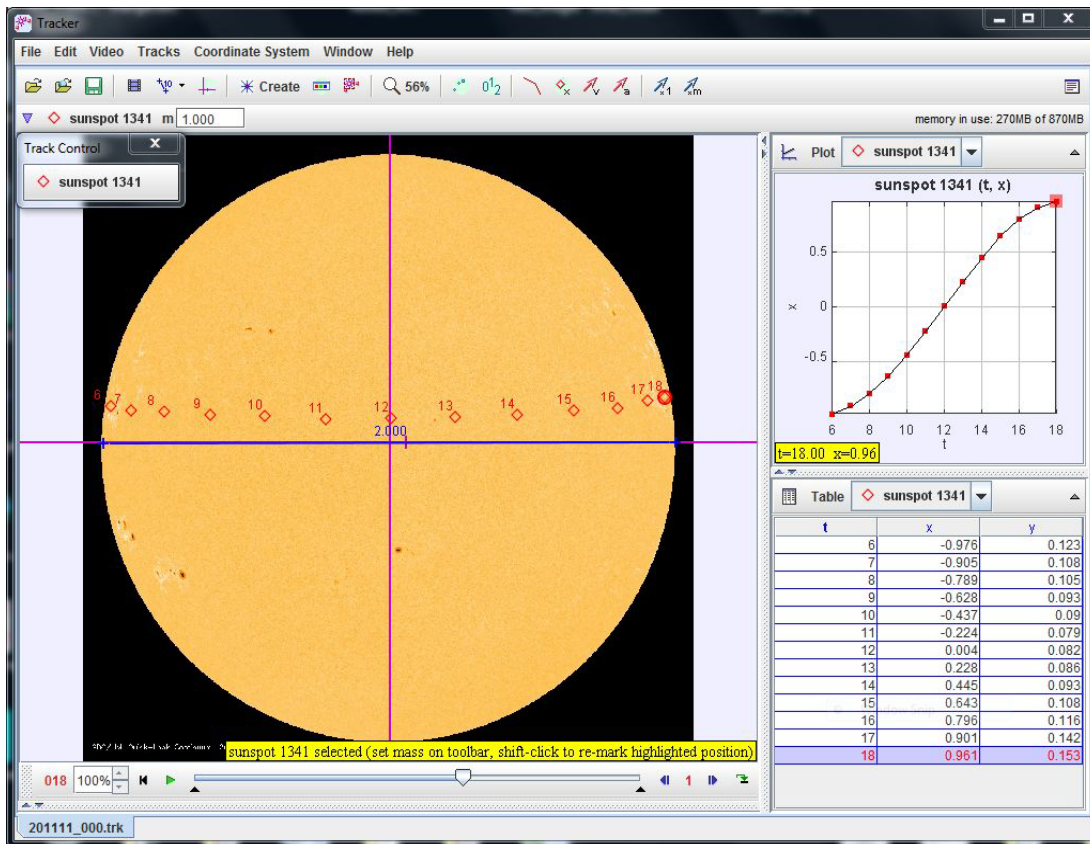


## Measurement of the Solar Rotation Rate with Tracker




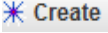



Measurement of the Solar Rotation Rate with Tracker uses a series of still images and the video analysis program Tracker to determine the length of the Sun's rotation by determining the angular speed of sunspots. This is an interesting exercise since the solar rotation rate changes from the solar equator to the pole (faster at the equator). The Sun's rotation rate at a latitude of  $26^\circ$  from its equator, called the Carrington Rate, is 27.27 days as seen from Earth (synodic period). We will use images from the NASA satellite SOHO (Solar & Heliospheric Observatory). This satellite orbits the Sun with the same orbital period as the Earth since it is situated at the first Lagrange point, L1, located between the Earth and Sun. Therefore, images from SOHO can be used to determine the synodic period of the Sun. Images from SOHO can be downloaded from [http://sohodata.nascom.nasa.gov/cgi-bin/data\\_query](http://sohodata.nascom.nasa.gov/cgi-bin/data_query) by searching for the HMI Continuum images in the month of interest. You can download a month's worth of images corresponding to the same time of day. In order for Tracker to automatically load these images as a movie these images must be renamed sequentially.

### Requires Tracker version 4.6 or greater

Download the tracker\_solar\_rotation.zip and unzip in a convenient location, such as your desktop. In the "tracker\_solar\_rotation" directory are a series of 31 images of the Sun taken by SOHO at the same time every day. These images are used to measure the solar rotation rate by tracking individual sunspots as described below.

