Bulletin de la Société Royale des Sciences de Liège, Vol. 80, 2011, p. 371 - 375

Observations of Be Disk Building: Optical Spectra of NW Serpentis (HD 168797) over 35 days

Erika D. Grundstrom[1,2], M. V. McSwain[3], C. Aragona[3],
T. S. Boyajian[4], A. N. Marsh[3], R. M. Roettenbacher[3*]

[1] Dept. of Physics & Astronomy, Vanderbilt University, Nashville, TN, USA
[2] Dept. of Physics, Fisk University, Nashville, TN, USA
[3] Dept. of Physics, Lehigh University, Bethlehem, PA, USA
[4] CHARA, Georgia State University, Atlanta, GA, USA

Abstract: The classical Be star NW Serpentis (HD 168797) is part of the CoRoT field and has long been studied photometrically and is known to have multi-periodic pulsational modes. Such pulsations are thought to be a way to generate the Be equatorial circumstellar disk. In an earlier survey, we identified this star as a possible non-radial pulsator and a known B←Be variable. During Fall 2008, we obtained 23 spectra over 35 nights in the Hα region. During this time, we observed Hα to go from purely photospheric absorption to double-peaked emission then "fade" back toward photospheric absorption. We present our determination of stellar parameters, our analysis of the circumstellar disk construction, and the possibility of a binary companion. These observations also suggest that frequent observations of Be stars known to be non-radial pulsators may yield more opportunities to study the disk-building phenomenon and thus assist in constraining theoretical models of disk generation.

1 Introduction

Be stars are rapidly rotating B-type stars that lose mass in an equatorial, circumstellar disk (Porter & Rivinius 2003) and cause Balmer and other line emission. Many Be stars exhibit short-term variability with a period range of a few hours to a couple of days. This short-term variability is detected in photometric studies (non-regular light curves) and in spectroscopic studies (line profile variability or *lpv*). While we do not yet know what causes the stellar material to actually leave the surface of the star, one of the prevailing theories is non-radial pulsation.

HD 168797 (NW Serpentis, HR 6873) is a $V = 6.14$ star with spectral type B2.5IIIe. It has an extensive photometric monitoring record spanning over two decades. It is also in the CoRoT field. During Grundstrom's (2007) spectroscopic survey of field Be stars, she identified HD 168797 as interesting on the basis of the variation in the Hα profile over two years. During the fall of 2008, we observed this star spectroscopically 23 times in a 35-day observing run and saw the growth of a double-peaked emission profile indicative of circumstellar disk growth.

[*] All were Visiting Astronomers, Kitt Peak National Observatory

2 Observations

We obtained 23 spectra in the Hα region (6370–7040 Å) of HD 168797 at the KPNO coudé feed telescope over 35 consecutive nights during 2008 October and November (HJD=2454756.6–2454791.7). We used grating B in second order with the OG550 order-sorting filter and the F3KB detector (for a resolution $\lambda/\triangle\lambda$ = 11400–12500). The spectra were wavelength-calibrated using Th-Ar comparison lamp spectra taken throughout the each night. These data do not appear to be coincident with any CoRoT observations.

The images were zero-corrected, flat-fielded, and wavelength-calibrated using standard procedures in IRAF.[1] The spectra were interpolated onto a log wavelength scale using a common heliocentric wavelength grid, and they were rectified to a unit continuum using line-free regions.

3 Physical Parameters from Spectral Models

In order to incorporate more recent research regarding determination of the physical parameters of B stars, we have found new values for $T_{\rm eff}$, $\log g$, and $V \sin i$. The method used by Frémat et al. (2006) of fitting metal lines to find effective temperature is not ideal as metallicity plays a role in the strength of such lines - one should use Hγ to get the most accurate estimates (Huang & Gies 2006).

