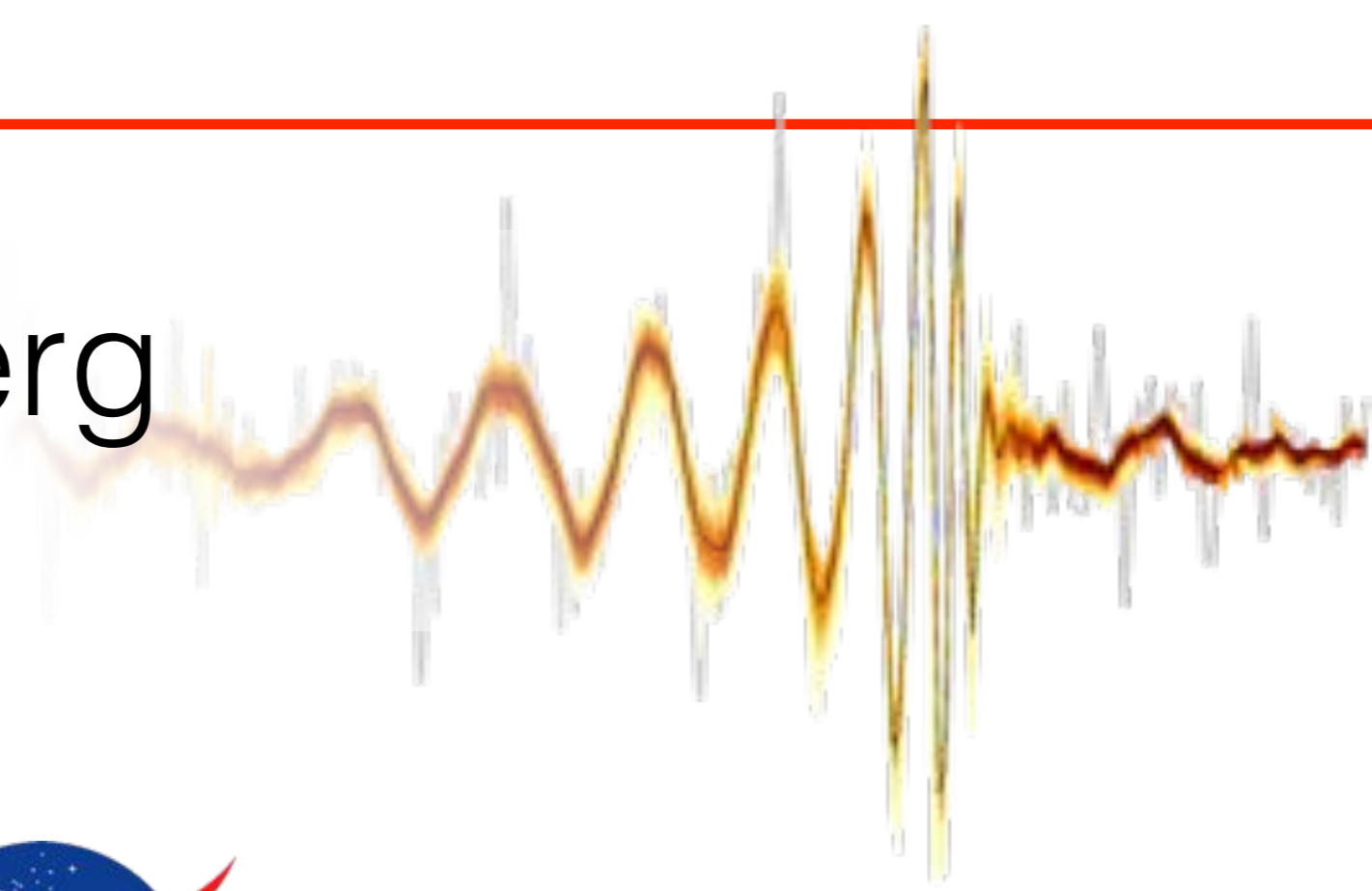


Gravitational Wave Astronomy

Tyson B. Littenberg

NASA/Marshall Space Flight Center











LIGO



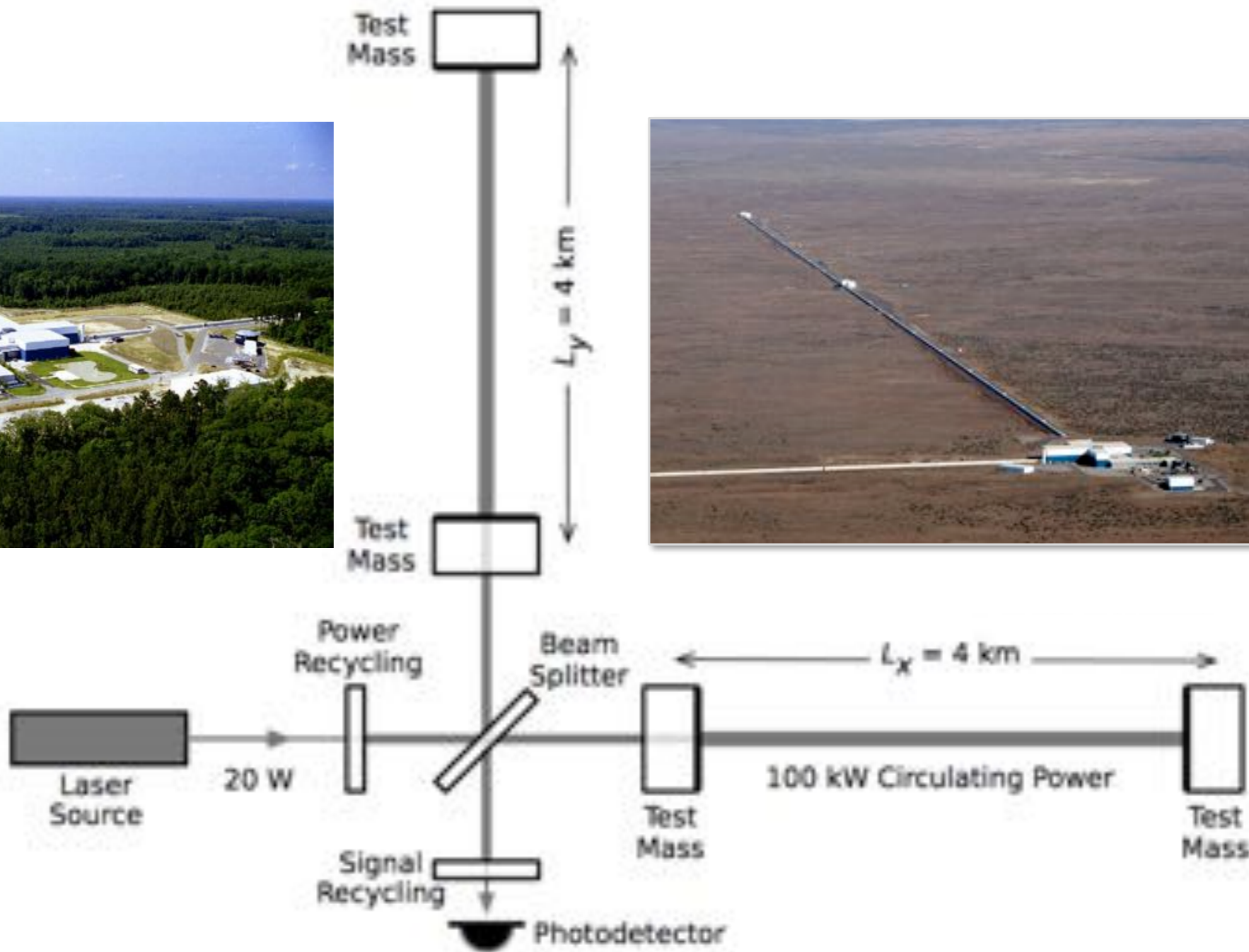
LASER

INTERFEROMETER

GRAVITATIONAL

WAVE

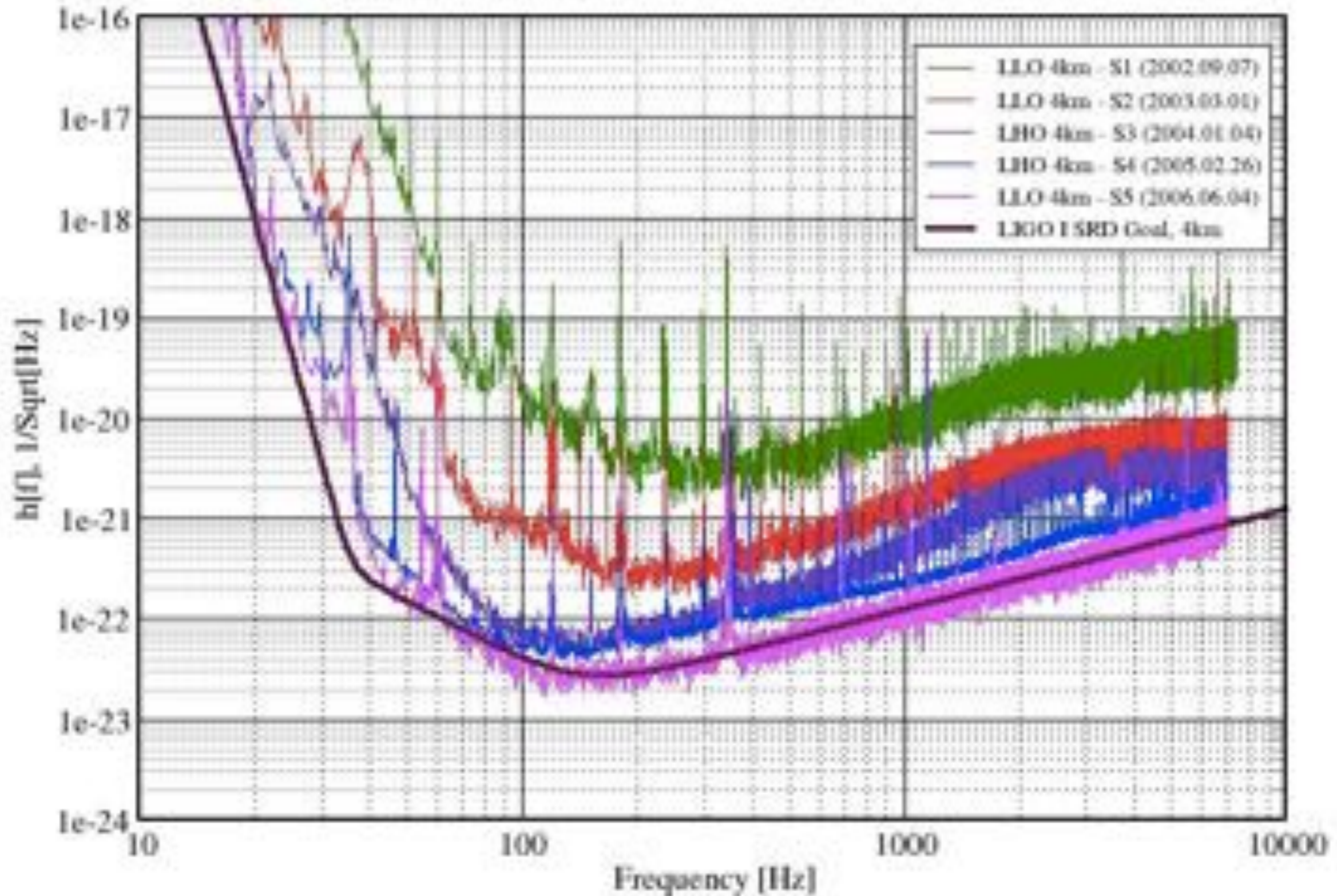
OBSERVATORY

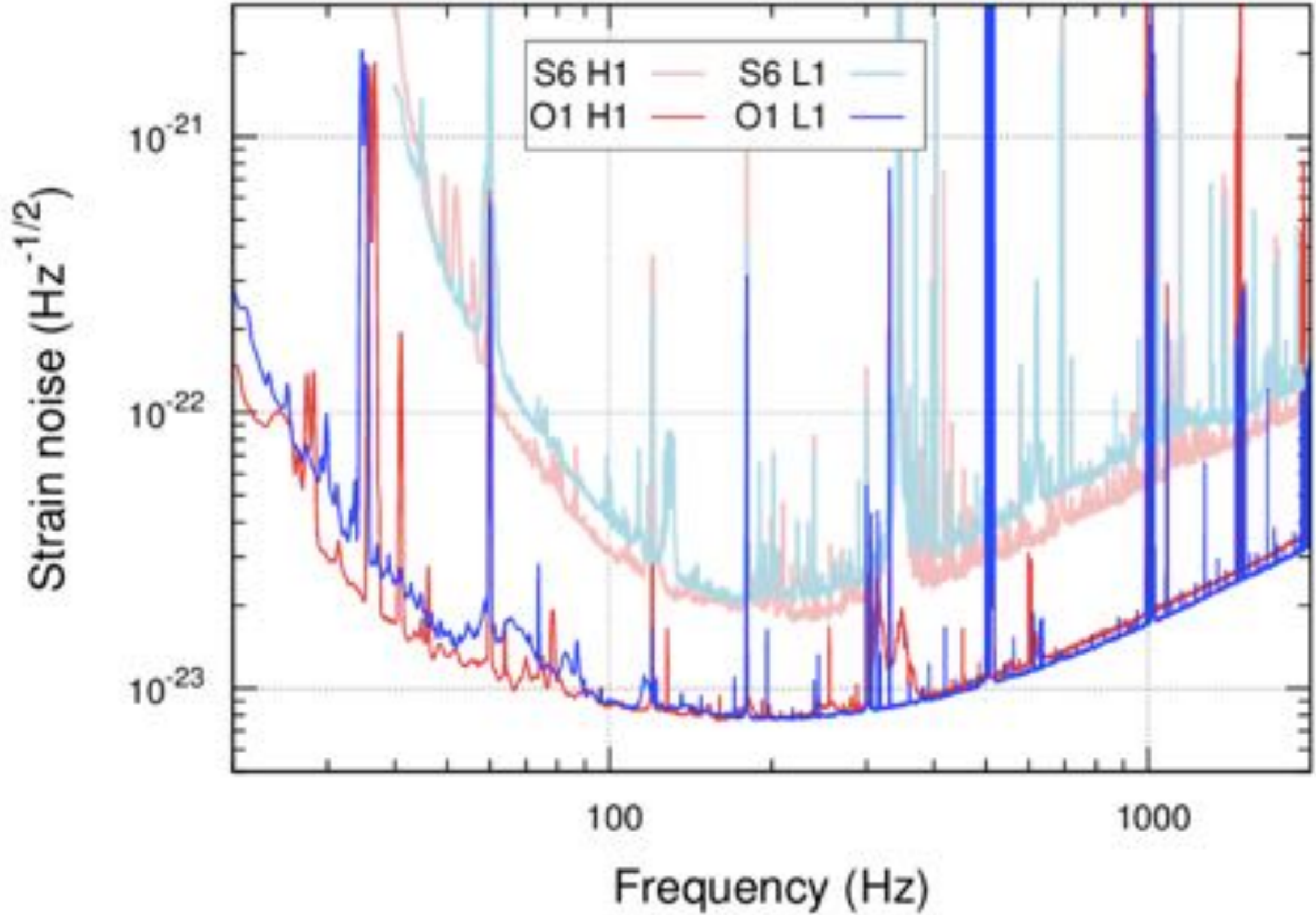




