



# The Next Decade in Astronomy

The Unanswered Questions

Dr. Jonathan Crass



# The Next Decade in Astronomy

- Recent discoveries
  - What have we learnt in the last decade?
- What's next?
  - What we don't know
    - The BIG questions
  - Tools for the next decade
- Beyond 2028

# Recent Discoveries

# The Demotion of Pluto

Low graphics | Accessibility help

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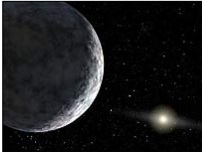
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## Astronomers detect '10th planet'

By Dr David Whitehouse  
Science Editor, BBC news website

**Astronomers in the United States have announced the discovery of the "10th planet" to orbit our Sun.**



The largest object found in our Solar System since Neptune in 1846, it was first seen in 2003 - but important details have only now been confirmed.

Designated 2003 UB313, it is about 2,800km across - a world of rock and ice and somewhat larger than Pluto.

Scientists say it is three times as far away as Pluto, in an orbit at an angle to the orbits of the main planets.

Astronomers think that at some point in its history, Neptune probably flung the small world into its highly inclined 44-degree orbit.

**A comparison of 2003 UB313 and other distant objects**

It is currently 97 Earth-Sun distances away - more than twice Pluto's average distance from the Sun.

### Bigger than Pluto

Its discoverers are Michael Brown of Caltech, Chad Trujillo of the Gemini Observatory in Hawaii, and David Rabinowitz of Yale University.

David Rabinowitz told the BBC News website: "It has been a remarkable day and a remarkable year. 2003 UB313 is probably larger than Pluto. It is fainter than Pluto, but three times farther away.

"Brought to the same distance from the Sun as Pluto, it would be brighter. So today, the world knows that Pluto is not unique. There are other Plutos, just farther out in the Solar System where they are a little harder to find."

**SEE ALSO:**

- Distant object found orbiting Sun 29 Jul 05 | Science/Nature
- 'New planet' forces rethink 17 Mar 04 | Science/Nature
- Astronomers discover 'new planet' 15 Mar 04 | Science/Nature
- New world found far beyond Pluto 03 Mar 04 | Science/Nature
- Huge rock-ice body circles Sun 17 Nov 03 | Science/Nature
- Large world found near Pluto 03 Jul 01 | Science/Nature

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- Discovery announcement
- The BBC is not responsible for the content of external internet sites

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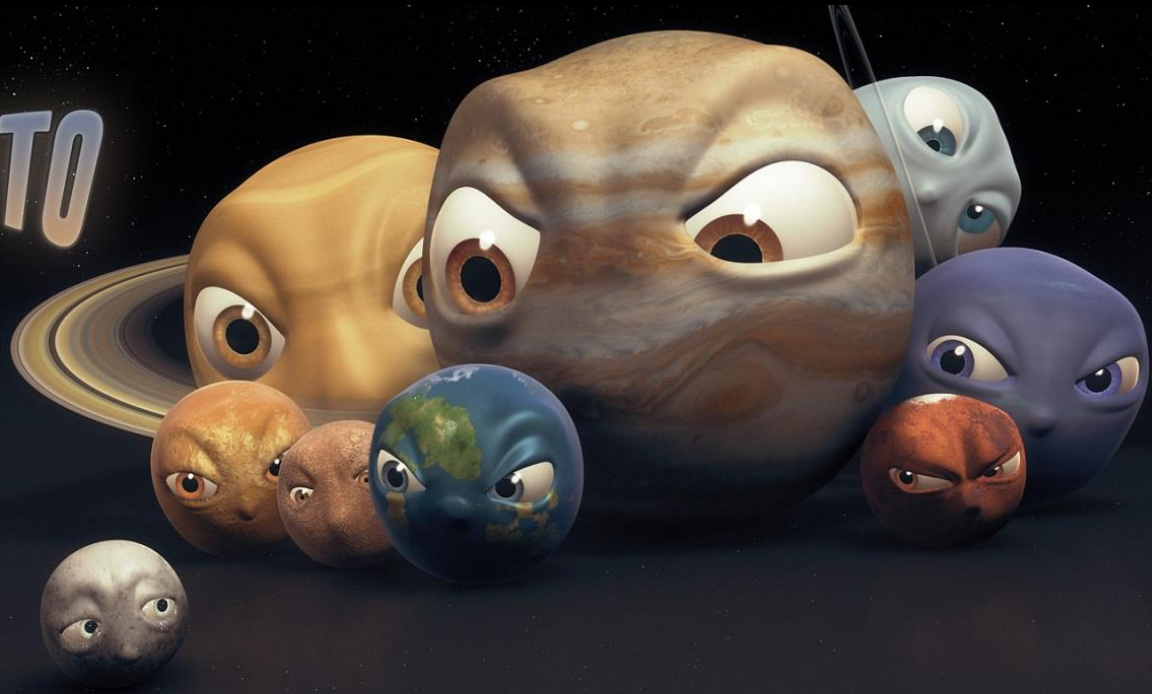


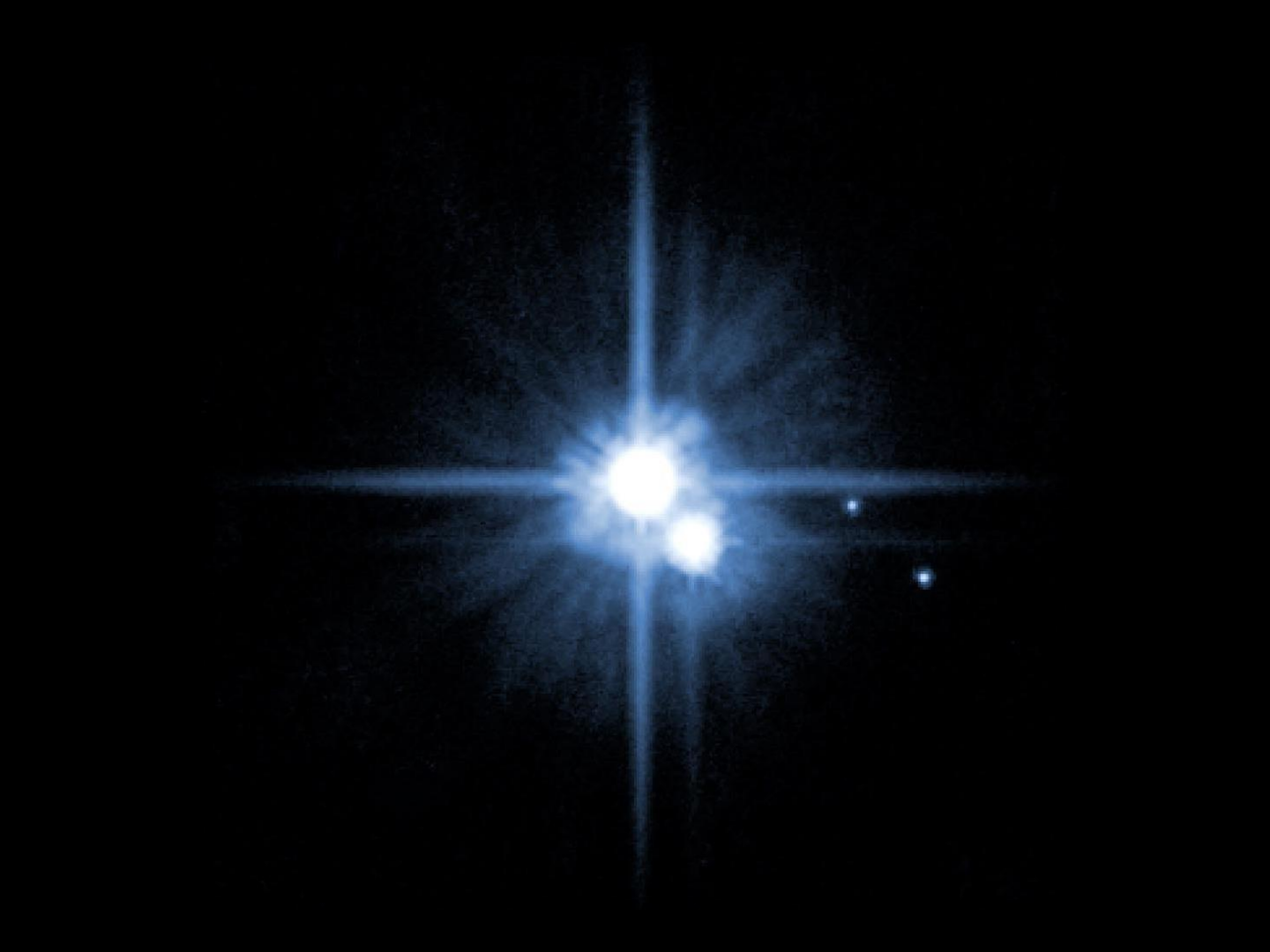
**RESOLUTION 84**  
The 25th Executive resolves that plans and other bodies  
except candidates in that Order System be defined into three  
distinct categories in the following way:

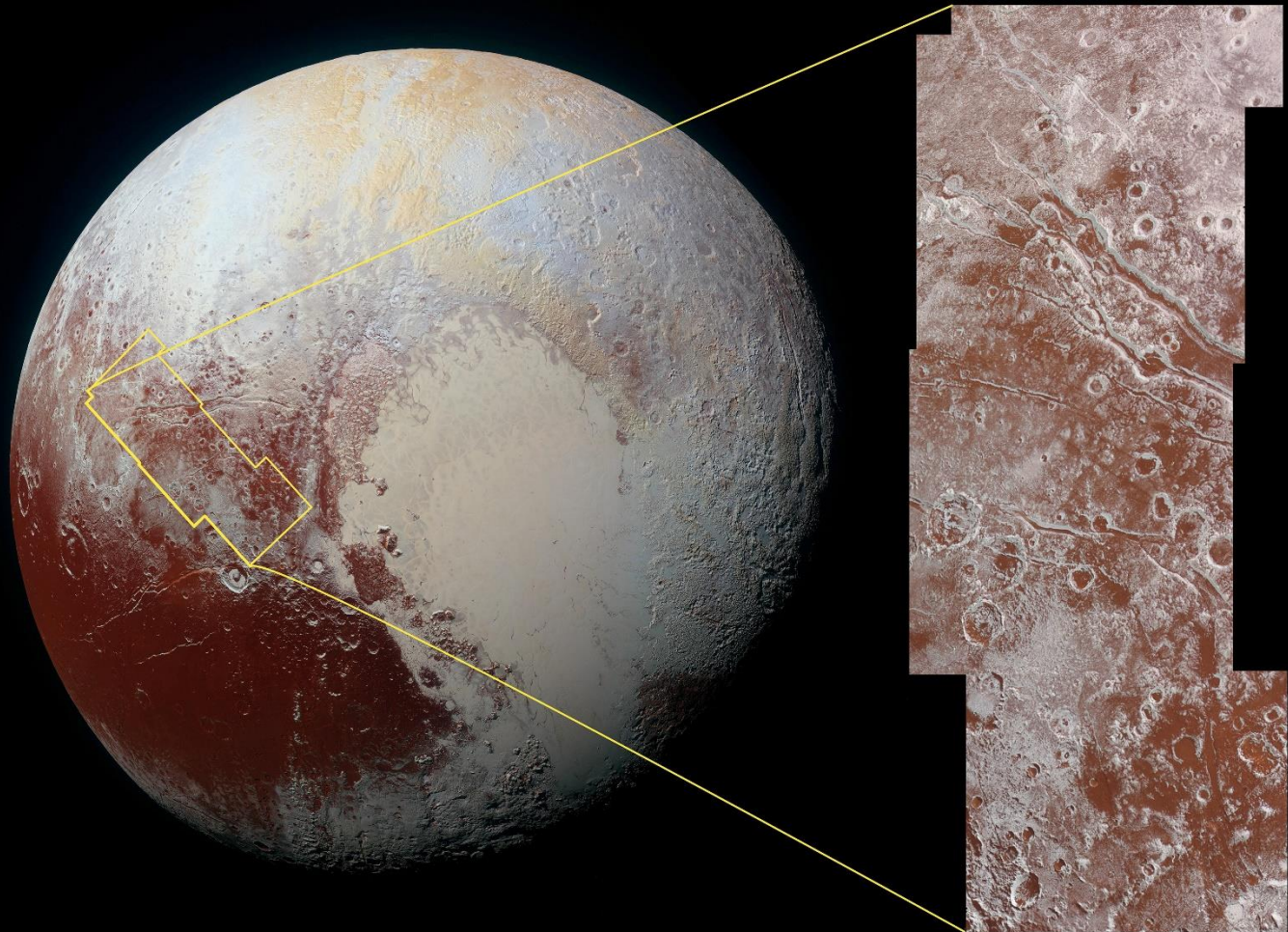
- 1. A "power" is a central body that is in order around the  
25th or has sufficient means for its self-governance to overcome  
any body forces so that it assumes a 100% total  
majority within its own sphere and is fully elected the  
majority around to order.
- 2. A "near power" is a central body that is in order  
around the 25th, it has sufficient means for its self-governance  
to overcome any body forces so that it assumes a  
majority within its own sphere, it is fully elected the  
majority around to order, and
- 3. A "non power" is a central body that is in order  
around the 25th, it has sufficient means for its self-governance  
to overcome any body forces so that it assumes a  
majority within its own sphere, it is fully elected the  
majority around to order, and

