The Independence of Neutral and Ionized Gas Outflows in Low-z Galaxies

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Abstract

Using a large sample of emission line galaxies selected from the Sloan Digital Sky Survey, we investigate the kinematics of the neutral gas in the interstellar medium (ISM) based on the Na I λ5890,5896 (Na D) doublet absorption line. By removing the Na D contribution from stellar atmospheres, we isolate the line profile of the Na D excess, which represents the neutral gas in the ISM. The kinematics traced by the Na D excess show high velocity and velocity dispersion for a fraction of galaxies, indicating the presence of neutral gas outflows. We find that the kinematics measured from the Na D excess are similar between AGNs and star-forming galaxies. Moreover, by comparing the kinematics traced by the Na D excess and those by the [O III] λ5007 line taken from Woo et al., which traces ionized outflows driven by AGNs, we find no correlation between them. These results demonstrate that the neutral gas in the ISM traced by the Na D excess and the ionized gas traced by [O III] are kinematically independent, and AGNs have no impact on the neutral gas outflows. In contrast to [O III], we find that the measured line-of-sight velocity shift and velocity dispersion of the Na D excess increase for more face-on galaxies due to the projection effect, supporting that Na D outflows are radially driven (i.e., perpendicular to the major axis of galaxies), presumably due to star formation.

Key words: galaxies: active – ISM: jets and outflows – techniques: spectroscopic

1. Introduction

Gas outflows are frequently observed in star-forming galaxies (SFGs) and active galactic nuclei (AGNs; e.g., Chen et al. 2010; Martin et al. 2011; Bae & Woo 2014; Harrison et al. 2014; Cicone et al. 2016; Woo et al. 2016). Such outflows transfer a vast amount of energy and momentum to the interstellar medium (ISM), plausibly affecting the evolution of the host galaxies (see Veilleux et al. 2005, for a review). Particularly, AGN-driven outflows may play a crucial role in quenching star formation in massive galaxies as theoretical studies suggest (see King & Pounds 2015, for a review), yet there is a lack of direct observational evidence for the star formation quenching in AGN-host galaxies (e.g., Husemann et al. 2013; Villar-Martín et al. 2016; Bae et al. 2017; Woo et al. 2017).

Outflows have been detected in different gas phases, e.g., neutral gas (e.g., Rupke et al. 2005; Chen et al. 2010; Lehnert et al. 2011), ionized gas (e.g., Greene et al. 2012; Woo et al. 2016), or hot plasma (e.g., McNamara et al. 2005; Aharounian et al. 2016). By examining the kinematics of the [O III] λ5007 line, for example, Woo et al. (2016) showed that the ionized gas outflows are prevalent in AGNs at z < 0.3, but not in SFGs (see also Bae & Woo 2014; Woo et al. 2017). To understand how AGN outflows affect star formation in host galaxies, it is of importance to investigate the cold, neutral gas outflows, which are more closely related to star formation.

The Na I λ5890,5896 (Na D) doublet is one of the tracers for measuring the properties of neutral gas (e.g., Rupke et al. 2005). Since the Na D line profile is contributed by the neutral gas in the ISM as well as stars, there were various attempts to separate the ISM component in the previous studies. For example, Heckman et al. (2000) compared the observed Na D line profiles of 32 far-IR-bright galaxies with those of late-type stars (e.g., K giants) in order to identify galaxies with the interstellar-dominated Na D line. Based on the fact that Na and Mg have similar first ionization potentials, Rupke et al. (2005) estimated the stellar contribution in the Na D line profile by utilizing the Mg I absorption line profile for their sample of IR-luminous starburst galaxies. As a more sophisticated approach to investigate the outflows in Na D, Chen et al. (2010) used two components, respectively, representing quiescent disk gas and outflowing gas, by modeling the Na D line profile with physical parameters, velocity and velocity dispersion as well as optical depth and covering factor, using stacked spectra of SFGs. Recently, Sarzi et al. (2015) investigated whether gas outflows in the Na D excess is due to AGNs, by exploiting ~450 radio galaxies. They concluded that Na D outflows are driven by star formation, because Na D outflows are detected only among SFGs. Since Sarzi et al. (2015) selected mostly massive early-type galaxies (∼90%), it is alternatively suggested that the Na D excess may be due to the template mismatch, and that stellar population models with Na-enhanced metallicities may reproduce the observed Na D profile (Jeong et al. 2013; Park et al. 2015).

