THE SATELLITES OF JUPITER

RONALD E. MICKLE
Denver, Colorado 80211

ABSTRACT

The objective of this paper is to deduce the revolution of the four Galilean satellites and the distances of those satellites from Jupiter. Galileo discovered Jupiter's four largest satellites, Io, Callisto, Ganymede and Europa, in 1610 with a telescope that would be regarded by today's standard as rudimentary (Kaufmann & Freedman 1999). The Galilean satellites, as they were to be called, are easily viewed from Earth with the most basic of telescopes. So easy, in fact, that just about anyone with a fairly inexpensive telescope can deduce their revolution around Jupiter and measure their distance from Jupiter.

Today, measurements of the ephemeris for the revolution of Jupiter's four largest satellites are easily made. For this paper, the data derived from observations was compared to data published by the Association of Lunar and Planetary Observers, the Astronomical Almanac for Year 2000 and Sky & Telescope Magazine. Eclipses, transits and occultation timings were also observed and recorded.

Interestingly, the margin of error between the published data and my observations over a two-month period were small. My research into the ephemerides for Jupiter and its Galilean satellites aided me in identifying each satellite.

1. MEASUREMENT PROCEDURES

Observations were made from Denver, Colorado, United States, using the University of Denver's historic Chamberlin Observatory's Clark 20-inch refracting telescope. Latitude and longitude coordinates are 40°N, 105°W.

1.1. MAGNIFICATION

The magnification of the telescope is computed by using the focal length of the objective lens/eyepiece in millimeters. The effective focal length of the Clark 20-inch refractor objective is 7797.516 mm (Denver Astronomical Society), rounded up to 7800mm.

Table1. Magnification of the Clark 20" refractor

Focal length (mm)	÷	Eyepiece	=	Magnification
7800		25mm		312x
7800		**32mm**[1]		**244x**
7800		40mm		195x

[1] The 32mm eyepiece was used exclusively for all measurements. The 40mm was used initially for occultations.

1.1. EYEPIECE FIELD-OF-VIEW (FOV)

The drift method was used to determine the FOV, which is explained in the American Association of Variable Star Observers website (see References). Computing the FOV for the 32mm Plössl eyepiece consisted of locating a star on, or near the celestial equator. The star was placed just outside the east side of the eyepiece field of view and the Right Ascension of the telescope disengaged. This allowed the star to "drift" into view from east to west. The time it took the star to drift from the east side of the eyepiece and exit the west side was measured in seconds using a stopwatch. Nine measurements were made for the 32mm eyepiece. This time was converted to arcseconds by using the Earth's rotational speed of 1^{o} /4-minutes. This is proportional to the FOV in arcseconds (unknown)/FOV in seconds using the before mentioned drift method. The formula is expressed as:

$1^{o}/4' = D/m$

D = FOV in arcseconds, UNKNOWN.

m = Measured drift of star across eyepiece in seconds.

For the 32mm eyepiece:

$1^{o}/4' = D/m$

$3600s/240s = D/56.31s$

$240(D) = 3600/56.31$

$D = 202{,}716/240$

$D = 844.65$ arcseconds ⇒ 844.65 arcs/60 = 14.1 arcminutes

D = FOV in arcseconds.

m = Nine measurements averaged to 56.31 seconds.

1^{o} = 3600 seconds.

4' = 240 seconds.

1.3. SOURCES OF DATA

Two types of data were used in this project: Measured and Published. Measured data is that taken through direct observations in this project. That data is then compared to Published data, which is published either through periodicals, textbooks or astronomical software programs (see References).

2. OBSERVATION DATES AND CONDITIONS

Jupiter and its four largest satellites (Kaufmann & Freedman 1999) were observed on 31 nights between September 9 and November 14, 2000. All observations were made using the University of Denver's historic Chamberlin Observatory's 20-inch aperture, f/15 Alvan Clark-George Saegmuller refractor.

Table 2. Observation dates

Obs No.	Date mmddyy	Seeing[2]
1	091000	IV
2	091200	III
3	091300	III
4	091400	III
5	091800	III
6	091900	III
7	092000	III
8	092400	III
9	092500	III
10	092600	III
11	100900	II
12	101000	II
13	101100	I
14	101200	I
15	101300	I
16	101500	II
17	101600	II
18	101700	II
19	101800	II
20	102100	I
21	102200	II
22	102400	II
23	102700	II
24	102800	I
25	102900	I
26	110800	II
27	110900	I
28	111010	I
29	111200	II
30	111300	I
31	111400	I

[2] "Seeing" as defined by *The Facts on File Dictionary of Astronomy*, uses the Antoniadi Scale: I=perfect seeing, II=good, III=moderate, IV=poor, and V=appalling.

