The era of gravitational wave astronomy

Karl Wette (OzGrav/ANU CGA)

30 Years of Gravity Research in Austral-Kiwi-Asia:
Past Reflections and Future Ambitions

September 2nd, 2024

Back in 1984 ...

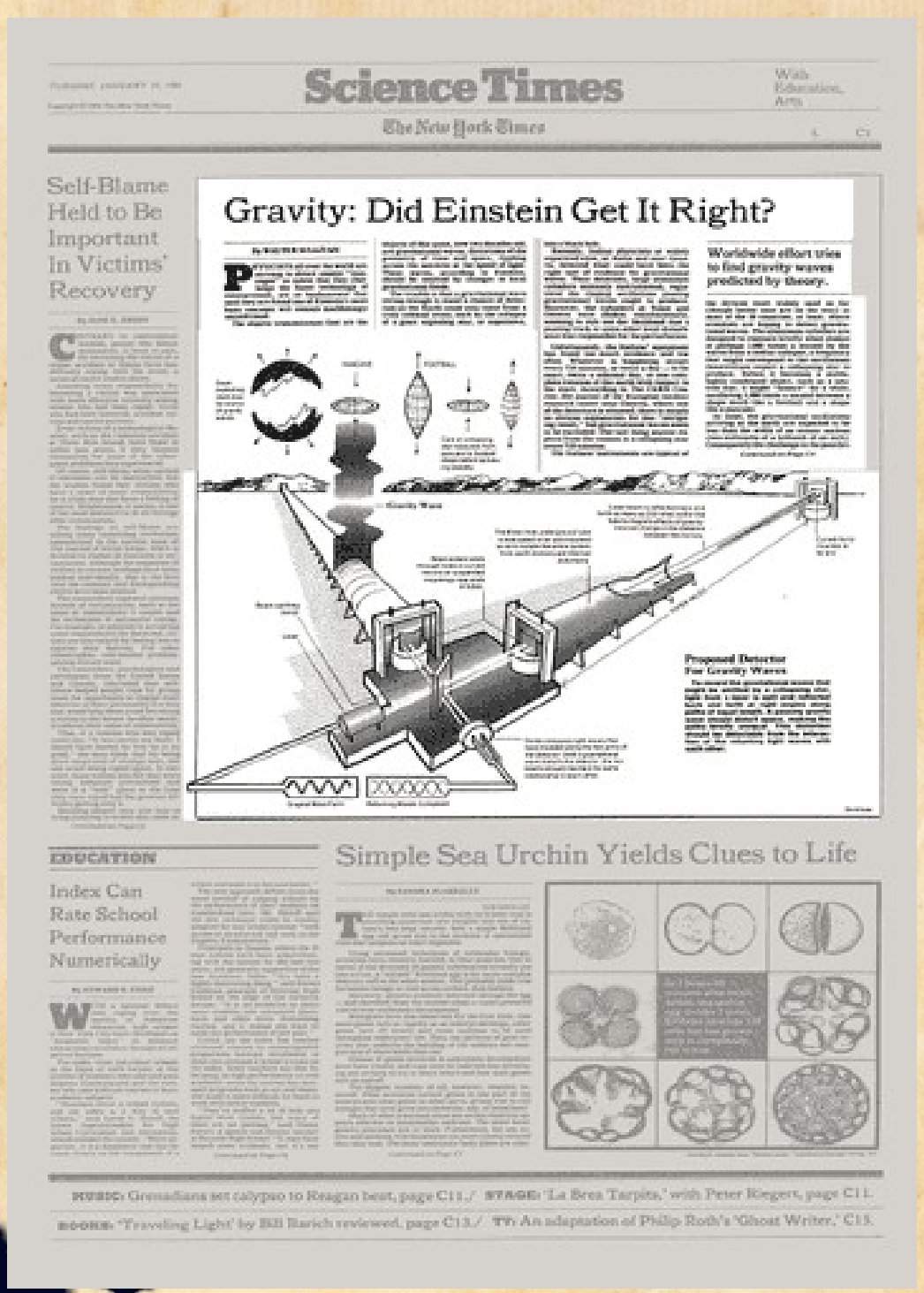
RKO Pictures (Australasia)

20th Television Animation

Supplied

Apple, Inc.

United International Pictures (UIP)



Science Times

The New York Times

Self-Blame Held to Be Important In Victims' Recovery

Gravity: Did Einstein Get It Right?

Worldwide effort tries to find gravity waves predicted by theory.

Proposed Detector For Gravity Waves

EDUCATION

Index Can Rate School Performance Numerically

Simple Sea Urchin Yields Clues to Life

MUSIC: Grenadians set calypso to Reagan beat, page C11./ STAGE: 'La Brea Tarpits,' with Peter Riegert, page C11.

BOOKS: 'Traveling Light' by Bill Barich reviewed, page C13./ TV: An adaptation of Philip Roth's 'Ghost Writer,' C13.

PHYSICISTS all over the world are striving to detect cosmic "messages" so subtle that they challenge the finest technology of measurement, yet so fundamental that until they are found one of Einstein's most basic concepts will remain maddeningly unconfirmed. The elusive transmissions that are the objects of this quest, **now two decades old**, are gravitational waves…

…

Unfortunately, the Italians' equipment [resonant bar detectors] has found too much evidence and too often. Whatever is happening occurs every **718 minutes, or twice a day** - to be exact, twice a sidereal day, or one complete rotation of the earth with respect to the stars.

…

Under the direction of Dr. Ronald W. P. Drever at the California Institute of Technology and Dr. Rainer Weiss at the Massachusetts Institute of Technology, designs using lasers are being developed for **L-shaped detectors that are three miles long** on each side...

With the Arts And Entertainment

Science Times

The New York Times

Orchids' Deceptions Are Part of a Grand Strategy

Long-lived flowers can afford high-risk means of survival.

Experts Clash Over Project To Detect Gravity Wave

Physicists say device could help them fathom black holes, but others fault its price.

The Earliest Wine: Vintage 3500 B.C. and Robust

In a time of cultural change, Sumerians appear to have taken solace in the grape.

Waves From the Mashbrem

THEATER

DANCE

JAZZ

In 1991 …

A PROPOSAL to stake $211 million in public money on the chance that gravity waves could be exploited to fathom black holes and other cosmic enigmas has deeply divided scientists and will force **Congress to make a difficult decision** in the next few weeks.

…

"I perused a list of about 2,000 astronomers and picked 70 …" Dr. [J. Anthony] Tyson said in an interview. "I got 60 replies, and they ran **4 to 1 against LIGO**. … I love gravity and the idea of LIGO … I just **don't think LIGO would have much chance** of achieving its goals in the next few years."

…

To the criticism many astronomers have directed at the project, Dr. [Rochus E.] Vogt replied: "**Astronomers are often slow to appreciate the opportunities offered by innovations in physics and technology** … Sooner or later, gravity-wave astronomy will come into its own. I only hope I shall be alive to see it."

Congress erupts into chaos with Marjorie Taylor Greene insulting physical appearance of House member

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"All the News That's Fit to Print"

The New York Times

Late Edition
Today, some sunshine giving way to times of clouds, cold, high 28. **Tonight,** a flurry or heavier squall late, low 15. **Tomorrow,** windy, frigid, high 21. Weather map, Page A19.

VOL. CLXV . . . No. 57,140 + NEW YORK, FRIDAY, FEBRUARY 12, 2016 $2.50

Clinton Paints Sanders Plans As Unrealistic

New Lines of Attack at Milwaukee Debate

By AMY CHOZICK and PATRICK HEALY

MILWAUKEE — Hillary Clinton, scrambling to recover from her double-digit defeat in the New Hampshire primary, repeatedly challenged the trillion-dollar policy plans of Bernie Sanders at their presidential debate on Thursday night and portrayed him as a big talker who needed to "level" with voters about the difficulty of accomplishing his agenda.

Foreign affairs also took on unusual prominence as Mrs. Clinton sought to underscore her experience and Mr. Sanders excoriated her judgment on Libya and Iraq, as well as her previous praise of former Secretary of State Henry A. Kissinger. But Mrs. Clinton was frequently on the offensive as well, seizing an opportunity to talk about leaders she admired and turning it against Mr. Sanders by bashing his past criticism of President Obama — a remark that Mr. Sanders called a "low blow."

With tensions between the two Democrats becoming increasingly obvious, the debate was full of new lines of attack from Mrs. Clinton, who faces pressure to puncture Mr. Sanders's growing popularity before the next nominating contests in Nevada and

CALTECH/M.I.T./LIGO LABORATORY

A worker installed a baffle in 2010 to control light in the Laser Interferometer Gravitational-Wave Observatory in Hanford, Wash.

WITH FAINT CHIRP, SCIENTISTS PROVE EINSTEIN CORRECT

A RIPPLE IN SPACE-TIME

An Echo of Black Holes Colliding a Billion Light-Years Away

By DENNIS OVERBYE

A team of scientists announced on Thursday that they had heard and recorded the sound of two black holes colliding a billion light-years away, a fleeting chirp that fulfilled the last prediction of Einstein's general theory of relativity.

That faint rising tone, physicists say, is the first direct evidence of gravitational waves, the ripples in the fabric of space-time that Einstein predicted a century ago. It completes his vision of a universe in which space and time are interwoven and dynamic, able to stretch, shrink and jiggle. And it is a ringing confirmation of the nature of black holes, the bottomless gravitational pits from which not even light can escape, which were the most foreboding (and unwelcome) part of his theory.

Long in Clinton's Corner, Blacks Notice Sanders

Courted Hard in South Carolina, Loyalists Listen Closely

By RICHARD FAUSSET

ORANGEBURG, S.C. — When Helen Duley was asked whom she would vote for in the South Carolina primary, she answered as if the very question were ab-

candidate she barely knew. "It makes me feel good," she said, chuckling, "that young people are listening to the elderly people." She now said she was an undecided voter and planned to do some homework on Mr. Sanders.

Mrs. Clinton has long looked

Last Occupier In Rural Oregon Is Coaxed Out

This article is by ***Dave Semi-***

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VOL. CLXV .

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By AMY
and PATR

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York Times

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FRIDAY, FEBRUARY 12, 2016 $2.50

CALTECH/M.I.T./LIGO LABORATORY

Laser Interferometer Gravitational-Wave Observatory in Hanford, Wash.

