University of Kent

Astronomy, Space Science and Astrophysics

Rotation Rate of Planet Mercury

Stage 1 - PH370 Physics Labs

Monday 29th Jan - 5th Feb 2018

Report Author: Lukasz R Tomaszewski
Lab Partner: Jordan Thijssen

Contents

1 Abstract

The aim of this experiment is to find the rotational velocity of planet Mercury through firing short electromagnetic radiation pulses to Mercury and receiving the reflected pulses back off the planets surface. The experiment was repeated 3 times using present date, a date of Mercury's inferior conjunction and a date of Mercury's greatest-eastern elongation. The final 3 answers weren't spot on correct due to human error but was close therefore the underlying physics does work and is proved throughout this report.

2 Introduction

This experiments main objective is to use electromagnetic waves to determine the rotational rate of planet Mercury. This was done by firing a sequence of short electromagnetic radiation pulses to three of many of planet Mercury's positions in orbit around the sun; random position on present date where Mercury is on the far side of the sun to Earth, inferior conjunction where Mercury is closest to Earth and the greatest-eastern elongation where Mercury is on the furthest eastern side of the Sun in relation to Earth.

Using the frequency data graph received from the electromagnetic radiation pulses that reflected off the planet Mercury's surface closest to Earth, highlighted to echoes; the lower frequency echo (rotational velocity component away from Earth) and the higher frequency echo (rotational velocity component towards Earth). The echoes were then implemented into a series of formulas highlighted in [3], the results produced in section 3.2 shows all three experiments; present date, inferior conjunction & greatest-eastern elongation.

3 Aims & Equipment

3.1 Apparatus

- CLEA Software

3.2 Data Collected

- Outgoing frequency
- Delay distance
- Distance parallel to Earth
- Distance perpendicular to Earth
- Shift in rotational velocity frequency
- Shift in frequency due to echo
- Rotational velocity of Mercury
- Equatorial rotational velocity
- Rotational period of Mercury
- Inferior conjunction
- Greatest-Eastern conjunction
- Greatest-Western conjunction

3.3 Risk Assessment

When performing any physical experiment, there are risks involved, in relation to this experiment there are ergonomic risks where physical fatigue aches & pains in joints & limbs. Lighting has the potential to cause glare thus will cause eye strain and headaches, upper limb disorders include effects such as tendinitis and carpal tunnel syndrome.

As the time duration of this experiment is 3-4 hours long, controlling these hazards and preventing them turning into risks is a priority. A computer is required to run the software thus swapping the operator of the computer regularly will reduce the risk of a single operator eye strain & headaches, during this stage the operators can stretch their legs to prevent upper limb disorders. In prevention of electrical hazards, the computer had a green PAT (portable appliance test) sticker which states its safe to use.

4 Experimental Procedure

4.1 Physics Behind the Experiment

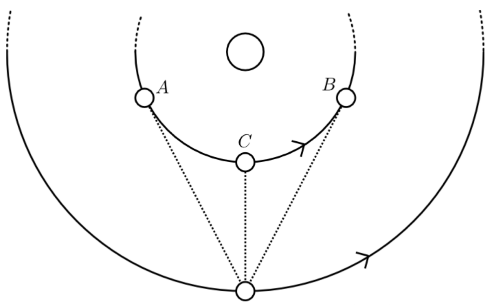

Figure 1: Mercury's position in orbit of the sun in relation to Earth.

As shown in fig. 1 which is located in [3], Mercury's orbit around the sun is much shorter than Earth's, therefore the period of rotation will be much less than Earth's. In this experiment, a series of short electromagnetic radiation pulses of known frequency will be fired and sent in a direct path to mercury and the received pulse which reflected off Mercury's surface will be plot a graph (frequency value against frequency intensity). The travel time of the pulses in each stage of this experiment will vary depending on the distance between Mercury and Earth.

A notable statement to make is that the outgoing pulse that is sent, the entire pulse will not all hit the planet Mercury's surface due the fact the pulse will stretch to cover a larger area but the part of the pulse that does hit the planets surface will hit the surface at different times as show in fig. 2 which is located in [3].

