Wolf-Rayet Stars
W.-R. Hamann, A. Sander, H. Todt, eds.
Potsdam: Univ.-Verlag, 2015
URL: http://nbn-resolving.de/urn:nbn:de:kobv:517-opus4-84268

Extremely Hard X-ray Emission from η Car Observed with *XMM-Newton* and *NuSTAR* around Periastron in 2014.6

K. Hamaguchi[1,2], M. F. Corcoran[1,3] and the η Car team
[1] *CRESST NASA Goddard Space Flight Center*
[2] *University of Maryland, Baltimore County*
[3] *Universities Space Research Association*

The super massive binary system, η Car, experienced periastron passage in the summer of 2014. We observed the star twice around the maximum ($\phi_{\rm orb}$ =0.97, 2014 June 6) and just before the minimum ($\phi_{\rm orb}$ =0.99, 2014 July 28) of its wind-wind colliding (WWC) X-ray emission using the *XMM-Newton* and *NuSTAR* observatories, the latter of which is equipped with extremely hard X-ray (>10 keV) focusing mirrors. In both observations, *NuSTAR* detected the thermal X-ray tail up to 40−50 keV. The hard slope is consistent with an electron temperature of ~6 keV, which is significantly higher than the ionization temperature (kT ~4 keV) measured from the Fe K emission lines, assuming collisional equilibrium plasma. The spectrum did not show a hard power-law component above this energy range, unlike earlier detections with *INTEGRAL* and *Suzaku.* In the second *NuSTAR* observation, the X-ray flux above 5 keV declined gradually in ~1 day. This result suggests that the WWC apex was gradually hidden behind the optically thick primary wind around conjunction.

1 Extremely Hard X-ray Emission from η Car

The super massive binary system, η Car, has been known to emit strong thermal X-ray emission below 10 keV from collision of winds from two stars (wind-wind collision: WWC). See the details of the η Car system and its WWC X-ray emission observed in the 2−10 keV band in the reviews by T. R. Gull and M. F. Corcoran et al. in these proceedings.

On the other hand, its X-ray characteristics above 10 keV are not well understood due to the limited imaging capabilities of previous hard X-ray observatories. The *INTEGRAL*'s coded mask instrument, which enables to map extremely hard X-ray emission with angular resolution of 12′ (FWHM), detected a point-like source within 2.′4 of η Car (Leyder et al. 2008, 2010). Without any known high energy sources around, η Car is considered as the best candidate of its counterpart. The flat spectrum, extending up to 100 keV, requires a hard power-law component. The *Suzaku*'s hard X-ray detector (HXD), whose PIN sensor had had the best sensitivity between 15−50 keV before *NuSTAR*, confirmed the presence of hard power-law emission with $\Gamma \approx 1.4$, as well as strong WWC thermal emission below ~25 keV (Sekiguchi et al. 2009).

The *AGILE* and *Fermi* γ-ray observatories discovered a relatively stable γ−ray source to the direction of η Car between 0.1−100 GeV (Tavani et al. 2009; Abdo et al. 2010). Eta Carinae is, again, the only known high energy source within its error circle, but its extremely high energy nature — as energetic as a neutron star — was unexpected from η Car. One promising mechanism that may explain both the extremely hard X-ray emission and the γ-ray emission is the acceleration of particles at the WWC regions to the GeV energy through the 1st-order *Fermi* mechanism; such particles should upscatter stellar UV up to γ-rays by Compton recoil. However, neither of the extremely hard X-rays nor GeV γ-rays looks well correlated with the WWC X-rays (Hamaguchi et al. 2014; Reitberger et al. 2015).

To understand the nature of extremely hard X-ray emission from η Car, we performed two joint broadband X-ray observations of the star with *XMM-Newton* and *NuSTAR* in the key orbital phases around periastron in the summer of 2014.6. *XMM-Newton* can obtain high resolution X-ray spectra below 10 keV covering the detailed profile of the Fe K emission line complex and the absorption structure of the Fe K edge, while *NuSTAR* can obtain high quality spectra in the hard X-ray band extending beyond 10 keV. Because *NuSTAR* is the first focusing X-ray telescope above 10 keV, it also allows us to determine an accurate location of the extremely hard X-ray source.

