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High Energy Phenomena in Eta Carinae

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Abstract. We have investigated with BeppoSAX the long term behaviour of the harder X-ray component of the supposed supermassive binary system η Car along its 5.52 year cycle. We have found that in March 1998 during egress from the last December 1997 eclipse, this component was the same as outside eclipse, but for a large (×3.5) increase of NH_h, that can be attributed to the presence or formation of opaque matter in front of the source near periastron. Unexpectedly, at that time the iron 6.7 keV emission line was 40% stronger. BeppoSAX has for the first time found a *hard X-ray tail* extending to at least 50 keV, that cannot be adequately fitted with an additional hotter thermal component. The 2–100 keV spectrum of η Car is instead well fitted with an absorbed powerlaw spectrum with photon index 2.53, suggesting non-thermal emission as an alternative model for the core source.

Key words. Colliding winds model—non-thermal emission—stars: η Car—X-ray emission.

1. The η Car phenomenon

The X-ray spectrum of the superluminous star η Car and its time variability is providing a fundamental key for understanding the emission mechanisms in very massive stars, and for unveiling the physical nature of η Car itself. The star shows a complex X-ray spectrum consisting of at least two distinct components:

- a spatially extended softer (∼0.5 keV) thermal source ηSX associated with the nebulosities surrounding the star, and
- a very bright point-like harder component ηHX with kT_h ∼4.7 keV centred on the stellar core, that dominates the spectrum in the 2–10 keV range (e.g., Tsuboi *et al.* 1997; Corcoran *et al.* 1998, Viotti *et al.* 1998, 2002).

The thermal ηHX component is commonly interpreted with colliding wind emission in a close binary system. The model is based on Damineli's (1996) discovery of a 5.52 year periodicity in the recurrent deep excitation minima of the optical emission line spectrum. Later, Damineli *et al.* (1997) attributed this variability to a highly eccentric orbital motion of two very massive stars, the primary being an S Doradus variable (or LBV) that has a 600–1200 km s^{-1} very massive wind. Its unseen companion should be a less evolved early-type star. It was found that the two last spectroscopic minima of June 1992 and December 1997 coincided with two X-ray eclipses detected by ROSAT, ASCA, and RossiXTE (Corcoran *et al.* 1995; Ishibashi *et al.* 1999: Corcoran *et al.* 2000). According to Augusto Damineli, the next spectroscopic event (and, consequently, the next X-ray eclipse) will occur in June 2003.

BeppoSAX observed η Car in four different phases of its 5.52 year spectroscopic cycle (Φ=0.828, 1.048, 1.371 and 1.457). We have found that the X-ray temperature (4.7 keV) and the unabsorbed luminosity ($\sim 1 \times 10^{-10}$ erg cm^{-2} s^{-1}) of the 2–10 keV component, supposed to be thermal, were nearly the same, but for a large ($\times 3.5$) increase of NH_h in March 1998 during egress from the last December 1997 eclipse (Fig. 1(a)). This effect was accompained by the presence in the optical spectrum of extended P Cygni absorptions (Viotti *et al.* 2002). We have also noted that after the December 1997 minimum, the recovering in the optical spectrum was slower than in X-rays.

2. The 6.7 keV iron line

A contrasting aspect of the BeppoSAX observations is the larger flux (and equivalent width) of the 6.7 keV emission line in March 1998 when the star was still in its low spectroscopic state, while in the other three epochs this line had the same strength within the errors (Rebecchi *et al.* 2001; Figure 1). At that time the nearby continuum flux was equal to that measured by BeppoSAX in December 1996, and in January and June 2000. This result seems to be pointing out to a formation region different from that of the continuum. If so, the iron abundances derived from the standard analysis procedure should be taken as upper limits.

3. The BeppoSAX high energy tail

BeppoSAX has for the first time detected η Car above 10 keV, a nd found that the flux is in excess with respect to the 4.7 keV thermal fit of the 2–10 keV intermediate energy spectrum (Rebecchi *et al.* 2001, Viotti *et al.* 2002). The last well exposed BeppoSAX observations of June 2000 not only confirmed the high energy tail in the X-ray spectrum of η Car, but also revealed that it extends to at least 50 keV (Fig. 1(b)). We were however unable to adequately fit the high energy excess with an additional hotter thermal component. The overall spectrum can instead be well described by an absorbed power law spectrum with photon index 2.53 ± 0.03, typical of a non thermal source. Alternatively, one might consider that the point source has a large temperature stratification. In this regard, we recall that the most recent CHANDRA observations have also suggested that the hot gas near η Car is not isothermal (Corcoran *et al.* 2001).

A further interesting feature is the possible weakening of the high energy tail in March 1998, when no PDS countrate above the background was detected (Rebecchi *et al.* 2001).

We remind that no present or planned future satellite will be able to observe η Car above 10 keV with the BeppoSAX sensitivity. In particular, η Car will be probably rather weak for INTEGRAL, though we expect a positive detection above 100 keV. Hence, BeppoSAX has been a unique opportunity to observe this source in this most crucial energy range.

