



UNIVERSITY OF  
BIRMINGHAM



# Astronomy In The City Gravitational Waves Special

[birmingham.ac.uk/gravitational-waves](http://birmingham.ac.uk/gravitational-waves)



# Astronomy in the City returns 9 March

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# The gravitational universe

Christopher Berry • @cplberry



Image:  
Daniel Berehulak/  
Getty Images

Gravitation is  
universal.

Objects move in  
straight lines.

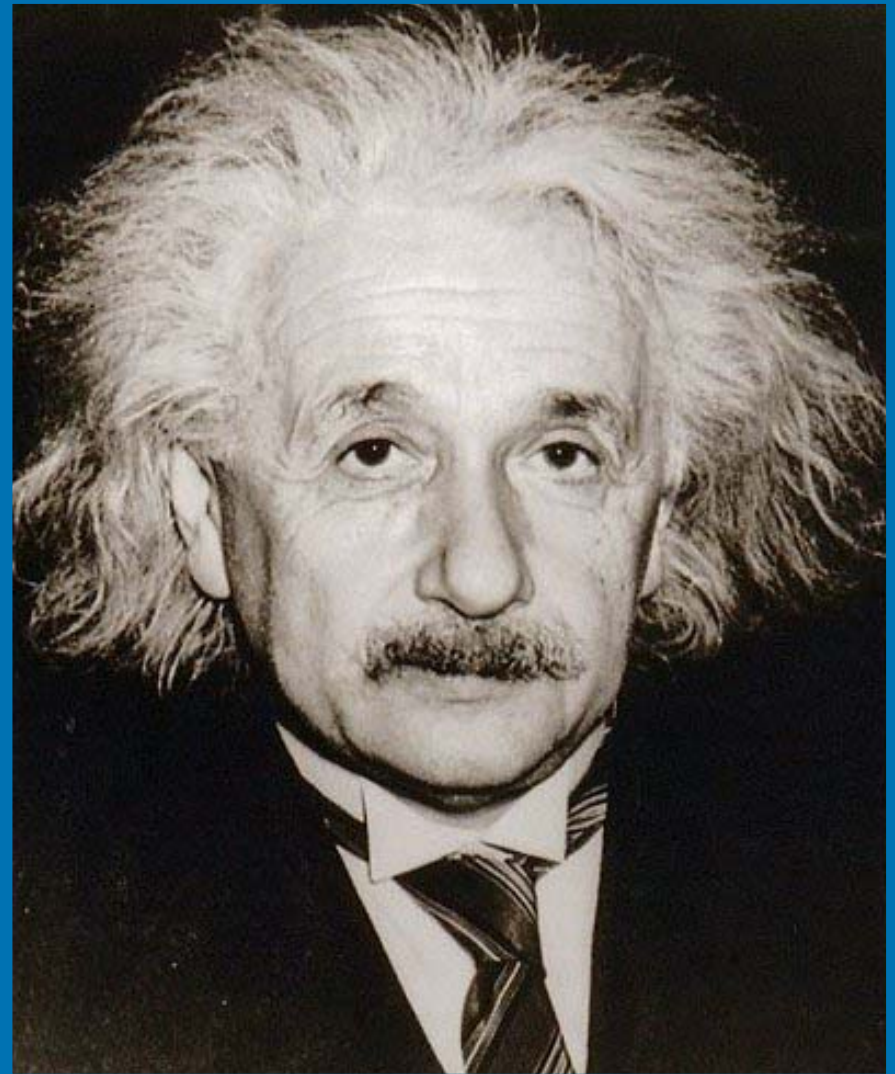




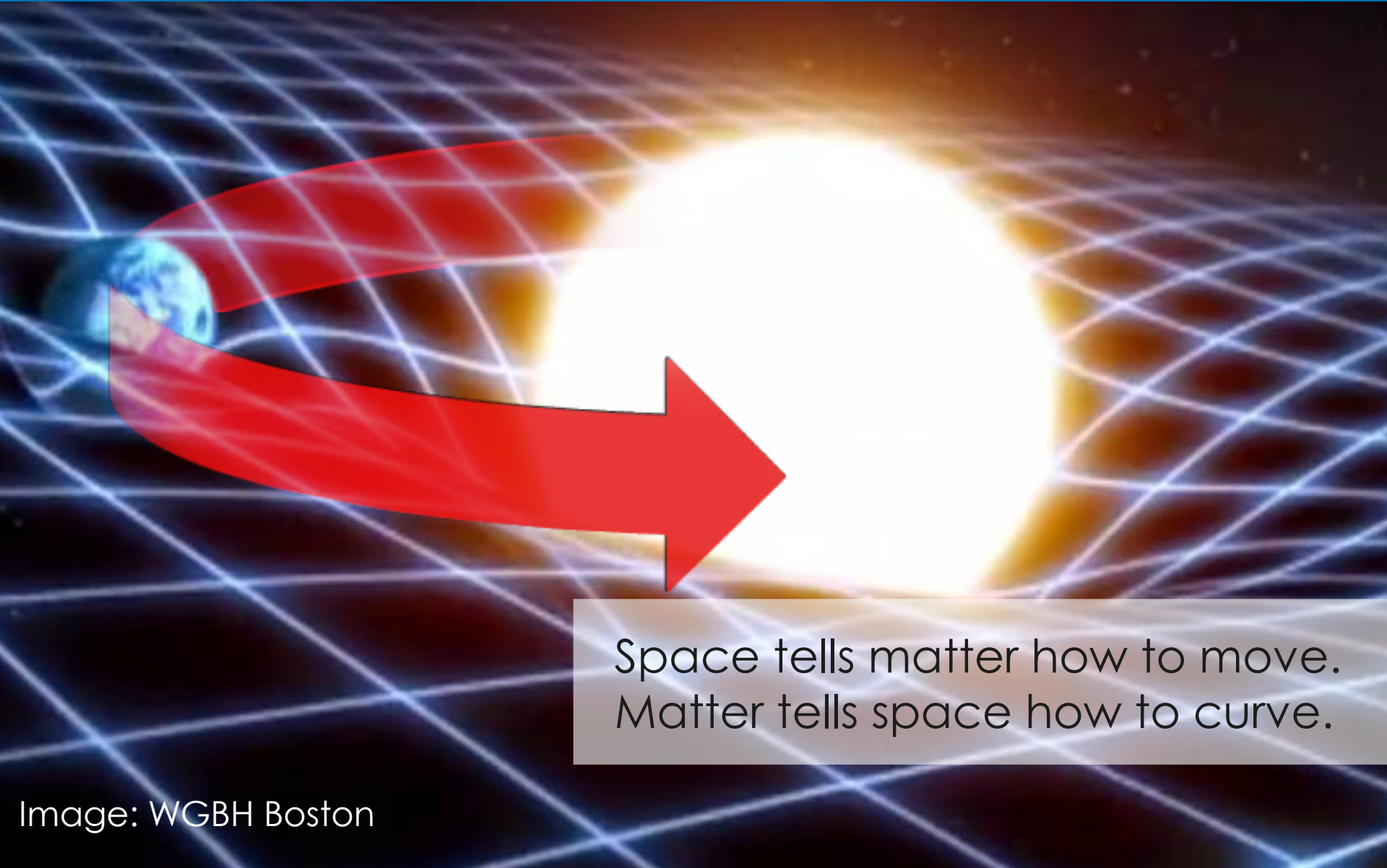
# Relativity

Space and time are linked.

Nothing can travel faster than the speed of light.



# Space-time



Space tells matter how to move.  
Matter tells space how to curve.

