Sunspots Term Project:

Measuring the Rotation Period (*sidereal rotation period*) of the Sun

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SC PHYS 1070: Introduction to Astronomy

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Introduction

1. *The purpose of this assignment* is to measure the sidereal rotation period of the Sun, given data from the Solar Dynamics Observatory (SDO), which can be found here: https://sdo.gsfc.nasa.gov. Sunspots from the data will be used to determine this solar rotation period. We will calculate the sidereal rotation period by measuring the synodic rotation period as seen by an observer on Earth, who is moving as a result of the Earth's orbital motion around the Sun. Knowing the Earth's period of revolution (365 Earth days), we can thus calculate the Sun's sidereal rotation period.

2. *On the SDO, HMI and the nature of sunspots*: The Solar Dynamics Observatory at NASA has been observing the sun since 2010, in an effort to understand space weather (such as solar wind) and solar variability. The two aspects of solar variability that SDO studies in relation to Earth are*:* the Sun's magnetic field's generation and structure, plus how the magnetic field's energy is released into the heliosphere and geospace (Solar Dynamics Observatory, n.d.). The HMI looks at the Sun's exterior in an attempt to predict what is happening in the interior. It measures the magnetic field of the Sun's photosphere using different colours and wavelengths (NASA Solar Dynamics Observatory, 2021). We are interested in studying the variable space weather because it affects human activity both on Earth and beyond. For example, a solar storm can knock out communication arrays here on Earth, or heavily radiate airplanes. We would ideally be able to make models that predict these events so we can take precautionary measures in such extreme cases.

3. *My observations' sources:* My observations consist of solar images taken from the SDO website at https://sdo.gsfc.nasa.gov/assets/img/browse/. These images, taken with the Helioseismic and Magnetic Imager, are included in Appendix A.

Presentation of observations and observation technique

1. My birthday is on September 18, so my link is https://sdo.gsfc.nasa.gov/assets/img/browse /index.php?b=2014%2F09%2F18. These files represent data taken at different times on September 18, 2014, through different filters and with several format sizes. I am focusing on the files whose names end in "_2048_HMIIC.jpg," meaning files from the Helioseismic and Magnetic Imager.

2. I downloaded the *first* "_2048_HMIIC.jpg" image for each of the 8 consecutive days: September 18, 19, 20, 21, 22, 23, 24, and 25. The timestamps were approximately the same time, at 2040 (i.e. 8:40 pm) Universal Time. The images show at least one clean spot group whose trajectory I can trace over the Sun's disk. In Appendix A, I have attached all 8 pictures. This is my 'raw data.' There are two images per page. The label for each image notes the file name, the timestamp, and the date of the image.

Reduction and calculations

1. *Marking the first spot's trajectory*

   The spot present in most of my images is outlined in blue pen in Appendix B (master image). This spot starts out on the far left of the solar disc and makes its way towards the right. The master image correctly shows the entire disk of the Sun and the eight spots (a time-lapse) of the same dot on different days. I have dated each of the eight spots numerically so we can see the progression more clearly.

2. *Marking the second spot's trajectory*
   In Appendix B, on the same master image, I have repeated this process with a *different* spot at a different latitude, now traced in digital purple pen. It is also starting from the far left and making its way to the right.

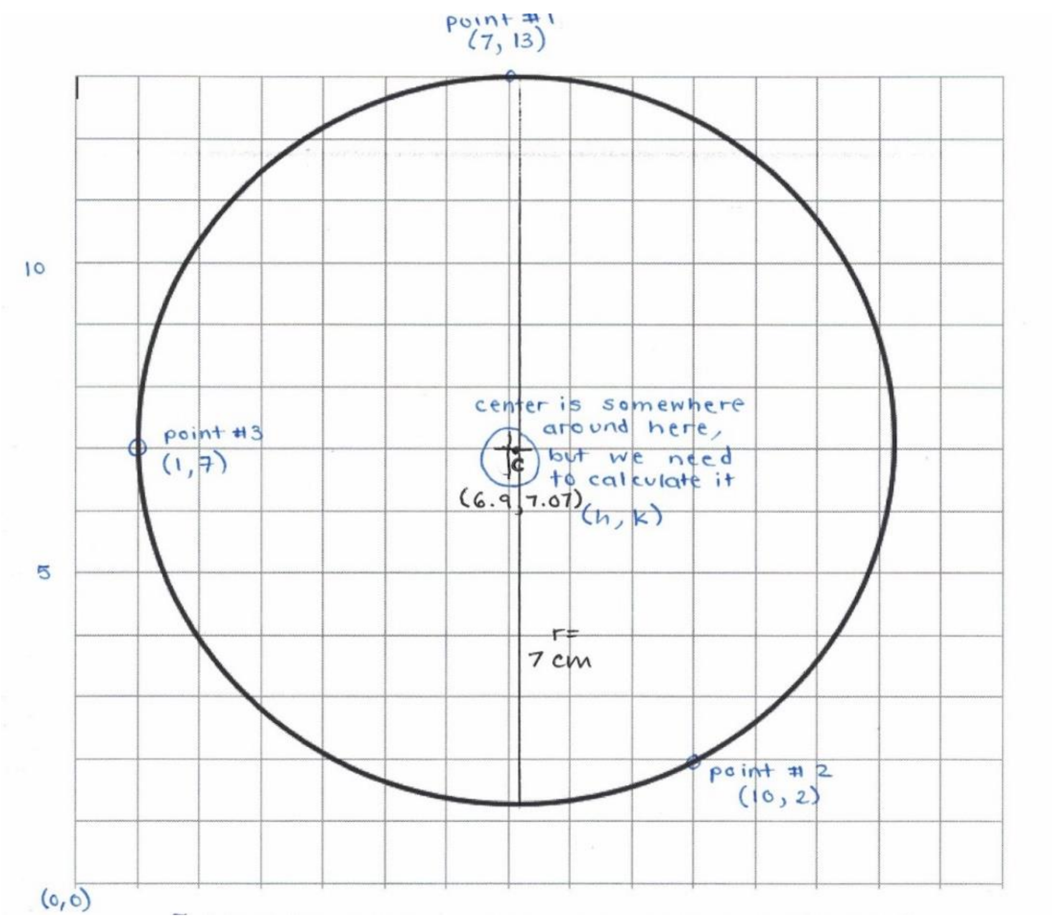
3. *An implicit assumption* in this exercise is that the sunspots are following a line of constant solar latitude. To a good approximation, even though there are projection effects to consider, I have drawn the best-fit-by-eye line through the spots, ignoring data that are close to the Sun's limb. You can view this in Appendix C's master image. I have marked the four cardinal directions, from the Sun's perspective, in the master image in Appendices B and C.

4. *Marking the chord, chord center M, disk center C, and diameter*
   In the master image in Appendix C, I have marked the center of the chord "M." I have marked the center of the disk "C." I have drawn a diameter on the Sun's disk through "C" and parallel to the chord. I determined *M*, the center of the best-fit chord, by measuring the length of the chord and dividing in two, like so

   $\ell_{chord} = 15$ cm

   M is the halfway point of the chord, $\therefore$
   M is at 15 cm/2 = 7.5 cm.

