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

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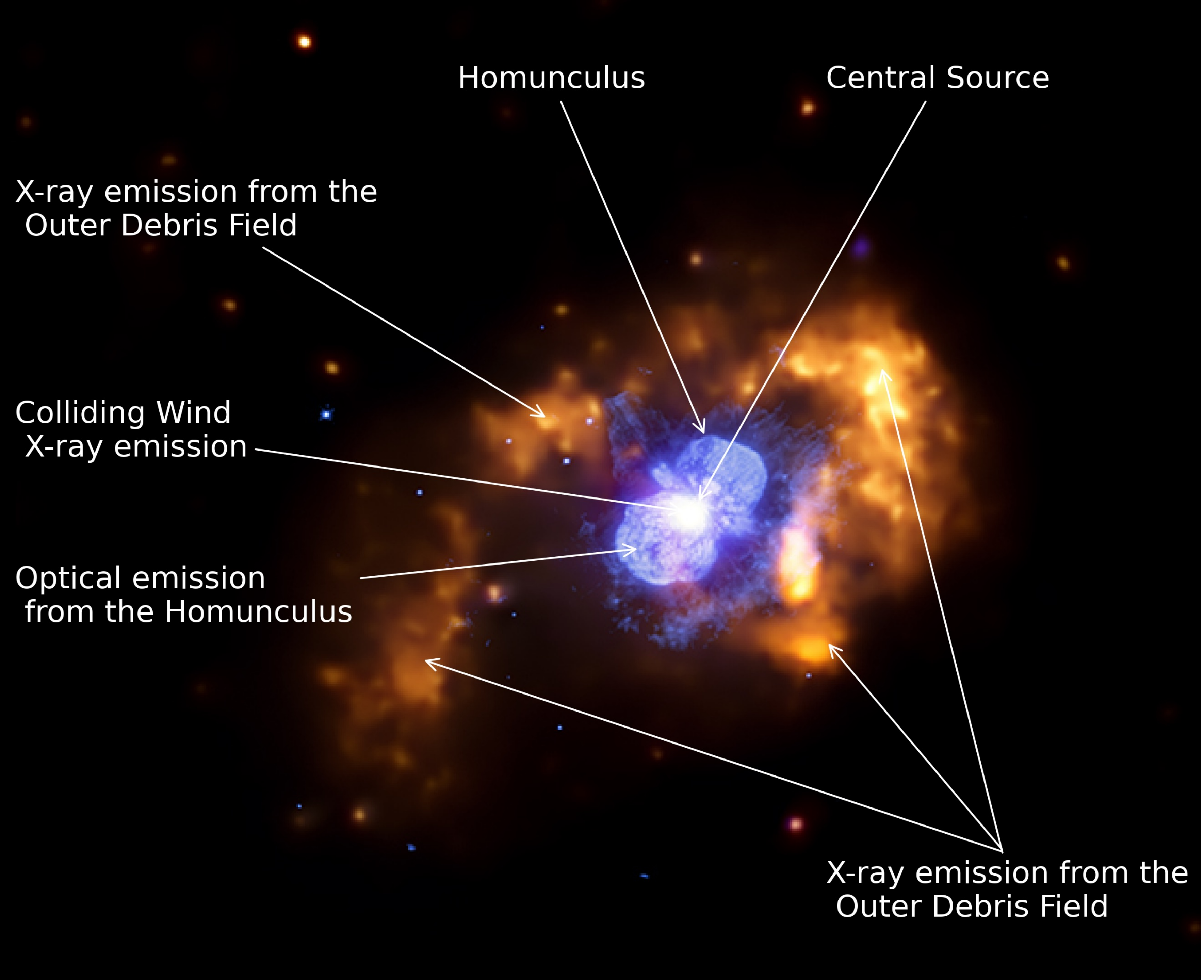
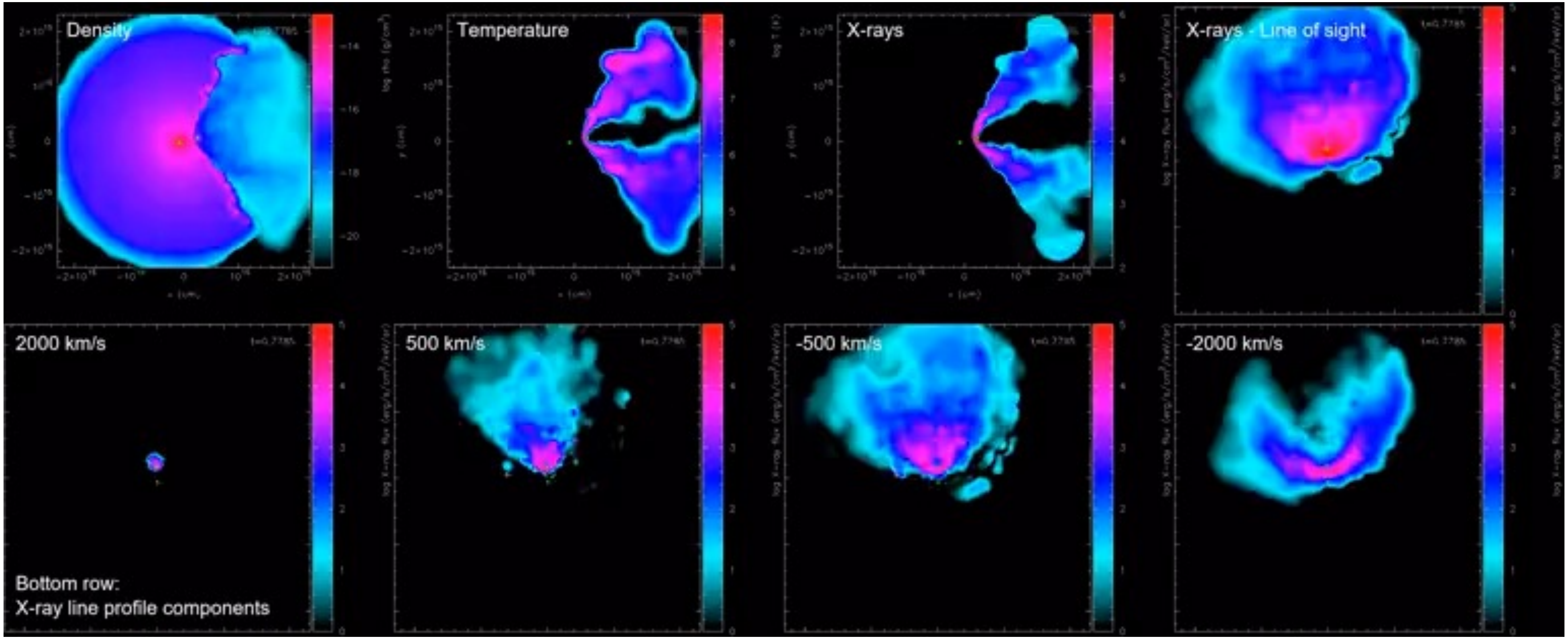
Eta Carinae (η Car)

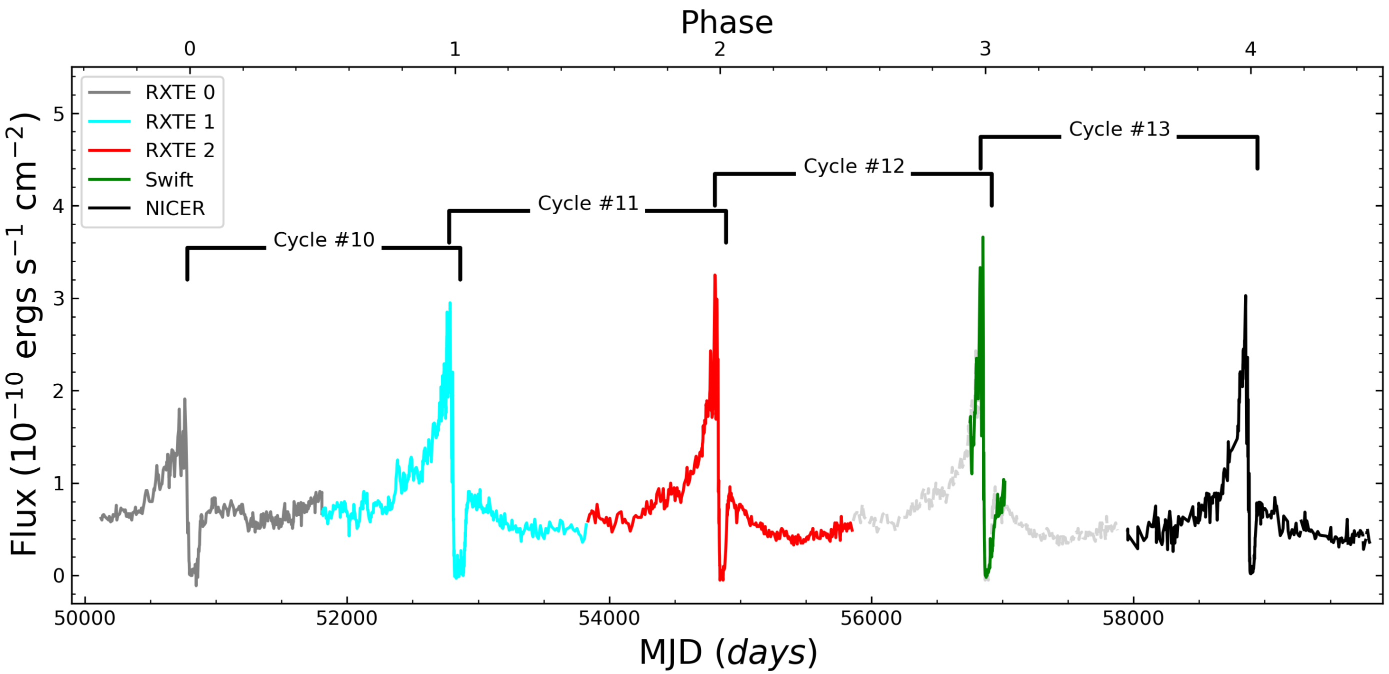


- The most massive star (>100 $M_\odot$) within 2.3 kpc.
- Around 1840 its brightness increased until became the 2nd brightest star in the sky.
- The 1840s event is known today as the great eruption and formed two bipolar structures called the homunculus nebula.
- Now we know η Car is a colliding wind 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 $1x10^8$ 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”.

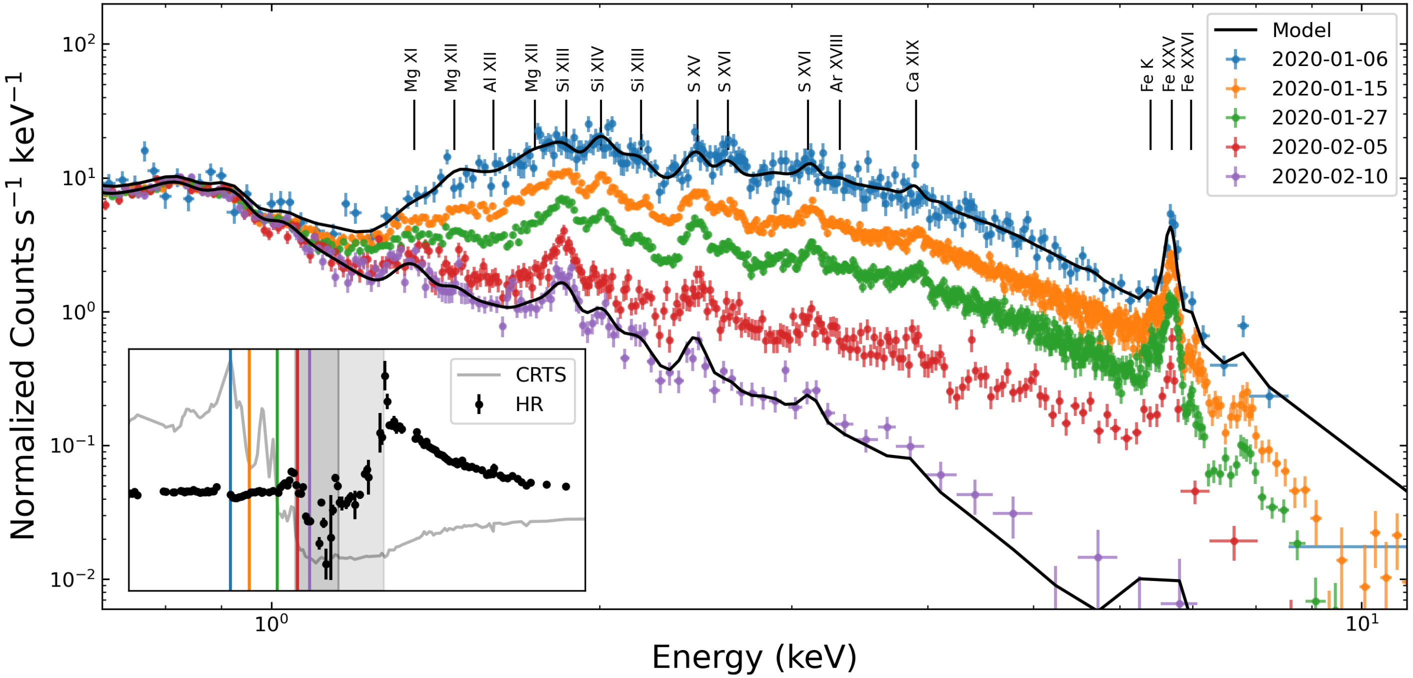
Hydrodynamics simulation of the colliding stellar winds in eta Carinae by C. M. P. Russell https://youtu.be/yQFesQbTFFk





