A&A 493, 1093–1097 (2009)
DOI: 10.1051/0004-6361:200810700

Astronomy & Astrophysics

Long-term optical monitoring of η Carinae★ *(Research Note)*

Multiband light curves for a complete orbital period

E. Fernández-Lajús[1,2,3], C. Fariña[1,2,3], A. F. Torres[1,2,3], M. A. Schwartz[1], N. Salerno[1], J. P. Calderón[1], C. von Essen[1], L. M. Calcaferro[1], F. Giudici[1], C. Llinares[4], and V. Niemela[5]

[1] Facultad de Ciencias Astronómicas y Geofísicas (FCAG) - Universidad Nacional de La Plata (UNLP) Observatorio Astronómico, Paseo del Bosque S/N, 1900 La Plata, Argentina
e-mail: eflajus@fcaglp.unlp.edu.ar
[2] Instituto de Astrofísica de La Plata (CONICET-UNLP), Argentina
[3] Fellow of CONICET, Argentina
[4] Astrophysical Institute Potsdam, An der Sternwarte 16, Germany
[5] In Memoriam (1936–2006)

Received 29 July 2008 / Accepted 30 October 2008

ABSTRACT

Context. The periodicity of 5.5 years for some observational events occurring in η Carinae manifests itself across a large wavelength range and has been associated with its binary nature. These events are supposed to occur when the binary components are close to periastron. To detect the previous periastron passage of η Car in 2003, we started an intensive, ground-based, optical, photometric observing campaign.

Aims. We continued observing the object to monitor its photometric behavior and variability across the entire orbital cycle.

Methods. Our observation program consisted of daily differential photometry from CCD images, which were acquired using a 0.8 m telescope and a standard *BVRI* filter set at La Plata Observatory. The photometry includes the central object and the surrounding Homunculus nebula.

Results. We present up-to-date results of our observing program, including homogeneous photometric data collected between 2003 and 2008. Our observations demonstrated that η Car has continued increasing in brightness at a constant rate since 1998. In 2006, it reached its brightest magnitude ($V \sim 4.7$) since about 1860. The object then suddenly reverted its brightening trend, fading to $V = 5.0$ at the beginning of 2007, and has maintained a quite steady state since then. We continue the photometric monitoring of η Car in anticipation of the next "periastron passage", predicted to occur at the beginning of 2009.

Conclusions.

Key words. stars: circumstellar matter – stars: variables: general – stars: individual: η Carinae – techniques: photometric

1. Introduction

η Carinae is the brightest ($V \sim 5$) Luminous Blue Variable star in the sky. The central object is surrounded by a nebulosity, a product of the mass ejection that occurred during the *"Great Eruption"* in the first half of the 19th century. It consists of a 18″ long axis bipolar reflection nebula, which was called "Homunculus" by Gaviola (1950).

The central star is suspected to be a binary system as first proposed by Damineli et al. (1997), from the evidence of the 5.5 years periodicity of the "spectroscopic events". These events consist of the attenuation or complete disappearance of high excitation lines (Damineli 1996; Damineli et al. 2000).

The most recent "spectroscopic event" occurred in 2003.5 and, for that reason, η Car was the target of an intensive multiwavelength observational campaign. Clear dips were registered in X-ray luminosity (Corcoran 2005), near-infrared *JHKL* photometry (Whitelock et al. 2004), and 7-mm (Abraham et al. 2005) and 3-cm wave emission (Duncan & White 2003). In the optical range, we carried out a multicolor CCD monitoring of η Car. Our observations started in January 2003, and we detected a minimum in the four *BVRI* bands (Fernández Lajús et al. 2003, hereafter Paper I), more than a week after detecting a minimun in X-ray luminosity. These sudden brightness fadings are occasionally referred to as "eclipse-like" events (e.g. Whitelock et al. 2004), and are explained well by a close binary scenario, in which the hot secondary star moves in a highly eccentric orbit of period 2022.7 days (Damineli et al. 2008b). Many of these events are supposed to be produced during periastron passages (Damineli et al. 1997) and extend over only a few months due to the high orbital eccentricity. Nevertheless, some other features vary continuously throughout the complete cycle (e.g. Duncan & White 2003; Damineli et al. 2008a).

