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Eta Carinae: an Astrophysical Laboratory

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Abstract. Eta Carinae (η Car), a Luminous Blue Variable, is a massive binary star system with a 5.54-year spectroscopic period. We present temporal surface plots of selected He I, H I, Fe II and [N II] stellar line profiles measured with HST/STIS sampled from 1998.0 to 2004.3. Our analysis suggests that the profile variations are due to 1) radial velocity variations of the primary star and 2) ionization effects due to the hot companion combined with its wind cavity.

Keywords. Stars: binaries: spectroscopic, mass loss, ejecta, individual (Eta Carinae)

1. Introduction

Eta Carinae has fascinated astronomers since its major event in the 1840s, when it rivaled Sirius in apparent magnitude for nearly two decades, then faded, only to brighten again in the 1890s. Today we see the central source with 6x10^6 L$_\odot$ and a wind of 10^{-3} M$_\odot$/yr at 600 km/s. A massive binary lies within an extended wind in turn engulfed by its ejecta, the Homunculus (1840s event) and the Little Homunculus (1890s). Damineli (1996) found a spectroscopic 5.5-year periodicity in He I λ10830. The minimum coincides with a drop in X-rays which also recurs with a 5.54-year period (Corcoran 2005).

With HST/STIS we systematically followed the variations of the central source and the response by the nebular ejecta with particular emphasis on the changes before, during and after the spectroscopic minimum. Many changes in the star and ejecta appear in the NUV spectra as discussed by Nielsen *et al.* (2006).

2. The Line Profiles

We examined changes in stellar wind line profiles for multiple lines, sampling a range of ionization potentials: He I (24.6 – 54.4 eV), H I (13.6 eV), Fe II (7.9 – 16.2 eV) and [N II] (14.5 – 29.6 eV). Changes in emission and absorption line profiles are quite apparent during the two observed spectroscopic minima (1998.0, ϕ =0 and 2003.5, ϕ =1.0).

In Figure 1 we show the time variability of the line profiles across the interval:

- He I: emission and absorption are systematically blue-shifted, narrow components, absorption maximum just before spectroscopic minimum, drops during minimum, and is weak during the early phase;
- H I: blue-shifted absorption peaks just before spectroscopic minimum;

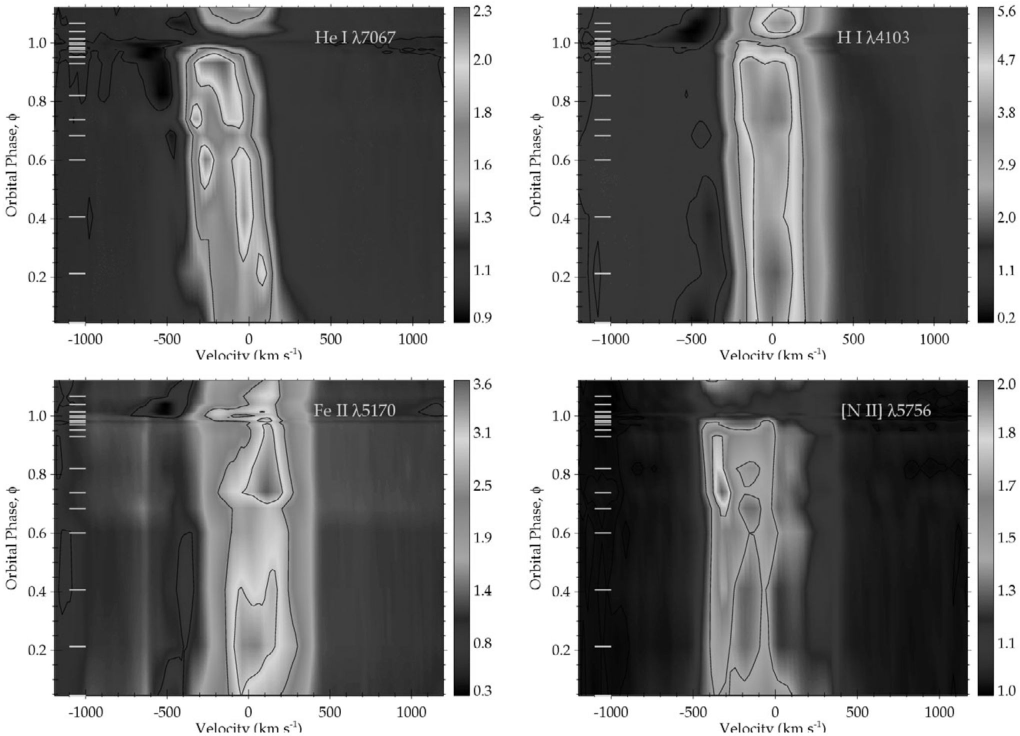

Figure 1. Temporal surface plots of line profiles from 1998.0 (ϕ =0.0) to 2004.3 (ϕ =1.2). From top left: He I λ7067, H I λ4103 (Hδ), Fe II λ5170, and [N II] λ5756.

- Fe II: absorption follows H I absorption, emission changes most on the blue side and is strongest in the early part of the period;
- [N II]: shows little velocity variation. Four narrow components have strong intensity variations out of phase with Fe II emission, due to ionization effects in the outermost wind.

