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TASTE

Teaching Astronomy at Educational Level

Teaching Astronomy at Educational Level: student materials

(Supported by the Erasmus+ project 2020-1-IT02-KA201-079528)

SOLUTIONS Unit 1

Introduction

This lecture series guides you through different units to be carried out in your classroom with your teacher (unit 1) and at a planetarium (units 2-4).

Not all sections are of the same difficulty so don't worry if one exercise is hard, the next one might be easier. Most concepts are touched on more than once.

You will encounter different content throughout this document marked with the following symbols:

Background information

Exercises
(you may need a tablet or similar with internet connection)

Activities
(you may need additional things supplied to you by your teacher)

Summaries and key points to remember

Don't hesitate to ask your teacher or planetarium staff for help. Have fun!

Unit 1: The apparent motion of the Sun and the stars

Part 1: The daily motion of the Sun and the stars

Exercise 1.1

Figure 1 shows a compilation of 38 panoramic photographs of the Sun during the first day of winter at a location near the Mediterranean Sea.

- Indicate the location of sunrise, highest point, and sunset.
- Indicate with an arrow in the sky how the Sun moves.
- Indicate with arrows on the ground the directions of east, south, and west.

Figure 1: 38 panoramic photographs of the Sun during one day.
Source: http://starsoverpeoria.blogspot.com/2016/12/winter-solstice-shortest-day-of-year.html

- What causes the motion of the Sun that you see in the sky? Explain using the images in Figure 2.

  Because the Earth rotates on its axis, we see the Sun moving in the sky.

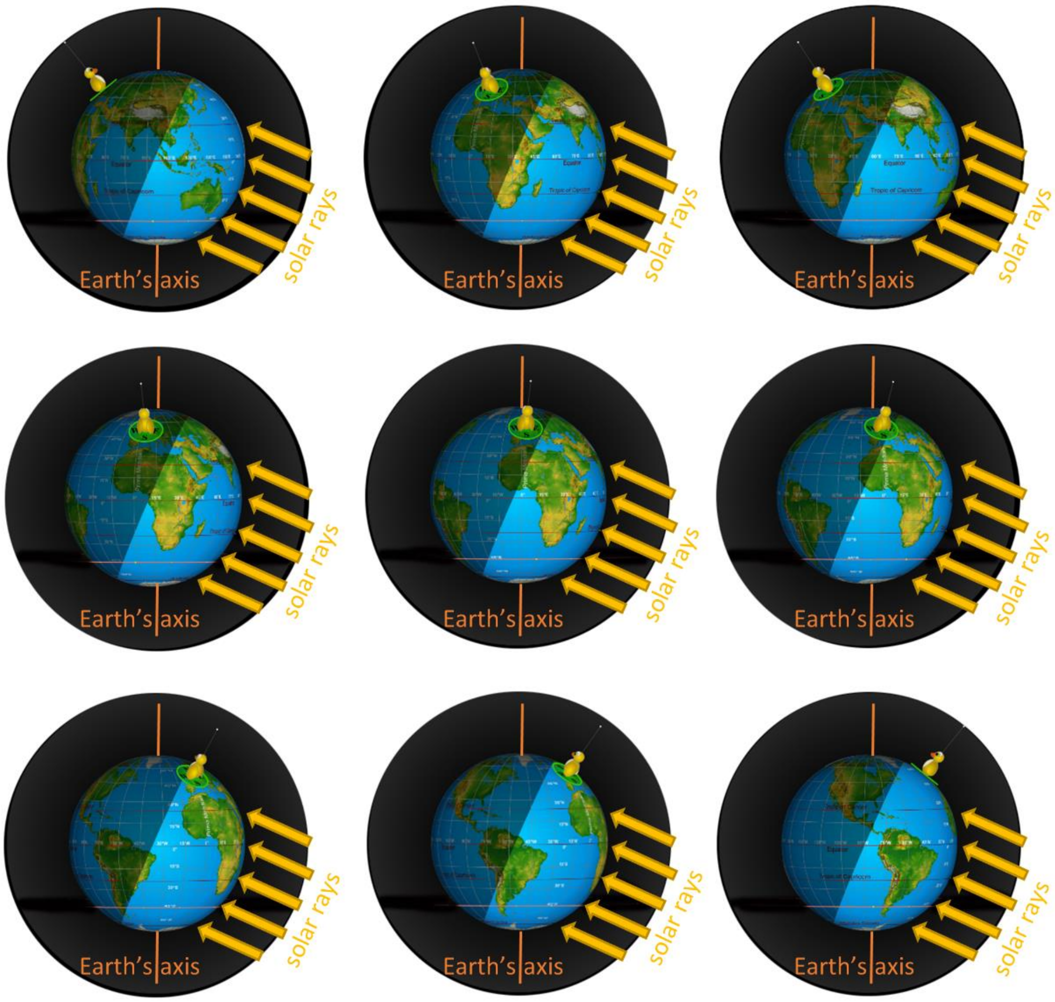

Figure 2: Images of the Earth during one day.
Source: https://www.viatienen.be/Erasmus/dailymotion.mp4

Exercise 1.2

In Figure 2, you see that the observer is standing on a green disk. This disk represents the local plane tangent to the Earth at the observer's location. We call this the observer's horizon plane. Each observer has its own horizon plane, depending on where that observer is standing. If the observer moves, the horizon plane also moves, so the observer is always standing on the horizon plane.

- We call the point in the sky directly above the observer the zenith of the observer (Figure 3).

Figure 3: Side view of observer (the duck) on horizon plane.

- We indicate the cardinal directions on the horizon plane: north indicates the direction to the North Pole of the Earth and south indicates the direction to the South Pole of the Earth (Figure 4).

Figure 4: Top view of observer on horizon plane.

- An observer in the northern hemisphere sees the pole star in the sky, in direction north. We connect the observer and the pole star with an orange line. The projection of this line on the horizon plane defines the direction north (Figure 5).

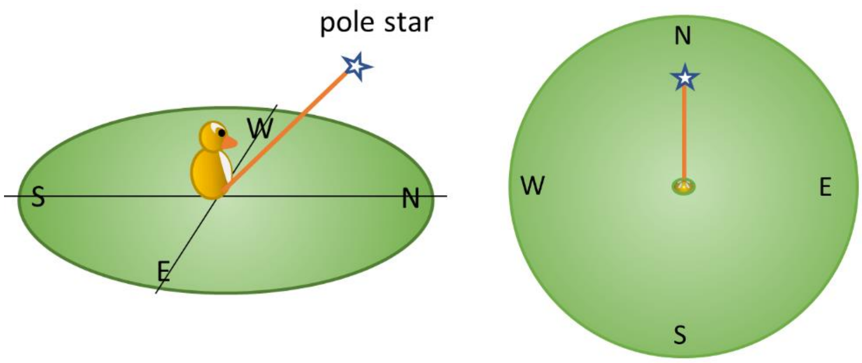

Figure 5: Observer on horizon plane with cardinal directions marked on it.

Only stars that are above the observer's horizon plane are visible to the observer. Figure 6 shows the horizon plane for an observer in Belgium together with that part of the sky that is visible to this observer.

- Indicate the zenith on the figure.
- Draw the connecting line between the observer and the pole star.
- Indicate on the horizon plane the four cardinal directions.

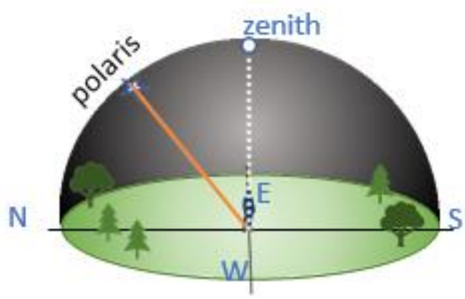

Figure 6: Observer in Belgium.

Exercise 1.3

For an observer in the northern hemisphere of the Earth, the pole star is always above the observer's horizon plane.
To understand which other stars are above the observer's horizon plane, we project the stars on a large imaginary sphere around the Earth, regardless of their actual distance from the Earth. We call this sphere the celestial sphere (see Figure 7).

- We take the radius of this sphere much larger than the Earth which has a radius of about 6400 km.
- The centre of the celestial sphere coincides with the centre of the Earth.
- We call the intersection of the equatorial plane of the Earth with the celestial sphere the celestial equator, just as we call the intersection of the equatorial plane with the globe the equator. You can think of the celestial equator as the projection of the Earth's equator on the celestial sphere.
- The Earth's axis points in the direction of the pole star.