We formed a mean blue spectrum using four spectra obtained between 2004–2006. Contemporaneous Hα spectra indicated that no emission was visible at these times, and furthermore no evidence of weak emission was present in the Hγ line. We omitted a fifth blue spectrum from the mean because its Hγ line profile was somewhat narrower than the others, suggesting that a weak emission disk was present at that time.

To measure the physical parameters of HD 168797, we used the new TLUSTY BSTAR2006 grid of metal line-blanketed, non-LTE, plane- parallel, hydrostatic model spectra (Lanz & Hubeny 2007). We used their models with solar metallicity and helium abundance and a microturbulent velocity of 2 km s^{-1}. We adopted the mean $V \sin i$ from Frémat et al. (2006), Abt, Levato & Grosso (2002), and Yudin (2001), using $V \sin i = 260$ km s^{-1} . We compared the Hγ line profile to the rotationally and instrumentally broadened model spectral line profiles at each value in the grid, minimizing rms^2 across the line region. We then refined our measurements to a higher precision using a linear interpolation between the available line profiles in the grid. Our best line fit indicated $T_{\rm eff} = 17650$ K and $\log g = 3.50$, shown in Figure 1. We determined the formal errors from the values above, however, we found that the placement of the continuum caused much larger errors than the formal errors from our line profile fits. Therefore, we adopted a lower limit for $T_{\rm eff}$ of 16000 K and an upper limit of 18000 K, and a range of acceptable $\log g$ between 3.3 – 3.5.

Rapidly rotating B stars may be distorted into an oblate spheroidal shape, so the surface gravity at the equator can be much lower than at the poles, and this $\log g_{polar}$ is a better indicator of the evolutionary state of the star. Huang & Gies (2006) performed detailed spectroscopic modeling of such distorted rotating stars to determine a statistical correction factor for $\log g$, averaged over all possible i, for a variety of stellar models. We made a bilinear interpolation between their models to convert our measured $\log g$ to $\log g_{\rm polar}$ for a more accurate comparison between slow and rapid rotators.

We also measured its mass, $M_\star$, and radius, $R_\star$, by interpolating between the evolutionary tracks for non-rotating stars from Schaller et al. (1992). The range of acceptable values of $M_\star$ and $R_\star$ correspond to our measured errors in $T_{\rm eff}$ and $\log g$. For simplicity, we assume the polar radius of

[1] IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation

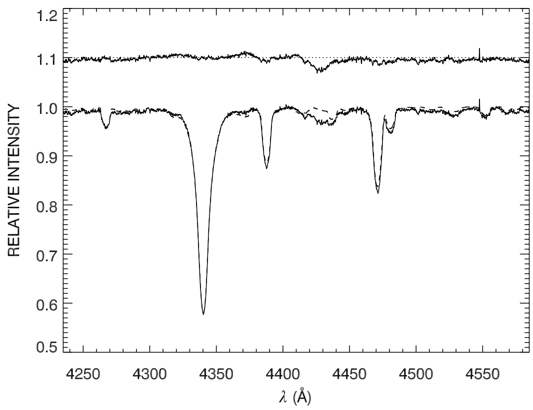

Figure 1: The mean blue spectrum of HD 168797 (from previous work by Grundstrom) compared to the best fit model derived from the Hγ data, with $V \sin i$ = 260 km s^{-1}, $T_{\rm eff}$ = 17650 K, and $\log g$ = 3.50. The residuals of the observed minus model spectrum are shown above (shifted by the value 1.1 for presentation). Note that the broad residual feature around λ4429Å is a diffuse interstellar band.

