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Motion of the Sky: Daily Motion Due to Earth's Rotation

The purpose of this exercise is to become familiar with the daily motion of the sky as seen from the Earth, and to see how this motion changes as you move to different latitudes on the Earth. The daily motion of the sky is called diurnal motion, and is discussed in Section 2-3 of Kaufmann and Freedman, *Universe*, Fifth Ed.

The Sun rises in the east, crosses the sky, and sets in the west. However, despite appearances, it is not really the Sun that is moving—the Sun is at rest at the center of the solar system. The apparent daily motion of the Sun is due to our own rotation—the fact that we look out into the Universe in a constantly changing direction as the Earth rotates. Turning toward the Sun causes the Sun to rise above the horizon, and turning away from it again causes it to set below the horizon.

The Sun is just one of a large number of objects in the sky. Other objects visible to the unaided eye are the Moon, five planets (Mercury, Venus, Mars, Jupiter, and Saturn), and many stars. If the daily motion of the sky is due to the Earth's rotation then, as our direction of view swings around the Universe, we should see the entire sky and everything in it constantly rising in the east, passing somewhere overhead, and setting in the west. The Sun should be only one such object.

Also, because the Earth is round, people at different latitudes are standing on ground that is tilted in different directions relative to the universe. Therefore, observers at different latitudes should see the apparent daily motion of the universe from different perspectives.

PART 1: Earth's Rotation and Daily Sky Motion

A. Screen Set-up

1. Restart the program and move to a location at about 45° north latitude. A good example is Seattle, Washington, at about 48° latitude (Settings/Viewing Location/North America/United States/ Seattle/Set Location).

2. Click the time-stop button on the date/time box (if this toolbar is not already on the screen, activate it by clicking Time in the Window menu), then set the date to March 21, 1999 (3/21/1999 AD), and the time to noon (12:00:00 PM). If you do not remember how to perform these steps, refer to Exercise 1, steps 5 and 6.

3. Face south by clicking the S button on the button bar near the top of the screen. If this button bar is not already visible on the screen, activate it by clicking Toolbar in the Window menu. After the screen adjusts direction, you should see a symbol showing south (S) on the horizon near the bottom of your screen.

   You may have expected that the Sun would be directly south at noon, whereas if you chose Seattle for your location the Sun is probably slightly east of south. This small offset is due to the fact that Seattle is not exactly at the center of its time zone (Pacific Time).

4. If the time step in the date/time box does not show 003 minutes, click on the time-step number to highlight it, and type 3. If the time step is not in minutes, click on the little up or down arrows next to the time step to select minutes.

B. Apparent Daily Motion of the Sky Due to the Earth's Rotation

1. First, check the direction of motion of the Sun in the sky by clicking the time-start button, with the right-pointing triangle on it, in the date/time box (the first button to the right of the time-stop button). This will move the time forward in a continuous sequence of three minutes per time step in the present set-up. Compass directions are given along the horizon near the bottom of the screen (if S is centered, then SE and SW should be visible near the left and right sides of the horizon). Motion toward the east would be toward the left on the screen, and motion toward the west would be toward the right. This motion will appear to carry the Sun across the sky in an arc, reaching its highest point around midday.

   After noting the direction of motion of the Sun in the sky, click the time-stop button and reset the time to noon (12:00:00 PM).

2. On your screen, the blue sky, which is produced by scattering of sunlight by the Earth's atmosphere, hides almost everything but the Sun. The Moon is bright enough to be seen in the daytime, and sometimes Venus is visible if you know exactly where to look. All other astronomical objects are "lost" in the brightness of the blue sky. In reality, however, all astronomical objects that are above the horizon are actually there in the daytime. Through the magic of computers, you can make all of the other objects visible with the click of a switch! Switch off daylight by clicking on Daylight in the Display menu. This shows the bright Sun, but eliminates the blue sky so you can see everything else. (This is the same view that you would have if the Earth had no atmosphere—the Sun in a dark sky with all of the other objects shining as if it were nighttime. Astronauts get an equivalent view to this from orbit or from the surface of the Moon.)