During the 67 nights in the observing schedule, there were approximately 23 weather nights when no observations were possible. Observation No.1 (Table 2) was made for the purpose of refining the technique of timing/measuring the satellites, and documenting the position and distance of each satellite with respect to Jupiter.

I observed the periods of revolution of the four Galilean satellites over this period. Observations are broken down into three methods: Normal, Snapshot and Orientation.

> *Normal* observations requiring a detailed group of three timings made of satellite distances and Jupiter's diameter, using the drift method.
>
> *Snapshot* observations entail minimal time spent at the observatory, generally less than one hour, making basic timings for the purpose of deducing the period of revolution of each satellite.
>
> *Orientation* observations are made from my residence using an 8" SCT telescope for a quick look at the arrangement of the Jovian satellites. No measurements are made.

According to the *Backyard Astronomers Guide*, 25 to 35 power per inch should be adequate for viewing Jupiter. For the Clark 20", that would result in:

25x/inch X 20-inches = 500x
35x/inch X 20-inches = 700x

To remain consistent and avoid possible confusion, the 32mm eyepiece was used for all measurable observations. Other eyepieces were used to observe surface detail of Jupiter. Note also that the 32mm eyepiece is a super plössl of good quality. Table 1 lists the magnification.

Prior to all observations, I calibrated my watch with the atomic clock in Boulder, Colorado. Unless otherwise noted, all times are Universal Coordinated Time (UT). NOTE: Daylight Savings Time ended in Denver, Colorado, at 0200 hours on October 29, 2000.

3. SATELLITE IDENTIFICATION

Identify each satellite: I started with the assumption that each was unknown. I was therefore looking at Jupiter with four bright points of light orbiting in close proximity. I thought about following existing nomenclature for assigning identification to each satellite, such as I, II, III or IV, or maybe using letters such as A-D. I decided against using the letters A-D because of the possibility of later confusing the letter C for Callisto. I decided to use numbers 1-4. Numbers were used during the first three weeks until all satellites were positively identified by their period of revolution and matched to their recognized names. For ease of recognition throughout this project, I then reverted to using the first letter of each satellites name, i.e. I=Io, C=Callisto, E=Europa and G=Ganymede.

I first thought keeping track of each satellite from night to night would be tricky, or even difficult. However, this proved to be one of the easier tasks. Combinations of satellite magnitude and velocity around Jupiter aided in keeping track of satellites. Bright Ganymede, at 4.5 Mv, was easily discernable from Europa and Callisto. Callisto and Io can be represented by the analogy of the Tortoise and the Hare, respectively.

4. PERIOD OF REVOLUTION FOR EACH SATELLITE

When I initially started this project, I viewed the task of deducing the revolutions of the satellites as one area requiring the least amount of attention. However, delving into the orbital revolution of these Galilean moons, I found the period of revolution involves *x*-number of days followed by *y*-number of hours. Three of four satellites are incremented at 13 and 18 hours, placing the satellite in daylight at the end of its orbital cycle. Therefore, two or three orbital periods had to pass before the satellite could be observed in darkness. Over three weeks went by before I devoted serious attention to this area. Luckily, I had made fairly good measurements during normal observations, and supplemented normal observations with snapshots in between to keep track of each satellite.

Table 3 below providew the period of revolution for each satellite. To measure the period of revolution of the Galilean satellite, an Initial Point of Measurement had to be identified by its distance from Jupiter, represented by Drift Seconds. Subsequent observations were made and it was noted when the satellite Return(ed) to Initial Point of Measurement.

Table 3. Periods of Revolution of the Galilean Satellites

Satellite[3]	**Initial Point of Measurement** mmddyy & time[4]	**Drift Seconds** from Jupiter & **E**ast or **W**est	**Return to Initial Point of Measurement** mmddyy & time[4]	**Period of Revolution** Published[5] (days)	**Period of Revolution** Observed (days)	**Deviation** (days)
I	110800, 0305	1.98s, E	111400, 1022	1.769	1.769	0.0
E	101000, 0355	13.7s, W	101800, 0725	3.551	3.568	0.017
G	100900, 0500	9.07s, E	101700, 0825	7.155	7.142	0.013
C	092600, 0615	27.38s, W	102900, 0900	16.689	16.557	0.132

[3] I=Io, E=Europa, G=Ganymede, C=Callisto.

