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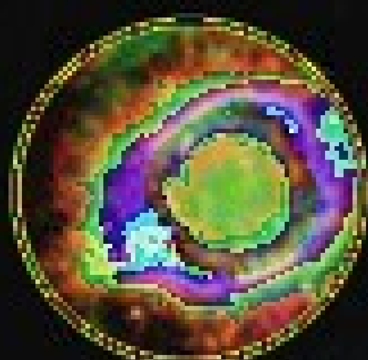
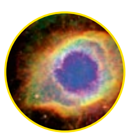
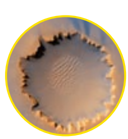


Atlas of Astronomical Discoveries



Govert Schilling

Atlas of Astronomical Discoveries



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Preface

Four hundred years is little more than a blink of an eye in terms of cosmic time. In 400 years the Sun rises nearly 150,000 times, it has been Wednesday 20,000 times, and a Full Moon more than 5,000 times. These are big numbers, but most celestial phenomena evolve much more slowly. The Earth may go around the Sun 400 times in as many years, but Saturn completes less than 14 orbits and Halley's Comet a little more than 5, while the dwarf planet Eris will have completed only 70% of a single orbit.

The night sky hardly changes in 400 years. The fastest moving star in the sky – which is only visible with a telescope – will have moved a little more than 1° further north, and to see any real changes in the shapes of the constellations you need to wait a hundred times longer. In 400 years, the Sun completes less than a millionth of its orbit around the center of the Milky Way. That is like walking around the Place de l'Etoile in Paris and only moving 1.5 mm.

Large numbers are the trademark of astronomy, but if we look at it in the right perspective, we see that the universe hardly changes in 400 years. The Sun may convert 50 quadrillion tons of hydrogen into helium in that time, but that is only a trillionth part of its total mass. And although the Andromeda galaxy has moved more than a trillion kilometers closer to the Milky Way, that only means that the light it emits takes a month less to reach us than the two and a half million years that we are used to.

In the age of the universe, 400 years is about the same as one minute in the life of an old person. In our Milky Way, a few hundred new stars may have seen the light, and in the vast cosmos with its countless galaxies, a few billion supernovas will have exploded. But generally speaking, the universe looks exactly the same today as it did at the start of the seventeenth century. In that period of time the universe has just blinked.

That makes it all the more remarkable when we look at what has changed in our understanding of the universe. From their rather inferior place in space, on a small planet at the edge of a spiral galaxy, astronomers have succeeded in penetrating to the depths of the universe and into the vaults of cosmic history. Our knowledge of the universe has undergone a revolutionary development, largely thanks to the invention of the telescope in 1608.

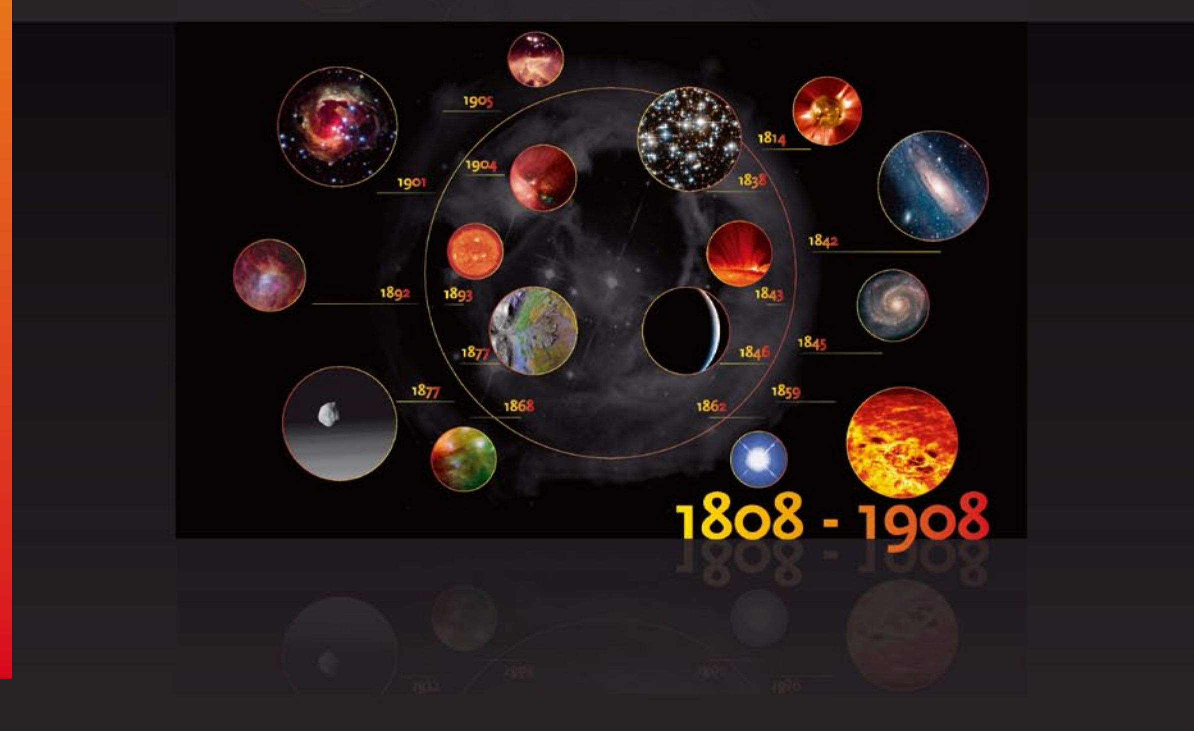
This *Atlas of Astronomical Discoveries* offers a spectacular review of the past 400 years of telescopic astronomy. In one hundred breathtaking snapshots, it looks at the most important astronomical discoveries since the invention of the telescope. Short texts tell familiar and less well-known stories behind these discoveries – stories of amazement, curiosity, perseverance and luck, but above all, stories of the unstoppable process of unraveling the secrets of the universe in which we all live.

