Bull. Astr. Soc. India (1982) **10**, 217–222

Places of formation of nineteen nearby classical Cepheids

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Received 1982 May 5; accepted 1982 June 30

Abstract. Places of formation of 19 nearby classical Cepheids have been computed in a model of our Galaxy which has axisymmetric and spiral-like components. For the axisymmetric component Schmidt's (1965) model is used, and spiral-like perturbations are approximated by logarithmic spirals. Different pattern speeds, Ω_p, have been used to get the best correlation of places of formation with a spiral structure. We conclude that best fit is obtained with $\Omega_p = 13.5$ km s^{-1} kpc^{-1}.

Key words: Cepheids—density wave

1. Introduction

A study of the migration of stars was initiated by Strömgren (1967) in an attempt to find correlation between the places of formation of stars and the spiral structure of the Galaxy. Strömgren (1967) suggested the possibility of testing the density wave theory of galactic spirals by checking whether the individual stars in the solar neighbourhood were indeed formed in the travelling spiral arms. He also reported his preliminary investigation of the ideas, based on the orbit calculations by Contopoulos & Strömgren (1965), in which only symmetrical field was considered.

Yuan (1969) calculated the orbits and places of origin for 25 moderately old B6-B8 stars, using the kinematic data specified by Strömgren (1967) and Schmidt (1965). The main difference between the two studies by Strömgren (1967) and Yuan (1969) lies in the different gravitational potentials used; Yuan (1969), unlike Strömgren (1965), uses the gravitational field of the density wave.

The study of the migration of nearby classical Cepheids by Wielen (1973) used the same parameters for the density waves as adopted by Yuan (1969) and found that the derived birthplaces of most nearby Cepheids are in agreement with the predictions of Lin's density wave theory (Lin 1969). He found that most of the nearby Cepheids probably originated in the Sagittarius arm and in the Perseus arm. Only the youngest nearby Cepheids are not formed within these main spiral arms but are born probably in the local arm. Palouš *et al.* (1977) determined the places of formation of 24 open clusters. They varied the angular rotation speed of spiral arms, Ω_p, to get the best correlation of places of formation with a spiral structure.

Forte & Muzzio (1976) used the density wave model of spiral structure to calculate the positions of the birthplaces, relative to the spiral wave, of ten open clusters which have good observational kinematic data. They found that the results agree well with the model. The youngest open cluster seem to have been born in between spiral arms, a result similar to the one found by Wielen (1973) for Cepheids.

In the present work places of formation of 19 nearby classical Cepheids have been computed. The kinematic data and age given by Wielen (1973, 1974) are used. Unlike Wielen (1973) different pattern speeds Ω_p have been used to get the best correlation of places of formation with a spiral structure. The gravitational potential given by Contopoulos (1974, personal communication) has been used.

2. Orbit computations

The computations of the birthplaces have been performed using the same method and parameters, except for the axisymmetrical part of the gravitational potential, employed by Wielen (1973) who in turn uses the same spiral pattern as Yuan (1969). For axisymmetrical part of the gravitational potential we have used the formula given by Contopoulos (1974, personal communication) which has also been used by Palouš *et al.* (1977) in the determination of places of formation of some clusters.

The equations of motion were numerically integrated backward in time using the modifield Runge-Kutta method (Gill's method). The present positions of the nearby classical Cepheids were taken from Wielen (1973, 1974) and are listed in table 1, in the line corresponding to $t = 0$. The unit of time is equal to 978×10^6 yr. The peculiar space velocity components U, V, W are also listed in table 1. These velocities are not corrected for an intrinsic K-term.

Table 1. Places and velocities of Cepheids at present and at the epoch of formation