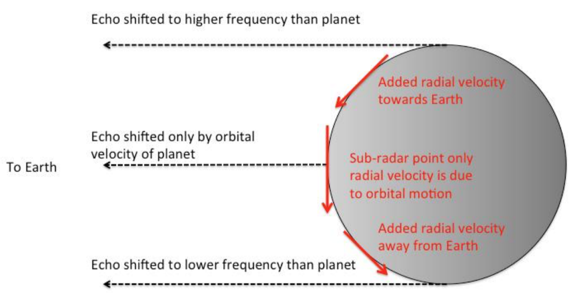

Figure 2: The sub radar point and radial velocities of the planets surface.

Due to Doppler effect, the returning echoes are slightly higher and lower, the returning echo received of the radial velocity towards Earth is a slightly higher frequency and the the returning echo received of the radial velocity away Earth is a slightly lower frequency. But due to the knowledge of the Doppler effect, the application can be applied.

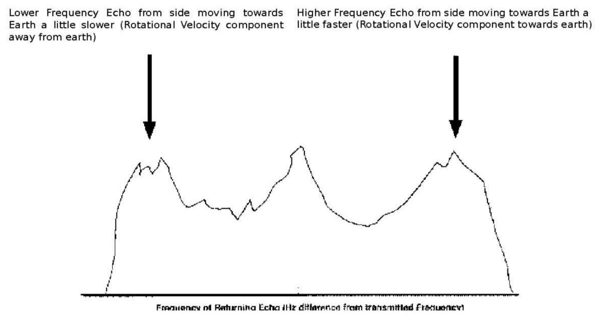

Figure 3: The received pulses graph.

fig. 3 which located in [3] shows that the left peak is Mercury's side moving towards Earth and the right peak is Mercury's side moving away from Earth and the middle peak being the sub radar point as shown in fig. 2.

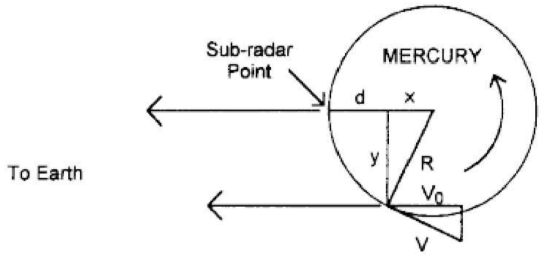

Figure 4: Geometrical view of the calculations within this experiment.

Using the geometrical view in fig. 4 which located in [3], calculations can be made with the data received back from the electromagnetic pulse which are highlighted in section 5 but d, x and y can be calculated without any received data but are of paramount importance in later equations. These geometrical parameters: d, x and y are located in section 5.1 of this report.

4.2 Present Date

January 29, 2018 UT: 20 Hrs, 06 Min, 46.1 Sec
Julian Date: 2458148.338033
Geocentric Position of Mercury:
Right Ascension: 19 Hrs, 58 Min, 39.7 Sec
Declination: -22 Deg, 13 Min, 57 Sec
Distance: 1.371394 AU (11.406 Light Minutes)
Ecliptic Longitude: 297 Deg, 16 Min, 40 Sec
Ecliptic Latitude: -1 Deg, 33 Min, 38 Sec

Figure 5: The data set used for the present date stage of this experiment, showing the astronomical measurements of Mercury in relation to Earth.

In the first stage of this experiment, using the CLEA software, and todays date a series of short electromagnetic radiation pulses were fired from Earth to Mercury, with the position of Mercury in relation to the Sun and Earth, as shown in fig. 5.

