Astronomy In The City
Gravitational Waves Special

birmingham.ac.uk/gravitational-waves

Astronomy in the City returns 9 March

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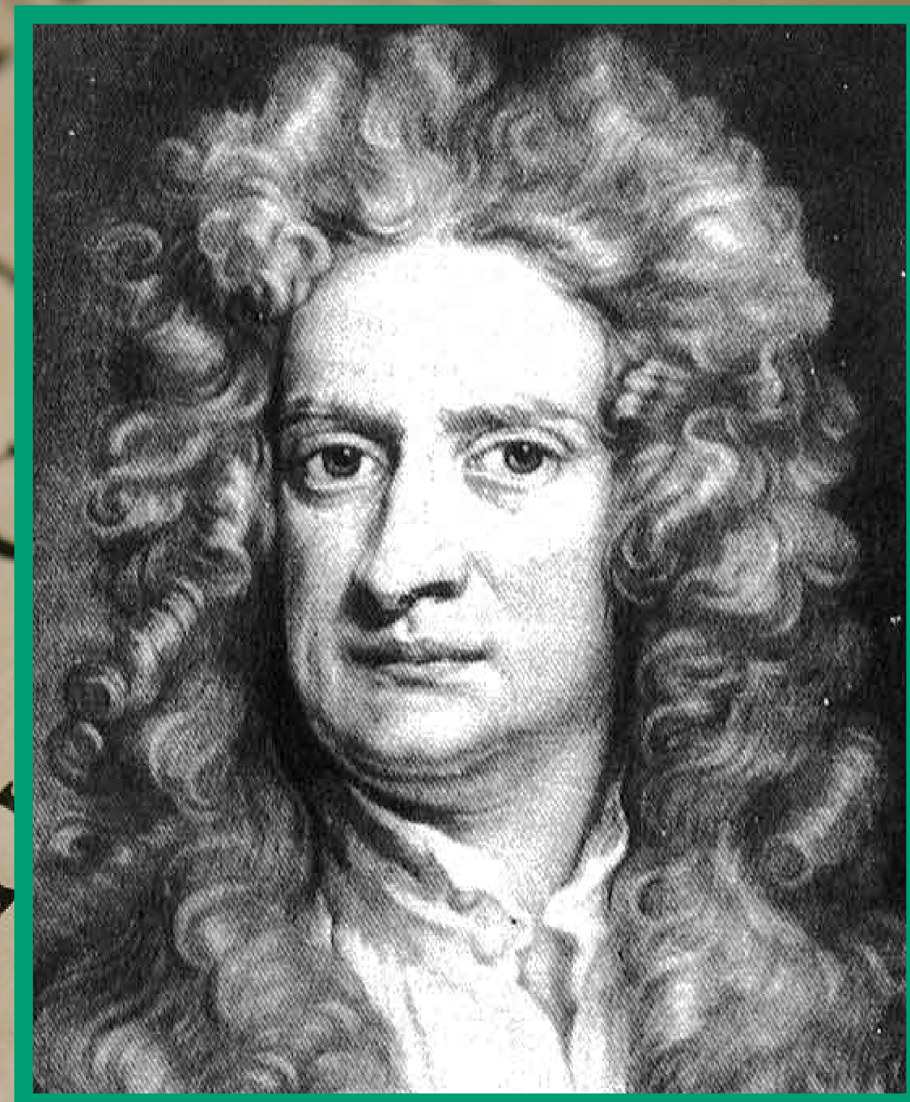
The gravitational universe

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.

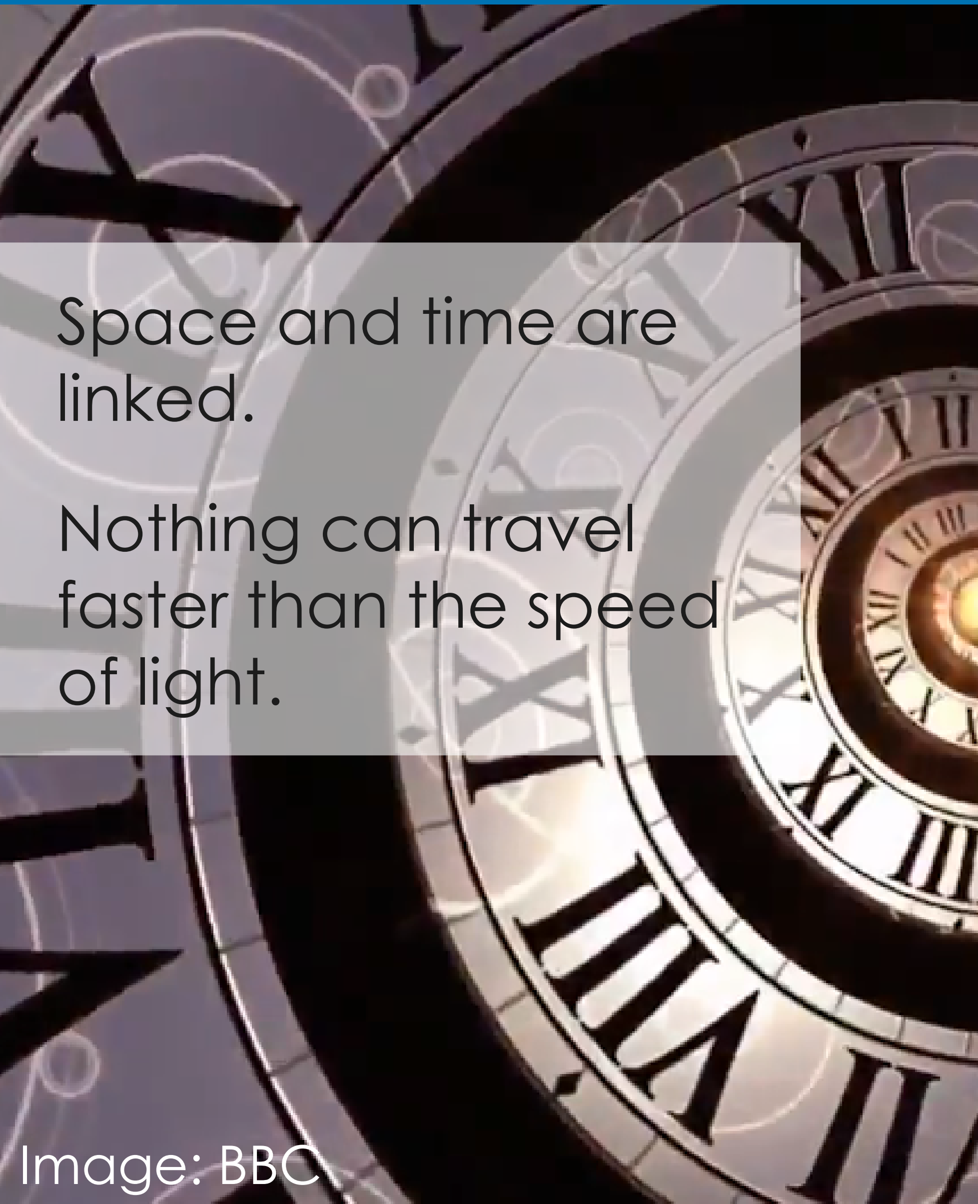
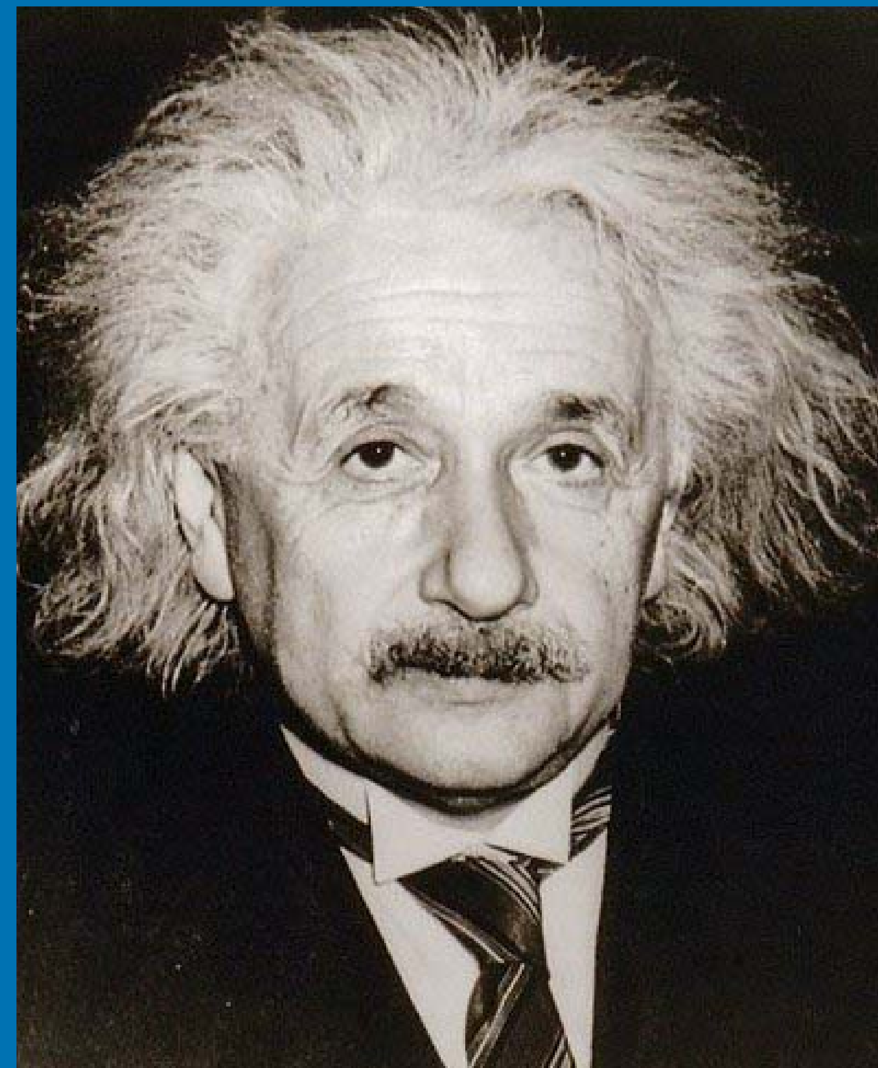
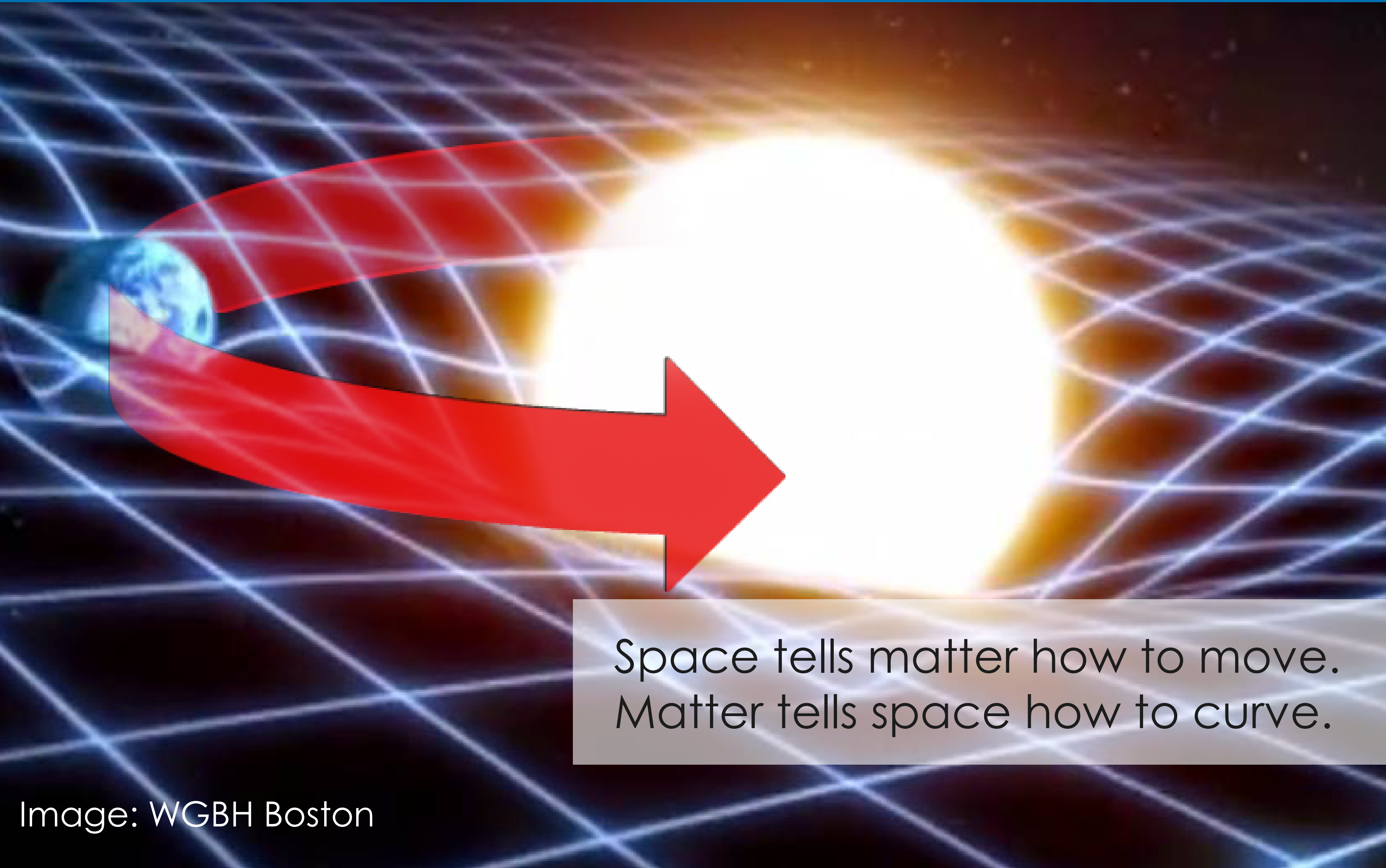


Image: BBC



Space-time


Space tells matter how to move.
Matter tells space how to curve.
Image: WGBH Boston

General relativity

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

Curvature

Mass

What does general relativity tell us?

