Where 'Voyager' has arrived to?
Constructivistic ways of teaching Astronomy

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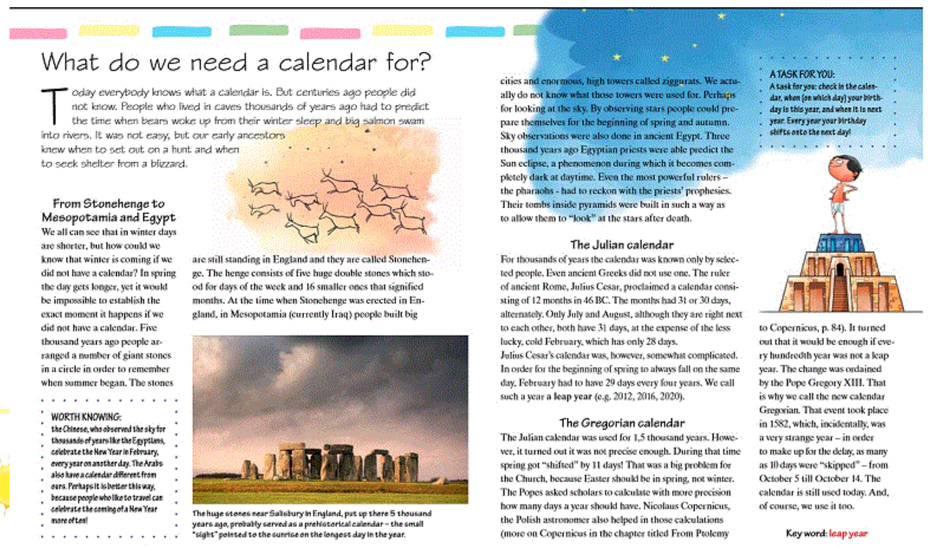
Books on astronomy [1-3] and space flights [4], that could be a first approach to teaching science at early, even pre-scholar age, can be divided into two groups. They represent: 1) pure phenomenology, i.e. series of nice pictures usually from NASA, 2) dogmatic ways of teaching – "Copernicus says that this is Earth which rotates, so Sun does not rise any more!". Non of these ways: 1) stimulates interest, either 2) transmits some notions useful for "man-in-the-street", i.e. for the adult life.

We propose a constructivistic way of introducing (not teaching) astronomy as one of the first subjects in Sciences: this was the constant movement of heavens that inspired first astronomers in Babylonia (probably around 1000 BC) to complete a catalogue of best visible stars (Mul.Apin). We follow this way; instead of declaring "on the sky you see stars, planets and comets" we say "Lay down on a blanket (not to take cold) in summer somewhere upon a lake [not on the seaside because we need points of reference and not in mountains as we need to see the horizon], look and dream". This is because in any (not only constructivistic) discovery, the first is always a real-world observation.


What do we need a calendar for?

Today everybody knows what a calendar is. But centuries ago people did not know. People who lived in caves thousands of years ago had to predict the time when bears woke up from their winter sleep and big salmon swam into rivers. It was not easy, but our early ancestors knew when to set out on a hunt and when to seek shelter from a blizzard.

From Stonehenge to Mesopotamia and Egypt

We all can see that in winter days are shorter, but how could we know that winter is coming if we did not have a calendar? In spring the day gets longer, yet it would be impossible to establish the exact moment it happens if we did not have a calendar. Five thousand years ago people arranged a number of giant stones in a circle in order to remember when summer began. The stones are still standing in England and they are called Stonehenge. The henge consists of five huge double stones which stood for days of the week and 16 smaller ones that signified months. At the time when Stonehenge was erected in England, in Mesopotamia (currently Iraq) people built big cities and enormous, high towers called ziggurats. We actually do not know what those towers were used for. Perhaps for looking at the sky. By observing stars people could prepare themselves for the beginning of spring and autumn. Sky observations were also done in ancient Egypt. Three thousand years ago Egyptian priests were able predict the Sun eclipse, a phenomenon during which it becomes completely dark at daytime. Even the most powerful rulers – the pharaohs - had to reckon with the priests' prophesies. Their tombs inside pyramids were built in such a way as to allow them to "look" at the stars after death.

