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SN 2017hpa: A carbon-rich type Ia supernova

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type:observation-IaSN
comment:对Ia 型 SN 2017hpa 光学+紫外（UBVRI+swift/uvot）波段测光以及光学波段测谱，-13.8天至108天

▶ details

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We present the optical (UBVRI) and ultraviolet (Swift-UVOT) photometry, and optical spectroscopy of Type Ia supernova SN 2017hpa. We study broadband UV+optical light curves and low resolution spectroscopy spanning from −13.8 to +108~d from the maximum light in B-band. The photometric analysis indicates that SN 2017hpa is a normal type Ia with ΔmB(15)=0.98±0.16 mag and MB=−19.45±0.15 mag at a distance modulus of μ=34.08±0.09 mag. The (uvw1−uvv) colour evolution shows that SN 2017hpa falls in the NUV-blue group. The (B−V) colour at maximum is bluer in comparison to normal type Ia supernovae. Spectroscopic analysis shows that the Si II 6355 absorption feature evolves rapidly with a velocity gradient, v˙=128±7 km s−1 d−1. The pre-maximum phase spectra show prominent C II 6580 Å absorption feature. The C II 6580 Å line velocity measured from the observed spectra is lower than the velocity of Si II 6355 Å, which could be due to a line of sight effect. The synthetic spectral fits to the pre-maximum spectra using syn++ indicate the presence of a high velocity component in the Si II absorption, in addition to a photospheric component. Fitting the observed spectrum with the spectral synthesis code TARDIS, the mass of unburned C in the ejecta is estimated to be ∼0.019~M⊙. The peak bolometric luminosity is Lbolpeak=1.43×1043 erg s−1. The radiation diffusion model fit to the bolometric light curve indicates 0.61±0.02 M⊙ of 56Ni is synthesized in the explosion.

- 对Ia 型 SN 2017hpa 光学+紫外（UBVRI+swift/uvot）波段测光以及光学波段测谱，-13.8天至 108天。
- $\Delta m_B(15)=0.98\pm0.16$ mag， $M_B=-19.45\pm0.15$ mag（峰值星等）， $D_L=34.08\pm0.09$ mag.（根据测光分析）
- (uvw1 - uvv) 颜色演化表明SN 2017hpa 属于 NUV-blue group。峰值处(B-V)颜色相比普通Ia型超新星更蓝。
- 测谱分析显示Si II 6355 吸收线有较快的演化，$\dot{v}=128\pm7\ km\ s^{-1}\ d^{-1}$。且峰值前的光谱显示出较强C II 6580吸收线。后者的速度比前者速度慢，原因可能是"a line of sight effect."
- 峰值前光普拟合显示Si II 吸收中存在一个光球成分之外的高速成分
- 光普拟合还给出喷射物中未燃烧的C质量为~0.019 $M_\odot$
- 热光度峰值为$L_{peak}^{bol}=1.43\times10^{43}erg\ s^{-1}$，热光变曲线拟合给出56Ni 合成量为 $0.61\pm0.02M_\odot$.

Q:

- 观测情况？
- NUV-blue group是什么？其颜色演化有何特征？与该超新星峰值处更蓝有联系吗？
- 什么样的"line of sight effect"导致不同谱线速度不一样？

A:

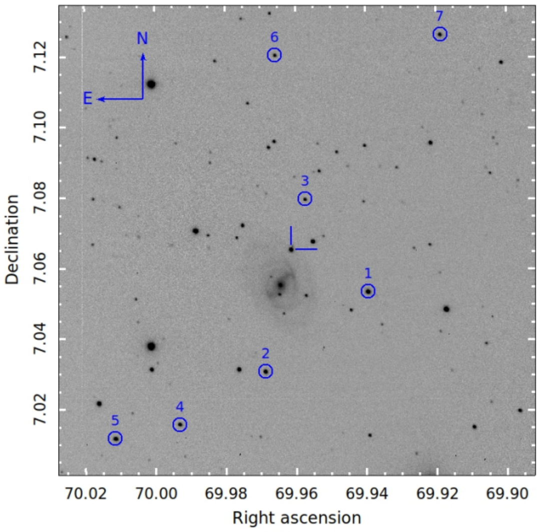


Figure 1. SN 2017hpa in the host galaxy UGC 3122. This is a ~7×7 arcmin^2 image in *V*-band (50 sec exposure) taken with HCT on 2017 October 31. The stars circled in blue (Ids 1–7) are the secondary standard stars used for calibration. The supernova is marked with crosshairs.

corrected for the instrumental response using spectra of spectrophotometric standards and brought to a relative flux scale. On the nights

Table 1. Parameters of SN2017hpa and its host galaxy.

