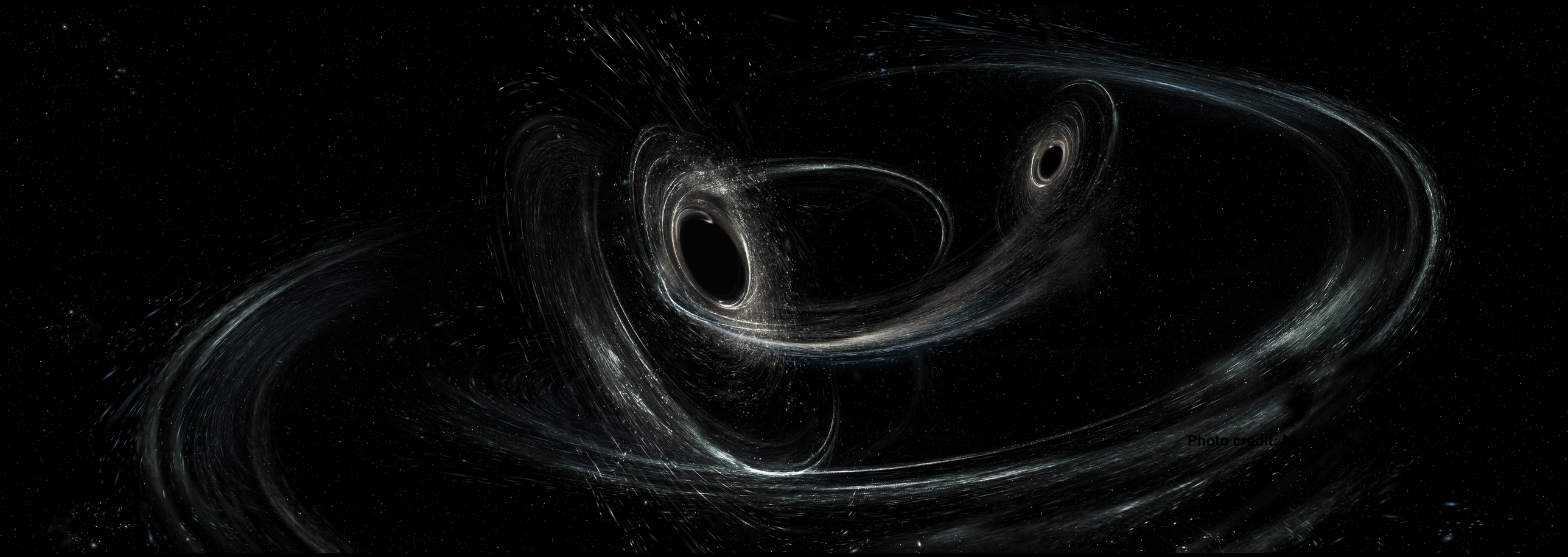
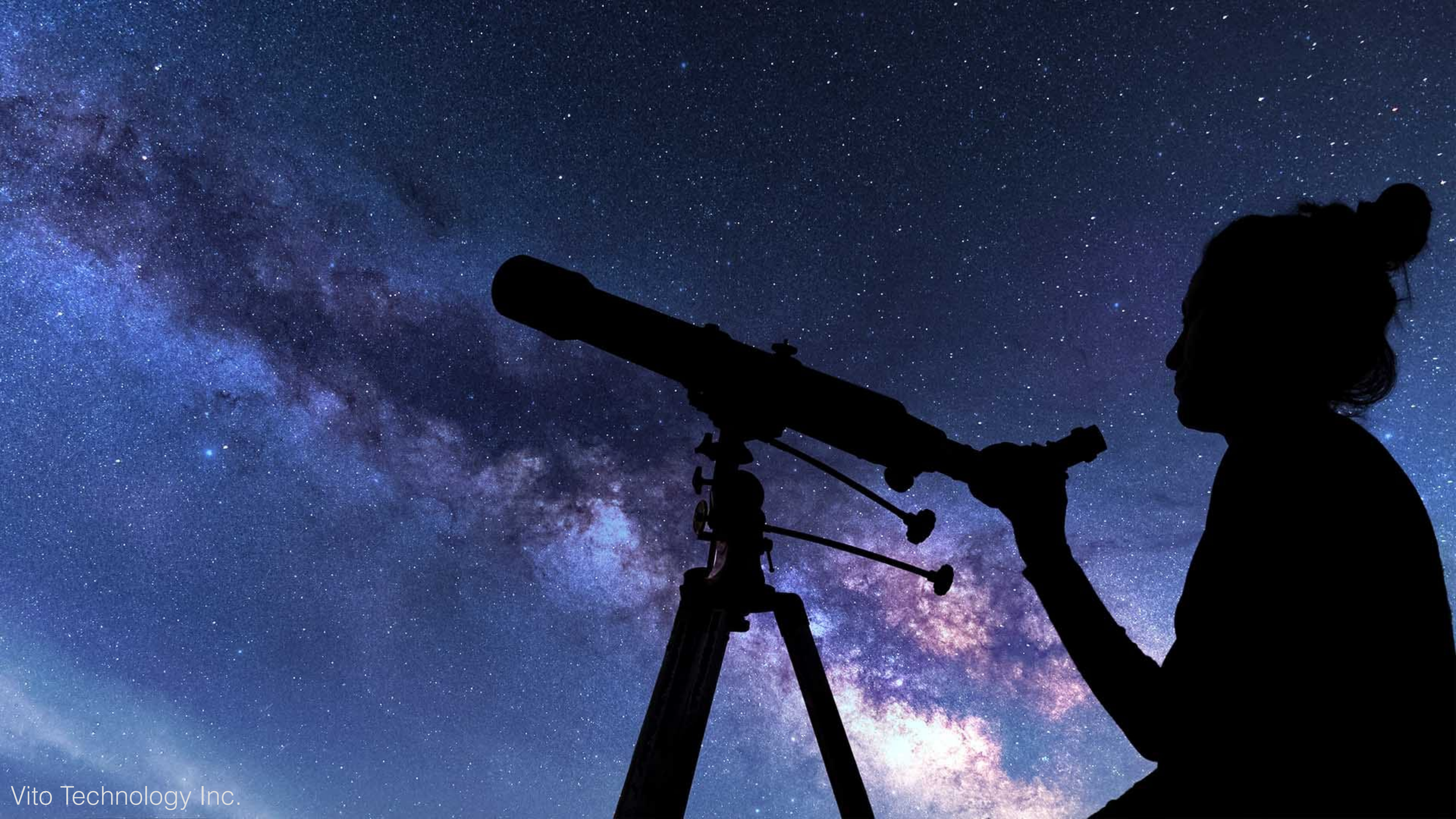
Unlocking the unseen Universe with gravitational waves



Jess McIver
CASCA - Toronto
June 4, 2024

THE UNIVERSITY OF BRITISH COLUMBIA



Vito Technology Inc.

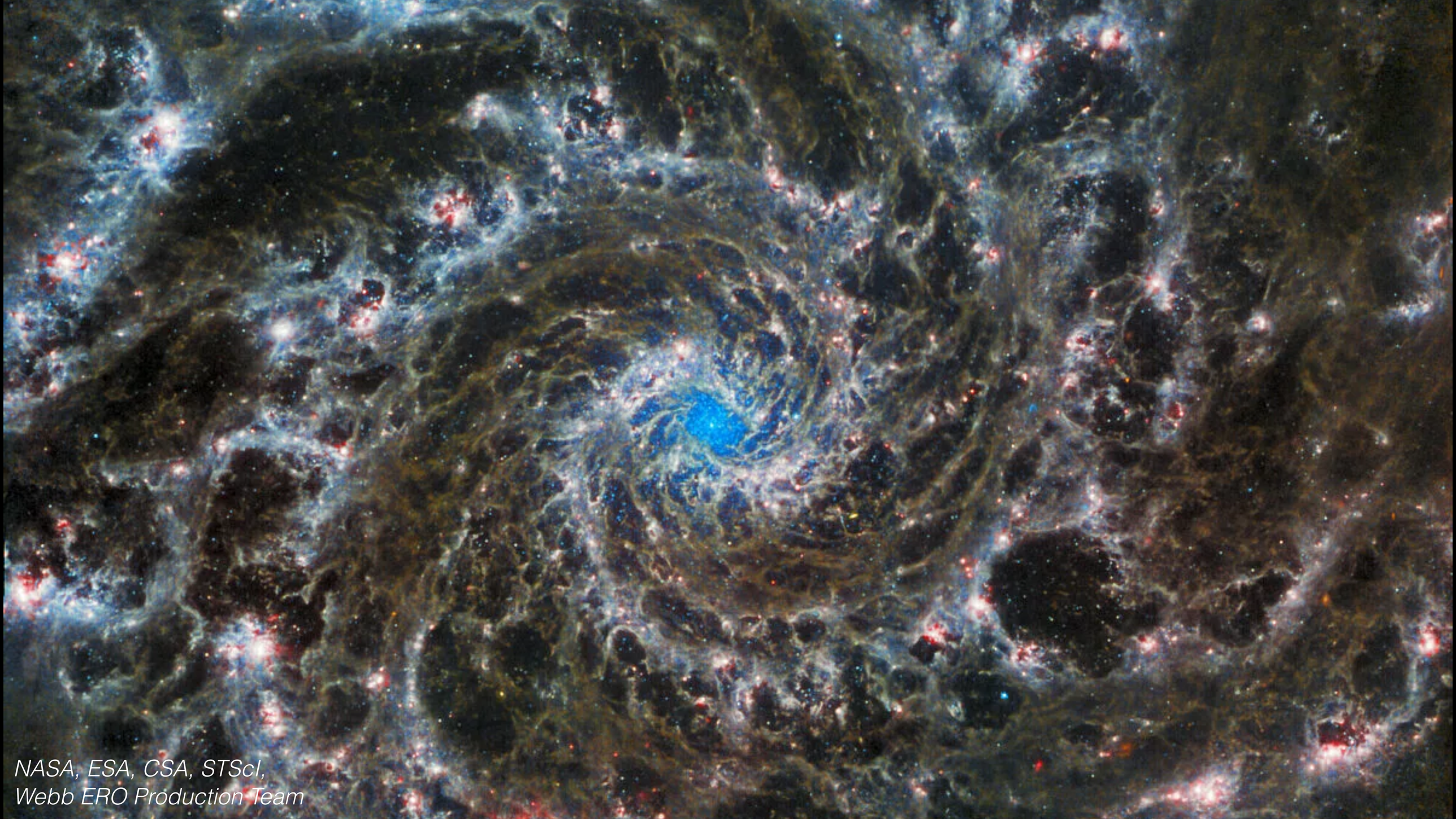
Alex Cherney


esa

Crab Nebula (2 kpc)

HST: NASA

UGC2847 (10 Mpc): Keck 10m



NASA, ESA, CSA, STScI,
Webb ERO Production Team

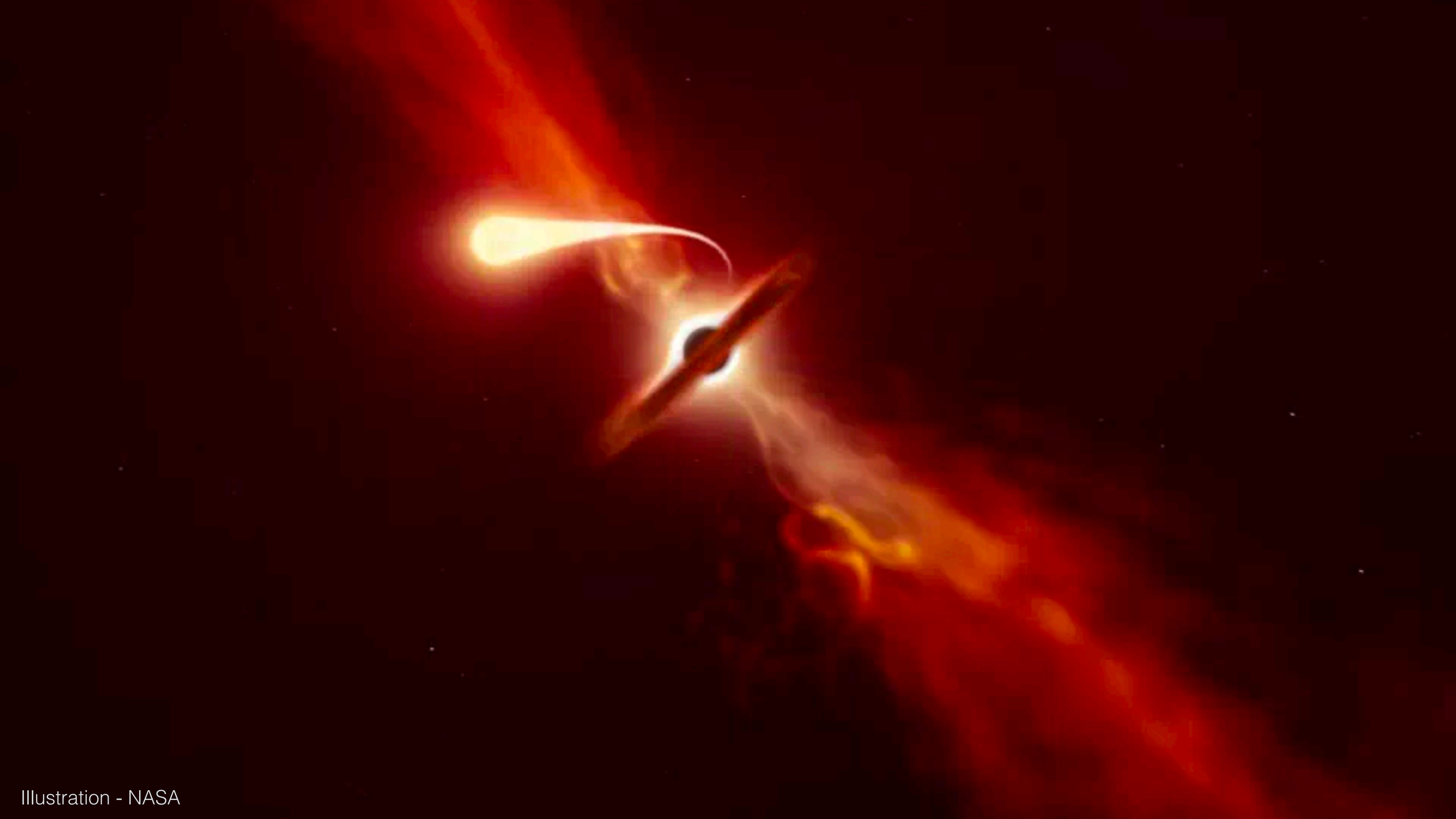
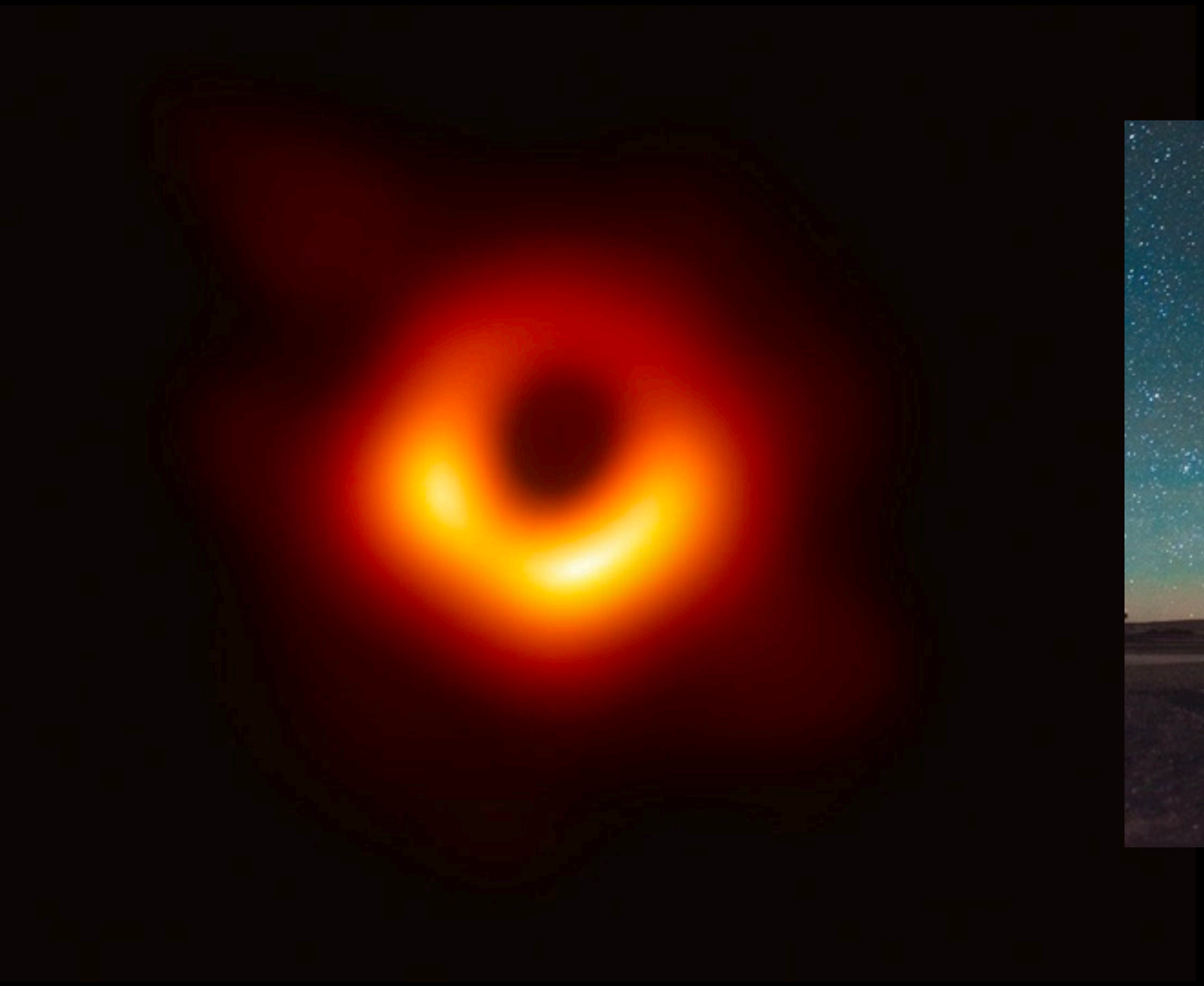
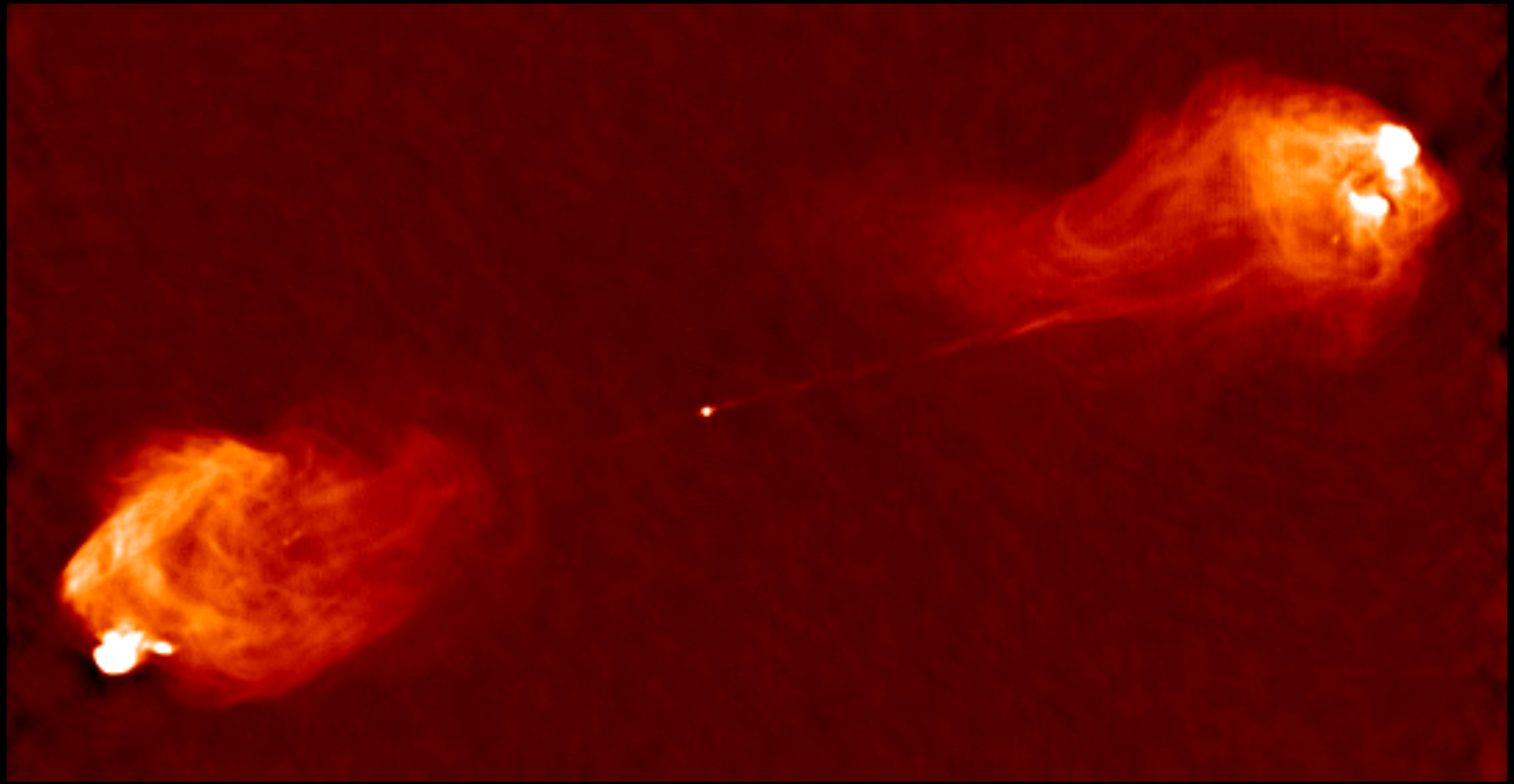


