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CCD photometry of WX Ceti in quiescence and outburst*

C. Sterken[1], N. Vogt[2,3], M. Uemura[4], T. Tuvikene[1],
M. Knudsen[1] and H. W. Duerbeck[1]

(1) Vrije Universiteit Brussel, Pleinlaan 2, 1050 Brussels, Belgium
(2) Instituto de Astronomía, Universidad Católica del Norte,
Avenida Angamos 0610, Antofagasta, Chile
(3) Department of Physics and Meteorology, Universidad de Valparaiso
Avda. Gran Bretaña 1111, Valparaiso, Chile
(4) Hiroshima University Astrophysical Science Center, Japan

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Abstract

WX Cet (Nova Cet 1963) – a SU UMa type dwarf nova – was observed in 2001 and in 2004–2005 during superoutburst and subsequent quiescence. This paper presents the complete light curve material in digital form, and provides a number of nightly-averaged *BVR* CCD frames of the WX Ceti field for calibration purposes.

Keywords: variable stars: WX Cet – variable stars: cataclysmic

1 Introduction

This paper is the first out of a series of data papers on archived and new observational data on cataclysmic and related variables.

WX Ceti, in early days classified as Nova Cet 1963 (Bamberg Variable 416, Strohmeier 1964), turned out to be a dwarf nova with infrequent outbursts of large amplitude. The detection of superhumps after the onset of the 1989 June superoutburst (O'Donoghue et al. 1991) placed WX Cet among the SU UMa stars, perhaps resembling WZ Sge (Bailey 1979). Mennickent (1994) presented time-resolved differential photometry and spectroscopy in the 5800–7000Å wavelength range of WX

*Based on observations obtained at European Southern Observatory, Observatorio Cerro Armazones, Las Campanas Observatory, and Concepción University.

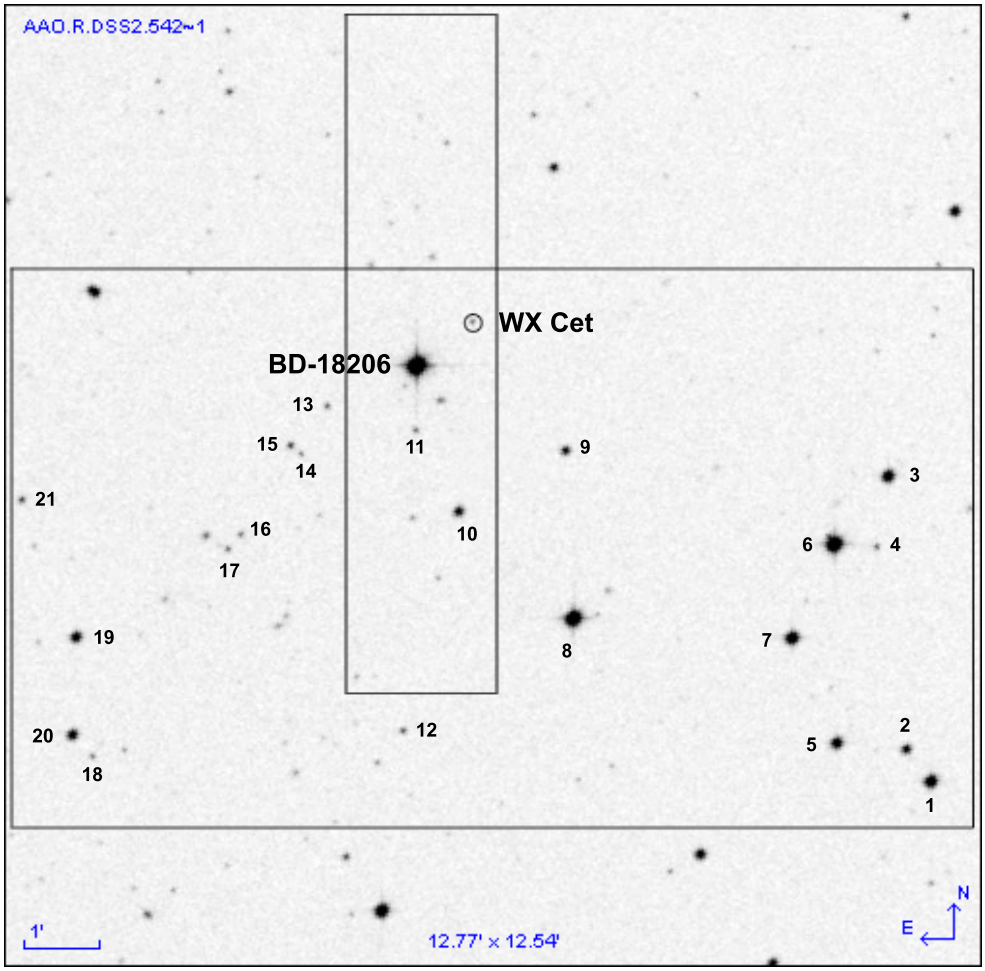

Figure 1: Aladin map of the WX Cet field. The large rectangle corresponds to a Danish 1.54-m CCD frame, the narrow vertical region represents a complete LCO frame.

Cet in quiescence, and derived possible orbital periods of 79 or 83 minutes. This ambiguity was finally removed by Thorstensen et al. (1996) who derived an orbital period of 82.9 minutes.

Rogoziecki & Schwarzenberg-Czerny (2001) observed WX Cet in quiescence and obtained a photometric period $P = 0.05827(2)$ d (83.9 m), in good agreement with the spectroscopic period of Thorstensen et al. (1996). These authors also noted that the orbital light curve sometimes shows alternations between single- and double hump profiles.

