

# Big Ideas in Astronomy

*A Proposed Definition of Astronomy Literacy*





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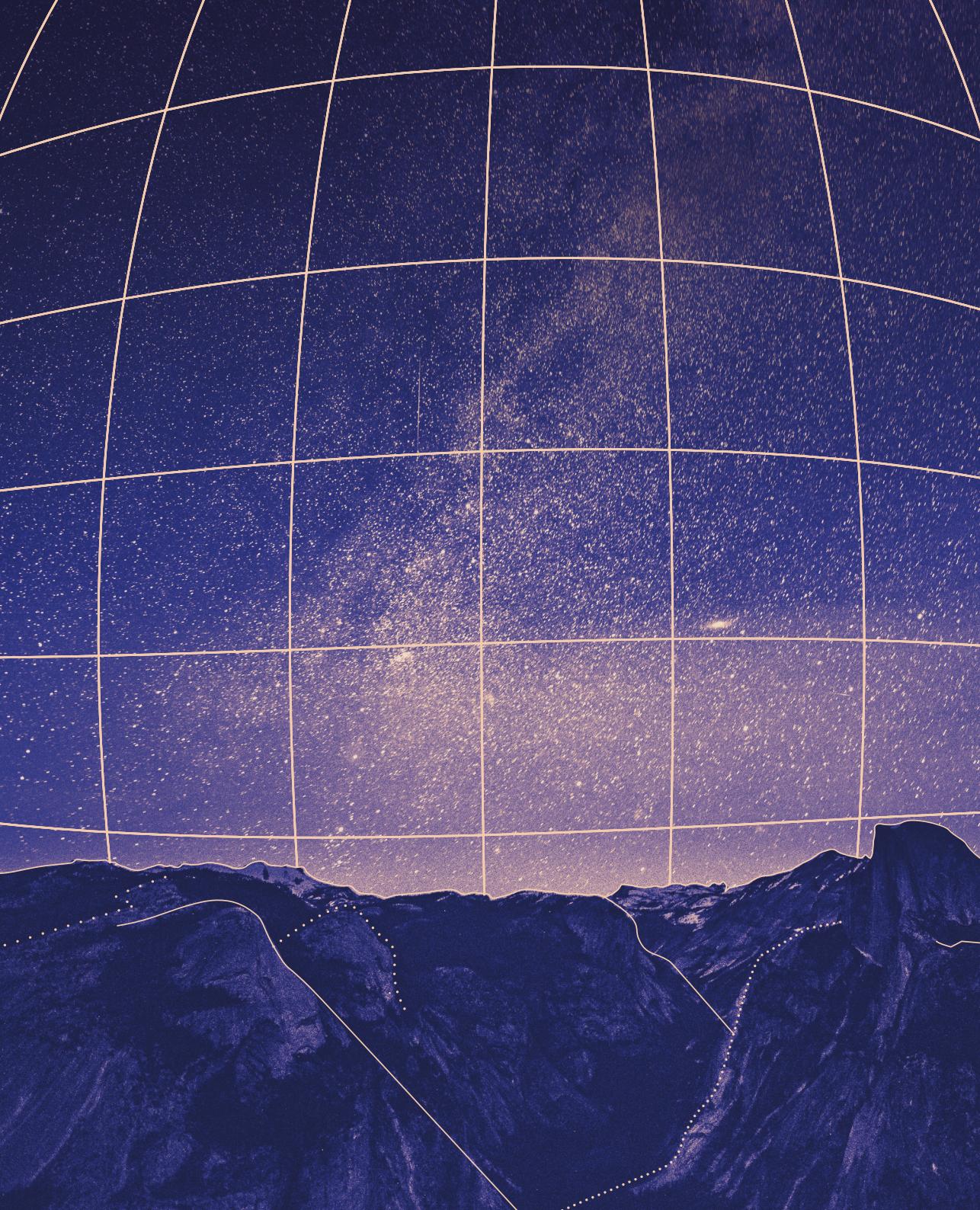
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# Big Ideas

1

*Astronomy is one of the oldest sciences in human history*

2

*Astronomical phenomena can be experienced in our daily lives*

3

*The night sky is rich and dynamic*

4

*Astronomy is a science that studies celestial objects and phenomena in the Universe*

5

*Astronomy benefits from and stimulates technology development*

6

*Cosmology is the science of exploring the Universe as a whole*

7

*We all live on a small planet within the Solar System*

8

*We are all made of stardust*

9

*There are hundreds of billions of galaxies in the Universe*

10

*We may not be alone in the Universe*

11

*We must preserve Earth, our only home in the Universe*

# Introduction

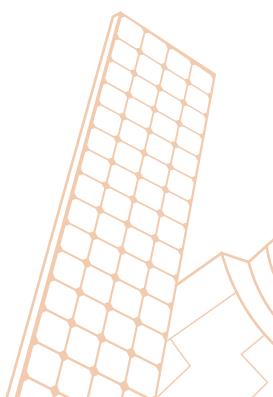
## *Astronomy for All.*

This is the motto of the International Astronomical Union (IAU) Office for Astronomy Outreach. If “All” is a very vast term to define society and its communities, “Astronomy” as a body of knowledge is also similarly vast. This project, “Big Ideas in Astronomy”, explores the issue: “What should science-educated citizens know about astronomy?”

As a result of several discussions, meetings, workshops, presentations, telecoms and text interactions in this document we propose a set of Big Ideas in Astronomy, a Roadmap to Astronomy Literacy Goals. This document establishes the “Big Ideas” and supporting concepts that all citizens on our planet should know about astronomy.

Big Ideas in Astronomy builds on the pioneering American Association for the Advancement of Science (AAAS) Project 2061. The AAAS Project 2061 started in 1986, the year Halley’s Comet passed near Earth. The AAAS was intrigued by what affects children’s connection to the natural world — who were starting school then will see the return of the Comet. What scientific and technological changes will they also see in their lifetime? How can education prepare them to make sense of how the world works; to think critically and independently; and to lead interesting, responsible, and productive lives in a culture increasingly shaped by science and technology? Big Ideas in Astronomy also expands on the work developed by other scientific disciplines and projects, namely: Climate Science Literacy, Earth Science Literacy Principles, Ocean Literacy and Big Ideas of Science.

Big Ideas in Astronomy presents eleven Big Ideas and expands on them through sub-ideas and additional information. This document is designed with educators and astronomers in mind, it is a guiding document to decide which topics they should address in their teaching, training sessions, outreach activities or resources development. However, this needs to be a dynamic document, and we welcome comments and remarks from the astronomy community, the astronomy education community and the science education community.

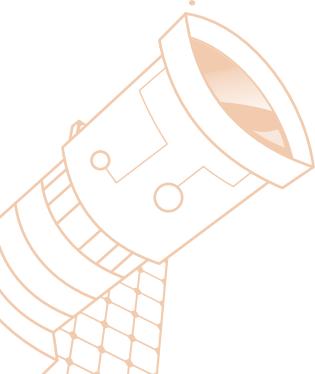


# Next steps

Our next step is the further development of this document, by undertaking a research project to systematically validate this document as an accurate representation of what experts think as astronomy literacy. Following this, we will be working on:

- ✗ Curriculum development aligned with these Big Ideas
- ✗ Development of assessment tools for the Big Ideas
- ✗ Educational materials guides
- ✗ Teacher professional development materials
- ✗ Policy-reports

The 2020-2030 IAU Strategic Plan places astronomy education at the core of the global astronomy endeavour. The IAU has set the goal to foster the use of astronomy for teaching and education at school level. We hope that this document contributes to this goal and provides the first analysis and framework of astronomy literacy goals for education.



# A brief Introduction to some of Astronomy's Big Ideas<sup>1</sup>

*by Pedro Russo*

Astronomy is the science that studies the origin and evolution of the Universe and everything in it. This definition seems simple, but the Universe is a vast place, filled with fascinating celestial objects of all sizes, shapes and ages, and with amazing phenomena.

As part of humanity's cultural and scientific history, astronomy has repeatedly revolutionized the way we think, the way we see our world and our place in the larger universe. In the past, advances in astronomy have been used for practical applications such as measuring time or navigating the vast oceans. Today, the results of the scientific and technological development of astronomy and related areas have become essential to many parts of our day-to-day life: computers, communication satellites, navigation systems, solar panels, wireless internet and many other technological applications.

Like any science, astronomy makes advances as a result of the accumulation of knowledge. Sometimes steady progress is accelerated by sudden breakthroughs in technology and thought, such as revolutionary idea of the Heliocentric view of the Solar System and The Big Bang Model. The Big Bang model tells the story of the evolution of the Universe. Around 14 billion years ago, the just-born "Universe" was infinitely small and hot. A sudden and continuing expansion and later cooling led to the formation of the fundamental building blocks of atomic and subatomic particles, which allowed the formation of galaxies, stars, planets and eventually life. Astronomers believe, based on the data so far, that the expansion of the Universe is mainly driven by a mysterious form of energy called Dark Energy.

If we look at the sky on a dark night, we see a band of light travelling across the sky from horizon to horizon. This band and all the stars we see in the sky are part of the galaxy we live in, the Milky Way Galaxy. Galaxies often form in filaments and clumps: groups of islands surrounding the vast empty seas of the Universe. Our galaxy contains hundreds of billions of stars, of which the Sun is only one, as anonymous as a grain of sand on a beach. These stars orbit harmoniously, following the natural laws of

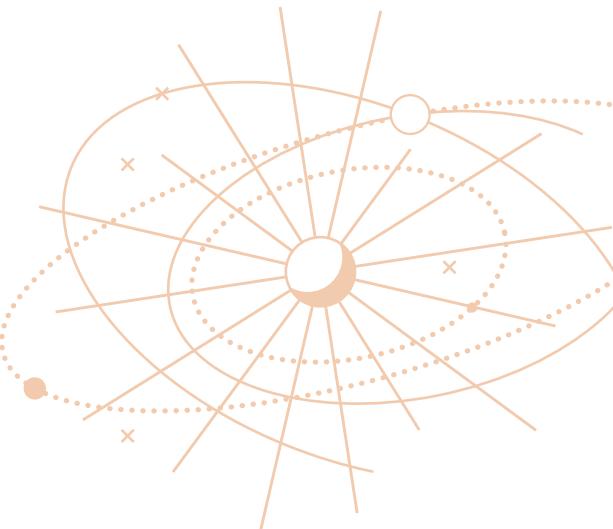
<sup>1</sup>. Originally published in the Portuguese news magazine Visão,  
3 January 2012

gravity, around the centre of the galaxy where there is a monstrous black hole. This “ocean” which is the Universe contains many other islands; ours is only one among hundreds of billions of galaxies that populate it.

Although it is a relatively average type of star, the Sun enjoyed, until recently, a special status for us humans: it was the only star we knew to be surrounded by planets. Today we know of thousands of stars with planets, called Exoplanets. It is estimated that more than 20% of stars which resemble our Sun are orbited by planets — some similar to Earth. Many of these planets are small and are orbiting at a comfortable distance from its star, which allows the existence of liquid water and, hence, maybe life.

But what is the Universe made of? The stuff we can see — planets, stars and galaxies — are all made of atoms, but there is something else, something vast, strange and mysterious, and no one knows what it is. Stars would be expected to orbit the centre of galaxies, in a similar way to how planets orbit the Sun in our Solar System. The closest planets to the Sun move faster than the outermost planets. But this does not happen: the stars in galaxies more or less orbit all with the same velocity around the centre of the galaxy. There must be something we are unable to see and which keeps the stars orbiting in this way. Astronomers call this “Dark Matter”. It is estimated that what we are able to see is only a small portion of everything that exists in the Universe. Everything else is not well understood and has not been directly observed yet!

Astronomy is not just about scientific advances or technological applications: it gives us the opportunity to broaden our limited horizons, discover the beauty and grandeur of the Universe and our place in it. This view, commonly referred to as “the cosmic perspective”, is one of the most important contributions of Astronomy to Humanity.