Parameters	Value	Ref.
SN2017hpa:		
RA (J2000)	$\alpha = 04^h39^m50.^s73$	2
DEC (J2000)	$\delta = +07°03'55.''22$	2
Galactocentric Location	11.''2 W, 35.''6 N	2
Discovery Date	t_d = 2017 October 25 08:18 (UTC) (JD 2458051.84)	2
Date of *B*-band Maxima	t_0 = 2017 November 08 17:45 (UTC) (JD 2458066.29 ± 0.11)	1
$\Delta m_{15}(B)$	0.98 ± 0.16 mag	1
Galaxy reddening	$E(B-V) = 0.1518 \pm 0.0069$ mag	3
Host reddening	$E(B-V) = 0.08 \pm 0.06$ mag	1
$(B-V)_0$	−0.26 ± 0.03	1
Peak Magnitude (*B*-band)	$M_B = -19.45 \pm 0.15$ mag	1
Distance modulus	$\mu = 34.08 \pm 0.09$ mag	1
Peak Luminosity	$L^{bol}_{peak} = 1.43 \times 10^{43}$ erg s^{-1}	1
^{56}Ni mass	$M_{Ni} = 0.61 \pm 0.02\ M_\odot$	
Ejected mass	$M_{ej} = 1.10 \pm 0.22\ M_\odot$	
$\dot{v}$	127.9 ± 6.1 km s^{-1} d^{-1}	1
R(Si II)$_{max}$	0.13 ± 0.02	1
v_{max}	9643 ± 110 km s^{-1}	1
v_{10}	8320 ± 120 km s^{-1}	1
Kinetic energy	$E_K = (0.80 \pm 0.23) \times 10^{51}$ erg s^{-1}	1
UGC 3122:		

- 测光：
  - UBVRI，2-m HCT(Himalayan Chandra Telescope)

    Bessell *UBVRI* photometric observations of SN 2017hpa were carried out using the Hanle Faint Object Spectrograph Camera (HFOSC), mounted on the 2-m Himalayan Chandra Telescope (HCT) of the Indian Astronomical Observatory (IAO)[3], Hanle, India. The HFOSC is equipped with a $2K \times 4K$ SITe CCD chip, and

    Table A3. Optical photometry of SN2017hpa from HCT.

Date (yyyy-mm-dd)	JD (2458000+)	Phase* (d)	*U* (mag)	*B* (mag)	*V* (mag)	*R* (mag)	*I* (mag)
2017-10-31	58.45	−7.8	15.68 ± 0.13	15.98 ± 0.03	15.95 ± 0.02	15.82 ± 0.02	15.75 ± 0.03
2017-11-01	59.43	−6.8	15.49 ± 0.15	15.77 ± 0.03	15.82 ± 0.02	15.69 ± 0.02	15.63 ± 0.02
2017-11-02	60.37	−5.9	15.37 ± 0.15	15.63 ± 0.06	15.75 ± 0.03	15.54 ± 0.03	15.52 ± 0.02
2017-11-09	67.19	0.9	15.26 ± 0.14	15.41 ± 0.02	15.39 ± 0.01	15.31 ± 0.02	15.43 ± 0.02
2017-11-10	68.21	2.0	15.36 ± 0.19	15.44 ± 0.03	15.40 ± 0.01	15.30 ± 0.01	15.45 ± 0.01
2017-11-15	73.27	7.0	15.69 ± 0.15	15.68 ± 0.03	15.39 ± 0.01	15.39 ± 0.01	15.61 ± 0.01
2017-11-19	77.43	11.1	—	16.04 ± 0.04	15.48 ± 0.01	15.63 ± 0.02	16.02 ± 0.04
2017-11-22	80.28	13.9	16.57 ± 0.09	16.36 ± 0.02	15.75 ± 0.01	15.79 ± 0.01	15.96 ± 0.02
2017-11-29	87.36	21.1	—	17.23 ± 0.02	16.26 ± 0.02	15.98 ± 0.01	15.83 ± 0.02
2017-12-17	105.24	38.9	—	18.38 ± 0.02	17.18 ± 0.02	16.74 ± 0.01	16.30 ± 0.02
2017-12-26	114.21	47.9	—	18.60 ± 0.03	17.48 ± 0.02	17.12 ± 0.01	16.76 ± 0.02
2017-12-29	117.24	50.9	—	18.62 ± 0.04	17.54 ± 0.02	17.20 ± 0.02	16.92 ± 0.02
2018-01-05	124.09	57.8	—	—	17.78 ± 0.02	17.48 ± 0.01	17.33 ± 0.03
2018-01-21	140.12	73.8	19.55 ± 0.25	19.02 ± 0.03	18.12 ± 0.03	17.94 ± 0.02	17.97 ± 0.03
2018-02-02	152.11	85.8	—	—	18.37 ± 0.02	18.25 ± 0.02	—
2018-02-03	153.14	86.9	19.95 ± 0.19	19.08 ± 0.07	18.40 ± 0.02	18.24 ± 0.03	18.26 ± 0.04
2018-02-09	159.27	93.0	—	—	18.58 ± 0.03	18.48 ± 0.02	18.63 ± 0.04