   I then determined the center of the solar disk by performing a grid calculation by hand, like so



I traced the same disc here and overlaid a grid. Length of diameter is unknown, but we can find 3 points on circumference and calculate diameter. We know the center is equidistant so:

$$(x_1-h)^2 + (y_1-k)^2 = r^2 \qquad r = \text{radius}$$
$$(x_2-h)^2 + (y_2-k)^2 = r^2$$
$$(x_3-h)^2 + (y_3-k)^2 = r^2$$

Plugging

① $(7-h)^2 + (13-k)^2 = r^2$
② $(10-h)^2 + (2-k)^2 = r^2$
③ $(1-h)^2 + (7-k)^2 = r^2$

Solve for h, k, and r

* expand ①②③

① $r^2 = h^2 - 14h + k^2 + 218 - 26k$
② $r^2 = h^2 - 20h + k^2 + 104 - 4k$
③ $r^2 = h^2 - 2h + k^2 + 50 - 14k$

* solve system of equations

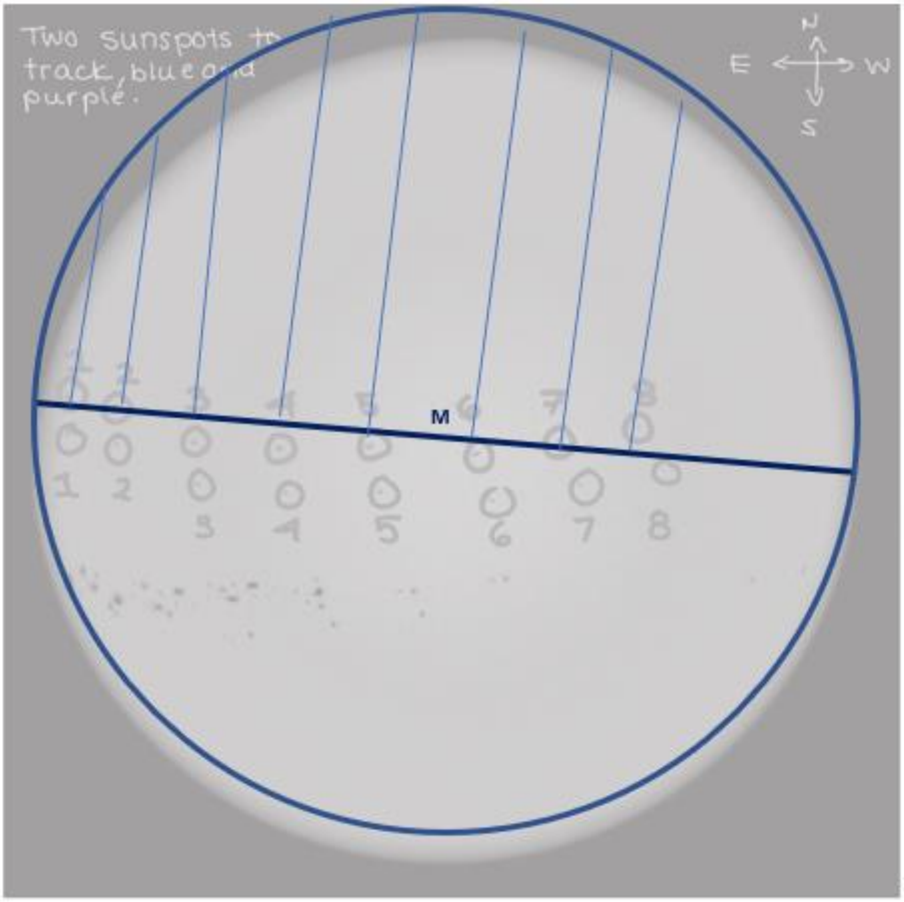
$r^2 = 35.15306122$ units, $r = 5.929$ units
$h = 6.928571429$ units, on grid
$k = 7.071428571$ units, on grid.

Now drawing line through C, we get radius of 7 cm and diameter of 14 cm.

5. *Latitudes of spot 1 and 2*
   Refer to Appendix C. $\Theta_1 = 10°$. $\Theta_2 = 347°$.

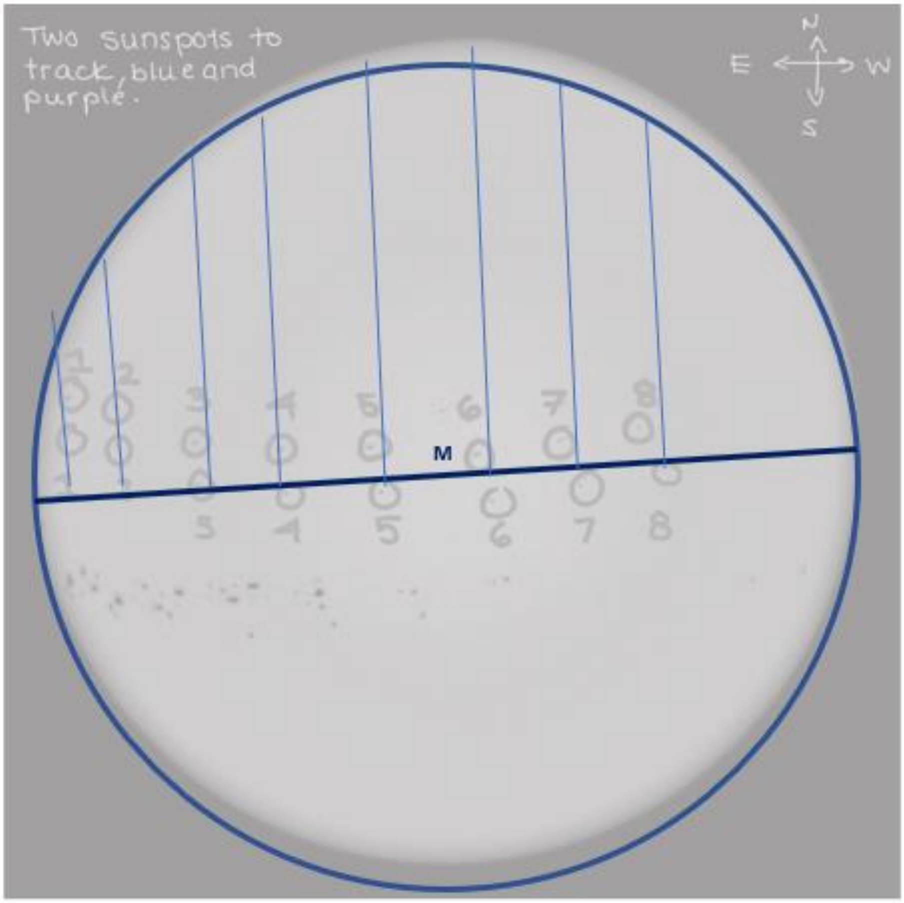
6. De-projecting the data to measure the angle, by hand:

   Spot 1 (chord 1)



Date of spot, time	Decimal days between spots	Angle size (°)
September 18, 2044	18-19: 0.997	3
September 19. 2040	19-20: 1	0
September 20, 2040	20-21: 1	356
September 21, 2040	21-22: 1	356
September 22, 2030	22-23: 1.0069	359
September 23, 2040	23-24: 1	359
September 24, 2040	24-25: 1	0
September 25, 2040		5

Spot 2 (chord 2)



Date of spot	Decimal days between spots	Angle size (°)
September 18, 2044	18-19: 0.997	10
September 19. 2040	19-20: 1	9
September 20, 2040	20-21: 1	0
September 21, 2040	21-22: 1	358
September 22, 2030	22-23: 1.0069	357
September 23, 2040	23-24: 1	353
September 24, 2040	24-25: 1	354
September 25, 2040		358

7. For each recorded angle and time (please refer to Appendix D to see each individual angle comparison calculation by hand*, for a total of 20 angle comparisons):

Angles compared	Angle (degrees)*	Time lapsed (days)	Synodic Rotation period at the higher latitude (sunspot 1) – calculated as angles divided by time lapsed – units of degrees per day	Average for the higher latitude (units of degrees per day)	Estimate for uncertainty in the average, plus reasons for uncertainty
Sept. 18 – Sept. 25	72	7.0039	10.279	=sum(all)/10 =10.504	Because the latitude deprojection was done by hand, it is very probable that the lines are not accurate. Add 5 degrees uncertainty (±2.5°).
Sept.18 – Sept. 24	62	6.0039	10.327		
Sept. 18 – Sept. 23	56	5.0069	11.185		
Sept. 19 – Sept. 25	66	6.0069	10.987		
Sept. 19 – Sept. 24	56	5.0069	11.185		
Sept. 19 – Sept. 23	47	4.0069	11.729		
Sept. 20 – Sept. 25	58	5.0069	11.584		
Sept. 20 – Sept. 24	50	4.0069	12.478		
Sept. 20 – Sept. 23	40	3.0069	13.303		
Sept. 21 – Sept. 25	48	4.0069	11.979		

