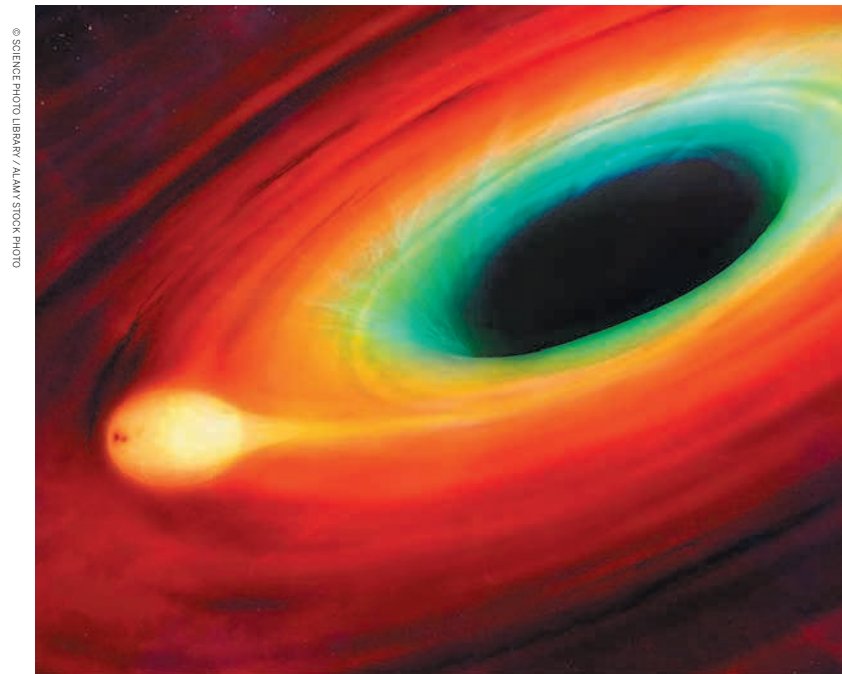


The Universe Contents

Foreword	6	History	64	Antarctica	136	Utopia Planitia	209	Umbriel	286	Comets	338
Introduction to the Universe	8	In Popular Culture	66	Great Barrier Reef	138	Vastitas Borealis	210	Oberon	287	Borrelly	340
Scale of the Universe	10	Mercury	68	Amazon Rainforest	140	Jupiter	212	Titania	288	C/1861 G1 Thatcher	341
Modern Observing Methods	12	Orientation	72	Ngorongoro Conservation Area	142	Orientation	216	Shepherd Moons	289	Churyamov-Gerasimenko	342
Today's Telescopes	14	Magnetosphere	73	Great Wall of China	144	Atmosphere	217	Neptune	290	Hale-Bopp	343
How to Use This Book	16	History	74	The Moon	146	History	218	Orientation	294	Halley	344
Naming Conventions	18	BepiColombo Mission	76	Orientation	150	Great Red Spot	222	Magnetosphere	295	Hartley 2	345
Highlights	20	In Popular Culture	77	History	152	Ring System	224	History	296	ISON	346
The Solar System	22	Caloris Planitia	79	In Popular Culture	156	Surface	225	In Popular Culture	299	'Oumuamua	347
Transits & Eclipses	28	Pantheon Fossae	80	Apollo 11	158	Clouds	226	Surface/Atmosphere	301	Shoemaker-Levy 9	348
Introduction to the Planets	30	Raditladi Basin	81	Orbital Gateway	160	Oceans	227	Rings	302	Swift-Tuttle	349
Manned Space Flight	48	Rachmaninoff Crater	82	Lunar Eclipses	161	Magnetosphere	228	Proteus	303	Tempel 1	350
The Quest for Orbit	48	Caloris Montes	83	Sea of Tranquility	163	Juno Mission	230	Triton	304	Tempel-Tuttle	351
Race to the Moon	50	Venus	84	South Pole-Aitken Crater	164	Io	232	Nereid	306	Wild 2	352
Shuttle Programme	51	Orientation	88	Copernicus Crater	165	Europa	234	Other Moons	308	Oort Cloud	353
The Present Day	52	Atmosphere	90	Montes Apenninus	166	Ganymede	236	Non-Planetary Solar System Objects	310	Exoplanets	354
The International Space Station	53	History	91	Oceanus Procellarum	167	Callisto	238	Asteroid Belt/Asteroids	312	2MASS J2126-814b	360
The Sun	54	In Popular Culture	94	Mars	168	Saturn	242	Bennu	314	51 Pegasi b	361
Orientation	58	Mariner 2	95	Orientation	172	Orientation	246	Ceres	316	55 Cancri	362
Atmosphere	60	Magellan Mission	96	Mapping Mars	173	History	248	Chariklo	317	Barnard's Star b	364
Heliosphere	61	Signs of Life	98	Martian Moons	174	Cassini Mission	253	EH1	318	CoRoT-7b	366
Solar Flares	62	Baltis Vallis	101	Atmosphere & Magnetosphere	177	Saturn's Rings	254	Eros	320	CVSO 30b and c	368
		Maat Mons	102	History	178	Magnetosphere	256	Ida	321	Epsilon Eridani	370
		Alpha Regio	103	In Popular Culture	182	Surface	257	Itokawa	322	Fomalhaut b	372
		Maxwell Montes	104	Investigating Mars	184	Titan	258	Phaethon	323	Gliese 163 b, c & d	373
		Aphrodite Terra	105	Curiosity Rover	188	Enceladus	260	Psyche	324	Gliese 176 b	374
		Earth	106	InSight Lander	190	Rhea, Dione & Tethys	262	Vesta	325	Gliese 436 b	375
		Orientation	110	Travelling to Mars	194	Iapetus	263	Kuiper Belt	326	Gliese 504 b	376
		Atmosphere	112	Polar Caps	196	Mimas	264	Dwarf Planets	328	Gliese 581 b, c & e	378
		Magnetosphere	113	Tharsis Montes	198	Phoebe	265	Eris	330	Gliese 625b	380
		History	114	Olympus Mons	200	Uranus	266	Farout	331	Gliese 667 cb & cc	381
		NASA Earth Science	120	Valles Marineris	201	Orientation	270	The Goblin	332	Gliese 832 b & c	382
		Mt Everest	124	Hellas Planitia	202	History	272	Haumea	333	Gliese 876 b, c, d & e	383
		Challenger Deep	126	Bagnold Dune Field	203	Surface/Atmosphere	275	Makemake	334	Gliese 3470 b	384
		Atacama Desert	128	Gale Crater	204	Aurorae	276	HAT-P-7b	387	GQ Lupi b	385
		Mauna Kea	130	Elysium Planitia	206	Magnetosphere	277	HAT-P-11b	388	HD 40307 g	390
		Chicxulub Crater	132	Syrtis Major Planum	208	Ring Systems	280	HD 69830 b, c & d	391		
		Silfra	133			Miranda	284				
		Death Valley	134			Ariel	285				

