Discovery of Metastable HeI* λ10830 Mini-broad Absorption Lines and Very Narrow Paschen α Emission Lines in the ULIRG Quasar IRAS F11119+3257

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Abstract

IRAS F11119+3257 is a quasar-dominated ultraluminous infrared galaxy, with a partially obscured narrow-line Seyfert 1 nucleus. In this paper, we present the near-IR (NIR) spectroscopy of F11119+3257, in which we find unusual Paschen emission lines and metastable HeI* λ10830 absorption associated with the previously reported atomic sodium and molecular OH mini-BAL (broad absorption line) outflow. Photoionization diagnosis confirms previous findings that the outflows are at kiloparsec scales. Such large-scale outflows should produce emission lines. We indeed find that high-ionization emission lines ([O III], [Ne III], and [Ne VI]) are dominated by blueshifted components at similar speeds to the mini-BALs. The blueshifted components are also detected in some low-ionization emission lines, such as [O II] λ3727 and some Balmer lines (Hα, Hβ, and Hγ), even though their cores are dominated by narrow (FWHM_NEL = 570 ± 40 km s⁻¹) or broad components at the systemic redshift of z = 0.18966 ± 0.00006. The mass flow rate (230–730 M☉ yr⁻¹) and the kinetic luminosity (L_k ≠ 10^{43.6–44.8} erg s⁻¹) are then inferred jointly from the blueshifted emission and absorption lines. In the NIR spectrum of F11119+3257, we also find that the Paschen emission lines are unique, in which a very narrow (FWHM = 260 ± 20 km s⁻¹) component is shown in only Paα. This narrow component most probably comes from heavily obscured star formation. Based on the Paα and Paβ emissions, we obtain an extinction at the H band, A_H > 2.1 (or a reddening of E_B–V > 3.7), and a star formation rate of SFR > 130 M☉ yr⁻¹ that resembles the estimates inferred from the far-IR emissions (SFR_{IR} = 190 ± 90 M☉ yr⁻¹).

Key words: galaxies: evolution – galaxies: individual (IRAS F11119+3257) – quasars: absorption lines – quasars: emission lines

1. Introduction

Through decades of studies of local galaxies, the tight correlation between the mass of the central black holes (BHs) and the velocity dispersion of the galaxy bulges (the so-called M–σ relation) is established, which indicates a close relation between supermassive BHs (SMBHs) and their host galaxies (Ferrarese & Merritt 2002; Kormendy & Ho 2013). On the other hand, observational evidences of quasar feedback have been found (see Fabian 2012, for a detailed review). Both analytical models (Scannapieco & Oh 2004) and numerical simulations (Silk & Fichtel 2005) discovered that quasar feedback is an important ingredient for regulating galaxy formation, which could lead to the close correlation between SMBHs and their host galaxies.

As one of the key components of quasar feedback, outflows are found in many quasars. Mildly relativistic FeK absorption lines (ultrafast outflows, or UFOs) are detected in at least ~35% of the radio-quiet active galactic nuclei (AGNs), which are regarded as evidence of AGN accretion disk winds (Tombesi et al. 2010). On the other hand, fast massive OH outflows (maximum speed ≥ 1000 km s⁻¹) are detected in 1/3 of the nearby galaxy mergers with Herschel (Veilleux et al. 2013). By comparing the energetics of the UFOs/disk winds and the massive molecular outflows, Tombesi et al. (2015) argue that an energy-conserving mechanism is the basis of the quasar outflow feedback. In addition to the extremely ionized FeK absorption line in the X-ray band and the molecular absorption lines in the far-IR (FIR), there are copious broad absorption line (BAL) species in the UV–optical spectrum of BAL quasars. Some high-ionization absorption lines like O VI, N V, and C IV doublets are nearly universal in BAL quasars, while Al III, Al II, Mg II, and Fe II lines are only significant in low-ionization BALs (LoBALs). The metastable HeI* absorption, on the other hand, is found to be prevalent in Mg II BALs (Liu et al. 2015), and associated atomic BALs like Na I are also reported (e.g., Liu et al. 2016). LoBALs generally trace relatively thick or dense outflow clouds, whose physical scale can extend to several kiloparsecs (e.g., Chamberlain & Arav 2015), i.e., could pose strong feedback to the host galaxies.

Sample studies have found that quasar emission lines are generally asymmetric and blueshifted, e.g., in C IV (Richards et al. 2011; Wang et al. 2011) and in [O III], [N II], [S II], etc. (Komossa et al. 2008; Zhang et al. 2011). On the other hand, high-ionization broad emission lines (BELs) in the Sloan Digital Sky Survey (SDSS) quasar composite spectrum (Vanden Berk et al. 2001) are generally blueshifted as compared to low-ionization lines. These are usually referred to as signs of emission-line outflows. In the meantime, blueshifted emission-line outflows are found to be associated with LoBALs in some quasars (e.g., Rupke & Veilleux 2013; Liu et al. 2016). By analyzing blueshifted absorption and
emission lines, some properties of the outflow material can be obtained: (1) physical conditions like position, density, and energetics (Sun et al. 2017); (2) geometry (Greene et al. 2012); and (3) abundances and chemistry (Dunn et al. 2010). These allow us to probe the driving mechanism of quasar outflows and the strength of outflow feedback to their host galaxies.

IRAS F11119+3257 is a ULIRG ($L_{IR} = 10^{12.58} L_\odot$; Kim & Sanders 1998), and a quasar, or more specifically a partially obscured narrow-line Seyfert 1 (NLS1) galaxy (FWHM$_{H\alpha} = 1980$ km s$^{-1}$; Komossa et al. 2006) in the local universe at $z = 0.18966 \pm 0.00006$. It is the key object in Tombesi et al. (2015), where both a UFO and a molecular outflow are detected. Thus, F11119+3257 is a perfect laboratory for studying physical properties of AGN outflows. In this paper, we report a detailed analysis of the blueshifted ionic/atomic absorption and emission lines in the optical–IR spectrum of F11119+3257. The detection of these lines helps in constraining physical properties of the massive molecular outflow. In the meantime, heavily obscured star formation activity in the host galaxy is probed using IR hydrogen emission lines and PAH/FIR emissions. The connection of the star formation with the galactic-scale outflow is then discussed. Throughout the paper, all uncertainties are at the 1σ level if not stated specifically. We adopt the standard ΛCDM model with $H_0 = 70$ km s$^{-1}$ Mpc$^{-1}$, $\Omega_M = 0.3$, and $\Omega_\Lambda = 0.7$.

### 2. Observation and Data Reduction

Photometric and spectroscopic data of F11119+3257 are tabulated in Table 1. Photometric data from optical (SDSS; York et al. 2000) and IR (Two Micron All Sky Survey [2MASS], Skrutskie et al. 2006; Wide-field Infrared Survey Explorer [WISE], Wright et al. 2010) bands are collected to study the spectral energy distribution (SED) of F11119+3257. Multiepoch photometries are also checked, and no significant variability is discovered. Catalina Sky Survey5 (Drake et al. 2009 ID: CSS_J111438.9+324133) V-band magnitude varied at a level of ~0.08 mag between 2005 May 5 and 2013 June 7, and PTF (Palomar Transient Factory; Law et al. 2009) magnitude varied at a level of ~0.04 mag between 2013 January 13 and 2014 April 4; both of the magnitude fluctuations are consistent with their measurement uncertainties, and no intranight variability in the infrared is found during WISE observations. The Infrared Astronomical Satellite (IRAS) photometries at 30, 60, and 100 μm (Moshir et al. 1990) and the SCUBA photometry at 850 μm (Clements et al. 2010) of F11119+3257 are collected to study cold dust emission and star formation activity of the host galaxy. The radio emission of F11119+3257 is detected by the VLA Faint Images of the Radio Sky at Twenty Centimeters Survey (FIRST; White et al. 1997). With a radio index of $\alpha = 20$, F11119+3257 can be referred to as “radio intermediate” (Komossa et al. 2006).