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Last Occupier In Rural Oregon Is Coaxed Out

This article is by ***Dave Semi-***

Liam Kidston; Alan Porritt: AAP; Lukas Coch / AAPIMAGE; Mike Bowers/The Guardian; Getty; NCA NewsWire / Damian Shaw

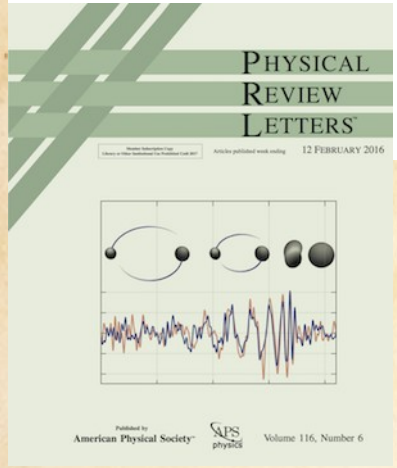
PRL 116, 061102 (2016)

Selected for a Viewpoint in *Physics*
PHYSICAL REVIEW LETTERS

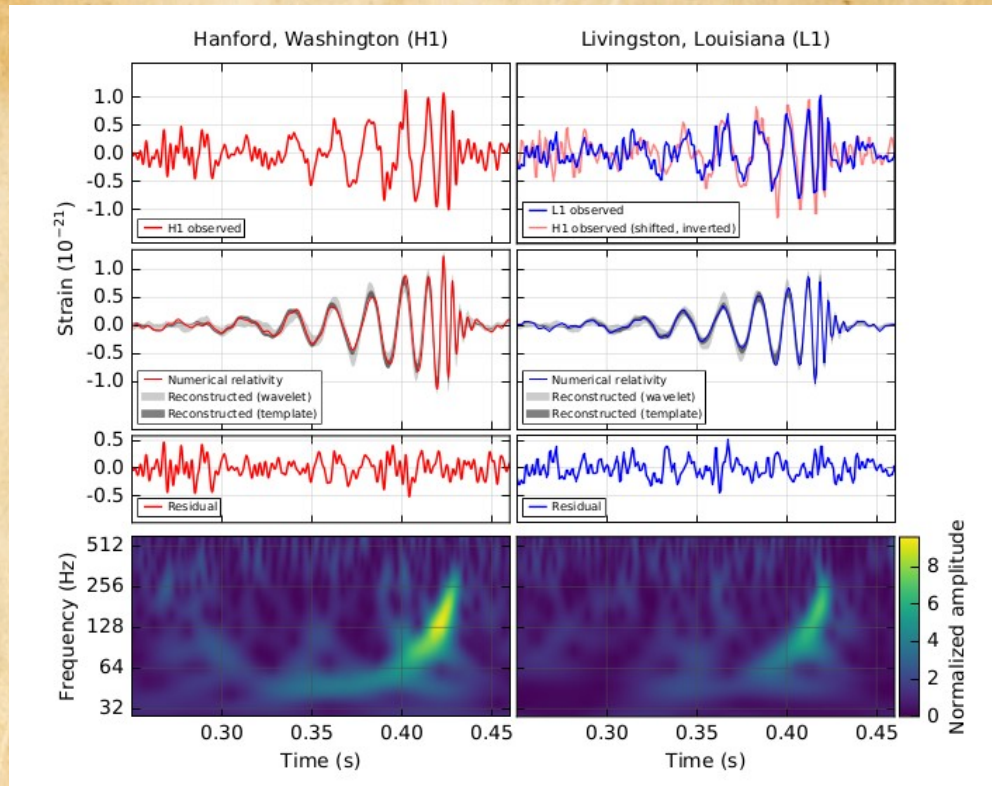
week ending
12 FEBRUARY 2016

Observation of Gravitational Waves from a Binary Black Hole Merger

B. P. Abbott *et al.*[*]
(LIGO Scientific Collaboration and Virgo Collaboration)
(Received 21 January 2016; published 11 February 2016)



A century after the fundamental predictions of Einstein and Schwarzschild, we report the first direct detection of gravitational waves and the first direct observation of a binary black hole system merging to form a single black hole. Our observations provide unique access to the properties of space-time in the strong-field, high-velocity regime and confirm predictions of general relativity for the nonlinear dynamics of highly disturbed black holes.



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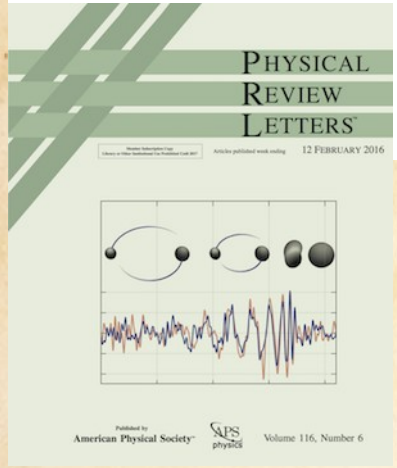

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Karl Wette

Australian Consortium for Interferometric Gravitational Astronomy (ACIGA)

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8 November 2012 ·

Teaching Einstein to kids in primary school http://t.co/z95ZX92g

THECONVERSATION.EDU.AU

Testing the theory: taking Einstein to primary schools

School students today are taught physics based on obsolete theories and outmoded ways of thinking. Instead of the truth, most learn a naiv…

Facebook

Australian Consortium for Interferometric Gravitational Astronomy (ACIGA)

2 December 2011 · but taken in July 2007 (at GR/Amaldi in Sydney)

Like Comment

Australian Consortium for Interferometric Gravitational Astronomy (ACIGA)

2 December 2011 · but taken in July 2007 (at GR/Amaldi in Sydney)

17 years later, I count
~16/30 people still in the field

Like Comment

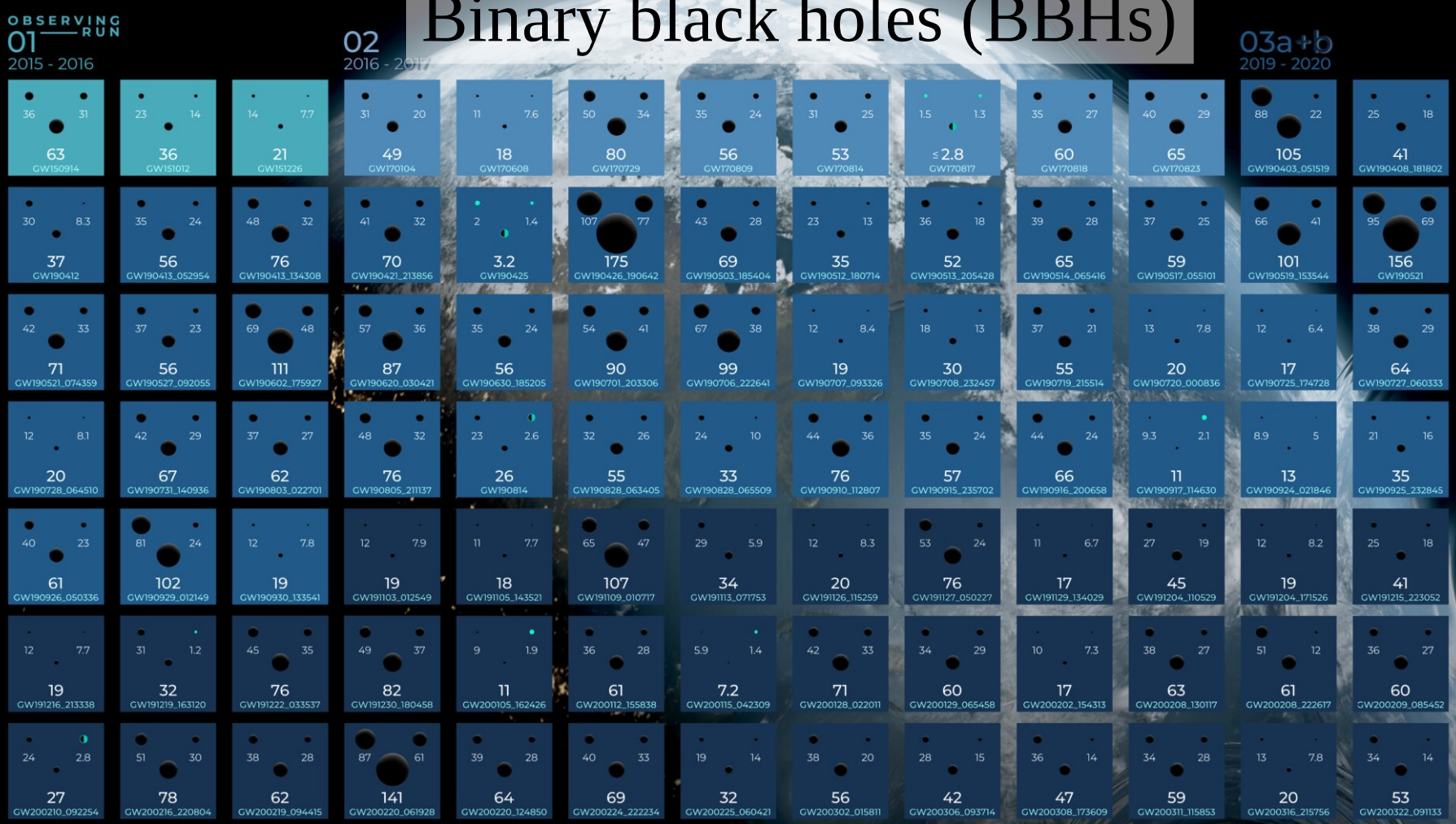
Australian Consortium for Interferometric Gravitational Astronomy (ACIGA)

2 December 2011 · but taken in July 2007 (at GR/Amaldi in Sydney)

4/30 women in this photo (~13%)
8/50 women at this event (~16%)

Like Comment

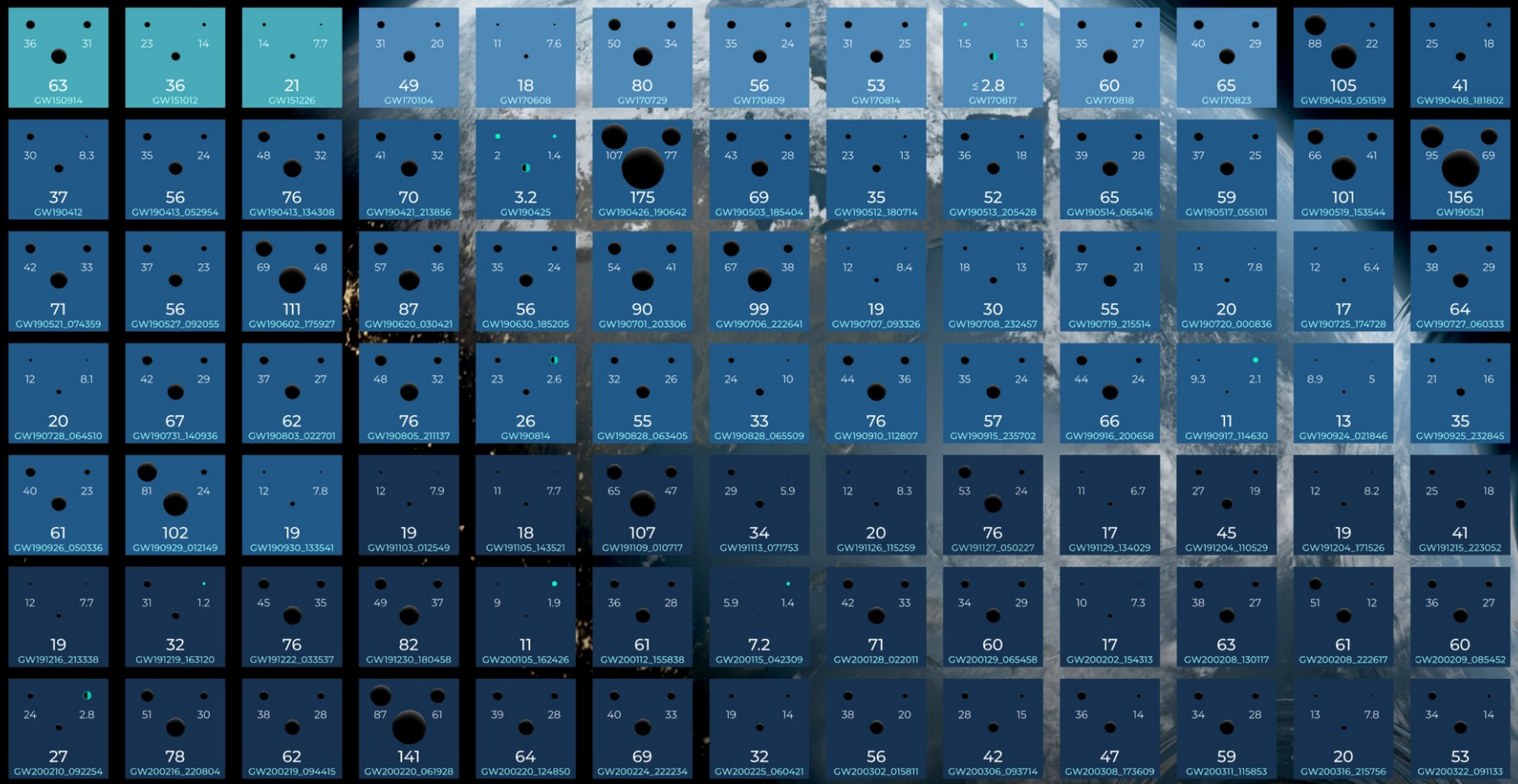
Binary black holes (BBHs)



