Somewhere in between astronomy and relativity

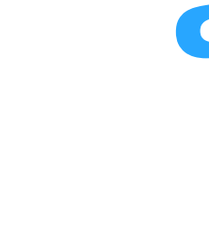
Davide Gerosa

University of Birmingham

January 29th, 2020

Astronomy in the City

Birmingham, UK



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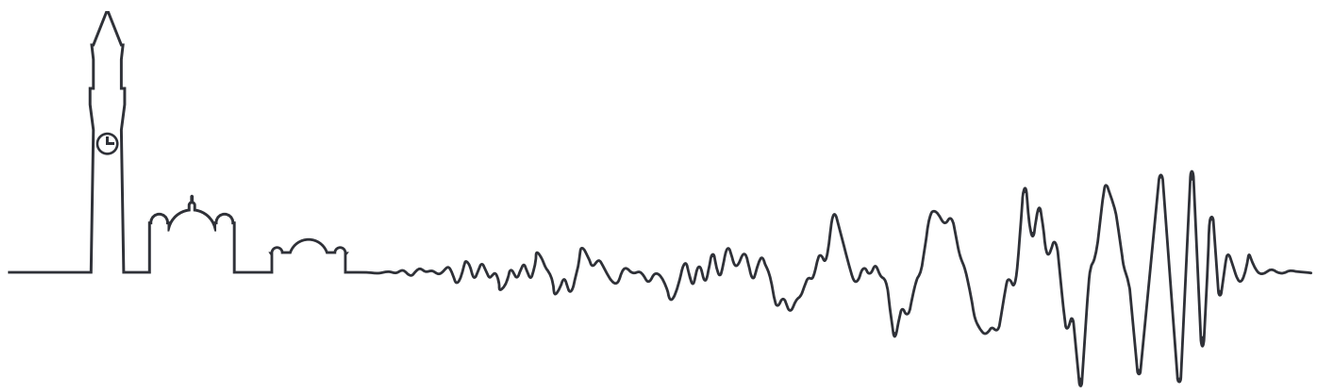
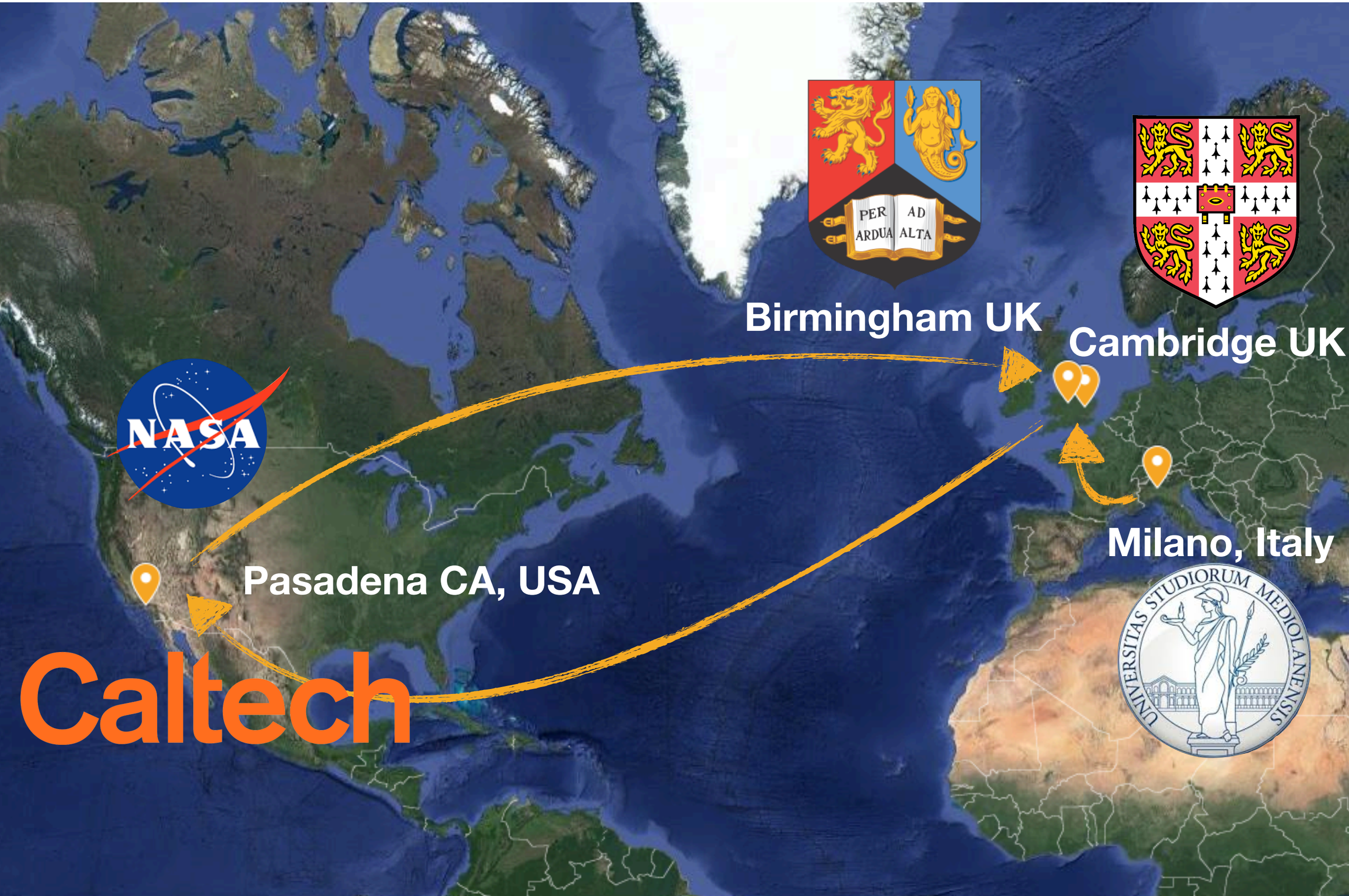


Institute for Gravitational Wave Astronomy

d.gerosa@bham.ac.uk — www.davidegerosa.com

About me


Birmingham UK
Cambridge UK
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Pasadena CA, USA
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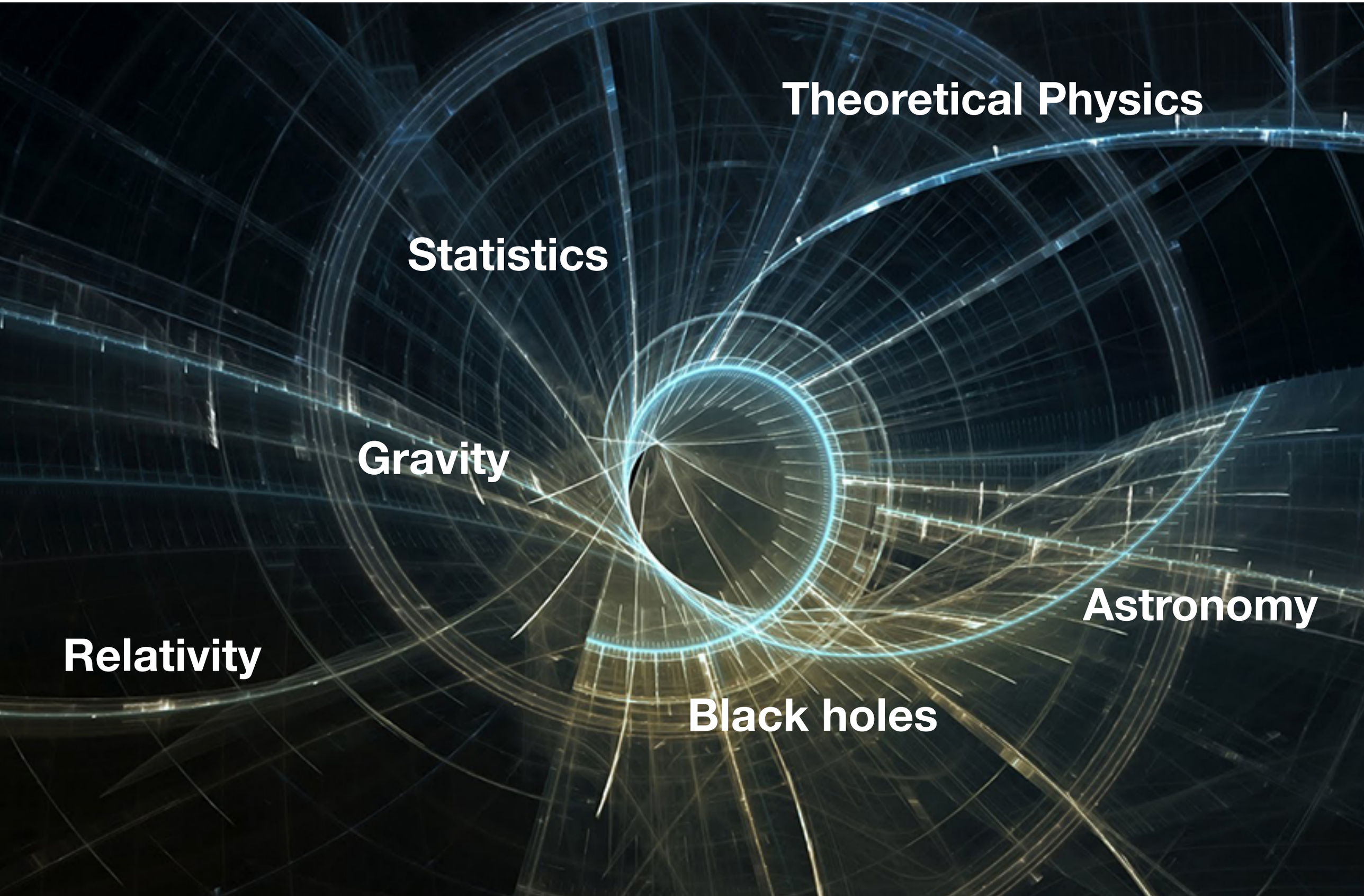
UNIVERSITAS STUDIORUM MEDIOLANENSIS

What I do


Theoretical Physics
Statistics
Gravity
Astronomy
Relativity
Black holes

What do we know about the Universe?

Planets

Stars

The Universe...

Galaxies

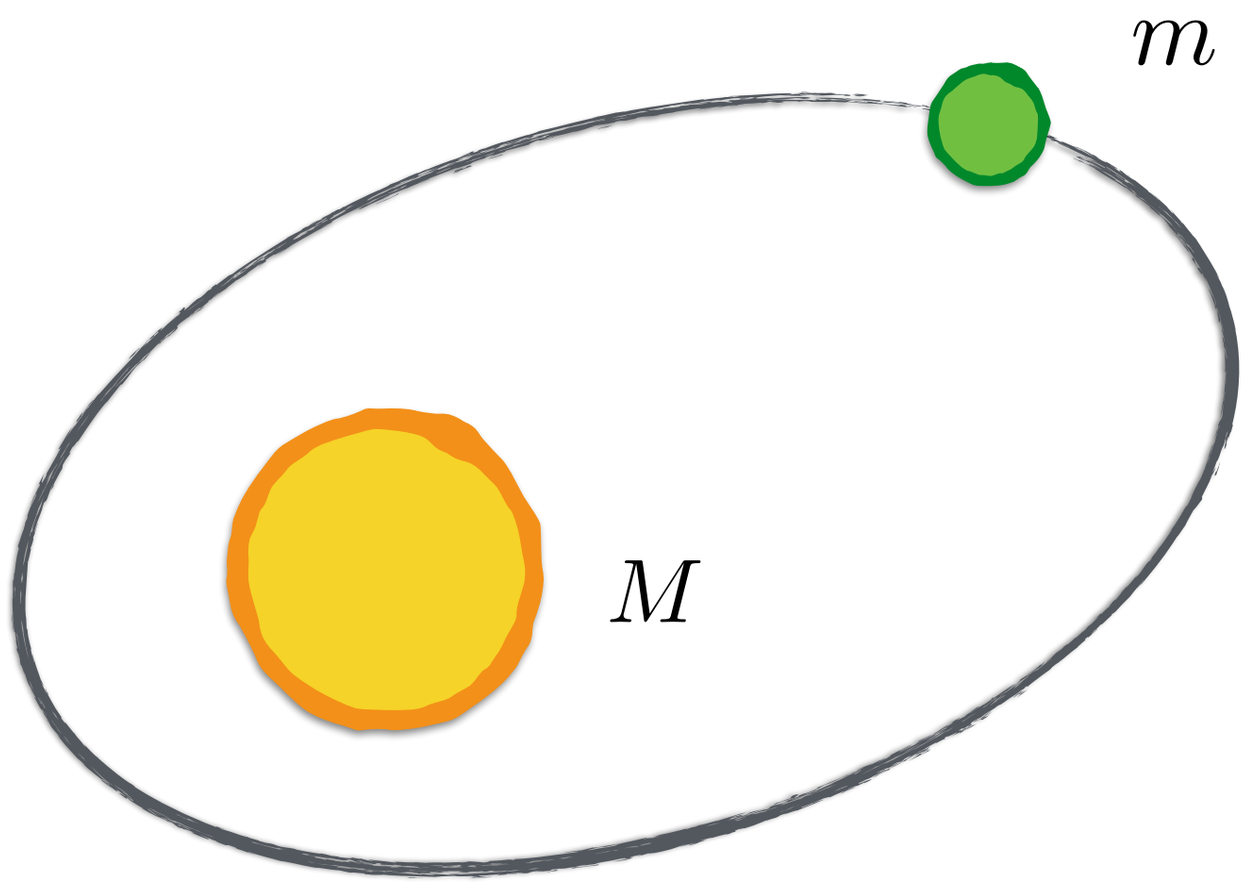
What do we actually see?

Can we use gravity?

Newton's law. It works but…

$$F = m\frac{GM}{r^2}$$

$$T^2 = \frac{4\pi}{GM}r^3$$



The Earth needs to know the mass of the Sun!
How is that possible? Instantaneous action?

What is gravity (really)?
What is the messenger of gravity?

