Classical Cepheids After 228 Years of Study

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Abstract A review is presented of much of our current observational knowledge of classical Cepheids. Outlined are the basic observational parameters of Galactic Cepheids derived over the past 228 years, with emphasis on current trends and ongoing problems. Although the calibration of the Cepheid period-luminosity (PL) relation has normally made use of variables in the Magellanic Clouds, presently that can be accomplished using only Galactic Cepheids. It is also possible to calibrate the PL relation without recourse to observations, given that their fundamental properties are well enough understood.

1. Introduction

Cepheids are yellow supergiant stars that can reveal to astronomers exactly how distant they are through regular measurement of their brightness variations in a few photometric bands. Much more is known about them today than fifty or one hundred years ago, yet, for every morsel of new information that is learned, further questions arise that make investigation of such stars a constantly challenging pursuit.

Cepheids are named for the bright example of the class, δ Cephei, whose regular variability over the course of 5.37 days was noticed by John Goodricke in October 1784, a month after his friend Edward Piggott noted light variations in η Aquilae, another bright Cepheid with a pulsation period of 8.36 days. The valuable characteristic of Cepheids as distance indicators was discovered more than a century later when Henrietta Leavitt noticed in 1908 that the mean brightness of Cepheids in the Small Magellanic Cloud correlated closely with the period of variability for the stars: the well-known Cepheid period-luminosity (PL) relation (Leavitt 1908; Leavitt and Pickering 1912). The relationship was calibrated using Galactic variables (Hertzsprung 1913), and Harlow Shapley was one of the first to make use of the feature for practical purposes in a study of the Sun's location within the Galaxy relative to globular clusters (Shapley 1918a, b), with distances to the latter inferred with respect to the short period "Cepheids" populating some of them. The distinction between classical Cepheids like δ Cep and η Aql and Type II Cepheids (BL Herculis objects, W Virginis variables, and RV Tauri stars) and RR Lyrae variables was not made until many years later. See Fernie (1969) for a detailed review.

The initial calibration of Cepheid luminosities and the application of the PL relation to the measurement of distances to nearby galaxies came soon thereafter. In fact, it is probably true that much of what we understand about cosmology and the nature of the universe is tied to knowledge of the Hubble constant H_0, as derived from observations of Cepheids in relatively nearby galaxies (Freedman *et al.* 2001).

Cepheids are also a topic of interest for stellar interior modellers. The simple linear, non-rotating, adiabatic models of a few decades ago are currently being replaced by much more sophisticated calculations involving differential rotation, more physically realistic mixing, and proper consideration of changing element abundances on interior opacity sources. In the future, fully three-dimensional models may eventually become the norm, consuming extraordinary amounts of computer calculation time per model. The time may eventually arrive when it will take a complete suite of models to match individual Cepheids, which appear to differ from one to another in very distinct ways, particularly in atmospheric contamination by CNO elements (Turner and Berdnikov 2004).

2. Properties of classical Cepheids

Cepheids display very repeatable light curves, most being asymmetric with a rapid rise to maximum light followed by a slower decline, with light minimum occurring 0.6–0.7 cycle after light maximum. The radial velocity variations are almost a mirror image of the light variations in the variables, indicating that Cepheids are brightest roughly when their photospheres are most rapidly expanding, and faintest roughly when they are contracting the fastest. There is a small phase shift between the two relations, radial velocity minimum occurring a few percent of the cycle length after light maximum. Short period Cepheids (periods $P < 10d$) tend to be of spectral types F5-F8 at light maximum, and G or K at light minimum, with correspondingly cooler spectral types for longer period variables (Kraft 1963).

Cepheids also display a feature known as the Hertzsprung progression (Figure 1), a secondary bump in their light curves that appears near light minimum (~0.5 cycle after maximum) in Cepheids with periods of about 5 days, but gradually closer and closer to light maximum in Cepheids of longer period, being coincident with light maximum at pulsation periods of ~10 days, giving them the appearance of having a double maximum or a broad maximum. For Cepheids of longer period the bump appears on the rising light portion of the light curve, progressing towards light minimum and disappearing at periods of ~20 days.

