Emission Line Variability in XX Ophiuchus

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ABSTRACT

We present the results of an analysis of nine years of spectra taken with the Coudé Feed telescope at KPNO of the Iron Star XX Oph. In addition to numerous iron lines, other metals such as Ti and the hydrogen Balmer series are seen in emission. Our study covers the years 2003 to 2012 and includes an episode in 2004 where photometry from the AAVSO shows a 1.5 magnitude drop in brightness. A corresponding change in the spectral features of the star including variations in the equivalent width of the most prominent lines is discussed.

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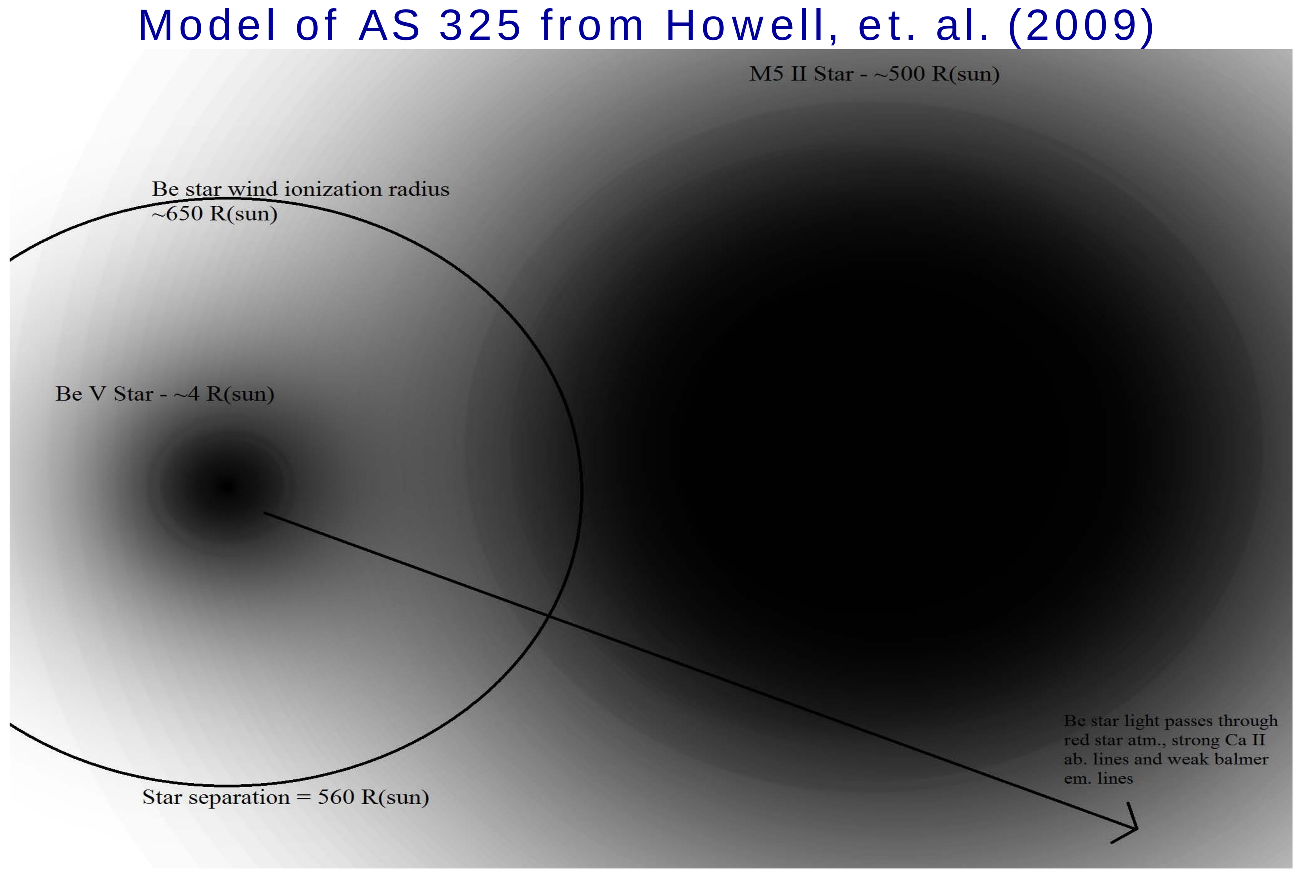
BACKGROUND

Merrill (1924) obtained a spectrum of XX Oph and announced that numerous hydrogen and iron emission lines were present. He applied the term "Iron Star" to this object.

