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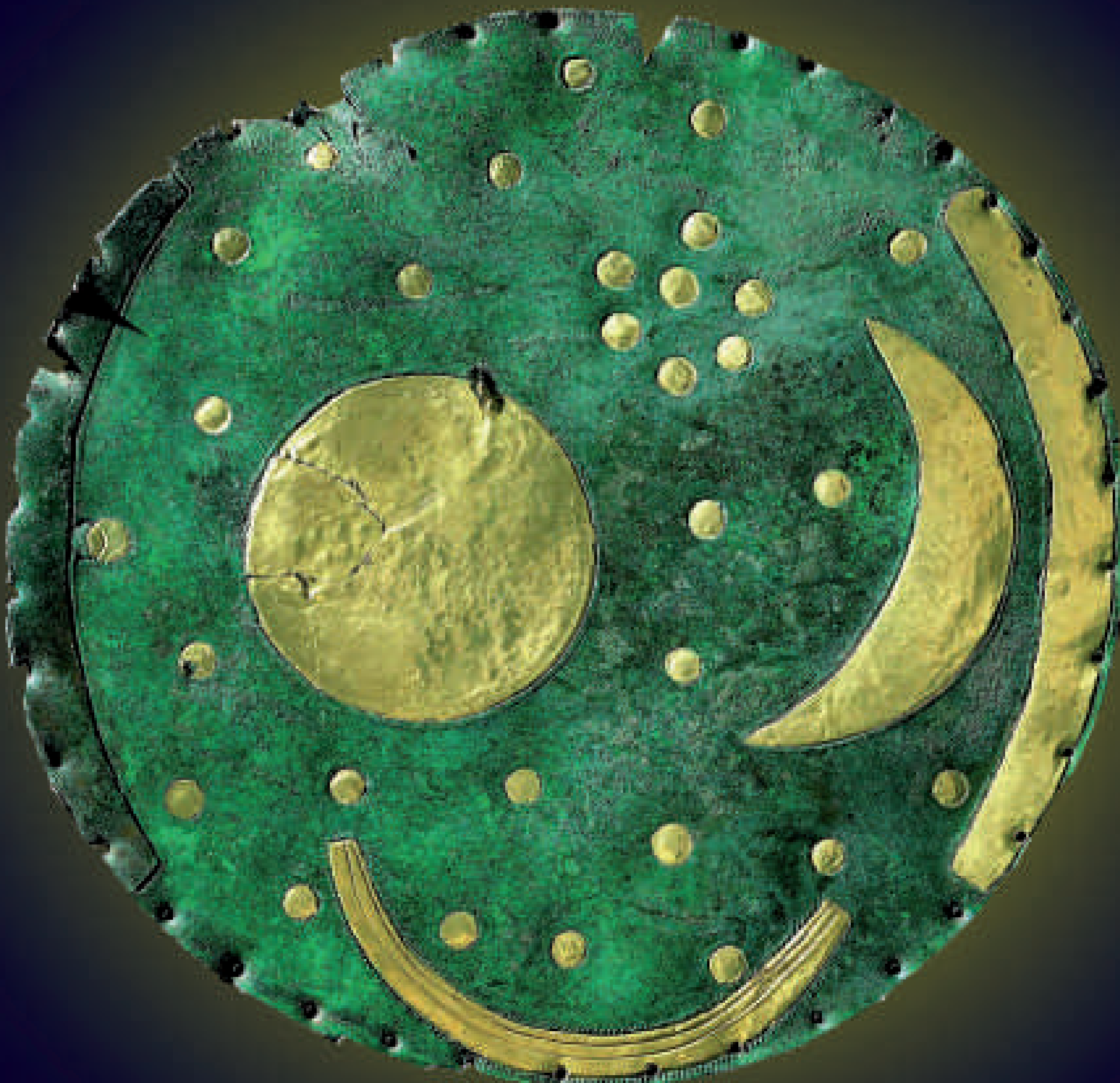

4440:
A Secret Number in Astronomy

Editorial

This issue of Spatium is devoted to the history of astronomy, more precisely to its evolution in Europe and the area adjacent to the Mediterranean Sea. It is a play on different stages: In the early days of astronomy, the observation of heavenly process was on the one hand a vital necessity to tune agricultural activities to the changing seasons and on the other hand the Sun was worshipped as the inexhaustible source of light and life. Early astronomers were priests therefore linking the art of objective observations with the richness of pious inspirations.

The initially united stages splitted off when scientists found that the wandering of the Sun, the Moon and the other celestial bodies is ruled by nothing else than a set of soulless mathematical functions. On the religious stage, emerging dogmas incorporated suitable world models that received the status of eternal truth irrespective of the continued progress made on the stage of science. Galileo Galilei contributed to further deepening the ditches between the two stages by stipulating that a hypothesis, in order to be scientifically acceptable, must be provable everywhere at any time. This of course was provocative news for the clerical establishment which did not hesitate to denounce him of heresy and to prohibit him to further teach his findings: the two stages had entered a state of fierce war for the next centuries.

Galilei even added a third stage that is the use of technical means to overcome the limitations of the human senses to observe nature. Although his means were nothing more than a pair of simple lenses packed in a tube of cardboard called telescope, the shiny objects that now suddenly became visible challenged the human spirit enough to let him make every effort to improve the miraculous device even further. In that sense, the history of astronomy is also the history of the evolution of technology and today's extensive use of space-borne instruments for astronomical research is nothing else than a continuation of Galiei's use of telescopes some 400 years ago.

All these different stages - and many more - were the subject of a most fascinating lecture Prof. Giovanni F. Bignami, then at the University of Pavia, now President of the Italian Space Agency, gave the Pro ISSI audience in November 2006. The present text follows loosely the lines of his presentation; may it provide our readers the same wealth of inspring thoughts as Prof. Bignami's talk offered his attentive audience…

Hansjörg Schlaepfer
Neerach, August 2007

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Front Cover
The recently found sky disk of Nebra, Central Germany, is the most ancient image of the sky. Dating back to 1600 B.C., it represents the Sun, the Moon and – probably - the Pleiades. It is assumed to have served determining the beginnings of new seasons for agricultural purposes, but it certainly served religious traditions as well. (Credit: Landesamt für Archäologie Sachsen-Anhalt, Germany, Hansjörg Schlaepfer)

4440: A Secret Number in Astronomy[1]

Dr. Hansjörg Schlaepfer, Neerach

Introduction

Mankind has been looking at stars with naked eyes for the last 4,000 years collecting data and understanding important astronomical facts. Since Galileo Galilei gave us the telescope, 400 years ago, astronomy from the ground has reached a profound comprehension of our universe; infinitely greater than had been possible in the previous millennia. In a spectacular acceleration, from millennia over centuries to decades, the last 40 years have given us astronomy from space, yielding a view of celestial objects over the whole electromagnetic spectrum, i.e. the most important channel through which the sky sends us information about itself. In decoding such information, gathered from telescopes in space, we have, once again, vastly surpassed the work done over the previous centuries and created entirely new scientific disciplines such as planetology or cosmology.

4,000 Years of Naked Eye Astronomy

From Early Testimonies...

There was a time – not too far back – when the night sky was really dark and crowded with uncountable stars. The Milky Way was the wonderful lane that leads from the ho-

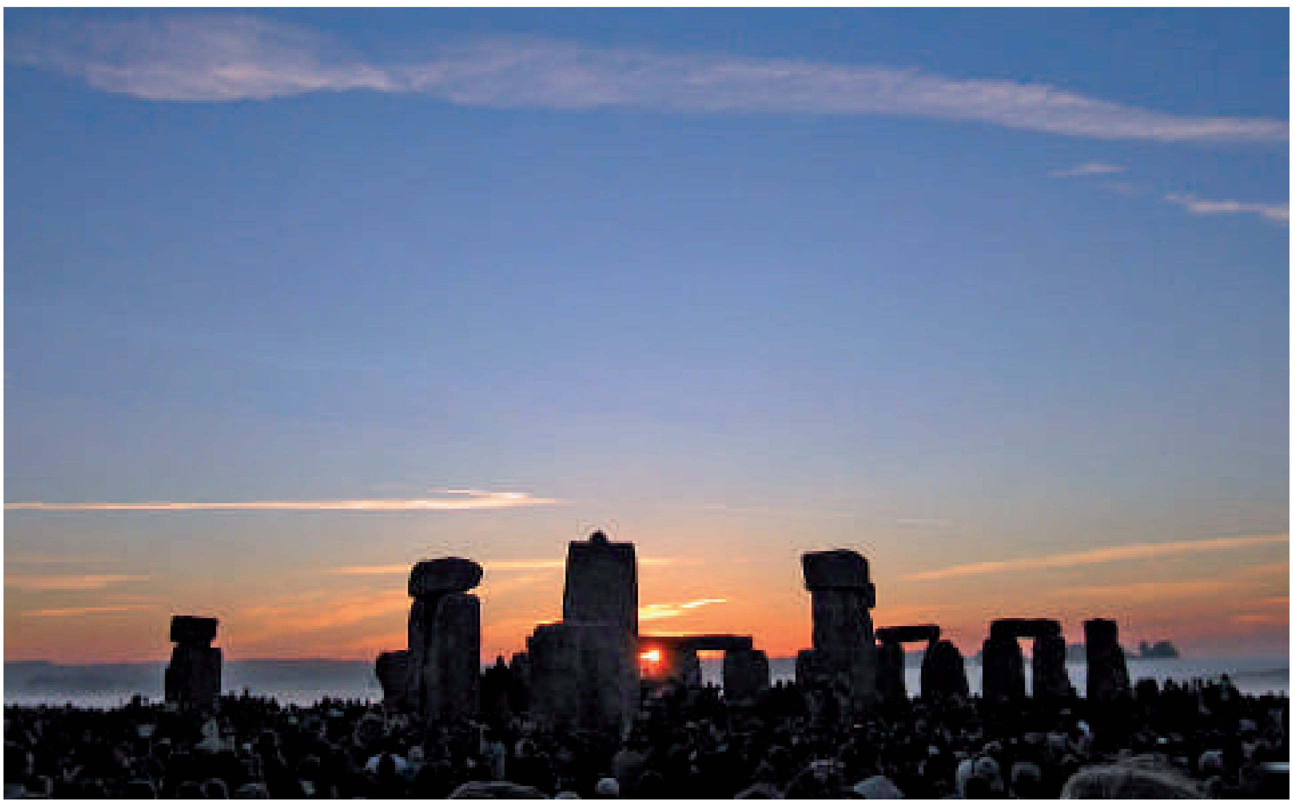

Fig. 1: Summer solstice over Stonehenge. The great stone circle was erected between 3000 B.C. and 1600 B.C. It consists of a circular structure, exactly aligned with the rising Sun at the solstice. (Credit: Andrew Dunn)

[1] The present text follows a lecture by Professor Giovanni F. Bignami, President, Italian Space Agency, Rome, for the Pro-ISSI audience on 13 November 2006 and is freely retold by Hansjörg Schlaepfer.

rizon to the zenith and down again to the opposite side. Today, atmospheric pollution absorbs most of this faint radiation and the scattering from the ubiquitous artificial light sources hides the beauties of the night sky to most of us. Fortunately, mankind has evolved under clear night skies and has been impressed by the silently wandering stars. We do not know the beginnings of their observations; the eons since have erased most, if not all, of the traces of early astronomical endeavours. Interestingly though, these seem to have evolved independently(?) at many different places all over the world some 4,000 years ago. One of these places is Stonehenge, UK **(Fig. 1)**, of which the oldest traces date back as far as 3000 B.C. The megalith's precise orientation towards the rising Sun at summer solstice is a clear indication, that astronomy played an important role in the life of their constructors.