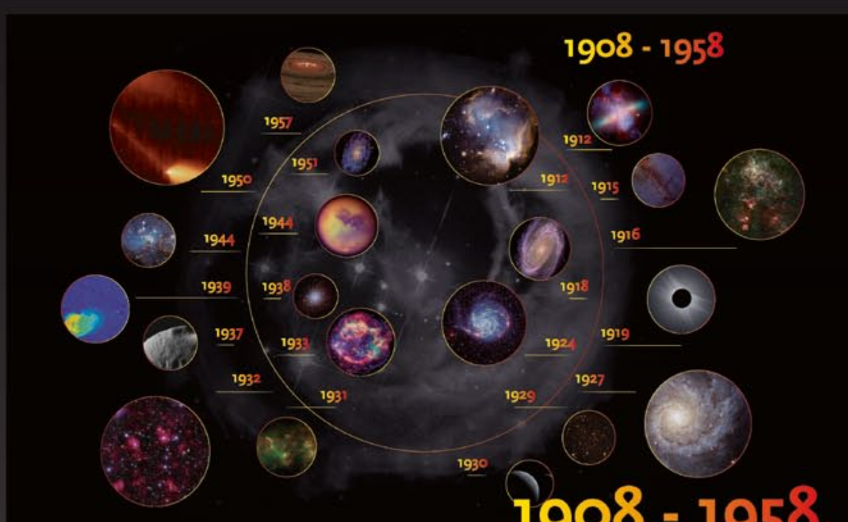
In the next 400 years, the cosmos will again change very little. But we are likely to have to wait much less for new revolutionary developments in astronomy. A few orbits of the Sun, at the most.

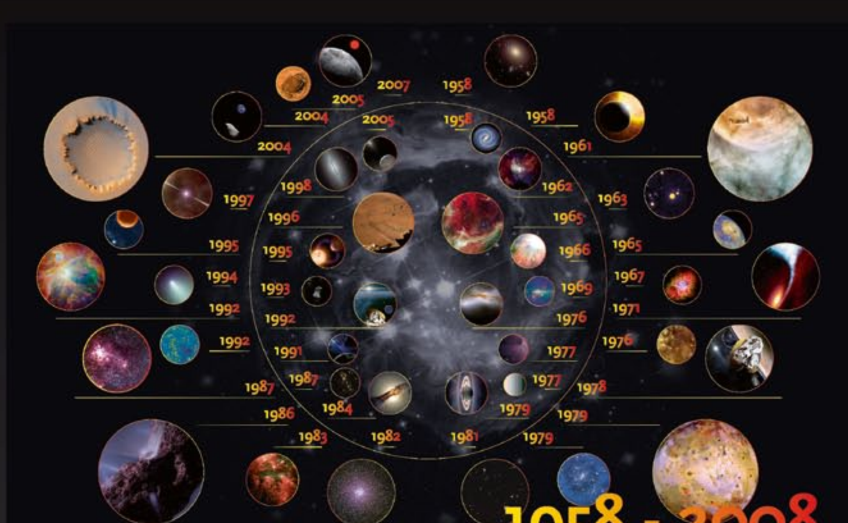
Govert Schilling


1608 - 1708


1708 - 1808


1808 - 1908


1908 - 1958
1908 - 1958


1958 - 2008

In the outer regions of a spiral galaxy, somewhere on the edge of the Virgo cluster, a star explodes. Shock waves from the supernova explosion cause a thin cloud of interstellar gas and dust particles to condense. The balance is disturbed, and gravity grabs its chance: the cloud contracts under its own weight. A hundred thousand years later, a new sun shines here.

The birth of a star is a violent, messy and incomplete process becuase not all of the matter in the collapsing cloud ends up in the star. One percent ends up in a flat, rotating disk which, over a period of ten million years, concentrates into a handful of planets – cold spheres of ice, stone and metal.

The Dawn of

One of these planets is a small, wet oasis with warm inland seas and a protective atmosphere. Cosmic hydrocarbons find a fertile medium for organic chemistry- Amino acids and proteins. Nucleic acids. DNA. The first living cell. Evolution.

More than four billion years later, *Homo erectus* looks skywards from the African savanna. Intrigued by the alternation of day and night, the phases of the Moon, and the twinkling stars in the night sky. A child of the universe, he stands eye-to-eye with his own origins. Astronomy is born.

The universe hardly changes in a few hundred thousand years. What does change though, is the way we humans look at the infinite and impalpable world beyond the Earth. The world of celestial bodies, with their own cycles and orbits. Marking the seasons, announcing the arrival of the monsoon, and seeming to control life on Earth.

Ursa Major and Orion are beacons for navigating the night sky. The equinoxes and solstices define the seasons, and the heliacal rising of Sirius presages the annual flooding of the Nile. Hunters, farmers, seamen – no one can live without the stars, and anyone who keeps a close eye on the firmament naturally becomes curious about the mysterious drama being played out among the stars.

Wandering stars pass through the Zodiac. Meteors shoot through the sky; a spectacular comet arcs above the horizon. Sometimes a new star appears, only to be extinguished again some months later. Every now and again the Sun is eclipsed. All of nature is in the magic grip of the cosmos.

Astronomy

Babylonians discover the regularity of celestial phenomena. The Chinese note the appearance of ‘guest stars’ and comets. The Greeks philosophize on the nature of things, on order and regularity, on *kosmos* versus *kaos*. In his geocentric model, Aristotle of Athens sees the planets as supported by crystal spheres. Eratosthenes of Cyrene measures the circumference of the Earth. Hipparchus of Rhodes catalogs the stars. Ptolemy of Alexandria draws and calculates, traces circles and epicycles, and explains the seemingly unpredictable movements in the firmament in a 13-volume mathematical treatise published in the middle of the second century.