Bopp & Howell (1989) observed low-ionization, metallic emission lines throughout the optical spectral region. Cool et al. (2005) provided photometric and spectroscopic evidence that XX Oph is a member of a binary system. Using this model, XX Oph is a Be type star; hot, spinning rapidly and with a strong wind. Its binary companion was proposed to be a M5 III.

There is only one other known "iron star", AS 325. Its spectrum is so similar to XX Oph's that the physical nature of the two is likely identical. Howell et al. (2009) have proposed a model of the AS 325 system shown below. The XX Oph system is likely similar. The H emission lines are likely from the Be star's wind and the metallic emission lines originate in the shock region where the Be star wind collides with the slower moving but denser M star wind.

Model of AS 325 from Howell, et. al. (2009)



Cool et. al,, used coude spectra from 2003 and 2004. We have used the same spectra as well as others collected since then and through 2012. Our study described herein has concentrated on the change in the spectra before and after a "photometric event" that began in March of 2004. XX Oph dimmed by ~ 1.5 magnitudes between March and October of 2004 and then returned to its more typical value thereafter (see adjacent AAVSO light curve).

Spectra before the 2004 event show numerous emission lines and a relatively flat continuum, with few absorption lines. After the 2004 event, our spectra show P Cygni profiles in H and Fe emission lines; they have blue shifted absorption lines accompanying the emission lines.

