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INVESTIGATION OF NOVA PER 2020 (V1112 PER)

In the paper, the evolution of the spectra of the classic Nova Per 2020 (V1112 Per) is described based on the spectra from databases ARAS (R = 9000—11000). The discussed spectra cover the period of the outburst. The comparative analysis results on the behavior of the profiles of the selected lines (H_α, H_β, He I λ 587.6 nm, Na ID, and Fe II) with changes in the star's brightness during the outburst are presented. Using the diffuse interstellar bands (DIBs) at λλ 578, 579.7, and 661.4 nm, visible in the high-resolution spectra, their equivalent widths were measured (W = 0.0402 for the λ 578 nm lines, W = 0.0140 for λ 579.7 nm, and W = 0.021 for the λ 661.4 nm), the interstellar extinction, the star magnitude $M_V = -8.03^m$, and the distance d = 4.5 kps to Nova Per 2020 were estimated. Based on the photometric data of the star, it was established that the light curve of the star belongs to the D class of light curves. From the spectrum of the star, it was found that Nova Per 2020 belongs to the classical Fe II type Nova.

***Keywords**: stars: novae, cataclysmic variables — stars: individual: Nova Per 2020 — techniques: spectroscopic — line: identification.*

INTRODUCTION

Nova Per 2020 (V1112 Per) was discovered by Seiji Ueda on November 25, 2020 [18] in images taken with a Cannon EOS 6D digital camera. Munari U. et al. [10] obtained a low-resolution spectrum and classified this object as a Nova. Photometry of the object showed that $V = 10.331$, $B - V = +0.658$, $V - R = 0.482$, and $V - I = 0.947$. Munari U. et al. [11] continued to study this object and obtained low- and high-resolution band spectra in the wavelength range from λλ 330 nm to 800 nm. On November 26.813, the Balmer, He I, N II(3), and O I lines showed P Cyg profiles. The next night, in the spectra taken on November 27.703, the He I and N I lines disappeared, and various multiplets of the Fe II line showing P Cyg profiles were found. Also, Munari U. et al. measured the observed interstellar Na I doublet lines and K I λ 769.9 nm lines. They showed that the small value of the equivalent widths (0.0197 nm) indicates the optically thin conditions and corresponds to $E(B - V) = 0.77$. For the Diffuse Interstellar Band line (DIB) (λ 661.4 nm), the value of the equivalent width (0.0186 nm) corresponds to $E(B - V) = 0.82$.

On November 28, 2020 S. Borthakur et al. [3] confirmed the spectral data of Munari et al. After taking spectra on November 26 and 27, they classified this

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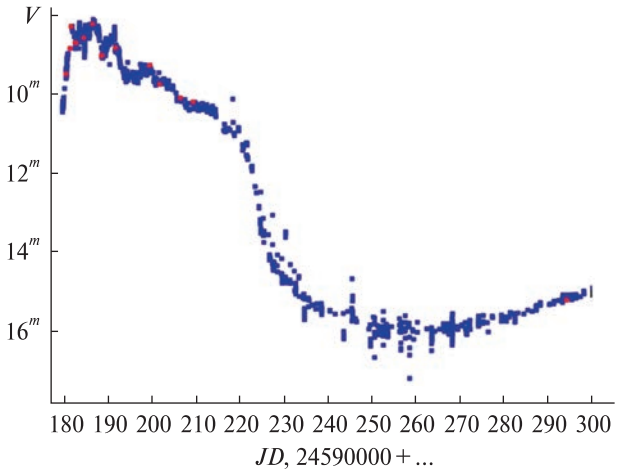

Figure 1. Light curve of Nova Per 2020. The red dots approximately correspond to the dates of the chosen spectral observation

Nova as a classical FeI I type Nova. Chochol D. et al. [4] obtained spectra of the Nova on December 1 and 2, 2020 and also found, in addition to the Fe II lines, H_α and H_β emission lines with slow and fast absorption components. Banerjee D. P. K. et al. [2] reported spectroscopic changes in the near-infrared spectrum of the star Nova Per 2020, obtained on December 6, 2020, covering wavelengths from 700 to 2500 nm. This spectrum appeared to be a typical spectrum of the Fe II type Nova, showing lines of the C I, H I, O I, and Na I type. Banerjee D. P. K. et al. [1] continued infrared photometric observations of Nova Per 2020 on January 15, 2021. They confirmed the beginning of dust formation (dust generation) in the Nova.