There are a number of archival spectroscopic observations of F11119+3257, which are also summarized in Table 1. In addition, we followed this quasar up with the TripleSpec spectrograph (Wilson et al. 2004) on the Hale 200-inch telescope (P200) at the Palomar Observatory on 2013 February 24. Four exposures of 200 s are taken in an A-B-B-A dithering mode. The 1D spectrum is then retrieved using the IDL SpexTool package (Cushing et al. 2004). With a higher spectral

### Table 1: Photometric and Spectroscopic Observations

| Band | Magnitude/Flux (mag/Jy) | Survey/Telescope | Observation Date (UT) | References |
|------|-------------------------|-----------------|----------------------|------------|
| $uv$PSF | 21.25 ± 0.10 mag | SDSS | 2004 Apr 16 | 1, 2 |
| $gr$PSF | 19.02 ± 0.02 mag | SDSS | 2004 Apr 16 | 1, 2 |
| $r$PSF | 17.21 ± 0.01 mag | SDSS | 2004 Apr 16 | 1, 2 |
| $i$PSF | 16.11 ± 0.02 mag | SDSS | 2004 Apr 16 | 1, 2 |
| $z$PSF | 15.84 ± 0.02 mag | SDSS | 2004 Apr 16 | 1, 2 |
| $J$ | 14.08 ± 0.03 mag | 2MASS | 2000 Jan 02 | 3 |
| $H$ | 12.91 ± 0.03 mag | 2MASS | 2000 Jan 02 | 3 |
| $K_s$ | 11.60 ± 0.02 mag | 2MASS | 2000 Jan 02 | 3 |
| W1 | 9.92 ± 0.01 mag | WISE | 2010 May 23 | 4 |
| W2 | 8.84 ± 0.01 mag | WISE | 2010 May 23 | 4 |
| W3 | 6.17 ± 0.01 mag | WISE | 2010 May 23 | 4 |
| W4 | 3.63 ± 0.01 mag | WISE | 2010 May 23 | 4 |
| 25 μm | 0.348 ± 0.022 Jy | IRAS | 1983 | 5 |
| 60 μm | 1.59 ± 0.18 Jy | IRAS | 1983 | 5 |
| 100 μm | 1.52 ± 0.17 Jy | IRAS | 1983 | 5 |
| 850 μm | 5.6 ± 1.9 mJy | SCUBA | 2003 Jan 18 | 6 |
| 1.4 GHz | 106.07 ± 0.12 mJy | FIRST | 1994 Jun 14 | 7 |

| Spectroscopies | | | | |
|----------------|-----------------|------------------|------------------|---|
| 3610–10390 [Å] | ... | SDSS/BOSS | 2013 Mar 16 | 8 |
| 9800–24500 [Å] | ... | P200/TSpec | 2013 Feb 24 | This work |
| 9000–20790 [Å] | ... | VLT/ISAAC | 2013 Mar 20 | 9 |
| 4.4–38.2(μm) | ... | Spitzer/IRS | 2004-May-11 | 10 |

References. (1) York et al. 2000; (2) Abazajian et al. 2009; (3) Skrutskie et al. 2006; (4) Wright et al. 2010; (5) Moshir et al. 1990; (6) Clements et al. 2010; (7) White et al. 1997; (8) Ahn et al. 2014; (9) ESO program: 088.B-0997(A); (10) Higdon et al. 2006, reduced data: Lebouteiller et al. 2011.
resolution and a broader wavelength coverage, the TripleSpec data thus render higher precision in measuring absorption lines and emission lines than the archival VLT/ISAAC spectrum of F11119+3257. All photometric and spectroscopic data are corrected for Galactic extinction at $E_{B-V}$ = 0.02 according to the updated dust map of Schlafly & Finkbeiner (2011). Before follow-up analysis, all data are deredshifted at $z = 0.18966 \pm 0.00006$ determined using the narrow emission lines (NELs; Section 3.2.2), and the laboratory vacuum wavelengths of the lines studied in this paper are adopted from Vanden Berk et al. (2001) (optical), Landt et al. (2008) (NIR), Sturm et al. (2002) (mid-IR [MIR]), and corresponding references therein.

3. Data Analysis

3.1. Spectral Energy Distribution and Extinction

Inspecting the broadband SED of F11119+3257 from optical to MIR, we find its color to be exceedingly red ($u - W_1$)_{F11119+3257} $\approx$ 11.3) as compared to typical type 1 quasars (i.e., ($u - W_1$)_{3C 273} $\approx$ 4.3) or even typical ULIRGs ($u - W_1$)$_{Mk 231} \approx$ 7.8). Therefore, heavy extinction in the optical band is expected in F11119+3257. Balmer emission line ratio of F11119+3257 also indicates an extinction to the BEL region (BELR) at $E_{B-V}$ $\approx$ 1.08 (Zheng et al. 2002). F11119+3257 is therefore heavily reddened, and its extinction curve needs to be figured out before modeling of the spectrum.

Since stellar absorption features are not obviously seen in F11119+3257, starlight can be ignored. And scattered AGN radiation, which usually results in a blue continuum in obscured quasars (Li et al. 2015), is also negligible, as the flux density at the blue end of the spectrum is low. It is thus assumed that the optical–IR continuum of F11119+3257 is dominated by the obscured AGN emission. By comparing the SED of F11119+3257 with the quasar composite (Zhang et al. 2017, a combination of the optical, NIR, and FIR quasar composite from Vanden Berk et al. 2001; Glikman et al. 2006; Netzer et al. 2007, respectively), we find that they agree roughly with each other in the MIR ($\sim$ $\lambda \in [3, 30]$ $\mu$m; see Figure 1). And significant extinction can be seen in both the optical band and the NIR; therefore, the physical extent of the obscurer should be large enough to fully cover both disk continuum and hot/warm blackbody radiation from the torus. Since the optical–IR SED of F11119+3257 is dominated by the transmitted AGN radiation, we follow the conventional method of assuming the quasar composite as the extinction-free spectrum in deriving the extinction curve. After scaling the quasar composite to F11119+3257 at WISE $W_4$, its extinction curve $A_\lambda$ is then calculated, $A_\lambda = -2.5 \log(f_{\lambda}^{\text{F11119+3257}}/f_{\lambda}^{\text{quasar composite}})$ (inner panel of Figure 1). This extinction curve is then fitted with a cubic polynomial, which is $A(\lambda) = -0.22 + 1.22\lambda + 0.12\lambda^2 + 0.07\lambda^3$, where $x = (\lambda/1\mu m)^{-1}$. Consisting of only four polynomial coefficients, the model of extinction curve is so simple that the effect of high-frequency spectral noises, i.e., sharp dips and peaks around emission and absorption lines, is largely avoided.

Figure 1. SED and extinction curve (inner panel) of F11119+3257. The spectrum (black lines) and photometric data (red squares) are compared with the quasar composite scaled at WISE $W_4$ (gray solid line). The observed extinction curve of F11119+3257 (black line in the inner panel) is compared with SMC (blue), average LMC (green), and average MW (orange) extinction curves at a similar color excess of $E_{B-V}$ = 1.18.
indicate $E_{B-V}$ in normal AGNs. Thus, the remarkable agreement between the extinction evaluated for both the continuum and the BELR indicates that F11119+3257 follows general properties of AGNs and the extinction evaluations are reasonable. In comparison with extinction curves of SMC, average LMC, and average Milky Way at $E_{B-V} = 1.18$ (Prevot et al. 1984; Fitzpatrick 1986; Fitzpatrick & Massa 2007), we find that the extinction curve of F11119+3257 is relatively steeper. Such a kind of steep extinction curve is similar to those reported in many other BAL quasars (e.g., Jiang et al. 2013; Zafar et al. 2015).

### 3.2. Emission Lines

#### 3.2.1. Continuum and Fe II Multiplets

Before modeling emission lines, broad spectral features, i.e., the continuum and the Fe II multiplets, need to be subtracted. For the featureless continuum, we first select multiple continuum regions with widths of $\Delta \lambda / \lambda = 0.001$ (triangles in the top panel of Figure 2). We then interpolate these continuum points into the entire spectrum in log $\lambda$–log $F_\lambda$ space (dashed lines in Figure 2(1)) and obtain the baseline model of the underlying continuum.