[4] All times are given in UT.

[5] Kaufmann & Freedman *Universe*

5. JUPITER'S DIAMETER AND DISTANCES OF THE SATELLITES FROM JUPITER

The distances of the satellites from Jupiter were measured using a stopwatch, by timing the seconds between the satellite and the limb of Jupiter. The center, or radius, of Jupiter was not used as a reference point because of the small distance in drift seconds, which was less than 2-seconds at times. The diameter of Jupiter could be determined using the same method for measuring satellite distance.

To determine either Jupiter's diameter, or the distance of a Galilean satellite from Jupiter, the formula $a/b = a'/b'$ was used. I first measured the time, in seconds, of either the diameter of Jupiter, or the time between the satellite and Jupiter. Next I applied the numbers derived from the FOV computations described in Measurements, section 2.1, to the formula $a/b = a'/b'$. The distance of a satellite (or diameter of Jupiter) in seconds of time, is represented as being directly proportional to the linear distance of the satellite from Jupiter (unknown) and the known FOV in arcseconds/eyepiece drift in seconds. This is expressed as:

$a/b = a'/b'$

a = eyepiece FOV in arcseconds.

b = eyepiece FOV using the drift method, expressed in seconds.

a' = linear diameter of Jupiter, or distance of an object/satellite (unknown).

b' = measured distance or size of object in seconds using the drift method.

5.1. DISTANCES OF SATELLITES FROM JUPITER

To illustrate how the distance between Io and Jupiter is converted from seconds of drift to arcseconds and –minutes, let’s look at observation No.4, taken on September 15, 2000. The drift seconds between Io and Jupiter averaged 5.76 seconds. Using the equation above results in the follows:

a/b = a´/b´

844.65” / 56.31s = a´ / 5.76s

56.31(a´) = 844.65(5.76)

a´ = 4865.184 / 56.31

a´ = 86.4”, or 1’ 26.4” distance
from Jupiter

a = 844.65”

b = 56.31 seconds

a´= ?, distance of Io from Jupiter in arcseconds

b´= 5.76 seconds

Overall, 123 groups of measurements were taken of Jupiter and its satellites. Listed below is a selection of six observations showing the measured distance of the satellite from Jupiter in arcminutes and –seconds, and the published data. Measured numbers in Table 4 were taken from observational notes. Using the formula a/b = a´/b´ as described above, we use the known eyepiece FOV measurements for *a* and *b*, and the seconds from the Average of Drift column below, for *b´*. The result is the Distance Measured column, displayed in arcminutes.

Table 4. Distance of Satellites from Jupiter

Date mmddyy	**Time**[4]	**Satellite**[3]	**Average of Drift** in seconds measured	**Distance** Measured	**Distance** Published[6]	**Deviation** arcseconds
091500	0555	C	7.56s	1’ 53.4”	1’ 48”	5.4
		G	7.0s	1’ 45”	1’ 43”	3.0
092500	0607	G	17.9s	4’ 28”	4’ 18”	10
		E	12.20s	3’ 03”	2’ 55”	8
		I	6.52s	1’ 37.8”	1’ 35”	3.8
		C	15.0s	3’ 45”	3’ 30”	15
101000	0730	G	7.21s	1’ 48.15”	1’ 44”	4.15
		E	1.15s	0’ 17.25”	0’ 15”	2.25
		I	7.20s	1’ 48”	1’ 44”	4
		C	6.73s	1’ 40.95”	1’ 35”	5.95
101900	0410	G	19.74s	4’ 56.1”	4’ 48”	8.1
		E	Too close to measure	n/a	0’ 06.2”	-
		I	7.42s	1’ 51.3”	1’ 49”	2.3
		C	Too close to measure	n/a	0’ 10”	-
102200	0255	G	11.28s	2’ 49.2”	2’ 47”	2.2
		E	10.18s	2’ 32.7”	2’ 32”	0.7
		I	4.88s	1’ 13.2”	1’ 12”	1.2
		C	35.2s	8’ 48”	8’ 41”	7

		G	21.59s	5’ 23.85”	5’ 12”	11.85
		E	6.11s	1’ 31.65”	1’ 29”	2.65
111300	0535	I	4.99s	1’ 14.85”	1’ 14”	0.85
		C	1.82s	0’ 27.3”	0’ 27”	0.3

[3] I=Io, E=Europa, G=Ganymede, C=Callisto.

