AST 120 Activity 3
The Celestial Sphere and the Motion of the Sun

Name	Full	Partial	None

In this activity we will continue examining the motion of the stars to fill in some details of our new Celestial Sphere model. Then we will examine the motion of the Sun to see how (if at all) it fits with our model for the Celestial Sphere.

Review of Celestial Coordinates

1. In the last activity you were introduced to equatorial coordinates (RA and Dec). Now let's look at the equatorial coordinate system in Stellarium.

   - Launch Stellarium. Make sure the program is set to Rome, GA.
   - Stop the flow of time and set the time to now.
   - Turn off the atmosphere and the fog.
   - Display the equatorial grid. This brings up a grid showing the equatorial coordinate system.

   Let's use this grid to find the coordinates for a star.[1] We'll try the star Mintaka. Move the cursor to the left and click on the Search icon (it looks like a magnifying glass). Type in Mintaka and hit return. If Mintaka is below the horizon then advance time until it is above the horizon. Use the equatorial grid to estimate the coordinates for Mintaka. After you have made your estimate you can check your answers by looking at the information for Mintaka displayed on the screen.

   RA = ______________ Dec = ______________

2. Near what special line in the equatorial coordinate system is Mintaka located?

3. Now let's run the animation. Click and drag the view slightly so that Stellarium will maintain a fixed view of the sky. Increase the time speed until the stars are moving noticeably. Do the stars move *relative to the RA/Dec coordinate grid*?

[1] We did this with the EJS Equatorial Coordinates program, but that was from the *outside*. Now we are going to determine coordinates from the *inside*.

4. Stop the animation and direct your view toward the zenith. Turn on the azimuthal grid to help you identify the exact location of your zenith. What are the coordinates of your current zenith in the equatorial system?

   RA = ______________ Dec = ______________

5. What would be the equatorial coordinates of your zenith one hour from now (advance time by one hour to find out)? Try to figure this out without using the software, but you can check your answer with the software.

   RA = ______________ Dec = ______________

6. Explain why it makes sense to measure RA in units of time.

7. What is the significance of the Declination coordinate of your zenith? How is it related to your latitude on Earth?

8. Explain how your answer to the previous question fits with our earlier discovery that the altitude of Polaris is equal to the latitude of the observer. [Hints: what is the Declination of Polaris? Given this, what is the angle between Polaris and your zenith? How does this relate to the angle between Polaris and your horizon?]

Motion of the Stars and Sun

OK, enough about equatorial coordinates for now. Hopefully the advantages of the equatorial system are clear. Now we are going to measure exactly how long it takes for the stars to go all the way around the sky (or for the Celestial Sphere to complete one full rotation, in our model).

1. In Stellarium, turn off the equatorial grid, but leave the azimuthal grid on. Find Sirius, the brightest star in the sky. Run the animation until Sirius is on the Meridian in the Southern sky at az=180° (if it is not already there). Try to get it right on the Meridian (use the Date/Time window - the clock icon on the left - to make fine adjustments). Record the time (to the nearest minute) and date of this transit below.

2. Now advance time using the Date/Time controls until Sirius returns to the Meridian at az=180° once more. Again, try to get it exactly on the Meridian. Record the time and date of this transit below.

3. What is the time interval between transits for Sirius (and for all the other stars)? Give your answer to the nearest minute. This time interval is known as a *sidereal day*.

4. Now let's do the same thing for the Sun. Find the Sun and advance time until the Sun is on the Meridian at az=180°. Record the Sun's transit time and date below. Note that the time at which the Sun transits (as seen from a particular location) is known as *local noon* because it is the time when the Sun is highest in the sky.

5. Note that in Rome, GA "local noon" does not occur at noon on our clocks. Why do you think this is? (Hint: recall that clock time is the same for everyone within a given time zone. Where is Rome located within the Eastern Time Zone? Will our location tend to make the sun pass overhead earlier or later than for other locations in this time zone? Is there anything else that is weird about how we define our clock time, at least during this time of the year?)

6. Advance time until the Sun's next transit. Try to get it right on the Meridian again. Record the time and date of this transit below.

7. What is the time interval between transits for the Sun? Give your answer to the nearest minute. This time interval is known as a *solar day* (or usually just a day).

8. Note that both the stars and the Sun move East to West across the Southern sky. But it apparently takes the Sun a little longer to go all the way around. *Relative to the stars* which direction is the Sun moving? (This issue of relative motion can be tricky, so don't hesitate to ask Dr. T for help.)

9. Let's verify this by advancing time by exactly one sidereal day (using the appropriate key command). What direction does the Sun appear to move relative to the stars?

