Detection of a Hot Binary Companion of η Carinae

G. Sonneborn (NASA's GSFC), R. C.Iping (NASA's GSFC & CUA), T. R. Gull (NASA's GSFC),
D. Massa (NASA's GSFC & SGT Inc.), & D. J. Hillier (U.Pitt.)

Background

• Huge outburst in 1840s made η Car the brightest star in the sky and produced today's bipolar ejecta
• Star still has very high mass loss rate (>10^{-4} $M_\odot$/yr) and luminosity (~$4x10^6$ $L_\odot$)
• Possibly the most massive star in the Galaxy
• Large ejected mass (~10 $M_\odot$) requires significant energy source (10^{50} erg)
–Outburst mechanism still unknown Stellar instability? Binary star merger?

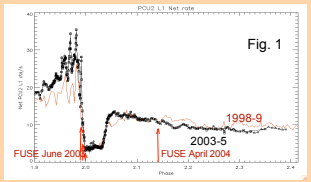
•Strong evidence that η Carinae is a binary.
•P~2023 days inferred from spectral and light changes in the visual (Damineli 1996, Damineli et al. 2000) and near IR (Whitelock et al. 1994, 2004).

• X-ray light curve varies strongly with P=2024±2 day (Ishibashi et al. 1999, Corcoran 2005).
•Two X-ray eclipses (1998.0 and 2003.5) observed .

• Colliding-wind binary implied by hard X-ray spectrum (Ishibashi et al. 1999, Pittard & Corcoran 2002, Corcoran 2005)
•Dense stellar wind from the massive LBV primary (η Car A) collides with the higher velocity, lower density wind of a hot O-type secondary (η Car B) in a highly-eccentric 5.54-year orbit.
•The presence of a hot secondary is also inferred from photoionization modelling of variability of doubly-ionized lines from the Weigelt blobs (Verner et al. 2005).

• η Car B has evaded direct detection because η Car A dominates the systemic light from the infrared through the UV longward of Lyman-α.

• Hot companion finally detected by FUSE (Iping et al. 2005 ApJ 633, L37)



RXTE X-ray light curve and eclipse in eta Car (Corcoran 2005) and FUSE observations in 2003-4

FUSE Observations

ObsID	Date	UT	phase	Exp s	Aper	p.a.
D0070102	2003 Jun 10	14:36	0.9888	15282	LWRS	195.3
D0070103	2003 Jun 17	03:33	0.9922	14311	LWRS	201.1
D0070104	2003 Jun 27	00:21	0.9972	4531	LWRS	209.5
D0070107	2004 Mar 29	14:36	0.1335	9202	LWRS	119.4
D0070108	2004 Mar 30	09:42	0.1340	34281	LWRS	120.2
D0070110	2004 Apr 9	03:23	0.1390	34476	HIRS	131.3
D0070111	2004 Apr 10	07:18	0.1395	24795	HIRS	132.7
D0070109	2004 Apr 11	21:16	0.1400	17118	HIRS	134.5

Abstract

A hot companion of η Carinae has been detected using high resolution spectra (905 - 1180 A) obtained with the Far Ultraviolet Spectroscopic Explorer (FUSE) satellite. Observations were obtained at two epochs of the 2024-day orbit: 2003 June during ingress to the 2003.5 X-ray eclipse and 2004 April several months after egress. These data show that essentially all the far-UV flux from η Car shortward of Lyman alpha disappeared at least two days before the start of the X-ray eclipse (2003 June 29), implying that the hot companion, η Car B, was also eclipsed by the dense wind or extended atmosphere of η Car A. Analysis of the far-UV spectrum shows that η Car B is a luminous hot star. N II 1084-1086 emission disappears at the same time as the far-UV continuum, indicating that this feature originates from η Car B itself or in close proximity to it. The strong N II emission also raises the possibility that the companion star is nitrogen rich. The observed FUV flux levels and spectral features, combined with the timing of their disappearance, is consistent with η Carinae being a massive binary system.

