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ASTRONOMY AND ASTROPHYSICS

Rotation modulation or/and pulsation in o Andromedae

I. The photometric results of an international multisite multitechnique campaign

J.P. Sareyan[1], **S. Gonzalez-Bedolla**[2], **G. Guerrero**[3], **J. Chauville**[4], **L. Huang**[5], **J.X. Hao**[5], **Z.H. Guo**[5], **S.J. Adelman**[6], **D. Briot**[4], **and M. Alvarez**[7]

[1] Observatoire de la Côte d'Azur, Département Fresnel, B.P. 229, F-06003 Nice Cedex, France
[2] Instituto de Astronomia, UNAM, Apdo.Postal 70-264, 04510, Mexico D.F., Mexico
[3] Osservatorio di Merate, Via E. Bianchi 46, I-22055 Merate, Italy
[4] Observatoire de Paris-Meudon, URA 335 du CNRS, F-92195 Meudon Cedex, France
[5] Beijing Astronomical Observatory, Chinese Academy of Sciences, Beijing 100080, P.R. China
[6] Department of Physics, The Citadel, 171 Moultrie Street, Charleston, SC 29409, USA
[7] Observatorio Astronomico Nacional, UNAM, Apdo 877, Ensenada, B.C. 22800, Mexico

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Abstract. We present the photometry of a month-long international campaign on the variable Be star *o* Andromedae. Excellent time coverage and photometric precision permit a critical comparison for the first time between the pulsational and the rotational modulation hypotheses. A multiperiodic analysis of data taken many years apart shows sets of close frequencies. The amplitude ratio between the ultraviolet and visible variations is what is expected for early-type star pulsation. But, the total amplitude and the order of importance of the frequencies is very different between observation campaigns.

A simple double wave periodic curve accounts for most of the light variation: a rotation/modulation model is considered, with activity variations in or just above the photosphere. Any model must explain the observed changes in the amplitudes of the frequence corresponding to the period and its first harmonic. A very simple model with two stable photospheric activity "features" is insufficient to explain the small variations observed around the mean values of the period and its light amplitude. Thus we propose that the photosphere, which is very probably oblate and seen almost equator-on, is divided into zonal bands undergoing differential rotation.

Key words: stars: individual: *o*And – stars: emission line, Be – stars: variables: other

1. Introduction

Whether or not the Be stars pulsate is an unsolved problem. The observed photometric periods are very close to the likely rotation periods. For both pulsation and rotation the large number of free parameters has permitted one to choose either interpretation without any strong contraindications. Given high dispersion spectroscopy with sufficient time resolution one could differentiate between both hypotheses, by comparing the behavior of the line centers and wings. Alternatively one could compare the light curve with the radial velocities of photospheric lines. A third approach is to observe the photometric variations as continuously as possible in some Be stars to see if any are true multiperiodic pulsators.

Hence we studied the well-known Be star *o* And to determine as many parameters as possible. We wanted:

- Longitude coordinated photometry during several weeks, to find period(s) without strong aliases and determine an accurate and precise ephemeris.

- Simultaneous spectroscopy from different sites, with high spectral and time resolution, to study any short time scale variation especially any correlated with the photometry. Hα spectroscopy should provide information about the variation of the physical conditions in the circumstellar region.

- Interferometry, both speckle and with the two telescope technique, should provide the relative positions of the system components during the campaign. Do close companions play a role on the star variability, i.e. by influencing the light and spectroscopic amplitudes by a tidal effect?

Our spectroscopic results will be published in a subsequent paper.

Sareyan et al. (1992, hereafter Paper 1) summarized work on Omicron Andromedae (HR 8762 = HD 217675, B6IIIpe+A2p), which is a multiple system of at least four stars (see Hill et al. 1988,1989):

- The principal component "A" of the system is the Be star (B5 II-III).

Send offprint requests to: J.P. Sareyan

Table 1. The observations

Observatory (observer)	Telescope	Photometer /PMT	Comparison stars	Filters	Julian dates range -2448000	Number of nights	Hours (total)	Data number (total)
1 San Pedro M. (SGB)	1.5m	"Danish" /EMI 9789QA	8766, 8733 8708 (8804)	uvby	877-884	8	53.3	3460
2 San Pedro M. (Michele Bossi)	84cm	"pulse counter" /AsGa cooled	8766, 8733	V	882-891	10	67.3	570
3 Xing Long (LH, ZHG)	60cm	/EMI 6256B	8733, 8805	b y	882-892	4	24.2	376
4 Mt Hopkins (SJA)	75cm automated	/AsGa cooled	8766, 8708	b y	893-897	5	22.8	144
5 San Pedro M. (JPS)	84cm	"pulse counter" /AsGa cooled	8766, 8733 8708	b V	893-898	6	41.6	1416
6 San Pedro M. (JPS)	1.5m	"Danish" /9789QA	8766, 8733 8708 (8804)	uvby	899-905	6	38.0	2356

- A spectroscopic binary "B1-B2" (probable spectral types B7-B8, and period about one month) is orbiting around component A with a period of decades.

- Speckle interferometry detected a companion "a" close to companion "A", but its distance and its period around component A is not yet well known (Sareyan et al. 1994a).

2. The photometric observations

The photometric observations (Table 1) were obtained between September 10 and October 9, 1992 at: San Pedro Martir Observatory (SPM, Baja California, Mexico), Four College Automated Photoelectric Telescope (Mount Hopkins, MH, Arizona, USA), and Xing Long Station of Beijing Observatory (XL, China). The comparison stars HR 8766 (HD 217782, A3Vn) and HR 8733 (HD 217101, B2IV-V) were observed at SPM and MH Observatories; HR 8708 (HD 216608, A3m+F6V) at SPM and XL Observatories. HR 8805 (HD218470, F5V) was also used at XL. Further HR 8804 (HD 218452, K5III) was used sometimes as a red standard at SPM.

