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# NARROW-BAND Hα PHOTOMETRY OF Be STARS: MONITORING FOR DISK VARIABILITY[1]

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## ABSTRACT

Classical Be stars are hot, rapidly rotating, main sequence stars that have in the past, or currently exhibit Balmer line emission in their spectra. They possess a circumstellar disk, the origins of which are still a mystery. Activity in the emission portion of their spectra is linked to activity in the disk itself. Large outburst events of Hα flux levels are signs of large disk-building events. We report here on the narrow-band photometry taken for a small set of 28 faint Be stars looking for any significant variability in this Hα flux. Although variability on the order of 0.10 magnitude was observed for several stars in our sample, no large outbursts were detected in the time span reported here.

*Subject headings:* photometry – stars: emission-line, Be – stars: variable – circumstellar disks

## 1. INTRODUCTION

The fundamental definition for a Be star, as the designation suggests, is a B-type star that shows, or has shown at some time, Balmer emission lines in its spectrum (Porter and Rivinius 2003). A great deal is still unknown about the Be star phenomenon, however. Circumstellar disks are known to exist for these stars and they have been shown to be Keplerian using interferometry (Martayan et al. 2011). As main sequence stars, however, they are not still forming. Thus, these disks are not accretion disks but are decretion disks of matter ejected from the star itself. It is yet to be determined exactly how these disks are formed. Be stars are known to be very rapidly rotating stars that have angular velocity versus critical angular velocity ratios upwards of 85-95% (Martayan et al. 2011). This leads to matter along the equatorial regions of the star travelling with enough velocity to bring it very close to becoming orbital. This rapid rotation is not enough to eject matter from the star into orbit, however. There must be an additional mechanism(s) that gives the material enough momentum to break free of the star and push it into the Keplerian orbit to form the circumstellar disk. Such mechanisms would likely be associated with some increase in luminosity of the star as the circumstellar disk itself would grow.

Stellar nonradial pulsations (NRPs) creating outwardly propagating circumstellar waves are one of the possible mechanisms that may very well play a role in forming the disk (Cranmer 2009). Photometric monitoring of Be stars for evidence of such activity may be employed to spot these events via larger stellar outbursts. In particular, increased Hα emission has been associated with disk- building events. The very origin of the Be classification makes note that it is the disk itself that produces the emission lines in the spectra of the star (Struve 1931). Although small pulsations of Be stars may be capable of energizing material enough to force it into orbit, larger outbursts of activity in the star are more likely responsible for large disk building phases. If these outbursts can be detected photometrically, characterizing their behavior for a large sample of stars will provide much needed information to improve models of the disk formation.

## 2. OBSERVATIONS

Since the Hα emission from the star is indicative of the presence of a circumstellar disk, variability of this emission can be used as a proxy for varying activity in the disk. Disks around many Be stars have gone through phases of building and loss activity as well as quiescent phases (Porter and Rivinius 2003). However, variability is present in the continuum as well. Hubert and Floquet (1998) found several bright Be stars whose Hipparcos magnitude (very close to the visual band) varied by a few tenths of a magnitude during outburst periods lasting hundreds of days. Such variability in the continuum, however, could arise from global changes in the star, not just the disk. In order to track changes specifically in the disk of the star, narrow-band observations in Hα are needed.

The Be stars chosen, as seen in Table 1, had to meet a few criteria to be considered for our observations. We chose stars with known visual band variability from the General Catalog of Variable Stars (GCVS) that were faint enough to avoid saturating the CCD detector at both observatories. In addition, the majority of our stars were chosen to be visible in both the Northern and Southern hemispheres to promote the ability to make more observations over the course of a year with our available observatories. Stars were also chosen based on the sur-

