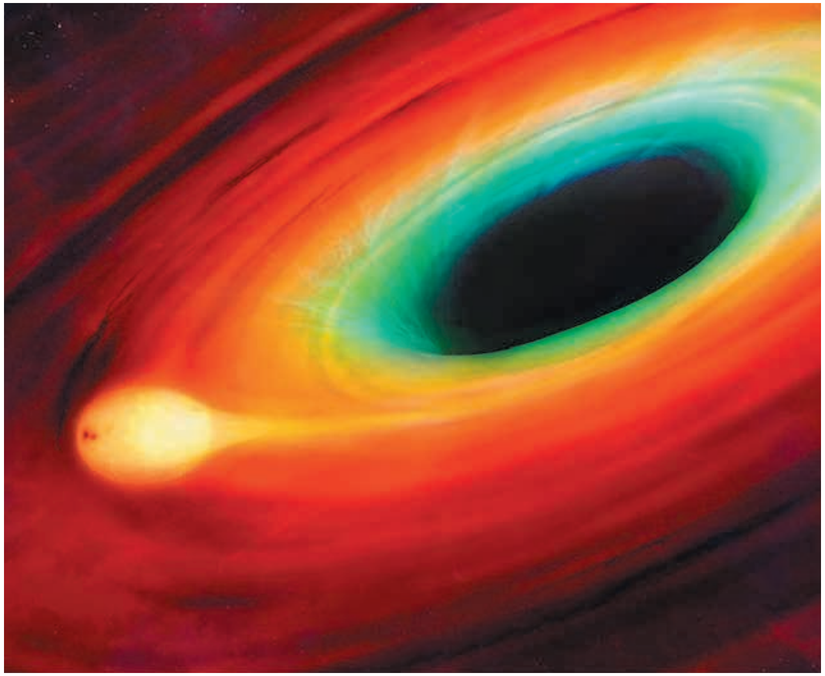
The Universe Contents

A star being distorted by its close passage to a supermassive black hole at the centre of a galaxy.



Welcome to the Universe

Bill Nye

Barred spiral galaxy NGC 1300.

Lonely Planet's *The Universe* gives us more perspective, often breathtaking, more insight, often deep – and more unusual facts, often ones you can't find anywhere else, regarding the profound happenstance of our existence. Simply put, the remarkable sequence of cosmic accidents required to enable us to be here on this planet and publish books like this one is astonishing. Unique to these pages are wonderful comparisons of Earth with the other worlds of our solar system and even those exoplanets orbiting other stars. They drive home the jaw-dropping idea that you and I, and everything we can observe around us, are made of the dust and gas blasted spaceward by exploding ancient Suns. And from the stardust and drifting gas, the extraordinary diversity of living things, including animals like you and me, emerged. You and I are at least one way that the cosmos knows itself. An utterly amazing idea that fills me with reverence every time I think on it.

While you are going about your business every day, thinking about what's happening on Earth right now, this book will help you think about a much grander timeline as well. From the comfortable surface of Earth, our deep-thinking ancestors observed our planet and its relationship, their relationship, to the night sky and the Sun. They learned where to live and how to survive. From the icy blackness of space, our spacecraft, built by our best scientists and engineers, make further observations that relentlessly show us Earth is like no other place in the solar system, and remains the only place we can live and thrive. By understanding the changes here over recent millennia, we can see that, if we're going to continue to thrive, we must preserve our environment. Otherwise, we'll go extinct, like 90% of the species that gave it a go on Earth before we showed up.

This cosmic perspective induces all of us to compare Earth to our neighbouring worlds out there. It's one thing to consider Earth as a pretty big place, especially if you tried to walk around it. It's another thing to think that 1300 Earths would fit inside a sphere the size of Jupiter, and over a million Earths would fit inside the volume of the Sun. While we're appreciating the visible differences of the traditional planets, what you might call their qualitative differences, this book helps us take it all in by the numbers, the planets' (and exoplanets') quantitative differences, and beyond that, the differences between our own Sun and the uncountable stars above, visible and invisible. In here, these essential distinctions are spelled out – or counted up.

