Union College Spring 2016

**Astronomy 50 Lab: Period and Size of Mars’ Orbit and Understanding of Retrograde Motion**

**Introduction**

Figuring out the orbits of the planets while observing from the Earth, which we now know orbits the Sun itself, is tricky. This difficulty was one of the main sources of confusion for the ancient astronomers in trying to build the model of the universe.

Even after Copernicus proposed a heliocentric model in which the Earth moves about the Sun, the details of the planets’ motions were hard to explain. A major breakthrough was accomplished by Johannes Kepler, who figured out the answers to several of the most significant problems through careful analysis of observations of Mars -- the data of which were obtained by the Danish astronomer Tycho Brahe. In this lab, you will use real data of the positions of Mars to reproduce Kepler’s method.

Without prior knowledge of the details of Mars’ orbit, observations only tell us the direction of Mars from Earth, and from the date we can infer the location of Earth on its orbit. However, particular constraints, as we’ll discuss, enable us to determine the basic aspects of Mars’ orbit.

The observations of the positions of Mars needed for this lab would take two years, which, of course, we can’t do in a 10-week trimester. Instead these two-years of data are provided for you. This is, ironically, the same situation that Kepler faced, as he got to analyze Tycho’s data.

**Procedure**

Table 1 (attached at back) lists data of the directions of Mars for numerous observation dates. The directions are given in angles (in the plane of the Solar System) relative to the direction of the Vernal Equinox. The Vernal Equinox (VE) is a location in the sky, corresponding to the position of the Sun on the first day in Spring, and chosen as the (0,0) position in the standard astronomy sky coordinate system. We will use these data (as if we had measured the positions of Mars in the sky ourselves) to infer the location of Mars in space on these dates.

**Part I: The Period of Mars’ Orbit:**

1. Set a large sheet of graph paper on your desk with the long dimension oriented left-right. On this paper, we’ll draw the Sun, and the orbits of Earth and Mars, as seen from above the North pole. From this perspective, the Earth orbits counter-clockwise. Draw a small circle at the center and write “S” inside, to represent the Sun. Use the curved edge of the protractor to draw another circle centered on the Sun, to represent the Earth’s orbit.

2. Make a small mark at the location on Earth’s orbit along the same horizontal line as the Sun and to the left of the Sun. Let this position be the position of the Earth on March 21, the first day of Spring. From this perspective, Earth orbits counterclockwise (ccw).

3. Note the two dates that Mars was in *opposition*. For each date, place the protractor with the Sun at the center and the 0o-line aligned with the *negative* x-direction (so that it indicates the position of Earth on March 21). If the position of Earth is a positive angle, then place the protractor so that the angle markings are toward the bottom of the page and measure the angle starting from the left-hand side of the protractor and going downward. If it is a negative angle, flip the protractor over so that the angle markings are toward the top of the page and measure the angle going upward from the left-hand side. Mark the position of Earth on its orbit.

4. Since opposition means in the direction opposite the Sun, draw two straight lines from the Sun and passing through the Earth to indicate the direction of Mars on each of these two dates.

5. Using the 2nd column in Table 1, calculate the number of days between the dates of opposition, and write your answer in the worksheet (Table 2 at back).

6. Without marking up the paper, follow the direction of Mars between the two dates of opposition, and determine how many orbits (less than one?, more than one?, more than two?) Mars completed between oppositions. In particular, take note of the positions of Mars on xxx. Note that there is an xx-month gap between the xxx.

7. Measure the angle between the two positions of Mars and calculate what percentage of an orbit Mars traveled between the two dates of opposition. (Remember, that if it went over one full orbit, then the percentage will be more than 100% and that the fraction of an orbit is given by the measured angle divided by 360o.)

8. Considering your answers to numbers 5 and 7, calculate how many days it takes Mars to complete one orbit. This is your inferred period of Mars’ orbit.

**Part II: Locating Mars Distance and Position in its Orbit**

Now that you know the period of Mars’ orbit, you can use this to triangulate Mars’ positions in space on some of these dates. We know that Mars must end up at the exact same location in its orbit after a time equal to one period later. For example, if the period was 1000 days, then, observations of the directions of the Mars from Earth separated by 1000 days should both point to the same physical location. Since the Earth will not be at the same location, the directions will be different, but they should meet (i.e. cross) at Mars’ position. Figure 1 depicts this.



**Figure 1**: The directions of Mars on dates separated by one full period of Mars’ orbit:

1. On Table 2, five observation dates occurring on the 21st of consecutive months in 1997 are listed. From Table 1, find the data points whose dates are one of Mars’ period later and write these dates in the second column of Table 2.