WORTH KNOWING: the Chinese, who observed the sky for thousands of years like the Egyptians, celebrate the New Year in February, every year on another day. The Arabs also have a calendar different from ours. Perhaps it is better this way, because people who like to travel can celebrate the coming of a New Year more often!

The huge stones near Salisbury in England, put up there 5 thousand years ago, probably served as a prehistorical calendar – the small "sight" pointed to the sunrise on the longest day in the year.

The Julian calendar

For thousands of years the calendar was known only by selected people. Even ancient Greeks did not use one. The ruler of ancient Rome, Julius Cesar, proclaimed a calendar consisting of 12 months in 46 BC. The months had 31 or 30 days, alternately. Only July and August, although they are right next to each other, both have 31 days, at the expense of the less lucky, cold February, which has only 28 days.
Julius Cesar's calendar was, however, somewhat complicated. In order for the beginning of spring to always fall on the same day, February had to have 29 days every four years. We call such a year a leap year (e.g. 2012, 2016, 2020).

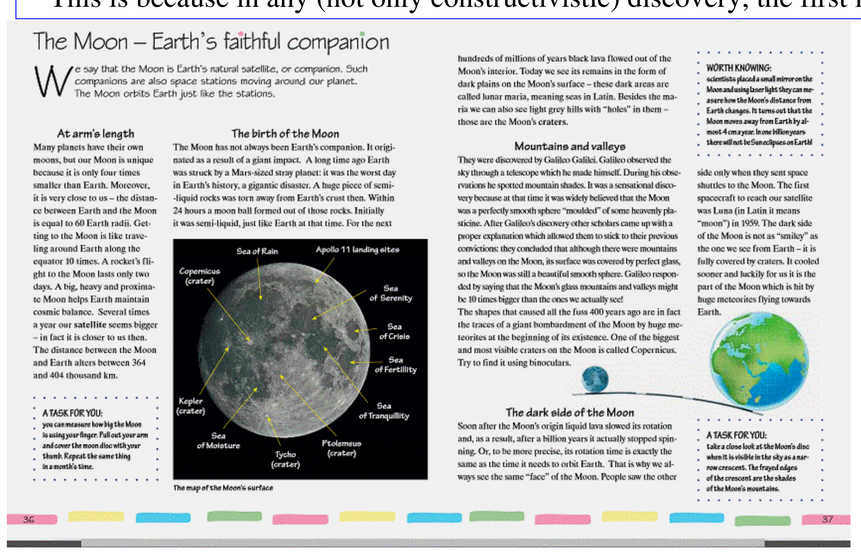
The Gregorian calendar

The Julian calendar was used for 1,5 thousand years. However, it turned out it was not precise enough. During that time spring got "shifted" by 11 days! That was a big problem for the Church, because Easter should be in spring, not winter. The Popes asked scholars to calculate with more precision how many days a year should have. Nicolaus Copernicus, the Polish astronomer also helped in those calculations (more on Copernicus in the chapter titled From Ptolemy to Copernicus, p. 84). It turned out that it would be enough if every hundredth year was not a leap year. The change was outdained by the Pope Gregory XIII. That is why we call the new calendar Gregorian. That event took place in 1582, which, incidentally, was a very strange year – in order to make up for the delay, as many as 10 days were "skipped" – from October 5 till October 14. The calendar is still used today. And, of course, we use it too.

A TASK FOR YOU: A task for you: check in the calendar, when (on which day) your birthday is this year, and when it is next year. Every year your birthday shifts onto the next day!

Key word: leap year

Fig. 1 *Little astronomer,* pages 8-9 from the guide


The Moon – Earth's faithful companion

We say that the Moon is Earth's natural satellite, or companion. Such companions are also space stations moving around our planet. The Moon orbits Earth just like the stations.