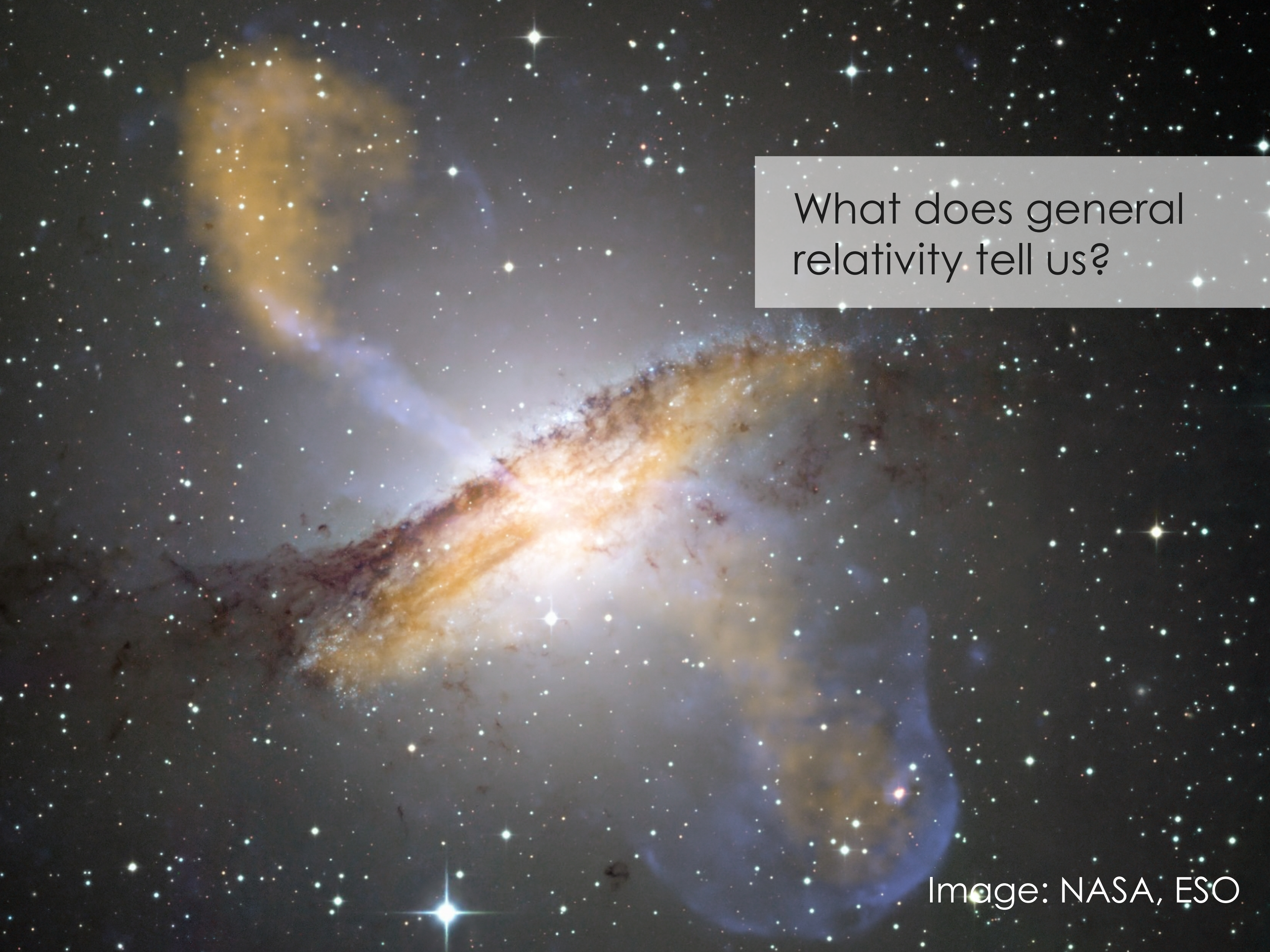
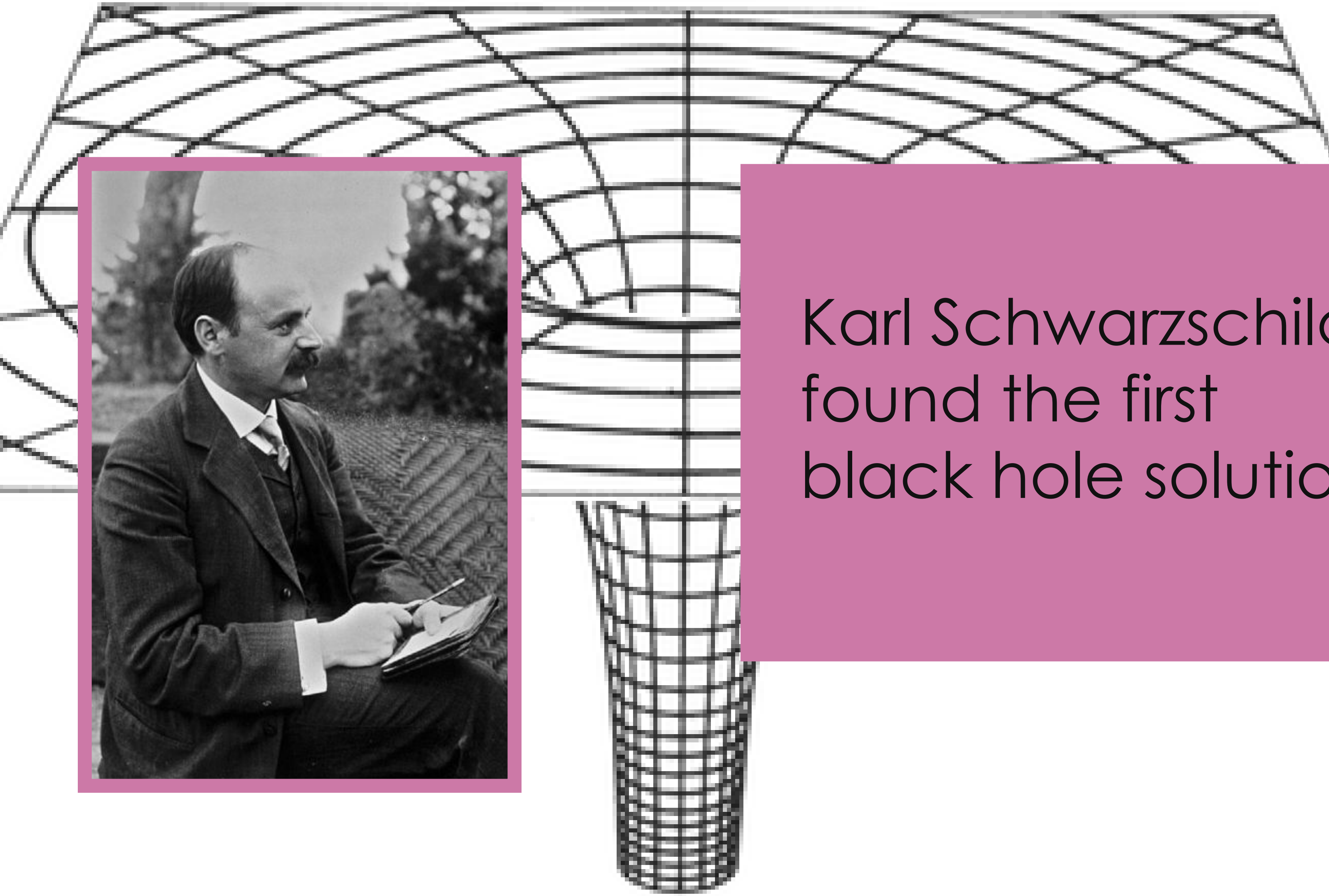
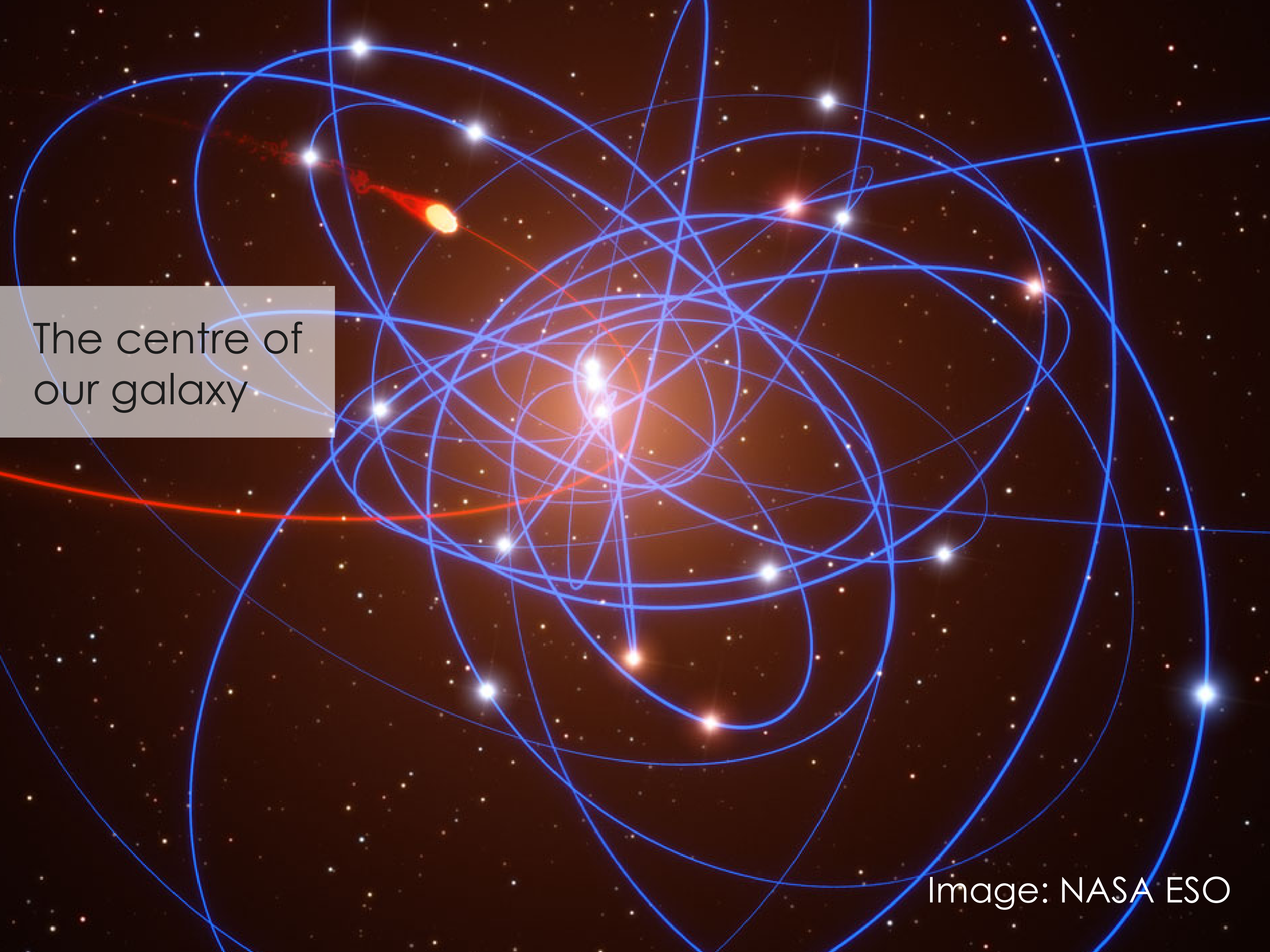


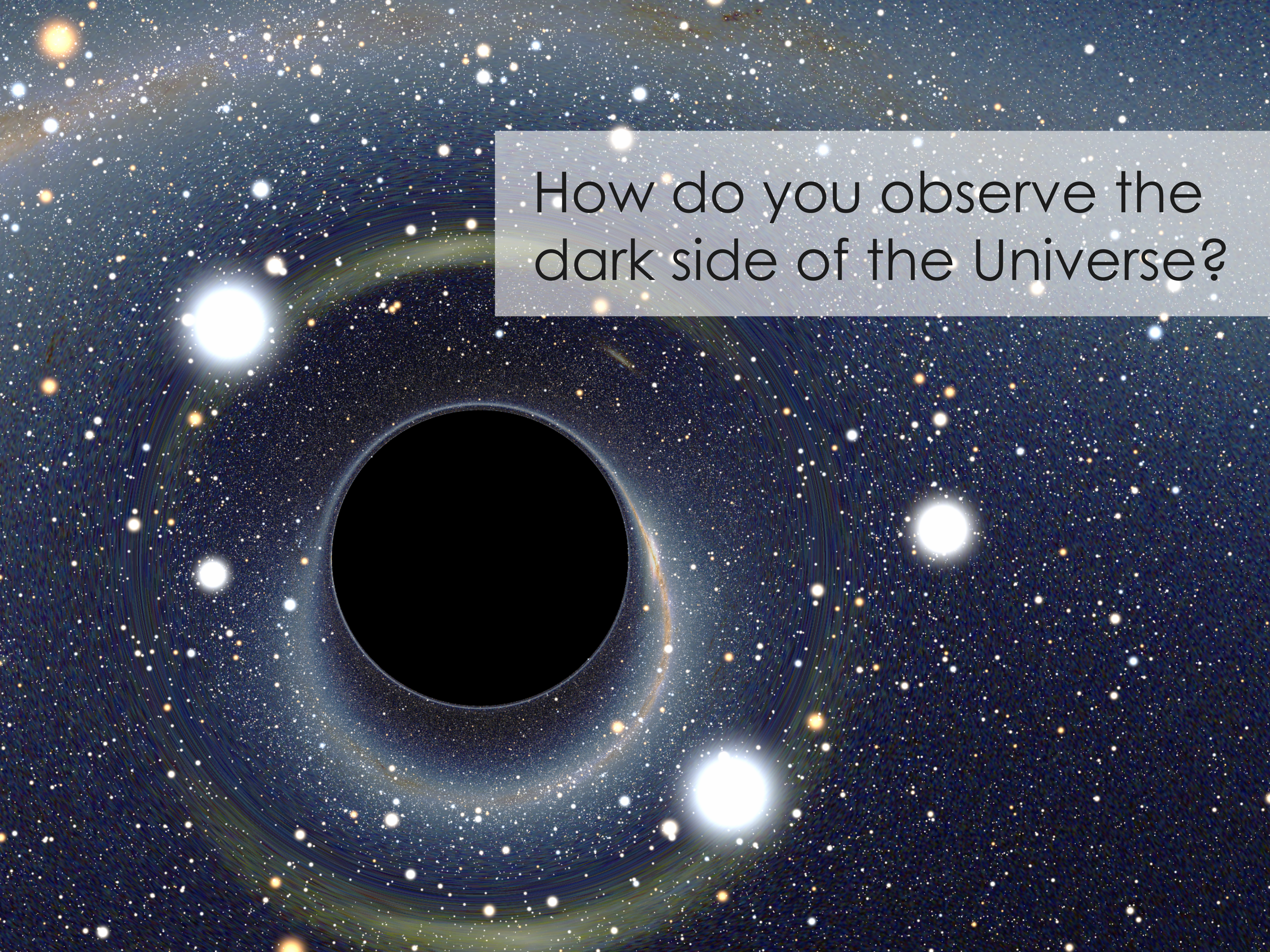
Image: NASA, ESO



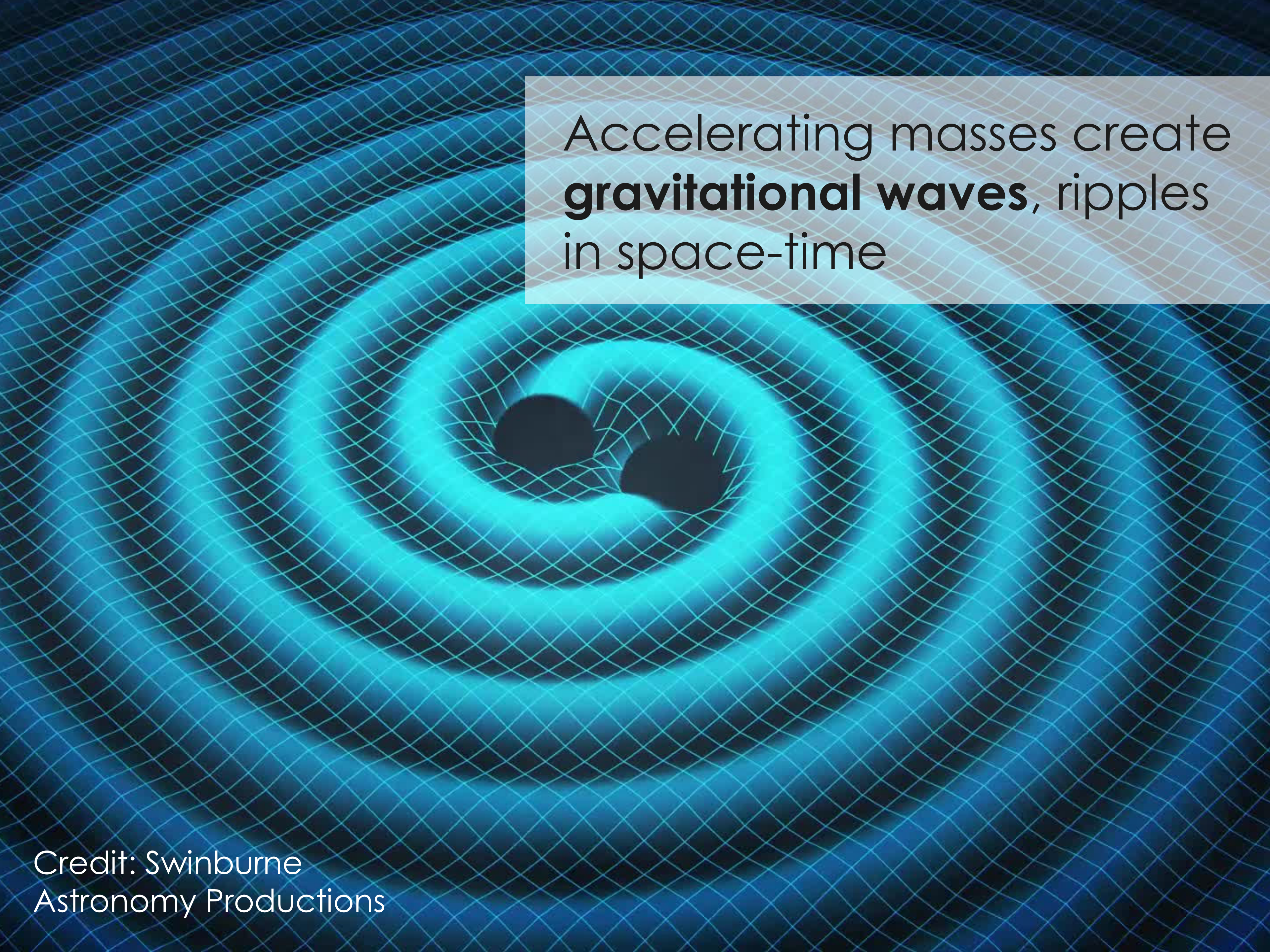
Karl Schwarzschild found the first black hole solution


The centre of our galaxy
Image: NASA ESO

How do you observe the dark side of the Universe?