The goal of this work was to study the evolution of the spectra of the Nova, taken from the ARAS database at the moments of the beginning of the outburst (emission), the post-maximum, and the beginning of dust formation (dust generation) in the time interval from 2020-11-26 to 2021-03-20.

PHOTOMETRY

To track the evolution of a star's spectrum and determine its absolute magnitude, photometric data are conventionally used. Photometric data for Nova Per 2020 (V1112 Per) were taken from the AAVSO database (https://www.aavso.org/LCGv2), and the light curve was plotted in the V-filter (Figure 1). The moment of maximum brightness corresponding to the date 2020-12-02 (0^d) was taken as the zero-reference point. Object studies cover dates from the pre-maximum, maximum, post-maximum outburst, and dust formation (dust generation) of Nova Per 2020.

Classical novae can be divided by photometric type into fast and slow novae [19]. The classification typically depends on the time interval within which a nova fades by 2 or 3 magnitudes (t_2 , t_3) relative to its maximum brightness. Fast super-Eddington novae ($t_2 < 13$, $t_3 < 30$ days) have smooth light curves with well-defined maximums. Slow Eddington novae ($t_2 > 13$, $t_3 > 30$ days) have structured light curves, and many of them are stagnant at maximum and late stages of dust formation. In our case, for t_2 and t_3, we determined $t_2 = 19.84^d$ and $t_3 = 33.7^d$. Therefore, this nova (Nova Per 2020) can be attributed to the slow Eddington novae.

From the shape of the light curves of the novae, one can obtain essential information about the physical processes during the outburst. Strope, Schaefer and Henden [15] classified Galactic novae based on the light-curve shapes into smooth (S), plateau (P), dust dip (D), cusp (C), oscillations (O), flat-topped (F), and jitter (J). In addition to classifications based on the outburst properties, these systems can also be classified via the evolutionary state of the donor star [6] into main sequence, sub-giant, or red giant star novae.

It was established that the light curve of Nova Per 2020 belongs to the dust dip (D) class. Therefore, considering the formula of Ozdonmez A. et al. [13] for the D-class light curves, the absolute magnitude was calculated:

$$M_V = -11.3(\pm 0.7) + 2.4(\pm 0.4)\log t_2,$$
$$M_V = -13.1(\pm 1.2) + 3.3(\pm 0.7)\log t_3.$$

For t_2, its estimate was $M_V = -8.19$, and, for t_3, it was estimated as $M_V = -8.06$.

The classical slow Nova Per 2020 belongs to the Fe type (we will discuss below the belonging to the Fe-type Nova). From the formula of Ozdonmez A. et al. [13] for Fe-type Novae

$$M_V = -10.7(\pm 0.3) + 2.1(\pm 0.2)\log t_2,$$
$$M_V = -11.7(\pm 0.5) + 2.4(\pm 0.3)\log t_3$$

we obtain

$$M_V = -7.98 \text{ (by } t_2),$$
$$M_V = -8.03 \text{ (by } t_3).$$

SPECTROSCOPY

Observations and processing. Nova Per 2020 (V1112 Per) was observed from November 25, 2020 to January 15, 2021 by different observers. Spectra of Nova Per 2020 (V1112 Per) uploaded to the ARAS database (https://aras-database.github.io/database/novaper2020.html) cover the time period from 2020-11-25 to 2021-03-20. We have chosen high-resolution spectra to reveal the structure of the profiles of various lines. The data on the selected spectra are shown in Table 1.

Further processing of the spectra was conducted using the Dech 30 software package (http://www.gazinur.com/DECH-software.html).

