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Abstract

Beginning in June 2003, undergraduate students and the author have spectroscopically monitored bright Be stars using a custom built fiber-fed spectrograph attached to the UCA Observatory 11-inch Schmidt-Cassegrain telescope. We have obtained 0.8 Angstrom/pixel resolution spectra of the H-alpha line for over forty Be-Stars. Some have been observed on multiple dates in order to detect any temporal changes. Line profiles, velocities, and observed variations for some of these stars will be presented.

Introduction

Be stars are spectral type B non-supergiant stars whose Balmer lines have been observed to have been in emission at some time (Jaschek et al., 1981). Emission lines indicate the presence of circumstellar gas that has been photoionized by the star. The line profile of the Balmer lines (e.g., H-alpha) offers clues to the shape, orientation, and speed (expansion and rotation) of the flattened circumstellar envelope. Be stars exhibit a variety of line profiles. In addition, the line profiles of many Be stars change over time. For some Be stars, the circumstellar envelopes dissipate and reform. The stellar absorption lines of these stars show that these are rapidly rotating stars.

Possible mechanisms that may contribute to the formation of the circumstellar disks include rapid rotation (Cranmer and Owocki, 1996), stellar winds (Dessart and Owocki 2003), magnetism (Poe and Friend, 1986), non-radial stellar pulsations (Maintz et al., 2003), and binary companions (Apparao, 2002). The mechanism for forming these disks is not well understood, nor is it clear what causes some Be stars to dissipate and reform their circumstellar disks.

Observations are needed to test the models for these stars. We and other Be star observers around the world are attempting to build up a sufficient database of the temporal-spectral-variations for as many different Be stars as possible. There are over 100 Be stars brighter than 6th magnitude that are visible during the year from our latitude. The work presented here represents part of the first several months of our observational work toward this goal.

Materials and Methods

UCA Observatory.--The UCA observatory is atop Lewis Science Center on the UCA campus. The UCA campus is located in Conway Arkansas, population ca. 45,000. Given the urban location, light pollution is a significant problem. This is one of the factors that restricts us to studying relatively bright objects.

The observatory facilities consist of a five m dome and a Celestron 11-inch (0.28 m) aperture f/10 Schmidt-Cassegrain telescope (C11). The 11-inch aperture is another factor in limiting us to bright objects. The equatorial fork mount of the telescope has been retrofitted with digital setting circles, which greatly improve the pointing precision and accuracy. Mounted on the C11 is a Meade ETX telescope with a Meade 216XT CCD camera, which is used for guiding while taking exposures with the C11.

Fiber-Fed Spectrograph.--A telescope the size of the C11 is restricted in the size and weight of instrumentation that can be mounted in its focal plane. This was the motivation for building a spectrograph system using a bench spectrograph and optical fibers to transport light from the focal plane of the telescope to the spectrograph. In this case, only a relatively small and lightweight assembly has to be mounted to the telescope. The fiber/coupler assembly holds the ends of the fibers in the focal plane and contains optics and video used to acquire stars onto the fibers. The design of our system is based mostly upon that built at Harvard (Kannappan and Fabricant, 2000; Kannappan et al., 2002). Their system required using an eyepiece for target acquisition and guiding; our system has a video camera system we have incorporated into the guider/coupler assembly.

Three 100-micron diameter optical fibers are used to transport light from the telescope to the bench spectrograph. One fiber is used to obtain starlight and the other two are able to monitor any sky background. Experience shows that thus far sky background is below any significant detectable limits. Therefore, sky subtraction has not been necessary.

The bench spectrograph consists of a fiber holder, collimating lens, reflection diffraction grating with 1800 lines/mm, 50mm camera lens, and a Finger Lakes MaxCam CCD camera. This results in 0.8 Angstrom/pixel resolution near H-alpha with 675 Angstrom coverage.

Data Acquisition.--The CCD camera for the bench spectrograph is controlled with a laptop computer running

MaxIM/DL. The images are saved in Flexible Image Transport System (FITS) format. Multiple zero-second exposure bias frames were acquired at the beginning of the night. Next, a spectrum of a mercury-neon lamp was acquired at the beginning of the night for the purpose of wavelength calibration. Since the spectrograph is a bench-spectrograph and is housed in a cabinet where there is little change in temperature during the night, the wavelength calibration is stable. Next, a spectrum of a bright spectroscopic standard star was obtained for the purpose of relative flux calibration. Once these calibration frames were obtained for the night, spectra of Be stars brighter than 7th magnitude near the meridian were acquired. To get an adequate signal-to-noise-ratio (SNR), exposures ranged from 10 to 45 minutes. To make fine guiding corrections to ensure that the light from the target star travels down the fiber, the observer must watch the video output from the guider/coupler and make necessary adjustments with the C11 control paddle.