Newton, the man

$$F = ma$$

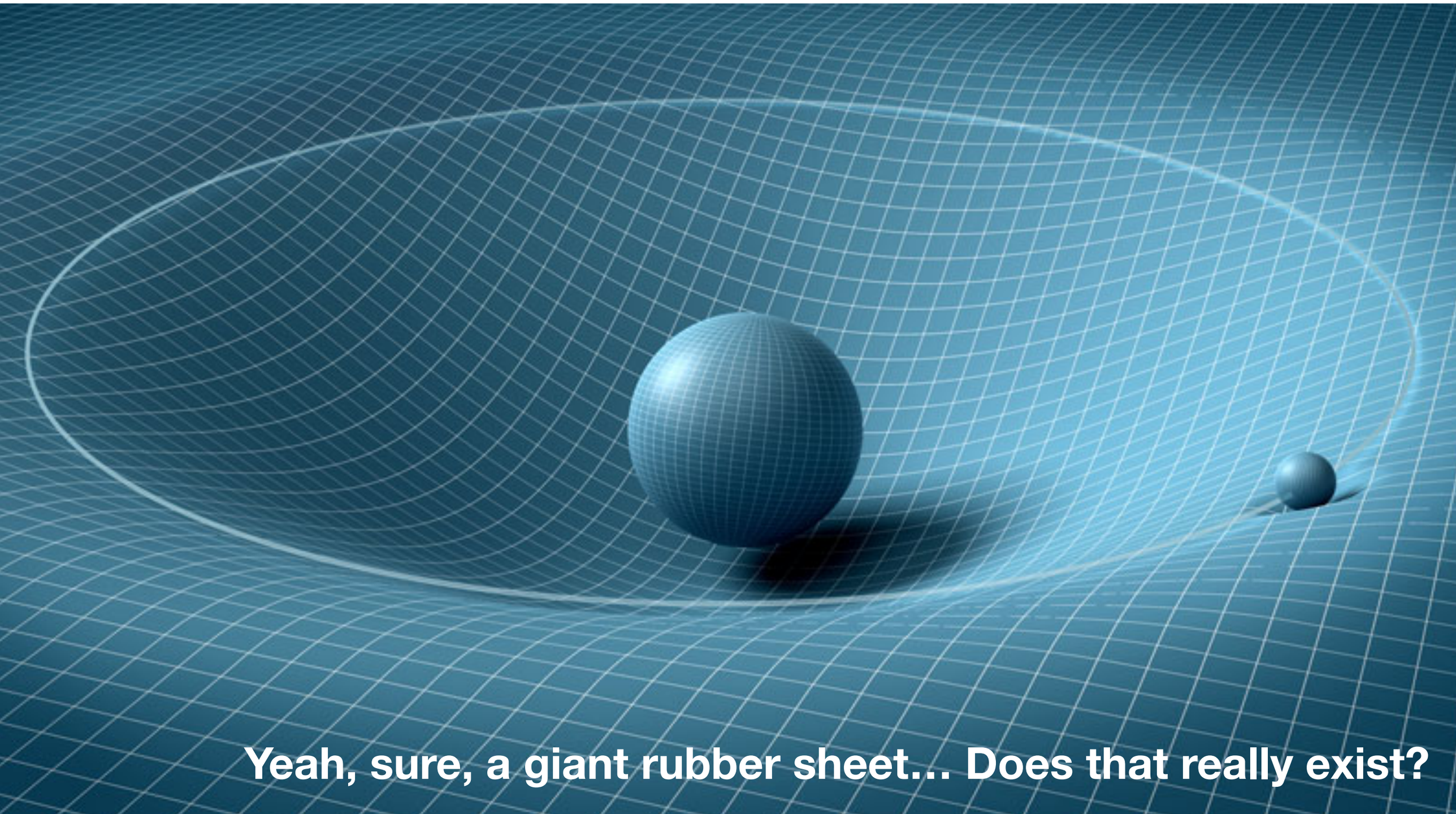
$$F = m\frac{GM}{r^2} \longrightarrow a = \frac{GM}{r^2}$$

Gravity is not a force!

compare to: $F = q\frac{kQ}{r^2}$

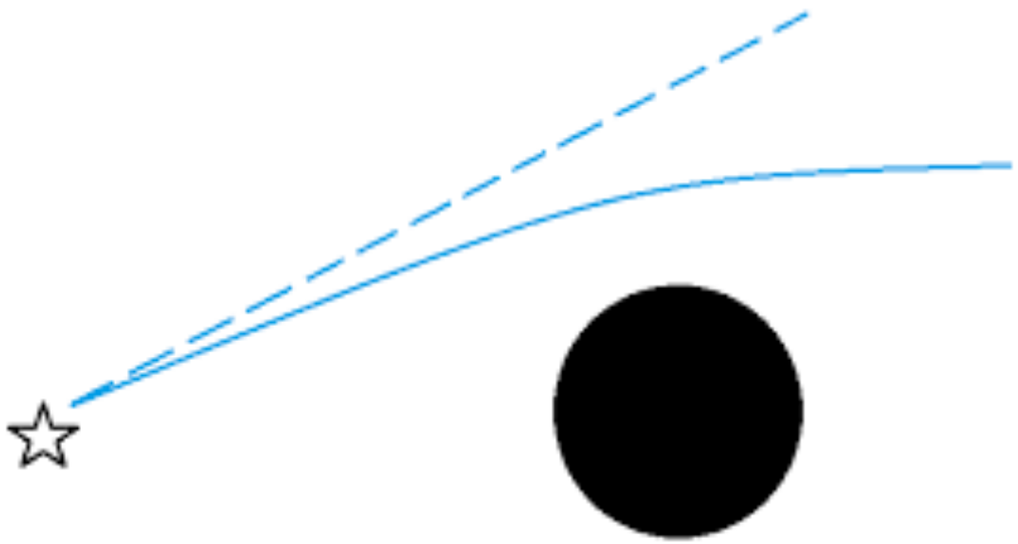
Einstein, the man

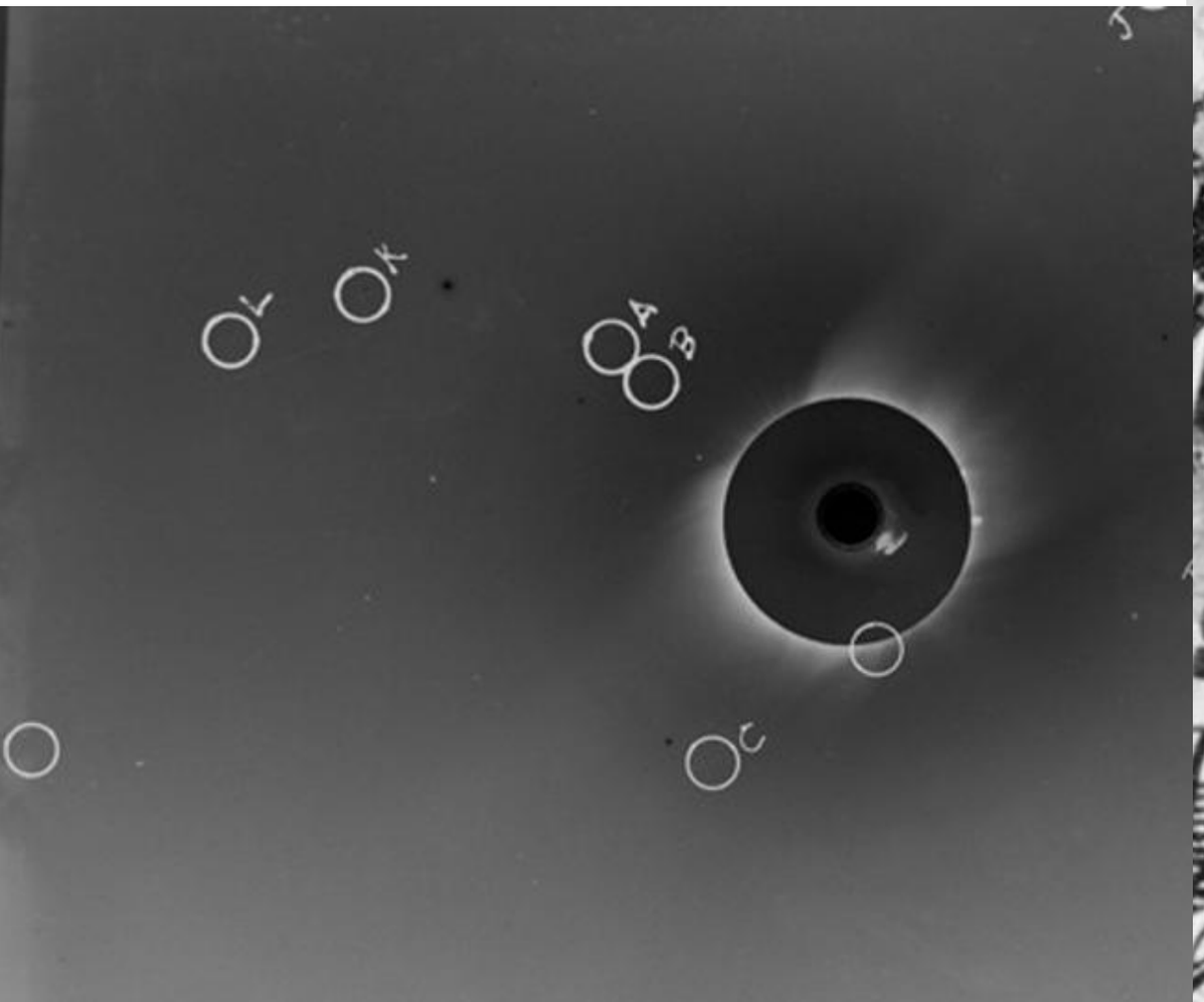
Mass (which is energy by the way) deforms space and time.
Gravity is inertia on a curved spacetime

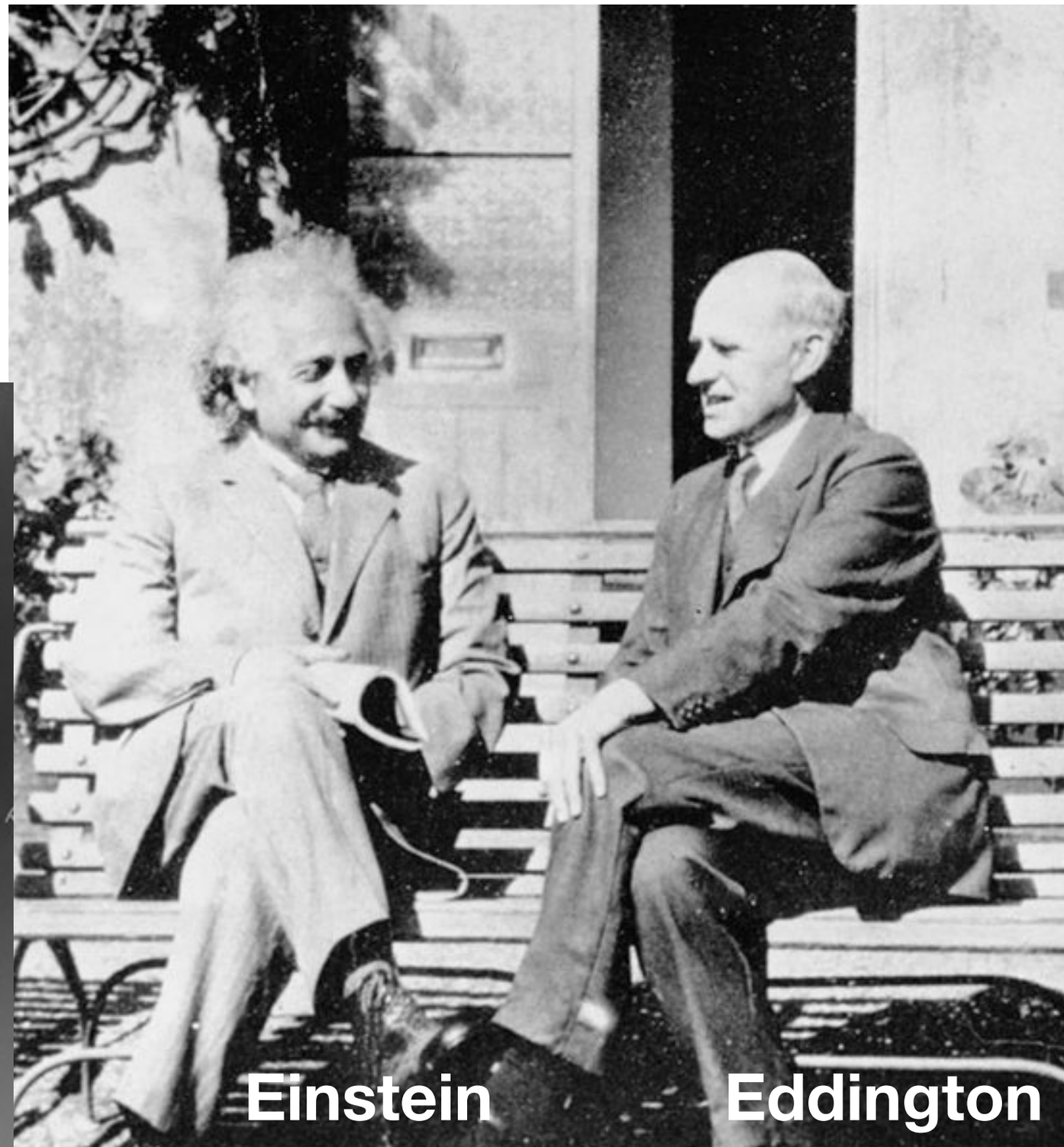


Yeah, sure, a giant rubber sheet… Does that really exist?

Eddington expedition (1919)







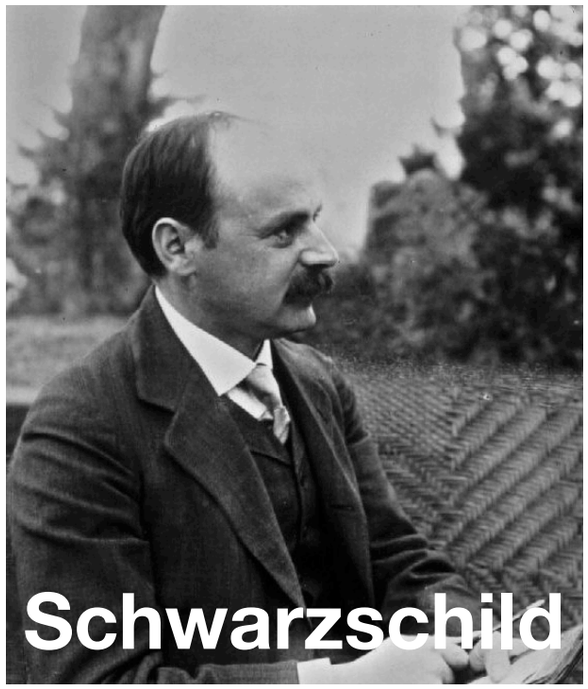
Einstein Eddington

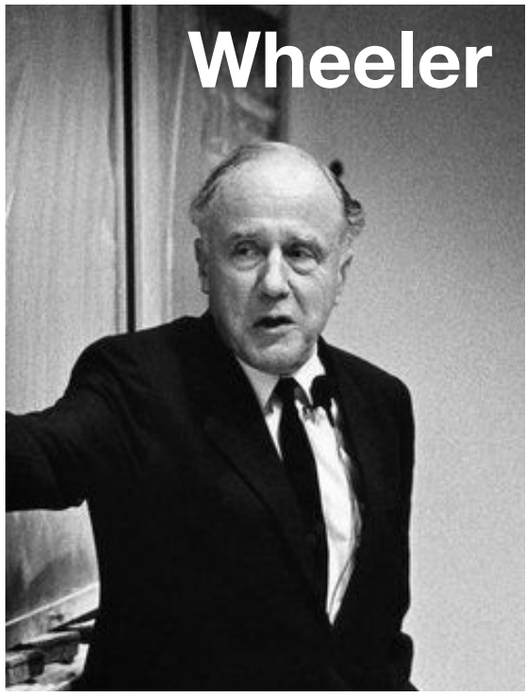
Black holes

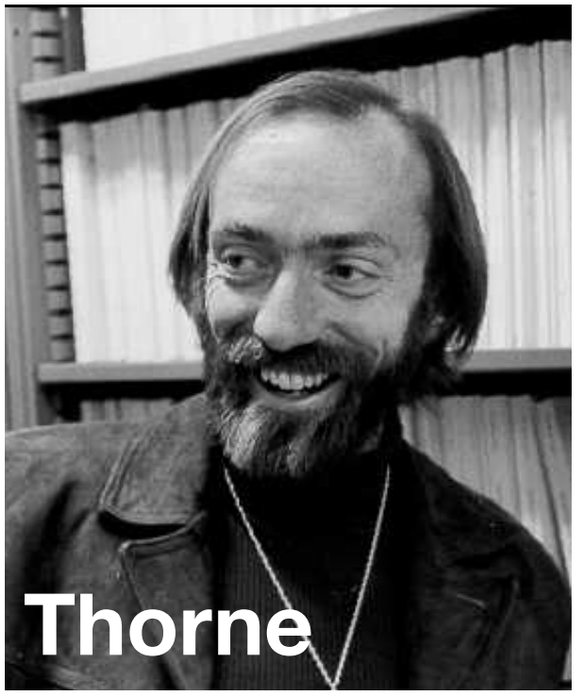
Regions of spacetime so compact not even light can escape. Sun in 1km