Illustration - NASA



M87 (17 Mpc) SMBH - Event Horizon Telescope



ESO

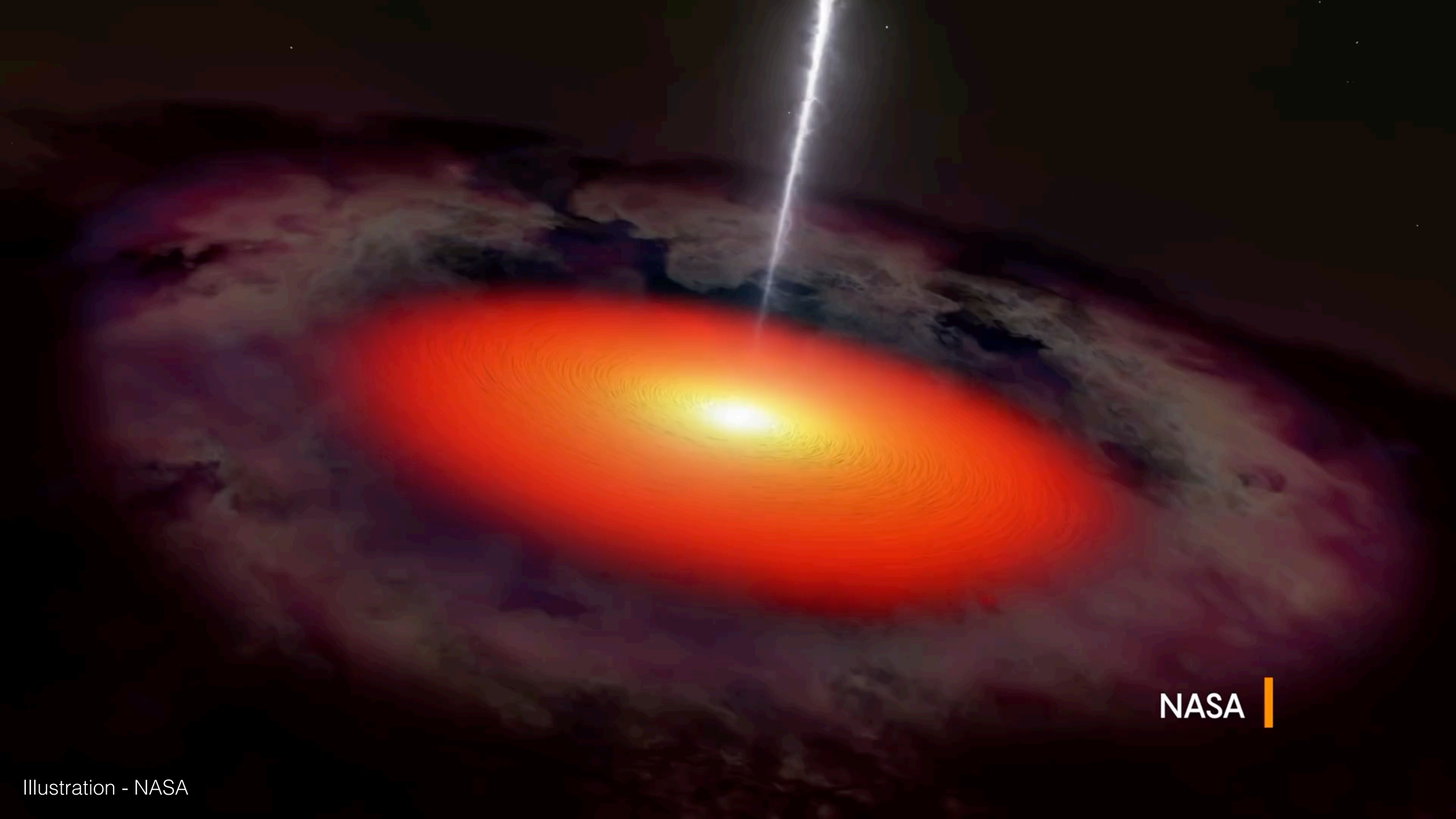


Illustration - NASA

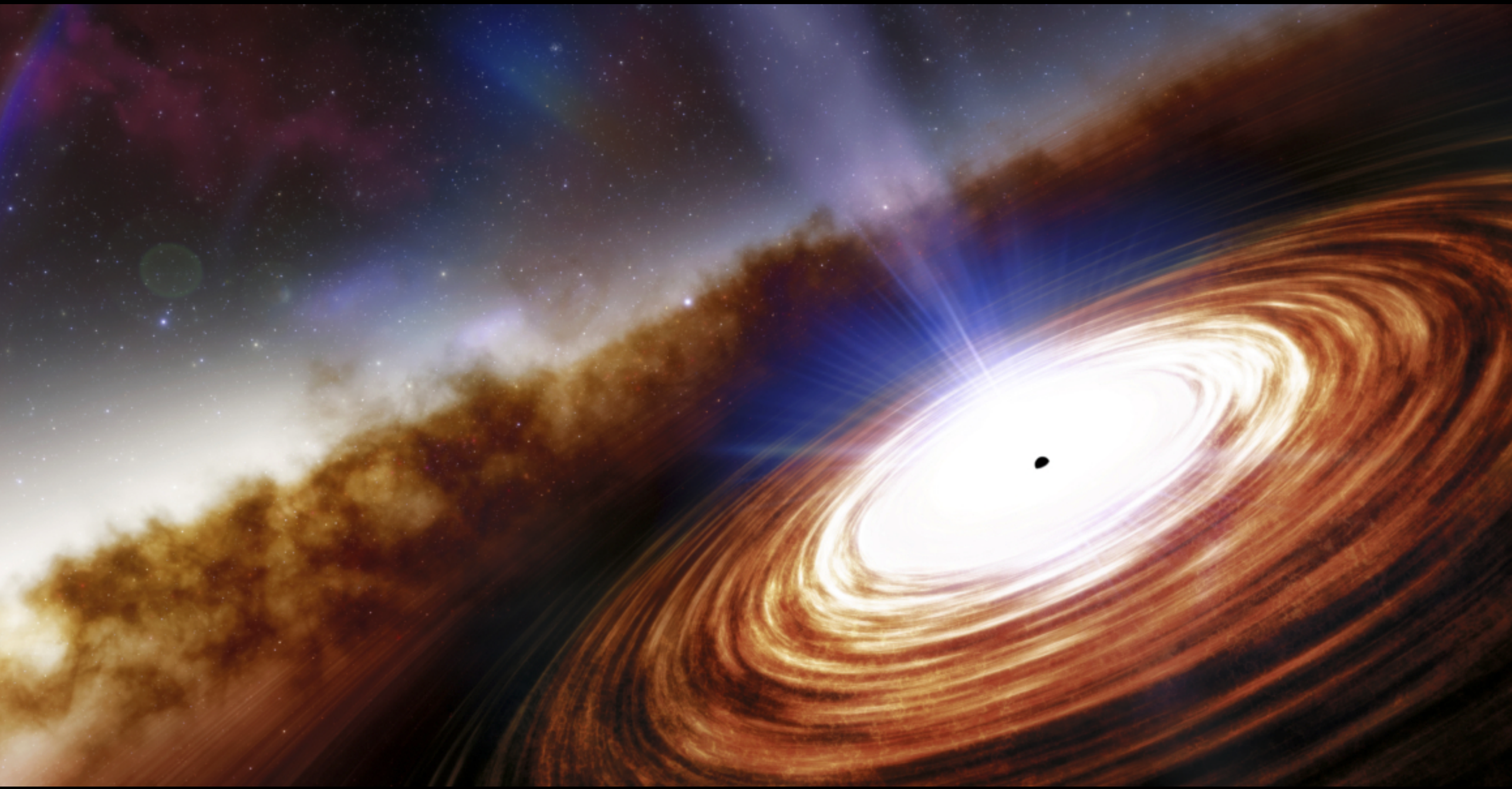
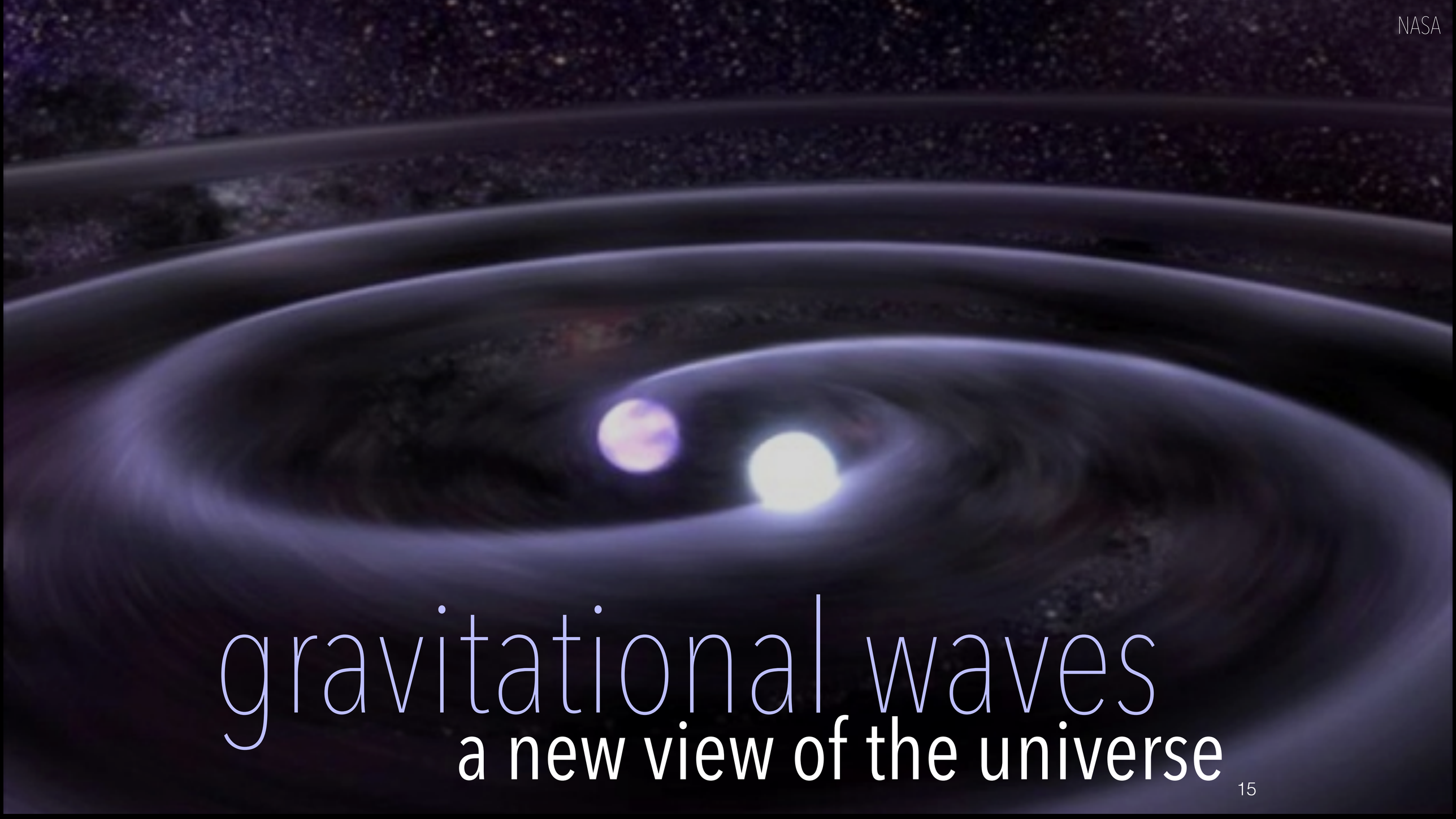


Illustration - NRAO

NASA, ESA, CSA, STScI, Webb ERO Production Team

Simulation - Northwestern Visualization, Carl Rodriguez



gravitational waves

a new view of the universe


waves come in many forms
Taiyo Masuda

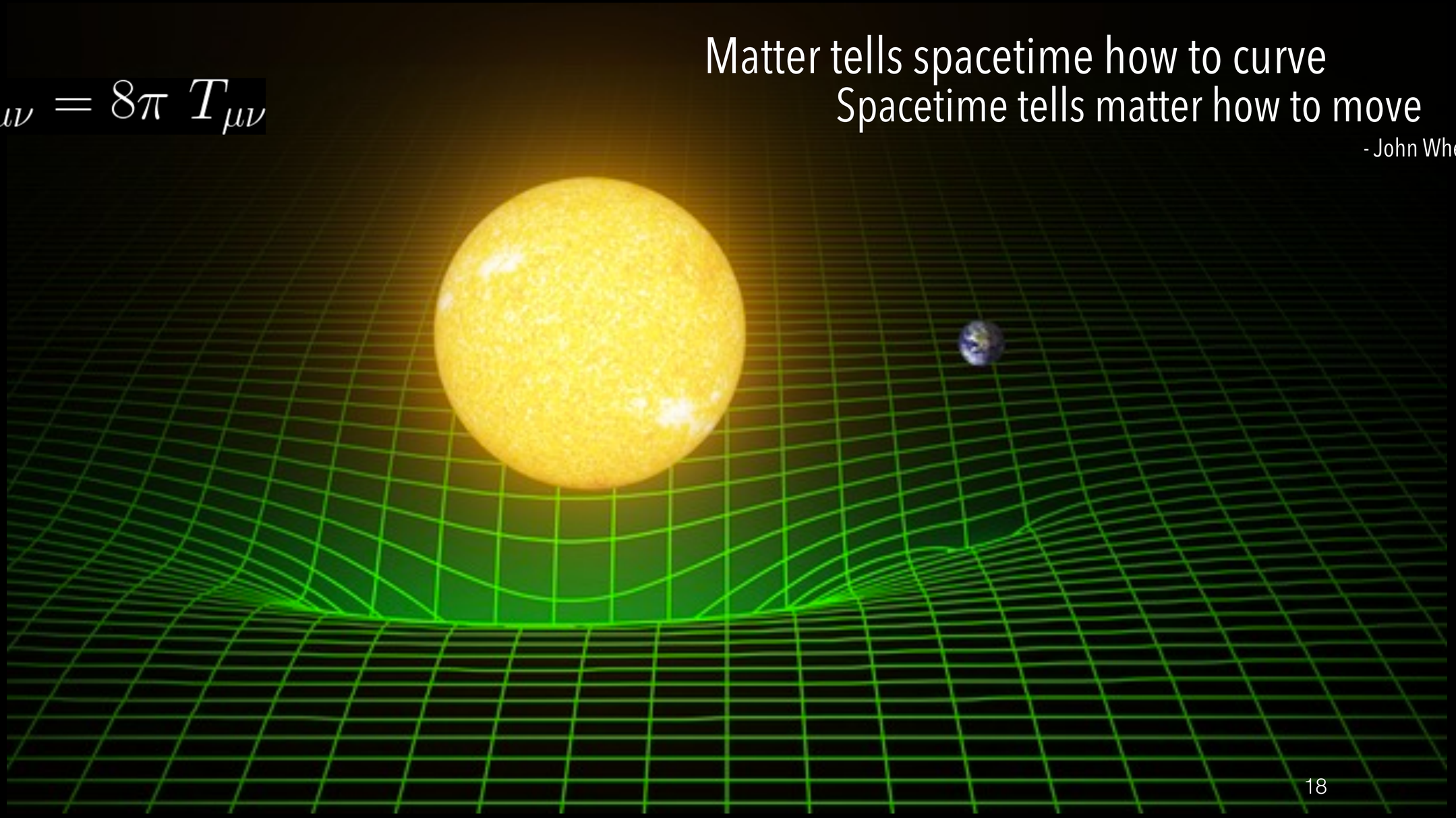
Daniel Lopez: El Cielo de Canarias

Einstein's Gravity: General Relativity

$$G_{\mu\nu} = 8\pi\, T_{\mu\nu}$$

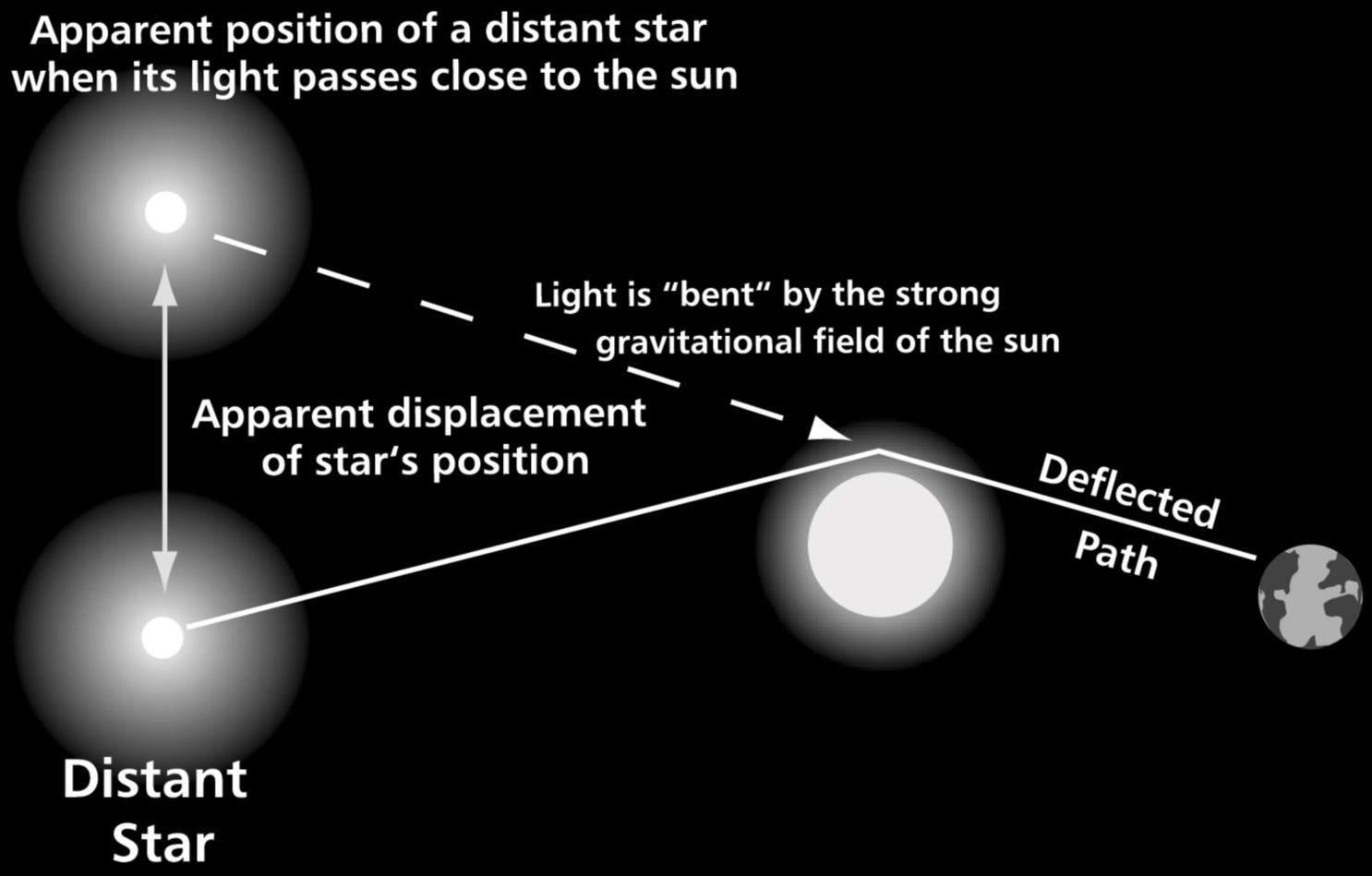
Matter tells spacetime how to curve
Spacetime tells matter how to move

- John Wheeler



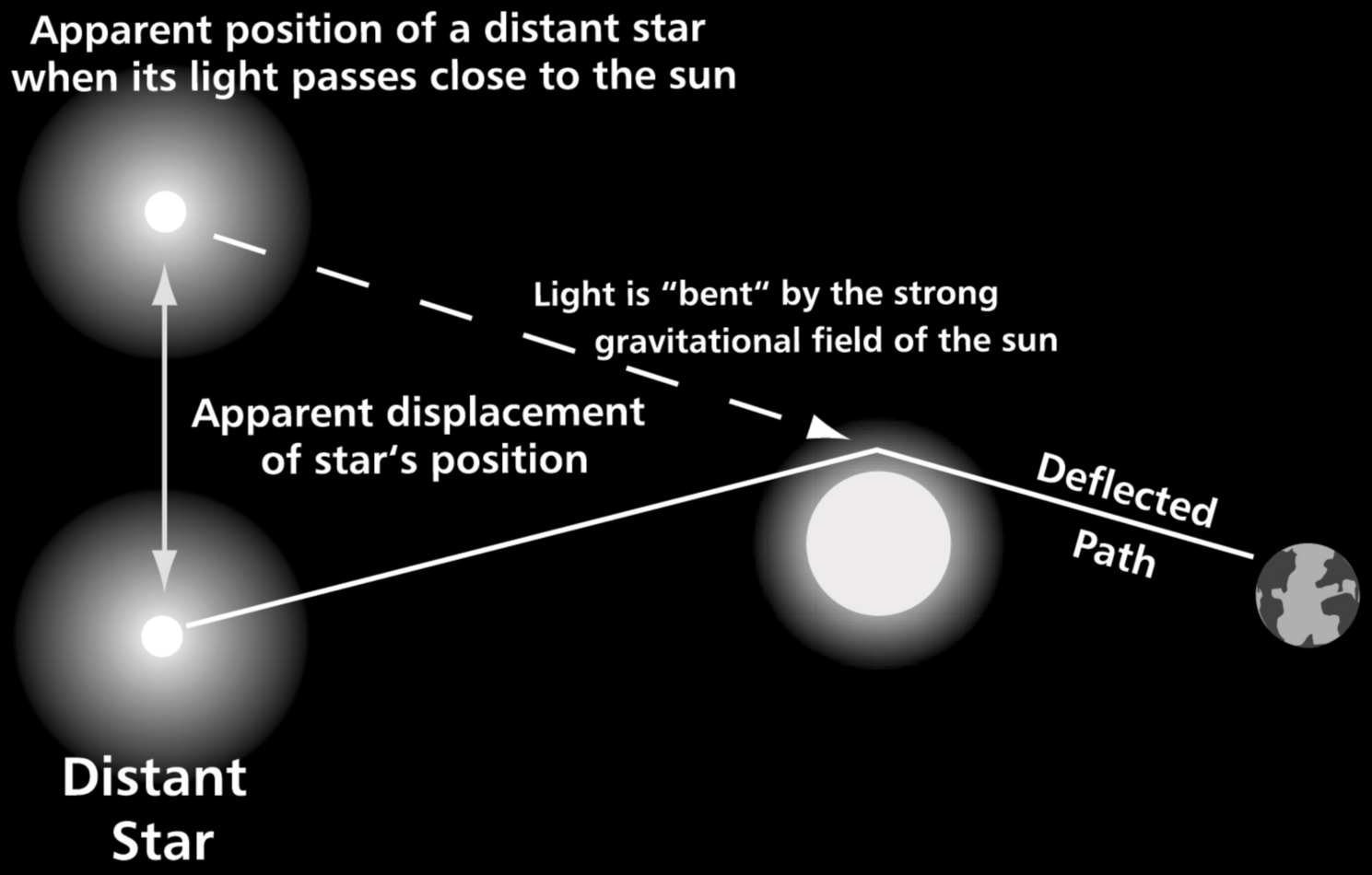
LIGO/Caltech

Einstein’s prediction: Gravity bends light



S. Brunier /ESO

Einstein's prediction: Gravity bends light



The New York Times.

LIGHTS ALL ASKEW IN THE HEAVENS

EINSTEIN THEORY TRIUMPHS

Stars Not Where They Seemed or Were Calculated to be, but Nobody Need Worry.

Measured by Eddington in 1919 during a total solar eclipse!