# Overview of The Big Ideas



## 1

*Astronomy is one of the oldest sciences in human history*

- 1.1 Understanding the sky and the movements of the Sun and planets was one of the first attempts to understand the natural world
- 1.2 Earlier cultures imagined patterns connecting stars in the night sky
- 1.3 Astronomy provided important timekeeping knowledge, essential for ancient agriculture
- 1.4 Astronomy was important for navigators in the past
- 1.5 Astronomy, by using the scientific method, is different from astrology
- 1.6 Earth was believed, by some earlier cultures, to be the centre of the Universe
- 1.7 The century-long Copernican Revolution led to the Sun replacing the Earth as the accepted centre of the Solar System
- 1.8 Over 400 years ago, astronomers undertook the first methodical observations within astronomy using a telescope
- 1.9 The Earth is approximately spherical in shape, and this has been demonstrated for centuries in many different ways

## 2

*Astronomical phenomena can be experienced in our daily lives*



- 2.1 We experience day and night because of Earth's rotation around itself
- 2.2 We experience seasons because of the tilt of Earth's axis of rotation as the Earth moves around the Sun in a year
- 2.3 We see different phases of the Moon throughout a Moon cycle
- 2.4 Eclipses occur due to special alignments of the Earth, the Sun and the Moon
- 2.5 The tides on Earth are a result of the gravity of the Sun and Moon
- 2.6 Light from the Sun is essential for most life forms on Earth
- 2.7 Particles from the Sun travel to the Earth and cause the auroras
- 2.8 Technology developed for astronomical research is part of our daily life

## 3

*The night sky is rich and dynamic*



- 3.1 We can see several thousands of stars with our eyes on a clear and dark night
- 3.2 All the stars we see with the unaided eye belong to our galaxy
- 3.3 The night sky can help you to orient yourself on Earth and navigate
- 3.4 The rotation axis of Earth wobbles (precesses) over thousands of years
- 3.5 Only a few celestial bodies are bright enough to be seen with the unaided eye when the Sun is above the horizon
- 3.6 Celestial objects rise in the East and set in the West due to the Earth's rotation
- 3.7 Stars twinkle due to our atmosphere
- 3.8 Millions of meteors enter the Earth's atmosphere daily

# 4

*Astronomy is a science that studies celestial objects and phenomena in the Universe*



- 4.1 Light (otherwise known as electromagnetic radiation) is the main source of information for astronomical research
- 4.2 On large scales, gravitation is the dominant interaction in the Universe
- 4.3 Gravitational waves and subatomic particles provide new ways of studying the Universe
- 4.4 Astronomy makes use of data obtained from observations and simulations to model astronomical phenomena in the framework of current theories
- 4.5 Astronomical research combines knowledge from different fields, such as physics, mathematics, chemistry and biology
- 4.6 Astronomy is divided into a number of specialties
- 4.7 Time and distance scales in astronomy are a lot larger than the ones we use in our daily life
- 4.8 Spectroscopy is an important technique allowing us to probe the Universe from a distance



# 5

*Astronomy benefits from and stimulates technology development*

- 5.1 Telescopes and detectors are crucial to the study of Astronomy
- 5.2 Some smaller telescopes can be linked together to act as one big telescope
- 5.3 Astronomical observatories are located on Earth and in space
- 5.4 Earth-based astronomical observatories are often located in remote regions all around the world
- 5.5 Astronomy today is part of “Big Science” and “Big Data”
- 5.6 Complex simulations and huge data in astronomy require the development of powerful supercomputers
- 5.7 Astronomy is a global science, with international teams, and where data and publications are shared freely
- 5.8 Numerous spacecrafts have been launched to space to study the Solar System

# 6

*Cosmology is the science of exploring the Universe as a whole*

- 6.1 The Universe is about 13.8 billion years old
- 6.2 The evolution of the Universe can be explained by the Big Bang model
- 6.3 The Universe is mainly composed of Dark Energy and Dark Matter
- 6.4 The Universe is expanding
- 6.5 The Universe is homogeneous and isotropic
- 6.6 The natural laws (e.g. gravity) that we study on Earth appear to work the same way throughout the Universe
- 6.7 We can only observe a fraction of the total Universe
- 6.8 Astronomers always observe the past
- 6.9 The Cosmic Microwave Background allows us to explore the early Universe
- 6.10 The expansion of space causes light from distant galaxies to be shifted
- 6.11 The large-scale structure of the Universe is composed of filaments, sheets and voids

# 7

*We all live on a small planet within the Solar System*



- 7.1 The Solar System was formed about 4.6 billion years ago
- 7.2 The Solar System is composed of the Sun, planets, moons, comets, asteroids, and icy bodies
- 7.3 There are eight planets in the Solar System
- 7.4 There are several dwarf planets in the Solar System
- 7.5 The planets are divided into terrestrial (rocky) planets and gas giants
- 7.6 Some planets have dozens of natural satellites
- 7.7 Earth is the third planet orbiting around the Sun, and has one natural satellite, the Moon
- 7.8 There are millions of asteroids which are remnants from the early formation of our Solar System
- 7.9 A comet is an icy object that acquires a tail when it is heated by the Sun
- 7.10 The Solar System has different boundary regions, one of which is called the Heliopause



*We are all made  
of stardust*

- 8.1 A star is a self-luminous body generating its energy by internal nuclear reactions
- 8.2 Stars form from massive clouds of dust and gas
- 8.3 The closest star to Earth is the Sun, which has a moderate size and mass, neither big nor small, compared to other stars
- 8.4 The colour of a star tells us its surface temperature
- 8.5 The space between stars can be largely empty or it can contain clouds of gas, which can produce new stars
- 8.6 A star goes through a life cycle which is largely determined by its initial mass
- 8.7 Massive stars end their life cycle as stellar black holes
- 8.8 New stars and their planetary systems are born from matter left behind by previous stars in that region
- 8.9 The human body consists of atoms that can be traced back to earlier stars



*There are hundreds of billions  
of galaxies in the Universe*



- 9.1 A galaxy is a large system of stars, dust and gas
- 9.2 Galaxies contain large amounts of dark matter
- 9.3 Galaxy formation is an evolutionary process
- 9.4 There are three main types of galaxies: Spiral, Elliptical and Irregular
- 9.5 We live in a spiral galaxy called the Milky Way
- 9.6 The spiral arms of galaxies are created by pile-ups of gas and dust
- 9.7 Most galaxies have a supermassive black hole at their centre
- 9.8 Galaxies can be extremely distant from each other
- 9.9 Galaxies form clusters
- 9.10 Galaxies interact with each other through gravity

# 10

*We may not be alone  
in the Universe*

- 10.1 Organic molecules have been detected outside Earth
- 10.2 Living organisms have been found to survive in extreme environments on the Earth
- 10.3 Traces of liquid water open up the possibility of primitive life on Mars
- 10.4 Some natural satellites in the Solar System appear to have the conditions for life to exist
- 10.5 There are numerous planets called exoplanets, which orbit stars other than the Sun
- 10.6 Exoplanets can be very diverse and are often found in systems
- 10.7 We are now close to the detection of an Earth-like planet
- 10.8 Scientists are searching for extraterrestrial intelligence

# 11

*We must preserve Earth,  
our only home in the Universe*

- 11.1 Light pollution affects humans, many other animals and plants
- 11.2 There is a lot of human-made debris in Earth's orbit
- 11.3 We monitor potentially hazardous space objects
- 11.4 Humans have a significant impact on the Earth's environment
- 11.5 The climate and the atmosphere are heavily affected by human activity
- 11.6 A global perspective is necessary to preserve our planet
- 11.7 Astronomy provides us with a unique cosmological perspective that reinforces our unity as citizens of the Earth

1

*Astronomy is one of the oldest sciences in human history*



*Lascaux prehistorical cave paintings showing a cluster of dots above the back of the aurochs, which resembles the asterism Pleiades.*

*Credits: Ministère de la Culture/Centre National de la Préhistoire/Norbert Aujoulat*



## 1.1

### Understanding the sky and the movements of the Sun and planets was one of the first attempts to understand the natural world

The first records of astronomical observations come from drawings and artefacts created by prehistoric people, documenting what they saw in the sky. In ancient cultures, Astronomy was related to religious and mythological beliefs. Astronomical phenomena were used to measure time and to create calendars, allowing such cultures to plan daily and seasonal events.

## 1.2

### Earlier cultures imagined patterns connecting stars in the night sky

Patterns in the night sky formed by connecting stars using imaginary lines are called constellations. The earliest constellations were defined by early cultures. These recognisable groups of stars were often connected to cultural stories and mythology from cultures such as Greek, Mayan and Chinese. In modern Astronomy, constellations are well-defined regions of the sky, which combine both ancient constellations and those defined in the 15th, 16th and 17th centuries. Some cultures, such as the Indigenous Australians and the indigenous people of South America, also identified patterns using the dark silhouettes in the luminous band of the Milky Way.

## 1.3

### Astronomy provided important timekeeping knowledge, essential for ancient agriculture

In many ancient cultures, astronomy was developed to increase the accuracy of farming calendars. As an example, Egyptians developed a calendar based on their observations of the star Sirius, using it to determine the annual flooding of the river Nile.

## 1.4

### Astronomy was important for navigators in the past

Many civilisations used the position of the stars and other celestial objects to navigate the land, seas and oceans. Celestial navigation is still taught to this day.

## 1.5

### Astronomy, by using the scientific method, is different from astrology

Until pre-modern times, the distinction between astronomy and astrology was vague. Today astronomy and astrology are clearly distinguished from each other. Astronomy is a science and astrology is not. Astrology uses positions of celestial objects to predict future events. However, extensive studies of astrology and its predictions show that astrology is not accurate in its predictions and is without any scientific foundation.

## 1.6

### **Earth was believed, by some earlier cultures, to be the centre of the Universe**

Early astronomers believed that the Earth was the centre of the Universe. This Geocentric view lasted for over one millennium in European and Asian Cultures. Other cultures, such as Islamic and Indian cultures, presented Heliocentric theories (with the Sun in the centre) not long after 0 BCE. Modern astronomers have found that the Universe appears to have no specific centre in space.

## 1.7

### **The century-long Copernican revolution led to the Sun replacing the Earth as the accepted centre of the Solar System**

In the 16th century, Copernicus proposed evidence for the Heliocentric theory in which the Sun was the centre of the Universe and Earth moved around it. Although we know now that the Sun is not the centre of the Universe, it is the centre of the Solar System and the Copernican Heliocentrism theory was revolutionary at that time, contributing to the development of modern Astronomy.

## 1.8

### **Over 400 years ago, astronomers undertook the first methodical observations within astronomy using a telescope**

Although he did not invent the telescope, Galileo was the first to use it for scientific purposes. His improvements of the refracting telescope led him to discoveries such as the phases of Venus, the rings of Saturn and the four largest moons of Jupiter, which are still referred to as Galilean moons. His discoveries provided compelling evidence that supported the Heliocentric view of the Universe.

