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Photometric observations of two type Ic-BL Supernovae: 2016coi and 2018ebt

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Abstract

CCD *BVRI* photometry is presented for the type Ic-BL Supernovae 2016coi and 2018ebt. The shape of the light curves for both objects is typical for this class of SNe. A change of brightness decline rate at about 100 days after maximum light is observed for SN 2016coi. The light curves of SN 2018ebt are best matched by those of SN Ic-BL 2002ap. For SN 2018ebt, we derived the dates and magnitudes of maximum light, rates of decline at late stages of evolution, and presented evidence for extinction in the host galaxy being negligible.

1 Introduction

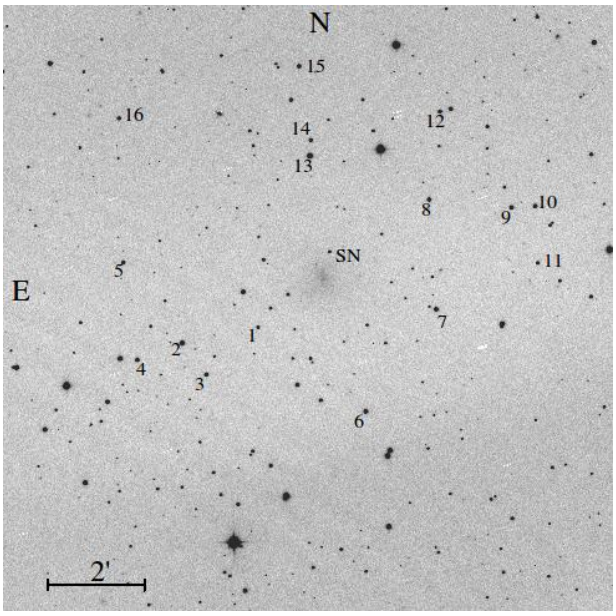

Figure 1. SN 2016coi and local standard stars from Kumar et al. (2018). The image was obtained with the C60 telescope in the R band.

A large fraction of massive stars end their lives with explosions due to the gravitational collapse of their cores, such events are recognized as core-collapse supernovae (CCSNe). Among the CCSNe, types Ib, Ic and IIb represent the "stripped-envelope" (SE) subcategory where the progenitor's outer envelope of hydrogen and/or helium is partially or

completely removed before the explosion (Filippenko, 1997). A sub-population of Type Ic (He poor or absent) SNe are characterized by very broad absorption lines in their spectra, which results from high expansion velocities of the ejecta. These events are designated as "broad-line" Ic SNe (Ic-BL) (Valenti et al., 2008). A small fraction of them are linked with long-duration gamma-ray bursts (GRBs), e.g. SN 1998bw/GRB 980425 (Galama et al., 1998), while no such association is observed for a majority of the Ic-BL events.

In this paper, we present the results of photometric observations of two recent bright type Ic-BL SNe: SN 2016coi and SN 2018ebt.

SN 2016coi was discovered on 2016-05-27.55 UT at the V-band magnitude $\sim$ 15.7 (Holoien et al., 2016) by the All Sky Automated Survey for Supernovae (ASAS-SN)[1]; it was located in the Sm galaxy UGC 11868, $z = 0.0036$, at $\alpha = 21^{\rm h}59^{\rm m}04\overset{\rm s}{.}14$, $\delta = +18°11'10\overset{''}{.}46$ (J2000). The SN was offset by $31\overset{''}{.}7$ north and $7\overset{''}{.}9$ west from the center of the host galaxy. It was classified as a pre-maximum "broad lined" Type Ic SN on 2016-05-28.52 UT (Elias-Rosa et al., 2016). SN 2016coi was extensively studied by Yamanaka et al. (2017), Prentice et al. (2018), Kumar et al. (2018), and Terreran et al. (2019).

SN 2018ebt was discovered by ATLAS[2] on 2018-07-21.49 UT at magnitude 15.58 in the 'orange' filter. The object was fainter than 19.29 mag in the same filter on 2018-07-19.50 UT. The SN was located at $\alpha = 20^{\rm h}41^{\rm m}54\overset{\rm s}{.}99, \delta = +64°12'52\overset{''}{.}6$ (J2000.0). The discovery was reported by the Transient Name Server (TNS)[3]. The host galaxy is GALEXASC J204152.80+641238.5, and the offsets from the center are $14\overset{''}{.}7$ east and $8\overset{''}{.}7$ north.

