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FAST OSCILLATIONS IN THE X-RAY LIGHT CURVE OF η CARINAE

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RESUMEN

η Carinae es un sistema binario formado por dos estrellas masivas, que pierden masa a través de fuertes vientos. La interacción entre los vientos origina choques que elevan la temperatura del plasma a 10^{6-8} K, produciendo rayos X. A pesar de que la forma general de la curva de luz puede ser explicada por la alta excentricidad de la órbita, y es usada para calcular el valor de la misma, las oscilaciones cortas y casi-periodicas no han podido ser explicadas hasta ahora. En nuestro trabajo proponemos que ellas son producidas por la precesión y nutación del eje de rotación de η Carinae, que no es perpendicular al plano de la órbita. Como la tasa de pérdida de masa y la velocidad del viento dependen de la latitud, la intensidad de los rayos X será una función de la latitud a la cual la superficie de la estrella intercepta el plano de la órbita. Suponiendo que el ángulo entre el eje de rotación y la perpendicular al plano de la órbita es de 30°, la amplitud de la nutación aproximadamente 5° y el periodo de nutación 22 días, conseguimos reproducir muy bien la curva de luz en rayos X.

ABSTRACT

η Carinae is a binary system formed by two massive stars, loosing mass through strong winds. The wind-wind interactions originate shocks that rise the plasma temperature to 10^{6-8} K, producing X-ray emission. Although the overall shape of the light curve can be explained and it is used to calculate the orbital eccentricity, the observed short quasi-periodic oscillations have not been explained yet. In our work we propose that these oscillations are produced by the nutation of the rotation axis of η Carinae, which is not be perpendicular to the orbital plane. Since in η Carinae, both the mass loss rate and the wind velocity are latitude dependent, the intensity of the emitted X-rays will be a function of the latitude at which the stellar surface intercepts the orbital plane. By assuming an angle of about 30° between the rotation axis and the perpendicular to the orbital plane, an nutation amplitude of about 5° and a nutation period of 22 days, we were able to reproduce very well the observed X-ray light curve.

Key Words: stars: binaries — stars: individual (**η** Carinae) — stars: winds, outflows

1. INTRODUCTION

The 2–10 keV emission of η Carinae was monitored by the *Rossi X-Ray Timing Explorer XRTE* since 1996, covering two minima in the periodic 5.52 year light curve (Corcoran 2005). During most of the orbital period, the X-ray intensity was modulated by low amplitude quasi-periodic flares, and the large flux increase that occurred before the minima was enhanced by short duration flares. Abraham & Falceta-Gonçalves (2007) showed that the rotation axis of η Carinae probably does not coincide with the axis of the orbital plane. Therefore, the torques induced by the companion star on η Carinae might produce the precession and nutation of its rotation axis, and the X-ray flux produced by wind-wind collision could be modulated because the wind velocity and mass loss rate of η Carinae are latitude dependent (Smith 2002).

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2. THE X-RAY MODEL

The X-ray flux density produced by the shock heated gas is a function of the orbital phase θ_s, and can be written as (Usov 1992):

$$F_X(\theta_s) = \frac{8\times10^{34}}{4\pi d^2 D}\frac{\dot{M}_p{}^{1/2}}{V_p{}^{5/2}}(\dot{M}_s V_s)^{3/2} e^{-\tau(\theta_s)}\,, \quad (1)$$

where d is the distance to η Carinae, taken as 2.3 kpc, $\tau(\theta_s)$ the optical depth for X-ray absorption, $\dot{M}_p$ and $\dot{M}_s$ are the mass loss rates of η Carinae and the companion star, expressed in units of 10^{-5} and 10^{-6} $M_\odot$ yr^{-1} respectively, V_p and V_s their respective wind velocities, in units of km s^{-1}, and D the separation between them, in units of 10^{13} cm. We assumed that $\dot{M}_s$ and V_s have constant values, but $\dot{M}_p$ and V_p depend on the latitude $\lambda\,(\theta_s)$ at which the orbital plane intercepts the side of η Carinae that faces

