Tallinna Tehnikaülikooli Füüsikainstituut

TALLINNA TÄHETORN
TALLINN OBSERVATORY

V

Number 3

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Oli kord ...
Once upon a time ...

TALLINNA TEHNIKAÜLIKOOL
FÜÜSIKAINSTITUUT
TALLINNA TÄHETORN

TALLINN UNIVERSITY OF TECHNOLOGY
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RU Cam revised

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Introduction

RU Cam is a W Vir type variable star (Harris, 1985) with a photometric period P$\sim$22^d (Samus et al. 2004). Harris (1985) estimated based on photometric data its distances from the Sun and from the galactic plane to be d=1.6 and z=0.7 kpc. These estimations accord with the value of the star's Hipparcos parallax 0.59 mas. RU Cam has a rich history of photometric studies.

The peculiar behavior of RU Camelopardalis was known before 1966, but it was still considered as a normal Population II Cepheid. In 1919 the only abnormality of characteristics in its spectrum was discovered, which manifested itself in clearly marked carbon features (Joy, 1919, Cannon, 1920). Its spectral type at minimum light was R0 (Sanford, 1927, 1928) or C6_2 (Keenan and Morgan, 1941) or C3_2e (Bidelman, 1954) and at maximum light it was close to K0. The hydrogen lines were in emission near median magnitude on the rising branch of the light curve and at velocity maximum between the 3rd and 6th days after minimum light (Sanford, 1928; Jehoulet, 1954; Climenhaga, 1960). Evidence of stratification effects are shown by the radial velocity measurements and the highly negative velocity of the emission components of CaII H and K (Faraggiana and Hack, 1967a, b) indicate the presence of expanding chromosphere. RU Cam is not metal poor, although it is a Population II star. The metal abundance is almost normal, with a slight excess of a factor of 2 or 3 for Ca, Ti, V, Ni and the rare earths with respect to Fe. Neither is the star H poor and the excess of carbon is not larger than 2 or 3 (Faraggiana and Hack, 1967b). An advanced evolutionary state of the star can be indicated by the high abundance of C3 (relative to C2) (Faraggiana and Hack, 1967b; Climenhaga, 1960) produced by the carbon cycle.

Demers and Fernie reported in the beginning of 1966, that no light variations exceeding $0\overset{m}{.}1$ - $0\overset{m}{.}2$ could be detected, but the star was still unstable with irregular fluctuations of the order of $0\overset{m}{.}2$. The speculations about ceasing pulsation in RU Cam started. There was suspicion that the star did not stop pulsating, but that the amplitude of its light variation temporarily decreased. Detre (1966) even suggested cyclic amplitude variations and predicted the increase of the amplitude. Demers and Fernie's announcement initiated photoelectric photometry of RU Cam at some observatories (Wamsteker, 1966, 1968; Cester, 1967, 1968, 1969; Broglia, 1967, 1969; Broglia and Guerrero, 1969a, b, 1971, 1972a, b, 1973; Broglia et al., 1978, Fernie and Watt, 1967; Fernie, 1968; Zaitseva, 1967, 1968; Zaitseva and Ljutiy, 1969, 1971, 1978; Zaitseva et al., 1973, Kovalenko, 1974), in order to investigate the peculiar behavior of the star.

The light variablility of RU Cam (BD +69°417 (8.5) = HD 56167 (K0) = 2.1907) was discovered by Mme L. Ceraski on Blazhko's plate collection obtained between 1899-1906 (Ceraski, 1907). Blazhko (1907) determined the period of light variation using his visual estimates of 1907 and photographic observations obtained between 1904-1906 and gave the elements for maximum light:

Max. = J.D. 2417620.0 + $22^{d}.27 \times E$

Luizet (1907, 1912), Ichinohe (1909), Shapley (1913), Silva (1922), Leiner (1923, 1929), Haas (1923), Edelberg (1932), Florja and Kukarkina (1953), published visual or photographic estimates, while Lenouvel and Jehoulet (1953), Lenouvel and Dagouillon (1954), Eggen et al. (1957), Lenouvel and Fiogére (1957), Delsemme and Delsemme-Jehoulet (1958), Michalowska-Smak and Smak (1965), Mitchell et al. (1964), Williams (1966) and Smak (1966) published photoelectric observations of RU Cam obtained before Demers and Fernie's announcement.

As Leiner (1923) had suspected the light curve of RU Camelopardalis varied from cycle to cycle and the period of the star was also changing (Haas, 1923; Leiner, 1929; Edelberg, 1932; Nielsen and Sjögren, 1943).

Although the star was listed to the Cepheid variables, Robinson (1933) drew the attention to the peculiarities of RU Cam in its spectrum, light curve, period and radial velocity, supposing these to have certain interrelationships. Payne-Gaposchkin (1941) noted the similarity of W Virginis and RU Cam in the shape of light curve, the variation of period, the correspondence between light and velocity curves, and the occurrence of bright lines at and following the minima.

The complex character of the variability of RU Cam during the 50's and early 60's was traced back on Sonneberg archival plates (Huth and Wenzel, 1966; Huth, 1966, 1967) and Huth ascertained that the light amplitude of the star might undergo considerable changes within several months. The large irregularities in the light variation of this object were obvious from a mere visual inspection of the time series of its luminosity, and it was also clear that the cycle length was also undergoing irregular fluctuations.

Parallel with the irregular behavior of the light variation the radial velocity changes of the star showed complex character (Demers and Crampton, 1966; Wallerstein and Crampton, 1967). During the period when the amplitude was smaller than $0^{m}.05$, no emission lines were visible in the spectrum of the star and its radial velocity seemed to be constant and approximately equal to Sanford's gamma velocity (Sanford, 1928). Wallerstein (1968) investigated the atmospheric parameters of the star during this "quiescent" period in the early 1965. Lloyd Evans (1983) suggested that there might be a possible connection between extreme irregularity and the occurrence of an overabundance of carbon in RU Cam.

Observations

The photoelectric photometry of RU Camelopardalis was observed in Tallinn Observatory (former observational station of Tartu Observatory which now is the educational observatory on Tallinn University of Technology) mostly by Ü. Kestlane and occasionally by P. Kalv and V. Harvig during the period from Oct. 1970 to Nov. 1984. This resulted in 118 observations, mostly one observation per night. The photoelectric photometers were attached to the Cassegrain focus of the 48 cm reflector AZT-14A (d/f=16).The method of observation and reducing has been described in formerly published article (Kalv et al. (2007)). The data of Ru Camelopardalis, comparison and check star for observations in Tallinn and observations in Konkoly are given accordingly in Table 1 and Table 2.

Due to the variety of optical data sources and photometric systems, combining these datasets required the application of small systematic corrections, to produce a consistent

Tabel 1: Brightness and colours of RU Cam, comparison and check stars

Star		Sp.	V	B
RU Cam	= HD 56167	C0,1-C3,2E(K0-R0)	8.48	9.63
Comp	= HD 56738	G0	7.99	8.57
Check	= HD 56819	F0	8.74	9.11

Tabel 2: Brightness and colours of the comparison stars by Szeidl et al. (1992)

Star		Sp.	V	B-V	U-B
BD +69°420	= HD 57201	(F8)	8.906	+0.506	+0.055
BD +69°422	= HD 57308	(GO)	8.021	+0.801	+0.487
BD +70°447	= HD 56323	(F5)	9.056	+0.326	+0.072
BD +70°448	=		9.059	+1.090	+0.934

light curves and colour diagrams. The Konkoly Observatory data were taken as the baseline for this procedure, as they covered the longest timespan.

Jälle RU Cam

RU Cam-i muutlikkust täheldas M. Ceraski aastal 1907 fotoplaatidelt, mis olid ülesvõetud aastail 1899-1906. $22^{\mathrm{d}}.27$ perioodiga sai ta heleduseks $8^{\mathrm{m}}.0$ kuni $9^{\mathrm{m}}.1$. Hiljem klassifitseeriti RU Cam tsefeiidi tüüpi muutlikku tähena. Tsefeiidid on tuntud oma sekundi murdosaga mõõdetava muutlikkuse tõttu. Muutlikkus on tingitud tähe struktuurist. Sisemine kuumenev kiht toimib ventiilitüüpi mehhanismina. Avatud ventiili korral pääseb kiirgus kergesti välja ja põhjustab tähe kokku tõmbumist. Seejärel ventiil sulgub ning takistab kiirgust väljumast, mis omakorda põhjustab tähe paisumist. Ventiilitüüpi mehhanismi põhjustab heeliumi ja vesiniku ionisatsioon tähes.