To overcome the limitations in the previous studies and to investigate whether the neutral gas outflows in the ISM are driven by AGNs, we investigate the gas outflows traced by the Na D excess using a large and unbiased sample of emission line galaxies selected from the Sloan Digital Sky Survey (SDSS). In this paper, we present the Na D kinematics for a large sample of SFGs and AGNs, reporting that the neutral gas kinematics are independent of the ionized gas kinematics. In Section 2, we describe our sample selection and fitting procedures for the Na D line. In Section 3, we present the kinematics of Na D excess and compare with [O III] kinematics. Finally, we conclude our results in Section 4.

2. Sample and Analysis

We utilized a large sample of ~113,000 galaxies with well-defined emission lines from Woo et al. (2017; see also Bae & Woo 2014; Woo et al. 2016; Kang et al. 2017), which is selected...
from the SDSS seventh data release (DR7; Abazajian et al. 2009). The sample includes ∼43,000 AGNs and ∼69,000 SFGs, which are classified based on the emission line flux ratio diagnostics using [O III], Hβ, [N II], and Hα lines (e.g., Kauffmann et al. 2003; Kewley et al. 2006). Woo et al. (2017) measured the ionized gas kinematics traced by velocity and velocity dispersion of [O III] by modeling the [O III] line profile with a single or double Gaussian model. The first and second moments of the best-fit line profile were used to calculate the flux-weighted velocity shifts ($V_{50}$) with respect to the systemic velocity (i.e., based on stellar absorption lines) and the velocity dispersion ($\sigma_{50}$), respectively. Then, the properties of ionized gas outflows and their connection to star formation were investigated in detail (see also Bae & Woo 2014; Woo et al. 2016).

Using the same sample, we now investigate the neutral gas kinematics by measuring the velocity and velocity dispersion from the Na D excess and directly compare them with the ionized gas kinematics. The Na D line often shows a larger line strength than other stellar lines due to the contribution from ISM. We will refer to this component as the Na D excess. Thus, in order to measure the kinematics of neutral gas in the ISM, we need to separate the ISM component from the stellar component in the Na D line profile. For separating the Na D excess component, we first fitted the stellar continuum over the spectral range 3700–7600 Å, which contains multiple strong stellar absorption lines, using the penalized pixel fitting code (pPXF, Cappellari & Emsellem 2004). We utilized a combination of simple stellar population (SSP) models (MILES, Sánchez-Blázquez et al. 2006), adopting solar metallicity and age spanning from 60 Myr to 12.6 Gyr. While we performed the fitting process with/without masking the Na D line, we find no significant difference since many other strong absorption lines are dominant in the fitting process.

Second, after subtracting the best-fit stellar population model, we fitted the Na D excess at a fixed wavelength range 5850–5940 Å using the pPXF. Note that the Na D excess represents the neutral gas in the ISM, which is presumably composed of non-outflowing quiescent gas in the disk as well as outflowing gas. We did not attempt to separate these two components since they are degenerate. Instead, we used the total line profile of the Na D excess for measuring the velocity and velocity dispersion to constrain the kinematics of the neutral gas in the ISM. To avoid any contamination, we masked the He I $\lambda$5876 line in the fitting process. Based on the best-fit model for the NaD excess, we measured the velocity shift ($V_{50}$) with respect to the systemic velocity, which is measured from the stellar continuum in the previous step, and velocity dispersion ($\sigma_{50}$) of the Na D excess. For comparison, we also used the observed profile of the Na D line, without subtracting the stellar component and obtained kinematic measurements, $V_{NaD}$ and $\sigma_{NaD}$. While our fitting method is different from that of the previous studies (e.g., Rupke et al. 2005; Chen et al. 2010; Lehner et al. 2011; Sarzi et al. 2015), our method is straightforward to use for comparing with the kinematics of [O III] and provides relatively good fitting results (see Figure 1). Since we focus on the Na D kinematics, a different choice of SSP models (e.g., initial mass function, metallicity, or age) does not affect the results.