On the Continent, more precisely in Central Germany, another milestone of early astronomical endeavours from that time period was found recently: the sky disk of Nebra, see the **front cover.** Dating back to 1600 B.C., it represents mankind's very first known image of the sky. The latest analytical technologies were used to unravel some of the disk's secrets: it is thought that its designers had contacts to the eastern Mediterranean area, to Mycenae and even further to Mesopotamia, where in the fertile half-moon between the rivers Euphrates and Tigris the Sumerian culture prospered at that very time. The Sumerians are known to have developed not only what could be called the first "professional" astronomers but also the means to bequeath much of their broad knowledge. They invented a form of writing in clay with a wedge-shaped stylus thereby producing documents that survived the many millennia since. Thanks to these documents, we know that the Sumerian priests studied the stars and knew to correlate astronomical alignments with the changing seasons. Based on their observations they set up a calendar consisting of a year with twelve months, each of which began at the first sighting of the new moon. Sometimes, based on a respective royal order, the eleventh months had to be repeated, in order to bring the lunar calendar in line again with the Sun's. A Sumerian day consisted of six watches, each being two double hours long. Each hour was divided into 60 minutes, and each minute was divided into 60 seconds. The year had nominally 360 days, and so their heavens were divided into 360 degrees. Many of these ancient concepts have survived thousands of years and constitute today our counting system for time and angles, while in the other areas the decimal system, presumably of Indian origin, has become the standard system.

The cuneiforms, as the Sumerian clay tablets are called, tell us also about the Sumerian endeavours to understand the processes in the sky in order to sow and to harvest at the appropriate time. No doubt, the need for sufficient food and water supply was at the root of their interest in astronomy and, since fertility of the fields was a gift from the gods at that time, religious and scientific endeavours could co-evolve in untroubled harmony...

While the Euphrates and the Tigris were the source of wealth for the Sumerians and the later Babylonians, another large river, the Nile, was the cradle for the Egyptian civilization. The Nil's periodic inundations, lasting from July to October, required the mastering of the calendar to tune agricultural activities to the river's habits: the Egyptians broke a year down into 365 days, which was largely sufficient for practical purposes, and it seems that further efforts to understand the mechanics of the heavens were not made, at least until the later Hellenistic period.

Not a great river, but a long sea shore was the key asset of the classic Greek civilization that evolved approximately at the same time on the northern shores of the Mediterranean Sea. The great Greek philosophers Socrates[2] and Plato[3] laid the foundations of our western philosophy. Socrates' thinking and Plato's dialogues are characterized by mythic-allegoric symbols for describing the world: their real world is that of the ideas, while the human perception

[2] Socrates, 470 B.C. – 399 B.C., ancient Greek philosopher.
[3] Plato, 427 B.C. – 347 B.C., ancient Greek philosopher.

of the physical world is at best a blurred image. In contrast, for Aristotle[4], a pupil of Plato, the visible appearances became real and the world of the ideas an imperfect approximation of the empiric reality: this was the dawn of science.

Regarding astronomy, it was Aristarchos of Samos[5], who approached nature under this new paradigm. He estimated the diameter of the Sun. The result was a factor of twenty too short, but nevertheless, Aristarchos' Sun had a volume equalling 250 Earth volumes making it much greater than the Earth. It was nothing else than a logical consequence to assume the Earth to circle the Sun (and not vice versa): the modern heliocentric world model was born.

Alexander the Great[6], the most successful military commander of the ancient world, was a contemporary of Aristotle. He enlarged the accessible world towards Central Asia and India thereby boosting not only trade and economic evolution, but cultural exchange with the newly discovered civilisations as well. He founded many cities, for example Alexandria in Egypt, which soon became the centre of the known world. Here, a famous Museion was erected, that is a temple for the Muses, or – in modern terminology – an academy of sciences. Its library became the world's largest counting up to 900,000 scrolls. Of course, such an impressive collection of knowledge attracted the very best scientists of the time. Eratosthenes of Kyrene[7], one of the first directors of the library, is known for having found the Earth's perimeter around 200 B.C. He observed a draw well in Syene, Upper Egypt, illuminated by the Sun at summer solstice right down to its floor, while at the same time a well in Alexandria was illuminated only partially at an angle of 7.2°. The distance between the two cities was known from the royal couriers to be 5,000 stadia. From these data he was able to estimate the Earth's perimeter at 39,250 km, just within 2% of the exact value.

... to the First Great Astronomers...

On the northern shores of the Mediterranean Sea, most probably in Nicaea, now Izmir, Turkey, Hipparchos[8], the greatest astronomer in ancient times, saw the light of the day in 190 B.C. He was the first to derive accurate quantitative models for the motion of the Sun and the Moon. To this end, he made use of observations and knowledge accumulated over centuries before. He was also the first to compile a trigonometric table allowing him to solve any triangle. With his solar and lunar theories together with his numerical trigonometry, he was probably the first to develop a reliable method to predict solar eclipses.

In contrast to Aristarchos, Claudius Ptolemy[9] found the Earth at the centre of the universe three hundred years later. Ptolemaeus used Hipparchos' system to explain the motions of the Sun, the Moon, and the five planets known at that time. It was accurate enough to predict the position of the planets for naked-eye observations. Ptolemaeus authored three major oeuvres which strongly influenced astronomy, of which one is the *Mathematical Syntaxis* (in Greek called ΜΕΓΙΣΤΗ ΣΨΝΤΑΞΙΣ, translated in Arabic as Al Magiste and later in Latin as Almagest). The Almagest is our most important source of information on ancient Greek astronomy, see **Fig. 2**. It includes a star catalogue containing 48 constellations with the same names as we still use today.

...to the Decline of European Astronomy...

Ptolemaeus's death in 168 and the destruction of the Alexandrian library that occurred presumably at approximately that time brought the evolution of western science to a sudden end. In addition, the philosophic schools of the late Roman Empire were oriented backward to

4 Aristoteles (English: Aristotle), 384 B.C., Stageira, Greece – 322 B.C., Chalkis, ancient Greek philosopher.
5 Aristarchos of Samos, 310 B.C., Samos, Greece – 230 B.C., Alexandria, Egypt, ancient Greek astronomer and mathematician.
6 Alexander the Great, 356 B.C., Pella, Northern Greece - 323 B.C., Babylon (today Iraq), King of Macedon.
7 Eratosthenes of Kyrene, 276 B.C. – 195 B.C., ancient Greek mathematician, geographer and astromer.
8 Hipparchos, 190 B.C., Nicaea, Asia Minor – 120 B.C., Rhodes, Greece, ancient Greek astronomer, geographer, and mathematician.
9 Claudius Ptolemaeus (English: Ptolemy), 90, Alexandria (?), Egypt – 168, Alexandria, Hellenistic mathematician, geographer, astronomer, and astrologer.

Fig. 2: A late copy of the Almagest by Ptolemy translated in Latin around 1451.
The drawings illustrate the computation of the duration of solar and lunar eclipses.

Plato, thereby creating an intellectual substrate that did not aim at scientific progress. Even worse, the initially suppressed Christianity became state religion. It was a fundamentalist movement that addressed mainly the "poors in spirit", social strata that were far away from any interest in science. The Ptolemaic system of a geocentric world was formulated just at the right time to enter the Christian dogmatic system, where it firmly stood for the next 1,400 years. In 529, Iustinianus I[10] closed the academy of Athens, the last Hellenistic school: the long dark night of the medieval time in Europe had begun. Although some early Christian philosophers, like for example Origen[11], tried to reconcile the evolving Christian doctrines with Hellenistic thinking, the new movement began to extinct everything not literally in line with the Bible. That became the destiny for the vast majority of the great testimonies of ancient human thinking, including for example the Almagest. A chance for survival had only those works that had been compiled or copied elsewhere by late-Roman librarians.

... to Arabian Astronomy ...

Fortunately though, science found a new culture medium on the eastern side of the Mediterranean Sea: In 622, Muhammed[12] founded a new religious and political movement unifying elements from Judaism and Christianity. The new religion, the Islam, rapidly developed an impressive unifying power: its influence eventually reached Andalusia in the west and Central Asia and China in the east. Like some 900 years before, under Alexander the Great, economy, handcraft and trade re-flourished. Damascus, later Baghdad, became the new world's capitals. And in contrast to the parochial Christianity, the evolving Islamic culture was open to new ideas and science was seen as an important cultural accomplishment. Under Kalif Al Mansur, around 760, sages from all over the world convened to make up the world's intellectual centre in Baghdad. The works of the ancient Greek thinkers were translated meticulously into Arabic and the classic Almagest of Ptolemy was not only studied but further developed also, see **Fig.3**. It was enriched by the Hindu-Arabic numeral system, now called the Arabic numerals. Kalif Al Mamun ordered the construction of a new great observatory near Baghdad in 829 and Muhammad Al Fagan was one of the leading astronomers there. He authored a book entitled "Elements of Astronomy", which served as a standard text book in Europe until the end of the 16th century.

Towards the year 1000, the centre of Arabic astronomy moved slowly to the west, first to Egypt, then to the Moorish Castile in Spain. Under the Kalifs of Cordoba, astron-

10 Flavius Petrus Sabbatius Iustinianus, 482, Iustiniana Prima (today Serbia) – 565, East Roman Emperor.
11 Origenes, (English: Origen), 185, Alexandria, Egypt (?) –254, Tyros, today Leban (?), one of the early fathers of the Christian Church.
12 Muhammed, 570, Mecca (today Saudi Arabia) – 632, Medina, founder of the Islam.

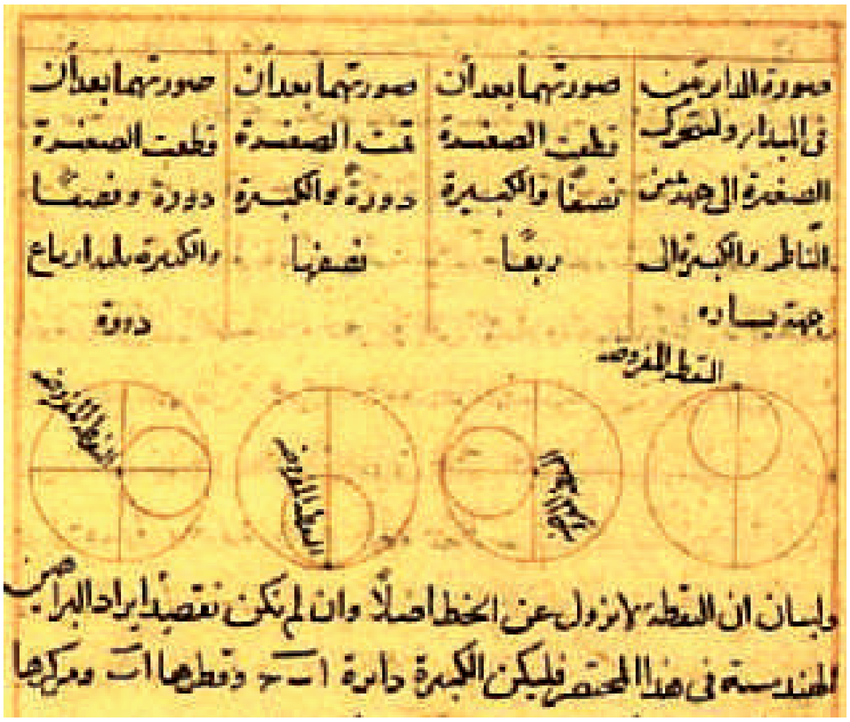

Fig. 3: An example of a late Arabic book based on Ptolemy's Almagest. The Picture shows a page of Nasir ad-Din at-Tusi's "Memoirs on Astronomy", written in the fourteenth century.

omy saw a first, albeit transitory, revival in Europe in the 11th and 12th century, but the "reconquista" by the Castilian Christians not only brought the Arabic presence in Europe, but also their scientific endeavours to an end. A land mark of occidental philosophy of that time is the Divina Comedia by Dante[13], one of the masterpieces of world literature, firmly rooting in the classic scholastic tradition.