At arm's length

Many planets have their own moons, but our Moon is unique because it is only four times smaller than Earth. Moreover, it is very close to us – the distance between Earth and the Moon is equal to 60 Earth radii. Getting to the Moon is like traveling around Earth along the equator 10 times. A rocket's flight to the Moon lasts only two days. A big, heavy and proximate Moon helps Earth maintain cosmic balance. Several times a year our satellite seems bigger – in fact it is closer to us then. The distance between the Moon and Earth alters between 364 and 404 thousand km.

A TASK FOR YOU: you can measure how big the Moon is using your finger. Pull out your arm and cover the moon disc with your thumb. Repeat the same thing in a month's time.

The birth of the Moon

The Moon has not always been Earth's companion. It originated as a result of a giant impact. A long time ago Earth was struck by a Mars-sized stray planet: it was the worst day in Earth's history, a gigantic disaster. A huge piece of semi-liquid rocks was torn away from Earth's crust then. Within 24 hours a moon ball formed out of those rocks. Initially it was semi-liquid, just like Earth at that time. For the next hundreds of millions of years black lava flowed out of the Moon's interior. Today we see its remains in the form of dark plains on the Moon's surface – these dark areas are called lunar maria, meaning seas in Latin. Besides the maria we can also see light grey hills with "holes" in them – those are the Moon's craters.

The map of the Moon's surface

Mountains and valleys

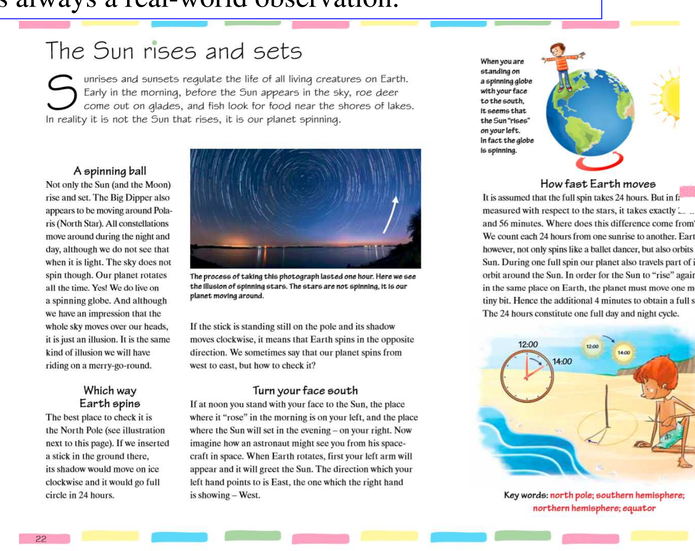
They were discovered by Galileo Galilei. Galileo observed the sky through a telescope which he made himself. During his observations he spotted mountain shades. It was a sensational discovery because at that time it was widely believed that the Moon was a perfectly smooth sphere "moulded" of some heavenly plasticine. After Galileo's discovery other scholars came up with a proper explanation which allowed them to stick to their previous convictions: they concluded that although there were mountains and valleys on the Moon, its surface was covered by perfect glass, so the Moon was still a beautiful smooth sphere. Galileo responded by saying that the Moon's glass mountains and valleys might be 10 times bigger than the ones we actually see!
The shapes that caused all the fuss 400 years ago are in fact the traces of a giant bombardment of the Moon by huge meteorites at the beginning of its existence. One of the biggest and most visible craters on the Moon is called Copernicus. Try to find it using binoculars.

The dark side of the Moon

Soon after the Moon's origin liquid lava slowed its rotation and, as a result, after a billion years it actually stopped spinning. Or, to be more precise, its rotation time is exactly the same as the time it needs to orbit Earth. That is why we always see the same "face" of the Moon. People saw the other side only when they sent space shuttles to the Moon. The first spacecraft to reach our satellite was Luna (in Latin it means "moon") in 1959. The dark side of the Moon is not as "smiley" as the one we see from Earth – it is fully covered by craters. It cooled sooner and luckily for us it is the part of the Moon which is hit by huge meteorites flying towards Earth.

