Baltic Astronomy, vol. 24, 345–352, 2015

EARLY PHOTOMETRIC AND SPECTRAL EVOLUTION OF NOVA CYGNI 2014 (V2659 CYG)

M. A. Burlak, V. F. Esipov and G. V. Komissarova

Sternberg Astronomical Institute, M. V. Lomonosov State University, Universitetskij prospect 13, Moscow 119992, Russia; marina.burlak@gmail.com

Received: 2015 November 2; accepted: 2015 November 30

Abstract. We present optical spectroscopic and $UBV(RI)_{\rm C}$ photometric observations of Nova Cygni 2014 (V2659 Cyg) from its rebrightening to the nebular stage. After the first maximum, the nova underwent several irregular flare-like rebrightenings, with amplitudes up to two magnitudes, accompanied with spectral changes. During the bright state, forbidden lines became weaker; the absorption components of Balmer, He I, Fe II, N I, N II, O I lines strengthened, indicating an increase in the density and mass-loss rate in the form of a wind.

Key words: novae, cataclysmic variables – stars: individual: V2659 Cyg

1. INTRODUCTION

Nova Cygni 2014 = V2659 Cyg (Kazarovets & Samus 2015) was discovered on March 31, 2014 by Nishiyama & Kabashima (2014) on two unfiltered CCD images as a 10.9 mag star and was designated PNV J20214234+3103296. On April 1, 2014, several groups of observers obtained low- and medium-resolution spectra of the nova (Munari et al. 2014; Arai 2014; Ayani 2014; Fujii 2014) that resembled those of a classical nova near maximum light, strongly affected by reddening. The spectrum was dominated by H I, Fe II, O I emission lines having a prominent P Cygni profile. The separation between the emission and absorption components ranged from –480 to –650 km s^{-1}; the full width at half maximum (FWHM) of the emission lines was approximately 500–860 km s^{-1}. The spectra indicated that the object was an Fe II nova. According to the Schlegel et al. (1998) extinction maps, the interstellar reddening in the direction close to that of the nova ($l = 70.526°$, $b = -3.287°$) is not higher than $E_{B-V} = 1$ mag. V2659 Cyg was not detected as an X-ray or radio source (Nelson et al. 2014).

2. OBSERVATIONS

Our photometry of V2659 Cyg was acquired in 2014 with the telescopes of the Crimean station of Moscow State University. The instruments used were: the Zeiss-1 0.6-m reflector with the UBV photometer constructed by Lyutyj (1971); the Zeiss-2 0.6-m reflector equipped with an Apogee AP-47p CCD camera; the AZT-5 0.5-m meniscus telescope equipped with an Apogee Alta U8300 CCD camera (see Table 1). The comparison star for UBV photometry was HD 334228,

Table 1. Photometric observations.

Telescope	Aperture, m	Detector	Filters	JD–2456000	$\Delta t_{\max}$, d
Zeiss-1	0.6	UBV-photometer	UBV	780–1006	23–249
Zeiss-2	0.6	Apogee AP-47p	$BV(RI)_C$	848–855	91–98
AZT-5	0.5	Apogee Alta U8300	$BV(RI)_C$	868–887	111–130

Table 2. Spectroscopic observations.

Date	JD–2456000	$\Delta t_{\max}$, d	Range, Å
2014 May 3	781	24	4000–9000
2014 May 27	805	48	4000–7400
2014 June 23	832	73	4000–9000
2014 June 30	839	82	4000–9000
2014 July 22	861	104	4000–9000
2014 July 25	864	107	5650–7280, 8280–10650
2014 August 27	897	140	4000–9900
2014 September 29	930	173	4000–9050
2014 October 20	951	194	4000–7400

which is an F2 II star with $U = 10.66$, $B = 10.42$, $V = 10.04$ (Lutz & Lutz 1972). The comparison stars for CCD photometry were chosen to minimize the difference in color: HD 334133 with $B = 10.85$, $V = 10.73$, $R_C = 10.40$, $I_C = 10.32$ and TYC 2672-2175-1 with $B = 11.71$, $V = 11.41$, $R_C = 10.98$, $I_C = 10.79$. B and V magnitudes for the comparison stars were obtained using the UBV photometer; their R_C and I_C magnitudes were taken from the AAVSO data base.