The baseline underlying continuum is then subtracted, and the Fe II multiplets are fitted in the four spectral regions showing prominent Fe II emissions. They are [4400, 4700] Å, [5120, 5700] Å, [6000, 6270] Å, and [6950, 7350] Å in the quasar’s rest frame (gray shaded regions in Figure 2(1)).

Following Dong et al. (2011), a two-component analytic form of Fe II emission lines incorporating the VJV04 Fe II template (Véron-Cetty et al. 2004) is used as the model. The narrow one of the two Fe II components is assigned with a Gaussian profile. Both Gaussian and Lorentzian profiles are tested for the broad Fe II component. Similar to many other NLS1s, the Lorentzian profile approximates the data better. On the other hand, though, it is found that this Fe II model cannot fit the data well, as the Fe II flux ratio in the Fe II windows of F11119+3257 is quite different from that of the VJV04 template: after the removal of the interpolated continuum, the integrated Fe II flux ratio of F11119+3257 at the $\lambda \lambda 4570$ ([4400, 4700] Å) and the $\lambda \lambda 5250$ ([5120, 5700] Å) windows is $F_{\lambda \lambda 4570}/F_{\lambda \lambda 5250} = 0.35$, much lower than that of the template quasar 1 Zw 1, $F_{\lambda \lambda 4570}/F_{\lambda \lambda 5250}$ (1 Zw 1) = 0.92. The relatively low flux of Fe II emission at shorter wavelengths in F11119+3257 indicates significant reddening of the Fe II emission. We thus apply the cubic polynomial extinction curve of F11119+3257’s continuum (Section 3.1) to the Fe II multiplets, with a scaling factor variable $E_{B-V}^{Fe II}$. Even though continuum windows are selected to avoid Fe II lines, some continuum points can still be contaminated by Fe II emissions. In order to solve the entanglement between continuum and Fe II multiplets, we performed the modeling iteratively:

1. **Step 1:** Interpolate continuum points (orange triangles in Figure 2(1)) to the spectrum in log $\lambda$–log $F_\lambda$ space to obtain the continuum model (orange dashed lines in Figure 2(1)).
2. **Step 2:** Subtract the continuum model and fit the Fe II emission in the four Fe II windows (orange solid line in Figure 2(1)).
3. **Step 3:** Subtract the Fe II emission model at continuum points and obtain the corrected continuum fluxes (red triangles in Figure 2(1)).

Step 4: repeat steps 1–3 until the fitted Fe II fluxes converge (with a precision of 1%).

Finally, at a best fit of $\chi^2$/dof $\approx 1.1$, modeled continuum and Fe II emissions are obtained (red lines in Figure 2(2)). The best-fit profile parameters of the Fe II emission lines are listed in Table 2, and extinction to the Fe II emission is calculated to be $E_{B-V}^{Fe II} = 1.4 \pm 0.1$. The uncertainty of continuum+Fe II multiplets is shown with pink shaded areas in the lower three panels of Figure 2, which is derived with a bootstrap approach. The continuum+Fe II multiplet model is then subtracted before follow-up analysis of the emission lines.

#### 3.2.2. Broad Emission Lines and Narrow Emission Lines

In the bottom three panels of Figure 2, an overview of F11119+3257’s emission lines is shown. We mark the laboratory wavelengths of the emission lines at a rest frame of $z = 0.18966 \pm 0.00006$ (see detailed description below) with dotted vertical lines.

At the first glance, the peak of strong Balmer, Paschen, and Brackett emission lines matches the dotted vertical lines. Also, the peaks of low-ionization forbidden lines like [O II] $\lambda\lambda 3727$ and [S II] $\lambda \lambda 6718, 6732$ match their dotted line marks, indicating that they share a similar systemic redshift. Since no obvious stellar absorption is detected, low-ionization NELs appear to be the best redshift indicator of F11119+3257. The [O II] $\lambda 3727$ emission line is commonly used as a redshift indicator. However, this doublet in F11119+3257 is highly asymmetric (Figure 5(4)), indicating that a significant portion of it is contributed by non-NEL components. Thus, the systemic redshift of the quasar cannot be measured directly with the [O II] $\lambda 3727$ emission line. Other optical low-ionization forbidden emission lines, i.e., O I $\lambda\lambda 6302$, [N II] $\lambda\lambda 6549, 6585$, and [S II] $\lambda\lambda 6718, 6732$, are blended with the prominent H$\alpha$ emission line. We thus have to model these NELs together with H$\alpha$ in the observed wavelength range of [7471, 8090] Å ([6280, 6800] Å at $z = 0.18966$). During the modeling, all these NELs are assumed to be Gaussians with the same FWHM, and their central wavelength ratios are fixed as their laboratory wavelength ratios. The flux ratio of the [N II] doublet is fixed at $F_{[N II] \lambda 6549}/F_{[N II] \lambda 6585} = 1.2/9.6$. On the other hand, five Gaussians (one narrow component at FWHM < 1000 km s$^{-1}$ and four broad components at FWHM > 1000 km s$^{-1}$) are assumed for H$\alpha$ to ensure a reasonable fit and a reliable determination of the relatively weak NELs. The redshift of the NEL system is found to be $z = 0.18966 \pm 0.00006$, which is regarded as the systemic redshift of F11119+3257. The modeled Gaussian width is FWHM = 570 ± 40 km s$^{-1}$ (Table 2). Fitting results are shown in panel (1a) of Figure 3, and modeled weak NELs are presented together with the Fe II multiplet model and the residual in panel (1b).

As shown in Figure 2, the most prominent broad hydrogen emission lines are Pa$\alpha$, Pa$\beta$, H$\alpha$, and H$\beta$. Among them, H$\alpha$ is blended with several weak NELs, and H$\beta$ is blended with the blueshifted [O III] $\lambda \lambda 4959, 5007$ emission lines. After removal of the modeled NELs, the line profile of H$\alpha$ is obtained. The line spectrum around H$\beta$ and [O III] is shown in panel (2a) of Figure 3, and the removed Fe II multiplet model is presented in panel (2b). The subtraction of the Fe II multiplets seems reasonable, and the line profiles of H$\beta$ and [O III] can be reliably obtained. For the H$\beta$+[O III] blend, we begin with...
solving the line profile of the $[\text{O III}]$ doublet. After scaling the $\text{H}_\alpha$ profile to match the peak of $\text{H}_\beta$ emission (panel (2a) of Figure 3), we found that in the rest-frame wavelength range of $[4940, 5020]$ (gray shaded region) the contribution of $\text{H}_\beta$ emission is negligible (weaker than the spectral flux fluctuations). Therefore, the emission of $[\text{O III}] \lambda\lambda 4959, 5007$ should dominate in this spectral region. In addition, the bulk flux of $[\text{O III}] \lambda 5007$ lies in this spectral region, as well as the peak of $[\text{O III}] \lambda 4959$. By convention, the line profiles of $[\text{O III}] \lambda 4959$ and $[\text{O III}] \lambda 5007$ are assumed to be the same, and the

Figure 2. Modeling of the continuum and the Fe II multiplets are shown in panel (1). Data points in the four Fe II windows are colored blue. The results with and without being modeled iteratively are colored red and orange, respectively (see Section 3.2.1 for a detailed description). Modeled continuum and continuum$+$Fe II are presented with dashed and solid lines, respectively. In panels (2a), (2b), and (2c), the modeled continuum points are indicated with purple circles. The best fit and the uncertainty of the continuum$+$Fe II multiplet model are shown with red lines and pink shading, respectively. We mark laboratory wavelengths of common emission lines with vertical lines. Spectral regions shaded by tilted lines indicate spectral regions affected by BALs (Section 3.3). The marked BALs are He I $\lambda 3889$, Ca II $\lambda 3934$, and Na I $\lambda\lambda 5891, 5897$ in panel (2a) and He I$'$ $\lambda 10830$ in panel (2b).
Table 2: Emission-line Components

| Component | $v_{R}^{a}$ (km s$^{-1}$) | FWHM (km s$^{-1}$) | Line Profile |
|-----------|--------------------------|-------------------|-------------|
| Fe II BEL | 10 ± 20                  | 1800 ± 200        | Lorentzian  |
| Fe II NEL | 120 ± 10                 | 740 ± 50          | Gaussian    |
| NEL       | 0 ± 10                   | 570 ± 40          | Gaussian    |
| Pa$\alpha^{b}$ | 0 ± 10                | 890 ± 50          | ...         |
| Pa$\beta^{b}$ | 0 ± 30                 | 1100 ± 300        | ...         |
| H$\alpha^{b}$ | -70 ± 10               | 1310 ± 40         | ...         |
| H$\beta^{b}$ | -130 ± 20              | 1450 ± 130        | ...         |

Notes.