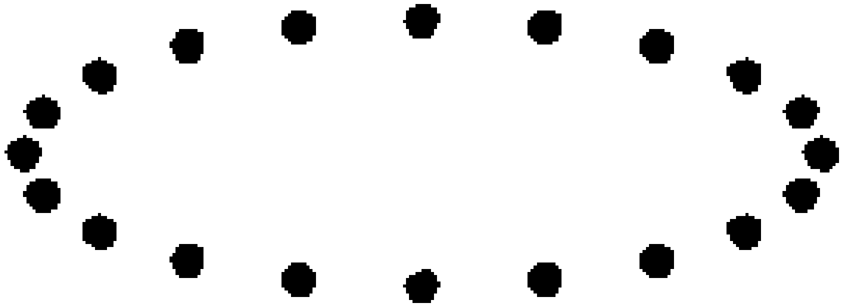


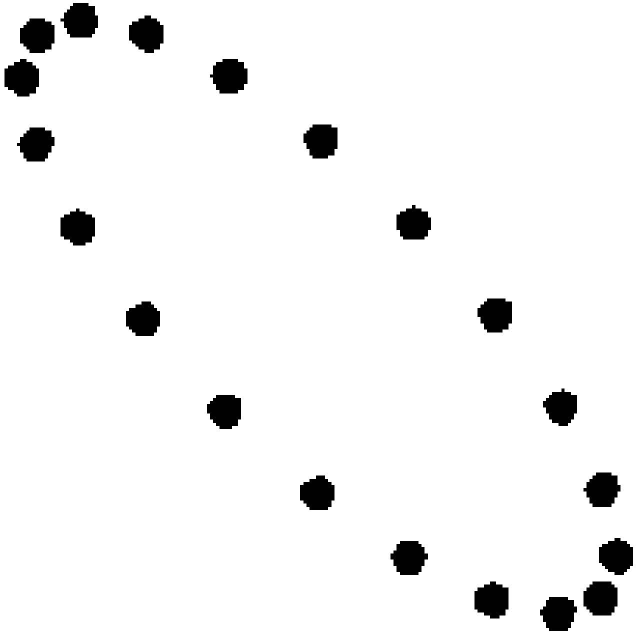
Accelerating masses create **gravitational waves**, ripples in space-time



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!

losc.ligo.org/events/GW150914/

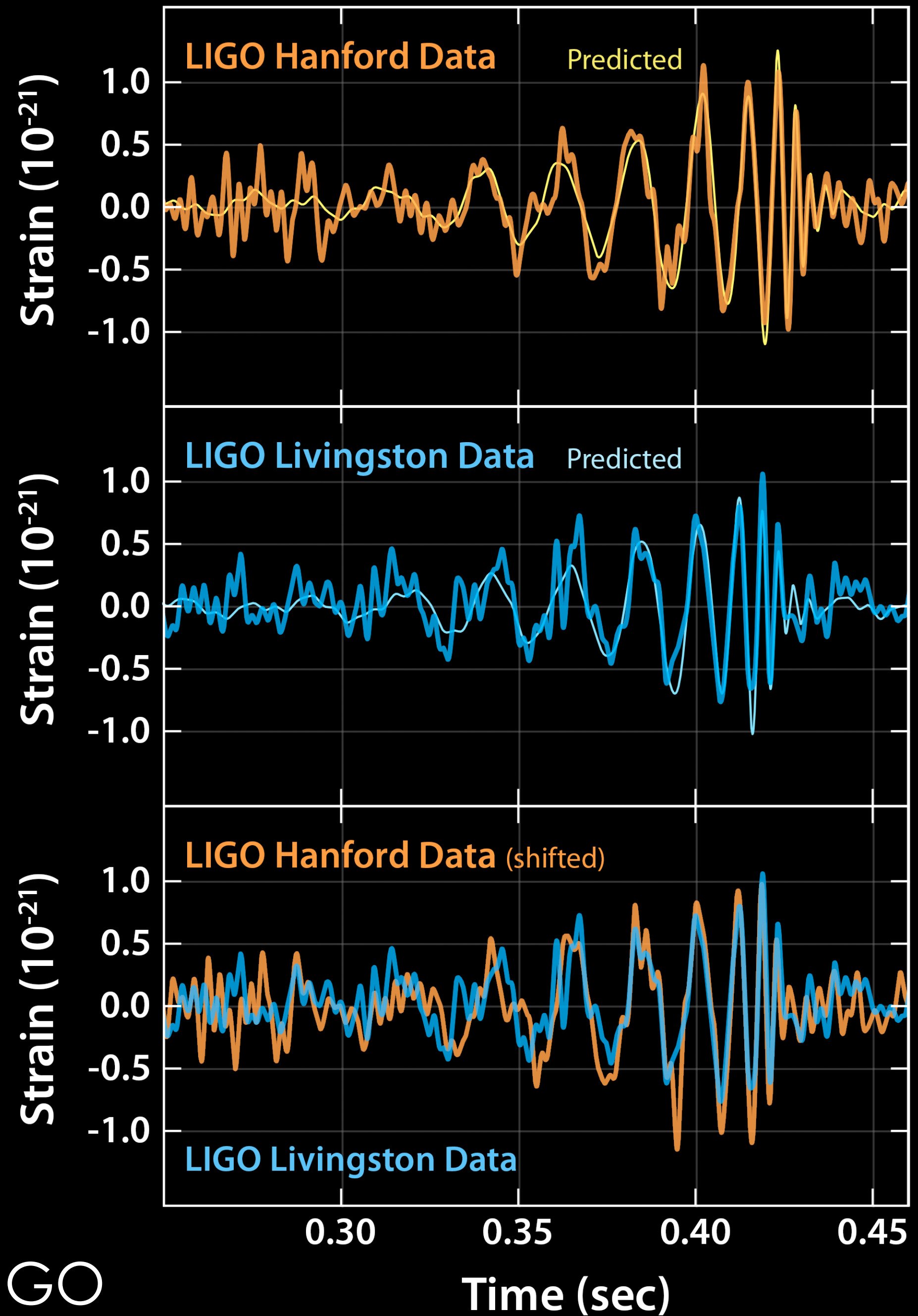
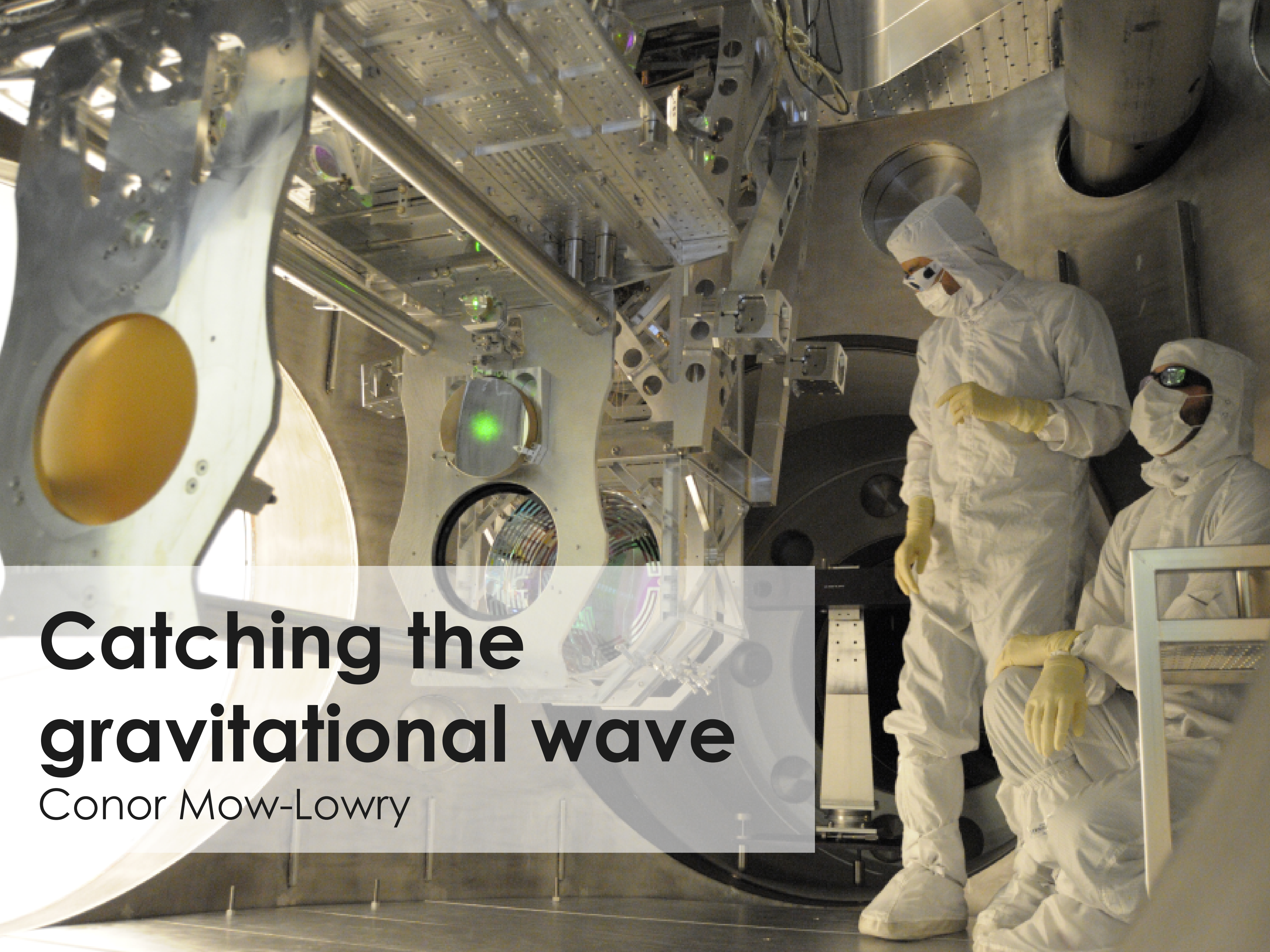
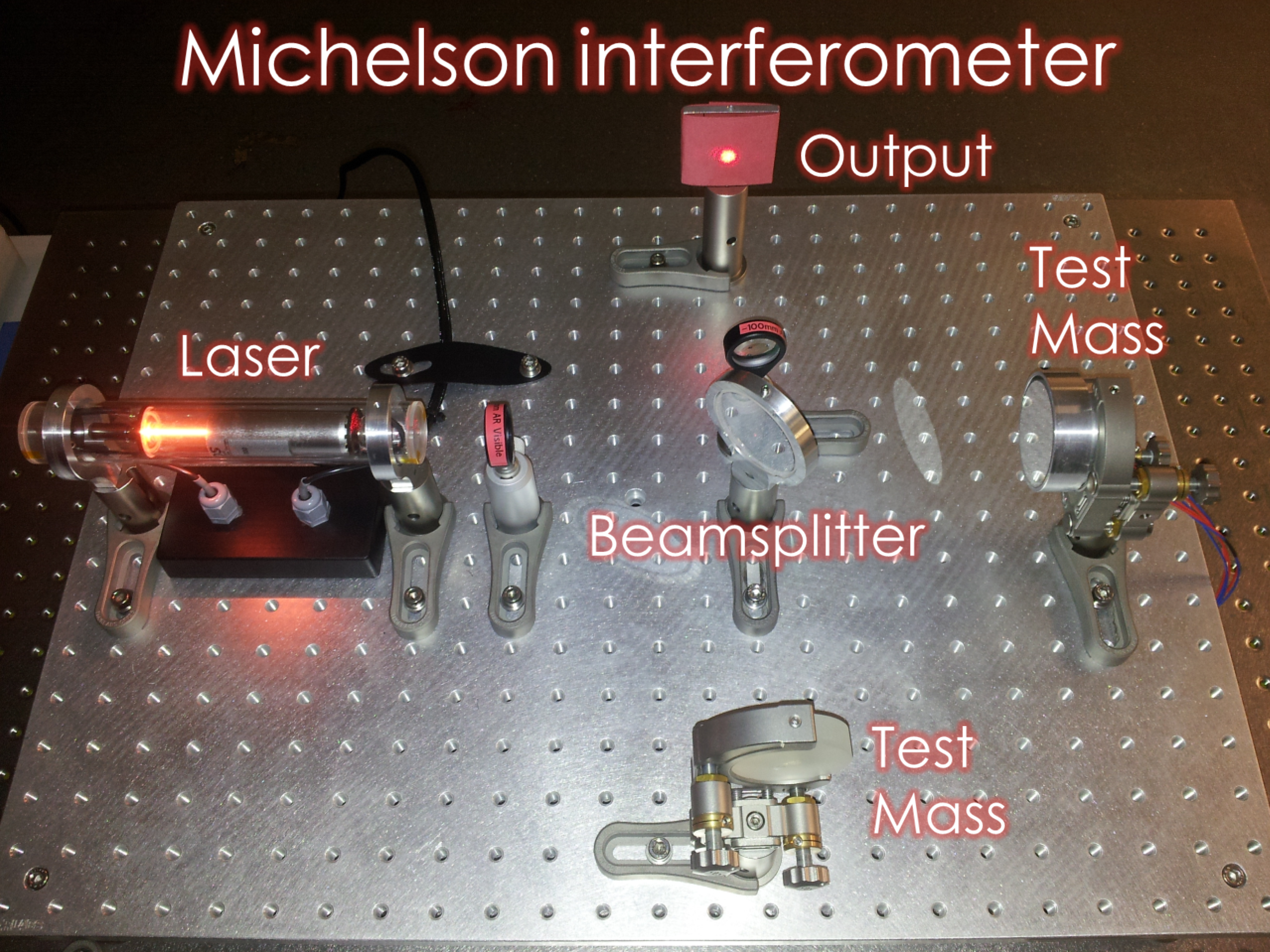