*Time since *B*-band maximum (JD 2458066.3).

  - UVOT

data were obtained from the *Swift* archive (https://www.swift.ac.uk/swift_portal/). The *UVOT* observations were made with broadband filters *uvw*2 (1928 Å), *uvm*2 (2246 Å), *uvw*1 (2600 Å), *u* (3465 Å), *b* (4392 Å) and *v* (5468 Å) starting from 2017 October 26 (JD 2458053.2) and continued till 2017 December 07 (JD

Table A2. UV-Optical photometry of SN 2017hpa with *Swift-UVOT*.

Date (yyyy-mm-dd)	JD (2458000+)	Phase* (d)	*uvw*1 (mag)	*u* (mag)	*b* (mag)	*v* (mag)
2017-10-26	53.25	−13.05	18.37±0.16	17.59±0.10	17.09±0.05	16.63±0.06
2017-10-28	54.58	−11.72	18.35±0.24	16.91±0.12	16.74±0.07	16.49±0.12
2017-10-30	56.98	−9.32	18.09±0.23	16.35±0.09	16.38±0.07	16.17±0.11
2017-11-03	60.89	−5.41	17.00±0.10	15.38±0.04	15.62±0.04	15.66±0.06
2017-11-09	67.48	1.18	16.80±0.13	15.37±0.07	15.46±0.05	15.31±0.08
2017-11-11	69.26	2.97	17.11±0.15	15.46±0.05	—	15.38±0.09
2017-11-13	71.11	4.82	17.19±0.09	15.61±0.09	15.54±0.04	15.31±0.05
2017-11-15	73.32	7.02	17.33±0.19	15.82±0.08	15.70±0.06	15.36±0.09
2017-11-17	75.18	8.88	17.86±0.25	15.95±0.08	15.80±0.06	15.39±0.05
2017-11-23	81.08	14.78	17.97±0.16	16.77±0.09	16.39±0.05	15.81±0.08
2017-11-24	82.35	16.05	18.31±0.19	16.93±0.09	16.53±0.06	15.84±0.07
2017-11-27	85.27	18.97	18.59±0.21	17.32±0.12	16.91±0.07	16.01±0.07
2017-12-01	88.86	22.56	19.36±0.56	17.46±0.16	17.21±0.10	16.20±0.10
2017-12-07	95.43	29.13	—	18.99±0.45	17.65±0.11	16.48±0.10

*Time since *B*-band maximum (JD 2458066.3).

- 测谱：
  - HCT 双光栅低分光谱

on 2017 October 30 (JD 2458057.4) and continued till 2018 February 25 (JD 2458175.1). Low resolution spectra were obtained using grisms, Gr7 (3500-7800 Å) and Gr8 (5200-9100 Å) available with the HFOSC. The log of spectroscopic observations is provided in Table A4. The two-dimensional images were pre-processed in

Table A4. Log of spectroscopic observations of SN2017hpa from HCT.