   Now click the time-start button again and observe what happens. If the motion of the Sun across the sky were due to the Sun actually moving, then the rest of the sky would remain stationary as the Sun moved past it. If the motion of the Sun were an illusion due entirely to our own motion, then our motion would affect all objects equally and the entire sky would appear to move. As you see, the Sun and all other objects follow arcs across the sky from east to west together.

When you have tried this step, click the time-stop button, reset the time to noon (12:00:00 PM), and click daylight back on.

3. Now try estimating the speed of motion of the Sun in the sky. Fold a sheet of paper into a strip so you can hold it close to the screen and still see the time-step buttons in the date/time box. (Do this very carefully to prevent any damage to the screen. If you are using a laptop, you may wish to skip this step because of the softer screen or find a safer way to measure distances on the screen.) Make a mark on the paper, and place the paper horizontally across the screen with the mark next to the Sun. Now, holding the paper so it does not move, click the time-start button and let the Sun move until the time shows 1:00:00 PM. Stop the motion at 1:00:00 PM exactly. (You can back the motion up or move it ahead one step at a time by using the single-step buttons—the outside two buttons in the date/time box—if you need to.)

   Now make a second mark on the paper at the new location of the Sun. Remove the paper from the screen and measure the distance between the marks.

   Next, measure the distance between S and SW along the horizon on the screen. This distance corresponds to a 45° angle (from S to W would be 90°, and S to SW is half this).

   Finally, calculate the angle that the Sun moved in one hour by dividing the distance between the marks on the paper by the distance between S and SW, and multiplying the result by 45°. (For example, if the distance between the marks were 1/5 of the distance between S and SW, then the Sun would have moved $1/5 \times 45° = 9°$ in one hour. Your answer should be larger than this.)

   Now, the Earth rotates through a full circle in 24 hours, and there are 360° in a circle. Therefore, through how many degrees does the Earth rotate in one hour? The answer you get should equal your measurement of the motion of the Sun in one hour, in degrees. In fact the two answers will probably differ by a small amount because of uncertainties in measurement and small but unavoidable distortions arising from mapping a spherical sky onto a flat screen. But the two answers should agree reasonably closely.

PART 2: Eastern Rising of Objects in the Sky

In this part of the exercise, you can see how the Sun and other objects behave as they rise above the eastern horizon.

A. Screen Set-up

Check that the sky motion is stopped. If the sky is moving, click the time-stop button in the date/time box. Then set the time to 6:00:00 AM, and click the E button in the button bar near the top of the screen, to face east. (If this button bar is not already visible on the screen, activate it by clicking Toolbar in the Window menu).

It is also important for this step to have a straight horizon. If the horizon is curved up or down, then place the cursor hand on the horizon, hold down the left mouse button, and drag the horizon up or down until it is straight.

B. Measuring the Angle that the Sun's Track Makes to the Horizon at Sunrise

Carefully note the point on the horizon where the Sun rises. If necessary, use the single-step buttons in the date/time box to move time forward or backward one step at a time, to place the Sun exactly on the horizon.

Click the time-start button and let the Sun rise until it reaches the edge of the screen. At that point, click the time-stop button. If necessary, use the single-step buttons to bring the Sun back onto the screen or advance it until it reaches the edge of the screen. Use a piece of paper laid on the screen to mark the angle that the Sun track makes with the horizon. Alternatively, if you have a protractor, then you can measure this angle in degrees. Work gently and be careful not to damage the screen when doing these measurements. (Again, if you are using a laptop, be especially careful or make hand-drawn diagrams without measuring directly on the screen.) The angle should be around 40° to 50° if the latitude of your location is between 40° and 50°.

Write down the latitude of your location, and the angle of rising of the Sun. The latitude and longitude are printed in the icon/location box; if this box is not visible on the screen, you can activate it by clicking Show Floating Palettes in the Window menu.

