

## PHOTOELECTRIC OBSERVATIONS OF W UMA STARS: U PEGASI AND AB ANDROMEDAE

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### RESUMEN

Se reportan observaciones fotoeléctricas recientes de los sistemas tipo W UMa, U Pegasi y AB Andromedae. De los tiempos de mínimos encontrados en la literatura junto con los obtenidos en las presentes observaciones se determinan las efemérides cuadráticas siguientes:

Para U Peg:  $HJD_{min} = 2436511.6706 (\pm 0.0035) + 0.3747818 (\pm 1.27 \times 10^{-7}) E - 1.08 \times 10^{-10} (\pm 0.0324 \times 10^{-10}) (E^2/2)$  y para AB And:  $HJD_{min} = 2440128.7945 (\pm 0.0035) + 0.33189162 (\pm 9 \times 10^{-8}) E + 8.74 \times 10^{-11} (\pm 0.16 \times 10^{-11}) (E^2/2)$ ; denotando un cambio continuo en sus periodos de  $-0.91$  s/siglo para U Peg y  $0.83$  s/siglo para AB And.

### ABSTRACT

Recent photoelectric-photometric data of the W UMa systems U Pegasi and AB Andromedae are reported. From the times of minima found in the literature and those obtained in the present paper, the following quadratic ephemerides were calculated:

For U Peg:  $HJD_{min} = 2436511.6706 (\pm 0.0035) + 0.3747818 \pm 1.27 \times 10^{-7}) E - 1.08 \times 10^{-10} (\pm 0.0324 \times 10^{-10}) (E^2/2)$  and for AB And:  $HJD_{min} = 2440128.7945 (\pm 0.0035) + 0.33189162 (\pm 9 \times 10^{-8}) E + 8.74 \times 10^{-11} (\pm 0.16 \times 10^{-11}) (E^2/2)$ ; implying a continuous change in the period of  $-0.91$  s/century for U Peg and  $0.83$  s/century for AB And.

**Key words:** STARS-W URSAE MAJORIS - STARS-VARIABLE - STARS-ECLIPSING BINARIES

### 1. INTRODUCTION

Because of their high abundance in space and their very conspicuous light curves, the W UMa stars are very important in the field of stellar evolution. They form the group which has aroused the most controversy among the close binary systems. Many models have been developed to explain the light curves of these stars which very often show instabilities. In addition, since this class of stars can be observed with rather modest telescopes, the amount of observational data available makes possible reliable determinations of their period behavior. Also, many of these stars show variations in their periods

which are explained with several hypotheses, namely, through apsidal motion, interaction with a third component of the system, changes in their separation, changes in the mass of the system or the interchange of mass among the components. To establish the mechanism that produces the changing period, continuous observations are needed (Wood 1950). With this idea in mind, it was decided to re-observe two W UMa type stars: U Pegasi and AB Andromedae. In this paper, new photoelectric observations of these two systems are presented and an analysis of their period behavior has been made.

U Pegasi, which was discovered by Chandler in 1894 (Chandler 1895), is a well studied system. The history of its observations can be found in Lafta and Grainger 1986, where a very complete compilation of the times of minima is also presented. These data together with the minima obtained from the photometry in this paper (Tables 2 and 3) were used to analyze the period variation of this system.

AB Andromedae has been studied since its

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TABLE 1

COORDINATES AND MAGNITUDES OF THE OBSERVED STARS

| Star           | BD        | $\alpha$                                        | (1900) | $\delta$     | $V$<br>(mag) | Type  |
|----------------|-----------|-------------------------------------------------|--------|--------------|--------------|-------|
| U Pegasi       | +15° 4915 | 23 <sup>h</sup> 52 <sup>m</sup> 52 <sup>s</sup> |        | +15° 23' 48" | 10.0         | W UMa |
| C <sub>1</sub> | +15 4916  | 23 53 46                                        |        | +15 17 14    | 8.8          | Ref.  |
| C <sub>2</sub> | +14 5077  | 23 52 09                                        |        | +15 04 13    | 7.9          | Ref.  |
| AB Andromedae  | +36 5017  | 23 06 46                                        |        | +36 21 06    | 10.5         | W UMa |
| C <sub>1</sub> | +36 5020  | 23 06 54                                        |        | +36 14 54    | 8.0          | Ref.  |
| C <sub>2</sub> | +36 5021  | 23 07 38                                        |        | +36 25 43    | 6.9          | Ref.  |

discovery in 1927 by Cuthnick and Prager (1927). A summary of the past observations can be found in Rovithis and Rovithis (1981). It has been reported that this star has shown asymmetries in its light curve (Bell, Hilditch and King 1984). From the times of minima found in the literature and those recently obtained by the authors of this paper, (Tables 4 and 5), an analysis of the variation of the period of this close binary was made.

## II. OBSERVATIONS

Most of the observations took place at the Observatorio Astronómico Nacional at San Pedro Mártir with the 84-cm reflecting telescope. The same equipment was used every night, namely, a dry-ice cooled RCA 31034A photocell with a pulse counting system and Johnson's  $V$  filter. The following observing method was adopted for both stars: two comparison stars were chosen for each program star according to the usual criteria that they must be of approximately the same magnitude as the variable star and that they be within two degrees of it. The characteristics of the program stars and their corresponding comparisons are shown in Table 1.

