Variable Hα Emission in the Nebular Spectra of the Low-luminosity Type Ia SN2018cqj/ATLAS18qtd

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Abstract

We present optical photometry and spectroscopy of the Type Ia supernova SN2018cqj/ATLAS18qtd. The supernova exploded in an isolated region at ~65 kpc from the S0 galaxy IC 550 at z = 0.0165 (D ≈ 74 Mpc) and has a redshift consistent with a physical association to this galaxy. Multicolor photometry show that SN2018cqj/ATLAS18qtd is a low-luminosity (M_B ≈ −17.9 mag), fast-declining Type Ia, with color stretch s_{BV} ≈ 0.6 and B-band decline rate Δm_{15}(B) ≈ 1.77 mag. Two nebular-phase spectra obtained as part of the 100IAS survey at +193 and +307 days after peak show the clear detection of a narrow Hα line in emission that is resolved in the first spectrum with FWHM ≈ 1200 km s\(^{-1}\) and L_{Hα} ≈ 3.8 × 10^{37} erg s\(^{-1}\). The detection of a resolved Hα line with a declining luminosity is broadly consistent with recent models where hydrogen is stripped from the nondegenerate companion in a single-degenerate progenitor system. However, the amount of hydrogen consistent with the luminosities of the Hα line would be ~10^{-3} M_\odot, which is significantly less than theoretical model predictions in the classical single-degenerate progenitor systems. SN2018cqj/ATLAS18qtd is the second low-luminosity, fast-declining SN Ia after SN2018fhw/ASASSN-18tb that shows narrow Hα in emission in its nebular-phase spectra.

Unified Astronomy Thesaurus concepts: Supernovae (1668); Type Ia supernovae (1728); High energy astrophysics (739); Transient sources (1851)

1. Introduction

Type Ia supernovae (SNe) are among the most energetic and common stellar explosions, contribute to the nucleosynthesis of iron-peak elements, and have been used extensively to trace the expansion history of the universe. However, the nature of their progenitors and explosion mechanisms is still unknown despite decades of detailed observations of hundreds of extragalactic SNe Ia and several Galactic supernova (SN) remnants. Multiple lines of observational evidence and theoretical modeling point to SNe Ia as thermonuclear explosions of carbon–oxygen (CO) white dwarfs (WD), but the properties of the progenitor system (e.g., WD mass; degenerate or nondegenerate companion; single; binary; or triple system) and the explosion mechanism (e.g., CO detonation/deflagration in an accreting WD, merger or collision of two WDs) are under debate (e.g., Wang & Han 2012; Hillebrandt et al. 2013; Maoz et al. 2014; Livio & Mazzali 2018 and references therein).

In the single-degenerate (SD) progenitor channel, a CO WD accretes matter (hydrogen or helium rich) from a nondegenerate companion until it reaches a critical mass, typically the Chandrasekhar mass, and explodes (e.g., Han & Podsiadlowski 2004; Nomoto & Leung 2018). One of the main predictions of the classical SD channel is that some amount of material (M ~ 0.1–0.5 M_\odot) is stripped from the nondegenerate companion by the SN shock and can be detected as narrow (ν ~ 1000–2000 km s\(^{-1}\)) emission lines from hydrogen or helium in late-time (>200 days after peak), nebular-phase spectra when the ejecta are optically thin (e.g., Wheeler et al. 1975; Chugai 1986; Marietta et al. 2000; Liu et al. 2012; Boehner et al. 2017; Botyánzski et al. 2018). Modifications to the classical SD channel can lead to the companion losing significant mass before the SN explosion, potentially hiding these signatures (Di Stefano et al. 2011; Justham 2011).

Several observational campaigns have targeted nearby SNe Ia looking for signatures of the stripped material, mainly searching for an hydrogen Hα line in deep nebular-phase optical spectra (e.g., Mattila et al. 2005; Leonard 2007; Lundqvist et al. 2013, 2015; Shappee et al. 2013, 2018; Maguire et al. 2016; Graham et al. 2017; Sand et al. 2018, 2019; Dimitriadis et al. 2019; Holmbo et al. 2019; Tucker et al. 2019a, 2019b), but have only obtained nondetections.

