A CEPHEID IS NO MORE: HUBBLE’S VARIABLE 19 IN M33

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ABSTRACT

We report on the remarkable evolution in the light curve of a variable star discovered by Hubble (1926) in M33 and classified by him as a Cepheid. Early in the 20th century, the variable, designated as V19, exhibited a 54.7-day period, an intensity-weighted mean $B$ magnitude of 19.59 ± 0.23 mag, and a $B$ amplitude of 1.1 mag. Its position in the P-L plane was consistent with the relation derived by Hubble from a total of 35 variables. Modern observations by the DIRECT project show a dramatic change in the properties of V19: its mean $B$ magnitude has risen to 19.08 ± 0.05 mag and its $B$ amplitude has decreased to less than 0.1 mag. V19 does not appear to be a classical (Population I) Cepheid variable at present, and its nature remains a mystery. It is not clear how frequent such objects are nor how often they could be mistaken for classical Cepheids.

Subject headings: Cepheids — stars: evolution — galaxies: individual (M33)

1. INTRODUCTION

In his seminal work, “A spiral nebula as a stellar system, Messier 33,” Hubble (1926) presented the discovery of 35 Cepheid variables in that galaxy, which were used to determine its distance. No other searches for variables in M33 were undertaken for the next fifty years, until the surveys of van den Bergh et al. (1975); Sandage & Carlson (1983); Kinman et al. (1987) that discovered a total of 77 new Cepheids and recovered many of Hubble’s objects.

The DIRECT project (Kaluzny et al. 1998; Stanek et al. 1998) started in 1996 the first modern CCD-based search for variables in M33, among other targets. Our first two seasons surveyed three $10^5 	imes 10^6$ fields located in the central area of M33; the variable star content of these fields has been presented in Macri et al. (2001a) and Stanek et al. (2001). Since these fields had been covered by all previous surveys, we cross-correlated our variable star catalog with published catalogs and successfully identified 57 of the 60 known Cepheids. Two of the three missing variables were short period Cepheids: B08 from Sandage & Carlson (1983) (P=3.2 d) and Q19113 from Kinman et al. (1987) (P=13.4 d). These variables are faint and close to our detection threshold; therefore, it was not surprising that they eluded our detection.

The third missing variable turned out to be a surprising object, and is the topic of this paper. It is V19 from Hubble (1926), classified by him as a 54.7-day Cepheid. It is a bright, isolated, and easy to identify star located some 6′ north of the nucleus. Hubble’s light curve exhibited a variation of 1.1 mag, which is not present in our data. Additionally, the mean $B$ magnitude of the object increased by ~0.5 mag since Hubble’s original observations.

§2 summarizes the existing photometry for this object; §3 addresses the current variability, periodicity, and location of this object in the H-R and PL diagrams; and §4 discusses the possible nature of this object and its known Galactic counterparts.

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2. PHOTOMETRY

2.1. Data from Hubble (1926)

The discovery of V19 by Hubble (1926) was based on observations obtained at the Mount Wilson 100-inch telescope in 56 epochs between August 1919 and September 1925, with two additional plates from September 1909 and August 1910. Magnitudes were measured using the Argelander method, and were based on local reference stars calibrated through a photometric sequence from the Selected Area 45. Hubble’s original magnitudes suffered from zero-point and scale errors, as pointed out by Sandage (1983) and Christian & Schommer (1987).

We calculated a new transformation between Hubble’s magnitude scale and the standard system, using our photometry (Macri et al. 2001b) for Hubble’s original comparison stars. We identified 121 of these stars in our CCD images, using the finding charts published by Sandage (1983) and performed a least-squares fit between Hubble’s photographic magnitudes and our CCD-based $B$ magnitudes. We found

$$m_B = 1.62(\pm 0.04) \left( m_{pg} - 18.5 \right) + 19.68(\pm 0.02),$$

where $m_B$ is the $B$ magnitude in the standard system and $m_{pg}$ is the photographic magnitude as measured by Hubble. The relation has a scatter of 0.18 mag after the rejection of 11 stars which deviated by more than 0.5 mag. Our coefficients agree with those derived by Christian & Schommer (1987). We corrected Hubble’s original measurements using the newly derived transformation, and analyzed the data using a suite of programs developed by the DIRECT project (Kaluzny et al. 1998). We derived a best-fit period of 54.71 days, identical to Hubble’s original value, and an intensity-weighted mean $B$ magnitude of 19.59 ± 0.23 mag. Figure 1 shows a phased light curve of V19 based on Hubble’s recalibrated data. The scatter in the light curve is consistent with the r.m.s. scatter of Equation 1.
2.2. DIRECT Data