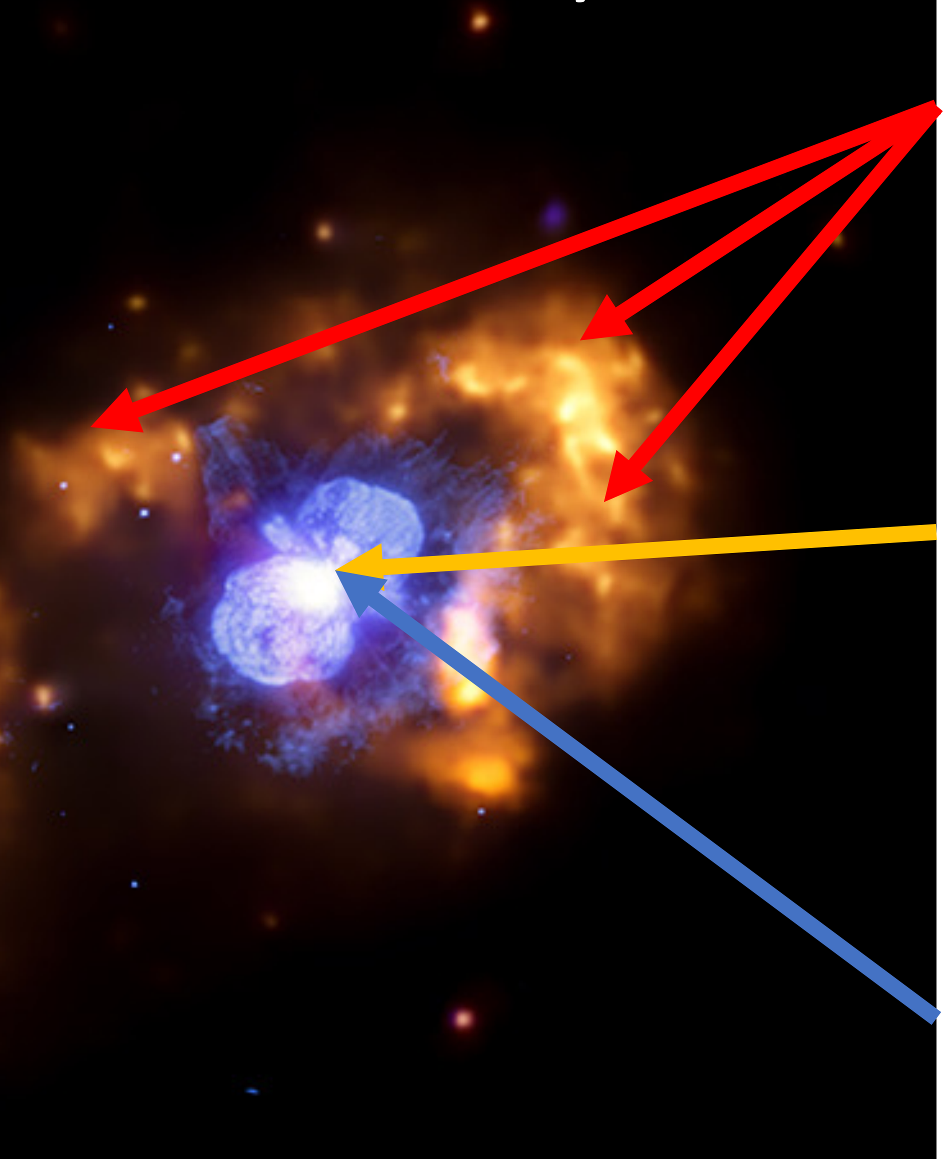
Why NICER?

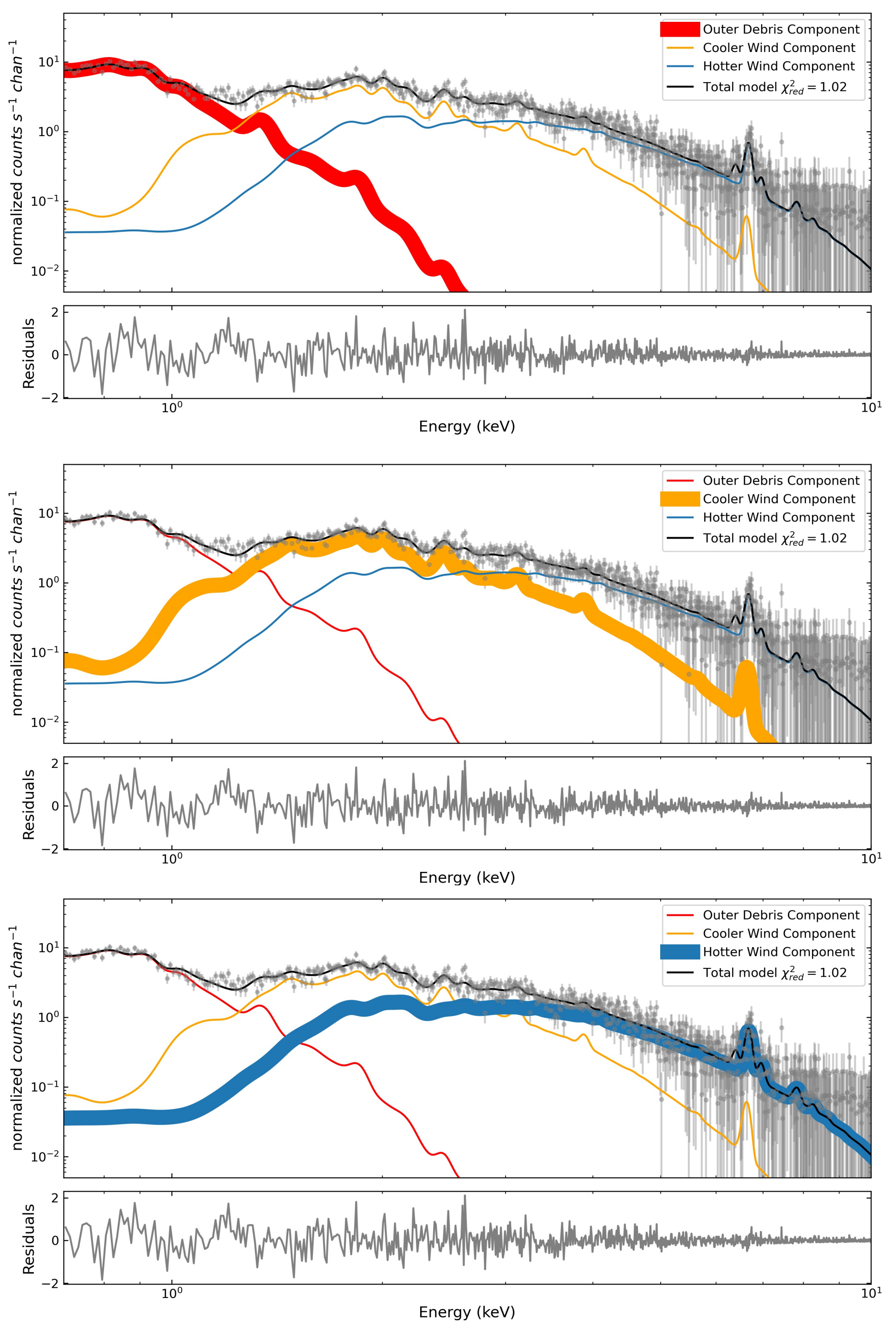
- NICER capabilities to allocate frequent observations are perfect for η Car's monitoring program.
- High-resolution spectra allow us to observe the changes in η Car's spectrum through the orbital motion of the components.
- NICER provides a unique opportunity to follow the soft X-ray emission below 2.0 keV.



η 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.