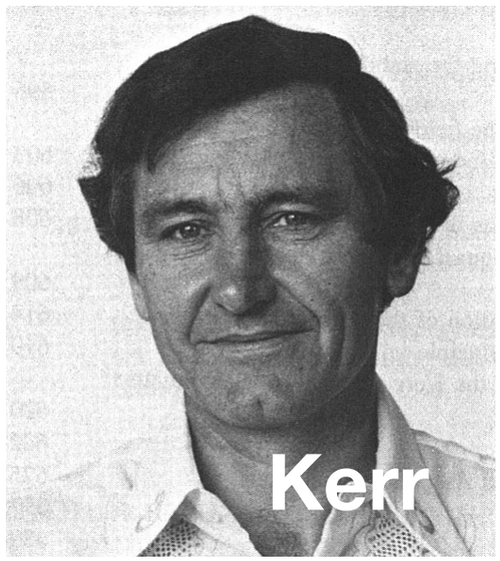
Neutron stars

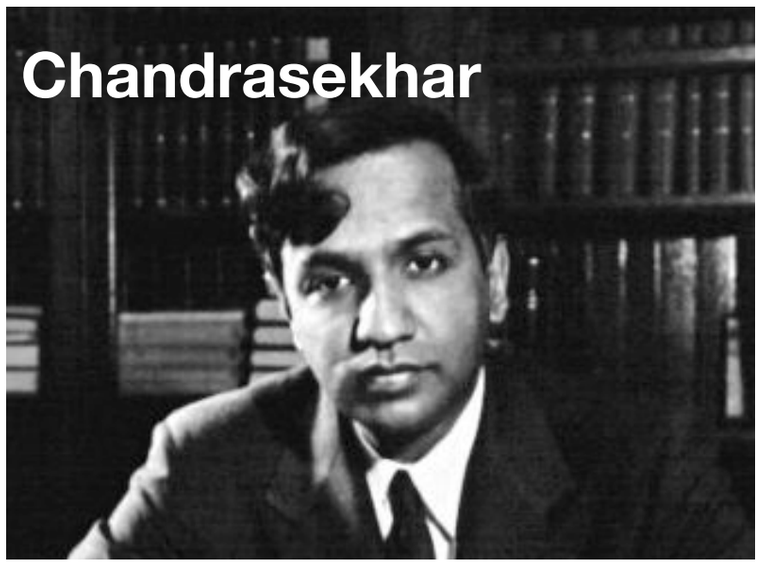
Basically a giant nucleus. Sun in 10km

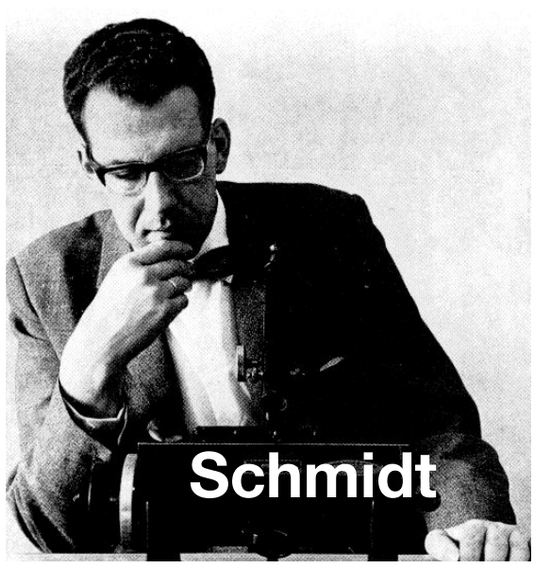


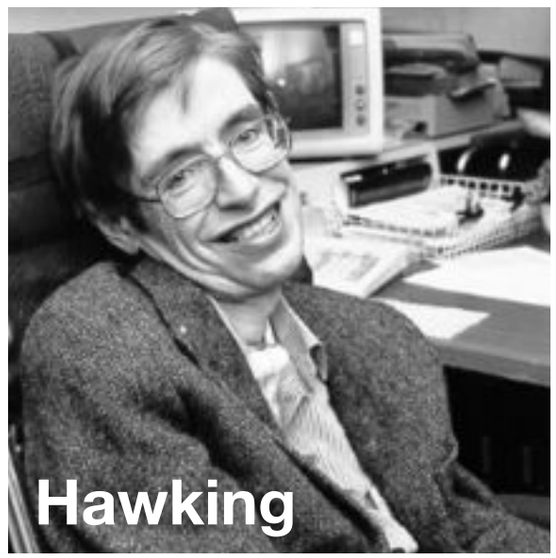




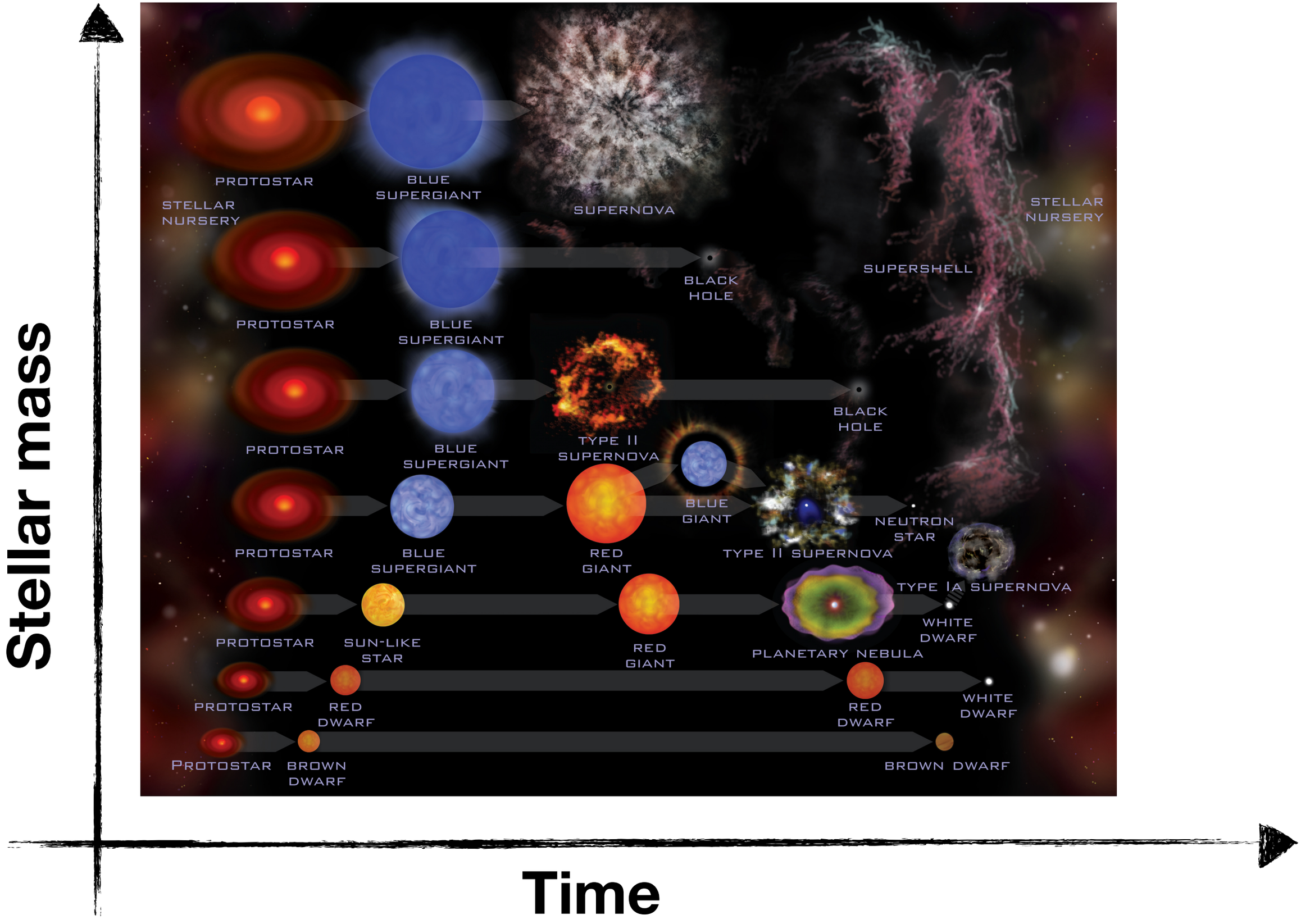




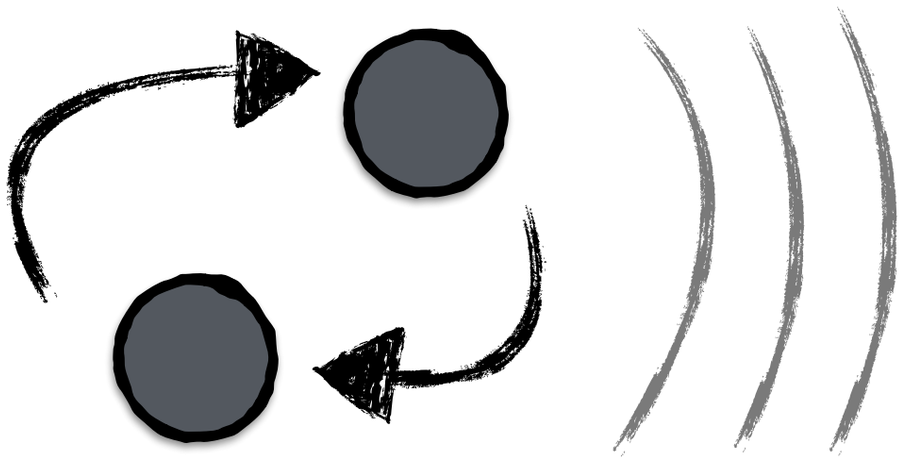




The stellar graveyard



How about two of them?



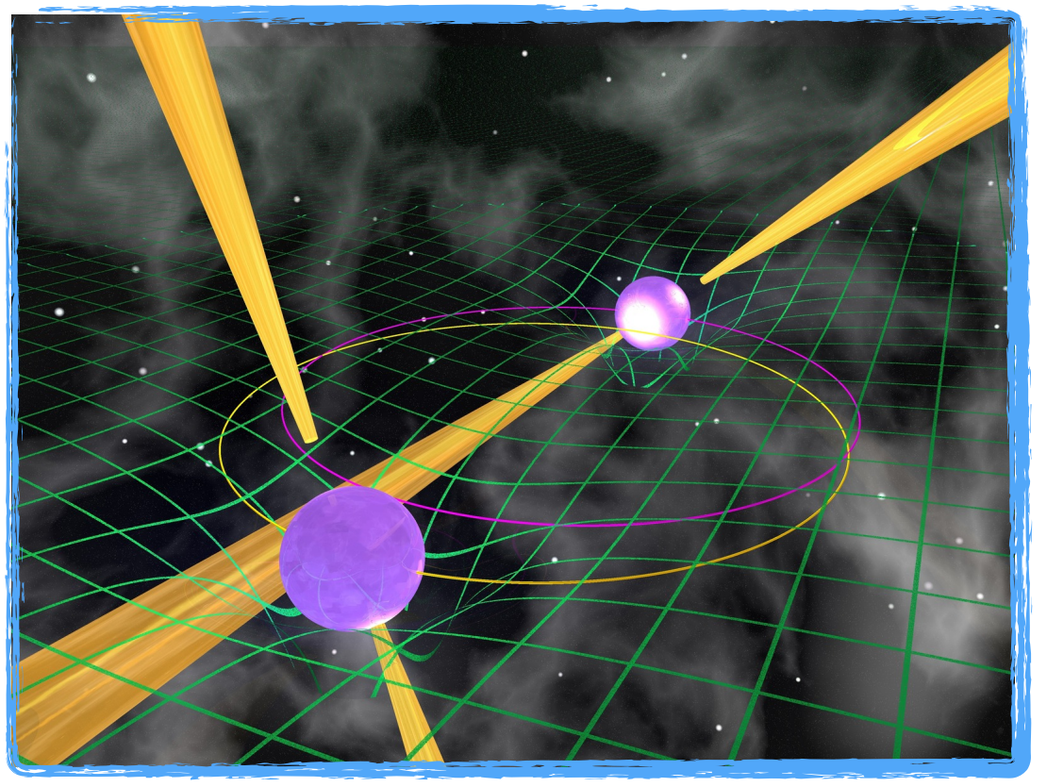
Emission of gravitational waves

Dissipation of energy and angular momentum

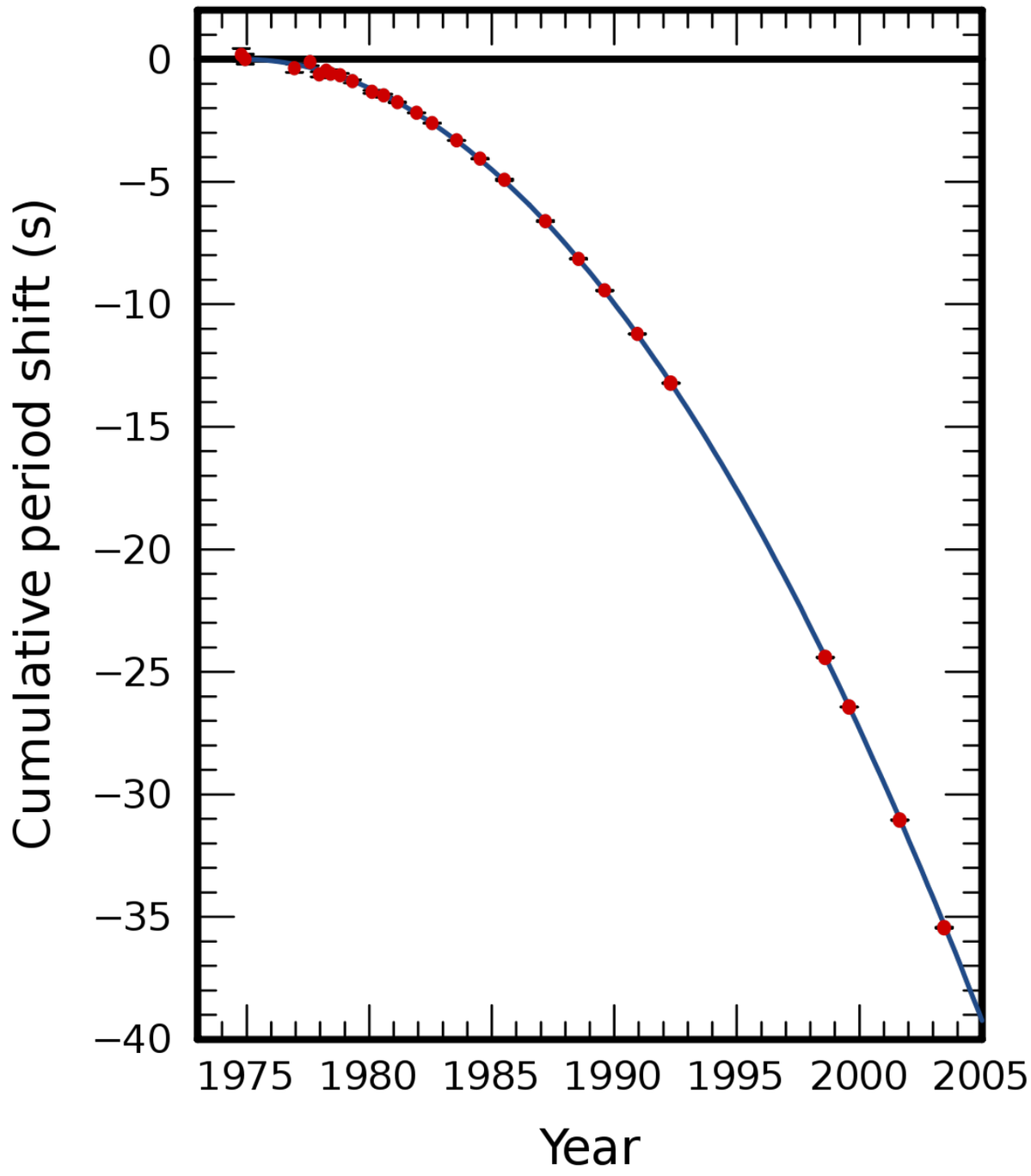
Newton’s third law

The orbit must shrink!

