INTERNATIONAL OLYMPIAD ON ASTRONOMY AND ASTROPHYSICS
Central Java - Indonesia

International Olympiad on Astronomy and Astrophysics

Data Analysis Problem

Problem 1

We have photometry and radial velocities data of the Cepheid type star HV2257, in Table 1-3 based on the observation by Gieren (MNRAS vol 265, 1993) . The pulsating period of the star is $P = 39.294$ days. A reference graph for temperature – color relation and bolometric correction tables are given in Figure 1 (Houdashelt *et al.*, 2000) and Table 4 (http://xoomer.virgilio.it/hrtrace/Straizys.htm). Given also that the solar luminosity is $L_{\odot} = 3.96 \times 10^{26} J\ s^{-1}$ and its bolometric magnitude $M_{\odot bol} = 4.72$.

a. Plot the light curve based on Table 1, only between phase 0.6 and 1
b. Plot the color in Table 2, only between phase 0.6 and 1
c. Plot the Radial Velocity curve from Table 3, only between phase 0.6 and 1
d. Calculate the distance to this pulsating star by using the observed data and supplementary data given in Table 4 and Figure 1. We assume that no extinction to this direction.

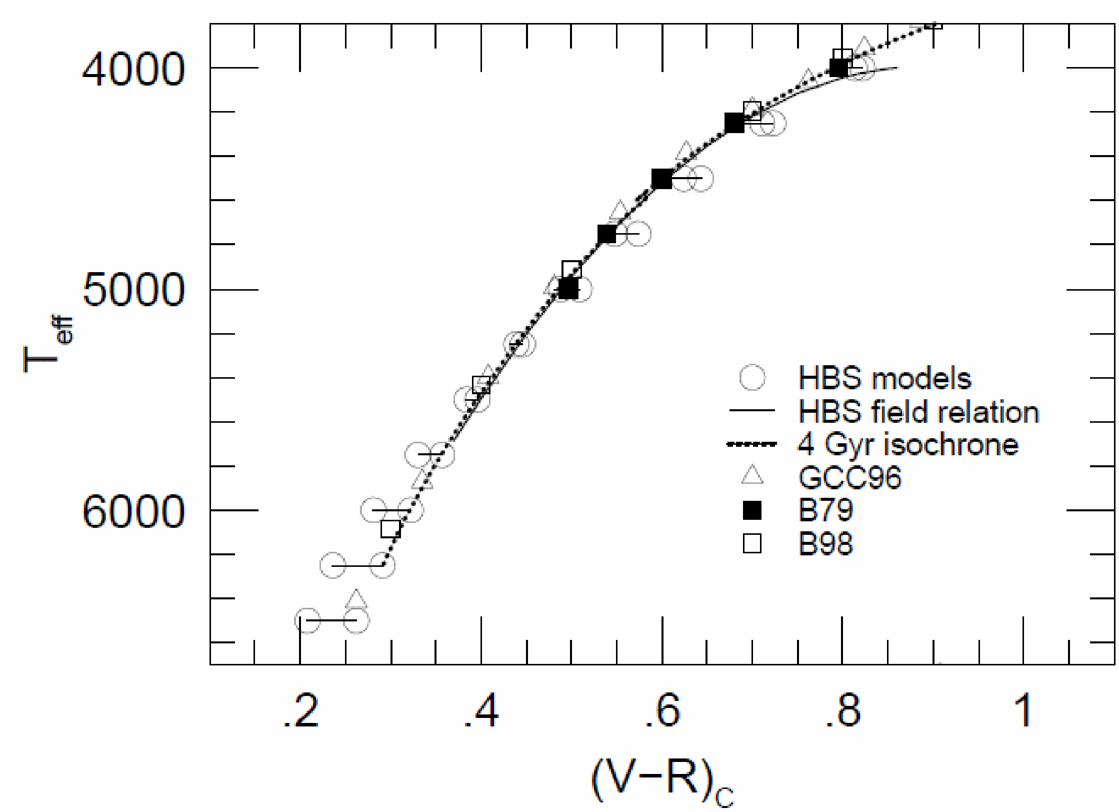

Fig. 1 The V-R color and temperature relation. Different symbol means different authors.