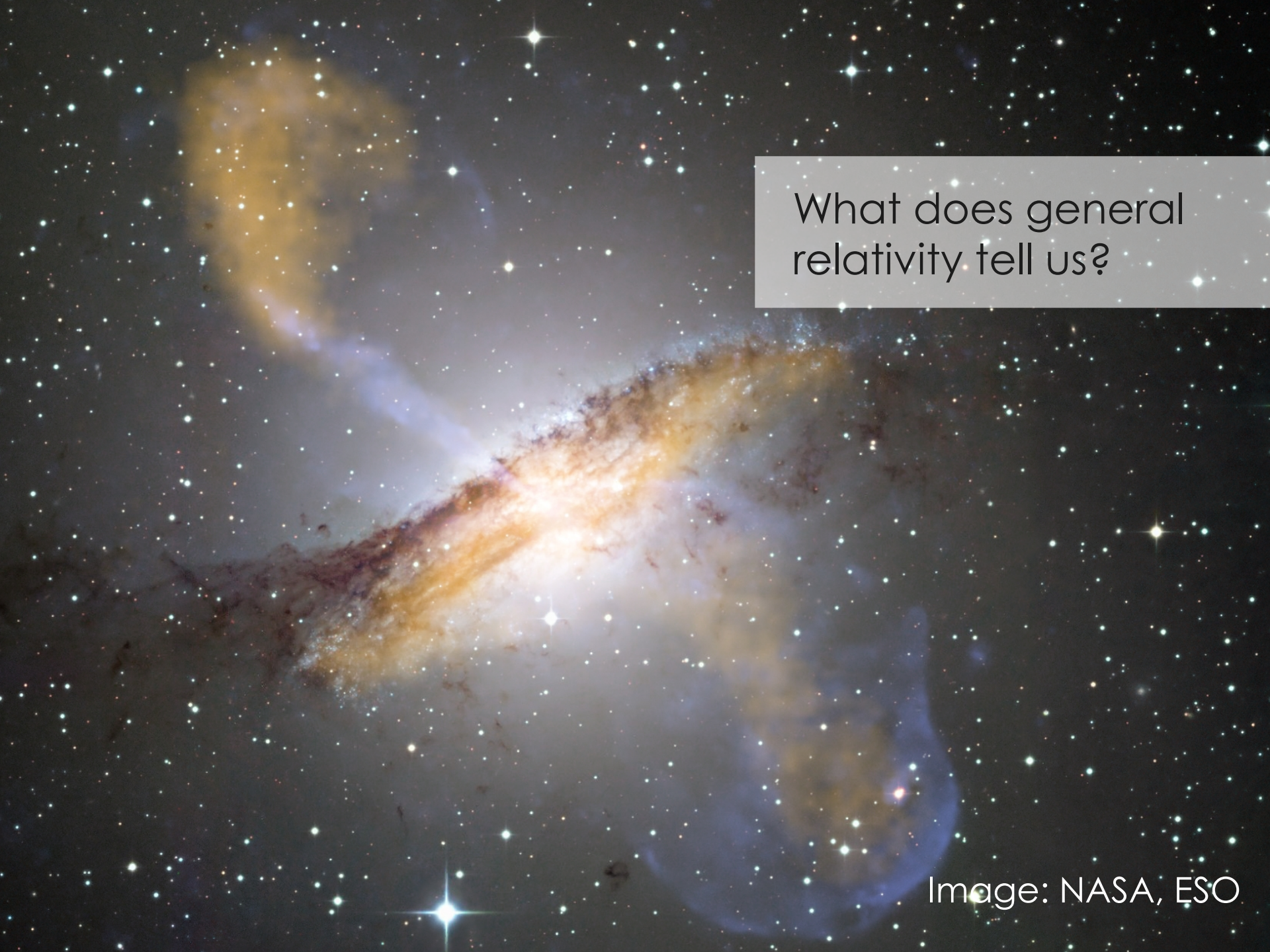
# General relativity

$$G_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

Curvature

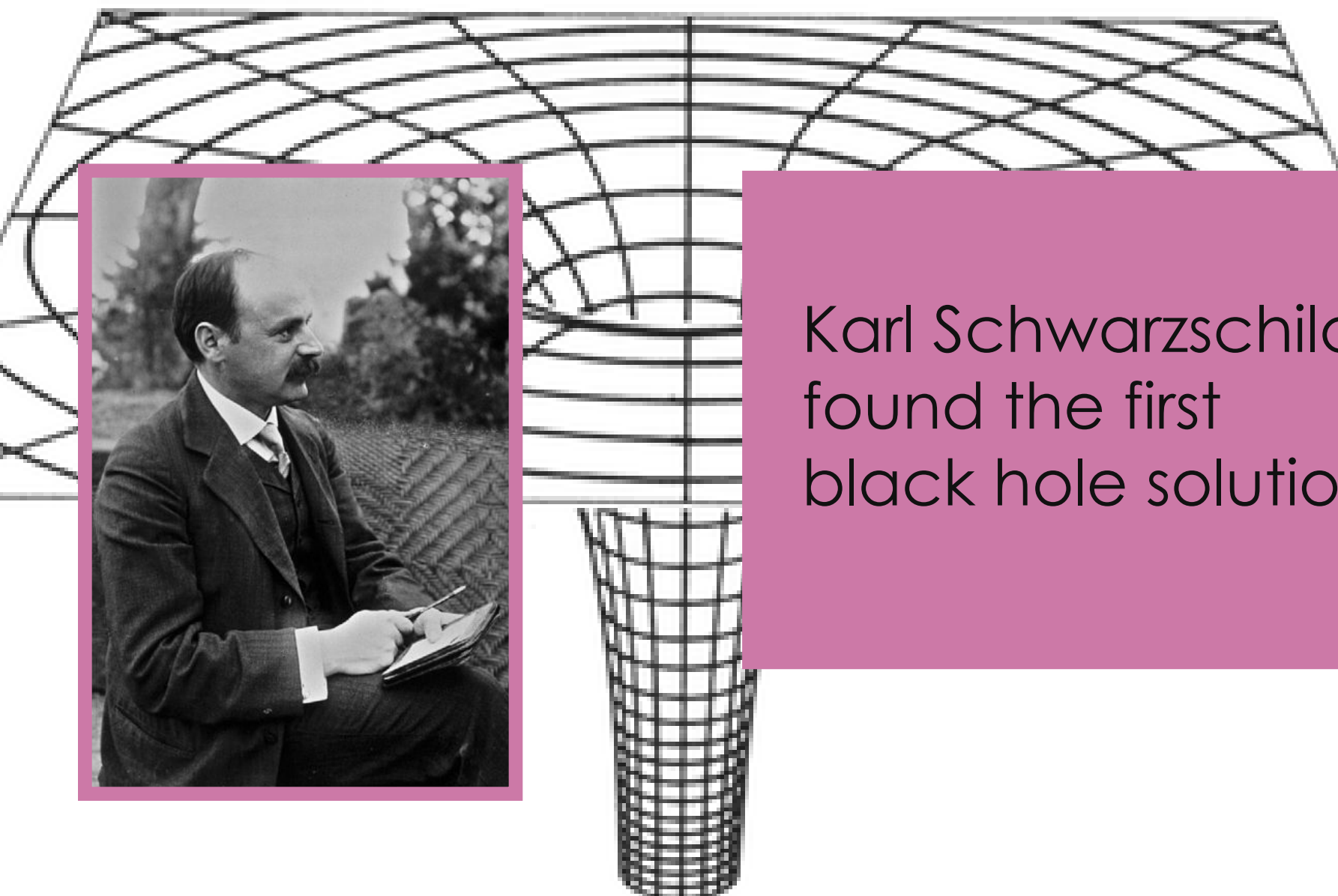
Mass



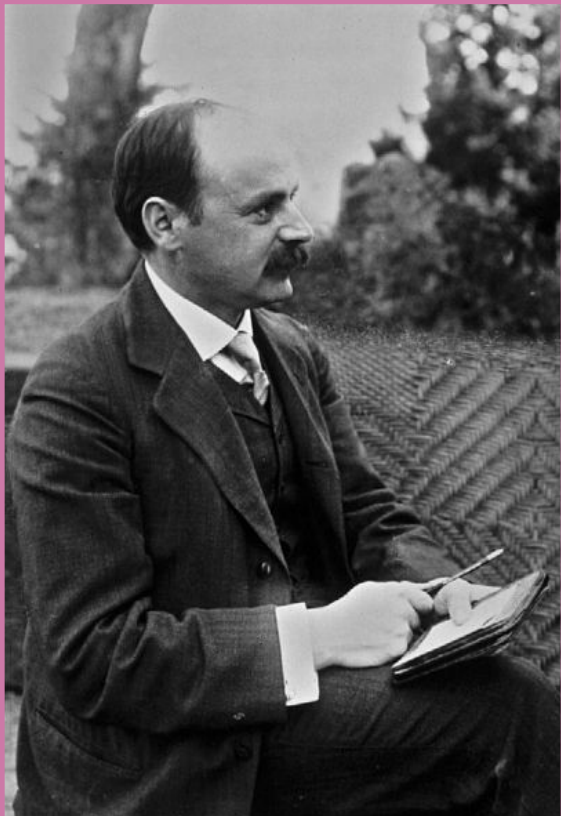
A composite astronomical image featuring a central galaxy with a bright, yellowish-white core and a diffuse, blueish-purple nebula extending from it. The background is filled with numerous stars of varying brightness. The image is presented in a dark, starry field.

What does general  
relativity tell us?

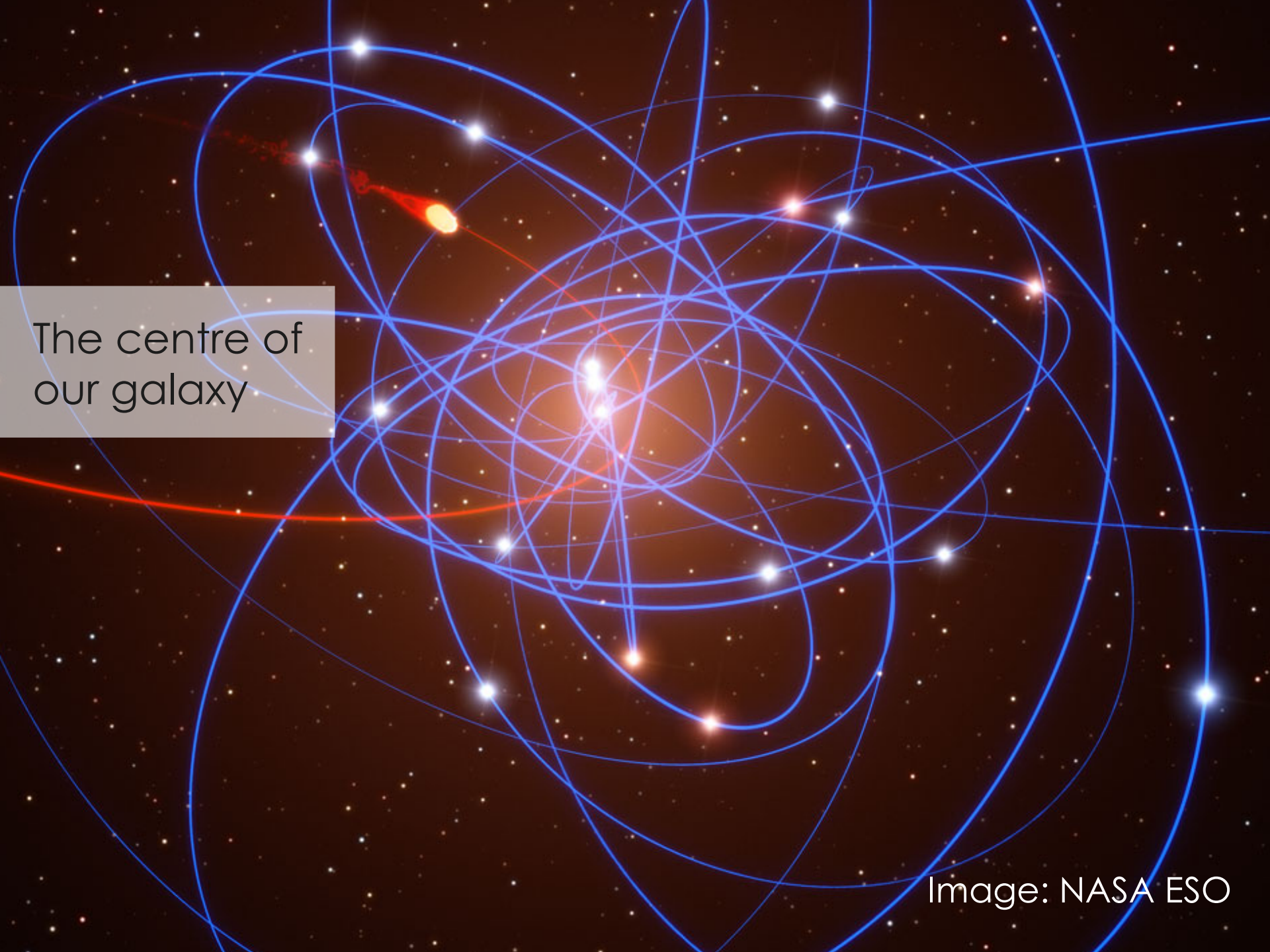
Image: NASA, ESO



Karl Schwarzschild  
found the first  
black hole solution



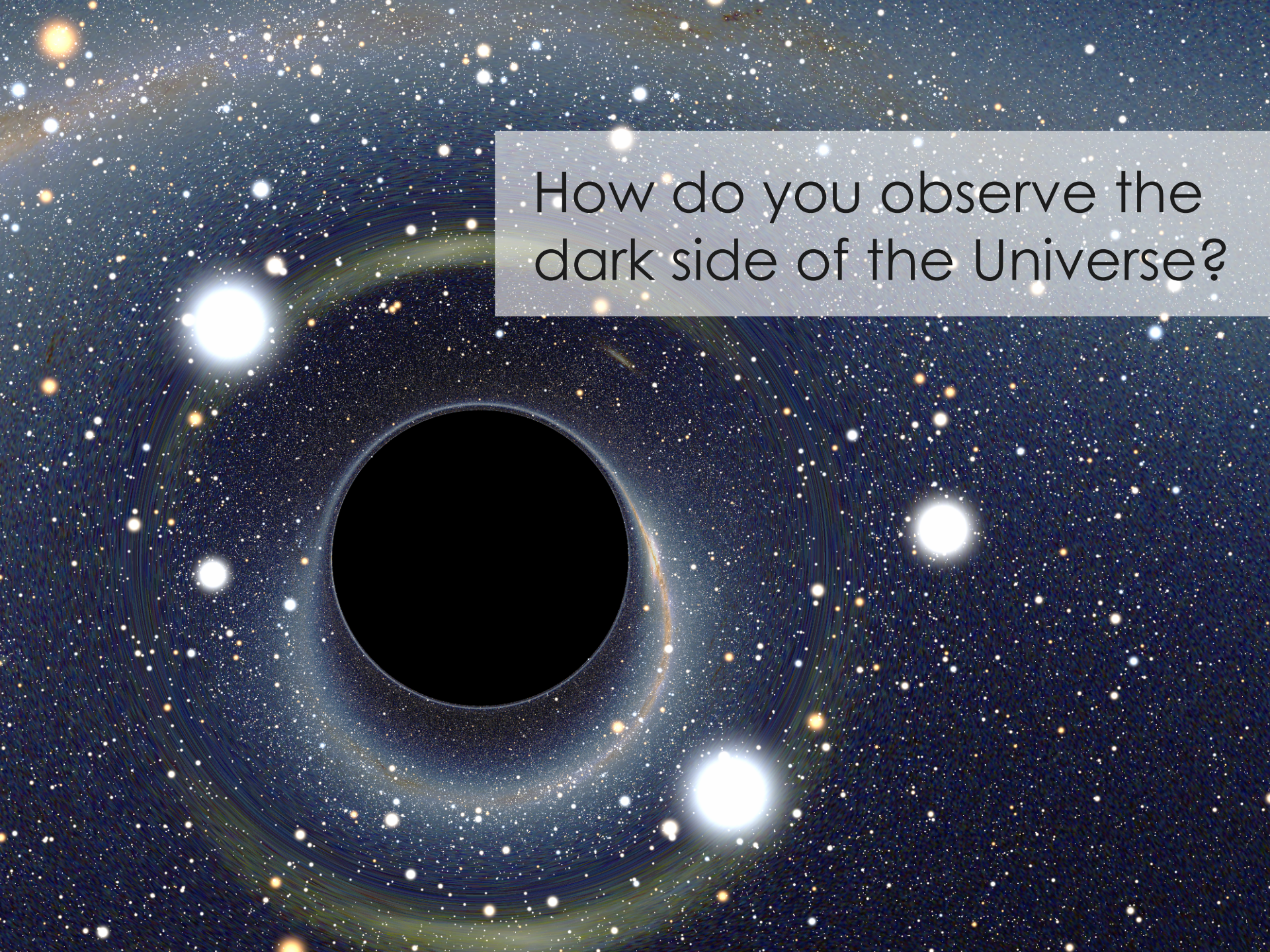




The centre of  
our galaxy

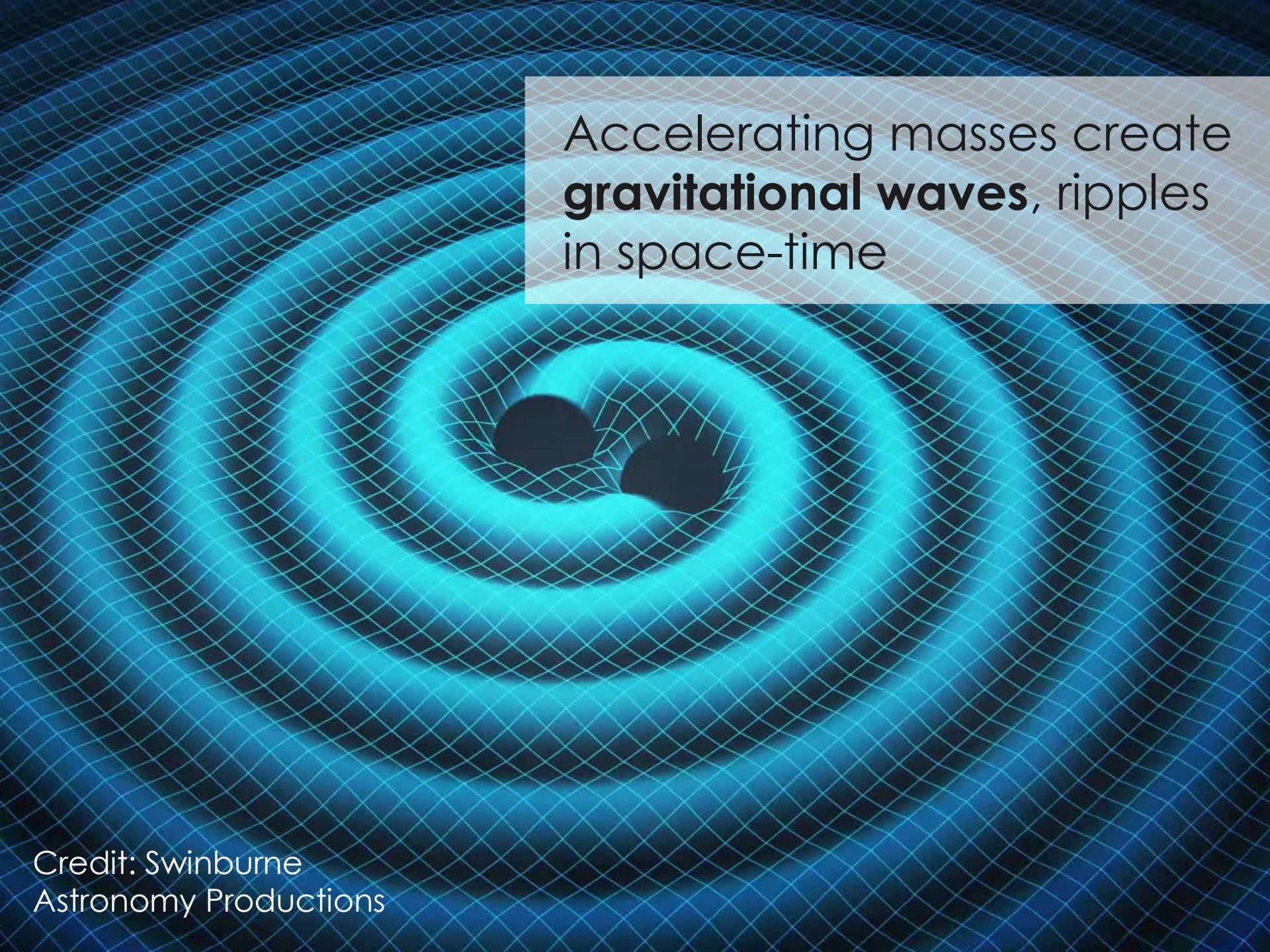
Image: NASA ESO



A black hole is depicted as a dark, circular void in the center of the image. It is surrounded by a glowing accretion disk that emits a spectrum of colors, including blue, green, and yellow. The background is a vast field of stars, with several prominent bright white stars and many smaller, dimmer stars scattered throughout. The overall scene is set against a dark, starry sky.

How do you observe the dark side of the Universe?