Best Strain Sensitivities for the LIGO Interferometers

Comparisons among S1 - S5 Runs LIGO-G060009-02-Z

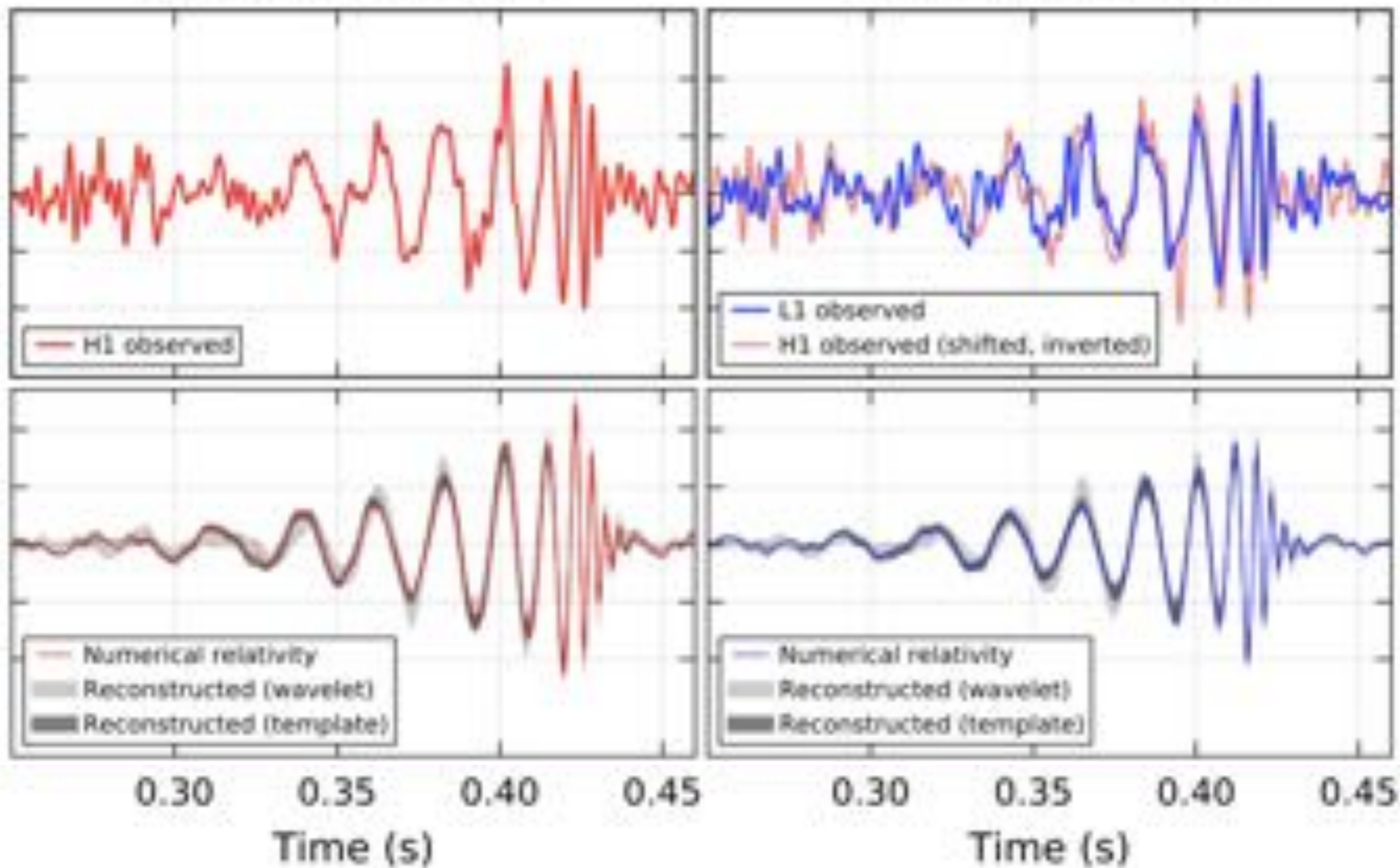


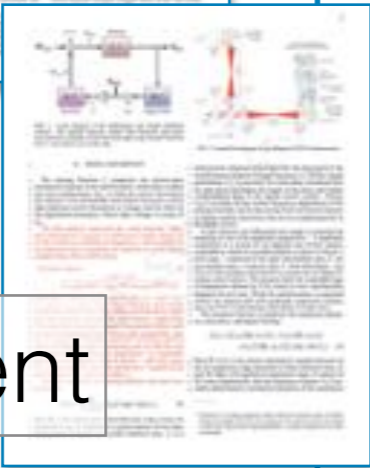
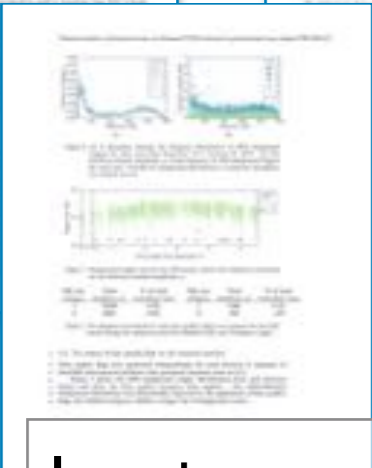
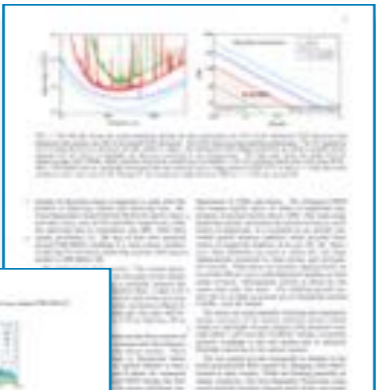
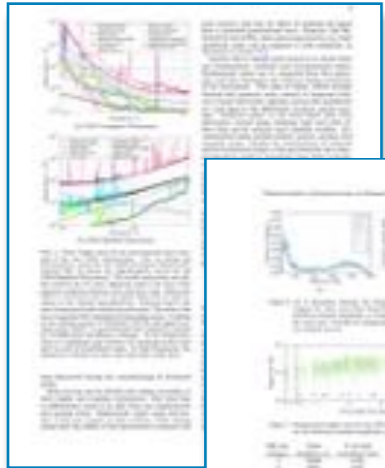




