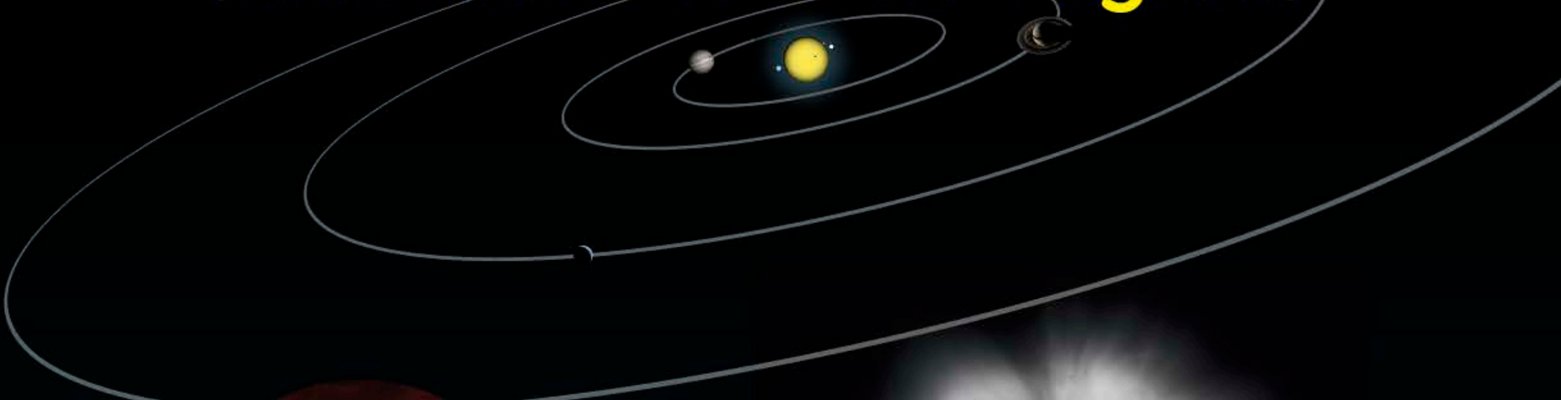
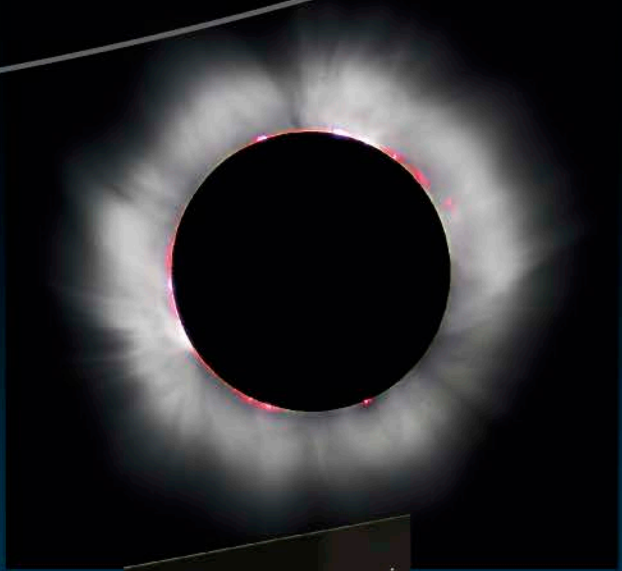
Astroset

Maan en planeten

English User Guide
(Translation of Dutch original)





To better understand the motions in the sky

This is the manual to using the ***Astroset Moon and planets****. There are two versions of the set: the standard set MDL-MPL, with the five paper models (A3 format), and the luxury MDL-MPL-Lux, which besides the paper models also contains all the necessary wooden beads and sticks.*
This manual will be improved when necessary and based on new ideas and insights. Your questions and comments are therefore always very welcome! Send these to: ***info@walrecht.nl****.*

More information: www.walrecht.nl

How to use the User Guide
In this User Guide ***bold*** *and* ***italics*** *are used with a specific purpose.*
Apart from the titles all the concepts (terms) have been written in bold type when they are explained in that paragraph.
When such a term is used elsewhere, where it is not explained, it will be shown in italics (names of products and books are also in italics). The index (at the end of this manual) will show you where it is explained.

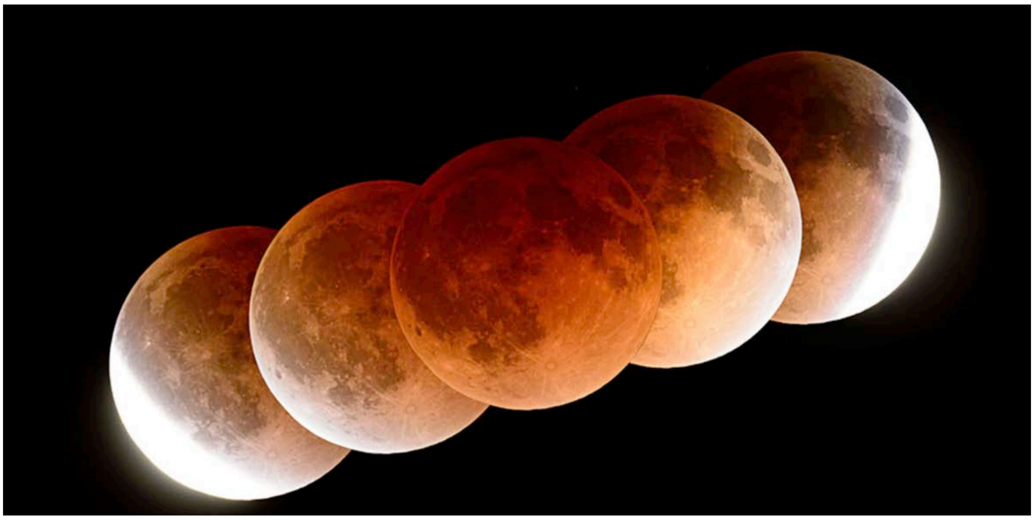
Introduction

The Astroset Moon and Planets
This Astroset is a set of two build-it-yourself cardboard models, the *Table Planetarium* and the *Earth-Moon model*, and two extra items: the *ellipse instrument* and a special *ruler* to determine the distances (in km and *Astronomical Units*) in the Table Planetarium, and beyond its outer edge. These items are all designed to help you understand the motions of the Sun, the Moon and the planets (**celestial mechanics**). It is therefore very useful for teaching.
The Astroset was only published in Dutch, as the *Astroset Maan en Planeten*. However, since the models contain not so much text, they can be used perfectly by others, without too much language problems. At the end of this User Guide you will find a list with the Dutch words and names, and their English translations.
This set consists of five cardboard plates, two of them printed doublesided. Besides these plates you will need other materials, like wooden beads en rods (which are present in the De Luxe set), pins and grey cardboard.

More information
For Dutch speaking people our book *Genieten van de sterrenhemel* provides all the information that you need to use and understand the models and celestial mechanics, as our book *Genieten van het zonnestelsel* does for the Solar System (see list of products, pag. 15) to our Dutch speaking customers.
We hope to find an international partner (i.e. a publisher) and realise English versions of all our products.

Earth-Moon model
The Earth-Moon model allows you to understand and/or demonstrate the most important aspects of the motion of the Moon around the Earth, like the phases of the Moon and solar and lunar eclipses. The model in the Astroset is officially called a **tellurion**.

Table Planetarium
The Table Planetarium allows you to understand and/or demonstrate the motions of the planets around the Sun, and against the background of the stars. These include the direction in which the planets orbit the Sun; how and why the Sun and planets move eastwards against the background of the fixed stars – but not always; what the Zodiac is; and what are the most important positions in the planet's orbits, relative to the Earth, influencing their visibility.
The Table Planetarium only shows the Sun and the four planets closest to the Sun: Mercury, Venus, Earth and Mars. These are sufficient to understand the planetary motions as they represent *inferior planets* (planets with orbits that are closer to the Sun than Earth's orbit) and *superior planets*: planets farther from the Sun, i.e. the other five planets of the Solar System.



Right, top*: the Moon seems to change shape in the course of a month: the phases of the moon.*
Right, middle*: a conjunction of Venus and Jupiter, in early July 2015. Mars was also in the area but invisible at this resolution. Conjunctions are wonderful to simulate with the Table planetarium.*
Photo © Marek Nikodem.
Right, bottom*: with the Earth-Moon model you can simulate solar and lunar eclipses. Here you see a series of pictures of a lunar eclipse on April 15, 2014. The pictures were taken by 'Mr. Eclipse', Fred Espenak. They are 'stacked' to show the Moon at different times near the maximum of the eclipse.*

The Earth-Moon model

The Earth-Moon model

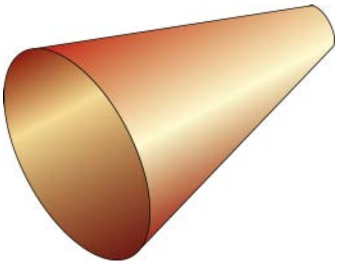
Motions of the Moon
This model is designed to learn to understand the movement of the Moon around the Earth, the *phases* of the Moon and what causes *solar* and *lunar eclipses*.
With the model you can show the direction in which the Moon orbits the Earth, in about one month time. If we would float high above the north pole of our planet, we would see the Moon moving anti-clockwise, for the same reason that all planets orbit the Sun in an anti-clockwise direction (see 'Eastwards', on page 6).
For this reason, we see that the Moon and the planets move eastwards, against the background of fixed stars. That may sound strange, as you know the Sun and most stars rise in the east and set in the west. But that is caused by the rotation of the Earth, once every day. This rotation is also eastwards, so we all move eastwards. That is why we see the Sun, stars and other object rise in the east, and consequently set in the west.
As the Moon rotates in the same amount of time it takes to orbit the Earth, we'll always see the same side facing us: the ***near side***.

The model
The Earth-Moon model shows all aspects of Moon's motion, except for the elliptical shape and the inclination of the Moon's orbit (see 'Ellipse instrument', page 10), which are impossible to show in a model like this.

The phases of the Moon
To demonstrate the phases of the Moon (or lunar phases) you'll need a bright flashlight – to provide the 'Sunlight'. Use it to shine through the large curcular hole on the front side, after dimming the other lights in the room. This way, Earth and Moon are always lit from one side, as in reality. In the next experiments always try to see 'the Moon' (so, the model) from the direction of 'the Earth'.
First place the model of the Moon between the Earth-model and the Sun (so the hole, the direction of the flashlight). This is the situation where the lit sight of the Moon facing away from us, and we therefore look at the unlit, dark side. We call this situation new moon (see illustration bottom right). You'll understand that, looking towards the bright 'Sun' (i.e. the flashlight), it is not possible to see the Moon. Unless… when the Moon moves in front of the Sun, but then we have a *solar eclipse*.
Now carefully rotate the disc of the Moon by pushing the model with your finger, of course anti-clockwise. Doing this, you'll create all other well-known phases: first quarter, full moon and last (or third) quarter.

