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Photometric Observations of the Type II-L Supernova SN 2020mmz

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Abstract

CCD $UBVRI$ photometry is presented for SN 2020mmz spanning 170 days of evolution. The dates and magnitudes of maximum light in different photometric bands and the parameters of the light curves are determined. The maximum luminosity and general behavior of the light curves are typical of the class SN II-L; the peculiar feature of SN 2020mmz is the fast brightness decline for the first 20 days after maximum.

Introduction

A large fraction of massive stars explode at the end of their lives due to the gravitational collapse of their cores, such events are recognized as core-collapse supernovae (CCSNe). Type II SNe are hydrogen-rich CCSNe, this class is not uniform. Barbon et al. (1979) proposed to divide SNe II into two major groups: SNe II-P, which have nearly constant luminosity for a time interval of $\sim$ 100 days after maximum, and SNe II-L, which are characterized by linear decline (in magnitudes) after maximum. Later it became clear that objects with intermediate parameters between SNe II-P and II-L also exist (Anderson et al., 2014). It is supposed that SNe II-L have lower mass of hydrogen envelope, the effect of energy input from interaction of the ejecta and circumstellar matter on the light curve is also considered (Blinnikov & Bartunov, 1993).

In this paper, we present the results of our photometric observations of bright type II-L Supernova SN 2020mmz.

The discovery by ZTF[1] of a transient source at $\alpha = 09^{\rm h}21^{\rm m}11\overset{\rm s}{.}57$, $\delta = +64°15'14\overset{''}{.}26$ on 2020-06-13.22 UT (JD 2459013.72) was reported by ALeRCE broker (Forster et al., 2020). It was detected with $g_{\rm ZTF} = 17.05$ ABmag, the last non-detection limits the brightness to $r_{\rm ZTF} > 18.49$ ABmag on 2020-06-05.25 UT (JD 2459005.75), 8 days before discovery.

The host galaxy is NGC 2814, a type Sb galaxy at redshift $z = 0.00531$, in a pair with NGC 2820, Sc edge-on galaxy with nearly the same redshift[2].

The classification spectrum was obtained on 2020-06-22.87 UT by Balcon (2020), who found good fits to the spectra of type II SNe. The photometric observations of SN 2020mmz were reported by ZTF[3] and Gaia[4].

[1] https://www.ztf.caltech.edu
[2] https://ned.ipac.caltech.edu/
[3] https://lasair-ztf.lsst.ac.uk/object/ZTF20abevbxv/
[4] http://gsaweb.ast.cam.ac.uk/alerts/alert/Gaia20djl/

Observations and reductions

We carried out photometric observations of SN 2020mmz in the $UBVRI$ bands from 2020-06-26 to 2020-12-14 with the 60-cm reflector of the Caucasus Mountain Observatory of Sternberg Astronomical Institute (K60) (Berdnikov et al., 2020), 60-cm telescope of the Crimean Observatory of Sternberg Astronomical Institute (C60), and with the 1-m reflector of the Simeiz Observatory (S100) (Nikolenko et al., 2019).

The standard image reductions and photometry were performed using IRAF[5]. Photometric measurements of the SN were made relative to local standard stars using PSF fitting with the IRAF DAOPHOT package.

The SN was located near the ridge line of a nearly edge-on galaxy, so the subtraction of galaxy background was necessary. The template images for subtraction were obtained at the K60 telescope in March 2022, when the SN had faded. The image of SN 2020mmz with local standards is shown in Fig. 1, the magnitudes of the comparison stars were taken from the SDSS[6] and PanSTARRS[7] databases and transferred to the Johnson–Cousins $UBVRI$ magnitudes using relations from Jester et al. (2005) and Kostov & Bonev (2018).

The magnitudes of comparison stars are reported in Table 1, and the results of the photometry of SN 2020mmz are presented in Table 2.