HD 149026 b 391	1E 2259+586 454	Owl Nebula 495	NGC 1512 544	Antennae Galaxies .. 559	Norma Cluster 578
HD 189733 b 394	3C 273 455	Pleiades 496	NGC 3370 545	Arp 273 561	Pandora's Cluster ... 579
HD 209458 b 396	Achernar 456	Polaris 497	Pinwheel Galaxy 546	Mayall's Object 562	Perseus Cluster 581
HIP 68468 b & c 398	Aldebaran 457	Procyon 498	Sagittarius Dwarf Elliptical Galaxy 548	NGC 2207 & IC 2163. 563	Phoenix Cluster 583
Kapteyn b & c 399	Algol 458	RCW 86 499	Sculptor Galaxy 549	NGC 2623 565	Virgo Cluster 584
KELT-9b 400	Alpha Centauri A 459	Regulus 500	Sombrero Galaxy.... 550	NGC 3256 566	
Kepler-10b & c 402	Alpha Centauri B 460	Rigel 501	Sunflower Galaxy ... 551		Glossary 590
Kepler-11b to g 403	Altair 461	Ring Nebula 502	Tadpole Galaxy 552	Galaxy Clusters 567	
Kepler-16 (AB)-b ... 404	Antares 462	Rosette Nebula 503	Triangulum Galaxy .. 553	Abell 1689 568	Index 596
Kepler-22b 405	Arcturus 463	Sagittarius A* 504	W2246-0526 554	Bullet Cluster 569	
Kepler-62b to f 406	Barnard's Star 464	SAO 206462 505	Whirlpool Galaxy 556	El Gordo 571	Acknowledgements... 605
Kepler-70b & c 407	Betelgeuse 465	SDSSJ0927+2943... 506		Fornax Cluster 572	Author Biographies ... 607
Kepler-78b 408	California Nebula ... 466	SGR 1806-20 507		Local Group 574	
Kepler-90b 409	Canopus 467	Sirius 508		Musket Ball Cluster.. 576	
Kepler-186b to f 410	Capella 468	Spica 509	Colliding Galaxies 558		
Kepler-444b to f 412	Cat's Eye Nebula ... 469	Tabby's Star 510			
Kepler-1625b 413	Crab Nebula 470	T Tauri 511			
Kepler-1647 (AB)-b . 414	Cygnus X-1 471	ULAS J1120+0641... 512			
Lich System (PSR B1257+12) 416	Deneb 472	UY Scuti 513			
Methuselah's Planet . 418	Dumbbell Nebula ... 473	Vega 514			
Pi Mensae b & c 420	Epsilon Aurigae 474	Veil Nebula 515			
Pollux b 421	Eta Carinae 475	VY Canis Majoris ... 516			
Proxima b 422	Ghost of Jupiter 476	W40 517			
PSO J318.5-22 424	GRS 1915+105 477				
Ross 128 b 425	HE 1256-2738 478	Galaxies 518			
TRAPPIST-1 426	HE 2359-2844 479	Andromeda Galaxy ... 522			
TrES-2b 428	Helix Nebula 480	Black Eye Galaxy ... 525			
WASP-12b 430	Herschel's Garnet Star481	Bode's Galaxy 526			
WASP-121 b 432	HLX-1 482	Canis Major Dwarf... 528			
Wolf 1061 b, c & d ... 434	Horsehead Nebula .. 483	Cartwheel Galaxy ... 529			
YZ Ceti b, c & d 437	HV 2112 484	Centaurus A 530			
	IGR J17091-3624... 485	Cigar Galaxy 531			
	Iris Nebula 486	Circinus Galaxy 532			
	Kepler's Supernova.. 487	Condor Galaxy 533			
	Kes 75 488	Grand Spiral Galaxy . 534			
	Little Dumbbell Nebula 489	Hoag's Object 535			
	Mira 490	Large and Small Magellanic Clouds .. 536			
	MY Camelopardalis . 491	Malin 1 Galaxy 539			
	North America Nebula492	Markarian 231 540			
	Omega Centauri ... 493	M77 541			
	Orion Nebula 494	M87 542			

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



Welcome to the Universe

© DESIGN FINCS INC / ALAMY STOCK PHOTO



Barred spiral galaxy NGC 1300.

Bill Nye

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 Universe

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.



© MAREK/VISION / ALAMY STOCK PHOTO

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,



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

including our Sun, are just some of the residents of this galaxy, along with millions of other stars too faint to be seen.

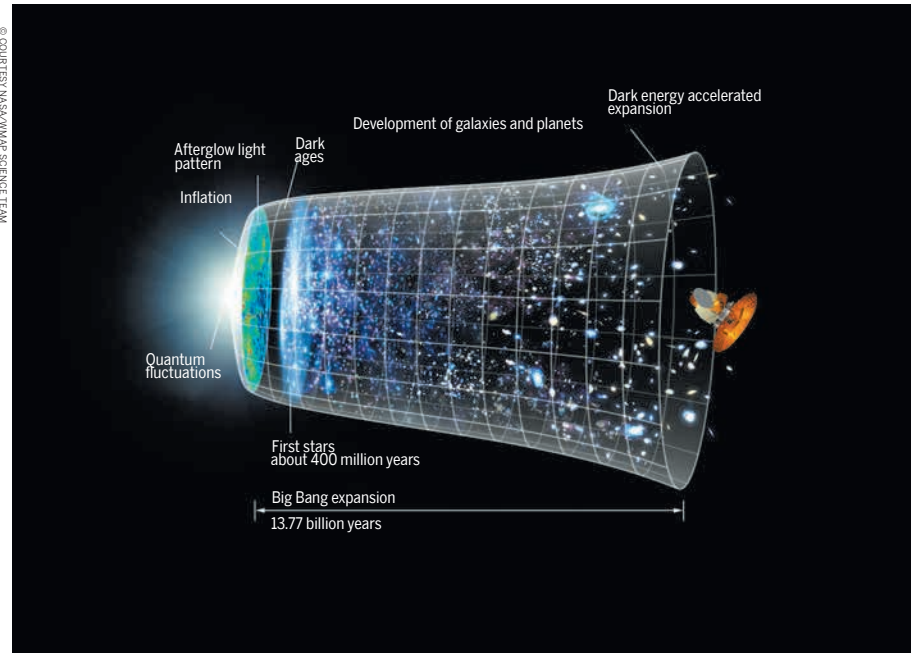
The further away a star is, the fainter it looks. Astronomers use this as a clue to figure out the distance to stars that are very far away. But how do you know if the star really is far away, or just not very bright to begin with? This problem was solved in 1908 when Henrietta Leavitt discovered a way 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).



A timeline of the Universe since the Big Bang.

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 cal-



Hubble Space Telescope in orbit.



© ALEXANDER CASHIN/SHUTTERSTOCK

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

ulation 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.

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



Lowell Observatory in Arizona.

© ISSANPANA/ALAMY/SHUTTERSTOCK

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.

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).



