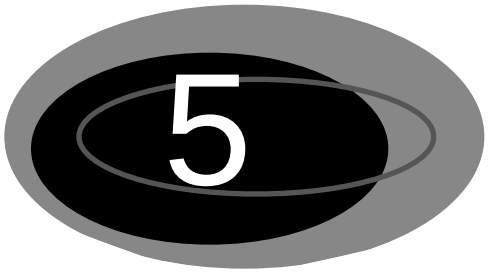

The Earth's Orbital Motion and the Sun's Apparent Motion Across the Sky

Our view of the sky is constantly changing. The two most evident changes are the apparent motion of the stars and constellations toward the west over the course of a single night, and the much slower shift of stars and constellations toward the west over the course of a year when viewed at the same time each night (say, 11 PM). The first of these changes is caused by the Earth's rotation, which makes the sky appear to rotate around the Earth's polar axis once every day, or 15° per hour; it also makes the Sun, Moon, and stars rise in the east and set in the west each day. The second change is caused by the Earth's orbital motion around the Sun; since the Earth makes a full orbit of 360° in about 365 1/4 days, our view of the universe at any given time of day or night changes by about 1° per day. The combined result of these two changes is that each star rises about 4 minutes earlier each night.

If we could see the stars in the daytime, then the most obvious effect of our orbital motion around the Sun would be an apparent motion of the Sun past the background stars. Unfortunately, this motion is

hidden from us by the blue sky of daylight (the stars are not visible when the Sun is up). By the magic of computers, however, we can simply turn off the blue sky to reveal the Sun's apparent motion against the background sky!

The plane containing the Sun and the Earth's orbit is known as the **ecliptic plane**, and the projection of this plane onto the sky forms a line or circle around the sky called the **ecliptic**. This path passes through a limited set of constellations known as the **Zodiac**, a band of constellations through which most of the brightest planets and the Moon appear to move as they orbit close to the ecliptic plane. This region of our sky played an important role in early astrology because the positions of the planets were used to predict the future, and these zodiacal constellations or "signs" are still used in modern astrology.

Some more information on the Earth's orbit and the apparent motion of the Sun can be found in the discussion of the seasons in Section 2-5 and Figure 2-13 of Kaufmann and Freedman, *Universe,* Fifth Ed.

This exercise will demonstrate the daily motion of the Sun past the background stars, and show the Sun's path—the ecliptic—around the sky.

A. Screen Set-up

1. After starting the program, check the icon/location box to see that the field of view is 100° (if this box is not visible on the screen, you can activate it by clicking Show Floating Palettes in the Window menu). If the field of view is not 100°, then click on the house button to reset the field of view to 100°.

2. Set the location to Chicago (Settings/Viewing Location/North America/United States/New York/Set Location).

3. If your viewing direction is not already toward the south (S), then click the S button on the button bar near the top of the screen. If this button bar 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.

4. Check that the Daylight Saving Time option is turned off. To

do this, check the small sun icon to the left of the time in the date/time box (if this box is not visible on the screen, activate it by clicking Time in the Window menu). The sun icon is yellow with 8 rays if DST is activated, but background color with 4 rays if DST is not activated. If the icon is yellow, then click on it to deactivate DST.

5. Stop the time by clicking the stop-time button in the date/time box; then
   a. set the date to December 21, 1999 (12/21/1999 AD);
   b. set the time to midday, 12:00:00 PM;
   c. set the time interval in the date/time box to 1 sidereal day. Be sure that the time units are sidereal days, not just days (which means solar days).

   The reason for setting the interval to 1 sidereal day is that the background sky returns to exactly the same position after 1 sidereal day, since 1 sidereal day is the true Earth rotation period with respect to the background stars. The stars then appear to be motionless as we advance time, making the motion of the Sun easier to see.

6. Switch off daylight by clicking on Daylight in the Display menu. You can now see the background stars behind the Sun.

B. The Sun's Motion

1. Step time forward by one sidereal day at a time with the single-step button in the date/time box. You will notice as you do this that the time displayed in the date/time box, which is Solar Time, actually advances by less than 1 day since 1 sidereal day is less than 1 solar day by 3 minutes, 56 seconds. (I.e., 1 sidereal day is equal to 23 hours, 56 minutes, 4 seconds in Solar Time.)

