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Photometry of δ Sct-type and Related Stars: Results of AD Ari, IP Vir and YZ Boo

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Abstract Photometric results of three δ Scuti stars, AD Ari, IP Vir and YZ Boo from new observations obtained at the Xinglong Station of the Beijing Astronomical Observatory (BAO) during 2000 and 2001 are reported. We present here the preliminary analyses. Detailed studies of these stars based on additional data will be published separately.

Key words: stars: variables: δ Scuti — stars: individual: AD Ari, IP Vir, YZ Boo — techniques: photometric

1 INTRODUCTION

Photometric studies of variable stars, especially the δ Scuti stars, short-period eclipsing binaries and pulsating white dwarfs with the 85-cm telescope at the Xinglong Station of the Beijing Astronomical Observatory (BAO) started in 1996, when two photometers were put into work on this telescope. Later, we launched a project to obtain Johnson V and Strömgren $uvby\beta$ photometry for the poorly studied variables of "pulsational interest", mostly the δ Sct and related variables or candidate variables in the lower part of the Cepheid instability strip. Since then, the 85-cm telescope has been dedicated to the photometry of δ Sct and related stars. Currently there are three photometric systems available for the telescope. They are the three-channel (3-CH) high-speed photoelectric photometer designed for the Whole Earth Telescope campaign (WET) (Nather et al. 1990; Jiang & Hu 1998), the four-channel (4-CH) Chevreton photoelectric photometer (Michel et al. 1990, 1995) dedicated to the STEPHI (STEllar Photometry International) (Michel et al. 1992) and the CCD light curve survey photometer (Wei et al. 1990; Zhou et al. 2001b). In addition, as a test system for the performance of the telescope, a new CCD photometer using an Apogee AP7 512×512 CCD is being under construction and is expected to start work by the end of 2001. For publishing part of the results obtained with this telescope, we plan to present some of the data and their analyses in a series of papers under the title 'Photometry of δ Sct and Related Stars'. This paper is the first of this series, giving the results of three δ Sct stars.

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2 OBSERVATIONS AND DATA REDUCTION

The photometry of three δ Sct stars, AD Arietis, IP Virginis and YZ Bootis was performed from 2000 February 26 to 2001 January 31 with the three photometers mounted on the 85-cm telescope at the Xinglong Station of BAO. IP Vir and YZ Boo were observed with the CCD photometer in 2000, while AD Ari with both the 3-CH and 4-CH photometers in 2001. Typical accuracy yielded from the magnitude differences between reference stars is 0.010–0.006, 0.005 and 0.004 mag for the CCD, 3-CH and 4-CH photometers, respectively. The observing log of the three stars is given in Table 1. Integration time for each point is 60 s for both AD Ari and IP Vir, and is 30 s or 40 s for YZ Boo.

Table 1 Observing Log of Johnson V Photometry of Three δ Sct Stars

Star	Nights	Measurements	Photometer
AD Ari	4	991	3/4-CH
IP Vir	7	1157	CCD
YZ Boo	4	1895	CCD

The time-series [i.e., pairs of Heliocentric Julian Day (HJD) versus magnitude] used for the pulsation analysis were first constructed by using one of the three routines VCCD (for reducing the raw CCD data), CHAN3 (for 3-CH) or CHAN4 (for 4-CH). Then the resulted time-series data were further reduced by using the routine DATED. All the four routines are written in a friendly-interface mode for DOS/Windows platform. With the on-line help and detailed tips, no tutorial was needed.

