The Algol-type binaries RW CrA and DX Vel as multiple systems.

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Introduction.

The eclipsing binaries **RW CrA** (HD 163726, *P = 1.68 days, V = 9.56, B8/A0* III) and **DX Vel** (HD 297655, *P = 1.12 days, V = 10.2, A5)* were discovered by Gaposchkin (1932) and Hoffmeister (1949), respectively. They were observed in 1965 and 1978 by C.J. van Houten using the 0.9m Dutch telescope, equipped with the simultaneous *VBLUW photometer of Walraven, at* the Leiden Southern Station, Broederstroom, South Africa. Multicolour Walraven photometry of the objects was published by van Houten et al. (2009). We compiled all available photometry of these objects including the data from the Hipparcos and ASAS all-sky surveys and added our own CCD photometry of the objects, obtained in 2012-16 by FRAM (Photometric Robotic Atmospheric Monitor): a 0.3m Schmidt-Cassegrain telescope, installed at the Pierre Auger Observatory, located in Argentina near the town of Malargűe and operated by the Institute of Physics, Czech Academy of Sciences. The telescope is equipped with the CCD camera G2-1600 of Moravian Instruments and Bessel set of filters.

Disentangling of (*B-U*) and (*V-B)* Walraven color indices and determination of T_{eff} of the primary component.

The colour indices of the light loss in primary and secondary minima were calculated directly from the ligh curves (LCs) in the Walraven system in different passbands without any additional assumptions. Observed colour indices of the primary and secondary components were dereddened using a two-colour (*B - U), (V - B*) Walraven diagram. Calculated "pure" colour indices were used for determination of the effective temperatures of the primary components using the well-known calibrations.

Analysis of the LCs and absolute parameters.

All available LCs of the binaries were analysed using the PHOEBE program of Prša & Zwitter (2005). We have got an individual solution for every source of data and then we took mean weighted values for the parameters (Table 1). The temperatures of the primary components were fixed. The temperatures of the secondary and tertiary components were found from PHOEBE solutions. The LCs solutions in all passbands presented in **Fig. 2** provide also luminosities of the components. For simplicity, we present only the third light L_{3V} supposing $L_1 + L_2 + L_3$ = 100%. The absolute parameters are presented in **Table 2**. We found the masses of the components by a non-direct method first described by Khaliullin (1985), which is based on an empirical mass-luminosity relation, the 3rd Kepler law and the relation between the absolute and relative radius.

