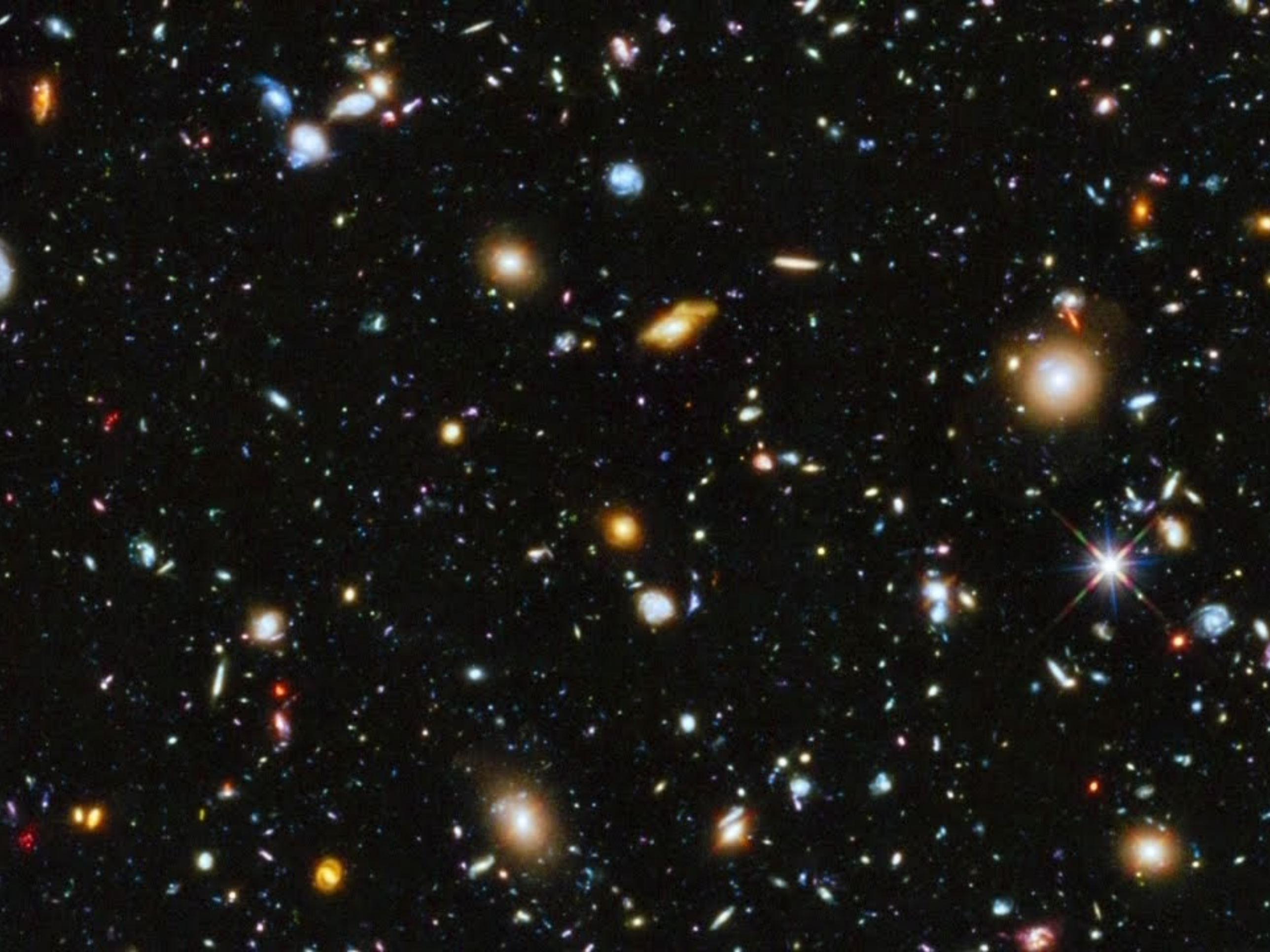
The Discovery of Gravitational Waves

Daniel Holz
The University of Chicago

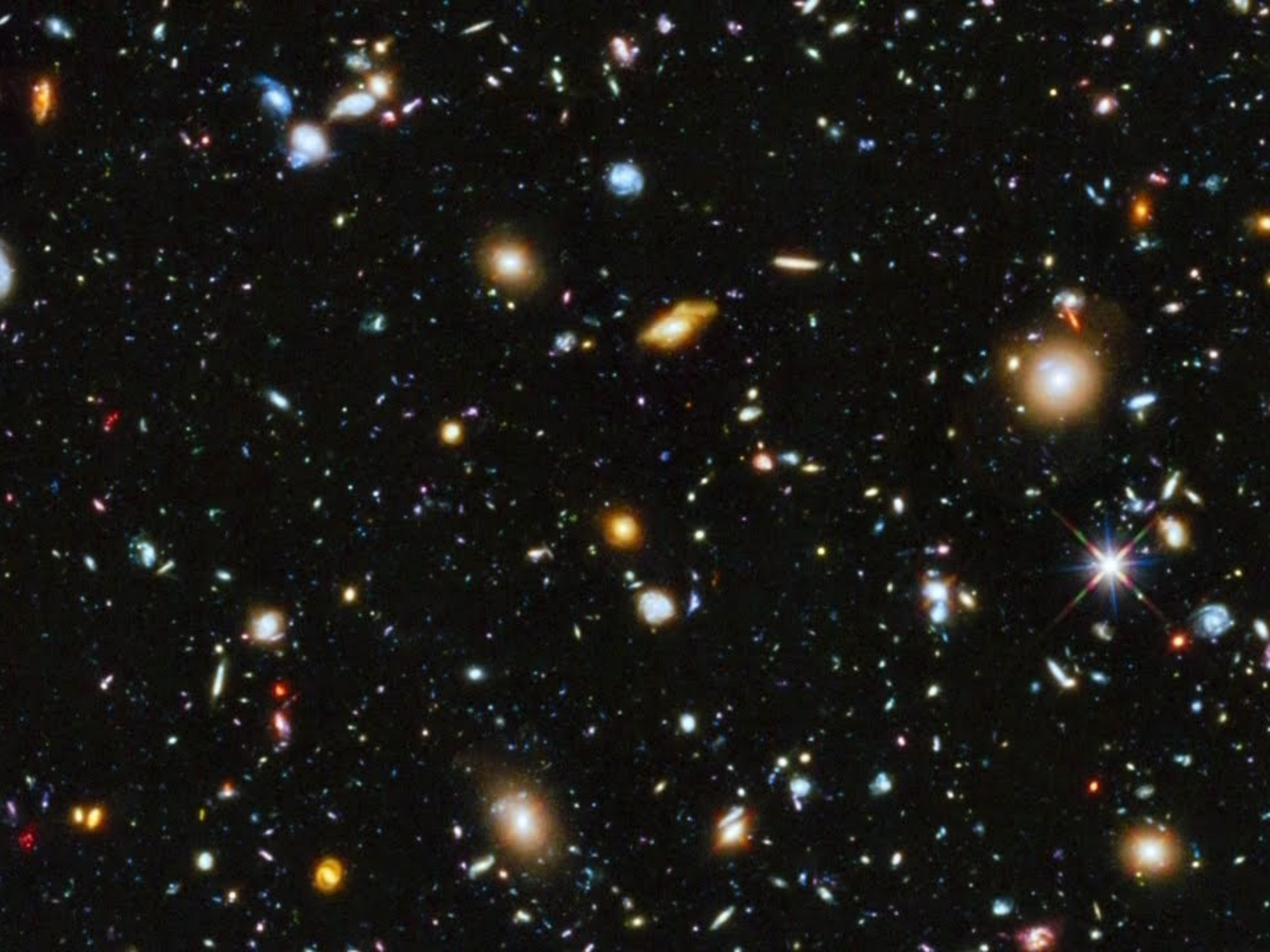


A long time ago…

…in a galaxy far, far away…

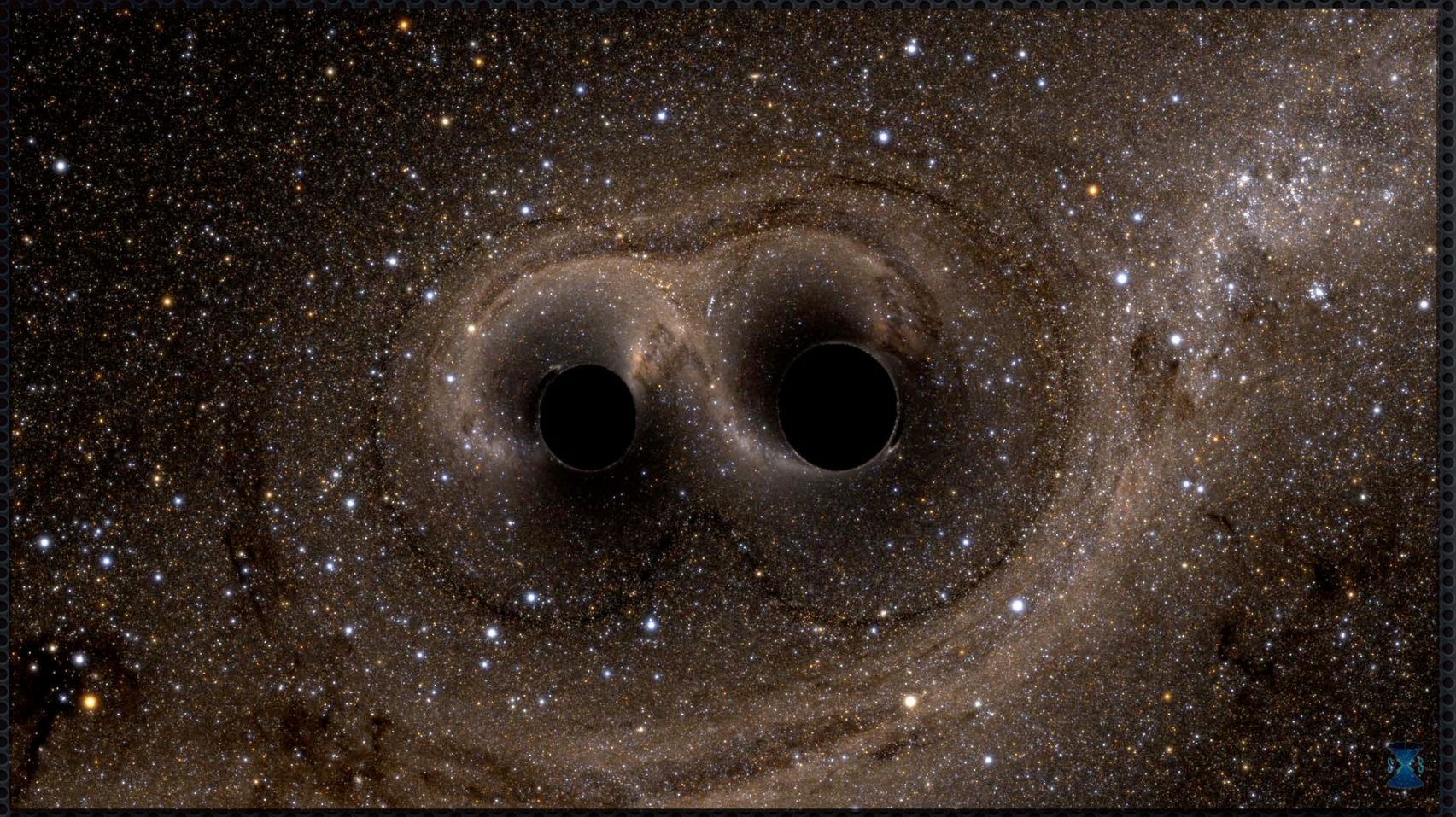
…two black holes collided…

…and echoed across the universe



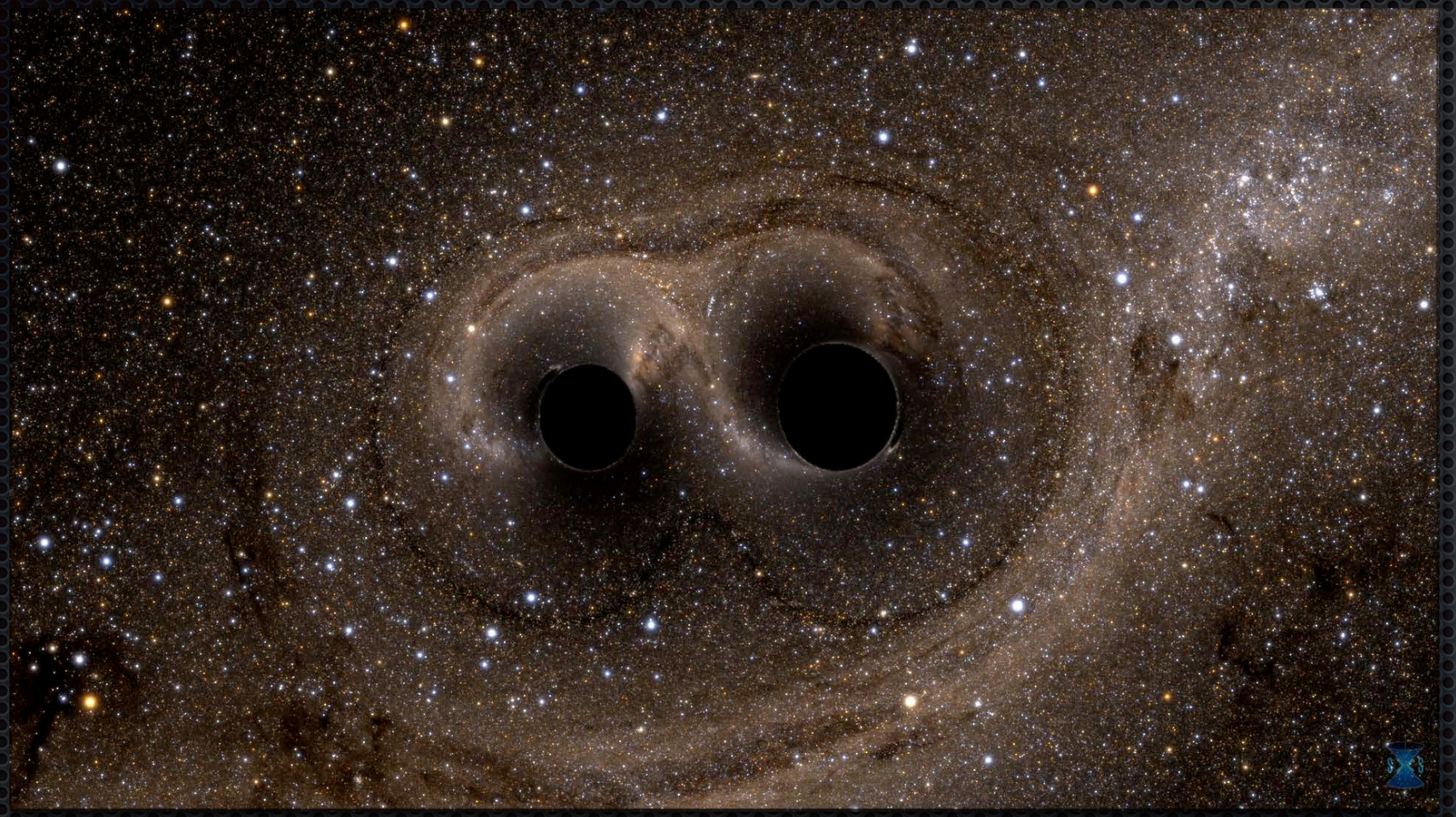
On September 14, 2015
we heard this echo

Why is this important?

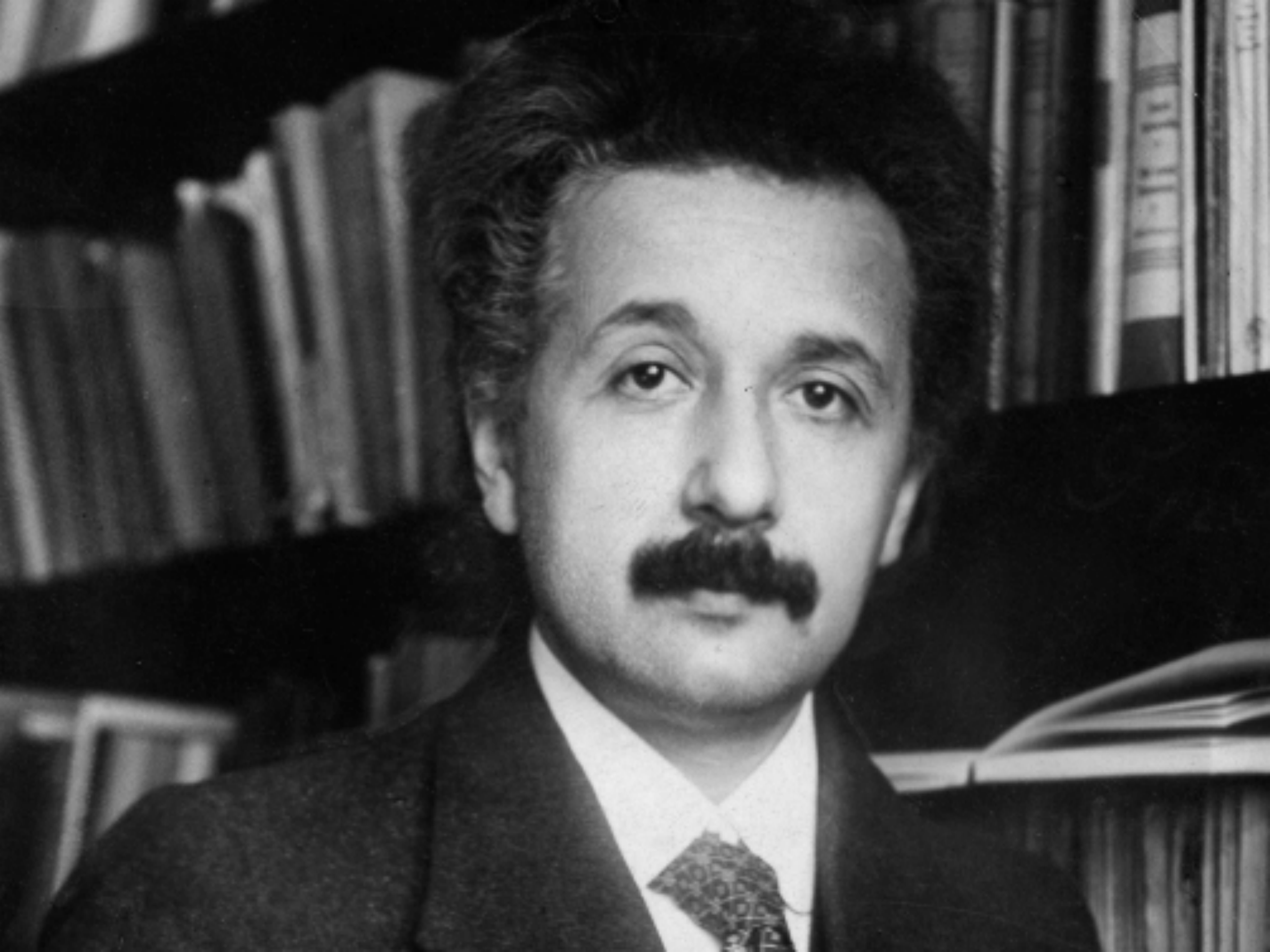


- Einstein was right
- Black holes exist
- A whole new way to “listen” to the Universe!

Why is this important?

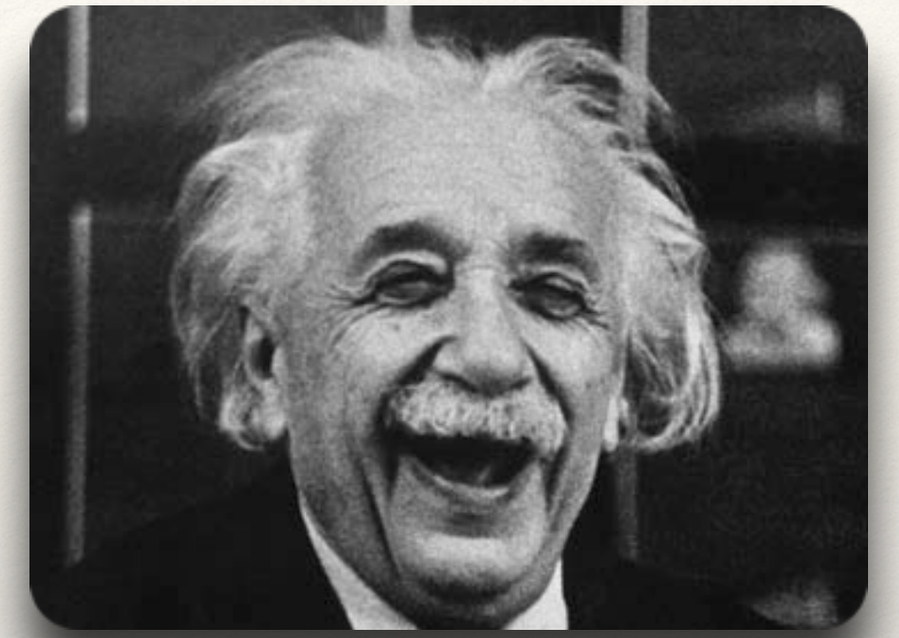


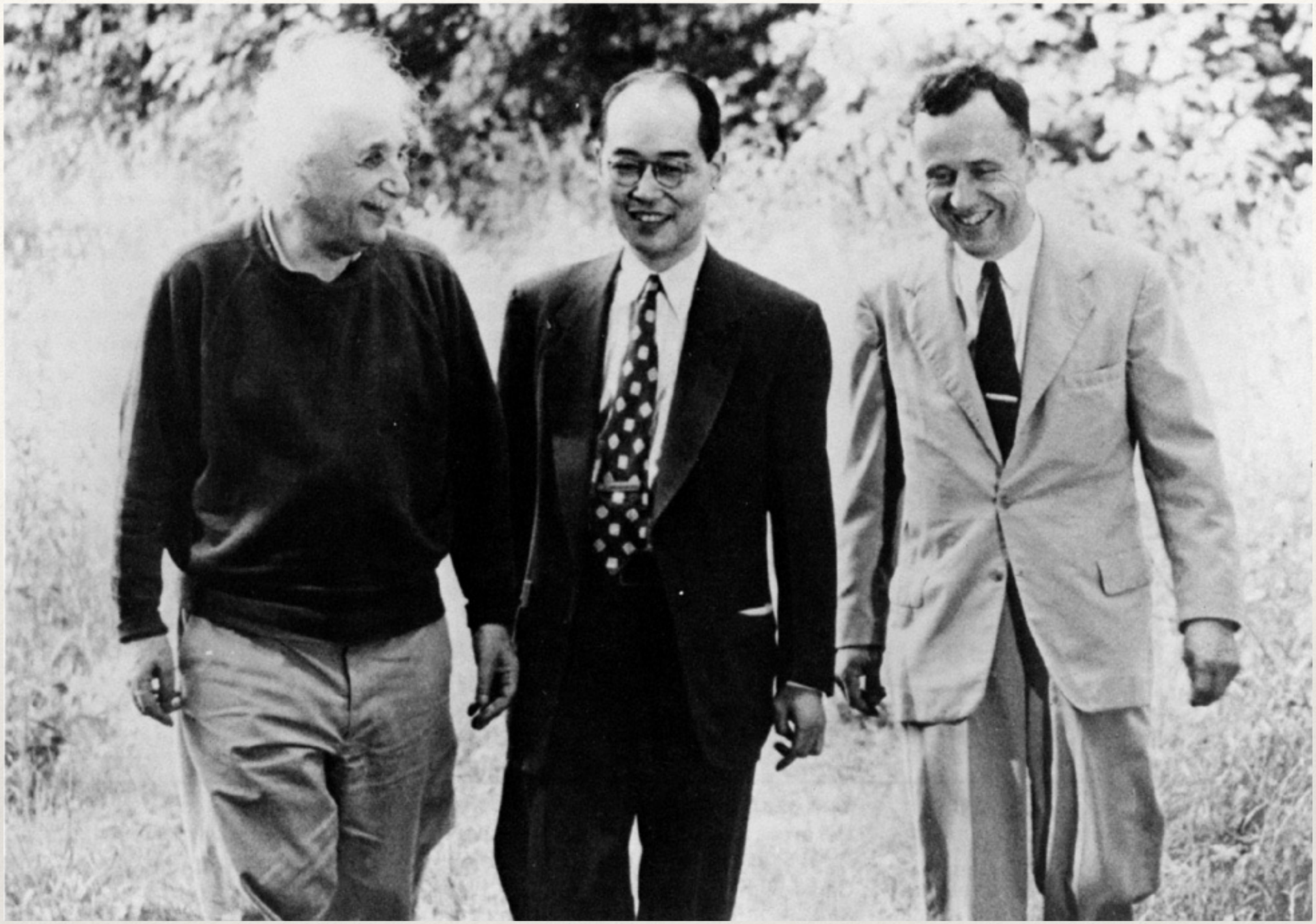
- Einstein was right
- Black holes exist
- A whole new way to “listen” to the Universe!



