Earth's Orbital Position
Using Galactic HI Interstellar Medium Velocity Measurements

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Abstract

The use if neutral hydrogen (HI) velocity measurements have been used to map the rotation rate of the Sun around the center of the Milky Way. By mapping the location of the HI interstellar medium (ISM) clouds, the predicted received velocity can be obtained at any point in the galaxy. This enables the use of the HI ISM velocity measurements to be used to determine the position of the HI receiver. The position of the Earth in the Milky Way can therefore be mapped using the HI measurements. The Earth's orbital path around the Sun can therefore be tracked over time. This orbital geometry includes the Doppler corrections for the Earth's rotation and orbital path around the Sun as well as the rotational velocity of the Sun and HI ISM sources.

Introduction

The Sun's rotation rate around the center of the Milky Way has been well documented (Katushkina, Provornikova, & Izmodenov, 2013) (Lockman, 2002) (Reid & Dame, 2016) (Sofue, 2017). A corollary to this analysis has provided the galactic positions of HI interstellar matter (HI ISM) sources in the galaxy. The use of HI velocity measurements for galactic navigation has been shown in Russel 2018. (Russel, 2018)

The received velocity contribution consists of the line-of-site velocity contribution of the HI ISM source and the Earth based measuring system. The Earth based system velocity consists of the rotation of the Earth and the orbital speed of the Earth around the Sun. If the Earth based measurement is made at the local meridian, then the Earth rotation velocity is zero. Therefore, the Earth orbital velocity becomes the major contributor.

This paper develops a model for the velocity contribution of the Earth's orbit to the HI ISM velocity measurements. This model should allow for an estimate of the Earth's orbital position using HI ISM velocity measurements throughout the year.

Theory

The Earth's rotation around the Sun should provide a measurable change in Doppler rate for HI ISM measurements dependent on its position in in the Sun's orbit relative to the observed object. By baselining the HI ISM velocity measurements, the velocities for an object should predictably change throughout the year in relation to the Earth's orbital position. Figure 1 shows the basic geometry of this hypothesis.

Measuring the HI ISM received velocity consists of many velocity components. (Figure 1)

- (A) Position and time of observation on Earth's surface
- (B) Rotation rate of Earth
- (C) Orbital path and rate of Earth around Sun
- (D) Rotation rate of Sun around the galactic center
- (E) Relative geometry of Sun and HI ISM source positions
- (F) Rotation rate of HI ISM source around the galaxy