Hulse-Taylor pulsar

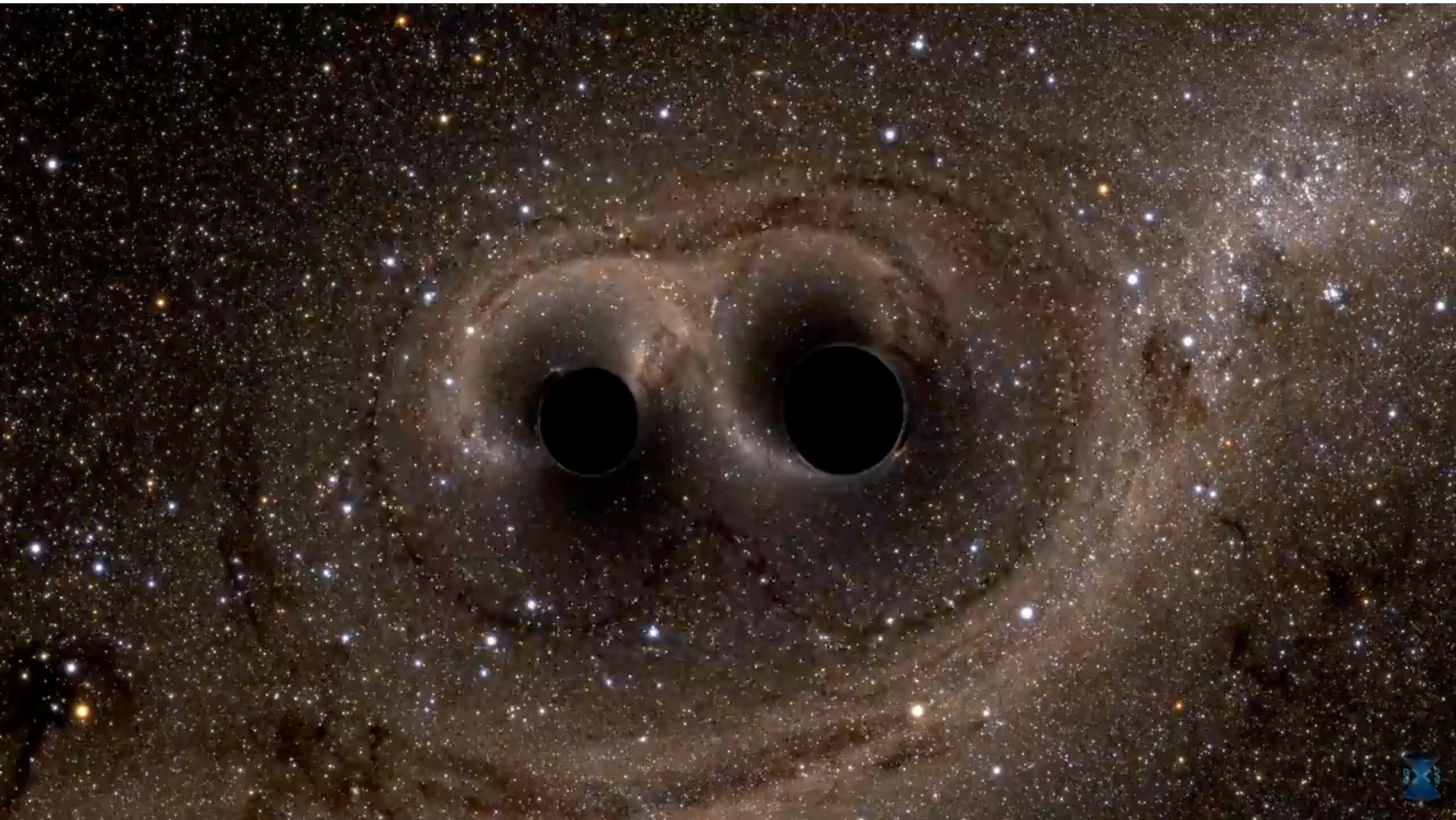


1993 Nobel prize



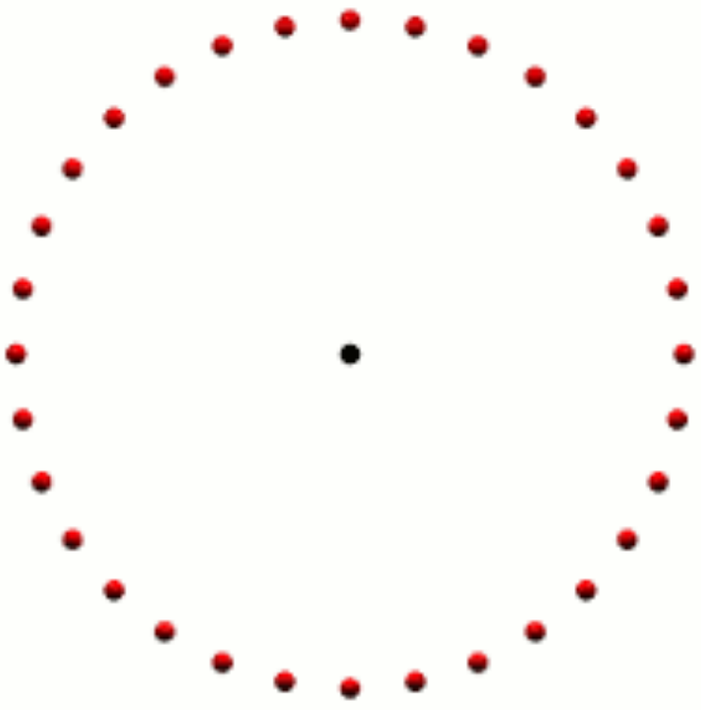
Black hole dance

Two black holes merging into one, on a stellar background



Ripples in the fabric of spacetime

Gravitational-wave propagation



Effect of a GW on a ring of masses

Gravitational-wave emission

strain $h \sim \dfrac{Mv^2}{r} \sim \dfrac{\Delta L}{L}$ measurement

mass, velocity, distance, detector

Binary cars?

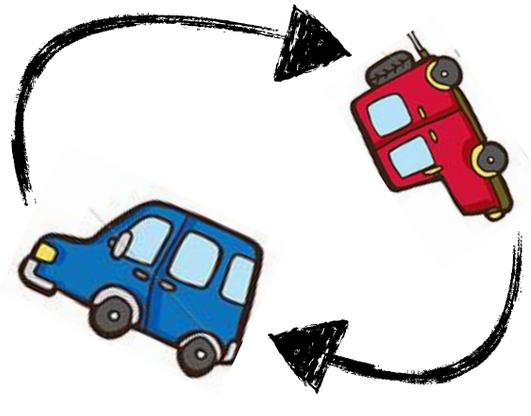
$M \sim 10^3 \mathrm{Kg}$

$v \sim 1000\,\mathrm{Km/h}$

on a 1 km track

$r \sim \lambda \sim R_{\mathrm{Earth}}$

$h \sim 10^{-42}$



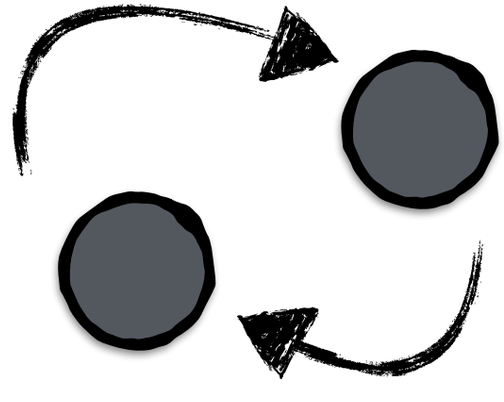
Binary black holes!

$M \sim 10 M_\odot \sim 10^{31} \mathrm{Kg}$

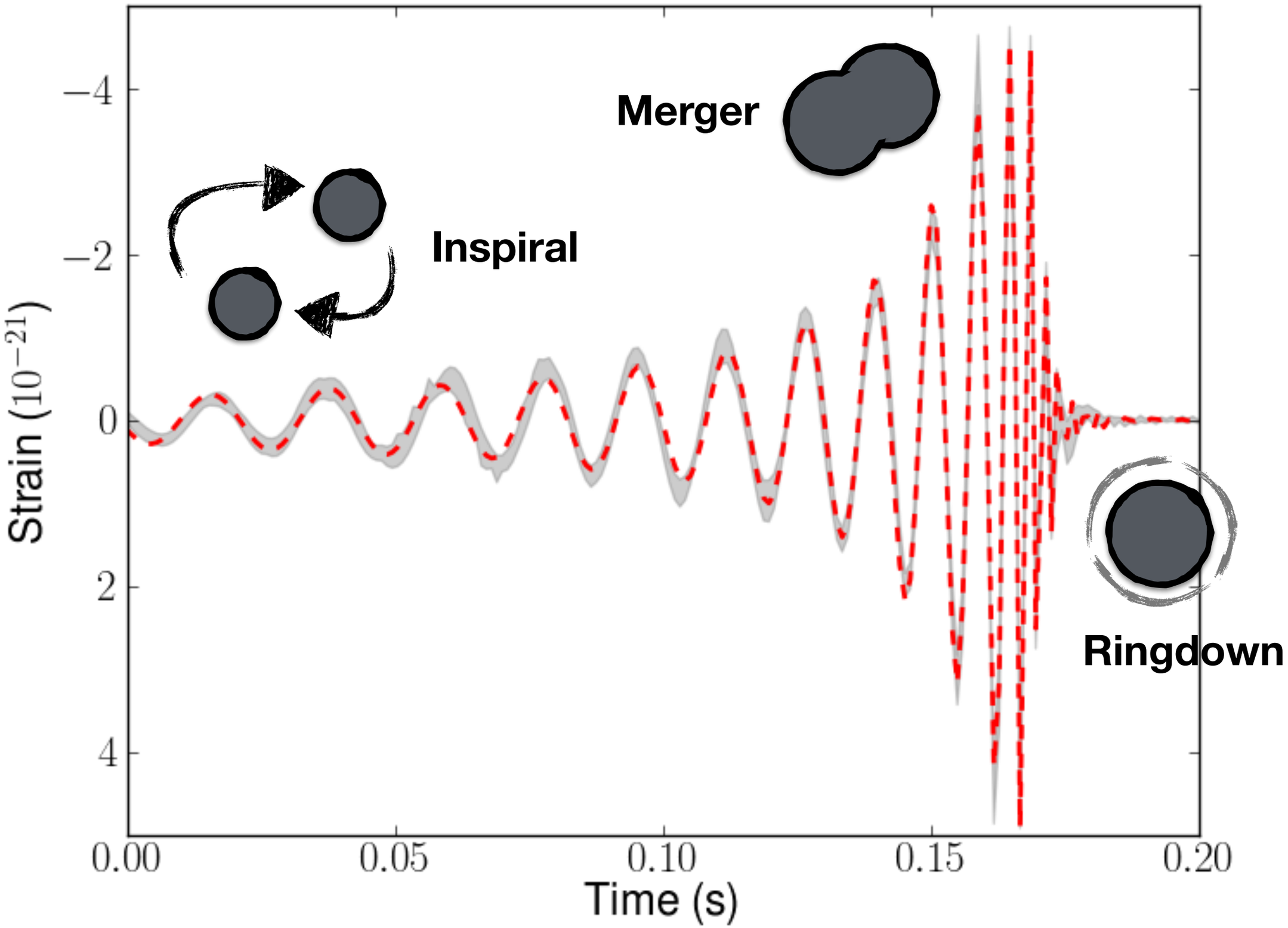
$v \sim 0.1c$

$r \sim 100\,\mathrm{Mpc}$

$h \sim 10^{-21}$



The signal we are after



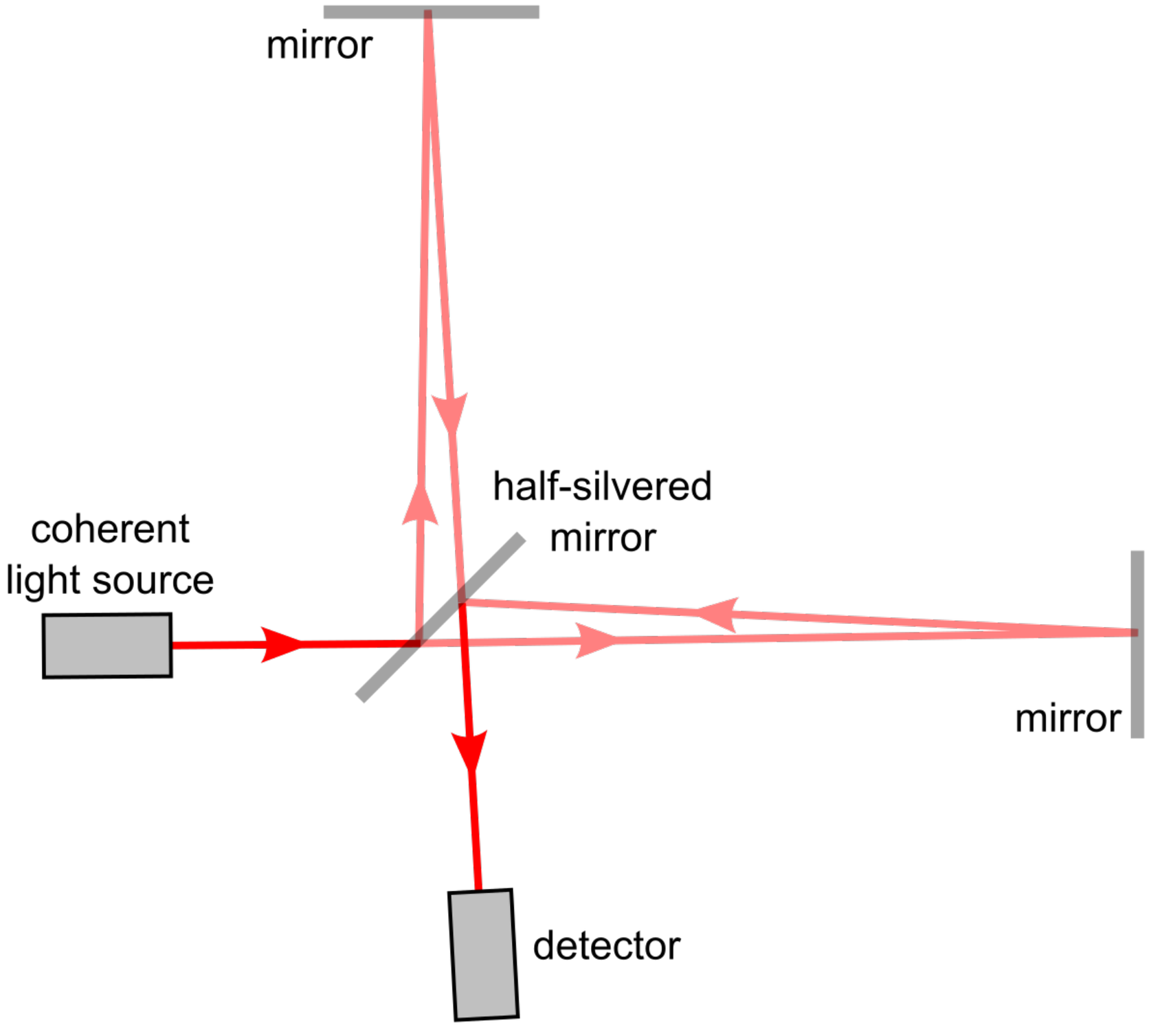
No worries we “just” need a precision of