Angles compared	Angle (degrees)*	Time lapsed (days)	Synodic Rotation period at the lower latitude (sunspot 1) – calculated as angles divided by time lapsed – units of degrees per day	Average for the lower latitude (units of degrees per day)	Estimate for uncertainty in the average, plus reasons for uncertainty
Sept. 18 – Sept. 25	74	7.0039	10.566	=sum(all)/10 = 10.7141	Because the latitude deprojection was done by hand, it is very probable that the lines are not accurate. Add 5 degrees uncertainty (±2.5°).
Sept.18 – Sept. 24	60	6.0039	9.994		
Sept. 18 – Sept. 23	50	5.0069	8.324		
Sept. 19 – Sept. 25	61	6.0069	10.155		

Sept. 19 – Sept. 24	56	5.0069	11.185		
Sept. 19 – Sept. 23	45	4.0069	11.231		
Sept. 20 – Sept. 25	58	5.0069	11.584		
Sept. 20 – Sept. 24	30	4.0069	7.487		
Sept. 20 – Sept. 23	38	3.0069	12.637		
Sept. 21 – Sept. 25	52	4.0069	12.978		

8. Calculated sidereal rotation period using average synodic period, by hand:

Let R = sidereal period and S = synodic period

∴ R = (S × 365.26 days)(S + 365.26 days)

* use 365.26 because thats the number of days in an Earth sidereal year

∴ R = (10.609 × 365.26)(10.609 + 365.26)

= 1,456,508.668 °/year

= 1.4565 x 10^6 °/year

Uncertainty = ± 0.5° + ± 0.5° = ± 1°

Questions, calculations, and conclusions

1. *Relative size of spot*

The single largest spot in my dataset is the one from the higher latitude (circled in blue on the master image) on September 20, i.e. spot #3. It makes up approximately 2 mm across on paper, and the solar diameter on paper is 92 mm. Thus the paper ratio of sunspot:sun is 2:92. In real diameter, the solar diameter is 1.3927 x 10^6 km, so

$$\frac{2 \text{ mm}}{92 \text{ mm}} = \frac{x \text{ km}}{1{,}392{,}700 \text{ km}}$$

$$x \text{ km} \doteq 30276.087 \text{ km}$$

$$\doteq 3 \times 10^4 \text{ km}$$

2. *Point in the solar cycle*

The Sun is currently in Solar Cycle 25; in the past year (2020), the number of sunspots have been as expected, around 250 sunspots.

3. *Comparison of rotation periods of spots*

The sunspots I observed were not at wildly different latitudes. Their rotation periods were approximately the same, as both chords were very close to the true diameter of the sun.

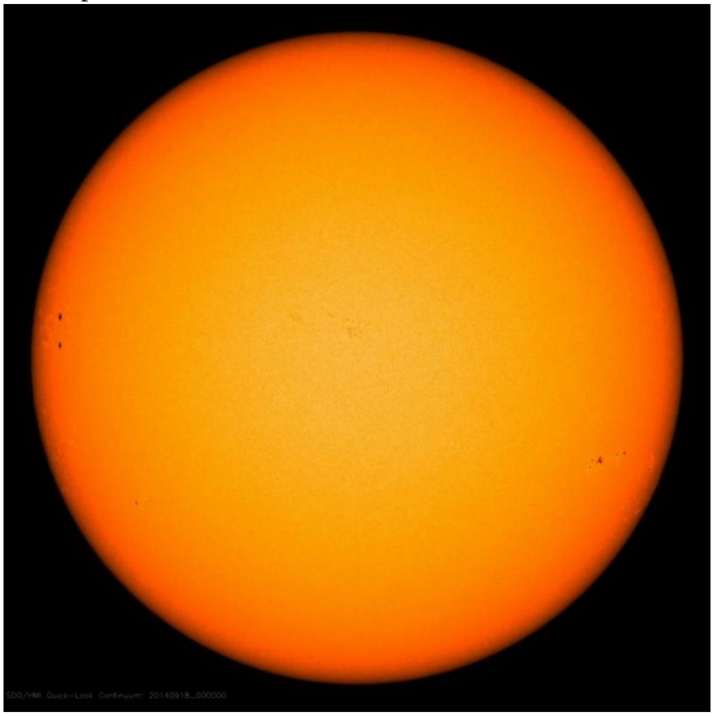
4. *Summary of findings*

In observing two sunspots' motion across the Sun's disc over 8 consecutive days in September 2014, I found that the spots travel at about 10°/day, giving a sidereal rotation period of 1.4565×10^6 °/year.

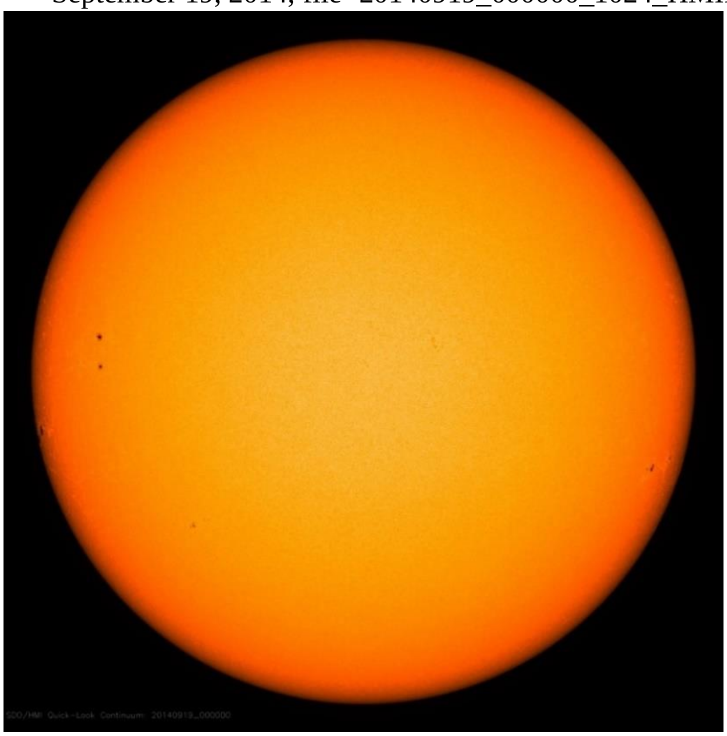
Appendices

A. **Appendix A:** The eight pictures of the Sun. All timestamps are in UT.

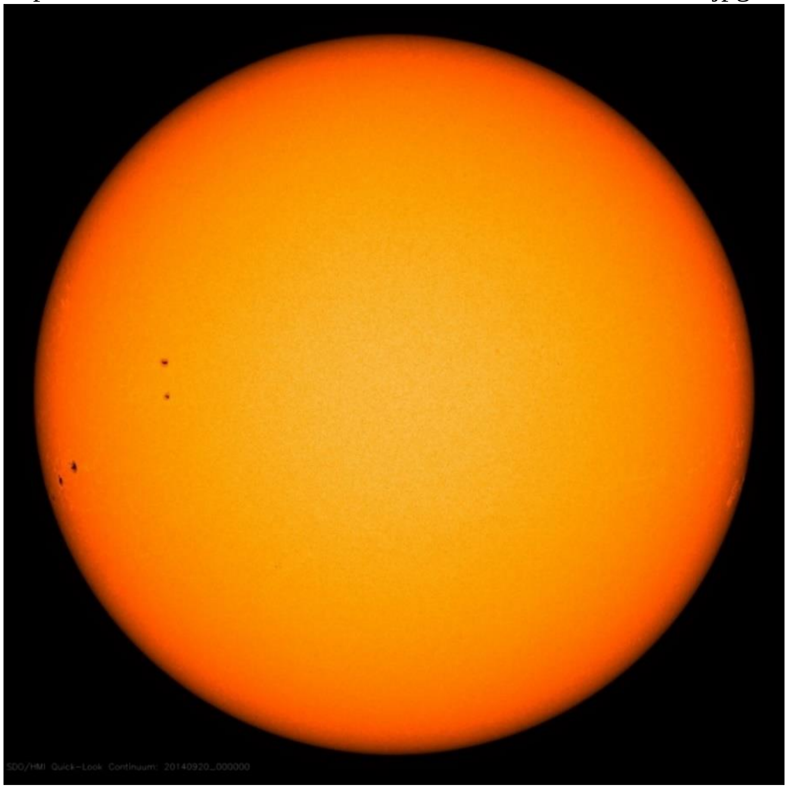
- September 18, 2014; file '20140918_000000_1024_HMIIC.jpg;' timestamp 2044