Following the 2003 observing campaign, we continued monitoring the photometric behavior during the complete orbital period, including the upcoming "eclipse-like" event, predicted for next January 2009. It is worth emphasizing the significant advantage of the daily availability of a telescope of the

★ Full Table 2 and Table 3 are only available in electronic form at the CDS via anonymous ftp to
cdsarc.u-strasbg.fr (130.79.128.5) or via
http://cdsweb.u-strasbg.fr/cgi-bin/qcat?J/A+A/493/1093

Table 1. Dates and Julian Day Numbers of the beginning and end of our annual η Car observing seasons.

Observing	Start		End	
season	date	JDN	date	JDN
2003[†]	Jan. 17, 2003	2 452 656	Aug. 29, 2003	2 452 881
2004	Nov. 14, 2003	2 452 957	Aug. 27, 2004	2 453 244
2005	Nov. 17, 2004	2 453 326	Aug. 30, 2005	2 453 612
2006	Nov. 16, 2005	2 453 690	Aug. 28, 2006	2 453 976
2007	Nov. 13, 2006	2 454 052	Aug. 31, 2007	2 454 344
2008	Nov. 23, 2007	2 454 428	Aug. 31, 2008	2 454 710

(†) Photometric data already published in Paper I.

appropriate size, and retaining the same instrumental configuration (i.e. "telescope + filter-set + detector"). This is a desirable factor when high-precision is sought in long-term ground-based photometric monitoring of η Car (Sterken et al. 2001, and references therein).

In this paper, we present the results of our long-term *BVRI* CCD differential photometry of η Car, performed between 2003 and 2008, covering the entire orbital period.

2. Observations

2.1. Images acquisition

Our observing program consists of the daily acquisition of digital images (weather permitting) during the annual observational seasons. Each season starts in the middle of November of the preceding year and finishes at the end of August (for details see Table 1). Observing seasons are separated by gaps of about 75 days, when the η Car position in the sky was beyond the telescope pointing limits or the airmass exceeded reasonable values. Image acquisition was performed using a CCD camera mounted on the 0.8 m "Virpi S. Niemela" (VSN) telescope (f/20.06 Cassegrain), with a Johnson-Cousins *BVRI* filter set, at La Plata Observatory[1], Argentina. The *BVRI* passbands used were those recommended by Bessell (1990) for coated CCDs. The camera is a Photometrics STAR I containing a Thomson TH7883PS coated scientific-grade, front-illuminated CCD chip. The chip array is 384 × 576 pixels (23 μm square pixel), giving $1\farcm9 \times 2\farcm8$ field images at the telescope focal plane, the scale being $0\farcs296$ per pixel. In Fig. 1, a typical frame is shown, in which the main stars employed for the photometry are identified. HDE303308 (V = 8.15), located at about 1′ NNE of η Car, is used as comparison star. CPD-59 2627 (=Tr16-3[2], V = 10.11) and CPD-59 2628 (=Tr16-1, V = 9.56) are considered to check the η Car photometry. The nearby stars Tr16-64 (V = 10.72), Tr16-65 (V = 11.09), and Tr16-66 (V = 11.98), located about 15″–20″ from the center of η Car are also labeled in the figure.

Every night, a series of images were acquired during a time interval of no longer than 30 min, for each filter. Each series comprised typically of about 10 or more images. In this way, more than 23 000 images of η Car were obtained using B, V, R, and I filters during the 2004 to 2008 observing seasons, consisting of more than 26 000 images since the beginning of the campaign in January 2003. Whenever possible, bias, dark, and flat-field frames were acquired. However, since calibration images were not available for all nights of the campaign, in this work we used only uncalibrated science frames.

[1] La Plata Observatory belongs to FCAG-UNLP.

[2] Following the nomenclature of Feinstein et al. (1973).