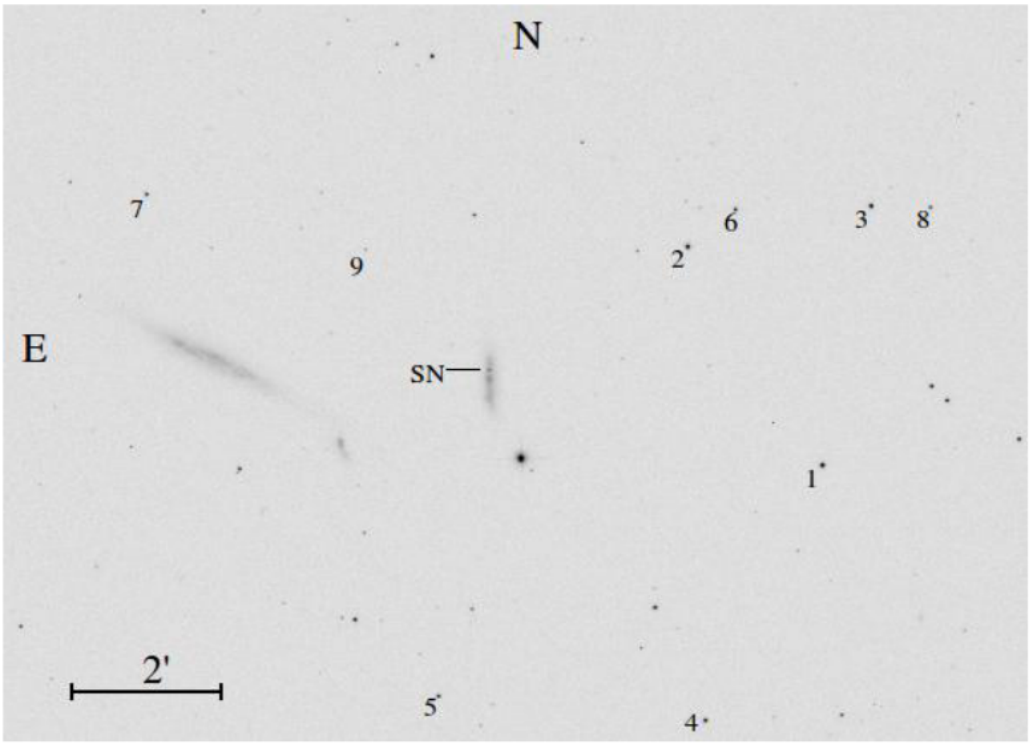

Figure 1. SN 2020mmz and local standard stars. The image was obtained at the K60 telescope in the R band.

[5]IRAF is distributed by the National Optical Astronomy Observatory, which is operated by AURA under cooperative agreement with the National Science Foundation

[6]skyserver.sdss.org/dr16/en/tools/search/radial.aspx

[7]https://catalogs.mast.stsci.edu/panstarrs/

Table 1: **Magnitudes of local standard stars for SN 2020mmz**

Star	U	B	V	R	I
1	15.09	14.89	14.31	13.96	13.60
2	15.36	14.93	14.13	13.65	13.21
3	16.32	15.64	14.77	14.24	13.79
4	16.18	15.87	15.14	14.70	14.29
5	16.55	16.37	15.65	15.22	14.81
6	17.14	16.49	15.58	15.03	14.55
7	16.98	16.68	15.91	15.44	15.02
8	17.10	16.92	16.24	15.83	15.39
9	17.23	16.93	16.14	15.67	15.23

Table 2: $UBVRI$ **photometry of SN 2020mmz**

JD−2459000	U	σ_U	B	σ_B	V	σ_V	R	σ_R	I	σ_I	Tel.
27.30	15.85	0.08	15.66	0.02	15.13	0.03	14.90	0.03	14.78	0.03	S100
28.29	15.96	0.04	15.68	0.03	15.08	0.04	14.87	0.04	14.73	0.04	S100
29.28	16.16	0.17	15.80	0.03	15.14	0.03	14.86	0.04	14.75	0.04	S100
30.27			15.93	0.05	15.18	0.03	14.89	0.03	14.76	0.03	S100
36.28			16.87	0.07	15.64	0.03	15.09	0.03	14.86	0.04	S100
100.55			18.50	0.07	17.30	0.02	16.93	0.03	16.34	0.03	C60
103.56			18.56	0.13	17.44	0.04	17.13	0.05	16.41	0.06	C60
109.51	18.53	0.13	18.48	0.06	17.55	0.03	17.11	0.03	16.50	0.02	K60
115.54	18.78	0.11	18.58	0.08	17.64	0.04	17.21	0.04	16.61	0.03	K60
120.52			18.59	0.08	17.73	0.03	17.25	0.03	16.71	0.02	K60
129.51	18.88	0.14	18.67	0.09	17.81	0.04	17.43	0.04	16.92	0.05	K60
140.54			18.81	0.06	18.14	0.05	17.67	0.03	17.13	0.04	K60
148.53			19.01	0.07	18.23	0.05	17.81	0.03	17.28	0.03	K60
158.51					18.35	0.06	17.91	0.07	17.31	0.05	K60
165.49			19.06	0.05	18.67	0.07	18.10	0.06	17.48	0.06	K60
166.42					18.78	0.04	18.27	0.07	17.62	0.05	C60
167.43			19.01	0.06	18.62	0.04	18.10	0.05	17.44	0.07	K60
172.25					18.76	0.08	18.19	0.08	17.65	0.09	C60
173.24							18.19	0.08			C60
176.43							18.19	0.09	17.48	0.08	C60
181.23							18.43	0.06	17.90	0.05	C60
181.48			19.51	0.18			18.12	0.13	17.59	0.13	K60
183.45			19.37	0.12	18.89	0.09	18.24	0.05			K60
184.33							18.25	0.09	17.70	0.08	C60
192.59			19.28	0.08	19.05	0.05	18.36	0.08	17.99	0.04	K60
197.53			19.28	0.06	19.11	0.05	18.35	0.05	18.17	0.06	K60