Spectroscopic observations were carried out in 2014 with the 125-cm reflector at the Crimean Station of Moscow State University equipped with a grating spectrograph and an SBIG ST-402 CCD (765 × 510 array, 9 μm pixels). The width of the slit was always kept constant to $4''$. The spectral resolution (FWHM) was 7.4 Å. The spectra were flux calibrated using the spectrophotometric standard star 40 Cyg observed on the same nights. The spectral energy distribution for 40 Cyg was adopted from Glushneva et al. (1998). A log of our observations is given in Table 2.

3. LIGHT CURVE

Fig. 1 shows the light curves of V2659 Cyg. The nova was discovered during its rise to maximum light, which was reached a few days later ($T_{\max}$ = JD2456757, $V_{\max} = 9.45$). After the first maximum, the light curve showed irregular variations of light superposed on a basic power-law decline. The brightness varied with an amplitude from 0.5 to 2 mag and timescales from 1 to 15 days. Similar behavior was demonstrated in all photometric bands, though the flares were better covered with observations in the V band. The rebrightening stage lasted for 150 days, then V2659 Cyg decayed smoothly.

In Fig. 2, we present the color–color diagram based on our photoelectric UBV observations. The colors dereddened with $E_{B-V} = 1$ are also plotted in the diagram. The true interstellar reddening for V2659 Cyg might be less than the upper limit for the direction close to that of the nova, but the position of the

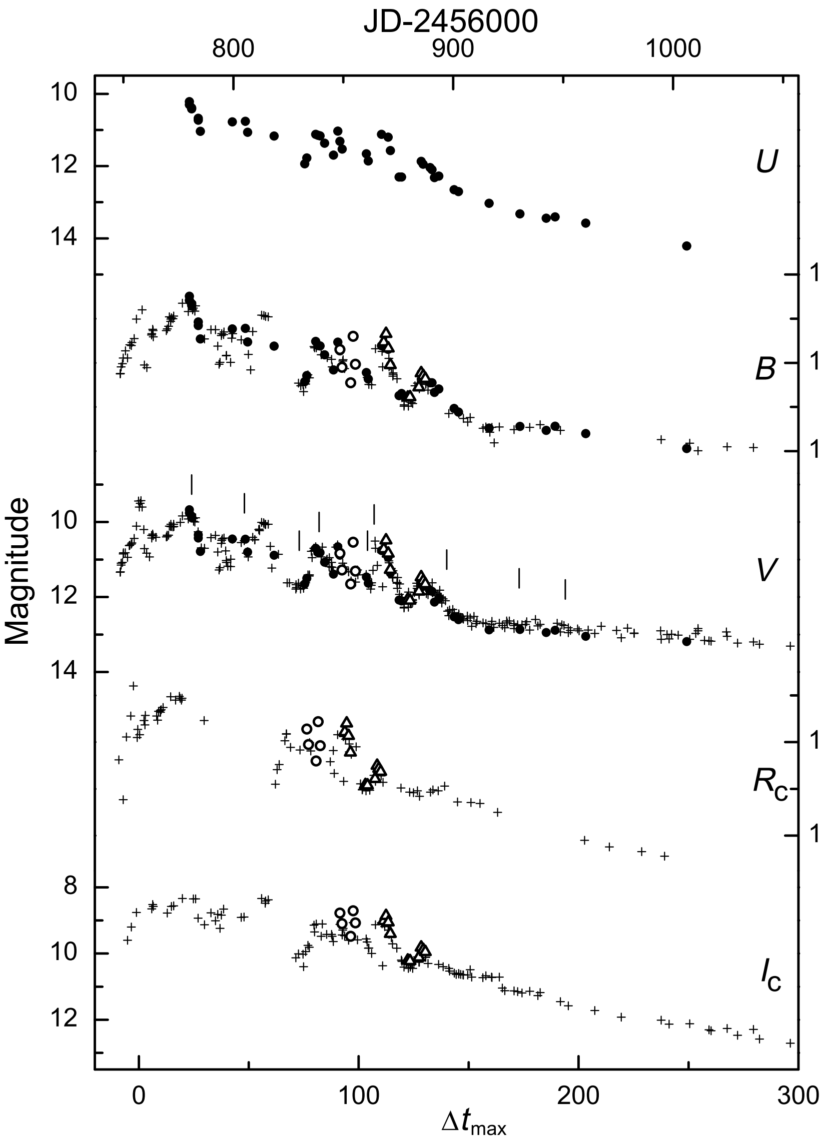

Fig. 1. The $UBVR_CI_C$ light curves of V2659 Cyg. Filled circles represent photoelectric UBV observations; open circles and squares represent CCD magnitudes obtained with the AZT-5 and Zeiss-2 telescopes, respectively. For comparison, we also show $BVRI$ magnitudes taken from the AAVSO database (small crosses). The short vertical lines indicate the epochs of our spectroscopic observations.