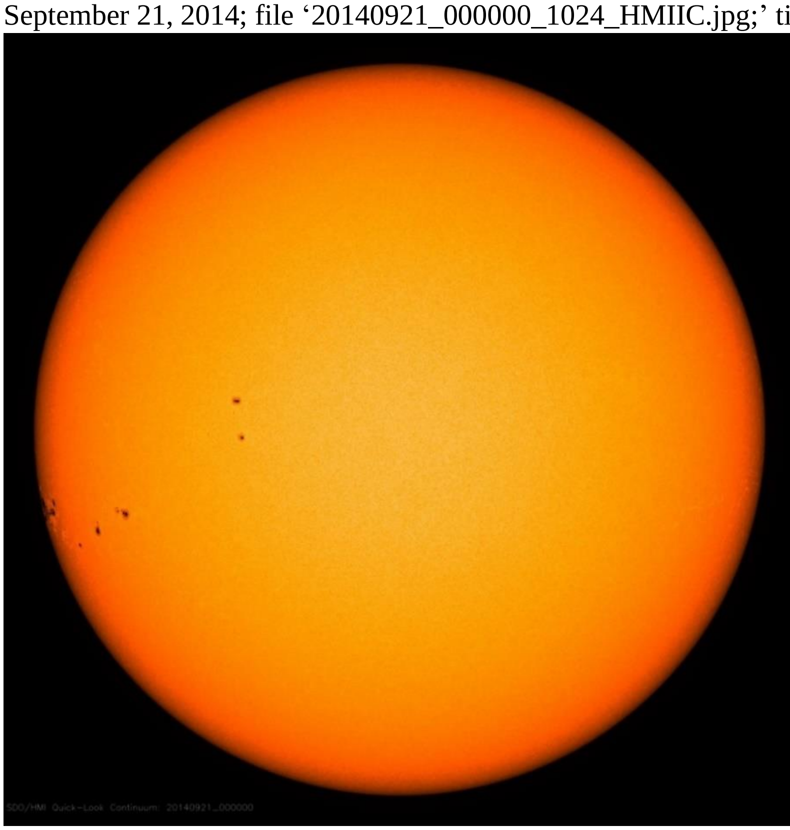
- September 19, 2014; file '20140919_000000_1024_HMIIC.jpg;' timestamp 2040



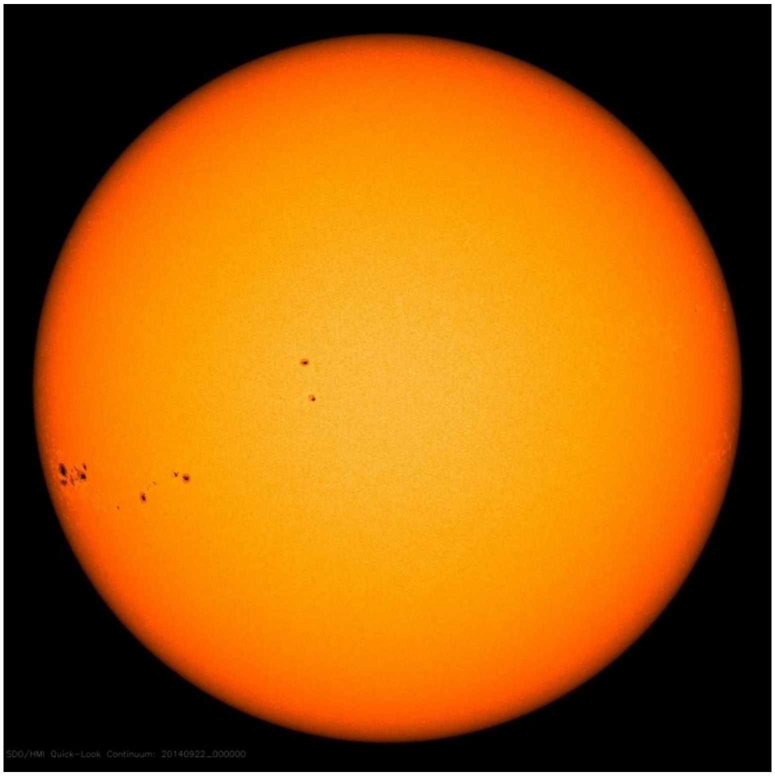
- September 20, 2014; file ‘20140920_000000_1024_HMIIC.jpg;’ timestamp 2040



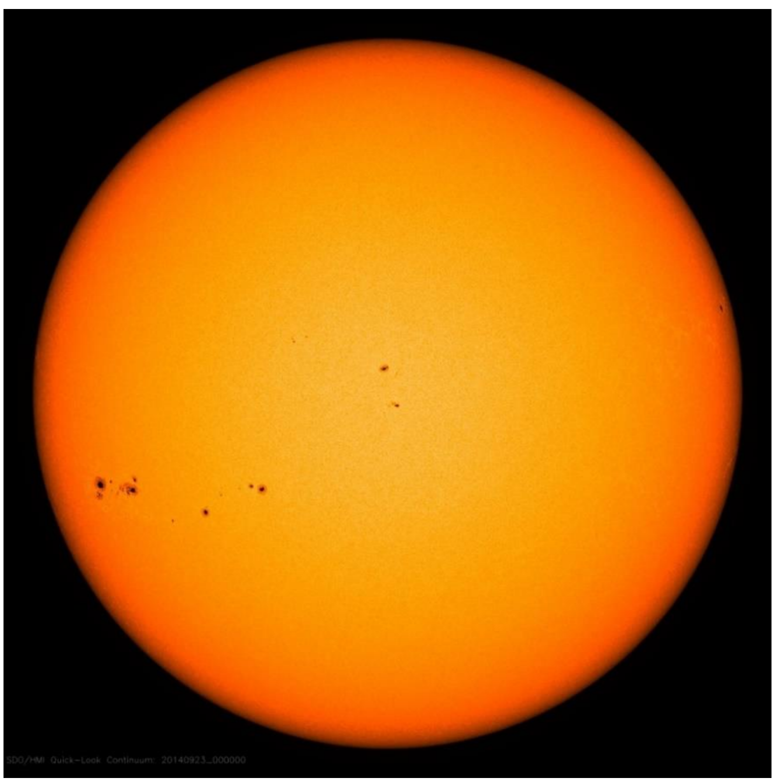
- September 21, 2014; file ‘20140921_000000_1024_HMIIC.jpg;’ timestamp 2040



