Black Holes

How dead stars warp space and time

30 min

Dr Steve Barrett

GSW 24 Aug 2021

Black Holes

A brief history

Why light can't escape a black hole

Einstein's General Relativity (without the horrible maths)

How can we 'see' black holes?

Is 'dark matter' just black holes?

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A Brief History

Black Hole [definition]:

A region of space from which nothing, not even light, can escape.

When did the concept of a black hole originate? Earlier than you think.

Rev John Michell (1783) – "If [the size of] a sphere of the same density of the Sun were to exceed that of the Sun in the proportion of 500 to 1 … all light emitted from such a body would be made to return towards it by its gravity."

In the 1800s the idea of such '**dark stars**' was largely ignored.

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A Brief History

Einstein (1915)
General Theory of Relativity

Schwarzschild (1916)
Calculation of gravity of a compact mass

Eddington (1926)
Stars compressed to the 'Schwarzschild radius'

Chandrasekhar (1931)
Massive stars at the end of their lives will collapse

Oppenheimer (1939)
Nothing can stop the collapse of massive stars

General Relativity predicts that time stops at the Schwarzschild radius and so such collapsed stars were called '**frozen stars**'.

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Escape Velocity

The escape velocity at the surface of a body depends on the ratio of the mass to the radius

$$\frac{M}{R}$$

Some escape velocities:

Velocity to escape the Moon = 2 km/s (= 5,000 mph)

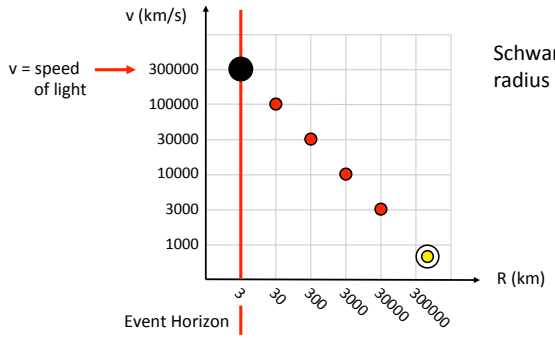
Velocity to escape the Earth = 11 km/s (= 25,000 mph)

Velocity to escape the Sun = 600 km/s (> 1,000,000 mph)

600 km/s may sound like a lot, but it is only 0.2% of the speed of light

Escape Velocity

Let's compress the Sun to smaller sizes and see what happens to the escape velocity.



Schwarzschild radius of 3 km

Escape Velocity

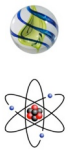
If we compress the Sun into a sphere of radius 3 km then we form a black hole.

What if we start with a body with a different mass?

For the Earth the Schwarzschild radius is ~ cm

Moon ~ 0.1 mm

Mt Everest ~ atom



We know of no way that this can happen for any mass smaller than that of a star, but that doesn't mean that it's impossible.

General Relativity

$$G = 8\pi T$$

The equation is sometimes reduced to the more prosaic description

Mass tells **space** how to **curve**

Space tells **mass** how to **move**

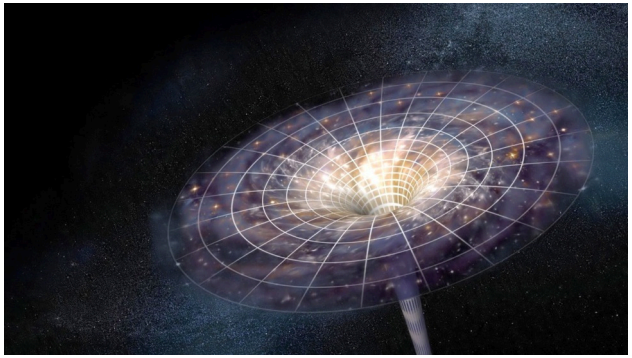
What do we mean by curved space?

Any image trying to explain this uses the analogy of 2-dimensional space curving into a third dimension.

To warp or curve 3-dimensional space we need a fourth dimension which humans, not unnaturally, find very difficult to imagine.

General Relativity

Black holes produce infinitely warped space



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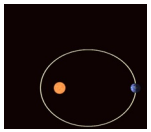
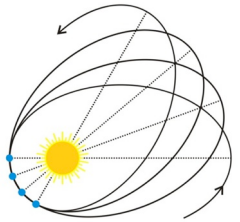
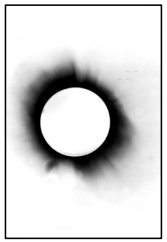
Predictions of General Relativity



The precession of the orbit of Mercury



Gravitational lensing



Stars seen during the total solar eclipse of 1919 were found to be slightly shifted in position.