Date (yyyy-mm-dd)	JD (2458000+)	Phase* (d)	Range (Å)
2017-10-30	57.43	−8.9	3500-7800; 5200-9100
2017-10-31	58.46	−7.8	3500-7800; 5200-9100
2017-11-01	59.47	−6.7	3500-7800
2017-11-02	60.39	−5.9	3500-7800; 5200-9100
2017-11-09	67.22	0.9	3500-7800; 5200-9100
2017-11-10	68.23	1.9	3500-7800; 5200-9100
2017-11-19	77.36	11.1	3500-7800; 5200-9100
2017-11-22	80.30	14.1	3500-7800; 5200-9100
2017-11-29	87.23	20.9	3500-7800; 5200-9100
2017-12-01	89.31	23.1	3500-7800; 5200-9100
2017-12-05	93.19	26.9	3500-7800; 5200-9100
2017-12-17	105.26	39.0	3500-7800; 5200-9100
2017-12-26	114.24	47.9	3500-7800; 5200-9100
2017-12-29	117.25	51.0	3500-7800; 5200-9100
2018-01-05	124.13	57.9	3500-7800; 5200-9100
2018-01-21	140.22	73.9	3500-7800; 5200-9100
2018-01-30	149.17	82.9	3500-7800; 5100-9100
2018-02-03	153.07	86.8	3500-7800
2018-02-09	159.14	92.8	3500-7800; 5200-9100
2018-02-13	163.13	96.8	3500-7800
2018-02-20	170.07	103.8	3500-7800
2018-02-25	175.06	108.8	3500-7800

*Time since *B*-band maximum (JD 2458066.3).

- 光变分析

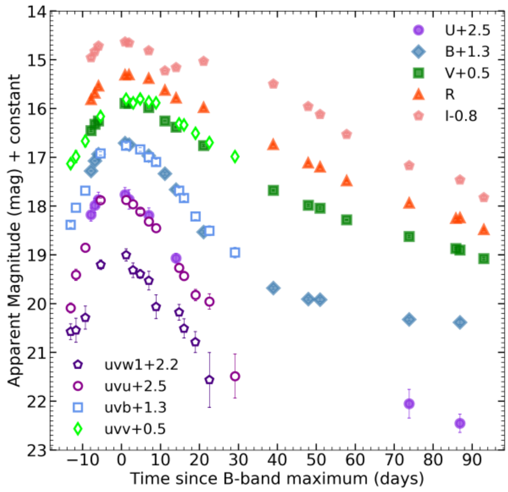


Figure 2. *UBVRI* and *Swift−UVOT* light curves of SN 2017hpa. The phase is measured with respect to *B* band maximum. The light curves in individual bands have been shifted for representation purpose as indicated in the legend.

