Solar Rotation

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I. INTRODUCTION

The goal of this lab is to determine the sidereal solar rotation rate and period. To accomplish this, I used solar images from October of 2014 and will trace a sunspot's motion from day to day.

In order to determine the motion of the sunspots, I used a simple cosine function to describe its motion.

$$x = R\cos\omega t + \delta \tag{1}$$

where x is the distance of the spot from the meridian and R is the distance from the meridian to the limb. Figure 1 shows this relationship.

In order to evaluate the frequency of rotation, ω, I linearized Equation 1 with respect to t

$$\omega t + \delta = \arccos x/R \tag{2}$$

This function can be easily fit with a linear regression and the reported synodic frequency, in d^{-1}, can be given as

$$\omega_0 = \omega \pm \omega \cdot S \tag{3}$$

where S is the standard error of the fit.

Also, to account for the motion of the Earth around the sun, we use the simple relation

$$\frac{1}{T_{sid}} = 1 + \frac{1}{T_{syn}} \tag{4}$$

II. DATA ACQUISITION

The images were all obtained from with courtesy from SolarMonitor.org. The images obtained were 6173 Å images caputred using the Solar Dynamics Observatory's (SDO) Helioseismic and Magnetic Imager (HMI). The HMI allows stabilized 1″ full-disk images of the sun.

SolarMonitor.org accumulates different solar image sources every day and displays them neatly on their website. From here it is easy to select a solar source, pick a date for observation, and download the FITS data file for the image.

I chose images from 2014 due to the heightened solar activity and found a large sunspot around October 31. I found 10 neighboring images that contained the sunspot and ended with a range of images from 2014 October 19 to 2014 October 29. Figure **??** shows examples of images from two dates within this range.

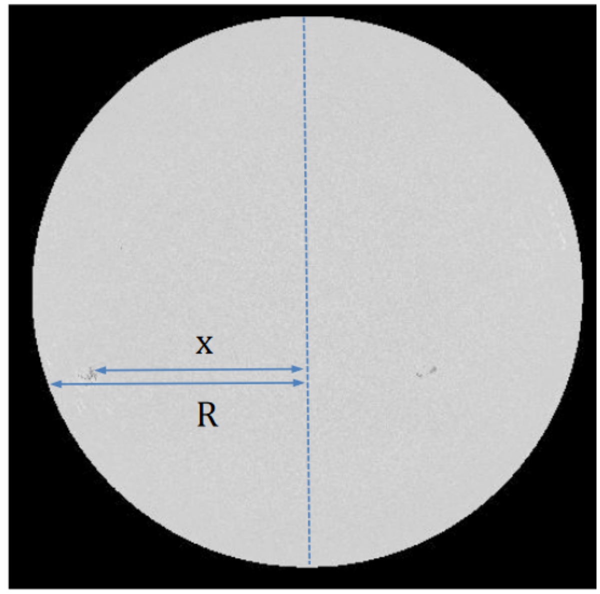


Figure 1: A visual of the limb width and sunspot location from each solar image

III. DATA ANALYSIS

To find the sunspot positions I loaded the 10 images into SAO's ds9. I started by finding what the meridian pixel value was, because the image is laid out from (0, 0) in the top-left and extending down and to the right.

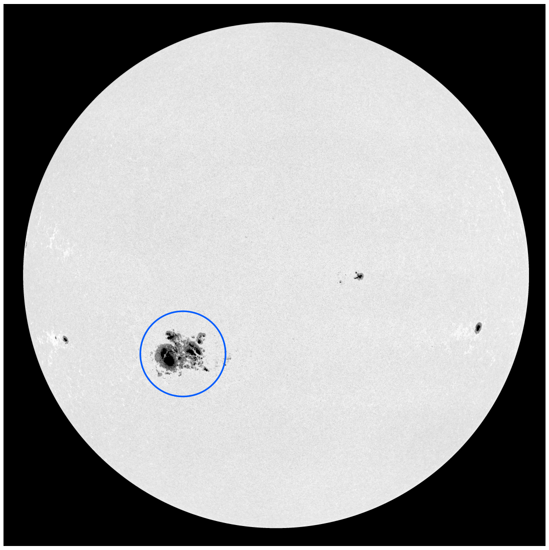
I picked what I thought the center of the sunspot of interest was and noted the y-position. This should stay consistent from each image. I then measured the meridian to limb length (R) with the first image and then found the relative position of the sunspot in each image to the meridian.

I also used Listing A to parse the dates from the headers of the FITS files and construct the data table. Into this table I recorded all of the relevant position values.

