Earth's Orbital Position in the Solar System using Galactic HI Measurements

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Abstract

The Sun moves in an almost circular path around the Milky Way. The Earth orbits the Sun at one astronomical unit in an elliptical orbit. The goal of this study is to determine if HI measurements using the Haswell, Colorado 60-foot dish and the SpectraCyber system can be used to determine the Earth's orbit position in the solar system with reference to the Milky Way center. Multiple observations were taken of HI at the same galactic longitude degrees. The different Doppler shifts correspond to the Earth's position at the times of observation. A Monte-Carlo model was developed to explore the Earth orbital parameters in order to match the observed Doppler shifts with the expected model. The measured results showed that the 62-degree angle of the Earth's orbit to the galactic plane showed good correlation.

1. Introduction

The theory that the Earth's orbital position can be estimated using the HI measurements was presented at the 2018 SARA Eastern Conference in Greenbank, WV. [1] Multiple HI Doppler velocity measurements have been taken approximately one month apart at the Deep Space Exploration Society's 60-foot dish. [2] The theory is that the change in the received Doppler velocity of a HI measurement taken at the same galactic longitude along the b=0 galactic latitude, is caused by the Earth's rotation and the velocity of the Earth around the Sun. The Earth's rotation effect was minimized by taking the measurements at the meridian. This left the difference in received velocity (Vr) between monthly observations caused by the location of the Earth in orbit and its resultant velocity contribution to Vr. The measurements were mapped onto a model and the orbital position was estimated.

2. Theory

The Sun goes around the Milky Way at approximately 220 km/s at 8.5 kpc radius. The Earth rotates around the Sun in an almost circular orbit at a mean radius of 1 astronautical unit (AU). Using a pitch-roll-yaw model, the Earth's orbit is pitched at an approximate 62 degrees in the direction of motion. The roll and yaw are considered at 0 degrees. Currently the Earth is at the closest approach to the galactic center at the summer solstice (June 22, 2018), though this will change over time. Figure 1 shows the basic geometry of the Earth and galactic plane.

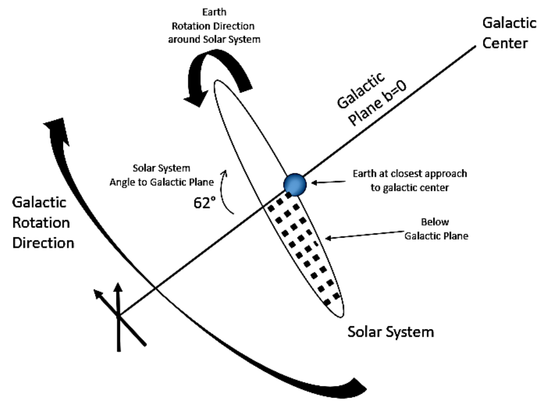


Figure 1: Earth - Galaxy Geometry

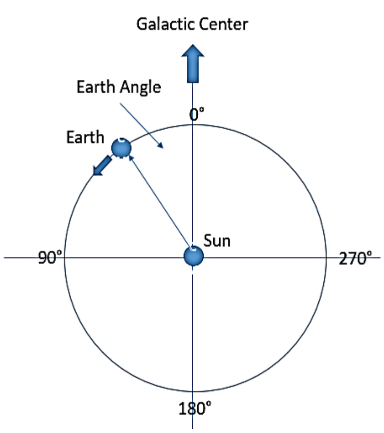
HI Doppler measurements show different velocity shifts throughout the year. The velocity change is based on the contribution of the Earth's orbital velocity to the total velocity measured (Vr).

A Monte-Carlo model was developed to show the effect of the Earth's orbital pitch to the Vr measurement. The maximum velocity contribution that the Earth's orbit can contribute is based on the velocity of the Earth around the Sun. The velocity equation for an object orbiting the Sun is:

$$V = \sqrt{\mu\left(\frac{2}{r} - \frac{1}{a}\right)} \qquad (1)$$

r: radius of Earth around Sun (aphelion 152.1x10^6 km, perihelion 147.1x10^6 km)
a: Semimajor axis (149.6x10^6 km)
µ: Sun's gravitational constant (1.32712440018x$10^{20}$$m^3s^{-2}$)

At aphelion V=29.29 km/s, at perihelion V=30.29 km/s. So, depending on the Earth's orientation to the observation, this provides the maximum velocity contribution to Vr. Figure 2 shows the Earth angle relative to the galactic center. Based on this picture the Monte-Carlo model produces the velocity contribution to Vr of the Earth as it orbits the Sun.



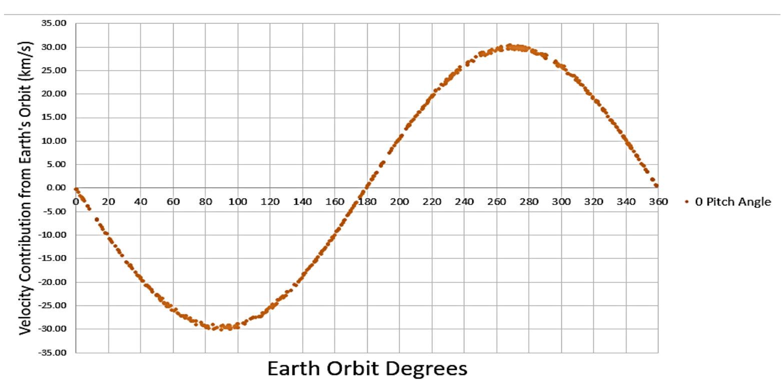


Figure 2 Earth Angle and Velocity Change Relative to the Galactic Center

The solar system is at a pitch angle of approximately 62 degrees. The contribution to Vr now gets adjusted by cos (pitch angle) as shown in figure 3. This reduces the Earth's velocity contribution to approximately ±15 km/s.