HR 8800, initially a supplemental comparison star, was quickly discovered to be variable (Sareyan et al. 1994b). The variability later found in the primary comparison star HR 8766 with a 0.14 d period and an amplitude less than 2 mmag (paper in preparation) does not affect our results in any significant manner. Its detection is an indication of the precision in our *o* And data.

The data reduction was performed at Meudon Observatory with GBFOM (Sareyan et al. (1992 Paper 1). By monitoring the different observing techniques, instruments and comparison stars, we have been able to minimize possible differences originating from these variables.

Six observation sets are spread over one month. The two overlaps of three nights between two different telescopes at SPM, and of five nights between SPM and Mt Hopkins permit a determination of a common "zero" for some filters. Overlaps of observations made in Western North America and in China (Sept. 15-16, 23-24, 24-25, 1992), provided continuous coverage for these nights, and helped reduce aliases in the period research.

All the observations will be sent to the SIMBAD Archives.

3. Analysis of the data and period research

3.1. Introduction

We simultaneously performed two different analyses on the same photometric data: The first one approximates the light curves by a double wave sinusoid fit, each time adjusted independently for each individual group of the observations (Table 1). As each group is homogeneous (same telescope and filters) these results have a very high internal precision. A second analysis uses all the data for a single filter (or its equivalent, when not readily available). These results depend on the adjustment between the different telescopes and filters. As they use the total time base of the observing campaign, they give the best complete multiperiodic analysis, but the first analysis is better for short time scale variations.

3.2. Double wave sinusoid analysis

A least-squares fit of a double wave sinusoid with a 0.3 to 3.0 d period was made for each group of observations and filter. To first approximation the *o* And light curves always are double wave sinusoids of 1.6 d period and contain 60 to 90 % of the

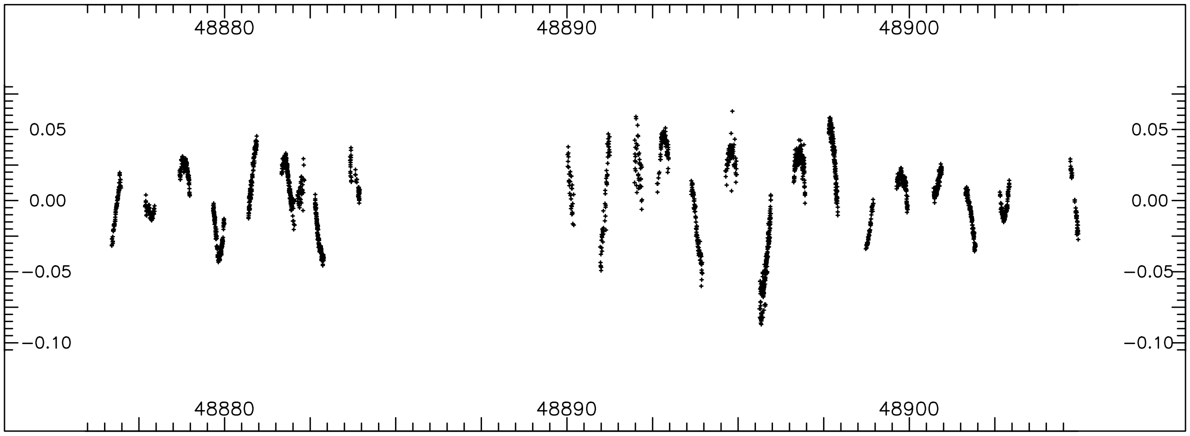

Fig. 1. Example of b data

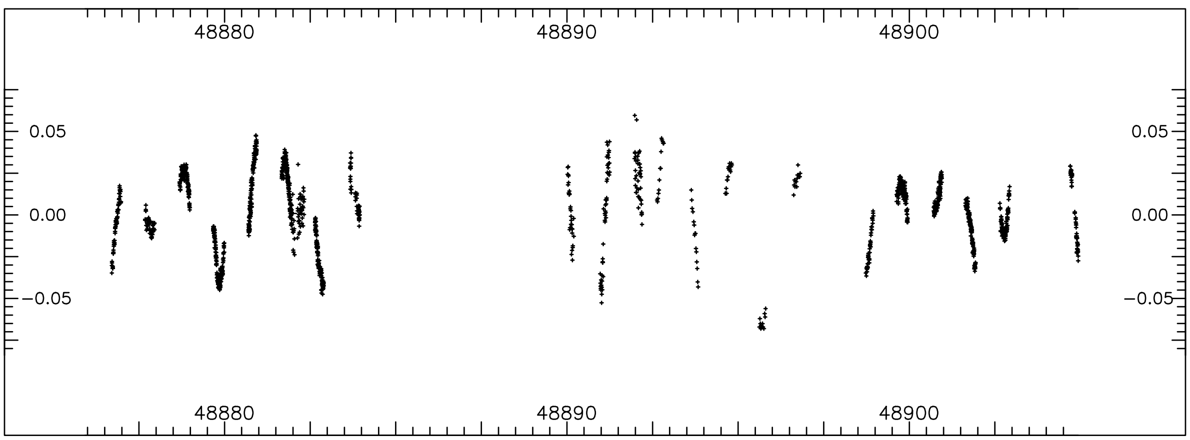

Fig. 2. Example of y data

Table 2. Double wave sinusoid analysis for the campaign. (Amplitudes A and B, see Eq. 2)

No	JD range (-2448800)	JD mean	Optimal double wave period found (days, σ)	Amplitudes found visible A(P)	B(P/2)	(σ)	(mmag.) UV A(P)	B(P/2)	(σ)	amplitudes ratio (P/(P/2))
1	76.5 - 83.95	80.3	1.561 (0.013)	21	15	(12)	28	20	(15)	1.4
2	81.8 - 90.95	86.4	1.611 (0.016)	19	20	(16)				1
3	82.0 - 92.2	87.1	1.65 (0.13)	32	34	(11)				1
4	92.6 - 96.8	94.7	1.692 (0.007)	48	26	(7)				1.8
5	92.7 - 97.9	95.3	1.622 (0.013)	41	29	(13)				1.4
6	98.75-104.95	101.8	1.592 (0.009)	13	13	(8)	19	18	(10)	1

signal in the light curves. But the fit for each group of observations results in different amplitudes and periods (Table 2). The differences are significant, being much larger than the computed standard deviation.

