NSV 11154 Is a New R Corona Borealis Star

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ABSTRACT. NSV 11154 has been confirmed as a new member of the rare hydrogen-deficient R Corona Borealis (RCB) stars based on new photometric and spectroscopic data. Using new photometry, as well as archival plates from the Harvard archive, we have constructed the historical light curve of NSV 11154 from 1896 to the present. The light curve shows the sudden, deep, irregularly spaced declines characteristic of RCB stars. The visible spectrum is typical of a cool (T eff ≲ 5000 K) RCB star, showing no hydrogen lines, strong C2 Swan bands, and no evidence of 13C. In addition, the star shows small pulsations that are typical of an RCB star and an infrared excess due to circumstellar dust, with a temperature of ∼800 K. The distance to NSV 11154 is estimated to be ∼14.5 kpc. RCB stars are very rare in the Galaxy, so each additional star is important to population studies leading to a better understanding of the origins of these mysterious stars. Among the known sample of RCB stars, NSV 11154 is unusual in that it lies well above the Galactic plane (5 kpc) and away from the Galactic center, which suggests that its parent population is neither thick disk nor bulge.

Online material: color figures, extended tables

1. INTRODUCTION

The R Corona Borealis (RCB) stars represent an extremely rare class of variable stars (Clayton 1996). They are cool supergiants, which are carbon-rich and hydrogen-deficient. Their defining characteristic is large irregular declines in brightness of up to 8 mag caused by the formation of carbon dust. Two scenarios have been suggested that attempt to clarify the origins of the RCB stars: the double degenerate (DD), and the final helium-shell flash (FF). The DD model suggests that RCB stars are formed by the merger of a CO and a He white dwarf, and the FF model involves stellar expansion after a helium-shell flash. The high 18O/16O ratios found in RCB stars favor the DD model. However, a few RCB stars show Li in their spectra, which may instead favor the FF model (Iben et al. 1996; Clayton 1996).

There could be as many as 3000 RCB stars in the Galaxy, based on the numbers found in the Large Magellanic Cloud.
(LMC), but only 55 have been discovered in the Galaxy so far (Clayton 1996; Alcock et al. 2001; Zaniewski et al. 2005; Tisserand et al. 2008).

About 45 years ago, Hoffmeister (1966) discovered that NSV 11154 was a variable star (S 9323 Lyr) and suggested that NSV 11154 is a short-period variable. NSV 11154 was also found to be variable in the ROTSE-I survey with an amplitude of 0.4 mag, and it was suggested that NSV 11154 is a long-period variable (Akerlof et al. 2000; Wils 2001). Haussler et al. (2009) examined 562 plates, obtained at Sonnenberg Observatory during 1964–1996, and found irregular brightness variations between 13.0 and 17.2 mag. On the basis of the light curve, they suggested that NSV 11154 may be an RCB star. In this article, we use newly acquired photometry and

![V-band light curves of NSV 11154. Top: DASCH plate photometry and upper limits (arrows). Middle: Sonneberg plate photometry. Bottom: ROTSE-I photometry.](image)
spectroscopy to attempt to confirm Haussler et al.’s suggestion that NSV 11154 is indeed an RCB star.

2. OBSERVATIONS AND DATA REDUCTION

The UCAC3 coordinates of NSV 11154 are \( \alpha(2000) = 18^h37^m51.254^s \) \( \delta(2000) +47\degr23\arcmin23.45\arcsec \) (Zacharias et al. 2010). The field of NSV 11154 is shown in Figure 1.

The Sonnenberg plate data, taken by a 40 cm astrograph on blue-sensitive photographic plates (Haussler et al. 2009), were downloaded for use in this study. The blue photographic magnitudes were transformed to Johnson \( V \) using \( V - m_{pg} = 0.17 - 1.09(B - V) \) (Arp 1961). The transformed data are plotted in Figure 2. There were 250 additional plates of the NSV 11154 field dating as far back as 1896, available from the Harvard College Observatory plate archive. These plates have been scanned, and photometry was done on the stars as part of the Digital Access to a Sky Century at Harvard (DASCH) program (Grindlay et al. 2009), from the scanning focused in the Kepler field. Note that NSV 11154 is a few degrees outside the Kepler field of view, and there are many more Harvard plates covering this star that are not scanned yet. The measured magnitudes in the DASCH database were converted from photographic magnitudes to Kepler Input Catalog (Sloan) \( g \) magnitudes (Brown et al. 2011). The DASCH data were then converted from \( g \) to Johnson \( V \) using \( V = g' + 0.12 - 0.56(B - V) \) (Fukugita et al. 1996). The DASCH data used here came from a 12-plate series from the archive covering the period 1989–1989 and have average uncertainties of 0.15 mag (Laycock et al. 2010). This will be further improved with photometric corrections now being optimized (Tang et al. 2011, in preparation). The Sonnenberg plates were obtained during 1964–1996, so there is an overlap of roughly 20 years with the DASCH data. The DASCH photometry is listed in Table 1 and is plotted in Figure 2.