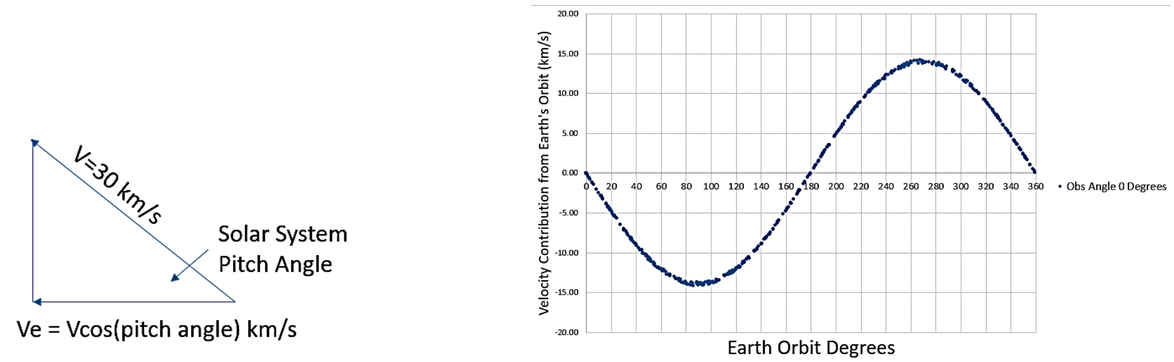


Figure 3: Effect of Pitch Angle on Velocity

Another primary parameter is the observation angle of the HI source in relationship to the galactic center. The observations were made in galactic quadrant 1 which is defined as 0-90 degrees galactic longitude from the galactic center as observed from Earth. The observation angle acts like a phase change to the sinusoid model. Figure 4 shows the shift in Earth angle based on different galactic observation angles. Note that this is assuming the 62-degree solar system pitch angle.

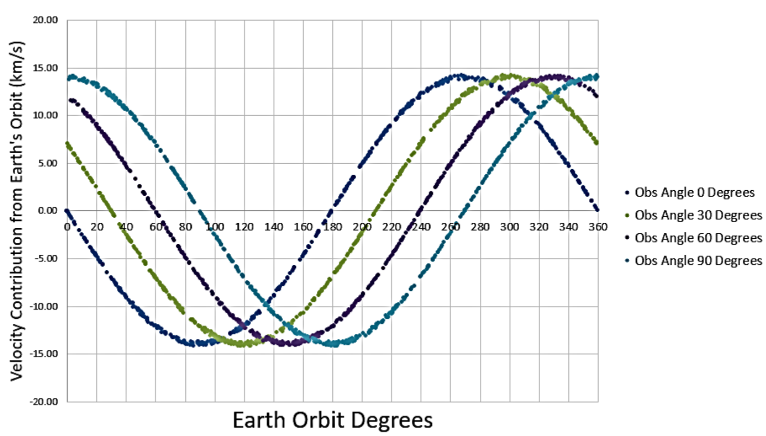


Figure 4: Galactic Longitude Observation Angle effect on Vr

The Monte-Carlo model was used to develop the appropriate plots for the HI observations made.

3. Observations

The observations of galactic HI were conducted with the Deep Space Exploration Society's (DSES) 60-foot radio telescope located near Haswell, Colorado [2]. (figure 5)

Figure 5: DSES 60-foot Dish and Communications Trailer

A SpectraCyber 1 [3] was used to receive and collect the data. The current observations were taken on 10/20/18, 11/17/18, 12/14/18 and 1/18/19. (figure 6)

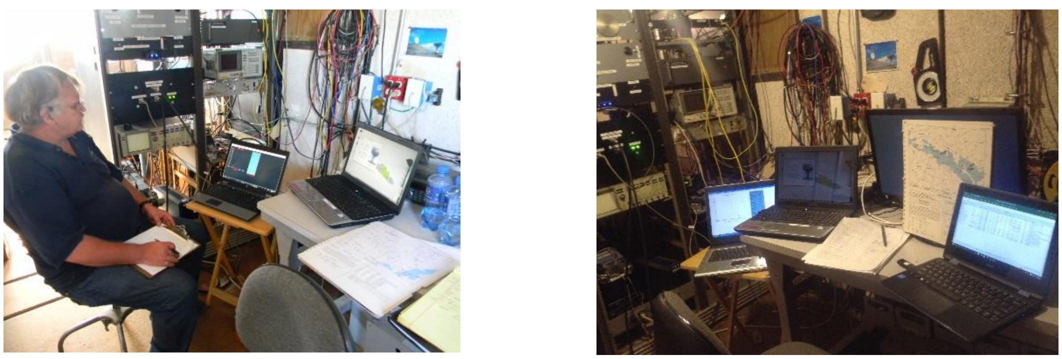
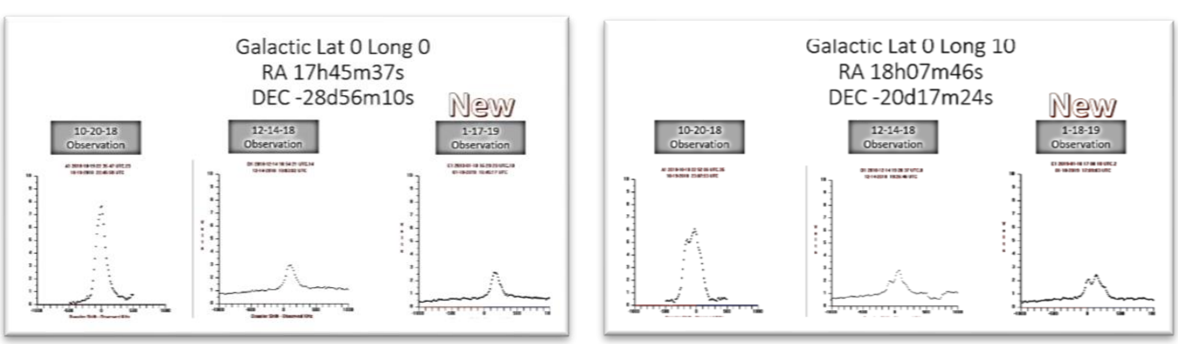
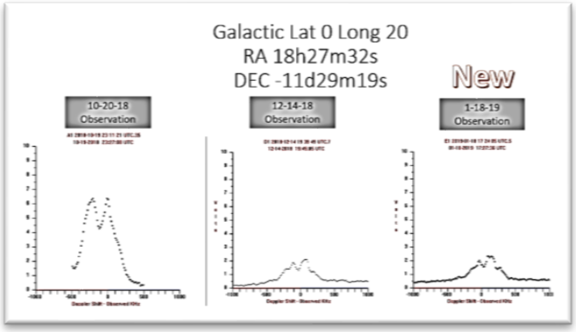


Figure 6: Operating Station in Communications Trailer

The SpectraCyber outputs are shown in figure 7. Note that the differences in signal amplitude are based on gain setting differences in order to get the voltage levels within the 10-volt maximum of the SpectraCyber. This did not affect the frequency measurements.