Fortunately, astronomy sparked off again in the eastern parts of the Arabic empire, more precisely in Baghdad and Megara, where new astronomical institutions were established. In the vicinity of Tabriz, in today's north-western Iran, an observatory was founded in 1259 that had a large library counting as much as 400,000 manuscripts. Some 200 years later, in 1420, the Mongol Ulugh Begh ordered the construction of an observatory on the Silk Road in Samarkand, today Uzbekistan. He personally developed the first star catalogue that was not simply an improvement of Ptolemy's oeuvre, but contained many new elements. This catalogue eventually became known in Europe and went into press in 1655, at a time, when it was already outdated by insights of European scientists.

...to the Revival of European Astronomy

Under the increasing Mongolic pressure the Arabian astronomy came to an end, while the occident was fortunately about to leave the dark medieval times and to become open for science. At that time, many precious goods were imported over the Silk Road from the east. It is probably on that path that the art of printing reached Europe around 1300. Initially, it was used to decorate clothes for religious purposes exclusively. The art of paper making, originally invented in China also, was imported during the Moorish conquest of Andalusia. The first paper mill was established in 1120 near Valencia; later mills were founded in Italy and Germany around 1400. In 1452, the German goldsmith Johannes Gutenberg invented the moveable type printing in Mainz. This new technology was quicker and more durable than the previous laborious woodblock printing, which required the different letters to be carved out from a solid block of wood. This new technology rapidly spread through Europe: in 1469, the first print press was established in Venice, 1470 in Paris, 1473 in Krakow, Poland, and it took more than 150 years for the first printing press to start operating in North America (1638).

Of course, the Church knew to put the promising technology rapidly into its service; but also scientists began to exploit printing for their

[13] Dante Alighieri, 1265, Florence, Italy – 1321, Ravenna, Italy, Italian poet and philosopher.

Fig. 4: Nicolas Copernicus: De revolutionibus orbium coelestium (1543).

needs. One of earliest great European scientists, who used the art of printing, was Nicolas Copernicus[14]. His Commentariolus (Little Commentary) was initially nothing more than a handwritten text outlining some of his ideas on a heliocentric world model. But around 1515 his friends urged him to publish and even the clerical establishment invited him to go into press. It was in 1543 only, the year of Copernicus' death, that his seminal oeuvre "De revolutionibus orbium coelestium" was printed, see **Fig. 4.** At first, the "De revolutionibus" did not cause any worries even though its contents were in contradiction to the official dogmas that adhered to the Ptolemaic world model. Rather, it took some 60 years for the clerical establishment to recognize the explosive force of that book and to put it rapidly on the "Index Librorum Prohibitorum", the list of the prohibited books considered a danger to the true faith.

At about the same time, Giordano Bruno[15], another adherer of the heliocentric world model and an early proponent of an infinite and homogeneous universe, was accused of heresy by the Roman inquisition. As he refused to recantate, he was burned at the stake in Rome and all his works were placed on the Index, where they remained for the subsequent 400 years.

Fortunately though, ideas cannot be extirpated by burning their proponents. Far to the north, in safe distance from the Roman inquisition, the Dane Tycho Brahe[16] was about to study law together with a variety of other subjects that attracted the youngster's interest. The solar eclipse in 1560 impressed him so deeply that he stopped his studies and began to devote himself to astronomy. As an intended lawyer he was used to work precisely and he quickly became aware of the need to improve and enlarge the available

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[14] Nicolas Copernicus, 1473, Thorùn (Prussia) – 1543, Frombork, Poland, mathematician, astronomer, jurist, physician, diplomat, and soldier.

[15] Giordano Bruno, 1548, Nola, Italy – 1600, Rome, Italian philosopher, priest, cosmologist, and occultist.

[16] Tycho Brahe, 1546, Knudstrup, Denmark – 1601, Prague, Danish astronomer.

astronomical instruments, and to construct entirely new ones, **Fig 5.** Assisted by his diligent sister Sophia he was able to make astronomical measurements of unprecedented precision.

Unfortunately for Sophia and Tycho, King Christian IV succeeded King Frederic II, who had been a strong supporter of their astronomical research. Brahe decided to leave Denmark and to move to Prague in 1599. There, during the last two years of his life, he was assisted by the young Johannes Kepler.

Thanks to its outstanding accuracy, Brahe's work marks the climax of naked eye astronomy, but also its end, as new means for observing the sky had silently emerged in the meantime that bore the potential of a quantum leap in astronomy...

Fig. 5: Tycho Brahe at work. Brahe is depicted in the centre of the image together with his assistant reading the scale on the right, the assistant responsible for the time reading on the right bottom and the assistant taking the notes on the left bottom.

400 Years of Astronomy with Telescopes

Small Things Change the World

Murano, a small town on an island in the Venetian lagoon, had been a commercial port since many centuries when in 1291, the Venetian Republic decreed its glassmakers to move to Murano as the glassworks represented a severe fire danger to the city of Venice. These glassmakers had developed and refined technologies to produce a variety of precious glass types amongst which were reading stones of the best then available quality **(Fig. 6).** Such reading stones were a necessity not only in the *Serenissima*[17], but found their customers far abroad, for example in the Netherlands. The legend tells that on a sunny summer morning some children played in the shop of the spectacles maker Hans Lippershey[18] in Middelburg. Incidentally, they found that the combination of two such lenses brought a new quality to the image as compared to that produced by a single lens. Lippershey, a clever businessman, immediately recognized the potential of the children's invention and successfully started building and selling pairs of lenses as telescopes all over Europe.

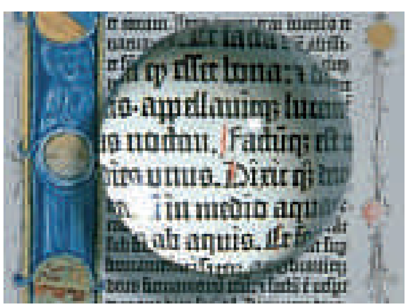


Fig. 6: A reading stone. (Credit: Carl Zeiss)

Such a novel device came to Pisa in Italy, specifically to Galileo Galilei[19]. The first of six children, young Galileo wanted to become a priest. At his father's urging, however, he enrolled for a medical degree at the University. But soon, Galilei recognized that medicine was not his favourite field. He then switched to mathematics, a decision for which humanity remains deeply indebted as it was the prerequisite for Galilei to become the father of modern physics. At the age of 25 already, he was appointed the chair of mathematics at the University of Pisa. A mere three years later, Galilei moved to the University of Padua to teach geometry, mechanics, and astronomy. During these fertile years as a professor, Galilei made his significant discoveries in both pure and applied science. He pioneered the use of quantitative experiments whose results could be analyzed subsequently with mathematical methods. Just three years after Lippershey's invention, in 1611, Galilei built his first own telescope that he presented to the then wealthy Venetians. Those welcomed Galilei's device enthusiastically for various purposes such as for military information gathering or for merchants who found it useful for their shipping business. Galilei on his part was more interested in gaining scientific insights. Those came along very quickly: in January 1610 already he

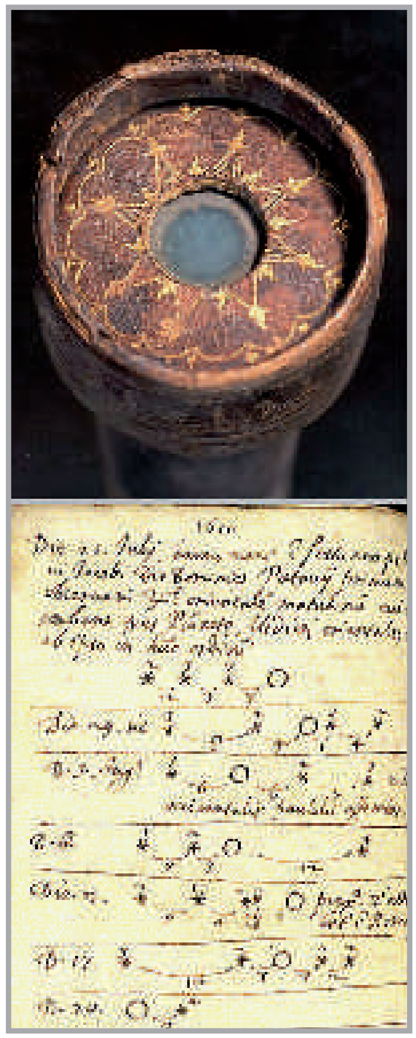


Fig. 7: A telescope used by Galileo Galilei (upper table) and an excerpt of his astronomical diary of 1610.

[17] La Serenissima, a name for the Republic of Venice, from the title Serenissimo, literally meaning "the most serene".
[18] Hans Lippershey, 1570, Wesel, Germany – 1619, Middelburg, the Netherlands, Dutch lensmaker.
[19] Galileo Galilei, 1564, Pisa – 1642, Arcetri (Italy), Italian physicist, astronomer, and philosopher.

discovered three of Jupiter's four largest moons: Io, Europa, and Callisto. A mere four nights later, he discovered Ganymede, Jupiter's fourth moon. In his diary **(Fig. 7)**, he noted that the moons appeared and disappeared periodically, which he attributed to their movement behind Jupiter. From this, he concluded that they were orbiting the planet. Unsuspectingly, Galilei published his discoveries in a small treatise called "Sidereus Nuncius" in 1610. The oeuvre was devoted to the Medici for the housing they offered him at their court. But the generous patrons did not realize what worries the booklet was about to cause: Galilei's finding of a planet that is orbited by smaller bodies was revolutionary, to say the least, as the officially still accepted geocentric world model required all celestial bodies to safely circle the Earth. Equally important from a scientific point of view was Galilei's trendsetting approach of making his claims visible for everybody, in contrast to the dogmatic approach to defining the truth "ex cathedra". The "Sidereus Nuncius" made Galilei a dangerous subject for the clerical establishment which did not hesitate to denounce him of heresy. Galilei went to Rome to defend himself against the accusations, but, after lengthy trials he was finally forbidden in 1616 to either advocate or teach Copernican astronomy furthermore. In addition, he was confined in Siena. Totally blind, he was allowed to retire to his villa in Arcetri, where he died quietly in 1642.