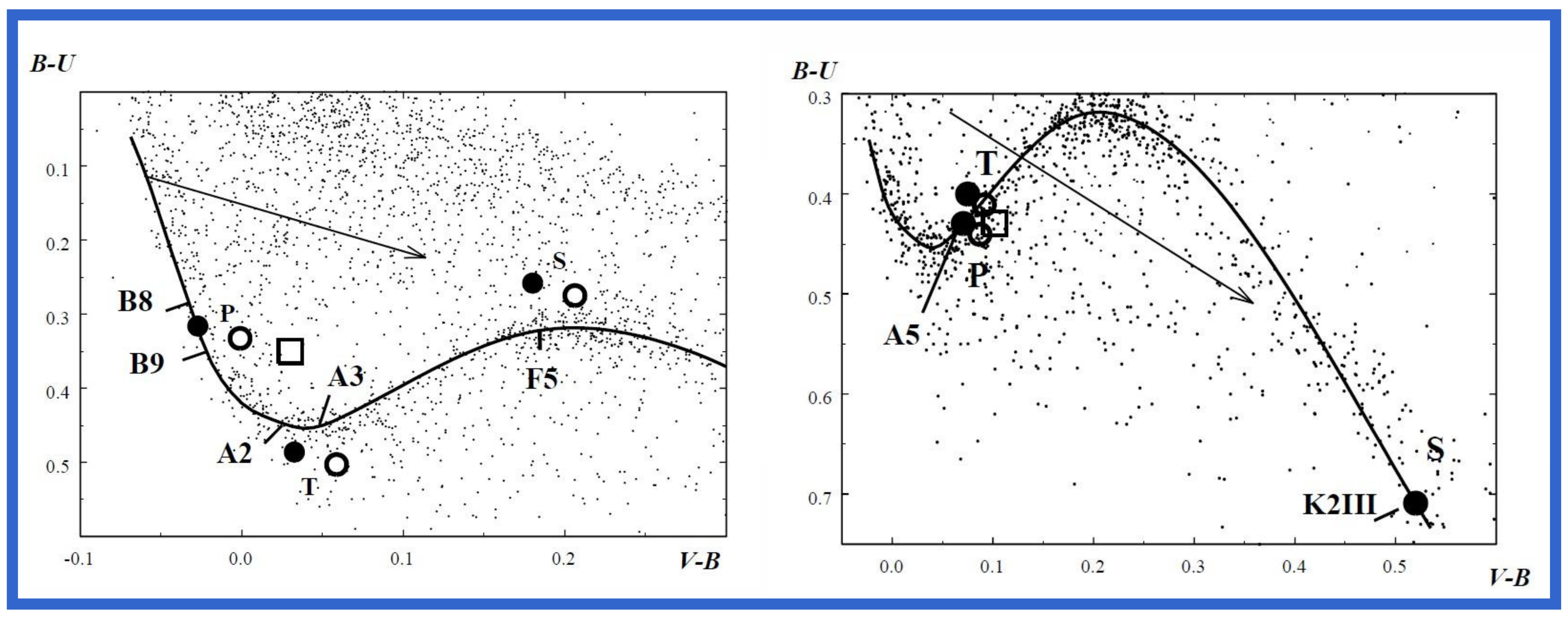

Fig. 1. The (*B - U), (V - B*) Walraven diagrams for RW CrA (left) and DX Vel (right). The arrow stays for the direction of the interstellar reddening. The solid line - standard main sequence from Walraven & Walraven (1977), the points - observations in the Walraven system from Nitschelm & Mermilliod (1990) catalogue. The open square marks the color indices of the combined light. Observed and dereddened indices of the primary (P), secondary (S) and tertiary (T) components are represented by open and full circles, respectively.

Table 1. The parameters derived from the Walraven photometry and LCs fittings.

Parameter	RW CrA	DX Vel
i [°]	89.54±0.05	83.0-85.1
Type of binary	detached	semidetached
$q(M_2/M_1)$	0.59±0.03	0.482±0.007
T_1[K] (fixed)	11100±150	7950±100
T_2[K]	6500±150	4460±70
T_3[K]	8700±200	8030±100
r_1	0.334±0.001	0.238±0.002
r_2	0.301±0.002	0.318±0.003
Ω_1	3.04±0.01	2.84±0.01
Ω_2	2.70±0.02	2.55±0.01
L_{3V}(%)	18.7±0.2	40.1±0.3

Parameter	RW CrA	DX Vel
M_1 [M☉]	3.6±0.2	1.7±0.2
$q(M_2/M_1)$	0.56±0.03	-
R_1 [R☉]	3.5±0.2	1.5±0.2
R_2 [R☉]	3.2±0.2	1.9±0.1
log g_1	3.90±0.03	4.33±0.03
log g_2	3.73±0.03	3.76±0.03
log g_3	3.92±0.05	4.44±0.03
d[pc]	1050±100	550±70

Table 2. The absolute parameters derived by a non-direct method.