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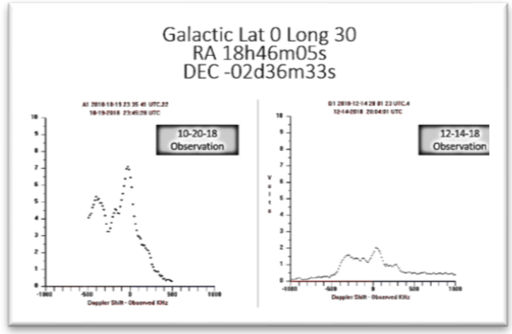
RA 18h27m32s
DEC -11d29m19s
New
10-20-18 Observation
12-14-18 Observation
1-18-19 Observation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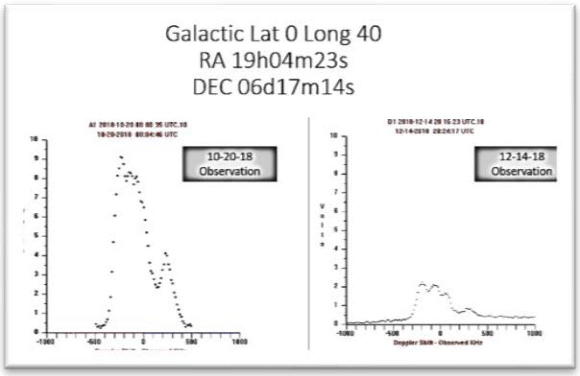
DEC -02d36m33s
10-20-18 Observation
12-14-18 Observation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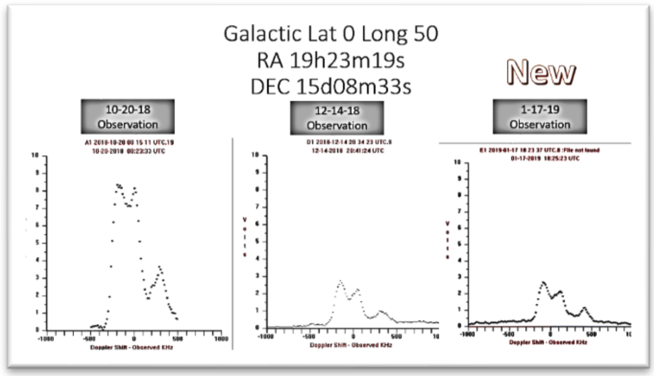
RA 19h04m23s
DEC 06d17m14s
10-20-18 Observation
12-14-18 Observation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DEC 15d08m33s
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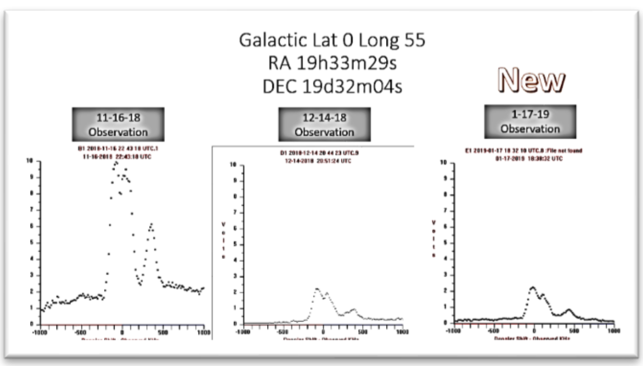
10-20-18 Observation
12-14-18 Observation
1-17-19 Observation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DEC 19d32m04s
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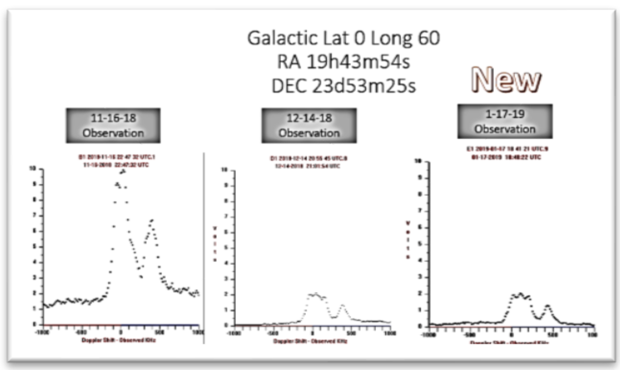
11-16-18 Observation
12-14-18 Observation
1-17-19 Observation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RA 19h43m54s
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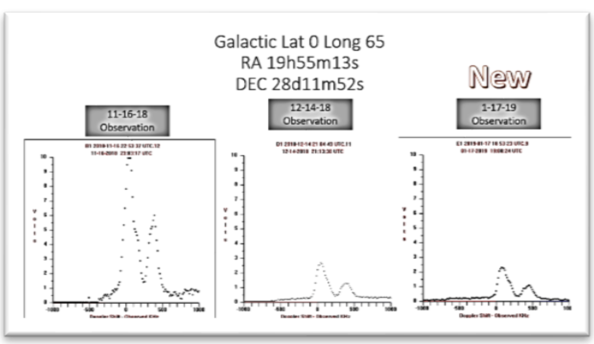
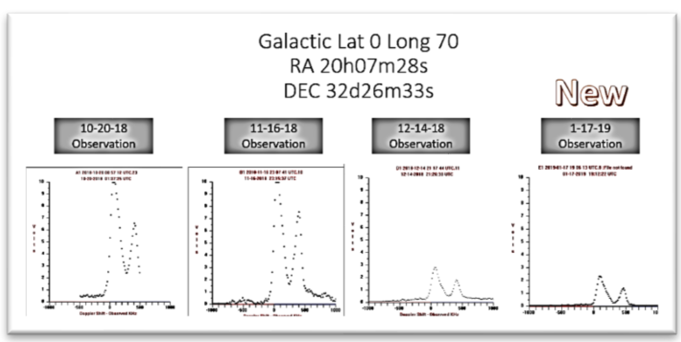
New
11-16-18 Observation
12-14-18 Observation
1-17-19 Observation