REFERENCES

AAVSO data: http://www.aavso.org

Bopp & Howell, 1989 PASP, 101, 981

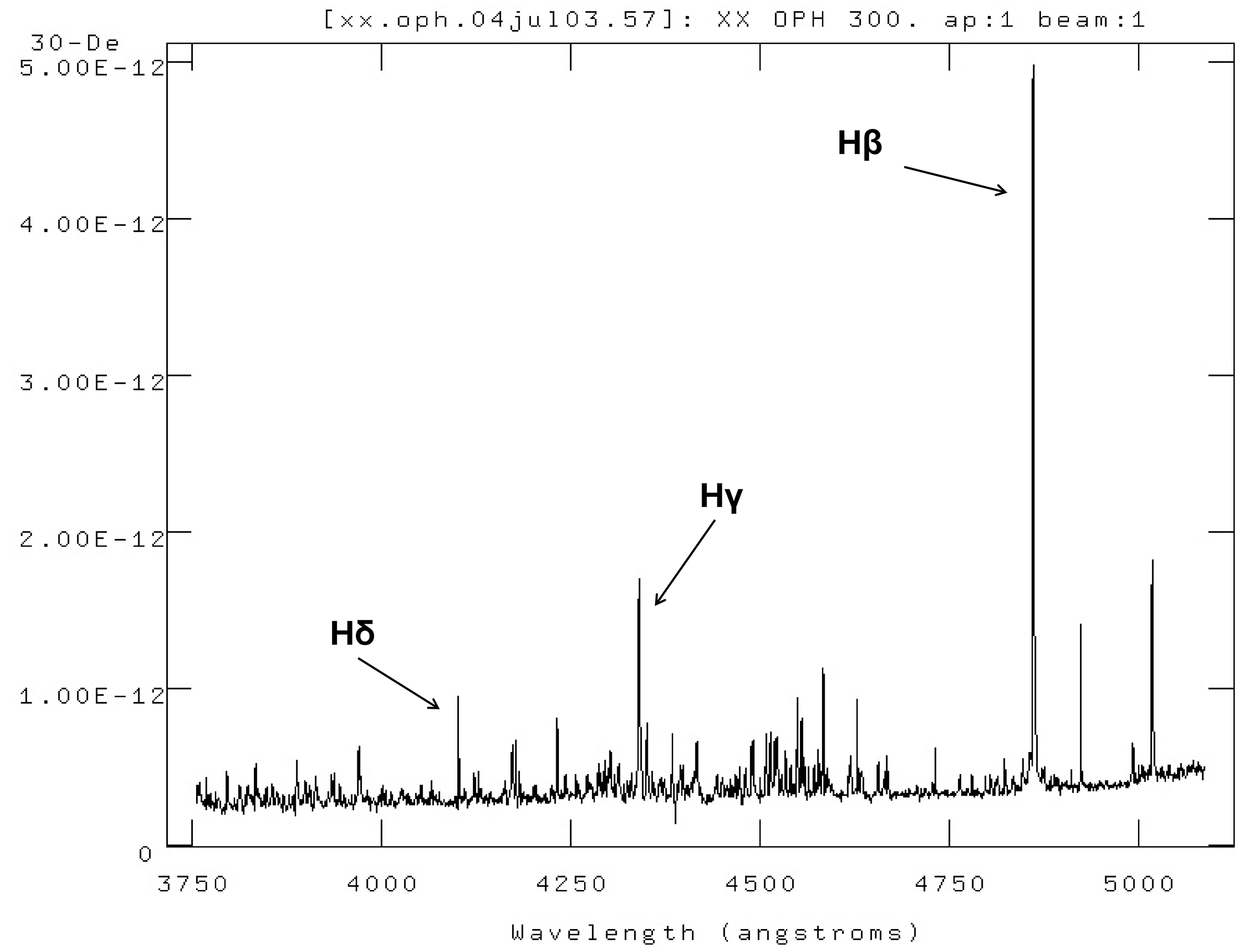
Cool et al., 2005 PASP,117,462

Howell et al., 2009 PASP, 121, 1

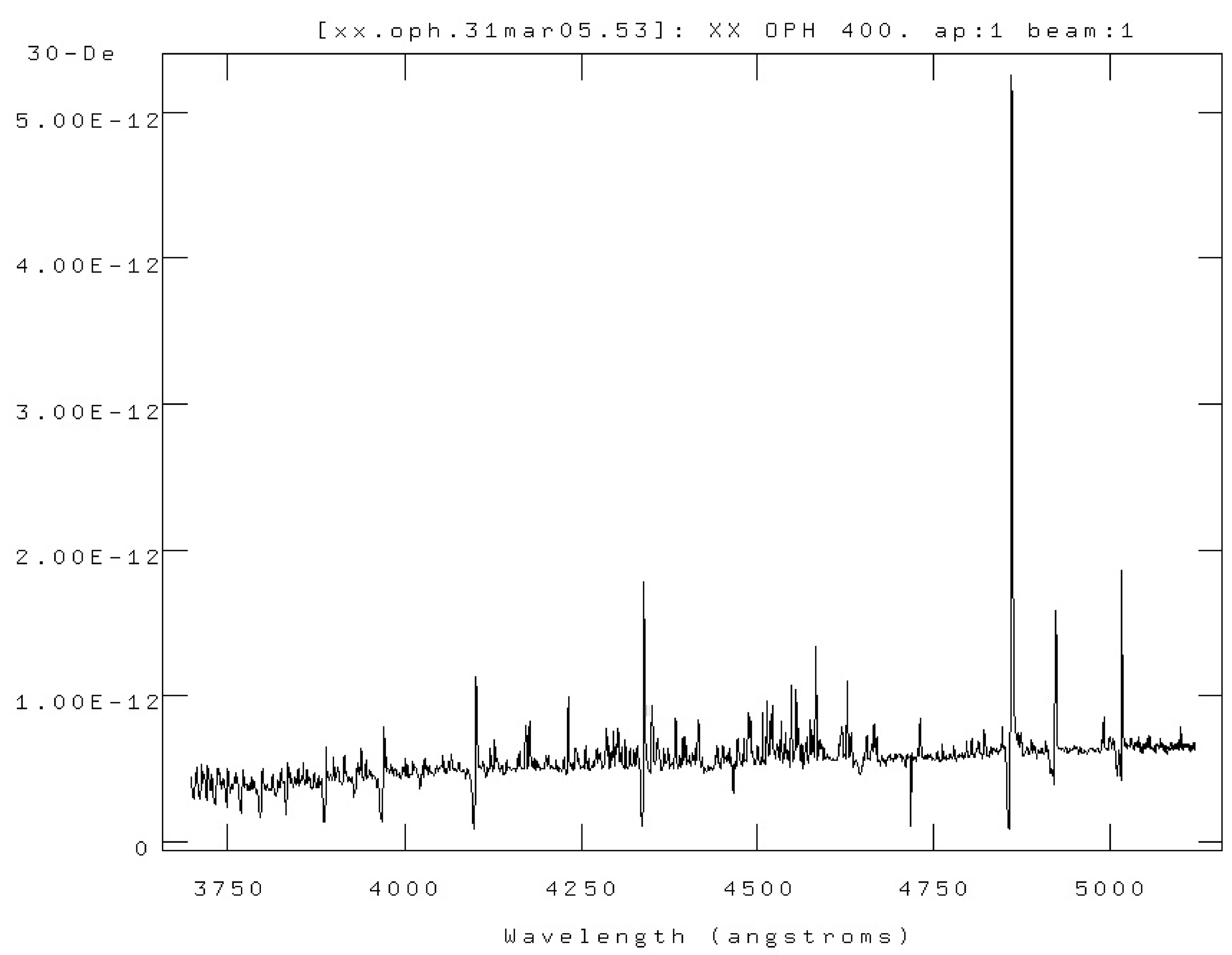
Merrill, 1924 PASP, 36, 225

DATA SET

We have acquired high signal-to-noise spectra of XX Oph from 2003-2012 using the Coudé Feed Telescope at KPNO. Samples are shown below in the blue spectrum from 3750 – 5100 Å . Spectra in the red from 6400 – 9000 Å are not shown.