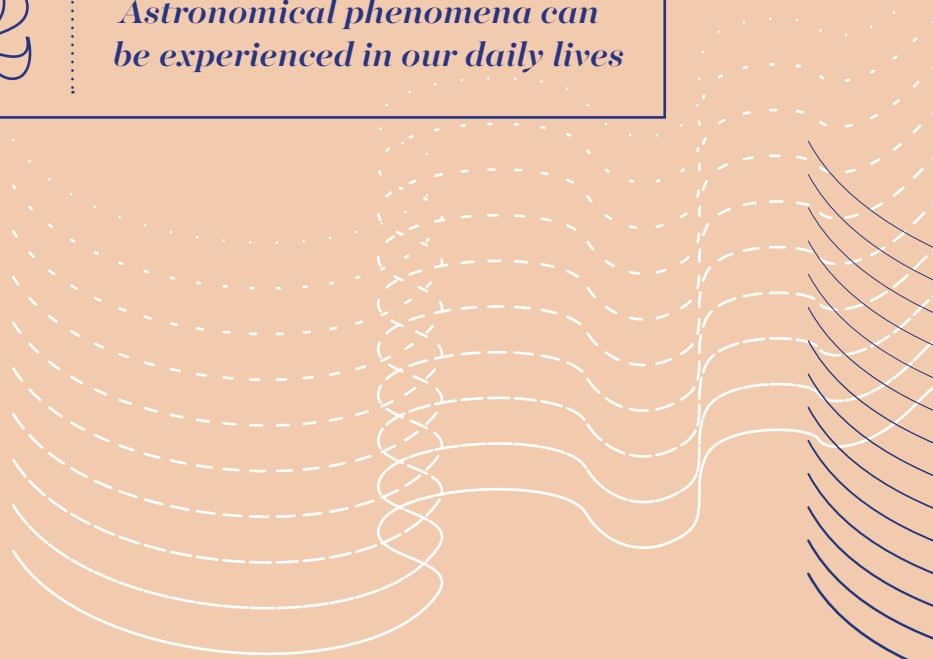
## 1.9

### **The Earth is approximately spherical in shape, and this has been demonstrated for centuries in many different ways**

Some early cultures in many areas of the world have described the Earth as a flat plane or disk as part of their description of the Universe. The idea that the Earth is a sphere has been around for a few millennia and has been a significant part of the worldviews of many cultures, becoming the dominant paradigm more than 1000 years ago. There are numerous empirical ways to test that the Earth is approximately spherical in shape (it is technically referred to as an oblate spheroid). One of the earliest mathematical methods was by Eratosthenes, who measured the circumference of the Earth by analysing the lengths of shadows cast by sticks at different locations in ancient Egypt (3rd century BCE).

2

*Astronomical phenomena can  
be experienced in our daily lives*



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*The awe-inspiring light show  
in the night sky – the Aurora  
Borealis (Northern Lights),  
in the wilderness of Alaska.*

*Credits: Jean Beaufort  
(Public Domain Pictures)*



## 2.1

We experience day and night because of Earth's rotation around itself

The side of the Earth facing the Sun experiences daytime, while the opposite side experiences nighttime. The time that Earth takes to rotate around its axis such that the Sun returns to the same position in the sky defines the duration of the (solar) day, which on average is 24 hours.

## 2.2

We experience seasons because of the tilt of Earth's axis of rotation as the Earth moves around the Sun in a year

The Earth's axis of rotation is tilted by 23.5° relative to its orbital plane around the Sun. For this reason, one of the Earth's Northern or Southern hemispheres is tilted towards the Sun while the other one is tilted away from it. The former experiences summer, as the sunlight falls more directly on its surface and the days are longer because the Sun reaches a higher altitude in the sky. On the other hand, the hemisphere tilted away from the Sun experiences winter because the sunlight falls at a highly inclined angle to the surface, spreading over a larger area. The days become shorter because the Sun is at a lower altitude in the sky.

## 2.3

We see different phases of the Moon throughout a Moon cycle

As the Moon orbits the Earth, its relative position with respect to the Sun and the Earth changes. The region of the Moon's surface which is lit by sunlight changes, producing the different phases we see from the Earth — New Moon, Waxing Crescent, Full Moon and Waning Crescent taking 29.53 days from Full Moon to Full Moon. While the phases of the Moon are (more or less) the same for any observer on Earth, the orientation of the Moon will vary, depending on the observer's hemisphere. For instance, some observers might see the crescent of the Moon open to the left while others, observing at the same time but from a different location, might see the crescent open to the right.

## 2.4

Eclipses occur due to special alignments of the Earth, the Sun and the Moon

Occasionally, when the Moon passes exactly between the Earth and the Sun, the Moon blocks the light from the Sun and casts a shadow on Earth, creating a solar eclipse. Occasionally, the Earth can be directly between the Sun and the Moon. In that case, the Earth casts a shadow on the Moon, obscuring its surface and creating a lunar eclipse. Eclipses can be partial, when just a fraction of the object is eclipsed, or total, when the whole object is eclipsed. A lunar eclipse occurs only at Full Moon and, consequently, can only be observed at night. At any given location on Earth, you are more likely to see a lunar eclipse than a solar eclipse. Lunar eclipses also last for longer periods of time than Solar eclipses.

## 2.5

The tides on Earth are a result  
of the gravity of the Sun and Moon

The Sun and, to a larger degree, the Moon cause tides on Earth. The Earth, especially its oceans, bulge out a bit both on the side closest to the Moon and Sun, and away from it. As the Earth rotates, these bulges reach the shorelines, causing the water level to increase there. When the Sun, Earth and Moon are in a straight line (at Full Moon and at New Moon), we experience higher "Spring tides". In contrast, when the Sun and Moon are at right angles to each other relative to the Earth (at First and Third Quarter Moon) we experience lower "Neap tides".

## 2.6

Light from the Sun is essential  
for most life forms on Earth

The Sun is the primary source of energy used by life forms on Earth. For instance, plants perform photosynthesis using sunlight, allowing their growth and, consequently, the production of molecular oxygen. That oxygen is used by animals for breathing. It is believed that the dinosaurs became extinct due to a lack of sunlight when an asteroid collided with the Earth. The resulting explosion transported large amounts of dust into the atmosphere, blocking the Sun's light. Sunlight also affects our physical and mental health. When exposed to sunlight, our skin produces vitamin D, which plays an important role in our body's biochemical processes. Some studies show a relation between human depression and the lack of exposure to sunlight.

## 2.7

Particles from the Sun travel  
to the Earth and cause the auroras

When strong eruptions, like solar flares or coronal mass ejections, occur on the surface of the Sun, a great amount of electrically charged particles is ejected. These particle storms may hit Earth's atmosphere and cause disturbances in its magnetic field. The interaction of electrically charged particles from the Sun with the molecules and atoms in the Earth's atmosphere gives rise to auroras — wonderful light shows, seen around the magnetic poles of the northern (Aurora Borealis) and southern (Aurora Australis) hemispheres. Occasionally, this can also affect some power supply systems on Earth, telecommunication systems, and can even damage satellites in orbit.

## 2.8

Technology developed for astronomical research  
is part of our daily life

Analytical tools and methods used to study astronomical data have been applied to industry, medical sciences and technology we use everyday. Detectors originally developed for astronomical research are now also used in digital cameras, like the ones we have in our mobile phones. Special glass developed for astronomical telescopes is used in manufacturing LCD screens and computer chips, as well as in ceramic stovetops. The knowledge transfer between astronomy and medicine has contributed to the development of magnetic resonance imaging (MRIs) and computerised tomography (CAT scanners), among other devices.

3

*The night sky is  
rich and dynamic*



---

*Star trails resulting from the Earth's rotation are seen in this long-exposure photo, taken at the Chajnantor plateau in the Chilean Andes.*

Credits: S. Otarola/ESO



## 3.1

### We can see several thousands of stars with our eyes on a clear and dark night

When we gaze up into the night sky, far away from the light pollution of cities and during a New Moon, we can see roughly 4000 stars with the naked eye. Depending on our location on Earth and on the time of observations, our Solar System's five brightest planets, the band of the Milky Way, two satellite galaxies of the Milky Way (the Large and Small Magellanic Clouds), and the Andromeda Galaxy (a big spiral galaxy) are also visible to the naked eye.

## 3.2

### All the stars we see with the unaided eye belong to our galaxy

Although there are billions of stars in other galaxies and trillions of galaxies in the observable Universe, they are orders of magnitude too far away for our eyes to distinguish them as individual points of light, and orders of magnitude fainter than the light gathering capability of our eyes.

## 3.3

### The night sky can help you to orient yourself on Earth and navigate

Looking up at the night sky allows you to find the cardinal directions. In the northern hemisphere, the easiest way to find North is to look for the star Polaris, also known as the North Star, which is very close to the celestial North pole. The easiest way of finding Polaris is through the constellations of the Ursa Major and Ursa Minor. In the southern hemisphere, with the lack of a visible star near the celestial South pole, the easiest way to find South is to use the constellation Crux and the two brightest stars in the constellation of Centaurus.

## 3.4

### The rotation axis of Earth wobbles (precesses) over thousands of years

As Earth rotates on its axis, it moves like a rotating spinning top. The direction of its axis of rotation changes in a slow precession with a period of about 26,000 years. This movement causes the axis to point in different directions over time and, as a consequence, the celestial North and South poles slowly change position over time. As an example, Polaris will eventually cease to indicate the North direction, although another star might, depending on the direction of the Earth's axis at the time. Although there is currently no bright star near the celestial South pole, in the future we will have a proper "South Star"!

## 3.5

### Only a few celestial bodies are bright enough to be seen with the unaided eye when the Sun is above the horizon

Most of the objects in the night sky are too dim to be observed against the bright, sunlit sky. A similar effect happens at night in cities, where, due to light pollution, we can see only a small fraction of the stars due to the brightening of the sky by artificial lighting. Only a few celestial bodies are bright enough to be seen with the unaided eye when the Sun is above the horizon. Depending on its phase, it is possible to see the Moon during the day. At certain times, Venus can be observed in the morning ("Morning star") or in the evening ("Evening star"). Very rarely, a particularly bright comet might be visible during the daytime.

## 3.6

### Celestial objects rise in the East and set in the West due to the Earth's rotation

Due to the Earth's rotation around its axis from West to East, an observer on the surface sees the whole sky move in the opposite direction, from East to West, seemingly rotating around our planet. This apparent movement of the sky around Earth is called Diurnal movement. This is the reason why we see every celestial body rise above the eastern half of the horizon, and setting along the western half.

## 3.7

### Stars twinkle due to our atmosphere

As a star's light enters our atmosphere and travels through its different layers, it constantly changes direction due to changing refraction in layers with different temperature and density. As a consequence, the brightness of a star's light, and the direction from which it reaches us here on Earth, is constantly changing. For an observer on Earth, the star appears to twinkle. For planets, the effect is much less apparent (or perceptible). The reason is that planets can actually be seen as small disks (readily discernible using binoculars, for example). Stars, on the other hand, appear to us as tiny points of light, and because all the light is coming from a single point, it is highly susceptible to changes in refraction.

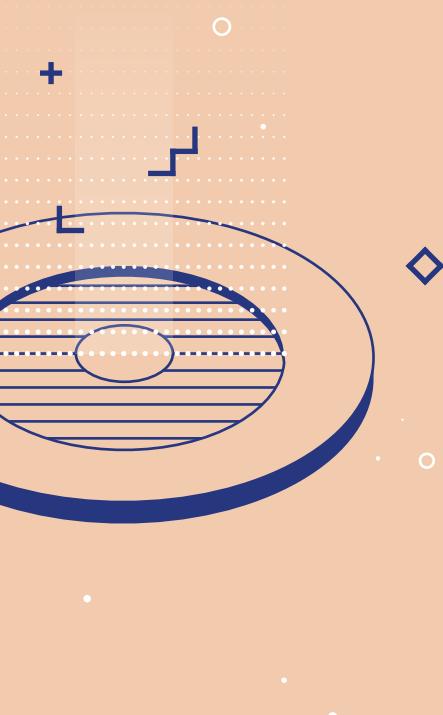
## 3.8

### Millions of meteors enter the Earth's atmosphere daily

A meteoroid is a small rocky or metallic object ranging from the size of a grain of sand to one metre. When it enters Earth's atmosphere it is heated by friction with the air particles which creates a streak of light in the night sky. This phenomenon is called a meteor (or a shooting or falling star). When a meteoroid survives its passage through Earth's atmosphere and lands on the surface, it is called a meteorite. Although millions of meteors occur in the Earth's atmosphere daily, most of the meteoroids that they originate from are burned out before reaching the ground.