1915: General Relativity

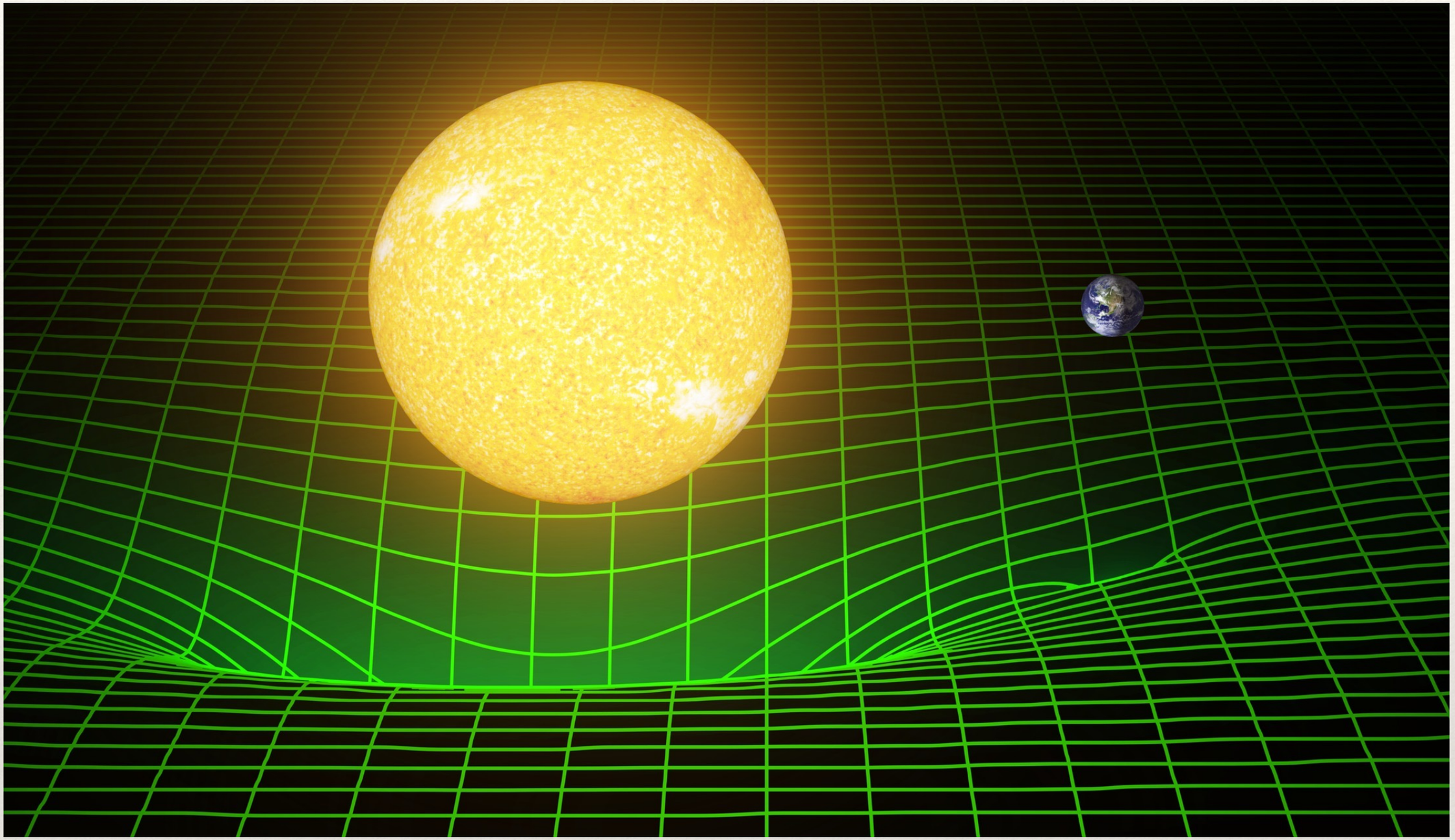
- Space and time are inextricably linked: **spacetime**
- Spacetime can become infinitely warped: **black holes**
- Spacetime can wiggle: **gravitational waves**





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

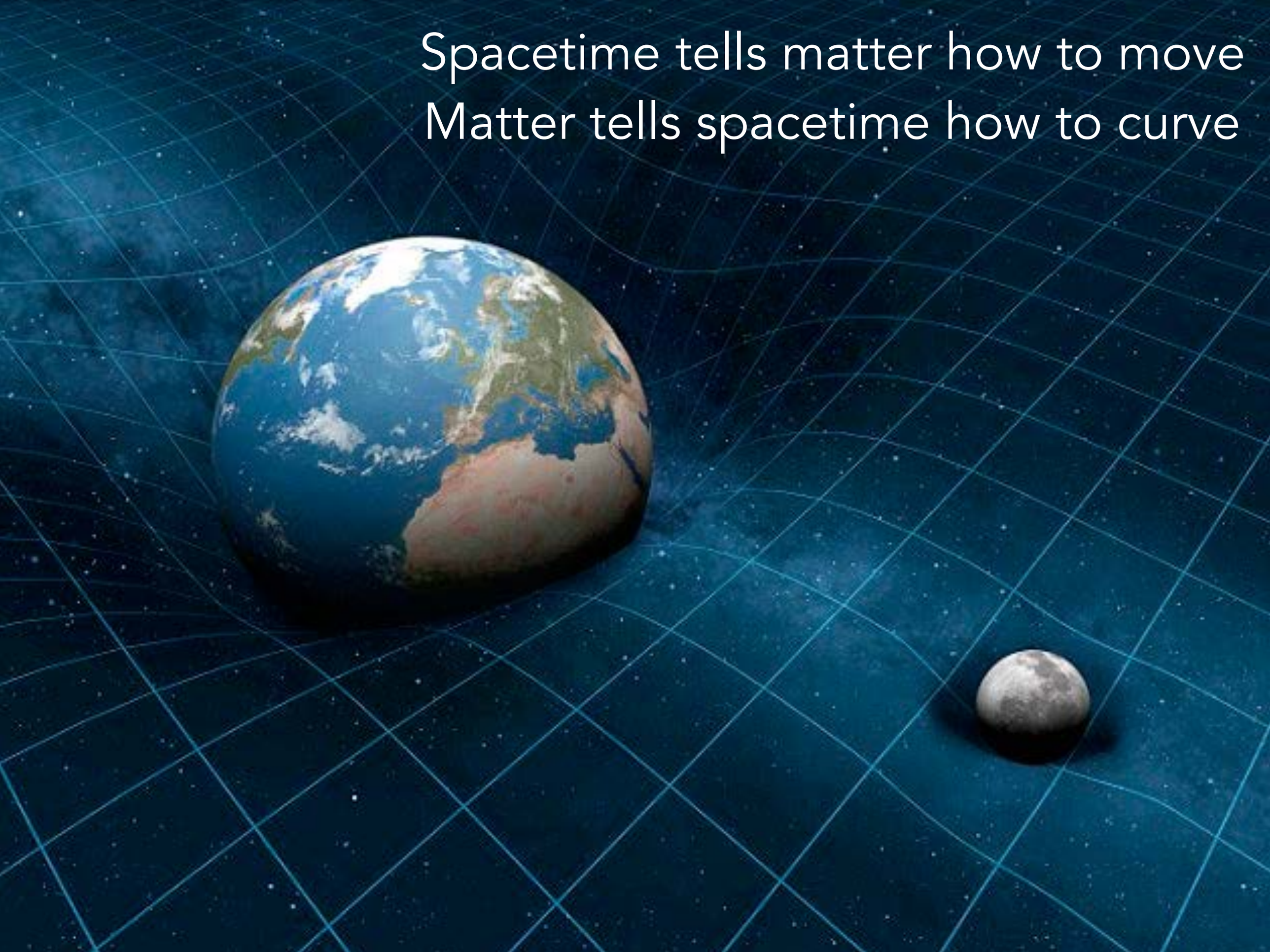
–John Archibald Wheeler



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

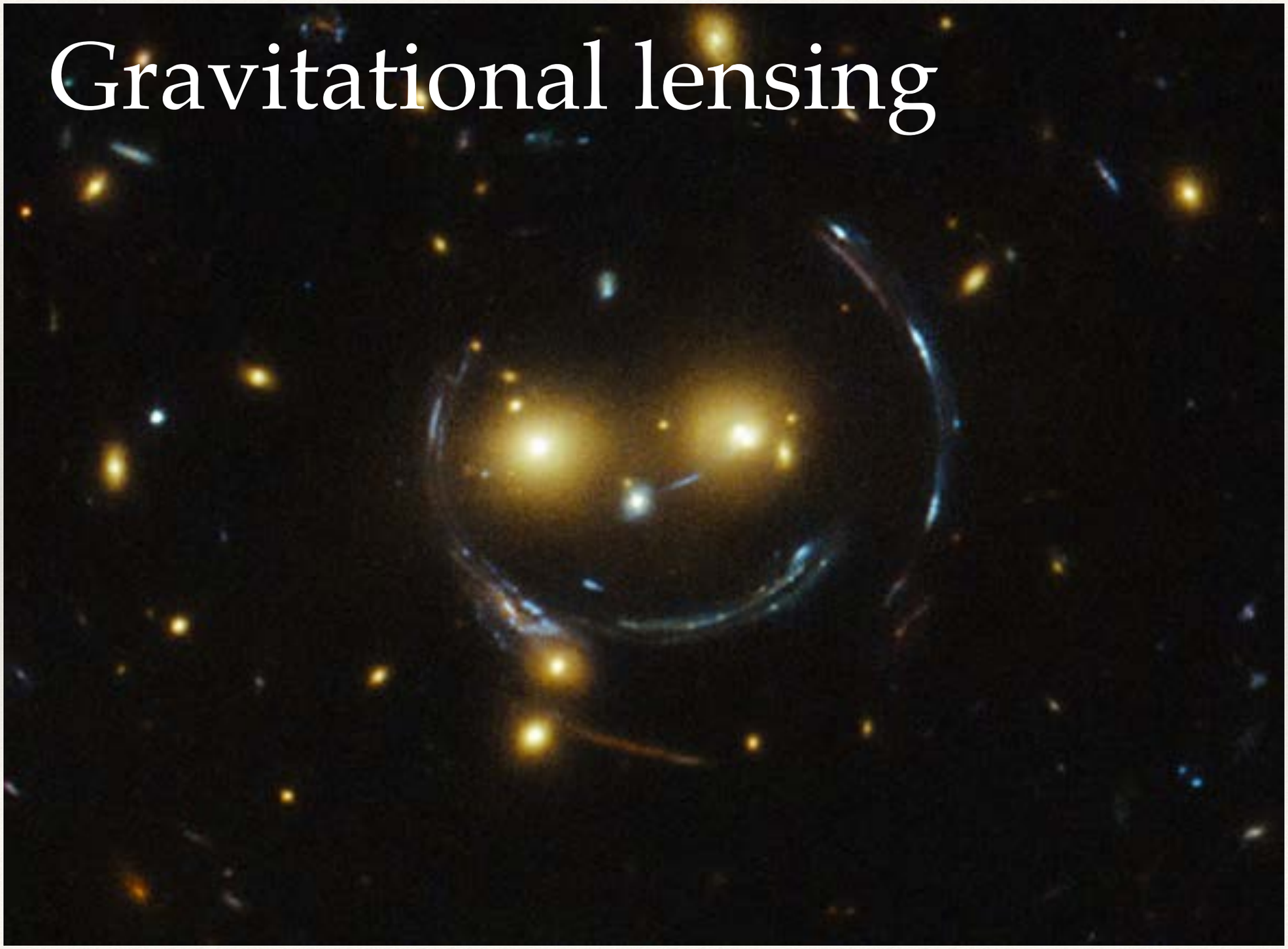
–John Archibald Wheeler

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

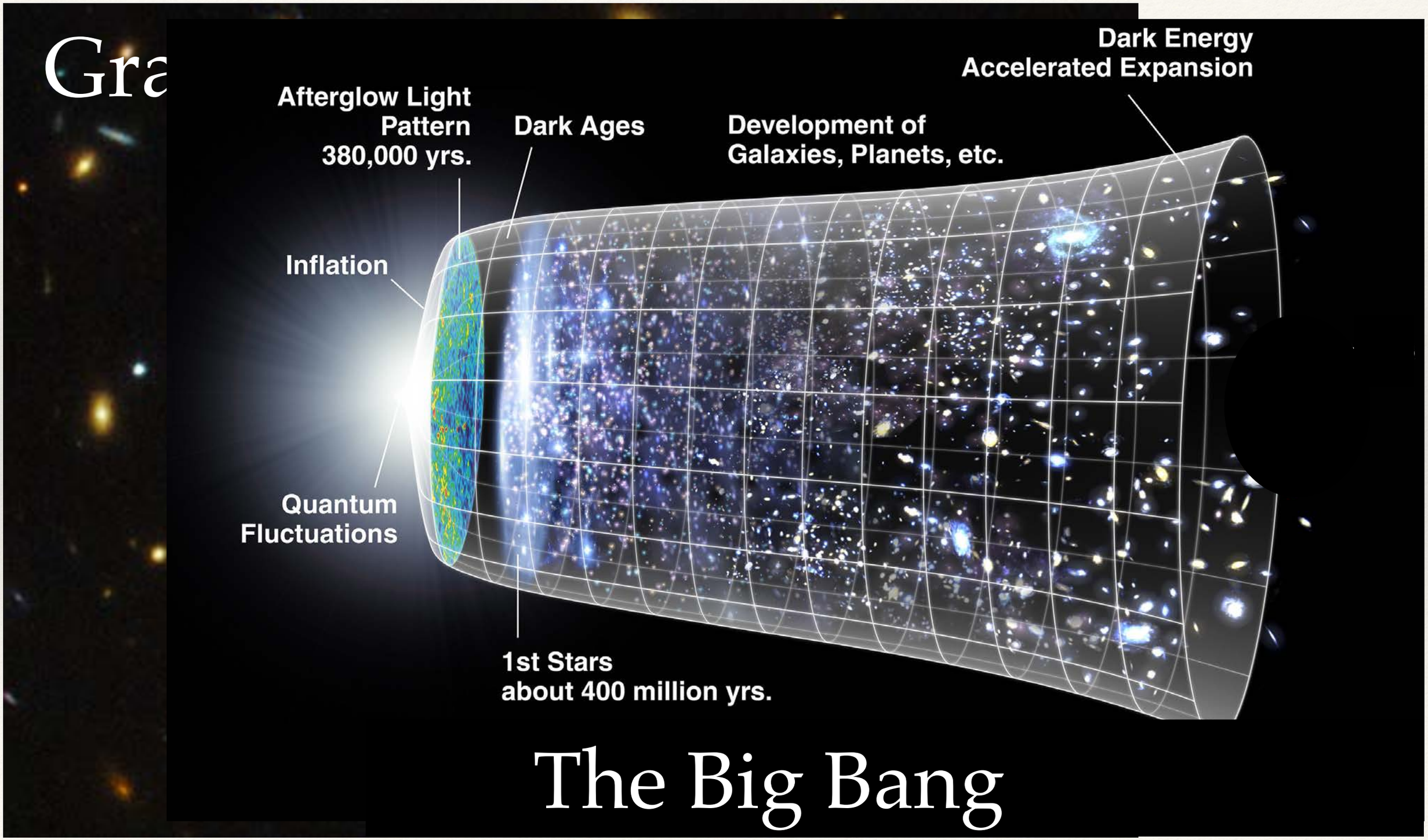


Einstein's theory works!

Einstein's theory works!

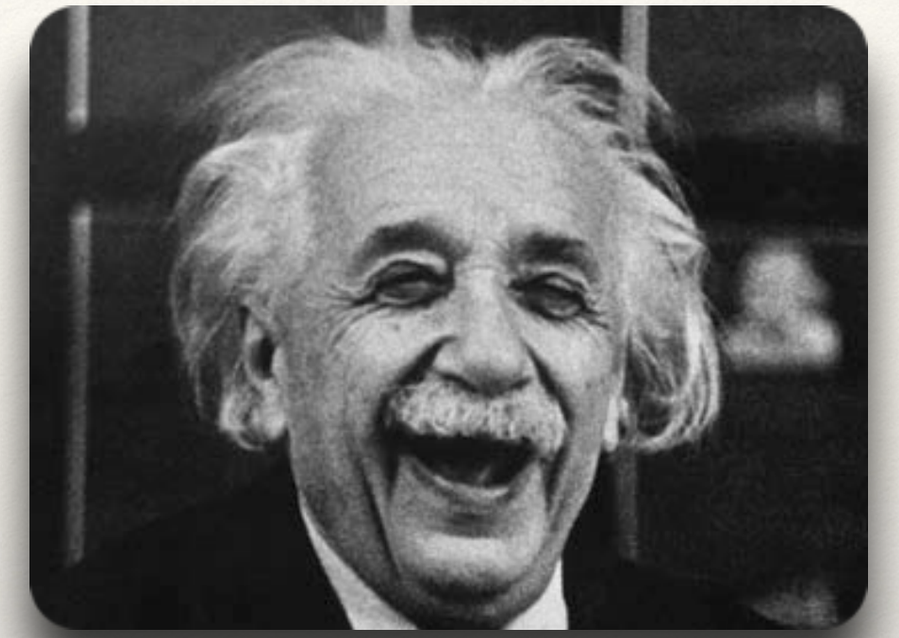


Einstein's theory works!