We observed WX Cet during the most recent superoutburst (July 2001 and December 2004) and subsequent quiescence from four observing stations. The photometric data have been analysed and the results will be presented elsewhere by Sterken et al. (2006), including the derivation of a more accurate value of the or-

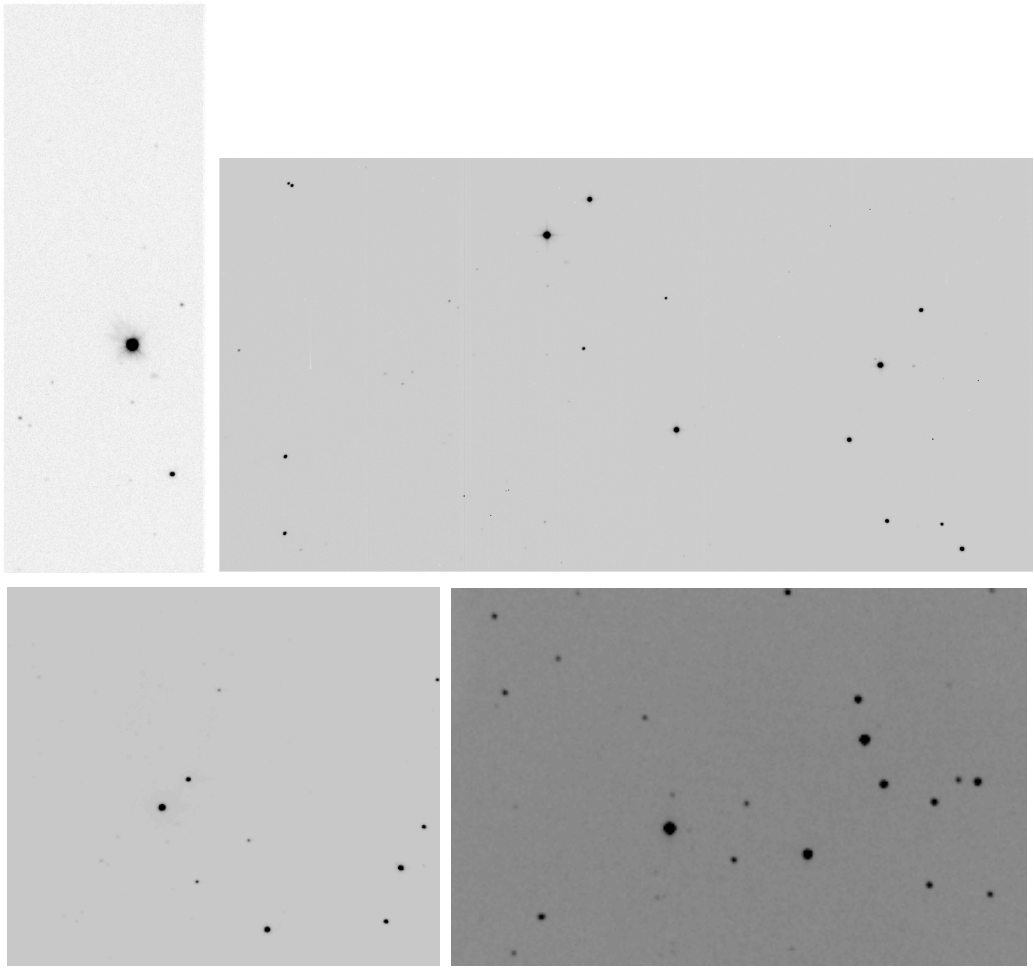

Figure 2: The WX Cet field as observed at LCO (*top left*) and at ESO (*top right*), OCA (*bottom left*) and at Concepción (rotated and cropped, *bottom right*). The bright star BD−18 206 is overexposed in all ESO V images.

bital period, the outburst frequency and the superhump period changes in the course of a superoutburst.

This paper presents all obtained light curves in graphical and tabular form. In addition, nightly-stacked CCD frames are presented for calibration purposes.

2 The data

2.1 July 2001, La Silla Danish 1.54-m

CCD time series (702 useful V images, 9 B frames and 28 R exposures) were obtained with the Danish 1.54-m telescope DFOSC 2k × 2k camera at ESO LaSilla (JD 2452093.83–2452099.95). Typical exposure times were 3–12 s. All frames were cor-

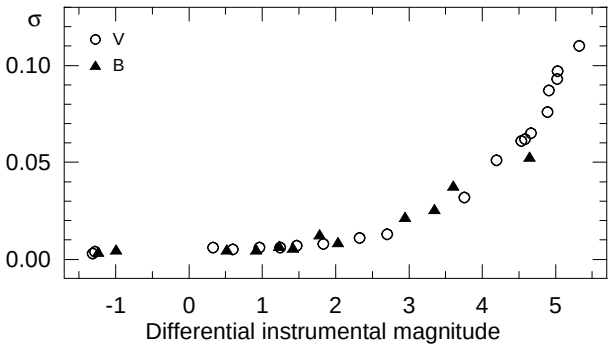

Figure 3: Relation between differential BV magnitude and standard deviation σ.

rected for bias and were flatfielded using sky flats. The magnitudes were extracted using aperture photometry procedures from the IDL Astronomy User's Library. The optimal aperture radius was 1.5 × FWHM and was kept fixed for all frames. Differential V magnitudes using star 7 were calculated (see the Aladin[1] chart in Fig. 1) and the observed fields in Fig. 2.

Star 4 shows irregular variability in V exceeding the 3σ level, and star 1 exhibits small-amplitude night-to-night changes. Table 1 gives the average differential V magnitude for each of the stars together with the standard deviation σ. The relation between these magnitudes and σ is shown in Fig. 3.

