Reddening and HeI $\lambda$10830 Absorption Lines in Three Narrow-line Seyfert 1 Galaxies

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Received 2017 May 13; revised 2017 July 17; accepted 2017 July 21; published 2017 August 18

Abstract

We report the detection of heavy reddening and the He I $\lambda$10830 absorption lines at the active galactic nucleus (AGN) redshift in three narrow-line Seyfert 1 galaxies: SDSS J091848.61+211717.0, SDSS J111354.66+124439.0, and SDSS J122749.13+321458.9. They exhibit very red optical to near-infrared colors, narrow Balmer/Paschen broad emission lines and He I $\lambda$10830 absorption lines. The ultraviolet-optical-infrared nucleus continua are reddened by the SMC extinction law of $E(B-V) \sim 0.74, 1.17$, and $1.24$ mag for three objects, which are highly consistent with the values obtained from the broad-line Balmer decrements, but larger than those of narrow emission lines. The reddening analysis suggests that the extinction dust simultaneously obscures the accretion disk, the broad emission-line region, and the hot dust from the inner edge of the torus. It is possible that the dust obscuring the AGN structures is the dusty torus itself. Furthermore, the Cloudy analysis of the He I $\lambda$10830 absorption lines proposes the distance of the absorption materials to be the extent scale of the torus, which greatly increases probabilities of the obscure and absorption materials being the dusty torus.

Key words: dust, extinction – galaxies: absorption lines – galaxies: individual (SDSS J091848.61+211717.0, SDSS J111354.66+124439.0, SDSS J122749.13+321458.9) – galaxies: ISM

1. Introduction

Active galactic nuclei (AGNs) emit over the entire electromagnetic spectrum and are widely believed to be produced by the accretion of matter onto a supermassive black hole in the center of the galaxy. Narrow-line Seyfert 1 galaxies (NLS1s) are a special subclass of AGNs in the evolution history. NLS1s typically show the narrower Balmer lines (FWHM < 2000 km s$^{-1}$), the stronger Fe II emission (Fe II/H$\beta > 0.5$), the weaker [O III] lines ([O III]/H$\beta < 3$), the stronger variability and steeper X-ray spectra (e.g., Goodrich 1989; Boroson & Green 1992; Wang et al. 1996; Leighly 1999; Marziani et al. 2001; Grupe et al. 2004) than other AGNs. NLS1s have lower black hole masses and higher $L/L_{Edd}$, thus they are considered to be in the quick growth stage of the central black hole (e.g., Mathur 2000; Grupe & Mathur 2004; Zhou et al. 2006; Komossa et al. 2008; Xu et al. 2012).

Because of these properties, NLS1s are generally thought to be in the early evolution stage (Grupe et al. 1999), and perhaps link between AGNs and normal galaxies (Zhang et al. 2009; Rovilos et al. 2009). According to the current AGN unified model, the differences between NLS1s and other Seyfert galaxies, i.e., broad-line Seyfert 1s and Seyfert 2s, are ascribed solely to orientation effects and anisotropic obscuration (Antonucci 1993). Although many studies suggest that NLS1s are observed from a nearly pole-on view (e.g., Osterbrock & Pogge 1985; Puchnarewicz et al. 1992; Taniguchi et al. 1999), it becomes apparent that they cannot be easily brought into the frame of the unified model. Fortunately, partially obscured objects provide a new way to see the inside of AGNs (e.g., Dong et al. 2005). Through the study of the spectral energy distribution (SED) extinction and the associated absorption lines, they are expected to provide some of the constraints on the physical and geometrical conditions in the centers of AGNs.

In this work, we report the extreme reddening and the detection of He I $\lambda$10830 absorption lines at the AGNs’ redshift in three NLS1s: SDSS J091848.61+211717.0, SDSS J111354.66+124439.0, and SDSS J122749.13+321458.9 (hereafter SDSS J0918+2117, SDSS J1113+1244, and SDSS J1227+3214), which were initially reported by the red Two Micron All Sky Survey (2MASS; Skrutskie et al. 2006) AGNs (Kuraszkiewicz et al. 2009) and the FIRST-2MASS red quasars (F2M; Glikman et al. 2007, 2012). We picked them up again during the series study of the reddening AGNs (e.g., Li et al. 2015; Liu et al. 2016; Pan et al. 2017; Zhang et al. 2017). We study the He I $\lambda$10830 absorption lines (the first detection reported by Leighly et al. 2011) as well as the continuum and hydrogen Balmer/Paschen broad emission lines of these objects. Different from the dust located on the inside of the torus in another NLS1 SDSS J2339-0919 (C.-W. Yang et al. 2017, in preparation), the heavy reddening and the He I $\lambda$10830 absorption lines in these three objects are due to the dust from the torus itself.

