Binarity and cluster membership of classical Cepheids

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Abstract

In view of the high incidence of binaries among Cepheids, photometric and physical companions exert adverse effects on the Cepheid related relationships. Companions may also cause physical effects (e.g., phase jump in the pulsation, slight excitation of non-radial modes). Many new binaries among Cepheids can be revealed by Gaia via radial velocity measurements and by deriving astrometric orbit from data to be obtained during the five year active lifetime of spacecraft.

Similarly to binarity, cluster membership of Cepheids also facilitates the calibration of the period-luminosity relationship independently of the pulsation. A brief summary on the membership of Cepheids in clusters in our Galaxy and both Magellanic Clouds is also given.

1. Cepheids from Hipparcos to Gaia

Hipparcos observed about 300 classical Cepheids, mainly the brighter ones (Fig. 1). Cepheids fainter than 10th magnitude have been generally unobserved and even much of them remains to be discovered, e.g., by Gaia (Fig. 2).

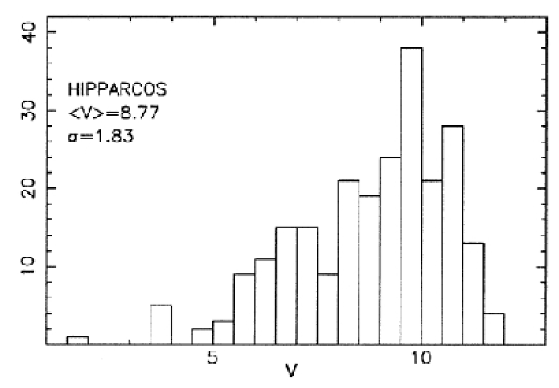

Figure 1: *Brightness distribution of Cepheids with known Hipparcos parallax [1].*

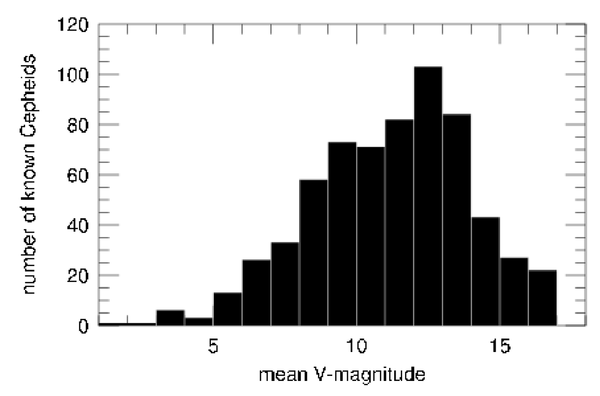

Figure 2: *Distribution of the apparent brightness for Galactic classical Cepheids.*

The period dependence of various physical properties of Cepheids (e.g., period-luminosity and period-radius relationships) are instrumental in establishing the cosmic distance scale and studying stellar structure and evolution. Precise calibration of these relationships is hindered by the photometric effect of the companions. In spite of the fact that binarity is common among Cepheids – at least 50 % of Cepheids are not solitary stars [2] – binarity is even neglected in many studies dealing with various Cepheid related relationships.

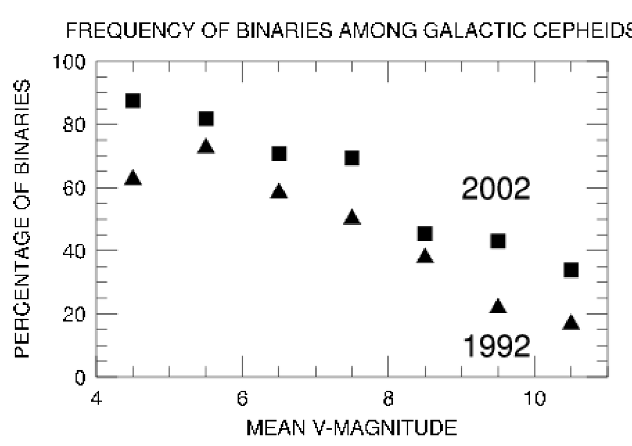

Figure 3: *Selection effect acting against revealing binaries among fainter Cepheids.*

Figure 3 indicates a strong selection effect in discovering binarity of Cepheids: for stars fainter than 9th magnitude, it is increasingly difficult to reveal a companion (dedicated spectroscopic observations are needed).

Figure 4 shows the conventional astrometric solution which is, in fact, a simplification in the case of binary stars. The sensitivity of Hipparcos was insufficient to perform an astrometric solution for the orbit of any Cepheid hosting binary system. Therefore, the derived Hipparcos parallax may have been influenced by neglecting the apparent orbital arc, i.e., by attributing all the angular displacement to parallactic and proper motions (see Fig. 5).