10. Did you notice anything else moving? If so, what do you think these strange stars might be?

11. Keep the azimuthal grid on, but also turn on the equatorial grid, the ecliptic, the equator, and the meridian. The ecliptic (the red line on your screen) is the name of the path that the Sun follows among the stars. Find where the ecliptic crosses the Celestial Equator (the blue line) and use the protractor provided to determine the angle between these two lines. Zoom into this point using the keyboard commands so that you can make an accurate measurement. Record your result below.

12. Zoom back out to the normal view. Find the Sun again, if necessary, and click it. Track the sun. Now go to the Date/Time window and **set the date to today and the time to the time you determined for local noon above**. Close the Date/Time window and stop the flow of time. Now advance the simulation by *solar* days until the Sun crosses the Celestial Meridian with an RA of 12^h. Note that the Declination of this point is $0°$, indicating that it is a point on the Celestial Equator. This point is known as the *autumnal equinox*, ♎. Record the date and the Sun's altitude below.

    date = ______________________________ alt = _______________

13. Advance by solar days until the Sun is at an RA of 18^h (this is the winter solstice). Note that here the Sun's Declination is not zero. What is it?

14. Record the date of the winter solstice and the Sun's altitude at local noon below.

    date = ______________________________ alt = _______________

15. Note that the time for local noon has changed. By how much, and in which direction, has it changed? Why do you think this is? (Hint: think about how we adjust our clocks every fall.)

16. Advance by solar days until the Sun is at an RA of 0^h. Again, the Sun's Declination is zero at this point, which is known as the *vernal equinox*, ♈. At this point both the RA and Dec are zero, so the vernal equinox serves as the origin for the equatorial coordinate system. Record the date and the Sun's altitude at local noon below.

    date = ______________________________ alt = _______________

17. Note that the time for local noon is now back to its original value. Why?

18. Advance by solar days until the Sun is at an RA of 6^h (this is the summer solstice). What is the Sun's Declination at this point?

19. Record the date of the summer solstice and the Sun's altitude at local noon below.

date = ______________________________ alt = _______________

20. Advance by solar days until the Sun returns to an RA of 12^h. Record the date below.

21. How many days does it take for the Sun to go all the way around the ecliptic? (Hint: compare the first date when it was at 12^h to the next date when it was at 12^h.)

22. The time for the Sun to go from one vernal equinox to the next (or from one autumnal equinox to the next, etc) is known as a *tropical year*. The length of the tropical year is related to the lengths of the sidereal and solar days that we measured earlier. Since the stars move relative to the Earth (circling Earth once every sidereal day), and the Sun moves relative to the stars (circling the Celestial Sphere once every tropical year) we can combine these motions to determine how the Sun moves relative to Earth (going around once every solar day). Mathematically the formula is:

$$\frac{1}{T_{sol}} = \frac{1}{T_{sid}} - \frac{1}{T_{ty}}$$

where T_{sol} is the length of the solar day, T_{sid} is the length of the sidereal day, and T_{ty} is the length of the tropical year. The minus sign on the left comes from the fact that the westward motion of the stars relative to Earth, and the eastward motion of the Sun relative to the stars, are in opposite directions. Use this formula and the standard values for the solar day ($T_{sol} = 24$ hours) and tropical year ($T_{ty} = 365$ days) to calculate the length of the sidereal day in hours. Note that you should first convert T_{ty} to hours so that all terms in the formula have the same units. Keep as many decimal places of accuracy as possible for this calculation.

23. Express your calculated value for T_{sid} in terms of hours and minutes. How does this result compare with the value for the sidereal day that you measured using Stellarium (see question 3)?

24. During what month is the Sun highest in the sky at local noon?

25. During what month is the Sun lowest in the sky at local noon?

26. Will Rome tend to be warmer when the sun is lower in the sky, or when it is higher? If you aren't sure, ask Dr. T for a demonstration.

27. Use the Date/Time window to set the date to the winter solstice. Turn off the ground so that you can see the horizon line (the 0 degree altitude line). Use the Date/Time window to find the time for sunrise (the time when the Sun crosses the horizon line moving upward). Record the sunrise time below.

28. Determine the time for sunset on the winter solstice.

29. What is the length of the period of daylight on the winter solstice?

30. Now determine the time for sunrise on the summer solstice.

31. Determine the time for sunset on the summer solstice.

32. What is the length of the period of daylight on the summer solstice?

33. Will Earth tend to be warmer when the sun is up for a long time each day, or when it is up for a short time?

34. Why is it warmer in the summer and colder in the winter? We have seen two different reasons for this, so make sure you list both of them. Explain how both of these things are related to the orientation of the ecliptic relative to the celestial equator.