Sellist pulseerimise mehhanismi kasutatakse tähe absoluutse heleduse määramiseks. Väikeste tsefeiidide korral tähe tuumast tähe pinnale liikuv kiirguslaine liigub ajaskaalas kiiremini kui suurte tähtede korral kuna läbitav distants on lühem. Suurtel tähtedel on seega pikem periood. Kuna suurtel tähtedel on rohkem pinda ja nad kiirgavad rohkem valgust, siis on nad ka heledamad. Roscoe Sanford avastas aastal 1928 RU Cam-il radiaalkiiruse ja spektri muutlikkuse. Maksimaalse heleduse korral oli spekter K0 ja minimaalse korral R0. Aastal 1966 hakkas RU Cam-i pulseerumine sumbuma ning lakkas 4 aastat hiljem. Sel ajal ei teadnud keegi, mis täpselt põhjustas pulseerumise lõppemise. Astrofüüsika teooria ütleb, et kui peatada pulseerimise mehhanism, siis pulseerumise lõppemiseks kuluks ikkagi 1000-10000 aastat.

RU Cam on W Vir-tüüpi täht, mille muutumist on jälgitud väga paljude vaatlejate poolt. Eriti tõusis huvi selle tähe vastu, kui eelmise sajandi kuuekümnendatel aastatel jäi mulje, et pulsseerumine sumbub. Nii vaadeldi ka Tallinna Tähetornis seda objekti aeg–ajalt 1970–1984. Suures osas toimusid samaaegselt intensiivsed vaatlused näiteks Ungaris. Kahjuks kasutati Tallinnas teist võrdlustähte ja vaatluste ühildamine osutus raskendatuks. Hoolimata sellest leidsime rahuldava seose ungarlaste teostatud ja teiste autorite fotoelektriliste vaatlusseeriate vahel, kui need kattusid mingis ulatuses. Visuaalsete vaatluste seostamine ei õnnestunud. HIPPARCOS-e vaatlustega seostamine aga ei olnud võimalik, kuna ei ole „kvaasisamaaegseid“ vaatlusi. 20. sajandi alguses oli RU Cam muutlikkuse amplituud umbes üks tähesuurus. Üldiselt oli objekti muutumise amplituud alates 20. sajandi kuuekümnendate aastate keskel V-värvis fotomeetriliselt kuni $0\overset{m}{.}3$ tähesuurust ja see muutus tsükliliselt ning oli vahel vaevu märgatav. Samal ajal aga visuaalsete vaatluste hajumine on umbes 1 tähesuurus ja kuigi neid on palju ja nad katavad suurema ajavahemiku on nende alusel mingite hinnangute tegemine kahtlane. Vastavalt ADS-ile on uusim RU Cam-ile pühendatud teaduslik uurimus (Kipper ja Klochkova, 2007), millest nähtub, et huvi antud objekti vastu pole kadunud.

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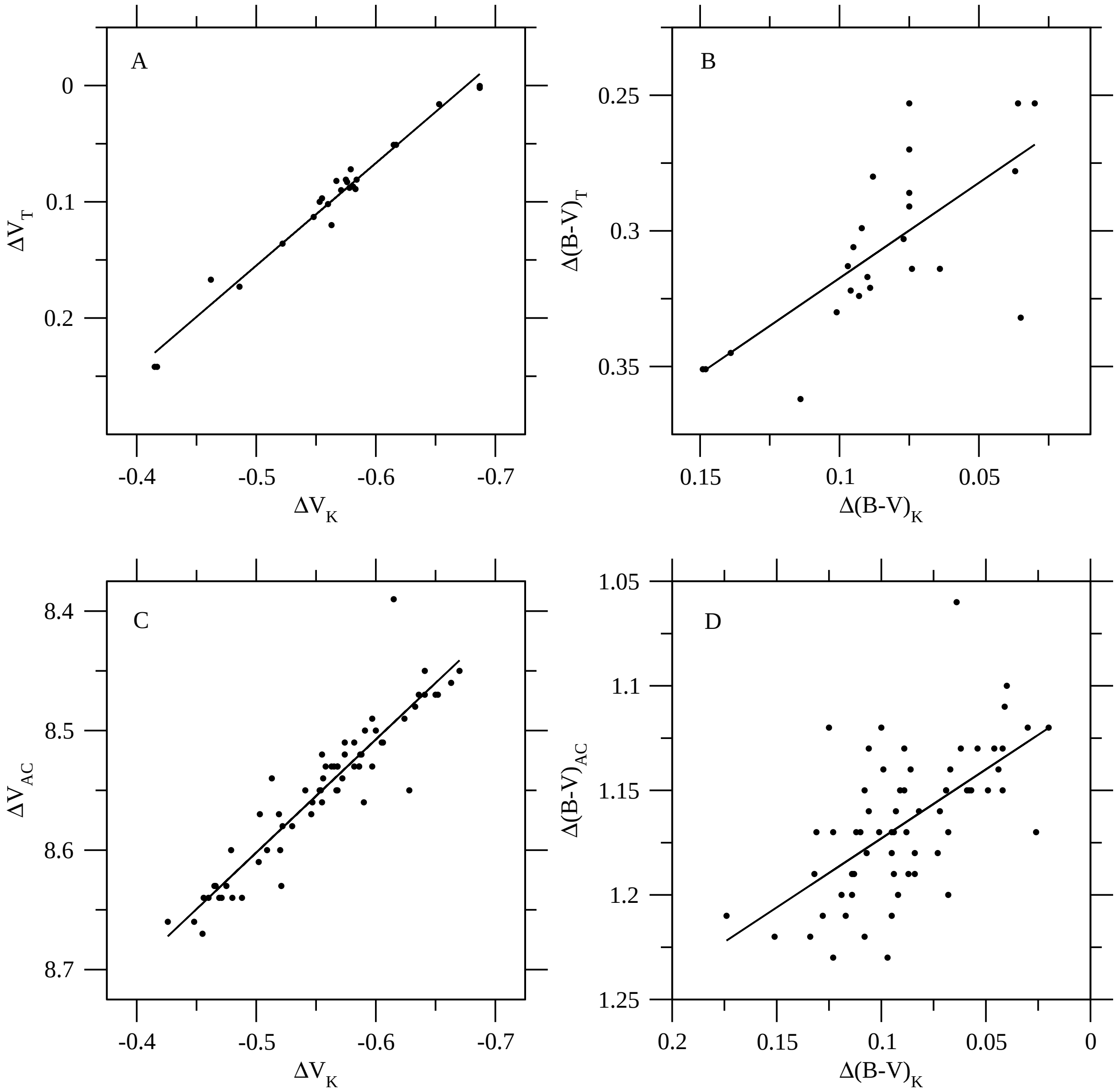

Figure 1: Calibration coefficients to Konkoly Observatory data baseline

A. $\Delta V = 1.135 \times \Delta V_T - 0.675$
B. $\Delta(B\text{-}V) = 1.422 \times \Delta(B\text{-}V)_T - 0.351$

T → Tallinn observations

C. $\Delta V = 1.057 \times \Delta V_{AC} - 9.598$
D. $\Delta(B\text{-}V) = 1.515 \times \Delta(B\text{-}V)_{AC} - 1.682$

AC → Zaitseva (1967, 1968)and Zaitseva and Ljutiy (1969, 1971, 1968) observations