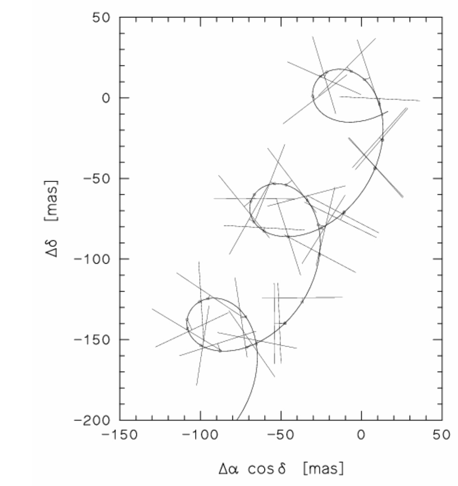

Figure 4: *Celestial displacement of a (solitary) star due to the parallactic and proper motions, as detected by Hipparcos.*

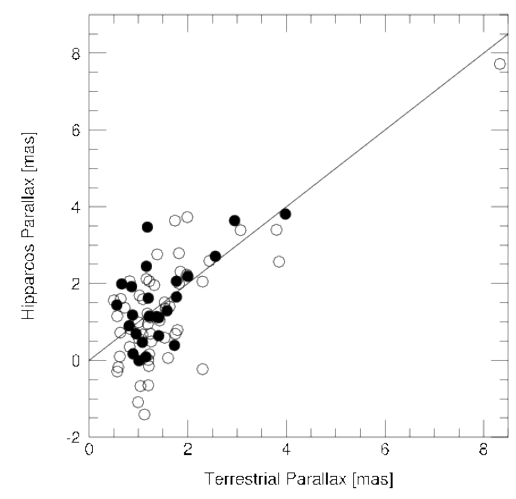

Figure 5: *Hipparcos vs. 'ground-based' parallax of the nearest Cepheids. Open circles denote Cepheids with known companion(s). Cepheids without (known) companions are marked with black dots.* Note that all negative parallax values belong to known binaries.

2. Other effects of binarity

A number of Cepheids with companions will certainly turn to be astrometric binaries for Gaia, because the angular size of the projected orbit is sufficiently large (see the last column in Table 1), and the time base of Gaia observations will be favourable to cover a complete orbit of typical binary systems involving a Cepheid component.

Cepheid	$\log P$	$\langle V \rangle$ (m)	E_{B-V} (m)	M_V (m)	Distance (pc)	Orbital period (d)	$a \times \sin i$ (AU)	Angular size of projected orbit (mas)
U Aql	0.846	6.48	0.4	−3.53	566	1856	1.3	**2.3**
FF Aql	0.807	5.37	0.21	−3.41	422	1434	0.7	**1.6**
RX Cam	0.898	7.68	0.54	−3.69	868	1115	1.3	**1.5**
Y Car	0.561	8.14	0.17	−2.65	1127	1000	0.7	**0.6**
YZ Car	1.259	8.71	0.37	−4.80	2970	657	0.6	**0.2**
DL Cas	0.903	8.97	0.48	−3.70	1725	685	1.0	**0.6**
AX Cir	0.722	5.89	0.29	−3.14	423	6530	6.1	**14.4**
SU Cyg	0.585	6.86	0.09	−2.72	725	549	1.4	**2.0**
MW Cyg	0.775	9.47	0.62	−3.31	1482	439	0.2	**0.2**
V1334 Cyg	0.678	5.87	0	−3.01	596	1938	2.5	**4.1**
Z Lac	1.037	8.42	0.38	−4.12	1868	382	0.4	**0.2**
T Mon	1.432	6.13	0.2	−5.33	1475	32450	24.1	**16.3**
S Mus	0.985	6.13	0.22	−3.95	760	505	0.7	**0.9**
AW Per	0.811	7.52	0.51	−3.42	744	14600	13.8	**18.6**
S Sge	0.923	5.61	0.11	−3.76	640	676	0.9	**1.5**
W Sgr	0.881	4.67	0.11	−3.63	391	1651	0.1	**0.4**
V350 Sgr	0.712	7.47	0.3	−3.11	852	1475	1.2	**1.4**
V636 Sco	0.833	6.65	0.21	−3.49	789	1360	1.5	**2.0**
α UMi	0.755	1.98	0	−3.24	111	10800	3.0	**27.0**
U Vul	0.903	7.13	0.59	−3.70	632	2510	0.5	**0.9**

Table 1: *Cepheids with known orbits.*

If the companion is not too faint, it obviously decreases the observable photometric amplitudes of the Cepheid. This effect depends on the difference between the effective temperature of the Cepheid and that of its companion. The pulsational radial velocity amplitude is also falsified without removing the orbital effect (see Fig. 6). Binarity is one of the causes of the scatter in the period-amplitude relationship.

The radius (and luminosity) of the Cepheids is usually determined by some version of the surface brightness method. The effect of the companion star has to be taken into account individually for each Cepheid, otherwise the derived radius is falsified (Fig. 7).