Figure 2 shows the general view of the chosen spectra, owing to which one can observe the evolution of various lines. Almost all lines (except H_α) showed P Cyg profiles at the beginning of the observation. The Balmer and He I lines (λλ 587.563, 667.815 nm) were clearly visible, as well as the lines of iron Fe II(42) (λλ 492.3921, 501.8434, 516.9030 nm) were also observed, which were noticeable from the very beginning. This gives us a reason to classify this star as a classical Fe II-type Nova. Starting from 2020-11-30 (-2^d), the emission component began to increase, and slow (narrow) and fast (wide, broad) absorption components appeared. At 2020-12-15 ($+13^d$), the slow emission component disappeared. At 2021-03-20 ($+108^d$), the Fe II(42) l 516.903 nm line was not observed. Another Fe II multiplet (74) λ 614.7735 nm showed a similar profile evolution. Starting from 2020-11-28 (-4^d), the N I(3) λλ

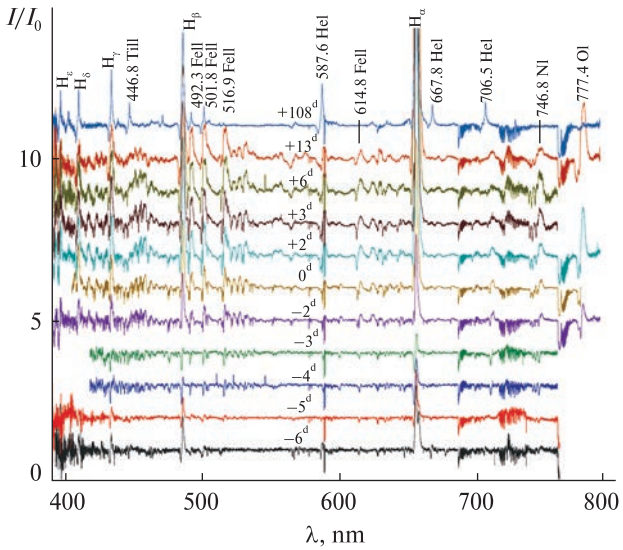

Figure 2. Spectra of Nova Per 2020

742.363, 744.229, and 746.831 nm lines were also observed in absorption, and from 2020-11-30 (-2^d), an emission component also appeared. On 2021-03-20 ($+108^d$), the N I(3) lines disappeared. Also, in the spectrum of Nova, oxygen lines O I(1) λ 777.4 nm had been observed, which were no longer observed on 2021-03-20 ($+108^d$). On 2021-03-20, the He I(10) λ 706.5188 nm and He I(46) λ 667.815 nm lines were clearly visible. For a more detailed analysis, we considered several selected H_α, H_β, He I λ 587.6 nm, Na I, and Fe II lines.

H_α line. Figure 3 shows the H_α line profile. As can be seen from the figure, at the beginning of the observation on 2020-11-26 (-6^d), the H_α line shows a pro-

Table 1. **The data on the selected spectra**

Date	JD	Resolution	λ, nm	Exposition time, s
2020-11-26	2459180.498	11000	393—760.4	7217
2020-11-27	2459181.427	11000	390—760.7	12030
2020-11-28	2459182.498	11000	418.6—759	6040
2020-11-29	2459182.577	11000	418.6—759	6039
2020-11-30	2459184.362	9500	387.5—886.9	19610
2020-12-02	2459186.382	9500	405.2—776.1	18039
2020-12-04	2459188.393	9500	386—887.5	18068
2020-12-05	2459188.584	11000	391.5—759	6039
2020-12-08	2459192.414	11000	391.5—759	7886
2020-12-15	2459199.494	11000	391.5—759	6039
2021-03-20	2459294.334	9500	373.9—893.8	5439