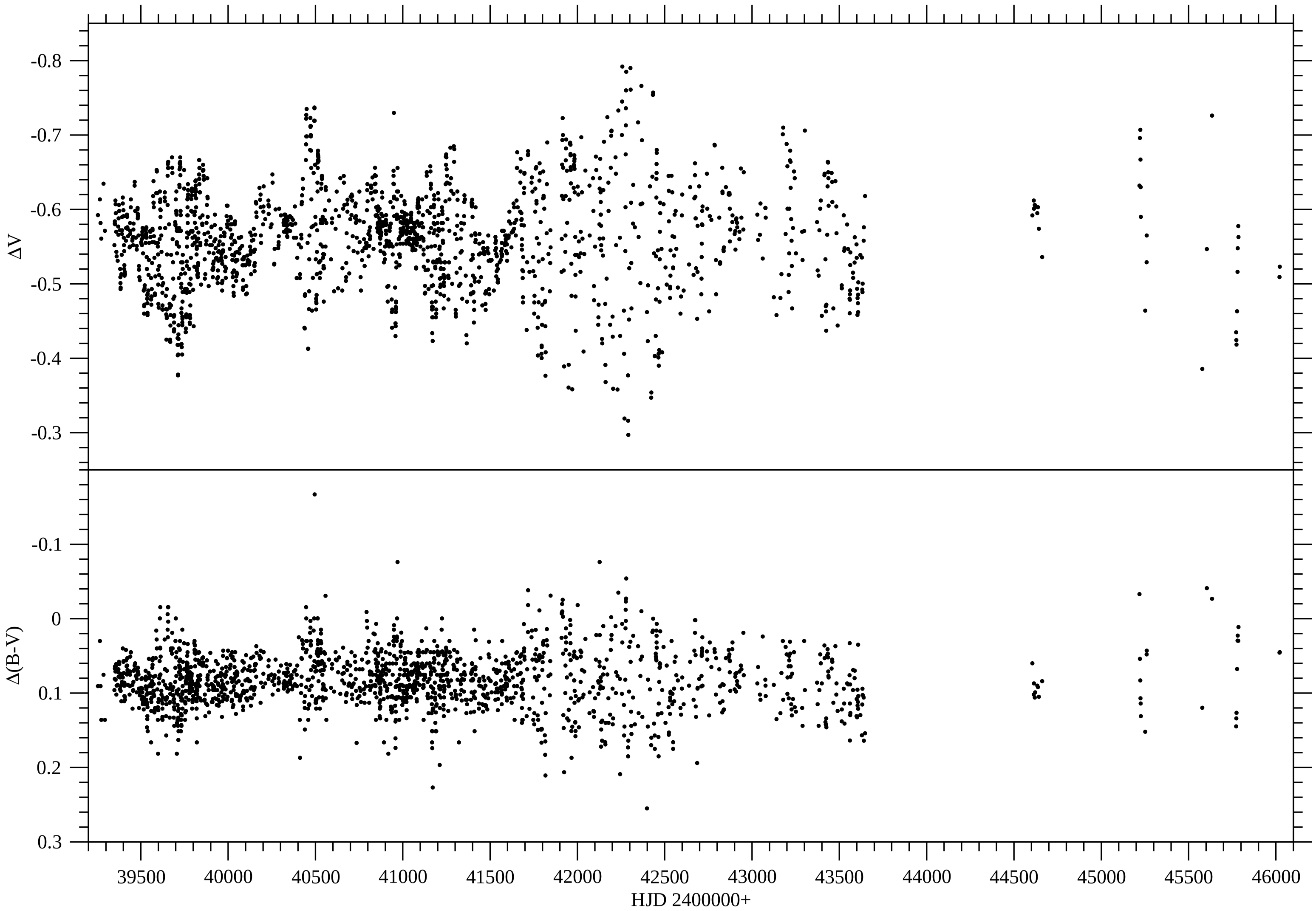

Figure 2: Observation results reduced to Konkoly Observatory data baseline

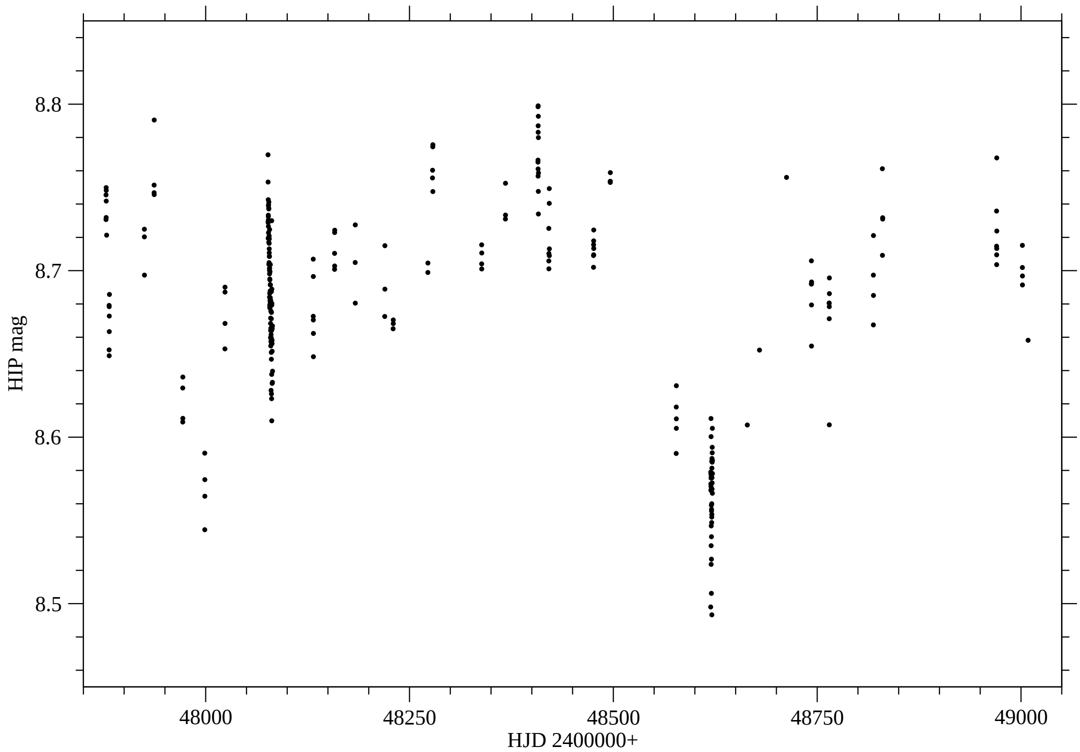

Figure 3: Light curve of RU Cam Hipparcos observations

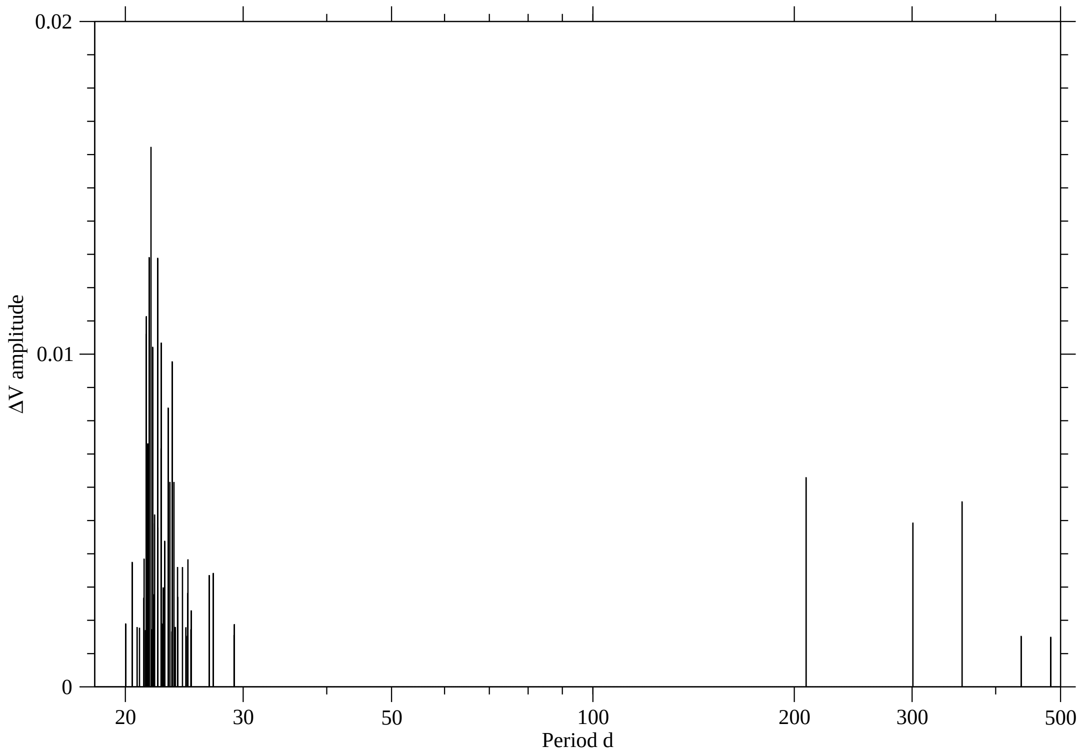

Figure 4: Time-series spectrum for RU Cam found by using the CLEAN algorithm (Roberts et al., 1989