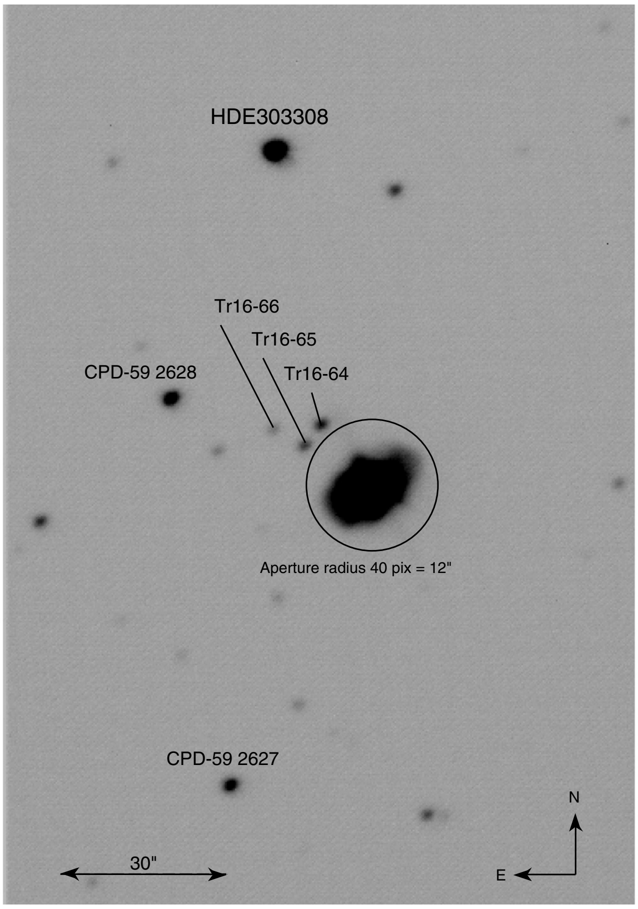

Fig. 1. One of our V images of the η Car frame. The location of the comparison star HDE303308 and checking stars CPD-59 2628 and CPD-59 2627 are indicated, as those faint but very near stars Tr16-64, Tr16-65 and Tr16-66. The figure also depicts the 40 pix = 12″ radius aperture considered to extract the instrumental magnitudes of η Car.

2.2. Data reduction

Instrumental magnitudes of each star were determined by means of aperture photometry. After Paper I, a new image-processing pipeline was written to complete aperture photometry for the brightest stars detected in our η Car CCD frame. This pipeline was developed by using the IRAF[3] command language and other tasks such as the APPHOT photometry package. With this tool, we proceeded to measure the images acquired during the entire campaign, including those of the 2003 observing season.

We fixed the aperture radius at 40 pix = 12″ to extract the instrumental magnitude of η Car and ensure that we measured both the integrated flux of the central object and the major part of the Homunculus nebula. This aperture also avoids the contribution of light from the neighboring stars Tr16-64, Tr16-65, and Tr16-66 (see Fig. 1). After the instrumental magnitudes had been obtained, we calculated differential magnitudes relative to HDE303308. This object was selected because it was the nearest bright star to η Car and constant in brightness (Sterken et al. 2001; Freyhammer et al. 2001). We used the same aperture for η Car as for HDE303308, as changes in the size or shape of the stellar intensity profiles (due to turbulence, bad focus, or tracking failure) might introduce spurious magnitude variations.

[3] IRAF is distributed by the NOAO, operated by the AURA, Inc, under cooperative agreement with the NSF, USA.