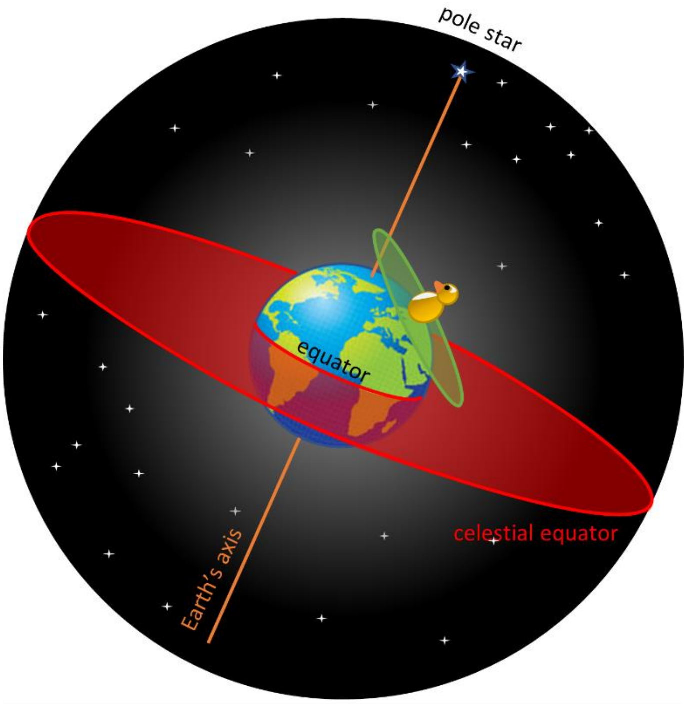

Figure 7: Earth and the celestial sphere.

In Figure 7 above, the Earth is represented large relative to the celestial sphere. Since the Earth is rather small relative to the celestial sphere, we better represent the Earth by a point at the centre of the celestial sphere. We then draw the horizon plane of an observer on the Earth at that point in the centre of the celestial sphere. Therefore, the angle between this horizon plane and the equatorial plane depends on where the observer is on Earth.

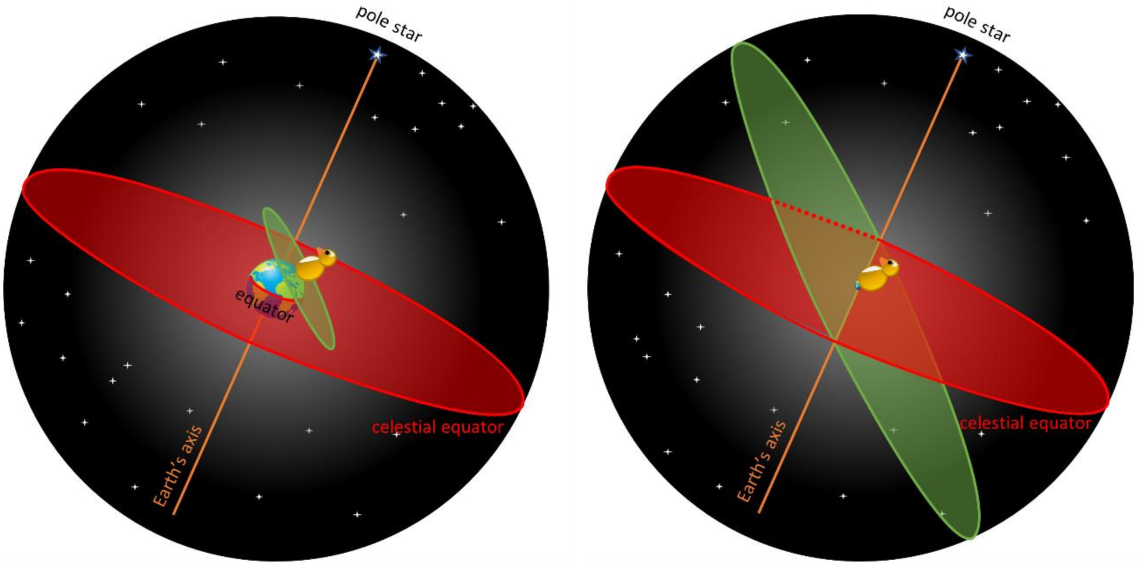

Figure 8: The celestial sphere.

- Indicate on Figure 8 which piece of the celestial sphere is visible to the observer at this time.

We now rotate the plane of the horizon so that it is horizontal.

- Indicate again on Figure 9 below which part of the celestial sphere is visible to the observer at this time. Also indicate the cardinal directions on the horizon plane.

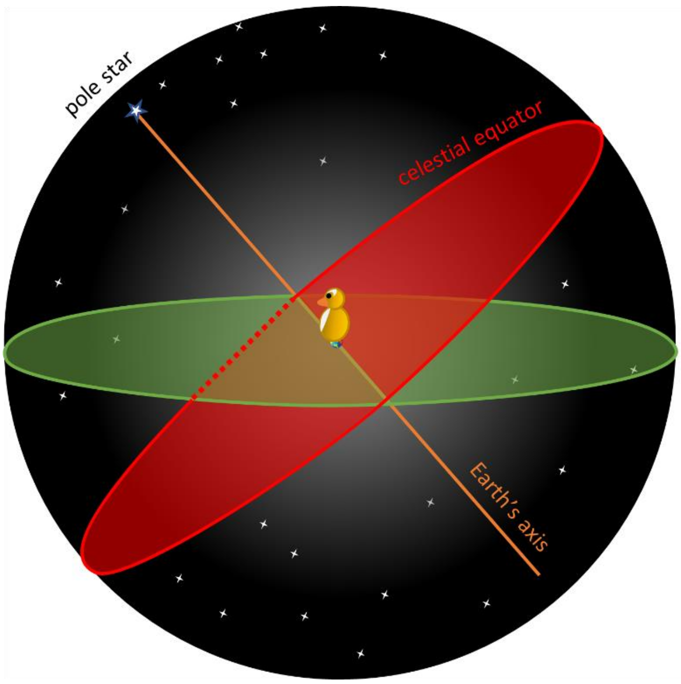

Figure 9: The celestial sphere with the horizon plane in a horizontal position.

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If we draw only the part of the celestial sphere that is visible to the observer at this time, we obtain Figure 10. The celestial equator runs exactly through the East and West points of the observer's horizon.

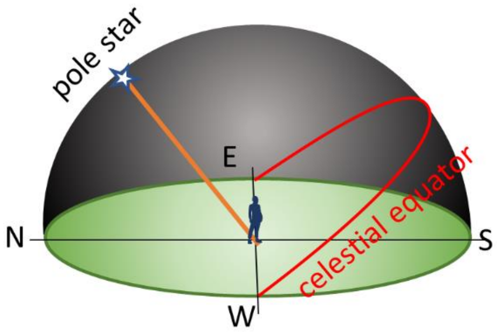


Figure 10: For comparison, an observer located in Belgium.

Figure 11 represents the horizon of an observer at the North Pole.

- Draw the pole star on this figure.
- Draw the celestial equator on this figure.
- Can you indicate on the horizon plane the different cardinal directions?

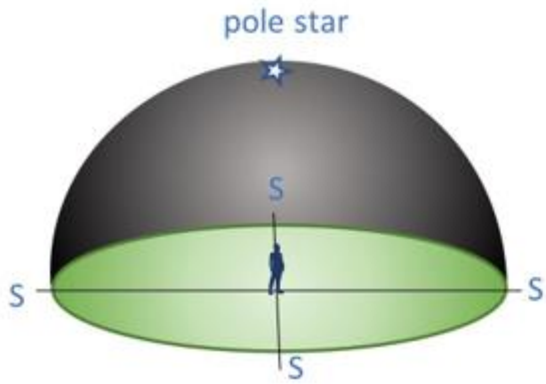


Figure 11: Observer at the North Pole.

Exercise 1.4

We represent a similar situation as in the previous exercise on the celestial sphere for an observer at the north pole, but we again show the Earth somewhat larger.

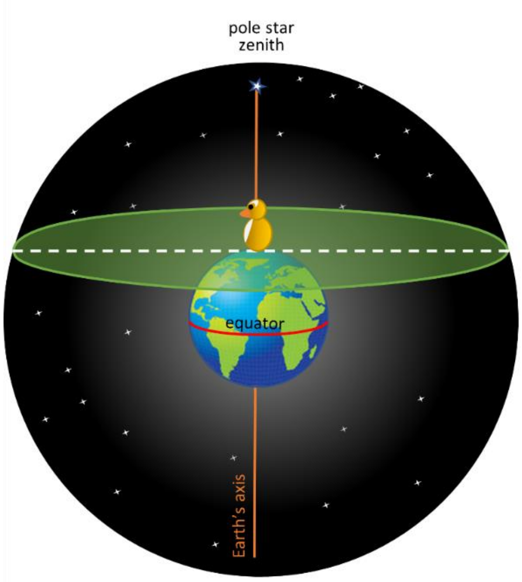


Figure 12: Celestial sphere and observer located at the North Pole.

An observer's position on Earth can be indicated relatively to the equator using an angle called latitude. An observer at the equator is at latitude 0° N, an observer at the North Pole is at latitude 90° N, an observer in Brussels is at latitude 51° N.