We based our identification of V19 on the finding charts of Hubble (1926), van den Bergh et al. (1975) and Humphreys & Sandage (1980), all of whom mark the same star as the variable. V19 is the DIRECT object D33J013357.1+304512.4, located at R.A.=1h33m57.1s, Dec.=-30d45m12.4s (J2000.0). We ruled out a misidentification of V19 with a nearby star in Hubble’s original finding chart by identifying all variables in the general vicinity (< 3’). This is a generous search area, given the fact that all other variables discovered by Hubble were recovered within a few arcseconds of previously published positions. The nearest variable of any kind is D33J013357.1+304455.2, a faint (V = 21.5) periodic variable located 17″ south of V19. The nearest Cepheid is D33J013354.9+304532.5, with a period of 36 days and located 39″ north-west of V19. The nearest Cepheid with a period close to Hubble’s original period for V19 is D33J013347.5+304423.2, with a period of 56 days and located 2.5′ to the south-west.

V19 was observed by the DIRECT project a total of 11, 116 and 60 times in BV I, respectively, during the 1996 and 1997 observing seasons. The description of the reduction and analysis of this data set was presented in Macri et al. (2001b). Additional observations of another DIRECT field which contains V19 were obtained during the 1999 season; for the purposes of this paper, we performed a preliminary reduction using the standard DIRECT pipeline (Kaluzny et al. 1998) and calibrated the resulting photometry using bright, non-variable stars from the database of Macri et al. (2001b). This third year of observations yielded an additional 19, 121 and 35 points in BV I, respectively. The mean BVI magnitudes of V19 obtained from the three seasons spanned by our data are 19.08±0.05, 18.21±0.05 and 17.30±0.05 mag, respectively. The light curves exhibit very little variation, of order 0.05 mag peak-to-peak. §3 contains the analysis of our light curve data 3.

2.3. Other photometric data

We searched the literature for additional observations of V19 obtained after 1926 and before 1996. The only time series photometry that we were able to locate was that of van den Bergh et al. (1975), who obtained 67 plates of M33 between January 1966 and November 1974 at the Palomar 48-inch Schmidt, using a variety of plate types and filters. The data for V19 consists of 19 points in B and 41 points in V. Unfortunately, the uncertainties quoted by the authors for the individual measurements is 0.7 mag, and there are no data available to check the absolute calibration of their photometric systems.

V19 was observed by Humphreys & Sandage (1980) in their survey for blue and red stars in M33, and was designated as R142 in their catalog. We corrected their tabulated photometry according to Wilson et al. (1990) and obtained B = 19.1 mag and B − V = 0.9 mag, consistent with our own determinations. Unfortunately, the authors did not obtain a spectrum for this star. Additionally, V19 is present in the fields surveyed by Kinman et al. (1987), but these authors do not list it in their compilation of variables.

Madore et al. (1985) reported the results of JHK observations of V19 and other M33 Cepheids conducted between 1980 and 1983 at a variety of telescopes using a photometer with a 5′ diameter aperture. However, the authors expressed concerns about possible contamination by field stars inside their aperture. Therefore, we analyzed K s-band images of V19, obtained by Don McCarthy with the PISCES camera (McCarthy et al. 1998) at the refurbished MMT, under 0.6″ seeing. These images show the presence of another star of similar infrared flux some 3″ away. A preliminary calibration of the MMT data, based on isolated 2MASS stars present in the field of view, yields a mean magnitude for V19 of K s = 16.1±0.05 mag. This, in turn, implies a V − K s color of 2.1±0.1 mag, which is somewhat redder than, but consistent with, the one predicted for a 55-day Cepheid, 1.9±0.1 mag (e.f. Equations 5 and 9 of Macri et al. 2001c).