nova in the color–color diagram does not support this notion. Several attempts were made to estimate its reddening using interstellar lines of Na I ($E_{B-V} = 2.10$, Tomov et al. 2014) and Li I ($E_{B-V} = 0.63$, Raj et al. 2014) but we consider $E_{B-V} = 1$ to be more likely.

In the case of V2659 Cyg, the application of maximum magnitude rate of

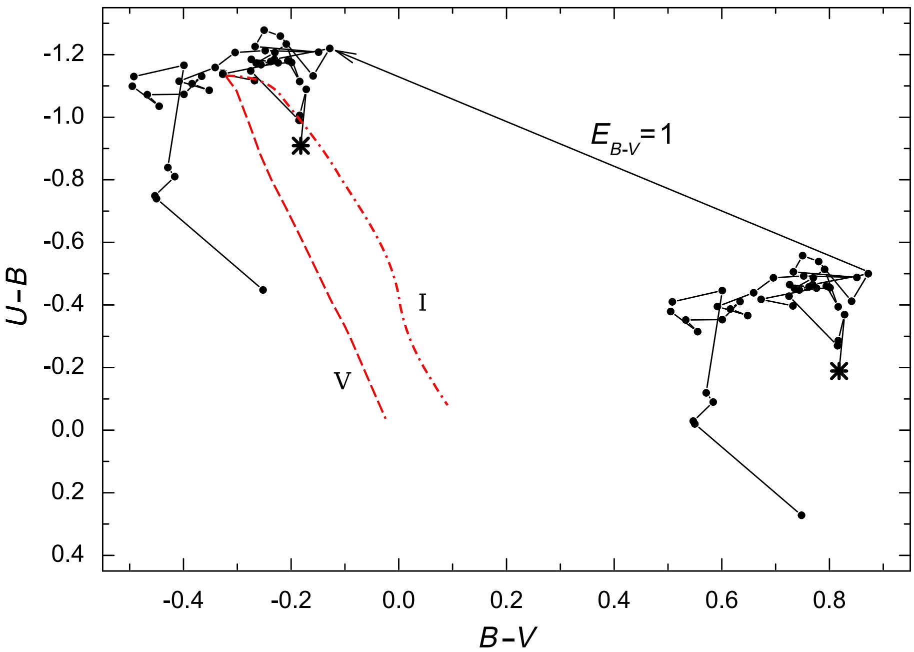

Fig. 2. The observed $U - B$ vs. $B - V$ diagram and the diagram dereddened with $E_{B-V} = 1$ for V2659 Cyg. The first observation is marked with an asterisk. We also plot parts of the main sequence (the dashed curve labeled "V") and the supergiant sequence (the dash-dotted curve labeled "I").

decline (MMRD) relations, which are commonly used for classical novae, is uncertain. First, it is not clear which flare is to be treated as maximum light since the peak brightness could be reached at different times in different bands, probably because of unequal light curve coverage in different filters. Second, for the novae like V2659 Cyg it is impossible to estimate the time to decline by 2 or 3 magnitudes from the peak (t_2 or t_3) because of irregular brightness oscillations. In order to roughly estimate the absolute maximum brightness of the nova and then its distance, we used the relation from van den Bergh & Pritchet (1986) derived for the rate of decline, d, measured in magnitudes per day over the brightest two magnitudes of the light curve. It should be noted that we defined d as the average decline rate over the whole period of oscillations. V2659 Cyg appeared slower than the slowest nova in the sample of van den Bergh & Pritchet (1986), thus providing only the upper limit of absolute peak brightness, $M_B \geq -6.42$. All uncertainties considered (namely, the ambiguity in determining the time of maximum light and decline rate; validity of applying the MMRD relations established for novae with smooth light curves to a nova with light oscillations in the first part of the light curve), we estimate a distance of $r \geq 5$ kpc for V2659 Cyg and its height above the Galactic plane of $z \geq 280$ pc. If the interstellar reddening is higher than adopted and/or if the nova is faster than we believed, the distance will be larger.