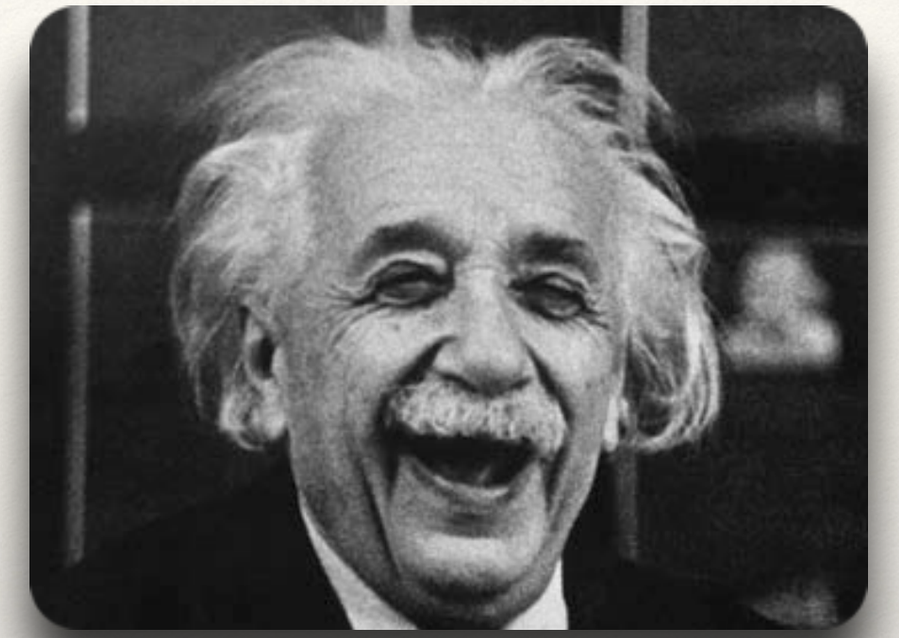
1915: General Relativity

- Space and time are inextricably linked: **spacetime**
- Spacetime can become infinitely warped: **black holes**
- Spacetime can wiggle: **gravitational waves**



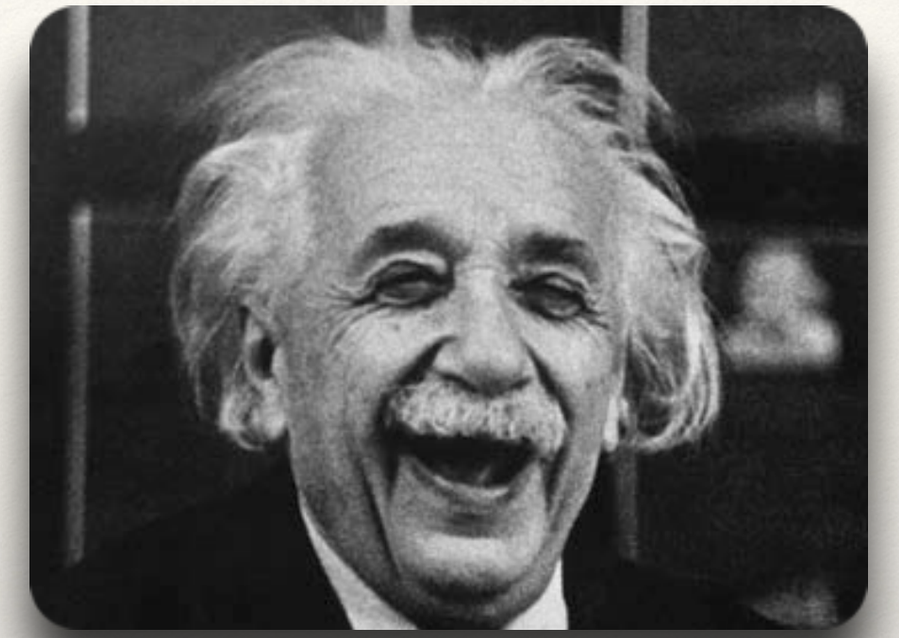
100 years later:

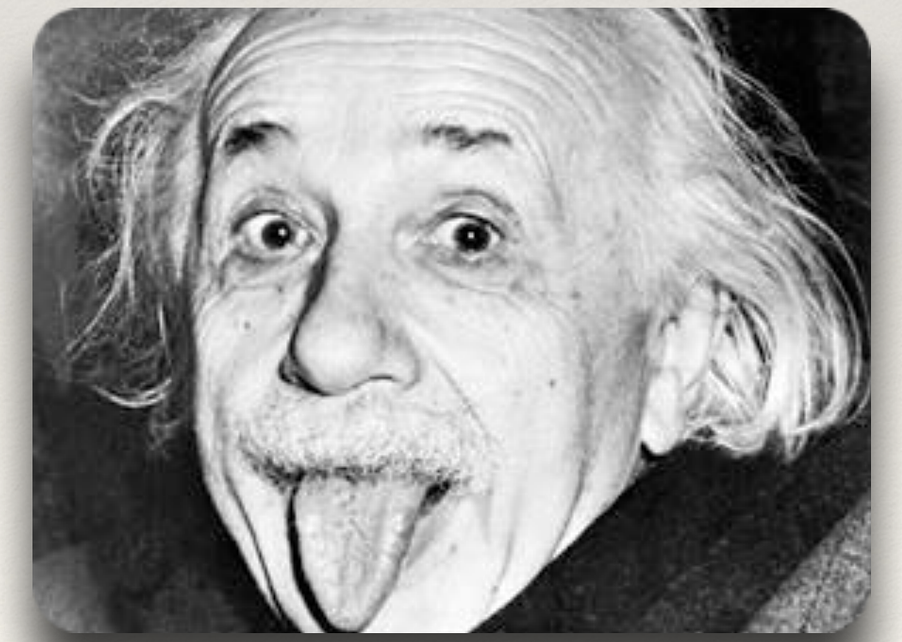
- Space and time are inextricably linked: **spacetime**
- Spacetime can become infinitely warped: **black holes**
- Spacetime can wiggle: **gravitational waves**



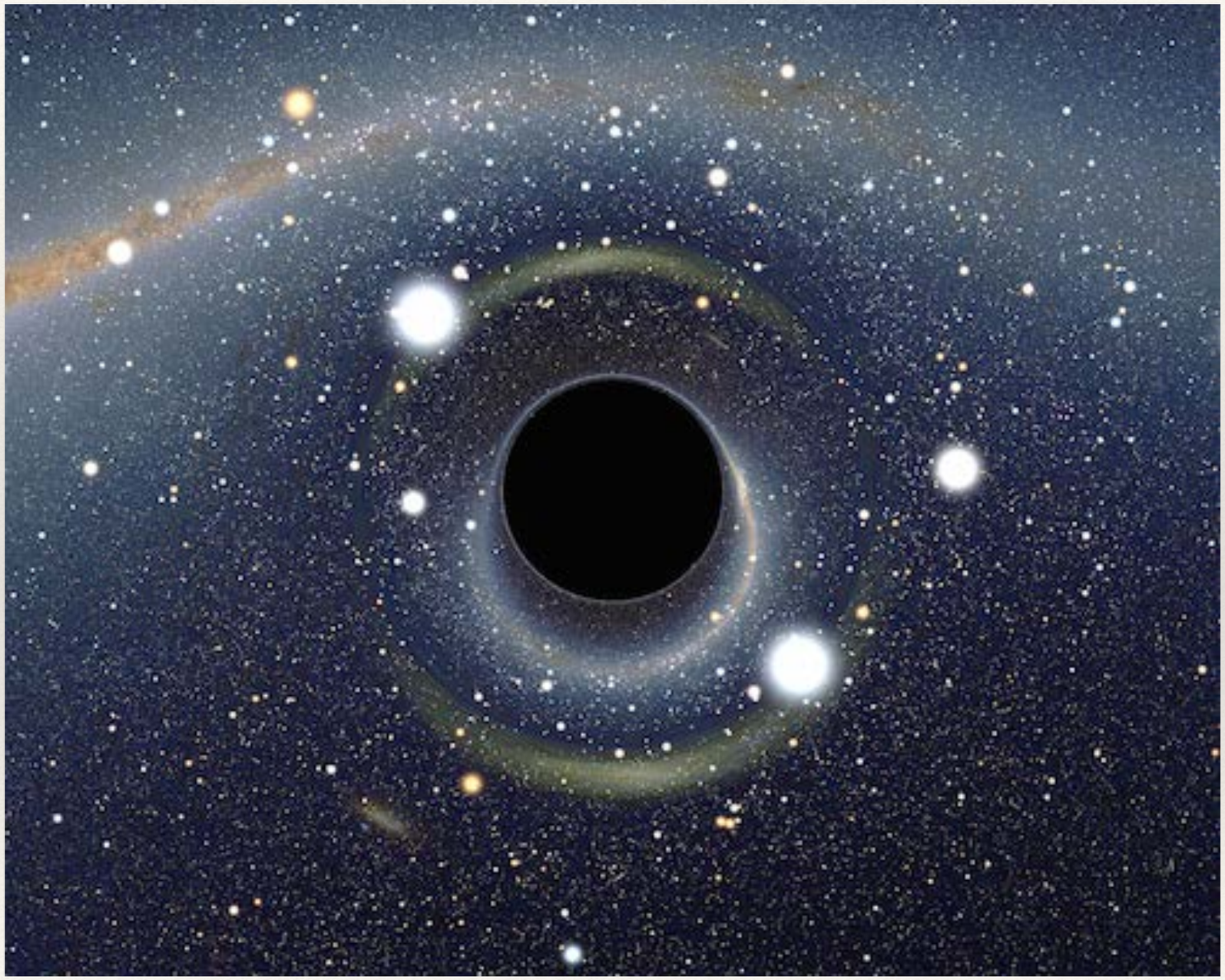
Still looking for black holes and gravitational waves!

- Space and time are inextricably linked: **spacetime**
- Spacetime can become infinitely warped: **black holes**
- Spacetime can wiggle: **gravitational waves**





Black Holes

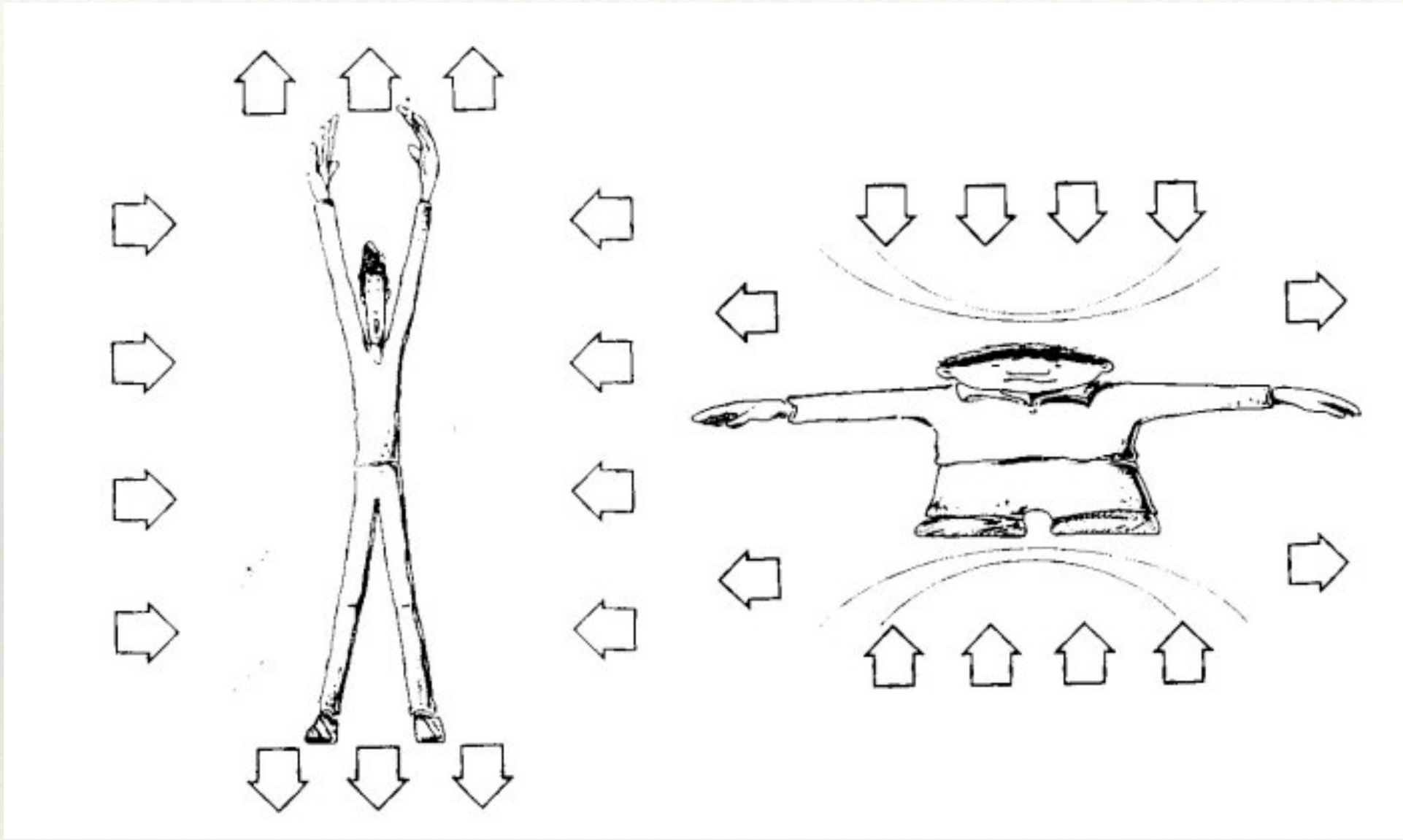


- Gravity is so strong that not even light can escape!

Gravitational waves

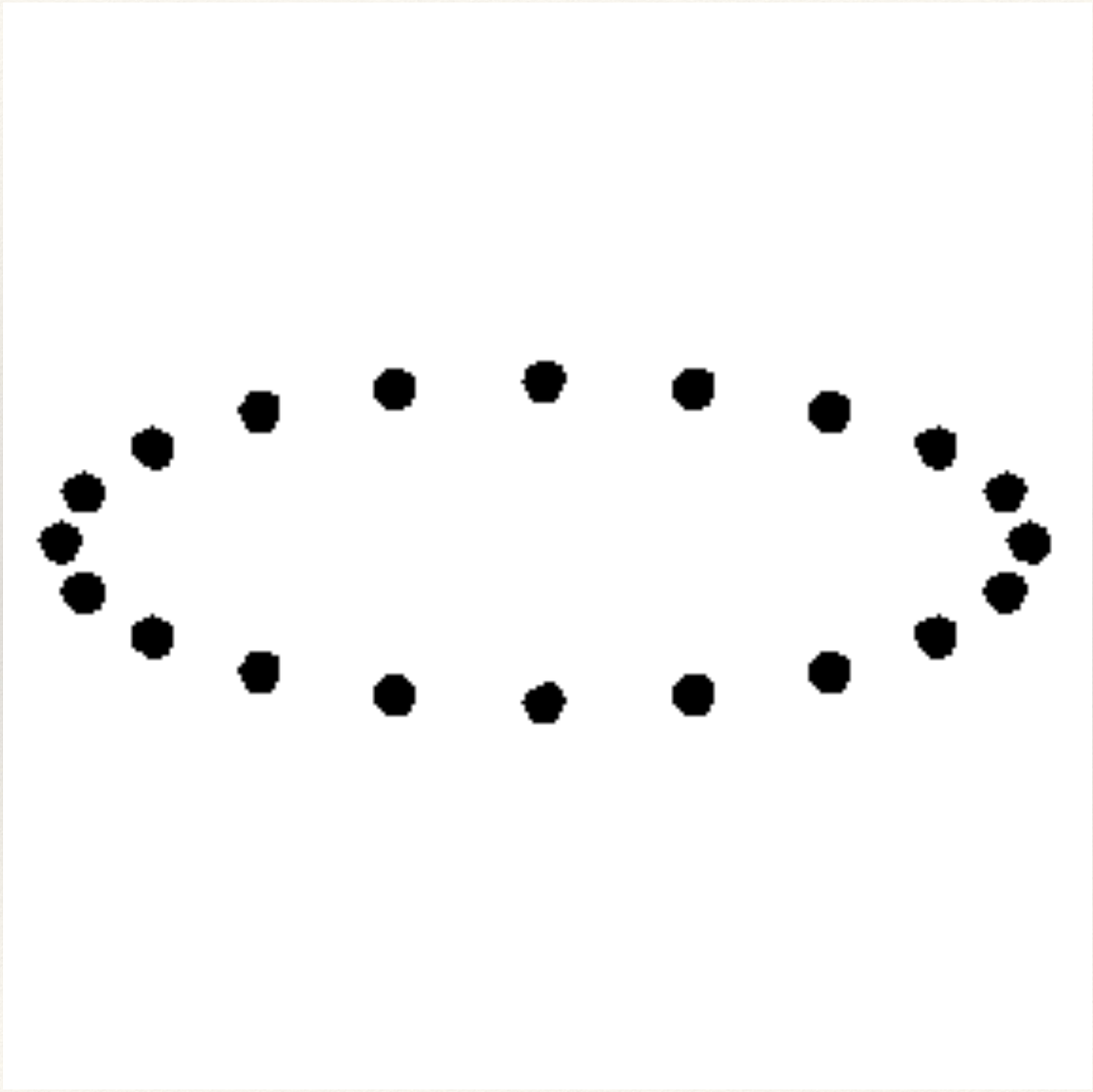
- Ripples in the fabric of spacetime

What do gravitational waves do?

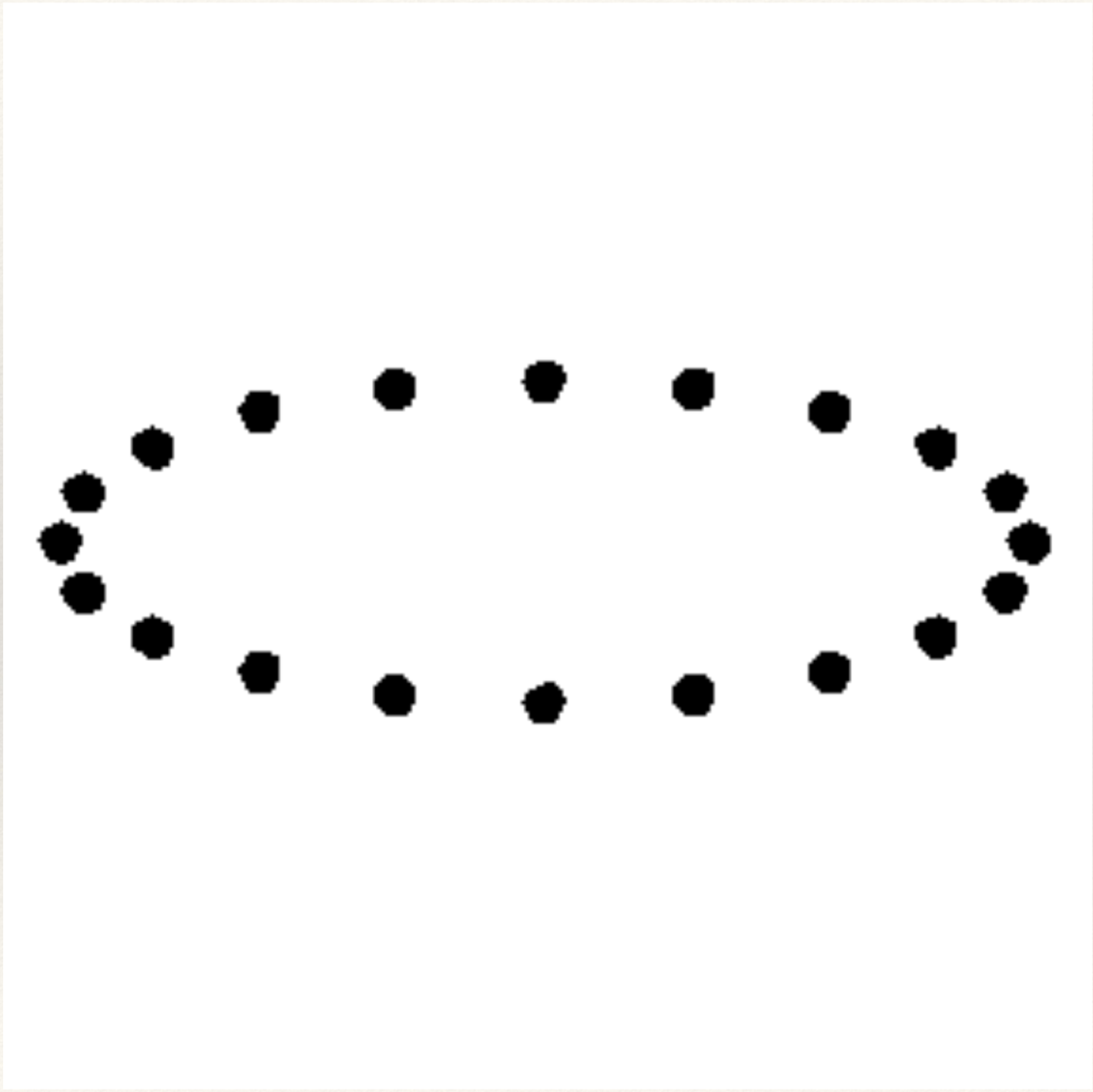


The effect of gravitational waves on matter is to stretch & squeeze it … but the effect is **really small**.

What do gravitational waves do?



What do gravitational waves do?



Why did this take 100 years?

- Gravitational waves have a minuscule effect as they pass by
- A "loud" gravitational wave would only change the distance between us and the next closest star (4.3 lightyears away) by the width of a human hair!

4.3 lightyears = 25 trillion miles

Earth

Alpha Centauri

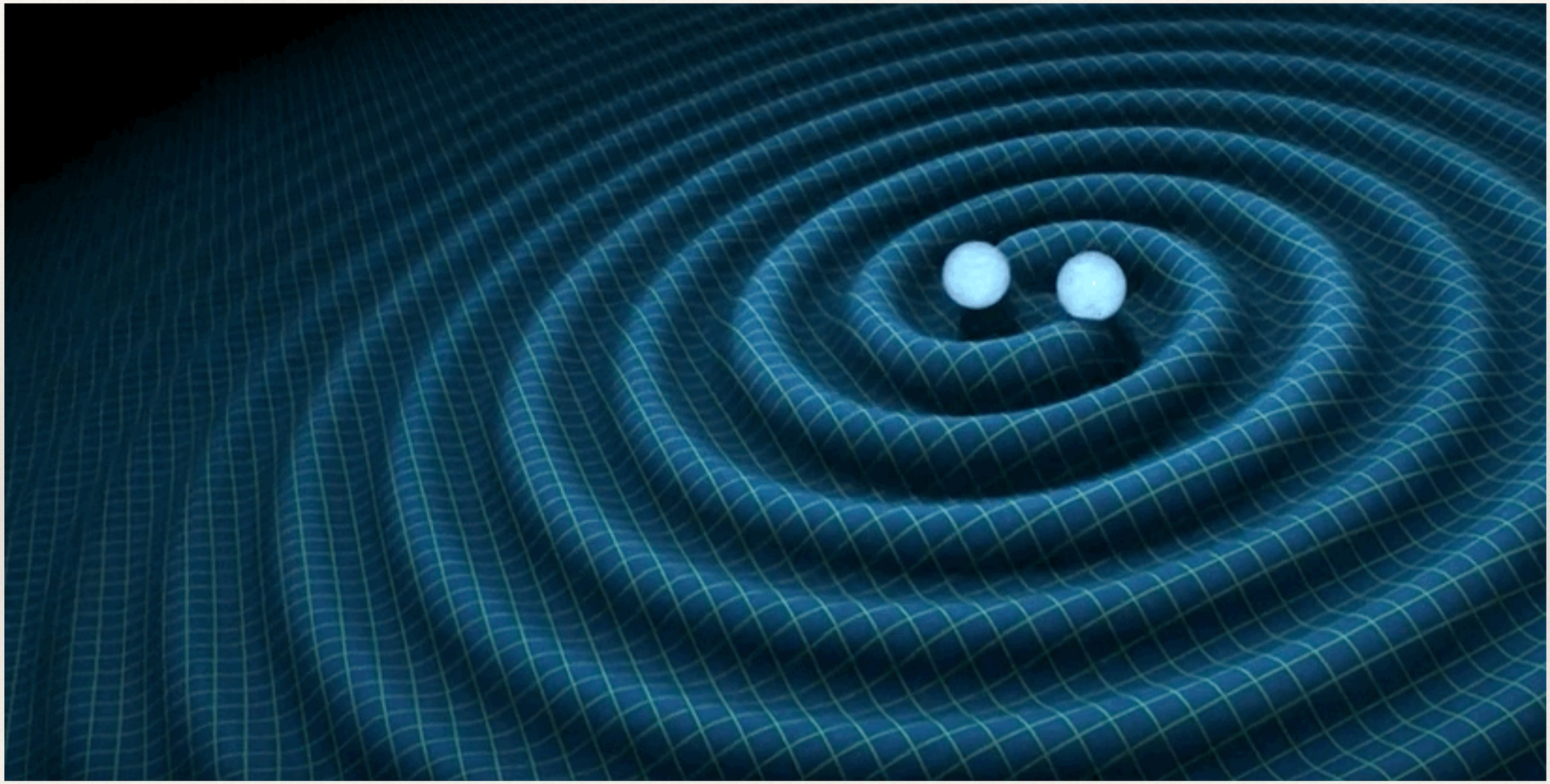
Why did this take 100 years?