2. Multiwavelength Observations

SDSS J0918+2117, SDSS J1113+1244, and SDSS J1227+3214 were best known for infrared-luminous dust-reddened quasars, and have been comprehensively observed. For these three objects, the broadband SEDs from the far-ultraviolet (FUV) out to the middle-infrared (MIR) are presented by the photometric data taken with the Galaxy Evolution Explorer (GALEX; Morrissey et al. 2007), the Sloan Digital Sky Survey (SDSS; York et al. 2000), the 2MASS survey, and the Wide-field Infrared Survey Explorer (WISE; Wright et al. 2010). Three objects in the SDSS images are unresolved and are classified to “STAR”, “psfMag” is theoretically the optimal
measure of their brightness. However, since the redshifts of SDSS J0918+2117 and SDSS J1227+3214 are 0.1493 and 0.1368 (Hewett & Wild 2010), we choose Petrosian magnitudes for two objects. Meanwhile, they are included in the 2MASS All-Sky Point Source Catalog, rather than the Extended Source Catalog for their unresolved images. Their optical to near-infrared colors suggest that they are much more heavily reddened than the normal red quasars and less than the true type-2 quasars. The photometric magnitudes are summarized in Table 1.

| Band  | Magnitude | Obs. Date | Magnitude | Obs. Date | Magnitude | Obs. Date | Survey/Telescope | References |
|-------|-----------|-----------|-----------|-----------|-----------|-----------|-----------------|-----------|
| FUV   | 22.88 ± 0.61a | 2010 Feb 04 | 23.61 ± 0.47 | 2008 Apr 02 | 21.60 ± 0.31 | 2007 Apr 14 | GALEX 1 |
| NUV   | 21.95 ± 0.25  | 2010 Feb 04 | 21.74 ± 0.12 | 2008 Apr 02 | 20.72 ± 0.17 | 2007 Apr 14 | GALEX 1 |
| u     | 19.82 ± 0.03  | 2004 Dec 13 | 21.55 ± 0.15 | 2008 Nov 02 | 20.18 ± 0.05 | 2008 Nov 02 | SDSS 2, 3 |
| g     | 18.17 ± 0.01  | 2004 Dec 13 | 21.04 ± 0.04 | 2003 Mar 31 | 18.79 ± 0.01 | 2004 May 12 | SDSS 2, 3 |
| r     | 17.13 ± 0.01  | 2004 Dec 13 | 19.87 ± 0.02 | 2003 Mar 31 | 17.53 ± 0.01 | 2004 May 12 | SDSS 2, 3 |
| i     | 16.42 ± 0.01  | 2004 Dec 13 | 18.85 ± 0.01 | 2003 Mar 31 | 16.60 ± 0.01 | 2004 May 12 | SDSS 2, 3 |
| z     | 16.25 ± 0.01  | 2004 Dec 13 | 18.05 ± 0.02 | 2003 Mar 31 | 16.41 ± 0.01 | 2004 May 12 | SDSS 2, 3 |
| J     | 14.81 ± 0.04  | 1998 Jan 12 | 16.14 ± 0.08 | 1997 Dec 18 | 14.83 ± 0.04 | 2000 Apr 12 | 2MASS 4 |
| H     | 13.74 ± 0.01  | 1998 Jan 12 | 15.03 ± 0.07 | 1997 Dec 18 | 13.85 ± 0.04 | 2000 Apr 12 | 2MASS 4 |
| K     | 12.58 ± 0.03  | 1998 Jan 12 | 13.67 ± 0.04 | 1997 Dec 18 | 12.90 ± 0.03 | 2000 Apr 12 | 2MASS 5 |
| W1    | 11.07 ± 0.01  | 2010 May 01 | 11.34 ± 0.01 | 2010 Mar 31 | 11.42 ± 0.02 | 2010 Jun 07 | WISE 5 |
| W2    | 10.03 ± 0.01  | 2010 May 01 | 9.86 ± 0.01  | 2010 Mar 31 | 10.31 ± 0.02 | 2010 Jun 07 | WISE 5 |
| W3    | 7.33 ± 0.01   | 2010 May 01 | 7.06 ± 0.01  | 2010 Mar 31 | 7.43 ± 0.02  | 2010 Jun 07 | WISE 5 |
| W4    | 4.80 ± 0.01   | 2010 May 01 | 5.25 ± 0.03  | 2010 Mar 31 | 4.81 ± 0.02  | 2010 Jun 07 | WISE 5 |
| F475W | ...         | ...         | ...         | 2005 May 26 | ...         | ...         | HST/ACS 6 |
| F814W | ...         | ...         | ...         | 2005 May 26 | ...         | ...         | HST/ACS 6 |
| 1100–6000 Å | ... | 2002 Apr 27 | ... | ... | ... | ... | HST/STIS 7 |
| 3800–9200 Å | ... | 2005 Nov 25 | ... | 2004 Mar 14 | ... | 2006 Mar 24 | SDSS 3 |
| 0.9–2.46 μm | ... | 2015 Mar 11 | ... | 2014 Jan 17 | ... | 2014 Jan 16 | P200/TripleSpec This work |