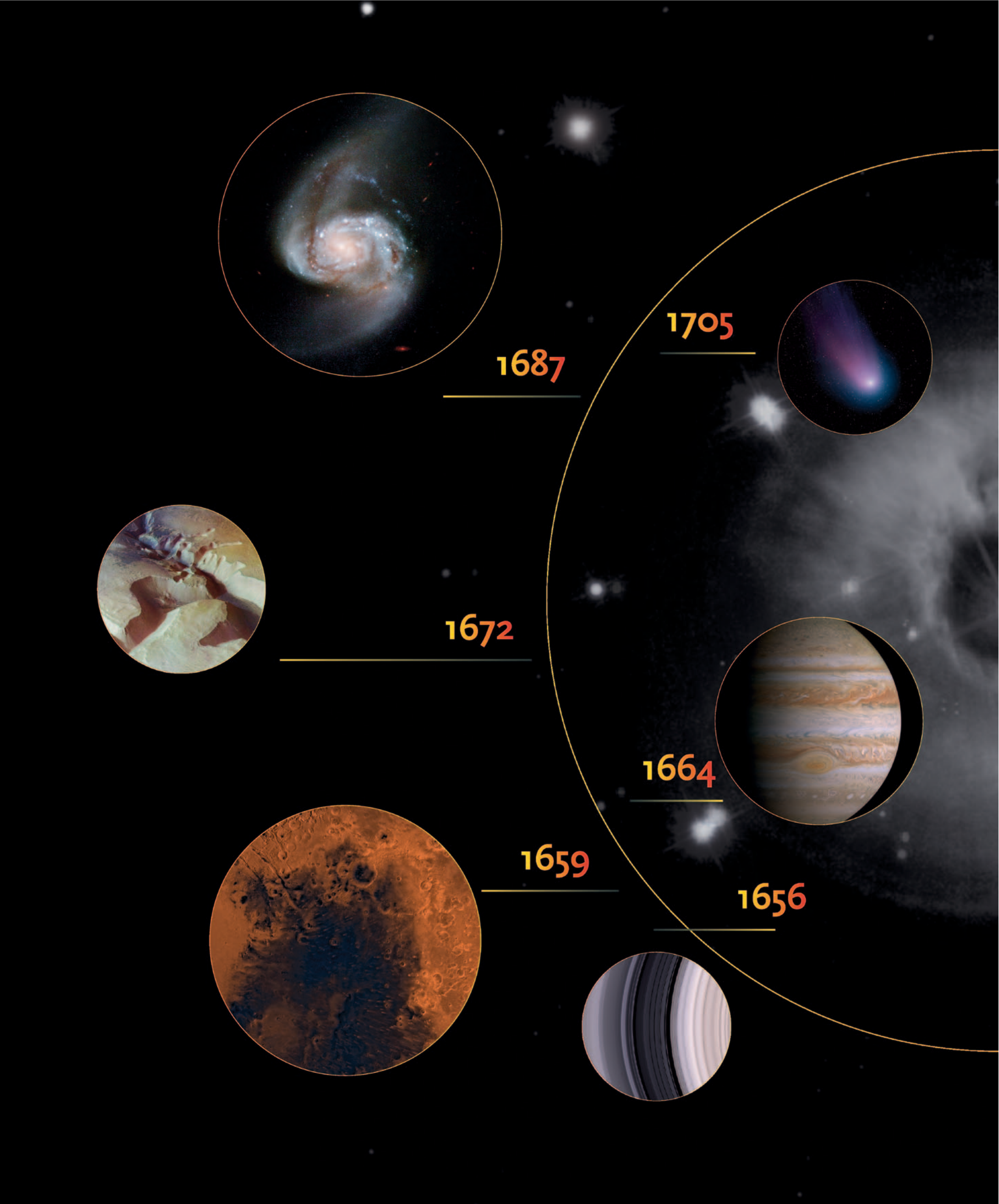
The geocentric worldview, with the Earth at the center and the celestial bodies around it in complex, multiple circular orbits, spreads throughout the Old World. In the ninth and tenth centuries, via India, it reaches Persia where mathematicians and astrologers at the palaces of the sultans and caliphs develop measuring instruments and determine the positions of celestial bodies in the sky. It then passes via North Africa to Spain, where King Alfonso X commissions the most accurate planetary tables ever produced, and from where the old Aristotelian ideas conquer the rest of Europe – a continent that is just starting to wrest itself free from the obscurity of the Middle Ages.

It is not until the mid-sixteenth century that the Polish canon and astronomer Nicolaus Copernicus drops a pebble into the still waters of Greek cosmology. The resulting circular ripples no longer place the Earth at the center of the universe, but the Sun at its center. The crystal spheres are shattered, the division of the cosmos into sublunar and superlunar dissipates like soap bubbles. In his life's work *On the Revolutions of the Heavenly Spheres*, Copernicus puts the Earth on the same level as the planets; it is not the geometric center of the universe but a world orbiting the Sun.

The Renaissance marks the cautious beginnings of modern science, where the worldview is based not on myth and tradition but on observation and experiment. Medieval natural philosophy shows its first hairline cracks and will break into two within a couple of hundred years. Astronomy and astrology part company, and science and faith no longer walk hand in hand.

While naturalists and philosophers embrace Copernicus' heliocentric worldview, observers like Tycho Brahe determine the positions of the stars and planets using gigantic quadrants, and theologians debate the implications of these new insights, a God-fearing spectacle-maker in Middelburg, the Dutch Republic, grinds two convex lenses and places them at both ends of a cardboard tube. Here, Hans Lipperhey builds the first working telescope and gives a public demonstration of his 'tube to see great distances' to Prince Maurits at the end of September 1608, heralding the advent of modern astronomy.