- Gravi ect as they pass b
- A "lo hange the distan tar (4.3 lighty hair!

Earth

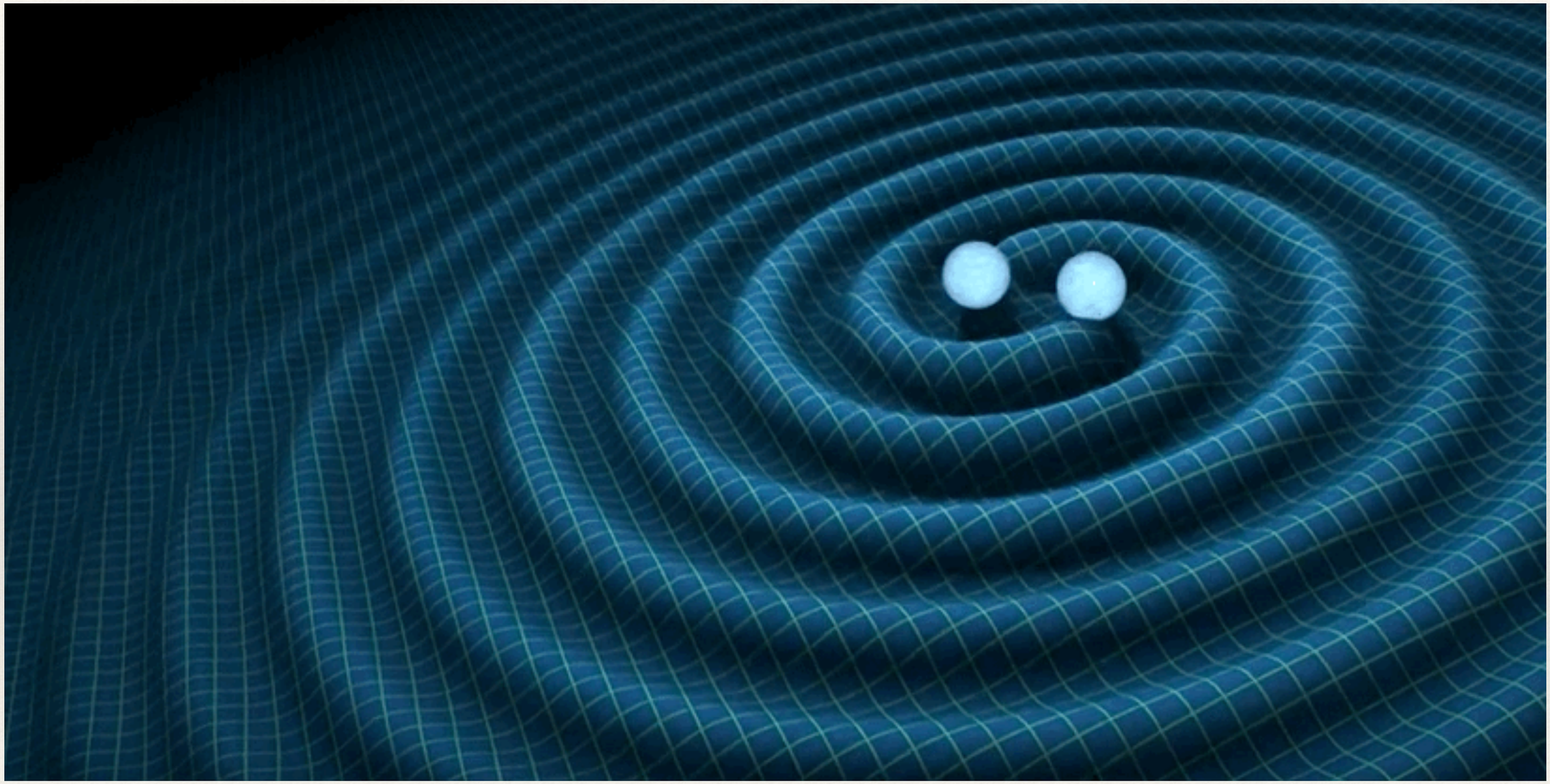
Alpha Centauri

Making waves



- Orbiting black holes generate gravitational waves!

Making waves

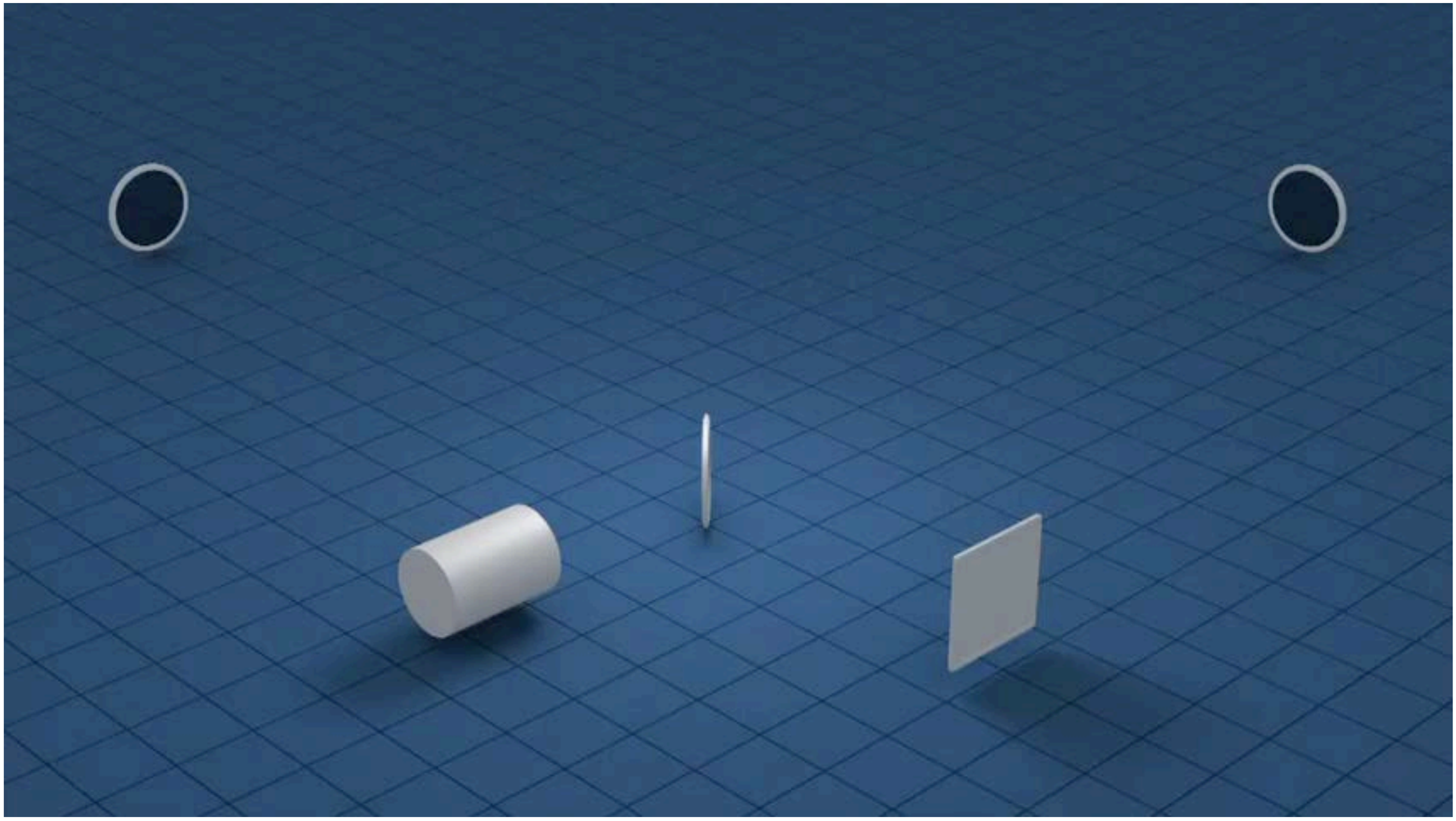


- Orbiting black holes generate gravitational waves!

How do we detect these waves?

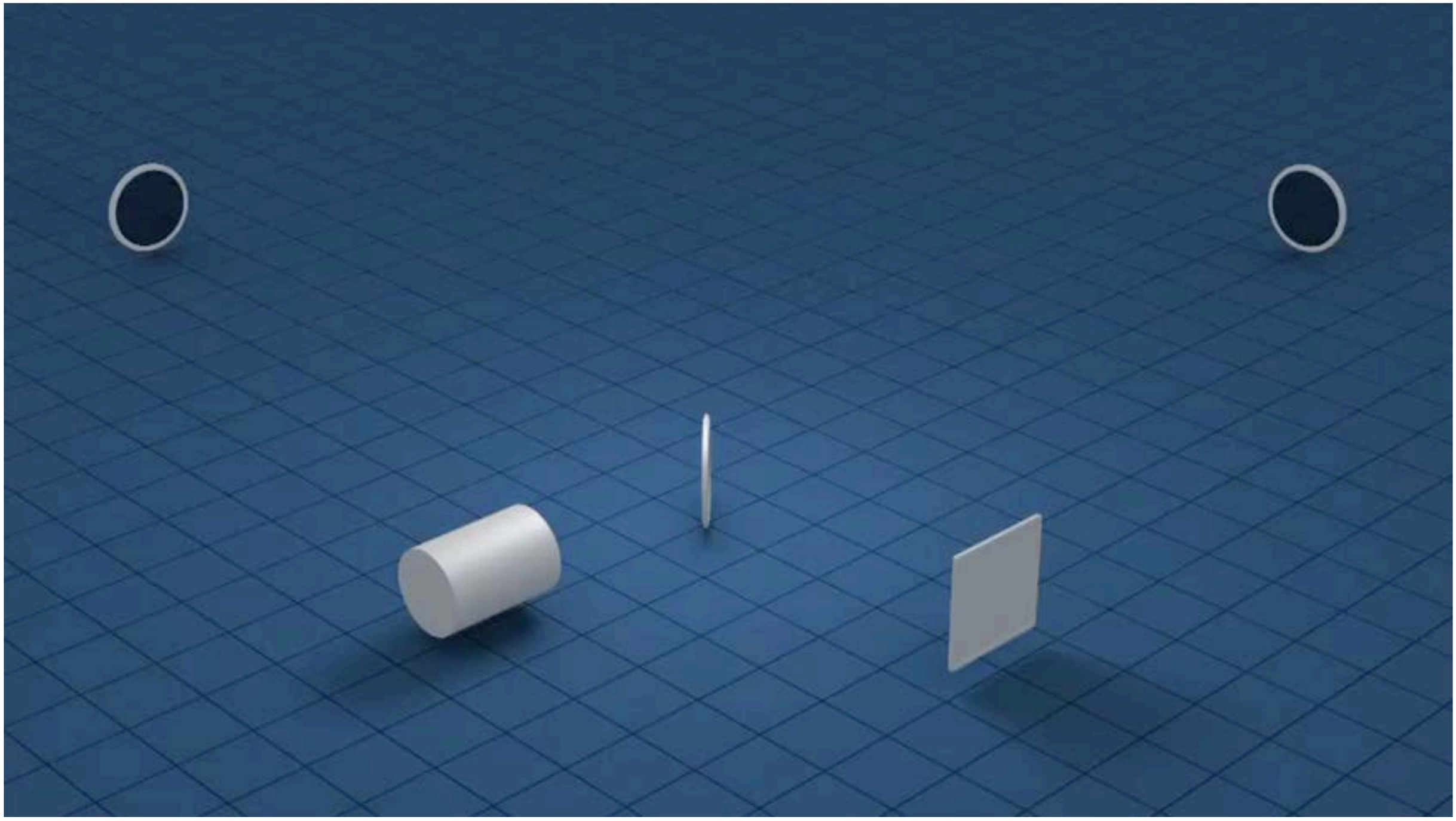
- We built the Laser Interferometer Gravitational wave Observatory (LIGO)
- It is the most sensitive machine ever built

How does LIGO work?



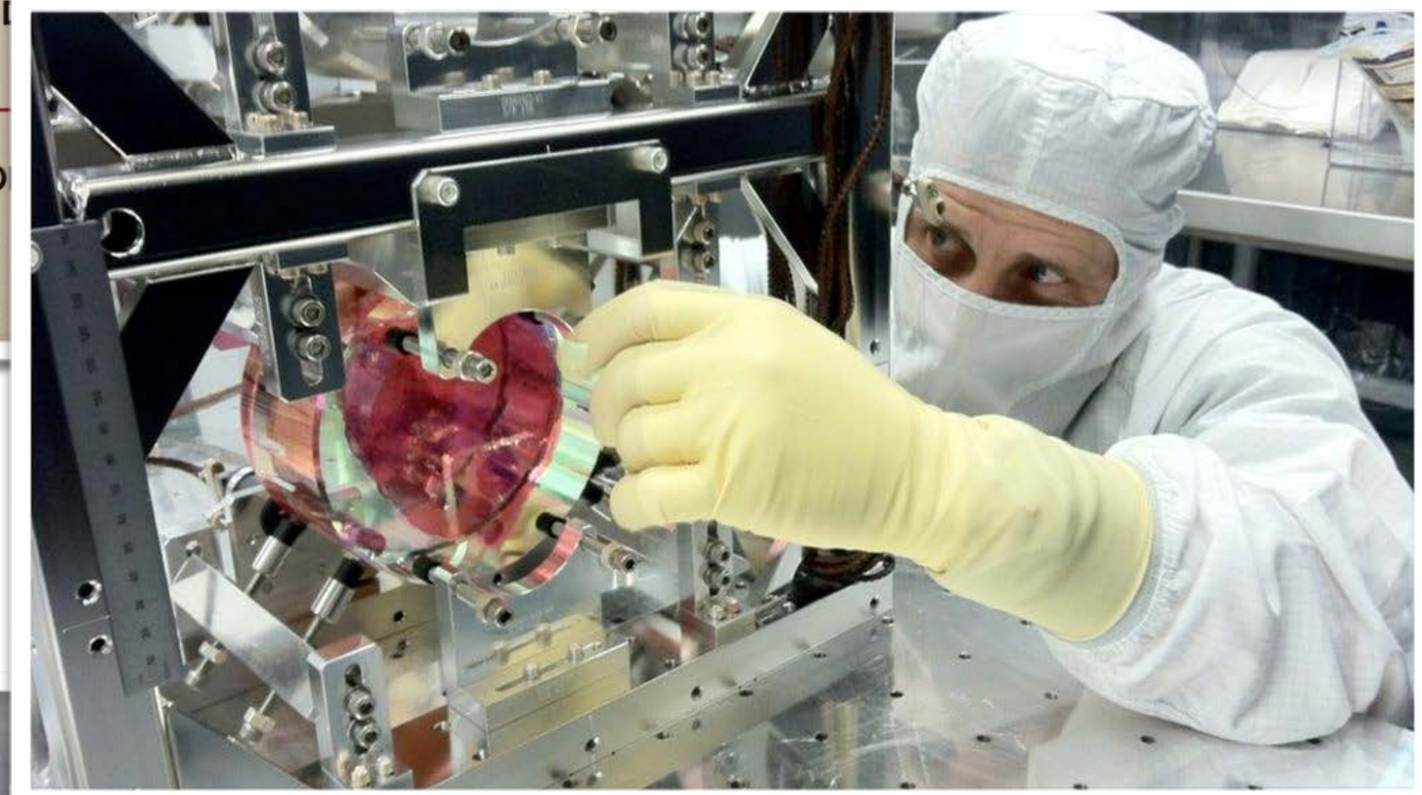
LIGO is the most precise measuring tool ever made.

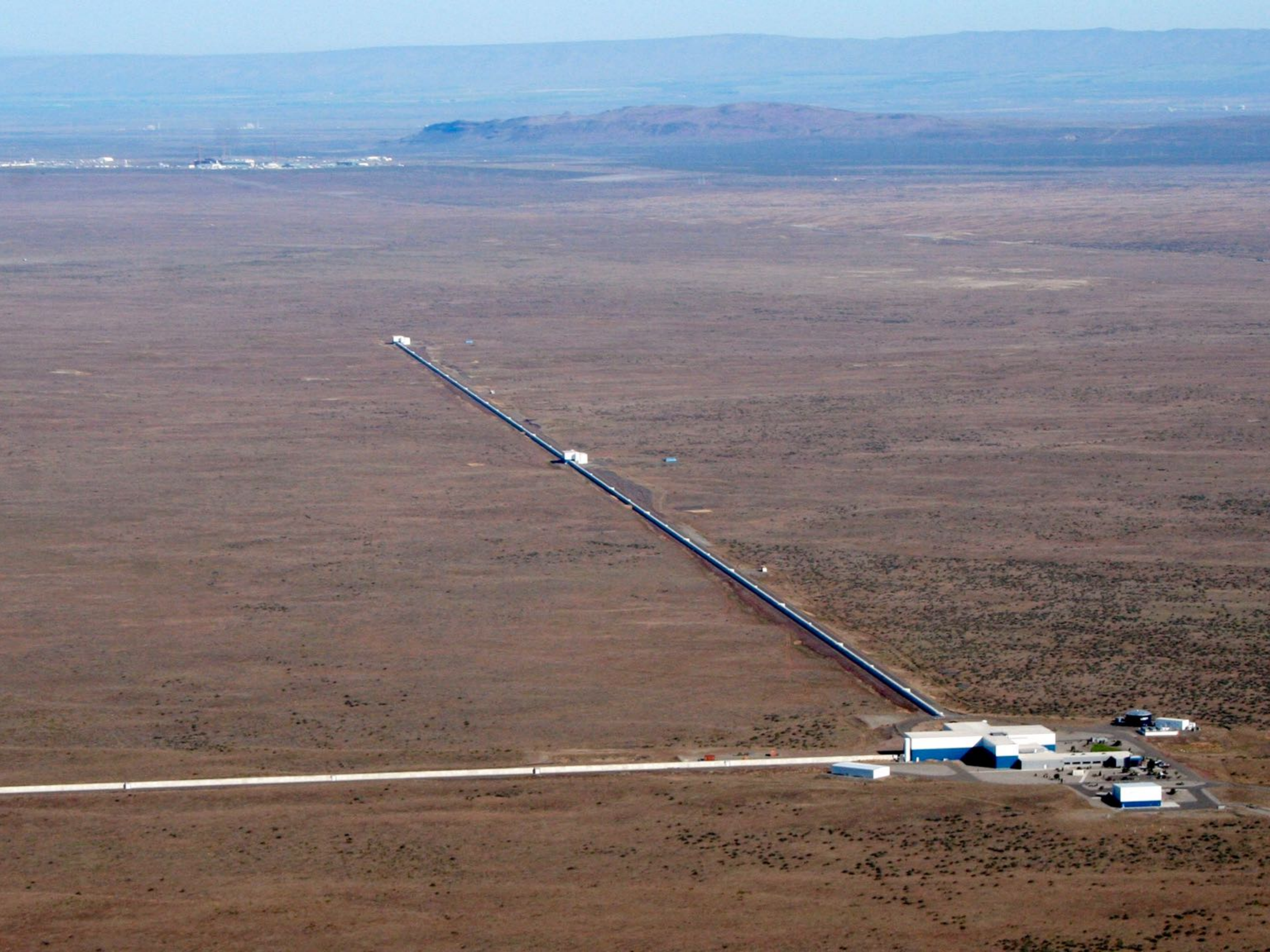
How does LIGO work?



LIGO is the most precise measuring tool ever made.

What is inside LIGO?





LIGO Scientific Collaboration

- Over 1,000 scientists from 83 institutions in 15 countries
- Many types of scientists involved:
  theorists, experimenters, data analysts, engineers, astrophysicists…

LIGO Scientific Collaboration

Trinity University
University of Maryland
Andrews University
Washington State University
California State University Fullerton
The University of Alabama in Huntsville
Sonoma State University
indigo
Montclair State University
University of Glasgow
Australian National University
Whitman College
American University
University of the West of Scotland
UWS
Texas Tech University
Tsinghua University
R·I·T
Stanford Junior University
Max Planck Institute for Gravitational Physics
Albert Einstein Institute
University of Strathclyde
Michigan
NASA
Goddard Space Flight Center
ICTP-SAIFR
The University of Western Australia
PAH
CITA | ICAT
Canadian Institute for Theoretical Astrophysics
L'institut Canadien d'astrophysique theo
Università degli Studi del Sannio
Massachusetts Institute of Technology
University of Cambridge
ACU
The University of Chicago
Montana State University
1848
The University of Adelaide Australia
Southern University
Agricultural & Mechanical College
Columbia University in the City of New York
Caltech
University of Minnesota
The University of Mississippi
University of Birmingham
The University of Melbourne
Universitas Scientiarum Szegedensis
UIB
Universitat de les Illes Balears
University of Washington
GEO 600
Tsing Hua University
UTRGV
University of Wisconsin
UWMilwaukee
Syracuse University
Cardiff University
Prifysgol Caerdydd
Sigill·Coll·Carleton
Northfield, Minn. A.D. 1866
Universität Hamburg
Monash University
INPE
UF University of Florida
Northwestern
Georgia Institute of Technology
Korean Gravitational-Wave Group
LSU
Louisiana State University
ACIGA
University of Southampton
Charles Sturt University
Embry-Riddle Aeronautical University
Leibniz Universität Hannover
Penn State
Hobart and William Smith Colleges
Science & Technology Facilities Council
Rutherford Appleton Laboratory

UChicago LIGO Group

Hsin-Yu Chen

Daniel Holz

Zoheyr Doctor

Ben Farr

Funded by the National Science Foundation

September 14, 2015

September 14, 2015

[calibration] Very interesting event on ER8 ligo x

Marco Drago <marco.drago@aei.mpg.de>

to burst, cbc, LIGO, Calibration, dac, burst, detchar, losc-devel, lsc-all

Hi all,
cWB has put on gracedb a very interesting event in the last hour.
https://gracedb.ligo.org/events/view/G184098

September 14, 2015

[calibration] Very interesting event on ER8 ligo x

Marco Drago <marco.drago@aei.mpg.de>

to burst, cbc, LIGO, Calibration, dac, burst, detchar, losc-devel, lsc-all

Hi all,
cWB has put on gracedb a very interesting event in the last hour.