Recently, Kollmeier et al. (2019) reported the discovery of a strong Hα line in emission with an integrated luminosity of L ~ 2.2 × 10^{38} erg s\(^{-1}\) and line width of FWHM ~ 1100 km s\(^{-1}\) in the +139 days nebular spectral of the fast-declining (color stretch s_{BV} ≈ 0.5 and Δm_{15}(B) ≈ 2.0 mag), low-luminosity (M_B ~ −17.6 mag) Type Ia SN2018fhw/ASASSN-18tb (Brimacombe et al. 2018). If this Hα detection is stripped hydrogen from the nondegenerate companion in an SD progenitor system, the amount of material needed to...
explain the line luminosity would be \( \sim 2 \times 10^{-3} M_{\odot} \). Vallely et al. (2019) presented more spectra, photometry, and an early rising light curve of SN2018fhw/ASASSN-18tb that put into question this interpretation of the observations and instead favor a scenario similar to Type Ia-CSM events (e.g., Hamuy et al. 2003; Prieto et al. 2007; Dilday et al. 2012; Silverman et al. 2013, see also Graham et al. 2019), where a strong H\(\alpha\) emission line and extra luminosity most likely originate in the interaction between the SN ejecta and a hydrogen-rich circumstellar medium (CSM).

In this paper, we present observations of the Type Ia SN2018cqj/ATLAS18qtd that show similarities to SN2018fhw/ASASSN-18tb, including the detection of an H\(\alpha\) emission line in late-time spectra of a low-luminosity SN Ia. The spectroscopic observations of SN2018cqj/ATLAS18qtd presented in this paper were obtained as part of the 100IAS survey (Dong et al. 2018; Chen et al. 2019; Kollmeier et al. 2019), a project using 5–10 m class telescopes to obtain nebular-phase optical spectra of a complete sample of \( \sim 100 \) SNe Ia within \( z \lesssim 0.02 \), to systematically study signatures of explosion asymmetries such as those discovered in SN2007on (Dong et al. 2015). In Section 2.1, we discuss the discovery, spectroscopic classification, and host galaxy environment of SN2018cqj/ATLAS18qtd. In Sections 2.2 and 2.3, we present the early and late-time optical light curve and spectra, respectively. In Section 3, we present a discussion of the results and conclusions.

2. Data and Analysis

2.1. Discovery, Classification, and Host Environment

SN2018cqj/ATLAS18qtd was discovered by the Asteroid Terrestrial-impact Last Alert System (ATLAS; Tonry et al. 2018b) transient survey at R.A. = 09:40:21.463 and decl. = −06:59:19.76 (J2000.0) on 2018 June 13.27 (all dates are UT) with orange magnitude \( o = 18.14 \pm 0.09 \) mag and had a prediscovery nondetection on 2018 June 11.25 with \( o > 18.58 \) mag (Tonry et al. 2018a). After initial inspection of archival imaging data from the Digital Sky Survey and Pan-STARRS1 (PS1; Chambers et al. 2016; Flewelling et al. 2016), we found no obvious host galaxy at the location of the transient. However, the NASA Extragalactic Database (NED) shows that the transient was located 3′1 from the nearby S0 galaxy IC 550 at \( z = 0.016455 \pm 0.000150 \) (Paturel et al. 2003; Jones et al. 2009), potentially making it a low-redshift supernova, and worth following up on (see Figure 1).

An optical low-resolution spectrum obtained by Khlat et al. (2018) on 2018 July 14.97, presented in Section 2.3, showed features characteristic of a SN Ia a few weeks after maximum at \( z \approx 0.02 \), making a physical association with the S0 galaxy IC 550 possible. We reanalyzed the spectrum using the Supernova Identification cross-correlation code (SNID; Blondin & Tonry 2007). Fitting the spectrum with SNID in the wavelength range 4200–7200 Å, cutting the low signal-to-noise ratio ends of the spectrum, we find that it is most consistent with a normal SN Ia at \( 31 \pm 7 \) days after maximum light and with a redshift \( z_{SN} = 0.0155 \pm 0.0019 \).