S. Brunier /ESO

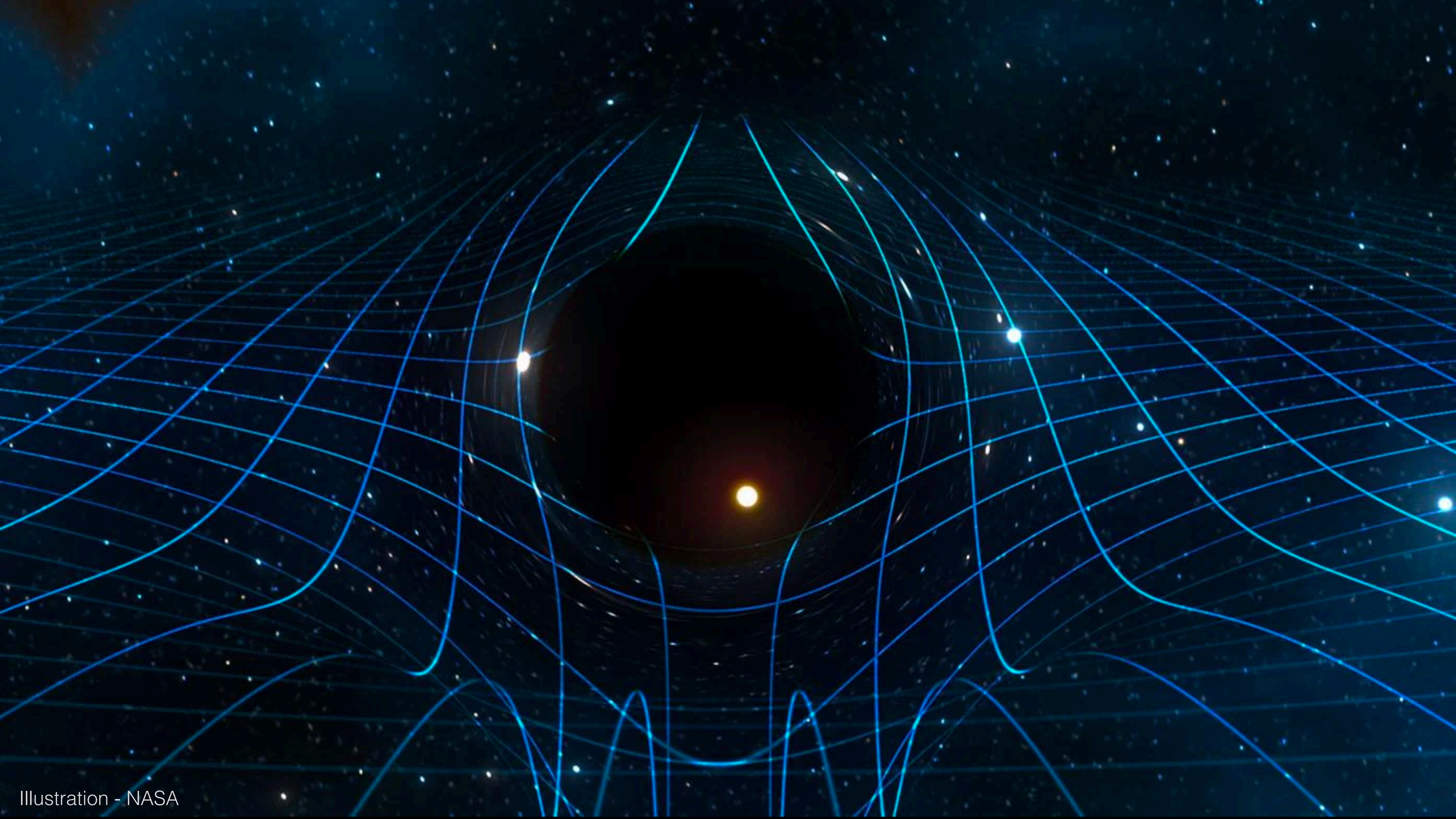


Illustration - NASA

Indirect evidence of gravitational waves

Hulse-Taylor Binary Pulsar

Won the Nobel Prize in Physics in 1993!

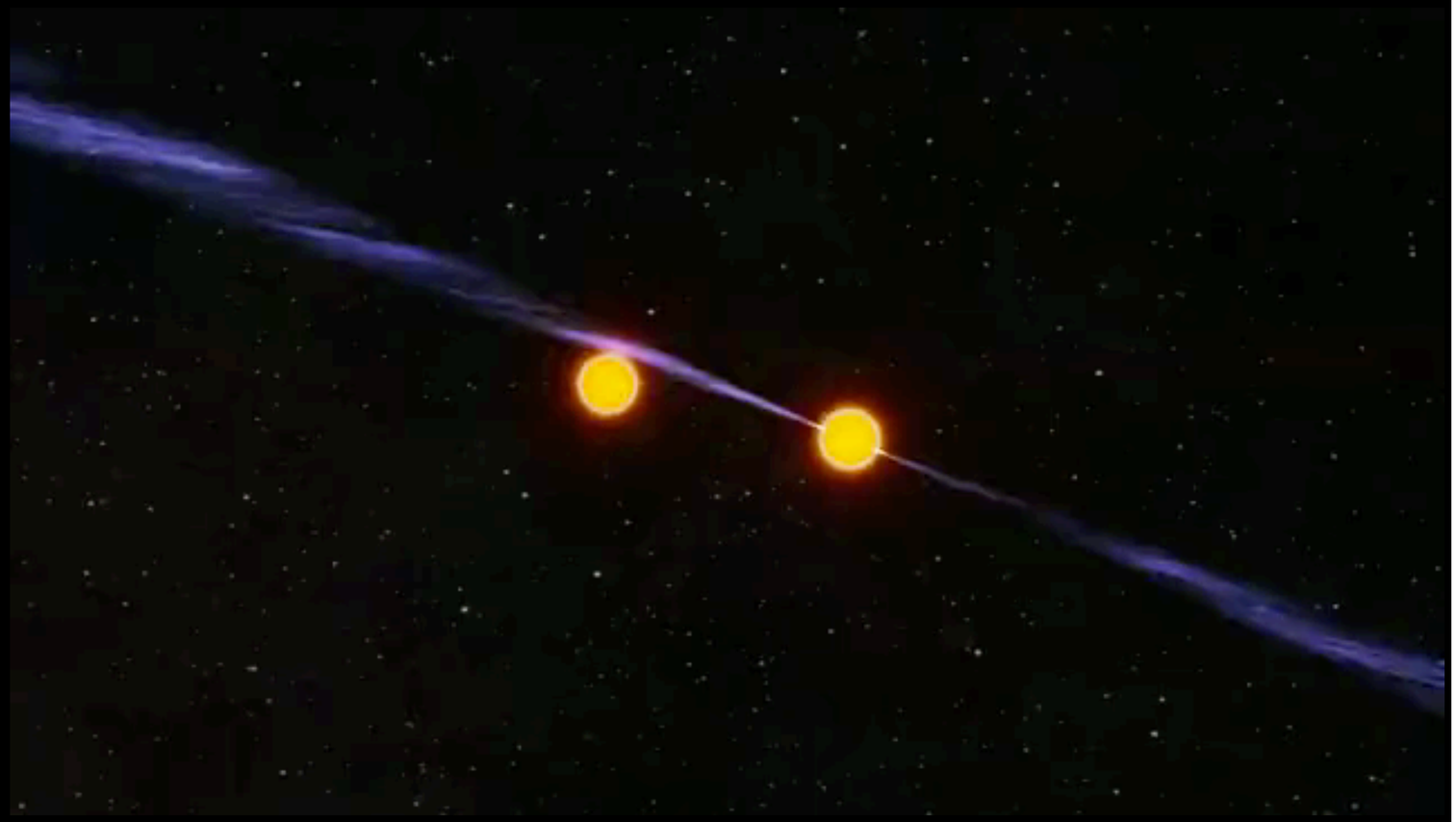
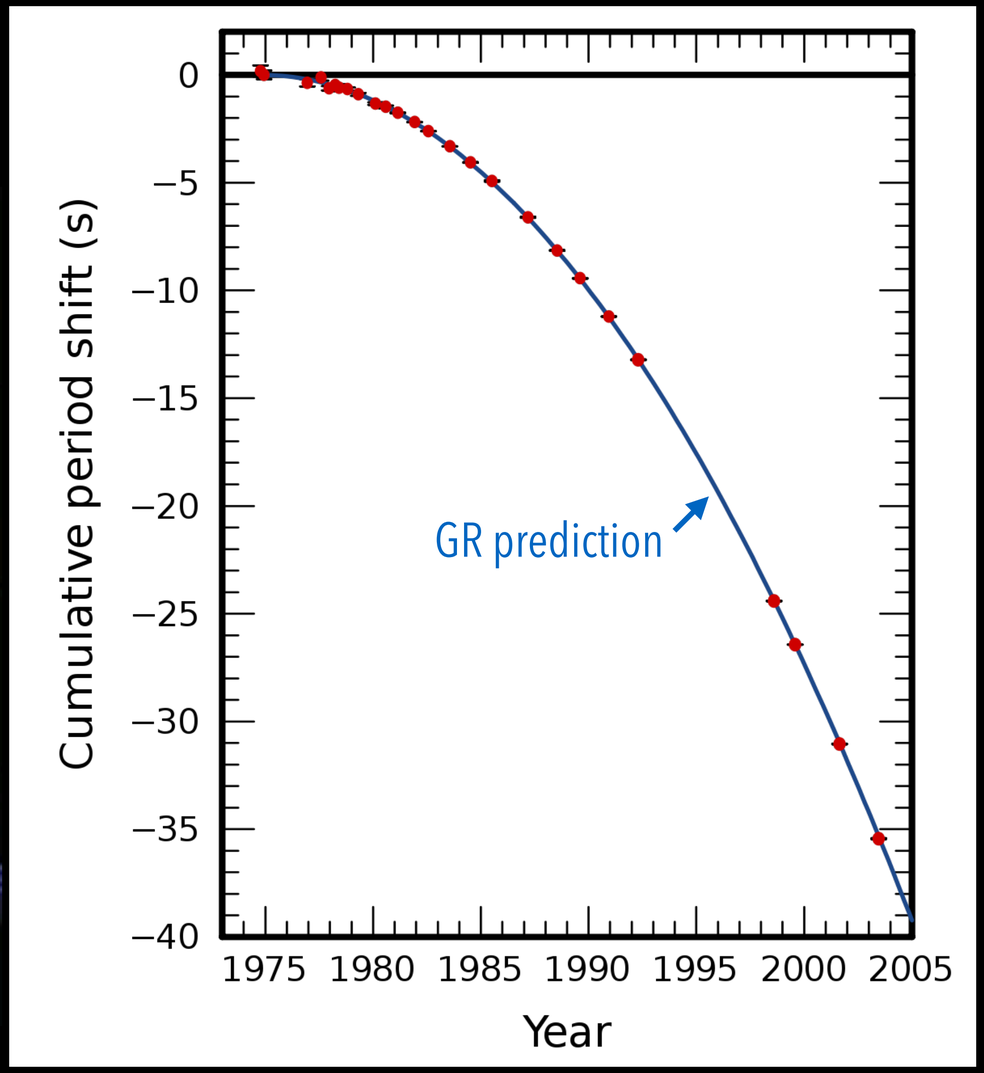
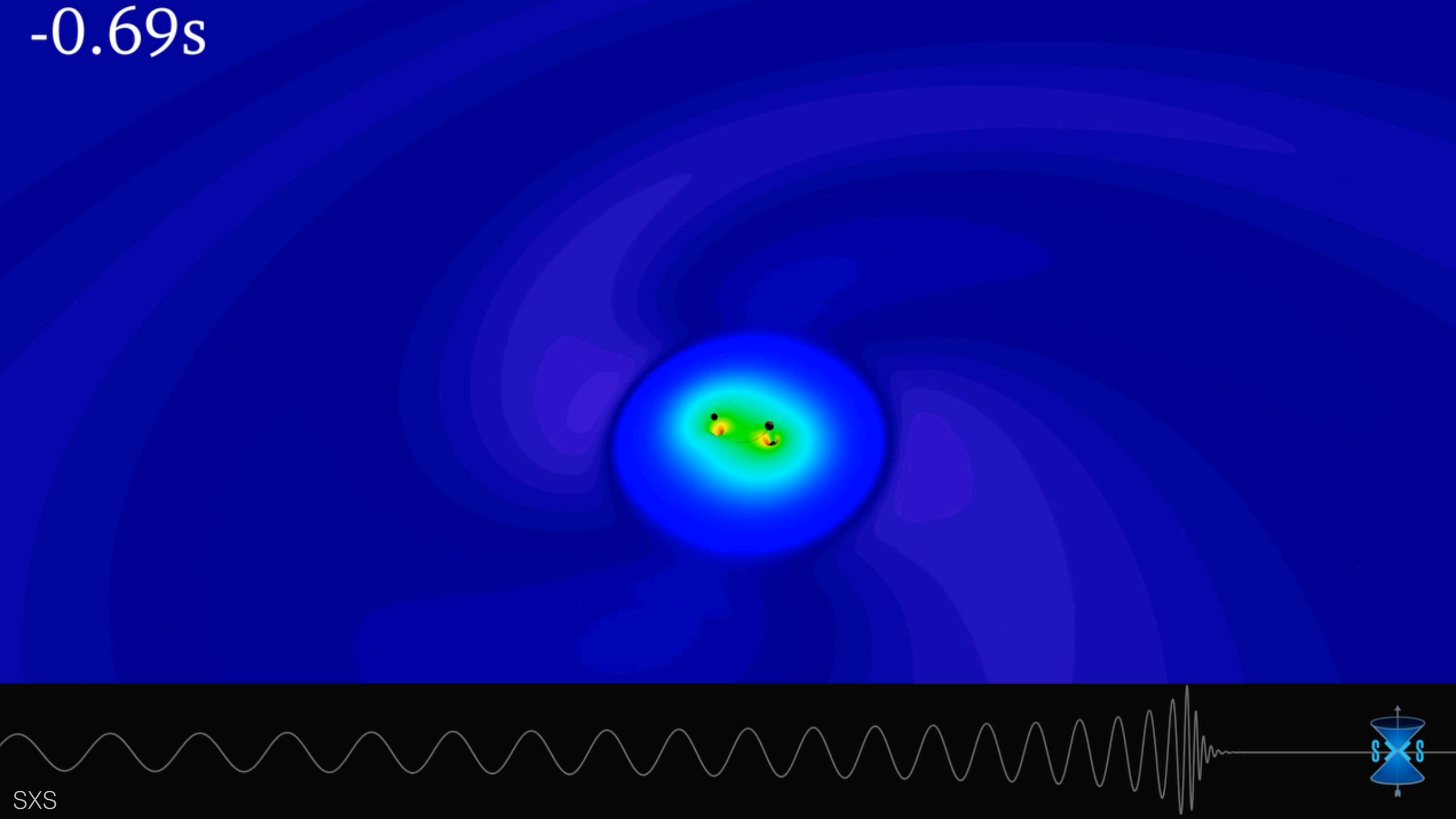
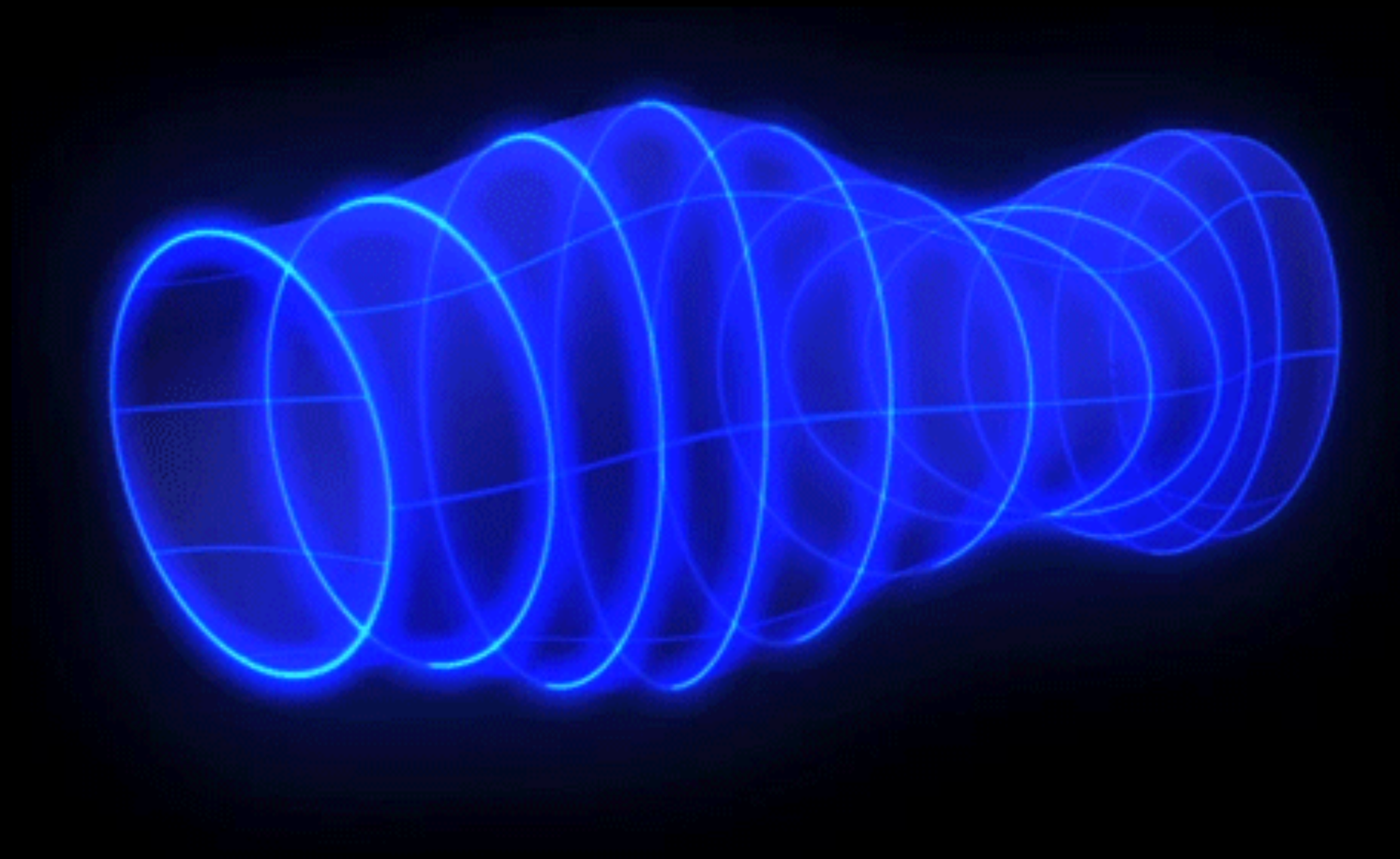


