Galactic Navigation using the Pioneer Spacecraft Pulsar Map

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Abstract

This paper analyzes the Pioneer and Voyager spacecraft pulsar map. The analysis includes the interpretation and identification of the pulsars in the map and the technique to triangulate the Sun's position using basic geometric measurements. The use of this map to navigate from an extrasolar planet to the Sun is also explored.

1. Introduction

In 1972, the Pioneer 10 spacecraft was launched to explore Jupiter and then became the first of five probes to have the necessary escape velocity to leave the solar system. [1] Pioneers 10 &11 and Voyagers 1 & 2 spacecraft contained a plaque developed by Frank Drake and Carl Sagan that shows the location of Earth using a pulsar map. The Deep Space Exploration Society [2] is preparing the 60-foot radio telescope for pulsar detection. This is the first of many papers planned involving pulsars and has been a good start in jump-starting the organizations learning curve. This paper also analyzes an approach on how an Extraterrestrial Intelligence (ETI) could interpret and use the map to navigate to Earth from an extrasolar planet.

2. Pulsar Map

The pulsar map is shown in Figure 1 [3]. The map includes a depiction of the hydrogen atom, a geometric depiction of pulsars relative to Earth and the galactic center, and a depiction of Earth's position in the solar system.

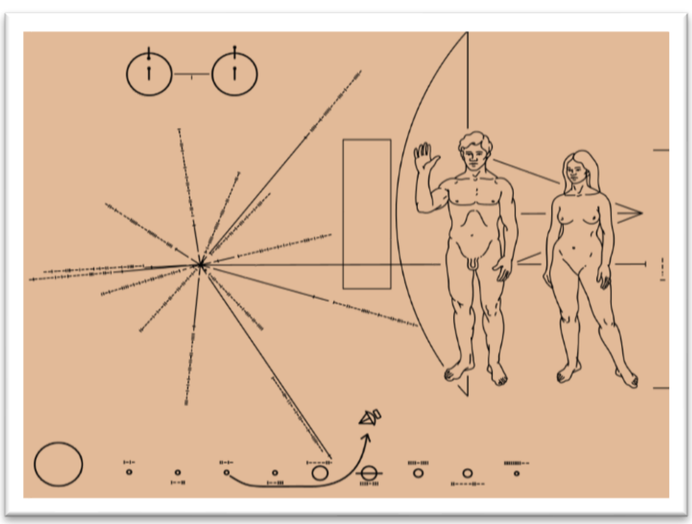


Figure 1: Pioneer and Voyager Spacecraft Pulsar Map

3. Analysis Approach

The analysis approach follows the work done by Johnston in 2007. [4] Step one is to identify the hydrogen symbol as a common timing reference. Step two is to interpret that the symbols on the map are binary numbers of 0s and 1s. The binary sequences are then converted to a base 10 count and applied to the hydrogen reference to get the pulsar periods. It should be noted that the conversion to base 10 is not necessary since the ratios can be derived independent of the base used. Step three is to locate the pulsars in the ETI's database and map them onto a galactic-centric star chart. Step four is to use the geometric lengths and angles on the pulsar map to triangulate the Earth's position in the galaxy.

The ETI's home star system can then be mapped on the galactic plane to determine distances and courses to the Earth.

4. Hyperfine Transition of HI

Neutral hydrogen conducts an electron spin flip which produces a photon with a frequency of 1 420 405 751.768 Hz. [5] This is referred to as the hyperfine transition of HI. This is represented graphically on the Pioneer plaque as shown in Figure 2.

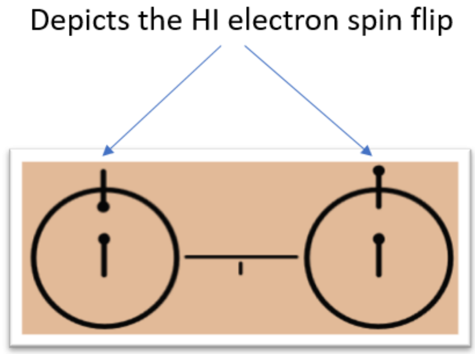


Figure 2: Hyperfine Transition of HI

This depiction provides a common physical reference that the ETI can measure and convert to their timing system.

5. Identifying the Pulsars

There is an assumption that an ETI will identify the lines as a galactic map and that the perpendicular lines and dashes at each end of a line are the binary representation of the pulsar period. The distance of the Sun to the galactic center is identified by the long horizontal line as shown in Figure 3. The pulsar lines are angled from the Sun's position with relative lengths bases on the Sun – galactic center line length.

