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AN Lyn: an unusual medium amplitude δ Sct star

E. Rodríguez[1], **S.F. González-Bedolla**[2,⋆], **A. Rolland**[1], **V. Costa**[1], **and P. López de Coca**[1]

[1] Instituto de Astrofísica de Andalucía, CSIC, Apartado 3004, E-18080 Granada, Spain
[2] Instituto de Astronomía, UNAM, Apartado 70-264, CP-4510 México D.F., Mexico

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Abstract. Simultaneous *uvby*β photometric observations of the medium amplitude δ Sct star AN Lyn have been collected and new times of light maxima have been obtained. The Fourier transform and classical O-C methods are used to analyse the pulsation of this star. The light curves are peculiar in the sense that the descending branches are steeper than the ascending ones. Amplitude variations are shown to be present from season to season. The analysis of the phase shifts between observed light and colour variations suggests that this star is a radial pulsator. In addition, intrinsic b-y, m_1 and c_1 values are also derived and the physical parameters are determined indicating that this variable is a nearly cold and evolved δ Sct star showing solar metal abundances and pulsating in the second overtone.

Key words: stars: variables: δ Scu – stars: individual: AN Lyn – stars: oscillations – techniques: photometric

1. Introduction

AN Lyn (BD+43°1894) is a pulsating star type δ Sct of medium amplitude and short period (ΔV=$0.^{m}18$, P=$0.^{d}0983$, Rodríguez et al. 1994). This star was discovered as variable by Yamasaki et al. (1981) in the UBV system of Johnson during the course of photometric observations of an eclipsing variable where AN Lyn was used as the comparison star. New photometric observations were collected by Yamasaki et al. (1983) in V, Pensado (1983) in UBV and Costa et al. (1984) with a filter similar to *b* of the Strömgren system. In addition, Agerer et al. (1983) reported some photographic and V photometric times of light maxima. From these works it seems that AN Lyn is a monoperiodic medium amplitude δ Sct star with a period of $0.^{d}0982739$. However, the monoperiodicity of this star has been the subject of controversy by Poretti et al. (1990) who reanalysed the data of Yamasaki et al. (1983). Nevertheless, Poretti et al. (1990) could not determine any reliable secondary frequency.

On the other hand, it has been pointed by earlier authors that two observationally different groups of pulsators seem to coexist among the δ Sct stars: First, variables with low amplitudes of pulsation (full visual amplitudes smaller than roughly $0.^{m}1$) where complex frequency spectra, nonradial pulsation, variable amplitudes of the nonradial modes with time scales of years and large rotational velocities are common. Second, variables with high amplitudes of pulsation (full visual amplitudes greater than roughly $0.^{m}3$) where simple frequency spectra, radial pulsation, no variability of the amplitudes and very small rotational velocities seems to be the role. However, we know (Rodríguez et al. 1994) only a few δ Sct pulsators of medium amplitude (full visual amplitudes between $0.^{m}1$ and $0.^{m}3$) as compared with the total group (they are less than 5% of the total number of δ Sct stars) and the number of monoperiodic variables among these stars is much less. Thus, AN Lyn promises to be a good object to study.

2. Observations

In order to analyse the light curves and physical parameters of AN Lyn we have collected simultaneous *uvby*β photometry of this star during the years 1994 and 1995 at the observatories of San Pedro Mártir, Mexico (1.5m telescope) and Sierra Nevada, Spain (0.9m telescope). Both telescopes are equipped with identical six-channel *uvby*β spectrograph photometers for simultaneous measurements in *uvby* and the narrow and wide H_β channels, respectively (Grønbech et al. 1976; Grønbech & Olsen 1977; Nielsen 1983). Twelve nights were devoted to measuring AN Lyn using the four *uvby* filters and two more nights using *uvby*β.

In these observations, HD 78512 was used as the main comparison star and HD 78572 and HD 79281 as check stars. The data obtained, as magnitude differences variable minus C1=HD 78512 in the standard system versus Heliocentric Julian Day, have been deposited in the Commission 27 IAU Archives of Unpublished Observations, file 320E, and can also be requested from the authors. As an example, the *v* observed light curves are plotted in Fig. 1 with the Fourier fitting obtained in Sect. 3.1. During the observations reported here, neither of the comparison stars showed any sign of variability.