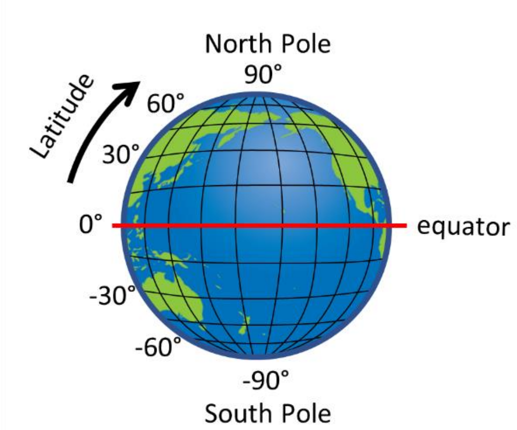


Figure 13: Latitude of an observer on Earth.

We now move the observer 20° to the south.

- At what latitude is the observer now located?

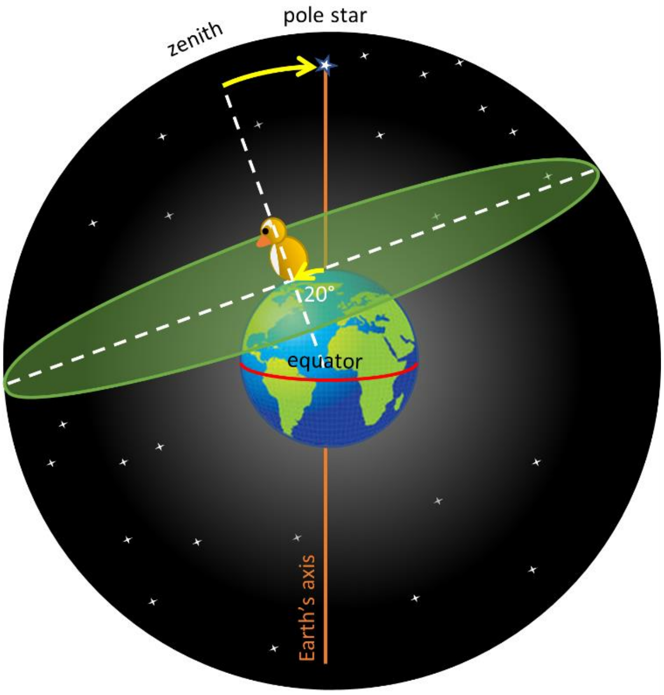


Figure 14: If the observer moves from the North Pole to the south, the pole star is not in the observer's zenith anymore.

We see that the pole star is not in the observer's zenith anymore. To check where the pole star is located relatively to the zenith, in Figure 15 we again make the Earth very small relative to the celestial sphere.

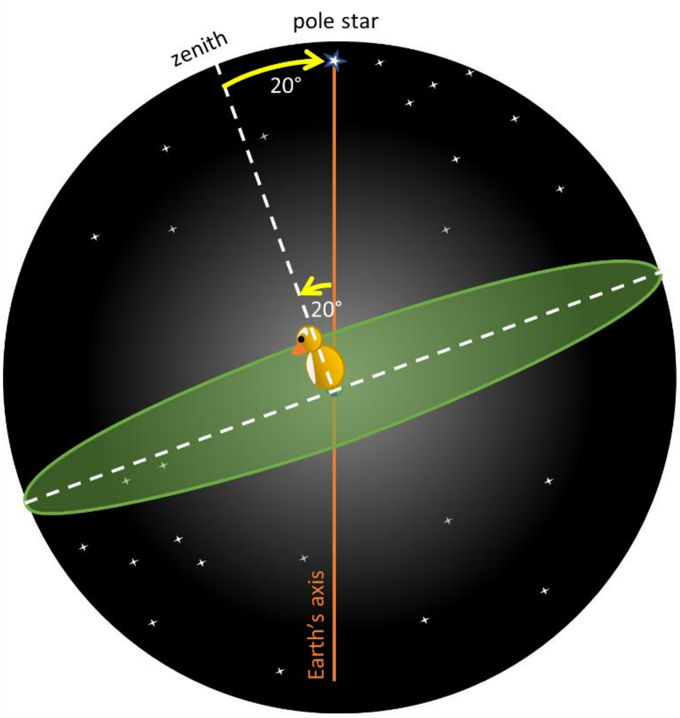


Figure 15: Celestial sphere as in Figure 12 without oversized Earth.

Figure 16 shows the horizon plane and the visible part of the celestial sphere for this new position of the observer:

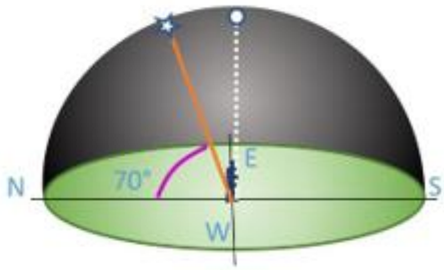


Figure 16: Observer located at latitude 70° N.

- Indicate the zenith and pole star on this figure.
- Draw the connecting line between the observer and the pole star.
- Indicate the cardinal directions on the observer's horizon plane.
- Where on this figure do you see an angle equal to the observer's latitude?

Now for different positions of the observer, indicate the following on Figures 17 and 18 below:

- The zenith.
- The polar star.
- The connecting line between the observer and the pole star.
- The angle corresponding to the observer's latitude.

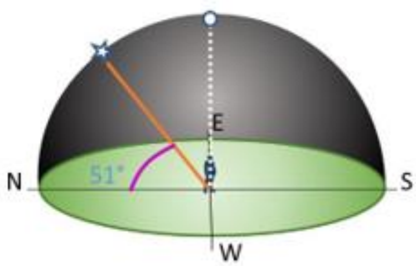


Figure 17: Observer at latitude 51° N.

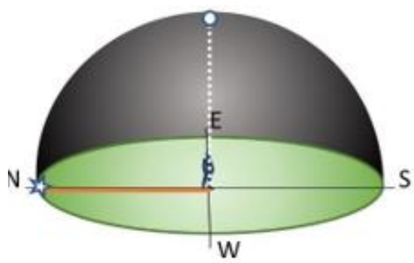


Figure 18: Observer at latitude 0° N.

From now on, we indicate the latitude with a purple arc (as in Figure 19 below).

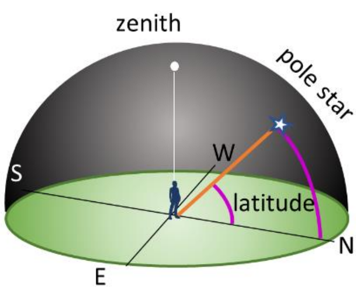


Figure 19: The angle between the horizon plane and the direction to the pole star corresponds to the observer's latitude. This figure is drawn for an observer in Belgium.

Exercise 1.5

In Figure 1 of Exercise 1.1, you have indicated where the Sun rises and sets. Figure 2 shows that, as an observer on Earth, you see the Sun moving in the sky. This is because the Earth spins on its axis.
We also represent the Sun as a point on the celestial sphere. When the Sun is above the observer's horizon plane, the celestial sphere turns blue. The sunlight is scattered by the atmosphere in all directions: then you can't see stars anymore in the sky because the scattered sunlight is overpowering the light of the stars.

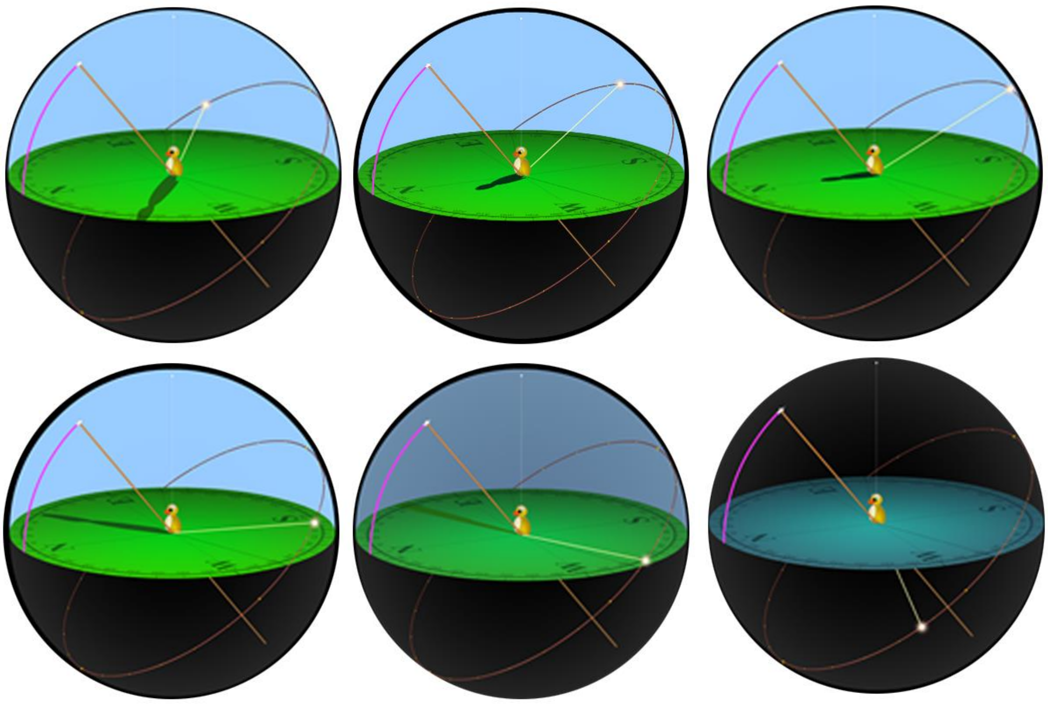


Figure 20: The Sun's position in the sky changes as the Earth rotates on its axis.
Source: https://www.viatienen.be/Erasmus/apparentmotionSun.mp4

As the Earth spins on its axis, the position of the Sun in the sky changes (as seen in Figure 20). Look back at Figure 2 for a moment to consider how the Earth's rotation causes the Sun's position in the sky to change throughout the day.
The Sun follows a path during its apparent motion in the sky. This path is called the Sun's path.