Table 3: RU Cam observations in Tallinn

HJD-2400000+	ΔV	$\Delta(B-V)$	HJD-2400000+	ΔV	$\Delta(B-V)$
40865.5654	0.082	0.308	41717.5914	-0.003	0.234
40867.4570	0.094	0.308	41717.6404	0.001	0.220
40871.4487	0.090	0.330	41725.4211	0.140	0.332
40871.5374	0.082	0.324	41756.4250	0.145	0.302
40885.5557	0.074	0.285	41765.4867	0.056	0.303
40921.3682	0.104	0.296	41767.4824	0.100	0.305
40921.6668	0.110	0.271	41773.5422	0.239	0.352
40925.3971	0.088	0.280	41777.5105	0.176	0.286
40932.2947	0.107	0.330	41782.5145	0.032	0.239
40932.7173	0.109	0.333	41785.5478	0.023	0.284
40949.3741	0.036	0.264	41794.4159	0.237	0.364
40949.5442	0.051	0.253	41795.4051	0.242	0.351
40958.2825	0.201	0.360	41800.3877	0.160	0.283
40958.3094	0.201	0.369	41801.3692	0.125	0.288
40958.4657	0.216	0.344	41806.4594	0.050	0.268
40987.4893	0.089	0.278	41813.4421	0.176	0.357
40987.6071	0.093	0.271	41817.4334	0.263	0.395
40991.2513	0.050	0.260	41909.4694	0.140	0.265
41013.3843	0.072	0.286	41910.4719	0.101	0.242
41014.4776	0.081	0.284	41911.4883	0.050	0.241
41021.4848	0.095	0.341	41912.4811	0.013	0.233
41022.4086	0.084	0.321	41913.5104	-0.016	0.240
41023.3926	0.072	0.322	41915.5165	-0.042	0.229
41023.5471	0.079	0.313	41917.5358	-0.022	0.245
41035.3002	0.102	0.299	41919.4646	0.054	0.338
41039.3810	0.100	0.321	41923.5585	0.252	0.392
41047.4609	0.079	0.298	41949.5165	0.277	0.343
41048.4063	0.070	0.297	41950.5447	0.250	0.333
41049.4000	0.081	0.291	41958.5200	-0.013	0.248
41052.4270	0.109	0.311	41960.3991	0.000	0.270
41057.4260	0.114	0.313	41960.5616	0.002	0.253
41060.3511	0.113	0.313	41961.3972	0.016	0.286
41062.4184	0.114	0.309	41970.4397	0.279	0.349
41064.4109	0.083	0.317	41982.5516	0.002	0.278
41065.3851	0.082	0.312	41983.3874	0.018	0.282
41066.4023	0.084	0.296	41987.5554	0.120	0.345
41068.3991	0.094	0.308	42001.3490	0.039	0.234
41069.3491	0.087	0.306	42017.2908	0.140	0.277
41072.3946	0.114	0.310	42045.5612	0.020	0.266
41076.4057	0.136	0.314	43525.5851	0.073	0.313
41079.3761	0.108	0.323	43527.3520	0.115	0.327
41080.3975	0.101	0.325	43529.6677	0.112	0.346
41081.4034	0.097	0.314	43544.4042	0.084	0.308
41083.3943	0.081	0.303	43550.4192	0.113	0.309
41693.4090	0.085	0.252	43559.4746	0.189	0.270

Table 3: RU Cam observations in Tallinn (*continued*)

HJD-2400000+	ΔV	$\Delta(B-V)$	HJD-2400000+	ΔV	$\Delta(B-V)$
43560.5710	0.173	0.362	43633.4463	0.154	0.319
43561.4406	0.162	0.309	45578.3978	0.255	0.331
43562.3528	0.132	0.338	45604.3273	0.113	0.218
43563.3529	0.117	0.336	45634.3051	-0.045	0.228
43587.4838	0.129	0.303	45772.3900	0.212	0.349
43588.4041	0.099	0.296	45773.4375	0.221	0.341
43601.5443	0.160	0.340	45774.5556	0.226	0.336
43603.5194	0.191	0.314	45777.4688	0.187	0.294
43604.3522	0.171	0.329	45780.3819	0.140	0.268
43607.4472	0.167	0.332	45781.4722	0.112	0.263
43620.3883	0.120	0.338	45784.4688	0.086	0.268
43629.4730	0.123	0.357	45785.5313	0.099	0.256
43631.4686	0.161	0.328	46020.4063	0.146	0.279
43632.3950	0.164	0.313	46022.2396	0.134	0.279

Table 4: RU Cam observations in Tallinn
shifted to Konkoly Observatory data baseline

HJD-2400000+	ΔV	$\Delta(B-V)$	HJD-2400000+	ΔV	$\Delta(B-V)$
40865.5654	-0.581	0.087	41035.3002	-0.559	0.074
40867.4570	-0.568	0.087	41039.3810	-0.561	0.105
40871.4487	-0.572	0.118	41047.4609	-0.585	0.072
40871.5374	-0.581	0.109	41048.4063	-0.595	0.071
40885.5557	-0.591	0.054	41049.4000	-0.583	0.062
40921.3682	-0.557	0.069	41052.4270	-0.551	0.091
40921.6668	-0.550	0.034	41057.4260	-0.545	0.094
40925.3971	-0.575	0.047	41060.3511	-0.546	0.094
40932.2947	-0.553	0.118	41062.4184	-0.545	0.088
40932.7173	-0.551	0.122	41064.4109	-0.580	0.099
40949.3741	-0.634	0.024	41065.3851	-0.581	0.092
40949.5442	-0.617	0.008	41066.4023	-0.579	0.069
40958.2825	-0.446	0.160	41068.3991	-0.568	0.087
40958.3094	-0.446	0.173	41069.3491	-0.576	0.084
40958.4657	-0.429	0.138	41072.3946	-0.545	0.089
40987.4893	-0.574	0.044	41076.4057	-0.520	0.095
40987.6071	-0.569	0.034	41079.3761	-0.552	0.108
40991.2513	-0.618	0.018	41080.3975	-0.560	0.111
41013.3843	-0.593	0.055	41081.4034	-0.564	0.095
41014.4776	-0.583	0.052	41083.3943	-0.583	0.079
41021.4848	-0.567	0.133	41693.4090	-0.578	0.007
41022.4086	-0.579	0.105	41717.5914	-0.678	-0.018
41023.3926	-0.593	0.106	41717.6404	-0.673	-0.038
41023.5471	-0.585	0.094	41725.4211	-0.516	0.121

Table 4: RU Cam observations in Tallinn
shifted to Konkoly Observatory data baseline(*continued*)

HJD-2400000+	ΔV	$\Delta(B-V)$	HJD-2400000+	ΔV	$\Delta(B-V)$
41756.4250	-0.510	0.078	42045.5612	-0.652	0.027
41765.4867	-0.611	0.079	43525.5851	-0.592	0.094
41767.4824	-0.561	0.082	43527.3520	-0.544	0.114
41773.5422	-0.403	0.149	43529.6677	-0.547	0.141
41777.5105	-0.475	0.055	43544.4042	-0.579	0.087
41782.5145	-0.638	-0.011	43550.4192	-0.546	0.088
41785.5478	-0.648	0.052	43559.4746	-0.460	0.032
41794.4159	-0.406	0.166	43560.5710	-0.478	0.163
41795.4051	-0.400	0.148	43561.4406	-0.491	0.088
41800.3877	-0.493	0.051	43562.3528	-0.525	0.129
41801.3692	-0.533	0.058	43563.3529	-0.542	0.126
41806.4594	-0.618	0.030	43587.4838	-0.528	0.079
41813.4421	-0.475	0.156	43588.4041	-0.562	0.069
41817.4334	-0.376	0.210	43601.5443	-0.493	0.132
41909.4694	-0.516	0.025	43603.5194	-0.458	0.095
41910.4719	-0.560	-0.006	43604.3522	-0.480	0.116
41911.4883	-0.618	-0.008	43607.4472	-0.485	0.121
41912.4811	-0.660	-0.019	43620.3883	-0.538	0.129
41913.5104	-0.693	-0.009	43629.4730	-0.535	0.156
41915.5165	-0.722	-0.025	43631.4686	-0.492	0.115
41917.5358	-0.700	-0.002	43632.3950	-0.488	0.094
41919.4646	-0.613	0.129	43633.4463	-0.500	0.102
41923.5585	-0.389	0.206	45578.3978	-0.385	0.119
41949.5165	-0.360	0.136	45604.3273	-0.546	-0.041
41950.5447	-0.391	0.122	45634.3051	-0.726	-0.026
41958.5200	-0.689	0.001	45772.3900	-0.434	0.144
41960.3991	-0.674	0.032	45773.4375	-0.424	0.134
41960.5616	-0.672	0.008	45774.5556	-0.418	0.126
41961.3972	-0.656	0.055	45777.4688	-0.463	0.067
41970.4397	-0.358	0.145	45780.3819	-0.516	0.029
41982.5516	-0.672	0.044	45781.4722	-0.547	0.022
41983.3874	-0.654	0.050	45784.4688	-0.577	0.029
41987.5554	-0.538	0.139	45785.5313	-0.562	0.011
42001.3490	-0.630	-0.018	46020.4063	-0.509	0.045
42017.2908	-0.516	0.042	46022.2396	-0.523	0.045