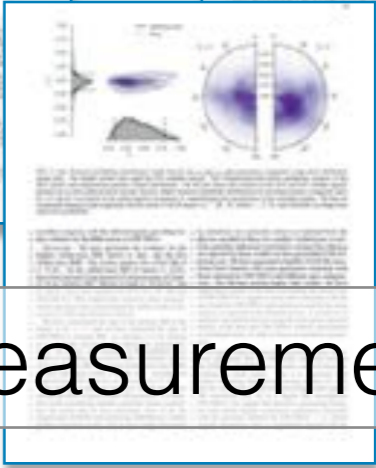
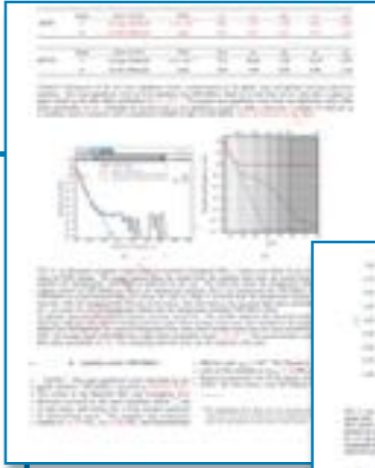
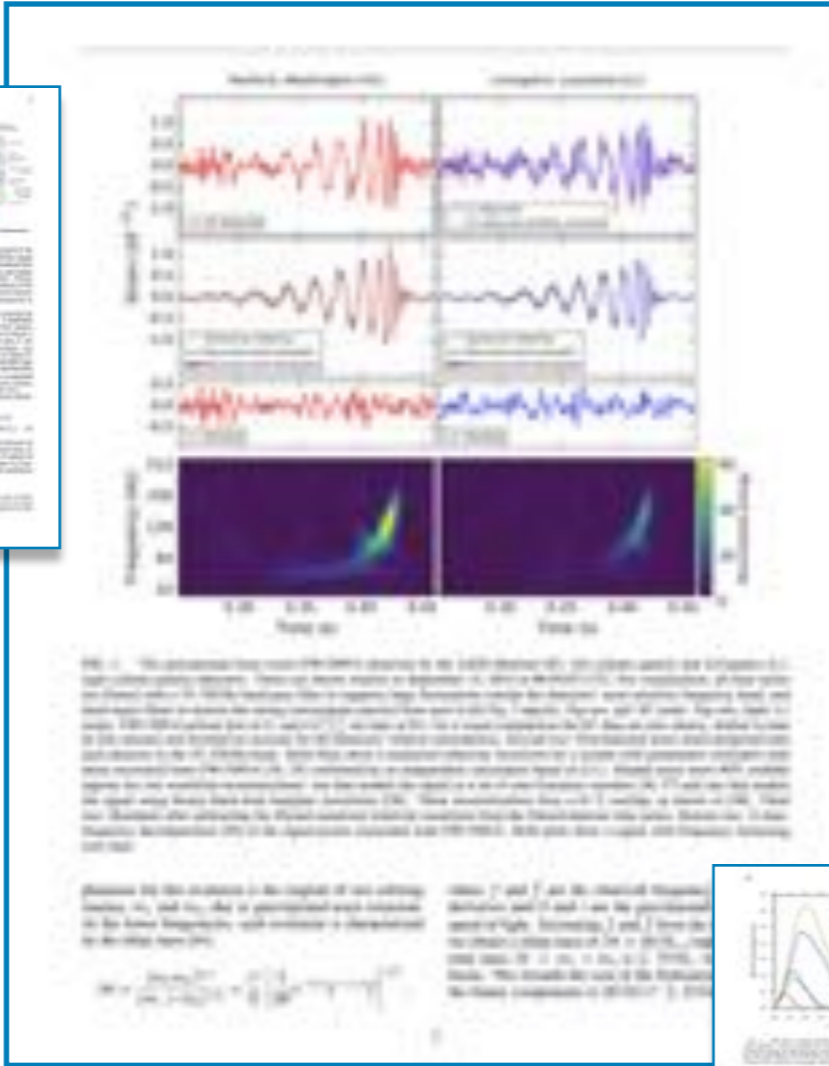
Hanford, Washington (H1)

Livingston, Louisiana (L1)

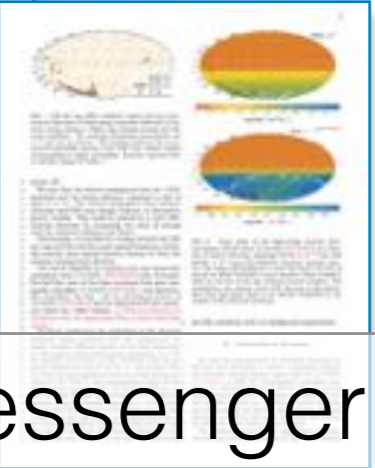
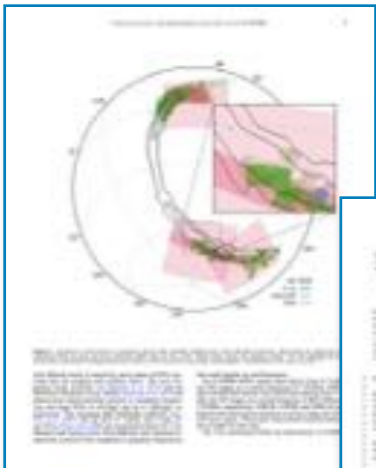




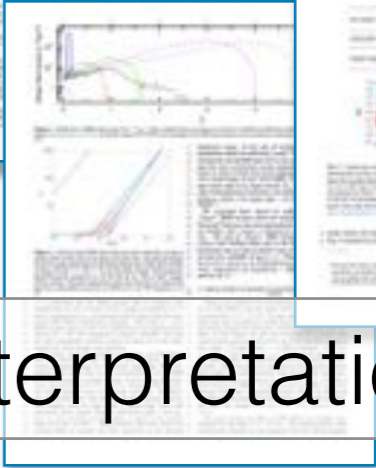
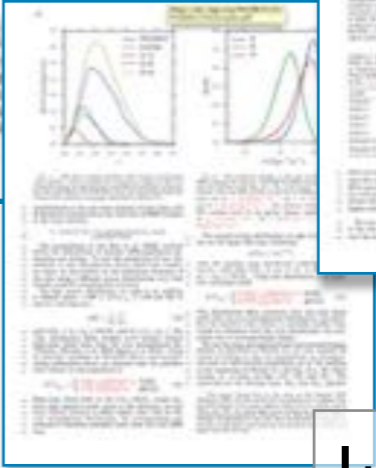
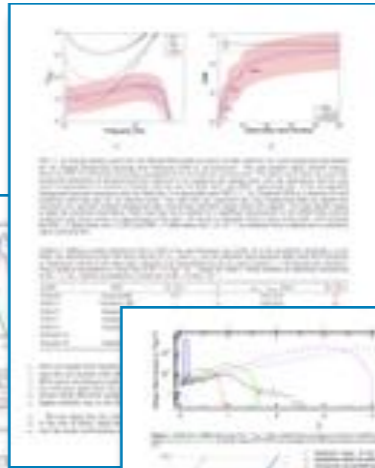
Instrument



Measurement



Multimessenger



Interpretation

The Bakersfield Californian
 THURSDAY, FEBRUARY 24, 2011 11:00 AM BAKERSFIELD, CALIF. 93311

MAKING WAVES

Lawsuit disputes union access to farms

500X **4.30**

The Huntsville Times

UAH 'AT THE CENTER' OF CONFIRMING EINSTEIN'S THEORY OF RELATIVITY

Huntsville ready to welcome Uber, Lyft and Zipcar

Lawmakers hold key to building mega-prisons

500X **4,000 ON** **249**

The Washington Post

U.S., Russia agree to a halt in Syrian war

Faculty line spotlighted in W. debate

U.S. House passes bill to fund Syria war

U.S. House passes bill to fund Syria war

The New York Times

U.S. House passes bill to fund Syria war

U.S. House passes bill to fund Syria war

U.S. House passes bill to fund Syria war

SANTA FE NEW MEXICAN

Hooper exits needed to counter 'You fell' Smith says

With faint chirps, scientists prove Einstein correct

LANL crew had faith discovery was matter of time

Measure to alter Army scholarship funding advanced

People's

LISTENING TO A WINTERWONDERGRASS

THE DENVER POST

"The skies will never be the same."

Ch. 11 may let chain play ball

EPH employees will be knee of chaos of new format

Surprise Valentine's Day **KING**

The Gazette

Edged in the end at Indiana

Cricket Hollow Zoo visitations 'pervasive,' judge finds

Einstein was right
 And here's why it matters

God's escape from recent past could prompt changes in procedure

Get Your Heart Right Take your Libby's!

The Boston Globe

Rivals debate their support for Obama

A whisper from across the universe

Deal set for trace, aid drops in Syria

Parents sue nurse after 17-month-old's murder case

With focus of film, a crucial protest

SLEEPYS
 Doorbusters 6 Hours Only!

The Bakersfield Californian
FRIDAY, FEBRUARY 12, 2016 • BAKERSFIELD.COM

MAKING WAVES Gravitational waves, that is: New scientific observation affirms Einstein's general theory of relativity
USA TODAY | 30

Lawsuit disputes union access to farms
Practice-related laborers' constitutional protection, challenge claims, if successful, will could hamper efforts by United Farm Workers to connect with ag laborers
USA TODAY | 2

At Democratic debate, Sanders, Clinton spar over plans for change
USA TODAY | 2

'Warmed Deadpool,' starring Ryan Reynolds, on loss at the shallow end
USA TODAY | 2

Bakersfield High captures 10th straight

The Huntsville Times

UAH 'AT THE CENTER' OF CONFIRMING EINSTEIN'S THEORY OF RELATIVITY

Huntsville ready to welcome Uber, Lyft and Zipcar

Lawmakers hold key to building mega-prisons

The Washington Post

U.S., Russia agree to a halt in Syrian war

Ex-will's tip led to gunfire at Md. Plaza

Fault line spotlighted in Wis. debate

Oregon siege ends as four surrender

Gravitational waves

The New York Times

U.S., Russia agree to a halt in Syrian war

Long in Clinton's Cabinet, Black's Notice Sanders

Lawmaker's tip led to gunfire at Md. Plaza

WEEKEND UPDATE: VON MILLER

The Denver Broncos linebacker and Super Bowl MVP discusses the discovery of gravitational waves.
(Season 45, 2016)

[MORE INFO](#)



Measure to alter lottery scholarship funding advances

As more wash ashore, severed feet pose mystery in Pacific Northwest

Passapick

Surprise your loved one this Valentine's Day

WING CHANG

Let Your Heart Skip a Beat on your Valentine!