0.00000000000000000000001

Pioneering GW detectors

First experimental attempt: 1960s, bar detector in Maryland

Lasers to detect gravity



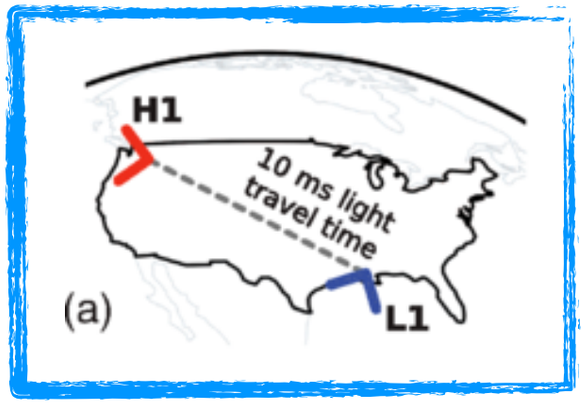
LIGO and Virgo on Google Maps

VIRGO Italy

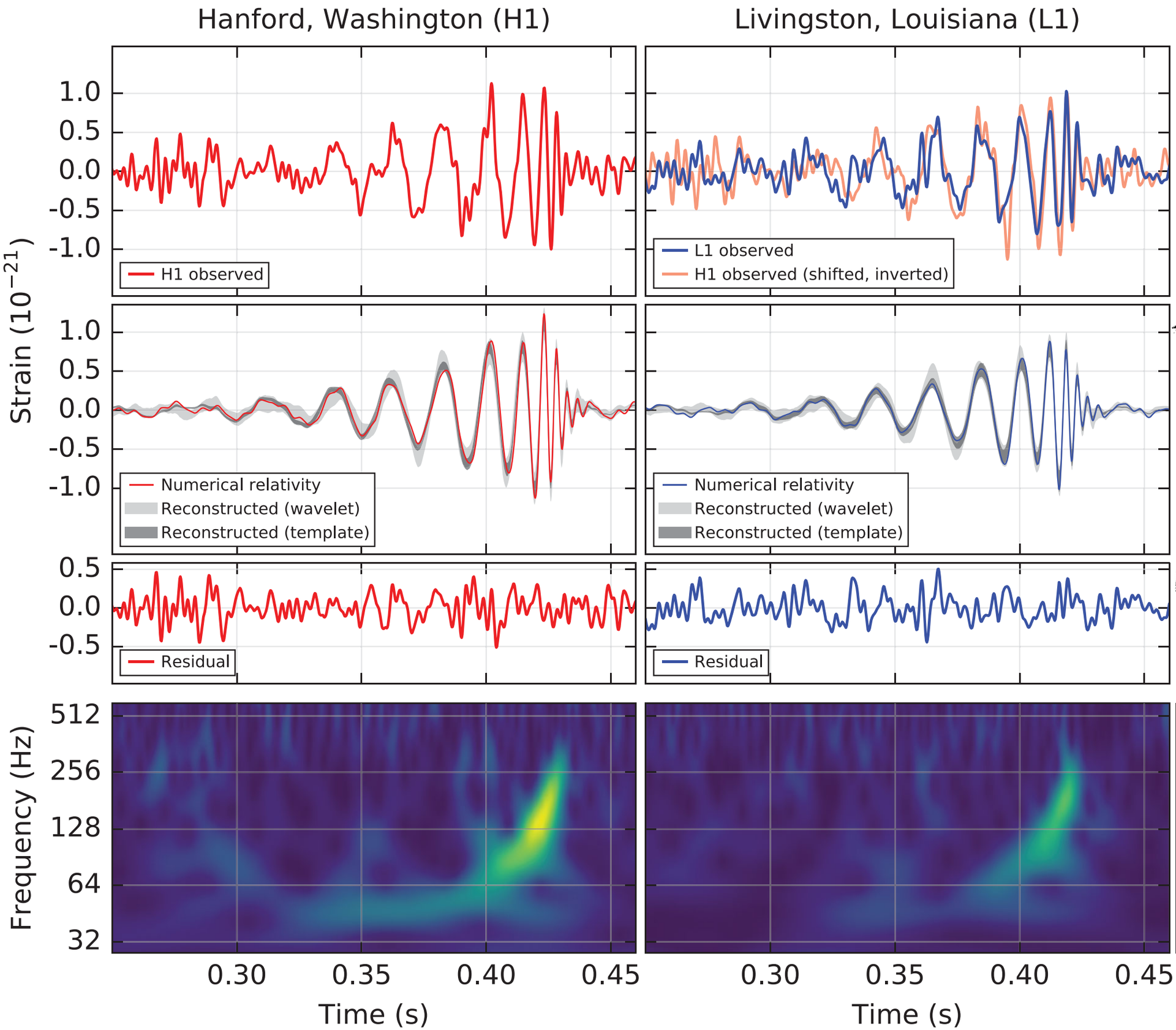
LIGO Lousiana

LIGO Washington

The LIGO twins



It all begun with GW150914



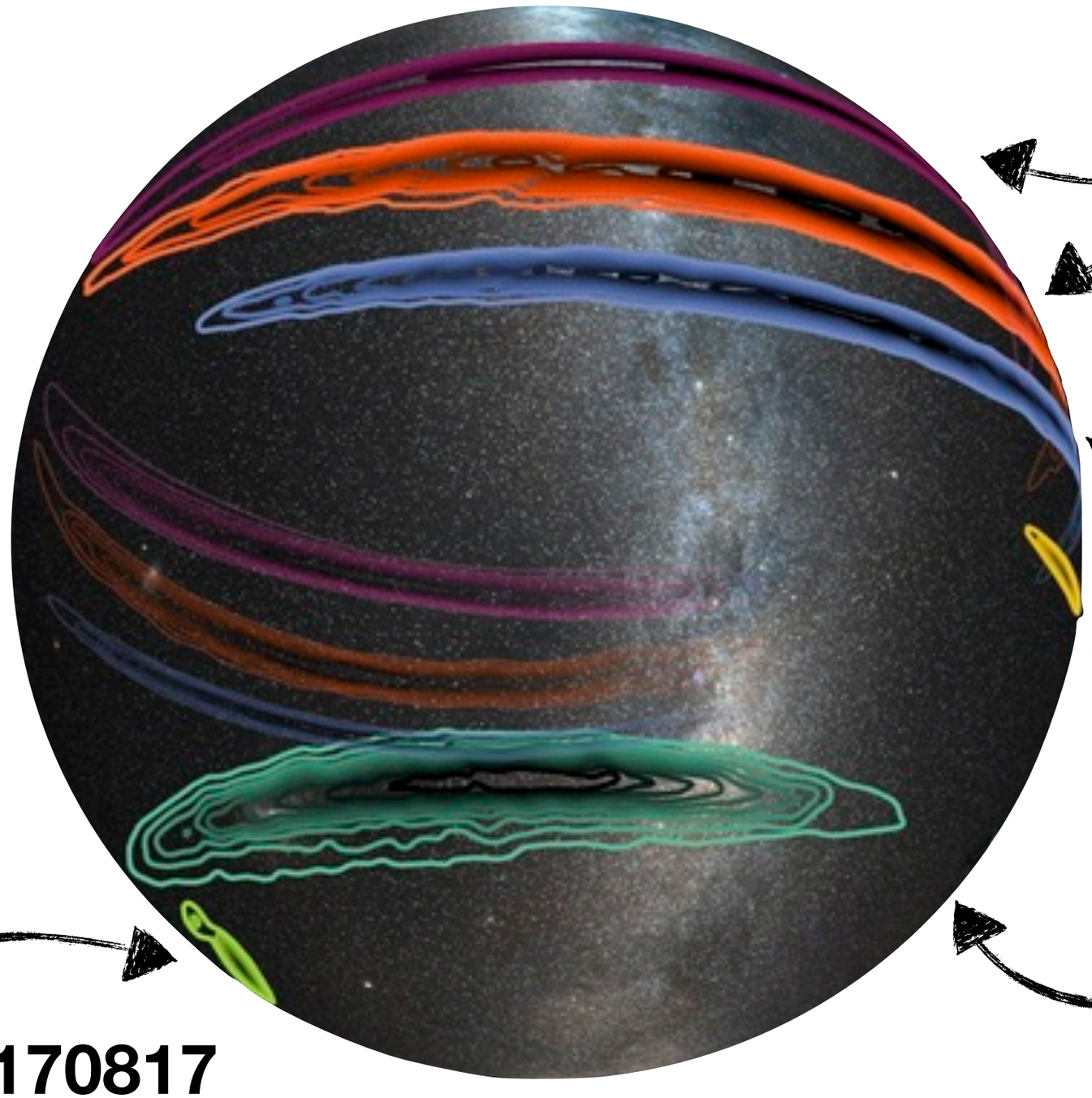
Data streams with minimal filtering

A numerical model…

in spectacular agreement

$$f \sim t^{8/3}$$

LIGO/Virgo: an incredible story…



GW170104

GW151012

GW151226

GW170814

There's a new kid in town

GW150914

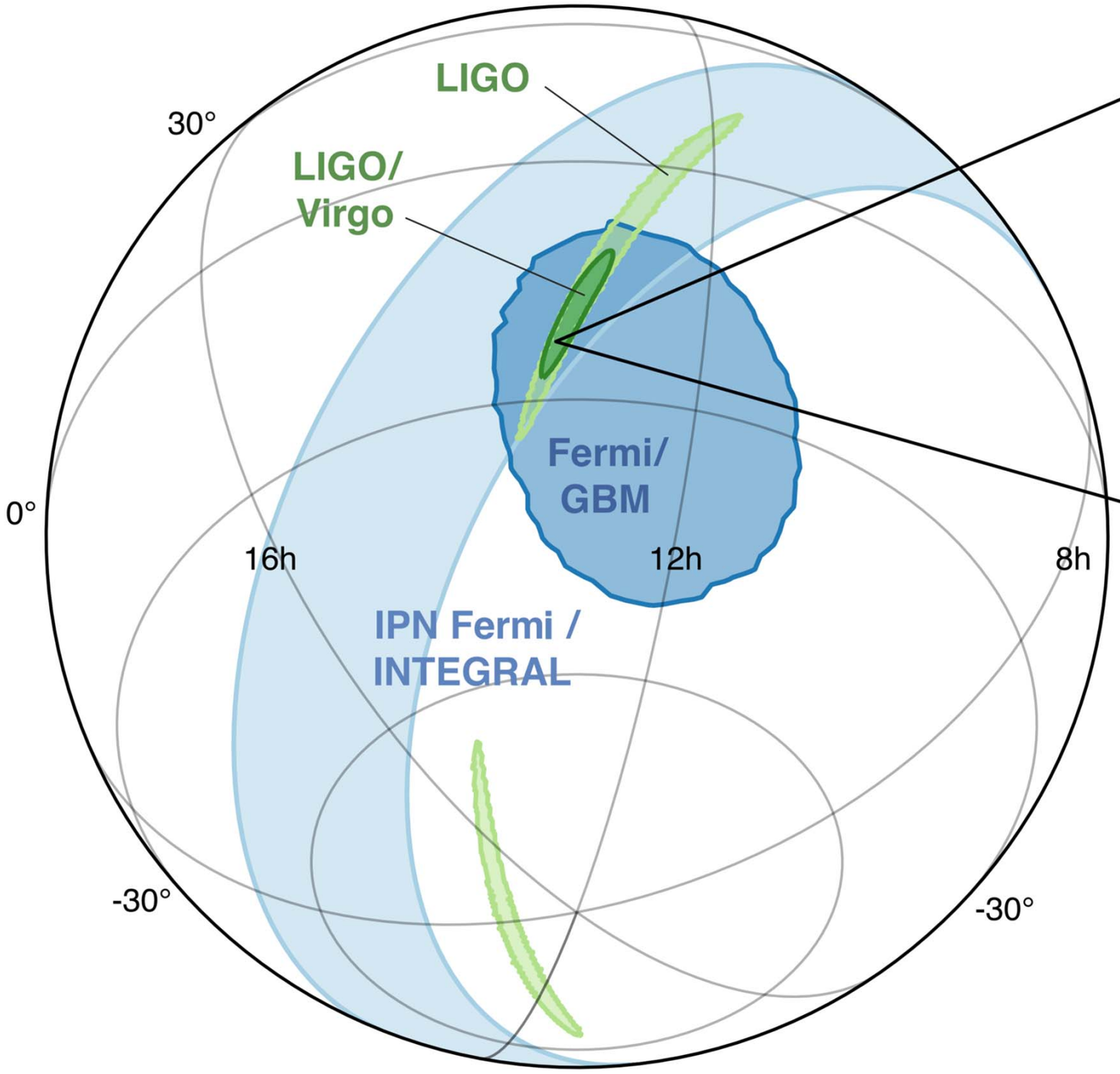
GW170817

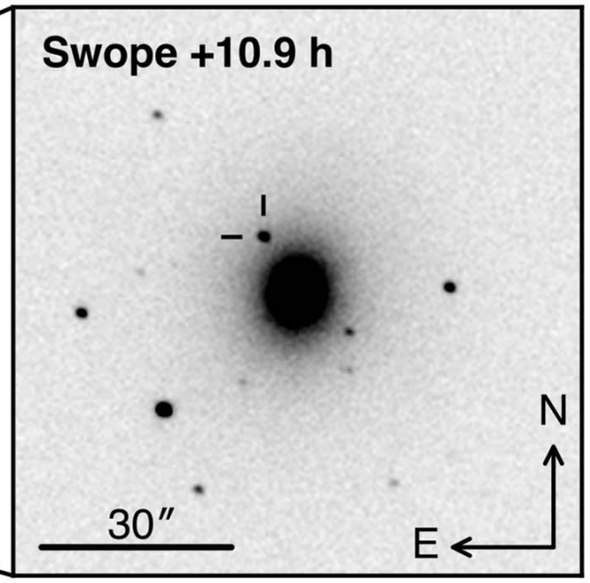
Neutron stars! Gamma rays, and optical counterpart, and X ray later, radio still on…

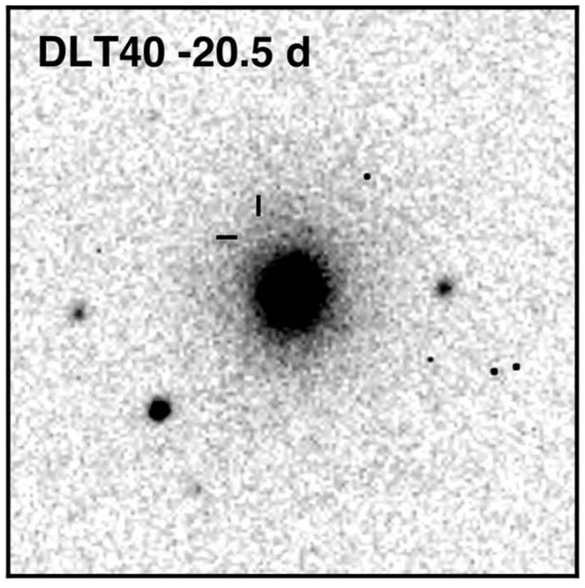
and now more than 40!