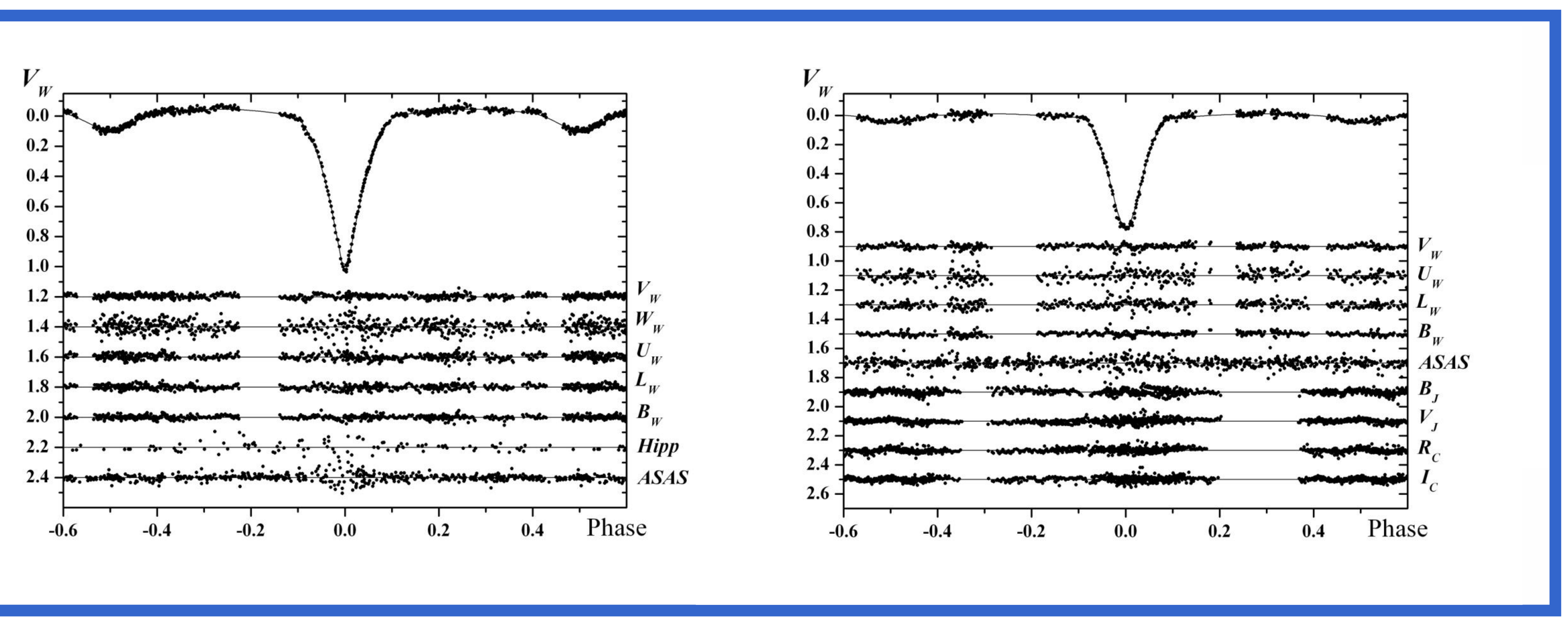

Fig. 2. Van Houten's RW CrA (left) and DX Vel (right) V_W observations with the best fits and the residuals of V_W, W_W, U_W, L_W, B_W, Hipparcos, ASAS and our *B*, *V*, R_C , I_C data after the best fits using the parameters from Table 1.

Parameter	RW CrA	DX Vel
P_3*(period)*[days]	13590±50	28840±200
P_3*(period)*[years]	37.2±0.2	78.9(5)
T_0 (time of periastron) [JD]	2457680±100	2457670±200
α_3 sin *i* [au]	4.57±0.03	1.13±0.13
e	0.93±0.01	0.84±0.03
ω [°]	4.5±0.5	223.5±3
$f(M)_3$ [M☉]	0.068	0.00023
M_3 [M☉]	2.2±0.3	1.1±0.2
i [°]	46±4	8±3

Table 3. Parameters of the third body orbits and estimated masses of the third bodies.

