NICER Monitoring of Colliding Wind and Extended X-ray Emission from Eta Carinae

David A. Espinoza-Galeas, PhD
david.espinoza@unah.edu.hn
UNIVERSIDAD NACIONAL AUTÓNOMA DE HONDURAS and
The Catholic University of America
Eta Carinae (\(\eta\) Car)

- The most massive star (>100 \(M_{\odot}\)) within 2.3 kpc.
- Around 1840 its brightness increased until became the 2\(^{\text{nd}}\) brightest star in the sky.
- The 1840s event is known today as the great eruption and formed two bipolar structures called the homunculus nebula.
- Now we know \(\eta\) Car is a colliding wind binary emitting X-rays.
• The system is an eccentric (e=0.9) long period (5.53 years) binary system with a Luminous Blue Variable (η Car-A) and mysterious companion (η Car-B).
• With very dense and strong winds reaching ~ 3000 km/s the shock region heats the gas up to $1 \times 10^8$ K, emitting X-rays between 2.0 – 10.0 keV.
• η Car also has an almost constant soft X-ray emission below <2 keV coming from an Outer Debris region which could be originated during the "Great Eruption".

Hydrodynamics simulation of the colliding stellar winds in eta Carinae by C. M. P. Russell [https://youtu.be/yQFesQbTFFk](https://youtu.be/yQFesQbTFFk)
Why NICER?

- NICER capabilities to allocate frequent observations are perfect for η Car’s monitoring program.
- High-resolution spectra allow us to observe the changes in η Car’s spectrum through the orbital motion of the components.
- NICER provides a unique opportunity to follow the soft X-ray emission below 2.0 keV.
NICER allows us to monitor at the same time the soft X-ray emission <2 keV from the Outer Debris and the harder X-ray emission between 2 -10 keV coming from the Colliding Wind Region in the center of the system.
Car’s spectrum observed by NICER

- NICER allows us to monitor at the same time the soft X-ray emission <2 keV from the Outer Debris and the harder X-ray emission between 2 - 10 keV coming from the Colliding Wind Region in the center of the system.
η Car’s Flux compared with RXTE and Swift

- NICER provides measures of the 0.5-10 keV η Car’s X-ray spectrum from φ ∼ 3.53 to φ ∼ 4.45 giving us almost a complete cycle.
- The apastron fluxes do not change >5%, indicating a change of no more than 0.25% in mass loss rate from η Car A or B.
- Flux measured by NICER follows the 1/D behavior for most of the orbit, like RXTE and Swift lightcurves.
η Car’s NICER look at periastron: The plunge and the recovery.
NICER observed that the plunge of the X-ray maximum started at $\phi \sim 3.98$, like the previous cycles indicating that it is strongly correlated with the orbital phase.

Analysis of $\eta$ Car’s spectrum going through the plunge shows an even decrease of mid and high energies, indicating that the minimum is more affected by the disruption of the CWR than column density.
• We have observed the shortest X-ray recovery: the flux starts to increase at $\phi = 4.009$ which is $\sim 7$ days earlier than the low limit estimated by Corcoran et al. (2010) in the 2009 periastron passage (RXTE 2 in magenta).

• The faster recovery of the high energies compared with mid energies during recovery shows how the CWR is recovered but is highly affected by column density.
η Car’s Hardness Ratio \((H-M)/(H+M)\); \(H = 6.5-7.5\) keV, \(M=2.5-3.5\) keV.

- Hamaguchi et al. 2007 showed a two-state solution of the minimum: Deep Minimum and Shallow Minimum.
- Measurements of the HRs with NICER constrain the Deep Minimum to \(3.995< \phi <4.004\) and the Shallow Minimum from \(4.004< \phi <4.013\).
Velocity of the wind in the apex of η Car’s CWR

- Inspection of η Car’s NICER spectrum does not show evidence of a decrease in X-rays due to absorption, suggesting that the decrease in flux is due to a decrease in temperatures at the CWR.

- Measurements of the temperature in the high-energy component showed a decrease in temperatures at the apex.

- This is the first time we have evidence of a temperature decrease in the CWR of η Car.

- Converting the temperature of the hot component approaching periastron passage indicates that the shock apex is moving into the acceleration zone of the wind of η Car B.
The NICER picture of η Car’s periastron passage.
The NICER picture of η Car’s periastron passage.
The NICER picture of η Car’s periastron passage.
The NICER picture of \( \eta \) Car’s periastron passage.
The NICER picture of η Car’s periastron passage.
The NICER picture of η Car’s periastron passage.
Monitoring of the soft X-ray emission < 2.0 keV.

- NICER provides for the first-time frequent measurements of the Outer Debris region, where most of the X-ray emission below 2.0 keV is coming.
- The NICER monitoring program showed a decline in the soft X-ray emission, indicating an expansion of the Outer Debris.
- Following a power law \((t-t_0)^{-3}\) to the time of the Great Eruption we found that X-ray emission was about \(\sim 10^{41}\) ergs s\(^{-1}\).
Summary

• NICER provides time-resolved measurements of the 0.5-10 keV η Car’s X-ray spectrum from φ ~3.53 to φ ~4.45 giving us almost a complete cycle.
• Flux measured by NICER follows the 1/D behavior for most of the orbit, similar to RXTE and Swift lightcurves.
• NICER observed that the plunge of the X-ray maximum started at φ ~3.98, similar to the previous cycles indicating that it is strongly correlated with the orbital phase.
• Measurements of the HRs with NICER constrain the Deep minimum to 3.995< φ <4.004 (18 days) and the Shallow minimum from 4.004< φ <4.013.
• We have observed the shortest X-ray recovery: the flux starts to increase at φ = 4.009 which is ~7 days earlier than the low limit estimated by Corcoran et al. (2010) in the 2009 periastron passage.
• The apastron fluxes do not change >5%, indicating a change of no more than 0.25% in mass loss rate from η Car A or B.
• The changes in the soft-band emission from the OD region seen for the first time by NICER may be caused by the expansion of the ejecta. If so, simple analysis indicates that the X-ray luminosity near the time of the Great Eruption was about ~ 10^{41} ergs s^{-1}. This is the first estimate of the X-ray luminosity of the Great Eruption and suggests that the X-ray luminosity at that time was comparable to the total luminosity at longer wavelengths.
• You can find all these NICER results in Espinoza-Galeas et al. 2022: doi:10.3847/1538-4357/ac69ce