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

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Types of Telescopes

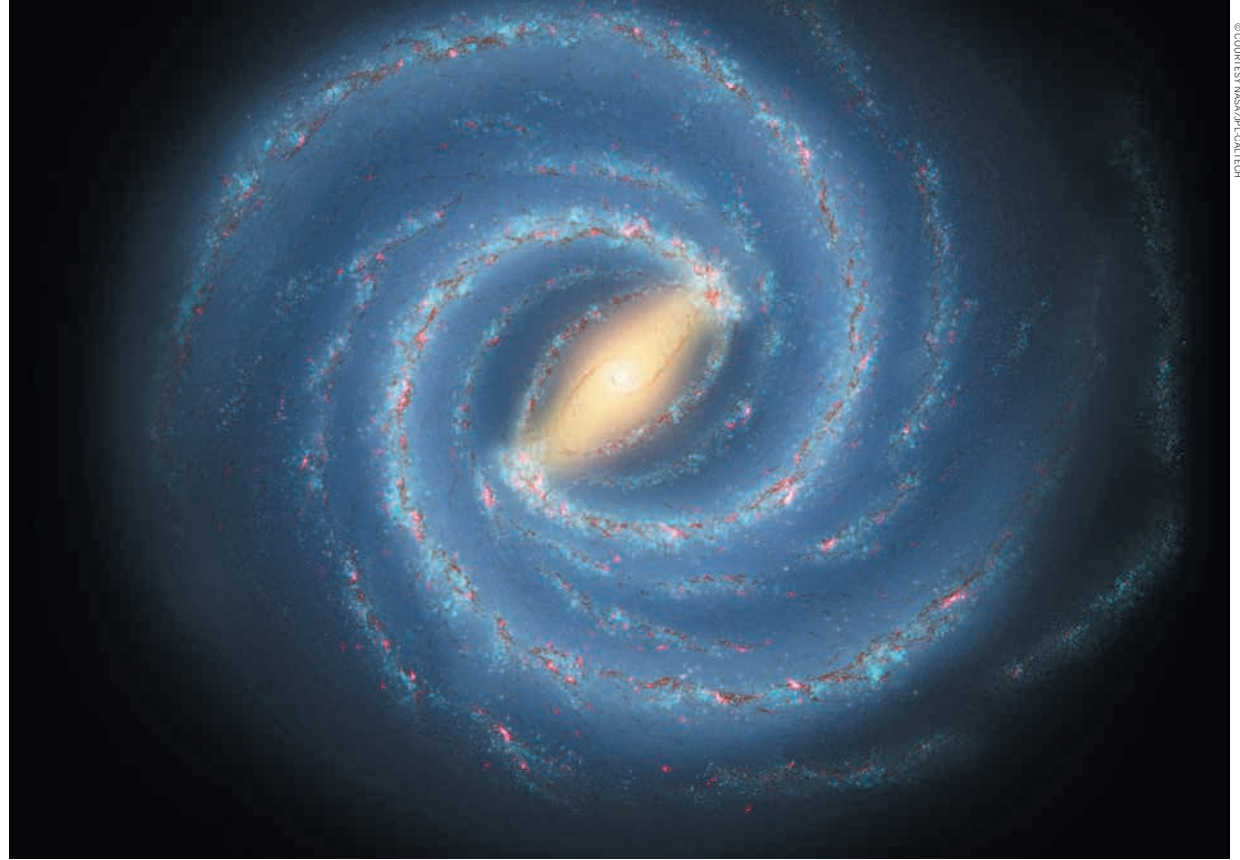
Astronomers gain knowledge by looking across the spectrum of light frequency. Typically, the tools they use fall within two broad categories: optical telescopes and radio telescopes. The instruments used to gather this data comb across the entire electromagnetic spectrum. Visible light rays (what we 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.

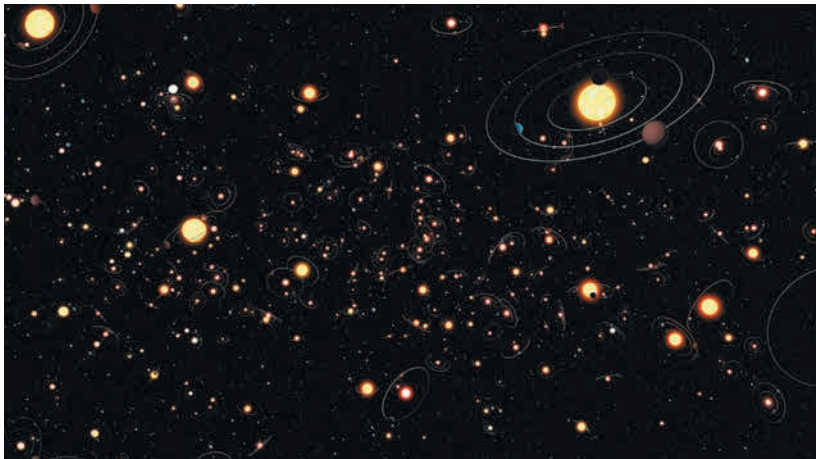
How to Use This Book

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



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.

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.

EARTH





PLANET TYPE
Terrestrial

NUMBER OF MOONS
One



© COURTESY NASA

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.



© ZOLTAN KATONA/SHUTTERSTOCK

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

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.

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.

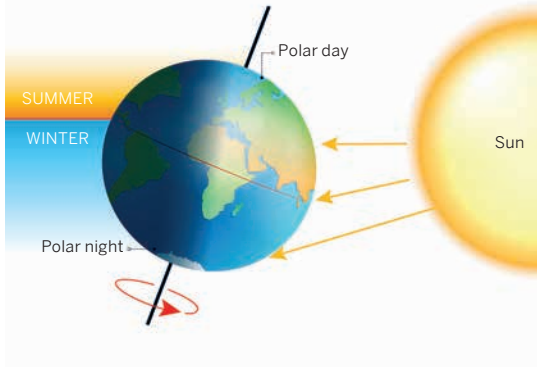
Getting There & Away



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 Seasons

© DESIGNUA/SHUTTERSTOCK



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



-- Surface area --
6.8x MORE
than Mercury



-- Surface pressure --
92x LESS
than Venus



-- Density --
8x DENSER
than Saturn



-- 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

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.

throughout the year. The other major factor affecting the planet's climate and short-term local weather is Earth's own atmosphere.



Hiawatha Glacier in Greenland, seen by NASA.

Index

A

asterisms, *see also* constellations, galaxies, star clusters

Big Dipper 546
Northern Cross 472
Spring Triangle 509
Summer Triangle 472, 514
Winter Hexagon 468, 498, 501
Winter Triangle 498

Asteroid Belt 311, 312–313

asteroids, *see also* comets, meteor showers

16 Psyche 324
2010 TK7 313
Bennu 314–315
Chariklo 311, 3177
EH1 318–319, 327
Eros 320
Ira 321
Itokawa 322
Phaethon 323, 327
Vesta 312, 316, 325

astronauts

Aldrin, Buzz 24, 50, 154, 156, 158–159, 163
Anders, Bill 50
Armstrong, Neil 24, 31, 50, 145, 149, 154, 156, 158–159, 163
Auñón-Chancellor, Serena 53
Borman, Frank 50
Chaffee, Roger 50
Chang-Diaz, Franklin 51
Chiao, Leroy 145
Collins, Michael 50, 156, 158–159
Gagarin, Yuri 31, 49, 154
Glenn, John 50, 51
Grissom, Gus 50
Leonov, Alexei 50
Liwei, Yang 145
Lovell, Jim 50
McClain, Anne 53
Musgrave, Story 51
Pogue, William 145
Savitskaya, Svetlana 50
Shepard, Alan 49
Swigert, Jack 157
White, Ed 50
Whitson, Peggy 53

astronomers & astral scholars

Abd al-rahman al-Sufi 522
Al-Biruni, Abu Rayhan 119
Anaxagoras 65
Aristotle 37, 119
Armstrong, Dr David 387
Armstrong, Jerry 557
Aryabhata 37, 119, 184
Barnard, Edward Emerson 365–366, 466