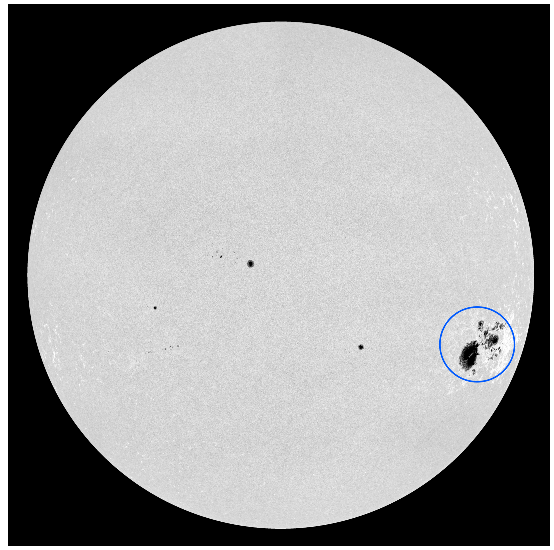
Then, using this table, I used python to do a linear regression of Equation 2. The python library uses a simple least-squares fit.

IV. RESULTS

The measurements from each image are listed in Table I. The linear fit is shown in Figure 3. The uncertainties were found using least squares propagation methods where the absolute uncertainty for the synodic frequency is shown in Equation 3. From this fit, I report the syn-



(a) 6173 Å image from 2014 October 21



(b) 6173 Å image from 2014 October 27

Table I: Sunspot Position Information

Date	Time	MJD	x	x/R
10/20/2014	10:58:15 PM	56950.95712	1165	0.644
10/21/2014	10:58:15 PM	56951.95712	805	0.445
10/22/2014	10:46:15 PM	56952.94878	404	0.224
10/23/2014	10:58:15 PM	56953.95712	19	0.01
10/24/2014	10:58:15 PM	56954.95712	-442	-0.244
10/25/2014	10:58:15 PM	56955.95711	-835	-0.462
10/26/2014	7:58:14 PM	56956.83211	-1142	-0.631
10/27/2014	7:58:14 PM	56957.83211	-1442	-0.797
10/28/2014	7:58:14 PM	56958.83211	-1663	-0.919
10/29/2014	7:58:14 PM	56959.83211	-1798	-0.994

odic period to be 0.011 408(26) yr and the sidereal period to be 0.011 279(25) yr

V. CONCLUSIONS

ACKNOWLEDGMENTS

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Appendix A: Analysis Scripts

Also see Jupyter Notebook at this Github page.

../src/parse_dates.py

```
from astropy.io import fits
from astropy.time import Time
import pandas as pd
from glob import glob

def main():
    filenames = glob('../data/*.fts')
    hdrs = [fits.getheader(filename) for filename in filenames]
    dates = [hdr['Date'] for hdr in hdrs]
    times = [hdr['date_obs'].split('␣')[-1] for hdr in hdrs]
    astro_times = [Time(date + '␣' + time, format='iso') for date, time in zip(dates, times)]
    mjd_times = [t.mjd for t in astro_times]
    df = pd.DataFrame()
    df['Date'] = dates
    df['Time'] = times
    df['MJD'] = mjd_times
    df.to_csv('table.csv')
```

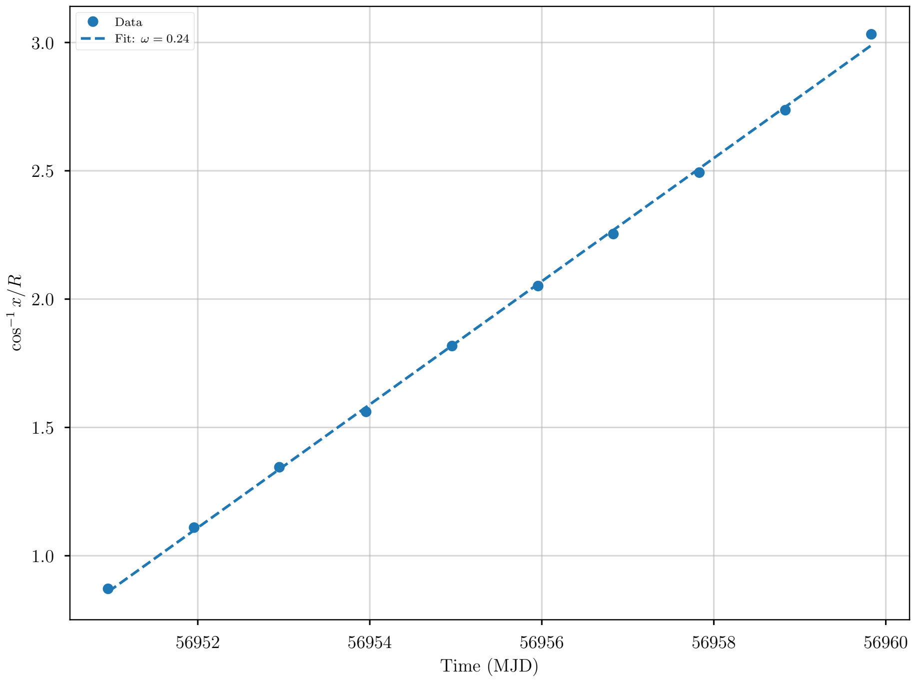

Figure 3: Linear fit of the linearized data showing the synodic frequency of the sun in d^{-1}.

```
if __name__=='__main__':
    main()
```