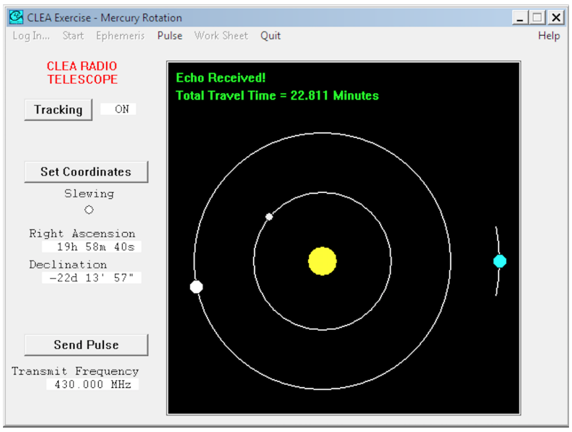

Figure 6: Screen shot of the CLEA software for the present date stage of this experiment showing the positions of Earth and Mercury in relation to the Sun.

While fig. 6 shows the positions of Mercury in relation to Earth around the Sun, as clearly shown this pulse out of all 3, this was had the longest travel time as Mercury was on the other side of the Sun in relation to Earth. After the 22.811 minutes the received pulse hit Earth and the experiment continued, the frequency were picked and the list of equations were filled to give a final answer to the rotational rate of planet Mercury which are all highlighted in section 5.2.

4.3 Inferior Conjunction

August 8, 2018 UT: 20 Hrs, 08 Min, 44.9 Sec
Julian Date: 2458339.339409
Geocentric Position of Mercury:
Right Ascension: 9 Hrs, 10 Min, 34.0 Sec
Declination: 11 Deg, 14 Min, 03 Sec
Distance: 0.603025 AU (5.015 Light Minutes)
Ecliptic Longitude: 136 Deg, 39 Min, 56 Sec
Ecliptic Latitude: -4 Deg, 49 Min, 28 Sec

Figure 7: The data set used for the inferior conjunction stage of this experiment, showing the astronomical measurements of Mercury in relation to Earth.

In the second stage of this experiment, much like in the first stage using the CLEA software, inputting a date of one of this years inferior conjunctions of Mercury in relation to Earth which was found at [2], the series of short electromagnetic radiation pulses were fired from Earth to Mercury again, with the position of Mercury in relation to the Sun and Earth, as shown in fig. 7.

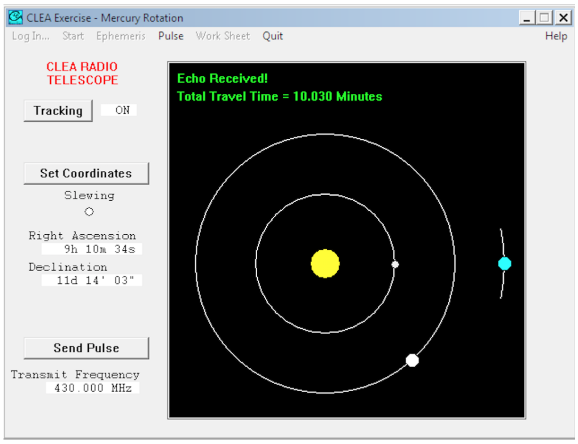

Figure 8: Screen shot of the CLEA software for the inferior conjunction stage of this experiment showing the positions of Earth and Mercury in relation to the Sun.

While fig. 8 shows the positions of Mercury in relation to Earth around the Sun. After the 10.030 minutes the received pulse hit Earth and the experiment continued much like section 4.2 and the data was collected as shown in section 5.3.

4.4 Greatest-Eastern Elongation

November 6, 2018 UT: 13 Hrs, 00 Min, 00.0 Sec
Julian Date: 2458429.041667
Geocentric Position of Mercury:
Right Ascension: 16 Hrs, 19 Min, 38.0 Sec
Declination: -24 Deg, 15 Min, 45 Sec
Distance: 1.020187 AU (8.485 Light Minutes)
Ecliptic Longitude: 247 Deg, 13 Min, 40 Sec
Ecliptic Latitude: -2 Deg, 47 Min, 15 Sec

Figure 9: The data set used for the greatest-eastern elongation stage of this experiment, showing the astronomical measurements of Mercury in relation to Earth.

In the third stage of this experiment, much like in the first & second stage, inputting a date of one of this years greatest-eastern elongations of Mercury in relation to Earth which was found at [2] into the CLEA software, the series pulses were fired from Earth to Mercury again, with the position of Mercury in relation to the Sun and Earth, as shown in fig. 9.