There are three special points on this path.

- Culmination point: this is the highest point.
- Sunrise: point where the Sun appears above the horizon.
- Sunset: point where the Sun disappears below the horizon.

Indicate these three points in Figure 21 of the Sun's path.

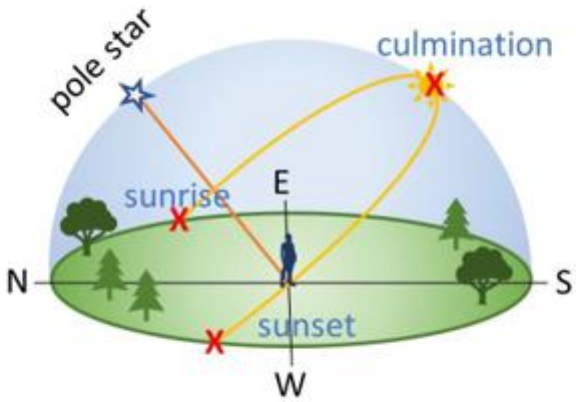


Figure 21: The Sun's path.

Exercise 1.6

The motion of the Sun is called „apparent motion" because the Sun does not actually move . We compare this situation to the motion of a train: imagine that you get on a train that then leaves the station. Take a look at this movie:
https://www.viatienen.be/Erasmus/relativemotion.mp4

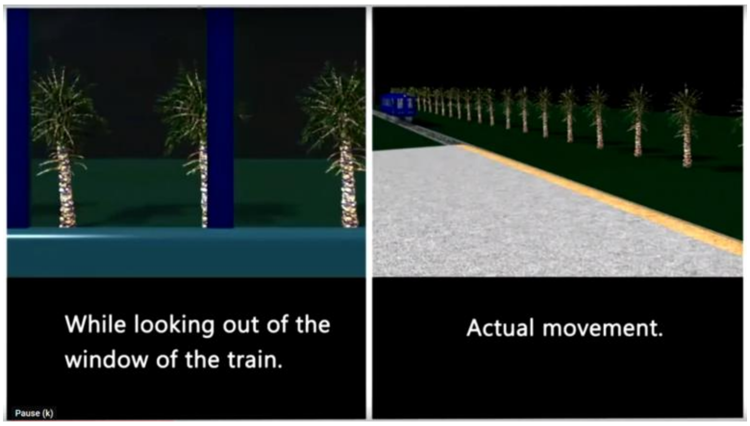


Figure 22: Visualization of apparent motion from https://www.viatienen.be/Erasmus/relativemotion.mp4.

You can see the trees moving from left to right when you look through the train's window, but of course what is really moving is the train leaving the station from right to left. The trees are not moving at all. Therefore, there is a difference between the motion you observe and what is happening in real life.
In the apparent motion of the Sun, exactly the same thing happens: The Earth rotates on its axis from west to east, but you see the Sun moving in the sky from east to west.

Exercise 1.7

In this exercise, we study stars. What do you think: do stars also make an apparent motion? If so, in what direction would that motion occur?

I expect the stars, like the Sun, to move from east to west, if I look south.

To check your idea, we use the browser-based software Stellarium (https://stellarium-web.org/).

1. On the home screen, look in the northern direction (N). Drag the landscape to the left until you look towards the south (S). East (E) will then be to your left and West (W) to your right as shown in the image 23 below.

Figure 23: Home- screen of Stellarium for an observer looking south.

2. We can use Stellarium to visualize how stars move in the sky during the night. To do that, we travel through time by clicking the time icon at the bottom right of the screen. A dialog box will then appear (see Figure 24). Now speed up time by dragging the slider to the right. What do you observe?

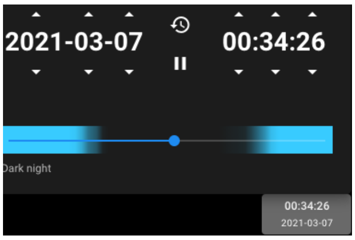


Figure 24: The panel for time settings of Stellarium.

3. Like the Sun, a star follows a path in the sky. This path is called a star trail. In Figure 25 below, mark the place where a star rises above the horizon, the culmination point, and the place where the star disappears below the horizon again. Draw the star's trail. Indicate the direction of the motion with an arrow.

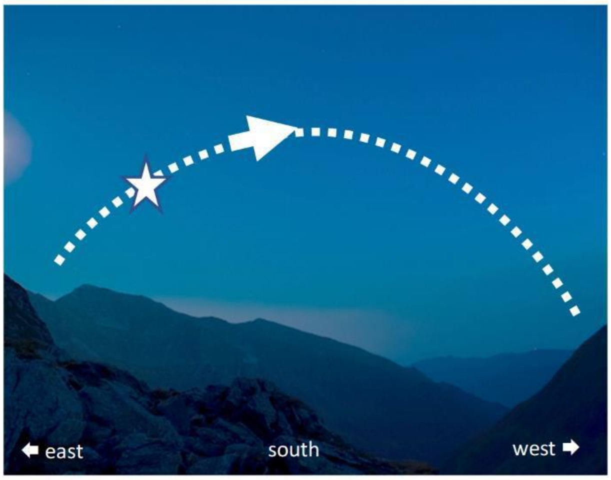


Figure 25: View to the south.

Exercise 1.8

The Sun’s path and stars trails lie in planes perpendicular to the Earth's axis because the Earth rotates on its axis.

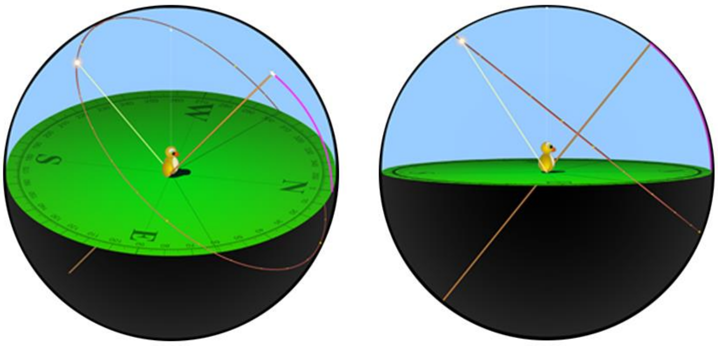
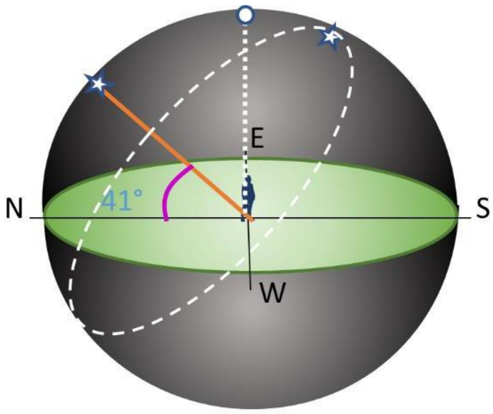


Figure 26: The path of the apparent motion of the Sun and the stars lies in planes perpendicular to the Earth's axis. On the figure, the red circle shows the path of the Sun for an observer in the northern hemisphere. The orange line shows the direction of the Earth's axis.

Figure 27 shows a star at the culmination point for three observers: at 41° N, at the equator and at the North Pole.