Moran et al. (2018) reported that a spectroscopic observation had been performed with the 2.56-m Nordic Optical Telescope equipped with ALFOSC on 2018-07-24.06 UT. The closest matches were found with SNe Ic-BL for phases at a few days before the peak or around the peak, and the redshifts between 0.02–0.03 or less. TNS also reported that SN 2018ebt had been classified by Masayuki Yamanaka as an SN Ib/c at $z = 0.005$ using the spectrum taken with the 1.5-m Kanata telescope on 2018-07-23.58 UT. Dugas et al. (2018) reported that spectrum obtained on 2018-08-14.86 UT with the Palomar 60-inch telescope had indicated SN type Ic and $z = 0.01$.

2 Observations and reductions

We carried out photometric observations of SN 2016coi from 2016-08-29 to 2017-01-30 and of SN 2018ebt from 2018-07-31 to 2018-11-25 using mainly the 60-cm reflector of the Crimean Observatory of Sternberg Astronomical Institute (SAI) (C60) and the 70-cm SAI reflector in Moscow (M70); some images were also obtained with the 1-m telescope of Simeiz Observatory (S100), the 50/70-cm meniscus telescope of SAI Crimean Observatory (C50), and the 60-cm reflector of Stará Lesná Observatory in Slovakia (S60).

The standard image reductions and photometry were made using IRAF[4]. Photometric measurements of the SNe were made relative to local standard stars using PSF fitting with the IRAF DAOPHOT package. The surface brightness of host galaxies at the locations of both SNe was low and did not affect the measurements, so the subtraction of galaxy background was not necessary. The image of SN 2016coi with local standards is shown in Fig. 1, the magnitudes of the stars were taken from Kumar et al. (2018). The results of our photometry are reported in Table 1, and the light curves are shown in Fig. 2, where

[1] http://www.astronomy. ohio-state.edu/ assassin/index.shtml
[2] http://fallingstar.com/home.php
[3] https://wis-tns.weizmann.ac.il/object/2018ebt
[4] IRAF is distributed by the National Optical Astronomy Observatory, which is operated by AURA under cooperative agreement with the National Science Foundation.

we also plotted the data from Kumar et al. (2018), Prentice et al. (2018), and Terreran et al (2019).