OzGrav, LVK

Boring?

Binary black holes (BBHs)



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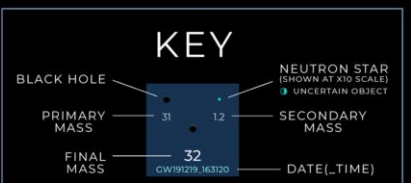


UNITS ARE SOLAR MASSES
1 SOLAR MASS = 1.989 x 10^{30}kg

Note that the mass estimates shown here do not include uncertainties, which is why the final mass is sometimes larger than the sum of the primary and secondary masses. In actuality, the final mass is smaller than the primary plus the secondary mass.

The events listed here pass one of two thresholds for detection. They either have a probability of being astrophysical of at least 50%, or they pass a false alarm rate threshold of less than 1 per 3 years.

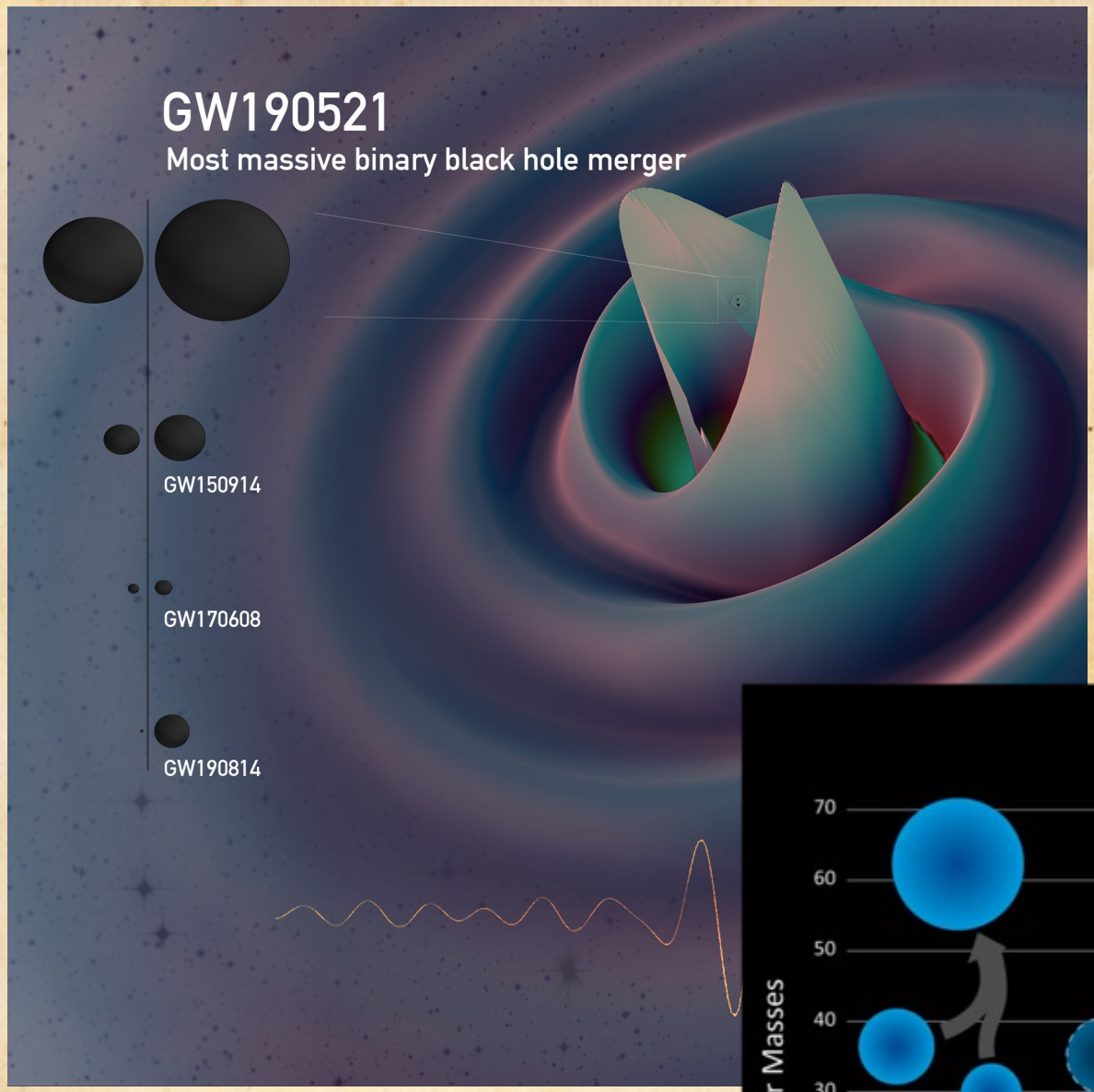
GRAVITATIONAL WAVE
MERGER
DETECTIONS
SINCE 2015

OzGrav

ARC Centre of Excellence for Gravitational Wave Discovery

LIGO VIRGO KAGRA

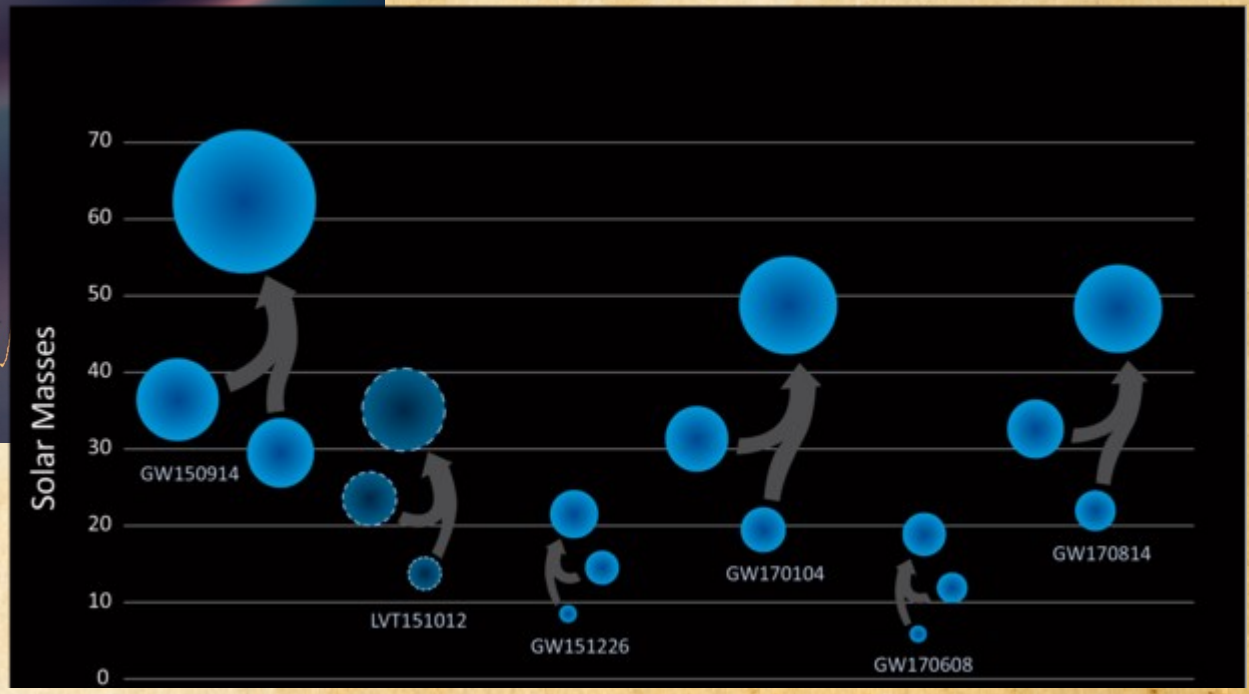
OzGrav, LVK



Exceptional* events:

⇐ Largest BBH
(GW190521)

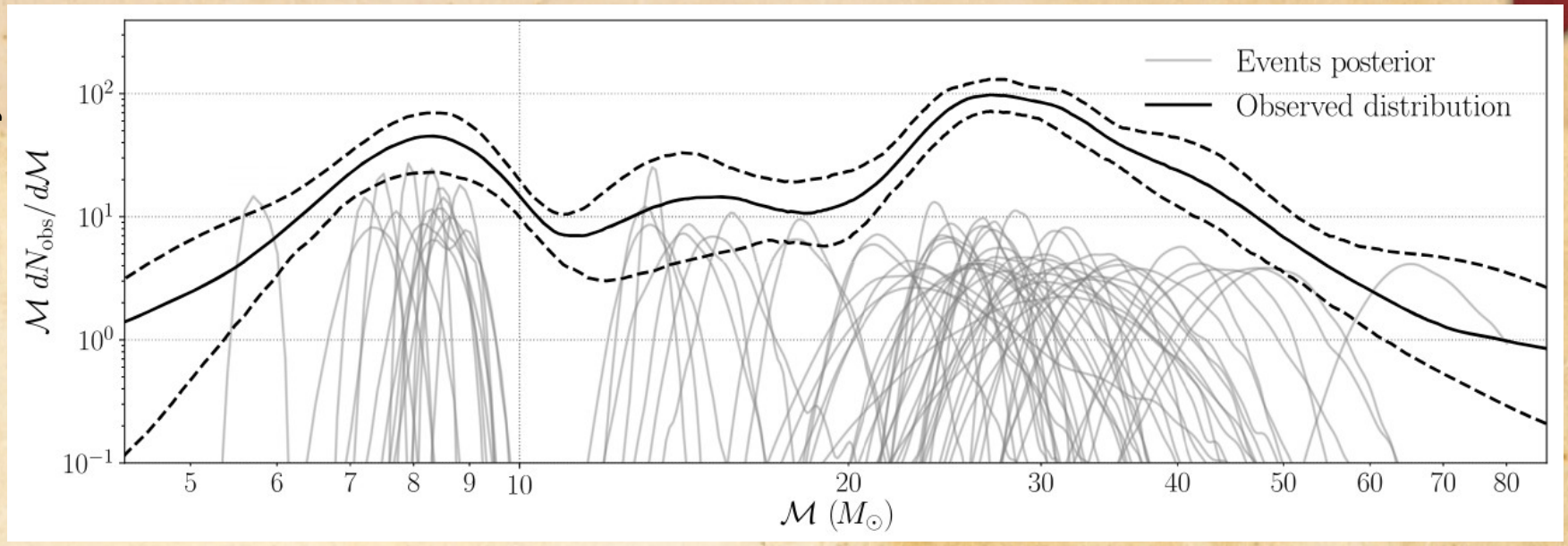
⇓Smallest BBH
(GW170608)