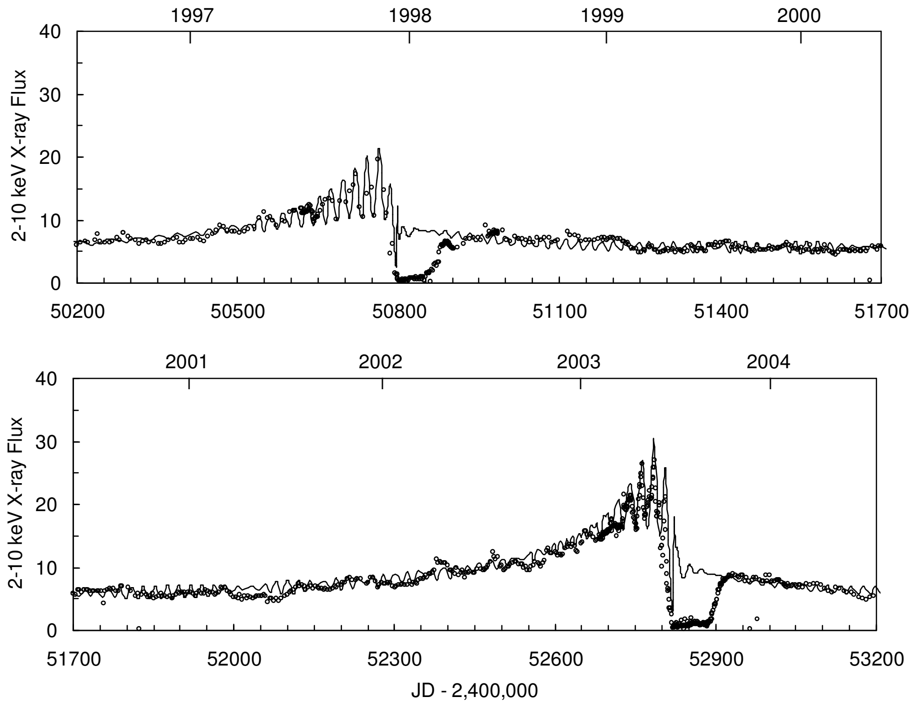

Fig. 1. Observed $2-10$ keV X-ray flux obtained from Corcoran(2005) shown as open circles, and best fitting model (continuous line), in which only photoelectric X-ray absorption by the wind of η Carinae intercepting the line of sight was considered.

the secondary star; we used for $\dot{M}_p(\lambda)$ and $V_p(\lambda)$ the expressions derived by Dwarkadas & Owoki (2002), for the case in which the rotation velocity is close to its critical value:

$$\dot{M}(\lambda) = \dot{M}(90°)\left[1-\Omega^2\cos^2\lambda\right], \quad (2)$$

$$V(\lambda) = V(90°)\left[1-\Omega^2\cos^2\lambda\right]^{1/2}, \quad (3)$$

with $\Omega = \omega/\omega_c$ and $\omega_c = (GM_p/R_p^3)^{1/2}$; G is the gravitational constant; M_p and R_p are the mass and radius of η Carinae, respectively. These expressions were already used to reproduce the observed wind velocity as a function of latitude in η Carinae, as well as the shape of the Homunculus nebula (Smith 2002; Dwarkadas & Owoki 2002).

The value of λ depends both on the orbital phase θ_s and on the angle φ that the rotation axis forms with the perpendicular to the orbital plane. We will assume that the rotation axis precesses around the orbital axis with period P_p, and also presents nodding motions, with amplitude $\Delta\varphi$ and period P_n.

3. RESULTS AND DISCUSSION

We used equations (1-3) to model the X-ray light curve of η Carinae, with the orbital parameters obtained by Abraham et al. (2005) from the 7-mm light curve observed close to the 2003.5 minimum: eccentricity $e = 0.95$, epoch and orbital angle at conjunction: June 29, 2003 (JD=2,454,819), $\theta_0 = -45°$, repectively, and orbital period $P_{\rm orb} = 2024$ days (Corcoran 2005). The parameters that gave the best qualitative fit to the general behavior of the complete light curve and to the amplitude and period of the oscillations close to the minima (see Figure 1) are: inclination of the rotation axis $\varphi = 29° \pm 4°$, nutation amplitude $\Delta\varphi = 4.^{\circ}5 \pm 0.^{\circ}5$, nutation period $P_n = 22.45 \pm 0.04$ days, precession period $P_p = 274 \pm 30$ years, $\Omega = 0.9745 \pm 0.0005$. From the inclination axis of η Carinae we estimated that, relative to the observer, the orbit has an inclination $i \sim 45° - 60°$, for $\eta = \dot{M}_s V_s/\dot{M}_p V_p$ varying between 0.2 and 0.1 (Abraham & Falceta-Gonçalves 2007).

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