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BD+61°2213: an interesting ellipsoidal or eclipsing variable in the open cluster NGC 7160

Petr Harmanec[1], **Hrvoje Božić**[2], **Philippe Eenens**[3], **and Jozef Žižňovský**[4]

[1] Astronomical Institute, Academy of Sciences of the Czech Republic, CZ-251 65 Ondřejov, Bohemia, Czech Republic (hec@sunstel.asu.cas.cz)
[2] Hvar Observatory, Faculty of Geodesy, Zagreb University, Kačićeva 26, HR-10000 Zagreb, Croatia (hbozic@geodet.geof.hr)
[3] Departamento de Astronomia, Universidad de Guanajuato, Apartado 144, 36000 Guanajuato, GTO, Mexico (eenens@carina.astro.ugto.mx)
[4] Astronomical Institute, Slovak Academy of Sciences, SK-059 60 Tatranská Lomnica, Slovakia (ziga@auriga.ta3.sk)

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Abstract. Light variability of BD+61°2213, first suspected more than 20 years ago, is confirmed on the basis of observations from three observatories. The light of BD+61°2213 apparently varies with a period of $1^{\rm d}.2028251$ and a double-wave light curve. Five available radial velocities of the star also define a large-amplitude curve with the same period. The star is, therefore, a binary as suspected earlier. We conclude, however, that it is more probably an ellipsoidal variable than an eclipsing binary. Its further spectral and photometric monitoring is desirable, especially since an accurate detemination of its physical elements could also improve the knowledge of the distance of the NGC 7160 cluster.

Key words: stars: binaries: close – stars: binaries: eclipsing – stars: binaries: spectroscopic – stars: individual: BD+61°2213 – Galaxy: open clusters and associations: individual: NGC 7160

1. Introduction

BD+61°2213 (NGC 7160*4, ADS 15430, $\alpha_{1950} = 21^{\rm h}52^{\rm m}21^{\rm s}$, $\delta_{1950} = +62°21'40''$) is a reddened B3 star and the fourth brigtest member of the open cluster NGC 7160. Its improved all-sky UBV magnitudes were derived by Harmanec et al. (1994):

$V = 8^{\rm m}.961$, $B - V = +0^{\rm m}.191$, $U - B = -0.466$.

Light variability of BD+61°2213 was first reported by Hill (1967a) and Hill (1967b) but no details were given; the star was tentatively classified as an eclipsing binary with the reference to its variable radial velocity - see Hayford (1932). Hill et al. (1976) published their individual observations of BD+61°2213, secured during 1972 and 1973 in the DAO photometric system and suggested that BD+61°2213 is a light variable. Subsequently, the star was included into the catalogue of suspected variables by Kukarkin et al. (1982) as NSV 13949.

BD+61°2213 was used occasionally as one of the transformation standards during systematic observations of Be and Ap stars and some binaries at Hvar and Skalnaté Pleso Observatories - see Harmanec et al. (1994). This was not, however, listed among good standards, observed frequently enough. Recently, it was observed again as a possible transformation standard during our observations of selected binaries and early-type rapid variables at San Pedro Mártir Observatory. Preliminary reductions of these observations clearly indicated that the star is variable. It was, therefore, re-observed more systematically at Hvar. The purpose of this paper is to demonstrate the variability of the star, derive probable timescales of the variability and call attention of spectroscopists and photometrists to its further monitoring which could possibly also help to improve our knowledge of the distance of the NGC 7160 cluster.

Send offprint requests to: P. Harmanec

2. Observations and reductions

Our analysis of the light variations of BD+61°2213 is based on the following sets of photoelectric observations:

1. 50 differential observations in the DAO photometric system relative to HD 208440 = NGC 7160*3, secured by Hill et al. (1976) at Mt. Kobau in 1972 and 1973. The DAO [55], [44] and [35] magnitudes were transformed into the standard UBV system of accurate magnitudes derived by Harmanec et al. (1994) with the help of transformation formulæ derived by us earlier – cf. Hill et al. (1997).
2. 5 differential UBV observations relative to HD 208440, secured at Hvar between 1973 and 1982 and published by Harmanec et al. (1997). These observations were carefully transformed to the standard system with the help of the reduction program HEC22, based on non-linear transformation formulæ. Details of the reductions were described by Harmanec et al. (1994) and the reduction software itself was published and fully documented by Harmanec & Horn (1998).
3. 107 accurate all-sky H_p observations secured from 1989 to 1993 during the Hipparcos satellite mission and published by Perryman et al. (1997). They were transformed into the standard V magnitude of the Johnson system following Harmanec (1998). The mean values of colour indices of BD+61°2213 derived by Harmanec et al. (1994) and quoted above were used in the transformation formula.