Note. 4 Details can be seen in http://classic.sdss.org/dr6/algorithms/photometry.html#which.

References. (1) Morrissey et al. (2007); (2) York et al. (2000); (3) Abazajian et al. (2009); (4) Skrutskie et al. (2006); (5) Wright et al. (2010); (6) Urrutia et al. (2008); (7) Kuraszkiewicz et al. (2009).
the rest frame, variability of the continuum strength and shape could be an issue. Fortunately, the two facts, i.e., the perfect matching of the optical/NIR spectra simply multiplied by a factor and the broadband SEDs and the high consistency of extinctions from the SED fitting and the Balmer decrements (see the next section), rule out the possibility of variability affecting the SED in these three NLS1s. When we take an overview of the features of the SEDs, it is obvious that the observed SEDs of all three objects show very different shapes from that of the average quasar spectrum, but in contrast to be similar with the heavily obscured quasar SDSS J000610.67+121501.2 reported in Zhang et al. (2017). In the optical and NIR bands, they are much lower than the average quasar spectrum; from the u- or NUV-band up to lower wavelengths, the SEDs slightly turn up (extremely weak in SDSS J0918+2117). The unique shape is considered to be caused by the spectral combination of two different continuum slopes (Zhang et al. 2017). When looking at the emission/absorption lines, the optical and NIR spectra show the significant broad/narrow emission lines, HeI $\lambda$ 10830 and weak CaII H and K (3969 and 3934 Å) absorption lines, which represent the contributions of the AGN and its host galaxy.

To model the SEDs, we used a phenomenological model due to the lack of a good physical understanding of the nature and geometry of the AGN and its host galaxy. Two principal components are superposed into the model: (1) the quasar composite and (2) the host galaxy starlight. The quasar composite (also used in Liu et al. 2016) is created by splicing the UV to optical quasar composite of Vanden Berk et al. (2001), the NIR quasar composite of Glikman et al. (2006), and the FIR quasar composite of Netzer et al. (2007). It contains the nucleus power-law continuum, the broad/narrow emission lines from the broad-/narrow-line regions, the NIR and MIR emission from the torus, and the more or less starlight contamination. We used the galaxy templates in the SWIRE library (Polletta et al. 2007) to approximately match the broadband SED shape of the host galaxy contribution. The SWIRE library provides us with the galaxy templates of six starbursts, three ellipticals, and seven spirals (ranging from early to late types, S0-Sdm) to represent the host galaxy starlight, which has wavelength coverage of 0.1–1000 μm. In addition, a warm dust component is added for SDSS J1113+1244 to make up the NIR peak located at the WISE W2-band. For SDSS J1227+3214, we add an extra high-temperature blackbody emission to repair the mismatch between the model and observed spectrum. Details will be given in the discussion of the individual objects below. Finally, we can decompose the broadband SED in rest-frame wavelength with the following model.

$$F_\lambda = C_1A_{E(B-V),\lambda}F_{\lambda,\text{QSO}} + C_2F_{\lambda,\text{HOST}} + C_3B_\lambda(T_{\text{dust}}),$$

where $F_\lambda$ is the observed spectrum, $F_{\lambda,\text{QSO}}, F_{\lambda,\text{HOST}},$ and $B_\lambda(T_{\text{dust}})$ are the quasar composite, the galaxy template, and the Planck function, respectively; $C_i$ ($i = 1, 2, 3$) are the factors for the the respective components; $A_{E(B-V),\lambda}$ is the dust extinction to the quasar composite by the SMC extinction law, and no reddening were assumed for other spectral components. The last item is alternative as needed, and the F-test analysis will decide whether we need to add the Planck function for the potential warm dust or another unknown component. We perform least-squares minimization using the IDL procedure MPFIT developed by Markwardt (2009).

