Estimating the distance (R_0) to the Galactic Center using type II Cepheids

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(a)

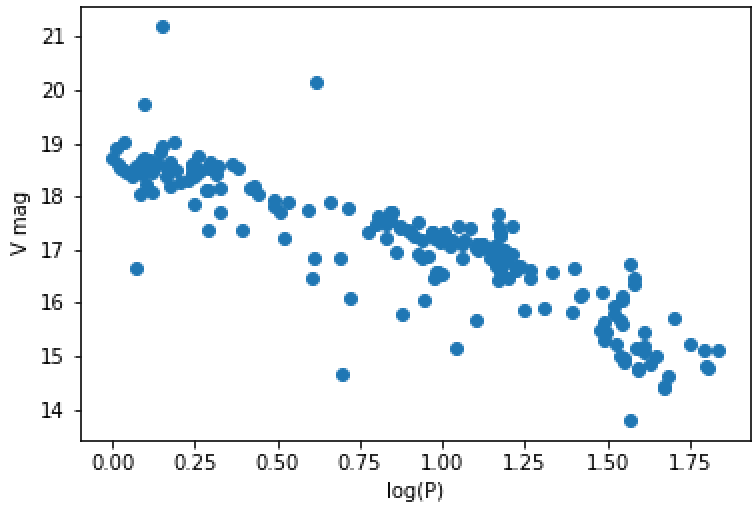

Figure 1: P-L relation:log(P) vs Vmag

The plot of log(P) and Vmag shows a linear relation between the variables with a negative gradient and a large scatter

(b) The scatter can be reduced by introducing a color correcting term to the P-L relation or alternatively use longer wavelengths such as NIR

(c)

$$WI = V - R(V - I)$$

where

$$V - I = (V - I)_0 + E_{v-I}$$

and by the linearized form of the Period-luminosity-color relation it can be shown that

$$V = V_0 + A_V$$

then the Wesenheit index becomes

$$WI = V_0 + A_v - R[(V - i)_0 + E_{V-I}$$

Using the expression

$$R = \frac{A_v}{E_{V-I}}$$

we get

$$WI = V_0 + R(E_{V-I}) - R(V - I)_0 - R(E_{V-I})$$

therefore

$$WI = V_0 - R(V - I)_0$$

(d)

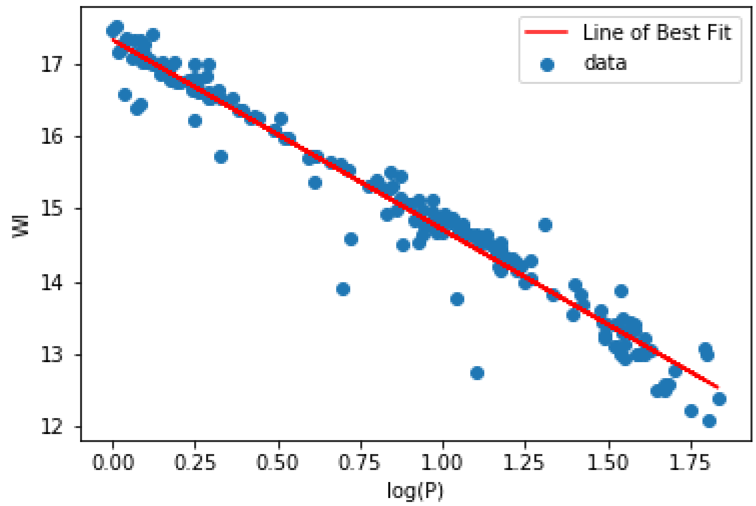

Figure 2: P-L-C relation: log(P) vs WI

Figure 2 shows a linear relation between the variables log(p) and WI it can be noted that the data points show a significantly lower spread.It is for this reason that it is often called the PLC relation, because as indicated in (c) introducing a color correction to the PL relation reduces the spread in the data points