The rocky and metallic compositions of Mars, Venus, and Mercury are very much like Earth's, but the environments of these other worlds are completely different. The text and pictures here will help you understand why. The unique chemical composition of the rocks, craters, and sands of the other worlds in the solar system has caused these extraterrestrial environments to have chemistries that are literally other worldly. These processes have conspired to produce radically different surface temperatures on Mars and Venus. Our discoveries in planetary science offer us a planet-sized lesson in the importance of the greenhouse effect, how our planet became habitable, and how the biochemistry of life changed the chemistry of the atmosphere and sea.

The story carries out away from the Sun, where we find the gas-giant planets: Jupiter and Saturn. They don't seem to even have surfaces as such. There's nowhere to stand, but they're so massive that, if you got too close, their gravity would crush you quick. On out further from the Sun we find Uranus and Neptune. They're very large and very cold, with enormous icy storm systems and winds moving at fantastic speeds. All of these other worlds in our solar system, the ones that are not Earth are very different, very interesting – and utterly hostile.

As you turn these pages, learning the facts of everything from our solar system to the far reaches of intergalactic space, consider that there's no other planet that we know of anywhere, upon which you could even catch a breath to be taken away, or seek a deciliter of water to be sipped – let alone be afforded an opportunity to live long and prosper. The Earth is unique, amazing, and our home.

From a cosmic perspective, we are a pretty big deal. We've changed the climate of a whole planet. Run the numbers for yourself. Climate change is our doing. If we're going to make it much farther on this world, we're going to have to engage in some un-doing. Right now, it's our chance to change things. We are but a speck in the cosmic scheme. But it's our speck, and the more we know and appreciate it, the better chance we have keeping it hospitable for species like us.

Introduction to the Universse

With 2 trillion estimated galaxies and uncountable stars, our Universe is filled with wild examples of exoplanets, stars, black holes, nebulae, galaxy clusters and more, which scientists are still probing.

Our Universe began in a tremendous explosion known as the Big Bang about 13.7 billion years ago. We know this by observing light in our Universe which has travelled a great distance through space and time to reach us today. Observations by NASA's Wilkinson Anisotropy Microwave Probe (WMAP) revealed microwave light from this very early epoch, about 400,000 years after the Big Bang.

A period of darkness ensued, until about a few hundred million years later, when the first objects flooded the Universe with light. The first stars were much bigger and brighter than any nearby today, with masses about 1000 times that of our Sun. These stars first grouped together into mini-galaxies; the Hubble Space Telescope has captured stunning pictures of earlier galaxies, as far back in time as ten billion light years away.

By about a few billion years after the Big Bang, the mini-galaxies had merged to form mature galaxies, including spiral galaxies like our own Milky Way. It had also expanded, racing under the force of the so-called Hubble constant. Now, 13.7 billion years from the Big Bang, our planet orbits a middle-aged Sun in one arm of a mature galaxy with a supermassive black hole in the middle. Our own solar system orbits the Milky Way's centre, while our galaxy itself speeds through space.

Under the Milky Way in San Pedro de Atacama, Chile.

