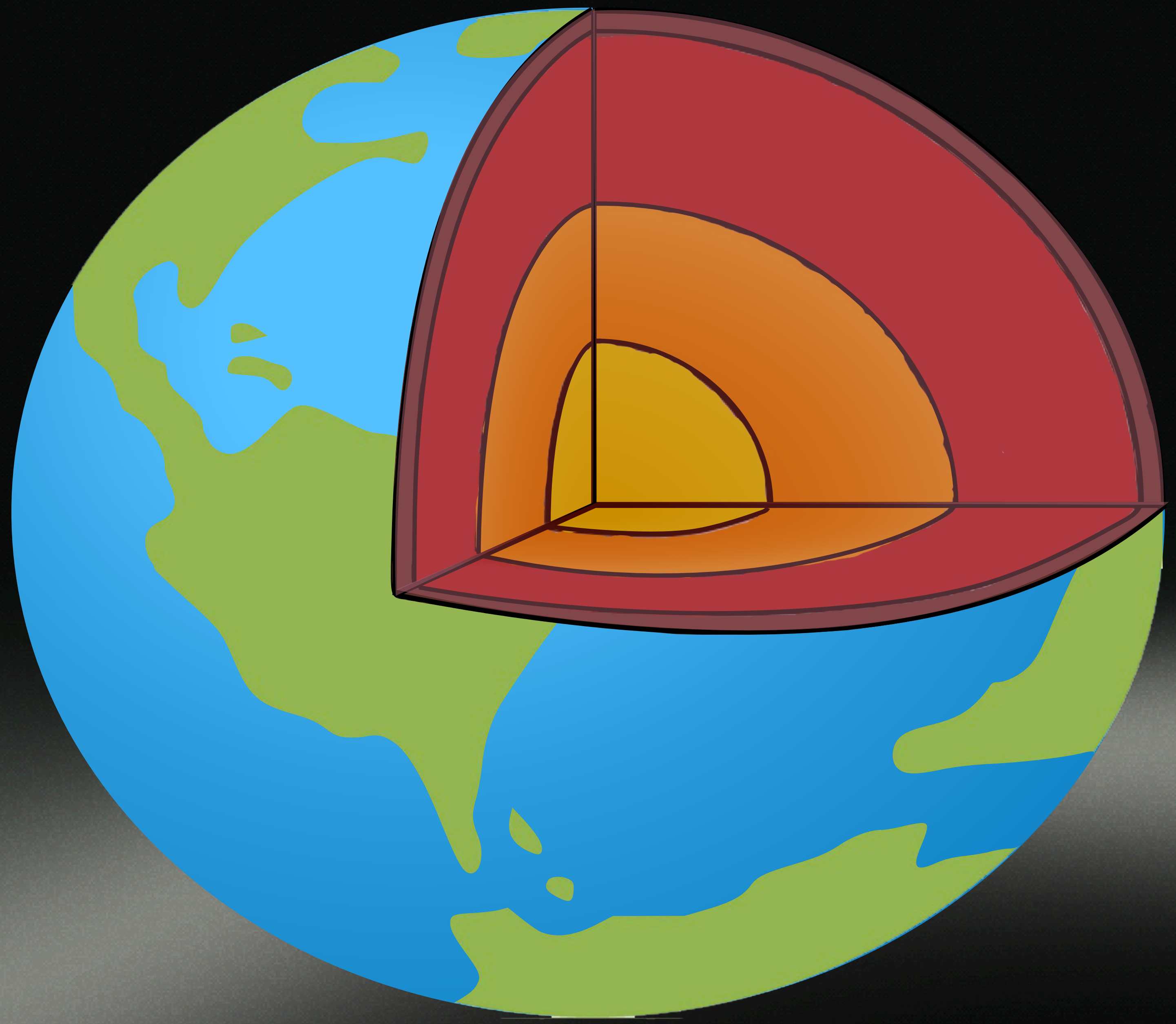
Tidal Forces



Tidal Forces

Tidal Forces

Gravitational Acceleration

- You'll notice in clips of Neil Armstrong and Buzz Aldrin jumping on the moon, they have a lot of air time between their jumps, unlike Buddy
- This is because the gravitational pull and acceleration (what is trying to keep you on the ground) on the moon is smaller than on Earth
- However, if tidal forces are changing the distance between the Earth's surface and the Earth's core, this means the gravitational acceleration is also going to change