$^{a}$ Relative velocity in the quasar's rest frame, $z = 0.18966$.
$^{b}$ Centroids and FWHMs of Fe II multiplets are derived from model parameters; centroids and FWHMs of H$\alpha$, H$\beta$, Pa$\alpha$, and Pa$\beta$ emission lines are directly measured.

Table 2, which differ significantly from each other. As the wavelength decreases from Pa$\alpha$ through Pa$\beta$ and H$\alpha$ to H$\beta$, the line centroids vary gradually from $\sim 0$ km s$^{-1}$ to blueshifted at $\sim 100$ km s$^{-1}$ in the quasar's rest frame. And the FWHM increases gradually from $\sim 900$ to $\sim 1450$ km s$^{-1}$. Such a trend of their profile changing suggests that these hydrogen emission lines are not dominated by the same single component. Being permitted lines of the most abundant element in the universe, hydrogen Balmer/Paschen emissions can be generated in various astrophysical environments. Thus, the emission-line systems in F11119+3257—the NEL, BEL, and blueshifted outflow emission line (OEL; Section 3.2.3) systems—may all contribute to these observed hydrogen emission. And different intensity ratios of these emission-line systems can lead to the line profile variations observed among these hydrogen lines. A brief comparison among the hydrogen lines is then made as an attempt to investigate the emission-line components.

Despite their differences, the red wings of these hydrogen lines resemble each other (in a velocity range of [200, 4000] km s$^{-1}$ in the quasar's rest frame). This is reasonable since the line flux in this velocity region is dominated by only the BEL system, which leads to the similarity of line profiles in this region. In Figure 4, different hydrogen lines are scaled by their fluxes in their red wings (in a velocity range of [200, 4000] km s$^{-1}$), and their profiles are compared. The Pa$\alpha$ emission line has the largest wavelength and thus lowest extinction, i.e., least affected by obscuring dust. We therefore use the line profile of Pa$\alpha$ as a reference since it preserves best the BEL component among these hydrogen lines. The line profiles of Pa$\alpha$ and Pa$\beta$ are similar in both their blue and red wings, while a narrow peak is found in only Pa$\alpha$ and none of the other hydrogen lines. The difference between Pa$\alpha$ and Balmer lines lies in two aspects (Figures 4(2), (3), (4)). (1) The sharp and narrow peak of Pa$\alpha$ appears prominent if Pa$\alpha$ is compared with Balmer lines. (2) Significant residual fluxes are found in the blue wings of Balmer lines if the scaled Pa$\alpha$ profile is subtracted. Using Pa$\alpha$ as a baseline model for the broad and narrow hydrogen emission-line component, the residual fluxes in the blue wings of Balmer lines are very likely associated with the other blueshifted emission lines like [O III], [Ne III], and [Ne V]. Since the Balmer BELs are suppressed more severely by dust extinction than the Paschen BELs, the relatively weak blueshifted emission-line components can be revealed in the blue wings of the Balmer lines. If this is the case, the OEL component then should be more easily observed in lines whose BEL endures stronger extinction, i.e., at shorter wavelengths, as in the case of the obscured quasar O I 287 (Li et al. 2015). This phenomenon is indeed observed: the relative strength of residual flux in blue wings of H$\beta$ is noticeably stronger than H$\alpha$. And for H$\gamma$ at an even shorter wavelength, the residual in the blue wing can be clearly seen under low signal-to-noise ratio even if the potential [O III] $\lambda 4363$ emission is treated as part of H$\gamma$ emission in the red wing. Since this residual flux is most clearly observed in H$\beta$, this blueshifted component is retrieved by subtracting the scaled Pa$\alpha$ line profile and will be investigated later in the follow-up section.

On the other hand, we find that the centers of all hydrogen emission lines are flat except that a weak but prominent narrow emission is found in the peak of Pa$\alpha$. By subtracting the profile of H$\alpha$ (the hydrogen line with the highest signal-to-noise ratio), the narrow Pa$\alpha$ peak is detected (brown line in Figure 4(2)) at a flux of $F_{\text{Pa}\alpha}$ peak $= (370 \pm 90) \times 10^{-17}$ erg s$^{-1}$ cm$^{-2}$. And the

Figure 3. Modeling of the H$\alpha$ blend is shown in panel (1a). Although the modeled NELs are weak, they can still be distinguished from Fe II multiplets and model residuals as shown in panel (1b). The H$\beta$ and [O III] blend is shown in panel (2a). The profile of [O III] $\lambda 5007$ (blue solid line) is derived in the gray shaded region, where Fe II emission (panel (2b)) is reliably removed and contribution from H$\beta$ is negligible. The derived [O III] $\lambda 4959$, 5007 emission is subtracted, and the H$\beta$ emission line (red solid line in panel (2a)) is obtained.

Figure 4. Different hydrogen lines are scaled by their fluxes in their red wings (in a velocity range of [200, 4000] km s$^{-1}$), and their profiles are compared. The Pa$\alpha$ emission line has the largest wavelength and thus lowest extinction, i.e., least affected by obscuring dust. We therefore use the line profile of Pa$\alpha$ as a reference since it preserves best the BEL component among these hydrogen lines. The line profiles of Pa$\alpha$ and Pa$\beta$ are similar in both their blue and red wings, while a narrow peak is found in only Pa$\alpha$ and none of the other hydrogen lines. The difference between Pa$\alpha$ and Balmer lines lies in two aspects (Figures 4(2), (3), (4)). (1) The sharp and narrow peak of Pa$\alpha$ appears prominent if Pa$\alpha$ is compared with Balmer lines. (2) Significant residual fluxes are found in the blue wings of Balmer lines if the scaled Pa$\alpha$ profile is subtracted. Using Pa$\alpha$ as a baseline model for the broad and narrow hydrogen emission-line component, the residual fluxes in the blue wings of Balmer lines are very likely associated with the other blueshifted emission lines like [O III], [Ne III], and [Ne V]. Since the Balmer BELs are suppressed more severely by dust extinction than the Paschen BELs, the relatively weak blueshifted emission-line components can be revealed in the blue wings of the Balmer lines. If this is the case, the OEL component then should be more easily observed in lines whose BEL endures stronger extinction, i.e., at shorter wavelengths, as in the case of the obscured quasar O I 287 (Li et al. 2015). This phenomenon is indeed observed: the relative strength of residual flux in blue wings of H$\beta$ is noticeably stronger than H$\alpha$. And for H$\gamma$ at an even shorter wavelength, the residual in the blue wing can be clearly seen under low signal-to-noise ratio even if the potential [O III] $\lambda 4363$ emission is treated as part of H$\gamma$ emission in the red wing. Since this residual flux is most clearly observed in H$\beta$, this blueshifted component is retrieved by subtracting the scaled Pa$\alpha$ line profile and will be investigated later in the follow-up section.