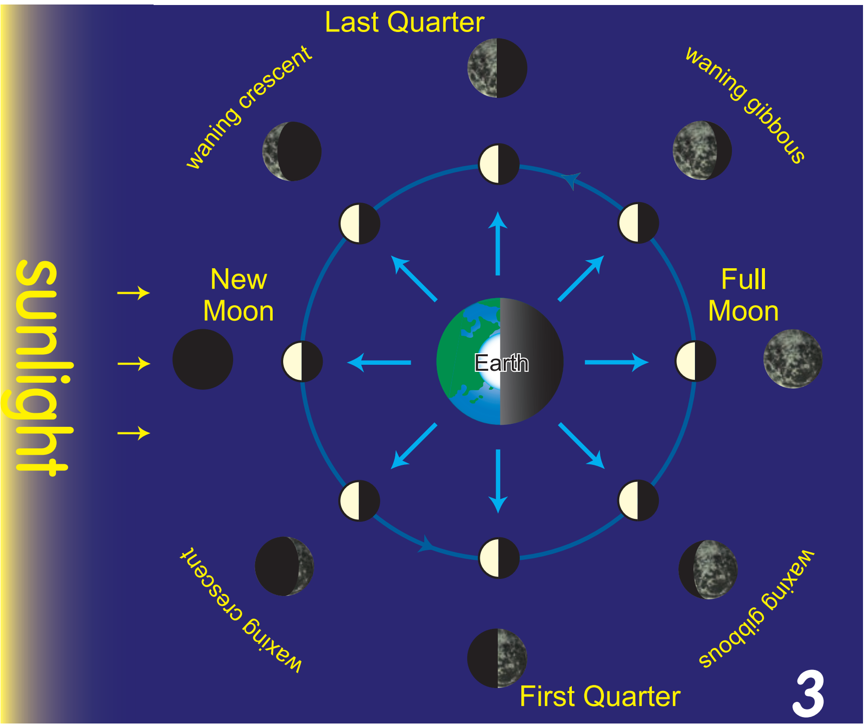
From New Moon to Full Moon
The first days after that we'll see a thin sliver of the Moon appear: the **Crescent Moon**. If you're lucky you can also see the dark part of the Moon's surface dimly lit. Earth as viewed from the Moon is almost fully lit by the Sun and the sunlight reflected off the Earth's bright clouds illuminates the Moon enough to be easily visible from Earth. We call this **earthshine**.
It seems that the Moon 'grows' on the right side and we call this **Waxing Moon**. The part between New Moon and First Quarter is also called **Waxing Crescent** in the English-speaking countries (as is the addition 'gibbous', see below).
About a week after New Moon our satellite has travelled a quarter of her orbit around Earth. The right half of the side of the Moon that is turned towards us (the **near side**) is now lit. This 'half Moon' is called **First Quarter**. After that every night we see the 'growing' of the Moon continue towards the left: the **Waxing Gibbous** phase.

Shadow cones
When the Sun illuminates a spherical object, like a planet or the Moon, the shadow of this object will be cone shaped. What is a cone? Well, think about the trafiic cones that are used to redirect traffic, or in the gym:



Naturally a shadow cone does have a pointed side.
The diameter of the Earth is almost four times that of the Moon. The Earth's shadow cone is thus much longer that the Moon's, and a lunar eclipse therefore lasts longer then a solar eclipse. The lenght of the Earth's shadow cone is, on average, 1 382 000 km, while the average distance to the Moon is 384 400 km. The lenght of the Moon's shadow cone is on average 375 000 km.

***Left, bottom**: a series of pictures of different phases of the Moon.*
Credit: © Fred Espenak, 2012.
***Below**: the main phases of the Moon.*



The Earth-Moon model

First or Last Quarter?
*There is this mnemonic device to recognise First and Last Quarters. First draw an imagenary line along the straight side of the (half) Moon, extending half the Moon's diameter upwards. If you can thus make the letter 'b' it is First Quarter: the 'b' being the 'first' metter of the word '**b**egin'. If you can make a 'd' of it, then it is Lats Quarter (last letter of 'en**d**'). See below.*

***Right**: we don't have one solar and one lunar eclipse every month, because the orbital plane of the Moon is tilted about 5° with respect to the plane of the ecliptic (see main text). Where the two planes intersect are two nodes: one where the Moon moves above the ecliptic plane, and one where she moves below it. The line between these nodes slowly rotates, in 18.6 years. This period is called the **saros**.*
***Below**: the three types of eclipses. Those wonderful words 'umbra' and 'penumbra' stand for distinct parts of a shadow (see side text on page 5).*

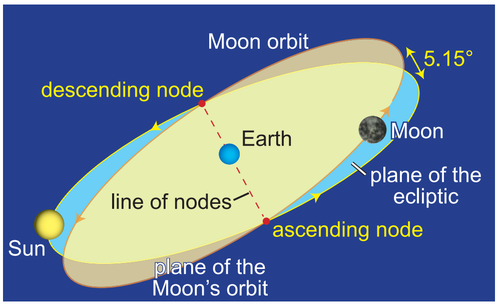
Two weeks after New Moon the Moon is between Earth and the Sun, having the sunlit half facing Earth completely: **Full Moon**. Try to simulate that phase with the model.
After Full Moon the Moon appears to get smaller, again from the right side. This is **Waning Moon** (first **Waning Gibbous**).
About three weeks after New Moon it is again half lit, but now on the left side: it is **Last (or Third) Quarter**. Subsequently it's the **Waning Crescent** phase, and then New Moon again. And so it goes on forever…

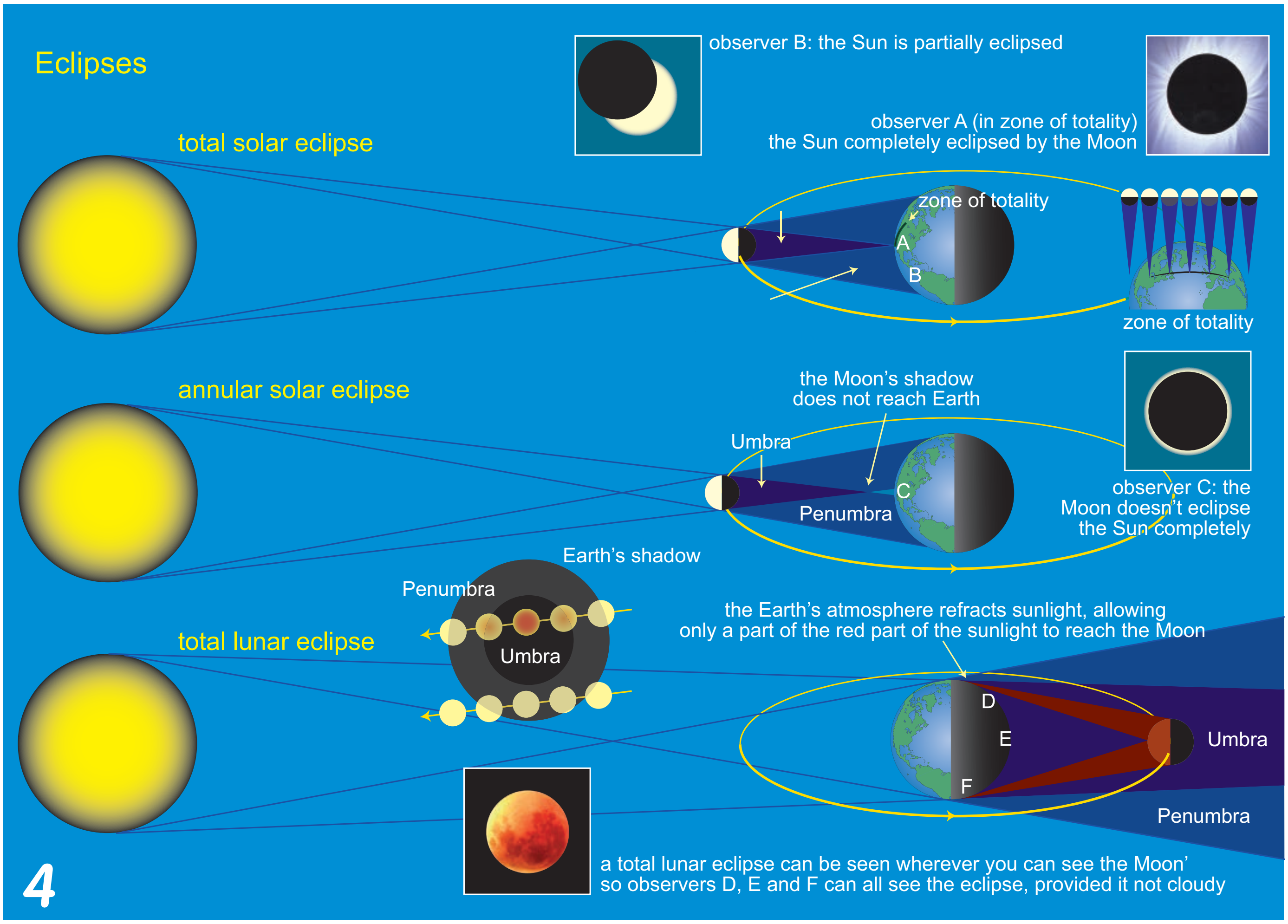
Special New Moons and Full Moons

Solar and lunar eclipses appear when the Sun, the Earth and the Moon are exactly aligned. We can watch a **total solar eclipse** happening when the Sun is blocked (occulted) by the Moon, and a **total lunar eclipse** when the Moon completely 'disappears' in the Earth's shadow (see text right side of page 3). Eclipses are mostly not complete (total) and then we'll have a **partial solar eclipse** or a **partial lunar eclipse**.
In the sky the Sun and the Moon appear to be of equal size. However, the Sun's diameter is about 400 times larger than that of the Moon. Since the Moon is also about 400 times closer to Earth it can thus completely eclipse the Sun. The Moon's shadow is conical and usually just reaches the Earth, causing a round area of shade: there is where it gets dark for a few minutes. This is **totality**.
The Moon's orbit is not a circle, but an ellipse (see below). Sometimes the Moon is too far away to eclipse the Sun completely and the Sun still shows a ring of light during totality. In that case we can see an **annular solar eclips** and this light is still very dangerous to look at!
But... when eclipses only happen when the Sun, the Earth and the Moon are aligned, why can't we admire a solar eclipse every New Moon, and a lunar eclipse every Full Moon?

Inclined Moon orbit

Orbits of planets and other Solar System objects are *inclined* and also *elliptical* (see side text page 10). The Moon's orbit is also inclined: over 5° (see the picture below), measured from the *plane of the ecliptic*. That is the plane of Earth's orbit around the Sun, which is frequently used as a reference plane.





The Earth-Moon model

The intersection of the Moon's orbit and the eliptic is called the **orbital node**. There are two such nodes. The **ascending node** is where the Moon moves north through the plane of the ecliptic, and the **descending node** is where she moves south through it. The line passing through both nodes is the **line of nodes**.

It's only when the Moon is in one of these nodes that she is also in the ecliptic plane. And only then eclipses can happen: the Sun is always on the ecliptic! This considerably decreases the chance of having an eclipse. In fact, a total lunar eclipse is the perfect Full Moon, and a total solar eclipse the perfect New Moon! Perfect things shouldn't come too easy. Annually there are at least two eclipses (in that case both solar eclipses) and at most seven: four solar and three lunar eclipses.

Solar eclipses

Due to the much smaller shadow cone of the Moon total solar eclipse can at any moment only be seen in a small, circular area on Earth. In that area it will get dark, birds stop singing and they and squirrels return to their nests; crickets chirp. Solar and wind power decrease. Everyone who has seen a total solar eclipse agrees that it was a very special experience.

This dark spot moves rapidly from west to east across the Earth. The lenght of the track can be thousands of kilometers long and we call this the **zone of totality**. During the eclipse that could be seen in Europe in August 1999, the zone of totality was 112 km at its widest. Due to Earth's rotation (east to west) and the Moon's eastward motion a solar eclipse is a short phenomenon: from 2 to 7.5 minutes. The long eclipses happen just once every 5000 years, the first happening on 16 July 2186.

