Black Holes

Christopher J. Moore

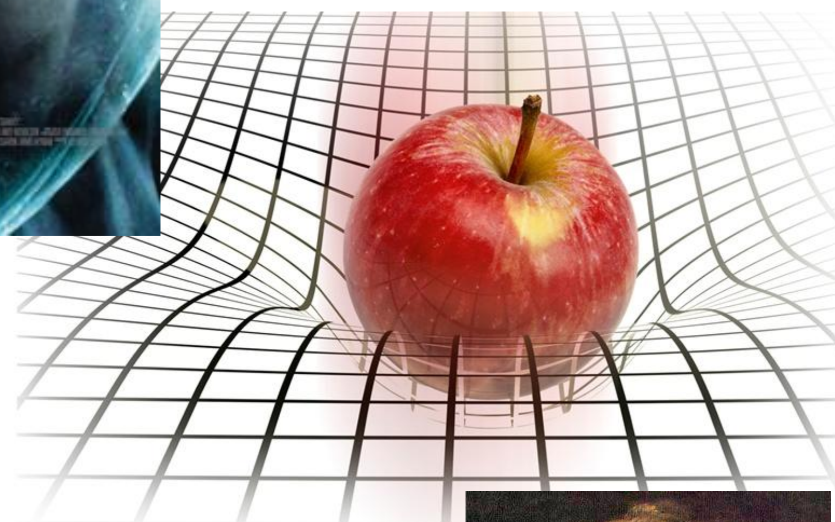
Astro In The City, December 2022

UNIVERSITY OF BIRMINGHAM | GRAVITATIONAL WAVE ASTRONOMY

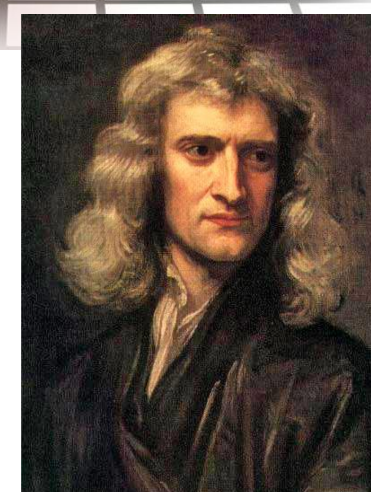
Gravity

Newton's law of gravitation...

every object pulls every other object towards it

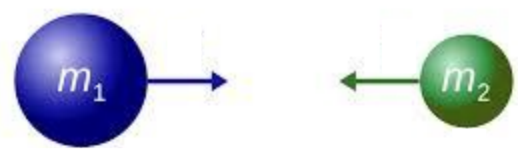


Gravity keeps us on the ground and keeps the Earth in orbit around the Sun



The force between any two objects depends only on their masses and their separation...

the strength of gravity, G, is universal

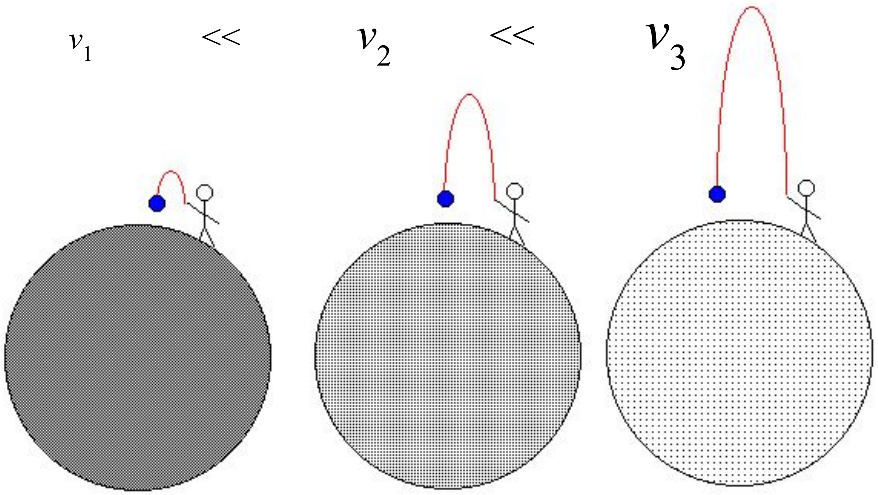


Escape Velocity

Gravity keeps us on the ground

But the Earth's gravity can be overcome...

