# XMM-Newton Observations of the 2003 X-ray Minimum of Eta Carinae

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## Abstract

The XMM-Newton X-ray observatory took part in the multi-wavelength observing campaign of the massive, evolved star Eta Carinae in 2003 during its recent X-ray minimum in June 2003. This paper reports on the first results of these observations, which were performed 1) before the minimum (five times in January, 2003), 2) near the X-ray maximum just before the minimum (two times in June) and 3) during the minimum (four times in July-August).

Hard X-ray emission from the point source of Eta Carinae was detected even during the minimum. The observed flux above 3 keV was ~$3\times10^{-12}$ ergs cm$^{-2}$ s$^{-1}$, which is about one percent of the flux before the minimum. Light curves from the individual observations show no time variability on the scale of a few kilo-seconds. Changes in the spectral shape occurred, but these changes were smaller than expected if the minimum is produced solely by an increase of hydrogen column density. Fits of the hard X-ray source by an absorbed 1T model show a constant maximum plasma temperature at around 5 keV and an increase of column density from $5\times10^{22}$ cm$^{-2}$ to $2\times10^{23}$ cm$^{-2}$. The spectra below 6 keV significantly deviate from the models that fit the higher energy emission. The X-ray minimum seems to be dominated by an apparent decrease of the emission measure, suggesting that most of the X-ray emission is completely blocked during the minimum. Partial covering plasma emission models might be considered for the spectral variation. The spectra also showed strong iron K line emission from both hot and cold gases, and weak line emission from Ni, Ca, Ar, S and Si.

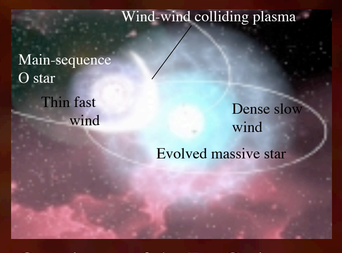
## Introduction

Earlier observations suggest:

- Eta Carinae is one of the Galaxy's most massive star.
- Eta Carinae is a binary star with a massive, hidden companion.
- Hard X-ray emission is produced in a strong bow shock when the wind from Eta Carinae collides with the wind from the companion.
- The X-ray minimum may be caused by partial or full eclipse by the wind of the primary star and/or collapse of the bow shock.

ASCA observation during the previous minimum (1997-98)

- Hard X-ray emission was observed, but $kT$, $N_H$ did not change strongly. The emission measure (*E.M.*) apparently scaled down.
- Emission during the minimum could be from unresolved nearby sources due to limited spatial resolution of ASCA.




Our picture of the Eta Carinae system

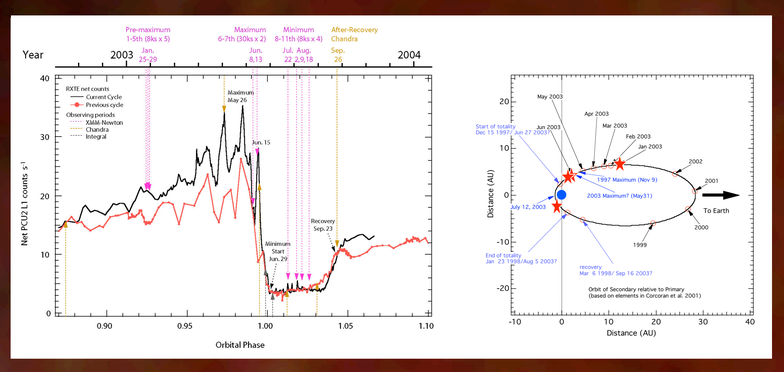
Goal of the XMM-Newton observations in this cycle

- Tracing change of spectral shape (e.g. $N_H$, $kT$).
- Studying structure and activity of the X-ray plasma and absorber.
  - For example, change of mass loss rate near the periastron phase and strength of the shock.
- Good points of XMM-Newton: large effective area, moderate spatial and spectral resolution.

## Observations

XMM-Newton made observations of Eta Carinae 11 times in 2003, two of which used TOO (Time Of Opportunity) allocation time. We greatly appreciate the XMM-Newton review committee's positive response!

Note: Here we use the word "X-ray minimum" as the interval of X-ray flux that is flat bottom in the RXTE light curve (i.e. July - mid September 2003 in this cycle).




