Laboratory Exercise 0
Eclipses and the Orbit of the Moon

Introduction

Unfortunately, it is not practical to have an outdoor observing project in this course. However, while that experience cannot be fully reproduced, recent developments in personal computers do allow us to simulate it in your home. In fact, the ability of the computer to display the sky on any date and to find objects, allows us to explore many aspects of the sky in more detail than would be possible outdoors in a limited amount of time.

Your course materials include a CD containing a program called *Stellarium*. If you have not yet installed this program, please do so now.

The sample lab exercise below will introduce you to the *Stellarium* program used in Labs 1 and 2. Utility and graphic programs will be introduced and described in the other labs as needed. *Stellarium* has a screenshot facility to allow you to work with information from the screen and include it in your lab reports.

The lab exercises are exercises not only in astronomy, but also in communication. To assist you in exploring the sky, the exercises have been developed to communicate clearly to you what it is you should do to see certain phenomena. You will make records of what you did, what you observed, and to what insight your observations led you. You must then communicate this information in written form, clearly but concisely, to your tutor. Although the results you will obtain will be astronomical in nature, the basic steps are more widely applicable.

This sample lab exercise consists of instructions and of a report generated in response to those instructions. The material is fairly ambitious, but ties in well with Unit 1. You should follow through all the steps and learn about both *Stellarium* and the orbit of the Moon. You will find Laboratory Exercise 1 more straightforward than this one, so don't worry!

As you work through this lab exercise, you will observe general aspects of the motion of the Sun and Moon. The exercise is also designed to demonstrate the cause of solar eclipses, and to give you the opportunity of finding the inclination of the Moon's orbit to the ecliptic.

Note: If you have a multi-screen system, please ensure that the program runs on the screen that contains your Start Up menu and task bar. Otherwise, you may have difficulty opening some of *Stellarium*'s built-in utilities.

Instructions

Work through the following set of instructions. You will be using many of these basic instructions in future exercises.

1. Start *Stellarium* as appropriate to your computer. Note the version number as the program starts. These instructions are for *Stellarium* 0.10.2, and we recommend that you use this version. If you use a more recent version, the instructions will likely work, but please include the version number in your report. We strongly recommend that you do *not* use an earlier version, since some commands were not available in earlier versions.

    Stellarium will fill the screen. Pressing the Ctrl and Esc keys at the same time will allow access to other programs. It is also possible to reduce *Stellarium* to a window by pressing the F11 function key. You may restore it to full screen by again pressing F11, or by using the toggle at the upper right of the screen.

2. Use the E key (upper or lower case) to show the grid of right ascension and declination (*E*quatorial grid). This grid is blue, with declination at the edges of the screen and right ascension at the top (and bottom if the horizon is not present there).

3. Use the Z key (upper or lower case) to show the position of the zenith and lines showing altitude angle (elevation angle) above the view horizon along with azimuth angles (*Z*enith grid). This grid is white or bronze, with altitude (angle) at the sides and azimuth at the top (and bottom if the horizon is not present there).

4. Use the mouse roller to set the field of view so that about 45 degrees is visible above the horizon. [**Note:** The horizon should be near the centre of the screen. You can click and drag with the mouse to move it.] Turn the grids off by again pressing the E and Z keys.

5. *Stellarium* will start on a certain date (usually today's date). Hit F5 and set the date to August 21, 2017, and the time for about noon (12 PM). You will likely notice a black spot near the Sun—that spot is the Moon. In addition, if you started this operation with a night sky, the Sun will now have appeared. You should see a daytime sky with the Sun visible but near the top of the screen. If not, and the date is correctly set, use the mouse, clicking and dragging, or the arrow keys, until you locate the Sun. The cardinal points are marked in red near the horizon, so you should have a red "S" near the bottom of your screen. Drag the time selection box to a corner of the screen.

6. Hit the F6 function key and, in the box that appears, choose a location near your home; for example, Edmonton, Canada. You may use this position for the remainder of the exercises, so check off the box "Use as Default." Drag this box to a corner of your screen, but do not close it.

7. Move your mouse to the Sun and click. Information about the Sun should appear at the upper left. In addition, some pink bars should appear to rotate around the Sun to indicate that it has been selected.

8. Hit the space bar. The selected object (Sun) will move to the centre of the screen. This is handy to know if you lose an object through time or field of view changes. Restore the view to that of Step 5 by clicking and dragging on the screen with your mouse.

9. Return to the time box and advance the date by one day (to 2017/8/22). You should see the Moon label to the left (eastward) of the Sun. Continue to increase the date and the Moon should continue to move eastwards off the screen. Do not adjust the field of view.

