From Geocentricty to Quantum Loop Gravity

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Preface

From Geocentricity to Quantum Cosmology is a book written for people interested in science. It describes the development of our view of the universe, mainly from the perspective of astrophysics/physics. The eight chapters start with the geocentric view of the sky, which is basically a consequence of what we observe on a daily basis: We see the sun, moon and stars rise and set, and this gives us the impression that we are at the center of the universe and that everything is moving around us. The ideas of ancient civilizations (from the Greeks to the Babylonians, the ancient Chinese, the culture on the American continent) were mainly based on philosophical arguments. They assumed that the sky above us was the place where the gods lived. But already in ancient Greece we find the first measurements that gave us the almost exact value of the Earth's circumference and showed that the sun is further away than the moon.

With more precise observation techniques, it became clear that we needed a calendar reform and it was also recognized that the geocentric model must be wrong. In 1543, N. Copernicus published his heliocentric system. Some of his ideas were later modified by J. Kepler, who explained that the orbits of the planets around the sun are ellipses and not perfect circles. I. Newton formulated his universal law of gravitation; at that time, his idea that this law applied on Earth and in space was revolutionary. With this law, the movement of the planets became completely predictable. The universe was seen as a cosmic clockwork and completely predictable. The latter was formulated by P.S. Laplace. However, it was soon realized that this was not the case. We cannot solve a problem involving more than two bodies. The solution of such an N-body problem is only an approximation and errors occur that increase with time. Moreover, we can never measure the positions and velocities of the objects with infinite precision.

By the beginning of the twentieth century, however, the heliocentric system was firmly established and it was also clear that the sun was only one of several hundred billion stars in the Milky Way. Around 1925, E. Hubble measured the distance to the Andromeda Nebula and it became clear that the Milky Way was only one of many (several billion) galaxies. He also discovered that the universe expands. This gave the subject a new dimension: expansion also means that there must be a point from which this expansion started, the Big Bang. The universe neither exists forever nor is it constant, as was previously thought.

To understand the physics of the Big Bang and the universe as a whole, we will give a brief introduction to the two great theories of twentieth-century physics: relativity and quantum theory. Both theories have changed our view of the world. According to the theory of relativity, time is not absolute, but depends on your frame of reference. Other quantities such as mass, length etc. also depend on the system in which they are determined. The general theory of relativity links the curvature of space-time to the distribution of mass. Quantum physics teaches us that strange things happen on a small scale: For example, we cannot simultaneously determine the position and speed of an object with high precision, and particles can pass through walls, etc. Physics becomes indeterministic. Both theories are necessary to understand the universe on a large and small scale (shortly after the Big Bang).

The interested reader can go through the few mathematical details in the chapters, but can also skip them. In the last chapters we show that there is more than just the visible matter, the so-called dark matter, and because the expansion of the universe is accelerating, we have the concept of dark energy. These two dark components make up about 95% of what exists in the universe. We give some possible explanations for this and also some ideas on how a new theory could reconcile relativity (valid at large scales) with quantum theory (valid at small scales), leading to quantum cosmology, string theory and loop quantum gravity.

In short, our view of the universe has changed considerably: from the geocentric to the heliocentric view of the world, our sun is just one of several hundred billion stars in the Milky Way, which in turn is just one of many billions of other galaxies. Perhaps our universe is just one of many multiverses.

Reading this book invites you on a fantastic journey. As already mentioned, in some cases mathematical details are mentioned that can be omitted. In boxes we give short summaries of the most important contents of the chapters. At the end of each chapter we provide some citations for further reading.

The author would like to express his special thanks to Anita, his children Roland, Christina and Alina and all his friends who share his passion for astrophysics.

Bad Gleichenberg, May, 2025

Contents

Chapter 1
Our geocentric image of the sky

In this chapter we look at how we observe the sky above us. The daily rising and setting of the sun, moon and stars. The sky has always been mystical to people and was believed to be the place where the gods could be found.

1.1 Why observe the stars

1.1.1 Rising and setting

When you observe the rising and setting of celestial objects such as the sun, the moon or the stars, you get the impression that we on Earth are at the center of everything and that these objects move around us during the course of a day or night.