2. Set time running forward by clicking on continuous run (the button to the right of the stop button in the date/time box). Experiment with time, moving it forward and backward to see the Sun's apparent motion.

3. Although the background stars remain fixed as you advance

time by 1 sidereal day steps, you may notice several star-like objects that move across the sky at a different rate than the Sun. These are, of course, the **planets**, orbiting the Sun at their own individual rates. You can identify each one by using the Object Identification Tool (the arrow 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) and by using the arrow icon to click on and label each object in turn. (To remove the final label, click on a blank patch of sky.)

4. Display the orbit of each planet as follows. Click Planets in the Window menu to display the planet box, and look to see if there is a list of planets; if not, then click on the triangle next to the Sun to display the planet names. For each of your identified planets in turn, click on the Orbit Column next to the planet's name to display the orbit, then click here again to remove the orbit from the screen. **Mercury** and **Venus** are close to the Sun and move in orbits that are more or less inclined to the ecliptic plane and hence do not follow the ecliptic exactly. The **Moon** also makes its appearance as you advance time, moving much more quickly across the sky every sidereal day than does the Sun. You can display the Moon's orbit by clicking on the Orbit Column next to the Moon's name; if the Moon is not visible in the list of planets, click on the triangle next to the Earth to display the Moon's name. When you are finished, you can click on the X at the top of the box to remove the box from the screen.

5. Run time backward until the Sun is against the right edge of the screen. Then step the time forward and count the number of sidereal days that elapse until the Sun reaches the left edge of the screen, having traveled about 100° across the sky. Divide 100° by the number of days taken for the Sun to move through this angle to obtain its motion per day. (For this rough estimate, you can assume that 1 sidereal day is equal to 1 solar day.)

6. The Sun's motion appears smooth, with evenly spaced daily steps, but in fact, its apparent speed across our sky varies because the Earth moves in an elliptical orbit, moving faster at some times and slower at others. This variation is discussed and illustrated in the exercise on the analemma.

7. In the steps above, you advanced the time by one sidereal day

per time-step to keep the stars fixed in the sky. This allowed you to see the apparent motion of the Sun relative to the stars. You may find the following exercise interesting and fun to try.

a. Starting from the position at the end of the previous step, run time backward until the Sun is at or close to the center of the screen, then click the stop button.
b. Change the time step from sidereal days to days (i.e., solar days).
c. Click the continuous run button. Because of the 1-solar-day time interval, you should see the Sun remain almost fixed in position while the background stars move past it. (Changes in the Sun's position at noon from day to day are discussed in the exercise on the analemma.)

As you watch this, imagine yourself on the outside edge of a merry-go-round, watching the Sun at the center of the merry-go-round. Since you are watching the center, the center stays fixed in your view while the rest of the universe continuously revolves around you. For the same reason, the constellations that we see at night shift slowly toward the west in a one-year cycle when we watch the sky from day to day (or night to night)(being on the Earth as it orbits the Sun is like being on a gigantic merry-go-round that takes one full year to go around once.

Questions

1. In which direction did the Sun appear to move in the New York sky from day to day, relative to the background stars, as the Earth orbited the Sun? How does this direction compare to the apparent direction of motion of the Sun from hour to hour in a single day, due to the Earth's rotation?

2. What was the shape of the path taken by the Sun (e.g., straight, curved)? This path defines the ecliptic plane. Switch on the ecliptic by clicking Ecliptic in the Guides menu, or press CTRL+3, to see this path displayed for you by the program. At this stage, you can use the Grabber Tool (with the hand cursor) to move around the horizon to see the shape of the ecliptic over other portions of the sky.

3. Approximately what was the solar motion in degrees per day across the background sky?

4. When you used solar day time intervals, in which direction did the background stars appear to move from day to day relative to the Sun (toward the east or toward the west)? Toward which direction, therefore, does the Earth move in its orbit around the Sun, as seen by someone facing the Sun at noon? (It may be easier to answer this question if you again imagine yourself at the edge of a merry-go-round and think about what you would see happening to the background scene if you were to keep your eyes on the center.)

Answers

1. Toward the east. Opposite to the daily motion, since the Sun appears to move toward the west from sunrise to sunset each day.

2. Curved.

3. Approximately 1° per day.

4. Toward the west.