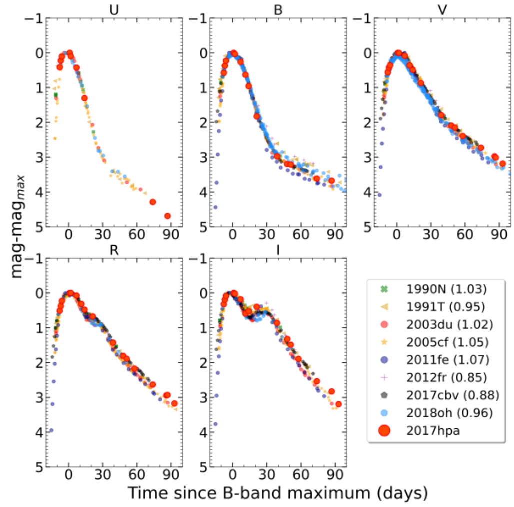
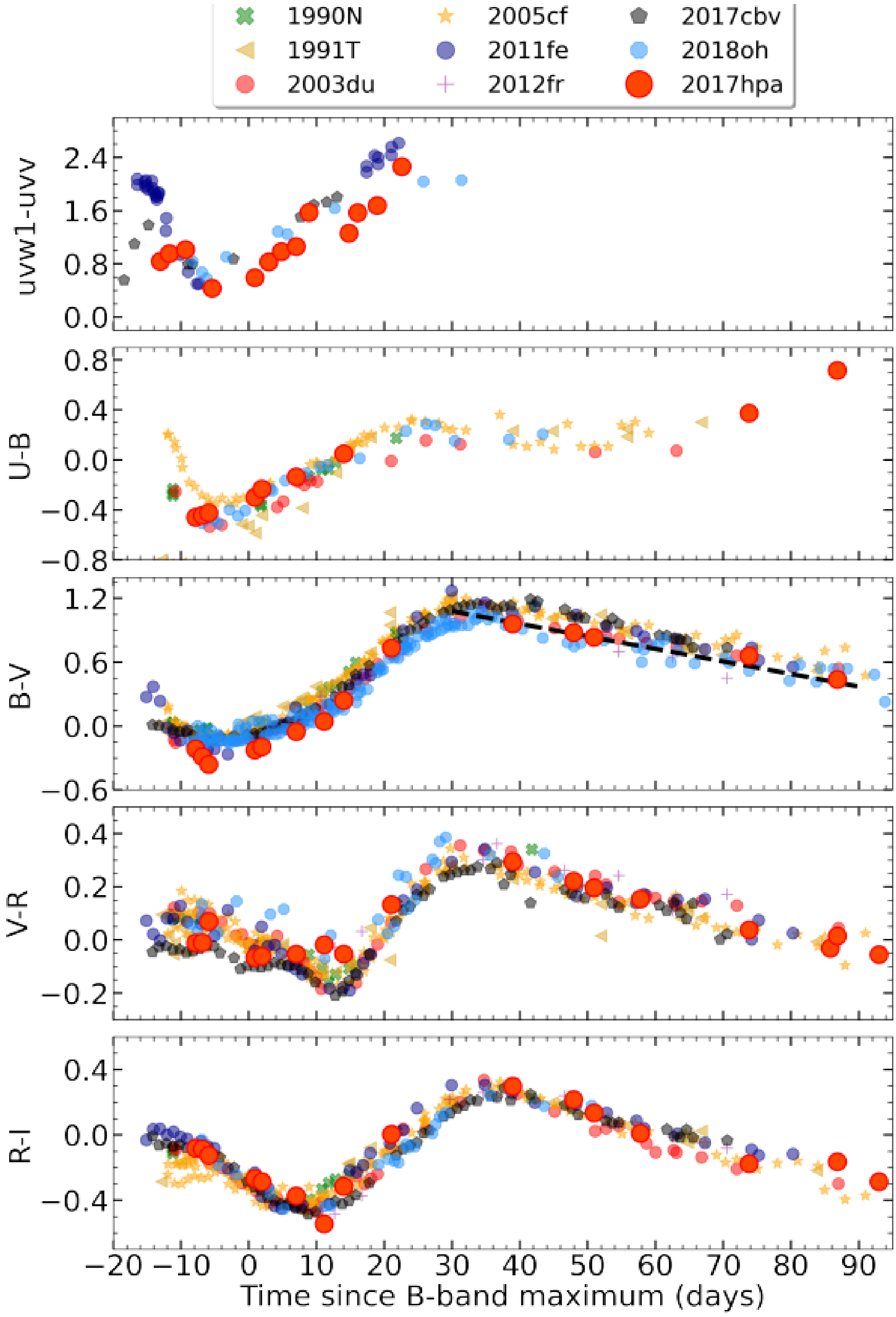


Figure 3. *UBVRI* light curves of SN 2017hpa compared with other normal SN Ia. The light curves have been shifted to match with their peak magnitudes and to the epoch of *B* maximum.

- I波段的双峰特征源自抛射物中铁族元素随温度降低的电离演化。Ia SN超新星的普遍特征。

magnitude 0.44 mag fainter than the peak. The double-peaked nature is directly related to the ionisation evolution of Iron Group Elements (IGE's) in the supernova ejecta, (Kasen 2006). As the ejecta expands, it cools down, and at a temperature $T \sim 7000$ K, the near-infrared emission of Fe/Co increases, which marks the transition from doubly to singly ionised state. The appearance of U band maximum before and V and R band maxima after the B band maximum

- 颜色演化



- (uvw1-uvv)更蓝，属于NUV-blue group。NUV-blue group：Milne et al. (2013):https://iopscience.iop.org/article/10.1088/0004-637X/779/1/23/pdf

6 In this work, we treat the UV wavelength range to be emission shortward of 4000 Å, NUV to be emission between 2500 and 4000 Å (u and $uvw1$ filters), and MUV to be emission between 1500 and 2500 Å ($uvm2$ and $uvw2$ filters).