Table 2 Published Works on 19 δ Sct Stars

No	Star	Photometer	References
1	AD Ari	3/4-CH	present work
2	AN Lyn	CCD, 3-CH	Zhou (2002)
3	AE UMa	CCD, 3-CH	Zhou (2001a)
4	BL Cam	CCD	Zhou et al. (2001d)
5	BR Cnc	3/4-CH	Zhou et al. (2001a)
6	DL UMa	4-CH	present work
7	EX Cnc	CCD	Zhou (2001c)
8	GSC 2683-3076*	CCD	Zhou et al. (2001b)
9	GSC 2293-1021*	CCD	Liu et al. (2000b)
10	HD 81882	3-CH	Zhou & Liu (2001)
11	HD 98851	3-CH	Zhou (2001d)
12	HR 5437	4-CH	Liu et al. (1999)
13	IP Vir	CCD	present work
14	SAO 16394*	4-CH	Liu et al. (2000a)
15	UV Tri	CCD, 3-CH	Liu et al. (2001)
16	V1821 Cyg	CCD	Zhou et al. (2001c)
17	V577 Oph	CCD	Zhou (2001b)
18	XX Cyg	CCD	Zhou et al. (2002)
19	YZ Boo	CCD	present work

For the present stars, AD Ari, IP Vir and YZ Boo, differential magnitudes in the sense *variable* minus *comparison* were calculated and labelled accordingly as AD Ari–C1, IP Vir–(C2+C3+C4)/3 and YZ Boo–C5, the comparison stars being

C1 = GSC 1217–1048 ($\alpha_{2000} = 02^{\rm h}16^{\rm m}48^{\rm s}.50$, $\delta_{2000} = 18^\circ22'14.3''$, $V = 9.9$ mag);
C2 = GSC 0325–1345 ($\alpha_{2000} = 14^{\rm h}39^{\rm m}57^{\rm s}.16$, $\delta_{2000} = 00^\circ04'56.9''$, $B = 13.4$ mag);
C3 = GSC 0325–0973 ($\alpha_{2000} = 14^{\rm h}40^{\rm m}07^{\rm s}.35$, $\delta_{2000} = 00^\circ02'23.1''$, $B = 14.7$ mag);
C4 = GSC 0325–1068 ($\alpha_{2000} = 14^{\rm h}40^{\rm m}07^{\rm s}.67$, $\delta_{2000} = 00^\circ06'09.0''$, $B = 13.8$ mag);
C5 = GSC 2569–1050 ($\alpha_{2000} = 15^{\rm h}23^{\rm m}31^{\rm s}.15$, $\delta_{2000} = 36^\circ51'35.0''$, $V = 11.3$ mag).

Table 2 gives a list of stars for which the above routines have been used to establish their time-series. Newly discovered variables are marked with an asterisk.

3 DATA ANALYSIS

In this part, we analyze the present time-series data of the three stars for pulsation using the period-search program PERIOD98 (Breger 1990; Sperl 1998). We refer the reader to Zhou et al. (1999, 2001a) for the procedure. Considering the status of the current data sets, our results should be regarded as preliminary. Further analysis and discussion will be the scope of subsequent papers.

3.1 AD Arietis

AD Ari (=HD 14147=SAO 92873=HIP 10701, V=7.43 mag, ΔV=0.06 mag, P_0=$0\overset{\rm d}{.}2699$, F0) (Handler 1999; Kasarovets et al. 1999; Rodríguez et al. 2000) is suspected to be a candidate of γ Doradus-type pulsating variables exhibiting both p- and g-modes because of its longer period and later spectral type. There is no detailed study since its discovery of δ Sct-type variability. With our observations, we detected two frequencies, $f_1 = 4.8014$ and $f_2 = 6.0403$ cycle d^{-1}. No pulsation frequencies were found beyond 10 cycle d^{-1}. Owing to the time coverage of the present data, the two frequencies might suffer from large uncertainty, f_1 might be daily aliased. The light curve along with the fit with the two frequency terms are presented in Fig. 1.