Q: *How fast would you need to jump to escape out into space?*



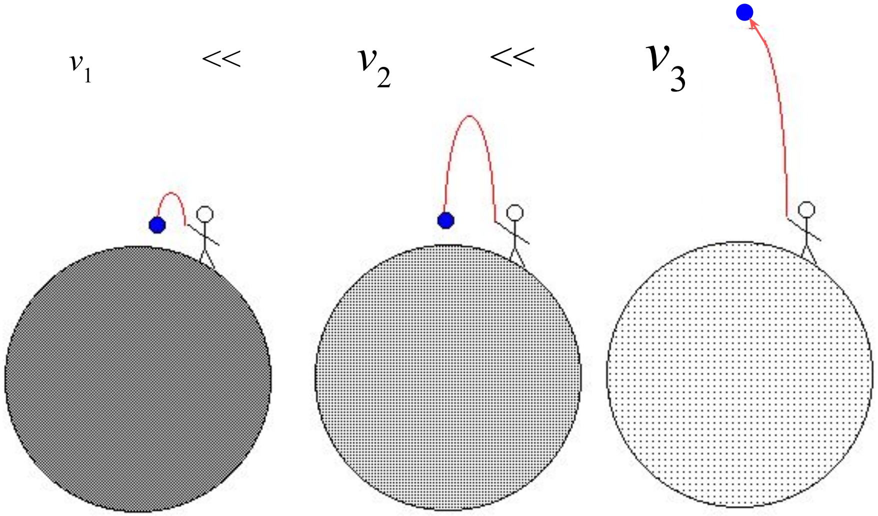
Escape Velocity

Gravity keeps us on the ground

But the Earth's gravity can be overcome...

Q: *How fast would you need to jump to escape out into space?*

A: *The escape velocity of the Earth is 40,000 km/h... that's 25,000 mph*



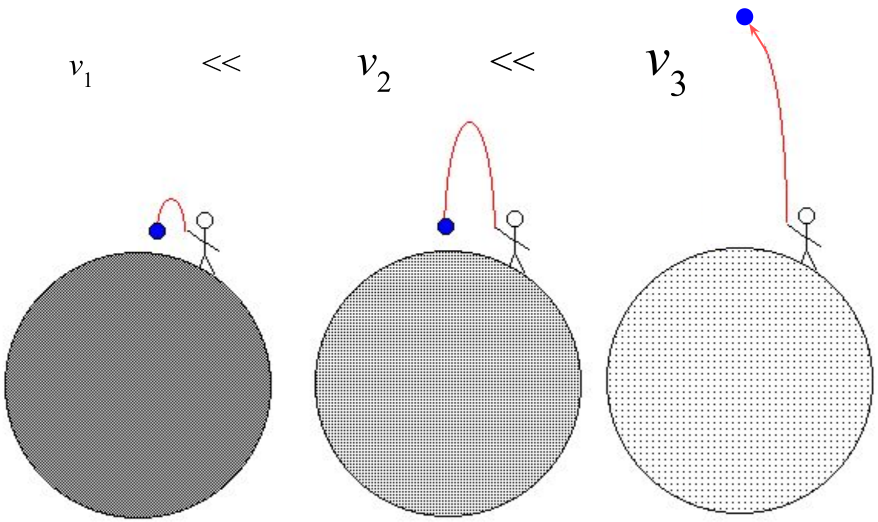
A bit too much for me to jump, but it can be done with rockets

Escape Velocity

What is the escape velocity on other planets?

Different objects have different escape velocities

$$v_{\text{escape}} = \sqrt{\frac{2GM}{R}}$$



Smaller, denser objects have a stronger gravitational pull...

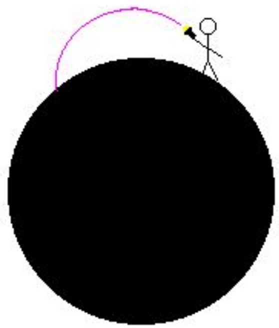
therefore, they have higher escape velocities

Escape Velocity

Is it possible to have an object so small and heavy that the escape velocity is the speed of light?

$$R_{\mathrm{BH}} = \frac{2GM}{c^2}$$

$v_{\mathrm{escape}} = c$ speed of light?