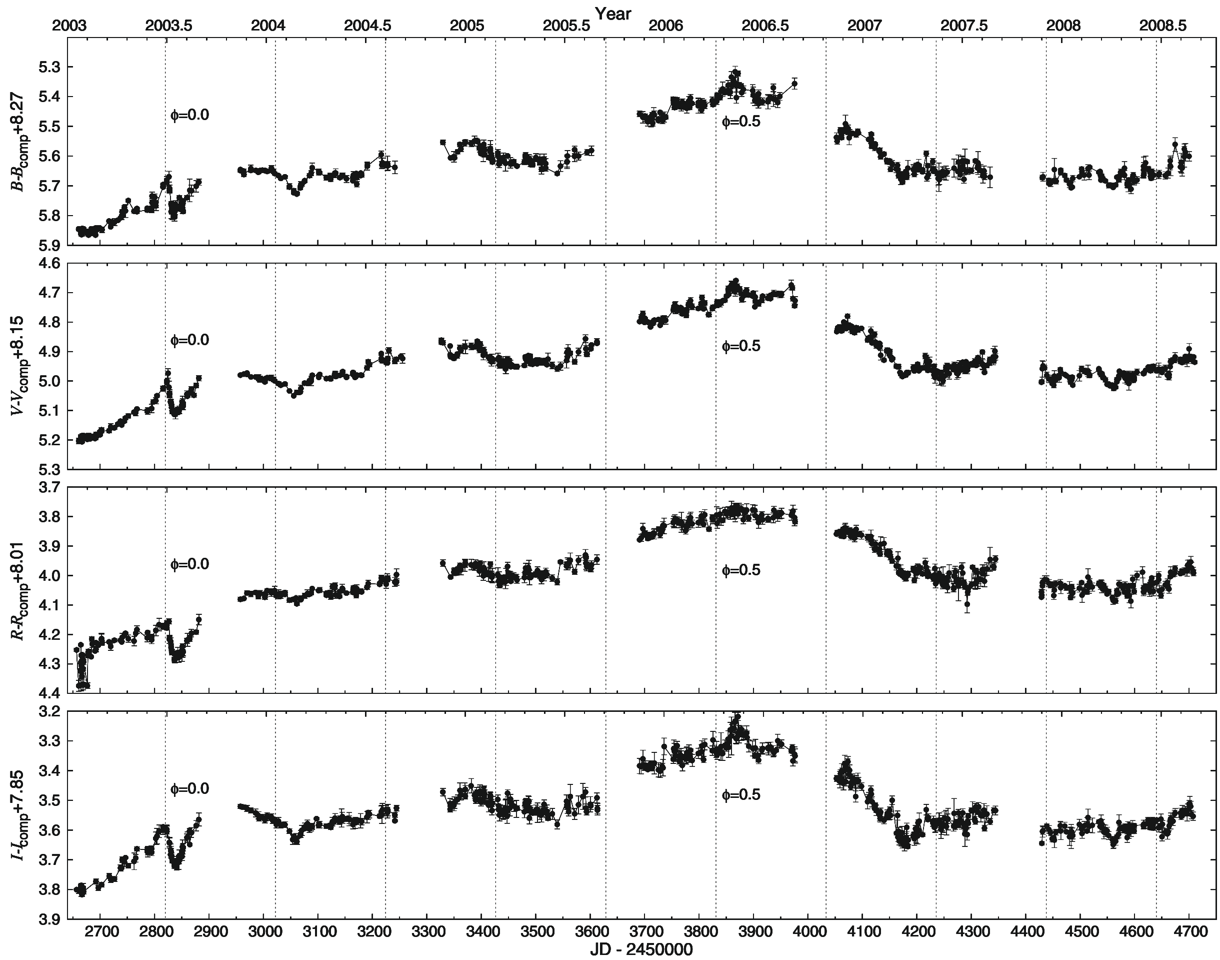

Fig. 2. *BVRI* light curves of η Car observed between January 17, 2003 and August 31, 2008. The photometric values of HDE303308 taken from Feinstein (1982) are used as zeropoints. Bars represent the standard deviations of the mean values. The vertical grid indicates the orbital phases in steps of 0.1, according to the ephemeris given by Damineli et al. (2008b). Phases ϕ = 0.0 and ϕ = 0.5 are labeled. The different annual observing seasons are clearly delimited by gaps.

We computed the mean differential magnitudes of η Car to be the weighted average of the relative magnitudes measured in each image belonging to the same series. The weights used for these averages were derived from the errors in individual measurements for each image. A 2σ (σ = std dev) rejection criteria was then applied, and revised mean values were calculated. The light curves were constructed from these mean values, and their standard deviations were adopted as a measure of the errors (ϵ). The averaged errors of our differential photometry were: $\epsilon_B = \pm 0.010$, $\epsilon_V = \pm 0.007$, $\epsilon_R = \pm 0.012$, and $\epsilon_I = \pm 0.015$ mag.