On the other hand, we find that the centers of all hydrogen emission lines are flat except that a weak but prominent narrow emission is found in the peak of Pa$\alpha$. By subtracting the profile of H$\alpha$ (the hydrogen line with the highest signal-to-noise ratio), the narrow Pa$\alpha$ peak is detected (brown line in Figure 4(2)) at a flux of $F_{\text{Pa}\alpha}$ peak $= (370 \pm 90) \times 10^{-17}$ erg s$^{-1}$ cm$^{-2}$. And the
width of the peculiar narrow emission component isFWHM_{Pa\beta, peak} = 260 \pm 20 \ km \ s^{-1}, significantly lower thanthe NEL component (FWHM_{NEL} = 570 \pm 40 \ km \ s^{-1}). We then check this narrow Paschen emission in Pa\beta. Bysubtracting the scaled H\alpha from Pa\beta, the excess flux at thepeak of Pa\beta is found to be F_{Pa\beta, peak} = (40 \pm 60) \times 10^{-17} \ erg \ s^{-1} \ cm^{-2}, consistent with nondetection. Therefore, the line ratio Pa\beta/H\alpha for this narrow emission is quite low(F_{Pa\beta, peak}/F_{H\alpha, peak} < 0.15) if case B flux ratios ofF_{Pa\beta}/F_{H\alpha} \approx 0.5 are considered (Hummer & Storey 1987).Positively detected only in Pa\alpha, this anomalous narrowPaschen emission is thus much weaker at shorter wavelength ascompared to model predictions. The most plausible explanation tothis phenomenon is that this Paschen emission-line componentis heavily reddened. By assuming an extinction law of either MW (Fitzpatrick & Massa 2007) or SMC (Prevote et al. 1984), an H-band (\lambda_{\text{eff}} \approx 16620 \ \AA)extinction of A_{\text{H}} > 2.1 (corresponding to E_{B-V} > 3.7) canbefigured. The low velocity dispersion and high extinction make thisemission-line component distinct from all the other

3.2.3. Outflow Emission Lines

As shown in the lower panels of Figure 2, the high-ionization forbidden lines like [O III] \lambda\lambda 4959, 5007 and [Ne V] \lambda 3427 are all significantly blueshifted in the rest frame of thequasar. Significant flux excess in the blue wings is also detectedin [O II] \lambda 3727, [Ne III] \lambda 3869, and [Ne III] \lambda 3968. On the otherhand, blueshifted residual fluxes in H\alpha and H\beta (Section 3.2.2) are found. They can all originate from theoutflow gas.

The blueshifted emission lines, [O III] \lambda 5007, [O II] \lambda 3727, [Ne III] \lambda 3869, [Ne III] \lambda 3968, and [Ne V] \lambda 3427, as well as the residual H\alpha and H\beta emission, are plotted together in Figure 5. It is found that for all these lines the majority of blueshifted emission is in a similar velocity range of \sim [-3500, 0] \ km \ s^{-1}. For [O III] \lambda 5007, [O II] \lambda 3727, and [Ne III] \lambda 3869, a significant amount of flux at v = 0 \ km \ s^{-1} is detected, which can come from the NEL fluxes centered at \nu = 0 \ km \ s^{-1} (Section 3.2.2). This should be removed before analyzing theblueshifted emission-line system. We assume that the NEL component of [O III] \lambda 5007 and [O II] \lambda 3727 is symmetric about \nu = 0 \ km \ s^{-1} and that the flux at \nu > 0 \ km \ s^{-1} isdominated by the NEL component. The “NEL” components (green dashed line in Figure 4) of [O III] \lambda 5007 and [O II] \lambda 3727 are then obtained and subtracted, which leaves theblueshifted emission-line components (blue dashed lines in Figure 5).

This blueshifted emission-line system, or the so-called [O III]“blue outliers,” are usually referred to as tracers of outflows (Komossa et al. 2008). We thus call them OELs in the follow-up analysis. This OEL system is broad (FWHM_{[O III]} \lambda 5007 = 1514 \ km \ s^{-1}). In [O III] \lambda 5007, the OEL with the highest spectral quality, a peak at \nu \sim -800 \ km \ s^{-1} is found. In addition to this low-speed peak, another broad component can be found that is centered at around \nu \sim -2000 \ km \ s^{-1}. It seems that the H\beta and [Ne III]OEL also follows such a two-component scenario. We thusdivide the OEL system into a high-speed component (fast OEL;\nu \in [-3500, -1500] \ km \ s^{-1}) and a low-speed component(slow OEL; \nu \in (-1500, 0] \ km \ s^{-1}). The integrated fluxes ofboth the fast OEL and the slow OEL components and flux-weighted average velocities for each line are listed in Table 3. Notice that the slow OEL component of [Ne III] \lambda 3869 can becontaminated by the He i' \lambda 3889 mini-BAL (marked region inpanel 5 of Figure 5); the integrated flux in this region is therefore a lower-limit estimation.

3.3. Broad Absorption Lines and Column Densities

Besides the Na I \lambda\lambda 5891, 5897 mini-BAL (Rupke et al.2005) and the blueshifted molecular OH absorption line(Veilleux et al. 2013), we noticed prominent metastable He i' \lambda 10830 and weak Ca II \lambda 3934 absorption lines in the optical–NIR spectrum of F11119+3257. The absorption troughs lie in a velocity range of \nu \sim [-3000, 0] \ km \ s^{-1} (centered at \sim -1000 \ km \ s^{-1}) relative to the systemic redshift of z = 0.18966, very similar to the OELs (Table 3). As presented in Section 3.1, the optical–NIR spectrum of F11119+3257 is dominated by the transmitted AGN radiation. The dust absorber appears to fully cover the AGN radiation in our sight.
line (covering factor is about 1), since both the reflected AGN emission and the starlight from the host galaxy are negligible.

For the weak absorption of Ca II λ3934, no prominent emission lines are found around the absorption trough. The continuum +Fe II model described in Section 3.2.1 is a reasonable normalization in this spectral region (Figure 6(1a)). Based on the normalized Ca II λ3934 absorption profile (Figure 6(1b)), we integrate the apparent optical depth (AOD; Savage & Sembach 1991) in the velocity range of \( v \in [-3000, 0] \) km s\(^{-1}\) and derive the upper limit of the ion Ca\(^{+}\)'s column density to be log \( N_{\text{Ca}^{+}} \) cm\(^{-2}\) < 14.0. On the other hand, the Na I λ5891, 5897 blend and the He I λ10830 absorption are close to emission lines (He I λ5877 and He I* λ10830 + Pa\(γ\)), respectively, which makes the simple continuum model invalid in approximating the absorption-free spectrum. Following Liu et al. (2015), we apply a pair-matching method to normalize these two absorption lines. For the Na I λ5891, 5897 blend, spectra of SDSS DR12 quasars (Pâris et al. 2017) at \( z < 0.5 \) are used as templates. Similar to Liu et al. (2016), we fix an optical depth ratio of

\[
\begin{array}{cccc}
\text{Transition} & \text{Flux}_{\text{Fast OEL}} \left(10^{-17} \text{ erg s}^{-1} \text{ cm}^{-2}\right) & \text{Flux}_{\text{Slow OEL}} \left(10^{-17} \text{ erg s}^{-1} \text{ cm}^{-2}\right) & \text{Average Velocity} v^a \\
\text{[O III] λ5007} & 650 \pm 90 & 1230 \pm 80 & -1330 \\
\text{Hβ} & 110 \pm 90 & 110 \pm 60 & -1640 \\
\text{[O II] λ3727} & 20 \pm 10 & 170 \pm 30 & -810 \\
\text{[Ne III] λ3869} & 65 \pm 40 & >90 & -1200 \\
\text{[Ne III] λ3968} & 50 \pm 30 & 60 \pm 30 & -1420 \\
\text{[Ne V] λ3427} & 30 \pm 20 & 70 \pm 20 & -1260 \\
\text{[Ne III]} & 500 \pm 400 & 1700 \pm 200 & -960 \\
\lambda15.56 \mu m & 600 \pm 500 & 1000 \pm 300 & -810 \\
\lambda14.32 \mu m & & & \\
\end{array}
\]