The ROTSE-I Northern Sky Variability Survey (NSVS) detected NSV 11154 as a variable (Akerlof et al. 2000). The photometric data were downloaded from the NSVS archive. The ROTSE-I images are unfiltered, and Wózniak et al. (2005) suggest that \( m_{\text{ROTSE}} \) is equivalent to Johnson \( V \), when it is actually very close to Cousins \( R \) (Bernhard et al. 2005). If the relation between \( m_{\text{ROTSE}} \) and \( V_T \) (Wózniak et al. 2004) is combined with the equations to convert from \( V_T \) to Johnson \( V \), then the conversion is equivalent to \( V = m_{\text{ROTSE}} + (V - R)_C = m_{\text{ROTSE}} + 0.55 \). The converted ROTSE-I photometry still seems to have a systematic shift from the actual Johnson \( V \) photometry of \( \sim0.2 \) mag. The ROTSE-I photometry is listed in Table 2 and is plotted in Figure 2.

New \( BVR_CI_C \) photometry has been obtained with the AAVSO Sonota Research Observatory (SRO) between 2010 October and 2011 June. The images were obtained with the 35 cm C14 OTA (SRO35) and the 50 cm f/4 Newtonian (SRO50). The images were flat-fielded and dark-subtracted.

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**TABLE 1**

| JD    | \( V \) | \( \sigma_V \) |
|-------|---------|---------------|
| 2,413,740.74 | 12.7    |               |
| 2,414,154.68 | 12.4    |               |
| 2,414,569.61 | 12.1    |               |
| 2,415,150.74 | >14.8   |               |
| 2,415,186.80 | >14.5   |               |
| 2,415,717.46 | 11.7    |               |
| 2,415,901.67 | 12.3    |               |
| 2,416,323.76 | 12.3    |               |
| 2,419,306.50 | >15.0   |               |
| 2,420,270.83 | 12.2    |               |

*NOTE.—* Table 1 is published in its entirety in the electronic edition of the PASP. A portion is shown here for guidance regarding its form and content.

**TABLE 2**

| JD    | \( V \) | \( \sigma_V \) |
|-------|---------|---------------|
| 2,451,275.3466 | 12.42   | 0.02          |
| 2,451,277.3501 | 12.41   | 0.01          |
| 2,451,277.3511 | 12.43   | 0.02          |
| 2,451,283.2551 | 12.52   | 0.02          |
| 2,451,286.3526 | 12.60   | 0.02          |
| 2,451,286.3537 | 12.58   | 0.02          |
| 2,451,287.3534 | 12.58   | 0.01          |
| 2,451,287.3544 | 12.61   | 0.02          |
| 2,451,288.3543 | 12.58   | 0.01          |
| 2,451,288.3553 | 12.58   | 0.01          |

*NOTE.—* Table 2 is published in its entirety in the electronic edition of the PASP. A portion is shown here for guidance regarding its form and content.

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See http://heasarc.nasa.gov/W3Browse/all/tycho2.html.
Aperture photometry was done using DAOPHOT in IRAF. The instrumental $BV$ magnitudes were transformed to standard magnitudes using a photometric $BV$ sequence of the field (5169jnc) provided by the AAVSO. In particular, two stars, 2MASS 18374206-4723474 and 18374814-4724267, were used. These stars are both in the Kepler Input Catalog (Brown et al. 2011). Their Sloan $gri$ magnitudes were transformed to Cousins $R$ and $I$ (Fukugita et al. 1996) and then were used to transform the SRO $RI$ instrumental magnitudes of NSV 11154 to standard $R_CI_C$ magnitudes. The uncertainties are $\sim0.01$–$0.02$ mag. The $BVRI_C$ photometry is listed in Table 3 and plotted in Figure 3. In addition, there is also photometry from 2MASS, AKARI, and IRAS for NSV 11154. These data are tabulated in Table 4. The 2MASS data were obtained during
a gap between the Sonnenberg and ROTSE-I photometry, but the star appears to be at or near maximum light. The entire historical light curve is plotted in Figure 4.

Spectra of NSV 11154 were obtained on 2009 August 18 using the 4 m telescope at Kitt Peak National Observatory with the Ritchey-Chrétien spectrograph using the BL380 grating, which has a resolution of 0.9 Å. Three consecutive 600 s spectra were summed. The spectra were not flux-calibrated. The wavelength calibration has an rms uncertainty of about 0.02 Å. The summed spectrum is plotted in Figure 5, along with the spectrum of a similar RCB star HV 5637 (Alcock et al. 2001).

3. DISCUSSION

The historical NSV 11154 light curve, seen in Figure 4 from 1896 to 2011, is fragmentary, but several deep declines are apparent. The last decline detected was in 1996, but the coverage since then has been spotty. No declines are seen in the recent ROTSE-I or SRO photometry. Although the light-curve data are sparse, NSV 11154 seems to be an active RCB star having frequent declines. There are at least 13 epochs where NSV 11154 is seen 2 mag or more below maximum light. These are listed in Table 5. The characteristic time between declines in RCB stars is typically about 1000 days, but there is a wide range in activity among the RCB stars (Feast 1986; Jurcsik 1996). From the ROTSE-I and SRO light curves it can be seen that NSV 11154 pulsates with a period of ∼50 days between 1999–2000 and ∼40 days in 2010–2011. The pulsations have an amplitude of ∼0.4 mag.

