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η CARINAE: THE NATURE OF THE 5.54-YR CYCLE

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RESUMEN

Los eventos de baja excitación en eta Carinae son conocidos desde hace más de cien años, pero nunca han sido completamente caracterizados. Hemos derivado el período de aquellos, $P_{pres} = 2022.7 \pm 1.3$ d, y mostramos que el mismo no puede haber cambiado por más de $\Delta P/P = 0.0007$ durante los últimos 60 años. Esto otorga una base fuerte para el escenario de binaridad. El así llamado evento de baja excitación es gobernado por el paso del periastro, cuando la estrella secundaria está profundamente inmersa en el viento de la primaria. Mostramos que los eventos en las líneas de excitación intensas están provocados por un blanketing en el campo de radiación de la estrella secundaria (la fuente ionizante). Descartamos la mayoría de los mecanismos propuestos previamente, tales como eyección del shell, colapso de la colisión viento-viento, o eclipse. Mostramos una serie de curvas de luz, ejemplificando las peculiaridades de cada rasgo, útil para planear campañas de monitoreo para el próximo mínimo, predicho a iniciarse el 11 de enero de 2009.

ABSTRACT

The low excitation events in eta Carinae are known for more than a century, but never fully described. We derived from different features the period $P_{pres} = 2022.7 \pm 1.3$ d, and show that it can't have been changing by more than $\Delta P/P = 0.0007$ over the last 60 years. This gives a strong support to the binary scenario. The so called low excitation event is driven by periastron passage, when the secondary star is deeply immersed in the wind of the primary. We show that the events in the high excitation lines are produced by a blanketing on the radiation field of the secondary star (the ionizing source). We rule out most of the previously proposed mechanisms: such as shell ejection, collapse of the wind-wind collision or eclipse. We show a sample of light curves, exemplifying the peculiarities of each feature, useful for planning monitoring campaigns for the next minimum, predicted to start on 2009/January/11.

Key Words: binaries: general — stars: individual (Eta Carinae)

1. INTRODUCTION

The high excitation lines ([Ne III], [Ar III], [S III] and [Fe III]) showed up in the spectrum 60 years ago. The narrow lines (forbidden and permitted) are emitted in the Weigelt blobs, at $\sim 0\farcs3$ and powered by the hot (T> 33000K) secondary companion. The broad permitted lines are formed in the wind of the primary star.

The high excitation lines disappeared briefly from the spectrum in several occasions, but was attributed to S Doradus incoherent oscillations. Damineli (1996) discovered that they were strictly periodic and Damineli, Conti, & Lopes (1997) proposed a binary model composed of two massive and evolved stars. The primary is the more luminous and colder (T$\sim$ 18000 K), responsible for the broad lines of low and intermediate excitation. The secondary companion would be hotter, responsible for the high excitation variable lines, and should be less luminous (and less massive), as it leaves no imprints in the observed spectrum. The orbit would be very eccentric (e>0.65), and, since the stars are evolve massive objects, there should be a strong wind-wind collision (WWC). Although there is no currently uncontested model this scenario has proved a framework for understanding the star and provided guidelines for fruitful observations.

A very dense X-ray monitoring campaign was started in 1996 with the RXTE satellite and revealed deep minima in 1997.95 and 2003.49 which coincided with the minima seen at other wavelengths (Corcoran 2005). X-ray observations inside and outside the minimum performed with Chandra and XMM furnished details on the column density ($N_{\rm H}$) too, and temperature and chemical composition of the colliding wind shock (Hamaguchi et al. 2007). Although the events have demonstrated to contain fundamental information about eta Carinae, their phenomenology has never been fully described.