SDSS J0918+2117—The combination of a scaled and reddened quasar composite with $E(B-V) = 0.74 \pm 0.01$ and a scaled Sc galaxy template can closely follow the observed magnitudes and spectra from the FUV-band to the W4-band. The sum and components are shown by red, green, and blue curves in Figure 1. In Kuraszkiewicz et al. (2009), the effects of the host galaxy on AGN optical/NIR colors suggest the host galaxy of SDSS J0918+2117 is an Sa galaxy with a 5 Gyr stellar population, and the host galaxy strength is 20 times weaker than the intrinsic/unreddened AGN at R band (Sa05, 20). In contrast, our modeled Sc template contributes approximately 14% of the total observed flux at the same band, in general agreement to the estimation of Kuraszkiewicz et al., considering the extinction correction. But for the constraint of the GALEX magnitudes, we will obtain the same host galaxy contribution (Sa05, 20) as Kuraszkiewicz et al. (2009).

SDSS J1113+1244—The best-fitting results are shown in Figure 2. We recovered the same $E(B-V) = 1.17$ value as

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**Figure 1.** Broadband SED of SDSS J0918+2117 from FUV to MIR by yellow squares, the spectra of HST/STIS, SDSS, and TripleSpec by black curves. The reddened quasar composite with $E(B-V) = 0.74 \pm 0.01$, the Sc galaxy template and their sum are shown by green, blue, and red curves. Overplotted for comparison is the quasar composite (gray curve).
reported in Urrutia et al. (2008), which appears to be well fit by this model. And the starlight template of the host galaxy is also an Sd galaxy. However, a dust emission with $T \sim 1050$ K (pink curve) is added as suggested in Urrutia et al. (2012), which was interpreted as the extra dust close to the sublimation radius (also see Glikman et al. 2006; Netzer et al. 2007; Mor & Trakhtenbrot 2011). However, the typical dust sublimation temperature is $\sim 1500–2000$ K (e.g., Tuthill et al. 2001; Monnier & Millan-Gabet 2002), and the extra “warm” dust in this object is probably not the inner edge of the torus. Its $HST/ACS$ images show the clear stellar-like feature (the AGN component) with the PSF Magnitudes of $22.87 \pm 0.25$ and $19.11 \pm 0.05$ for the F475W and the F814W filters (Table 5 of Urrutia et al. 2008; green squares), which have a good agreement with our modeled quasar component (green curve).

SDSS J1227+3214—Its phenomenological model is similar to that of SDSS J1113+1244, the only difference is the mismatch of the two-component model and the observed data at the optical band. A reddened quasar composite and an Sdm galaxy template can almost be determined by the $GALEX$, SDSS-u, and WISE photometric (green and blue curves in Figure 3). The mismatch (with the center wavelength of $\sim 8000 \AA$) looks like a blackbody emission with a high temperature of $\sim 3200$ K (pink curve in Figure 3). That suggests that there are more low-mass (e.g., M1-type) stars in the host galaxy. The final three-component model is consistent with the UV-to-IR observed magnitudes. Addition of the high-temperature blackbody indeed makes the phenomenological model look weird, thus, we tried to enhance the host dust emission to make up the mismatch. However, the hot ($\sim 1500–2000$ K) dust at the sublimation radius cannot shift the peak of dust emission to the mismatch wavelength range. We also tried to perform a two-dimensional decomposition of the AGN and host galaxy for the $r$-band image using GALFIT (Peng et al. 2010), in which the image is adopted as the PSF + Sérsic model. An effective decomposition is expected to put an independent constraint on the SED of the AGN. While the GALFIT shows that the $r$-band image contains the PSF
Magnitude of 18.35 (green squares for comparison), the Sérsic component of 18.22 mag, $n = 2.81$, and $r_e = 0.62$, under great uncertainty, since the SDSS image has a relatively short exposure time and low spatial resolution due to the seeing limit. Like SDSS J1113+1244, the HST/ACS imaging in the future can seek final clarification. The host galaxy starlight (Sd template and perhaps low-mass stars) is the dominant component of the UV and optical wavelength band. The modeled starlight of SDSS J1227+3214 lowers the contribution of the AGN, and thus raises our measured $E(B - V)$ from 0.71 mag and 0.94 mag (Glikman et al. 2012; LaMassa et al. 2016) to 1.24 ± 0.02 mag. On the other hand, the Balmer decrement analysis in the next section shows that the extinction to the Balmer lines is highly consistent with that of the broadband SED, the consistency strengthens our confidence about the phenomenological model of SDSS J1227+3214.