The origin of the bump has been a matter of debate for decades, and has been attributed to either a light echo of the surface pulsation from the stellar core or surface excitation of the second overtone mode, for which the period is extremely close to one-half of the fundamental mode period (the periods of adjacent pulsation modes become shorter by a factor of ~0.7 as one goes to higher order modes, so the period of the second overtone mode relative to the fundamental mode is 0.7 × 0.7 ≈ ½). A subset of short-period Cepheids displays light curves that are almost perfectly symmetric (Figure 2), matching sine waves so closely (see the sine wave light curve in the lower part of the figure) that they were referred to as s-Cepheids. The nature of such objects is controversial. Efremov (1968) argued that their symmetric light curves were the signature of Cepheids in the first crossing of the instability strip, although that may be a simple consequence of the small amplitudes for some stars. The two s-Cepheids SZ Tau and V1726 Cyg, whose light curves are plotted in Figure 2, are members of the clusters NGC 1647 (Turner 1992) and Platais 1 (Turner *et al.* 2006b), respectively, and appear to pulsate in the first overtone and fundamental mode, respectively, in high order strip crossings. Other s-Cepheids that are likely members of open clusters seem equally split between fundamental mode and overtone pulsation.

Thirty years ago Simon and Lee (1981) introduced Fourier diagnostics to the study of Cepheid light curves. It had been recognized previously that light curves could be matched to Fourier series quite well, the only question being how many terms to include when there were gaps in the light curve coverage. Simon took the matter further by noting that certain combinations of low-order Fourier series terms, sine term amplitudes and phase offsets, such as R_{21}, the ratio of amplitudes for the second order to first order terms, and ϕ_{21}, the normalized difference in phase offsets between the second and first order terms, correlated smoothly with pulsation period, except for a discontinuity at P = 10d where the secondary bump passes through light maximum (see, for example, the behavior of R_{21} shown by Zabolotskikh *et al.* 2005). For short-period Cepheids there is a heavily-populated primary sequence, considered to coincide with fundamental mode pulsators, and a less-populated secondary sequence, considered to represent overtone pulsators, subsequently confirmed by Fourier decomposition of the light curves of double mode Cepheids (e.g., Antonello and Mantegazza 1984; Pardo and Poretti 1997). The technique was also extended to s-Cepheids by Antonello and Poretti (1986) in order to demonstrate that they are likely overtone pulsators, although the definition of "s-Cepheid" was broadened somewhat in the process and it is unclear what parameters like R_{21} and ϕ_{21} mean when the data are noisy and the second order term in the Fourier series may actually be zero.

Another characteristic of Cepheids is that all undergo changes in pulsation period as a result of stellar evolution. Cepheids represent post-hydrogen burning stages of stars with main sequence masses in excess of about 4 $M_{\odot}$, progenitors that had spectral types hotter than B5 in a former life. They are currently yellow supergiants in a variety of short-lived evolutionary stages between that of B dwarfs and their later existence as red supergiants. Most are evolving through the instability strip for the second or third time as core helium burning objects, some may be passing through it for the fourth or fifth time as shell helium burning stars, and a rare few seem likely to be in the first crossing, the stage of hydrogen shell burning that lasts an order of magnitude or more less time than other stages.

As yellow supergiants evolving through the instability strip in the Hertzsprung-Russell (H-R) diagram, Cepheids become unstable to pulsation because the regions of hydrogen (H) and helium (He, He^+) ionization lie deep enough to drive radial expansion and contraction through a piston-type mechanism. Evolution through the instability strip takes on the order of a half million years for some stars, so it is not a process normally detectable in the course of a human lifetime. But it does result in very small changes in average radius for the stars as they evolve, increases for stars evolving towards the cool side of the instability strip in the Hertzsprung-Russell (HR) diagram, and decreases for stars evolving towards the hot side. That produces small, cumulative changes in pulsation period that are readily detectable from O–C analyses of their light curves, as noted by Szabados (1983), Fernie (1984), Turner (1998), and Turner *et al.* (1999).