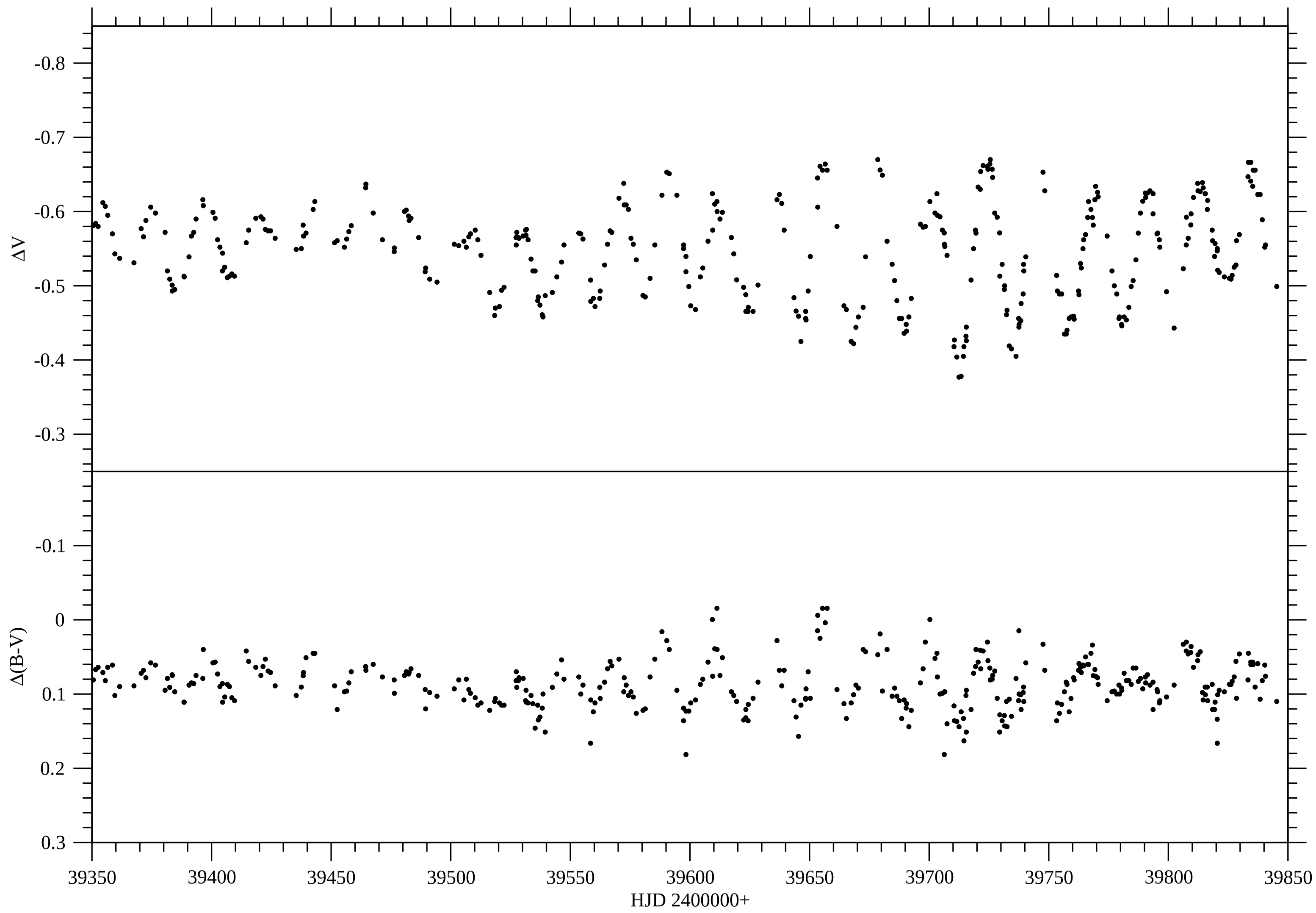

Figure 5: Zoomed light curve fragment of RU Cam (1)

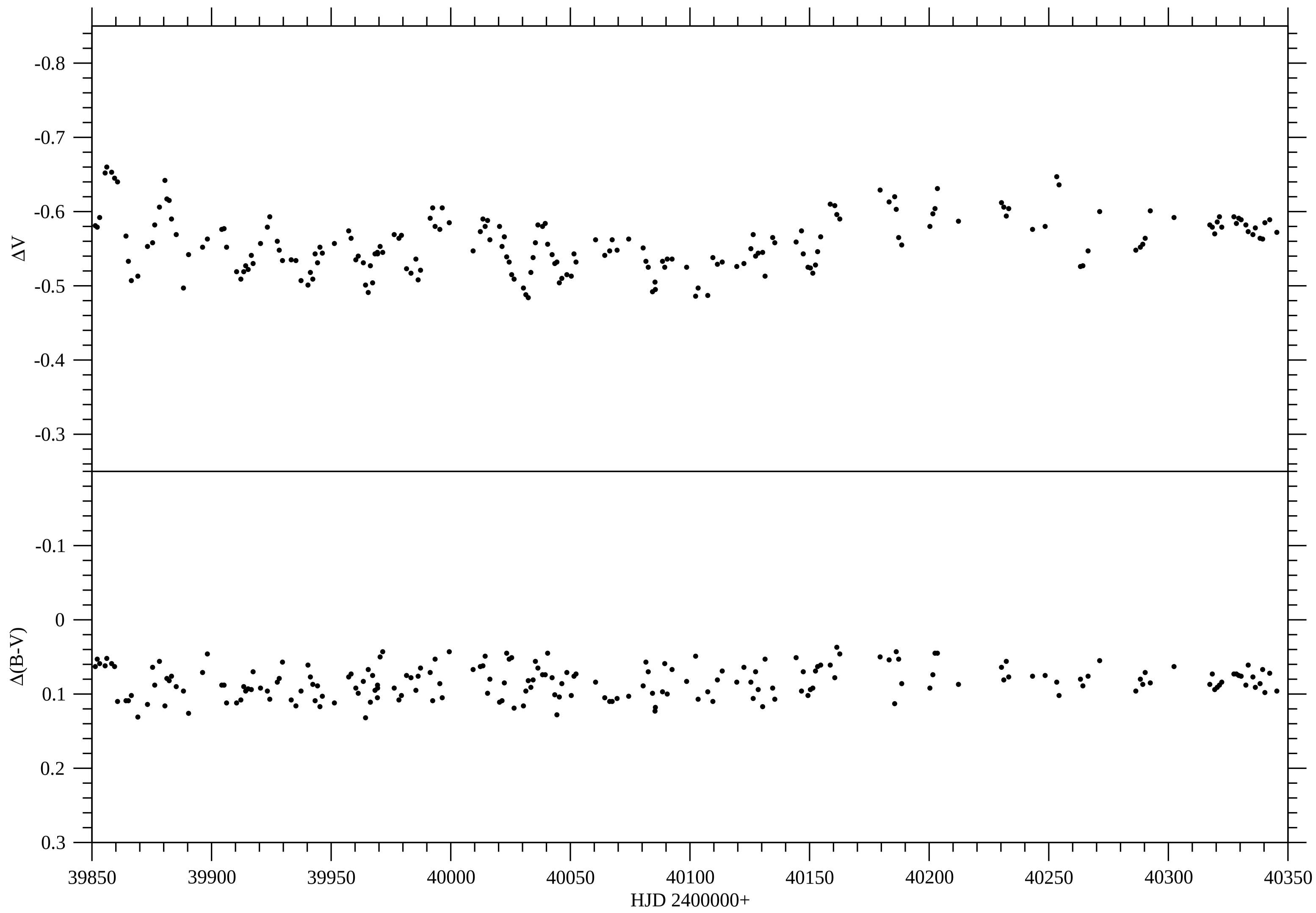

Figure 6: Zoomed light curve fragment of RU Cam (2)