The centre of the zone of totality the eclipse will be at its **maximum**, where the Moon and the Sun are perfectly aligned. Around the zone of totality is a large area where the solar eclipse is partial. The farther you are from that zone, the less the Sun will be eclipsed. It will not get dark there, for even the slightest sliver of sunlight is really blinding! It is very dangerous to your eyes, so always take care not to look at the Sun without protection, a pair of eclipse glasses. **Never use sunglasses or a CD disc!** These may let through less visible light, but the infrared light passes unhindered and is very harmful. Never experiment with your eyes!

Annular solar eclipses

Like planets the Moon has an elliptical orbit, which means that its distance to the Earth varies over a period of almost a month. The average distance of the Moon to the Earth is more than 384 000 km, larger than the average lenght of the Moon's *shadow cone*. Most of the time this shadow cone doesn't even reach Earth! In that situation the Moon will not eclipse the Sun completely, as seen from the Earth, and during maximum the edge of the Sun will still be visible, like a ring around the Moon: an *annular solar eclipse*.

Lunar eclipses

When the Earth is exactly between the Sun and the Moon, the Moon will disappear in the shadow (cone) of the Earth and we see a lunar eclipse. Solar eclipses are more frequent then lunar eclipses, but the chance that we see a lunar eclipse is much greater. That's because we can see a lunar eclipse anywhere where you can see the Moon: on half the globe, as it is Full Moon. When you see a Full Moon the Sun has set. So a lunar eclipse is visible when it's dark (or in the twilight), and everywhere where it is dark! And clear of course…

Umbra and penumbra

*A shadow of an object consists of two parts. The part where the shadow is the darkest is called the **umbra**. When you are in the umbra of a solar eclipse you will see a total eclipse. When the Moon is in the umbra of the Earth it will not be completely dark: you'll see a reddish Moon (see below). Sunlight consists of all colours of the rainbow, the spectrum, the mix of all these colours resulting in the white light we see. The blue part of sunlight, on one side of the spectrum, is scattered in all directions by the air molecules in the atmosphere, causing the nice blue colour of the sky. The red part of the sunlight, on the other side, is not scattered but refracted, 'bent', by the Earth's atmosphere, continuing its journey under an angle which allows it to reach the Moon. The same thing as when the Sun or the Moon are just above the horizon.*

*The **penumbra** is where still some sunlight arrives. That's because the Sun is not light point source, but a sphere. In this area all colours come through, but less than normal.*

Poor vision in red light

*Our eyes are not good at seeing red light in the dark. That's because we have two types of light-sensitive cells in our eyes: the **cones**, which detect colours well but are quite insensitive; and the **rods**, which are more sensitive to light but cannot distinguish colours. Rods are least sensitive to longer wavelengths: red light! If you have used white light in the dark, it may take fifteen minutes for your eyes to adapt again to the dark. When you use just red light in the dark you won't have that problem.*

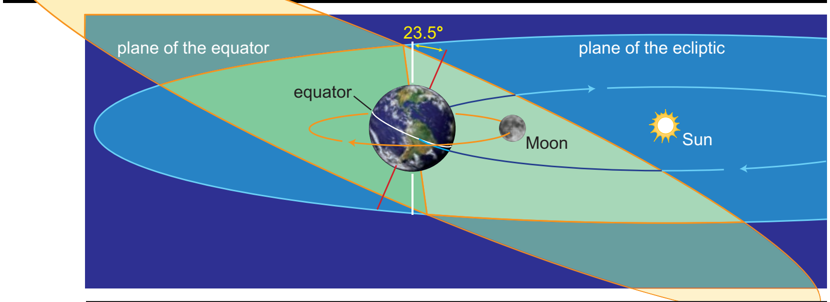
Maximum

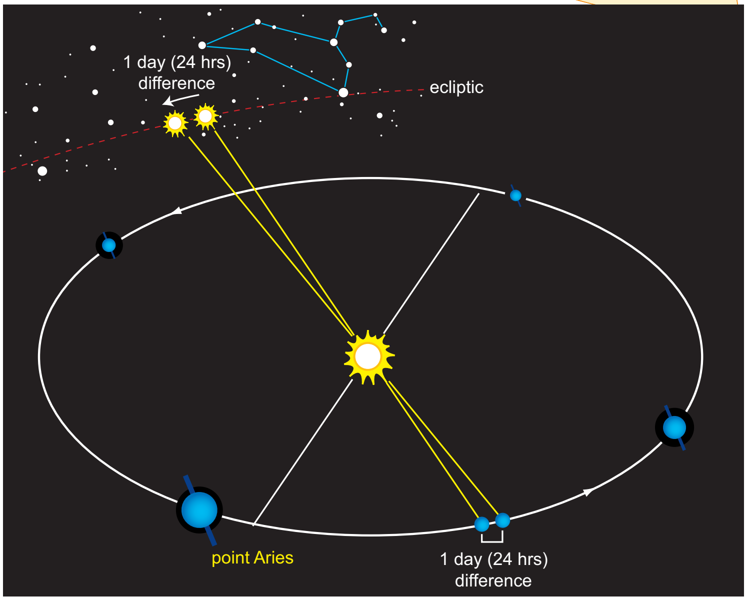
*The midpoint of the time of totality, when an eclipse is the most complete, is known as the **maximum** of the eclipse.*

***Bottom left**: the eclipsed Moon is copper red in color. We can hardly see that colour because our eyes are insensitive to red light at night (see side text on page 10). The term ' Blood Moon ' is an exaggeration like only Americans can think of.*
Photo: © Jens Hackmann, 2007.
***Bottom right**: a solar eclipse is a very special experience.*

Inferior and superior planets
There are planets closer to the Sun than the Earth, the inferior planets (Mercury and Venus), and planets further away than the Earth, the superior planets. Planets orbit the Sun, just like Earth. And they all move anti-clockwise. That is the normal direction of all (dwarf-) planets and large moons in the solar system. That means that the planets and the Moon all move eastward against the background of the fixed stars. The closer a planet is to the Sun, the faster it moves, also in the sky. Thus, you'll notice this movement of inferior planets sooner than with the superior planets.

***Below**: when you look 'into the plane' of planetary orbits you will see that the planets are neatly aligned. Here you look from slightly above the plane, so they are not perfectly aligned here.*
***Middle**: the planes of the ecliptic and the equator.*
Bottom left*: because the Earth moves around the Sun, a 'little' step every day, the Sun moves a little to the east daily, relative to the fixed stars.*





The Table Planetarium

The motion of Sun and planets

The Table planetarium enables you to learn all about the motion of the planets around the Sun, and in the sky. For instance, you can see in which direction the planets orbit the Sun; how the Sun and planets move in an eastbound direction, but sometimes stop and start moving in the 'wrong' direction for some time; what the Zodiac really is; and what important planetary positions we can point out in the orbits, as seen from the Earth, with their implications for the visibility of the planets.
The Table planetarium contains the Sun and just the four planets closest to the Sun: the *inferior planets* Mercury and Venus (see side text left), Earth and the *superior planet* Mars. The four giant planets are also outer planets and are similar to Mars in their behaviour in the sky, so are not necessary in the model.
We will first deal with some concepts that are important to understand and use the Table Planetarium.

Eastward

All the planets and most other solar system objects move in the same direction around the Sun: seen from above (north of) the Sun counter clockwise. That is an eastbound direction. Large satellites (moons) of the Solar System also move that way around their planet (see below). That has to do with how the solar system was formed, out of a large disc of gas and 'dust' (small particles of metal, rock, water, ammonia, methane and more) that rotated around the Sun in this way. The exception among large moons is Neptune's Triton, which was captured by the planet after the formation of the Solar System.
In the course of the time the planets and the Moon in an eastbound direction against the sky. As does the Sun, but that's because Earth orbits our star!

Constellations of the Zodiac

The orbital period of the Earth is 365¼ days, or one **year**. For convenience, we'll keep that on 365 days. Each complete day the Earth thus travels 1/365th part of its orbit around the Sun. And each complete day the Sun has moved a part of its path against the background of the fixed stars! See the illustration. That motion is from west to east, as the Earth moves anti-clockwise. This is also something that you can perfectly illustrate with the Table Planetarium.
In the course of one year the Sun moves along an accurately known 'path'. However, you cannot see that, because during the day you can't see stars! The Sun, our own star, is much too bright and outshines all the other stars. But there is one situation when you can see the brightest stars by day: during a total solar eclipse, when it gets dark for a few minutes.

The ecliptic

Because we can see eclipses of the Sun always along the 'Sun's path', we call that path the **ecliptic**: the path of eclipses. The ecliptic crosses twelve well-known constellations: the **constellations of the Zodiac** (please look them up in the model, or in a planisphere/star wheel). These constellations, which apart from Libra are all named after animals and people from Greek mythology, owe their fame to the fact that they are 'visited' by the Sun every year. Only a few of them are really striking patterns of stars, for instance Gemini and Leo.
Astrologers attach great importance to these 'signs of the Zodiac', although the actual positions of the Sun in the sky no longer match the positions according to astrology. Besides the Sun moves for a week through Scorpius, and then for three weeks through Ophiuchus: a thirteenth constellation of the Zodiac!

The plane of the ecliptic

The orbits of all planets, moons, asteroids and other objects are tilted, or **inclined**. There's just nothing at all in the Universe that is perfectly round or neatly upright. But what exactly is 'tilted' in the Universe?
In your room you can hang a painting straight

because you have planes of reference: the floor, walls and ceiling. In space there is no top or bottom, let alone a straight floor, to work from. Astronomers found a solution for that. They invented an imaginary
'floor', based on the orbital plane of the Earth. When you imagine a disc with the orbit as its edge, you get a flat surface, a **plane**. But since it is an imaginary plane you can make it as big as you need: it is infinite! So this plane works everywhere.

The reason we see the Sun move along the ecliptic (see below) is the Earth's orbit, and therefore we call it the *plane of the ecliptic*. Almost all planets move roughly in that plane, but Mercury (7°) and Venus (3.5°) have slightly inclined orbits (smaller objects, may have larger inclinations, like Pluto: 17°). Therefore, in the sky, we always find planets near the ecliptic. That means that the Sun is regularly close to one or more planets, during *conjunctions*, overshining those planets!

There are more such planes, such as the **plane of the equator** (of Earth) and the Galactic plane (of the Milky Way).

Inferior planets

In the sky inferior planets are always near the Sun. That is why we can never see them around midnight. Mercury is so close to the Sun that it's angular distance (see side text on page 15) to the Sun is at best about 28° to the left or right of the Sun. In that situation Mercury rises about 2 hours and 15 minutes before the Sun and sets about 2 hours and 15 minutes after the Sun. Such situations are the best to observe the little planet, as it normally disappears in the bright sunshine.

Venus is the second planet from the Sun and can therefore also be further away from the Sun in the sky: a maximum of 47.8 °. Although the planet can be so bright that you can see her even during the day, if you know where to look, Venus is particularly brilliant when the angular distance is large (see side text page 8). Than you can see Venus more than 4 hours after sunset ('evening star') or more than 4 hours before sunrise ('morning star'). See also the illustration (bottom, right).

The angular distance between two bodies in the sky is also called the **elongation**. When an inferior planet is farthest away from the Sun (in the sky!) than the planet is in greatest elongation. You have **greatest western elongation** and **greatest eastern elongation**.

