PHYS 1070 3.0 Winter 2008/2009 Assignment

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

Deadline: April 21, 2009

(Remember, this assignment must be typed for submission).

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.

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

- Start the program and move to a location at about 45º north latitude. A good example is Toronto, Ontario, at about 44º latitude. (View/Viewing Location [or Ctrl L], type Toronto [it will show up near the bottom of the box], wait a second for it to show up & Set Location).

- Click the time-stop button on the date/time box (if this toolbar is not on the screen, activate it by clicking View/Show Toolbar), then set the date to March 21, 1999 (3/21/1999 AD), and the time to noon (12:00:00 PM). To do this, click the appropriate digits in the toolbar and alter them using the keyboard.

- Face south by pressing S on your keyboard. Alternately, you can face any direction by pressing the key corresponding to the first letter of the direction name on the keyboard (E for east, etc.). 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 Toronto for your location the Sun is probably slightly east of south. This small offset is due to the fact that Toronto is not exactly at the center of its time zone (Eastern Time).

• You will need to set the time step to 3 minutes; to do so, click on the drop down menu directly right of the time display which is located in the top left corner of the window (it should be displaying "1x" meaning real-time). Under discrete time steps, select minutes (it should now appear as 1 min…). Click the 1 and change it to 3.

• Next, 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 toolbar (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).

• 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 Hide Daylight in the View menu, or pressing Ctrl D. 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 set daylight back on.

• 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 45º angle (from S to W would be 90º, 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 45º. (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 x 45º = 9º in one hour. Your answer should be larger than this.)

Q1. Submit this piece of paper and this calculation.

- Now, the Earth rotates through a full circle in 24 hours, and there are 360º in a circle. **Q2. 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.

- 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 (to change from AM to PM, or vice versa, click it and press P for PM and A for AM), and face east.

- 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 relatively straight (since the level of ground is not uniform, get it as straight as you can).

- 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 lap-top, be especially careful or make hand-drawn diagrams without measuring directly on the screen). The angle should be around 40^o to 50^o if the latitude of your location is between 40^o to 50^o

- 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 the Info button on the toolbar to the left of the screen. An extension will open up: click View Info then Location to reveal latitude and longitude information.

- Set the clock back to 6:00:00 AM, set your location to Honolulu, Hawaii and follow a similar procedure to measure the new angle of rising of the Sun to reach the upper edge of the screen. **Q3. 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	(Ctrl L/click Latitude/Longitude taskbar & enter 90 in Latitude)

Q4. At what angle does the Sun rise for someone at 0^o latitude?

Q5. At what angle does the Sun rise for someone at 90^o latitude? (If the Sun just skims along the horizon, then the rising angle is 0^o.)

Q6. What happens to the rising angle of the Sun as you move from the equator (0^o) to the North Pole (90^o)

Q7. 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^o minus your latitude**
c) **The rising angle of the Sun does not depend on your latitude.**

Q8. What is different about the sunrise in Dunedin, New Zealand compared with that at Toronto, Ontario?

Q9. 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 Toronto?

Q10. 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 Toronto?

Q11. 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 Toronto?

Q12. 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 your are right. How does this compare to Toronto, Ontario?

- Check that the sky motion has been stopped, and if not then click the time-stop button. Set your location back to Toronto, set the time to 1:00:00 AM, set the compass direction to east and adjust the horizon to be horizontal again. Then click the time-start button. You should see the 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 face west, and set the time to 4:00:00 PM. If the sky is not blue, then switch on daylight by pressing Ctrl D.

- 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, Jupiter, Saturn, Venus and the Moon are seen to set just after the Sun on this date and from this location.

- Latitude on 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 and 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 View Options in the left toolbar, then click

Constellations and check both Labels and Stick Figures boxes. Look for Scorpius, then uncheck the boxes 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 below. 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.)

Q13. For which of these cities is the pattern of stars in Scorpius completely above the horizon?

Q14. At about what latitude does the tail of Scorpius begin to disappear from view (i.e., never rises above the horizon)?

Q15. Above about what latitude is *no* part of Scorpius ever visible?

Q16. 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?

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

- ***View Northward from Minneapolis.*** ***Q17.*** **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 downwards, whereas stars on the right, including Cassiopeia, are moving upward. **Q18. 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, and then set the time to 7:00:00 PM on October 1, 1999 (10/01/1999 AD).