Send offprint requests to: E. Rodríguez (eloy@iaa.es)
⋆ Deceased

To transform our data into the standard $uvby\beta$ system we have used two different sets of transformation equations corresponding to the two different data sets collected at San Pedro Mártir and Sierra Nevada Observatories. In the first case, we have used the transformation equations derived by González-Bedolla et al. (1995, priv. comm.) with typical deviations in the transformations of: $0.^{m}012$, $0.^{m}007$, $0.^{m}007$, $0.^{m}007$ and $0.^{m}009$ for V, b-y, m_1, c_1 and β, respectively. In the second case, a set of standard stars was selected during the present work from the list of Crawford & Mander (1966) and Crawford & Barnes (1970). The typical deviations obtained in these transformation equations were: $0.^{m}007$, $0.^{m}005$, $0.^{m}006$, $0.^{m}005$ and $0.^{m}007$, respectively. After these transformations, the two data sets showed very good agreement with each other.

3. Results

3.1. Frequencies

Analysis of frequencies was carried out using the Discrete Fourier Transform method, as described in López de Coca et al. (1984), on our data in the *v* filter. The periodograms showed a principal peak at ν=10.1757 cd^{-1}, very close to that frequency which corresponds to the period P=$0.^{d}0982739$ derived from earlier works. After prewhitening for this frequency, the resulting periodogram suggests that there is another peak at 9.56 cd^{-1} with very low amplitude ($\sim0.^{m}004$) as compared with the amplitude of the main peak ($\sim0.^{m}094$). Similar results are found when the filter *b* is analysed. Nevertheless, for the other two *uy* filters the existence of the secondary frequency is not evident: in these two last cases, the noise and also the power at low frequencies are too large. It is the same as that occurring when other data sets, from earlier authors, are analysed: no signals of secondary frequencies are found in the spectra. Then, we must regard the secondary frequency as not definitive: more data are necessary to obtain conclusions.

Assuming AN Lyn as a monoperiodic pulsator, the classical O-C method has been applied to our data. Seventeen times of light maxima (listed in Table 1) were obtained as averages over the three *vby* bands using the method described in Rodríguez et al. (1990). We adopted as initial epoch T_0=$2449398.^{d}7497$ (our first light maximum) and P=$0.^{d}0982739$ (derived by us from earlier authors). A least squares fit of a linear ephemeris leads to the following elements: T=$2449398.^{d}7489$ ($\pm$0.0005) and P=$0.^{d}09827342$ ($\pm$0.00000015). Resulting cycles E_i and residuals O-C are listed in the third and fourth column of Table 1. The standard deviation of the fit is of $0.^{d}0009$. This value seems to be good and the residuals appears to be randomly distributed around zero. Then this linear ephemeris seems to be good enough to describe our data.

Table 2 lists the results of the Fourier decomposition applied to our data using the frequency corresponding to the period obtained above. Fig. 1 shows the observed light curves in the *v* band with the Fourier fitting versus Heliocentric Julian Day. As can be seen, the synthetic light curves seem to reproduce the data satisfactorily.

Table 1. Times of maxima of AN Lyn obtained in this work with the resulting cycles E_i and residuals O-C

i	T_i(HJD) 2400000.+	E_i (cycles)	(O–C) (days)
1	49398.7497	0	0.0008
2	49398.8478	1	0.0007
3	49398.9439	2	-0.0015
4	49701.0376	3076	-0.0003
5	49702.0202	3086	-0.0005
6	49703.0036	3096	0.0002
7	49704.9687	3116	-0.0002
8	49705.9516	3126	0.0000
9	49706.9355	3136	0.0012
10	49707.0329	3137	0.0003
11	49736.5132	3437	-0.0014
12	49737.3999	3446	0.0008
13	49737.4960	3447	-0.0014
14	49739.4630	3467	0.0002
15	49740.5447	3478	0.0009
16	49741.5269	3488	0.0003
17	49742.4109	3497	-0.0013

However, we have also tried to analyse our maxima together with all those available in the literature but a definite conclusion about the behaviour of the period of AN Lyn has not been obtained. Probably an effect of binarity is present in this star. More observations are necessary in order to understand the whole set of times of light maxima of this star.