The study of Cepheid period changes through O–C analysis is an excellent way to test stellar evolutionary models (Turner *et al.* 2006a). But period changes can also arise from other effects: orbital motion about a companion, which produces cyclical variations in O–C data over the orbital period of the system, random changes in pulsation period, which for some Cepheids, for example, V1496 Aql (Berdnikov *et al.* 2004), can dominate evolutionary effects, and possibly mass loss (Neilson *et al.* 2012). The existence of such complications makes it imperative to establish Cepheid pulsation periods from existing photometric data as carefully as possible. Fourier techniques, for example, can sometimes generate erroneous results. By contrast, the Hertzsprung method takes full advantage of the repeatability of Cepheid light curves to best advantage, particularly when used in O–C analyses (Tsesevich 1971; Belserene 1988; Berdnikov 1992), and generates the most accurate results.

The light amplitudes for Cepheids vary in magnitude according to the filter used to observe them, being largest in the ultraviolet and smallest in the infrared. Maximum blue (ΔB) or visual (ΔV) light amplitude also increases progressively with pulsation period, with the exception of a small dip for $P \approx 10^d$ where the light curve bump is coincident with light maximum. The largest amplitude Cepheids are found just to the hot side of instability strip center, with variables of smaller amplitude towards the strip edges (Kraft 1963; Hofmeister 1967; Sandage and Tammann 1971; Payne-Gaposchkin 1974; Pel and Lub 1978; Turner 2001; Sandage *et al.* 2004). That characteristic was combined with rate of period change by Turner *et al.* (2006a) in order to produce a parameter capable of estimating the strip crossing mode for individual Cepheids (Turner *et al.* 2006b; Turner 2010).

For many years Polaris held the record as the smallest amplitude Cepheid, particularly in the decades around 1988, when its visual amplitude dropped to 0.025 magnitude (Turner 2009). But, at their current level near 0.055 magnitude, the pulsations of Polaris are an order of magnitude larger than those of HDE 344787, a recently discovered double-mode Cepheid that is rapidly becoming a challenge to observe as its light amplitude decreases towards its eventual demise as a variable star (Turner *et al.* 2010b). Both stars display the largest rates of period increase for Cepheids with pulsation periods of 4 to 5 days, a signature of variables crossing the instability strip for the first time. The discovery of X-ray emission from Polaris and a few other bright Cepheids (Engle *et al.* 2009) is an additional complication that challenges our understanding of the stars.

3. Calibration of the PL relation

The calibration of the Cepheid PL relation was for many years accomplished by deriving the slope of the relationship using Cepheids in the Magellanic Clouds, where interstellar extinction and differential reddening is small, and fixing the zero-point using Milky Way Cepheids of known distance. The last step was not without challenges. The large masses and short-lived evolutionary state of Cepheids make them relatively rare objects. None are closer than ~100 parsecs, which was traditionally the limit for trigonometric parallax determinations with older refracting telescopes. Nearby Cepheids (e.g. Polaris) are also relatively bright, presenting problems for parallax measurements from photographic plates.

The launch of the Hipparcos satellite two decades ago changed the situation, since its on-board telescope/detector combinations had the capability of measuring absolute parallaxes of high precision for stars brighter than about tenth magnitude, including a sample of more than 200 Cepheids. Most Cepheids measured by Hipparcos have very accurate parallaxes, but there is a subset of objects of lower quality and precision that comprises a relatively large proportion (~1/2) of the sample (Turner 2010). A smaller group of ten classical Cepheids have also had their parallaxes measured using the Hubble Space Telescope (HST) by more traditional methods (Benedict *et al.* 2002, 2007), with improved precision and an accuracy generally better than the Hipparcos results. The zero-point for the PL relation is now considered to be firmly established (see Turner 2010; Turner *et al.* 2010a).

An alternate route to the calibration is by means of Cepheids belonging to open clusters, since zero-age main-sequence (ZAMS) fits for open clusters can provide distance estimates for cluster members with a precision reaching ~2% in the best cases, the accuracy depending upon the ZAMS calibration tied to the nearby Hyades and Pleiades clusters and the effects of metallicity on the main-sequence luminosity zero-point. In the 1960s the sample of Galactic clusters containing short period Cepheids as bona fide members was only a half dozen or so, which made it difficult to fix the slope of the relation with much confidence, but the sample now numbers twenty-four of all periods (Turner 2010), with a potential to reach forty to fifty stars, allowing both the slope and zero-point to be established independent of Cepheids in the Magellanic Clouds.

