The Next Decade in Astronomy
The Unanswered Questions
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 2026
Recent Discoveries
Astronomers detect '10th planet'

By Dr David Whitehouse
Science Editor, BBC News website

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 2.8 billion km 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 pulled the small world into its highly inclined 44-degree orbit.

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.
Water in the Solar System
Comets

In 2004, the NASA Stardust mission chased after Comet Wild 2.
Discovery of Exoplanets
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 – 1989
WMAP – 2001
Planck – 2009
## The Big Bang

<table>
<thead>
<tr>
<th></th>
<th>Age of the Universe (Billion Years)</th>
<th>Hubble Constant (km s$^{-1}$ Mpc$^{-1}$)</th>
<th>Baryons</th>
<th>Dark Matter</th>
<th>Dark Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>WMAP</strong></td>
<td>13.69</td>
<td>69.32</td>
<td>4.6%</td>
<td>24.0%</td>
<td>71.4%</td>
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<tr>
<td><strong>Planck</strong></td>
<td>13.82</td>
<td>67.3</td>
<td>4.9%</td>
<td>26.8%</td>
<td>68.3%</td>
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</tbody>
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BICEP2 B-mode signal

Credit: Steffen Richter, Harvard University
Maybe Gravitational Waves & Inflation

**Cosmic inflation: 'Spectacular' discovery hailed**

*By Jonathan Amos*

Science correspondent, BBC News

The measurements were taken using the BICEP2 instrument at the South Pole telescope facility. Scientists say they have extraordinary new evidence to support a Big Bang Theory for the origin of the Universe.

**Telescope captures view of gravitational waves**

*Images of the infant Universe reveal evidence for rapid inflation after the Big Bang.*

*Ron Cowen*

17 March 2014

Astronomers have peered back to nearly the dawn of time and found what seems to be the long-sought "smoking gun" for the theory that the Universe underwent a spurt of wrenched, exponential growth called inflation during the first tiny fraction of a second of its existence.
Maybe Gravitational Waves & Inflation
Maybe Gravitational Waves & Inflation
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
2010:

New Worlds, New Horizons in Astronomy and Astrophysics
Other Roadmaps

The ASTRONET Infrastructure Roadmap:
A Strategic Plan for European Astronomy

Enduring Quests Daring Visions
NASA Astrophysics in the Next Three Decades
Identification and characterization of nearby habitable exoplanets
Gravitational Wave Astronomy

Credit: NASA/Goddard Space Flight Center
Time-domain astronomy

www.spacetelescope.org
“Astrometry is the branch of astronomy that involves precise measurements of the positions and movements of stars and other celestial bodies.”
Astrometry
The epoch of reionization
The epoch of reionization
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

- GAIA – Launched 2013
- LISA Pathfinder – Launched 2015
- James Webb Space Telescope (JWST) – Launches 2018
- JUNO – Jupiter – Arrives 2016
- Juice – Jupiter – Launches 2022
- New Horizons – Kuiper Belt – January 2019
- Dawn Mission – Vesta & Ceres – Arrived 2015
- InSight Lander – Mars – Launches 2016
- ExoMars – Astrobiology mission – Orbiter, stationary lander (2016 launch) and Rover (2018)
- Mars Exploration Program: 2020 Mission
- Europa Flyby Mission – 2020s
- OSIRIS-Rex – Sample from asteroid - 101955 Bennu – Launches 2016
- Solar Probe Plus – Launches 2018
- ESA Solar Orbiter – Launches 2017
- ESA BepiColombo – Mercury – Launches 2017
- ESA Euclid – Map geometry of dark universe – Launch 2020
- ESA CHEOPS – Exoplanets – Launches 2017
- Transiting Exoplanet Survey Satellite (TESS) – Launches 2017
- Athena launch - 2028

Ground Based Missions

- Upgrades to existing telescopes - Ongoing
- ALMA – From 2014
- Square Kilometer Array (SKA) – From 2019
- Extremely Large Telescopes – 2020s
  - European Extremely Large Telescope (E-ELT)
  - Thirty Meter Telescope
  - Giant Magellan Telescope
Beyond 2026

• Science missions take many years to plan, specify and develop the collaborations between scientists

• There is still however always one important factor…
Beyond 2026

• Many missions have been suggested but two were recently selected:
  – The Advanced Telescope for High-energy Astrophysics (Athena+)
  – Laser Interferometer Space Antenna (LISA)

• Also, 2016 is the year where NASA starts work on projects after the James Webb Space Telescope
“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