3.2 IP Virginis

IP Vir ($\alpha = 14^{\rm h}40^{\rm m}08.0^{\rm s}$, $\delta = 00^\circ01'45.0''$, equinox=2000.0, V=11.60 mag, ΔV=0.10 mag, P_0=$0\overset{\rm d}{.}0652$, F1) was reported by Landolt (1990) to be a δ Sct-type variable. Joner, Hintz and Collier (1998) presented evidence that IP Vir is a double-mode variable with a period ratio of π_1/π_0=0.774, indicating a metal abundance of [Fe/H]=−0.3. Based on a series photoelectric and CCD observations over six years, these authors obtained two pulsation frequencies at 15.3357 and 19.8128 cycle d^{-1}. However, we failed to verify the second frequency in our data. Additional data are needed to obtain further insight into the pulsation of the star. Figure 2 displays the fitting to the light curves with only the main frequency $f_0 = 15.3343$ cycle d^{-1}.

3.3 YZ Bootis

YZ Boo (=HIP 75373, V=10.57 mag, ΔV=0.42 mag, P_0=$0\overset{\rm d}{.}1041$, A8) is a Pop. I high-amplitude δ Sct star (HADS) with fundamental mode pulsation. It was classified earlier as an RR Lyrae star (Heiser & Hardie 1964; Gieren et al. 1974) or as a dwarf Cepheid (Fernley et al. 1987; Kim & Joner 1994a, 1994b, 1996). Up to now the relation between dwarf Cepheids and δ Sct stars is still ambiguous. Stars like YZ Boo, are young Pop. I short-period (not exceed 0.3 days), large-amplitude ($\Delta V \geq 0.3$ mag), slow-rotation ($v \sin i < 30\,{\rm km\ s^{-1}}$) pulsating variables. They are often classified as HADS.

Using our data we detected f_0=9.5238±0.0001 cycle d^{-1}, $2f_0$, $3f_0$ and f_1=10.0200±0.0008

cycle d^{-1} with the standard error of fitting of σ=0.0204 mag, which is about twice the observational error. The period ratio of π_1/π_0=0.95 means a nonradial pulsation mode for f_1. Is YZ Boo another example of HADS that pulsate in the mixed radial and nonradial mode? Our data were not sufficient to ensure that f_1 is intrinsic to the variable, and the nonradial term strongly needs confirmation. The synthetic light curve fitted with the four frequency terms is plotted in Fig. 3.