Einstein was right

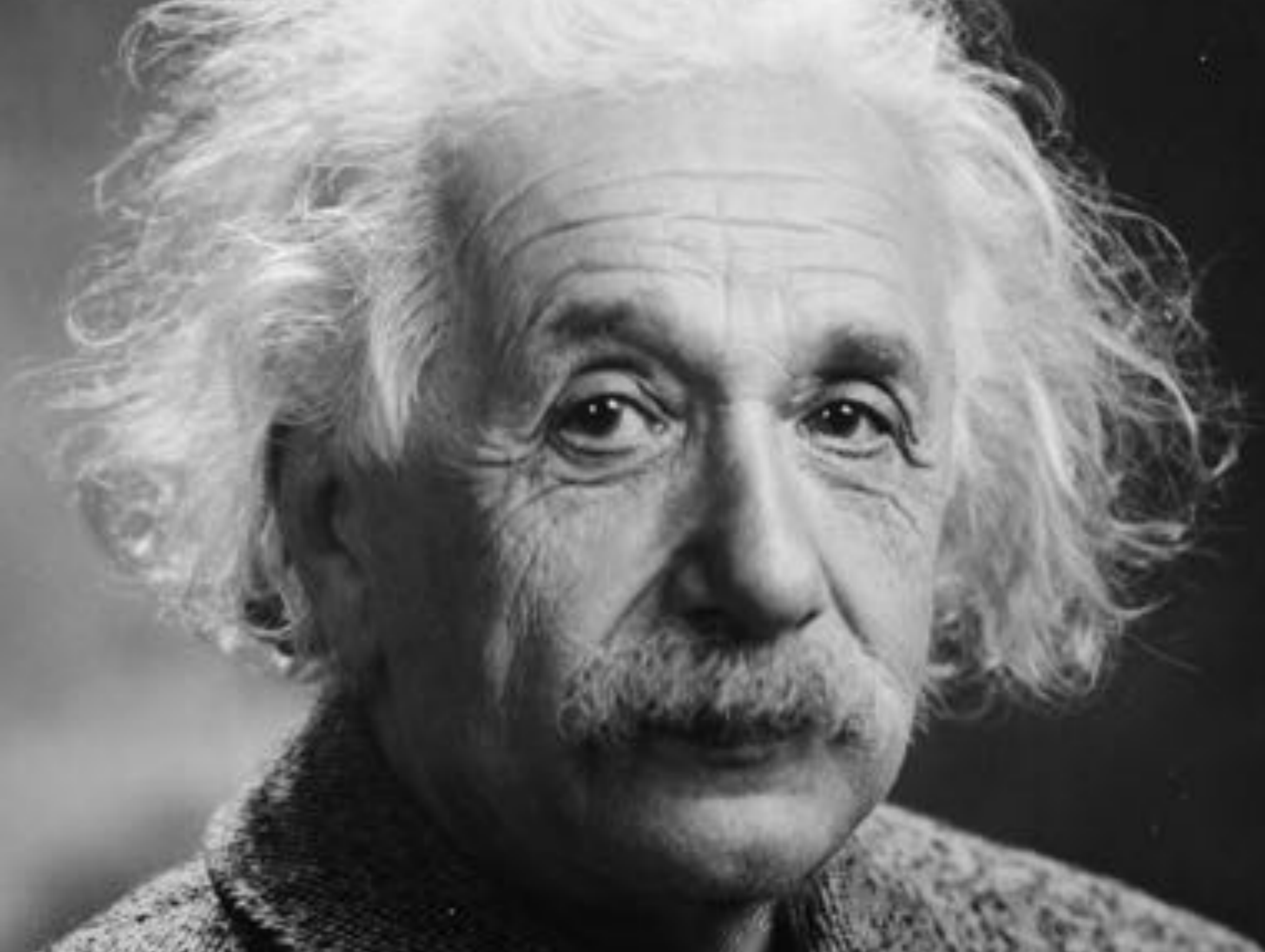
And here's why it matters

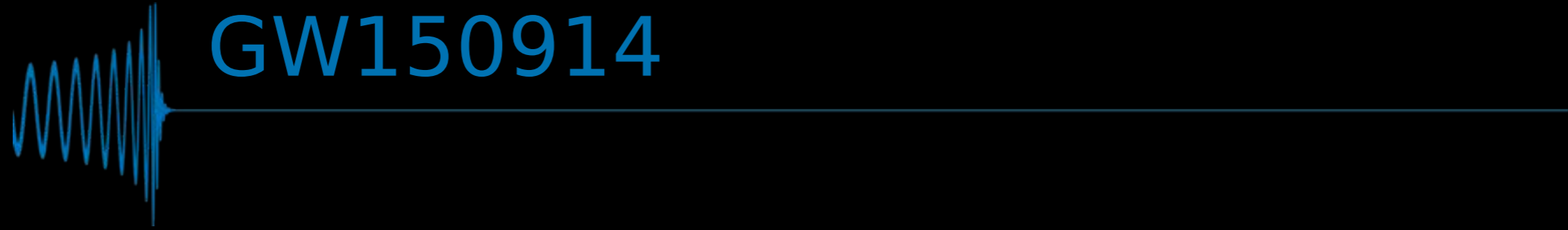
Goal's escape from research park could prompt changes in procedure

With flurry of data, a no-school predictor

DA abandons murder case

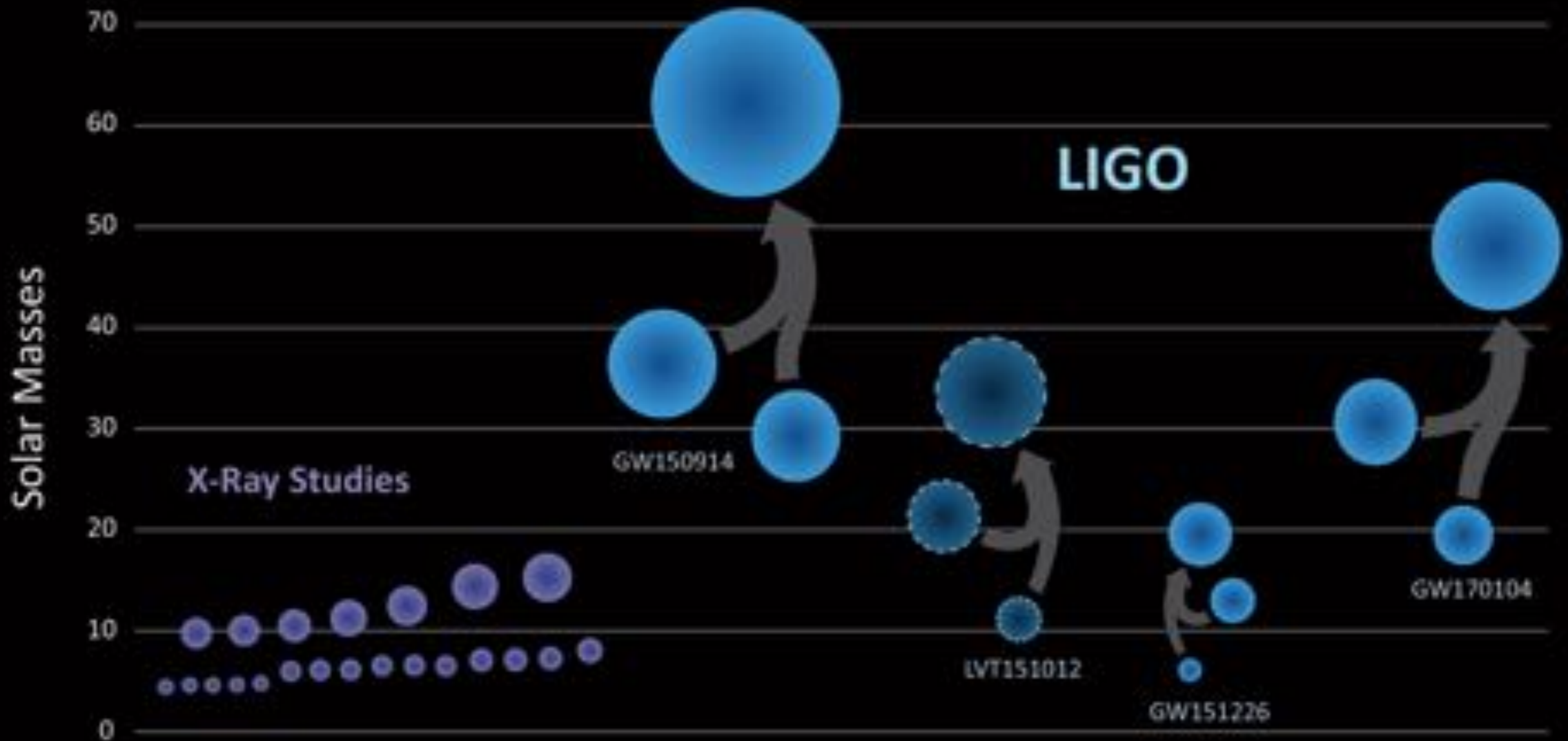
SLEEPYS
The Mattress Professionals
Doorbusters 6 Hours Only!
SATURDAY 10AM-4PM