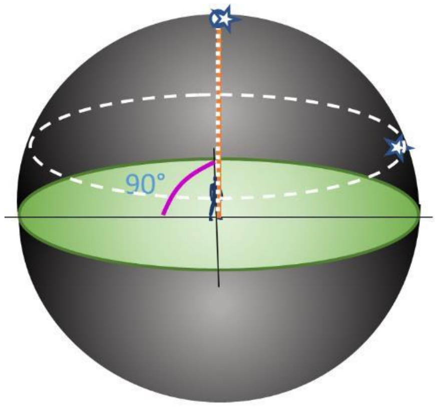
- Indicate the zenith and pole star on each figure.
- Sketch the star trail of this star on each figure.

a) 41 °N



Observer at latitude 41° N

b) North Pole



Observer at the Noth Pole

c) equator

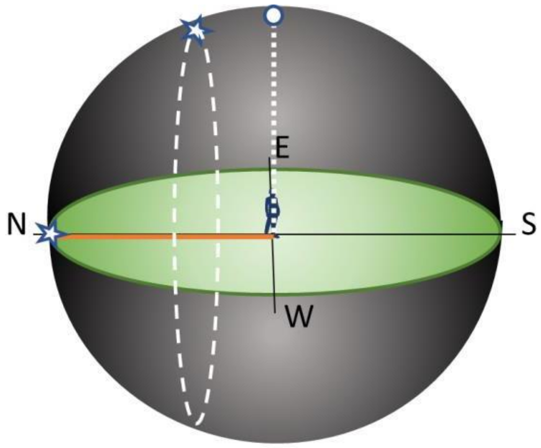


Figure 27: Star trails for observers at different locations on Earth: latitude 41 °N (a, top left), at the North Pole (b, top right) and at the equator (c, bottom).

To remember…

- Looking to the North Pole, the Earth rotates on its axis counterclockwise. This is the real motion, which takes (about) 24 hours (one day).
- We see the Sun moving in the sky clockwise. If you look towards the south, this motion is from east to west. This is an apparent motion.
- The path that the Sun follows in the sky is called the Sun's path.
- For an observer in the northern hemisphere, the Sun reaches its highest point in direction South.
- The stars have a fixed position on the celestial sphere. We see an apparent motion of the stars during the night as the Earth rotates on its axis. This apparent motion for an observer in the northern hemisphere proceeds clockwise if you look towards the south. However, when observing the stars, sometimes you look up towards the north. Switching the view from south to north flips the apparent clockwise motion toward a counterclockwise motion. Therefore, we observe the stars to apparently rotate counterclockwise, making a full circle around Polaris, the pole star, within 24 h.
- The path that a star follows for an observer on Earth is called the star trail.

Part 2: The Sun's path and the star trails throughout the year

Exercise 2.1

A photographer has taken pictures of the sunset near the Taj Mahal in India at different times throughout the year. He took one photo each month from the same location. Describe the position of the sunset in the different photographs.

We see that the sunset changes throughout the year. The position of the sunset varies between two extreme points: the rightmost point in December and the leftmost point in June.

Figure 28: Sunrise near the Taj Mahal at different times of the year.
Source: Astronomy picture of the day, https://apod.nasa.gov/apod/ap201221.html

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Exercise 2.2

The Sun apparently moves in the sky from east through south to west, but the Sun's path is different every day: the position of sunrise, culmination point and sunset are slightly different every day.
The height of the culmination point, or culmination height for short, is the maximum altitude that the Sun reaches in its path across the sky during the day. In Belgium, for example, this is 62.5° on the first day of summer. The unit is "degrees". Therefore, the culmination height is an angle. It is the angle between the parallel rays of the Sun and the plane of the observer's horizon at noon when the Sun is in its highest point in the sky.

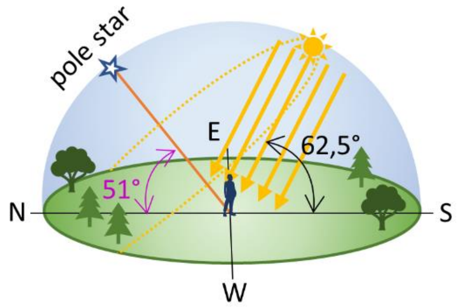

Figure 29: The culmination height, shown as an angle on the figure,

for an observer at 51° N on 21 June.

On the first day of spring and autumn, the Sun rises exactly in the east and sets exactly in the west.

- Draw the Sun’s path on Figure 30 for an observer at 51° N, on the first day of spring.
- Indicate the angle representing the culmination height.
- How large is this angle?

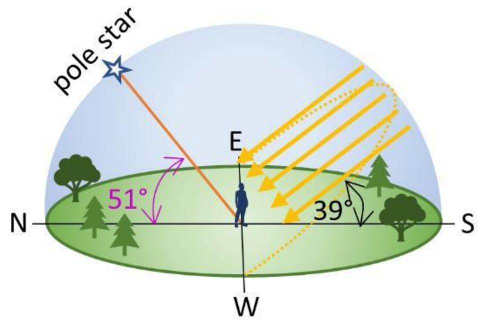

Figure 30: Observer at 51 °N.

On December 3rd, the culmination height for an observer at 51° N is equal to 17°.

- In Figure 31, indicate the angle representing the culmination height.
- Draw the Sun’s path on that day.
- Indicate the position of sunrise and sunset.

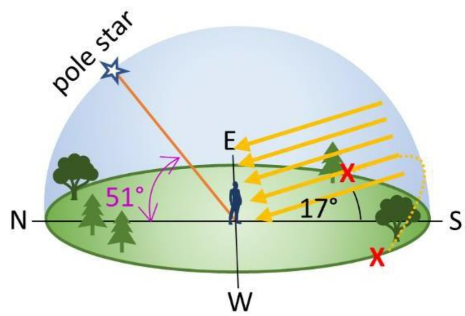

Figure 31: Observer at 51 °N.

Exercise 2.3

Figure 32 shows the Earth in its orbit around the Sun at four different times of the year: the first day of summer (left), the first day of winter (right), and the first day of spring and autumn. Note that this figure is not drawn to scale. The plane in which the motion of the Earth around the Sun takes place is the ecliptic plane.
The solar rays always strike the Earth parallel to the ecliptic plane.

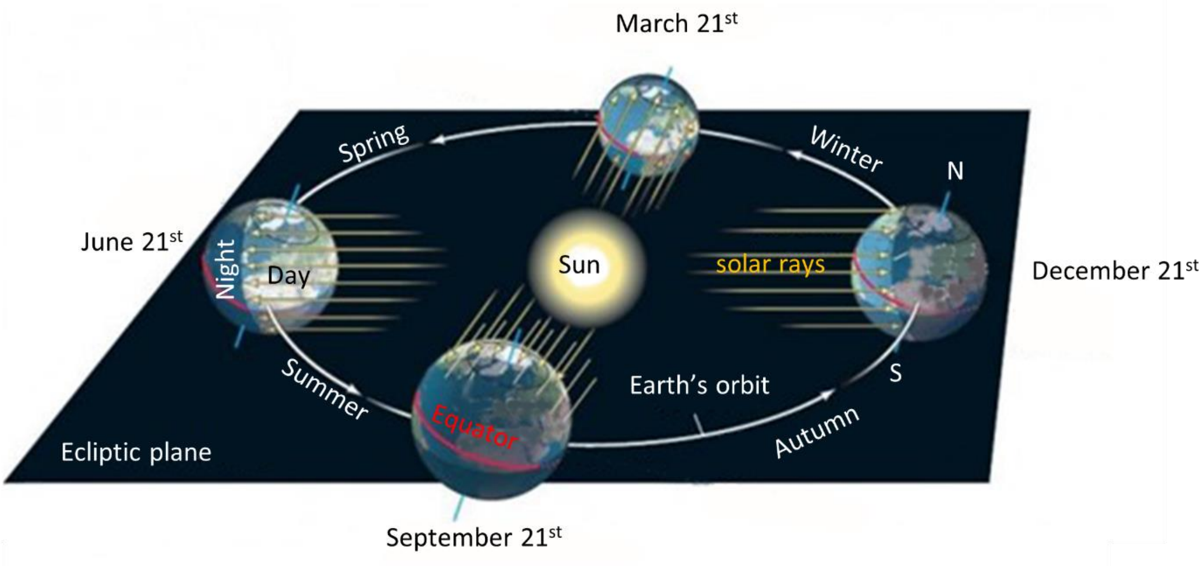

Figure 32: The Earth in its orbit around the Sun at different times of the year. Attention: This figure is not drawn to scale! Image: https://geography.name/the-earths-revolution-around-the-sun/.

The Earth's axis makes an angle of 23.5° with the normal to the ecliptic plane. Also, the angle between the equatorial plane and the ecliptic plane is 23.5° as shown in Figure 33.