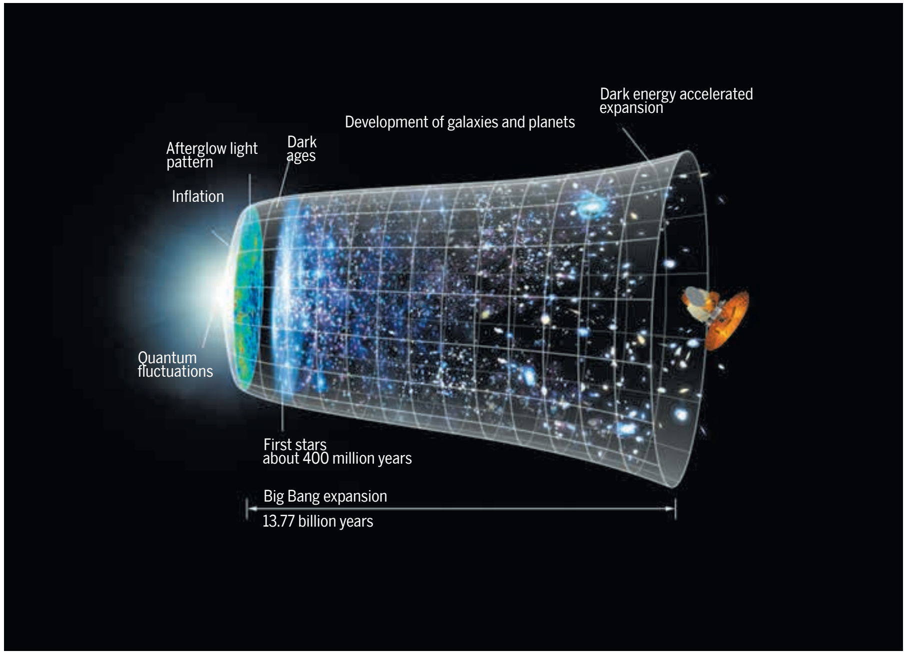
Scale of the Universe

Throughout history, humans have used a variety of techniques and methods to help them answer the questions 'How far?' and 'How big?'. Generations of explorers have looked deeper and deeper into the vast expanse of the Universe. And the journey continues today, as new methods are used, and new discoveries are made.

In the third century BC, Aristarchus of Samos asked the question 'How far away is the moon?' He was able to measure the distance by looking at the shadow of the Earth on the moon during a lunar eclipse.

It was Edmund Halley, famous for predicting the return of the comet that bears his name (p. 344), who three centuries ago found a way to measure the distance to the Sun and to the planet Venus. He knew that the planet Venus would very rarely, every 121 years, pass directly between the Earth and the Sun. The apparent position of the planet, relative to the disc of the Sun behind it, is shifted depending on where you are on Earth. And how different that shift is depends on the distance from both Venus and the Sun to the Earth. This rare event, the transit of Venus, occurred again most recently on June 8, 2004. It was knowing this fundamental distance from the Earth to the Sun that helped us find the true scale of the entire solar system for the first time.

When we leave the solar system, we find our star and its planets are just one small part of the Milky Way Galaxy. The Milky Way is a huge city of stars, so big that even at the speed of light, it would take 100,000 years to travel across it. All the stars in the night sky, including our Sun, are just some of the residents of this galaxy, along with millions of other stars too faint to be seen.



A timeline of the Universe since the Big Bang.

This Hubble Space Telescope image captures the effect of gravitational lensing by dark matter in a galaxy cluster.

The further away a star is, the fainter it looks. Astronomers use this as a clue to figure out the distance to stars that are very far away. But how do you know if the star really is far away, or just not very bright to begin with? This problem was solved in 1908 when Henrietta Leavitt discovered a way to tell the 'wattage' of certain stars that changed their pulse rate linked to their wattage. This allowed their distances to be measured all the way across the Milky Way.

Beyond our own galaxy lies a vast expanse of galaxies. The deeper we see into space, the more galaxies we discover. There are billions of galaxies, the most distant of which are so far away that the light arriving from them on Earth today set out from the galaxies billions of years ago. So we see them not as they are today, but as they looked long before there was any life on Earth.

Finding the distance to these very distant galaxies is challenging, but astronomers can do so by watching for incredibly bright exploding stars called supernovae. Some types of exploding stars have a known brightness – wattage – so we can figure out how far they are by measuring how bright they appear to us, and therefore the distance to their home galaxy. These are called 'standard candles'.