Note.
\(^a\) Flux-weighted relative velocity in the quasar’s rest frame.
\[ \frac{\tau_{Na I} \lambda 5891}{\tau_{Na I} \lambda 5897} = 2 \] and obtain the absorption-line profile of \( \text{Na I} \lambda 5891 \) (black line in Figure 6(2b)). By integrating AOD, the column density of atomic sodium is found to be \( \log N_{Na I}/\text{cm}^{-2} = 13.7 \pm 0.1 \). A pair-matching method is then performed to normalize the \( \text{He I} \quad \lambda 10830 \) min-BAL, with 92 infrared quasar spectra from infrared quasar spectral atlases (Glikman et al. 2006; Rif
ciel et al. 2006; Landt et al. 2008). We assume a covering factor of 1 and measure the column density of atomic helium in the metastable \( 2S \) state via calculating AOD. The results based on the P200/Tripplespec and the VLT/ISAAC data are \( \log N_{He I} /\text{cm}^{-2}(\text{Tripplespec}) = 13.4 \pm 0.2 \) and \( \log N_{He I} /\text{cm}^{-2}(\text{ISAAC}) = 13.3 \pm 0.3 \), consistent with each other. Provided that the Tripplespec data have higher resolution and show more detailed absorption features, we adopt the more reliable Tripplespec result in the follow-up analysis. Since the emission-line spectrum around \( \text{He I} \quad \lambda 10830 \) is complex and the number of template spectra is limited, the normalization is not as good. In addition to the \( \text{He I} \quad \lambda 10830 \) +Pa\( \gamma \) BEL, there can be significant \( \text{He I} \quad \lambda 10830 \) OELs (in the velocity range of \( v \in [-3000, 0] \) \( \text{km} \text{s}^{-1} \)) described in Section 3.2.3) in the absorption trough. In the meantime, part of the IR radiation comes from blackbody components (Section 3.1), which may not be fully covered by the absorbing gas. In view of these facts, the directly normalized \( \text{He I} \quad \lambda 10830 \) absorption can be significantly underestimated; it is thus regarded as the lower limit of the column density for the metastable atomic helium, i.e., \( \log N_{He I} /\text{cm}^{-2} > 13.2 \).
also significantly blueshifted (Spoon & Holt 2009). As described in Section 3.2.3, we apply the same method in retrieving the [Ne III] 15.56 μm and [Ne V] 14.32 μm OELs, which are similar two-component profile to their optical counterparts; their fluxes are also calculated and listed in Table 3.

4. Discussion

4.1. Properties of the Quasar

Similar to some previous reports, the SED modeling in Section 3.1 reveals that F11119+3257 is heavily obscured in the optical and NIR. Thus, the intrinsic optical–NIR fluxes are much stronger than what we observed, and dereddening needs to be carried out before estimating luminosity and ionizing fluxes. The BH mass of F11119+3257 has been evaluated in some previous sample studies. One estimate is $10^{7.2} M_\odot$ by Kawakatu et al. (2007), which is based on directly observed monochromatic luminosity at 5100 Å and the width of the BELs. The other estimate is $10^{9.44} M_\odot$ by Veilleux et al. (2009), which is based on the H-band luminosity. In sample studies, it is a reasonable assumption that the accretion rate is similar among AGNs when BH mass is estimated according to luminosity. However, for special AGNs like NLS1s, BH masses estimated with this method tend to be too large, as the Eddington ratio of NLS1s is intrinsically higher than that of typical AGNs. Thus, it is more reliable to estimate the BH mass of F11119+3257 based on the scaling relation between the BH and the BELR. Such empirical correlations are established mostly based on extinction-free AGNs. However, the extinction toward F11119+3257 is likely to be among the strongest of the “type 1” AGNs studied in Kawakatu et al. (2007). Unlike sample studies that did not focus mainly on individual objects, we think that it is necessary to reestimate the BH mass after extinction correction in this paper. Applying the relation of the BH mass to the Hα line width and the extinction-free luminosity (Greene & Ho 2005), we estimate that $M_{BH} = 1.0^{+0.4}_{-0.2} \times 10^9 M_\odot$. Considering the quasar luminosity of...
$L_{bol} = 10^{12.61} L_\odot \approx 1.6 \times 10^{46} \text{ erg s}^{-1}$ (Veilleux et al. 2013), an Eddington ratio of $L_{bol}/L_{Edd} \approx 1.0$ is found, which is typical among NLS1s. If the MF87 (Mathews & Ferland 1987) SED of active galaxies is assumed, the incident rate of ionizing photons is $Q_H \approx 1.6 \times 10^{50} \text{ s}^{-1}$.

### 4.2. Physical Condition of Outflow Material

Since all the absorption lines lie in a similar velocity range, the blueshifted Na I λλ8981, 5897, He I λ 10830, and Ca II λ3934 mini-BALs are very probably associated with the OH outflow. Photoionization properties of the outflow gas can be constrained with the measured ionic (Ca II λ3934), atomic (Na I λλ8981, 5897) and metastable (He I λ 10830) column densities. An attempt to investigate physical properties of the outflow material is thus conducted with CLOUDY (c13.03; Ferland et al. 1998) photoionization simulations. Given that the line profiles of the broad absorptions are rather complex, the actual gas cloud is likely to be multithreaded. However, constrained by the insufficient data quality and limited number of lines being detected, only one-zone photoionization simulation is conducted. The general physical property of the outflow gas could be estimated if simulations converge.

The MF87 AGN SED is assumed as the incident radiation field for the outflowing material in CLOUDY simulations. Since atomic sodium is the most robust column density measurements available, we set up the stopping criteria (thickness of the cloud) for CLOUDY to be $N_{Na} = 10^{13.7}$ cm$^{-2}$. With the detection of molecular absorption, the incident radiation field cannot be too strong, or molecules would be destroyed. And a moderate number density of atoms is required to allow molecules to grow. Two-dimensional grids of CLOUDY simulations with ionization parameter $U$ ranging from $10^{-4}$ to 1 and hydrogen number density $n_H$ ranging from 1 to $10^{10}$ cm$^{-3}$ are carried out. Four discrete metallicity values are assumed, i.e., 0.3, 1.0, 3.2, and 10.0 $Z_\odot$, where $Z_\odot$ stands for solar abundance. Since we found heavy extinction in F11119+3257, dust depletion should be taken into account when dealing with gas-phase absorption. We assume a depletion pattern of the Galactic warm cloud (Welty et al. 1999), which happens to approximate the depletion pattern observed in several quasar proximate dusty absorbers (Ma et al. 2017; Pan et al. 2017). The corresponding depletions of sodium and calcium are $-0.4$ and $-2.0$ dex, respectively.

Based on the incident radiation ($Q_H \approx 1.6 \times 10^{50} \text{ s}^{-1}$) and the definition of ionization parameter $U = \frac{Q_H}{4\pi R n_H v}$, the distance $R$ of the absorber can be figured when $U$ and $n_H$ are specified (thin dotted lines in Figures 8–9). The matched region between model prediction and measured column densities is shown in Figures 8–9. The column density measurement $N_{Na} < 10^{14.0}$ cm$^{-2}$ (thick dashed line in Figures 8–9) puts a constraint of $U \leq 10^{-1}$, if a common interstellar medium (ISM) number density of $n_H < 10^6$ cm$^{-3}$ is assumed. And the lower limit of log $N_{He}^{23/25}$ requires a distance of $R < 10$ kpc and a number density of $n_H \gtrsim 10^7$ cm$^{-3}$ in the parameter space investigated. In addition, if the gas-to-dust ratios of the dust-rich MW (Bohlin et al. 1978) and the relatively dust-deficient SMC (Martin et al. 1989) are assumed, the hydrogen column densities corresponding to the measured extinction $E_B-V = 1.18$ are $N_{H}(SMC) = 10^{22.7}$ cm$^{-2}$ and $N_{H}(MW) = 10^{21.8}$ cm$^{-2}$, respectively (thick dashed-dotted lines in Figures 8–9), for typical ISM with $n_H < 10^6$ cm$^{-3}$, the hydrogen column density of $N_{H}(SMC) = 10^{22.7}$ cm$^{-2}$ does not overlap with the column density measurements of other species in the parameter space. Thus, the MW gas-to-dust ratio is preferred, indicating that the outflow gas is relatively dust-rich and has a relatively high metallicity. On the other hand, $N_{H}(MW) = 10^{21.8}$ cm$^{-2}$ only overlaps with other elemental column densities in parameter space with metallicities of $Z \in [0.3, 3.2]Z_\odot$. Briefly speaking, these column density measurements suggest that the outflow material is located at a distance of kiloparsec scale toward the central engine, similar to previous estimates based on the OH mini-BAL (Tombesi et al. 2015).