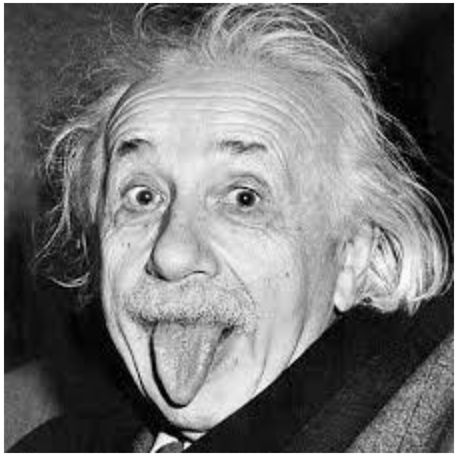


This would be a **Black Hole**

Black Holes: the history of an idea

Black holes are not a new idea…

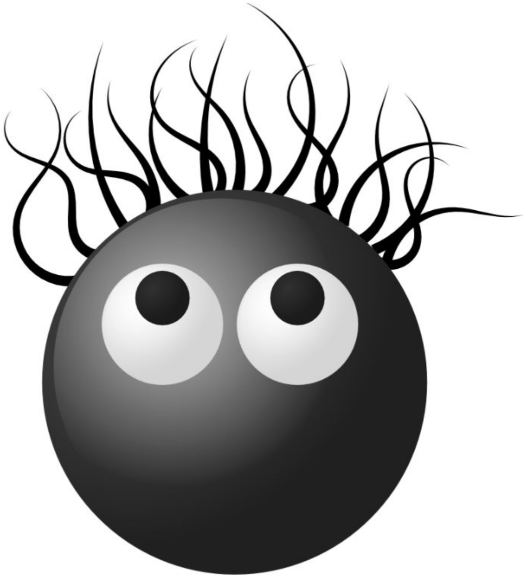
first suggested in 1700s, independently by
John Michell (1784) and Laplace (1799)



It remained a theoretical idea for a very long time…

most physicists thought they couldn't/didn't exist

Black holes seemed even less likely when Einstein realised the speed of light is maximum possible speed



Q: *How is it possible to know something exists if nothing, not even light, can come out?*

Evidence for Black Holes

Over the last 60 years, we have gathered plenty of evidence for black holes...

- Accretion ≈ 1960s
- Orbits around nothing 1995 - 2008
- Gravitational waves 2015
- Direct imaging 2019

Black holes have been on a slow journey from science fiction to science fact

Accretion

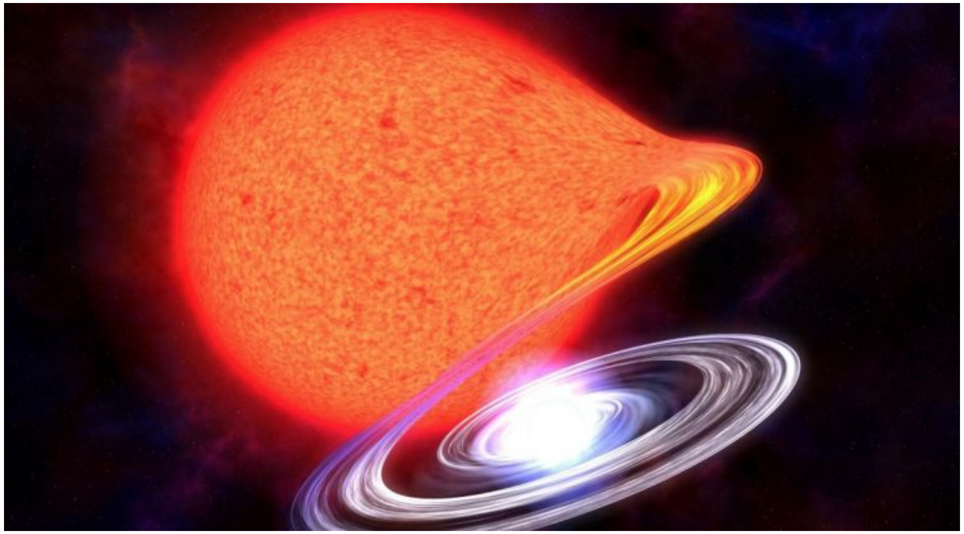
If we can't see the black hole itself, we can things around it...