We measured the equivalent width (EW) of the Na D absorption line for both the excess component and the total profile, and obtained the uncertainty of EWs using Monte Carlo simulations based on flux errors. The pseudo-continuum around Na D was defined using the mean flux in the wavelength ranges, 5850–5870 Å and 5920–5940 Å. Based on the Monte Carlo simulation results using a small random subsample, we found that the uncertainties of Na D velocity shift and velocity dispersion strongly depend on the Na D EW. Since it is extremely time-consuming to perform Monte Carlo simulations for all galaxies, we alternatively obtained an empirical functional form for assigning the uncertainty of the Na D velocity shift and velocity dispersion as a function of the Na D EW. Thus, we adopted the representative uncertainties of the Na D velocity and velocity dispersion, using the measured Na D EW of each galaxy.

To avoid unreliable measurements, we focus on a sample of galaxies that have a strong Na D absorption line, i.e., the EW of total Na D is larger than three times of its uncertainty. We further rejected 12 AGNs and 3 SFGs with a complex Na D profile, which was difficult to fit using our method. Note that the removal of these 15 galaxies does not affect our results. As a final sample, we used 27,013 AGNs (∼62% of total AGN sample) and 6783 SFGs (∼10% of total SFG sample) in this study. Among them, we selected galaxies with the Na D excess if the fraction of the Na D excess is more than 50%, i.e., $f_{NaD, excess} > 0.5$, where the Na D excess fraction, $f_{NaD, excess}$ is defined by the ratio between EW of Na D excess and EW of the total Na D line (i.e., EW (Na D excess)/EW (Na D total)). The number of the Na D-excess galaxies with $f_{NaD, excess} > 0.5$ is 1201 among SFGs (∼18% of the selected SFGs) and 1886 among AGNs (∼7% of the selected AGNs). Note that even if we select galaxies with a lower Na D-excess fraction, e.g., $f_{NaD, excess} > 0.3$, we obtained qualitatively the same results. In addition to the Na D-excess galaxies, we also selected galaxies with little Na D excess, i.e., $f_{NaD, excess} < 0.1$. These galaxies are composed of 1864 SFGs, ∼27% of the selected SFGs, and 13,606 AGNs, ∼50% of the selected AGNs. This fraction indicates that approximately ∼50% of AGNs show no significant signature of the ISM component in the Na D line profile. We will utilize the kinematics measured from the Na D excess to examine the ISM gas kinematics in the next section.
excess component \( V_{\text{NaD, excess}} \) has a long tail to negative values, indicating that many of these objects show a blueshifted Na D excess profile (see Figure 1 left). The mean \( V_{\text{NaD, excess}} \) is \(-75 \pm 97 \text{ km s}^{-1}\) and \(-77 \pm 122 \text{ km s}^{-1}\), respectively, for SFGs and AGNs, indicating that strong outflows of the neutral gas are present. We perform the Kolmogorov–Smirnov (K–S) test to investigate whether SFGs and AGNs have the same \( V_{\text{NaD, excess}} \) distribution. The results show that the two distributions are not the same (K–S statistic = 0.108, \( p < 0.001 \)), presumably due to the difference of the host galaxy mass and star formation rate, etc. Nevertheless, the similar mean and dispersion of the two distributions suggest that the origin of the outflows are similar.

In the case of the velocity dispersion of the Na D excess component, the mean ratio between \( \sigma_{\text{NaD, excess}} \) and \( \sigma_{\text{star}} \) is less than one for both SFGs (0.83 ± 0.57) and AGNs (0.72 ± 0.46), suggesting that the nongravitational kinematic component traced by the Na D excess is weaker than the gravitational component traced by stellar absorption lines. Although the distributions are not statistically the same (K–S statistic = 0.148, \( p < 0.001 \)), the two distributions are similar. It is not likely that AGN activity caused the neutral gas outflows in the ISM since SFGs also show similar outflows in the ISM.

These results may indicate that neither AGN nor star formation activities are a dominant source of neutral gas outflows in the ISM, as similarly reported by previous studies with various samples (e.g., Colbert et al. 1996). On the other hand, since AGNs with strong [O III] outflows tend to have a relatively high star formation rate as star-forming main-sequence galaxies (Woo et al. 2017), it is also reasonable to assume that the neutral gas outflows are caused by star formation activity both in SFGs and AGNs.