Sl No.	Star	Cluster or Association	Mean error tg (km s^{-1})	Time t (10^7 yr)	Positions (kpc)			Space velocities (km s^{-1})			Ω_p (km s^{-1} kpc^{-1})
					ξ	η	ζ	U	V	W	
1	α UMi	Pleiades	±1	0	−.05	+.08	+.05	− 2	−13	1	0
				−5.9	.97	−.21	+.04	−23	10	−1	11.0
				−5.9	.95	−.18	+.04	−24	10	−1	13.5
				−5.9	.94	−.16	+.04	−24	10	−1	15.0
				−5.9	.91	−.12	+.04	−25	9	−1	17.5
				−5.9	.88	−.09	+.04	−24	8	−1	20.0
2	δ Cep		±2	0	−.07	.27	0	−10	− 9	−2	0
				−4.8	.75	−.08	−.02	−20	9	0	11.0
				−4.8	.73	−.06	−.02	−20	9	0	13.5
				−4.8	.72	−.05	−.02	−20	9	0	15.0
				−4.8	.70	−.03	−.02	−19	8	0	17.5
				−4.8	.67	−.01	−.02	−19	7	0	20.0
3	SU Cas		±5	0	− .22	.23	.05	7	8	−1	0
				−9.4	−1.13	4.03	.07	2	−19	0	11.0
				−9.4	−1.15	4.12	.07	1	−20	0	13.5
				−9.4	−1.14	4.15	.07	0	−19	0	15.0
				−9.4	−1.11	4.16	.07	−2	−18	0	17.5
				−9.4	−1.06	4.13	.07	−4	−16	0	20.0
4	η Aql		±2	0	.20	.18	−.06	− 5	−2	−6	0
				−4.0	.52	−.27	−.01	−10	+6	8	11.0
				−4.0	.51	−.26	−.01	−10	+5	8	13.5
				−4.0	.50	−.26	−.01	−10	+5	8	15.0
				−4.0	.49	−.25	−.01	− 9	+5	8	17.5
				−4.0	.47	−.24	−.01	− 8	+4	8	20.0

Continued

Table 1—*Continued*

Sl No.	Star	Cluster or Association	Mean error *tg* (km s⁻¹)	Time *t* (10^7 yr)	Positions (kpc) ξ	η	ζ	Space velocities (km s⁻¹) *U*	*V*	*W*	Ω_p (km s⁻¹ kpc⁻¹)
5	β Dor		±6	0	.01	−.27	−.18	6	−0	10	0
				−3.3	−.19	−.10	.17	4	−4	−11	11.0
				−3.3	−.20	−.09	.17	4	−4	−11	13.5
				−3.3	−.20	−.09	.17	5	−4	−11	15.0
				−3.3	−.21	−.08	.17	6	−5	−11	17.5
				−3.3	−.22	−.08	.17	6	−5	−11	20.0
6	ζ Cem		±2	0	−.33	−.09	.07	2	.13	−4	0
				−3.2	−.81	.12	−.04	25	3	6	11.0
				−3.2	−.82	.12	−.04	25	3	6	13.5
				−3.2	−.82	.12	−.04	25	3	6	15.0
				−3.2	−.83	.12	−.04	26	3	6	17.5
				−3.2	−.83	.13	−.04	26	3	6	20.0
7	FF Aql		±8	0	.27	.31	.05	1	−10	−11	0
				−5.5	1.02	−.34	−.03	−19	8	−12	11.0
				−5.5	1.01	−.33	−.03	−20	8	−12	13.5
				−5.5	1.01	−.32	−.03	−21	8	−12	15.0
				−5.5	0.99	−.29	−.03	−21	8	−12	17.5
				−5.5	0.97	−.27	−.03	−21	7	−12	20.0
8	l Car		±7	0	0.10	−.42	−.05	−9	4	0	0
				−1.4	0.21	−.56	−.01	−6	6	−4	11.0
				−1.4	0.21	−.56	−.01	−5	6	−4	13.5
				−1.4	0.20	−.56	−.01	−5	6	−4	15.0
				−1.4	0.20	−.56	−.01	−5	6	−4	17.5
				−1.4	0.20	−.56	−.01	−5	6	−4	20.0
9	X Sgr		±4	0	.39	.01	0	−5	−4	−2	0
				−4.1	.88	−.74	−.02	−13	7	1	11.0
				−4.1	.88	−.73	−.02	−14	7	1	13.5
				−4.1	.87	−.73	−.02	−14	7	1	15.0
				−4.1	.87	−.72	−.02	−14	7	1	17.5
				−4.1	.86	−.72	−.02	−14	7	1	20.0
10	DT Cyg		±8	0	.1	.42	−.08	−4	14	11	0
				−8.0	−1.08	.92	−.15	17	−9	4	11.0
				−8.0	−1.17	1.05	−.15	21	−11	5	13.5
				−8.0	−1.23	1.13	−.15	22	−13	5	15.0
				−8.0	−1.31	1.26	−.15	24	−15	6	17.5
				−8.0	−1.36	1.37	−.15	24	−16	6	20.0
11	RT Aur		±11	0	−.46	−.03	0.07	−11	−13	3	0
				−6.1	.77	−.03	+.07	−22	13	−0	11.0
				−6.1	.74	+.01	+.07	−22	12	−.0	13.5
				−6.1	.73	+.03	+.07	−22	12	−0	15.0
				−6.1	.69	+.08	+.07	−22	11	−0	17.5
				−6.1	.65	+.12	+.07	−21	10	−0	20.0
12	W Sgr		±8	0	.44	.01	−.03	−19	13	−10	0
				−3.9	.75	−1.47	−.06	8	21	8	11.0
				−3.9	.75	−1.47	−.06	8	21	8	13.5
				−3.9	.75	−1.47	−.06	8	21	8	15.0
				−3.9	.75	−1.47	−.06	8	21	8	17.5
				−3.9	.74	−1.46	−.06	8	20	8	20.0
13	SZ Tau	NGC 1647	±11	0	−.45	0	−.15	20	3	−15	0
				−6.9	−1.38	3.59	−.21	4	−21	12	11.0
				−6.9	−1.36	3.57	−.21	3	−20	12	13.5
				−6.9	−1.35	3.56	−.21	2	−19	12	15.0
				−6.9	−1.32	3.53	−.21	+0	−18	12	17.5
				−6.9	−1.29	3.49	−.21	−2	−17	12	20.0

