Probing Cosmic Graveyards with Gravitational Waves

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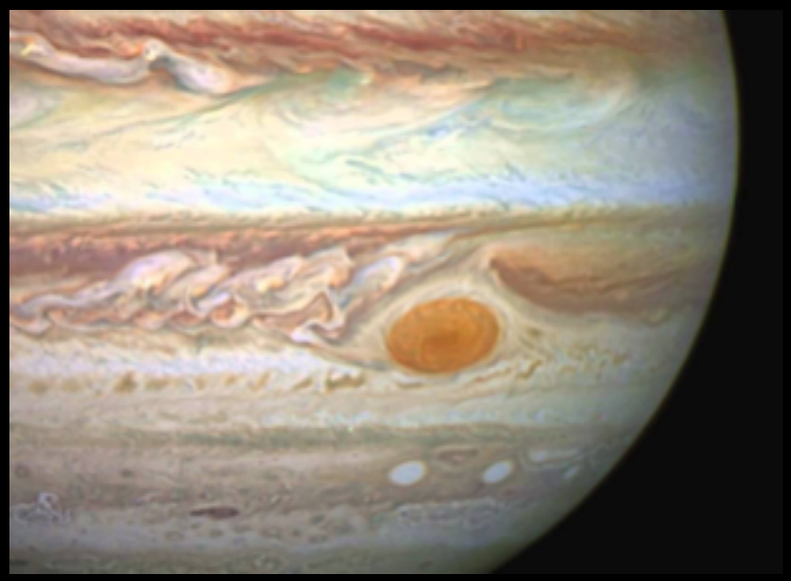
CIERA ADLER PLANETARIUM

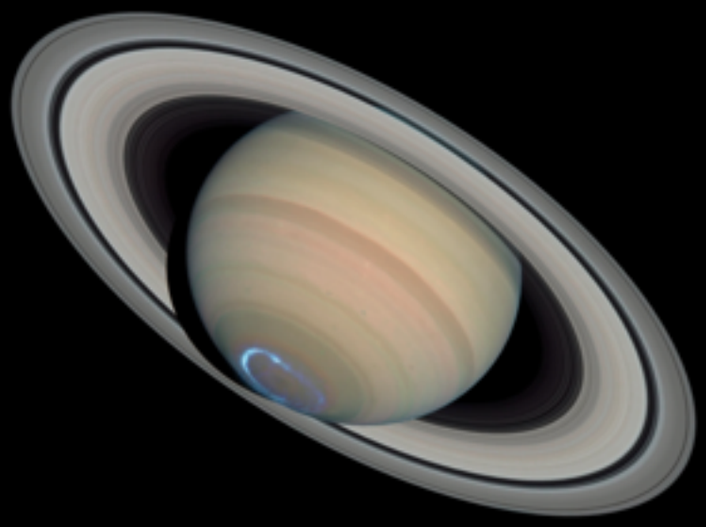
Quarknet LIGO Workshop
University of Illinois • Chicago
14 July 2016

Storyline

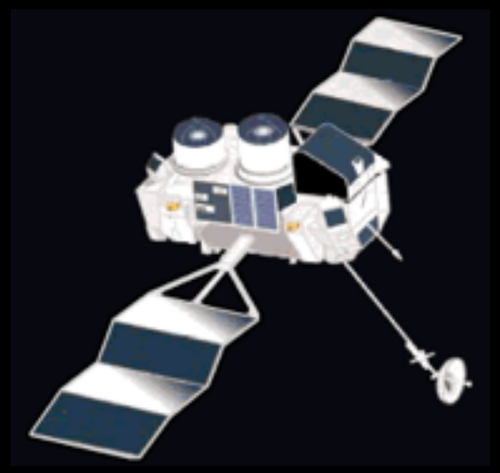
- A new kind of astronomy
- About Gravitational Waves
- The Gravitational Wave Spectrum
- LIGO & the Dawn of GW Astronomy

The COSMOS





Photons as Messengers





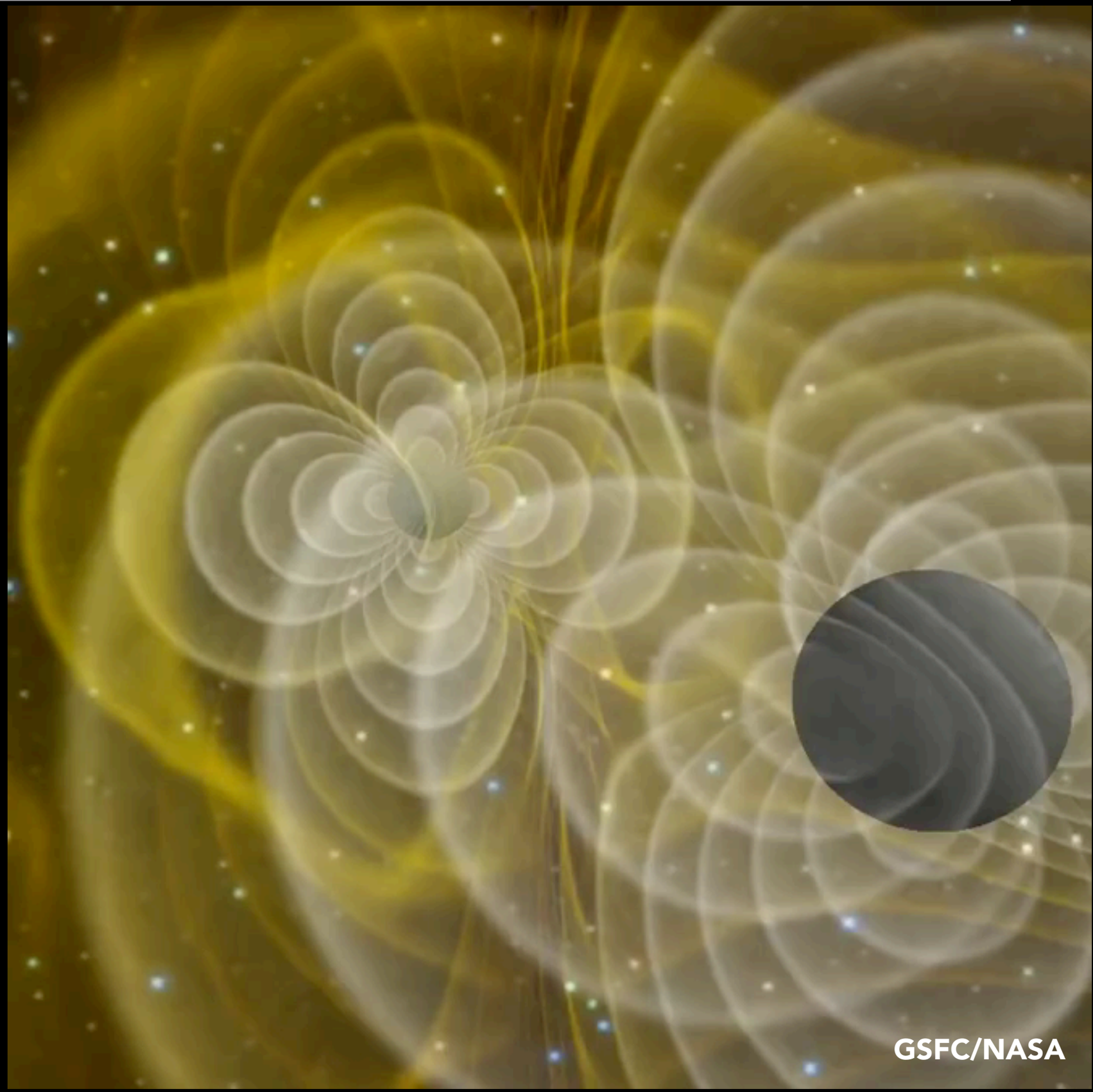






What are gravitational waves?

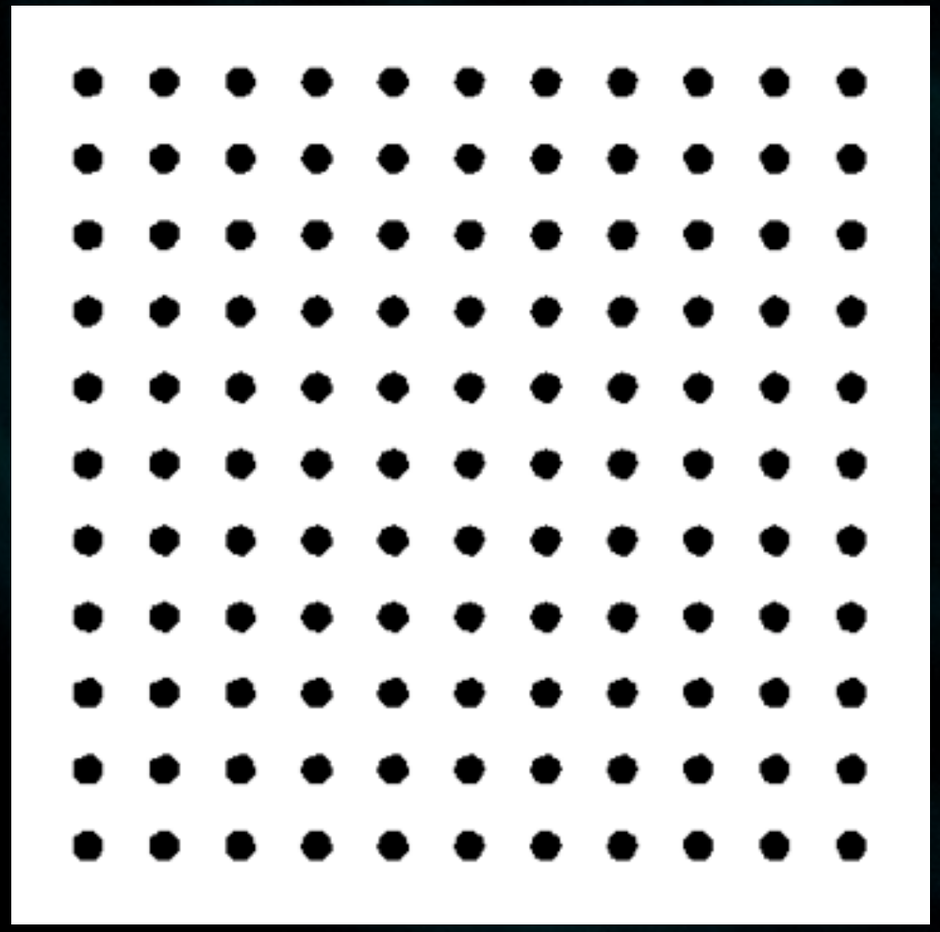
- Gravitational waves are a consequence of special relativity
  - **Nothing can travel faster than the speed of light**
  - **If a gravitational field changes, that information must propagate at a finite speed**