Eric Chassande-Mottin <ecm@apc.univ-paris7.fr>

to burst, cbc

Hi Marco,

very interesting indeed! Looks like a high-mass inspiral?
I don't see any CBC event in the neighbors section of the GraceDB entry.
Does that mean that GST LAL nor MBTA saw the event?

September 14, 2015

[calibration] Very interesting event on ER8 ligo x

Marco Drago <marco.drago@aei.mpg.de>

to burst, cbc, LIGO, Calibration, dac, burst, detchar, losc-devel, lsc-all

Hi all,
cWB has put on gracedb a very interesting event in the last hour.

Eric Chassande-Mottin <ecm@apc.univ-paris7.fr>

to burst, cbc

Andrew P Lundgren <aplundgr@syr.edu>

to burst, calibration, cbc, LIGO, dac, burst, detchar

Hi all,

The Omega scans have finished and I do not see any DQ issues at the time of the trigger.
range.

September 14, 2015

[calibration] Very interesting event on ER8 ligo x

Marco Drago <marco.drago@aei.mpg.de>

to burst, cbc, LIGO, Calibration, dac, burst, detchar, losc-devel, lsc-all

Hi all,
cWB has put on gracedb a very interesting event in the last hour.

Eric Chassande-Mottin <ecm@apc.univ-paris7.fr>

to burst, cbc

Andrew P Lundgren <aplundgr@syr.edu>

to burst, calibration, cbc, LIGO, dac, burst, detchar

Hi all,

The Omega scans have finished and I do not see any DQ issues at the time of the trigger.
range.

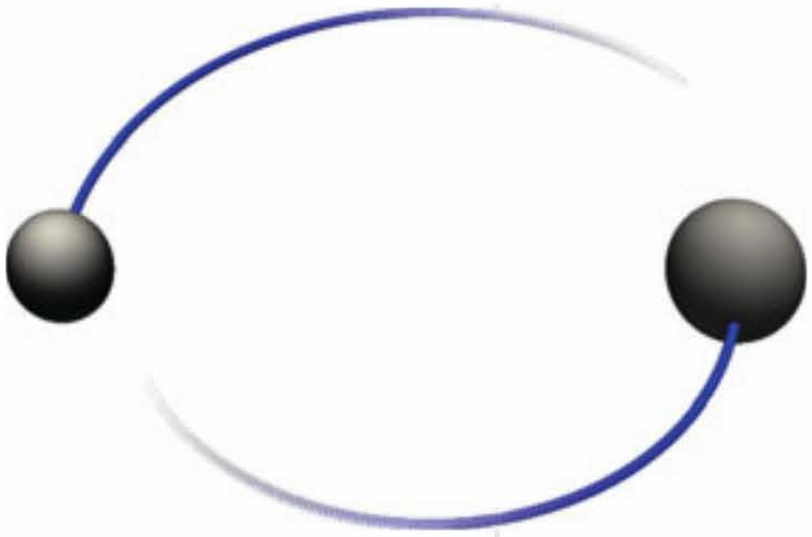
Klimenko, Sergey <klimenko@phys.ufl.edu>

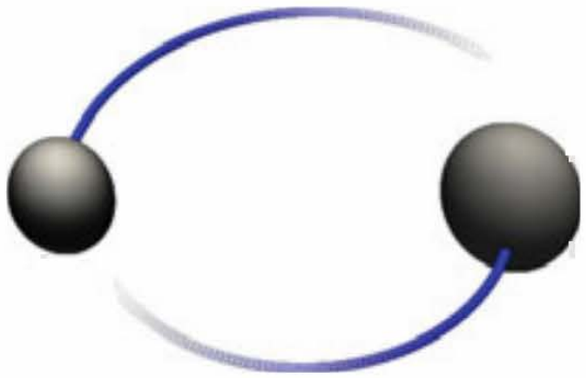
to David, Gabriela, Dave, Stan, burst, calibration, cbc, dac, detchar

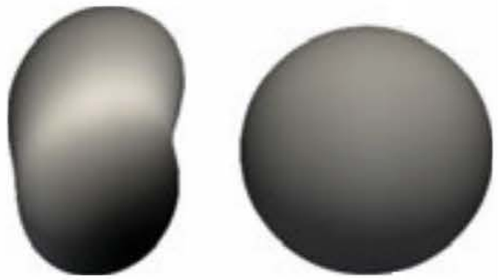
This is clean and very significant inspiral with Mchirp = 27 +- 2 Mo.
The polarization is close to circular.
The cWB ER8 offline analysis accumulated ~236 years of background
so far - this event FAR << 1.e-10 Hz. If this is not injection,
I guess, we need to do the detection checklist…
Sergey

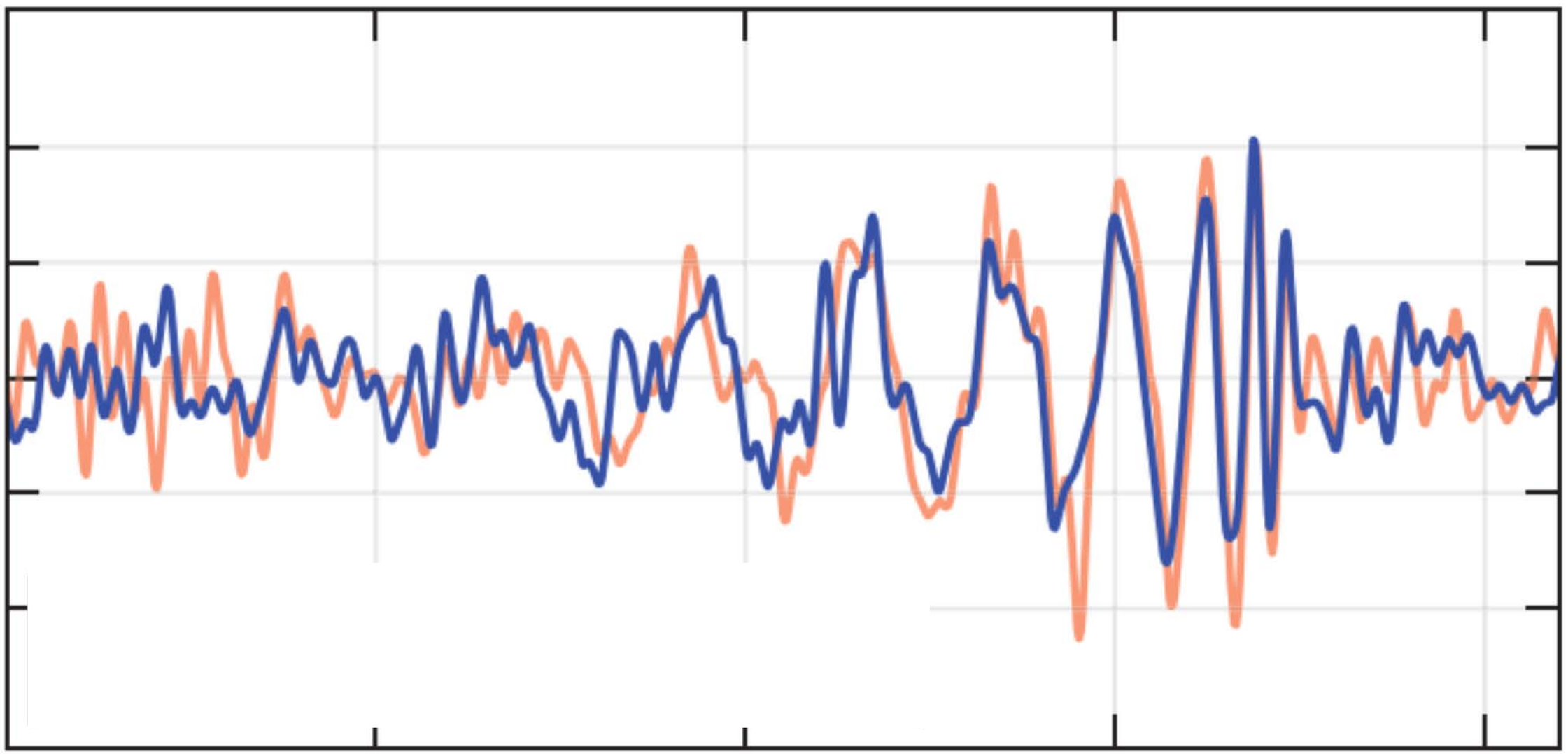
Inspiral

Merger



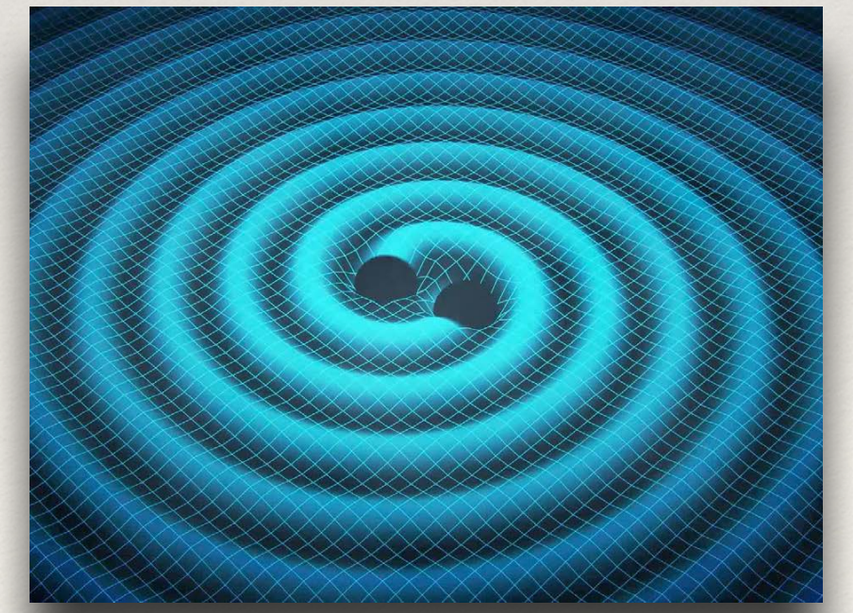






What did we detect?

- Two black holes crashing into each other at over half the speed of light
- Each black hole was 30 times more massive than the Sun
- These black holes were 1 billion trillion miles away
- This event emitted more energy than the entire rest of the Universe **combined** (for a fraction of a second)

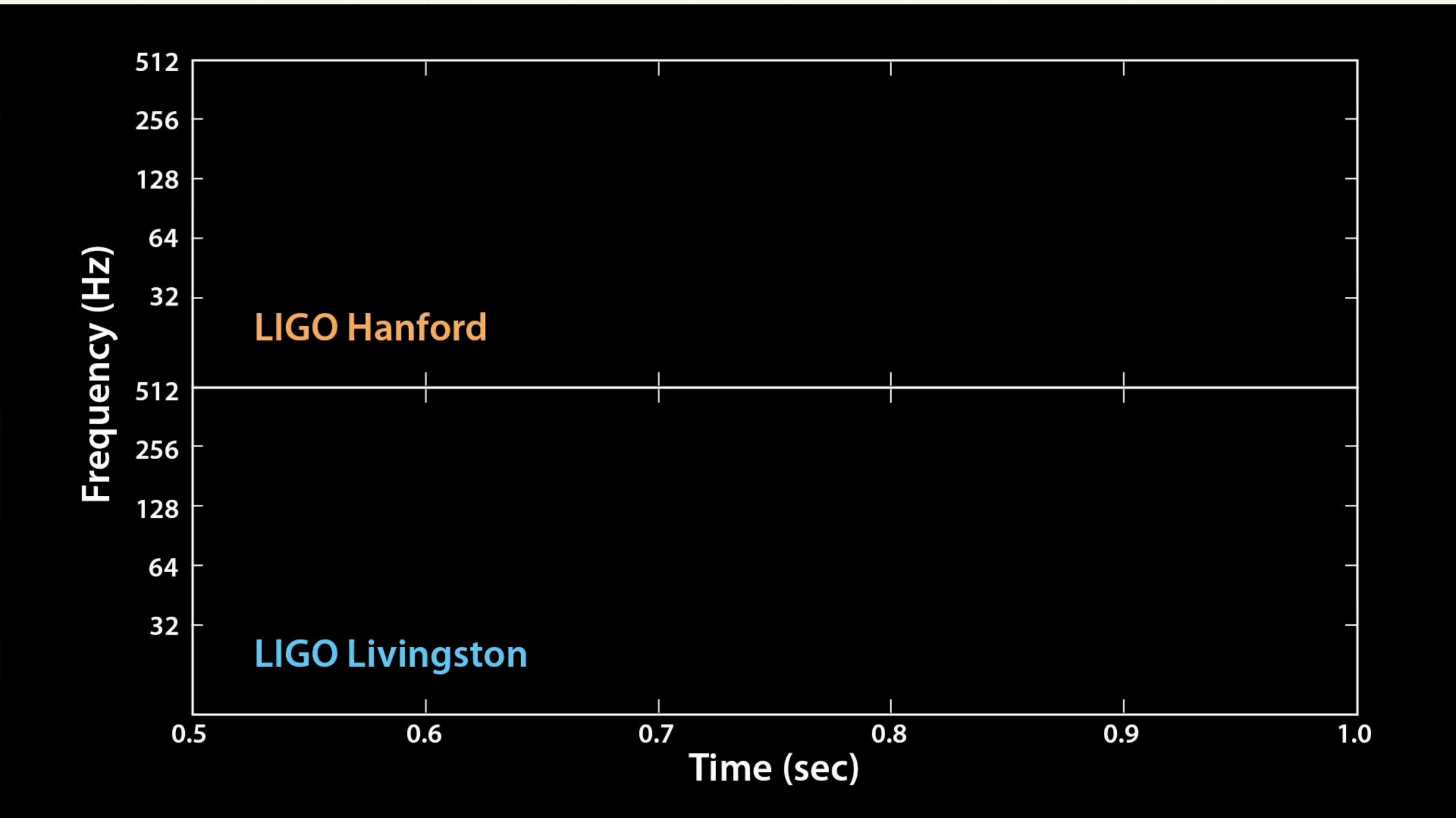


How big are the black holes?

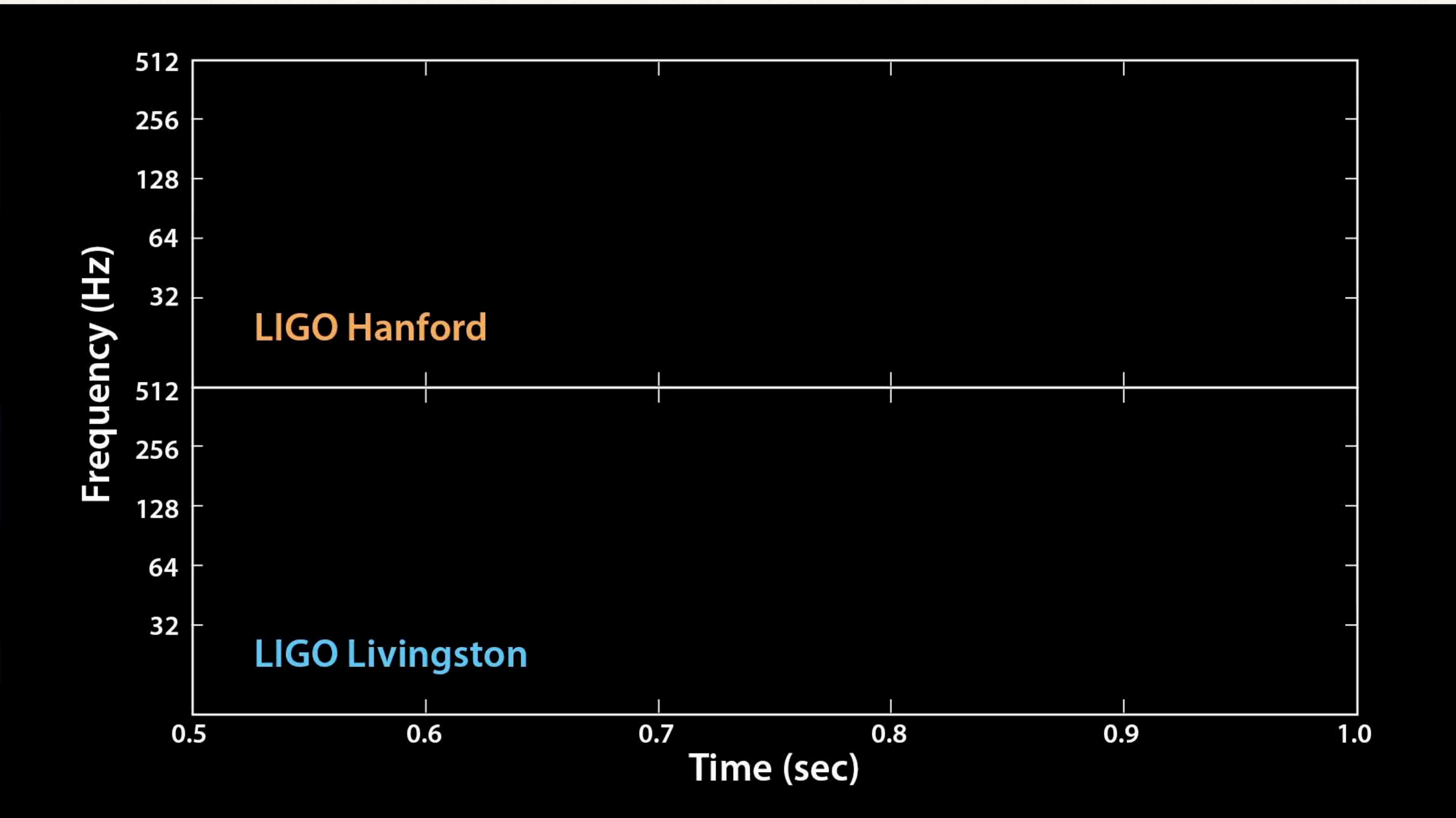
How big are the black holes?

How big are the black holes?