## Procedure

1. **Open the program Tracker.** If you do not have Tracker version 4.6 or greater on your computer, you may download an installer from: <http://www.compadre.org/osp/items/detail.cfm?ID=7365>.
2. **Load the entire image series into Tracker as frames of a movie.** From Tracker's Menu, select Video | Import... and navigate to the "tracker\_solar\_rotation" directory and open the (image) file "201111\_000.jpg" corresponding to a SOHO image of November 0 (or October 31) 2011. Since the files in this directory are sequentially numbered (i.e. 201111\_000.jpg, 201111\_001.jpg, ...), Tracker will load them all. Press the green play button, , to check that all of the images have loaded.
3. **Set the time  $\Delta t$  between frames to 1 second.** Right click on the video or on the video control slider and select the Clip Settings menu item. Set the Frame duration to 1s. Note that this the time in between images is actually 1 day.
4. **Set the origin of the coordinate system.** Select the show coordinate axes icon, , to overlay the axes on the images. Drag and set the coordinate axes to the center of the Sun such that the coordinate cross is centered on the Sun's image.
5. **Set the scale of image.** Click on the calibration tools icon,  , and add a new calibration stick. Drag each of the ends of the stick to one edge of the Sun near, if not on top of, the coordinate axes. This then will give the length of this calibration stick as the diameter of the Sun. Double-click on the number and set to 2 (as in 2 solar radii).
6. **Pick a sunspot and track its position over the time.** Select the Create the new track icon,  , and select Point Mass. By default, the Track Control window will call this new track mass A. You can right-click on the mass A field and change its name to sunspot A. Find an easy sunspot to track that maintains its shape as it crosses the Sun. You may want to right-click in the video to Zoom In or Zoom Out to aide your view of the sunspot. Shift-click on a sunspot to begin tracking your sunspot. Tracker will step forward to the next image so that you can continue tracking the position of that sunspot for the entire sequence. You may start or stop tracking at any frame, so you do not need to choose a sunspot that is visible at the start of the image sequence.
7. **Use Tracker to calculate the x position in each frame.** We are only interested in the x position of the sunspot. The graph already shows this: x vs. t, but the table does not. On the data table, click on  and in the dialog box deselect y. Close the dialog box.

8. **Use Tracker to do data analysis of x.** Right-click on the cells of the data table and select “Analyze...” Tracker’s built-in data tool will open. Check the box for fit and select the sinusoidal fit in the fit name drop down. The fit equation is:  $x = a \sin(bt + c)$ . Check Autofit box to run the fit algorithm. If the data and the fit are right on top of each other, go to step 9. If not, click on the value cells of the table of a, b, and c values. A small pair of up/down buttons will appear. Adjust the “a” parameter so that the sin curve’s amplitude matches your data. Adjust the “c” parameter so that the sin curve crosses  $x=0$  at the middle of the graph. Now adjust the “b” parameter which changes the frequency of the sine curve so that the curve closely resembles your data. Now check the Autofit box. Your fit curve should now overlap your data.
9. **Calculate the angular speed,  $\omega$ .** We are only interested in the b value from the sinusoidal fit, which is the angular speed of the sunspot,  $\omega$ . Since  $\omega = 2\pi/T$ , obtain the solar rotation rate for this sunspot, calculate:  $T = 2\pi/\omega$ . Remember, this period is in days.
10. **Repeat for several other sunspots and note the results. Compare your results against the Carrington Rate of 27.27 days.**

### Questions

Do your results support the observation that the Sun rotates faster at its equator vs. at its poles? Use your data to support your result.

### Note on Images

Additional images from SOHO can be used in these exercises. Simply open a browser and download a series of images from [http://sohodata.nascom.nasa.gov/cgi-bin/data\\_query](http://sohodata.nascom.nasa.gov/cgi-bin/data_query) by searching for the HMI Continuum images in the month of interest. You can download a month’s worth of images corresponding to the same time of day. In order for Tracker to automatically load these images as a movie these images must be renamed sequentially.

### Final Comment

An important consideration is that the Sun is a sphere and therefore when tracking sunspots one is seeing their motion projected on a disk. The motion of sunspots, therefore, is analogous to circular motion viewed (almost) edge on—i.e. sinusoidal. To deal with this, we set the scale of the image to 2.0 (or 2 solar radii) and tracked the x position of the sunspot. We then use Tracker’s built-in Data Tool to fit the x vs. t data to a sine function,  $x = a \sin(bt + c)$ , where a is the amplitude, b is the angular velocity, and c is the phase shift of the sine function.