The photometric behavior of V2659 Cyg is not unique. Classifying nova light curves, Strope et al. (2010) grouped 14 objects with brightness oscillations in the first part of decline into class J. All these novae display light variations (jittering) of

Table 3. *UBV* photometry of V2659 Cyg.

JD(2456000+)	U	B	V	JD(2456000+)	U	B	V
780.521	10.301	10.49	9.672	860.501	11.66	12.218	11.468
780.528	10.218	10.587	9.759	861.388	11.858	12.364	11.631
781.5	10.413	10.699	9.883	867.366	11.123	11.611	10.76
781.508	10.39	10.66	9.845	870.405	11.2	11.693	10.941
784.531	10.727	11.155	10.43	871.388	11.568	12.055	11.359
784.535	10.676	11.073	10.341	875.372	12.303	12.742	12.083
785.521	11.039	11.457	10.784	876.456	12.301	12.696	12.104
799.507	10.776	11.23	10.454	885.399	11.869	12.235	11.587
805.476	10.762	11.22	10.458	886.286	11.945	12.332	11.716
806.479	11.064	11.529	10.803	889.439	12.04	12.451	11.817
818.486	11.169	11.622	10.887	890.376	12.097	12.45	11.849
832.451	11.937	12.424	11.654	891.428	12.318	12.67	12.137
833.431	11.776	12.29	11.499	893.415	12.278	12.593	12.038
837.448	11.121	11.515	10.699	900.417	12.654	13.033	12.528
838.460	11.148	11.609	10.815	902.368	12.704	13.114	12.606
839.422	11.163	11.618	10.817	916.34	13.03	13.476	12.875
841.458	11.369	11.817	11.073	930.333	13.32	13.439	12.868
845.496	11.696	12.161	11.392	942.25	13.44	13.53	12.946
847.519	11.033	11.533	10.661	946.313	13.405	13.434	12.887
848.491	11.315	11.727	10.886	960.212	13.58	13.6	13.05
849.447	11.531	12.07	11.29	1006.201	14.21	13.938	13.19

substantial amplitude (typically exceeding half a magnitude) that look like isolated brightenings superposed on the basic smooth power-law decline. In some cases, e.g. V4745 Sgr, V5558 Sgr, the flares are separated; in others, e.g. V868 Cen, V2659 Cyg, light variations are less regular.

4. SPECTRAL EVOLUTION

Vertical marks in Fig. 1 indicate the epochs of our spectroscopic observations: seven spectra were obtained during the rebrightening stage and two spectra were taken during the nebular stage. We present all of the spectra in Fig. 3. The first observation was carried out when the nova had been at the second maximum ($\Delta t = 24$ d). We can identify Balmer, N I, O I, [O I], Fe II, Na I, Ca II lines with P Cyg profiles in the spectrum. The absorption components imply an expansion velocity of –800 to –1000 $\mathrm{km\,s^{-1}}$. The spectrum confirms the classification of V2659 Cyg as an Fe II nova. The emission components of He I lines were barely distinguishable, though the absorption ones were clearly seen.

By the time of our next observation ($\Delta t = 48$ d), the spectrum changed only slightly: the [O I] lines became stronger, N II 5678 Å appeared. On June 23 ($\Delta t = 73$ d), there were the [N II] 5755 Å and [O II] 7320,7330 Å forbidden lines; the Ca II triplet lines (8498, 8542, 8662 Å) disappeared; the emission components of He I lines became a little stronger. During the next four observations, we were fortunate enough to catch the nova two times just before it started to brighten ($\Delta t = 73$ d and 104 d) and two times in its bright state ($\Delta t = 82$ d and 107 d). In the bright state, forbidden lines ([O I], [N II], [O II]) became weaker, although they did not disappear completely; the absorption components of Balmer, He I, Fe II, N I, N II, O I lines became stronger. It is worth mentioning that, during the whole rebrightening stage, the spectrum underwent no significant changes that would