So how big is the Universe? No one knows if the Universe is infinitely large, or even if ours is the only Universe that exists. And other parts of the Universe, very far away, might be quite different from the Universe closer to home. At the time of publication using our most advanced technology and given the current size of the ever-expanding Universe, scientists estimate it is roughly 46 billion light years, or 440 sextillion km (274 sextillion mi). If it's hard to wrap your head around that number, welcome to the club. The Universe is almost inconceivably big, and we have only observed a small portion of it (astronomers estimate we have observed roughly 4% of the known Universe).

Modern Observational Methods

In 1609 an Italian physicist and astronomer named Galileo became the first person to point a telescope skyward. Although that telescope was small and the images fuzzy, Galileo was able to make out mountains and craters on the moon, as well as a ribbon of diffuse light arching across the sky – which would later be identified as our Milky Way Galaxy. After Galileo's and, later, Sir Isaac Newton's time, astronomy flourished as a result of larger and more complex telescopes. With advancing technology, astronomers discovered many faint stars and the calculation of stellar distances. In the 19th century, using a new instrument called a spectroscope, astronomers gathered information about the chemical composition and motions of celestial objects.

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Hubble Space Telescope in orbit.

© ALEXANDER CASPAR/SHUTTERSTOCK

Today's observatories have significantly larger apertures than the basic telescopes of Galileo's day, but the principle is the same.

Twentieth century astronomers developed bigger and bigger telescopes and, later, specialised instruments that could peer into the distant reaches of space and time. Eventually, enlarging telescopes no longer improved our view, because the atmosphere which helps sustain life on Earth causes substantial distortion and reduction in our ability to view distant celestial objects with clarity.

That's why astronomers around the world dreamed of having an observatory in space – a concept first proposed by astronomer Lyman Spitzer in the 1940s. From a position above Earth's atmosphere, a telescope would be able to detect light from stars, galaxies, and other objects in space before that light is absorbed or distorted. Therefore, the view would be a lot sharper than that from even the largest telescope on the ground.

In the 1970s the European Space Agency (ESA) and the National Aeronautics and Space Administration (NASA) began working together to design and build what would become the Hubble Space Telescope. On 25 April 1990, five astronauts aboard the space shuttle Discovery deployed the eagerly anticipated telescope in an orbit roughly 600 km (380 mi) above the Earth's surface. That deployment and, later, the unprecedented images that Hubble delivered represented the fulfillment of a 50-year dream and more than two decades of dedicated collaboration between scientists, engineers, contractors, and institutions from all over the world.

Since Hubble was launched, a number of other space telescopes have been successfully deployed to advance our knowledge of the Universe. These include the Spitzer Space Telescope, named for the man whose idea sparked a new era in telescopes and observation.

Today's Telescopes

Around the world, astronomers, space scientists and astrophysicists plying the depths of the Universe work in a variety of scientific fields, combining physics, chemistry, biology and other sciences to advance human knowledge of space. Much of their work relies on data from telescopes devoted to the observation of celestial objects. These can be either ground-based (located here on our planet) or space-based, rotating in orbit around Earth.

Ground-based telescopes are typically located in places around the world that meet a certain set of observing conditions. Broadly speaking, this includes locations with good air quality, low light pollution, and often high altitude to reduce the impact of the atmosphere on observations. Generally, you'll find the world's top observatories on mountains, in deserts, and/or on islands – sometimes a combination of all three. Well-known locations with multiple ground-based telescopes include Mauna Kea in Hawaii, the Atacama Desert in Chile, and the Canary Islands.

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Lowell Observatory in Arizona.

Space-based telescopes are, as their name suggests, located outside the Earth's atmosphere in orbit. As such, they often have much greater ability to capture high-resolution images of celestial objects, unaffected by the interference of our atmosphere. The most popular space telescopes include the Hubble and Spitzer Space Telescopes, both operated by NASA's Jet Propulsion Lab (JPL) in California. Other space telescopes include the Transiting Exoplanet Survey Satellite (TESS) and forthcoming James Webb Space Telescope (which will replace the Hubble).