Image: LIGO

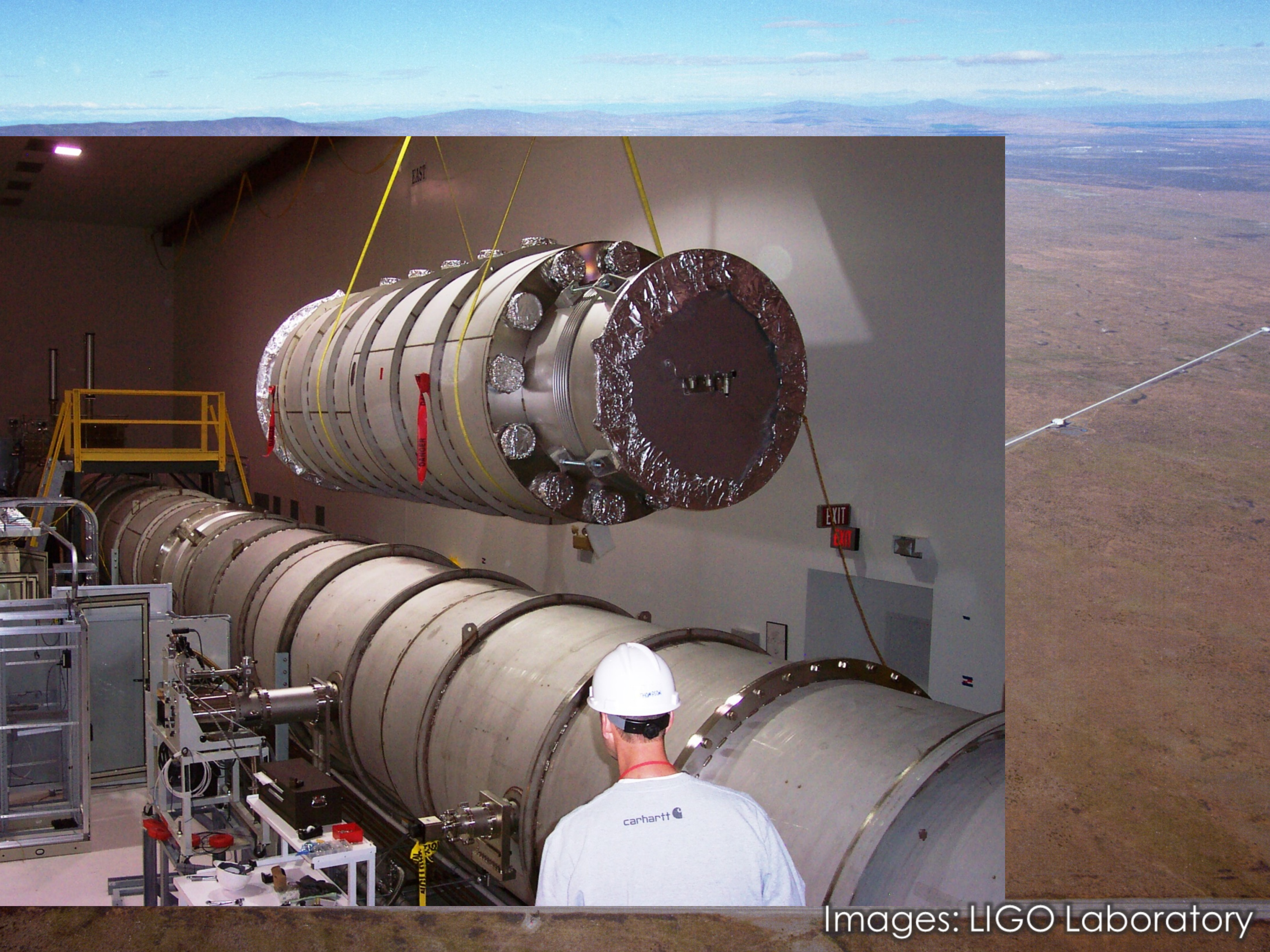


Catching the gravitational wave

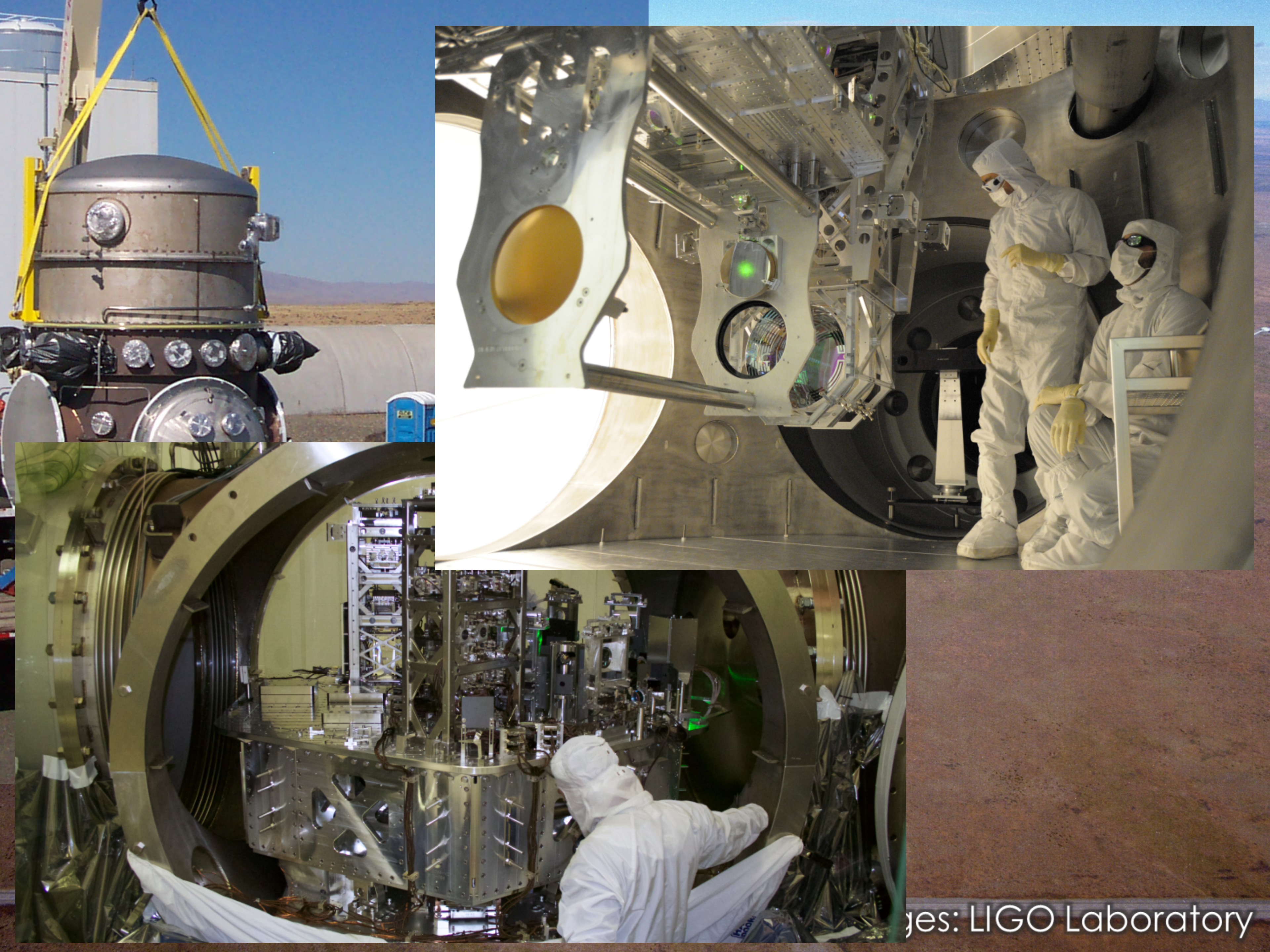
Conor Mow-Lowry

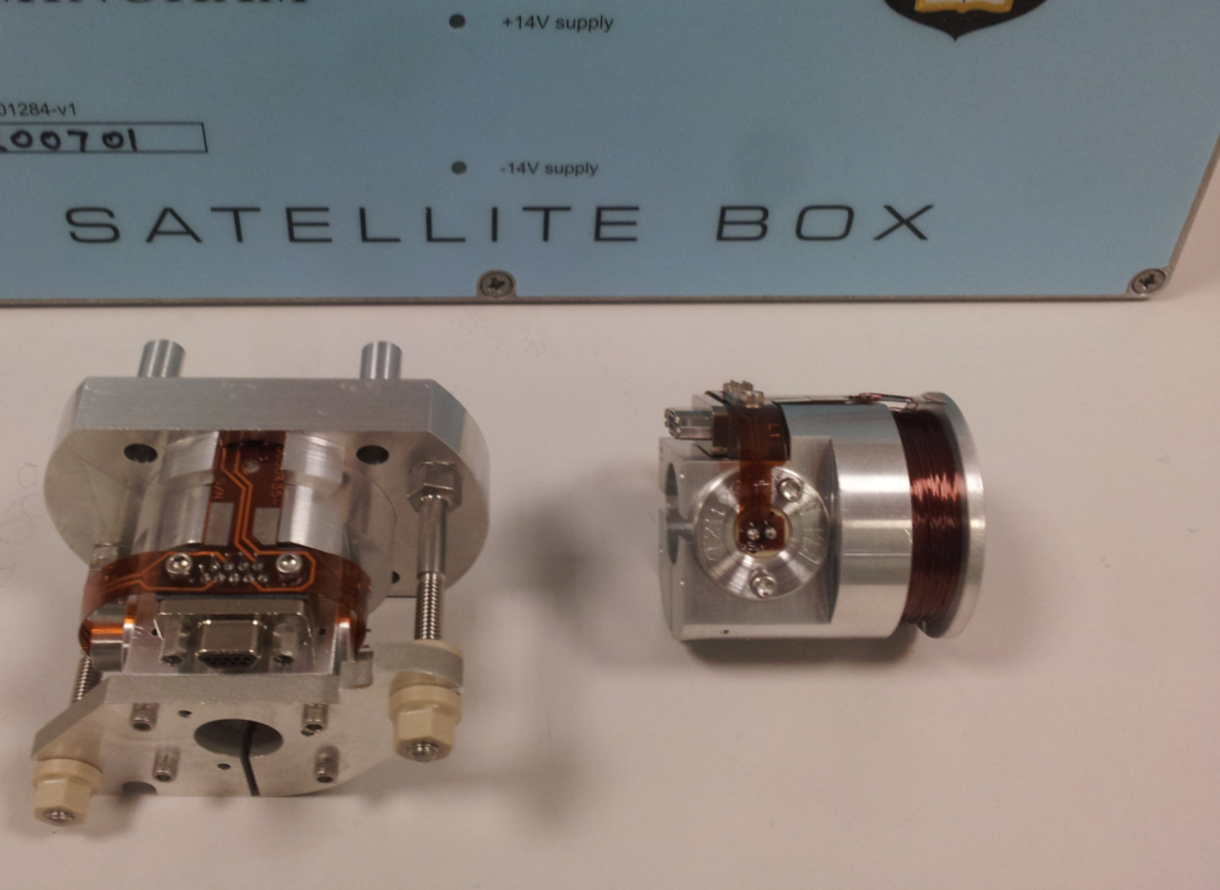

Michelson interferometer
Output
Test Mass
Laser
AR Visible
-100mm
Beamsplitter
Test Mass

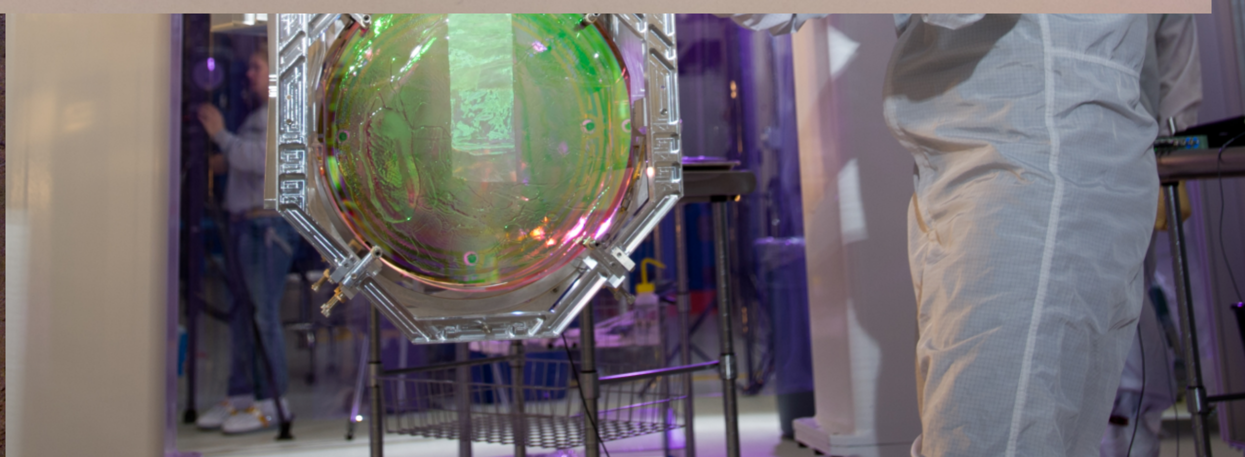
Images: LIGO Laboratory and Google Maps

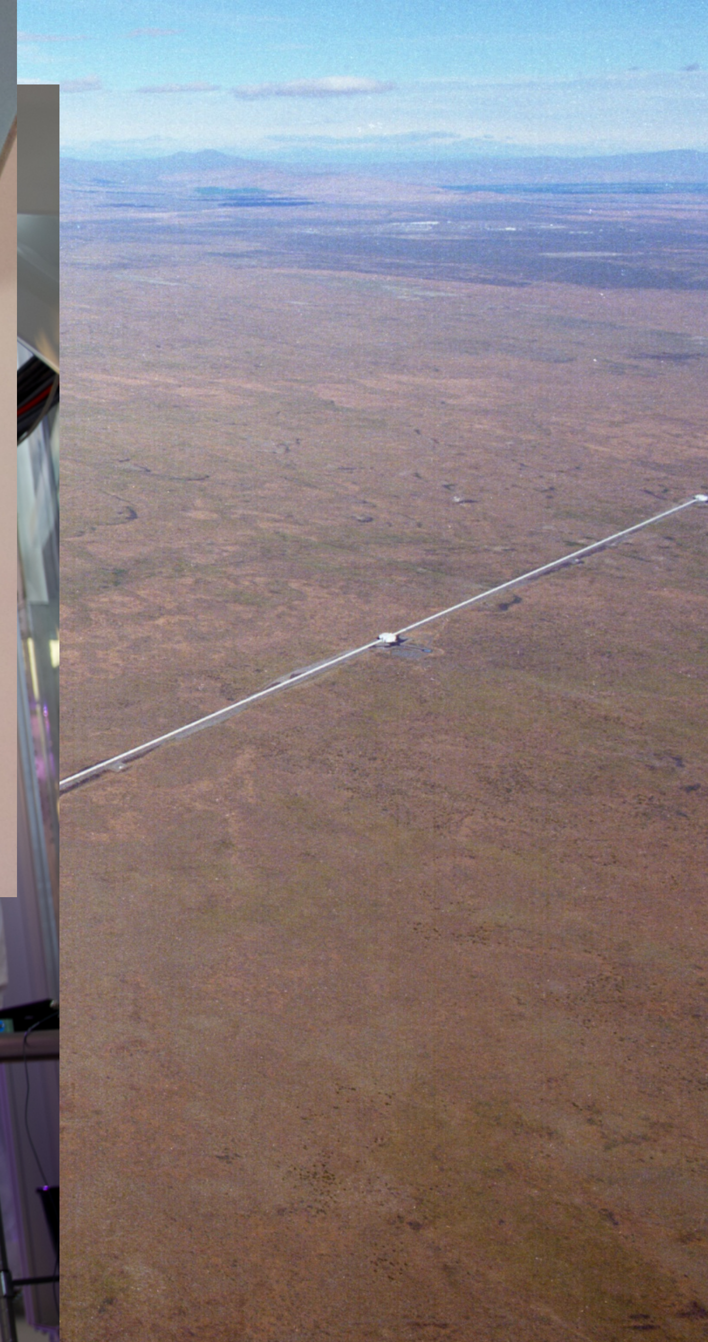


Images: LIGO Laboratory


ges: 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!