Take the sun, for example. It rises in the east and sets in the west. However, it was soon realized that the point at which it rises and sets varies over the course of a year. This is shown in Fig. 1.2. In summer, it rises in the north-east and sets in the north-west for people living in the northern hemisphere of the earth. During midday, the sun is high above the horizon. The shadows of objects are very short. In winter, the sun rises in the south-east and sets in the south-west. During midday, the shadows are much longer and the height above the horizon is lower than in summer. The length of the day varies depending on the season. In summer the days are very long, in winter they are short. There are two dates in the year when the night and day are the same length: the *equinoxes*. This occurs at the beginning of spring and fall.

The explanation of the *seasons* is shown in Fig. 1.1.

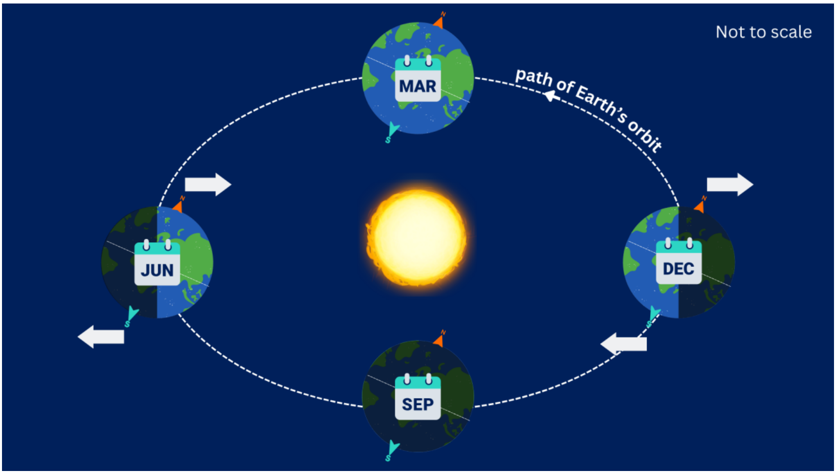

Fig. 1.1 Explanation of the seasons. The obliquity of the Earth's axis of rotation (the angle of inclination is about 23.5 degrees) remains constant. In the northern summer, the North Pole appears to be tilted towards the sun.(c) SchoolsObs@ljmu.ac.uk

In ancient times, the path that the sun takes over the course of a year was called the *ecliptic*. There are 12 constellations along the ecliptic, the *zodiacal constellations*; their names are:

- aries

- taurus
- gemini
- cancer
- leo
- virgo
- libra
- scorpius
- sagittarius
- capricornus
- aquarius
- pisces

The ancients also knew that the sun is in the constellation Aries at the beginning of spring.

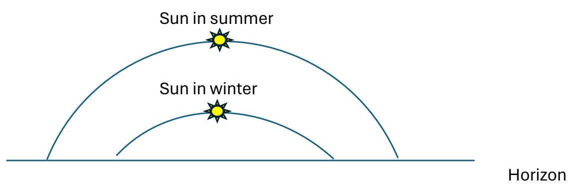

Fig. 1.2 The daily movement of the sun across the sky. In winter, the sun moves in a lower orbit than in summer

The daily movement of the sun, moon, planets and stars across the sky (rising and setting) gives the impression that we are at the center of the universe and that all objects around us are moving (geocentric universe).

1.1.2 The seasons and the calendar

We must emphasize here that astronomy also had very practical origins. As soon as ancient cultures became sedentary, it became important to know the seasons. The seasons determine when they had to cultivate their fields and so on. Therefore, a *calendar* was important. By simply observing the length of the shadow, it was possible to determine midday and the winter and summer *solstices*. The length of the shadow therefore depends on the

- time during one day
- time during a year.

The situation at midday for the beginning of winter and summer is shown in Fig. 1.3.

