Laboratory Exercise 1

Motions of the Sun and Moon (*Stellarium Version*)

Introduction

The Sun and the Moon are the most easily observed of all celestial objects. They have been studied since ancient times and have continuing importance in our lives. The month is based on the length of the Moon's cycle of phases. The apparent motion of the Sun resulting from the Earth's rotation gives us the important division between day and night. As the Earth revolves around the Sun in its orbit, the position of the Sun relative to the stars appears to change, and the alternate inward and outward tilt of the hemispheres of the Earth gives rise to the seasons.

In this laboratory exercise, you will study the orbit of the Moon and its periods of revolution. In doing so, you will learn to analyse a graph, a widely applicable skill. You will also study the motion of the Sun, and see how variations in its altitude cause the seasons and influence the length of day.

Part 1: The Orbit of the Moon

Follow the instructions below carefully, and keep notes of your observations.

1. Start *Stellarium* on your computer. Use the E key to enable the right ascension-declination grid, and the Z key to enable the elevation bars.

   Note: The spacing on the grids changes with the zoom, and the values are indicated around the edges of the screen, except where the horizon is present. If it helps you to measure, you may turn off the horizon by clicking on the symbol that looks like a hill with two trees in the command bar that will appear if you bring the cursor near the bottom of the screen.

   The position should have been saved since your practice in Lab 0. If not, set it for a location near your home. [Recall the F6 function key.]

2. Adjust the zoom so that, much as in Lab 0, about 45° degrees is visible, but point West.

3. Adjust the time until it is near sunset. The zoom should allow you to see the setting Sun for most latitudes and times of year. Describe the position of the Sun at sunset.

4. Advance by days until you see the Moon near the western horizon. If more than one month goes by and you still do not see the Moon, zoom out so as to include more length of horizon, and repeat.

5. Once you have found the Moon in the evening sky, use F4 to open the View window, and under Sky, click on "Scale Moon." This will enlarge the Moon allowing phases to be seen even with quite wide zoom.

   Press E to toggle off the equatorial grid. The altitude-azimuth grid (white) should still be visible. Angles in this grid system correspond to real angles for the altitude (elevation in degrees above the horizon). Since the azimuth (angle around the horizon from north) lines converge at the zenith, they are not true angular separations, except at the horizon. In addition, there is distortion in the projection fitting the sky onto your screen. The most useful references for angle are thus the lines of equal altitude, corrected for distortion. Deduce what the separation of lines of equal altitude is at the zoom setting you are using.

6. Rotate the view so that the Moon is near the centre on the right side of the screen. Make sure time is stopped by pressing the 7 key. Use Ctrl-S to take a screenshot, making sure you know where it will be stored (see Lab 0 for how to change this). We recommend that you print the screenshot unless you know how to measure and add graphics to a png file. You can preview the screenshot by opening a window to show the folder where you placed it, and then clicking on it. You can print it from the previewer.

7. Now, advance one day at a time, transferring the position of the Moon from the screen and marking it (along with the day) on the printout.

8. The Moon will eventually move out of the field of view. This disappearance corresponds to the time at which the Moon becomes full. Since your observation time is near sunset, and the full moon rises at sunset (and later phases rise later in the night), you will need to change your observing time. Advance the hour until just before dawn, and the Moon should move to near the western horizon. Take another printout, and repeat Step 7. If for any reason more printouts are needed to show a nearly full cycle of lunar motion, please take them. You should have a total of about 25 points on your printouts.

9. Now make a table, showing the day and the number of degrees moved on that day.

   The distance moved (in centimetres or millimetres) should be recorded between adjacent days. You can convert this measurement to the number of degrees moved by measuring the distance between *nearby* elevation markers. They are separated by a known number y of degrees, and we will denote the physical distance between them by x, in whatever units you used. Then, each unit of distance corresponds to y/x degrees, so multiplying the measured distances (in millimetres or centimetres) by y/x will give the corresponding distances in degrees.

   Multiplying through, you should now have a table showing day of month, raw data in millimetres or centimetres, and angle moved in degrees, for several days in each of five weeks. Make sure that your answers are reasonable in light of the values found in Lab 0.

10. To interpret this data, it is useful to make a graph. You may do so by hand, plotting the day of the month as the *x*-coordinate (i.e., the abscissa or horizontal value), and the degrees moved as the *y*-coordinate (the ordinate or vertical value).

    A second way is to use the "Graphical Analysis" program by Vernier Software found on the CD supplied with your course materials, or your own program (e.g., Microsoft Excel™).