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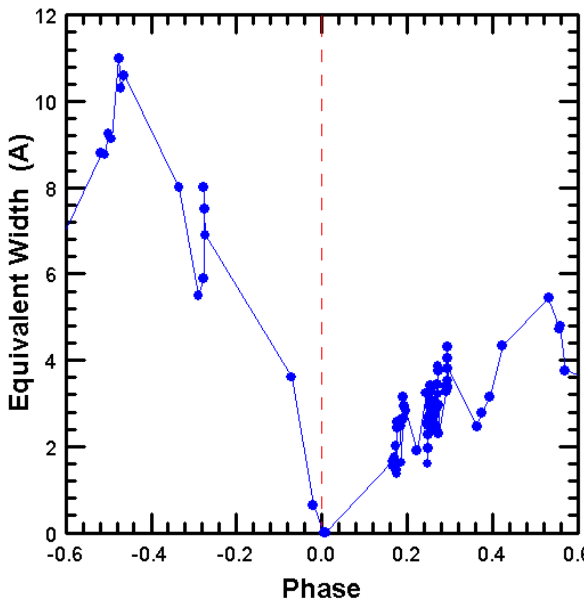

Fig. 1. Line intensities of [Ne III] 3868 Å showing that variations occur along all the 5.5-yr cycle. This rules out any mechanism for the events driven by (or resticted to) periastron passage, like shell ejection, wind-wind collapse or eclipse.

We label the events by numbers following Groh & Damineli (2005): number one (#1) is assigned to event observed in 1948 by Gaviola, so that the event of 2003.49 is #11. We call *cycle* #1 the time interval between the starting of two consecutive minima, so that cycle #9 started at the 1992.42 minimum and finished when cycle #10 was starting in 1997.95. Because of observational reasons, the starting point of a cycle is defined by the disappearance of He I λ 6678 Å narrow component. With this definition, phases along the cycle are defined in a unique way for all measured quantities.

2. RESULTS

The main results of our work are:

1. The period length derived from all spectral features - X-rays, optical photometry, JHKL photometry, radio cm and mm flux, equivalent width of forbidden and permitted emission lines, P Cygni absorption components and radial velocity curve of emission lines are in good agreement, ranging from 2026 to 2021 days.

2. The present day period is $P_{pres} = 2022.7 \pm 1.3$ d or $P_{pres} = 5.538 \pm 0.004$ yr.

3. The average period along the last 60 years is: $P_{avg} = 2020 \pm 4$ d.

4. The period length cannot have changed by more than 0.1% along the last 60 years, giving strong support to the binary scenario.

5. The phase zero of the cycle is defined by the disappearance of the narrow component of He I lines: JD = 2452819.8.

6. The epoch of the minimum is different for different features, spanning a range of few days before phase zero up to a month after phase zero.

7. The fact that the event is seen from different directions: our line-of-sight, the Weigelt blobs, FOS4 position near the pole of the Homunculus, and the ionized gas in the Little Homunculus caps, rules out that the event is driven by an eclipse.

8. The fact that the event encompasses the whole cycle, as the case of high excitation forbidden lines, and radio flux, rules out any mechanism for the event that is confined to periastron passage, like shell ejection, collapsing of the wind-wind shock or eclipse.

9. The date JD = 2452850, which is 30 days after phase zero and almost in the middle of the X-ray minimum, shows a remarkable coincidence of maximum column density ($N_{\rm H}$), maximum depth of H-α P Cygni absorption, and minimum in the Fe II 8490 Å line. This could be the epoch of periastron passage or alternatively, the opposition of the secondary star.

10. The He I 10830 Å line shows a deep P Cygni profile during the minimum, reaching speeds up to -1400 km s^{-1}. It is not clear if such high velocities are from the wind of the primary or from the secondary star.

11. The radial velocity curves of permitted emission lines, Pa-γ, He I 6678, He II 4686 and Si XIV Ly-α, show a well behaved pattern: the higher the excitation energy, the larger is the variance of the speeds. Since the speed is higher for the higher excitations, the RV curves do not represent directly either the orbital motion nor the speeds along the walls of the shock cone. They may represent speeds perpendicular to the walls of the cone shock.

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DISCUSSION

Z. Abraham - The light curve of the high ionization lines in the Weigert blobs is very similar to that at 7 mm. The slow rise can be interpreted as due to the time needed to re-ionize the gas in the dense blobs.
A. Damineli - Since the time delay for the recovering phase of the event is proportional to the ionization energy and not to the critical density of the forbidden line. In this way the behavior is a signature from the ionizing source, not from the reprocessed gas.

Tony developing some new steps in hip-hop dancing.