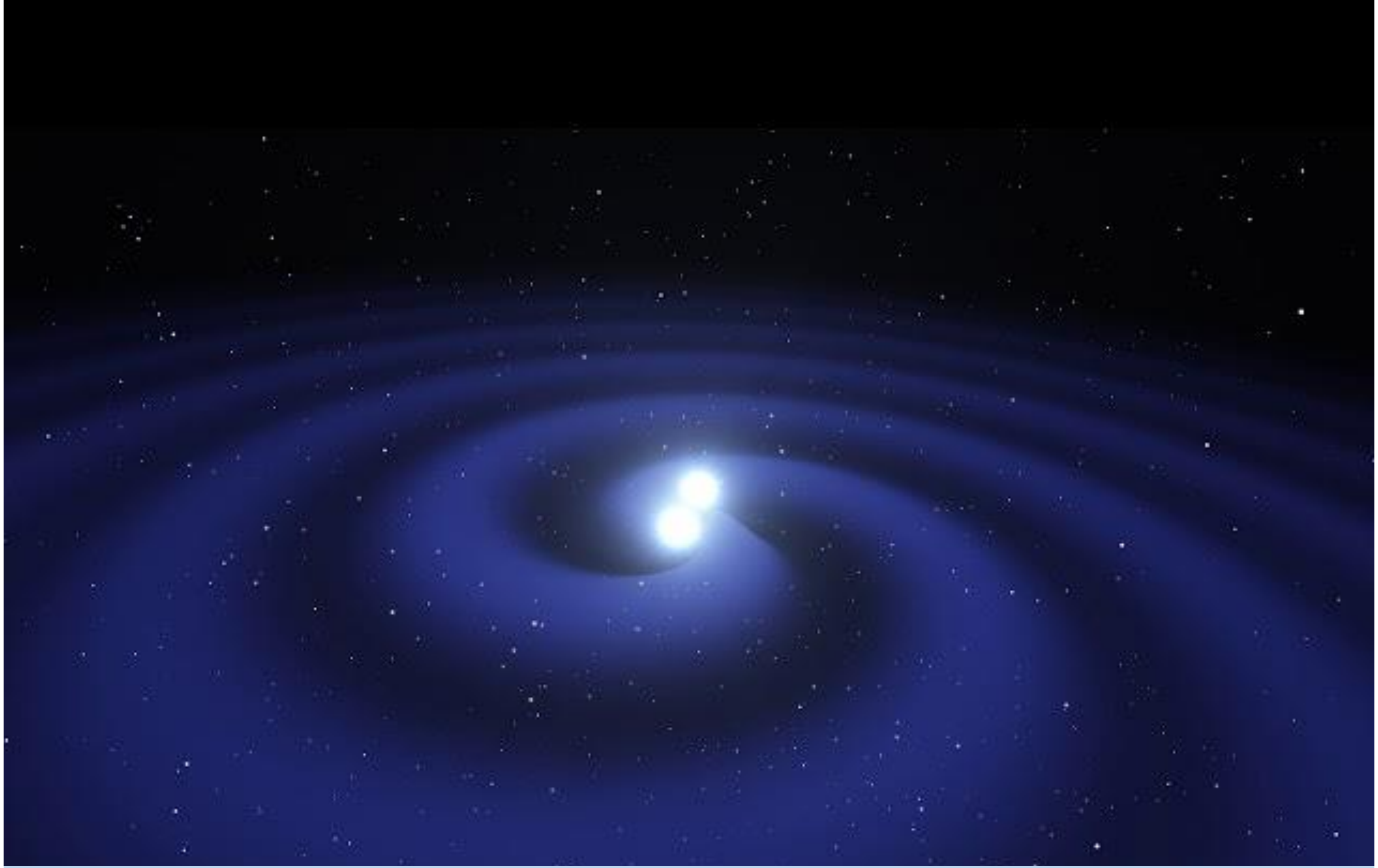


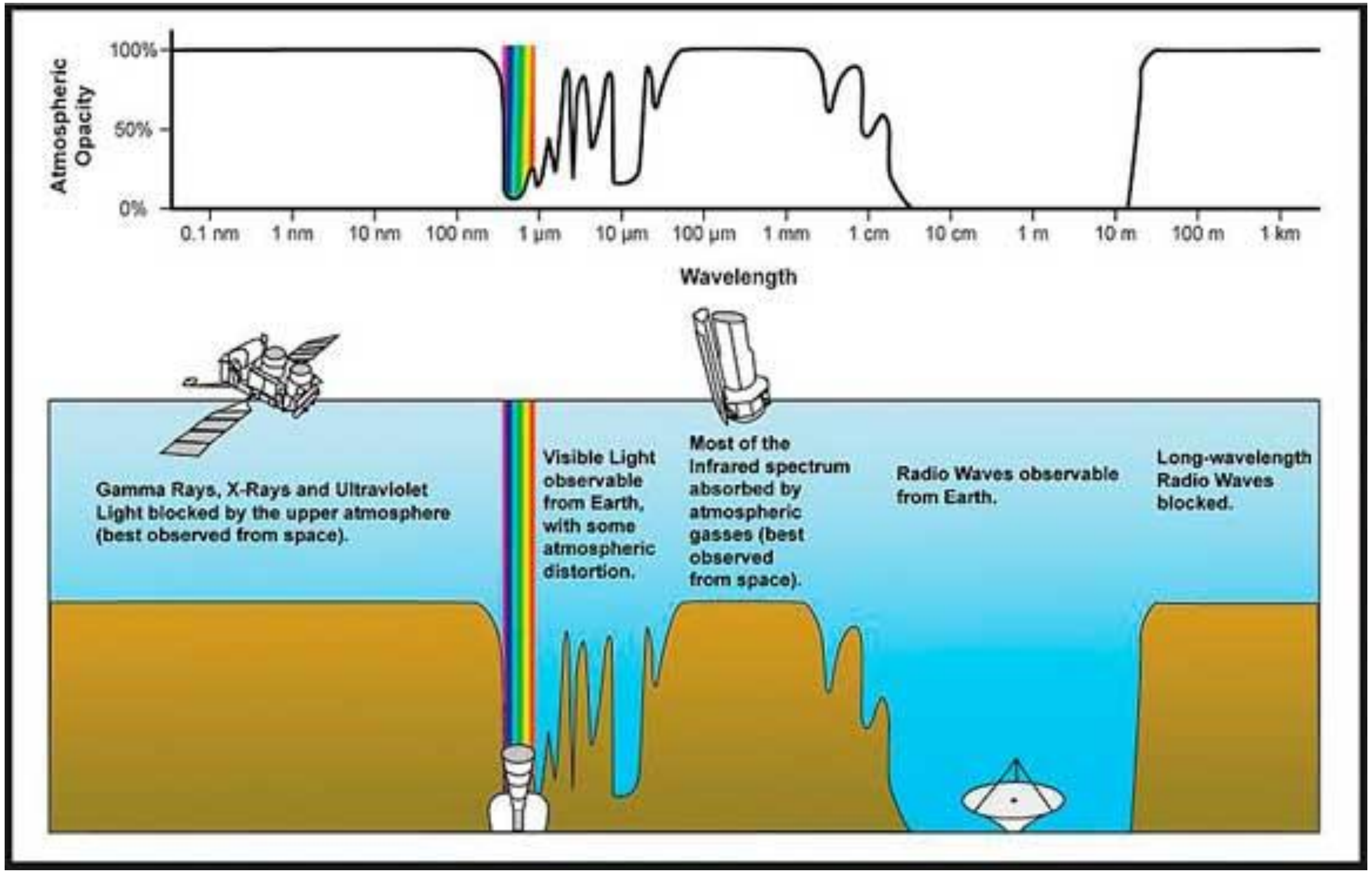
# Astronomia XXI wieku – czarne dziury, ciemna energia, ciemna materia

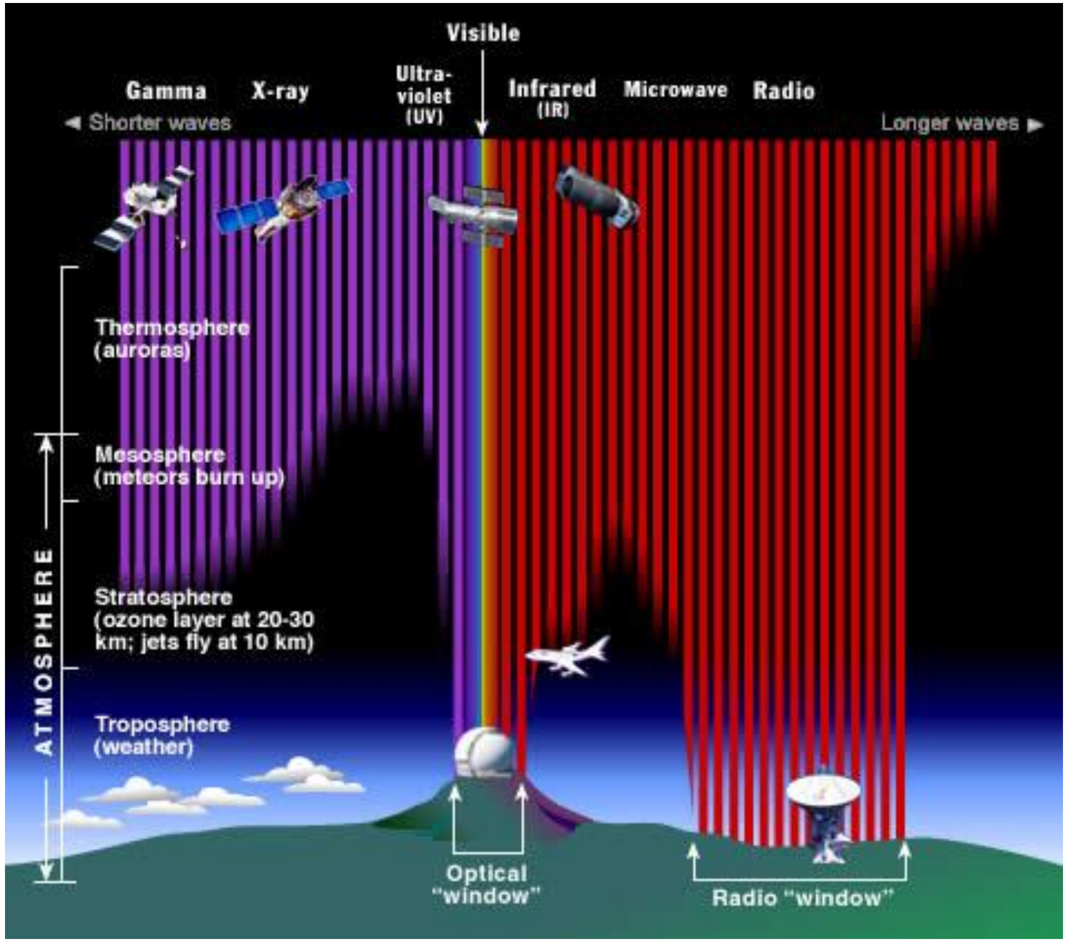
Plan prezentacji:

- Astronomia fal elektromagnetycznych
- Astronomia fal grawitacyjnych
- Astronomia neutrinowa

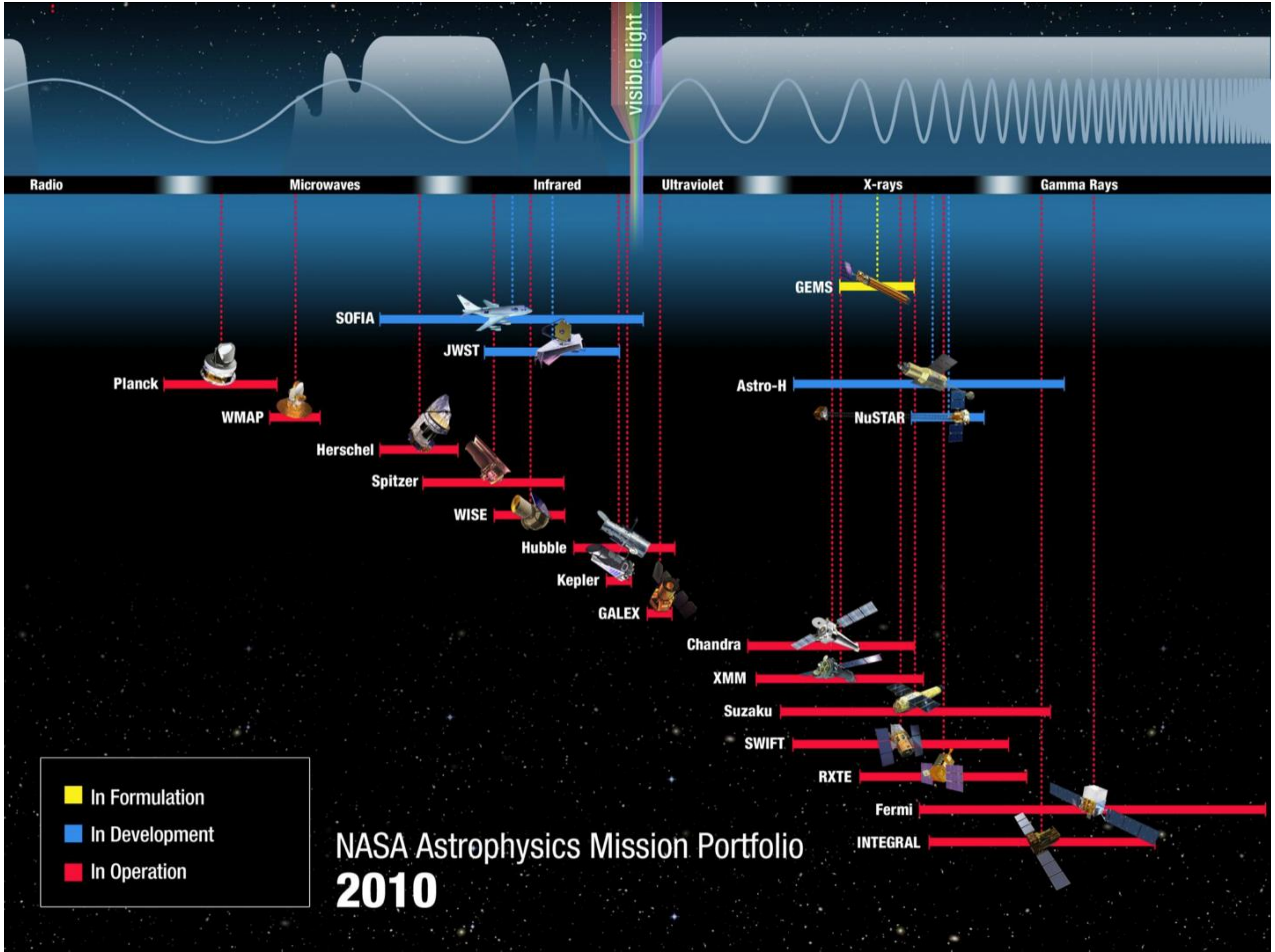
- Planety pozasłoneczne
- Ewolucja gwiazd – gwiazdy neutronowe, czarne dziury
- Kosmologia – ciemna energia, ciemna materia

# Rola atmosfery Ziemi w obserwacjach astronomicznych





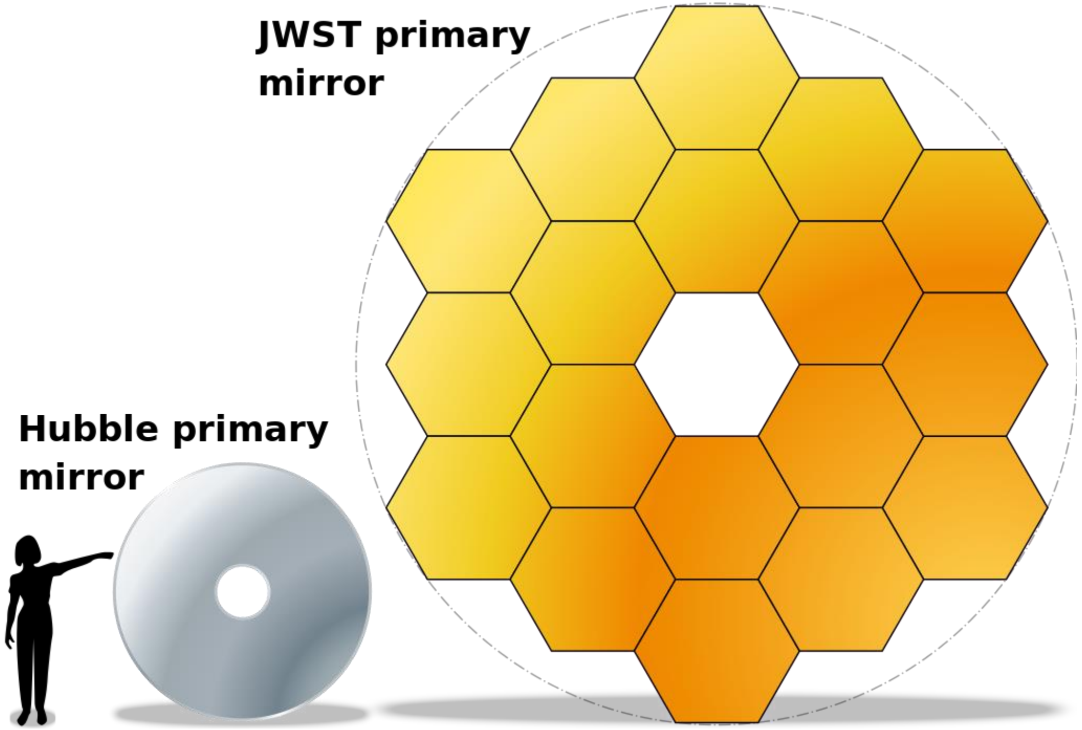
# Obserwatoria kosmiczne (pozatmosferyczne)



# Hubble Space Telescope

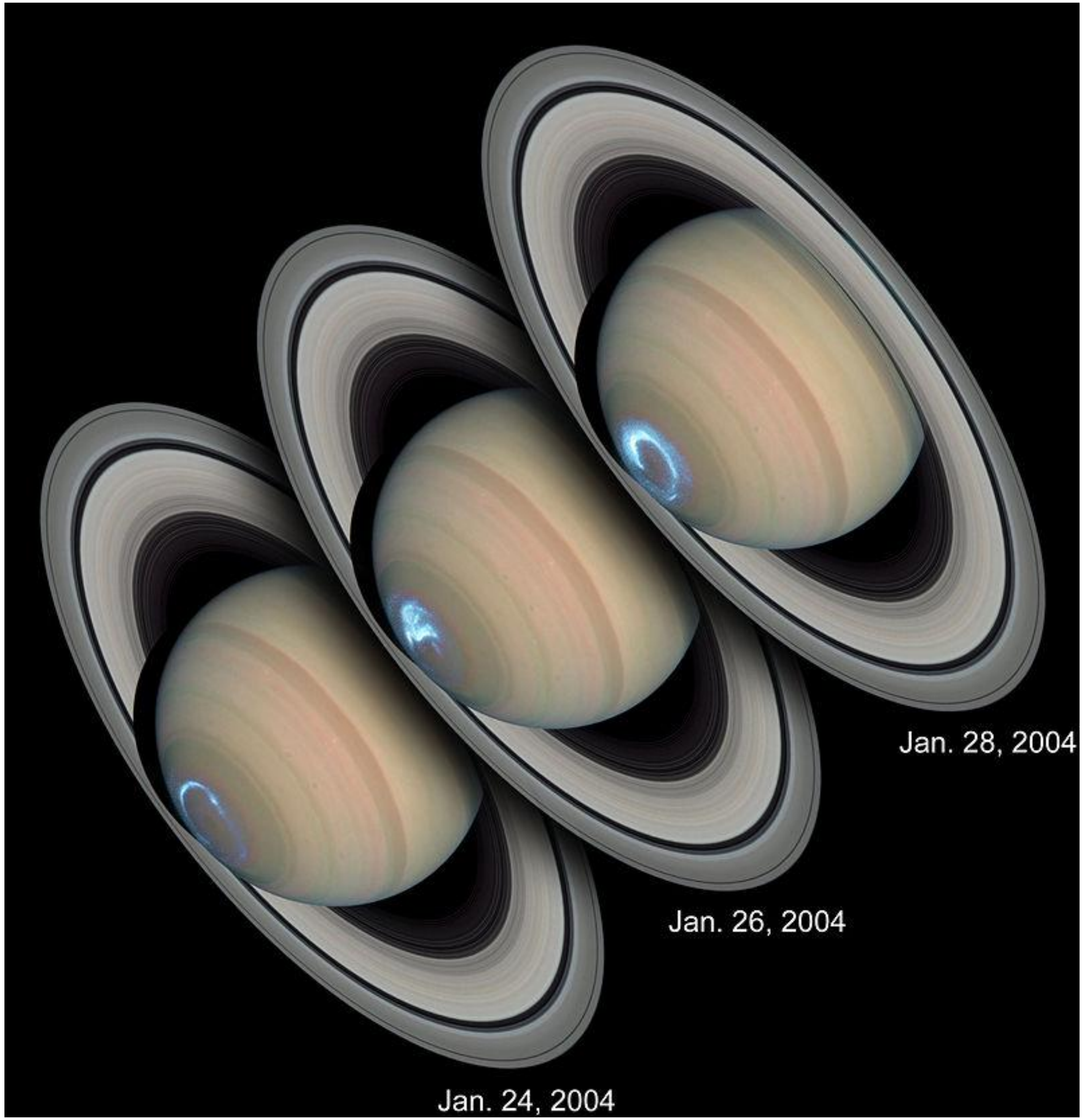
24 kwietnia 1990 umieszczony na orbicie (545 km nad Ziemią)

| | |
|---|---|
| Średnica | 2.4 m |
| Ogniskowa | 57.6 m |
| Focal ratio | $f/24$ |
| Powierchnia | 4.5 m$^2$ |



# Hubble Space Telescope

A pillar of gas and dust in the Carina Nebula



Saturn's southern aurora.