The point in the sky where the sun is at the beginning of spring is also known as the *vernal equinox*. This point determines the seasons. Thus the length of a year must therefore correspond to the time it takes for the sun to repeat its position at the vernal equinox. This period is also referred to as a *tropical year*. The length of a tropical year is 365 days, 5 hours, 48 minutes and 46 seconds, which corresponds to 365.2422 days. The first calendar in ancient *Egypt* had 360 days, i.e. 12 months with 30 days each. However, such a calendar deviates from the tropical year by more than five days each year. For example, the beginning of spring takes place in different months every 6 years, which is impractical. Therefore, 5 additional days were added to the length of a year. These days were called *epagomenal days*.

Let us take a closer look at a calendar with a length of one year = 365 days. Each year an error of 0.2422 days is made. Roughly speaking, the error is therefore 1 day after 4 years and 10 days after 40 years, which

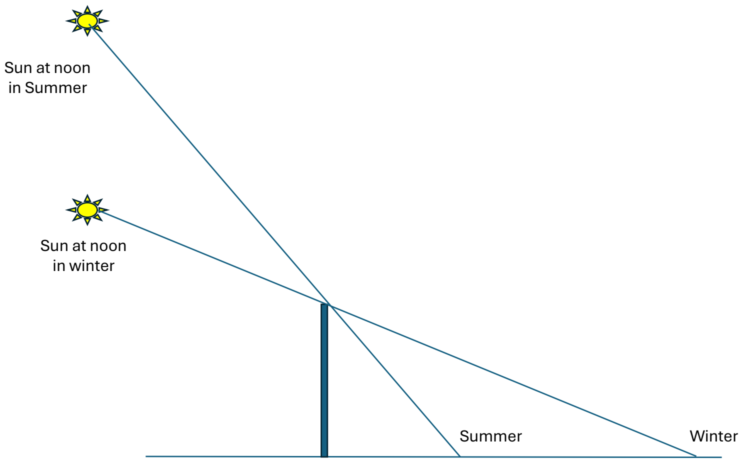

Fig. 1.3 The length of a shadow at midday varies according to the seasons. At the beginning of the winter solstice it reaches the ground at point*Winter* , at the beginning of summer it reaches the ground at point *Summer* at noon

people also noticed. The annual flooding of the Nile was very important to the Egyptians. They noticed that these floods coincided with the heliacal rising of the star *Sirius* (they called it *Sothis*) in the morning sky. Heliacal rising means that the sun has moved far away from Sirius so that it becomes visible in the morning sky. But because the calendar was not correct, the heliacal rising of Sothis changed from year to year.

The ancient Egyptians recognized the need for a calendar reform. This was done by the Decree of Canopus by *Ptolemy III* in 238 B.C. The length of a year was defined as follows:

Every fourth year there is a leap year with 366 days, the normal years had 365 days. Now the year had a length of 365.25 days, the error to the tropical year is only 0.0077 days per year.

This Ptolemaic calendar reform failed, but was finally officially introduced in Egypt by Augustus in 26 or 25 BC and is now known as the

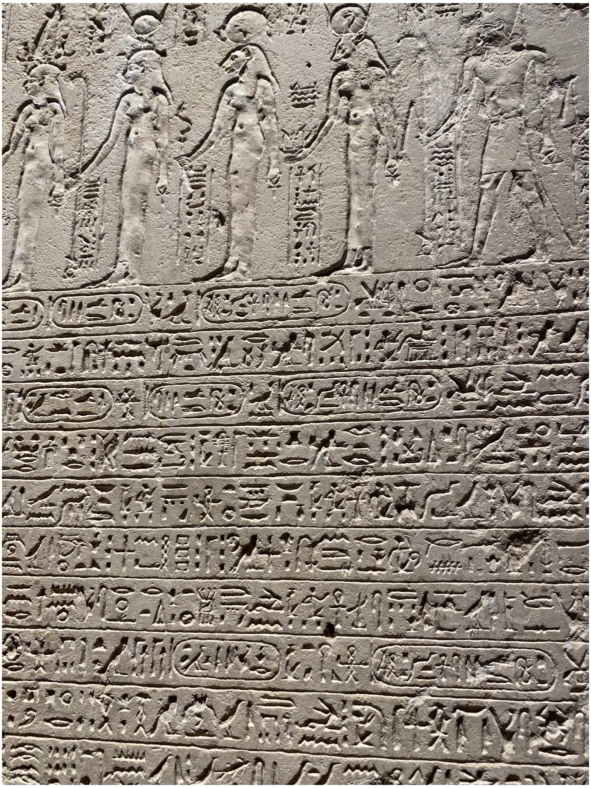

Fig. 1.4 The decree of Canopus, in which the length of a year is set at 365.25 days

Alexandrian calendar. *Julius Caesar* had previously introduced a 365+1⁄4-day year in Rome in 45 BC as part of the *Julian calendar*.