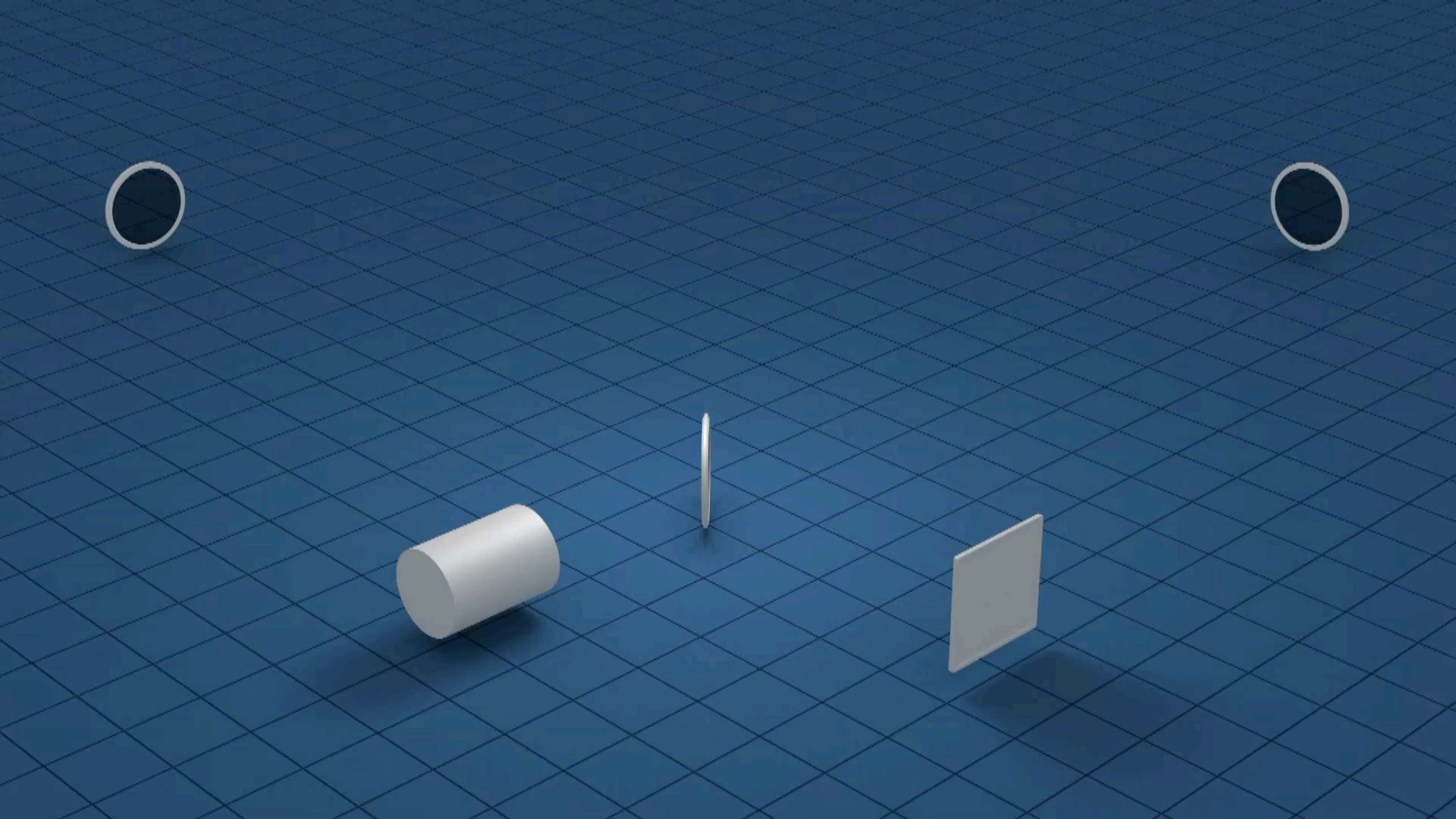
Illustration - John Rowe



Weisburg, Nice & Taylor, 2010


-0.69s
SXS

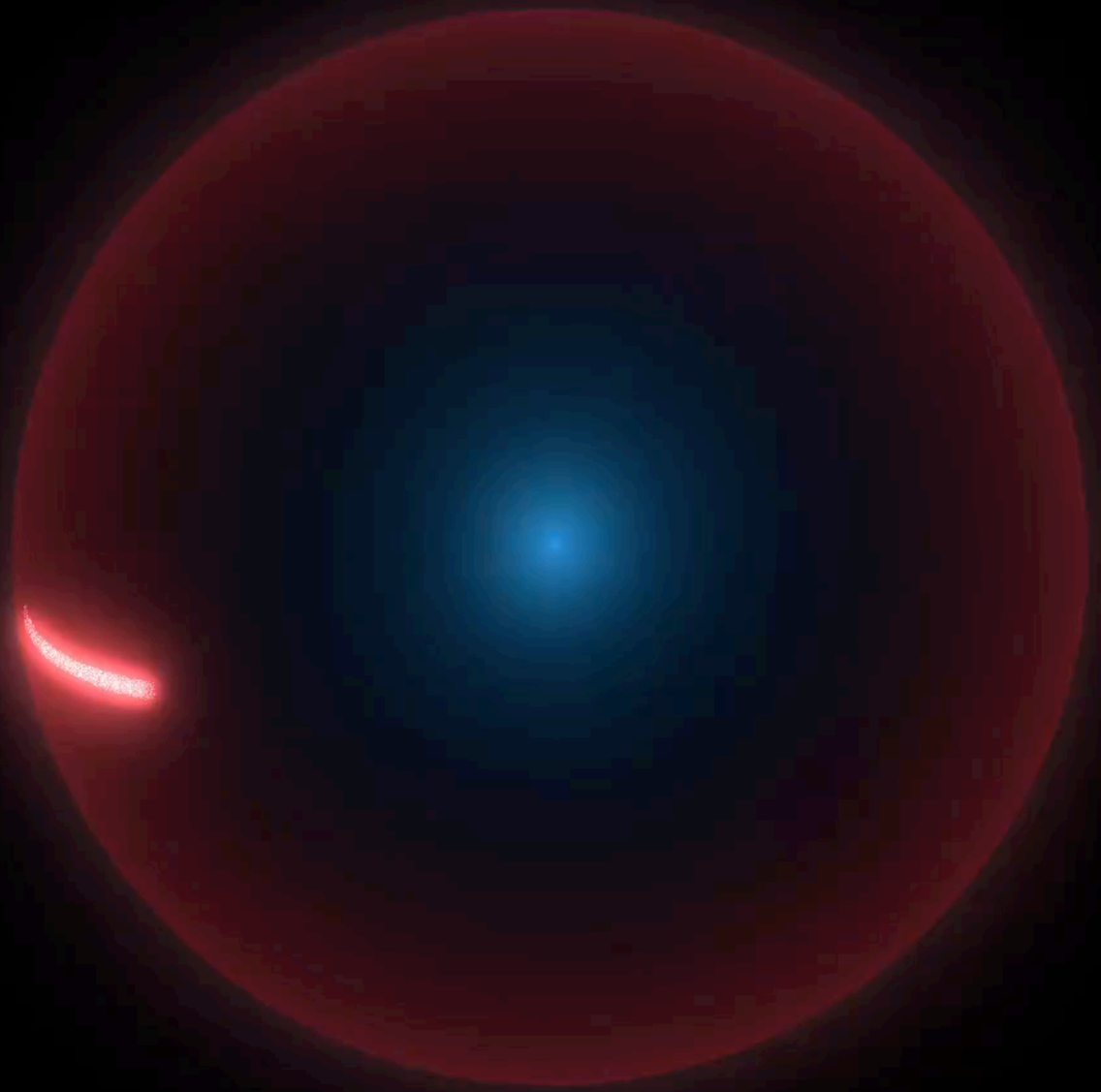




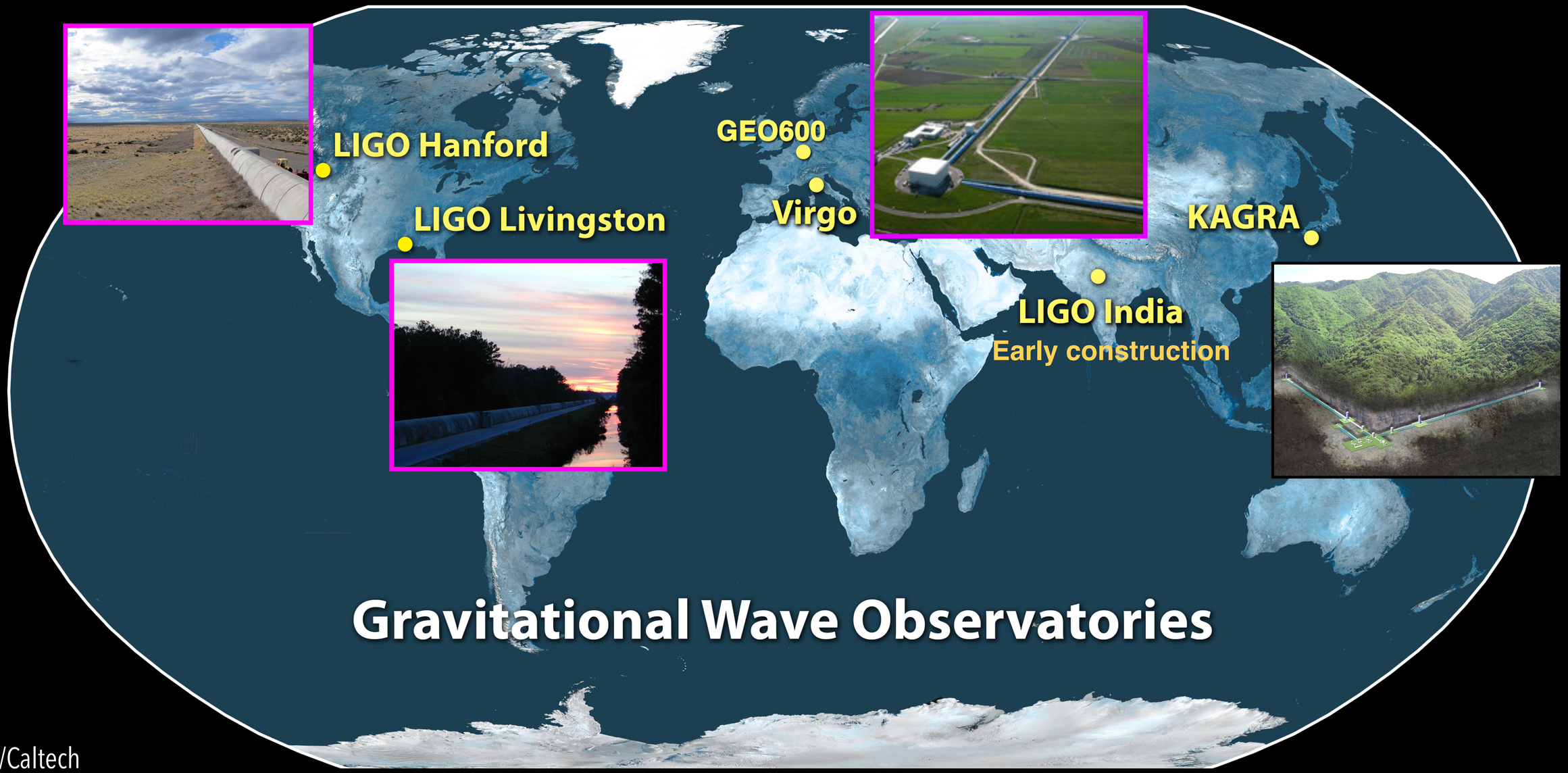

Science
AAAS

LIGO: A passion for understanding, Kai Staats

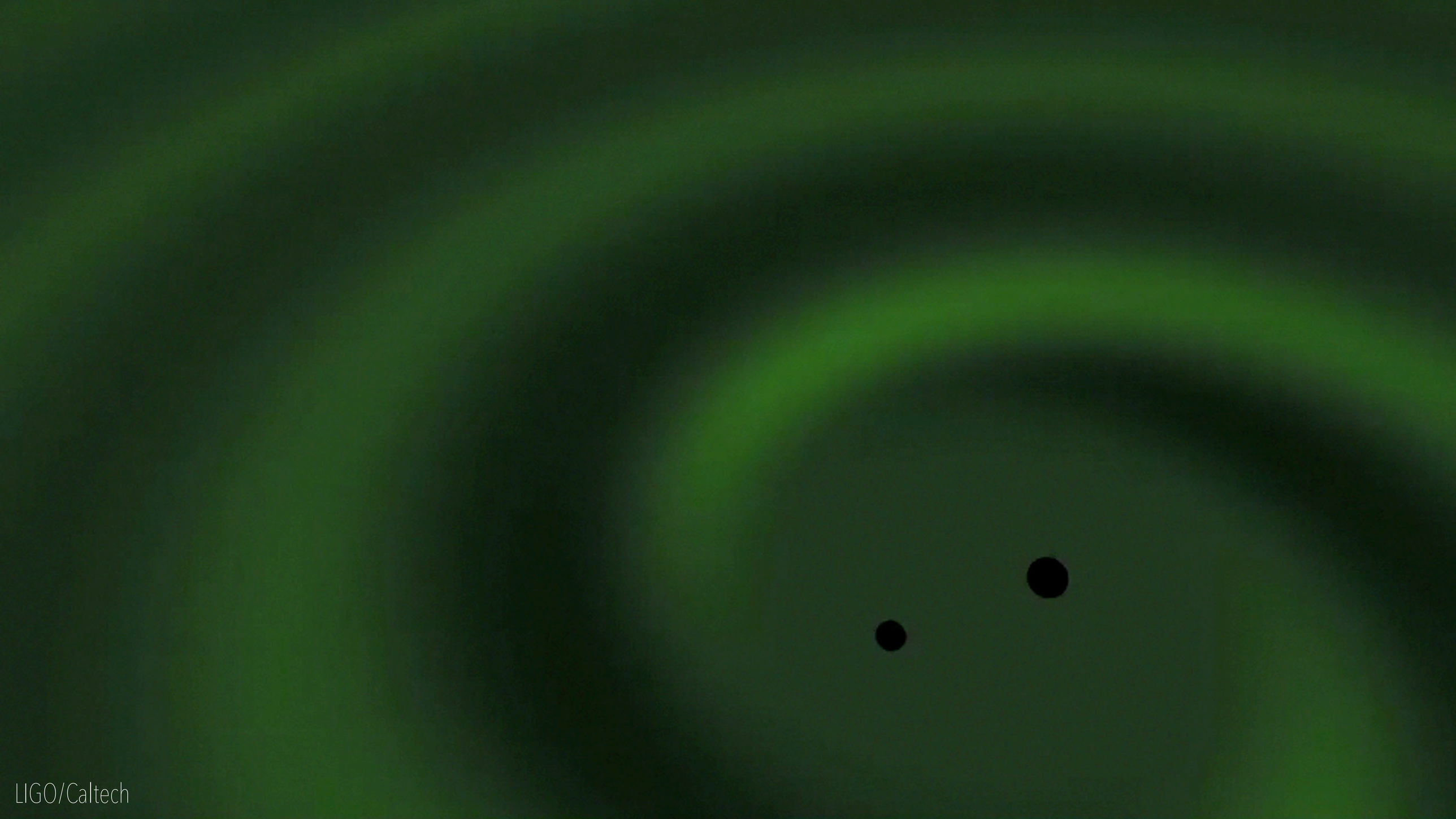
The Advanced LIGO documentary project, Les Guthman

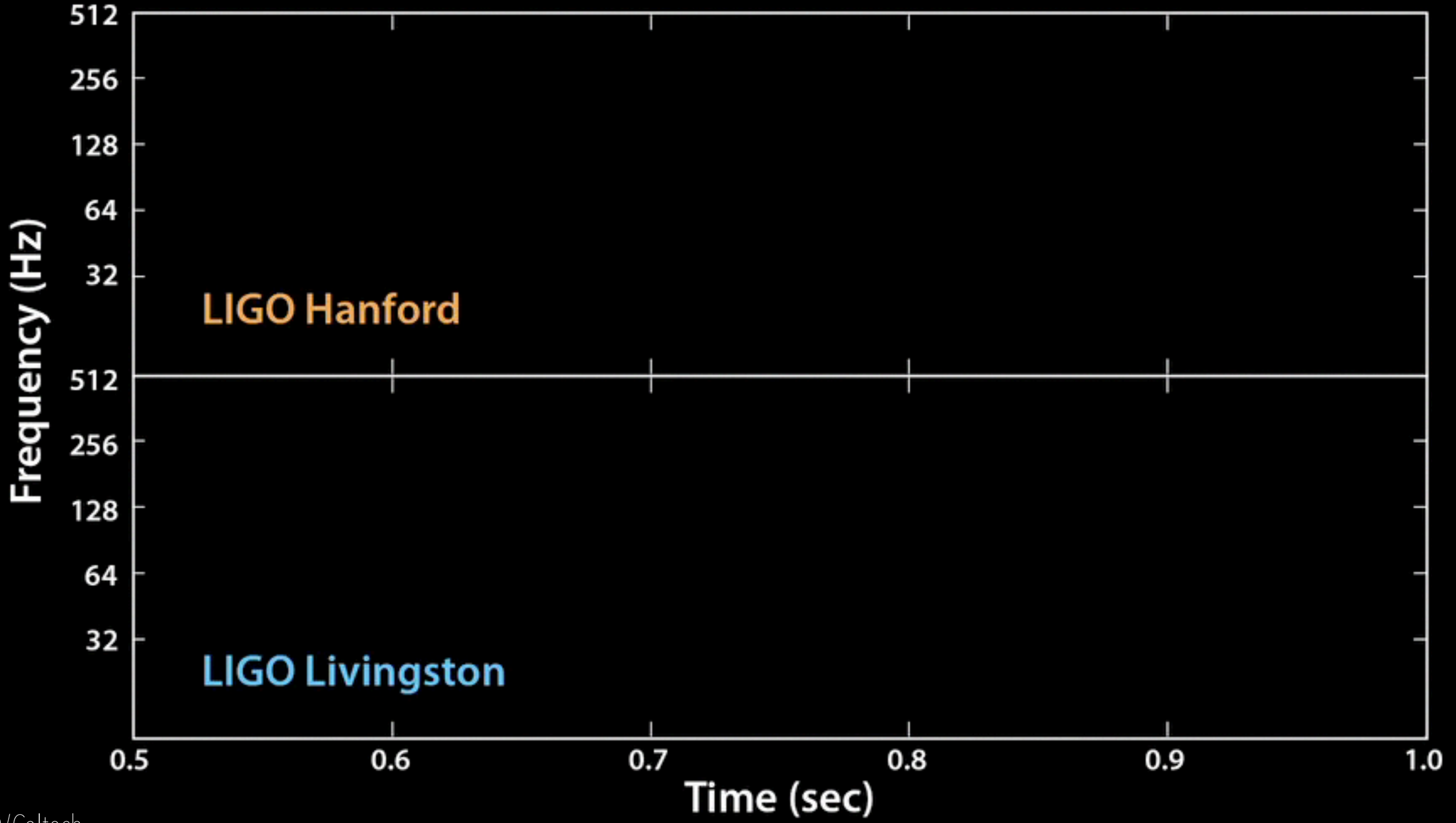


Current GW detector network (IGWN)

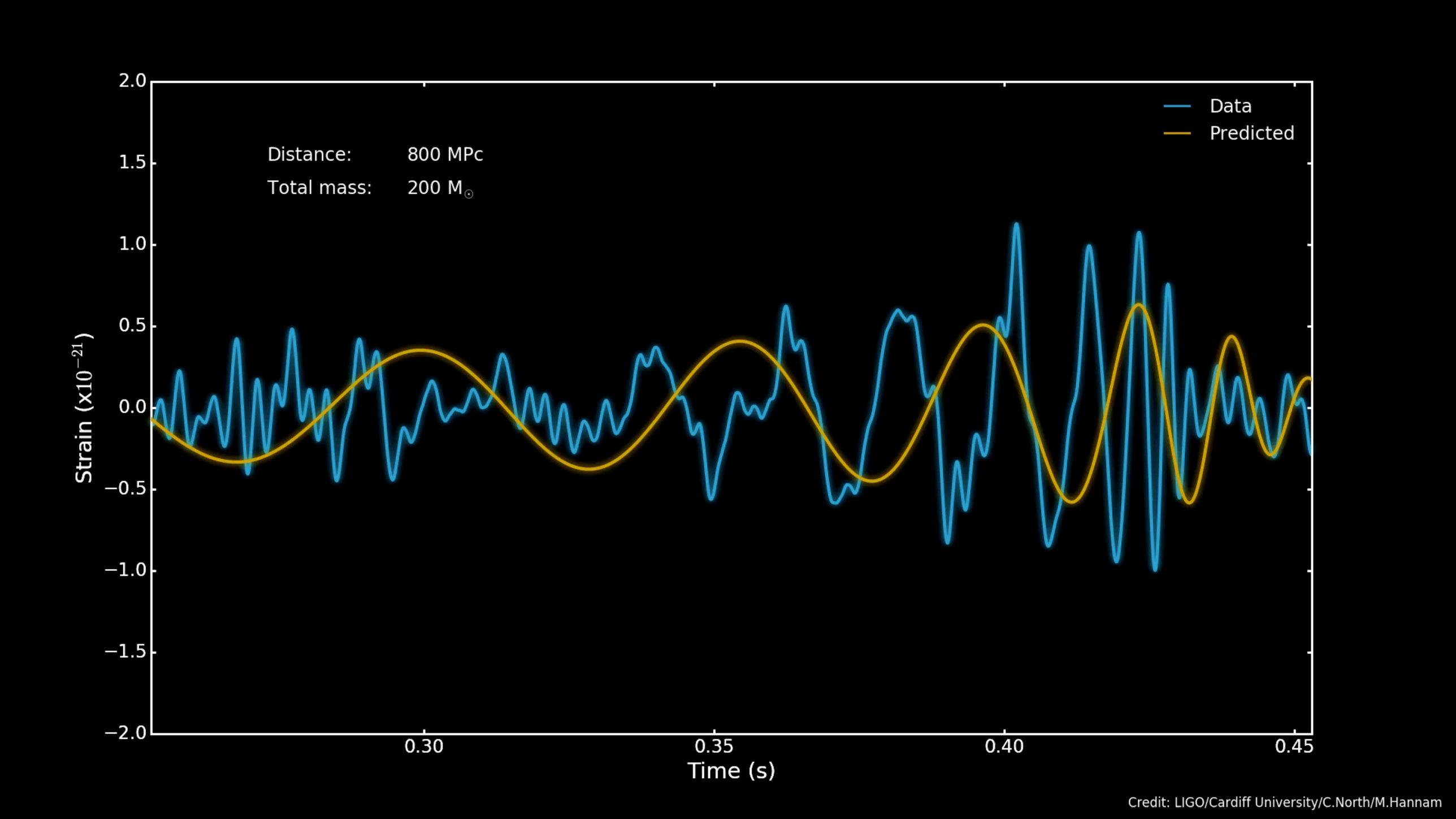


LIGO/Caltech


LIGO/Caltech



LIGO/Caltech



Credit: LIGO/Cardiff University/C.North/M.Hannam

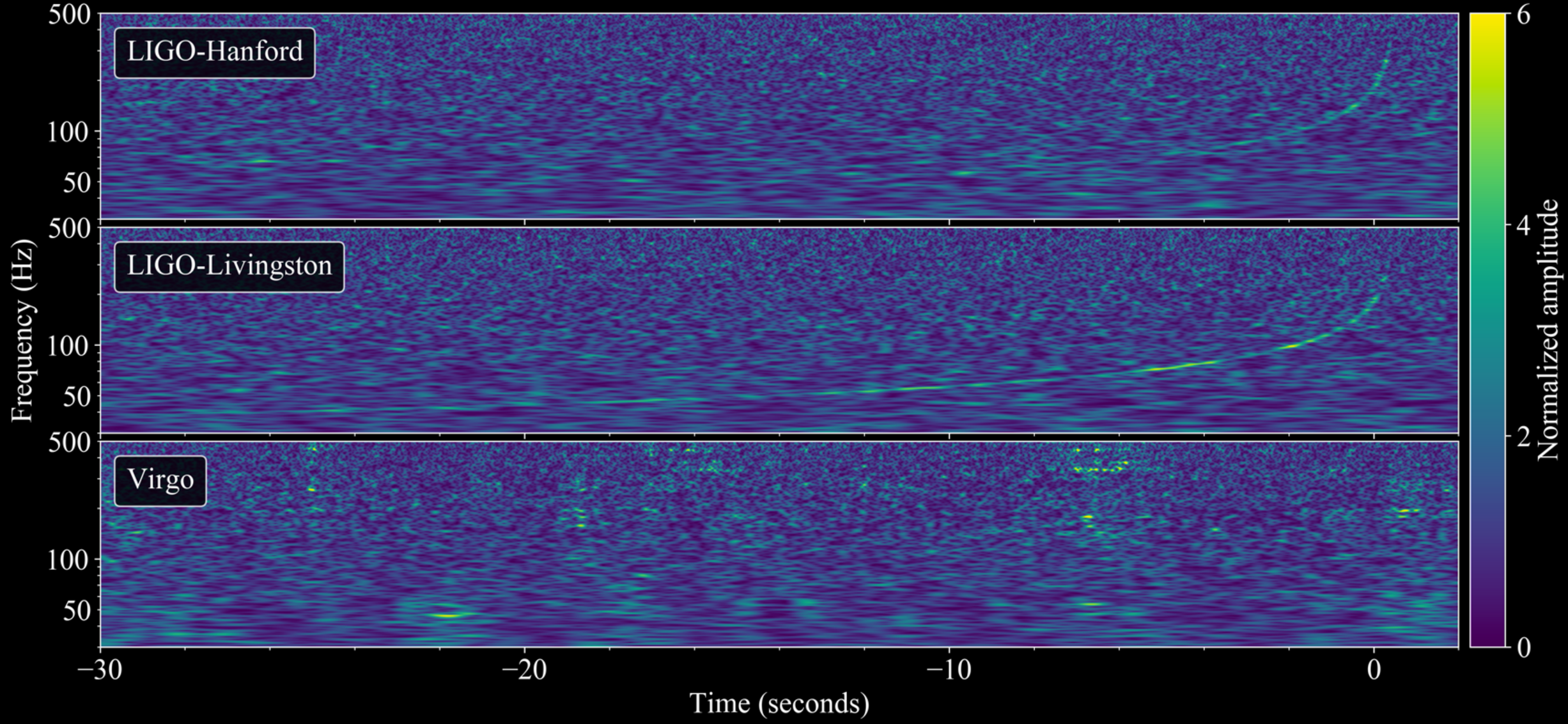
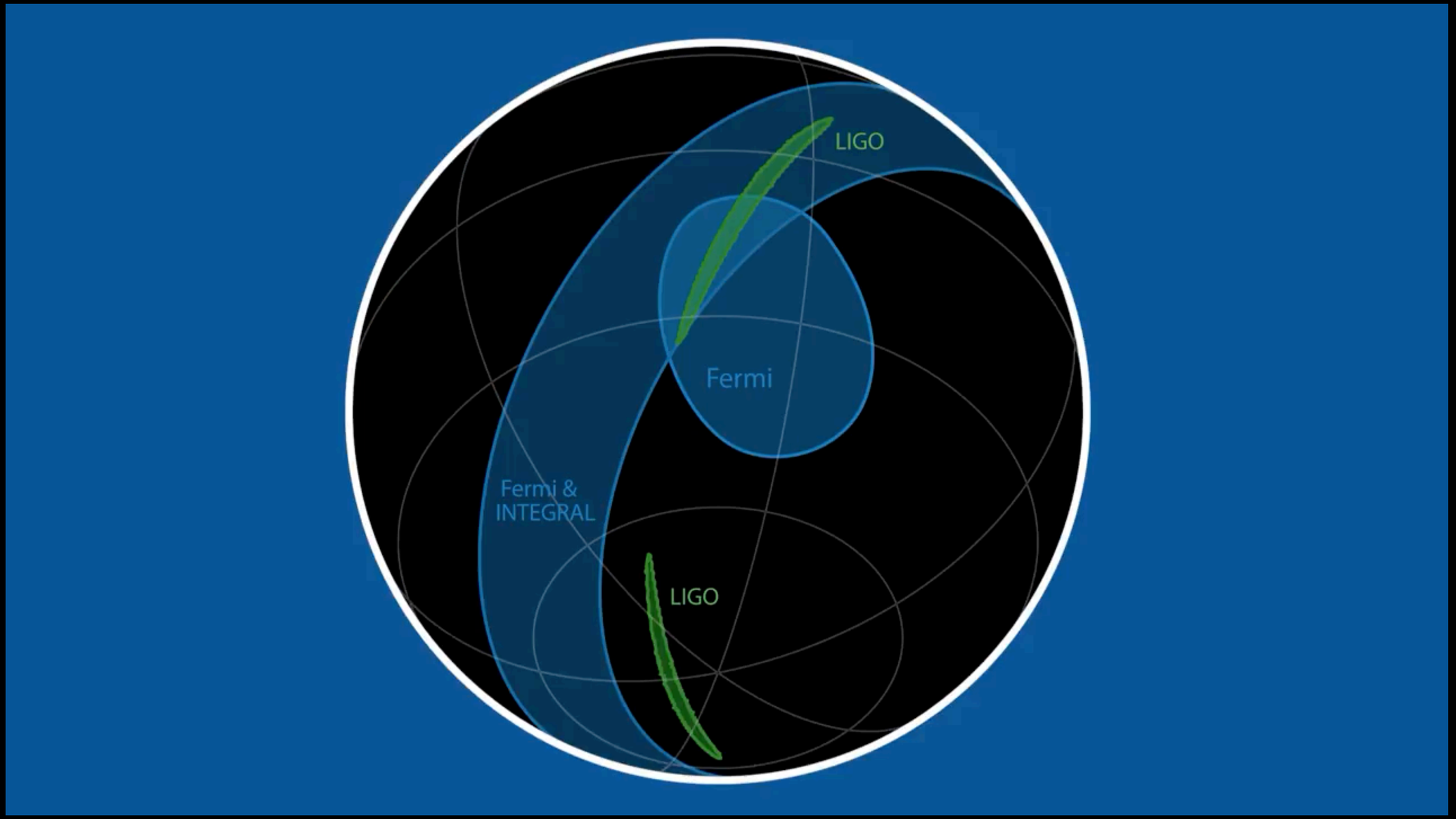