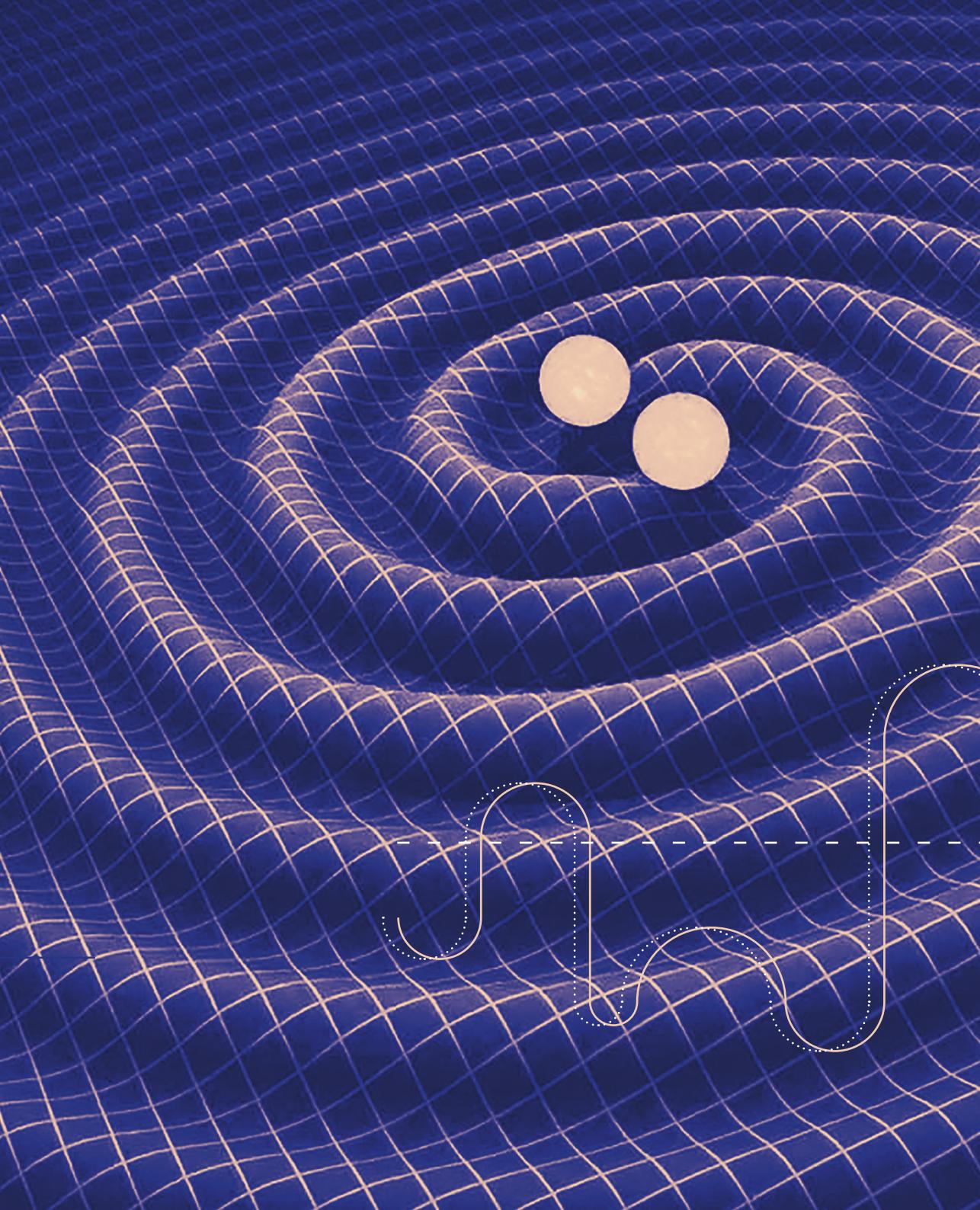
4

*Astronomy is a science that studies celestial objects and phenomena in the Universe*



Artist's impression of  
the gravitational waves  
generated by binary neutron  
stars, spiraling towards each  
other before they merge.

Credits: R. Hurt/Caltech-JPL



## 4.1

### Light (otherwise known as electromagnetic radiation) is the main source of information for astronomical research

Since most celestial objects are too far away to travel to, we must rely on the electromagnetic radiation (light) of these objects to study them. Different wavelengths of the electromagnetic spectrum provide information about various mechanisms of astronomical phenomena and the nature of celestial objects. In modern astronomy, the study of the Universe is mainly conducted using the whole electromagnetic spectrum: radio, microwaves, infrared, visible, ultraviolet, X-rays and gamma-rays.

## 4.2

### On large scales, gravitation is the dominant interaction in the Universe

On average, astronomical objects carry no net electric charge. The dominant way in which such objects interact over long distances is gravitation. Gravitation is what makes planets orbit the Sun, stars orbit galaxy centres, and keeps the hot plasma of stars together in spherical shape. Most astronomical phenomena can be described using the law of gravitation, but in the most extreme situations the general theory of relativity is required to provide an accurate description.

## 4.3

### Gravitational waves and subatomic particles provide new ways of studying the Universe

The existence of gravitational waves — ripples in space-time — was theoretically predicted by the general theory of relativity in the early 20th century. Their first confirmed direct detection was achieved in 2015, and scientists can now use them as a new window to study the Universe. Gravitational waves are generated by strong gravitational interactions, such as the merger of two massive black holes or neutron stars. Astronomers also detect various kinds of subatomic particles, such as neutrinos, electrons or protons to learn about the interior of our Sun and some of the most energetic processes in the cosmos.

## 4.4

### Astronomy makes use of data obtained from observations and simulations to model astronomical phenomena in the framework of current theories

Astronomers create mathematical models of astronomical objects, their associated phenomena and their evolution. The framework of these models is given by the fundamental theories in physics and chemistry. Some models consist of elementary mathematical relations, more complex models make use of numerical simulations. The most sophisticated simulations are run on some of the largest supercomputers in the world. Observational data from telescopes and detectors is used to test and refine models. The interaction between observational evidence and models is an important aspect of discovery.

## 4.5

Astronomical research combines knowledge from different fields, such as physics, mathematics, chemistry and biology

Professional astronomical research combines knowledge from mathematics, physics, chemistry, engineering, computer sciences, as well as other fields. This broad view has proven essential for revealing and modelling the nature of astronomical objects and phenomena. For example, to understand the nuclear reactions taking place inside stars, scientists need nuclear physics; in order to detect the resulting elements in the atmospheres of stars, they need chemistry. Engineering is essential for the manufacturing of telescopes and detectors, and the development of custom software is crucial for analysing the data provided by these instruments.

## 4.6

Astronomy is divided into a number of specialties

Since a good description of astronomical objects and phenomena requires a good knowledge of other scientific fields, modern astronomy is commonly divided in specialties according to the main topics addressed. Some of these specialties include: astrobiology, cosmology, observational astronomy, astrochemistry and planetary science. Astronomers may also pick a specialty of studying one particular kind of object, such as white dwarf stars. Given the important role that physics plays within astronomy, the terms "astrophysics" and "astronomy" are used interchangeably.

## 4.7

Time and distance scales in astronomy are a lot larger than the ones we use in our daily life

The Moon is the closest celestial object to Earth at a distance of about 384,400 km. Our Sun has a diameter of 1.39 million km, a mass of about 1900 trillion billion kg, and it is the closest star to Earth at a distance of about 150 million km (which defines the Astronomical Unit, au). The star closest to the Sun is Proxima Centauri which is about 4.25 light-years away. One light-year is the distance that light travels in one year, which is just over 9 trillion kilometres. Our galaxy is 100,000-120,000 light-years in diameter and other galaxies can be as far as billions of light-years away. The units in astronomy are a lot larger than we could imagine. Astronomical time scales are long and ages of millions or billions of years are typical.

## 4.8

Spectroscopy is an important technique allowing us to probe the Universe from a distance

Several characteristics of astronomical objects can be revealed only by studying their spectrum — the rainbow-like decomposition of their light into myriads of different colours, each characterised by the light's wavelength. By analysing the light collected from these objects, astronomers can determine details such as their elemental composition, temperature, pressure, magnetic field, among other characteristics.

# 5

*Astronomy benefits from and  
stimulates technology development*

Two of the four 8m-class telescopes which form the Very Large Telescope (VLT), located high in the Chilean Andes.

Credits: ESO/P. Horálek



## 5.1

### Telescopes and detectors are crucial to the study of Astronomy

Since electromagnetic waves are the main source of information in astronomy, telescopes and detectors play an important role when it comes to collecting and analysing these waves. Larger telescopes collect more light, allowing astronomers to identify and analyse very faint objects. Larger telescopes also have more resolving power, allowing astronomers to study their target objects in finer detail. While early astronomical observations were performed by looking directly through a telescope, detectors today allow astronomers to document their observations objectively, at many different wavelengths.

## 5.2

### Some smaller telescopes can be linked together to act as one big telescope

By linking together many telescopes, astronomers can make them work as a single big telescope using a technique called interferometry. The resolution of the combined instruments will be that of a single telescope with a diameter equal to the greatest distance between any two of the smaller, linked telescopes. This allows astronomers to see smaller and finer details in astronomical objects as well as distinguish between separate objects, such as a star and its planetary system.

## 5.3

### Astronomical observatories are located on Earth and in Space

Earth's atmosphere absorbs radiation from most of the electromagnetic spectrum. It is transparent to visible light, some ultraviolet and infrared, and shortwave radio, but otherwise mostly opaque. Most ultraviolet bands and large portions of infrared light, as well as X-rays, cannot penetrate the atmosphere. For this reason, most of the telescopes that collect light other than visible, radio and a smaller number of other wavelength bands, must be placed in space. Although visible light can be observed from the surface, the turbulence of Earth's atmosphere affects the quality of the images, so some optical telescopes are also placed in space.

## 5.4

### Earth-based astronomical observatories are often located in remote regions all around the world

Few locations on Earth provide pristine observing conditions, owing to high altitudes, an absence of light pollution and transparency of the atmosphere to certain wavelengths. These locations can often be hostile, hard to access, and are usually far removed from larger human settlements. Astronomers either travel to those locations for their observations, allow experienced local telescope operators to carry them out for them, or make use of robotic telescopes, which are operated remotely.

## 5.5

### Astronomy today is part of “Big Science” and “Big Data”

Astronomical surveys have started producing large amounts of data, and this will increase by many orders of magnitude in the coming years. This evolution is called “Big Data Astronomy”, where the focus is on finding novel ways to store, deliver and analyse this data. This has led to the development of various citizen science projects to tap into the acute pattern recognition ability of humans. Modern telescopes and instruments are expensive, and their construction requires a variety of technical skills. They are commonly constructed by international organisations or consortia involving numerous astronomical institutes from different countries.

## 5.6

### Complex simulations and huge data in astronomy require the development of powerful supercomputers

The processing of vast amounts of data from both simulations and observations requires computers that are capable of performing complex simulations in a short amount of time. Current supercomputers can perform in the order of a couple of hundred quadrillion calculations every second. These supercomputers allow astronomers to create simulated Universes and compare them with observations from large-scale surveys.

## 5.7

### Astronomy is a global science, with international teams, and where data and publications are shared freely

The data available from most professional observatories is publicly available. Over the course of their career, astronomers will typically work in different countries. Larger astronomical projects, from the construction of telescopes and instruments to coordinated observing campaigns, are frequently undertaken in collaboration between researchers and institutes from different nations. Astronomy is global and international. We are all crew members of “Spaceship Earth”, under one sky, exploring the cosmos.