10. Continue to increase the days until 2017/9/19, noting the Moon entering from the right (west) a few days before this date. You should also note a generally southward motion of the Sun and of Venus. Would the Moon in fact likely be visible during the daytime at this point? Click on Venus and note its magnitude. When Venus is very bright (about –4 magnitude) it can be seen during daytime, as *Stellarium* suggests. How could you observe the Moon when it is near the Sun?

11. Add one more day, so that the Moon passes the Sun moving eastward. Describe the position of the Moon, and infer whether it passed north or south of the Sun when it passed it.

12. Now adjust the time to approximately one month before 2017/8/21, and describe the motion of the Moon relative to the Sun on the days when it was closest. Conclude what the Moon does normally each month as it passes the Sun in the sky.

13. Reset the date to 2017/8/21 at noon. Make sure the view is much as before; in particular, ensure that south is at the bottom. By selecting (if deselected) the Sun and hitting the spacebar, or by using your mouse to adjust zoom and view, bring the Sun and Moon to the centre, and zoom in so that you can see both as circular objects. [Use the "Page Up" and "Page Down" keys, or the wheel on your mouse to zoom.]

14. Next, adjust the latitude in the position box (F6 if you have closed it) so that as much of the Sun is covered by the Moon as possible. Describe the motion required on the surface of the Earth to result in an apparent north-south motion of the Moon with respect to the Sun.

    Then, adjust also the longitude to cover yet more of the Sun. You may also adjust the time. If you do so, time may start to advance, which we do not want at this point in the exercise. Press the "7" key to make sure that time stops. Note that the current time is shown near bottom centre of the screen. If time is running, this time will change from that which you set in the time box.

    Identify a place and time at which a total solar eclipse may be viewed on this date. To prove that you "saw" the eclipse, zoom out to get a nice sky view. Next, press F2 (Configuration) and then the Tools tab,

and select a directory in which to save your screenshot. In cases like this one, where the sky is dark, choose to invert the screenshot ("Invert colors"). Close this box, but keep the date and place boxes open. Press Ctrl-S (hold the Ctrl key down and press the S key) and a screenshot file should appear in the selected directory.

15. Either press F4 or move the mouse at the lower left to activate the "Sky and Viewing Options" box, and within it select the tab labelled "Markings". Check the box for "Ecliptic" and a pink line should appear to mark this important line, the apparent path of the Sun. Note the position of the Moon with respect to the ecliptic. Change the time in steps of days (and zoom as needed) and note the motion of the Moon north or south with respect to the ecliptic. Note whether the direction of north-south motion is consistent with the results of Steps 11-12, and conclude whether this is an ascending or descending node eclipse.

16 Return to the time of the eclipse, and make sure that you have a good view toward the south as before. Advance the time by six months using the month adjuster in the "Date and Time" box. The Moon should be visible, having made six circuits of the Earth (each being nearly a month). If not, zoom out slightly. Adjust the days until the Moon comes closest to the Sun. Does an eclipse take place? Find when the Moon crossed the ecliptic, and determine whether it was near the ascending or descending node. If the nodes were stationary, how did the Sun get to be near this node?

17. Use a protractor (note that printable protractors are easily found on the web), or if you know enough math, just use a ruler, to measure the angle between the Moon's path and the ecliptic (this angle is called the inclination). Describe your method. [This may not be as easy as it first appears.] If the Moon's path lay in the ecliptic, what implication would that fact have for eclipses?

18. Return to the date of the eclipse and adjust for a view much as before during the eclipse. Advance the time by days. Recall that the eclipse took place at the node crossing by the Moon, and find the next time the Moon crosses this node. Describe the position of the Sun at this time.

Advance in time until the Moon roughly lines up with the Sun in the north-south direction. Assuming that the node is fixed in space (it actually moves slowly), what is the name and value of the period required for the Moon to move from the node back to the same node? What is the name and value of the period required for the Moon to line up with the Sun again (i.e., to repeat its orientation relative to the Sun)? Why is the second period longer than the first? By roughly how much angle (how many degrees) do the Sun and Moon appear to move in a day with respect to the stars or to a fixed point such as the node?

19. Comment on the realism of this lab.

Note: Include the plots you printed or saved along with your report.

Sample Laboratory Report
Laboratory Exercise 0

I started *Stellarium* as described in the Laboratory Exercise, using a Dell Latitude E6500 computer running Windows XP. The *Stellarium* version number was 0.10.2. The time was initially 2009-09-02 at about 18:50, as shown at the bottom of the screen; the position was Paris, France.