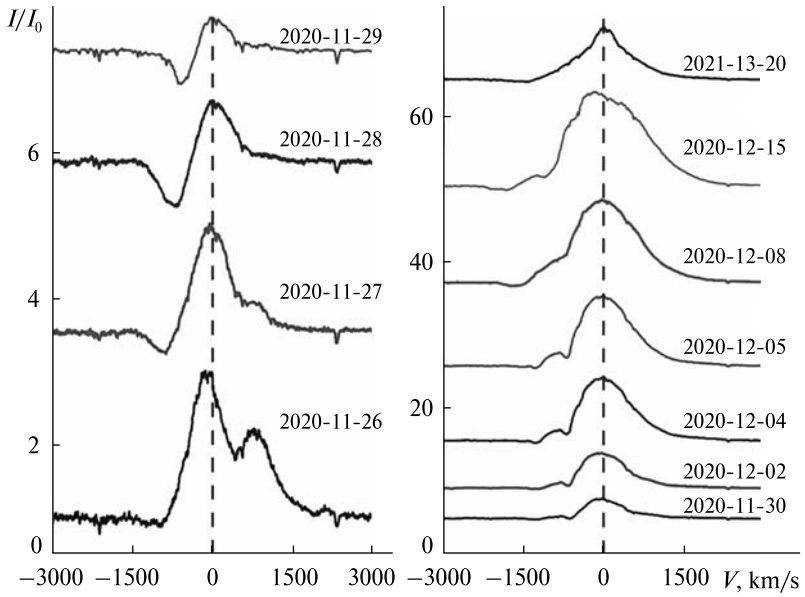

Figure 3. Evolution of H_α line

file with 2 emission components (radial velocities –104 and +774 km/s). The next day, 2020-11-27 (-5^d), the P Cyg profile appeared, and the absorption component showed a radial velocity of -916 km/s. The red emission component weakened and disappeared on 2020-11-28 (-4^d). On 2020-11-29 (-3^d), the H_α line showed a P Cyg profile with strong absorption components, also observed on 2020-11-29 (-3^d). The radial velocities of the absorption components were equal to –737 km/s and –646 km/s, respectively. On 2020-11-30 (-2^d), the line profile changed highly, the emission profile enhanced, and 2-component (slow and fast) absorption arose with radial velocities equal to –650 km/s and –1295 km/s, respectively. In the spectrum on 2020-12-08 ($+6^d$), the slow component disappeared, and the velocity of the fast component reached –1730 km/s. On 2020-12-15 ($+13^d$), the line showed 2 absorption components with radial velocities of –1140 km/s and –1930 km/s. On 2021-03-20 ($+108^d$), in the H_α line, along with a strong R component emission, a weak violet V component arose, radial velocities for the R components are RV = –12.47 km/s, absorption — RV = –1540 km/s, violet emission — RV = = –2540 km/s.

H_β line. As can be seen from Figure 4, the H_β line profile, except for some dates, shows a profile similar to the H_α line profile. At the beginning of the observation on 2020-11-26 (-6^d), and up to, unlike the H_α line, the H_β shows a P Cyg profile (the radial velocity of emission –7 km/s, the absorption –870 km/s). Until 2020-11-29 (-3^d), a similar profile is observed, the radial velocities are equal to –737 km/s and –560 km/s, respectively. Since 2020-11-30 (-2^d), the profile has changed significantly, the emission component has increased, and a 2-component absorption has appeared. The radial velocities are –657 km/s and –1232 km/s, respectively. In the spectrum for 2020-12-08 ($+6^d$), the narrow slow component has disappeared, and the fast wide component shows a radial velocity of –1655 km/s. On 2020-12-15 ($+13^d$), two absorption components of –1113 km/s and –1744 km/s are observed. On 2021-03-20 ($+108^d$), in the H_β line, along with the strong emission of the R component, a weak violet V component appeared for the R component RV = –2.9 km/s, for absorption RV = –1428.6 km/s, the radial velocity of the violet component RV = –3162 km /s.

