MWC 349A and B Are Not Gravitationally Bound: New Evidence

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Received 2017 August 2; revised 2017 November 7; accepted 2017 November 7; published 2017 December 20

Abstract

The age and evolutionary status of MWC 349A, the unique emission-line star with maser and laser radiation in hydrogen recombination lines, remain unknown, because the spectrum of the star is veiled by bright emission from the ionized disk and wind. The major argument for this massive (>10 M☉) star being evolved is its association with a close-by (2.4 arcsec) companion, MWC 349B, whose B0III spectrum implies an age of a few million years. However, newly obtained high-resolution spectra of MWC 349B reveal a difference of ≈35 km s⁻¹ in the radial velocities of the two stars, which makes their being gravitationally bound highly improbable. An estimate of the relative proper motion of the two stars seems to confirm this conclusion. This reopens the previously suggested possibility that MWC 349A is a young massive star in a region of active star formation close to Cyg OB2 association. MWC 349B, which moves with a speed ≥35 km s⁻¹ relative to Cyg OB2, may be a runaway star from this association.

Key words: binaries: visual – stars: early-type – stars: emission-line, Be – stars: individual (MWC 349A, MWC 349B) – stars: pre-main sequence

1. Introduction

MWC349 is a visual double star with a spectrally unclassified luminous emission-line component MWC 349A (hereafter “star A”) and a B0III component MWC 349B (“star B”), 2.4 arcsec apart (Cohen et al. 1985). The massive, ionized outflow from star A and its circumstellar disk is a source of bright radio emission with unique characteristics. It is the brightest known stellar source of centimeter radio continuum and the only known source of high-gain maser and infrared laser emission in hydrogen recombination lines (see a brief review in Strelnitski et al. 2013). The mass of star A has been estimated by several authors to be from (10–15) M☉ (Zhang et al. 2017) to (25–30) M☉ (Ponomarev et al. 1994; Thum et al. 1994). The age and the evolutionary status of this massive star are uncertain. A direct spectral classification is impossible, because the absorption spectrum of the star’s atmosphere is completely floored by exceedingly strong emission lines from its ionized envelope. Some indirect arguments have been presented for both the star being a luminous massive pre-main-sequence object and for it being an evolved supergiant (see Gvaramadze & Menten 2012 for a review of hypotheses).

One of the strongest arguments in favor of the latter hypothesis is the possible physical connection of star A with the less luminous and probably less massive star B, whose B0III spectrum indicates an age of ~5 Myr. Cohen et al. (1985), as well as Taf oy a et al. (2004), presented some evidence of a possible physical connection between the two stars, based on the shape of the radio continuum isophotes. However, Meyer et al. (2002) offer alternative explanations for the radio nebula shape and argue, based on their spectro-polarimetry of the two stars and constraints from the interstellar polarization, that star B is appreciably farther from us than star A and therefore they cannot be physical companions, although both are probably connected with the Cyg OB2 association.

Manset et al. (2017) argue, based on their estimate of the reddening of the two stars, that star B cannot be much farther from us than star A and that it may be within the nebula of star A. Strelnitski et al. (2013) drew attention to a possible physical connection of star A with a compact molecular cloud in the region of active star formation triggered by the mass outflow from Cyg OB2. If this connection is real, star A may be very young, and may even be the first case of a >10 M☉ Herbig Ae/Be star in a very short pre-main-sequence phase, just after having dispersed most of the surrounding molecular cloud.

Using the high-resolution spectra of stars A and B obtained with the TRES spectrograph of the 1.5 m Tillinghast Reflector at the Fred L. Whipple Observatory, Drew et al. (2016) came to the conclusion that the radial velocities of stars A and B are probably different by an amount several times greater than that allowed by a gravitationally bound system. However, the TRES spectrum of star B was heavily contaminated by the bright emission spectrum of star A, which caused considerable uncertainty in the measured radial velocities of its absorption lines. An independent confirmation came recently with the publication of radial velocity of star B by Manset et al. (2017) and with our own measurement using a high quality spectrum obtained with the HIRES echelle spectrograph on the Keck I telescope.

In this paper, we re-examine the results and conclusions briefly reported in Drew et al. (2016) and present the confirming Keck/HIRES result and a supporting argument based on an estimate of the relative proper motion of the two stars. The observations and reductions are described in Section 2 and the results in Section 3. In Section 4, we obtain the upper limit for the radial velocity difference between stars A and B if they are gravitationally bound and show that the observed velocity difference is several times greater than this limit, and thus that the two stars are very likely not gravitationally bound. We also obtain a preliminary estimate
of the relative proper motion of the two stars, which seems to confirm their high relative velocity. Section 5 summarizes our conclusions.