The gold rush

- A third GW detector is the only reasonable way to do this
- Time coincidence with gamma rays and fast communication
- Still some 50 galaxies…



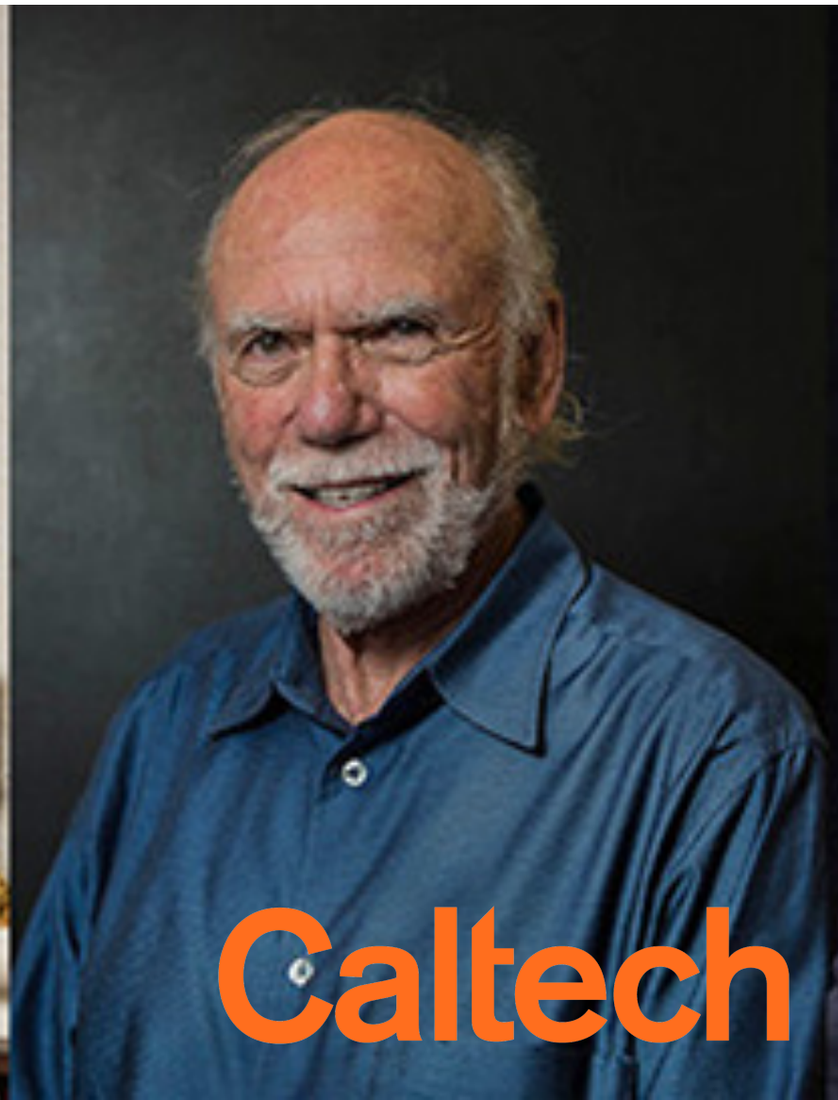




2017 Nobel Prize

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

R. Weiss | **B. Barish** | **K. Thorne**

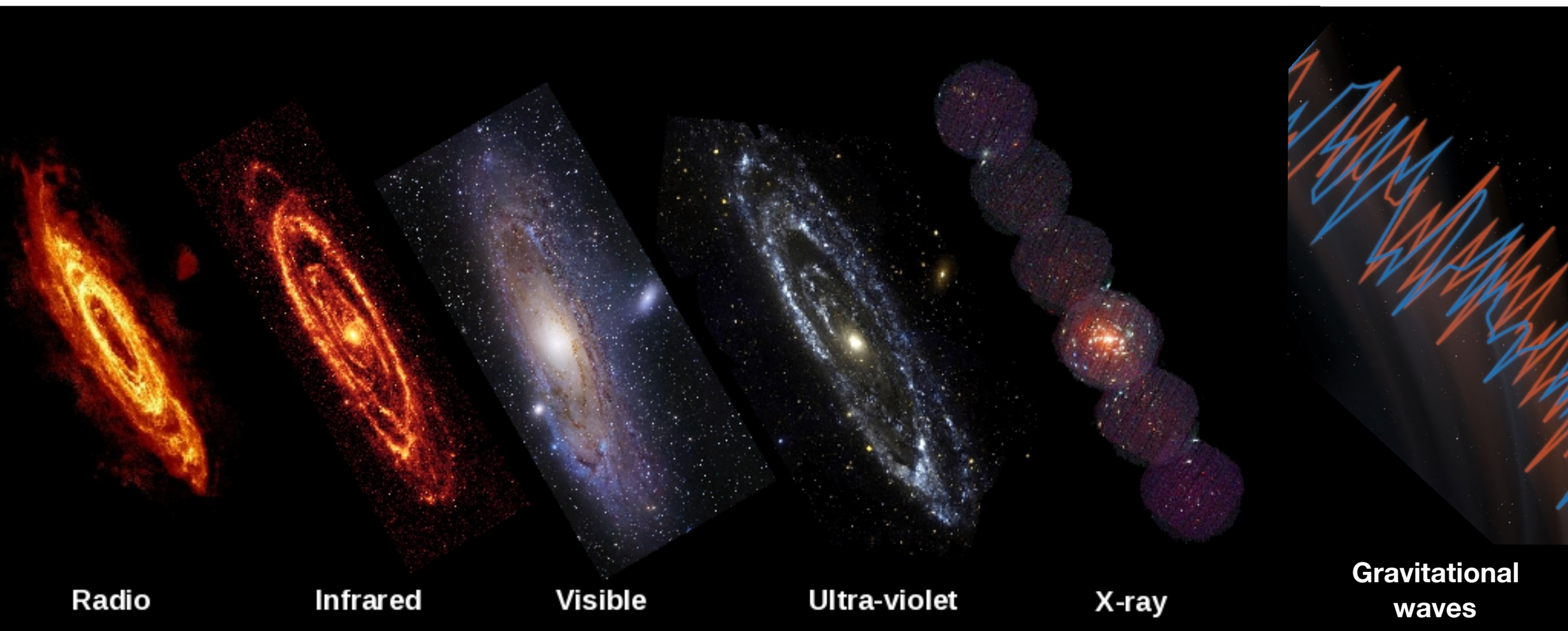


Just passing by…

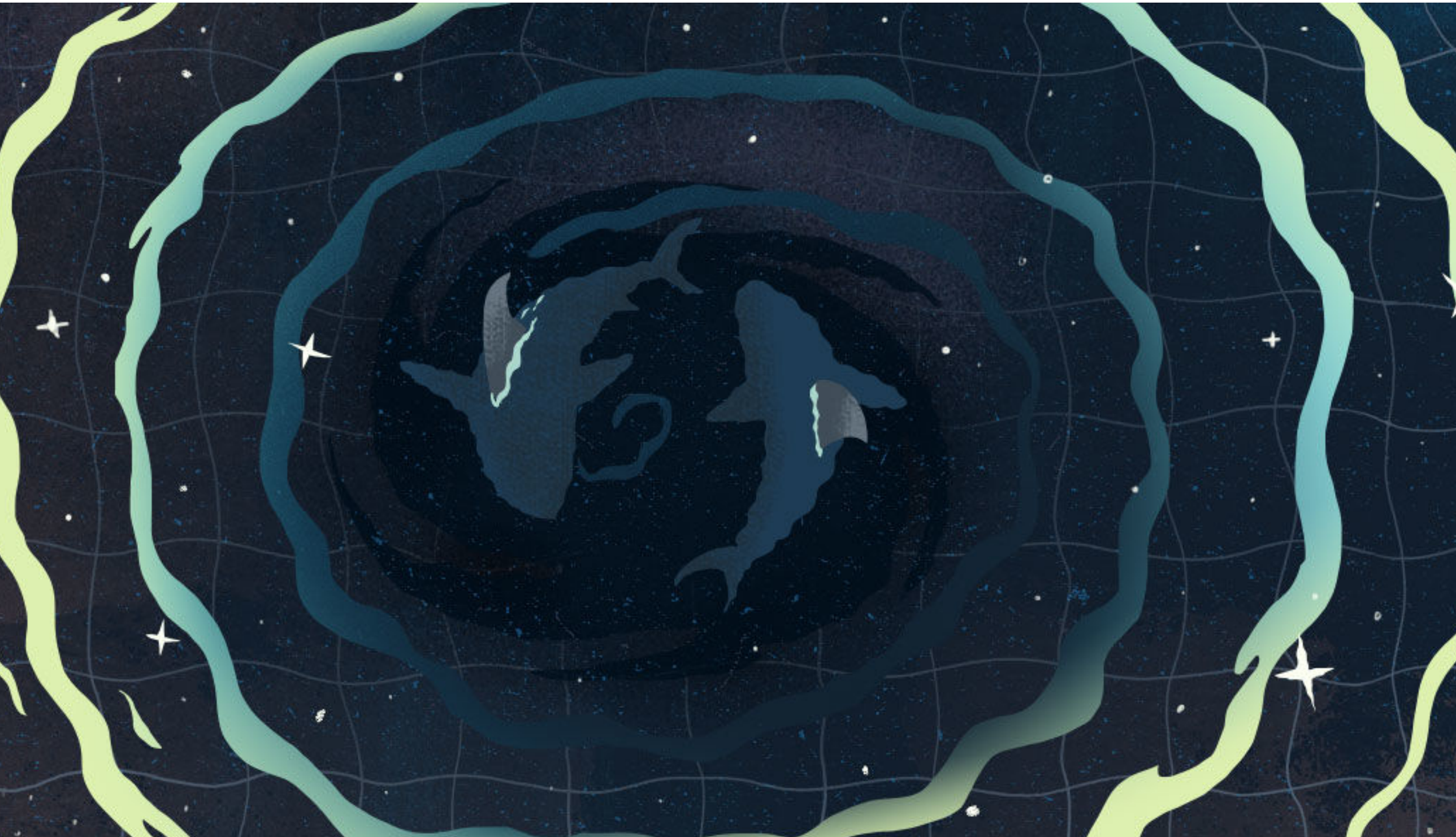
Credits:
My hometown's newspaper

A new window on the Universe

- **Gravitational-waves are a fundamentally new way!**
- Serendipitous discoveries came with new electromagnetic bands (X-ray binaries, gamma-ray bursts, pulsars, CMB…)