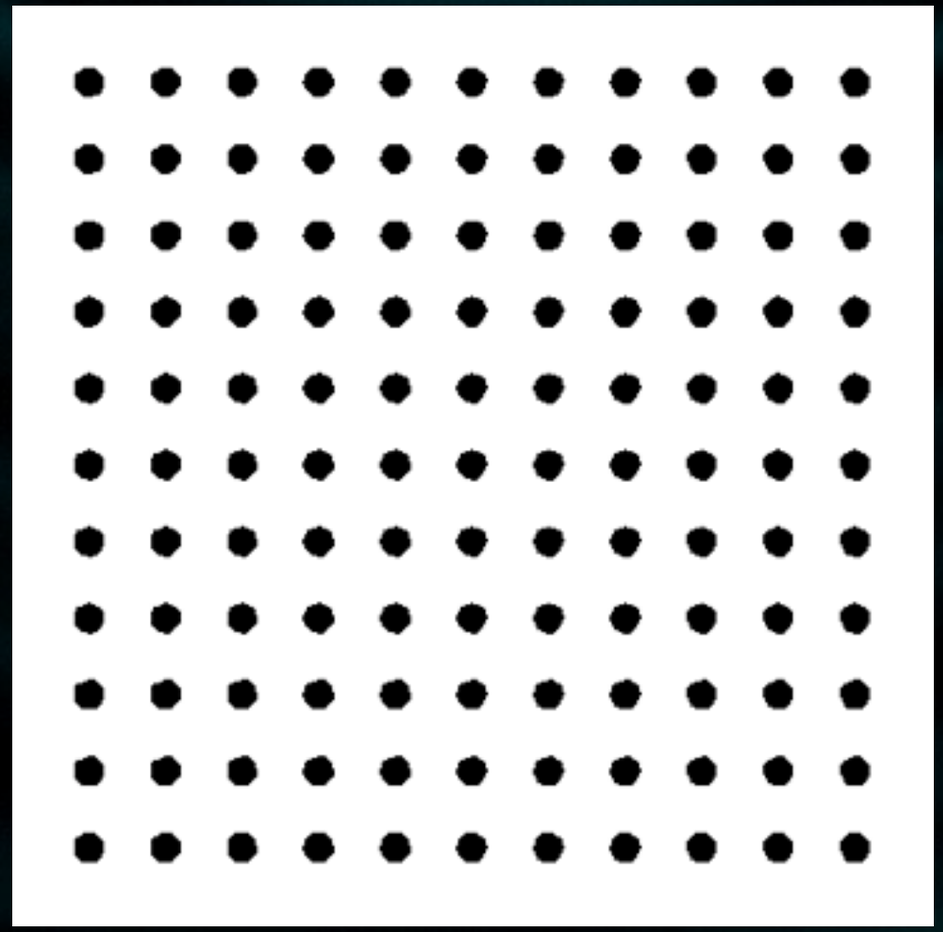


How do you detect waves?

- If you want to detect a physical phenomenon, you ask yourself "**what does it do to physical systems?**"

- Gravitational waves **change the proper spacetime distance between points.**





Wave action on particles...

- A passing gravitational wave changes **proper distances** in a plane transverse to the direction of propagation
- Characterized by a **dimensionless strain h**

What you have to measure; fixed by your experimental capability

Real world input, fixed by astrophysics and is usually SMALL!

$$h = \frac{\Delta L}{L}$$

What you can control – the size of your experiment! Fixed by your pocketbook

Typical Wave Strengths

Angry Motorist:

$$h \sim 7 \times 10^{-52}$$

Battleships Colliding:

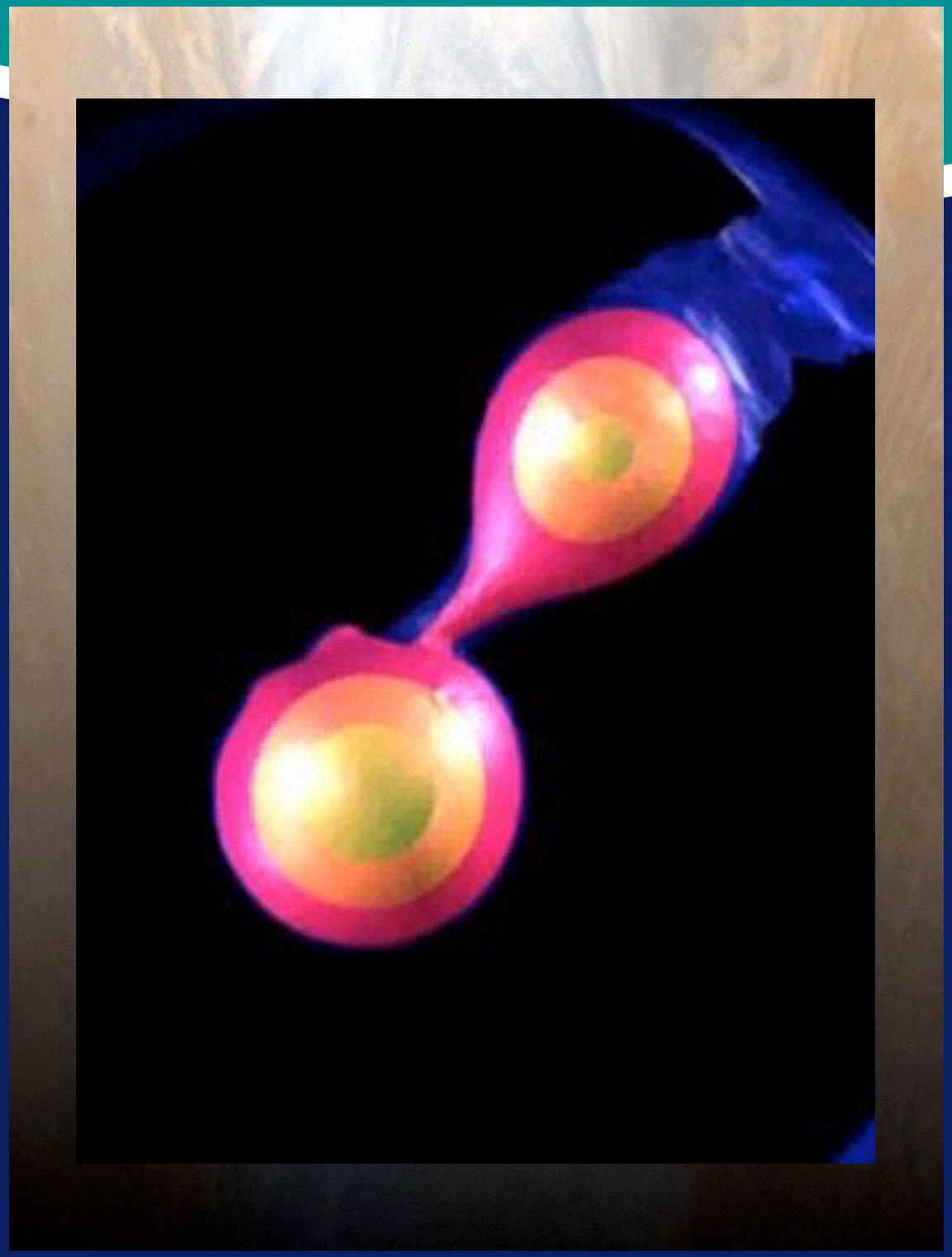
$$h \sim 5 \times 10^{-46}$$

Io orbiting Jupiter:

