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$uvby\beta$ PHOTOMETRY OF THE RR LYRAE STAR AT AND

J. H. Peña and R. Peniche[1]

Instituto de Astronomía
Universidad Nacional Autónoma de México

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RESUMEN

Se presenta fotometría Strömgren $uvby\beta$ de la estrella AT And. Del análisis de estos datos se corrobora la constancia del período compilado por Kholopov (1985). La fotometría de Strömgren se ha utilizado para la determinación del enrojecimiento y de los parámetros físicos $\log g$ y $\log T_e$ así como la metalicidad [Fe/H]. Se discute la determinación de M_V considerando a AT And como una estrella del tipo RR de Lira.

ABSTRACT

Strömgren $uvby\beta$ photoelectric photometry of the variable star AT And is presented. Analysis of this data corroborates the periods compiled by Kholopov (1985). Strömgren photometry has been used for the determination of reddening and the physical parameters $\log g$ and $\log T_e$, as well as the metallicity [Fe/H]. The determination of M_V is discussed assuming AT And is an RR Lyrae star.

Key Words: **PHOTOMETRY — STARS: VARIABLES (RR LYRAE)**

1. INTRODUCTION

The variable star catalogue (Kholopov 1985) lists the following for AT And: ΔV variation within the range 10.42 to 10.92, with spectral class F0-F7; it is classified as a RRAB star. On the other hand, Simbad reports it to be a Variable Star of RR Lyrae type of V mag of 10.78 and spectral type F2.5; however, AT And is unusual in the sense that it might not be a regular RRAb star; Fernley & Barnes (1997) consider that it may be an anomalous Cepheid.

The analysis presented here is similar to a study of AC And (Peña et al. 2003, hereinafter Paper I) which was motivated by the works of Kovacs & Buchler (1994), and Fernie (1994). In the latter, Fernie speculates that it would be extremely useful to have new photometry, carried out in a system such as Strömgren or Geneva, that would provide checks on the metallicity, luminosity, temperature, etc., of AC And; this, of course, can be generalized for other RR Lyrae stars. Kovacs & Buchler (1994) mention the difficulties they encountered while modelling AC And and they specifically propose the obtention of an accurate value of Z, the determination of the temperature and the luminosity of the star, a precise determination of the period changes with a more precise analysis of the already existing data and with the combination with new observations. Since both Kovacs & Buchler (1994) and Fernie (1994) have pointed out that Strömgren $uvby\beta$ photometry provides unique opportunities for determining physical characteristics of stars, a photometric campaign of AT And was carried out in 1992.

Hence we can summarize goal of the present paper to be the obtainment of new observations of this star in both $uvby$ and Hβ. Considering this star to be an RR Lyrae, we have calculated its reddening and hence derived its unreddened colors. Physical parameters have been calculated.

[1] Deceased.

2. OBSERVATIONS

As in the case of AC And in Paper I, the observations of AT And were carried out at the Observatorio Astronómico Nacional, México. The telescope employed in the campaign was the 1.5 m telescope to which the spectrophotometer was attached. As has already been mentioned, this instrument is capable of observing simultaneously in the $uvby$ filters of the Strömgren system and, almost simultaneously, in the N and W filters that define the Hβ index. The description of the photometric equipment can be found in Schuster & Nissen (1988).

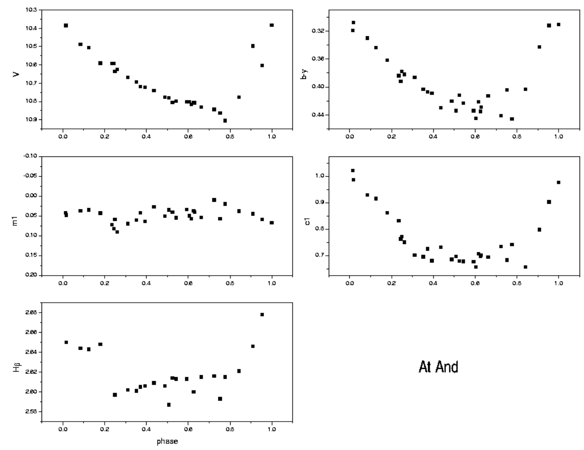

Fig. 1. Final photometric results of AT And are presented schematically (dots). These values are in excellent agreement with those of Epstein & Epstein (1973) (crosses) which are also in Strömgren $uvby\beta$ system. The ephemerides utilized to calculate the phase were those of Kholopov (1985).