2 *XMM-Newton* + *NuSTAR* Observations in 2014.6

The first joint observation started on 2014 June 6 near periastron when the X-ray flux had already increased by a factor of 4 from that around apastron. The second observation started on 2014 July 28 when the X-ray emission had almost dropped by two orders of magnitude from the X-ray maximum — it was only several days before entering to the deep X-ray minimum phase when the WWC thermal X-ray emission is suspected to be eclipsed by the thick primary stellar winds.

Fig. 1 shows X-ray images of the η Car field in multiple energy bands during the first observation. Eta Carinae at center dominates emission below 30 keV; the source position does not shift significantly between the energy bands. The emission almost disappears in the 30−79 keV band.

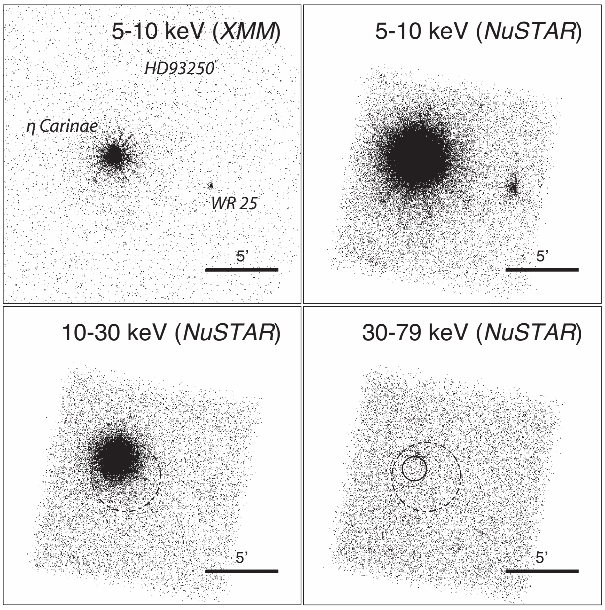

Fig. 1: X-ray images of the η Car field on 2014 June 6. The dotted bar circles show the 90% confidence range of the *INTEGRAL* source (Leyder et al. 2010) and the solid and dotted circles do the 95.4% confidence ranges of the *Fermi* source in the low-energy and high-energy bands, respectively (Reitberger et al. 2015).

2.1 First Observation

The *XMM-Newton* observation started 32 ksec after the start of the *NuSTAR* observation and covered a part of the latter half of the *NuSTAR* observation (top left panel of Figure 2). During these observations, η Car did not show any long-term X-ray variation, though it might exhibit small fluctuations on timescales of ~1 ksec.

The top right panel of Figure 2 shows the *XMM-Newton* and *NuSTAR* spectra of η Car above 3 keV. The *NuSTAR* spectra clearly extend up to ~50 keV. The spectral slope above ~9 keV matches very well with optically-thin thermal emission from kT ~6 keV plasma.

Both of the *NuSTAR* FPMA/FPMB spectra show marginal excess above 50 keV over the extrapolation of the thermal tail, but this excess is smaller than the raw background count rate. Since the image above 50 keV shows no hint of a point source at the η Car position, the excess is probably caused by uneven background structure.

2.2 Second Observation

The *XMM-Newton* observation started 20 ksec after the *NuSTAR* observation start and covered until the middle of the *NuSTAR* observation (bottom left panel of Figure 2). The short *XMM-Newton* observation for ~34 ksec did not show a clear time variation, but the long *NuSTAR* observation for ~102 ksec displayed a gradual flux decrease by ~40% above ~5 keV.

The 5−10 keV light curve seems to follow an exponential decay. We fitted this light curve by an exponential plus constant model and found an acceptable fit with an e-folding time of 0.48 (0.34−0.78) day. The 3−5 keV and 10−25 keV light curves also show similar flux declines.

The bottom right panel of Figure 2 shows the *XMM-Newton*/PN, MOS1 and *NuSTAR*/FPMA, FPMB spectra of the second observation. The spectra above ~10 keV have a similar slope to those of the first observation, suggesting kT ~6 keV plasma emission. They also showed an apparent small excess above 40 keV, but, again, the image above 30 keV did not show any clear point source at the position of η Car and this excess is lower than the background level.