RXTE light curve with the periods of the XMM-Newton and Chandra observations (*left*) and the periods on the binary orbit calculated by Corcoran et al. (2001) (*right*).

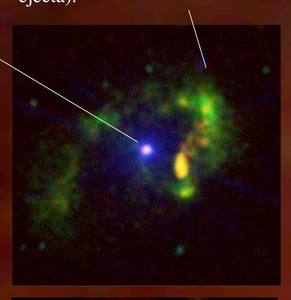
## Results

### Image

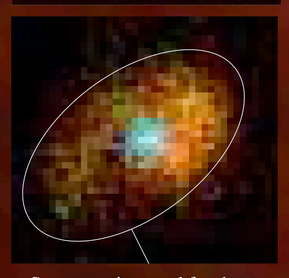
- The central point source emits hard X-rays during the minimum.
- The X-ray flux may bottom out around July 20, 2003.

Central source: embedded very hot plasma (~$5\times10^8$ K) perhaps made by wind-wind collision from both stars.

Ring: extended soft source made by the ancient wind outflow interacting with the interstellar medium (or previous ejecta).



True color image of Eta Carinae taken with Chandra.

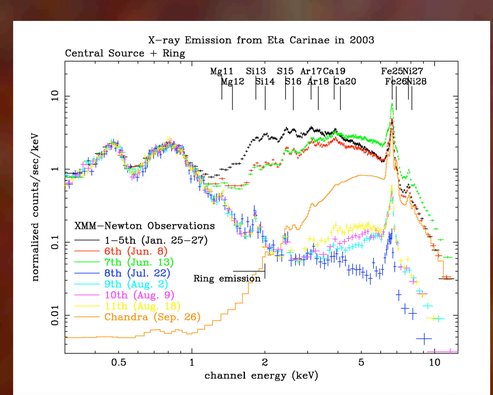


True color image taken with XMM-Newton on July 22, 2003.

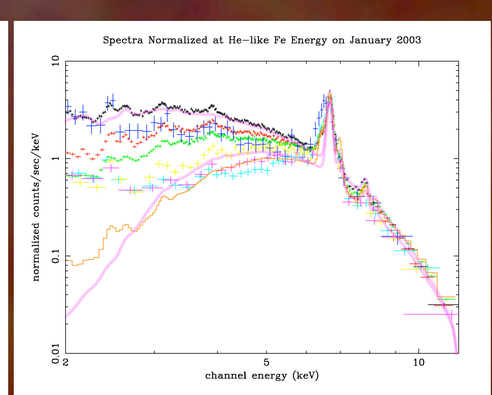
Source region used for the spectral and timing analysis.

### Spectra

- X-ray emission above 2 keV (i.e. from the central source) dramatically decreased during the minimum.
- Slope above 7 keV, which corresponds to $kT$ ~5 keV, did not change significantly.
  - The variation is more like an apparent decrease of plasma *E.M.*
  - It is similar to the feature seen in the previous cycle.
- Medium band flux (2-6 keV) gradually decreased compared with the higher energy band.
  - It corresponds to $N_H$ increasing from $5\times10^{22}$ cm$^{-2}$ to $2\times10^{23}$ cm$^{-2}$ assuming an absorbed 1-temperature model.
  - The models do not reproduce the spectral shapes well, that is, the spectra need additional components.
- Eta Carinae has at least two variable components (apparent *E.M.* decrease and $N_H$ increase).
  - The $N_H$ increase seems to be followed by the apparent *E.M.* decrease.



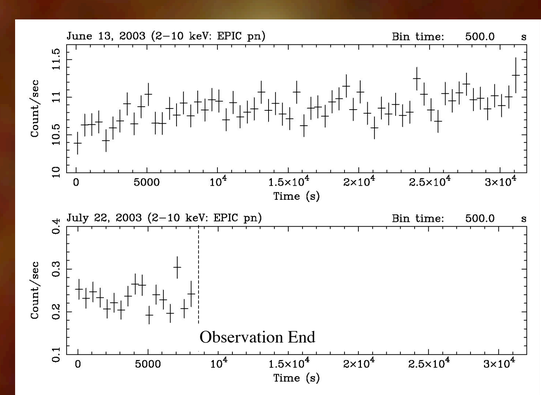

XMM-Newton EPIC pn spectra and Chandra best-fit model with EPIC pn effective area. Each spectrum shows strong Helium-like Fe line and fluorescent Fe line. It also shows Ni, Ca, Ar, S, Si and Mg lines. Hydrogen-like lines are not strong in high Z spices (Ca. Fe, Ni).