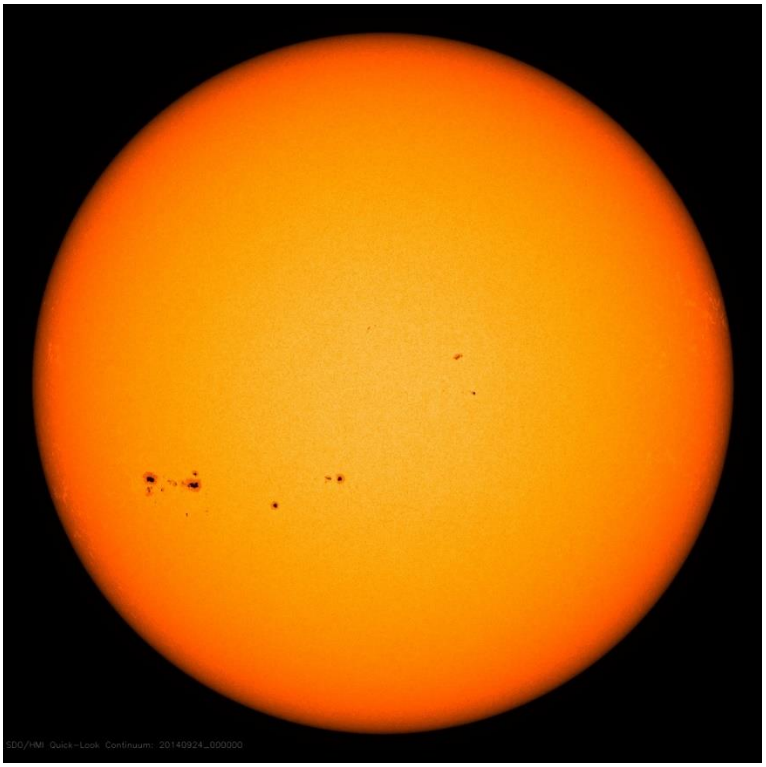
- September 22, 2014; file ‘20140922_000000_1024_HMIIC.jpg;’ timestamp 2030



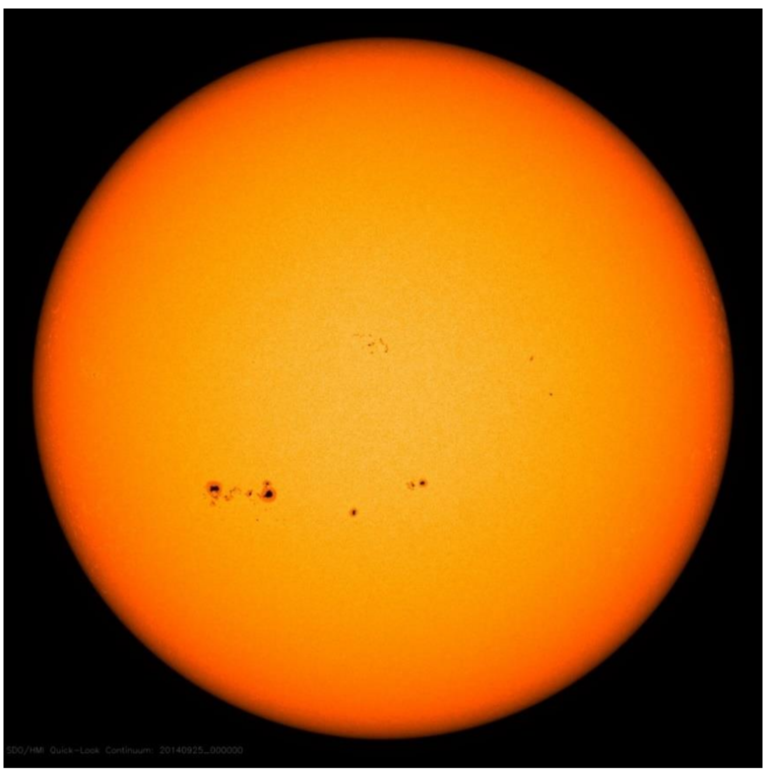
- September 23, 2014; file ‘20140923_000000_1024_HMIIC.jpg;’ timestamp 2040



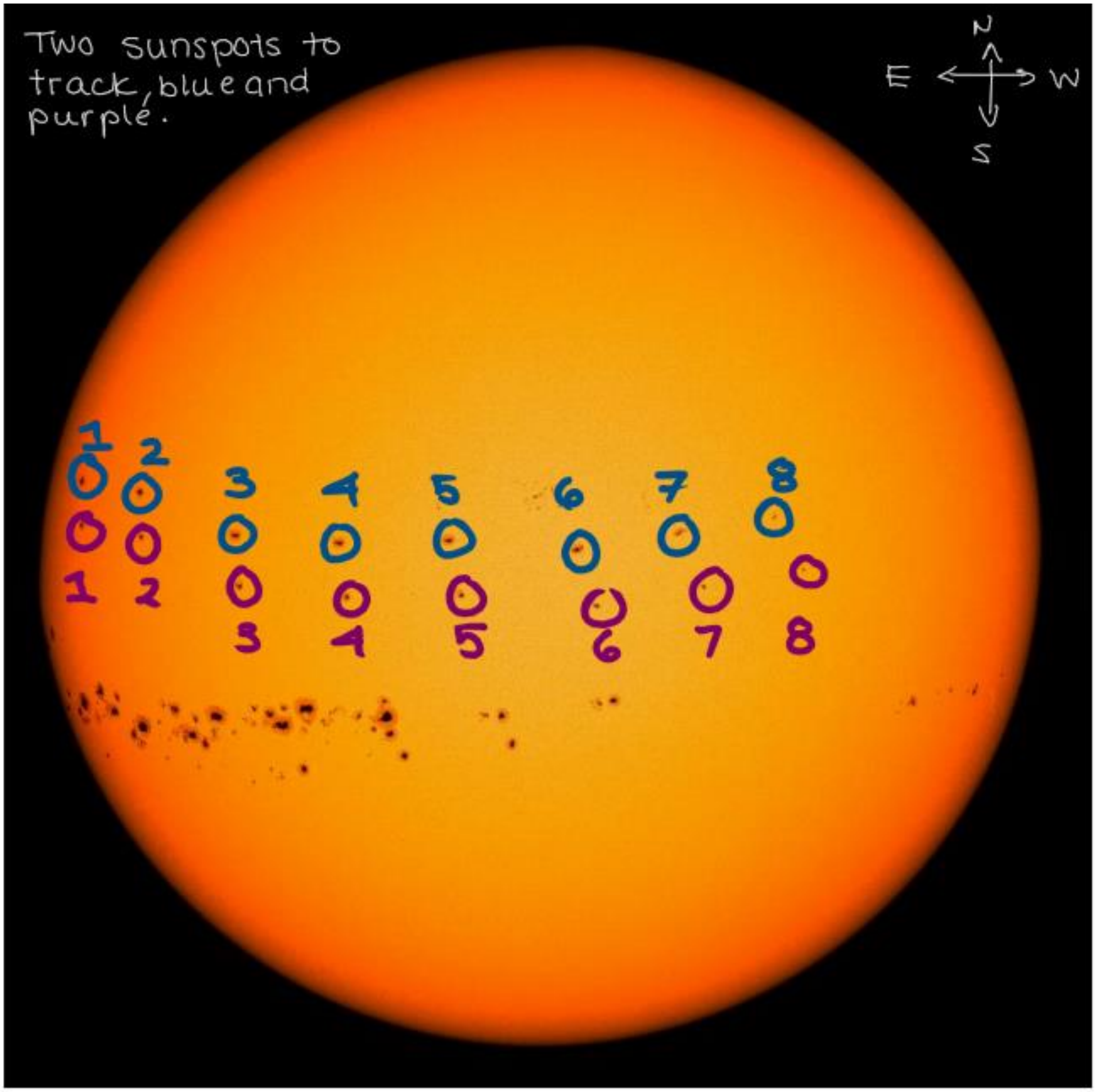
- September 24, 2014; file ‘20140924_000000_1024_HMIIC.jpg;’ timestamp 2040