Since Cepheids are so regular in their variability, their parameters can also be established by the Baade-Wesselink method, a technique proposed by Baade (1926) and developed for practical use by Wesselink (1946). The luminosity of a star is the product of its surface area and surface brightness. For a spherical object, a reasonable approximation for an evolved star like a Cepheid, the surface area is $4\pi R^2$, where R is the star's radius, and the surface brightness is the radiance, given by $\sigma T_{\mathrm{eff}}^4$, where σ is the Stefan-Boltzmann constant and T_{eff} is the star's effective temperature. The star's luminosity is therefore $L = 4\pi R^2 \sigma T_{\mathrm{eff}}^4$. During a Cepheid's pulsation cycle it reaches the same effective temperature or surface brightness at different phases, yet there can be a difference in brightness at those phases of Δm, in magnitudes. The ratio of the star's radii at such times, $\mathrm{R}_2/\mathrm{R}_1$, is equal to $10^{0.2\Delta \mathrm{m}}$, while the differences in the star's radius, $\mathrm{R}_2 - \mathrm{R}_1$, can be found independently using measures of its radial velocity, which track the cyclical motion of the surface layers, thereby allowing the average radius to be established. In particular, the radial motion of the star's surface is given by $v_R = p\ (V_{\mathrm{R}} - V_0)$, where V_R is the measured radial velocity, V_0 is the systemic velocity of the star along the line of sight, and p is a factor, typically close to 4/3, to correct the measured velocity for the fact that it represents the combined light originating from photospheric radiation coming from the entire nearside hemisphere of the Cepheid.

Over the course of a complete light cycle, the surface of a Cepheid moves through a distance $4\Delta R$, where ΔR is the amount by which the mean radius of the star increases or decreases during the interval. That value can be obtained through numerical integration of the radial velocity curve, namely $4\Delta R = p \int (V_R - V_0)\, dt$ in calculus notation, where the integral is over the entire cycle. If the semi-amplitude of the radial velocity curve is denoted by ΔV_R (in km s^{-1}) and it is approximated by a sine wave, it follows that $\Delta \mathrm{R} \approx 2.63 \times 10^{-2}\, P\, \Delta V_R\, R_\odot$, where P is the pulsation period in days and the projection factor has been approximated as 4/3. For the bright Cepheid δ Cep, $P = 5.37$ days and the radial velocity varies between +3 and –36 km s^{-1} (i.e., $\Delta V_R = \pm 19.5$ km s^{-1}). The estimated radius variations are therefore about $\pm 2.8\ R_\odot$, close to the actual value of $\pm 2.3\ R_\odot$ about a mean radius of 43 $R_\odot$ (Turner 1988), the difference being accounted for by a slightly smaller adopted value of p and the non-sinusoidal nature of the light and velocity curves for δ Cep. The radius variations for δ Cep therefore amount to ±5%, typical of most Cepheids, where the range is from less than 1% to ~10% in extreme cases.

The method of isolating phases of identical surface brightness during a Cepheid's cycle is all-important. When the technique is applied correctly, a plot of radius ratios versus radius differences should generate a tight loop traced out counterclockwise for phase pairs running from light maximum to light minimum (Evans 1976; Turner 1988), and the slope should be close to the reciprocal of the minimum radius (Abt 1959). The use of a color index like *B–V* to isolate such phases, the situation for most early applications of the Baade-Wesselink method, generates results contrary to expectations (e.g., Turner 1988), primarily because the colors are affected by variable atmospheric line blanketing created by a combination of cyclical spectral line broadening arising geometrically from the general expansion and contraction of the stellar photosphere and a sudden, large increase in atmospheric microturbulence during the contraction phases (Benz and Mayor 1982; Turner *et al.* 1987). Most recent applications have used color indices less affected by such influences, such as *V–I* spanning visual to infrared wavelengths, or indices in the infrared itself, which are more closely linked to stellar surface brightness variations (e.g., Gieren *et al.* 1989). Narrow band spectrophotometric indices also work well (Turner 1988; Turner and Burke 2002). Current techniques mainly employ the former, typically using variants that employ sophisticated statistical methods to test the validity of the results.