FUV spectra of η Car are unlike any other object observed by FUSE

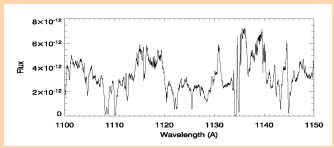


Figure 2

- Strong FUV continuum unexpected from T_{eff}=15,000 K atmosphere (UV and visual modelling by Hillier et al. 2001, 2005)
- Broad spectral features not readily identified
- Strong ISM lines are like other Carina stars

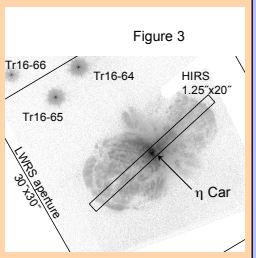
Correcting for Unwanted Field Stars

The LWRS observations of η Car also include two 11th mag B stars that lie 14" from η Car. They account for ~50% of the observed far-UV flux in LWRS observations. During some of the LiF1 HIRS observations, we serendipitously obtained spectra of the B stars through the HIRS slit of the SiC1 channel. The comparison of SiC1 HIRS observation with the eclipse ingress observation enables us to disentangle the LWRS spectra and reveal the spectrum of η Car B. A three-step process shows that the LiF1 HIRS spectrum of η Car is dominated by the flux of η Car B, and not η Car A.

1. The LiF1 HIRS spectrum of η Car plus the SiC1 HIRS spectrum of the nearby B stars accounts for all FUV flux from the system obtained through the LWRS aperture at nearly the same epoch. This implies that the LWRS spectra are dominated by η Car and the nearby B stars and that there is very little contribution from other sources, such as the surrounding nebulosity.
2. The LWRS spectrum of η Car at the start of the X-ray minimum (when the secondary is expected to be eclipsed) is nearly all due to the B stars and that η Car A contributes very little to the FUV flux of the system.
3. The FUV spectrum outside of eclipse (when η Car B is expected to contribute to the flux) is much stronger and consistent with a source of higher effective temperature than η Car A.

•HST/ACS 2200 Å image of eta Car (June 2003)
•Homunculus and nearby stars clearly visible
•Tr16-64 is B1.5V, V=11
•Tr16-65 is similar
•LWRS and HIRS apertures shown for 10 Apr 2004
•LiF1 HIRS fixed on target
•Alignment of other channels changes 10-20" due to thermal effects
•SiC1 HIRS on Tr16-64&65 serendipitously
•SiC2 on η Car for 7 of 17 ks of 11 Apr observation

Figure 3



Mysterious FUV Spectrum Explained (A+B=C)

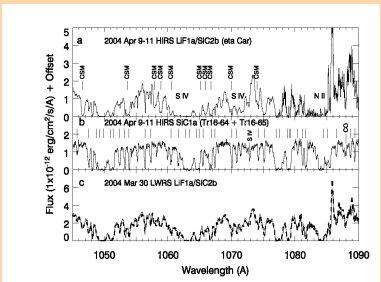


Figure 4

a) FUSE LiF1a (1045-1077A) and SiC2b (1077-1090A) HIRS aperture spectra of η Car, corrected for HIRS point-source throughput of 65%. Locations of high-velocity circumstellar absorption are marked by `CSM'. The location of S IV 1062 -1073 are also indicated.

b) SiC1a HIRS spectrum of Tr16-64 and Tr16-65. The vertical ticks mark the location of H_2 Lyman lines with J ≤ 6. Full SiC1 spectrum of η Car B is shown in Fig. 7.

c) LiF1a LWRS spectrum of η Car (η Car itself plus Tr16-64 and -65) from 2004 March 30. The dashed line is the sum of panels a and b, which almost exactly reproduces the LWRS spectrum.

