



## Period study of the $\delta$ Scuti variable DE Lac

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**Abstract.** DE Lac is a high-amplitude  $\delta$  Scuti variable with a period of 0.253694 days. New CCD photometric monitoring of DE Lac was carried out on 2013 December 18 and 2014 January 5, by using the 1.0-m reflecting telescope at Yunnan Observatories. Photometric observations of DE Lac were also obtained by using the 85-cm telescope at Xinglong Station of National Astronomical Observatory. By using a few new determined times of maximum light together with those collected from the literature, the period changes in Observed-Calculated ( $O - C$ ) diagram are analyzed. We discover that the pulsating period of DE Lac is increasing continuously at a rate of  $\dot{P} = +3.7 \times 10^{-8}$  days/year. It is compatible with the prediction from the stellar evolution model calculations. Meanwhile, we collect other  $\delta$  Scuti stars that have exhibited period changes.

*Keywords* : techniques: photometric – stars: variable:  $\delta$  Scuti – stars: individual: DE Lacertae

### 1. Introduction

The high-amplitude  $\delta$  Scuti stars (HADS) are the  $\delta$  Scuti stars with V-band amplitudes more than 0.30 magnitudes. HADS stars include Population I stars close to the main sequence and evolved Population II SX Phe type variable stars which are moving from the main sequence to the giant branch in the Hertzsprung-Russell diagram. They are characterized by pulsating periods of several hours ( $< 0.3$  days), amplitudes of variability of 0.3 – 0.7 magnitudes, and low rotational

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velocities ( $v \sin i < 30 \text{ km s}^{-1}$ ). These pulsations exhibit multiple modes and possibly non-radial modes; many are primarily fundamental-mode pulsators. An analysis of the Chang *et al.* (2013) catalogue shows that about a quarter of  $\delta$  stars (406 in 1473) are HADS. The period evolution of HADS is not well understood. Stellar evolution theory predicts an increasing period (Breger & Pamyatnyk 1998), but also decreasing period changes are possible during the short time, and have been observed. So, it is important to regularly obtain accurate data to monitor the period behavior of HADS.

DE Lacertae ( $\alpha_{2000} = 22^{\text{h}}10^{\text{m}}07^{\text{s}}.8$ ,  $\delta_{2000} = 40^{\circ}55'11''$ ,  $10^{\text{m}}.08 - 10^{\text{m}}.43$  (V),  $P = 0.2536934$  day, F5-F8) is listed as a  $\delta$  Scuti type variable in the General Catalogue of Variable Stars (GCVS). It is a SX Phoenicis type variable star in the SIMBAD Catalogue. Ishchenko (1948) and Gorazdo-Lesnykh (1962) used the photometric method to monitor DE Lac and suggested that DE Lac might be a dwarf cepheid type variable. Crawford (1975) pointed out that  $[Fe/H] = 0.26$ . Woolley & Aly (1996) gave a mean velocity of  $\gamma = +0.4 \text{ km sec}^{-1}$  and a total velocity amplitude of  $2K = 30.6 \text{ km sec}^{-1}$ . McNamara & Laney (1976) reported  $\mu\nu\text{by}\beta$  photometry and radial velocity measurements of DE Lac; they gave average reddening of  $E(b - y) = 0^{\text{m}}.087$ , temperature variations between 7600 K and 6700 K, the total velocity amplitudes of  $26.5(2) \text{ km sec}^{-1}$  and mean velocity of  $-16.5(2) \text{ km sec}^{-1}$ .

In order to investigate the period changes of DE Lacertae, all of the times of the light maximum that have been published were collected. We studied the variation of the pulsation period through the classical  $O-C$  method, and analyzed the  $O-C$  diagram with a nonlinear fit. The new observations and data reduction are in Section 2; Section 3 gives the  $O-C$  analysis and period change study. The last Section presents the discussions and conclusions respectively.