The reduction to the instrumental system has been described extensively in Paper I. In it, both the procedure and the accuracy attained in this season were reported. Each measurement consisted of five ten-second integrations of each star and one ten-second integration of the sky for the $uvby$ filters and five ten-second integrations for the narrow and wide filters, with one ten-second integration of the sky. The percentage error in each measurement of AT And is δ $(u, v, b, y,$ N, W$)$ = (0.010, 0.008, 0.007, 0.009, 0.011, 0.011) magnitudes and the accuracy in time is 0.0024 d. A set of standard stars was observed to transform the instrumental observations into the standard system. The final accuracy of the season has been obtained from a direct comparison of the photometric values from the standard stars compared to the values from the literature. This comparison was shown in Figure 1 of Paper I in which emphasis was put on the range of magnitudes and color indexes, which lie well above the values at which AT And lies. Furthermore, a linear fit of the obtained versus the literature values gives the coefficients shown in Table 1 of Paper I. These values can be considered to be the uncertainties of the measurements.

The final photometric results of AT And are presented schematically (dots) in Figure 1 and listed in Table 1 (available in the electronic version of this paper, at www.astroscu.unam.mx) in which Column 1 is the HJD for the $uvby$ system; Columns 2 the V magnitude, Columns 3 to 5 the color indexes $b-y$, m_1, and c_1; Column 6 gives the Hβ index. The HJD of the Hβ is not presented because the difference between both times is very small (less than 0.001 d minimizing noise by interpolating the HJD's of the Hβ to that of the $uvby$ values, so it will be assumed to be the same as the $uvby$ times). In order to have representative numerical values, mean values were calculated at minimum light and are presented in Table 2; also shown are the $[m_1]$, $[c_1]$ unreddened indexes calculated from the means. These values are in excellent agreement with those of Epstein & Epstein (1973) which refer also to the Strömgren $uvby\beta$ system. They list the following values: 0.42, 0.08, 0.68, for $(b-y)$, m_1, and c_1 at minimum light.

3. REDDENING DETERMINATION

Since a reddening determination is needed before a direct comparison with the theoretical models can be made, it was done through the calibrations proposed by Nissen (1988), which are based on the intrinsic color indexes. The results of using the above mentioned prescription were calculated for all phases, but were later restricted for minimum light to avoid the times near maximum light. Then, a mean $E(b-y)$ was calculated between phases 0.3 to 0.75 as 0.1247 with a standard deviation of 0.0246. The obtained value is consistent with that determined by Epstein & Epstein (1973) of 0.08 mag for AT And. Once the reddening had been determined, unreddened colors were evaluated from the well-known relations $E(c_1) = 0.2$, $E(b-y)$, and $E(m_1) = -0.18\ E(b-y)$. These values are listed in Table 3 (available in the electronic version of this paper, at www.astroscu.unam.mx) by increasing phase. The table includes the following: Column 1 the time in days of the $uvby$ system, consecutively, the phase utilizing the ephemerides of Kholopov (1985); in subsequent columns the unreddened V_0, $(b-y)_0$, m_0, c_0, β, are presented and, finally, the $u-b$ and the unreddened indexes $[m_1]$ and $[c_1]$. It is important to point out that AT And is at all times an F star, consistent with the report of the Variable Star Catalogue. These data are unique because, as has been stated, no interpolation over time is required and the data provide the possibility of calculating the physical variations of a periodic star as a function of phase. Emphasis should be made on the fact that a whole-cycle coverage was obtained with only three consecutive nights of observation and that, when calculated in phase, the data describe the whole-cycle; the mean photometric values were evaluated only

TABLE 2

MEAN MAGNITUDES AND COLOR INDEXES FOR AT AND AT MINIMUM LIGHT

Star	$\langle V\rangle$	$\langle b-y\rangle$	$\langle[m_1]\rangle$	$\langle c_1\rangle$	$N_{\rm obs}$	Hβ	$N_{\rm obs}$	$\langle[m_1]\rangle$	$\langle[c_1]\rangle$
AT And	10.775	0.418	0.046	0.697	14	2.606	14	0.121	0.613

between phases 0.3 and 0.75, as proposed by McNamara (1997) for eluding the zones of maximum activity of a pulsating star, and are presented at the end of Table 3.