1. All other bodies, except candidates, existing in the Order System  
shall be defined as "Other Order System Bodies".

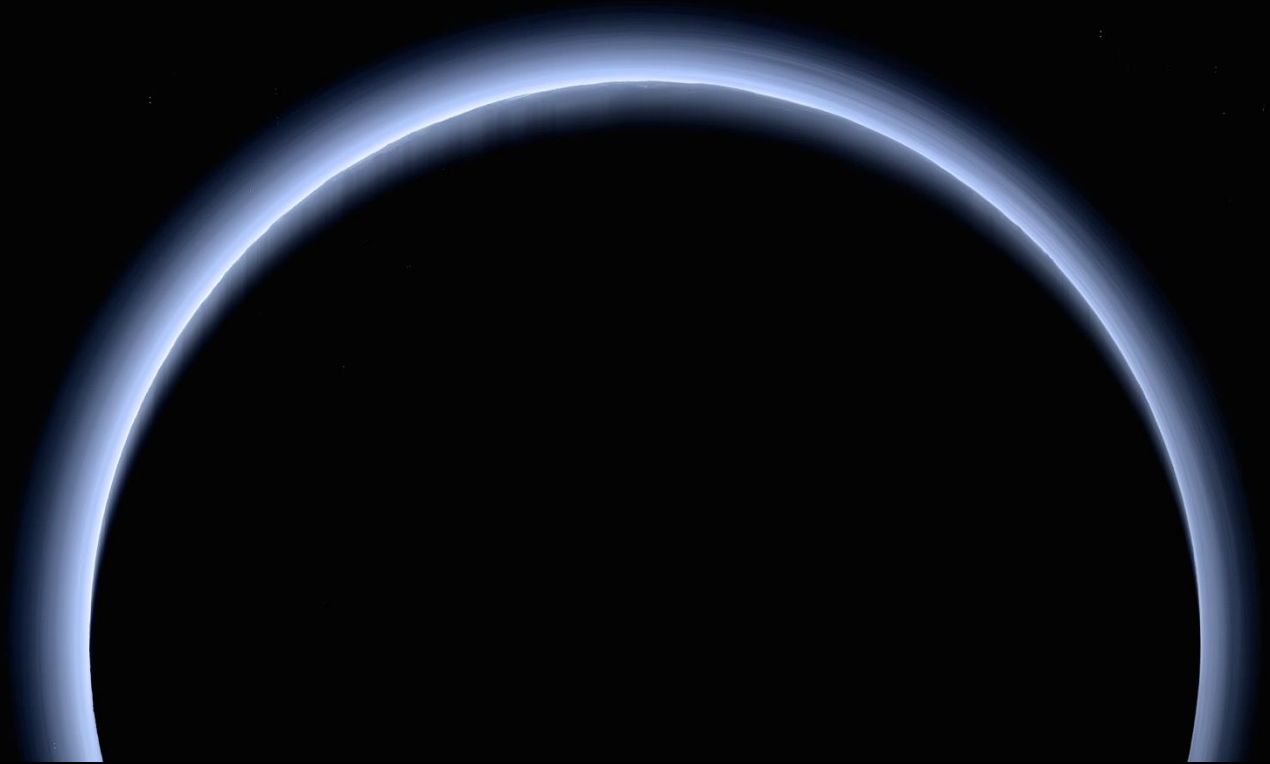
POOR  
PLUTO



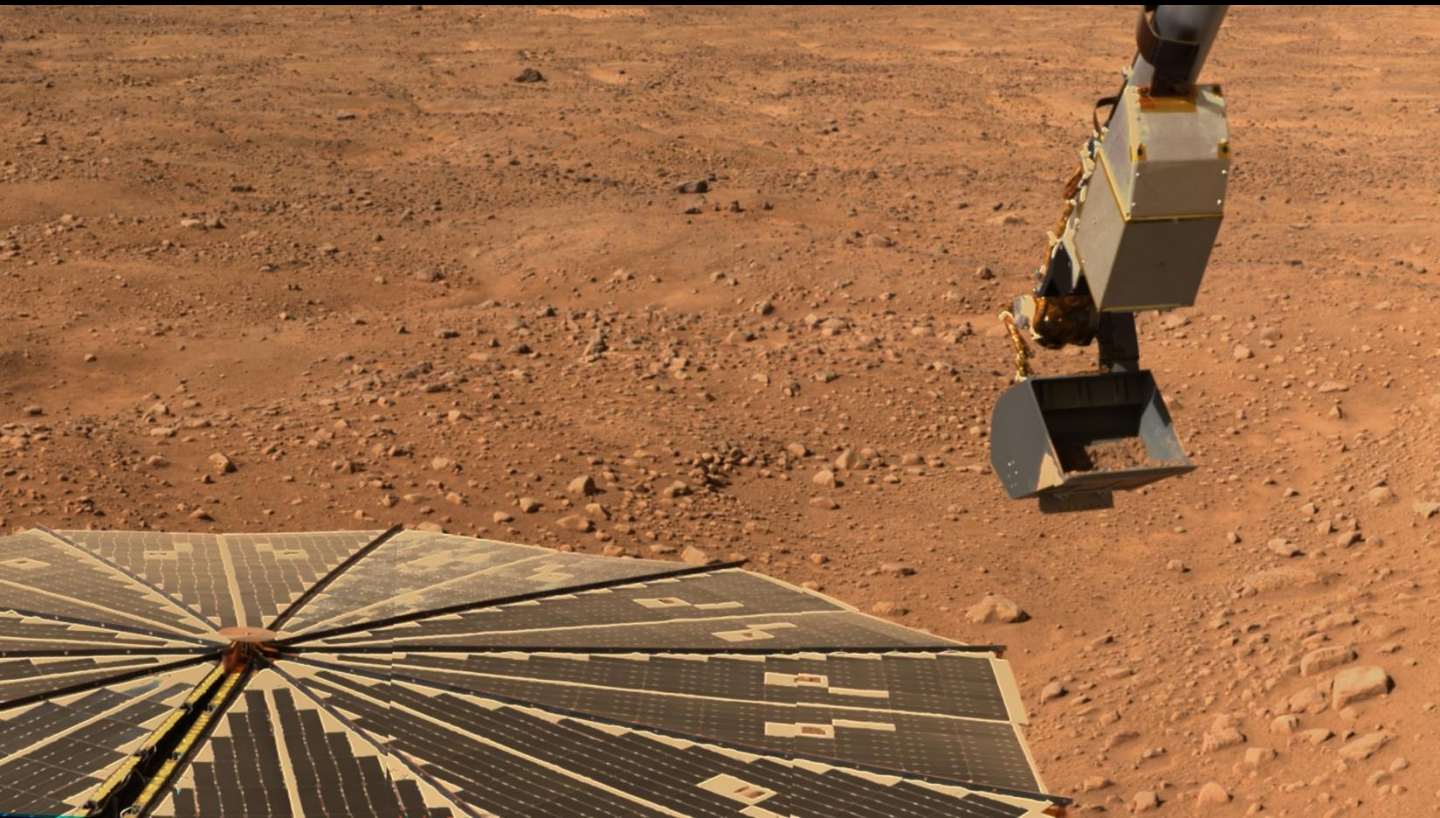


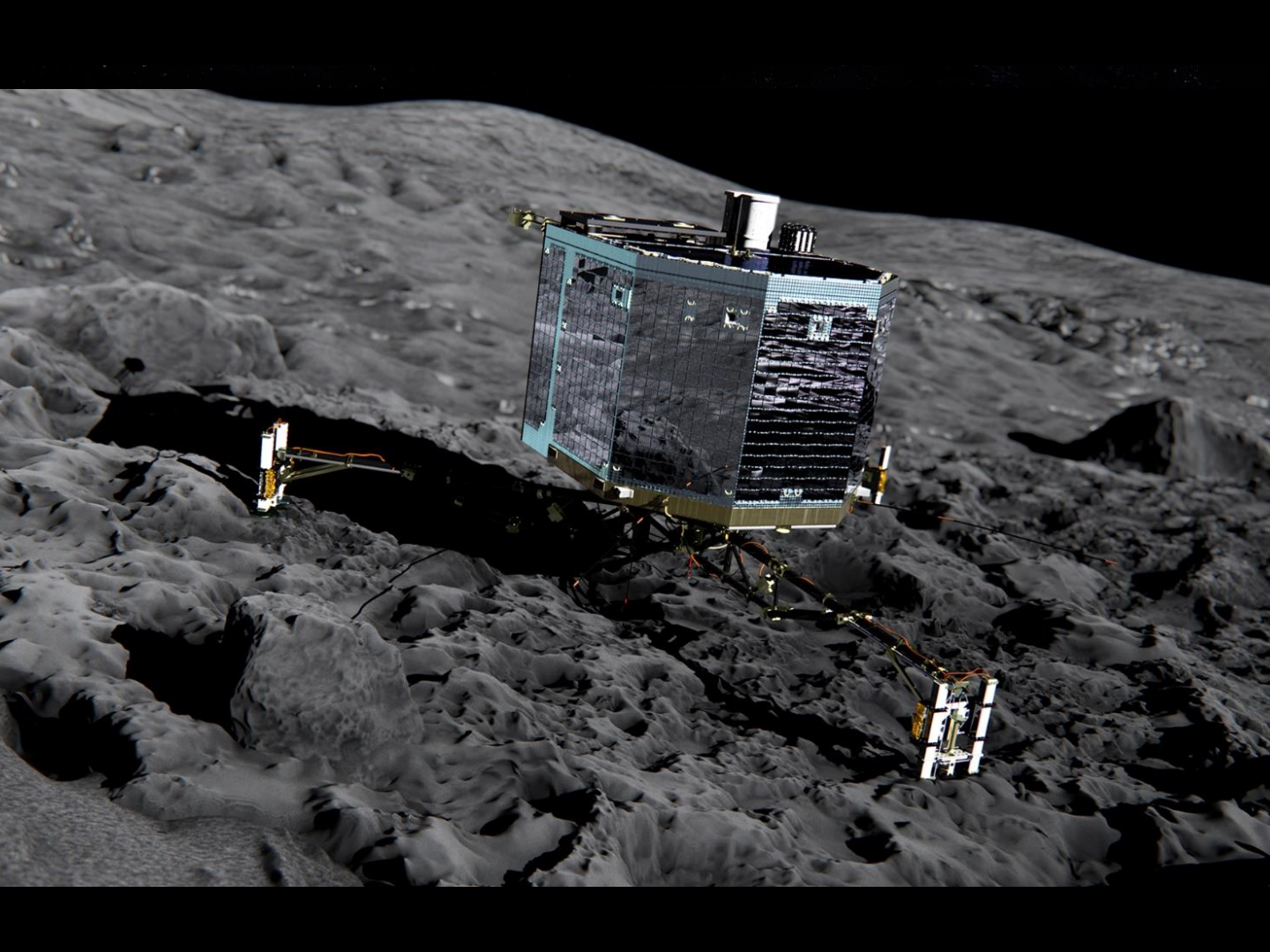


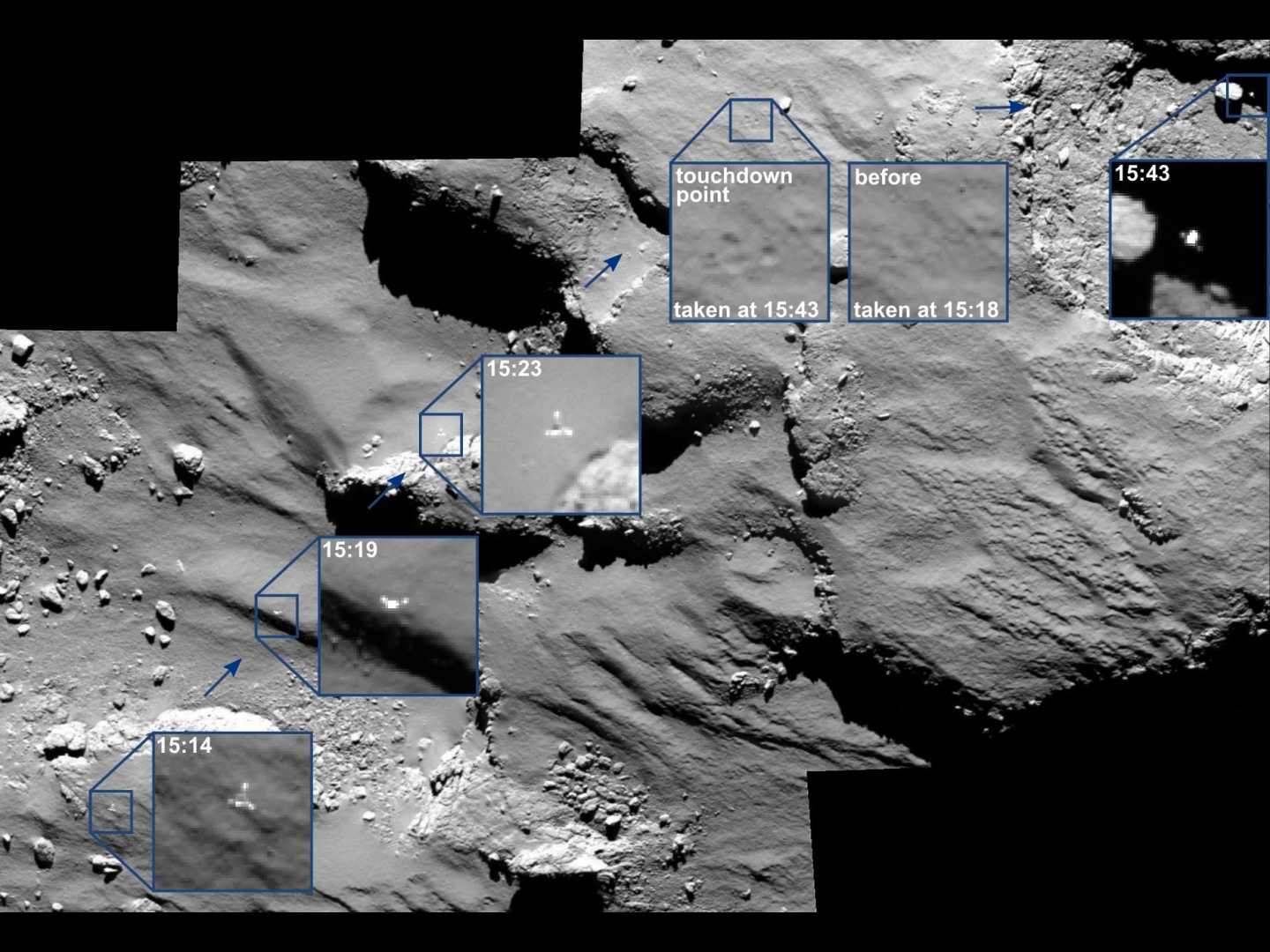




# Water in the Solar System







touchdown  
point

before

15:43

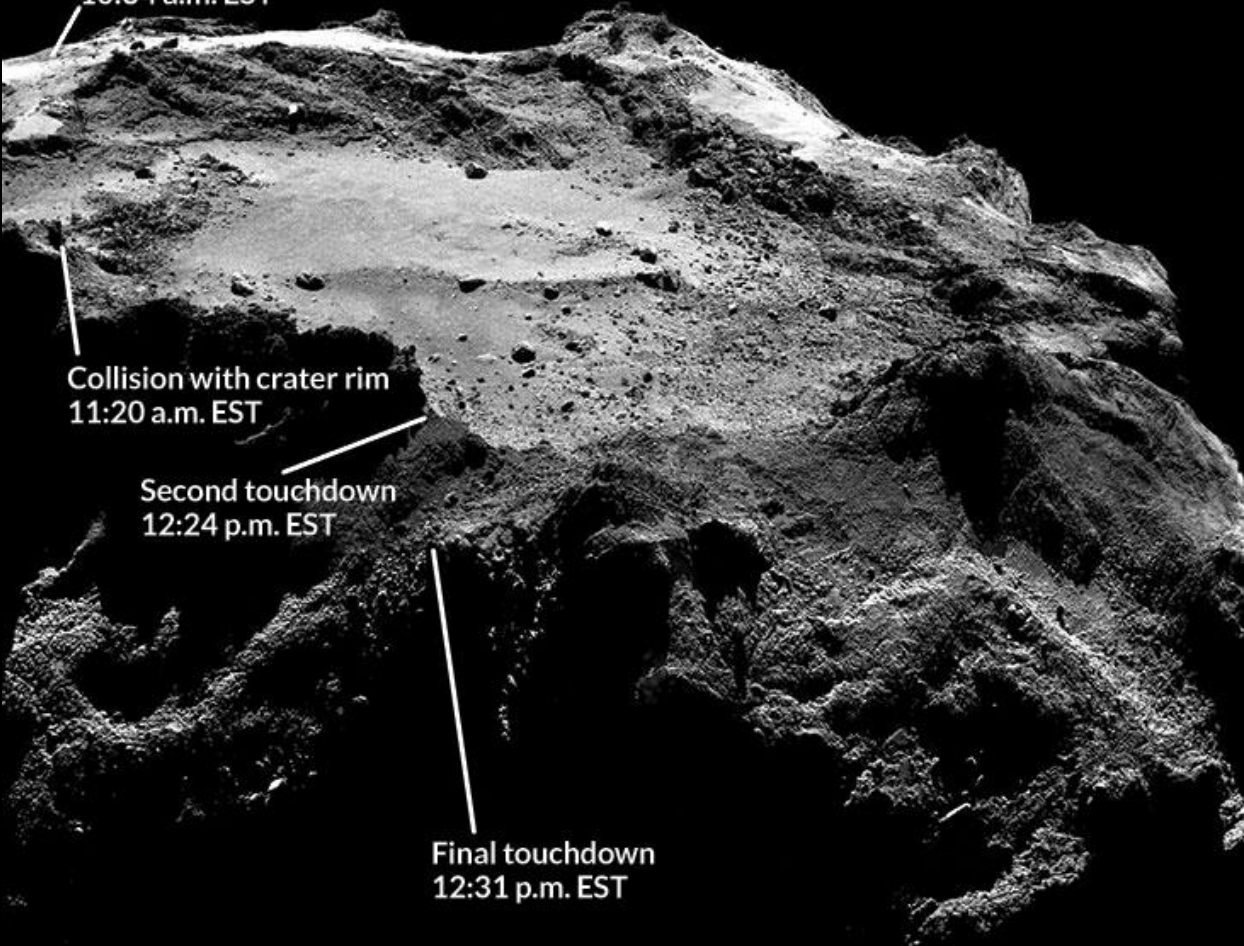
taken at 15:43

taken at 15:18

15:23

15:19

15:14



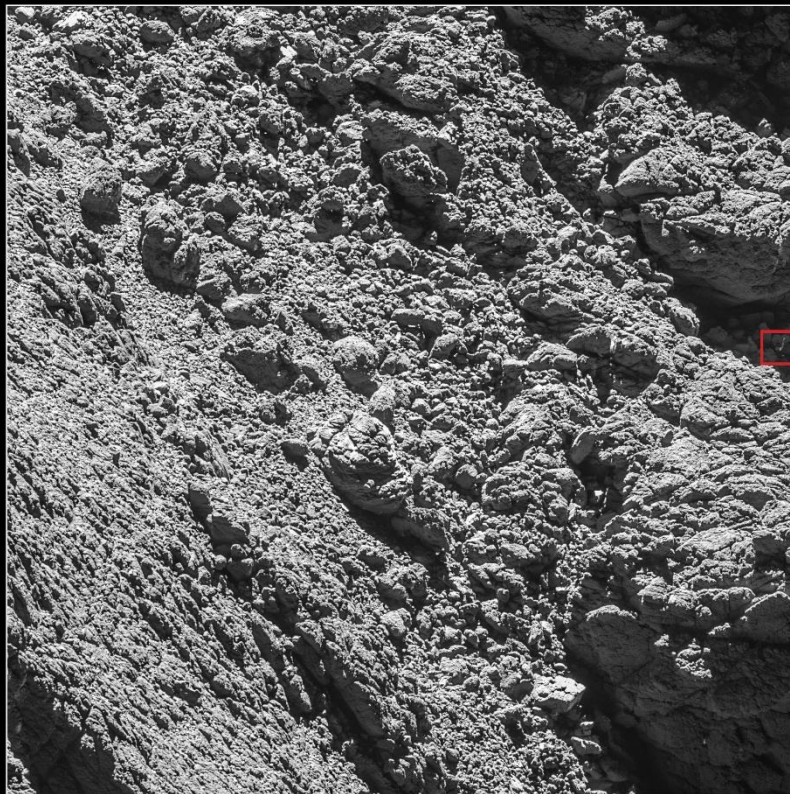
First touchdown  
10:34 a.m. EST

Collision with crater rim  
11:20 a.m. EST

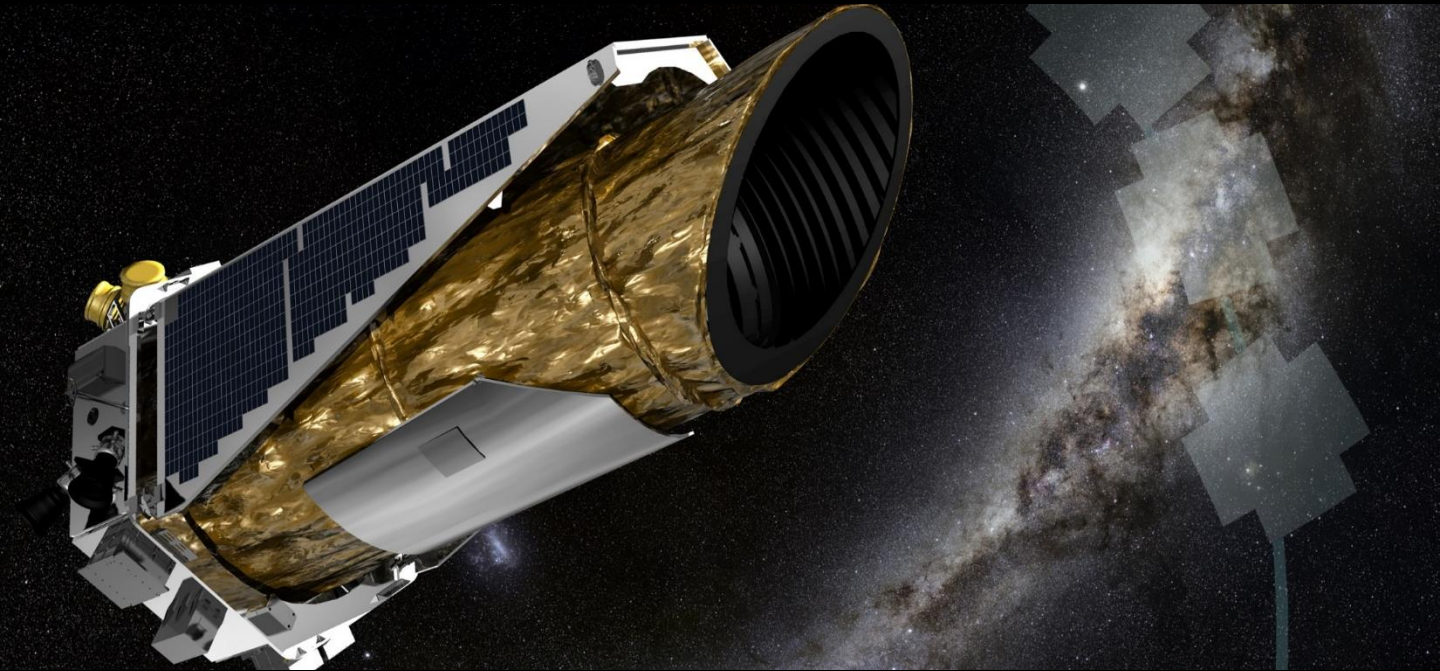
Second touchdown  
12:24 p.m. EST

Final touchdown  
12:31 p.m. EST





# The Discovery Exoplanets





# 3706 confirmed planets

2,900 discovered by transit method  
669 discovered by radial velocity  
44 discovered by imaging

54 discovered by microlensing  
39 discovered using other methods