He I λ 587.6 nm line. The area of He I λ 587.6 nm and Na I is given in Figure 5. As can be seen from Figure 5 at the beginning of the observation on 2020-11-26 (-6^d), the He I λ 587.6 nm line shows a P Cyg profile. The He I(46) λ 667.8 nm line shows a similar structure (see Figure 5), the velocity of the absorption component is RV = –497 km/s, and the

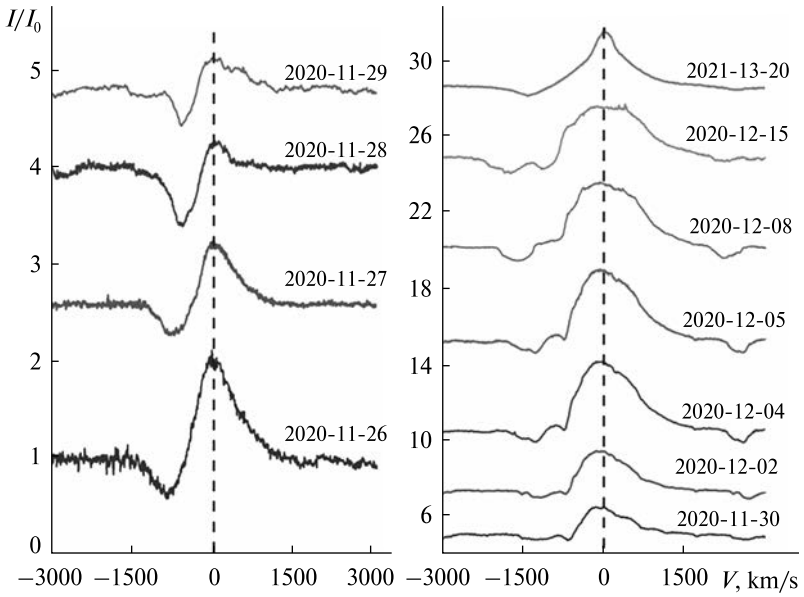

Figure 4. Evolution of H_β line

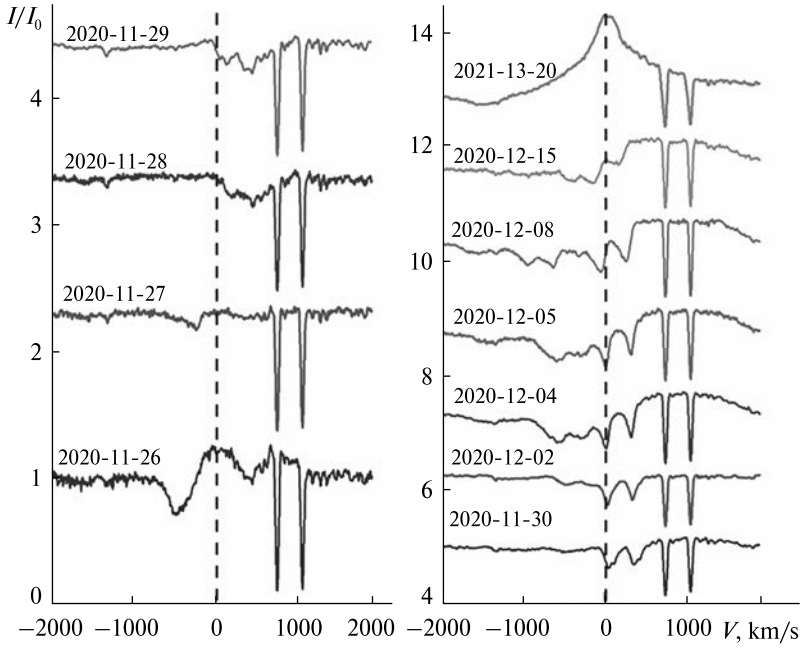

Figure 5. Evolution of He I and Na I lines (the intensity shifted by 1 unit along the *OY*-axis)

emission component RV = 11.5 km/s. The line He I λ 587.6 nm begins to disappear with increasing brightness and is hardly observed on 2020-11-27 (-5^d). On the dates 2020-11-28 and 29, it completely disappears and appears only on 2020-11-30 (-2^d). The P Cyg profile with the wide emission component begins to be observed with decreasing brightness. On 2021-03-20 ($+108^d$), a narrow central emission and