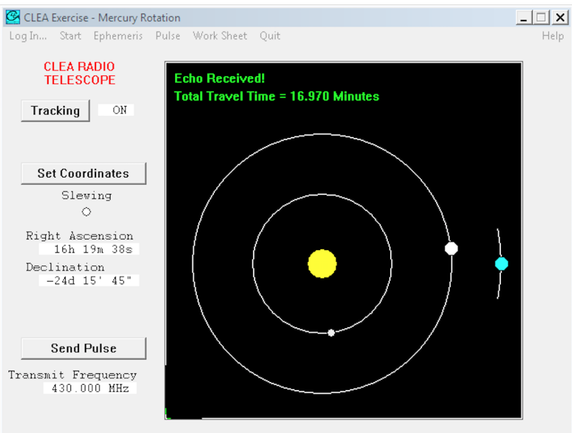

Figure 10: Screen shot of the CLEA software for the greatest-eastern elongation stage of this experiment showing the positions of Earth and Mercury in relation to the Sun.

While fig. 10 shows the positions of Mercury in relation to Earth around the Sun. After the 16.970 minutes the received pulse hit Earth and the experiment continued much like section 4.2 & section 5.3 and the data was collected as shown in section 5.4.

5 Results & Disscussion

5.1 Geometrical Parameters

5.1.1 Delay Distance

$$d = \frac{c\Delta t}{2} \tag{1}$$

Where;
Speed of Light $\Rightarrow c = 3_{\times 10^8}$
Change in Time $\Rightarrow \Delta t =$ section 4.1

Using eq. (1), the delay distance parameter was calculated for further use in the present date experiment (section 5.2), inferior conjunction experiment (section 5.3) and greatest-eastern elongation experiment (section 5.4).

$$T + 120 \Rightarrow d = \frac{3_{\times 10^8} \times 120_{\times 10^{-6}}}{2} = 18_{\times 10^3}$$

$$T + 210 \Rightarrow d = \frac{3_{\times 10^8} \times 210_{\times 10^{-6}}}{2} = 31.5_{\times 10^3}$$

$$T + 300 \Rightarrow d = \frac{3_{\times 10^8} \times 300_{\times 10^{-6}}}{2} = 45_{\times 10^3}$$

$$T + 390 \Rightarrow d = \frac{3_{\times 10^8} \times 390_{\times 10^{-6}}}{2} = 58.5_{\times 10^3}$$

(2)

5.1.2 Distance parallel to our line of sight

$$x = R_{Merc} - d \tag{3}$$

Where;
Radius of Mercury $\Rightarrow R_{Merc} = 2.24_{\times 10^6}$
Delay Distance $\Rightarrow d = eq.\ (1)$

Using eq. (3), the distance parallel to our line of sight parameter was calculated for further use in the present date experiment (section 5.2), inferior conjunction experiment (section 5.3) and greatest-eastern elongation experiment (section 5.4).

$$T + 120 \Rightarrow x = 2.24_{\times 10^6} - 18_{\times 10^3} = 2.402_{\times 10^6}$$

$$T + 210 \Rightarrow x = 2.24_{\times 10^6} - 31.5_{\times 10^3} = 2.3885_{\times 10^6}$$

$$T + 300 \Rightarrow x = 2.24_{\times 10^6} - 45_{\times 10^3} = 2.375_{\times 10^6}$$

$$T + 390 \Rightarrow x = 2.24_{\times 10^6} - 58.5_{\times 10^3} = 2.3615_{\times 10^6}$$

(4)

5.1.3 Distance perpendicular to our line of sight

$$y = (R_{Merc}^2 - x^2)^{\frac{1}{2}} \tag{5}$$

Where;

Radius of Mercury $\Rightarrow R_{Merc} = 2.24_{\times 10^6}$

Distance parallel to our line of sight $\Rightarrow$

$x = eq.\ (3)$

Using eq. (5), the distance perpendicular to our line of sight parameter was calculated for further use in the present date experiment (section 5.2), inferior conjunction experiment (section 5.3) and greatest-eastern elongation experiment (section 5.4).