# IS ANYBODY OUT THERE? Earth-like planet Ross 128b may be a 'comfortable' home for alien life and it's getting closer by the day

Astronomers spot mystery world which could finally answer the question of whether we're alone in the universe

By Margi Murphy  
10th November 2017, 11:00 am | Updated: 10th November 2017, 2:54 pm



COMMENT NOW

A PLANET the same size of Earth and with a similar surface temperature... closest known comfortable abode...

# The galaxy's best bet for alien life? Planet the same size and temperature as our own found just 11 light years away may be the 'closest known home for life' (and it's moving closer to us every day)

- The planet, named Ross 128b, was found orbiting a red dwarf star
- It is the same size as Earth and has a similar surface temperature
- It is currently 11 light years away, and would take 141,000 years to reach
- But the planet is slowly moving towards us, and is expected to be closer than Proxima B in 79,000 years

By SHIRAZI BEST FOR MAILONLINE  
PUBLISHED: 11:00, 15 November 2017 | UPDATED: 17:25, 15 November 2017

6.2k SHARES

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# New Earth-Size Planet Found Around Nearby Star

The potentially habitable world is called Ross 128b, and it sits just 11 light-years away.

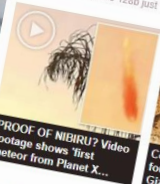
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Home News Weird Nibiru FOUND? Scientists locate Earth-sized planet Ross 128b just 11 light-years away



# Nibiru FOUND? Scientists locate Earth-sized planet Ross 128b just 11 light-years away

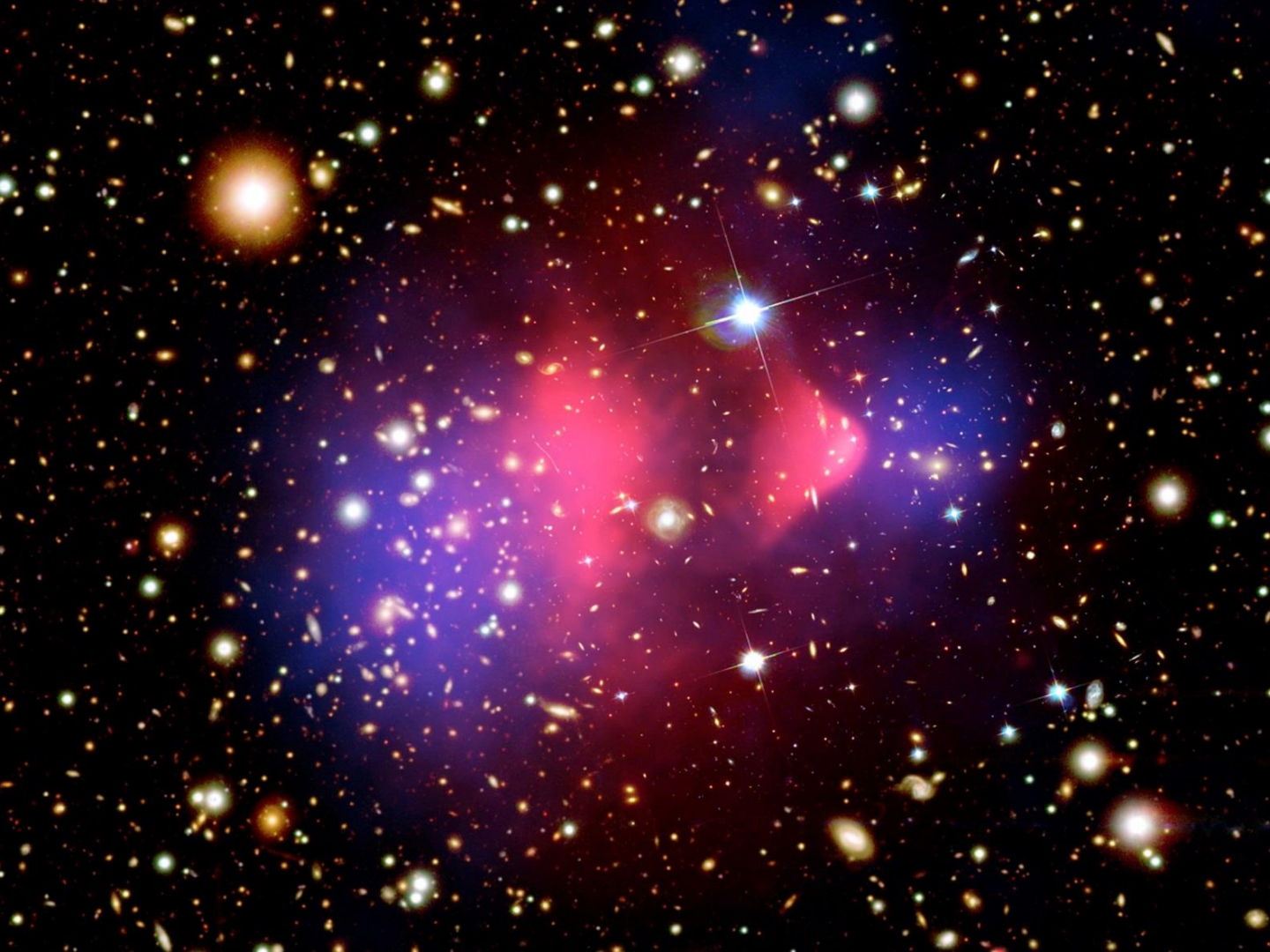
ASTRONOMERS have discovered an Earth-like planet called Ross 128b with similar temperatures which could harbour alien life – the very thing Nibiru conspiracy theorists have alleged is real.

By SEAN MARTIN  
PUBLISHED: 15:19, Wed, Nov 15, 2017 | UPDATED: 16:52, Wed, Nov 15, 2017

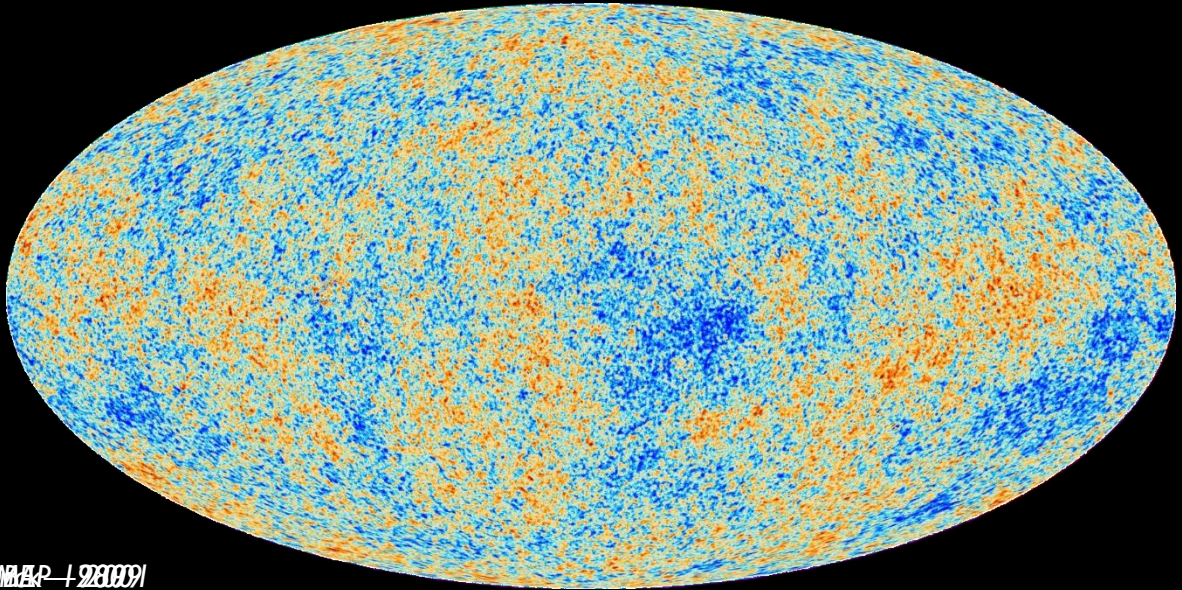
# Dark Matter

- Up until 2006, we'd only seen the 'effects' of there being more mass
  - Galaxy Rotation Curves
  - Fluctuations in the Cosmic Microwave Background