Data Reduction.--The raw FITS frames are transferred to a LINUX workstation running Interactive Reduction and Analysis Facility (IRAF). The FITS frames are exported to IRAF format. The zero-second bias frames are combined to form a master bias frame. This master bias frame is then subtracted from the raw spectral frames. The two-dimensional spectra are extracted and summed from each of these frames, producing one-dimensional spectra. The lines in the mercury-neon lamp spectrum are then identified, and a wavelength as a function of pixel number solution is fit. The stellar spectra are then wavelength calibrated with this solution. The spectra of the spectral standard stars are used to relative-flux calibrate the spectra of the Be stars. A spectral response function is determined by comparing the observed standard star spectrum with the known flux per bandpass. To relative-flux calibrate the spectra of the Be stars, this response function is applied. Finally, the Be star spectra are normalized to the continuum level of the spectra. This allows us to compare H-alpha line profiles of the same star on different dates.

Data Analysis.--IRAF is used to measure the physical parameters of the H-alpha line profiles of the Be stars. These include parameters such as equivalent widths, peak intensity relative to the continuum, full-width-at-half-maximum velocities, and for double peaked profiles, the relative intensities of the two peaks (Andrillat, 1983). This allows us to determine quantitatively any changes in line profiles over time.

Results

We have observed over forty Be stars during 2003. Ten of these stars are presented based on the criteria that they had emission lines and were observed on multiple dates between June 2003 and August 2003. The displayed spectra of these ten stars are relative to the continuum level (I/Ic) and have not been smoothed.

The 48 Librae profiles obtained on 22 and 27 June 2003 June are shown in Fig. 1. The two profiles are identical, demonstrating no significant changes over five days. This star is known to be a spectroscopic variable over longer time periods (Aydin and Faragiana, 1978). Both profiles are asymmetric and double peaked, with the blue side weaker than the red side of the profile, similar to that reported by Banerjee, Rawat, and Janardhan (2000). The FWHM velocity of the profile is about 570±63 km/sec.

Delta Scorpii became a Be star in the year 2000 (Fabregat and Reig, 2000). Shown in Fig. 2 are profiles obtained on four nights in June and July 2003. The profiles show a single peak with FWHM velocity of 337±63 km/sec. The profiles did not show any significant changes over the month of observations.

Chi Ophiuchi was observed six times between 12 June 2003 and 23 July 2003. The line profiles are shown for four of the dates in Fig. 3. The single peaked line profile peak I/Ic intensity varied between 6.1±0.1and 7.6±0.1. The FWHM velocity varied between 284±63 km/sec and 300±63 km/sec. The profile from 15 March 1999 reported by Banerjee, Rawat, and Janardhan (2000) showed a single peak with a slight red shoulder and I/Ic of about 11.5.

Observations of Omicron Herculis from 12 June 2003 and 31 July 2003 are shown in Fig. 4; they show a weak emission feature with a FWHM velocity of 280±63 km/sec within a broad absorption feature.

4 Aquilae was observed on 20 June 2003 and 8 July 2003. The single peak profiles (Fig. 5) with FWHM velocity of about 450±63 km/sec are within a broad absorption feature. The I/Ic intensity may have changed slightly.

Fig. 6 shows the line profiles of V923 Aquilae from 27 June 2003 and 24 July 2003. The profiles from these two dates are nearly identical, and have a double peak asymmetric profile. The blue side of the profile is weaker than the red side. The FWHM velocity is about 235±63 km/sec.

The profiles of Beta^2 Cygni are shown in Fig. 7. The observations were recorded on 22 June 2003 and 24 July 2003. The single peak profile, which is sitting in a shallow broad emission feature, has a FWHM velocity of about 375±63 km/sec. The intensity of the emission line was observed to be slightly stronger in June. The H-beta profile reported by Lacy (1977) for 12 July 1975 showed no emission with H-beta in absorption.

V1294 Aquilae was observed on 3 and 8 July 2003. Fig. 8 shows that the profile remained unchanged. The single peak profile exhibits a symmetric broad base. The FWHM velocity is approximately 500±63 km/sec.

Observations of 59 Cygni from 23 June 2003 and 8 July 2003 (Fig. 9) show nearly identical single peak profiles with a FWHM velocity of about 600±63 km/sec.