To obtain a homogeneous data set for the entire campaign, we measured again all images taken during the 2003 observing season, using the aperture size mentioned above. We compared these results with those published in Paper I, which were extracted using a larger aperture radius i.e. 75 pix = 22″. An excellent correlation between both data sets was verified. Nevertheless, in further analysis, we considered the small aperture to be the superior choice, because it eliminates any contamination from the neighboring stars, and reduces the background noise that would be introduced by a larger aperture. Furthermore, to estimate the seeing for each image, we measured the *FWHM* of the stellar profile of HDE303308. A typical *FWHM* for the entire campaign was about 3″.

The procedure for determining the mean differential magnitudes of the check stars relative to HDE303308 was exactly the same as described above for η Car, apart from that a smaller aperture radius (10 pix = 3″ ~ 1 *FWHM*) was considered for extracting the instrumental magnitudes. Since images of both stars were always underexposed because the exposure times were optimized for the light flux of η Car, we chose this aperture to maximize the signal-to-noise ratio.

The check star CPD-59 2627 has exhibited an almost constant flux throughout the entire campaign, in agreement with the results of Freyhammer et al. (2001). The other check star, CPD-59 2628, is an eclipsing binary (cf. Freyhammer et al. 2001), for which we reproduced a light curve quite accurately. For this star, we also developed a numerical eclipsing-binary model using the Wilson-Devinney Code (e.g. Wilson & Van Hamme 2004, and references therein). The difference (O−C) between our observational data and the model provides us with a control tool for the η Car photometry. The standard deviation of these differences is about 0.02 mag in all bands.

3. Results

In Fig. 2, we show the light curves resulting from our *BVRI* differential photometry of η Car during the 2004−2008 observing seasons. For completeness, we also include the 2003 observing season data. In this figure, we have used as zeropoints the *UBVRI* Johnson-Kron-Cousins photometry of HDE303308

Table 2. Relevant data of our *BVRI* differential photometry of η Car against HDE303308. This is an extract of the electronic table, where we list the Julian Date (JD), the band (Bd), the mean differential magnitude (Δm), and the rms error (ϵ) of η Car, CPD-59 2627, and CPD-59 2628, the full width half maximum of HDE303308 (*FWHM*), and the number of images considered in deriving the mean values (n).

		η Car		CPD-59 2627		CPD-59 2628		HDE303308	
JD	Bd	Δm	ϵ	Δm	ϵ	Δm	ϵ	*FWHM* ($''$)	n
2 454 311.4378	*B*	–2.630	0.015	2.019	0.071	1.342	0.014	3.5	10
2 453 601.4763	*V*	–3.259	0.004	1.965	0.007	1.334	0.020	3.2	10
2 452 876.4586	*R*	–3.818	0.007	1.912	0.011	1.341	0.011	3.7	11
2 454 130.6201	*I*	–4.307	0.009	1.897	0.018	1.366	0.014	2.9	9

provided by Feinstein (1982), i.e. $B = 8.27, V = 8.15, R = 8.01$, and $I = 7.85$. Top axis depicts the year and the vertical lines represent different values of the orbital phase (ϕ), separated by an increment of 0.1. The phase values are derived from the ephemeris $\mathrm{JD}_{\mathrm{min}} = 2\,452\,819.8 + 2022.7$ E given by Damineli et al. (2008b), which corresponds to the time of minimum of the narrow component of HeI λ6678 line.

Each light curve consists of more than 600 points. These data are available as an electronic table at the CDS[4]. An excerpt from it is presented in Table 2, which contains, in successive columns: the JD, the band, the mean differential magnitude, and its rms error of η Car, CPD-59 2627, and CPD-59 2628, the *FWHM* (in arc sec) determined for HDE303308, and the number of images used to evaluate the mean values.