For the data set # 3, obtained at Xing Long, 1.65 d is a best compromise *in the 1-2 d range* (a somewhat stronger peak appears at 0.695 d). The apparent period seems to increase significantly, and then decrease during our month of observations. Period length is correlated with the variations of the amplitude, with a ρ coefficient of 0.8, according to the least squares solution:

$$\text{amplitude (mag)} = 0.24 \times \text{Period (days)} - 0.36 \quad (1)$$

During the first part of the campaign (observation sets # 1 and 2, Table 2), the amplitudes of P and P/2 are rather close, and have a small value (20 mmag). Then they both increase to more than 30 mmag (# 3). After which, observations (# 4 and 5), they differ significantly with the amplitude of P/2 decreasing slowly to 30 mmag, while that of P increases to the 50 mmag

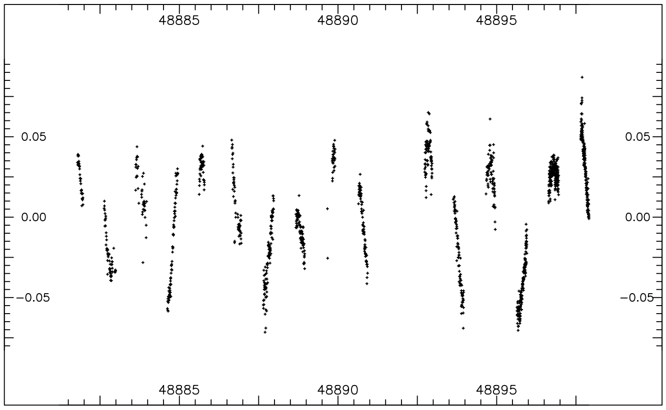

Fig. 3. Example of V data

level. Finally (# 6), the amplitudes of both P and P/2 decrease rapidly to a common low value of 13 mmag. Although the double wave analyses were performed independently on each data group, the rather large difference between the optimal periods for observation data sets # 4 and # 5 is difficult to explain except perhaps by damping of the amplitude around JD 2448897. The ratio between the amplitudes of P and P/2 fluctuates around 1.4 with values of about 1.0 being the minimum (observation sets # 2, 3 and 6), and a maximum about 1.8 (# 4).

When we fit together all available data *in each color* u, v, b, y and V, weighting the measurements accordingly to the length of the observation strings (i.e. 2 for b, y, V, and 1 for u, v), and then for each color set, adjusting the double wave curve by least squares, we obtain for the whole campaign a rather good fit, whatever the color, for an average period of 1.587 d. This value is the best determination for a single double wave sinusoidal fit to the whole 1992 campaign (Fig. 6). This fit is given as:

$$a = A \sin \frac{2\pi t}{P} + B \sin (\frac{4\pi t}{P} + \phi) \quad (2)$$

where a is the resulting amplitude, A and B the respective amplitudes of P and P/2 (Table 2).

The initial light minimum (the deepest light minima are sharper than other extrema) derived from this 1.587 d average period occurs at

HJD = 2448875.004 ± 0.014

To check these average values for the whole campaign, we adjusted *through all the data* a single 1.587 d double wave (Fig. 6) which results in the following ephemeris:

Light minima (HJD) = 2448875.148 ± 0.007 + 1.587 E

The resulting amplitudes for each color are given in Table 3.

For P and P/2, these amplitudes have respective average values of 22.3 and 16.9 mmag in the "vby" visible; 23.9 and 18.4 mmag if we include the V measurements (as the same filters have not been used throughout the campaign (Fig. 1). The amplitudes in Table 3 are implicitly weighted by those in Table 2).

When available (Table 2), the ultraviolet amplitudes are on the average greater than those in the visible, by a factor of 1.4 (for P) and by a factor 1.33 (for P/2). This confirms the tendency detected in 1987 (Paper 1), when the same factors were then, respectively, 1.8 (for P) and 1.15 (for P/2).

Table 3. Amplitudes (in mmag) of a single double wave sinusoid adjusted on the whole campaign data

period,filter	u	v	b	y	V
P=1.587	27.2	20.1	26.4	20.5	27.7
P/2=0.7935	18.0	13.5	20.7	16.5	23.0

Table 4. Direct period analysis for our 1992 campaign

1992	Periods (days)	Amplitudes (mmag)
P_1	1.5876 ± 0.0008	26.6 ± 0.3
P_2	0.7905 ± 0.0002	20.7 ± 0.3
P_3	0.6940 ± 0.0002	18.8 ± 0.3
P_4	6.02 ± 0.03	8.1 ± 0.3
P_5	1.385 ± 0.002	6.8 ± 0.3
P_6	9.7 ± 0.1	5.6 ± 0.3
P_7	1.914 ± 0.007	4.8 ± 0.4

3.3. Direct period analysis

3.3.1. 1992 data

The data sets # 1 and 2, obtained with different observational equipment at the SPM, contain three overlapping nights (J.D. 2448881, 882 and 883). Thus, we could derive approximate ΔV values, obtained at the 84-cm telescope, as function of the Δy and Δ(b-y) values of the 150-cm telescope. Hence we were able to analyze together observation sets # 1, 2, 5 and 6 using the least-squares power spectrum method of Vanicek (1971), which is well adapted to the multiperiodic resolution of a superposition of sinusoidal signals. The derived periods were then adjusted to their final values by a least-squares non-linear fit. These periods, their respective amplitudes and corresponding errors are presented in Table 4.