$$h \sim 3 \times 10^{-25}$$

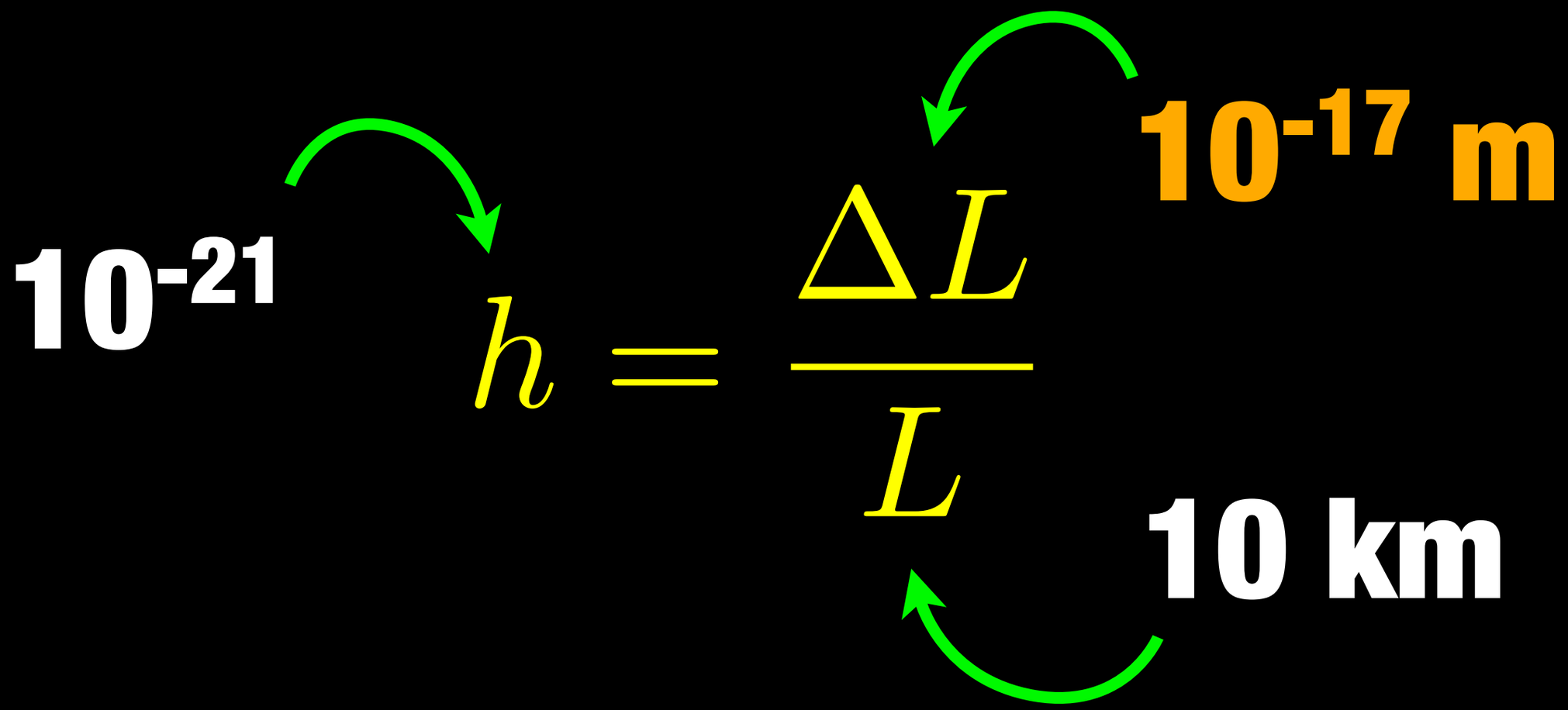
NS Binary at Galactic Center:

$$h \sim 2 \times 10^{-19}$$



What we have to do...

- Astrophysics told me ***h***
- My construction friends told me what ***L*** could be
- ***ΔL*** is what I have to be able to measure...