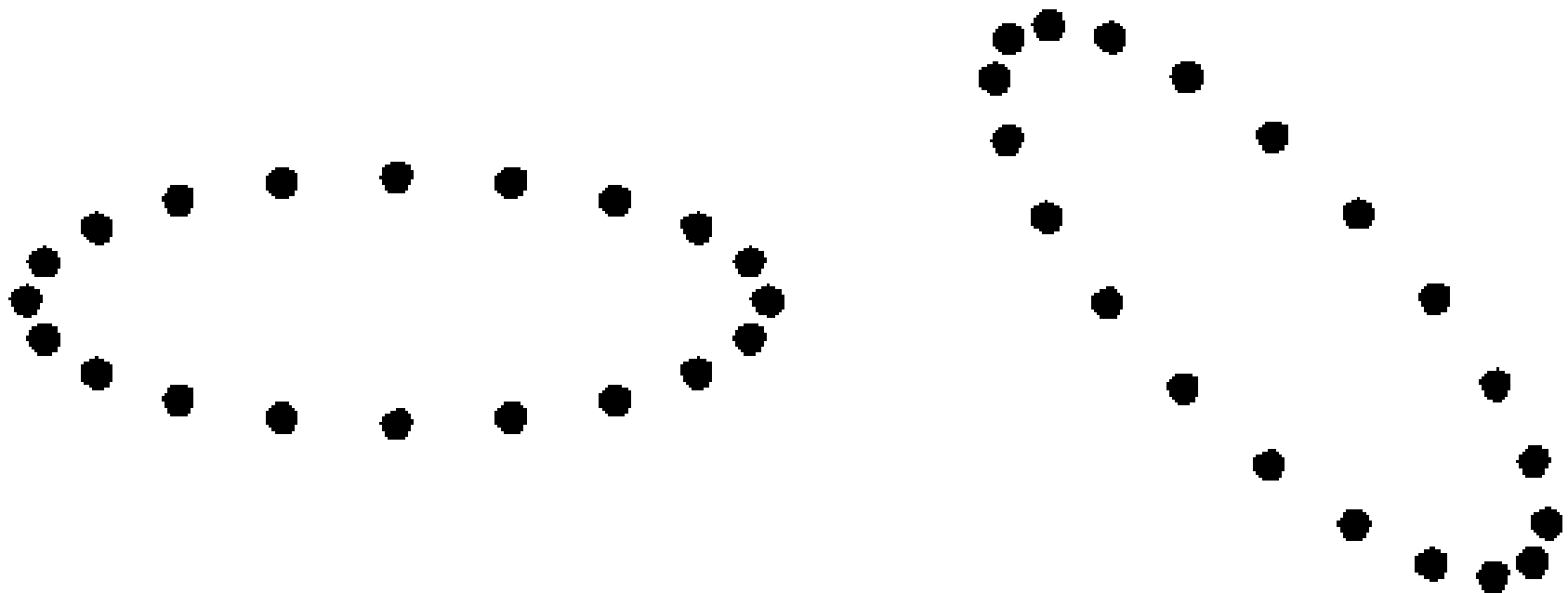


Accelerating masses create  
**gravitational waves**, ripples  
in space-time

Credit: Swinburne  
Astronomy Productions



# Stretch and squash



**Gravity** is a universal force, the dominant force in astrophysics

It is described by the curvature of spacetime in **general relativity**

**Black holes** are important astrophysical objects

**Gravitational waves** are a new means of doing astronomy

# We have detected gravitational waves!

[lsc.ligo.org/events/GW150914/](http://lsc.ligo.org/events/GW150914/)

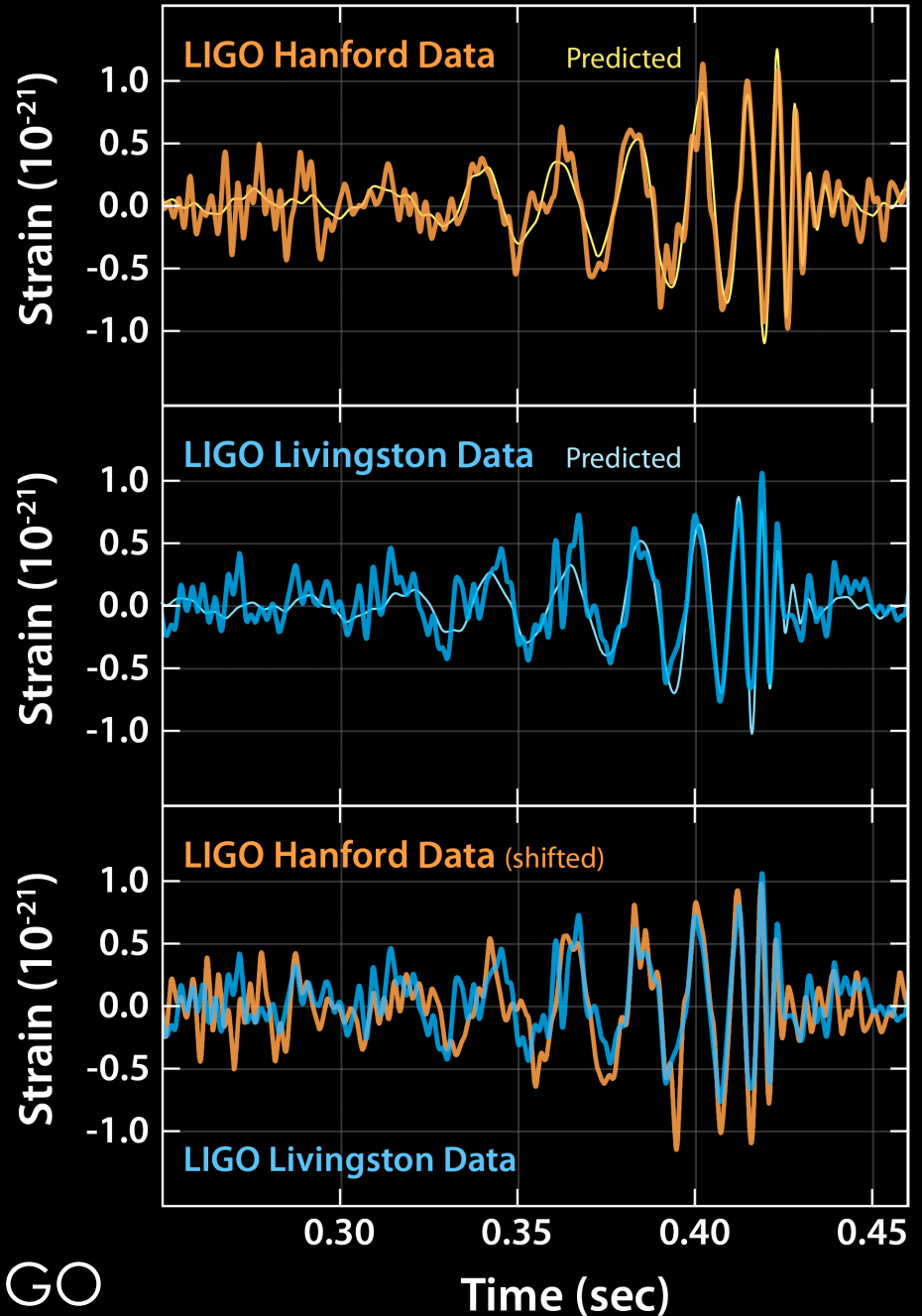
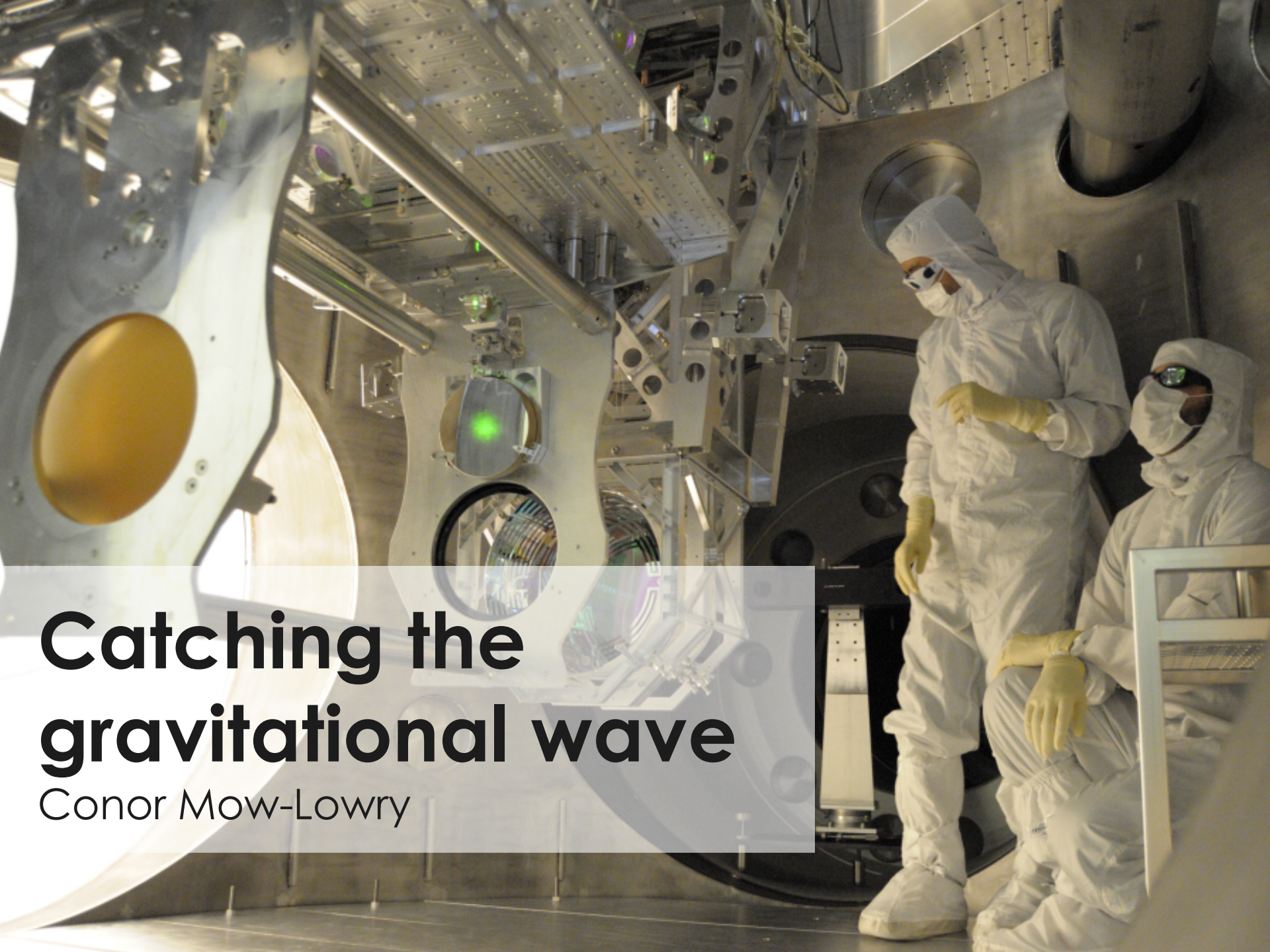