Figure 5 shows the visible spectrum of NSV 11154 compared with the LMC RCB star HV 5637. The spectrum of NSV 11154 is typical of a cool (≤5000 K) RCB star with strong CN and C₂ absorption bands (Clayton 1996; Alcock et al. 2001). There is no sign of either Hβ or Hγ, indicating extreme

![Fig. 4.—Historical light curve of NSV 11154 from 1896–2011. Symbols are the same as in Fig. 2. Several deep declines are detected.](image-url)
hydrogen deficiency. The CH band at 4300 Å is also absent. In addition, the $^{12}\text{C}\,^{13}\text{C}$ band at 4744 Å is weak or absent, while the $^{12}\text{C}\,^{12}\text{C}$ band at 4737 Å is very strong, indicating a high $^{12}\text{C}$ to $^{13}\text{C}$ ratio. This is typical of most RCB stars. NSV 11154 lies well out of the Galactic plane at $b^\prime = +21.8^\circ$, and so the estimated foreground extinction is quite small, $E(B-V) = 0.07$ mag (Schlegel et al. 1998). NSV 11154 has an observed $(B-V) = 1.1$ mag, which is consistent with it being $\lesssim 5000$ K and lightly reddened (Lawson et al. 1990).

The measured colors of NSV 11154, $B-V = 1.1$ and $V-I = 1.2$, assuming little or no reddening, are consistent with an absolute magnitude of $M_V = -4$ mag (Alcock et al. 2001; Tisserand et al. 2009). Then, if the foreground extinction is $A_V \sim 0.2$ mag, the distance to NSV 11154 is $14.5 \pm 1.5$ kpc. This also implies that NSV 11154 is 5.4 kpc above the Galactic plane. Most RCB stars are within 2 kpc of the plane (Zaniewski et al. 2005). Only two other RCB stars in the Galaxy, UX Ant and U Aqr, are as far above or below the plane as NSV 11154. Also, most RCB stars are seen toward the Galactic center, but NSV 11154 has $l^\circ = 76.0^\circ$. NSV 11154 lies well away from the extended body of the Sagittarius dwarf galaxy (Majewski et al. 2003).

Using the photometry in Table 4, an SED for NSV 11154 has been plotted in Figure 6. This SED can be fit very well by two blackbodies representing the star and the dust shell, 4500 K and 800 K, have been fit to the data. The dashed line is the sum of the two blackbodies. See the electronic edition of the PASP for a color version of this figure.

### TABLE 5

| JD  | Length (d) |
|-----|------------|
| 2.415,150 | ................. | ... |
| 2.419306 | ................. | ... |
| 2.423,981 | ................. | $\sim$2525 |
| 2.427,246 | ................. | ... |
| 2.428,314 | ................. | ... |
| 2.430,616 | ................. | ... |
| 2.437,851 | ................. | ... |
| 2.440,150 | ................. | $\sim$1775 |
| 2.444,099 | ................. | $\sim$375 |
| 2.445,027 | ................. | $>150$ |
| 2.445,742 | ................. | $\sim$400 |
| 2.448,682 | ................. | $\sim$375 |
| 2.449,422 | ................. | $>450$ |

*The photometry shown in Figs. 2 and 3 is fragmentary, so the decline epochs and lengths of the declines are best estimates.*

### 4. SUMMARY

The suggestion of Haussler et al. (2009), on the basis of the light curve, that NSV 11154 is an RCB star was correct. The spectrum and colors of NSV 11154 show it to be a cool ($\lesssim 5000$ K) RCB star. Archival photometry and new $BVRCIC$ photometry have been collected, giving a historical light curve from 1896 to the present. The new photometry shows that NSV 11154 has a semiregular pulsation period of 40–50 days with an amplitude of 0.4 mag. Although the light curve is fragmentary, NSV 11154 has had a number of deep declines, showing it to be an active RCB star. The star also displays a significant IR excess, indicating the presence of dust with $T \sim 800$ K, which is typical of RCB stars.
Only 55 other RCB stars are known in the Galaxy, so each addition is important to population studies, which will help us to better understand the origins of these mysterious stars. NSV 11154 lies well above the Galactic plane, which is quite different from most other RCB stars, which seem to fit into an old disk or bulge population. This may favor the final flash model for this star, since the higher stellar density of the Galactic center region is more conducive to formation of RCB stars by the double-degenerate scenario. Despite being very rare, RCB stars may be a key to understanding the late stages of stellar evolution. Their measured isotopic abundances imply that many RCB stars are produced by the mergers of double-degenerate white dwarfs, which may be the low-mass counterparts of the more massive mergers thought to produce Type Ia supernovae. Therefore, knowing the population of RCB stars in the Galaxy will help determine the frequency of these white dwarf mergers.

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