Gravitational Wave Spectrum

BIG BANG WAVES

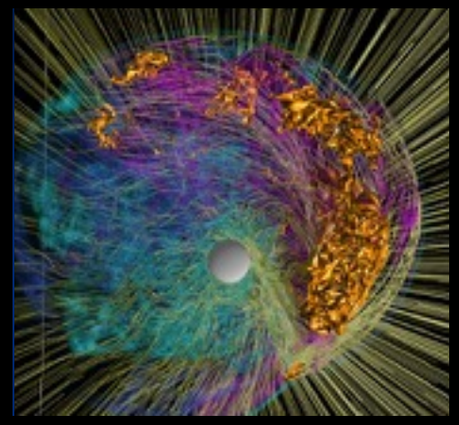
SUPERMASSIVE BH BINARIES

EXPLOSIONS

STARS + SMBH

BINARY MERGERS

COMPACT BINARIES



AGE OF THE COSMOS

YEARS HOURS SECONDS MILLISEC

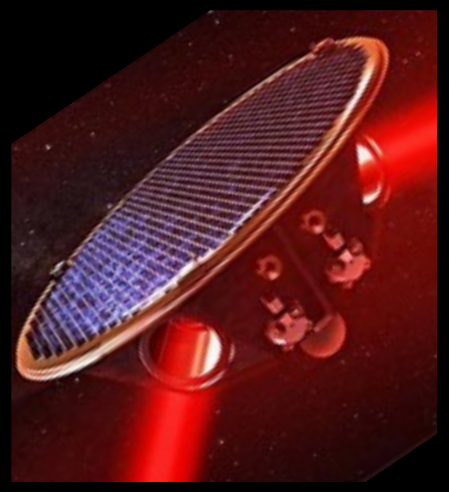
PERIOD

FREQ

10^{-16} 10^{-12} 10^{-11} 10^{-10} 10^{-8} 10^{-6} 10^{-4} 10^{-2} 1 10^{2} HZ

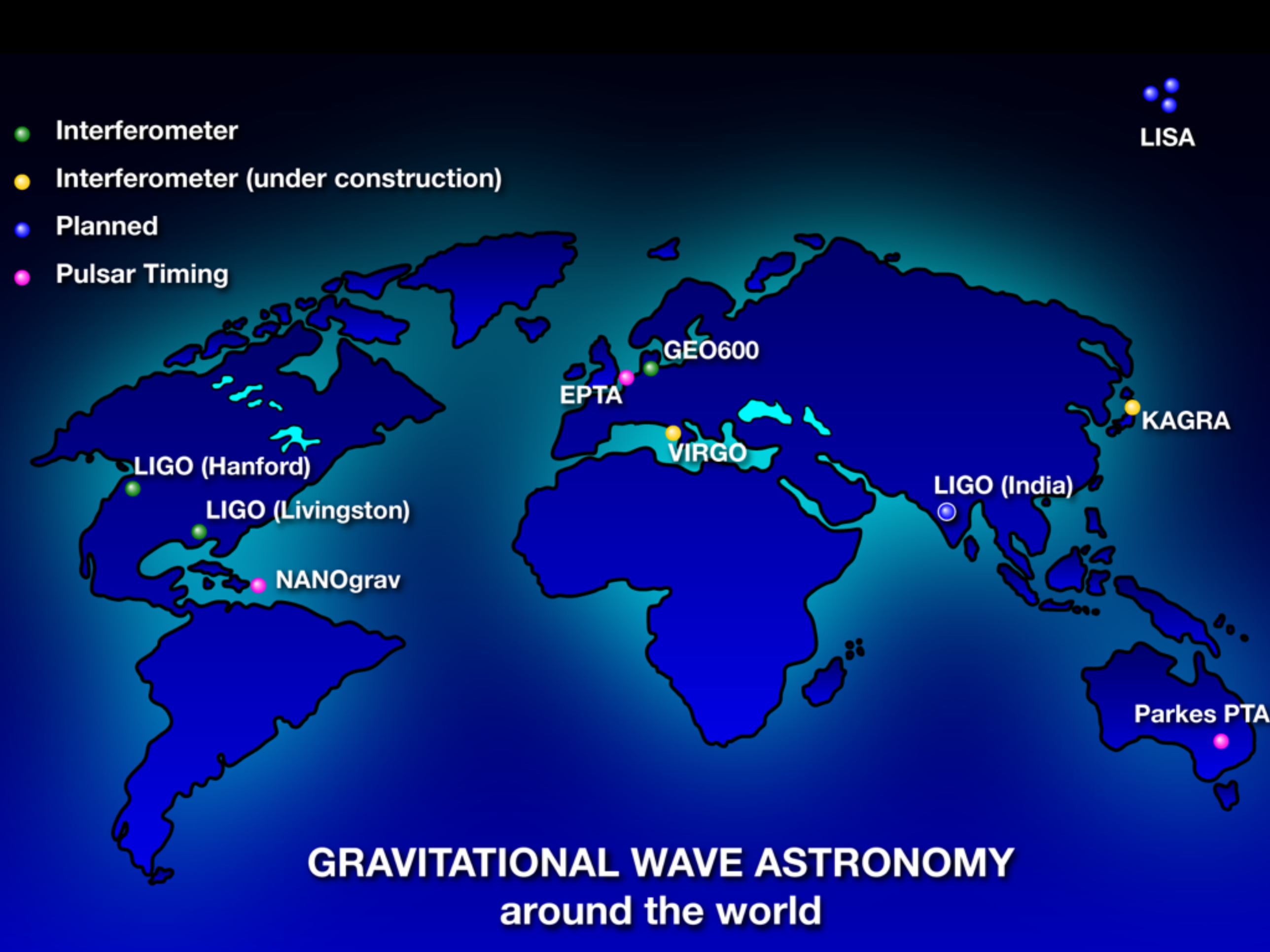
CMB

Pulsar Timing

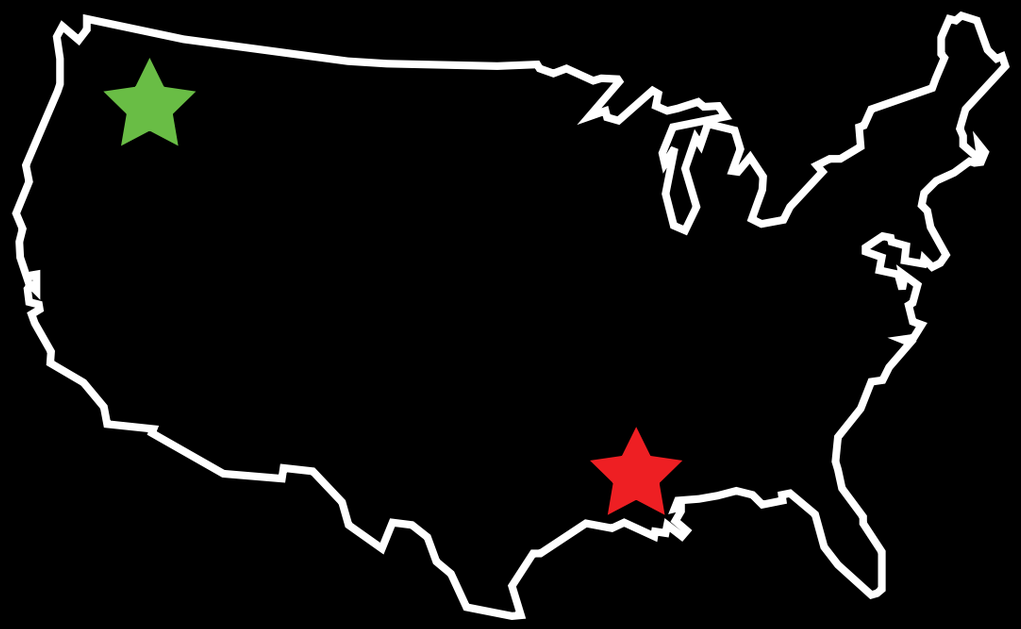


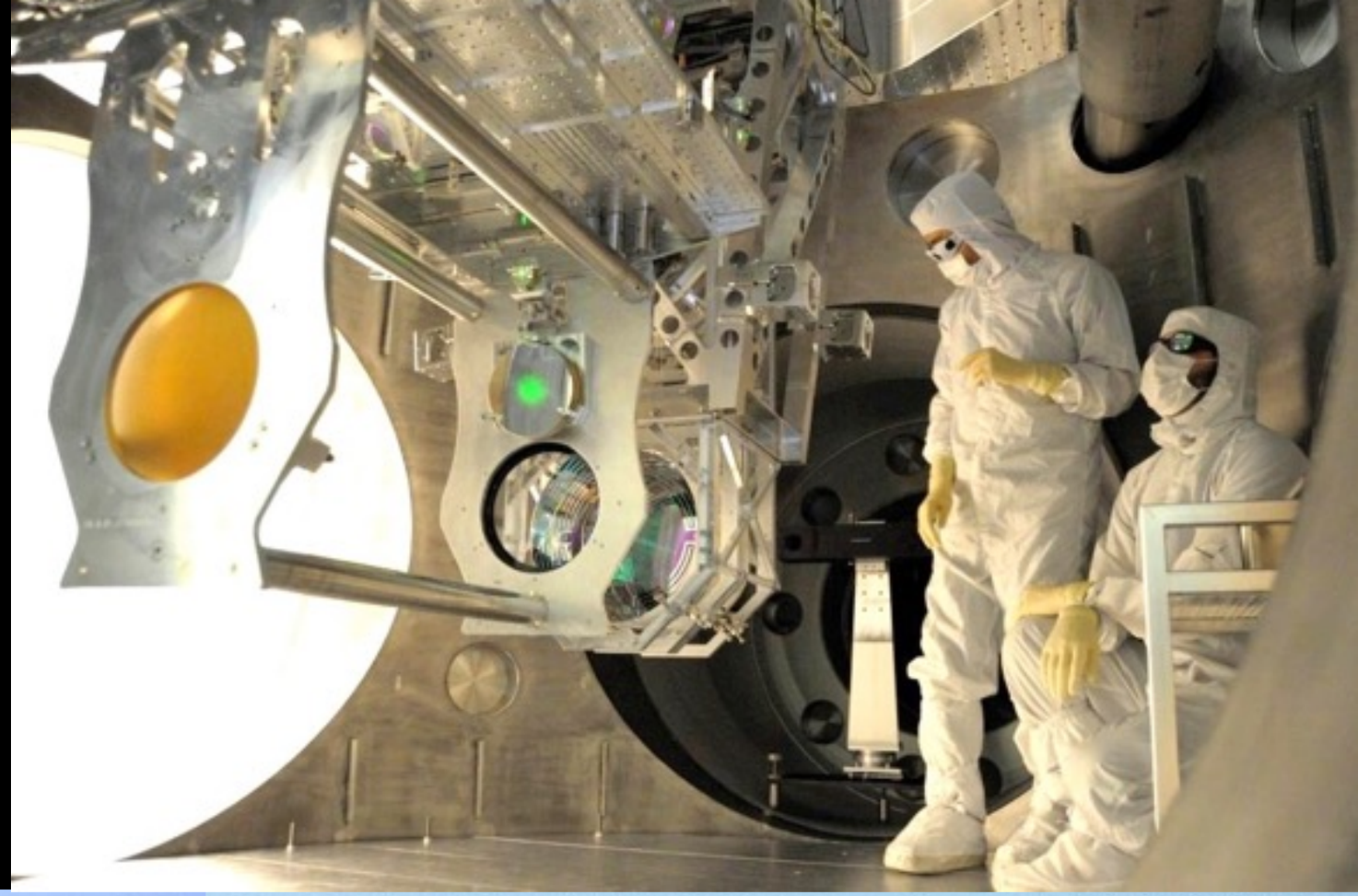
Space

Ground


Interferometer
Interferometer (under construction)
Planned
Pulsar Timing
LISA
GEO600
EPTA
KAGRA
VIRGO
LIGO (Hanford)
LIGO (India)
LIGO (Livingston)
NANOgrav
Parkes PTA
GRAVITATIONAL WAVE ASTRONOMY
around the world