$$T + 120 \Rightarrow y = ((2.24_{\times 10^6})^2 - (2.22_{\times 10^6})^2)^{\frac{1}{2}}$$
$$= 294.612_{\times 10^3}$$

$$T + 210 \Rightarrow y = ((2.24_{\times 10^6})^2 - (2.21_{\times 10^6})^2)^{\frac{1}{2}}$$
$$= 389.189_{\times 10^3}$$

$$T + 300 \Rightarrow y = ((2.24_{\times 10^6})^2 - (2.20_{\times 10^6})^2)^{\frac{1}{2}}$$
$$= 464.516_{\times 10^3}$$

$$T + 390 \Rightarrow y = ((2.24_{\times 10^6})^2 - (2.18_{\times 10^6})^2)^{\frac{1}{2}}$$
$$= 528.883_{\times 10^3}$$

(6)

5.2 Present Date

Comparing the appearance of the received pulse fig. 12 to the initial pulse fig. 11, clearly shows it is broader than the initial pulse. The smooth gradient climb leading up to the sub-radar point which states the frequency shift had greater intensity as it hit the sub-radar point. A notable difference is that fig. 12 is around 45,000Hz lower than the initial frequency.

The following fig. 13, fig. 14, fig. 15 & fig. 16 graphs show the pulses received at 90 second intervals, apart from fig. 13 which is at a 120 second interval from fig. 12.

5.2.1 Received Pulses Graphs

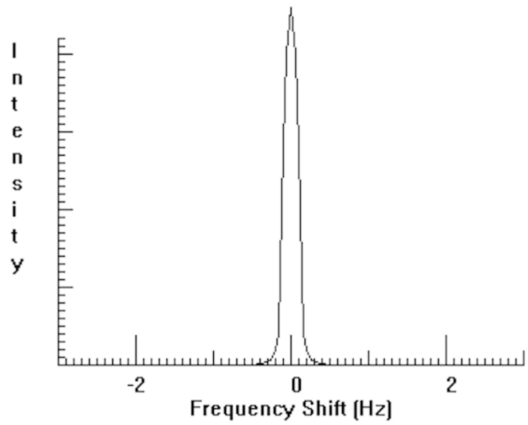

Figure 11: Outgoing pulse of the electromagnetic signal.

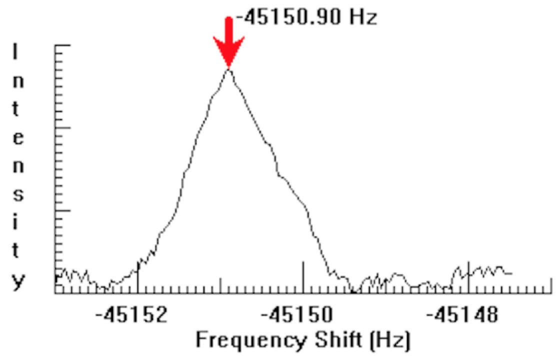

Figure 12: Received pulse of the electromagnetic signal.

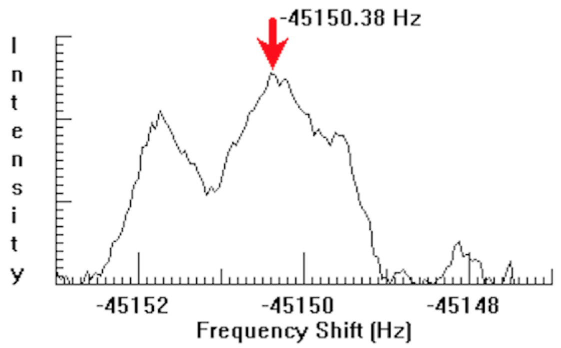

Figure 13: T+120s interval of the electromagnetic signal from the received pulse.