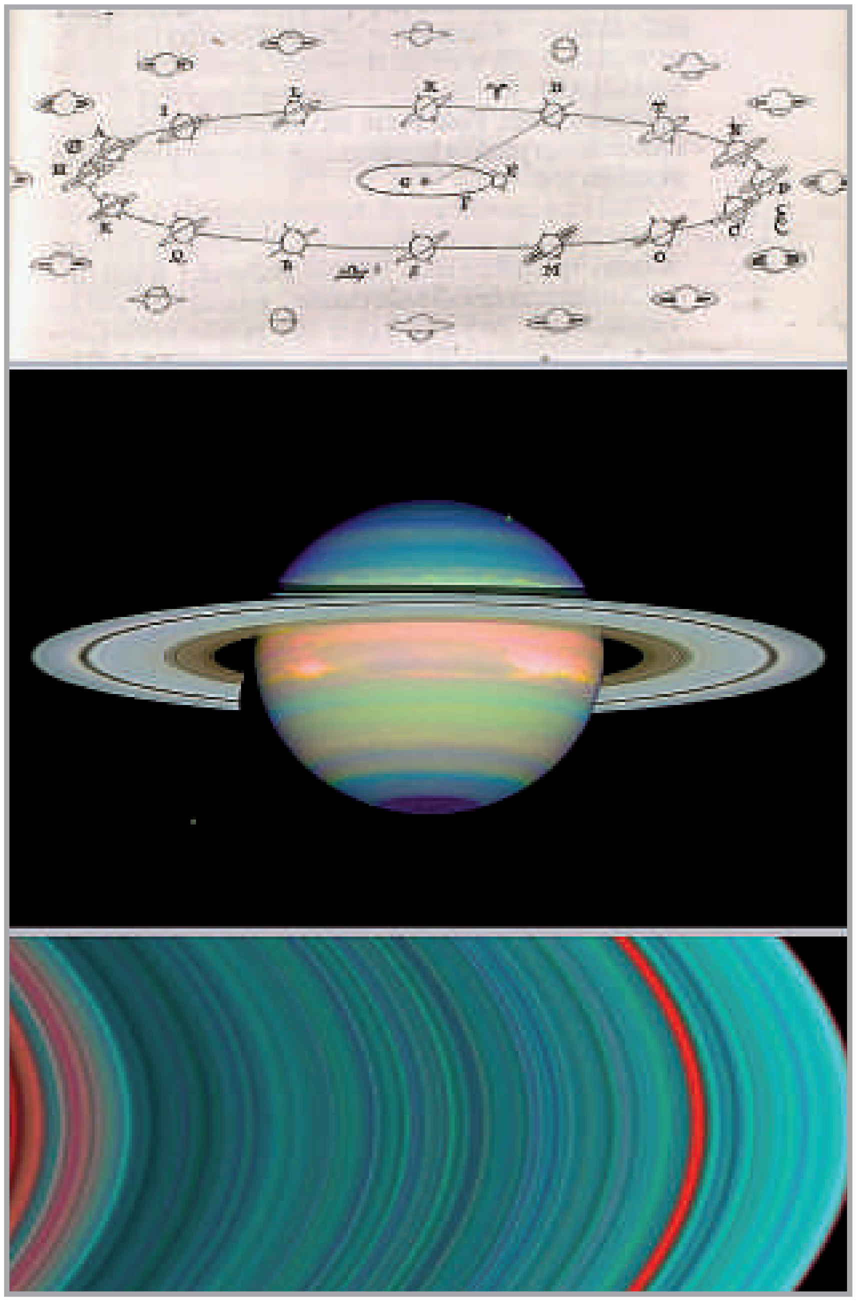


Fig. 8: Saturnian impressions: The upper table shows an excerpt of Christiaan Huygens' observations of Saturn of 1655. The middle table presents a false colour image of Saturn in the infrared acquired by the Hubble Space Telescope in 1998. The table below shows the Saturnian ring system observed by the Cassini spacecraft in 2004.

Again in a safe distance from the inquisition, more precisely in the Imperial Free City of Weil der Stadt, now in the German state of Baden-Württemberg a boy was born in 1571. Nothing in the early life of Johannes Kepler[20] would have indicated that this youngster of fragile health was later to become one of mankind's most prominent scientists. His father Heinrich died when Johannes was five, and his mother was tried for witchcraft. Still, she showed him a comet in 1577 that left a long trace not only on the sky but in the youngster's mind as well. He began studying theology, but soon it turned out that he was an excellent mathematician, so he switched and became a teacher of mathematics and astronomy in Graz, Austria. In early 1600, Kepler met Tycho Brahe near Prague, where he stayed as a guest. He was allowed to analyze some of Brahe's observations of Mars. Brahe was impressed by Kepler's theoretical abilities and soon allowed him further access to his data. Two days after Brahe's unexpected death in late 1601, Kepler was appointed his successor as imperial mathematician: he inherited his master's records as well as the responsibility to complete the unfinished work. During the following years and after careful analysis of Brahe's data, Kepler realized that the planetary orbits follow three relatively simple mathematical laws. Two of them are derived in the "Astronomia nova", 1609, while the third is contained in the later "Harmonices mundi", 1619. When Kepler heard of Galileo's telescopic discoveries, he started theoretical and experimental investigations of telescope optics as well. He published the results in "Dioptrice", 1611, where he described an improved telescope also, now known as the astronomical or Keplerian telescope, using two convex lenses that can produce higher magnification than Galileo's combination of convex and concave lenses.

Kepler's oeuvre was a seminal success and found enthusiastic readers all over Europe. One of those was the Dutchman Christiaan Huygens[21] who was building his own telescopes at that time. He managed to improve their imaging performance to such an extent as to allow him the discovery of Saturn's moon Titan in 1655. He also examined Saturn's planetary rings, and found that they must consist of rocks. But Huygens was not only a diligent observer, but also a gifted physicist: he derived the wave nature of the light and developed the probability theory as well. And his hobby, as to say in modern terms, was the existence of life on other planets: he published his reasoning in the book "Cosmotheoros", presumably one of the very first oeuvres on exobiology.

The Quest for Astronomical Discoveries

The seventeenth century saw Europe in a deep crisis; the Thirty Years' War was fought between 1618 and 1648, basically a conflict between Protestants and Catholics, but also a dispute on the role of the religion in the modern state. Devastating famine and disease all over Europe was one of its terrible consequences. Nevertheless, in some isolated spots, science was able to survive. Far to the south of Europe, Giovanni Domenico Cassini[22], a contemporary of Christiaan Huygens, studied mathematics and astronomy and became a professor for astronomy at the University of Bologna. In 1665, he determined both the rotation periods of Jupiter and Mars, and was one of the first to observe the polar caps of Mars. On invitation by the *Roi Soleil,* Louis XIV, Cassini moved to Paris. Based on his collaboration with Christiaan Huygens, he developed and used very long air telescopes. In 1672, he was able to measure the distance of Mars by triangulation and thereby to refine the dimensions of the solar system. Specifically, he determined the value of the astronomical unit (AU), just 7% short of the currently accepted value of 149,597,870,691 metres. Cassini discovered also Saturn's moons Iapetus, Rhea, Tethys, and Dione and the gap separating the two parts of the Saturnian rings that later received the name Cassini Division in his honour.

[20] Johannes Kepler, 1571, Weil der Stadt, Germany – 1630, Regensburg, German mathematician, astronomer and astrologer.
[21] Christiaan Huygens, 1629, The Hague (the Netherlands) – 1695, The Hague, Dutch mathematician, astronomer and physicist.
[22] Giovanni Domenico Cassini, 1625, San Remo, France – 1712, Paris, Italian/French astronomer, engineer, and astrologer.

In England, struck also by religious quarrels, another genius was about to revolutionize physics and the observational means in the hands of astronomers. Sir Isaac Newton[23] published the "Philosophiae Naturalis Principia Mathematica" in 1687, where he described the universal law of gravitation and the three laws of motion, laying the groundwork for classical mechanics. This allowed him to derive Kepler's laws of planetary motion from a purely theoretical point of view. He showed that the motion of objects on Earth and of celestial bodies is governed by the same set of natural laws. The unifying and predictive power of his laws became central to the advancement of the heliocentric system at the time. Based on his studies of the properties of light, he concluded that any refracting telescope (based on lenses) must suffer from the dispersion of light into the different colours. This led him to invent the reflecting telescope today known as the Newtonian telescope.

While Newton's mirror telescope constituted a major progress in observational astronomy, another star in mankind's history did not even need to observe the universe with his eyes, but rather used the overwhelming power of his rational thinking to develop theories on the evolution of the solar system: Immanuel Kant[24]. Besides an enormous wealth of philosophical oeuvres, he wrote the "Allgemeine Naturgeschichte und Theorie des Himmels", 1755, where he correctly derived the theory of the evolution of planetary systems based on Newtonian mechanics. According to Kant, our solar system has been formed out from a form of nebula where the different planets concretized independently from each other. In addition, he saw our solar system as being merely a smaller version of the fixed star systems, such as the Milky Way and other galaxies.

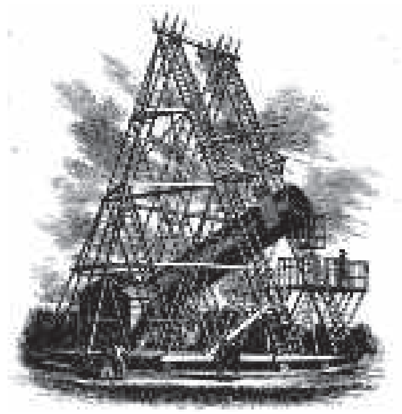


Fig. 9: The 12 m telescope built by William Herschel.

The early eighteenth century allowed Europe to recover from its sufferings finally and art and sciences were reaching new highs. It was the time of the baroque, the time of Johann Sebastian Bach and Georg Friedrich Händel. Music was the favourite subject of the young William Herschel[25] in Hanover, Germany. Born around 1738 as one of ten children, young Friedrich Wilhelm came to the Hanoverian Guards regiment, which was ordered to England in 1755, when the crowns of England and Hanover were united under George II. A gifted youngster, Friedrich quickly learned English and at the age of nineteen, he changed his name to Frederick William Herschel. He became a successful music teacher, bandleader and composer like his father, but eventually he got interested in mathematics and astronomy also. He started polishing mirrors and building telescopes of which he constructed over 400 of various and increasing size during his lifetime. The largest and most famous one is a reflecting telescope with a 12 m focal length and an aperture of 126 cm, see **Fig. 9.** This instrument allowed him to discover planet Uranus in 1781, which prompted him to give up his career as a musician and to become a great astronomer. Later, Herschel discovered Mimas and Enceladus, two Saturnian moons, and Titania and Oberon, two moons of Uranus. From studying the proper motion of stars, he was the first to realize that the solar system is moving through space, and he determined the approximate direction of that movement. He also studied the structure of the Milky Way and concluded correctly that it has the shape of a disk.