WORTH KNOWING: scientists placed a small mirror on the Moon and using laser light they can measure how the Moon's distance from Earth changes. It turns out that the Moon moves away from Earth by almost 4 cm a year. In one billion years there will not be Sun eclipses on Earth!

A TASK FOR YOU: take a close look at the Moon's disc when it is visible in the sky as a narrow crescent. The frayed edges of the crescent are the shades of the Moon's mountains.


The Sun rises and sets

Sunrises and sunsets regulate the life of all living creatures on Earth. Early in the morning, before the Sun appears in the sky, roe deer come out on glades, and fish look for food near the shores of lakes. In reality it is not the Sun that rises, it is our planet spinning.

A spinning ball

Not only the Sun (and the Moon) rise and set. The Big Dipper also appears to be moving around Polaris (North Star). All constellations move around during the night and day, although we do not see that when it is light. The sky does not spin though. Our planet rotates all the time. Yes! We do live on a spinning globe. And although we have an impression that the whole sky moves over our heads, it is just an illusion. It is the same kind of illusion we will have riding on a merry-go-round.

The process of taking this photograph lasted one hour. Here we see the illusion of spinning stars. The stars are not spinning, it is our planet moving around.

Which way Earth spins

The best place to check it is the North Pole (see illustration next to this page). If we inserted a stick in the ground there, its shadow would move on ice clockwise and it would go full circle in 24 hours.

If the stick is standing still on the pole and its shadow moves clockwise, it means that Earth spins in the opposite direction. We sometimes say that our planet spins from west to east, but how to check it?

Turn your face south

If at noon you stand with your face to the Sun, the place where it "rose" in the morning is on your left, and the place where the Sun will set in the evening – on your right. Now imagine how an astronaut might see you from his spacecraft in space. When Earth rotates, first your left arm will appear and it will greet the Sun. The direction which your left hand points to is East, the one which the right hand is showing – West.

When you are standing on a spinning globe with your face to the south, it seems that the Sun "rises" on your left. In fact the globe is spinning.

How fast Earth moves

It is assumed that the full spin takes 24 hours. But in fact measured with respect to the stars, it takes exactly 23 and 56 minutes. Where does this difference come from? We count each 24 hours from one sunrise to another. Earth, however, not only spins like a ballet dancer, but also orbits the Sun. During one full spin our planet also travels part of its orbit around the Sun. In order for the Sun to "rise" again in the same place on Earth, the planet must move one more tiny bit. Hence the additional 4 minutes to obtain a full spin. The 24 hours constitute one full day and night cycle.

would run backwards!

NORTH POLE
THE GLOBE
NORTHERN HEMISPHERE
EQUATOR
SOUTHERN HEMISPHERE

A TASK FOR YOU: on a sunny day put a stick in sand. Mark the stick's shadow on the ground. In two hours' time check where the shadow is. Has it moved like the hand of a clock?

Key words: north pole; southern hemisphere; northern hemisphere; equator

Fig. 2 *Little astronomer,* pages 36-37 from the guide

Fig. 3 *Little astronomer,* pages 22-23 from the guide

Interactive teaching

Keeping attention of some 200 kids for 60 minutes requires a vivid narration, with a cognitive goal promised ("where has Voyager arrived to?") and interlaced with interesting experiments. Using multimedia (starting rockets, a hammer falling on the Moon, kangaroo jumping instead of walking by Apollo astronauts, travel of Voyager), involving young "students", but firmly controlling the pace to arrive to the conclusion - is the key for the success.

Children after lessons insist for weeks on internet asking questions on stars, Solar System, black holes, flights to other galaxies. A continuous demand for new lessons from different schools (and foundations for children education) is the best evaluation.