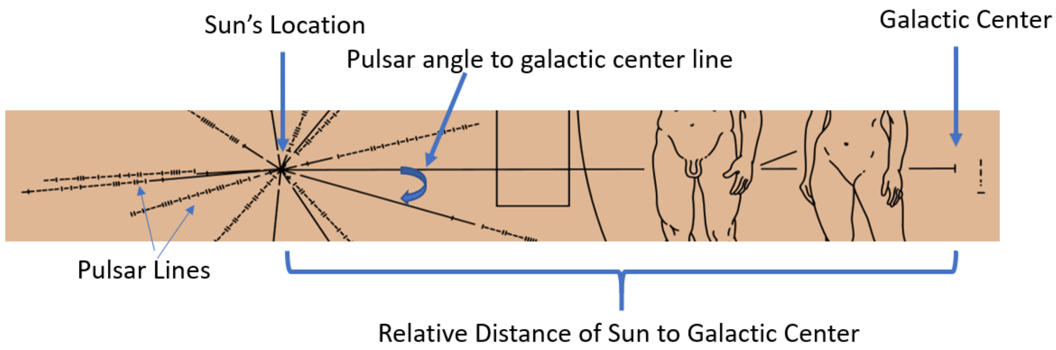


Figure 3: Relative Galactic Distance Line

A pulsar line consists of multiple parts (Figure 4):

- The line segment closest to the center is a relative length that depicts the distance of the pulsar from the Sun.
- The next segment is a relative length that depicts the pulsar's distance above or below the galactic plane – Z-axis.
- The next segment consists of perpendicular lines which can be interpreted as 1s, and dashes which can be interpreted as 0s. The binary number is read with the least significant bit at the end of the line.
- Angles – the angles of each pulsar line are read clockwise from the central galactic line.

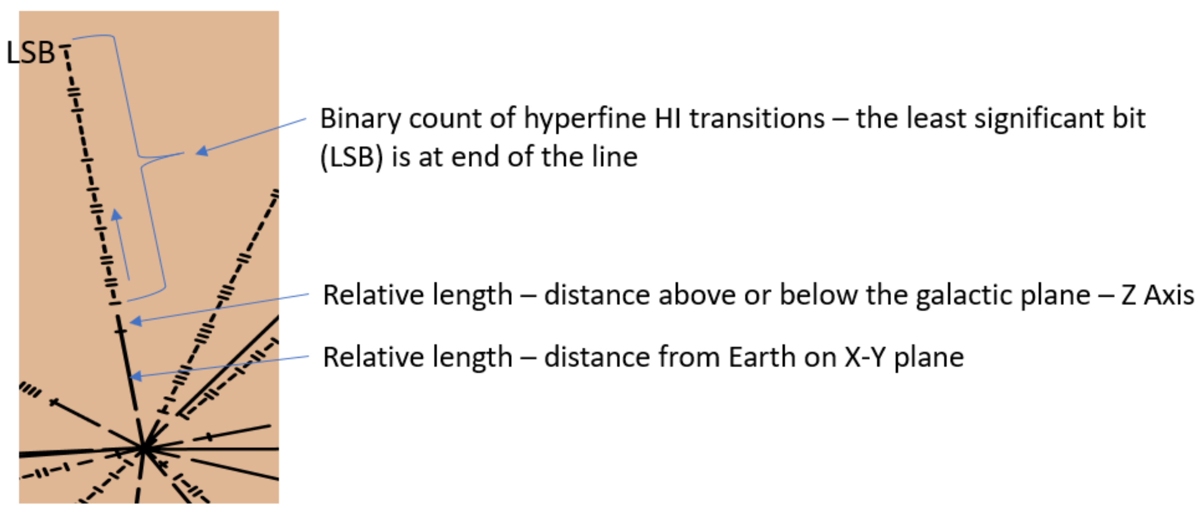


Figure 4: Description of a pulsar line

The pulsars were numbered clockwise from the galactic center line. The binary numbers are read based on Figure 5.

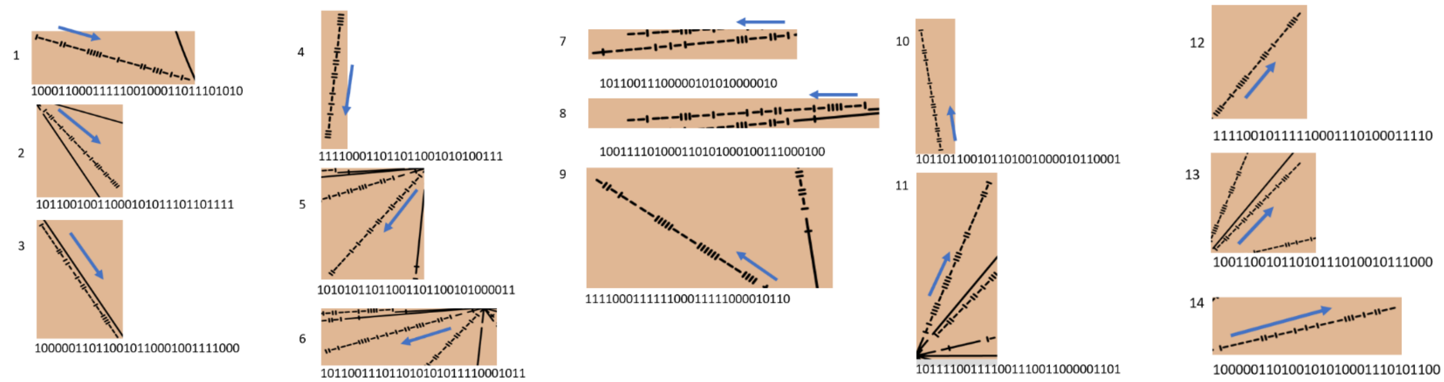


Figure 5: Binary Interpretation of pulsar lines.