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Table 1

Phase	V mag
0.11	12.81
0.13	12.84
0.14	12.87
0.16	12.88
0.19	12.90
0.19	12.94
0.24	12.99
0.43	13.32
0.46	13.31
0.46	13.32
0.51	13.36
0.54	13.41
0.54	13.45
0.56	13.46
0.59	13.53
0.59	13.52
0.61	13.55
0.64	13.60
0.64	13.62
0.72	13.68
0.74	13.61
0.77	13.45
0.79	13.18
0.80	13.12
0.80	13.07
0.82	12.80
0.82	12.78
0.82	12.73
0.84	12.57
0.85	12.54
0.85	12.53
0.87	12.48
0.87	12.47
0.89	12.49
0.90	12.51
0.92	12.51

Table 2

Phase	V – R
0.22	0.71
0.24	0.73
0.25	0.74
0.27	0.75
0.29	0.75
0.29	0.75
0.34	0.77
0.51	0.87
0.53	0.85
0.53	0.87
0.57	0.85
0.60	0.87
0.60	0.88
0.62	0.87
0.64	0.90
0.64	0.90
0.66	0.88
0.68	0.91
0.69	0.90
0.76	0.88
0.78	0.82
0.80	0.79
0.82	0.70
0.82	0.70
0.82	0.68
0.84	0.60
0.84	0.59
0.84	0.58
0.86	0.53
0.86	0.51
0.87	0.52
0.88	0.51
0.89	0.51
0.90	0.55
0.91	0.53
0.93	0.56

Table 3

Phase	RadVel (km/s)
0.03	232
0.05	234
0.08	234
0.08	237
0.13	242
0.13	246
0.18	243
0.20	249
0.23	250
0.28	254
0.33	259
0.35	261
0.36	260
0.38	266
0.40	265
0.44	266
0.46	272
0.46	265
0.49	270
0.51	270
0.54	272
0.54	273
0.56	274
0.59	274
0.61	273
0.62	274
0.64	274
0.67	276
0.67	274
0.69	274
0.71	274
0.72	276
0.74	278
0.77	271
0.77	264
0.79	253
0.80	259
0.82	242
0.85	230
0.87	228
0.90	224
0.92	224
0.92	225
0.95	228
0.96	228

Table 4. Bolometric correction

T_{eff}, K	BC, mag
9600	-0.25
9400	-0.16
9150	-0.10
8900	-0.03
8400	0.05
8000	0.09
7300	0.13
7100	0.11
6500	0.08
6150	0.03
5950	0.00
5800	-0.05
5500	-0.13
5250	-0.22
5050	-0.29
4950	-0.35
4850	-0.42
4700	-0.57
4600	-0.75
4400	-1.17
3900	-1.25
3750	-1.40
3550	-1.60
3400	-2.00

Problem 2

You are given BVRIJHKLMN photometry of 2 stars from the constellation Cassiopeia (Table 5). For both, it is believed that their light is affected by extinction on diffuse ISM only.

a) Using the data given in Tables 5 to 9, plot $E_{\mathrm{X-V}}/E_{\mathrm{B-V}}$ as a function of $1/\lambda_{\mathrm{X}}$ for filters B, V, R, I, J, H, K, L, M, N for both stars, fitting appropriate curves to guide the eye (in particular, note that $E_{\mathrm{X-V}}/E_{\mathrm{B-V}} \sim const.$ as $1/\lambda_{\mathrm{X}} \to 0$).

b) Using the graphs obtained in a), estimate R_{V} and R_{r} for each star and hence find the expected values of these parameters corresponding to diffuse ISM in our Galaxy.

You are now going to apply these results in order to derive a distance estimate for IC 342, a spiral galaxy in Cassiopeia obscured by Milky Way. You should assume that the properties of ISM in IC 342 are similar to those of ISM in our Galaxy.

a) Using the period-magnitude diagrams for 20 Cepheids from IC 342 (Figures 2 and 3) and assuming the period-luminosity relations

$$\langle M_{\mathrm{r}} \rangle = -2.91\left(\log\left(\frac{P}{\mathrm{day}}\right) - 1\right) - 4.04 \quad \text{and} \quad \langle M_{\mathrm{i}} \rangle = -3.00\left(\log\left(\frac{P}{\mathrm{day}}\right) - 1\right) - 4.06$$

where $\langle M_{\mathrm{r,i}} \rangle$ are the mean absolute magnitudes in filters r and i, find A_{r} for objects in IC 342, and using the conversion formula

$$R_{\mathrm{r,r-i}} = \frac{A_{\mathrm{r}}}{E_{\mathrm{r-i}}} = \left(\frac{E_{\mathrm{r-V}}}{E_{\mathrm{B-V}}} + \frac{A_{\mathrm{V}}}{E_{\mathrm{B-V}}}\right)\frac{E_{\mathrm{B-V}}}{E_{\mathrm{r-i}}} = \frac{\frac{E_{\mathrm{r-V}}}{E_{\mathrm{B-V}}} + R_{\mathrm{V}}}{\frac{E_{\mathrm{r-V}}}{E_{\mathrm{B-V}}} - \frac{E_{\mathrm{i-V}}}{E_{\mathrm{B-V}}}},$$

find the distance to IC 342.