Image: LIGO Laboratory

Information in a gravitational wave

Walter Del Pozzo

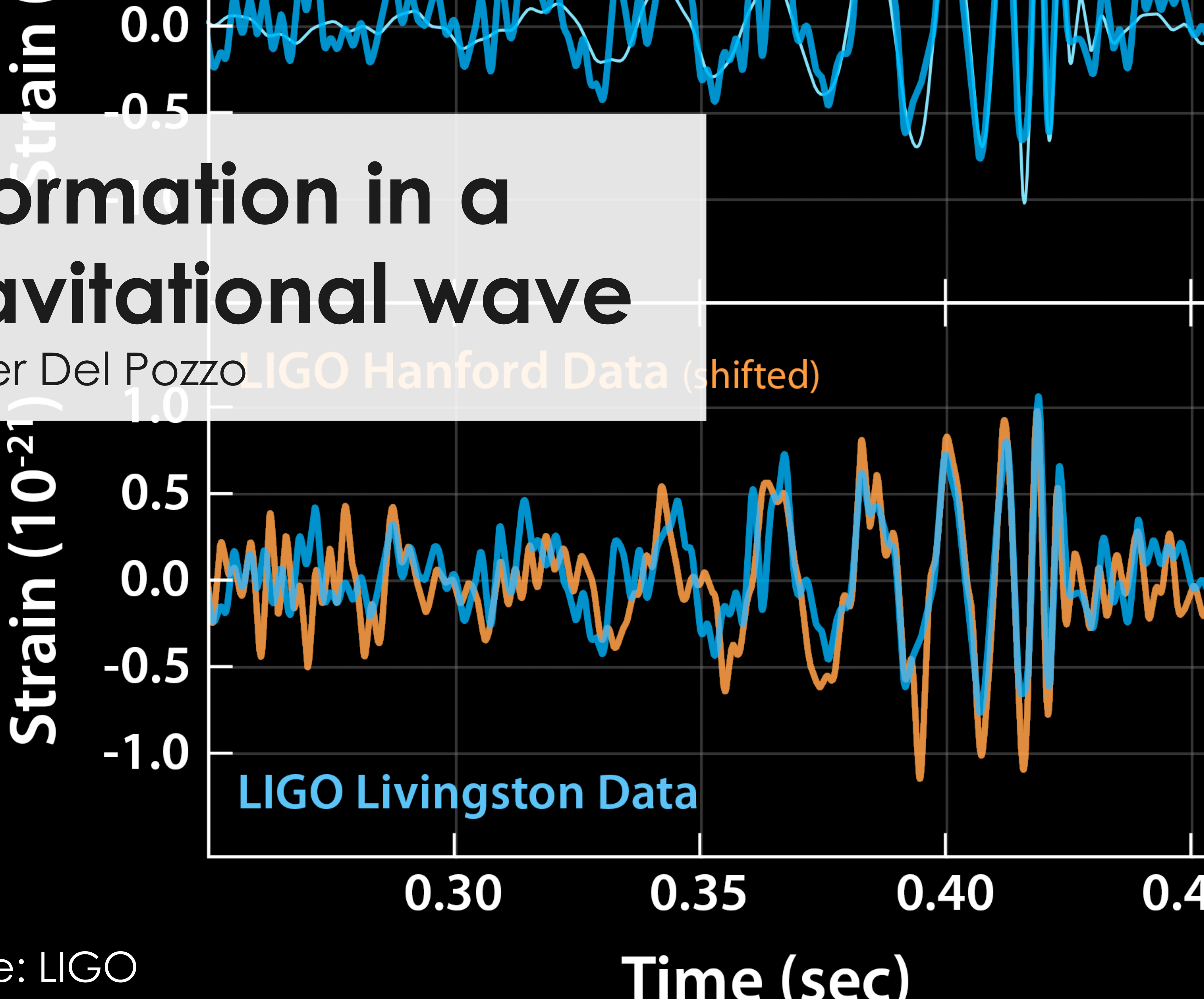
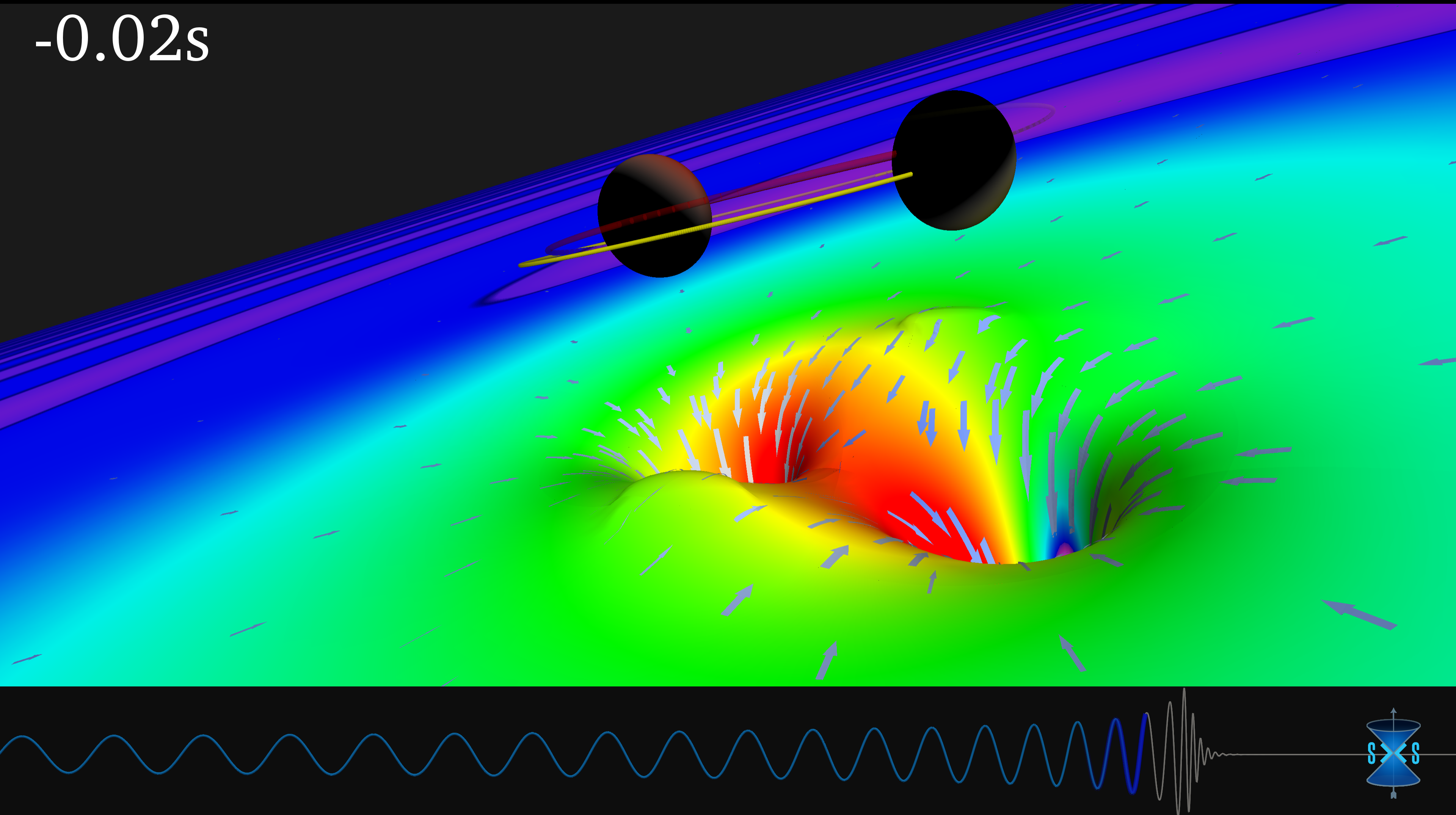
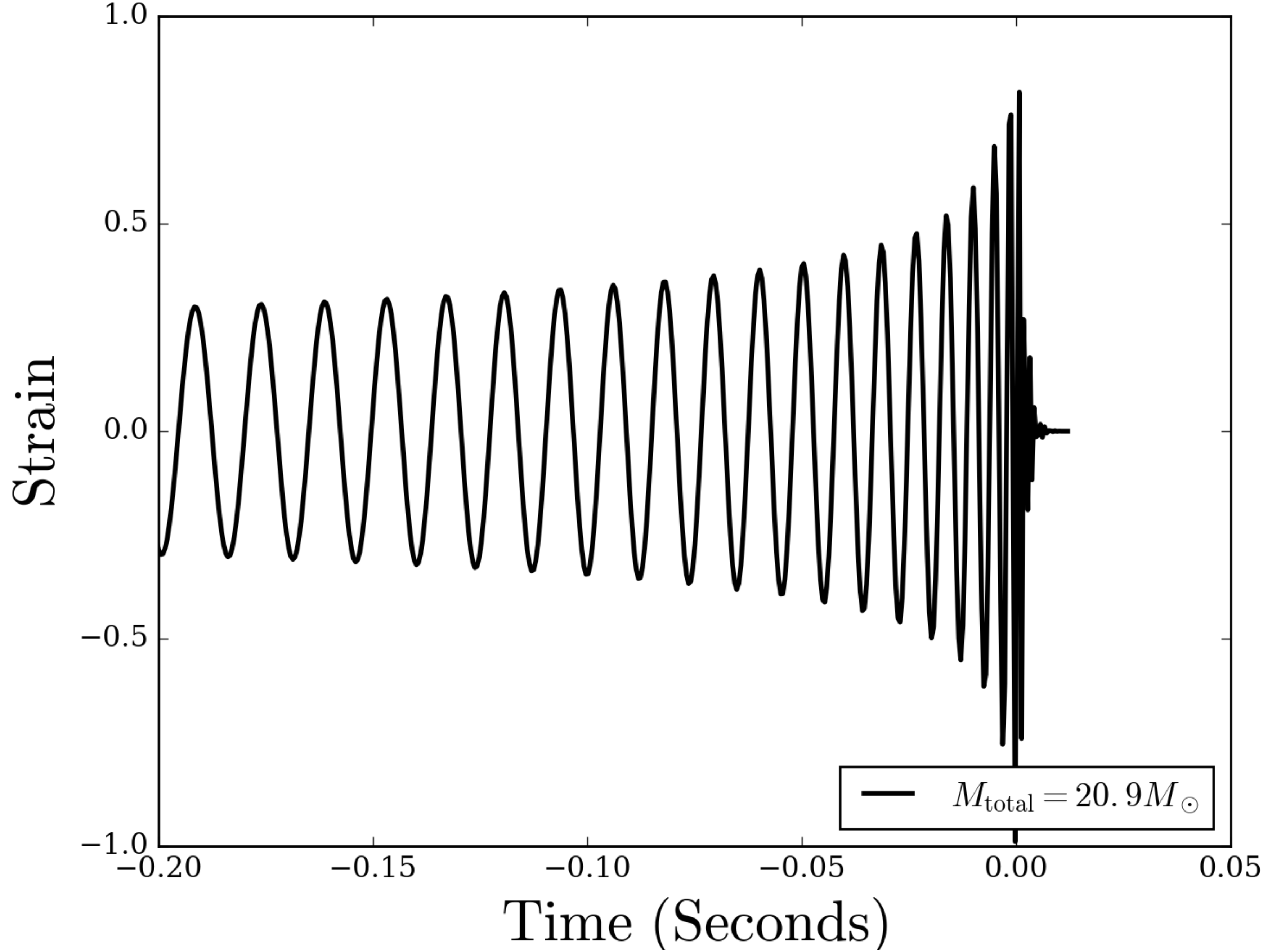


Image: LIGO


-0.02s



1.0
0.5
0.0
−0.5
−1.0
−0.20
−0.15
−0.10
−0.05
0.00
0.05
Strain
Time (Seconds)
$M_{\rm total} = 20.9 M_\odot$

Black hole binary masses

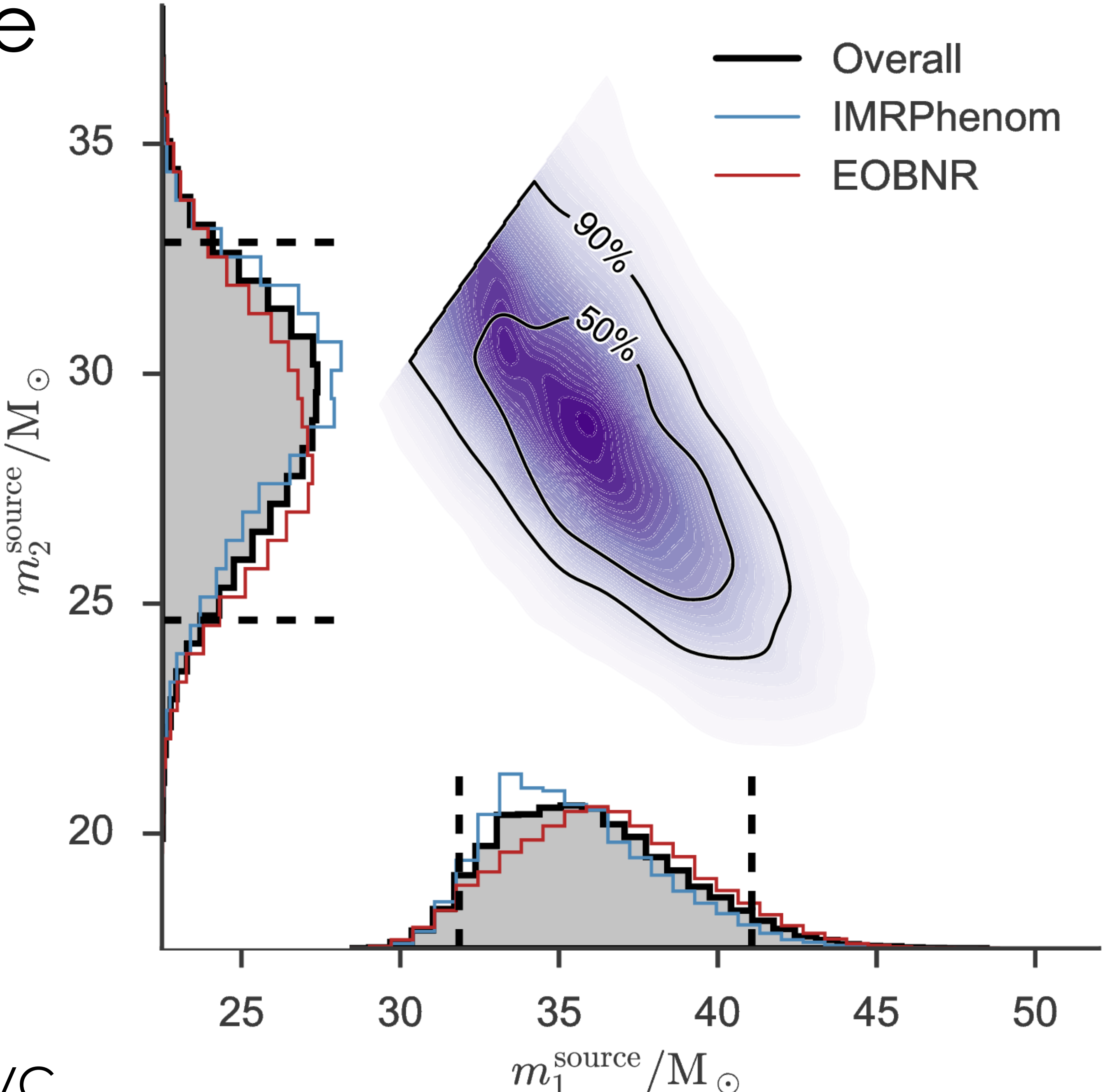


Image credit: LVC

Final black hole

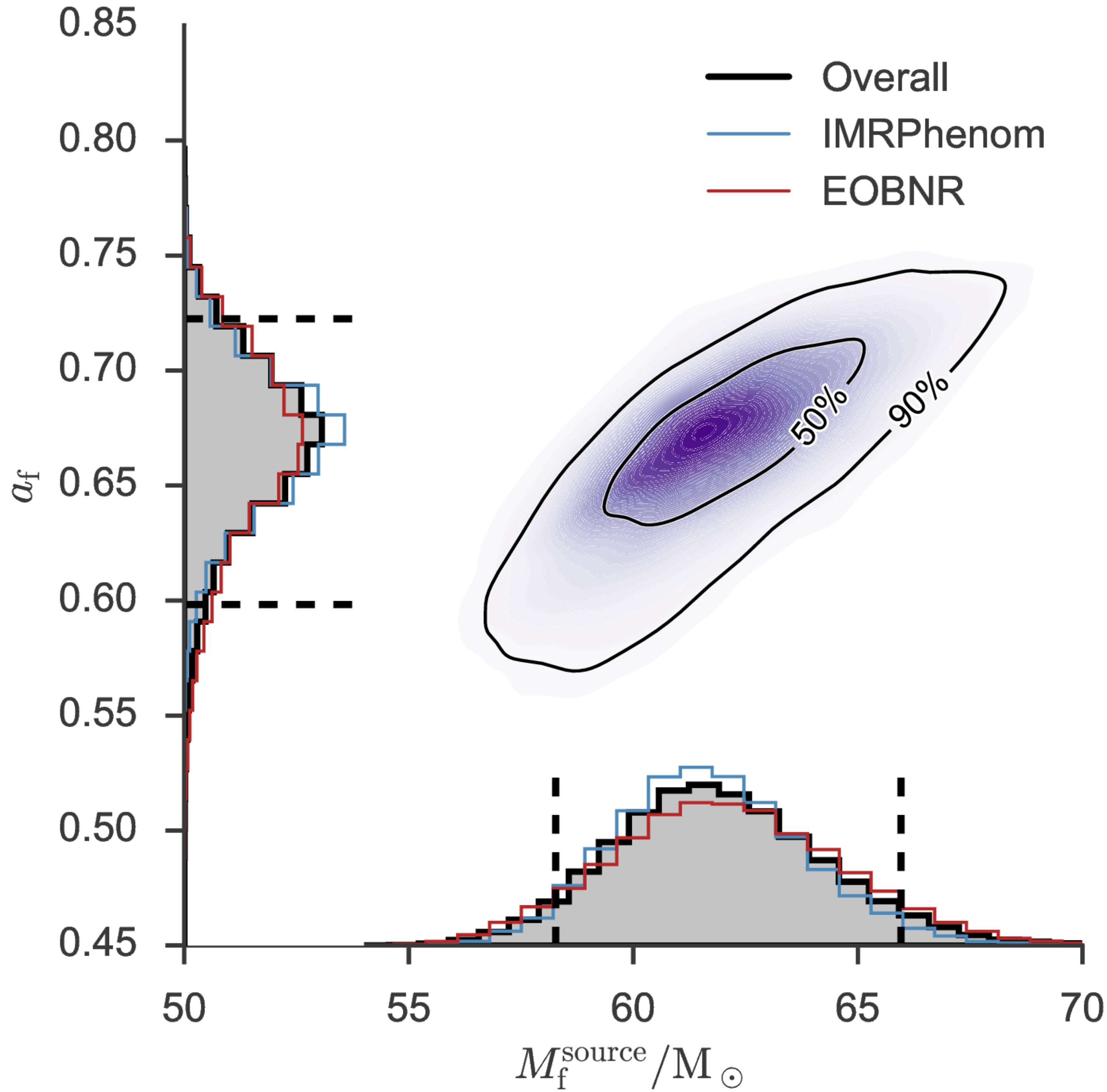
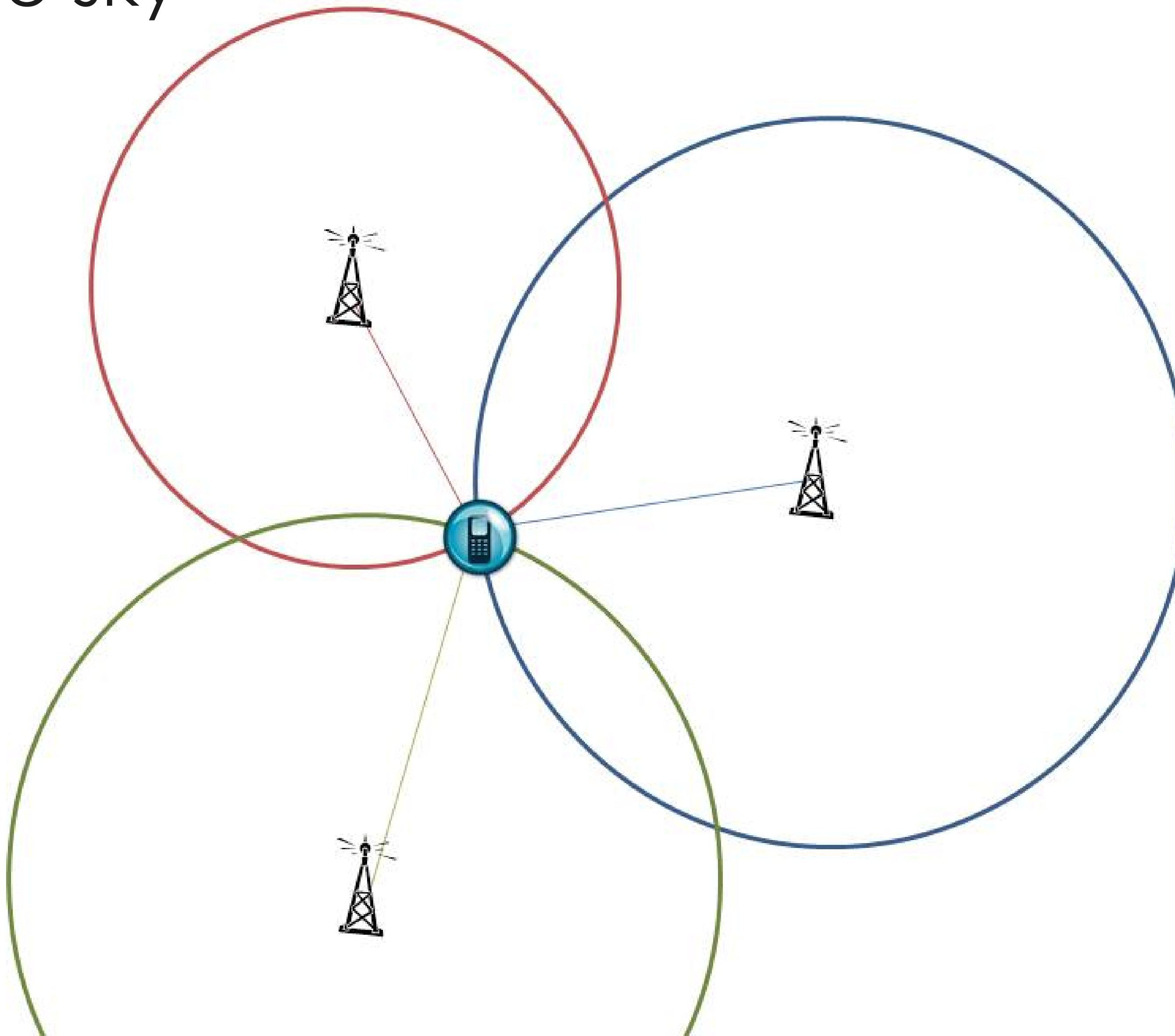