The hint to the ETI to use Base 10 may be the male figure holding up his hand with five fingers. The fact that he has two hands may provide an insight that Earthlings use Base 10. (Figure 6)

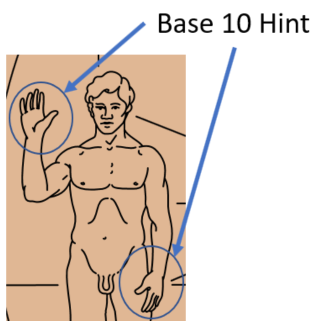


Figure 6: Base 10 Hint

Note that the use of base 10 in the analysis is purely for the benefit to the author and that an ETI will likely NOT be using a base 10 numbering system at all. But, of course, humans also use base 2, base 8, and base 16, frequently too. [6] Table 1 shows the conversion from the binary to base 10 count for each pulsar. This number is the count of hyperfine transitions of HI.

#	Binary from Pulsar Map	Base 10 (HI Transition Units)
1	1000110001111100100011011101010	1178486506
2	10110010011000101011101101111	374101871
3	100000110110010110001001111000	551117432
4	111100011011011001010100111	126726823
5	10101011011001101100101000011	359455043
6	101100111011010101011110001011	753751947
7	10110011100000101010000010	47057538
8	100111101000110101000100111000100	5320116676
9	111100011111110001111000010110	1014906390
10	101101100101101001000010110001	764842161
11	101111001111001110011000001101	792520205
12	11110010111111000111010001110	509549854
13	10011001011010111010010111000	321746104
14	100000110100101010001110101100	550675372

Table 1: Conversion Table from binary to HI Transition Counts

By multiplying this count by 1/ 1,420,405,751.7680 hz., the pulsar period in seconds is obtained. Table 2 converts the HI transition counts to the pulsar period in seconds.

#	Binary from Pulsar Map	Base 10 (HI Transition Units)	Hyperfine transition period of HI (seconds)	Period (seconds)
1	1000110001111100100011011101010	1178486506	7.04024183762E-10	0.8296830005
2	10110010011000101011101101111	374101871	7.04024183762E-10	0.2633767644
3	100000110110010110001001111000	551117432	7.04024183762E-10	0.3880000002
4	111100011011011001010100111	126726823	7.04024183762E-10	0.0892187481
5	10101011011001101100101000011	359455043	7.04024183762E-10	0.2530650432
6	101100111011010101011110001011	753751947	7.04024183762E-10	0.5306595992
7	10110011100000101010000010	47057538	7.04024183762E-10	0.0331296448
8	100111101000110101000100111000100	5320116676	7.04024183762E-10	3.7454908003
9	111100011111110001111000010110	1014906390	7.04024183762E-10	0.7145186428
10	101101100101101001000010110001	764842161	7.04024183762E-10	0.5384673781
11	101111001111001110011000001101	792520205	7.04024183762E-10	0.5579533904
12	11110010111111000111010001110	509549854	7.04024183762E-10	0.3587354200
13	10011001011010111010010111000	321746104	7.04024183762E-10	0.2265170382
14	100000110100101010001110101100	550675372	7.04024183762E-10	0.3876887793
	HI hyperfine transition	1420405751.7680	hz	

Table 2: HI transition counts to pulsar period

6. Finding the Pulsars in the Galaxy

The next step is to find the pulsars that match the pulsar periods. The VizieR database has a significant pulsar list. [7] The database was queried for the pulsars with the closest matching periods. The results are shown in Table 3.

Pulsar Line #	Pulsar Line Period (seconds)	Database Pulsar Period (seconds)	Period Differences (seconds)	Jname	Bname	RA J2000 (d m s)	DEC J2000 (d m s)	dist (kpc)	GLON (deg)	GLAT (deg)	Pdot	Pulsar Line #
1	0.829683	0.829724	-0.000041	1731-4744	1727-47	17 31 41.9935	-47 44 33.024	4.87	342.5655	-7.6682	1.64E-13	1
2	0.263377	0.263377	0.000000	1456-6843	1451-68	14 56 00.0359	-68 43 38.893	0.45	313.869	-8.5431	9.88E-17	2
3	0.388000	0.388481	-0.000481	1243-6423	1240-64	12 43 17.1585	-64 23 23.851	12.2	302.0508	-1.5322	4.50E-15	3
4	0.089219	0.089309	-0.000090	0835-4510	0833-45	08 35 20.5721	-45 10 34.957	0.5	263.5521	-2.7873	1.25E-13	4
5	0.253065	0.253065	0.000000	0953+0755	0950+08	09 53 09.3307	+07 55 36.069	0.12	228.9082	43.6965	2.29E-16	5
6	0.530660	0.530661	-0.000001	0826+2637	0823+26	08 26 51.4501	+26 37 22.795	0.38	196.9621	31.7423	1.71E-15	6
7	0.033130	0.033403	-0.000274	0534+2200	0531+21	05 34 31.9475	+22 00 52.210	2	184.5575	-5.7843	4.21E-13	7
8	3.745491	3.745521	-0.000031	0528+2200	0525+21	05 28 52.3004	+22 00 00.391	2.27	183.8572	-6.8965	4.00E-14	8
9	0.714519	0.714519	0.000000	0332+5434	0329+54	03 32 59.4082	+54 34 42.838	1.43	144.9953	-1.2207	2.05E-15	9
10	0.538467	0.538469	-0.000002	2219+4754	2217+47	22 19 48.1256	+47 54 53.572	2.45	98.3846	-7.598	2.77E-15	10
11	0.557953	0.557953	0.000000	2018+2839	2016+28	20 18 03.8556	+28 39 54.295	1.1	68.0989	-3.9829	1.49E-16	11
12	0.358735	0.358736	-0.000001	1935+1616	1933+16	19 35 47.8390	+16 16 39.815	7.94	52.4361	-2.0925	6.00E-15	12
13	0.226517	0.226518	-0.000001	1932+1059	1929+10	19 32 13.9578	+10 59 32.332	0.17	47.3814	-3.8843	1.16E-15	13
14	0.387689	0.387689	0.000000	1645-0317	1642-03	16 45 02.1282	-03 17 59.115	2.9	14.114	26.0615	1.78E-15	14