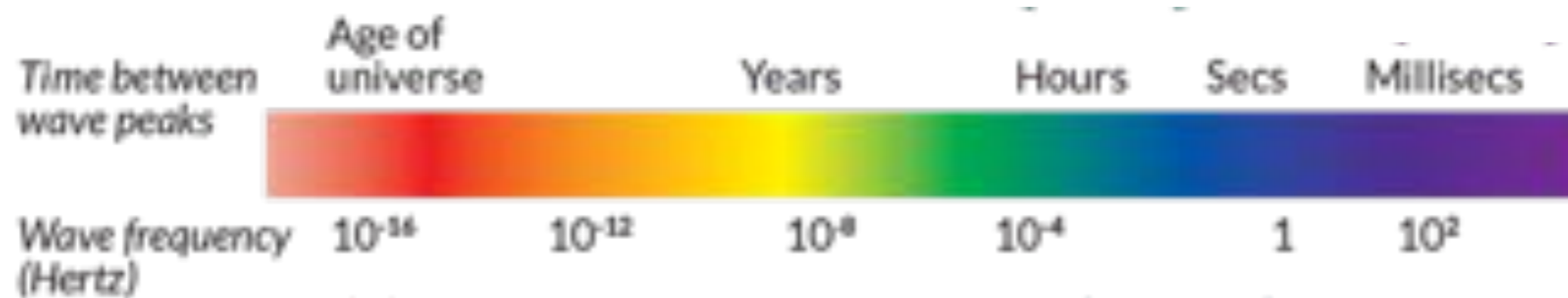
time observable by LIGO

Black Holes of Known Mass

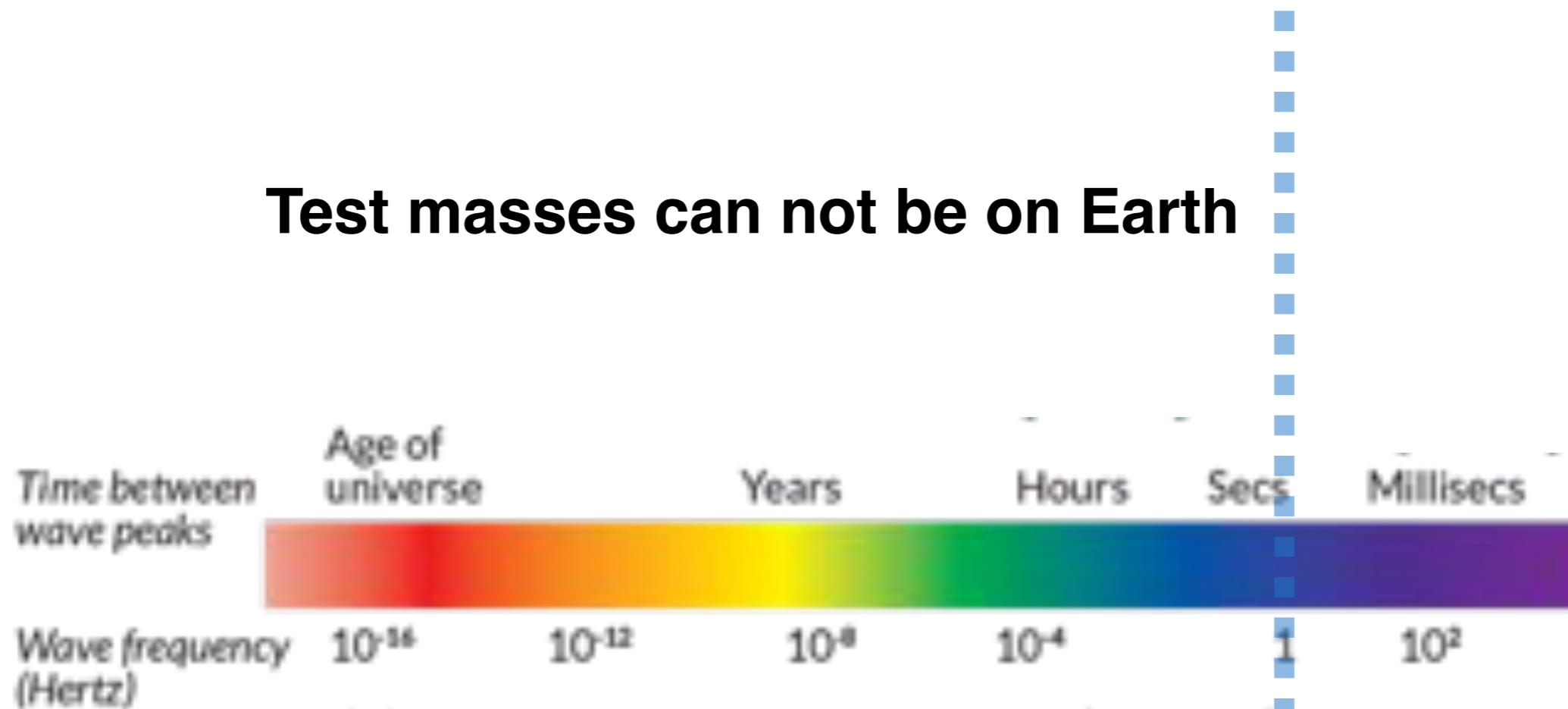




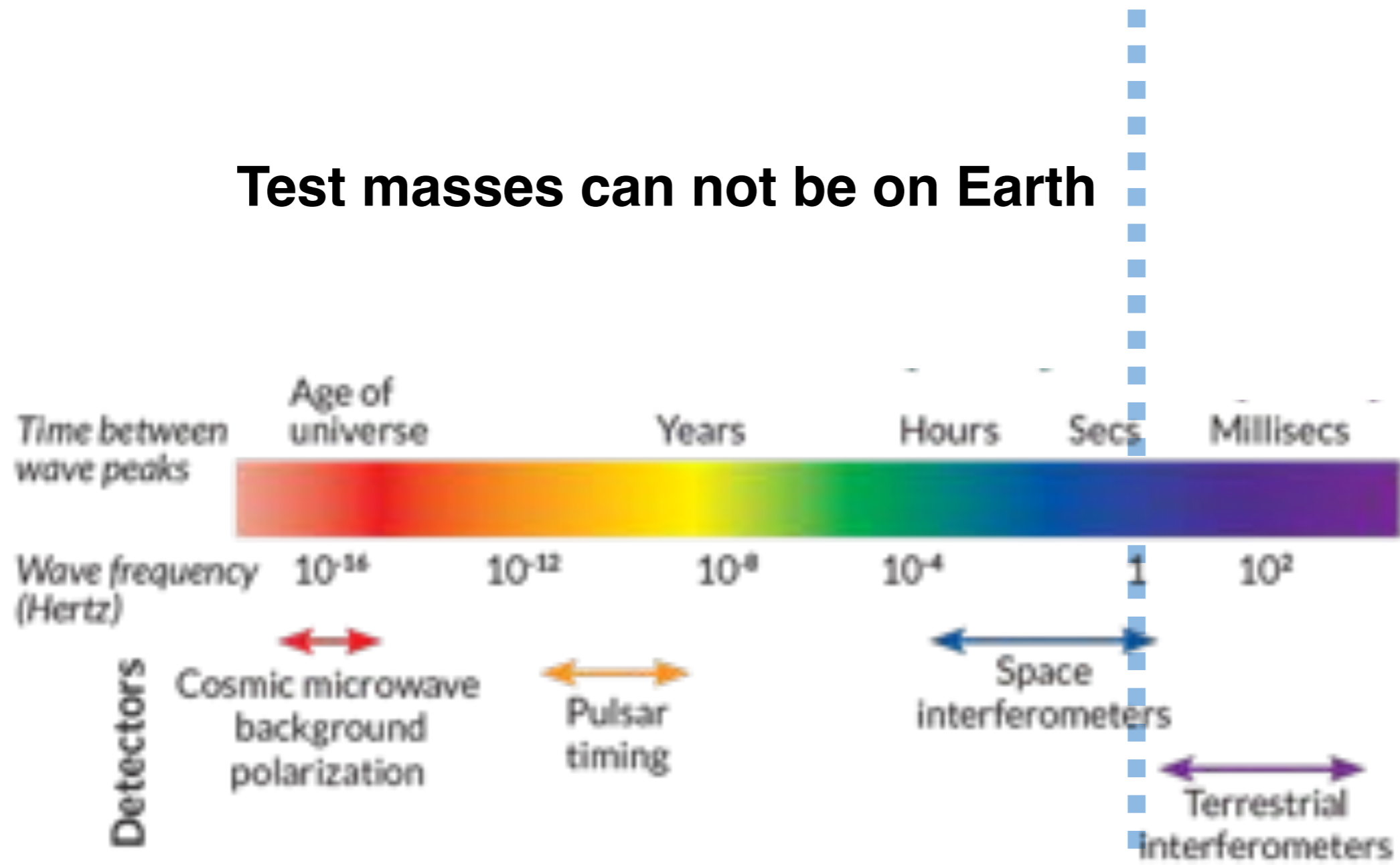


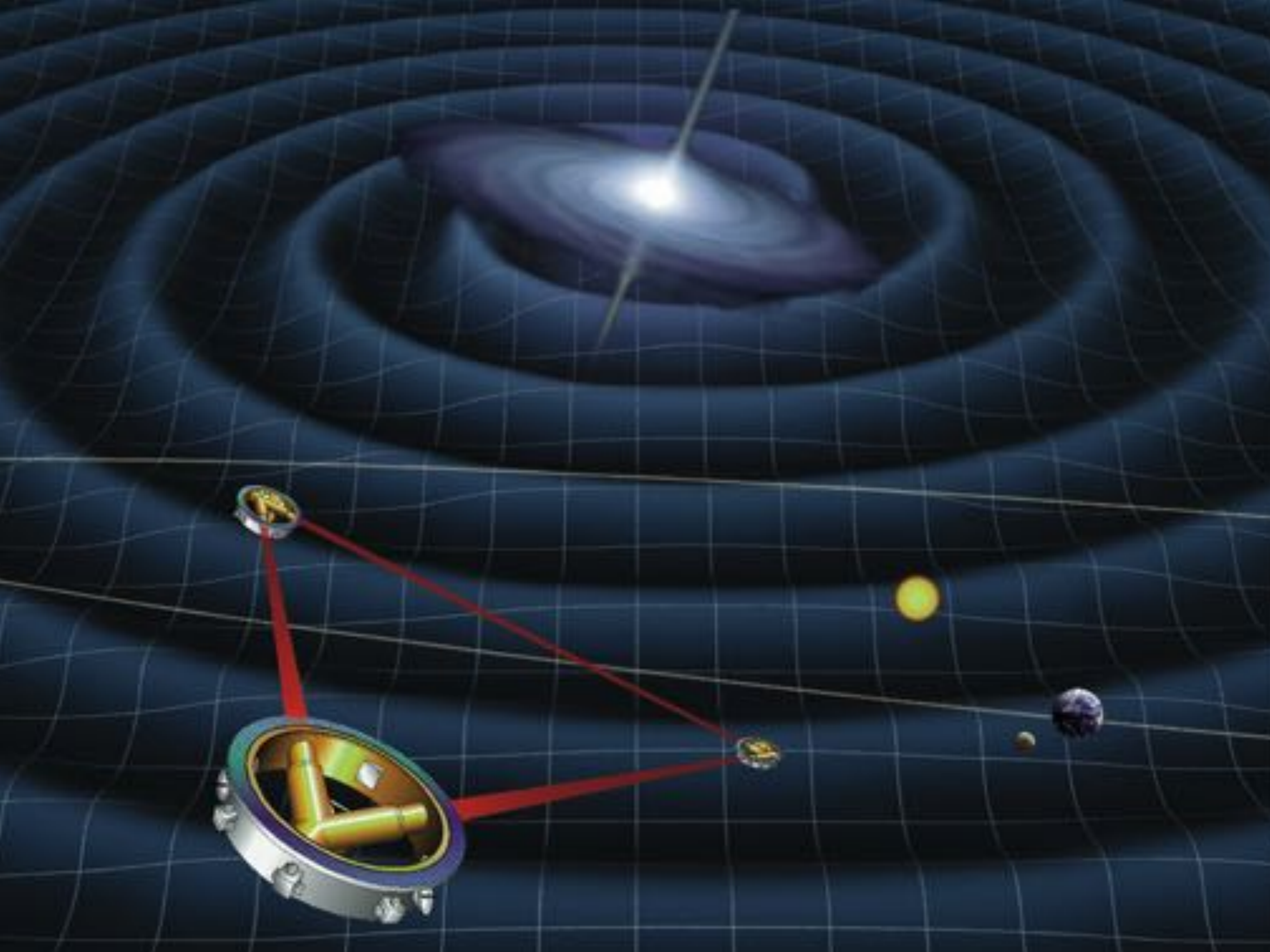


Test masses can not be on Earth

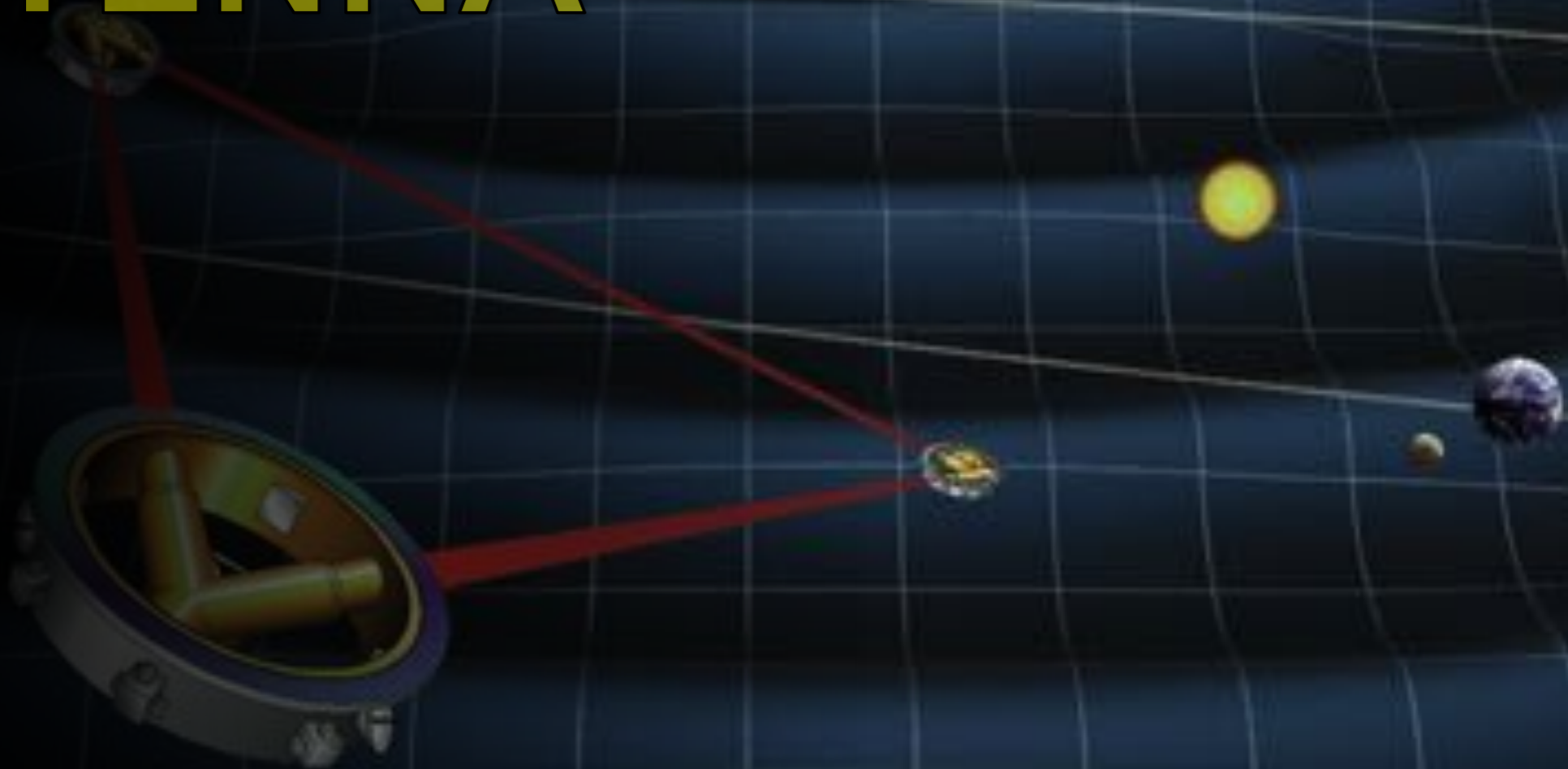