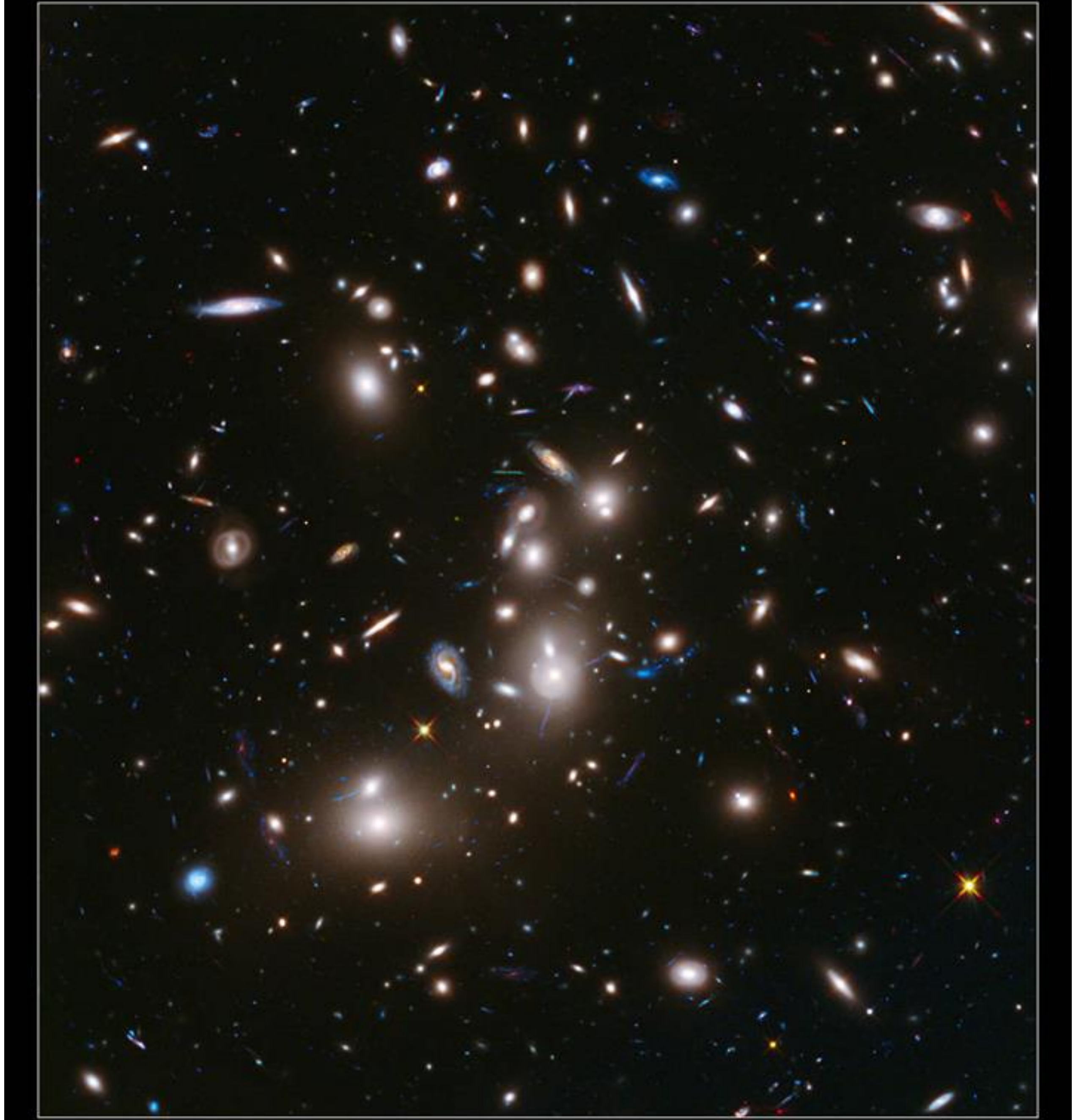
# Hubble Space Telescope

Stars forming in the Eagle Nebula

Star cluster Pismis 24 with nebula

**Hubble Frontier Field Abell 2744**

*Hubble Space Telescope* • ACS • WFC3

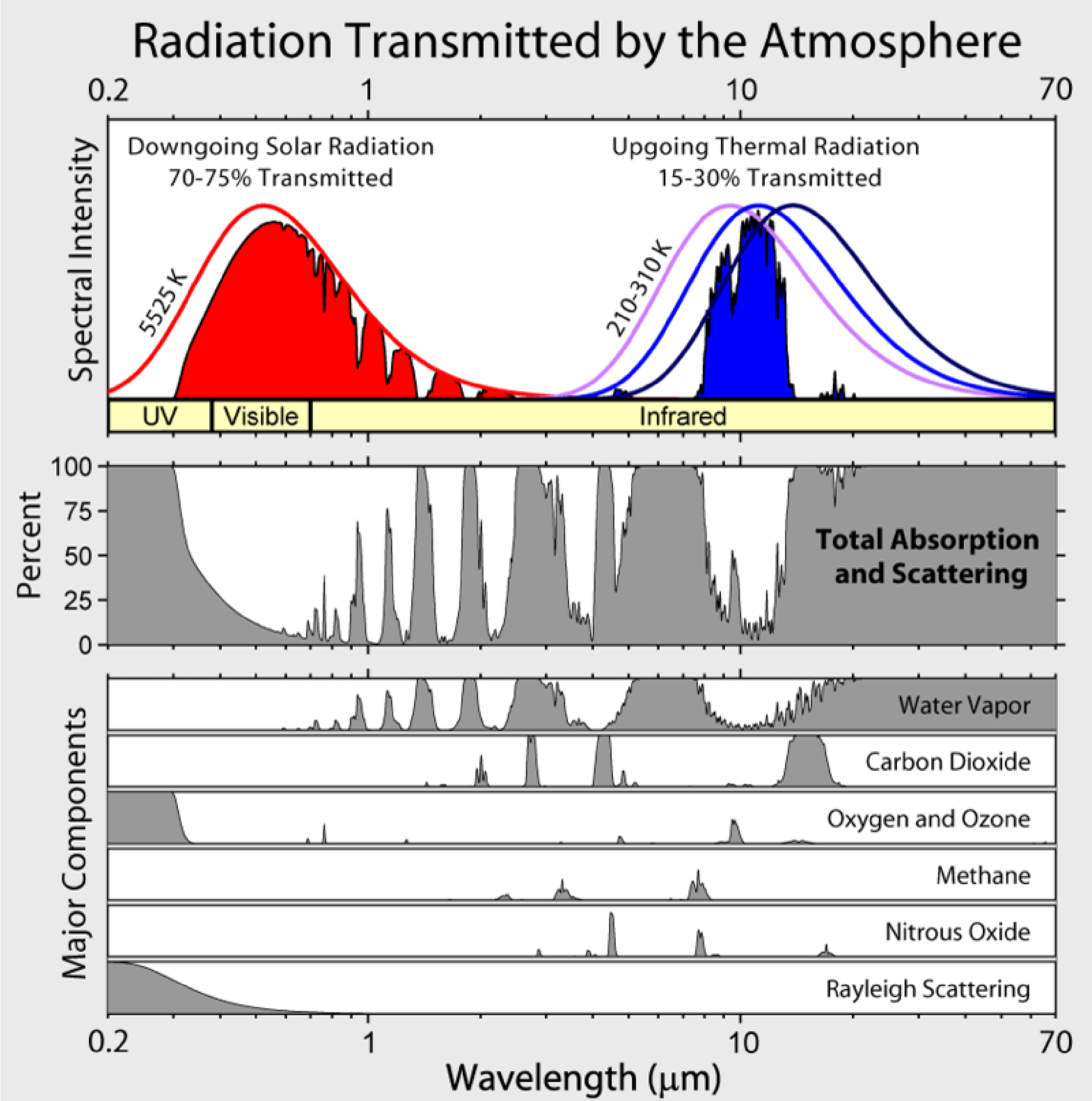


NASA and ESA

STScI-PRC14-01a

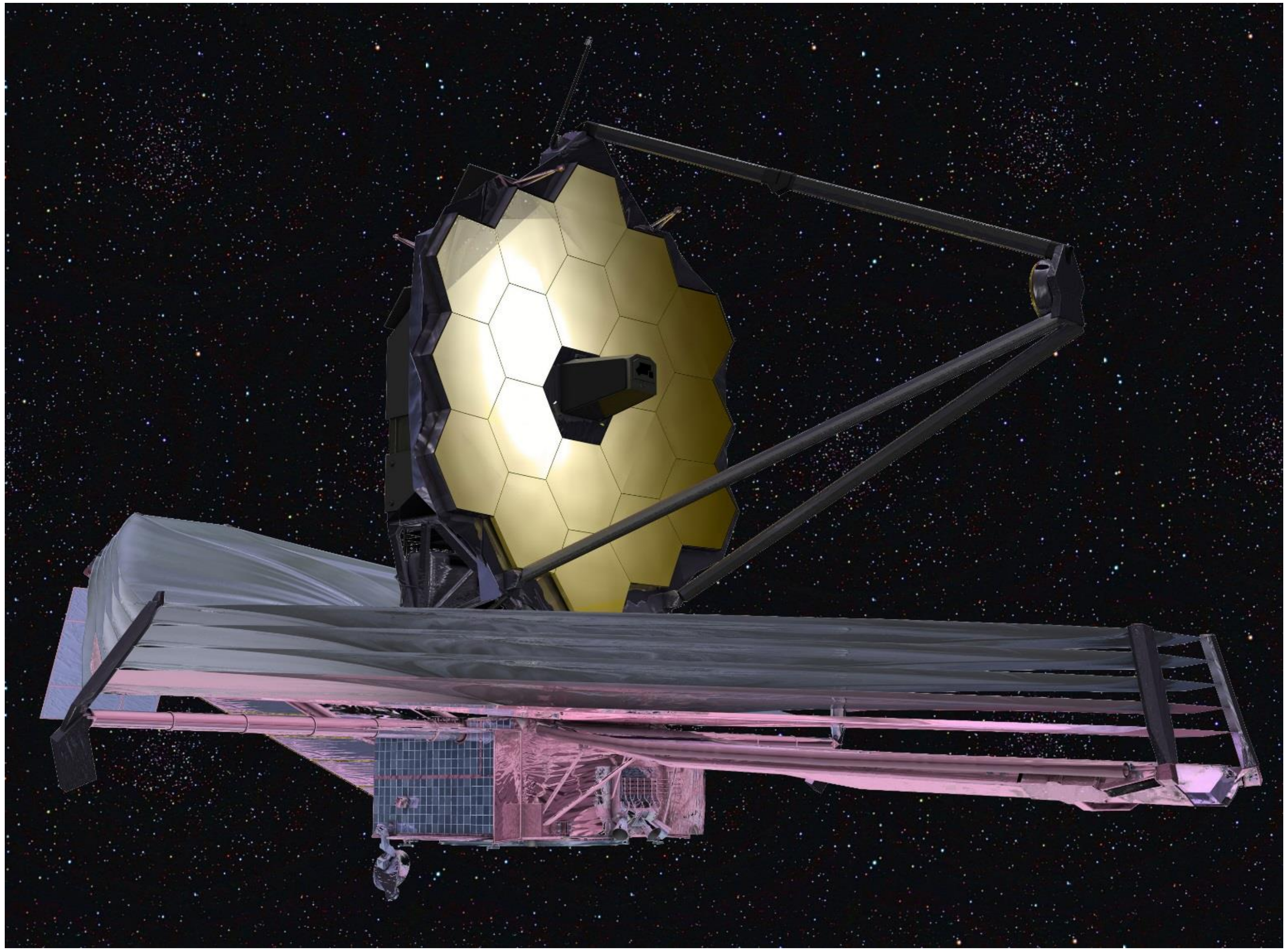
Gromada galaktyk
(zdjęcie wykonane przez teleskop Hubble’a)

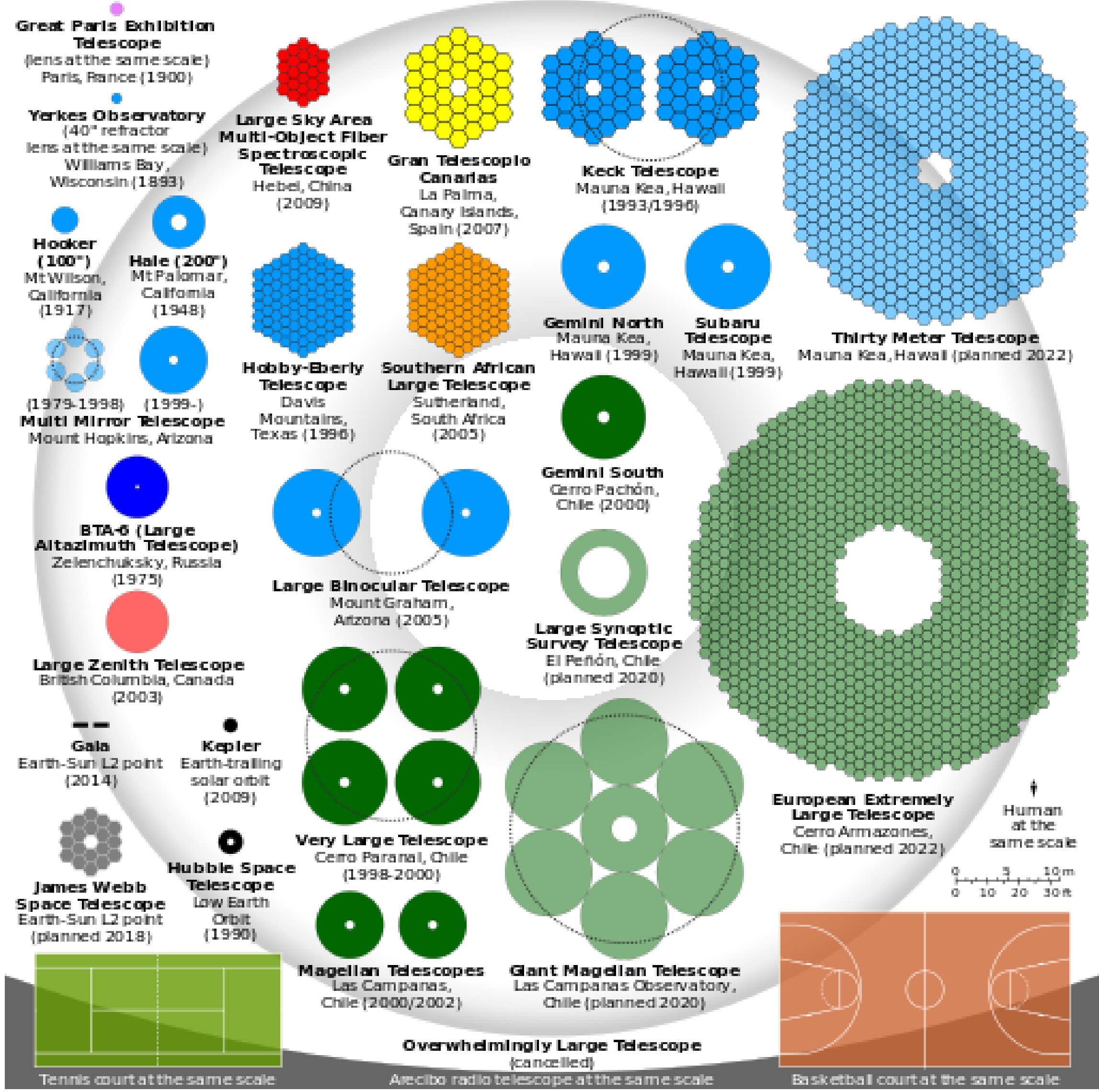
# James Webb Space Telescope



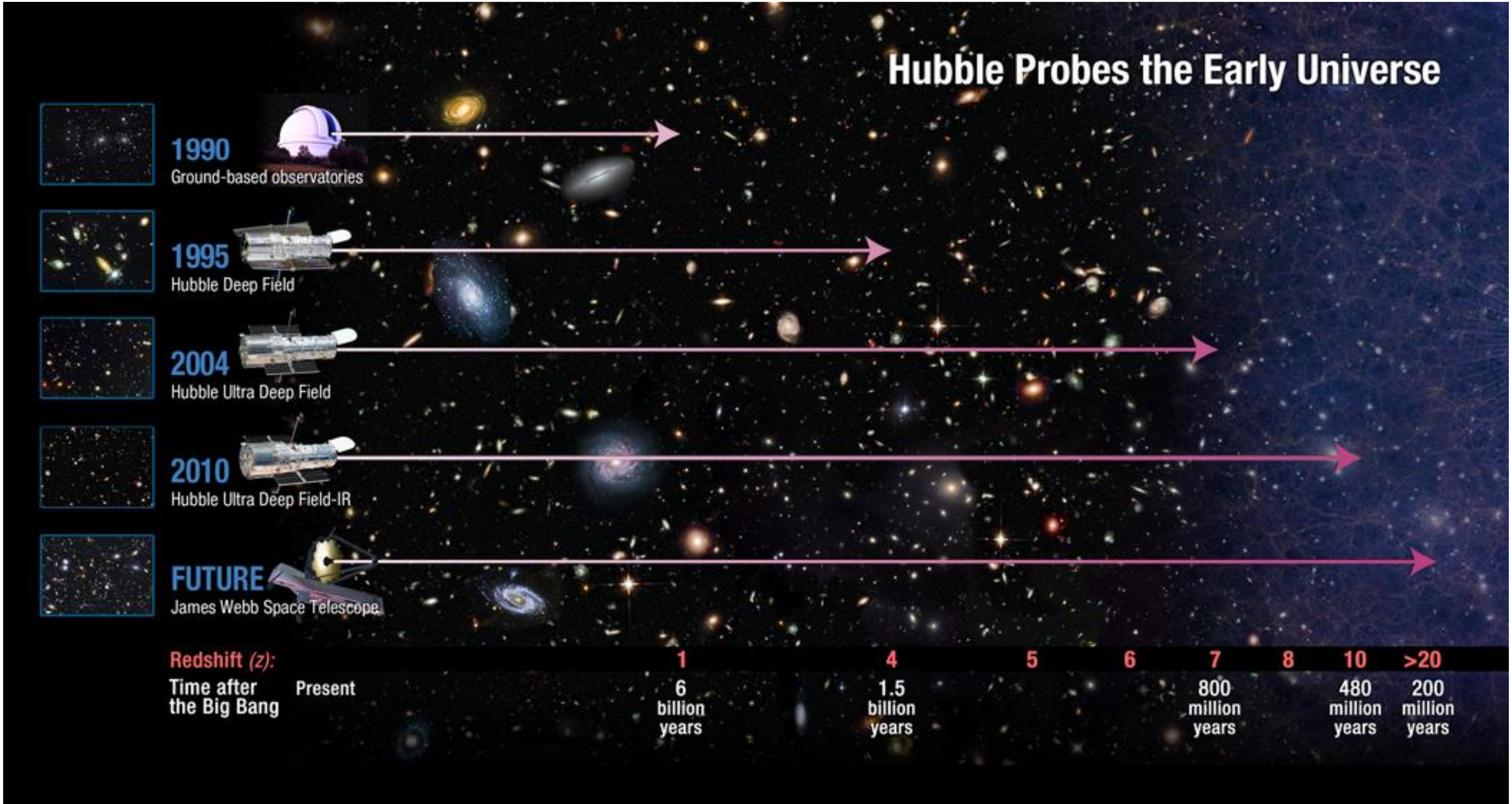
| | |
|---|---|
| Diameter | 6.5 m (21 ft) |
| Focal length | 131.4 m (431 ft) |
| Collecting area | 25 $m^2$ (270 sq ft) |

# James Webb Space Telescope





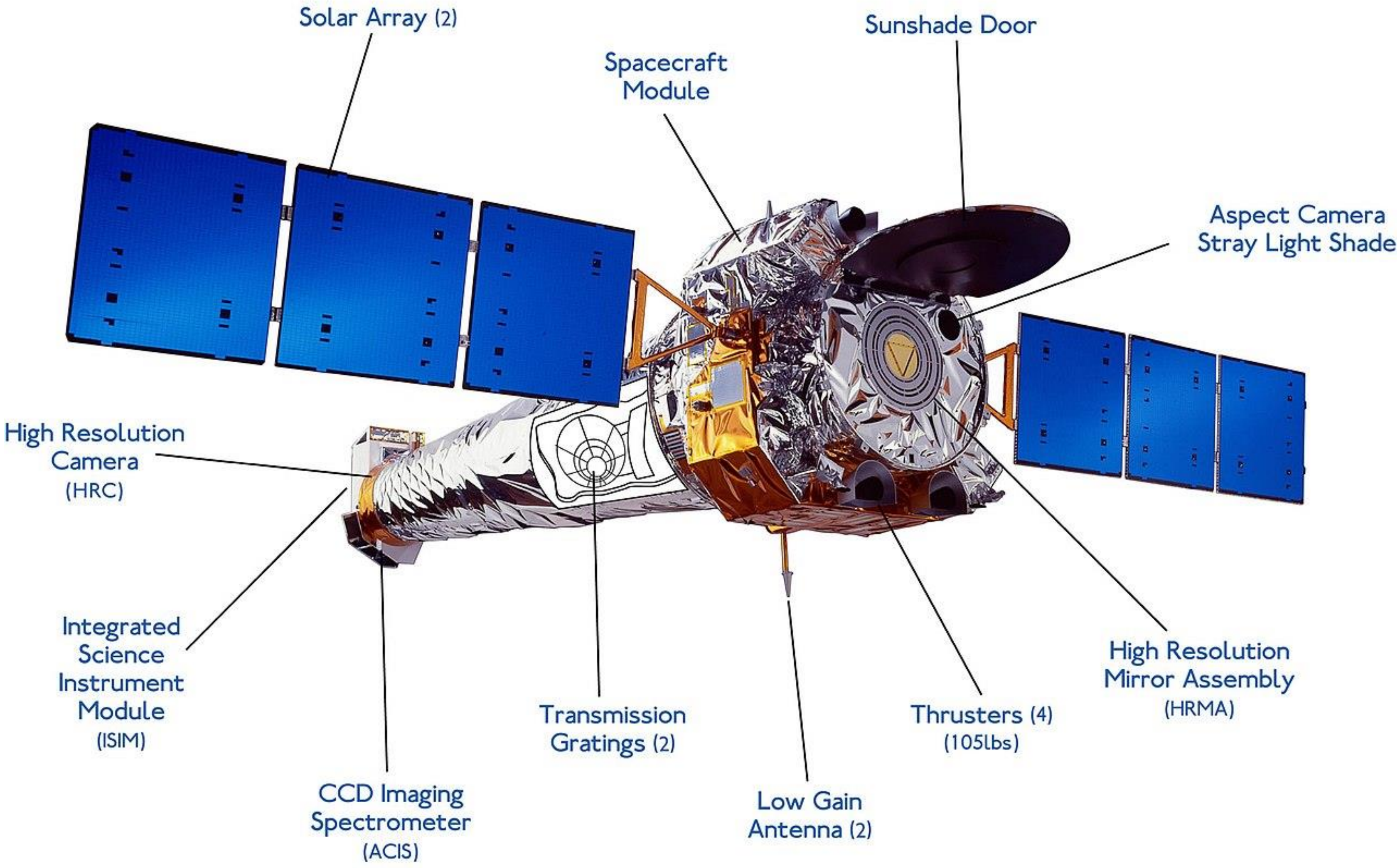
# Jak dalekie obiekty kosmiczne można zobaczyć teleskopami optycznymi ?



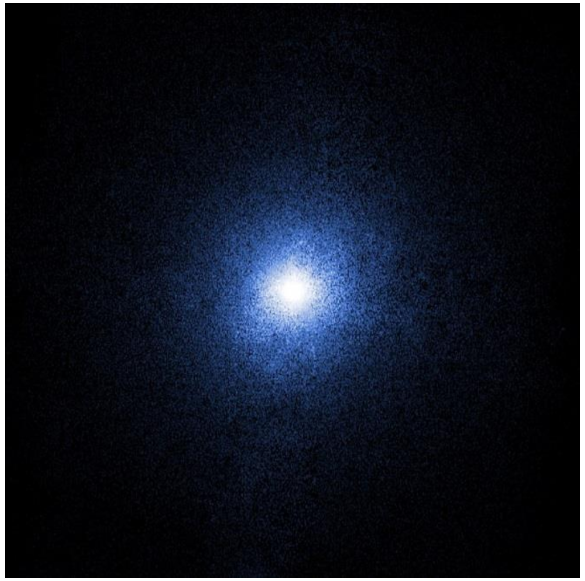
# Chandra X-ray Observatory

Wystrzelone 23 lipca 1999

λ = (0.12 – 12) nm



X-ray flare from Sagittarius A*, supermassive black hole in the Milky Way

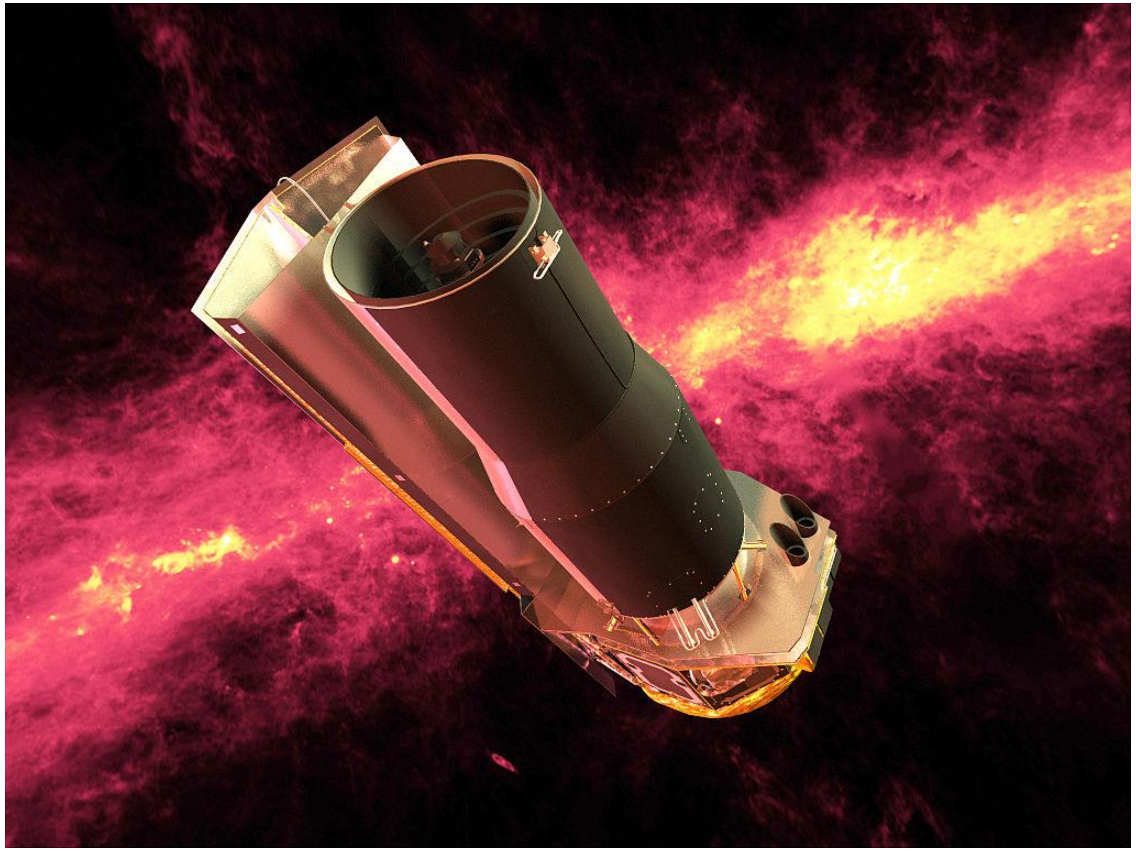


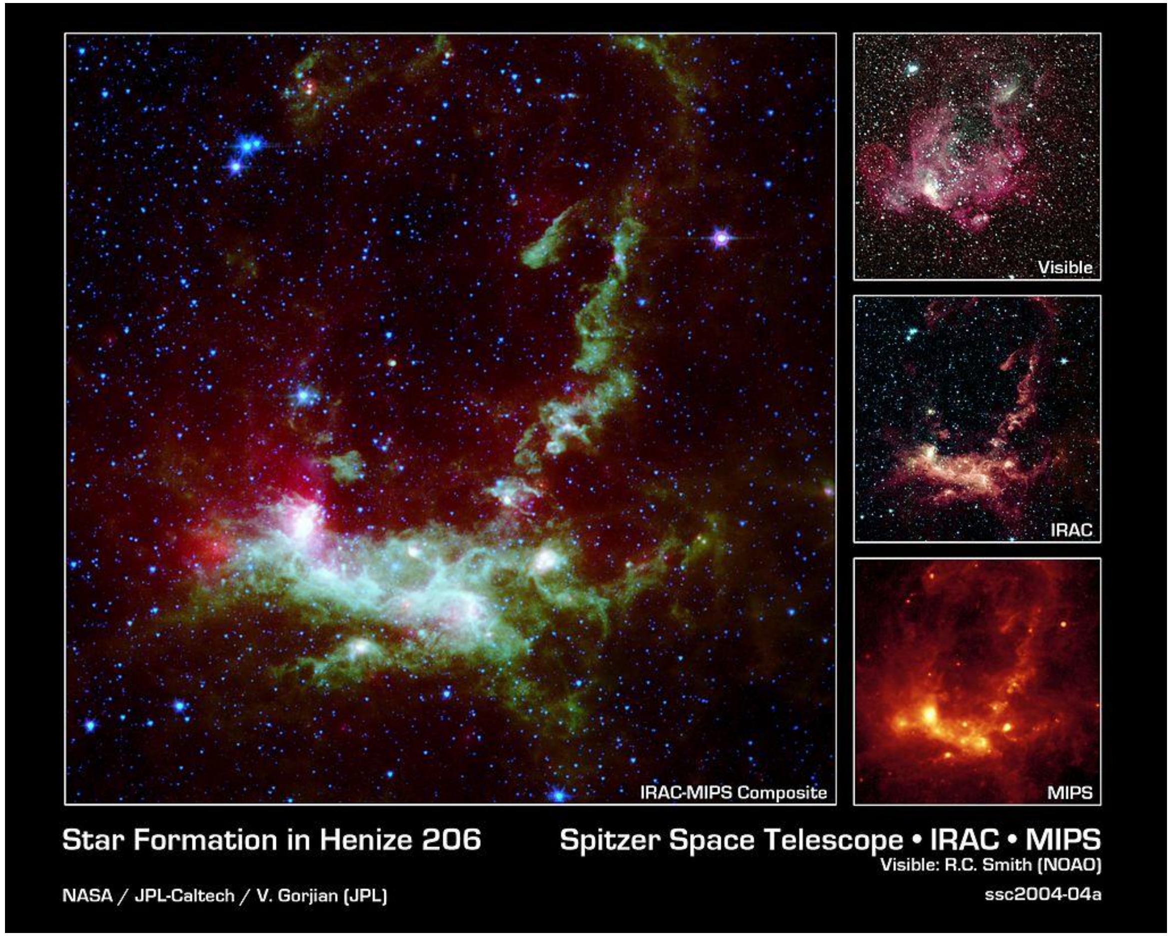
Cygnus X-1, first strong black hole discovered