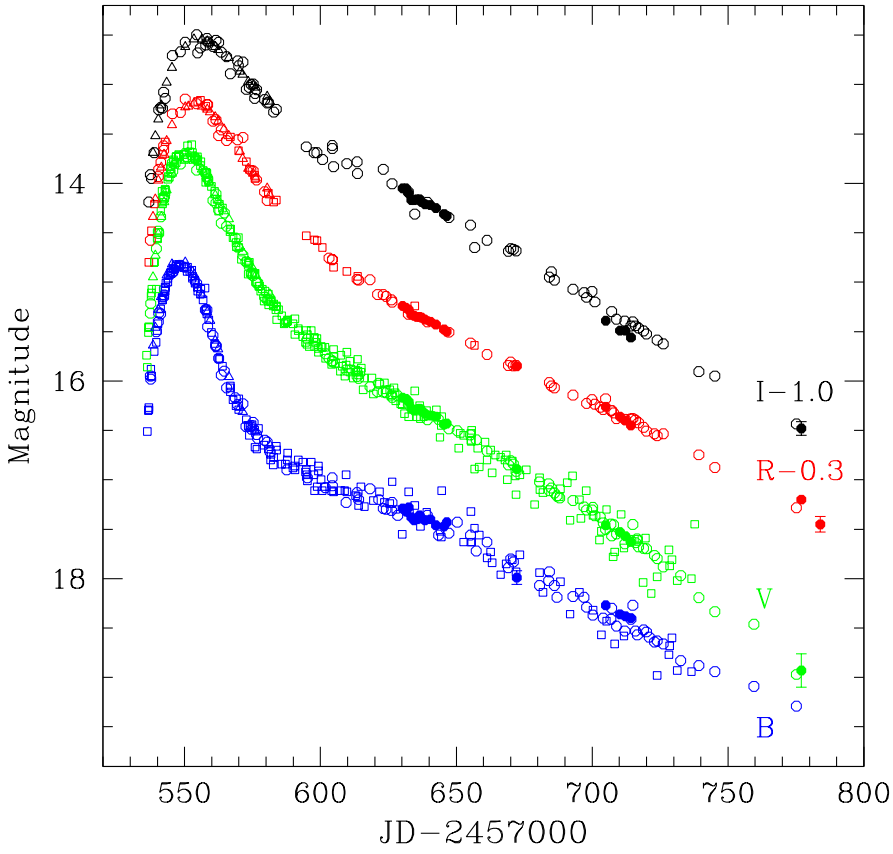

Figure 2. The *BVRI* light curves of SN 2016coi. Dots show our data; circles, triangles and squares present the data from Kumar et al. (2018), Prentice et al. (2018), Terreran et al. (2019).

The image of SN 2018ebt is shown in Fig. 3, the magnitudes of local standards are presented in Table 2. The *gri* magnitudes of local standard stars were obtained from the Pan-STARRS database[5] and transformed to *BVRI* magnitudes using relations by Kostov and Bonev (2018). The errors of *gri* magnitudes are less than 0.01 mag, and we used the dispersion of transformation equations as estimates of the errors of *BVRI* magnitudes.

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

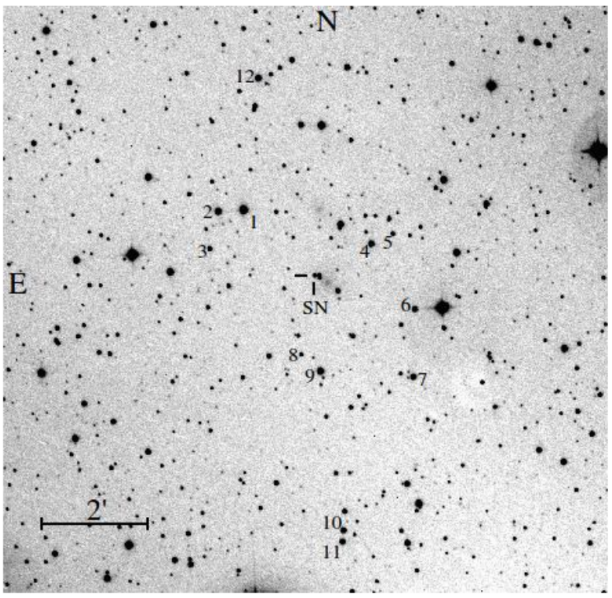

Figure 3. SN 2018ebt and local standard stars. The image was obtained with the C60 telescope in the R band.

Table 1. Observations of SN 2016coi

JD 2457000+	B	σ_B	V	σ_V	R	σ_R	I	σ_I	Tel.
630.39	17.29	0.03	16.17	0.02	15.54	0.02	15.05	0.02	C60
631.53	17.32	0.04	16.18	0.02	15.56	0.02	15.05	0.02	C60
632.51	17.28	0.03	16.21	0.02	15.58	0.02	15.10	0.02	C60
633.53	17.38	0.03	16.28	0.02	15.63	0.02	15.17	0.02	C60
634.42	17.41	0.03	16.30	0.02	15.64	0.02	15.17	0.02	C60
635.46	17.40	0.03	16.29	0.02	15.65	0.02	15.16	0.02	C60
636.48	17.36	0.03	16.28	0.02	15.65	0.02	15.16	0.02	C60
637.39	17.39	0.03	16.30	0.02	15.66	0.02	15.19	0.02	C60
638.40	17.41	0.03	16.33	0.02	15.68	0.02	15.21	0.02	C60
640.49	17.40	0.03	16.35	0.02	15.70	0.02	15.22	0.02	C60
642.48	17.46	0.03	16.36	0.02	15.73	0.02	15.25	0.02	C60
645.52	17.47	0.03	16.44	0.02	15.78	0.02	15.31	0.02	C60
646.40	17.43	0.03	16.43	0.02	15.80	0.02	15.33	0.02	C60
672.22	17.99	0.07	16.89	0.04	16.15	0.02			M70
705.17	18.27	0.03	17.46	0.02	16.56	0.02	16.39	0.02	C60
710.22	18.36	0.04	17.53	0.03	16.66	0.03	16.49	0.03	C60
712.21	18.38	0.03	17.57	0.02	16.70	0.02	16.49	0.02	C60
714.27	18.40	0.03	17.63	0.02	16.75	0.02	16.56	0.03	C60
777.16			18.93	0.17	17.50	0.03	17.48	0.07	S100
784.19					17.75	0.08			S100