U Pegasi was observed during the nights of November 2-3 and 3-4, 1989, while the observations of AB Andromedae were carried out during the nights of October 27-28, 28-29, November 1-2 and 4-5, 1989. The photoelectric data obtained are shown in Table 2 for U Peg and Table 4 for AB And. The light curves of U Peg for the observed nights are shown in Figure 1. The light curves of AB And for each night are shown in Figure 3. In all cases each observation consisted of 30 s integrations on each star. The sequence of observations followed was C, C, V, C, C, V, etc., with a 10 s integration of the sky each 40 minutes. The photometric values plotted are the instrumental magnitude differences

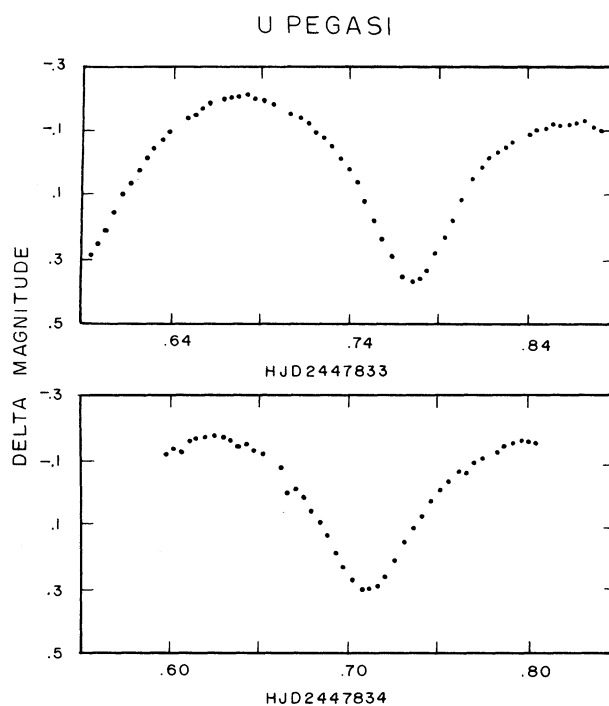


Fig. 1. a) and b) Light curves of the observed nights of U Peg.

between the variable star and one of the comparison stars, which for convenience will be designated by C<sub>1</sub> in Table 1, interpolated at the time of the observation of the variable. An average of the differences was then subtracted from each run to establish the zero baseline. The data points are accurate to 0<sup>m</sup>.005; the average time interval between successive points is 0<sup>d</sup>.005 while the accuracy in time for each point is 0<sup>d</sup>.0007.

In addition  $ubv\gamma$ - $\beta$  data for both stars were obtained on the night of November 8, 1989 with the

TABLE 2  
PHOTOELECTRIC OBSERVATIONS OF U PEGASI

| HJD<br>2440000+ | $\Delta$ MAG | HJD<br>2440000+ | $\Delta$ MAG | HJD<br>2440000+ | $\Delta$ MAG |
|-----------------|--------------|-----------------|--------------|-----------------|--------------|
| 7833.596        | 0.284        | 7833.770        | 0.353        | 7834.639        | -0.131       |
| 7833.599        | 0.249        | 7833.775        | 0.365        | 7834.643        | -0.134       |
| 7833.603        | 0.204        | 7833.780        | 0.357        | 7834.648        | -0.117       |
| 7833.608        | 0.153        | 7833.784        | 0.333        | 7834.652        | -0.106       |
| 7833.613        | 0.098        | 7833.789        | 0.281        | 7834.662        | -0.066       |
| 7833.617        | 0.062        | 7833.793        | 0.229        | 7834.666        | 0.015        |
| 7833.622        | 0.021        | 7833.798        | 0.176        | 7834.671        | -0.001       |
| 7833.626        | -0.016       | 7833.803        | 0.117        | 7834.675        | 0.030        |
| 7833.630        | -0.049       | 7833.809        | 0.053        | 7834.680        | 0.066        |
| 7833.635        | -0.074       | 7833.814        | 0.013        | 7834.685        | 0.105        |
| 7833.639        | -0.101       | 7833.818        | -0.013       | 7834.689        | 0.147        |
| 7833.649        | -0.142       | 7833.823        | -0.032       | 7834.694        | 0.202        |
| 7833.653        | -0.150       | 7833.828        | -0.050       | 7834.699        | 0.248        |
| 7833.657        | -0.172       | 7833.832        | -0.065       | 7834.703        | 0.287        |
| 7833.662        | -0.189       | 7833.841        | -0.089       | 7834.708        | 0.313        |
| 7833.668        | -0.204       | 7833.845        | -0.102       | 7834.712        | 0.313        |
| 7833.673        | -0.206       | 7833.850        | -0.109       | 7834.717        | 0.304        |
| 7833.678        | -0.207       | 7833.854        | -0.121       | 7834.721        | 0.273        |
| 7833.682        | -0.213       | 7833.858        | -0.118       | 7834.727        | 0.224        |
| 7833.687        | -0.203       | 7833.863        | -0.121       | 7834.732        | 0.165        |
| 7833.692        | -0.194       | 7833.867        | -0.130       | 7834.737        | 0.122        |
| 7833.698        | -0.183       | 7833.872        | -0.131       | 7834.742        | 0.086        |
| 7833.707        | -0.157       | 7833.877        | -0.115       | 7834.747        | 0.039        |
| 7833.712        | -0.141       | 7833.882        | -0.103       | 7834.752        | 0.007        |
| 7833.717        | -0.121       | .....           | .....        | 7834.757        | -0.022       |
| 7833.721        | -0.100       | .....           | .....        | 7834.762        | -0.057       |
| 7833.726        | -0.079       | 7834.598        | -0.107       | 7834.767        | -0.051       |
| 7833.730        | -0.053       | 7834.602        | -0.120       | 7834.771        | -0.078       |
| 7833.735        | -0.014       | 7834.607        | -0.110       | 7834.776        | -0.092       |
| 7833.740        | 0.019        | 7834.611        | -0.144       | 7834.784        | -0.112       |
| 7833.744        | 0.062        | 7834.616        | -0.153       | 7834.789        | -0.129       |
| 7833.748        | 0.122        | 7834.621        | -0.158       | 7834.793        | -0.139       |
| 7833.754        | 0.183        | 7834.625        | -0.163       | 7834.798        | -0.150       |
| 7833.758        | 0.241        | 7834.630        | -0.158       | 7834.802        | -0.143       |
| 7833.764        | 0.292        | 7834.634        | -0.148       | 7834.807        | -0.138       |