On the other hand, the blueshifted emission lines are also detected in a similar velocity range (Table 2). Similar to the outflow in SDSS J1634+2049 reported by Liu et al. (2016), such a resemblance in speed suggests that these blueshifted emission lines possibly originate from the absorption-line outflow. We therefore compare the predicted emission-line ratios of the CLOUDY simulations with the observed fluxes of the OELs. There appear to be two distinct OEL components, the fast OEL and the slow OEL (Section 3.2.3). Their line ratios are quite different and may arise from different regions of the outflow gas. Thus, these two OEL systems are compared separately with the mini-BAL system. The strongest OEL, [O III] λ5007, is used as a normalization to the other emission lines. The matched regions of these line ratios are marked with colored stripes in Figure 8 (slow OEL) and Figure 9 (fast OEL). And since [Ne III] λ3869 is probably contaminated by He I absorption (Section 3.2.3), the relatively weaker [Ne III] λ3866 is investigated instead in the photoionization diagnoses. We found that for the component with higher fluxes, which more likely represents the bulk of the outflow material (i.e., slow OEL), a solution for the emission-line ratios can only be found at the solar abundance ($Z = Z_\odot$; Figure 8)(2). The resulting photoionization parameters are log $U \approx -2.0$, log $n_H \approx 2.7$, $R \approx 3.1$ kpc, and log $N_{H} \approx 21.6$ cm$^{-2}$ (red diamond in Figure 8). For the fast OEL component (Figure 8), if solar abundance is adopted, a best-fit model is found with log $U \approx -1.6$, log $n_H \approx 2.5$, $R \approx 2.3$ kpc, and log $N_{H} \approx 21.8$ cm$^{-2}$ (black star in Figures 8–9). The corresponding gas-to-dust ratios are close to the MW, consistent with the assumption of solar abundance. After a brief comparison between the best-fit parameters of the fast and the slow OEL components, we find that they are generally consistent with each other. In the meantime, model results suggest that the fast OEL component might be closer to the central illuminant and endures a higher incident radiation, which could shield the material more distant in the outflow gas and allow molecules to grow.

Since the modeled physical parameters of the fast and the slow OEL components are similar, the two sets of results are considered together in estimating the physical condition of the outflow gas. The thickness of outflowing cloud is estimated to be $\Delta R = N_{H}/n_H \in [2, 12]$ pc, much smaller than the estimated distance $R$. Thus, the bulk of the outflowing material follows roughly the geometry of a partially filled thin shell ($\Delta R/R \ll 1$). Following Borguet et al. (2012), the mass flow rate ($M$), momentum flux ($\dot{P}$), and kinetic luminosity ($\dot{E}_K$) can be derived: $M = 4\pi R^2 \Omega \eta_3 n_H V$, $\dot{P} = MV$, $\dot{E}_K = \frac{1}{2} M V^2$, $\Omega$ is the global covering factor of the outflow, and $\eta_3$ is the proton mass. The flux-weighted average velocities of the OELs are $v \in [-1449, -810]$ km s$^{-1}$ for different lines (Table 3). According to CLOUDY simulations, distance and column
density are in the ranges of $R \sim 2.3$–3.1 kpc and $N_H \sim 10^{21.6}$–21.8 cm$^{-2}$. Solar abundance is favored, which corresponds to a mean atomic mass per proton of $\mu = 1.4$. As demonstrated in Liu et al. (2016), strong extinction can lead to large uncertainty in calculating global covering fraction. In the case of F11119+3257, the ratio between observed EW([O III]) and CLOUDY predictions suggests 0.1% $\approx \Omega \approx 10\%$. The uncertainty is too large for a reasonable estimation of the energetics of the outflow. Therefore, the relatively more reliable covering factor estimation based on the *Herschel* OH spectrum $C_{A}(\text{OH}) = 0.20 \pm 0.05$ is adopted (Tombesi et al. 2015). The kinematics of the outflow material is then $M \sim 230$–730$M_\odot$ yr$^{-1}$, the momentum flux is $P \sim 2.2$–12.7 $L_{\text{AGN}}/c$, and the kinetic luminosity is $L_{\text{k}} \sim 10^{43.6}$–44.8 $L_{\odot}$. The estimated distance of the outflow is consistent with recent results based on spatially resolved observations of the CO OEL (at a scale of $\sim 7$ kpc; Veilleux et al. 2017).

### 4.3. Star Formation in the Host Galaxy

During the analysis of the emission lines, the narrow Paschen emission (Section 3.2.2) discovered in only Pa$\alpha$ caught our interest. Such NELs usually come from the NELR of the quasar or from the H II regions around newly formed O stars that trace star formation activity in the host galaxy. The Paschen emission is of only half the width of the other NELs, which makes it unlikely that it originated from the NELR. On the other hand, if we apply the heavy extinction $A_H > 2.1$...
The extinction-free luminosity of $\lambda 3727$ is then $L_{[O\ II]\lambda 3727} > 5.8 \times 10^{47}$ erg s$^{-1}$, even larger than the bolometric luminosity of the quasar. Thus, the Paschen emissions are unlikely NELs of the quasar, which makes the star formation region the most plausible origin. Assuming a case B line ratio for the anomalous hydrogen emission lines, the luminosity of $H\alpha$ associated with the narrow Paschen component after extinction correction is $L_{H\alpha,\text{peak}} > 1.7 \times 10^{43}$ erg s$^{-1}$. An SFR of SFR$_{Pa\alpha,\text{peak}} > 130 \ M_\odot$ yr$^{-1}$ is obtained according to the relation $\text{SFR} = L_{H\alpha}/1.26 \times 10^{41}$ erg s$^{-1}$ (Kennicutt 1998).

Since extinction is tightly correlated with SFR as studied in star-forming galaxies (Xiao et al. 2012), the heavy extinction to the narrow Paschen emission is expected, as the star formation rate is high. The lower limit of the SFR based on the anomalous Paschen emission is of a similar order of our previous estimates based on FIR emission (SFR$_{\text{FIR}} = 190 \pm 90 \ M_\odot$ yr$^{-1}$), and the extinction to the star formation region is also present in the Spitzer spectrum as the prominent silicate absorption. Detection of the narrow Pa$\alpha$ emission indicates that spectroscopy of the IR hydrogen emission lines can be powerful probes to the starburst regions that are usually heavily obscured. With the launch of the James Webb Space Telescope (JWST), the narrow Brackett ($1.46–4.05$ μm) and Pfund ($2.28–7.46$ μm) emissions from the H II region can be observed in detail, which will help to precisely measure the obscuration and spatial distribution of the star formation region.

In the previous section, we showed that a large amount of kinetic energy is injected into the host galaxy in the form of powerful outflows. Such strong galactic-scale feedback in F11119+3257 can be responsible for the violent star formation.

Figure 9. Similar to Figure 8, CLOUDY simulations vs. the measure mini-BAL column densities and the fast OEL flux ratios are shown. In panel (2) (solar abundance), we mark the best guess of photoionization parameters with a black star, which is around log $U \sim 1.6$, log $n_{H} \sim 2.5$, and $R \sim 2.3$ kpc. And the red diamond is the best guess for the slow OELs.
activity, or regulate star formation processes. On the other hand, stellar feedback at high SFR can also play a significant role in forming outflows. The simulation in Biernacki & Teyssier (2018) shows that, in a dark matter hole of mass approximately $2 \times 10^{12} M_\odot$, continuous SFR at $\sim 100 M_\odot \text{ yr}^{-1}$ can launch massive ($\sim 20 M_\odot \text{ yr}^{-1}$) molecular outflow at a scale of $\sim 20 \text{ kpc}$. At $\sim 190 M_\odot \text{ yr}^{-1}$, the more violent SFR in F11119+3257 is capable of contributing significantly to the massive molecular outflow observed. According to some previous findings (Davé et al. 2011, etc.), however, the fast wind speed of the outflow ($\sim 1000 \text{ km s}^{-1}$) in F11119+3257 can only be caused by AGN feedback. Given the power and scale of the outflow, it must interact with the violent star formation observed. Follow-up spatially resolved observations and simulations are needed to reveal the detailed processes of the interactions.