Table 5 BVRIJHKLMN photometry of two stars in Cassiopeia

Star	MK class	$\frac{B}{\mathrm{mag}}$	$\frac{V}{\mathrm{mag}}$	$\frac{R}{\mathrm{mag}}$	$\frac{I}{\mathrm{mag}}$	$\frac{J}{\mathrm{mag}}$	$\frac{H}{\mathrm{mag}}$	$\frac{K}{\mathrm{mag}}$	$\frac{L}{\mathrm{mag}}$	$\frac{M}{\mathrm{mag}}$	$\frac{N}{\mathrm{mag}}$
HD 4817	K3Iab	8.08	6.18	4.73	3.64	2.76	1.86	1.54	1.32	1.59	-
HD 11092	K4II	8.66	6.57	-	-	3.10	2.14	1.63	1.41	1.65	1.44

Table 6 $(B-V)_0$ intrinsic colours for selected sp. types and luminosity classes

	$\frac{(B-V)_0}{\mathrm{mag}}$	
	II	Iab / Ia
F0	-	0.15
G0	0.73	0.82
K0	1.06	1.18
K3	1.40	1.42
K4	1.42	1.50

Table 7 Infrared intrinsic colours for selected sp. types of supergiant stars

	$\frac{(V-R)_0}{\mathrm{mag}}$	$\frac{(V-I)_0}{\mathrm{mag}}$	$\frac{(V-J)_0}{\mathrm{mag}}$	$\frac{(V-H)_0}{\mathrm{mag}}$	$\frac{(V-K)_0}{\mathrm{mag}}$	$\frac{(V-L)_0}{\mathrm{mag}}$	$\frac{(V-M)_0}{\mathrm{mag}}$	$\frac{(V-N)_0}{\mathrm{mag}}$
F0	0.20	0.31	0.36	0.51	0.60	0.64	0.65	0.82
G0	0.55	0.90	1.14	1.52	1.71	1.72	1.72	1.98
K0	0.95	1.59	2.01	2.64	2.80	2.87	2.79	3.14
K3	1.13	1.96	2.41	3.14	3.25	3.39	3.25	3.63
K4	1.20	2.13	2.59	3.37	3.44	3.62	3.46	3.84

Table 8 Infrared intrinsic colours for selected sp. types of giant stars

	$\frac{(V-R)_0}{\mathrm{mag}}$	$\frac{(V-I)_0}{\mathrm{mag}}$	$\frac{(V-J)_0}{\mathrm{mag}}$	$\frac{(V-H)_0}{\mathrm{mag}}$	$\frac{(V-K)_0}{\mathrm{mag}}$	$\frac{(V-L)_0}{\mathrm{mag}}$	$\frac{(V-M)_0}{\mathrm{mag}}$	$\frac{(V-N)_0}{\mathrm{mag}}$
K0	0.60	1.03	1.23	1.72	1.94	1.97	1.90	1.92
K3	0.86	1.39	1.84	2.40	2.69	2.82	2.70	2.73
K4	0.96	1.61	2.16	2.77	3.05	3.22	3.08	3.02

Table 9 Effective wavelengths of selected photometric filter

Filter	B	V	R	I	J	H	K	L	M	N	r	i
$\lambda_{\mathrm{F}}/\mathrm{nm}$	450	555	670	870	1200	1620	2200	3500	5000	9000	650	820