Bjorker, Gordon L 229
Bode, Johann Elert 272, 526, 531

Cassini, Giovanni 43, 262–263
Cassini, Jean-Dominique 249
Cochran, William D 374
Colombo, Giuseppe (Bepi) 76
Copernicus, Nicolaus 65, 165
Crabtree, William 93
Curtis, Heber 524, 543
de Pellepoix, Antoine Darquier 502

Disney, Mike 539
Doyle, Laurence 415
Dunlop, James 530, 544
Eddie, Lindsay 207
Edgeworth, Kenneth 326
Endl, Michael 374
Farrell, Sean 482
Flammarion, Camille 208
Fleming, Williamina 483
Gale, Walter Frederick 195
Galilei, Galileo 31, 33, 40, 42, 65, 75, 93, 148, 152, 216, 219, 232, 237, 240–241, 249, 250, 297, 298, 496

Galle, Johann Gottfried 46, 298, 304

Gassendi, Pierre 75
Gilmore, Gerry 548
Goddard, Robert H 156
Goodricke, John 458
Hall, Asaph 38, 174, 180
Halley, Edmund 137, 344
Harding, Karl Ludwig 480
Harriott, Thomas 32, 65, 75
Hartley, Malcolm 345
Hawking, Stephen 471
Herschel, Caroline 281, 549
Herschel, John 261, 533
Collins, Michael 50, 156, 158–159
Herschel, William 44, 261, 268, 272, 273, 281, 283, 287, 288, 445, 476, 481, 486, 492, 515, 534, 545

Hoag, Art 535
Hodierna, Giovanni Battista 553
Horrocks, Jeremiah 93
Hubble, Edwin 524, 574
Huygens, Christiaan 39, 42, 173, 180, 208, 249, 250, 258

Ibata, Rodrigo 548
Irwin, Mike 548
Jenniskens, Peter 318
Kepler, Johannes 487
Kuiper, Gerard P 283–284, 306, 326
Lassell, William 283, 285, 286, 304, 305

Leavitt, Henrietta 484, 537
Le Verrier, Urbain Joseph 46, 298

Levy, David 348
Liu, Michael 424
Malin, David 539

Marius, Simon 241
Mascareño, Alejandro Suarez 380
Mayall, Nicholas 562
Méchain, Pierre 495, 541, 546, 550–551

Meléndez, Jorge 398
Messier, Charles 470, 473, 489, 495, 502, 542–543, 585, 586

Montanari, Geminiano 458
Nevski, Vitali 346
Novichonok, Artyom 346
Oberth, Hermann 53, 156
Oort, Jan 353

Orosz, Jerome 415
Parker, Eugene 61
Pickering, Edward Charles 458
Pickering, William 265
Pigott, Edward 525
Poppenhaeger, Katja 395
Ptolemy, Claudius 42, 65, 493
Puckett, Tim 557

Ross, Jerry 51
Sagan, Carl 498
Scheiner, Christoph 65
Schiaparelli, Giovanni 39, 173, 179, 202, 208, 349
Shoemaker, Carolyn and Eugene 348

Showalter, Mark 309
Slipher, Vesto 523
Strabo 119
Taylor, Patrick 323
Thorne, Kip 471, 484
von Braun, Wernher 53
Wild, Paul 352
Wolf, Max 435
Wolszczan, Alexander 416
Zwicky, Fritz 529
Żytkow, Anna 484

atmosphere

Earth 28, 36, 108, 112, 113, 116
HAT-P-11b 389
HD 209458 b 396
Jupiter 40, 214–217, 225
Mars 38, 170–171, 177
Mercury 32, 71–72, 73
Moon (Earth) 151
Neptune 25, 46, 293, 296, 300–301
Rhea, Saturn 262
Saturn 42, 244–245, 246–247
Sun, 60
Titan, Saturn 258–259
Triton, Neptune 305
Uranus 24, 44, 268–269, 274–275
Venus 24, 34, 87, 89, 90, 98, 99

aurorae 25, 112, 228, 236–237, 252, 273, 274, 276, 277

B

black holes 447–449

Cygnus X-1 449, 471
GRS 1915+105 477
HLX-1 441, 482
IGR J17091-3624 485
Sagittarius A* 58, 482, 504
SDSSJ0927+2943 506
ULAS J1120+0641 512

C

canyons & channels, *see also* craters

Baltis Vallis, Venus 35, 100–101
Chasma Boreale, Mars 197
Death Valley, Earth 122, 134–135
Grand Canyon, Earth 127
Mariana Trench, Earth 37, 126–127
Valles Marineris, Mars 24, 26, 195, 201
Verona Rupes, Miranda, Uranus 26

comets 338–353, *see also* asteroids, meteor showers

9P/Tempel 1 345
Borrelly 339, 340
C/1490 Y1 317
C/1861 G1 Thatcher 341
Chariklo 311, 317
Churyumov-Gerasimenko 342
Hale-Bopp 311, 343
Halley's Comet 339, 344
Hartley 2 345
ISON 311, 346, 353
Shoemaker-Levy 9 219, 311, 348
Siding Spring 187, 353
Swift-Tuttle 349
Tempel 1 339, 350
Tempel-Tuttle 351
Wild 2 339, 352

constellations

, *see also*

asterisms, galaxies, star clusters

Andromeda 522–524, 561
Aquarius 383, 426–427, 480, 554–555
Aquila 461, 477, 488
Auriga 430–431, 468, 474
Australe 578
Black Eye 525
Boötes 463
Camelopardalis 491
Cancer 362–363, 384, 565, 576–577
Canes Venatici 551, 556–557
Canis Major 498, 508, 516, 528, 563
Carina 467, 475, 569
Cassiopeia 454
Centaurus 398, 422–423, 459, 460, 493, 499, 530

Cepheus 481, 486
Cetus 437, 490, 541
Circinus 499, 532
Coma Berenices 525, 539
Corvus 559
Cygnus 387, 388–389, 400–401, 403, 404, 405, 407, 408, 410–411, 413, 414–415, 471, 472, 492, 510, 515
Dorado 373, 536–538
Draco 380, 402, 409, 428–429, 469, 552
Eridanus 370–371, 456, 534
Fornax 572–573
Gemini 421
Grus 382
Hercules 392–393
Horologium 544
Hydra 476, 478
Hydrus 536–538
Leo 375, 500, 506, 512, 545
Libra 378
Lupus 385, 505
Lyra 406, 412, 502, 514
Mensa 420, 536–538
Monoceros 366–367, 503
Norma 578
Octans 360
Ophiuchus 364–365, 434–435, 464, 487
Orion 369, 465, 483, 494, 501
Pavo 533
Pegasus 361, 396–397
Perseus 458, 466, 489, 581–582
Phoenix 482, 571, 583
Pictor 390, 399
Piscis Austrinus 372
Puppis 391, 432–433
Sagittarius 279, 504, 507, 548
Scorpius 381, 418–419, 462, 485
Sculptor 479, 529, 549, 579–580