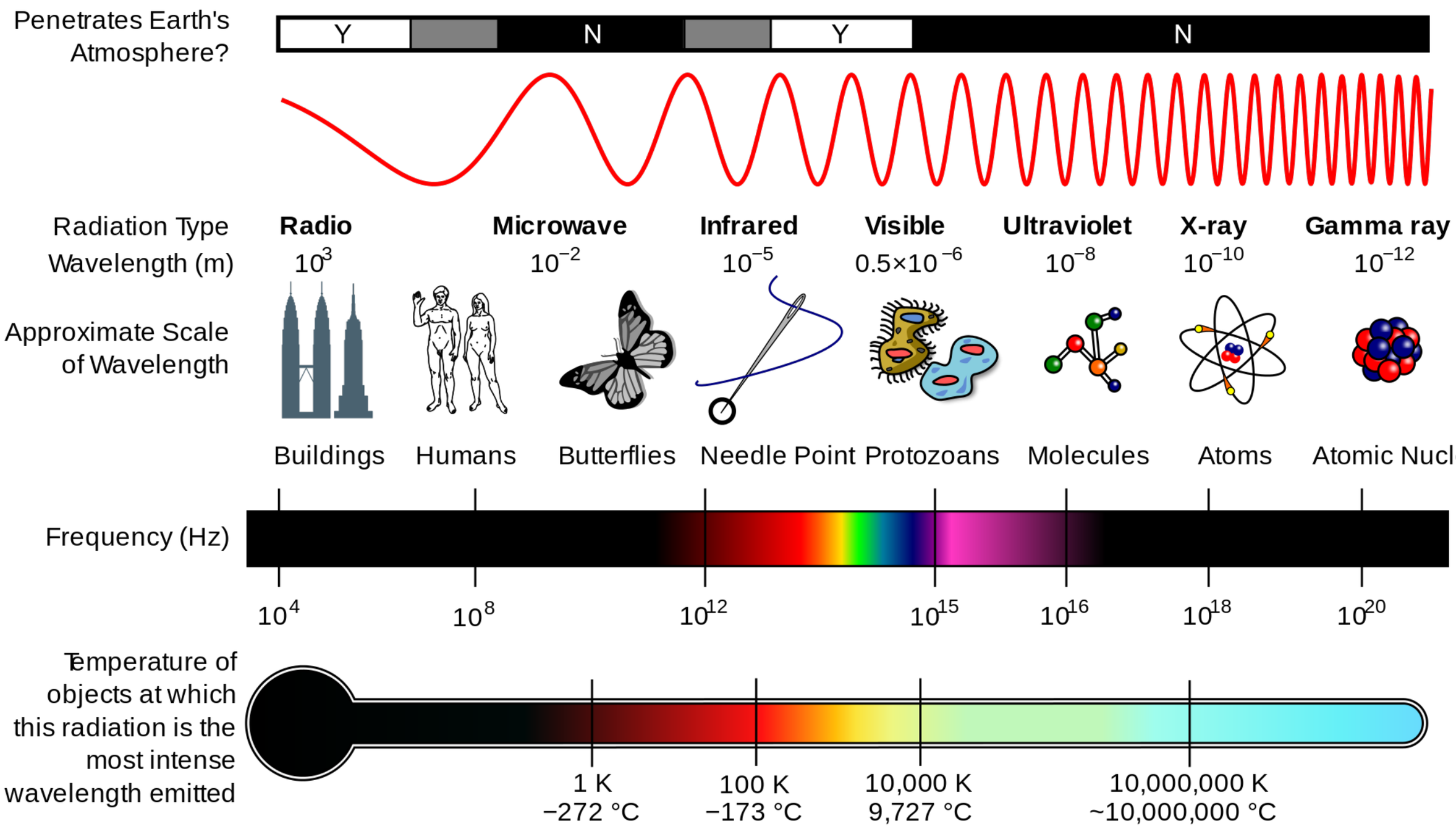


Expect the unexpected

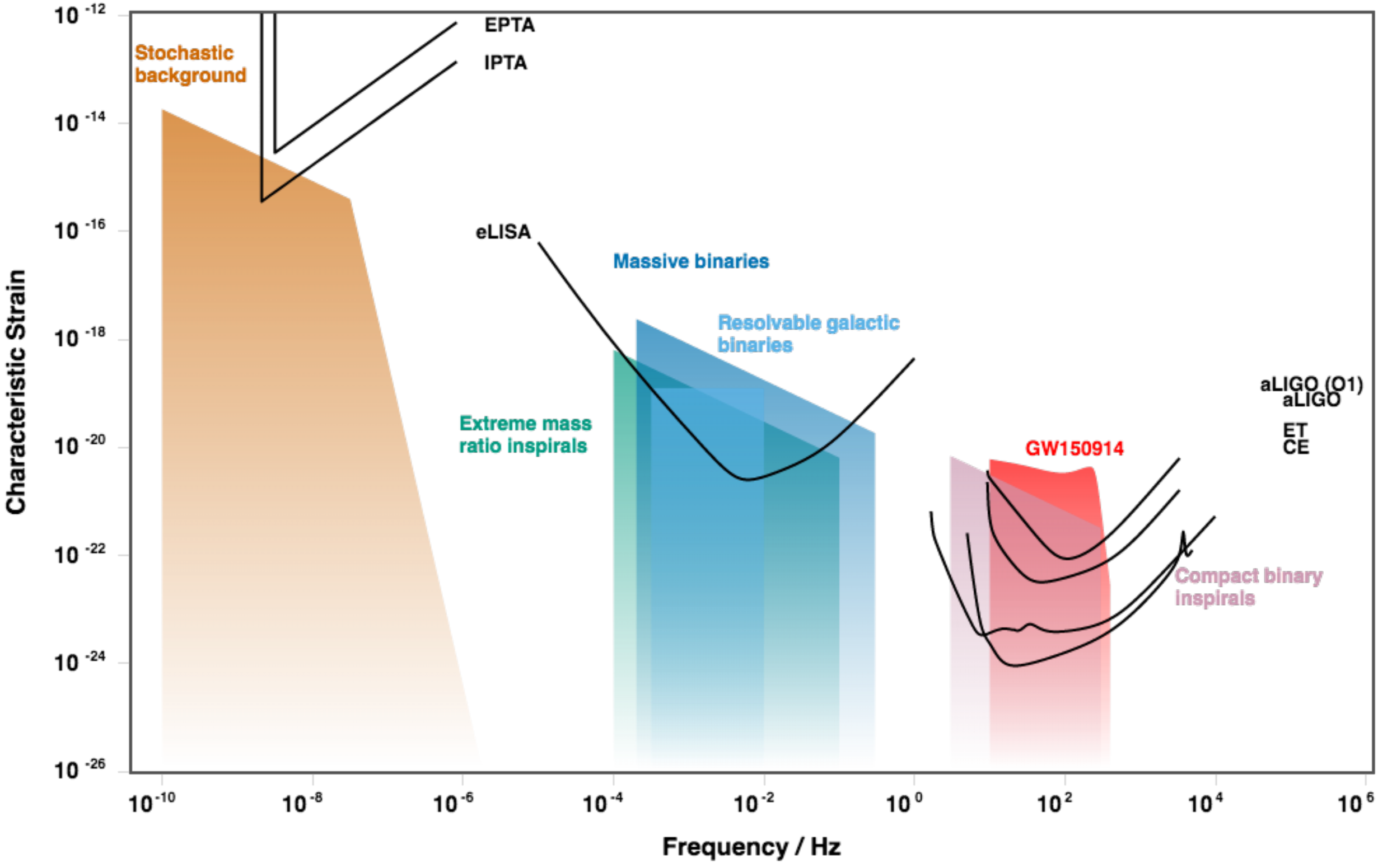


Listening to the Universe

The light spectrum

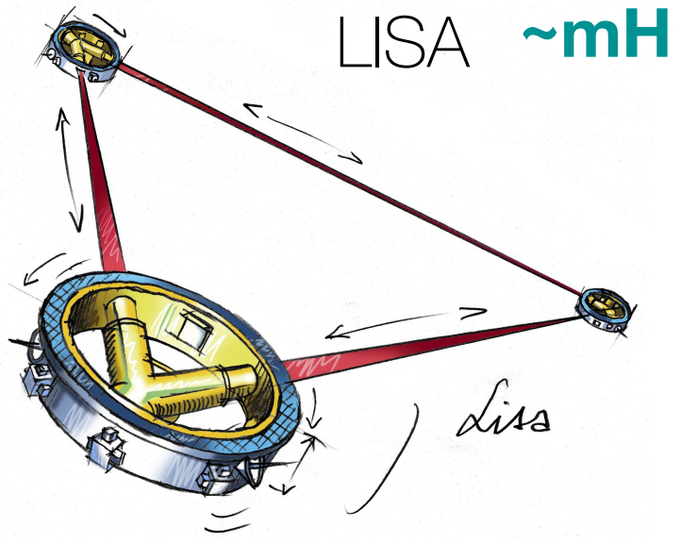


The gravity spectrum

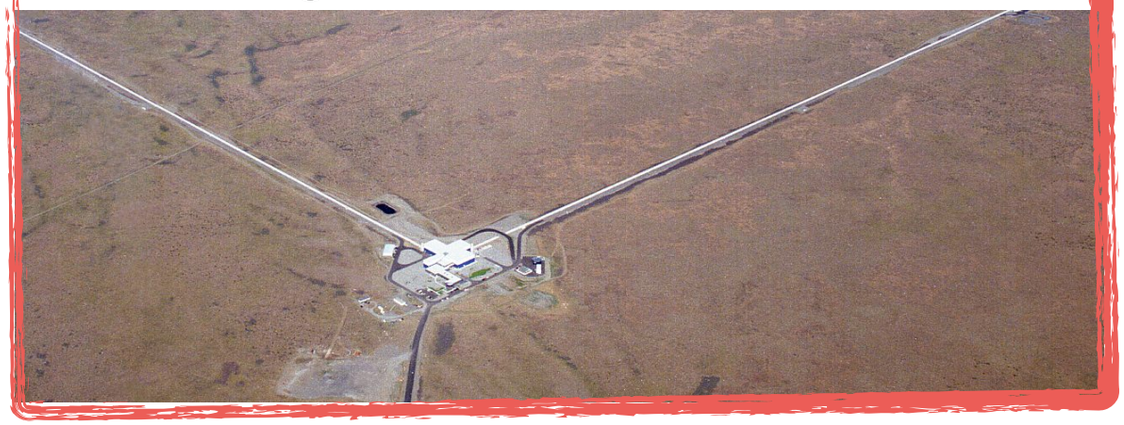


The future is bright and loud

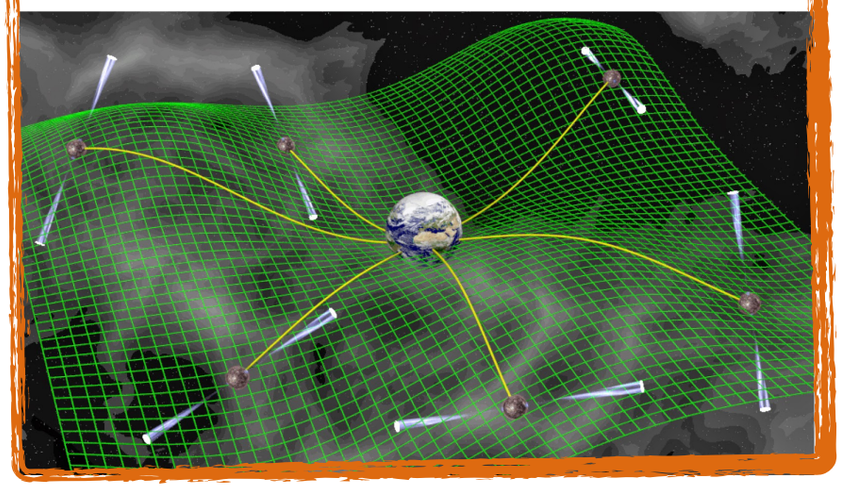
LISA ~mHz

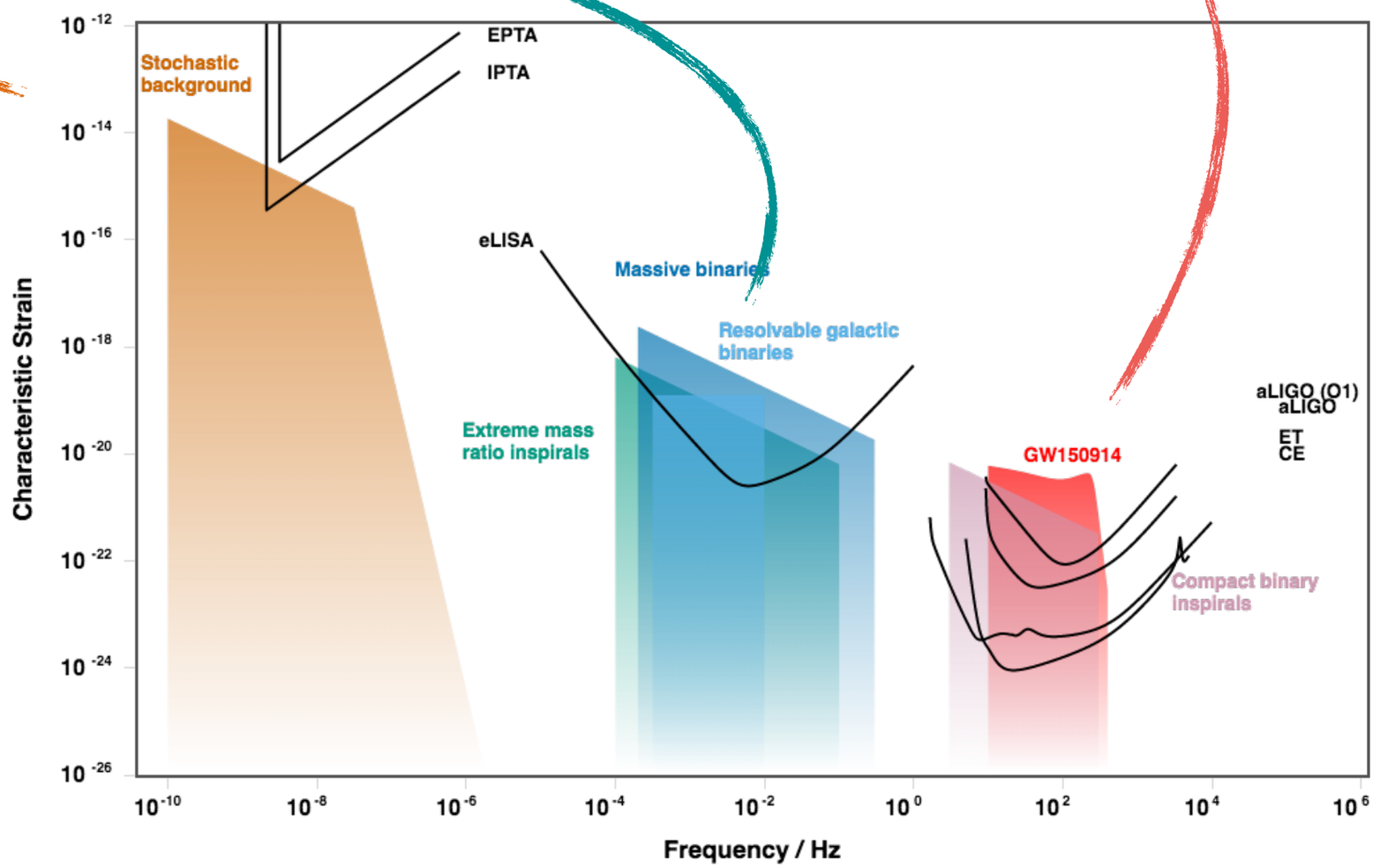


LIGO, Virgo, and more ~100Hz

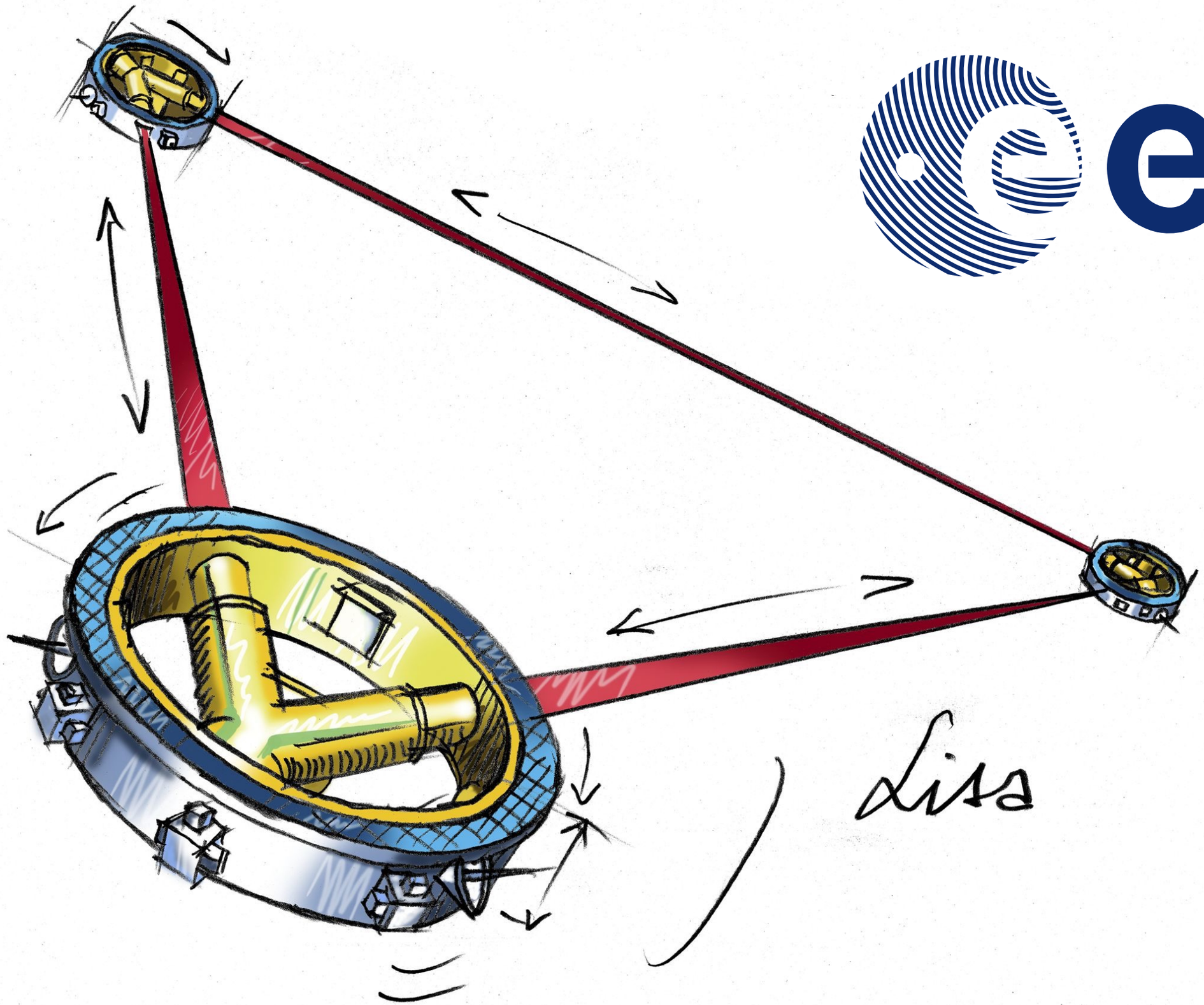


Pulsar timing arrays ~nHz

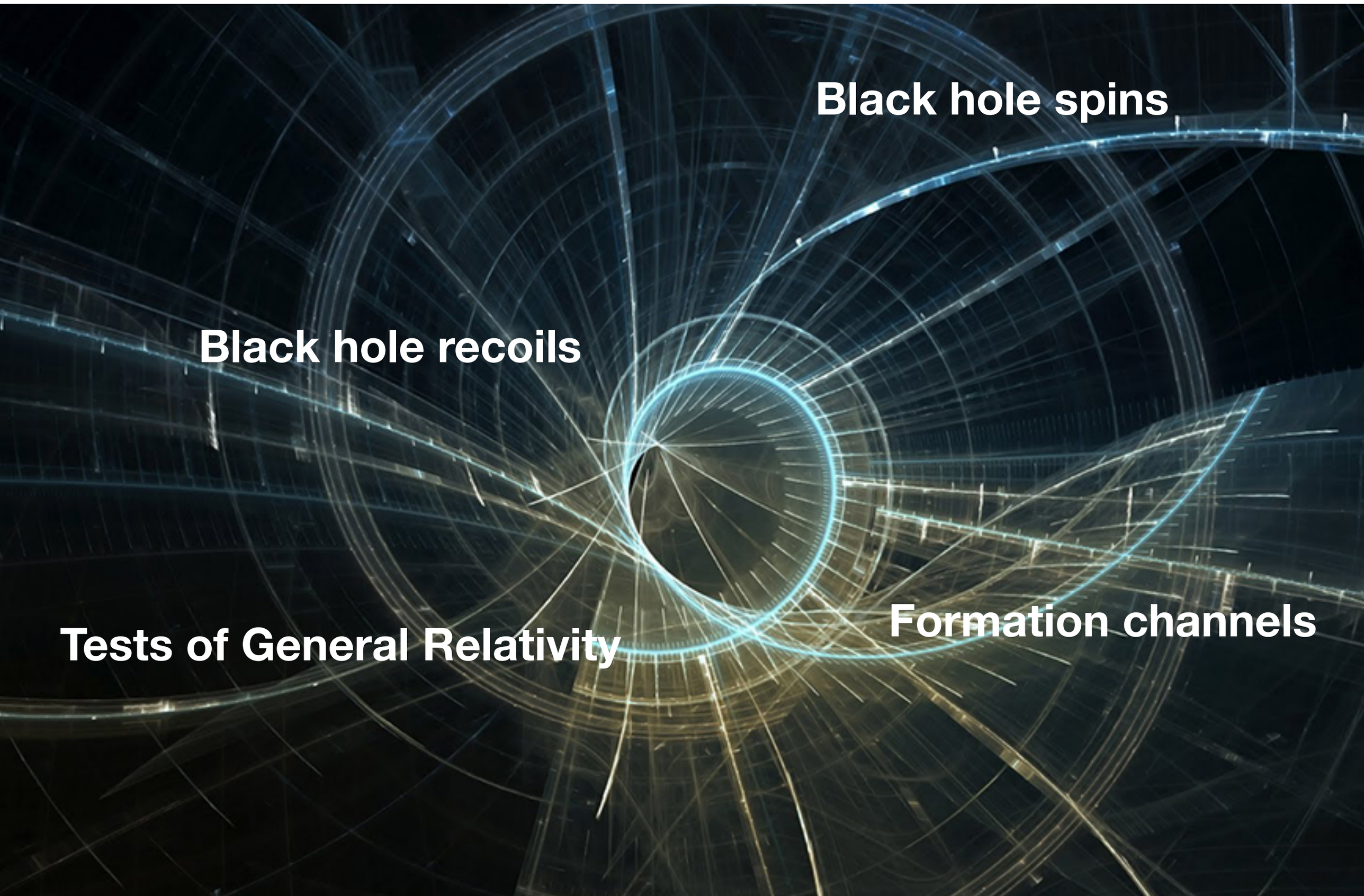




LISA: the next revolution



What I (really) do

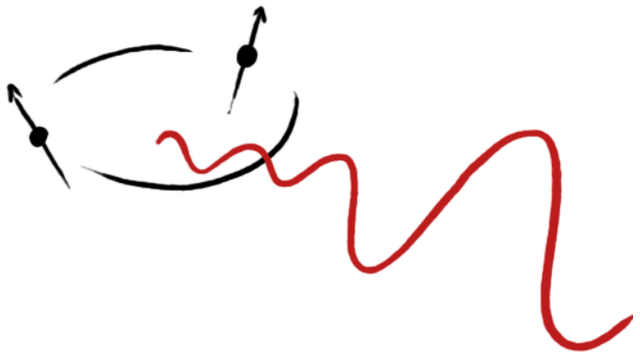


Can BHs really make it?