XMM-Newton spectra normalized at Helium-like Fe line intensity on January 25-29, 2003. Each color means the same as in the left panel. Pink lines represent absorbed 1T thin-thermal plasma (Mekal) models with $kT$ = 5 keV, $N_H$ = $5\times10^{22}$ cm$^{-2}$ (upper line) and =$2\times10^{23}$ cm$^{-2}$ (lower line), *E.M.* =$1.7\times10^{57}$ cm$^{-3}$ and abundance = 0.87 solar.

### Light Curve

- Hard X-ray emission (2-10 keV) before the minimum had small time variation of ~5% in ~30 ksec.
- No significant time variation in $\chi^2$-test during the minimum.
- The lack of short-timescale variability is consistent with colliding wind models.




Background subtracted EPIC pn light curves in the 2-10 keV band before the minimum (*upper panel*, June 13, 2003) and during the minimum (*lower panel*, July 22, 2003).

## Discussion

a). Spectral variation is similar to the previous cycle (Corcoran et al. 2000; Viotti et al. 2002).

⇨ The variation is periodic, supporting that Eta Carinae forms a binary system.

b). Spectral slope above 7 keV did not change significantly.

⇨ Plasma did not significantly cool down nor heat up, that is, X-ray plasma was more or less stable during the minimum.

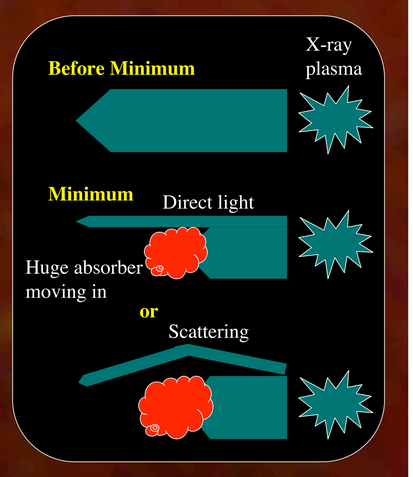
⇨ The intrinsic X-ray luminosity would not have strong variation.

⇨ Most of the X-rays would be blocked by absorber (we think thick winds from the evolved star) to explain the X-ray decrease during the minimum.

⇨ $N_H$ of the blocker should be more than ~$8\times10^{24}$ cm$^{-2}$ if X-ray emission before the minimum is absorbed more than ~99%.

c). $N_H$ increase delayed from the flux decrease.

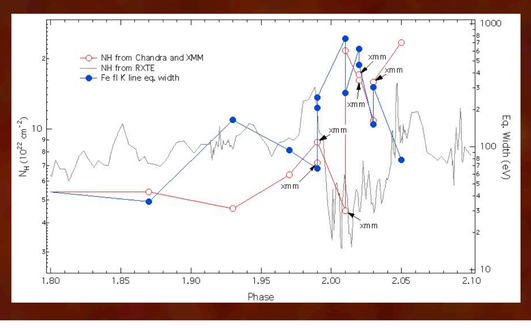
⇨ Outflow from the central source may increase during the minimum as is suggested by Corcoran et al. (2001).




Schematic view of discussion b & d.

d). What is the X-ray emission during the minimum?

- Partial Covering - Part of X-ray emission was not blocked by absorber.
  - Absorption by smooth wind: It seems difficult to keep opening area around 1-2% for ~3 months.
  - Absorption by clumpy wind: Need a simulation.
- X-ray scattering - X-ray emission is scattered off the blocker and passes through less dense region.
  - Thomson scattering: Equivalent width of Fe fluorescent line is up to ~800 eV, which is consistent with simulations of X-ray scattering (Inoue 1985).
  - Dust scattering: It is possible though hard X-rays are less scattered and dust scattering is strong forward scattered.




Absorption column density and equivalent width of Fe K fluorescent lines measured in the Chandra and XMM-Newton spectra. $N_H$ of the XMM-Newton data and Chandra has discrepancy in the applied model: XMM-Newton spectra assumes a simple absorbed 1-temperature model for the central source, while Chandra assumes a simple absorbed 2-temperature model.

## References

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