An early estimate for the projection factor of $p = 1.412$ by Getting (1934) was later reduced to 1.31 from model atmosphere calculations (Parsons 1972; Karp 1975), then increased back to values near 1.4, with a period dependence, when Hindsley and Bell (1986) used more recent Kurucz model atmospheres. The values used in Baade-Wesselink analyses then varied from author to author over the next two decades, until more recent stellar atmosphere models were employed and Gray and Stephenson (2007) noted that a toy model for the pulsation of bright Cepheids implied values of p closer to 1.3 in some cases, depending upon the source of radial velocity measures. More recent work by Nardetto *et al.* (2009, and in press), Laney and Joner (2009), and Neilson and Lester (2011) continue to argue the case for different values near 4/3 ±0.1, with a possible period dependence.

The method of measuring radial velocities is an extremely important consideration. Most lines visible in Cepheid spectra, the lines of neutral iron (Fe I) for example, are formed at higher layers of a Cepheid's atmosphere than the deeper regions generating the stellar continuum. Since pulsation results in a variable extension, or stretching, of the atmosphere rather than a simple up-down displacement, the lines used for radial velocity measurement should be higher ionization species like singly ionized iron (Fe II) to properly track the radial motion of the deeper layers where the light originates that is responsible for the brightness differences Δm. But many radial velocity observations in the literature were obtained using cross-correlation techniques, often dominated by low ionization species, which is why the value of p may continue to be debated.

The debate may be of only minor concern, however. Independent studies of the period-radius relation for Galactic Cepheids by Laney and Stobie (1995), Gieren *et al.* (1998), and Turner and Burke (2002) yield nearly identical values for the slope and zero-point of the relation, despite different methodologies, with the average Cepheid radius being almost exactly proportional to $P^{3/4}$ (Turner *et al.* 2010a). The radius of any Cepheid can therefore be estimated reliably from its pulsation period, provided that it corresponds to fundamental mode pulsation in the star. A polynomial linking a star's effective temperature to its reddening-free $B–V$ color index has been derived by Gray (1992), allowing one to derive a Cepheid's luminosity directly. The technique generates results that are a close match to Cepheid luminosities established from trigonometric and open cluster parallaxes (Turner and Burke 2002; Turner 2010; Turner *et al.* 2010a), where any such comparison also requires a knowledge of bolometric corrections for Cepheids in order to link absolute bolometric magnitudes M_{bol} (= –2.5 log L) to intensity-averaged absolute visual magnitudes $<M_V>$, where the bolometric correction BC = $M_{\mathrm{bol}} - <M_V>$.

The importance of an accurate knowledge of the interstellar reddening affecting individual Cepheids now becomes clear. For the above technique to yield reliable results, it is essential to account properly for the reddening produced within our Milky Way Galaxy or, for extragalactic Cepheids, in other galaxies. For many years reddenings for Galactic Cepheids have been obtained from a variety of sources essentially linked to period-color relations, which do not account for the intrinsic temperature width of the instability strip and the distribution of individual Cepheids within it. Considerable use has been made, for example, of compilations by Fernie (1990a, b), which are of that type. More direct reddenings are available, for example those tied to reddening-free indices (e.g. Turner *et al.* 1987) or to space reddenings (Turner 2001; Benedict *et al.* 2002, 2007; Laney and Caldwell 2007; Turner *et al.* 2011), which entail use of reddenings derived for close neighbors of Cepheids to infer color excesses for the variables. Cepheids belonging to open clusters play an important role in the latter. Kovtyukh *et al.* (2008) have also used the relationship of Gray (1992) between stellar effective temperature and unreddened $B–V$ color with model stellar atmosphere fits to Cepheid spectra over their pulsation cycles to deduce their reddenings from their observed color variations, a novel inversion of the normal procedure.

The period-luminosity relation that results from using the above relationships with Galactic Cepheids of well-established reddening and Cepheids with HST or cluster parallaxes is shown in Figure 3. The derived relationship is described by log $L/L_{\odot} = 2.409 + 1.168 \log P$. The scatter is intrinsic, and results from the temperature width of the instability strip. Cepheids of a given period can be small amplitude variables on the hot or red edges of the strip, or large amplitude variables just blueward of strip center.

