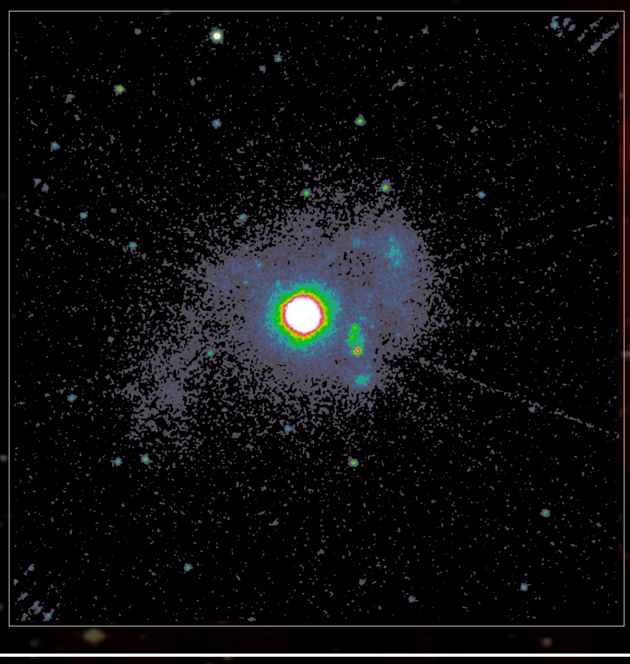
Eta Carinae: Taking the Plunge

Characterization of the Colliding Wind Region in the Superluminous Massive Binary, Eta Carinae

David A. Espinoza-Galeas[1,2], Michael F. Corcoran[1,2], Kenji Hamaguchi[2,3], Chris Russell[4]

[1]Catholic University of America, [2]NASA/GSFC, [3]CRESST/UMD, [4]Pontificia Universidad Católica de Chile

Introduction

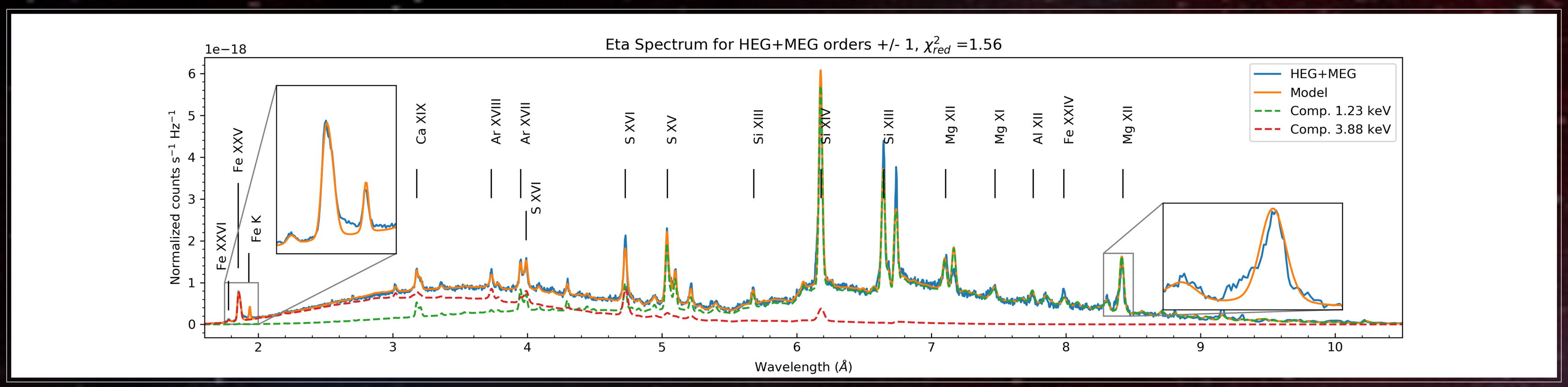


η *Car* is a massive ($M > 100M_\odot$) long period, eccentric binary. The two stars in the system each possess strong stellar winds which reach velocities up to 3000 km/s. The thermal X-rays from the collision of the massive slow wind from the Luminous Blue Variable component (η *Car* A) and the lower density, much faster wind of the companion (η *Car* B) provide our best understanding of the colliding wind shock and constrain the mass loss from the two stars. The system has an extreme eccentricity of $e \approx 0.9$ and a period of 5.53 years. The stellar separation varies by a factor of 100, causing strong changes in the colliding wind shock and the observed X-ray emission. The stars go through periastron passage in February 2020 and the system is currently showing a significant increase in X-ray emission prior to reaching a minimum state which starts on February 16, 2020, about 2 days prior to periastron passage.