Results and conclusions

The light curves are shown in Fig. 2. The upper limit on JD 2459005.75 and the discovery magnitude on JD 2459013.72 allow us to conclude that our observations started near the maximum light.

The maximum light was reached on JD 2459028±2 in the V, R, I bands, the maximum magnitudes are $V_{\max} = 15.08$, $R_{\max} = 14.84$, $I_{\max} = 14.72$ with uncertainties about 0.05 mag. The maximum in the U, B filters was probably reached 1–3 days earlier. After the maximum, the brightness decline was very fast in the B, V bands: 0.17 and 0.11 mag day^{-1}, respectively. Our observations have a large gap between JD 2459036 and 2459100. After the gap, the decline was much slower: 0.0088, 0.018, 0.015, 0.019 mag day^{-1} for the B, V, R, I bands. The data from ZTF in g, r bands and from Gaia in Gaia-G filter show the rate of decline similar to our results for the V, R, I bands: about 0.016 mag day^{-1}. The Gaia magnitudes partly fill the gap in our data, they show that the slow decline has started at JD 2459050 or even earlier, so we can suppose that the change of slope occurred in the JD 2459040–50 interval.

The location of SN 2020mmz in a nearly edge-on spiral galaxy allows us to expect high reddening in the host galaxy. The color curves of SN 2020mmz are presented in Fig. 3 and compared to the color curves of five SNe II-L for which the reddening was small and reliably determined: 1979C (Balinskaya et al., 1980), 1980K (Buta, 1982), 1998S (Fassia et al., 2000), 2014G (Bose et al., 2016), and ASASSN2015nx (Bose et al., 2018). The shifts of the $(B-V)$ color curves of the five SNe for the best match with the curve for SN 2020mmz near maximum light allow us to estimate the reddening: $E(B-V) = 0.58 \pm 0.05$ mag. The observed colors for SN 2020mmz are plotted in Fig. 3, while the color curves of SNe from the comparison sample were shifted vertically, by an amount calculated as the difference between the reddening of comparison SNe and SN 2020mmz. Figure 3 reveals large differences between color curves of SNe II-L in the shape of the curves and in the values of colors. For SN 2020mmz, the difference near maximum light is larger for the $(U-B)$ color, where SN 2020mmz is significantly redder than other SNe, and for the $(R-I)$ color, where SN 2020mmz is bluer. But at late epochs, the greater difference is that for the $(V-R)$ color, as SN 2020mmz becomes bluer than other SNe by about 1 mag.

The absolute V-band light curve of SN 2020mmz is presented in Fig. 4; the light curves of the five SNe II-L are plotted for comparison. The distance modulus $\mu = 31.83$ was computed for SN 2020mmz based on its reported redshift and $H_0 = 73$ km s^{-1}Mpc^{-1}. Using the data on maximum magnitude and extinction presented earlier, and assuming $R_V = 3.1$, we can calculate the maximum absolute magnitudes $M_{V\max} = -18.55$, $M_{R\max} = -18.41$. The accuracy of these estimates is low due to possibility of large errors in determination of the color excess and uncertainty of the parameter R_V.

The data on the five SNe II-L were taken from the references reported earlier. The maximum absolute magnitude and general behavior of the light curve for SN 2020mmz do not differ from the other SNe. The peculiar feature of SN 2020mmz is the fast decline for the first ∼20 days after maximum. For the other SNe II-L, the decline is more monotonous and the rate for the first 20 days in the V band is between 0.028 and 0.049 mag day^{-1}. For SN 2020mmz, this rate is 0.11 mag day^{-1}, more than 2 times faster than the largest rate for the SNe II-L from our comparison sample.