LIGO

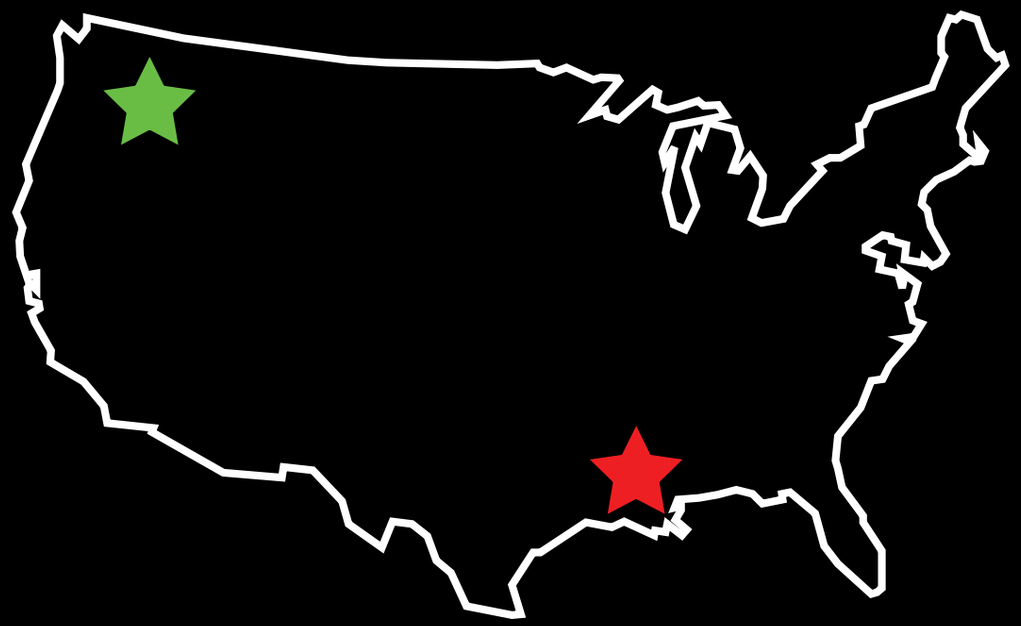


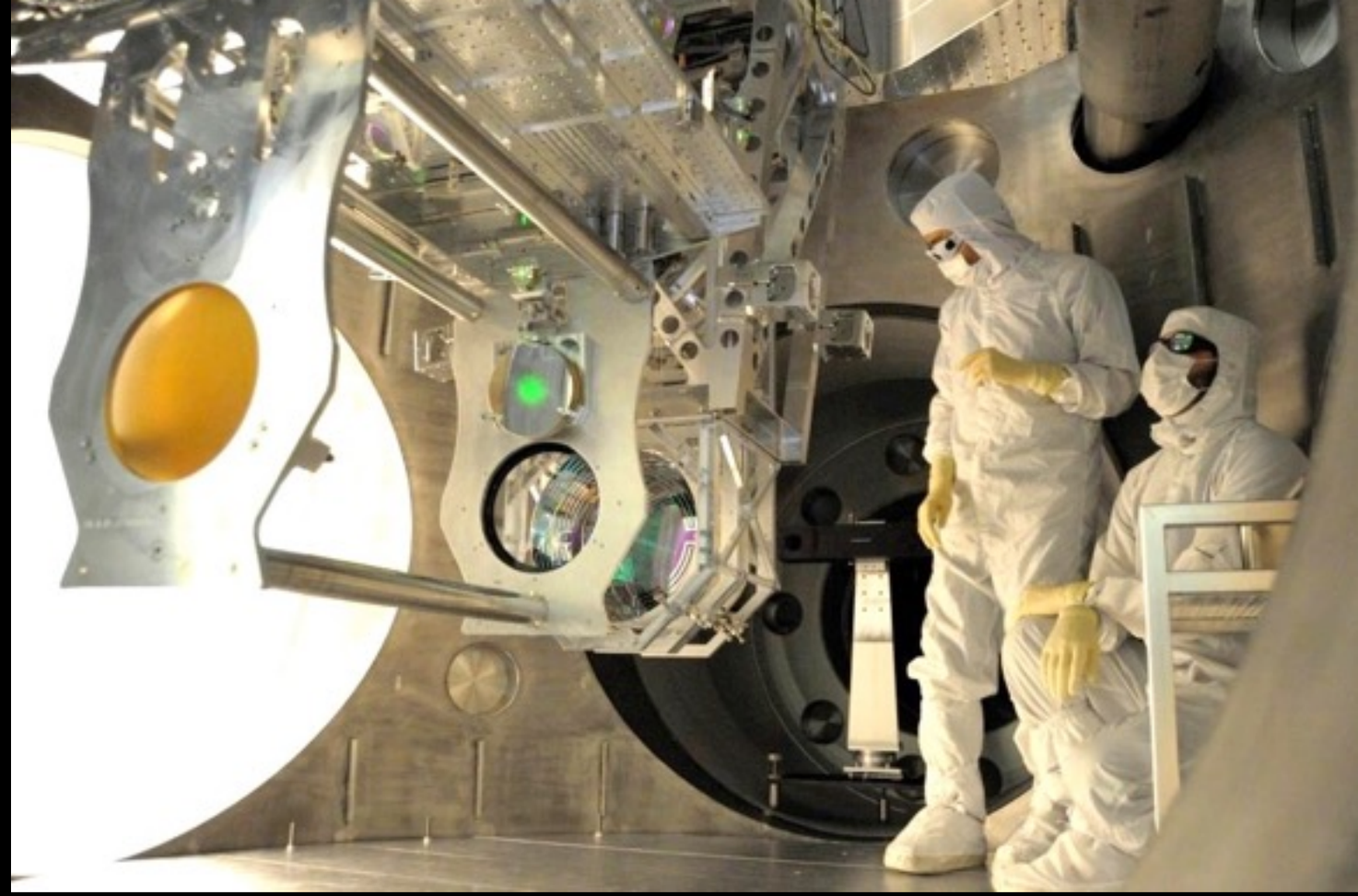


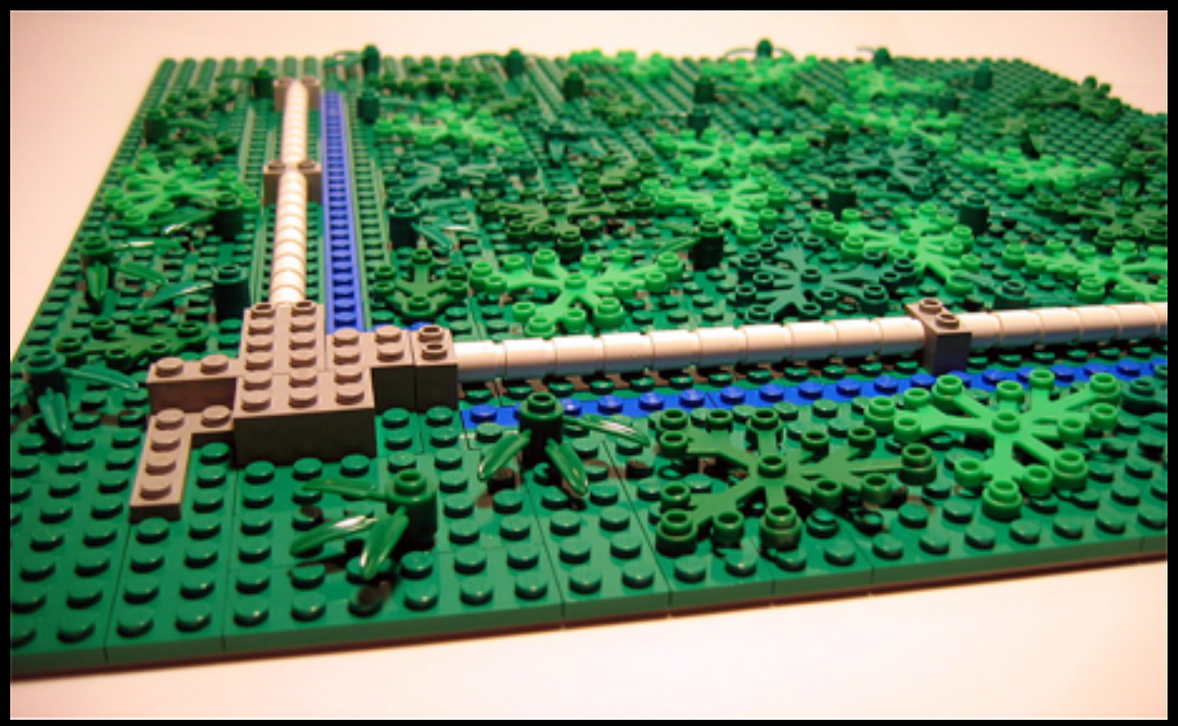
LIGO – Livingston, LA

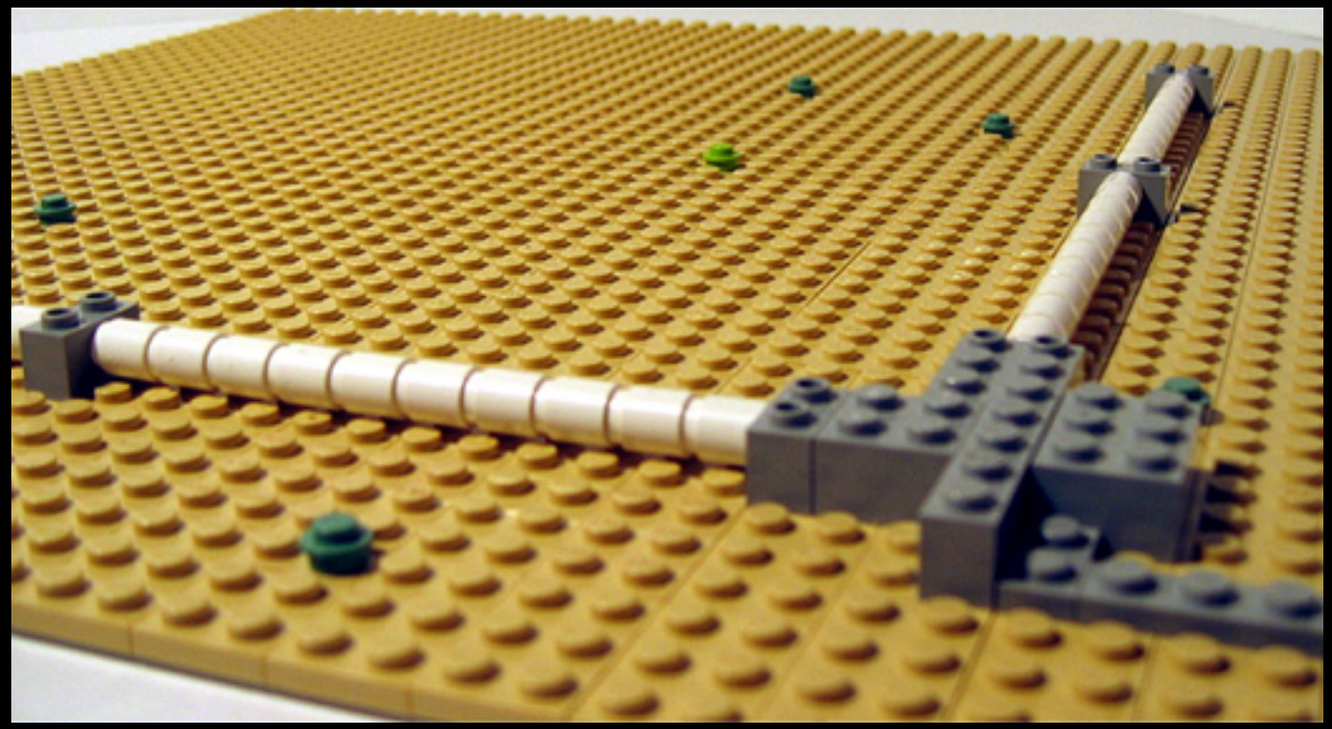
LIGO – Hanford, WA

LIGO





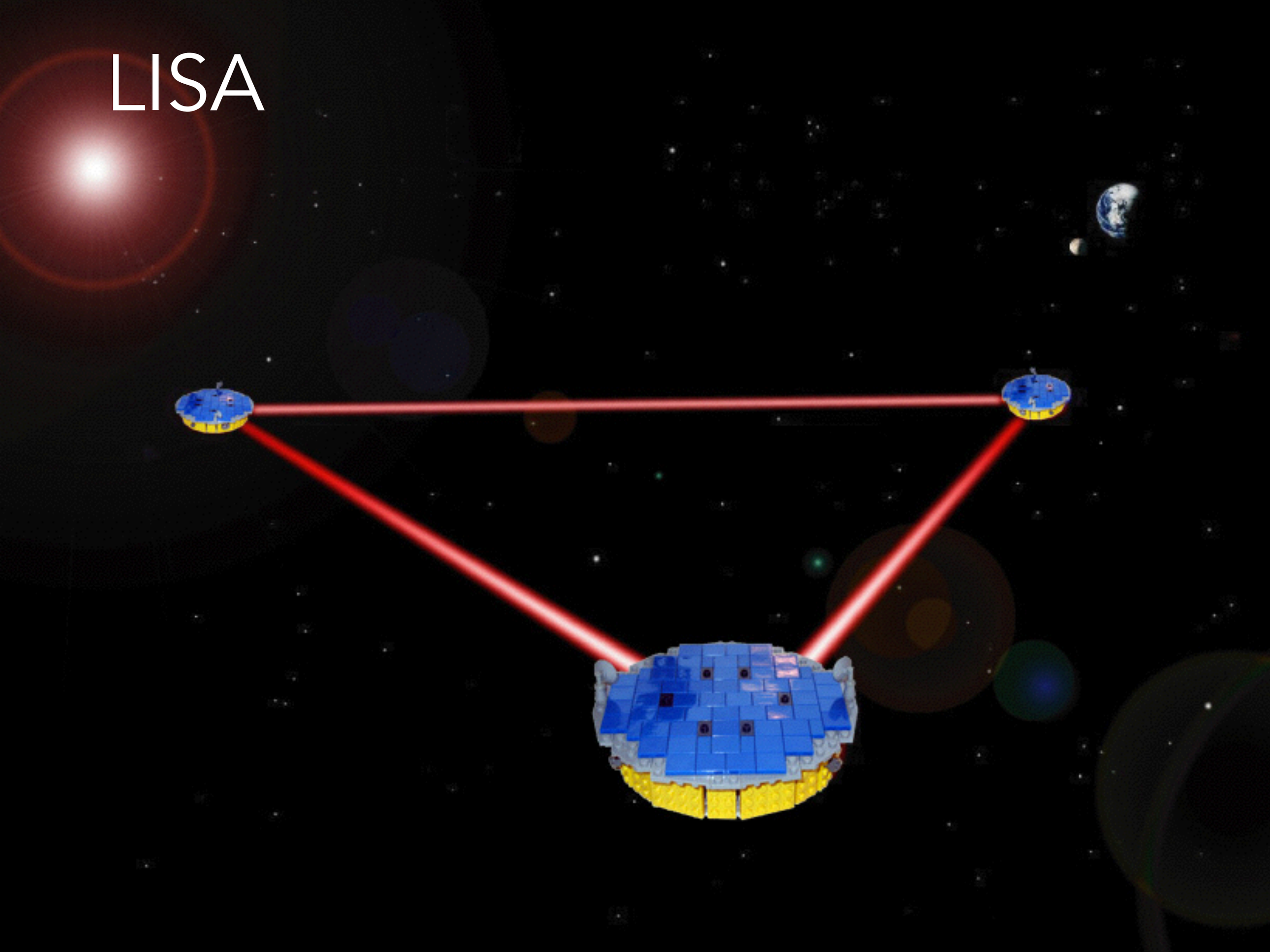




LISA