Table 3: Pulsar Line Periods Mapped to VizieR Database

It should be noted that the VizieR database is based on Earth observations and position in the galaxy. The pulsar periods observed are based on the distance of the Earth from each pulsar. A pulsar generally spins down over time. The spin down rate is denoted by Pdot in table 3 as the seconds a pulsar spins down per second. In order to determine how an ETI will observe the pulsar period it is necessary to determine the base period at the pulsar. Table 4 uses the estimated distance of each pulsar to the Earth and applies the Pdot to determine the base pulsar period. Note that the period of a pulsar will be faster to the observer than at the pulsar. Pulsars also have changes to their pulsar rates called “glitches”. It would be important to have the complete glitch history of each pulsar to properly estimate the base period. Therefore table 4 is just a rough estimate using the VizieR J2000 Pdot values.

Pulsar #	Earth Distance (kpc)	Light Years/pc	Earth Light Years Distance	PDOT s/s	Sec/yr	PDOT S/Yr	Delta Period (seconds)	J2000 Period (seconds)	Base Period of Pulsar (seconds)
1	4.87	3.26156	15,884	1.64E-13	3.2E+07	5.16E-06	0.081985	0.829724	0.911709
2	0.45	3.26156	1,468	9.88E-17	3.2E+07	3.12E-09	0.000005	0.263377	0.263381
3	12.20	3.26156	39,791	4.50E-15	3.2E+07	1.42E-07	0.005648	0.388481	0.394129
4	0.50	3.26156	1,631	1.25E-13	3.2E+07	3.94E-06	0.006420	0.089309	0.095729
5	0.12	3.26156	391	2.29E-16	3.2E+07	7.23E-09	0.000003	0.253065	0.253068
6	0.38	3.26156	1,239	1.71E-15	3.2E+07	5.39E-08	0.000067	0.530661	0.530728
7	2.00	3.26156	6,523	4.21E-13	3.2E+07	1.33E-05	0.086597	0.033403	0.120000
8	2.27	3.26156	7,404	4.00E-14	3.2E+07	1.26E-06	0.009347	3.745521	3.754868
9	1.43	3.26156	4,664	2.05E-15	3.2E+07	6.46E-08	0.000301	0.714519	0.714820
10	2.45	3.26156	7,991	2.77E-15	3.2E+07	8.72E-08	0.000697	0.538469	0.539166
11	1.10	3.26156	3,588	1.49E-16	3.2E+07	4.71E-09	0.000017	0.557953	0.557970
12	7.94	3.26156	25,897	6.00E-15	3.2E+07	1.89E-07	0.004903	0.358736	0.363639
13	0.17	3.26156	554	1.16E-15	3.2E+07	3.65E-08	0.000020	0.226518	0.226538
14	2.90	3.26156	9,459	1.78E-15	3.2E+07	5.62E-08	0.000531	0.387689	0.388220

Table 4: Calculating the Baseline Pulsar Periods

7. Converting Pulsars to Galactic-Centric Coordinates

The galactic coordinates in Table 3 are Earth centric. An ETI would be using a galactic coordinate system that references the center of the galaxy. The ETI would not have the same starting angles, however the visual geometry on the map will help convert the picture to an ETI perspective. Converting to galactic-centric coordinates also provides a more realistic position if the ship is not in the solar system (Table 5). Note that the distances are in parsecs (pc).

Pulsar Line #	Galactic Latitude (deg)	Galactic Longitude (deg)	Distance from Sun (pc)	Pulsar Line #	Gal -X (pc) (Earth-Centric)	Gal -Y (pc) (Earth-Centric)	Gal -Z (pc) (Earth-Centric)	Pulsar Line #	Gal - X (pc) (Galactic-Centric)	Gal-Y (pc) (Galactic-Centric)	Gal-Z (pc) (Galactic-Centric)
1	-7.67	342.57	4870	1	-1446	-4605	-650	1	-1446	3895	-650
2	-8.54	313.87	450	2	-321	-308	-67	2	-321	8192	-67
3	-1.53	302.05	12200	3	-10337	-6472	-326	3	-10337	2028	-326
4	-2.79	263.55	500	4	-496	56	-24	4	-496	8556	-24
5	43.70	228.91	120	5	-65	57	83	5	-65	8557	83
6	31.74	196.96	380	6	-94	309	200	6	-94	8809	200
7	184.56	-5.78	2000	7	201	1984	-159	7	201	10484	-159
8	-6.90	183.86	2270	8	-152	2248	-273	8	-152	10748	-273
9	-1.22	145.00	1430	9	820	1171	-30	9	820	9671	-30
10	-7.60	98.38	2450	10	2403	354	-324	10	2403	8854	-324
11	-3.98	68.10	1100	11	1018	-409	-76	11	1018	8091	-76
12	-2.09	52.44	7940	12	6290	-4837	-290	12	6290	3663	-290
13	-3.88	47.38	170	13	125	-115	-12	13	125	8385	-12
14	26.06	14.11	2900	14	635	-2526	1274	14	635	5974	1274