The redshift derived with SNID from the supernova features is fully consistent, within the 1\( \sigma \) uncertainties, with the redshift of IC 550, which makes a physical association between SN2018cqj/ATLAS18qtd and the S0 galaxy likely. Throughout the rest of the paper, we assume that IC 550 is the host galaxy of SN2018cqj/ATLAS18qtd, which at \( z_{CMB} = 0.017596 \) (from the NED) gives a luminosity distance of \( D_L = 74.3 \) Mpc with an assumed Hubble constant of \( H_0 = 72 \) km s\(^{-1}\) Mpc\(^{-1}\). At this distance, the projected physical separation between the supernova and the center of IC 550 is \( \sim 65 \) kpc, which would imply that it went off in the outer halo of the S0 galaxy. However, we cannot rule out that the host is a smaller dwarf galaxy closer to
the supernova in a galaxy group with IC 550. Figure 1 shows a color composite image of the environment of SN2018cqj/ATLAS18qtd obtained using the deepest archival images of the field from the Dark Energy Camera Legacy Survey (DECaLS; Dey et al. 2019). The DECaLS DR7 grz coadds give strong nondetection upper limits at the position of the supernova of $g > 25.8$ mag ($M_g > -8.7$), $r > 24.6$ mag ($M_r > -9.8$) and $z > 23.4$ mag ($M_z > -11.0$) at 5σ, which rule out an association of the progenitor galaxy with dwarf galaxies down to the luminosities of massive globular clusters (McConnachie 2012).

\section*{2.2. Photometry}

We obtained five epochs of photometric follow-up observations of SN2018cqj/ATLAS18qtd, close to its peak magnitude, in the BVgr bands between 2018 June 26.4 and July 10.0 with the Las Cumbres Observatory Global Telescope Network (LCOGT; Brown et al. 2013) 1 m telescopes at the Cerro Tololo InterAmerican Observatory (CTIO) and the Siding Spring Observatory. We ran point-spread-function (PSF) photometry on the LCOGT pipeline-reduced images using the DoPHOT package (Schechter et al. 1993; Alonso-García et al. 2012). We calibrated the BVgr magnitudes using the AAVSO Photometric All-Sky Survey (APASS; Henden et al. 2015).

We also retrieved five epochs of g-band photometry obtained between 2018 June 22.0 and 29.0 by the All-Sky Automated Survey for SuperNovae (ASAS-SN; Shappee et al. 2014; Kochanek et al. 2017) from the Bohdan Paczyński unit in CTIO. The ASAS-SN images were reduced with an automated pipeline using the ISIS image subtraction package (Alard & Lupton 1998; Alard 2000) and the photometry was calibrated with APASS stars in the field.

Additionally, we obtained four late-time (>190 days after peak) V-band photometric measurements of SN2018cqj/ATLAS18qtd between 2019 January 7.4 and May 3.5 from images obtained with the FORS2 instrument (Appenzeller et al. 1998) on the VLT UT1 Antu 8.2 m telescope at the ESO Paranal Observatory and with the WFCCD instrument on the du Pont 2.5 m telescope at the Las Campanas Observatory. The images were reduced using standard techniques in IRAF.
The spectral resolution is measured as the FWHM of the luminosity, fast-declining Type Ia SN2011fe (blue points and line; Munari et al. 2013) and the low-peak luminosity, fast-declining Type Ia SN1991bg (red point and line; Turatto et al. 1996).

The spectra will be made publicly available through the Weizmann Interactive Supernova data REPository (WISEREP; Yaron & Gal-Yam 2012).

Table 2

| JD      | Wavelength Range (Å) | Resolution (Å) | Exposure Time (s) | Airmass | Telescope/Instrument |
|---------|----------------------|----------------|-------------------|---------|---------------------|
| 2458314.5 | 3800–9300             | 8.2            | 160               | 2.3     | du Pont/WFCCD       |
| 2458490.9 | 4200–9600             | 9.9            | 7040              | 1.1–1.4 | VLT UT1/FORS2       |
| 2458607.5 | 4200–9600             | 9.9            | 5800              | 1.0–1.4 | VLT UT1/FORS2       |

Note. The spectral resolution is measured as the FWHM of the [O I] 5577 Å sky line.