*at the time of discovery

www.ligo.org/detections/GW190521.php, www.ligo.caltech.edu/news/ligo20171115

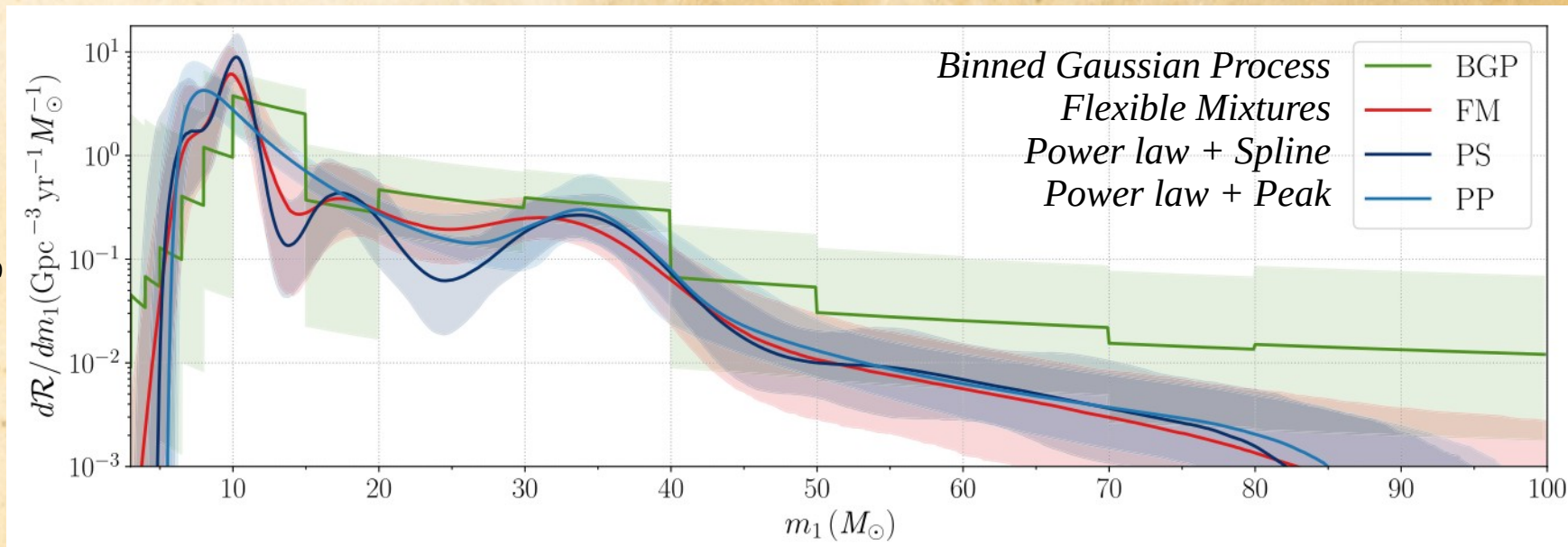
Black hole mass spectrum



Number density

Chirp mass

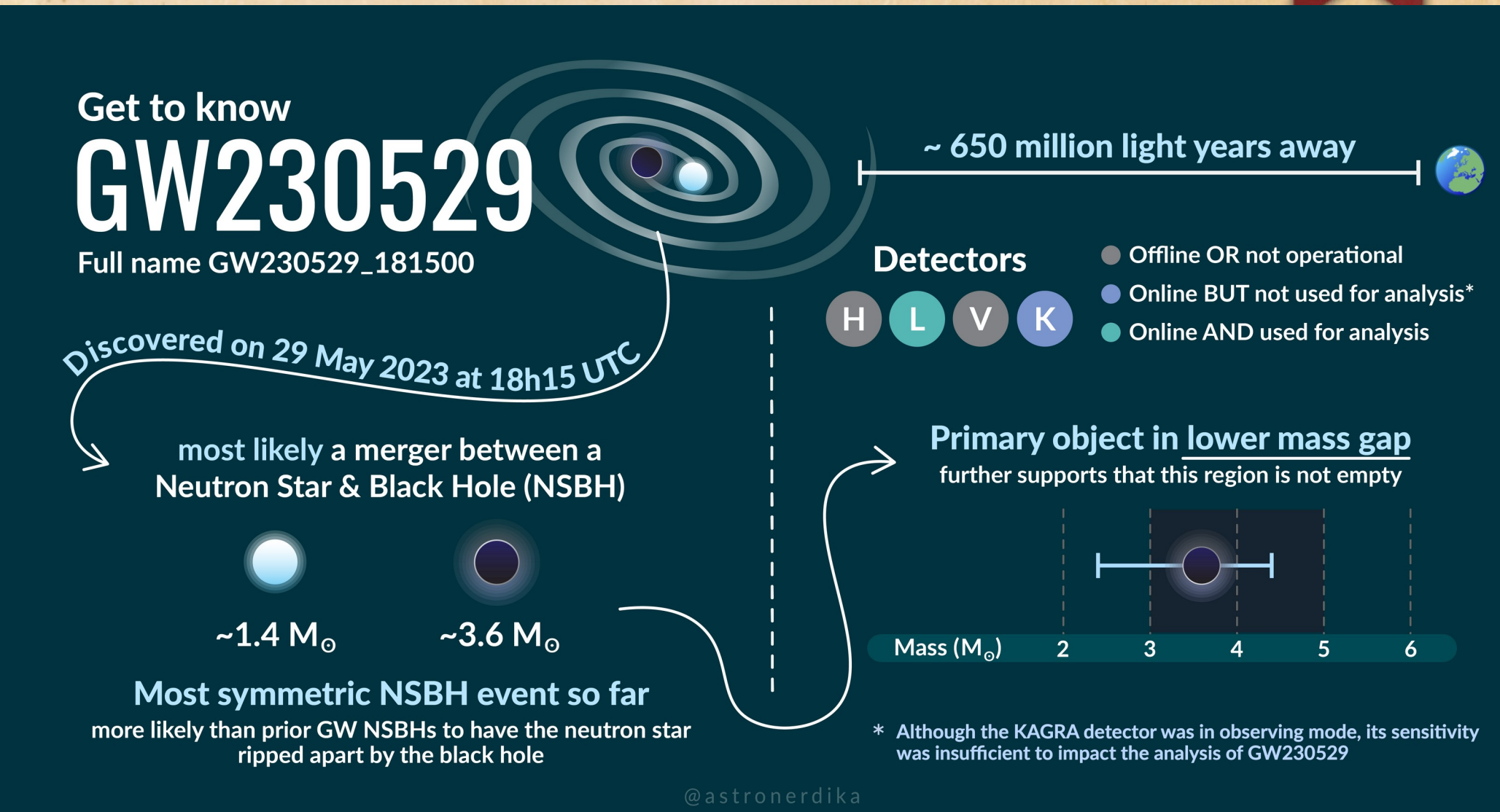
Abbott et al. PRX, DOI:10.1103/PhysRevX.13.011048