Table 5: Galactic Coordinator Converter

The pulsar map does not show the plotting axis used. Figure 7 plots the pulsar positions in the X-Y plane. Note that the Y-axis is in the direction of the galactic center, the X-axis is perpendicular to the Y-axis along the galactic plane and the Z-axis is above and below the galactic plane. The X-Y plane appears to be the closest to the pulsar map. Note that the actual pulsars 7 & 8 are reversed in position from the pulsar map.

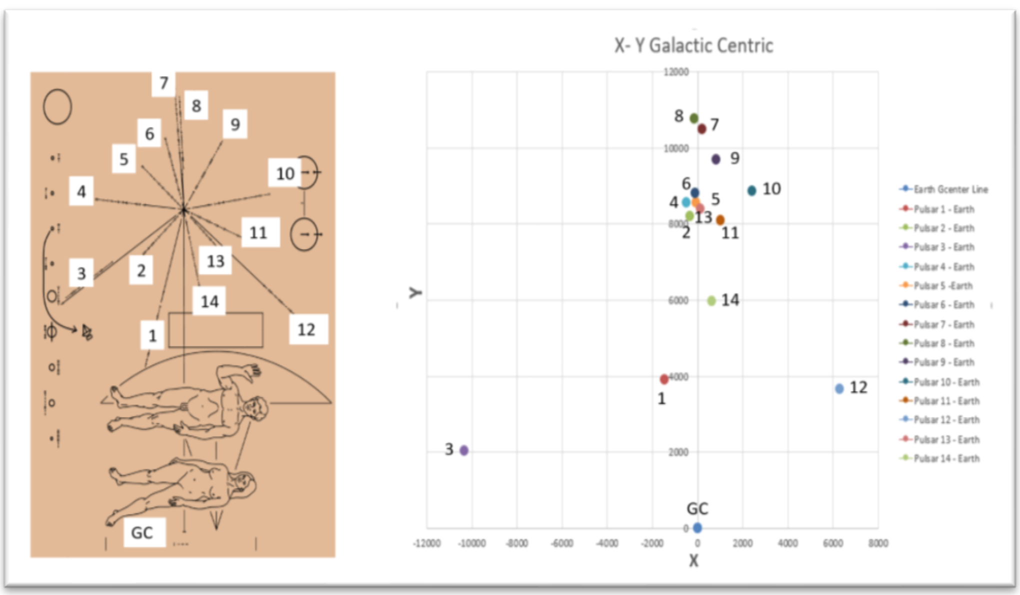
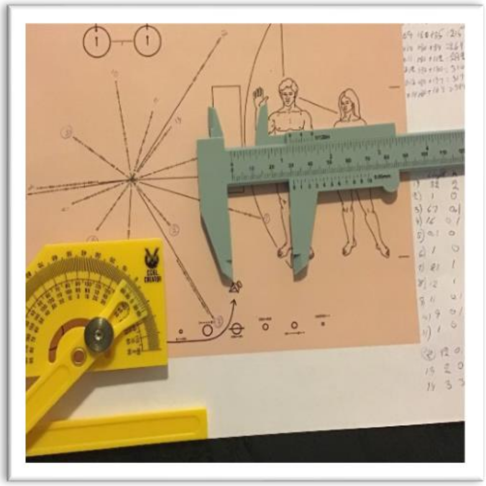


Figure 2: Plotting the pulsar positions

8. Scaling and Triangulating the Sun's Position using the Pulsar Map Geometry

Now that the pulsars are mapped in the galactic X-Y plane, the actual distances can be determined. The lengths and angles of each pulsar line were measured. (Figure 8)



Pulsar #	Relative Length (mm)	Relative Height (mm)	Angle from GC (CW) (Degrees)
0	131	0	0
1	32	2	-21
2	1	0	-55
3	67	0.1	-58
4	16	0.1	-97
5	0.1	0	-134
6	1	0	-162
7	21	1	-177
8	12	1	-178
9	11	0.1	-215
10	9	0.1	-264
11	1	0	-292
12	42	0.1	-310
13	2	0	-317
14	3	3	-344

Figure 3: Measuring Lengths and Angles

The next step is to determine the scale. This was done by measuring the length between 4 pulsar pairs and then calculating the X-Y actual galactic distance between the pairs using the galactic-centric VizieR database values from Table 5. An average of the 4 measurements was taken as the scale in parsecs/millimeter (pc/mm). (Table 8)

Pulsars	Distance (X-Y) (pc)	Map Distance (mm)	Ratio (pc/mm)
1 to 3	9084.6	47	193.3
1 to 12	7739.2	46	168.2
1 to 4	4756.6	35	135.9
9 to 10	1780.8	7	254.4
		Average	188.0

Table 8: Scaling Calculation

The scale was used on each measurement as shown in Table 9. Note that there is a > 220% error from the scaled measurements and the known actuals. Note that there were three pulsars which were less than 3% error. Sources of error may include the use of a photograph to do the measurements plus the small scale of the reproduction. The pulsar lengths chosen were also very small compared to the galactic Y axis. A selection of a smaller scale using the closer pulsars may help in future maps.