# Spitzer Space Telescope

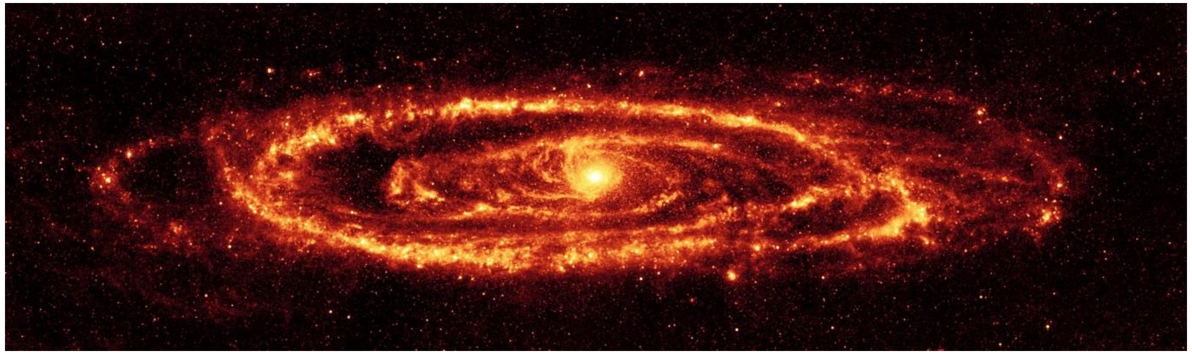
Wystrzelony 25 sierpień 2003

| | |
|---|---|
| Diameter | 0.85 m (2.8 ft)[1] |
| Focal length | 10.2 m (33 ft) |
| Wavelengths | infrared, 3.6–160 µm |





The Andromeda Galaxy taken by MIPS at 24 micrometers



## Co to są fale grawitacyjne

- Fala to zaburzenie, które się propaguje.

Co jest zaburzane w wyniku propagacji fali grawitacyjnej?

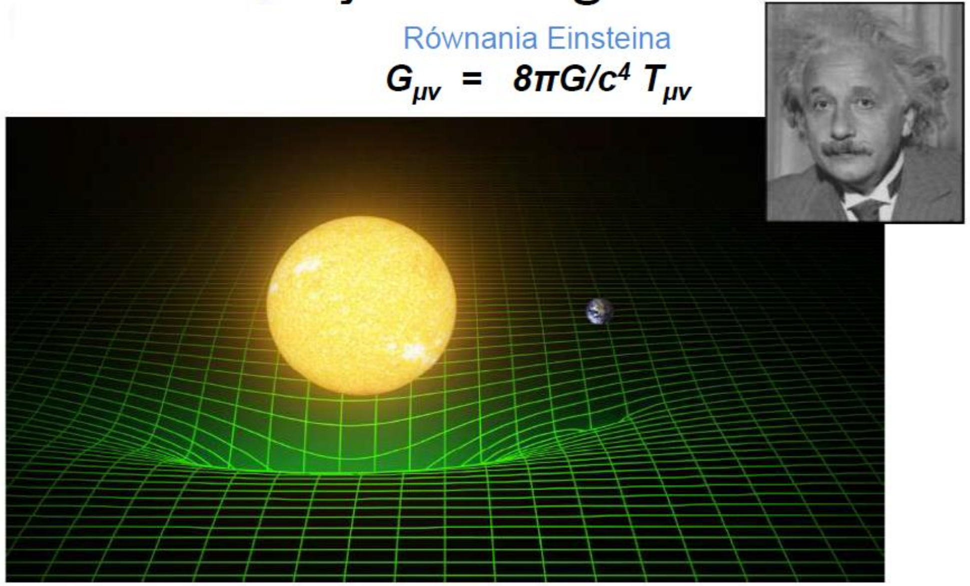
Courtesy: Prof. Andrew Davidhazy -

**Czasoprzestrzeń!**

## Grawitacja według Einsteina

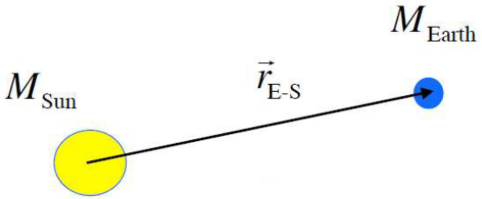
Równania Einsteina

$$G_{\mu\nu} = 8\pi G/c^4\, T_{\mu\nu}$$



**John Wheeler**: **Materia mówi czasoprzestrzeni jak się zakrzywiać,**

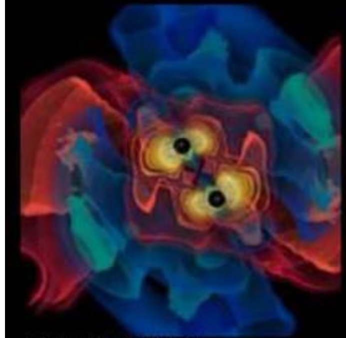
## Grawitacja według Newtona



- Działanie na odległość:

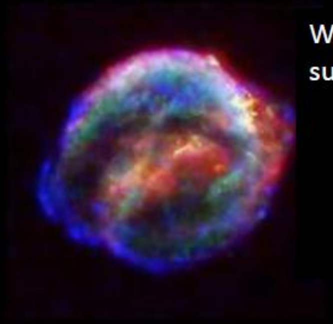
$$\vec{F}_{\text{On Earth}} = -\frac{G M_{\text{Sun}} M_{\text{Earth}}}{r^2_{\text{E-S}}}\,\hat{r}_{\text{E-S}}$$

## Źródła fal grawitacyjnych

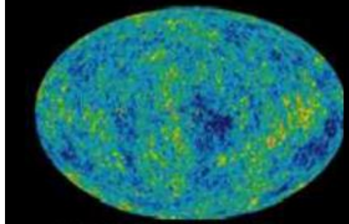


Credit: AEI, CCT, LSU

Zlewanie układów podwójnych gwiazd – np. gwiazd neutronowych, czarnych dziur



Wybuchy gwiazd supernowych

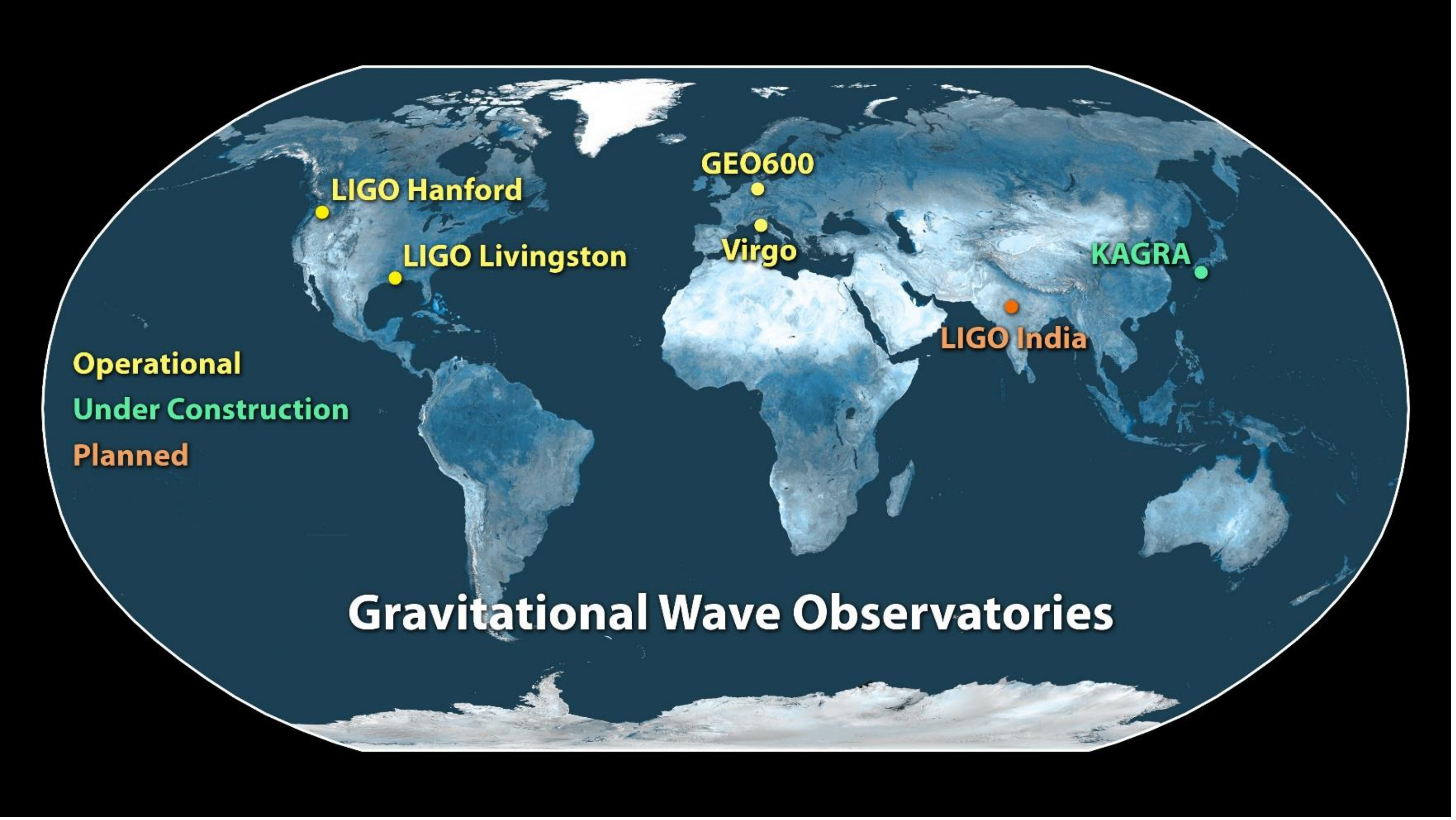


NASA/WMAP Science Team

Stochastyczne promieniowanie tła powstałe po wielkim wybuchu

Casey Reed, Penn State

Rotujące gwiazdy neutronowe – pulsary



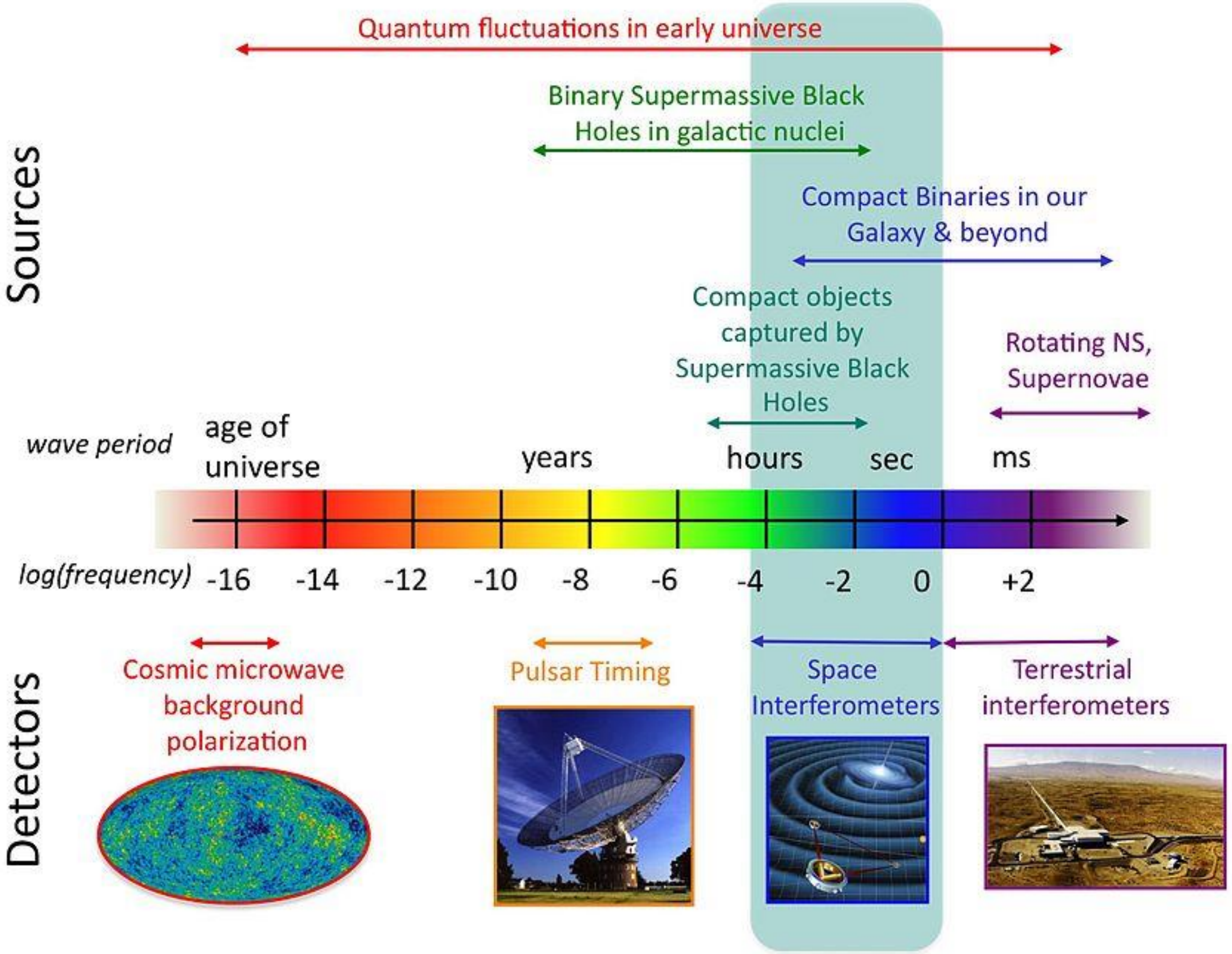
**Kamioka Gravitational Wave Detector (KAGRA)**

GEO600 ↑

← Virgo

LIGO Hanford

# The Gravitational Wave Spectrum



Sources

Quantum fluctuations in early universe

Binary Supermassive Black Holes in galactic nuclei

Compact Binaries in our Galaxy & beyond

Compact objects captured by Supermassive Black Holes

Rotating NS, Supernovae

*wave period*: age of universe, years, hours, sec, ms

*log(frequency)*: -16, -14, -12, -10, -8, -6, -4, -2, 0, +2

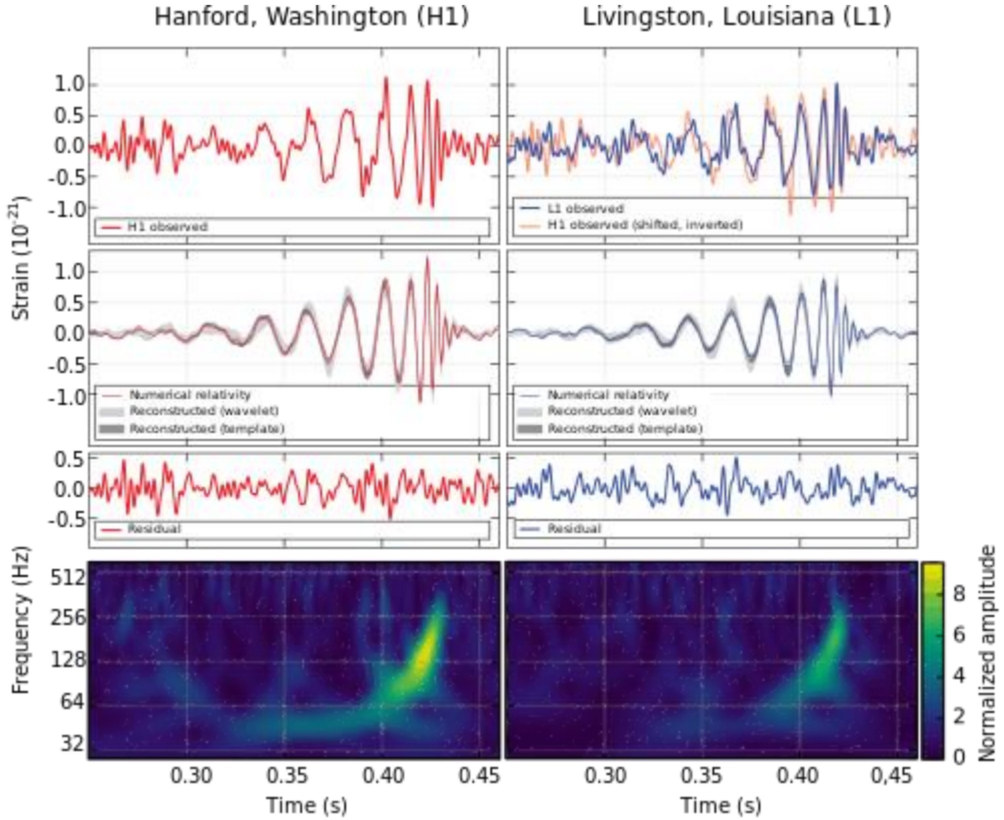
Detectors

Cosmic microwave background polarization

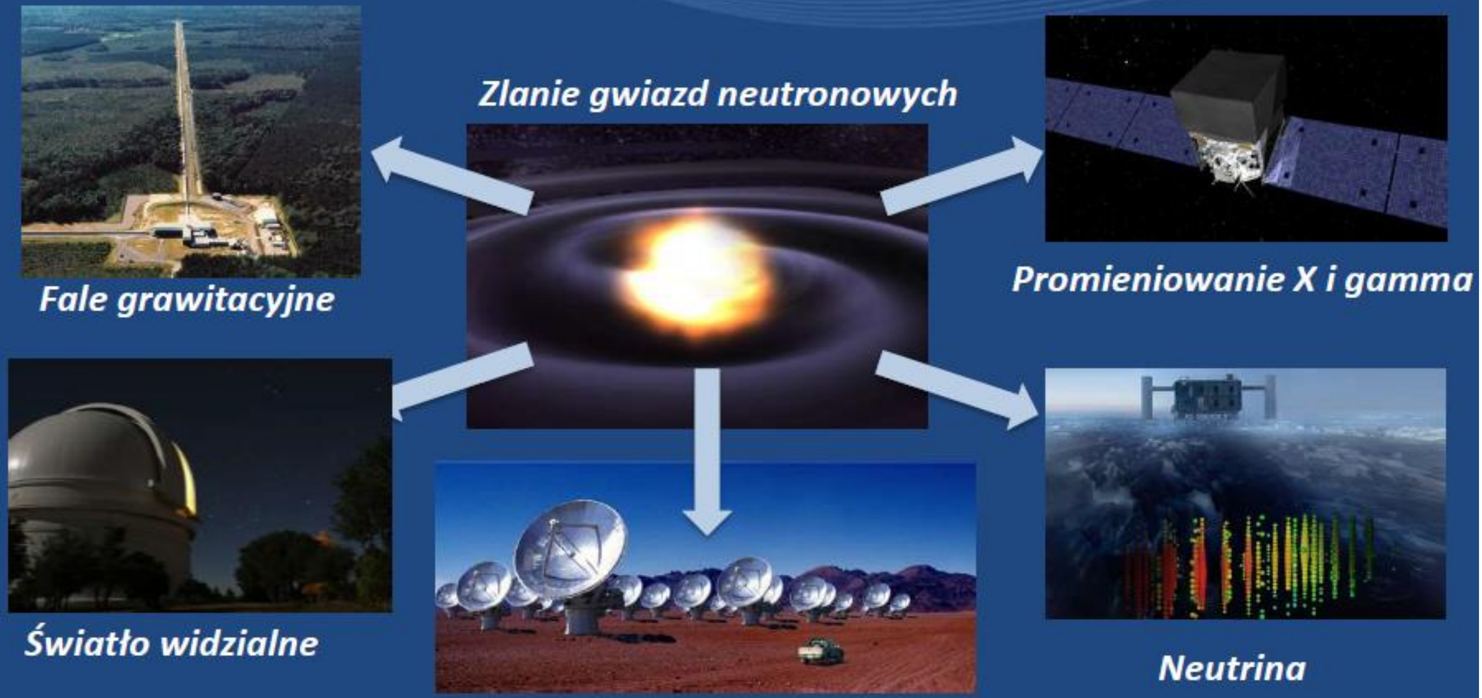
Pulsar Timing

Space Interferometers

Terrestrial interferometers



# Wieloaspektowe obserwacje z falami grawitacyjnymi



*Zlanie gwiazd neutronowych*

*Fale grawitacyjne*

*Promieniowanie X i gamma*

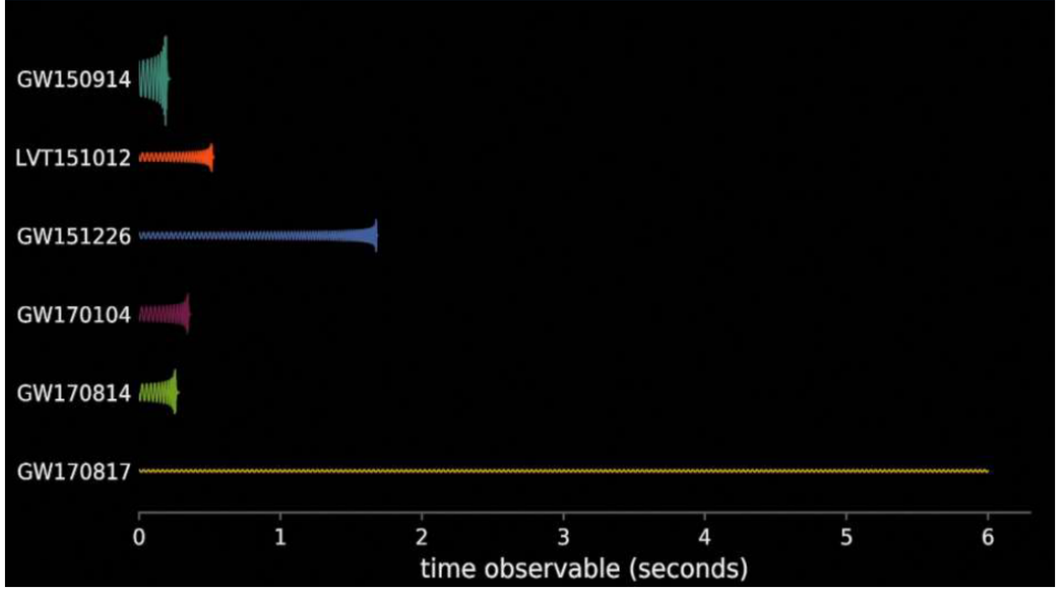
*Światło widzialne*

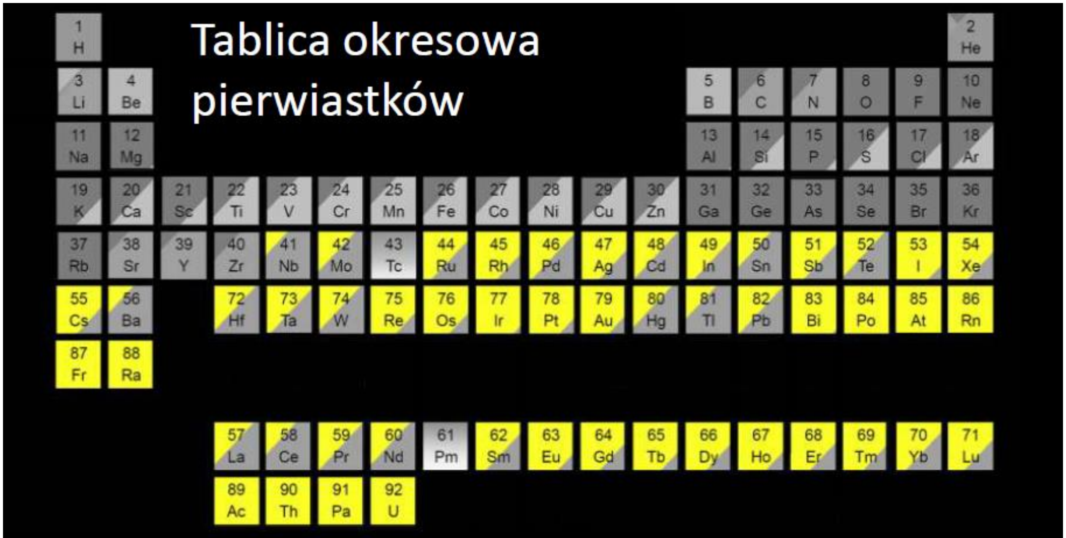
*Neutrina*

*Fale radiowe*

- Detektory LIGO i Virgo zarejestrowały sygnał fali grawitacyjnej pochodzący ze zlewania się dwóch gwiazd neutronowych
- Satelity Fermi i Integral uchwyciły towarzyszące temu zlaniu błyski gamma
- Obserwatoria optyczne zaobserwowały towarzyszącą zlaniu kilonovę