Merger rate

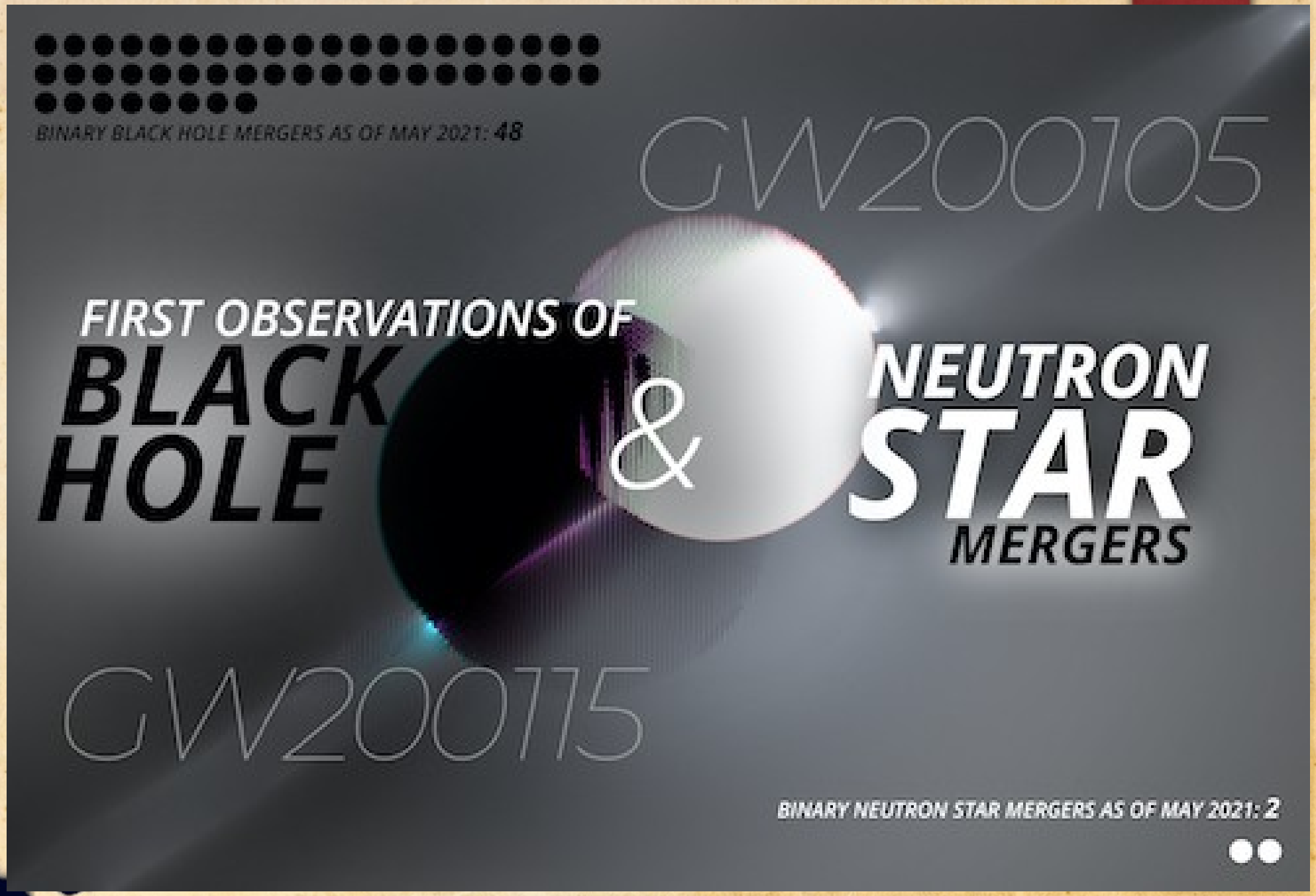
Primary black hole mass

The exceptional informs the population



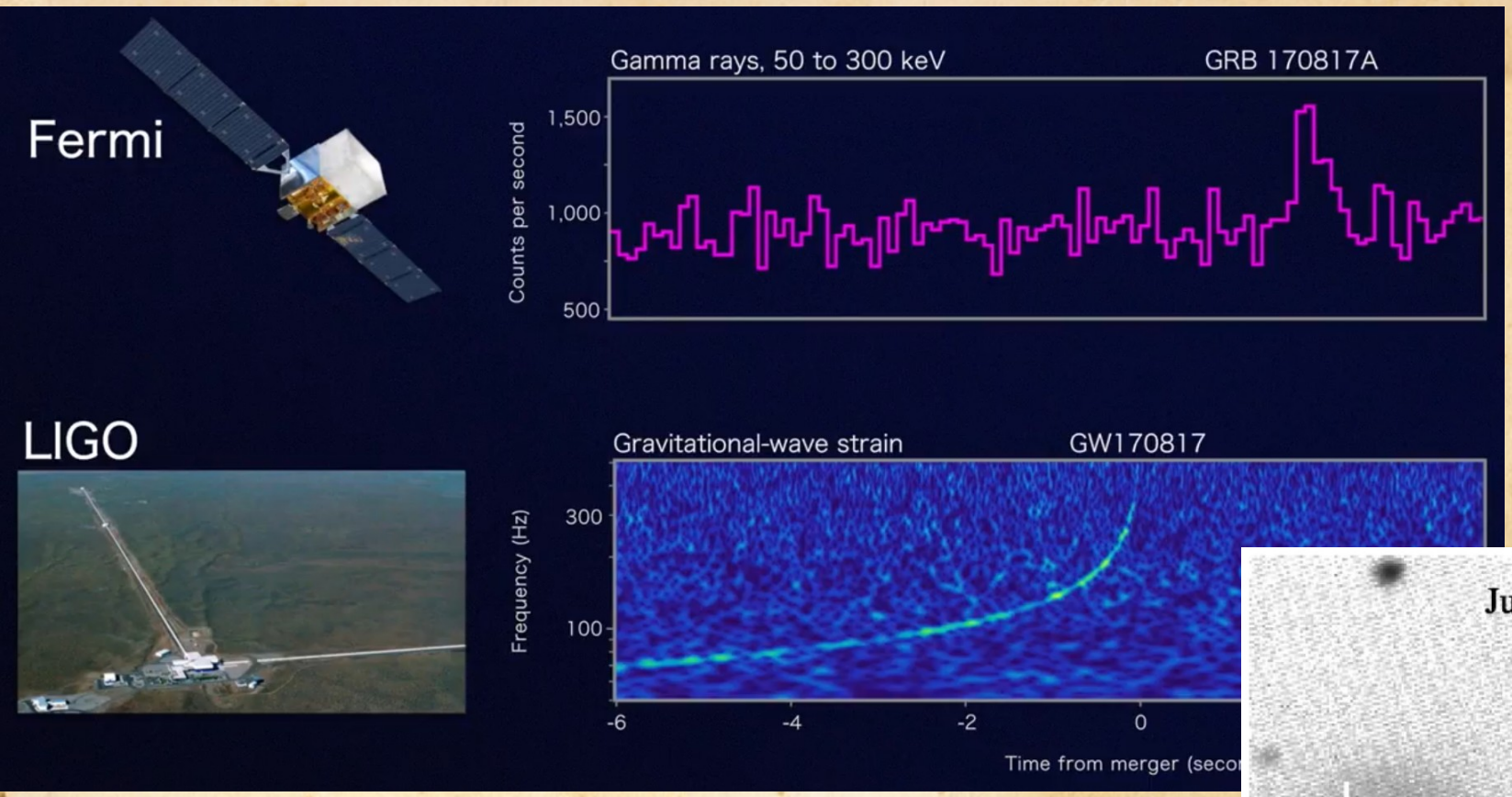
S. Galaudage/Observatoire de la Côte d'Azur

Neutron star – black hole binaries (NSBHs)