1.5-m telescope of the Observatorio Astronómico Nacional using with a *uvby- $\beta$*  photometer that allows the simultaneous obtention of data in each filter. The method used in the data acquisition and reduction has been reported earlier (see for example, Peniche *et al.* 1990). The uncertainties for the photometric values obtained from the standard stars of all the season have an accuracy of  $\delta(V, b-\gamma, m_1, c_1, H\beta)$  of (0.012, 0.007, 0.011, 0.011, 0.009). The photometric values derived are presented in Table 6.

III. ANALYSIS

In order to determine the period accurately,

a long time span of observations is required to provide a sufficiently large amount of times of minimum light. In many stars there are some indications in the O-C residuals of a secular period variation if a constant period is assumed. (See for example, Figures 2a and 4a of the present paper). In these cases, it can be assumed that the period is not constant. Hence, the following expression must be used,

$$P = P_0 + \alpha E \tag{1}$$

where  $P_0$  is the period at a given epoch,  $E$ , and  $\alpha$  is the rate at which the period is changing, (which also includes the case of a constant period when  $\alpha = 0$ ).

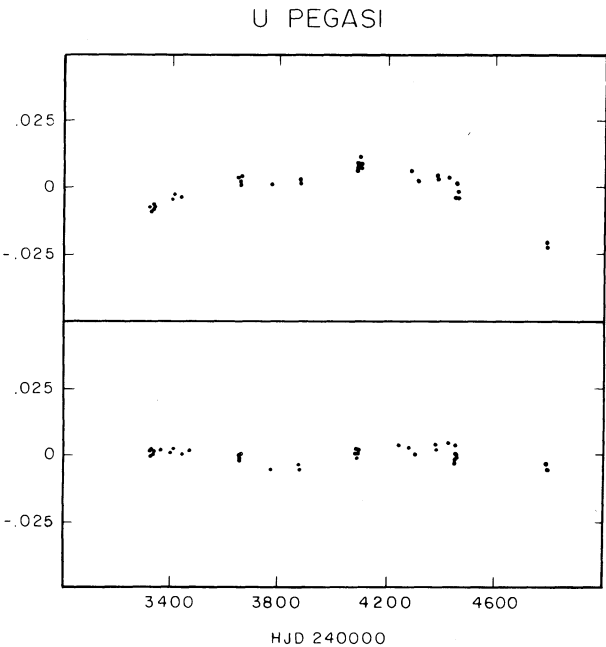


Fig. 2. a) O-C residuals versus HJD for U Peg from the linear ephemeris  $HJD = 2436511.6663 + 0.3747809 E$  derived in this paper. b) O-C residuals versus HJD for the quadratic ephemeris  $HJD = 2436511.6706 + 0.3747818 E - 1.08 \times 10^{-10} E^2/2$  derived in this paper.

If

$$P = dT/dE \tag{2}$$

then

$$dT = (P_0 + \alpha E)dE \tag{3}$$

so, integration

$$T = T_0 + P_0 E + (\alpha/2) E^2 \tag{4}$$

This equation gives the general expression of the ephemeris if a regular period variation (1) is assumed. From these relations, if a fixed uncertainty in the determination of the times of minimum light is assumed (typically  $dT = 0.0035$ ), the accuracy of  $P$  and  $\alpha$  can be estimated from the time coverage of the observations or from the number of cycles covered in such a time interval.

a) *U Pegasi*

For U Pegasi, assuming a period of  $0.37478094$ , the number of cycles covered in the time span of the observations (Table 3) is  $E = 39094$  which gives for the accuracy in the period  $1.27 \times 10^{-7}$  d and for the accuracy in the quadratic coefficient  $3.24 \times 10^{-12}$  d. The times of minima, covering a time span of 40 years, were used to analyze the period behavior of U Pegasi. These times of minima are shown in Table