As a general note, pulsars distances are often estimated from the dispersion measure and the model of the distribution of free electrons in the galaxy. Such estimates can have large errors; therefore, it may account for the large scatter in the distance scale calibration. For relatively nearby and strong pulsars, VLBI parallax can produce distances with errors of just a few prevent. [8]

Pulsar #	Relative Length (mm)	Relative Height (mm)	Angle from GC (CW) (Degrees)	X (mm)	Y (mm)	Y Corr (mm) for Galactic Center (131 mm- Y)	Convertion (pc/mm)	Pulsar Map Scaled Distance (pc)	Calculated Actual (Distance to Earth) (pc)	% Error
0	131	0	0	0.0	131.0	131.0	188.0	24,623	8500	190%
1	32	2	-21	-11.5	29.9	101.1	188.0	6,015	4870	24%
2	1	0	-55	-0.8	0.6	130.4	188.0	188	450	-58%
3	67	0.1	-58	-56.8	35.5	95.5	188.0	12,593	12200	3%
4	16	0.1	-97	-15.9	-1.9	132.9	188.0	3,007	500	501%
5	0.1	0	-134	-0.1	-0.1	131.1	188.0	19	120	-84%
6	1	0	-162	-0.3	-1.0	132.0	188.0	188	380	-51%
7	21	1	-177	-1.1	-21.0	152.0	188.0	3,947	2000	97%
8	12	1	-178	-0.4	-12.0	143.0	188.0	2,256	2270	-1%
9	11	0.1	-215	6.3	-9.0	140.0	188.0	2,068	1430	45%
10	9	0.1	-264	9.0	-0.9	131.9	188.0	1,692	2450	-31%
11	1	0	-292	0.9	0.4	130.6	188.0	188	1100	-83%
12	42	0.1	-310	32.2	27.0	104.0	188.0	7,894	7940	-1%
13	2	0	-317	1.4	1.5	129.5	188.0	376	170	121%
14	3	3	-344	0.8	2.9	128.1	188.0	564	2900	-81%

Table 9: Scaled Pulsar Map Distances

The angle measurements were then plotted. Based on the pulsar map, it was assumed that the Sun was on the X= 0 axis. Therefore, a calculator was developed that allowed for the selection of the Y-axis for each pulsar line and the angle was then calculated and matched to the measured angle. The tabulated results are shown in Table 10.

Pulsar #	Gcent - X (pc)	Gcent-Y (pc)	Gcent-Z (pc)	Alt Angle	Pulsar Map Measured Angle (Degrees)	Calc Angle Based Y2 Input (Degrees)	X2 (pc)	Y2 (pc)	Calculated Distance (pc)	Actual (Distance to Sun) (pc)	% Error
1	-1446	3895	-650	21	21	21.0	0	7660	4033	4870	-17%
2	-321	8192	-67	55	55	55.0	0	7967	392	450	-13%
3	-10337	2028	-326	58	58	58.0	0	8480	12185	12200	0%
4	-496	8556	-24	83	97	83.0	0	8495	500	500	0%
5	-65	8557	83	46	134	46.0	0	8493.8	91	120	-24%
6	-94	8809	200	18	162	18.0	0	8519	305	380	-20%
7	201	10484	-159	3	177	-3.0	0	6600	3889	2000	94%
8	-152	10748	-273	2	178	2.0	0	6500	4251	2270	87%
9	820	9671	-30	-35	215	-35.0	0	8500	1430	1430	0%
10	2403	8854	-324	-84	264	-84.0	0	8600	2416	2450	-1%
11	1018	8091	-76	-68	292	-68.0	0	8503	1098	1100	0%
12	6290	3663	-290	-50	310	-50.0	0	8940	8210	7940	3%
13	125	8385	-12	-43	317	-43.0	0	8519	183	170	8%
14	635	5974	1274	-16	344	-16.0	0	8190	2306	2900	-20%
						Sun Distance to GC	Average	8140		8500	-4%
							Stdev	739			

Table 10: Calculated Distances using Pulsar Map Angle Measurements

The results are better! The average galactic Y position of the Sun is only 4% from the “actual” value used. Pulsars 7 and 8 show a significant variation, even though pulsar 8 was within 1 % error for the length measurements. Sources of error should be reduced using the actual pulsar map instead of using a photograph reproduction. The plot of the angle measurements is shown in Figure 9.