Again we find periods P_1 and P_2 as the most important contributions to the amplitude. P_1 is quite close to the value found for the best double wave period fit for the whole campaign (i.e. 1.587 d), and P_2 is equal to $P_1/2$ within 0.4 %. From the above values given the rough error bars: $P_5 \simeq 2P_3$ (to 0.2 %), $P_6 = 7P_5$ and in addition a beat between P_3, P_2 and P_4 :
$1/P_3 \simeq 1/P_2 + 1/P_4$ (to 0.7 %).

3.3.2. Same analysis of previous data

Previous extensive observational sets *o* And were made in 1975 by Bossi et al. (1977, hereafter Paper 2) and in 1987 by Sareyan et al. (1992, Paper 1). The same type of analysis as in Table 4 on the 1975 V measurements gives the periods and amplitudes of Table 5.

Table 5 shows results similar to those of Table 4 in many aspects: P_b = $P_a/2$ within 0.3 %, and the central column of

Table 5. Direct period analysis for 1975 data (from Paper 2)

1975	Periods (days)	Difference with the closest period present in 1992	Amplitudes (mmag)
P_a	1.578 ± 0.001	- 0.6 % (P_1)	37.4 ± 2.5
P_b	0.7865 ± 0.0002	- 0.5 % (P_2)	42.6 ± 1.9
P_c	0.6958 ± 0.0004	+ 0.3 % (P_3)	14.5 ± 2.0
P_d	5.80 ± 0.02	- 3.7 % (P_4)	20.1 ± 2.3
P_e	1.0977 ± 0.0007	not present	21.0 ± 2.0
P_f	1.870 ± 0.002	- 2.3 % (P_7)	27.9 ± 2.9

Table 4 indicates the good agreement between most of the periods found in 1992 and 1975. However, apart from the first two periods, the order of importance of the periods based on their respective amplitudes is quite different in 1975 and 1992.

P_5 was absent in 1975, and the differences between P_1 and P_a, P_2 and P_b, seem to be significant. This is also true for P_4 and P_d, and for P_7 and P_f. The third period P_3 found in 1992, with an amplitude of the same order as the first two ones P_1 and P_2, was only marginally seen in 1975, and vice versa for P_7 (P_f in 1975).

But nonetheless, at least for $P_1 \simeq P_a$, for $P_2 \simeq P_b$, for $P_3 \simeq P_c$, and to a lesser extent for $P_4 \simeq P_d$ and $P_7 \simeq P_f$, the agreement between the values of the periods is remarkable between 1975 and 1992.

Further P_1 and $2 \times P_2$ in 1992, P_a and $2 \times P_b$ are closer (0.3 to 0.4 %) than P_1 to P_a and P_2 to P_b (0.5 to 0.6 %). Thus, between 1975 and 1992, although the actual *values* of the first and second periods are slightly different, their *quotient* remains equal to 0.5 with high precision.

3.3.3. Pulsational energy

For pulsation, the squared amplitudes (A^2) are proportional to the energy available in each mode. Therefore, for the pulsation hypothesis, the total energy available in the pulsation as well as its redistribution between modes has been significantly modified between 1975 and 1992. Table 6 gives, in the visible, $A^2/\Sigma(A^2)$, an indicator of the fraction of the total energy present in each period P_i. Hence the total (if pulsational) energy in 1975 was three times that in 1992. Each of the first two periods found in 1975 represents an energy level comparable to the total energy present in 1992. In 1992 and in 1975, the first two periods are responsible for most of the total variability of the star (respectively, 69 % and 64 % in terms of pulsational energy). This justifies the double wave sinusoid *first* approximation which we used in some of the preceeding sections.

4. Discussion

4.1. Introduction

Most important in the period determinations of our 1992 data is the permanent presence of a double wave sinusoidal light curve of period P ∼ 1.6 d, with a total amplitude varying from year

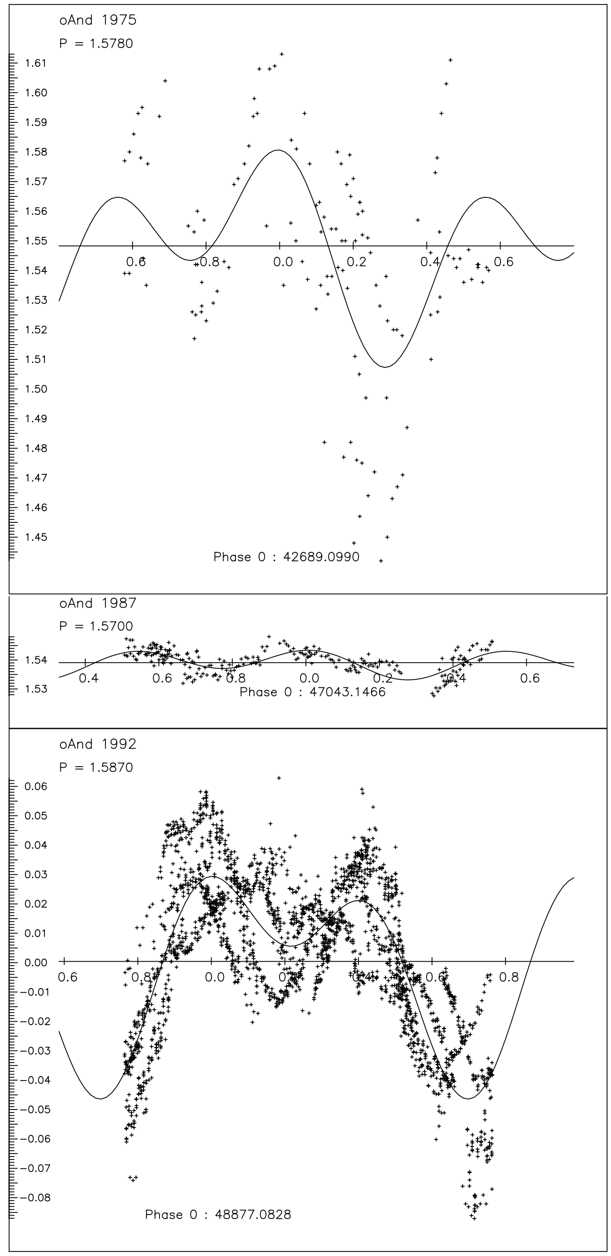

Fig. 4. Double wave analysis of the campaigns carried out in 1975, 1987 and 1992 (blue filter, same HJD and magnitude scales)

to year (this is still true during the quiescent phases (Paper 1), where the amplitudes are quite small). From 1975 to 1992, the amplitude ratio between P and its harmonic P/2 is also variable, the ratio range being 1.8 to 0.5. This double wave variation is in any case responsible for more than 50% of the total light variation observed.