3. As a first step the residuals O-C were calculated from the linear ephemeris ( $\alpha = 0$ )

$$HJD_{min} = 2436511.6663 (\pm 0.0035) + 0.3747809 (\pm 1.27 \times 10^{-7}) E$$

which was determined through the use of a computer program that has already been described by Hobart *et al.* 1989. The residuals from this ephemeris are shown in the third column of Table 3 under the heading  $(O-C)_L$ . The standard deviation of these residuals is equal to  $0.0071$ . The plot of

TABLE 3

| TIMES OF MINIMA AND O-C RESIDUALS OF U PEGASI FOR LINEAR AND QUADRATIC FITS |      |                    |                    |      |
|-----------------------------------------------------------------------------|------|--------------------|--------------------|------|
| HJD                                                                         | Min. | (O-C) <sub>L</sub> | (O-C) <sub>Q</sub> | Ref. |
| 2433182.8561                                                                | I    | -0.00624           | 0.00170            | 1    |
| 2433190.7262                                                                | I    | -0.00654           | 0.00136            | 1    |
| 2433190.9132                                                                | II   | -0.00693           | 0.00097            | 1    |
| 2433202.7181                                                                | I    | -0.00763           | 0.00022            | 1    |
| 2433230.6408                                                                | II   | -0.00611           | 0.00160            | 1    |
| 2433244.5075                                                                | II   | -0.00630           | 0.00134            | 1    |
| 2433255.5630                                                                | I    | -0.00684           | 0.00075            | 1    |
| 2433558.7624                                                                | I    | -0.00518           | 0.00095            | 1    |
| 2433924.5497                                                                | I    | -0.00404           | 0.00043            | 2    |
| 2433998.9448                                                                | II   | -0.00295           | 0.00120            | 3    |
| 2434303.4545                                                                | I    | -0.00273           | 0.00014            | 2    |
| 2434685.3586                                                                | I    | -0.00037           | 0.00099            | 2    |
| 2436481.6864                                                                | I    | 0.00257            | -0.00165           | 4    |
| 2436483.7490                                                                | II   | 0.00387            | -0.00035           | 4    |
| 2436484.6839                                                                | I    | 0.00182            | -0.00241           | 4    |
| 2436508.6702                                                                | I    | 0.00214            | -0.00214           | 4    |
| 2436511.6688                                                                | I    | 0.00250            | -0.00180           | 4    |
| 2436515.6057                                                                | II   | 0.00420            | -0.00010           | 4    |
| 2437636.0099                                                                | I    | 0.00090            | -0.00561           | 5    |
| 2438689.7081                                                                | II   | 0.00259            | -0.00510           | 6    |
| 2438691.7693                                                                | I    | 0.00250            | -0.00520           | 6    |
| 2438692.7072                                                                | II   | 0.00345            | -0.00425           | 6    |
| 2440826.9010                                                                | I    | 0.00741            | -0.00008           | 5    |
| 2440827.8396                                                                | II   | 0.00906            | 0.00156            | 5    |
| 2440831.7729                                                                | I    | 0.00716            | -0.00033           | 5    |
| 2440832.7122                                                                | II   | 0.00951            | 0.00201            | 5    |
| 2440837.7692                                                                | I    | 0.00697            | -0.00052           | 5    |
| 2440888.7399                                                                | I    | 0.00746            | 0.00002            | 5    |
| 2440891.7381                                                                | I    | 0.00742            | -0.00002           | 5    |
| 2440892.6793                                                                | II   | 0.01166            | 0.00422            | 5    |
| 2440893.8008                                                                | II   | 0.00882            | 0.00138            | 5    |
| 2442347.3879                                                                | I    | 0.00820            | 0.00298            | 7    |
| 2442741.2810                                                                | I    | 0.00658            | 0.00224            | 7    |
| 2443021.6134                                                                | I    | 0.00286            | -0.00077           | 8    |
| 2443785.0431                                                                | I    | 0.00387            | 0.00244            | 9    |
| 2443785.2312                                                                | II   | 0.00458            | 0.00315            | 9    |
| 2443789.3530                                                                | II   | 0.00379            | 0.00237            | 10   |
| 2444185.3093                                                                | I    | 0.00407            | 0.00398            | 11   |

TABLE 3 (CONTINUED)

| HJD          | Min. | (O-C) <sub>L</sub> | (O-C) <sub>Q</sub> | Ref. |
|--------------|------|--------------------|--------------------|------|
| 2444469.3857 | I    | -0.00344           | -0.00251           | 12   |
| 2444490.3786 | I    | 0.00171            | 0.00273            | 12   |
| 2444500.4922 | I    | -0.00376           | -0.00271           | 13   |
| 2444501.4295 | II   | -0.00341           | -0.00236           | 13   |
| 2444502.5554 | II   | -0.00185           | -0.00079           | 13   |
| 2444503.4923 | I    | -0.00191           | -0.00084           | 13   |
| 2444504.6165 | I    | -0.00205           | -0.00098           | 13   |
| 2447833.7754 | I    | -0.02188           | -0.00409           | 14   |
| 2447834.7121 | II   | -0.02188           | -0.00409           | 14   |