11. Bearing in mind what we have learned about orbits, interpret your graph. You should be able to tell when the moon was nearest and farthest from the Earth. What is the relation between the average number of degrees moved per day and the sidereal period of the Moon? Is this value consistent with the sidereal period as determined by other means?

13. Return to *Stellarium* and zoom out until the entire sky is visible.

    To improve accuracy and ease of use, you may wish to turn the atmosphere off and use an ocean horizon. You may turn off the atmosphere by clicking on the symbol that looks like a cloud with the sun behind it in the command bar that will appear if you bring the cursor near the bottom of the screen. To select an ocean horizon, press the F4 function key. Select "Landscape" from the menu at the top, and then choose "Ocean" from the menu at the left-hand side.

    Advance the time until the Sun is setting in the West. Advance the days until the Moon rises as the Sun sets (you may need to adjust the time as well). What is the phase of the Moon at such a time? It is not necessary to make a hard copy, but do record the date.

14. Advance about one month, and again find the day when the Moon rises as close as possible to sunset. Repeat at least five times. What is the average spacing between these special dates? To what period of the Moon does this value correspond? Compare it to the sidereal period.

Part 2: Apparent Motion of the Sun

Follow the instructions below carefully, and keep notes of your observations.

1. Reset the zoom so that about 45° may be seen above the horizon, and face West. The horizon, from SW to NW, should be across the bottom of the screen. Use the Z key to show the alt-az grid (white) and, if necessary, press the E key to make the equatorial grid (blue) invisible.

2. Set the date to the winter solstice and the time to around sunset, and note the position of the Sun. It will be useful to ensure that the atmosphere is "turned on" using the cloud-Sun symbol in the bottom control bar. Adjust both the time and the zoom so that the Sun is nearly setting. At this point it will be useful to turn off the atmosphere for a more well-defined indication of the Sun's position. Have the Sun not

too near the edge of the screen, leaving at least 10% of the screen width to its left. Take a screenshot and print it. You should likely "Invert colors" for clarity and to save ink.

3. Advance by days for one month. Describe the motion of the Sun as seen at this fixed time of day. Carefully transfer the position of the Sun to the printout, and mark the month/day number beside it. You may mark more points than one per month if you wish, but not less. Depending on the quality of your printout you may wish to darken the markings, including the alt-az labelling, to aid in locating the points on the plot.

4. Repeat this operation until you reach a date upon which the Sun appears to jump dramatically. This jump is due to the shift to daylight savings time (DST). Describe the direction of the jump, and what effect this will have on the local time at which the Sun sets. Adjust the time by one hour to remove the effects of DST. Mark the position on the DST change date. Continue to repeat the monthly readings, including compensating appropriately for the end of DST in the autumn, until you have recorded the apparent motion of the Sun over one full year.

5. Join the points and describe the apparent motion of the Sun over one year. The resulting curve is known as an "analemma."

6. Using the elevation lines as reference, determine the obliquity of the ecliptic. Explain why the length of the days varies with the seasons, based on what you see in your diagram. Do this by considering how many hours it will take the Sun to move to set on the western horizon, from the fixed time at which you took your observations.

7. Set the time for around 1 PM at the winter solstice. Face due South, with the alt-az lines visible. Zoom in on the Sun, and drag and click so that it is near the right hand side of the screen, with about 10° of azimuth visible on the screen to its left.

   Press Alt-[(i.e., hold the Alt key and press the [key) to make the sidereal time advance by 7 sidereal days. Verify that there are stars in the field of view and that they do not move, while the Sun does move eastward. Return to the original date and time by pressing Alt-]. Carefully estimate the azimuth of the Sun (neglect any north-south motion). Again advance one sidereal week and carefully estimate the azimuth of the Sun. The azimuth difference does not correspond to "real" angle around you; rather, it is the angle moved with respect to the zenith. We must correct the scale by measuring the length of one degree of elevation and one degree of azimuth, much as in Step 9 of the previous section. Determine how many degrees the Sun appeared to move per day in the winter.

8. Repeat these steps at the summer solstice.

9. Compare the daily angular motions found to determine whether the Sun is nearer the Earth in summer than in winter. Assume these are the

extremes of the Sun's distance from Earth, and compare the eccentricity of the Earth's orbit to that of the Moon's orbit.

9. It may not seem realistic to use grids in the sky to do these measurements. Comment on how they could be done if you had a way to count sidereal time and a stick that would cast a shadow.

Mail your report, complete with graph and printouts, to your tutor for grading. Be sure to attach a completed tutor–marked exercise form, from the course package, and to keep a copy, in case the original goes astray in the mail.