Conjunction

When a planet is in about the same direction as the Sun, we speak of *conjunction*. For inferior planets there are two possibilities: **inferior conjunction**, when the planet is between the Earth and the Sun; and **superior conjunction** when the planet is on the other side of the Sun, other words: so behind the Sun!

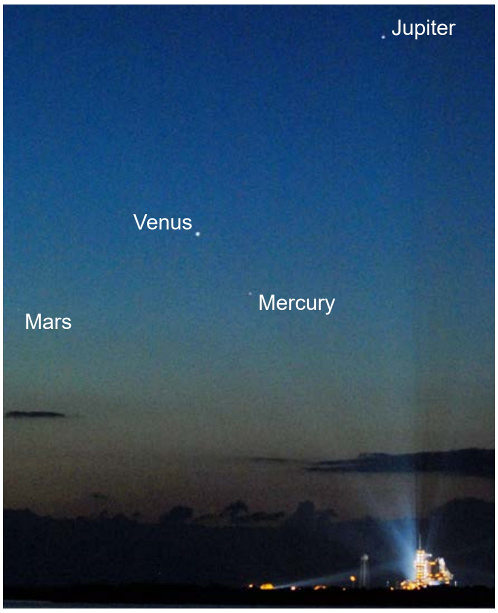
Mercury and Venus are the only planets that can move in front of the Sun, as a dark dot. We call that a **transit**. In 2004 and 2012 there were **transits of Venus**. These are very rare (the next will be in 2117!) because the orbit of Venus

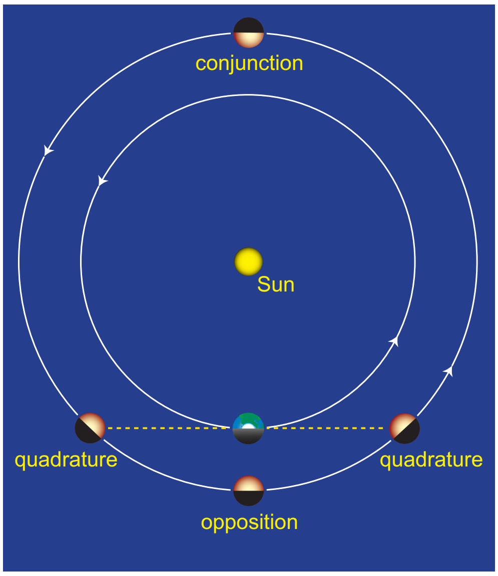
Bottom left: *the orbit of a superior planet with the most important postions (or moments) given. In* ***quadrature*** *a planet is 90° from the Sun, compared with the situations of First and Last Quarter for the Moon. It is, however, not the best moment to observe a superior planet. That is opposition. Inferior planet can of course never reach quadrature. Why not?*

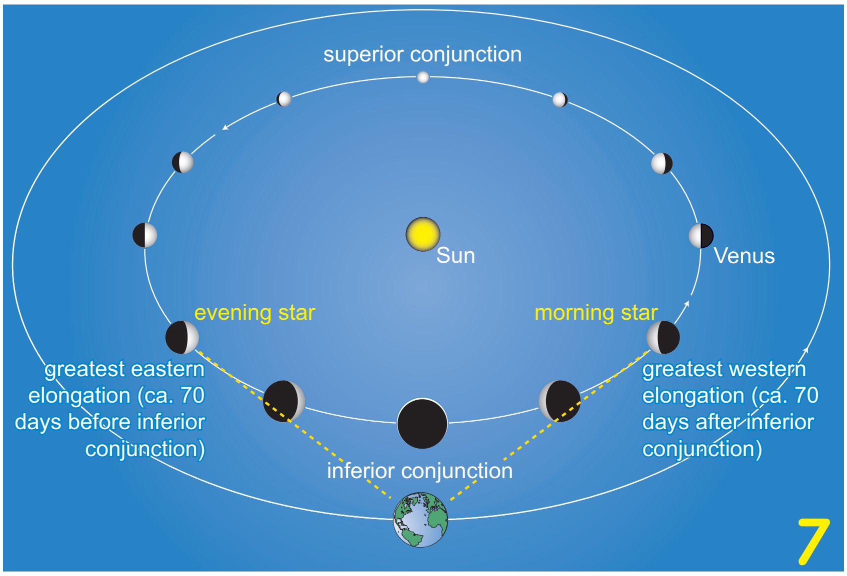
Middle: *sometimes several planets can be seen in the sky together. Here you see a conjunction of four of the five planets that are visible to the naked eye (Saturn had not yet risen). The picture was taken just before the launch of the Space Shuttle Endeavour, on May 16, 2011. Mars here is very hard to see here (particularly in the printed version), as had recently been in conjunction with the Sun and is far away. This also applies to Jupiter but that planet is much larger and therefore usually brighter than Mars.*

Top right: *just like the Moon, Venus shows* ***phases****, and therefore also a sickle shape now and then, when the* ***angular distance*** *between Venus and the Sun is large (see page 8).*

Bottom right: *the orbit of the planet Venus, containing the key positions in the orbit of of an inferior planet, like superior and inferior conjunctions and the two greatest elongations.*







Angular distance

*The **angular distance** is the angle between the directions in which two objects can be seen, for example two stars, two planets or a planet and the Sun. So when someone says a planet is close to a star, during a **conjunction**, what is meant is that their angular distance **in the sky** is small. See for more information page 15.*

3.5° tilted as seen from Earth, and therefore Venus usually has its inferior conjunction (in the sky) above or below our star. Only if Venus or Mercury in the neighborhood of a button we can see a transition. Only when Venus or Mercury are in one of the nodes (see page 5) a transit may occur. **Transits of Mercury** are much more frequent, with about 13 or 14 per century. This is in part because Mercury is closer to the Sun and has a shorter orbital period.

Phases of Venus

During Venus' orbit around the Sun we see the illuminated part of the planet continuously changing, because of the angle between the Sun, Venus and Earth. The illustration on the previous page shows that. Venus knows phases, like the Moon.

In superior conjunction we see Venus fully illuminated, although it is extremely hard to see. Not only is the planet furthest away, it is also outshone by the Sun! In inferior conjunction, we look at the dark side of Venus, and of course that is also not a good time to marvel at the planet.

Elongations are the best moments to observe inferior planets. This is for two reasons: the reasonably short distance from Earth to Venus, and the brightness. The latter depends on how we see her lit. The series of photos on the top right illustrates that. Inferior planets are either lit for the most part, but far away and thus small (in the sky); or they are much closer to the Earth, but all we see is a narrow crescent. When Venus is at its brightest, during an elongation, it is because then there is the best 'mix' of distance and lighting (in the picture sequence above Venus was in greatest eastern elongation on 29 March 2004).

***Top right:** a series of pictures of Venus, made between 27 February and 8 June 2004, with the same **magnification**. You don't see Venus in superior conjunction here (that was on 18 August 2003), but when the angular distance to the Sun is already much larger. The bottom right is Venus during the Venus transit of 2004!*

***Below**: what causes Mars to make loops.*

Superior planets

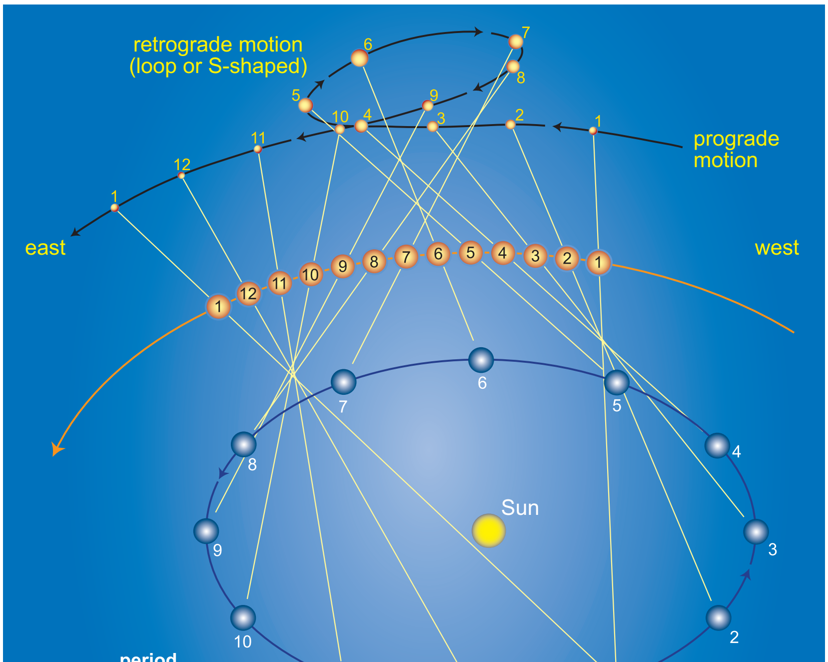
In contrast with inferior planets, superior planets, like Mars and Jupiter, can be visible around midnight. They can be in conjunction with the Sun, but of course never in inferior conjunction, as that would mean the planet would be between the Sun and the Earth!

So for these planets there is only **one type of conjunction**, and in that situation the total distance from the Earth is the greatest: the distance of the planet to the Sun *plus* the distance from the Earth to the Sun. Apart from being very far away the planet will also be so close to the Sun (in the sky) that we can barely see it.

If a superior planet is aligned with the Sun and the Earth, with the Earth between the Sun and the planet, that planet is in **opposition**. In that case the distance from Earth is the shortest: the distance of the planet to the Sun *minus* the distance from the Earth to the Sun. Opposition is therefore the best moment to observe a superior planet. You understand why an inferior planet can never be in opposition.

Planet 'loops'

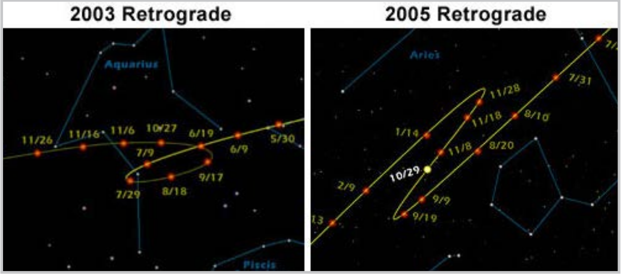
If a planet would stand still in the sky, so not orbit the Sun, the time difference between conjunction and opposition would be exactly half a year on Earth. But typically, the planets shift slightly eastward from night to night, drifting slowly against the backdrop of stars. Because of that the time difference much larger. If we would follow the planets for a while with respect to the Sun and their place in relation to the Sun, we see that they appear to 'dance'



	period (days)	freq.*
Mercury	8-15	111-121 d
Venus	20	584 d
Mars	72	25.6 m
Jupiter	121	13.1 m
Saturn	138	12.4 m
Uranus	151	12.15 m
Neptune	158	12.07 m

**) frequency, in months, except for Mercury and Venus, which are shown in days*
Example: Mars makes a loop every 25.6 months, one loop taking 72 days

around the Sun. From time to time they stop moving eastward (they are **stationary**) and change direction: for a few months they head west before turning back around and resuming their easterly course. This happens around opposition for superior planets, around inferior conjunction for inferior planets. We call that backward movement **retrograde** motion. After a while the planet will again be briefly stationary and then pick up its normal **prograde** motion. The planet' s apparent path over the months, against the starry background, will show a 'loop' or 'S' shape between the two stationary moments. It is, in fact, an illusion, caused by planets orbiting the Sun at different speeds and overtaking each other in the process. The illustration bottom left shows the mechanism behind the loops of Mars, in which the planets' positions are per month. Other superior planets do the same, but the loops become smaller as the distances to the planets increase. Mars, for instance, retreats about 19° before resuming its normal motion, Jupiter 10° and Saturn 7°. Mercury and Venus make the biggest loops and do that continously. A full loop-movement of Venus takes 584 days.