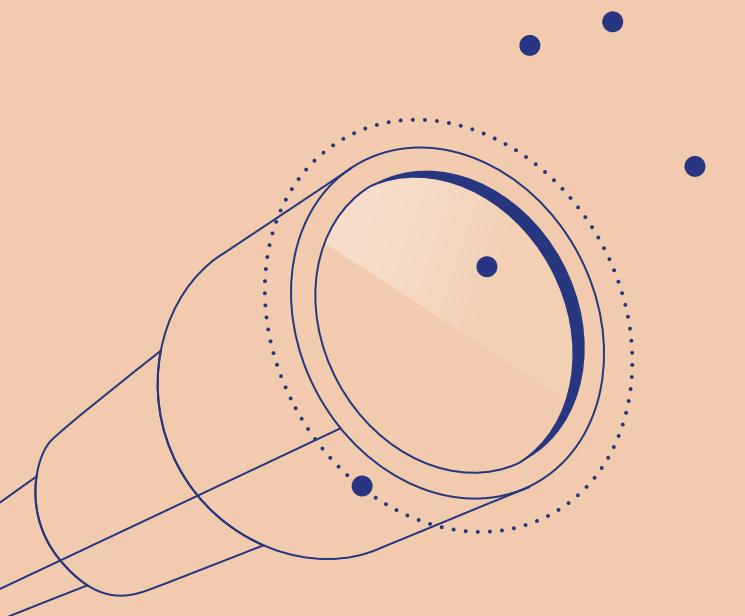
## 5.8

### Numerous spacecrafts have been launched to space to study the Solar System

In order to explore and learn more about our place in the Universe, we have been sending robotic probes throughout the Solar System. Some of these probes orbit planets, moons, or even asteroids, while others have landed on such objects. Among some places in the Solar System that have been visited (landing, orbit or fly-by) by robotic probes are all the planets, the dwarf planet Pluto, our Moon and other moons of Jupiter and Saturn, comets and asteroids.

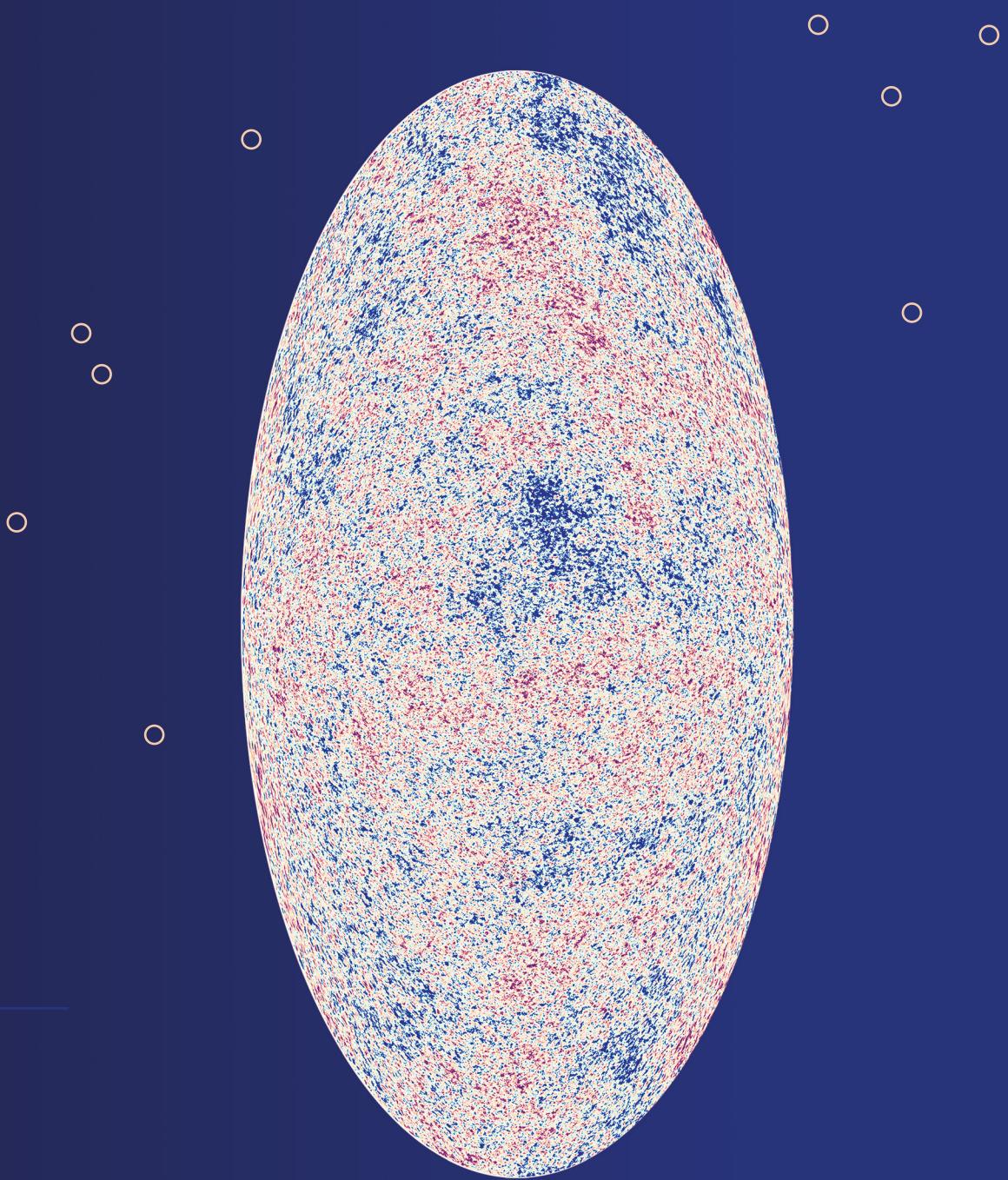
# 6

*Cosmology is the science of  
exploring the Universe as a whole*



An image of the Cosmic  
Microwave Background  
(CMB) radiation, the relic left  
over from when the Universe  
was 380,00 years old.

Credits: ESA and the  
Planck Collaboration



# 6.1

## The Universe is about 13.8 billion years old

The estimated age of the Universe based on modern observations and on state-of-the-art cosmological models for its early evolution, is 13.8 billion years. Cosmology is a research field which studies the evolution and the structure of the Universe.

# 6.2

## The evolution of the Universe can be explained by the Big Bang model

According to the best available evidence, all the matter and energy we see around us were contained in a volume smaller than an atom 13.8 billion years ago. The Universe expanded from this very high density and temperature phase into its present state. The hot, dense early phase is known as the Big Bang, and the models describing the expanding Universe are referred to as LambdaCDM (where Lambda stands for the Dark Energy component of the Universe, and CDM for Cold Dark Matter). Contrary to regular explosions, where matter is flung out into previously existing empty space, all available space was filled with matter from the very beginning, but the average matter density has decreased ever since. Ever since galaxies formed, the average distances between them has been constantly increasing. The Big Bang model makes numerous testable predictions about our current universe, most of which have been confirmed using observational data.

# 6.3

## The Universe is mainly composed of Dark Energy and Dark Matter

The stars, the air we breathe, our bodies and everything we see around us consist of atoms, which themselves are composed of protons, neutrons and electrons. This so-called baryonic matter, is what we interact with in our daily life. Observational evidence shows that it represents only about 5% of the total energy of the Universe. In fact, the Universe is mainly composed of an unknown form of energy known as Dark Energy (around 68%), and an unusual form of matter called Dark Matter (around 27%). The nature of the so-called Dark Energy and Dark Matter is an active area of research, especially through observations of their influence on the baryonic matter.

# 6.4

## The Universe is expanding

As the Universe expands in a systematic way on large scales, clusters of galaxies move away from each other. Observational data shows that, as one would expect from this kind of expansion, the more distant a galaxy is from us, the faster it moves away from us. Hypothetical alien observers in other galaxies would find the same. Bound systems, such as clusters of galaxies, and groups of galaxies bound by their own gravity, or galaxies themselves, are not affected by cosmic expansion. Within galaxy clusters and groups, individual galaxies can be orbiting each other, or they can be on a collision course with each other. The latter is true for the Milky Way and the Andromeda Galaxy.

## 6.5

The Universe is  
homogeneous and isotropic

At the largest scales, matter in the Universe appears to be uniformly distributed. Because of this nearly uniform density and structure, the Universe looks nearly the same at any location (homogeneous) and in every direction (isotropic).

## 6.6

The natural laws (e.g. gravity) that we  
study on Earth appear to work the  
same way throughout the Universe

There have been many tests to see if the laws of physics, such as the laws governing gravity, thermodynamics and electromagnetism, are the same on Earth and in the distant Universe. So far, all such tests indicate that the fundamental laws of physics apply throughout the whole Universe.

## 6.7

We can only directly observe  
a fraction of the total Universe

Since light travels in space at a finite velocity, and cannot have started its journey until after the Big Bang phase, there are distant regions of the Universe we cannot yet observe. The reason for this is simply that light from those regions has not had enough time to reach our detectors on Earth. We can only see objects that lie inside a certain region that is called the “Observable Universe,” comprising all objects whose light has had the necessary time to reach us. Astronomers are able to look at objects in the very outskirts of this region. Those appear to us in the form they were when the Universe just began.

## 6.8

Astronomers always  
observe the past

Due to the finite velocity of light, astronomers never see objects as they are now, but always as they were in the past. We can only see the Sun as it was about eight minutes ago, since light from the Sun takes about eight minutes to reach us. We see the Andromeda Galaxy as it was about 2.5 million years ago, since it takes the galaxy’s light that long to arrive on Earth. In this way, astronomers always observe the past, even up to 13.8 billion years ago. Observing astronomical objects at various distances thus provides us with a cross-section of cosmic history.



## 6.9

The Cosmic Mierowave Background allows us to explore the early Universe

The oldest electromagnetic radiation, emanating from the most distant regions in the Universe that we can observe, is the Cosmic Microwave Background radiation. It is the relic left over from the hot and dense early Universe, imprinted with information from a time when the Universe was about 380,000 years old. The Cosmic Microwave Background allows us to measure key characteristics of the Universe as a whole: the amount of Dark Matter, baryonic matter and Dark Energy it contains, the geometry of the Universe and its current expansion rate. The Cosmic Microwave Background shows that the Universe is nearly isotropic and thus also provides indirect evidence for homogeneity.

## 6.10

The expansion of space causes light from distant galaxies to be shifted

Cosmic expansion influences the properties of light in the Universe. Light reaching us from distant galaxies is increasingly redshifted with larger distances. This cosmological redshift can be understood either directly in terms of wavelengths of light increasing with the cosmic scale factor or as a Doppler effect. That is why distant galaxies can only be observed in the infrared or radio bands, and why the Cosmic Microwave Radiation reaches us mostly in the microwave regime.