Supernova explosions still occur everywhere in the universe. New stars and planets are continually being born. There may be countless hidden oases in the universe where life has evolved because the cosmos is infinitely large and will last forever. But, in at least one place in that unimaginably large and immeasurable vastness, in the outer regions of a spiral galaxy, somewhere on the edge of the Virgo cluster, an irreversible step has been taken. Here, on our small Earth, we have started exploring and unraveling the secrets of the universe, and astounding discoveries are coming together to form a breathtaking picture of the world we live in.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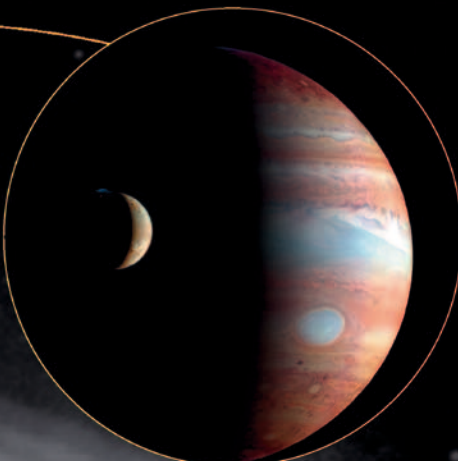

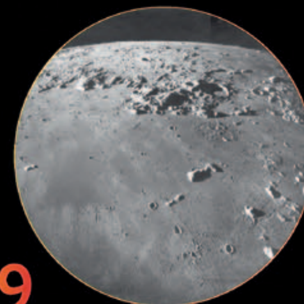

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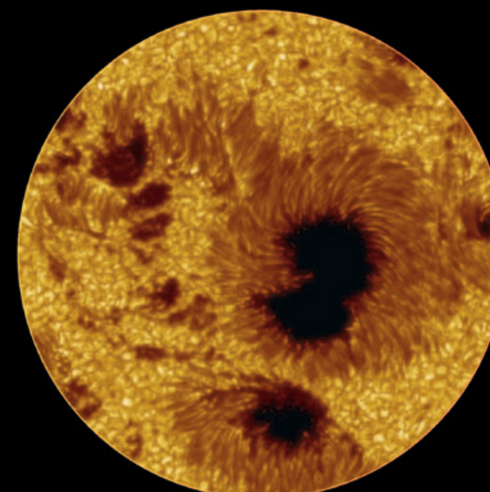

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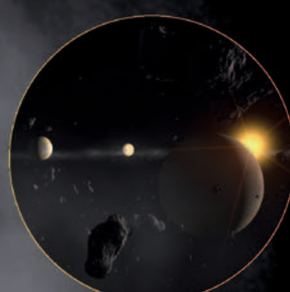

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1638

The invention of the telescope unleashes a revolution in astronomy. (until 1608 the only way we can look at the universe is through our own eyes, and they are not the most sensitive instruments imaginable). But now the human eye has a helping hand, and a complete new world opens up.

New Vistas and

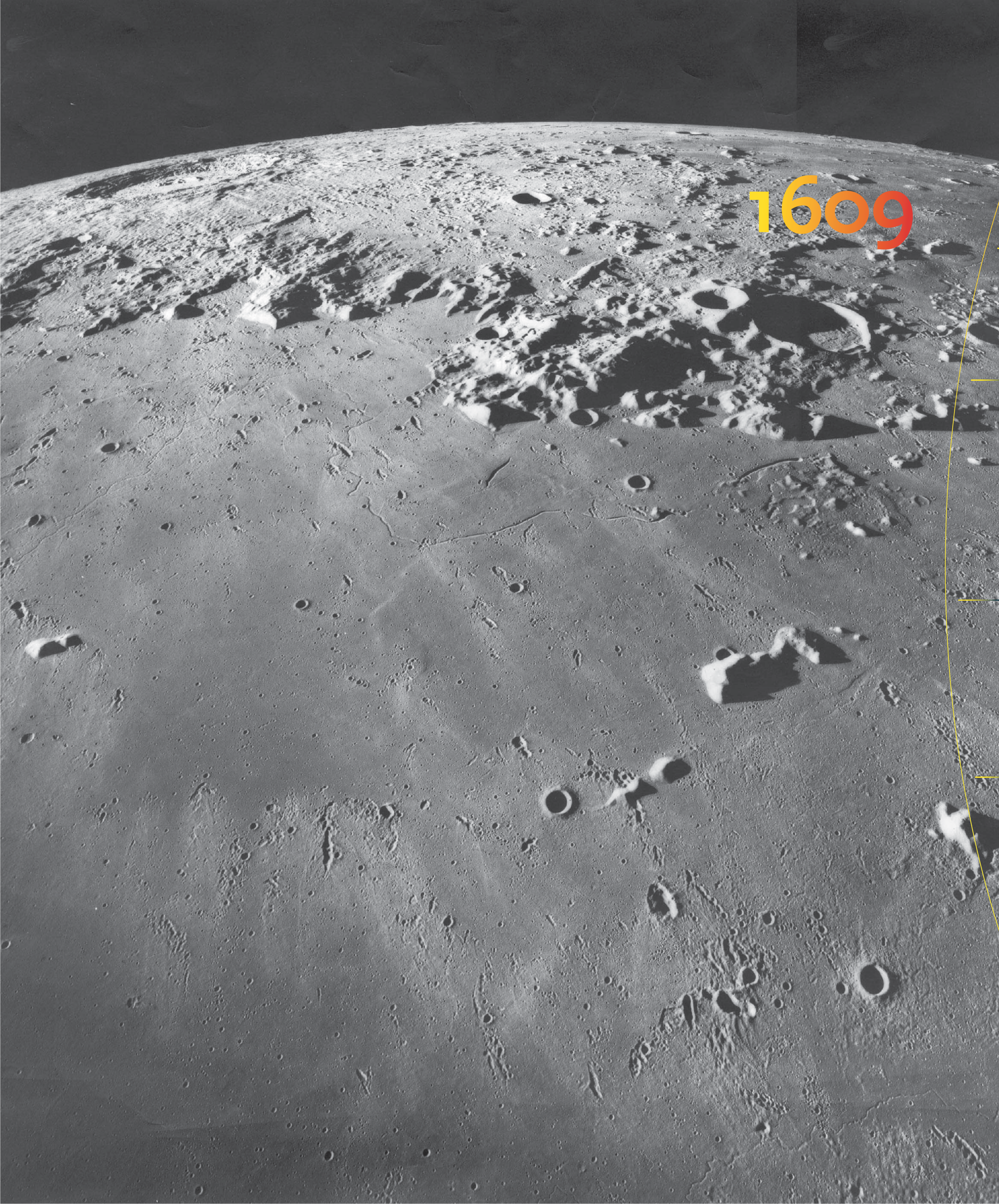
The first telescopes that astronomers aim at the night sky have poor quality lenses and a minuscule field of view, and suffer from chromatic dispersion and imaging errors, but even with these small, simple instruments they are able to make revolutionary discoveries. Wherever they look, astronomers observe new objects and details.