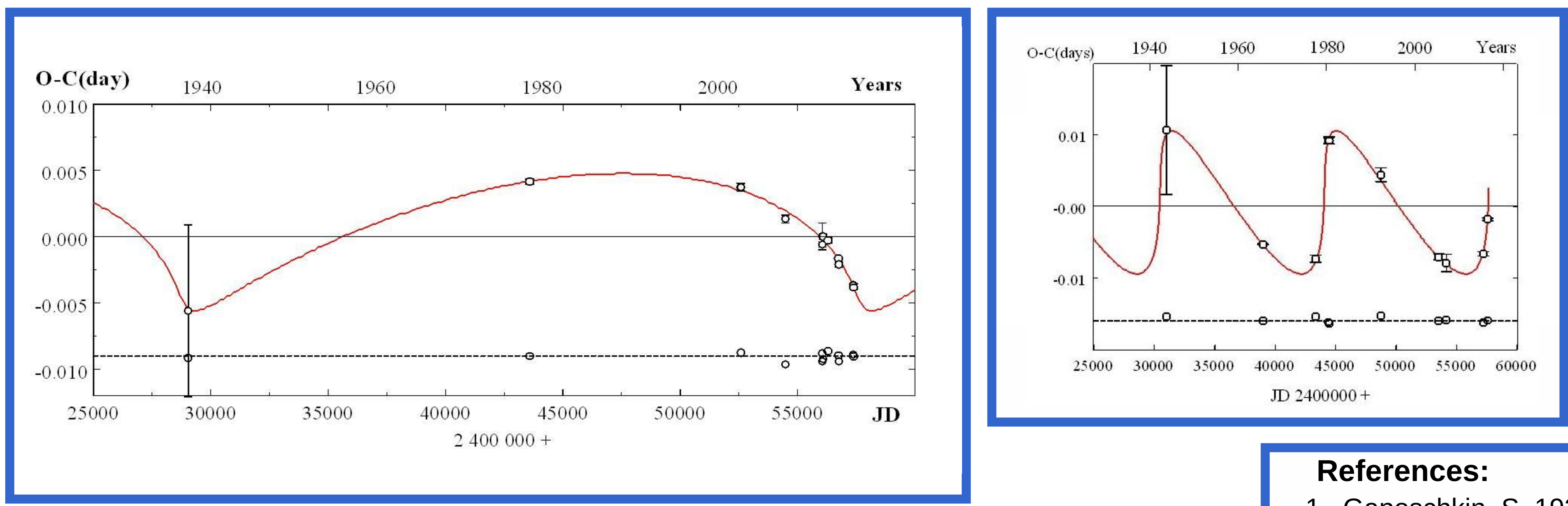

Fig. 3. The ETV diagrams for RW CrA (right) and DX Vel (left), constructed using the ephemerides (1) and (2), respectively, fitted by a LITE curve (top) and their residuals after the subtraction of the adopted solution (bottom).

The eclipse time variation diagrams and the LITE orbits.

All reliable observed times of minimum light of RW CrA and DX Vel were used to construct and analyze the Eclipse Time Variation (ETV) diagrams. The *O - C* residuals in the ETV diagram of RW CrA and DX Vel, presented in Fig. 3, were calculated using the linear ephemerides:

RW CrA: **HJD Min I = 2438987.453 + 1.6836009 x *E.*** **(1)**

DX Vel: **HJD Min I = 2438583.4618 + 1.11730365 x *E.*** **(2)**

The residuals from this formulae were fitted by the LITE orbits. Parameters of the orbit, mass function of the triple system and an estimation of the third body mass for systems RW CrA and DX Vel are given in Table 3. We obtained the inclination of the third body orbits from the estimated masses of the third components. The larger scatter of ASAS residuals of RW CrA in Fig. 2 may be caused by the changes of the orbital inclination *i* with time due to a possible precession of the orbit that follows from non-coplanarity of its orbits. Other LCs do not show such an effect, but they were obtained in shorter time intervals than 7.5 years of the ASAS observations. We fitted all LCs of DX Vel in semidetached mode by the same parameters, except the inclination of the binary orbits, which is responsible for changes of minima depths with time. This effect can be caused by the precession of the orbit of the eclipsing binary as the orbits of the binary and the third body are non-coplanar. We obtained 4 estimates of the orbital inclination of DX Vel in 4 independent epochs:

van Houten, *i* = 83.79° ± 0.08°, apastron of the third body,
ASAS, HJD 2452578, *i* = 82.78° ± 0.09°, intermediate position,
ASAS, HJD 2454482, *i* = 83.10° ± 0.11°, intermediate position,
our observations, *i* = 85.11° ± 0.08°, periastron of the third body.

Conclusions.

We have found reliable parameters of the southern Algol-type detached binary RW CrA and semidetached one DX Vel. Due to the lack of radial velocity data, the masses of their components were computed by a non-direct method.

The study of ETV diagrams enabled us to discover the presence of the third bodies in RW CrA and DX Vel with the periods of 37.2 years and 78.9 years, respectively. The changes in minima depths of both systems could be explained by long term variations of their orbital inclinations because their binary and the third body orbits are not coplanar.

High resolution spectra of studied systems are needed to get the masses of components of these triple or possible quadruple systems from the radial velocity curves.

More details of our investigation can be found in Volkov et al. (2017).

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