Galactic Lat 0 Long 65
RA 19h55m13s
DEC 28d11m52s
New
11-16-18 Observation
12-14-18 Observation
1-17-19 Observation


Galactic Lat 0 Long 70
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DEC 32d26m33s
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11-16-18 Observation
12-14-18 Observation
1-17-19 Observation

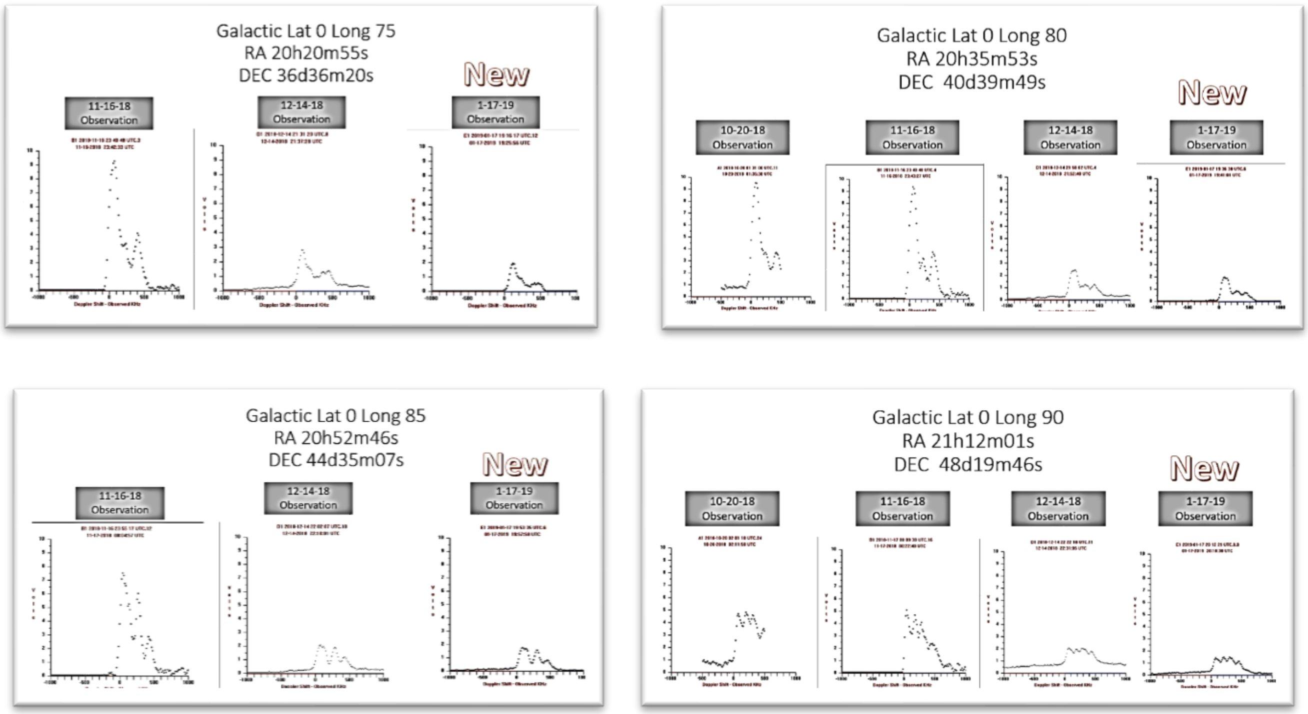

Figure 7: Hi Observations

The frequency for the left peak of each plot was measured and the velocity was calculated using the formula.

$$V = \frac{f_{base} - f_{measured}}{f_{base}} x\ c \qquad (2)$$

f_{base}: HI base frequency (1,420.405,751 MHz)
$f_{measured}$: measured frequency of observation
c: speed of light in vacuum (299,790,000 m/s)

The results for each measurement are shown in table 1.

Galactic Long (Deg)	Most Neg Freq (Hz)	Measured Velocity Vr (km/Second)	Observation Date
0	1,420,405,751	0.0	10/20/2018
0	1,420,405,851	21.1	12/14/2018
0	1,420,405,891	29.5	1/18/2019
2	1,420,405,876	26.4	1/18/2019
5	1,420,405,786	7.4	12/14/2018
5	1,420,405,861	23.2	1/18/2019
7	1,420,405,876	26.4	1/18/2019
10	1,420,405,601	-31.7	10/20/2018
10	1,420,405,666	-17.9	12/14/2015
10	1,420,405,756	1.1	1/18/2019
12	1,420,405,891	29.5	1/18/2019
15	1,420,405,651	-21.1	12/14/2015
15	1,420,405,831	16.9	1/18/2019
20	1,420,405,541	-44.3	10/20/2018
20	1,420,405,621	-27.4	12/14/2015
20	1,420,405,711	-8.4	1/18/2019
25	1,420,405,381	-78.1	12/14/2015
30	1,420,405,346	-85.5	10/20/2018
30	1,420,405,441	-65.4	12/14/2018
35	1,420,405,576	-36.9	12/14/2018
40	1,420,405,511	-50.7	10/20/2018
40	1,420,405,546	-43.3	12/14/2018
45	1,420,405,561	-40.1	12/14/2018
45	1,420,405,651	-21.1	12/14/2018
50	1,420,405,556	-41.2	10/20/2018
50	1,420,405,591	-33.8	12/14/2018
50	1,420,405,651	-21.1	1/18/2019
55	1,420,405,671	-16.9	11/17/2018
55	1,420,405,651	-21.1	12/14/2018
55	1,420,405,726	-5.3	1/18/2019