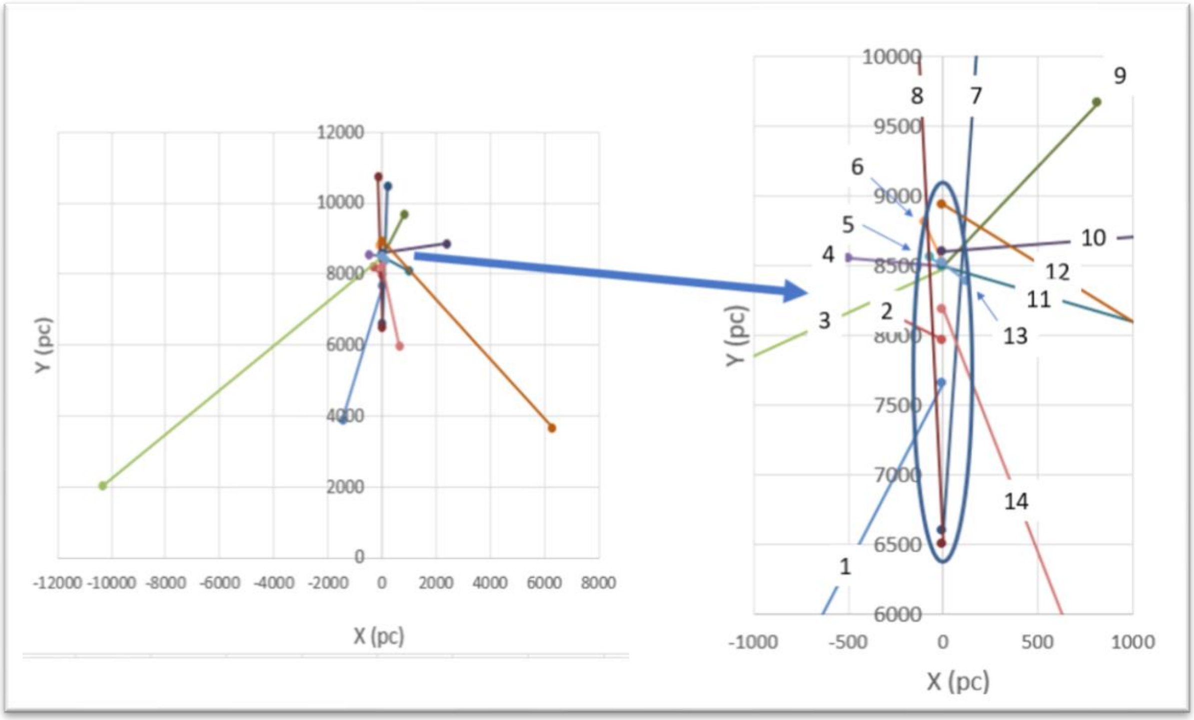


Figure 4: Triangulation using Pulsar Map Angle Measurements

This analysis shows that the position of the Sun in the galaxy can be estimated. The final step by the ETI would be to determine if any star systems in their database fall within this area in the galaxy. At a minimum, a lot of radio telescopes will be aimed into this region.

9. Using the Pulsar Map by an ETI to find the Sun

The pulsar map has been shown to be within 4% error in position of the Sun. This error should be improved if the ETI has the original map and uses precision measurements. A representative ETI civilization was chosen from the star Kepler 452b from a list of habitable exoplanets. [9] This exoplanet is farther away than some but will allow a larger scale as a graphical demonstration of finding the Sun. All other exoplanets of any distance can also use these methods. Kepler 452b is located at galactic coordinates: longitude: 077.86, latitude: +09.98 at a distance from Earth of 1402 light years. [10] The galactic-centric coordinates are shown in Table 11.

Pulsar Line #	Galactic Latitude (deg)	Galactic Longitude (deg)	Distance from Sun (pc)	Pulsar Line #	Gal -X (pc) (Earth-Centric)	Gal -Y (pc) (Earth-Centric)	Gal -Z (pc) (Earth-Centric)	Pulsar Line #	Gal - X (pc) (Galactic-Centric)	Gal-Y (pc) (Galactic-Centric)	Gal-Z (pc) (Galactic-Centric)
1	-7.67	342.57	4870	1	-1446	-4605	-650	1	-1446	3895	-650
2	-8.54	313.87	450	2	-321	-308	-67	2	-321	8192	-67
3	-1.53	302.05	12200	3	-10337	-6472	-326	3	-10337	2028	-326
4	-2.79	263.55	500	4	-496	56	-24	4	-496	8556	-24
5	43.70	228.91	120	5	-65	57	83	5	-65	8557	83
6	31.74	196.96	380	6	-94	309	200	6	-94	8809	200
7	184.56	-5.78	2000	7	201	1984	-159	7	201	10484	-159
8	-6.90	183.86	2270	8	-152	2248	-273	8	-152	10748	-273
9	-1.22	145.00	1430	9	820	1171	-30	9	820	9671	-30
10	-7.60	98.38	2450	10	2403	354	-324	10	2403	8854	-324
11	-3.98	68.10	1100	11	1018	-409	-76	11	1018	8091	-76
12	-2.09	52.44	7940	12	6290	-4837	-290	12	6290	3663	-290
13	-3.88	47.38	170	13	125	-115	-12	13	125	8385	-12
14	26.06	14.11	2900	14	635	-2526	1274	14	635	5974	1274
Kepler 452b	9.99	77.86	430	Kepler 452b	414	-89	75	Kepler 452b	414	8411	75
								Gal Center	0	0	0

Table 11: Kepler 452b Galactic -Centric Coordinates

The pulsar periods observed at Kepler 452b are dependent on the number of light years distance between the two locations. This time delay based on the distance of Kepler 452b to each pulsar was multiplied by the Pdot to get the net period rate change based on observed age of the pulsar. Note that the pulsar period will appear to be faster as the distance to the observer increases. The observed period rate is not a result of any pulsar characteristics but do to the observer viewing the pulsar at an earlier time in the lifetime of the pulsar due to the finite speed of light. [6] The results are shown in Table 12.