4.4. Implications of MIR Emission Lines

As shown in Section 3.4, prominent blueshifted MIR neon lines are detected in F11119+3257. It is an interesting fact that the line profile of the MIR neon emission lines is similar to that of optical neon lines, suggesting that both of them should rise from the outflow gas. A comparison study of the optical and MIR neon lines can probably implicate physical properties of the emission-line region. Given the large difference in wavelength between the optical ($\sim 0.4 \mu m$) and the MIR ($\sim 15 \mu m$) neon lines, potential extinction to the outflow gas can be investigated since extinction at the optical bands is much stronger than in the MIR. Heavy extinction is found for both the continuum and the BELs of F11119+3257; the OELs can also be obscured. The observed OEL flux ratios are [Ne III] $\lambda 15.56 \mu m$/[Ne III] $\lambda 3968$(observed) $\approx 13.7$ and [Ne V] $\lambda 14.32 \mu m$/[Ne V] $\lambda 3427$(observed) $\approx 16.8$. However, the predicted emission-line ratios for the OELs by CLOUDY simulations are only around [Ne III] $\lambda 15.56 \mu m$/[Ne III] $\lambda 3968$ (CLOUDY) $\approx 1.8$ and [Ne V] $\lambda 14.32 \mu m$/[Ne V] $\lambda 3427$ (CLOUDY) $\approx 2.0$ (Figure 10). The relatively lower fluxes of the blueshifted neon lines at the optical bands are very likely due to dust extinction given the association of the outflow with the obscuring dust. If the cubic extinction curve for the continuum is applied, an extinction of $E_{B-V, \text{OELR}} \approx 0.5$ for the outflow can be derived. This value is lower than the extinction to the BELR, consistent with the changing profiles of the hydrogen emission lines observed (OELs become stronger at shorter wavelengths as compared to BELs; Section 3.2.2).

On the other hand, the MIR-to-optical neon line intensity ratios can also be affected by factors other than extinction, as upper levels of these transitions are different. CLOUDY simulations of emissivity structures of these neon lines in clouds illuminated by AGNs reveal some clues. Thick gas slabs (log $N_H/cm^{-2}$ = 23) with various physical conditions are assumed in CLOUDY modeling, and results are shown in Figures 11(1)–(5), respectively. The structures of temperature ($T_e$), line emissivities, and cumulative line ratios are in the top, middle, and bottom panels, respectively. First of all, as number density rises from $n_H = 10^7 cm^{-3}$ (Figure 11(1)) to about $n_H = 10^6 cm^{-3}$ (around the critical density of these neon lines; Figure 11(5)), the line emissivities rise dramatically, and the cumulative line ratios show an entirely different pattern. Besides number density, it is clear that the emissivity and line ratios are mainly determined by the temperature of the gas, which is affected by physical conditions like ionization parameter $U$ (Figure 11(1) vs. Figure 11(4)), metallicity $Z$ (Figure 11(1) vs. Figure 11(2)), and the presence of dust (Figure 11(1) vs. Figure 11(3)). In the case of the outflow gas in F11119+3257, the observed line ratios of [Ne III] $15.56 \mu m$/[Ne III] $\lambda 3968$(observed) $\approx 13.7$ and [Ne V] $14.32 \mu m$/[Ne V] $\lambda 3427$(observed) $\approx 16.8$ are hard to explain as caused by the change of the physical conditions as shown in the figures. The variation of neither $n_H$, nor $U$, nor dust content can boost the MIR/optical neon ratios to be over 10. A higher metallicity (Figure 11(2)), though, can result in an [Ne III] $15.56 \mu m$/[Ne III] $\lambda 3968$ ratio similar to our observation, but the predicted [Ne V] $14.32 \mu m$/[Ne V] $\lambda 3427$ intensity ratio becomes much too large. Therefore, the case of F11119+3257 implicates that a comparison study of MIR and optical neon lines can provide additional diagnoses to the physical conditions (e.g., extinction) of the emission-line regions of galaxies.

5. Summary and Prospects

In this paper, we carry out a comprehensive study of the continuum, emission lines, and absorption lines of the fast molecular outflow candidate, a ULIRG + partially obscured NLS1 IRAS F11119+3257. A systemic redshift of $z = 0.18966 \pm 0.00006$ is determined by modeling low-ionization NELs. And significant dust extinction at $E_{B-V} \approx 1.18$ is found for both the continuum and the BELs. The dereddened optical spectrum reveals a powerful AGN with
a BH mass of $M_{BH} = 1.0 \times 10^4 M_\odot$, which accretes at around the Eddington rate of $\dot{m}_{Edd} \approx 1$. BALs from ions (Ca II $\lambda 3934$) and neutral atoms (Na I $\lambda 5891, 5897$ and the metastable He I $\lambda 10830$) are detected at velocities ($\sim -1000$ km s$^{-1}$) similar to that of the molecular OH 119 $\mu$m mini-BAL. Photoionization diagnosis of the ionic, atomic, and molecular lines found that the mini-BAL outflows are at kiloparsec scale, consistent with previous reports. At similar speeds to the mini-BAL, a blueshifted emission-line system is identified in several ions ([O III] $\lambda 4959, 5007$, [O II] $\lambda 3727$, [Ne III] $\lambda 3869$, and [Ne VI] $\lambda 3427$) and atomic hydrogen (H$\alpha$, H$\beta$, and H$\gamma$). The similarity in kinetic properties between the blueshifted emission and absorption lines suggests that they could be associated. The blueshifted emission lines are broad and are divided into two components: the slow OEL component ($-1500, 0$) km s$^{-1}$ and the relatively high ionization fast OEL component ($-3500, -1500$) km s$^{-1}$. After inspecting the predicted emission-line ratios of the mini-BAL outflows, we find that it will match the line ratios of the fast and slow OEL components if solar abundance and a dust-to-gas ratio similar to the MW are assumed. And the physical conditions of the fast and slow OEL components are similar even though they differ largely in their line ratios. These results indicate that the OELs very likely originated from the mini-BAL outflows. A joint analysis based on these ionic/atomic/molecular mini-BALs and OELs reveals the position ($R \sim 3$ kpc from the BH) and physical properties ($n_H \sim 10^{2.6}$ cm$^{-3}$ and $N_H \sim 10^{2.7}$ cm$^{-2}$) of the galactic-scale outflow. Furthermore, the mass flow rate ($M \sim 230-730 M_\odot$ yr$^{-1}$), the momentum flux ($P \sim 2.2-12.7 L_{AGN}/c$), and the kinetic luminosity ($E_k \sim 10^{43.6-44.8} \sim 0.003-0.030 L_{AGN}$) are obtained. In addition, the presence of the blueshifted [Ne III] and [Ne V] emission lines in the MIR provides chances to investigate additional properties of the outflow gas, and an extinction of $E_{B-V} \sim 0.5$ is inferred for the outflow region. Besides, we found that the Paschen emission line in F11119+3257 is unique, in which a very narrow (FWHM$_{Pas}$ peak $= 260 \pm 20$ km s$^{-1}$ < FWHM$_{NeI}$/2) emission line component is found only in Pa$\alpha$. By checking this Paschen emission-line component in Pa$\alpha$ and Pa$\beta$, a heavy extinction at $A_H > 2.1$ (corresponding to $E_{B-V} > 3.7$) is found. The most plausible explanation of this anomalous Paschen emission is that it comes from heavily obscured star formation, and a lower limit of SFR$_{Pa\alpha}$ peak $> 130 M_\odot$ yr$^{-1}$ is obtained. The result is of a similar order of the estimates inferred from FIR emissions (SFR$_{FIR} = 190 \pm 90 M_\odot$ yr$^{-1}$). This shows that hydrogen emission lines in the IR (Paschen series, Bracket series, etc.) can be powerful probes to the star formation regions even if they are heavily obscured.

With such a massive molecular outflow and high SFR, F11119+3257 is among the best laboratories to study both the formation of galactic-scale outflows and the outflow–star formation interactions. At a physical scale of $3 \sim 3 kpc$ ($\sim 1$") for $z = 0.18966$, the emission lines from both the galactic-scale outflow and the star formation region can be spatially resolved by next-generation telescopes like $JWST$. The spatially and spectrally resolved observations will enable a clear view of the outflow and the star formation processes and their interactions.

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