Lastly, we retrieved archival HST/WFPC2 frames in which V19 is present (dataset u2c604, proposal # 0538) from the Space Telescope Archive. The images were obtained in the F 439W and F 547M filters and show the object (at x=92, y=283 on WF4) to be well isolated, with no detectable companions inside our ground-based seeing disk.

3. ANALYSIS

We computed the J s index (Stetson 1996) using all 237 V measurements from the DIRECT data, and found a value of J s = 0.807, which is above the standard DIRECT threshold of 0.75. However, the overall r.m.s. scatter is only 0.025 mag, below our usual threshold of 0.04 mag. Therefore, the star does not meet the standard criteria for variability adopted by the DIRECT project.

We attempted to find a period from our data, using the standard DIRECT technique of a modified Lafler-Kinman algorithm (Stetson 1996) and the CLEAN algorithm of Roberts et al. (1987). No convincing periods were found, which is not surprising given that our frameto-frame random photometric error (arising from the limitations of fixed-position PSF photometry) is of the order of 0.02 − 0.03 mag. We conclude that if the 54.7-day periodicity seen by Hubble is still present, its amplitude must be less than 0.05 mag. Long-term follow-up observations using larger telescopes would be most useful to detect any small-scale periodicity and/or variability.

Figure 2 shows the B-band light curve of V19 from 1910 to 2000, based on the data from Hubble (1926), vhk75, and this work. The intensity-weighted mean magnitude shows a dramatic increase, from 19.59±0.23 mag in 1919–1925 to B = 19.08±0.05 in 1996–1999, while the amplitude of pulsation decreases from 1.1 mag to undetectable levels. Figure 3 shows the location of V19 in the H-R diagrams of Macri et al. (2001b). We also plot the location of 130 Cepheids with P > 10 days present in the inner region of M33 (Macri et al. 2001a). Figure 4 shows the location of V19 in the BVI Cepheid P-L relations defined by the same set of variables, using Hubble’s original period of 54.7 days. These figures indicate that the modern optical magnitudes of V19 are somewhat brighter than, but still consistent with, those of 55-day Cepheids in M33.

3 The light curve of V19 and its finding chart can be found at the DIRECT Web page: http://cfa-www.harvard.edu/~kstanek/DIRECT
4. DISCUSSION

The cessation of pulsations, or any significant decrease in amplitude (i.e., by a factor of ten), has never been observed in a classical Cepheid. V19 may be the first case, or it may belong to another class of variable stars. We present here four classes of variable stars whose pulsational behaviour may explain the nature of V19.

**Population II Cepheids**: RU Cam, a 22-day Cepheid which in 1965 abruptly decreased in amplitude from 1 mag to about 0.1-0.2 mag (Demers & Fernie 1966), was later shown to be a W Virgo variable (Population II Cepheid) that exhibited a highly unstable and modulated light curve thereafter (Kollath & Szeidl 1993). Even before the 1965 event, Payne-Gaposchkin (1941) had suggested that RU Cam may be a W Virgo variable. However, RU Cam is of little relevance to our case, because in order for V19 to be a Population II Cepheid, it should be about 2 magnitudes fainter (see Alcock et al. 1998) than Population I Cepheids of similar period. Furthermore, W Virgo variables are not known to change their mean magnitude, although a few RV Tauri variables (longer-period Population II Cepheids) do that cyclically.

**Peculiar Population I Cepheids**: These objects are extremely rare and entirely confined to much shorter periods. A case in point is the classical Cepheid V473 Lyr of \(P = 1.49\) days (e.g., Burki et al. 1986; Andrievsky et al. 1998). It has an amplitude modulation of a factor of 15 which resembles the beating of two closely spaced pulsation modes. This phenomenon is not understood, but it is most likely associated with the interaction of high-order modes. Furthermore, the interval corresponding to low amplitudes in V473 Lyr has a short duration; in general, the phenomenon seems to have very little in common with V19. A more relevant object in this category could be Polaris, now established to be a Population I Cepheid pulsating in the first overtone mode (Feast & Catchpole 1997). It has a period of 3.97 days, and its amplitude has decreased by a factor of 3 over the past 50 years. Despite earlier reports, this amplitude decrease has stabilized over the past 15 years; the pulsation amplitude is practically constant since 1986 (Hatzes & Cochran 2000). As in the case of V473 Lyr, the amplitude decrease could be due to high-order mode interactions (Evans et al. 2001). However, the pulsation amplitude of Polaris has always been very low \((\leq 0.1\) mag in V\), which makes the comparison with V19 difficult. Finally, we should note that there are stars inside the Cepheid instability strip that are not variable, for reasons that are still unknown.

