# Period variation of the classical Cepheid W Gem over a century (1895-2024)

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**Abstract**:

This study analyzes 235 new times of visual, CCD, photoelectric and photographic maximum of the classical Cepheid W Gem. The corresponding observations were made between 1895 and 2024. On this new and large observational basis, the period variations of this star are re-visited. Without contradicting the theory or previous studies, we show that visual observations are important for a long-term monitoring of the period variations of well-selected bright Cepheids. This study establishes the period rate of change of W Gem at – 1.74 s/yr. The O-C diagrams show no periodic variation. W Gem appears to be a single Cepheid.

**Résumé**:

Cette étude présente 235 nouveaux instants de maxima visuels, CCD, photoélectriques et photographiques, de la céphéide classique W Gem collectés entre 1895 et 2024. Sur cette nouvelle et vaste base observationnelle, les variations de la période de cette étoile sont réexplorées. Sans bouleverser la théorie ni les études précédentes, l'étude montre que les observations visuelles sont d'une grande utilité pour un suivi à long terme des variations de période de céphéides brillantes bien sélectionnées. Cette étude établit le taux de variation de période de W Gem à – 1.74 s/yr. Les diagrammes des O-C ne montrent aucune variation périodique. W Gem ne semble pas appartenir à un système binaire.

## 1. Introduction

The classical Cepheid W Gem has been added to the GEOS Cepheid program till the first years of that "pro-am" group founded in 1974. The actual aim of that visual observational program is a survey of Cepheids with periods known to be variable, as noticed by Szabados in his classical studies (1977, 1980, 1981, 1991).

The table 1 gives the current elements of the GCVS (Samus et al., 2017) for W Gem. In note, the GCVS underlines a variable period and a possibly faint blue companion.

Table 1: GCVS current elements for W Gem.

| α (h:m:s) J2000.0 | δ (° ' '') J2000.0 | HJD origin (+2400000) | Period (days) | V mag. range | M-m | Spectra | Ref. of the ephemeris |
|---|---|---|---|---|---|---|---|
| 06 34 57.45 | +15 19 49.7 | 42755.191 | 7.913779 | 6.54-7.38 | .30 | F5-G1 | Szabados 1980 |

Szabados (1980) gives a first O-C diagram with broken lines and the actual reference ephemeris. Later, Szabados (1991), reexamines his interpretations and proposes a parabola to fit the new times of maximum he collected (Figure 1a and 1b).

The existence of a faint companion is attested by Pel (1976), Szabados (1985 and 1991), mainly on the basis of a large variation of radial velocity measurements. But Moffett and Barnes (1987) show that the uncertainty of the available measurements of radial velocity, larger than expected, does not allow to recognize a binary Cepheid system. In their paper about the Cepheids binary systems, and on the basis of annual variations of radial velocities, Evans et al. (2015) finally put W Gem in a single Cepheids class. But Evans (2015) cannot produce a complete and proper O-C diagram.

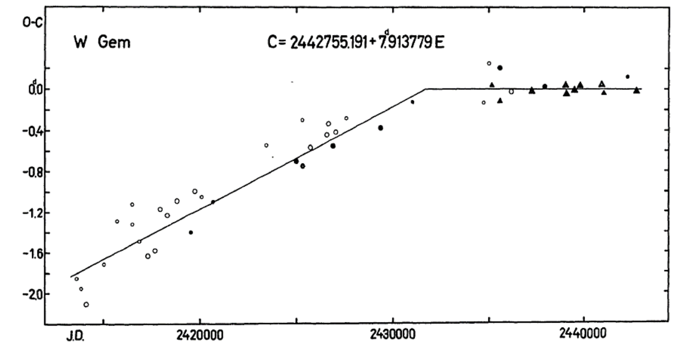


Figure 1a: O-C diagram for W Gem from Szabados (1980), first interpretation.

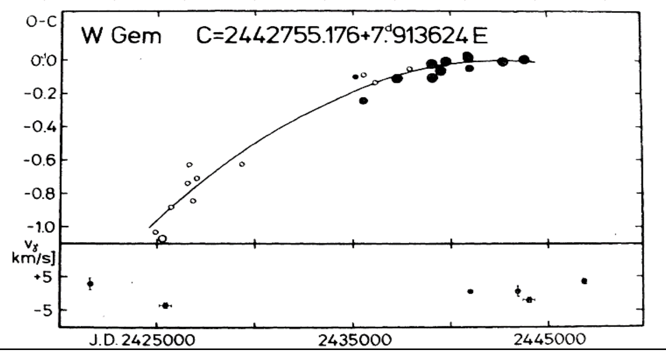


Figure 1b: O-C diagram for W Gem from Szabados (1991), second interpretation.