2. Observations and Data Reduction

2.1. The Tillinghast/TRES Data

The spectra of both stars were obtained on 2014 October 31 using the TRES fiber-fed echelle spectrograph on the 1.5 m Tillinghast Reflector at the Fred L. Whipple Observatory. The spectral resolving power was 44,000 (6.8 km s$^{-1}$). The spatial resolution, limited by the input of the fiber optics feed with a diameter of 2.4 arcsec, was comparable to the angular separation of the stars. As a result, the spectrum of star B was strongly contaminated by very bright emission lines of star A.

We used the IRAF$^6$ package splot to analyze the spectra. In order to extract the uncontaminated absorption spectrum of star B, a simple decontamination procedure was applied based on the assumption that the measured intensity $I_{A}$ at each wavelength $\lambda$ of star B’s spectrum is the sum of the intensity due to this star, $I_{0A}$, and a fraction $f$ of $I_{A}$—the observed intensity of the spectrum of star A. Thus, the uncontaminated intensity is given by the equation, $I_{A} = I_{0A} - f \cdot I_{A}$. The unknown “contaminating fraction” $f$ was determined visually for the wavelength interval comprising each of the measured lines by gradually increasing the value of $f$ and looking for the appearance of the absorption profile that would show neither signatures of contaminating emission, nor signatures of “over-subtraction” of the emission (i.e., the reversed pattern of the contaminating emission line). Since most of star A’s emission lines have a characteristic double-peaked profile, it was relatively easy to recognize the signatures of both residual contamination and “over-subtraction.” Still, this procedure was plagued by considerable uncertainty in the centroid radial velocity of each measured absorption line.

2.2. The Keck/HIRES Data

The Keck/HIRES echelle spectrograph (Vogt et al. 1994) data were acquired on 2017 May 19th and 20th. With the seeing of $\approx$0.8 arcsec, we were able to obtain uncontaminated individual spectra of stars A and B by placing the slit perpendicular to the line connecting the images of the stars. A total exposure time of 600 s on MWC 349B, using the C1 decker, resulted in an S/N $\approx$ 30 per 1.3 km s$^{-1}$ pixel, with an instrumental resolution of FWHM = 6.25 km s$^{-1}$. The HIRES data were reduced using standard XIDL$^7$ reduction packages.

3. Results

Using the decontamination procedure described in Section 2.1, we measured the heliocentric radial velocities of three He I absorption lines in the Tillinghast/TRES spectrum of star B. The adopted vacuum rest wavelengths of the three lines (5877.27, 6680.00, and 7067.17 Å) are the weighted averages of the strongest components of each line taken from the NIST database (Kramida et al. 2015). Figure 1 shows, as an example, the decontaminated profile of the 6680.00 Å line, whose centroid is at 6680.69 ± 0.02 Å, corresponding to the heliocentric radial velocity $V_{R}(6680) = +31 \pm 1$ km s$^{-1}$. The mean value of the heliocentric radial velocity over the three measured lines is given in the fourth column of Table 1. The error of the mean value (estimated from the scatter of the individual values of $V_{R}$) is considerably larger than the formal errors of the centroid of the fitting Gaussian for each line because of the uncertainty in determining the optimal value of the contamination fraction $f$ in the decontamination procedure.

We determined the radial velocity of star B with the Keck/HIRES spectrum using the 5877.27 He I absorption line.$^8$ After continuum fitting and normalization of the spectrum, a least-squares Gaussian fit to the absorption line gave a best-fit centroid of 5877.798 ± 0.014 Å, or $V_{R}$(HEL) = $+27.2 \pm 1.5$ km s$^{-1}$ (Figure 2 and Table 1).