Galactic Long (Deg)	Most Neg Freq (Hz)	Measured Velocity Vr (km/Second)	Observation Date
60	1,420,405,766	3.2	10/20/2018
60	1,420,405,701	-10.6	11/17/2018
60	1,420,405,711	-8.4	12/14/2018
60	1,420,405,771	4.2	1/18/2019
65	1,420,405,771	4.2	11/17/2018
65	1,420,405,786	7.4	12/14/2018
65	1,420,405,816	13.7	1/18/2019
70	1,420,405,791	8.4	10/20/2018
70	1,420,405,771	4.2	11/17/2018
70	1,420,405,801	10.6	12/14/2018
70	1,420,405,831	16.9	1/18/2019
75	1,420,405,821	14.8	11/17/2018
75	1,420,405,831	16.9	12/14/2018
75	1,420,405,861	23.2	1/18/2019
80	1,420,405,841	19.0	10/20/2018
80	1,420,405,806	11.6	11/17/2018
80	1,420,405,801	10.6	12/14/2018
80	1,420,405,831	16.9	1/18/2019
85	1,420,405,791	8.4	11/17/2018
85	1,420,405,816	13.7	12/14/2018
85	1,420,405,831	16.9	12/14/2018
90	1,420,405,826	15.8	10/20/2018
90	1,420,405,791	8.4	11/17/2018
90	1,420,405,801	10.6	12/14/2018
90	1,420,405,831	16.9	1/18/2019

Table 1: Vr Observation Calculations

4. Analytical Technique

The analysis technique developed was to curve fit the observation Vr data onto a model that included the pitch angle, observation longitude angles, and the Earth radius velocity.

The first step is to use Monte-Carlo Model to produce a velocity vs. Earth orbit angle curve for each longitude angle measured. The expected pitch angle of the Earth's orbit to the galactic plane was added. Both the longitude angles and the pitch angle were spread to account for uncertainties. This was simply done by adjusting the minimum and maximum values in the Monte-Carlo model. The pitch angle selected between 60.2 degrees [4] and 63 degrees [5]. The longitude measurement angle was ±1 degree based on antenna beamwidth and pointing error. (figure 8)

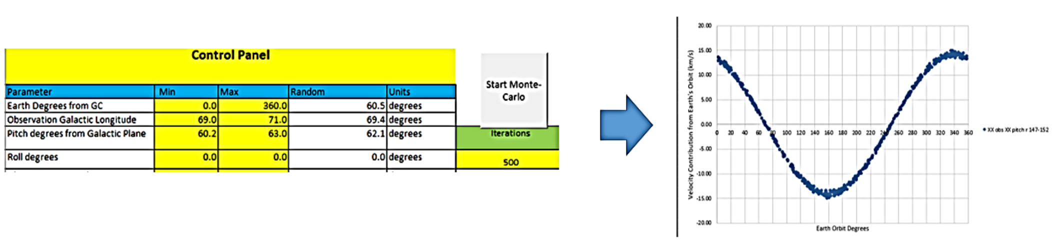

Figure 8: Monte-Carlo Input and Output for 70 Degree Galactic Longitude Measurement

Step two was to plot the VR measurements and visually curve fit them to the plots. Another model was developed that allowed for the Vr measurements to be plotted on the Monte-Carlo curve. (Figure 9)

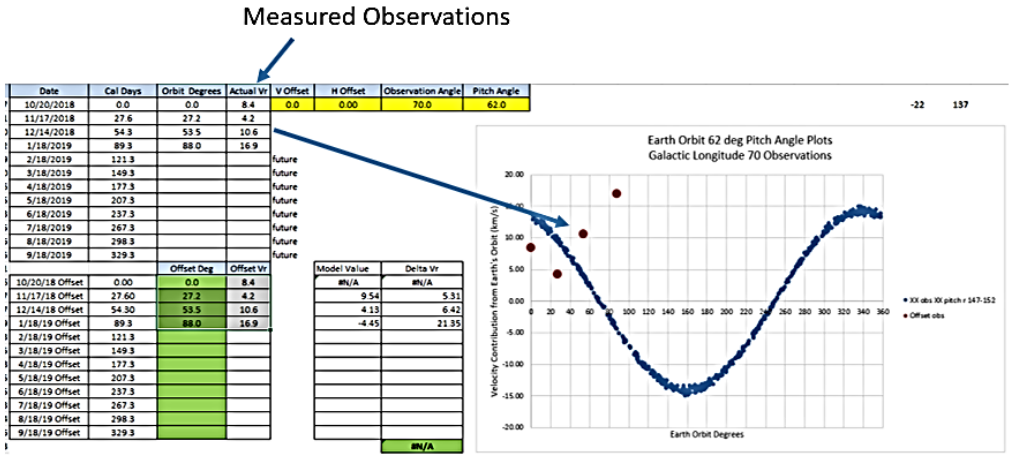

Figure 9: Measured Vr Observations Plotted on Curve

Step 3 is to shift the raw measured values horizontally and vertically in order to get the most accurate curve fit. An added tool was developed to compare the shifted measurements with the curve and provide an indicator of the least difference between the values. (figure 10)

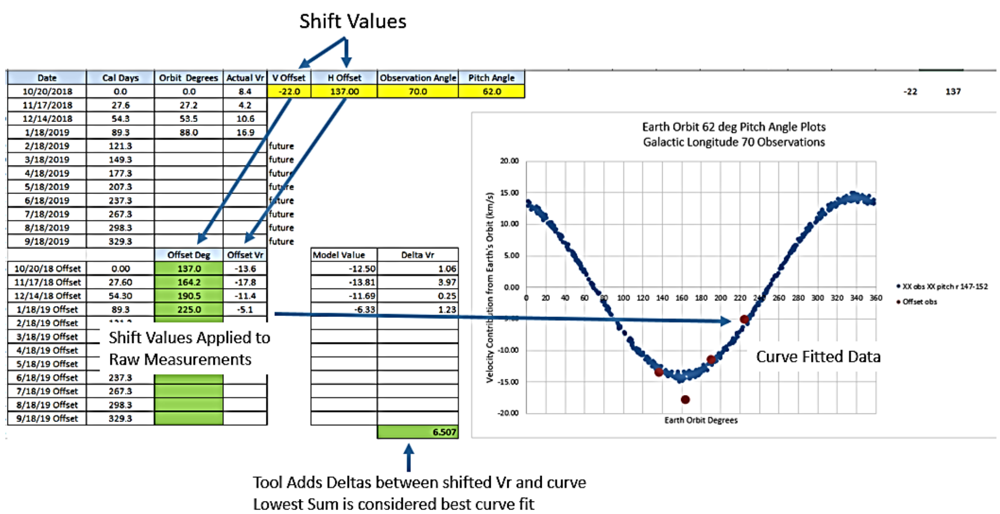

Figure 10: Curve Fitting the Raw Vr onto Curves

This technique was conducted on the four days of observations. Note that the more observation days measured should provide more data to get a good curve fit. (figures 11-24)