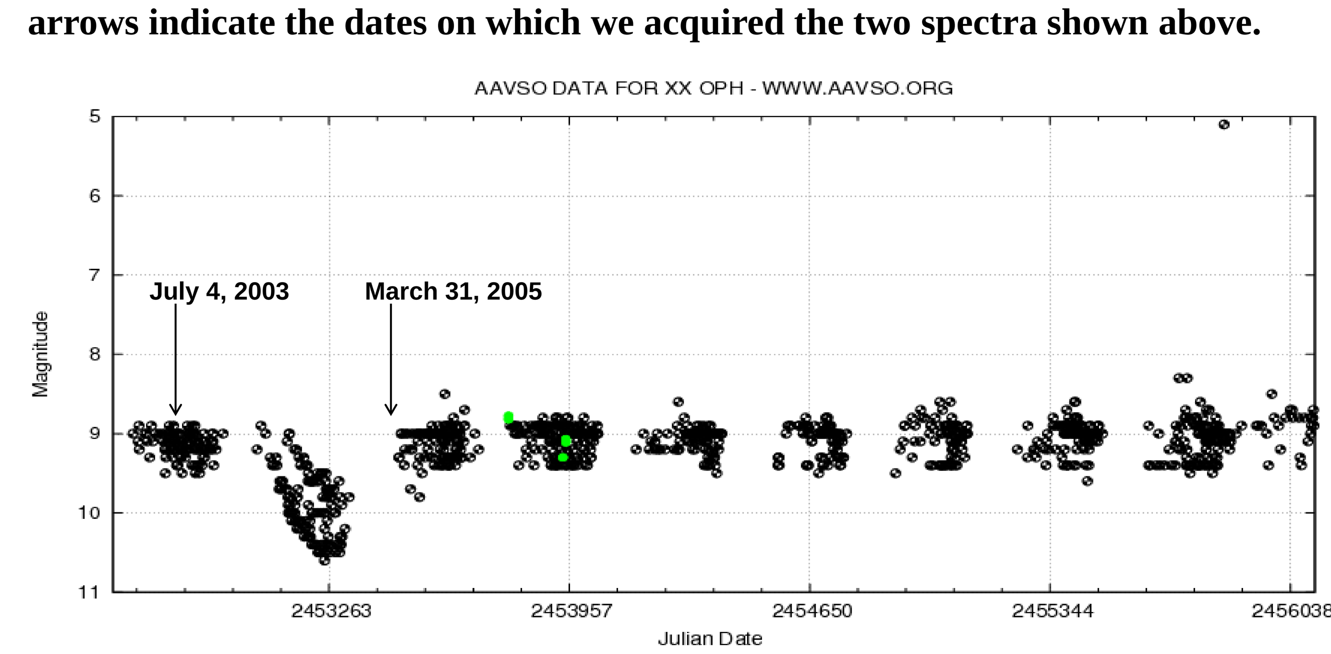


Above: Taken in July 2003, 8 months before the start of the photometric event. Most emission lines are from H and Fe. Note the absence of absorption lines.
Below: Taken in March 2005, 12 months after the beginning of the photometric event. Almost all emission lines now have P Cygni profile absorption features.