3.2. Amplitude variations

Table 2 shows that the amplitude in the V band is, for the first harmonic, of $0.^{m}0671$ ($\pm$0.0007). This value is smaller than one could expect as compared with those from the bibliography. In fact, an analysis of the different data sets from earlier authors reveals that amplitude variations are present in the pulsation of AN Lyn. We have analysed the 1980 B and V data of Yamasaki et al. (1981), the 1982 V data of Yamasaki et al. (1983), the 1982 b data of Costa et al. (1984) and those 1982-1983 B and V data of Pensado (1983). Table 3 lists the amplitudes, for the first harmonic, obtained from the different data sets available in the literature together to the ones obtained from our data (our data have been separated in three different sets: 1994, data collected at San Pedro Mártir Observatory in 1994; 1995, data collected at Sierra Nevada Observatory in 1995; 1994-1995, full data set collected in this work). In all the cases these amplitude determinations were carried out making the same Fourier fitting with two terms for the frequency 10.1757 cd^{-1} corresponding to the period obtained in Sect. 3.1. For the sake of homogeneity, Johnson's B and Strömgren's *b* amplitudes have been transformed to V equivalent amplitudes using our *uvby* data and assuming that the *b* and *v* measurements can be averaged to approximate the variations in B. Then, factors of 0.762 ($\pm$0.014) and 0.827 ($\pm$0.016) can be applied to transform B and *b* amplitudes to V amplitudes. The results are listed in column 4 of Table 3. As can be seen, there is a very good agreement among the amplitudes

Table 2. Fourier analysis

	u		*v*		*b*		V		b–y		c_1	
H	A (mag)	φ (rad)	A (mag)	φ (rad)	A (mag)	φ (rad)	A (mag)	φ (rad)	A (mag)	φ (rad)	A (mag)	φ (rad)
ν	0.0728	3.242	0.0937	3.044	0.0805	3.046	0.0671	3.034	0.0134	3.103	0.0384	5.799
	10	13	6	6	7	8	7	10	4	30	10	26
2ν	0.0054	5.520	0.0074	6.206	0.0065	6.150	0.0055	5.992	0.0015	0.551	0.0056	3.804
	10	172	6	78	7	98	7	130	4	303	10	178
mean value (mag)	1.8974		1.9515		1.9126		1.8639		0.0487		-0.0930	
	7		4		5		5		3		7	
residuals (mag)	0.0141		0.0087		0.0097		0.0109		0.0063		0.0153	
T_{or}(HJD)	2449398.7203											

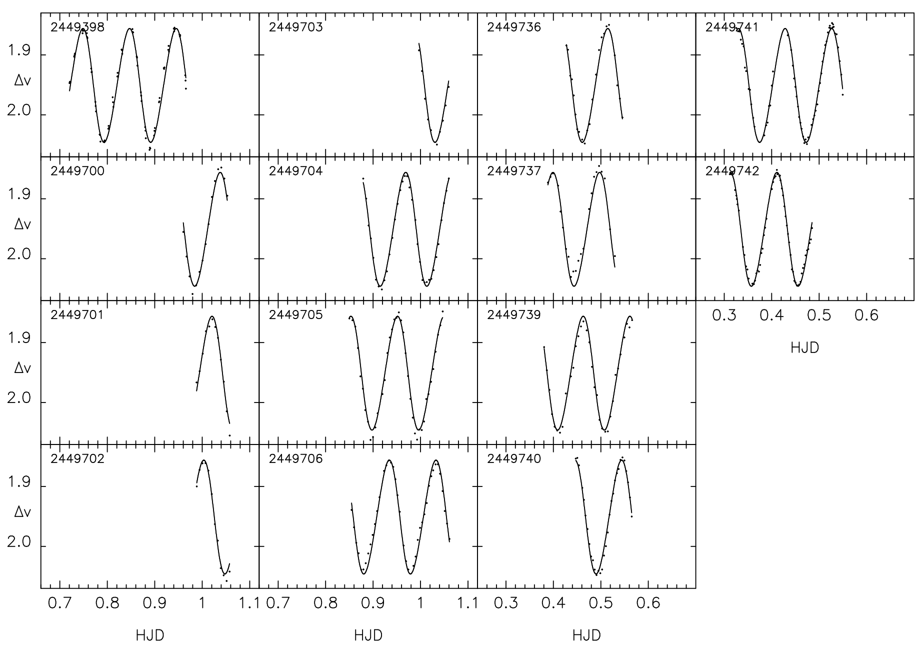

Fig. 1. Observed light curves of AN Lyn in the *v* band with the Fourier fitting versus Heliocentric Julian Day

obtained for the same epoch from different and independent data sets. In particular, in the years 1982-1983 four different data sets have been used. Moreover, amplitude variations seem to be present from season to season, especially between the epochs 1982-1983 and 1994-1995. In the last case, the V amplitude of AN Lyn is about 25% lesser than in 1982-1983.

