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Analysis of the B and Be-star populations of the double cluster h and χ Persei

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Abstract. We present blue optical spectra of 92 members of h and χ Per obtained with the *WIYN* telescope at Kitt Peak National Observatory. From these spectra, several stellar parameters were measured for the B-type stars, including $v \sin i, T_{\rm eff}$, $\log g_{\rm polar}$, $M_\star$, and $R_\star$. Strömgren photometry was used to measure $T_{\rm eff}$ and $\log g_{\rm polar}$ for the Be stars. We also analyze photometric data of cluster members and discuss the near- to mid-infrared excesses of Be stars.

Keywords. open clusters and associations: individual (NGC 869, NGC 884), stars: emission-line, stars: Be

1. Introduction

NGC 869 and NGC 884 (h and χ Persei, respectively) comprise a well-known double cluster rich in massive B-type stars, and have been the focus of many studies over the years. Recent studies show that NGC 869 and NGC 884 have nearly identical ages of $\sim 13 - 14$ Myr, common distance moduli of d$M \sim 11.85$ mag, and common reddenings of $E(B-V) \sim 0.5 - 0.55$ (Currie *et al.* 2009; Slesnick *et al.* 2002; Bragg & Kenyon 2005).

Currie *et al.* (2008; hereafter C08) identified two populations of NGC 869 and NGC 884 stars with detected *Spitzer* MIPS 24 μm excess emission: 20 A and F-type stars with luminous debris-disk emission and 57 brighter, earlier stars with weaker excess emission. They identify most of the latter group as candidate Be stars. However, only 21 were previously listed as Be stars (e.g., Bragg & Kenyon 2002; Slesnick *et al.* 2002).

In this study, we analyze blue optical spectra of 92 early-type cluster members, including 16 candidate Be stars from C08, and investigate their near- to mid-infrared (IR) excesses. With continued monitoring of these stars in both the optical and IR regimes, we hope to explore these excesses as a reasonable means for identifying potential Be stars within clusters, as well as to investigate the transient natures of the disks surrounding the known Be stars in NGC 869 and NGC 884.

2. Overview

Blue optical spectra of 92 members of NGC 869 and NGC 884 were obtained on 2005 November 14–15 using the *WIYN 3.5m* telescope with the Hydra spectrograph. The observed spectra cover a wavelength range of 4250–4900 Å.

Shown in Figure 1 are samples of the model spectral fits used to measure values for $v \sin i, T_{\rm eff}$, and $\log g$ for B-type stars. $v \sin i$ was determined by comparing the He I $\lambda\lambda$4387, 4471,4713, and Mg II λ4481 lines with the Kurucz ATLAS9 models (Kurucz 1994) and taking a weighted average of these four values. For stars having $T_{\rm eff} \geqslant 15\,000$ K, the TLUSTY BSTAR2006 models (Lanz & Hubeny 2007) were used to find $T_{\rm eff}$ and $\log g$

using the Hγ line. For stars having $T_{\rm eff} \leqslant 15\,000$ K, the Kurucz ATLAS9 models were used (Kurucz 1994). The method of Huang & Gies (2006; hereafter HG06) was used to determine $\log g_{\rm polar}$. For Be stars, Strömgren photometry available from the WEBDA database was used to derive $T_{\rm eff}$ and $\log g_{\rm polar}$ based on the methods of McSwain *et al.* (2008). The masses and radii for all stars were determined from the Schaller *et al.* (1992) evolutionary tracks, which are shown plotted with $T_{\rm eff}$ and $\log g_{\rm polar}$ in Figure 2.