Set the clock back to 6:00:00 AM, set your location to Honolulu (Settings/Viewing Location/North America/United States/Honolulu/Set Location), and follow a similar procedure to measure the new angle of rising of the Sun, this time allowing the Sun to reach the upper edge of the screen. Write down the latitude and the rising angle for Honolulu. Repeat this step for the following viewing locations, resetting the clock each time and writing down the latitude and the rising angle for each location:

Quito, Ecuador	(South America/Others/Quito, Ecuador)
Dunedin, New Zealand	(Australasia/New Zealand/Dunedin)
Murmansk, Russia	(Europe/Russia/Murmansk)
The North Pole	(click on the latitude number in the icon/location box, and type 90)

Questions

1. At what angle does the Sun rise for someone at 0° latitude?

2. At what angle does the Sun rise for someone at 90° latitude? (If the Sun just skims along the horizon, then the rising angle is 0°.)

3. What happens to the rising angle of the Sun as you move from the equator (0°) to the North Pole (90°).

4. Based on your answers to the questions above, which one of the following statements do you think is correct?
   a. The rising angle of the Sun is equal to your latitude.
   b. The rising angle of the Sun is equal to 90° minus your latitude.
   c. The rising angle of the Sun does not depend on your latitude.

5. What is different about the sunrise in Dunedin, New Zealand compared with that at Seattle, Washington?

6. Suppose that you are in Dunedin, New Zealand, the time is noon, and you are facing the point on the horizon where the Sun rose. Based on how the Sun rises in Dunedin, in which direction (left or right) would you need to turn to face the Sun at noon in Dunedin? How does this compare to Seattle?

7. Based on how the Sun rises in Dunedin, in which compass direction (north or south) would you need to face to see the Sun at noon? How does this compare to Seattle?

8. Based on how the Sun rises in Dunedin, in which direction would the Sun be moving at noon (from left to right or from right to left)? If you wish, you can check this directly by setting the time to 12:00:00 PM and your location to Dunedin, and clicking the time-start button. How does this compare to Seattle?

9. In which compass direction would the Sun be moving at noon in Dunedin (from east to west or from west to east)? Check the compass directions near the bottom of the screen to find if you are right. How does this compare to Seattle, Washington?

C. Rising of Other Objects

Check that the sky motion has been stopped, and if not then click the time-stop button. Set your location back to Seattle, set the time to 1:00:00 AM, set the compass direction to east (click E on the button bar near the top of the screen; if necessary, first click Window/Toolbar to activate this button bar) and adjust the horizon to be horizontal again. Then click the time-start button. You should see stars continuously rising above the eastern horizon at the same angle from which the Sun rose. Throughout the night, new stars and constellations are always rising in the east, and the old ones are setting in the west and disappearing from view.

Now take a moment to see what happens as objects set. Click the time-stop button, then click W (for west) at the top of the screen, and set the time to 4:00:00 PM. If the sky is not blue, then switch on daylight by clicking Daylight in the Display menu.

Click the time-start button, and watch what happens until about 9

PM. You should see the Sun approach the horizon and set at the same angle from which it rose in the east. After the sky gets dark you should see all of the stars setting at the same angle as the Sun set. This is a further indication that the motion of the sky is an illusion caused by our own rotation. As an added bonus, Venus and the Moon are seen to set just after the Sun on this date and from this location.

D. The Effect of Latitude on the Appearance of Constellations: Southward View

Latitude on the Earth not only affects the angle from which we view the Sun but it also determines whether (and how) we see all of the other objects in the sky. In this step you can see how our latitude affects the visibility of the constellations that we see when we look southward (from the northern hemisphere). Later in this exercise, you can see how their visibility changes when we look northward from different locations in the northern hemisphere.

Check that the sky motion is stopped, and if not then click the time-stop button. Set your location to Kingston, Jamaica (click Settings/Viewing Location/Central America/Kingston, Jamaica/Set Location), and click the S button to face south. Then set the date to June 10, 1999 (06/10/1999 AD) and the time to midnight (12:00:00 AM).