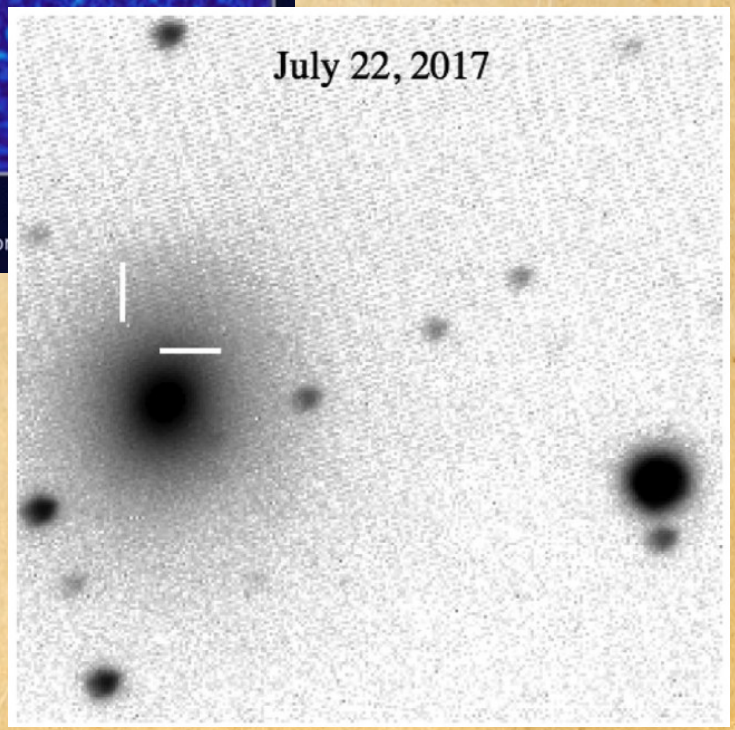


www.ligo.org/detections/NSBH2020.php

Binary neutron stars (BNSs) – GW170817

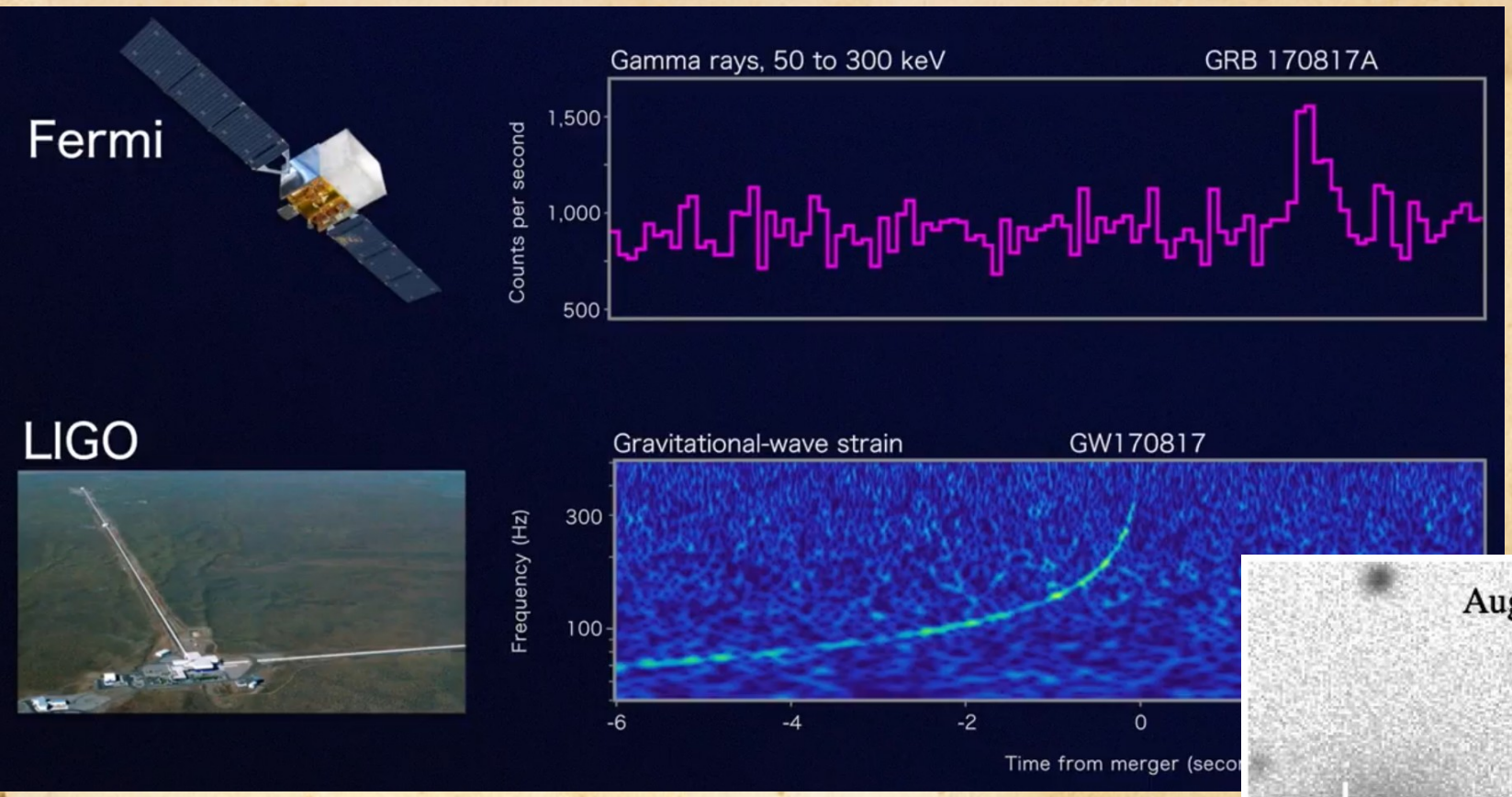


LIGO; https://youtu.be/-Yt5EmEgz2w

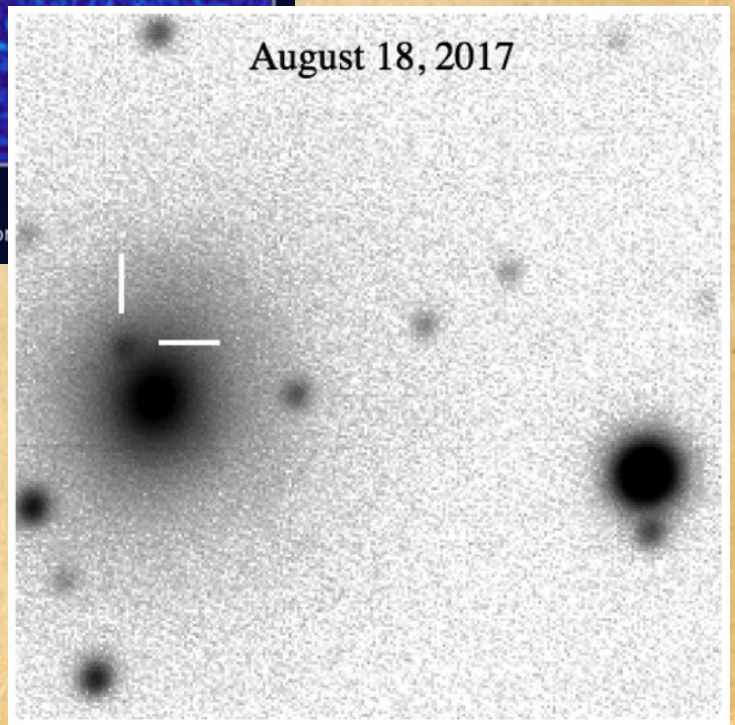


Andreoni et al. PASA, DOI:10.1017/pasa.2017.65

Binary neutron stars (BNSs) – GW170817

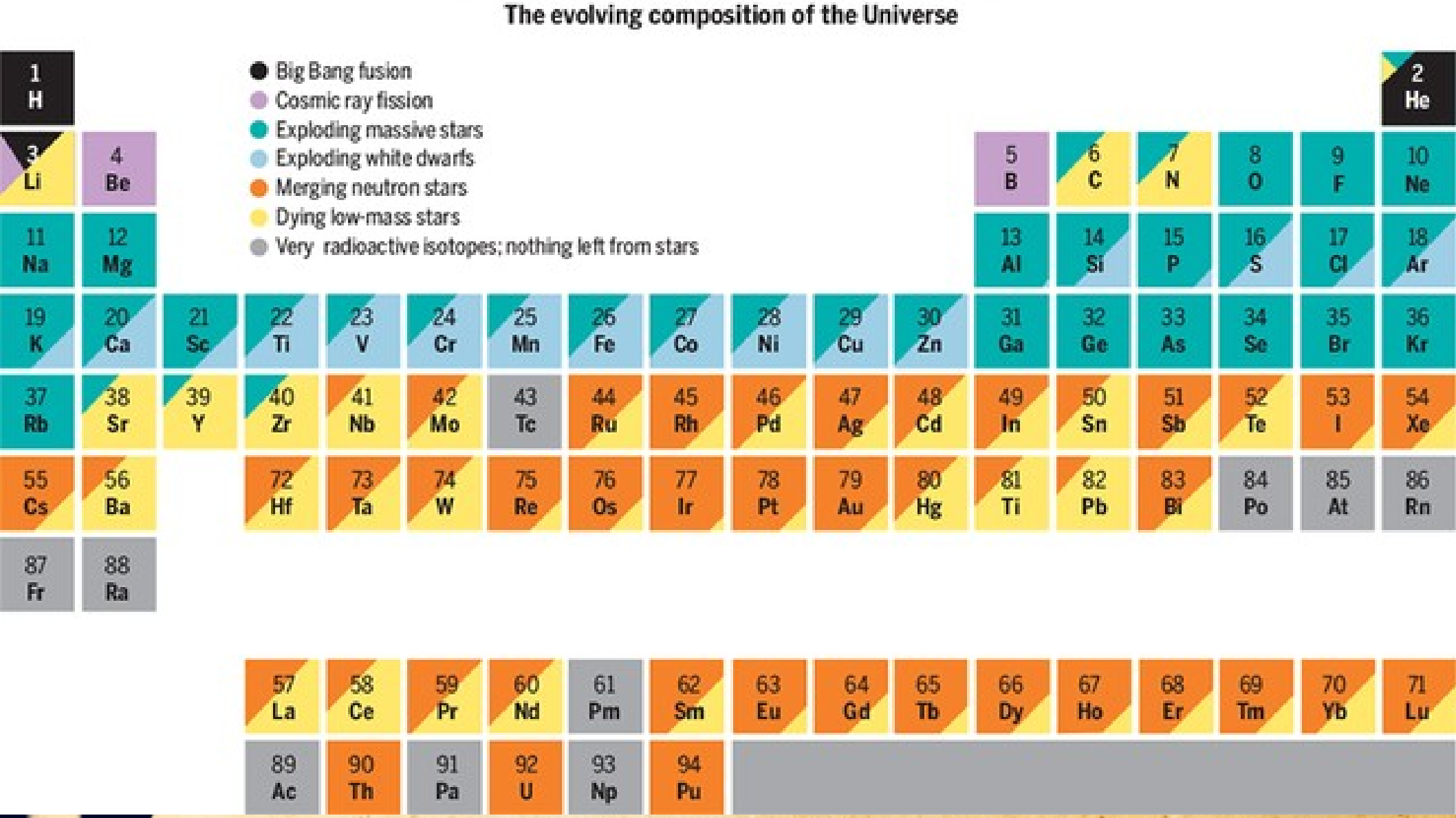


LIGO; https://youtu.be/-Yt5EmEgz2w



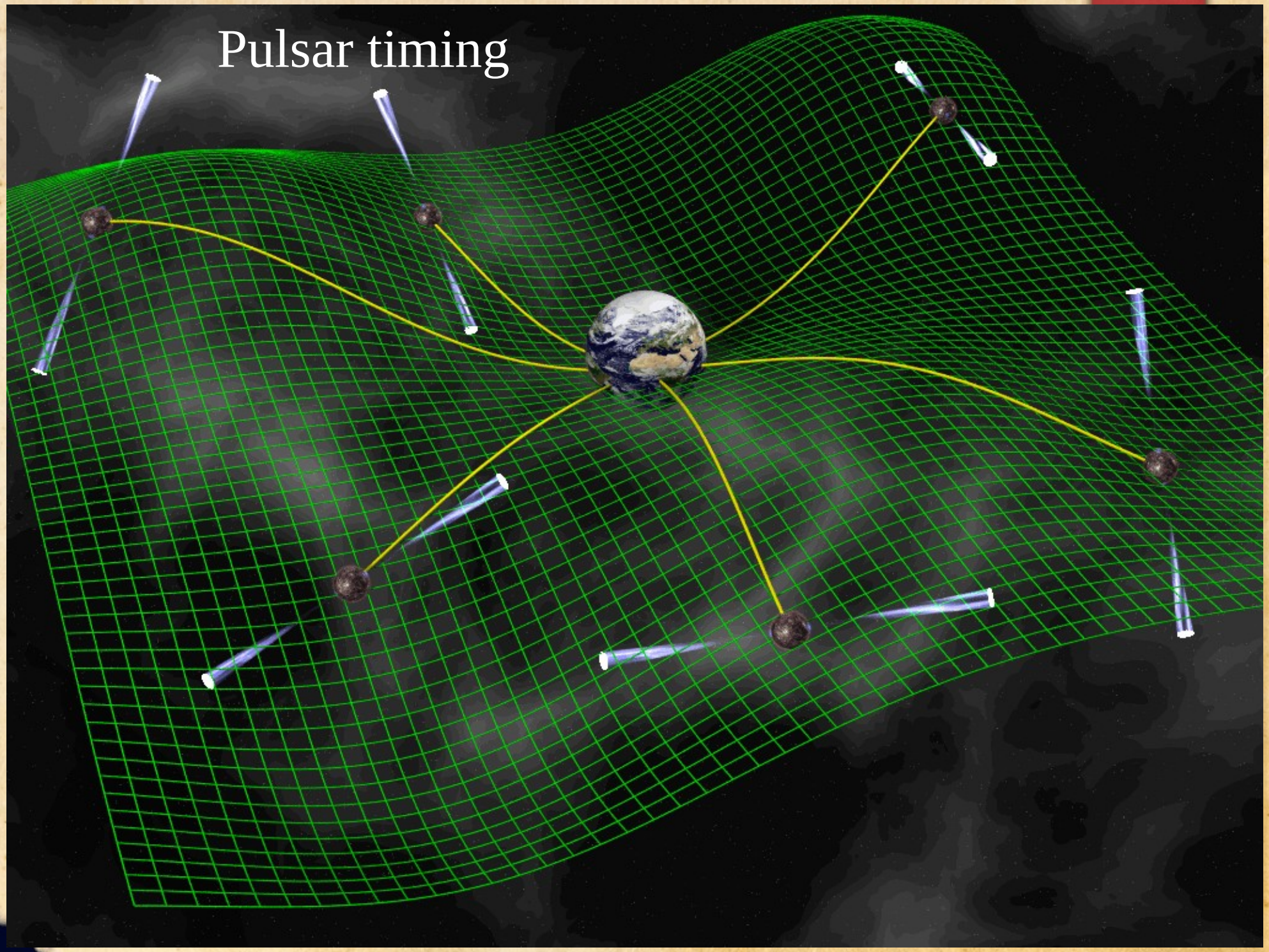
Andreoni et al. PASA, DOI:10.1017/pasa.2017.65