Table 1: Newly Determined Stellar Parameters (numbers in parentheses are range of acceptable values)

$T_{\rm eff}$	17650 K (16000–18000 K)
$\log g$	3.5 (3.3–3.5)
$\log g_{polar}$	3.80
$M_\star$	6.63 $M_\odot$ (5.64–7.36)
$R_\star$	5.35 $R_\odot$ (4.88–6.32)
V_{crit}	397 km s^{-1} (324–438)
inclination	≈51° (39°–63°)

the star, $R_{\rm p}$ is equal to $R_\star$, and a rotationally distorted star has an equatorial radius $R_{\rm e} = 1.5R_{\rm p}$ in the Roche approximation. The resulting critical velocity is $V_{\rm crit} = (GM_\star/R_{\rm e})^{1/2}$. If we assume that the Be star is nearly critically rotating, with true rotational velocity $V_{\rm rot}$ equal to 90-95% of $V_{\rm crit}$ (Townsend, Owocki & Howarth 2004), we can constrain the inclination, i, of the rotation axis. Values for all parameters are summarized in Table 1.

We also found that by using these values, we obtained an excellent fit to the Hα line when it is purely photospheric as it was during our first three observations of this data set.

4 Preliminary Analysis

In looking at the Hα emission wings (Fig. 2,3) we notice that they are limited by approximately 260 km s^{-1} (the same as the projected rotation velocity of the star). The emission peaks are at slower speeds in our earlier observations, then these peaks slowly shrink as they move outward toward the faster regions as over the course of our observations. This implies that there was an outburst of material, with matter which escaped the surface of the star for a short period of time (and slowed as per Kepler's laws) but slowly fell back to the surface (and sped up). We note that it takes longer to dissipate this disk than it did to build it.

The height of the peaks changes over the course of our observations implying more material on one side (redward earlier, switching to blueward over the course of a few days). We can infer two

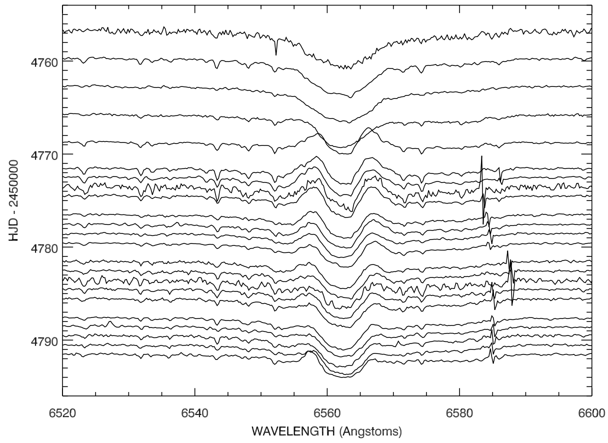

Figure 2: Time series plot of the 23 spectra in the Hα region over the 35 day observation period (time increasing down).

possible mechanisms for this observation: 1) the circularization of a blob (or several blobs) of material as it rotates around the star (as suggested for μ Cen by Rivinius et al. 1998); 2) the presence of a spiral density wave in this circumstellar disk (Okazaki 1991). This is the more unlikely as the timescales required are much longer (~years) than the few day timescales observed here.

4.1 Line Profile Variability

While some Be stars experience outbursts like this at periastron, our investigation of radial velocity variations (RVVs) is currently inconclusive. There do seem to be some RVVs between the peaks which may be indicative of spectroscopic evidence of non-radial pulsation. This star is known to have multiperiodic pulsations (from photometric studies by Gutiérrez-Soto et al. 2007) so perhaps we will be able to find such evidence in our data. We will investigate our data further. Also, we will undertake further work using the He I λ6678 line - we do not trust it entirely as it is partially filled with emission and shows some evidence of non-radial pulsation signatures. However, discussions with conference attendees have caused us to look at it more closely.

5 Conclusions

Our serendipitous spectroscopic observation of the interesting Be star NW Serpentis (HD 168797) demonstrates the need for long term, consistent observation of certain stars - we were very fortunate to catch this very short-lived transition. We hope our observations will help provide constraints for models of Be stars and disks in general.

In general, we find that this star is just barely spinning fast enough to throw material off of the equator. We also find it can build a disk in three days (or less!) - perhaps the process is rather explosive (possibly like μ Cen - see Hanuschik et al. 1993)? Only further observations can answer that question. During our observations, we found that the disk falls back onto the star and only the material that is nearest the star (i.e. the fastest material) is emitting photons by the end of the observational period. We can provide no guidance at this time as to whether or not this system is a binary.