2.3. Spectroscopy

We obtained three optical long-slit spectra of SN2018cqj/ATLAS18qtd. Table 2 has a summary of the observations. The classification spectrum was obtained on 2018 July 14.97 with the WFCCD instrument on the du Pont 2.5 m telescope at Las Campanas Observatory. Two sets of nebular-phase spectra were obtained with the FORS2 instrument on the VLT UT1 telescope. The first set of five exposures was obtained as part of the period 102 regular ESO program 0102.D-0287(A) between 2019 January 5.2 and 9.2, with a total exposure time on source of 7040 s. The second set of four exposures was obtained as part of the period 103 DDT program number 2103.D-5008(A) between 2019 May 3.1 and 5.0, with a total exposure time on source of 5800 s.

Standard reductions of all the 2D spectral images up to flat-fielding were obtained with tasks in IRAF ccdproc. The wavelength calibration, 1D spectral extraction, and flux calibration of each individual spectrum were done with tasks in longslit, twodspec, and onedspec packages in IRAF. For the nebular-phase spectra, we combined the fully reduced 1D spectra in each of the two sets of exposures obtained in 2019 January and May, respectively. We checked and applied small offsets (≤1 Å) to the wavelength calibration of each individual spectrum using the strong [O I] sky emission line at 5577.3 Å. To obtain good absolute flux calibration of the final nebular-phase spectra to measure emission line fluxes, we obtained synthetic V-band magnitudes from the spectra and applied multiplicative factors to match the V-band photometry measured from the acquisition images (listed in Table 1).

The spectra of SN2018cqj/ATLAS18qtd are shown in Figure 3. In the left panel of the figure, we show the classification spectrum and the two nebular-phase spectra scaled and offset in flux (arbitrarily) for clarity. The wavelengths in the spectra are corrected to the rest frame using the redshift of IC 550. The two nebular-phase spectra show the clear detection of a narrow, but resolved, emission line at approximately the wavelength of the Hα transition. In the same panel, we show the +18 days and the +139 days nebular-phase spectrum of SN2018fhw/ASASSN-18tb for comparison (Kollmeier et al. 2019; Vallely et al. 2019). The nebular-phase spectrum of SN2018fhw/ASASSN-18tb has a significantly stronger intrinsic Hα emission line with respect to the local continuum and also in peak/integrated flux (as we show below).

In the right panel of Figure 3 we show the profiles of the Hα line in the two nebular-phase spectra of SN2018cqj/ATLAS18qtd. We corrected the fluxes in each spectrum for Galactic extinction (Schlafly & Finkbeiner 2011), and fitted and subtracted a third-order polynomial to the continuum around the narrow Hα emission line. The x-axis in the panel shows the velocity with respect to the Hα wavelength in the laboratory (6562.82 Å) after correcting the wavelengths to the rest frame using the redshift of IC 550. We also show a Gaussian profile with the FWHM of the skylines (see Table 2) scaled to the central velocity and peak of the Hα emission line in the +193 days spectrum. This shows that the Hα emission line is clearly resolved with respect to the instrumental profile in the +193 days spectrum.

Figure 2. Left: BVgri light curves around peak of the Type Ia SN2018cqj/ATLAS18qtd. The lines are the best-fit SNooPy (Burns et al. 2011) SN Ia light-curve template. We have applied an arbitrary offset in magnitude to each band, shown in the labels. Right: late-time V-band light curve of SN2018cqj/ATLAS18qtd (filled black circles). For comparison, we also show the late-time light curves of the normal Type Ia SN2011fe (blue points and line; Munari et al. 2013) and the low-peak luminosity, fast-declining Type Ia SN1991bg (red point and line; Turatto et al. 1996).
The Hα profile of the +193 days spectrum is best fit with a two-component Gaussian profile with the following best-fit parameters: \( F_1 = (4.55 \pm 0.40) \times 10^{-17} \text{ erg s}^{-1} \text{ cm}^{-2} \), \( \lambda_1 = 6568.72 \pm 0.73 \text{ Å} \), FWHM\(_1\) = 28 ± 3 Å and \( F_2 = (1.13 \pm 0.38) \times 10^{-17} \text{ erg s}^{-1} \text{ cm}^{-2} \), \( \lambda_2 = 6569.92 \pm 0.49 \text{ Å} \), FWHM\(_2\) = 9 ± 2 Å, where \( F \) is the integrated line flux, \( \lambda \) is the rest-frame wavelength at peak, and FWHM is the full-width at half maximum of the Gaussian profile in the rest frame. The Hα profile of the +307 days spectrum is best fit with a single Gaussian with best-fit parameters: \( F = (6.96 \pm 1.55) \times 10^{-18} \text{ erg s}^{-1} \text{ cm}^{-2} \), \( \lambda = 6567.94 \pm 0.99 \text{ Å} \), FWHM = 9 ± 2 Å.