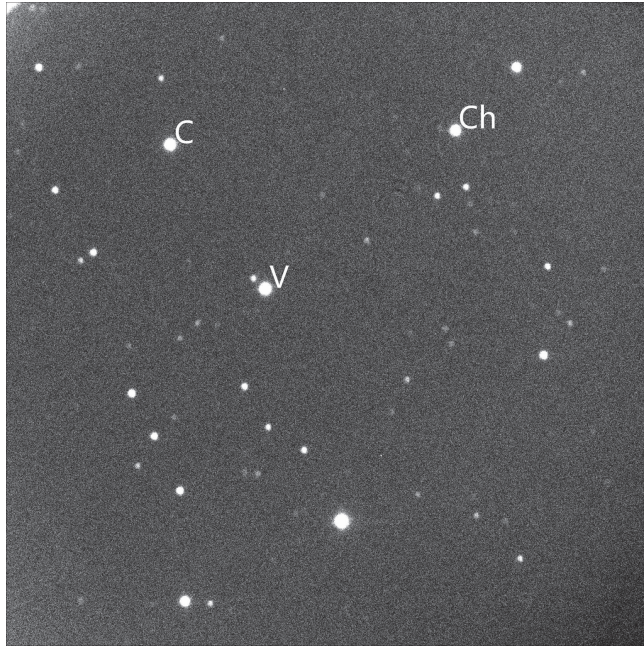
## 2. New observations and data reduction

Photometric observations of DE Lac were obtained on 2013 December 18 and 2014 January 5 by using the 1.0-m reflecting telescope at Yunnan Observatories (YNOs) that is equipped with a Cassegrain-focus multicolor CCD photometer. An Andor DW436 2K CCD camera together with the wide-band, Johnson-Cousins  $I_c$  filter, attached to this Cassegrain telescope was used. To increase the photometric precision, we also observed the variable star without filters sometimes. The variable star was also observed on 2014 January 2 using the 85-cm telescope at the Xinglong Station of National Astronomical Observatory (NAO). The telescope is equipped with a primary-focus multi-color CCD photometer where a PI1024 BFT (Back-illuminated and Frame-Transfer) camera was used as the detector (Zhou *et al.* 2009).

The CCD images were reduced with PHOT (measure magnitudes for a list of stars) of the aperture photometry package of IRAF. TYC 3203-503-1 was chosen as the comparison star, while another nearby star, TYC 3202-536-1, in the same field of view was chosen as the check star. The coordinates and magnitudes of these stars are listed in Table 1. One of the CCD images is shown in Fig. 1, where “V”, “C”, and “Ch” refers to the variable, the comparison and the check stars. The light curves in  $I_c$  band and without filters obtained on 2014 January 5 are displayed in Fig. 2.

**Table 1.** Coordinates and magnitudes of DE Lac, the comparison, and the check stars.

Targets	Names	$\alpha_{2000}$	$\delta_{2000}$	$B$	$V$
Variable	DE Lac	22 <sup>h</sup> 10 <sup>m</sup> 07.8 <sup>s</sup>	40°55′10″.6	10.74	10.43
The comparison	TYC 3203-503-1	22 <sup>h</sup> 10 <sup>m</sup> 13.5 <sup>s</sup>	40°56′45″.5	12.02	10.73
The check	TYC 3202-536-1	22 <sup>h</sup> 09 <sup>m</sup> 56.8 <sup>s</sup>	40°56′59″.9	11.70	11.06

**Figure 1.** One of the CCD images of DE Lac obtained by using the 1.0-m reflector telescope in YNOs. “V”, “C” and “Ch” refer to DE Lac, the comparison and the check stars, respectively.

Based on those new observations, the times of several light maxima are determined by fitting a three-degree polynomial on each observed light peak and listed in Table 2.