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Table 1—*Continued*

Sl No.	Star	Cluster or Association	Mean error *tg* (km s^{-1})	Time *t* (10^7 yr)	Positions (kpc) ξ	η	ζ	Space velocities (km s^{-1}) *U*	*V*	*W*	Ω_p (km s^{-1} kpc^{-1})
14	Y Sgr		±12	0	.49	.11	− 02	6	−11	−18	0
				−4.6	1.02	−.41	−.16	−22	2	− 1	11.0
				−4.6	1.02	−.40	−.16	−23	2	− 1	13.5
				−4.6	1.02	−.40	−.16	−23	2	− 1	15.0
				−4.6	1.01	−.39	−.16	−24	2	− 0	17.5
				−4.6	1.00	−.38	−.16	−24	2	− 0	20.0
15	AH Vel		±13	0	−.07	−.56	−.07	18	−13	−8	0
				−5.7	0.11	0.75	0.05	−27	− 9	9	11.0
				−5.7	0.07	0.79	0.06	−25	−10	9	13.5
				−5.7	0.05	0.81	0.06	−24	−11	9	15 0
				−5.7	0.01	0.84	0.06	−22	−12	8	17.5
				−5.7	−0.02	0.88	0.06	−20	−13	8	20.0
16	T Vul		±8	0	0.17	0.54	−0.10	−0	3	−23	0
				−5.5	0.06	0.25	−0.25	−1	2	− 3	11.0
				−5.5	0.03	0.28	−0.25	1	1	− 3	13.5
				−5.5	0.01	0.30	−0.25	2	+0	− 3	15.0
				−5.5	−0.03	0.34	−0.25	3	−1	− 3	17.5
				−5.5	−0.07	0.40	−0.26	5	−2	− 2	20.0
17	U Sgr	M 25	±15	0	0.60	0.15	−0.05	+15	−19	−3	0
				−4.2	1.07	0.05	−0.01	−33	− 6	6	11.0
				−4.2	1.07	0.05	−0.01	−33	− 6	6	13.5
				−4.2	1.07	0.06	−0.01	−34	− 6	6	15.0
				−4.2	1.06	0.06	−0.01	−34	− 6	6	17.5
				−4.2	1.05	0.07	−0.01	−34	− 6	6	20.0
18	U Vul		±15	0	0.37	0.54	0	−20	8	−23	0
				−3.7	0.84	−0.72	−0.15	− 1	19	16	11.0
				−3.7	0.83	−0.72	−0.15	− 1	19	16	13.5
				−3.7	0.83	−0.72	−0.15	− 1	19	16	15.0
				−3.7	0.83	−0.71	−0.15	− 1	19	16	17.5
				−3.7	0.82	−0.71	−0.15	− 1	19	16	20.0
19	U Aql		±15	0	0.53	0.32	−0.13	−14	22	9	0
				−4.1	0.33	−1.29	+0.14	22	19	7	11.0
				−4.1	0.33	−1.29	+0.14	23	19	7	13 5
				−4.1	0.32	−1.29	+0.14	23	19	7	15.0
				−4.1	0.32	−1.28	+0.14	23	19	7	17.5
				−4.1	0.31	−1.28	+0.14	24	19	7	20.0