On the basis of a huge study realized in 2006, Meyer (2023) gives extended survey of several classical Cepheids of the german BAV group. On the basis of 112 new times of maximum, Meyer (2023b, 2023c) can draw a new O-C diagram (Figure 2) and can compute a period rate for the fitted parabola. His quadratic term is equal to **$-2{,}1.10^{-7}\times E^2$** (E being the number of cycles). It is common since the works of Parenago (1957) and Szabados (1991) in particular, to calculate the period variation ($\frac{dP}{dt}$) in sec/year in the following way (Abdel-Sabour & Sanad 2020):

$$\frac{dP}{dt}[\text{in s/yr}] = \frac{(2\times \textit{squared term in } E^2)}{\textit{period}} \times (\mathbf{365.25\times 24\times 3600}) \quad \textbf{(1)}$$

For Meyer's paper (2023b, 2023c) the period rate for W Gem is equal to **$-1{,}67$ s.yr$^{-1}$**.

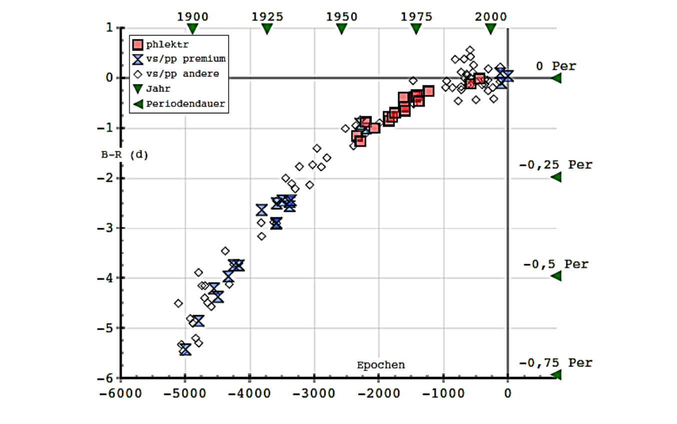


Figure 2: O-C diagram for W Gem, from 112 times of maximum collected by Meyer (2023b, 2023c).

The light curve of W Gem is characterized by the presence of an almost double maximum, also well evidenced on the best series of visual observations, as shown on figure 3.

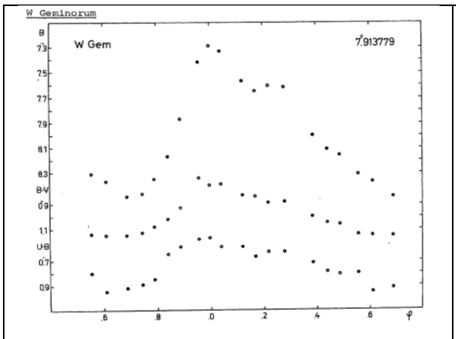


Figure 3a: V-Light curve of W Gem from Szabados (1980).

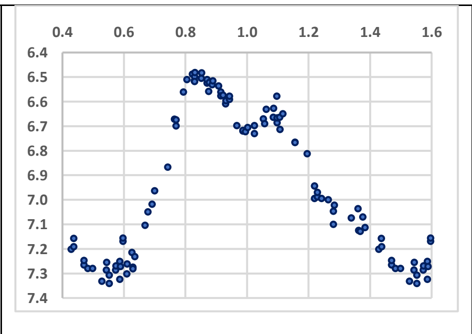

Figure 3b: 2018-2019 V-light curve from AAVSO/Vollmann (computed in this paper).

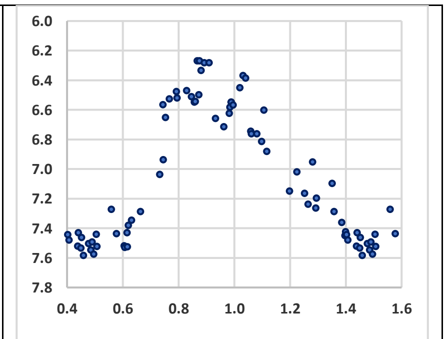

Figure 3c: 2023 Visual light curve from GEOS/Ferrand (raw data, computed in this paper).