All bands exhibit similar behavior throughout the entire campaign. The 2003.5 event is clearly appreciable as an increasing light phase which starts at about JD 2 452 790 ($\phi \sim -0.015$), or even before. After reaching maximum light at JD 2 452 825 ($\phi \sim 0.0026$), the brightness declines suddenly by about 0.13 mag, reaching a minimum 12 days later (JD 2 452 837, $\phi \sim 0.01$). Following this photometric event, a broad maximum is spread over 218 days, reaching a second minimum at around JD 2 453 055 ($\phi \sim 0.12$). This minimum appears to be present in the same orbital phase, two and four cycles behind, if we consider the data published by van Genderen et al. (2006); Sterken et al. (1999). Gradually, the object recovers the global brightening tendency exhibited since 2003.0, lasting 2006.35. The brightening rate computed was typically 0.13 mag yr^{-1} (0.12, 0.13, 0.14, and 0.12 mag yr^{-1} for B, V, R, and I respectively). This secular brightening rate is almost identical to that η Car displayed during the 1997–1999 brightening (cf. Sterken et al. 1999; Davidson et al. 1999; Martin & Koppelman 2004).

After about JD 2 453 540, η Car's brightness increases to a maximum at about JD 2 453 860 ($\phi \sim 0.51$), the magnitude being ~4.7 in the V band. The V-band magnitude then decreases by the amount $\Delta V \sim 0.35$, returning almost to its initial brightness before JD 2 453 540. This behavior corresponds to a ~630 day wide maximum delimited by two minima at JD 2 453 540 and JD 2 454 172. Since then, η Car holds a constant brightness (neglecting shallower fluctuations), and toward the end of the 2008 observing season, appears to be starting to brighten slightly.

Figure 2 illustrates that fluctuations occur for a significant part of the orbital cycle. Most of them are due to the S Dor nature of η Car, although some others must be related to its binarity. Large scale features, such as secular brightening or fading, become more evident in a global context. To illustrate this, we compiled the light curve of η Car from 1820 to 2008, which is depicted in Fig. 3. We have plotted all the historical visual estimates between 1822 and 1916 (Frew 2004). We decided to extend the curve through to the present exclusively with instrumental measurements, i.e. photographic, photoelectric, and CCD. They included our V observations (see Fig. 2) and the data published by Hoffleit (1933); O'Connell (1956); Feinstein (1967); Feinstein & Marraco (1974); Sterken et al. (1996, 1999); van Genderen et al. (2006). The photographic data (Hoffleit 1933; O'Connell 1956) were transformed to visual magnitudes using a zeropoint of −0.85 mag, to match those of Frew (2004). While the major part of the photoelectric magnitudes were extracted with apertures similar to the one adopted in this paper, the data from Sterken et al. (1996, 1999) were obtained with a smaller aperture. Therefore, we applied zeropoints to these two datasets of −0.15 and −0.20 mag, respectively. The time series, as used to compile Fig. 3, are given in Table 3[5].

As is evident in Fig. 3, η Car has been increasing in brightness since about 1940. It changed the increasing rate around 1950, and more recently in 1997, reaching the maximum $V \sim 4.7$ in 2006[6]. The object later faded and then remained at a brightness of $V \sim 5$, showing no secular variations.

4. Concluding remarks

In the following, we outline the main results derived from our photometry since January 2003:

- the system maintained its tendency to brighten in the four photometric bands until 2006.35, when the maximum brightness in 150 years was reached;
- after this maximum in 2006.35, the brightness of η Car started to decline. Since 2007.2, the *BVRI* light curves have remained at almost constant brightness, showing a slight brightness rise in the days of writing of this report. As we could expect considering the events of 2003, such an increase is probably associated with an upcoming periastron passage;
- just after the last periastron passage in 2003.5, the photometry displayed a wide maximum, called an "egress-maximum" by van Genderen et al. (2006), which finished at a clearly evident minimum;
- the maximum peak was reached shortly after the orbital phase $\phi \sim 0.5$. This encourages us to relate it with some type of phenomena occurring during apastron passage. The light fluctuation detected about that maximum peak is quite symmetrical, covering 30% of the period. This would be consistent with the flux variations that occur after the periastron passage, reported by Duncan & White (2003); Damineli et al. (2008a). Nevertheless, we cannot discount a possible coincidence that an S Dor phase just happened to occur at that particular orbital moment;

[4] Centre de Données astronomiques de Strasbourg, `http://webviz.u-strasbg.fr/viz-bin/VizieR`

[5] Table 3 is available only in electronic form at the CDS.