3.3. Photometry

To study the variation of the physical parameters of this star, the phases of all individual observations were calculated according to the above derived linear ephemeris. Fig. 2 shows the resulting light and colour index variations of AN Lyn along the cycle of pulsation. In this figure we can see that the descending branch of the V light curve is steeper than the ascending one. This is similar to that occurring in the two high amplitude δ Sct stars V1719 Cyg and V 798 Cyg (Poretti & Antonello 1988). However, this behaviour is unusual among the δ Sct type pulsators. Moreover, as these authors point out, such an asymmetry has so far never been encountered in other regularly pulsating stars.

In Fig. 2 and Table 2 we can also see that the β and b-y curves are phased with the V curve while the maximum in the c_1 index occurs some hundredths of a cycle after the maximum in V due to the temperature and gravity variations along the pulsation cycle (Garrido & Rodríguez 1990). In addition, the m_1 index curve of AN Lyn shows no variation. This suggests that AN Lyn is a star with metal abundances similar to the solar ones (Rodríguez et al. 1991). From Table 2 we also find that light maximum in the V band occurs after both maxima in *v*, *b* and b-y in 0.6 ($\pm$0.9), 0.7 ($\pm$1.0) and 4.0 ($\pm$2.2) degrees, respectively. These phase shifts suggest radial pulsation for this star by comparing with the "amplitude ratios versus phase shifts" diagrams

Table 3. Amplitudes for the first harmonic, as determined by means of the Fourier analysis (i.e., semiamplitudes), on different data sets. The sources are: (1) Yamasaki et al. 1981, (2) Yamasaki et al. 1983, (3) Costa et al. 1984, (4) Pensado 1983, (5) present work

Year	Filter	Amplitude (mag)	V Equivalent Amplitude (mag)	Source
1980	B	0.098	0.075	1
		4	4	
1980	V	0.079	0.079	1
		3	3	
1982	V	0.089	0.089	2
		1	1	
1982	b	0.112	0.093	3
		3	4	
1982-1983	B	0.116	0.088	4
		4	5	
1982-1983	V	0.091	0.091	4
		4	4	
1994	V	0.068	0.068	5
		1	1	
1995	V	0.067	0.067	5
		1	1	
1994-1995	V	0.067	0.067	5
		1	1	

of Garrido et al. (1990). Moreover, in our case, the following values of Δv/Δy=1.396 ($\pm$0.024), Δb/Δy=1.200 ($\pm$0.023) and Δ(b-y)/Δy=0.200 ($\pm$0.008) can be obtained for the amplitude ratios between the observed light and colour variations. The value of Δ(b-y)/Δy=0.200 suggests again radial pulsation for AN Lyn, however the values obtained for Δv/Δy and Δb/Δy seem to be too small. Nevertheless, these values agree very well with those obtained for some known radial high amplitude δ Sct stars (Garrido et al. 1990). Please note that Fig. 2 of Garrido et al. (1990) refer to a δ Sct model with T_e=8000 K, log g=4.0 and Q=0.030 and the amplitude ratios (but not the phase shifts) have a strong dependence on the adopted atmospheric parameters of the model. Then these effects suggest radial pulsation for AN Lyn in good agreement with the results obtained by Rodríguez et al. (1996) for a large sample of monoperiodic medium and high amplitude δ Sct stars.

The standard magnitude differences of AN Lyn minus C1=HD 78512 were transformed to apparent magnitudes of the variable assuming the following values for C1: V=8.^{m}79, b-y=0.^{m}137, m_1=0.^{m}172, c_1=0.^{m}939 and β=2.^{m}782 (Perry & Johnston 1982; Hauck & Mermilliod 1990). Then, the individual observations were sorted by phase into twenty equally spaced bins around the cycle. Mean points for the magnitudes and colour indices were calculated for the midpoint phase of each bin. These normal points are listed in Table 4. The standard errors of these normal points are typically of 0.^{m}003, 0.^{m}002, 0.^{m}002, 0.^{m}004 and 0.^{m}005 for V, b-y, m_1, c_1 and β, respectively. The reddening can be derived by comparing the intrinsic and observed b–y indices at normal points along the cycle using the reference lines of