To summarize these results, unitary extinction can resolve the AGN’s reddening from the UV out to the MIR by the SMC extinction law, which suggests that the dust simultaneously affects the UV–optical continuum and the IR emission of the torus; in other words, the dust obscures the AGN structures inside of the torus. It is possible that they are the torus itself or the dust exterior to the torus. Meanwhile, studies of the host galaxies of NLS1s suggest that NLS1s tend to have smaller host galaxies (e.g., Krongold et al. 2001), and the host galaxies of NLS1s show a higher fraction of bars (e.g., Crenshaw et al. 2003; Ohta et al. 2007; Bian & Huang 2010; Olguín-Iglesias et al. 2017), grand-design nuclear dust spirals, and stellar nuclear rings (e.g., Deo et al. 2006; León Tavares et al. 2014). Similarly, the SED fitting shows the host galaxies of these three NLS1s are all the late-type spirals, which might indicate more efficient fueling of their black holes.

4. Balmer and Paschen Emission Lines

As shown in Figures 1–3, broad emission lines of hydrogen Balmer and Paschen series were detected by the SDSS optical spectrographs and the P200 TripleSpec spectrograph, with the only exception that in SDSS J1113+1244, the Po line lies beyond the wavelength coverage of the TripleSpec, due to the higher systemic redshift. Through the measurement of Balmer and Paschen broad lines and the comparison with the intrinsic flux ratios of AGNs, the dust extinction can be derived from the observed Balmer decrements at a different angle.

In this work, we are only concerned about strong and easily decomposable lines, i.e., H α, Hβ, and Po, and ignored other complicated and/or low-S/N lines. The optical and NIR spectra are heavily reddened and contaminated by the host galaxy, as introduced above, thus the power law usually used is not ideal to describe the continuum in a large wavelength range. For the three spectral regimes: $Hβ + [O III] λλ4959,5007$, $Hα + [N II] λλ6548,6583$, and $Pα$, a first-order polynomial is adopted to fine-tune the local continuum (independently for each regime) within a limited wavelength range. Because the Balmer lines are heavily blended with strong Fe II multiplets, in the $Hβ + [O III] λλ4959,5007$ and $Hα + [N II] λλ6548,6583$ regimes, we also adopted the I Zw 1 Fe II template provided by Véron-Cetty et al. (2004) and convolved it with a Gaussian kernel in velocity space to match the widths of broad/narrow Fe II multiplets in the observed spectra. The polynomial and Fe II multiplets were collectively referred to as the underlying pseudocontinuum, and were first subtracted from the observed spectra to further study the emission lines. The continuum windows are [4200, 4720] Å and [5080, 5300] Å for Hβ + [O III] λλ4959,5007, [6150, 6250] Å and [6850, 6950] Å for Hα + [N II] λλ6548,6583, and [1.82, 1.94] μm and [1.92, 1.94] μm for Pα. It is worth noting that the broad emission lines (listed in Table 2 of Vanden Berk et al. 2001) in the continuum windows are masked in the pseudocontinuum fitting. In the panels of Figure 4, the local continua and broad/narrow Fe II multiplets are marked by pink and blue lines.

After subtracting the pseudocontinuum models, we modeled the broad and narrow emission lines as multiple Gaussians: three Gaussians for broad Balmer and Paschen components and one Gaussian for narrow Balmer and Paschen components and other narrow lines. Additionally, one extra Gaussian was adopted to model the blue wing of the [O III] line (e.g., Komossa et al. 2008; Zhang et al. 2011). The [O III] $λλ4959,5007$ doublets were assumed to have the same shift and profile; the same was applied to [N II] $λλ6548,6583$ doublets and [S II] $λλ6716,6731$ doublets (e.g., Osterbrock & Pogge 1987). The flux ratios of the [O III] doublets and [N II] doublets were fixed to the theoretical values of 2.98 (e.g., Dimitrijević et al. 2007) and 2.96 (Storey & Zeipen 2000), respectively. The measured [S II] $λλ6716/6731$ ratios have a large dispersion, from 0.81 to 1.44 (Table 5 in Osterbrock & Pogge 1987), then the flux ratio of the [S II] doublet is free in the fitting. The details of these components: broad components in green and narrow components in cyan, are shown in the panels of Figure 4. The measured broad-line parameters are listed in Table 2.