$\sigma_L = 0.00706$  (Linear fit)

$\sigma_Q = 0.00243$  (Quadratic fit)

1) LaFara (1952); 2) Kwee (1958); 3) Huruhata *et al.* (1957); 4) Binnendijk (1960); 5) Rigterink (1972); 6) Gordon (1975); 7) Patkos (1976); 8) Mallama *et al.* (1977); 9) Zhai *et al.* (1984); 10) Pohl and Glmen (1981); 11) Patkos (1980); 12) Aslan *et al.* (1981); 13) Rovithis and Rovithis (1982); 14) Present paper.

such residuals versus HJD is shown in Figure 2a, which clearly shows that the period of this system is decreasing. From the form of this graph, it is seen that the quadratic term in equation (5) is necessary to describe better the times of minima. This quadratic term implies, according to equation (1), a continuous variation of the period.

A quadratic least squares fit gives

$$\begin{aligned} \text{HJD}_{\min} = & 2436511.6706 (\pm 0.0035) + \\ & + 0.3747818 (\pm 1.27 \times 10^{-7}) E - \\ & - 1.08 \times 10^{-10} (\pm 0.0324 \times 10^{-10}) E^2/2. \end{aligned}$$

The residuals obtained from this quadratic ephemeris are shown in the fourth column of Table 3 under the heading (O-C)<sub>Q</sub>. The corresponding plot of residuals versus HJD is shown in Figure 2b. The description of the times of minima given by the quadratic ephemeris is seen to be better. The standard deviation calculated for these quadratic residuals is 0<sup>d</sup>.0024, numerically smaller than the standard deviation obtained for the linear analysis.

b) *AB Andromedae*

This star was analyzed in the same way. The times of minimum light are shown in the first column of Table 5. The accuracy in the period and in the quadratic coefficient were calculated to be  $9 \times 10^{-8}$  d and  $1.63 \times 10^{-12}$  d respectively corresponding to a time span of 50.17 years or 55175 cycles. The residuals for the linear ephemeris

$$\begin{aligned} \text{HJD}_{\min} = & 2440128.7945 (\pm 0.0035) + \\ & + 0.33189114 (\pm 9 \times 10^{-8}) E \end{aligned}$$

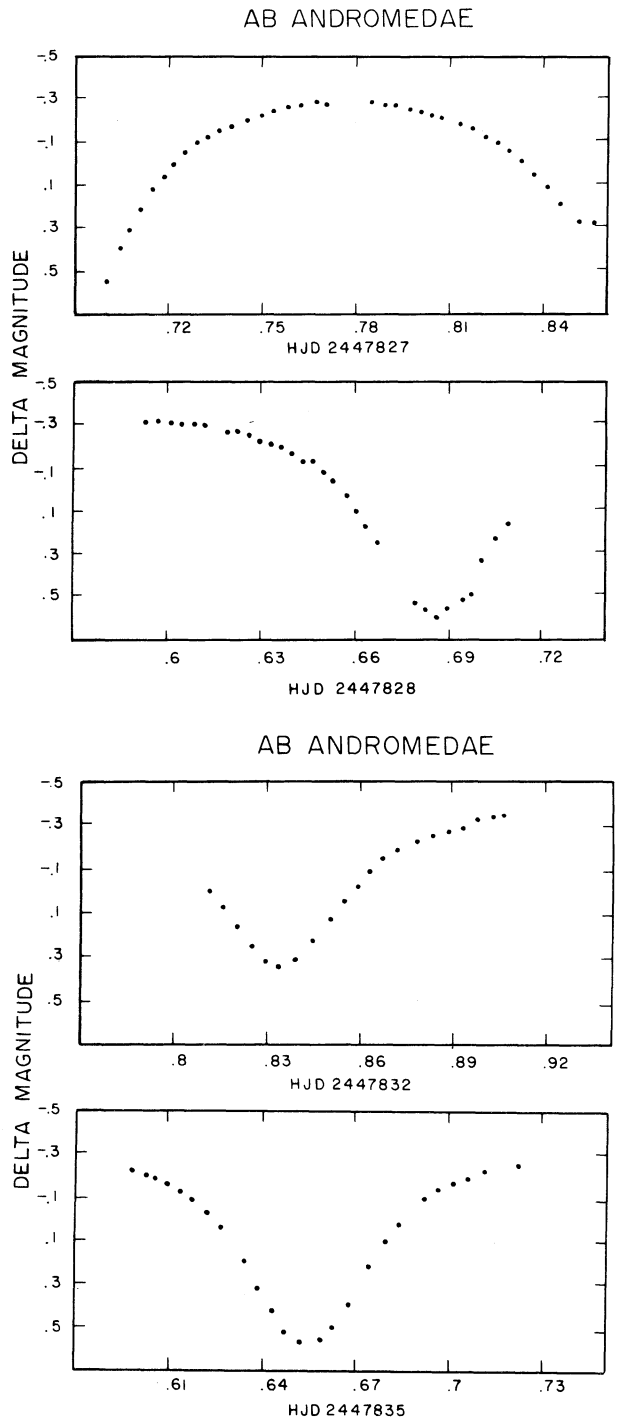


Fig. 3. a), b), c), and d) Light curves of the observed nights of AB And.