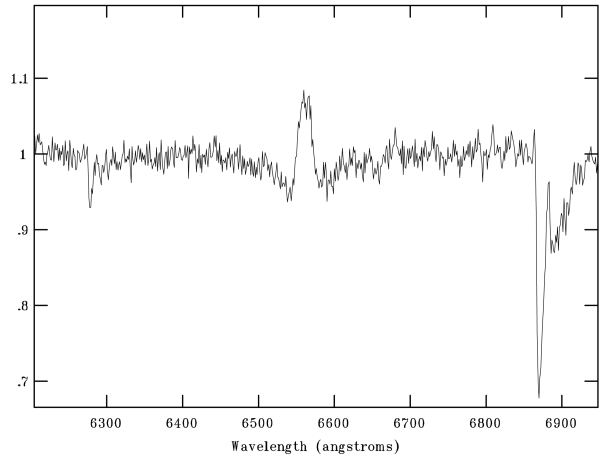

Figure 4: DFOSC spectrum during outburst with Hα emission line.

Two spectra during outburst were obtained with the DFOSC instrument (600 s exposure). We observe several emission lines (see Fig. 4), in particular emission in Hα, Hβ and Hγ. The spectra were obtained in the morning of July 6th –

[1]Aladin has been developed and is maintained by the Centre de Données astronomiques de Strasbourg (CDS), see `http://aladin.u-strasbg.fr/aladin.gml`.

Table 1: Average differential instrumental V-magnitude (with respect to star 7) and standard deviation σ for field stars numbered in Fig. 1. † refers to an outlier that was removed.

star	ΔV	N	σ	star	ΔV	N	σ
1	0.328	492	0.006	12	4.665	604	0.065
2	2.324	554	0.011	13	5.027	618	0.097
3	0.599	628	0.005	14	5.322	497	0.110
4	4.535	581	0.061	15	4.197	651	0.051†
5	0.960	605	0.006	16	4.909	603	0.087
6	−1.316	637	0.003	17	4.580	637	0.062
8	−1.284	636	0.004	18	4.887	527	0.076
9	2.704	655	0.013	19	1.246	650	0.006
10	1.831	655	0.008	20	1.466	628	0.007
11	5.017	627	0.093	21	3.757	641	0.032

mid-exposure times of observations are HJD 2452096.850 with grism 8 and HJD 2452096.867 with grism 4.

2.2 July 2001, LCO Polish 1.3-m

132 V, 226 B and 173 R images were obtained with the 8k ×8k CCD mosaic at the Polish 1.3-m telescope at Las Campanas Observatory (LCO). Each of the 8 subframe CCDs covers 18 × 9 arcmin (JD 52093.84–52099.90). The integration times ranged between 4 and 12 s. Only a 476 × 626 window centered on WX Cet and BD−18 206 = GSC 05851-00965 was read out. Reductions were carried out in the same way as in the previous Section, and differential magnitudes in V using comparison star BD−18 206 were derived.

2.3 August 2001, LCO Polish 1.3-m

74 V and 47 B images were obtained with the same instrument as mentioned in the previous Section (JD 2452148.86–2452150.79). The twilight flats used for all the LCO data are evening flats from August 23 in B and evening flats from August 19 in V. Reductions were carried out in the same way as in Section 2.1, differential magnitudes in V were derived using star 10 as comparison. We point out an outlying result on HJD 24452148.90089: though the frame looks quite normal (but with slightly elongated images like in some other frames), a $\sim 0\overset{\mathrm{m}}{.}6$ flare-like deviation is sandwiched in between two almost identical magnitudes obtained less than 6 minutes apart.

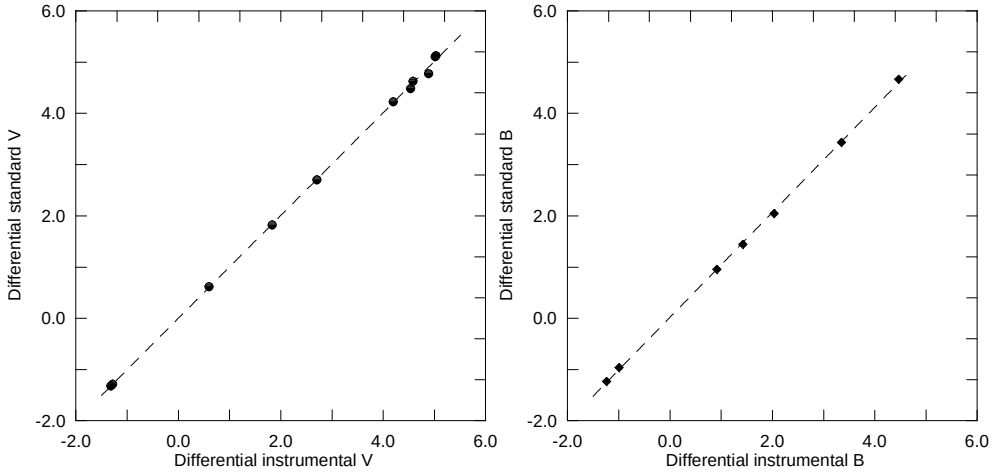

Figure 5: Relationship between differential BV magnitudes in the instrumental system and the Henden sequence.

2.4 December 2004, Armazones 0.41-m telescope

Data were obtained at Observatorio Cerro Armazones (OCA) with a 41-cm Schmidt-Cassegrain telescope and an SBIG ST-9 camera (R filter; JD 2453349.55–2453361.64). Exposure time was 10 s. Reductions were carried out in the same way as in Section 2.1.

2.5 December 2004 and January 2005, Concepción 0.3-m telescope

Data were obtained at Concepción University from December 26, 2004 to January 16, 2005 with the 30-cm Schmidt-Cassegrain telescope and SBIG ST-7XMEI camera (no filter) with exposure times of 30 s. Star 7 was used as comparison star, the resulting differential magnitudes were obtained in the same way as in Section 2.1.Note that the Concepción image quality is rather poor as traces of dust on the CCD window are not completely removed by the flatfielding. This, together with the fact that the telescope is of rather modest size for such a faint star, makes these images not very suitable for calibration of the field.