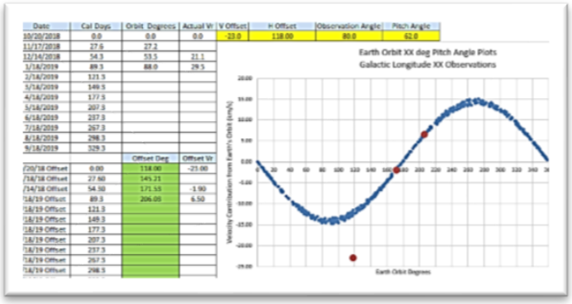

Figure 11: 0 Degrees Longitude Observation Angle

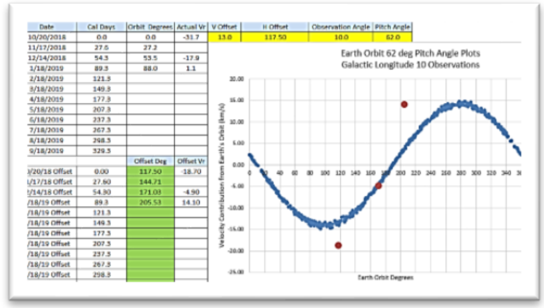

Figure 12: 10 Degrees Longitude Observation Angle

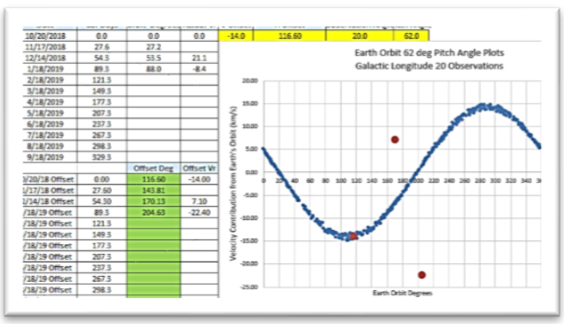

Figure 13: 20 Degrees Longitude Observation Angle

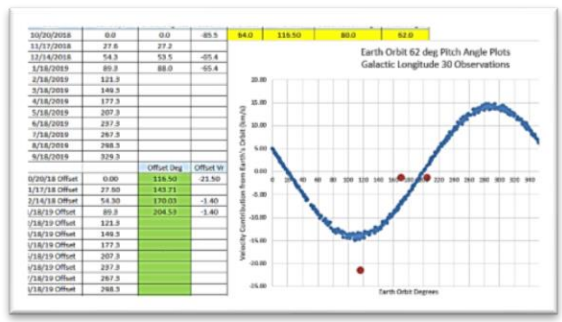

Figure 14: 30 Degrees Longitude Observation Angle

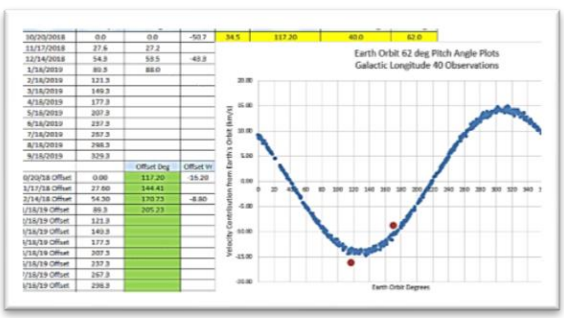

Figure 15: 40 Degrees Longitude Observation Angle

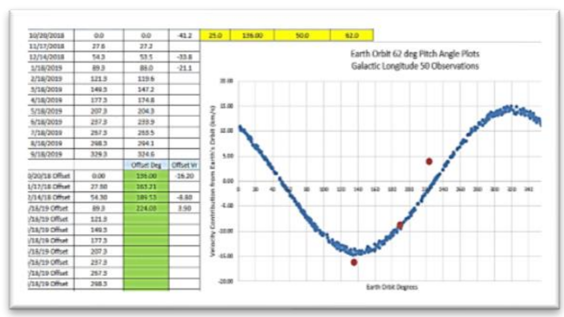

Figure 16: 50 Degrees Longitude Observation Angle

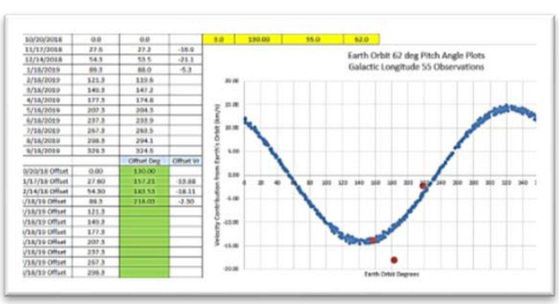

Figure 17: 55 Degrees Longitude Observation Angle

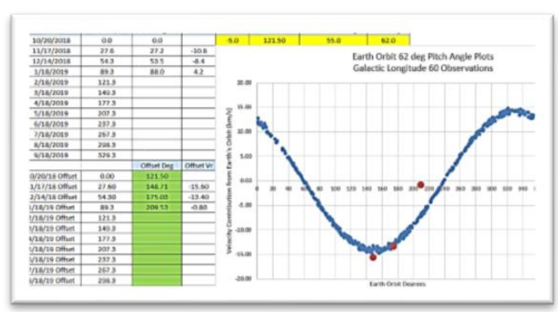

Figure 18: 60 Degrees Longitude Observation Angle

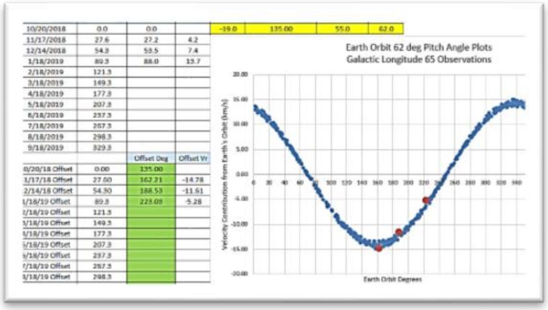

Figure 19: 65 Degrees Longitude Observation Angle

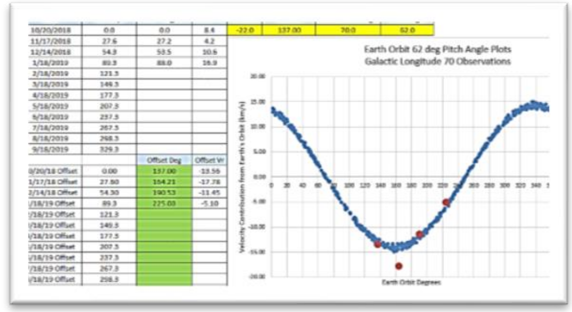

Figure 20: 70 Degrees Longitude Observation Angle

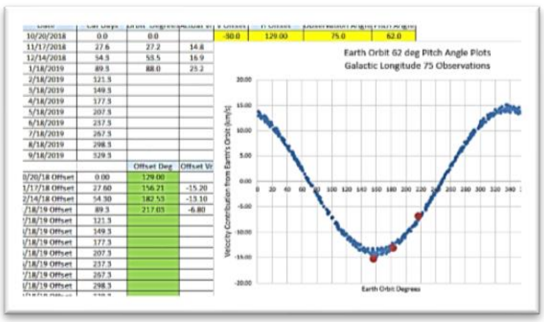

Figure 21: 75 Degrees Longitude Observation Angle

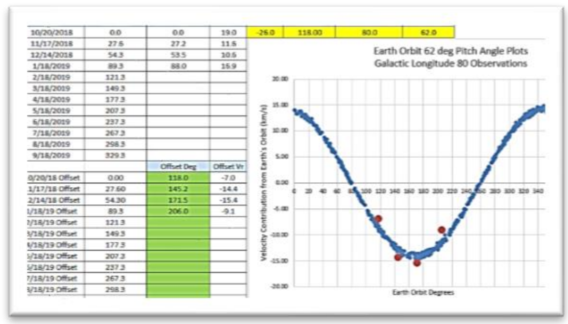

Figure 22: 80 Degrees Longitude Observation Angle

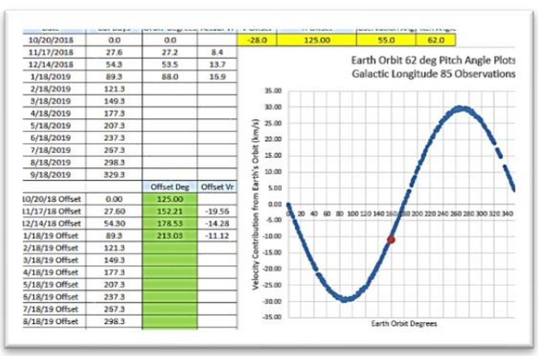

Figure 23: 85 Degrees Longitude Observation Angle