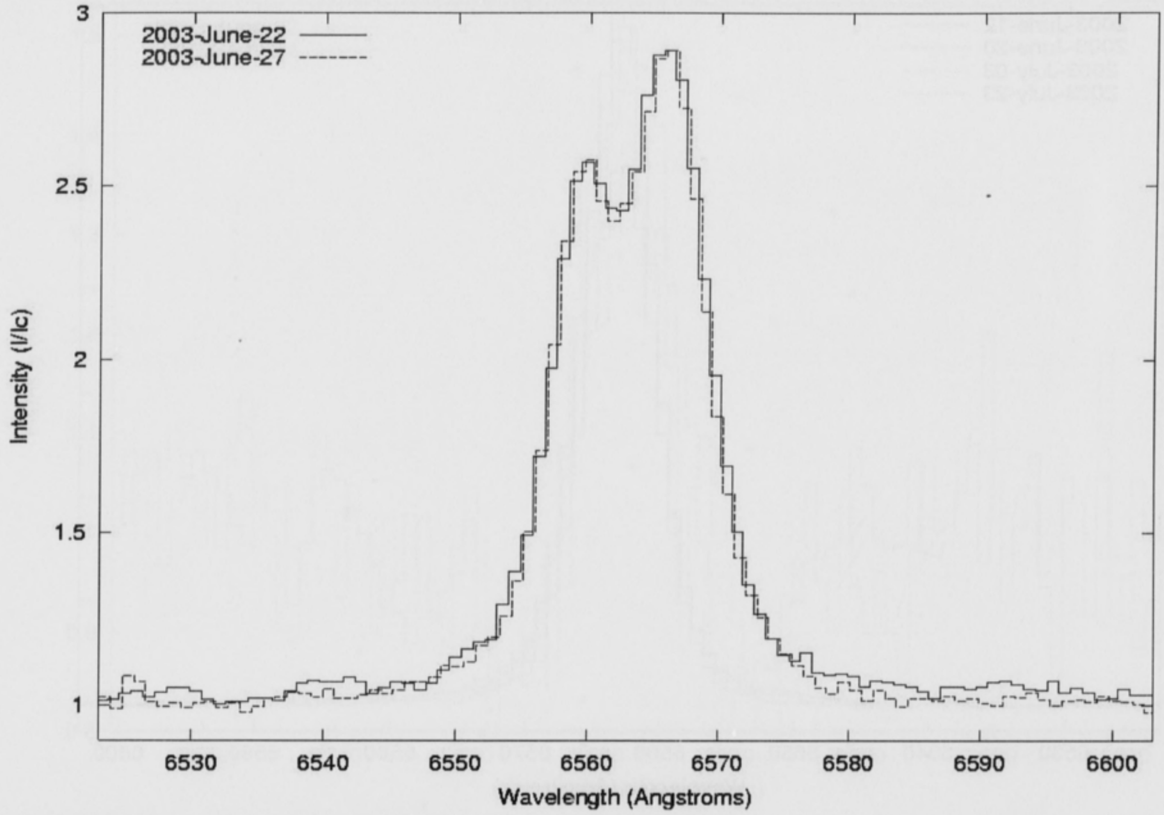

Fig. 1. 48 Librae H-alpha line profile normalized to the continuum (I/Ic).

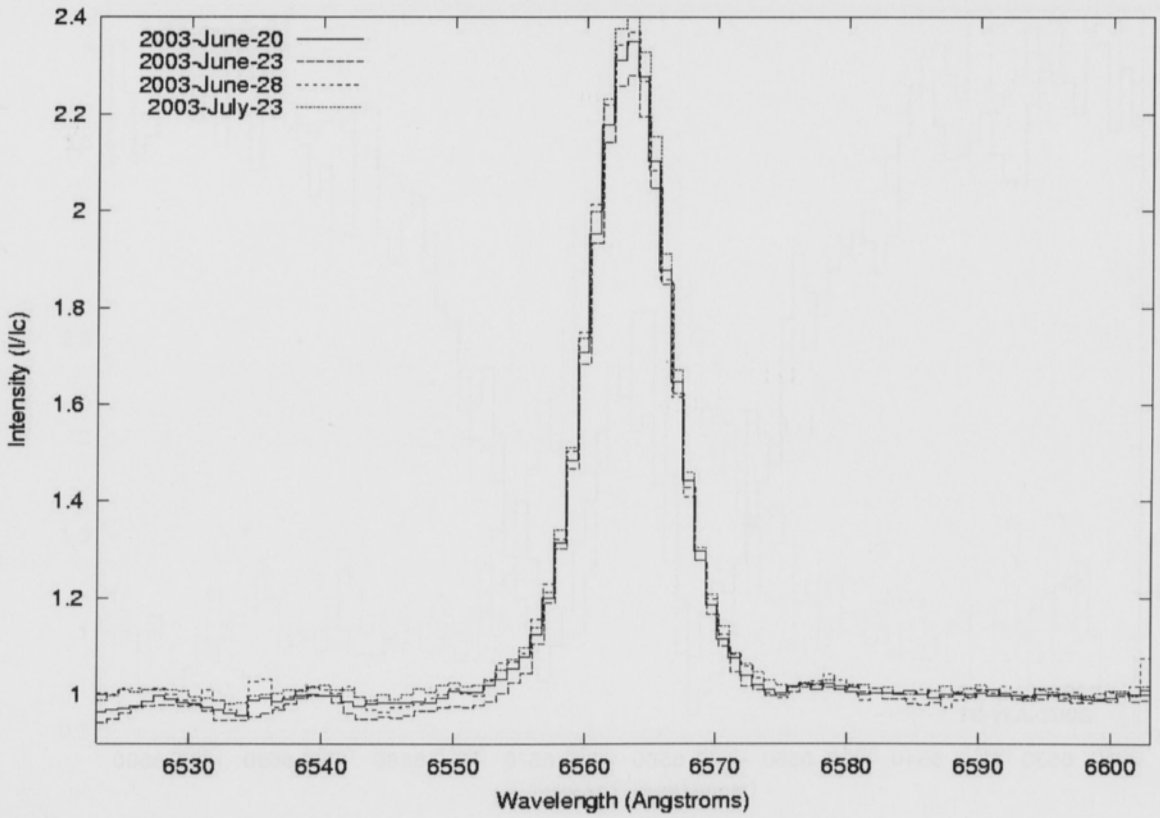

Fig. 2. Delta Scorpii H-alpha line profile normalized to the continuum (I/Ic).