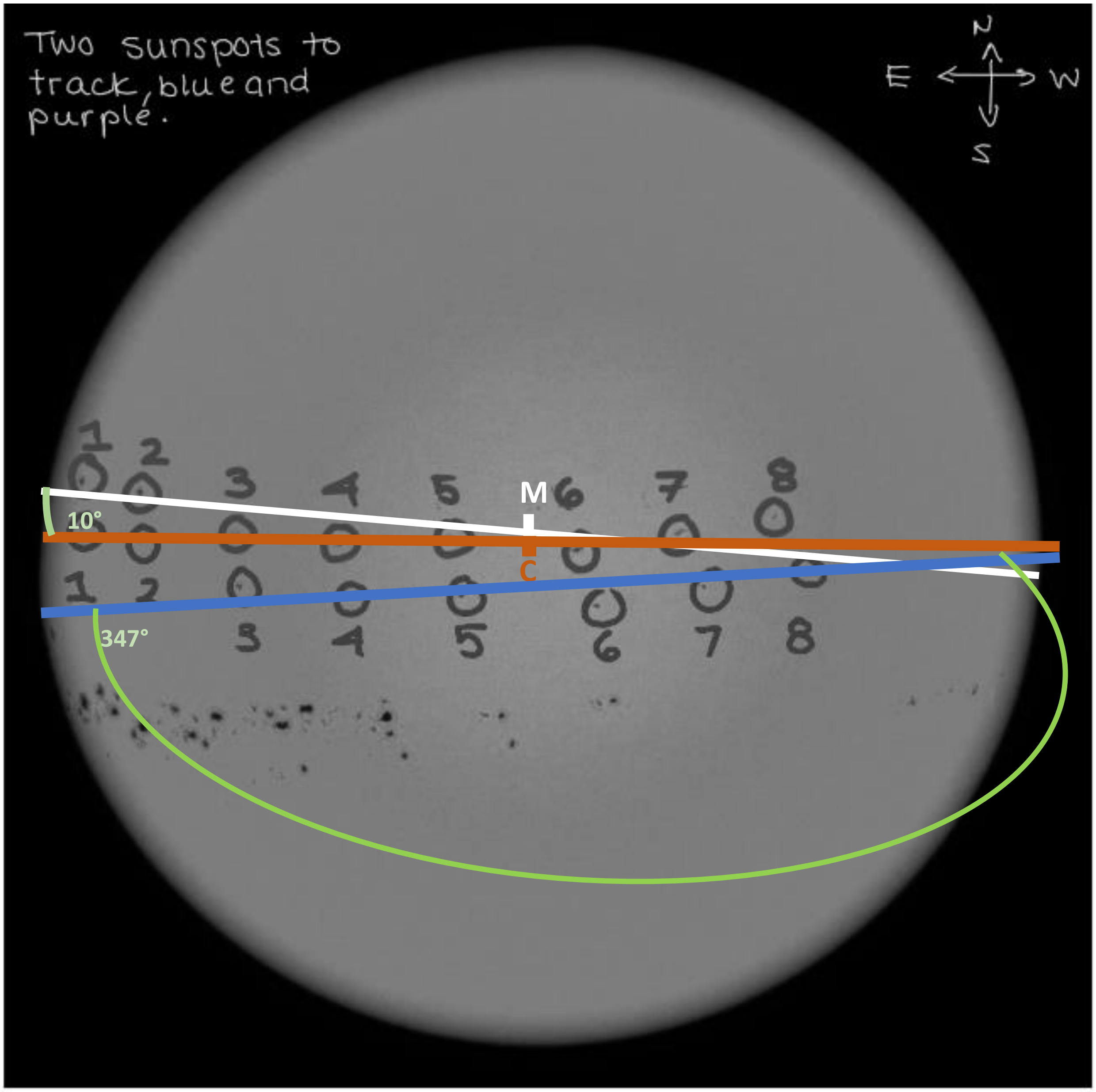
- September 25, 2014; file ‘20140925_000000_1024_HMIIC.jpg;’ timestamp 2040



B. **Appendix B**: The master image of the Sun's disk, with two sunspot groups over eight days (time-lapse) traced in digital pen.

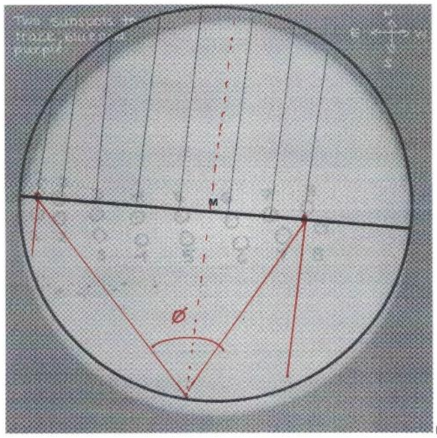


C. **Appendix C:** Master image with best-fit line (white for spot one, blue for spot two), cardinal directions, center of chord *M*, center of Sun's disk *C* (orange), diameter of Sun's disk through *C* (orange for spot one, blue for spot two), and latitude angle (mint green).