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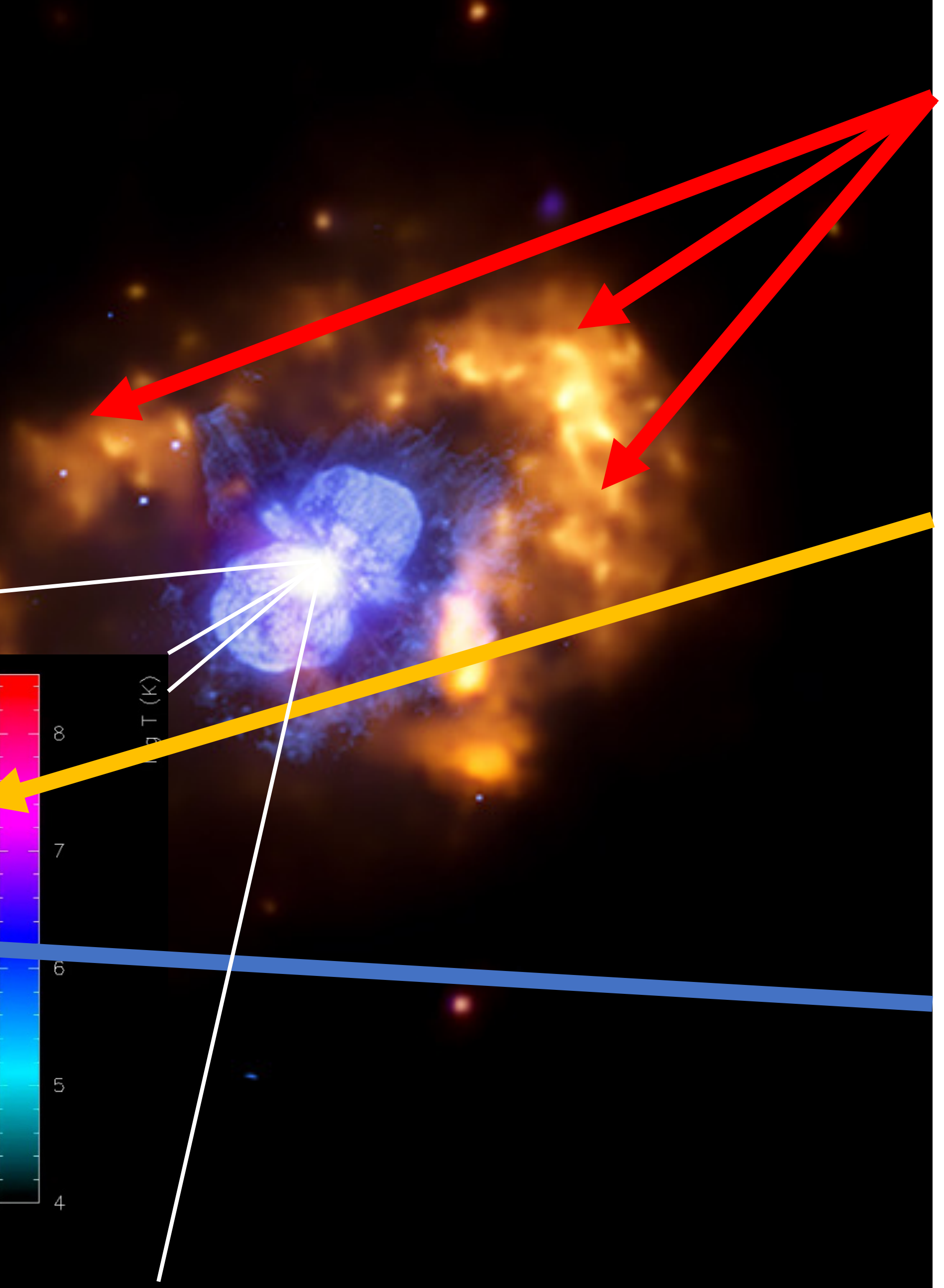
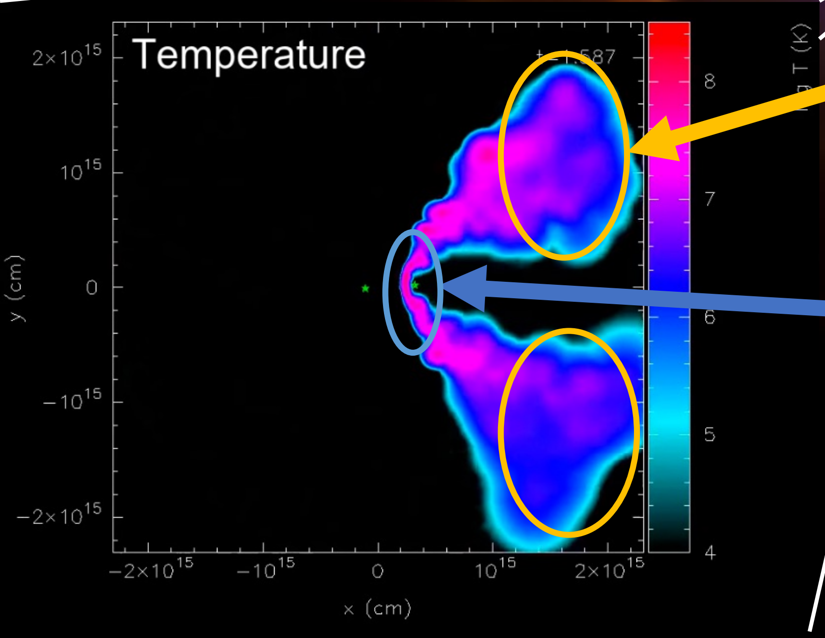
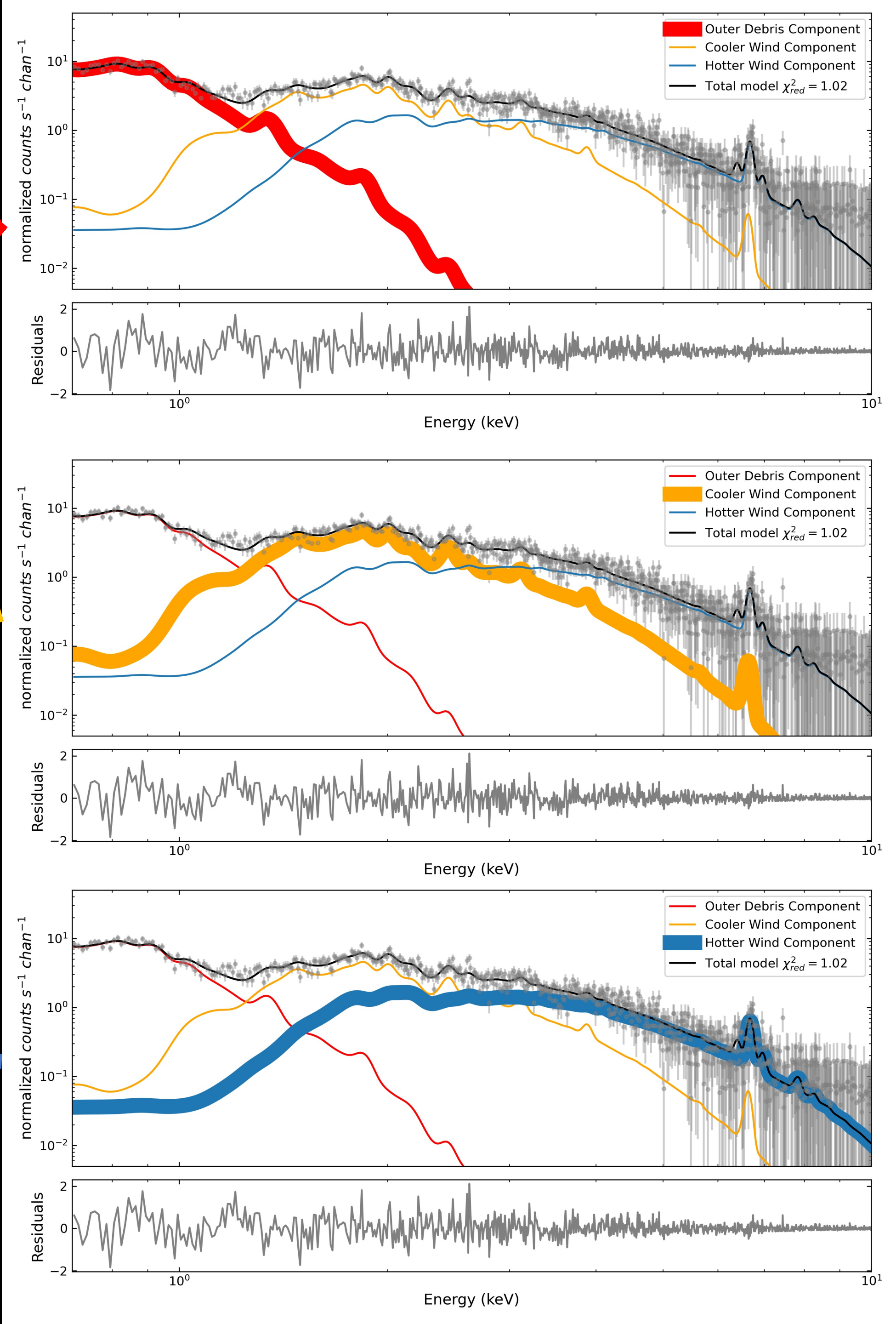
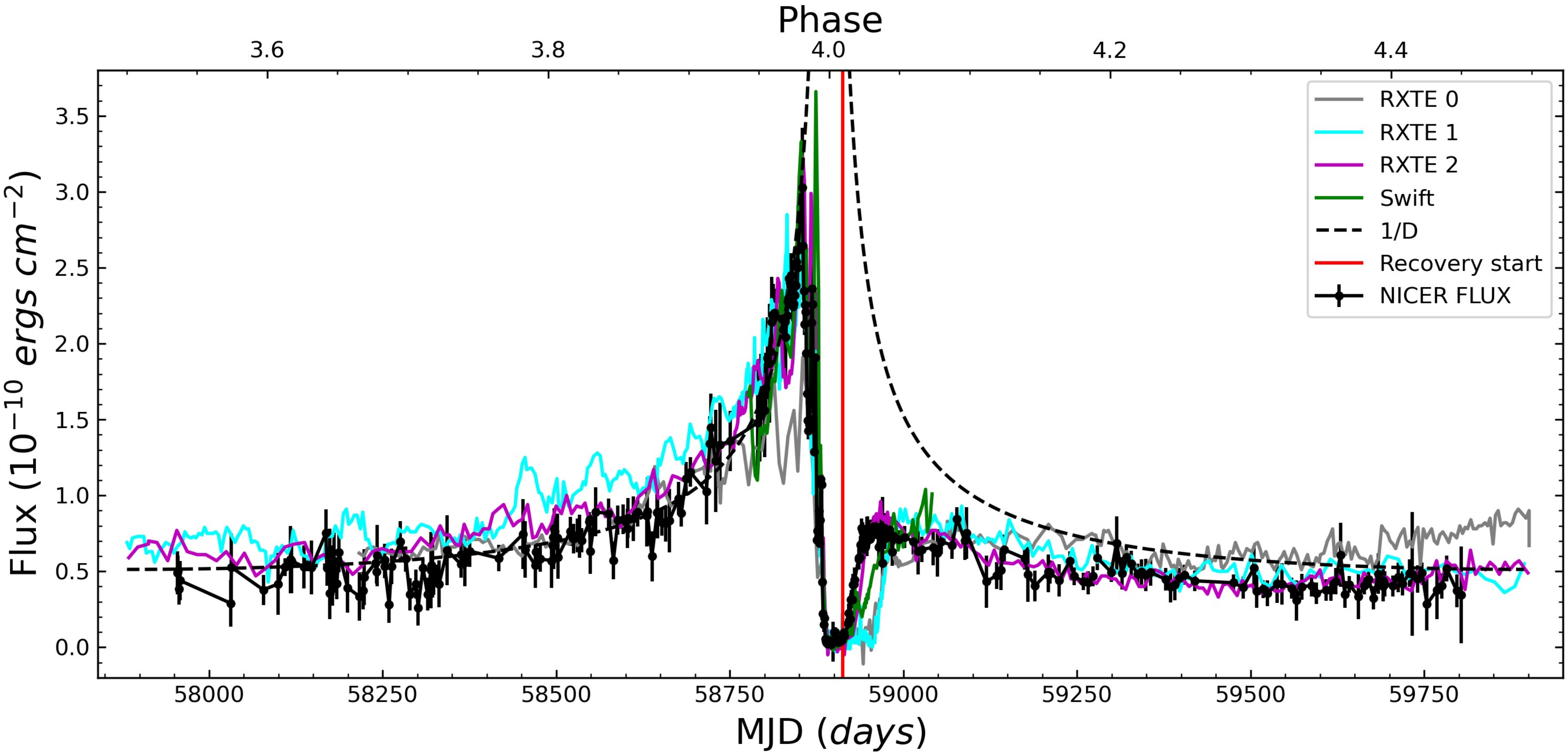




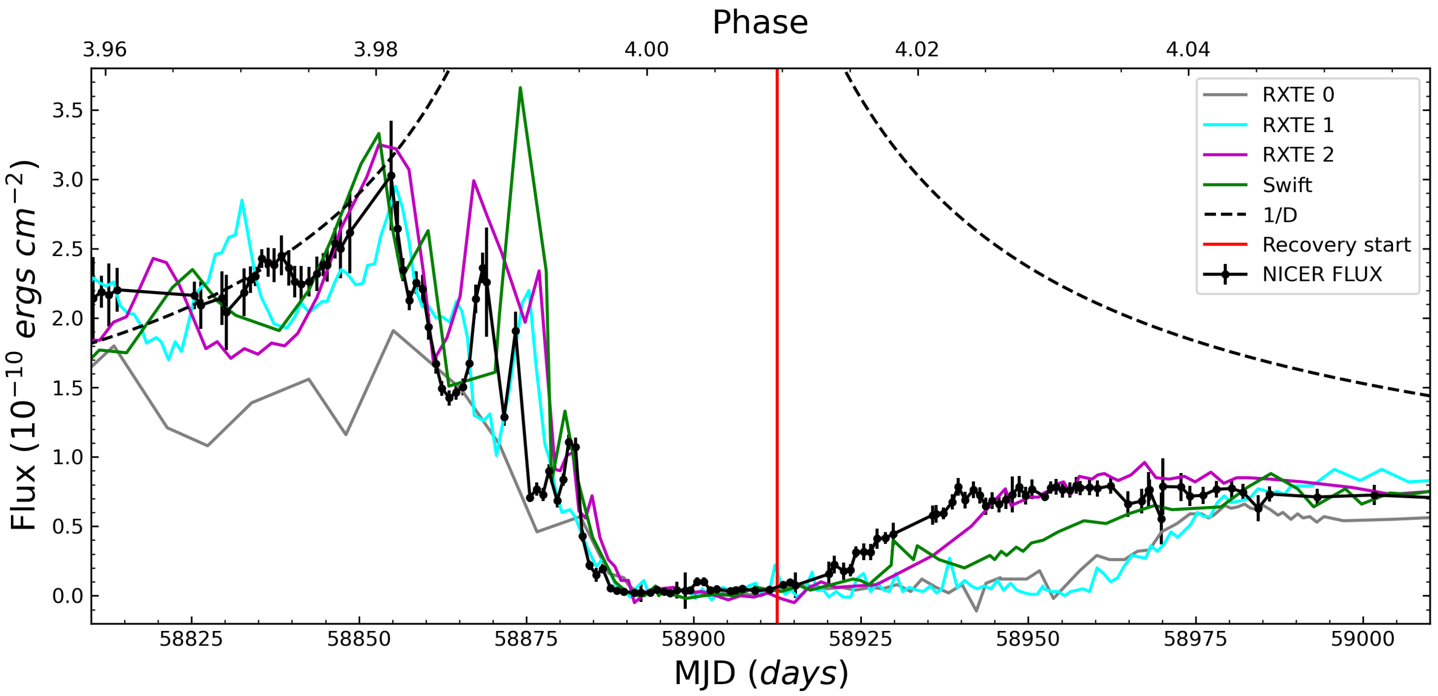


η Car's Flux compared with RXTE and Swift

- 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.