The actual length of a year is the tropical year = 365.2422 days. The Julian calendar has a length of 365.25 days.

1.1.3 The moon

The moon is also a spectacular object in the sky and was already observed by ancient civilizations. They recognized that there are two different periods of the moon:

- *sidereal month*: After a sidereal month, the moon appears in the same place in the sky. For example, if the moon is in the constellation aries, it will reappear in this constellation after a sidereal month.
- *synodic month*: After a synodic month, the moon will show the same phase. For example, if the moon is full tonight, it will be full again after a synodic month, but the moon will be in a different constellation than after a sidereal month. If the moon is in the constellation aries after a sidereal month, it will be in the constellation Taurus after a synodic month. The name synodic comes from the Greek *synod*, which means coming together. The phases of the moon are related to the position of the moon in its orbit around the earth.
- The length of the sidereal month is about 27 days, 7 hours and 43 minutes, the length of the synodic month is about 29 days, 12 hours and 44 minutes.

This is shown in Fig.1.5.

The synodic month determines the phases, the sidereal month the position of the moon in the sky. The movement of the moon roughly determines the length of a month.

A year has more than 12 months. In lunar calendars, a lunar month is the time between two consecutive syzygies of the same type: new moon or

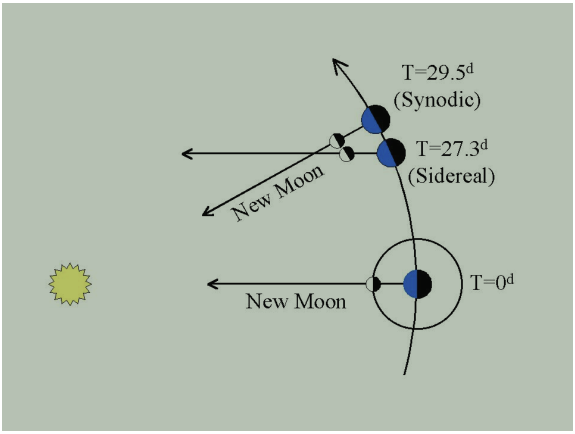

Fig. 1.5 The difference between a sidereal and a synodic month. After a sidereal month, the moon appears at the same position in the sky, but due to the movement of the Earth around the Sun, it takes more than 2 days longer for the moon to show the same phase.

full moon. In ancient Egypt, the lunar month began on the day on which the waning moon was no longer visible shortly before sunrise. In the Islamic calendar, the month begins when the young crescent moon first becomes visible in the evening.

The movement of the moon was studied by the *Babylonians* around 500 B.C. They precisely determined the sidereal, synodic and *draconitic months*. What is a draconitic month? The moon moves in its own orbit in the sky. This orbit intersects the ecliptic at two points called nodes or draconic points. A solar or lunar eclipse can only occur when the moon is close to these points:

- Solar eclipse: when the new moon is at one of the draconic points
- Lunar eclipse: when the full moon occurs near these points.

This is shown in Fig. 1.6 for solar eclipses and in Fig. 1.7 for lunar eclipses.