The metallicity, (Nissen 1988), is determined only when the stars are in the F spectral type stage. The mean determined [Fe/H] value was 1.0759 ± 0.0994. To corroborate this value, Preston (1959) was considered. For AT And he lists five spectral classifications for phases between 0.01 and 0.55; considering the well-known relation of $\Delta S = 10$ [Sp(H) – Sp(Ca II)] he reports for AT And a ΔS value of 3 for spectral types at minimum light. This value (Suntzeff, Kraft, & Kinman 1994) is transformed for RRAB stars through $[{\rm Fe/H}] = -0.158\Delta S - 0.408$ into 0.882, a value close, within the uncertainties given, to that obtained in the present paper.

There are several ways to determine the absolute magnitude. This can be done by assuming that AT And is a RR star (which has been disputed); then the relation as a function of the metallicity proposed by McNamara (1997) $M_V = 0.287$ [Fe/H] $+0.964$ can be employed which, for our metallicity value of 1.0759 ± 0.0994 gives 0.655 ± 0.029 mag; more recent evaluations of the M_V for RR Lyrae stars have been developed by, among others, McNamara (2001, $M_V = 0.30$ [Fe/H] $+0.92$), which is based mainly on the results derived from globular clusters, Carreta et al. (2000; M_V (RR) = 0.18 ([Fe/H]+1.5) + 0.73), Gratton et al. (1997; M_V (RR) = (0.22 ([Fe/H] + 1.5) + 0.43), and Groenewegen & Salaris (1999; $M_V = 0.18$ [Fe/H] + 0.77), which are based on Hipparcos parallaxes. The summary of the results is presented in Table 4.

As can be seen, independently of the method, the absolute magnitude values yield basically the same results. The distance was evaluated in the customary way considering a mean value of the mean apparent visual magnitude for all phases (10.1696 ± 0.1380 mag) or for minimum light (10.2837 ± 0.0584 mag), and the M_V value for each author. The results are listed in Table 4 and the mean distance value, assumed as characteristic of AT And is 824 ± 39 pc (distance modulus of 9.58 ± 0.10 mag). Other physical quantities, like $\log T_e$ and $\log g$, depend on the intrinsic colors of the star along the cycle.

4. PHYSICAL PARAMETERS

The determination of effective temperature and surface gravity can be done from the mean intrinsic color indexes already presented. The unreddened values of the star $(b-y)_0$ and c_0 are used to obtain $\log T_e$ and $\log g$ by positioning these indexes on the theoretical model grids of Lester, Gray, & Kurucz (1986) and are shown schematically in Fig. 2. We find that the $(b-y)_0$ and c_0 indexes describe a loop within the $T_{\rm eff}$ limits of 6000 and 7000 K and around a $\log g$ of 3.0. The $\langle(b-y)_0\rangle$ and $\langle c_0\rangle$ indexes of AT And give a $\langle T_{\rm eff}\rangle = 6100$ K and $\langle\log g\rangle = 2.5$ which gives the bulk characteristics, but no detail around the different phases. Other possibilities for determining the temperatures, assuming the star is an RR Lyrae star, might be the numerical relations found empirically by McNamara (1997) who gives $\langle T_{\rm eff}\rangle = -1039\log P + 6467$ and $\langle T_{\rm eff}\rangle = 108$ [Fe/H] + 6874. In these cases, once the period and the metallicity have been found, the corresponding $\langle T_{\rm eff}\rangle$ values are 6685 K and 6758 K, respectively, hotter but still within the temperature range of the values determined from the Lester et al. (1986) grids.

5. PERIODIC CONTENT OF AT AND

Since one of the most important characteristics needed to define the nature of a variable star is the determination of its periodic content, it is unavoidable to determine, or to confirm the periodic content of AT And. Kovacs & Buchler (1994) recommend that "*the period change should be further studied with more precise analysis of the already existing data and with the combination of new observations*". In view of this statement, the accuracy of the period was tested using available data which provide a long time basis to verify the frequencies of pulsation with sufficient precision and to corroborate their constancy.

The only other data in the Strömgren $uvby\beta$ photoelectric photometry of the variable star AT And known to us with a long time basis is that of Epstein (1969), which provides a time span of 8674 days (or 14060 cycles given the ephemerides

TABLE 4

ABSOLUTE MAGNITUDE AND REDDENING VALUES OF AC AND

M_V	Distance	Method	Remarks
0.655	826	[Fe/H]	McNamara (1997)
0.5763	856	[Fe/H]	Groenewegen & Salaris (1999)
0.5972	847	[Fe/H]	McNamara (2001)
0.8063	770	[Fe/H]	Carreta et al. (2000)