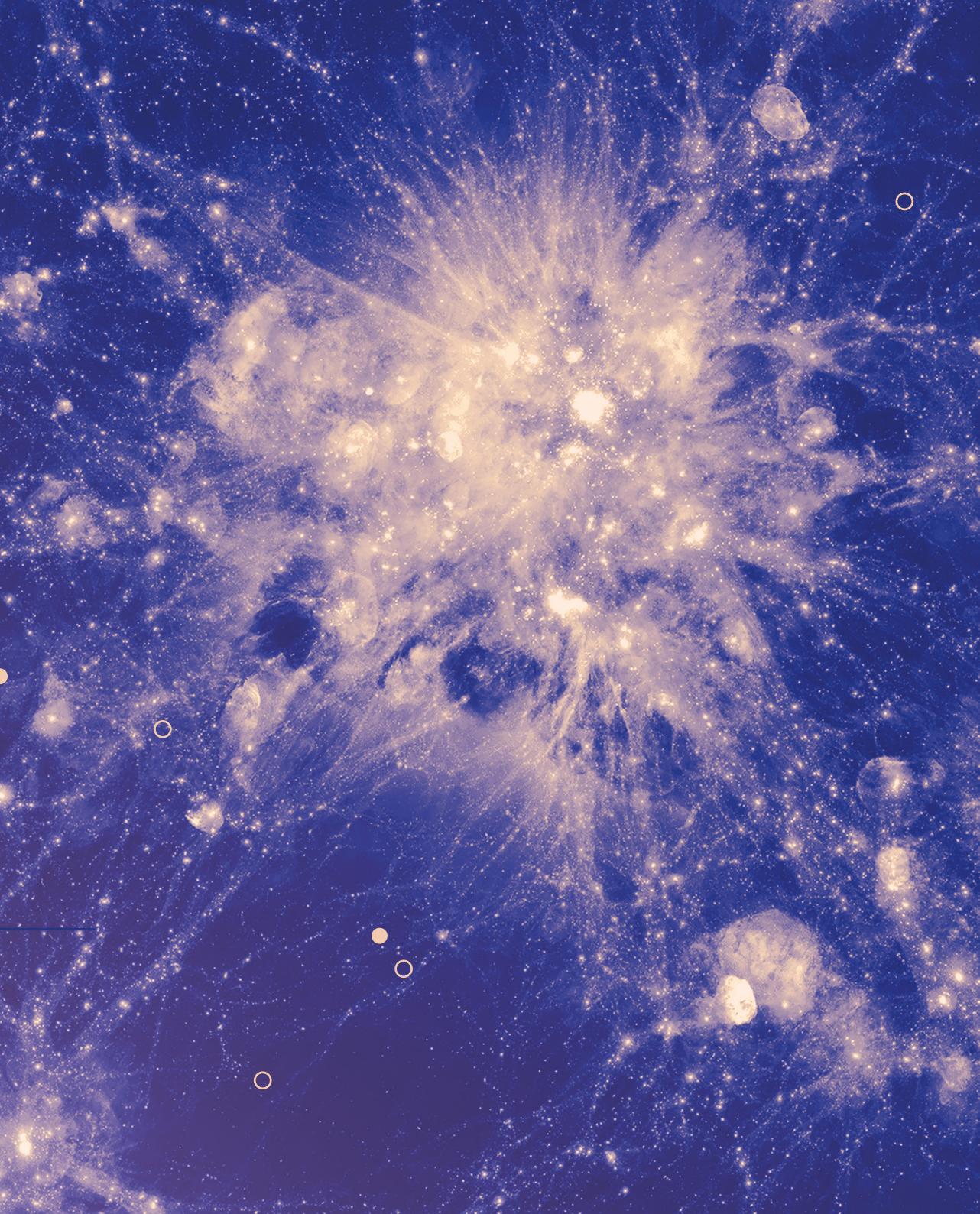
## 6.11

The large-scale structure of the Universe is composed of filaments, sheets and voids

Large redshift surveys of the Universe have revealed that on large scales in the order of a few hundred million light-years, the Universe resembles a three-dimensional, sponge-like web of filaments and voids, which astronomers call the “cosmic web”. Filaments and sheets contain millions of galaxies. These large-scale structures extend over hundreds of millions of light-years and are typically tens of millions of light-years thick. The filaments and sheets form boundaries around voids, which are in the order of hundred million light-years in diameter, and contain only very few galaxies.

A large-scale cosmological simulation showing the evolution of a section of the Universe, where dark matter density is overlaid with the gas velocity

Credits: The Illustris Collaboration





*We all live on a small planet  
within the Solar System*

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*Artistic impression of some of the exoplanets orbiting a star called TRAPPIST-1 which has, at least, seven Earth-size rocky planets in its orbit.*

*Credits: ESO/M. Kornmesser*



## 7.1

### The Solar System was formed about 4.6 billion years ago

Radioactive dating of the oldest Earth rocks known has allowed us to determine the age of the Solar System. This age is also consistent with the dating of lunar rock samples and even meteorites found on Earth's surface.

## 7.2

### The Solar System is composed of the Sun, planets, moons, comets, asteroids, and icy bodies

Our Solar System consists of a central star that we call the Sun and of every object in its orbit, under the influence of its gravity. These objects include planets and their natural satellites, dwarf planets, asteroids, meteoroids and comets. The Sun accounts for more than 99.99% of the Solar System's total mass.

## 7.3

### There are eight planets in the Solar System

According to the 2006 International Astronomical Union resolution, in order for an object to be a planet it must fulfil three criteria. The first is that it must orbit the Sun. The second is that a planet must have enough mass for gravity to transform it into an approximate spherical shape, and finally, its gravitational influence must be sufficient so as to clear its orbital neighbourhood from other objects. Objects that are not moons and obey the first two rules, but not the third, are called dwarf planets. Counting from the Sun, the planets in our Solar System are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus and Neptune.

## 7.4

### There are several dwarf planets in the Solar System

Dwarf planets are all smaller than Earth's Moon, which has a diameter of about 3489 km. Pluto is currently the largest of the dwarf planets, followed by Eris, Haumea, Makemake and Ceres. Each of these objects are solid, with icy surfaces, and have similar compositions. Ceres is located between the orbits of Mars and Jupiter, while the other four dwarf planets are found beyond Neptune's orbit, in the Kuiper belt.

## 7.5

### The planets are divided into terrestrial (rocky) planets and gas giants

The four planets closest to the Sun are called terrestrial planets. All of these planets have a solid surface and are composed mostly of rock. Mercury has no atmosphere but compared to Earth, Venus has the densest atmosphere and Mars the thinnest atmosphere. In contrast with the small inner planets, the four outer planets, which are called gas giants, are much larger. These planets are mainly gaseous (hydrogen and helium) and their atmospheres are very dense. All the gas giants have rings around them. Saturn has by far the most impressive ring system, which is visible even through a fairly small telescope.

## 7.6

### Some planets have dozens of natural satellites

With the exception of Mercury and Venus, all planets have at least one natural satellite. Earth is the only planet in the Solar System which possesses only one moon. Mars has two moons. Contrasting with the terrestrial planets, all the gas giants have a great number of objects orbiting them. With over 79 confirmed moons, Jupiter is the planet with the most natural satellites, followed by Saturn, Uranus, and Neptune.

## 7.7

### Earth is the third planet orbiting around the Sun, and has one natural satellite, the Moon

Our home planet is the third planet counting from the Sun and has an almost circular orbit. Earth's atmosphere is mainly composed of nitrogen and oxygen and the average temperature at its surface, which is covered for over 70% by water, is 22 degrees Celsius. The Moon is the Earth's only natural satellite and the only celestial object upon which humans have set foot.

## 7.8

### There are millions of asteroids which are remnants from the early formation of our Solar System

Remnants from the early formation of the Solar System can be found in the asteroid belt, located between the orbits of Mars and Jupiter, and the Kuiper belt, located beyond Neptune's orbit. These asteroids range in size from about 10 m to 1000 km and the combined mass of all the asteroids in the Solar System is less than the mass of Earth's Moon.

## 7.9

### A comet is an icy object that acquires a tail when it is heated by the Sun

Comets are mainly formed by ice, but they also contain dust and rocky material. The ice is volatile and evaporates when the comet approaches the Sun due to solar winds and radiation, creating a tail that can stretch for millions of kilometres. The comet's tail always points in the opposite direction of the Sun, independently of the direction the comet is moving. A secondary dust tail is slightly bent in the direction opposite to the comet's movement. Most of comets are believed to come from two specific regions: the Kuiper Belt, located beyond Neptune's orbit, and the Oort Cloud, at the edges of the Solar System.

## 7.10

### The Solar System has different boundary regions, one of which is called the Heliopause

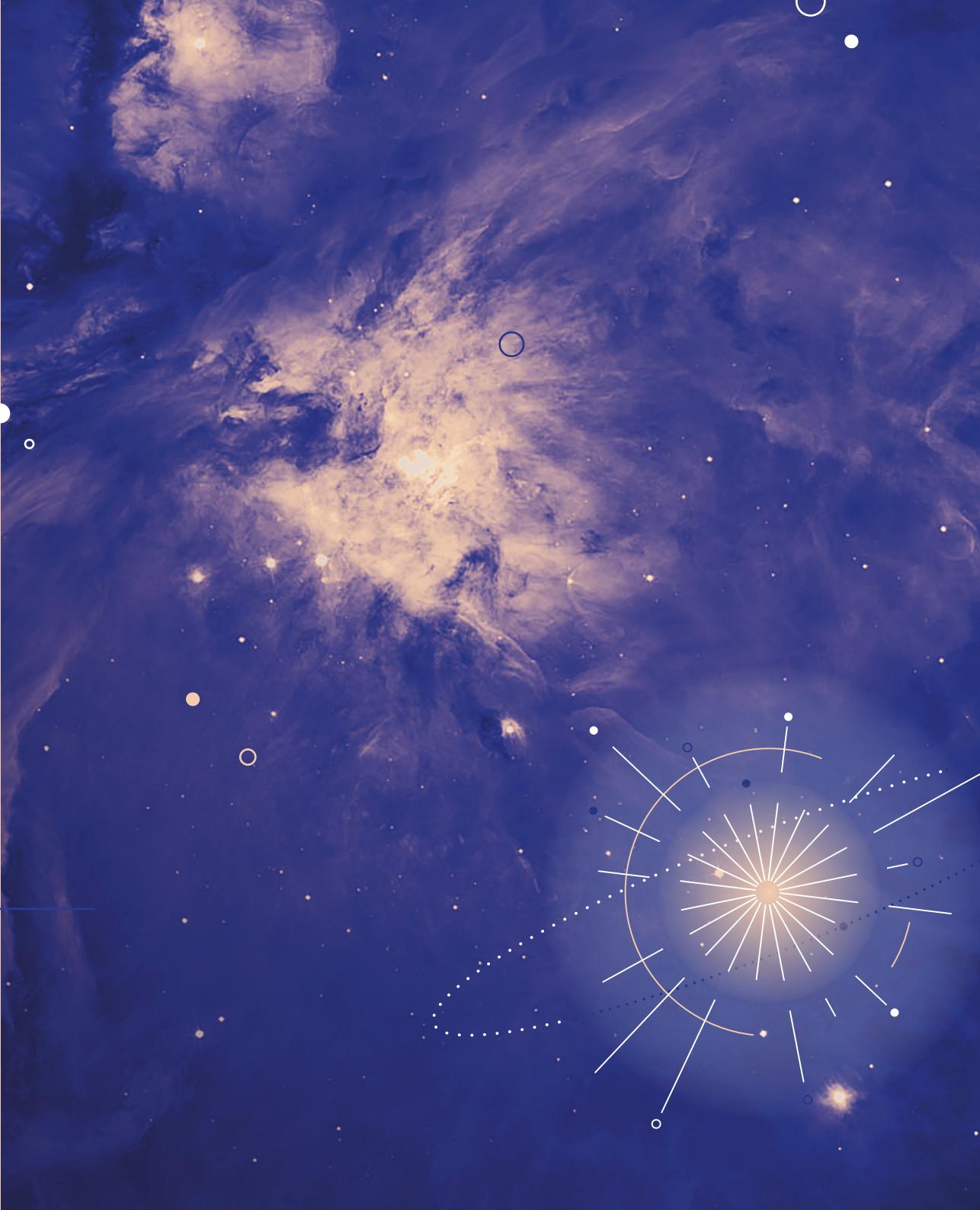
There is no unique definition for the boundary of the Solar System. The region where charged particles from the Sun (via the Solar Wind) begin to interact with charged particles from other stars is called the Heliosheath. This region is limited by the Heliopause, beyond which lies the Heliosphere, where cosmic rays are no longer affected by the solar wind. In 2012, spacecraft Voyager 1 was the first human-made object to cross the Heliopause.



*We are all made  
of stardust*

The Orion Nebula (M42),  
the closest massive star  
forming region nearly  
1500 light years away.