Image: LVC

Multiple detectors can localise the source in the sky



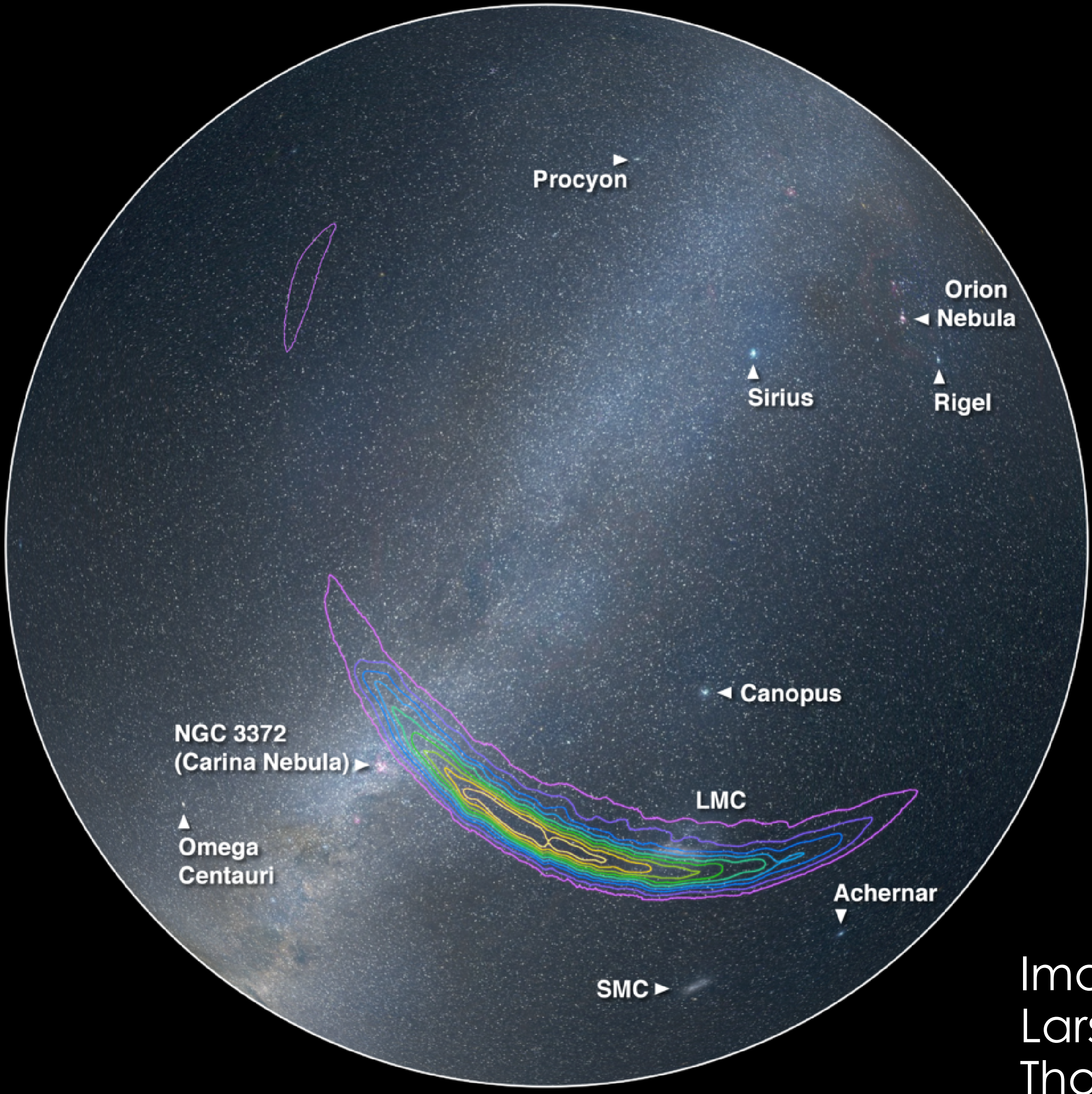


Image: LVC/Shane Larson/Roy Williams/ Thomas Boch

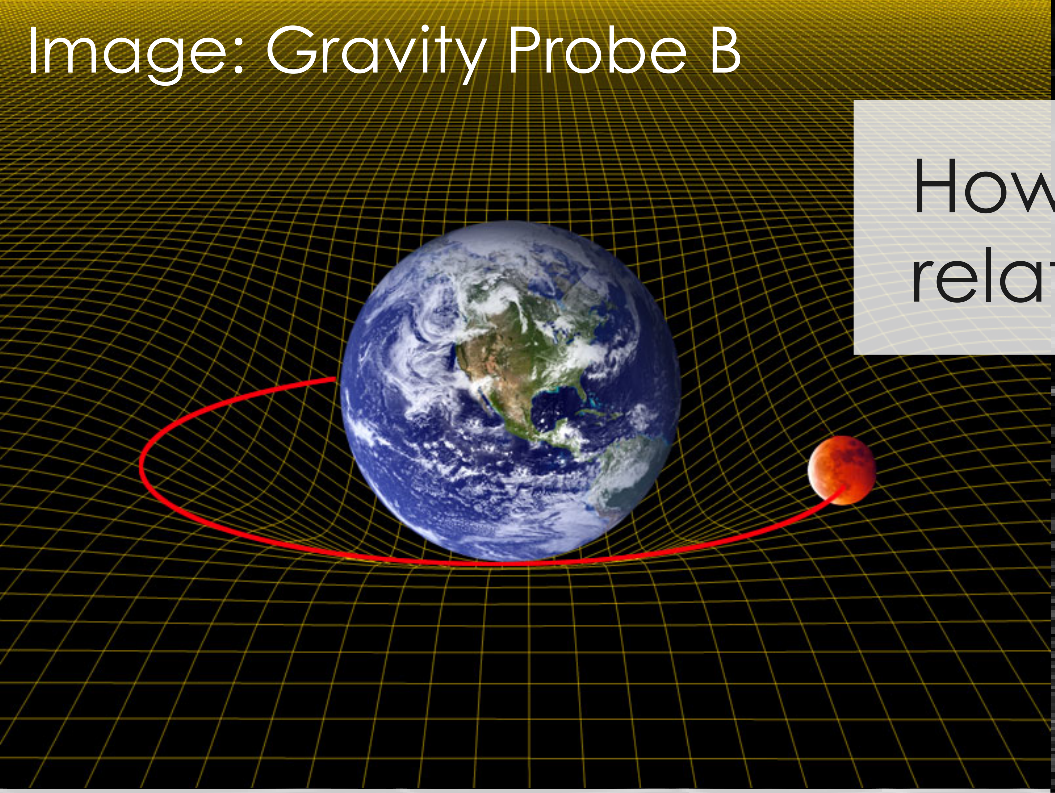


Image: Gravity Probe B

How do we know general relativity is correct?

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

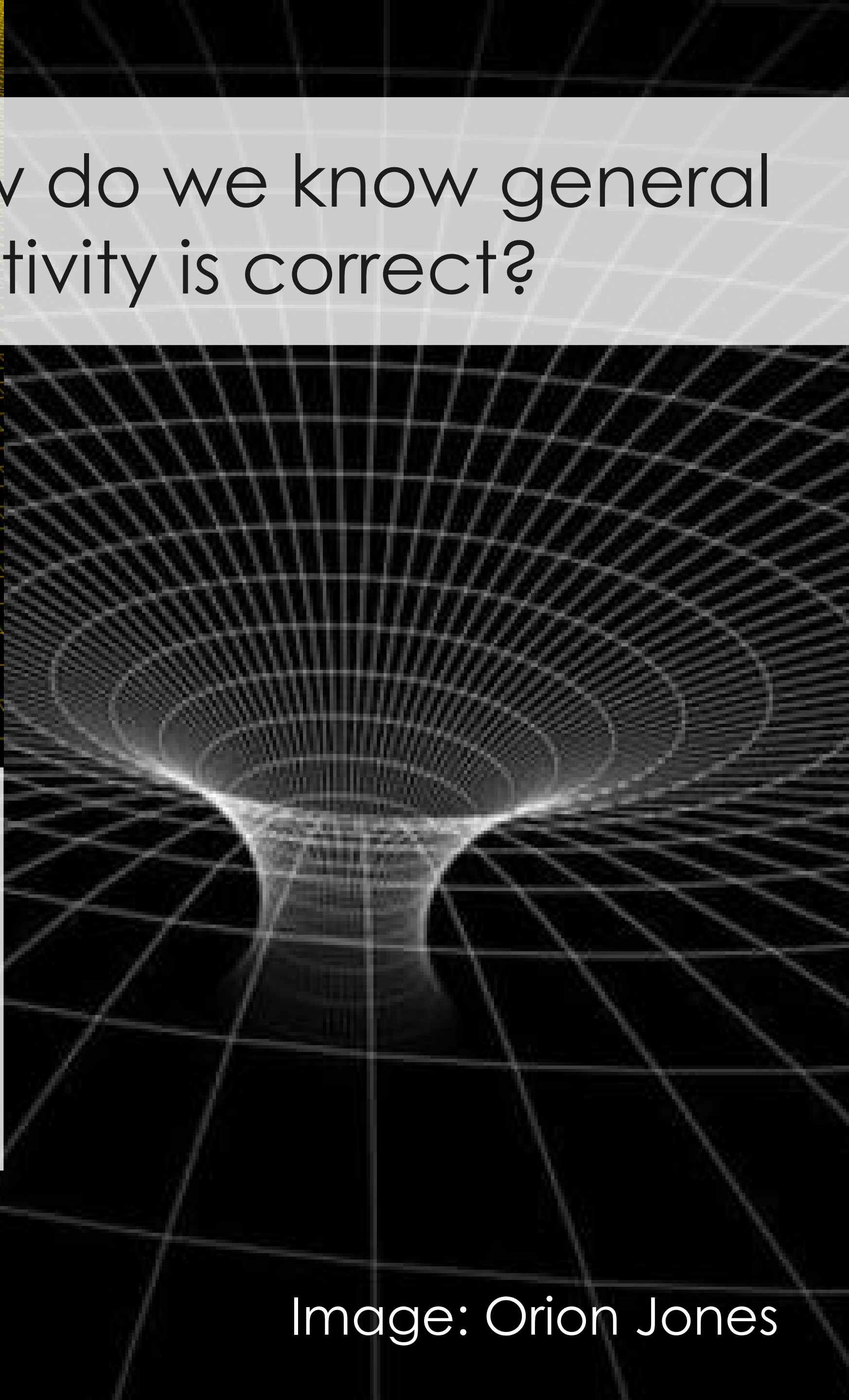


Image: Orion Jones

Testing the wave

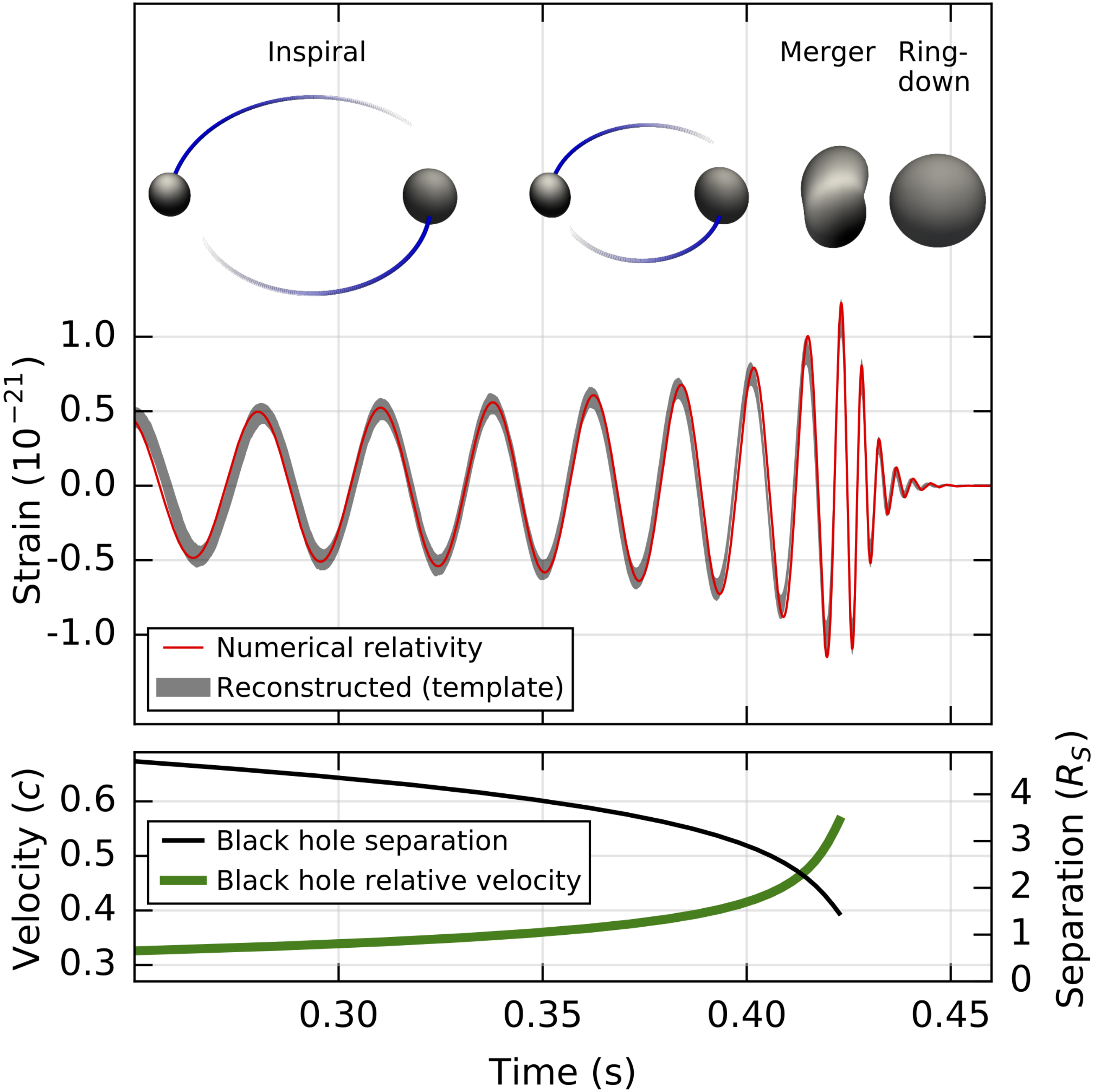
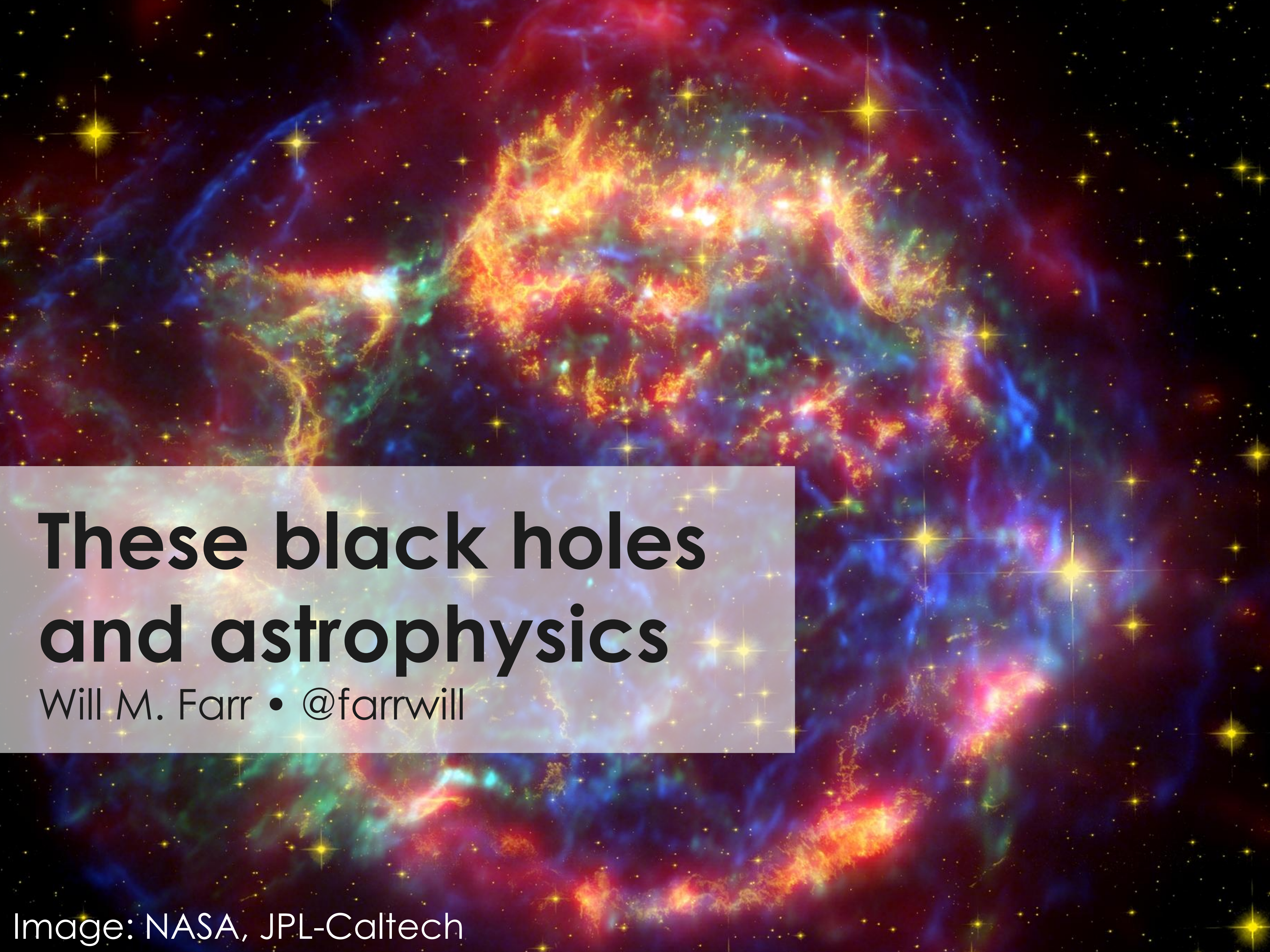