Find the constellation Scorpius. It should be in the upper middle part of the screen, and it is shaped like a fishhook. If you do not see it, or wish to check your identification, switch on the constellation lines and names by clicking Constellations in the Guides menu, look for Scorpius, then click Guides/Constellations again to switch the constellations off again.

Notice carefully how far Scorpius is above the southern horizon. Also notice that you are seeing the constellation due south, and therefore you are seeing it at the highest position it reaches in the sky for that location.

Now set your location to each of the cities listed on the following page. In each case notice where Scorpius is located relative to the horizon. For Calgary and Fairbanks, you will have to reset the time to 12:00:00 AM, since they are in different time zones than Kingston or New York. You may also have to check the date. When you are viewing Scorpius from Calgary, note carefully where Scorpius is relative to Libra, so you may find Scorpius again when you move to Fairbanks. At any time click the constellations on and off again if it helps in finding Scorpius.

New York	(North America/United States/New York)
Calgary, Alberta	(North America/Canada/Calgary)
Fairbanks, Alaska	(North America/United States/Fairbanks, AK)

(*Note:* You may have to turn off the daylight to see the stars in Fairbanks, since the sky never gets completely dark in the summertime at this high latitude. To do this, click Daylight in the Display menu.

Questions

1. For which of these cities is the pattern of stars in Scorpius completely above the horizon?

2. At about what latitude does the tail of Scorpius begin to disappear from view (i.e., never rises above the horizon)?

3. Above about what latitude is *no* part of Scorpius ever visible?

4. Suppose that a scientist in Fairbanks has applied for a research grant to study a globular cluster of stars near the middle of Scorpius, using an observatory just outside Fairbanks. If you were on the granting agency, what would be your response to this proposal? Would your response change if the research proposal included a request for funds to travel to an observatory in Texas?

E. The Effect of Latitude on the Appearance of Constellations: Northward View

In this part of the exercise, you can see how the visibility of constellations in the sky changes when we look northward from different locations in the **northern** hemisphere.

Check that the sky motion is stopped; if not, click the time-stop button. Set your location to Minneapolis, Minnesota (click Settings/Viewing

Location/North America/United States/Minneapolis/Set Location), and click the N button to face north. Set the date to October 1, 1999 (10/01/1999 AD) and the time to 7 PM (7:00:00 PM). Switch off daylight by clicking the button with the small sun on it.

Find the Big Dipper in the left part of the screen, and use it to find the North Star, Polaris.

View Northward from Minneapolis

Write down the latitude of Minneapolis, and make a note of where the North Star is, compared to the top and bottom of the screen (e.g., close to the top, about half way down, close to the bottom, etc.).

Click the time-start button in the date/time box, and watch what happens in the sky. Stars on the left, including the Big Dipper, are moving downward, whereas stars on the right, including Cassiopeia, are moving upward. Is there one star that remains at rest while all other stars move around it in circles? Which star is this?

As the sky rotates around the pole, watch what happens to the Big Dipper, especially between about 10 PM and 1 AM. Notice that, on the lower-left-hand side of the screen, stars are setting below the horizon, and on the lower-right-hand side of the screen stars are rising above the horizon; but, as seen from Minneapolis, the Big Dipper never sets. It approaches the northern horizon, but passes above the horizon without setting, and then gets higher in the sky again. Stars or constellations that move in circles around the Pole without ever setting are called circumpolar.

View Northward from Houston

Stop the sky motion by clicking the time-stop button, set your location to Houston, TX (click Settings/Viewing Location/North America/United States/Houston/Set Location), and then set the time to 7:00:00 PM on October 1, 1999 (10/01/1999 AD).

Write down the latitude of Houston, and make a note of where the North Star is, compared to the top and bottom of the screen (e.g., close to the top, about half way down, close to the bottom, etc.).