Nucleosynthesising the Universe



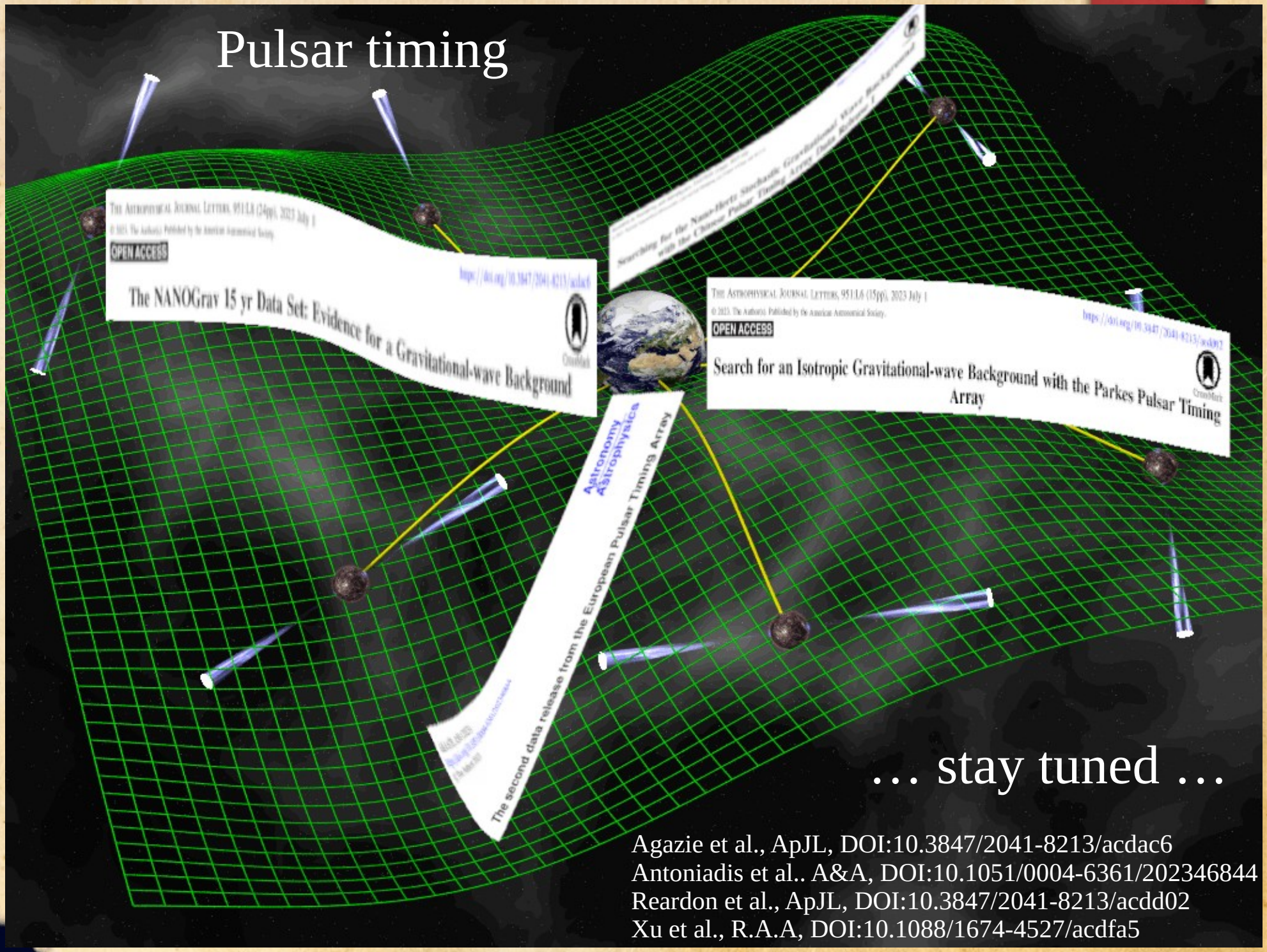
J. A. Johnson, Science, DOI:10.1126/science.aau9540

Pulsar timing



David J. Champion

Pulsar timing



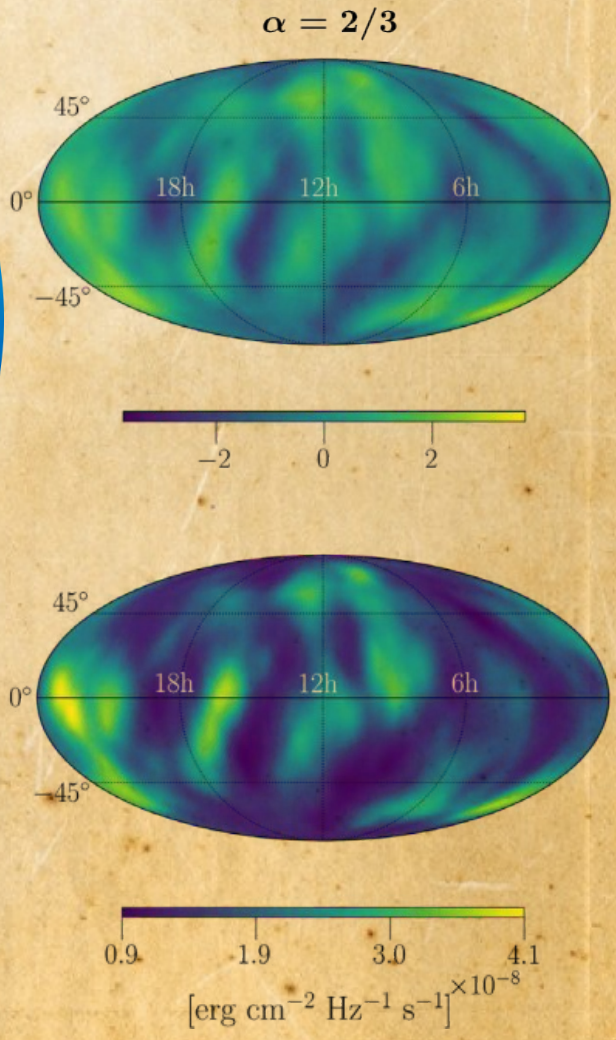
… stay tuned …

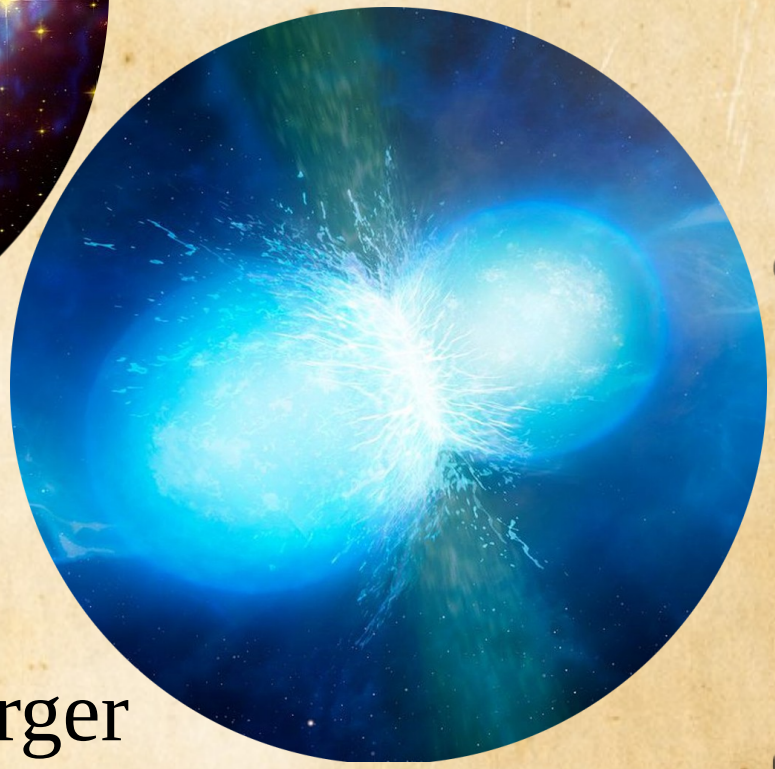
Agazie et al., ApJL, DOI:10.3847/2041-8213/acdac6
Antoniadis et al.. A&A, DOI:10.1051/0004-6361/202346844
Reardon et al., ApJL, DOI:10.3847/2041-8213/acdd02
Xu et al., R.A.A, DOI:10.1088/1674-4527/acdfa5