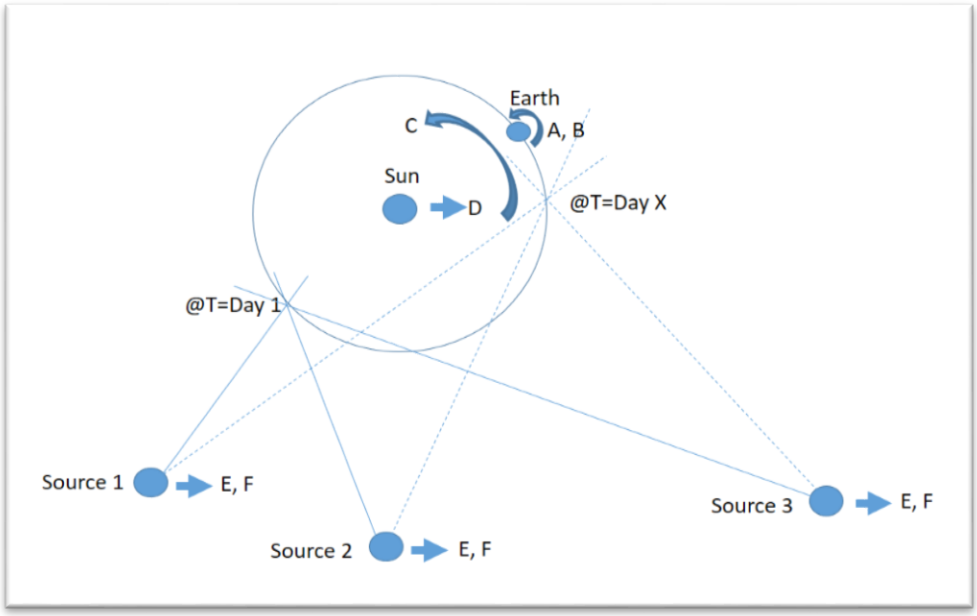

Figure 1: Velocity Contributions of the HI ISM Source Measurements

Position and time of observation on Earth and the Earth's rotation

The measured Doppler velocity can be affected by the location and time of the observation. For ease of calculations, measurements of the HI ISM should be taken at the observer's local meridian. This effectively minimizes the Earth's rotation Doppler contribution.

Orbital Path and Rate of Earth around the Sun

The Earth's orbital velocity around the Sun can be estimated using the formula:

$$V = \sqrt{\frac{GM}{r}}$$

Gravitational Constant (G) =6.667x10^{-20} $km^3/(kg\ s^2)$

Mass of Sun (M) = 1.9885 x 10^{30} kg

Mean Radius of Earth around Sun (r) = 1 AU = 149,598,000 km

V = 29.78 km/s

The inclination of the Earth's orbit to the galactic plane is i=60.2°. (Figure 2)

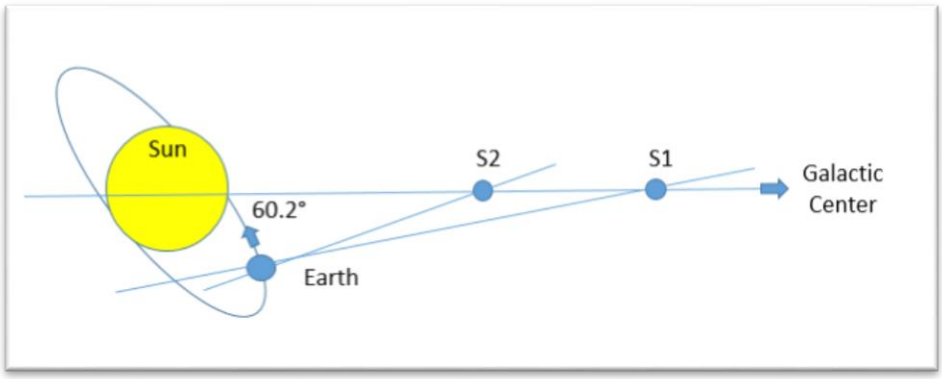

Figure 2: Sun – Galactic Center plane inclination

The maximum velocity of the Earth toward the galactic center is therefore: (figure 3)

$$V = 29.8\frac{km}{s}\cos(60.2°) = 14.8\ km/s$$

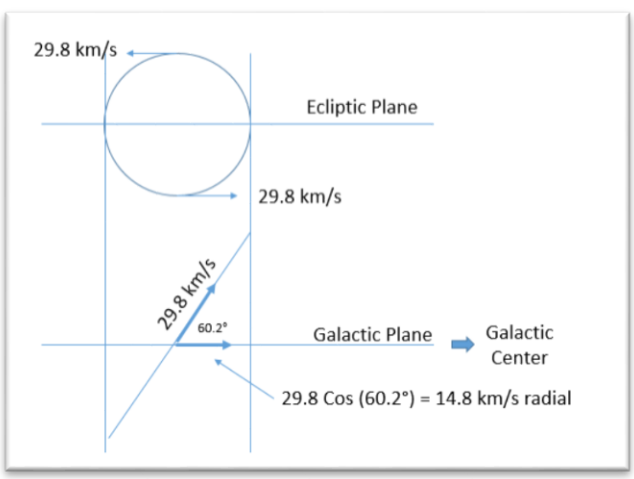

Figure 3: Radial Velocity Calculation

Rotation Rate of Sun Around the Galactic Center

The Milky Way galaxy is divided into four quadrants as viewed from the top (figure 4). The galactic coordinates are based on the Sun centered longitude which is measured from 0-360° along the long axis of the galaxy. The latitude coordinates are perpendicular to the plane measured from 0-90°.