[1]Based on observations obtained with the SARA Observatories, which are owned and operated by the Southeastern Association for Research in Astronomy (http://www.saraobservatory.org).
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TABLE 1
Observed Stars

| Star Designation | Spectral Type | Camera | No. of Nights Observed | Date Range (JD - 2453000) | Hα Emission Mag. Var. Range | Visual Mag. Range |
|---|---|---|---|---|---|---|
| MN CMa | B0.5III | U42 | 5 | 2902-2953 | 0.06 | 0.19 |
| | | QSI | 8 | 2897-3070 | 0.05 | 0.19 |
| | | E6 | 5 | 2676-2704 | 0.06 | 0.19 |
| MO Cam | BV | U42 | 5 | 2902-2969 | 0.14 | 0.20 |
| NSV 01701 | B1IV | U42 | 6 | 2902-2969 | 0.04 | 0.35 |
| OY Gem | BV | U42 | 5 | 2902-2953 | 0.11 | ... |
| | | QSI | 6 | 2897-3048 | 0.13 | ... |
| | | E6 | 3 | 2676-2693 | 0.03 | ... |
| V0374 Cep | B4V | U42 | 6 | 2880-3105 | 0.08 | 0.29 |
| V0388 Pup | B4/B5III | U42 | 4 | 2902-2953 | 0.03 | 0.21 |
| | | QSI | 10 | 2897-3086 | 0.04 | 0.21 |
| | | E6 | 5 | 2676-2704 | 0.01 | 0.21 |
| V0397 Lac | B1.5V | U42 | 6 | 2869-3104 | 0.03 | ... |
| V0408 Pup | B2/B3III | U42 | 4 | 2902-2953 | 0.04 | 0.32 |
| | | QSI | 10 | 2897-3086 | 0.04 | 0.32 |
| | | E6 | 5 | 2676-2704 | 0.03 | 0.32 |
| V0415 Lac | B1:IV | U42 | 6 | 2880-3105 | 0.11 | 0.25 |
| V0418 Cep | B5V | U42 | 7 | 2876-3104 | 0.14 | ... |
| V0435 Cep | B2III | U42 | 7 | 2876-3104 | 0.10 | 0.20 |
| V0436 Vul | ... | U42 | 6 | 2869-3105 | 0.02 | 0.11 |
| | | E6 | 6 | 2698-2836 | 0.00 | 0.11 |
| V0450 Cep | B1IV-V | U42 | 7 | 2880-3104 | 0.10 | 0.17 |
| V0450 Vul | B1V | U42 | 6 | 2869-3105 | 0.08 | 0.21 |
| | | E6 | 7 | 2683-2836 | 0.05 | 0.21 |
| V0525 Cep | BV | U42 | 6 | 2880-3105 | 0.08 | 0.11 |
| V0548 Per | B1V | U42 | 7 | 2876-2969 | 0.04 | 0.12 |
| V0783 Cas | BV | U42 | 5 | 2902-2969 | 0.05 | 0.11 |
| V1437 Aql | B9V | U42 | 6 | 2869-3103 | 0.04 | 0.14 |
| | | QSI | 4 | 3070-3125 | 0.02 | 0.14 |
| | | E6 | 5 | 2683-2836 | 0.02 | 0.14 |
| V1446 Aql | B5V | U42 | 8 | 2869-3104 | 0.08 | 0.12 |
| | | QSI | 5 | 3070-3125 | 0.07 | 0.12 |
| | | E6 | 10 | 2683-2842 | 0.05 | 0.12 |
| V1462 Aql | B5V | U42 | 5 | 2869-3104 | 0.06 | ... |
| | | QSI | 2 | 3096-3118 | 0.04 | ... |
| | | E6 | 10 | 2683-2842 | 0.03 | ... |
| V1463 Aql | B5V | U42 | 5 | 2869-3104 | 0.06 | 0.14 |
| | | QSI | 3 | 3096-3125 | 0.01 | 0.14 |
| | | E6 | 10 | 2683-2842 | 0.04 | 0.14 |
| V2103 Cyg | B8V | U42 | 6 | 2869-3105 | 0.14 | 0.12 |
| | | E6 | 5 | 2698-2836 | 0.03 | 0.12 |
| V2166 Cyg | B2V | U42 | 7 | 2869-3104 | 0.15 | 0.11 |
| | | E6 | 6 | 2698-2813 | 0.04 | 0.11 |
| V2175 Cyg | BV | U42 | 5 | 2896-3104 | 0.12 | 0.12 |
| V2243 Oph | B3V | U42 | 6 | 3048-3105 | 0.03 | 0.12 |
| | | QSI | 5 | 3070-3125 | 0.01 | 0.12 |
| | | E6 | 9 | 2683-2842 | 0.06 | 0.12 |
| V2385 Oph | BV | U42 | 5 | 3048-3105 | 0.03 | 0.16 |
| | | QSI | 3 | 3035-3096 | 0.05 | 0.16 |
| | | E6 | 9 | 2683-2842 | 0.04 | 0.16 |
| V4383 Sgr | O+ | U42 | 5 | 3048-3103 | 0.05 | 0.13 |
| | | QSI | 5 | 3035-3125 | 0.04 | 0.13 |
| | | E6 | 8 | 2683-2842 | 0.06 | 0.13 |
| V4400 Sgr | B2V | U42 | 5 | 3048-3104 | 0.04 | 0.28 |
| | | QSI | 5 | 3035-3125 | 0.03 | 0.28 |
| | | E6 | 9 | 2683-2842 | 0.08 | 0.28 |
| V4409 Sgr | B8V | U42 | 7 | 2869-3104 | 0.08 | 0.50 |
| | | QSI | 5 | 3070-3125 | 0.09 | 0.50 |
| | | E6 | 9 | 2683-2842 | 0.03 | 0.50 |