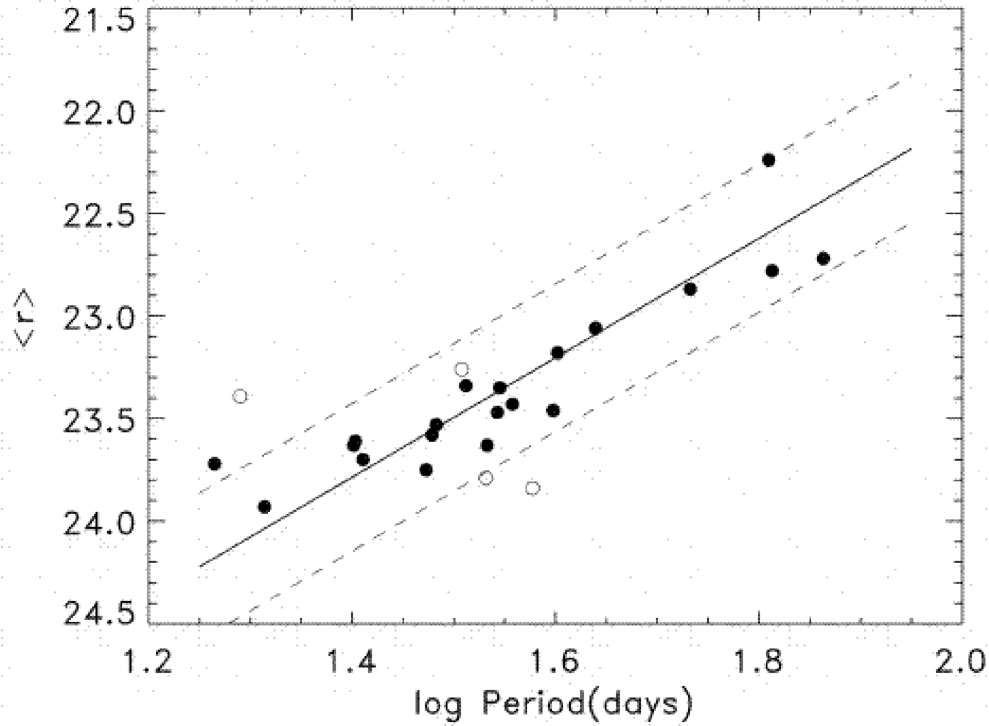

Fig. 2 $\langle r \rangle$ is the mean apparent magnitude in filter r

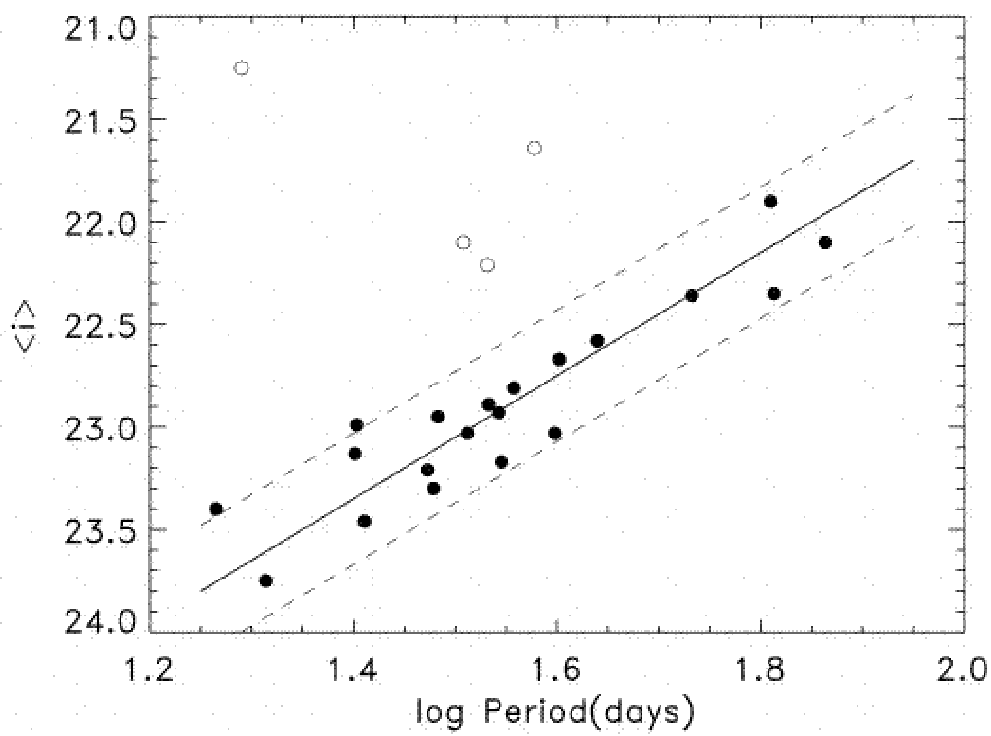

Fig. 3 $\langle i \rangle$ is the mean apparent magnitude in filter i