Peters and Mathews 1963
Peters 1964

Power emitted in gravitational waves:

$$\frac{da}{dt} = -\frac{64}{5}\frac{G^3 M^3}{c^5 a^3}\frac{q}{(1+q)^2}$$



GW-driven inspiral timescale

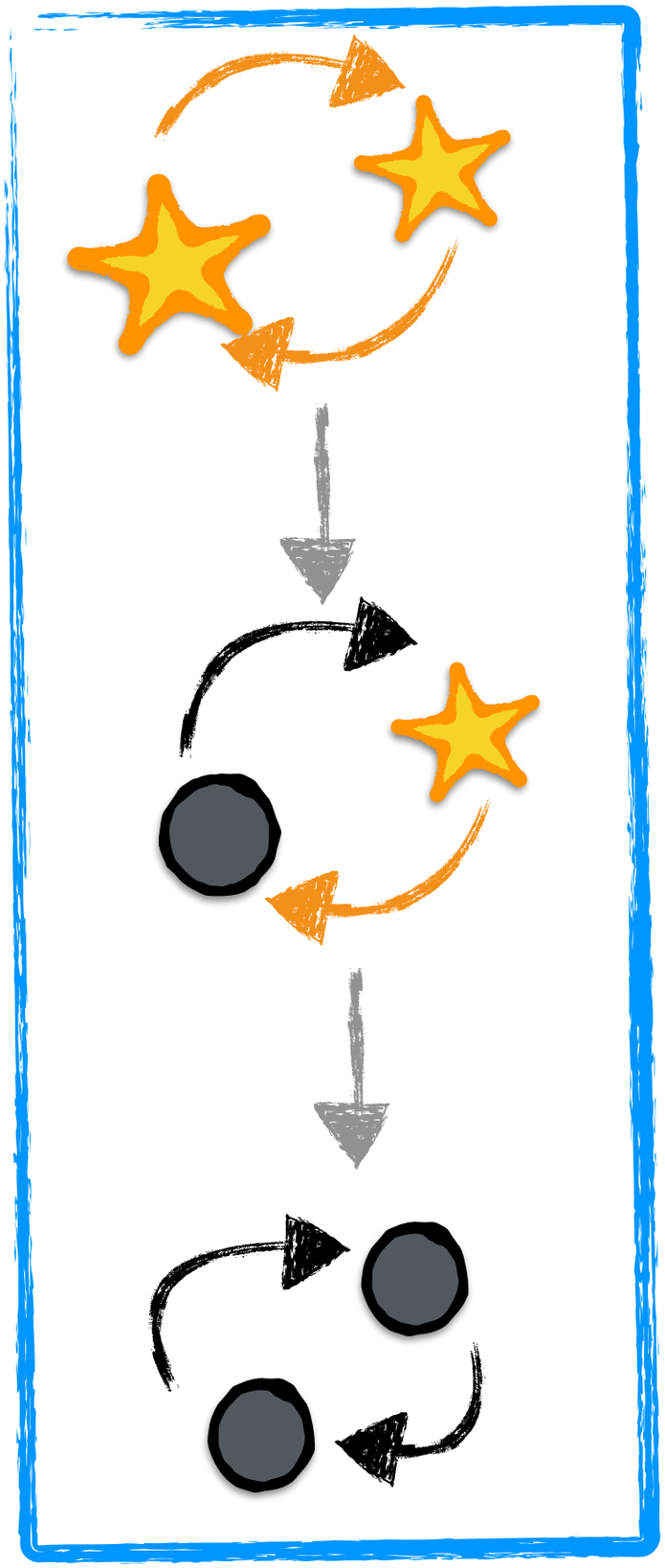
$$t_{\rm GW} \sim a\frac{dt}{da} \sim a^4$$

Gravitational waves are efficient below

$$a_{\rm GW} = 1.2\times 10^{11}\left(\frac{t_{\rm GW}}{1.4\times 10^{10}{\rm yr}}\right)^{1/4}\left(\frac{M}{M_\odot}\right)^{3/4}{\rm cm} \sim 10R_\odot$$ stellar-mass BHs

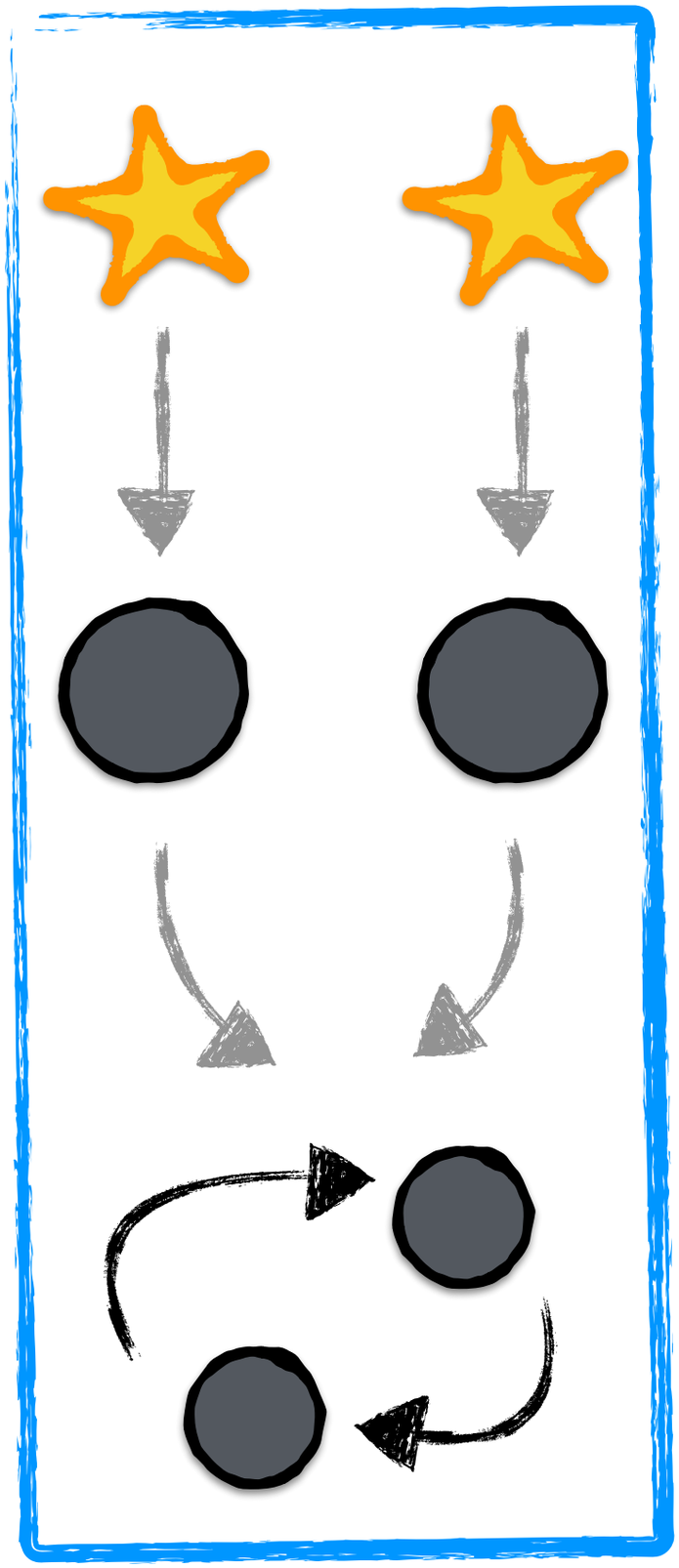
Relativity alone cannot explain the LIGO events!
We need some **astrophysics!**

Have we been together for so long?



Yes! I've known you since you were a star

Don't you remember? We just met in cluster

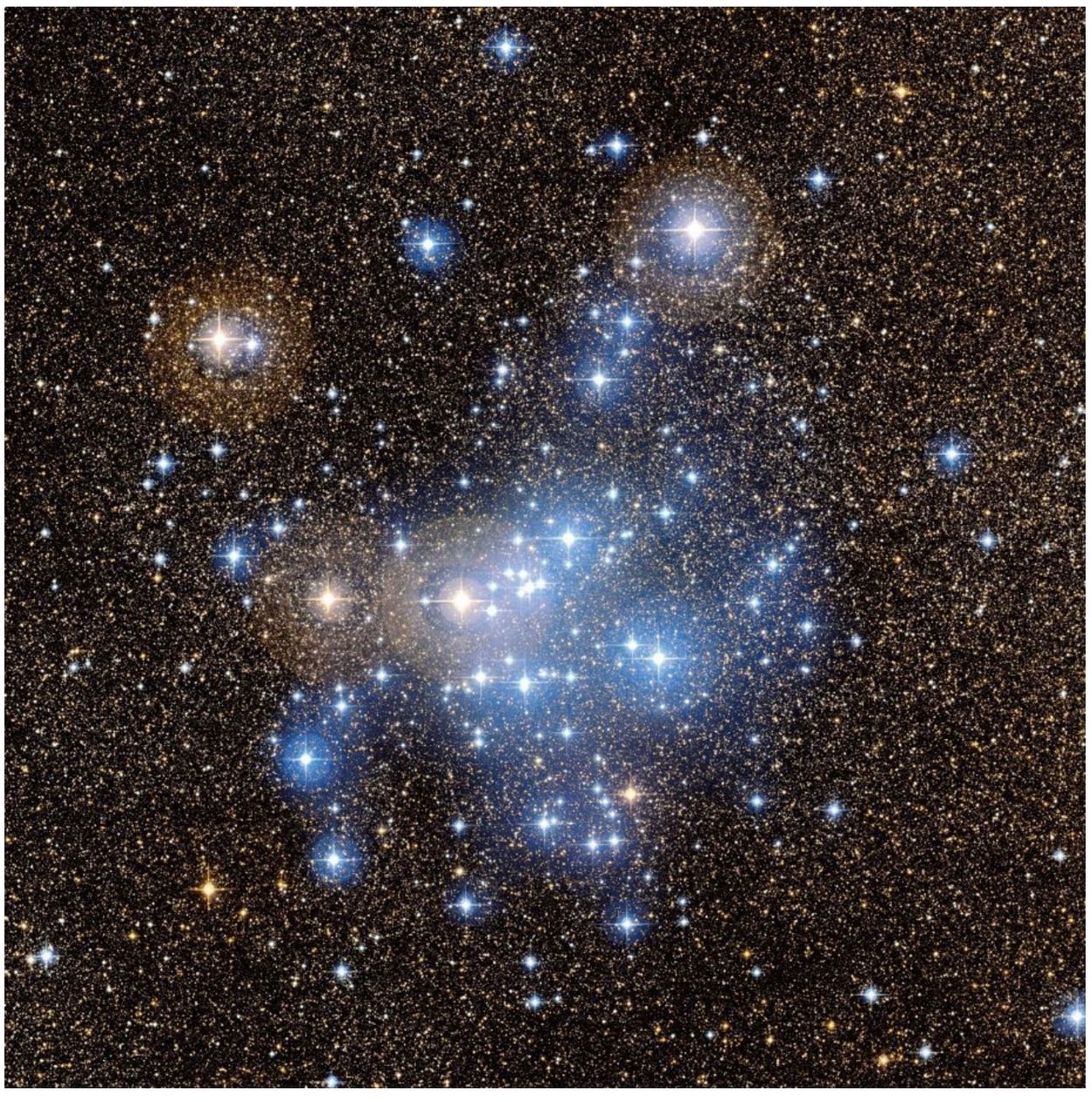


Where do LIGO sources come from?

What's this interplay between astronomy and relativity?

Black holes from binary stars?

Black holes from clusters?



“In my entire scientific life, extending over forty-five years, the most shattering experience has been the realization that an exact solution of Einstein's equations of general relativity, discovered by the New Zealand mathematician, Roy Kerr, provides the absolutely exact representation of untold numbers of massive black holes that populate the universe.

This shuddering before the beautiful, this incredible fact that a discovery motivated by a search after the beautiful in mathematics should find its exact replica in Nature, persuades me to say that beauty is that to which the human mind responds at its deepest and most profound.”

S. Chandrasekhar (Truth and Beauty)

Somewhere in between astronomy and relativity

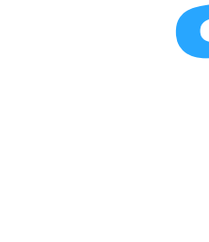
Davide Gerosa

University of Birmingham

January 29th, 2020

Astronomy in the City

Birmingham, UK



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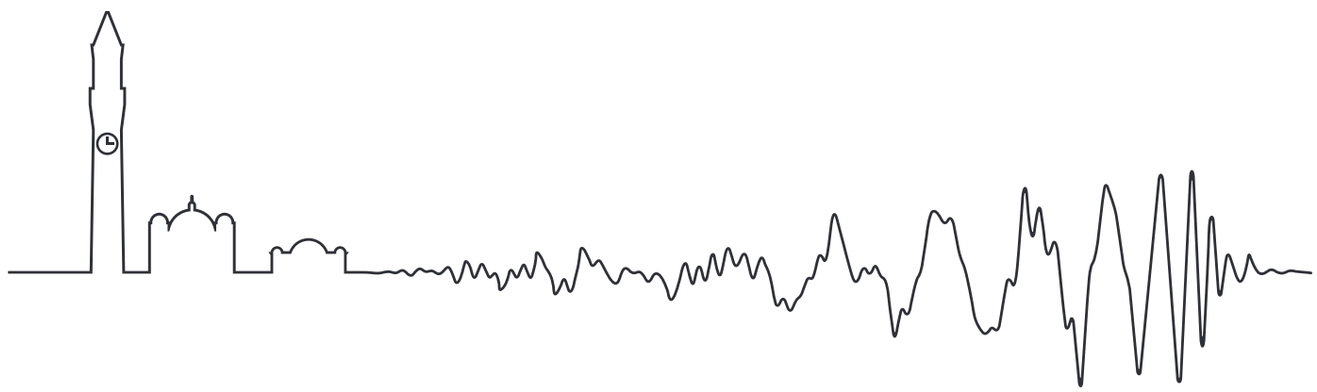

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d.gerosa@bham.ac.uk — www.davidegerosa.com