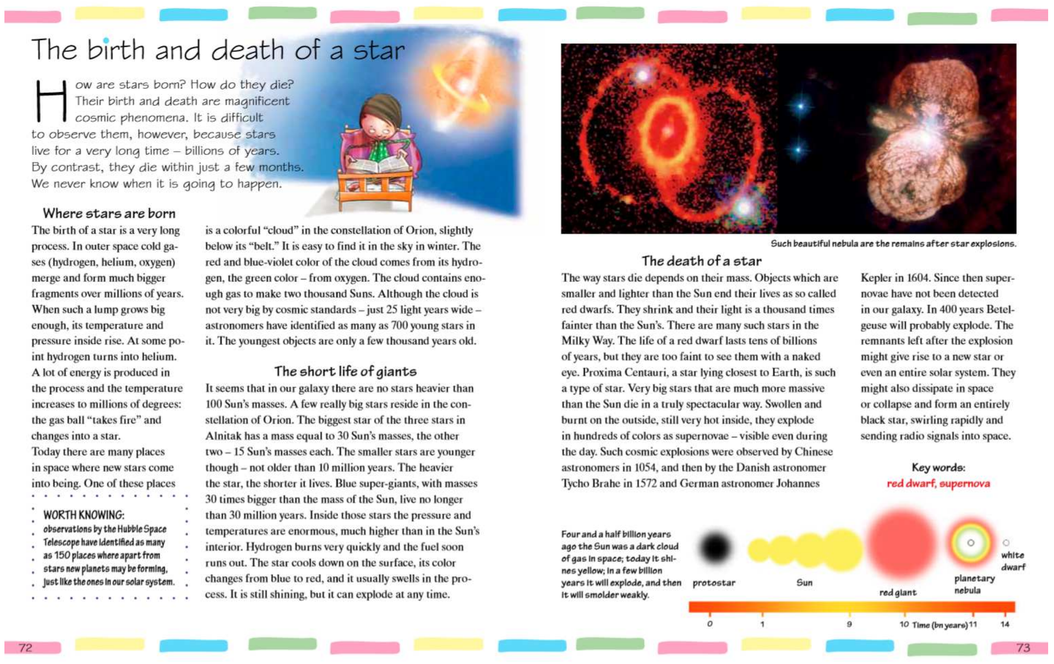
Constructivistic requirements

Itinerary (walking-like) scenarios are based on series of experiments that constitute a didactical narration: like pearls aligned in a necklace. Three other „inter" are needed: inter-active, inter-disciplinary (to meet interest of different pupils) and inter-esting, obviously.

Further, narration needs to fulfil three functions: ludic (to make physics fun), didactical (to deliver well defined notions, abilities and social competences) and scientific (to leave students with some unanswered questions). For example, the didactical transmission can be „the state of absence of gravity is not the lack of the gravitational field but the state of the free fall"; the social competence, after showing a pupet falling in the absence of gravity, can be: „ never try the free fall, you could become a scrambled egg. The best walking on Moon is the kangaroo jumping – try it at gymnastics, and so on.

Conclusions

In spite of (thanks to?) numerous books and internet images, children at early years of primary school are keen on listening on astronomy and space flights. Several thousands of pupils all over Poland followed our interactive lessons and the demand is still rising. Also the book is selling well.


The birth and death of a star

How are stars born? How do they die? Their birth and death are magnificent cosmic phenomena. It is difficult to observe them, however, because stars live for a very long time – billions of years. By contrast, they die within just a few months. We never know when it is going to happen.

Where stars are born

The birth of a star is a very long process. In outer space cold gases (hydrogen, helium, oxygen) merge and form much bigger fragments over millions of years. When such a lump grows big enough, its temperature and pressure inside rise. At some point hydrogen turns into helium. A lot of energy is produced in the process and the temperature increases to millions of degrees: the gas ball "takes fire" and changes into a star.
Today there are many places in space where new stars come into being. One of these places is a colorful "cloud" in the constellation of Orion, slightly below its "belt." It is easy to find it in the sky in winter. The red and blue-violet color of the cloud comes from its hydrogen, the green color – from oxygen. The cloud contains enough gas to make two thousand Suns. Although the cloud is not very big by cosmic standards – just 25 light years wide – astronomers have identified as many as 700 young stars in it. The youngest objects are only a few thousand years old.