Table 2. Magnitudes of local standard stars for SN 2018ebt

Star	B	σ_B	V	σ_V	R	σ_R	I	σ_I
1	13.72	0.05	12.98	0.03	12.53	0.04	12.09	0.05
2	14.88	0.05	14.05	0.03	13.56	0.04	13.07	0.05
3	16.72	0.05	15.93	0.03	15.45	0.04	14.99	0.05
4	15.81	0.05	14.75	0.03	14.09	0.04	13.50	0.05
5	17.35	0.05	16.51	0.03	15.99	0.04	15.47	0.05
6	15.77	0.05	14.96	0.03	14.46	0.04	13.97	0.05
7	15.68	0.05	14.73	0.03	14.16	0.04	13.65	0.05
8	17.74	0.06	16.76	0.03	16.17	0.04	15.59	0.05
9	14.62	0.05	13.89	0.03	13.45	0.04	13.04	0.05
10	15.86	0.05	14.86	0.03	14.25	0.04	13.70	0.05
11	15.93	0.05	14.87	0.03	14.23	0.04	13.70	0.05
12	14.72	0.05	14.08	0.03	13.69	0.04	13.28	0.05

The $BVRI$ magnitudes of SN 2018ebt are reported in Table 3, and the light curves are shown in Fig. 4. We plotted the data from ATLAS and the BV magnitudes reported by the Open Supernova Catalogue (OSC)[6]. The V-band magnitudes from the OSC showed good agreement with our data, while the B-band magnitudes were significantly brighter. We shifted these B magnitudes by 0.35 mag for consistency with our data.

3 Results and conclusions

SN 2016coi. The light curves shown in Fig. 2 appear typical for type Ib/c SNe. The magnitudes from the three major data sets (Kumar et al., 2018; Prentice et al., 2018; Terreran et al., 2019) are in a good agreement, although the scatter of the B, V magnitudes from Terreran et al. (2019) is significantly larger than of those from the other sources. Our data agree with these sets and are useful for studying the behavior of SN luminosity at late stages. There is a change of slope on the tail at about 100 days past maximum, which is evident in the B-band light curve and may be noticed also in the V band; this fact was not reported in previous studies. The rate of decline in the B band in the JD 2457590–2457650 time interval (in mag/day) is 0.0099, while that in the JD 2457650–2457780 time interval is 0.0149. For the V band, the rates are 0.0158 for JD 2457590–2457680 and 0.0211 for JD 2457680–2457780. In the R and I bands, the linear decline can be approximated with a single rate, respectively 0.0141 and 0.0156.