for example, gas and dust

Many astronomical objects have disks of orbiting material

As the material spirals in, it speeds up, gets hot, and the disk glows

Accretion disks are some of the brightest objects in the universe



As the gas piles up on the central object, it shines brightly as it grows

Accretion

If we can’t see the black hole itself, we can things around it…

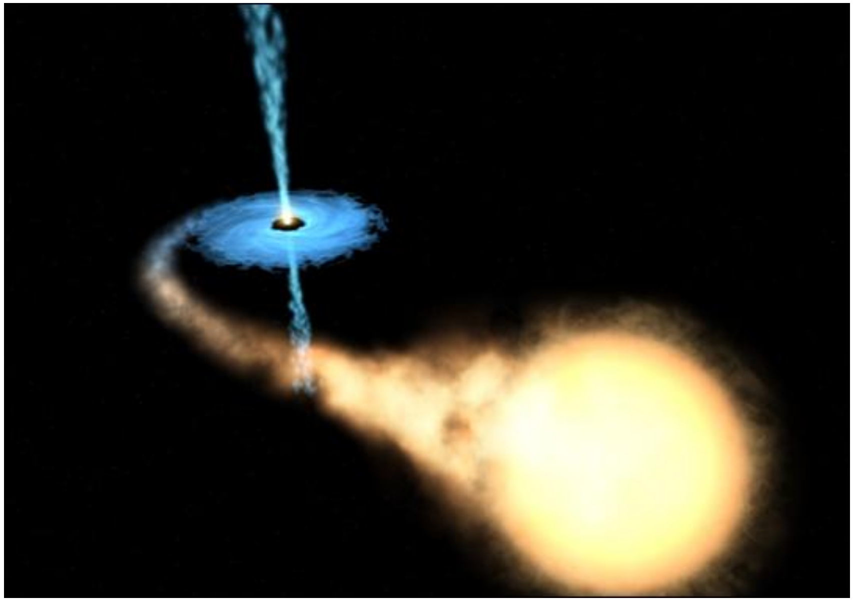
for example, gas and dust

Many astronomical objects have disks of orbiting material

As the material spirals in, it speeds up, gets hot, and the disk glows

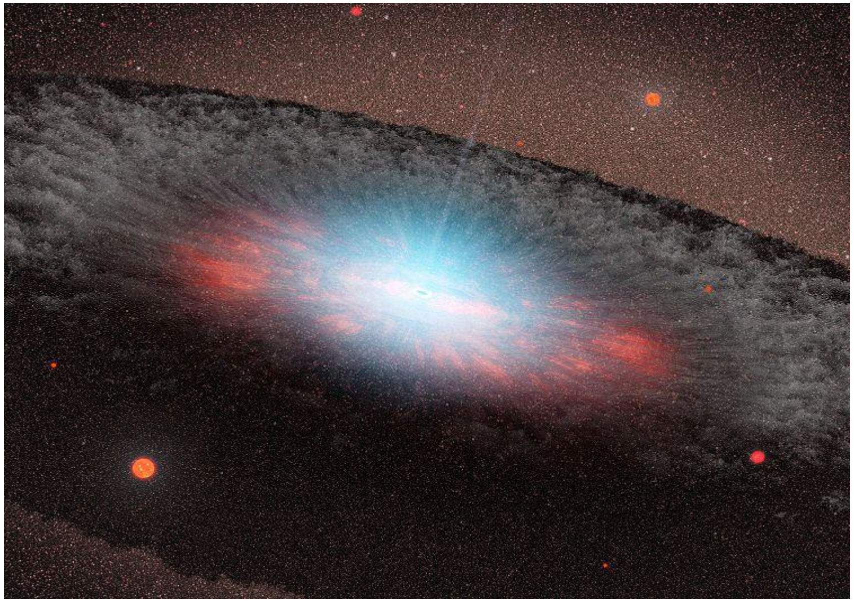
Accretion disks are some of the brightest objects in the universe

Where did the central object go?