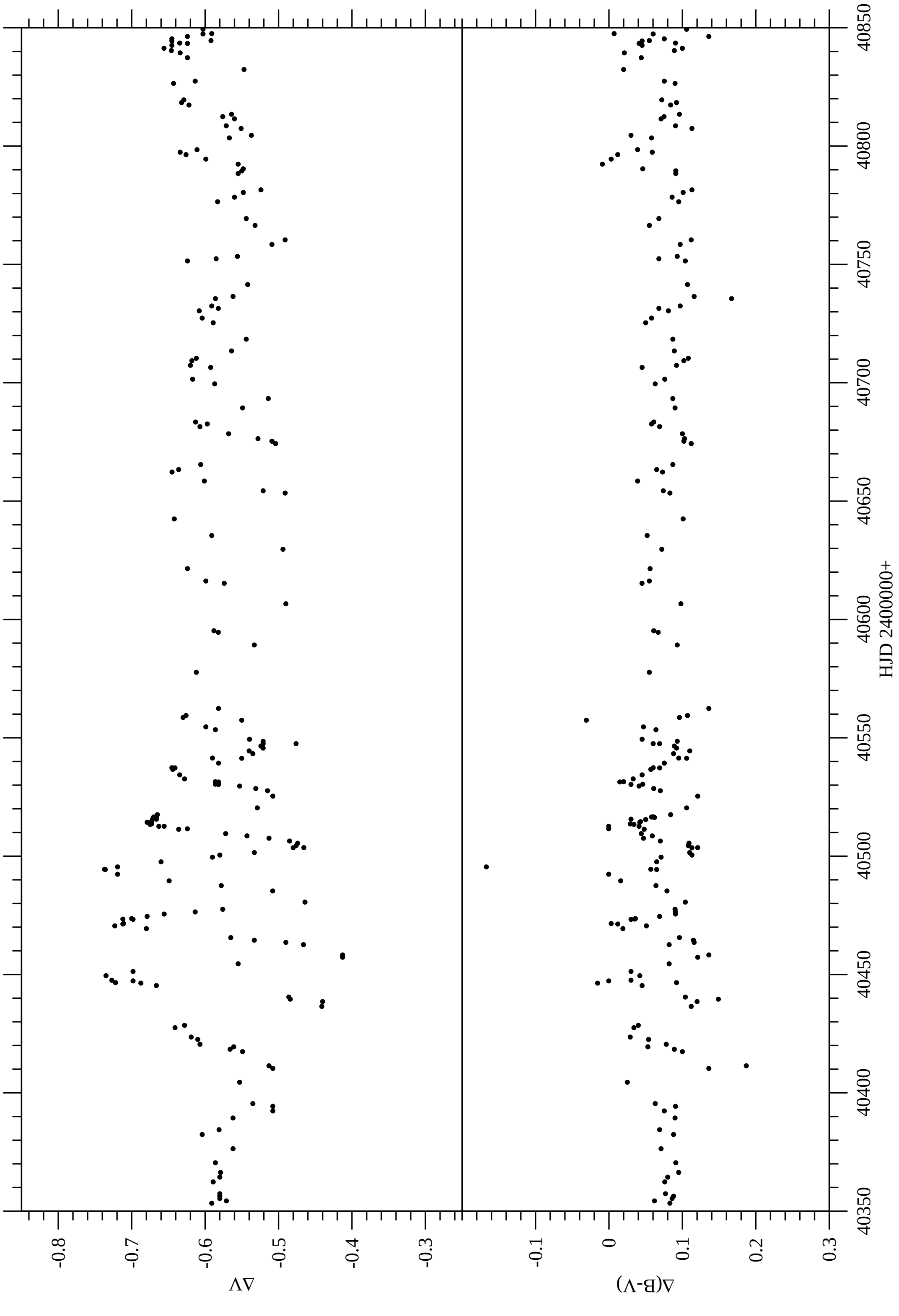

Figure 7: Zoomed light curve fragment of RU Cam (3)

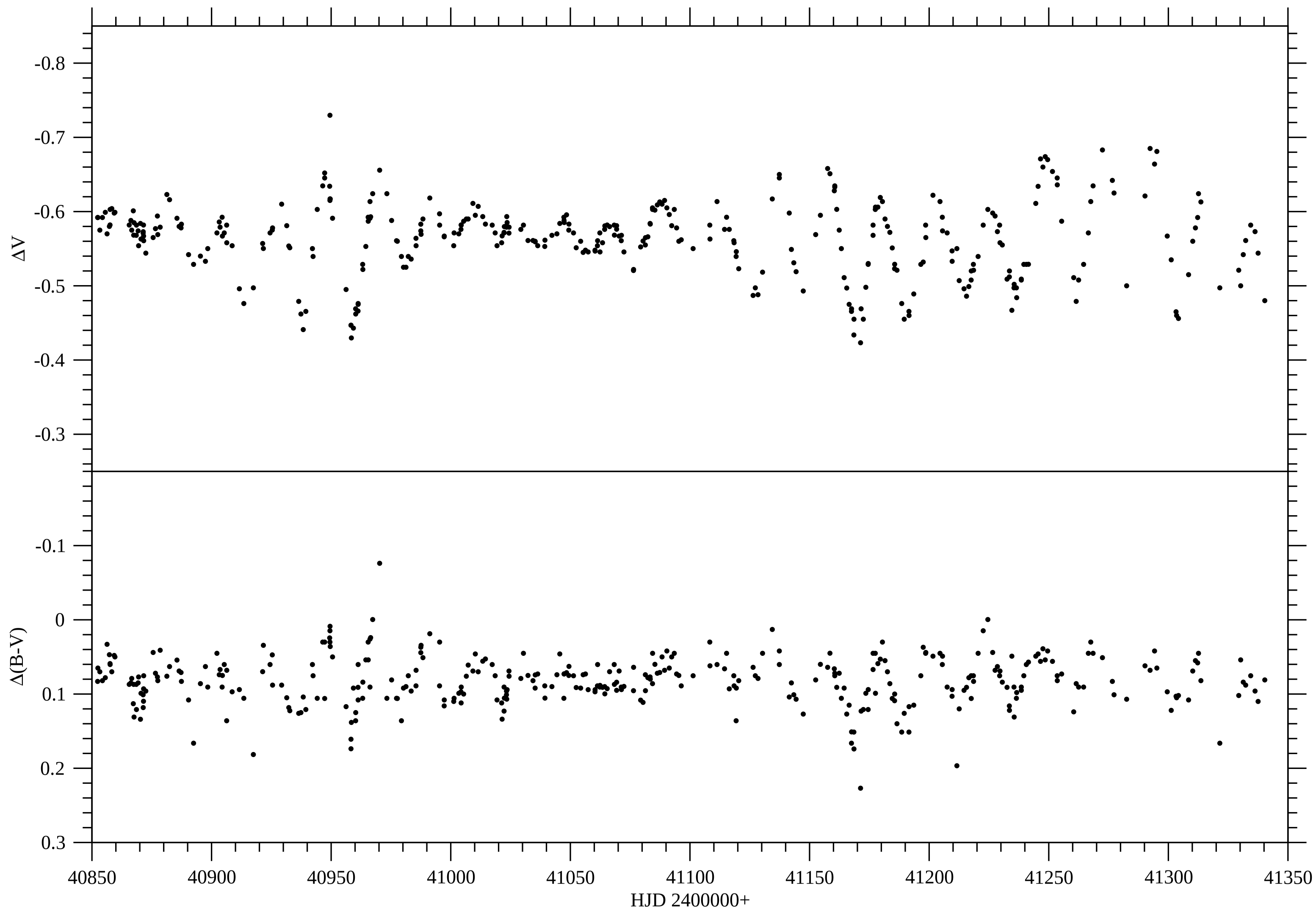

Figure 8: Zoomed light curve fragment of RU Cam (4)