### 3.2. Comparison to [O III] Kinematics

In this section, we directly compare the kinematics of Na D with the kinematics traced by the [O III] line, which represent the ionized gas outflows driven by AGNs, by adopting [O III] velocity shift and velocity dispersion measurements from Woo et al. (2017). If AGNs affect both ionized and neutral gas at the same time, we expect a correlation between the kinematics of the Na D excess and [O III]. First, we compare the velocity shifts of Na D with that of [O III] in Figure 3, finding no correlation between them. For SFGs without the Na D excess (top-left), the distribution is narrow and negligible for both [O III] and Na D (i.e., \( V_{\text{[O III]}} = -2 \pm 33 \text{ km s}^{-1}\) and \( V_{\text{NaD}} = -11 \pm 32 \text{ km s}^{-1}\), respectively), indicating no outflows in [O III] or Na D as expected. For AGNs without the Na D excess (top-right), the distribution of [O III] velocity shift is somewhat broader \( (V_{\text{[O III]}} = 0 \pm 46 \text{ km s}^{-1}) \) than that of SFGs, due to the presence of AGN-driven ionized gas outflows, while the distribution of Na D velocity shift is similar to that of SFGs \( (V_{\text{NaD}} = 0 \pm 32 \text{ km s}^{-1}) \), confirming our expectation that there is no AGN effect on the stellar Na D lines. Since the majority of galaxies show a weak velocity shift in [O III] due to the projection effect since the direction of AGN outflows is expected to be perpendicular to the line of sight for type 2 AGNs (see the detailed model prediction based on the Monte Carlo simulation by Bae & Woo 2016), we focus on a subsample with the robust \( V_{\text{[O III]}} \) measurements (i.e., \( V_{\text{[O III]}} > 3\sigma \)). For this subsample (cyan and orange points in Figure 3), we find that \( V_{\text{[O III]}} \) is significantly larger in AGNs.

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1. Note that, hereafter, we quote the mean and the 1σ dispersion of the distribution.

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![Figure 2](image-url)
than in SFGs. This trend is consistent with the general population of SFGs and AGNs (see Woo et al. 2017 for the detailed comparison of [O iii] kinematics between AGNs and SFGs). In contrast, there is no difference in the distribution of $V_{\text{NaD}}$ between AGNs and SFGs since stellar kinematics are not affected by AGN activity or star formation.

Now, we turn to galaxies with the Na D excess, which represents the kinematics of the neutral gas in the ISM (bottom panels in Figure 3). For SFGs with the Na D excess (bottom-left), the distribution of $V_{\text{NaD,excess}}$ is skewed with a long tail to negative values ($V_{\text{NaD,excess}} = -75 \pm 97 \text{ km s}^{-1}$), suggesting that some fraction of SFGs have strong outflows. In contrast, $V_{\text{[O iii]}}$ shows on average zero velocity shift with a narrow distribution ($V_{\text{[O iii]}} = -11 \pm 29 \text{ km s}^{-1}$) as expected since there is no AGN. In other words, the neutral outflows traced by the Na D excess can be strong even without AGN activity. In the case of AGNs with the Na D excess (bottom right), the distribution of $V_{\text{[O iii]}}$ is much broader and blueshifted ($V_{\text{[O iii]}} = -25 \pm 70 \text{ km s}^{-1}$) than that of SFGs with the Na D excess as expected from the fact that [O iii] outflows are driven by AGNs. In contrast, we find no significant difference of $V_{\text{NaD,excess}}$ between AGNs and SFGs. The distribution of $V_{\text{NaD,excess}}$ of AGNs is shifted to negative values with a mean of $-77 \pm 122 \text{ km s}^{-1}$, which is similar to that of SFGs with the Na D excess. We find no clear correlation between $V_{\text{[O iii]}}$ and $V_{\text{NaD,excess}}$ in AGNs, indicating that the neutral gas outflows traced by the Na D excess and the ionized gas outflows driven by AGN are kinematically independent.

Second, we compare the velocity dispersion of Na D and [O iii] after normalizing them by stellar velocity dispersion ($\sigma_{\text{stellar}}$) in Figure 4. We find no clear correlation between Na D and [O iii] velocity dispersions in any subsample. In the case of AGNs, there is a large range of [O iii] velocity dispersion for a given low velocity dispersion of Na D excess. At the same time, for a given low velocity dispersion of [O iii], there is also a large range of Na D velocity dispersion. These results indicate that neutral gas outflows manifested by the Na D excess are not directly connected to AGN outflows.