In practice

Working with the model

How do you use the Table planetarium to explain all these astronomical concepts? We will deal with that step by step.

Normal planetary motions

What is very important is that the planets all move in the same direction around the Sun: seen from above the north pole anti-clockwise. That's why planets have an motion from west to east, in the sky, but of course with different speeds. The closer a planet is to the Sun, the faster it moves. We come back to this later.

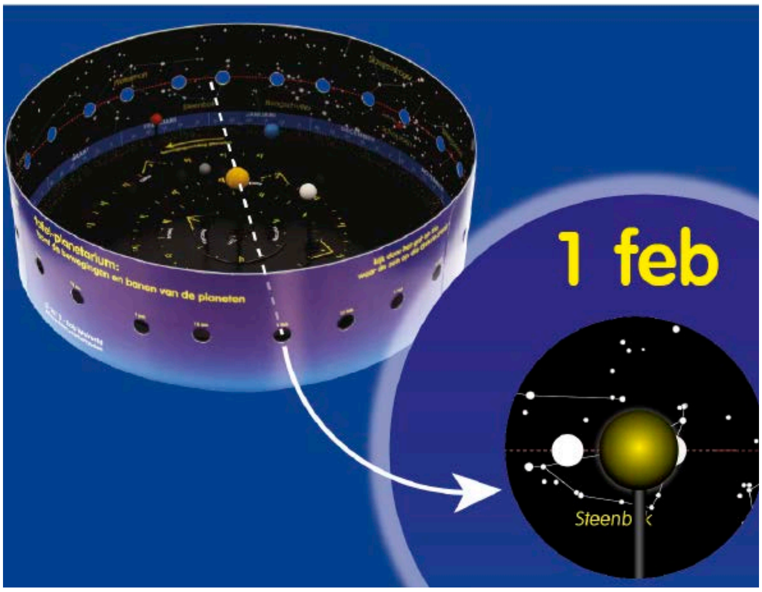
The ecliptic and the Zodiac

Besides, you should remember that the planets can always be found near the *ecliptic*. The Table planetarium shows the ecliptic on the inside of the high standing border. The ecliptic runs through a group of famous constellations: those of the Zodiac. These are the constellations where the Sun passes through it in the course of the year. Actually, there are thirteen (see page 6).

Where is the Sun?

The high border has 24 holes, with a date printed above each hole. One of the fun things about the Table Planetarium is that you can see through those holes to see in which constellation the Sun is on the stated date. For example, if you look through the 15 September hole, you will see that the Sun on that date is in the constellation of the Leo (the Lion)! Following the annual movement of the Sun completely you can learn to understand the ecliptic better.

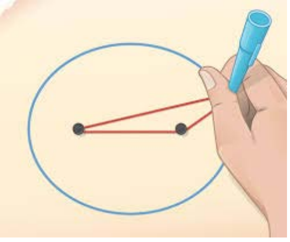
Top left: *planets can describe* ***loop*** *or* ***S****-shaped forms in the sky planet when they move retrograde. Here you can see the tracks across the sky made by Mars in 2003 (left) and 2005. One is a definite loop, the other an 'S'. You'll also see that Mars was stationary around 27 or 28 July 2003, and also on 18 September. Planets move eastward, normally, so in both illustrations they move from right to left. Credit: NASA/JPL-Caltech.*
Bottom left: *when you look at the 'Sun' in the Table Planetarium, through the hole of 1 February, you'll see that it was in the constellation Capricorn that day. That is, one of the constellations of the Zodiac. Are you a 'Capricorn'? Then, naturally, you cannot see 'your' constellation, because the Sun is there, and the Sun outshines all other stars completely (except during an eclipse!). So go out and look at your constellation half a year after (of before…) your birthday.*
For Capricorn it is best to observe it in the summer.
Bottom right: *a very nice and beautiful picture of a conjunction of the bright planets Venus and Jupiter, on 1 July 2015, just after sunset. Photo Marek Nikodem (Bydgoszcz, Poland).*



Elliptical orbits

Orbits, like the orbit of the Moon around the Earth or that of a planet around the Sun, are not circular but elliptical. A circle has a ***center point****: you can draw with a pair of compasses. An ellipse has no center, but two* ***focal points****. You could draw one with two thumb tacks or nails in a sheet of paper on a board, and a piece of string in which you place your pen. If you put the two pins are close together you draw something that almost is a circle, place them far away from each other and you'll get an elongated ellipse.*

An elliptical orbit naturally also has two focal points and in the case of a planet the Sun is in one of those points (the other focal point is empty). That means that there is always one point of the orbit which is closest to the Sun, ***perihelion****; and one that is furthest from: the* ***aphelion*** *('apo': 'away from'; 'peri': 'near'; 'helium' is derived from 'Helios': the Sun). The perihelion of the Earth is about 147 million km from the Sun, the aphelion about 152 million km. That gives Earth the least excentric ('most circular') planetary orbit in the Solar System, after Venus and Neptune. In the case of the Moon's orbit around the Earth, we call these points* ***perigee*** *when the Moon closest to the Earth (as close as 356 400 km), while in* ***apogee*** *the Moon is farthest from Earth (maximum 406 700 km). The 'geum' stands for 'Earth', just like 'geo'). In the case of moons around other planets we speak of* ***periapsis*** *and* ***apoapsis****.*



Opposition, conjunctions and elongaties

It's not hard to demonstrate important alignments and positions in orbits with the Table Planetarium, using the illustrations on pages 7 and 8. Just place Venus (the model on the disc) in inferior and superior conjunction; then in *greatest eastern elongation* (the largest possible angle between Venus and the Sun – in the sky). Next, put Mars in *conjunction* and then in *opposition*.

Conjunction is the situation when two or more heavenly bodies are close toe ach other in the sky: a planet and the Sun or another star, or two planets or a planet and the moon. Please try that out with the Table planetarium: place two planets or a planet and the Sun in such a way that, seen from Earth (here the model!), they are right next to each other.

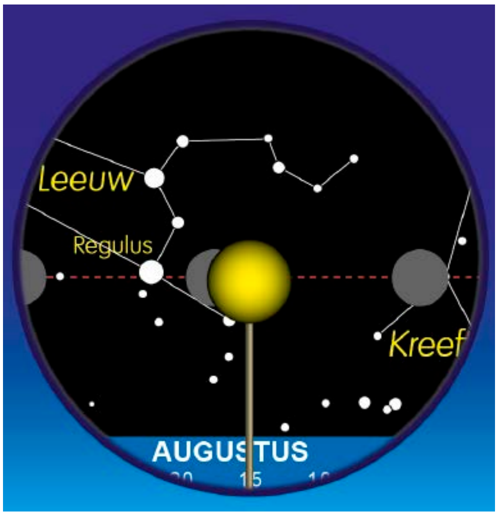
Planet loops

Planets move slower in their orbit as they get further from the Sun. Mercury moves at 48 km/s, Venus at 35, Earth at 30 and Mars at 24 km/s. They also have different **orbital periods**: the time it takes to complete one orbit. Earth's orbital period is 365.25 days: one year. The orbital periods for the other planets involved:

Mercury	*88 days*
Venus	*224 days and 17 hrs*
Earth	*365 days and 6 hrs*
Mars	*1 year, 321 days and 17 hrs*

Because they have different orbital periods the planets overtake each other occasionally. This can be compared to when you sit in a stationary train while another train just leaves in the opposite direction of that you're facing. Then it feels like you're going backwards!

When planets do this, it leads to the interesting phenomenon that a planet, seen from Earth, temporarily moves in the wrong direction for some months (retrograde motion) and may even make a loop or S-shaped track! See also the series of illustrations on pages 12 to 14.



Right*: when you look through the hole in the high border, with 15 aug printed above it, towards the 'Sun' in the model, you will see that the Sun is then in the constellation of Leo (Lion, Leeuw in Dutch). See page 16 for translations.*

Illustrating planet loops

When you would move the 'planets' (so rotate their discs) step by step, in a manner consistent with the differences in their relative orbital periods, you can simulate and track planet loops. You'll see how the eastbound motion of a planet stops (it is *stationary*), how the planet apparently starts movings westward for a while (*retrograde*), is stationary again and then returns to its normal eastbound movement again.

For this purpose, you would need some sort of calendar on all the planet discs. We used a simplified division into 'months', that is perfect for informative and enjoyable demonstrations. What we did was dividing each disc into these 'months', the Earth-disc divided into its real 12 months. Based on the actual orbital periods the best workable relationship would then be 3 : 8 : 12 : 24. This system, which is shown on the planet discs, is wonderful to work with.

On the bottom of the 'planet tray' you'll notice a big, fat arrow. That's the point of reference. When you configure the different planet discs you do so relative to that arrow.

Marking planetary positions

When you start working with the planetary positions in relation to each other and in the sky, and from moment to moment, you also need something to mark the positions somehow. That's where the small markers ('arrows') come in handy. You can place these arrows on the high border of the Table Planetarium or on the Mars-extension. You can now follow the movement of the planet concerned very accurately, because there are arrows in the set from 1 to 8 'months', and also for each of the four 'weeks' in these months (for 1, 1¼, 1½, 1¾, 2 months, etc.). In practice you will use the arrow with the fractions (like 4½) only to mark positions around the two times when a planet is stationary, in order to determine those moments more exactly.

To start with the planetarium

What you need to do is the following. Insert the special Mars-extension in the bottom of the Table Planetarium, when you use the red planet for your demonstration. The Mars-model is too close to the edge to use the border. When you use Venus or Mercury you can use the high border. What you now need are the arrows to **mark** the positions of Mars, in the sky (so, as seen from Earth). Furthermore, you need a long, thin stick to determine those positions, measured from the center of the Earth-model and through the centre of the model of the other planet. That's because it's from the Earth that we see it all.

Each planet disc shows the month numbers. For the discs of Earth and Mars these are not all the way through, because it is not necessary. The month numbers are indicated by thick strokes. Between the month numbers are thinner strokes: ‘two weeks’. Apart from the Mars-disc they also have dots between the lines, for the ‘weeks’ 1 and 3 (‘week’ 2 already has a thin stroke).

Now rotate the discs of the planet involved and the Earth to position month 1, so point the ‘1’ on either disk toward the big arrow on the bottom of the Table Planetarium. Use the stick (or a large ruler) to determine the position of arrow ‘1’ on the border of the Planetarium or the Mars-extension.

Then rotate both discs to position 2, or one of the ‘week’ positions, and place arrow ‘2’. Continue this prodedure for as long as long you deem necessary (you can stop when the normal movement has apparently set in).

When you do this, you’ll easily see the points or moments of the *stationary* phase, when the *retrograde* motion starts, when it is stationary again and ultimately when it picks up its normal eastbound path again. You will not be able to produce planet loops, or S-shapes, because that only happens because the orbits all a bit tilted. In the Table Planetarium all orbits are of course perfectly in the same plane.