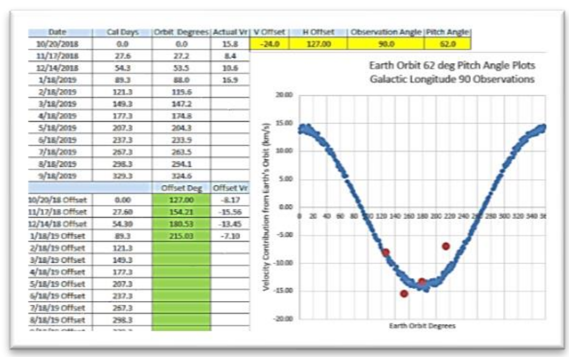

Figure 24: 90 Degrees Longitude Observation Angle

The curve fitted results were correlated and the average value of the Earth angle was calculated for each observation day in order to come up with the best Earth position on that day. (table 2)

Pitch Angle	Galactic Longitude Observed	Earth Degrees at 10/20/2018	Earth Degrees at 11/18/18	Earth Degrees at 12/14/18	Earth Degrees at 1/18/19
62	0	118.0	145.2	171.5	206.0
62	10	117.5	144.7	171.0	205.5
62	20	116.6	143.8	170.1	204.6
62	30	116.5	143.7	170.0	204.5
62	40	117.2	144.4	170.7	205.2
62	50	136.0	163.2	189.5	224.0
62	55	130.0	157.2	183.5	218.0
62	60	121.5	148.7	175.0	209.5
62	65	135.0	162.2	188.5	223.0
62	70	137.0	164.2	190.5	225.0
62	75	129.0	156.2	182.5	217.0
62	80	118.0	145.2	171.5	206.0
62	85	125.0	152.2	178.5	213.0
62	90	127.0	154.2	180.5	215.0
	Average	124.6	151.8	178.1	212.6
	STDev ±	7.7	7.7	7.7	7.7

Table 2: Curve Fit Results

5. Visualizing the Results

The results can be represented like a clock face with noon being the direction of the galactic center. The Earth is rotating counter-clockwise. Based on these results, the Earth is now starting back toward the direction of the galactic center. (figure 25)