By comparing SFGs with/without the Na D excess (left panels in Figure 4), we find no significant distribution of the $\sigma_{\text{[O iii]}}$. For example, the mean and rms dispersion of the distribution is $0.97 \pm 0.30$ and $0.98 \pm 0.31$, respectively, for SFGs with/without the Na D excess. In other words, there are no strong ionized gas outflows traced by [O iii], regardless of the presence of the ISM component in the Na D line. In the case of Na D, the distribution of the $\sigma_{\text{NaD,excess}}$ (mean value of $0.83 \pm 0.57$) is different from that of the $\sigma_{\text{Na D}}$ (mean value of $1.12 \pm 0.49$), reflecting that the Na D excess component represents nongravitational outflow kinematics. In the case of AGNs, we find no difference of the $\sigma_{\text{[O iii]}}$ distribution between AGNs with/without the NaD excess (right panels in Figure 4), suggesting that the kinematics of [O iii] and the Na D excess have different origins.

When we compare SFGs and AGNs, we find qualitatively the same trend of the distribution of the normalized $\sigma_{\text{NaD,excess}}$ between AGNs and SFGs, while the distribution of $\sigma_{\text{[O iii]}}$ is different between SFGs and AGNs as there is a long tail toward the high velocity dispersion. These results indicate that the kinematics of the Na D excess is apparently independent of AGN activity.

### 3.3. Comparison of the Line Skewness

In this section, we compare the line skewness of the Na D excess and [O iii]. The line skewness can be measured by
fitting the line profile using Gauss–Hermite series as follow:

\[
L(y) = \frac{A e^{-y^2/2}}{\sigma \sqrt{2\pi}} \left[ 1 + \sum_{m=3}^{M} h_m H_m(y) \right],
\]

where \(H_3 = y(2y^2 - 3)/\sqrt{3}, H_4 = [4(y^2 - 3)y^2 + 3]/\sqrt{24},\) and \(y \equiv (v - V)/\sigma.\ A\) is the amplitude of the line, \(V\) is the mean radial velocity, and \(\sigma\) is the velocity dispersion of the line if we assume the line profile to be a Gaussian (van der Marel & Franx 1993). Note that if both \(h_3\) and \(h_4\) are equal to zero, the profile becomes a Gaussian.

In practice, we measured the skewness coefficient \(h_3\) of the Na D excess and the [O III] line, using the pPXF and PROFIT (Riffel 2010), respectively. Since the measurement of skewness is sensitive to the quality of the spectra, we selected \(\sim 200\) AGNs that have sufficient signal-to-noise ratios (i.e., \(S/N > 50\)) for the skewness analysis, and measured the \(h_3\) coefficient in Equation (1). For this subsample, we measured the \(h_3\) of the Na D excess, [O III], and stellar lines, respectively, and compare them.

In the case of the Na D excess, the \(h_3\) coefficient ranges \(\sim \pm 0.1,\) with a mean \(0.00 \pm 0.04,\) indicating that the Na D-excess profiles do not show strong skewness. Since the Na D excess represents the ISM gas, which is composed of quiescent and outflowing components, the mean value close to zero indicates that quiescent gas may be dominant. On the other hand, if the outflowing gas is dominant as manifested by a strong blueshift, the line profile is also symmetric with weak skewness. In the case of stars, the \(h_3\) coefficient from stellar lines shows a mean value of \(-0.01 \pm 0.02\) with a narrow range of \( \pm 0.05,\) which is consistent with the expectation from a symmetric line-of-sight velocity distribution of stars in a galactic bulge. Thus, compared to stars, neutral gas traced by Na D excess shows somewhat larger distribution of skewness, reflecting the nongravitational outflows.

In the case of [O III], we measure the mean \(h_3\) coefficient as \(0.00 \pm 0.12,\) indicating the skewness in the [O III] line profile is small on average. This result is consistent with the distribution of the [O III] velocity shift shown in Figure 3, reflecting that a majority of type 2 AGNs show very small flux-weighted velocity shift (Bae & Woo 2014; Woo et al. 2016, 2017). The trend of skewness of [O III] is similar to that of velocity shift since both of them represent the asymmetry of the line profile. On the other hand, we find that the \(h_3\) range of [O III] is much broader than Na D, up to \( \pm 0.5\) (bottom panel in Figure 5), indicating that there are AGNs with strongly skewed [O III] lines, reflecting ionized gas outflows.