Types of Telescopes

Astronomers gain knowledge by looking across the spectrum of light frequency. Typically, the tools they use fall within two broad categories: optical telescopes and radio telescopes. The instruments used to gather this data comb across the entire electromagnetic spectrum. Visible light rays (what we see when we view the stars with the naked eye) are actually only a small part of this spectrum; radio waves, infrared, ultraviolet, X-rays and gamma-rays are all also examined for the information they contain about far-off objects.

Ground-based observatories often focus on radio waves, which can be captured by antennas, and visible and infrared light, which are gathered at large optical telescopes. The technique of spectroscopy can help parse the information encoded in these rays. Other electromagnetic waves such as X-rays are best received in space, and these are monitored by telescopes in orbit where Earth's atmosphere doesn't get in the way.

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For non-professional astronomers, the Zeiss Telescope at Griffith Observatory, CA, offers a glimpse at the heavens.

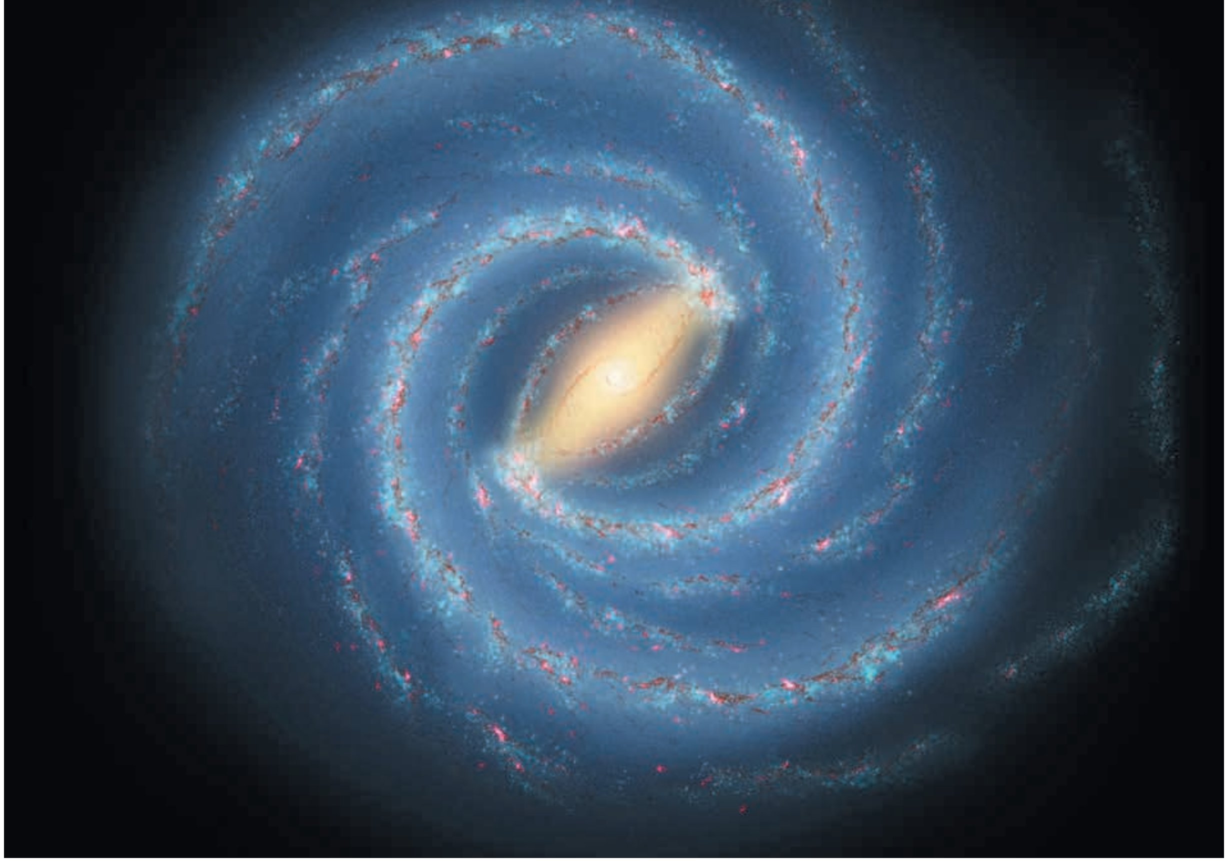
How to Use This Book

Like its namesake, the book you hold is big – and like our understanding of the Universe, it is also, by necessity, incomplete. Astronomers continue to explore the Universe with ever-improving technology, unlocking previously unknown secrets and mysteries. In these pages, you'll discover some you likely don't already know, and undoubtedly have questions and hypotheses about what we'll discover next.

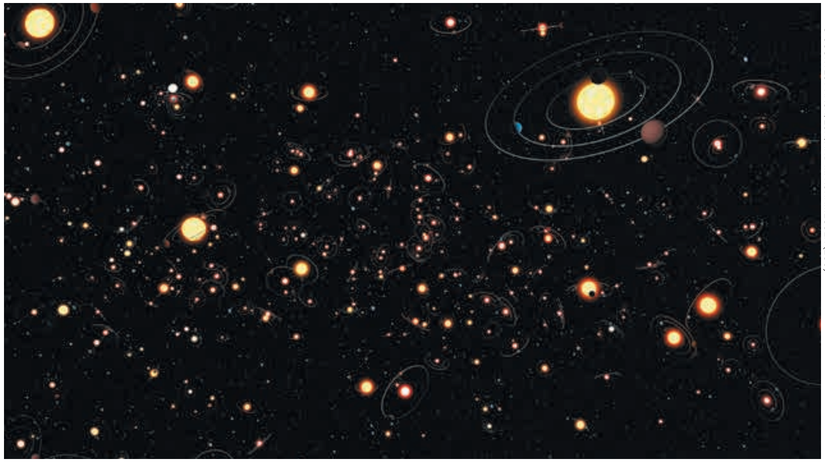
As you work through this text, the general organisation of the book will lead you from home on our Earth out into the far reaches of the solar system, then into our neighbouring stars and planetary systems and finally into the rest of our galaxy and the Universe as a whole, via carefully selected examples