We present a new detailed X-ray line identification of the colliding wind spectrum, and analysis of line profile variability over the past 20 years using Chandra High Energy Transmission Grating observations to characterize the physics of the colliding wind region and to compare with 3-D hydrodynamic models. We include in our analysis new HETGS observations obtained in May, July and October 2019. Our new Chandra X-ray observations are compared with X-ray monitoring observations by the NICER X-ray telescope installed at the ISS.

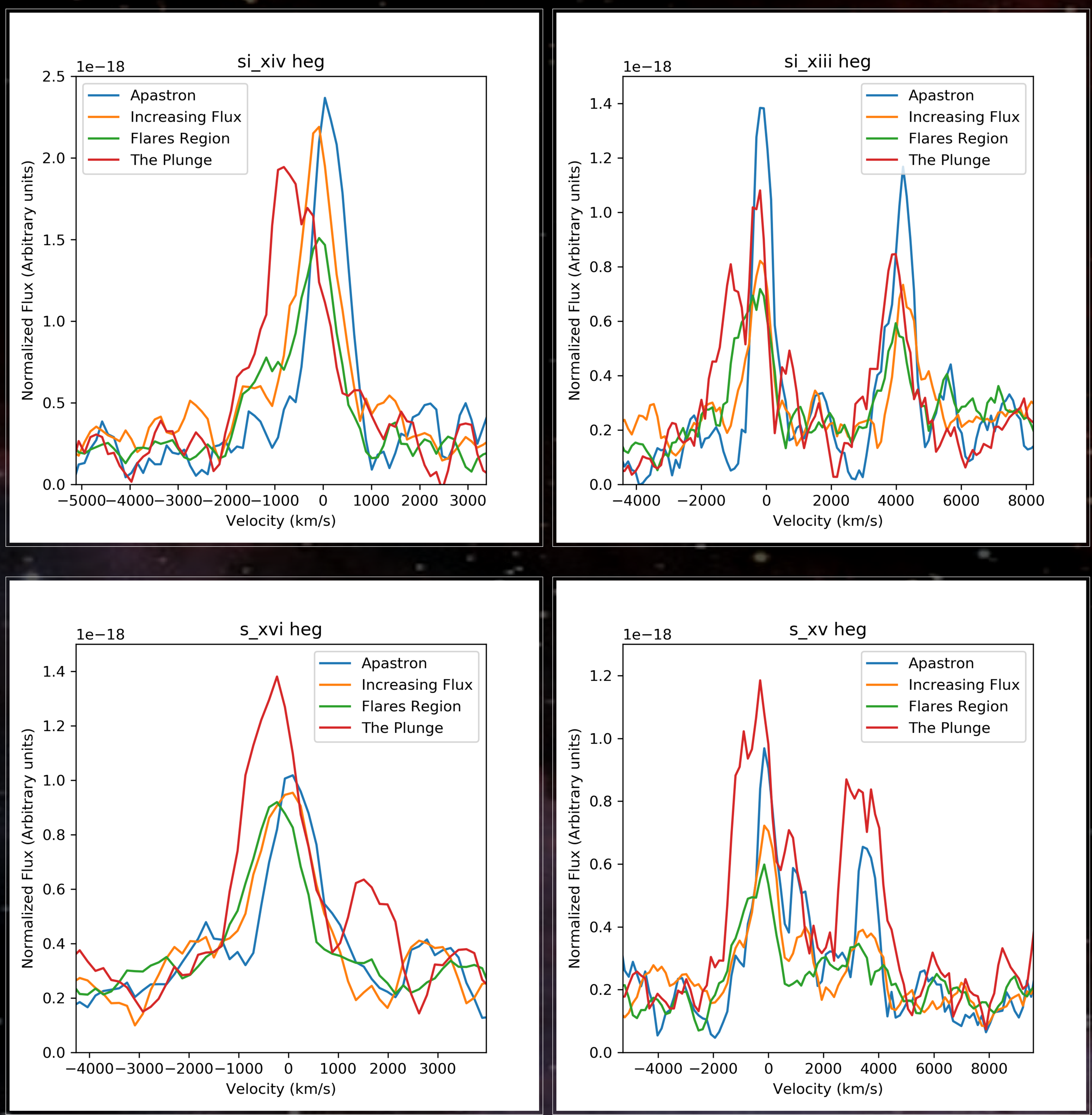
The 1.5 Msec Spectrum

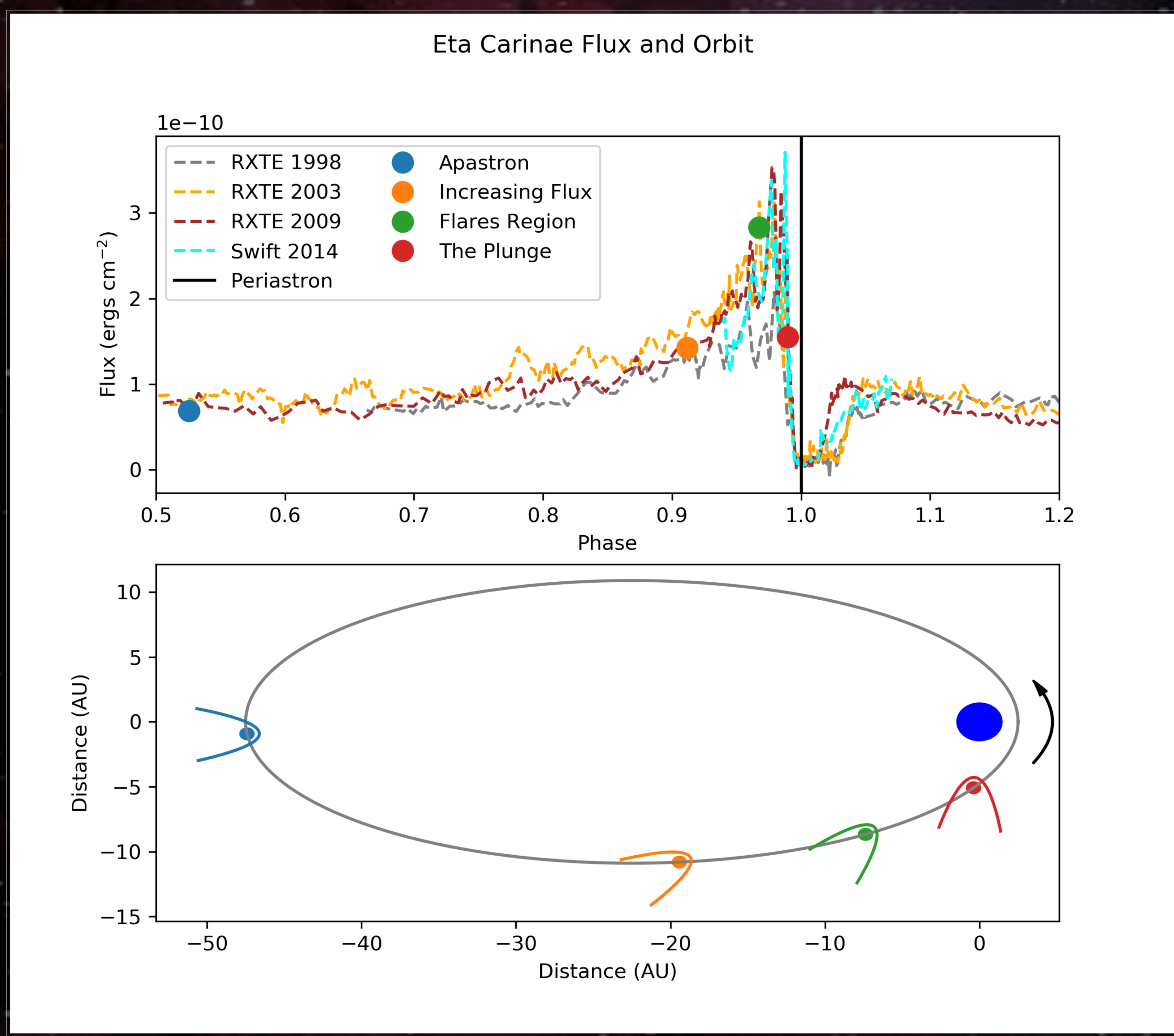
We combined more than 50 *Chandra* HETG ± 1 order MEG+HEG observations of η *Car* to produce the deepest, highest resolution spectrum of η *Car* yet obtained, with a total exposure time in excess of 1.5 Msec. Using this combined spectrum, we made a definitive line identification of the η *Car* X-ray emission. This combined spectrum is well described using a two-temperature thermally broadened emission from collisionally-ionized plasma in thermal equilibrium, calculated using the AtomDB atomic database ("bvapec") model.
There are a number of spectral features which are not well explained by the model. We have observed an extended excess on the long wavelength side of the Fe XXV line and the fluorescent Fe K. We also see excess blueshifted emission on some strong lines that is not well explained by a thermally-broadened line profile. This "blue excess" is especially prominent in strong emission lines at wavelengths > 5Å where the cooler component dominates the X-ray emission.