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Black Holes Are Born

Core collapse of a massive star – Supernova

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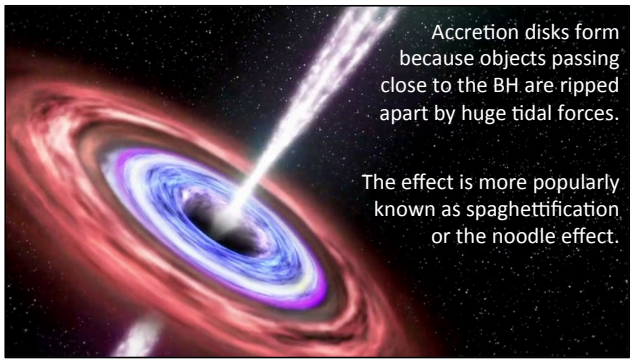
Black Holes Feed

Accretion disk and x-ray jets



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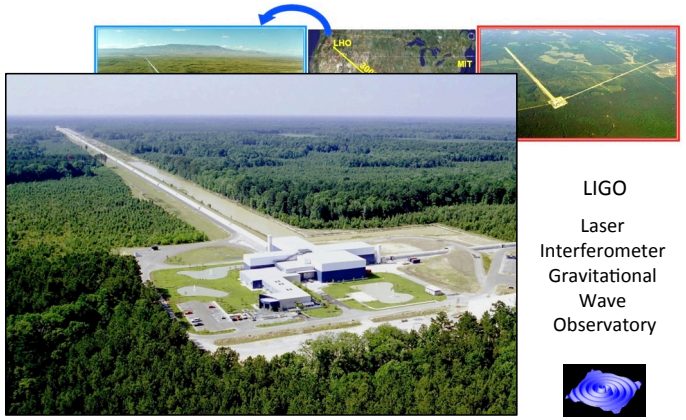
Detecting Gravitational Waves



LIGO

Laser Interferometer Gravitational Wave Observatory

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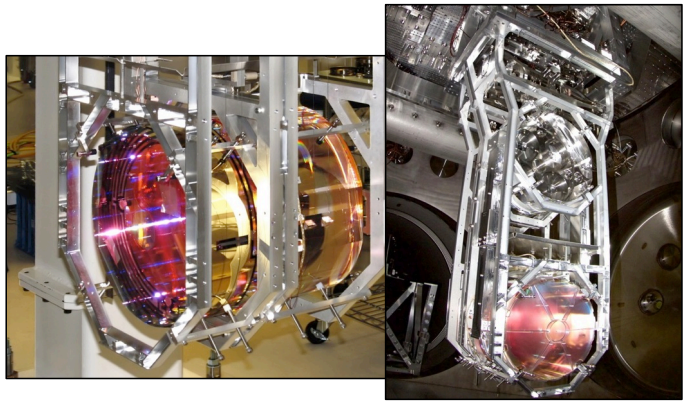
Detecting Gravitational Waves



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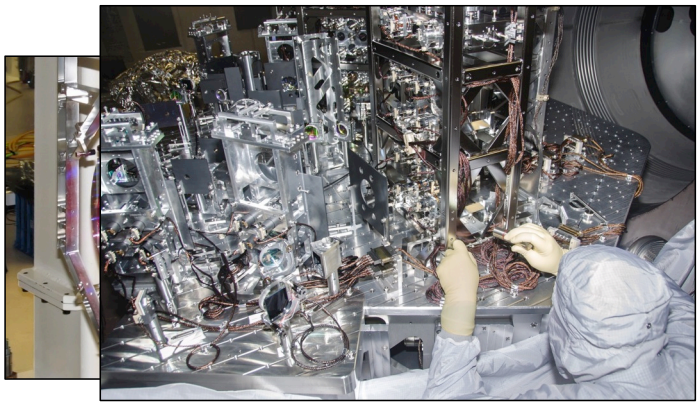
Detecting Gravitational Waves