Q19. 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 and then set the time to 4:00:00 PM on 10/01/1999 AD.

Q20. 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.). Turn daylight off, 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 and set the time to 8:00:00 PM on 10/01/1999 AD.

Q21. 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 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?

Q22. 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 90E minus your latitude.
c. The angle of the North Star above the horizon does not depend on your latitude.

Q23. Where would you expect to see the North Star if you were standing at the North Pole?

Q24. 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).

Q25. 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?

THE SUN'S POSITION AT MIDDAY AND THE ANALEMMA

The Sun's position at midday at any site will not always be on the observer's meridian. One reason for this is that the site may be offset from the center of the time zone (i.e., the site is not on the central meridian of the time zone); this produces an offset of the Sun from the observer's meridian at noon that remains constant throughout the year. If time zone boundaries were ideal, then this offset could be as large as ½ hour; but in fact time zone boundaries sometimes deviate from ideal for political reasons, resulting in offsets of up to about an hour for some locations.

In addition to this constant offset, there is also a varying deviation of the Sun from the meridian that is caused by the combination of two effects. The first of these is the Earth's elliptical orbit, which results in a variable speed of the Earth around the Sun, as described by Kepler's second law. The changing orbital speed of the Earth around the Sun changes the apparent speed of the Sun across our sky, day by day. The second effect is the tilt of the Earth's spin axis to its orbital plane, also called the ecliptic plane. This also causes a variation in the speed of the apparent motion of the Sun.

The varying deviation of the Sun east or west described in the previous paragraph, when combined with the annual motion of the Sun north and south due to the seasons, results in a figure-eight pattern for the Sun's midday position in our sky over the course of a year. This figure-eight pattern is called the **analemma,** and is often found on globes representing the Earth. This truly amazing multiple exposure photograph required a year to take, at a rate of one exposure approximately every 8 days!

The shape of the analemma became more important when sundials were used to tell the time by tracing the movement of the shadow of a vertical post upon the ground. The analemma provided corrections, amounting at times to 16 minutes, to times determined by this shadow at different times of the year.

The present exercise demonstrates the analemma by tracing the apparent motion of the Sun in the sky at midday for a whole year at a chosen site.

- After starting the program, check the top toolbar to see that the field of view is 100^o (locate the slider in the top right corner of the screen- this controls field of view). If it isn't 100^o, adjust it accordingly.

- Set the location to Calgary, Alberta, Canada, near 50^o latitude. At this latitude the Sun is always visible on the screen at noon; that is, it is above the horizon in midwinter and not out of view above the top of the screen in midsummer.

- If your viewing direction is not already toward the south, make it so. If this button is not visible, activate it by clicking Toolbar in the window menu. After the screen adjusts direction, you should see the symbol S on the horizon near the bottom of your screen.

- Check that the Daylight Saving Time option is turned off. To do this, check the small sun icon to the left of date in the date/time box. The sun icon is yellow if DST is activated blank if DST is not activated. If the icon is yellow, click on it to deactivate DST.

- Stop the time by clicking the time-stop button in the date/time box; then:

a. Set the date to the winter solstice, December 21, 2000 AD (12/21/2000 AD);
b. Set the time to midday, 12:00:00 PM;
c. Set the time interval in the date/time box to 7 days. (Make sure you use "days," which actually means solar days and not "sidereal days," since you want to trace the Sun's apparent motion at midday every 7 solar days).

- Switch off daylight by clicking on Daylight in the Display menu. This will enable you to see the stars moving across the daytime sky, week-by-week.

- After the above set-up, the Sun should be at a low angle above the southern horizon. You will notice that the Sun is *not* due south at this time. This is because Calgary is offset from the center of its time zone, the Mountain Standard Time zone, by about 36 minutes. You can adjust for this offset, if you desire, by changing the local time to 12:36:00 PM.

- The shadows of the trees are cast across the ground before you. You can think of these trees as representing a sundial for measuring time at this location. The position of the Sun in the sky will move these shadows around, as we shall see.

- You need to move your viewpoint so that the Sun is just above the bottom of the screen at this time so that you can follow the path of the Sun through the full year. To do this, use the Grabber Tool to move the sky downward (click and hold the left mouse button while sliding the mouse toward you).