are shown in the third column of Table 5 under the heading (O-C)<sub>L</sub>. A standard deviation of 0<sup>d</sup>.013 is calculated. The plot of these residuals versus HJD (Figure 4a) shows that the period is



TABLE 4

| PHOTOELECTRIC OBSERVATIONS OF AB ANDROMEDAE |              |                 |              |                 |              |
|---------------------------------------------|--------------|-----------------|--------------|-----------------|--------------|
| HJD<br>2440000+                             | $\Delta$ MAG | HJD<br>2440000+ | $\Delta$ MAG | HJD<br>2440000+ | $\Delta$ MAG |
| 7827.700                                    | 0.548        | 7828.601        | -0.310       | 7832.862        | -0.083       |
| 7827.705                                    | 0.397        | 7828.604        | -0.306       | 7832.866        | -0.138       |
| 7827.707                                    | 0.308        | 7828.608        | -0.302       | 7832.871        | -0.180       |
| 7827.711                                    | 0.219        | 7828.612        | -0.295       | 7832.877        | -0.221       |
| 7827.715                                    | 0.124        | 7828.619        | -0.268       | 7832.882        | -0.246       |
| 7827.719                                    | 0.061        | 7828.622        | -0.270       | 7832.887        | -0.268       |
| 7827.721                                    | 0.005        | 7828.626        | -0.256       | 7832.892        | -0.280       |
| 7827.726                                    | -0.046       | 7828.629        | -0.222       | 7832.897        | -0.315       |
| 7827.729                                    | -0.089       | 7828.632        | -0.214       | 7832.902        | -0.333       |
| 7827.732                                    | -0.116       | 7828.636        | -0.194       | 7832.905        | -0.338       |
| 7827.737                                    | -0.149       | 7828.639        | -0.171       | ....            | ....         |
| 7827.740                                    | -0.171       | 7828.643        | -0.129       | ....            | ....         |
| 7827.746                                    | -0.199       | 7828.646        | -0.124       | 7835.598        | -0.224       |
| 7827.750                                    | -0.217       | 7828.650        | -0.076       | 7835.602        | -0.202       |
| 7827.753                                    | -0.236       | 7828.653        | -0.034       | 7835.605        | -0.188       |
| 7827.758                                    | -0.261       | 7828.657        | 0.036        | 7835.609        | -0.159       |
| 7827.762                                    | -0.267       | 7828.660        | 0.109        | 7835.613        | -0.128       |
| 7827.767                                    | -0.281       | 7828.664        | 0.179        | 7835.618        | -0.088       |
| 7827.771                                    | -0.277       | 7828.667        | 0.258        | 7835.622        | -0.032       |
| 7827.785                                    | -0.280       | 7828.679        | 0.532        | 7835.627        | 0.036        |
| 7827.789                                    | -0.270       | 7828.682        | 0.567        | 7835.634        | 0.190        |
| 7827.793                                    | -0.260       | 7828.686        | 0.601        | 7835.638        | 0.309        |
| 7827.797                                    | -0.243       | 7828.689        | 0.557        | 7835.643        | 0.420        |
| 7827.801                                    | -0.231       | 7828.694        | 0.514        | 7835.647        | 0.514        |
| 7827.804                                    | -0.216       | 7828.697        | 0.494        | 7835.652        | 0.563        |
| 7827.807                                    | -0.203       | 7828.700        | 0.330        | 7835.659        | 0.552        |
| 7827.813                                    | -0.174       | 7828.705        | 0.228        | 7835.663        | 0.498        |
| 7827.817                                    | -0.152       | 7828.709        | 0.162        | 7835.668        | 0.387        |
| 7827.821                                    | -0.120       | ....            | ....         | 7835.674        | 0.210        |
| 7827.825                                    | -0.089       | ....            | ....         | 7835.679        | 0.101        |
| 7827.829                                    | -0.048       | 7832.811        | 0.004        | 7835.684        | 0.019        |
| 7827.832                                    | -0.004       | 7832.816        | 0.087        | 7835.692        | -0.095       |
| 7827.837                                    | 0.056        | 7832.820        | 0.166        | 7835.696        | -0.139       |
| 7827.841                                    | 0.114        | 7832.825        | 0.253        | 7835.701        | -0.169       |
| 7827.845                                    | 0.189        | 7832.829        | 0.326        | 7835.706        | -0.191       |
| 7827.851                                    | 0.276        | 7832.834        | 0.347        | 7835.711        | -0.222       |
| 7827.856                                    | 0.284        | 7832.839        | 0.315        | 7835.722        | -0.253       |
| ....                                        | ....         | 7832.844        | 0.227        | ....            | ....         |
| ....                                        | ....         | 7832.850        | 0.134        | ....            | ....         |
| 7828.593                                    | -0.312       | 7832.854        | 0.053        | ....            | ....         |
| 7828.596                                    | -0.315       | 7832.858        | -0.013       | ....            | ....         |

smoothly increasing and that a quadratic term in the ephemeris would give a better fit to the residuals than a linear one. The quadratic ephemeris is found to be

$$\begin{aligned} \text{HJD}_{\min} = & 2440128.7945 (\pm 0.0035) + \\ & + 0.33189162 (\pm 9 \times 10^{-8}) E + \\ & + 8.74 \times 10^{-11} (\pm 0.16 \times 10^{-11}) E^2/2. \end{aligned}$$

The O-C residuals for this ephemeris are shown in the fourth column of Table 5 under the heading (O-C)<sub>Q</sub> and are plotted versus HJD in Figure 4b. It can be seen that this quadratic ephemeris gives a better description than the linear one. The standard deviation of these residuals is  $\sigma_{\alpha} = 0.008$  which is less than the corresponding value for the linear ephemeris.