X-ray binaries - nearby stellar-mass black holes

Quasars - supermassive black holes in distant Universe



Orbiting Stars

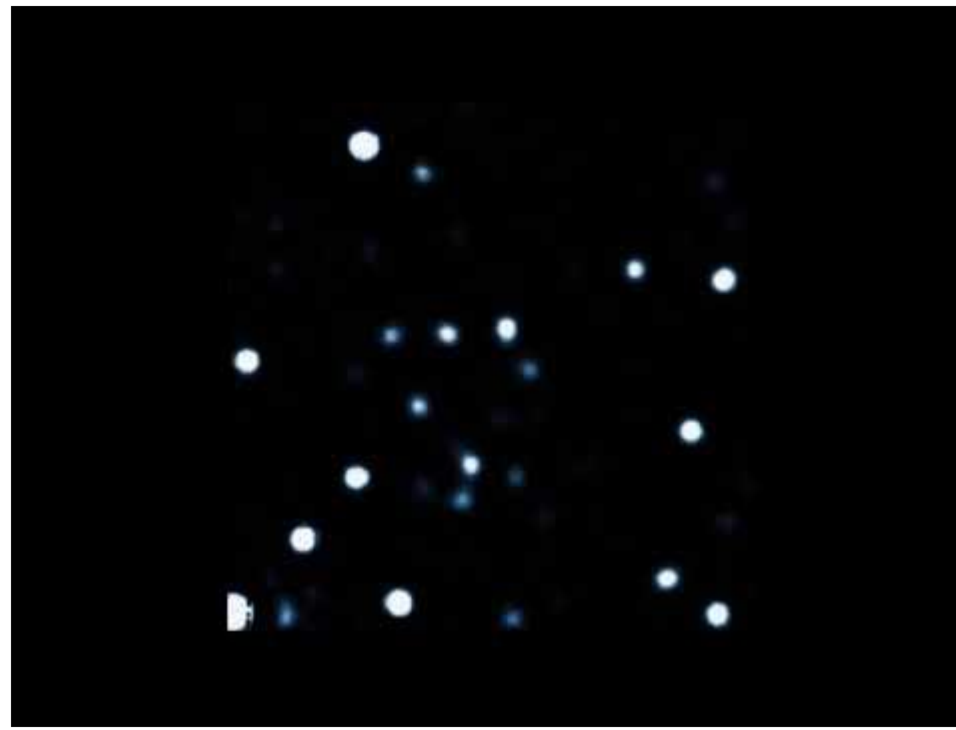
The 2020 Nobel Prize in Physics

Reinhard Genzel & Andrea Ghez

“for the discovery of a supermassive compact object at the centre of our galaxy”

If we can’t see the black hole itself, we can things around it...

for example, orbiting stars



There is a supermassive black hole in the centre of our own galaxy

$$M_{BH} \approx 4,000,000\, M_\odot$$

Since 1995, we have tracked the orbits of several stars, but they don’t seem to be orbiting anything!