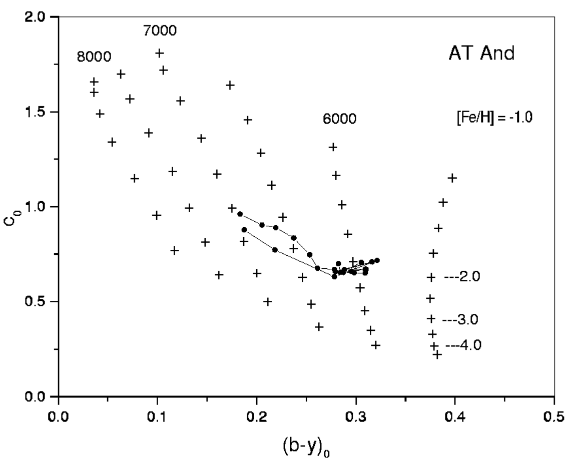

Fig. 2. Position of the loop described by AT And along the cycle of pulsation on the theoretical grids of Lester et al. (1986).

of Kholopov (1985): epoch = 2442343.4205, period = 0.61691475 d. What we have done is to merely form the combined data sets and put them in phase utilizing the above mentioned ephemerides. The results are amazing (Fig. 1) since no phase shift can be observed in either the magnitude or the color indexes, confirming the constancy of the determined period at least during the 24 yr time basis.

6. DISCUSSION

From what has been said, the RRAB nature of AT And has been questioned by Fernley & Barnes (1997) who consider that it may be an anomalous Cepheid. Its true nature should be unequivocally revealed by accurately determining its periodic content as well as by fixing its position in the H-R diagram or in the PLR or, once the physical parameters are determined, by comparing these observed photometric values with theoretical models.

As in Paper I, we might consider Fernie's (1994) point of view for the sake of discussion. We now know that the period of AT And is indisputable. Hence, the location of AT And on the $X-$axis (Period in days) in Fig. 1 of Fernie (1994), Fig. 3, is correct and locating it on the $Y-$axis $\langle M_V \rangle$ could lead us to a circular argument since we are assuming it is a RR Lyrae star. However, if we consider that AT And might be a RR Lyrae star, we would have to look where the rest of the RR Lyrae stars would lie in this diagram. To fill the gap we might consider a sample of these stars provided by McNamara (1997). If we take his data into account for the absolute magnitudes of such stars, as well as their periods, and position them in Fernie's (1994) Fig. 1, they do not lie on the line joining δ Scuti and Cepheid stars, but on a parallel line, one magnitude above (Fig. 3). As we can see, however, AT And lies perfectly well in the RR Group both according to the period values as well as to the M_V range. From this, we do not find any suggestion that AT And cannot be a RR Lyrae star. Hence, given the position of the RR Lyrae stars, their periods, their magnitudes and the uncertainties of the absolute magnitude derived here (±0.10 mag), as well as its metallicity, effective temperature and surface gravity, we prefer to assume that AT And is an RR Lyrae star.

7. CONCLUSIONS

We have presented new observations in multicolor Strömgren photometry of this star; we have confirmed the constancy of the period; we have determined the metallicity, the reddening and the distance to the star; the physical parameters $\log g$ and $\log T_{\rm eff}$ have been evaluated along the cycle of pulsation. Finally, in conclusion, we have parameterized the badly needed data for theoreticians to fulfill their aims.

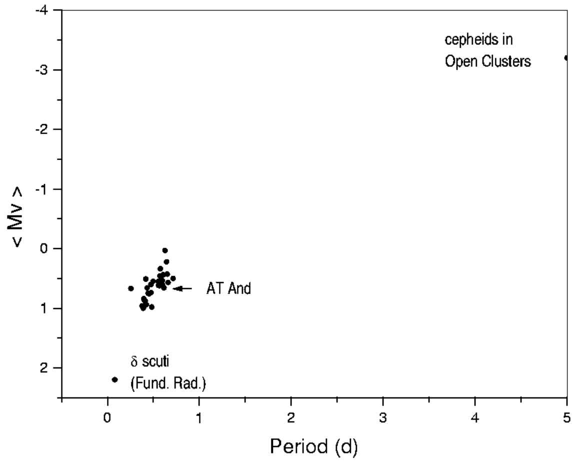

Fig. 3. Location of AT And and some other RR Lyrae stars in the Period-Luminosity relation common to classical Cepheids and δ Scuti stars taken from Fernie (1994).

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José H. Peña: Instituto de Astronomía, UNAM, Apdo. Postal 70-264, México, D. F., México (jhpena@astroscu.unam.mx).