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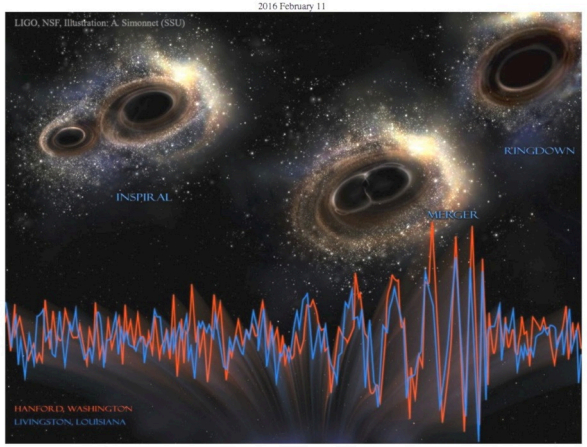
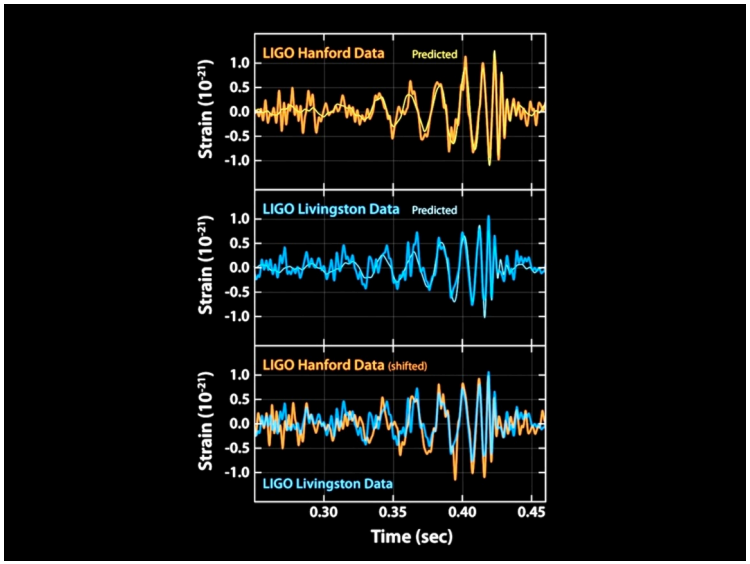
Astronomy Picture of the Day

Discover the cosmos! Each day a different image or photograph of our fascinating universe is featured, along with a brief explanation written by a professional astronomer.

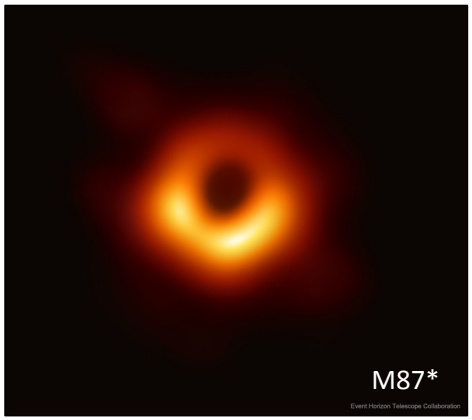
2016 February 11



LIGO Detects Gravitational Waves from Merging Black Holes
Illustration Credit: LIGO, NSF, Aurore Simonnet (Sonoma State U.)



Event Horizon Telescope



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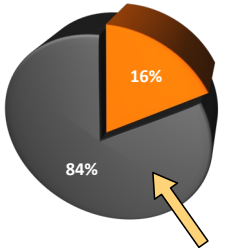
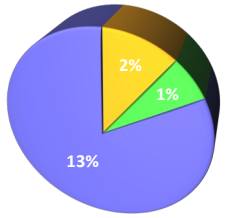
Composition of Matter

Stuff we know about
Stuff we don't





H and He
Stars

What is this "dark matter"?

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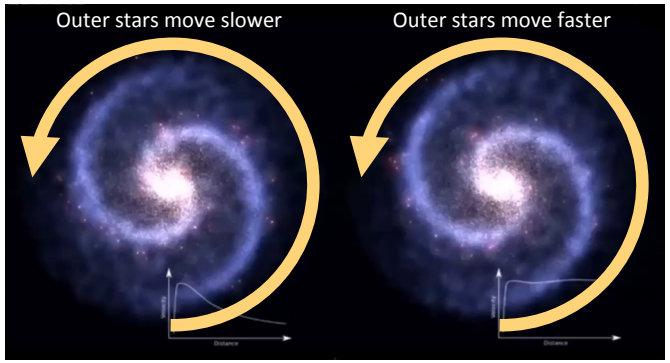
Evidence For Dark Matter