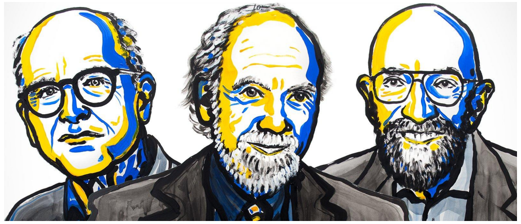
Gravitational Waves

Q: *What happens when black holes come together?*

Gravitational Waves

The 2017 Nobel Prize in Physics

Rainer Weiss
Barry C. Barish
Kip S. Thorne



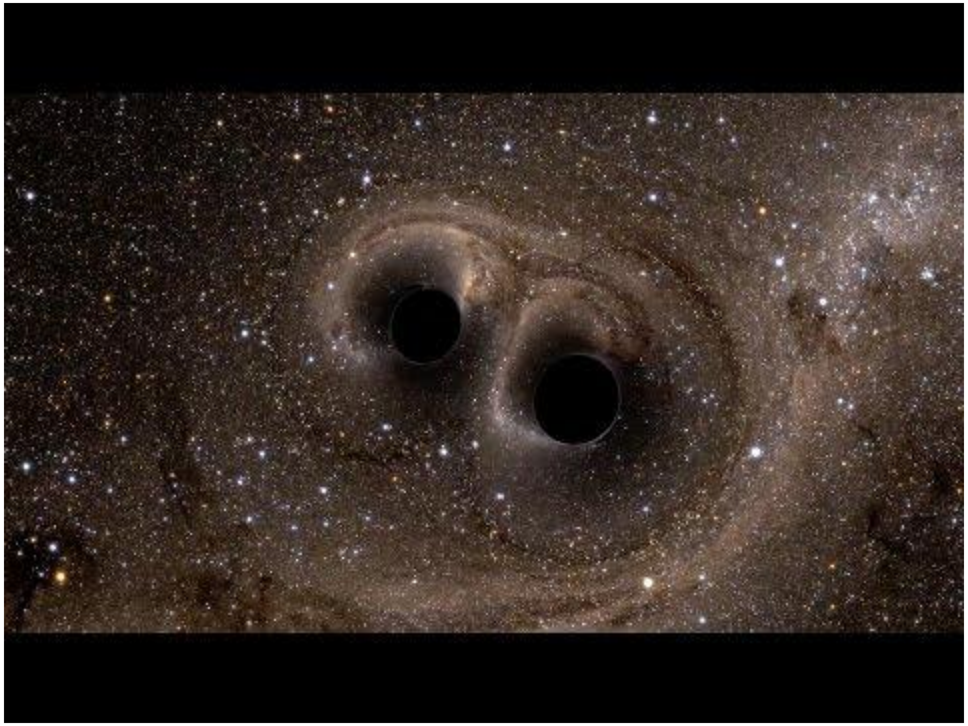
“for decisive contributions to the LIGO detector and the observation of gravitational waves”

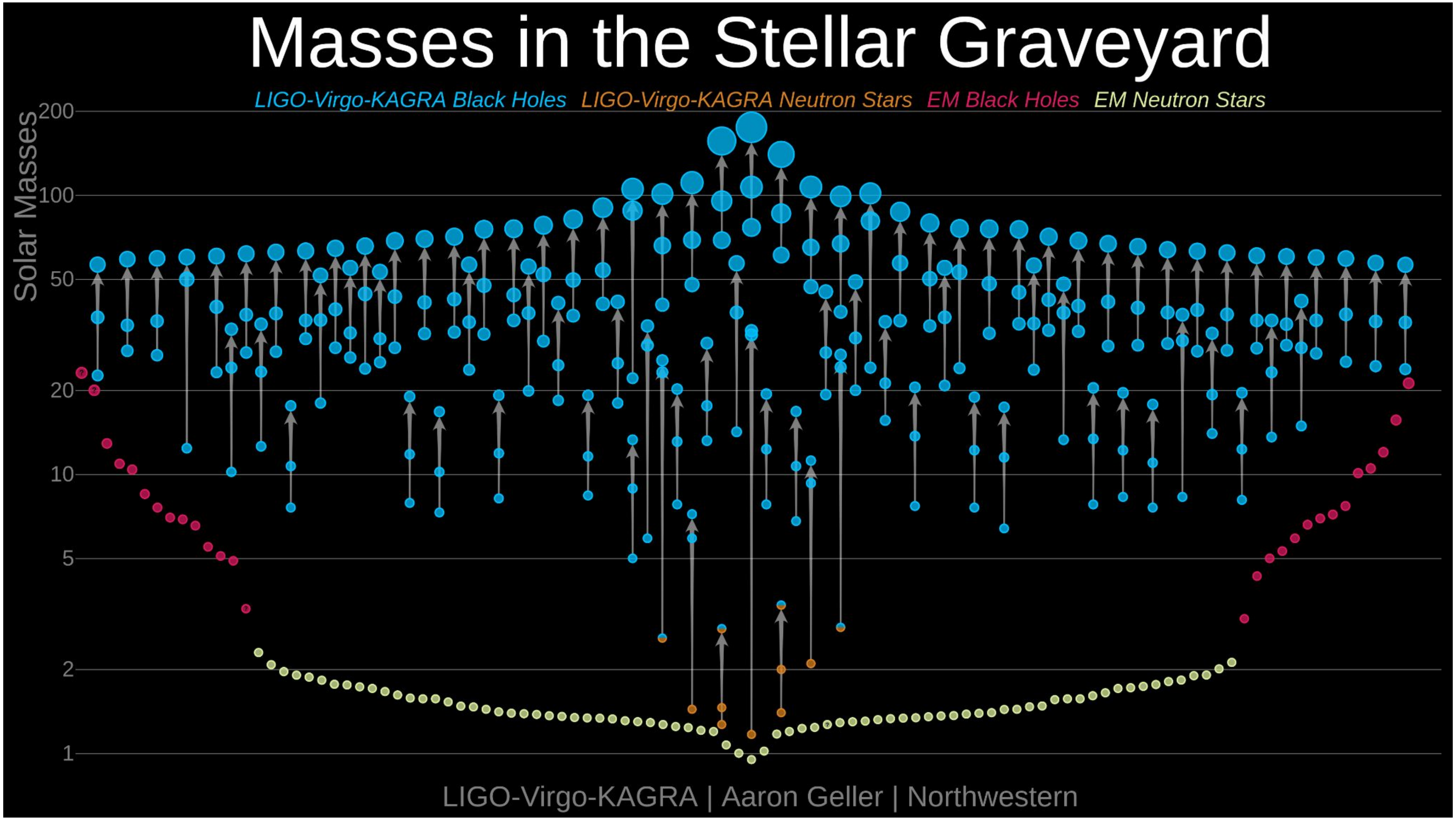
Q: *What happens when black holes come together?*