Scutum 513
Serpens 517, 535
Taurus 374, 457, 470, 496, 511
Triangulum 553, 578
Tucana 484, 536–538
Ursa Major 495, 526–527, 531, 540, 546–547, 562
Ursa Minor 497
Vela 566
Virgo 376, 416–417, 425, 455, 509, 542–543, 550, 568, 584–586
Vulpecula 394–395, 473

craters (impact & volcanic)

, *see also* canyons & channels

Alphonsus Crater, Moon (Earth) 154
Apollodorus, Mercury 80
Argyre Planitia, Mars 197
Aristarchus, Moon (Earth) 167

Caloris Basin, Mercury 26, 74, 83
Caloris Planitia, Mercury 78–79, 80, 81
Chicxulub Crater, Earth 122, 132
Copernicus Crater, Moon (Earth) 162, 165
Eddie Crater, Mars 207
Gale Crater & Bagnold Dune Field, Mars 188–189, 195, 203–205
Hellas Planitia, Mars 195, 197, 202
Herschel Crater, Mimas, Saturn 43, 264
Hiawatha Glacier, Earth 111
Ngorongoro Conservation Area, Earth 123, 142–143
Pantheon Fossae, Mercury 33, 78, 80
Rachmaninoff Crater, Mercury 74, 78, 82
Raditladi Basin, Mercury 78, 81
Sacajawea Patera, Venus 86
South Pole-Aitken Crater, Moon (Earth) 155, 162, 164
Stickney Crater, Phobos, Mars 174
Tycho Crater, Moon (Earth) 153
Utopia Planitia, Mars 27, 195, 209

D

dwarf planets 326–327

Ceres 27, 311, 316, 326
Eris 311, 328, 330, 336
Haumea 311, 329, 333
Makemake 329, 333, 334–335
Pluto 109, 294, 311, 328–329, 330, 336–337

E

Earth 24, 26, 27, 28–29, 36–37, 56, 60, 61, 62, 65, 98–99, **106–145**, 148–167, *see also* atmosphere, canyons & channels, craters, magnetosphere, volcanoes & mountains
Amazon rainforest 123, 140–141
Antarctica 123, 136–137
Atacama Desert 122, 128–129
Great Barrier Reef 37, 123, 138–139
Great Wall of China 123, 144–145
Silfra Fissure 122, 133
exoplanets 354–437, *see also* giants, hot Jupiters, hot Neptunes, ice giants, Neptune-Like, Super-Earths

G

galaxies (other than Milky Way)

518–566, *see also* asterisms, star clusters
 Andromeda 521, 522–524, 553, 558, 574, 575
 Antennae 521, 559–560
 Arp 273 561
 Black Eye 521
 Bode's 521, 526–527
 Canis Major Dwarf 521, 528, 537, 575
 Cartwheel 529
 Centaurus A 530
 Cigar 521, 526–527, 531
 Circinus 532
 Condor 521, 533
 ESO 243-49, 482
 Grand Spiral 534
 Hoag's Object 521, 535
 IC 1613 574
 IC 2163 563–564
 Large Magellanic Cloud 467, 521, 536–538, 574–575
 Leo I 574
 Malin 1 539
 Markarian 231 540
 Mayall's Object (Arp 148) 562
 Messier 32 574, 575
 Messier 49 584–585
 Messier 77 541
 Messier 84 585
 Messier 86 584–85
 Messier 87 521, 542–543, 584–585
 Messier 110 281, 575
 NGC 147 574
 NGC 185 574
 NGC 205 574
 NGC 1275 581–582
 NGC 1316 573
 NGC 1365 573
 NGC 1387 573
 NGC 1399 572–573
 NGC 1512 544
 NGC 2207 563–564
 NGC 2623 565
 NGC 3077 527
 NGC 3256 566
 NGC 3370 545
 NGC 4038 559–560
 NGC 4039 559–560
 NGC 4388 585
 NGC 5195 556
 NGC 6822 574
 Pinwheel 521, 546–547
 Sagittarius Dwarf Elliptical 537, 548, 575
 Sagittarius Dwarf Irregular 575
 Sculptor 549
 Small Magellanic Cloud 467, 484, 536–538, 541, 575
 Sombrero 550, 586
 Sunflower 551
 Tadpole 552

Triangulum 553, 574, 575
 UGC 1810 561
 UGC 1813 561
 W2246-0526 554–555
 Whirlpool 556–557
galaxy clusters 567–587
 Abell 1689 568
 Bullet Cluster 569
 Coma 567
 Dorado Group 573
 El Gordo 571
 Fornax Cluster 572–573
 Hydra-Centaurus 566
 Local Group 521, 553, 574–575, 578
 Markarian's Chain 585
 Messier 66 Group 575
 Messier 81 Group 575
 Messier 101 Group 547, 575
 Musket Ball Cluster 576–577
 Norma Cluster 578
 Pandora's Cluster 579–580
 Perseus Cluster 581–582
 Phoenix Cluster 583
 Virgo A 585
 Virgo B 585
 Virgo Cluster 521, 574, 584–586
 Virgo Supercluster 575, 584
gas giants 25, 40–41, 42–43
 2MASS J2126-8140 360
 55 Cancri b 362–363
 55 Cancri d (Lippershey) 363
 CVSO 30b 369
 CVSO 30c 369
 Epsilon Eridani b 371
 Fomalhaut b 372
 Gliese 504 b 376
 Gliese 832 b 382
 Gliese 876 b 383
 Gliese 876 c 383
 GQ Lupi b 385
 Jupiter 214–241
 Kepler-16 (AB)-b 404
 Kepler-1625b 413
 Kepler-1647 (AB)-b 414–415
 Methuselah 418–419
 Pollux b (Thestia) 421
 PSO J318.5-22 424
 Saturn 244–265
Great Attractor 578
greenhouse effect & climate change 24, 34, 37, 86, 92, 98, 99, 116, 117, 136, 139, 382

H

heliosphere 61
Holst, Gustav 43, 45, 77
hot Jupiters
 51 Pegasi b 361
 Aldebaran b 457
 HAT-P-7b 387
 HD 80606b 386
 HD 149026 b 392–393

HD 189733 b 394–395
 HD 209458 b 396–397
 KELT-9b 400–401
 TRES-2b 428–429
 WASP-12b 430–431
 WASP-121 b 432–433
hot Neptunes
 Gliese 436 b 375, 384
 Gliese 3470 b 384
 Gliese 4370 b 384
 HAT-P-11b 388–389

I

ice giants 26, 44–45, 46–47
 55 Cancri c (Brahe) 363
 55 Cancri f (Harriot) 363
 CoRoT-7c 367
 Neptune 292–309
 Uranus 268–289
International Astronomical Union 81, 176, 205, 319, 328, 334, 337, 361, 362, 365, 421
interstellar objects
 2014 FE72 331
 Biden (2012 VP113) 332
 Farout (2018 VG18) 331
 Goblin, The (2015 TG387) 332
 'Oumuamua 311, 347
 Sedna 332