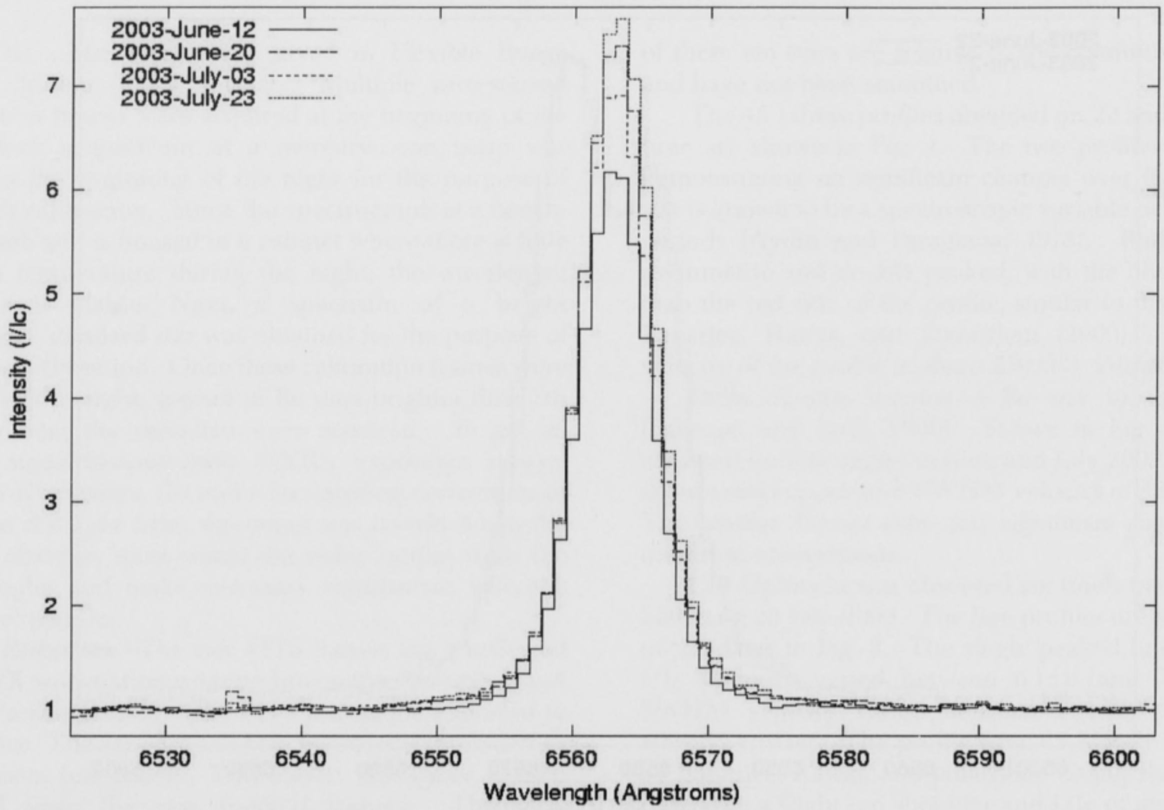

Fig. 3. Chi Ophiuchi H-alpha line profile normalized to the continuum (I/Ic).