While the Northern Italian Valtellina valley is well known for its fine wine made of the Nebbiolo grape, it is certainly not so for scientific importance. But in the rural town

[23] Sir Isaac Newton, 1643, Woolstrope, Lincoln (UK) – 1727, Kensington, founder of classical mechanics.
[24] Immanuel Kant, 1724, Königsberg (Prussia) – 1804, Königsberg, German philosopher.
[25] Sir Frederick William Herschel, 1738, Hanover (Germany) – 1822, Slough (UK), German-British astronomer and composer.

of Ponte in Valtellina, Giuseppe Piazzi[26] saw the light of the day in 1746. He began his career with theological studies and finished his novitiate at the convent of San Antonio, Milan. Later, he studied at various Italian universities and became a professor for dogmatic theology in Rome. But he was not only a gifted clergyman, but an excellent mathematician as well. In 1780, one year after the French revolution, he was called to the chair of higher mathematics at the academy of Palermo, Sicily, where the Bourbon King Ferdinand I of the Two Sicilies was on the throne. A fervent supporter of astronomy he gave Piazzi a major grant for building an observatory. In order to acquire the best available instruments, Piazzi went on a shopping tour throughout Europe, specifically to Paris and to England. The equipment he had acquired was placed on top of a tower of the Royal Palace in Palermo. Observations began in 1791, and the first report was published just one year later. The excellent equipment – and the clear sky of Sicily – allowed him to make scientific contributions soon, such as to estimate more precisely the obliquity of the ecliptic, the length of the tropical year, and the parallax of the fixed stars. He saw the necessity for a revision of the existing star catalogues and for the exact determination of their positions. In 1803, he published a list of 6,784 stars and in 1814 a second catalogue containing no less than 7,646 stars. While he was at his regular nightly work in early 1801, Piazzi made the discovery of his life: a heavenly body he identified as a fixed star at first. But upon repeating the measurements during the following nights, he found that this star had shifted slightly. Therefore it would rather have been a planet, or as he called it cautiously, *a new star.* Unfortunately, he was not able to observe this new star any longer as it was lost in the glare of the Sun. Even worse, he was unable to compute its orbit with the then available methods for regaining it after passing the Sun. Fortunately, the German mathematician Carl Friedrich Gauss[27], another star in the science firmament, read about Piazzi's discovery and difficulties and, after some weeks of intense calculations, developed a new method of orbit determination that allowed Piazzi to successfully locate the new star again. Gauss published his results in 1809 under the name of "Theoria motus corporum coelestium in sectionibus conicis solem ambientum" (theory of motion of the celestial bodies moving in conic sections around the Sun), which was to become a major cornerstone of the art of astronomical computation. Then only, it became clear that Piazzi's assumption was correct and this object was not a comet but much more like a small planet. Piazzi named it *Ceres Ferdinandea,* honouring the Roman and Sicilian goddess of grain Ceres and his sponsor, King Ferdinand I. The Ferdinandea part of the name had to be dropped later for political reasons, while the reference to the immortal goddess could be maintained without causing worries. Ceres turned out to be the first, and largest, of the asteroids in the belt between Mars and Jupiter. Under the terms of a 2006 International Astronomical Union resolution, Ceres is now called a dwarf planet, just like the former planet Pluto.

Giuseppe Piazzi had the fortune to find a wealthy patron willing to support his scientific endeavours. Others are wealthy enough to devote themselves to their passion like for instance the British William Lassell[28], who made a fortune by brewing beer. But he was not only interested in fine beverages, but also in astronomy; so he decided to build an observatory near Liverpool which he equipped with a respectable 24-inch reflector telescope. Like many others, he ground the mirrors himself to an excellent quality, but in contrast to others he pioneered an equatorial mount of his telescope for easy tracking of celestial objects as the Earth rotates. Et voilà: spectacular discoveries did not wait for long. Invited by William Herschel to observe Neptune, he discovered Triton, its largest moon in 1846, in 1848 he independently co-discovered Hyperion, a moon of Saturn, and in 1851 Ariel and Umbriel, two

[26] Giuseppe Piazzi, 1746, Ponte in Valtellina (Italy) – 1826, Naples, Italian monk, mathematician, and astronomer.
[27] Carl Friedrich Gauss, 1777, Brunswick, Lower Saxony (Germany) – 1855, Göttingen, Hanover, German mathematician and scientist.
[28] William Lassell, 1799, Bolton, Lancashire (UK) – 1880, Maidenhead, British astronomer.

new moons of Uranus. Lassell realized that the atmospheric conditions in Liverpool were unfavourable for astronomy at that time already and, thriving for new discoveries, he decided to move to Malta, where he made further observations until his death in 1880.

The Martian Saga

The next to silently enter the astronomical scene is Giovanni Virginio Schiaparelli[29]. As hydraulic engineer and civil architect he received an appointment as a teacher of mathematics in an elementary school in Turin in 1856, which however did not fully satisfy him. "Without taking into account my almost absolute poverty", as he wrote later, he decided to devote himself to astronomy. In 1857, a small stipend terminated his poverty at least partially, and enabled him to receive training in astronomy in Berlin. Upon his return to Italy he assumed the post as *secondo astronomo* at the famous observatory at the Brera Palace in Milan. Although the instruments were outdated, Schiaparelli made the best use of the available resources, and in April 1861 he succeeded in making a major discovery: Hesperia, the 69th asteroid. However, political turmoil suddenly changed his life. In 1860, Giuseppe Garibaldi dispossessed the King of the Two Sicilies, and in 1861 Victor Emmanuel II became the first King of the united Italy. The new sovereign provided Schiaparelli with a telescope of far superior quality that allowed him to study the planets in more detail. During the fall of 1877 Mars was close to the Earth. This constellation prompted Schiaparelli to study this neighbouring planet carefully for the purpose of drawing up a new map. Thanks to his meticulous observations, the result was a tremendous advance over anything that had appeared before. This forced him, however, to set up a new nomenclature of the Martian topography that was consistent with his observations. Exploiting his intimate knowledge of classical literature and the Bible, he chose the names for the topology of Mars that are still valid today, **Fig. 10.** His map was the first to include surface features called "canali" by Schiaparelli. This term was later mistranslated to the English "canals", a failing that played an important role in the planet's subsequent mystification.

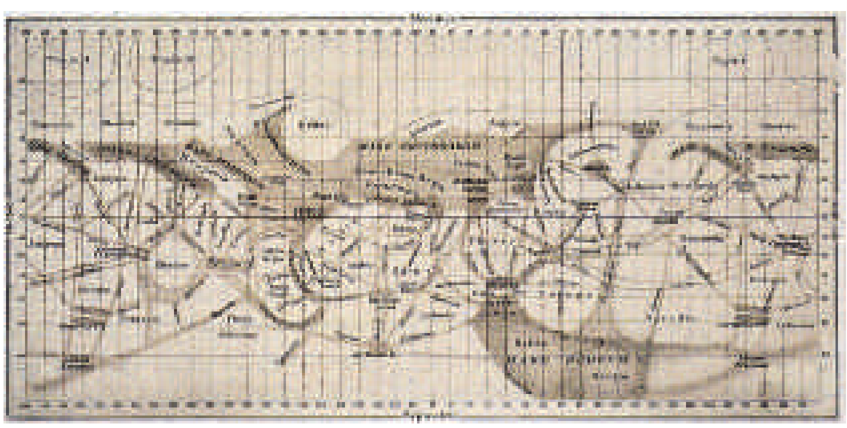


Fig. 10: The map of Mars by Giovanni Virginio Schiaparelli, 1890.

Unfortunately, Schiaparelli lost eye sight in his older years. This in turn was recognized as the chance of his life by one of his diligent readers, Percival Lowell[30]. The seminal mistranslation of the "canali" to the English "canals" triggered the businessman, a descendant of the distinguished and wealthy Boston Lowell family, to set up his own observatory. In search of the best-suited site, he travelled throughout the United States to finally choose Flagstaff, Arizona, at an altitude of over 2,500 m, where he built an excellent observatory. Lowell's belief was that the Martians were keeping their planet alive via a global channel network that brings water from the Martian polar caps to the equatorial zones. He published this hypotheses in three books including detailed maps of the Martian surface: this was the beginning of the Martian saga and the intelligent Martians.

[29] Giovanni Virginio Schiaparelli, 1835, Savigliano (Italy) – 1910 Milan, Italian astronomer.
[30] Percival Lowell, 1855, Boston (USA) – 1916, Flagstaff, Arizona, US American astronomer.

The Birth of Modern Astronomy

While Lowell's work strongly fostered the general public's interest in space research, it had only a limited impact on space science. The contrary is true for another American, who in his younger years studied law in Oxford, but was fascinated by astronomy also: Edwin Hubble[31]. After studies at the University of Chicago he was offered a position at the Mount Wilson Observatory in California, where the world's largest telescope was just completed at that time. His main interest was focussed on the cepheids, a class of stars that periodically brighten and dim again with a frequency which is a uniform function of their brightness. Therefore, the intrinsic brightness can be inferred from the period, independently from their actual distance from the Earth, qualifying them as the ideal yard sticks to measure distances in the universe. Based on these findings he discovered the proportionality between the distances of the cepheids and their velocity away from the Earth, more precisely with their red shift. He was able to plot a trend line that showed that the universe is rapidly expanding: the Big Bang was born. This in turn was bad news for Albert Einstein[32] on the other side of the Atlantic, who, some years before, had formulated his cosmological equation: in line with the general consensus at that time he had assumed that the universe is static and eternal. To this end he had to tune the equation appropriately by introducing an artificial term, which became known as the cosmological constant. When he learnt about the findings of Hubble, Einstein quickly cancelled this term and qualified it as the biggest blunder of his life.

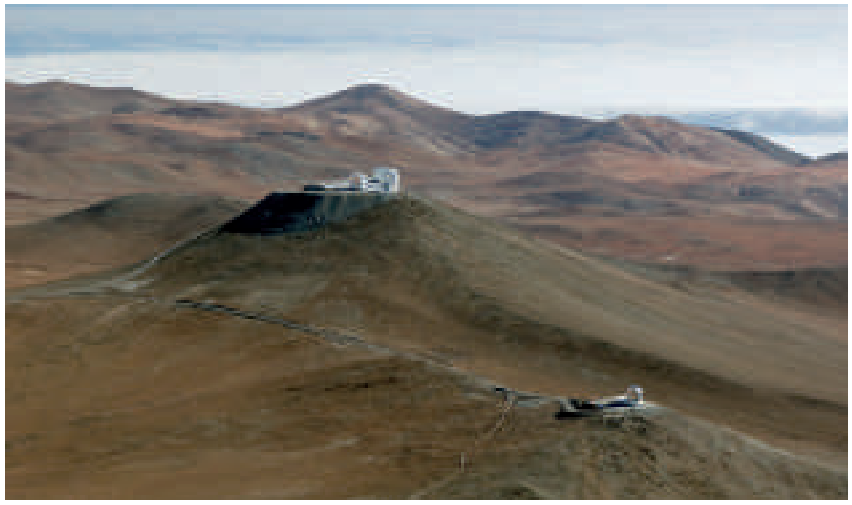


Fig. 11: Aerial view of the European Southern Observatory Paranal site with the Visible and Infrared Survey Telescope in the foreground and the four Very Large Telescopes in the background (Credit: Gerhard Hüdepohl, ESO)

That was around 1929, when not only scientific breakthroughs shocked the world, but also the collapse of the Wall Street stock market followed by a global economic crisis. In Germany, Hitler came to power some years later. World War II broke out. Science and engineering were forced to serve the development of new and more efficient weapon systems. This was the case also for a group around Wernher von Braun[33] in the German Peenemünde who was developing liquid-fuel rocket engines for aircraft and jet-assisted take-offs as well as for long-range ballistic missiles. After WWII, his group was transferred to Fort Bliss, Texas, where these *"Prisoners of Peace"* continued their work in rocketry and helped the United States to build up an own rocket programme. In 1946, the first US-built V2 rocket was launched at White Sands Missile Range. The American government, however, was not really interested in their work at that time and only embarked on a modest rocket-building programme. That, however, changed dramatically from one day to the other, when in autumn 1957, the Soviet Sputnik 1 spacecraft beeped around the Earth

[31] Edwin Powell Hubble, 1889, Marshfield, Missouri (USA) – 1953, San Marino, California, US American astronomer.
[32] Albert Einstein, 1879, Ulm (Germany) – 1955, Princeton (USA), theoretical physicist, Nobel Prize 1921.
[33] Wernher Magnus Maximilian Freiherr von Braun, 1912, Wirsitz (Prussia) – 1977, Alexandria, Virginia (USA), German scientist.

as the first artificial satellite. Although it was not equipped with a science payload, it marked the dawn of a new era in astronomy: from now on, the technical means were available to transport scientific instruments to space, where they could observe the universe unhampered by the partially opaque atmosphere, and even more, to visit and to probe celestial objects in situ, at least within our solar system.