Image: LIGO

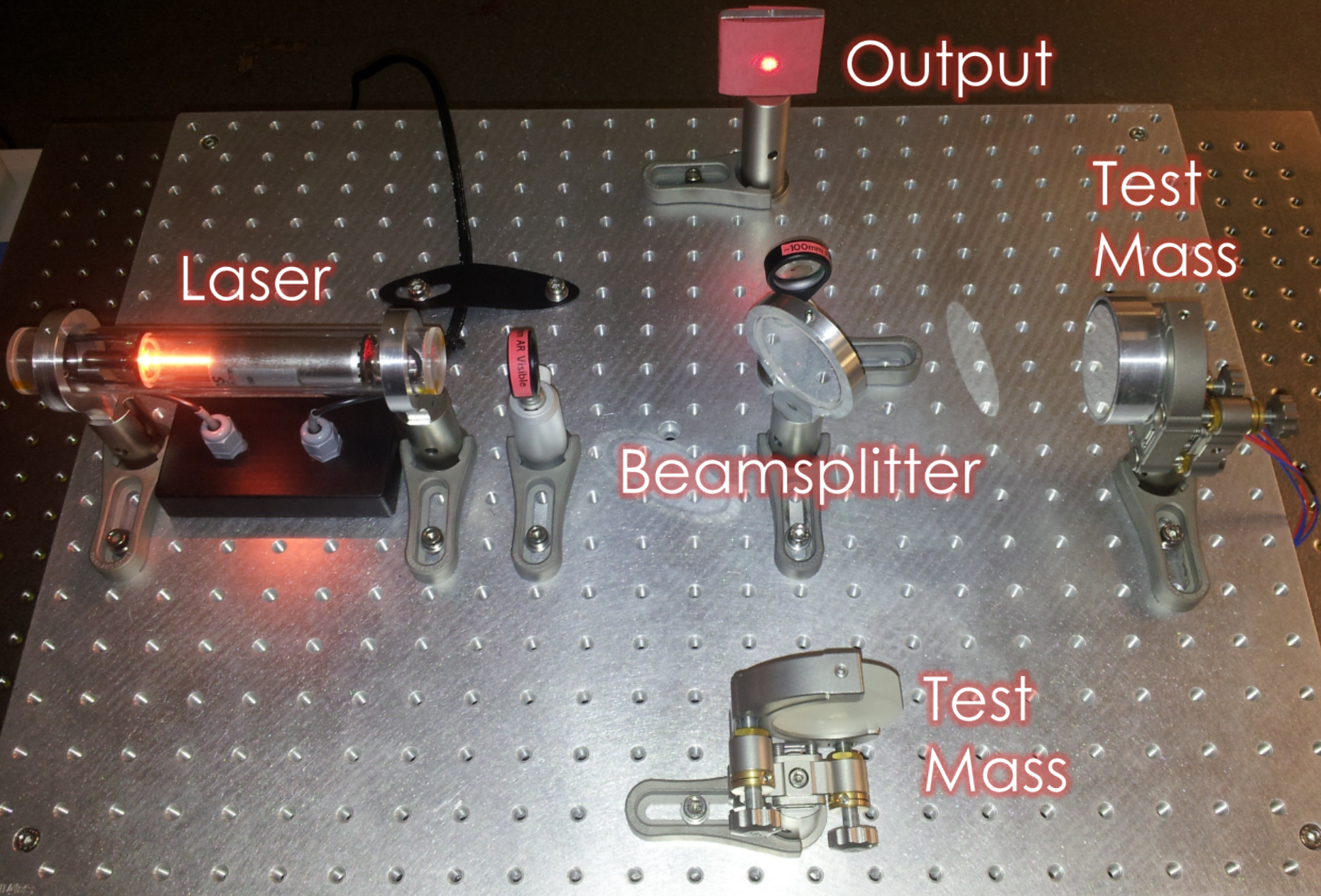


# Catching the gravitational wave

Conor Mow-Lowry



# Michelson interferometer







Images: LIGO Laboratory and Google Maps





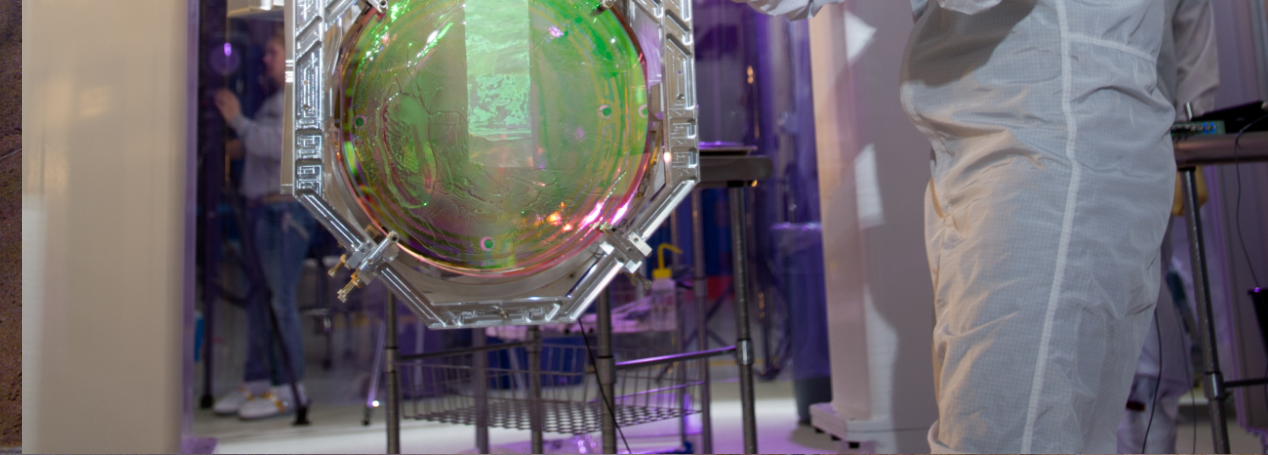
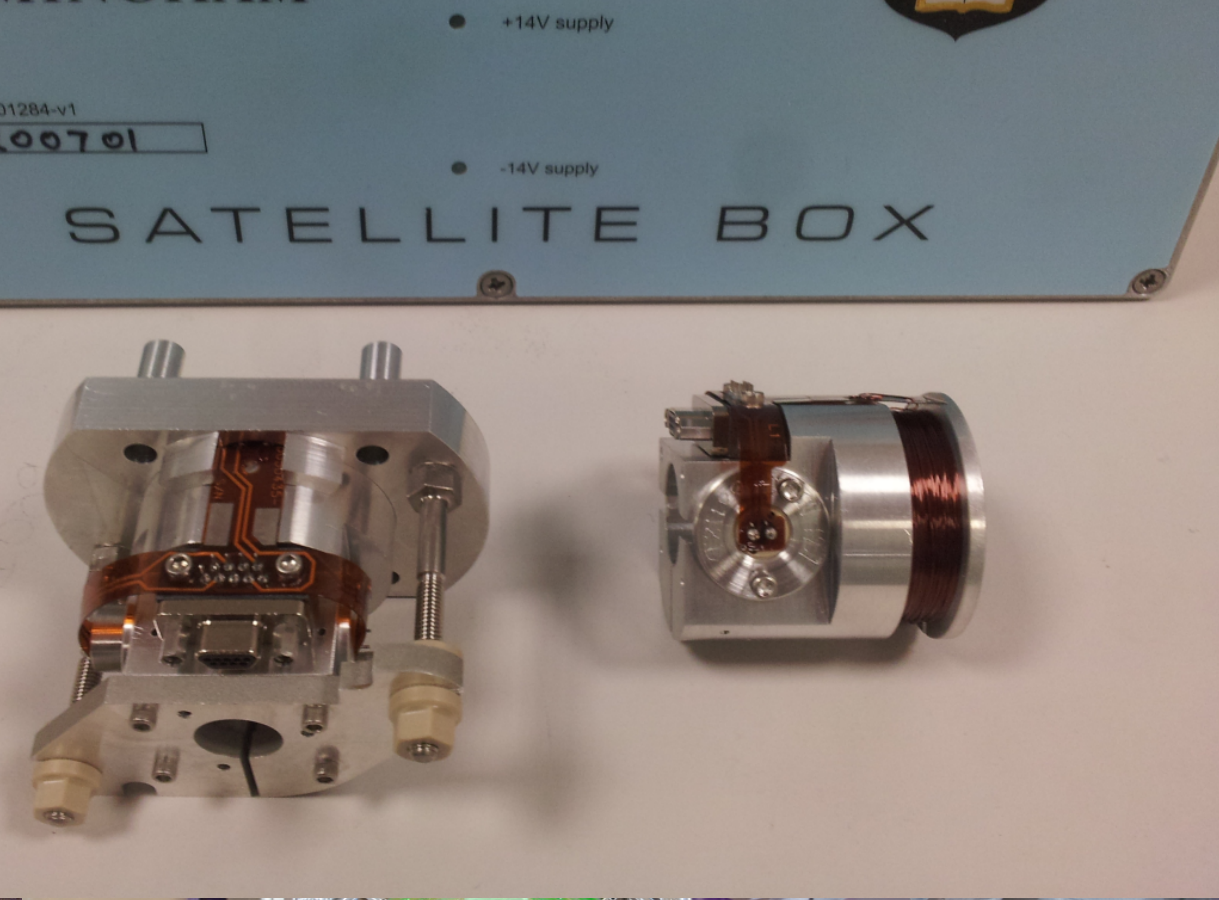
Images: LIGO Laboratory





Images: LIGO Laboratory





Images: LIGO Laboratory



# How to catch the wave

1. Start with the frequency of light as a clock
2. Make relative measurements (only changes!)
3. Enhance the signal optically
4. Average over many atoms in the mirrors
5. Create a very quiet place for the test masses

Then... wait for the perfect wave!

LIGO was only possible after **decades of work** by **hundreds of scientists** around the world!

# Information in a gravitational wave

Walter Del Pozzo **LIGO Hanford Data (shifted)**

Strain ( $10^{-21}$ )

1.0  
0.5  
0.0  
-0.5  
-1.0

**LIGO Livingston Data**

0.30

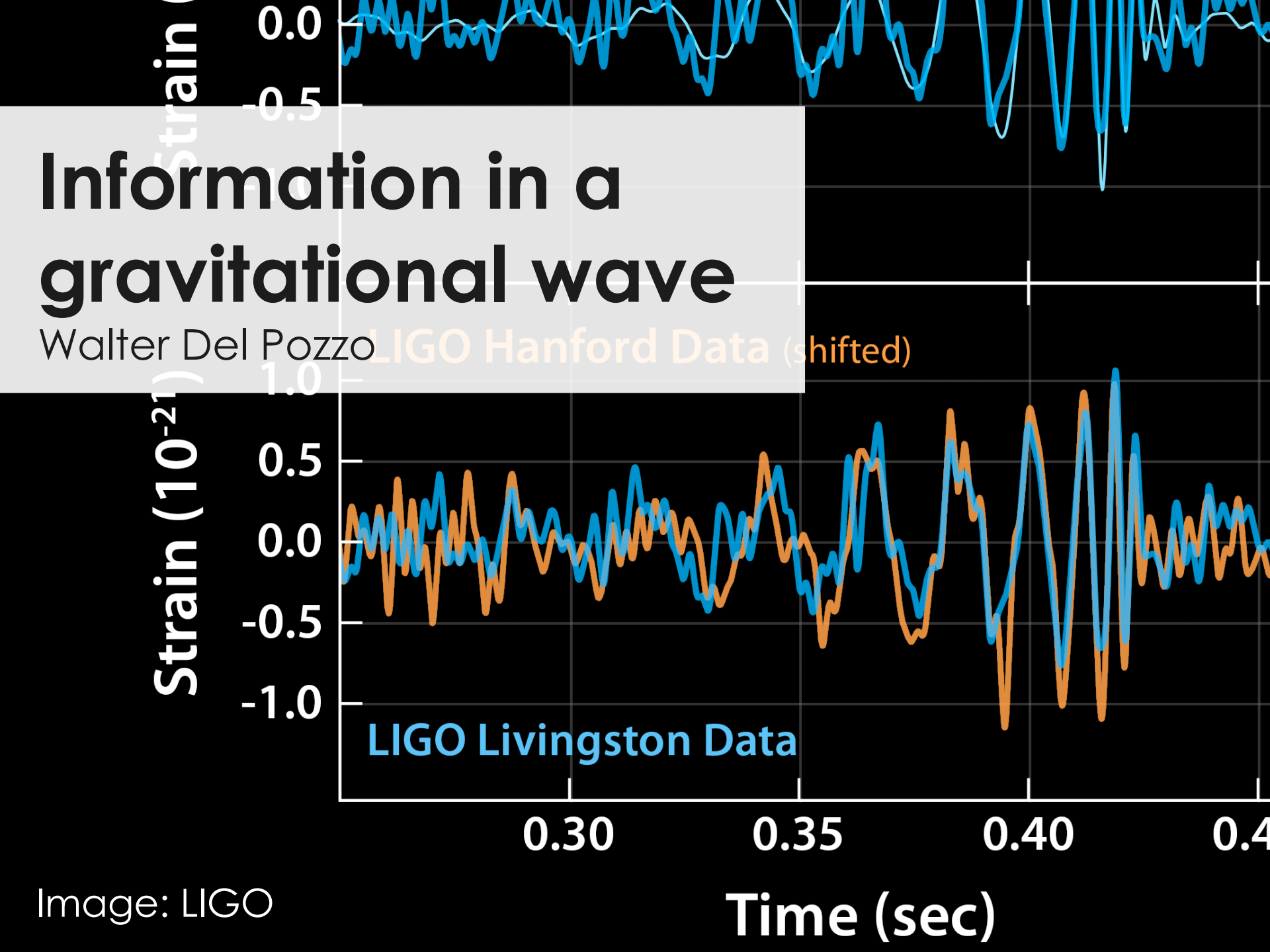
0.35

0.40

0.4

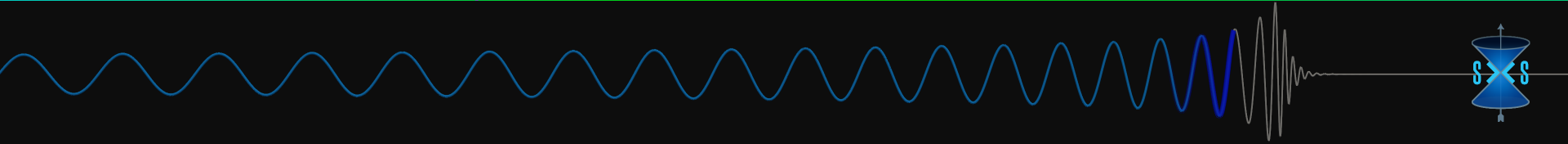
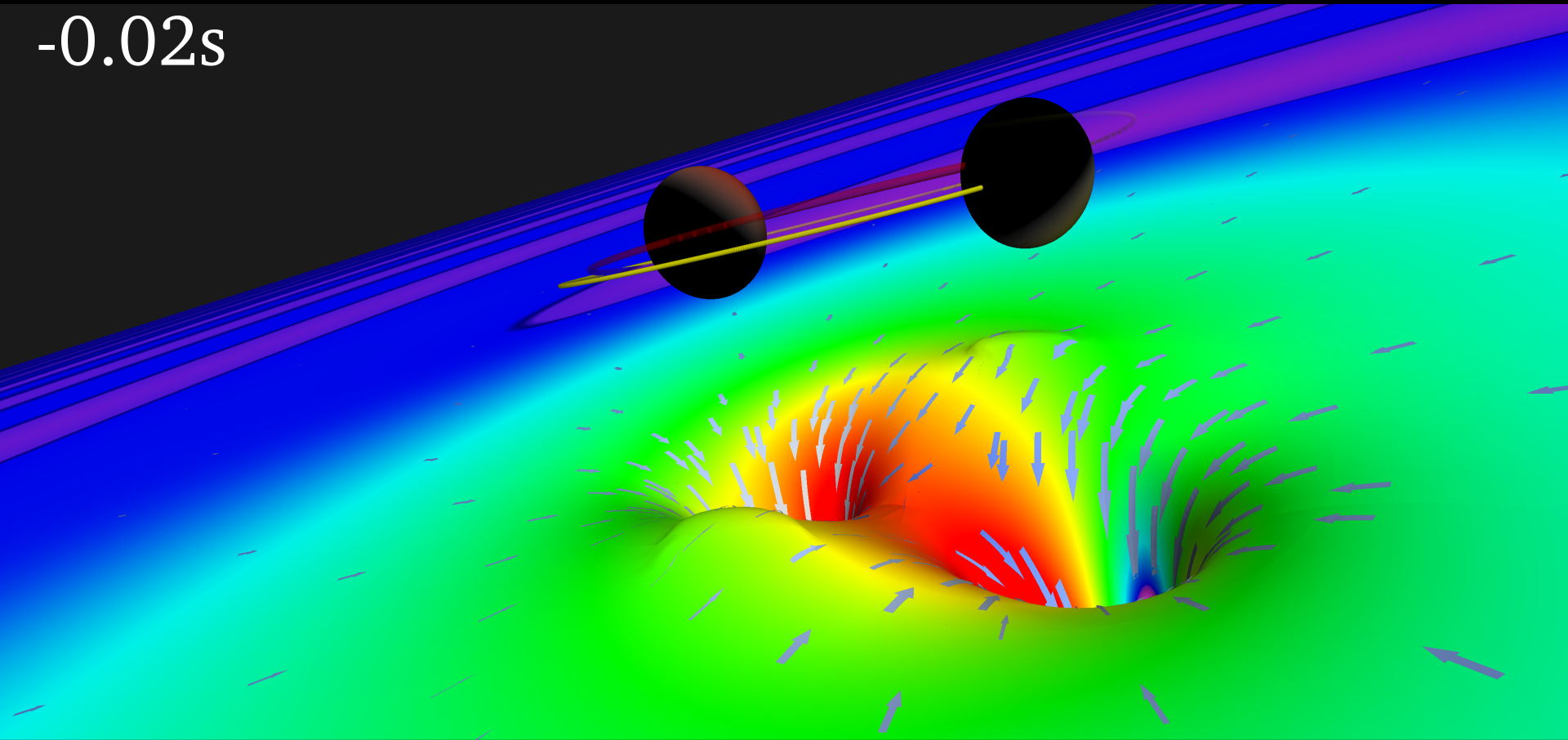
Time (sec)