Stars Near η Car

Name	r"	p.a.	V[a]	(B-V)[a]	(U-B)[a]	F_λ[b]
Tr16-64	13.97	41.0	10.72	0.10	-0.74	4.5
Tr16-65	13.84	60.3	11.09	0.14	-0.65	2.5
Tr16-66	20.00	61.0	11.98	0.16	-0.57	0.9

[a] Data from Feinstein, Marraco & Muzzio (1973)
[b] 2200A flux from HST/ACS image; units are 10^{-13} erg/cm²/s/A

The Spectrum Vanishes

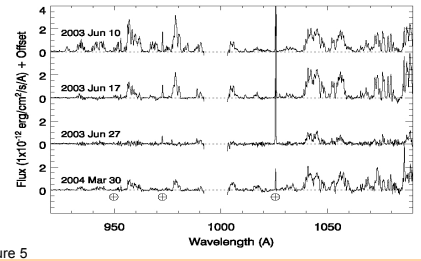


Figure 5

Several LWRS spectra of η Car were obtained in 2003 June. The X-ray flux was decreasing during this time frame as η Car approached the X-ray eclipse (see Fig. 1).

The LWRS spectra on June 10 and 17 are nearly identical to spectra obtained in 2004 Mar. The spectrum on 2003 June 27, however, is completely different, being nearly identical to the SiC1a HIRS spectra (Fig. 4b).

The 2003 June and 2004 March LWRS spectra with the B stars subtracted are shown in Fig. 5. There is almost a complete cancellation on June 27, with only a small amount of residual flux from η Car present in limited wavelength regions (e.g. 1040-1046 A).

In the 1100 - 1185 A region, the June 27 spectrum has normal interstellar line profiles in many Fe II lines, N I 1134, etc. All the strong high velocity absorption present in every other LWRS observation of η Car is not present, indicating that the primary source of FUV flux on that date is located outside of the Homunculus, i.e. the stars Tr16-64 and Tr16-65.

SUMMARY

- FUSE has detected a hot companion of η Carinae
- Essentially all the FUV flux from η Car disappears right as X-ray eclipse begins
  - η Car B eclipsed by dense wind or extended atmosphere of η Car A
- η Car B is a hot star
  - η Car B T_{eff} ≥25,000 K (η Car A T_{eff} ~ 15,000 K)
- N II 1085 emission feature is also eclipsed at same time as FUV continuum
  - Originates very close to η Car B: stellar wind or wind-wind collision zone
- η Car B wind velocity ~1100 km/sec
  - Based on S IV 1062-73 and C III 1175 lines
  - Colliding winds model (Pittard & Corcoran 2002) suggested v~3000 km/sec - not found in FUSE spectra
  - Higher wind speed may not be observable if wind distorted by collision bow shock with wind of η Car A.

Wind Lines

- S IV and C III have wind velocities of ~1100 km/s with weak emission
- Strong N II 1085 emission
- N II seen as P Cyg line only in ON and WN stars

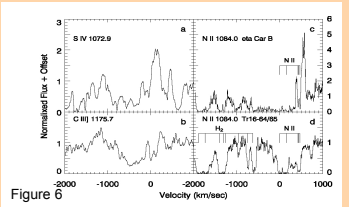


Figure 6

Comparison of normalized line profiles of a) S IV 1072.9, b) C III] 1175, and c) N II 1084-86 from the HIRS spectrum of η Car B. Tr16-64/65 is shown in d) to illustrate the ISM features in the N II region. The spectra were normalized over a wide (~10A) region around each feature. The rest wavelengths for the ISM lines of the N II multiplet and adjacent H_2 are marked. The zero point of the velocity scale is the wavelength given in each panel.

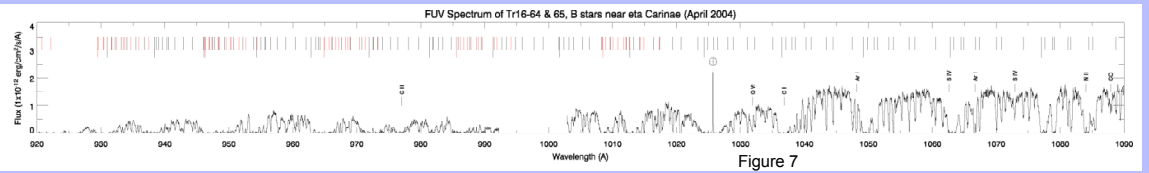


Figure 7