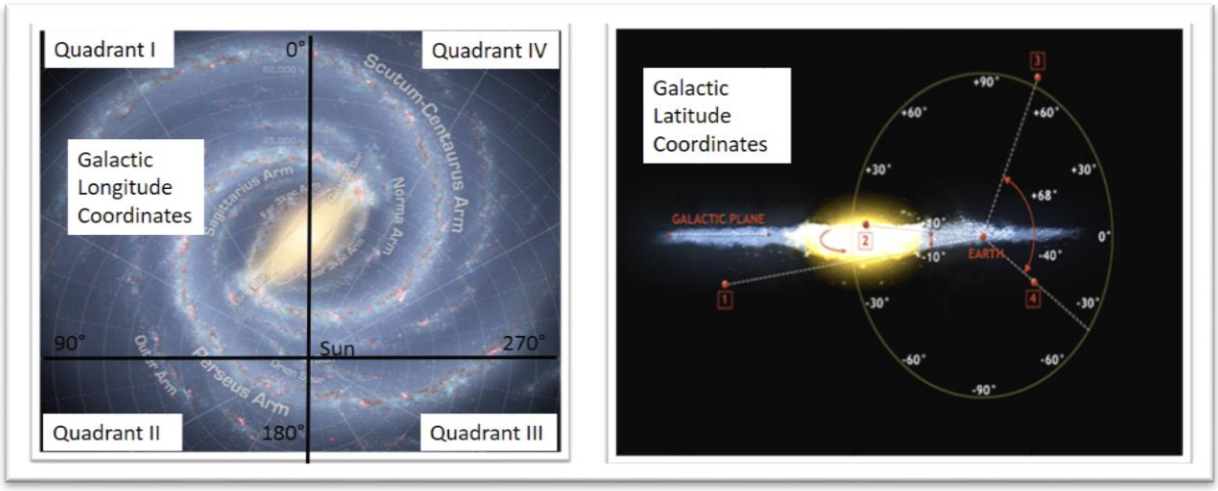

Figure 4: Galactic Coordinates (Charting the Milky Way From the Inside Out, 2015) (Galactic Navigation, n.d.)

Rotation Rate Geometry

Radio telescopes measure the Doppler shift of the HI line of a HI ISM. This Doppler shift is a combination of the velocity components of the Earth-Sun system and the HI ISM cloud along the line of site. One technique to analyze the HI measurements is referred to as the tangent method.

The tangent method uses the geometry in figure 5 to calculate the velocity of the Sun around the galaxy (Vo), where R is the distance of the HI ISM from the galactic center and Ro is the distance of the Sun from the galactic center.

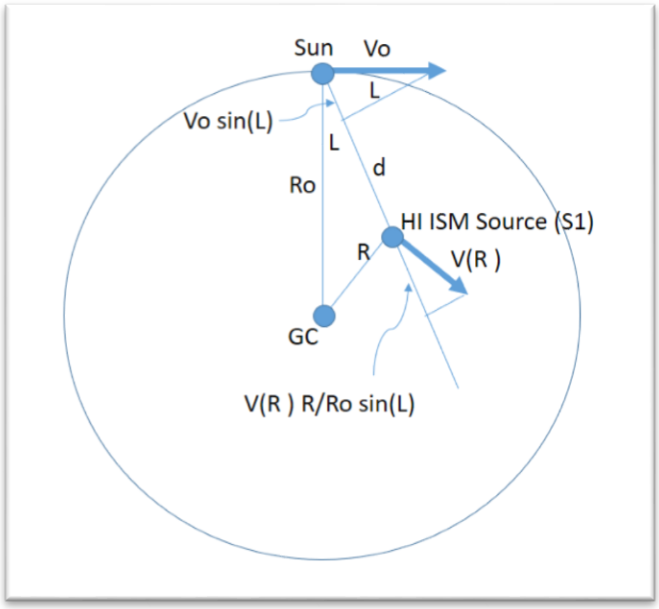

Figure 5: Rotation Rate Geometry (Rudolph) (Sofue, 2017)