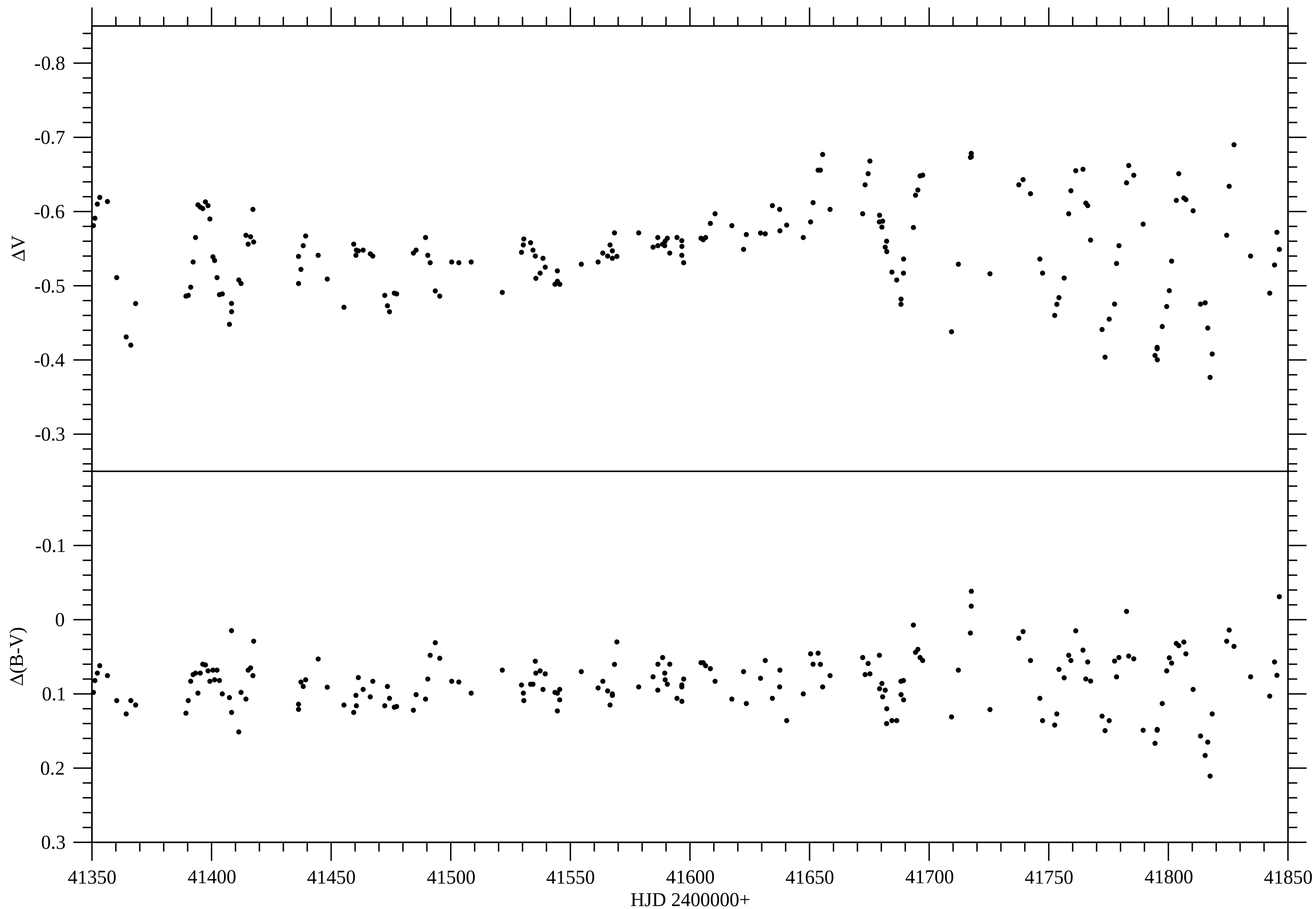

Figure 9: Zoomed light curve fragment of RU Cam (5)

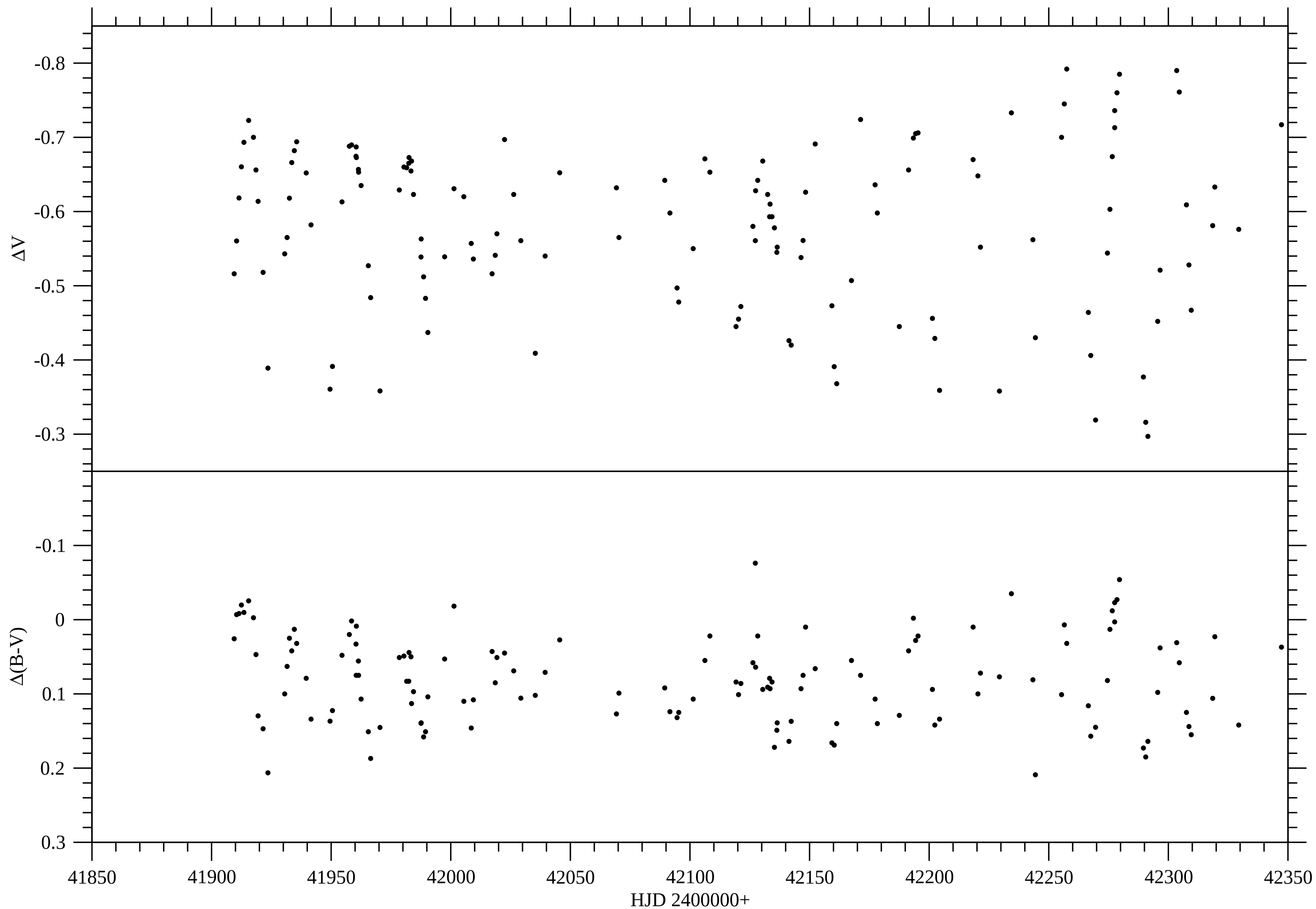

Figure 10: Zoomed light curve fragment of RU Cam (6)

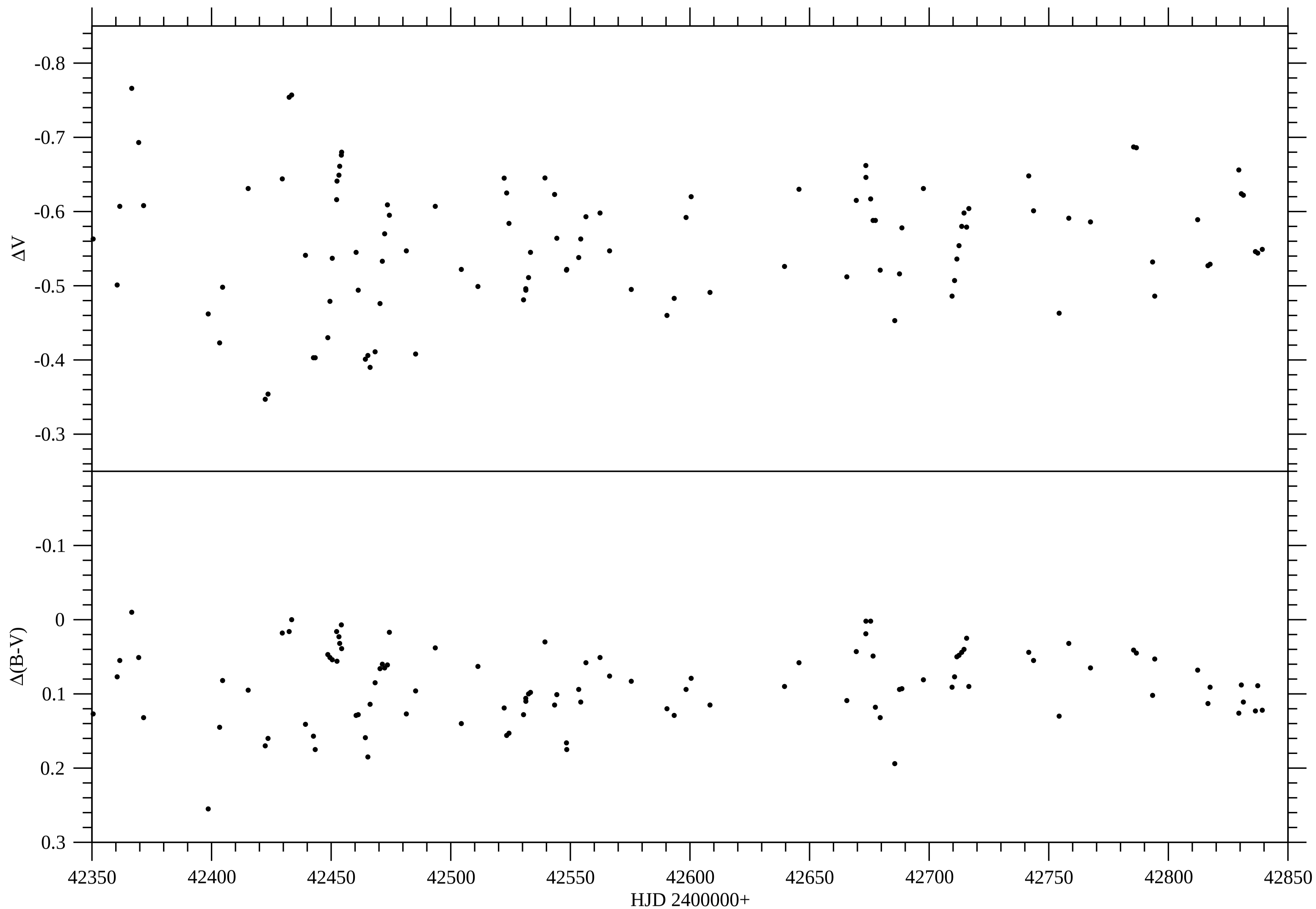

Figure 11: Zoomed light curve fragment of RU Cam (7)