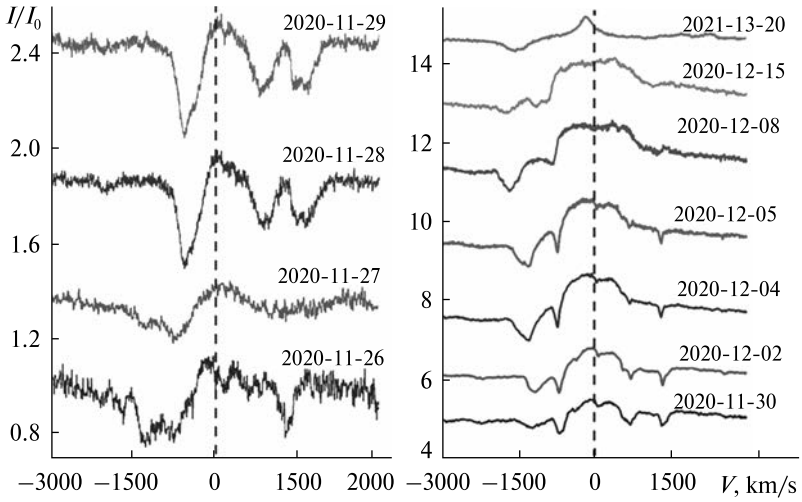

Figure 6. Evolution of Fe II (λ 501.8 nm) line

a wide absorption are observed, the radial velocities are RV = 0 km/s and RV = –1492 km/s, respectively.

Na I (D1, D2) line. At the beginning of the observation, the Na I line is observed as a narrow absorption, inherent only to the interstellar medium (RV = = –6, –9 km/s). A wide absorption in the shortwave part of the Na I doublet line is observed on 2020-11-28/29. It is possible that this Na I line belongs to the star itself (the resolution makes accurate identification difficult). However, starting from 2020-11-30 (-2^d), Na I stellar lines are clearly visible. At the same time, weak absorption components are visible on the red side of the Na I line, which most likely belongs to the stellar wind. Each doublet line shows a double component, radial velocities D2(weak) RV = –632 km/s, D2(strong) RV = –690 km/s; D1(weak) RV = –626.5 km/s, D1(strong) RV = –687.6 km/s. On 2020-12-02 (0^d), the weak component of the doublet is not observed, but another broad high-velocity component begins to be observed. Radial velocities, respectively, are D2(1) RV = -686 km/s, D2(2) RV = –1167 km/s; D1(1) RV = –688.2 km/s, D1(2) RV = –1168 km/s. This Na I doublet structure is observed until 2020-12-15 ($+13^d$). It can be seen from Figure 5 that Na I stellar lines were not observed on 20-03-2021 ($+108^d$).

Fe II (λ 501.8 nm) line. Six days before the maximum, a P Cyg profile was observed (Figure 6): a weak emission component and a double absorption component with radial velocities of –782 km/h and –1276 km/h, respectively. The next day, the same profile remained with radial velocities of –734 km/h and –1307 km/h, respectively.

On 2020-11-28, the absorption turned into a single component with a radial velocity of –566 km/h. On this date, two unknown absorption lines were also observed. On 2020-11-29, a weak single component P Cyg profile (absorption) was observed as of the 28th date. On 2020-11-30, emissions increased, and absorption became two-component –667.2 km/h and 1218.8 km/h. On 2020-12-02, a similar pattern was observed, but the radial velocities became –693.5 km/h and 1165.1 km/h. Until 2020-12-08, the radial velocities changed, and the absorption velocity became 1656.4 km/h. On 2020-12-15, two absorption components were observed: –1150 km/h of the first and –1719.0 of the second absorption component. Data on 2020-03-20 show an absorption profile, a radial velocity of –1543 km/h, and an emission component of –164.7 km/h.