The length of the draconitic month is 27 days 5 hours 5 minutes. The draconitic month is the time between the passage of the moon through the same node; the two nodes are the intersections of its orbit with the ecliptic. The Babylonians discovered the *Saros cycle*. 242 draconitic months

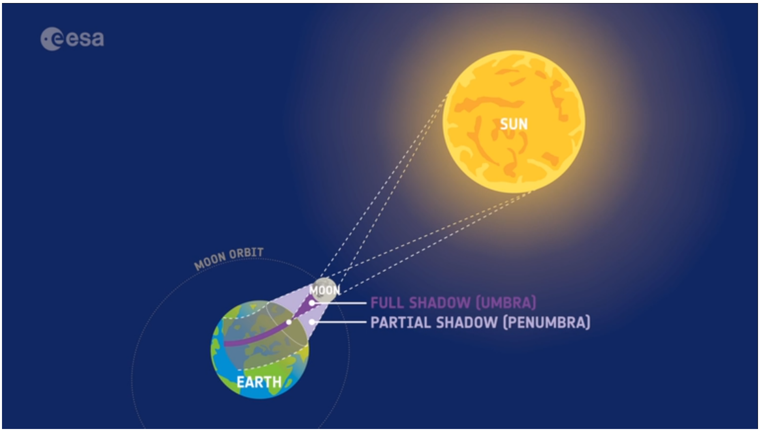

Fig. 1.6 A solar eclipse occurs when the moon is exactly between the earth and the sun in the ecliptic during its new moon phase (c) ESA.

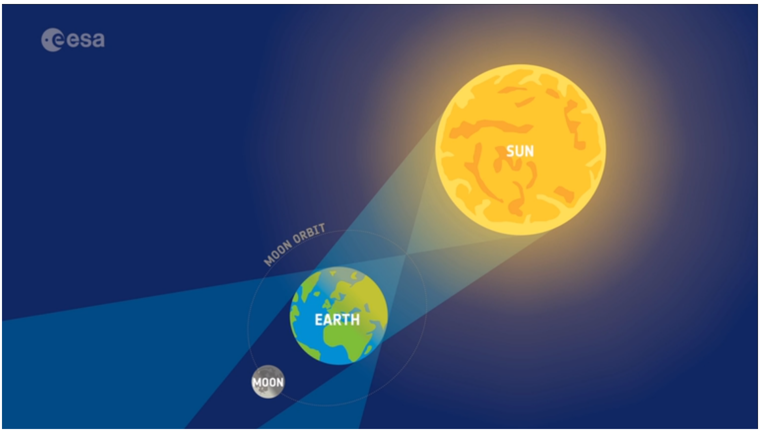

Fig. 1.7 A lunar eclipse occurs when the moon is exactly behind the Earth and the sun in the ecliptic during its full moon phase (c) ESA.

correspond almost exactly to 223 synodic months = 18 years, 11 days and 8 hours. Two eclipses separated by a Saros cycle have a very similar geometry. They occur at the same nodal point with the Moon at almost the same distance from the Earth and at the same time of year. Since the Saros period does not correspond to a whole number of days, its main disadvantage is that the subsequent eclipses are visible from different parts of the Earth. The additional shift of 1/3 day means that the Earth must rotate an additional $\sim$ 8 hours or $\sim$ 120^o each cycle. For solar eclipses, this results in a shift of the path of each successive eclipse by $\sim$ 120^o to the west. A Saros series therefore returns to the same geographical region approximately every 3 Saros (54 years and 34 days). This method was used by the ancients to predict eclipses.

> Solar and lunar eclipses are predictable because they only occur when the moon must be near the draconitic points at new or full moon.

1.1.4 The movement of the planets

As the sun and moon, the planets move across the sky and are always very close to the ecliptic. In ancient cultures the five known *planets* were:

- Mercury: this planet can only be seen in the evening or morning sky after or before sunset.
- Venus: also known as the morning or evening star; it is the brightest of all the planets and at certain times is even visible to the naked eye in the daytime sky.
- Mars: the red planet has always attracted people. It can appear very bright and conspicuous in the sky, but there are also times when this planet is too close to the sun and is invisible.
- Jupiter: is the second brightest planet, in very rare cases Mars becomes brighter than Jupiter.
- Saturn: is as bright as the brightest stars.

The planets move between the constellations, but their movement is much more complicated than that of the sun or the moon. Mars, Jupiter and Saturn can sometimes be seen throughout the whole night when they are in *opposition*. At the time of their opposition, these planets rise in the east while the sun sets in the west. Venus and Mercury, on the other hand, are never visible throughout the whole night as they are always close to the sun. The movement of the planets in the sky is not regular. There are times when the planets move in retrograde, forming loops in the sky. Explaining these loops posed major problems for early astronomers.