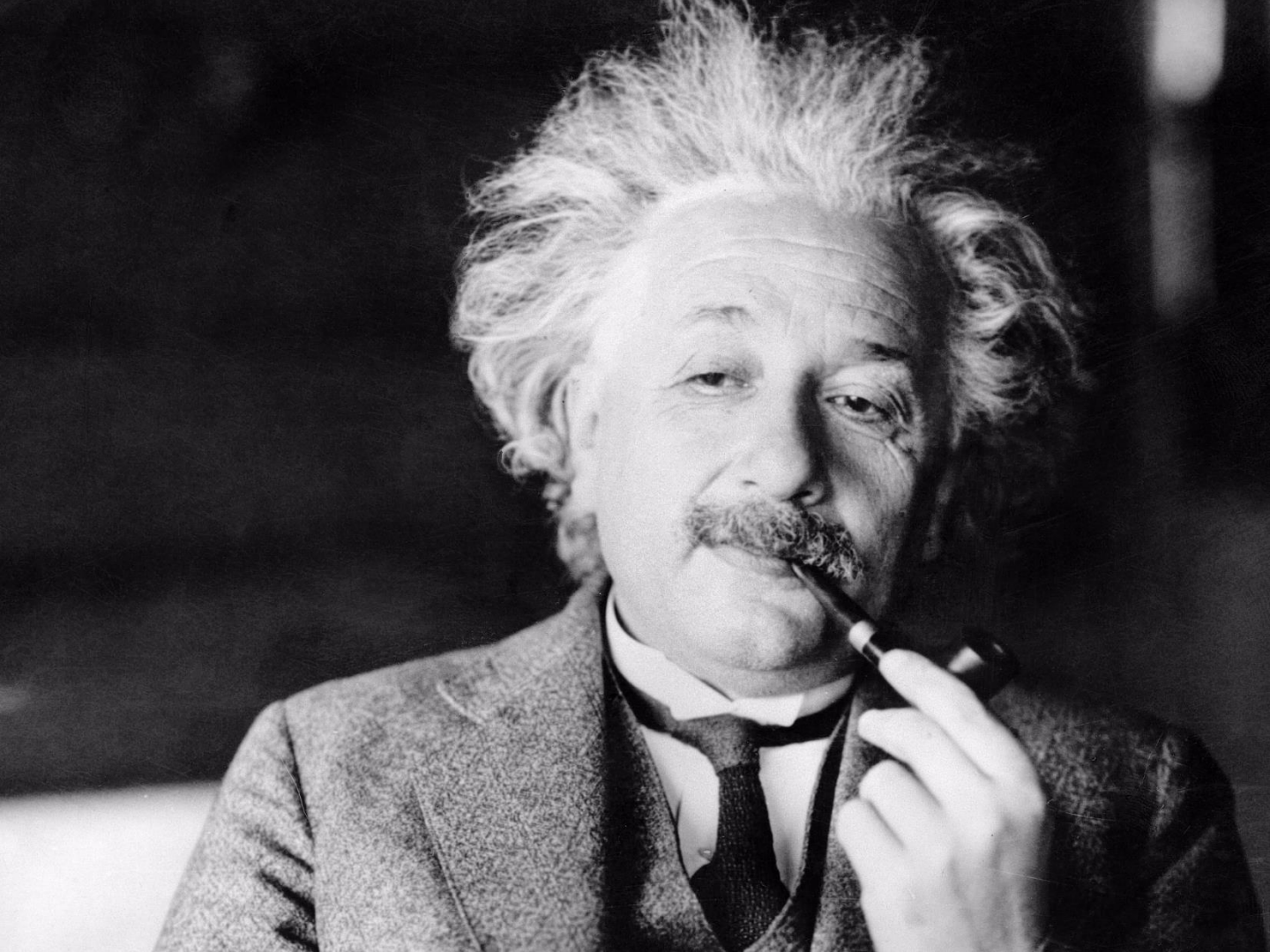
# The Big Bang



COBE/DMSP-1 22800091

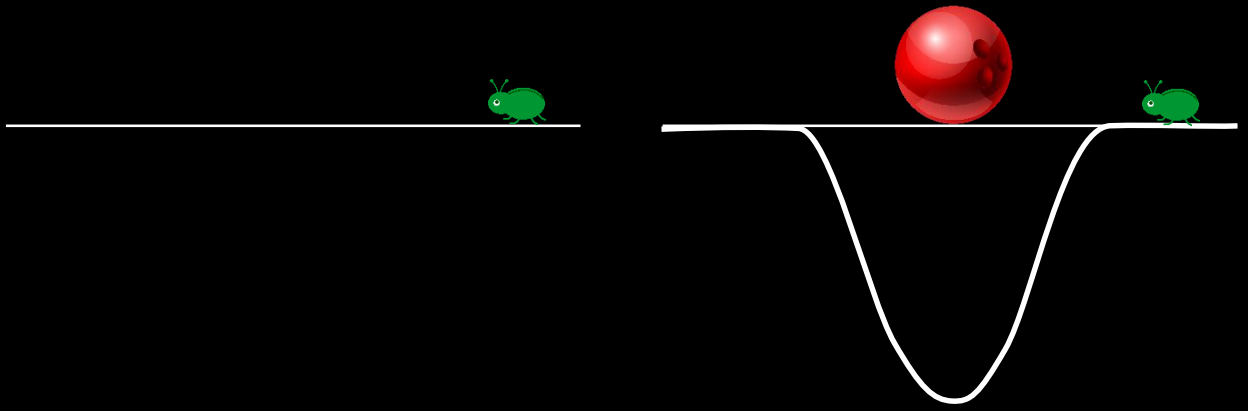
# The Big Bang

	Age of the Universe (Billion Years)	Hubble Constant ( $\text{km s}^{-1} \text{Mpc}^{-1}$ )	Baryons	Dark Matter	Dark Energy
WMAP	13.69	69.32	4.6%	24.0%	71.4%
Planck	13.82	67.3	4.9%	26.8%	68.3%