Vo: Sun's velocity around galactic center: (220 Km/second)
Ro: Distance of the Sun to the Galactic center (8.5 Kpc; 1 pc = 3.09 x 10^{10} meters)
Distance Reference: Ro (Eisenhauer, et al., 2003) 8.0 +- 0.4kpc
L: Galactic Longitude
V(R): Velocity of a cloud of gas related to R distance from the galactic center
R: Cloud distance to Galactic center, Galactic rotation radius
d: Clouds distance to the Sun

For R< Ro, the measured velocity, Vr, is calculated as (Sofue, 2017):

$$Vr = V(R)\frac{Ro}{R}sin(L) + Vo\ sin(L)$$

HI Line Doppler Data

The rotation rate can be calculated using the tangent method if the HI Doppler velocity is measured in either quadrant I or IV. In quadrant I, the frequency with the highest velocity is used as the closest source to the galactic center. This galactic model (Rotation Rate Simulator and Database) retrieves HI measured data and displays it based on galactic latitude and longitude as shown in figure 6.

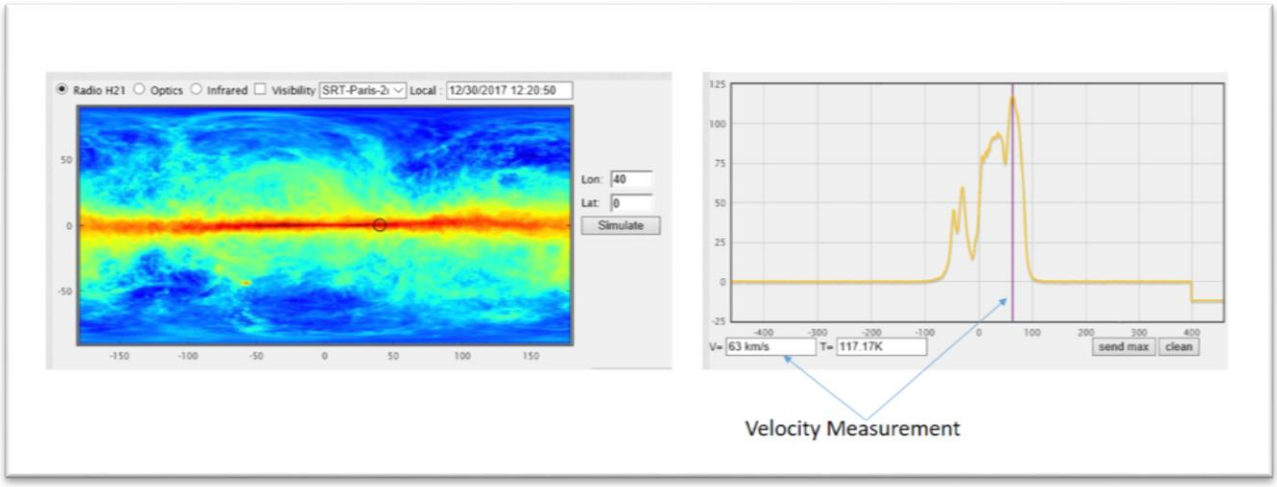

Figure 6: Database Output (Rotation Rate Simulator and Database)

The Earth is closest to the galactic center near the summer solstice on June 23. The approximate orbital position of the Earth relative to the galactic center can be plotted. (figure 7)