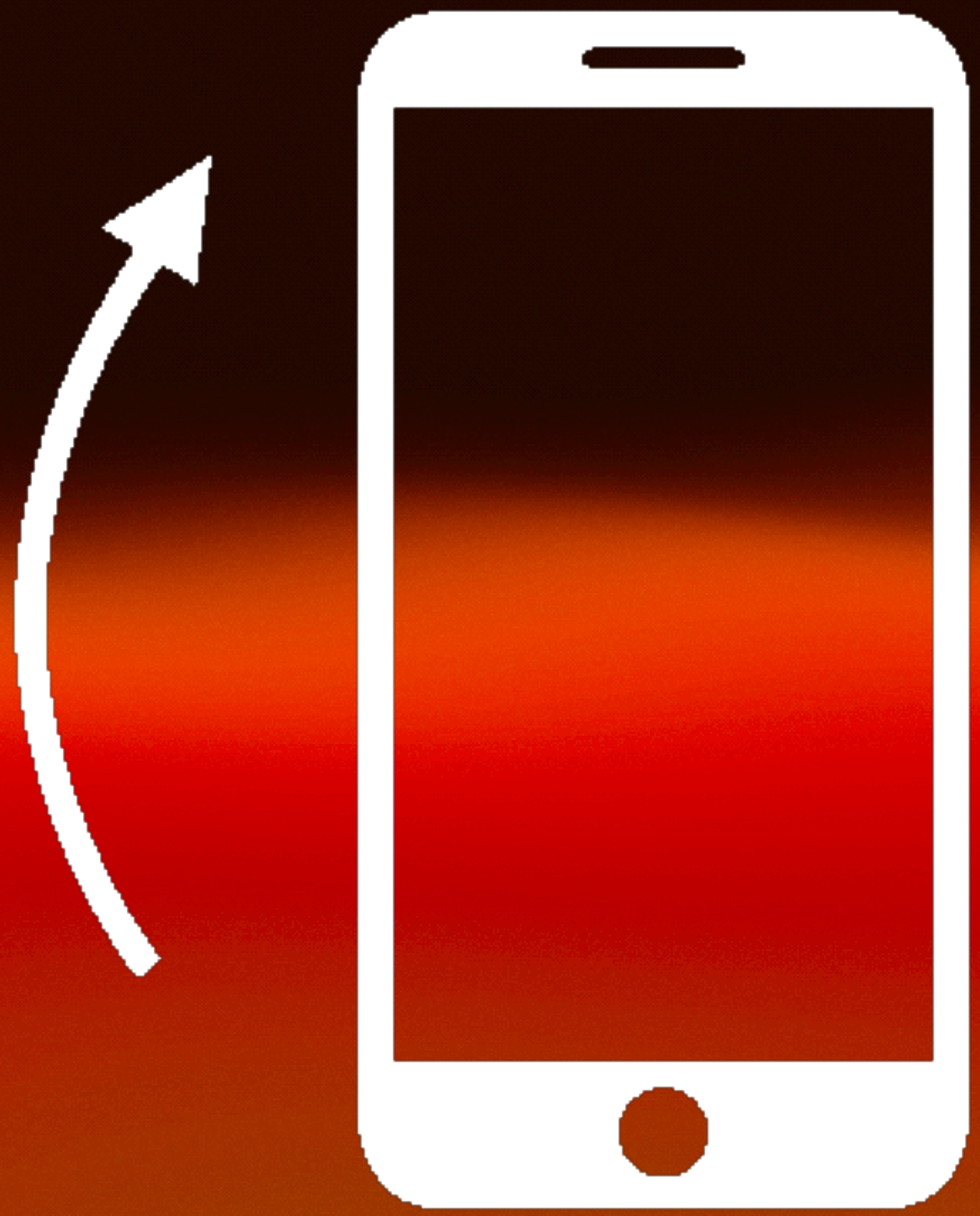
Tidal Forces

- So, the moon has a smaller gravitational acceleration and force than the Earth because it is smaller and the material under the surface is less dense than what is here on Earth
- Back on Earth, then if we have a changing gravitational acceleration because the distance is changing between the surface and the core, can we measure this?
- What if we have different materials under the surface we're standing on?
- We need to find a way to measure this

We need to build a gravity sensor

Smart phone accelerometers

- Nowadays, the vast majority of people have a smartphone, which can rotate between landscape and portrait mode
- The phone can detect this by a small internal device called an accelerometer
- This detects the motion and orientation of the smart phone to rotate the phone between portrait and landscape
- Can we use this technology to measure changes in gravitational acceleration?