# Wykryte sygnały fal grawitacyjnych



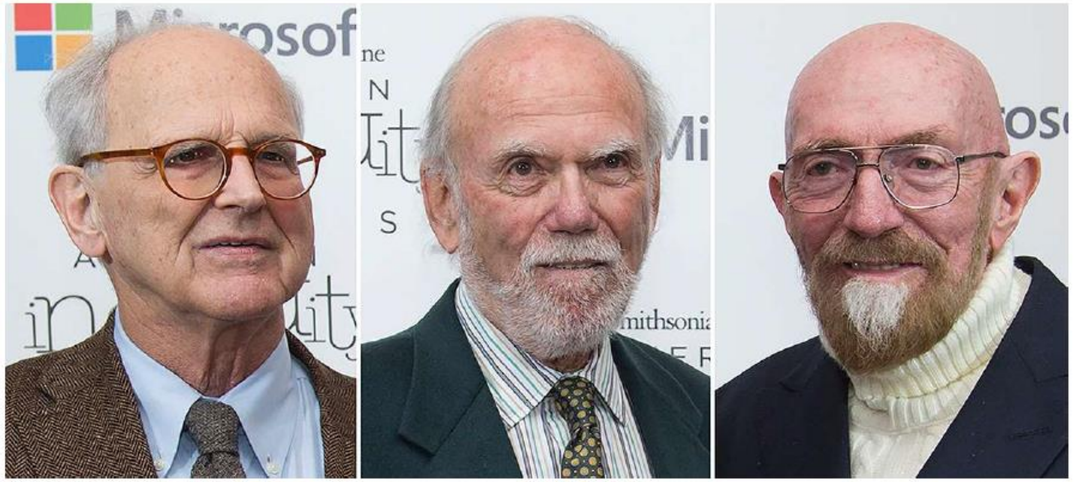


## Tablica okresowa pierwiastków

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 H | | | | | | | | | | | | | | | | | 2 He |
| 3 Li | 4 Be | | | | | | | | | | | 5 B | 6 C | 7 N | 8 O | 9 F | 10 Ne |
| 11 Na | 12 Mg | | | | | | | | | | | 13 Al | 14 Si | 15 P | 16 S | 17 Cl | 18 Ar |
| 19 K | 20 Ca | 21 Sc | 22 Ti | 23 V | 24 Cr | 25 Mn | 26 Fe | 27 Co | 28 Ni | 29 Cu | 30 Zn | 31 Ga | 32 Ge | 33 As | 34 Se | 35 Br | 36 Kr |
| 37 Rb | 38 Sr | 39 Y | 40 Zr | 41 Nb | 42 Mo | 43 Tc | 44 Ru | 45 Rh | 46 Pd | 47 Ag | 48 Cd | 49 In | 50 Sn | 51 Sb | 52 Te | 53 I | 54 Xe |
| 55 Cs | 56 Ba | | 72 Hf | 73 Ta | 74 W | 75 Re | 76 Os | 77 Ir | 78 Pt | 79 Au | 80 Hg | 81 Tl | 82 Pb | 83 Bi | 84 Po | 85 At | 86 Rn |
| 87 Fr | 88 Ra | | | | | | | | | | | | | | | | |
| | | | 57 La | 58 Ce | 59 Pr | 60 Nd | 61 Pm | 62 Sm | 63 Eu | 64 Gd | 65 Tb | 66 Dy | 67 Ho | 68 Er | 69 Tm | 70 Yb | 71 Lu |
| | | | 89 Ac | 90 Th | 91 Pa | 92 U | | | | | | | | | | | |

**Wytworzone w wyniku zlania się gwiazd neutronowych (kolor żółty)**

# Nagroda Nobla z Fizyki w 2017r za detekcję fal grawitacyjnych



**Ray Weiss**
(doświadczalnik)

**Barry Barish**
(menedżer)

**Kip Thorne**
(astrofizyk)

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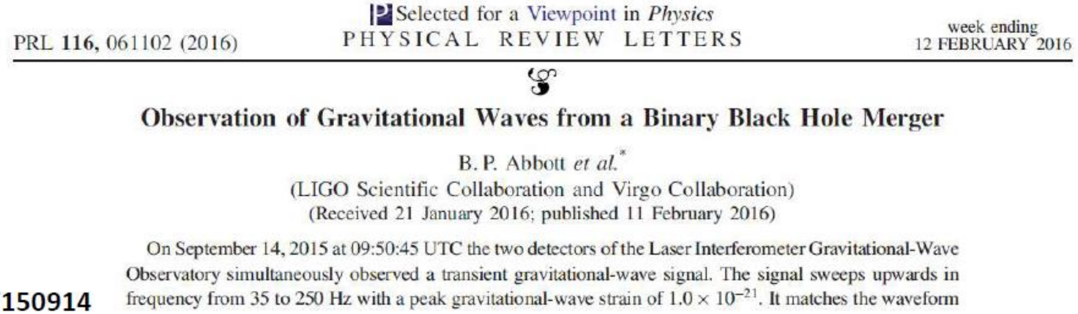
# Pierwsza bezposrednia detekcji fali grawitacyjnej



Selected for a Viewpoint in *Physics*

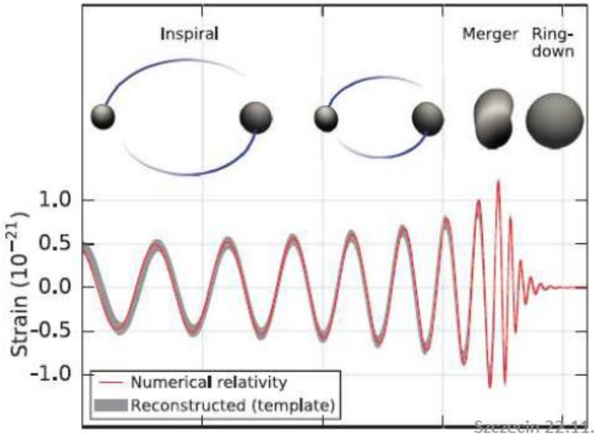
PRL **116,** 061102 (2016) PHYSICAL REVIEW LETTERS week ending 12 FEBRUARY 2016

**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)

On September 14, 2015 at 09:50:45 UTC the two detectors of the Laser Interferometer Gravitational-Wave Observatory simultaneously observed a transient gravitational-wave signal. The signal sweeps upwards in frequency from 35 to 250 Hz with a peak gravitational-wave strain of $1.0 \times 10^{-21}$. It matches the waveform

**GW150914**



- **Niezwykle czuły detektor**
- **Doskonałe modele wykrywalnych źródeł FG**
- **Wyrafinowane metody analizy danych,**

a i przyroda była dla nas łaskawa – nie było gwarancji, że detektory LIGO wykryją fale grawitacyjne !

---

# 1.3 miliardów lat temu …

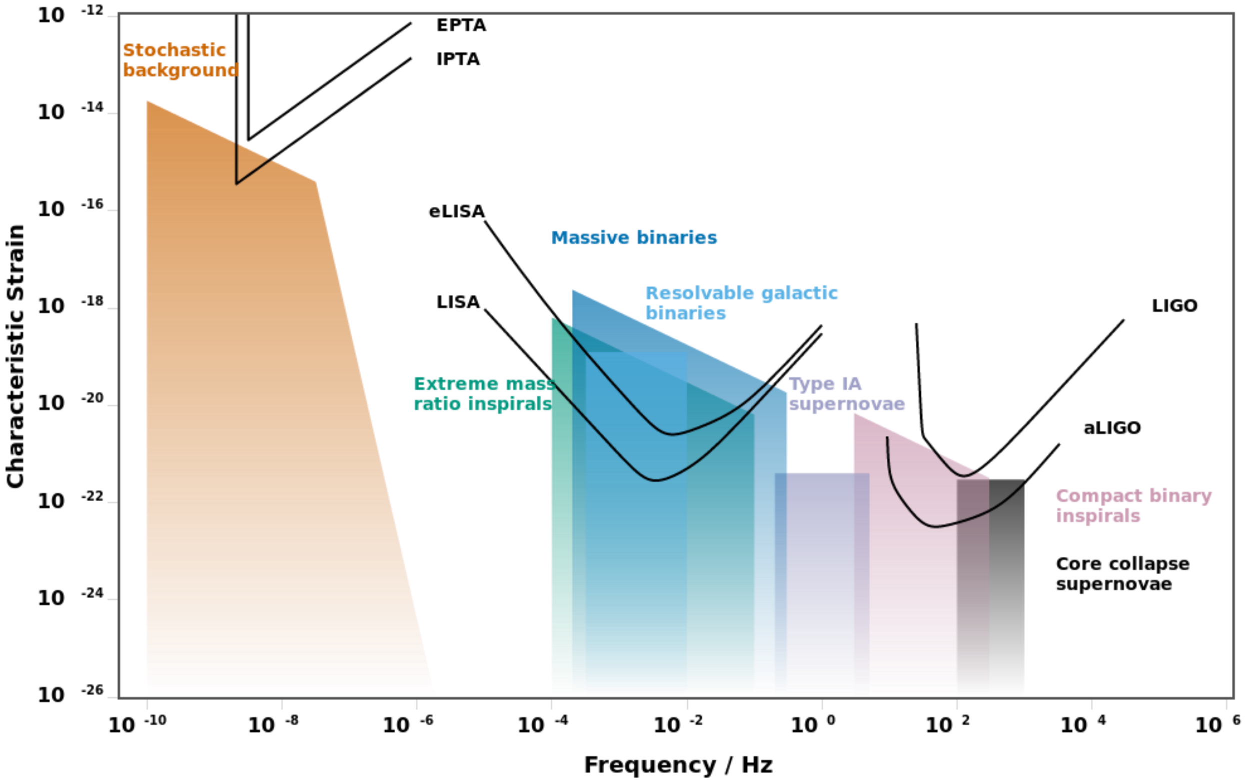
Czarna dziura #1
36X bardziej masywna niż Słońce

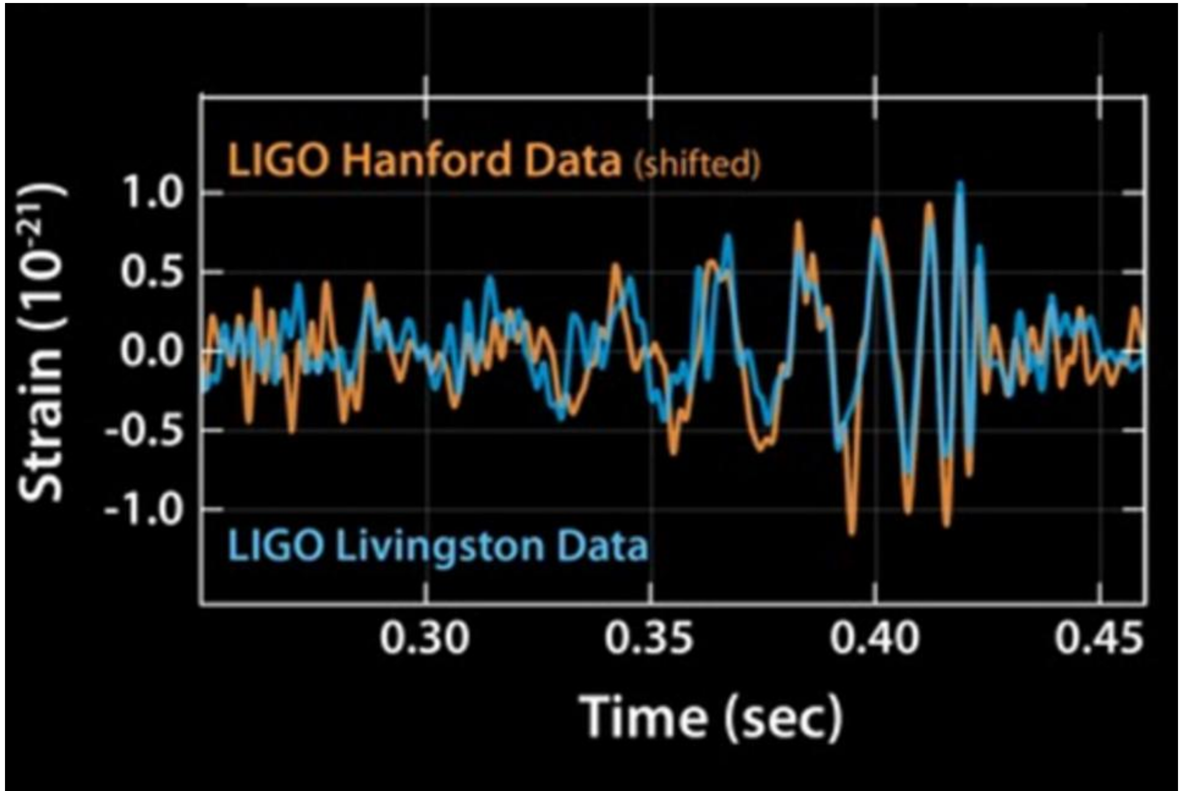
Czarna dziura #2
29X bardziej masywna niż Słońce

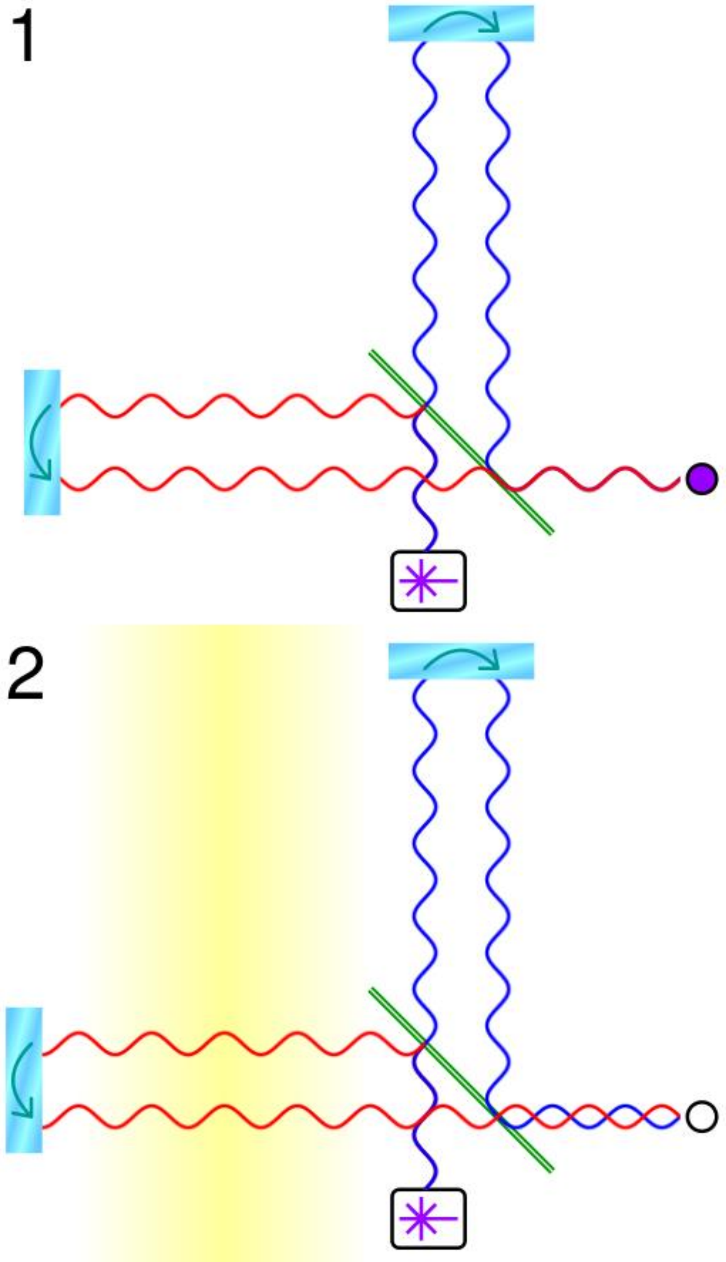
---

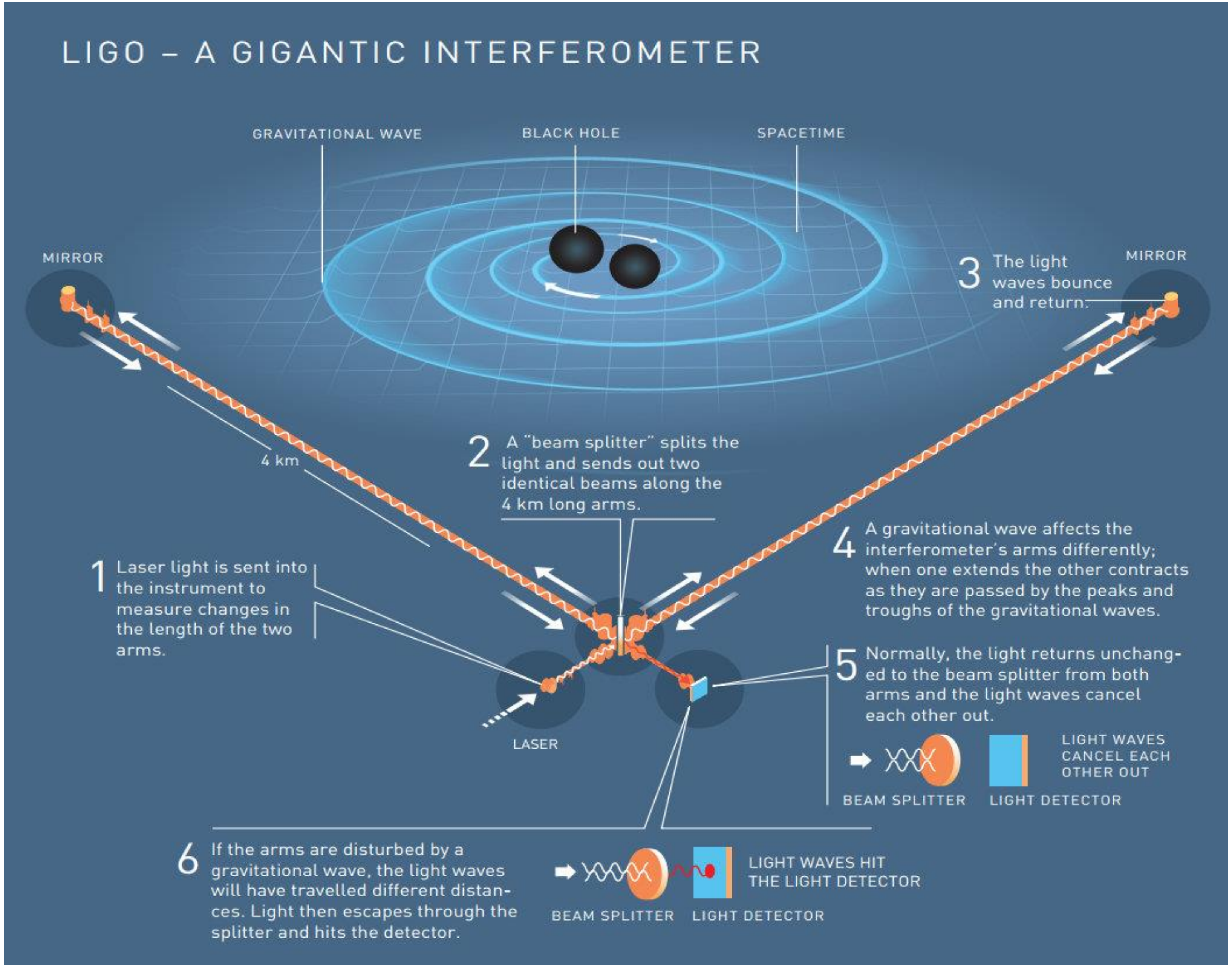
W wyniku zlania 3 masy słońca zostały zamienione na fale grawitacyjne

# Laser Interferometer Gravitational-Wave Observatory (LIGO)









LIGO – A GIGANTIC INTERFEROMETER

1 Laser light is sent into the instrument to measure changes in the length of the two arms.

2 A "beam splitter" splits the light and sends out two identical beams along the 4 km long arms.

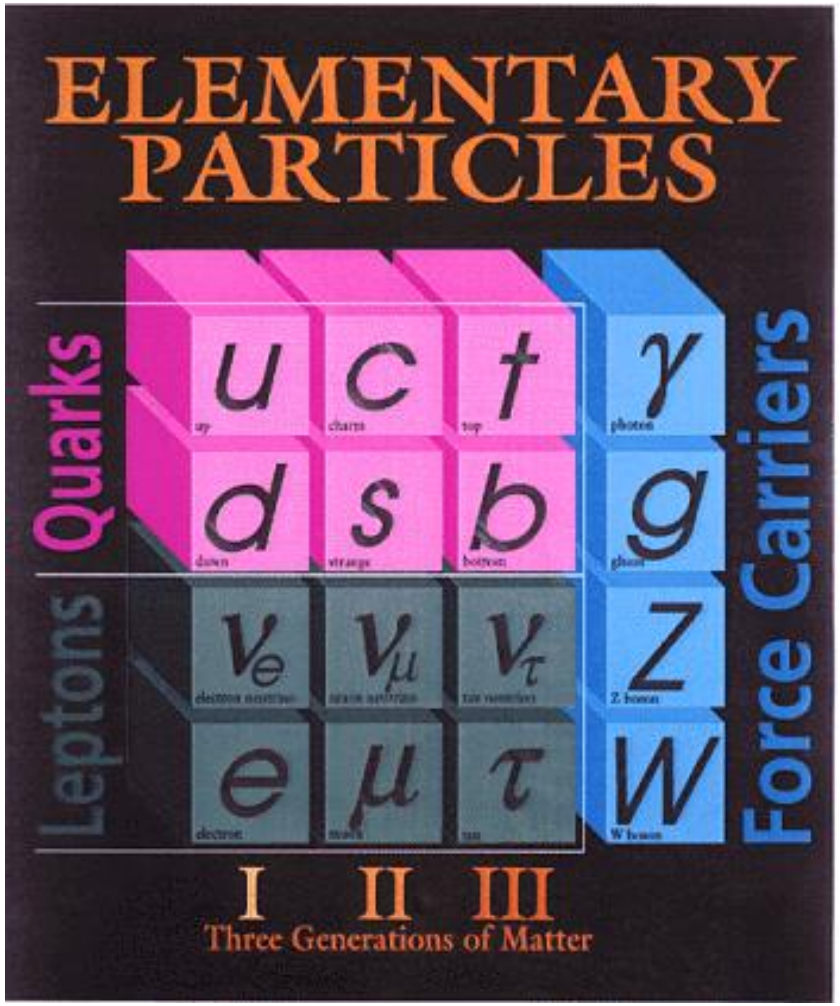
3 The light waves bounce and return.

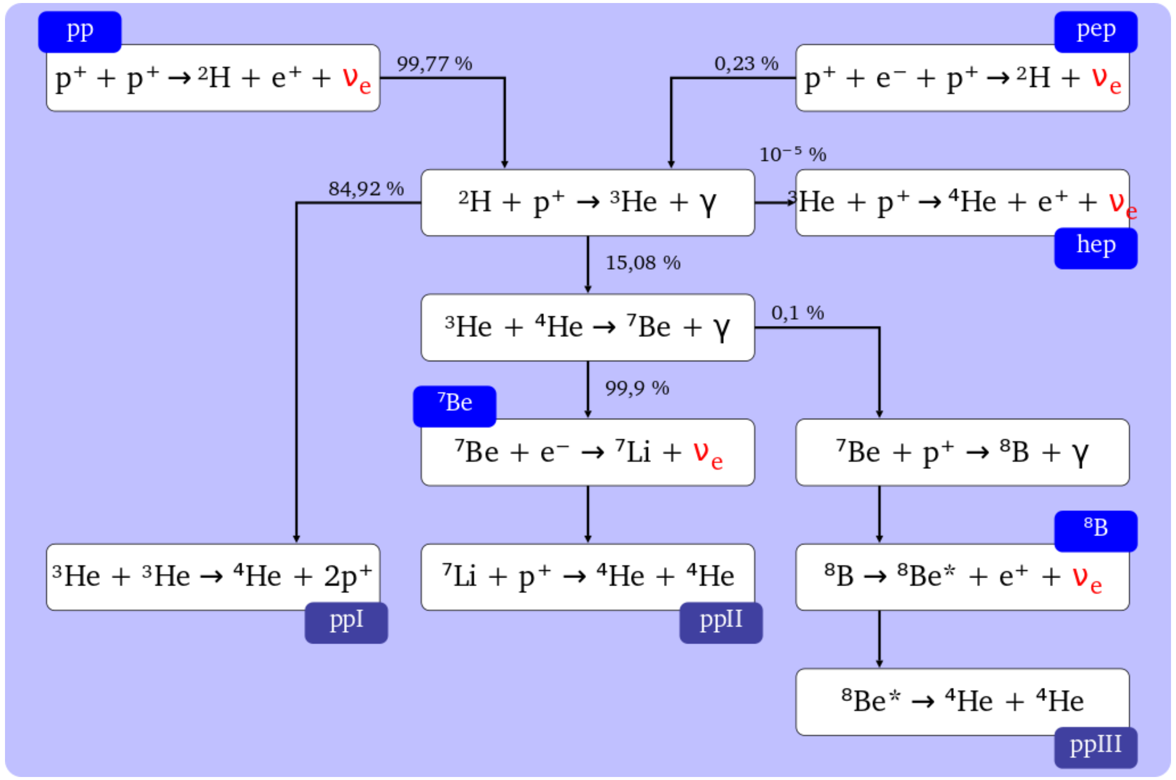
4 A gravitational wave affects the interferometer's arms differently; when one extends the other contracts as they are passed by the peaks and troughs of the gravitational waves.