3 V calibration

Kato et al. (2001) used BD−18 206 = GSC 05851-00965 (Tycho-2 $V = 10.59 \pm 0.02$, $B-V = 0.67 \pm 0.09$) as primary comparison star, its constancy being confirmed by several fainter check stars in the same CCD images. This star is saturated in most of the outburst images and hence the magnitude of WX Cet relative to the other fainter field stars is to be used.

A. Henden[2] lists a set of $V, B-V$ values for some stars in the WX Cet field.

[2] `ftp.nofs.navy.mil/pub/outgoing/aah/sequence/wxcet.dat`

These data yield the tight relationships (Fig. 5):

$$\begin{aligned} V &= 13.167 + 1.0035 \times V' && (1)\\ &\pm \quad 0.025 \quad 0.0015 \\ B &= 13.781 + 1.0317 \times B' && (2)\\ &\pm \quad 0.023 \quad 0.0083 \end{aligned}$$

where V' and B' are instrumental magnitudes.

4 Results

Figure 6 shows a composition of light curves (Danish 154/LCO, OCA and Concepción). Because of the long time-baseline of our data – including the use of different detectors and passbands – we prefer to give our results in the instrumental system as well as transformed to the standard scale.

4.1 Light curves in tabular form

The differential V magnitudes obtained in July 2001 at the Danish and Las Campanas telescopes, are shown in Fig. 7. The V scale follows Eq. 1, but the July 2001 LCO differential V magnitudes (relative to BD−18 206) were corrected by $10\overset{\mathrm{m}}{.}619$ in order to bring the LCO light curve in accord with the ESO light curve. Using $V = 10.648$ (Henden sequence) or the Tycho-2 ($V = 10.59 \pm 0.2$) leaves a substantial difference between both sets of data. Fig. 8 shows the light curves obtained at Armazones, and Fig. 9 shows one example of the light curve obtained with the equipment at Concepción.

Light-curve data are available as ASCII Tables `DAN_WX_V, DAN_WX_B, DAN_WX_R, LCO_WX_V, LCO_WX_B, OCA_WX_R, CPC`. Field star differential magnitudes are given in `DAN_V, DAN_B, DAN_R and OCA_R`.

4.2 Nightly-averaged CCD frames

For each night we normalised and combined the good-quality frames (i.e. well-focused and properly flatfielded images exposed in the linear regime of the CCD) into a single average frame (medians and averages). All Danish and OCA frames in which the maximum measured ADU for star 8 exceeds 49 000 were excluded (this star was saturated on all V frames). The frames obtained in July 2001 at LCO were not combined as these frames contain no information of stars other than WX Cet and BD−18 206. The Concepción averaged frames are not very suitable for rigorous calibration purposes. Table 2 lists the filenames and the number N of added frames for each observing night.

Table 2: FITS filenames and number N of co-added images.

file	band	N	file	band	N	file	band	N
010701	V	108	041209	R	481	20041225	–	29
010701	B	2	041210	R	555	20041226	–	142
010702	V	116	041211	R	514	20041228	–	147
010703	V	17	041212	R	260	20041229	–	244
010703	B	7	041213	R	502	20050101	–	233
010703	R	19	041214	R	507	20050102	–	236
010704	V	74	041215	R	354	20050103	–	134
010705	V	42	041216	R	493	20050104	–	133
010707	V	91	041217	R	31	20050105	–	159
			041218	R	501	20050106	–	167
			041219	R	312	20050108	–	238
			041220	R	489	20050109	–	165
			041221	R	475	20050110	–	200
						20050114	–	30
						20050115	–	144
						20050116	–	152

Acknowledgments

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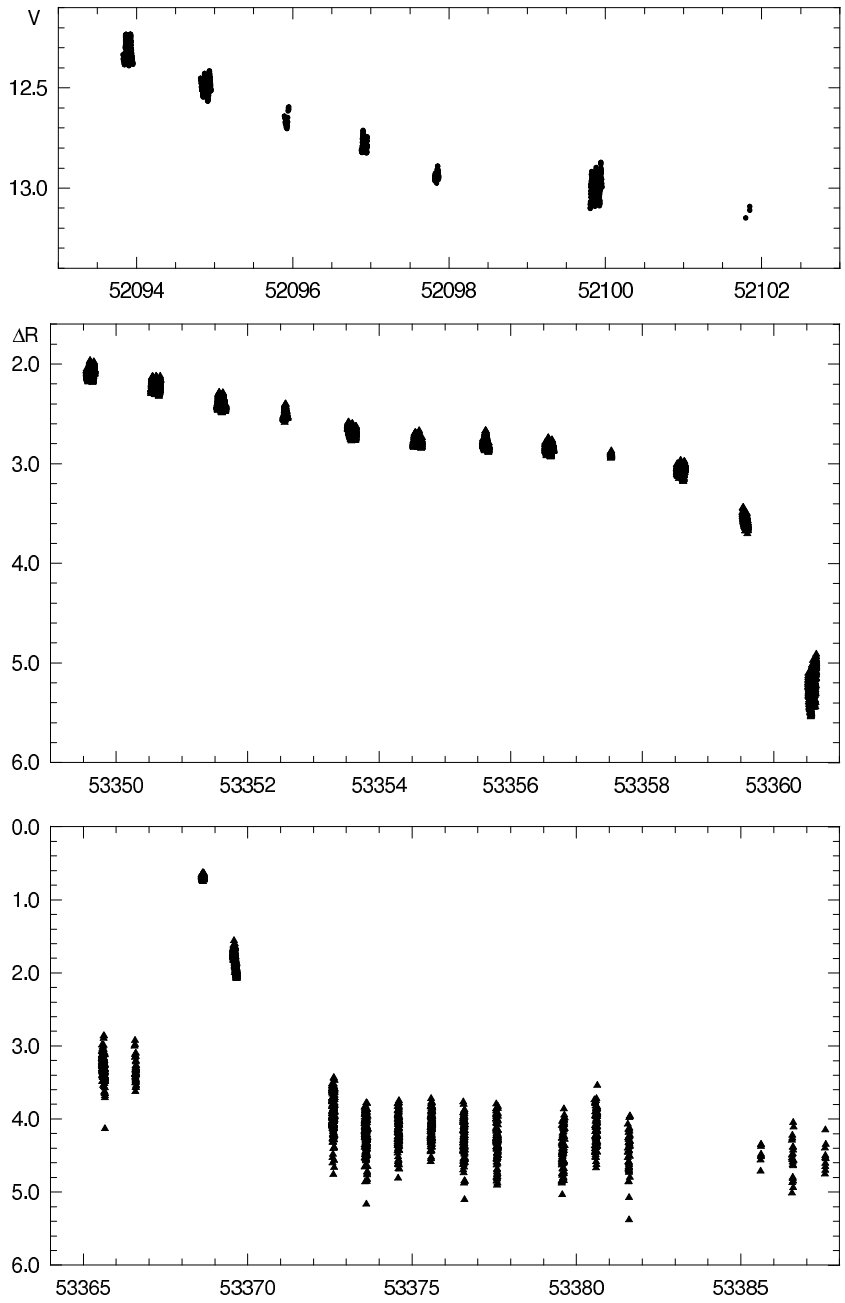