WORTH KNOWING: observations by the Hubble Space Telescope have identified as many as 150 places where apart from stars new planets may be forming, just like the ones in our solar system.

The short life of giants

It seems that in our galaxy there are no stars heavier than 100 Sun's masses. A few really big stars reside in the constellation of Orion. The biggest star of the three stars in Alnitak has a mass equal to 30 Sun's masses, the other two – 15 Sun's masses each. The smaller stars are younger though – not older than 10 million years. The heavier the star, the shorter it lives. Blue super-giants, with masses 30 times bigger than the mass of the Sun, live no longer than 30 million years. Inside those stars the pressure and temperatures are enormous, much higher than in the Sun's interior. Hydrogen burns very quickly and the fuel soon runs out. The star cools down on the surface, its color changes from blue to red, and it usually swells in the process. It is still shining, but it can explode at any time.

Such beautiful nebula are the remains after star explosions.

The death of a star

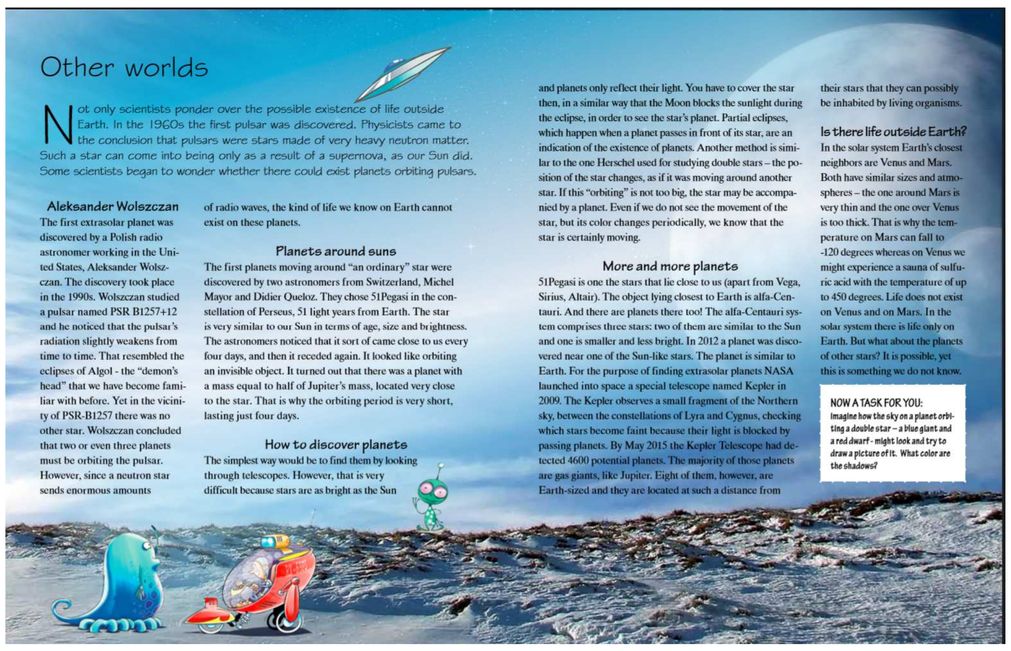
The way stars die depends on their mass. Objects which are smaller and lighter than the Sun end their lives as so called red dwarfs. They shrink and their light is a thousand times fainter than the Sun's. There are many such stars in the Milky Way. The life of a red dwarf lasts tens of billions of years, but they are too faint to see them with a naked eye. Proxima Centauri, a star lying closest to Earth, is such a type of star. Very big stars that are much more massive than the Sun die in a truly spectacular way. Swollen and burnt on the outside, still very hot inside, they explode in hundreds of colors as supernovae – visible even during the day. Such cosmic explosions were observed by Chinese astronomers in 1054, and then by the Danish astronomer Tycho Brahe in 1572 and German astronomer Johannes Kepler in 1604. Since then supernovae have not been detected in our galaxy. In 400 years Betelgeuse will probably explode. The remnants left after the explosion might give rise to a new star or even an entire solar system. They might also dissipate in space or collapse and form an entirely black star, swirling rapidly and sending radio signals into space.