In Veilleux & Osterbrock (1987), they adopted $Hα/Hβ = 3.1$ for active galaxies and 2.85 for H II region galaxies (e.g., Ferland & Netzer 1983; Gaskell 1984; Gaskell & Ferland 1984). Recently, the large sample statistics suggested that the intrinsic value of broad-line $Hα/Hβ$ is 3.06 with a standard deviation of 0.03 dex (Dong et al. 2008). Gaskell & Ferland (1984) presented that the relative strengths of $Pα$ and $Hβ$ for low-density gas was very close to the Case-B value, 0.34, here it was assumed to be applicable for the broad emission lines. Based on the observed Balmer decrements of $Hα/Hβ$ and $Pα/Hβ$, we calculated the values of $E(B - V)$ assuming the extinction curve of the SMC (Table 2). The deviation of the intrinsic ratios did not enter into our calculation, otherwise, larger errors will be applied to the estimated $E(B - V)$. The extinctions to the Balmer lines are highly consistent with those to the broadband SEDs, the broad emission-line regions (BLRs) of these three objects have the same intense dust-enshrouded as the continuum. While the measurements from the Balmer decrement $Pα/Hβ$ is currently smaller, it is possible that the problem lies in the intrinsic relative ratio of $Pα$ and $Hβ$ broad lines.

For NLS1s, the strength and decrement measurements of the narrow emission lines are heavily dependent on the emission-line profile decomposition and have large uncertainty, thus we do not employ the results of narrow lines and list them in Table 2. To study the extinction difference of broad and narrow emission lines, we try to use the profile ratio of Balmer lines to explore the difference. In Figure 5, we show the flux ratios of $Hα$ and $Hβ$ emission lines in the velocity space, where the emission profiles are calculated from the observed spectra subtracting the underlying pseudocontinuum and [N II] $λλ6548,6583$ doublet. It is
clear that there are obvious troughs at 0 km s$^{-1}$ in the profile ratio curves, which implies that the narrow emission-line region (NLR) has smaller extinction than the BLR. Generally, the dust in the AGNs exist in the large-scale galactic environment or the dusty torus around the AGN. The extinction difference of broad and narrow emission lines suggests that the dust affecting the SED and the BLR are from the dusty torus.

5. He I$^+$ λ10830 Absorption Lines

The redshifted He I$^+$ λ10830 emission lines of two objects (SDSS J0918+2117 and SDSS J1227+3214) are detected by the $J$-band TripleSpec spectra; Figures 1 and 3), and the narrow ($\sim$300–400 km s$^{-1}$) and deep ($\sim$60%) He I$^+$ λ10830 absorption troughs are identified in the peaks of the emission lines. Unfortunately, the $H$-band TripleSpec spectrum only covers part of the blue wing of the He I$^+$ λ10830 emission line of SDSS J1113+1244 with low-S/N, and the absorption region of He I$^+$ λ10830 falls into the gap at 1.85 μm. The same extinction of the reddening quasar SEDs and Balmer decrements suggests that the absorption materials can obscure the power-law continuum, broad emission lines, and the hot dust emission, rather than the host galaxy. Thus, when we calculated the normalized spectra, we first removed the host galaxy contribution (blue (and pink) curves in Figures 1 and 3) from the observed spectra. Since the He I$^+$ λ10830 absorption troughs are quite narrow, the unabsorbed fluxes are estimated using spline interpolation by masking the absorption troughs (left panels of Figure 6). In the right panels, we also plot the normalized spectra of He I$^+$ λ10830 absorption troughs in the velocity space obtained by dividing the observed spectra subtracting the host galaxy starlight by the unabsorbed fluxes. Note that, the typical 1σ error of the starlight is $\sim$10%, the
Table 2

Broad Emission-line Parameters and Balmer Decrement

| Line          | SDSS J0918+2117 |   | SDSS J1113+1244 |   | SDSS J1227+3214 |   |
|---------------|----------------|---|----------------|---|----------------|---|
|               | Centroid (Å)   | FWHM (km s\(^{-1}\)) | Flux (10\(^{-17}\) erg cm\(^{-2}\)) | Centroid (Å) | FWHM (km s\(^{-1}\)) | Flux (10\(^{-17}\) erg cm\(^{-2}\)) | Centroid (Å) | FWHM (km s\(^{-1}\)) | Flux (10\(^{-17}\) erg cm\(^{-2}\)) |
| H\(\beta\)    | 4862.62        | 1383 | 1763 ± 47 | 4862.60 | 1658 | 357 ± 18 | 4862.74 | 1175 | 1069 ± 26 |
| H\(\alpha\)   | 6564.02        | 1381 | 11652 ± 230 | 6563.25 | 1832 | 3145 ± 143 | 6565.70 | 1244 | 10844 ± 294 |
| P\(\alpha\)   | 18759.37       | 1123 | 2019 ± 307 | ... | ... | ... | 18758.55 | 1094 | 3591 ± 283 |

Decrement Value | E\((B - V)\) | Value | E\((B - V)\) | Value | E\((B - V)\) | Value |
|----------------|-------------|-------|-------------|-------|-------------|-------|
| H\(\alpha\)/H\(\beta\) | 6.61 ± 0.22 | 0.84 ± 0.04 | 8.81 ± 0.59 | 1.15 ± 0.07 | 10.14 ± 0.38 | 1.30 ± 0.04 |
| P\(\alpha\)/H\(\beta\)  | 1.15 ± 0.18 | 0.50 ± 0.06 | ... | ... | 3.36 ± 0.28 | 0.94 ± 0.03 |

Note. Adopting the multicomponent profile of the broad emission lines.