The problem of elliptical orbits

The orbits of planets (and all other objects in the solar system) are not circular but more or less *elliptical*. Elliptical orbits in the solar system have the Sun in one of the two focal points, with a *perihelion* and an *aphelion* (see side text on page 10). This means that orbits are also *eccentric*! In addition, orbits are also tilted more or less, up to 44° for the dwarf planet Eris! Obviously inclinations are impossible to show with this type of model.

Ellipse instrument

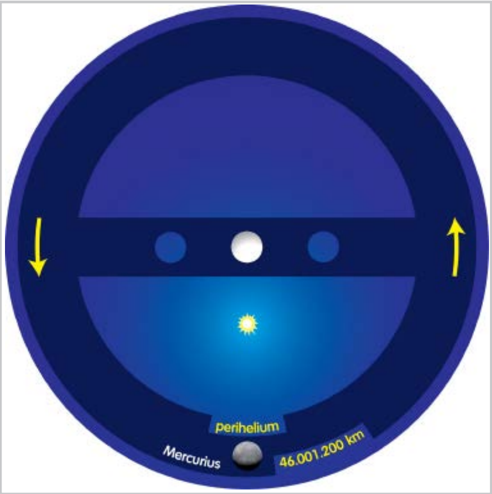
It is not possible to show elliptical orbit in a model like this. An *ellipse* has no center point, where you can simply push in a drawing pin: it has two *focal points*. That is why there is an additional instrument in the Astroset, the *ellipse instrument*. This useful instrument (designed by Tom Peters) can help you to better understand *perihelion* and *aphelion*.

We use the orbit of Mercury as an example, because its orbit is the most elliptical of the planets: its perihelion is 46.0 million km from the Sun, its aphelion 69.8 million km. These values for Earth are 152.1 and 147.1 million km, for Venus 107.4 and 108.2 million km and for Mars 249.2 and 206.7 million km. For smaller objects these ranges are much larger. The dwarf planet Pluto, for instance, moves between 4.5 billion and 7.5 billion km from the Sun!

Usually we use the average distances for planets, dwarf planets and other solar system objects, for a general idea of the distances. The distances and dimensions in this instrument are not to scale.

Ruler to determine distances to planets

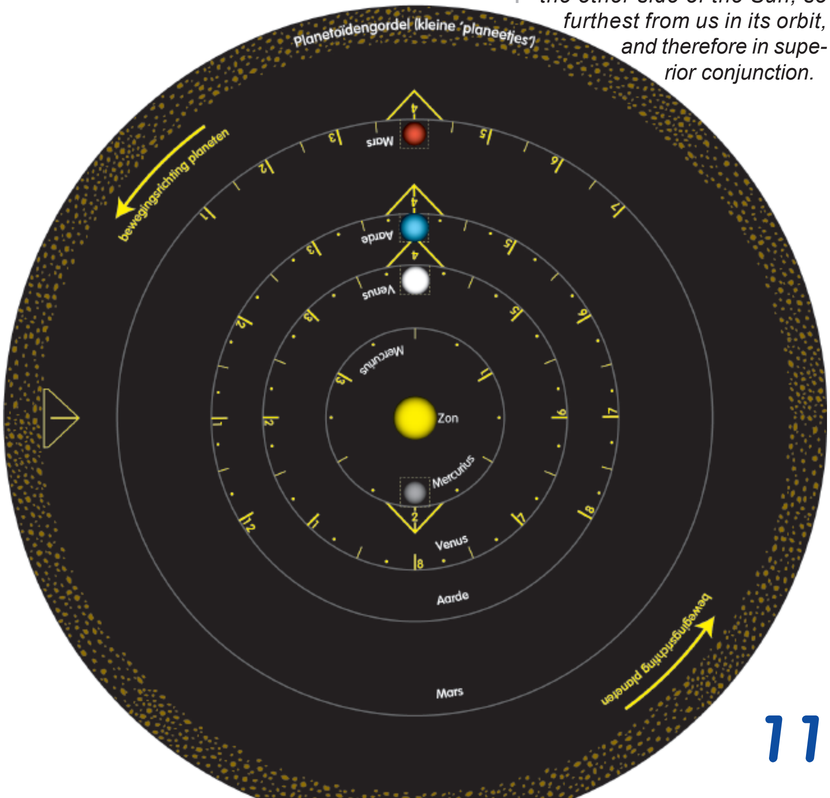
Another additive is the small ruler to measure the distances (in km and AE, see side text) in the Table Planetarium up to Mars. However, the reversed side also shows the distances of the Sun to the other planets and dwarf planets at the same scale. With it you can determine the distances of Jupiter, Saturn and the other planets to the model Sun in the Table Planetarium. Of course, the planet models (so the wooden beads) are not to scale. You would not even be able to see them on this scale! For that purpose we have the very special and informative Solar System model (see product list).



Astronomical Unit

Distances in the Solar System lead to very large numbers. Neptune, for instance, is 4.5 billion km from the Sun. As long as we know the (average) distance from the Earth to the Sun accurately enough (149.6 million km) astronomers use that distance as an alternative distance unit in the Solar System and the surroundings: the ***astronomical unit (AE)****. Thus 1 AE is 149.6 million km. That puts Neptune at 30 AE. Also see the distances in AE and km on the special Ruler.*

Left*: the ellipse instrument.*
Below*: the Table Planetarium allows you to simulate important configurations of the planets, like conjunctions en oppositions. In this case you see Earth and the neighbor planets Mercury (grey), Venus (white) and Mars (red) neatly aligned. In this situation Mars is in* ***opposition****. The inferior planets Mercury and Venus are in conjunction with the Sun, what means that seen from Earth they are in the same direction as the Sun. Of course this is bad for observation, as the Sun outshines them. But you can see another thing: Venus is between the Sun and the Earth, and therefore closest to our planet. It is in* ***inferior conjunction****, which means that the planet is larger in the sky, although we look at the dark side of Venus. Mercury is on the other side of the Sun, so furthest from us in its orbit, and therefore in superior conjunction.*



The Table Planetarium

Retrogade motion-series

*The Table Planetarium allows you to perfectly illustrate the retrograde movement that planets now and then show. It is caused by planets overtaking each other. On this and the next two pages you will see a series of illustrations to show what causes this backwards motion. At the top (1) you see the **start situation**, with Earth and Mars in a configuration that is useful to begin the demonstration with. Using Mars, we need the 'Mars extension', because the Tale Planetarium's size is too small for the model Mars to correctly show it motions (remember that the distances are greatly reduced: the Earth is in reality at about 150 million km, and Mars is on average circa 228 million km from the Sun! For Mercury and Venus these numbers are, respectively, about 58 million km and about 108 million km.*

Periods

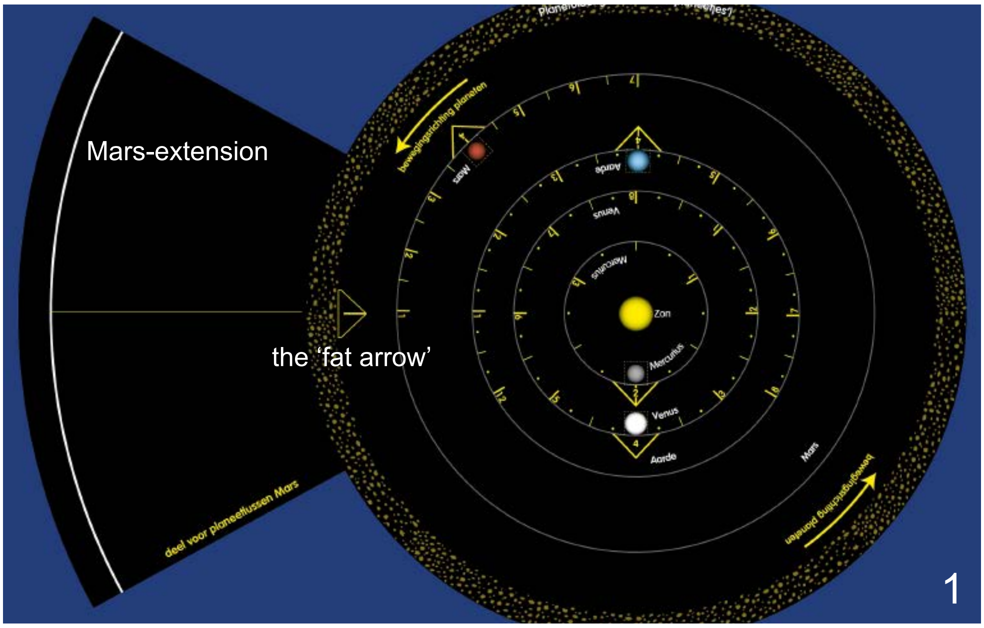
The real ratio of the orbital periods is simplified in the Table Planetarium:

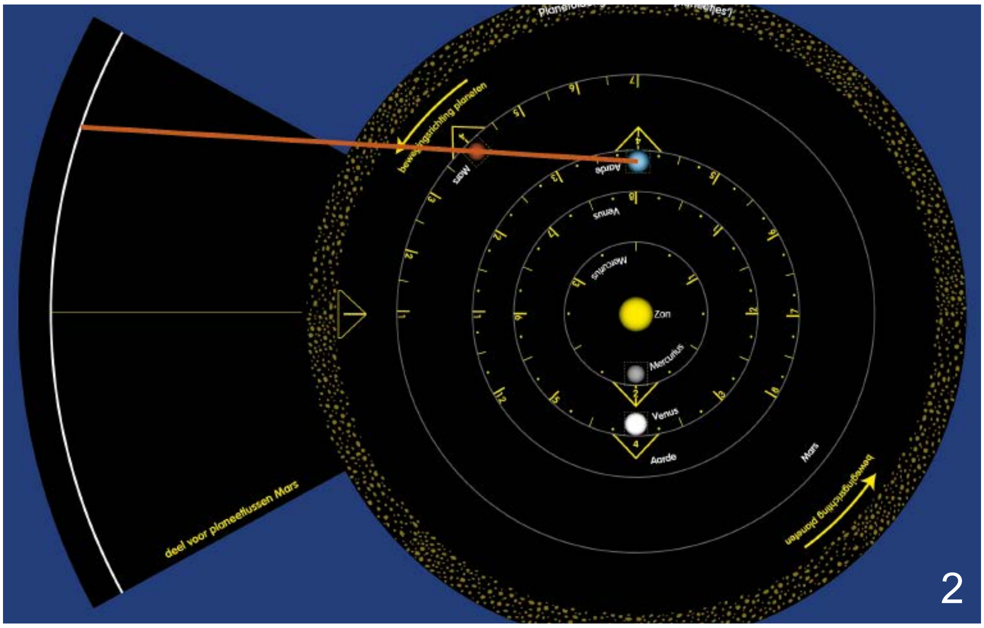
Mercury:	*3 months*
Venus:	*8 months*
Earth:	*12 months*
Mars:	*24 months*