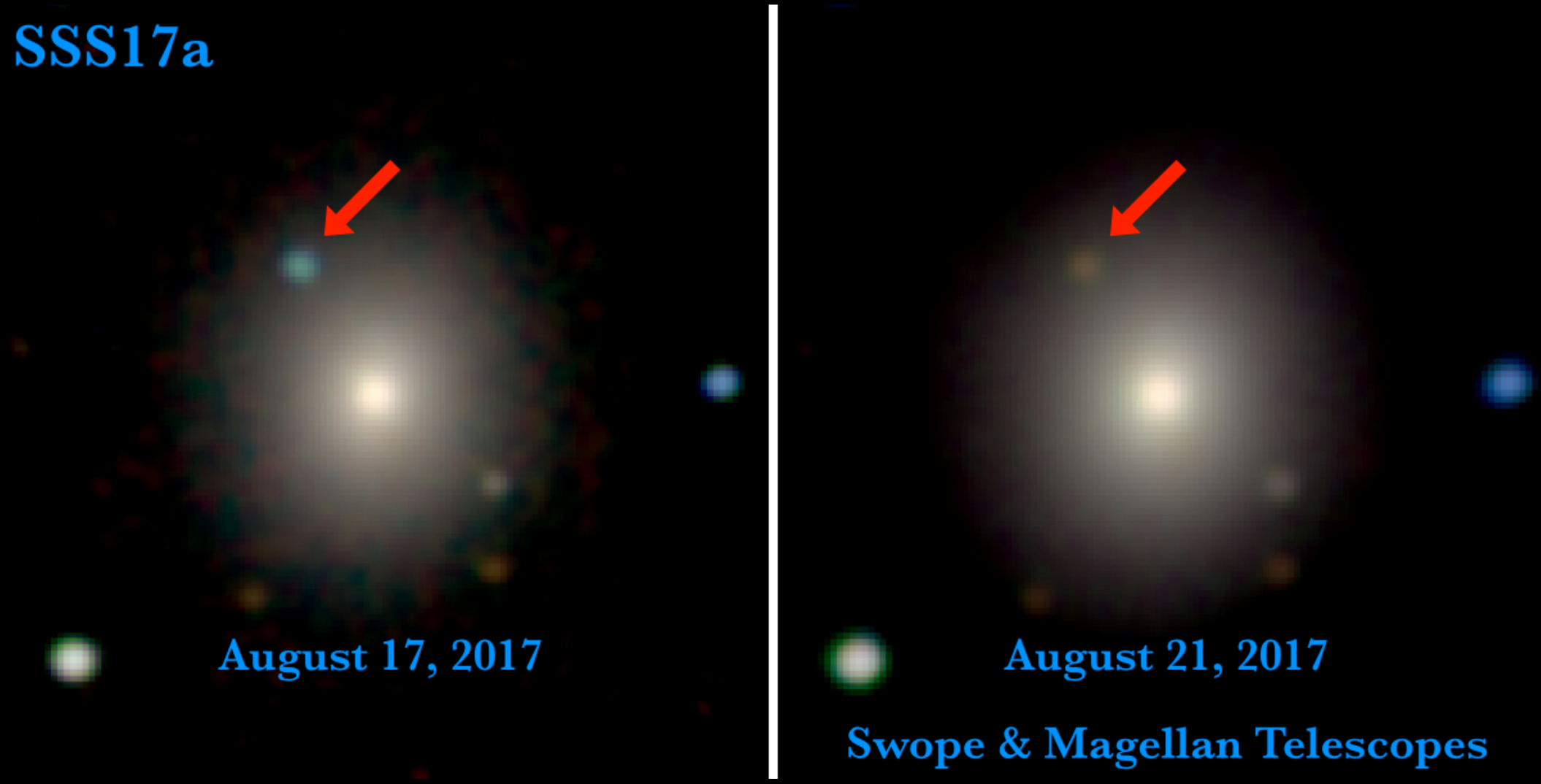
Image:LIGO/Caltech

Audio simulation: Scott Hughes, MIT

Sky localization with GWs



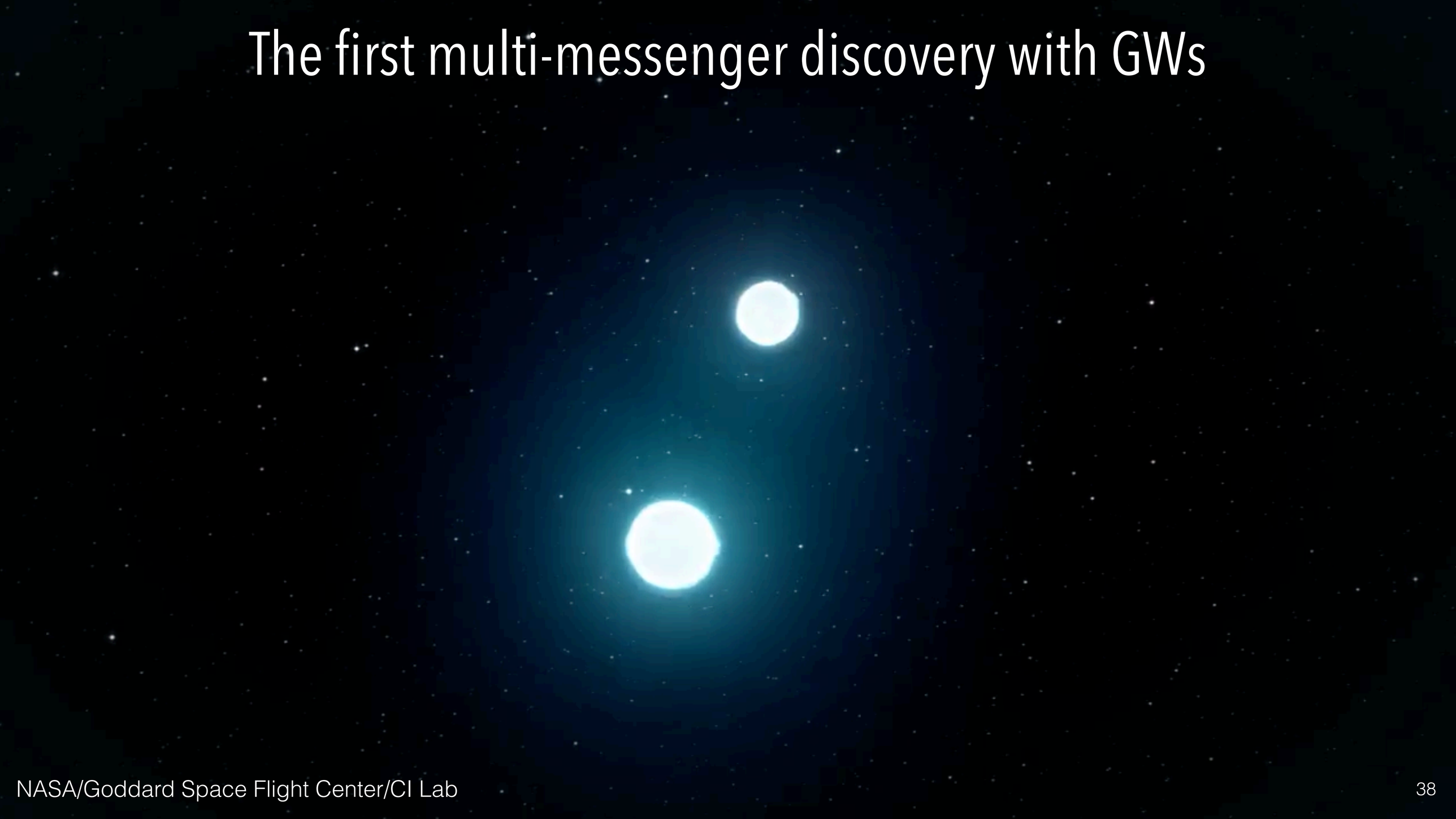
Discovery of an optical counterpart



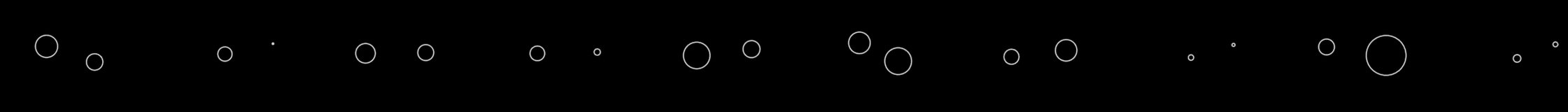
D. Coulter et al. 2017 arXiv 1710.05452

Image: 1M2H/UC Santa Cruz and Carnegie Observatories/Ryan Foley

The first multi-messenger discovery with GWs

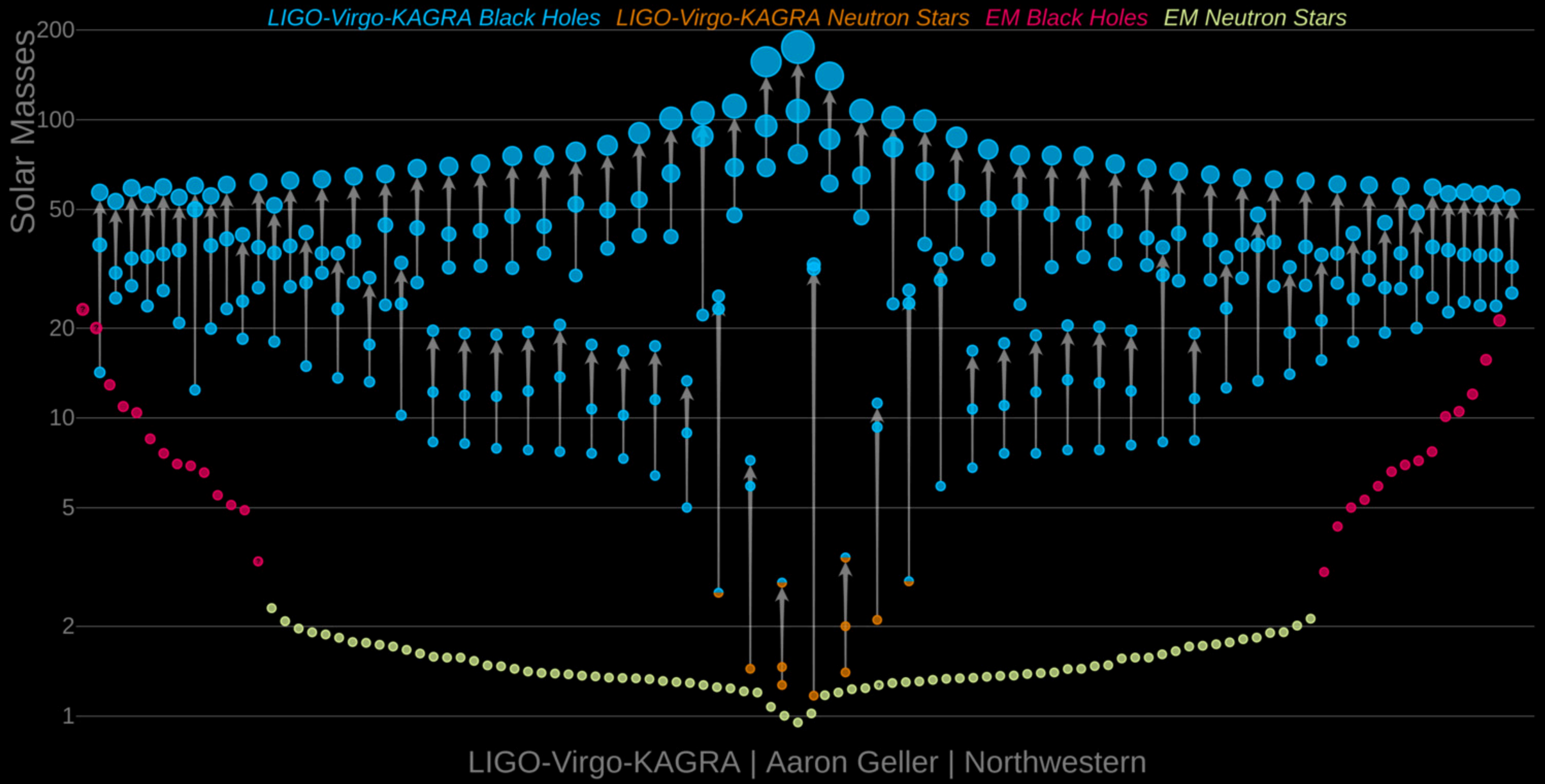


NASA/Goddard Space Flight Center/CI Lab

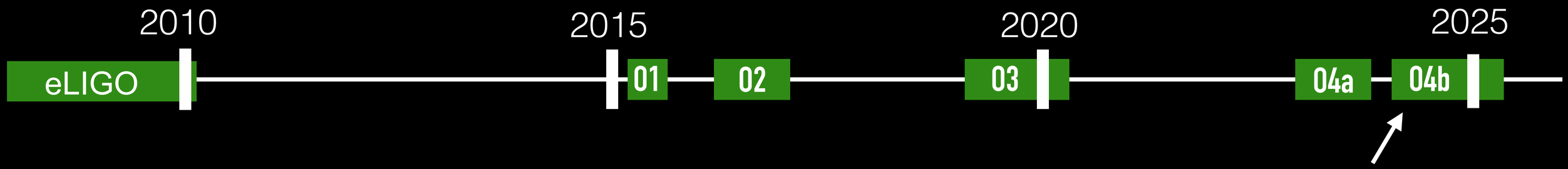


Zoheyr Doctor / CIERA / LIGO-Virgo Collaboration

The stellar graveyard



Timeline of Advanced LIGO and Advanced Virgo



Mostly black hole mergers →

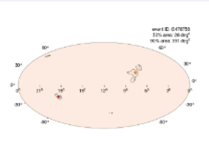
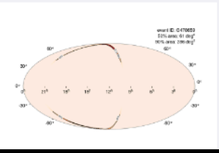
GraceDB Public Alerts ▾ Latest Search Notifications Pipelines Documentation Logout

Authenticated as: Jess McIver

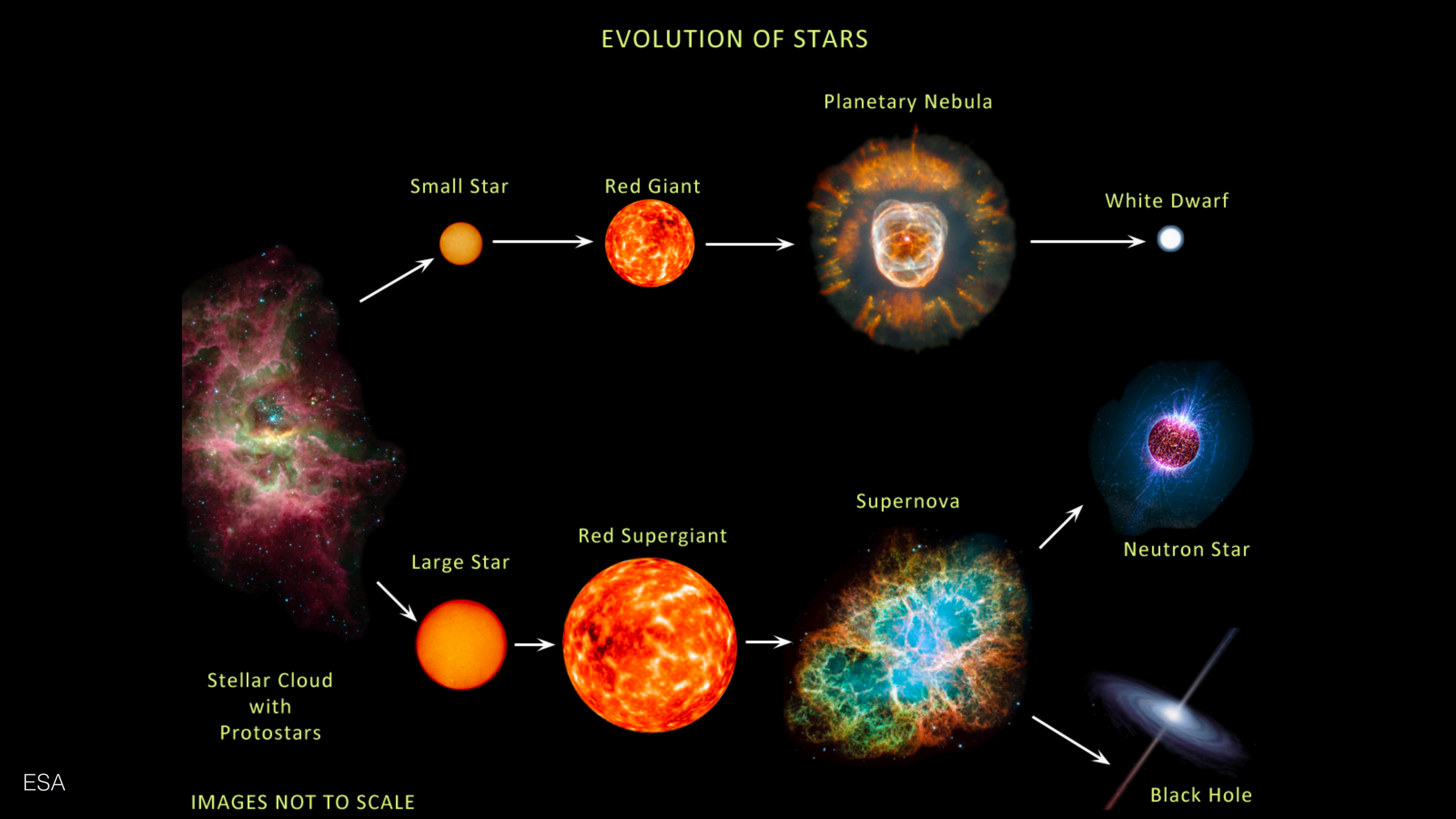
LIGO/Virgo/KAGRA Public Alerts

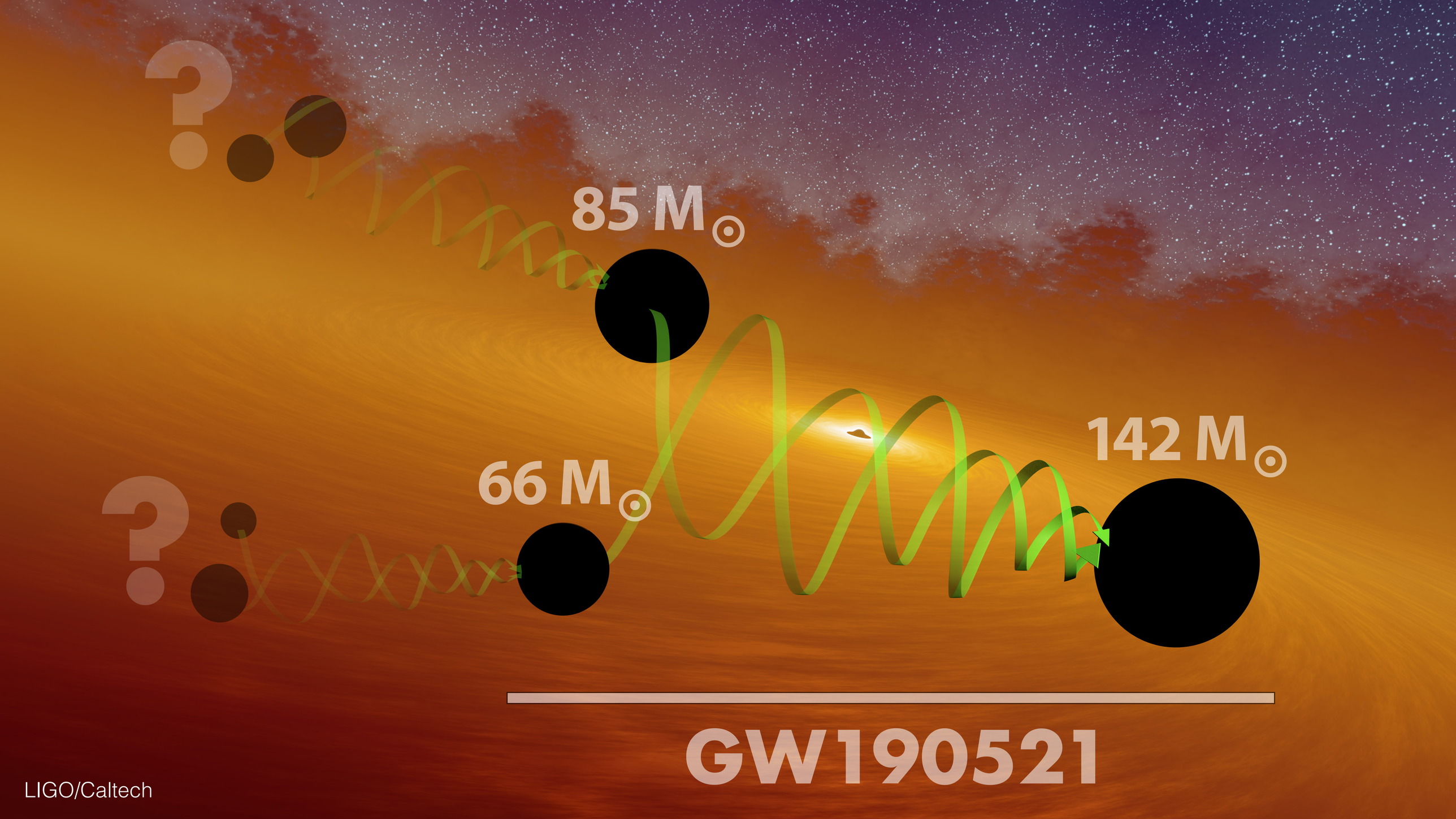
O4 Significant Detection Candidates: **105** (119 Total - 14 Retracted)

O4 Low Significance Detection Candidates: **1946** (Total)

Event ID	Possible Source (Probability)	Significant	UTC	GCN	Location	FAR
S240429an	Terrestrial (98%), BNS (2%)	Yes	April 29, 2024 05:23:03 UTC	GCN Circular Query Notices | VOE		1 per 11.049 years
S240428dr	BBH (>99%)	Yes	April 28, 2024 22:54:40 UTC	GCN Circular Query Notices | VOE		1 per 1.5024e+06 years

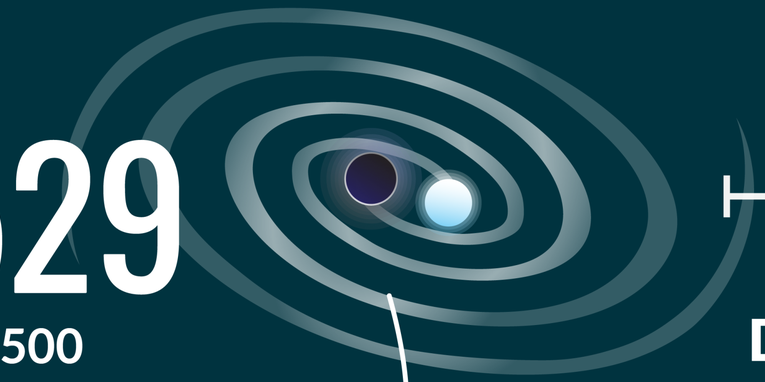
graceb.ligo.org


EVOLUTION OF STARS
Planetary Nebula
Small Star
Red Giant
White Dwarf
Supernova
Neutron Star
Red Supergiant
Large Star
Stellar Cloud
with
Protostars
Black Hole
ESA
IMAGES NOT TO SCALE


85 M⊙
66 M⊙
142 M⊙
GW190521
LIGO/Caltech

Recent news!