5million
kilometer arms!

LISA



LISA Pathfinder

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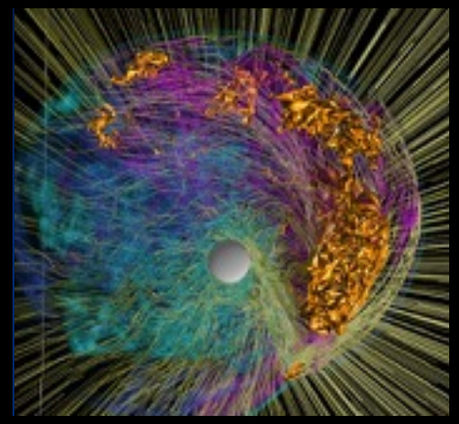

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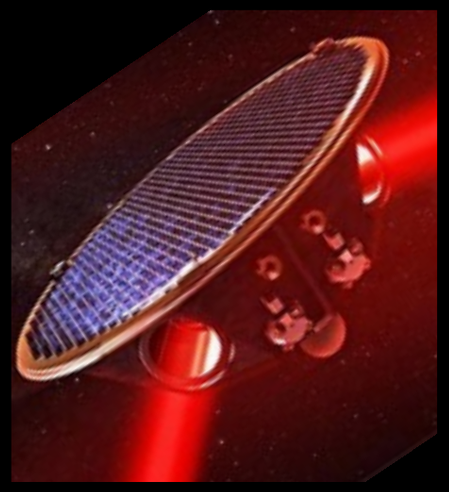
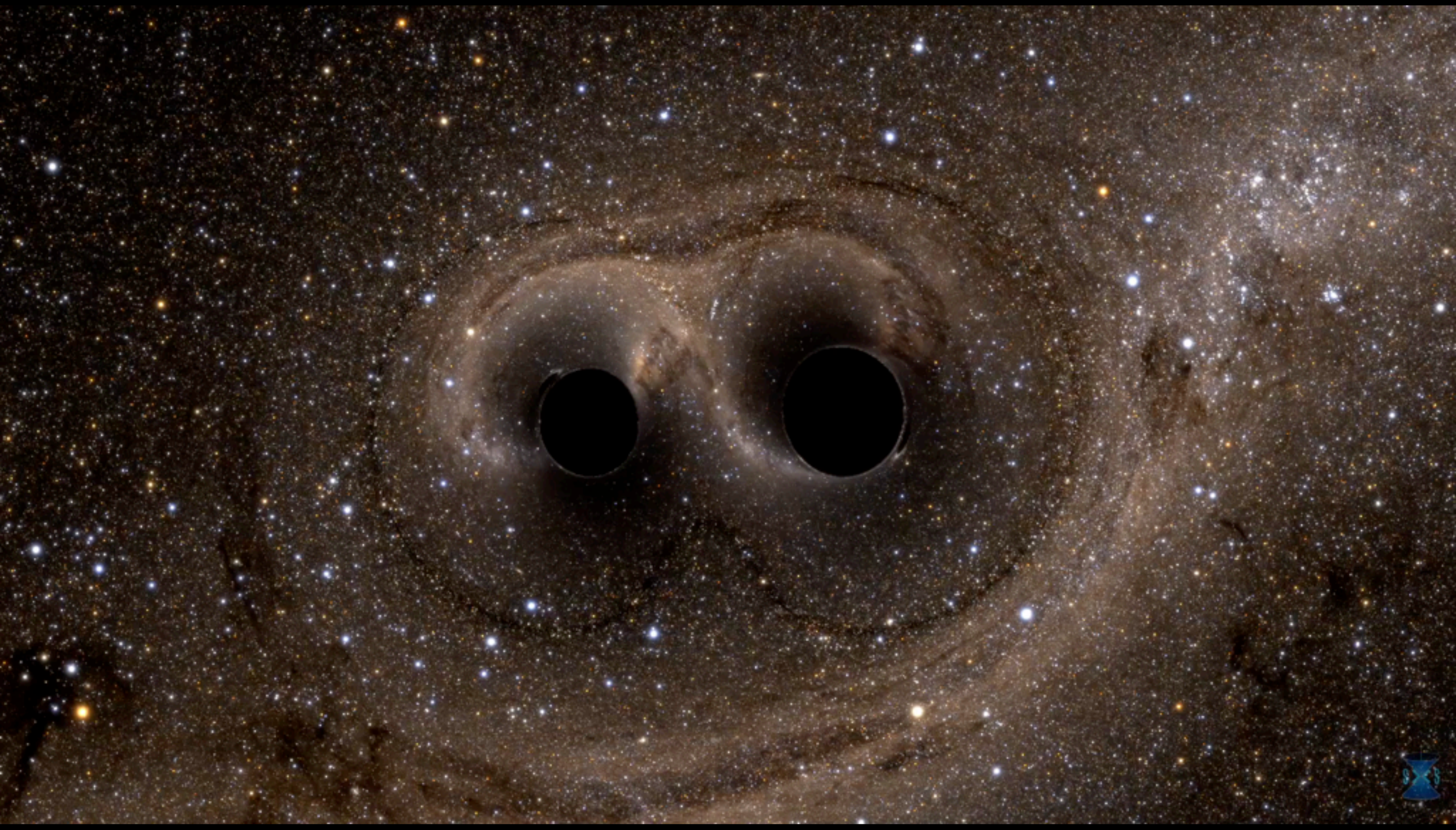