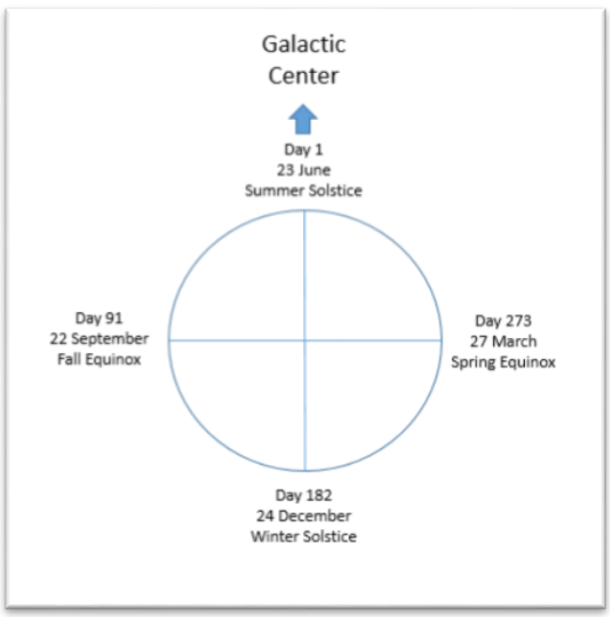

Figure 7: Earth's Approximate Yearly Orbital Position Relative to Galactic Center

Using the Earth's maximum velocity towards the galactic center, the Earth's radial velocity can be calculated for different positions of the Earth's orbit for HI ISM sources at different galactic longitudes. Figure 8 shows the results of these calculations for selected galactic longitudes in galactic quadrant I.