Figure 6: Composite light curves. Top to bottom: Danish 154 V, Armazones R, Concepción (no filter). Magnitude scales and time scales differ.

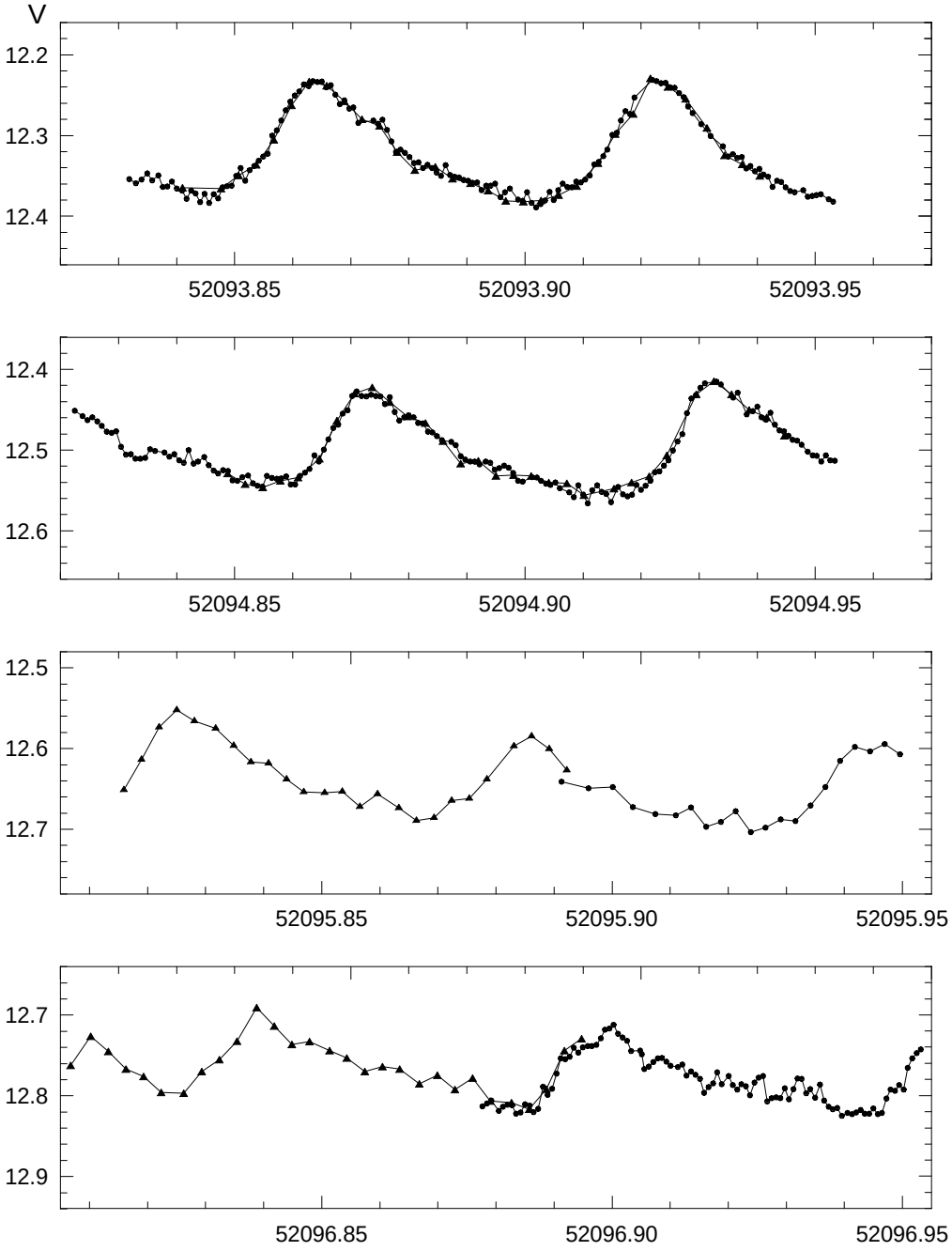

Figure 7: Danish 154 (•) and LCO (▲) V-light curves.