References. — Visual Magnitude Ranges taken from the General Catalog of Variable Stars (GCVS).

rounding star field. Too crowded of a field would not allow accurate aperture photometry, however too sparse of a field would not give us the comparison stars desired. We aimed to have at least two non-varying comparison stars of comparable magnitude to the Be star in the field available.

### 2.1. *Monitoring for Variability*

Images were obtained using the SARA North 0.9-meter telescope with an Apogee Alta U42 CCD camera and the SARA South 0.6-meter telescope with a Quantum Scientific Imaging (QSI) 683 CCD camera. Prior to December 2011 SARA South was equipped with an Apogee Alta E6 CCD camera.

In addition to the different telescopes and CCD cameras at the SARA North observatory versus the SARA

South observatory, each has a slightly different set of filters that were used for these observations. Table 2 shows the two sets of filters that were used including the wavelength measures (in nanometers) of the centers and widths of each filter. The two Hα filters used are very similar narrow-band filters centered at the same wavelength. Their band pass widths are slightly different, with the filter in the South slightly wider than that of the North. The next difference in the two filter sets lies with the continuum filter used in each case. For the North, we used a typical narrow-band red continuum filter that has a center wavelength on the short side of the spectrum from the Hα filter. In the South, however, we did not have access to a typical red continuum filter, which led us to use the available redshifted Hα filter with a center on the opposite side of the continuum from the true red continuum filter. In both the North and South we were looking to compare the flux levels produced in the narrow-band Hα with those of the surrounding continuum. The goal was to produce an *index* of activity in Hα from differential photometry between the Be and comparison star (see equation 1).

All images were calibrated using Mira Pro 7 software using the bias, dark, and flat frame images from each night. Aperture photometry was performed on the variable and comparison stars in each image to produce instrumental magnitudes for each filter, also using Mira Pro 7 software. Once the aperture photometry was completed, all necessary data were exported to an Excel spreadsheet for analysis.

Differential magnitudes of the Be star and a comparison star were computed once instrumental magnitudes were collected from an image. This produced a difference in instrumental magnitudes for both the Hα and the red continuum images. These differences were then compared to each other to produce an *index* which was the most sensitive indicator of the variability in Hα emission for the Be star. We define this index as

$$H\alpha\ Index = (V_{H\alpha} - C_{H\alpha}) - (V_{RC} - C_{RC}) \qquad (1)$$

where $V_{H\alpha}$ is the instrumental magnitude of the Be star in the Hα filter and $C_{H\alpha}$ is the instrumental magnitude of the comparison star in the Hα filter while $V_{RC}$ and $C_{RC}$ are the corresponding instrumental magnitudes for the red continuum filter. The same process was used to monitor any variability in the comparison star by producing a differential magnitude of the comparison star and a secondary check star, whenever one was available in an image, to be sure any variability was only occurring in the Be star itself.