J

Jupiter 24, 25, 26, 27, 40–41, 152, 212–241, 313, 345, 348, 350 *see also* atmosphere, magnetosphere, ring systems
 Great Red Spot 24, 27, 40, 47, 215, 219, 221–223, 229
 Little Red Spot 223

K

Kuiper Belt 304, 306, 309, 311, 326–327, 339, 342

L

Late Heavy Bombardment (LHB) theory 153
life, conditions that could support 25, 27, 36–37, 38, 41, 43, 47, 56, 60, 92, 98–99, 108–145, 109, 129, 181, 189, 205, 215, 238, 253, 259, 261, 377, 378, 380, 382, 406, 414–415, 426–427, 434–435, 460
liquid oceans & presence of water, *see also* water-ice 25, 26, 27, 98–99, 115, 117, 122, 126–127, 131, 133, 136–137, 138–139, 143, 187, 205,

210, 229, 234–235, 238, 258–259, 286
lunar eclipse 28–29, 118, 161

M

magnetosphere
 Earth 113
 Jupiter 221, 227, 228–229, 326
 Mars 177
 Mercury 73, 76
 Moon (Earth) 151
 Neptune 295
 Saturn 252, 256
 Uranus 276–277
Mars 24, 26, 27, 38–39, 52, 129, 152, 168–211, 313, *see also* atmosphere, canyons & channels, craters, magnetosphere, volcanoes & mountains
 dark spots 39, 173, 195, 208
 Olympia Undae 197
 Polar Ice Caps 195, 196–197
 Vastitas Borealis 195, 210–211
Mercury 24, 26, 29, 32–33, 65, 68–83 *see also* atmosphere, craters, magnetosphere, volcanoes & mountains
meteor showers & meteorites, *see also* asteroids, comets
 ALH84001 186
 Eta Aquarids 344
 Geminids 323
 Leonids 351
 Lyrids 341
 Orionids 344
 Perseids 349
 Quadrantids 318–319, 323
Messier Catalogue 19
Monoceros Ring 521, 528
Moon (Earth) 24, 28–29, 31, 37, 39, 50, 52, 83, 110, 146–167, 194, *see also* atmosphere, craters, magnetosphere, volcanoes & mountains
 Imbrium Sculpture 83
 Oceanus Procellarum 162, 167
 Sea of Tranquility 162–163
moons
Haumea
 Hi'iaka 333
 Namaka 333
Ida asteroid
 Dactyl 321
Jupiter
 Adrastea 224, 240
 Amalthea 224, 240
 Callisto 27, 41, 148, 221, 238–239
 Europa 25, 26, 27, 41, 215, 219, 221, 232, 234–235

Ganymede 26, 41, 43, 148, 221, 232, 236–237
 Io 25, 26, 41, 148, 219, 221, 232–233, 304
 Metis 224, 240
 Thebe 224, 240
Kepler-1625b
 exomoon 413
Makemake
 MK2 334
Mars
 Deimos 39, 152, 171, 174–175, 180
 Phobos 39, 43, 152, 171, 174–175, 180
Neptune
 Despina 308
 Galatea 302, 308
 Halimede 297, 308
 Hippocamp 297, 308–309
 Laomeidia 297, 308
 Larissa 308–309
 Naiad 308
 Nereid 47, 300, 303, 305, 306–307
 Neso 297, 308
 Proteus 300, 303, 309
 Psamathe 297
 Sao 297, 308
 Thalassa 308
 Triton 26, 47, 297, 298, 300, 304–305, 309
Pluto
 Charon 336
 Hydra 336
 Kerberos 336
 Nix 336
 Styx 336
Saturn
 Dione 252, 262
 Enceladus 25, 26, 43, 245, 252, 256, 260–261
 Epimetheus 249, 253
 Hyperion 253
 Iapetus 27, 252, 263
 Janus 249, 253
 Mimas 27, 43, 252, 260, 264
 Pandora 253
 Phoebe 43, 245, 249, 252, 263, 265
 Prometheus 253
 Rhea 252, 262
 Tethys 252, 260, 262
 Titan 26, 27, 43, 148, 217, 245, 249, 250, 252, 258
Uranus
 Ariel 273, 274, 283, 285
 Belinda 283
 Bianca 283
 Cordelia 283, 289
 Cressida 283
 Cupid 273
 Desdemona 283
 Juliet 283
 Mab 273
 Miranda 26, 27, 273, 274, 283

Oberon 44, 273, 274, 283, 287, 288
 Ophelia 283, 289
 Portia 283
 Puck 283, 289
 Rosalind 283
 Titania 44, 45, 273, 274, 283, 288
 Umbriel 273, 274, 283, 286

N

nebulae 442
 California Nebula 466
 Carina Nebula 475
 Cat's Eye Nebula 441, 469
 Crab Nebula 470
 Dumbbell Nebula 473
 Ghost of Jupiter 476
 Helix Nebula 480
 Hind's Variable Nebula 511
 Horsehead Nebula 441, 483
 Iris Nebula 486
 Little Dumbbell Nebula 489
 NGC 604 553
 North America Nebula 492
 Orion Nebula 494
 Owl Nebula 495
 Ring Nebula 502
 Rosette Nebula 503
 Solar Nebula 64
 Tarantula Nebula 536, 537
 Veil Nebula 515
 W40 517
Neptune 25, 26, 27, 46–47, 290–309, 313, 326, *see also* atmosphere, magnetosphere, ring systems,
 Great Dark Spot 25, 47, 295
 vortices 295
Neptune-Like exoplanets
 HD 40307 g 390
 HIP 68468 c 398

O

observatories, *see also* space centres, telescopes
 Arecibo Observatory, Puerto Rico 73, 323
 Berlin Observatory, Germany 298
 Calar Alto Observatory, Spain 369
 Cerro Tololo Observatory, Chile 308
 European Southern Observatory, Chile 369, 378, 379, 385, 391, 399, 422–423, 434–435, 437
 Geneva Observatory, Switzerland 379
 Keck Observatory, Hawaii 273, 297, 369, 379

Kuiper Airborne Observatory 273
Las Campanas Observatory, Chile 359
La Silla Observatory, Chile 373, 374, 378, 398
Lick Observatory, USA 466, 562
Mauna Kea Observatory, Hawaii 131, 308, 331, 332
McDonald Observatory, USA 284, 374
Paris Observatory, France 276
Perth Observatory, Australia 273
Stratospheric Observatory for Infrared Astronomy 531
Winer Observatory, USA 401
Oort Cloud 311, 326, 339, 346, 353

P

planetary storms 24, 25, 27, 38, 40, 42, 43, 47, 73, 90, 117, 177, 215, 222–223, 257, 295, 298, 301

Planet X 41

R

ring systems

Chariklo 317
Gliese 876c 383
Haumea 333
Jupiter 41, 215, 221, 224
Neptune 27, 47, 295, 300, 302
Saturn 24, 27, 42–43, 248, 249, 252, 253, 254–255
Uranus 27, 45, 271, 273, 274, 280

rockets

Atlas V-401 190
Atlas V 551 231
Saturn V 158

S

Saturn 24, 26, 27, 42–43, **242–265**, 326, *see also* atmosphere, craters, magnetosphere, ring systems
north pole 247
science-fiction
2001: A Space Odyssey 157, 233, 250
2010: The Year We Make Contact 233
Asimov, Isaac 33, 43, 77, 94, 182, 239, 259, 371
Babylon 5 370–371
Bradbury, Ray 77, 94, 205
Clarke, Arthur C 43, 77, 259
Cloud Atlas 41, 220
Dick, Philip K 239, 259