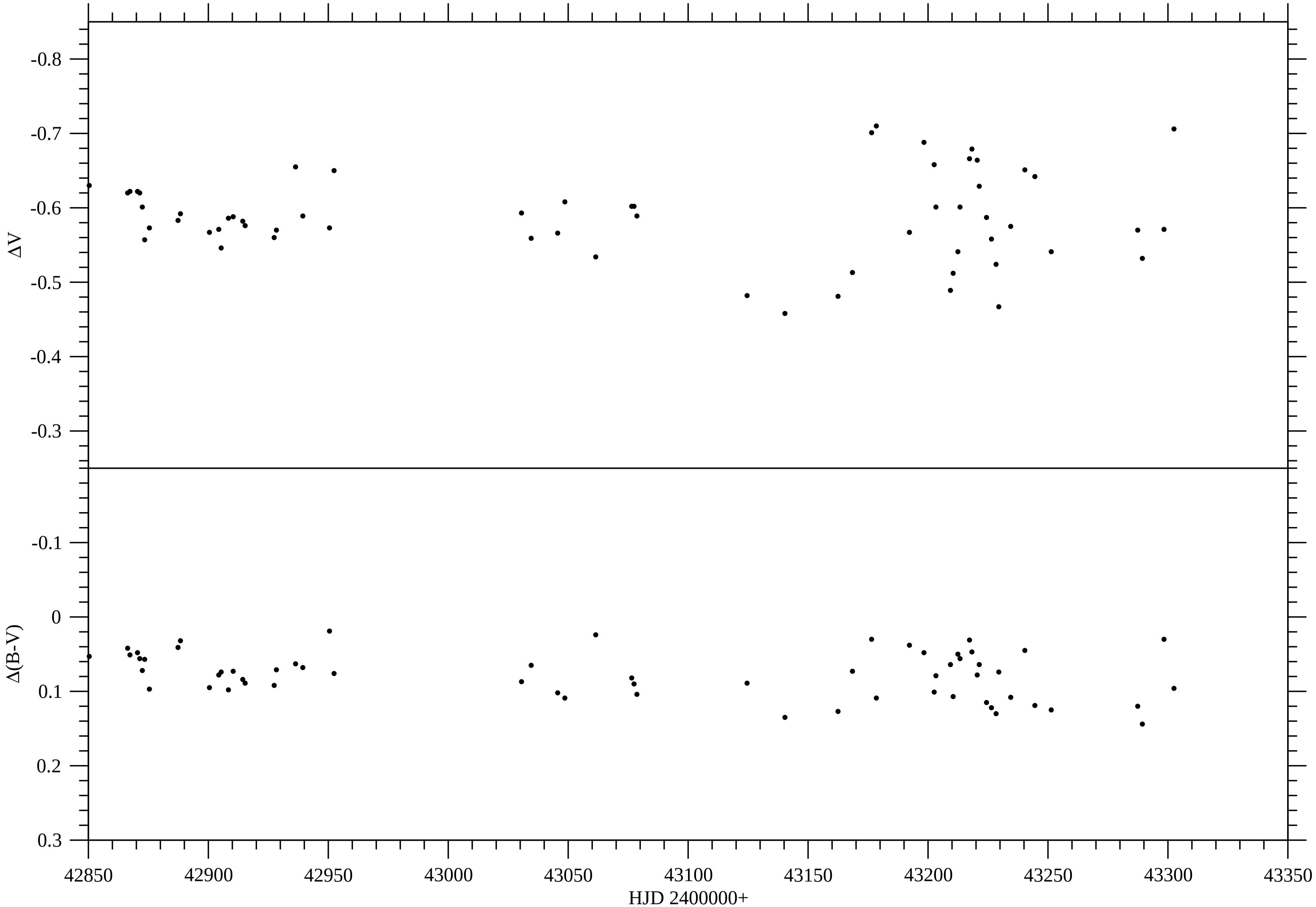

Figure 12: Zoomed light curve fragment of RU Cam (8)

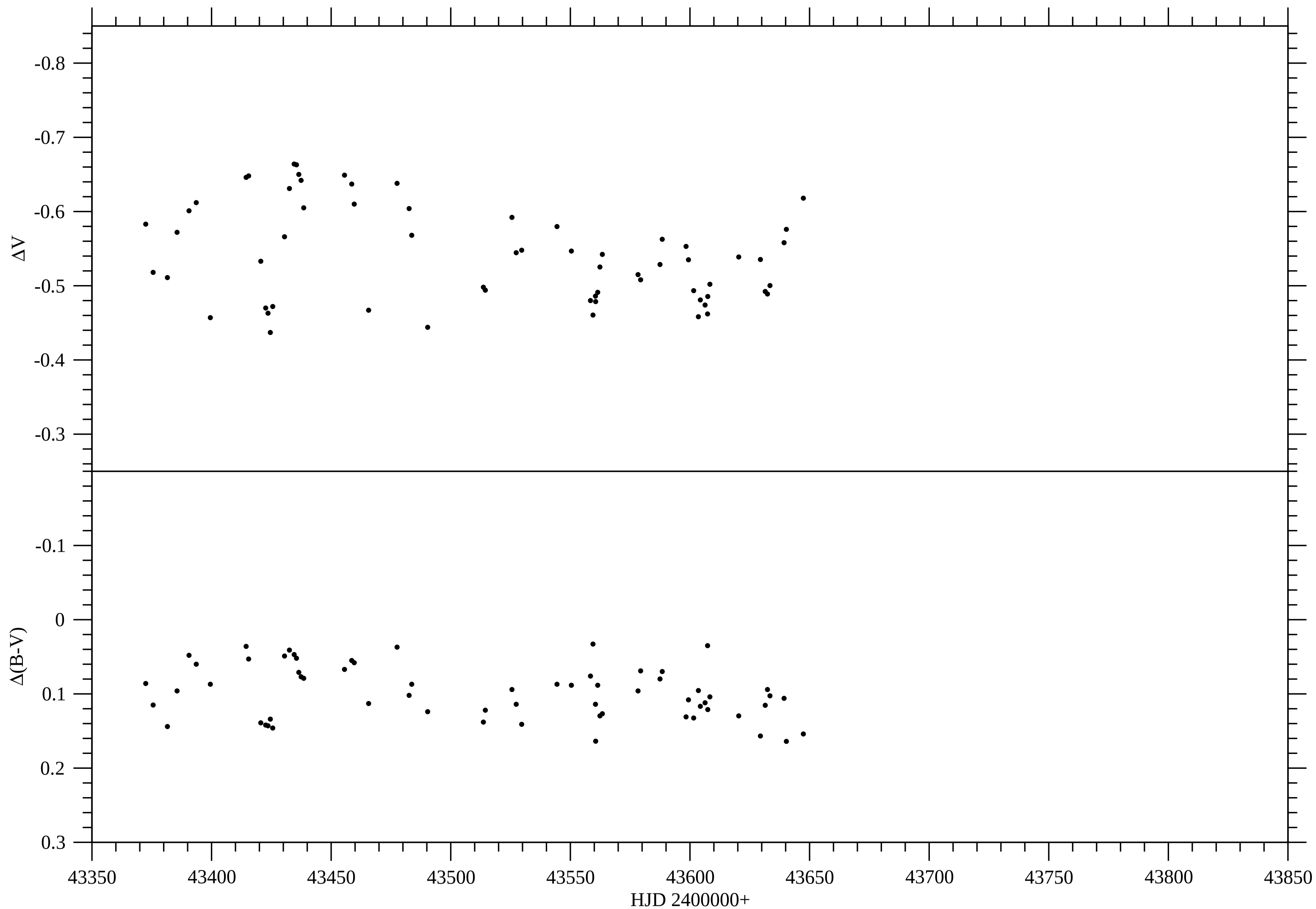

Figure 13: Zoomed light curve fragment of RU Cam (9)