The equatorial grid was turned on with the E key, and the altitude-azimuth grid with the Z key. The equatorial grid moved slowly westward while the altitude-azimuth grid was stationary. By clicking and dragging slightly downward, with no need to change the scale, about 45 degrees was set at the top of the screen, based on the altitude-azimuth grid. The grids were then turned off using the E and Z keys.

The "Date and Time" box was activated by pressing F5. The date was set for 2017/8/21, and the time for 12:00:00. The Sun had not previously been visible but was now in the upper left of the screen with a black dot over it. The "Location" box was activated by pressing F6. Edmonton was selected from a list, which resulted in a latitude of N 53°34′12.00″, a longitude of W 133°32′24.00″, and an altitude of 669 m. This location was set to default.

Clicking on the Sun resulted in the appearance of faint information about the Sun in the upper left corner, and of pink bars rotating around the Sun. Hitting the space bar caused the Sun to move to the centre of the screen. The original view was approximately restored by clicking and dragging.

When the date was advanced by one day, the black dot no longer covered the Sun, and the Moon was identified to the left of the Sun. After an advance of one more day, the Moon left the screen. As the days were advanced, the Moon again became visible at the upper right (seen through the Location box) on 2017/9/15. The Sun moved generally downward in the sky as the days advanced, and Venus appeared and also moved downward.

The date was advanced to 2017/9/19, and the Moon was now very near the Sun. Its magnitude was about –2.5, and it was likely too close to the Sun to be observed in the daytime sky. Venus was about –3.5 magnitude and far from the Sun, so would possibly have been visible according to the criteria in the instructions. To observe the Moon when too near the Sun to see during the day, observations could be done after sunset or before sunrise. Possibly optical aid would help.

When the date was advanced by one day, the Moon moved past the Sun toward the East. Imagining a line between the two positions, the Moon would have passed above the Sun; that is, to its North.

The time was set back two months, to 2017/7/20. The Moon was visible at upper right, but the field of view had to be changed slightly to bring the

Sun in from the top. As the days were increased one by one, the Moon appeared to pass below (i.e. south of) the Sun between 2017/7/22 and 2017/7/23. As the Moon passes the Sun, moving eastward in the sky relative to the Sun, it usually appears to go either North or South.

The date was reset to 2017/8/21 at noon. The Sun was selected by clicking, and the spacebar was pressed to centre it on the screen. Zooming so that the bar at the bottom said FOV 1.5°, showed that the Moon covered the bottom (South) half of the Sun, approximately.

Motion southward on the surface of the Earth made the Moon appear to move northward. The Sun presumably moves northward as well, but the Moon is much closer, so its apparent motion dominates. There came a point (near 30°) where further motion southward seemed to make the Moon appear to move more right-left than up-down, so then motion was done in longitude. Making the West longitude less (i.e. moving eastward) seemed to allow the Moon to cover more of the Sun, but now the Moon was covering the Sun's northern half, so it was necessary to move northward. This motion was taken in small steps, and the Moon was made to cover the Sun completely at N 40°34'12" and W 99°32'24". The time was not changed, remaining at 12:00:00 noon. The screenshot was saved to directory C:/courses/ASTR210/Lab0, and came out as file stellarium-001.png. A copy is included here.
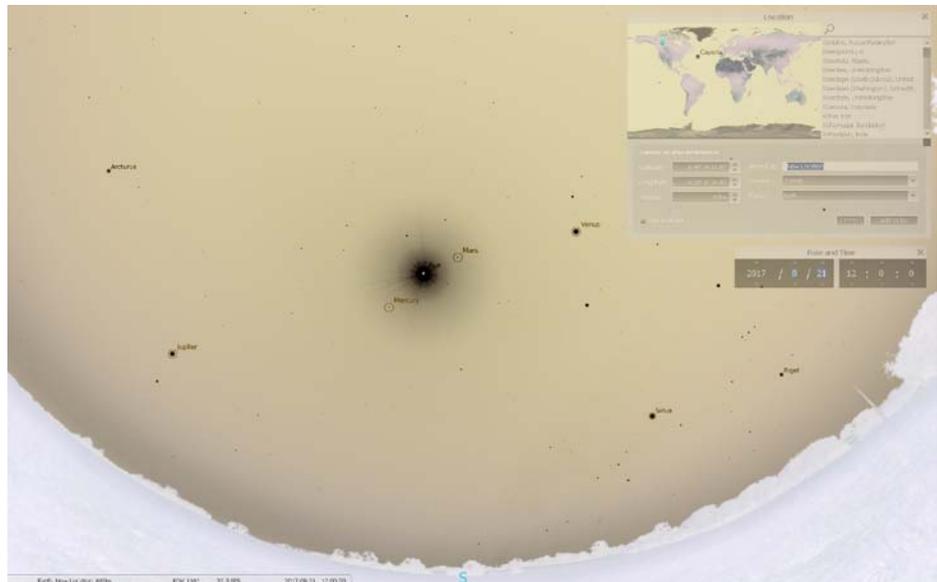
Many bright planets and stars will be visible during this eclipse, and the position from which it is observable at noon is in the central USA.