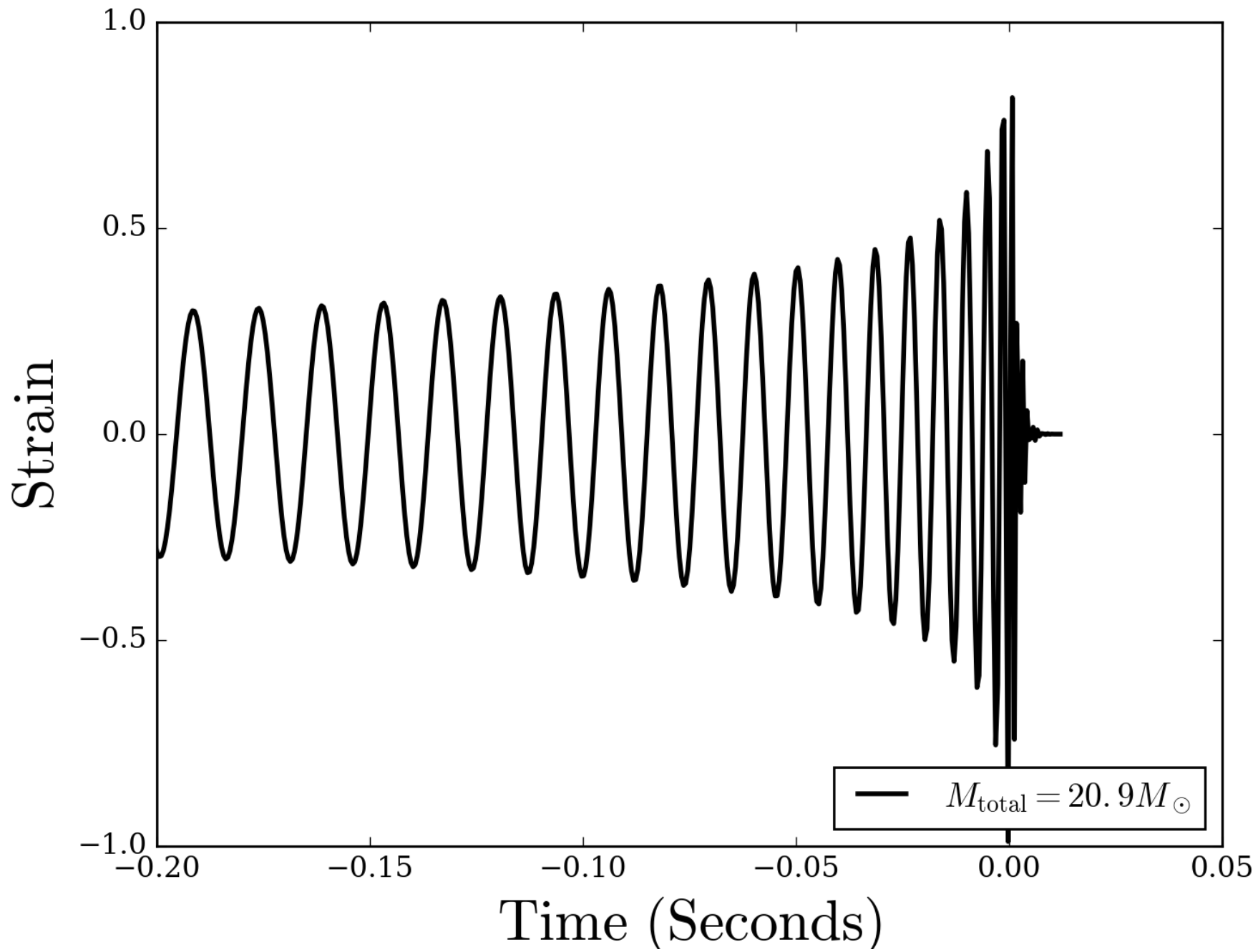
Image: LIGO



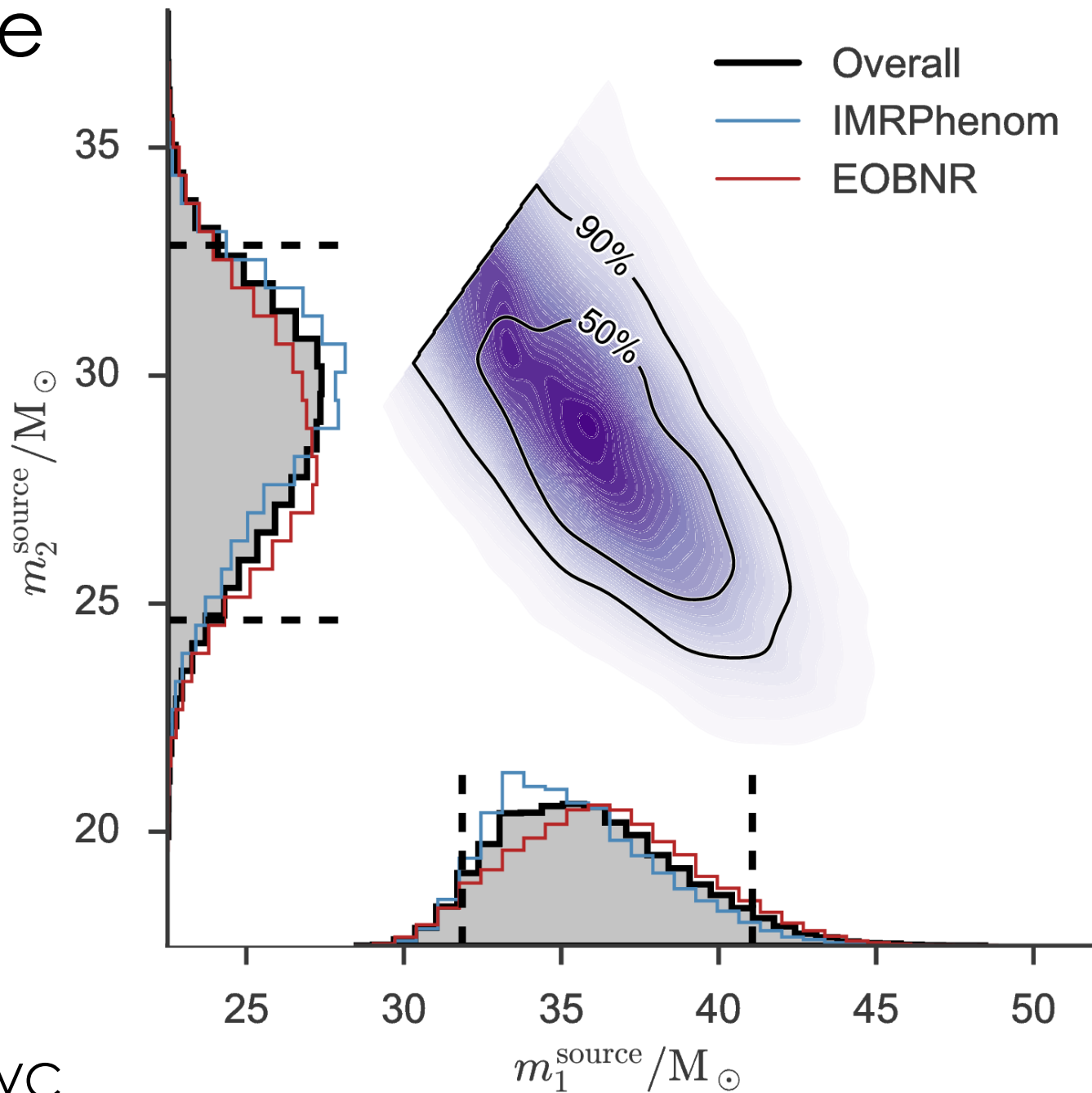


-0.02s





# Black hole binary masses



Final  
black  
hole

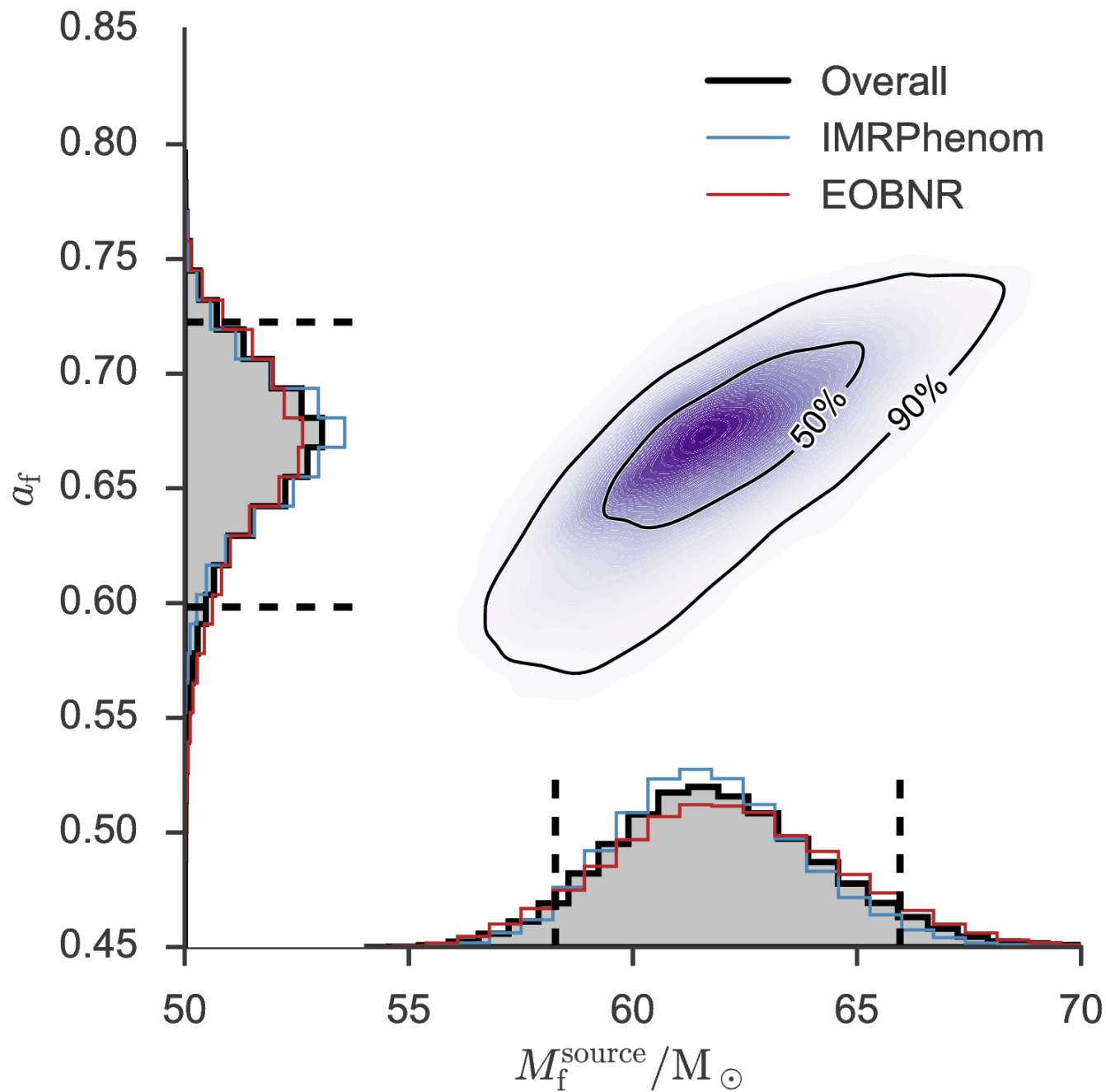
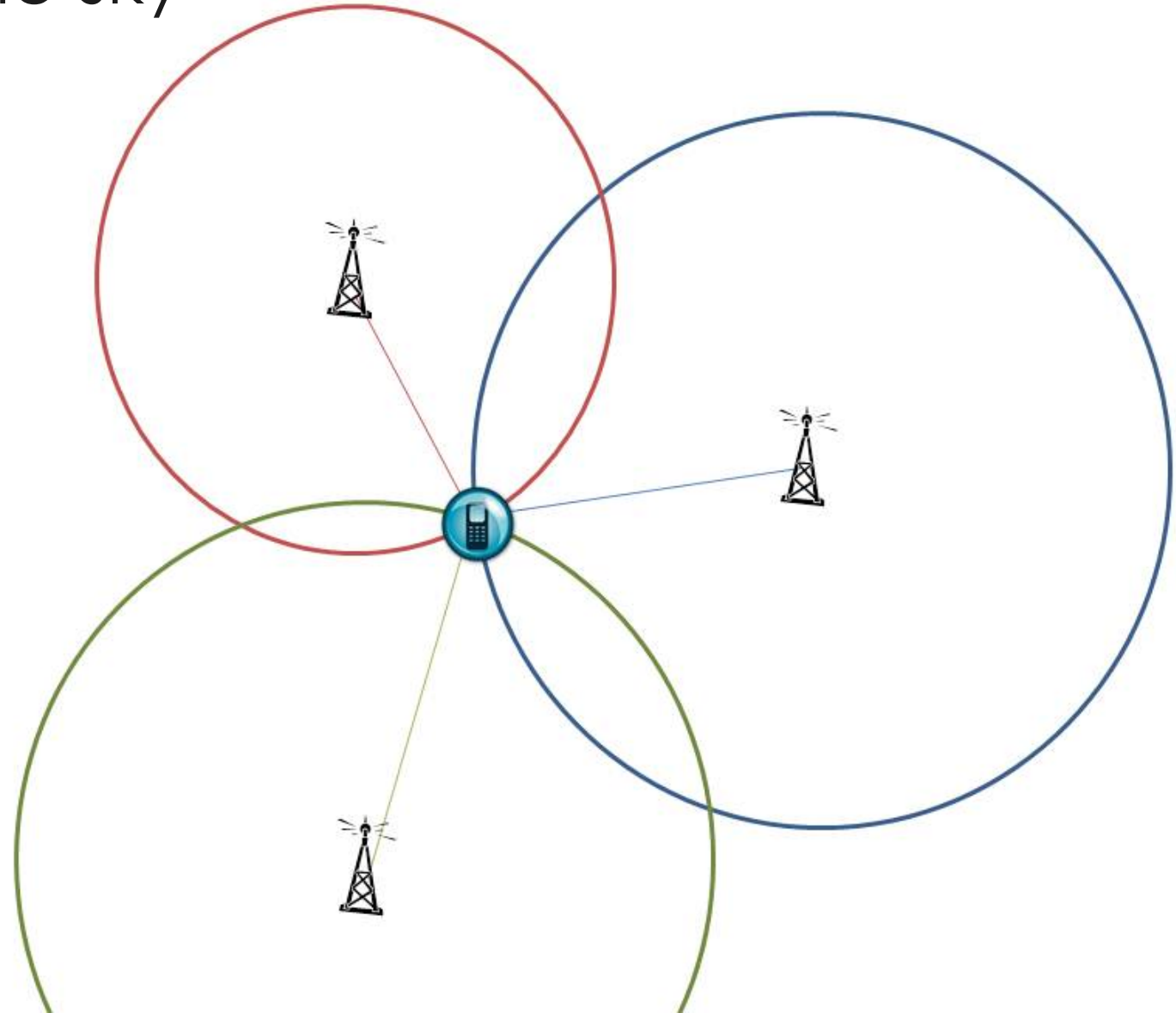