[6] It is worth mentioning that the last time η Car showed that V magnitude was in early 1860s in the fading phase after the *"Great Eruption"*.

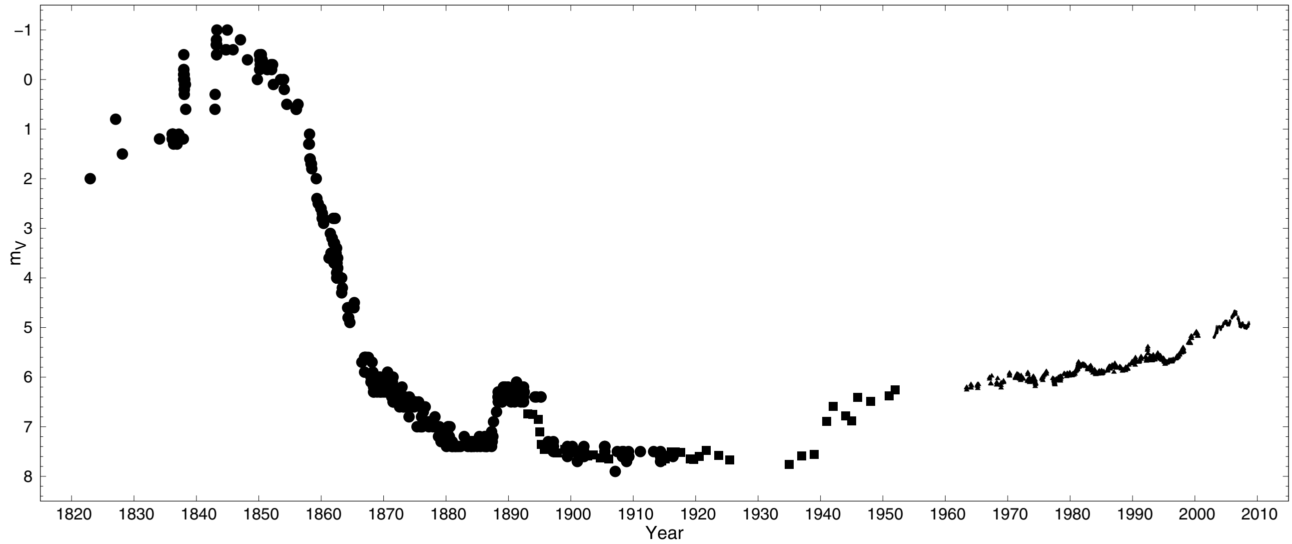

Fig. 3. Light curve of η Car since 1820 until 2008 including visual (●), photographic (■), photoelectric (▲) and our V CCD (•) observations. The maximum peak reached in 2006 and the consecutive decline are clearly visible.

– the time at which a minimum occurred was estimated from the 2003.5 event, and by adopting a 2022.7 days period, the next optical photometric dip might be expected in January 28, 2009. The onset of the 2009-event might have occurred about one or two months before.

We have provided reliable and densely sampled multiband light curves of η Car + Homunculus, covering the entire orbital period of the proposed binary system. This consistent and homogeneous data set provides invaluable information for further modeling, analysis, and interpretation, which we expect to enhance our understanding of the physical nature of η Car.

5. Present and future prospects

Our optical monitoring of η Car remains in process. Our up-to-date light curves can be found at our web-page[7]. The following improvements are being performed:

– Different aperture sizes and point spread function fittings will be tested in extracting the instrumental magnitudes and analyzing the contribution to the light curves of different areas of the Homunculus.
– Hα and Johnson U filters have been included in our observation program at La Plata and CASLEO[8] observatories, respectively.
– We propose to complement our daily monitoring with all-night long observations of η Car, certainly from Dec 2008, to ensure that we will be able to derive the light curves of the anticipated 2009 "eclipse-like" event in the U, B, V, R, I, and Hα bands.