### 2.2. *Calibration Issues Between the Different Instrumental Systems*

A point of concern with these observations was whether the slightly different filter set and the different CCDs used at the SARA South observatory would produce results photometrically similar to those provided by the SARA North system. Our goal is to be able to monitor several stars using both observatories to acquire a much larger data set on a longer time scale to better analyze for both long and short term variability. Although we are working to standardize the two systems, there are a few difficulties with attempting that calibration. First,

TABLE 2
Filter Sets

| | Filter | Center (nm) | Width (nm) |
|---|---|---|---|
| North | Hα | 656.3 | 4.5 |
| | Red Continuum | 645.3 | 7.0 |
| South | Hα | 656.3 | 7.0 |
| | Redshifted Hα | 660.0 | 6.0 |

as noted in section 2.1, there are two different sets of filters for SARA North and SARA South. This means flux levels being captured aren't going to be identical even if the same telescope and camera were used. The primary difference between the two sets being the red continuum filter utilized in the North is on the shorter end of the spectrum from the Hα line in question, where the redshifted Hα filter of the South is on the longer end of the emission line and in fact overlaps by 2.8 nm into the wider Hα filter band pass used in the South.

The other difficulty involved in combining data from the North observatory with the South observatory is that there are, as previously noted, different CCD cameras in use at each telescope. The Apogee U42 is back illuminated and has a different response curve, as well as quantum efficiency, from the front illuminated QSI and Apogee E6 cameras. In addition, the field of view for each camera is different, being significantly smaller for the QSI camera. This requires the use of different comparison stars for some object fields which creates a major calibration problem. Although we can identify some common background stars among the different fields of view, the stars are faint with low signal-to-noise ratios in many cases. Thus, it is difficult to establish a reliable and precise level of correction to the instrumental magnitudes obtained between the different systems. We are continuing to build a large data set on brighter comparison stars present in object fields for both observatories to establish the correction factors needed to standardize the instrumental magnitudes between the two systems.

For the observations presented here, we have not yet been able to combine the observations within one standardized system. Thus, we have separately analyzed the data from each CCD camera to look for variability within the observations of the Be stars. In Table 1, this analysis is presented with separate rows indicated to identify the data set by the CCD camera used to obtain it.

## 3. RESULTS & CONCLUSION

Table 1 shows the 28 stars that were monitored over the past 14 months in an attempt to capture any emission outburst activity, as well as produce the calibration corrections necessary to combine data from the North and South sets into one long time stream. The stars' designation and spectral type are shown in the first two columns followed by a column listing which CCD camera was used for a particular data string. The next two columns show the number of nights each star was observed using the given camera and the range of dates over which it was observed. For some stars at extreme northern or southern declinations, observations were made at only one observatory. The sixth column shows the range in our value of the Hα *index*, in magnitudes, as determined by the differential photometry between the narrow-band continuum and H$\alpha$ filters. The last column shows the visual magnitude range of variability as indicated in the GCVS.

We determined an instrumental noise level of 0.02 magnitudes for our observations by taking an average of the deviance within all of the primary comparison star to secondary check star data for all observations. Thus, only an H$\alpha$ *index* variability of 0.06 magnitude or greater would be considered potentially significant, such variability existing at the three sigma level. Our monitoring observations produced the following results as seen in column five of Table 1. Some stars showed significant variability, but not necessarily within the data sets at both observatories (e.g., OY Gem and V2166 Cyg). However, we note these data sets were obtained at different epochs within the overall time span of the observations. None of the stars observed here exhibited variability on a scale large enough to be considered an outburst indicative of any disk building activity. Approximately 50% of the stars monitored exhibited variability at the level of 0.06 magnitude or below, while the other 50% had possible significant variability in our *index* value. The maximum variability observed was only 0.15 magnitude, well below that expected for a true outburst of activity in a Be star. These variations are possibly related to the intrinsic broadband variability of the Be stars or could be indicative of low levels of activity within the circumstellar disk. There was also no evidence of any periodic type behavior in the variability for any star or any indication of a long time scale increase in the narrow-band H$\alpha$ emission which might indicate the beginnings of a disk building event.

We are continuing the monitoring program for these stars with an initial goal to standardize the observations between the two observatories. More observations are also needed to better characterize the small amplitude variability detected here to help improve the modeling of Be star circumstellar disks.

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