Table 1. Journal of differential photoelectric observations of BD+61°2213 relative to HD 208440 = NGC7160*3. All quoted errors of the V magnitude are the mean rms errors per 1 observation of unit weight

Source	Station	Epoch covered (JD-2400000)	No. of obs.	V (mag.)	$B-V$ (mag.)	$U-B$ (mag.)	Remarks
Hill et al. (1976)	13	41499.77–41560.93	17	8.969± 0.020	0.186	−0.464	A
Hill et al. (1976)	13	41837.84–41938.73	33	8.969± 0.020	0.183	−0.465	A
Harmanec et al. (1997)	1	41954.46–45205.46	5	8.973± 0.030	0.182	−0.462	
this paper	3	45228.45–45231.39	2	8.963± 0.007	0.209	−0.480	
Perryman et al. (1997)	61	47865.67–47886.92	6	8.952± 0.013	–	–	B
Perryman et al. (1997)	61	47916.76–48174.26	33	8.959± 0.018	–	–	B
Perryman et al. (1997)	61	48261.32–48606.36	43	8.964± 0.020	–	–	B
Perryman et al. (1997)	61	48629.01–48972.36	18	8.976± 0.023	–	–	B
Perryman et al. (1997)	61	49017.68–49044.75	7	8.966± 0.014	–	–	B
this paper	30	51060.89–51065.70	8	8.954± 0.029	0.190	−0.461	
this paper	1	51080.29–51100.37	22	8.950± 0.010	0.201	−0.467	

Notes: Column "Station" Running numbers of observing stations follow the numbering system used in the Ondřejov data archives, cf. Harmanec & Horn (1998): 1... Hvar 0.65-m reflector, EMI6256B tube; 3... Skalnaté Pleso 0.60-m reflector, EMI6256B tube; 13... Mt. Kobau 0.41-m reflector, a four-channel photometer; 30... San Pedro Mártir 0.84-m reflector, the "cuenta-pulsos" photometer with an RCA 31034 tube; 61... Hipparcos satellite photometry.
Column "Remarks" A... DAO [55], [44] and [35] photometry transformed into the standard UBV system following Hill et al. (1997); B... Hipparcos H_p photometry transformed into Johnson V following Harmanec (1998).

4. 8 UBV differential observations relative to HD 208440, secured at San Pedro Mártir in 1998 and reduced to the standard system again with the help of HEC22 rel. 13.1 program.
5. 22 differential UBV observations relative to HD 208440, secured at Hvar and also reduced with HEC22 rel.13.1.

To derive final UBV values for analyses, the following mean Hvar all-sky UBV values of the comparison HD 208440, derived by Harmanec et al. (1994)

$V = 7^{\rm m}.935$, $B-V = +0^{\rm m}.074$, $U-B = -0.729$

were added to the standard magnitude differences BD+61°2213 − HD 208440 for all differentially obtained observations. In most cases, all-sky or differential (again relative to HD 208440) observations of the check star HD 208218 = NGC 7160*1 were also obtained. The journal of all data sets is in Table 1 where also mean or seasonal mean UBV values of the variable are listed. We note that the rms errors of the mean values of BD+61°2213 exceed those of the check star HD 208218. While it is true that HD 208218 is much brighter than BD+61°2213 and can, therefore, suffer from a somewhat smaller observational scatter, it is necesarry to realize that both stars were reduced in most cases relative to HD 208440 the brightness of which is closer to BD+61°2213 than to HD 208218. The mean values of Table 1 seem, therefore, indicate variability of BD+61°2213.

It is fair to warn the readers that our comparison star, HD 208440, is also suspected of variability and was listed as NSV 25788 by Kazarovets et al. (1998) on the basis of a report by Rufener (1989) who once observed it as faint as $8^{\rm m}.12$. However, none of the photometric data sets at our disposal, including the Hipparcos observations, shows evidence of similar light decreases of HD 208440. Also Ardeberg & Sarg (1974) give $V = 7^{\rm m}.95$ for HD 208440 on the basis of 3 observations obtained in summer 1968.