## 2. Collecting observations

Since the end of the years 1970s, W Gem has been observed very regularly by GEOS members, among other classical Cepheids, which allows an examination of its long-term period behavior. These observations have not been published or only internally (Figer, 1978; Busquets, 1983, Dalmazzio, 1997, 1998 and 1999). As well as a large part of the observations made by BAV members, those of GEOS have remained largely unknown and could not be taken into account in recent studies of this star. The availability of a large amount of numerical data now allows for a thorough study as suggested by Percy (2021) in his study on the period behavior of RU Cam.

The present study thus proposes to scan the professional classical literature and the productions of variable star observer associations to collect times of the maximum of light for W Gem. Eight sources are used here: the old photographic and photoelectric measurements provided by the articles collected in the ADS server, and the McMaster International Cepheid Database (CDB); the CCD measurements made by the KWS and ASAS-SN surveys accessible on the servers of these automatized telescopes, and also, through the AAVSO VSX server. The measurements collected by the AAVSO and accessible via the use of the VSTAR software. The times of maximum observed by the members of the German BAV group are available via their "Data for scientists" server and a huge list of times of maximum provided by Meyer (2023). Finally, the observations published internally (and now in open access) by the GEOS and the systematic collection of unpublished observations since the 1980s by a few assiduous GEOS observers[1]. Our list of 235 times of maximum distributed between JD 2413266 and 2460378, provides 101 new times of maximum from visual observations made by GEOS, BAV and AAVSO, i.e., nearly 43% of the total collected times of maximum. Note that a large part of the available observations, almost 30%, have not a clearly type of photometry identified (un.=unknown in the following tables and files to download).

Then, we have collected 235 times of maximum, twice the number used by Meyer in his study (Meyer, 2023a,b,c).

Figure 4 represents the respective contributions of the different sources of data. Figure 5 shows the distribution between photographic (pg), Johnson V filter (V) and visual (vis.) measurements. The collected times of maximum from AAVSO is made of two sets: the ones published by Berdnikov et al. (2003), and the others computed by the author of this paper from the data available via the AAVSO VSTAR software. All times of maximum extracted by the author from the data sets provided by the KWS and ASAS-SN servers, have been computed using the tools provided by the software Peranso© (Pauzen & Vanmunster, 2016) and MAVKA (Andrych and Andronov, 2020), as well as personal numerical processes developed on Excel©.

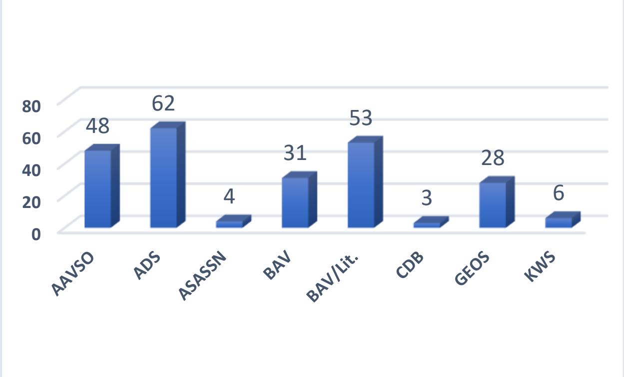


Figure 4: Distribution of the contributions of the sources of times of maximum of W Gem collected for the present paper (Table 2).

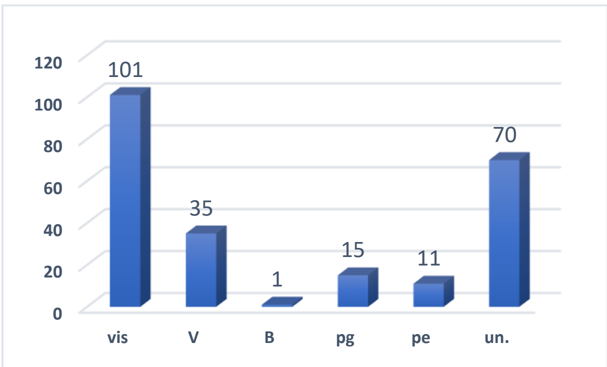


Figure 5: Distribution of the times of maximum according to the type of photometry.

[1] The internal publications of the GEOS are now in open access : http://geos.upv.es/index.php/publications/NCOA/.