3. Places of formation and conclusions

The positions of the Cepheids at the epoch of formation $t = -\tau$ are determined from the computed orbits, which in the Ω_p system, corotating with the spiral density wave and in which the wave is at rest, are given in table 2 and plotted in figure 1. In figure 1 the present position of the density wave is given. The portion of the galactic plane with an excess density according to this density wave is indicated by the shaded regions. The positions of places of formation of Cepheids relative to this density wave are indicated by the filled circle.

We have computed the places of formation of Cepheids adopting five different rotation speeds Ω_p, 11.0, 13.5, 15.0, 17.5 and 20.0 km s^{-1} kpc^{-1}. We assume that the classical Cepheids are born in the spiral arms or in those parts of the galactic plane where there is an excess density due to the density-wave.

Palouš *et al.* (1977) concluded that there exist two equally acceptable angular speeds Ω_p for getting the best correlation between the spiral arms and the places of

Table 2. The places of formation of classical Cepheids in the Ω_p system (with positions in kpc)

Sl No.	Star	$\Omega_p = 11$		$\Omega_p = 13.5$		$\Omega_p = 15.0$		$\Omega_p = 17.5$		$\Omega_p = 20$	
		ξ_p	η_p	ξ_p	η_p	ξ_p	η_p	ξ_p	η_p	ξ_p	η_p
1	α UMi	4.16	−6.89	3.16	−5.92	2.63	−5.27	1.88	−4.09	1.31	−2.79
2	δ Cep	2.90	−5.93	2.20	−5.01	1.83	−4.42	1.33	−3.37	0.96	−2.27
3	SU Cas	3.58	−9.95	1.31	−8.11	−0.22	−6.75	−1.09	−4.20	−1.72	−1.45
4	η Aql	2.18	−5.37	1.66	−4.54	1.39	−4 01	1.01	−3.11	0.72	−2.17
5	β Dor	0.97	−4.72	0.60	−3.94	0.40	−3.46	0.13	−2.64	−0.06	−1.80
6	ζ Gem	0.25	−4.68	−0.11	−3.86	−0.29	−3.36	−0.53	−2.51	−0 71	−1.64
7	FF Aql	3.90	−6.61	3.02	−5.68	2.56	−5.06	1.90	−3.96	1.40	−2.76
8	l Car	0.54	−2.59	0.45	−2.23	0.40	−2.02	0.33	−1.65	0.27	−1 29
9	X Sgr	2.81	−5.66	2.26	−4.88	1.96	−4.38	1.54	−3.51	1.21	−2.60
10	DT Cyg	4.59	−9.71	2.56	−8.41	1.50	−7.42	0.03	−5.48	−0.97	−3.26
11	RT Aur	4.09	−7.09	3.02	−6.08	2.45	−5.39	1.66	−4.13	1.06	−2.76
12	W Sgr	2.94	−6.15	2.36	−5.41	2.05	−4.94	1.59	−4.13	1.22	−3.27
13	SZ Tau	0.74	−7.52	−0.42	−5.78	−0.95	−4.65	−1.55	−2.67	−1.80	−0.62
14	Y Sgr	3.15	−5.82	2.51	−4.95	2.17	−4.42	1.70	−3.47	1.34	−2.46
15	AH Vel	2.68	−6.69	1.73	−5.55	1.25	−4.80	0.59	−3.46	0.15	−2.04
16	T Vul	2.81	−6.86	1.88	−5.78	1.39	−5.07	0.71	−3.80	0.23	−2.43
17	V Sgr	2.61	−5.01	2.11	−4.19	1.86	−3.67	1.50	−2.77	1.24	−1.84
18	V Vul	2.46	−5.25	1.99	−4.52	1.75	−4.05	1.39	−3.25	1.12	−2.42
19	V Aql	2.67	−6.43	2.03	−5.63	1.69	−5.12	1.19	−4.22	0.78	−3.27