The seventeenth century is the age of the great voyages of discovery, of new horizons on the other side of the world’s oceans. In science, too, new vistas are opening up. It is an age of astonishment and as yet not understood connections, especially in astronomy. Are there seas on the Moon? Does Saturn have handles? Are there distant suns in the Milky Way? How far away are all these objects? And how do they influence each other?

Cosmic Laws

But it is also the age of new laws. Mathematical laws that describe the paths of the planets; physical laws that determine the motions of celestial bodies. Newton’s laws of gravity make it possible to explain, calculate and predict the orbits of planets and comets, although we still know little about their physical properties.

Astronomers finally get the cosmos in their sights. The telescope is their weapon; the hunt for the secrets of the universe has begun.


1609

Mountaineering on the Moon

Galileo Galilei Discovers Mountains on the Moon

The Greek sage Democritus was already writing about mountains and valleys on the Moon in the fifth century BC, but prejudices and misconceptions are tenacious. For many centuries the Moon, like the Sun, was considered a heavenly body in the most literal sense – a perfect, almost divine object in no way at all comparable to the pock-marked Earth.

The telescope is hardly a year old, however, when that idea has to be jettisoned. On July 26th, 1609, the English scientist Thomas Harriot has already made the first drawings of the Moon, as seen through a simple telescope. Harriot's sketchbook shows blemishes and craters. But he does not publish his observations or a physical description of what he has drawn.

A few months later, on November 30th in Tuscany, Galileo Galilei directs his self-built telescope at the Moon. Galileo's latest telescope has a magnification of 20, showing details never seen by anyone before. He sees an irregular shadow line. Large and smaller craters. Mountains. A landscape full of light and shadow, peaks and troughs. The Moon looks like the Earth!

Galileo's Moon drawings are published in early 1610. *Sidereus Nuncius* (*Starry Messenger*) unleashes a revolution in astronomy. The telescope offers a new perspective on the cosmos. Planets are small disks that reveal details, like phases and moons. Not everything in the universe rotates around the Earth, and the Moon is not a divinely perfect sphere, but a world like ours. Can there be water there? Or life?

The topography of the Moon is first charted accurately at the end of the eighteenth century. Johann Schröter makes wonderful drawings of deep craters, long mountain ridges, winding valleys and high, isolated mountain peaks that cast long shadows over the Moon landscape. Just how high are the mountains? How steep and impenetrable are their slopes?

Astronomers try to capture the extreme lunar landscape in maps, drawings and plaster models. Writers and artists go even further; in science fiction and space art the Moon becomes a world of high, sharp peaks, deep ravines and vertical rock faces.

It is the absence of an atmosphere that causes this new misconception. On the Moon, shadows remain sharp and pitch black, even if the Sun is low and they are tens of kilometers long. In reality the mountains on the Moon are not much steeper than those here on Earth.

With stereo photography and altitude meters the topography of almost the entire surface of the Moon is charted. Space probes, like NASA's Lunar Reconnaissance Orbiter, have done that in even greater detail. Four hundred years after Galileo's discovery we know the mountains on the Moon as well as we do the Rocky Mountains and the Himalayas. How long before we see the first lunar mountaineers?

Geologist Harrison Schmitt is the only scientist to have set foot on the Moon. He was the lunar module pilot of the Apollo 17 mission, which made the last manned flight to the Moon in December 1972. (NASA)

Craters, mountains and 'rilles' dominate the lunar landscape in the area of the crater Euler. The origin of the small, elongated string of craters has still not been determined conclusively; they may be related to volcanic activity at some time in the Moon's past. (NASA)

Children of Jupiter

Galileo Galilei Discovers Moons Around Another Planet

It is January 1610 and, on every clear night, Galileo Galilei can be found outside with his self-built telescope. The winter sky above the hills of Tuscany is breathtakingly beautiful; one just can't get enough of it. On Thursday the 7th, Galileo points his telescope at Jupiter, shining brightly in the constellation of Taurus, about halfway between the Pleiades and the almost Full Moon. That night, in a single, short glance, he discovers three new worlds.