Acknowledgements. The authors acknowledge the authorities of the FCAG-UNLP for the use of the observational facilities at La Plata Observatory. We acknowledge the participation of the following astronomers and students of the FCAG-UNLP during the observations: Violeta Bazzano, Ayeray Bonansea, Dr. Roberto Gamen, Maximiliano Haucke, Matilde Iannuzzi, Lorena Mercanti, Ángeles Moliné, Alejo Molina Lera, Cintia Peri, Cecilia Scalia, Lautaro Simontacchi, and M. Florencia Teppa Pania. Their presence during observations was of a significant help and they are gratefully acknowledged. We warmly thank Federico Bareilles for several, important contributions on the computational resources and eng. Ezequiel Garcia for the maintenance of and improvements to the telescope and its equipment. We thank the referee, Dr. C. Sterken, for valuable suggestions, which improved the presentation of this paper. We remember Reinhardt Glinschert, our telescope mechanician, who passed away last January 2008, and our "maestra" Virpi Niemela, who inspired this program and left us in December 2006.

[7] http://etacar.fcaglp.unlp.edu.ar/
[8] Complejo Astronómico el Leoncito, San Juan, Argentina.

References

Abraham, Z., Falceta-Gonçalves, D., Dominici, T. P., et al. 2005, A&A, 437, 977
Bessell, M. S. 1990, PASP, 102, 1181
Corcoran, M. F. 2005, AJ, 129, 2018
Damineli, A. 1996, ApJ, 460, L49
Damineli, A., Conti, P. S., & Lopes, D. F. 1997, New Astron., 2, 107
Damineli, A., Kaufer, A., Wolf, B., et al. 2000, ApJ, 528, L101
Damineli, A., Hillier, D. J., Corcoran, M. F., et al. 2008a, MNRAS, 386, 2330
Damineli, A., Hillier, D. J., Corcoran, M. F., et al. 2008b, MNRAS, 384, 1649
Davidson, K., Gull, T. R., Humphreys, R. M., et al. 1999, AJ, 118, 1777
Duncan, R. A., & White, S. M. 2003, MNRAS, 338, 425
Feinstein, A. 1967, The Observatory, 87, 287
Feinstein, A. 1982, AJ, 87, 1012
Feinstein, A., & Marraco, H. G. 1974, A&A, 30, 271
Feinstein, A., Marraco, H. G., & Muzzio, J. C. 1973, A&AS, 12, 331
Fernández Lajús, E., Gamen, R., Schwartz, M., et al. 2003, Inform. Bull. Variable Stars, 5477, 1
Frew, D. J. 2004, J. Astronomical Data, 10, 6
Freyhammer, L. M., Clausen, J. V., Arentoft, T., & Sterken, C. 2001, A&A, 369, 561
Gaviola, E. 1950, ApJ, 111, 408
Hoffleit, D. 1933, Harvard College Observatory Bulletin, 893, 11
Martin, J. C., & Koppelman, M. D. 2004, AJ, 127, 2352
O'Connell, D. J. K. 1956, Vist. Astron., 2, 1165
Sterken, C., de Groot, M. J. H., & van Genderen, A. M. 1996, A&AS, 116, 9
Sterken, C., Freyhammer, L., Arentoft, T., & van Genderen, A. M. 1999, A&A, 346, L33
Sterken, C., Freyhammer, L. M., Arentoft, T., & van Genderen, A. M. 2001, in P Cygni 2000: 400 Years of Progress, ed. M. de Groot, & C. Sterken, ASP Conf. Ser., 233, 39
van Genderen, A. M., Sterken, C., Allen, W. H., & Walker, W. S. G. 2006, J. Astronomical Data, 12, 3
Whitelock, P. A., Feast, M. W., Marang, F., & Breedt, E. 2004, MNRAS, 352, 447
Wilson, R. E., & Van Hamme, W. 2004, Computing Binary Star Observables, available at ftp://ftp.astro.ufl.edu/pub/wilson/lcdc2003/