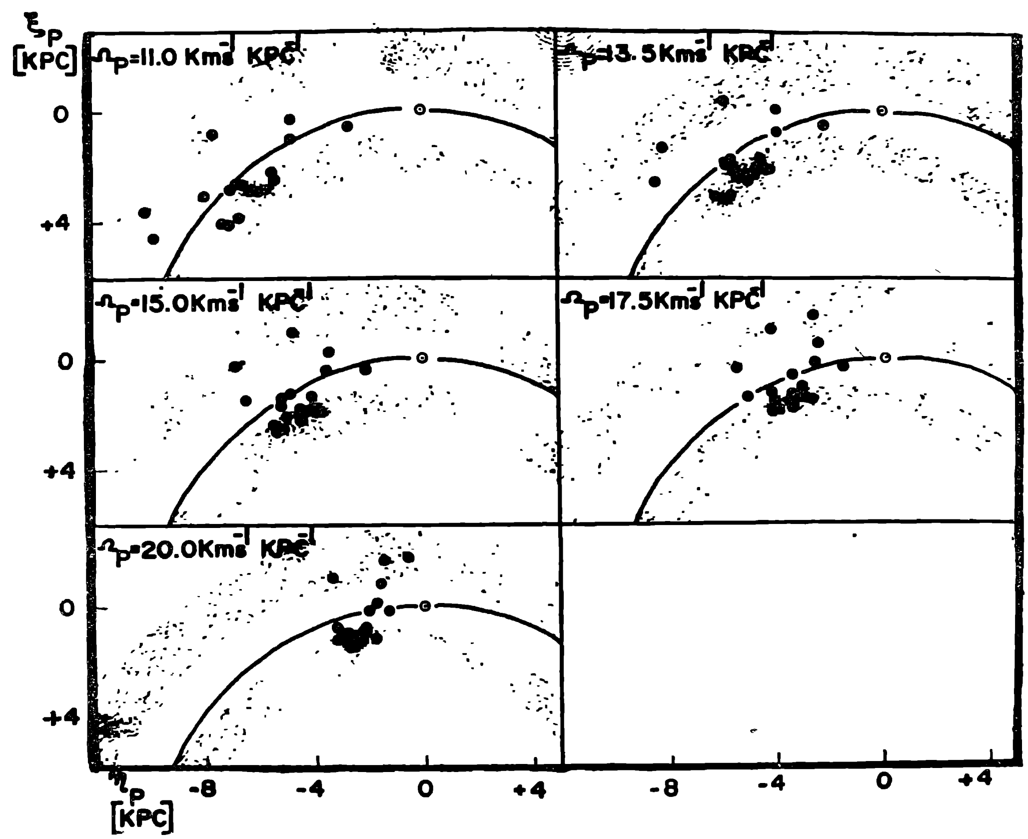

Figure 1. Birthplaces of classical Cepheids in a system that rotates with the spiral wave. The shaded areas correspond to the Perseus and Sagittarius arms; the full line shows a circular orbit through the sun, for comparison. The present location of the sun is at the origin of the coordinates while the birthplaces of Cepheids are shown by ●. The angular rotation speed of the density-wave is Ω_p.

formation of open clusters, namely $\Omega_p = 13.5$ and $20.0 \text{ km s}^{-1} \text{ kpc}^{-1}$. We have obtained the best correlation only for the speed $\Omega_p = 13.5 \text{ km s}^{-1} \text{ kpc}^{-1}$. Palouš *et al.* (1977) have used in their calculations clusters ranging in age between 10^6 and 800×10^6 yr, whereas in our samples we have used young and moderately young Cepheids only. Since normally the relative error in age estimation of a cluster is about 40 per cent (Palouš *et al.* 1977) and in some cases even up to 70 per cent, the absolute error for older clusters will therefore be comparatively high. Therefore, we cannot put high confidence on the basis of the samples of older clusters or stars unless the age estimation methods are precise.

Acknowledgement

The author thanks Dr S. D. Sinvhal for guidance and helpful discussions.

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