of known exoplanets, stars, nebulae and galaxies, as well as even more exotic deep-sky objects. You'll discover as much as we know about our celestial neighbourhood, and our place in it. In addition to planets and moons, get to know our Sun, explore the asteroid belt and the Kuiper Belt, and learn what lays beyond, in interstellar space.

Outside our solar system, the book guides you to some of the notable neighbouring stars, stellar systems, and exoplanets we've discovered. You'll understand how we search for planets where life might exist and the stars they orbit. Some of these are located within the Milky Way; others we've observed from our particular perspective in the Universe though they live far beyond the boundaries of what we consider our galaxy.

Finally, the book steps out to the edge of the observable Universe – at least what we've observed with the technology available today. You'll get to know the structure of the Milky Way as well as an orientation to neighbouring galaxies like the Andromeda Galaxy which is visible from Earth. You'll explore other galactic formations and zoom even further out to learn about galactic clusters and superclusters. By the end of the book, you'll have a sense for the structure of the entire Universe as well as some of the big questions we still have as we ponder our place in it. You may not be able to plan your next vacation on the basis of the planetary moons, exoplanets and stunning nebulae featured, but you'll find lots to amaze and awe.



An artist's concept of our Milky Way Galaxy.



This artist's illustration gives an impression of how common planets are around the stars in the Milky Way.

EARTH

PLANET TYPE
Terrestrial

NUMBER OF MOONS
One

Earth as seen from space.

Earth at a Glance

Despite the number of planets, not to mention universes, which astrophysicists and astronomers now believe might exist, one fact remains: Earth is the only planet we know of that sustains life.