Cepheids that are members of binary systems or open clusters can also be used to establish a Cepheid period-mass relation. Cepheids in open clusters have identical ages to cluster members, which can be established from model isochrone fits to the unreddened color-magnitude diagrams for the clusters (e.g., Turner *et al.* 2008). The inferred ages for cluster Cepheids can then be used with published models by Meynet *et al.* (1993) to establish masses for stars at the terminal stages of core hydrogen burning, designated as M_{RTO}, for stars at the red turnoff (RTO) for the clusters. Such masses should be close to, or perhaps slightly smaller than, the masses of the corresponding Cepheids. An analysis of that type was made by Turner (1996), subsequently updated by Turner *et al.* (2010a) to include more recent results for a few clusters (Turner *et al.* 2006b, 2008, 2009).

More recent results are now available for TW Nor in Lyngå 6 (Majaess *et al.* 2011) and SU Cas in Alessi 95 (Turner *et al.* 2012), and can be combined with masses derived for the binary Cepheids W Sgr (Evans *et al.* 2009), OGLE-LMC-CEP0227 (Pietrzyński *et al.* 2010), and V350 Sgr (Evans *et al.* 2011). The results, presented in Figure 4, confirm the consistency of binary masses and evolutionary masses for Cepheids, and suggest a simple relationship between the mass of a Cepheid and its pulsation period. Turner (1996) found that Cepheid masses scale as $P^{1/2}$, but the data of Figure 4 appear to vary as $P^{0.4}$. The implication is that the pulsation period varies as $M^{2½}$. The deviation of long-period Cepheids from a simple $P^{1/2}$ relationship could alternatively be evidence for the importance of mass loss for such stars (e.g., Marengo *et al.* 2010; Neilson *et al.* 2011).

The same data can be used to construct a period-age relation for Cepheids in open clusters, as displayed in Figure 5. The best-fitting linear relation to the data is given by $\log t = 8.48 - 0.724 \log P$. In this case, the slope of the relationship cannot be interpreted in terms of a simple power law, being tied as it is to the evolutionary models of Meynet *et al.* (1993).

4. The extragalactic setting

The use of the period-luminosity relation for extragalactic Cepheids usually involves a reddening-free formulation referred to as the Wesenheit function, after Madore (1976, 1982). An example for Johnson system *BV* magnitudes is $W_{BV} = \langle M_V \rangle - R_V\,(B-V)$, where R_V is the ratio of total-to-selective extinction for interstellar dust. For Cepheids a value of $R_V \cong 3.3$ seems valid, although there is no guarantee that it applies to dust in all directions of the Galaxy, or within other galaxies, for that matter. All reddening-free relations are at best an approximation; in the case of the Wesenheit function it reduces the intrinsic scatter in period-absolute magnitude relations, but overcorrects for intrinsic color spread of the instability strip. It works only if Cepheids in other galaxies are very similar in their intrinsic properties to Galactic Cepheids, and the dust extinction properties are more-or-less the same. Because of concerns about the latter, however, standard usage involves observations of Cepheids in the visible to near-infrared region, where the effects of interstellar extinction are reduced.

The extension of photometric imaging to increasingly fainter brightness limits is also generating reliable photometry for Type II Cepheids and RR Lyrae variables in nearby galaxies. Type II Cepheids include BL Her variables (P = 1–8 days), W Vir stars (P = 8–20 days), and, in recent years, the RV Tau variables, which exhibit period doubling, a phenomenon that has attracted considerable attention in the last year from its ubiquitous nature. Together with the RR Lyrae variables, Type II Cepheids appear to describe a unique PL relation of their own that can be used to establish galaxy distances reliably (e.g., Majaess *et al.* 2009; Majaess 2010). Likewise, radially pulsating δ Sct variables follow a PL relation similar to that for classical Cepheids (Fernie 1992), and both relations, when combined, provide a powerful tool for establishing accurate distances to nearby galaxies.