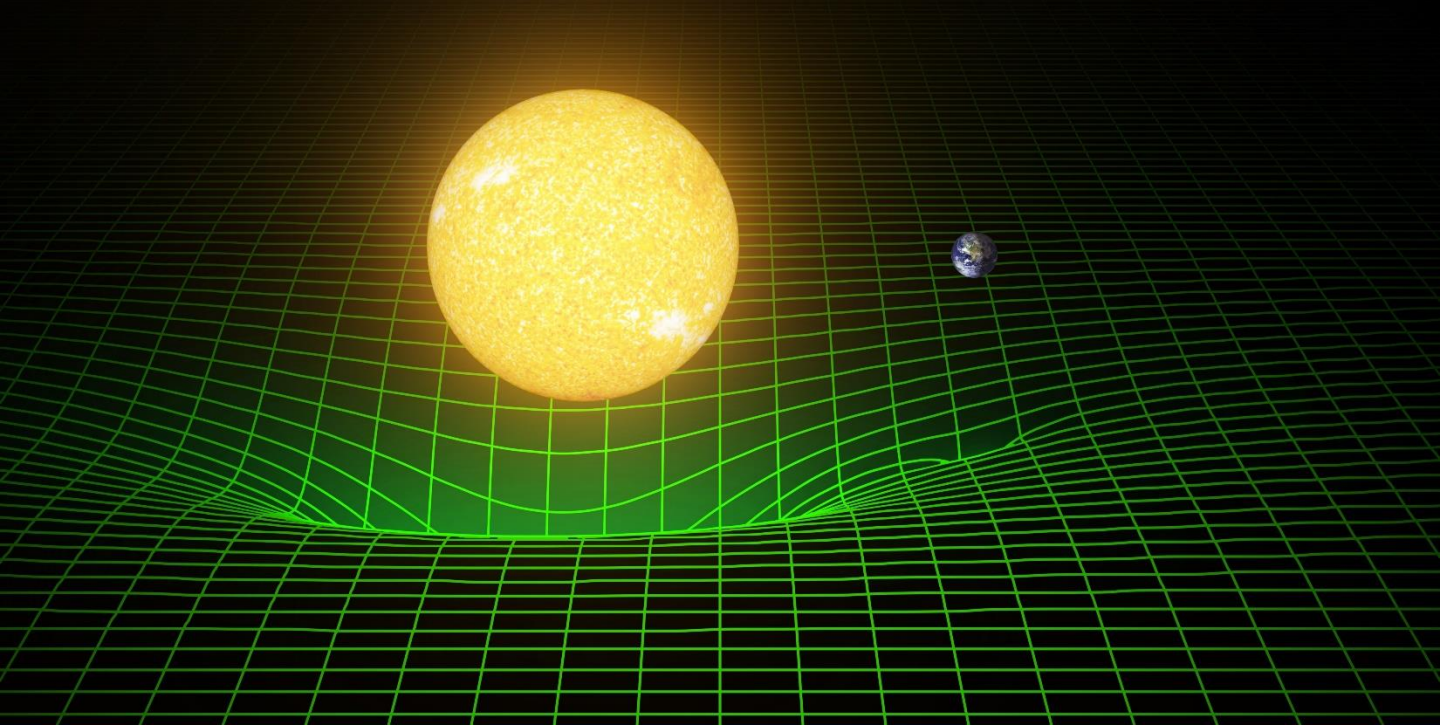




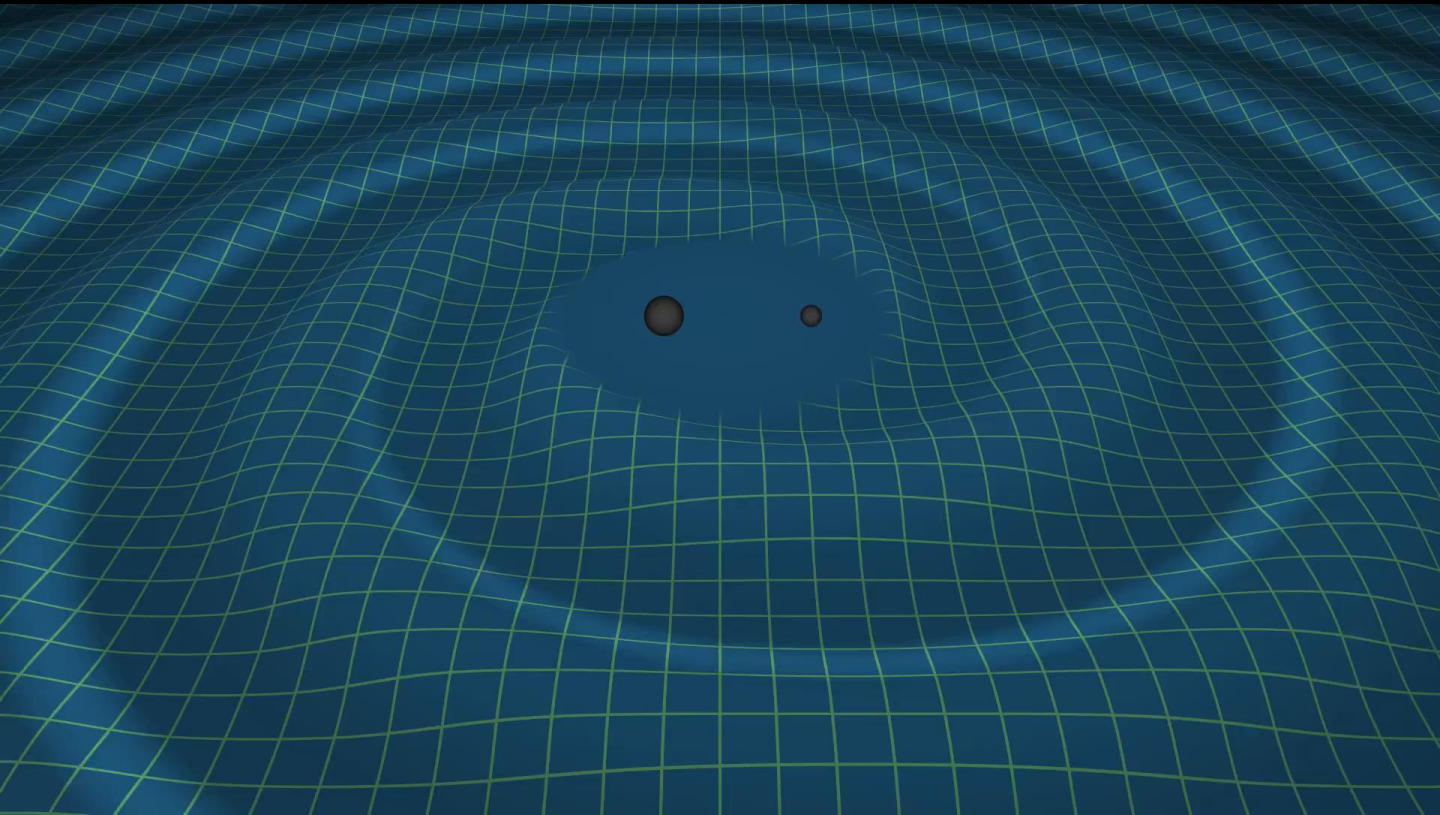
# Gravitational Waves



# Gravitational Waves



# Gravitational Waves





# Maybe Gravitational Waves & Inflation

BBC NEWS ENVIRONMENT

17 March 2014 Last updated at 10:46 ET

## Cosmic inflation: 'Spectacular discovery' hailed

By Jonathan Amos  
Science correspondent, BBC News



The measurements were taken using the BICEP2 telescope facility at the South Pole.

Scientists say they have extra evidence to support a Big Bang Theory for the origin of the universe.

Researchers believe the ripples in the sky by the super-rapid expansion of the universe have occurred just fractions of a second after everyth...

**Inflation: A compact guide to big science All the Universe's matter is mapped**

nature International weekly journal of science

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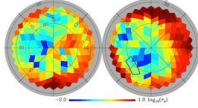
Archive | Volume 507 | Issue 7452 | News | Article

NATURE | BREAKING NEWS

## Telescope captures view of gravitational waves

Images of the infant Universe reveal evidence for the Big Bang.

Ron Colwell  
17 March 2014




Full-galaxy dust map muddles search for gravitational waves

Planck probe's survey of polarized light casts further doubt on BICEP2 discovery claims and could complicate Planck's own plans.

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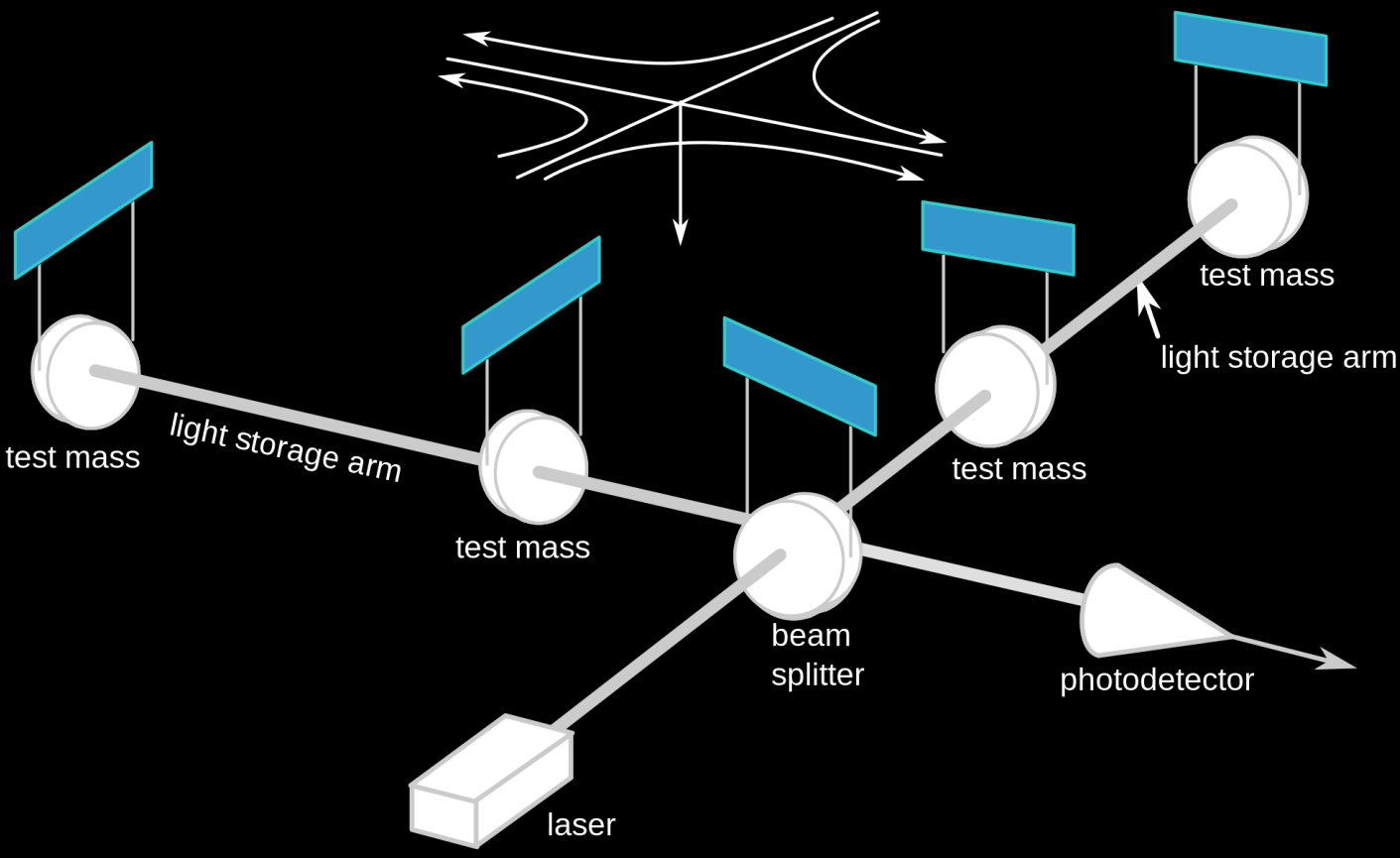
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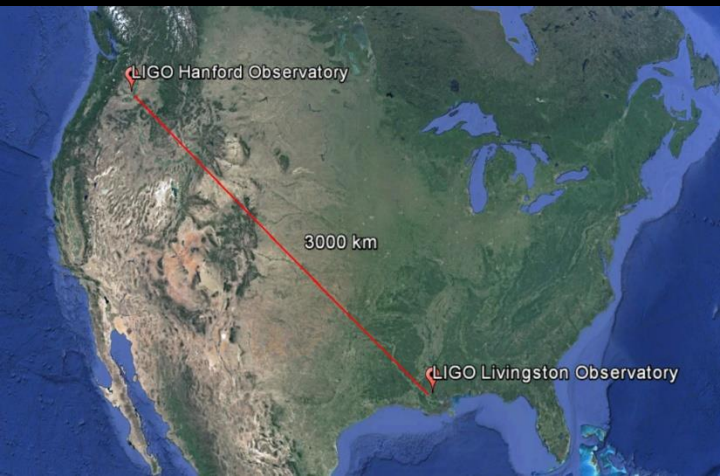
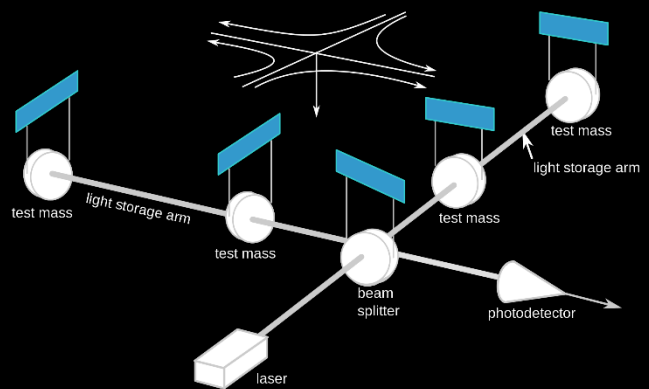
1. Earth has water older than the Sun  
*Nature* | 26 September 2014
2. Forensic chemistry could stop African plant thieves  
*Nature* | 26 September 2014
3. Stone Age groups made similar toolmaking breakthroughs  
*Nature* | 25 September 2014
4. UN climate summit scores high on passion  
*Nature* | 25 September 2014
5. Force of nature gave life its asymmetry  
*Nature* | 25 September 2014

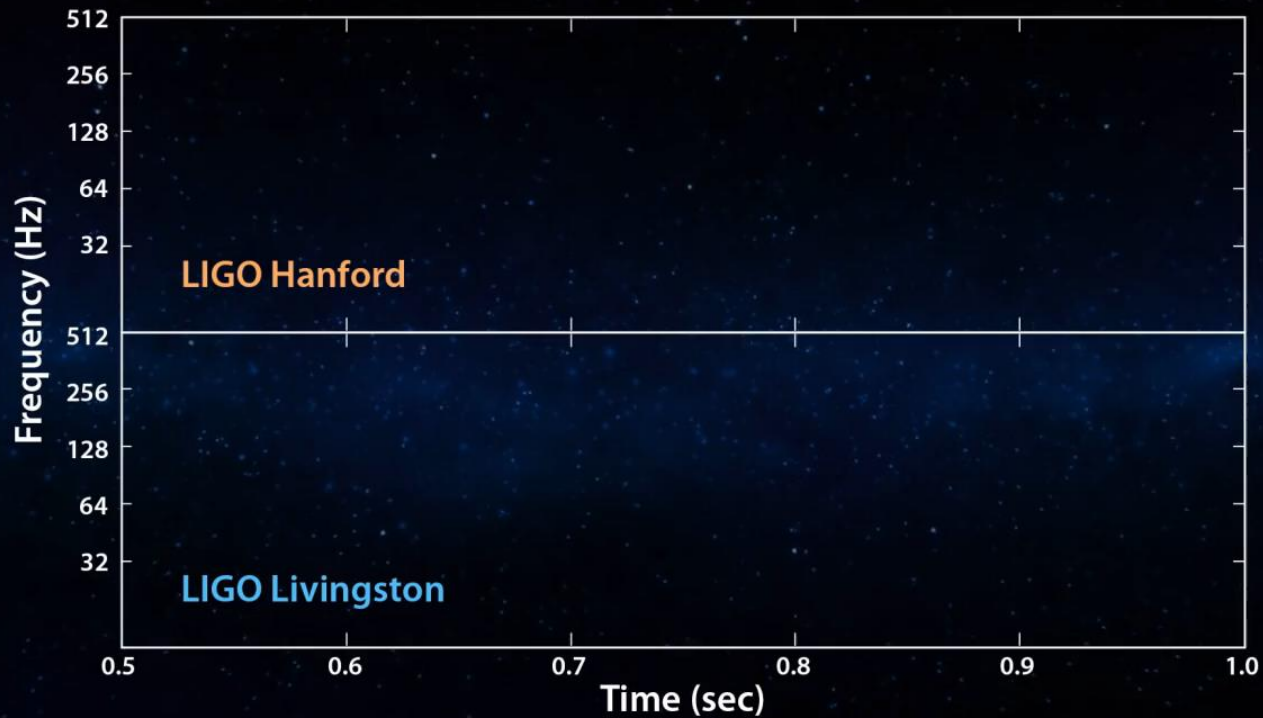


Astronomers have peered back to nearly the dawn of time and found what seems to be the first 'smoking gun' for the theory that the Universe underwent a spurt of wrenching, exponential growth called inflation during the first tiny fraction of a second of its existence.