TABLE 1

$uvby\beta$ PHOTOELECTRIC PHOTOMETRY OF AT AND

Time	V	$b-y$	m_1	c_1	$H\beta$
92.74136	10.635	0.378	0.059	0.772	2.597
92.77905	10.667	0.386	0.070	0.702	2.602
92.80452	10.693	0.403	0.061	0.695	2.601
92.8301	10.723	0.409	0.064	0.680	2.606
92.88829	10.776	0.420	0.051	0.685	2.606
92.91092	10.805	0.412	0.041	0.679	2.614
92.92225	10.799	0.423	0.055	0.678	2.613
93.66855	10.864	0.404	0.057	0.683	2.593
93.72366	10.776	0.403	0.038	0.657	2.621
93.76469	10.497	0.343	0.045	0.798	2.646
93.79259	10.604	0.312	0.059	0.903	2.678
93.8319	10.384	0.308	0.048	0.986	2.650
93.87316	10.488	0.330	0.037	0.929	2.644
93.89821	10.506	0.344	0.035	0.915	2.643
93.93182	10.590	0.362	0.043	0.861	2.648
94.66731	10.719	0.407	0.042	0.725	2.605
94.70723	10.740	0.430	0.027	0.732	2.609
94.80367	10.802	0.434	0.034	0.676	2.613
94.82389	10.807	0.435	0.037	0.696	2.600
94.8463	10.830	0.413	0.054	0.694	2.615
94.88435	10.843	0.441	0.010	0.734	2.616
94.91713	10.904	0.446	0.020	0.742	2.615
94.75153	10.781	0.434	0.035	0.696	2.587

Time shown = HJD -2448800

TABLE 3

UNREDDENED COLOR INDEXES AND PHOTOMETRIC VALUES FOR THE STAR AT AND

time	phase	V_0	$(b-y)_0$	m_0	c_0	$H\beta$	$[u-b]$	$[m_1]$	$[c_1]$
93.8319	0.0504	9.848	0.183	0.070	0.961	2.65	1.698	0.103	0.924
93.8732	0.1173	9.952	0.205	0.059	0.904	2.644	1.663	0.096	0.863
93.8982	0.1579	9.970	0.219	0.057	0.890	2.643	1.673	0.097	0.846
93.9318	0.2124	10.054	0.237	0.065	0.836	2.648	1.671	0.108	0.789
92.7414	0.2827	10.099	0.253	0.081	0.747	2.597	1.646	0.127	0.696
92.7791	0.3437	10.131	0.261	0.092	0.677	2.602	1.614	0.139	0.625
92.8045	0.3850	10.157	0.278	0.083	0.670	2.601	1.623	0.134	0.614
94.6673	0.4046	10.183	0.282	0.064	0.700	2.605	1.623	0.115	0.644
92.8301	0.4265	10.187	0.284	0.086	0.655	2.606	1.626	0.138	0.598
94.7072	0.4693	10.204	0.305	0.049	0.707	2.609	1.646	0.104	0.646
92.8883	0.5208	10.240	0.295	0.073	0.660	2.606	1.627	0.127	0.601
94.7515	0.5411	10.245	0.309	0.057	0.671	2.587	1.634	0.113	0.609
92.9109	0.5575	10.269	0.287	0.063	0.654	2.614	1.585	0.115	0.597
92.9223	0.5759	10.263	0.298	0.077	0.653	2.613	1.634	0.131	0.593
94.8037	0.6256	10.266	0.309	0.056	0.651	2.613	1.612	0.112	0.589
94.8239	0.6584	10.271	0.310	0.059	0.671	2.600	1.640	0.115	0.609
94.8463	0.6947	10.294	0.288	0.076	0.669	2.615	1.628	0.128	0.611
94.8844	0.7564	10.307	0.316	0.032	0.709	2.616	1.636	0.089	0.646
93.6686	0.7856	10.328	0.279	0.079	0.658	2.593	1.605	0.130	0.602
94.9171	0.8095	10.368	0.321	0.042	0.717	2.615	1.674	0.100	0.653
93.7237	0.8749	10.240	0.278	0.060	0.632	2.621	1.539	0.111	0.576
93.7647	0.9414	9.961	0.218	0.067	0.773	2.646	1.574	0.107	0.729
93.7926	0.9867	10.068	0.187	0.081	0.878	2.678	1.645	0.115	0.841
Mean at Minimum	0.5532	10.239	0.293	0.068	0.672	2.6057		0.121	0.613
Std. dev	0.1389	0.058	0.016	0.016	0.020	0.0086		0.014	0.020

Time shown = HJD − 2448800