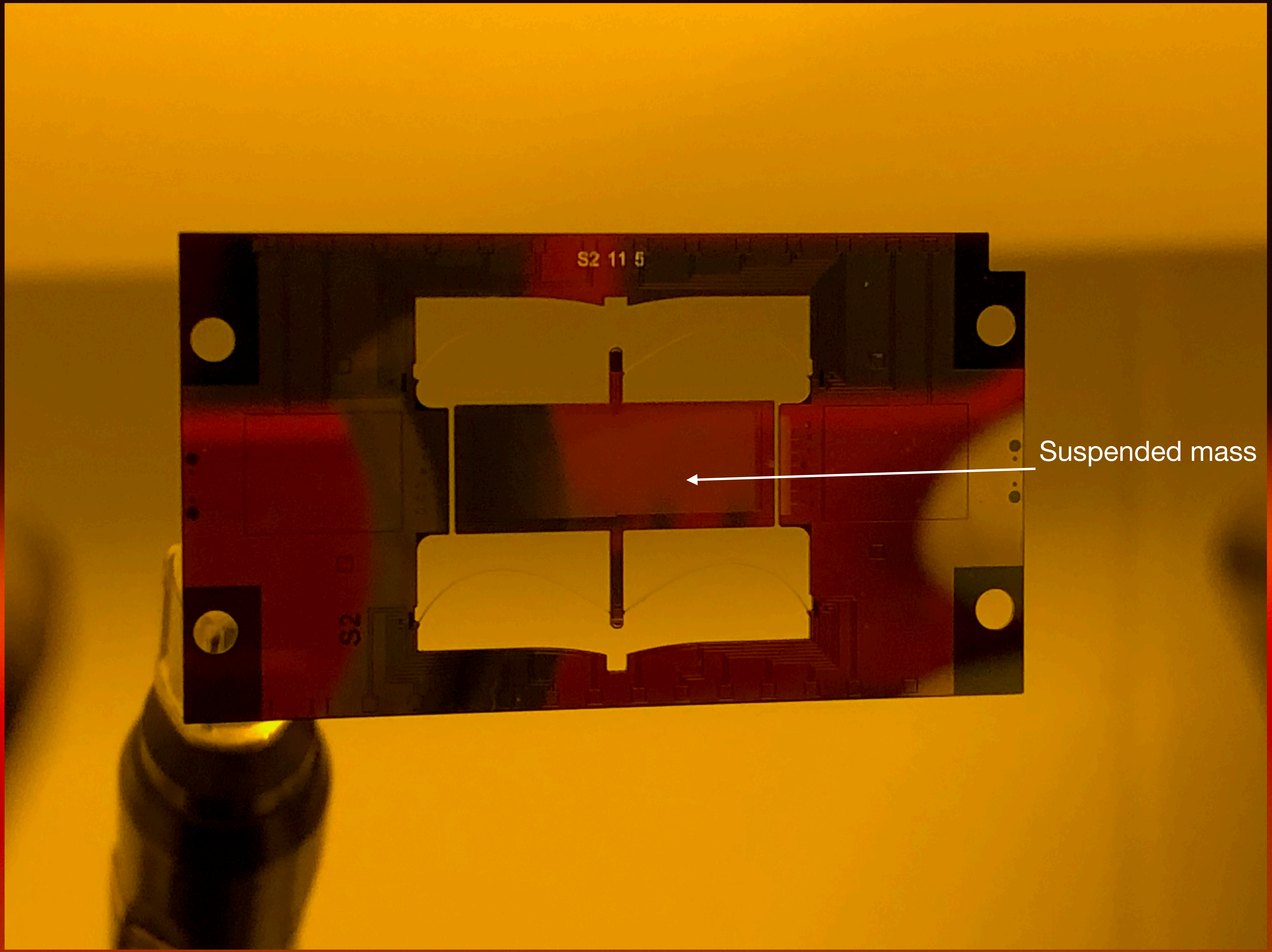


Yes we can!