Figure 5. Observed profile ratios of H\(\alpha\) and H\(\beta\) emission lines in velocity space. The troughs at 0 km s\(^{-1}\) in the profile ratio curves imply that the Balmer narrow lines have smaller extinction than the Balmer broad lines.

The effect of the starlight uncertainties to the normalized spectra is negligible.

Theoretically, for a partially obscured absorber, the normalized intensity in the troughs is

\[ I(\nu) = 1 - Cf(\nu) + Cf(\nu)e^{-\tau(\nu)}, \]

where \(Cf(\nu)\) is the percentage covering factor of the absorber, and \(\tau(\nu)\) is the optical depth. Then, the column densities of He I* as a function of velocity are calculated using the general expression (e.g., Arav et al. 2001)

\[ N(\Delta\nu) = \frac{m_e c}{\pi e^2 \lambda_0 f_0} \tau(\Delta\nu) \]
\[ = \frac{3.7679 \times 10^{14}}{\lambda_0 f_0} \tau(\Delta\nu) \text{ [cm}^{-2} \text{ (km s}^{-1}\text{)}^{-1}], \]

where \(\lambda_0 = 10830 \text{ Å}\) and \(f_0 = 0.5392\) are the wavelength and the oscillator strength\(^5\) of He I* \(\lambda 10830\), respectively. The total column density is obtained by integrating Equation (3).

For SDSS J0918+2117 and SDSS J1227+3214, the minimum residual fluxes in the absorption troughs are 0.36 and 0.25, respectively. There are two extreme possibilities: (1) the He I* \(\lambda 10830\) absorption line is completely obscured but unsaturated, the column density of He I* can be directly calculated to be \(N_{\text{He}\nu} = (1.44 ± 0.27) \times 10^{13} \text{ cm}^{-2}\) for SDSS J0918+2117, and \(N_{\text{He}\nu} = (1.08 ± 0.09) \times 10^{13} \text{ cm}^{-2}\) for SDSS J1227+3214. Since the optical depth ratio of He I* \(\lambda 10830/\lambda 3889 = 23.1\), the He I* \(\lambda 3889\) absorption trough is so weak that the trough will be drowned in the spectral noise. (2) The He I* \(\lambda 10830\) absorption line is partly obscured but saturated. In this situation, we used the maximum absorption depths of the He I* \(\lambda 10830\) troughs as the covering factors for two cases, which are \(Cf = 0.64\) and 0.75, respectively. Due to the spectral noises within the potential He I* \(\lambda 3889\) absorption troughs, the upper limits of He I* \(\lambda 3889\) absorption depths are 0.13 and 0.20 at the 2\(\sigma\) level. Then the upper limits of the He I* column densities in SDSS J0918+2117 and SDSS J1227+3214 are approximated to be \(N_{\text{He}\nu} = 5.48 \times 10^{13} \text{ cm}^{-2}\) and \(4.40 \times 10^{13} \text{ cm}^{-2}\), respectively. Both above situations are in agreement with the observation. The true \(N_{\text{He}\nu}\) of the He I* \(\lambda 10830\) absorption lines in SDSS J0918+2117 and SDSS J1227+3214 should be somewhere in-between them.

As we know, the column density of He I* is insensitive to hydrogen density \(n_\text{H}\) in a wide range, while \(H(n = 2)\) is sensitive to the density of the gas; meanwhile, He I* grows in front of the ionization front of hydrogen and stops growing behind it, i.e., \(N_{\text{He}\nu}\) depends on the ionization parameter \(U\) (e.g., Arav et al. 2001; Ji et al. 2015; Liu et al. 2015; Sun et al. 2017). Thus, the absorptions of metastable helium and hydrogen Balmer are good indicators of \(U\) and \(n_\text{H}\), respectively. Furthermore, the ionization parameter depends on the distance