Get to know
GW230529
Full name GW230529_181500



~ 650 million light years away

Discovered on 29 May 2023 at 18h15 UTC

Detectors

H L V K

- Offline OR not operational
- Online BUT not used for analysis*
- Online AND used for analysis

most likely a merger between a
Neutron Star & Black Hole (NSBH)

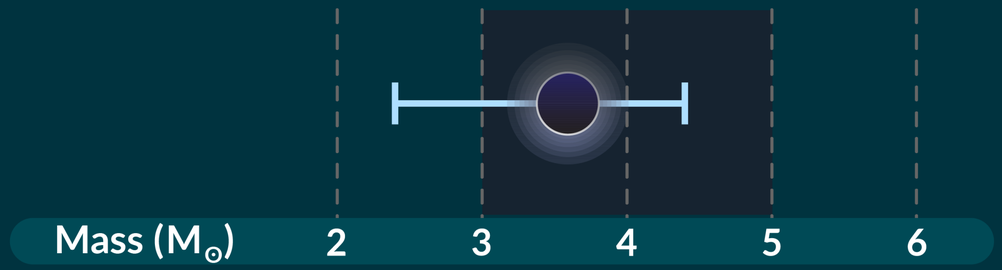
~1.4 $M_\odot$ ~3.6 $M_\odot$

Most symmetric NSBH event so far

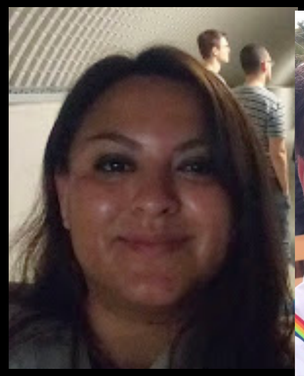
more likely than prior GW NSBHs to have the neutron star ripped apart by the black hole

Primary object in lower mass gap

further supports that this region is not empty



* Although the KAGRA detector was in observing mode, its sensitivity was insufficient to impact the analysis of GW230529



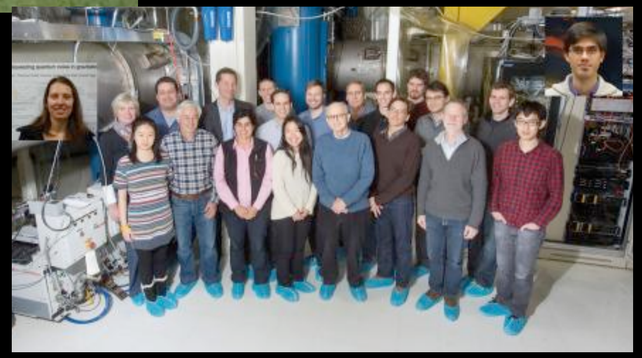




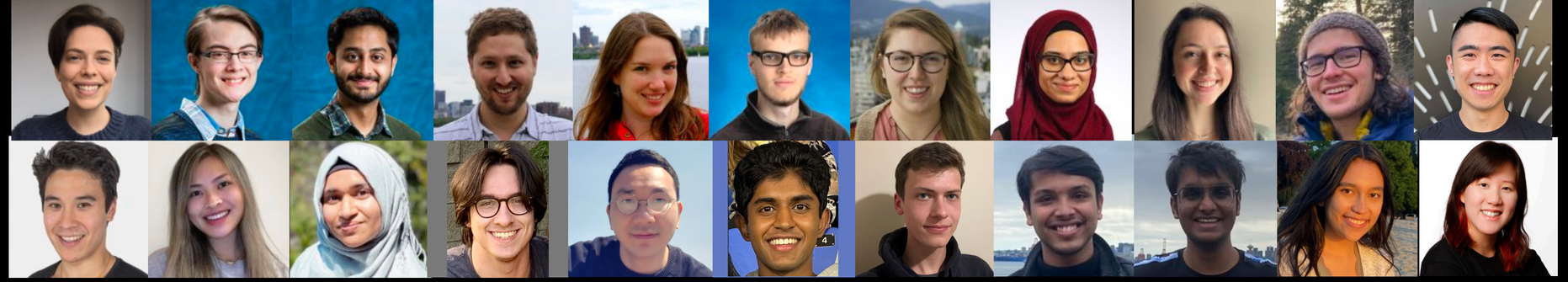
LSC

Over **1600** people
from **100** institutions
and **20** countries
worldwide!

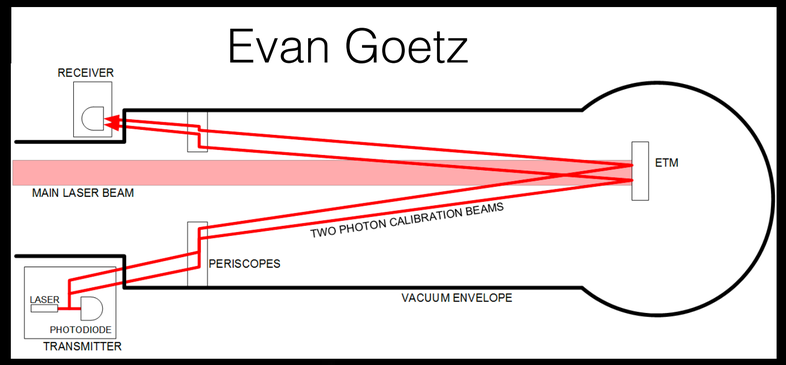


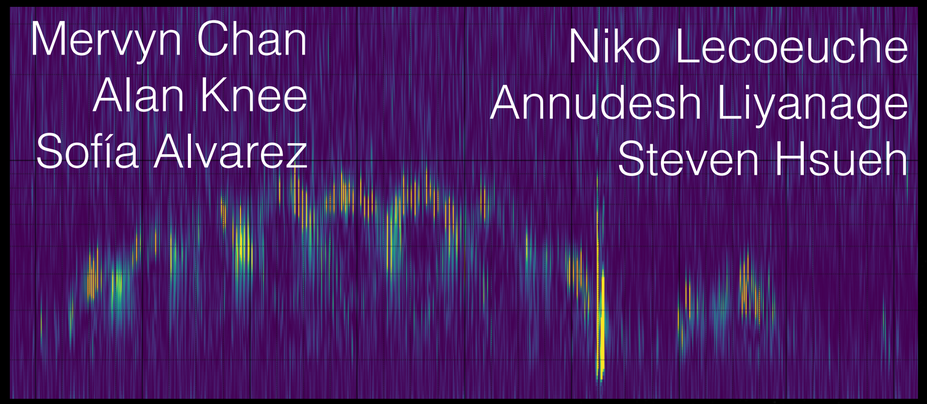


The UBC GW astrophysics group



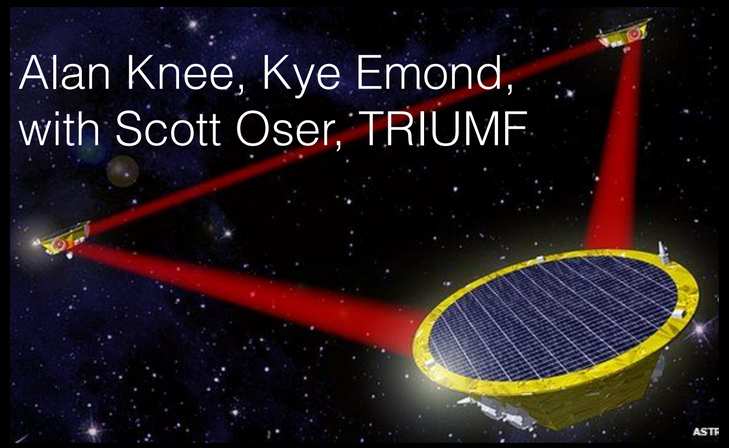
https://gravitational-waves.phas.ubc.ca/



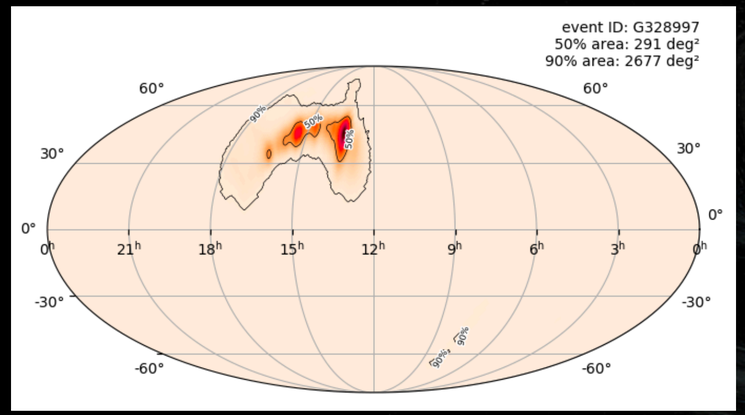


Evan Goetz, Alan Knee,
Neev Shah, Kat Nell

Evan Goetz
Helen Du
Alan Knee

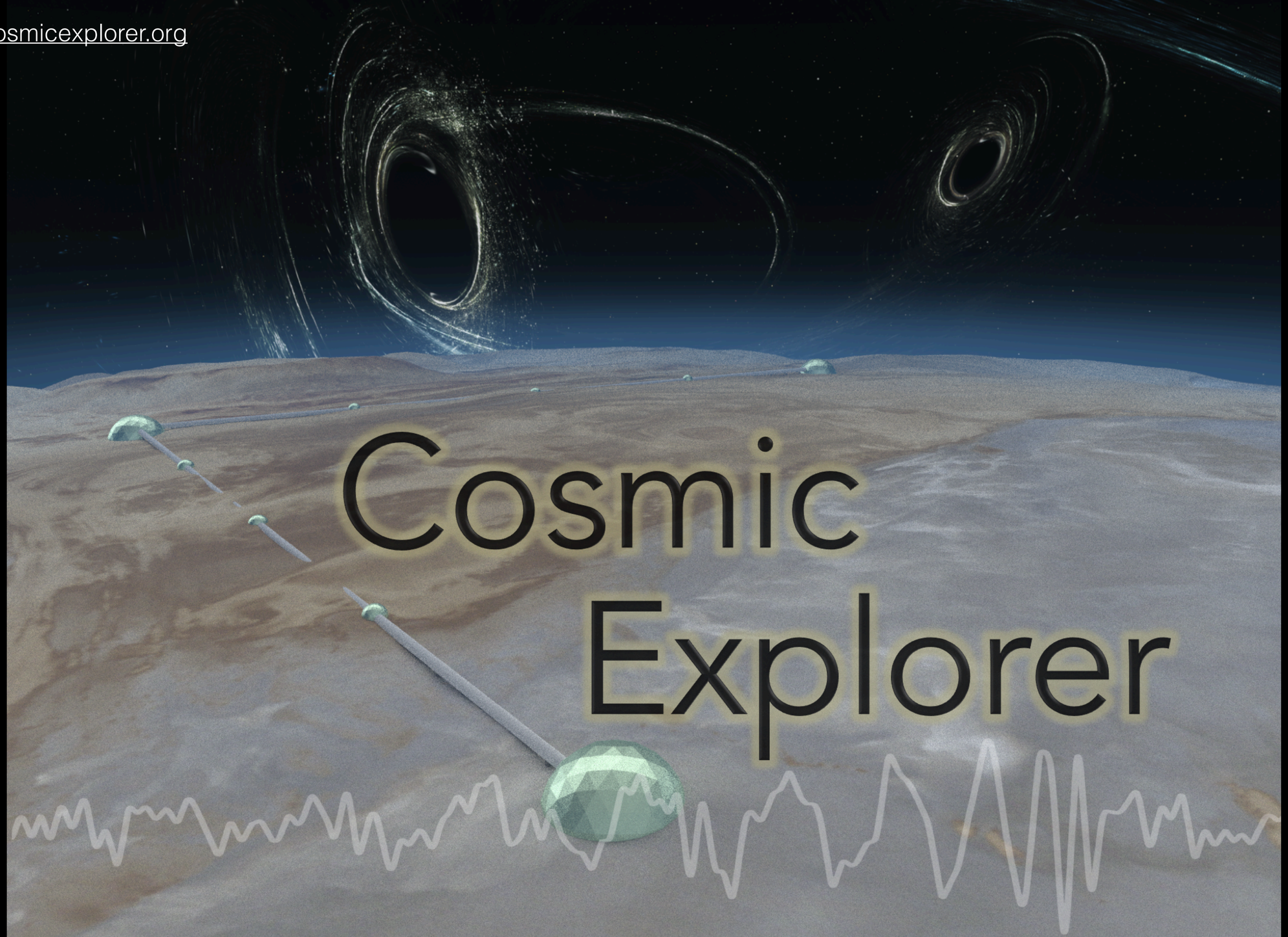


Mervyn Chan, Miriam Cabero

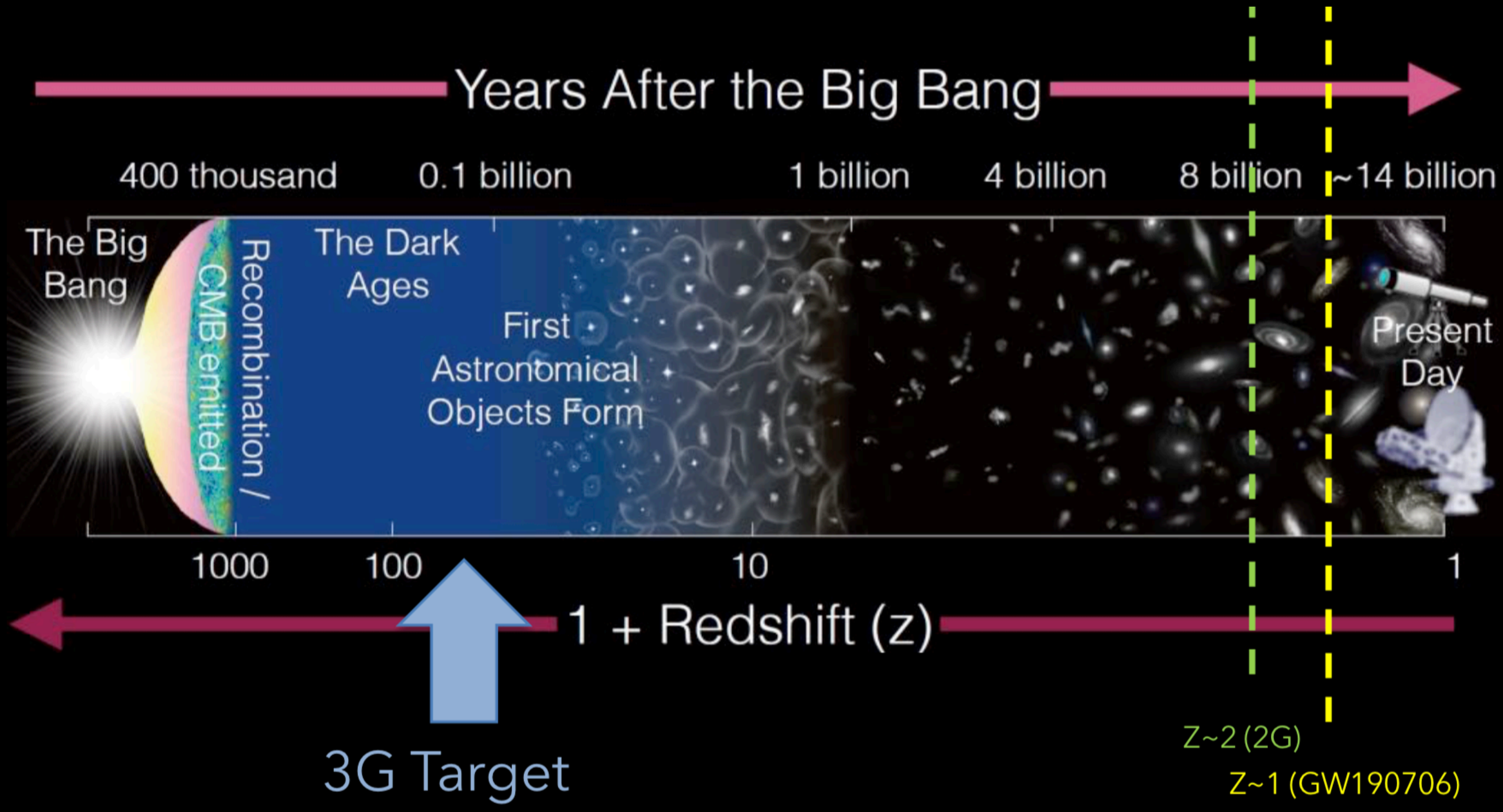


Alan Knee
Heather Fong
Neev Shah
Vaibhav Garg

Source: cosmicexplorer.org




40 km
Lion's Head
Wiarton
Sauble Beach
Owen Sound
Meaford
Collingwood
Midland
Gravenhurst
Minden
Orillia
Kawartha Lakes
Barrie
Innisfil
Port Elgin
Kincardine
Hanover
Walkerton
Newmarket
Richmond Hill
Markham
Brampton
Toronto
Oshawa
Peterborough
Campbellford
Marmora
Tweed
Sydenham
Kingston
Greater Napanee
Belleville
Deseronto
Prince Edward
Cobourg
Brighton
Goderich
Listowel
Fergus
Guelph
Kitchener
Mississauga
Oakville
Hamilton
Stratford
Grand Bend
St. Marys
Brantford
St. Catharines
Niagara Falls
Welland
Fort Erie
Buffalo
Lockport
Brockport
Rochester
Fairport
Batavia
Geneseo
Canandaigua
Geneva
Auburn
Baldwinsville
Oswego
Fulton
Lake Ontario
London
Ingersoll
Strathroy
Tillsonburg
Simcoe
Port Dover
St Thomas
Aylmer
Perth