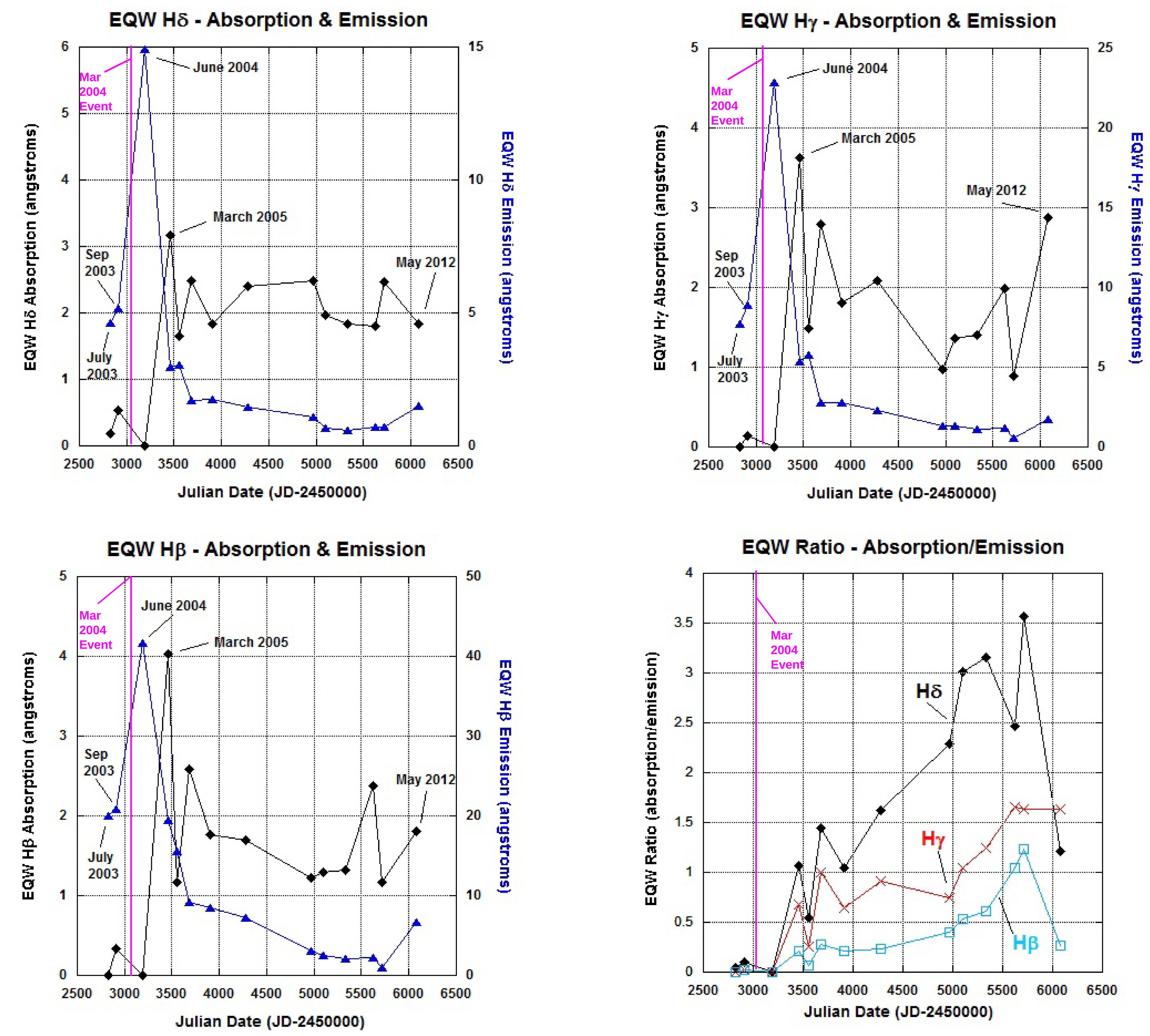


AAVSO Light Curve

The plot below shows the light curve of XX Oph from AAVSO data for the period 2003 to 2012. Note the drop in brightness during 2004. The green data points are V magnitudes from CCDs, all other points are visual estimates. The arrows indicate the dates on which we acquired the two spectra shown above.



RESULTS and DISCUSSION



Three of the plots above show the change in the equivalent width (EQW) of the absorption (black diamonds) and emission (blue triangles) components of the P Cygni profiles for Hδ, Hγ and Hβ as a function of time. The fourth plot shows the variation in the ratio of the EQW of the absorption to the emission components of each line. A timeline of spectral changes:

September 2003: Our last spectrum prior to the March 2004 photometric event. Weak or no P Cygni profiles.
March 2004: Shown as a vertical pink line above, this marks the approximate beginning of the photometric event.
June 2004: Our first spectrum after the March 2004 photometric event. Emission strengths have increased by a factor of 2-3, but the absorption component is either absent or weakly present.
March 2005: P Cygni profiles are now present in all Balmer and metal emission lines. The absorption component peaks while the emission component has weakened by a factor of 2 or more from its maximum in June 2004.
After March 2005: The Balmer emission strength continues to decrease to less than values in 2003. Absorption strength decreases but remains above its near zero value prior to the March 2004 event.
May 2012: Emission line strengths may be increasing. Additional spectra from October 2012 and future 2013 spectra will determine if this trend is real.

- Balmer emission is from the hot wind of the Be star; metal-line emission arises in the shock region where the Be star wind strikes the slower moving, denser wind from the M star. P Cygni absorption lines arise in the expanding but denser material around each star in the system.
- It is noteworthy that all 3 Balmer lines have no or weak P Cygni profiles prior to the March 2004 event.
- Balmer emission line strength increases dramatically after March 2004, but prior to the appearance of P Cygni profile absorption lines; which we did not detect until our March 2005 observations.
- The overall system shows a dimming of light in 2004; the subsequent rise in the Balmer absorption strength corresponds to a decrease in the Balmer emission strength.

Discussion

- The above suggests that between Sep 2003 and June 2004 there was a major mass ejection event that enhanced the Balmer emission. Was this an ejection of the presumed disk around the Be star? An ejection from the red star?

- The delayed peak in the P Cygni absorption lines until the Balmer emission weakened suggests the material from the mass ejection either: (1) caught up with the slower moving material resulting in a density enhancement; or (2) the ejected material cooled to form opaque dust, increasing the opacity of the system. The later seems more likely.

- Alternatively, the 2004 magnitude drop could correspond to an eclipse by the M star, separate from the mass ejection that led to the Balmer emission enhancement. However, the lingering presence of the P Cygni profiles long after the system returned to its original magnitude cannot be easily explained by an eclipse event.

Future Work

- Analyze additional nights of archival and future coude spectra from 2008-2013
- Analyze red spectra, especially the Hα line which changes width and in some cases bifurcates
- Examine the change of line strength in metallic species of different ionization levels

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