- In order to trace the motion of the Sun week by week, you need to tape a piece of transparent plastic or tracing paper to your screen. Mark the corners of your screen on the transparent sheet with a felt pen or marker. Be very careful not to damage the screen when you do this. Mark the Sun's position, then single-step the time forward by 7 days and mark the Sun's position again. Continue this process for a whole year of time, tracing out the Sun's position, or the analemma. Leave the plastic or tracing paper where it is for the next step.

- Switch on the equatorial coordinate grid (click the View Options tab on the left toolbar, then Guides, and check Celestial Grid), and mark the Right Ascension grid lines on either side of the analemma and all of the declination grid lines in the vertical direction. These are 1-hour right ascension and 10^{o} declination intervals. Now remove your plastic film or tracing paper from the screen so that your can make measurements on it. **The tracing must be handed in with the assignment**.

Q26. The reason for the north-south motion of the sun is the tilt of the Earth's axis to the ecliptic plane. **Using the declination lines on your plot, estimate this tilt by measuring the maximum N-S excursion of the Sun in degrees of declination over a full year.** This will be twice the tilt-angle of the Earth's axis. It is the change in the angle of the Sun in the sky that produces seasonal changes upon the Earth.

Q27. Estimate the maximum error in a sundial from the width of your plot, assuming that the Sun would be "on time" if it were on the center line that runs lengthwise through the analemma. This makes the sundial error equal to one half of the width of your analemma. For reference, one interval of Right Ascension on the screen is equal to 1 hour of time, or 60 minutes, since one hour or Right Ascension is the angle through which the Earth rotates in 1 hour.

Q28. At what times of the year will the sundial be most accurate?

Q29. At what times of the year will the sundial be most inaccurate?

- The shape of the analemma will be the same from any position on Earth. You can test this hypothesis by moving to another location, say Sao Paulo, Brazil. Reset the date to 12/21/2000 AD, and the time to 12:00:00 PM. Check that daylight savings time is off. Remember that the Sun will now be in the northern sky from the southern hemisphere so face north. In order to see the Sun, you will have to move the sky down so that the Sun is just visible at the top of the screen at this time. Now set time running at 7-day intervals to see the analemma for Sao Paolo. As you see, it is the same shape as it was from a northern latitude site.

- A question that is sometimes asked is, "If the Sun is at its furthest South at the time of the solstice, on the shortest day of the year, December 21, why is this *not* the date of the latest sunrise?" In fact, the date of latest sunrise is close to the last day of the year, several days later! In the steps below, you can answer this question in terms of the analemma and the position of the Sun as it moves through the time of the solstice.

- Set up again for Calgary, Canada

- Reset the date to 12/21/2000 AD.

- Set the time to 8:42:00 AM

- Set the time interval to 1 solar day (the time-step labeled “days”).

- Check that Daylight Saving Time is off.

- Check that daylight is off.

- Face east. You should see the Sun on the horizon near the SE position, just under the hills

- In order to demonstrate this sunrise effect, it is best to magnify the view of the sky in the region of the Sun. To do this, locate the field of view toolbar on the right corner of the screen that you found before. Centre your view as best as possible on the Sun, and click the magnify button on the toolbar continuously until the field of view is 4^{o}. You can see what the current field of view is by locating the number under the adjustable sliding bar. You will need to keep adjusting the position of your view in order to keep the Sun visible. At 4^{o}, the Sun should appear as a sizable orange sphere. If you lose the sun after magnifying, zoom out once, find the Sun and center on it, and then magnify again.

- You should see the Sun near the center of the screen, just touching the horizon. The horizon will appear as a translucent shaded green area of the sky. If necessary, centre the Sun on the screen. If the lower edge of the Sun is well below the horizon or above the horizon, temporarily set the time interval to 10 seconds and step forward or backward to place the Sun at a position just touching the horizon; then reset the time interval to 1 day.

- You can see that on the winter solstice the Sun is just rising at Calgary at the time shown on the screen. Now, advance the time by 1-day steps. You will see that, for several days after December 21, the analemma motion of the Sun places it further below the horizon at 8:42:00 AM than it was the previous day. This means that sunrise will be later on these days than on the shortest days.

- Experiment to find the date of latest sunrise, and record this date.

- Set the date to the latest sunrise date, then change the time interval to 10 seconds and step time until the Sun is just clear of the horizon. Record this time.

Q30. On what date does the latest sunrise occur?

Q31. About how many days after the winter solstice does the latest sunrise occur?

Q32. By how many minutes in the day is this sunrise later than sunrise at the solstice?