- We can develop sensors that can measure changes in gravitational acceleration
- These gravity changes can for example be from tidal forces, or changes in underground material
- These sensors are called gravimeters
- One such gravimeter developed at Glasgow is known as, Wee-g
    - Pun that works on multiple levels

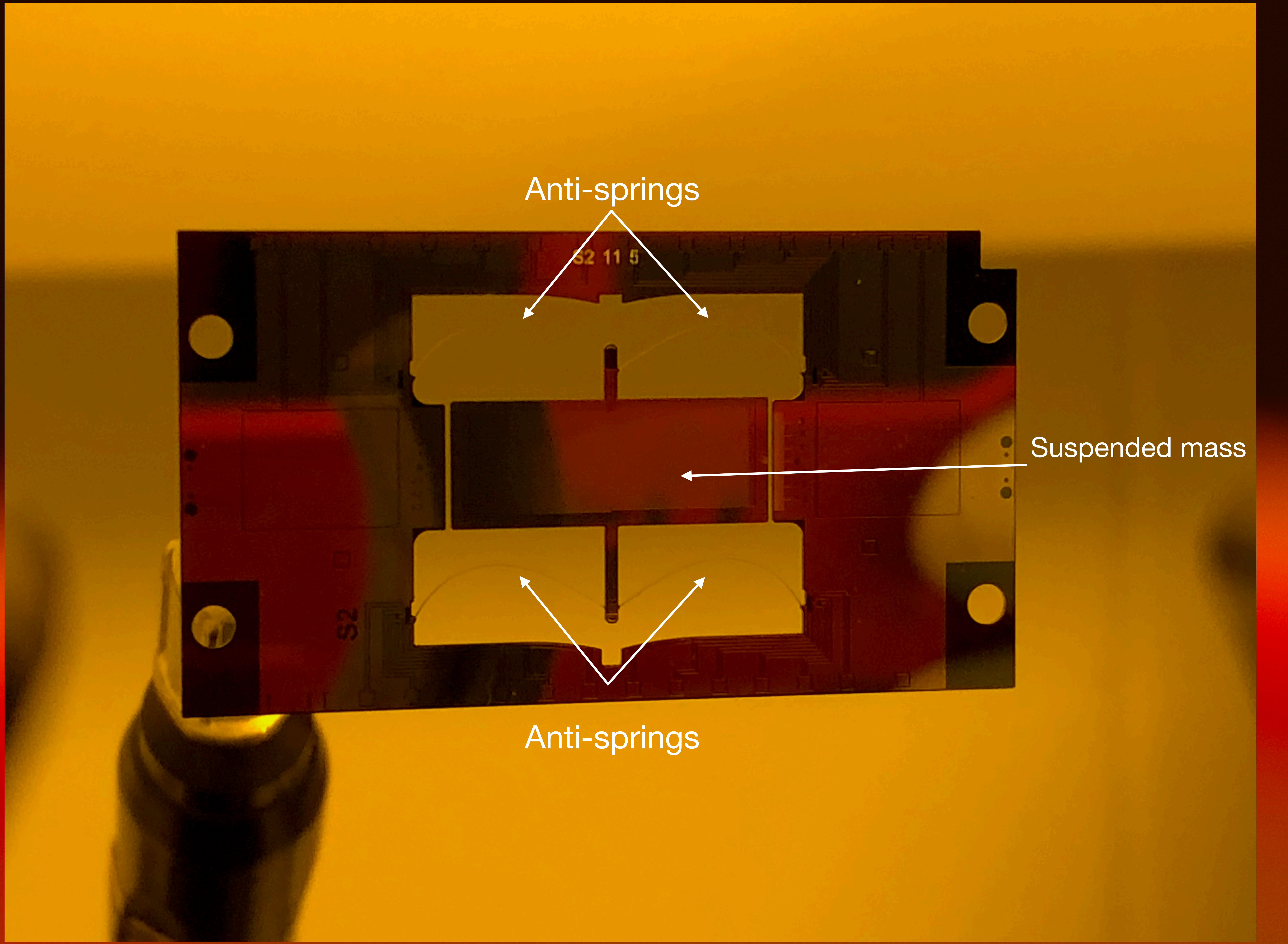
Wee-g

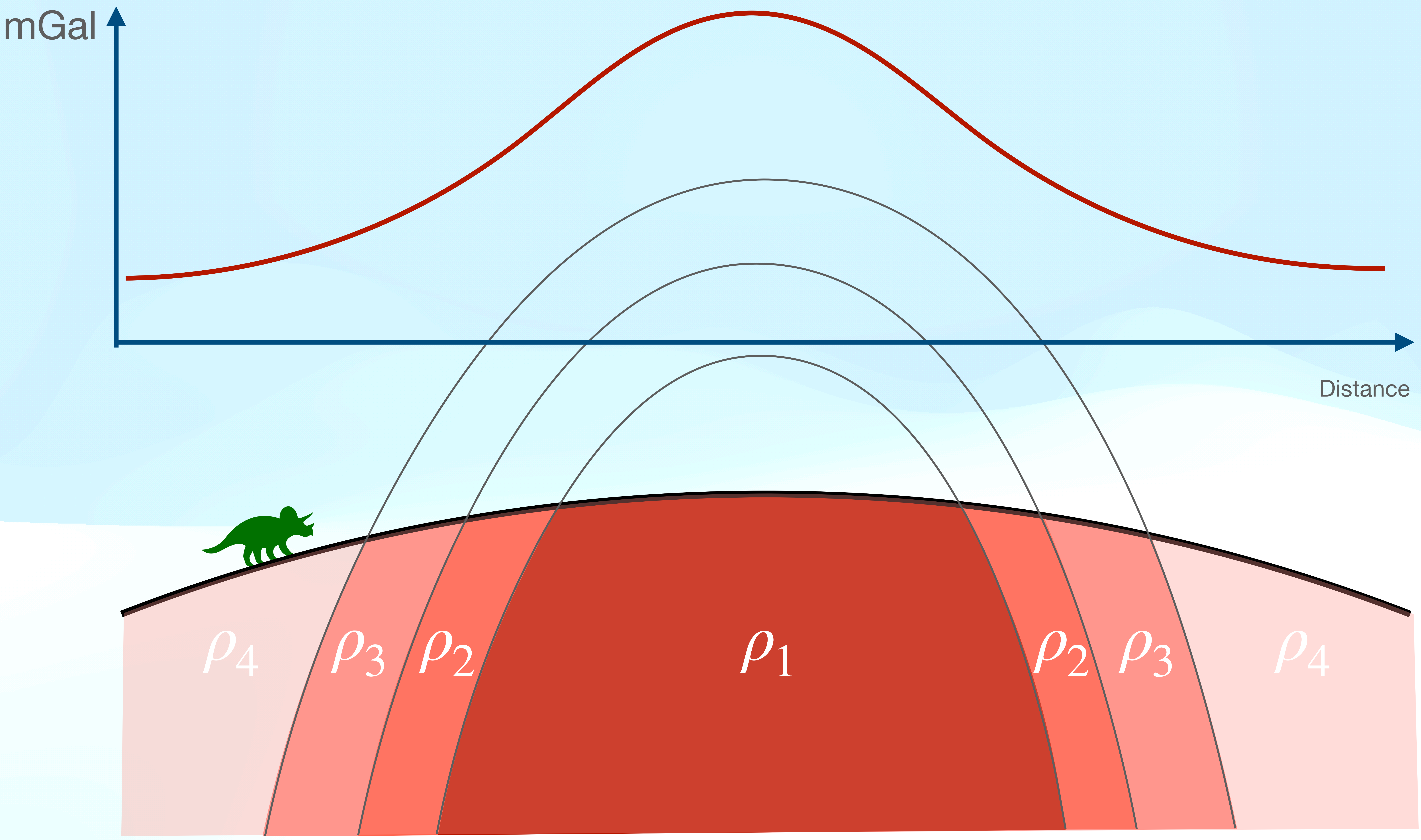
- The principle of Wee-g is that when a change in gravity is observed, such as a change in material underground, the suspended mass will move up or down
- For example, if this sensor is measuring gravity on solid ground, it would measure a different level of gravity if it was measuring over a tunnel



Wee-g

- Notice that the suspended mass is held in place by 4 anti-springs
- Technology used in experimental astrophysics is being utilised in mechanical engineering, to then be used in areas of civil engineering and environmental monitoring
- So, how can we use this for volcano monitoring?





Regions of different densities
(Darker the red, the stronger the acceleration)

Volcano Monitoring

- The benefit of Wee-g compared to industrial commercial gravimeters is it is significantly “cheaper”
  - Around £10,000 rather than £100,000+
- This means we can install multiple Wee-g sensors in one location for the same cost of 1 commercial gravimeter
- Very useful for volcano monitoring where underground magma flow can be slow (until explosive at the surface)!