Click the time-start button and watch the motion of the sky. Notice that all stars of the Big Dipper, except the one that is closest to the North Star, set below the horizon.

View Northward from Port of Spain, Trinidad

Click time-stop, set your location to Port of Spain, Trinidad (click Settings/Viewing Location/Central America/Port of Spain/Trinidad/Set Location), and then set the time to 4:00:00 PM on 10/01/1999 AD.

Write down the latitude of Port of Spain, and make a note of where the North Star is, compared to the top and bottom of the screen (e.g., close to the top, about half way down, close to the bottom, etc.).

Click the time-start button and watch the motion of the sky. What happens to the Big Dipper?

View Northward from Fairbanks, Alaska

Finally, click time-stop, set your location to Fairbanks, Alaska (click Settings/Viewing Location/North America/United States/Fairbanks, AK/Set Location), and set the time to 8:00:00 PM on 10/01/1999 AD.

Write down the latitude of Fairbanks, and make a note of where the North Star is, compared to the top and bottom of the screen (e.g., close to the top, about half way down, close to the bottom, etc.). If you cannot see the North Star, use the Big Dipper to estimate its location.

Click the time-start button and watch the motion of the sky. How does the number of circumpolar stars for Fairbanks compare to the number of circumpolar stars for Port of Spain?

Questions

1. Based on your notes about latitude and the location of the North Star above the horizon, which one of the following statements do you think is correct?
    a. The angle of the North Star above the horizon equals your latitude.
    b. The angle of the North Star above the horizon equals 90° minus your latitude.
    c. The angle of the North Star above the horizon does not depend on your latitude.

2. Where would you expect to see the North Star if you were standing at the North Pole?

3. Where would you expect to see the North Star if you were standing on the equator? (You might like to check this one by setting your location to Quito, Ecuador, in South America, and the time equal to 3:00:00 PM on 10/01/1999. Use the Big Dipper to find the North Star.)

4. If you were south of the equator, say in Australia, would you expect to see circumpolar constellations anywhere in the sky? If so, in what part of the sky would they be?

Answers

Measuring the Angle That the Sun's Track Makes to the Horizon at Sunrise

1. 90° from the horizon (i.e., the stars rise straight up from the horizon).

2. 0°.

3. The angle gets smaller (the stars rise at an angle closer to the horizon).

4. B. The rising angle of the Sun is equal to 90° minus your latitude.

5. At both locations the Sun rises in the East, but in Dunedin, New Zealand, the Sun's path angles toward the North after sunrise, whereas in Seattle, Washington, the path angles toward the south.

6. You would have to turn toward the left in Dunedin, but toward the right in Seattle.

7. You would need to face North in Dunedin, south in Seattle.

8. From right to left in Dunedin, from left to right in Seattle.

9. From east to west in both Dunedin and Seattle.

The Effect of Latitude on the Appearance of Constellations: Southward View

1. Kingston, Jamaica, and New York.

2. Between latitudes 41° (New York) and 51° (Calgary); so perhaps about 45°. (You can test this by clicking on the latitude number in the icon/location box with the date and time set as stated for part D, then typing a series of latitudes from 41° to 51°, one after the other. You will see Scorpius approaching and then sinking below the horizon as you increase the latitude of your viewing location.)

3. Probably about 70°, since just a few stars of Scorpius are visible above the horizon in Fairbanks, at latitude 65°. (You can test this the same way as given in the answer to question 2, above.)

4. Deny the grant; a globular cluster in the middle of Scorpius would never be visible from the observatory because it would never rise above the horizon. Yes, approve the grant, because Scorpius is easily visible from Texas.

The Effect of Latitude on the Appearance of Constellations: Northward View

1. A. The angle of the North Star above the horizon equals your latitude.

2. Directly overhead (at the zenith).

3. Exactly on the horizon (actually it would appear to be slightly above the horizon because of atmospheric refraction).

4. Yes, in the southern part of the sky, around the South Celestial Pole.