It is, however, interesting to note here that the space age did not terminate the research with Earth-borne systems. Rather, rapid technological progress made numerous discoveries with Earth-bound telescopes possible. One of the most famous sites of astronomy is the La Silla **(Fig. 11)**, one of the driest places on Earth, where the European Southern Observatory (ESO) international organization operates a suite of the most advanced telescopes from its headquarters at Garching near Munich, Germany. As an example, just lately, ESO announced that Prof. Mayor of the University of Geneva and his colleagues have discovered there the first extra-solar star that has an Earth-like planet just in the right distance to the central star to possibly harbour liquid water. This extra-solar planet will be a hot candidate for the search for life beyond the boundaries of the solar system with future space missions.

40 Years of Space-Based Astronomy

There is no doubt: space technology has allowed astronomers to make quantum steps in the understanding of the universe in a way that exceeds all what has been done in the millennia before. The sheer number of past, current and planned space missions requires us to concentrate on some of the most important milestones in the history of space-based astronomy.

The Moon

The Moon with its distance of about 384,000 km from the Earth offers itself as a natural first object for space missions. Indeed, only two years after Sputnik 1, i.e. in 1959, the history of space-based astronomy began with the launch of the Russian Luna 2 spacecraft, the very first space mission. On its journey to the Moon, it discovered the solar wind. It then splashed onto the surface of the Earth's companion thereby becoming the first artificial object there. In the same year, in late 1959, the Luna 3 spacecraft reached a Moon orbit that allowed for the exploration of the far side that had never been seen before, **Fig. 12.**

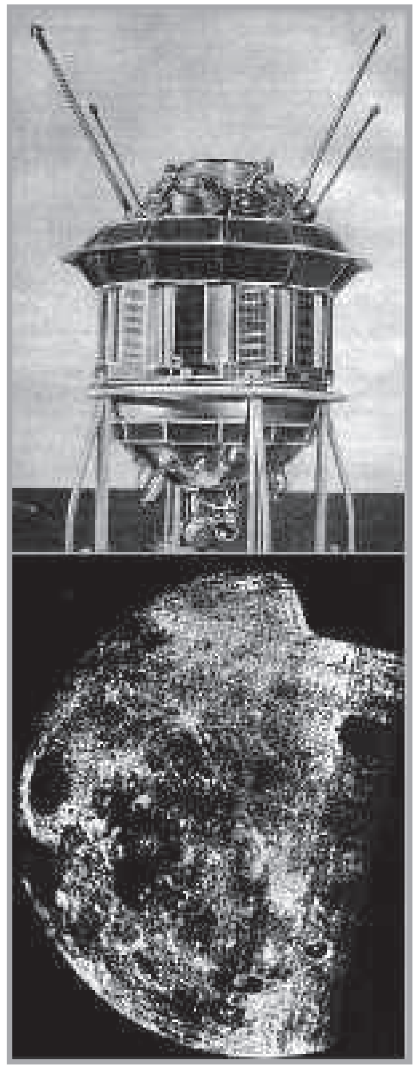


Fig. 12: The Soviet Luna 3 spacecraft. It was the first space probe to reach an orbit around the Moon and to explore its far side (table below).

During the subsequent years, the Soviets rapidly improved their mastering of space technology and went on with the Luna programme. It was in 1966 when the Luna 9 spacecraft performed a spectacular first soft landing on the surface of the Moon and returned the first detailed images from its surface, **Fig. 13.**

The unexpected advent of the Soviet Sputnik 1 spacecraft caused an outright shock in the western world: the United States multiplied their space effort to catch up with the Soviet Union. On 25 May 1961, President John F. Kennedy announced the objective of landing an American astronaut on the Moon before the end of the decade. To this end, NASA was created, and the financial backing of space programmes was dramatically increased. A co-ordinated country-wide approach in such different areas as large rocket motors, computer and telecommunication technology, and many others, allowed NASA to realize President Kennedy's vision on 20 July 1969: Neil A. Armstrong, mission commander of Apollo 11, became the first human to set his foot on the surface of the Earth's companion. "That's one small step for a man, one giant leap for mankind", he reported to ground control. The mission was a complete success, not only with regard to human exploration of space, but also in the field of space science: a few minutes after stepping onto the dusty Moon surface, Armstrong rolled out the solar sail experiment developed by Professor Johannes Geiss of the University of Bern **(Fig. 14)**, thereby executing the first man-tended space experiment. It consisted of an aluminium foil that trapped the particles arriving from the Sun. Upon its return to the laboratories in Bern, the trapped particles were out-gassed from the foil and analyzed to unravel the secrets about the composition of the Sun and the history of the solar system. The experiment was successfully repeated three times during subsequent Apollo missions.

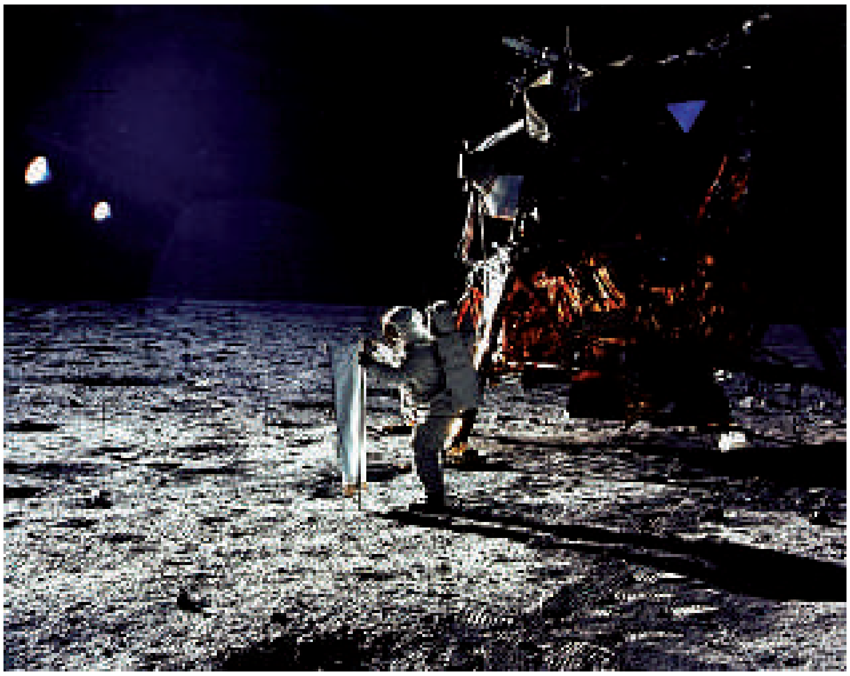


Fig. 14: US Astronaut Neil A. Armstrong. The picture shows him unfurling the solar wind experiment of the University of Bern. (Credit: NASA)

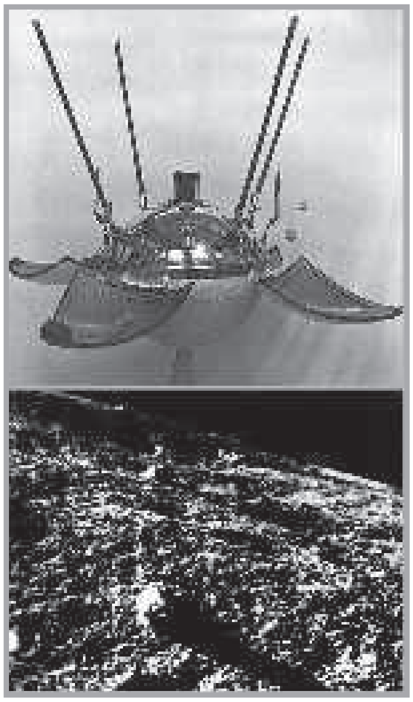


Fig.13: The Soviet Luna 9 spacecraft. It was the first probe that landed on the Moon and returned images from its landing site (table below).

Since 1972, when the last humans explored the Moon, it was visited by automated probes only, such as the US Clementine spacecraft in 1994 and ESA's first mission to the Moon, SMART-1, in 2005. Current plans of NASA as well as ESA intend to exploit the Moon as an attractive first outpost when it comes to travelling to Mars. This vision, however, may turn into reality in the 2030 time frame only.

The Planets

The success of Soviet spacecraft prompted NASA to devise space science missions also. The first successful US spacecraft was Mariner 2, that reached an orbit around Venus in 1962. Its instruments confirmed Venus to be a very strange world covered with cool clouds over an extremely hot surface. The subsequent Mariner 4 spacecraft performed the first close-by trajectory with Mars in 1964 and returned the first detailed pictures of its surface, **Fig. 15.**

Within the class of planets, Mars and Venus are the prime objects of space missions thanks to their orbits that bring them relatively close to Earth. To reach the outer solar system, very powerful launchers are required that provide the spacecraft with sufficient energy, while a journey to the innermost planet Mercury requires complex orbital manoeuvres to bring the spacecraft down to the appropriate orbit. The first space probe to reach Mercury was the US Mariner 10 vehicle. Launched in 1973, it became the first spacecraft successfully exploiting the gravity field of planets to change its trajectory: it flew by Venus and used its gravitational field to bring its perihelion down to the level of Mercury's orbit. This manoeuvre was originally inspired by the orbital mechanics calculations of the Italian scientist Giuseppe Colombo[34]. The images transmitted by Mariner 10 in 1974 are still the best available information on Mercury's surface, as no other spacecraft has visited this planet since.

Breathtaking successes in the advancement of space technology took place on the Soviet side also. Their Venera 13 was the first spacecraft to successfully land on the hostile surface of Venus: the lander survived for two hours in an environment characterized by a temperature of 450 °C and a pressure equalling 84 times that of the Earth's atmosphere, **Fig. 16.** Its instruments witnessed a loud thunder: Venera 13 became the first space probe to record sound from another world.

It was in the mid-nineties that Mars re-entered into the focus of planetary research. This planet is the closest to the Earth and not too dissimilar to our home planet. This qualifies Mars as the preferred object for human exploration. In addition, Mars is suspected to possess liquid water underneath its surface, which, at least theoretically, could be the basis for some actual or fossil form of life. In 1996, NASA launched the Mars Global Surveyor to successfully map the planet's surface paving the way for subsequent exploration missions. One year later, the Mars Pathfinder arrived at Mars together with the rover Sojourner that explored the Martian surface. This mission returned huge amounts of detailed information on the Martian surface. End of 2003, ESA's Mars Express mission entered a Martian orbit from which it continues to transmit detailed three-dimensional images of the planet's surface as well as information on its subsurface structure thanks to its surface-penetrating radar sensor. In 2004, Mars received the visit of the US twin Spirit and Opportunity, two remotely controlled rovers. Although their expected life time was some 90 days they continue to defy the hostile environment and to successfully explore the Martian surface.