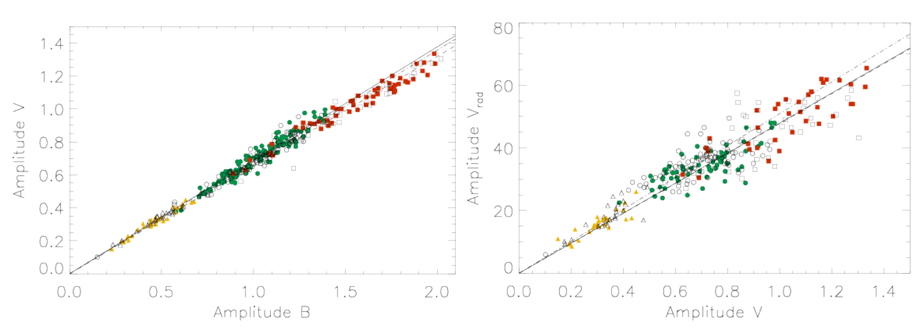

Figure 6: *Interrelation of various amplitudes (*left: *V vs. B photometric amplitudes;* right: *radial velocity vs. V amplitudes. Cepheids in binary systems (denoted with empty symbols) show a stronger deviation from the ridge-line fit. (Grouping into s-Cepheids, short- and long-period Cepheids is irrelevant here.)*

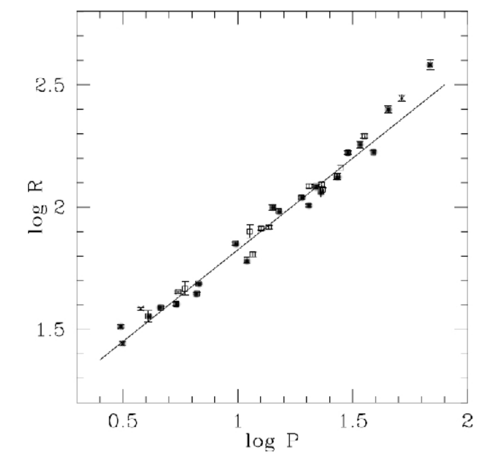

Figure 7: *Period-radius relation for Cepheids adopted from [3]. Cepheids with known companions, denoted with filled characters, show wide scatter around the fitted linear relationship.*

There is growing evidence that non-radial modes can be slightly excited in the pulsation of classical Cepheids [5]. Another physical effect of the companion is the occasional phase jump in the pulsation observed, e.g., in the $O-C$ diagram of Polaris (Fig. 8). Other binary Cepheids (V532 Cyg, X Lac, etc.) also show such phase jump.

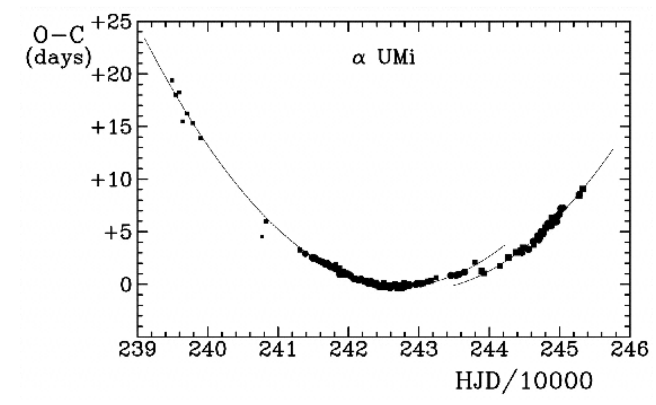

Figure 8: *$O-C$ diagram of Polaris, a Cepheid with physical companion, showing a phase jump in the pulsation [4].*

3. Cluster membership of Cepheids

Gaia data will be instrumental in confirming cluster membership of many Cepheids. The distance of such Cepheids can be determined by various methods (surface brightness, ZAMS fitting, binarity, double-mode pulsation). Then the independently derived distances can be intercompared, leading to a more precise calibration of the period-luminosity relationship.

The sample of cluster-member Cepheids is rather large:

- in the Milky Way Galaxy: 46 Cepheids in 42 clusters/associations (12 in spectroscopic binary systems, 1 double-mode pulsator);
- in the Large Magellanic Cloud: 289 Cepheids in 144 clusters (7 double-mode Cepheids);
- in the Small Magellanic Cloud: 134 Cepheids in 83 clusters (3 double-mode Cepheids).

Most promising cases are:

- In our Galaxy: NGC 7790 (3 Cepheids: CEa Cas, CEb Cas, CF Cas), NGC 6067 (2 Cepheids: QZ Nor, V340 Nor), NGC 6649 (double-mode Cepheid V367 Sct), NGC 129 (DL Cas, Cepheid in a spectroscopic binary), M 25 (U Sgr, Cepheid in a spectroscopic binary).
- in the LMC: NGC 1866 (23 known Cepheids), NGC 1943 (13 known Cepheids), NGC 1958 (15 known Cepheids, including a double-mode pulsator), NGC 2031 (14 known Cepheids), NGC 2058 (14 known Cepheids), NGC 2065 (10 known Cepheids, including a double-mode pulsator).
- In the SMC: SMC0048 (4 known Cepheids, including a double-mode pulsator), SMC0048 (2 known Cepheids, including a double-mode pulsator).

The Magellanic sample is based on the OGLE-III data. Because of limited space, bibliography for cluster membership of Cepheids is not given here.

4. Acknowledgements

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References

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