Table 7 gives the average parameters of the double wave sinusoids fitting the data of 1975, 1987 and 1992, i.e. the most complete observational data sets available. The amplitudes are an average between the visible and the ultraviolet values. We call here Max1, Max2 and Min1, Min2 respectively the principal and

Table 6. Comparison between 1992 and 1975 direct analyses: amplitudes and energies

Period (d)	1992	A (mmag)	A^2	$A^2/\Sigma(A^2)$ %	1975	A	A^2	$A^2/\Sigma(A^2)$ %
~ 1.58	P_1	26.6	708	43	P_a	37.4	1399	28
~ 0.79	P_2	20.7	428	26	P_b	42.6	1815	36
~ 0.69	P_3	18.8	353	21	P_c	14.5	210	4
~ 5.9	P_4	8.1	66	4	P_d	20.1	404	8
~ 1.38	P_5	6.8	46	3	-	-	-	-
~ 9.7	P_6	5.6	31	2	-	-	-	-
~ 1.1	-	-	-	-	P_e	21.0	441	9
~ 1.9	P_7	4.8	23	1	P_f	27.9	778	15
			—				—	
$\Sigma(A^2)$			1656				5047	

Table 7. Average double wave sinusoidal light curves for the 1975, 1987 and 1992 campaigns (see text).

year	<period P> (d)	ΔP (with 1992)	P ampl. (mmag)	(P/2)ampl (mmag)	Phase of(P/2)	Phase of Max1	Phase of Min2	Phase of Max2	reference
1992	1.587	0%	23.4	17.9	143°	0.31	0.52	0.70	this paper
1987	1.570	-1.1%	2.8	4.4	145°	0.28	0.51	0.73	from Paper 1
1975	1.578	-0.6%	23.9	25.8	107°	0.71	0.46	0.27	from Paper 2

secondary maxima, and the deepest (principal) and secondary light minima.

Between 1975 and 1992, the shape of the mean double wave light curve has changed with the secondary light maximum being before the primary one (1975) or after it (in 1987 and 1992). Further the light minima remained approximately at a 0.5 phase difference throughout the 17 years (see Fig. 4), as noted by Harmanec et al. (1987) in their 1983-85 observations. In addition to a primary period and its first harmonic (the double wave sinusoid), the light curve contains residuals whose amplitudes are small but significantly larger than the white noise. For the data taken during 17 years (1975-1992), a direct mathematical period search without a priori light curve shape assumption gives two more coinciding determinations (namely the periods $P_3 \simeq P_c$ and $P_7 \simeq P_f$) in the 0.5 to 2 days range.

These results may be analyzed in two different ways. Thus we have separated above the period finding methods and the derived results: Either the derived periods are purely pulsational, and we are observing a multiperiodic pulsating variable star, or the primary period and its harmonic constitute evidence for permanent activity, through the classical double wave sinusoid shape of the light curves, obtained by rotational modulation. In both case some observations must be explained. Now we will discuss the incompatibilities and contradictions of these models.

Figs. 5 and 6 show a comparison between the "multiperiodic" analysis and the "single double wave" analyses: there are 21 free parameters (periods, amplitudes, phases) in the first case, and only 4 in the second, with respective r.m.s. errors (and correlations) of 6.6 mmag ($\rho = 0.87$) and 15.7 mmag ($\rho = 0.66$).

4.2. The pulsation hypothesis

4.2.1. UV / visible amplitude ratio

The observed amplitudes are on the average greater in the ultraviolet than in the visible: the ratio of these amplitudes is, in our 1992 campaign, around 1.4. Within the precisions of each campaign, this same 1.4 ratio already appears in 1975 (Paper 2) and in 1987 (Paper 1). It could have been even greater in the 1950's (Schmidt, 1959). This ratio is typical of β Cephei pulsation (which is mostly a temperature variation of the star's photosphere).

4.2.2. Periods

The β Cep variables have much shorter periods than those present here. They pulsate in the radial and/or the first non radial modes, i.e. with periods of a few hours. Longer periods (days), are likely to be g modes (Dziembowski, 1994).

The long period pulsators for which an identification as well as precise amplitudes are given, show a $\Delta U/\Delta$(visible) amplitude ratio of the same order as that we find here. For example, this ratio is about 1.6 in 53 Per for its two periods - about 2.2 and 1.7 d (Huang et al., 1994) - i.e. significantly different from previous determinations, as already pointed out by Jerzykiewicz (1994). The 1.6 ratio means a dominant thermal term in the light and colour variations. However, the "53 Per" are slow early spectral type rotators ($v \sin i = 19 km s^{-1}$, and type B2IV for 53 Per itself). In some slow pulsating B stars (Waelkens, 1991), e.g. HD74560, the same 1.6 ratio is present in the three periods detected.