The total integrated fluxes and luminosities of the Hα line in both nebular-phase epochs are: \( F(193) = (5.7 \pm 0.6) \times 10^{-17} \text{ erg s}^{-1} \text{ cm}^{-2} \), \( L(193) = (3.8 \pm 0.9) \times 10^{-3} \text{ erg s}^{-1} \), and \( F(307) = (7.0 \pm 1.7) \times 10^{-18} \text{ erg s}^{-1} \text{ cm}^{-2} \), \( L(307) = (4.6 \pm 1.4) \times 10^{-9} \text{ erg s}^{-1} \). In the flux uncertainties we have included an overall flux-calibration uncertainty given by the errors in the magnitudes in Table 1 and we have also added a 10% uncertainty in the luminosity distance.

3. Discussion and Conclusions

We have presented optical photometry, spectroscopy, and archival imaging of SN2018cqj/ATLAS18qtd that show that this transient is a fast-declining (color stretch \( \Delta V_B \approx 0.6 \) and B-band decline rate \( \Delta m_{15}(B) \approx 1.77 \) mag), low-peak luminosity (\( M_{\text{Bmax}} \approx -17.9 \) mag) SN Ia that exploded in the outer halo of the S0 galaxy IC 550 (\( D \approx 74 \) Mpc) at a projected separation of \( \sim 65 \) kpc or in an unidentified dwarf galaxy in the same galaxy group. Nebular-phase spectra obtained with the VLT FORS2 instrument at +193 and +307 days after peak brightness show the detection of a strong, narrow line in emission associated with the supernova. The emission line is consistent with Hα at a velocity of \( \sim 300 \) km s\(^{-1} \) with respect to the recursion velocity of IC 550.

SN2018cqj/ATLAS18qtd is the second case of a fast-declining, low-peak luminosity SN Ia observed by the 100IAS survey with an intrinsic Hα line in emission detected in its nebular-phase spectra after SN2018fhw/ASASSN-18tb (Kollmeier et al. 2019; Vallely et al. 2019). Kollmeier et al. (2019) discussed the possibility that the Hα detected in SN2018fhw/ASASSN-18tb could be stripped hydrogen from a hydrogen-rich nondegenerate companion in a single-degenerate progenitor system and estimated a stripped mass of \( \sim 2 \times 10^{-5} M_\odot \) using the models of Botyánszki et al. (2018). The amount of hydrogen could be as high as \( \sim 10^{-2} M_\odot \) taking into account the lower Ni yield of SN2018fhw compared with normal SNe Ia. Other possibilities for the origin of the Hα line discussed by Kollmeier et al. (2019) included interaction between the SN ejecta and the CSM of the progenitor system, akin to the luminous Type Ia-CSM events (e.g., Hamuy et al. 2003; Prieto et al. 2007; Dilday et al. 2012; Silverman et al. 2013), and fluorescent UV pumping in a slowly expanding shell of material.

The detailed properties of the line emission in SN2018fhw/ASASSN-18tb—the Hα luminosity did not show significant variations (within a factor of two) in spectra obtained between +37 and +148 days after peak and the nondetection of the Hβ line which implied a high Balmer decrement of \( F(\text{H} \alpha)/F(\text{H} \beta) \sim 6 \), and the smooth early light-curve rise observed by the Transiting Exoplanet Survey Satellite (TESS)—led Vallely et al. (2019) to suggest that the Hα emission line originated from ejecta-CSM interaction instead of from stripped hydrogen in a single-degenerate system.