Without dark matter

With dark matter

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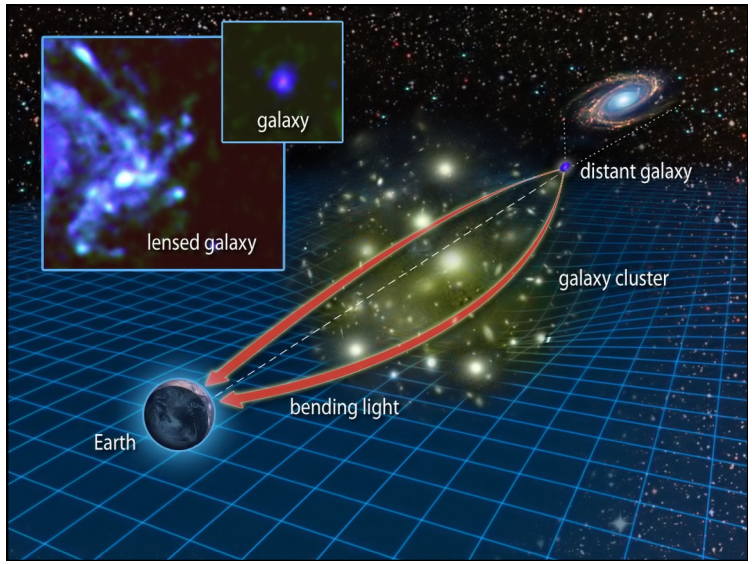

Gravitational Lensing

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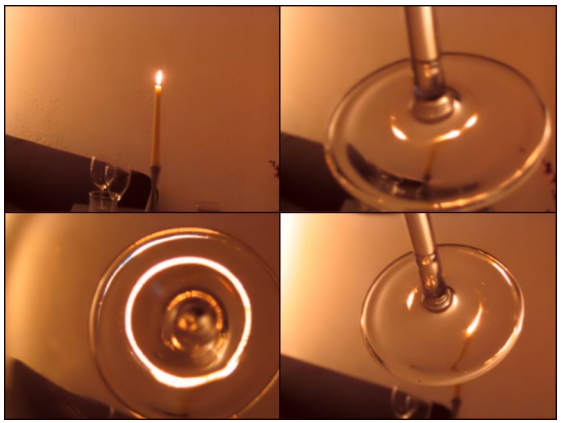
Gravitational Lensing



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WIMPs or MACHOs

WIMPs

"*Weakly Interacting Massive Particles*"

If they exist, it is hoped to find them with the Large Hadron Collider

MACHOs

"*Massive Astrophysical Compact Halo Objects*"

These are objects composed of 'normal' matter that emit no light

Could dark matter be just lots of black holes?

If so, how could they be detected?

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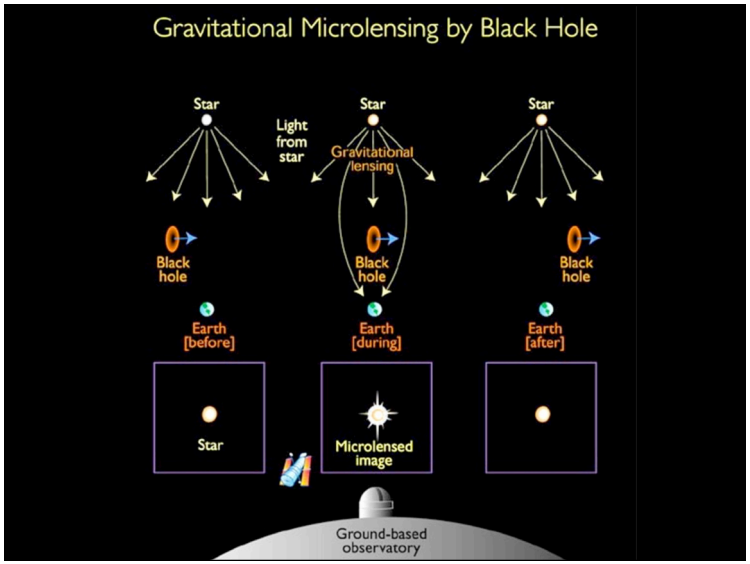

30 min

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At most, black holes could account for only a few % of dark matter

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Black Holes

www.liverpool.ac.uk/~sdb/Talks

30 min

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