1.1.5 The stars

The ancients recognized that there was a fundamental difference between the sun, moon and planets and the stars. The latter appear to be fixed in the sky, showing no movement other than the daily movement across the sky. The sky was divided into *constellations*, many of which date back to Greek mythology. Today, the sky is divided into 88 constellations. Let us look at some examples. In winter, we see a very conspicuous and bright constellation in the northern hemisphere, *Orion*. The two brightest stars are *Rige*l (called β Orionis or β Ori in modern astronomy, because it is the second brightest star in this constellation), and *Betelgeuse* (α Ori, because it is the brightest star in this constellation). In ancient Egypt, this constellation was regarded as a god called *Sah*. The reason for this was that Orion rises before the helical rising of Sirius, which was an indicator of the flooding of the Nile. In Greek mythology, Orion was a strong hunter (Fig. 1.8). According to one myth, Orion dared to say that he would kill every animal on earth. The angry goddess Gaia tried to kill Orion with a scorpion. This is why the two constellations never appear in the sky at the same time. When Orion rises in the east, Scorpio has already set in the west.

Another interesting myth concerns the constellations of Cassiopeia, Perseus and Andromeda. *Cassiopeia* was the queen of Ethiopia. Her father was *Cepheus*, also a nearby constellation. According to the myth, Cas-

Fig. 1.8 Orion, a very striking constellation in the winter sky of the northern hemisphere. (c) Sanu, N.

siopeia claimed that her daughter Andromeda was more beautiful than the *Nereids*. The Nereids are sea nymphs (female spirits of the water) who had 50 daughters. The god *Cronos* divided the world between his three sons: *Zeus* received the heavens, *Hades*, the underworld and *Poseidon* the sea. This is why the god Poseidon wanted to punish them and sent the sea monster *Cetus* to Ethiopia. *Cepheus* was told that the only way to save his kingdom was to sacrifice his daughter *Andromeda* to Cetus. Andromeda was therefore chained to a rock where she waited for Cetus. Fortunately, *Perseus* arrived with the head of *Medusa*. According to the story, anyone who stared at the terrible head of Medusa was immediately turned into a stone. So when the monster Cetus appeared, Perseus showed him the head of Medusa and Cetus immediately turned into stone and the beautiful Andromeda was saved.

Perseus, Cassiopeia, Andromeda, Cetus, Cepheus are constellations that can be seen in the northern sky.

So for the ancient cultures, the sky was full of gods, nymphs, etc. But they also recognized two other important facts:

- Some constellations are always visible, all night long and all year round. These are the *circumpolar constellations*. Cepheus, for example, is one of them (for the northern hemisphere).
- During the night, all constellations appear to revolve around a specific point in the sky. This point indicates the direction to the north (for the northern hemisphere).
- It has also been found that if you move south, you can see some stars and constellations that cannot be observed from a more northerly location on Earth.

These facts can be easily explained by assuming that the Earth is not flat, but a sphere. If the Earth were flat, then the same constellations would be visible in the sky, no matter where the observer is located. If the Earth is a sphere, then it is obvious that the constellations in the sky south of the equator must be very different from the constellations north of the equator. This is shown in Fig. 1.9. Let us consider an observer in the northern hemisphere, i.e. north of the equator (green line) at location A on the spherical Earth. His horizon is tangent to the sphere and he sees the yellow stars, but is unable to see the red stars. An observer in the southern hemisphere only sees the red stars, but not the yellow stars. An observer at the North Pole (N) sees all the stars north of the equator and they never rise or set, all are circumpolar stars. An observer at the equator can see all the stars, but there are no circumpolar stars.