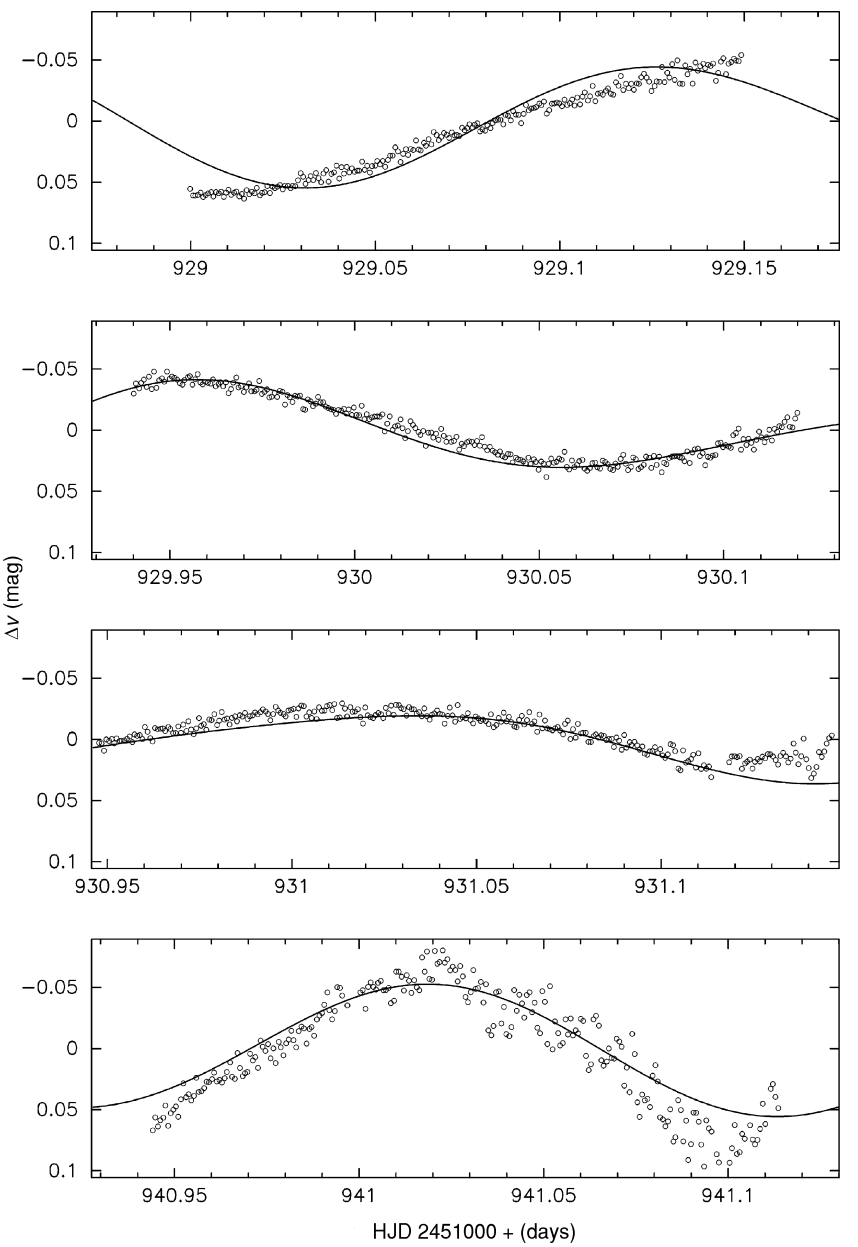

Fig. 1 V differential light curve (open cycles) of AD Ari together with the fit with 2 sinusoids.