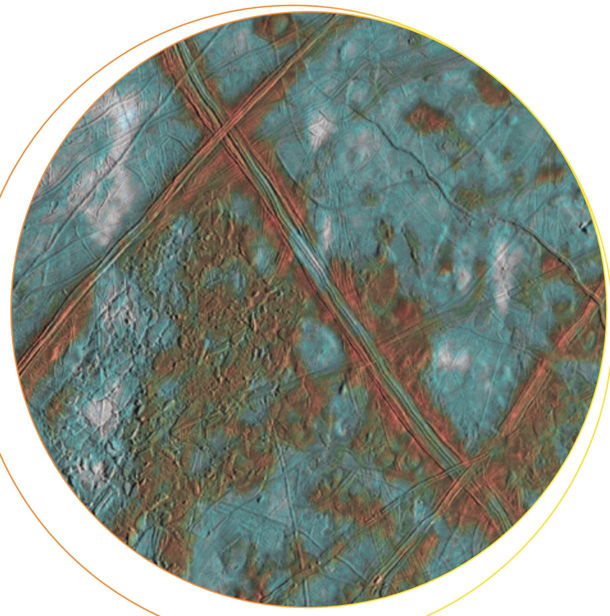
Close to the bright planet, Galileo sees three stars, two to the east and one to the west. Do they belong to Taurus? Galileo is not sure. The three stars are surprisingly bright, and they are all neatly lined up. He makes a sketch of their position.

The next night, Galileo observes Jupiter again. The planet has moved a little in the night sky, but the three stars seem to have moved along with it, although all three are now to the west. Night after night Galileo keeps a close watch on the mysterious objects. And, then, on Wednesday January 13th, he discovers a fourth star.

Galilei describes his discovery in the *Sidereus Nuncius* (*Starry Messenger*), published in March 1610. Jupiter has four companions, four moons. From the Earth we see their orbits edge-on, which makes it look as though they move back and forth, each at its own pace. The solar system has four new celestial bodies.

The discovery is further evidence of the validity of Copernicus' heliocentric worldview. In his book *De Revolutionibus Orbium Coelestium* (*On the Revolutions of the Heavenly Spheres*) Nicolaus Copernicus writes in 1543 that the Earth is not the center of the universe, but orbits the Sun, just like the other planets. The book encounters fierce resistance, especially by the Vatican. How can there be other centers around which celestial bodies rotate other than the Earth? And anyway, if the Earth moves, wouldn't the Moon get left behind?

Galileo realizes that the four moons he has discovered prove that Copernicus was right. They orbit Jupiter, which means that the Earth is not the only center of motion. In addition, they move through space along with their parent planet, which he surmises must also be the case for our Moon and planet Earth.



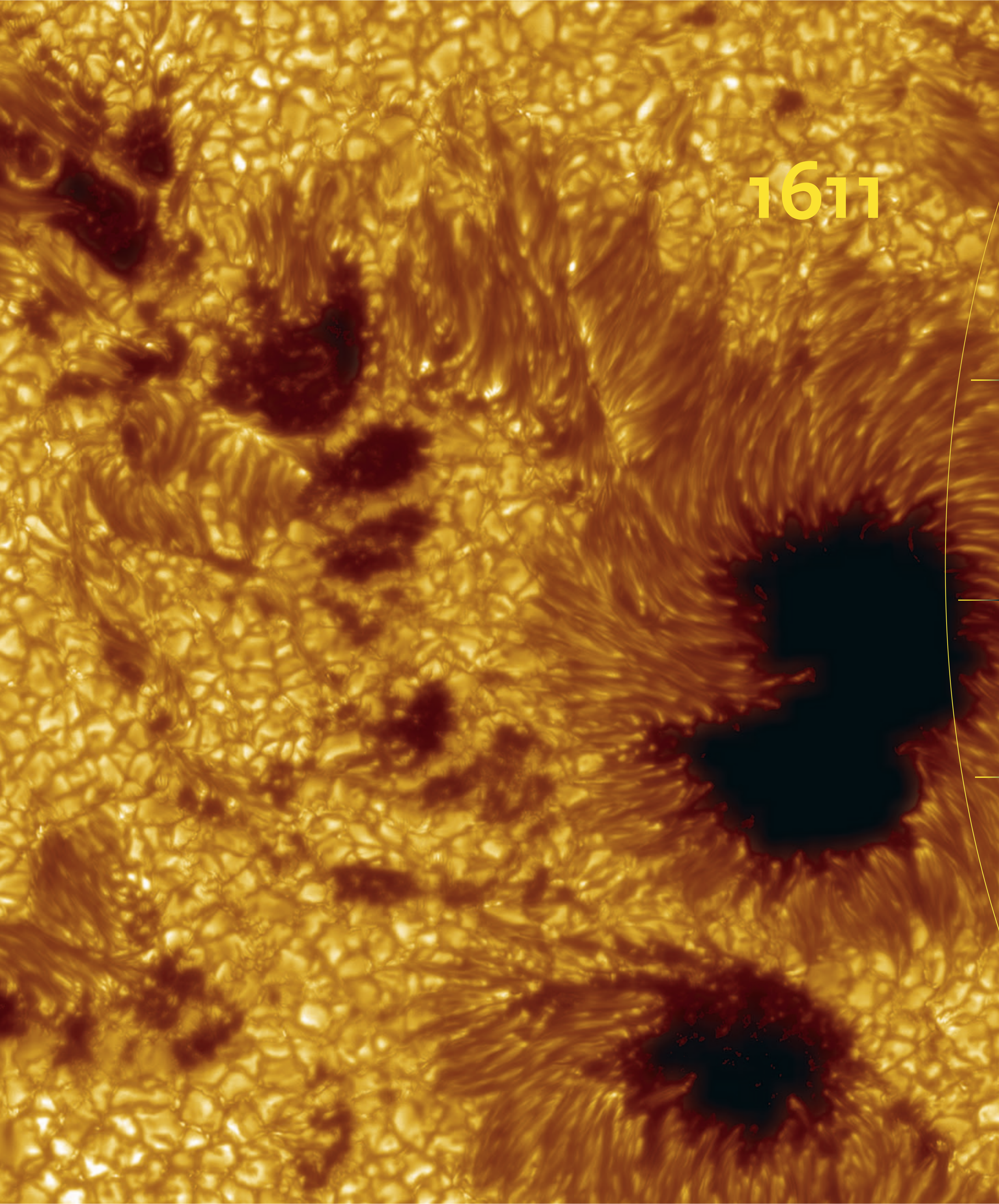
In 1614, at the suggestion of Johannes Kepler, the German Simon Marius (who also claims to have seen the moons in January 1610) gives them their current names: Io, Europa, Ganymede, and Callisto – four lovers of Zeus, the king of the gods. Galileo's proposal to name them after Tuscan nobles is not adopted.