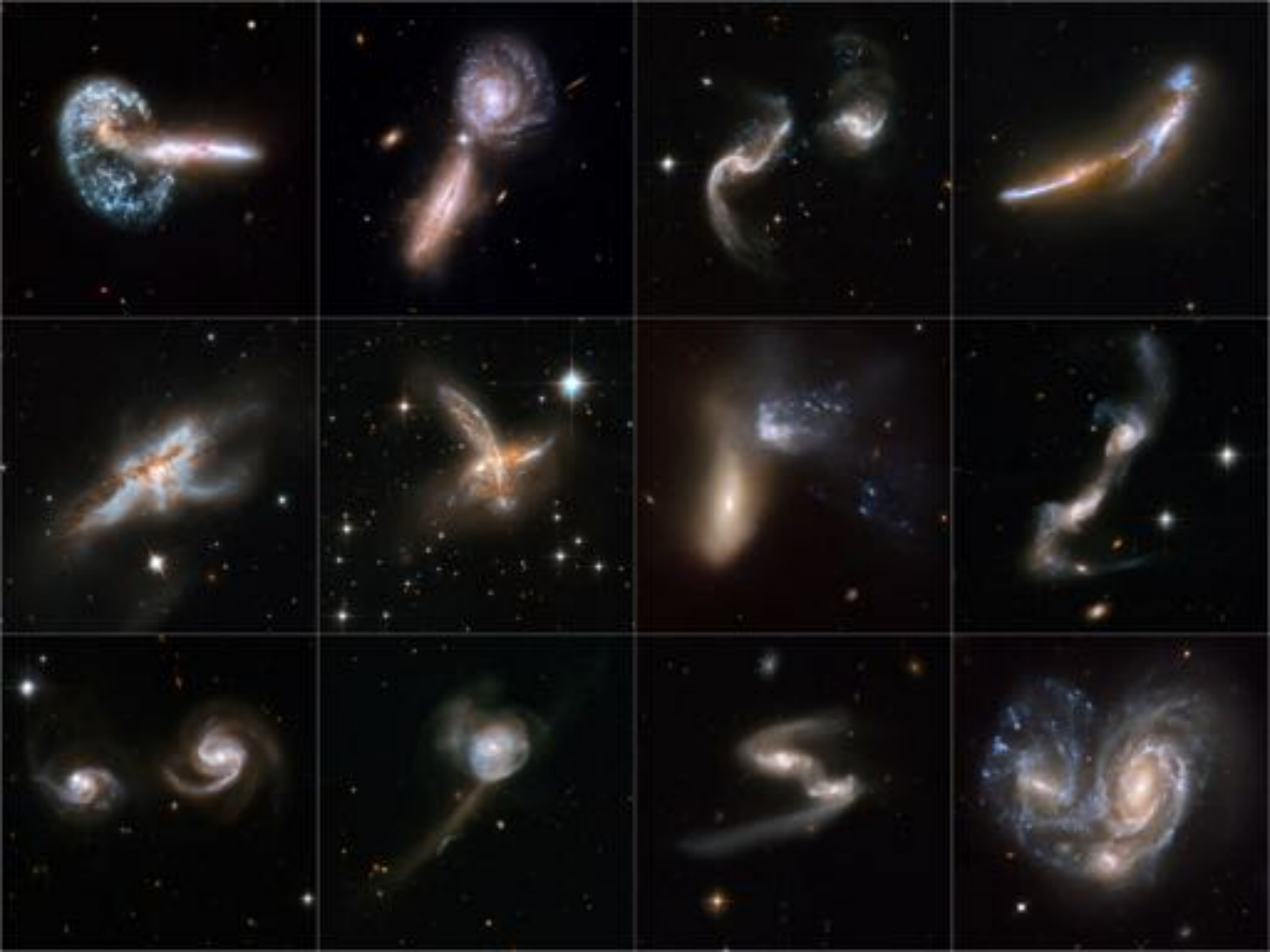
Test masses can not be on Earth





LASER INTERFEROMETER SPACE ANTENNA







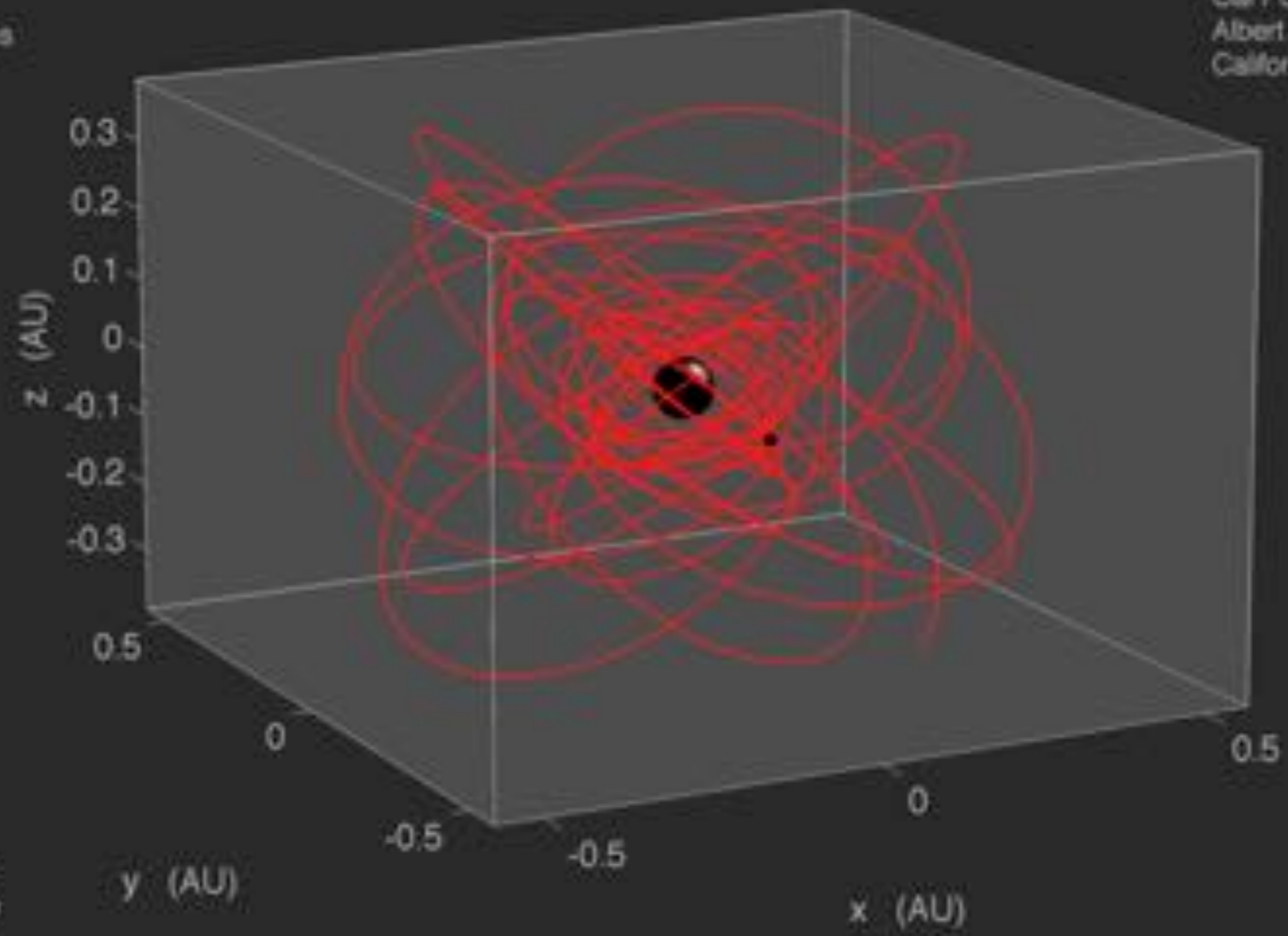
100 days before merger, 28% of light speed

Steve Drasco
Cal Poly, San Luis Obispo
Albert Einstein Institute
California Institute of Technology