TABLE 5

AB ANDROMEDAE  
TIMES OF MINIMA AND O-C RESIDUALS  
FOR LINEAR AND QUADRATIC FITS

| HJD          | Min. | (O-C) <sub>L</sub> | (O-C) <sub>Q</sub> | Ref. |
|--------------|------|--------------------|--------------------|------|
| 2429523.5830 | I    | 0.03812            | 0.00886            | 1    |
| 2429550.6312 | II   | 0.03719            | 0.00812            | 2    |
| 2429907.7398 | II   | 0.03092            | 0.00428            | 2    |
| 2430257.8803 | II   | 0.02626            | 0.00191            | 2    |
| 2430611.8379 | I    | 0.02195            | -0.00019           | 2    |
| 2430962.6450 | I    | 0.02012            | 0.00006            | 1    |
| 2431046.6150 | I    | 0.02166            | 0.00209            | 1    |
| 2431350.4580 | II   | 0.01831            | 0.00046            | 2    |
| 2431707.9018 | II   | 0.01535            | -0.00058           | 2    |
| 2432133.0469 | II   | 0.00790            | -0.00588           | 2    |
| 2432413.1603 | II   | 0.00517            | -0.00727           | 2    |
| 2432793.6710 | I    | 0.00267            | -0.00804           | 1    |
| 2433207.3684 | II   | -0.00224           | -0.01121           | 2    |
| 2433886.5780 | I    | -0.00786           | -0.01428           | 3    |
| 2434264.6000 | I    | -0.00988           | -0.01502           | 4    |
| 2435075.4070 | I    | -0.01294           | -0.01575           | 5    |
| 2435370.4600 | I    | -0.01117           | -0.01326           | 6    |
| 2435782.3360 | I    | -0.01208           | -0.01328           | 7    |
| 2436069.4210 | I    | -0.01292           | -0.01357           | 8    |
| 2436109.5784 | I    | -0.01440           | -0.01498           | 9    |
| 2436124.6801 | II   | -0.01371           | -0.01427           | 9    |
| 2436132.6461 | II   | -0.01309           | -0.01364           | 9    |
| 2440128.7945 | I    | 0.00000            | 0.00000            | 10   |
| 2440129.7901 | I    | -0.00009           | -0.00010           | 10   |
| 2440131.7816 | I    | 0.00003            | 0.00003            | 10   |
| 2440158.6648 | I    | 0.00007            | 0.00002            | 10   |
| 2440158.8313 | II   | 0.00060            | 0.00056            | 10   |
| 2440828.7568 | I    | 0.00388            | 0.00267            | 11   |
| 2440828.9226 | II   | 0.00373            | 0.00252            | 11   |
| 2440829.7525 | I    | 0.00390            | 0.00269            | 11   |
| 2440829.9181 | II   | 0.00356            | 0.00235            | 11   |
| 2440883.6855 | II   | 0.00459            | 0.00327            | 11   |
| 2440883.8511 | I    | 0.00425            | 0.00293            | 11   |
| 2440885.6769 | II   | 0.00465            | 0.00332            | 11   |
| 2440885.8427 | I    | 0.00450            | 0.00318            | 11   |
| 2440886.6728 | II   | 0.00487            | 0.00355            | 11   |
| 2440886.8382 | I    | 0.00433            | 0.00300            | 11   |
| 2444136.3931 | I    | 0.01304            | 0.00086            | 12   |
| 2444136.5579 | II   | 0.01189            | -0.00029           | 12   |
| 2444137.3871 | I    | 0.01136            | -0.00082           | 12   |
| 2444137.5525 | II   | 0.01082            | -0.00137           | 12   |
| 2444138.5486 | II   | 0.01124            | -0.00095           | 12   |
| 2444912.0257 | II   | 0.01603            | 0.00002            | 13   |
| 2444912.8597 | I    | 0.02031            | 0.00429            | 13   |
| 2444913.8542 | I    | 0.01913            | 0.00311            | 13   |
| 2445260.8456 | II   | 0.01834            | 0.00045            | 13   |
| 2445261.0098 | I    | 0.01660            | -0.00129           | 13   |
| 2445262.8367 | II   | 0.01809            | 0.00020            | 13   |
| 2445263.0015 | I    | 0.01695            | -0.00095           | 13   |
| 2447828.6893 | I    | 0.02026            | -0.01442           | 14   |