(e) Figure 2 shows the fitted line through the data. An expression relating V_0, $logP$, $s, c\ and\ I_0$. The linear fit expression can be given as

$$WI = s(logP) + c$$

$$V_0 - R(V-I)_0 = s(logP) + c$$

$$V_0 = s(logP) + R(V-I)_0 + c$$

From the fit parameters of the line of best fit we extracted the best fit values to be

$$s = -2.62 \pm 0.04 \ \ and \ \ c = 17.33 \pm 0.04$$

(f & g)

$$V_0 = s(logP) + R(V-I)_0 + c$$

with values is expressed as

$$V_0 = -2.62log(P) + 2.55(V-I)_0 + 17.33$$

this expression can be rewritten as

$$(V-I)_0 = \frac{1}{R}(V_0 - s * log(P) - c)$$

now since $m - V_0 = 18.5$ we can find $V_0 = m - 18.55$ which then leads to a list of $(V-I)_0$ values with average $< V_0 - I_0 >= -6.44$

(h)

$$V_0 = -2.62log(P) + 0.91$$

(i) To find the distance to the galactic centre we made use of the DIBRE Dust Map to compute A_v From the data returned two extinction values are available $A_V(SandF)$ and $A_v(SDF)$.In order to account for the total extinction between the sun and the bulge we calculated an average extinction value, this was formulated as taking the averages $< A_V(SandF) >= 2.39155$ and $< A_v(SDF) >= 2.78085$ and then once again averaging these values to get $A_v = 2.5862$ which is used as the estimate for extinction within the solar circle. From the expression given in (h) we can find the absolute magnitudes for the stars given in the $bulge_t2cephs.dat$ text file. Using the distance modulus expression

$$V - V_0 = 5log(\frac{R_0}{10}) + A_v$$

and solving for R_0

$$R_0 = 10^{(\frac{V-V_0-A_V}{5}+1)}$$

An R_0 estimate was then calculated for each star the average of these values we take to be the best estimate for the for the distance to the galactic center.For all 61 data points provided the best estimate comes out to be

$$R_0 = 10861.58 \pm 1468.09pc$$

where the standard deviation of the individual estimates is used an uncertainty.

An interesting observation is that removing the last two data points which have large values for their R_0 estimates OGLE-BLG-T2CEP-356 has $R_0 = 12329.66884pc$ and OGLE-BLG-T2CEP-356 has $R_0 = 11136.07469pc$ results in an overall estimate of

$$R_0 = 9589.68 \pm 196.20pc$$

(j) The estimate $R_0 = 10861.58 \pm 1468.98$pc is not in agreement with the definition of R_0 by the IU which estimates it to be around $R_0 = 8.5$pc. I do however think it a reasonable estimate having about 25% error in the actual value.

Inspecting the data relieves that alot of the individual estimates for R_o were larger than 10pc. This could be due to the way the extinction within the solar circle was established. Perhaps a better approach would have been to find $R_0(SandF)$ and $R_0(SDF)$ independently and then taken a mean of these two values as the best estimate. Additionally it could be that the sample was taken of cepheids close to galactic plane which generally has a high extinction this would also have an impact on the accuracy of our estimate.Lastly the sample size was rather small, it is probable that with a larger sample population we could extract values that are a bit more accurate.

In closing this practical has highlighted to me the power of the P-L relation and cepheids in determining distances but I think what I appreciate a bit more now is the complexity of dealing with extinction to high accuracy.