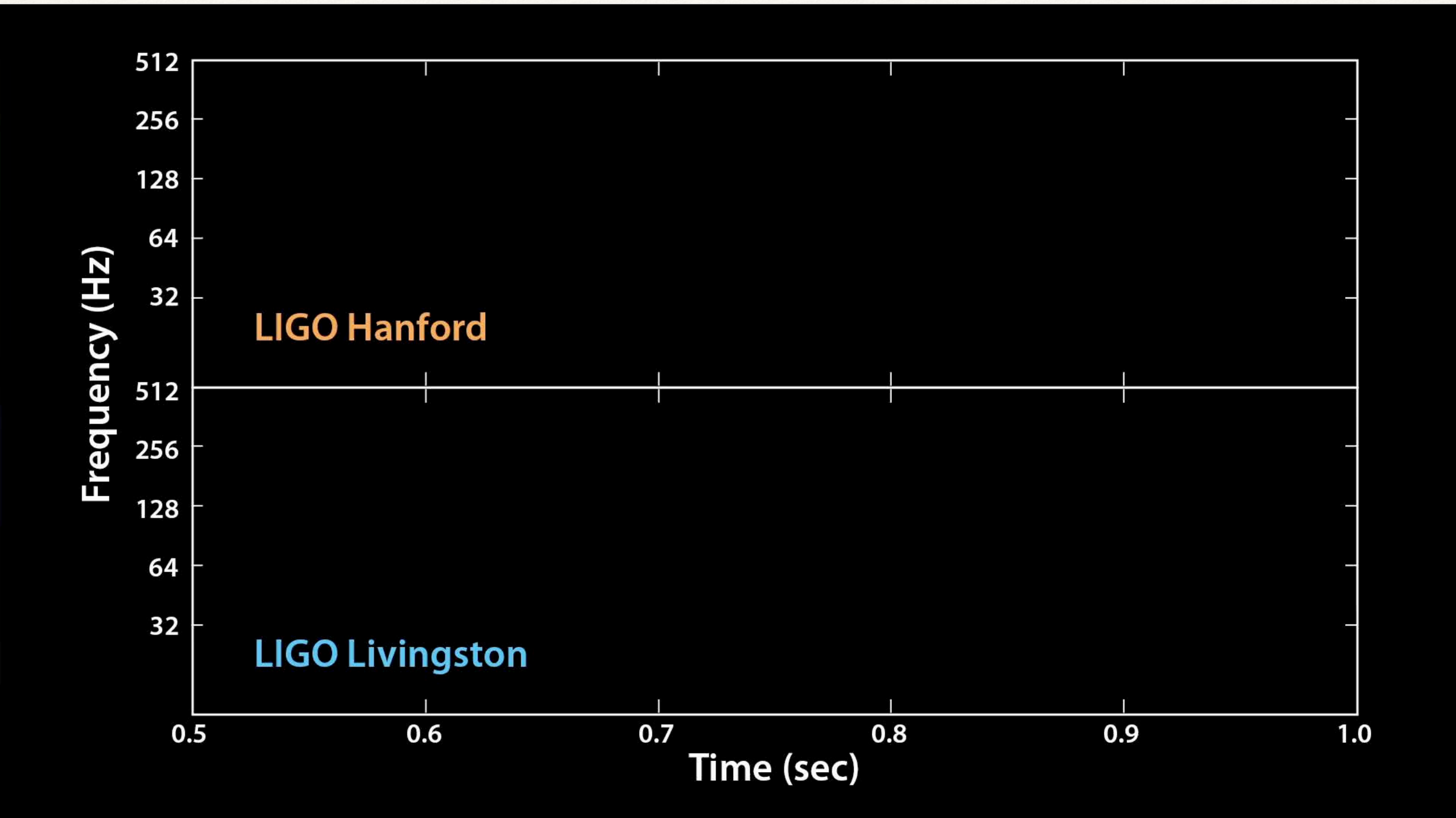
The sound of 2 black holes colliding



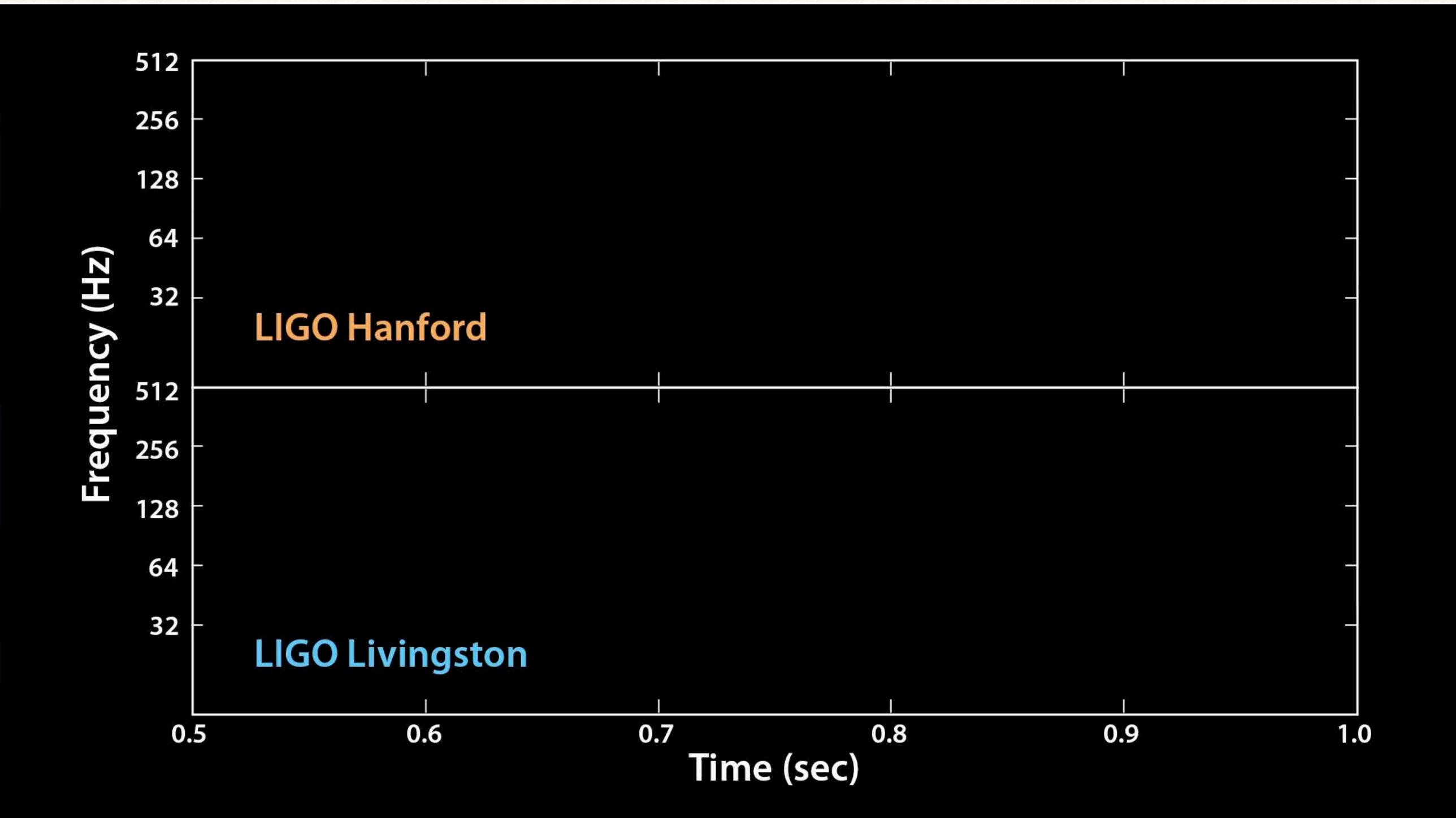
The sound of 2 black holes colliding



The sound of 2 black holes colliding



The sound of 2 black holes colliding



The Announcement: Feb. 11, 2016

Streamed all over the world,
including University of Chicago

Chicago Tribune

digitalPLUS SPORTS FINAL

Skid puts Bulls in tough spot at All-Star break
Chicago Sports

City to host its first NHL draft
Chicago Sports

Jackie Robinson West parents sue league, others
Chicagoland, Page 4

For science, a cosmic milestone

Detection of gravitational waves proves prediction Einstein made a century ago

By Amina Khan
Tribune Newspapers

In a groundbreaking discovery, scientists announced Thursday that they had detected gravitational waves created by the violent collision of two black holes more than 1 billion light-years from Earth, a resounding confirmation of Albert Einstein's postulation a century ago about the ripples in the fabric of space and time.

The detection, made with the Laser Interferometer Gravitational-Wave Observatory, or LIGO, is the culmination of a decadeslong search for signs of this elusive phenomenon — and an achievement some said is on par with the discovery of the Higgs boson, which earned its theorists a Nobel Prize in 2013.

The news exhilarated astronomers and physicists. Because the evidence of gravitational waves is captured in audio form, the finding means astronomers will now be able to hear the soundtrack of the universe and listen as violent collisions reshape the cosmos. It will be like going from silent movies to talkies, they said.

The discovery, described in a paper in Physical Review Letters, will open a new window into the universe, said David Reitze, executive director of LIGO, designed and built by researchers at the California Institute of Technology and the Massachusetts Institute of Technology.

"This was truly, I think, a

Turn to ***Discovery, Page 16***

have authority over all of the nation's youth teams.

U.S. Soccer did not return a call seeking comment. In November, it said that its recommendation came on the advice of its medical committee, though it added that "science on head injuries is still developing."

Mary Jane Bender of Illinois Youth Soccer said her group's policy change is meant to promote safety. She said the group would have done it earlier but was waiting for U.S. Soccer to clarify what should happen when a young player heads

Turn to ***Heading, Page 9***

"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

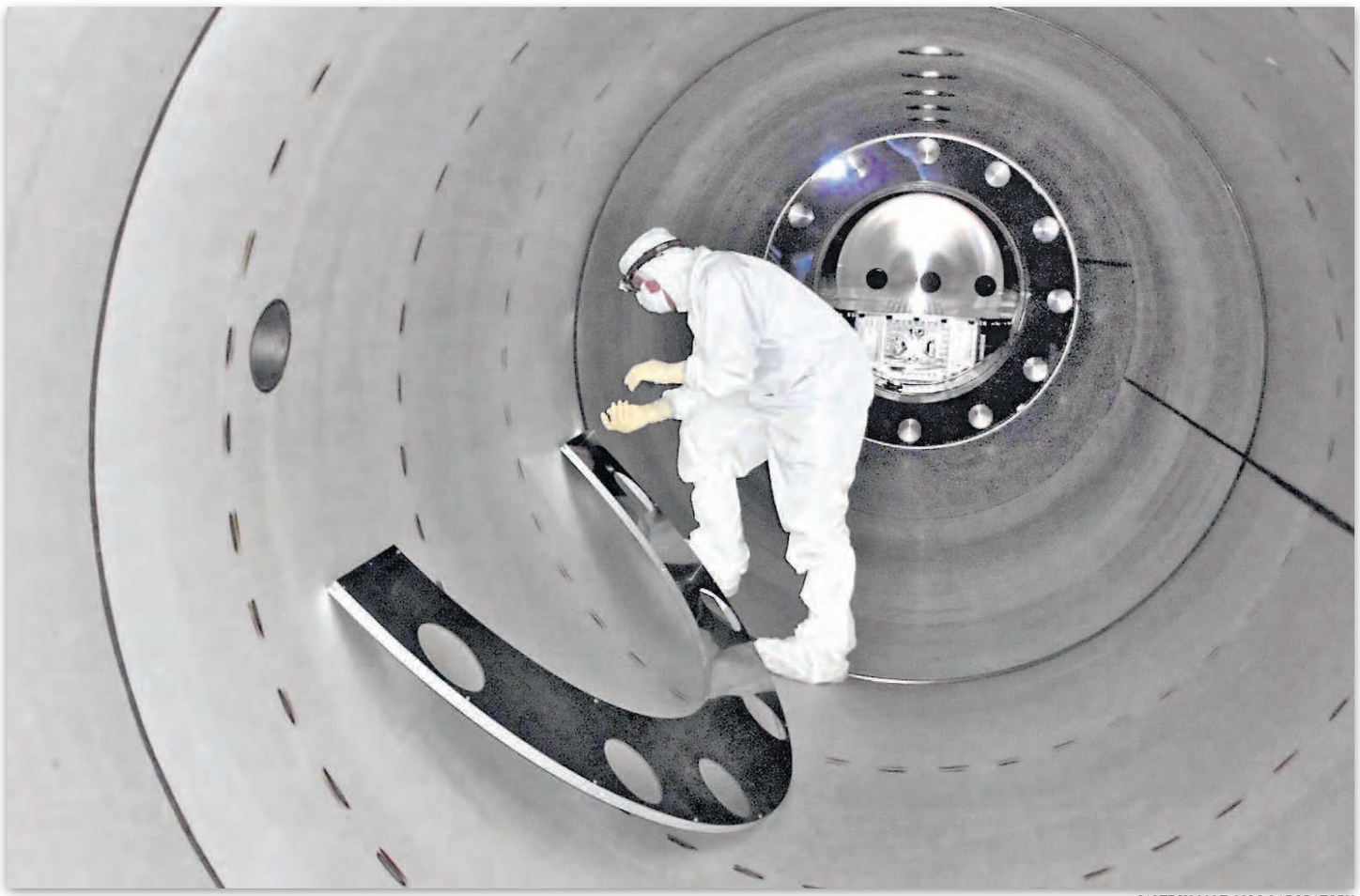
By AMY CHOZICK and PATRICK HEALY

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 South Carolina.

She is wagering that even voters excited by Mr. Sanders's inspiring message will reconsider



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

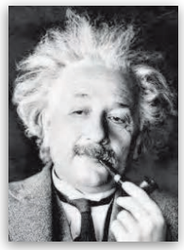
A RIPPLE IN SPACE-TIME

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.



More generally, it means that a century of innovation, testing, questioning and plain hard work after Einstein imagined it on pa-

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 absurd.

"What I'm seeing is a bunch of confusion, hearsay and foolish-

eran: Hillary Clinton."

But that was late January. In-

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 forward to the Feb. 27 Democratic contest in South Carolina, the first state where blacks will

Last Occupier In Rural Oregon Is Coaxed Out

*This article is by **Dave Seminara**, **Richard Pérez-Peña** and **Kirk Johnson.***

PRINCETON, Ore. — They im-

Los Angeles Times

$2.00 DESIGNATED AREAS HIGHER © 2016 WST FRIDAY, FEBRUARY 12, 2016 latimes.com

GINA FERAZZI Los Angeles Times

A JOSHUA TREE is backlighted by the setting sun in one of the areas given national monument status.

California desert gains 3 national monuments

BY LOUIS SAHAGUN

BARSTOW — President Obama designated three new national monuments in the California desert Thursday, expanding federal protection to 1.8 million acres of landscapes that have retained their natural beauty despite decades of heavy mining, cattle ranching and off-roading.

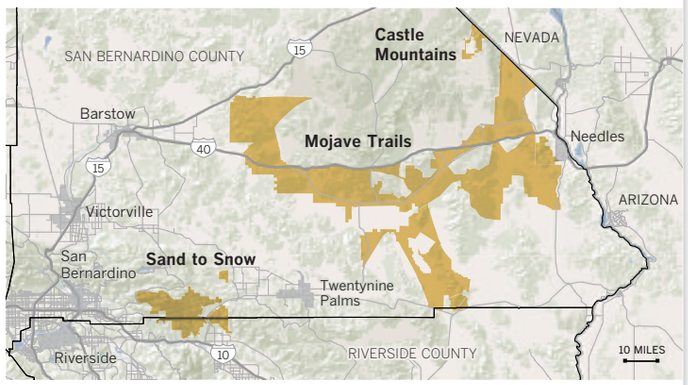
The designation was requested by U.S. Sen. Dianne Feinstein, who for a decade has sought to protect land that wasn't included in the 1994 California Desert Protection Act. That measure covered nearly 7.6 million acres, elevated Death Valley and Joshua Tree to national park status and created the Mojave National Preserve.

Unable to gain momentum on her California Desert Conservation and Recreation Act last year,

[See Monuments, A15]

National monuments designated

The White House has not released the official boundaries of the three new monuments designated Thursday by President Obama. Here are the boundaries proposed by Sen. Dianne Feinstein in 2015.



Coastal panel defends firing of its director

The secret-session ouster vote despite an outpouring of public support leaves many wanting answers.

BY TONY BARBOZA AND DAN WEIKEL

MORRO BAY, Calif. — Until Wednesday, the California Coastal Commission usually held true to its populist roots. It was born of a citizen uprising against development more than four decades ago, and over the years, the agency was known for transparency and responsiveness to public concerns.

Which explains why so many Californians feel punched in the solar plexus today.

The commission fired Charles Lester, its executive director, in a secret session Wednesday, with little public explanation, after hearing from more than 200 people who opposed his dismissal and virtually none who favored it.

"Given the long history of the commission as a unique agency created out of the initiative process and the additional sense that this is the public's commission in a way that any other state agency is not, commissioners owe the public a good explanation as to why they did what they did," said Mel Nutter, a Long Beach attorney and a member of the Coastal Commission from 1977 to 1985.

"The public thinks it's their coast, not just the coast of a few folks," Nutter said.

The commission voted 7 to 5 during its regular meeting in Morro Bay to fire Lester, the first time an executive director in its 44-year history. Panelists deliberated his fate and took the action in closed session, saying that Lester had not waived his privacy rights related to his personnel evaluations, which are confidential.

"You made a mockery of the public process when there's overwhelming support for retaining Dr. Lester," Robin Rudisill of Venice told commissioners as they continued their regular meeting Thursday. "It just felt like the decision was made long ago and no matter what happened it wasn't

[See Commission, A12]

Einstein was right: 'We can hear the universe'

Gravitational waves, theorized a century ago, detected at last.

BY AMINA KHAN

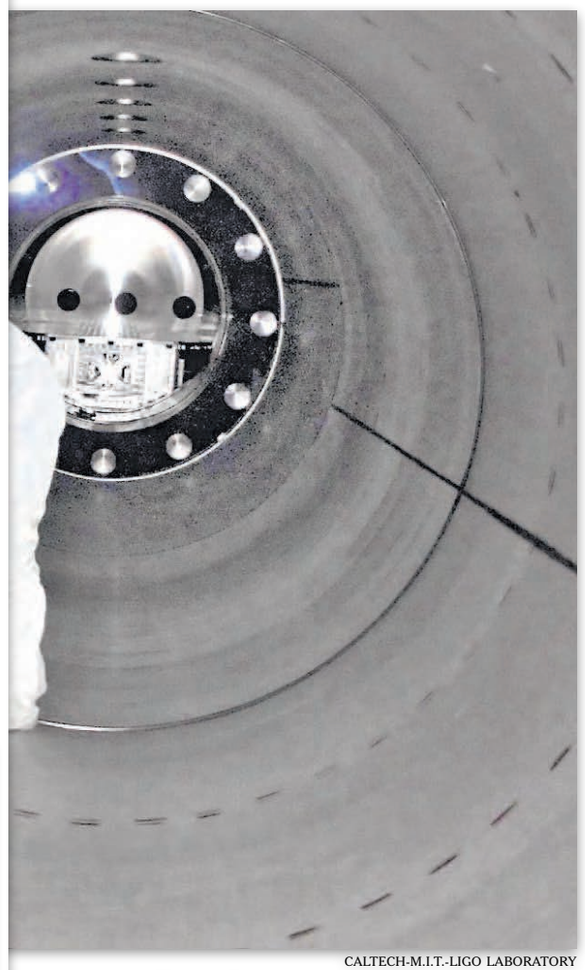
More than a billion years ago, in a galaxy far away, two black holes surrendered to one another's inexorable attraction and collided with such force that it disturbed the very fabric of the uni-

k 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.

Y 12, 2016 $2.50



CALTECH-M.I.T.-LIGO LABORATORY

Gravitational-Wave Observatory in Hanford, Wash.

WITH FAINT CHIRP, SCIENTISTS PROVE EINSTEIN CORRECT

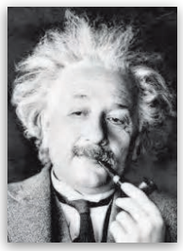
A RIPPLE IN SPACE-TIME

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.



More generally, it means that a century of innovation, testing, questioning and plain hard work after Einstein imagined it on pa-

e Sanders

e barely knew. "It eel good," she said, that young people to the elderly peo- said she was an un- and planned to do ork on Mr. Sanders. on has long looked he Feb. 27 Demo- t in South Carolina, e where blacks will

Last Occupier In Rural Oregon Is Coaxed Out

*This article is by **Dave Seminara**, **Richard Pérez-Peña** and **Kirk Johnson**.*

PRINCETON, Ore. — They im-

The Washington Post

Prices may vary in areas outside metropolitan Washington.

SU V1 V2 V3 V4

Gravitational waves Einstein foresaw are detected

BY JOEL ACHENBACH AND RACHEL FELTMAN

Scientists announced Thursday that they have succeeded in detecting gravitational waves from the violent merging of two black holes in deep space. Their work was hailed as a triumph for a controversial, exquisitely crafted, billion-dollar physics experiment and as confirmation of a key prediction of Albert Einstein's general theory of relativity.

The achievement will inaugurate a new era of astronomy, one in which gravitational waves can be tools for studying the most exotic objects in the universe, scientists proclaimed at a euphoric briefing at the National Press Club in Washington.

"Ladies and gentlemen, we have detected gravitational waves. We did it!" said David Reitze, executive director of the Laser Interferometer Gravitational-Wave Observatory

GRAVITY CONTINUED ON A8

MATT MCCLAIN/THE WASHINGTON POST

California Institute of Technology professor Kip Thorne co-founded LIGO, which detected the waves.

BY CARISSA WOLF, MARK BERMAN AND KEVIN SULLIVAN

BURNS, ORE. — The 41-day armed occupation of a remote Oregon wildlife refuge ended peacefully Thursday as the last four anti-government activists surrendered to FBI agents, following a dramatic and emotional hour-long negotiation with the final holdout broadcast live on YouTube.

After repeatedly threatening to shoot himself, complaining that he couldn't get marijuana, and ranting about UFOs, drone strikes in Pakistan, leaking nuclear plants and the government "chemically mutating people," the last occupier, David Fry, 27, lit a cigarette, shouted "Hallelujah" and walked out of his barricaded encampment into FBI custody.

Fry's surrender, which had an audience of more than 30,000 people listening live, capped an extraordinary 18 hours in which the country's growing and extreme anti-government move-

OREGON CONTINUED ON A10

Fiore, negotiator: A controversial politician helps the occupiers. **A10**

BY ANN E. MARIMOW, JUSTIN JOUVENAL AND DANA HEDGPETH

ABINGDON, MD. — Elizabeth Rupp said she always suspected that her ex-husband shot her on New Year's Eve 17 years ago. He vanished afterward, and she didn't see him again until a chance encounter at a Panera restaurant in Abingdon in December.

Rupp said the scruffy man stopped her short. He looked like David Brian Evans, but she wanted to make sure. On Wednesday, she went back and convinced herself it was him. Then she dialed 911.

The chaos that erupted next claimed the lives of two Harford County sheriff's deputies in one of the deadliest days for Maryland law enforcement in recent memory. Authorities said that Evans, 68, unexpectedly fired at them and then was killed by other deputies.

The Harford County Sheriff's Office identified the victims Thursday as Senior Deputy Patrick Dailey, a 30-year veteran, and Senior Deputy Mark Logsdon, who had been with the office for 16

SHOOTING CONTINUED ON A2

A JOS

C

3 national monuments

BY LOUIS SAHAGUN

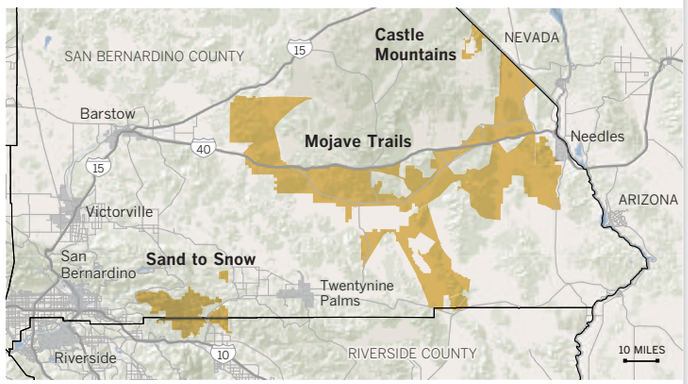
BARSTOW — President Obama designated three new national monuments in the California desert Thursday, expanding federal protection to 1.8 million acres of landscapes that have retained their natural beauty despite decades of heavy mining, cattle ranching and off-roading.

The designation was requested by U.S. Sen. Dianne Feinstein, who for a decade has sought to protect land that wasn't included in the 1994 California Desert Protection Act. That measure covered nearly 7.6 million acres, elevated Death Valley and Joshua Tree to national park status and created the Mojave National Preserve.

Unable to gain momentum on her California Desert Conservation and Recreation Act last year,

National monuments designated

The White House has not released the official boundaries of the three new monuments designated Thursday by President Obama. Here are the boundaries proposed by Sen. Dianne Feinstein in 2015.



many Californians feel punched in the solar plexus today.

The commission fired Charles Lester, its executive director, in a secret session Wednesday, with little public explanation, after hearing from more than 200 people who opposed his dismissal and virtually none who favored it.

"Given the long history of the commission as a unique agency created out of the initiative process and the additional sense that this is the public's commission in a way that any other state agency is not, commissioners owe the public a good explanation as to why they did what they did," said Mel Nutter, a Long Beach attorney and a member of the Coastal Commission from 1977 to 1985.