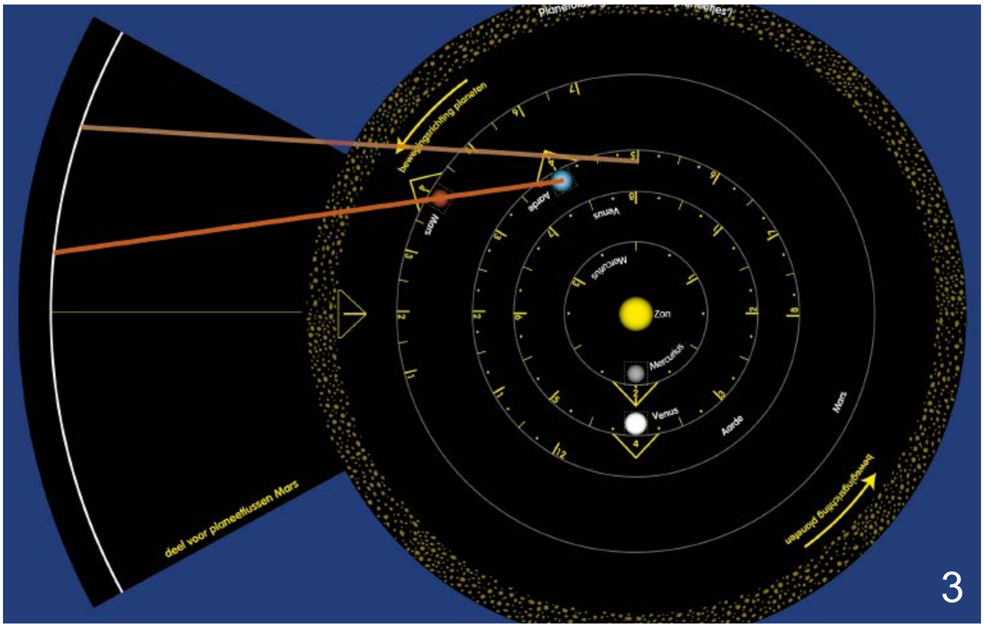
Start of the demonstration

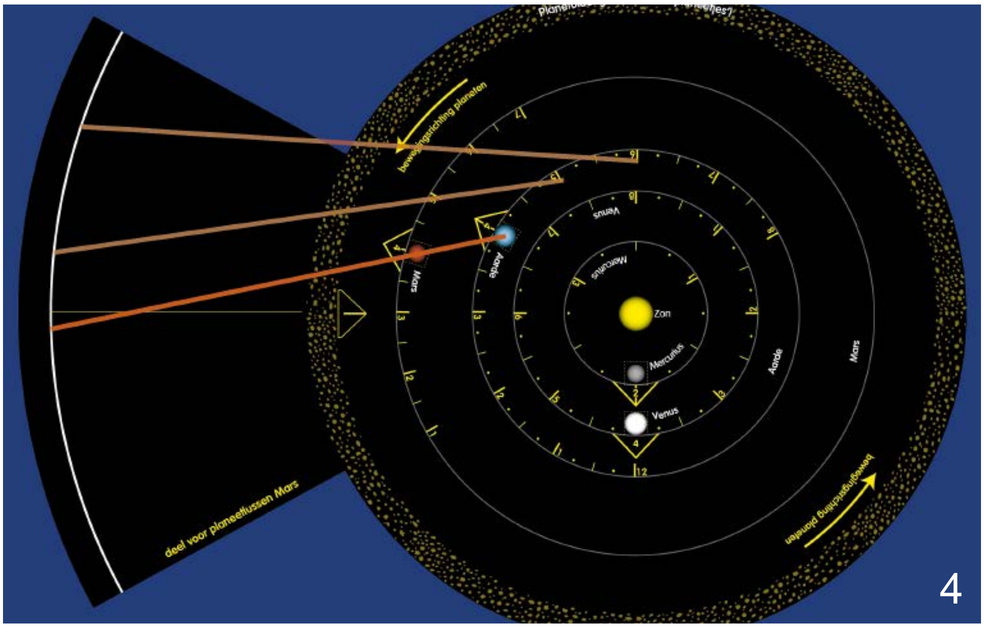
What's important now is to place the planets involved in the demonstration at position '1'. We only use Mars and Earth now, so ignore Venus and Mercury, although you can perfectly use the inferior planets for a demonstration. Then you don't even need the Mars extension: the high border of the Table Planetarium will do nicely.
Rotate the Earth and Mars discs, so to have the yellow '1' of both discs opposite the thick arrow on the bottom of the planetarium.

The illustrations:
1. *the start situation.*
2. *the start situation, with the direction to Mars, as seen from Earth, indicated with an orange line. In the demonstration you can use a 40 cm long rod or something else. Use arrow '1' to mark the start position of Mars, on the border of the Mars extension.*
3. *After 1 'month' (position '2') Mars has moved eastbound, as it normally does. Place arrow '2'.*









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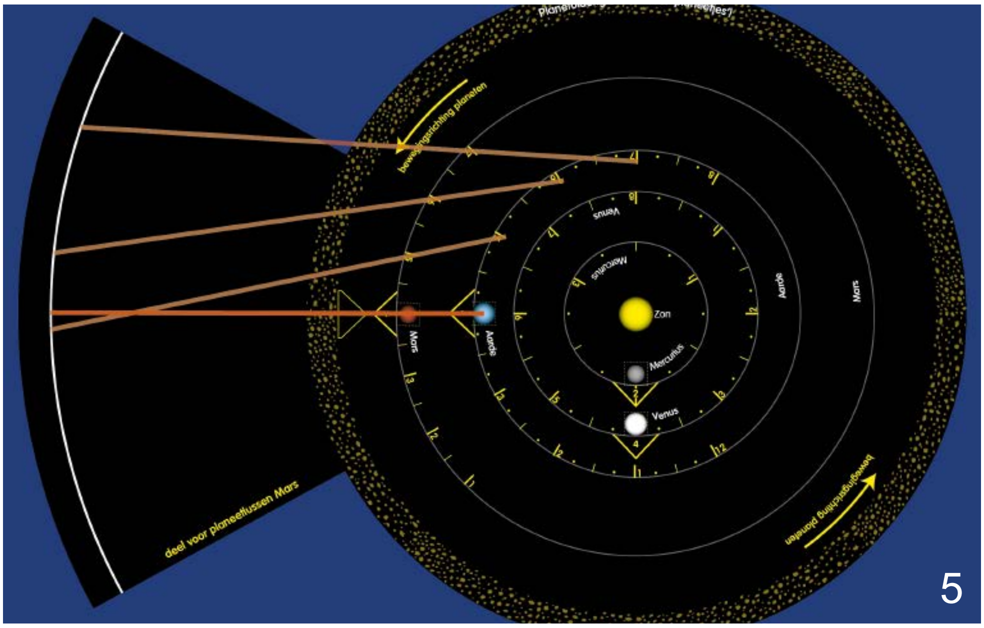

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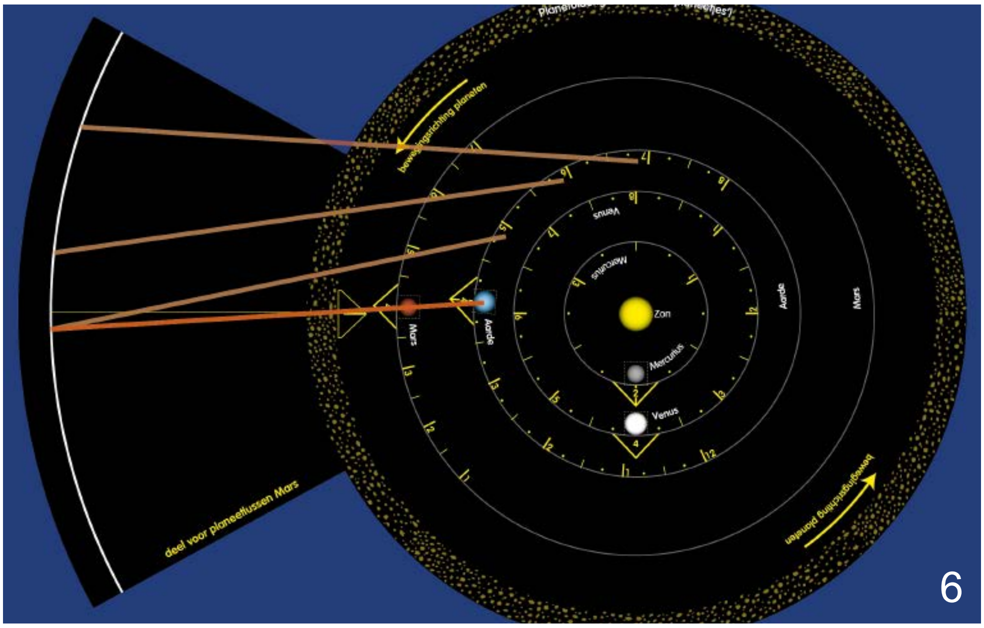


6

Possible demonstrations:
1. Direction of movement

The Table planetarium shows many aspects of the orbits of planets, for instance the fact that all the planets and most of the smaller Solar System objects move in an ***eastbound*** *direction around the Sun. They do that because, when seen from above the Sun's north pole, all planets move anti-clockwise. The reason for this is not difficult: the* ***solar nebula****, the huge cloud of gas and dust from which the Sun and the rest of the Solar System emerged 4.567 billion years ago was slowly rotating. The formation of the Solar System began when that solar nebula started to contract, due to the radiation of 'nearby' heavy young, hot stars or the shock wave of a supernova explosion. This contraction made the cloud spin faster. That is the* ***Law of Conservation of Angular Momentum****, a law you can see at work when a figure skater performs a pirouette: she will spin faster as she pulls her arms closer to her body.*
The faster rotation changed the shape of the cloud into a disc: the ***protoplanetary disc****. The Sun, the planets and other solar system objects all formed within that disc, and therefore all move in the same direction around the Sun, and the Sun and most other objects also rotate from west to east. That is the reason why on Earth we see stars rise in the east and set in the west (apart from the circumpolar stars, see side text on page 15).*

(continued on page 14)

The illustrations:

4. *after 2 'months', with the yellow '3' opposite the thick arrow, Mars still moves eastbound.*

5. *after 3 'months' Mars moves in* ***westbound****! Not long before, a 'week' maybe, Mars had to have slowed down and stopped movement in the sky for a moment (it was* ***stationary****), after which the* ***retrograde*** *motion started. To determine the phases more accurately you better start using the 'week arrows'.*

6. *You can determine the exact* ***moment*** *when Mars was* ***stationary*** *by making the steps smaller. In other words, by using not only the positions for the 'months', but also those of the 'weeks': the arrows for 3¼, 3½ and 3¾.*

The Table Planetarium

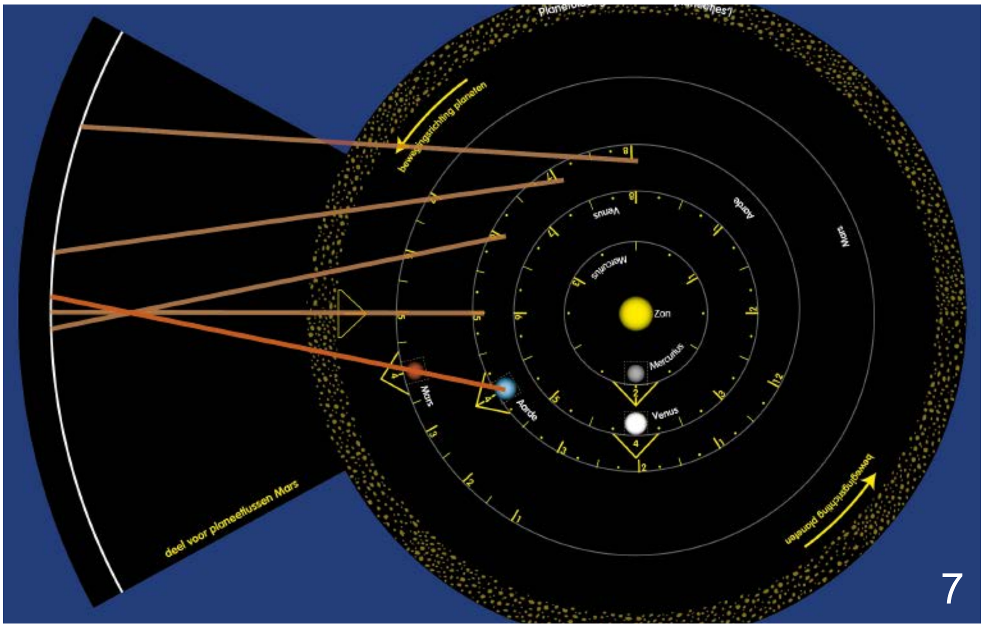
(Continued from page 11)

However, Venus rotates in the ‘wrong’ direction, probably because it was flipped upside down by a large impact in the early Solar System. Uranus was put on its side for (again probably) the same reason. Some smaller objects, such as asteroids, ice dwarfs and comets, have a retrograde and/or very tilted orbit. Such deviant behaviour may have been caused by colissions of the influence (gravity) of a large planet, after the formation of the Solar System.