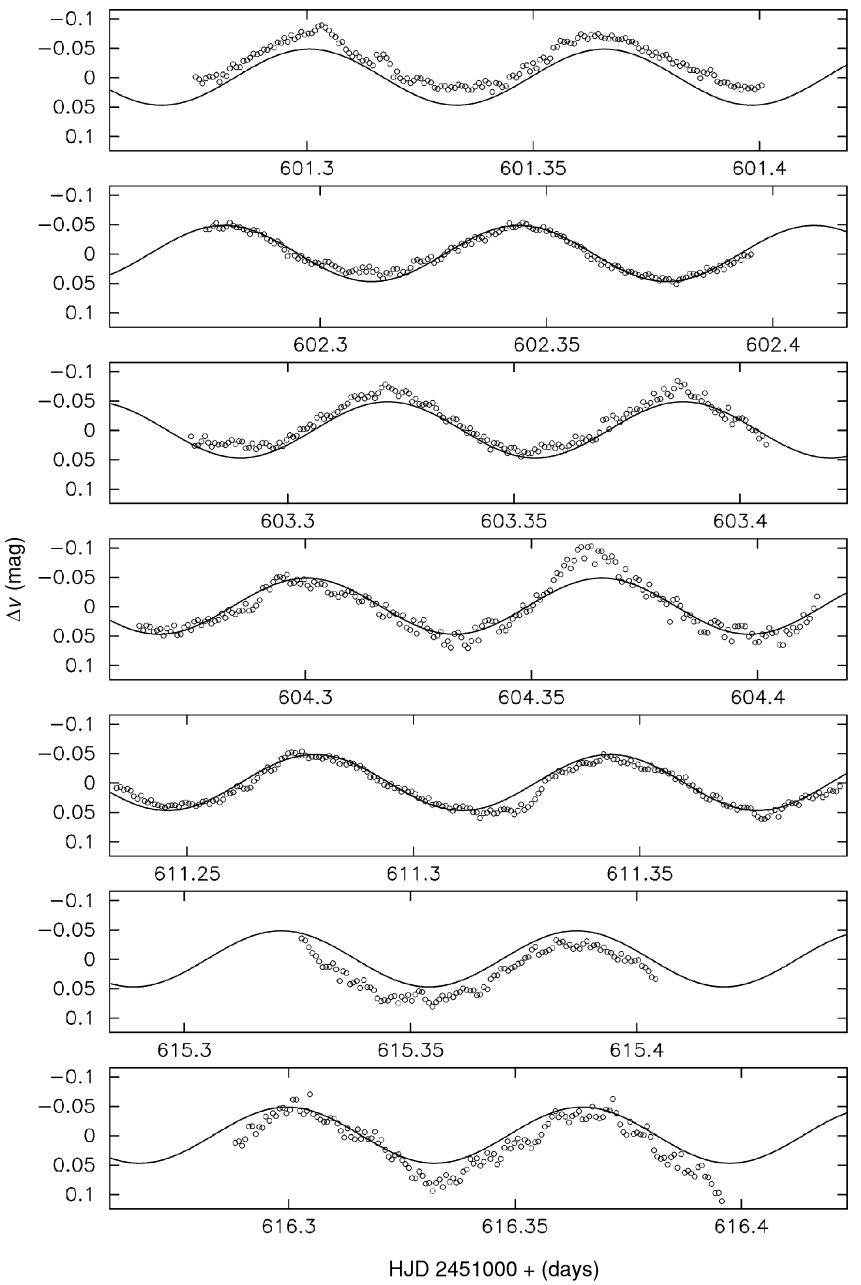

Fig. 2 V differential light curve (open circles) of IP Vir together with the single frequency (f_0) sinusoid.