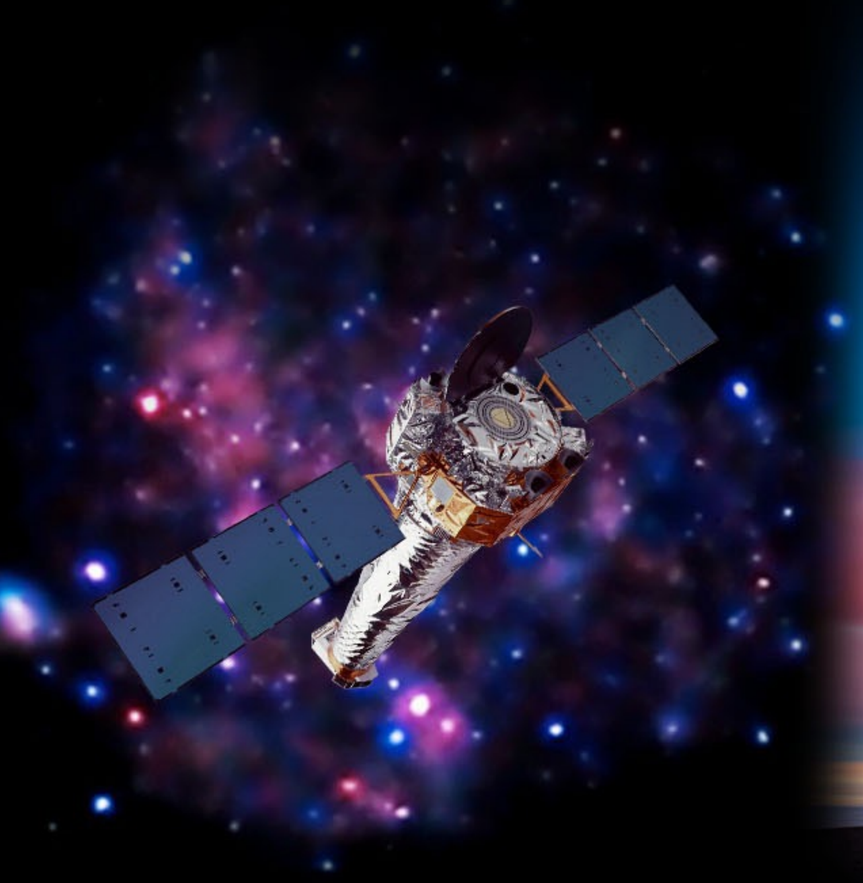
Slide by G. Losurdo

Electromagnetic Wave Windows

X-Ray

Optical

Radio



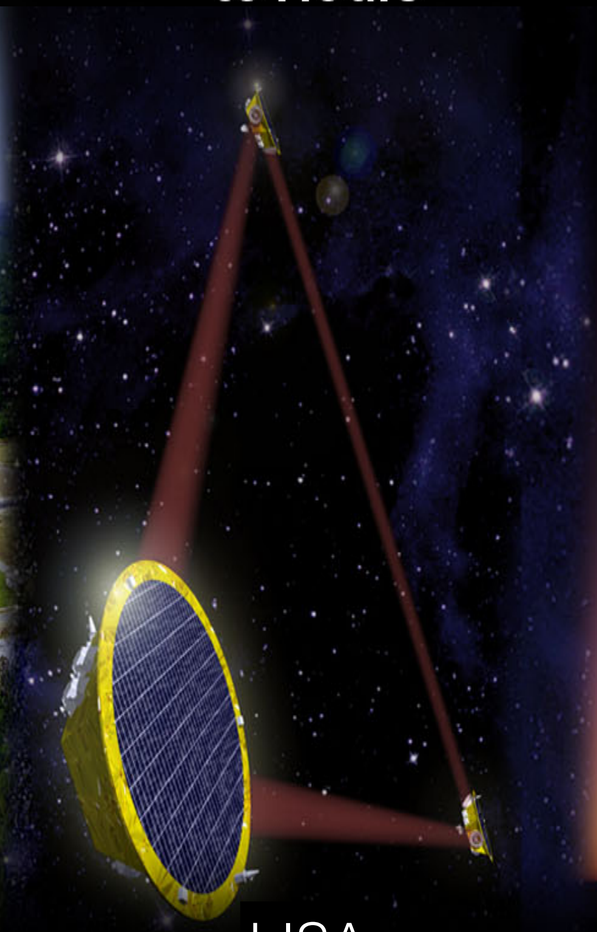
L. Nuttall

Gravitational Wave Periods

Milliseconds

LIGO/Virgo

Minutes to Hours

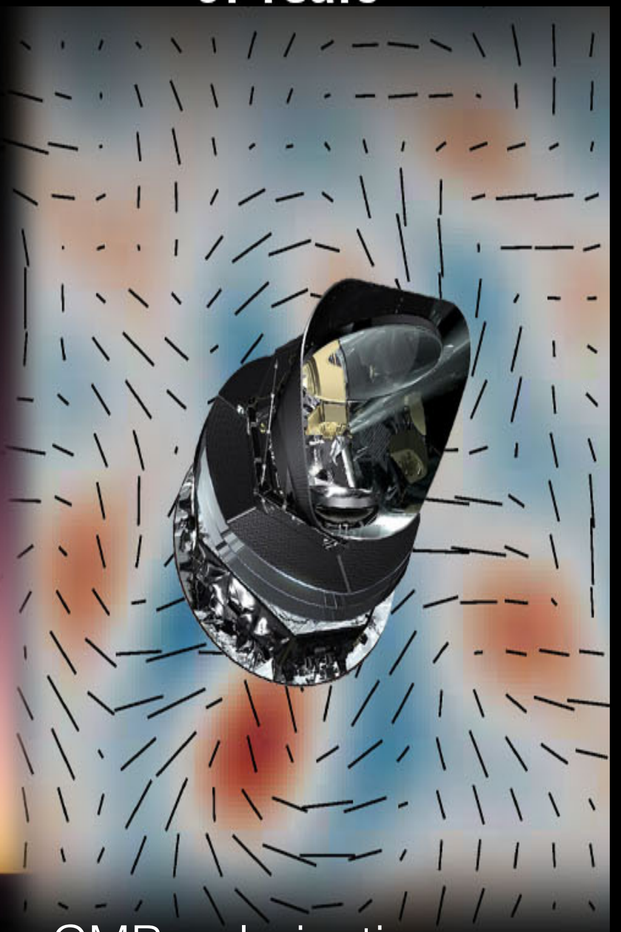


LISA

Years to Decades

Pulsar timing

Billions of Years



CMB polarization

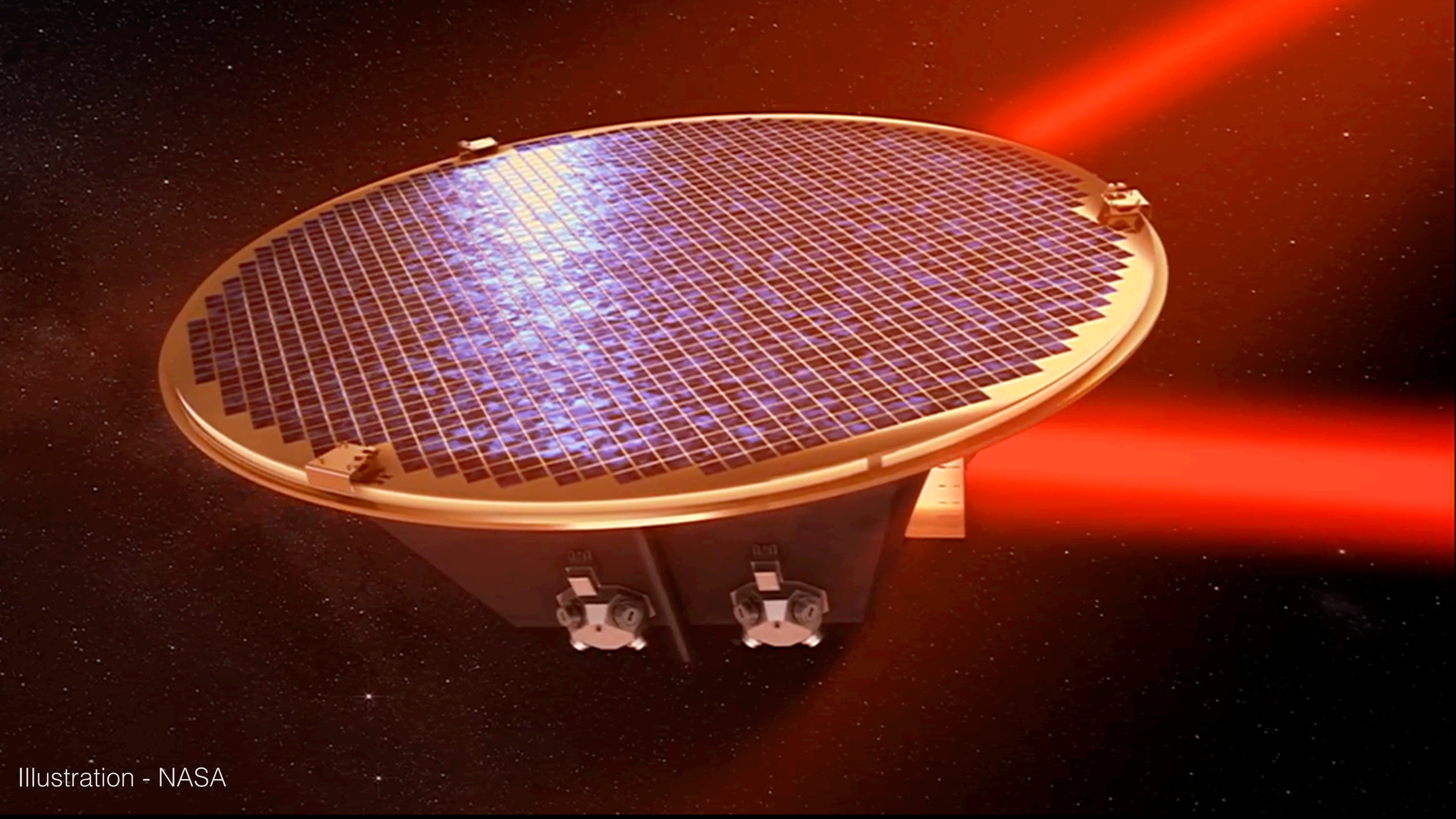


Illustration - NASA

Illustration -NASA

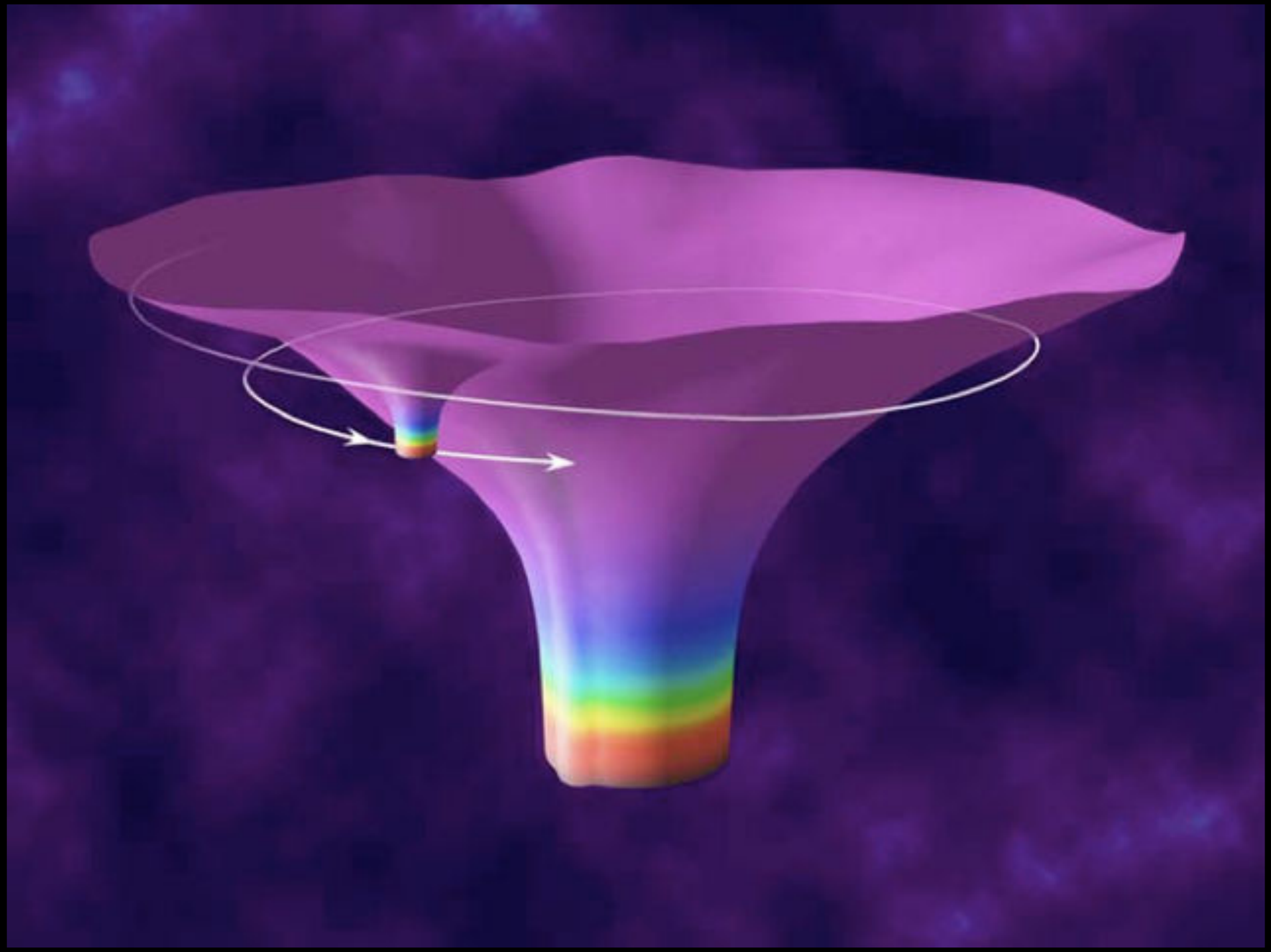


Illustration - https://en.wikipedia.org/wiki/Extreme_mass_ratio_inspiral

Merging galaxies NGC 2623. NASA/ESA (Hubble)

Illustration - NSF

Illustration
NASA, ESA, CSA, Joseph Olmsted (STScI)

Pulsar Timing Arrays

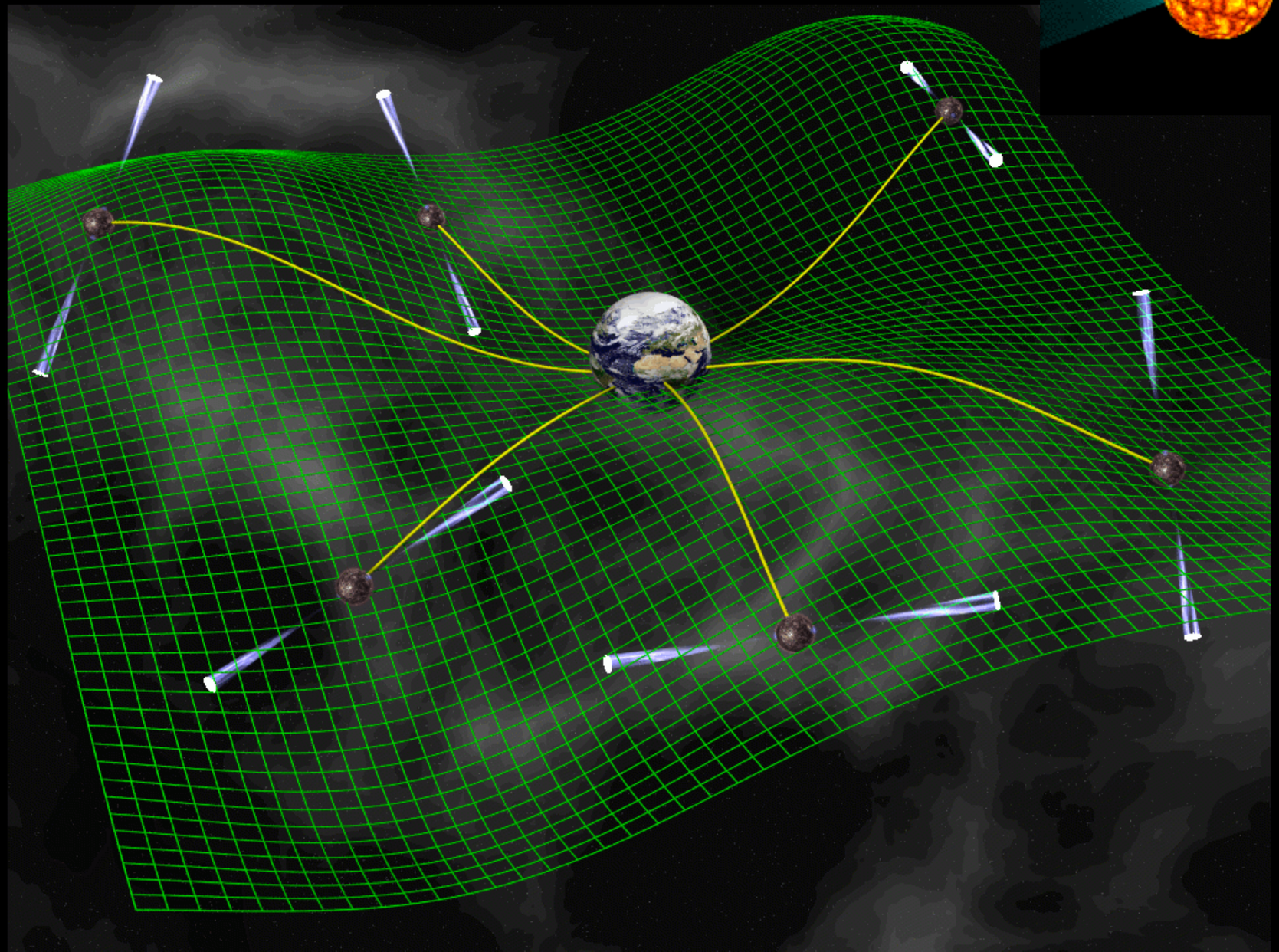
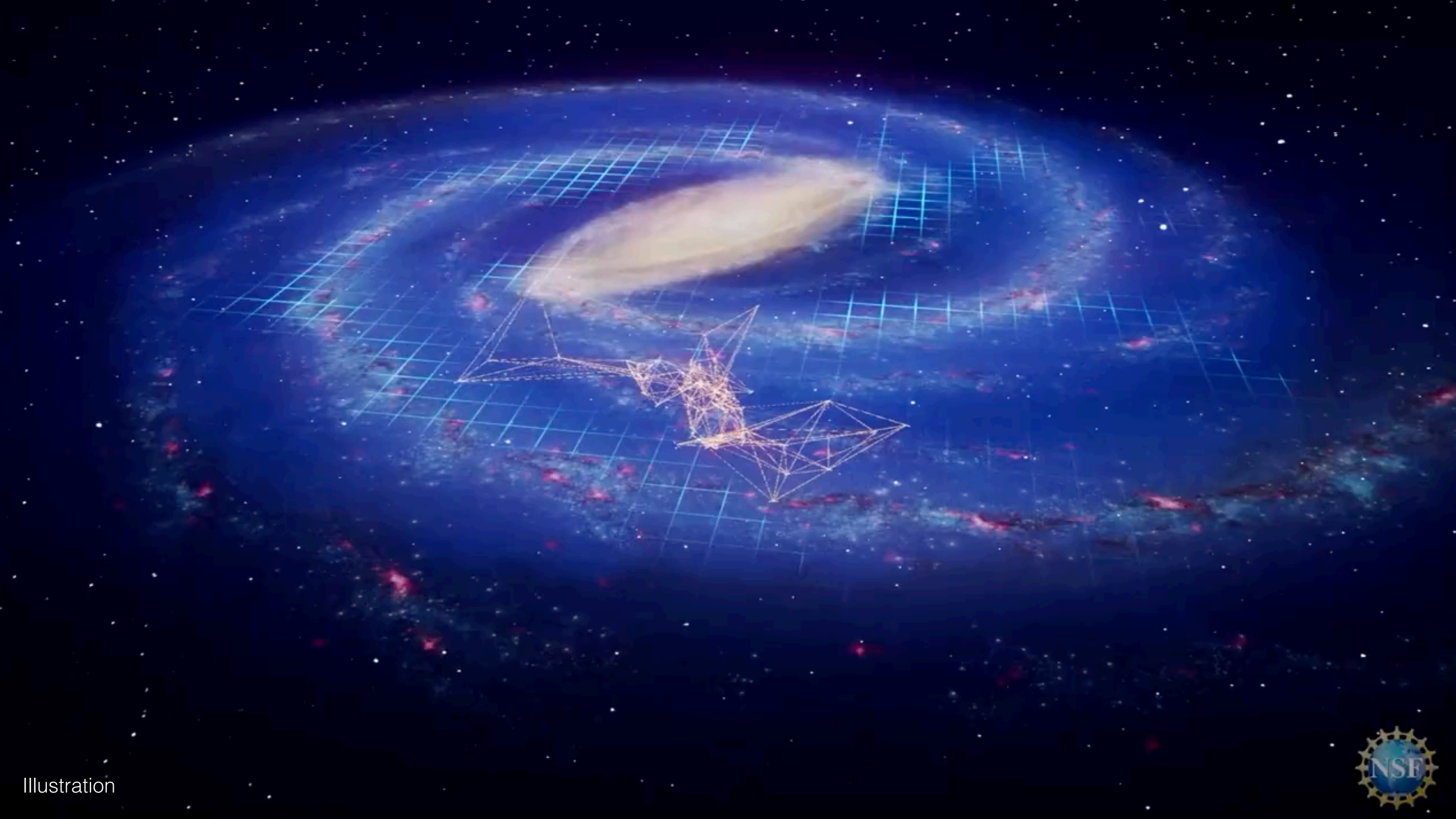