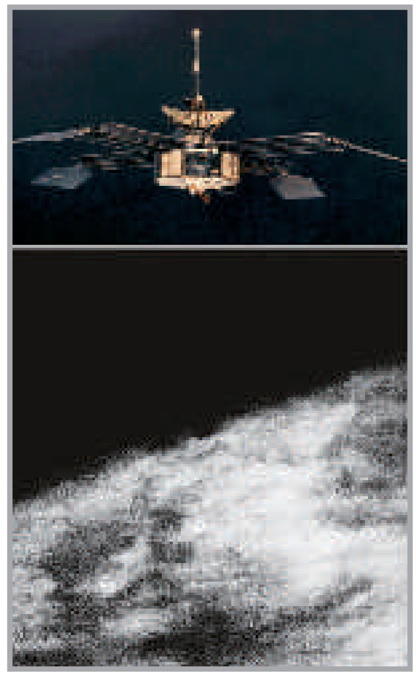


Fig. 15: The US Mariner 4 spacecraft (upper table) and the first close-up picture of Mars (below). (Credit: NASA)

Fig. 16: The Soviet Venera 13 spacecraft (above) and a detail of the Venus surface (below).

[34] Giuseppe Colombo, 1920, Padova (Italy) – 1984, Padova, Italian mathematician and engineer.

The Sun

Mastering complex orbital manoeuvres was one of the key requisites for another milestone in space-based astronomy: Ulysses, a joint ESA/NASA mission that was launched from the US Space Shuttle in 1990. Its objective was to explore the Sun from high latitudes for the first time. The first part of Ulysses' orbit brought the spacecraft away from the Sun towards Jupiter whose enormous gravitational field was exploited to jettison it out of the ecliptic plane on an orbit over the polar regions of the Sun **(Fig. 17, middle table).** After 17 years of operation, its suite of instruments continues to provide first-class scientific data and to contribute to the understanding of our most important star, the Sun[35].

The Outer Solar System

One of the very landmarks in the outer solar system exploration is the US Pioneer 10 spacecraft. Launched in 1972, it was the first to visit the planet Jupiter, after which it followed an escape trajectory out of the solar system. Its last weak signal was received in early 2003, when it was 14 billion km away from Earth, but it presumably continues its journey into the realm of interstellar space.
Just like Ulysses, the NASA Galileo spacecraft was launched from a Space Shuttle flight also. Its main objective was to explore Jupiter and its four moons. On its way, it executed the first asteroid fly-by and arrived at Jupiter in 1995, becoming the first spacecraft to orbit the giant gas planet. One of the stunning results of the Galileo mission is that the moon Europa most probably harbours a water ocean beneath its icy surface which might allow some form of life to develop, as liquid water is thought to be one of the key ingredients for life[36].

The dimensions of the universe by far exceed the capabilities of our imagination. Even the solar system, nothing more than a tiny part of the Milky Way which itself is only one of billions of galaxies in the universe, has dimensions which make its exploration lengthy endeavours that often exceed the active life of the scientists who invented the mission. The US Voyager 1 spacecraft **(Fig. 18)** is no exception thereof: launched in 1977, thirty years ago, it visited Jupiter and Saturn and was the first probe to provide detailed images of the moons of these planets. It is now the farthest man-made object from Earth, still rushing away from the Sun at a faster speed than any other space probe so far. In August 2006, it reached the milestone of 100 Astronomical Units, that is a distance of 15 billion km from the Earth. It is assumed to have entered now the heliosheath, the region between the solar system and the interstellar space[37]. At this distance, the signals from Voyager 1 take more

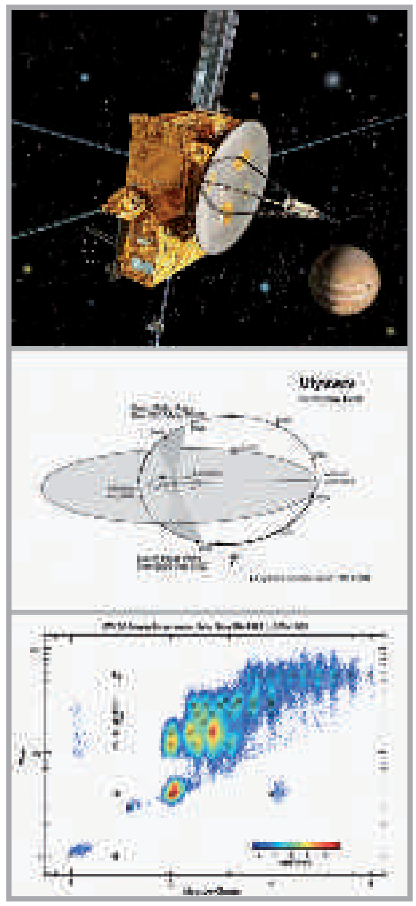


Fig: 17: The Ulysses spacecraft. The current third orbit brings it from Jupiter towards the southern polar regions of the Sun, then to the perihelion in August 2007, to the northern polar regions and back to Jupiter's orbit again. The table below shows example data returned by the Solar Wind Ion Composition Spectrometer (SWICS) instrument that was developed at the University of Bern. It displays the results of solar wind measurements, more precisely the particle counts as a function of particle mass over particle mass per charge ratio. (Credit: Physikalisches Institut, Universität Bern)

[35] See also Spatium 2: Das neue Bild der Sonne.
[36] See also Spatium 16: Astrobiology.
[37] See also Spatium 17: The Heliosphere.

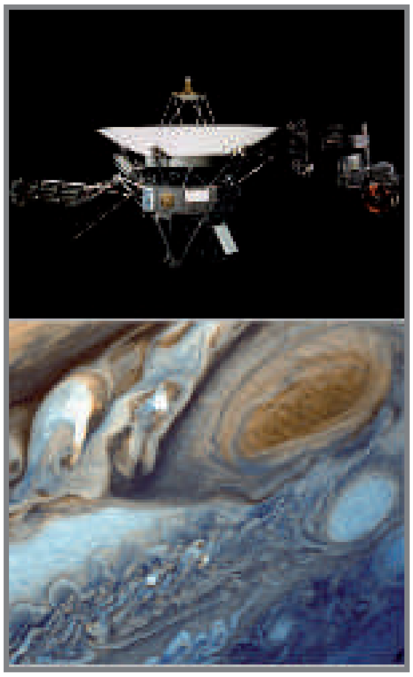


Fig. 18: NASA's Voyager 1 spacecraft. Launched in 1977 it returned the first detailed pictures of the giant planet's atmosphere, of which a false colour image is shown in the table below. (Credit: NASA)

than thirteen hours to reach the control centre on Earth. The spacecraft has reached escape velocity; together with Pioneer 10, Pioneer 11, and Voyager 2 it is now an interstellar space probe forever rushing away from the solar system.

From the Voyager 1 mission, it was known that the Saturnian moon Titan is covered by a dense methane atmosphere. As on Earth methane is always the by-product of biological processes, Titan began to challenge the international scientific community. It was in 1997 that the joint ESA/NASA mission Huygens/Cassini was launched that reached Saturn after a seven years journey in 2004. On Christmas Day 2004, the Cassini spacecraft jettisoned its twin, the Huygens probe, towards Titan, where it arrived on 14 January 2005. A complex and fully automatic sequence of re-entry manoeuvres was needed to reduce the probe's relative speed from some 40,000 km per hour to a velocity that allowed the use of parachutes. During descent, the probe explored the properties of the moon's enigmatic atmosphere, and transmitted the data via the Cassini orbiter to ground control on Earth. Then it performed successfully the first landing in the outer solar system. The probe remained active for a further 70 minutes at an ambient temperature as low as –180°C, gathering the first images from the surface of Titan, while Cassini continues to orbit Saturn and to explore its many moons[38].

A further mission to the outer solar system is NASA's New Horizons spacecraft currently heading towards Pluto to visit the dwarf planet in 2015 for the first time and to explore its moons Charon, Nix and Hydra. Launched in early 2006 by the powerful Atlas V-500 vehicle, the New Horizons spacecraft could be inserted directly into an Earth- and solar-escape trajectory with an Earth-relative speed in excess of 16 km per second qualifying it as the fastest spacecraft launch up to now.

Comets and Interplanetary Dust

So far, space missions concentrated on the exploration of the Moon and of the planets, as their gravity field helps to guide spacecraft on their final course to the target object. Perfect mastering of celestial mechanics is required when it comes to explore smaller objects like comets[39]. It was ESA's Giotto probe that succeeded in 1986 to execute the first close fly-by of a comet and to transmit the first detailed images of its cometary nucleus, **Fig. 19.** The

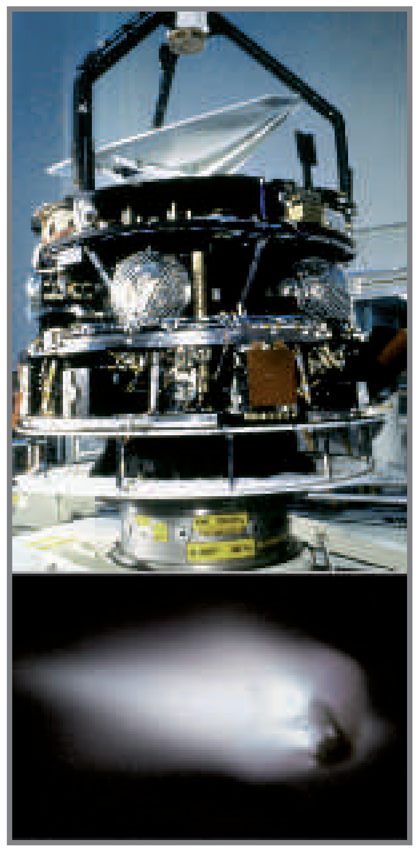


Fig. 19 shows the Giotto spacecraft (upper table). Giotto executed the first visit to a comet at close quarters by flying by the comet Halley in 1986. The lower table shows the first ever image of a comet's nucleus. (Credit: ESA)

[38] See also Spatium 15: Titan and the Huygens Mission.
[39] See also Spatium 4: Kometen.

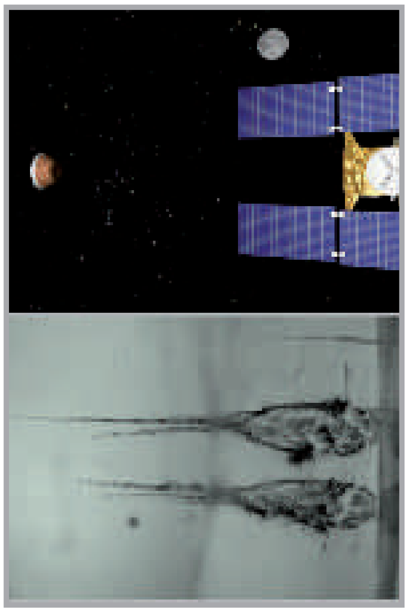


Fig. 20: The Stardust spacecraft. The upper table shows the spacecraft jettisoning the dust sample container back to the Earth, while on the lower table two impacts of dust particles can be seen, that penetrated the storage material from the right. (Credit: NASA)

comet Halley explored by Giotto is a notable comet in the sense that it is the first that was recognized as periodic. Historical records show that Chinese astronomers observed the comet's appearance as early as in 240 B.C. and regular observations after 240 B.C. are recorded by Japanese, Babylonian, Persian, and other astronomers.