For future work, we are investigating further observations and an association with the resource of amateur astronomers with their own spectrographs - a collaboration will provide an unprecedented amount of data and hopefully we can catch NW Ser building another disk.

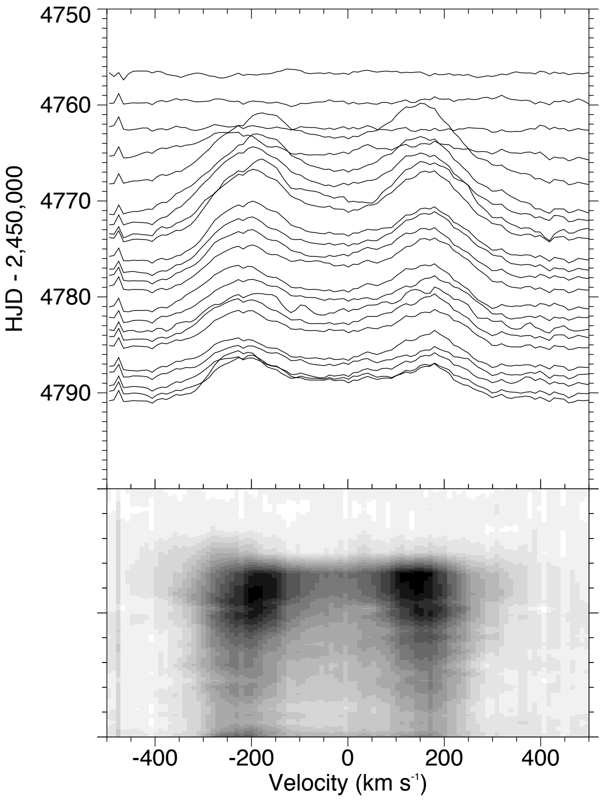

Figure 3: The upper plot shows the Hα line profile of NW Ser with the photospheric component removed over our continuous 35 nights of observation, sorted by HJD, and the lower plot shows a gray-scale image of the same line using the same chronological order. The intensity at each velocity in the gray-scale image is assigned one of 16 gray levels based on its value between the minimum (bright) and maximum (dark) observed values. The intensity between observed spectra is calculated by a linear interpolation between the closest observed phases.

Acknowledgements

This work has been supported in part by NASA grant #NNX08AV70G and NSF Career grant AST-0349075. EDG gratefully acknowledges travel support from the American Astronomical Society.

References

Abt, H. A., Levato, H., & Grosso, M. 2002, ApJ, 573, 359

Frémat, Y., Neiner, C., Hubert, A.-M., Floquet, M., Zorec, J., Janot-Pacheco, E., & Renan de Medeiros, J. 2006, A&A, 451, 1053

Grundstrom, E. D. 2007, Ph.D Dissertation, Georgia State Univ.

Gutiérrez-Soto, J., Fabregat, J., Suso, J., et al. 2007, A&A, 472, 565

Hanuschik, R. W., Dachs, J., Baudzus, M., & Thimm, G. 1993, A&A, 274, 356

Huang, W. & Gies, D. R. 2006, ApJ, 648, 591

Lanz, T. & Hubeny, I. 2007, ApJS, 169, 83

Okazaki, A. T. 1991, PASJ, 43, 75

Porter, J. M., & Rivinius, Th. 2003, PASP, 115, 1153

Rivinius, Th., Baade, D., Stefl, S., Stahl, O., Wolf, B. & Kaufer, A. 1998, A&A, 333, 125

Schaller, G., Schaerer, D., Meynet, G., & Maeder, A. 1992, A&AS, 96, 269

Townsend, R. H. D., Owocki, S. P., & Howarth, I. D. 2004, MNRAS, 350, 189

Yudin, R. V. 2001, A&A, 368, 912