The O-C of these times of maximum have been calculated on the basis of the ephemeris given by Szabados (1980). The data concerning these times of maximum are collected in table 2, computed on the following ephemeris (2):

**HJD maximum = 2442755.191 + 7.913779 × E (2),** E being the number of cycles elapsed since the ephemeris origin.

Table 2: Sample of the list of the 235 collected times of maximum of W Gem analyzed in this article. O-C are computed on ephemeris (2).

| HJD MAX +2400000 | E | O-C | ADS | AAVSO | BAV | CDB | GEOS | KWS | ASASSN | Type of photom. | Source | Observer | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13266,3500 | -3726 | -2,10 | -2,10 | | | | | | | vis | ADS | Luizet 1905b | AN 169, 401, 1905 (Sanford 1930) |
| 13266,6500 | -3726 | -1,80 | -1,80 | | | | | | | vis | ADS | Kukarkin | Kukarkin, 1962 |
| 13267,2800 | -3726 | -1,17 | -1,17 | | | | | | | vis | ADS | Sawyer 1897 | Szabados 1980 |
| …/… | | | | | | | | | | | | | |
| 59974,0710 | 2176 | -1,50 | | | | | | -1,50 | | V | KWS | KWS | KWS this paper |
| 59974,2300 | 2176 | -1,34 | | | | | -1,34 | | | vis | GEOS | Boistel | GEOS this paper |
| 60092,5410 | 2191 | -1,74 | | -1,74 | | | | | | V | AAVSO | Tomlin | AAVSO this paper |
| 60203,5770 | 2205 | -1,50 | | -1,50 | | | | | | V | AAVSO | Vollmann | AAVSO this paper |
| 60290,4630 | 2216 | -1,66 | | | | | -1,66 | | | vis | GEOS | Ferrand | GEOS this paper |
| 60290,5620 | 2216 | -1,56 | | -1,56 | | | | | | V | AAVSO | Tomlin | AAVSO this paper |
| 60377,6730 | 2227 | -1,50 | | | | | -1,50 | | | vis | GEOS | Ferrand | GEOS this paper |

The data can be downloaded from the following links:

**Table 2 -** **Excel .xls format.**

**Table 2 -** **CSV.csv format (with commas).**

**Table 2 -** **TXT.txt format (with tabulations).**

### 3. O-C diagram and period variation of W Gem

The time of maximum of table 2 allow to draw the diagram of O-C (in days) computed on the ephemeris (2). Figure 6 shows the O-C of maxima the color of the points corresponding to different sources. In figure 7 the totality of the O-C is modeled by a quadratic function (the best-fit parabola). Figure 6 and 7 illustrates the very good compatibility of the visual and V maxima determinations.