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Science & Environment

## Einstein's waves win Nobel Prize in physics

By Paul Rincon and Jonathan Amos  
BBC Science News

3 October 2017 | Science & Environment

Weiss (L) takes half the prize, Thorne (C) and Barish (R) share the other half

the guardian

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## Nobel prizes

### Nobel prize in physics awarded for discovery of gravitational waves

£625,000 prize awarded to Rainer Weiss, Barry Barish and Kip Thorne for their work on Ligo experiment which was able to detect ripples in the fabric of spacetime

Live reaction to the scientists from Ligo winning the physics Nobel

20,397 views  
283 likes  
Hannah Devlin and Ian Sample  
Twitter 3 October 2017 11:21 EDT

Nobelprize.org

The Official Web Site of the Nobel Prize

## 2017 Nobel Laureates

### 2017 PHYSICS PRIZE QUESTION

Did you know that gravitational waves were predicted by Albert Einstein a hundred years ago?

Share this: English (great), Swedish (great)

## Press Release: The Nobel Prize in Physics 2017

3 October 2017

The Royal Swedish Academy of Sciences has decided to award the Nobel Prize in Physics 2017 with one half to

Rainer Weiss  
LIGO/VIRGO Collaboration

and the other half jointly to

Barry C. Barish  
LIGO/VIRGO Collaboration

and

Kip S. Thorne  
LIGO/VIRGO Collaboration

for decisive contributions to the LIGO detector and the observation of gravitational waves

### Gravitational waves finally captured

1 September 2015, the universe's gravitational waves were captured for the very first time. The waves, which were predicted

SCIENCE

## 2017 Nobel Prize in Physics Awarded to LIGO Black Hole Researchers

IN DEMAND VIDEO: OCT 3, 2017

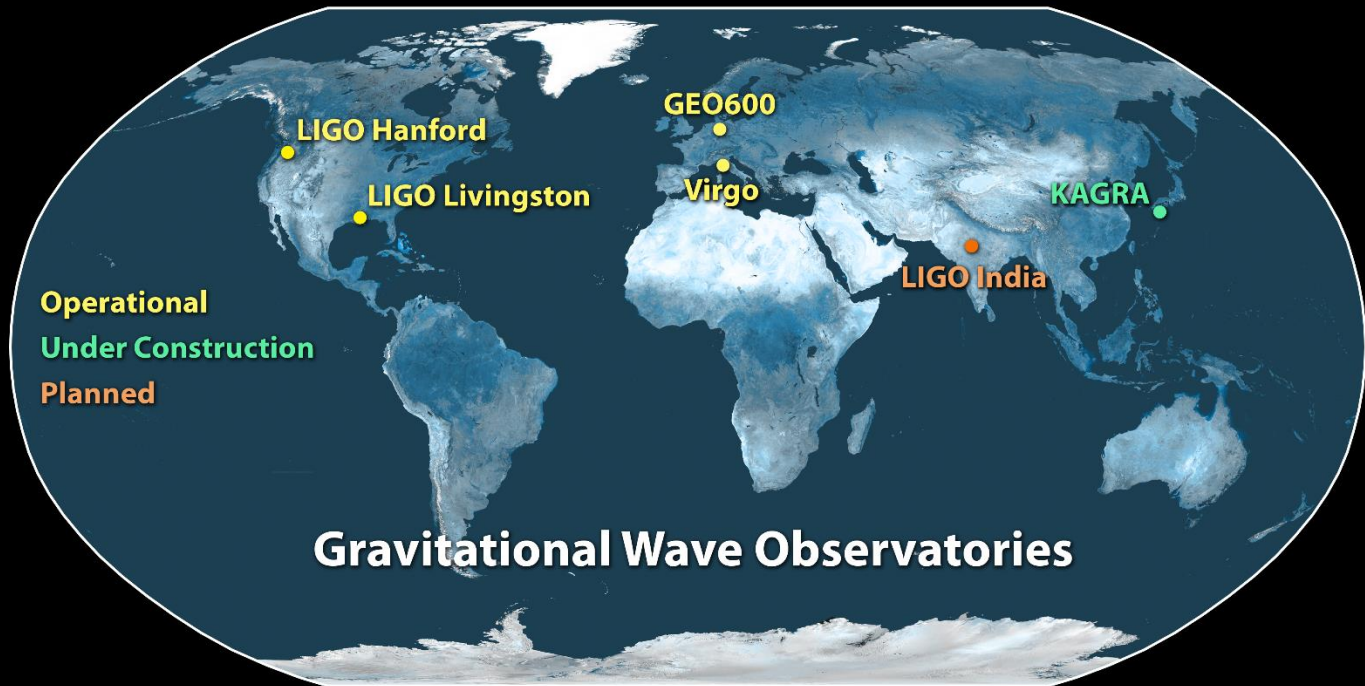
SCIENCE VIDEO: LIGO Hears Gravitational Waves Einstein Predicted

More than a hundred years ago, Einstein predicted the existence of gravitational waves, but until now they were undetectable. As direct evidence, gravitational waves were finally captured in 2015. This photo is a heavy simulation showing a binary black hole system.

Rainer Weiss, a professor at the Massachusetts Institute of Technology, and Kip Thorne and Barry Barish, both of the California Institute of Technology, were awarded the Nobel Prize in Physics on Tuesday for the discovery of ripples in space-time known as gravitational waves, which were predicted

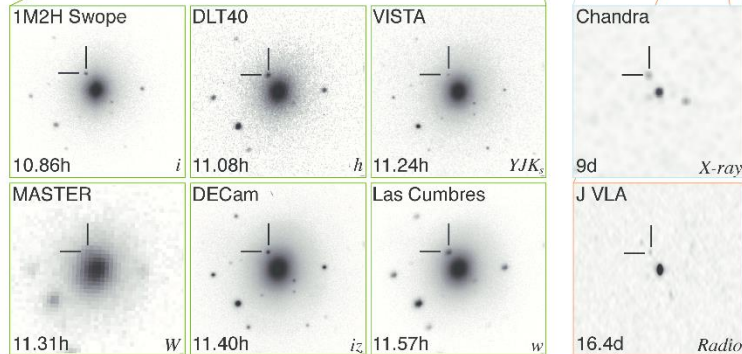
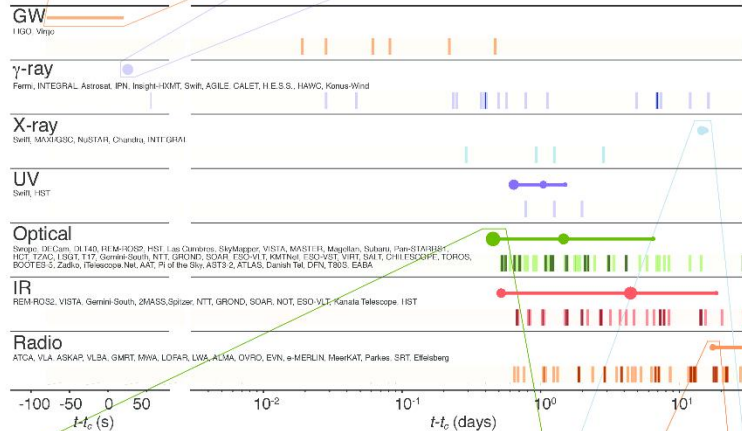
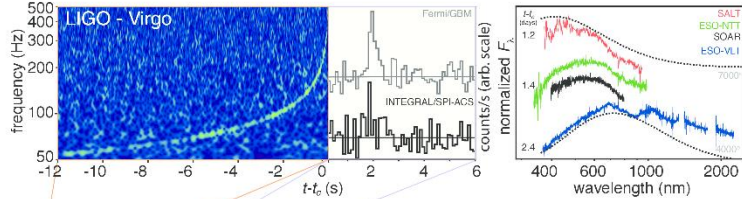
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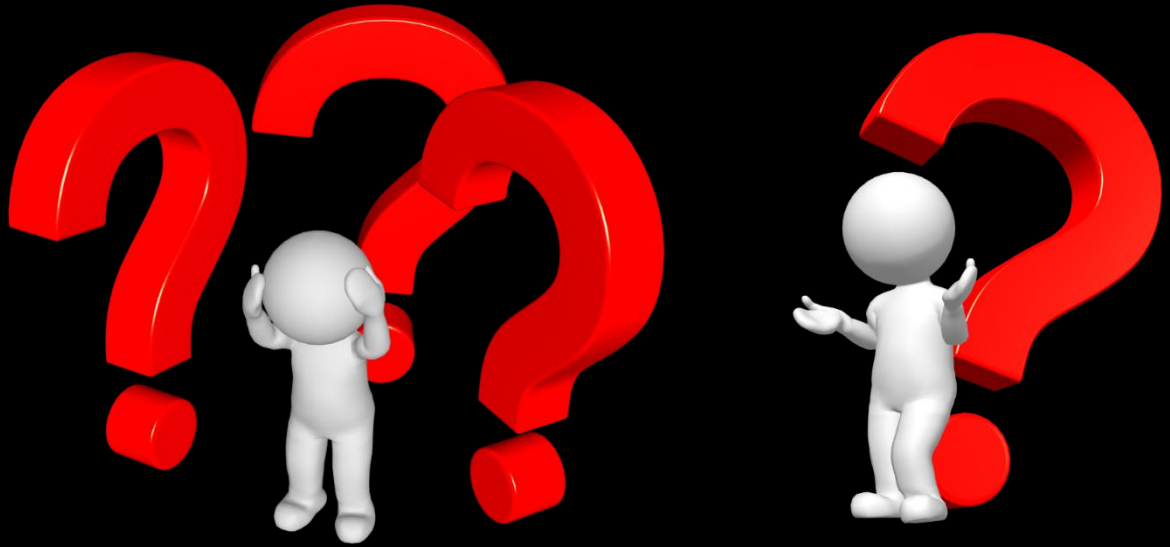
- First-Time Gravitational Waves Detected, Confirming Einstein's Theory
- Third Gravitational Wave Detected, From Black Hole Merges 3 Billion Light Years Away
- 3 Who Studied Unusual States of Matter Win Nobel Prize in Physics
- 2017 Nobel Prize in Medicine Goes to 3 Americans for Body Clock Studies
- Nobel Prize in Chemistry Awarded for 3D Views of Life's Biological Machinery