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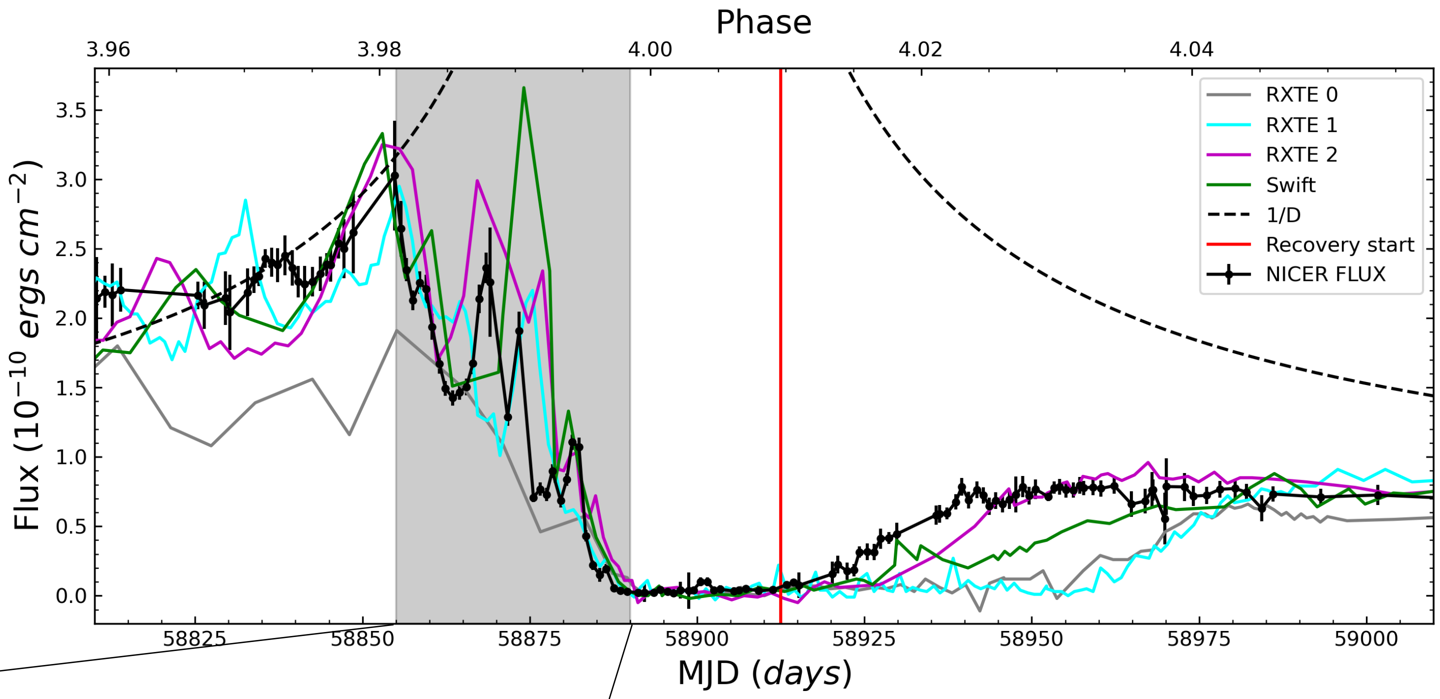
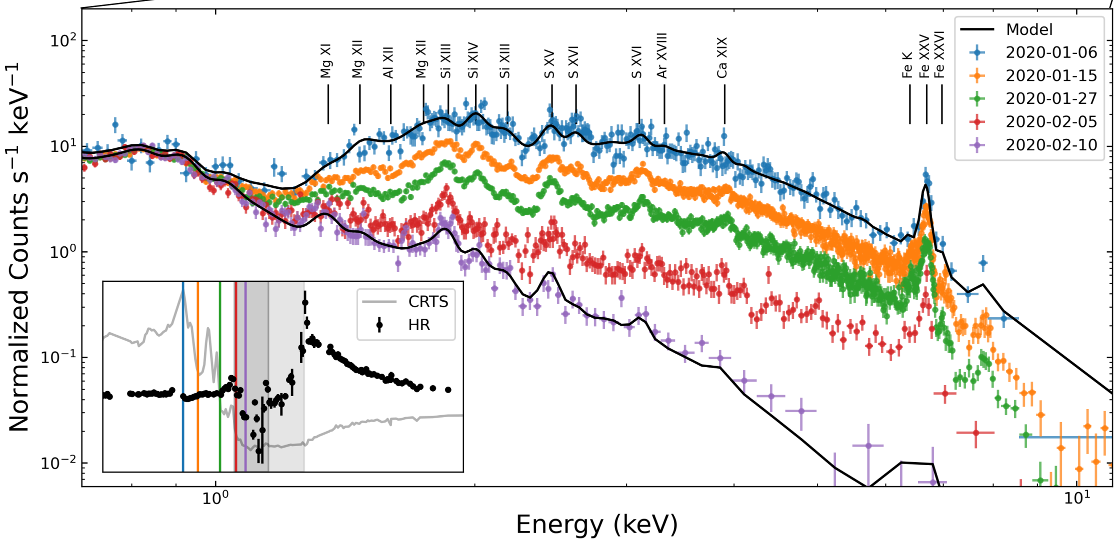
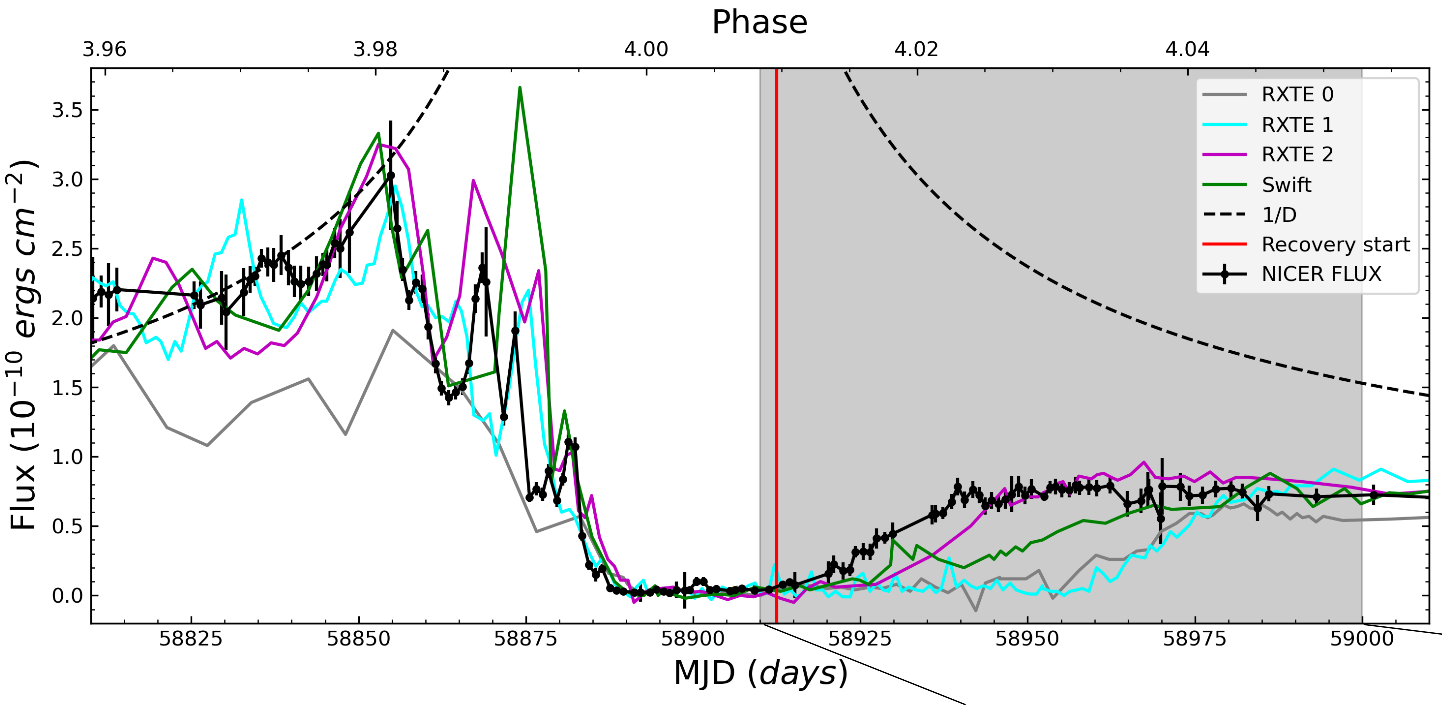


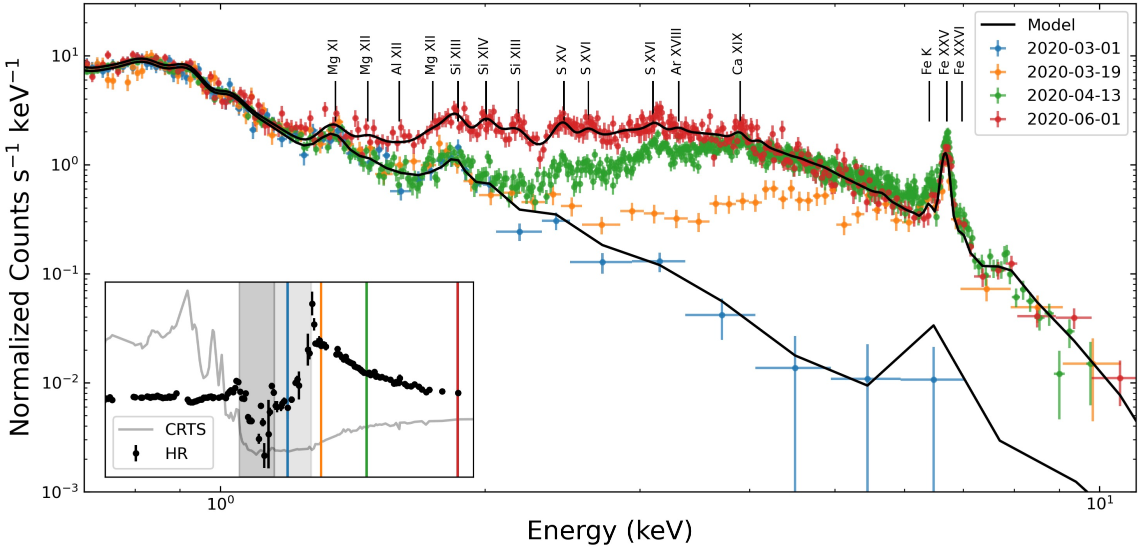


- NICER observed that the plunge of the X-ray maximum started at ϕ ~3.98, like the previous cycles indicating that it is strongly correlated with the orbital phase.

- Analysis of η 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.

η Car’s NICER look at periastron: The plunge and the recovery.