As in SN2018fhw/ASASSN-18tb, the detailed properties of the late-time emission observed in SN2018cqj/ATLAS18qtd can shed light on the origin of the Hα line detected in the two nebular-phase spectra. The Hα emission line is clearly resolved in the +193 days spectrum, with a FWHM of the broad Gaussian component of \( \sim 1200 \) km s\(^{-1} \) after correcting for the intrinsic spectral resolution listed in Table 2 (\( \sim 450 \) km s\(^{-1} \)), but is unresolved in the +307 days spectrum. However, we note that the lower signal-to-noise ratio of the second nebular component would in part hinder the detection of a broad component. The total integrated luminosity of the Hα line decreases by a factor of \( \sim 8 \) between the +193 and +307 days spectra. On the other hand, the V-band continuum magnitude is intermediate between SN2011fe (normal SN Ia) and SN1991bg.
(fast decliner) with a consistent late-time decline rate of 0.015 mag day$^{-1}$, as shown in Figure 2, and the V-band flux decreases by a factor of $\sim 5$ between these epochs. We also searched for the H$\beta$ line in the $+193$ days spectrum and do not detect it. Using the method outlined in Tucker et al. (2019a), we obtain a $10\sigma$ upper limit on the H$\beta$ flux of $F(\text{H}\beta) \approx 10^{-17}$ erg s$^{-1}$ cm$^{-2}$ (extinction corrected), which implies a lower limit on the Balmer decrement of $F(\text{H}\alpha)/F(\text{H}\beta) \gtrsim 6$, similar to SN2018fhw/ASASSN-18tb.

In summary, most of the properties of the late-time emission in the fast-declining, low-luminosity Type Ia SN2018cqj/ATLAS18qtd are broadly consistent with the signatures expected when hydrogen is stripped from the nondegenerate companion star in a single-degenerate progenitor system (e.g., Botyánszki et al. 2018; Tucker et al. 2019a): the detection of a resolved H$\alpha$ line with $\nu \sim 1000$ km s$^{-1}$ with an integrated luminosity that decreases in time roughly following the luminosity evolution of the supernova. Also, in the case of SN2018cqj/ATLAS18qtd the V-band light curve behaves like other normal and fast-declining SNe Ia at $\sim 200$–300 days after peak, and it does not show significant extra luminosity from ejecta–CSM interaction as it has been clearly observed in Type Ia-CSM events (Silverman et al. 2013). The main property that is shared with Type Ia-CSM events and also SN2018fhw/ASASSN-18tb is the high value of the Balmer decrement, which points to either high host galaxy extinction or that the origin of the emission line is different from the classical Case-B recombination with a Balmer decrement of 2.86 (Osterbrock & Ferland 2006). We can, however, rule out significant host galaxy extinction because of the host galaxy environment of the SN and also because the shape of the continuum of the nebular-phase spectra is consistent with low-extinction SNe Ia.

We can use the luminosities of the H$\alpha$ lines in the nebular spectra of SN2018cqj/ATLAS18qtd to constrain the amount of hydrogen stripped off the putative companion to the white dwarf in the single-degenerate scenario interpretation. In Figure 4 we show the evolution of the H$\alpha$ luminosity as a function of time since explosion (filled circles). We have assumed a B-band rise-time from explosion to maximum light of 14 days for fast-declining SNe Ia (Zheng et al. 2017). The three lines in Figure 4 have a constant amount of stripped hydrogen of $M_H = 10^{-4}, 10^{-3}, 10^{-2} M_\odot$ and were obtained from the models of Botyánszki et al. (2018), adapted in Equation (1) of Tucker et al. (2019a) to include the luminosity evolution of SNe Ia between 200 and 500 days after explosion. From the H$\alpha$ luminosities measured in the two nebular-phase spectra of SN2018cqj/ATLAS18qtd, we get a stripped hydrogen mass of $M_H = (1.2 \pm 0.2) \times 10^{-3} M_\odot$ and $(0.7 \pm 0.2) \times 10^{-3} M_\odot$.

We can also use the linear relation between the peak luminosity of the nebular H$\alpha$ line and the amount of stripped material derived by Mattila et al. (2005), as shown in Leonard (2007). From their relation, we get stripped hydrogen masses of $M_H \sim 0.27 M_\odot$ and $\sim 0.07 M_\odot$ from the two nebular-phase spectra of SN2018cqj/ATLAS18qtd. The Mattila et al. (2005) models have some limitations compared with the Botyánszki et al. (2018) models: they use spherically symmetric change for
radiative transfer calculations, assume a uniform density of solar-abundance material at the center of the ejecta up to a fixed velocity of 1000 km s\(^{-1}\), and do not carry out time-dependent calculations. These are the main reasons we use to highlight the radiative transfer calculations, assume a uniform density of

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(\(\text{Botyánszki et al. 2018}\)) models. However, despite the more realistic models, we note the potential for systematic uncertainties introduced due to the theoretical limitations of Botyánszki et al. (2018). More realistic estimates will need a broader range of binary models, hydrodynamics models, and fuller treatment of atomic processes and radiative transfer.