The word 'Earth' is at least 1000 years old, an amalgam of the Saxon 'ertha', the Dutch 'aerde' and the German 'erda' – all of which mean 'ground'. (Earth is the only planet not named after a Greek or Roman deity.) The third-closest planet to the Sun, our home is the fifth-largest planet in the solar system. If the Sun were the size of the average household door, the Earth would be the size of a nickel. The Earth orbits the Sun, which is in fact a star, at a distance of 150 million km (93 million mi) and one orbit takes 365 days. Earth is the only world in our solar system featuring liquid water on its surface. But, along with its fellow terrestrial planets, Earth is composed of a molten core, a rocky mantle and a solid crust. With one moon and no rings, the Earth is protected from incoming meteoroids by its atmosphere, which breaks up incoming debris.

The first Earthling to see its home from orbit was a terrier named Laika, who circled the planet in 1957 aboard Sputnik 2. Although she did not survive the trip, two subsequent Soviet space dogs – Belka and Strelka – became, in 1960, the first living creatures to return from orbit alive, paving the way for human explorers. Popular culture has generated countless alternative views of Earth, with the planet and its population governed by everything from apes to a stone monolith. But how much longer travellers, canine or otherwise, will be able to thrive on Earth is the subject of heated debate. Quite literally.

The fate of Earth is inextricably linked to that of the Sun. Models predict that, in around 5 billion years, the Sun will become a red giant. It will increase to 100 times its present size, reaching a luminosity 2000 times its current level. At that point it will vaporise the Earth, whose water will have already evaporated. But that leaves plenty of time to take in Earth's natural wonders: oceans, mountains, deserts and jungles – all teeming, exclusively in the entire known Universe, with an extravagant abundance of life.

Laika, the first dog in orbit, lives on in countless commemorations.

DISTANCE FROM SUN
1 AU

LIGHT-TIME TO THE SUN
8.25 minutes

LENGTH OF DAY
24 hours

LENGTH OF ORBITAL YEAR
365.25 days

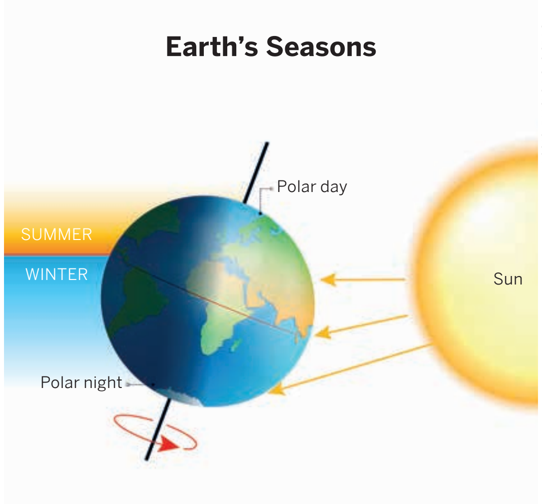
ATMOSPHERE
Nitrogen, oxygen, trace gases

Top Tip

Visitors to Earth should plan their itinerary while there's still time. Venice is sinking, Machu Picchu is collapsing and the lush Congo Basin could be two-thirds gone by 2040, while experts say at least 27 species go extinct each day. Sobering facts, only partly offset by the regular new discoveries being made of countless new species in the Amazon and deep ocean.

Getting There & Away

With commercial space travel imminent, be sure you know what you're signing up for. The Earth's moon can be reached in about three days, while suborbital flights can pass in under an hour. But travelling to the former ninth planet from the Sun, Pluto, took New Horizons, launched in 2006 and the fastest probe ever to leave Earth, nine and a half years. For now, leaving our home planet is only for a rare few.



Earth's axis determines how the seasons change throughout the year.

Orientation

If there is anybody else out there, what would they see looking at Earth? A planet whose radius of 6371 km (3959 mi) makes it the biggest of the terrestrial planets and the fifth-largest planet overall. With an average distance of 150 million km (93 million mi), Earth is exactly one astronomical unit away from the Sun because one astronomical unit (abbreviated as AU), is the distance from the Sun to Earth. This unit provides an easy way to quickly compare other planets' relative distances from the Sun. It takes about eight minutes for light from the Sun to reach Earth.