A: *They merge together and form a bigger black hole*

But as they do so they give off **gravitational waves**

These waves in the gravitational field can be detected by measuring minute changes in the distance between a pair of objects





Masses in the Stellar Graveyard
LIGO-Virgo-KAGRA Black Holes
LIGO-Virgo-KAGRA Neutron Stars
EM Black Holes
EM Neutron Stars
Solar Masses
200
100
50
20
10
5
2
1
LIGO-Virgo-KAGRA | Aaron Geller | Northwestern

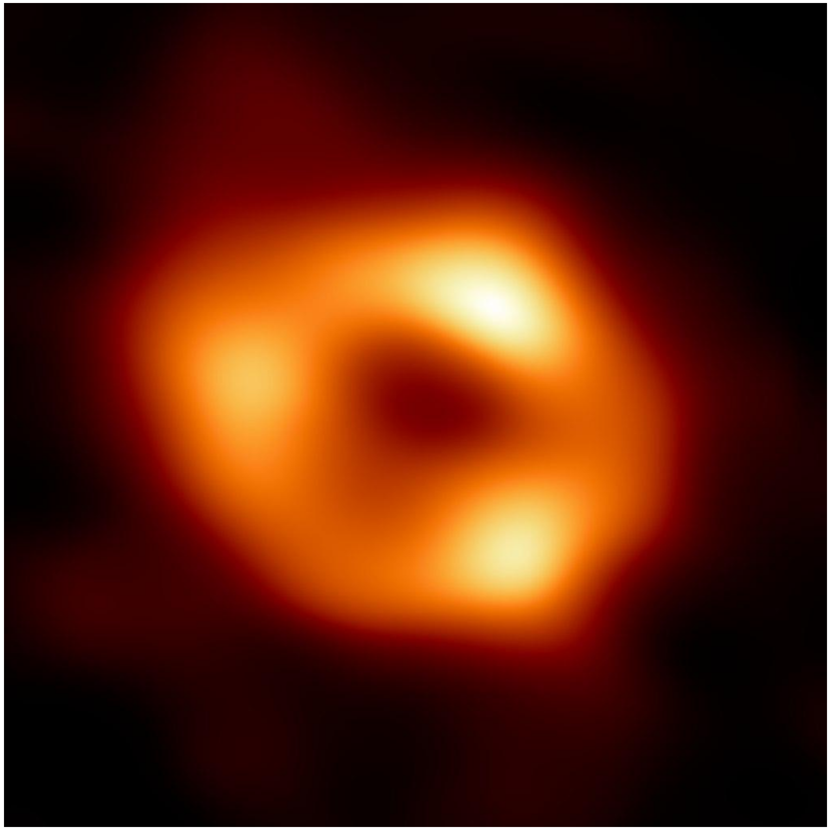
Take a Photo!

Most recently, it has also become possible to zoom in on the black hole at the centre of our own galaxy

This is the nearest thing to "*taking a photo*" of a black hole

Again, what we are seeing is not the black hole itself, but the surrounding gas and dust

This was done for the first time by the Event Horizon Telescope imaging a black hole called M87



Thank you for listening!