It is obvious that celestial bodies like planets, moons and even comets are scientifically attractive objects as they contain much information on their own evolution and that of the solar system as a whole. It is, however, less obvious that the interplanetary dust, that are the particles in the interplanetary space, is a promising scientific object as well. The dust may stem from comets, which in the vicinity of the Sun receive enough thermal energy to evaporate some of their matter into space. But the dust may be the in-fall from interstellar space as well, making it even more promising. The objective of the US Stardust mission **(Fig. 20)** was to collect samples of such dust and to return them back to Earth. More specifically, it was intended to capture both interstellar dust and cometary dust samples from comet Wild 2 and its coma. The dust was captured by a specially developed medium called aerogel, a silicon-based solid with a porous, sponge-like structure, in which 99.8 percent of the volume is empty space. This medium served to decelerate the high velocity dust particles without altering their chemical composition and to conserve them safely during the rest of the flight. After a journey of more than 5 billion km, the sample container landed on Earth in 2006. In an unprecedented effort, the analysis of the dust particles is currently executed by a great number of scientists all over the world.

The Universe

While all the previously mentioned missions were focused on a specific target object such as a moon, a planet, a comet or interplanetary dust, a general purpose space-borne telescope is doubtlessly an attractive further application of space technology. The Earth's atmosphere is transparent in some wavelengths, such as for instance in the visible region, where the Sun by chance has its maximum radiative intensity, but it blocks many other wavelengths preventing Earth-bound sensors to receive any information from the universe. An observatory outside the atmosphere could easily overcome these problems, and it is no wonder that such ideas had been put forward long before the required technological assets were at hand. This exactly is the case for the Hubble Space Telescope (HST), **Fig. 21**, for which the preparative actions had been initiated as early as in 1946. But great things require their time: beset by delays and budget problems, it went into orbit in 1990 as a joint NASA/ESA endeavour only, and when it was there, its main mirror was found to be defective. Fortunately though, the HST was the first spacecraft conceived as an astronaut-tended instrument that periodically would receive updates as the technologies advance. Therefore, NASA decided to execute a repair mission with the objective of upgrading the defective mirror by a specifically designed lens that had to be installed on the orbiting telescope by an astronaut. This was the great chance for our Swiss astronaut Claude Nicollier, who, together with his US colleagues, managed to perfectly execute the challenging repair work in a breathtaking extravehicular activity in late 1993. When the telescope was switched on again after the repair and the now bright and sharp images reached the control centre on the Earth, it became quickly clear that the HST is one of the most important milestones in space-borne astronomy[40].

[40] See also Spatium 12: Ten Years Hubble Space Telescope.

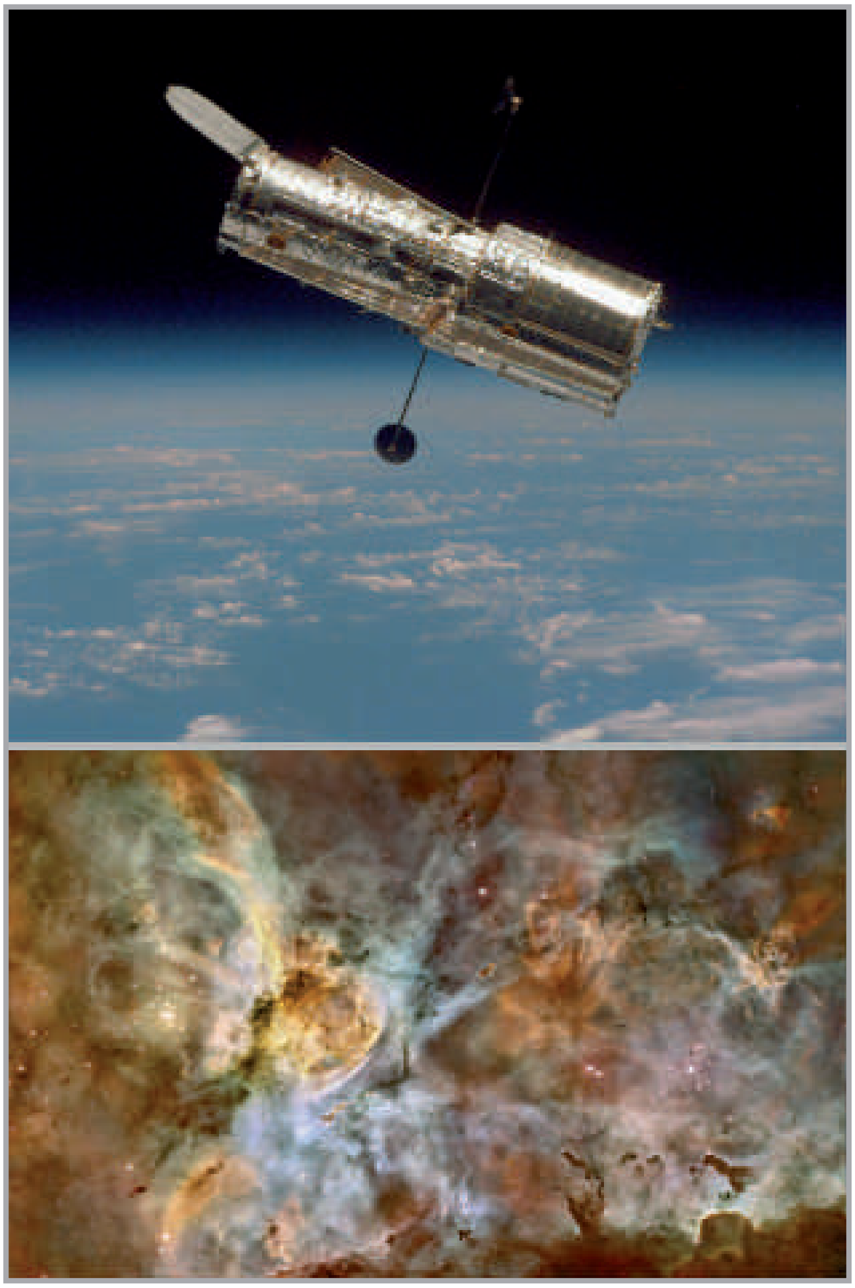


Fig. 21: The Hubble Space Telescope. Since its launch 17 years ago, the spacecraft has transmitted almost 500,000 images of more than 25,000 celestial objects. This information allowed scientists all over the world to publish about 7,000 scientific papers. In celebration of its 17th anniversary a team of astronomers has assembled one of the largest panoramic images ever taken with HST: the lower table shows the central region of the Carina Nebula spanning over 50 light years. (Credit: ESA/NASA)

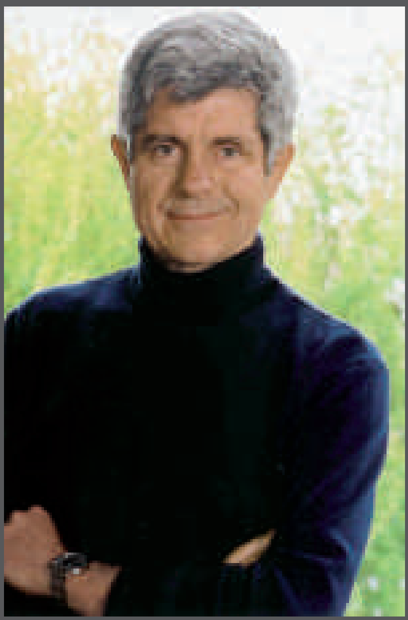
Outlook

Past and ongoing space missions have revealed an incredible amount of information about the solar system and the universe. But, the fascination of science is that an answered question always rises many new ones. Space research makes no exception thereof. One of the key open issues refers to the nature of the dark matter[41]. In the midforties already, the Swiss astronomer Fritz Zwicky became aware of the problem that the dynamic behaviour of galaxies cannot be explained by the universal laws of Kepler taking into account the visible mass of the galaxies only. He therefore stipulated an additional source of gravitational pull to keep the stars together. This missing mass is called now dark matter, but its very nature remains unknown. Another puzzling discovery was made in the last few years: according to our expectation, the expansion of the universe should be continuously decelerating. But in contrast, it seems to be accelerated by a so far unknown force termed dark energy.

These are just two examples that challenge new generations of space scientists. Many problems remain open and may become the subject of fascinating discoveries in the years to come. And beyond all attempts to understand the mechanics of the universe there remains the question of whether the human spirit is really alone in this incredible vast universe.

[41] See also Spatium 7: In Search of the Dark Matter in the Universe.

The Author



Giovanni Fabrizio Bignami received his laureate in physics in 1968 at the University of Milan. Here, he worked as an assistant to the Chair of Advanced Physics the next years. In 1971 he began his career in science politics when he became research scientist at the Italian Consiglio Nazionale delle Ricerche (Italian National Research Council). A fellowship allowed him to work at the NASA Goddard Space Flight Center from 1973 to 1975, where he was involved in the analysis and interpretation of gamma ray astronomy data. During this research activity he discovered one of the brightest neutron stars, the Geminga in the Gemini constellation. Its name is a contraction of "Gemini gamma-ray source", and coincidentally means "it's not there" in the Italian Milanese dialect. This discovery won him 1993 the "Bruno Rossi" Prize of the American Astronomical Society together with J. Halpern.

From 1974 to 1975 G. F. Bignami was a visiting assistant professor at the Catholic University of America in Washington DC, in 1970 he was a visiting scientist at the Max Planck Institute für Kernphysik in Heidelberg, Germany. Later, he served the Italian National Space Agency (ASI) and the European Space Agency (ESA) in several functions. He participated in ESA's Astronomy Working Group (1984–88), in ESA's Space Science Advisory Committee (1994–98), he was an Italian Delegate to ESA's Science Programme Committee (1998–2002), then Vice-Chairman of ESA's Science Programme Committee (1999–2002) and Chairman of ESA's Space Science Advisory Committee (from 2002), just to give an incomplete list of his activities for ESA. On national grounds, he served ASI as Director of Science (1997–2002) in a phase when his budget doubled from 50 M€ to 110 M€. In early 2007, G. F. Bignami's career culminated by the nomination as President of the Italian Space Agency. On the academic side, G. F. Bignami served as Professor in Physics at the University of Cassino, Italy, and Professor of Astronomy at the University of Pavia (from 1997).

One of the key concerns of G. F. Bignami is the co-operation between the two neighbouring countries Italy and France. This is why he served as a member of the Scientific Council of the French Centre National de Recherche Spatiale (CNRS) and later as a Director of the Centre d'Etude Spatiale des Rayonnements at Toulouse.

G. F. Bignami's scientific activities are linked to the majority of space science missions. He held major responsibilities for instance in ESA's XMM-Newton mission as a Principal Investigator for the European Photon Imaging Camera. Quite naturally, such an impressive scientific career led to a number of honours and awards amongst which only the Officier de l'Ordre National du Mérite de la République Française can be mentioned here.

An important endeavour of Bignami concerns public outreach and science popularization activities. He currently gives about 30 public talks per year, writes regularly for major Italian as well as international newspapers and magazines. And last but not least, as a diligent student of old languages, he published a book containing the first English translation (in iambic pentameters) of Galileo Galilei's longest poem.