Large black hole:
shown to scale
3,000,000 solar masses
90% maximal spin

Small black hole:
shown enlarged
270 solar masses
negligible spin

Trace duration
1 day



"plus" waveform viewed
from 45 degrees latitude



Scale = 0 kpc



LISA Pathfinder



Image: ESA/ATG Medialab

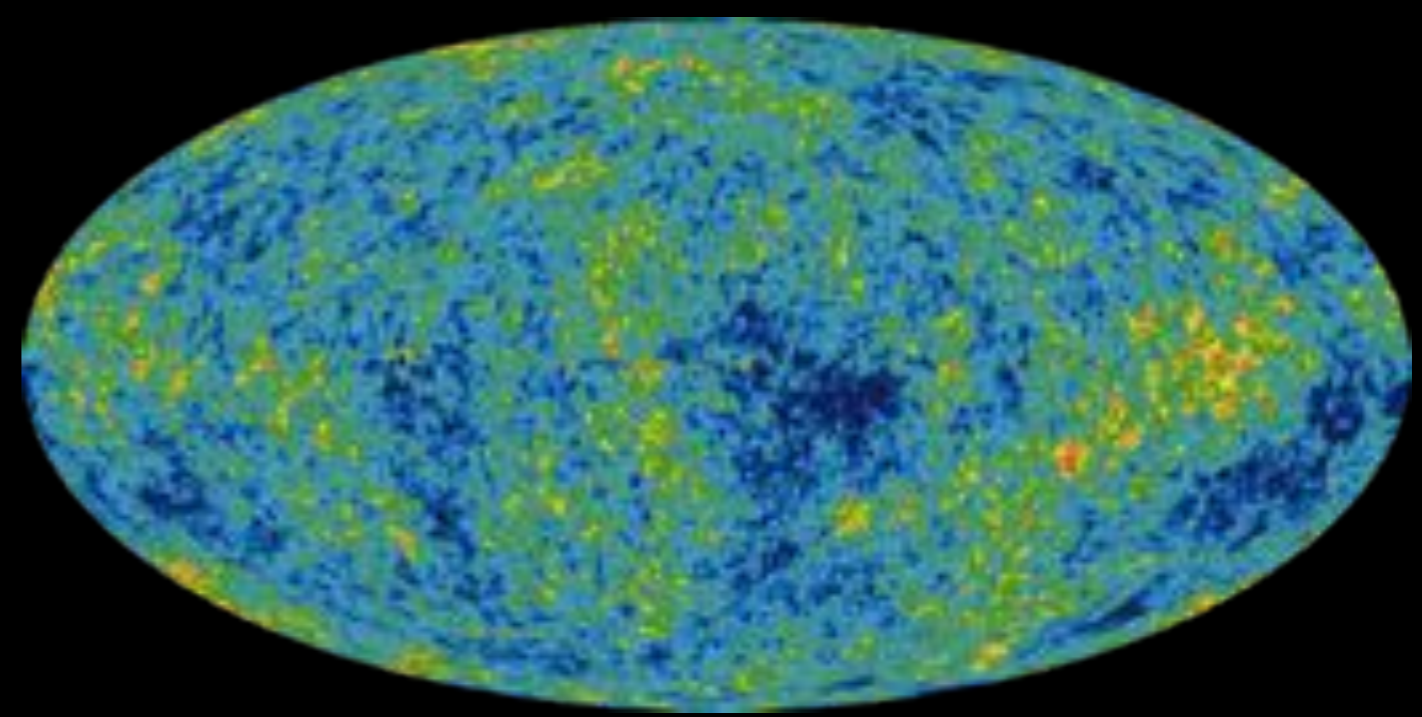


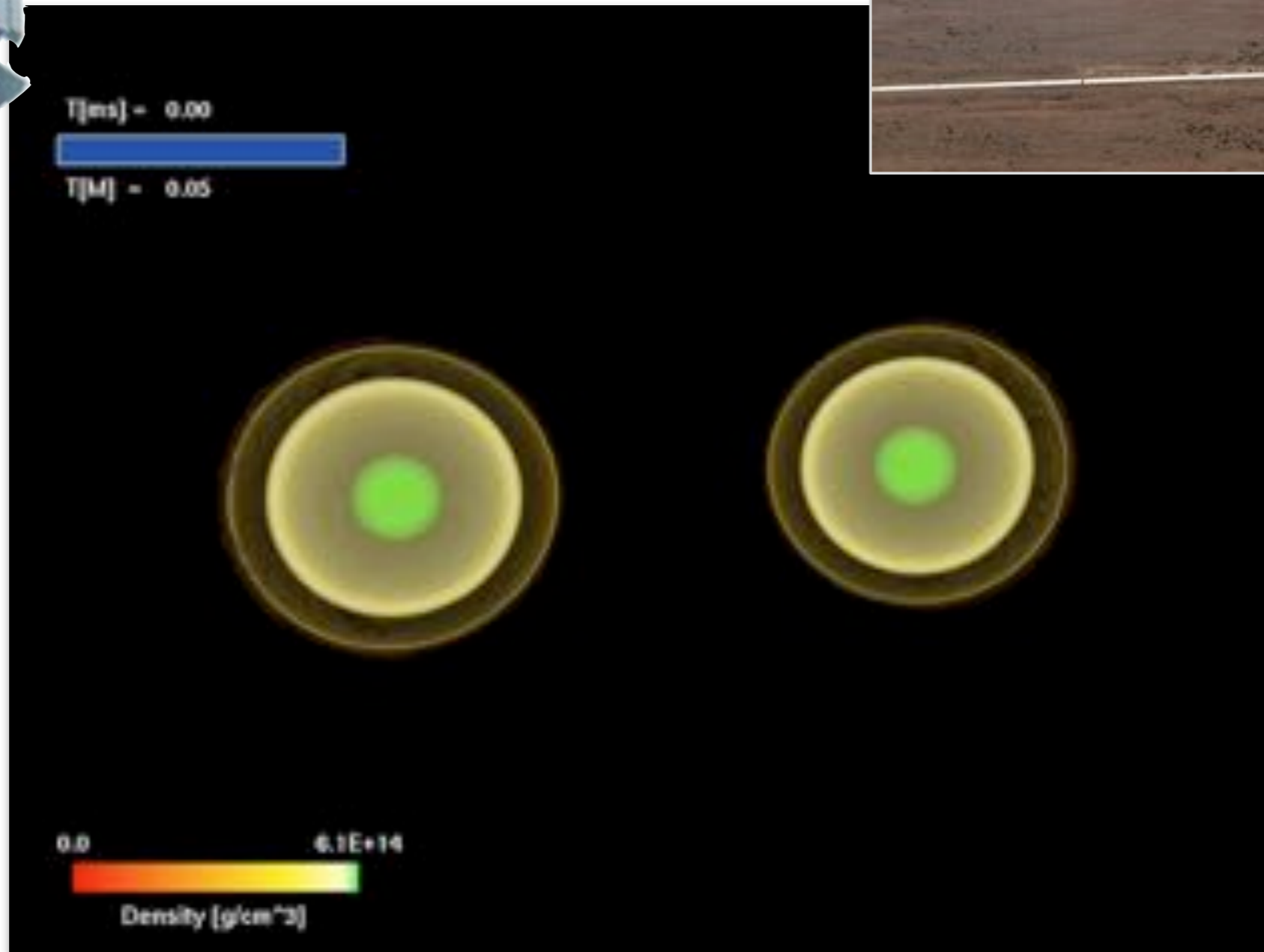
Image: ESA



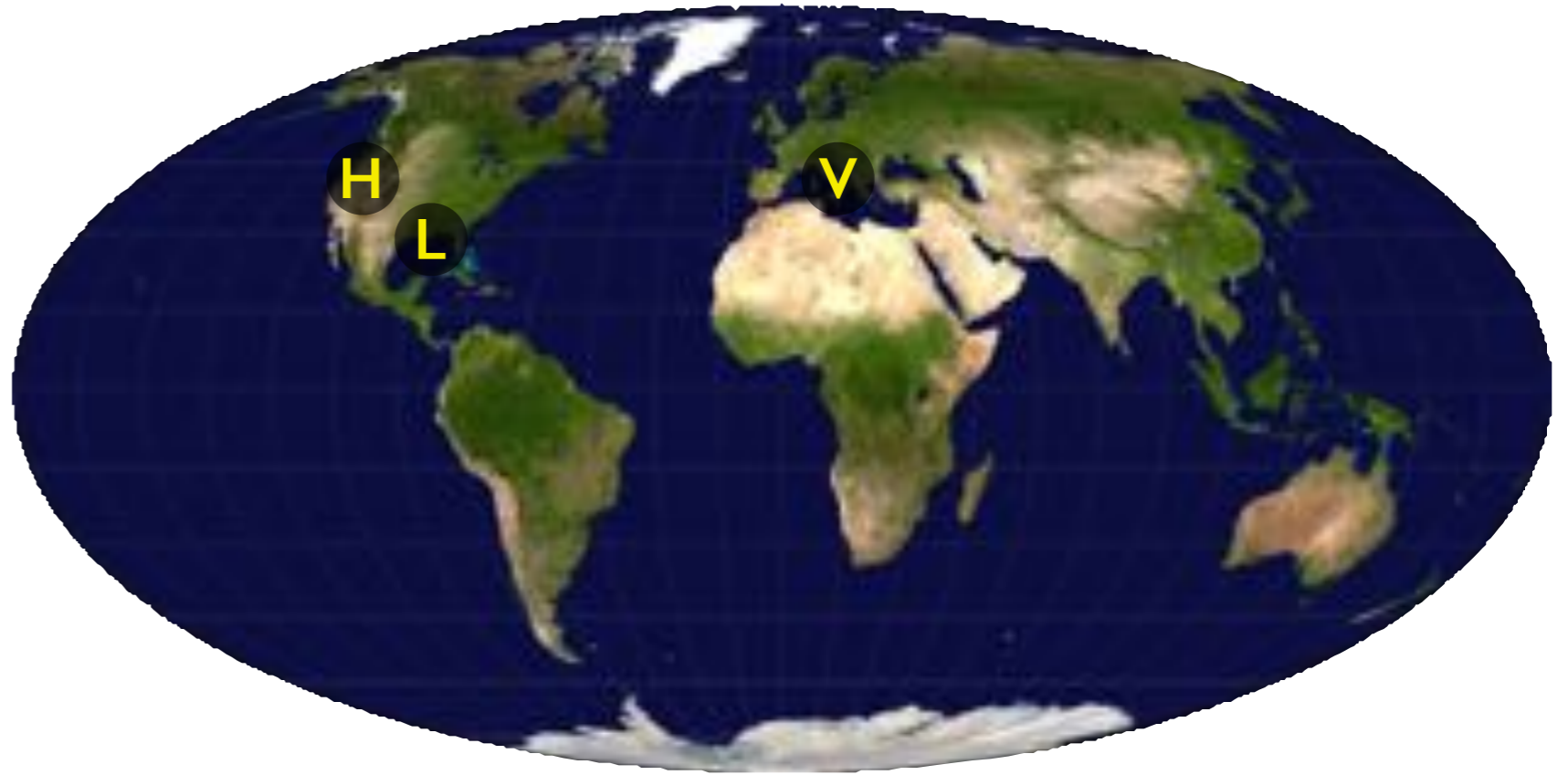
Image: ESA

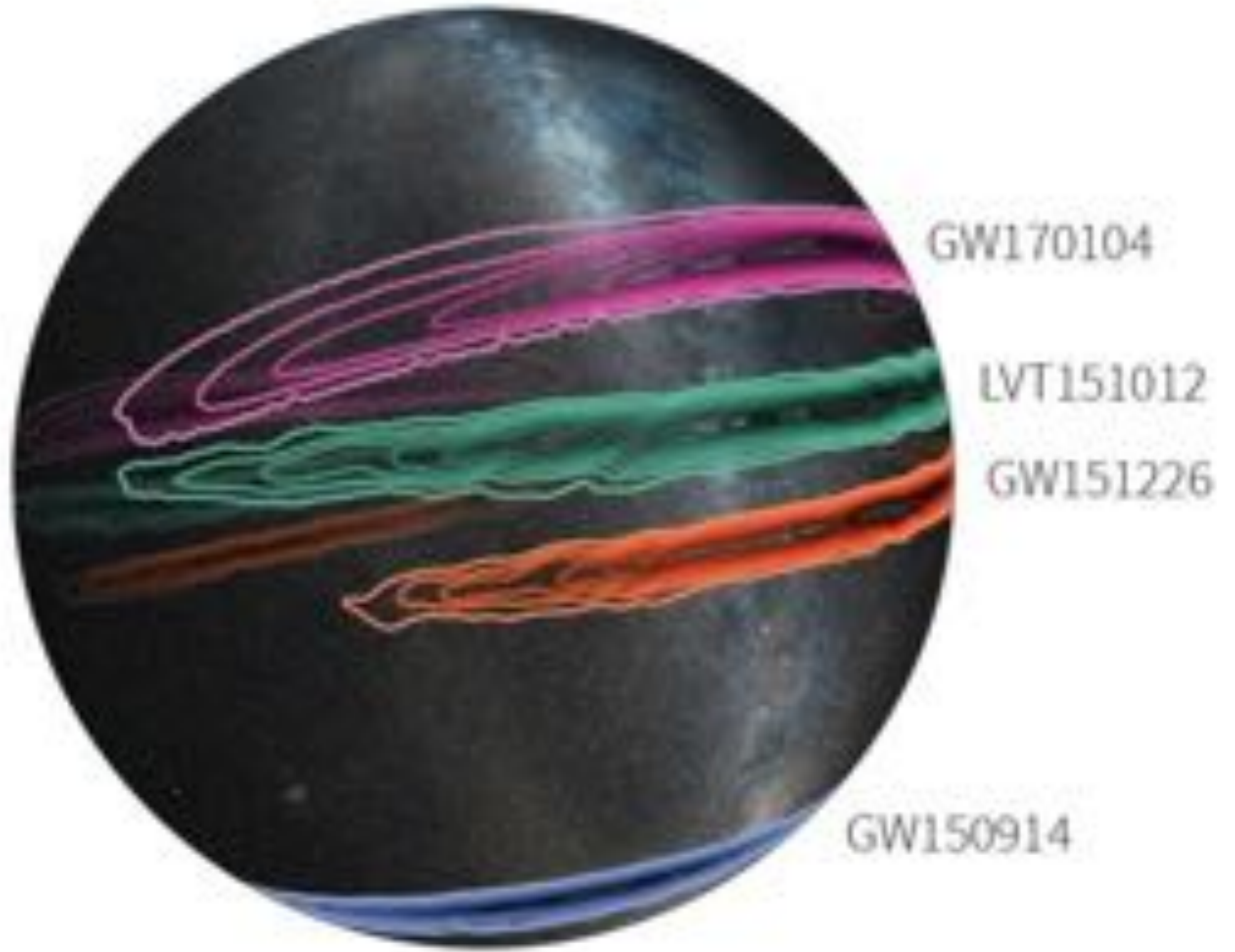


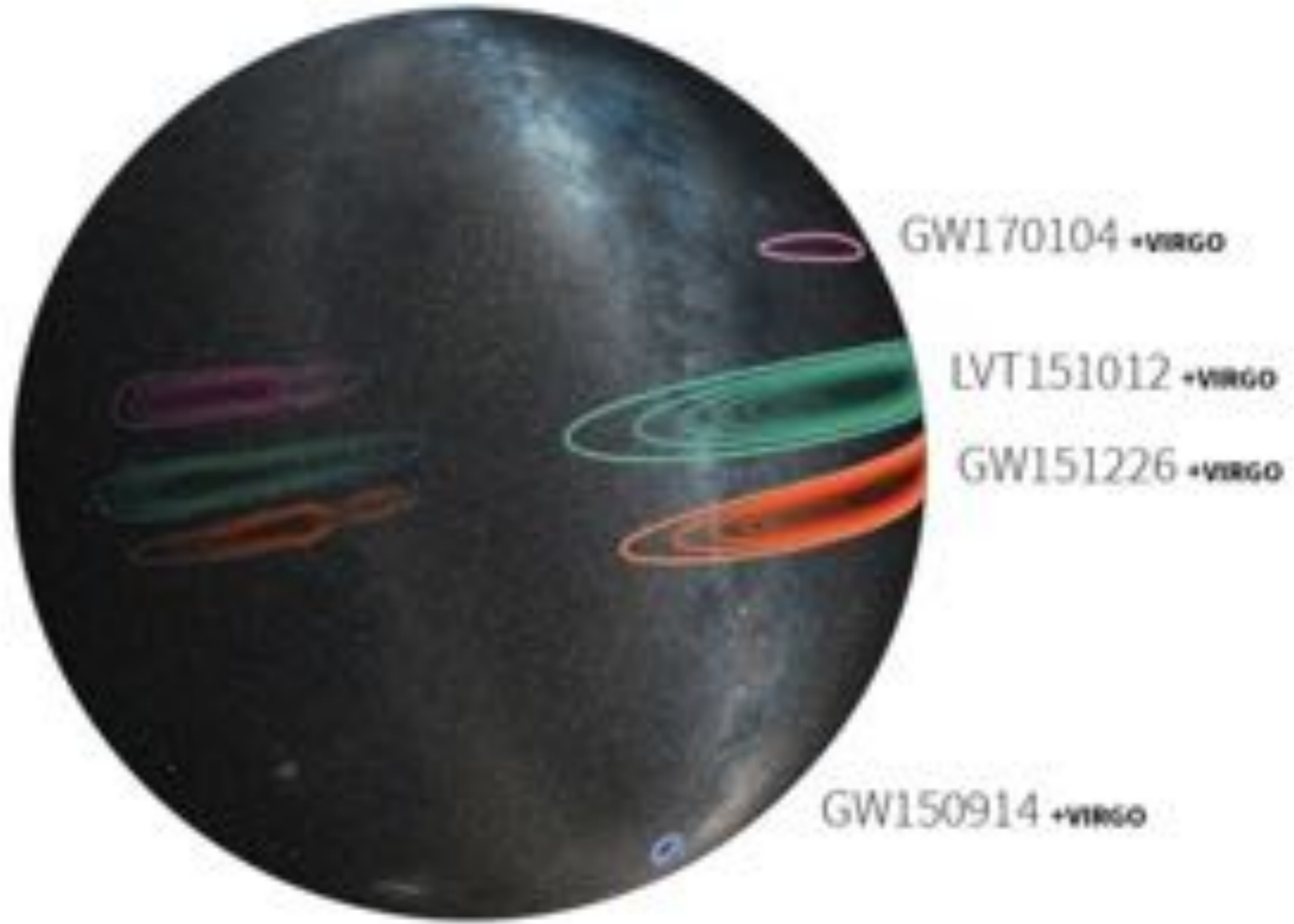


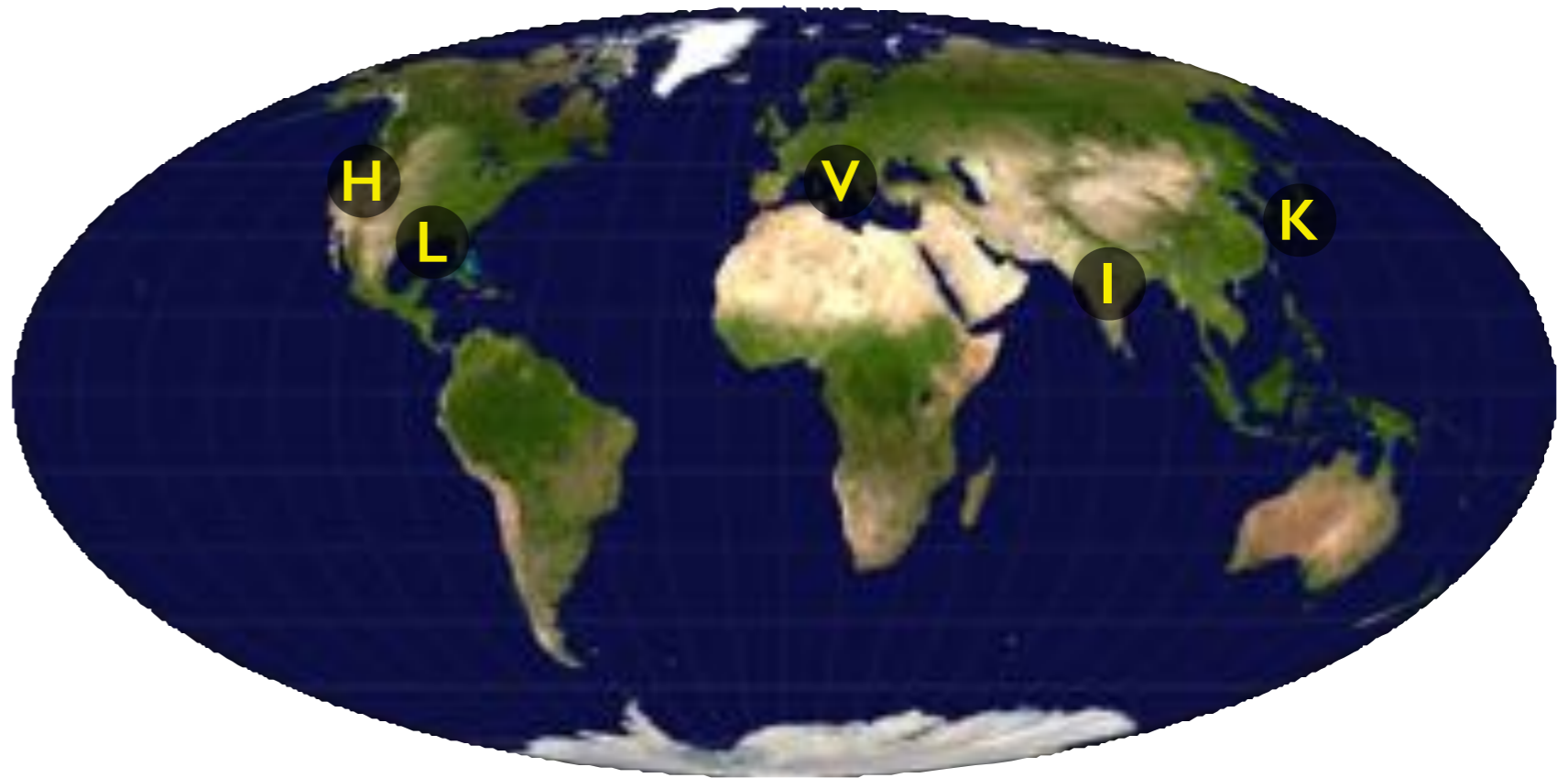












Gravity Spy + Classify - Zooniverse

Secure | <https://www.zooniverse.org/projects/zooniverse/gravity-spy/classify>

App | DWY10104_CBOPE | NASA SPACE | WebTADS | NASA Travel | MJDG

Gravity Spy | About | Classify | Help | Collect | Store

LIGO has announced its first gravitational wave event! Look for a special tutorial when classifying in workflow. You may find some Gravity Spy software that causes temporary issues with the tooling. We apologize for any inconvenience.

Hanford

Frequency (Hz)

Time (s)

Normalized energy

| Source | Frequency | Timing |
|------------------------|---------------------|----------------------|
| 1000 Line | Light Modulation | Repeating Wave |
| 1400 Noise | Low Frequency Burst | Scattered Light |
| Air Compressor (60 Hz) | Low Frequency Line | Steady |
| My | None of the Above | Tone |
| Chop | No (GWS) | Multi-cycle waveform |
| Extremely Loud | Filtered Down | Wandering Line |
| Halls | Power Line (60 Hz) | Whistle |
| See Help | | |

Showing 20 of 22. 10 items shown

Classify | Done

Show the project tutorial

Restart the project introduction

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Gravity Spy | About | Classify | Help | Collect | Run

LIGO has announced its first gravitational wave event! Look for a special tutorial when classifying in workflow. You may also notice some Gravity Spy software may cause temporary issues with the tooling. We apologize for any inconvenience.

Hanford

Frequency (Hz)

Time (s)

Normalized energy

| Source | Frequency | Sound |
|------------------------|---------------------|---------------------|
| 1000 Line | Light Modulation | Repeating Wave |
| 1400 Noise | Low Frequency Burst | Scattered Light |
| Air Compressor (60 Hz) | Low Frequency Line | Gravelly |
| My | None of the Above | Tones |
| Chop | No (GWS) | Multi-tone Harmonic |
| Extremely Loud | Filtered Down | Wandering Line |
| Halls | Power Line (60 Hz) | Whistle |
| Not Fish | | |

Showing 20 of 22. 10 items shown

Check & Save | Done

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LIGO has announced its first gravitational wave event! Look for a special tutorial when classifying in workflow. In the meantime, our software may cause temporary issues with the tooling. We apologize for any inconvenience.