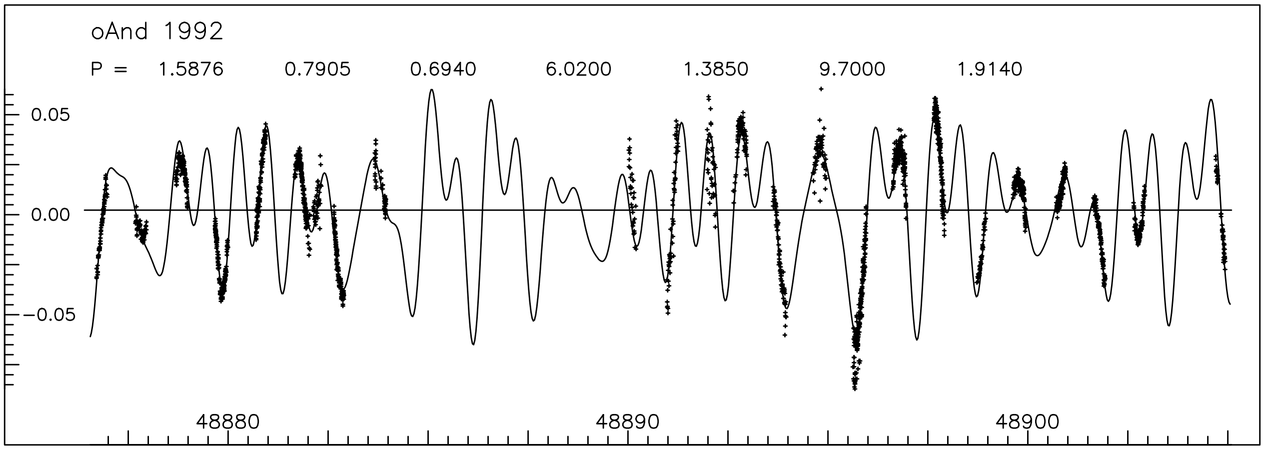

Fig. 5. The campaign b data as analyzed by the 7 periods of Table 4

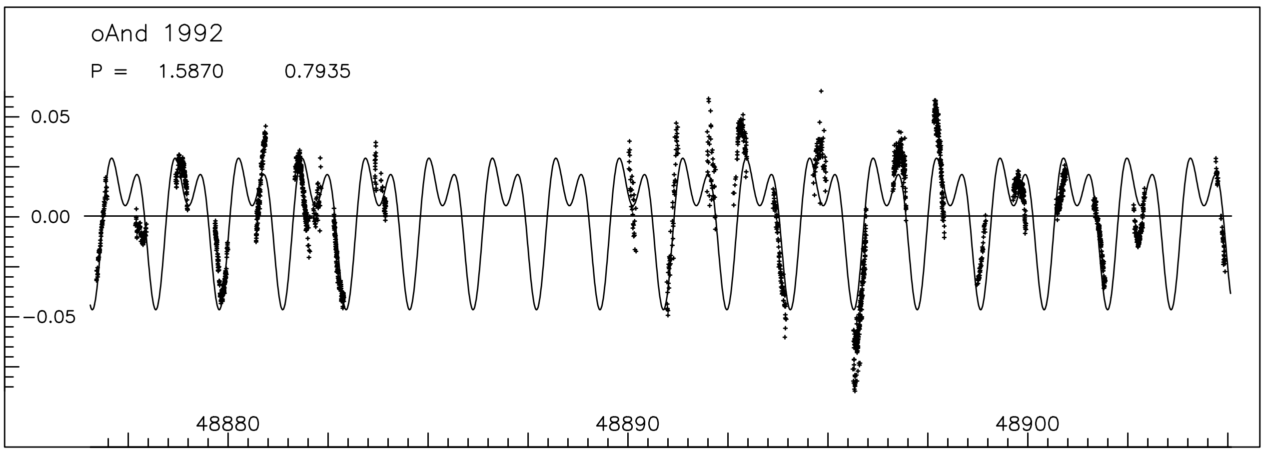

Fig. 6. The campaign b data as analyzed by a single double wave period (1.587d)

If not due to pulsation, this $\Delta U/\Delta V$ ratio could indicate that in B stars the activity takes place in more or less extended features, the color temperature of which is significantly different from the surrounding photosphere (like the sunspots, a whole spectral class colder than the photosphere).

For slow rotators or *non rotating* B stars, a low l, high g modes instability domain exists (Dziembowski et al., 1994), with periods between 0.5 and 3.5 d. This period domain is the same as that of the rotation periods in most classical Be stars. We expect the Coriolis force to play an important role in the pulsation of rapidly rotating stars, and especially when the ratio Ω/ω of rotation to pulsation frequencies is around unity.

The periods of *o* And show a multiperiodic appearance, reinforced by that, in the pulsation hypothesis and some can be found over a period of 17 years: - The most permanent and significant period is P_1 at 1.6 d with its first harmonic P_2 (=$P_1/2$ within 0.4 %), although the mean value of P_1 itself can change significantly by a small amount. This very specific relation between these two most important periods should be included in any pulsation model.

- P_3, P_5 and P_7, in the same 0.7 - 2 d range, show very large amplitude variations - up to a complete disappearing of P_5 in 1975 and P_e in 1992. But similar large amplitude variations do occur on the principal P_1 and P_2 periods (see their amplitudes in 1987, Table 7).

4.2.3. Amplitudes

Any pulsation model must explain why the amplitudes can vary so much during a decade or half a decade, a extent of time negligible compared to stellar evolution. Alternatively it should link directly the pulsations to stellar activity, with time constants in this same range. The total pulsational energy *in the 0.7 to 2 days range* can vary by a factor 3 in 17 years, and even go down to almost zero in the meantime, as observed in 1987: the pulsational energies are respectively proportional to 1560 in 1992, 4600 in 1975 (and around 20 in 1987, where no real multiperiodic analysis can be carried out, due to the very low amplitudes and S/N ratio). Furthermore, the relative importance of the different periods has changed dramatically from 1975 to 1992 as discussed above. Thus the principal problem for the multiperiodic pulsation model is to account for the quite large amplitude variations, i.e. the redistribution of the energy between modes (and the identification of these modes). It should also provide an explanation for the variation of the total pulsational energy. But the longer periods detected (P_4 and P_6 at ~ 6 and ~ 10 d) cannot play any important role in that respect: the proportion of the total (pulsational ?) energy they carry has remained constant between 1975 and 1992, and the values of their amplitudes could only account for a very small fraction of the energy redistribution between the different periods (Table 6).