Date	Days from Summer Solstice (22 June)	Earth Deg from GC		Velocity Long 0	Velocity Long 10	Velocity Long 20	Velocity Long 30	Velocity Long 40	Velocity Long 50	Velocity Long 60	Velocity Long 70	Velocity Long 80
22-Jun	0.0	0		0.0	-2.5	-5.0	-7.3	-9.4	-11.2	-12.7	-13.8	-14.4
2-Jul	10.1	10		2.5	0.0	-2.5	-5.0	-7.3	-9.4	-11.2	-12.7	-13.8
12-Jul	20.3	20		5.0	2.5	0.0	-2.5	-5.0	-7.3	-9.4	-11.2	-12.7
22-Jul	30.4	30		7.3	5.0	2.5	0.0	-2.5	-5.0	-7.3	-9.4	-11.2
30-Jul	40.6	40		9.4	7.3	5.0	2.5	0.0	-2.5	-5.0	-7.3	-9.4
9-Aug	50.7	50		11.2	9.4	7.3	5.0	2.5	0.0	-2.5	-5.0	-7.3
19-Aug	60.8	60		12.7	11.2	9.4	7.3	5.0	2.5	0.0	-2.5	-5.0
30-Aug	71.0	70		13.8	12.7	11.2	9.4	7.3	5.0	2.5	0.0	-2.5
9-Sep	81.1	80		14.4	13.8	12.7	11.2	9.4	7.3	5.0	2.5	0.0
19-Sep	91.3	90		14.7	14.4	13.8	12.7	11.2	9.4	7.3	5.0	2.5
29-Sep	101.4	100		14.4	14.7	14.4	13.8	12.7	11.2	9.4	7.3	5.0
9-Oct	111.5	110		13.8	14.4	14.7	14.4	13.8	12.7	11.2	9.4	7.3
19-Oct	121.7	120		12.7	13.8	14.4	14.7	14.4	13.8	12.7	11.2	9.4
29-Oct	131.8	130		11.2	12.7	13.8	14.4	14.7	14.4	13.8	12.7	11.2
8-Nov	141.9	140		9.4	11.2	12.7	13.8	14.4	14.7	14.4	13.8	12.7
19-Nov	152.1	150		7.3	9.4	11.2	12.7	13.8	14.4	14.7	14.4	13.8
29-Nov	162.2	160		5.0	7.3	9.4	11.2	12.7	13.8	14.4	14.7	14.4
9-Dec	172.4	170		2.5	5.0	7.3	9.4	11.2	12.7	13.8	14.4	14.7
19-Dec	182.5	180		0.0	2.5	5.0	7.3	9.4	11.2	12.7	13.8	14.4
29-Dec	192.6	190		-2.5	0.0	2.5	5.0	7.3	9.4	11.2	12.7	13.8
8-Jan	202.8	200		-5.0	-2.5	0.0	2.5	5.0	7.3	9.4	11.2	12.7
18-Jan	212.9	210		-7.3	-5.0	-2.5	0.0	2.5	5.0	7.3	9.4	11.2
29-Jan	223.1	220		-9.4	-7.3	-5.0	-2.5	0.0	2.5	5.0	7.3	9.4
8-Feb	233.2	230		-11.2	-9.4	-7.3	-5.0	-2.5	0.0	2.5	5.0	7.3
18-Feb	243.3	240		-12.7	-11.2	-9.4	-7.3	-5.0	-2.5	0.0	2.5	5.0
28-Feb	253.5	250		-13.8	-12.7	-11.2	-9.4	-7.3	-5.0	-2.5	0.0	2.5
10-Mar	263.6	260		-14.4	-13.8	-12.7	-11.2	-9.4	-7.3	-5.0	-2.5	0.0
20-Mar	273.8	270		-14.7	-14.4	-13.8	-12.7	-11.2	-9.4	-7.3	-5.0	-2.5
30-Mar	283.9	280		-14.4	-14.7	-14.4	-13.8	-12.7	-11.2	-9.4	-7.3	-5.0
10-Apr	294.0	290		-13.8	-14.4	-14.7	-14.4	-13.8	-12.7	-11.2	-9.4	-7.3
20-Apr	304.2	300		-12.7	-13.8	-14.4	-14.7	-14.4	-13.8	-12.7	-11.2	-9.4
30-Apr	314.3	310		-11.2	-12.7	-13.8	-14.4	-14.7	-14.4	-13.8	-12.7	-11.2
10-May	324.4	320		-9.4	-11.2	-12.7	-13.8	-14.4	-14.7	-14.4	-13.8	-12.7
20-May	334.6	330		-7.3	-9.4	-11.2	-12.7	-13.8	-14.4	-14.7	-14.4	-13.8
30-May	344.7	340		-5.0	-7.3	-9.4	-11.2	-12.7	-13.8	-14.4	-14.7	-14.4
9-Jun	354.9	350		-2.5	-5.0	-7.3	-9.4	-11.2	-12.7	-13.8	-14.4	-14.7
19-Jun	365.0	360		0.0	-2.5	-5.0	-7.3	-9.4	-11.2	-12.7	-13.8	-14.4

Figure 8: Galactic Quadrant 1: Earth Orbital Velocity Corrections

Calibration of the Data using Actuals of galactic longitudes 10° and 40°

The HI ISM source received velocity (Vr) of two sources were extracted from the database. (Rotation Rate Simulator and Database) (Note that two sources are needed to resolve for ambiguity) Both measurements were made on December 11. For approximation, the December 9 data from figure 8 was used. The velocity correction was subtracted from the actuals to develop a yearly Vr prediction for the two sources throughout a yearly orbit. (figure 9)