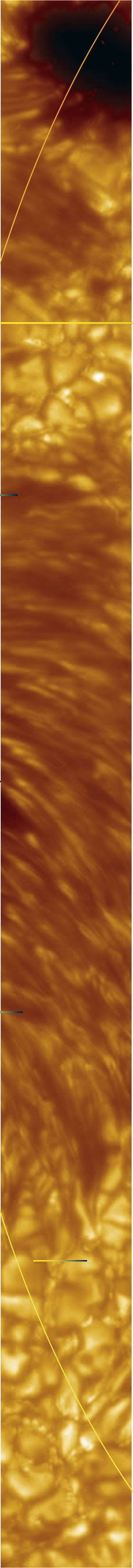
In 1979 the American space probe Voyager 1 takes the first close-up pictures of Jupiter's four large moons, four complete worlds with volcanoes, craters and subterranean oceans. At the end of the 1990s, another planetary probe charts them in great detail. The probe is called Galileo, after their Italian discoverer.

The icy surface of Jupiter's moon Europa is crisscrossed with cracks and fissures. It is likely that there is an ocean of liquid water under the ice. Europa is smaller than the Moon, but probably contains more water than the Earth. (NASA/JPL/University of Arizona)

The moon Io contrasts with the night side of the giant planet Jupiter. This photograph was made by the space probe New Horizons, on its way to Pluto. On the rim of Io, the eruption of a sulfur volcano can be seen. (NASA/JHU-APL)

1610


1611



Tarnished Blazon

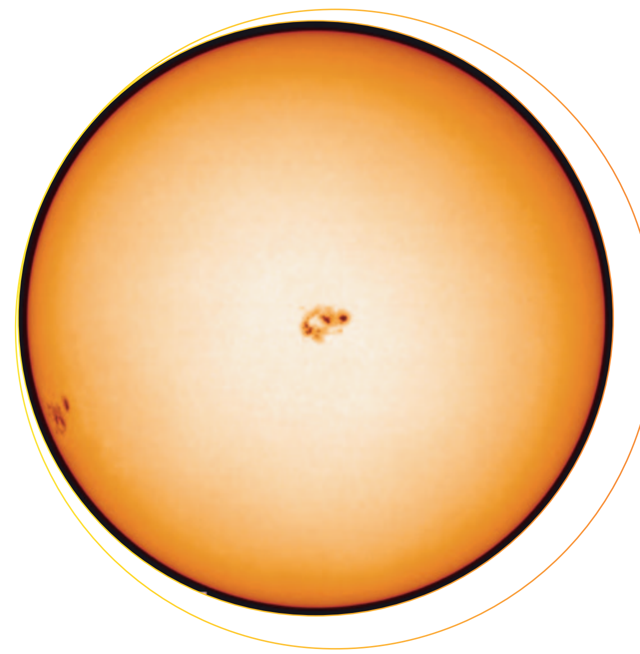
Johannes Fabricius Discovers Spots on the Sun

Johannes Fabricius inherits his interest in the night sky from his father David, who is a preacher in Eastern Friesland and a fanatical amateur astronomer. In August 1596, David discovers a star in the constellation of Cetus that varies in brightness. He corresponds with leading astronomers like Tycho Brahe, Michael Maestlin and Johannes Kepler.

His son, Johannes, studies in the Netherlands, where the telescope was invented a few years previously. Early in 1611, around his 24th birthday, he returns to his home in Osteel and takes a telescope with him. Together with his father, he observes the stars in the night sky.

On Wednesday March 9th, on his father's 47th birthday, Johannes is up early. It is a beautiful day, and shortly after sunrise he points the telescope cautiously at the Sun. The bright light hurts his eyes but he is not imagining things: there are dark spots clearly visible in the blinding surface.

Father and son keep a close eye on the Sun in the days that follow. The spots move from east to west- the Sun is rotating on its axis! Johannes has also learned that you have to publish scientific discoveries, so that you can lay claim to them later. On June 13th, his essay *De Maculis in Sole Observatis, et Apparente earum cum Sole Conversione Narratio* (*Narration on Spots Observed on the Sun and Their Apparent Rotation with the Sun*) appears in print.



➋ On October 24th, 2003, a large group of sunspots was visible in the middle of the Sun. A second group appeared on the left rim. The increased sunspot activity of the Sun in the fall of 2003 was accompanied by powerful solar flares. (NASA/ESA)

➌ This close-up of active region 10030 was made with the Swedish solar telescope on La Palma. Sunspots are many hundreds of degrees cooler and lie deeper than the area around them. (Royal Swedish Academy of Sciences)

It is not until the following year that Christoph Scheiner and Galileo Galilei publish their own observations of sunspots. Galileo spends a lot of time looking at the sun, but only near sunrise and sunset. Later he uses a safer method: he projects the image of the Sun on a white card. A similar technique is used by Scheiner. Learned European astronomers begin to conduct a heated debate on the true nature of the black spots, and the contribution of the two amateurs from Eastern Friesland is forgotten. Johannes Fabricius dies in 1616 at the age of 29. His father is murdered a year later by a farmer from his own parish who he had accused of stealing a goose.