5 Normally, the light returns unchanged to the beam splitter from both arms and the light waves cancel each other out.

6 If the arms are disturbed by a gravitational wave, the light waves will have travelled different distances. Light then escapes through the splitter and hits the detector.

# Neutrino

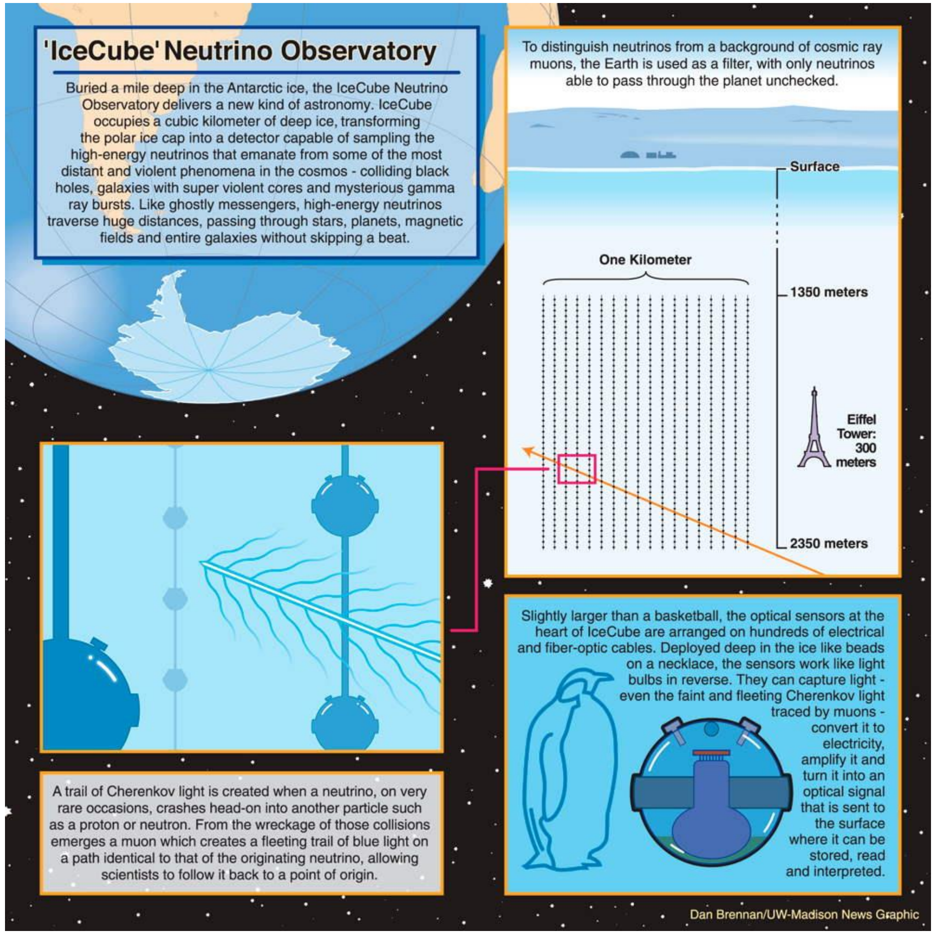




Solar neutrinos (proton–proton chain) in the Standard Solar Model

A **neutrino** (denoted by the Greek letter ν) is a fermion (an elementary particle with half-integer spin) that interacts only via the weak subatomic force and gravity. The mass of the neutrino is much smaller than that of the other known elementary particles. The majority of neutrinos in the vicinity of the Earth are from nuclear reactions in the Sun, about 65 billion ($6.5\times10^{10}$) solar neutrinos per second pass through every square centimeter perpendicular to the direction of the Sun. Neutrinos can be created in several ways, including in beta decay of atomic nuclei or hadrons, nuclear reactions such as those that take place in the core of a star, supernovae, and when accelerated particle beams or cosmic rays hit atoms. The neutrino was postulated first by Wolfgang Pauli in 1930 to explain how beta decay could conserve energy, momentum, and angular momentum (spin). For each neutrino, there also exists a corresponding antiparticle, called an *antineutrino*, which also has no electric charge and half-integer spin. They are distinguished from the neutrinos by having opposite signs of lepton number and chirality

# Obserwatoria neutrinowe



## 'IceCube' Neutrino Observatory

Buried a mile deep in the Antarctic ice, the IceCube Neutrino Observatory delivers a new kind of astronomy. IceCube occupies a cubic kilometer of deep ice, transforming the polar ice cap into a detector capable of sampling the high-energy neutrinos that emanate from some of the most distant and violent phenomena in the cosmos - colliding black holes, galaxies with super violent cores and mysterious gamma ray bursts. Like ghostly messengers, high-energy neutrinos traverse huge distances, passing through stars, planets, magnetic fields and entire galaxies without skipping a beat.

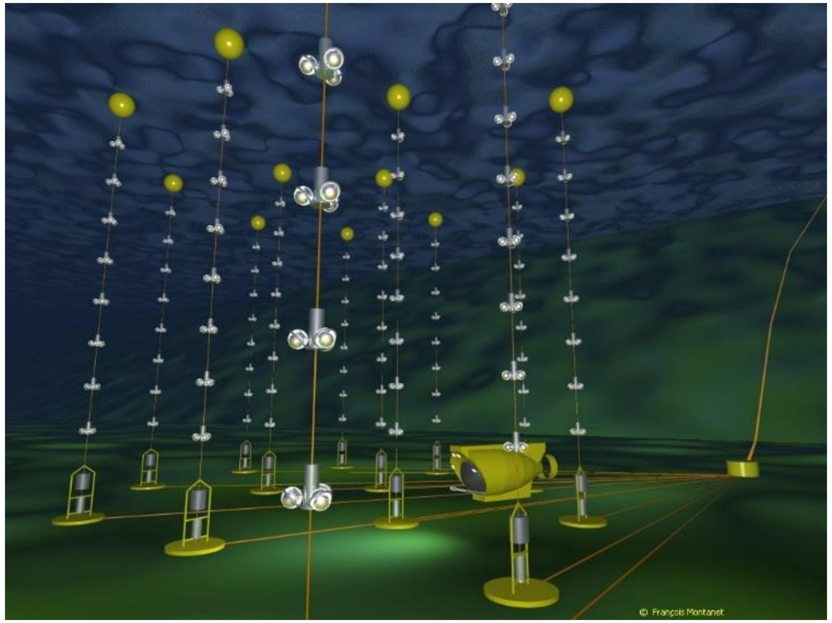
To distinguish neutrinos from a background of cosmic ray muons, the Earth is used as a filter, with only neutrinos able to pass through the planet unchecked.

A trail of Cherenkov light is created when a neutrino, on very rare occasions, crashes head-on into another particle such as a proton or neutron. From the wreckage of those collisions emerges a muon which creates a fleeting trail of blue light on a path identical to that of the originating neutrino, allowing scientists to follow it back to a point of origin.

Slightly larger than a basketball, the optical sensors at the heart of IceCube are arranged on hundreds of electrical and fiber-optic cables. Deployed deep in the ice like beads on a necklace, the sensors work like light bulbs in reverse. They can capture light - even the faint and fleeting Cherenkov light traced by muons - convert it to electricity, amplify it and turn it into an optical signal that is sent to the surface where it can be stored, read and interpreted.

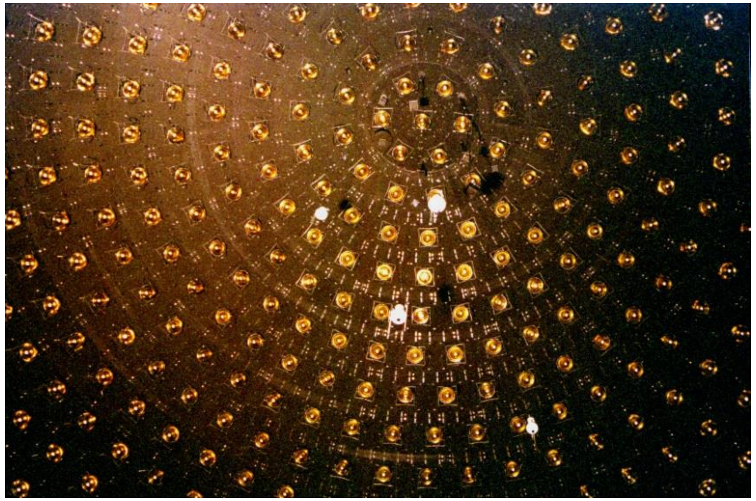
Dan Brennan/UW-Madison News Graphic

A model of KamiokaNDE

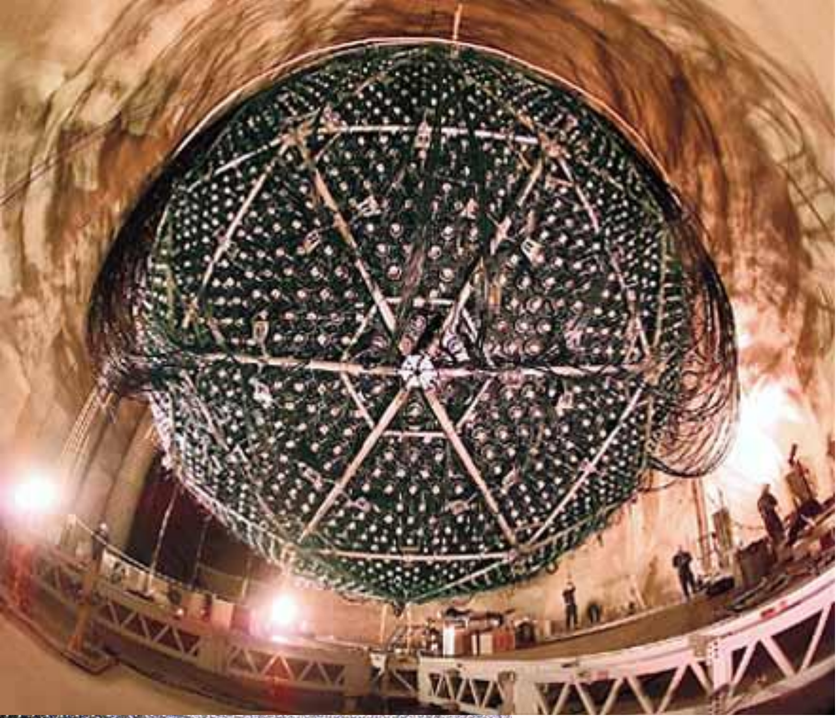


Antares neutrino detector deployed under water

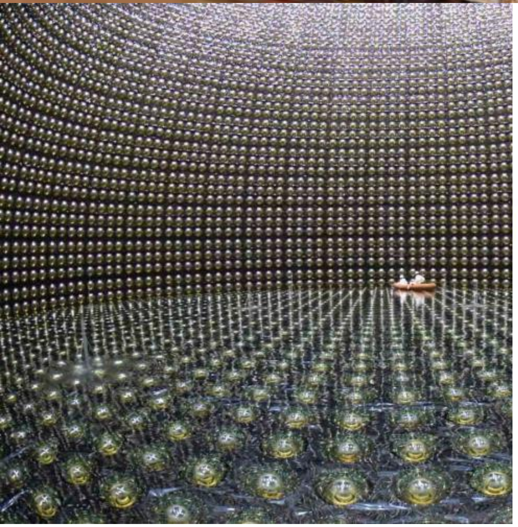
The inside of the MiniBooNE neutrino detector

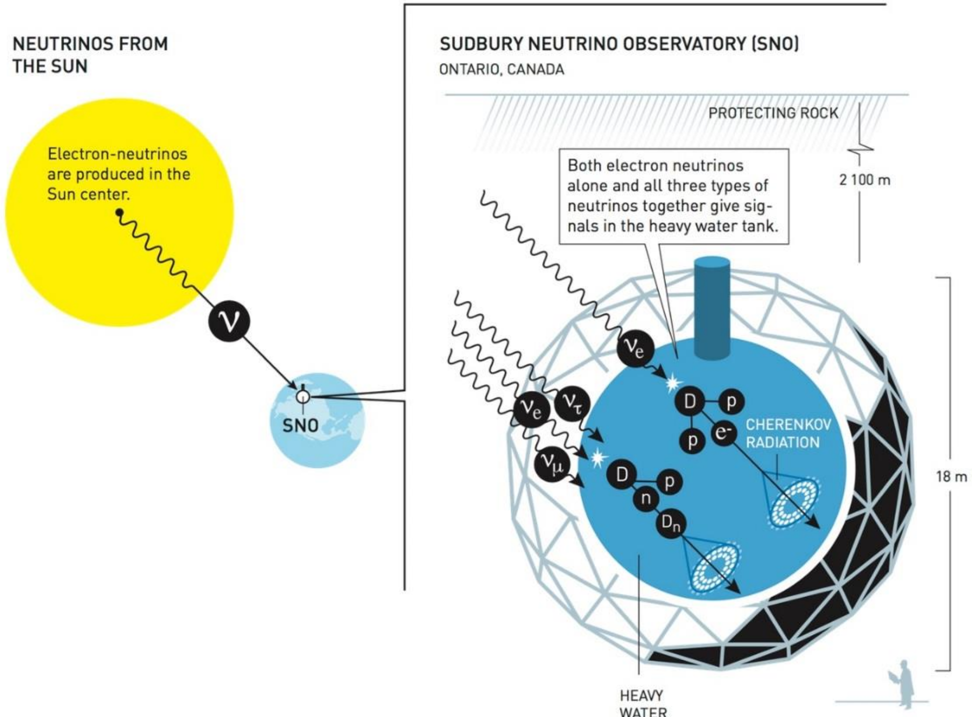


# Sudbury Neutrino Observatory



SNO can be thought of as a type of telescope, though it bears little resemblance to the image most of us associate with that word. It consists of an 18-meter-wide stainless steel geodesic sphere inside of which is an acrylic vessel filled with 1,000 tons of heavy water (deuterium oxide). Honeycombing the sphere are 9,522 ultra-sensitive light-sensors called photomultiplier tubes. When neutrinos passing through the heavy water interact with deuterium nuclei, faint flashes of light, called Cerenkov radiation, are emitted. The photomultiplier tubes detect these light flashes and convert them into electronic signals that scientists can analyse.





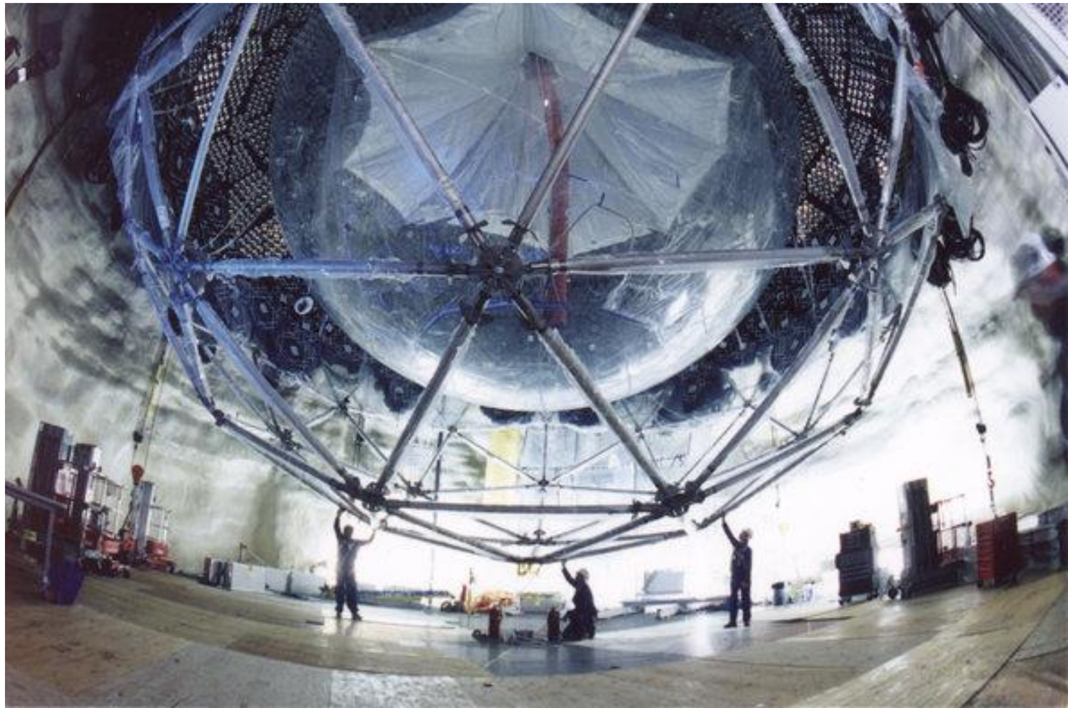
NEUTRINOS FROM THE SUN

Electron-neutrinos are produced in the Sun center.

SUDBURY NEUTRINO OBSERVATORY (SNO)

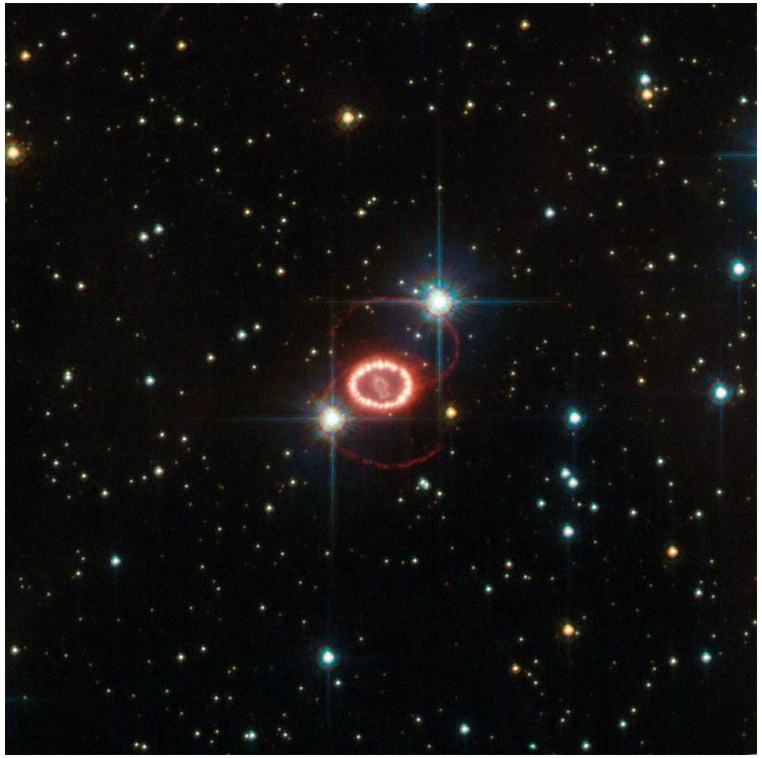
ONTARIO, CANADA

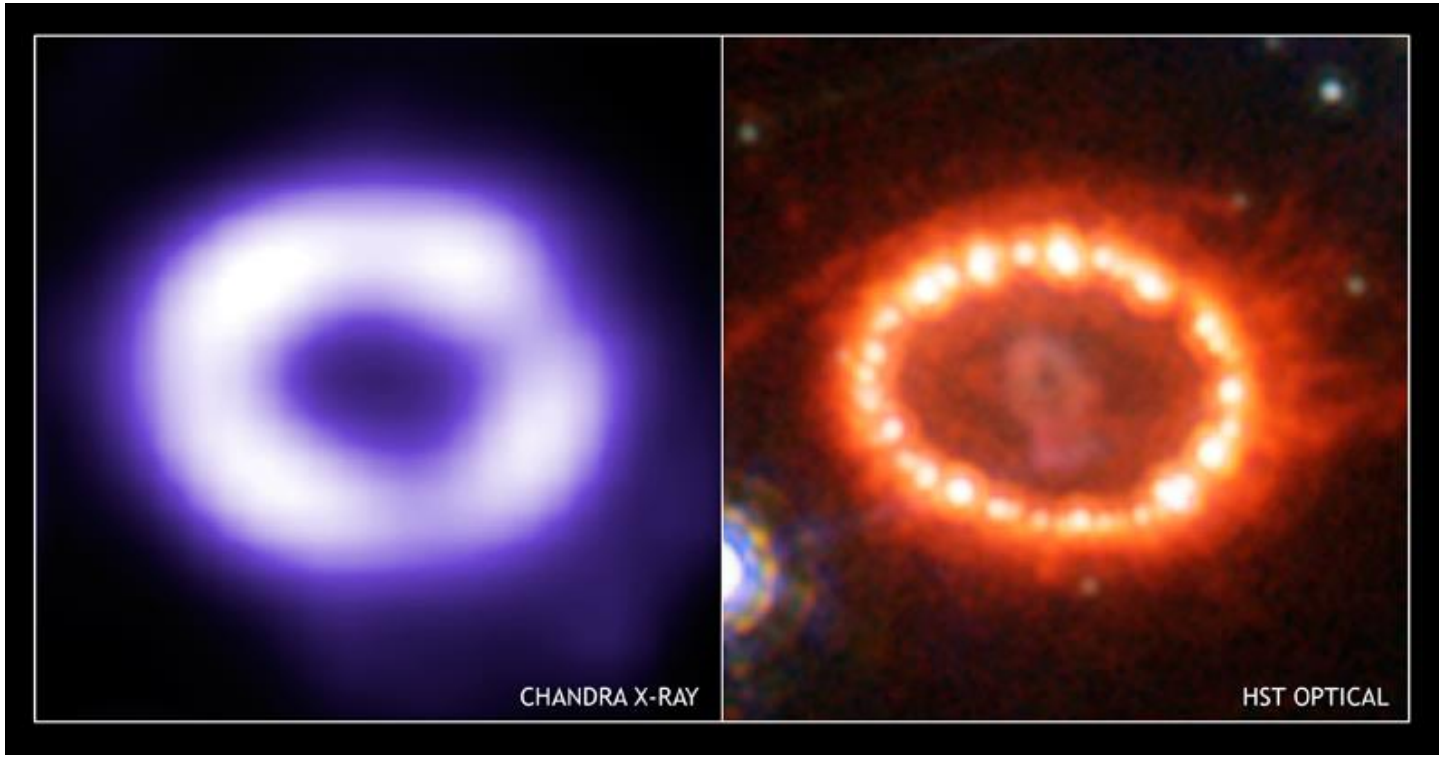
Both electron neutrinos alone and all three types of neutrinos together give signals in the heavy water tank.