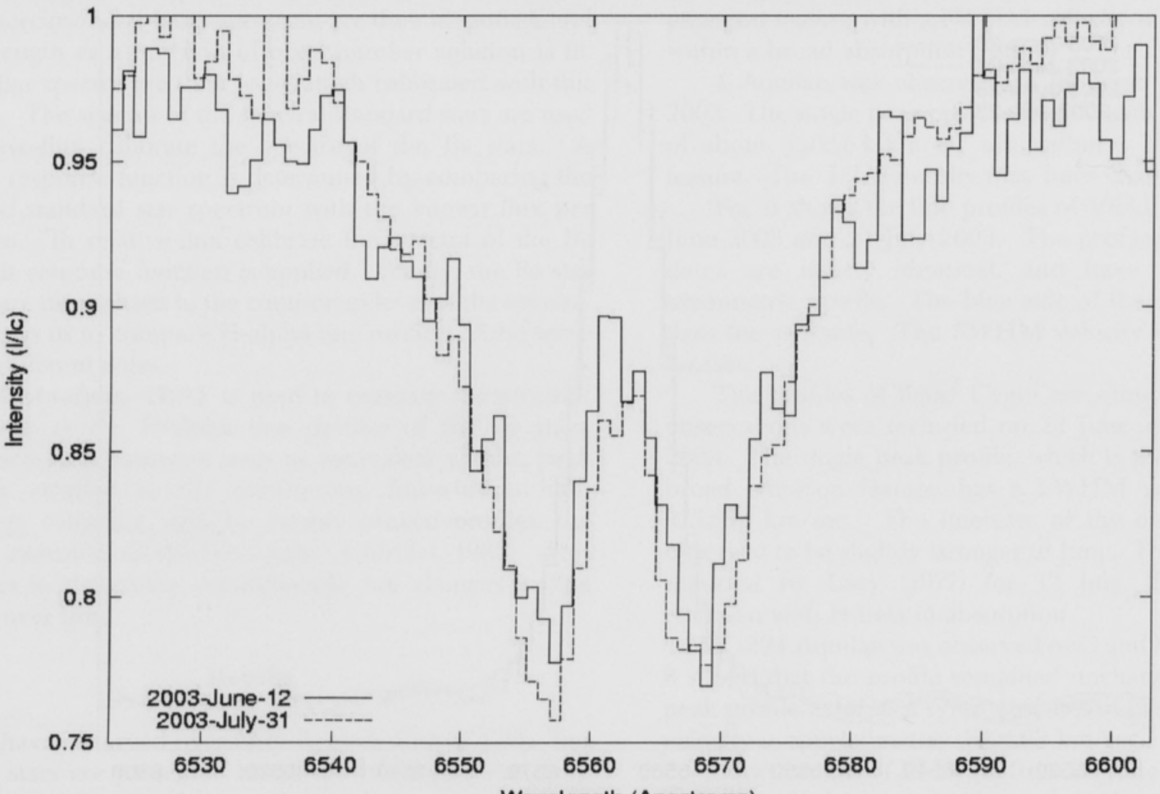

Fig. 4. Omicron Herculis H-alpha line profile normalized to the continuum (I/Ic).

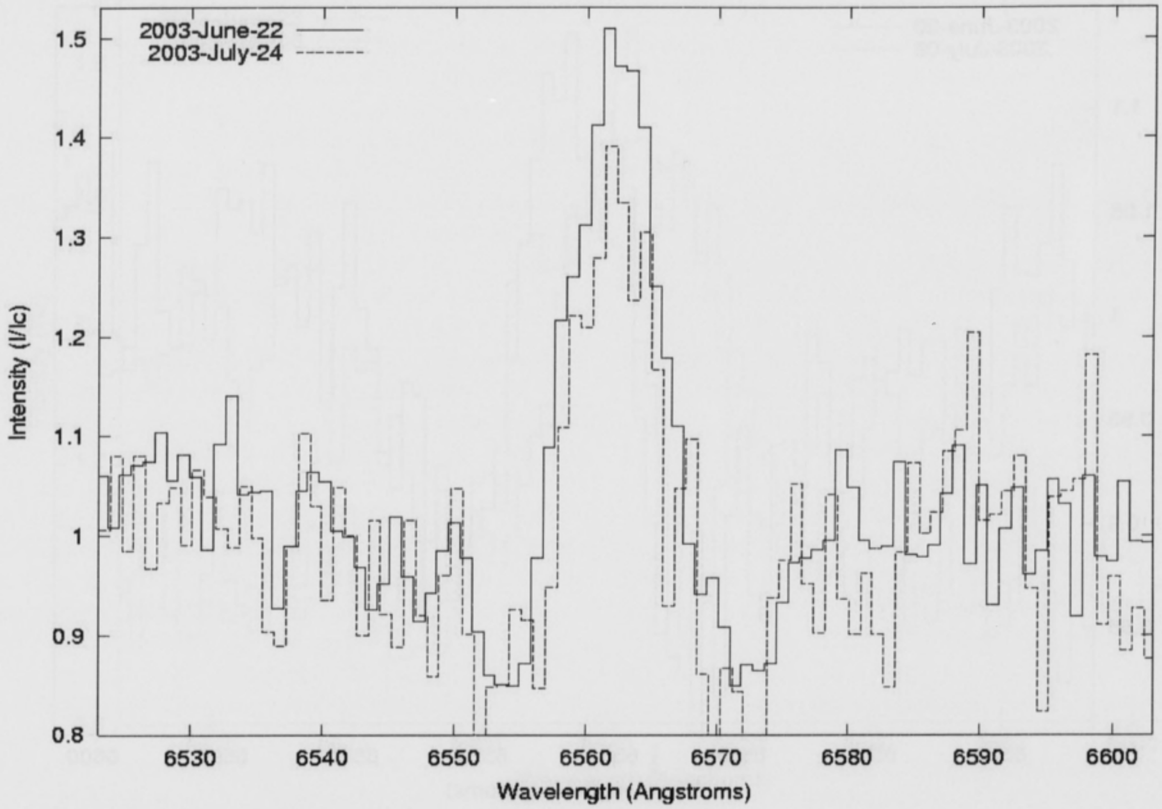

Fig. 5. 4 Aquilae H-alpha line profile normalized to the continuum (I/Ic).