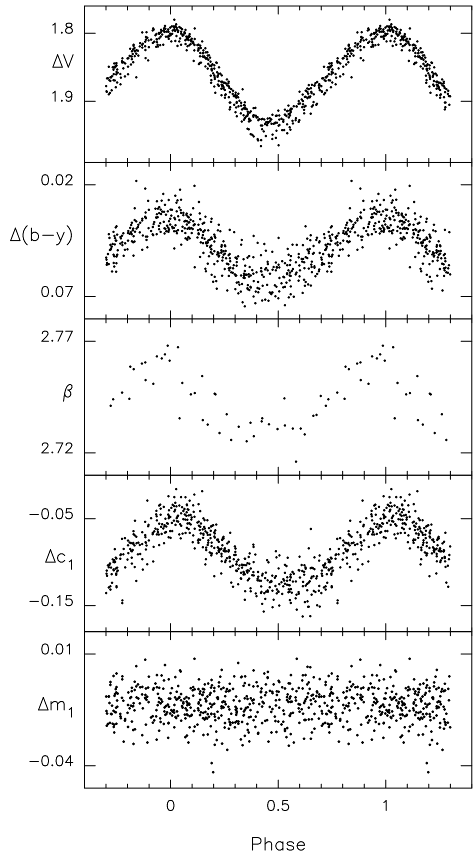

Fig. 2. Light curve and colour index variations of AN Lyn along the pulsation cycle

Philip & Egret (1980) with the appropriate corrections for gravity and metallicity (Crawford 1975a, Philip et al. 1976). Thus, a mean colour excess of E_{b-y}=0.^{m}002 ($\pm$0.002) is found along the cycle. Using E_{c_1}=0.2E_{b-y} and E_{m_1}=–0.32E_{b-y} (Crawford 1975b), very small corrections of less than one thousandth must be applied to the c_1 and m_1 observed values of AN Lyn to obtain the corresponding intrinsic values.

Temperatures and gravities have been calculated using the (log g,T_e) versus [c_0,(b-y)$_0$] diagrams from Lester et al. (1986) for [Me/H]=0.0. In Fig. 3, the (b-y)$_0$ and c_0 values, corresponding to normal points, are plotted in the (log g,T_e) grid. The effective temperature of AN Lyn varies from T_e=7400 K at light maximum to T_e=7150 K at light minimum while the effective surface gravity varies from log g=3.72 to log g=3.59. The mean values obtained along the cycle are $<T_e>$=7270 K and $<$log g$>$=3.65. We can also calculate the metal abundance from the δm_1 parameter at minimum light (phases from 0.30 to 0.75), when the metal lines are strongest and m_1 is most sensitive to abundance differences. Values of 0.^{m}019 and –0.12 are obtained for $\delta m_{1_{min}}$ and [Me/H], respectively, using the reference lines given by Philip & Egret (1980) and Smalley's (1993) calibration for metal abundances. This last result is in very good agreement with the observed behaviour of the m_1 index curve along the pulsation cycle in Fig. 2, where no significative variation is observed. In fact, a variation of m_1 of

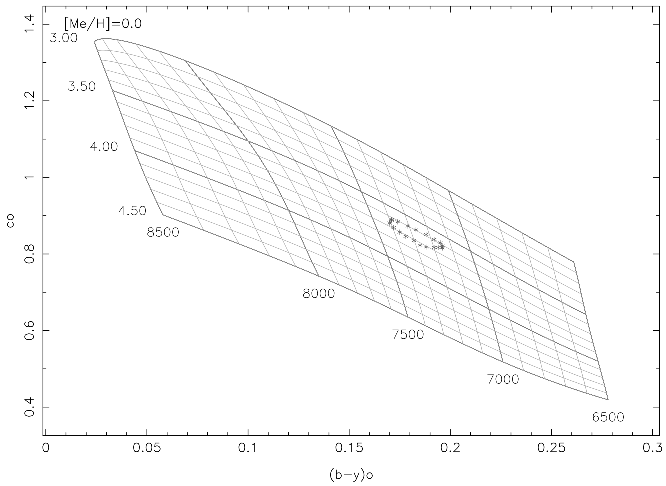

Fig. 3. Observed loop of AN Lyn in the (c_1, b-y) diagram. T_e and log g lines are from Lester et al. (1986) for [Me/H]=0.0