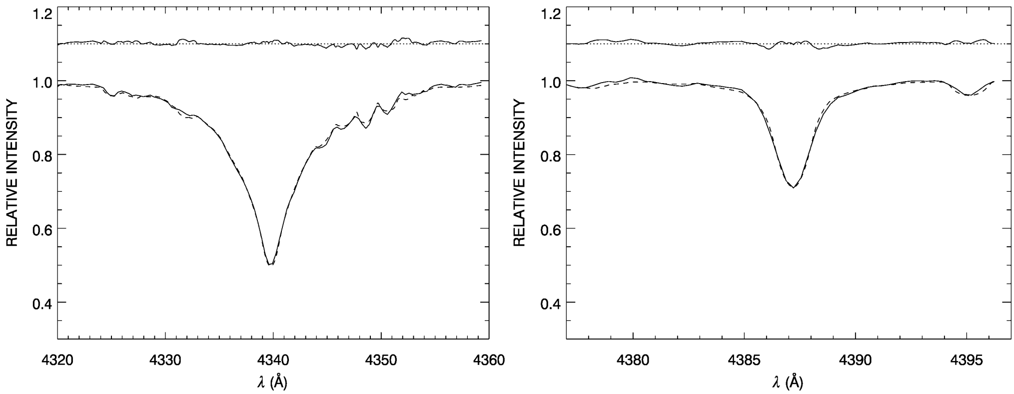

Figure 1. Sample spectral-line fits for NGC 869–90. Shown on the left is Hγ and on the right is He Iλ4378. The solid line is our observed spectrum while the dashed line displays our model fit to the line, with the computed residual shown above, shifted for clarity.

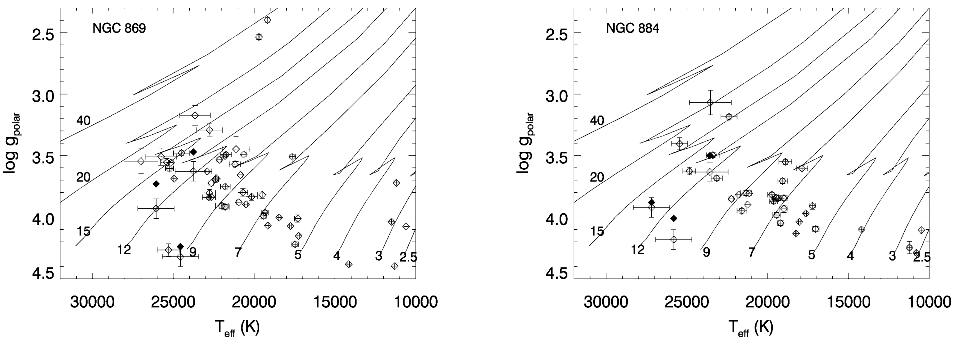

Figure 2. For both NGC 869 *(left)* and NGC 884 *(right)*, $T_{\rm eff}$ and $\log g_{\rm polar}$ are plotted with the evolutionary tracks of Schaller *et al.* (1992). The zero-age main-sequence mass of each evolutionary track is labeled along the bottom. Normal B-type stars are shown as open diamonds while Be stars are filled diamonds.

3. Results

Sixteen Be candidates from C08 are present in our sample or that of HG06. Three of these 16 stars show no evidence of circumstellar emission in our spectra, although all have been observed to be Be stars in the past (Keller *et al.* 2001). Ten of the C08 Be candidates in our spectra show emission. Stellar parameters for the remaining three candidates are found in HG06, thus we cannot comment on the presence of emission at the time of observation. In addition, we find Be emission in one star (No. 1772) that was not observed by C08, and we present results for one additional star (No. 1268) identified as a Be star by Keller *et al.* (2001). These results are summarized in Table 1.

