The Precataclysmic Binary HS 1136+6646 May Have a Companion

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ABSTRACT. Because of the similarity of the primary star of HS 1136+6646 to the planetary nebula central star BE Ursae Majoris, we performed wide-field imaging of the former with an Hα filter. No nebulosity was detected. On the other hand, the point-spread function of the star appears extended. A partially resolved red component is detected in an image from the five-band Sloan Digital Sky Survey. Most importantly, a companion is easily resolved in a Hubble Space Telescope acquisition image from the published Space Telescope Imaging Spectrograph observations. A companion to the precataclysmic binary is present at a separation of 1′349 at a position angle of 54°34′. Evidence indicates that it is likely of spectral type K. We cannot demonstrate conclusively that this component has common proper motion with the close binary. However, the similar apparent μ magnitudes and spectral types of HS 1136+6646B and the resolved component make it likely that we have, in reality, a hierarchical triple system. In any case, the presence of this component needs to be taken into account in future ground-based studies.

1. INTRODUCTION

HS 1136+6646 (hereafter HS 1136) is a hot young DAO white dwarf plus K7 V secondary star in a close detached binary. The discovery from the Hamburg Schmidt survey was reported in Heber et al. (1996). Sing et al. (2004) determined parameters for the individual components and found an orbital period of 0.83607 days. Radial velocity measurements of both components for the individual components and found an orbital period of in Heber et al. (1996). Sing et al. (2004) determined parameters white dwarf plus K7 V secondary star in a close detached binary. Moreover, the optically derived temperature was difficult to reconcile with the far-UV spectrum of the Lyman line region. The Far Ultraviolet Spectroscopic Explorer spectrum shows the presence of O vi absorption lines and a spectral energy distribution whose slope persists nearly to the Lyman limit, suggesting that the Balmer-line $T_{\text{eff}}$ estimate is too low. Fits to the Lyman lines by Good et al. (2004) indicate a far higher value of 120,000 K—among the highest determinations for a DAO white dwarf—with log g of 6.5. These parameters suggest that the system could have left the common envelope even more recently than the 7.75 × 10^5 yr estimate by Sing et al. (2005). Indications are that the secondary star may be over-luminous compared to a main-sequence star of its mass, that it is still bloated, or is out of thermal equilibrium from the common envelope phase.

The secondary is irradiated by strong UV radiation, causing strong variations in the strengths of the emission lines versus orbital phase. BE Ursae Majoris (Ferguson et al. 1999 and references therein) is a similar close DAO+K binary also showing a strong orbitally modulated “reflection effect.” Again, only rough estimates of $T_{\text{eff}}$ and log g were given by the above authors, suggesting that the primary star could be similar to that of HS 1136.

An additional property of the BE UMa system is the presence of a large planetary nebula of low surface brightness (Liebert et al. 1995). As part of a program by the second author of that paper to look for ancient planetary nebulae (Tweedy & Kwitter 1994), a 50′ field around BE UMa was imaged in Hα $\lambda$6563, [O iii] $\lambda$5007, and [N ii] $\lambda$6584. The [N ii] observation yielded a nondetection, the [O iii] data a marginal one; but the Hα image revealed a very faint nebula centered on the binary system, about 5′ in diameter.

This led us to try a similar observation of HS 1136 to see if the systems were similar in yet another property. In § 2 we report that no nebula was detected. Instead, we made a different discovery, which is discussed in § 3.

2. THE SEARCH FOR A PLANETARY NEBULA

90Prime is a wide-field imager mounted at the prime focus of the Steward Observatory 2.3 m Bok reflector (Williams et al. 2004). The detector is a mosaic of four thinned Lockheed 4096 × 4096 pixel CCDs. The f/2.98 system provides a plate

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Fig. 1.—Hα image centered on HS 1136 obtained with the 90Prime camera. Three 15 minute exposures were stacked to make this combined image. North is up and east is to the left. The image displayed is 15′ on a side.

scale of 0′.45 pixel$^{-1}$. We centered the binary star on chip 1, the cosmetically best chip (i.e., no bad columns). Figure 1 shows the resulting image taken through an Hα filter. Scattered light in the upper left part of the figure is from a 6th magnitude star, 3 Draconis, 25′ northeast of HS 1136. This complicates the potential detection of faint nebulosity. In any case, no evidence of nebulosity is seen. Because of the complication, we did not try to estimate a sensitivity limit above which a nebula is not present.