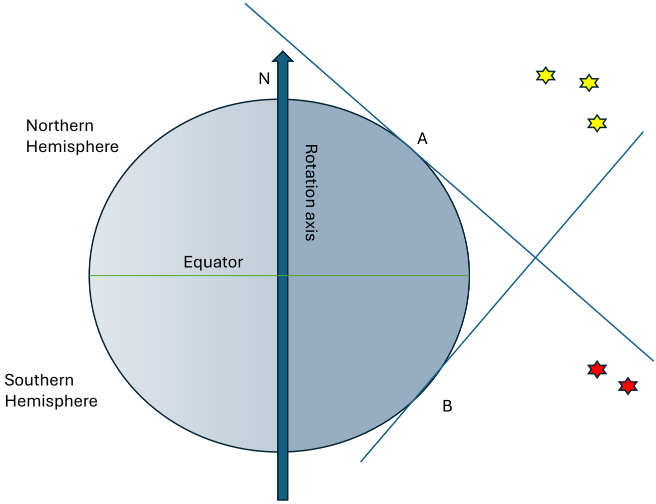

Fig. 1.9 How we can see different stars (constellations) at different locations on Earth

Simple observations show that the Earth cannot be a plane.

1.2 The scientific method

In this section we give examples of the first true scientific methods used to determine the parameters of the Earth and the distances in the solar system. These methods were used by the ancient Greeks.

1.2.1 What is science

The definition of science, of scientific knowledge, can be given by discussing the methods used to obtain scientific facts. These methods must obey certain rules:

- The methods or experiments must be reproducible. Any person to whom the instruments used are made available must be able to reproduce the results and, of course, must obtain similar results.
- The methods or experiments that have been carried out must be fully described.
- As soon as there is an experiment that comes to different conclusions, the theory or fact can no longer be correct.

The first observations and interpretations of the movements and phenomena observed in the sky were interpreted as myths or supernatural forces. One example is the interpretation of solar eclipses in ancient China. It was believed that during a solar eclipse a dragon (Latin: draco) devoured the sun and the Sun was released again at the end of the eclipse. As we have seen, eclipses can only occur when the moon is at its orbit in the ecliptic at new moon (solar eclipse) or full moon (lunar eclipse). These points were therefore called draconic points after the belief that a dragon spits out the sun. Weather phenomena were also interpreted by mythology. Thunder and lightning play a major role in Greek mythology. The god of the sky, Zeus, uses the power of the elements as a weapon. If a storm broke out, it was because Zeus was angry. When he got angry, he became very destructive and hurled lightning bolts with such ferocity that they caused violent storms that wreaked havoc on the earth. It was said that lightning was invented by the goddess of wisdom, Athena, and that since lightning was an invention of the gods, any place struck by lightning was sacred.

But there were also other opinions. The Greek philosopher *Socrates* (470-399 BC) (Fig. 1.11) is credited with saying during a thunderstorm: "That's not Zeus up there – that's a vortex of air". Socrates did not document his teachings. Everything that is known about him comes from the accounts of others: above all the philosopher *Plato* and the historian *Xenophon*, who were both his students, the Athenian dramatist *Aristophanes* (Socrates' contemporary) and Plato's student *Aristotle*, who was born after Socrates' death. His famous sentence is: "I know that I know nothing". Socrates died in Athens in 399 BC after a trial for blasphemy and corruption of youth. He spent his last day in prison surrounded by friends and followers who offered him an escape route, which he refused. He died the next morning, as he had been sentenced, after drinking poisoned hemlock. A fundamental feature of Plato's Socrates is the Socratic method, or the method of refutation (elenchus in Greek). The typical elenchus proceeds as follows. Socrates begins a discussion on a topic with a well-known expert on that topic, usually in the company of some young men and boys, and proves in dialog that the expert's beliefs and arguments are contradictory. Socrates initiates the dialog by asking his interlocutor for a definition of the topic. When he asks further questions, the interlocutor's answers ultimately contradict the first definition. The conclusion is that the expert did not really know the definition.

This is also an important method in science: always be skeptical, ask for pure definitions without contradictions, check your results. You could summarize the seven steps of the scientific method:

- question,
- research,
- hypothesis,
- experiment,
- data analysis,
- conclusion, and
- communication.

The scientific method is a systematic way of conducting experiments or studies that allows you to explore the things you observe in the world and answer questions about them.

Find a cause-and-effect relationship by asking a question about something you have observed. Gather as much evidence as you can about what you observed because this can help you explore the connection between your evidence and what you observed and determine if all of your evidence can be combined to answer your question in a meaningful way