There is no direct information on the radial velocity of star A because of the lack of its atmospheric absorption spectrum. However, its probable radial velocity can be estimated from the optical and radio data on the outflow and the disk of the star (e.g., Gordon et al. 2001; Aret et al. 2016). Here we adopt star A’s systemic velocity based on the SMA interferometry of the circumstellar disk in masering H30α and H26α lines (Zhang et al. 2017): $V_{A}$(LSR) = $+7.2 \pm 0.2$ km s$^{-1}$ (the error estimate is based on the difference of $\approx$0.2 km s$^{-1}$ between the velocity values obtained with the two lines). For the “standard” solar motion adopted at SMA, the heliocentric velocity corresponding to this LSR velocity is $V_{A}$(HEL) = $-9.9 \pm 1.0$ km s$^{-1}$ (N. Patel 2017, private communication; we increased the probable error to account for the small uncertainty of the LSR to HEL transformation). This value of $V_{A}$(HEL) is in agreement with the heliocentric radial velocity of the ionized envelope of the star as measured by Aret et al. (2016) using the forbidden optical lines of [O I] and [Ca II]: $V_{env}$(HEL) = $-9 \pm 2$ km s$^{-1}$.

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$^6$ IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

$^7$ http://www.aol.com/~xavier/IDL/

$^8$ The HIRES spectra of both stars will be discussed in further detail in an upcoming paper (R.A. Jorgenson et al. 2017, in preparation).
Using the above values of $V_{b}(HEL)$ obtained with the two spectrographs, we calculated the values of $\Delta V_{BA} = V_{b}(HEL) - V_{a}(HEL)$. They are shown in the fifth column of Table 1, together with their estimated errors.

4. Discussion

Given the much larger uncertainty of the Tillinghast/TRES result, the agreement between the values of $\Delta V_{BA}$ obtained with this spectrograph and with Keck/HIRES is remarkably good. These results are also corroborated by the recently published radial velocity of star B based on the measurement of two HeI lines in a spectrum obtained with the 3.6 m CFHT telescope (Manset et al. 2017), see Table 1. Thus, we can firmly conclude from three independent results that the radial velocity difference of stars B and A is not less than $\approx 35$ km s$^{-1}$.

We now show that this velocity difference is much larger than the difference allowed for a gravitationally bound pair of stars with the probable parameters of MWC 349A and B and the probable distance to them.

The radial velocity of a component of a binary (let it be component 1) is given by the standard equation:

$$V_1 = V_0 + K_i [\cos(\omega + \nu) + e \cos \omega],$$

where $V_0$ is the radial velocity of the binary’s center of mass, $\omega$ is the argument of periapsis of the orbit, $\nu$ is the true anomaly of the star within the orbit, $e$ is the orbit’s eccentricity,

$$K_i = \sqrt{G(m_1 + m_2)a_1 \sin i} / \sqrt{a^3(1 - e^2)},$$

is the radial velocity semi-amplitude, $i$ is the inclination of the orbital rotation axis to the line of sight, $a \equiv a_1 + a_2$ is the sum of the semimajor axes of the orbits of components 1 and 2, $m_1$ and $m_2$ are the masses of the components, and $G$ is the gravitational constant.

With similar expressions for $V_2$ and $K_2$ for component 2 and with the usual radial velocity sign convention (positive for recession and negative for approach), the observed absolute value of the difference of radial velocities of the components,

$$\Delta V_1 = |V_1 - V_2|,$$

is maximum when (1) the plane of the orbits is seen edge-on ($i = 90^\circ$); (2) the stars reach their highest orbital speeds, i.e., each of them is at the periapsis of its orbit ($\nu = 0$); (3) the velocity vectors are parallel to the line of sight, i.e., the line of the major axes of the orbits is perpendicular to the line of sight ($\omega = 0$). For this configuration, one gets from Equations (1)–(3) as well as two equations for component 2 analogous to Equations (1) and (2)

$$\Delta V_1 = (1 + e) \sqrt{G(m_1 + m_2)} / (a(1 - e^2)).$$

The linear distance between the stars when they are at their periapsides is $\delta = a(1 - e)$. Taking into account (1) that in the orbit configuration described above the line connecting the components lies in the plane of the sky, and thus $\delta = \theta \cdot D$, with $\theta$ being the observed angular separation of the components and $D$ being the distance to the object, and (2) that $\theta \cdot D < \delta$ for any deviation of the line connecting the components from the plane of the sky, we finally get the upper limit,

$$\Delta V_1 \leq \sqrt{G(1 + e)(m_1 + m_2)} / \theta \cdot D \leq 2G(m_1 + m_2) / \theta \cdot D.$$
possibility that the large radial velocity difference is due to the orbital motion (if star B is itself a binary) seems quite improbable. The period $P$ of a binary can be presented in the form,

$$P = 0.97 \cdot 10^7 \frac{m_3^3}{(m_1 + m_2)^2} \frac{K_i}{M_\odot} \left( \frac{V_{\text{BA}}}{\text{km s}^{-1}} \right)^{-3} \frac{\sin^3 i}{(1 - e^2)^{3/2}}.$$  

