Term Project PHYS 1070.03

Solar Rotation

Due Date: May 19th, 2009 (11:30am, in class)

Introduction:

The objective of this term project is to determine the solar rotation period by using photos of the Sun taken from the archives of the SOHO (Solar and Heliospheric Observatory) satellite. A very similar project is described in *The Rotation of the Sun* published in *Sky & Telescope* (handed out in class). The article provides excellent introductory and background information, as well as a good description of the reduction technique. Read it thoroughly (at least the first four pages) before beginning your write-up.

All bodies in the universe, including the Sun, possess angular momentum and therefore rotate. The Sun's rotation is an artifact of the primordial angular momentum of the gas cloud from which the Solar system formed some 4.6 Gyr ago.

Your goal is to measure *the sidereal rotation period of the Sun* for three different latitudes using archival data measured by the SOHO spacecraft. The sidereal rotation period is the rotation period in a frame of reference fixed with respect to the stars. The sidereal rotation period is obtained by measuring the synodic rotation period, as seen by an observer on Earth, who of course is moving as a result of Earth's orbital motion around the Sun. Knowing Earth's period of revolution, it is easy then to determine the sidereal rotation period for each of the three latitudes.

Read these instructions carefully. Precisely what you must do is outlined below, though you are always free to do more. You must hand in a typed, formal report in the following format;

a) An introduction describing the background and rationale of the project as well as the SOHO satellite (about 1 page).

b) Presentations of the observations from the archives (that is copies of the downloaded pictures with the sunspots) including a brief description of the observations and the time when the observations were made.

c) Reductions and calculations including the de-projection procedure, angles measured and synodic period derived with uncertainties, for each of three sequences of images with sun spots at three clearly different latitudes.

d) Conclusions and answers to questions contained in section III below, including your result for the sidereal period of rotation.

I. Image selection procedure:

Find MDI continuum images suitable for tracing sunspots for a particular latitude over a time period of about 10 days.Then two other sequences of such images need to be found but each now showing sunspots at a clearly different latitude. The three sequences of images can be for different date ranges. Seven images per sequence are sufficient. That means that 21 images should be downloaded, 7 images for each latitude. The images can be downloaded from the SOHO website. Go to :

a) http://sohowww.nascom.nasa.gov/ . Then
b) click on "data/archive." Then
c) click on "Search and Download Data" in the left column . Then
d) select MDI Continuum, Images, Resolution 512, and put in some Start and End Dates to find images that you think are best for your project.

II. Reduction Procedure:

1. Take your sequence of images for a particular latitude and trace the location of a particular sunspot or sunspot group by copying the 7 positions on one single sheet of paper with the solar disk clearly indicated. Label the positions with the observe times. Note that the SOHO images are oriented such that the North Pole of the Sun is up and East to the left. Mark the north and south pole of the Sun and also east and west. Connect the traced spots with a best-fit (by eye) line of latitude running across the Sun disk, like the figure on page 4 of the *Sky & Telescope* lab.

2. Because of projection effects, the data may seem strangely spaced. You must therefore de-project the data before analysis can take place. Either above or below your Sun disk with the 7 positions, draw a semi-circle so that the diameter of the semi-circle is equal to the length of your latitude line. If you now draw lines perpendicular to the latitude line from the spots to the semi-circle, you can see where the spots actually were on the surface of the Sun. Draw lines connecting the centre of the semi-circle to the semi-circle with the spots.

3. As shown in the *Sky & Telescope* lab, measure the angle that each well-identified spot moved through during your observations. Note that you do not have to do this for every possible pair of angles. Measure 12 angles. List the angles in a table.

4. Calculate the (synodic) rotation period for each measured angle and list your calculated values also in the table. Compute the mean, μ, of your values for the rotation period and the standard deviation, σ_μ, of that mean. The mean is given as: $\mu = \frac{1}{N}\sum_{i=1}^{N} x_i$ and the standard deviation is given as: $\sigma_\mu = \frac{1}{N-1}\sqrt{\sum_{i=1}^{N}(x_i - \mu)^2}$, where x_i are your computed values for the period and N = 12. Add the mean and the standard deviation of the mean to the table.

5. Now repeat the procedure for your second and third set of 7 images each with a sunspot or a group of sunspots at a clearly different latitude. Add the measured angles, the computed rotation periods and the means and their standard deviations to the table.

III. Answer the following Questions:

1. What assumption about sunspots is fundamental for determining the rotation of the Sun by this method?

2. Since Earth has moved in its orbit around the Sun during your measurements, you have measured the synodic rotation period for each of the three sequences of images. Calculate the sidereal rotation period and its uncertainty for each of the three sequences of images.

3. For the largest single sunspot in the SOHO data, estimate the relative size of the spot in a) solar diameters, b) kilometers and c) Earth diameters?

4. What part of the Solar Cycle is the Sun in at the present time. Search the web or consult the book.

5. Compare your values for the rotation periods at the three different latitudes. Compute the three possible differences, and the errors by summing in quadrature the standard deviations of the means. So for the difference, $\Delta\mu_{jk} = \mu_j - \mu_k$, of two values for the rotation period at two different latitudes, the error of the difference is given as $\sigma_{\Delta\mu_{jk}} = \sqrt{\sigma_{\mu_j}{}^2 + \sigma_{\mu_k}{}^2}$. How much larger are the differences than their errors? Did you find significant differences, with $\frac{|\Delta\mu_{jk}|}{\sigma_{\Delta\mu_{jk}}} > 2$? Please comment. (Note; $|\Delta\mu_{jk}|$ is the magnitude of the difference, it is always positive). Compare your values with the accepted rotation periods for the equator and poles of the Sun. Since these accepted rotation periods are different, what does this reveal about the nature of the Sun?

6. On the SOHO website there are images (and archives) for other wavelengths taken by other instruments on the satellite. From the "Latest SOHO images" webpage, describe very briefly what the "EIT 284" data tell us about the Sun.

<u>17 May 2009-- Note:</u> The original equation under 5. , $\sigma_{\Delta\mu_{jk}} = \sqrt{\mu_j{}^2 + \mu_k{}^2}$, had typos. As said in words, the error of the difference is given by "summing in quadrature the standard errors of the means." The standard errors of the means are σ_{μ_j} and σ_{μ_k}. So the standard error of the difference is: $\sigma_{\Delta\mu_{jk}} = \sqrt{\sigma_{\mu_j}{}^2 + \sigma_{\mu_k}{}^2}$. Students will however not be penalized if they use the old expression.