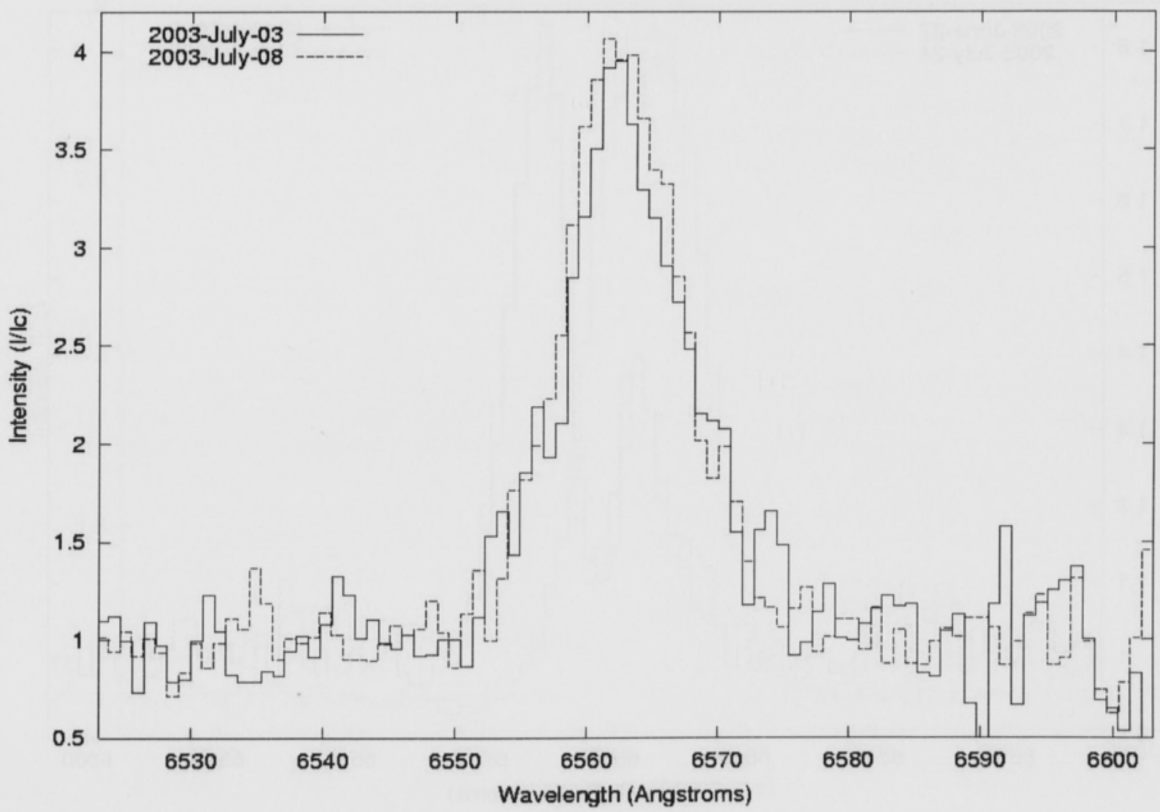

Fig. 6. V923 Aquilae H-alpha line profile normalized to the continuum (I/Ic).

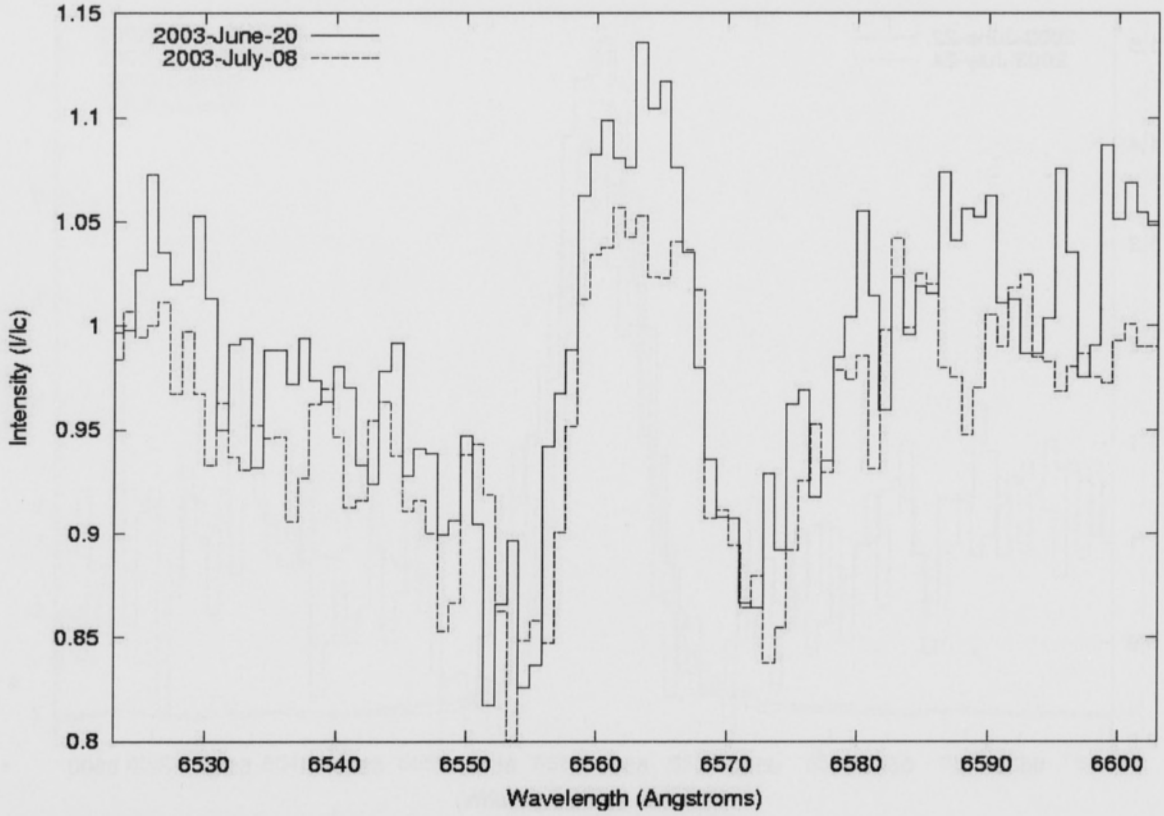

Fig. 7. Beta[2] Cygni H-alpha line profile normalized to the continuum (I/Ic).