Key words: red dwarf, supernova

Four and a half billion years ago the Sun was a dark cloud of gas in space; today it shines yellow; in a few billion years it will explode, and then it will smolder weakly.

protostar · Sun · red giant · planetary nebula · white dwarf
0 1 9 10 Time (bn years) 11 14

Fig. 4 *Little astronomer,* pages 72 - 73 from the guide


Other worlds

Not only scientists ponder over the possible existence of life outside Earth. In the 1960s the first pulsar was discovered. Physicists came to the conclusion that pulsars were stars made of very heavy neutron matter. Such a star can come into being only as a result of a supernova, as our Sun did. Some scientists began to wonder whether there could exist planets orbiting pulsars.

Aleksander Wolszczan

The first extrasolar planet was discovered by a Polish radio astronomer working in the United States, Aleksander Wolszczan. The discovery took place in the 1990s. Wolszczan studied a pulsar named PSR B1257+12 and he noticed that the pulsar's radiation slightly weakens from time to time. That resembled the eclipses of Algol - the "demon's head" that we have become familiar with before. Yet in the vicinity of PSR-B1257 there was no other star. Wolszczan concluded that two or even three planets must be orbiting the pulsar. However, since a neutron star sends enormous amounts of radio waves, the kind of life we know on Earth cannot exist on these planets.

Planets around suns

The first planets moving around "an ordinary" star were discovered by two astronomers from Switzerland, Michel Mayor and Didier Queloz. They chose 51Pegasi in the constellation of Perseus, 51 light years from Earth. The star is very similar to our Sun in terms of age, size and brightness. The astronomers noticed that it sort of came close to us every four days, and then it receded again. It looked like orbiting an invisible object. It turned out that there was a planet with a mass equal to half of Jupiter's mass, located very close to the star. That is why the orbiting period is very short, lasting just four days.

How to discover planets

The simplest way would be to find them by looking through telescopes. However, that is very difficult because stars are as bright as the Sun and planets only reflect their light. You have to cover the star then, in a similar way that the Moon blocks the sunlight during the eclipse, in order to see the star's planet. Partial eclipses, which happen when a planet passes in front of its star, are an indication of the existence of planets. Another method is similar to the one Herschel used for studying double stars – the position of the star changes, as if it was moving around another star. If this "orbiting" is not too big, the star may be accompanied by a planet. Even if we do not see the movement of the star, but its color changes periodically, we know that the star is certainly moving.

More and more planets

51Pegasi is one the stars that lie close to us (apart from Vega, Sirius, Altair). The object lying closest to Earth is alfa-Centauri. And there are planets there too! The alfa-Centauri system comprises three stars: two of them are similar to the Sun and one is smaller and less bright. In 2012 a planet was discovered near one of the Sun-like stars. The planet is similar to Earth. For the purpose of finding extrasolar planets NASA launched into space a special telescope named Kepler in 2009. The Kepler observes a small fragment of the Northern sky, between the constellations of Lyra and Cygnus, checking which stars become faint because their light is blocked by passing planets. By May 2015 the Kepler Telescope had detected 4600 potential planets. The majority of those planets are gas giants, like Jupiter. Eight of them, however, are Earth-sized and they are located at such a distance from their stars that they can possibly be inhabited by living organisms.

Is there life outside Earth?

In the solar system Earth's closest neighbors are Venus and Mars. Both have similar sizes and atmospheres – the one around Mars is very thin and the one over Venus is too thick. That is why the temperature on Mars can fall to -120 degrees whereas on Venus we might experience a sauna of sulfuric acid with the temperature of up to 450 degrees. Life does not exist on Venus and on Mars. In the solar system there is life only on Earth. But what about the planets of other stars? It is possible, yet this is something we do not know.

NOW A TASK FOR YOU: Imagine how the sky on a planet orbiting a double star – a blue giant and a red dwarf - might look and try to draw a picture of it. What color are the shadows?

Fig. 5 *Little astronomer,* pages 96-97 from the guide

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