[4] All times are given in UT.

[6] *Space Explorer II Astronomy Software, V 2.1* and *Starry Night Pro* Astronomy Software

5.2. DIAMETER OF JUPITER

Using the same formula mentioned earlier in section 6.1, the diameter of Jupiter is computed as:

a/b = a´/b´

844.65” / 56.31s = a´ / 2.86s

56.31(a´) = 844.65” (2.86s)

a´ = 2415.699 / 56.31

a´ = 42.9”, diameter of Jupiter

a = 844.65”

b = 56.31 seconds

a´= diameter of Jupiter in arcseconds (unknown)

b´= 2.86 seconds

Table 5 shows the diameter of Jupiter may be measured, in seconds, using the drift method. Once the measurement in seconds is made, the formula a/b = a´/b´ is applied to convert seconds into a measured linear diameter of arcseconds. The Deviation illustrates the difference between measured data and published data.

Table 5. Diameter of Jupiter using the Drift Method

Date mmddyy	**Time**[3]	**Average of Drift** in seconds	**Measured**	**Published**[6]	**Deviation** arcseconds
091500	0555	2.86s	42.9”	41.78”	1.12
092500	0607	2.9s	43.5”	43.18”	0.32
101000	0730	2.95s	44.25”	45.05”	0.8
101900	0410	3.08s	46.2”	46.15”	0.05
102200	0255	3.10s	46.5”	46.48”	0.02
111300	0535	3.23s	48.45”	48.29”	0.16

[4] All times are given in UT.

[6] *Space Explorer II Astronomy Software, V 2.1*

5.3. ANGULAR DIAMETER OF JUPITER USING THE SMALL ANGLE FORMULA

The angular diameter of Jupiter, measured in kilometers, can be calculated using measurements derived from observations provided in this paper, and applying them to the Small Angle formula below:

$D = ad / 206{,}265$

D = linear diameter of Jupiter, unknown

a = angular size in arcseconds

d = known distance to Jupiter

206,265 = number of arcseconds in a circle divided by 2π (ratio of the circumference of a circle to that circles radius)

Applying the small angle formula to observation No.4, of September 15, 2000, we first convert the diameter of Jupiter from seconds in drift to arcseconds, as explained in section 6.2. From notes taken for observation No.4, that equates to 42.9 arcseconds, represented by *a*. The distance to Jupiter, represented by *d*, is provided in Space Explorer II Astronomy Software as 4.716 AU. Therefore, the linear diameter of Jupiter is as follows:

$D = ad / 206{,}265$

$D = 42.9'' (4.716\ \text{AU}) / 206{,}265$

$D = 42.9'' (4.716\ \text{AU} \times 1.496 \times e8\ \text{km}) / 206{,}265$

$D = 42.9'' \times 7.055136 \times e8\ \text{km} / 2.063 \times e5$

$D = 3.0267 \times e5 / 2.063$

$D = 1.467 \times e5\ \text{km}$ (Baseline diameter for Jupiter is 142,984km)……..

D = linear diameter of Jupiter, unknown

a = 42.9”

d = 4.716 AU (1 AU = 1.496 x e8 km)

206,265 = number of arcseconds in a circle divided by 2π (ratio of the circumference of a circle to that circles radius)

…therefore, the angular diameter of Jupiter, which was measured at 1.467 x e5 km, would be found in Table 6, column labeled Diameter of Jupiter Measured. This is compared to the Published Diameter of Jupiter of 1.42984 x e5 km and shows a Deviation of 3,716 km. To convert the diameter from drift seconds to arcseconds, the formula $a/b = a'/b'$ was used.

Table 6. Angular diameter of Jupiter using the Small Angle formula

Date & Time[4]	**Diameter of Jupiter** (km) Measured	**Diameter of Jupiter** (km) Published[5]	**Deviation** (km)
091500, 0555	1.467e5	1.42984e5	3,716
092500, 0607	1.442e5	"	1,216
101000, 0730	1.531e5	"	10,100
101900, 0410	1.430e5	"	26
102200, 0255	1.429e5	"	94
111300, 0535	1.432e5	"	276

[4] All times are given in UT.