high NUV/optical ratio (SNe 2006dd, 2008Q, SNF20080514-002, SNe 2008hv, 2009dc, 2011by, and 2011fe), while in M10, only SN 2008Q exhibited that tendency. Throughout this paper, we will refer to this group as the "NUV–blue" SNe Ia, and the larger group as "NUV–red." The separation between the two

- 更蓝的原因可能与峰值前未燃烧的carbon有关。

is discussed in Section 3.2. The $(B-V)$ colour at B-band maximum is -0.26 ± 0.03 mag, which is bluer than the comparison SNe. The $(uvw1 - uvv)$ colour of SN 2017hpa is bluer, similar to the other NUV-blue objects (see Fig. 4) and hence can be included in the NUV-blue group as defined by Milne et al. (2013). However, the $(uvw2 - uvv)$ colour evolution could not be verified. Recent studies of carbon positive SNe have shown bluer near UV colours (Thomas et al. 2011b; Silverman & Filippenko 2012; Milne et al. 2013), which could be due to unburned carbon present during pre-maximum phases. The $(U-B)$ colour at maximum is slightly redder

- 关于光球速度(Si II 6355)与C的速度（C II 6580）不一致：碳元素集团运动速度与实现方向不一致，夹角逐渐变小。

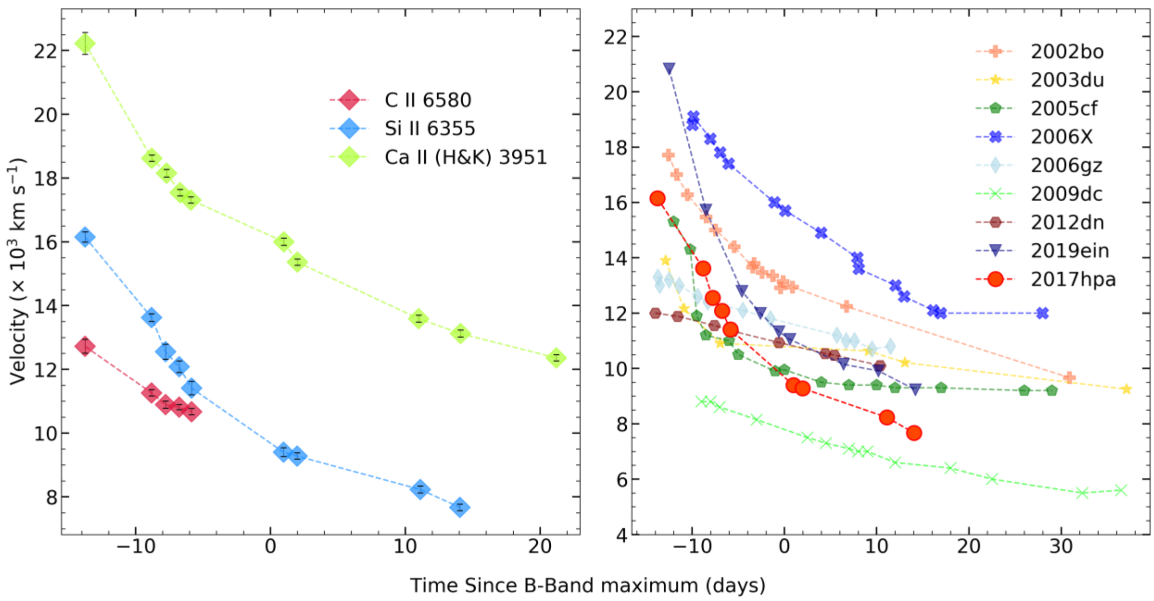
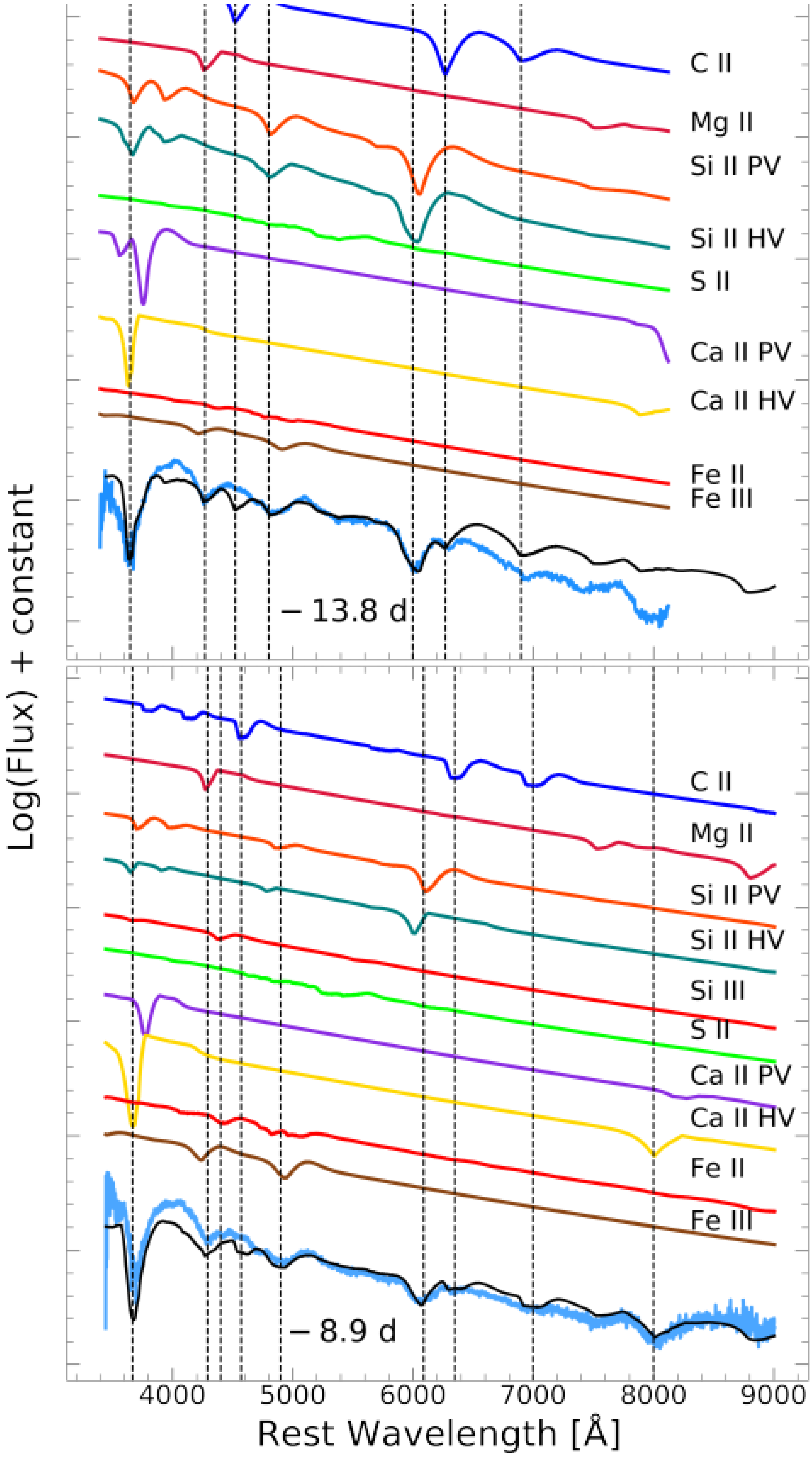