Image: LVC


These black holes
and astrophysics
Will M. Farr • @farrwill
Image: NASA, JPL-Caltech

What we know

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

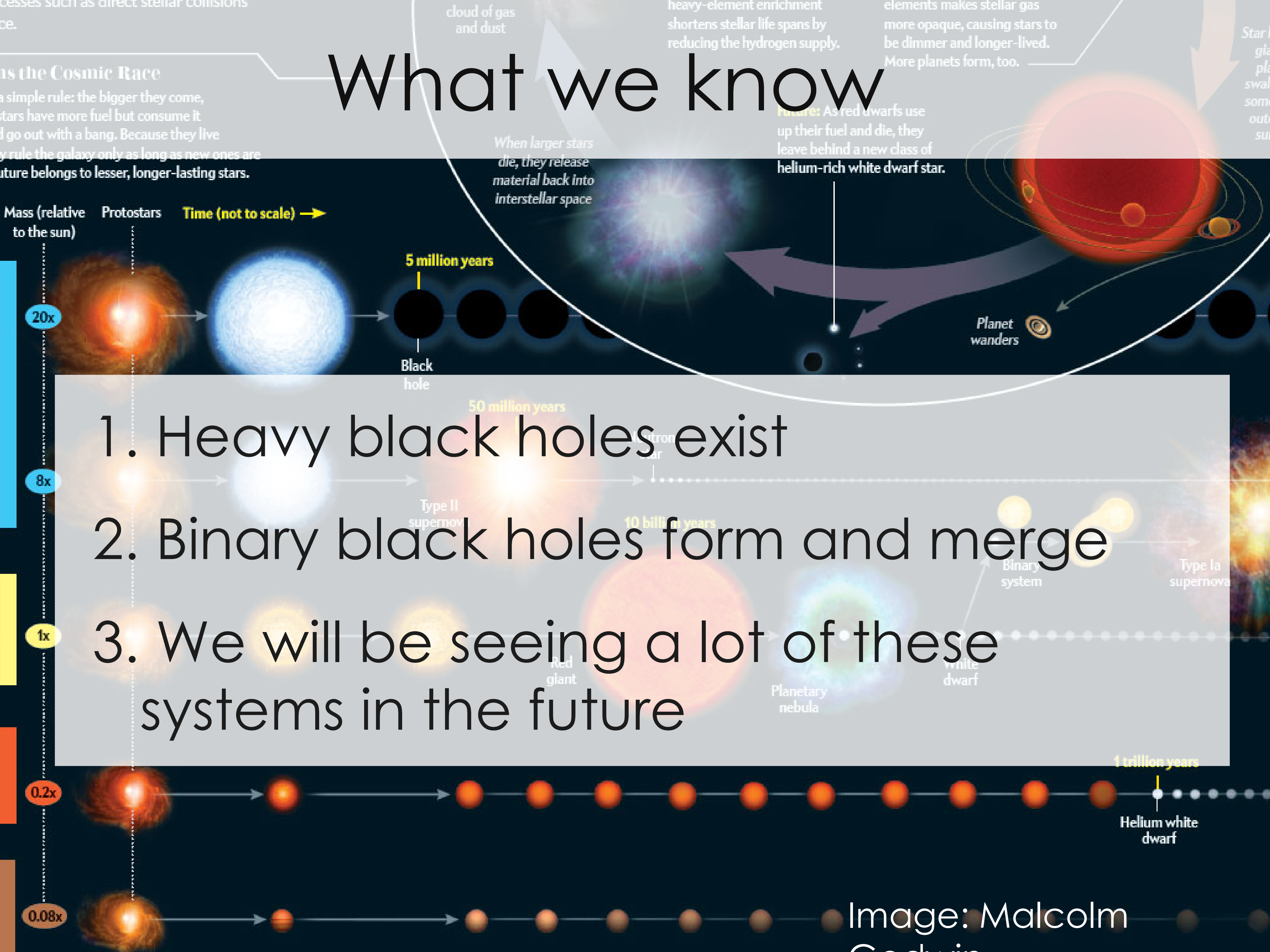


Image: Malcolm Godwin

Image: NASA, C. Reed

Living as a binary

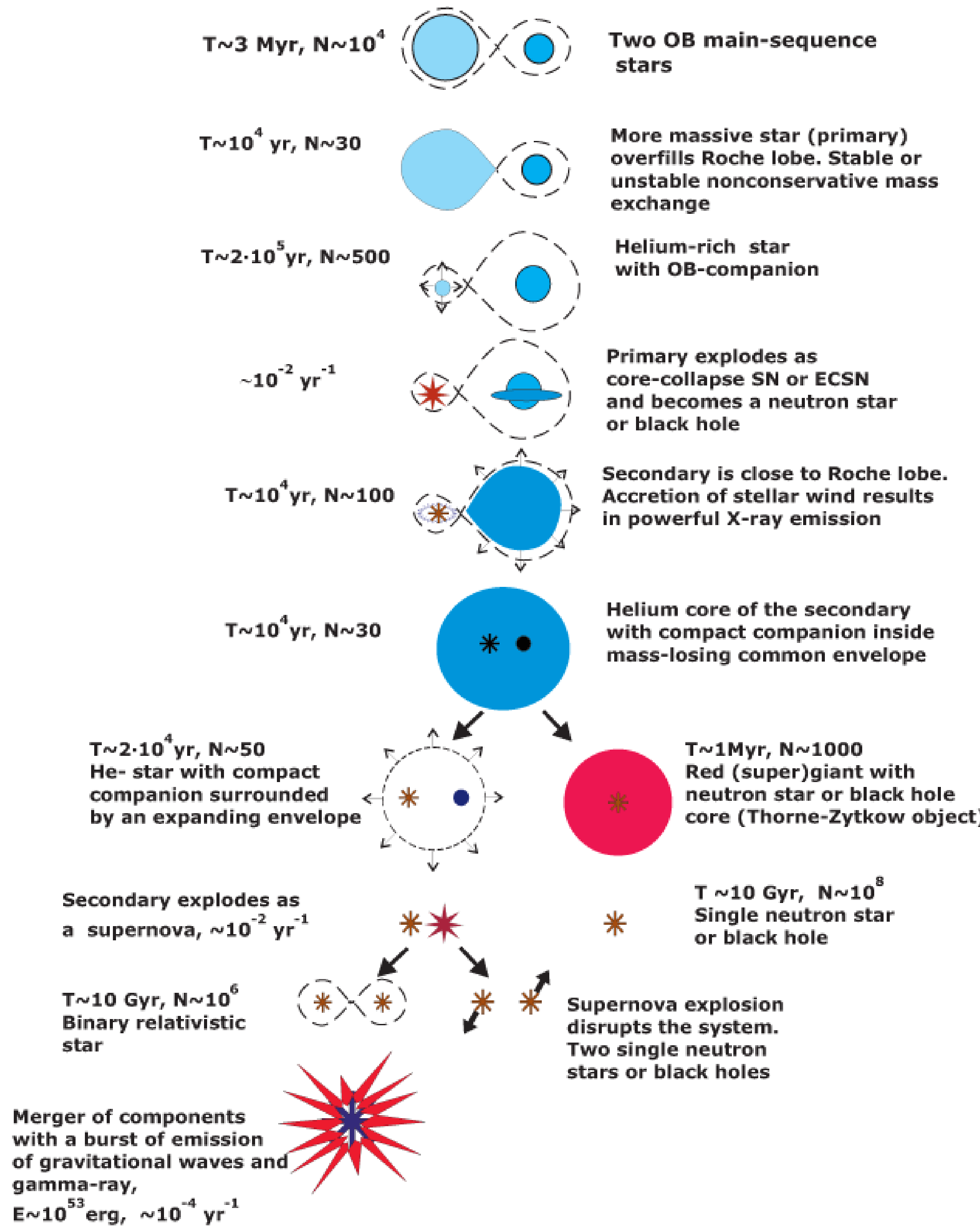


Image: Postnov & Yungelson (2014)

Assembling a binary

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

We will see lots!

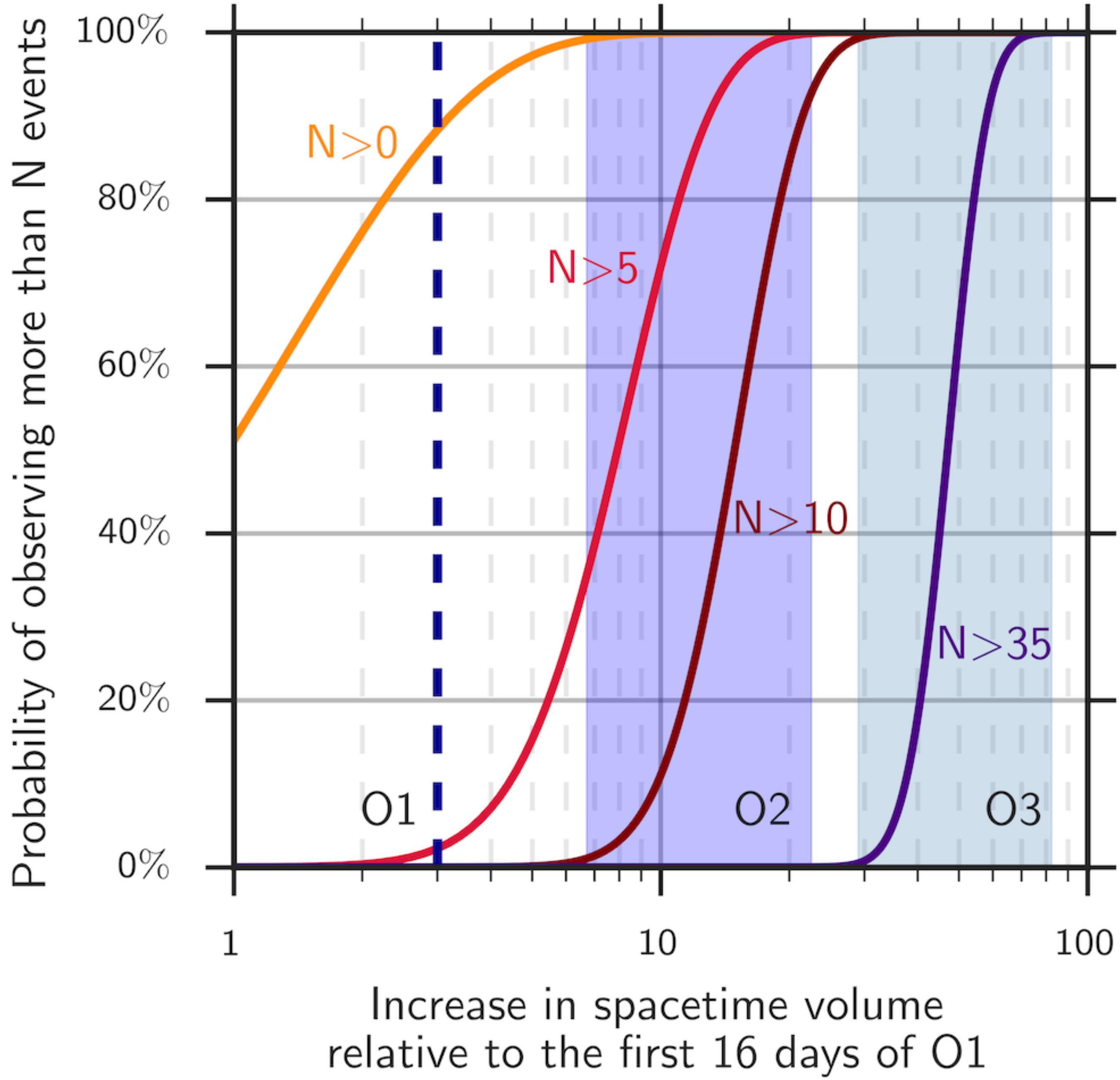
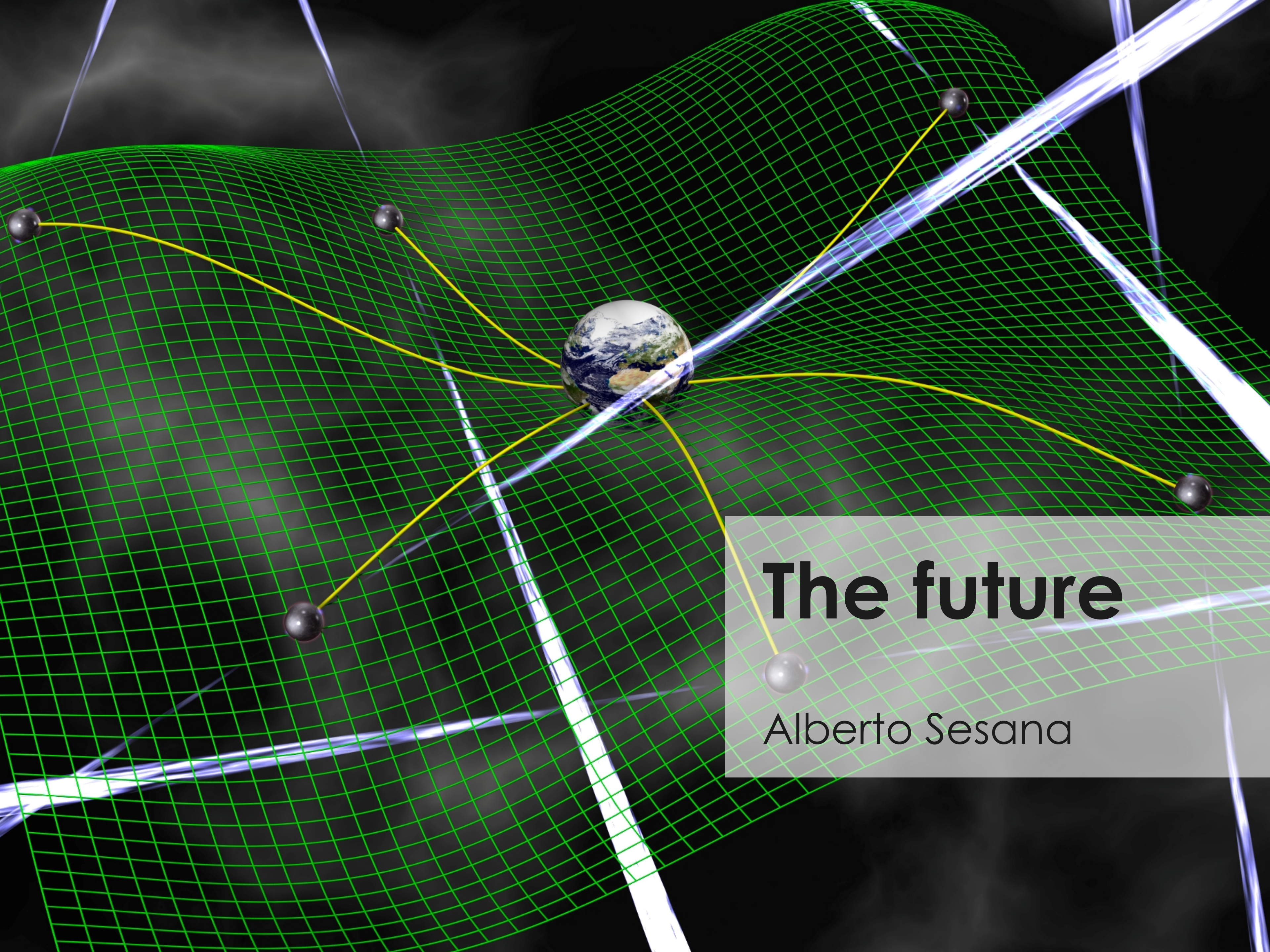