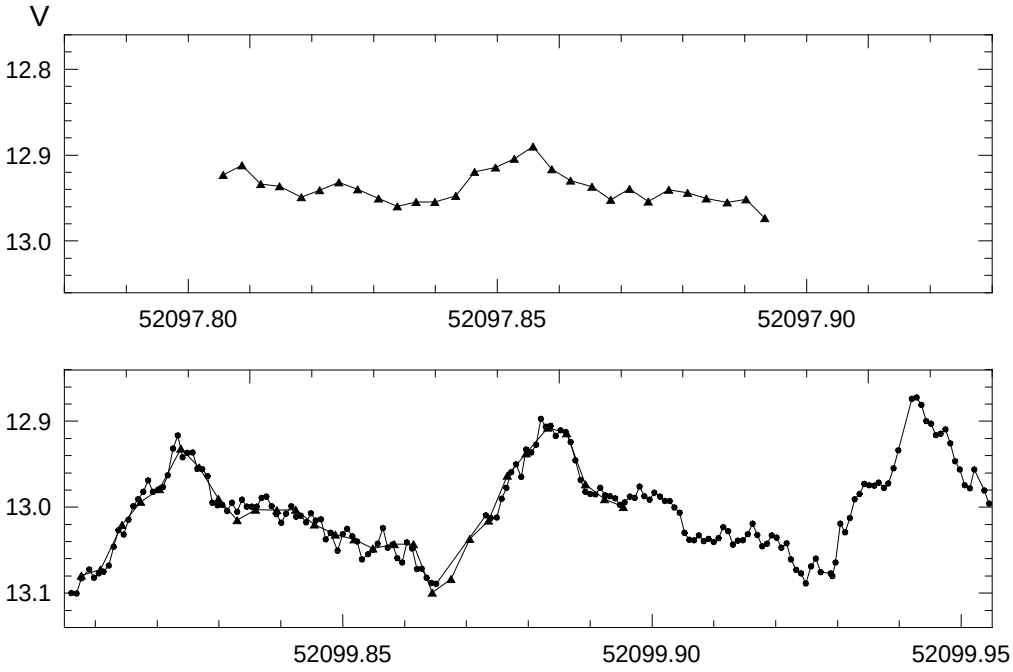

Figure 7: Continued.

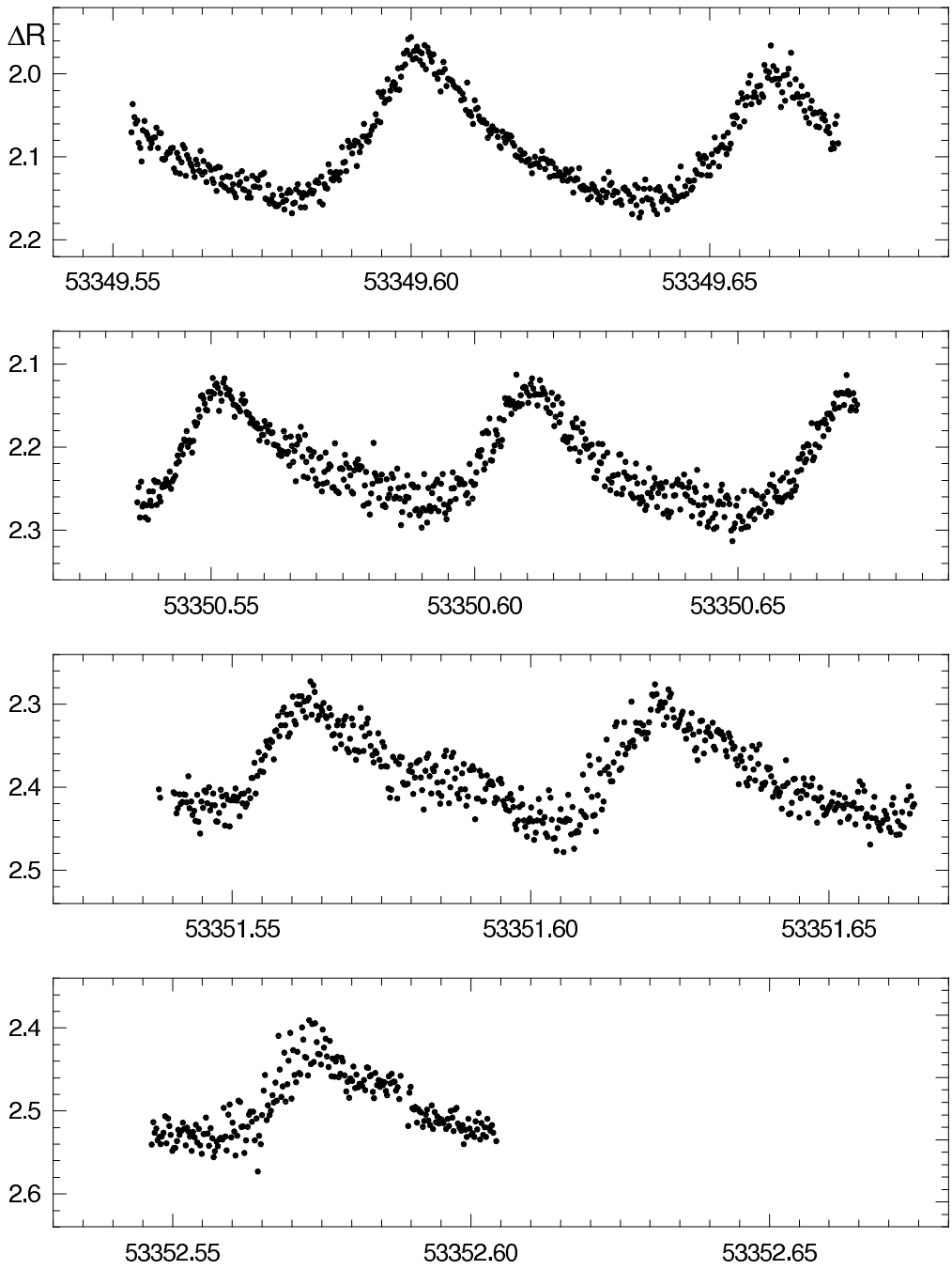

Figure 8: Armazones differential *R*-light curves (with respect to BD-18206).