2. For each pair of dates, using different colored pencils for each pair:

 a. Locate the positions of Earth on the graph paper following the same instructions as in Part I about the use of the protractor.

 b. Use a protractor to indicate the direction of Mars by moving the protractor so that the Earth is in the center, and 0o-line aligned with the *positive* x-direction. If the direction of Mars is a positive angle, then place the protractor so that the angle markings are toward the top and measure the angle to Mars starting from the right-hand side of the protractor and going upward. If it is a negative angle, flip the protractor over so that the angle markings are toward the bottom of the page and measure the angle going downward from the right hand side. Draw a line starting at Earth and passing through this angle.

 c. Note where the pair of lines cross, and mark this with a dark dot and a date to indicate a position of Mars in its orbit.

3. Repeat step 2 for each pair of dates separated in time by Mars’ period. Use a different color for each pair (to reduce the confusion on the graph).

4. Draw a smooth curve connecting all the dots to trace out Mars’ orbit.

5. Using the Earth’s orbital radius to determine scale of your diagram (do you know the distance of the Sun from the Earth?), calculate the average distance of Mars from the Sun.

**Part III**

1. Consider only the dates in 1999 and answer the following questions

a. How does the position of Mars change along its orbit? In which direction does Mars move?

b. How does the direction angle of Mars (as seen from Earth) change in time---in which direction does Mars appear to move to observers on Earth during this period?

2. Explain why we see retrograde motion of the outer planets. Are they actually moving backwards? Imagine being in a car on the highway going 65 mph and passing a car going 50 mph. What direction does the other car appear to be moving, relative to the background trees?

**Questions to Consider for Discussion:**

1. Most of the ancient astronomers did not believe that the Earth was moving and so they devised a geocentric (“Earth-centered”) model. In this model, how must they have interpreted the retrograde motions of the outer planets? (You can try looking up “epicycles” to find a detailed answer.)

2. Using more precise methods, Kepler (in the very early 1600s) discovered that Mars’ orbit was elliptical, which was a huge surprise. No one before that had conceived that the planets’ orbits were not perfect circles. This modification to Copernicus’ heliocentric model created a model which predicted the positions of the planets perfectly (to within measurement error). Comment on the ability of a theory to predict observation and/or experimental results as verification of the validity of that theory.

**Table 1**: Directions of Mars on Assorted Dates from 1997 to 2001

|  |  |  |  |
| --- | --- | --- | --- |
| Date | Days from Start | Earth Position | Mars position wrt Earth |
|   |   | (degrees from March 21) | (degrees ccw from +x-axis) |
| Mar 21, 1997 | 212 | 0 | 173.4 |
| Apr 21, 1997 | 243 | 30.6 | 165.6 |
| May 21, 1997 | 273 | 60.1 | 169.3 |
| Jun 21, 1997 | 304 | 90.7 | -178.8 |
| Jul 21, 1997 | 334 | 120.3 | -164.7 |
| Feb 05, 1999 | 898 | -43.4 | -149.4 |
| Mar 08, 1999 | 929 | -12.8 | -143.7 |
| Apr 07, 1999 | 959 | 16.8 | -145.5 |
| **Apr 24, 1999** | **976** | **33.5** | **opposition (-146.5)** |
| May 08, 1999 | 990 | 47.3 | -154.2 |
| Jun 8, 1999 | 1021 | 77.9 | -158.2 |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
| **Jun 13, 2001** | **1757** | **82.5** | **opposition (-97.5)** |

**Table 2**: Worksheet

1. Number of Earth days between oppositions of Mars \_\_\_\_\_\_\_\_\_\_\_\_\_

2. Amount of orbit Mars moved between oppositions \_\_\_\_\_\_\_\_\_\_\_

3. Period (number of Earth days) for one orbit \_\_\_\_\_\_\_\_\_\_\_\_\_\_

4. Pairs of dates separated by one Mars period:

 a. \_\_\_Mar 21, 1997\_\_\_\_ and \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

 b. \_\_\_Apr 21, 1997\_\_\_\_\_ and \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

 c. \_\_\_May 21, 1997\_\_\_\_ and \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

 d. \_\_\_Jun 21, 1997\_\_\_\_\_ and \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

 e. \_\_\_ Jul 21, 1997\_\_\_\_\_ and \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

5. Direction of motion of Mars on dates near opposition: cw \_\_\_\_\_\_ or ccw \_\_\_\_\_\_

 Apparent direction of Mars, from Earth, near opposition: cw \_\_\_\_\_\_ or ccw \_\_\_\_\_\_\_

6. Explanation for Retrograde motion