4.3. The activity hypothesis

The projected rotational velocity measurements of o Andromedae is 330 km/s^{-1} according to the BS catalogue (Hoffleit and Jaschek, 1982) The equatorial velocity of the principal B5II-IIIe component of the system (243 km/s^{-1}, Hill et al. 1989) show that its rotation period is between 1.2 and 2.1 d (with a likely radius of $9 \pm 1 R_{\odot}$, see Paper 1), most likely between 1.4 and 1.9 d. The almost continuous presence of a shell at Hα shows that this principal component of the system is likely to be seen almost equator-on and, due to its fast rotation, the star is likely to appear as an oblate "disk". Recent speckle measurements (F.Morand, private communication) show that the orbit of its spectroscopic binary companion (the system B1-B2) seems to be almost in the plane of observation. Thus the entire system of the three principal components is seen "side-on", a further probability for the main (Be) star to be seen equator-on. Thus any feature linked to stellar rotation is likely to appear with a period between 1.4 and 1.9 d, i.e. close - if not identical - to the 1.6 d period detected in photometry.

The main permanent characteristic of the light curves of o And - whatever their amplitudes - is a double wave shape of rather constant period. In many variables this is interpreted as the signature of stellar activity at or just above the photosphere, in well-defined regions, as this double wave variability appears with time constants typical of the star's rotation (Balona, 1995).

In o And, the general shape of the light curves can be accounted for if there exist "on" the star two permanent "darker features" of unequal importance, at a longitude difference close to 180°. According to this assumption, the smaller "feature" was in 1992 located after the big one, at a longitude difference slightly over 180° in the sense of rotation.

By "features" or "spots", we mean here limited regions of stellar activity, on the photosphere or just above it, and corotating with the star's photosphere. These regions reduce the total light output of the star and thus the light curve is modulated by their crossing in front of the observer. Their presence in o And decreases the mean luminosity of the star by a few percent, as pointed out by Archer (1958), while the polarization increases with the amplitude of the light variation (Harmanec et al. 1987). The variations of the stellar activity (the importance of the "features") can easily account for the main variations of the amplitudes of the light curves, from year to year, and even from a week to another, if the activity time constants involved are rather short (a few days, i.e. a few rotations), as suggested by our 1992 data. In comparison, the sun is a very mild star in terms of stellar activity in the visible continuum.

We know that on the sun -for still unknown reasons- the spots do not appear at completely random latitudes during the 11-22 years cycle (the "butterfly" diagram), nor do they appear at random longitudes. "Active longitudes" regions exist, showing a "tendency to occur at 180° separations in opposite hemispheres and to survive the transition from old to new cycle" (Wilson, 1994, p.58). Until the mechanisms producing such activity are better known, it is not difficult to imagine that other stars could behave likewise and display more activity at given longitudes (about 180° too in our case).

We will try to solve three questions using this hypothesis:

a) Why do we get a slightly different main period at different dates ?

b) Where do the other periods found in the precedent analysis come from ?

c) How can we explain the color index of the variations?

- a) The main period P has been always found around 1.6 d, but its value has been significantly different from an observing campaign to another:

- 1.600 d (Schmidt 1959) in the 1956 to 1958 observations
- 1.578 d (Paper 2) in 1975
- 1.57 d (Paper 1) in 1987
- 1.587 d on the average in 1992, with variations from week to week in the 1.56 to 1.69 range (Table 2), i.e. more variation within a month than between the different campaigns.

Such discrepancies (at most 6% around ~ 1.6 d), in the activity / rotation hypothesis, could be due to differential rotation with latitude in the star's photosphere. On the sun - which is a rather slow rotator ($V_{eq} \sim 2$ km s^{-1}) -, the rotation periods are continuously decreasing from the poles to the equator (from almost +30 % to -6 % of the mean 26.5 d rotation period: see Table 8).

The direct evidence on a rapid rotator -Jupiter- is that, even if the mean rotation of the planet is constant (as measured at radio wavelengths), there exist different characteristic rotation periods in the visible, according to the different latitude bands systems. Of course these variations occur in a very shallow region at the planet's "surface", but it shows that at least in that case a fast rotator can no longer be considered as having the same angular velocity over all its surface. The band to band differences in rotation periods can attain +1.5 to -3.5 % of the average 35730 s rotation period of Jupiter. A "band system" exists in the giant planets of the solar system, and it is especially clear in the most rapid rotators (being a diffuse system in Neptune, it is better seen in Saturn, and it is well marked and permanent in Jupiter, with respective rotation periods around 16, 10 and 10 hours).

That stellar rapid rotators do not behave like solid bodies was considered long ago (see e.g. Tassoul 1978). Differential rotation, i.e. the presence of zonal bands with different velocities analogous to the zonal belts in the atmosphere of the giant planets, could answer the above questions. Such a model has been investigated by Cranmer and Collins (1993). Moreover, the Be photospheric line profile variations (the "bumps" moving along

Table 8. Differential rotation periods (in days)

	on oAnd (tentative)	on the sun	on Jupiter (extrema)
Equatorial	1.385	25	0.399
Average	1.59	26.5	0.414
High latitude	1.91	∼34	0.420

the line profiles), observed in many Be stars at wavelengths corresponding to radial velocities larger than the rotational velocity, are generally attributed to an accelerated equatorial zone (see e.g. Kambe et al. 1993).