Image: LVC



The future

Alberto Sesana

LIGO is just one window

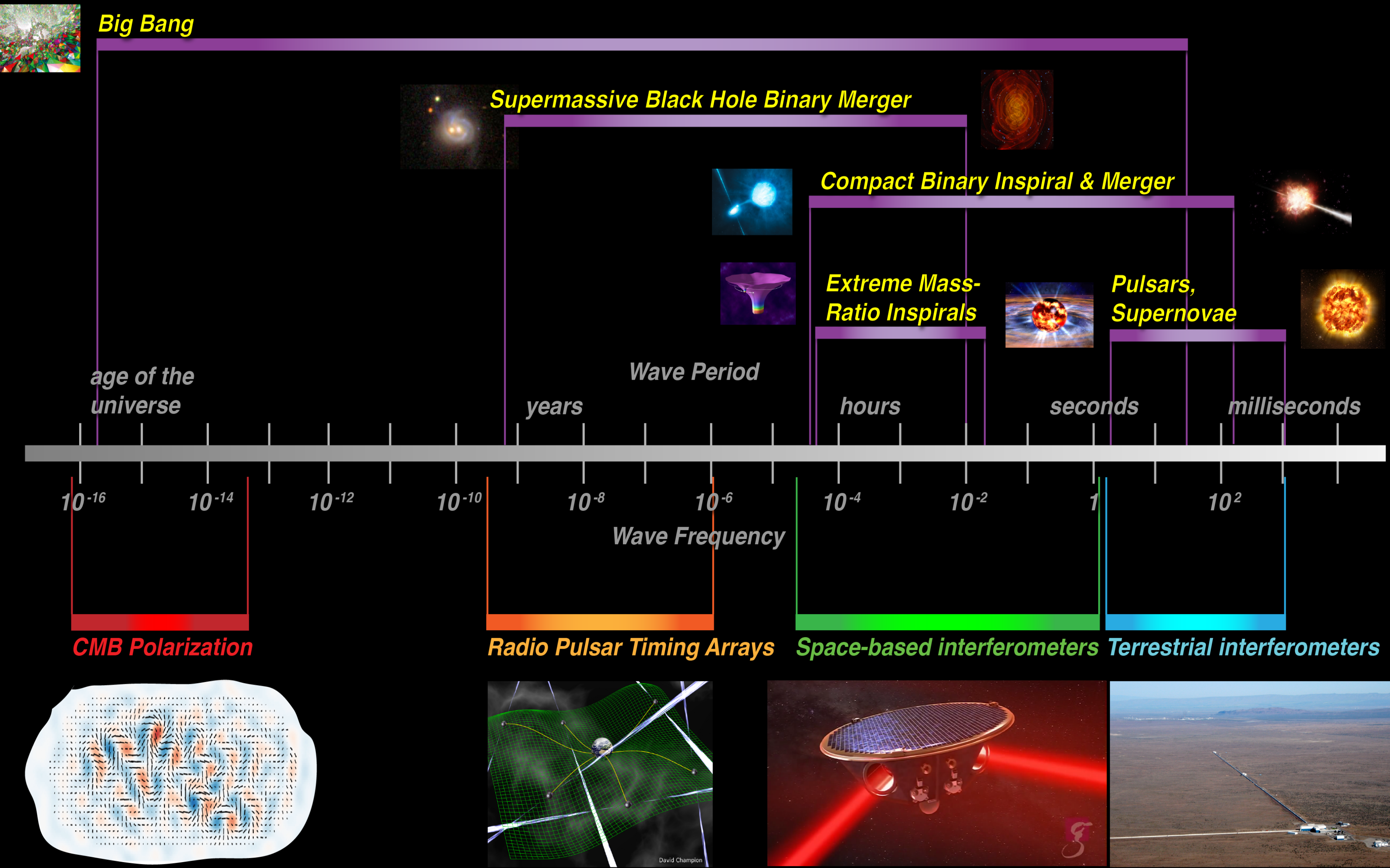


Image: Ira Thorpe

EPTA/LEAP (Europe)

PPTA (Australia)

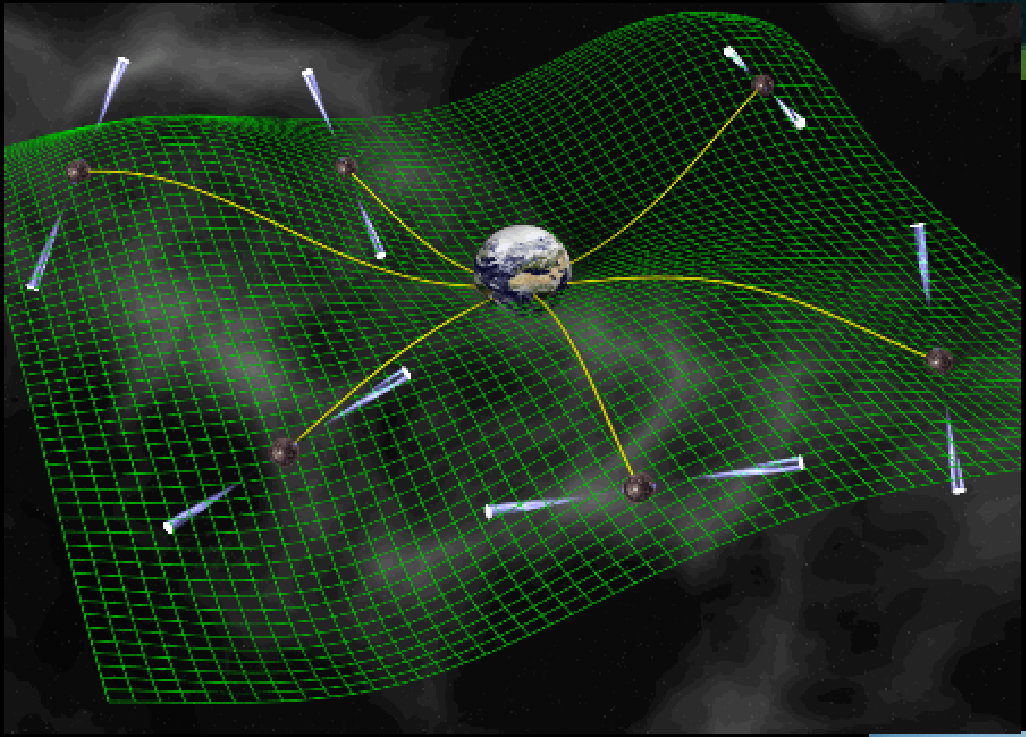
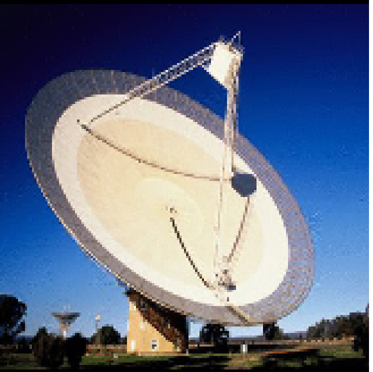


Image: David Champion

NANOGrav (North America)

EPTA/LEAP (Europe)

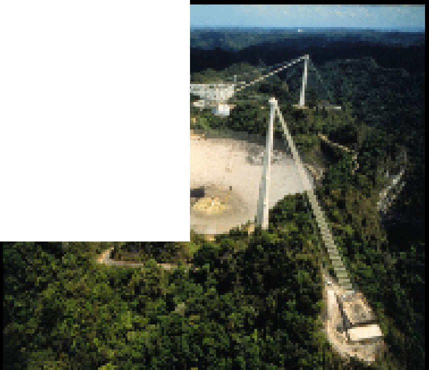


PPTA
(Australi

INTERNATIONAL PULSAR TIMING ARRAY

IPTA

Image:
David
Champion



(North America)

evolving **L**aser **I**nterferometer **S**pace **A**ntenna

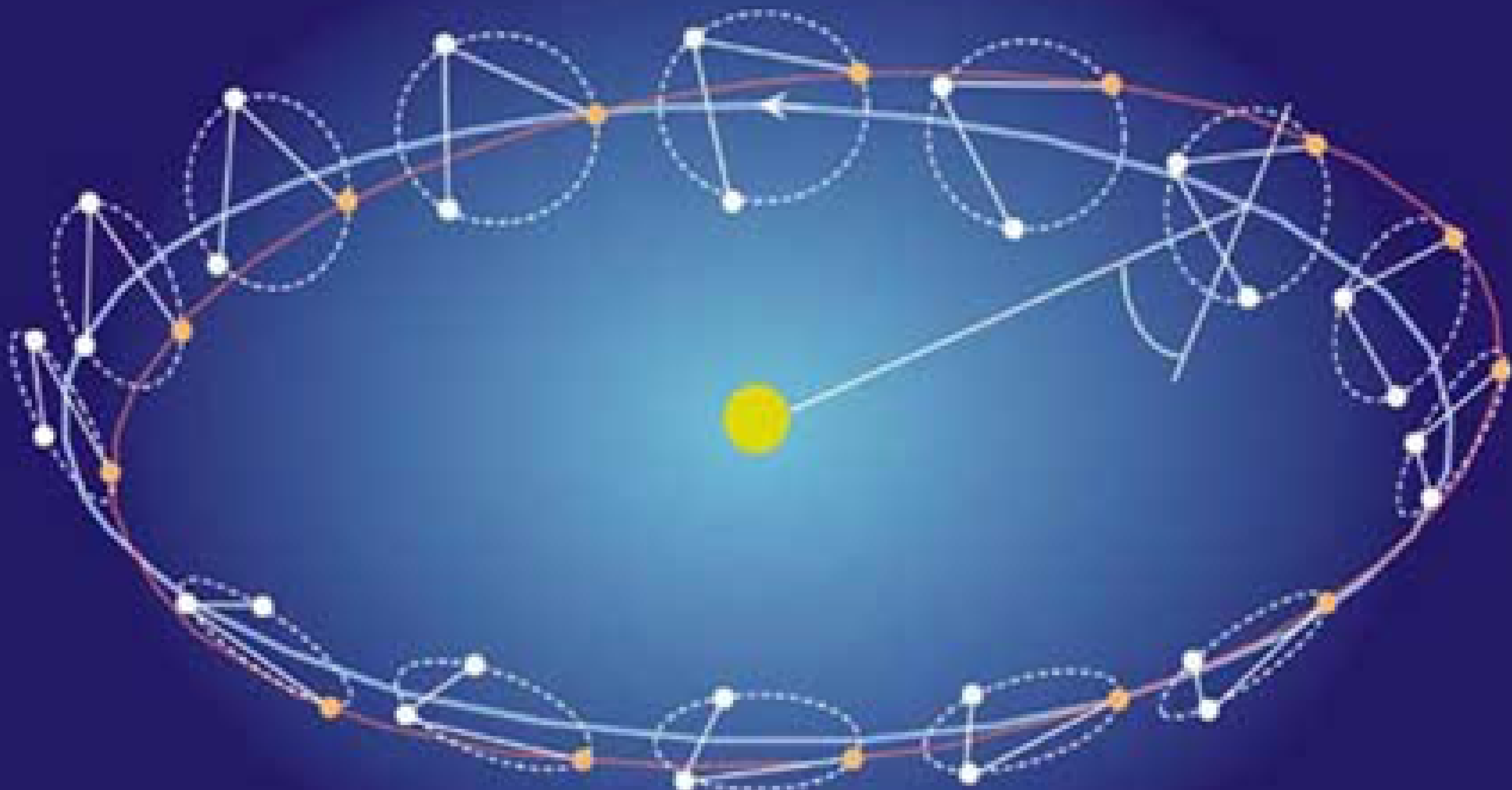
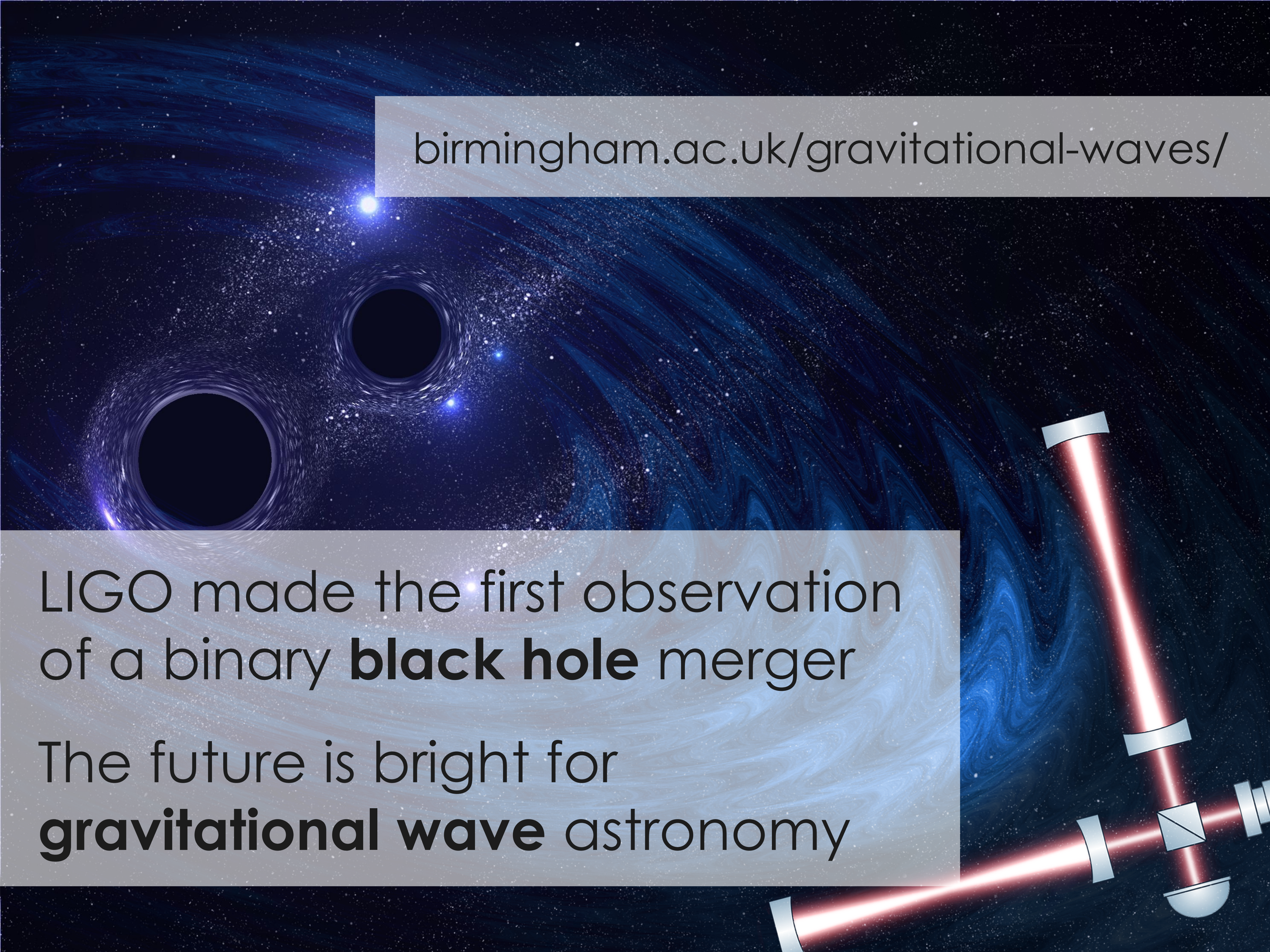


Image: ESA

LISA Pathfinder takes off!

Image: ESA


birmingham.ac.uk/gravitational-waves/
LIGO made the first observation of a binary **black hole** merger
The future is bright for **gravitational wave** astronomy

UNIVERSITY OF BIRMINGHAM

Thank You

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

Visit birmingham.ac.uk/astro-in-the-city for more information

birmingham.ac.uk/gravitational-waves