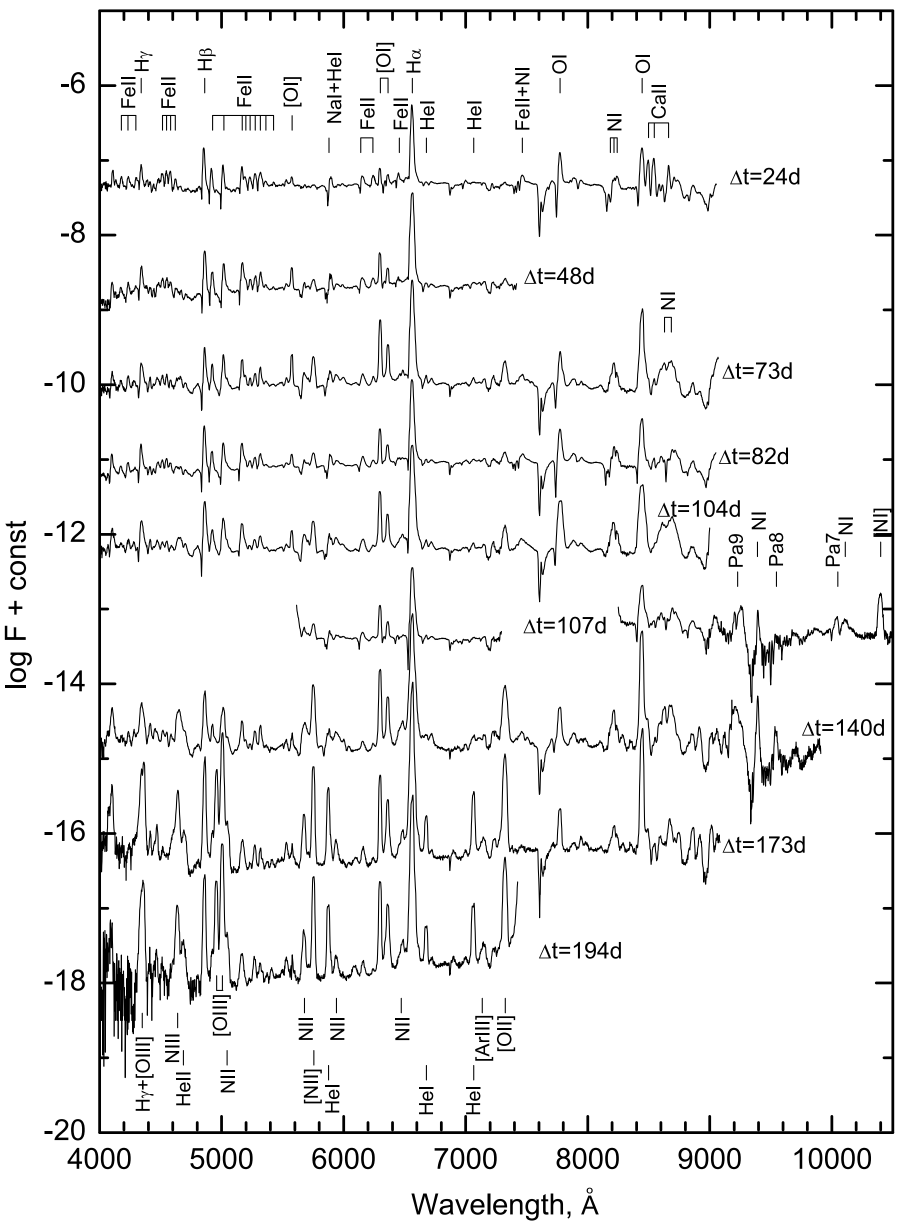

Fig. 3. Spectral evolution of V2659 Cyg. For clarity, individual spectra were moved along the ordinate.

have pointed out a variation in excitation conditions. The absorption component strengthening at light maxima is considered to indicate an increase in the density and in the mass-loss rate in the form of a wind. Williams (2012) attributes this behavior at secondary maxima not to the growth of effective temperature but to the increase in photospheric radius that is due to a variable wind.

Our seventh observation (Δt = 140 d) fell on the end of the rebrightening stage, when V2659 Cyg had started to decline smoothly. At that time, there were the same lines in the spectrum as during the rebrightening stage but they had lost the absorption components. Only He I lines retained P Cyg profiles.