D. **Appendix D: angle comparison calculations, x 20**

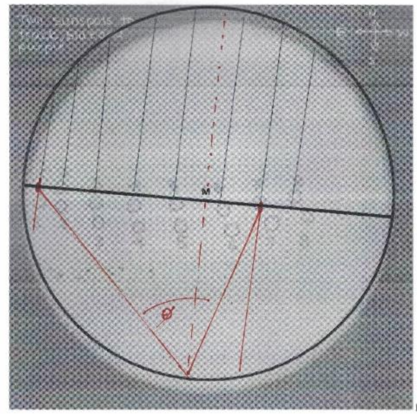
HIGH LATITUDE SPOT.
COMPARE SEPT 18 · SEPT 25



$\emptyset = 72°$

72° / 7.0039 days ≐ 10.279° travelled /day

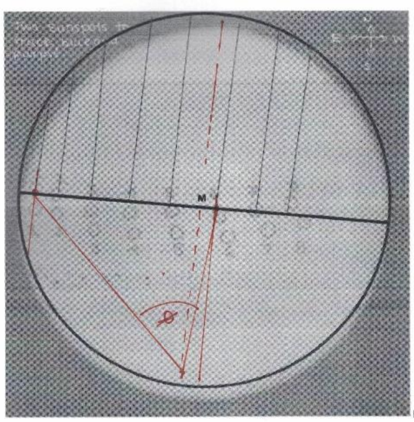
HIGH LATITUDE SPOT.
COMPARE SEPT. 18 · SEPT. 24



$\emptyset = 62°$

62° / 6.0039 days ≐ 10.327° travelled / day

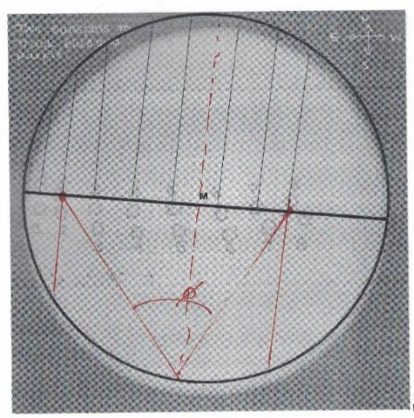
HIGH · LATITUDE SPOT.
COMPARE SEPT 18 · SEPT 23



$\emptyset = 56°$

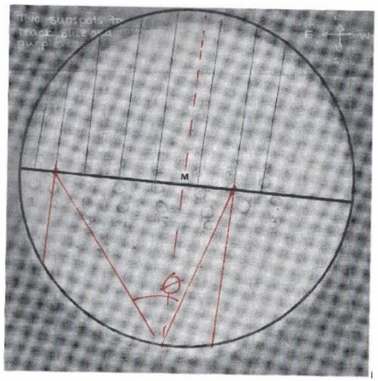
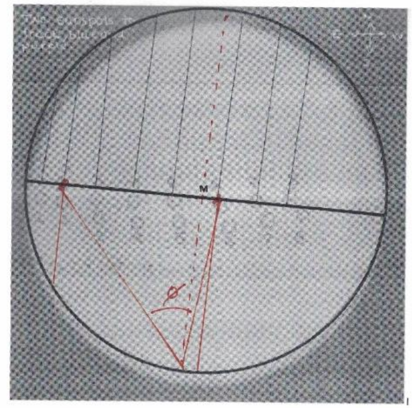
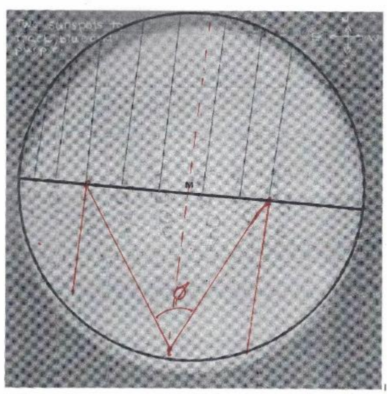
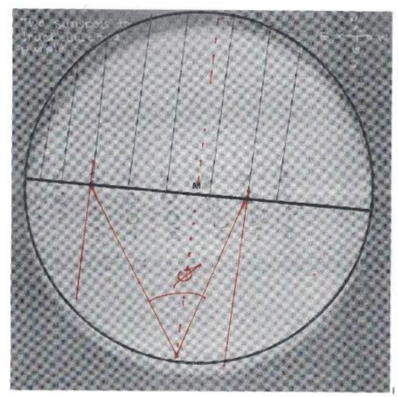
56° / 5.0069 days ≐ 11.185° travelled/day

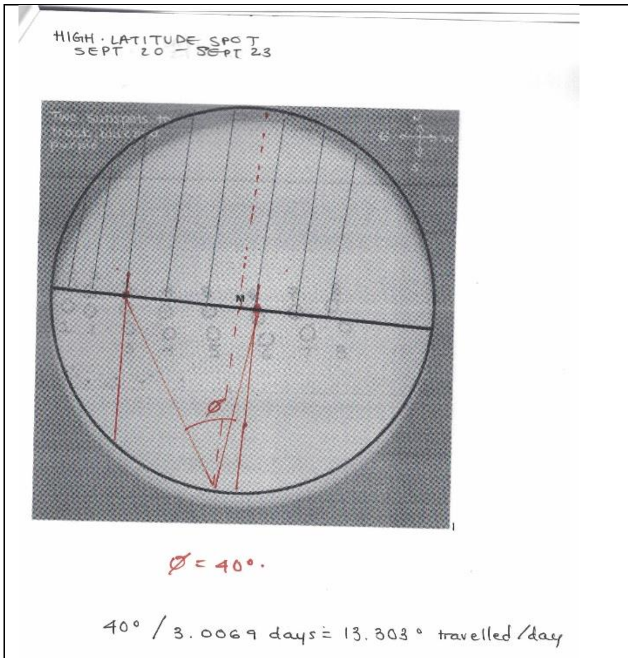
HIGH LATITUDE SPOT.
SEPT. 19 – SEPT. 25

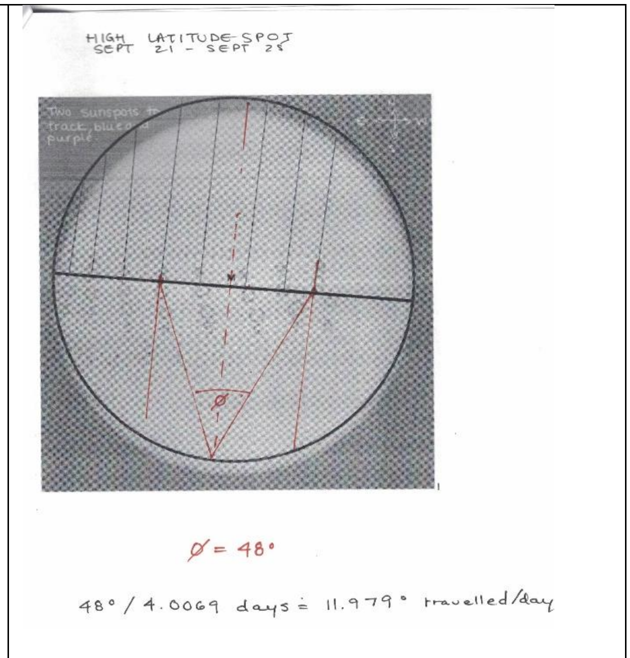


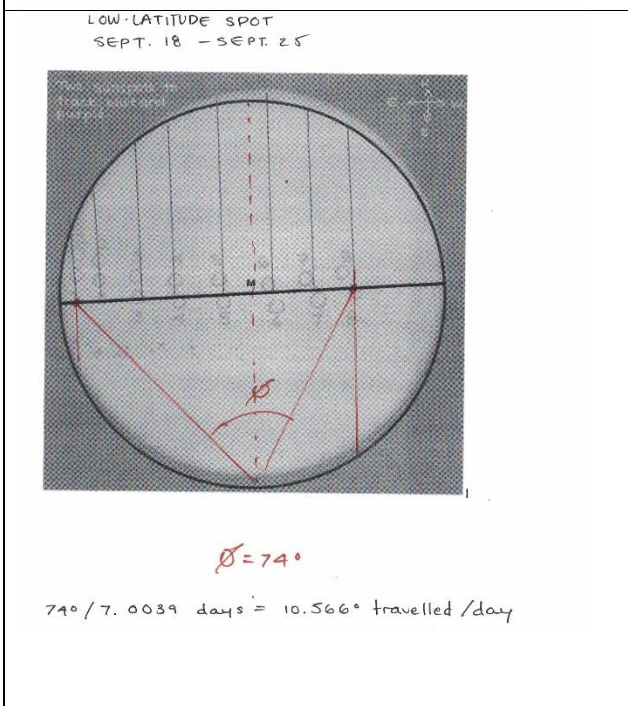
$\emptyset = 66°$.

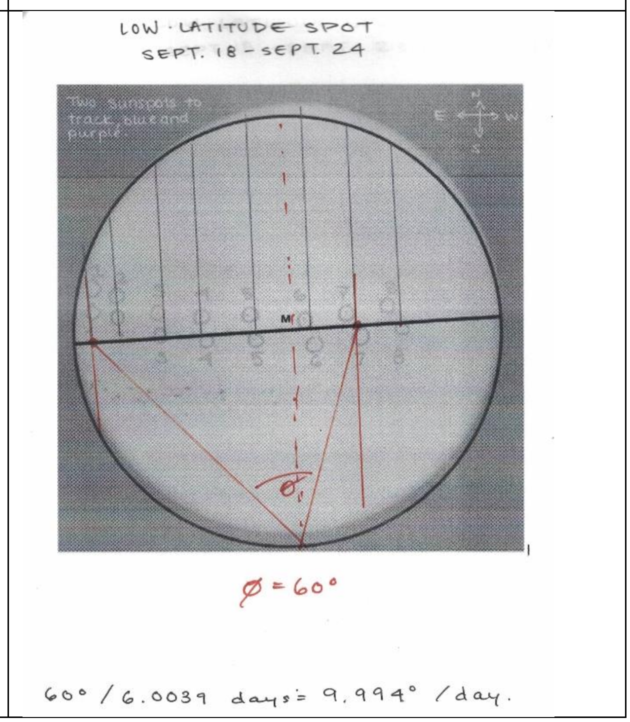
66° / 6.0069 days = 10.987° travelled/ day

HIGH-LATITUDE SPOT. SEPT. 19 – SEPT. 24  Ø = 56° 56° / 5.0069 days ≐ 11.185° travelled / day	HIGH LATITUDE SPOT SEPT 19 · SEPT · 23  Ø = 47° 47° / 4.0069 days ≐ 11.729° / day
HIGH-LATITUDE SPOT SEPT. 20 – 25  Ø = 58° 58° / 5.0069 days ≐ 11.584° travelled / day	HIGH-LATITUDE SPOT SEPT 20 – SEPT 24  Ø = 50° 50° / 4.0069 days ≐ 12.478° travelled/da