Space

Ground

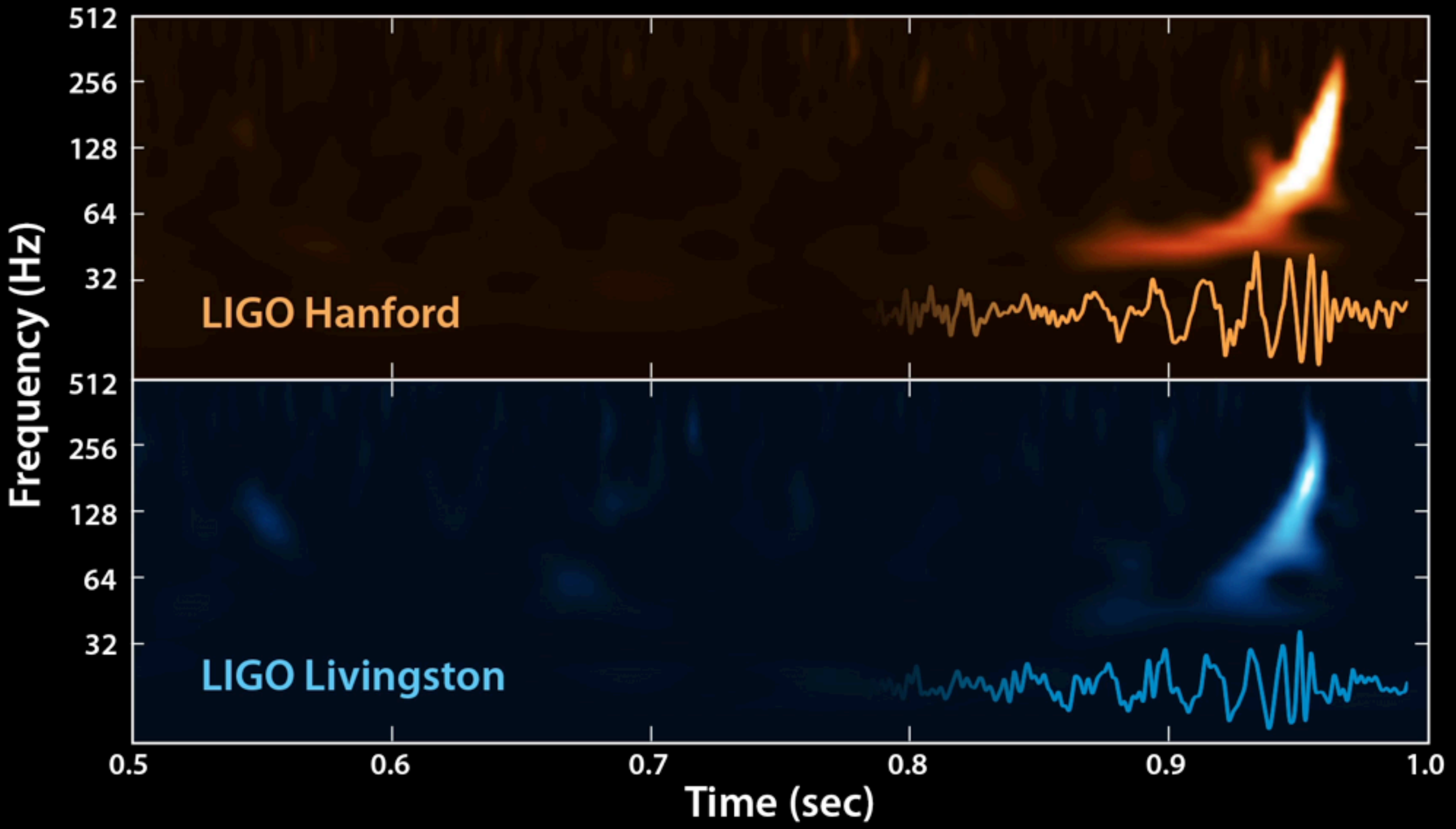
GW150914



29 solar mass black hole + a 36 solar mass black hole

1.3 billion lightyears away (400 Mpc)

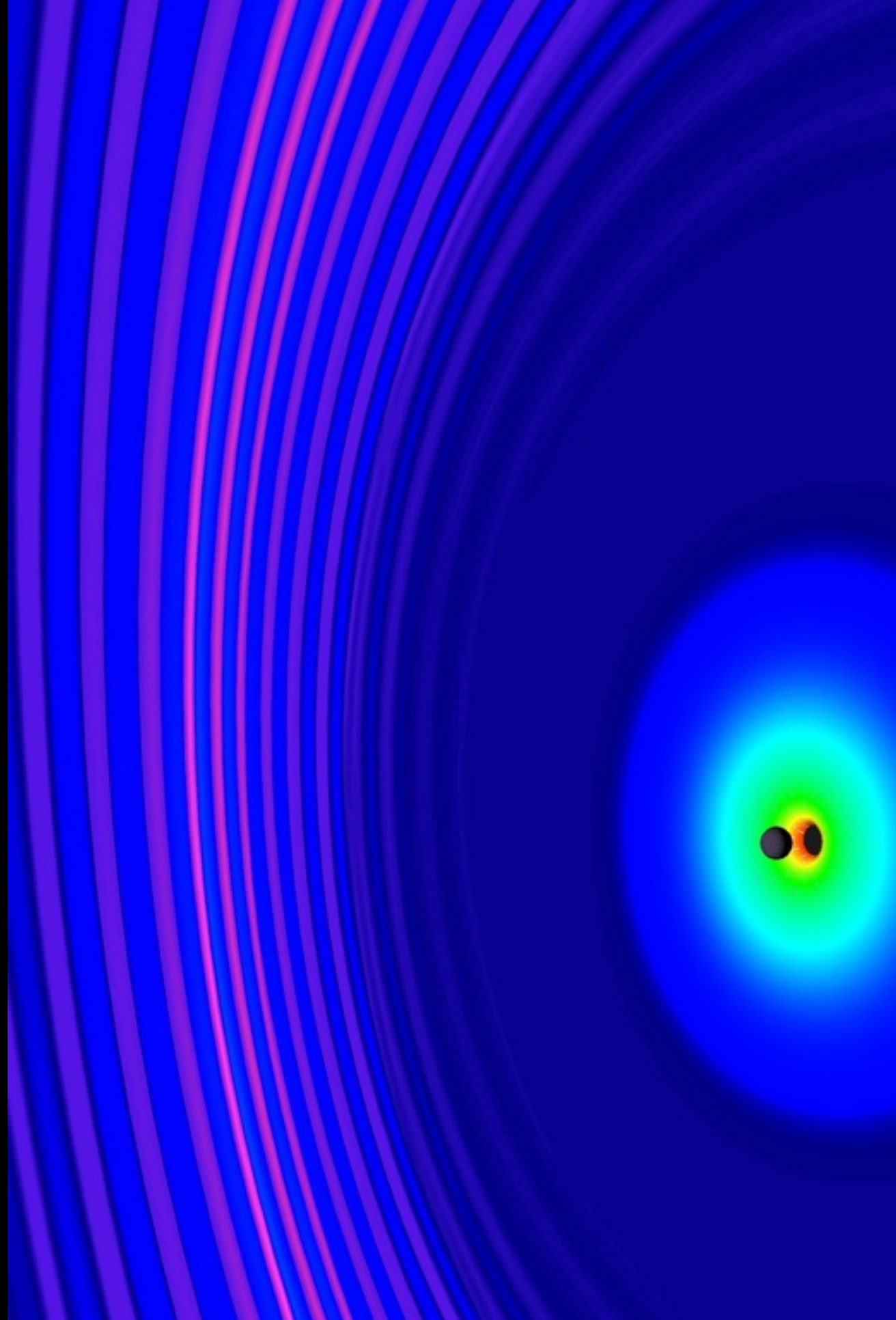
GW150914



C. Messenger (Glasgow)
& LIGO

GW150914

- Surprises
  - Expected the first events would be ***neutron stars***
  - The black holes are ***bigger*** than expected!
- *How many are there?*
- Origin scenarios?



GW150914

- **Population III stars?**
- The first stars form in almost pure hydrogen, and can be **HUGE**.

GW150914

- **Dense stellar clusters?**
- If you pack stars together, they can collect in **runaway mergers**

CR7
ESO/M. Kommesser

Last thoughts…

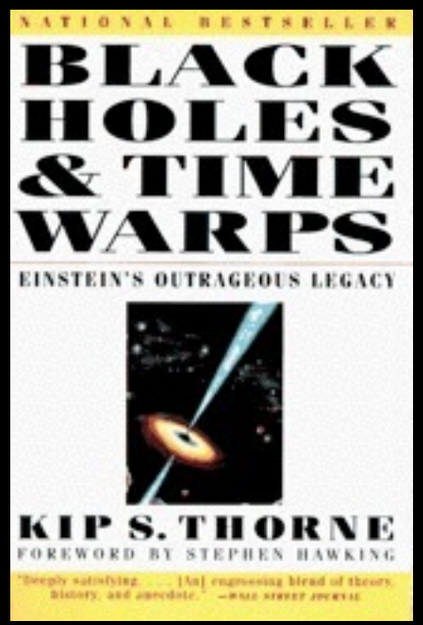
Technology is providing us with new ways to see the Cosmos

Gravity will reveal secrets about the most awesome and enigmatic things astronomers know about

We can see things with gravity that cannot be seen with light!

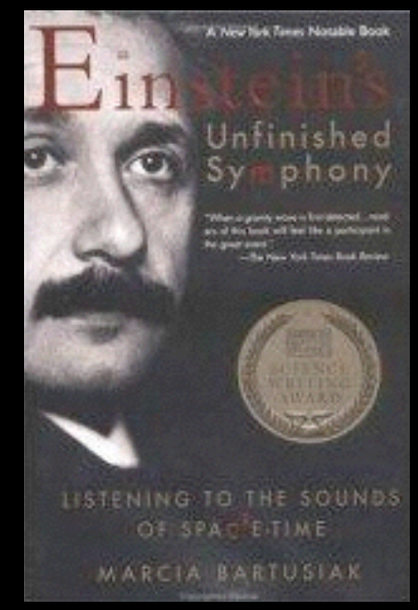
This is just **the beginning…**

A FEW OTHER THINGS TO READ



BLACK HOLES & TIME WARPS (Kip S. Thorne)

Einstein's Unfinished Symphony (Marcia Bartusiak)



Resources

sciencejedi.com/professional/advocacy/

tinyurl.com/GWtemplate

tinyurl.com/GWmeasure

tinyurl.com/ligoDetection

Blog & Videos

writescience.wordpress.com

tinyurl.com/grCentennial

tinyurl.com/grVideos

tinyurl.com/ligoYouTube

ADLER PLANETARIUM CIERA

THANKS!