**UU Herculis stars**: These are supergiants with Cepheid-like pulsations that exhibit occasional standstills (Sasselov 1984). Pulsations cease abruptly and at mid-cycle (corresponding to the mean magnitude of the star), last a couple of months, and then abruptly start again (Sasselov 1983). The UU Herculis stars may alternate between Cepheid-like and RV Tauri-like pulsations (over timescales of several years) with periods of 30 to 90 days, which are always of relatively low amplitude \((\sim 0.3\) mag in V\). UU Her is the only exception, with amplitudes as high as 0.6 mag in V. Most stars in this class have infrared excesses, low metallicities, and show variable emission in the Hα line (Klochkova et al., 1997).

**Luminous Blue Variables**: Given its luminosity \((M_V \approx -6.4\) mag\), V19 appears to be more closely related to the Luminous Blue Variables (LBVs), which are not always blue. One example is 164 G Sco \((M_V = -8.4, T=10,000K, R \approx 175R_\odot\), after Lamers et al. 1998). It shows multiperiodic variability \((45 - 55\) days\) of very low amplitude \((\leq 0.1\) mag in V\). Occasionally, LBVs experience dramatic outbursts and mass loss episodes which could considerably alter their effective radii and temperatures for extended periods of time. There also exist other luminous supergiants which are not LBVs but exhibit Cepheid-like pulsations, such as V810 Cen (Kienzle et al. 1998). However, their pulsations have always been observed to be low \((\leq 0.1\) mag\) and multiperiodic.

Each of the types described above belongs to a different evolutionary state. The W Virginis (and RV Tauri) variables are most likely low-mass AGB (and tip-of- or post-AGB) stars (hydrogen- and helium-shell burning). The same appears to be true for the majority of UU Her stars (a related object which "wanders" across the HR diagram is FG Sge). Hence their lower luminosity and common circumstellar infrared excesses. They often show emission in the absorption profile of the Hα and other strong lines. There is no evidence that V19 possesses any of the above characteristics and its luminosity is incomparably higher. The remaining types of variables (LBVs, V810 Cen) are very massive supergiants. At a given pulsation period they are brighter than Population I Cepheids and they are unlikely to be mistaken for Cepheids, due to their low amplitudes and multi-periodic pulsation.

In summary, V19 does not belong to any of the above types: it is too luminous to be a low-mass Population II star, and its pulsation was too regular and high-amplitude 75 years ago to be a massive microvariable supergiant. Therefore, V19 appears to be a high-mass Population I star that behaves more like a low-mass Population II RV Tauri variable.

Given the bright and isolated nature of V19, and its location in the host galaxy, it is likely that most photographic plates of M33 obtained at 2-m class (or larger) telescopes during the 20th century will yield precise photometry for this object. We encourage the astronomical community to contact us if they are in possession of plate material that might help constrain the past behavior of V19. Future observations, including spectroscopy and long-term, multi-band photometric follow-up, will help resolve the nature of this object. Such resolution is desirable in order to avoid misclassifying objects like V19 as classical Cepheids in distant galaxies.

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Fig. 1.— (left) Phased light curve of V19, based on the period and magnitudes published in Hubble (1926). The original photographic magnitudes have been corrected into the standard $B$ band using Equation 1.

Fig. 2.— (right) $B$-band light curve of V19 from 1910 to 1999, based on the data of Hubble (1926), van den Bergh et al. (1975), and the present work.

Fig. 3.— (left) Color-magnitude diagrams of M33 from Macri et al. (2001b), showing the location of V19 ($\star$) and $P > 10$ d Cepheids ($\bullet$).

Fig. 4.— (right) P-L relations of M33 Cepheids ($\bullet$) from Macri et al. (2001a), showing the location of V19 ($\star$).