Credits: NASA, ESA,  
M. Robberto (Space Telescope  
Science Institute/ESA) and  
the Hubble Space Telescope  
Orion Treasury Project Team



## 8.1

A star is a self-luminous body generating its energy by internal nuclear reactions

Stars are formed by very hot plasma (a gas where the electrons and nuclei of atoms are largely separated) that is held together by its own gravity. The energy of a star is generated by nuclear reactions taking place in its centre, which initially fuse hydrogen into helium, via the proton-proton chain (and for more massive stars via the carbon-nitrogen-oxygen CNO cycle) before moving onto fusing higher elements. Stars are stabilised by the pressure sustained via the energy set free during their central fusion processes, which counteracts the star's urge to collapse under its own gravity. In this way, most stars of similar or less mass to our Sun remain stable for a few billions or even tens of billions of years.

## 8.2

Stars form from massive clouds of dust and gas

The gravitational collapse of giant cold molecular clouds give birth to stars. As the cloud collapses, it fragments into cores whose central regions get ever denser and hotter. Beyond critical values for temperature and pressure, nuclear fusion ignites, and a star is born. This young star is initially surrounded by a protoplanetary disk of dust and gas. Over the course of millions of years, this disk differentiates into planets and smaller bodies.

## 8.3

The closest star to Earth is the Sun, which has a moderate size and mass, neither big nor small, compared to other stars

With an equatorial diameter of about 1.4 million kilometers, the Sun, the nearest star to Earth, is so big that we could fit roughly 1.3 million Earths inside. Even though our star is enormous compared to our planet, there are much bigger stars in the Universe. The supergiant VY Canis Majoris, with about 1800 times the diameter of the Sun, is the largest star known to date. If placed in the centre of the Solar System, the surface of VY Canis Majoris would extend beyond the orbit of Jupiter. There are also stars much smaller than the Sun. The closest star, Proxima Centauri, is a red dwarf with a diameter of about 200,000 kilometers, only 20 times the diameter of the Earth.

## 8.4

The colour of a star tells us its surface temperature

Stars can have surface temperatures between a few thousand degrees Celsius and fifty thousand degrees Celsius. Hot stars radiate away most of their energy in the blue and ultraviolet region of the electromagnetic spectrum (at short wavelengths), and thus look blueish to our eyes. Cooler stars look reddish, since they radiate away most of their energy in the red and infrared regions of the electromagnetic spectrum (at long wavelengths).

## 8.5

The space between stars can be largely empty or it can contain clouds of gas, which can produce new stars

The space between the stars contains minute traces of matter in the form of gas, dust and high energy particles ("cosmic rays"). This matter content is called the Interstellar Medium. It can be more or less dense in different parts of the galaxy. However, even the most dense regions of the interstellar medium are still one thousand times less dense than the best vacuum created in a laboratory.

## 8.6

A star goes through a life cycle which is largely determined by its initial mass

Computer simulations reveal that the first stars had life spans of some millions of years. In contrast, the average life expectancy of a star similar to the Sun is about 10 billion years. Low-mass red dwarf stars can live for trillions of years. A star with a mass similar to that of our Sun will eventually evolve into a red giant star and later on eject most of its mass to space, leaving behind a compact White Dwarf star surrounded by what is called a planetary nebula. A star with at least eight solar masses will evolve into a red supergiant before exploding in an event called supernova, leaving behind a neutron star or a stellar black hole.

## 8.7

Massive stars end their life cycle as stellar black holes

A black hole is a region of space whose extreme gravitational field prevents anything, even light, from escaping once it has crossed the event horizon. The event horizon is a region surrounding a black hole, where the speed needed to escape its gravitational field is greater than the speed of light. Theoretical models predict that at the centre of a black hole is a singularity, where the density of matter and curvature of spacetime approaches infinity. Stellar mass black holes have masses in the order of a few tens of solar masses, in a region having a radius of some few kilometres to tens of kilometres (depending on the mass).

## 8.8

New stars and their planetary systems are born from matter left behind by previous stars in that region

Apart from hydrogen, most of the helium and a small amount of lithium, all elements in the present Universe have been produced inside stars. Low-mass stars, like the Sun, produce elements up to oxygen by nuclear fusion, while massive stars can create elements heavier than oxygen and up to iron. Elements heavier than iron, like gold and uranium, are created during high-energy supernova explosions and stellar collisions. As they die, stars release most of their mass into the interstellar medium. From this matter, new stars form, in the cosmic version of a recycling process.

## 8.9

The human body consists of atoms that can be traced back to earlier stars

Elements other than hydrogen and helium were mainly created in the interior of stars, and released into space in the last stages of these stars' lives. This is the origin of most of the elements that make up our bodies, such as the calcium in our bones, the iron in our blood and the nitrogen in our DNA. In the same way, the elements making up animals, plants, and indeed most of the things we see around us, were produced by stars billions of years ago.



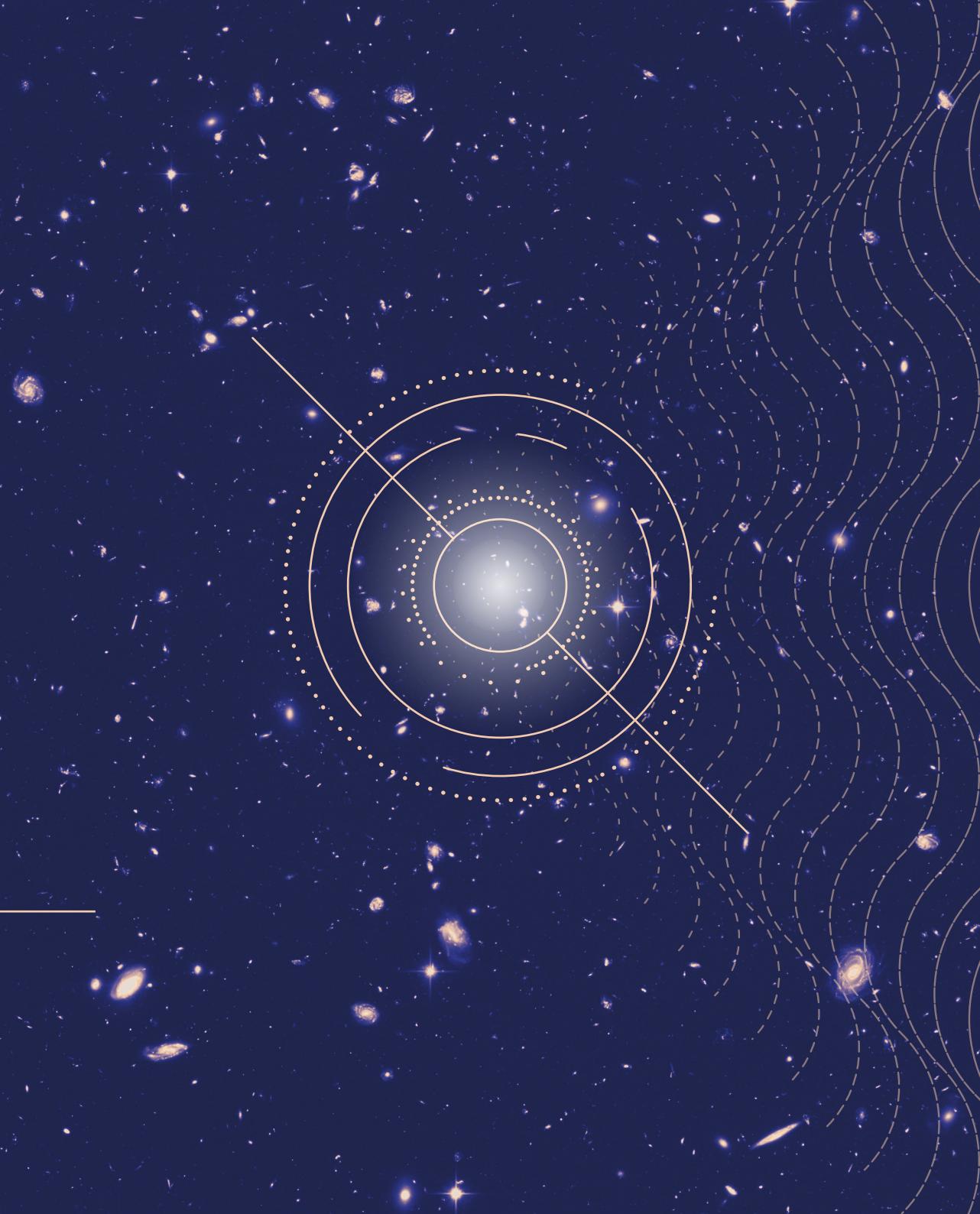
9

*There are hundreds of billions  
of galaxies in the Universe*

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*The Hubble Ultra Deep Field, a snapshot of a small region of space (nearly 1/10 the diameter of the Full Moon) containing nearly ten thousand galaxies.*

*Credits: NASA, ESA, and S. Beckwith (STScI) and the HUDF Team*



## 9.1

### A galaxy is a large system of stars, dust and gas

A galaxy contains between a few million to hundreds of billions of stars, bound together by their gravitational force. A galaxy's stars can be part of stellar clusters, or part of a larger population of separate stars pervading the galaxy. In addition, a galaxy contains stellar remnants, dust, gas and dark matter. Many galaxies have a supermassive black hole at their centre.

## 9.2

### Galaxies contain large amounts of Dark Matter

Dark Matter is a hypothetical type of matter which does not emit or interact with the electromagnetic radiation, and thus is impossible to see by direct observations. Although Dark Matter cannot be seen, it has mass, and its existence is inferred from its gravitational effects on visible objects. Such effects include, the motion of visible objects, or the distortion of images due to gravitational lensing. Galaxies are surrounded by a much larger halo of Dark Matter — in a sense, what we see of a galaxy is only the tip of the iceberg.

## 9.3

### Galaxy formation is an evolutionary process

Over the first hundreds of millions of years of the Universe's history, Dark Matter evolves into numerous large, denser regions, called halos. As hydrogen and helium gas fell onto these halos, the first galaxies and the first stars formed. Larger spiral galaxies like the Milky Way evolved as they attracted and incorporated numerous smaller galaxies. Large elliptical galaxies formed when more massive galaxies collided and merged. Depending on their gas reserves, and on heating through exploding stars or activities in a galactic centre, these galaxies formed new stars at an increased or slower rate.

## 9.4

### There are three main types of galaxies: Spiral, Elliptical and Irregular

Accordingly to their visual morphology, galaxies are categorised into spiral, elliptical and irregular galaxies. These types differ not only in shape but also in their contents. Spiral galaxies have flattened spiral arms formed predominantly by bright young stars and large quantities of gas and dust. In contrast, elliptical galaxies contain less gas. Their stars are mostly old and distributed in an ovoid or spherical shape. Some galaxies, including most dwarf galaxies, have neither of these two standard shapes and are called irregular.

## 9.5

### We live in a spiral galaxy called the Milky Way

Our Milky Way is a spiral galaxy with a bar at the centre. The Solar System is located at about 25,000 light-years from the centre, in a spiral arm. The visible part of our galaxy is a disk-shaped collection of stars with a diameter of about 100,000 light-years and a thickness of only about 2,000 light-years. In this disk, young stars and dust form spiral arms. During a dark night and from a suitably dark location, we can see a minute fraction of the more than 100 billion stars within the Galactic disk as an enormous hazy band arching across the sky. This is our view from within our home galaxy.

## 9.6

### The spiral arms of galaxies are created by pile-ups of gas and dust

A widely accepted theory about the formation of spiral arms is that they are the result of a density wave moving through the disk of a galaxy, causing the stars, gas and dust to pile up in a way similar to a traffic jam on a busy highway. This gives rise to denser regions in the disk which are seen as spiral arms. These high density regions contain a lot of gas and dust, which are essential for the formation of new stars. Hence, the spiral arms contain many young bright stars, showing that these regions have a high star formation rate.

## 9.7

### Most galaxies have a supermassive black hole at their centre

A typical galaxy contains an estimated 100 million stellar-mass black holes. These types of black holes are formed when a massive star ends its life in a supernova explosion. Supermassive black holes are found in the centres of most galaxies, and are the largest type of black hole, with masses between a few million and more than a billion solar masses. Our Milky Way has a supermassive black hole at its centre with a mass of about 4 million solar masses. The first direct image of the event horizon of a black hole at the center of galaxy was achieved in 2019, by combining data from eight radio telescopes around the world.