Volcano Monitoring

Volcano Monitoring - NEWTON-g

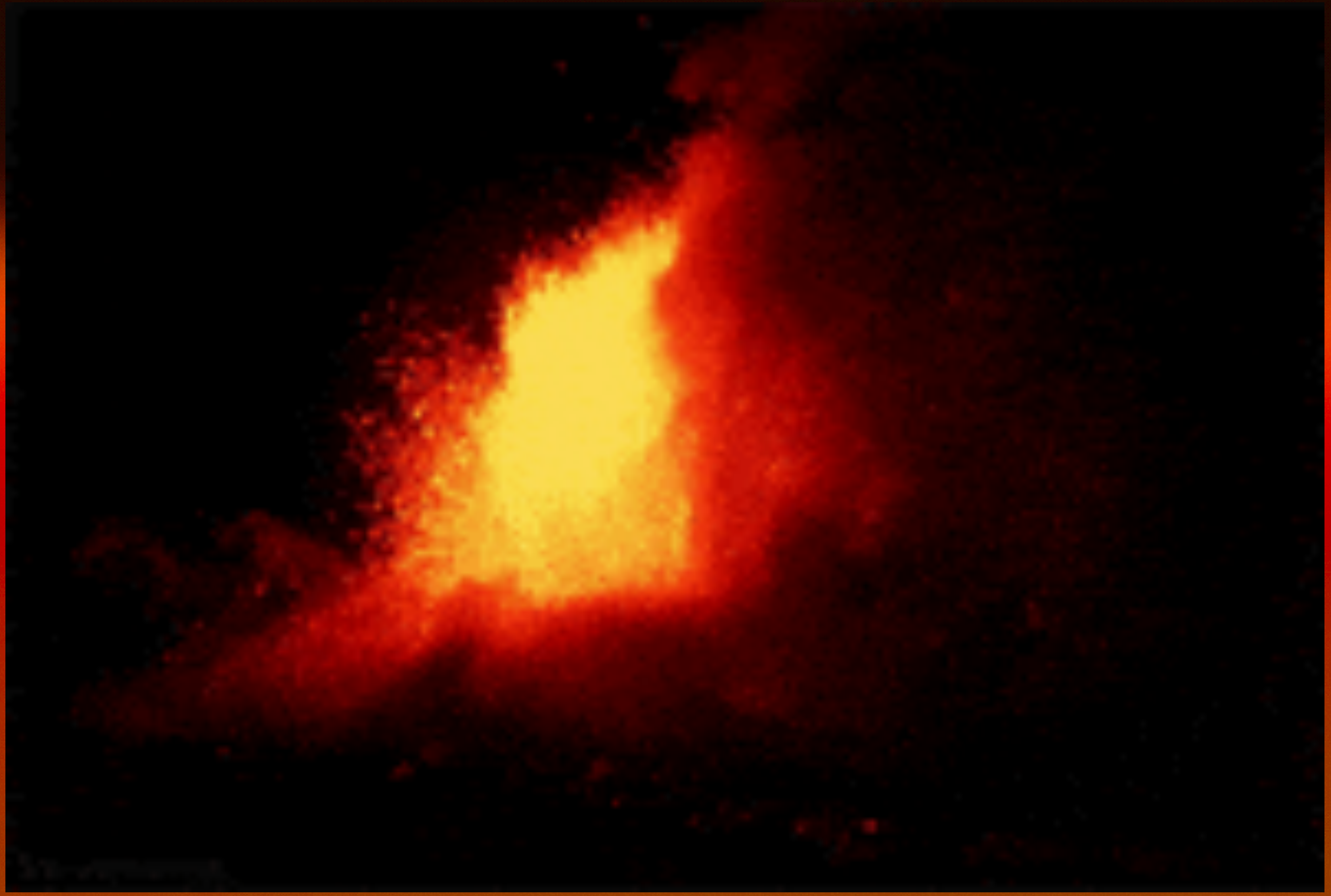
- The NEWTON-g project is the first ever multi-gravimeter set-up is currently under construction on Mount Etna in Sicily, where multiple Wee-g sensors are currently being installed as part of a long term volcano monitoring system

Volcano Monitoring - NEWTON-g

- These sensors will aim to detect new magma channels underground as the magma will create a density change, therefore a change in gravitational acceleration

Volcano Monitoring - NEWTON-g

- Possible to deploy further sensors at other volcanoes around the world
- Not a bad place to start with the most active volcano in Europe though



Other Areas Wee-g can be utilised

- As well as volcano monitoring, Wee-g can be used to look at other areas of environmental monitoring:
  - Groundwater monitoring
  - Mineshaft detecting
  - Underground tunnel detecting
  - Airborne gravimetry on drones for hard to reach areas
  - Sinkhole detection
- Lots of areas to explore in the future

Conclusion

- There is no limit to how much technology can influence unrelated areas of research, and this goes for your future studies too
- For example, we have looked at how technology developed to detect crashing black holes in our galaxy can be utilised for environmental monitoring of volcanos on Earth
- This has only been a small snapshot of the vastly diverse options that would be available to you through studying physics

Thank you for your time