\(^5\) Oscillator strengths are from NIST Atomic Spectra Database (http://physics.nist.gov/PhysRefData/ASD/).
and 3.4 \times 10^{-2} \text{ cm}^{-2}$, LaMassa et al. 2016). We calculated a series of photoionization models with different ionization parameters and gas densities. The ranges of parameters are $-4 \leq \log_{10} U \leq 1$ and $3 \leq \log_{10} n_{\text{H}} \text{ (cm}^{-3}) \leq 10$ with a step of 0.2 dex. Figure 7 shows the column densities of the He I and H(\(n=2\)) ions as functions of ionization parameter $U$. The light magenta areas are the estimated $N_{\text{HeI}}$ ranges of SDSS J0918+2117 and SDSS J1227+3214 (top panels). The overlapping regions are two possible ionization parameter spaces (in front of or behind the ionization front) for the He I $\lambda 10830$ absorption. We also estimated the upper limits of H\(\alpha\) absorption depths of 0.10 and 0.26 at 2\sigma level from the spectral noises. If H\(\alpha\) absorption lines have similar profiles of He I $\lambda 10830$, the corresponding column densities are $N_{\text{HeI}}(\log_{10} = 2.44 \times 10^{12} \text{ cm}^{-2}$ and $3.55 \times 10^{12} \text{ cm}^{-2}$, those constrain the gas density to be in the light green areas (bottom panels). For the ionization parameter region of $\log_{10} U \geq 0$, the extremely high ionization can only exist in the BLR of the AGNs (Figure 5.3 in Peterson 1997), meanwhile, the dust also cannot survive in such a high ionization environment. For the low-ionization region, we carefully calculated the ranges of $U$ for a given $n_{\text{H}}$, and found the lower limit of $R$ with the parameter combination of $\log_{10} n_{\text{H}} = 8$ and $\log_{10} U \sim -3.5$. The lower limits of $R$ are $\sim -9.5 \text{ pc}$ and $8.2 \text{ pc}$ for SDSS J0918+2117 and SDSS J1227+3214, respectively. Similarly, the extent scales of the torus are on the scale of $\sim 10 \text{ pc}$ (Kishimoto et al. 2011; Burtscher et al. 2013). The analysis of absorption lines also suggests the absorption materials are perhaps the dusty torus itself.

### 6. Conclusion

We performed a multiwavelength study of the continuum, Balmer, and Paschen broad emission lines and He I $\lambda 10830$...
absorption lines of three NLS1s. Their optical-infrared colors present the extreme reddening of the continuum, thus they were initially reported as red 2MASS AGNs or F2M quasars. The multiband SED analysis indicates that the nucleus continua of SDSS J0918+2117, SDSS J1113+1244, and SDSS J1227+3214 are heavily suppressed by dust reddening with $E(B-V) = 0.74 \pm 0.01, 1.17 \pm 0.02, \text{and} 1.24 \pm 0.02$, respectively. When we use the galaxy templates in the SWIRE library to represent the host galaxy contribution, the host galaxy types are Sc, Sd, and Sdm galaxies, and the galaxy starlight dominates the emission of the UV-band. The follow-up TripleSpec observations on the P200 telescope provide H$\alpha$/P$\alpha$ emission lines and He$\alpha$ $\lambda$10830 absorption lines. The emission-line fitting suggests that the extinctions to the Balmer edges the use of the Hale 200-inch Telescope at Palomar Observatory through the Telescope Access Program (TAP), as well as the archive data from the GALEX, SDSS, 2MASS, and WISE surveys. The Telescope Access Program (TAP) is funded by the Strategic Priority Research Program, the Emergence of Cosmological Structures (XDB09000000), National Astronomical Observatories, Chinese Academy of Sciences, and the Special Fund for Astronomy from the Ministry of Finance. Observations obtained with the Hale Telescope at Palomar Observatory were obtained as part of an agreement between the National Astronomical Observatories, Chinese Academy of Sciences, and the California Institute of Technology. Funding for SDSS-III has been provided by the Alfred P. Sloan Foundation, the Participating Institutions, the National Science Foundation, and the U.S. Department of Energy Office of Science. The SDSS-III website is http://www.sdss3.org/.

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### References

Abazajian, K. N., Adelman-McCarthy, J. K., Agüeros, M. A., et al. 2009, ApJS, 182, 543
- Ai, Y. L., Yuan, W., Zhou, H., et al. 2013, AJ, 145, 90
- Antonucci, R. 1993, ARA&A, 31, 473
- Arav, N., Brotherton, M. S., Becker, R. H., et al. 2001, ApJ, 546, 140
- Bian, W., & Huang, L. 2010, SCPMA, 53, 256

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**Figure 7.** Column densities of the He$^+$ and H(2) ions as functions of ionization parameter $U$ for electron densities from $10^3$ to $10^{10}$ cm$^{-3}$. The light magenta and light green areas are the estimated $N_{\text{He}}$ and $N_{\text{H}(2)}$ ranges, respectively.