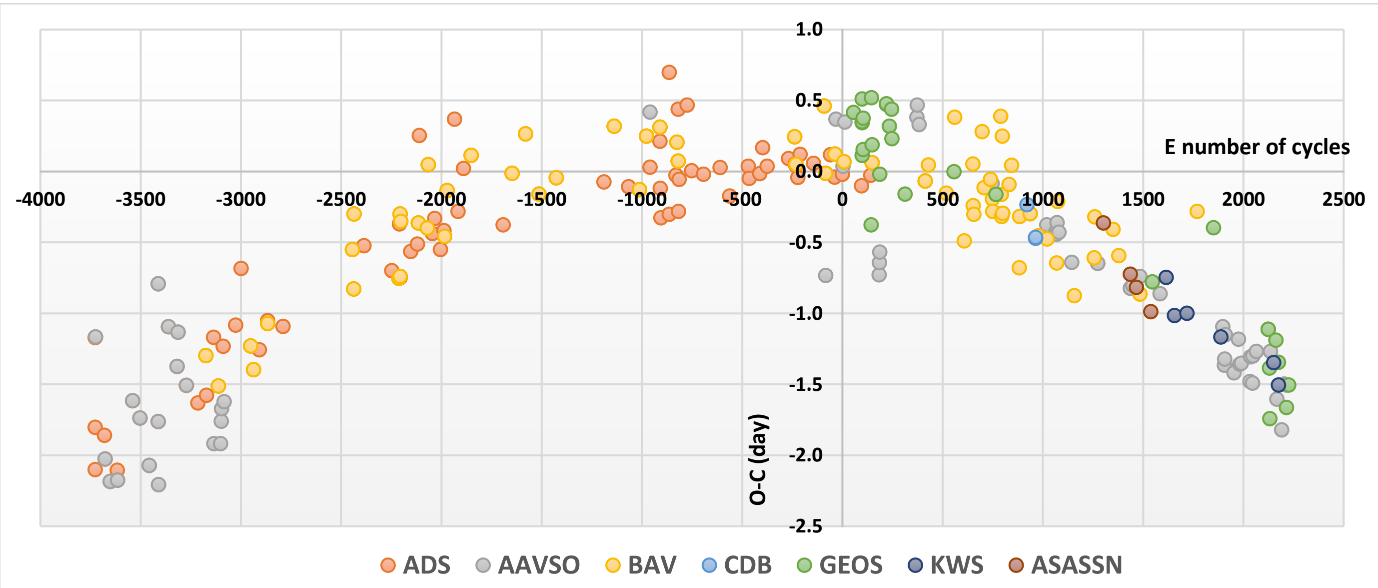


Figure 6: W Gem, O-C diagram by source of observations, computed on the GCVS ephemeris (2) (this paper).

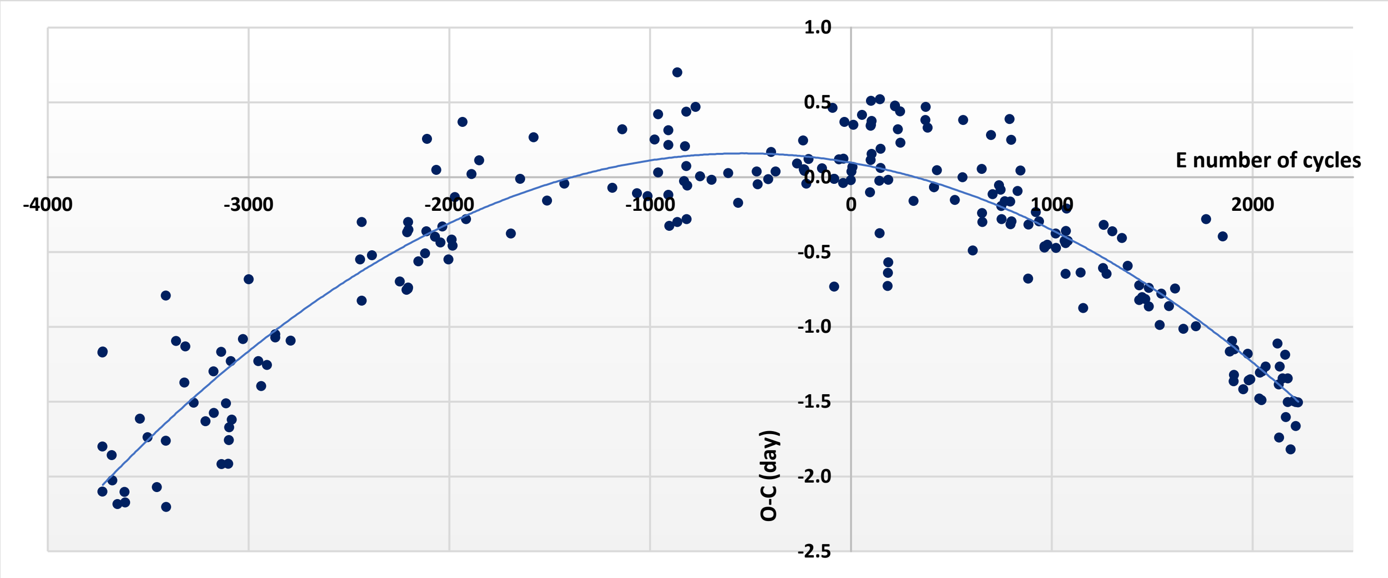


Figure 7: W Gem, diagram of the O-C computed on (2) and modeling by a quadratic function (3) (this paper).

In figure 7 the totality of the O-C is modeled by a quadratic function (the best-fit parabola):

$$\boldsymbol{O - C\ (days) = -2.1752 \times 10^{-7} \times E^2 - 2.33 \times 10^{-3} \times E + 9.707 \times 10^{-2}}\ \textbf{(3).}$$

## 4. Long-term variations in the period of W Gem

The modeling of figure 7 allows to obtain the quadratic term (in $E^2$) which conditions the period variation of W Gem on the long term.