Table 4. Photometry (normal points) of AN Lyn

Phase	V	b-y	m_1	c_1	β
0.00	10.591	0.173	0.159	0.889	2.758
0.05	10.594	0.173	0.159	0.891	2.754
0.10	10.605	0.176	0.159	0.885	2.749
0.15	10.623	0.181	0.158	0.874	2.744
0.20	10.646	0.185	0.158	0.863	2.739
0.25	10.668	0.190	0.158	0.851	2.735
0.30	10.688	0.194	0.158	0.839	2.732
0.35	10.707	0.197	0.158	0.829	2.731
0.40	10.719	0.198	0.160	0.822	2.731
0.45	10.724	0.198	0.161	0.816	2.730
0.50	10.720	0.198	0.159	0.816	2.731
0.55	10.711	0.196	0.159	0.817	2.731
0.60	10.697	0.194	0.160	0.817	2.732
0.65	10.681	0.190	0.161	0.818	2.736
0.70	10.665	0.187	0.160	0.824	2.740
0.75	10.648	0.184	0.159	0.835	2.745
0.80	10.631	0.180	0.159	0.846	2.751
0.85	10.615	0.177	0.160	0.858	2.755
0.90	10.603	0.174	0.161	0.870	2.758
0.95	10.595	0.172	0.160	0.881	2.759

only $0.^m002$, in the same sense of the light curve, would be expected from the grids ($\Delta m_1{}^*$,β) (Rodríguez et al. 1991) for [Me/H]=–0.12, $<\beta>=2.^m742$ and log g=3.5.

In order to calculate the mass, luminosity and age of this star, the evolutionary tracks from Schaller et al. (1992) have been used for Z=0.020. Assuming mean values of T_e=7270 K and log g=3.65, a mass of 2.00($\pm$0.1) $M_\odot$ was obtained in a post-main sequence stage of evolution. The age corresponding to the position of this star in the log g-log T_e diagram is of 1.1($\pm$0.2) 10^9 years and $M_{bol}=1.^m0(\pm0.2)$. When a main-sequence stage is considered for AN Lyn, a mass of 2.18 $M_\odot$, an age of 0.9 10^9 years and $M_{bol}=0.^m9$ are found. Finally, a value of $Q=0.^d021$ ($\pm$0.004) (Breger 1990) can be obtained for the pulsation constant using the formula of Petersen & Jørgensen (1972). This suggests that AN Lyn is oscillating in the second overtone of radial pulsation.

4. Conclusions

AN Lyn is a medium amplitude δ Sct star showing peculiar light curves in the sense that the descending branches are shorter than the ascending ones. This behaviour has been never found in other regularly pulsating stars. In particular, this is unusual among the δ Sct type pulsators. This is similar to that occurring in the two high amplitude δ Sct stars V1719 Cyg and V798 Cyg (Poretti & Antonello 1988). These stars might form a subgroup of pulsators displaying different physical conditions generating the atypical light curve.

From analysis of the different data sets available in the bibliography, we find that amplitude variations are present from season to season in AN Lyn. This is similar to that found, in the last few years, in a number of multimode nonradial pulsating δ Sct stars of low amplitude and also in the two low amplitude nonradial δ Sct stars τ Peg (Breger 1991) and 28 And (Rodríguez et al. 1993) where only one pulsation frequency seems to be shown. Amplitude variations, with time scales of years, have been also found in the monoperiodic low amplitude δ Sct star BF Phe (Poretti et al. 1996) where the nature of the pulsation mode has still not been clarified. However, for any of the known high amplitude δ Sct stars, long term amplitude variability had not been established at the time.

On the other hand, the analysis of the phase shifts between observed light and colour variations suggests that this star is a radial pulsator. Moreover, the derived physical parameters indicate that AN Lyn is a nearly cold and evolved δ Sct star showing solar metal abundances and pulsating in the second overtone.

However, its monoperiodicity has been not confirmed. Nevertheless, we could not determine any reliable secondary frequency. In the same sense, the analysis of all maxima available in the literature does not lead to a conclusion about the behaviour of the period of AN Lyn. In these last two aspects more observations are needed over the coming years to get a definitive conclusion.

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