We split the *NuSTAR* observation into three evenly spaced intervals and extracted spectra from each interval to track the spectral variation. The spectral shape above 5 keV did not apparently change between the intervals; only the spectral normalization decreased.

3 Nature of the Extremely Hard X-ray Emission

The *NuSTAR* spectra clearly showed that the thermal X-ray slope of η Car extended up to the 40−50 keV energy range. This slope is consistent with bremsstrahlung thermal emission with kT ~6 keV, which was significantly higher than ionization temperature of Fe K shell ions measured from the *XMM-Newton* spectra. This result may suggest that the Fe K emission line has significant contribution of cooler plasma emission, or the hottest plasma does not reach ionization equilibrium.

During the second observation, the X-ray flux above 5 keV gradually declined by ~40% in a day. This decline can be reproduced with a constant flux plus an exponential decay with τ ~0.5−1.5 day, which smoothly connects to the deep minimum onset on August 1st. This decline shows no color variation, suggesting that the hottest plasma was gradually hidden from the sight. A spectral fit also suggests extremely strong absorption ($N_{\rm H}$~7×10^{23} cm^{-2}), which is as high as the absorption measured after the deep minimum. These results support the hy-

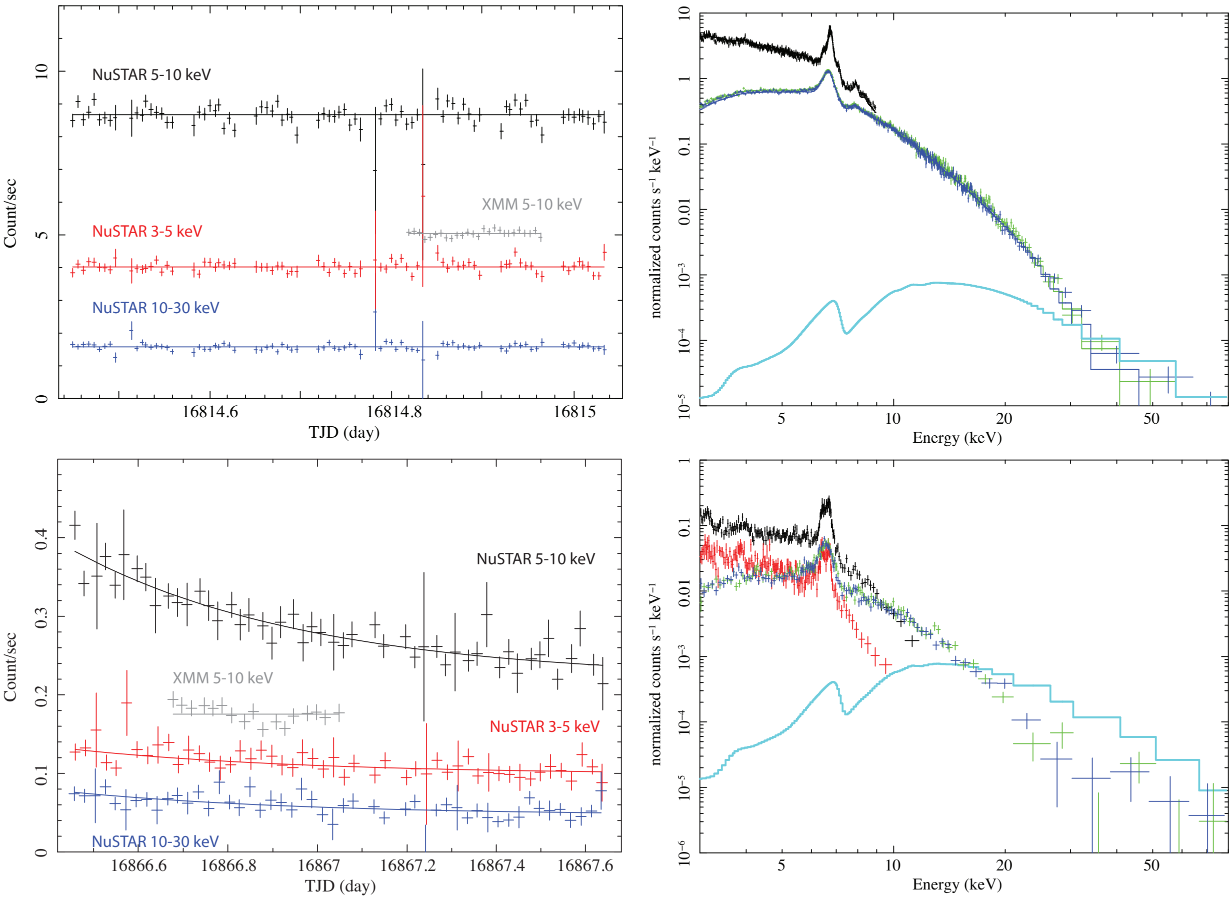

Fig. 2: Light curves (*left*) and spectra (*right*) of the first (*top*) and second (*bottom*) observations. *Left*: *XMM-Newton* EPIC PN (*grey*, 5−10 keV) and *NuSTAR*/FPMA+FPMB (*red*: 3−5 keV, *black*: 5−10 keV, *blue*: 10−30 keV) light curves. *Right*: *XMM-Newton* PN/MOS1 (*black*/*red*) and *NuSTAR* FPMA/FPMB (*green*/*blue*) spectra of η Car. The solid cyan line on each panel shows the power-law component measured from the *Suzaku* observations (Hamaguchi et al. 2014).

pothesis that the deep minimum is produced by an eclipse of the WWC apex by the thick primary wind at conjunction.

The *NuSTAR* data did not show any hint of power-law emission above ∼30 keV within the *INTEGRAL* error circle, giving an upper-limit below the *INTEGRAL* and *Suzaku* detection before 2011. The power-law source should have been faint during the observations in 2014. The GeV γ-ray source was rather stable around this orbital phase, suggesting an increase of the absorption to the power-law source during these observations, or no connection between the extremely hard X-ray and γ-ray power-law sources.