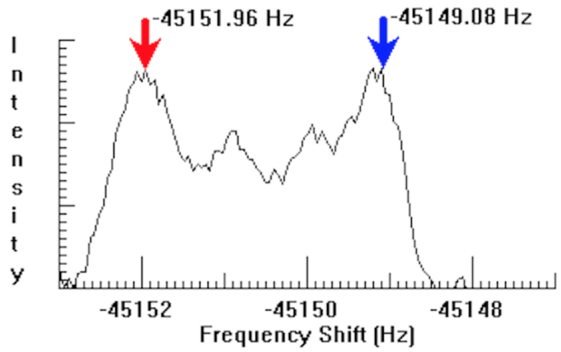

Figure 14: T+210s interval of the electromagnetic signal from the received pulse.

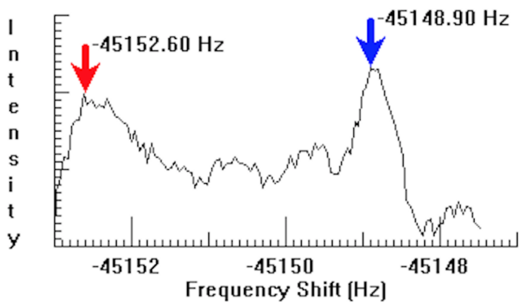

Figure 15: T+300s interval of the electromagnetic signal from the received pulse.

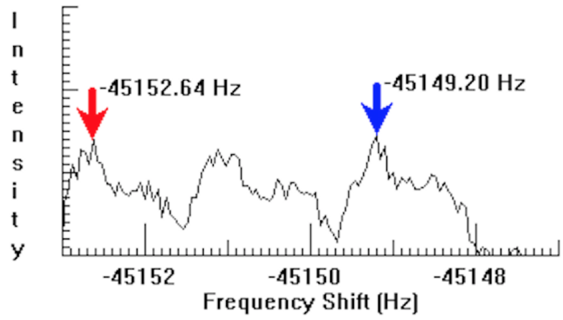

Figure 16: T+390s interval of the electromagnetic signal from the received pulse.

5.2.2 Shift in frequency due to rotational velocity

$$\Delta F_{Total} = \frac{F_{Right} - F_{Left}}{2} \tag{7}$$

Using eq. (7) and the graphs in section 5.2.1 the equations can be filled and the final answer can be produced.

$$T + 120 = \frac{-45150.38 - (-)45151.74}{2} = 0.68Hz$$

$$T + 210 = \frac{-45149.08 - (-)45151.96}{2} = 1.44Hz$$

$$T + 300 = \frac{-45148.90 - (-)45152.60}{2} = 1.85Hz$$

$$T + 390 = \frac{-45149.20 - (-)45152.64}{2} = 1.72Hz$$

$$\tag{8}$$

5.2.3 Shift in frequency due to echo

$$\Delta F_C = \frac{\Delta F_{Total}}{2} \tag{9}$$

Using eq. (9) and the answers from eq. (8) the shift in frequency due to echo can be calculated.

$$T+120 = \frac{0.68}{2} = 0.34Hz$$

$$T+210 = \frac{1.44}{2} = 0.72Hz$$

$$T+300 = \frac{1.85}{2} = 0.925Hz \tag{10}$$

$$T+390 = \frac{1.72}{2} = 0.86Hz$$

5.2.4 Rotational velocity of the edge of Mercury

$$V_0 = c\left(\frac{\Delta F_C}{f}\right) \tag{11}$$

Where;
Speed of Light $\Rightarrow c = 3_{\times 10^8}$
Transmitted Frequency $\Rightarrow f = 430_{\times 10^6}$

Using eq. (11) and the answers from eq. (10) the rotational velocity of the edge of Mercury can be calculated.

$$T+120 = 3_{\times 10^8}\left(\frac{0.34}{430_{\times 10^6}}\right) = 0.237ms^{-1}$$

$$T+210 = 3_{\times 10^8}\left(\frac{0.72}{430_{\times 10^6}}\right) = 0.502ms^{-1}$$

$$T+300 = 3_{\times 10^8}\left(\frac{0.925}{430_{\times 10^6}}\right) = 0.645ms^{-1}$$

$$T+390 = 3_{\times 10^8}\left(\frac{0.86}{430_{\times 10^6}}\right) = 0.600ms^{-1} \tag{12}$$