"The public thinks it's their coast, not just the coast of a few folks," Nutter said.

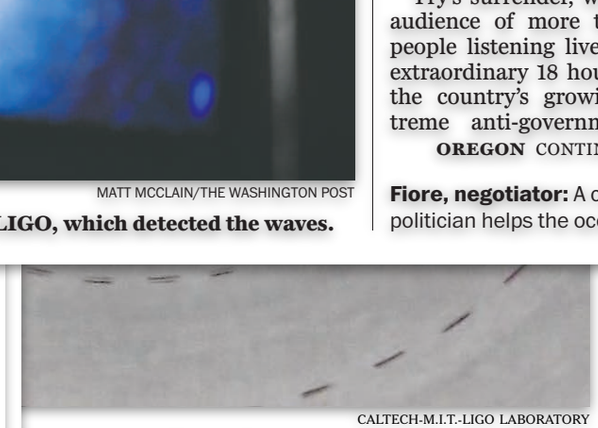
The commission voted 7 to 5 during its regular meeting in Morro Bay to fire Lester, the first time an execu-

Einstein was right: 'We can hear the universe'

Gravitational waves, theorized a century ago, detected at last.

BY AMINA KHAN

More than a billion years ago, in a galaxy far away, two black holes surrendered to one another's inexorable attraction and collided with such force that it disturbed the very fabric of the uni-



CALTECH-M.I.T.-LIGO LABORATORY

Gravitational-Wave Observatory in Hanford, Wash.

e Sanders

e barely knew. "It eel good," she said, that young people to the elderly peo- said she was an un- and planned to do ork on Mr. Sanders. n has long looked he Feb. 27 Demo- t in South Carolina, e where blacks will

Last Occupier In Rural Oregon Is Coaxed Out

*This article is by **Dave Seminara**, **Richard Pérez-Peña** and **Kirk Johnson**.*

PRINCETON, Ore. — They im-

tion

ne giving way
old, high 28. **To-**
heavier squall
ow, windy, frig-
map, Page A19.

$2.50

T CHIRP,
S PROVE
CORRECT

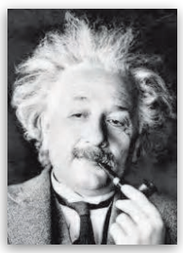
SPACE-TIME

lack Holes
Billion
s Away

VERBYE

sts announced
ney had heard
sound of two
ing a billion
fleeting chirp
t prediction of
theory of rela-

g tone, phys-icists 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.



More generally, it means that a century of innovation, testing, questioning and plain hard work after Einstein imagined it on pa-

$2.00 THE NATION'S NEWS FEBRUARY 12 - 14, 2016

USA TODAY WEEKEND

GRAVITATIONAL WAVES CONFIRMED

Gravitational waves, ripples that can be unleashed by movements of massive objects in space, travel at the speed of light through the fabric of space-time. Albert Einstein had predicted their existence in 1916.

- Two black holes swinging around each other create gravitational waves as they spiral closer together.
- Ultimately, the black holes (center of spiral) collide, releasing more gravitational waves.

ILLUSTRATION BY R. HURT, CALTECH-JPL, VIA EPA

'A WHOLE NEW WINDOW ON THE UNIVERSE'

Discovery affirms Einstein theory

Traci Watson
Special to USA TODAY

In a discovery that promises to revolutionize astronomy, scientists have made the first direct observations of gravitational waves – bizarre ripples in space time foreseen by Albert Einstein a century ago.

The find is a triumph for Einstein's celebrated general theory of relativity, the basis of his 1916 prediction that the fabric of the universe is perturbed by gravitational energy. The find is also a triumph for the mammoth scientific apparatus – the Laser Interferometer Gravitational-wave Observatory (LIGO) – that was the first to pick up the stealthy advance of these waves, in this case created by the violent union of two black holes 1.3 billion years ago.

Other scientists hailed the find as the kind of advance that comes along only once or twice in a lifetime.

Because gravitational waves carry information about their source, the ability to detect these weird undulations will allow researchers to study distant and elusive features of the universe. Black holes too far way to study using today's techniques, for example, should become easy scientific prey with the help of gravitational waves.

Study of the universe via gravitational waves "will be the astronomy of the 21st century," predicted Arizona State University's Lawrence Krauss, who is not part of the LIGO team. "This is a whole new window on the universe."

As far back as the 1970s, scientists garnered indirect evidence for such waves, spawned by the movements of massive objects in space, such as spinning supernovae or whirling pairs of neutron stars. The $1 billion LIGO directly captured the wave itself, which, if confirmed, would be "a monumental extra step," said Cole Miller of the University of Maryland, who is not affiliated with LIGO.

LIGO's twin detectors, one in Hanford, Wash., the other in Livingston, La., picked up the wave on Sept. 14, 2015 – several days before official data collection was scheduled to resume after a five-year renovation of the equipment.

The gravitational waves detected by LIGO came from the final moments before the collision of two black holes somewhere in the Southern Hemisphere.

NEWSLINE

IN NEWS

Clinton, Sanders agree systems in U.S. are broken
Sixth debate has candidates trying to win minority support.

In Japan, the girls give guys gifts on Valentine's Day

IN MONEY

MICHAEL REYNOLDS, EPA

Fed's Yellen says negative rates not 'off the table'

RUSSIA, U.S. REACH DEAL IN SYRIA WAR

Cease-fire could begin in a week, but it's far from certain

Jim Michaels
USA TODAY

Diplomats meeting in Munich agreed early Friday to implement a "cessation of hostilities" in Syria's long-running civil war and bring aid into the country to stem

---

prices may vary in areas outside metropolitan Washington.

BY ANN E. MARIMOW, JUSTIN JOUVENAL AND DANA HEDGPETH

ABINGDON, MD. — Elizabeth Rupp said she always suspected that her ex-husband shot her on New Year's Eve 17 years ago. He vanished afterward, and she didn't see him again until a chance encounter at a Panera restaurant in Abingdon in December.

Rupp said the scruffy man stopped her short. He looked like David Brian Evans, but she wanted to make sure. On Wednesday, she went back and convinced herself it was him. Then she dialed 911.

The chaos that erupted next claimed the lives of two Harford County sheriff's deputies in one of the deadliest days for Maryland law enforcement in recent memory. Authorities said that Evans, 68, unexpectedly fired at them and then was killed by other deputies.

The Harford County Sheriff's Office identified the victims Thursday as Senior Deputy Patrick Dailey, a 30-year veteran, and Senior Deputy Mark Logsdon, who had been with the office for 16

SHOOTING CONTINUED ON A2

3 national m

BY LOUIS SAHAGUN

BARSTOW — President Obama designated three new national monuments in the California desert Thursday, expanding federal protection to 1.8 million acres of landscapes that have retained their natural beauty despite decades of heavy mining, cattle ranching and off-roading.

The designation was requested by U.S. Sen. Dianne Feinstein, who for a decade has sought to protect land that wasn't included in the 1994 California Desert Protection Act. That measure covered nearly 7.6 million acres, elevated Death Valley and Joshua Tree to national park status and created the Mojave National Preserve.

Unable to gain momentum on her California Desert Conservation and Recreation Act last year,

National monu

The White House has not monuments designated T proposed by Sen. Dianne

ing in Morro Bay to fire Lester, the first time an execu-

such force that it disturbed the very fabric of the uni-

---

tion
ne giving way
ld, high 28. **To-**
heavier squall
ow, windy, frig-
map, Page A19.

$2.50

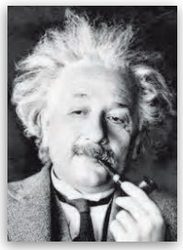
T CHIRP,
S PROVE
CORRECT

SPACE-TIME

lack Holes
Billion
s Away

VERBYE
sts announced
ney had heard
sound of two
ing a billion
fleeting chirp
t prediction of
heory of rela-

g tone, physcists 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.



More generally, it means that a century of innovation, testing, questioning and plain hard work after Einstein imagined it on pa-

D ON A10

troversial
iers. A10

LF,
N
VAN

lay armed
e Oregon
peacefully
our anti-
rendered
a dramat-
ong nego-
holdout
be.
tening to
ning that
ana, and
ne strikes
nuclear
vernment
ople," the
, 27, lit a
allelujah"
arricaded
stody.
h had an
n 30,000
apped an
in which
and ex-
t move-

$2.00 THE NATION'S NEWS FEBRUARY 12 - 14, 2016

USA TODAY WEEKEND

Frankfurter Allgemeine

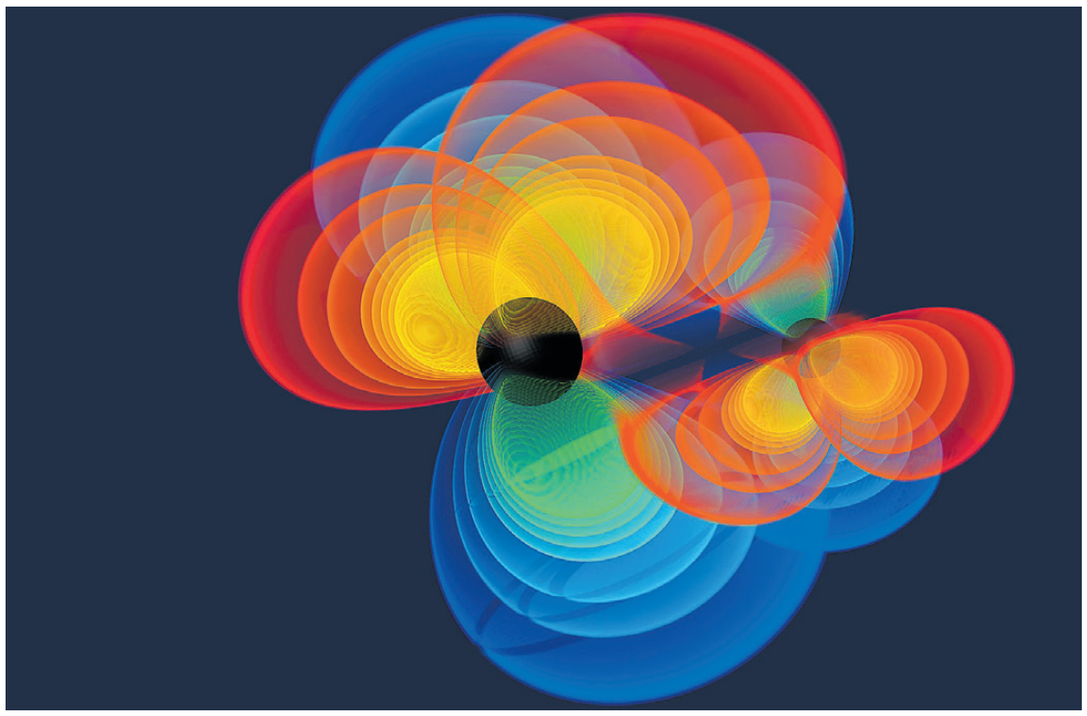
ZEITUNG FÜR DEUTSCHLAND

Freitag, 12. Februar 2016 · Nr. 36 / 6 D 3 HERAUSGEGEBEN VON WERNER D'INKA, JÜRGEN KAUBE, BERTHOLD KOHLER, HOLGER STELTZNER 2,60 € D 2954 A F.A.Z. im Internet: faz.net

Ayrault wird Außenminister Frankreichs

mic. PARIS, 11. Februar. Der französische Präsident François Hollande hat bei der Regierungsumbildung am Donnerstag die Grünen zurück an den Regierungstisch geholt. Neuer Außenminister wird Hollandes ehemaliger Premierminister Jean-Marc Ayrault. Der 66 Jahre alte Ayrault war Ende März 2014 nach der Wahlniederlage der Sozialisten bei den Kommunalwahlen zurückgetreten. Der ehemalige Deutschlehrer folgt auf Laurent Fabius, der Präsident des Verfassungsrats werden soll. Die Vorsitzende der Partei „Europa Ökologie – Die Grünen" (EELV), Emmanuelle Cosse, wird neue Wohnungsbauministerin. Der grüne Senator Jean-Vincent Placé wird Staatsminister für die Staatsreform, die grüne Abgeordnete Barbara Pompili Staatsministerin für Umwelt, Energie und das Meer. Placé und Pompili hatten die EELV im Streit verlassen. An der grünen Parteibasis ist die Regierungsbeteiligung weiter umstritten. Die bisherige Beraterin für kulturelle Angelegenheiten im Elysée-Palast, Audrey Azoulay, ersetzt die glücklose Fleur Pellerin als Kulturministerin. Umweltministerin Ségolène Royal wird künftig auch verantwortlich für internationale Klimaverhandlungen. „Es ist eine Regierung, die handeln, die reformieren, die vorankommen muss", sagte Hollande am Donnerstagabend im Fernsehen. *(Siehe Seiten 5 und 8.)*

Einstein hat wieder mal recht



Farbenspiele – Das sehen Physiker, wenn sie massereiche schwarze Löcher in ihren Computern miteinander kollidieren lassen. Denn dabei entstehen Gravitationswellen – jene winzigen Verzerrungen von Raum und Zeit, die sich mit Lichtgeschwindigkeit in alle Richtungen ausbreiten. Um den Effekt, den Albert Einstein vorhergesagt hat, besser darstellen zu können, erhalten die Wellen verschiedene Farben. Seit Donnerstag wissen die Forscher, dass sie mit ihren Simulationen richtig lagen und Einsteins Wellen tatsächlich existieren. **Seite 9** Foto AEI Potsdam

Einsteins Beben

Von Manfred Lindinger

Es ist eine Jahrhundertentdeckung in der Physik, die eine internationale Forschergruppe gestern verkündet hat. An mehreren Orten in der Welt wurden fast gleichzeitig Pressekonferenzen abgehalten, um dieses historische Ereignis auf dem Erdball zu verbreiten und gebührend zu feiern. Zu Recht, denn der Anlass ist ohne Zweifel mit der Entdeckung des Higgs-Teilchens vor vier Jahren zu vergleichen. Einer internationalen Forschergruppe ist es gelungen, erstmals „Gravitationswellen" zu messen, also jenes Beben des Raum-Zeit-Gefüges, das Albert Einstein vor fast genau hundert Jahren vorhergesagt hatte. Es wurde von zwei schwarzen Löchern ausgelöst, die in der Tiefe des Alls miteinander verschmolzen sind.

Die Entdeckung ist ein großer Erfolg für die Grundlagenforschung und ein schlagender Beweis dafür, dass der Vater der allgemeinen Relativitätstheorie mit seinen Prognosen wieder mal recht behalten hat. Einstein glaubte seinerzeit allerdings selbst nicht ernsthaft daran, dass man seine unsichtbaren Wellen jemals würde messen können. Der Effekt sei einfach viel zu winzig. Und tatsächlich haben sich Gravitationswellen, die von allen beschleunigten Körpern abgestrahlt werden – also auch von Erde und Mond –, seit fast sechzig Jahren dem direkten Nachweis erfolgreich entzogen. Es gab dank astronomischer Beobachtungen allerdings reichlich Hinweise, dass man nicht einem Hirngespinst nachjagte. Der Grund, warum das Jagdglück so lange ausgeblieben war, ist einfach: Die Instrumente der Physiker waren bislang nicht empfindlich genug, um den Effekt auch tatsächlich messen zu können. Das hat sich erst im vergangenen Jahr dank der beiden amerikanischen Ligo-Antennen geändert, die nun endlich Gravitationswellen empfangen haben. Sie wurden kräftig aufgerüstet, mit in Deutschland entwickelter Lasertechnik.

Mit dem Nachweis von Gravitationswellen hat sich auch ein neues Fenster ins Universum geöffnet. Man kann nun schwarze Löcher oder Neutronensterne beobachten, die von normalen Teleskopen nur sehr schwer erfasst werden können. Die Gravitationswellenforschung wird auch im öffentlichen Ansehen kräftigen Aufwind bekommen. Sie musste – auch hierzulande – stets mit weniger Mitteln auskommen als andere Disziplinen. Einsteins Beben in Raum und Zeit wird wohl auch hier endlich Wirkung zeigen.

Zwischen den Fronten

Von Ann-Dorit Boy

中華民國105年2月12日 農曆丙申年正月初五 星期五
United Evening News
聯合晚報
第10212號
西元2016年2月12日 編輯中心：(02)86925830 FAX：(02)86925832 客服專線：0809-080-186 廣告：(02)86926829 每份報價10元

兩岸 蔡向美表明持續馬方式 重震裳 A4

路透

美國「雷射干涉儀重力波觀察站」(LIGO)偵獲的重力波，由兩個13億光年前相撞的黑洞發出，圖為電腦擊擬。

黑洞相撞 震波傳到地球

發現旅行13億光年重力波

愛因斯坦又對了 A3

科學家首度偵獲愛因斯坦一百年前假設的宇宙重力波，立大功的是美國「雷射干涉儀重力波觀察站」(LIGO)的偵測器。 路透

震災頭七・雨和淚 A2

霍金：天文學可能發生革命性變化

【編譯彭淮棟／綜合報導】愛因斯坦又對了！美國科學家11日宣布，偵測到13億光年前黑洞併撞黑洞的活動，從而首度發現愛因斯坦一百年前在廣義相對論中假設的「重力波」(gravitational wave)；這項發現是對廣義相對論百年慶的絕佳獻禮，也為研究宇宙起源開啟新紀元。

科學家把黑洞相撞合併產生的重力波轉成音波，在記者會播放：在澎湃的其他雜音之中，有個重擊聲穿透而出，清晰可聞。

轉成音波 清晰可聞

LIGO(雷射干涉儀重力波觀察站)團隊發言人龔薩雷茲說，「這就是我一直在找的聲音」。麻省理工學院天文物理學家馬瓦拉說，這是研究天文學的新工具，「我們啟動了一種新感官，從前我們能看天文現象，現在還能用聽的」。

偵測到重力波的消息在科學界流傳數月，11日終於在華府一場記者會獲得證實。加州理工學院物理學家萊茲說：「諸位女士先生，我們偵測到重力波。我們做到了！」

13億光年前，兩個相互環繞運行的黑洞高速相撞形成一個更大的黑洞。原來的黑洞，一個是太陽質量的29倍，另一個是太陽質量的36倍。

相撞產生的波以光速旅行，去年9月14日通過地球，被守候已久的美國兩個巨型雷射偵測站偵獲。兩個偵測站，一個設在路易斯安那州，一個在華盛頓州，相隔三千公里，合稱「雷射干涉儀重力波觀察站」(LIGO)。

物理學上，「干涉」指「波」在空間中重疊時而形成新波形的現象。

LIGO與加州工學院及麻省理工學院合作，大約50年前開始測量空間-時間的延展與收縮，藉此直接追蹤重力波，數十年努力終於有成。

時空漣漪 首獲證實

兩個黑洞相撞，在時間與空間的結構中產生力道極大的風暴；在這風暴裡，時間加速，變慢，復又加速，造成空間的形狀拗扭彎曲，科學界喻之為「時空漣漪」；這整個漣漪現象，科學界理論上並未置疑，但從未獲得直接證據。

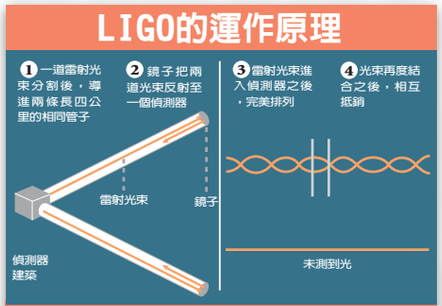
「這是科學史上重要的一刻。」英國天文物理學家霍金接受英國廣播公司（BBC）專訪時表示：「重力波提供看待宇宙的嶄新方式，發現它們的能力，可能使天文學蔚生革命性的變化。」

霍金說，這項發現是首度發現黑洞的二元系統，是首度觀察到黑洞融合，「除了檢驗（愛因斯坦的）廣義相對論，我們可以期待透過宇宙史看到黑洞，甚至可以看到宇宙大爆炸時期初期宇宙的遺跡、看到一些最大的能量。」

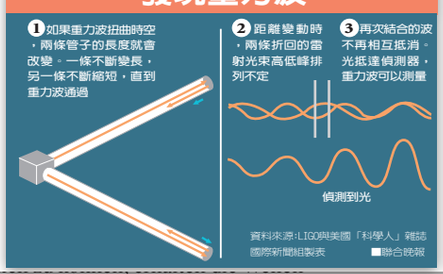
重力波以光速傳遞，無法加以阻擋；由於重力波產生的時空扭曲非常微小，在此之前科學家從未成功觀測到。

過去數十年來許多跨國科學團隊都致力於找尋重力波存在證據，但重力波對於附近時空的衝擊因距離地球太遠，弱不可見，加深觀測的難度。LIGO可偵測質子直徑萬分之一的長度變化，有10餘國一千多名科學家參與研究。