EXTRA SLIDES

CIERA

ADLER
PLANETARIUM

1932
Karl Jansky
Radio Astronomy

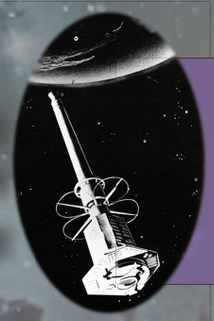
1965
Penzias & Wilson
Microwave Astronomy

1977
WIRO
Infrared Astronomy

1609
Galileo
Optical Astronomy

1962
Sounding Rockets
X-ray Astronomy

1961
Explorer 11
Gamma-ray Astronomy



1912
Hess
Cosmic-ray Astronomy

1968
Davis & Bahcall
Neutrino Astronomy

2016+
LIGO
Gravitatoinal
Wave Astronomy

10^{3}

10^{-2}

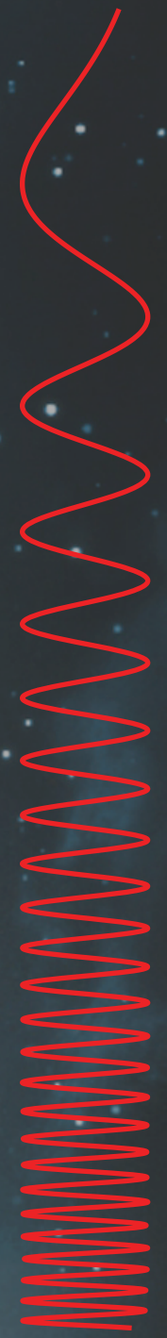
10^{-5}

5×10^{-7}

10^{-8}

10^{-10}

10^{-12}



Chirping Binaries

- Gravitational waves provide a unique method for measuring **distance**

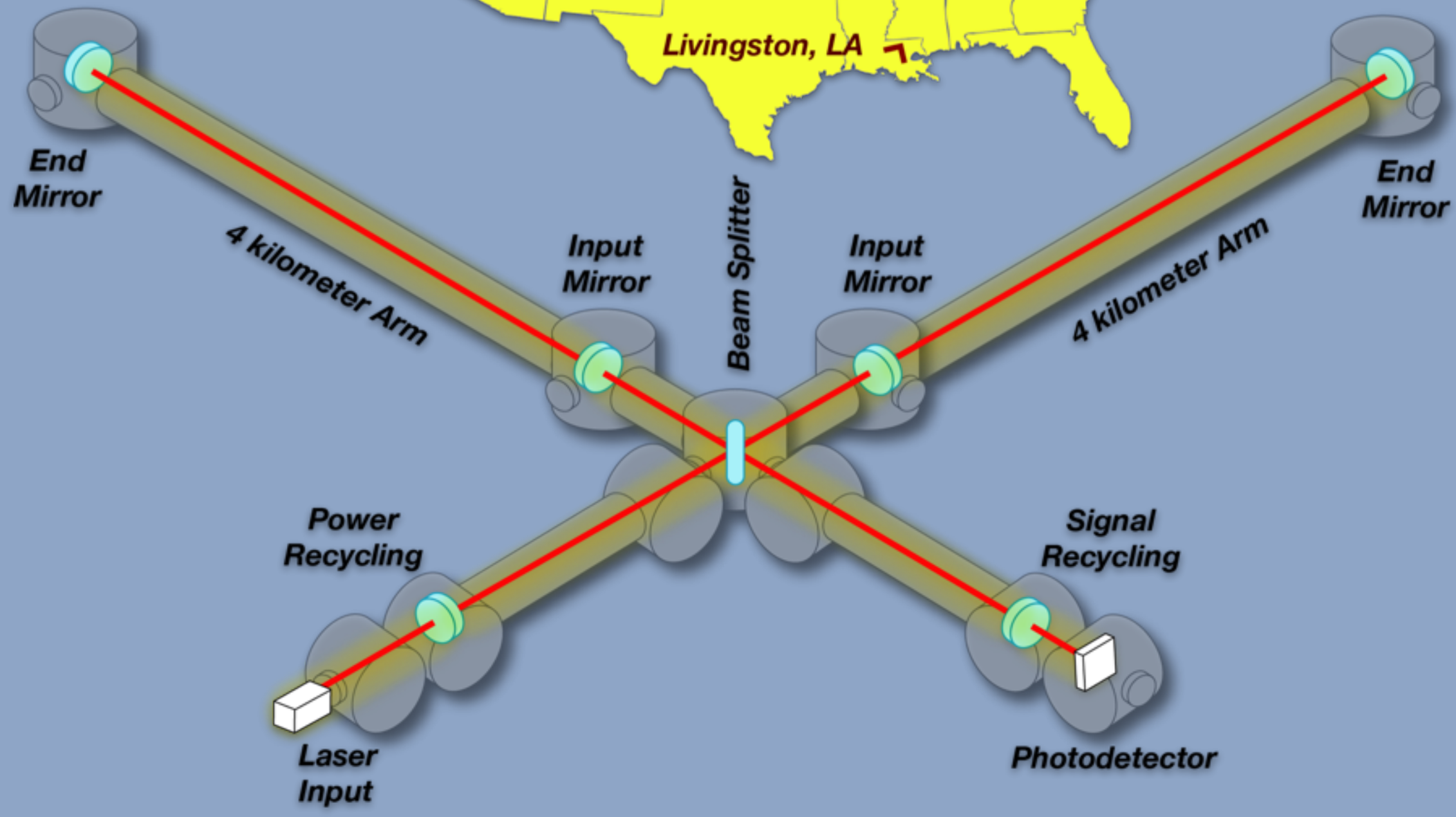
$$h = \frac{\mathcal{M}_c}{D} \left(\pi f \mathcal{M}_c\right)^{2/3}$$

$$\dot{f} = \frac{96}{5} \frac{f}{\mathcal{M}_c} \left(\pi f \mathcal{M}_c\right)^{8/3}$$

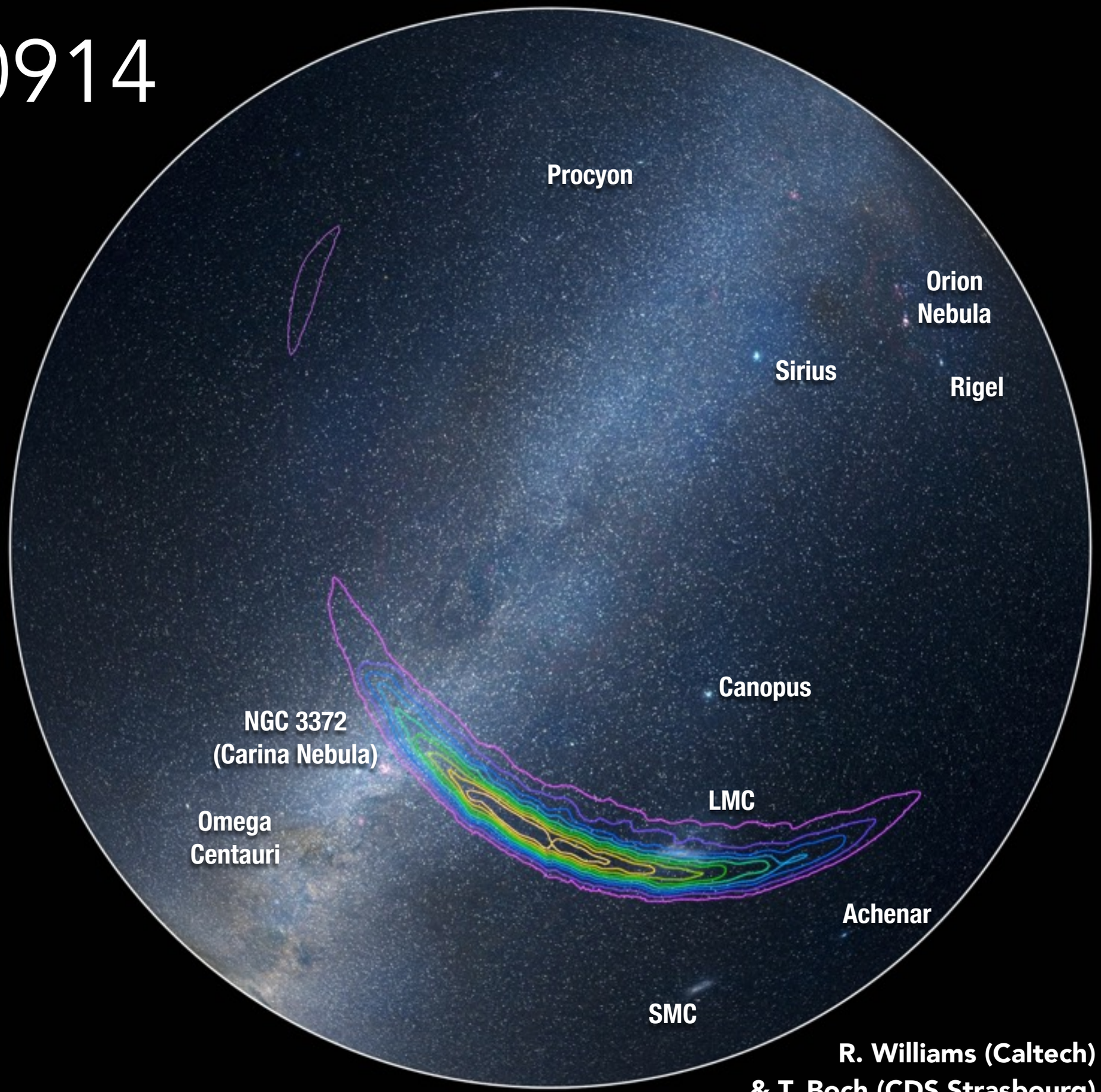
$$D = \frac{5}{96\pi^2} \frac{1}{h} \frac{\dot{f}}{f^3}$$

LIGO


Hanford, WA
Livingston, LA


End Mirror
4 kilometer Arm
Input Mirror
Beam Splitter
Input Mirror
4 kilometer Arm
End Mirror
Power Recycling
Signal Recycling
Laser Input
Photodetector

GW150914



R. Williams (Caltech)
& T. Boch (CDS Strasbourg)