Figure 11. Velocity evolution of C II λ6580, Si II λ6355 and Ca II λ3951 for SN 2017hpa (left panel). Comparison of the velocity evolution of Si II λ6355 for SN 2017hpa with other SNe Ia (right panel).

to be ~ 1 within 10%. The discrepancy between the photospheric velocity (as measured by Si II velocity) and the carbon velocity is explained by Parrent et al. (2011) as being due to a clumpy carbon layer that is offset by an angle θ from the line of sight. The angle can be estimated if $v_{\rm C\,II} < v_{\rm Si\,II}$. The observed velocity ratios indicate θ to be ~ 40° on day −13.8 and ~ 25° on day −5.9. It is suggested that the change in the ratio (and angle from the line of sight) is indicative of an initial asymmetry that became more symmetric as the SN evolved to maximum, or a clumpiness that became more homogeneous as the SN ejecta evolved. Another possible explanation for the lower

- 光谱拟合


C II
Mg II
Si II PV
Si II HV
S II
Ca II PV
Ca II HV
Fe II
Fe III
− 13.8 d
C II
Mg II
Si II PV
Si II HV
Si III
S II
Ca II PV
Ca II HV
Fe II
Fe III
− 8.9 d
Log(Flux) + constant
4000
5000
6000
7000
8000
9000
Rest Wavelength [Å]