One feature of this camera at prime focus is a continual need to monitor the instrument focus. When checking for this after the observations with isophotal contour plots, it became apparent to us that the target star appeared elongated at a position angle of 60° (or 240°) from due north (Fig. 2, left), while several stars of similar magnitude in the field appeared almost perfectly circular (one of them is shown in Fig. 2, right). This strongly suggested to us that HS 1136 was not a point source, but instead would turn out to be either a barely resolved source or a partially resolved blend of two or more sources. Figure 3 shows the radial profiles for HS 1136 (filled circles) versus those for four comparison stars. That HS 1136 is more extended than the others is indisputable. The result was not due to the instrument’s being out of focus, although the seeing at this time, obtained by extracting the point-spread functions (PSFs), was ~1.6 (see Fig. 3).

The question was then, Had we discovered a very compact nebula in Hα around this unusual binary, instead of an old nebula? A logical test was to try a very short exposure in broadband $V$, a wavelength range in which only weak nebular emission could be anticipated. We made this observation (not
Fig. 2.—Contour plots of counts, in which each contour is a successive factor of 2 below the peak for HS 1136 (left) and one of the several reference stars in the field also measured (right). North is up and east is to the left. That HS 1136 is extended relative to a seeing-dominated point source is apparent.

shown here), but the HS 1136 PSF again showed extension, and the comparison stars did not. Some other explanation besides nebular emission had to be sought.

3. THE RESULT OF HIGHER RESOLUTION IMAGING: A COMPANION

The field of interest is covered by the Sloan Digital Sky Survey (SDSS; Gunn et al. 1998; York et al. 2000; Stoughton et al. 2002). In a color image taken from the SDSS DR5 Finding Chart Tool Web site (Fig. 4), a fainter companion to HS 1136 at the same orientation as indicated by Figure 2 (left) is apparent. This image shows that the companion is much redder than the optical light of the close binary, the latter dominated by the very hot primary. As we show below, visual inspection of other SDSS stellar sources strongly suggests that the companion is of spectral type K or M.

An acquisition image from the previously published spectrum, taken with the Space Telescope Imaging Spectrograph (STIS) on the Hubble Space Telescope, is shown in Figure 5. The USNO-B1 (Monet et al. 2003) position of HS 1136 is \( \alpha = 11^\text{h}39^\text{m}05^\text{s}.570, \delta = +66^\circ30'17".75 \) (J2000.0). The wide companion is separated by \( \mu = 1".349 \) at \( \theta = 54".391 \), or at position \( \alpha = 11^\text{h}39^\text{m}05^\text{s}.945, \delta = +66^\circ30'18".45 \). Since the STIS imaging used the broadband clear imaging 50CCD mode, the bandpass encompasses a wavelength range from 2000 Å to past 1 \( \mu \)m, although the sensitivity peaks around the \( B, V, \) and \( R \) bands. The relative brightness or count ratio of HS 1136AB to the resolved companion is \( 5.5 : 1 \) (nearly 2 mag).

The measured proper motion from the USNO-B catalog is \( 3".23 \) in 50 yr at a position angle of 248°2, and the wide companion to the close binary is not resolved. If we assume that the resolved companion is an unrelated field star with negligible proper motion, the two stars would currently be moving apart.

Fig. 3.—Azimuthally summed radial distribution of counts for HS 1136 (filled circles) and four reference stars (solid curves). The FWHM of the latter indicates a seeing of about 1′6. The extension of the HS 1136 counts past 1′ is consistent with the presence of the close companion.
If we consider the POSS I fields (epoch 1954.1), the red and blue images are symmetrical and coincident, with no evidence of an offset, even though the proper motion difference between HS 1136 and a stationary companion would have resulted in a 1.9 separation on the opposite side of HS 1136. However, the effective image size at the Palomar Oschin Schmidt scale of 67" mm^{-1} is several times this separation. Thus, the companion has not been demonstrated as sharing a common proper motion.

Estimating the 3.84 yr of proper motion between the SDSS and STIS ACQ images for the close binary and resolved component shows that each has moved around 0".25 in roughly similar directions (close binary: \( \mu = 0".23 \) in 3.84 yr, \( \theta = 239^\circ \); resolved component: \( \mu = 0".26 \) in 3.84 yr, \( \theta = 288^\circ \)). Note that what we call the resolved component is close but is not technically resolved by the Rayleigh criteria in the \( z \)-band image, complicating its proper motion calculation.