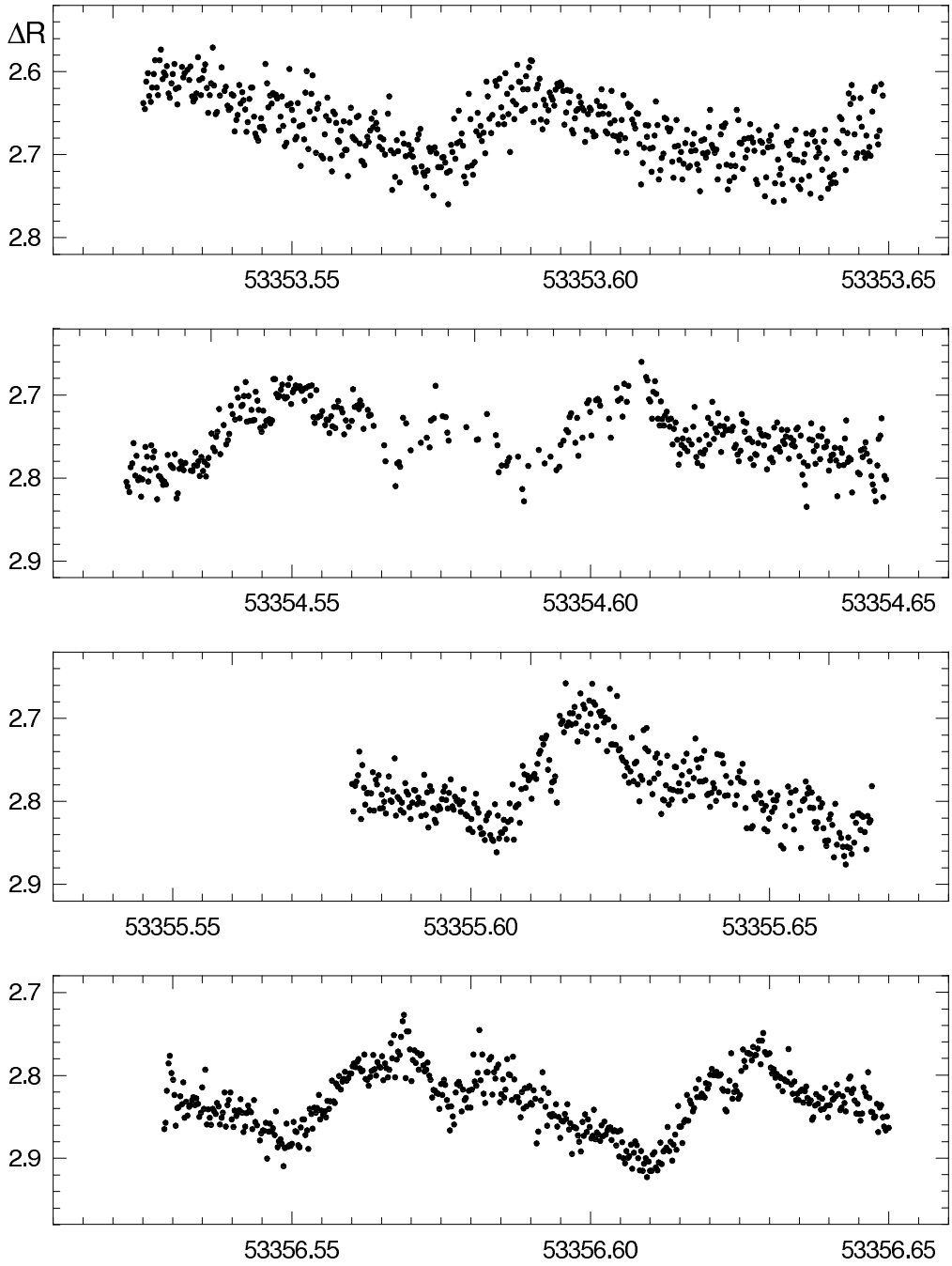

Figure 8: Continued.