References

Abdo, A. A., Ackermann, M., Ajello, M., et al. 2010, ApJ, 723, 649

Hamaguchi, K., Corcoran, M. F., Takahashi, H., et al. 2014, ApJ, 795, 119

Leyder, J.-C., Walter, R., & Rauw, G. 2008, A&A, 477, L29

Leyder, J.-C., Walter, R., & Rauw, G. 2010, A&A, 524, A59

Reitberger, K., Reimer, A., Reimer, O., & Takahashi, H. 2015, ArXiv e-prints

Sekiguchi, A., Tsujimoto, M., Kitamoto, S., et al. 2009, PASJ, 61, 629

Tavani, M., Sabatini, S., Pian, E., et al. 2009, ApJ, 698, L142

Jesús A. Toalá: Why do you ignore the low energy part of the *XMM-Newton* spectrum ($E \leq 3\,\mathrm{keV}$)? It will help you to better constrain the column density!

Kenji Hamaguchi: The Eta Carinae spectra have multiple temperature components, each of which has individual line of sight absorption. The soft band spectrum mostly originates from cooler components and does not quite help to constrain the absorption to the hottest plasma. We normally use the Fe K edge feature at 7.1 keV for measuring absorption to the hottest plasma emission.

Lidia Oskinova: Very interesting result! Do you see any background source in *NuSTAR* images that could be confused with *Fermi* and *INTEGRAL* sources?

Kenji Hamaguchi: Thank you! No, we have not found any sources within the *Fermi* and *INTEGRAL* error circles in the *NuSTAR* hard band images.

Vikram Dwarkadas: You have assumed a mass-loss rate to carry out the simulations. Is the large column density consistent with the material in the wind + wind collision region, or do you need other absorbers?

Kenji Hamaguchi: The wind-wind colliding simulations using the current best estimate of the mass loss rate and the orbital parameters give the maximum absorption of $\sim\ 10^{24}\,\mathrm{cm}^{-2}$ or more around conjunction. This is consistent with the observed column density ($8 \times 10^{23}\,\mathrm{cm}^{-2}$) measured right before the bottom flux phase, deep minimum, which is probably produced by an eclipse of the wind-wind colliding plasma. We thus do not require additional absorption components to explain the observation result.