We have retrieved the SDSS \( ugriz \) magnitudes corresponding to the image of HS 1136+6646, using the Explore tool in SkyServer. The resolved component is virtually undetected in \( u \) but is nearly resolved in the \( z \)-band image. SkyServer has separated the two components into the close binary SDSS J113905.78+663017.8 and the resolved component SDSS J113905.98+663018.3. PSF photometry from the SDSS Web site lists \( u = 13.298 \pm 0.014, r = 13.914 \pm 0.03, i = 14.084 \pm 0.08, \) and \( z = 14.159 \pm 0.034 \) for the close binary, and \( u = 18 \pm 6, r = 16.12 \pm 0.31, i = 14.457 \pm 0.048, \) and \( z = 14.052 \pm 0.028 \) for the resolved component. The \( g \)-band flux is saturated and therefore not used. The \( z \)-band flux from the close binary and resolved component can be estimated by convolving a synthetic spectrum of the white dwarf (Sing 2005) with the \( z \)-band filter and applying the photometric corrections of Holberg & Bergeron (2006). We find that the white dwarf “A” component has an estimated \( z \) magnitude of 15.2, while the binary companion “B” is 14.7.

Unfortunately, the separate PSF magnitudes other than those in the \( z \) band are unreliable. This is illustrated by the colors of the resolved component \( (r - i = 1.659 \) and \( i - z = 0.432) \), which do not give main-sequence colors. The \( z \) magnitudes of the two main-sequence stars are observed as being similar and should therefore both contribute to the overall flux of HS 1136+6646 in the spectroscopic and photometric observations reported by Sing et al. (2004). These authors showed that the secondary star in HS 1136+6646 (which we now know is a composite of two stars) was consistent with a K7 V–type star from the optical down to the infrared. The two main-sequence stars, with similar \( z \) magnitudes, would therefore have to be of similar K spectral type to give these consistent colors across the wide spectral range.

Analyzing the photometry of the 50CCD image can provide further hints as to the spectral type of the HS 1136C component. We convolved the clear bandpass of the 50CCD image with the observed spectral energy distributions of (1) the white dwarf primary, (2) a K7 V close binary with \( z = 14.7 \), and (3) a resolved G–M component with \( z = 14.025 \). A synthetic brightness ratio of HS 1136AB to HS 1136C was then calculated for different resolved companion spectral types and compared with the observed 5.5 : 1 ratio. We found that a K4 V or K5 V spectral type is most consistent for HS 1136C, giving ratios of 5.3 : 1 and 5.8 : 1, respectively, while G or M types are ruled out, with a G5 V star giving a ratio of 3.3 : 1, while an M3 V star gives a ratio of 12.9 : 1. Even a spectral type of K3 V, with a ratio of 4.7, or K7 V, with 7.0, are unlikely matches. With its main-sequence stars having similar magnitudes, type, and proper motion, it would seem likely that HS 1136+6646 is a triple-star system, although further studies will be needed for a definitive proof.

Note that Tokovinin et al. (2006) found via adaptive optics (AO) observations that 13 of 62 solar-type spectroscopic binaries have tertiary companions. Similar observations of HS 1136AB and its neighbor, using an AO system, should be sufficient to establish more accurately the color and likely spectral type of the latter, and also to establish whether its magnitude is consistent with it being a companion at a similar distance.

4. CONCLUSIONS

We failed to detect any diffuse nebuila surrounding the young post-CE system HS 1136. However, we did uncover evidence of an apparent third component contributing to the optical light. It is presently unclear whether this component, easily resolved in the HST acquisition image, is an unrelated field star or a
Fig. 5.—Acquisition image taken with the STIS on the Hubble Space Telescope. The red companion is fully resolved at the separation marked in the figure and at the orientation indicated in the previous figures. The STIS wavelength band is very broad but centered near $V$. The companion is 1.9 mag fainter than the HS 1136 binary. The proper motion measurement is indicated by the arrow and is discussed in the text.

common proper motion companion, making it a hierarchical triple system. Evidence indicates that it is likely of spectral type K. Regardless, ground-based spectroscopic and photometric studies of this systems need to take into account the presence of the additional star.

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