Image: LVC

Multiple detectors can localise the source in the sky





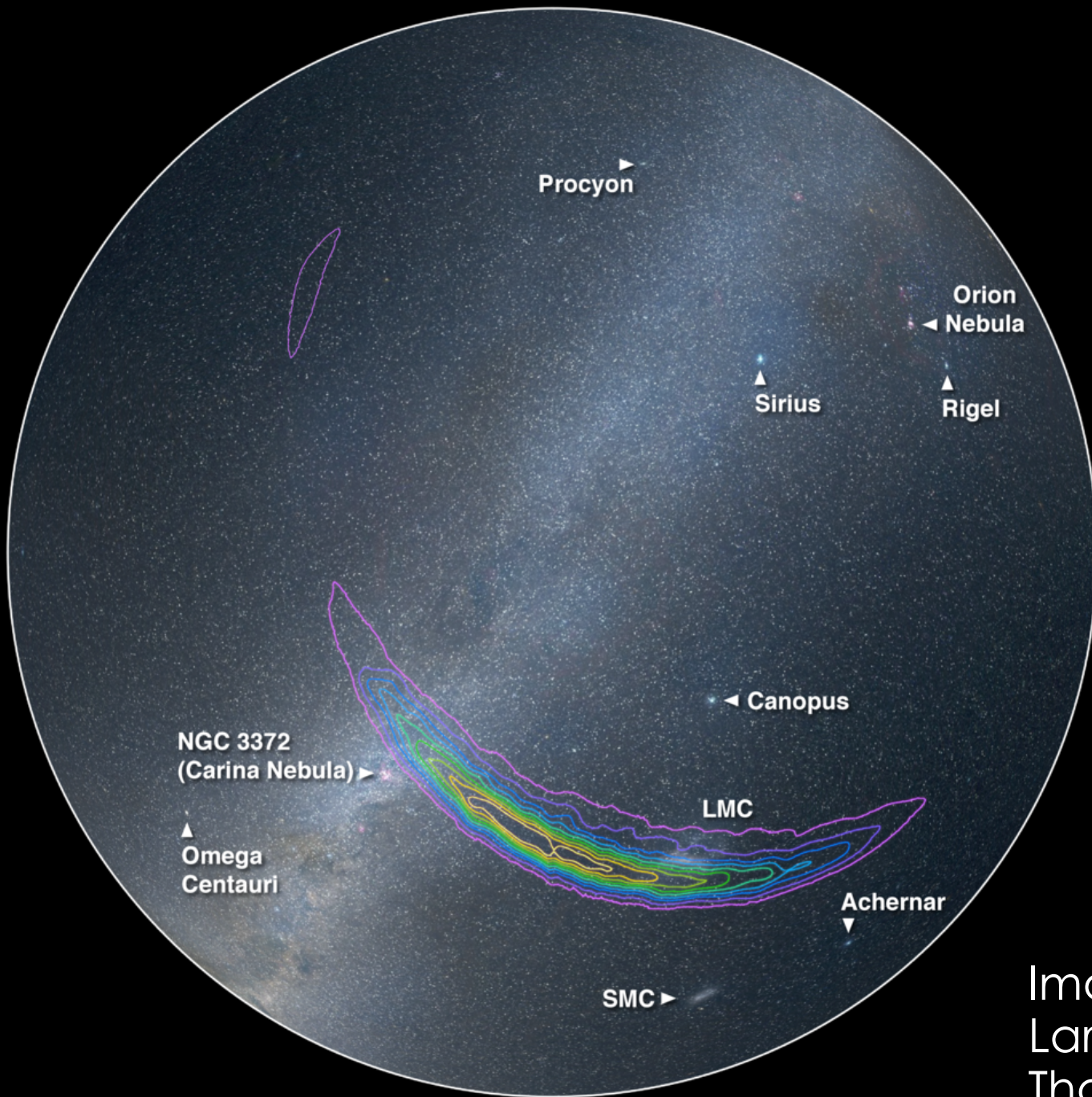
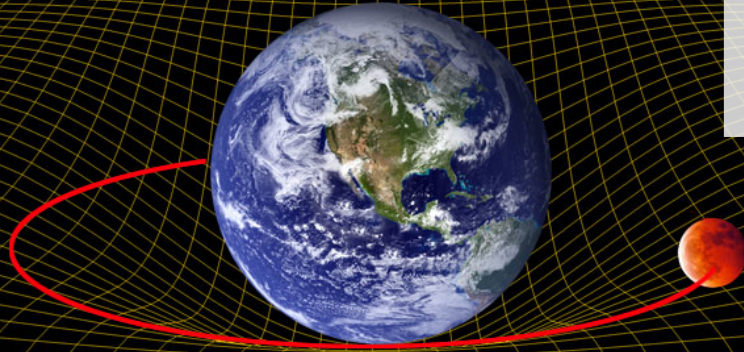
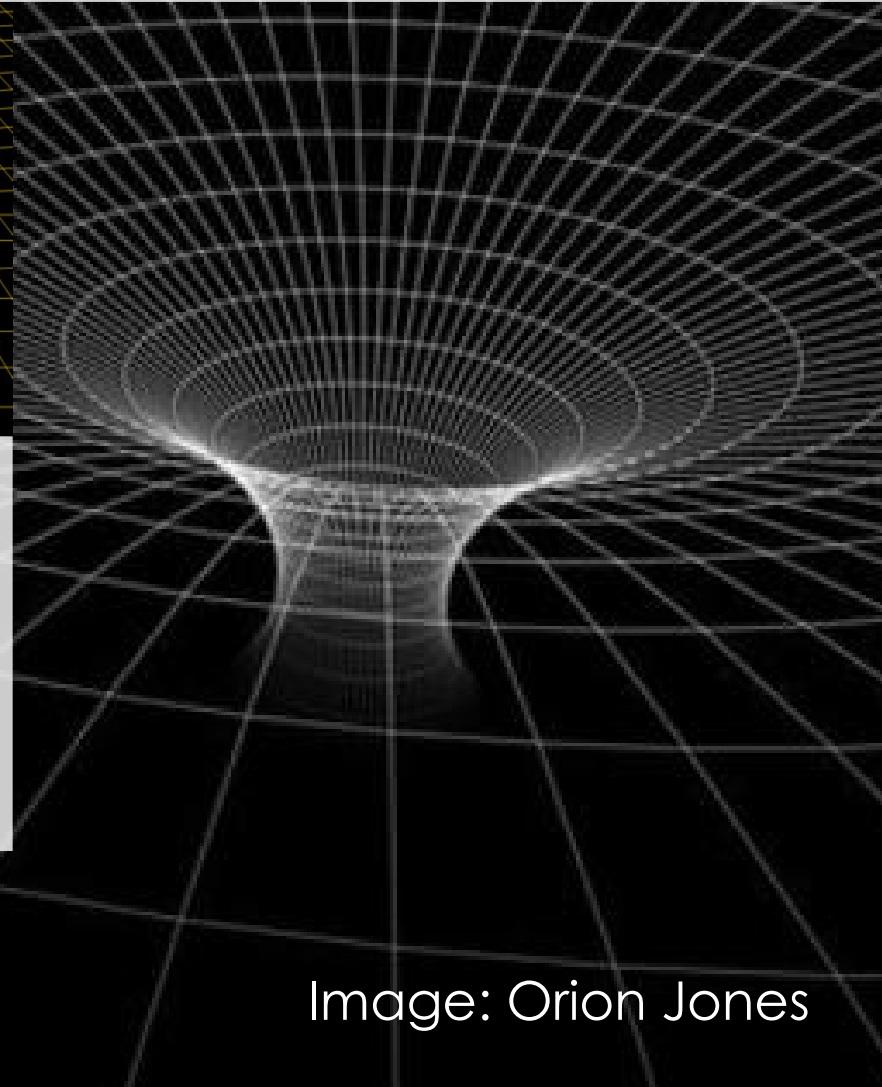


Image: LVC/Shane Larson/Roy Williams/Thomas Boch

How do we know general relativity is correct?