5.2.5 Equatorial velocity of Mercury

$$V = V_0\left(\frac{R_{Merc}}{y}\right) \tag{13}$$

Where;
Radius of Mercury $\Rightarrow R_{Merc} = 2.24_{\times 10^6}$
Geometrical parameter $\Rightarrow y = eq.\ (5)$

Using eq. (13) and the answers from eq. (12) & eq. (5) the equatorial velocity of Mercury can be calculated.

$$T+120 = 0.237\left(\frac{2.24_{\times 10^6}}{294.612_{\times 10^3}}\right) = 1.947ms^{-1}$$

$$T+210 = 0.502\left(\frac{2.24_{\times 10^6}}{389.189_{\times 10^3}}\right) = 3.121ms^{-1}$$

$$T+300 = 0.645\left(\frac{2.24_{\times 10^6}}{464.516_{\times 10^3}}\right) = 3.360ms^{-1}$$

$$T+390 = 0.600\left(\frac{2.24_{\times 10^6}}{528.883_{\times 10^3}}\right) = 2.745ms^{-1} \tag{14}$$

5.2.6 Planet rotational period

$$P_{Rot} = \frac{2\pi R_{Merc}}{V} \tag{15}$$

Where;
Radius of Mercury $\Rightarrow R_{Merc} = 2.24_{\times 10^6}$

Using eq. (15) and the answers from eq. (14) the rotational period of Mercury can be calculated.

$$\begin{aligned} P_{Rot} &= \frac{2*\pi*2.24_{\times 10^6}}{\left(\frac{1.947+3.121+3.360+2.745}{4}\right)} \\ &= 5.444_{\times 10^6}s \\ &= 63.00Days \end{aligned} \tag{16}$$

5.3 Inferior Conjunction

Using the same layout of equation to solve the present date stage of this experiment seen in section 5.2 my final answer for the Mercury's rotational period for the inferior conjunction stage of this experiment is;

$$P_{Rot} = \frac{2 * \pi * 2.24_{\times 10^6}}{\left(\frac{2.136 + 3.146 + 3.324 + 2.777}{4}\right)} \tag{17}$$
$$= 5.343_{\times 10^6} s$$
$$= 61.84 Days$$

5.4 Greatest-Eastern Elongation

Using the same layout of equation to solve the present date stage of this experiment seen in section 5.2 my final answer for the Mercury's rotational period for the greatest-eastern elongation stage of this experiment is;

$$P_{Rot} = \frac{2 * \pi * 2.24_{\times 10^6}}{\left(\frac{3.121 + 2.991 + 3.360 + 2.777}{4}\right)} \tag{18}$$
$$= 4.870_{\times 10^6} s$$
$$= 56.37 Days$$

5.5 Analysis

The actual period of rotation of planet Mercury is 58.646 days [1]

Analyzing the 3 final results for the rotational period of planet Mercury and comparing them to the actual period of rotation, the result weren't far off but they didn't exactly come close to the actual value. Even though using a simulated software, human error is partly to blame, the equations were double checked but still the underlying physics behind this experiment remain true.

6 Conclusion

To conclude this experiment, using geometry to calculate a planets rotational period is clever even thought the values from this experiment weren't spot on but they were close enough to prove that with exact data the underlying physics in section 4.1 are true.

Using the same value for the transmitted frequency and set geometrical parameter in section 5.1 allowed each stage of this experiment to be conducted fairly, thus leaving the only variable in the frequency shift due to rotational velocity in eq. (8) thus allowing only the position of the planet in orbit of the Sun relative to Earth to be the only deciding factor between all 3 stages of this experiment.

References

[1] Michael A.Seeds. *The Solar System.* Brooks Cole, third edition edition, June 2002. ISBN-10: 0534394493.

[2] F. Espenak. astropixels.com/ephemeris/astrocal/astrocal2018gmt.html, November 2014.

[3] G. Roch. Llr.1 rotation rate of planet mercury. University of Kent Moodle 2017, June 2017. Lab script 2017.