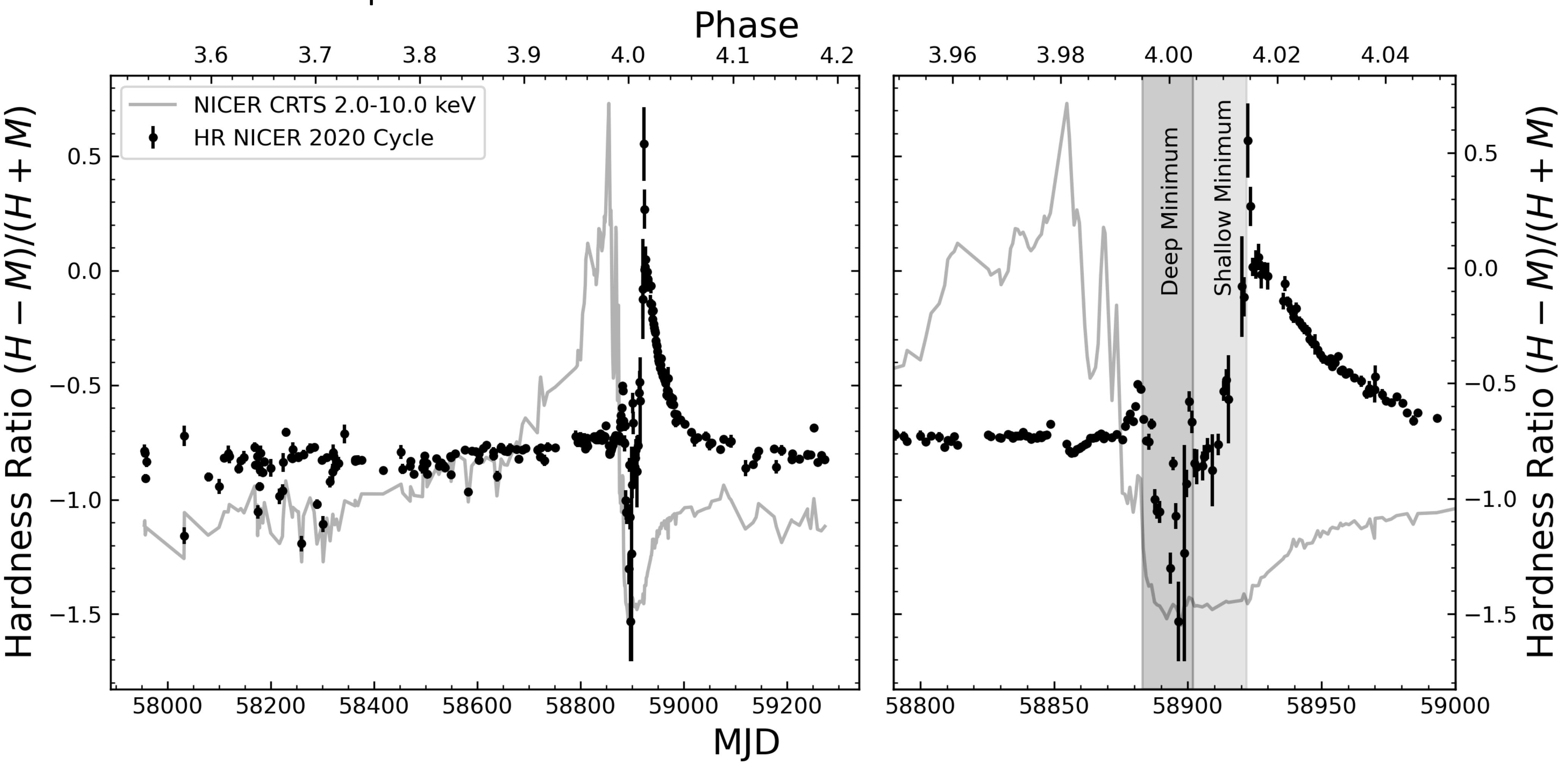


- We have observed the shortest X-ray recovery: the flux starts to increase at ϕ = 4.009 which is ~7 days earlier than the low limit estimated by Corcoran et al. (2010) in the 2009 periastron passage (RXTE 2 in magenta).

- 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.

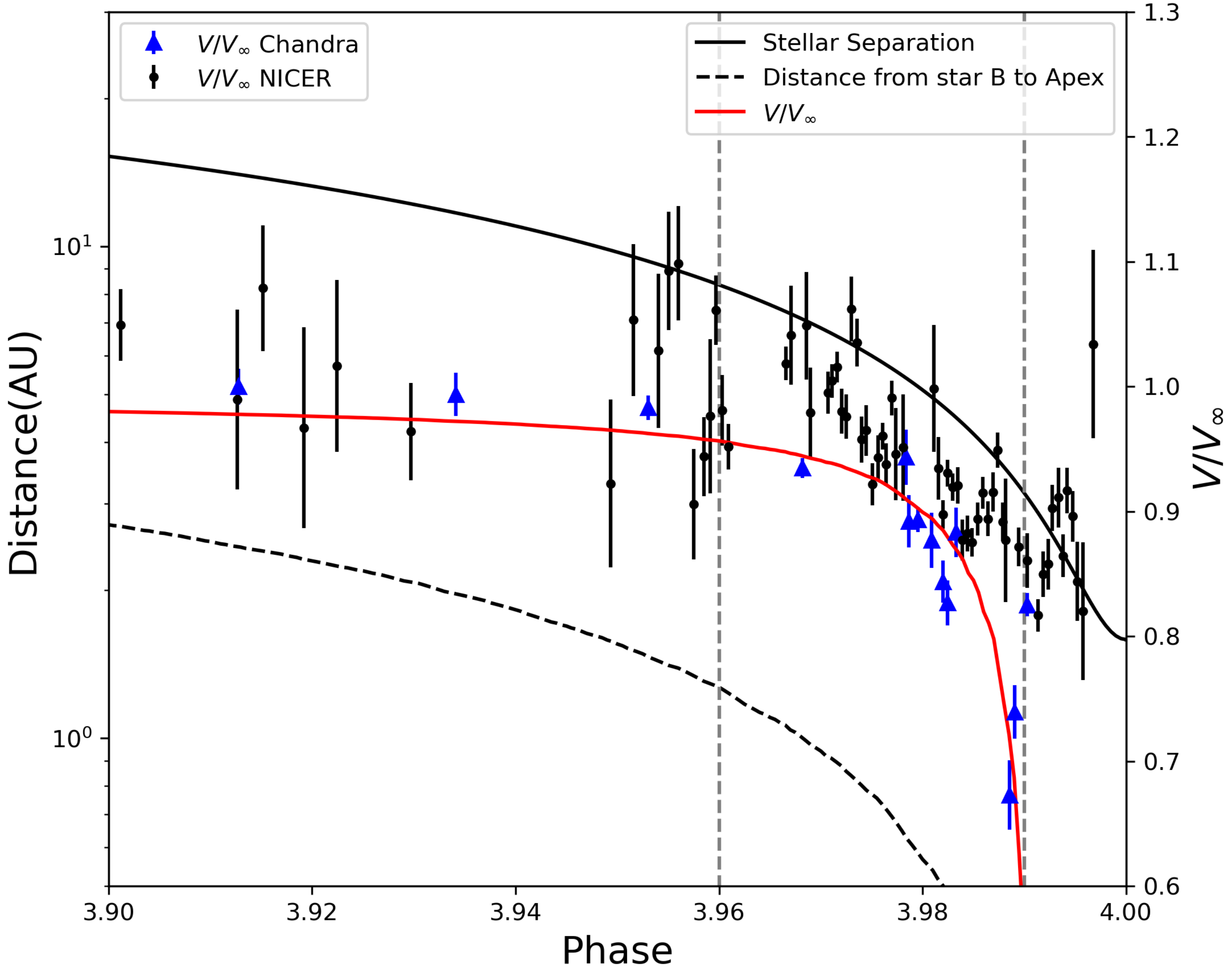
η Car’s Hardness Ratio (H-M)/(H+M); H = 6.5-7.5 keV, M=2.5-3.5 keV.

- 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< ϕ <4.004 and the Shallow Minimum from 4.004< ϕ <4.013.

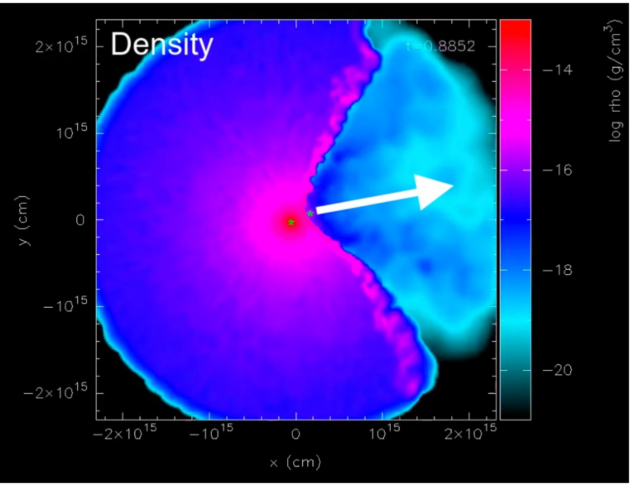


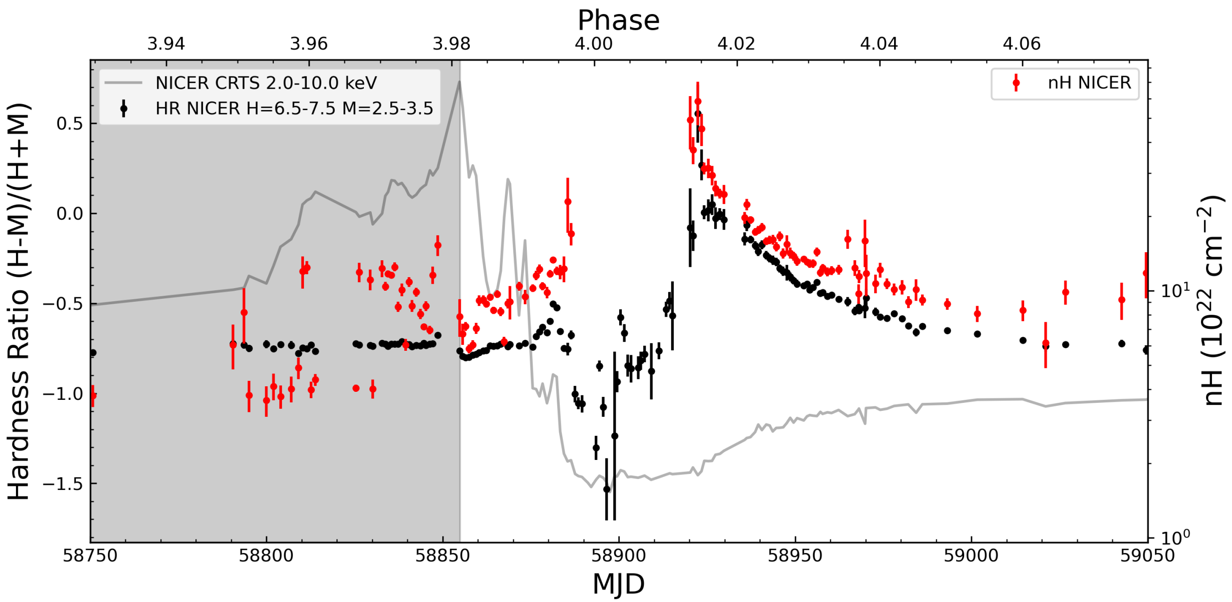
Velocity of the wind in the apex of η Car's CWR

- 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.





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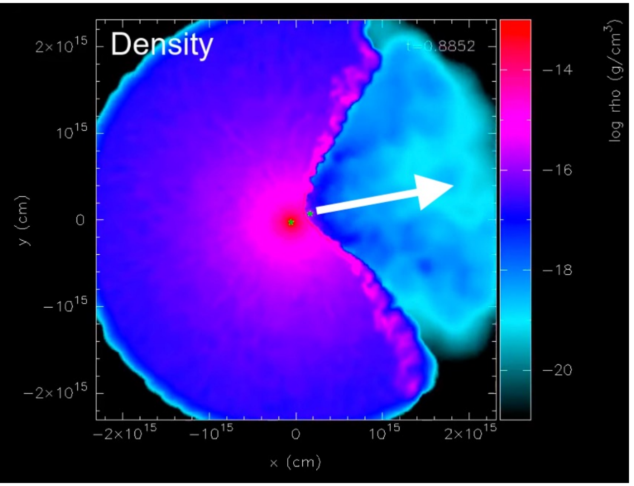