For W Gem, with a quadratic term equal to $\boldsymbol{-2.175 \times 10^{-7} \times E^2}$, and then, the period rate computed on the formula (1) is refined to the value of **– 1.74 s.yr⁻¹.**

The figure 8 shows the diagram of the quadratic residuals corresponding to the previous data. The mean residuals is equal to 0.002 day and the standard variation is equal to 0.279 day. Three points are larger than the usual limit of 3×St. Dev. value. We have kept these data in our table 2 for further developments.

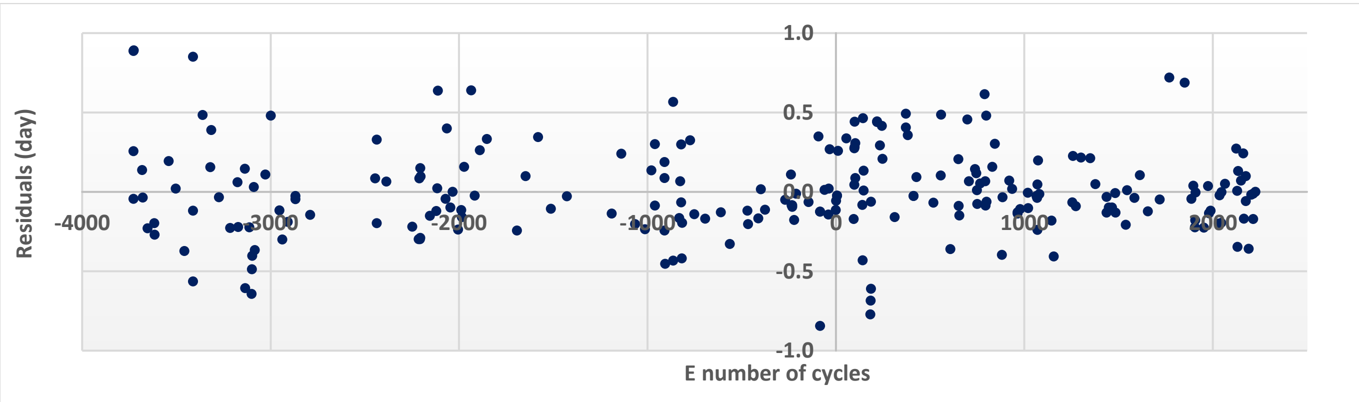


Figure 8: W Gem, residuals diagram (in day) (this paper).

From these diagrams, it appears that there is no evidence for a periodic variation of the O-C.

## 5. Conclusion

The present study of observations spread over nearly 130 years significantly completes the database of observed new times of maximum of W Gem. In agreement with recent studies (Meyer 2023), the period variation rate calculated on a base of 235 new W Gem times of maximum, has been specified:

$$\frac{dP}{dt} = (-1.74 \pm 0.1)\ s/yr.$$

The O-C diagrams computed in this paper and the conclusions of Evans' paper (2015) lead to classify W Gem as a single Cepheid.

We show how much can be gained from visual observations of long-period Cepheids - but not only -, and this study best answers Percy's (2021) call in his article on RU Cam: "*Skilled amateur astronomers can still make significant contributions to variable star research, even in this age of massive automated sky surveys* [...]".

**Aknowledgements:**
The present study has made use of the following online tools and software facilities:
AAVSO VSTAR software: https://www.aavso.org/vstar-overview (Benn 2012)
AAVSO VSX The international variable stars index server: https://www.aavso.org/vsx/
ASAS-SN website: https://www.astronomy.ohio-state.edu/asassn/index.shtml
ADS bibliographical search: https://ui.adsabs.harvard.edu/classic-form
BAV data for scientists: https://www.bav-astro.eu/index.php/veroeffentlichungen/service-for-scientists/bav-data
McMaster Cepheid Photometry and Radial Velocity Data Archive: https://physics.mcmaster.ca/Cepheid/.
KWS (Kamogata/Kiso/Kyoto Wide-field Survey): http://kws.cetus-net.org/
GCVS (Samus et al. 2017)
GEOS website: http://geos.upv.es/ and unpublished observations (private communications)
GEOS Open Access Publications: http://geos.upv.es/index.php/publications
GEOS Github deposit for Cepheids: https://github.com/GEOS-Cepheids
MAVKA software: https://katerynaandrych.wixsite.com/mavka (Andrych & Andronov 2020)
PERANSO software: https://www.cbabelgium.com/peranso/index.html (Paunzen & Vanmunster 2016)

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