Comparing Line Profiles at Different Phases

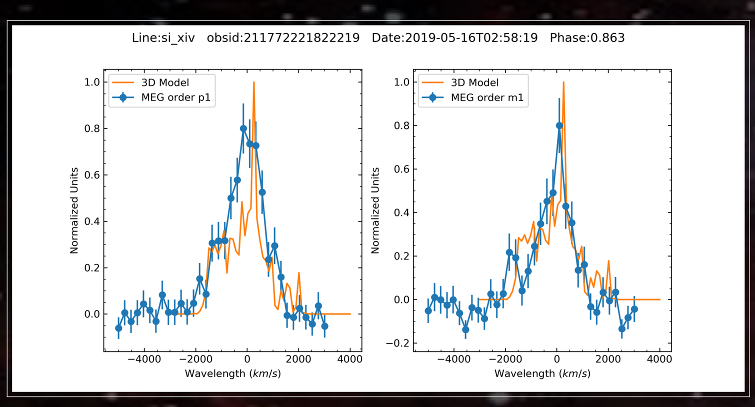
Below we illustrate how the line profiles vary with separation between the two stars. We fit strong H-like and He-like emission lines in individual *Chandra* observations with gaussian line profiles to measure centroids, widths and intensities to follow their changes with separation between the stars over the orbit. The four panels in the figure below show Si XIV, Si XIII, S XVI, S XV emission lines for different observations at different orbital phases. The figure on the right shows the RXTE and Swift lightcurve with the Chandra observations marked.

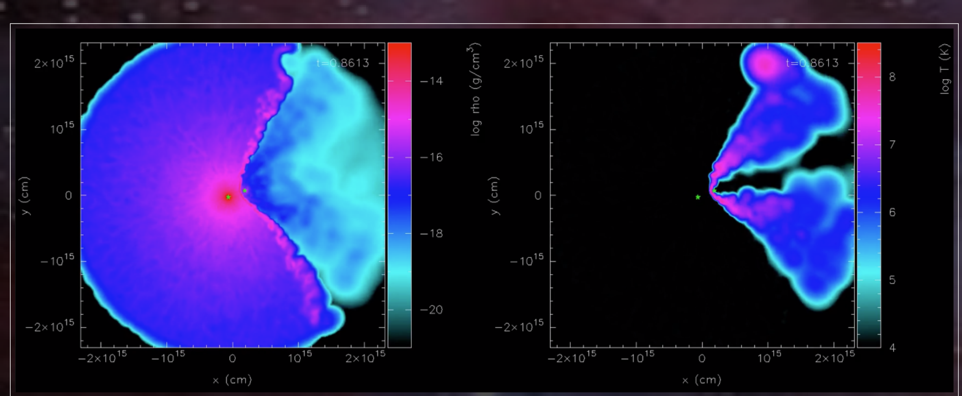




Comparing Line Profiles with Theoretical Models (PRELIMINARY!)