The \(\text{H}\alpha\) emission line detected in the two nebular-phase spectra of SN2018cqj/ATLAS18qtd shows a redshift of \(~300\text{ km s}^{-1}\) with respect to the recession velocity of the S0 galaxy IC 550. In the single-degenerate scenario, there is a viewing angle dependence in the material stripped off the companion and shifts in the centroid of the \(\text{H}\alpha\) line of \(~10\ \AA\) (\(\pm 500\text{ km s}^{-1}\)) from the rest-wavelength can be expected (Botyánszki et al. 2018). This velocity shift could also be caused by a different intrinsic velocity of the progenitor of SN2018cqj/ATLAS18qtd with respect to the central regions of IC 550, either as a fast-moving star in the outer halo of the galaxy (the central velocity dispersion of IC 550 is \(\sigma = 158 \pm 15\text{ km s}^{-1}\), Campbell et al. (2014) or if it comes from a different host galaxy in the same galaxy group as IC 550. Another possibility is that the emission line we detect is not \(\text{H}\alpha\), but a transition from a different ion. Jerkstrand et al. (2015) and Fang & Maeda (2018) have interpreted the \(\text{H}\alpha\)-like emission detected in the nebular-phase spectra of SNe IIb as the [N II] transitions at 6548 and 6584 \(\text{Å}\). This interpretation appears less likely for SN2018cqj/ATLAS18qtd because in both cases it would involve larger blueshifts/redshifts with respect to the laboratory wavelengths and there is no theoretical prediction or expectation of detecting [N II] in SNe Ia.

The stripped hydrogen mass estimates using the models of Botyánszki et al. (2018) for SN2018cqj/ATLAS18qtd are comparable to the estimates obtained for SN2018fw/h/ASASSN-18tb (Kollmeier et al. 2019), but significantly lower than the \(M_H \approx 0.1-0.5\,M_\odot\) of stripped hydrogen expected in classical single-degenerate models from subgiant, main-sequence or red giant companion stars (Marietta et al. 2000; Liu et al. 2012; Boehner et al. 2017). Also, the host galaxy environments of SN2018fw/h/ASASSN-18tb (in a dwarf elliptical galaxy) and SN2018cqj/ATLAS18qtd (possibly in the outer halo of an S0 galaxy) are associated with old stellar populations, consistent with other low-luminosity, fast-declining SNe Ia (Gallagher et al. 2008; Panter et al. 2019). These properties are very different from the younger, more massive hydrogen-rich companions of single-degenerate systems that have been proposed to explain Type Ia-CSM events (e.g., Hamuy et al. 2003; Prieto et al. 2007; Dilday et al. 2012; Silverman et al. 2013), which are found in star-forming galaxies and have much higher peak and \(\text{H}\alpha\) luminosities (\(L_{\text{H}\alpha} \approx 10^{40}\text{ erg s}^{-1}\)), and also some more normal SNe Ia with time-variable and/or blueshifted Na I absorption lines detected in their spectra (e.g., Patat et al. 2007; Sternberg et al. 2011). Perhaps this points to a different physical origin for the \(\text{H}\alpha\) in emission detected in the two fast-declining, low-luminosity Type Ia in the 100IAS survey. In a future paper, we will report the statistics of \(\text{H}\alpha\) detections in the complete sample of SN Ia with nebular-phase spectra from 100IAS survey, which will hopefully give us interesting observational clues into the physical origin of the \(\text{H}\alpha\) detected in these systems.

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References

Alard, C. 2000, A&AS, 144, 363
Alard, C., & Lupton, R. H. 1998, ApJ, 503, 325
Alonso-García, J., Mateo, M., Sen, B., et al. 2012, AJ, 143, 70
Appenzeller, I., Fricke, K., Füriger, W., et al. 1998, Msngr, 94, 1
Blondin, S., & Tonry, J. L. 2007, ApJ, 666, 1024