**Operational**  
**Under Construction**  
**Planned**

# Gravitational Wave Observatories





**What we don't know**

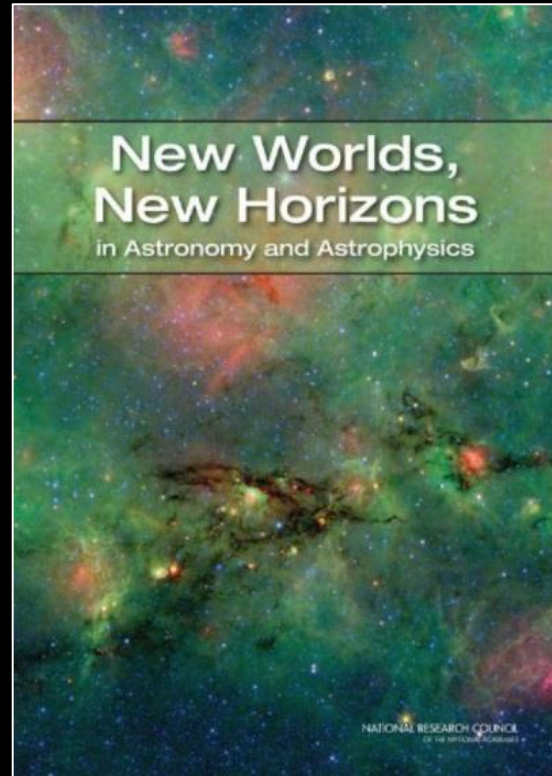
# Decadal Surveys

- 1964: Ground-based Astronomy: A Ten Year Program
- 1972: Astronomy and Astrophysics for the 1970s
- 1982: Astronomy and Astrophysics for the 1980s
- 1991: The Decade of Discovery in Astronomy and Astrophysics
- 2001: Astronomy and Astrophysics in the New Millennium
- 2010: New Worlds, New Horizons in Astronomy & Astrophysics
- 2020: ???

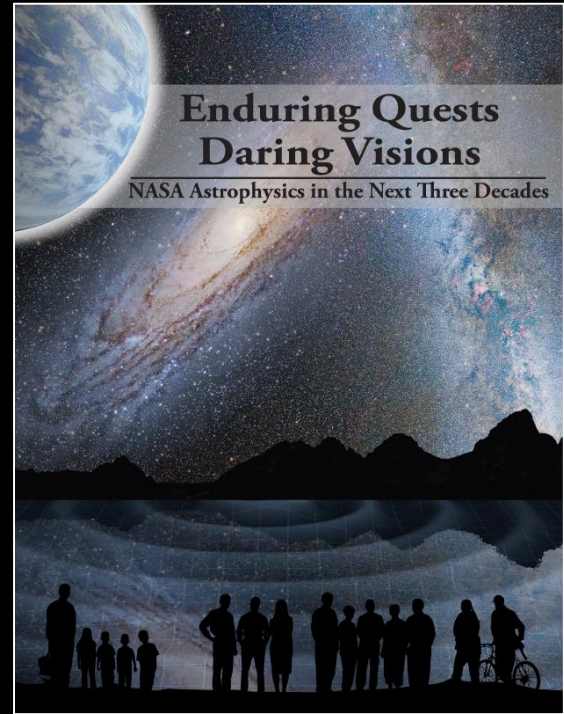
# Decadal Surveys

2010:

New Worlds, New  
Horizons in Astronomy  
and Astrophysics



# Other Roadmaps

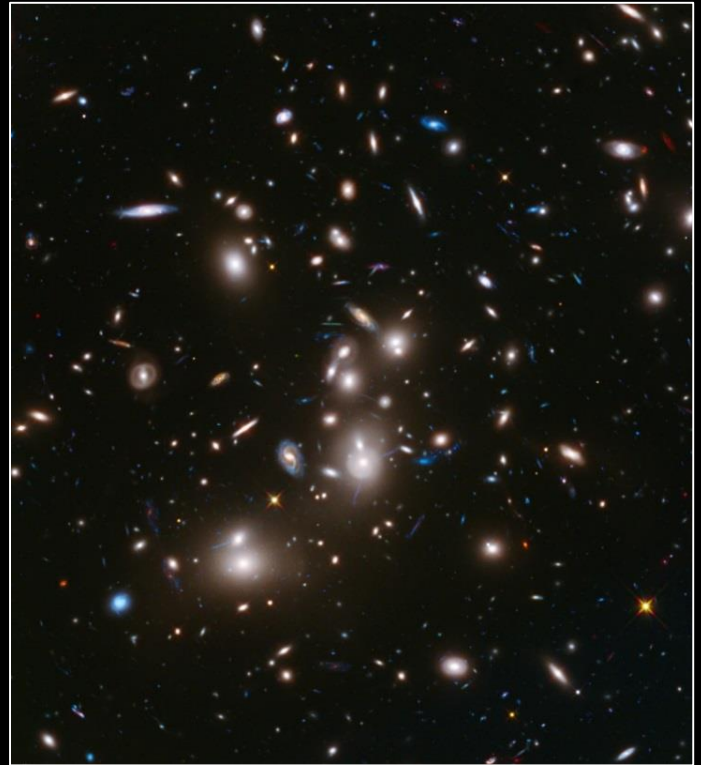
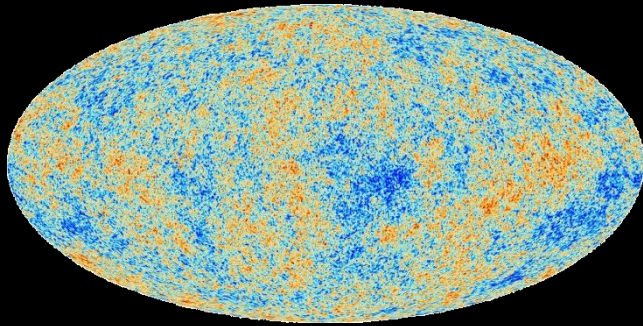


# The current and future priorities

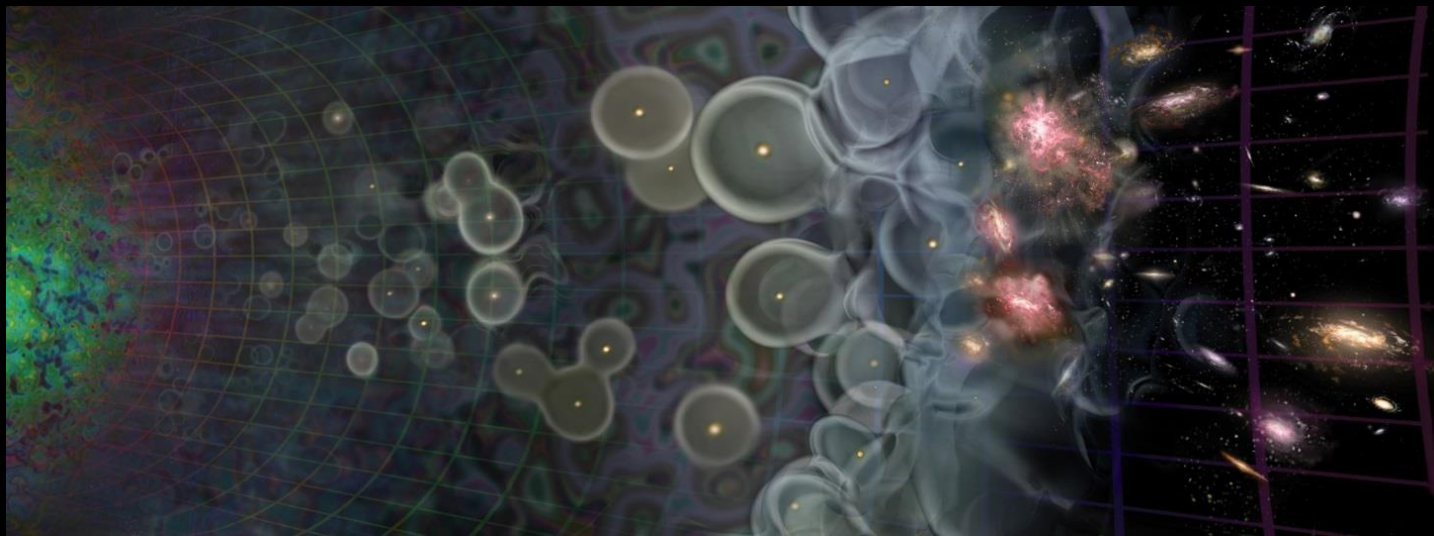
- Identification and characterization of nearby habitable exoplanets
- Studying how the universe changes:
  - “Time-domain astronomy”
- Understanding how the universe formed:
  - How do we create the galaxies we see today?



# The epoch of reionisation



# The epoch of reionisation



What does

**DARK**

mean?

# The BIG Questions

- Are we alone?
  - Exoplanets
  - The search for life
- How did we get here?
  - Stars and the elements
  - Galaxies and their history
- How does our Universe work?
  - The extremes of nature



**Tools for the Next Decade**

# Future Missions

## Space Based Missions

- James Webb Space Telescope (JWST) – Launches 2019
- JUNO – Jupiter – Arrived 2016
- Juice – Jupiter – Launches 2022
- New Horizons –Kuiper Belt – January 2019
- Dawn Mission – Vesta & Ceres – Arrived 2015
- InSight Lander – Mars – Launches 2018
- ExoMars – Astrobiology mission – Orbiter, stationary lander (2016 launch) and Rover (2020)
- Mars Exploration Program: 2020 Rover
- Europa Flyby Mission – 2020s
- OSIRIS-Rex – Sample from asteroid - 101955 Bennu – Launched 2016
- Parker Solar Probe – Launches 2018
- ESA Solar Orbiter – Launches 2019
- ESA BepiColombo – Mercury – Launches 2018
- ESA Euclid – Map geometry of dark universe – Launch 2020
- ESA CHEOPS – Exoplanets – Launches 2018

- Transiting Exoplanet Survey Satellite (TESS) – Launches 2018
- Athena launch – 2028
- WFIRST – 2020s
- ESA LISA – 2034
- ESA PLATO - 2026

## Ground Based Missions

- Upgrades to existing telescopes - Ongoing
- Large Synoptic Survey Telescope – 2021
- Square Kilometer Array (SKA) – From 2019
- Extremely Large Telescopes – 2020s
  - European Extremely Large Telescope (E-ELT)
  - Thirty Meter Telescope
  - Giant Magellan Telescope





**Beyond 2028**



# Beyond 2028

- Science missions take many years to plan, specify and develop the collaborations between scientists
- There is still however always one important factor...



# Beyond 2028

- Many missions have been suggested but two were recently selected:
  - The Advanced Telescope for High-energy Astrophysics (Athena)
  - Laser Interferometer Space Antenna (LISA)
- Looking beyond the upcoming James Webb Space Telescope
  - Concepts such as LUVOIR:
    - Large UV/Optical/Infrared Surveyor



“There are known knowns. These are things we know that we know. There are known unknowns. That is to say, there are things that we know we don't know. But there are also unknown unknowns. There are things we don't know we don't know.”

*Donald Rumsfeld*