Table 1. Measured physical parameters for Be stars

Cluster Star[1]	$v \sin i$ (km s^{-1})	$T_{\rm eff}$ (K)	$\log g_{\rm polar}$ (dex)	$M_\star$ ($M_\odot$)	$R_\star$ ($R_\odot$)	Be Cand.[2]	Comment	Ref.
NGC 869–49	172	23757	3.63	12.3	8.9	Y	Emission present	This work
NGC 869–517	178	…	…	…	…	Y	Emission present	This work
NGC 869–566	306	21183	3.57	10.4	8.7	Y	No emission present[3]	This work
NGC 869–846	205	22747	3.29	14.7	14.3	Y	Weak emission present	This work
NGC 869–847	87	27000	3.54	17.8	11.8	Y	Weak emission present	This work
NGC 869–1162	66	19175	2.40	33.6	60.8	Y	No emission present[3]	This work
NGC 869–1261	285	26065	3.93	12.0	6.2	Y	Strong emission present	This work
NGC 869–1268	151	24491	3.48	14.8	11.6	N	No emission present[3,4]	This work
NGC 869–1278	197	24562	4.32	9.0	3.4	Y	Emission present	This work
NGC 884–1772	379	…	…	…	…	…	Emission present	This work
NGC 884–1926	106	27190	3.92	13.5	6.7	Y	Strong emission present	This work
NGC 884–2091	236	…	…	…	…	Y	Emission present	This work
NGC 884–2138	153	23579	3.63	12.0	8.7	Y	Emission present	This work
NGC 884–2165	79	26571	4.03	11.9	5.5	Y	—	HG06
NGC 884–2402	141	28238	3.81	15.6	8.1	Y	—	HG06
NGC 884–2468	134	10500	4.11	2.7	2.4	Y	No emission present[3]	This work
NGC 884–2563	308	25820	4.18	10.7	4.4	Y	Strong emission present	This work
NGC 884–2949	168	18240	3.96	6.4	4.4	Y	—	HG06

Notes:
[1] Identification numbers from the WEBDA database. [2] Be candidate in C08. [3] Stars not showing emission in our observations are likely transient Be stars. [4] Identified as Be star by Keller *et al.* (2001).

Spectral-energy distributions (SEDs) for three stars in NGC 869 and NGC 884 are displayed in Figure 3. UBV magnitudes are from the WEBDA database, $JHK_{\rm s}$ are from the 2MASS survey, and *Spitzer* [8] and [24] μm are from C08. These magnitudes were converted to fluxes using the methods detailed in Bessell *et al.* (1998), Cohen *et al.* (2003), Colina *et al.* (1996), Reach *et al.* (2005), and Rieke *et al.* (2008). Assuming a constant $E(B-V) = 0.52$ mag for NGC 869 and NGC 884 (Bragg & Kenyon 2005; Slesnick *et al.* 2002), reddened blackbody curves have been overlaid on these plots to investigate their near- to mid-IR excesses. All three stars shown in Figure 3 are proposed Be candidates (C08), with NGC 884–2138 and NGC 869–49 having emission present in our optical spectra and observed near- to mid-IR excess. NGC 884–2165 is not included in our spectroscopic sample but has previously been identified as a Be star and has observed IR excess (Keller *et al.* 2001).

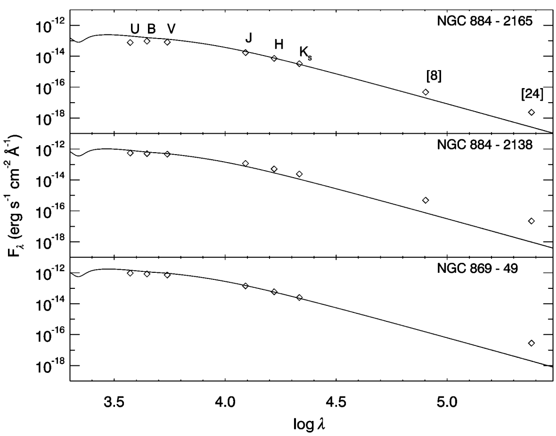

Figure 3. SEDs for three stars in NGC 869 and NGC 884. Reddened blackbody curves are overlaid on these plots to investigate their near- to mid-IR excesses.

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4. Conclusions and further work

We have measured the physical parameters of 77 B-type stars and 15 Be stars in NGC 896 and NGC 884. Sixteen Be candidates from C08 are present in our sample or that of HG06. Of these 16 Be candidates, three stars show no evidence of emission in our optical data and are likely transient Be stars. Ten of these Be candidates show emission in our spectra. Those Be candidates without emission in our spectra should be monitored in the future to further investigate their transient nature.

In the future, IRAC 3.6–5.8 μm data will be combined with the optical and IR fluxes used here to investigate the observed SEDs. We will fit the new SEDs using modern flux models rather than blackbody curves. Modifications accounting for variable reddening throughout the clusters will also be made. These new SED fits can then be used to model the Be disk sizes and temperatures.

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