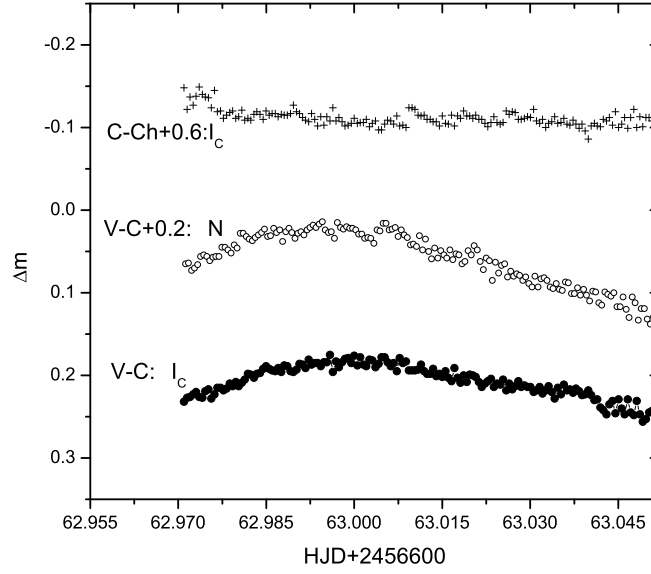
### 3. Period change of DE Lac

To analyze the period changes of DE Lac, all available times of light maxima were collected. The times are mainly from Gorazdo-Lesnykh (1962), McNamara et al. (1976), Agerer (2003), Hübscher (2005), Hübscher et al. (2005, 2006) and the present authors (these are listed in Table 2). The  $O - C$  values with respect to the following linear ephemeris (Gorazdo-Lesnykh 1962),

$$Max.(HJD) = 2428807.131 + 0^d.253694 \times E, \quad (1)$$

**Table 2.** New CCD times of light maximum.

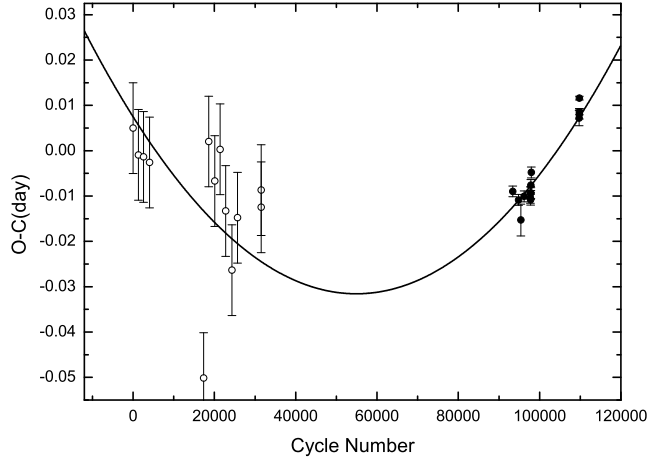
HJD (days)	Errors (days)	Filters	Telescopes
2456645.9956	0.0017	N	1.0-m
2456659.9497	0.0011	N	85-cm
2456662.9975	0.0004	$I_c$	1.0-m
2456662.9945	0.0007	N	1.0-m



**Figure 2.** CCD photometric light curves of DE Lac were observed on 2014 January 5. Solid dots refer to  $I_c$  band, while open circles to those data obtained without filters. Those shown with a plus sign are the magnitude differences between the variable and the comparison stars in  $I_c$  band.

are calculated. The corresponding  $O - C$  curve is shown in Fig. 3, where those  $O - C$  values are plotted along with the cycle number  $E$ . Open circles in the figure refer to the visual and photographic observations (hereafter “VP”), while solid circles refer to photoelectric and CCD (hereafter “PC”) data. As displayed in Fig. 3, the  $O - C$  diagram shows an upward parabolic change suggesting that the pulsating period of DE Lac is increasing continuously. A least-square solution yields,

$$\begin{aligned}
 \text{Max.}(\text{HJD}) &= 2428807.1385(\pm 0.0005) \\
 &+ 0.253692580(\pm 0.000000004) \times E \\
 &+ 1.29(\pm 0.16) \times 10^{-11} \times E^2.
 \end{aligned} \tag{2}$$



**Figure 3.** A plot of the ( $O - C$ ) curve of DE Lac with respect to the linear ephemeris given by Gorazdo-Lesnykh (1962). The solid line indicates a long-term increase in the pulsating period. Open circles refer to visual or photographic observations. Solid circles refer to photoelectric and CCD data. Vertical lines indicate the errors.

During the analysis, the weight of 1 was assigned to the “VP” observations, while the weight of 10 was assigned to “PC” data, and the weighted least-squares method was used. The quadratic term in Eqn. (2) reveals a linear increase at a rate of  $\dot{P} = +3.7(\pm 0.46) \times 10^{-8}$  days/year (or 3.2 s in about 1000 years). The solid line in Fig. 3 represents the linear period increase.

#### 4. Discussion and conclusions

We have collected all the times of light maxima covering 66 years and studied the behavior of the pulsation period change of DE Lacertae with the classical  $O - C$  method, and calculated the commonly used measure  $(1/P)dP/dt = 14.6 \times 10^{-8} \text{ year}^{-1}$ . It is comparable to the theoretical prediction (Breger & Pamyatnyk 1998). DE Lacertae is probably a main-sequence star, its period change might mainly be a result of stellar evolution at present.