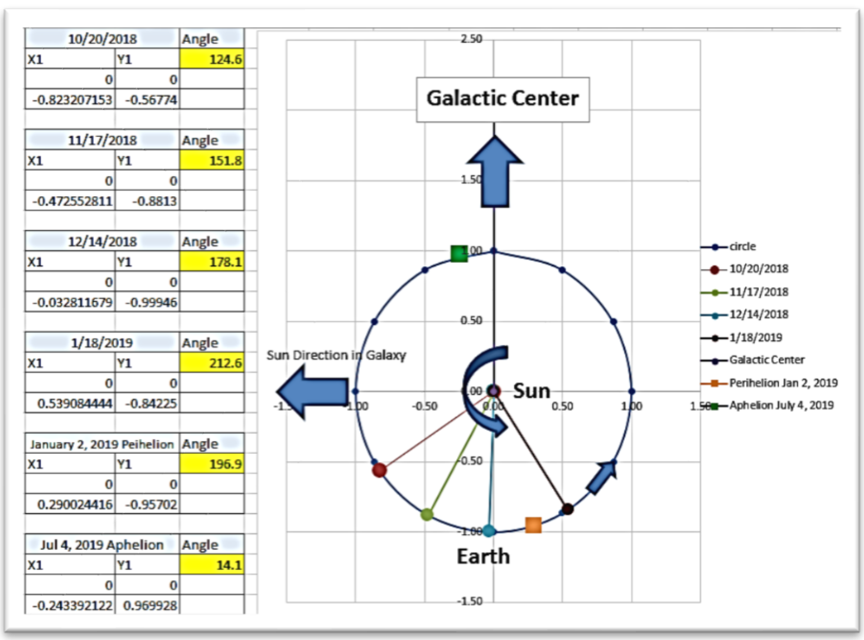

Figure 25: Average Earth Position in Orbit for each Observation Day

6. Error Analysis

Error Analysis is based on the effect of the frequency, Ro, Vo, and pointing ranges on R and V(R). The estimates were made by substituting the error ranges into the calculations and determining the change of each result [6]. The results of this analysis are shown in table 3.

Parameter	Value	±Error	Units
Vo	238	14	km/s
Ro	8.05	0.45	Kpc
frequency	1,420,405,751	10	hz
Pointing		0.17	deg
Beamwidth		0.86	deg
Total Pointing Error (X-Axis)		**1.03**	**deg**
V (R) Error (Ro)		0.00	km/s
V(R) Error (pointing)		2.10	km/s
V(R) Error (Vo)		12.1	km/s
V(R) Error (freq)		2.00	km/s
Total V(R) Error		**16.20**	**km/s**
Percentage Error (Y-Axis)	Based on 243.3 km/sec	**6.7%**	**km/s**

Table 3: Error Analysis

The results are close to expected values; however, the curve fitting approach should get more accurate with more observations. Figure 26 shows the galactic longitude 0 measurements overlaid on the model. Note that the measurements indicate that the Earth was the farthest from the galactic center on approximately 12/14/18.

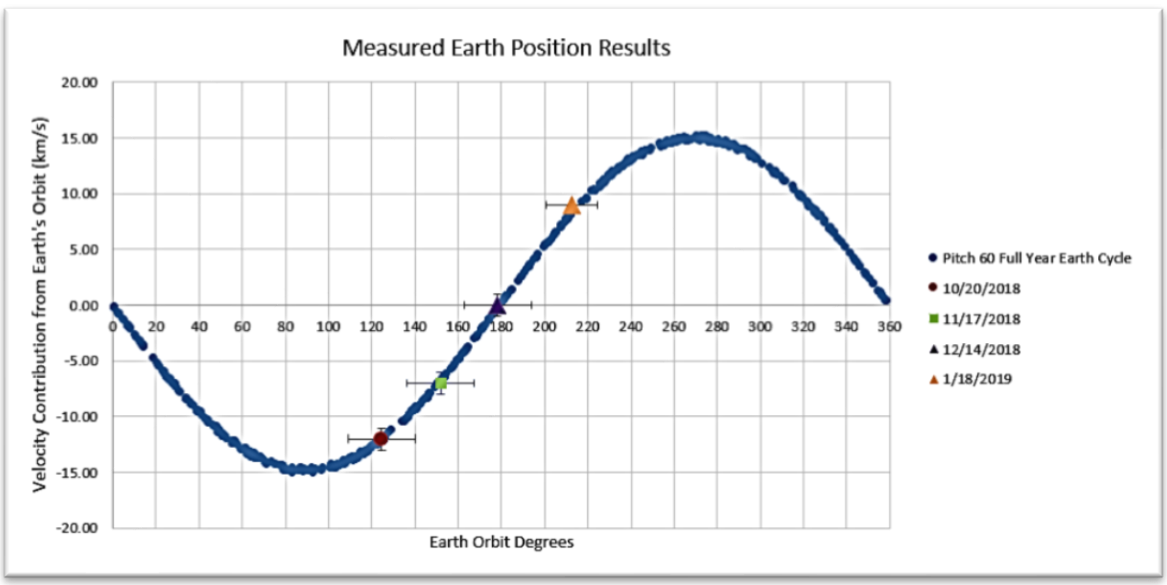

Figure 26: Observation Day Earth Positions with Error Ranges Plotted on a 0 galactic Longitude Observation Angle Curve

7. Estimating the Date of the Earth's Closest Approach to the Galactic Center

The Earth's closest approach to the galactic center can now be estimated using the Earth degrees and the observation dates. The Earth calendar days are therefore:

$$Calendar\ Days = \frac{365\ \text{Calendar Days}}{360\ Earth\ Orbit\ Degrees}\ (Measured\ Earth\ Orbit\ Degrees)\ \ (2)$$

The results indicate that the average Earth angle from the galactic center on 1/18/19 was 212.6 degrees. This is equivalent to 215.6 calendar days since the galactic center closest approach. This puts the Earth's closes approach to the galactic center at June 16, 2019. The standard deviation of the data range is shown in figure 23 as 7.7 degrees or 7.8 calendar days. The range of closes approach is therefore between 7/9/19 and 7/23/19. The next expected galactic center closest approach is June 21, 2019 [7] which corresponds to the North American summer solstice. The HI measurement method brackets the expected closest approach and appears to be a viable approach to track the Earth's position around the solar system.

8. Summary

The use of galactic HI measurements to estimate the Earth's position around the Sun are promising. The results show good fit of the Vr measurements to the Monte-Carlo models. The position of the Earth in the model, based on HI Doppler measurements, appears to be properly moving in its orbit. The data supports the Earth's orbit having a pitch angle of between 60.2 and 63 degrees. Future observations need to be made to get the maximum and minimum Doppler readings over a year. The observations at galactic latitude b=0, do not provide enough information to determine the roll and yaw values of the Earth's orbit. Future measurements at different galactic latitudes may provide the need data to model roll and yaw.

This technique is excellent for educational purposes. It provides the student with an experiment that uses real radio astronomy data to show the position of the Earth in the solar system. Further refinement of the technique may also lead to a detailed estimate of the Earth's orbital parameters.

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