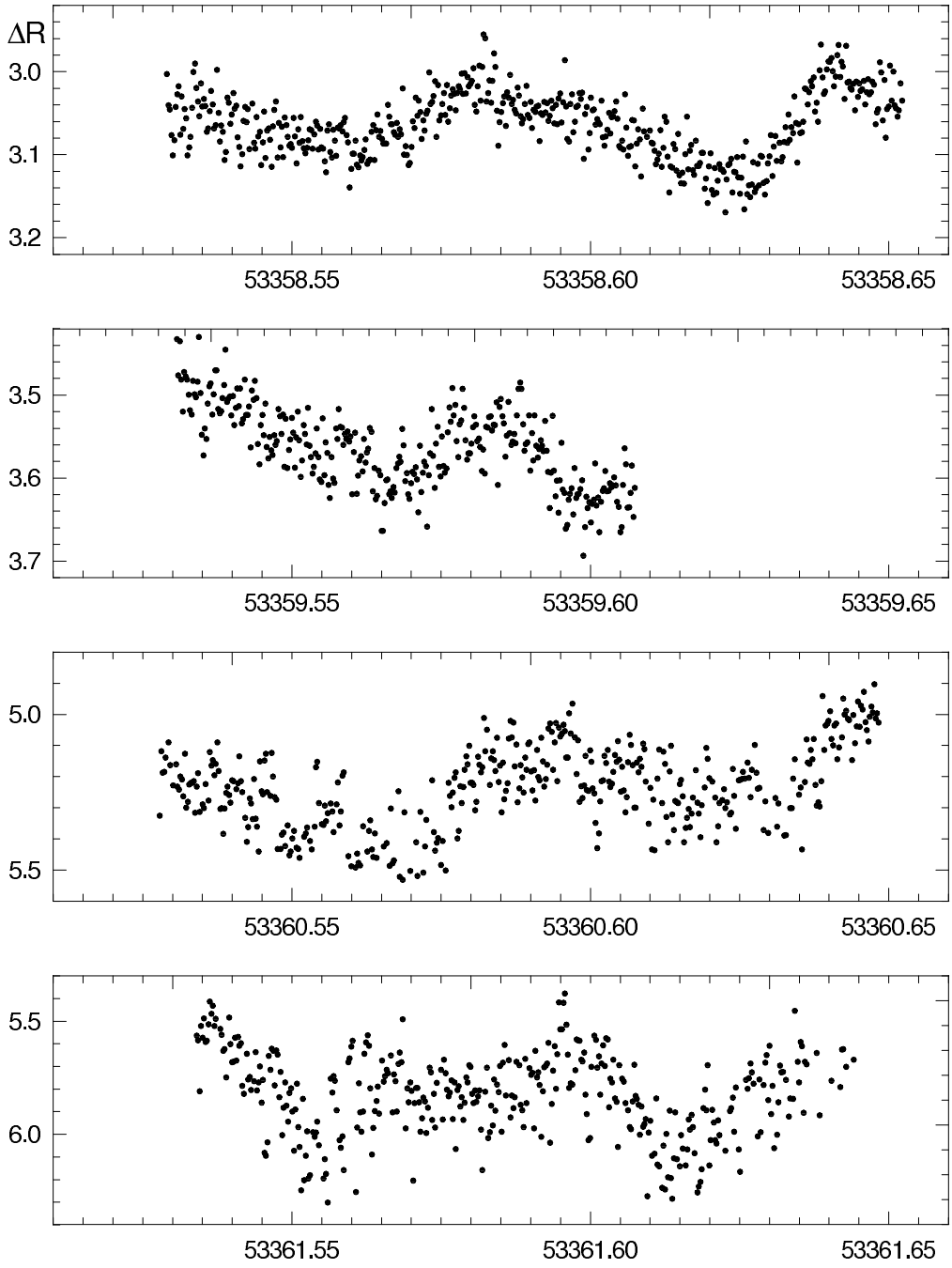

Figure 8: Continued. Note the change in R magnitude scale in the lower 2 graphs.

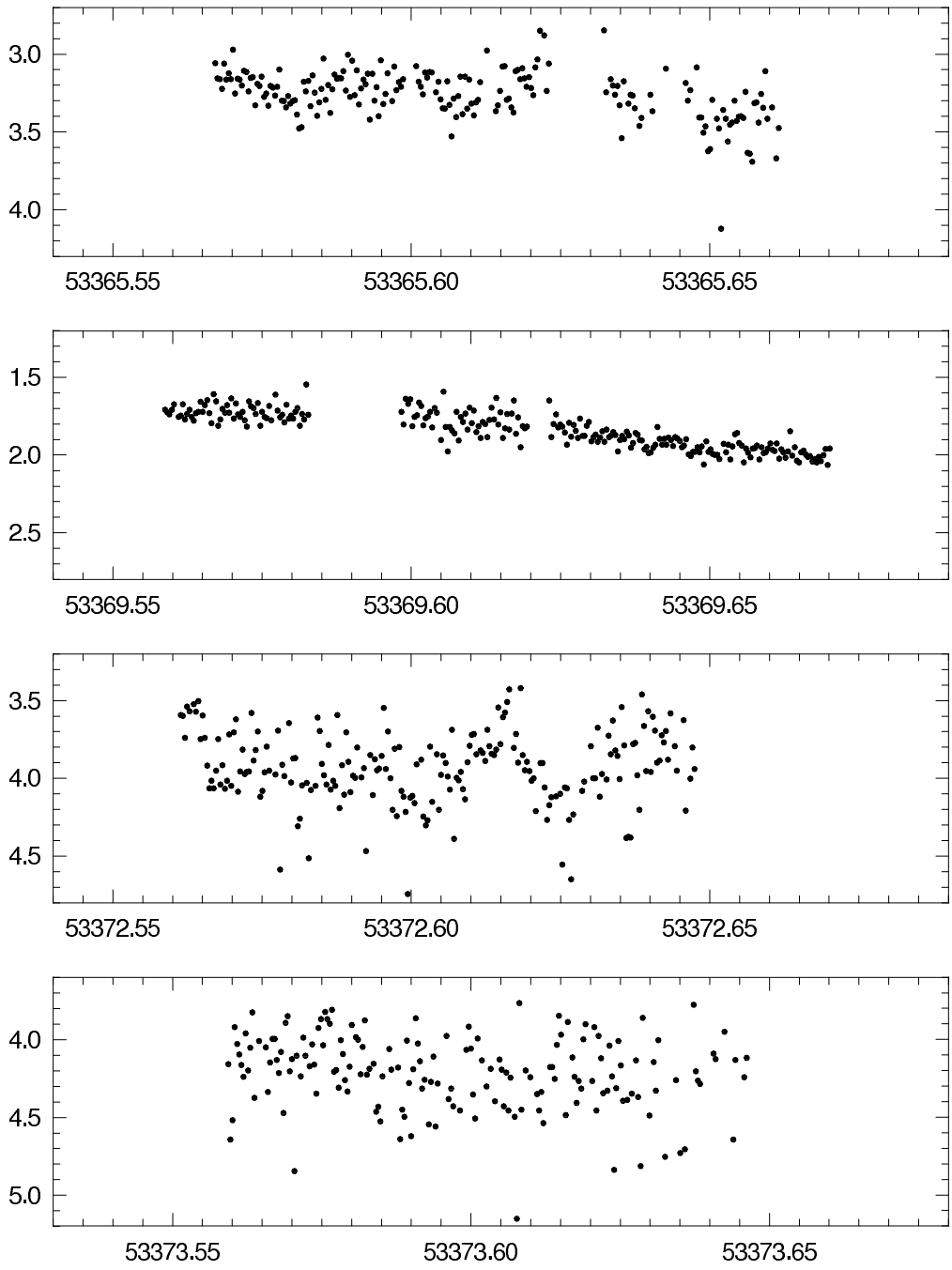

Figure 9: Sample of Concepción light curves (no filter).