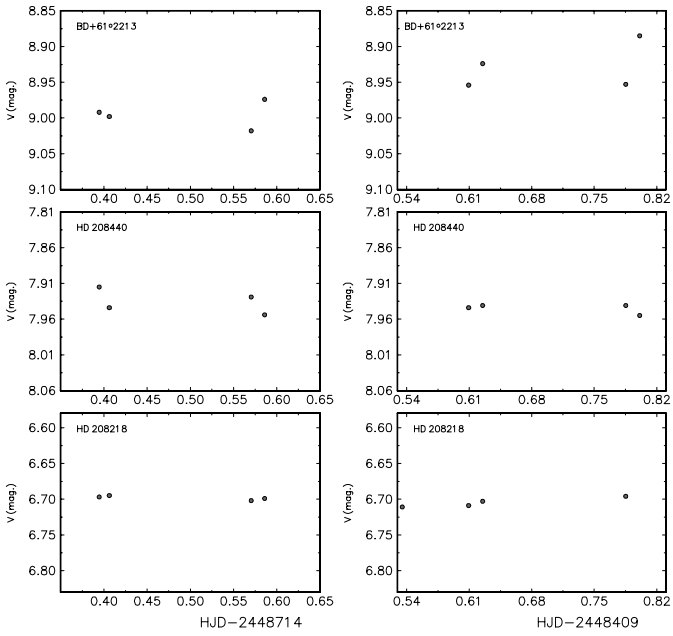

Fig. 1. Time plots of Hipparcos all-sky photometry of BD+61°2213 and its comparisons HD 208440 and HD 208218, transformed to the standard Johnson V magnitude, for two longest series of observations secured within one day. One can see real light variation of BD+61°2213 between the two series of observations

To investigate the variability of BD+61°2213 further and to map the possible time scales of the variations, we inspected various sample plots of the V observations of BD+61°2213 and its comparisons vs. time. As an illustrative example, two longest se-

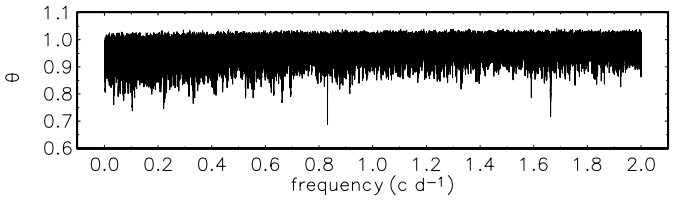

Fig. 2. The PDM periodogram of all 195 V observations of BD+61°2213 secured between 1972 and 1998 which shows that the variations have a periodic component near $1^{\rm d}.2$

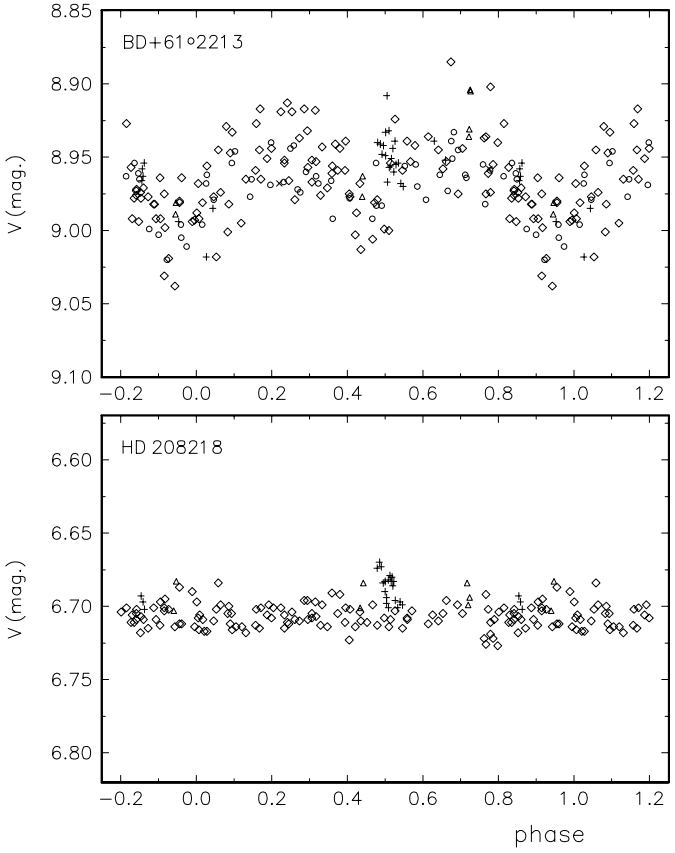

Fig. 3. All V observations of BD+61°2213 and its check star HD 208218 are plotted vs. phase of the $1^{\rm d}.2028251$ period. A double-wave variation, reminiscent of an ellipsoidal or eclipsing variable, is clearly seen. Data from different observatories are show by different symbols as follows: +... Hvar; x... Skalnaté Pleso; circle... Mt. Kobau, triangle... San Pedro Mártir; diamond... Hipparcos