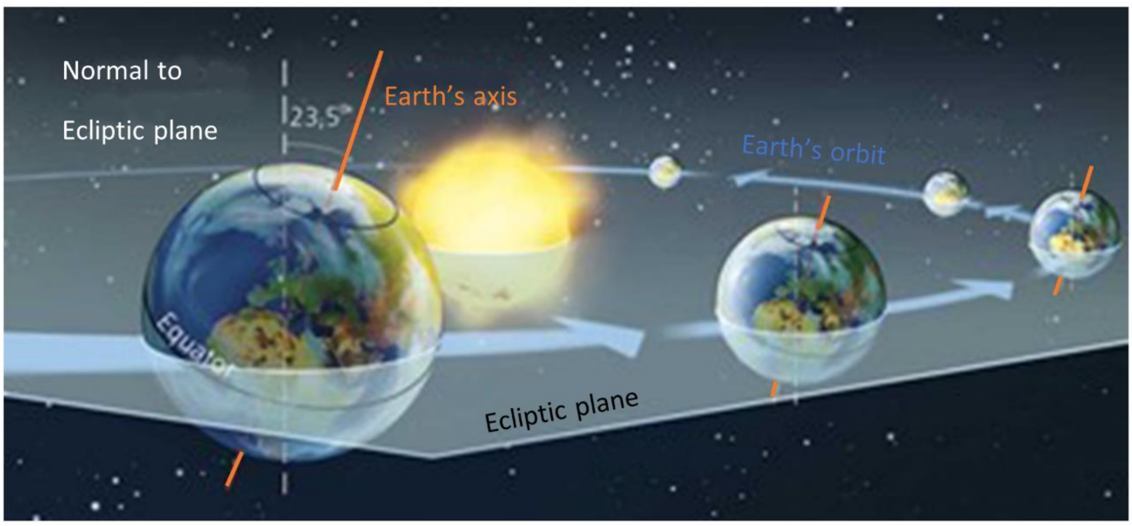

Figure 33: The ecliptic plane in which the Earth moves around the Sun. Attention: This figure is not drawn to scale! Image: https://www.blinklearning.com/coursePlayer/clases2.php?idclase=40033109&idcurso=734099.

Draw the solar rays on June 21st on the figure below. Also indicate where on Earth it is day and where it is night.

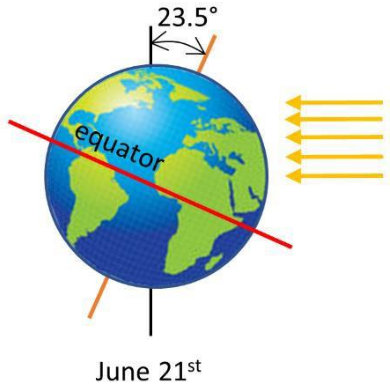

Figure 34: Draw the solar rays on June 21.

What is the angle between the solar rays and the equatorial plane on this day?

23.5°

Exercise 2.4

We now represent the ecliptic plane and the equatorial plane on the celestial sphere.

What is the angle between the two planes?

23.5°

The line where the ecliptic plane intersects the celestial sphere is called the ecliptic (Figure 35). Since the Sun and the Earth are always in the ecliptic plane, the Sun will always be seen on the ecliptic from the Earth's point of view.

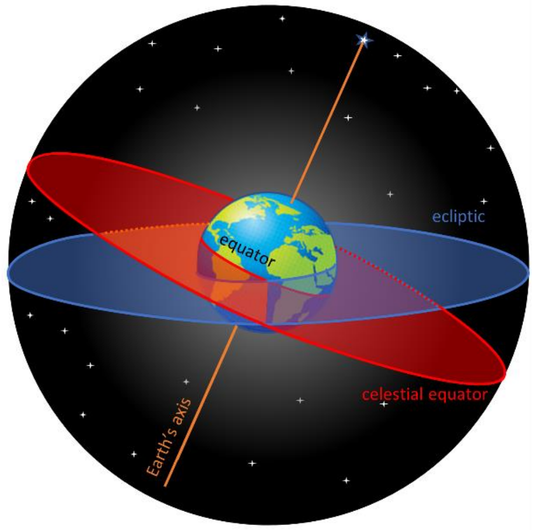

Figure 35: Ecliptic plane and ecliptic.

We now also draw the plane of the horizon for an observer at 51° N (Figure 36).

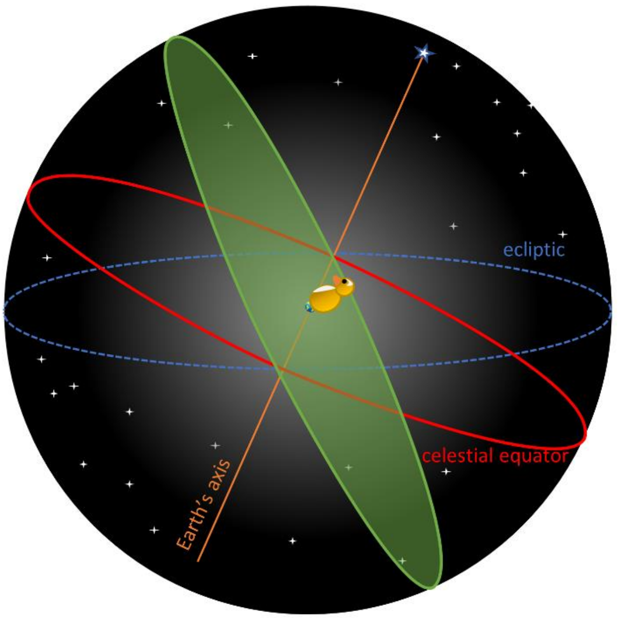

Figure 36: The plane of the horizon, together with the ecliptic and the celestial equator

The ecliptic and the celestial equator are both partially visible to the observer at 51° N because they are above the observer's horizon plane. Draw both lines in Figure 37, for the observer's position shown in Figure 36.

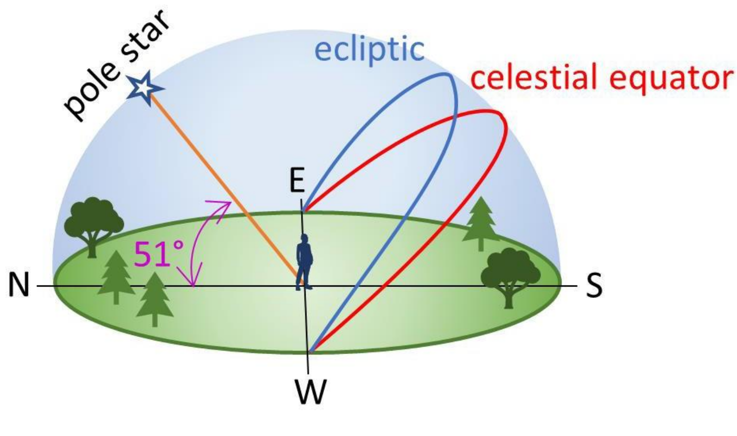

Figure 37: Ecliptic and the celestial equator for an observer at 51 °N.

Exercise 2.5

Figure 38 shows a part of the celestial sphere, together with the Sun, the Earth and a number of constellations. The ecliptic is also indicated.

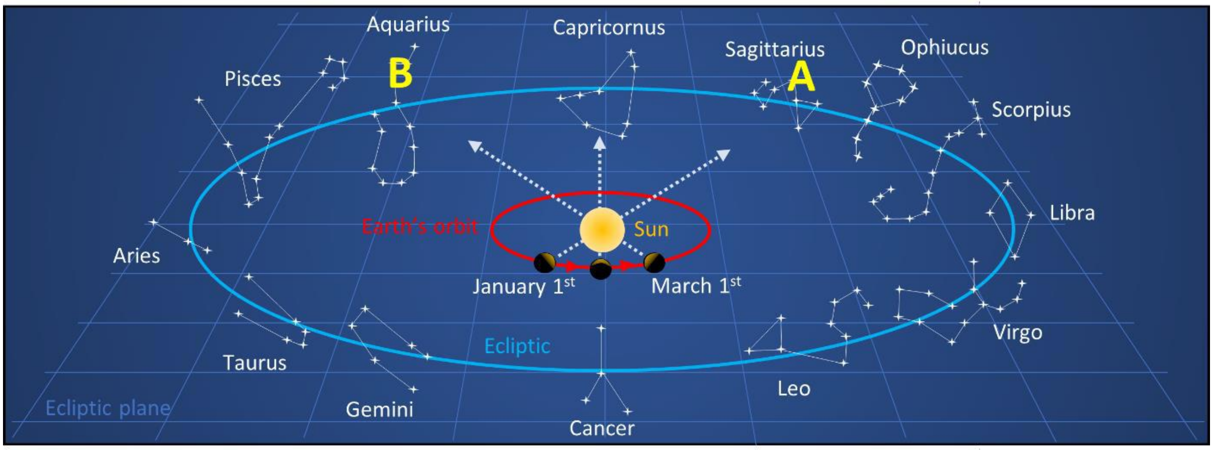

Figure 38: Motion of the Earth around the Sun. Note that this figure is not drawn to scale. Image: https://studylib.net/doc/14223319/the-sun-and-the-celestial-sphere.

Because the Earth moves around the Sun, the projection of the Sun onto the celestial sphere changes for an observer on Earth.

- In which constellation does the observer on Earth see the projection of the Sun on January 1st?

  Sagittarius

- Write down a letter A on the ecliptic at the location of the projection of the Sun on January 1st.

- In which constellation does the observer on Earth see the projection of the Sun on March 1st?

  Aquarius

- Write down a letter B on the ecliptic at the place of the projection of the Sun on March 1st.

From the point of view of an observer on Earth, the Sun's projection on the ecliptic changes throughout the year. Unlike the other stars, the Sun has no fixed projection point on the celestial sphere.