- b) In the above hypothesis, even the "exotic" periods (P_5, $P_7 \simeq P_f$ of Tables 3 and 4) could be explained by different rotation periods of specific bands showing evidence of the star's activity (and the period P_5 being twice P_3, as mentionned before, could be a lower latitude replica of the couple P_1 - P_2, with its two active regions about 180° apart). In this model, the local variation of the stellar activity in each band could modulate the amplitude of the light curve, hence the different periods around a mean 1.6 d and the "discrepant" amplitudes found. If this is true, the longer periods found with larger amplitudes in our 1992 data (Eq. 1) shows that if the velocity is a maximum at the equator, the larger "photospheric features" should spread out at higher latitudes.

This model has many degrees of freedom to account for the observations, and particularly for the different periods found in the data (in Jupiter, sinusoidal oscillations are also present in some bands, with periods around tens of days).

- c) There is no reason to believe that what appears on the photosphere or projected onto it (the "features") is neutral grey: the sunspots themselves are of K spectral type, on a G type photosphere. As mentionned before, when o And shows high amplitude variations, it appears redder, and its mean apparent magnitude increases. So, in the activity / rotation model of o And, the activity appears as a global decrease of the light output of the star, even more pronounced in the blue than in the red. This could be due to cooler "spots" on the photosphere, or to a non grey attenuation of the light output by some screening linked to the activity.

Thus this same model can account for the amplitude variation ratio between UV and visible, i.e. the larger amplitudes observed towards the blue wavelengths: the light output difference between the unperturbated photosphere and the photosphere bearing darker features (when the rotation brings them towards the observer) is larger in the blue than in the red if the active regions appear of later spectral type.

4.4. The stellar activity: intensities and time constants

If we consider the above model, we have shown (Paper 1) that the role of activity can be reduced to ∼1% of the total flux (in 1987) during more than 8 days, i.e. about 5 rotations of the star: We found then total variation ranges of 15 mmag (u) and 10 mmag (b).

In 1983-85, Harmanec et al. (1987) found large amplitude and shape variations within a few months. In 1987, Percy et al. (1988) found rapid variations (to ∼0.05 magnitude within a night), sometimes less than a month before our own observations "in quiescent phase". This decrease in amplitude, by at least a factor ∼ 5, is rather difficult to explain in terms of pulsation. It gives an idea of the probable violence of the stellar activity, the time constants being under one month.

An example of such violent active phenomena with very short time scale has already been pointed out in the same star o And by Ghosh et al. (1986). The time constants involved in the increase of amplitudes, i.e. the activity, was one of the questions asked for in Paper 1.

If Table 2 represents real periods and amplitudes, we have for the first time an idea of the time constants involved in the increase of the activity. Whatever the activity might affect (the two principal "features" modulating the light output with periods P_1 and P_2, or the equatorial perturbations -periods P_5 and $P_3 = P_5/2$-, or even the higher latitudes -P_7-) the perturbation appears at most in a few days, i.e. at most in a few rotations of the star. This gives a new threshold on the time constants of the activity in o And: the activity varies significantly in less than a few days.

4.5. Binarity

Could the multiplicity of the star explain a part of the light curves characteristics or/and give any explanation on the long time scale behavior of the star ? The closest discovered companion was thought to have a 3.7 years orbit around the (Be) principal component, its mean speckle distance being measured at 0.05". The position and distance predictions for 1992 (0.077" at 1992.738) could not be confirmed by the speckle measurements carried out on Aug.10th and Oct.6th at the 6 m. Russian Telescope at Zelentchuk (Sareyan et al.,1994a). The closest component "a" could have been at that time at a distance of 0.02 to 0.04" from the (principal) Be star (Balega Y., Balega I., Belkine I., private comm.). If the system distance is 188 ± 27 pc, the 0.03" ± 0.01" distance means 5.6 ± 1.9 AU. This in turn gives possible periods around 5 to 4 years if the Be component is a star of 6 to 7 $M_\odot$, and with a range of 1 to 5 $M_\odot$ for the component "a".

So it is very unlikely that this close companion can play a role, even in the long term modulation we observe (and in which no clear periodicity appears). If the system of o And is more complex, an even closer companion could trigger the long term star's activity through tidal effects, but this is still pure speculation.

5. Conclusion

- In the activity / rotation hypothesis the main star of the system o Andromedae can be described as a rapid rotator appearing very probably as an oblate "disk", seen close to or equator-on.

The double wave mean shape of the light curves shows that two main features exist permanently "on" - or projected onto

- the surface of the star, at medium latitudes, almost at a 180° longitude difference. Long term variations of the activity modulates deeply their relative importance. In the photospheric band model, short-term activity takes place on "parallel" bands or regions and it can spread out or decrease independently from the two main activity features mentionned above. These superficial bands/regions of the star (photosphere) are circulating at speeds different from the mean rotation of the star (like the Jupiter bands system), and very probably at lower speeds at higher latitudes.

In this model, the physical structures connected to the activity appear and disappear in a few rotations of the star: either their color temperature is lower than the rest of the star, or they attenuate much more the light output towards the shorter wavelengths. These "spots-features" develop in surface and/or intensity, and very probably migrate (progressively ?) towards higher latitudes, leading to the amplitude increase observed in the light variations. Eq. (1) shows a correlation between the amplitude and the period increase.

- The pulsation hypothesis is supported mainly by the amplitudes ratio between UV and visible, and by the fact that a multiperiodic analysis carried out at a distance of 17 years exhibits sets of close periods. However, a very large modulation of the total amplitude occurs, even considering the two main frequencies. These two main frequencies are in a 2/1 ratio. However, the difference between their *values*, 17 years apart, is small, but significant.

The secondary periods completely changed their relative importance over the same time duration. The time scale of all these amplitude variations / energy redistribution could be much shorter than years, possibly occuring within weeks. The mode identification of these eventual pulsations in the 0.6-2d range is still an unsolved problem. A simple description of *o* And as a multiperiodic pulsator seems still difficult to formulate out.

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