[5] Kaufmann & Freedman *Universe*

5.4. DISTANCE EXPRESSED IN JUPITER-DIAMETERS

To express the distance of the Galilean moons in Jupiter-diameters, I took the measured distance of the satellite in drift seconds, and divided that distance by the measured diameter of Jupiter, also in drift seconds.

To compare the measured data to published data, I applied the same method, only using the published linear diameter and distances in arcseconds and -minutes. The formula used is:

S = m/D

S = **S**atellite distance in Jupiter-diameters, (unknown).

m = distance of satellite, **m**easured either in drift seconds or linear from Baseline data.

D = **D**iameter of Jupiter. Seconds if drift method is used; linear if Baseline data is used.

For example, using measured data from observation No.4 for September 15, 2000, at 0555 UT, we see that the Ganymede was, on average, 7.0 seconds from Jupiter, while Jupiter was 2.86 seconds in diameter. Applying the formula above, Ganymede's distance from Jupiter is equivalent to 2.447 Jupiter-diameters.

S = m/D

S = 7.0s/2.86s

S = 2.447

S = distance in Jupiter-diameters (unknown)

m = 7.0s

D = 2.86s.

Table 7 expresses the distance of the satellites in Jupiter-diameters.

Table 7. Distances of Satellites from Jupiter in Jupiter-diameters

Date & Time[4]	**Satellite**[3]	**Distance of Satellite**[7] Measured	÷	**Diameter of Jupiter**[7] Measured	=	**Distance** Jupiter-Diameters	**Published** Jupiter-Diameters
091500, 0555	G	7.0s	÷	2.86s	=	2.45	2.47
	C	7.65s			=	2.64	2.59
092500, 0607	G	17.9s	÷	2.9s	=	6.17	5.97
	E	12.20s			=	4.21	4.05
	I	6.52s			=	2.25	2.20
	C	15.0s			=	5.17	4.86
101000, 0730	G	7.21s	÷	2.95s	=	2.44	2.30
	E	1.15s			=	0.39	0.33
	I	7.20s			=	2.44	2.30
	C	6.73s			=	2.28	2.10
101900, 0410	G	19.4s	÷	3.08s	=	6.41	6.24
	E	n/a			=	n/a	-
	I	7.42s			=	2.41	2.36
	C	n/a			=	n/a	-
102200, 0255	G	11.28s	÷	3.10s	=	3.64	3.59
	E	10.18s			=	3.28	3.27
	I	4.88s			=	1.57	1.55
	C	35.2s			=	11.35	11.21
111300, 0535	G	21.59s	÷	3.23s	=	6.68	6.46
	E	6.11s			=	1.89	1.84
	I	4.99s			=	1.54	1.53
	C	1.82s			=	0.56	0.56

[3] I=Io, E=Europa, G=Ganymede, C=Callisto.

[4] All times are given in UT.

[7] *Measured* distance is in drift seconds.

6. OCCULTATIONS AND ECLIPSES

Scientists have used the subtler information offered through an occultation or the reappearance of a satellite from behind the planet's limb, to hone the accuracy of their predictions. Also, the study of satellite eclipse provides more data to make the most accurate astronomical observations currently possible.

Table 8 shows six observations for occultations, transits and eclipses.

Table 8. Occultations, transits and eclipses

Satellite[3]	Event[9], **Start Time**[4], Date Published[8]	**Start Time**[4] Measured	Event[9], **End Time**[4], Date Published[8]	**End Time**[4] Measured
I	Sh, I, **0748,** 091300	**0810**	Tr, **0910**, 091300	**0907**
G	Oc, D, **0556**, 091900	**0557**	R, **0742**, 091900	**0744**
I	Sh, I, **0941**, 092000	**0943**	Tr, **1150**, 092000	not observed
G	Ec, D, **0428**, 092600	**0429**	R, **0629**, 092600	**0626**
E	Ec, D, **0414**, 101700	**0414**	Oc, R, **0843**, 101700	**0843**
I	Ec, D, **0915**, 111300	**0914**	Oc, R, **1148**, 111300	**1146**

[3] I=Io, E=Europa, G=Ganymede, C=Callisto.
[4] All times are given in UT.
[8] *Astronomical Almanac for Year 2000* and *Sky & Telescope Magazine*
[9] Oc=occultation, Ec=eclipse, Sh=shadow, Tr=transit, I=ingress, D=disappears, R=reappears

7. DISCREPANCIES IN MEASURED AND PUBLISHED DATA

Discrepancies between the **Measured** and **Published** data can be attributed to the different sources used to obtain the baseline. For example, in observation No. 21, October 22, 2000, at 0255 hours UT, the published geocentric distance given for Jupiter is:

1. 4.237 AU, Meade Space Explorer II
2. 4.236 AU, Starry Night Pro
3. 4.25 AU, Astronomical Almanac for Year 2000

Although the differences were small, the published data differed in each resource (see References).