The ecliptic line was turned on; it went diagonally across the sky. Since the Moon covered the Sun, it must have been on the ecliptic, and it appeared that way. As determined by changing time by days, the Moon was north of

the ecliptic after the eclipse, and south of the ecliptic before the eclipse; that is, it moved south to north during the eclipse, which was an ascending node eclipse. From Steps 11-12, about a month before the eclipse the Moon passed south of the Sun, and a month later, north of the Sun. These observations are also consistent with the northward motion at the time of the eclipse.

About six months later, the Moon was again near the Sun in the sky, passing closest on 2018/2/15. However, an eclipse did not take place and the Moon crossed the ecliptic between 2018/2/13 and 2018/2/14, moving southward. This is thus the descending node. The Sun was near the descending node six months later, since the Earth had moved halfway around it in its orbit, and the two nodes are about 180° apart.

To measure the inclination, I reset to the time of the eclipse and centred the Sun. I reset the zoom so that the Moon was near my protractor edge one day later. I also clicked off the Sun so that it was no longer forced to be in the centre. Going back to the eclipse, I placed the centre of my protractor at the position of the Moon on the screen, and approximately aligned the 0-180 line with the ecliptic. I held it in place and advanced the time by one day. The Sun was no longer at the middle of the protractor, but the ecliptic line was, although the ecliptic seemed to rotate a bit. I aligned my protractor with the new position of the ecliptic and read the position of the Moon as 5.2° clockwise from the ecliptic. The inclination of the Moon's orbit seems to be about 5°. If it was zero, the Sun and Moon would line up both at new and full moon, and there would be a solar eclipse and a lunar eclipse each lunar month.

I returned to the eclipse time, and then advanced the time forward so that the Moon left the screen and then re-entered from the right on 2017/9/12. It appeared to cross the ecliptic between 2017/9/17 and 2017/9/18. Since it was about equal distance above and below on the two dates at noon, we can conclude that it crossed about 2017/9/18 at 00:00. Counting the clicks to change days, there were 27 days to get back to the time of the eclipse from 2017/9/17. To this must be added one-half day to get to 2017/9/18 at 00:00. The Moon took 27.5 days to go around the sky from the node back to the same node. This is the sidereal period of the Moon, since the node is considered fixed in space like the stars.

Setting back to 2017/9/17 and advancing by days, the Moon appeared to go by (north of) the Sun between 2017/9/19 and 2017/9/20, so it passed the Sun near 2017/9/20 at 00:00, two days later than it passed the node. This period was thus 29.5 days. Since this was the period from instance in which the Moon one lined up with the Sun (eclipse) to the next, it is the synodic period. The synodic period is longer, since the motion of the Earth around the Sun makes the Sun appear to move eastward in the sky relative to a fixed point such as a star or a node. Thus the Moon must put in extra time in its eastward motion to catch up.

The Moon's sidereal period is 27.5 days, and in this time it moves 360°, so about 13° per day. Since it took two more days to catch up to the Sun, this

means that the Sun had moved about 26° past the node in about 30 days, or roughly one degree per day. Since the Sun appears to go around the Earth, i.e. 360°, in the 365-day year, this result seems about right.

Summary

This laboratory exercise demonstrated that both the Sun and Moon move eastward in the sky: the Sun in the ecliptic, and the Moon at a small angle to the ecliptic. The Moon moves about 13 degrees in one day, and the Sun much less, about one degree per day.

When the Sun is near a node of the Moon's orbit, a solar eclipse can occur when the Moon passes through the node. At other times of year, the Moon passes north or south of the Sun, and no eclipse is seen. Even six months later, when the Sun was near the other node, no eclipse was seen, so the line-up must be very precise to give an eclipse. This is why they are rare.

The inclination of the Moon's orbit to the ecliptic was measured as 5.2°.

This lab was a bit unrealistic, since we could see things in the daylight sky that might be hard to see. Also, it was never cloudy. Real observing would be more difficult. Likely the portrayal of the eclipse was quite accurate, since the sky got dark.

Comments on Laboratory Report

In this report, the ideas of doing-observing-interpreting have been mixed together to make a running commentary. The main points indicated in the exercise are then summarized at the end. Attention was paid to answering specific questions in the exercise. This strategy provides an effective means of communicating back to the instructor. It also helps you to keep organized and complete the lab correctly.