ries of the Hipparcos observations are plotted in Fig. 1. One can see that the data scatter is increasing with the decreasing magnitude of the object as expected. However, there is no convincing evidence of real rapid (shorter than about $0^{\rm d}.3$) light variations of BD+61°2213. On the other hand, a real light variation of BD+61°2213 between the two series of observations is clearly observed. This is also confirmed by our San Pedro Mártir observations which show that the brightness of BD+61°2213 changed for $0^{\rm m}.05$ between two consecutive nights. On the other hand, the mean values of Table 1 show a rather good secular stability.

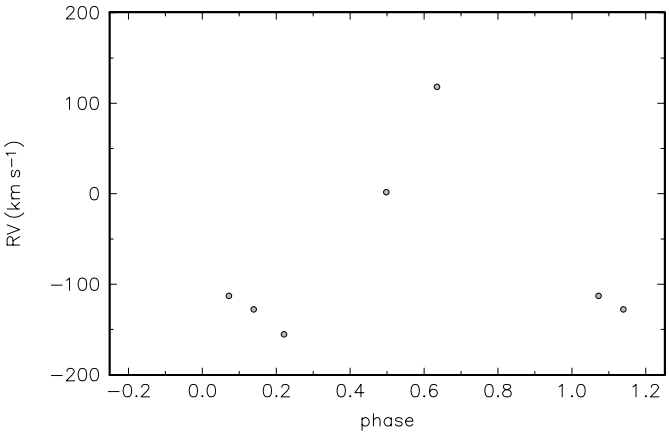

Fig. 4. Available radial velocities of BD+61°2213 plotted vs. phase of photometric period and epoch. It is seen that the star is indeed a large-amplitude spectroscopic binary

We therefore subjected all V observations to a period search over the range of periods from $0^{\rm d}.5$ to $1000^{\rm d}.0$ using the PDM (phase dispersion minimalization) period search technique – see Stellingwerf (1978). The resulting PDM periodogram is shown in Fig. 2. A period of $1^{\rm d}.2028269$ and its one-day alias were clearly detected as the best ones, without too much aliasing problems. A non-linear least-squares fit of the data carried out with the help of program Period98 (version 1.0.6) by Sperl (1998) led to an improved ephemeris $T_{\rm min.1}$ = HJD 2446299.237(12) + $1^{\rm d}.2028251(13) \times$ E.

Only this period and its first harmonics were sufficient to a good description of the variations observed, all higher harmonics having (formal) amplitudes of the fit below $0^{\rm m}.003$. The rms of the fit per one observation was $0^{\rm m}.020$, i.e. slightly higher than what would be expected for the data noise only, and addition of higher harmonics did not decrease this value significantly. The light curve corresponding to the least-squares fit is shown in Fig. 3.

In Fig. 4 we also plot five available radial velocities of BD+61°2213 from the papers by Hayford (1932), Liu et al. (1989) and Liu et al. (1991) for the ephemeris given above. It is seen that there is a good mutual correspondence between the phases of expected conjunctions of the putative binary system and the phases of the light minima. This finding firmly confirms earlier tentative reports that the star is a binary. As demonstrated by, e.g., Harmanec (1981), most of the known B binaries have orbital periods between 1 and 3 days. The observed value of the orbital period of BD+61°2213 falls inside that range.

3. Discussion of results

Very preliminary attempts to derive orbital and light curve solutions from the available data indicated that the star is probably an ellipsoidal, rather than eclipsing binary. There are two reasons for such a conclusion: First, a massive eclipsing binary would

have much deeper eclipses for such a short orbital period. Second, for inclinations close to 90°, the primary mass from the radial-velocity curve would be too small for an early-B star.

However, given the very small number of available radial velocities as well as some uncertainty in the exact value of the orbital period over the long interval covered by radial-velocity data, we postpone a serious attempt for the determination of basic physical elements of BD+61°2213 for the future. Obviously, an accurate detemination of physical properties of this binary could also help to improve our knowledge of the distance of the cluster NGC 7160 from us.

Systematic spectral and photometric observations of BD+61°2213 are, therefore, very desirable.

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