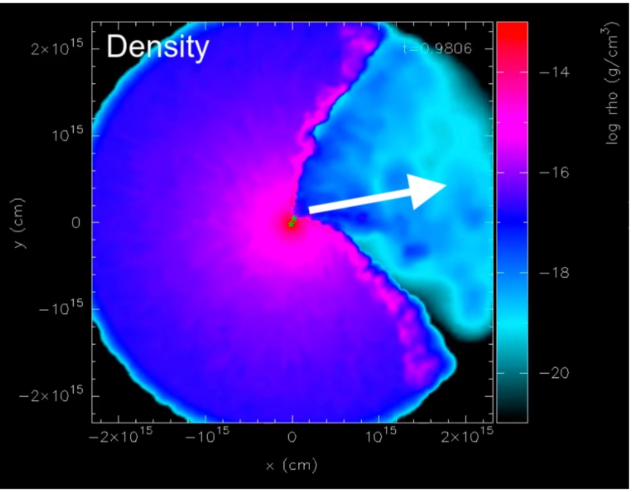

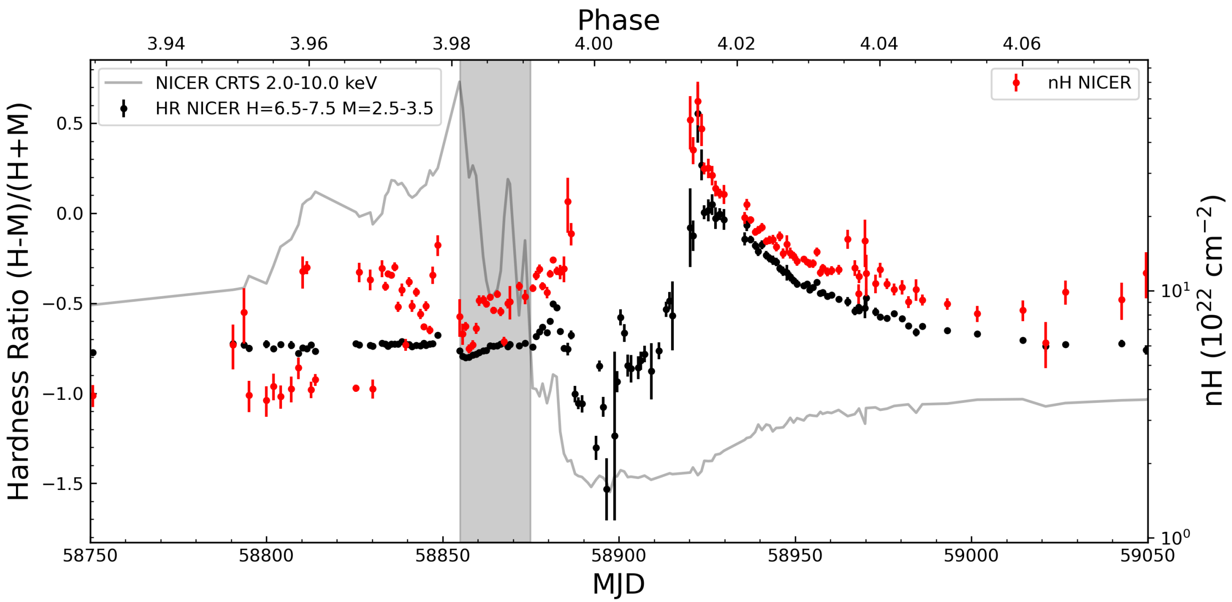

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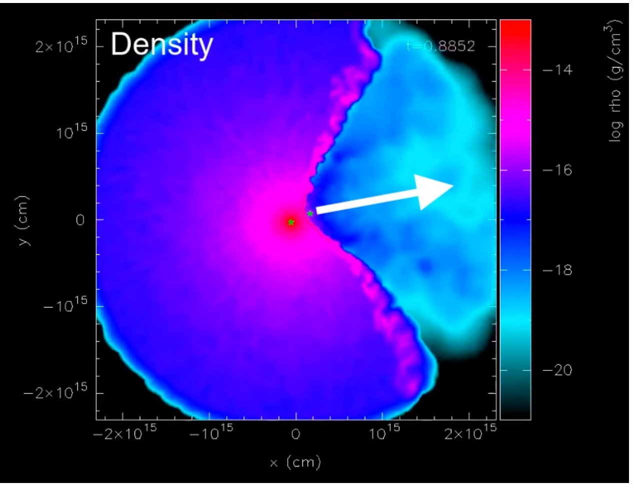

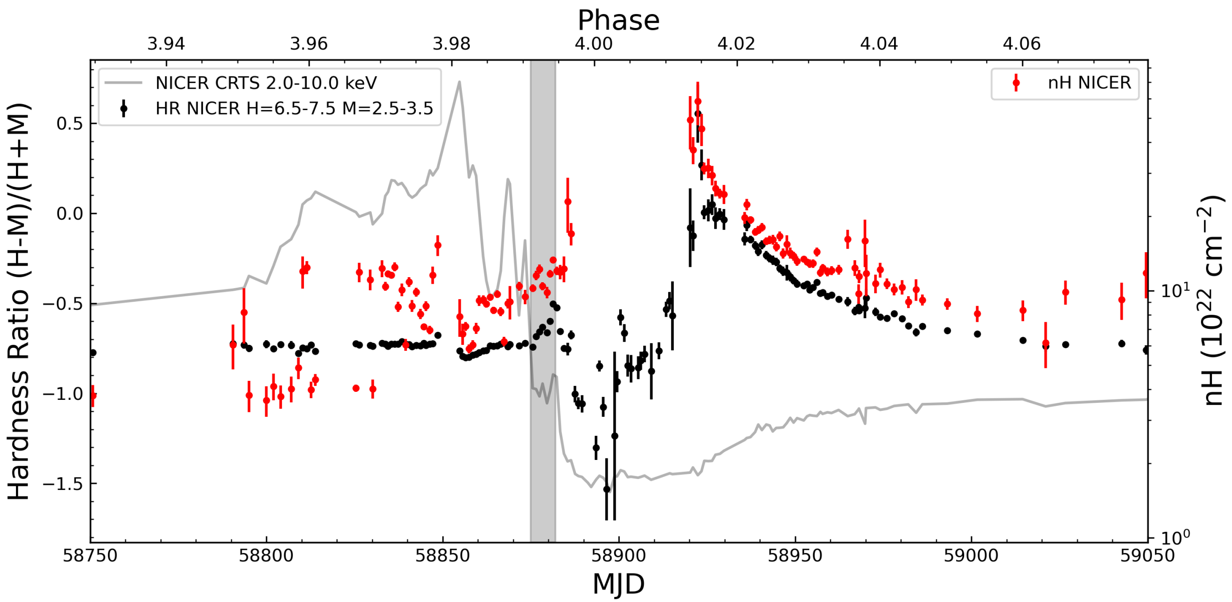

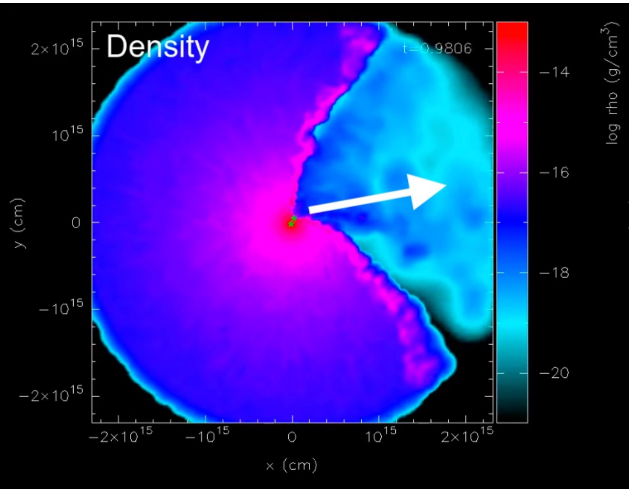

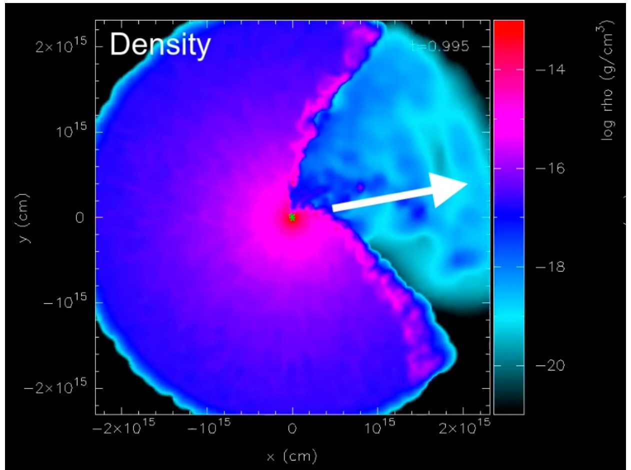

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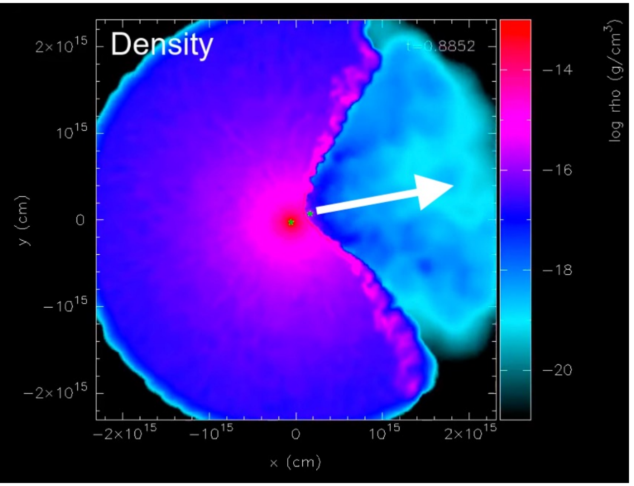

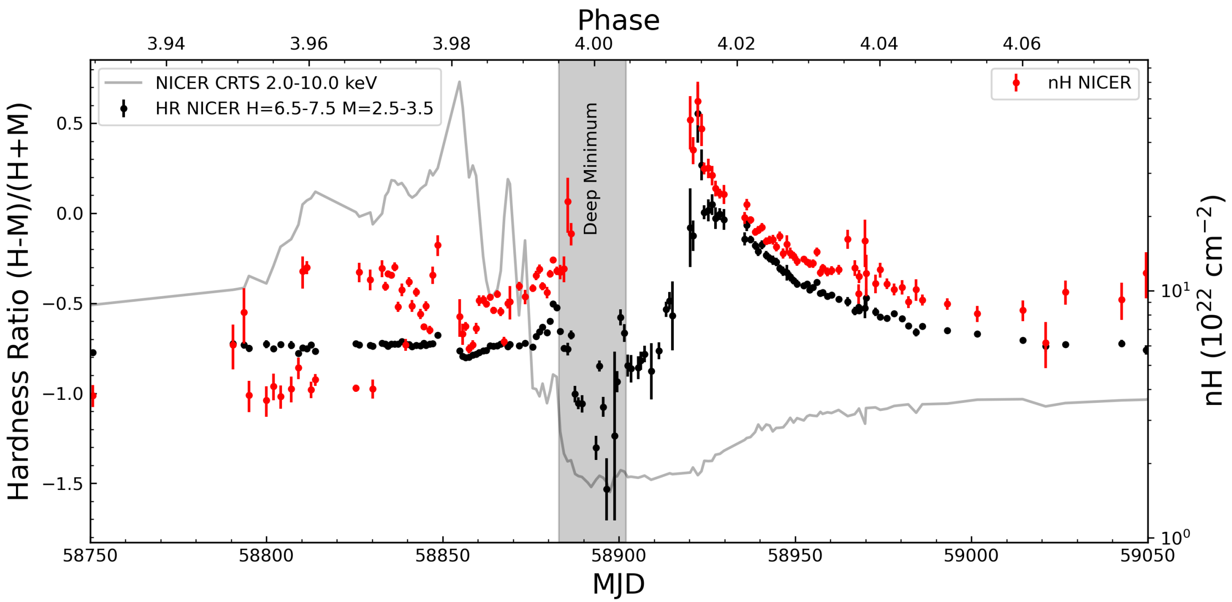

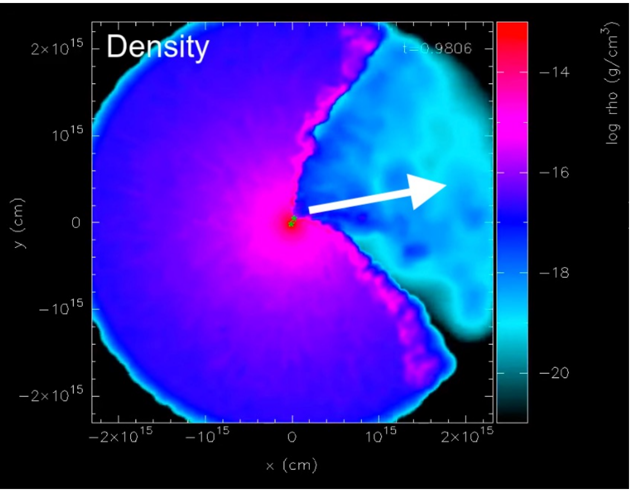

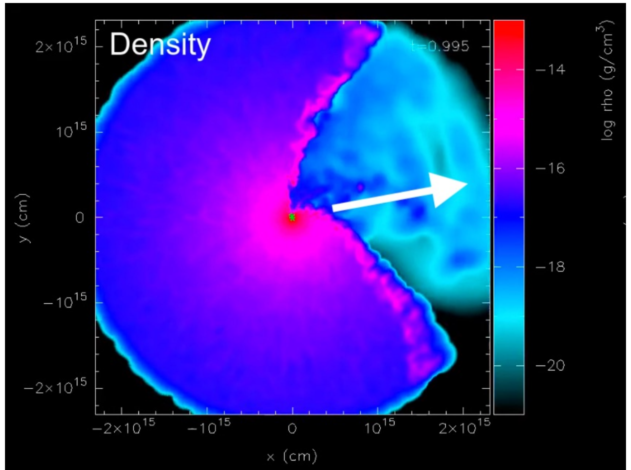

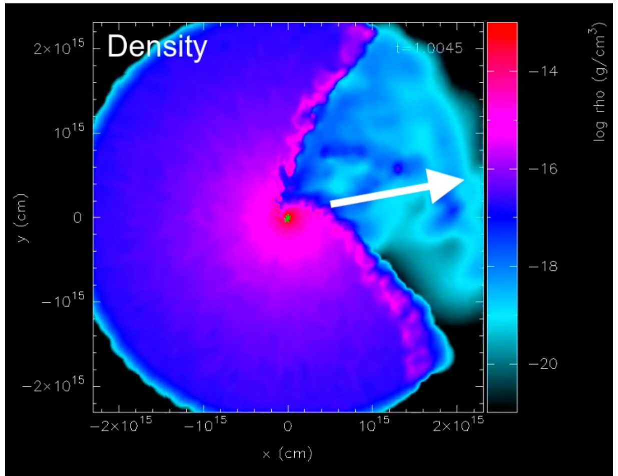

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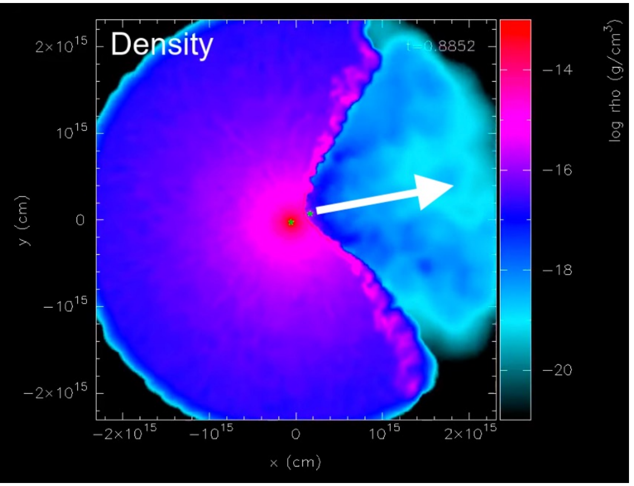