David J. Champion, Karl Wette

Bursts from e.g. supernovae

Stochastic background of many sources

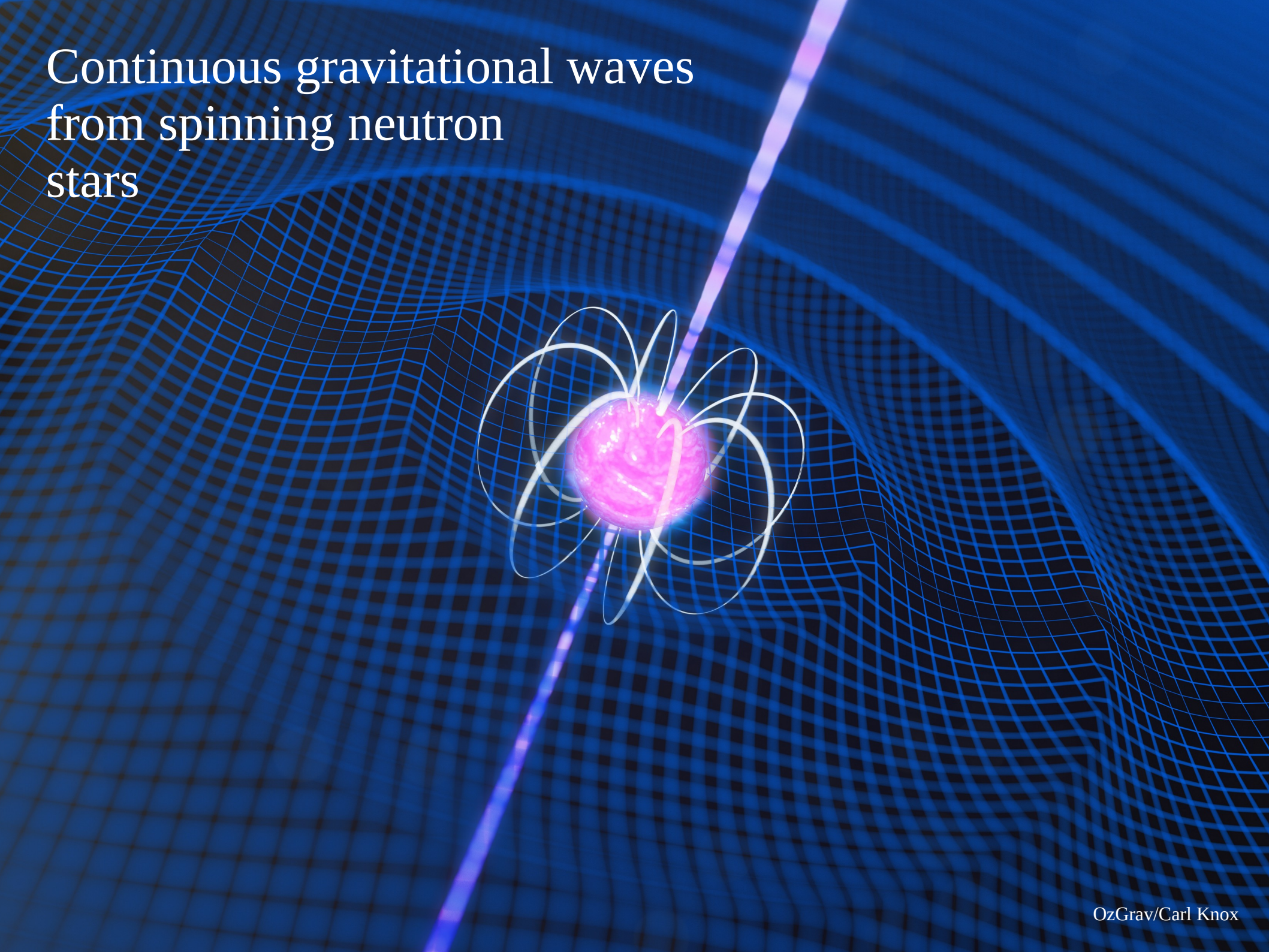




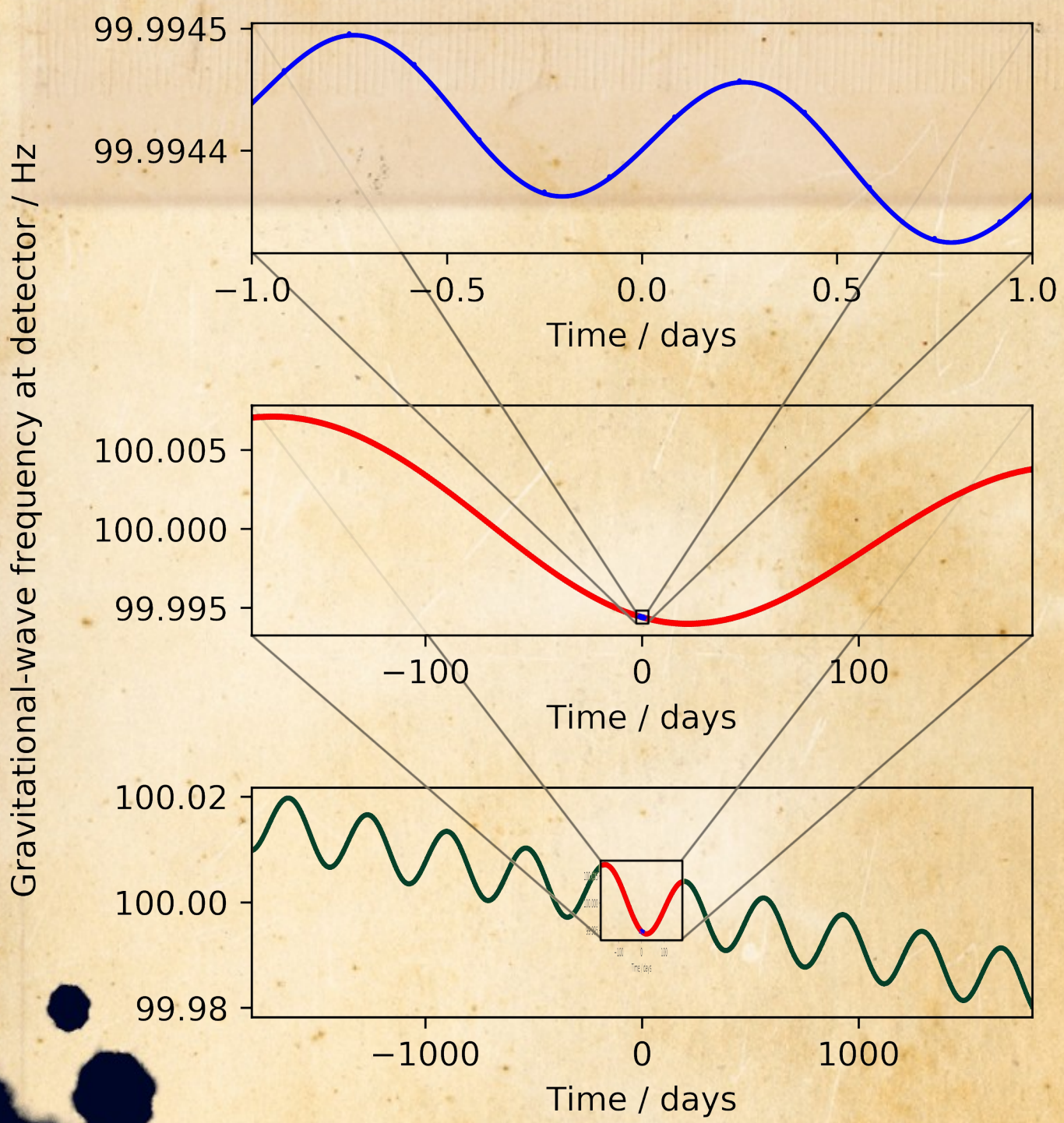
Post-BNS merger remnants – long-lived neutron star??

spitzer.caltech.edu; University of Warwick/Mark Garlick;
Abbott et al., PRD, DOI:10.1103/PhysRevD.104.022005

Continuous gravitational waves from spinning neutron stars



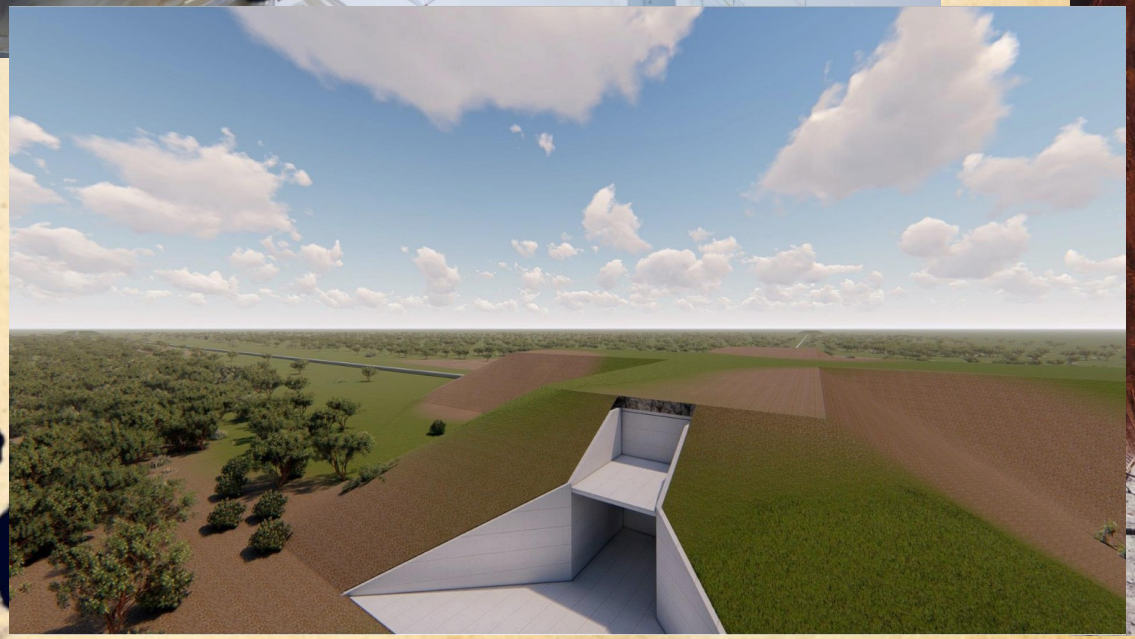
OzGrav/Carl Knox



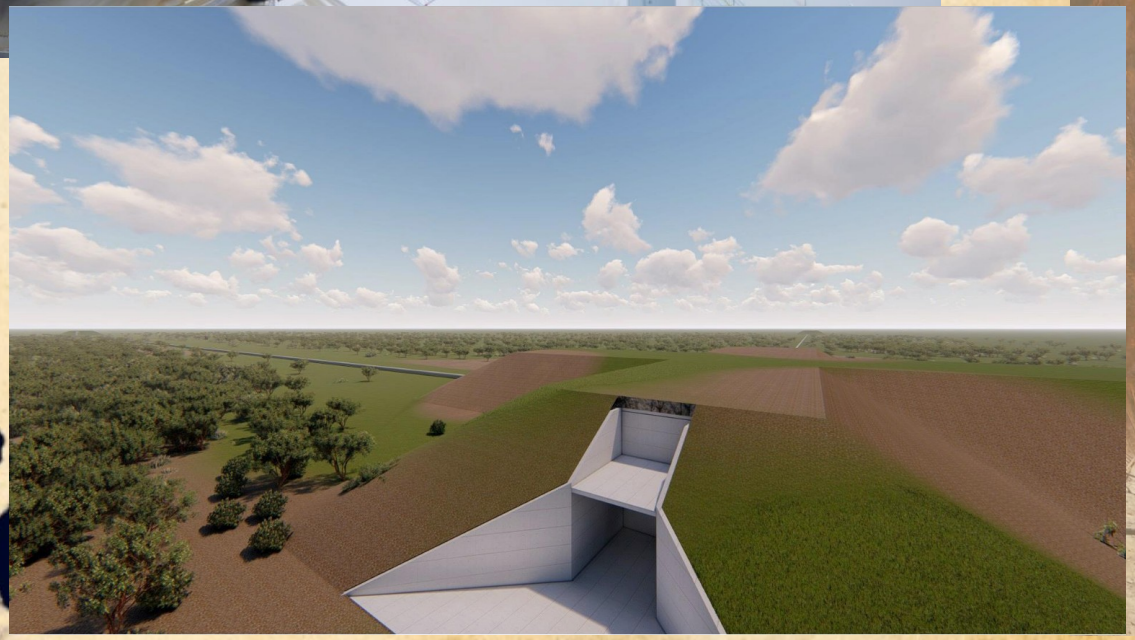
The challenge:

- Weak signals
- Noisy data
- Signal evolves over disparate timescales (days to years)
- Vast number of filters required to match all possible signals; compute cost grows steeply with observing time
- Sensitivity grows slowly with time

The future…?



The future…?



www.einsteintelescope-emr.eu, news.mit.edu. C. Blair et al., DOE

The Astrophysical Journal, 662:504–511, 2007 June 10

ON THE RARITY OF DOUBLE BLACK HOLE BINARIES: CONSEQUENCES FOR GRAVITATIONAL WAVE DETECTION

Krzysztof Belczynski,[1,2] Ronald E. Taam,[3] Vassiliki Kalogera,[3] Frederic A. Rasio,[3] and Tomasz Bulik[4,5]

Received 2006 December 1; accepted 2007 January 31

ABSTRACT

Double black hole binaries are among the most important sources of gravitational radiation for ground-based detectors such as LIGO or VIRGO. Even if formed with lower efficiency than double neutron star binaries, they could dominate the predicted detection rates, since black holes are more massive than neutron stars and therefore could be detected at greater distances. Here we discuss an evolutionary process that could very significantly limit the formation of close double black hole binaries: the vast majority of their potential progenitors undergo a common-envelope (CE) phase while the donor, one of the massive binary components, is evolving through the Hertzsprung gap. Our latest theoretical understanding of the CE process suggests that this will probably lead to a merger, inhibiting double black hole formation. Barring uncertainties in the physics of CE evolution, we use population synthesis calculations and find that the corresponding reduction in the merger rate of double black holes formed in galactic fields is so great (by $\sim$500) that their contribution to inspiral detection rates for ground-based detectors could become relatively small ($\sim$1 in 10) compared to double neutron star binaries. A similar process also reduces the merger rates for double neutron stars, by a factor of $\sim$5, eliminating most of the previously predicted ultracompact NS-NS systems. Our predicted detection rates for Advanced LIGO are now much lower for double black holes ($\sim 2\ \mathrm{yr}^{-1}$), but are still quite high for double neutron stars ($\sim 20\ \mathrm{yr}^{-1}$). If double black holes were found to be dominant in the detected inspiral signals, this could indicate that they mainly originate from dense star clusters (not included here) or that our theoretical understanding of the CE phase requires significant revision.

Subject headings: binaries: close — black hole physics — gravitational waves — stars: evolution — stars: neutron

Thanks for listening!