5. Cepheids and the AAVSO

Despite the existence of over 200,000 visual observations of Cepheids in the AAVSO International Database, the variables have not received the same degree of attention from AAVSO observers as Miras and cataclysmic binaries, possibly because they represent a smaller sample of stars of perceived regular behavior. Nevertheless, the bright variable δ Cep has been a popular target for beginning observers and interested amateurs, and AAVSO visual and CCD observations have been extremely useful for studies of Cepheid period changes (Berdnikov *et al.* 2003; Turner 1998; Turner *et al.* 2001, 2007). Brightness estimates for Cepheids published in the *Journal of the AAVSO* by students at the Maria Mitchell Observatory (e.g., Starmer 1989) have also been useful for such studies (see references in Turner 1998), and there have also been relevant articles on period-finding and O–C analyses (Belserene 1988, 1989) that are useful for the analysis of Cepheid period changes. Visual observations of δ Cep by AAVSO observers appear to be accurate, despite large scatter, although the finder chart for visual observers needs to be updated to make it applicable for non-dark-adapted observers (Turner 1999, 2011). Reference magnitudes on AAVSO charts for the nearby variable μ Cep are more closely tied to the Johnson system, for example.

The future of Cepheid observations by the AAVSO is unclear, given the large survey instruments that are beginning to appear. Yet AAVSO observations of bright Cepheids should continue to fill a niche where data are needed. The recently developed project by Variable Stars South observers for precision monitoring of bright southern Cepheids (Walker 2011) is an excellent example. As evident from the recent AAVSO observing campaign on Hubble's variable V1 in the Andromeda galaxy M31, a Cepheid with a period of ~30 days (*AAVSO Alert Notice 422*), Cepheids continue to make interesting objects for observation.

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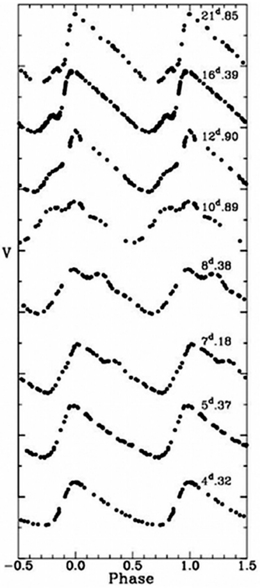

Figure 1. The Hertzsprung progression seen in the light curves of, from top to bottom, the Cepheids WZ Sgr, X Cyg, Z Sct, VX Per, S Sge, η Aql, δ Cep, and Y Lac. Visual magnitude steps are 1.0 magnitude between large divisions and the pulsation periods are indicated. The data are from Moffett and Barnes (1980, 1984), and have been offset in order to fit comfortably in the diagram.

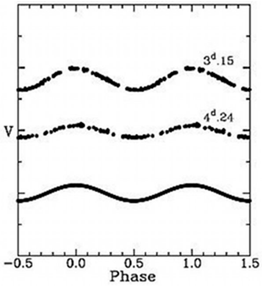

Figure 2. Light curves of, from top to bottom, the Cepheids SZ Tau, V1726 Cyg, and a simulated sine wave Cepheid with an amplitude of A_V = 0.25 magnitude. Terminology is the same as in Figure 1. The data are from Milone (1970) and Turner *et al.* (2001), offset to fit comfortably in the diagram.

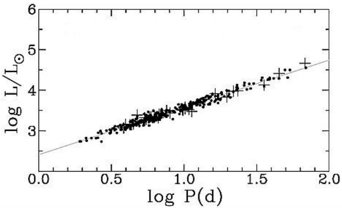

Figure 3. The period-luminosity relation for Galactic Cepheids of well-established reddening (points) and with HST or cluster parallaxes (plus signs).

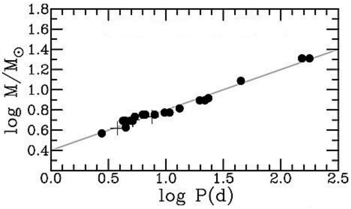

Figure 4. The Cepheid period-mass relation defined by members of open clusters (filled circles) and binaries (plus signs). The plotted relation is described by $M \sim P^{0.4}$.

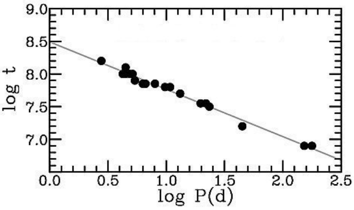

Figure 5. The Cepheid period-age relation defined by members of open clusters. The plotted relation is described by log t = 8.49 – 0.724 log P.