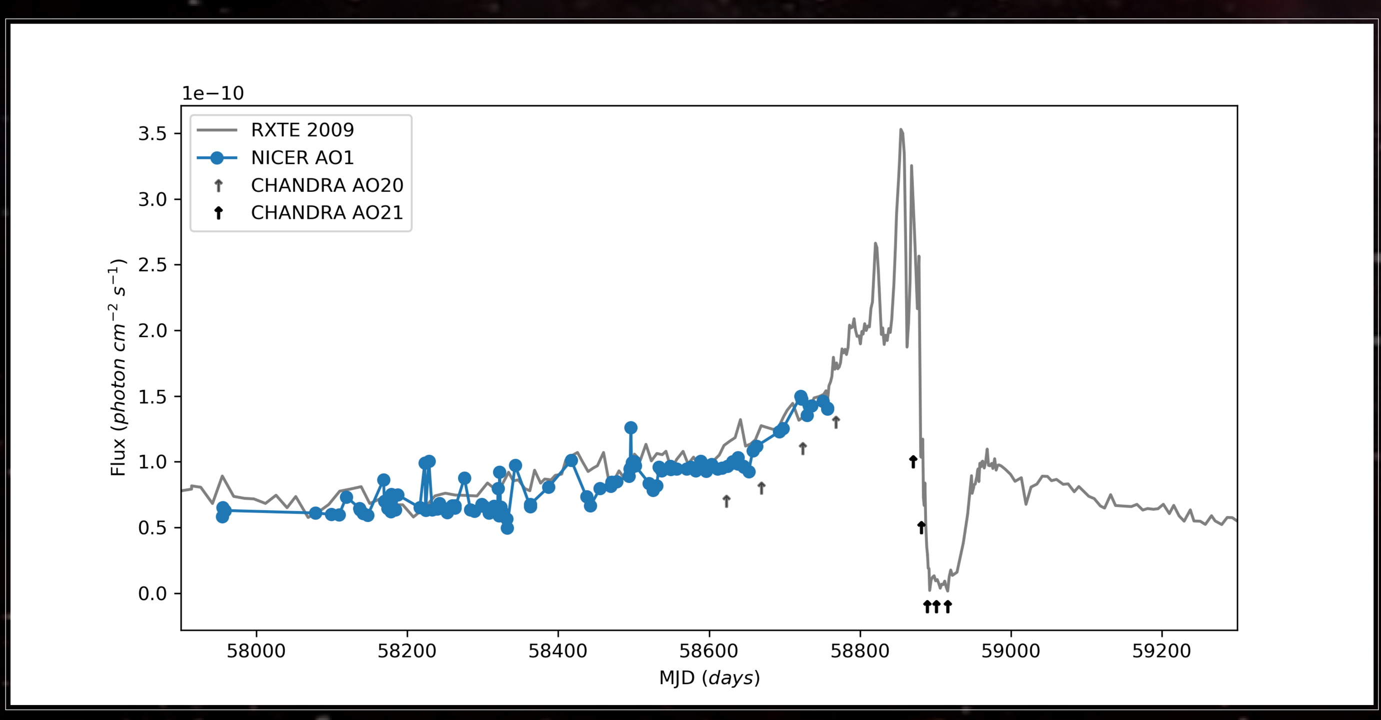
Theoretical 3-D models from Chris Russell have been used to simulate X-ray emission lines profiles that can be used to compare with η *Car*'s *Chandra* observations.





Even *NICER* Monitoring

Using *NICER* we are monitoring η *Car*'s 2–10 keV X-ray flux variation in conjunction with the new HETGS observations. This monitoring program has been used to give context to new *Chandra* observations in AO20 and will continue been used for approved observations in the next *Chandra* cycle. We also have requested continued *NICER* monitoring for the next *NICER* cycle of observations to follow η *Car*'s X-ray flux after its periastron through recovery.



Results

- We have confirmed the appearance of a blueshifted excess on the Si XIV, S XVI and Mg XII profiles
- We have identified more than 50 emission lines in η *Car*'s X-ray spectrum between 1.5 and 12Å, including ions like Ca XX, Ca XIX, Ar XVIII, Ar XVII, S XVI, S XV, Si XIV, Si XIII, Cl XVII, Mg XII, Mg XI, Fe XXIV, Fe XXV, and Fe XXVI. This is the most complete line identification for this system to date.
- Preliminary comparison with profiles generated by 3-D hydrodynamic shock models indicate that these variations can be explained by the expected variations in shock density, shape and orientation to the line of sight.
- Lines become more blueshifted and broader as the stars approach each other. Preliminary comparison with profiles generated by 3-D hydrodynamic shock models indicate that these variations can be explained by the expected variations in shock density, shape and orientation to the line of sight.

Future Work

- Continued line profile analysis to refine 3-D models and constrain changes in the mass loss with time.
- Determination of variation of temperature and density along the shock at different phases and times.
- New HETGS and ACIS non-grating observations and joint HST/STIS observations will be combined with new high-spatial/spectral imaging with VLTI/MATISSE (by G. Weigelt) and ground-based spectrometry (by A. Damineli & N. Richardson) to detail and distinguish orbital variations from non-phase dependent changes in the colliding wind shock as the stars take the plunge at periastron passage in February 2020.

References

Behar et al. 2007ApJ...666L..97B
Corcoran et al. 2001ApJ...562.1031C
Henley et al 2008ApJ...680..705H
Pittard & Corcoran 2002AA...383..636P
Russell et al. 2016 MNRAS, Volume 458, Issue 3, p.2275-2287
Russell et al. 2013 in Massive Stars: From α to Ω, held 10-14 June 2013 in Rhodes, Greece

CONTACT:
David Abraham Espinoza Galeas
84espinozagaleas@cua.edu