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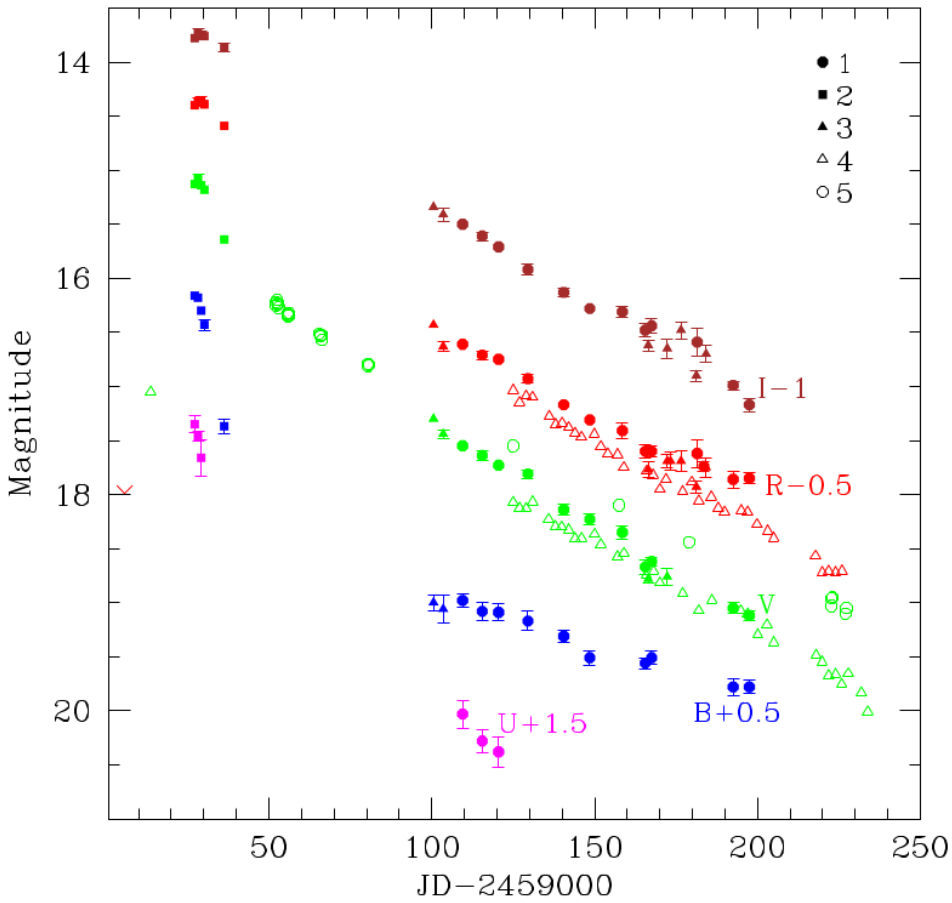

Figure 2. The light curves of SN 2020mmz. 1, 2, 3: our results, obtained with the K60, S100, C60 telescopes, respectively; 4: ZTF magnitudes (g filter in green, r filter in red); 5: Gaia G magnitudes; the V symbol is the upper limit in the r band from ZTF.