Hanford

Frequency (Hz)

Time (s)

Normalized energy

Hanford

Frequency (Hz)

Time (s)

Normalized energy

Real Fish

Real Fish are similar to like glaciers, but resemble a fish with a head, fins, and a tail.

How confident are you? No Some Definitely not

Show the project tutorial

Restart the project introduction

FIELD GUIDE

Gravity Spy + Classify - Zooniverse

Secure | <https://www.zooniverse.org/projects/zooniverse/gravity-spy/classify>

App | DWY10104_CBOPE | NASA SPACE | WebTADS | NASA Travel | MJDG

Gravity Spy | About | Classify | Tools | Gallery | News

ZOO has announced its first gravitational wave event! Look for a special tutorial when classifying an waveform located 300 Mpc away and about 100 miles to the Gravity Spy software that cause temporary issues with the tooling. We apologize for any inconvenience.

Hanford

Frequency (Hz)

Time (s)

Normalized energy

| Source | Frequency | Setting |
|------------------------|---------------------|----------------------|
| 1000 Line | Light Modulation | Repeating Wave |
| 1400 Noise | Low Frequency Burst | Scattered Light |
| Air Compressor (60 Hz) | Low Frequency Line | Grainy |
| My | None of the Above | Tones |
| Chop | No (GEO) | Multi-scale Harmonic |
| Extremely Loud | Filtered Down | Wandering Line |
| Walls | Power Line (60 Hz) | Whistle |
| My List | | |

Showing 10 of 11. 11 items total

[Done & Talk](#) [Done](#)

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Refresh the project instructions

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FIELD GUIDE

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App | DWY10104_CBOPE | NASA SPACE | WebTADS | NASA Travel | MJDG

Gravity Spy | About | Classify | Help | Collect | Settings

LIGO has announced its first gravitational wave event! Look for a special tutorial when classifying in workflow version 3.0r10 and above. You also notice Gravity Spy software may cause temporary issues with the tooling. We apologize for any inconvenience.

Hanford

Frequency (Hz)

Time (s)

Normalized energy

You responded 'Kit Fish'.
When our experts classified this image, they labeled it as a Light Modulation.
Some of the glitch classes can look quite similar, so please keep trying your best.
Check out the tutorial and the field guide for more guidance.

[Talk](#) [Help](#)

[View the project tutorial](#)

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[FIELD GUIDE](#)

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Gravitational Wave Astronomy

Tyson B. Littenberg

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