TABLE 5 (CONTINUED)

| HJD          | Min. | (O-C) <sub>L</sub>     | (O-C) <sub>Q</sub> | Ref. |
|--------------|------|------------------------|--------------------|------|
| 2447832.8336 | II   | 0.01592                | -0.01879           | 14   |
| 2447835.6538 | I    | 0.01505                | -0.01969           | 14   |
| $\sigma = 0$ |      | .01297 (Linear fit)    |                    |      |
| $\sigma = 0$ |      | .00752 (Quadratic fit) |                    |      |

1) Woodward 1951; 2) Oosterhoff 1950; 3) Domke and Pohl 1952; 4) Ashbrook 1952, 1953; 5) Szafraniec 1955; 6) Szafraniec 1956; 7) Szafraniec 1957; 8) Satanova and Grigorevsky 1957; 9) Binnendijk 1959; 10) Landolt 1969; 11) Riegerink 1973. 12) Rovithis-Livaniou and Rovithis 1981; 13) Bell, Hilditch and King 1984; 14) Present paper.

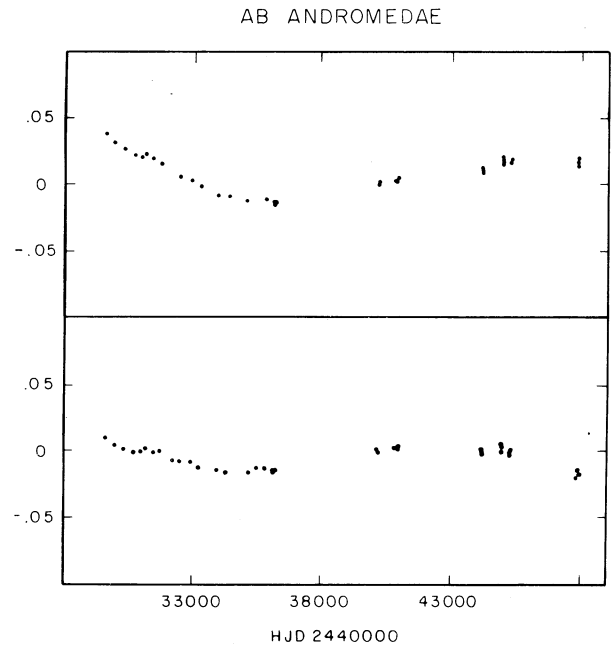


Fig. 4. a) O-C residuals versus HJD for AB And from the linear ephemeris  $HJD = 2440128.7945 + 0.33189114 E$  derived in this paper. b) O-C residuals versus HJD from the quadratic ephemeris  $HJD = 2440128.7945 + 0.33189162 E + 8.74 \times 10^{-11} E^2/2$  derived in the present paper.

#### IV. DISCUSSION

From the analysis of the period behavior carried out in this paper, one can safely conclude that U Pegasi has a smoothly decreasing period with a rate of change of  $-0.91$  s/century, while the period of AB Andromedae is continuously increasing at the rate of  $0.83$  s/century. The O-C residuals of this quadratic fit suggest a sinusoidal variation that, in general, is explained by the presence of a third unseen object. More observations are encouraged

TABLE 6  
wavy-H $\beta$  PHOTOELECTRIC OBSERVATIONS  
OF U PEG AND AB AND

| Star   | V     | b-y   | m <sub>1</sub> | c <sub>1</sub> | H $\beta$ | HJD      | Phase  |
|--------|-------|-------|----------------|----------------|-----------|----------|--------|
|        |       |       |                |                |           | 2447838+ |        |
| AB And | ....  | ....  | ....           | ....           | 2.558     | 0.6922   | 0.0554 |
| AB And | 9.570 | 0.546 | 0.340          | 0.278          | ....      | 0.6926   | 0.0558 |
| AB And | ....  | ....  | ....           | ....           | 2.579     | 0.7370   | 0.1002 |
| AB And | ....  | ....  | ....           | ....           | 2.563     | 0.7387   | 0.1019 |
| AB And | 9.566 | 0.542 | 0.340          | 0.289          | ....      | 0.7388   | 0.1020 |
| AB And | ....  | ....  | ....           | ....           | 2.582     | 0.7395   | 0.1027 |
| U Peg  | ....  | ....  | ....           | ....           | 2.620     | 0.7485   | 0.0476 |
| U Peg  | ....  | ....  | ....           | ....           | 2.587     | 0.7498   | 0.0489 |
| U Peg  | ....  | ....  | ....           | ....           | 2.589     | 0.7517   | 0.0508 |
| U Peg  | ....  | ....  | ....           | ....           | 2.584     | 0.7528   | 0.0519 |
| U Peg  | ....  | ....  | ....           | ....           | 2.578     | 0.7546   | 0.0537 |
| U Peg  | 9.488 | 0.398 | 0.184          | 0.347          | ....      | 0.7548   | 0.0539 |
| U Peg  | ....  | ....  | ....           | ....           | 2.603     | 0.7555   | 0.0546 |
| U Peg  | ....  | ....  | ....           | ....           | 2.604     | 0.7573   | 0.0564 |
| U Peg  | ....  | ....  | ....           | ....           | 2.598     | 0.7593   | 0.0584 |

in order to increase the time span for U Peg and AB And and so to obtain more accurate values for the rate of change of their periods.

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