$$G_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$





# Testing the wave

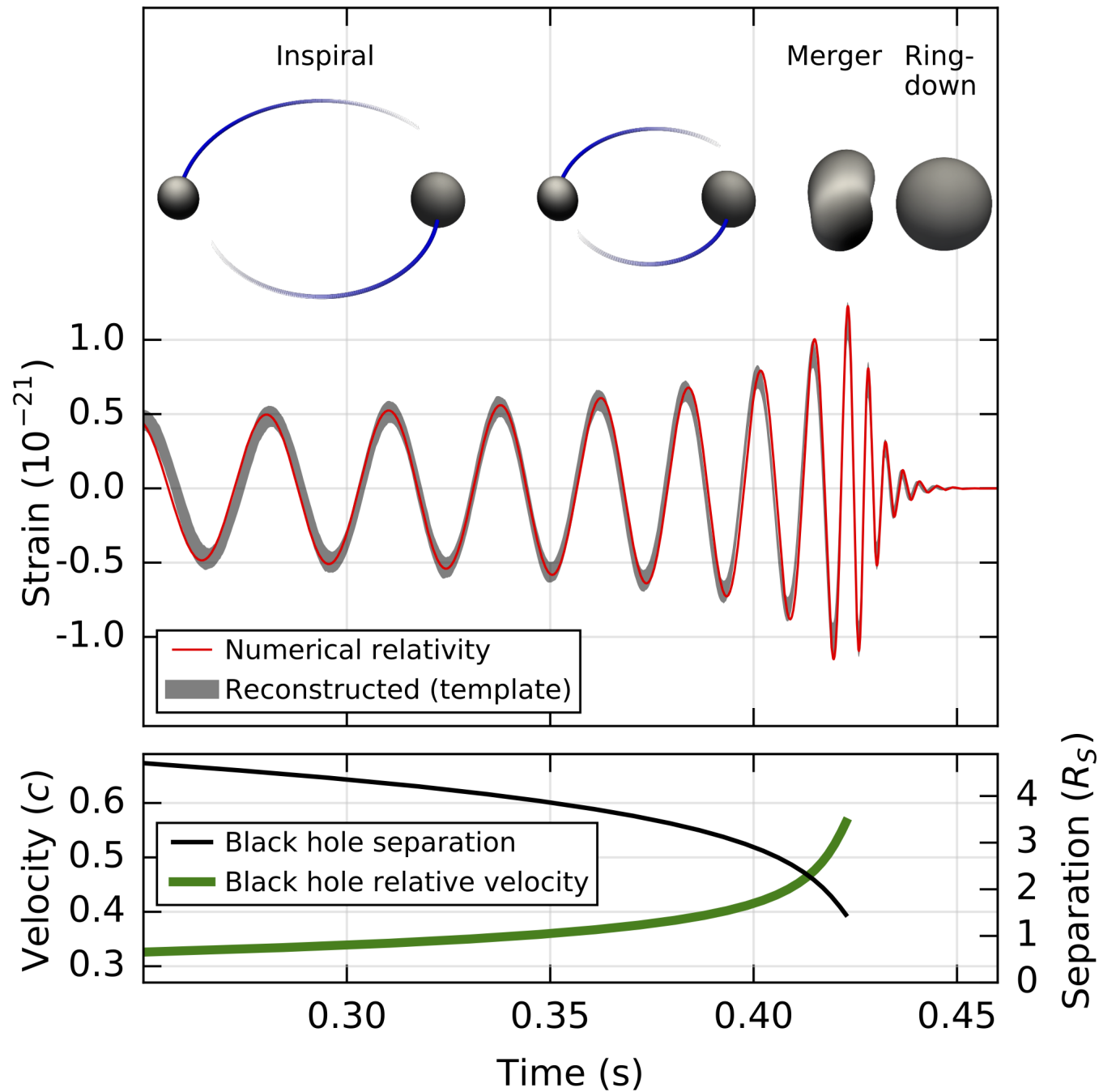


Image: LVC



# These black holes and astrophysics

Will M. Farr • @farrwill

Image: NASA, JPL-Caltech

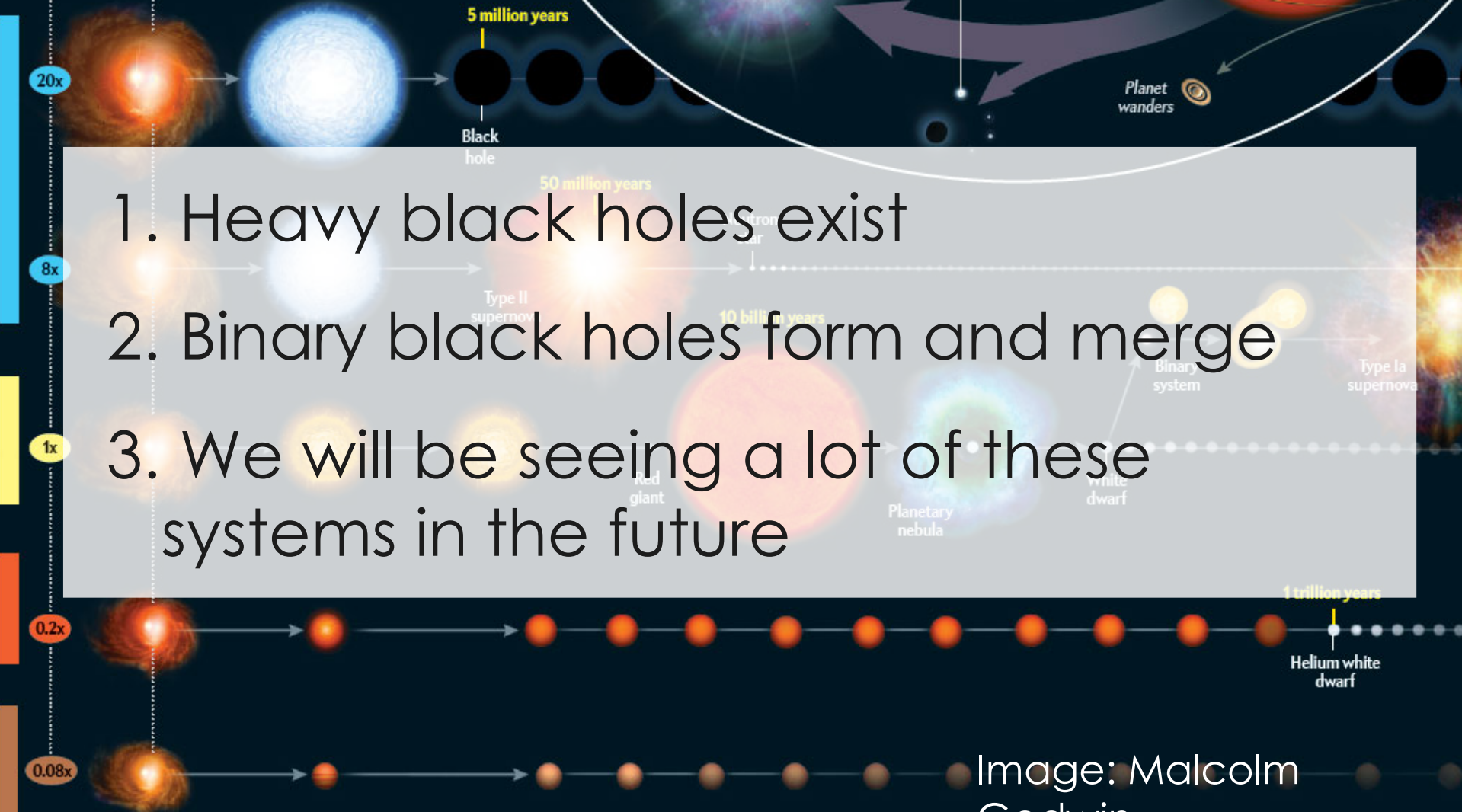


# What we know

## As the Cosmic Race


A simple rule: the bigger they come, stars have more fuel but consume it and go out with a bang. Because they live longer, they rule the galaxy only as long as new ones are being born. The future belongs to lesser, longer-lasting stars.

Mass (relative to the sun) Protostars Time (not to scale) →



1. Heavy black holes exist
2. Binary black holes form and merge
3. We will be seeing a lot of these systems in the future



The image depicts two bright blue stars in a dark, star-filled space. The larger star on the left is surrounded by a dense, blue, fibrous-looking stellar wind that radiates outwards. A smaller, similar star is positioned to its right and slightly further away. The background is a deep blue and black space filled with numerous distant stars and faint nebulae. A semi-transparent white rectangular box is overlaid on the upper right portion of the image, containing text.

Weak stellar winds  
Low metallicity



# Living as a binary

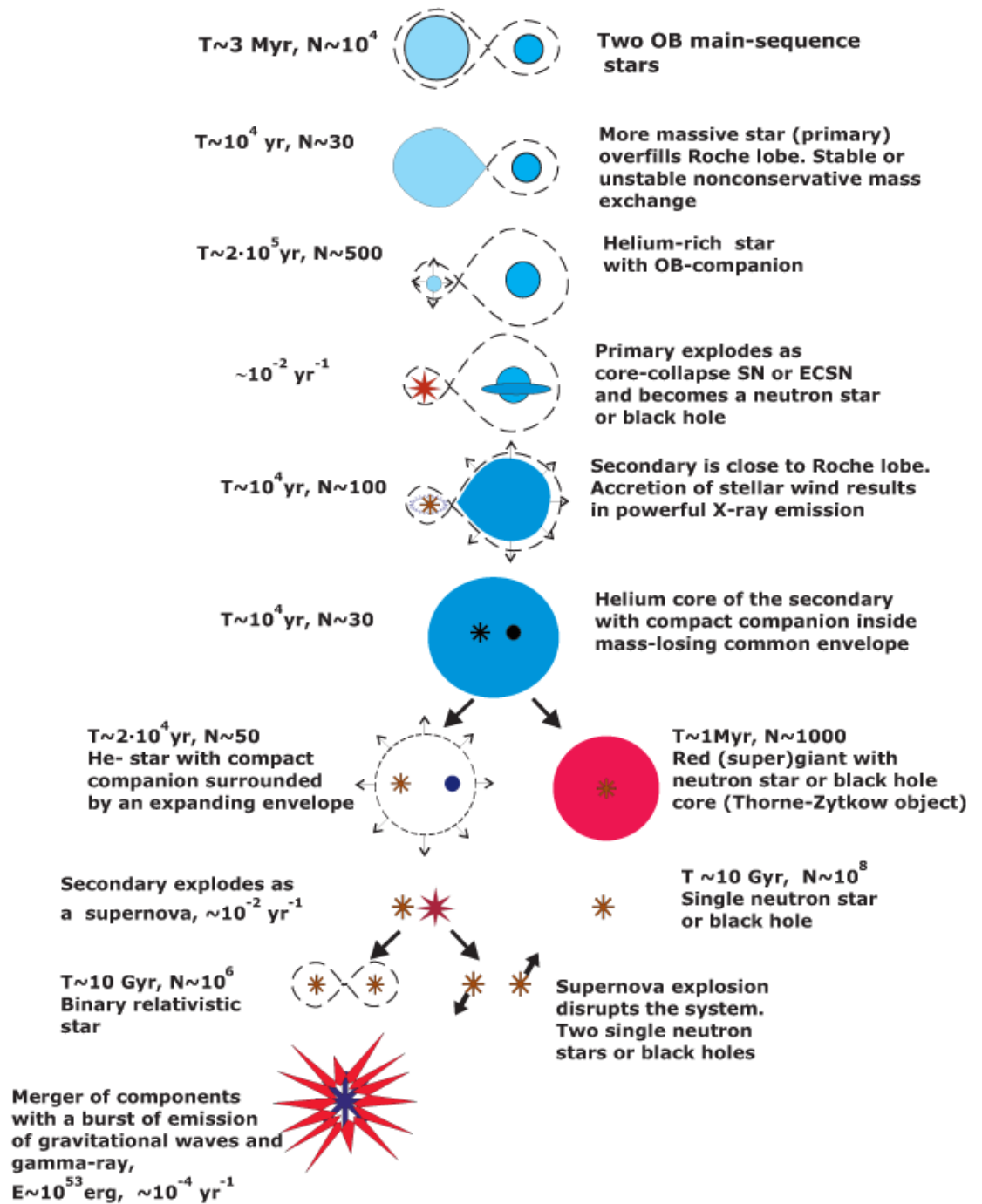


Image: Postnov & Yungelson (2014)



# Assembling a binary



Image: J.-C. Cuillandre/G. Anselmi/Hawaiian Starlight



We will see lots!

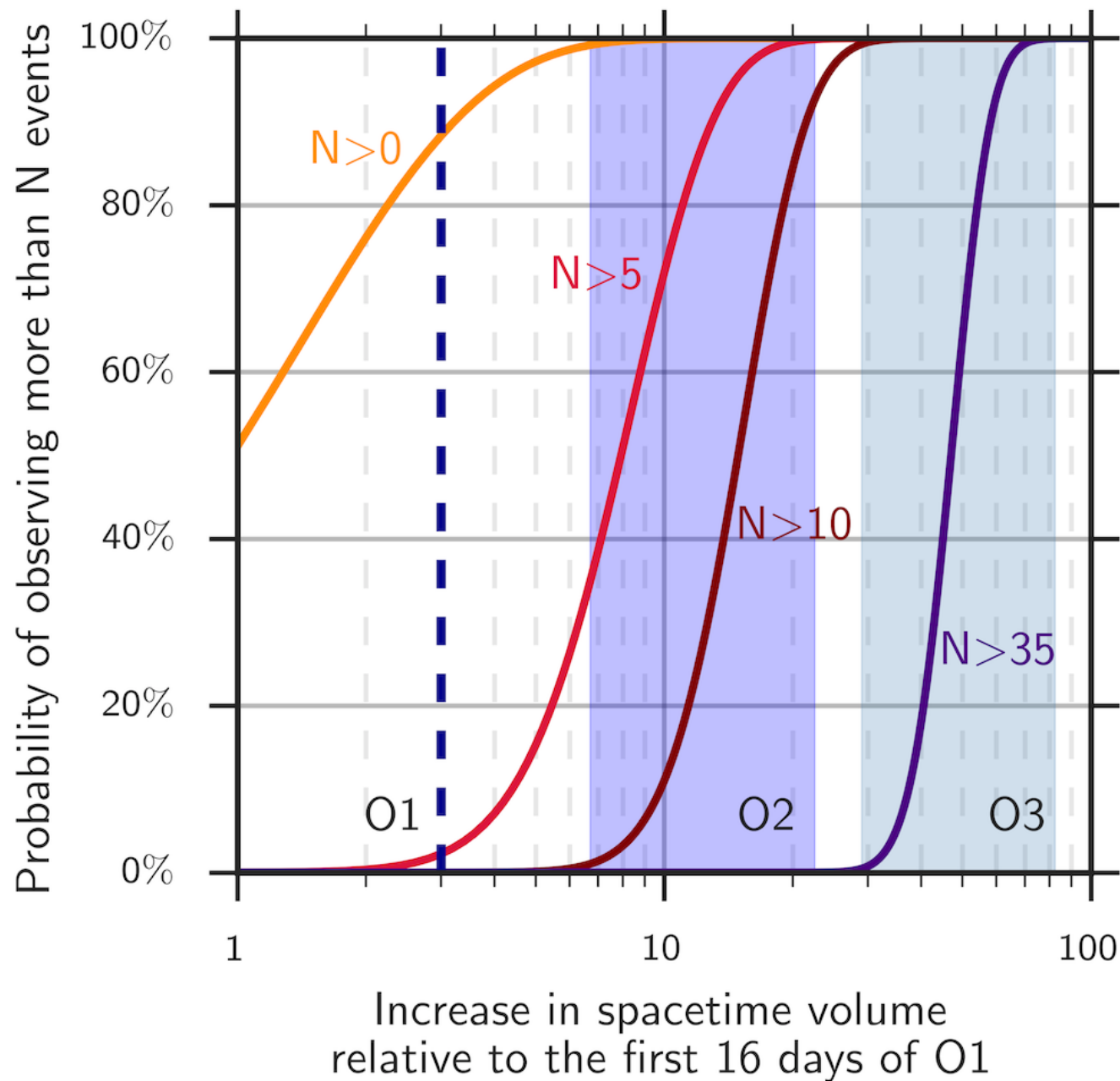
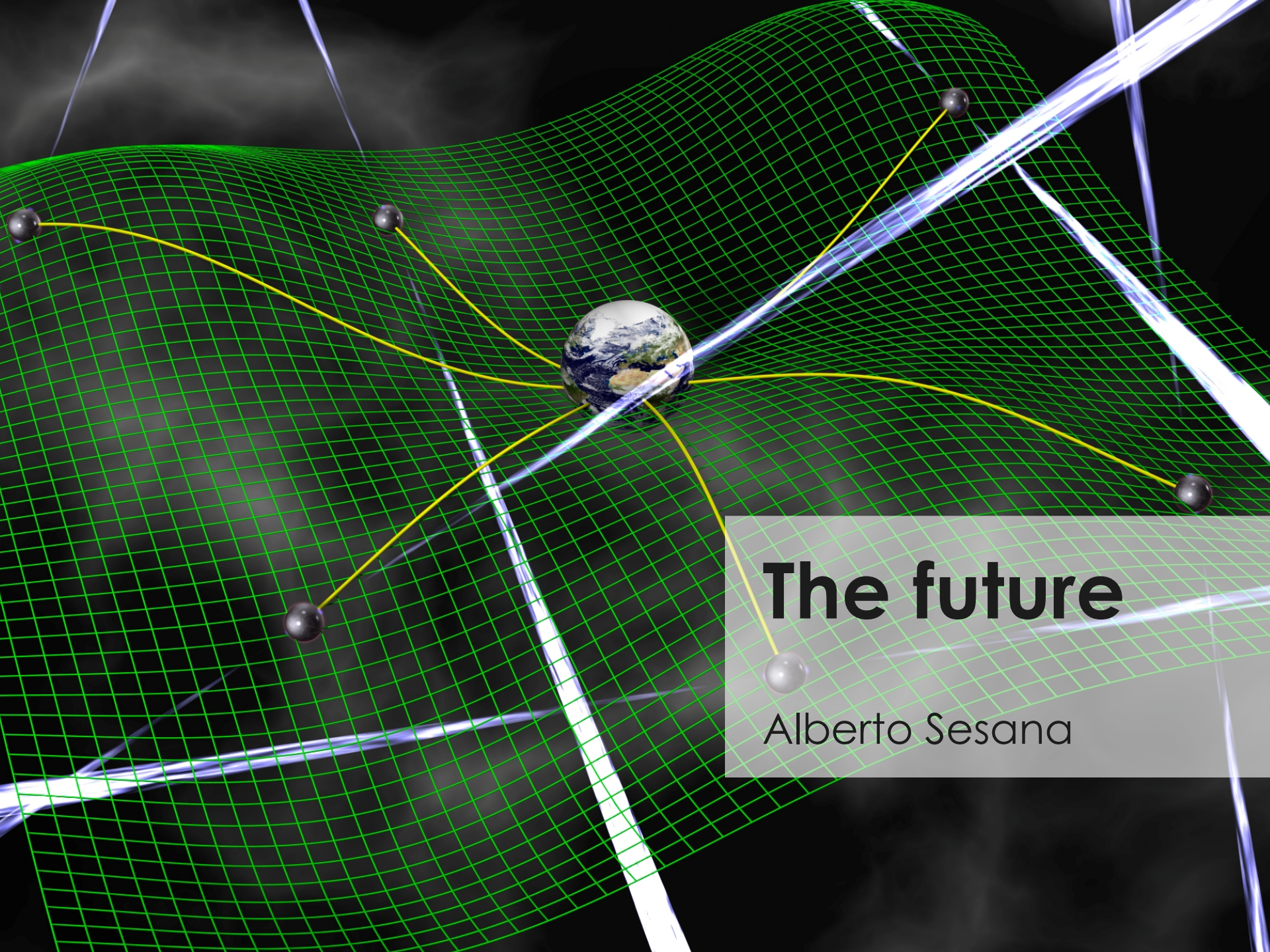