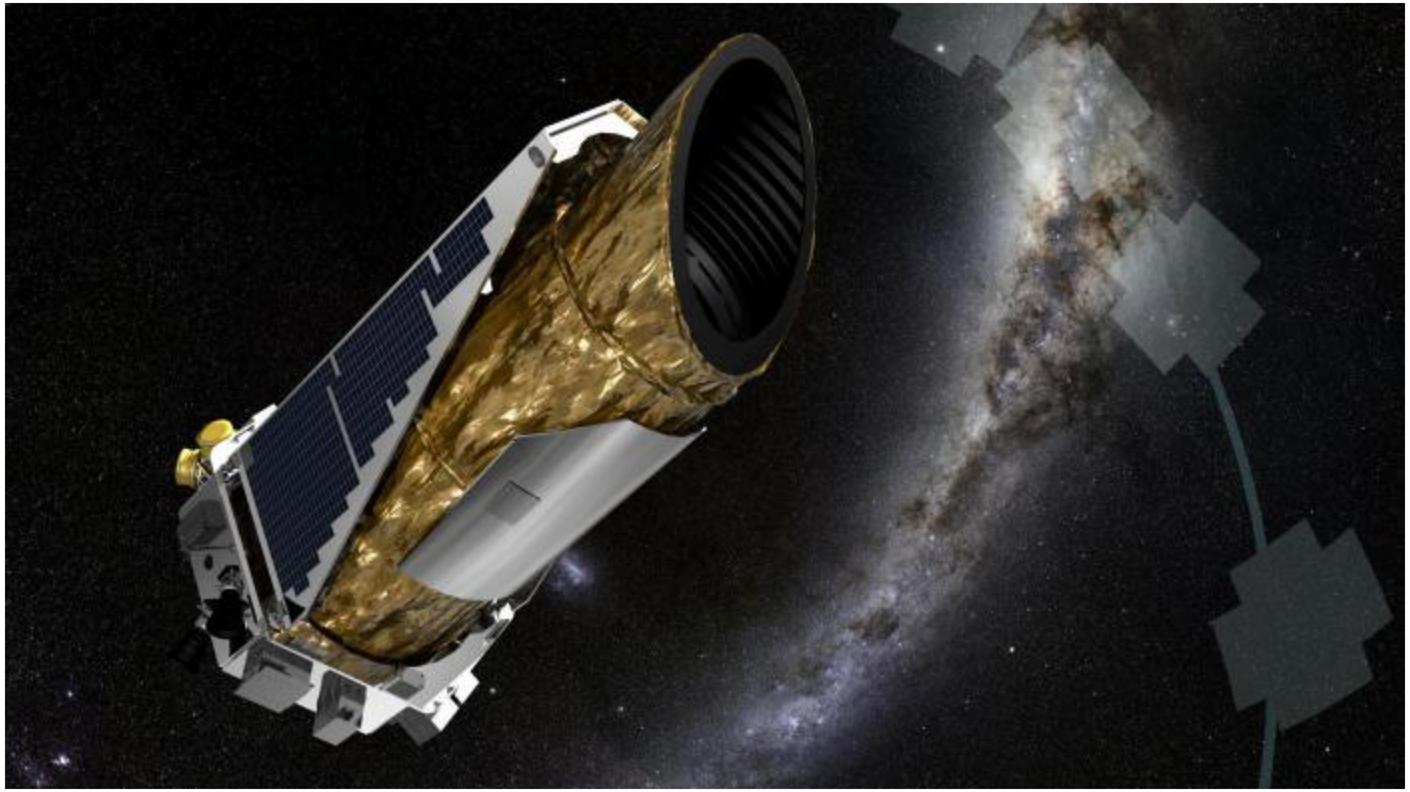
# Astronomia neutrinowa

**SN 1987A** was a supernova in the outskirts of the Tarantula Nebula, in the Large Magellanic Cloud (a nearby dwarf galaxy).
It occurred approximately 51.4 kiloparsecs (168,000 ly) from Earth.[4] This was close enough that it was easily visible to the naked eye
and it could be seen from the Southern Hemisphere. It was the closest observed supernova since SN 1604,
which occurred in the Milky Way itself. The light from the new supernova reached Earth on February 23, 1987.[5]
As the first supernova discovered in 1987, it was labeled “1987A”. Its brightness peaked in May, with an apparent magnitude of about 3
, and slowly declined in the following months. It was the first opportunity for modern astronomers to study the development
of a supernova in great detail, and its observations have provided much insight into core-collapse supernovae.
07:35 UT, Kamiokande II detected 12 antineutrinos; IMB, 8 antineutrinos; and Baksan, 5 antineutrinos; in a burst lasting less than 13 seconds.





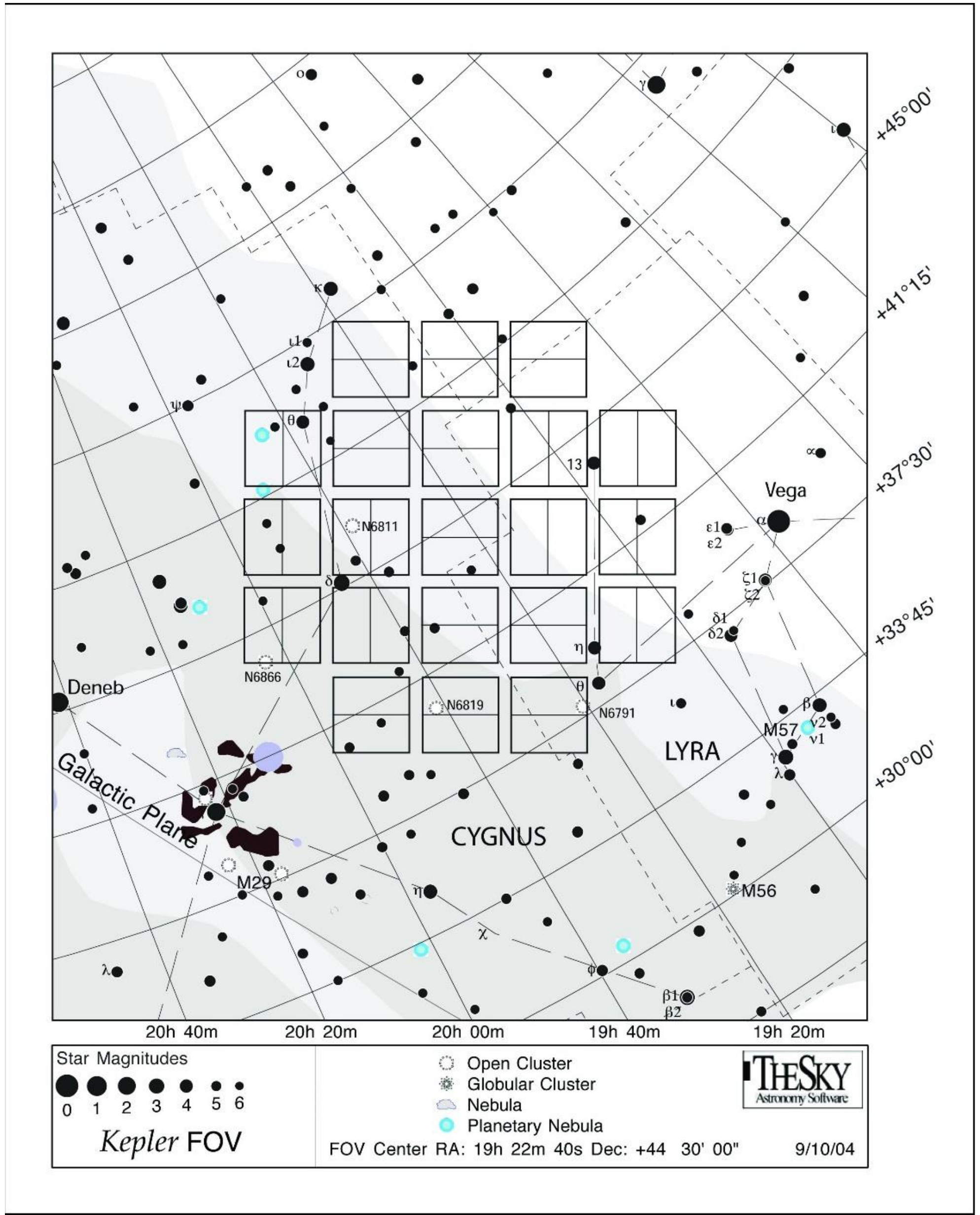
# Planety pozasłoneczne

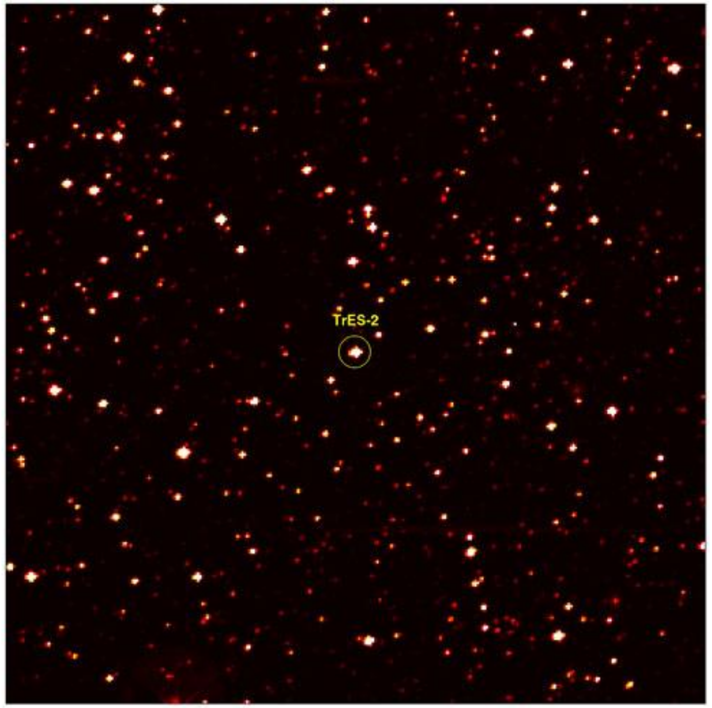


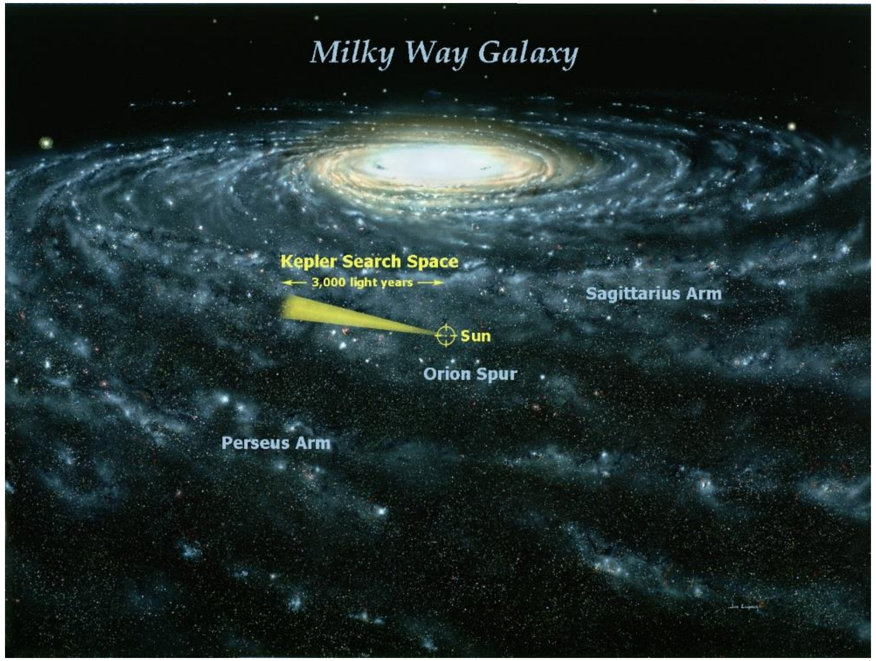
Kosmiczny Teleskop Keplera

Został umieszczony na orbicie wokółsłonecznej 7 marca 2009 roku, w ramach 10. misji programu Discovery.
Ma aperturę 0,95 m, masę 1052,4 kilogramów w momencie startu i jest wyposażony w największą matrycę CCD do tej pory wyniesioną w kosmos, posiadającą 95 megapikseli

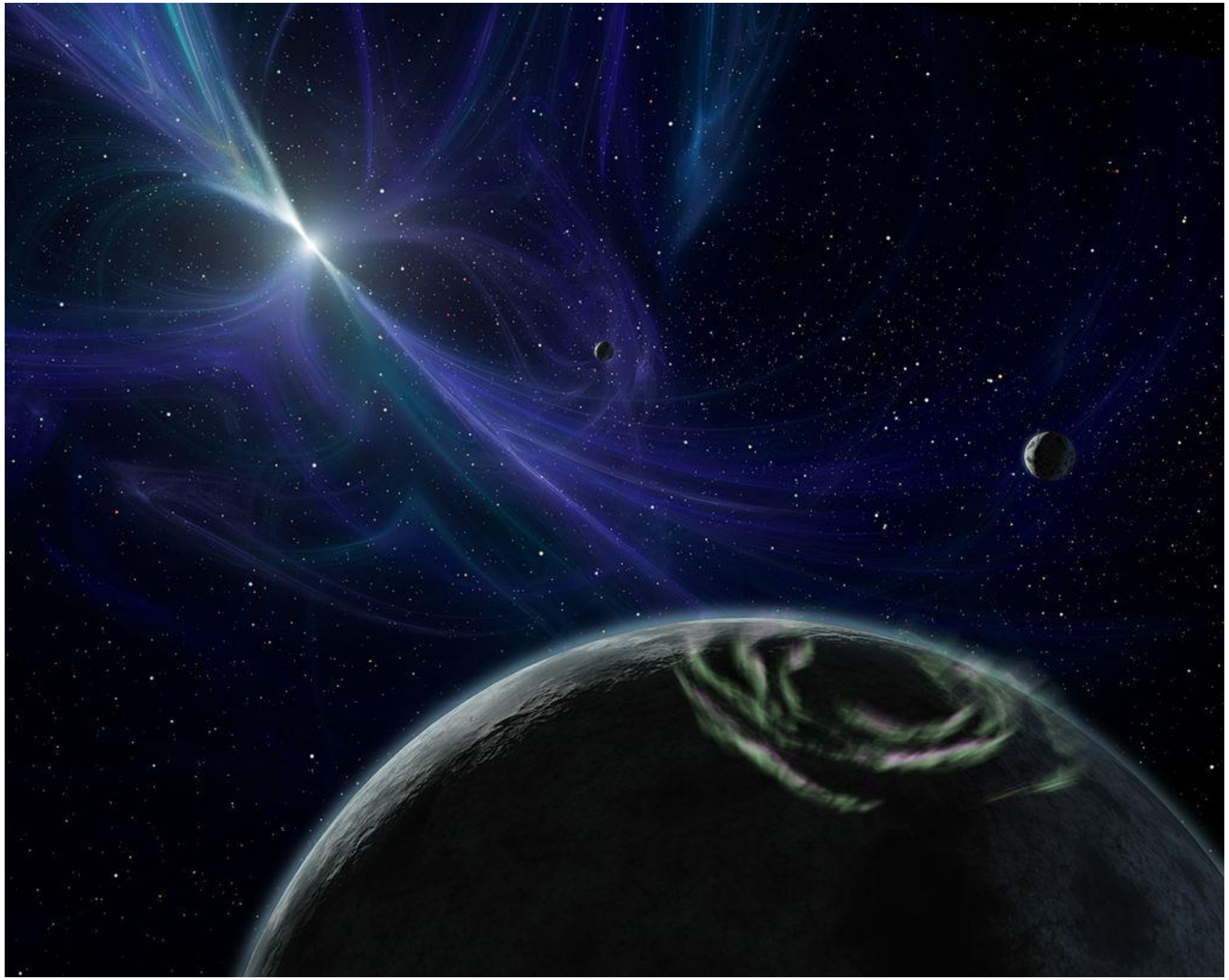
# Kosmiczny teleskop Keplera







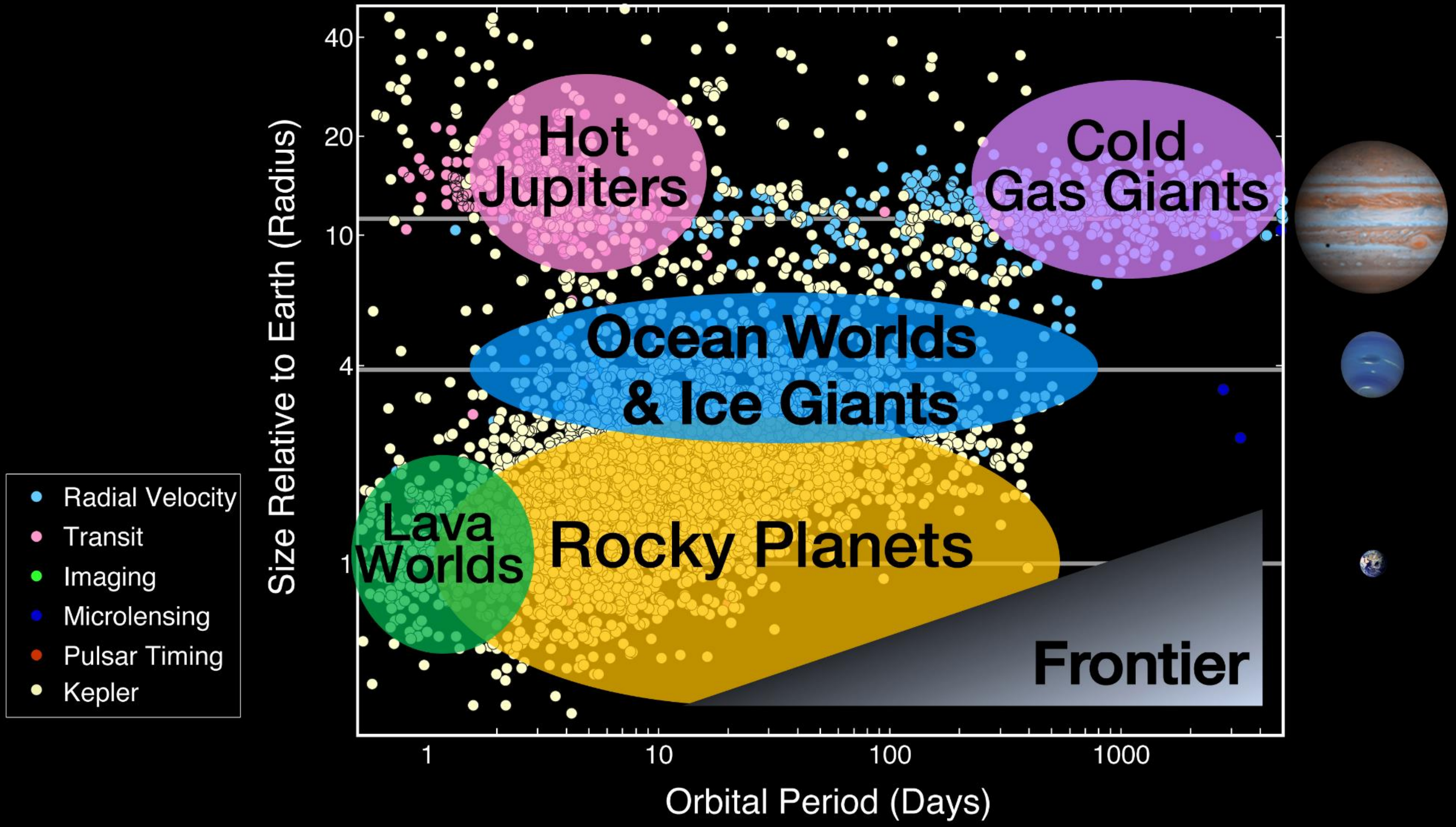
# PSR B1257+12



| Companion (in order from star) | Mass | Semimajor axis (AU) | Orbital period (days) | Eccentricity | Inclination | Radius |
|---|---|---|---|---|---|---|
| **A (b / Draugr)** | 0.020 ± 0.002 $M_\oplus$ | 0.19 | 25.262 ± 0.003 | 0.0 | ~50° | — |
| **B (c / Poltergeist)** | 4.3 ± 0.2 $M_\oplus$ | 0.36 | 66.5419 ± 0.0001 | 0.0186 ± 0.0002 | 53° | — |
| **C (d / Phobetor)** | 3.9 ± 0.2 $M_\oplus$ | 0.46 | 98.2114 ± 0.0002 | 0.0252 ± 0.0002 | 47° | — |

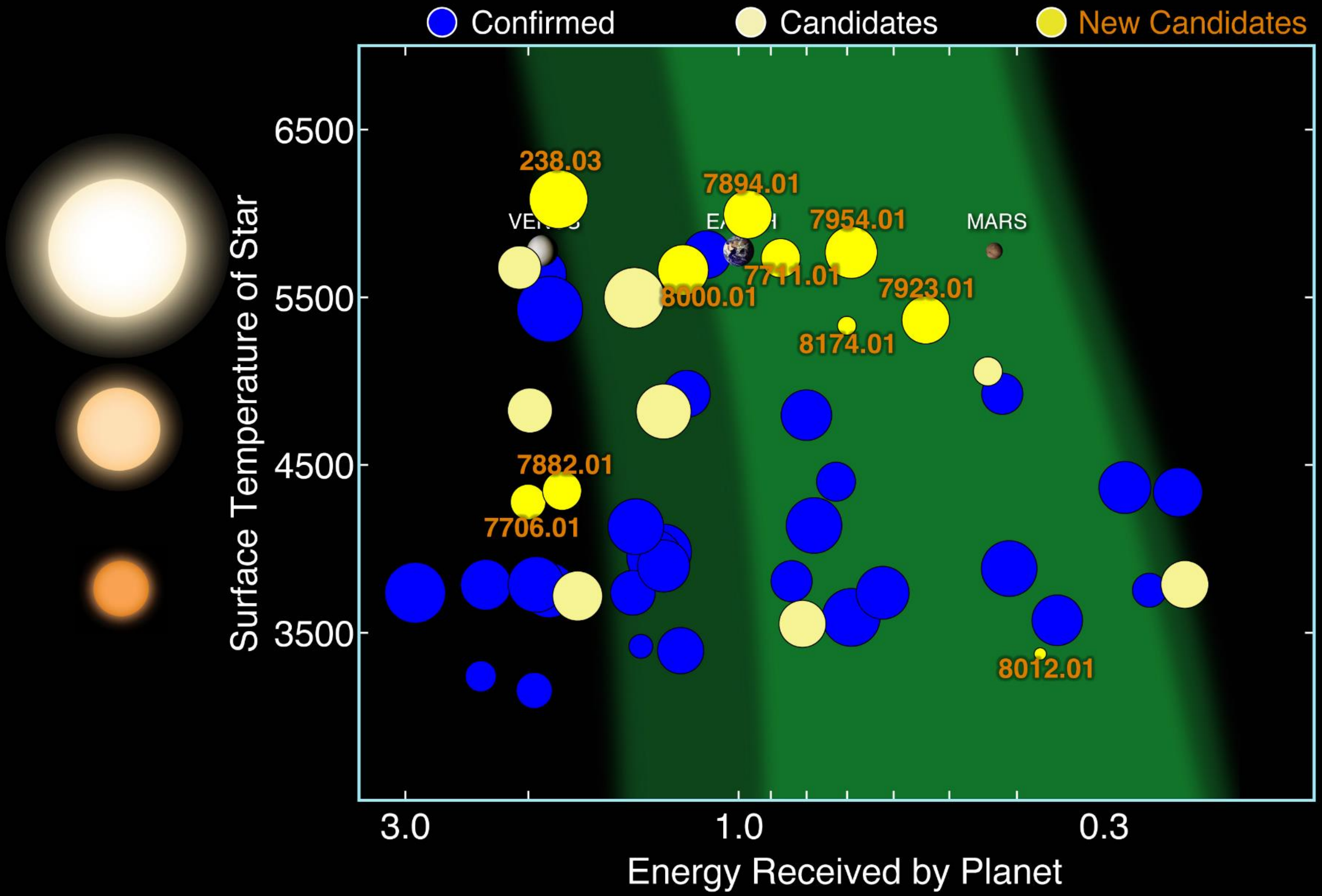
PSR B1257+12 was discovered by the Polish astronomer Aleksander Wolszczan on 9 February 1990 using the Arecibo radio telescope. It is a millisecond pulsar, a kind of neutron star, with a rotation period of 6.22 milliseconds (9,650 rpm), and was found to have anomalies in the pulsation period, which led to investigations as to the cause of the irregular pulses. In 1992 Wolszczan and Dale Frail published  a famous paper on the first confirmed discovery of planets outside our solar system. Using refined methods one more planet was found  orbiting this pulsar in 1994.