Since the uncertainty of \(h_3\) is very large, we focus on AGNs with relatively large \(h_3,\) i.e., \([h_3] > 0.1,\) which is 18% of the subsample of \(\sim 200\) AGNs. When we compare the distribution of the \(h_3\) coefficient between the Na D excess and [O III] using these AGNs, we find no correlation between the \(h_3\) coefficients of the Na D excess and [O III] (bottom panel in Figure 5). In other words, while [O III] manifests outflows by the skewness of the line profile, the Na D excess does not exhibit outflows as strong as [O III]. The results further support the independence of kinematics between neutral and ionized gas outflows in AGNs.

3.4. Gas Kinematics versus Host Galaxy’s Inclination

The independence of the kinematics between the Na D excess and [O III] suggests that the neutral gas outflows in the ISM is not related to AGN activity. Instead, star formation-driven outflows may be responsible for the detected kinematics of the Na D excess (e.g., Sarzi et al. 2015). In this case, the measured velocity shift and velocity dispersion along the line of sight may depend on the host galaxies’ inclination since the direction of star formation-driven outflows is along the rotational axis of host galaxies, while AGN-driven outflows have a random direction with respect to the stellar disk (e.g., Veilleux et al. 2005; Bae & Woo 2014). In fact, previous studies reported that the strength of ISM outflows correlates with the inclination of the galaxies. For example, using a small set of 32 starburst galaxies, Heckman et al. (2000) reported that the outflows indicated by the velocity shift of the Na D excess are systematically found in more nearly face-on galaxies than other galaxies, concluding that the outflows are in the direction of the minor axis of the galaxies. Using a larger sample of SDSS SFGs, Chen et al. 2010 showed that the line-of-sight outflow velocity is more or less constant when the inclination of the galaxies is more face-on (i.e., \(< 60^\circ\)), which is consistent with the radial direction (perpendicular to the disk) of gas outflows.

If the outflows in the Na D excess are driven by AGNs, and the direction of outflows is random compared to host galaxy inclination. Thus, we do not expect any trend between the projected velocity of outflows and host galaxy inclination. In contrast, if the outflows are driven by SF, then the outflow
Figure 6. Velocity and velocity dispersion diagram of Na D (top) and [O III] (bottom) for SFGs (left) and AGNs (right). Different colors represent the minor-to-major axis \((b/a)\) ratio: (1) \(b/a > 0.8\) (red, ~face-on); (2) \(0.6 < b/a < 0.8\) (orange); (3) \(0.4 < b/a < 0.6\) (cyan); and (4) \(b/a < 0.4\) (blue, ~edge-on). Normalized histograms are given in each panel. A crosshair in each panel represents a typical 1\(\sigma\) uncertainty.

4. Conclusion

By utilizing a large sample of emission line galaxies selected from the SDSS at low redshift \((z < 0.3)\), we examined the kinematics of the Na D excess as a tracer of neutral gas outflows in the ISM. We found signatures of strong neutral gas outflows in the galaxies with the Na D excess, regardless of AGN activity, which is consistent with a recent study on the neutral and ionized gas kinematics for radio AGNs (Sarzi et al. 2015), while the advantage of this study is that we used an unbiased sample of AGNs and SFGs, regardless of the host galaxy’s properties, e.g., radio activity. The fact that the kinematic signatures manifested by Na D excess is similar between SFGs and AGNs, may suggest that neither AGN nor star formation activities are a dominant energy source of the observed neutral gas outflows in the ISM. To further constrain the ambiguity, we compared the kinematics of neutral and ionized gas outflows in AGNs and SFGs. The main results indicate that the kinematics of the Na
D excess and [O III] are independent to each another, suggesting that AGN outflows have no or little impact on the neutral gas that is traced by the Na D excess. This conclusion is supported by the recent theoretical studies that showed that AGN outflows tend to escape via a low-density channel in the ISM, e.g., ionized gas (Gabor & Bournaud 2014; Bieri et al. 2017). By comparing the Na D-excess kinematics with host galaxy’s inclination, we found that the primary driver of the kinematics manifested by the Na D excess is possibly star formation-driven outflows, of which the direction is along the rotational axis of the host galaxies (Heckman et al. 2000).

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