Pulsar #	Kepler 452b Distance (pc)	Kepler 452b Light Year Distance	Base Period of Pulsar (seconds) J2000	Calculated Change in Period (seconds)	Kepler 452b Expected Observed Period (seconds) (J2000)
1	4,937	16,103	0.911709	0.083116	0.828592
2	780	2,543	0.263381	0.000008	0.263373
3	12,509	40,799	0.394129	0.005791	0.388338
4	927	3,023	0.095729	0.011902	0.083827
5	501	1,634	0.253068	0.000012	0.253056
6	658	2,145	0.530728	0.000116	0.530612
7	2,096	6,838	0.120000	0.090774	0.029226
8	2,430	7,925	3.754868	0.010005	3.744863
9	1,328	4,332	0.714820	0.000280	0.714540
10	2,076	6,771	0.539166	0.000590	0.538576
11	700	2,284	0.557970	0.000011	0.557960
12	7,563	24,668	0.363639	0.004670	0.358969
13	303	987	0.226538	0.000036	0.226502
14	2,726	8,890	0.388220	0.000499	0.387721

Table 12: Kepler 452b Expected Pulsar Period Observations

Plotting the Sun and Kepler 452b positions in the X-Y and X-Z axis shows the relative courses required to navigate between the two. (Figure 10)

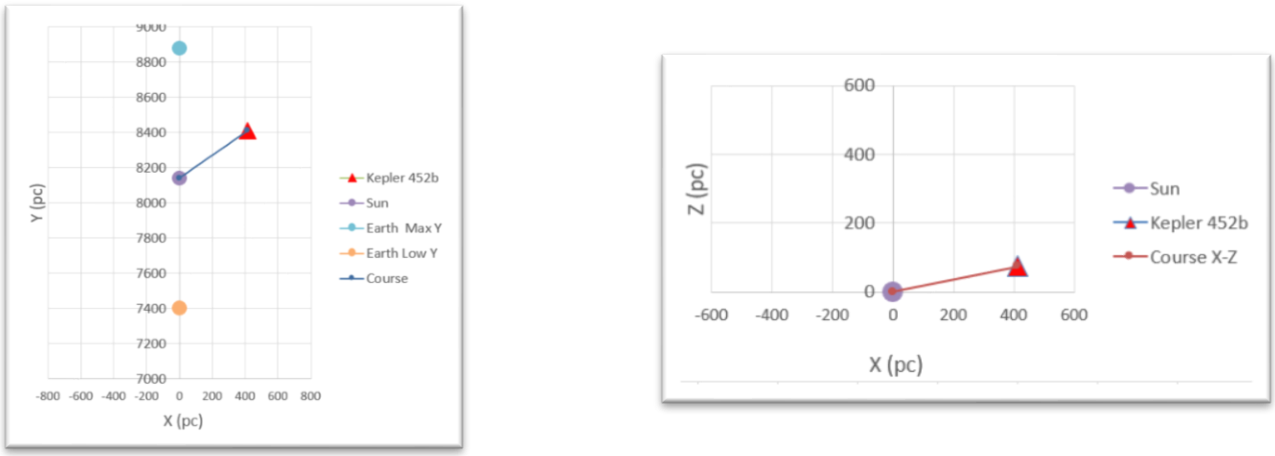


Figure 5: Kepler to Sun Course X-Y Plane and the X-Z Plane

It should be noted that the trajectory for a ship traveling slowly will have to account for differential galactic rotation. [8] It is also not clear that the pulsars shown can be observed by the ETI planet. Pulsars give off highly directional beams of radiation. A planet would have to be in the sweeping beam to detect the pulsar and measure the period. Therefore, an ETI may only have the coordinates for a few pulsars in the map, which may result in a larger area of uncertainty for detecting the Sun. [6]

10. Summary

The exercise to decipher the Pioneer spacecraft pulsar map was undertaken to increase the learning curve of the Deep Space Exploration Society, which is preparing the 60-foot radio telescope for pulsar observations. The SETI work being done by the organization also provides the opportunity to research the use of the pulsar map to navigate from an exoplanet to the Earth as the map was designed to do. The author made a lot of assumptions based on being an Earthling that an ETI may not have made, however, there were enough graphical clues to interpret the map and provide a rough estimate of the Sun's position in the galaxy.

The exercise to interpret the Pioneer spacecraft pulsar map is an excellent exercise to use for students! It provides elements of pulsar spin dynamics, galactic coordinates, and basic 3-dimensional geometry.

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Special thanks to Dr. Dayton Jones and Joe Martin for thorough reviews and recommendations for improvements on this paper.

Thanks also to Jeff Lichtman and Steve Plock for their support.

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