Diffuse interstellar bands (DIBs). DIBs are absorption features observed in the spectra of astronomical objects in the Milky Way and other galaxies. They are caused by the light absorption of the interstellar medium. Currently, about 500 bands are visible in the ultraviolet, visible, and infrared wavelengths. In the optical band, we can observe lines (DIBs) with wavelengths of λλ 443, 496.4, 578, 579.7, 585, 619.6,

620.3, 627, 628.4, 637.9, 661.4, 666, and 722.4 nm. In the spectra we studied, the DIBs lines λλ 578, 579.7, and 661.4 nm are clearly visible. Their equivalent widths were measured: W = 0.0402 nm for the line λ 578 nm, W = 0.0140 nm for λ 579.7 nm, W = = 0.021 nm for the line λ 661.4 nm.

For the lines l 578 nm and λ 579.7 nm, respectively:

• According to the Friedman formula $EW = 0.51E(B - V)$, we got $E(B - V)_{578} = 0.78$, and according to Yuan $EW = 0.61E(B - V)$, we got $E(B - V)_{578} = 0.66$.

• According to Krelovski [8], $E(B - V)_{578} = 0.766$, $E(B - V)_{579.7} = 0.94$.

• According to Zamanov [20], $E(B - V)_{578} = 0.933$, $E(B - V)_{579.7} = 1.14$.

DIB lines represent the valuable tool for estimating reddening (as well as distance), in particular, for these Novae that experience the most interstellar absorption. As in the region of λ 661.4 nm, DIBs have almost no telluric lines, and this makes it possible to estimate their equivalent widths more accurately, according to [9]:

$$E(B - V) = 4.40 \cdot EW(661.4) = 0.924.$$

According to Krylovski's $EW = 0.61E(B - V)$, we got $E(B - V) = 0.87$. According to Zamanov $E(B - V) = = 0.99$. Thus, for $E(B - V)$, the optimal value for all lines can be taken as 0.965.

Considering the interstellar absorption $A_v = = 3.1 \cdot E(B - V)$, $A_v = 2.9915$, using the following formula, the distance was calculated as:

$$d = 10^{0.2(m - M + 5 - Av)}.$$

For the maximum brightness value, we found $m = 8.205$.

For D type

At $M_v = -8.19$, $d = 4.79$ kpc

At $M_v = -8.06$, $d = 4.52$ kpc

For Fe type

$M_V = -7.98$, $d = 4.35$ kpc

$M_V = -8.03$, $d = 4.45$ kpc.

SUMMARY

In this paper, the evolution of various spectral lines of Nova Per 2020 was examined using spectra taken from the ARAS database, as well as photometric data from the AAVSO. Based on the photometric data of the star, it was revealed that the light curve of the star belongs to the D class of light curves. From the spectrum of the star, it was established that Nova Per 2020 belongs to the classical Fe II type novae. The distance to the star was calculated from the DIBs lines. Using calculation methods of different authors, $d = 4.5$ kpc was found.

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ДОСЛІДЖЕННЯ НОВОЇ ЗІРКИ PER 2020 (V1112 PER)

У статті описано еволюцію спектрів класичної нової зірки V1112 (Per 2020) на основі спектрів баз даних ARAS (R = = 9000...11000). Обговорювані спектри охоплюють період максимуму спалаху. Наведено результати порівняльного аналізу поведінки профілів вибраних ліній (H_α, H_β, He I λ 587.6 нм, Na I D та Fe II) при зміні блиску зірки під час спалаху. Для ліній дифузних міжзоряних смуг λ = 578, 579.7 і 661.4 нм, видимих у спектрах високої роздільності, отримано еквівалентні ширини (W = 0.0402 для лінії λ 578 нм, W = 0.0140 для лінії λ 579.7 нм, W = 0.021 для лінії λ 661.4 нм), оцінено міжзоряне поглинання, зоряна величина $M_V = -8.03^m$ і відстань d = 4.5 кпк до Nova Per 2020. На основі фотометричних даних зірки виявлено, що крива блиску зірки належить до D-класу кривих блиску. За спектром зірки було виявлено, що Nova Per 2020 є класичною новою типу Fe II.

***Ключові слова*:** зірки: нові, катаклізмічні змінні — зірки: окремі: Per 2020 — методи: спектроскопічні — лінія: ідентифікація.