2. Inferior & superior planets

*The Table planetarium includes the four planets that are closest to the Sun: the **inferior planets** Mercury and Venus, the Earth and the **superior planet** Mars. Other superior planets are Jupiter, Saturn, Uranus and Neptune. For the purpose of Table Planetarium one superior planet (Mars) is sufficient as they exhibit similar behaviour in the sky. Besides, just adding Jupiter at this scale would make the Table Planetarium too large: it should be 34 cm from the model Sun! Just for fun we have included a small **Ruler**, with distances in km and **AE**, so you can even use the planetarium as a small scale model.*

The illustrations:
***7.** after 4 ‘months’: Mars still moves **retrograde**, or ‘backwards’.*
***8.** after 5 ‘months’ Mars has picked up its normal eastbound movement again. It must again have been **stationary** shortly before! Can you determine when that must have been? When I try to determine this I notice that Mars still moved retrograde 3 ‘weeks’ before (so after 4¼). But setting the Table Planetarium for 4½ and 4¾ ‘weeks’ (one and two weeks ago) you’ll notice that Mars was at about the same point in the sky on both moments. Therefore it was **stationary** in that period!*
***9.** after 6 ‘months’ it is clear that Mars has definitely picked up its normal, prograde motion.*



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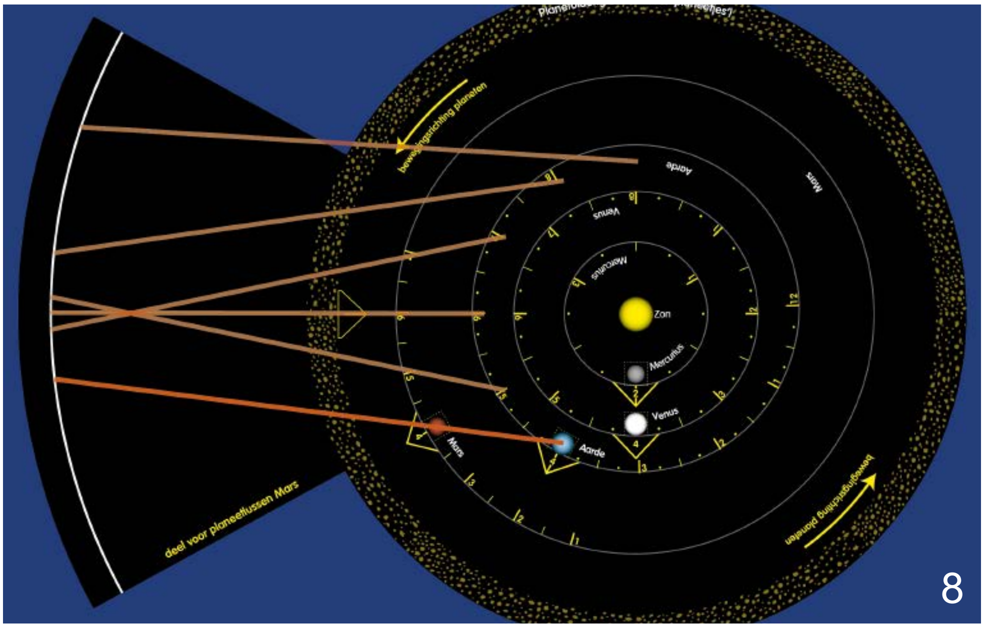

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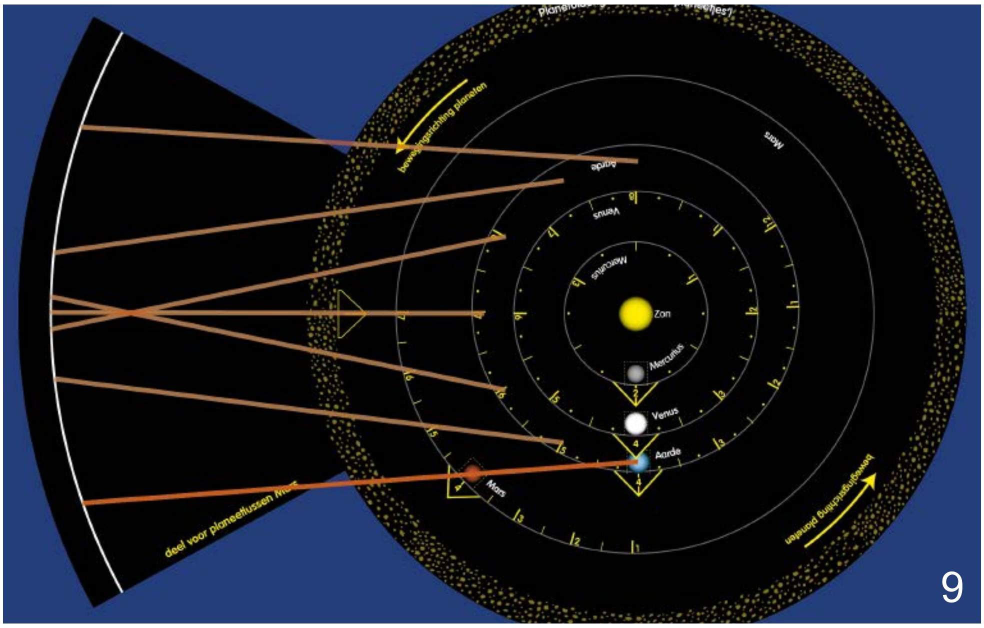

9

The Astroset Moon and Planets

Index

Circumpolar stars

Star rise in the east and set in the west, don’t they? Well, not all do so. Depending on where you are on Earth certain stars and constellations that are (in the sky!) close to the pole star (or the south celestial pole, if you are on that hemisphere) never set. They are visible all year round, provided it is dark... and the weather is clear. We call such stars and constellations ***circumpolar****.*

Angular distance

In the sky you see stars, planets, nebulae and more in all directions. The distances can vary tremendously, from the Moon’s 384 000 km from Earth, to the Andromeda Nebula at 2.5 million light years! To enjoy the starry sky, you can ignore distances. It is useful, though, to know where you can find everything, the patterns, how the objects are placed in the sky in relation to each other. For that we use the ***angular distance****. This is the angle between the directions in which two objects can be seen, for example two stars, two planets or a planet and the Sun. This angle is measured in degrees (°). Each degree is divided into 60 arc minutes (‘) and each arc minute in 60 arc seconds (“). The diameter of the Sun, for instance, is approximately 0.5° or 30’, or 1800”. The distance from the top front star of the seven stars of the Big Dipper (Dubhe) to the pole star is 28°. When people speak of conjunctions of planets, or planets with bright stars, or planets with the Moon, it usually means angular distances of a few degrees at most.*

Programme Rob Walrecht Productions

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**) English versions will become available as from 2019*
***) English versions available for 50°N, English Star Wheel for 40°N*

Dutch Astroset
*This **Astroset Maan en Planeten** is (at the moment of writing) only published in Dutch. Our own possibilities to distribute versions in English or other languages are too limited to allow us to publish these ourselves.*
*We hope to find **partners** (publishers) in other countries some day, to make our kits of models and instruments, books, posters and planispheres available to a wider, global audience.*

Translation
However, the models in this Astroset do not contain that much text, so by offering the translation into English here, others can understand and use them.
We have not translated larger texts, as they involve either just an explanation of what the Astroset is for, an explanation for something that is covered by this manual or information about our other Dutch products - so for Dutch-speaking people.
We also presume that the Dutch names for the months of the year can be easily understood by eneryone else.

Good luck!

Translations

General

Separators
In the Netherlands dots are used as separators in numbers. To give a few examples:
1,5 = 1.5
39,8 AE = 39,8 AU
46.001.200 km = 46,001,200 or 46 001 200 km

Names of constellations

Leeuw:	Leo (Lion)
Kreeft:	Cancer (Crab)
Tweelingen:	Gemini (Twins)
Stier:	Taurus (Bull)
Ram:	Aries (Ram)
Vissen:	Pisces (Fishes)
Waterman:	Aquarius (Water Carrier)
Steenbok:	Capricorn (Sea Goat)
Boogschutter:	Sagittarius (Archer)
Slangendrager:	Ophiuchus (Serpent Holder)
Schorpioen:	Scorpius (Scorpion)
Weegschaal:	Libra (Scales)
Maagd:	Virgo (Virgin)

Plate 1 - Table Planetarium 1

Tafelplanetarium:	Table Planetarium

toont de bewegingen en banen van de planeten:
shows the motions and orbits of the planets

kijk door het gat en zie waar de zon op die datum staat: look through the hole and see where the Sun is on that date

onder:	bottom

Reverse:

Plak aan:	glue to

Plate 2 - Table Planetarium 2
Planetoïdengordel (kleine ‘planeetjes’):
Asteroid Belt (small ‘planets’)

Bewegingsrichting planeten:
Direction of movement of the planets

Plate 2 – Ellipse instrument

gemiddeld:	average
aphelium:	aphelion
perihelium:	perihelion

Plate 3 – Table Planetarium 3

Zon:	Sun
Mercurius:	Mercury
Aarde:	Earth
Stationair:	stationary

Plate 3 – liniaal (km en AE)
liniaal (km en AE): Ruler (km and AU), (for determining distances in and outside the Table Planetarium)

miljoen:	million
miljoenen km:	millions of km

Afstanden andere planeten:
distances to other planets
Afstanden enkele dwergplaneten:
distances to a few dwarf planets

AE: AU (Astronomical Unit, unit of distance)

* cm van de ‘zon’ in het Tafelplanetarium:
cm from the ‘Sun’ in the Table Planetarium

gem.:	average

Plate 4 – Table Planetarium 4
deel voor planeetlussen Mars:
Mars extension (for planet loops demonstration)

Plate 5 – Earth-Moon model inside

zonlicht:	sunlight
nieuwe maan:	New Moon
eerste kwartier:	First Quarter
volle maan:	Full Moon
laatste kwartier:	Last Quarter
wassend:	waxing
afnemend:	waning

(standaardjes voor de aarde en de maan):
little supports for Earth and Moon models

Aarde:	Earth
Maan:	Moon

Plate 5 – Earth-Moon model outside
Om de fasen van de maan en verduisteringen te leren begrijpen:
to learn to understand the phases of the Moon and eclipses

richt vanaf deze kant een zaklamp:
point the flashlight from this side

dit witte deel uitknippen of uitsnijden:
cut out this white part