1 Appendix

NAME	I	V	P	logp	WI	V-0
OGLE-LMC	17.734	18.452	1.813952	0.258626	16.6211	-0.048
OGLE-LMC	15.711	16.632	18.32355	1.26301	14.28345	-1.868
OGLE-LMC	14.166	14.953	35.65993	1.55218	12.94615	-3.547
OGLE-LMC	17.612	18.124	1.916018	0.2824	16.8184	-0.376
OGLE-LMC	14.739	15.796	33.18533	1.520946	13.10065	-2.704
OGLE-LMC	18.037	18.513	1.087924	0.036599	17.2992	0.013
OGLE-LMC	18.005	18.597	1.242642	0.094346	17.0874	0.097
OGLE-LMC	17.842	18.585	1.746099	0.242069	16.69035	0.085
OGLE-LMC	17.762	18.379	1.761347	0.245845	16.80565	-0.121
OGLE-LMC	17.979	18.633	1.502964	0.176948	16.9653	0.133
OGLE-LMC	14.089	14.789	39.25662	1.593913	13.004	-3.711
OGLE-LMC	16.193	17.184	11.58081	1.063739	14.65695	-1.316
OGLE-LMC	16.184	17.119	11.54461	1.062379	14.73475	-1.381
OGLE-LMC	14.312	15.103	61.87571	1.79152	13.08595	-3.397
OGLE-LMC	14.061	15.243	56.52148	1.752213	12.2289	-3.257
OGLE-LMC	15.458	15.891	20.29564	1.307403	14.78685	-2.609
OGLE-LMC	15.986	16.968	14.45475	1.160011	14.4639	-1.532
OGLE-LMC	17.964	18.609	1.379587	0.139749	16.96425	0.109
OGLE-LMC	15.989	16.853	8.674863	0.938263	14.6498	-1.647
OGLE-LMC	18.036	18.469	1.108126	0.044589	17.36485	-0.031
OGLE-LMC	15.884	16.58	9.759502	0.989428	14.8052	-1.92
OGLE-LMC	16.271	17.179	10.71678	1.030064	14.8636	-1.321
OGLE-LMC	15.511	16.101	5.234801	0.7189	14.5965	-2.399
OGLE-LMC	18.096	18.718	1.246675	0.095753	17.1319	0.218
OGLE-LMC	14.042	15.102	67.96544	1.832288	12.399	-3.398
OGLE-LMC	16.091	17.026	13.57787	1.132832	14.64175	-1.474

LMC_t2cephs.dat

Figure 3: Table 1: Sample of data from LMC

name	vmag	p	v0	r
OGLE-BLG-T2CEP-009	17.63	1.9	0.179666	9393.488043
OGLE-BLG-T2CEP-011	15.38	15.39	-2.20057	9974.084352
OGLE-BLG-T2CEP-015	18.09	1.28	0.62911	9439.261639
OGLE-BLG-T2CEP-016	18.16	1.92	0.167751	12056.18334
OGLE-BLG-T2CEP-017	18.53	1.1	0.801551	10677.01289
OGLE-BLG-T2CEP-018	18.07	1.62	0.361071	10581.46665
OGLE-BLG-T2CEP-020	17.97	1.66	0.333317	10235.20718
OGLE-BLG-T2CEP-022	18.62	1.05	0.854484	10860.83442
OGLE-BLG-T2CEP-025	15.85	10.14	-1.72582	9952.309845
OGLE-BLG-T2CEP-027	15.49	15.47	-2.20646	10520.90077
OGLE-BLG-T2CEP-032	15.39	16.31	-2.26663	10329.6564
OGLE-BLG-T2CEP-033	16.36	7.03	-1.30902	10388.78098
OGLE-BLG-T2CEP-036	16.92	3.7	-0.57869	9605.007392
OGLE-BLG-T2CEP-037	17.9	1.38	0.543517	8996.149029
OGLE-BLG-T2CEP-046	15.71	14.8	-2.15609	11375.67403
OGLE-BLG-T2CEP-047	17.14	4.8	-0.87485	12182.33137
OGLE-BLG-T2CEP-061	18.28	1.12	0.781049	9606.169465
OGLE-BLG-T2CEP-065	18.4	1.03	0.876366	9715.982094
OGLE-BLG-T2CEP-069	18.27	1.78	0.2539	12189.33692
OGLE-BLG-T2CEP-070	17.24	2.94	-0.31707	9866.747201
OGLE-BLG-T2CEP-076	18.14	1.34	0.576985	9893.795156
OGLE-BLG-T2CEP-086	15.48	15.15	-2.18268	10358.48448
OGLE-BLG-T2CEP-088	15.2	25.72	-2.78491	12015.5038
OGLE-BLG-T2CEP-118	15.84	9.89	-1.69741	9777.838433
OGLE-BLG-T2CEP-133	17.34	2.3	-0.03773	9084.591136
OGLE-BLG-T2CEP-136	16.09	11.16	-1.83488	11687.88791