## 9.8

### Galaxies can be extremely distant from each other

The Milky Way's closest neighbour is the Canis Major Dwarf galaxy, at a distance of about 25,000 light-years. Distant galaxies appear very faint to us and are therefore difficult to observe. In order to obtain images of distant galaxies, it is necessary to employ large telescopes with high resolving power, and take long exposures to gather enough light from these objects.

## 9.9

### Galaxies form clusters

Galaxies are not scattered randomly throughout the Universe. Rather, the average galaxy is part of a galaxy cluster. These clusters consist of hundreds or even thousands of galaxies bound together by their mutual gravitational attraction. Clusters of galaxies themselves are also grouped together in bigger structures called superclusters. The Milky Way is part of what is called our Local Group of galaxies, which includes more than 54 galaxies. The Local Group is an outlying member of the Virgo Cluster, which is part of the Virgo Supercluster, which is in turn part of the Laniakea Supercluster.

## 9.10

### Galaxies interact with each other through gravity

Interactions between galaxies influence their appearance and evolution. In the past was believed that one type of galaxy could evolve to a different type throughout its life but current scientific knowledge shows that the gravitational interactions are the reason behind some types of galaxies. For example, elliptical galaxies may be created by mergers between large predecessor galaxies, and at the same time these events may trigger an intense star formation burst in the interacting galaxies.

Colour composite image of Centaurus A, revealing the lobes and jets emanating from the active galaxy's central black hole.

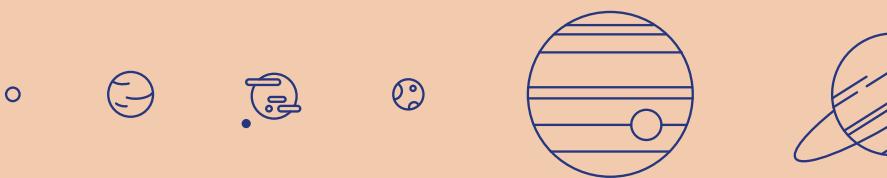
Credits: ESO/WFI (Optical);  
MPIfR/ESO/APEX/A.Weiss et al. (Submillimetre); NASA/CXC/CfA/R.Kraft et al. (X-ray)





# 10

*We may not be alone  
in the Universe*



An image by the Cassini spacecraft, wooing Earth and the Moon, as seen from Saturn nearly one and half billion kilometres away.

Credits: NASA/JPL-Caltech/  
Space Science Institute



## 10.1

Organic molecules have been detected outside Earth

Organic molecules contain carbon, which is a basic building block for life as we know it. Observations of the interstellar medium show that organic molecules, such as simple amino acids, are present in space. Organic molecules have also been found in comets and meteorites. It is very likely that such molecules were already present in the gas and dust from which our Solar System was formed.

## 10.2

Living organisms have been found to survive in extreme environments on the Earth

While most life on Earth is sensitive to environmental conditions, some organisms, the extremophiles, have been found to survive in extreme conditions showing that life can exist where it is least expected to. These organisms can be very resistant to a wide range of temperatures, pressures, pH and radiation exposure. Some of them live in places such as deserts, poles, deep inside the ocean or even in volcanoes. One of the most resilient organisms known can survive in vacuum conditions. These facts are cautious grounds for optimism when it comes to the possibility of life on other planets or moons, which often present comparatively harsh environmental conditions.

## 10.3

Traces of liquid water open up the possibility of primitive life on Mars

Liquid water is a key factor for the development of life as we know it. For this reason, the search for liquid water on other planets and their moons has been an important goal in the search for extraterrestrial life. In 2015, liquid water was found on the surface of Mars, confirming a long-held suspicion about its existence on this planet. Although this water is mixed with salts and maintains the liquid state only in some specific conditions, its presence gives an extra reason to believe that simple life forms may have existed or still exist on Mars.

## 10.4

Some natural satellites in the Solar System appear to have the conditions for life to exist

Among the many moons orbiting the giant planets of the Solar System, some share characteristics with terrestrial planets, such as dense atmospheres and volcanic activity. Europa, one of the largest moons of Jupiter, has a frozen surface that might cover a liquid ocean. Scientists believe that this ocean might provide the right conditions for simple life forms to exist. Another candidate to host simple life is Titan, one of the largest moons of Saturn. Titan is rich in complex organic compounds, has a dense atmosphere, liquid methane on the surface, and has been hypothesised to feature a subsurface water ocean.

## 10.5

There are numerous planets called exoplanets, which orbit stars other than the Sun

Since the discovery of the first planet orbiting another star, thousands of planets orbiting stars other than the Sun, called exoplanets, have been detected. The number of discovered exoplanets continues to increase at an accelerating pace, and we are now able to characterize the population of exoplanets in the solar neighbourhood.

## 10.6

Exoplanets can be very diverse and are often found in systems

Exoplanets show a wide range of physical and orbital properties. With masses ranging from that of Mercury to several times that of Jupiter, exoplanets can have a radius of hundreds of kilometers to several times the radius of Jupiter. Exoplanet orbital periods can be as short as a few hours, and their eccentricities can be as high as those of a Solar System comet. Most exoplanets tend to be found in systems, comprised of several planets orbiting the same star.

## 10.7

We are now close to the detection of an Earth-like planet

By pushing the precision of the detection methods, we are now able to find planets with a mass as low as one Earth mass and a size of about the radius of the Earth. Our search so far, limited as it is, has shown that the Solar neighbourhood is teeming with planets. Some of these planets even orbit inside the so-called habitable zone around the host star. Based on definition, a planet orbiting inside the habitable zone receives just the right amount of radiation from its star as to allow for the existence of liquid water on its surface.

## 10.8

Scientists are searching for extraterrestrial intelligence

One way of searching for extraterrestrial civilizations is to look for signals that could not be naturally produced by any known astronomical phenomena. The systematic search for such signals is known as the Search for Extraterrestrial Intelligence (SETI). So far, no such signals have been found, but SETI antennas continue to scan the sky, looking for any clue of advanced life beyond Earth.

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*We must preserve Earth,  
our only home in the Universe*

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*Earth's night view from  
the International Space  
Station, where it is possible  
to see artificial lights from  
South Korea and Japan.*

*Credits: NASA*



## 11.1

### Light pollution affects humans, many other animals and plants

For millions of years, life on Earth has developed in the absence of artificial light, with species adapting to diurnal or nocturnal activities. Since the invention of electricity, humans have increasingly reduced nocturnal darkness with artificial lights, causing serious light pollution issues, which has many implications for Earth's environment. Wildlife is affected as artificial lights both change an animal's habitat and directly disrupt its physiology. For example, some predator species hunt only when it is dark, while other species use the darkness to hide from predators. We are also losing the dark skies that our ancestors have enjoyed. In many urban and suburban environments, the Milky Way is now all but impossible to see at night.

## 11.2

### There is a lot of human-made debris in Earth's orbit

With the development of space technology, humanity has been able to send numerous objects into space using rockets. Since the start of the era of space exploration, the amount of human-made debris in space, such as pieces of rockets or old satellites, has increased dramatically. Currently there are an estimated 500,000 pieces of debris, also known as space junk, orbiting Earth. As space junk travels at high speeds, any collision with a spacecraft or satellite can cause serious damage. This is particularly risky for the International Space Station and other crewed spacecraft.

## 11.3

### We monitor potentially hazardous space objects

During the early stages of the Solar System's formation, the newly formed planets were frequently struck by smaller bodies like asteroids. Some craters on Earth's surface and all those seen on the Moon's are direct evidence that those impacts can be very hazardous. Although it is still a topic of research and debate, it is believed that the extinction of the dinosaurs may have been due to a big asteroid impact with Earth, roughly 65 million years ago. Although the probability of an impact of this magnitude is very low nowadays, it is important to monitor all the celestial objects that may become a potential threat to life on Earth. Within the next few years, monitoring programs by space agencies, observatories and other institutions should be able to identify all potentially hazardous asteroids one kilometer or larger in size. None of the known asteroids are presently on a collision course with Earth.

## 11.4

### Humans have a significant impact on the Earth's environment

Industrial society has brought us numerous advantages, but has also caused several environmental problems on Earth. Through deforestation and the pollution of rivers, oceans and the atmosphere, we are damaging the vital sources of clean air and water that are necessary for life on Earth. Humanity has caused the extinction of numerous species, and continues to dig for minerals and energy resources in endangered environments. Global warming is changing our environment on large scales, placing us and many species at risk.

## 11.5

### The climate and the atmosphere are heavily affected by human activity

Without its atmosphere, our planet would be an icy world with an average temperature of  $-18^{\circ}\text{C}$ . However, the greenhouse gases of the atmosphere partially absorb the heat radiation emanating from the ground and radiates it back towards the Earth's surface, which makes the Earth habitable. Human activity has drastically increased the levels of the major greenhouse gases in the Earth atmosphere, creating an imbalance in the Earth's energy budget. The increase of these gases causes more energy being trapped on the Earth, creating higher average temperatures. The Earth is unable to radiate the excess energy away via its natural systems, thereby altering global climate patterns, which are sensitive to energy imbalances.

## 11.6

### A global perspective is necessary to preserve our planet

Every single person is an inhabitant of this planet. The concepts of global stewardship and responsibility can help us understand that everyone can act, as part of a group or individually, to help solve global problems. It is necessary to conserve Earth for our descendants. At present, Earth is the only planet in the Universe we know for certain to be able to sustain life.

## 11.7

### Astronomy provides us with a unique cosmological perspective that reinforces our unity as citizens of the Earth

All human beings on Earth live under one sky, and share the view into the depths of the Cosmos. Images from space showing the "Blue Marble" of planet Earth have provided us with a renewed understanding of our common spaceship. Seen from the outside, the borders between individual countries seem insignificant. Images from spacecraft like Voyager 2 and Cassini help us realise that the "Pale blue dot" is a mere speck in the vastness of the Universe.

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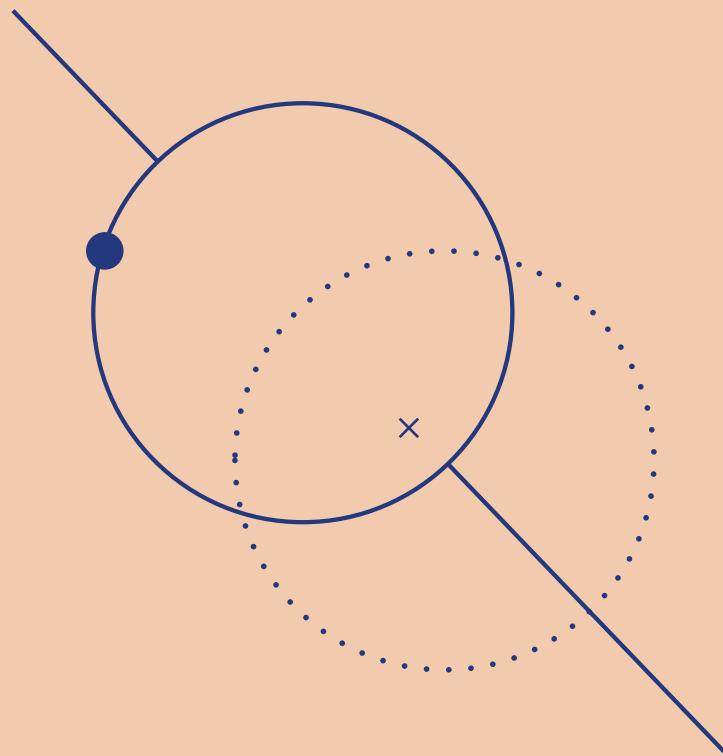
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