We now draw the celestial sphere again with the Earth in the centre, together with the celestial equator and the ecliptic.

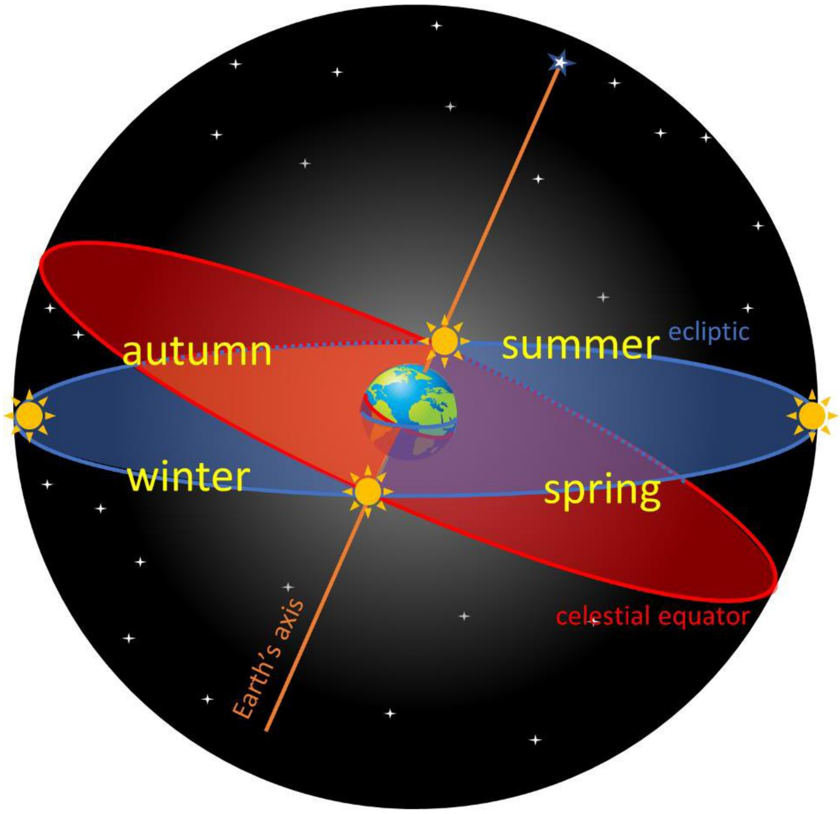

Figure 39: Celestial sphere with the celestial equator and the ecliptic.

- In Figure 39, indicate the position of the projection of the Sun on the ecliptic for the four times of the year, which are also shown in Figure 32.
- Indicate with an arrow the direction of the motion of the projection of the Sun on the ecliptic through the year.
- Determine the angle between the equatorial plane and the solar rays, which always strike the Earth parallel to the ecliptic plane, for the four times of the year.
    - Beginning of winter (December 21st) → angle = (-) 23,5°
    - Beginning of spring (March 21st) → angle = 0°
    - Beginning of summer (June 21st) → angle = 23,5°
    - Beginning of autumn (September 21st) → angle = 0°

Exercise 2.6

Because the solar rays always strike the Earth parallel to the ecliptic plane and because the ecliptic plane makes an angle of 23.5° with the equatorial plane, the angle between the parallel solar rays and the equatorial plane changes throughout the year as a result of the Earth's revolution.

Figure 40 shows the Sun on the ecliptic on May 1st. The indicated angle is the angle between the incident solar rays and the equatorial plane. How large do you estimate that angle?

(a) 5°
(b) 14°
(c) 21°
(d) 25°

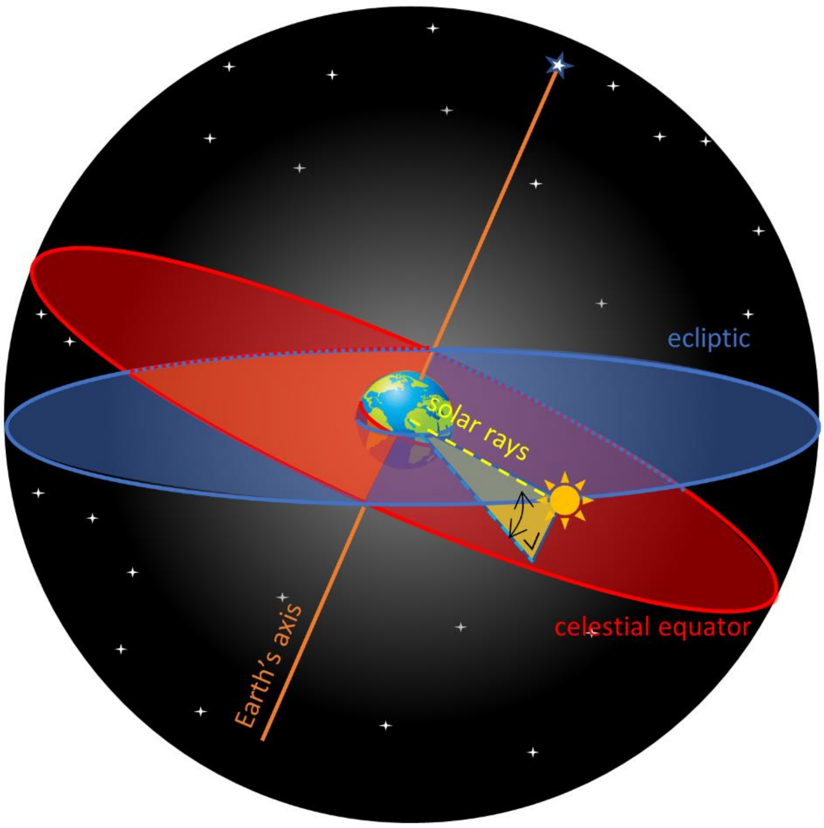

Figure 40: Like Figure 39, but now including solar rays.

Exercise 2.7

In Figure 41, on the left you see the Sun's path from the observer's point of view on Earth and on the right, you see a representation of the Sun on the celestial sphere. Connect each drawing on the left with the correct drawing on the right.

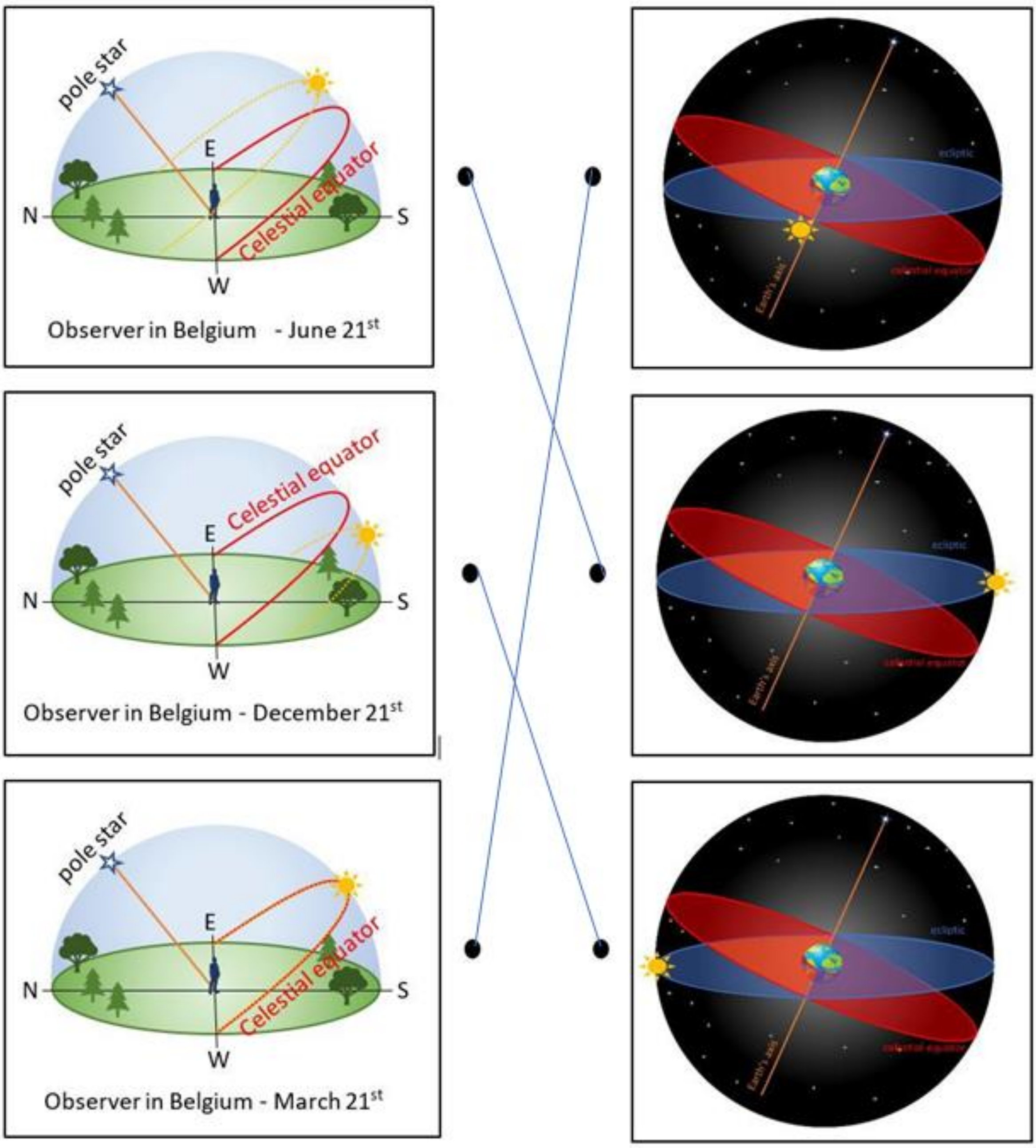

Figure 41: Sun's path from the observer's point of view on Earth (left) and representation of the Sun on the celestial sphere (right).