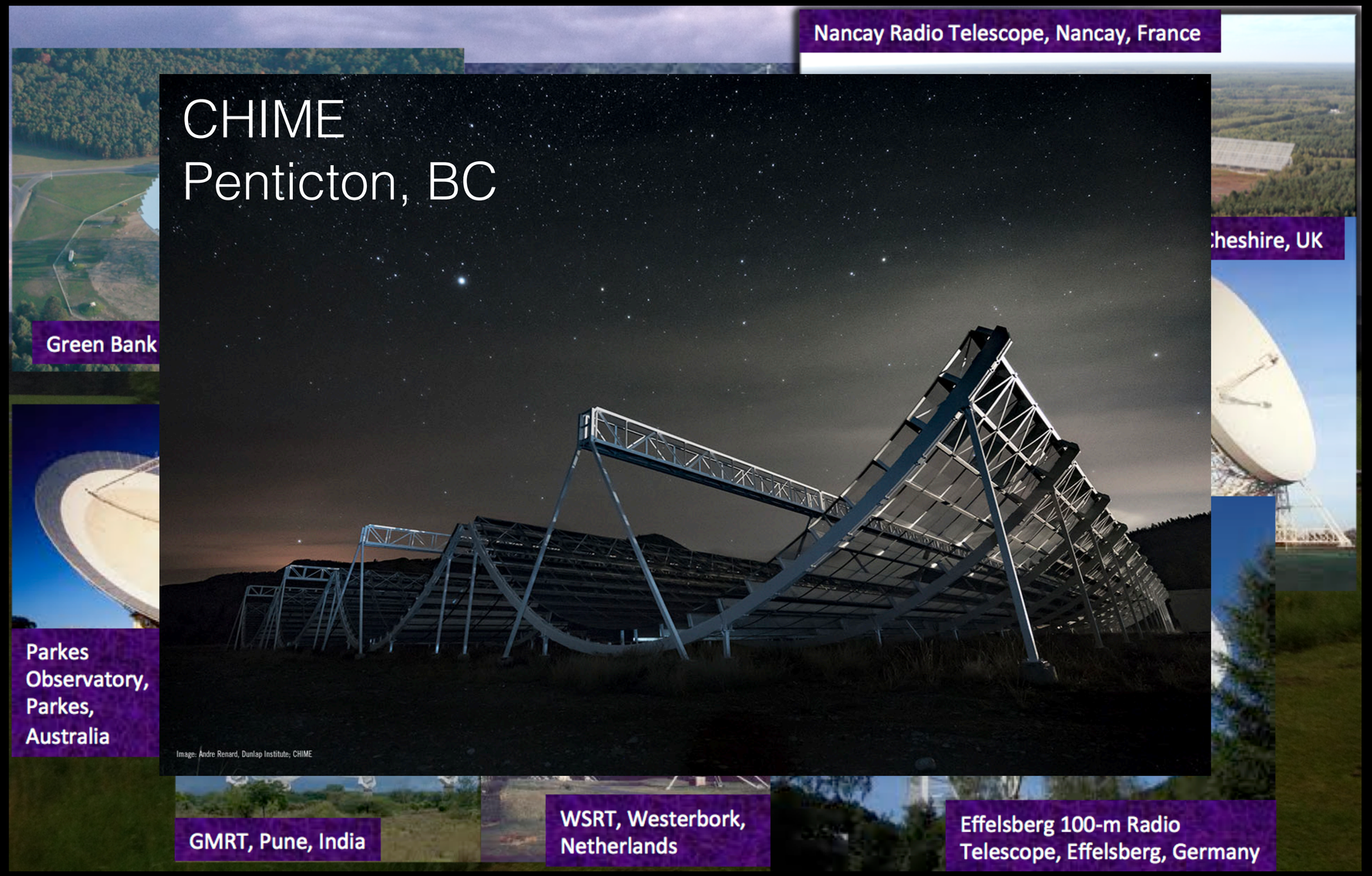
Illustration
David J Champion



Illustration

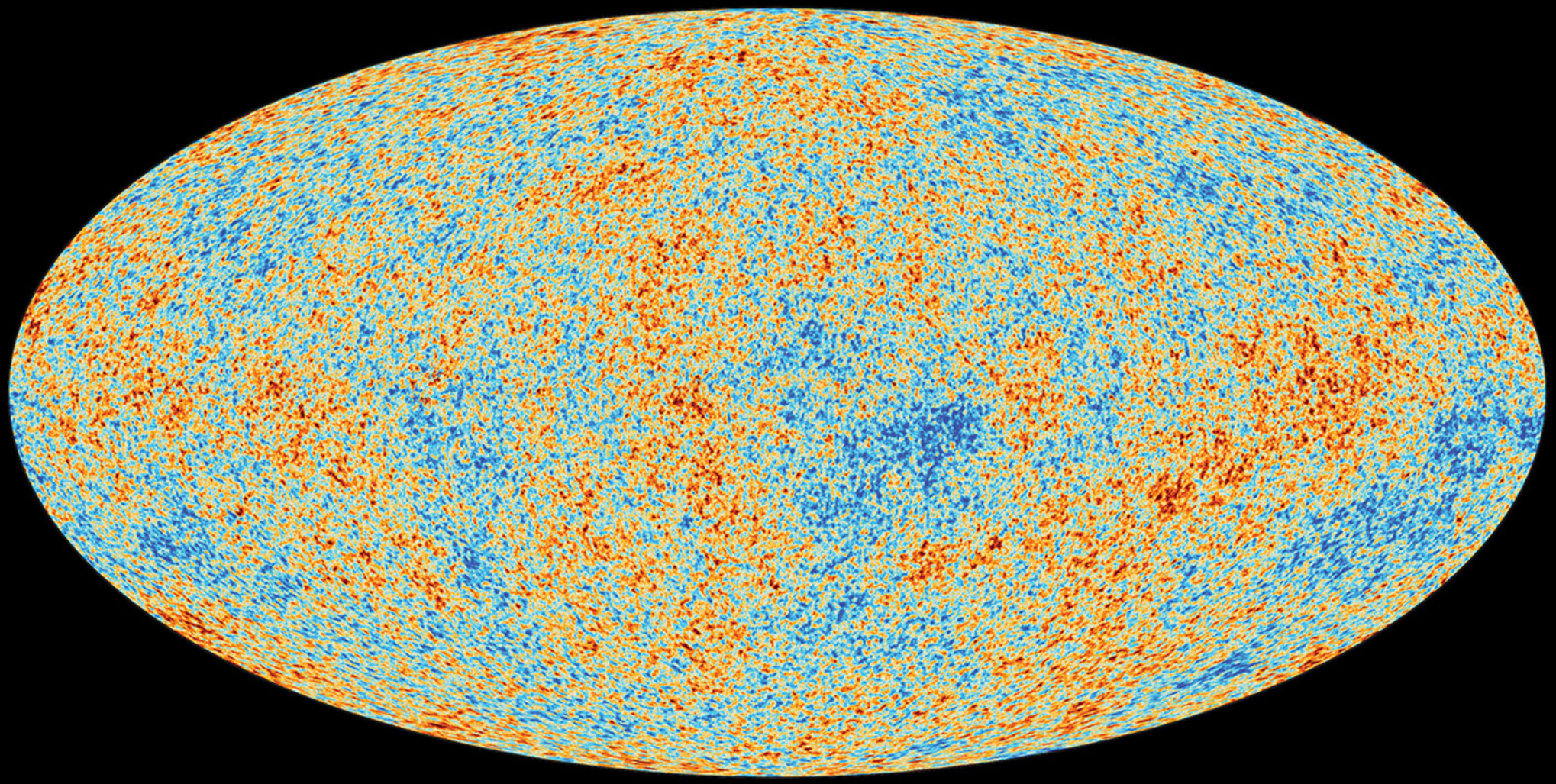
An International Radio Telescope Effort

An International Radio Telescope Effort



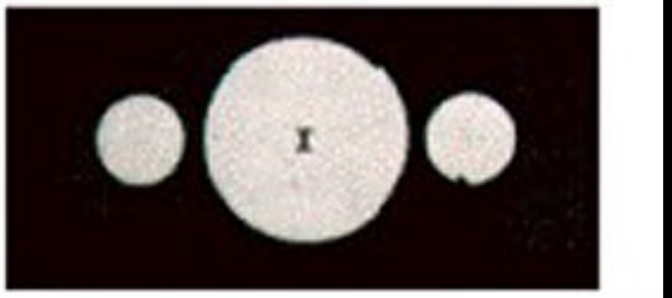
→ THE COSMIC MICROWAVE BACKGROUND

Planck Legacy Release 2018

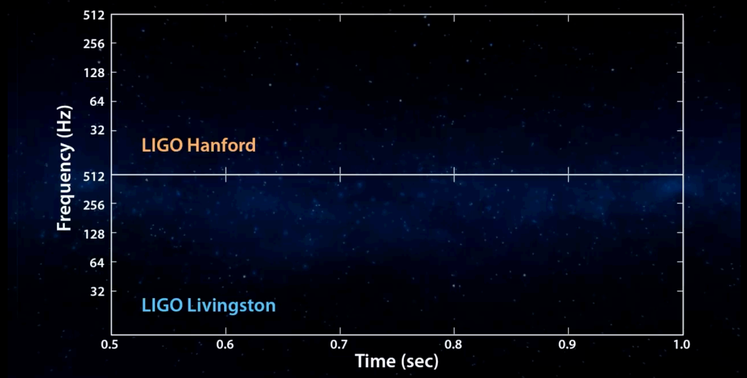


Credit: ESA/Planck Collaboration

This is just the beginning of gravitational wave astrophysics!



Galileo first sketch
1610



Slide by G. Losurdo

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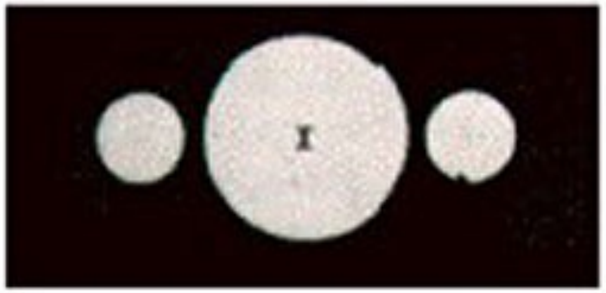
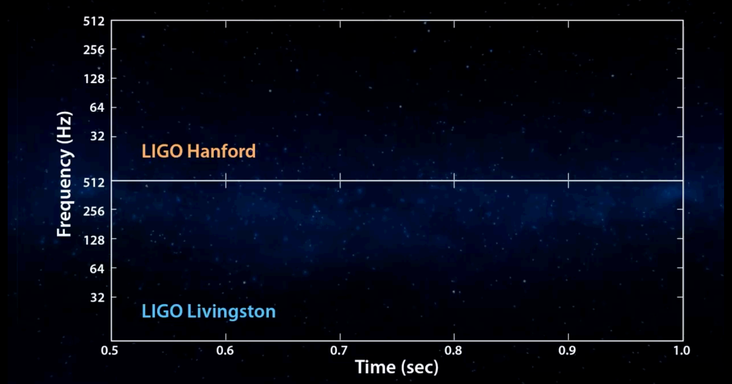
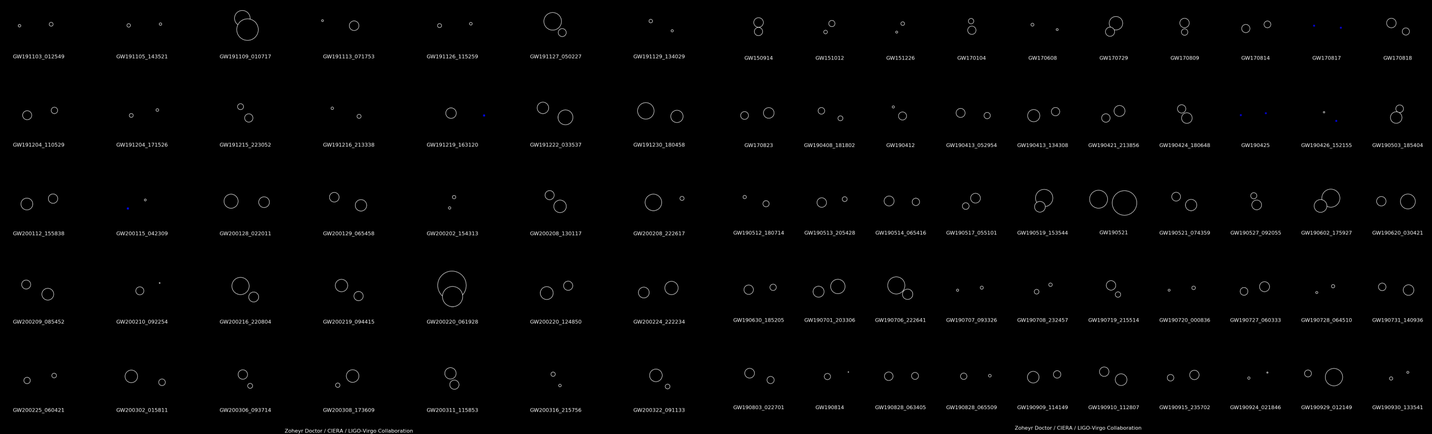


Galileo first sketch
1610

Better telescope
1616

Rice





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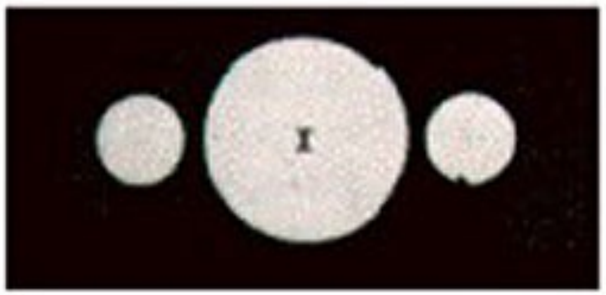
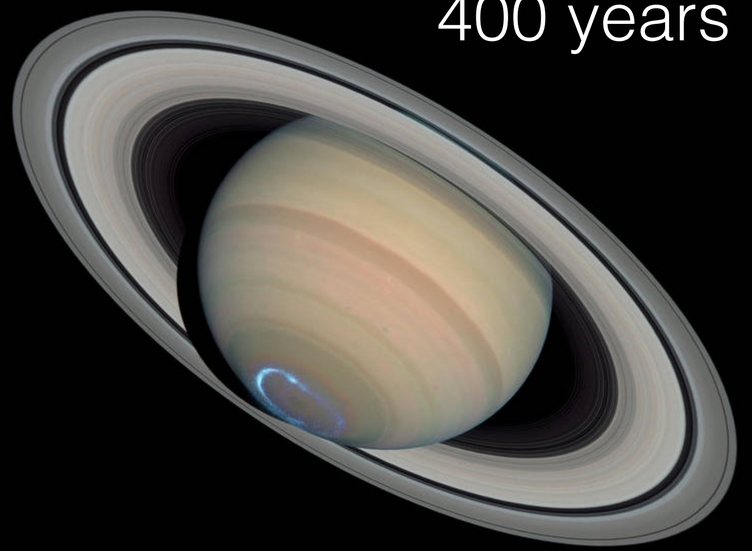


Galileo first sketch
1610

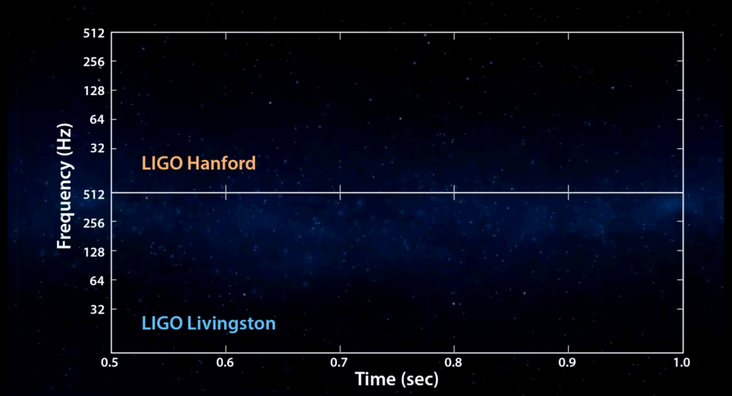
Better telescope
1616

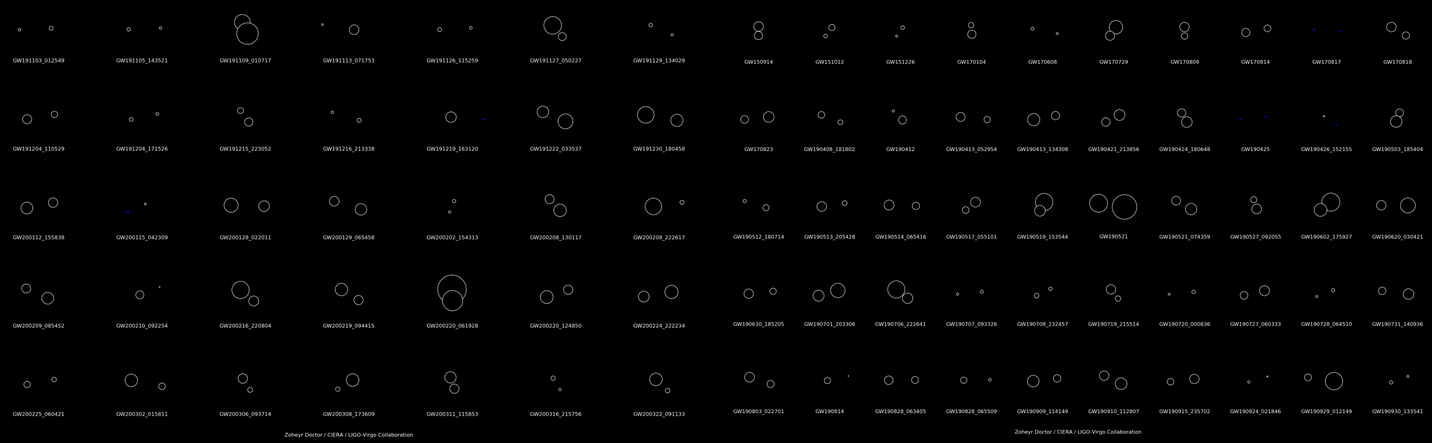
Rice

400 years later…



HST





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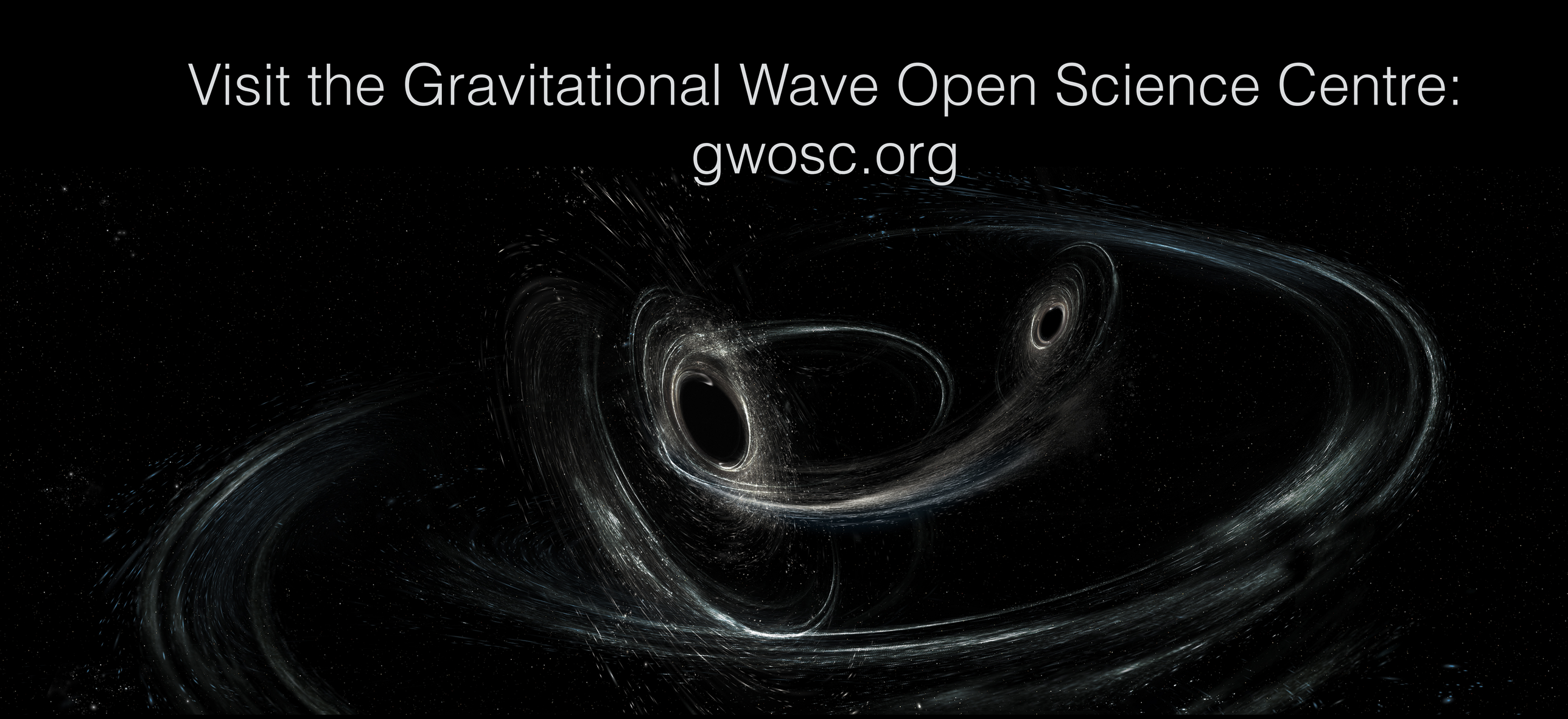
Slide by G. Losurdo

Visit the Gravitational Wave Open Science Centre: gwosc.org



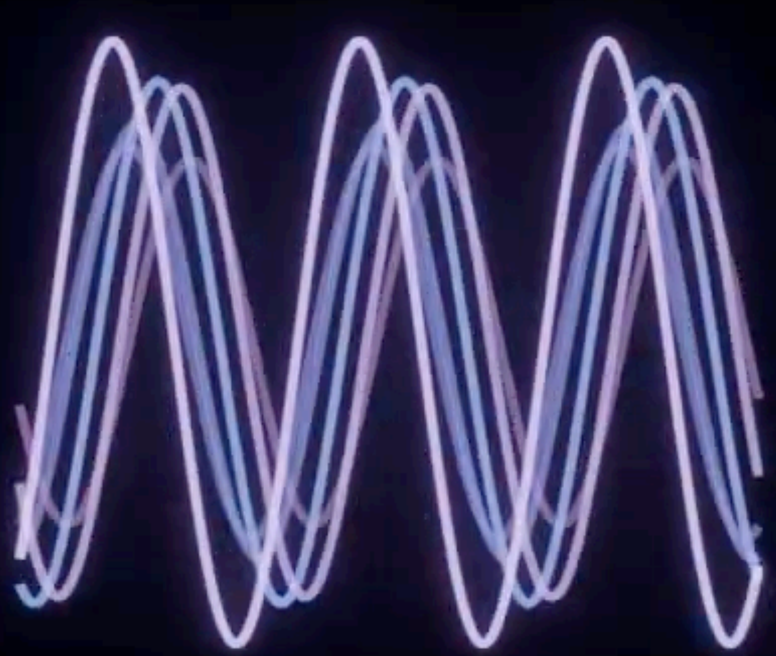
Help us out on GravitySpy.org!

NSF/LIGO/Sonoma State University/A. Simonnet

Kai Staats

Quantum Physics

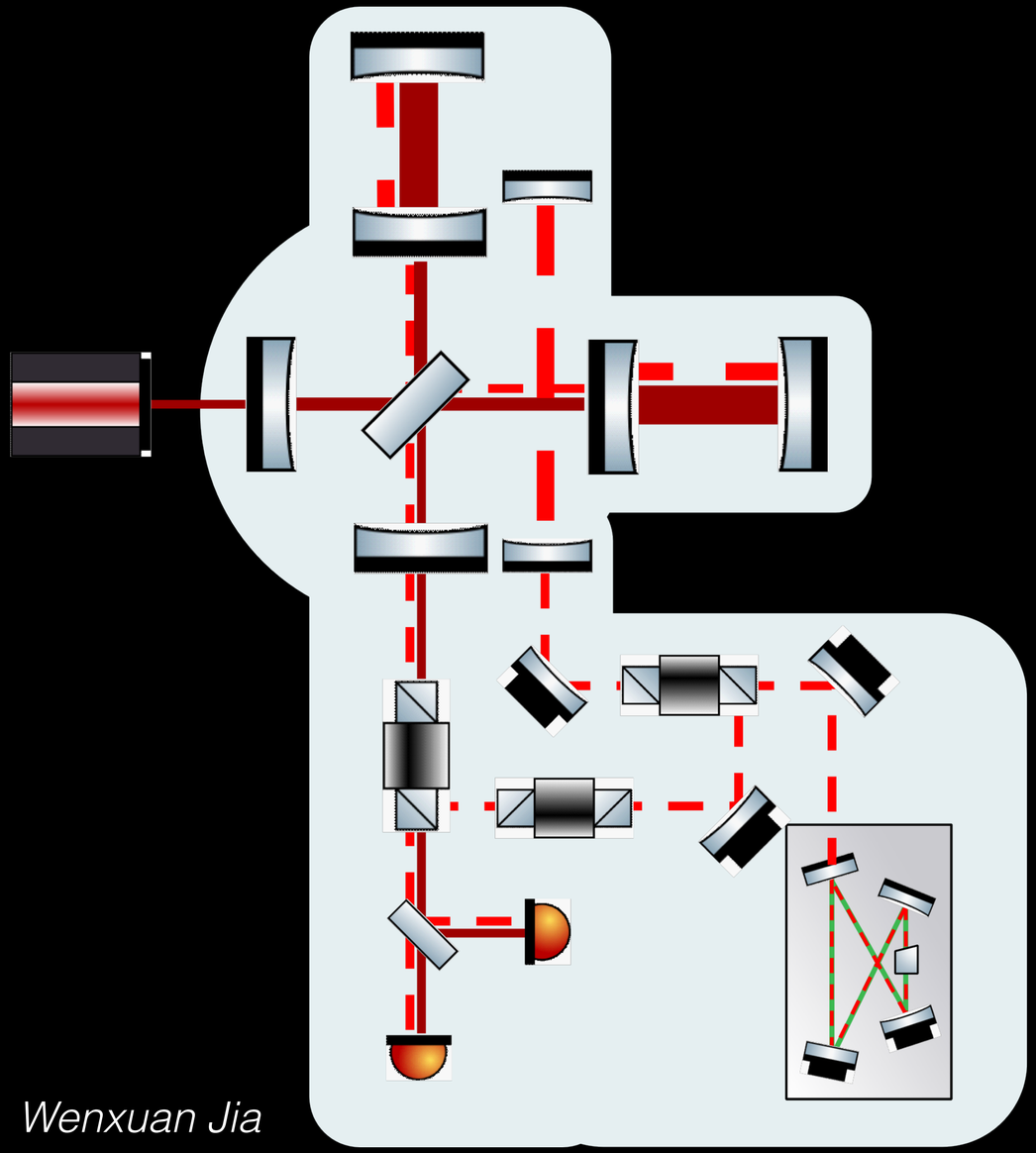
But due to quantum physics, there will always be uncertainty (noise) in the light wave



This noise limits LIGO's sensitivity to weak signals

Caltech/MIT/LIGO Lab/NSF, Robert Hurt

New for O4: a 300 m filter cavity



Wenxuan Jia

LIGO Lab