[6] https://sne.space/

Table 3. Observations of SN 2018ebt

JD 2458000+	B	σ_B	V	σ_V	R	σ_R	I	σ_I	Tel.
331.38	16.46	0.06	15.25	0.04	14.90	0.04	14.48	0.06	M70
334.34	16.68	0.06	15.35	0.04	14.98	0.04	14.55	0.06	M70
341.28	17.14	0.06	15.69	0.03	15.21	0.04	14.69	0.05	M70
343.33	17.34	0.07	15.90	0.04	15.38	0.04	14.80	0.05	M70
345.26	17.54	0.08	16.02	0.04	15.50	0.05	14.90	0.05	M70
348.32	17.74	0.07	16.25	0.03	15.67	0.04	15.04	0.05	M70
348.55	17.70	0.07			15.71	0.05	15.12	0.07	S100
354.31	18.14	0.07	16.63	0.03	16.04	0.04	15.38	0.05	M70
355.26	18.12	0.07	16.66	0.03	16.07	0.04	15.42	0.05	M70
358.28	18.43	0.08	16.86	0.04	16.27	0.05	15.58	0.06	M70
359.46	18.39	0.09	16.92	0.04	16.32	0.04	15.61	0.05	C60
360.39	18.34	0.06	16.97	0.04	16.34	0.04	15.67	0.05	C60
360.51	18.37	0.07	16.95	0.04	16.35	0.05	15.68	0.06	S60
361.44	18.35	0.06	17.00	0.03	16.39	0.04	15.69	0.05	C60
362.42	18.37	0.06	17.04	0.03	16.41	0.05	15.70	0.06	C60
368.28	18.53	0.11	17.11	0.06	16.59	0.06	15.88	0.05	M70
369.35	18.53	0.06	17.23	0.03	16.64	0.05	15.93	0.05	C60
371.41	18.51	0.06	17.23	0.04	16.67	0.05	15.93	0.06	C60
374.52	18.54	0.07	17.32	0.03	16.75	0.04	16.02	0.05	C60
378.51	18.75	0.10	17.40	0.04	16.85	0.05	16.08	0.06	C60
379.40	18.72	0.07	17.45	0.03	16.88	0.04	16.17	0.05	C60
380.46	18.75	0.07	17.47	0.04	16.92	0.05	16.19	0.06	C60
393.23	18.77	0.08	17.67	0.04	17.17	0.05	16.52	0.06	M70
403.21	18.95	0.08	17.84	0.04	17.30	0.05	16.73	0.05	M70
404.17	19.03	0.09	17.90	0.04	17.29	0.05	16.75	0.06	M70
407.16	19.22	0.10	17.95	0.04	17.47	0.06	16.84	0.06	M70
408.18	19.11	0.10	17.91	0.05	17.43	0.05	16.82	0.06	M70
410.16	19.05	0.13	17.99	0.06	17.41	0.06	16.84	0.06	M70
414.17	19.14	0.15	18.15	0.07	17.54	0.06	17.00	0.08	M70
434.29	19.54	0.07	18.45	0.04	17.92	0.05	17.23	0.05	C60
437.26	19.56	0.09	18.51	0.04	17.99	0.05	17.31	0.05	C60
444.37			18.69	0.11	18.08	0.07	17.32	0.07	C60
445.19			18.74	0.17	18.10	0.11	17.76	0.09	C50
446.18	19.61	0.07	18.59	0.04	18.13	0.05	17.53	0.06	C60
448.20	19.46	0.14	18.74	0.10	18.25	0.10	17.63	0.13	C60

SN 2018ebt. We compared the light curves of SN 2018ebt to those for a number of well-studied SNe Ic and Ic-BL and found the best match with SN Ic-BL 2002ap (Foley et al., 2003; Yoshii et al., 2003). The fit of the B- and V-band light curves is very good, but for the R and I bands, the brightness on the linear tail declined faster in the case of SN 2018ebt. Using the fit, we can derive dates and magnitudes of maximum light for SN 2018ebt: $B_{max} = 16.00$; $V_{max} = 14.98$; $R_{max} = 14.72$; $I_{max} = 14.56$. The maximum in the B band was reached on JD 2458325, and in the other bands, about 2–4 days later. The linear tail of the light curves started at about JD 2458365, the rates of brightness decline on the tail in the B, V, R, I bands are respectively 0.0129, 0.0191, 0.0199, 0.0217 mag/day.