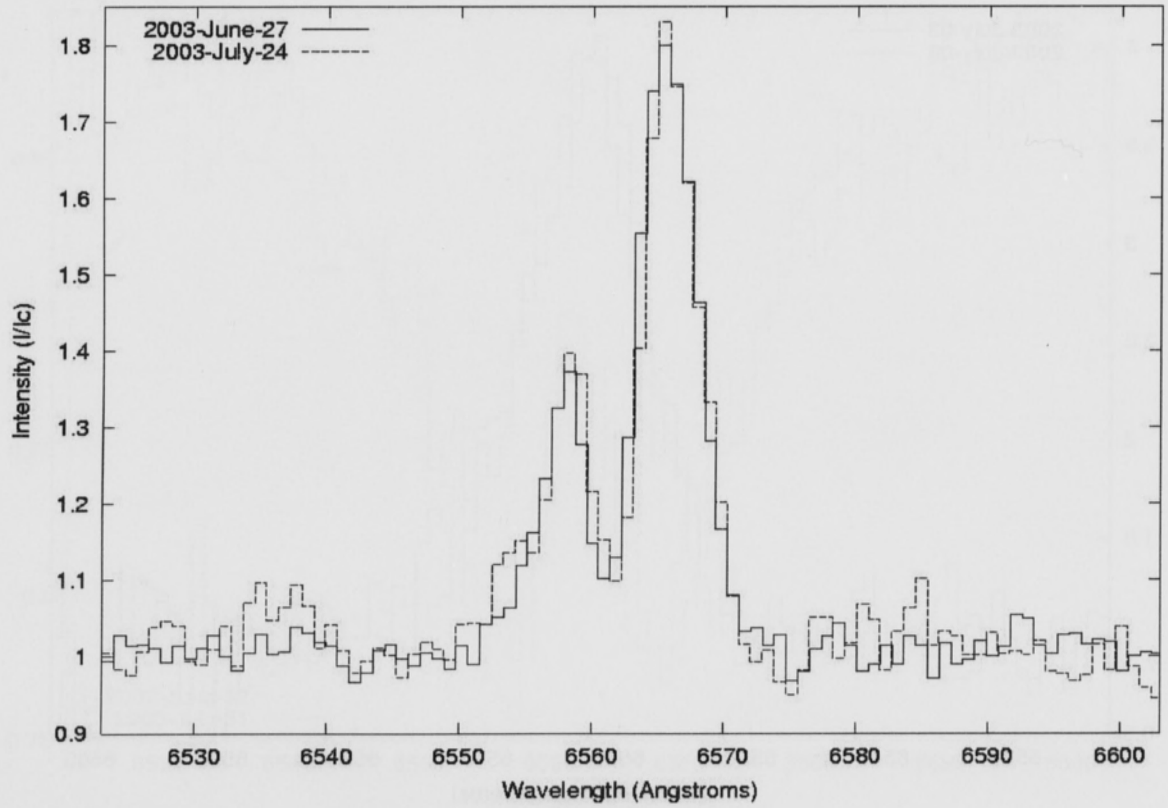

Fig. 8. V1294 Aquilae H-alpha line profile normalized to the continuum (I/Ic).