# Exoplanet Populations



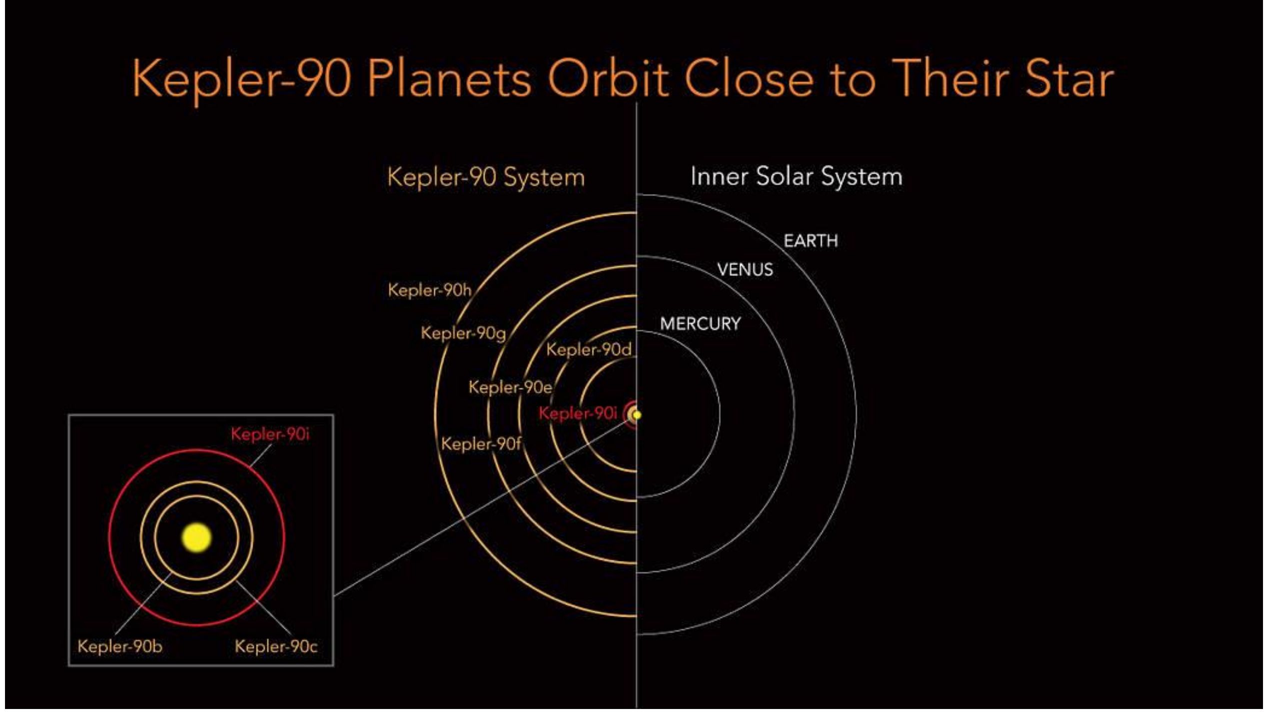
# Kepler Habitable Zone Planets

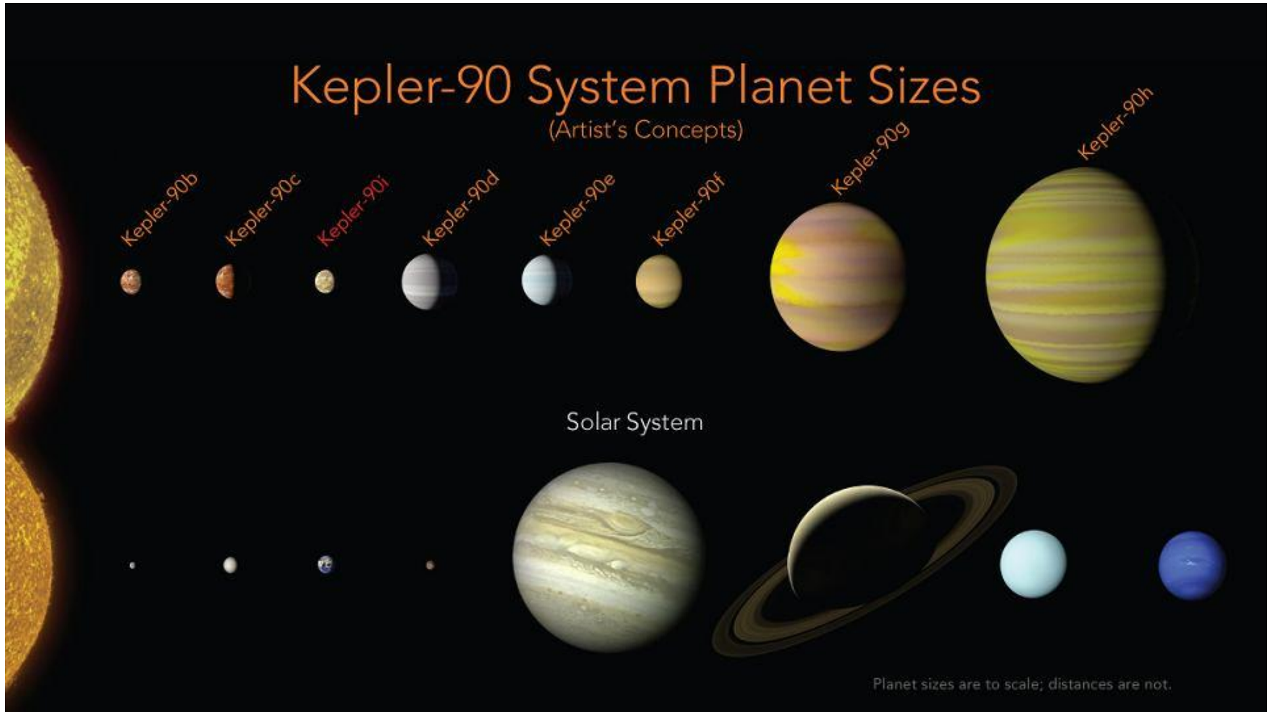
*As of June 2017*



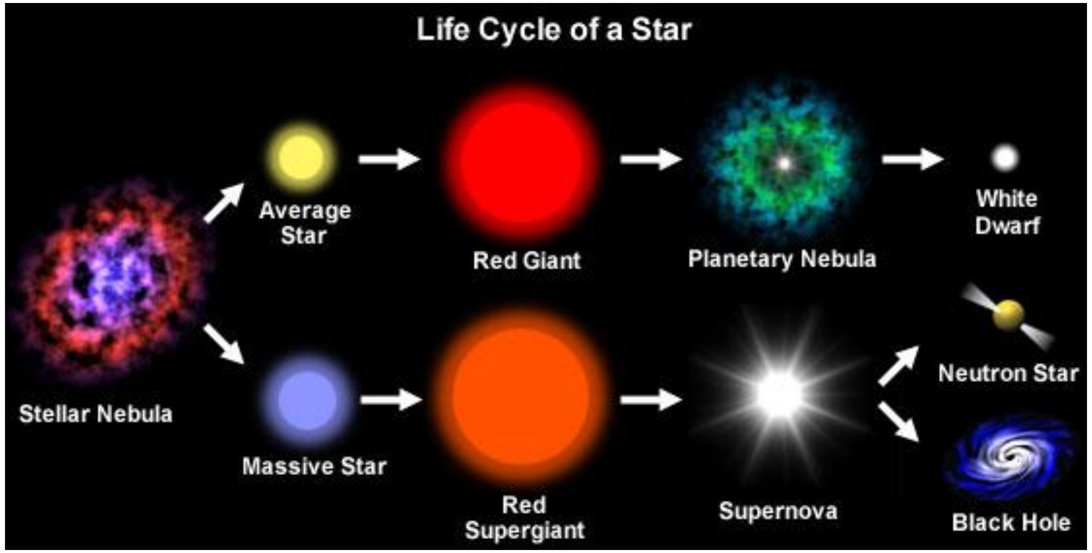
# Kosmiczny teleskop Keplera

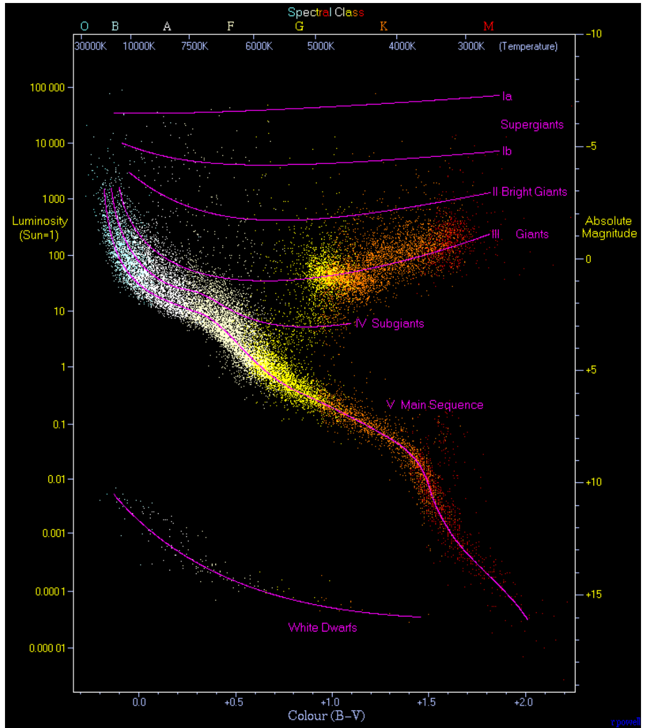
**Kepler-90** is a G-type main sequence star located about 2,545 light-years (780 pc) from Earth in the constellation of Draco. It is notable for having a planetary system that has an equal number of observed planets to the Solar System.
On 14 December 2017, NASA and Google announced the discovery of an eighth planet, Kepler-90i, in the Kepler-90 system



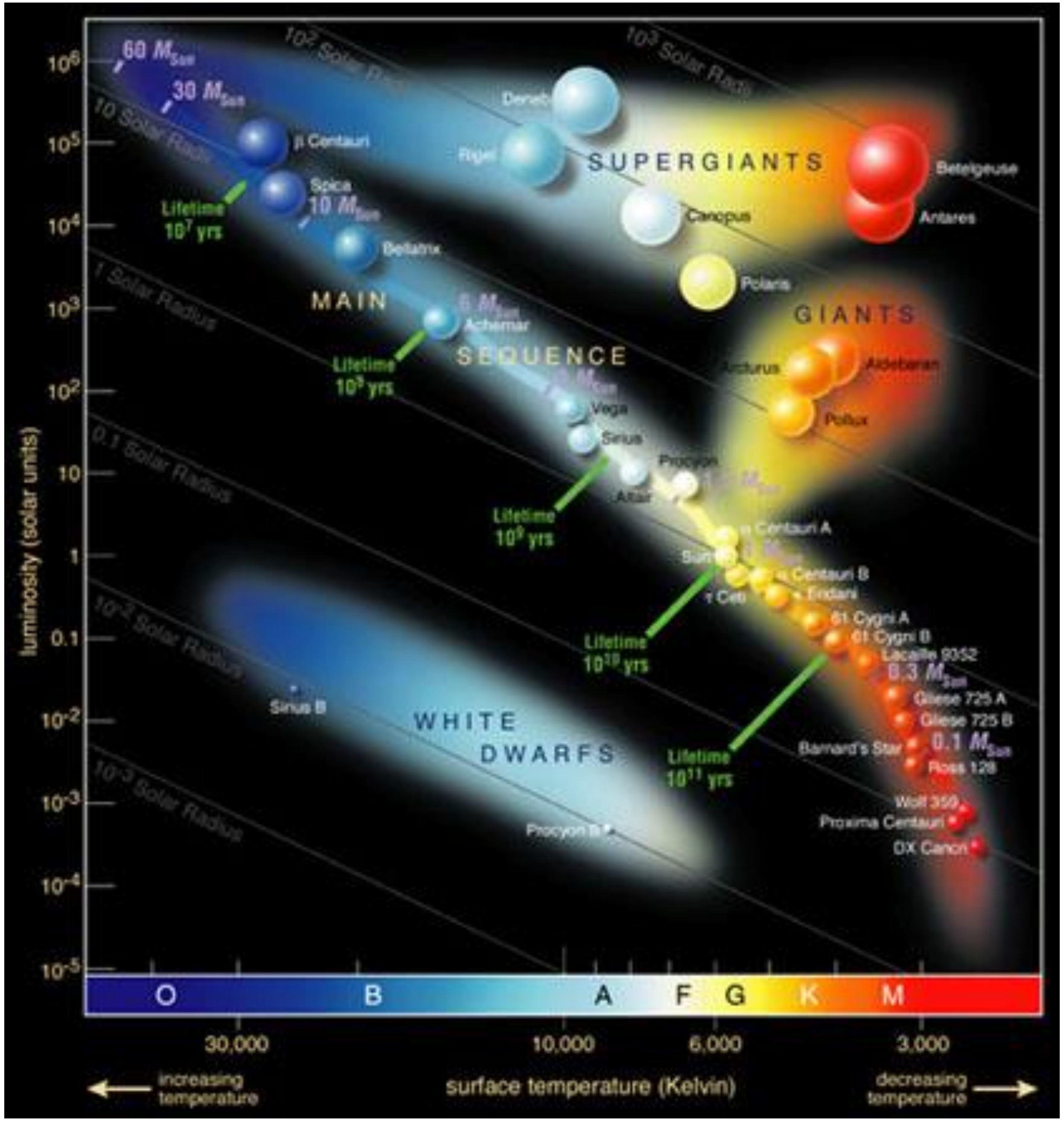


# Ewolucja gwiazd



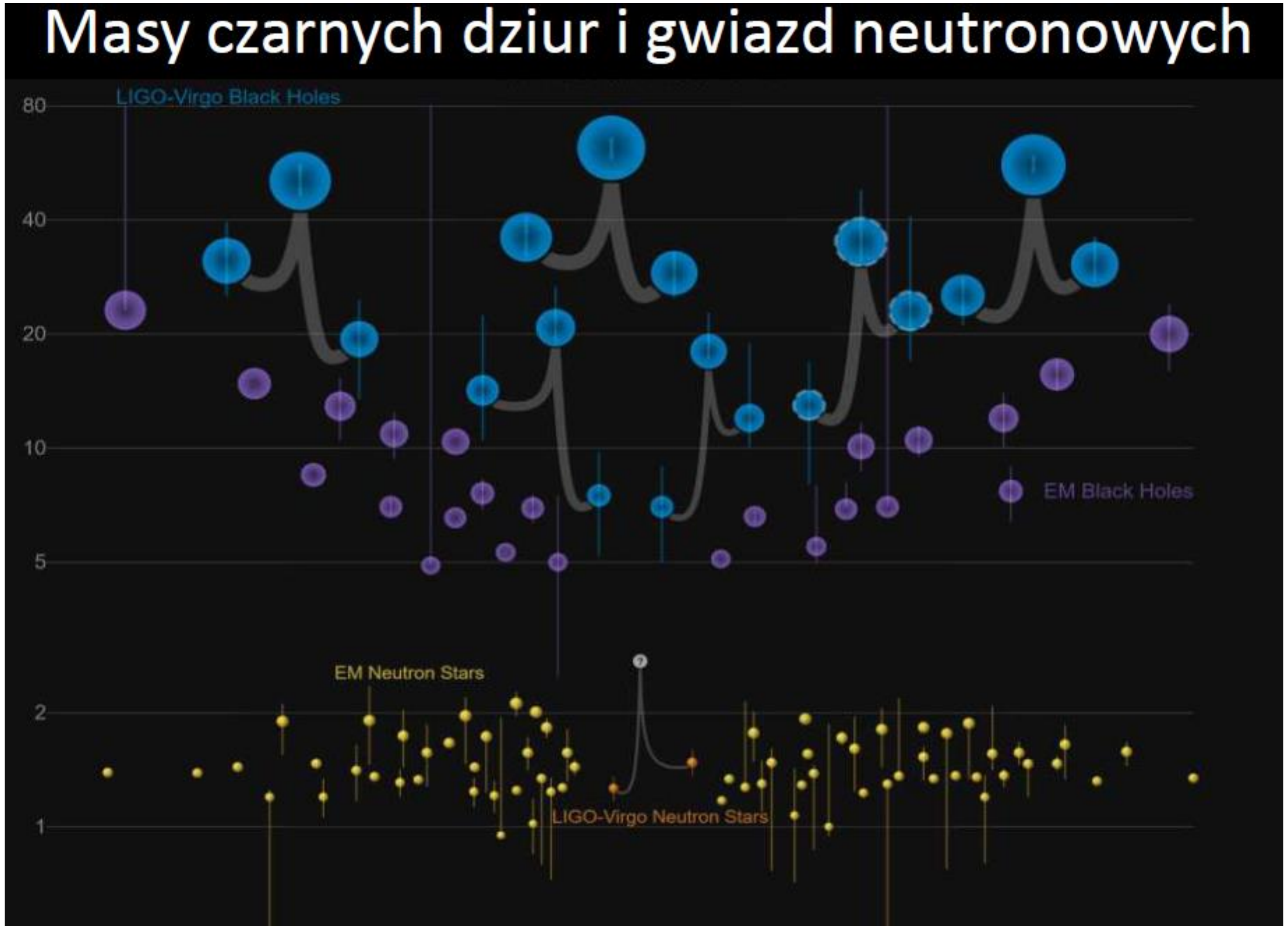


An observational Hertzsprung–Russell diagram with 22,000 stars plotted from the Hipparcos Catalogue and 1,000 from the Gliese Catalogue of nearby stars

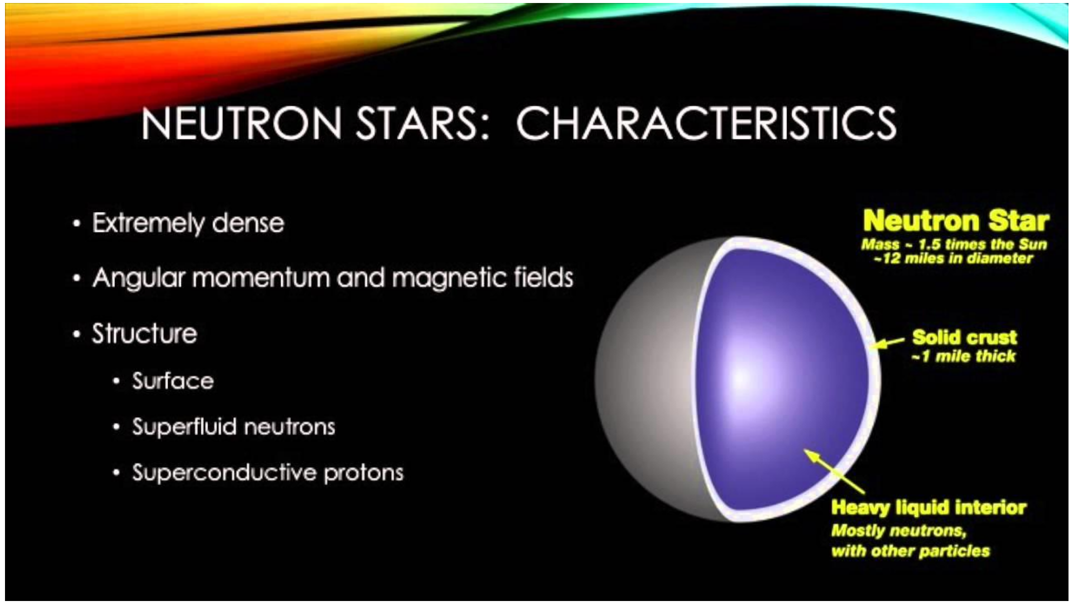


Hertzsprung–Russell diagram

# Czarne dziury i gwiazdy neutronowe



Masy czarnych dziur i gwiazd neutronowych



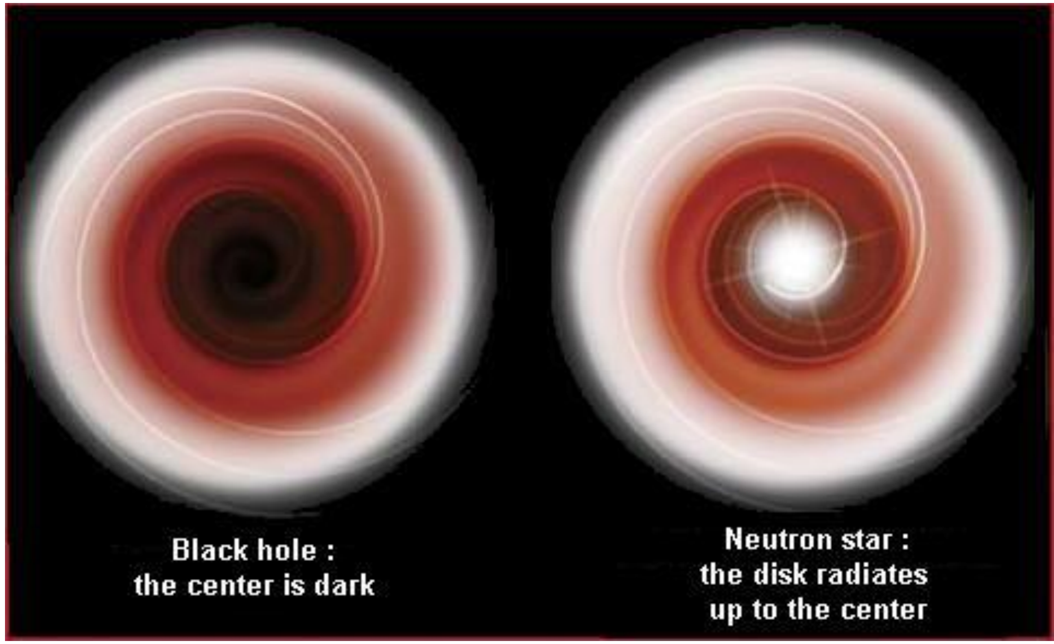
## NEUTRON STARS:  CHARACTERISTICS

- Extremely dense
- Angular momentum and magnetic fields
- Structure
  - Surface
  - Superfluid neutrons
  - Superconductive protons

**Neutron Star**
*Mass ~ 1.5 times the Sun*
*~12 miles in diameter*

**Solid crust**
*~1 mile thick*

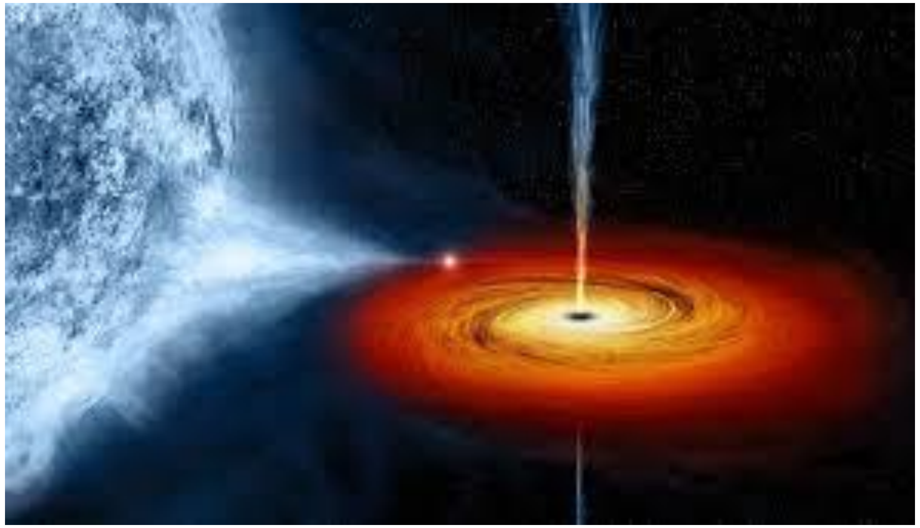
**Heavy liquid interior**
*Mostly neutrons,*
*with other particles*



Black hole :
the center is dark

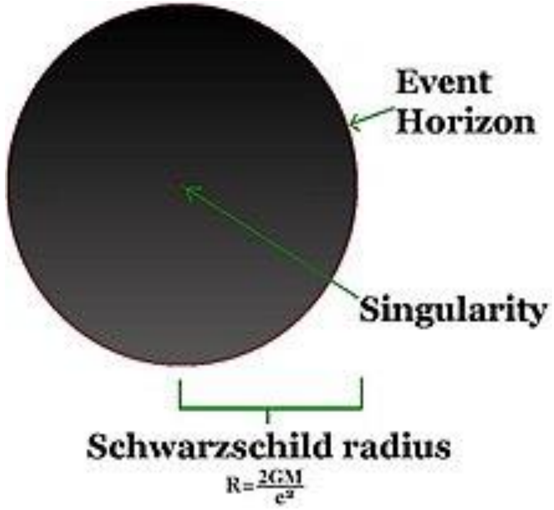
Neutron star :
the disk radiates
up to the center

# Czarne dziury

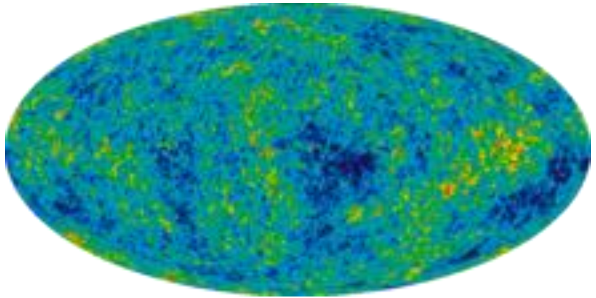


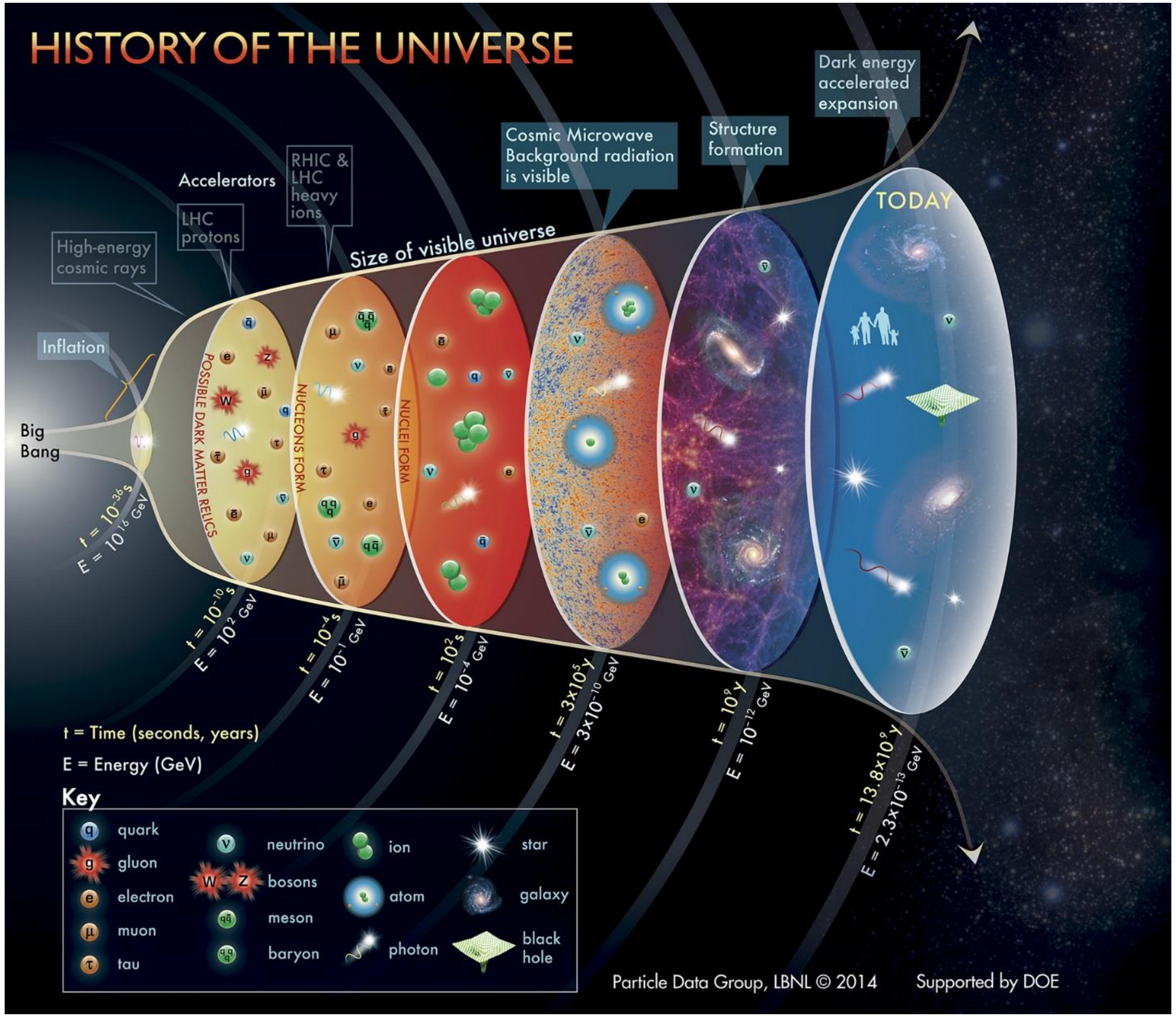
Black hole classifications

| Class | Mass | Size |
|---|---|---|
| Supermassive black hole | ~$10^5$–$10^{10}$ $M_{\text{Sun}}$ | ~0.001–400 AU |
| Intermediate-mass black hole | ~$10^3$ $M_{\text{Sun}}$ | ~$10^3$ km ≈ $R_{\text{Earth}}$ |
| Stellar black hole | ~10 $M_{\text{Sun}}$ | ~30 km |
| Micro black hole | up to ~$M_{\text{Moon}}$ | up to ~0.1 mm |