Date	Earth Angle from GC	Velocity KM/s GL=10	Velocity KM/s GL=40	
22-Jun	0	28.4	44.3	
2-Jul	10	31.0	46.4	
12-Jul	20	33.5	48.8	
22-Jul	30	36.0	51.2	
30-Jul	40	38.3	53.8	
9-Aug	50	40.4	56.3	
19-Aug	60	42.2	58.8	
30-Aug	70	43.7	61.1	
9-Sep	80	44.8	63.2	
19-Sep	90	45.4	65.0	
29-Sep	100	45.6	66.5	
9-Oct	110	45.4	67.5	
19-Oct	120	44.8	68.2	
29-Oct	130	43.7	68.4	
8-Nov	140	42.2	68.2	
19-Nov	150	40.4	67.5	
29-Nov	160	38.3	66.5	
9-Dec	170	36.0	65.0	Actual
19-Dec	180	33.5	63.2	
29-Dec	190	31.0	61.1	0 Velocity
8-Jan	200	28.4	58.8	
18-Jan	210	26.0	56.3	
28-Jan	220	23.7	53.8	0 Velocity
8-Feb	230	21.6	51.2	
18-Feb	240	19.8	48.8	
28-Feb	250	18.3	46.4	
10-Mar	260	17.2	44.3	
20-Mar	270	16.5	42.5	
30-Mar	280	16.3	41.1	
10-Apr	290	16.5	40.0	
20-Apr	300	17.2	39.3	
30-Apr	310	18.3	39.1	
10-May	320	19.8	39.3	
20-May	330	21.6	40.0	
30-May	340	23.7	41.1	
9-Jun	350	26.0	42.5	
19-Jun	360	28.4	44.3	

Figure 9: Calibrated Vr Predictions for Sources at Galactic Longitude 10° and 40°

The data from figure 9 was plotted versus a 360° orbit. (figure 10)

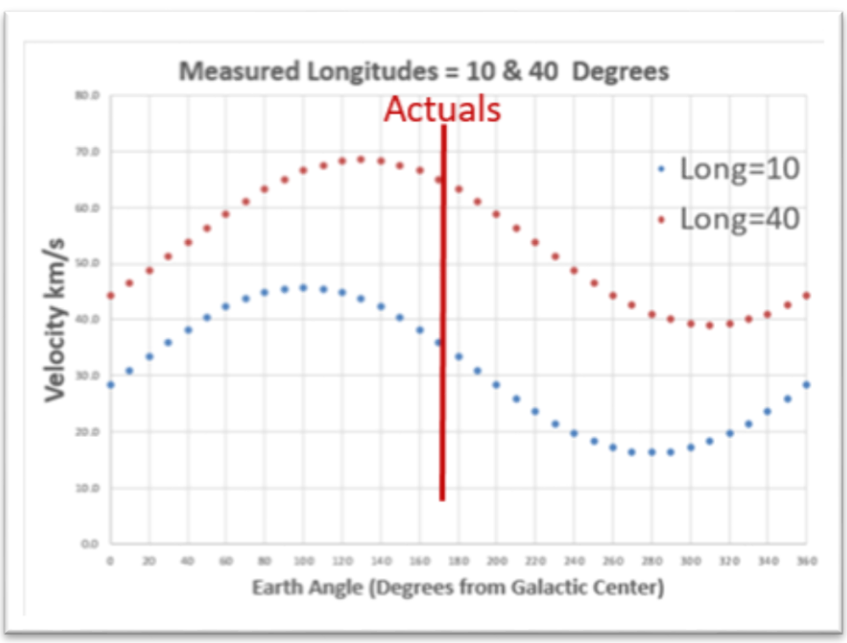

Figure 10: Predicted Vr for HI ISM Sources at galactic longitudes 10° and 40°

Summary

Earth's orbit provides a velocity Doppler contribution to all HI ISM source measurements. By baselining the HI ISM source Vr measurements, the orbital velocity contribution of a measurement can be extracted. This velocity information can therefore be used to estimate the Earth's orbital position. The estimated Vr measurements will be verified throughout the next year to determine how they compare with the actual Earth's orbital position.

Data Request

The SARA community is requested to collect HI ISM data throughout the year to track the Earth's orbit. Table 1 provides a ready input form. Please email the data to Dr. Russel (DrRichRussel@netscape.net). Credit will be provided on results papers in the future SARA publications. Request that observations be conducted on the meridian (azimuth = 180 degrees) to minimize Earth rotation Doppler effects.

Table 1: Data Request Form

Date	UTC	Galactic Latitude	Galactic Longitude	Maximum Frequency (Hz)	Vr (km/second)	Comments

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