Exercise 2.8

Figure 42 shows the star Aldebaran of the Taurus constellation somewhat larger and marked in yellow.

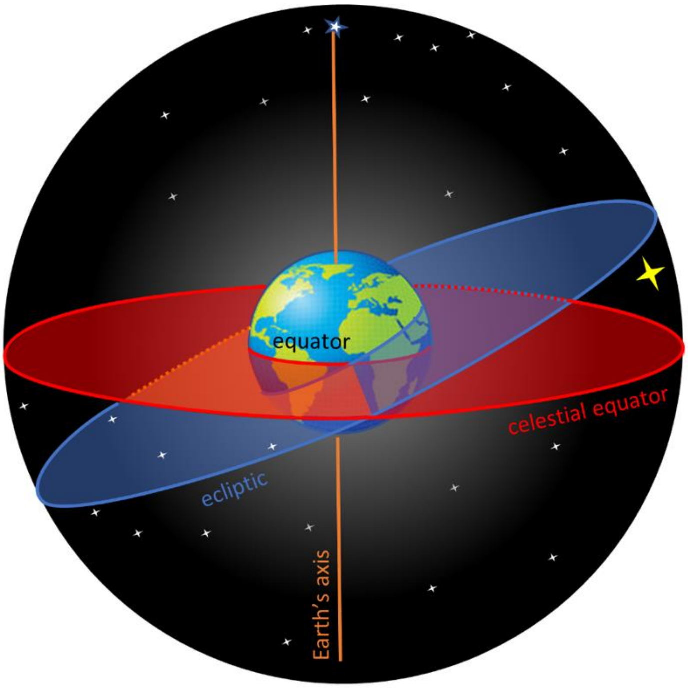

Figure 42: Celestial sphere with the star Aldebaran marked.

The starlight of Aldebaran strikes the Earth at an angle of 16° to the equatorial plane.

- Draw the star trail of the star Aldebaran in Figure 43.
- Mark the culmination height on the figure.
- Do you think that this culmination height changes throughout the year? Why (or why not)?

NO, it doesn't change, because the star trails don't change throughout the year.

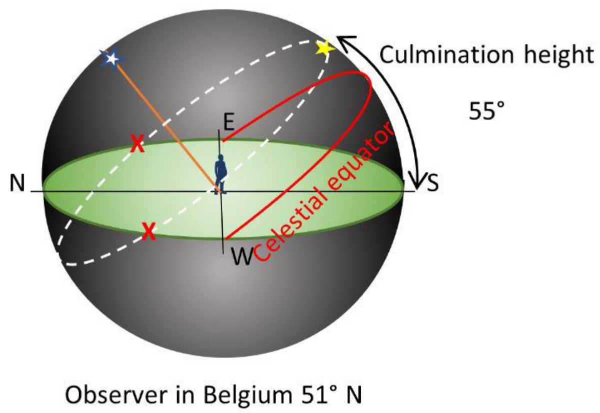

Figure 43: Draw the star trail of Aldebaran in this image for an observer located in Belgium, 51° N.

Exercise 2.9

Due to the motion of the Earth around the Sun, the position of the Sun's projection on the celestial sphere changes throughout the year. This is not the case for all other stars: the position of their projection on the celestial sphere does not change.

The figure below shows the various constellations of the zodiac together with the Sun and the Earth. All these constellations lie along the ecliptic on the celestial sphere.

- Can you observe the constellation Leo in September? Why (or why not)?
  - No. The projection of the Sun is in the same position on the celestial sphere as the projection of the stars of the constellation Leo. So when the Sun is above the horizon, so are the stars of the constellation. Through the atmosphere, the light of the Sun will outshine the light of the stars, so that you cannot see them.
- Which constellations indicated on the figure, are visible in May? Why (or why not)?
  - We look at the night side of the Earth in the figure below. Virgo, Libra and Scorpio may have been observed during a night in the month of May (if there are no clouds).
- What can you conclude about the visibility of star constellations throughout the year?
  - Whether you can see certain stars during a certain night depends on the time of year: you cannot observe stars that are above the horizon together with the Sun.

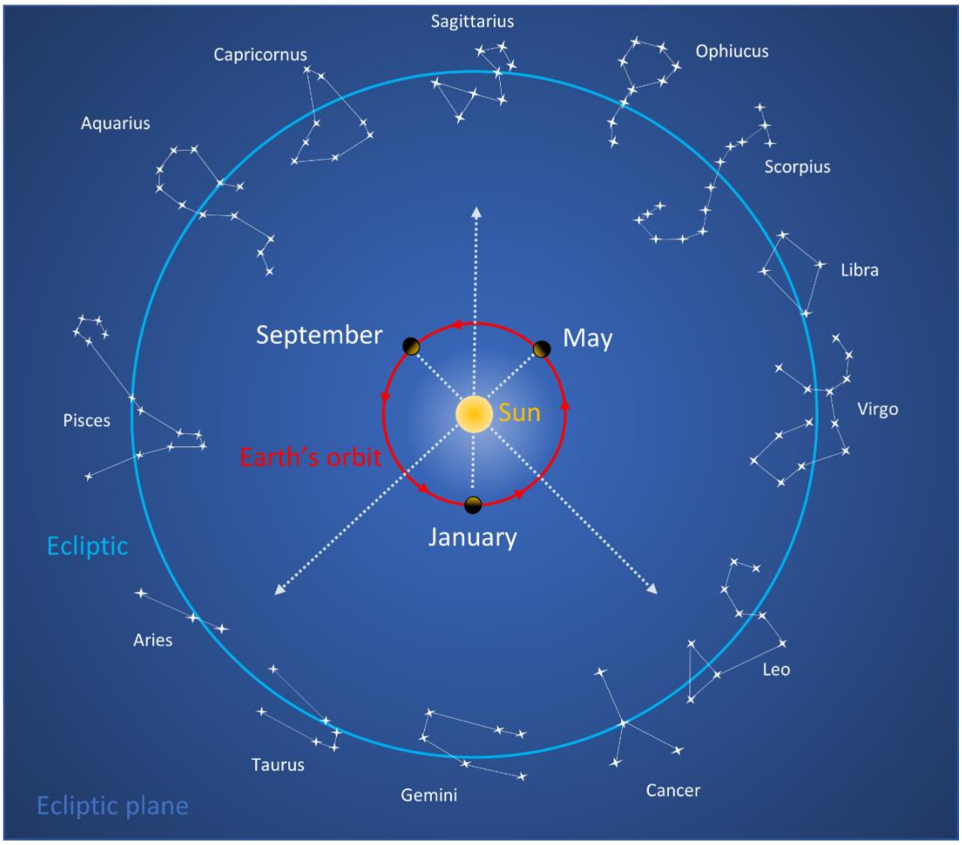

Figure 44: Because of the motion of the Earth around the Sun, you do not see the same stars every night.

To remember...

- The Sun’s path changes from day to day throughout the year. This is a consequence of the Earth's revolution, the motion of the Earth around the Sun. It takes the Earth one year to complete one revolution. As a result of this motion and the tilt of the Earth's axis relatively to the plane of the ecliptic, the culmination height changes from day to day. Consequently, the position of the sunrise and sunset also changes from day to day.

- The culmination height of a star does not change throughout the year. Also, the positions of the star rise and star set do not change. This means that the star trail does not change throughout the year. This is clearly different from the Sun. Therefore, the motion of the Earth around the Sun has no influence on the star trails, but it does have another important consequence: if the light rays of the star must pass the Sun before reaching the Earth, then you can’t observe the star at that time of the year because the Sun's light is more intense than the starlight. The star can therefore be above the horizon of the observer at a time when the Sun is above the horizon as well, but the star is not visible to the observer. The motion of the Earth around the Sun ensures that you do not see the same stars every night.

- The time at which a star rises above the horizon and sets also changes from day to day. It is also possible that you see a star rise during the night, but that you don't see it set anymore because the Sun appears above the horizon already before the star sets.

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