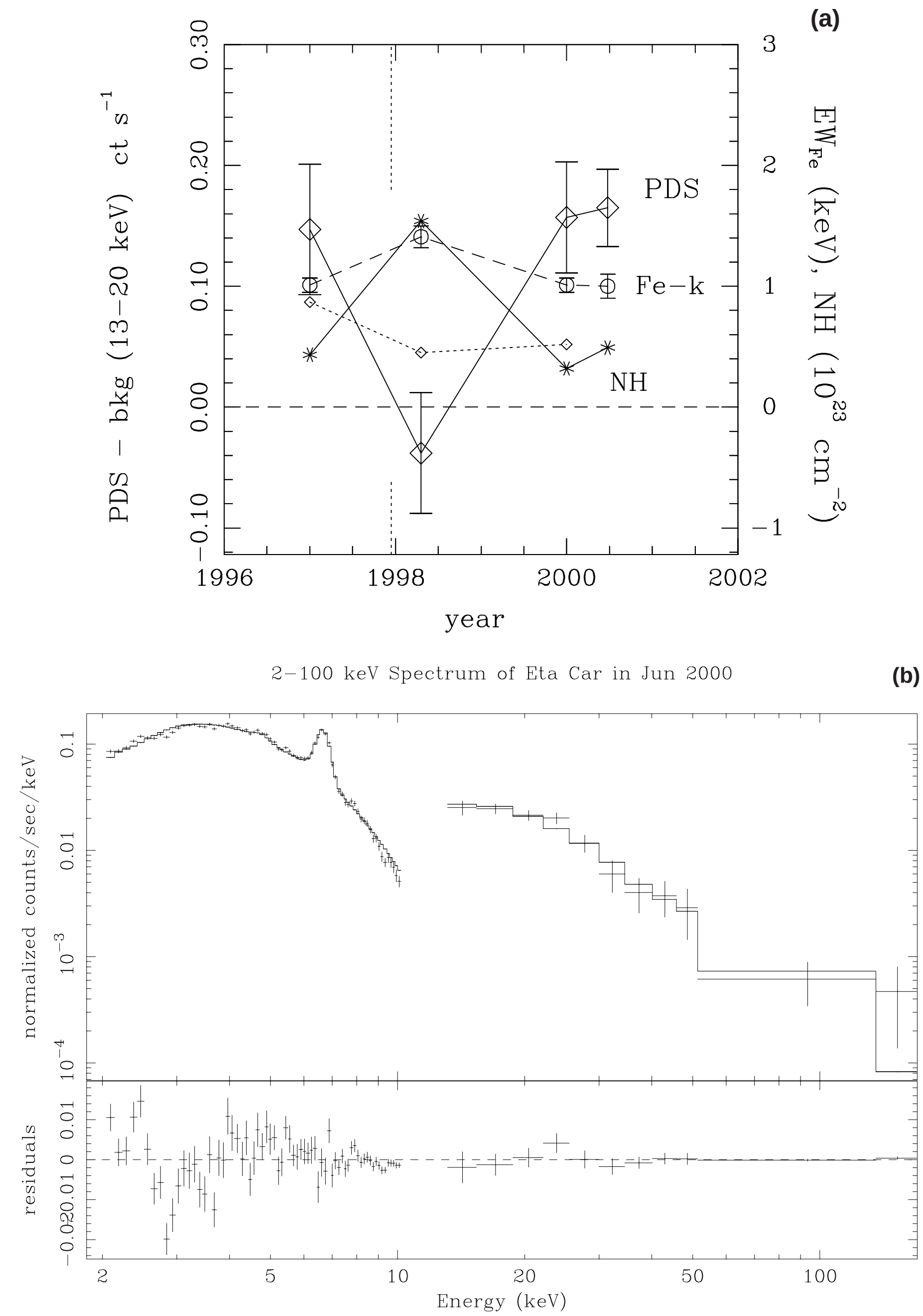

Figure 1. BeppoSAX observations of η Car. **(a)** Time variation of the 13–20 keV countrate (PDS, s^{-1}), the 6.7 keV–line equivalent width (in keV, dashed line), and the H I column density (in 10^{23} cm^{-2}) during the four BeppoSAX observations. The expected PDS countrate extrapolated from the 4.7 keV intermediate energy spectrum is shown for comparison (dotted line). The vertical lines mark the December 1997 minimum. **(b)** The 2–100 keV (MECS+PDS) countrates in June 2000 fitted with a powerlaw (ν=2.53).

4. A zero-order interpretation

In principle, the high temperature of the core X-ray emission of η Car can be explained by winds' collision from two gravitationally bounded stars – one being an early-type massive star with a high velocity wind, and the other one an S Doradus-type variable (or LBV) with a 600–1200 km s^{-1} very massive wind (Viotti *et al.* 1989). The model would imply a gradual increase of the X-ray flux when the stars approach periastron, which however is only marginally supported by the RossiXTE observations. One needs to introduce an additional process to explain the X-ray flux minimum, e.g., a large absorption by matter present around the stars near periastron. The peculiar behaviour of the iron line observed by the ASCA and BeppoSAX observations near the 1997–1998 eclipse, and the future observations of the next June 2003 eclipse may solve the problem with the use of a more detailed model, also based on the observations in other frequency bands.

Even more intriguing are the results of the BeppoSAX 10–100 keV observations of η Car, that seem to disprove the thermal emission model currently proposed for the 2–10 keV spectrum (which actually is the hard energy band covered by most of the X-ray satellites that have pointed η Car). In this regard, a crucial test should be provided by the future INTEGRAL observations, which will be, or will not be able to trace the spectrum of η Car beyond 100 keV, and to look whether the power spectrum extends to higher energies. At any rate, the constancy of the 10–20 keV flux during three different phases of the 5.52 years cycle is difficult to reconcile with current colliding-wind models. Multifrequency observations of the next event of June 2003 will be of the highest scientific interest.

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