Many sunspots are larger than the Earth, and a sizeable group of spots can be a few hundred thousand kilometers across. Special telescopes, including the Dutch and Swedish solar telescopes on La Palma and Tenerife, now make detailed photos and movies of sunspots almost daily.

Sunspots are not black but look dark because they are a few thousand degrees cooler than the rest of the Sun. They are caused by distorted magnetic fields that prevent gas from bubbling up from the interior of the Sun. This creates a cooler area on the surface that is also a little lower than its surroundings.

Cosmic Order

Johannes Kepler Discovers the Laws of Planetary Motion

It is July 19th, 1595. Johannes Kepler is 23 years old when he suddenly has a revelation while giving a mathematics lecture in Graz. He describes it a year and a half later in his book *Mysterium Cosmographicum (The Cosmographic Mystery)*. The brilliant German mathematician and astronomer is convinced that the dimensions of a planet's orbit display a regularity that is related to the five Platonic solids. Kepler is on the tracks of a divine plan.

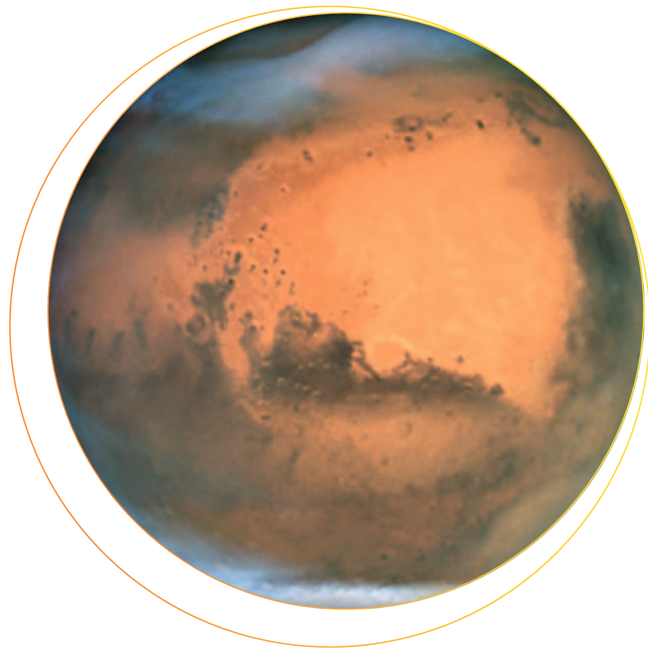
Johannes Kepler has one foot in the past and the other in the future. He marks the turning point between intellectual darkness and scientific enlightenment. Kepler is a mystic and astrologer, but also discovers the laws of planetary motion and improves the Dutch telescope.

In the classical Greek worldview the planets move at constant speed in perfectly circular orbits, and the Earth is at the center of the cosmos. Nicolaus Copernicus dethroned the Earth in 1543, but held on to the concept of uniform circular motion; Kepler finishes the job Copernicus had started.

In 1600 Kepler moves to Prague, where he assists the great Danish astronomer Tycho Brahe. Tycho gets him to tackle a problem he himself cannot solve: the motion of the planet Mars, which defies explanation in terms of circles. After Tycho's death in 1601 (Kepler succeeds him as court astronomer to Emperor Rudolf II), Kepler has his second revelation: Mars does not move in a circle but in an ellipse, and its orbital speed varies gradually.

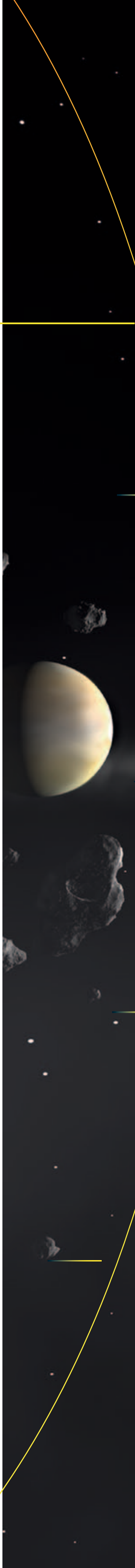
These are exciting years and Kepler writes a standard work on optics. In October 1604, he discovers a new star in the constellation Serpens, and in 1609 he publishes his *Astronomia Nova (The New Astronomy)*, describing and explaining the properties of elliptical orbits.

Kepler's first law says nothing more than planets follow elliptical orbits, with the Sun at one focus. His second law, also discussed in *Astronomia Nova*, describes how a planet's orbital speed varies according to its distance from the Sun. But Kepler's book of cosmic laws was not completed until 1619. In *Harmonices Mundi (Harmony of the Worlds)* he describes how the dimensions and orbital periods of the planets are related – his third law.



Kepler never takes complete leave of his mystical ideas. In *Harmonices Mundi*, he refers again to the Platonic solids, and to divine harmonics created by the planets. For someone living on the cusp of two ages, there is perhaps not such a great difference between the mathematical order of planetary motions and the geometry of the cosmographic mystery.

Kepler's laws are universal, and they apply not only to our solar system, but also to other planetary systems, binary stars and distant galaxies. What was revealed to Kepler may not have been a divine plan, but it was certainly a cosmic order.



Johannes Kepler discovered his laws of planetary motion when he was investigating the planet Mars. This photo of Mars was made by the Hubble Space Telescope and shows a dust storm in the northern polar region of the planet. (NASA/ESA/Hubble Heritage Team)

Planets and asteroids follow elliptical orbits and all obey Kepler's laws of motion. This illustration shows a planetary system around another star, where three Neptune-like planets and numerous smaller lumps of rock have been discovered. (ESO)