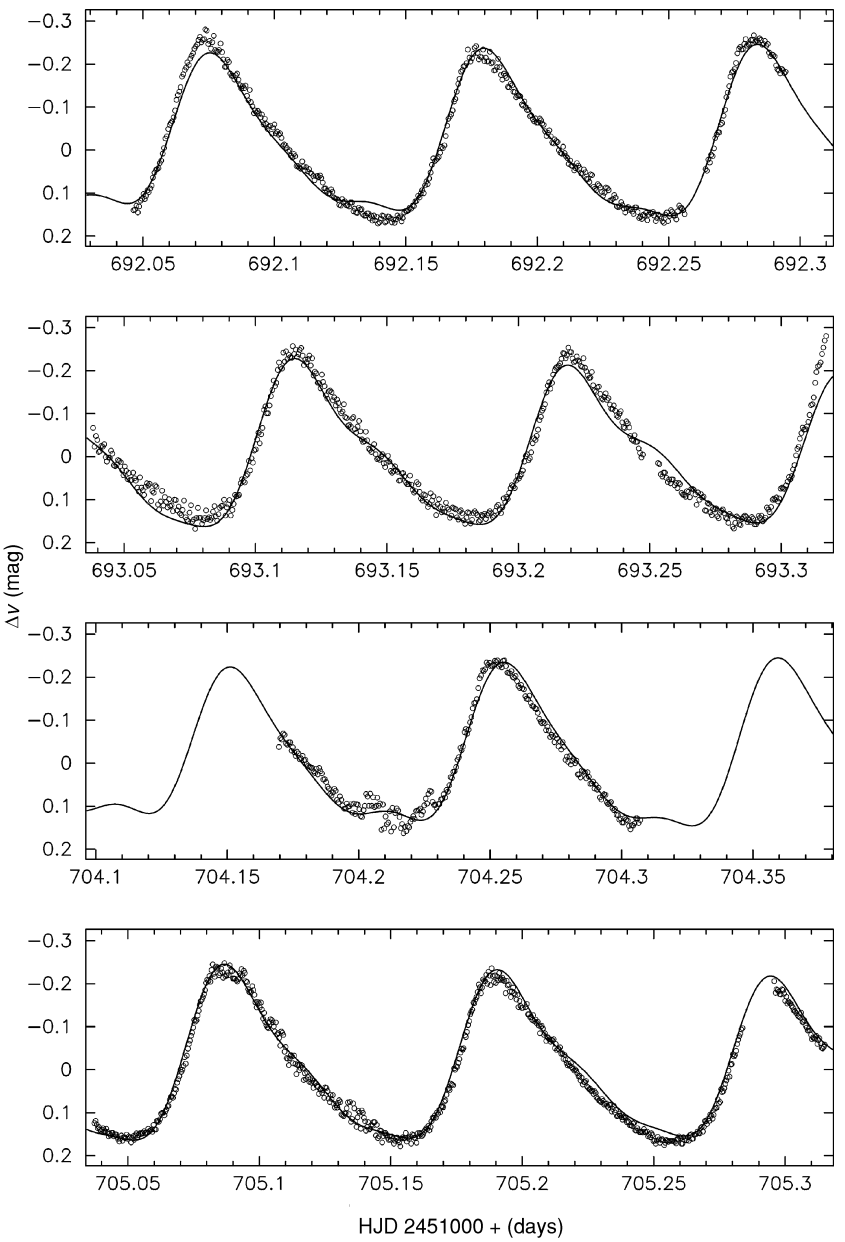

Fig. 3 V differential light curve (open circles) of YZ Boo together with the computed curve from four sinusoids.

In addition, we determined the times of maximum light. Eight maxima are listed in Table 3 where the cycles are calculated with the ephemeris $\mathrm{HJD_{max}} = 2442146.3546 + 0.10409156\mathrm{E}$ (Gieren et al. 1974; GCVS). The error of determination of the maxima is ~ 0.0003 days. Previous studies by Szeidl & Mahdy (1981), Jiang (1985), Peniche et al. (1985) and Hamdy et al. (1986) have claimed different continuous period increases (of about $\frac{1}{P}\frac{\mathrm{dP}}{\mathrm{dt}} = 3\times10^{-8}$ yr^{-1})(Breger & Pamyatnyhk 1998). After the study of Hamdy et al.(1986), period variation in YZ Boo has not been investigated or revised. Therefore some new maxima are helpful for examining any variations in the main period. Furthermore, Hamdy et al. (1986) noticed the possibility of an overtone pulsation besides the fundamental mode. However, we did not find any more information on that after a literature search on the Internet. Before making a further study on the period variation and on the behaviour of possible bi-modal pulsation, we need to acquire additional times of maximum light as well as time-series measurements in the coming observing season. With an update of the O–C diagram we can then attempt to clarify the period-variation behaviour and to check for amplitude variability in different data sets.

Table 3 New Times (HJD 2400000+ days) of Maximum Light of YZ Boo

Times (HJD)	Cycles	Times (HJD)	Cycles
51692.0740	91705	51693.2195	91716
51692.1772	91706	51704.2522	91822
51692.2821	91707	51705.0870	91830
51693.1145	91715	51705.1892	91831

4 FINAL REMARKS

In this paper we have reported some preliminary photometric results on three δ Sct stars, AD Ari, IP Vir and YZ Boo along with a short introduction to four routines: VCCD, CHAN3, CHAN4 and DATED. Table 2 summarizes all the works in which the routines were used to construct the times series. These routines are available to the users of the 85-cm telescope, and they may be modified according to the users' requirements. The quality of the current data sets is such that additional observations of the three stars would be useful. For studying the long-term behaviour of the period and amplitude of IP Vir and YZ Boo, it is better to take advantage of the data available in the literature together with our new data. Our knowledge on AD Ari is poor. In order to reveal the nature of the star, we plan to carry out a bi-site campaign to make intensive measurements not only in V but also in the Strömgren $uvby\beta$ colors. The present paper is the opening paper of our series 'Photometry of δ Sct and Related Stars', intended to report on the works already done or underway on the telescope. In-depth studies on individual stars will be the contents of forthcoming papers.

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