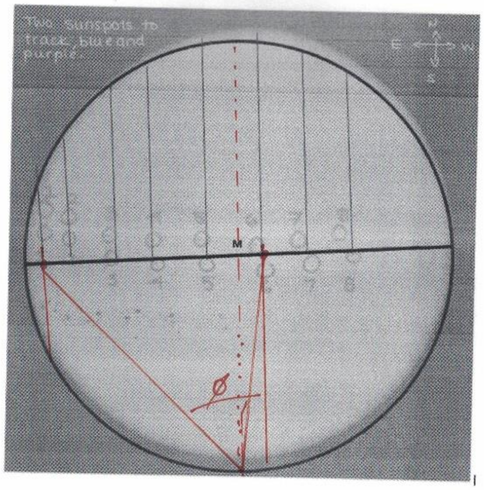

HIGH · LATITUDE SPOT
SEPT 20 – SEPT 23
Ø = 40°.
40° / 3.0069 days = 13.303° travelled /day


HIGH LATITUDE SPOT
SEPT 21 – SEPT 25
Ø = 48°
48° / 4.0069 days = 11.979° travelled/day


LOW · LATITUDE SPOT
SEPT. 18 – SEPT. 25
Ø = 74°
74° / 7.0039 days = 10.566° travelled /day


LOW · LATITUDE SPOT
SEPT. 18 – SEPT. 24
Ø = 60°
60° / 6.0039 days = 9.994° /day.

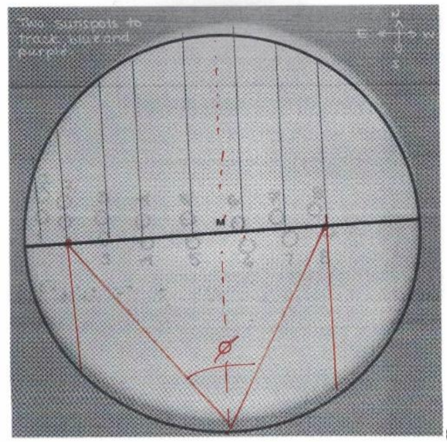
LOW-LATITUDE SPOT
SEPT. 18 – SEPT. 23



$\phi = 50°$

50°/ 5.0069 days ≐ 8.324° travelled/day

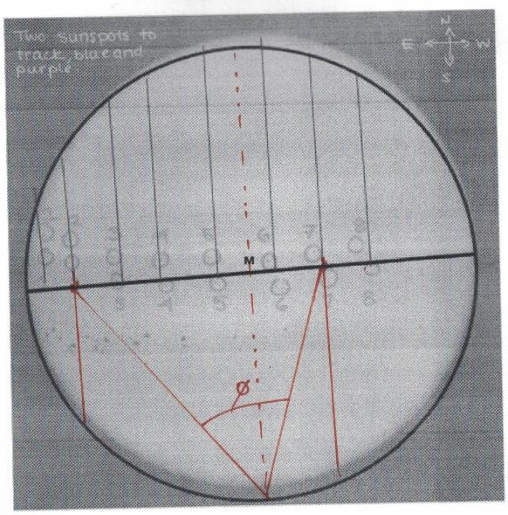
LOW-LATITUDE SPOT
SEPT. 19 – SEPT 25



$\phi = 61°$

61° / 6.0069 days ≐ 10.155° travelled/day

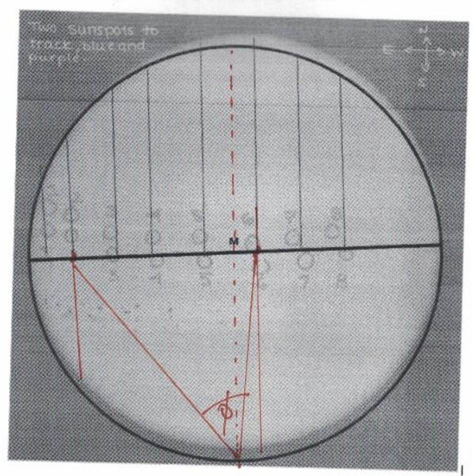
LOW-LATITUDE SPOT
SEPT 19 – SEPT 24



$\phi = 56°$

56° / 5.0069 days ≐ 11.185°/day

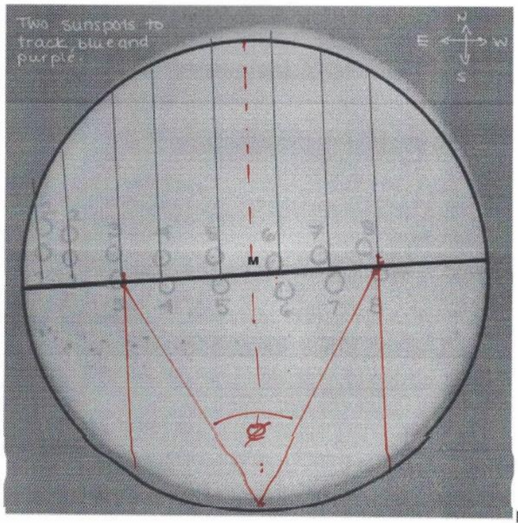
LOW-LATITUDE SPOT
SEPT 19 – SEPT 23



$\phi = 45°$

45° / 4.0069 days = 11.231° /day

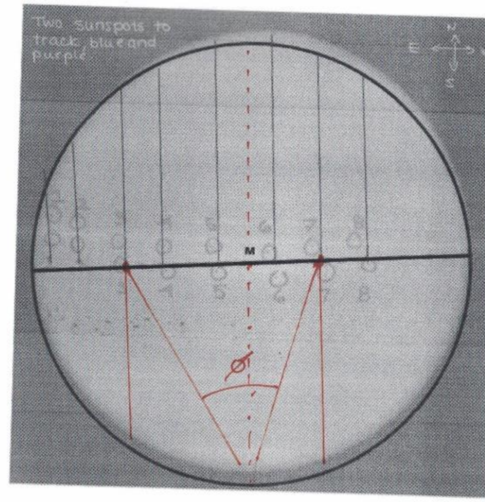
LOW-LATITUDE SPOT
SEPT 20 – SEPT 25



Ø = 58°

58° / 5.0069 days = 11.584°/day

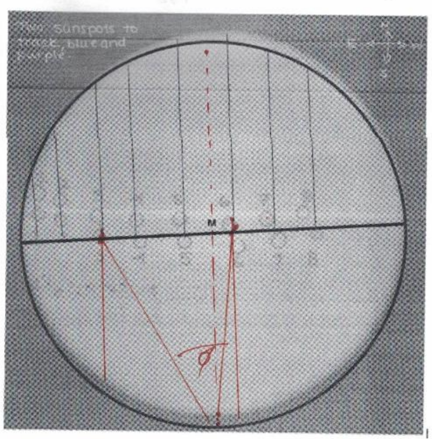
LOW-LATITUDE SPOT
SEPT 20 – SEPT 24



Ø = 30°

30° / 4.0069 days = 7.487°/day

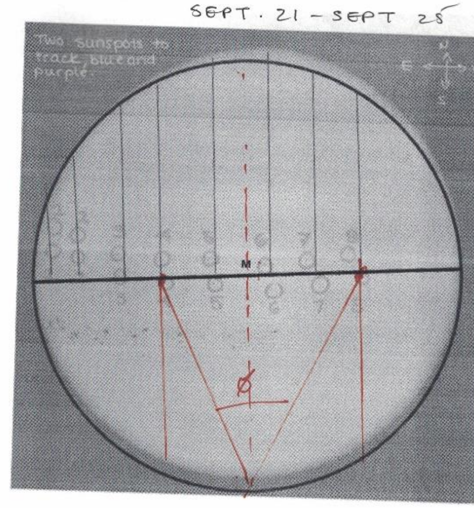
LOW-LATITUDE SPOT
SEPT 20 – SEPT 23



Ø = 38°

38° / 3.0069 days = 12.638°/day.

LOW-LATITUDE SPOT
SEPT. 21 – SEPT 25



Ø = 52°

52° / 4.0069 days = 12.978°/day

References

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