(6)

Substituting the observed $\Delta V_{\text{BA}} \approx 35$ km s$^{-1}$ for $K_1$, and supposing that the mass of the component 2 in the star B binary is comparable or smaller than the probable mass of component 1 (star B, $\sim 20 M_\odot$), and that the eccentricity of the orbit is not too large, it is found from Equation (6) that the probable period of the binary is $\sim 1000$ days or less. During an orbital period, the radial velocity of star B (and thus $\Delta V_{\text{BA}}$) must change by at least $\approx 35 \cdot 2 \approx 70$ km s$^{-1}$. However, the three independent spectra taken with the intervals of 413 and 929 days showed practically the same values of $\Delta V_{\text{BA}}$, which is consistent with the earliest and the latest spectra, separated by 1342 days, coincided within $\approx 6\%$ uncertainties of the obtained $\Delta V_{\text{BA}}$. This corresponds to only $\approx 3\%$ of the expected radial velocity amplitude, if star B is a binary. Such a coincidence is highly improbable, all the more so when one considers a very close amplitude, if star B is a binary. Such a coincidence is highly improbable. The period $P$ of a binary can be presented in the form,

$$P = 2\pi \left( \frac{a}{1 - e^2} \right)^{3/2} \frac{1}{K_1},$$

where

$$a = \frac{2M}{3} \frac{1-e^2}{1+e^2}.$$  

These values are in agreement with the typical proper motion parameters for the Cyg X star-forming complex (e.g., Rygl et al. 2012), although the uncertainty of measurements still allow for a peculiar motion of star A with a speed of several tens of kilometers per second. A preliminary estimate of the proper motion of star B relative to star A can be done by comparing the separation of the two stars—$d = 2''14 \pm 0''1$ in position angle $p_1 = 280^\circ \pm 2^\circ$, obtained in 1983 July (Cohen et al. 1985), with the positions of the stars determined in the CDSS survey in 2003 September: R.A. = $308^h 18^m 96^s 57'$; decl. = $40^\circ 66' 01'' 71$; R.A. = $308^h 18' 86' 74''$, decl. = $40^\circ 66' 03'' 88$, with an uncertainty $\pm 0'' 05$ in both coordinates (Ahn et al. 2012). This gives the separation $d_2 = 2''79 \pm 0''05$ in the position angle $p_2 = 286^\circ \pm 1^\circ$. It is easy to see then that the observed angle covered by star B in the plane of the sky, in the reference frame of star A, is $0''5 \pm 0''2$. This was covered over 20 years, thus the relative proper motion was $25 \pm 10$ mas yr$^{-1}$, which, at a distance of $\approx 1.5$ kpc, corresponds to a relative transverse velocity of the two stars approximately $200 \pm 100$ km s$^{-1}$. This large relative transverse velocity seems to corroborate our conclusion that stars A and B are not gravitationally bound. However, this crude estimate is not based on a consistent astrometric study, which is still needed.

5. Conclusion

Recent measurements of absorption lines in the spectrum of MWC 349B, the visible companion of the peculiar emission-line star MWC 349A, reveal a large difference of radial velocities of the two stars—much larger than the theoretical upper limit for a gravitationally bound binary. This makes it improbable that the two stars are physically connected, which opens the possibility that the $\approx 10 M_\odot$ star A is very young and may even still be in its short pre-MS phase. With its high positive radial velocity, star B may be a runaway star from Cyg OB2 association. A preliminary estimate of the relative proper motion of the two stars seems to support these conclusions, but a targeted astrometric study is needed to provide a decisive measurement.

We gratefully acknowledge David Latham for his help in organizing the TRES observations and for important suggestions on the draft of the paper. P.D. acknowledges financial support by the NSF REU grant 0851892, by the Nantucket Maria Mitchell Association, and by the University of Texas at Austin College of Natural Sciences. Some of the data presented herein were obtained at the W. M. Keck Observatory, which is operated as a scientific partnership among the California Institute of Technology, the University of California, and the National Aeronautics and Space Administration. The Observatory was made possible by the generous financial support of the W. M. Keck Foundation. The authors wish to recognize and acknowledge the very significant cultural role and reverence that the summit of Maunakea has always had within the indigenous Hawaiian community. We are most fortunate to have the opportunity to conduct observations from this mountain. Finally, we thank the anonymous referee for critical remarks that led to a considerable improvement of the text.
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