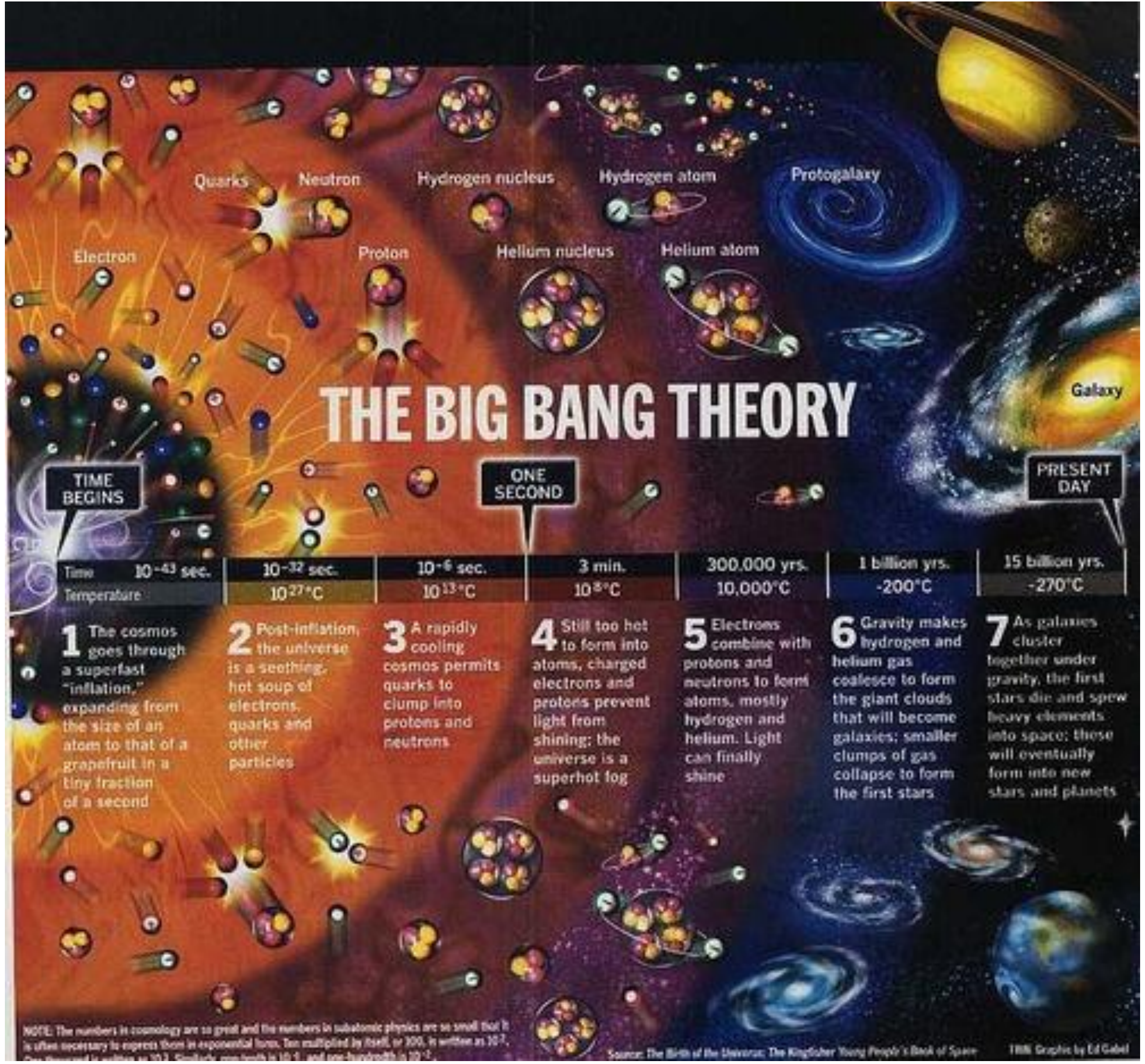
# Kosmologia





Particle Data Group, LBNL © 2014

Supported by DOE



| Time | 10^-43 sec. | 10^-32 sec. | 10^-6 sec. | 3 min. | 300,000 yrs. | 1 billion yrs. | 15 billion yrs. |
|---|---|---|---|---|---|---|---|
| Temperature | | 10^27°C | 10^13°C | 10^8°C | 10,000°C | -200°C | -270°C |

**1** The cosmos goes through a superfast "inflation," expanding from the size of an atom to that of a grapefruit in a tiny fraction of a second

**2** Post-inflation, the universe is a seething, hot soup of electrons, quarks and other particles

**3** A rapidly cooling cosmos permits quarks to clump into protons and neutrons

**4** Still too hot to form into atoms, charged electrons and protons prevent light from shining: the universe is a superhot fog

**5** Electrons combine with protons and neutrons to form atoms, mostly hydrogen and helium. Light can finally shine

**6** Gravity makes hydrogen and helium gas coalesce to form the giant clouds that will become galaxies; smaller clumps of gas collapse to form the first stars

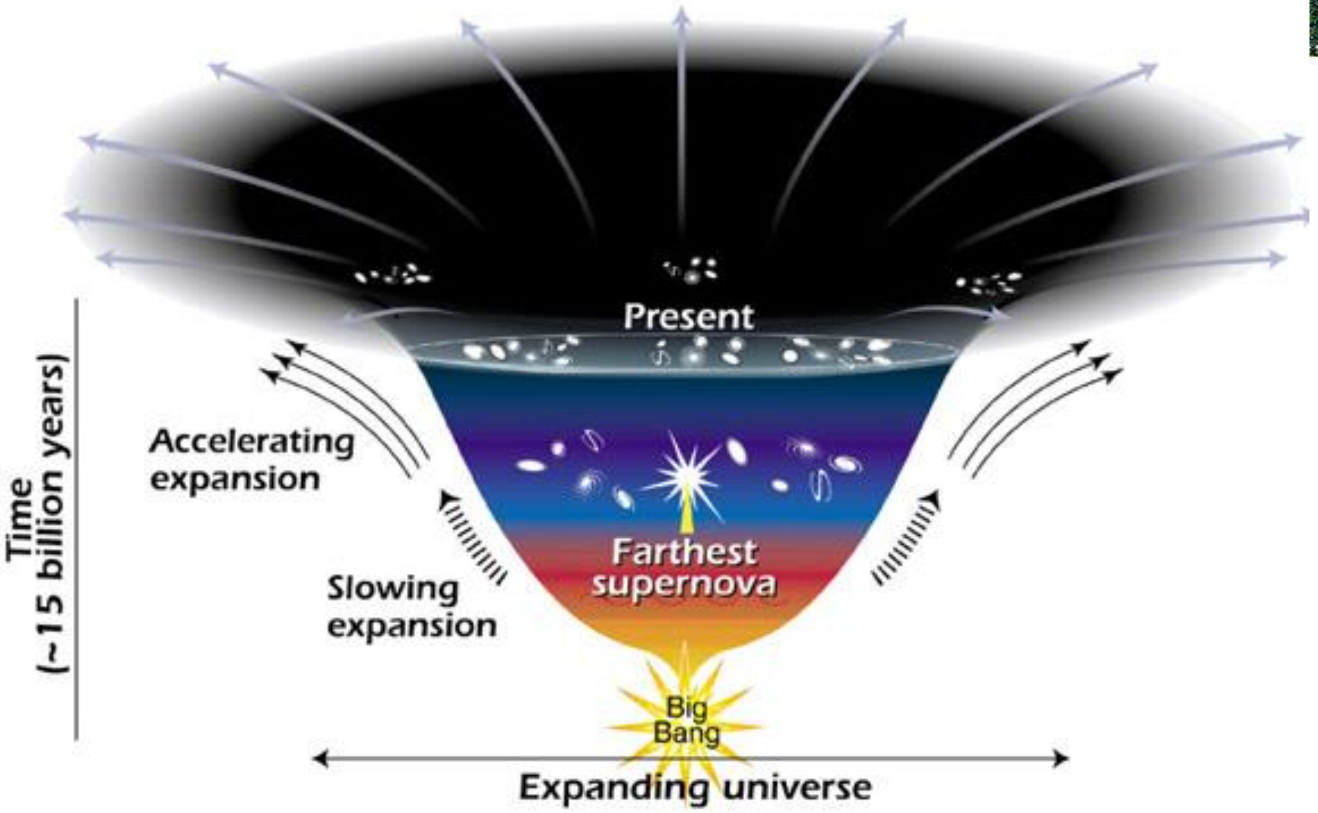
**7** As galaxies cluster together under gravity, the first stars die and spew heavy elements into space; these will eventually form into new stars and planets

NOTE: The numbers in cosmology are so great and the numbers in subatomic physics are so small that it is often necessary to express them in exponential form. Ten multiplied by itself, or 100, is written as $10^2$.

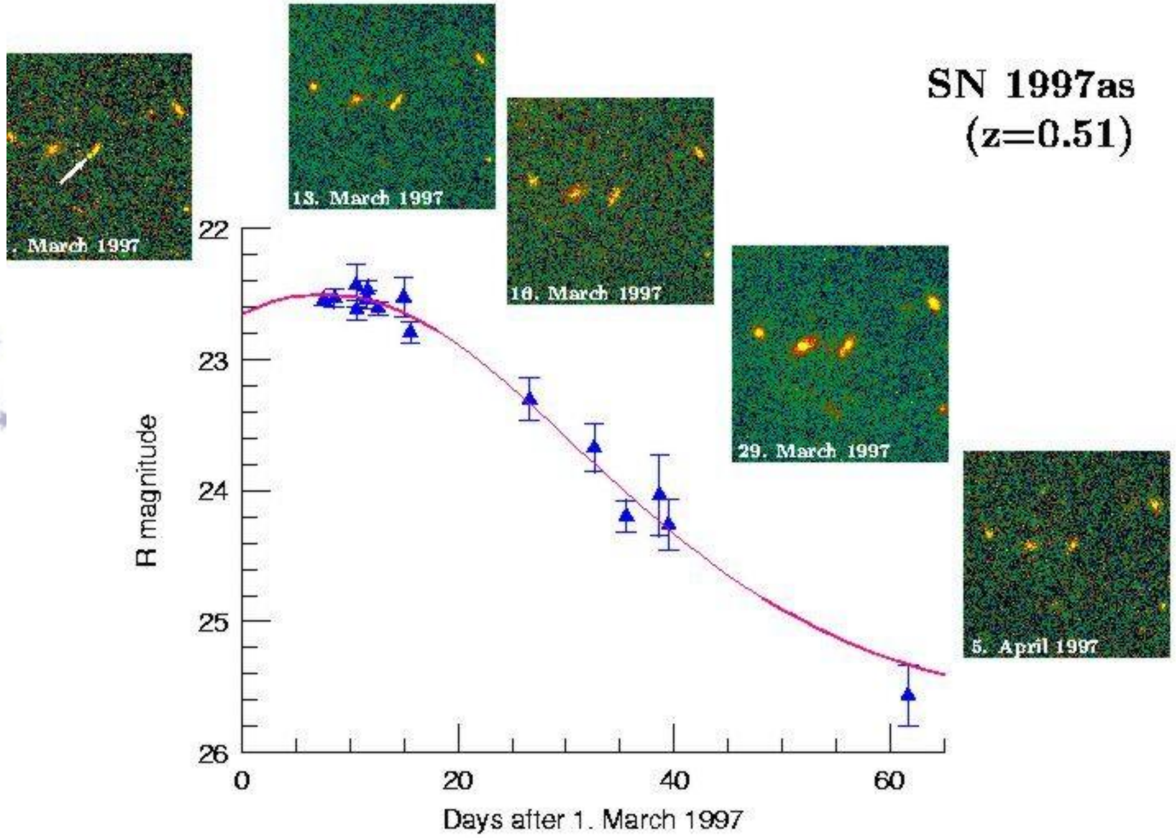
Source: *The Birth of the Universe: The Kingfisher Young People's Book of Space*

TIME Graphic by Ed Gabel

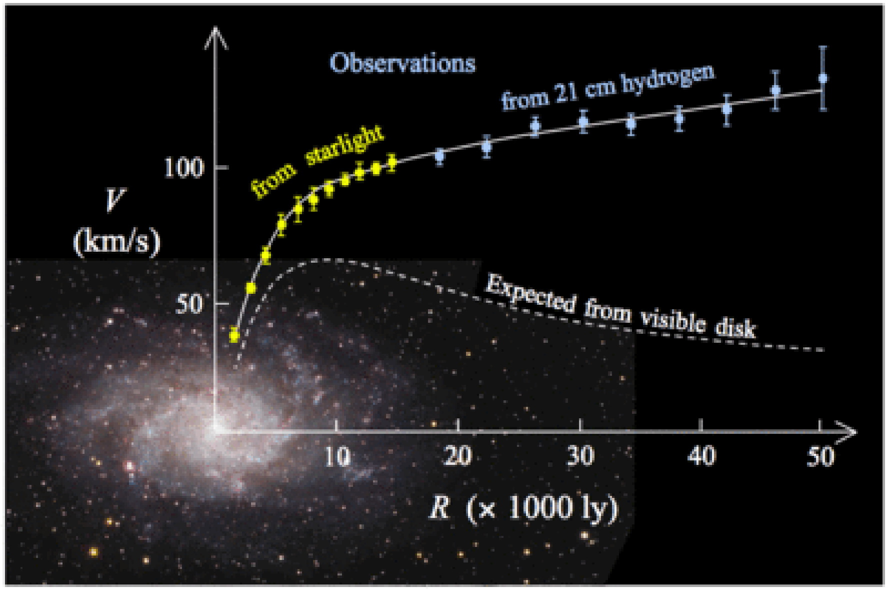
# Kosmologia

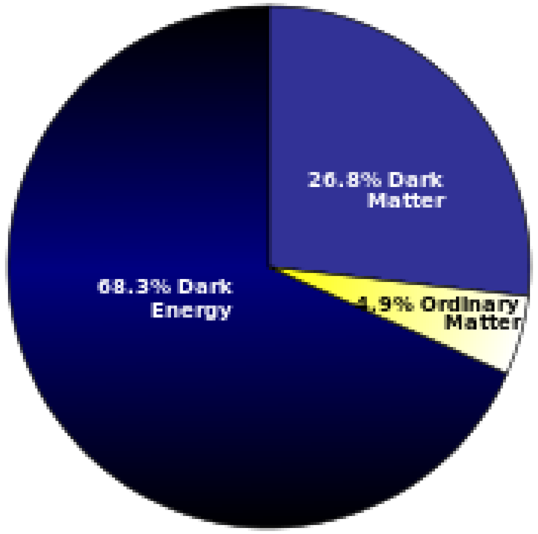


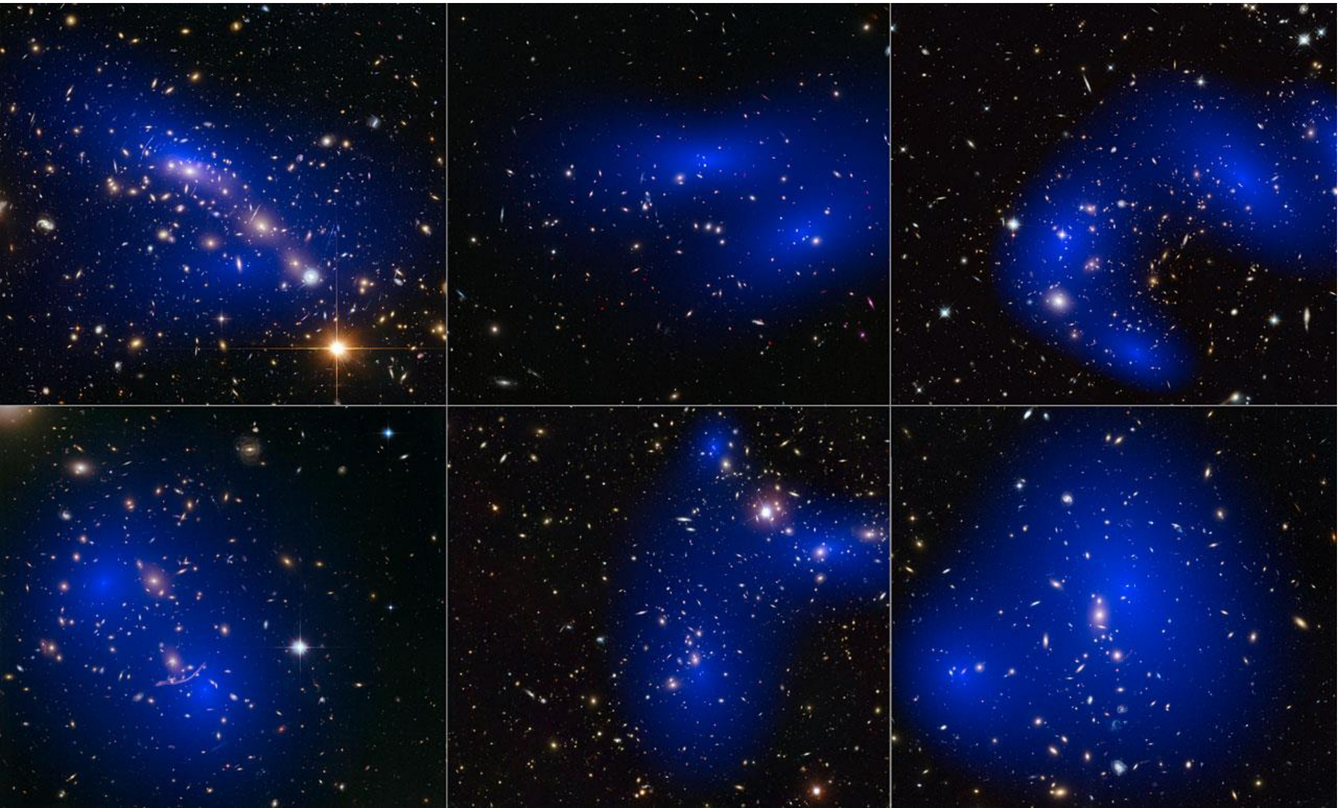
This diagram reveals changes in the rate of expansion since the universe's birth 15 billion years ago. The more shallow the curve, the faster the rate of expansion. The curve changes noticeably about 7.5 billion years ago, when objects in the universe began flying apart at a faster rate. Astronomers theorize that the faster expansion rate is due to a mysterious, dark force that is pushing galaxies apart.

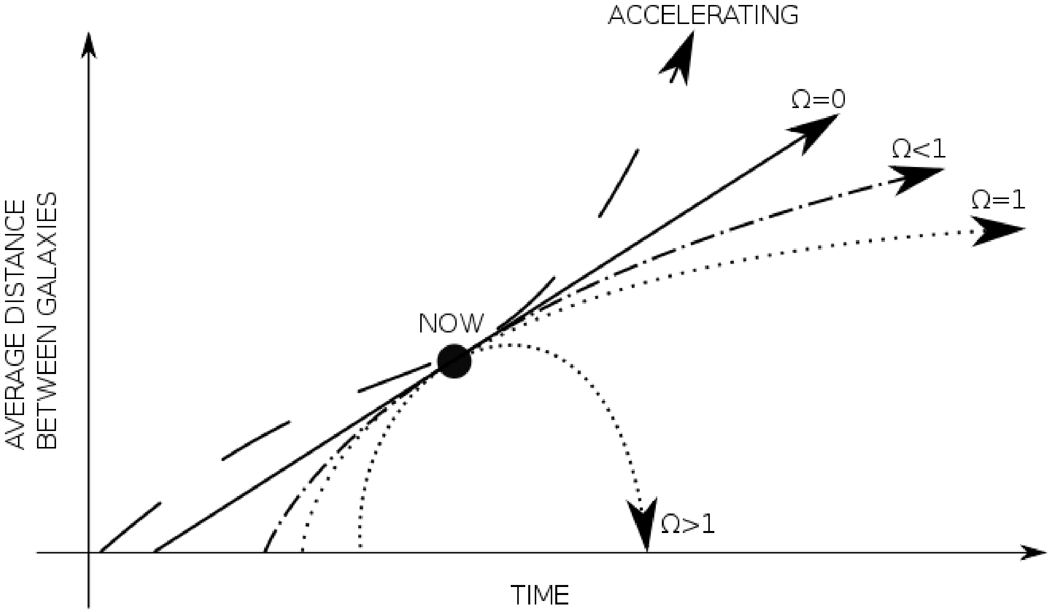


# Ciemna materia
# Ciemna energia









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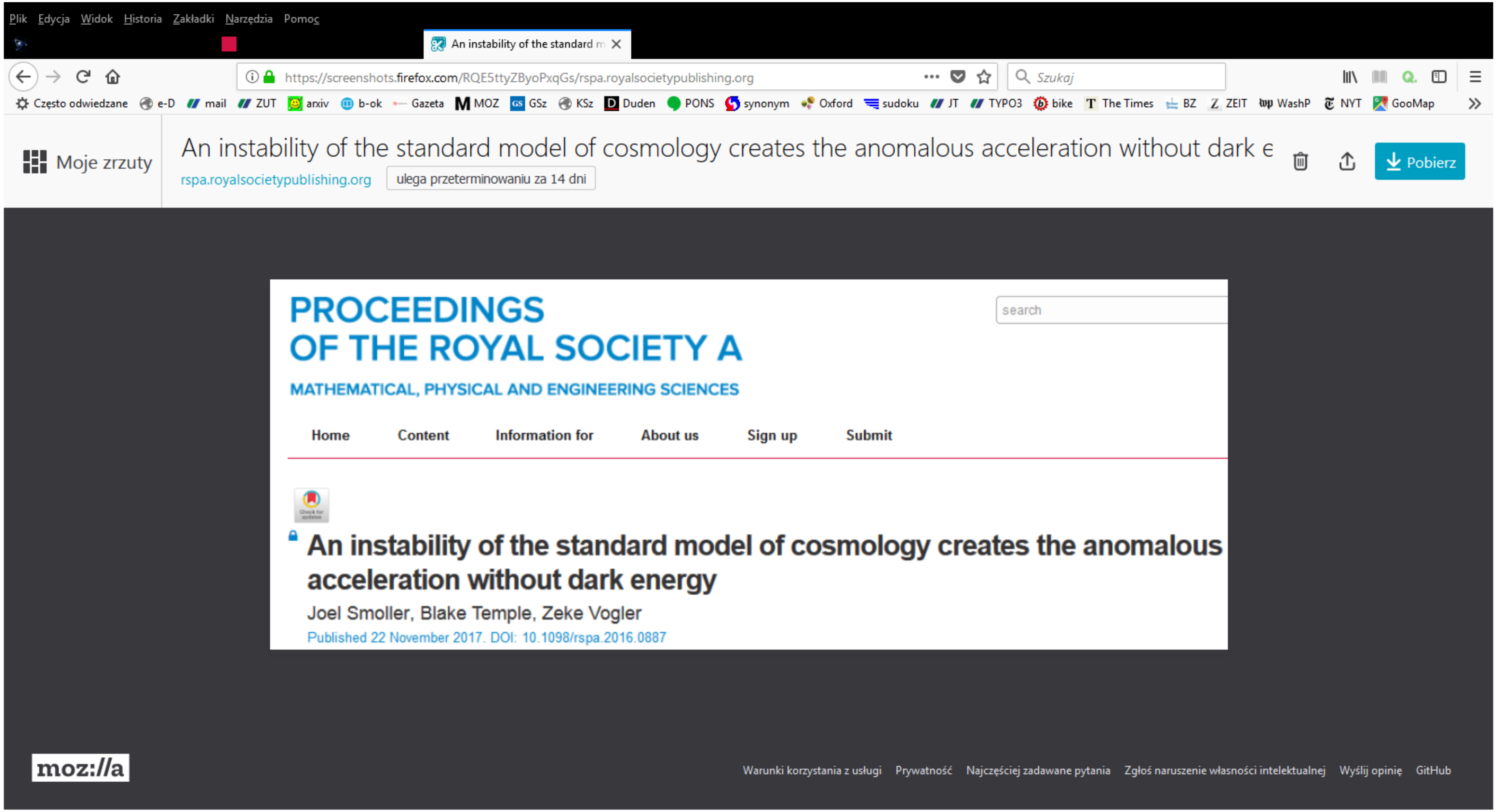

An instability of the standard model of cosmology creates the anomalous acceleration without dark e

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An instability of the standard model of cosmology creates the anomalous acceleration without dark energy

Joel Smoller, Blake Temple, Zeke Vogler

Published 22 November 2017. DOI: 10.1098/rspa.2016.0887