As Earth orbits the Sun, it rotates once every 23.9 hours. It takes 365.25 days to complete one trip around the Sun. That extra quarter of a day presents a challenge to our calendar system, which counts one year as 365 days. To keep yearly calendars consistent with Earth's orbit around the Sun, every four years sees the addition of one extra day, a leap day, more commonly expressed by the year in which it is added – a leap year.

In fact, the length of Earth's day is increasing. When Earth was formed, 4.6 billion years ago, its day would have been roughly six hours long. Around 620 million years ago, this had increased to 21.9 hours. Today, the average day is 24 hours long, but its length is increasing by about 1.7 milliseconds every century. This is caused by the moon, whose gravity slows Earth's rotation through the tides it helps create. Earth's spin causes the position of its tidal ocean bulges to be pulled slightly ahead of the Moon-Earth axis, which creates a twisting force that in turn decreases the speed of Earth's rotation.

Earth *vs* the Planets

-- Radius --
11x
SMALLER
than Jupiter

-- Mass --
17x
LESS
than Neptune

-- Volume --
1321x
LESS
than Jupiter

-- Surface gravity --
2.5x
LESS
than Jupiter

-- Mean temperature --
-466°C (-808°F)
COLDER
than Venus

(0000)
-- Surface area --
6.8x
MORE
than Mercury

-- Surface pressure --
92x
LESS
than Venus

-- Density --
8x
DENSER
than Saturn

(0000)
--Length of Day --
1.41x
LONGER
than Uranus

-- Orbit Period --
53%
SHORTER
than Mars

Earth's axis is an imaginary pole going right through the planet's centre from top to bottom. Earth spins around this pole, making one complete turn each day. That is why we have day and night, and why every part of Earth's surface gets some of each. When Earth was young, it is thought that something big hit Earth and knocked it off-kilter. So instead of rotating with its axis straight up and down, it leans over a bit. As Earth orbits the sun, its tilted axis always points in the same direction. This means that throughout the year, different parts of Earth get the sun's direct rays. This tilt causes the yearly cycle of the seasons.

Roughly speaking, the northern hemisphere is tilted towards the Sun between the months of April and September, while the southern hemisphere is tilted away. With the Sun higher in the sky, direct solar heating is greater in the north, creating summer conditions. Conversely, reduced solar heating in the south induces winter. Six months later, the situation is reversed. At the beginning of their respective spring and fall seasons, both hemispheres receive roughly equal amounts of heat from the Sun. Today, the Earth's axis is tilted 23.5 degrees from the plane of its orbit around the sun. But this tilt changes. During a cycle that averages about 40,000 years, the tilt of the axis varies between 22.1 and 24.5 degrees. As the axis changes, the seasons as we know them can become exaggerated.

Distance from the Sun, however. doesn't impact our experience of the seasons. While the difference between perihelion (when Earth is closest to the Sun) and aphelion (our farthest point from the Sun) is over 4.8 million km (3 million mi), relative to our total distance from the Sun it isn't much, and has no appreciable impact on how Earth's weather changes throughout the year. The other major factor affecting the planet's climate and short-term local weather is Earth's own atmosphere.

Fun Fact: Guest from Above

In November 2018, NASA glaciologists discovered a prime example of just what can happen when the atmosphere is off its game: a large impact crater hiding beneath more than a half-mile of ice in northwest Greenland. The crater, under the Hiawatha Glacier, was created by a meteorite estimated to have struck at least 12,000 years ago. The crater is 300 m (1000 ft) deep and 13 km (19 mi) in diameter. NASA's Operation Icebridge discovered the crater's existence using radar data gathered on polar flights.

Hiawatha Glacier in Greenland, seen by NASA.

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