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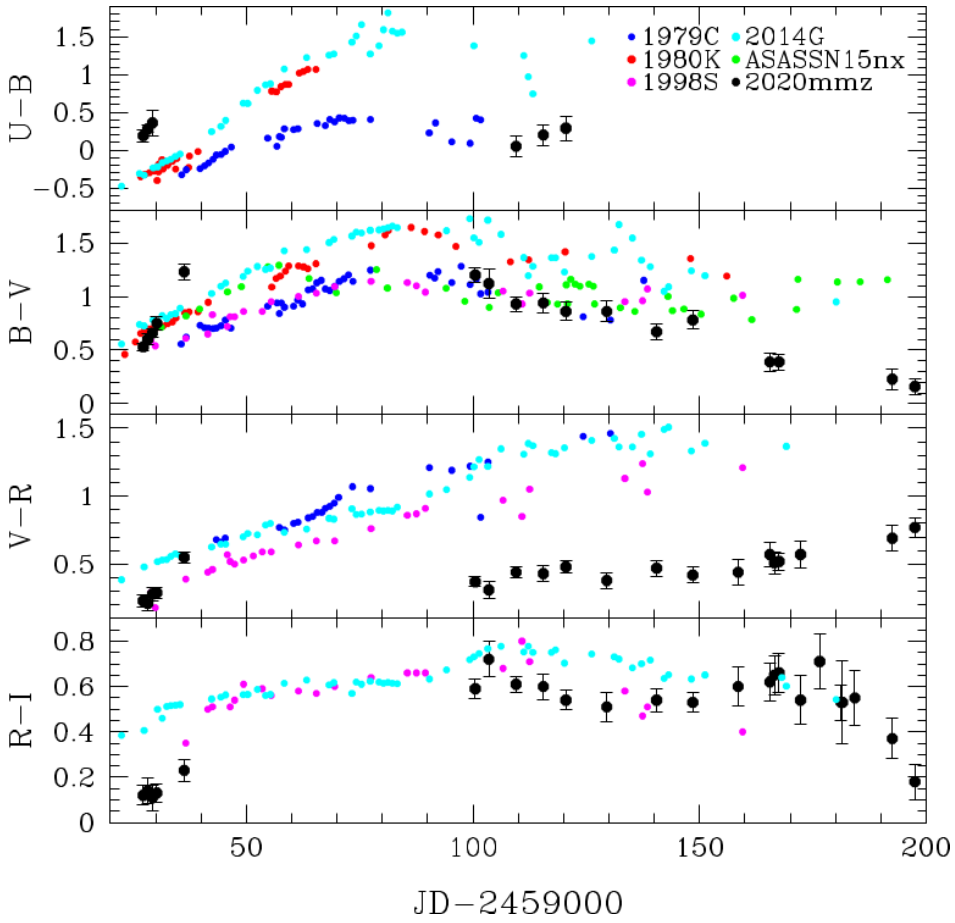

Figure 3. The color curves of SN 2020mmz compared to those for five SNe II-L.

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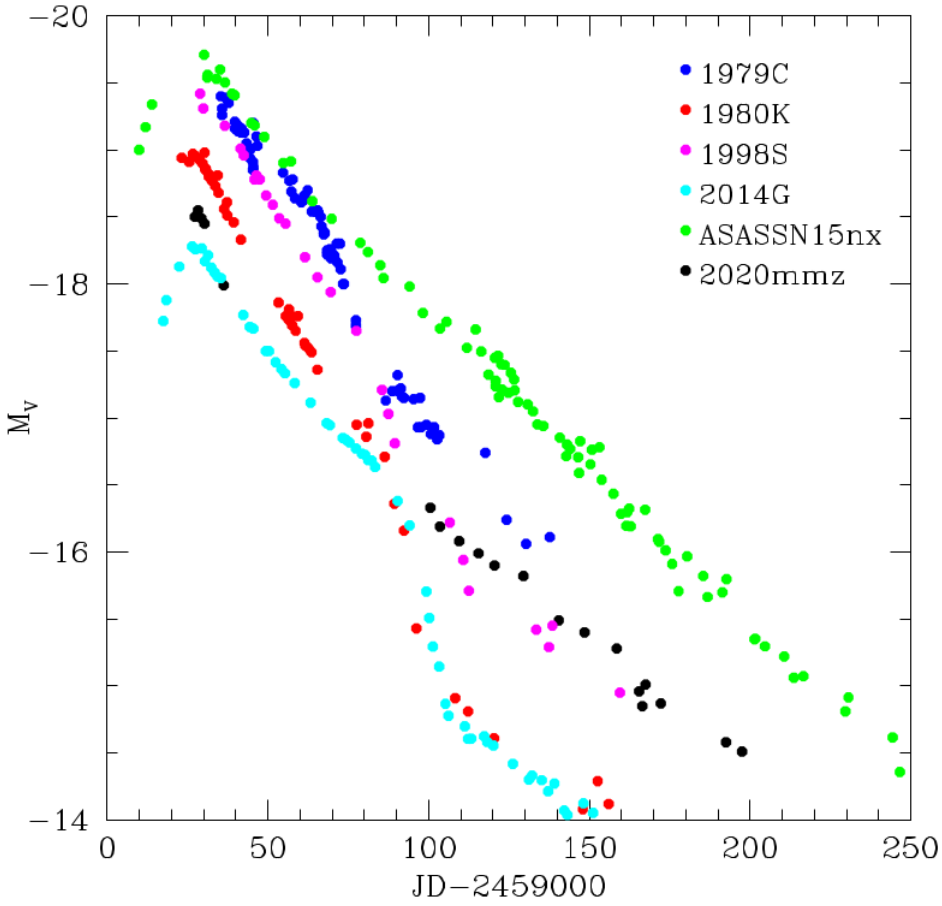

Figure 4. The absolute V-band light curves of SN 2020mmz compared to those for five SNe II-L.