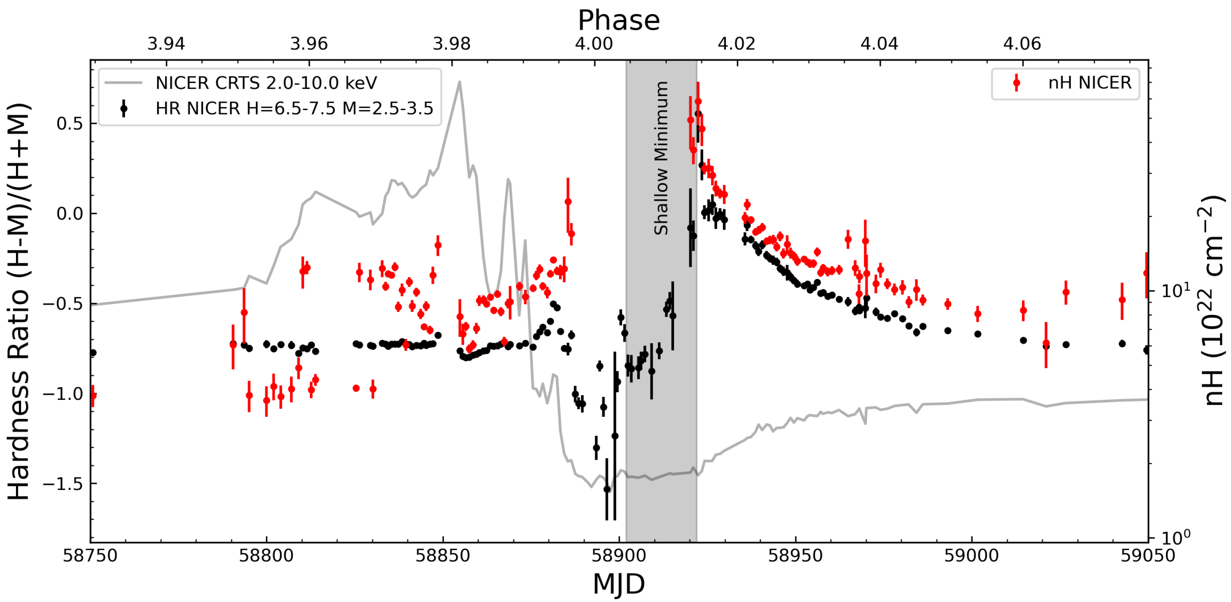

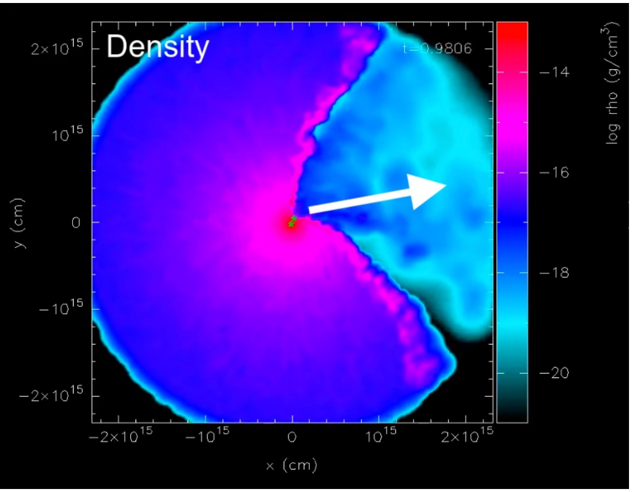

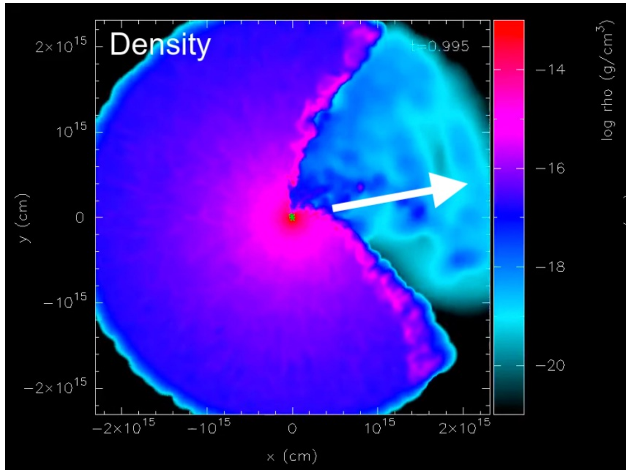

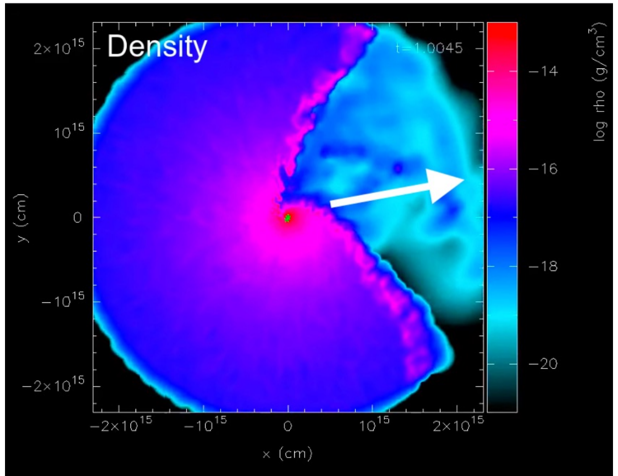

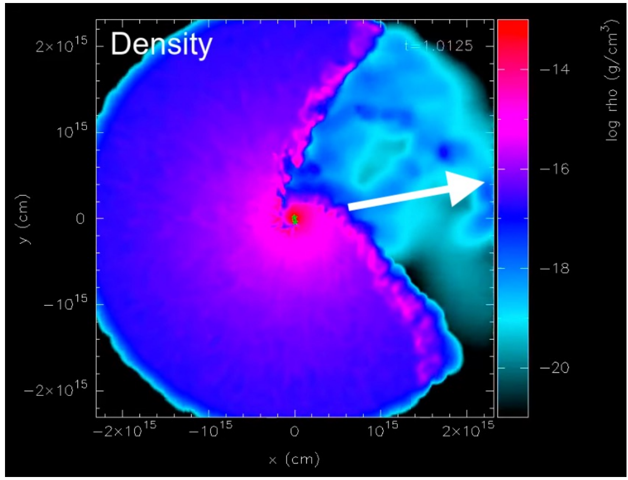

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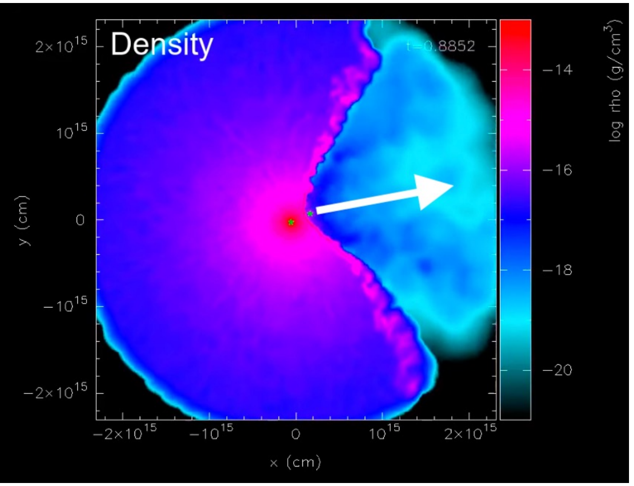
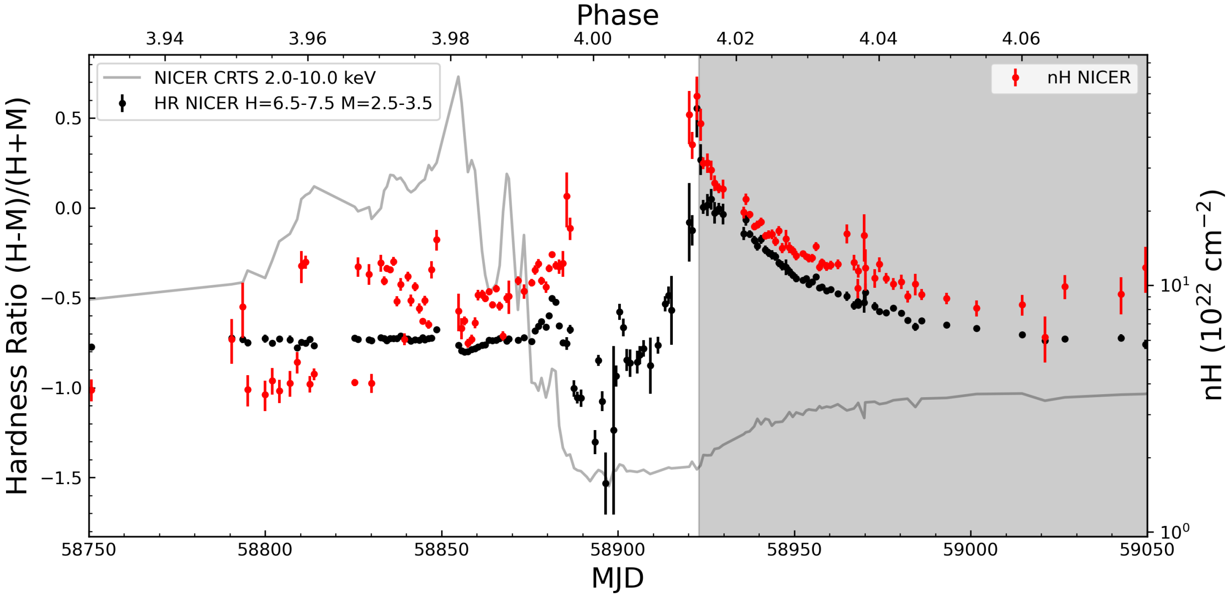
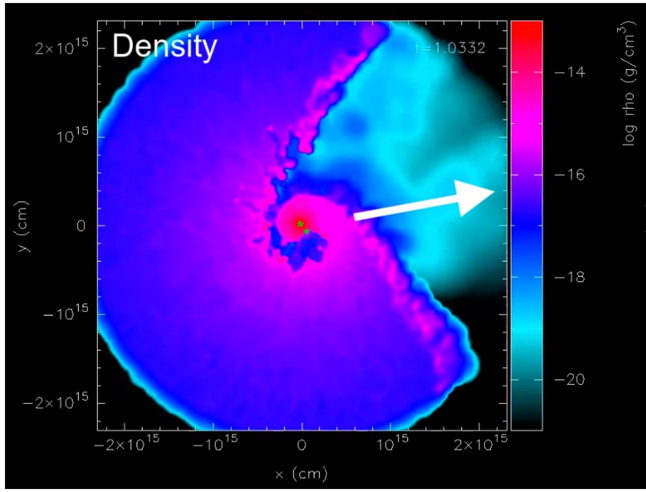
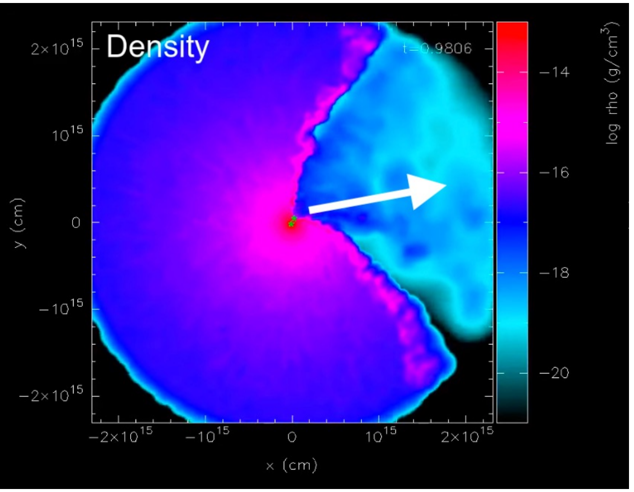
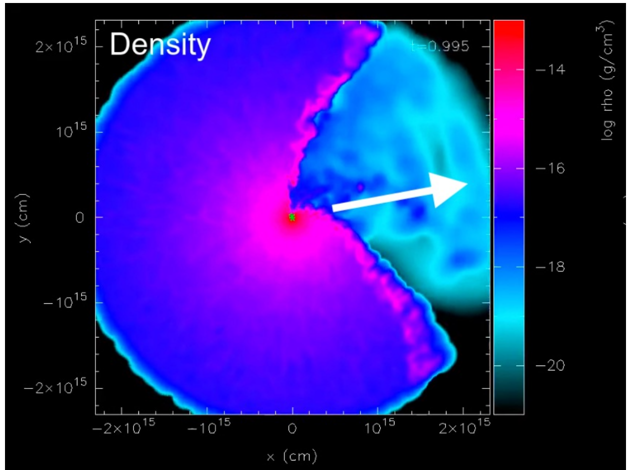
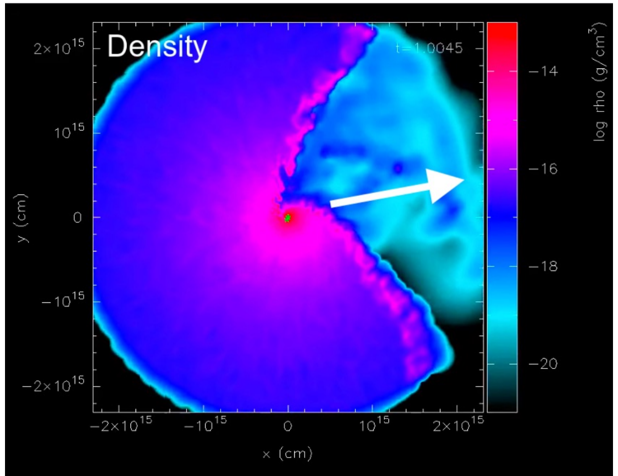