We have collected and recalculated the observed period changes for some HADS (see Table 3). It was a pity, a potentially confusing variety of different unit can be found in the literature by different authors. So, we recalculated the period changes in the form of  $(1/P)dP/dt$  in units of  $\text{year}^{-1}$ , as Breger & Pamyatnyk (1998) did. Zhou (2011) found a continuous period change of GP And with a rate of  $(1/P)dP/dt = 5.49 \times 10^{-8} \text{ year}^{-1}$ . Yang et al. (2012) suggested XX Cyg to have an increasing period change  $(1/P)dP/dt = 1.19 \times 10^{-8} \text{ year}^{-1}$  and located on the top of the evolutionary tracks. XX Cyg is a post-main-sequence star. Al Vel (Walraven et al. 1992) has the same order of pulsation period change as DE Lac.

**Table 3.** Observed period changes of Delta Scuti stars

Stars	Pop.	Periods (days)	$(1/P)dP/dt$ ( $10^{-8}$ year $^{-1}$ )	References
IP Vir	I	0.067	-0.5	Joner et al. (1998)
GP And	I	0.078682737	5.49	Zhou & Jiang (2011)
AI Vel	I	0.086	15	Walraven et al. (1992)
EH Lib	I	0.08841326	0.944	Boonyarak et al. (2011)
BE Lyn	I	0.09586951	-2.49	Boonyarak et al. (2011)
YZ Boo	I	0.104091576	0.63	Rachel et al. (2008)
AD CMi	I	0.122974498	1.3	Boonyarak et al. (2011)
RS Gru	I	0.147	-11	Rodríguez et al. (1995b)
	I	0.147010864	14.3	García (2012)
DY Her	I	0.148631170	-2.8	Boonyarak et al. (2011)
VZ Cnc	I	0.17836372	1.4	Boonyarak et al. (2009)
BS Aqr	I	0.197822622	-2.7	Fu (2000)
DE Lac	I	0.253694	14.6	This paper
CY Aqr	II	0.061038366	3.09	Boonyarak et al. (2011)
DY Peg	II	0.07292633	-4.5	Li & Qian (2010)
AE UMa	II	0.086017078	5.4 ( $P_0$ )	Niu et al. (2013)
	II	0.293615846	-2.8 ( $P_1$ )	Niu et al. (2013)
XX Pyg	II	0.134865117	1.19	Yang et al. (2012)

The evolutionary change in  $T_{\text{eff}}$  and  $M_{\text{bol}}$  leads to a period change as follows,

$$\frac{1}{P} \frac{dP}{dt} = -0.69 \frac{dM_{\text{bol}}}{dt} - \frac{3}{T_{\text{eff}}} \frac{dT_{\text{eff}}}{dt} + \frac{1}{Q} \frac{dQ}{dt}, \quad (3)$$

where  $M_{\text{bol}}$  is the absolute bolometric magnitude, in other words, luminosity,  $Q$  is the pulsation constant in days, and the coefficient of 0.69 has been derived by multiplying the coefficient of 0.3 by  $\ln 10$  from the differentiation. From Eqn. (3), it can be seen that the period of a pulsating star increases when both  $T_{\text{eff}}$  and  $M_{\text{bol}}$  decrease, the term  $\frac{1}{Q} \frac{dQ}{dt}$  is very small relative to  $\frac{1}{P} \frac{dP}{dt}$ . Breger & Pamyatnyk (1998) pointed out that stellar evolution leads to increasing periods in the vast majority of stars, with period increases of  $(1/P)dP/dt$  from  $10^{-10}$  year $^{-1}$  on the main sequence to  $10^{-7}$  year $^{-1}$  for the longer-period evolved variables. However, from Table 3, we can see that the observed period changes are from  $10^{-9}$  year $^{-1}$  to  $10^{-7}$  year $^{-1}$  with equal distribution between period increase and decrease. On the other hand, Rodríguez et al. (1995a,b) provided the evidence that the observed period changes were not caused by evolution alone. Therefore, more theoretical research and observational study are needed.

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