bulge_t2cephs.dat

Figure 4: Table 2: Sample of data from bulge cepheids

C	D	E	F	G	H	I	J	K	L	M
00, 525)										
|dec	|cutout_size	|E_B_V_SandF	|mean_E_B_V_	|stdev_E_B_V_S	|max_E_B_V_S	|min_E_B_V_Sa	|AV_SandF	|E_B_V_SFD	|mean_E_B_V_	|stdev_E_
|double	|float	|float	|float	|float	|float	|float	|float	|float	|float	|float
|deg	|deg	|mags	|mags	|mags	|mags	|mags	|mags	|mags	|mags	|mags
-29.45988	5	1.0207	1.0212	0.0862	1.1869	0.8556	3.1641	1.1868	1.1874	0
-25.6399	5	0.949	0.9523	0.0373	1.0268	0.8958	2.9419	1.1035	1.1073	0
-27.10524	5	1.2072	1.2173	0.0911	1.4	1.0851	3.7423	1.4037	1.4155	
-27.24744	5	1.2621	1.2713	0.0597	1.3645	1.1615	3.9126	1.4676	1.4782	0
-27.5239	5	1.2934	1.3199	0.0253	1.3869	1.2903	4.0096	1.504	1.5347	0
-27.05473	5	1.1374	1.1418	0.0276	1.2023	1.0975	3.5258	1.3225	1.3276	0
-26.93146	5	1.2221	1.2252	0.0422	1.3162	1.162	3.7884	1.421	1.4247	0
-26.91644	5	1.206	1.2175	0.056	1.3341	1.1329	3.7386	1.4023	1.4157	0
-22.36929	5	0.8011	0.8105	0.0197	0.8417	0.779	2.4834	0.9315	0.9424	0
-20.99298	5	0.5931	0.5945	0.0098	0.6118	0.5684	1.8386	0.6896	0.6912	0
-23.44946	5	0.8186	0.8158	0.0169	0.8507	0.7811	2.5378	0.9519	0.9486	0
-24.24016	5	0.8672	0.8621	0.0221	0.9119	0.8182	2.6883	1.0084	1.0024	0
-23.97368	5	0.7916	0.7964	0.0286	0.8505	0.7359	2.4538	0.9204	0.926	0
-33.87526	5	1.3911	1.3668	0.1079	1.577	1.1918	4.3125	1.6176	1.5893	0
-23.85021	5	0.8907	0.8901	0.0826	1.0502	0.7421	2.7611	1.0357	1.035	
-24.34155	5	1.444	1.4793	0.1449	1.7291	1.2133	4.4763	1.679	1.7201	0
-33.28705	5	1.2671	1.2593	0.0514	1.3672	1.179	3.9279	1.4733	1.4643	0
-33.42115	5	1.2699	1.2165	0.0505	1.2886	1.0845	3.9367	1.4766	1.4146	0
-33.61466	5	0.994	1.0081	0.0331	1.0771	0.952	3.0813	1.1558	1.1723	0
-23.30181	5	1.2423	1.2543	0.0584	1.3779	1.155	3.8511	1.4445	1.4585	0
-23.13585	5	1.2641	1.2932	0.0825	1.4384	1.1591	3.9186	1.4698	1.5037	0
-37.11417	5	0.5709	0.5771	0.0316	0.6264	0.5195	1.7697	0.6638	0.6711	0
-33.95899	5	0.987	1.0347	0.1404	1.4047	0.8542	3.0597	1.1477	1.2032	0
-33.42133	5	0.9717	0.9586	0.0389	1.0248	0.8643	3.0124	1.1299	1.1147	0
-30.14268	5	0.8564	0.8886	0.0435	0.9763	0.8176	2.6547	0.9958	1.0333	0
-31.9173	5	1.1945	1.1793	0.0497	1.3037	1.108	3.7028	1.3889	1.3713	0
-30.13825	5	0.8385	0.849	0.0353	0.921	0.7923	2.5995	0.975	0.9872	0
-29.2064	5	1.0441	1.0486	0.0297	1.1158	0.9749	3.2368	1.2141	1.2193	0
-30.26114	5	0.974	0.9475	0.0595	1.0415	0.8448	3.0193	1.1325	1.1018	0
-30.34228	5	0.9352	0.962	0.046	1.047	0.8833	2.8992	1.0875	1.1186	0

extinction.tbl

Figure 5: Table 3: Sample of data from DIBRE Dust Map