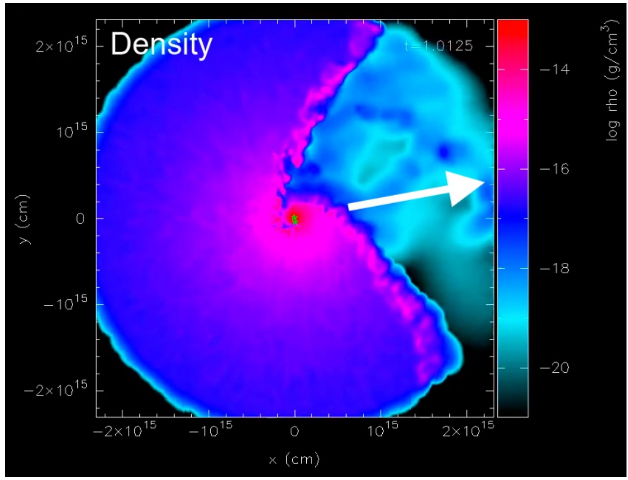






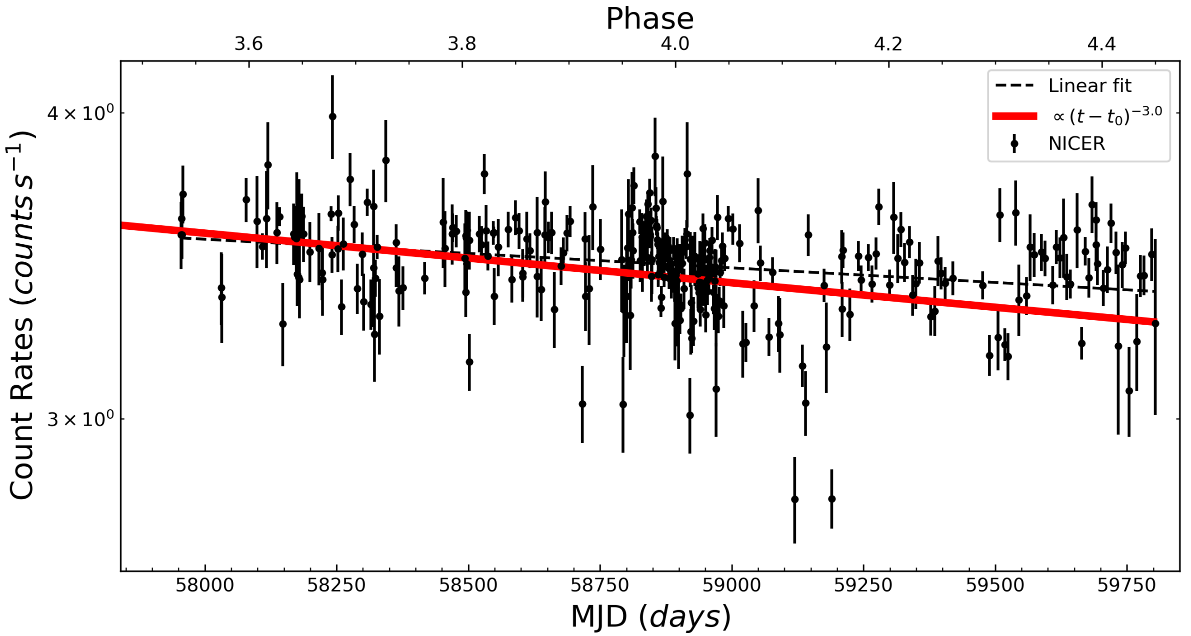


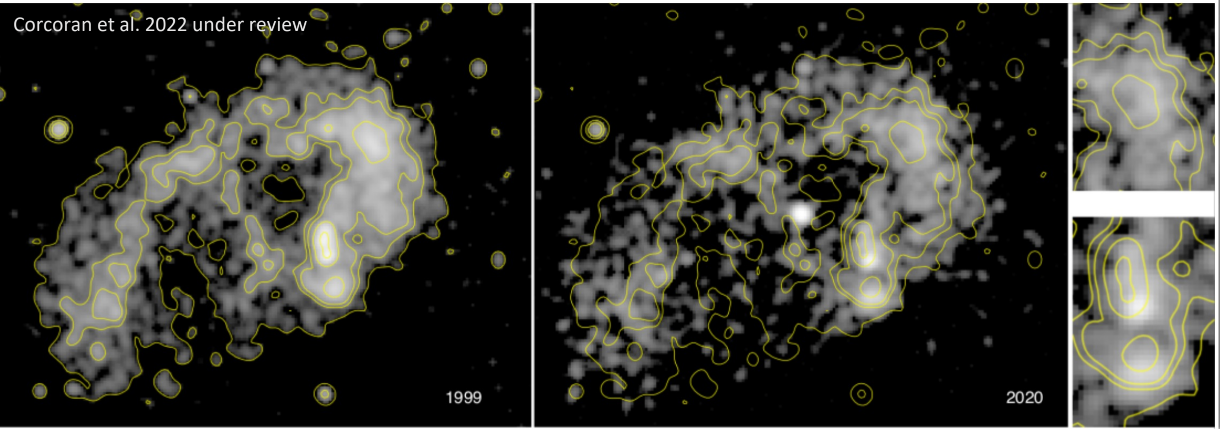


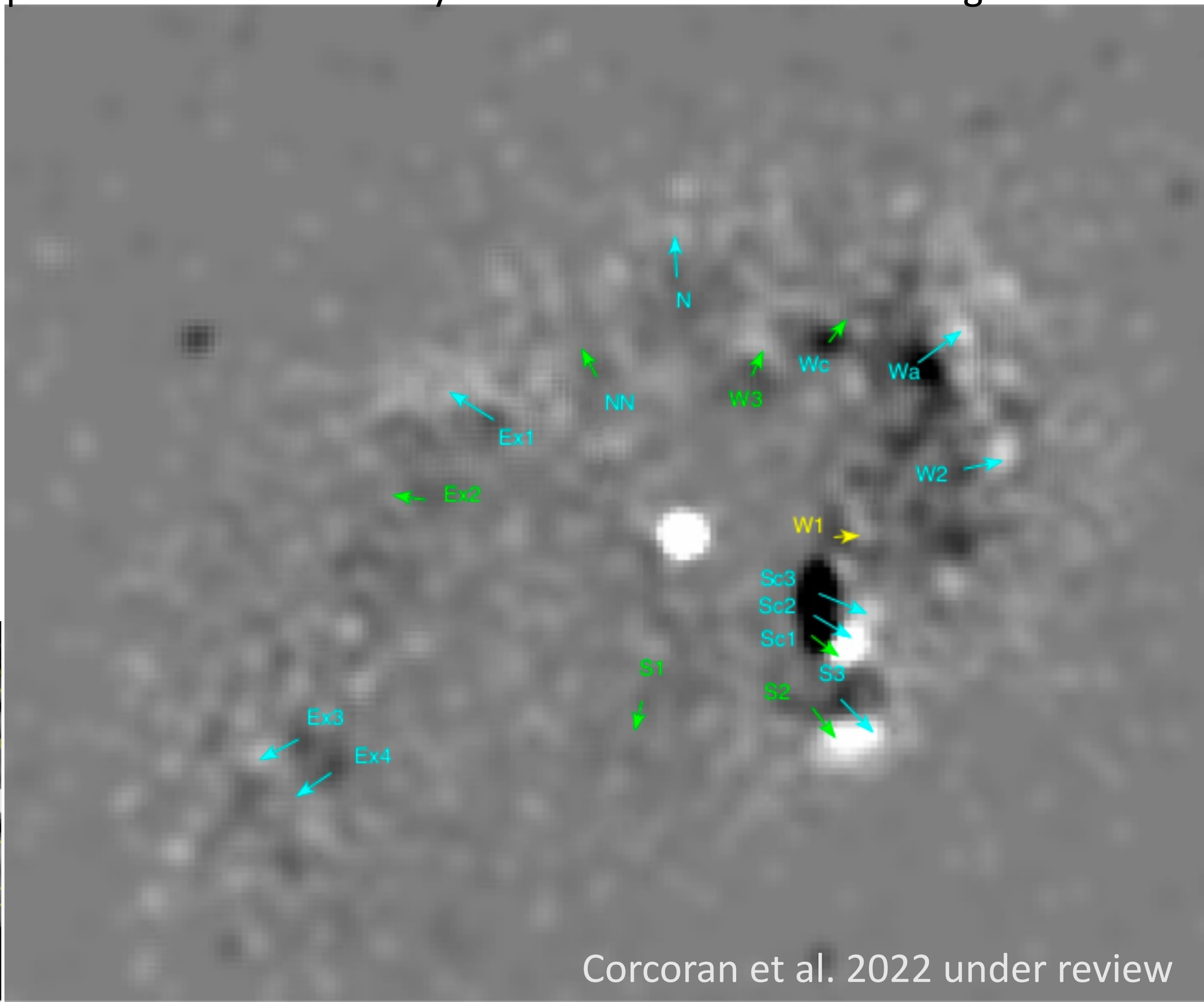


Monitoring of the soft X-ray emission < 2.0 keV.

- 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 $(t\text{-}t_o)^{-3}$ 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 $\phi \sim 3.53$ to $\phi \sim 4.45$ 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 $\phi \sim 3.98$, 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 $3.995 < \phi < 4.004$ (18 days) and the Shallow minimum from $4.004 < \phi < 4.013$.
- We have observed the shortest X-ray recovery: the flux starts to increase at $\phi = 4.009$ 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 $\sim 10^{41}$ 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