7.1. DISCREPANCIES FOUND BY PROJECT OBSERVER: TIME MEASUREMENTS

Several discrepancies can be identified in the measurements, the first being the timer. A digital kitchen timer (no laughs please) with a displayed accuracy to one second was initially used. Only a few measurements were made using this timer. A digital stopwatch, identical to timepieces used in sports and accurate to 0.01 seconds, was used for the majority of timings.

Timings during normal observations were conducted by taking three separate measurements and then averaging the group of three. I view timing measurements of 2-seconds or less to be questionable in accuracy even though the groups of three timings, in most cases, were consistently close.

Some timings of the Galilean satellites exceeded 30 seconds; that is, some observations of Callisto required more than 30 drift-seconds to time. And to achieve the most accurate timing, each satellite was measured three times and then averaged. Callisto required between 3 and 5 minutes for three timings, allowing for the scope to be slewed back to its starting point, recording the timings, and starting the process over. During that time, the other satellites would be moving in their orbit. The published data used was from the start time for the observing run.

7.2.2. HUMAN VISION

Measurements of the FOV, using the drift method, were conducted on three separate nights. Each night the drift method was applied in the same manner as the previous night, with no deviation. Since the drift method relies on visually timing when the target star enters the eyepiece until it exits, there is an inherent margin of error associated with visual measurements. The human eye, with all its marvels, is still limited by its own acuity, and that of the human brain to interpret what it has seen.

7.2.3. OPTICS

Although the lens of the Clark 20” telescope is considered of excellent quality, especially when it was manufactured over 106 years ago, it does exhibit curvature at the edges. Under ordinary viewing situations, this presents no problem; but it does decrease the accuracy when trying to time the entry into, or exit from, the FOV of Jupiter or one of the Galilean satellites. The lens also exhibits some coma, but this is confined to the edges. Near the center of the field of view, there is little aberration.

8. THE TELESCOPE

8.1. First Light

Construction of the Chamberlin Observatory building was completed in 1891, with the telescope seeing first light in 1894. A 28-foot steel tube houses the 20-inch objective lens. Initially, the telescope was designed with a set of 500-lb weights used for the clock drive; that has since been replaced with an electric drive. The RA and declination are manually driven; hence, no electric slewing to celestial objects. The moveable part of the telescope exceeds five tons.

Alvan Clark and Sons of Cambridge, Massachusetts, United States, manufactured the 20-inch lens, which was cast in France at a cost of $11,000.

8.2. VIEWING ORIENTATION

The Clark 20” refractor projects an inverted, horizontally flipped view to the observer. With the addition of a diagonal mirror for easier viewing, North and South are oriented as such, but East and West are reversed. The eyepiece can be rotated for ease of use by the observer, but the observer must be cognizant of this, since rotation of the diagonal can easily present the object being viewed, such as Jupiter, with the appearance of being oriented opposite the correct compass axis.

During the early evenings of September, Jupiter and its Galilean satellites were low on the eastern horizon, requiring the telescope to be swung close to horizontal and placing the viewing over 30 feet above ground level. While this made for a precarious placement of the observer high on the observing platform, it also allowed earlier viewing while Jupiter was low on the horizon.

9. SUMMARY

The purpose of this project was to identify each Galilean satellite, deduce the periods of revolution of each satellite, and compare the measured data with published data. I was able to identify Io, Europa, Ganymede and Callisto by tracking them, on the average, every other night for over 2-months. Through observations and measurements I was able to deduce the approximate period of revolution for Io as 1.8 days, Europa as 3.6 days, Ganymede as 7.1 days, and Callisto as 16.6 days. The distances of the satellites from Jupiter varied, sometimes from minute to minute; other times it took days to detect variance patterns in satellites.

Finally, I compared my measured data to published data, and found that in most cases, both measurements were very close. The project was also a very gratifying and humbling experience and made me *feel akin to Galileo*!

10. REFERENCES

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