Image: LVC



# The future

Alberto Sesana



# LIGO is just one window



Big Bang

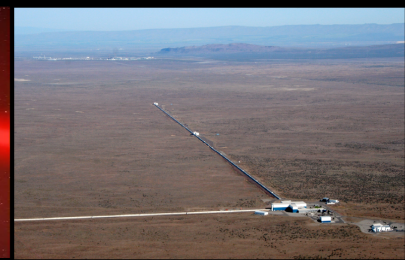
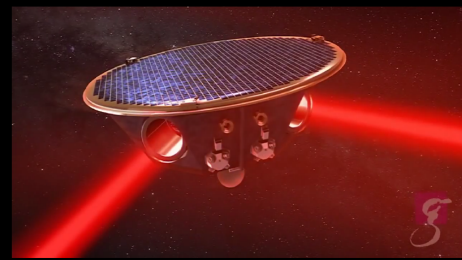
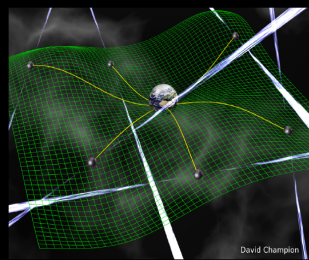
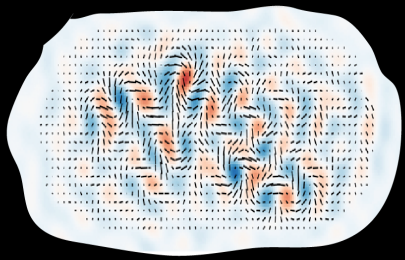
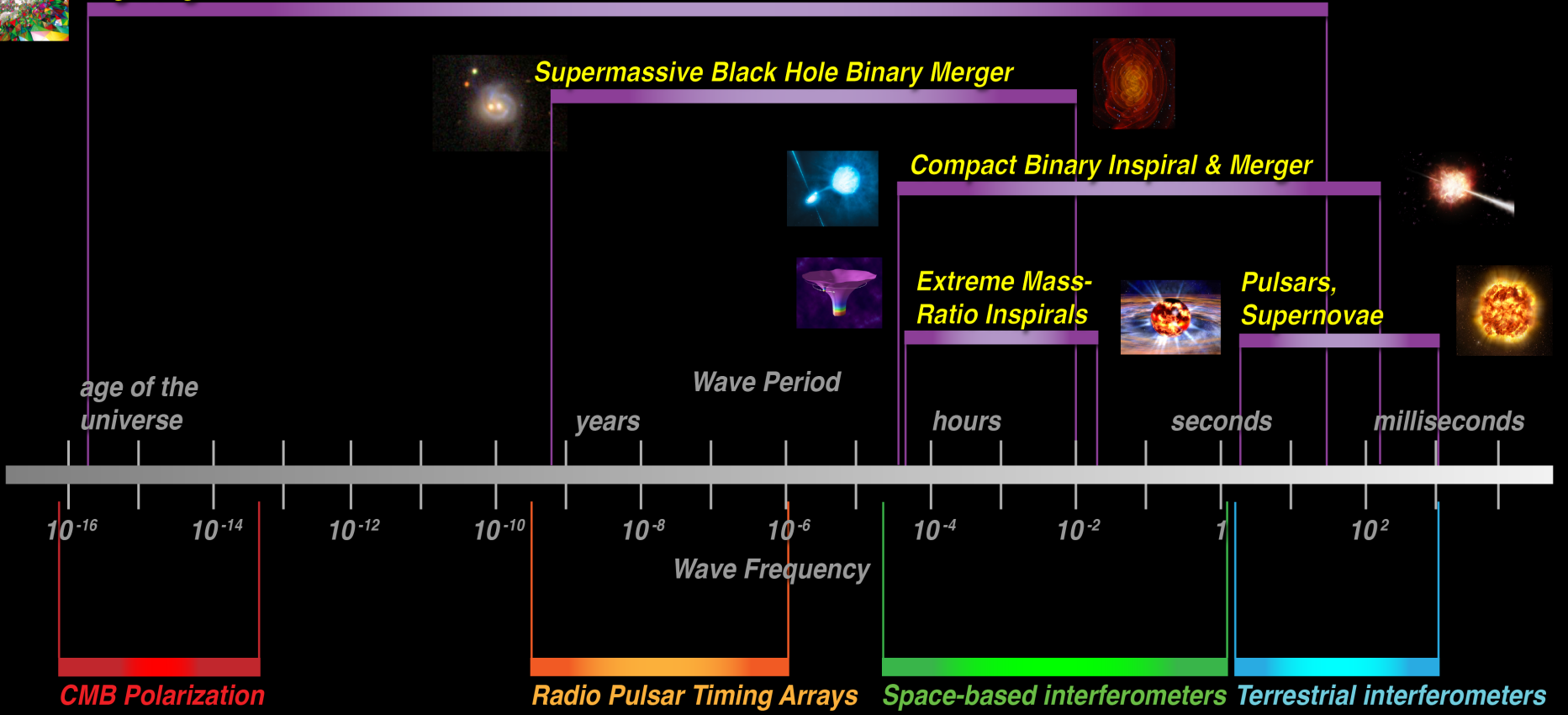
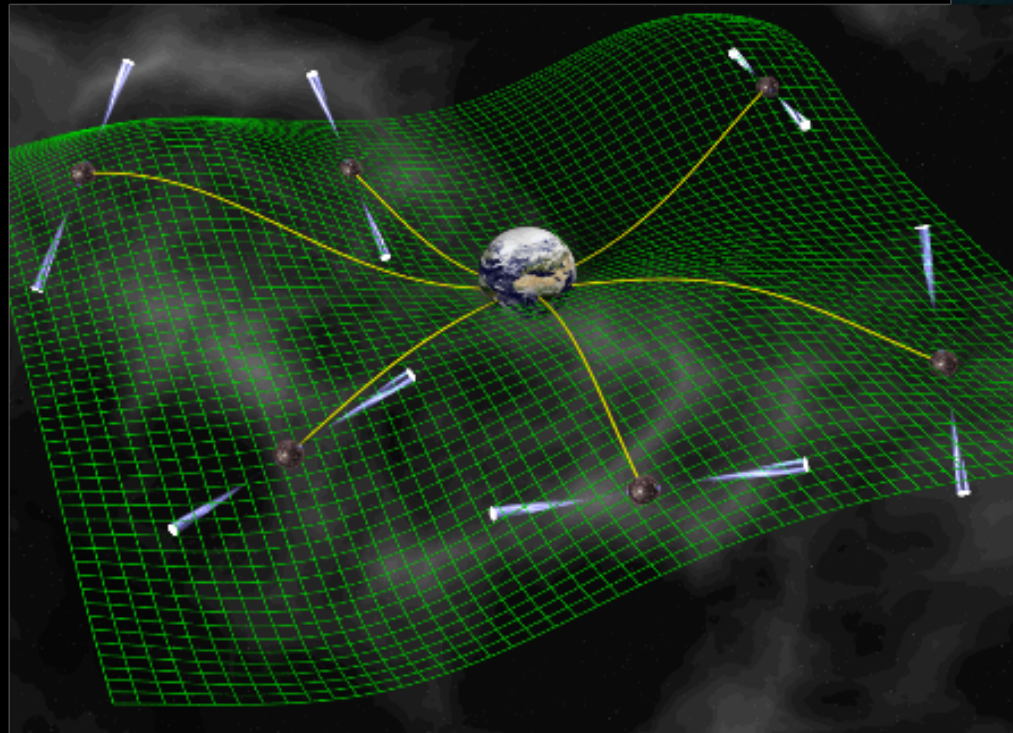


Image: Ira Thorpe

# EPTA/LEAP (Europe)



PPTA  
(Australia)

Image:  
David  
Champion

NANOGrav  
(North America)





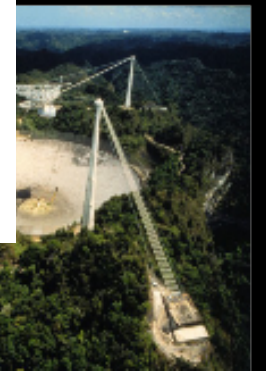
FPTA/LEAP (Europe)



PPTA  
(Australia)

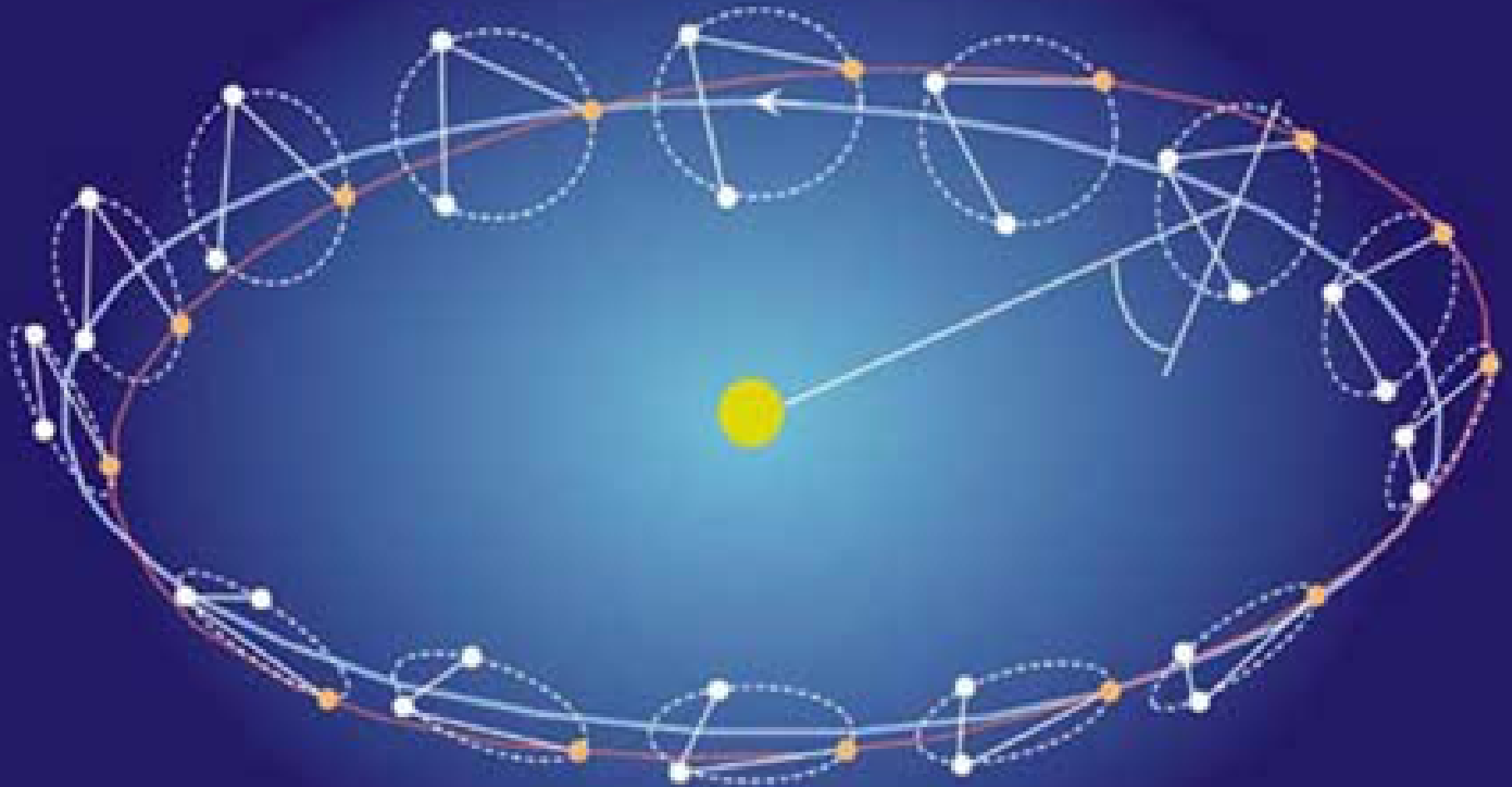


Image:  
David  
Champion



(North America)

# evolving Laser Interferometer Space Antenna





00:01

LISA Pathfinder  
takes off!

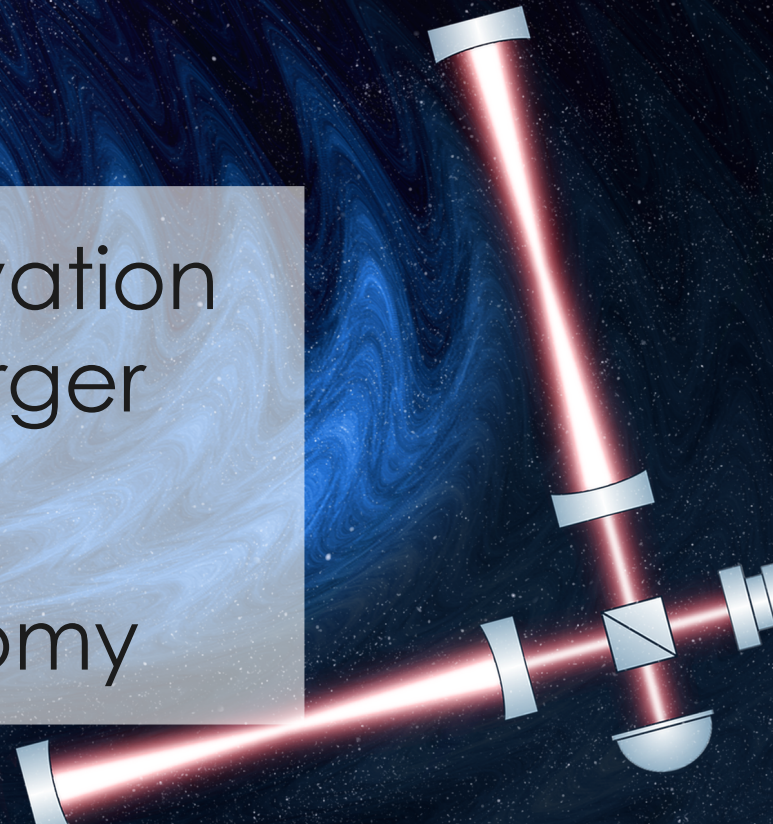
Image: ESA



[birmingham.ac.uk/gravitational-waves/](http://birmingham.ac.uk/gravitational-waves/)

LIGO made the first observation  
of a binary **black hole** merger

The future is bright for  
**gravitational wave** astronomy







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# Thank You

Coming Up: Astronomy in the City - Wednesday 9 March 2016

Visit [birmingham.ac.uk/astro-in-the-city](http://birmingham.ac.uk/astro-in-the-city) for more information

[birmingham.ac.uk/gravitational-waves](http://birmingham.ac.uk/gravitational-waves)