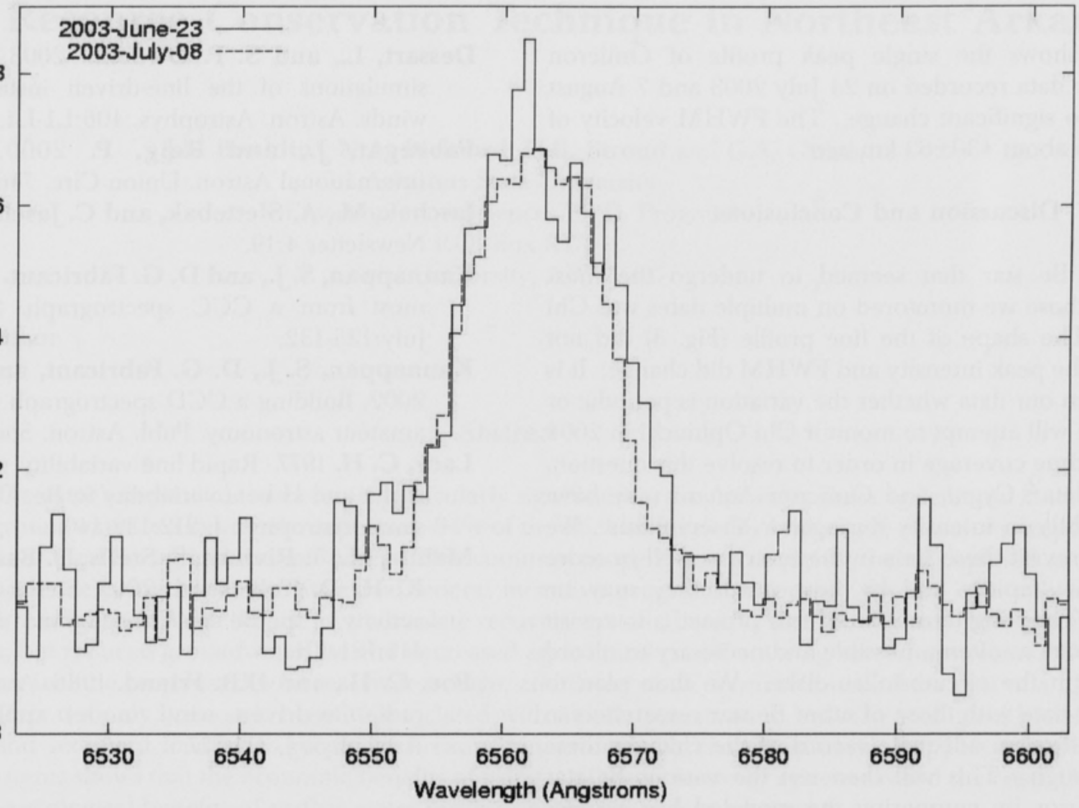

Fig. 9. 59 Cygni H-alpha line profile normalized to the continuum (I/Ic).

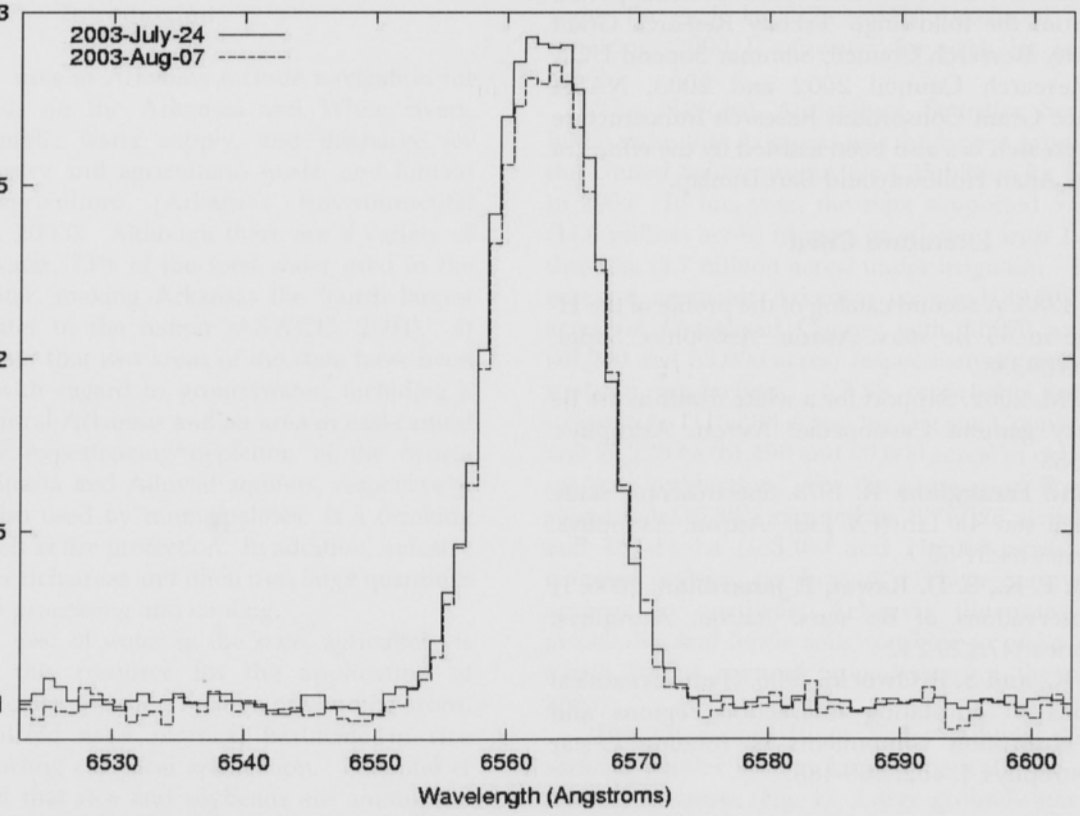

Fig. 10. Omicron Aquarii H-alpha line profile normalized to the continuum (I/Ic).

Fig. 10 shows the single peak profile of Omicron Aquarii. The data recorded on 24 July 2003 and 7 August 2003 show no significant change. The FWHM velocity of the profiles is about 430±63 km/sec.

Discussion and Conclusions

The Be star that seemed to undergo the most variation of those we monitored on multiple dates was Chi Ophiuchi. The shape of the line profile (Fig. 3) did not change, but the peak intensity and FWHM did change. It is not clear from our data whether the variation is periodic or random. We will attempt to monitor Chi Ophiuchi in 2004 with denser time coverage in order to resolve this question. 4 Aquilae, Beta^2 Cygni, and Omicron Aquarii may have changed slightly in intensity during our observations. We will need to revisit these stars in the future as well in order to verify how rapidly and by how much they may be fluctuating. The long term goal of this project is to revisit our project stars as often a possible and necessary to record the changes in the circumstellar disks. We then plan to combine our data with those of other Be star researchers in order to achieve an adequate record of the changes these stars go through. This will then test the various Be star model scenarios by comparing the modeled line profiles and variations with the observed.

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