A month after the light oscillations stopped, the nova showed a well-developed nebular spectrum: [O III] 5007 Å exceeded Hβ in intensity. Other forbidden lines, such as [O I], [Ar III], [O II], [N II], grew too. Strong He I lines appeared in emission, and we also could identify He II lines. Fe II lines were replaced by [Fe III], [Fe VI], [Fe VII] transitions. The emergence of the nebular spectrum evidences for a decrease in density and optical depth.

As demonstrated by Williams (2012), the O I intensity ratio $R = \lambda 8446/\lambda 7773$ can serve as an indicator of spectrum-forming gas density since these lines are excited in different ways. O I 8446 Å is strong enough due to the wavelength coincidence between H I Lyβ and O I 1027Å. O I 7773 Å, which is not a triplet transition like O I 8446 Å is, but a quintet one, can be also strong if the electron density in nova ejecta is of the order of $n_{\rm e} \sim 10^{12}$ cm^{-3} or more. We measured the O I intensity ratio from the spectra of V2659 Cyg obtained at different epochs: the ratio was 2 during the rebrightening stage and grew to 15 when the nova entered the nebular stage, indicating that the electron density in the nova ejecta had decreased.

5. DISCUSSION

To date it is not well understood what exactly makes some novae to oscillate with an amplitude of up to 1–2 mag at the first part of their light curves. All such novae tend to be slow or very slow, they seem not to form dust and to belong to Fe II spectral class. Tanaka et al. (2011) analyzed spectra of six novae with light variations and proposed the following scenario. First, as the nova photosphere expands rapidly, the effective temperature drops. At maximum light, the optically thick envelope radius reaches its maximum and the absorption lines are very strong. Then, the optically thin envelope where emission lines originate keeps on expanding, but the photosphere starts to recede, causing continuum and absorption-line weakening. Later, some novae undergo a single or multiple photosphere reexpansion followed by continuum strengthening, whereas emission lines radiated by the optically thin envelope do not increase in intensity. However, this scenario does not explain why some novae do undergo light oscillations in the first part of their light curve and others do not. Besides, it is also necessary to understand why in some cases light variations look like isolated flares separated by intervals when brightness remains rather constant, whereas other novae demonstrate chaotic light jittering.

6. CONCLUSIONS

We traced both the photometric and spectral evolution of V2659 Cyg from the rebrightening to nebular stage. Having passed through a series of irregular rebrightenings with an amplitude of up to 2 mag, accompanied with absorption-line strengthening, the nova declined monotonously. Using interstellar extinction maps of Schlegel et al. (1998) and AAVSO photometric data, we estimated a distance of $r \geq 5$ kpc for V2659 Cyg and its height above the Galactic plane, $z \geq 280$ pc. Photometric and spectral changes observed during the rebrightening stage are probably due to a variable wind.

REFERENCES

Arai A. 2014, Cent. Bur. Electron. Telegrams, 3842
Ayani K. 2014, Cent. Bur. Electron. Telegrams, 3842
Fujii M. 2014, Cent. Bur. Electron. Telegrams, 3842
Glushneva I. N., Doroshenko V. T., Fetisova T. S. et al. 1998, VizieR Online Data Catalog III/208
Kazarovets E. V., Samus N. N. 2015, Peremennye Zvezdy/Variable Stars, 35, 3
Lutz J., Lutz T. 1972, AJ, 77, 376
Lyutyj V. M. 1971, Soobshch. Gos. Astron. Inst. Sternberg, No. 172, 30
Munari U., Cetrulo G., Degano D. et al. 2014, Cent. Bur. Electron. Telegrams, 3842
Nelson T., Linford J., Chomiuk L. et al. 2014, ATel, 6108
Nishiyama K., Kabashima F. 2014, Cent. Bur. Electron. Telegrams, 3842
Raj A., Munari U., Lee B.-C. et al. 2014, ATel, 6181
Schlegel D. J., Finkbeiner D. P., Davis M. 1998, ApJ, 500, 525
Strope R. J., Schaefer B. E., Henden A. A. 2010, AJ, 140, 34
Tanaka J., Nogami D., Fujii M. et al. 2011, PASJ, 63, 159
Tomov T., Swierczynski E., Puchalski D. et al. 2014, ATel, 6060
van den Bergh S., Pritchet C. J. 1986, PASP, 98, 110
Williams R. 2012, AJ, 144, 98