Doctor Who 45, 271, 299, 522
Event Horizon 47, 299
Futurama 220, 259, 299
Gattaca 259
Herbert, Frank 371
Interstellar 250
Io 41
Jupiter Ascending 41, 220
Le Voyage dans la Lune 157
Lewys, CS 77
Lovecraft, HP 77
Mars Attacks 182
Martian, The 39, 183
Martian Chronicles 205
Marvel 522
Men in Black 220
Rice Burroughs, Edgar 182
Sebald, WG 43
Star Trek 47, 209, 250, 259, 299, 522
Star Wars 43, 135, 404, 414
Sunshine 66, 77
Superman 522
Total Recall 183
Verne, Jules 156
Vincent, Harl 239
Vonnegut, Kurt 259
WALL-E 250
War of the Worlds, The 39, 182
Wells, HG 47, 182

solar eclipses 28–29, 60

solar storms & flares 59–63

solar wind 33, 36, 56, 61, 62, 72, 73, 112, 113, 177, 276, 485

space centres & research facilities, *see also* observatories, telescopes

Ames Research Center, USA 309, 358, 401, 412, 432
Antarctic Halley Research Station 137
Anderson Mesa Station, USA 318
Cape Canaveral, USA 230
Goddard Space Flight Center, USA 35, 98–99, 207, 229, 255, 366, 415, 423, 433, 454
Jet Propulsion Laboratory, USA 95, 118, 363, 422–423, 459
Johnson Space Center, USA 156, 184
Kennedy Space Center, USA 51, 156, 158
SETI Institute, USA 309, 318, 371, 415
Sydney Institute for Astronomy in Australia 482
spacecraft & satellites 48–53, *see also* space telescopes
Akatsuki 92–93
Apollo 1 50, 158–159
Apollo 8 50, 154

Apollo 11 24, 50, 148, 149, 154, 156, 158–159, 163
Apollo 12 165, 167
Apollo 13 156
Apollo 15 166
Apollo 20 165
ARTEMIS 155
Atlantis 51, 52, 97
BepiColombo 33, 76
Cassini 41, 43, 219, 239, 245, 247, 249, 250, 252–253, 255, 258, 260, 262, 263, 264, 283
Challenger 51
Chandrayaan-1 155
Chang'e 1 155
Chang'e 4 52, 155, 164
Clementine 155
Columbia 51
Curiosity rover 181, 185, 188–189, 192, 195, 204–205
Dawn 184, 316, 325, 340
Deep Impact (EPOXI) 339, 345, 350
Deep Space 1 339, 340
Discovery 51
Earth Observing System (EOS) 121
Endeavour 51
Europa Clipper 41, 234–235
ExoMars Trace Gas Orbiter 187
Explorer 1 49
Freedom 7 49
Friendship 7 50
Galileo 215, 219, 224, 233, 238, 239, 321, 348
Gemini 4 50
GPM Core Observatory 121
GRACE 120
GRAIL 155
Hayabusa 320
Helios A & B 363, 397, 419
Huygens probe 249, 250
ICESat-2 121
InSight lander 38–39, 171, 181, 190–193, 206–207
International Space Station 39, 51, 53, 145, 160, 184, 185, 194
Juno 41, 219, 221, 226, 229, 230–231, 239
Kaguya 155
KREX-2 129
Landsat 120, 141
LCROSS 155
LRO 155
Luna 1, 2 & 3 154
Lunar Orbital Platform-Gateway 39, 160, 194
Lunar Orbiter 1 154
Lunar Prospector 155
Lunar Reconnaissance Orbiter 29
Lunokhod 1 155

Magellan 35, 92, 93, 96–97, 99, 102
Mariner 1 95
Mariner 2 87, 93, 95
Mariner 4 171, 180
Mariner 7 171
Mariner 9 174, 180, 198, 201
Mariner 10 75, 79
Mars 2 & 3 180
Mars Atmospheric and Volatile Evolution 187
Mars CubeSat One 190
Mars Express 187, 207
Mars Global Surveyor 173, 180, 181
Mars Odyssey 181, 187, 192, 193
Mars Pathfinder 181
Mars Reconnaissance Orbiter 181, 187, 188, 193, 196
Mars Science Laboratory 188–189
MAVEN 193
Mercury Magnetospheric Orbiter 76
Mercury Planetary Orbiter 76
MESSENGER 33, 71, 75, 80, 82
Mir 53
Multi-Mission Space Exploration Vehicle 185
NEAR-Shoemaker 320
New Horizons 71, 109, 219, 239, 273
Opportunity, Mars Exploration Rover 155, 181, 187–188
Orion Multi-Purpose Crew Vehicle 39, 194
OSIRIS-REx 314–315
Parker Solar Probe 57
Philae 342
Phoenix 181
Pioneer 10 219, 239, 250, 297, 457
Pioneer 11 219, 245, 249
Pioneer Venus 99, 102, 104
Psyche 324
Ranger 7 154
Ranger 9 154
Rosetta 342
Salyut 1 53
Skylab 53, 145
SMAP 121
SMART-1 155
SORCE 120
SpaceShip Two VSS Unity 52
Spirit, Mars Exploration Rover 181, 187, 188
Sputnik 1 49, 158
Sputnik 2 49, 109
Stardust-NEXT 339, 350, 352
Suomi NPP 120
Surveyor 1 154
SWOT 121
TEMPO 121
Trace Gas Orbiter 193

Transiting Exoplanet Survey Satellite 35, 99, 359, 420
Ulysses 219, 348
Vega 92
Venera series 92, 93
Venera 3 92
Venera 15 35, 101, 103
Venera 16 101, 103
Venus Express 93, 103
Viking 1 180
Viking 2 171, 209
Vostok 2 50
Vostok 1 49, 154
Voyager 1 41, 43, 215, 219, 224, 239, 245, 247, 249, 250, 264, 271, 353
Voyager 2 25, 45, 47, 215, 219, 239, 245, 249, 250, 255, 264, 269, 271, 273, 275, 283, 286, 287, 288, 293, 295, 297, 298, 300, 303, 304, 305, 306, 308–309, 348
space telescopes, *see also* spacecraft & satellites
Chandra X-ray Observatory 395, 448, 459, 523, 534, 564, 568, 573, 581, 582
CoRoT 359, 367
Hubble 47, 236, 239, 250, 271, 273, 275, 276, 283, 295, 297, 298, 309, 336, 348, 359, 372, 383, 388, 396, 397, 401, 413, 418, 419, 427, 431, 432–433, 437, 448, 497, 502, 520, 523, 524, 526, 527, 538, 540, 567, 578
James Webb 35, 99, 359, 377, 389, 401, 433
Kepler 279, 358, 389, 402–415, 409, 410–411, 427, 428, 510
Nuclear Spectroscopic Telescope Array 532
Spitzer 249, 359, 363, 371, 386, 389, 392, 401, 402, 426, 427, 431, 474, 510
Wide-Field Infrared Survey Telescope 359
XMM Newton Observatory 395, 448
spectra 453
star clusters & systems 445, *see also* asterisms, constellations, galaxies
55 Cancri 362–363
Algol 458
Alpha Centauri 58, 459, 460
Capella 468
GRS 1915+105 477
Lich system 357, 416–417
Messier 54 548
MY Camelopardalis 441, 491
NGC 2244 503