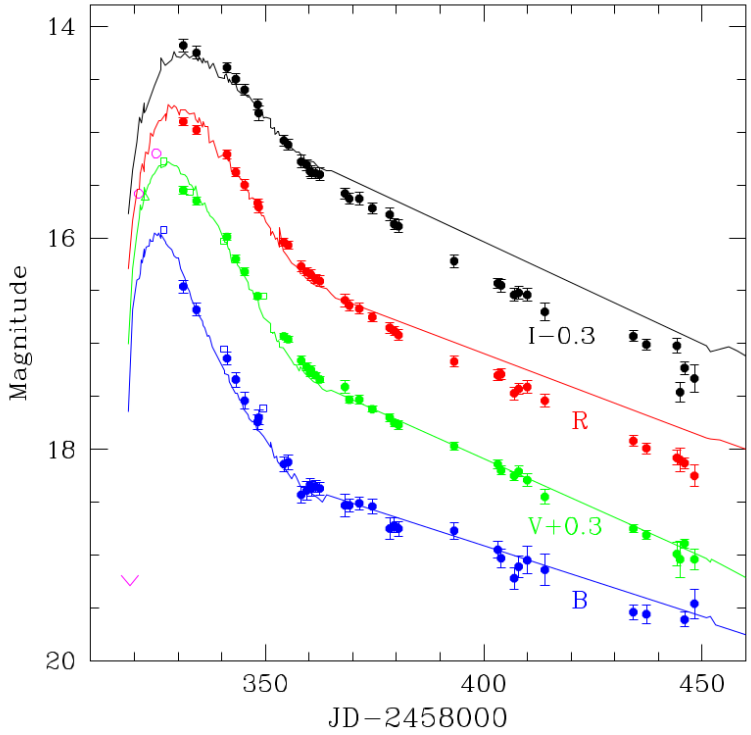

Figure 4. The $BVRI$ light curves of SN 2018ebt. Dots show our data, squares are for the B, V magniudes from the OSC (B magnitudes shifted by 0.35 mag), magenta circles and upper limit mark show the data from ATLAS. The lines are the light curves of SN 2002ap.

The color curves of SN 2018ebt and SN 2002ap are compared in Fig. 6 after correction for extinction. The Galactic reddening $E(B-V) = 0.26$ mag was accepted for SN 2018ebt[7], and for SN 2002ap we took $E(B-V) = 0.08$ mag (Foley et al., 2003). The comparison allows us to conclude that extinction in the host galaxy is negligible for SN 2018ebt. The shape of the color curves is similar for both SNe, although some differences are evident. The $V-R$ color of SN 2002ap is redder on the tail, and for the $R-I$ color, the maximum difference is at stages closer to maximum light.

The redshift of the parent galaxy is unknown, and the redshift estimates based on the spectra of the SN are uncertain. The smallest value of redshift, z=0.005, reported by Masayuki Yamanaka via TNS corresponds to the absolute magnitude at maximum $M_V = -17.4$ mag, which is close to the value for SN 2002ap, $M_V = -17.1$ mag (Yoshii et al. 2003). We consider this estimate of z most probable, but the redshift of the host galaxy is needed to derive a more reliable luminosity of SN 2018ebt and to compare this object to other SNe of similar class.

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[7] http://ned.ipac.caltech.edu

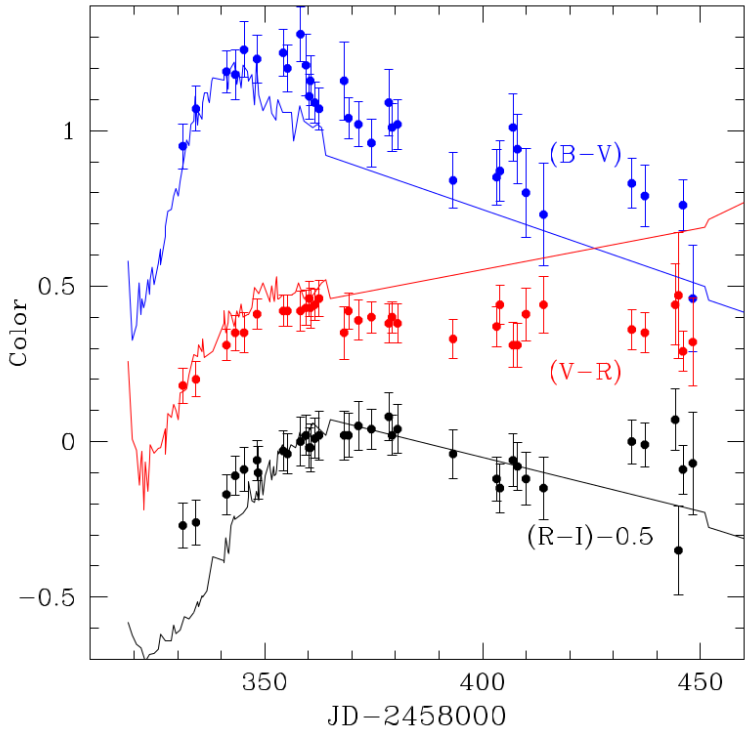

Figure 5. The color curves of SN 2018ebt. Dots show our data, lines are the color curves of SN 2002ap.

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