These changes are due to the companion. The blue-shifted He I profile places the companion star at apastron on the observer's side of the primary. The hotter, faster, less-massive secondary wind is blowing a cavity out of the primary wind. The secondary's UV radiation ionizes an adjacent portion of the primary wind to He^+, which shifts in shape and position as the secondary sweeps around its orbit (Figure 2).

We built a simple model of the He^+ zone to understand the source of the He I emission and absorption. Models of η Car (Hillier et al. 2005) show that little He I emission is due to the primary star exciting its own stellar wind. Helium is mainly neutral in the primary wind as far UV photons are required to even populate the lowest excited states. He I lines represent the highly excited regions of the bowshock and the adjacent portion of the primary wind. The blue-shifted, narrow emission line components originate from the cooling region beyond the wind-wind interaction surface extending into the primary wind to the boundary of the hard UV radiation of the hot, secondary star. Absorption originates from the He^+ region of the primary wind in line of sight from the primary star to the observer. Unfortunately, the wind-wind interface is highly distorted due to the motion of the secondary, especially near periastron (Figure 3).

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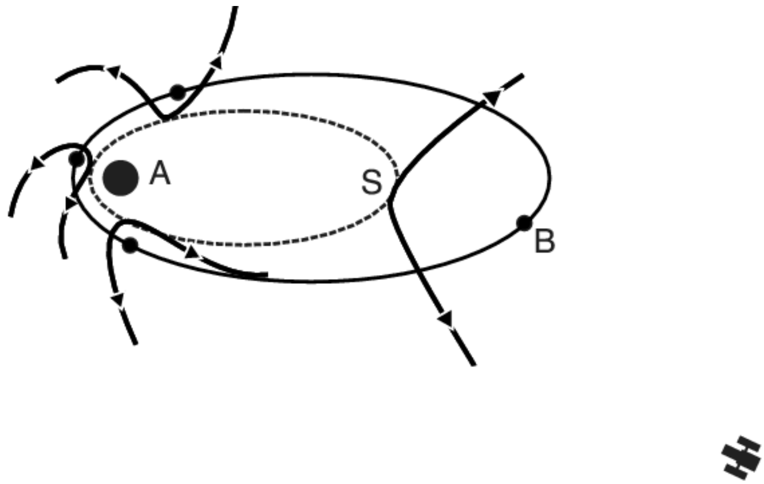

Figure 2. Schematic of binary orbit and distortion of the wind-wind structure. Based upon models by Pittard & Corcoran 2002, the eccentricity is 0.9 with major axis of 30 AU. The HST views the system 41° out of the plane.

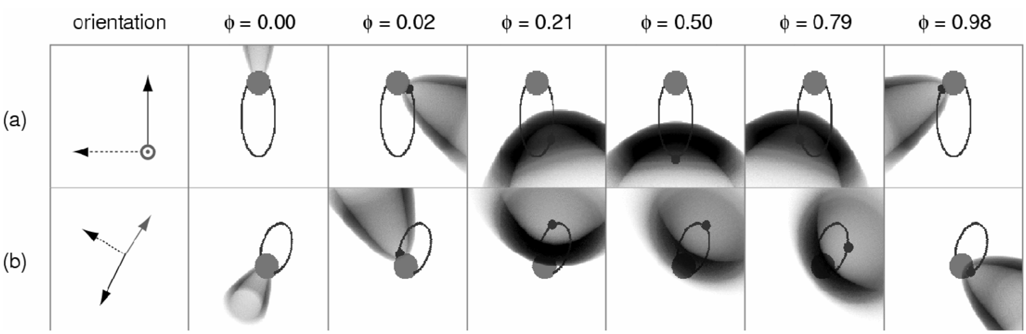

Figure 3. Visualization of the He^+ zone located in the η Car system. Top row (a) views the system with the plane lying in the sky: the Z-axis (red) points into the paper, the X-axis (dashed arrow) and the Y-axis (solid) lie in the skyplane. The orbital major axis is in the $-$Y direction and the minor axis in the $-$X direction. Bottom row (b) views the system with the Z-axis (red) pointed along the axis of the bipolar Homunculus ($-41°$ into the plane, consistent with Homunculus geometry derived by Davidson *et al.* (2001). The locations of Weigelt blobs B, C and D, plus the orientation of the radio continuum monitored by Duncan & White (2003), rotated the orbit into the skirt such that the major axis ($-$Y direction) is at position angle $-45°$. It projects almost on top of the $-$Z-axis. NOTE: The model does not include the coriolis distortions which dominate near periastron, but are small near apastron (ϕ =0.5).

Discussion

The He I absorption samples a subset of the interacting winds and the H I absorption has a very significant time delay that damps the orbital variations. However, these observations suggest that the secondary star and its wind cavity sample the primary wind to considerable depth during periastron. A detailed hydrodynamic model is required to interpret the radial velocity measures in order to obtain a mass function. With such a model in hand, we will learn much about wind properties, including clumping, ionization structure by future selective observations especially across periastron in January 2009.

Acknowledgements

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