Omega Centauri 493
Pleiades 441, 466, 496
Polaris 497
Regulus 500
Rigel 441, 472, 501
Spica 509
Trumpler 16 475
stars
1E 2259+586 454
2005cs 557
2011fe 547
3C 273 455
55 Cancri A 362–363
55 Cancri B 362–363
Achernar 456
Aldebaran 457
Alpha Centauri A and B 58, 423, 459, 460
Alpha Centauri C 459
Alnitak 483
Altair 461
Antares 462
Arcturus 463
Barnard's Star 364–365, 464
Betelgeuse 441, 465
binary stars 445
black dwarfs 447
brown dwarfs 376–377, 443
Canopus 467
Capella Aa and Ab 468
Capella H and L 468
Castor 421
Copernicus 363
CVSO 30 369
Deneb 472
Epsilon Aurigae 441, 474
Epsilon Eridani 357, 370–371
Eta Carinae 475
Fomalhaut 372
Gliese 163 373
Gliese 176 374
Gliese 436 375
Gliese 581 378
Gliese 625 380
Gliese 667 C 381
Gliese 832 382
Gliese 876 383
GQ Lupi b 385
HAT-P-11 388–389
HD 189777 395
HD 209458 397
HD 40307 390
HD 69830 357, 391
HE 1256-2738 441, 478
HE 2359-2844 441, 479
heavy metal subdwarfs 443
Herschel's Garnet Star 481
HIP 68468 357, 398
HV 2112 484
hypergiants 444
Kapteyn 399
KELT-9 400–401
Kepler-10 402
Kepler-11 357, 403
Kepler-16 AB 404
Kepler-1647 414–415

Kepler-186 410–411
 Kepler-444 412
 Kepler-62 406
 Kepler-70 357, 407
 Kepler-90 409
 Kepler's Supernova 441, 487
 Kes 75 488
magnetars 446
 Mira 490
 Mira B 490
 MY Camelopardalis 491
neutron stars 446
orange dwarfs 443
 Pi Mensae 420
 Pi Mensae b 420
 Pollux 421
 Procyon 498
 Procyon B 498
protostars 442
 Proxima Centauri 58, 422–423, 460
 PSR B1257+12 416, 417
 PSR B1620-26 419
pulsars 446–447
quasars 447
 RCW 86 499
red dwarfs 443
red giants 65, 109, 444
red supergiants 481
 SAO 158687 273
 SAO 206462 505
 SGR 1806-20 507
 SIMPO136 377
 Sirius A & B 467, 508
 SN 1994ae 545
 SN 1994i 557
 SN 2011dh 557
 SN 2018ivc 541
 Sun 55–67
supergiants 444
 supernova 1987A 538
 supernova 1993J 527
 supernova 1993J 521
supernovas 447
 Tabby's Star 441, 510
 TRAPPIST-1 426–427
 TrE-2 A 428
 T Tauri 511
 TYC 9486-927-1 360
 ULAS J1120+0641 512
 UY Scuti 441, 513
 Vega 514
 VY Canis Majoris 58, 516
 WASP-12 430–431
white dwarfs 65, 447
 Wolf 1061 434–435
 Xi Persei 466
yellow dwarfs 443
yellow giants 444
 YZ Ceti 437
Sun 28–29, 36, **55–67**, 108, 109, 113, 161
Super-Earths
 55 Cancri e (Janssen) 363
 Barnard's Star b 364–365, 464
 CoRoT-7b 366–367

Gliese 176 b 374
 Gliese 581 c 378–379
 Gliese 625 b 380
 Gliese 876 d 383
 HD 40307 g 390
 HIP 68468 b 398
 Kepler-22b 405
 Kepler-78b 408
 Pi Mensae c 420
 Proxima b 422–423
 PSR B1257+12c (Poltergeist) 417
 PSR B1257+12d (Phobetor) 417
 Ross 128 b 425
 Wolf 1061 d 435

T

telescopes (ground) *see also* observatories, space centres & research facilities, space telescopes
 Anglo-Australian Telescope, Australia 420
 Arecibo Radio Telescope, Chile 104
 Atacama Large Millimeter/sub-Millimeter Array, Chile 129
 Blanco, Chile 308
 Canada-France-Hawaii telescope, Hawaii 539
 Event Horizon Telescope 542–543, 585
 Galileo National Telescope, Canary Islands 359
 Hobby-Eberly, McDonald Observatory, USA 374
 International Scientific Optical Network, Russia 346
 Kilodegree Extremely Little Telescope, USA 401, 415
 Pan-STARRS, Hawaii 424
 Subaru, Mount Kea, Hawaii 331
 Transiting Planets and Planetesimals Small Telescope, Chile 426
 Very Large Telescope, Chile 368–369, 385, 456
 Warsaw Telescope, Las Campanas Observatory, Chile 359
 transits 29, 75, 92, 249, 392, 403, 413, 414

U

Ultraluminous X-ray Sources (ULXs) 564
Uranus 25, 26, 27, 44–45, 88, **266–289**, 326, *see also* atmosphere, canyons & channels, ring systems
 dark spot 275

V

Venus 24, 26, 29, 32, 34–35, 65, 76, **84–105**, 304, *see also* atmosphere, canyons & channels, craters, magnetosphere, volcanoes & mountains
 Alpha Regio 100, 103
 Aphrodite Terra 100, 105
 Ishtar Terra 105
volcanoes & mountains
 Aeolis Mons, Mars 205
 Alps, Earth 117
 Altiplano-Puna volcanic complex, Earth 129
 Andes, Earth 117, 128
 Appalachian Mountains, Earth 115
 Beta Regio, Venus 103
 Caloris Montes, Mercury 78, 79, 83
 Chilean Coast Range, Earth 128
 Eifuku, Earth 127
 Elysium Planitia, Mars 195, 206–207
 Everest, Earth 26, 37, 115, 122, 124–125, 127
 Grapevine Mountains, Earth 135
 Himalayas, Earth 117
 K2, Earth 124
 Kilauea, Earth 26
 Kilimanjaro, Earth 117
 Maat Mons, Venus 26, 100, 102
 Mauna Kea, Earth 115, 122, 130–131
 Mauna Loa, Earth 131
 Maxwell Montes, Venus 35, 89, 100, 103, 104, 105
 Mid-Ocean Ridge, Earth 37, 115
 Mons Hadley, Moon (Earth) 166
 Mons Huygens, Moon (Earth) 166
 Montes Apenninus, Moon (Earth) 162, 166
 Loolmalasin, Earth 143
 Olympus Mons, Mars 24, 26, 173, 179, 195, 200
 Rockies, Earth 117
 Rwenzori Mountains, Earth 157
 Tharsis Montes, Mars 195, 198, 199
 Ural Mountains, Earth 115

W

water-ice, *see also* liquid oceans 33, 73, 75, 151, 155, 181, 187, 207, 226, 262, 316



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