LIGO的運作原理



發現重力波



資料來源：LIGO與美國「科學人」雜誌 國際新聞組製表 聯合晚報

LIGO是兩個觀察站的合稱，其一坐落路易斯安那州。路透

Zwischen den Fronten

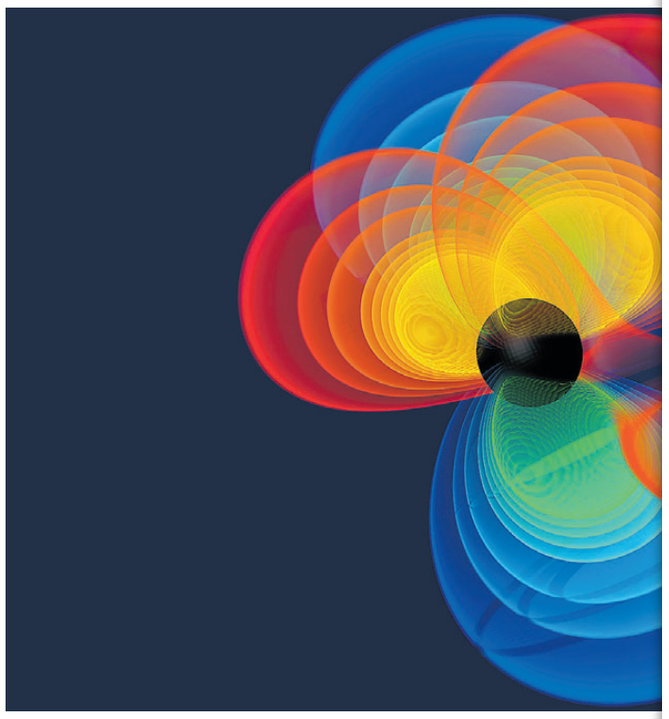
Von Ann-Dorit Boy

Freitag, 12. Februar 2016 · Nr. 36 / 6 D 3
HERAUSGEGEBEN VON WERNER D'INKA, JÜ

Ayrault wird Außenminister Frankreichs

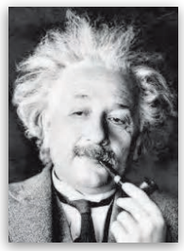
mic. PARIS, 11. Februar. Der französische Präsident François Hollande hat bei der Regierungsumbildung am Donnerstag die Grünen zurück an den Regierungstisch geholt. Neuer Außenminister wird Hollandes ehemaliger Premierminister Jean-Marc Ayrault. Der 66 Jahre alte Ayrault war Ende März 2014 nach der Wahlniederlage der Sozialisten bei den Kommunalwahlen zurückgetreten. Der ehemalige Deutschlehrer folgt auf Laurent Fabius, der Präsident des Verfassungsrats werden soll. Die Vorsitzende der Partei „Europa Ökologie – Die Grünen" (EELV), Emmanuelle Cosse, wird neue Wohnungsbauministerin. Der grüne Senator Jean-Vincent Placé wird Staatsminister für die Staatsreform, die grüne Abgeordnete Barbara Pompili Staatsministerin für Umwelt, Energie und das Meer. Placé und Pompili hatten die EELV im Streit verlassen. An der grünen Parteibasis ist die Regierungsbeteiligung weiter umstritten. Die bisherige Beraterin für kulturelle Angelegenheiten im Elysée-Palast, Audrey Azoulay, ersetzt die glücklose Fleur Pellerin als Kulturministerin. Umweltministerin Ségolène Royal wird künftig auch verantwortlich für internationale Klimaverhandlungen. „Es ist eine Regierung, die handeln, die reformieren, die vorankommen muss", sagte Hollande am Donnerstagabend im Fernsehen. *(Siehe Seiten 5 und 8.)*

Einstein hat wieder mal recht



Farbenspiele – Das sehen Physiker, wenn sie massereiche schwarze Löcher in ihren Computern miteinander kollidieren lassen. Denn dabei entstehen Gravitationswellen – jene winzigen Verzerrungen von Raum und Zeit, die sich mit Lichtgeschwindigkeit in alle Richtungen ausbreiten. Um den Eff… besser darst… verschiedene Farben. Seit Donnerstag wissen die Forscher, dass sie mit ihren Simulationen richtig lagen und Einsteins Wellen tatsächlich existieren. **Seite 9**

Foto AEI Potsdam



中華民國105年2月12日 農曆丙申年正月初五 星期五
United Evening News
聯合晚報
第10212號
西元2016年2月12日 編輯中心：(02)86925830 FAX：(02)86925832 客服專線：0809-080-186 廣告：(02)86925829 每份報價10元

兩岸 蔡向美表明持續馬方式 重震裝 A4

路透

美國「雷射干涉儀重力波觀察站」(LIGO)偵獲的重力波，由兩個13億光年前相撞的黑洞發出，圖為電腦擘擬。

黑洞相撞 震波傳到地球

發現旅行13億光年重力波

愛因斯坦又對了 A3

科學家首度偵獲愛因斯坦一百年前假設的宇宙重力波，立大功的是美國「雷射干涉儀重力波觀察站」(LIGO)的偵測器。 路透

震災頭七・雨和淚 A2

霍金：天文學可能發生革命性變化

【編譯彭淮棟／綜合報導】愛因斯坦又對了！美國科學家11日宣布，偵測到13億光年前黑洞併撞黑洞的活動，從而首度發現愛因斯坦一百年前在廣義相對論中假設的「重力波」(gravitational wave)；這項發現是對廣義相對論百年慶的絕佳獻禮，也為研究宇宙起源開啟新紀元。

科學家把黑洞相撞合併產生的重力波轉成音波，在記者會播放：在澎湃的其他雜音之中，有個重擊聲穿透而出，清晰可聞。

轉成音波 清晰可聞

LIGO(雷射干涉儀重力波觀察站)團隊發言人龔薩雷茲說，「這就是我一直在找的聲音」。麻省理工學院天文物理學家馬瓦瓦拉說，這是研究天文學的新工具，「我們啟動了一種新感官，從前我們能看天文現象，現在還能用聽的」。

偵測到重力波的消息在科學界流傳數月，11日終於在華府一場記者會獲得證實。加州理工學院物理學家萊茲說：「諸位女士先生，我們偵測到重力波。我們做到了！」

13億光年前，兩個相互環繞運行的黑洞高速相撞形成一個更大的黑洞。原來的黑洞，一個是太陽質量的29倍，另一個是太陽質量的36倍。

相撞產生的波以光速旅行，去年9月14日通過地球，被守候已久的美國兩個巨型雷射偵測站偵獲。兩個偵測站，一個設在路易斯安那州，一個在華盛頓州，相隔三千公里，合稱「雷射干涉儀重力波觀察站」(LIGO)。

物理學上，「干涉」指「波」在空間中重疊時而形成新波形的現象。

LIGO與加州工學院及麻省理工學院合作，大約50年前開始測量空間-時間的延展與收縮，藉此直接追蹤重力波，數十年努力終於有成。

時空漣漪 首獲證實

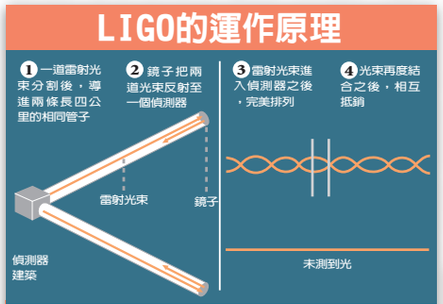
兩個黑洞相撞，在時間與空間的結構中產生力道極大的風暴；在這風暴裡，時間加速，變慢，復又加速，造成空間的形狀拗扭彎曲，科學界喻之為「時空漣漪」；這整個漣漪現象，科學界理論上並未置疑，但從未獲得直接證據。

「這是科學史上重要的一刻。」英國天文物理學家霍金接受英國廣播公司（BBC）專訪時表示：「重力波提供看待宇宙的嶄新方式，發現它們的能力，可能使天文學蛻生革命性的變化。」

霍金說，這項發現是首度發現黑洞的二元系統，是首度觀察到黑洞融合，「除了檢驗（愛因斯坦的）廣義相對論，我們可以期待透過宇宙史看到黑洞，甚至可以看到宇宙大爆炸時期初期宇宙的遺跡、看到一些最大的能量。」

重力波以光速傳遞，無法加以阻擋；由於重力波產生的時空扭曲非常微小，在此之前科學家從未成功觀測到。

過去數十年來許多跨國科學團隊都致力於找尋重力波存在證據，但重力波對於附近時空的衝擊因距離地球太遠，弱不可見，加深觀測的難度。LIGO可偵測質子直徑萬分之一的長度變化，有10餘國一千多名科學家參與研究。



Zwischen den Fronten

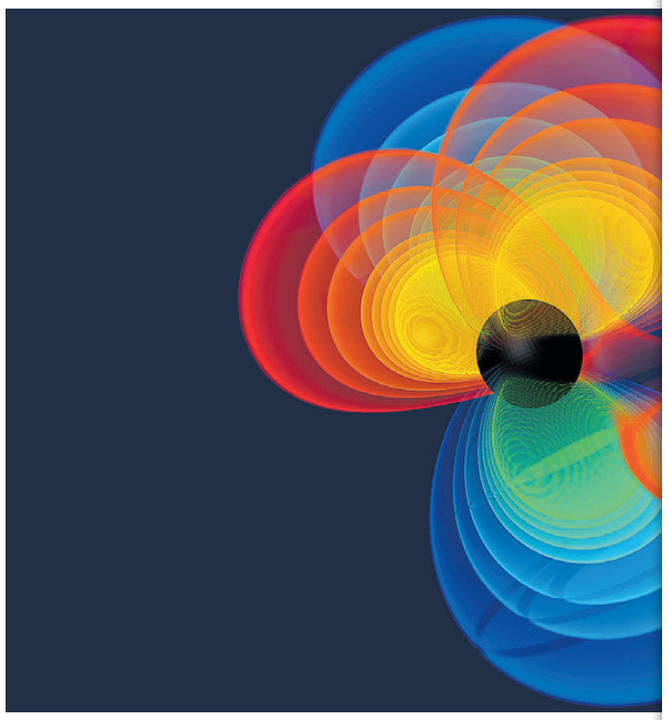
Von Ann-Dorit Boy

Frankfurter
ZEITUNG FÜ
Freitag, 12. Februar 2016 · Nr. 36 / 6 D 3
HERAUSGEGEBEN VON WERNER D'INKA, JÜ

Ayrault wird Außenminister Frankreichs

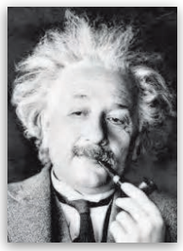
mic. PARIS, 11. Februar. Der französische Präsident François Hollande hat bei der Regierungsumbildung am Donnerstag die Grünen zurück an den Regierungstisch geholt. Neuer Außenminister wird Hollandes ehemaliger Premierminister Jean-Marc Ayrault. Der 66 Jahre alte Ayrault war Ende März 2014 nach der Wahlniederlage der Sozialisten bei den Kommunalwahlen zurückgetreten. Der ehemalige Deutschlehrer folgt auf Laurent Fabius, der Präsident des Verfassungsrats werden soll. Die Vorsitzende der Partei „Europa Ökologie – Die Grünen" (EELV), Emmanuelle Cosse, wird neue Wohnungsbauministerin. Der grüne Senator Jean-Vincent Placé wird Staatsminister für die Staatsreform, die grüne Abgeordnete Barbara Pompili Staatsministerin für Umwelt, Energie und das Meer. Placé und Pompili hatten die EELV im Streit verlassen. An der grünen Parteibasis ist die Regierungsbeteiligung weiter umstritten. Die bisherige Beraterin für kulturelle Angelegenheiten im Elysée-Palast, Audrey Azoulay, ersetzt die glücklose Fleur Pellerin als Kulturministerin. Umweltministerin Ségolène Royal wird künftig auch verantwortlich für internationale Klimaverhandlungen. „Es ist eine Regierung, die handeln, die reformieren, die vorankommen muss", sagte Hollande am Donnerstagabend im Fernsehen. *(Siehe Seiten 5 und 8.)*

Einstein hat wieder mal recht

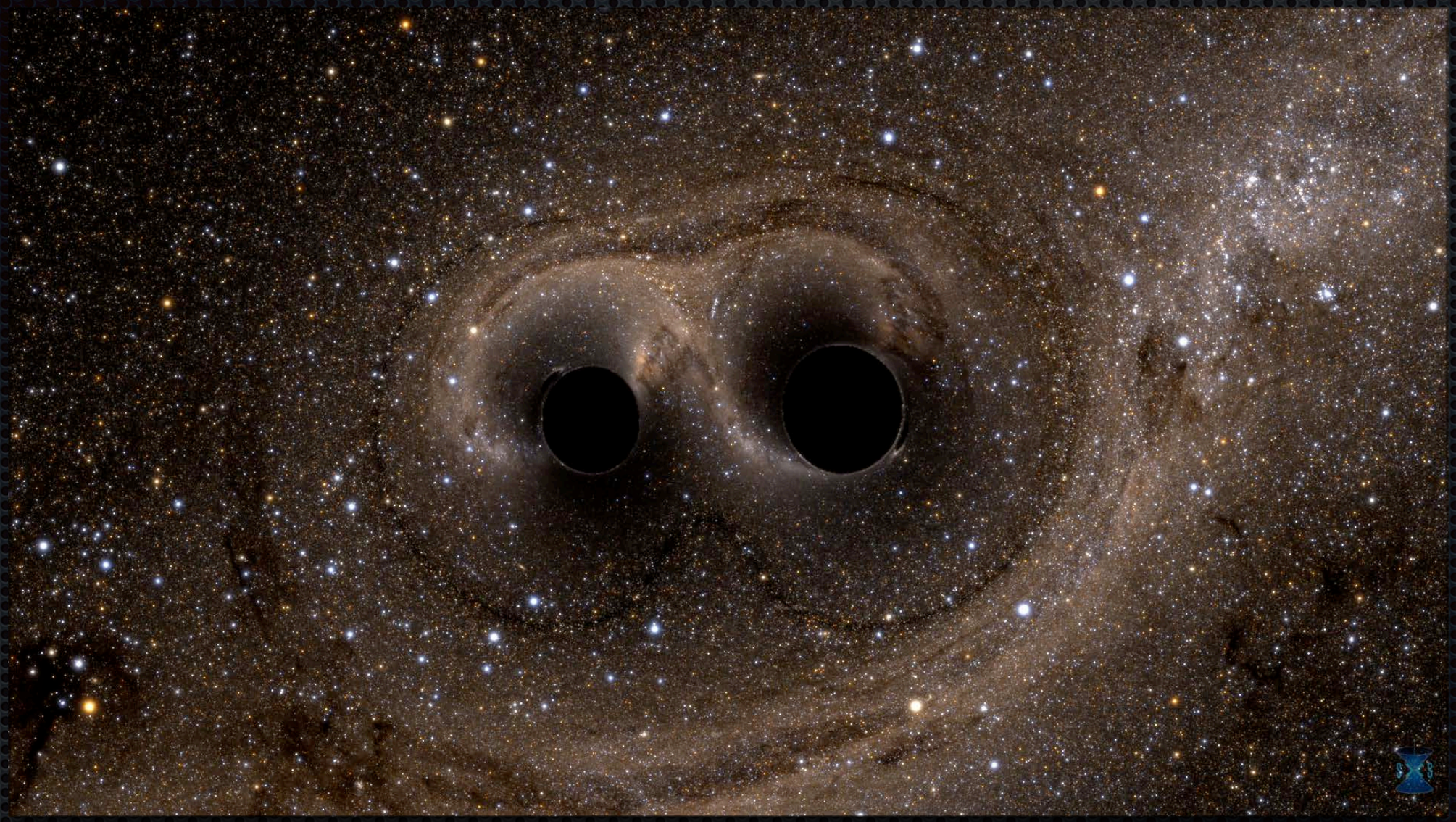


Farbenspiele – Das sehen Physiker, wenn sie massereiche schwarze Löcher in ihren Computern miteinander kollidieren lassen. Denn dabei entstehen Gravitationswellen – jene winzigen Verzerrungen von Raum und Zeit, die sich mit Lichtgeschwindigkeit in alle Richtungen ausbreiten. Um den Effe… besser darst… verschiedene Farben. Seit Donnerstag wissen die Forscher, dass sie mit ihren Simulationen richtig lagen und Einsteins Wellen tatsächlich existieren. **Seite 9**

Foto AEI Potsdam

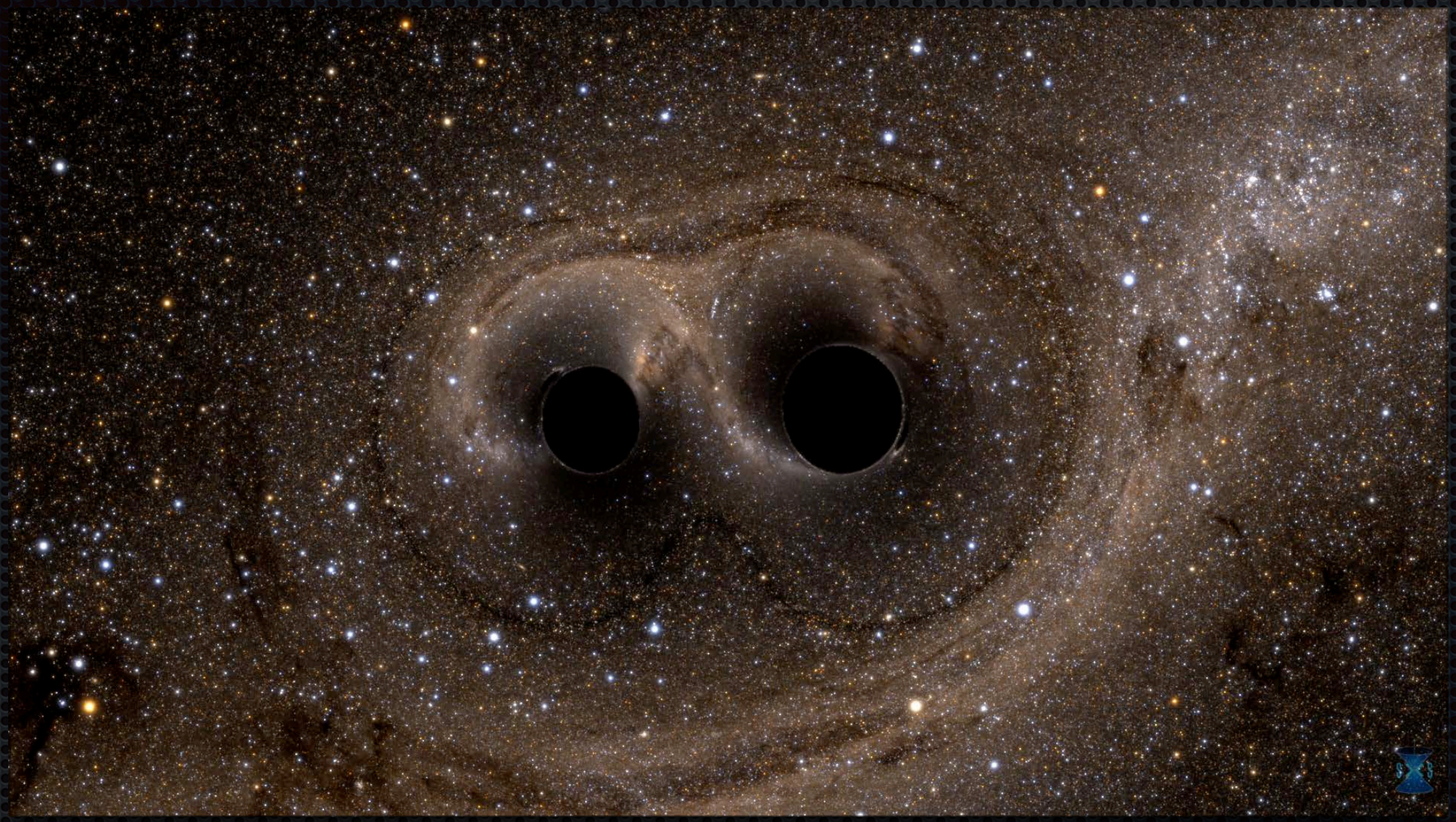


Why is this important?

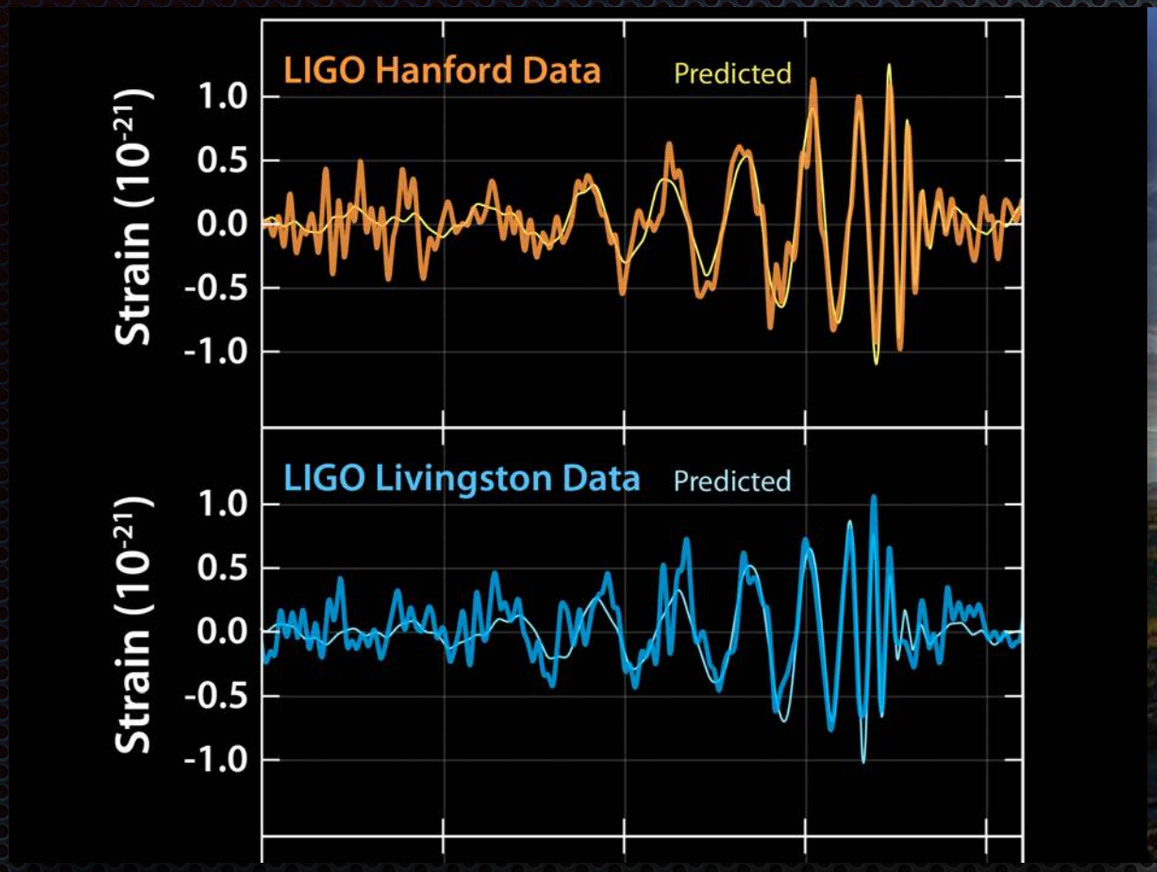


- Einstein was right
- Black holes exist
- A whole new way to “listen” to the Universe!

Why is this important?



- Einstein was right
- Black holes exist
- A whole new way to “listen” to the Universe!



We've opened a new window.
These two black holes are just the very first glimpse!