OUTFLOWS IN SODIUM EXCESS OBJECTS

Jongwon Park1, Hyunjin Jeong2,3, and Sukyoung K. Yi1

1 Department of Astronomy, Yonsei University, Seoul 120-749, Korea; yi@yonsei.ac.kr
2 Korea Astronomy and Space Science Institute, Daejeon 305-348, Korea
3 Korea University of Science and Technology, Daejeon 305-350, Korea

Received 2015 April 28; accepted 2015 July 8; published 2015 August 12

ABSTRACT

Van Dokkum and Conroy revisited the unexpectedly strong NaI lines at 8200 Å found in some giant elliptical galaxies and interpreted them as evidence for an unusually bottom-heavy initial mass function. Jeong et al. later found a large population of galaxies showing equally extraordinary Na D doublet absorption lines at 5900 Å (Na D excess objects: NEOs) and showed that their origins can be different for different types of galaxies. While a Na D excess seems to be related to the interstellar medium (ISM) in late-type galaxies, smooth-looking early-type NEOs show little or no dust extinction and hence no compelling signs of ISM contributions. To further test this finding, we measured the Doppler components in the Na D lines. We hypothesized that the ISM would have a better (albeit not definite) chance of showing a blueshift Doppler departure from the bulk of the stellar population due to outflow caused by either star formation or AGN activities. Many of the late-type NEOs clearly show blueshift in their Na D lines, which is consistent with the former interpretation that the Na D excess found in them is related to gas outflow caused by star formation. On the contrary, smooth-looking early-type NEOs do not show any notable Doppler components, which is also consistent with the interpretation of Jeong et al. that the Na D excess in early-type NEOs is likely not related to ISM activities but is purely stellar in origin.

Key words: catalogs – galaxies: abundances – galaxies: elliptical and lenticular, cD – galaxies: evolution – galaxies: spiral – galaxies: stellar content

Supporting material: machine-readable table

1. INTRODUCTION

The behavior of sodium spectral features has garnered much attention because it has become known that some galaxies show enhanced Na D doublet strengths at 5890 and 5896 Å and enhanced Na I doublet strengths at 8183 and 8195 Å. Numerous studies have been performed over the last three decades to understand these lines, but it is still unclear exactly how some galaxies exhibit a sodium excess.

Recent research focused on the variations of an initial mass function (IMF) has provided an interesting possibility. The stellar IMF is usually considered a universal function, but the possibility of a non-universal IMF has been raised by several authors (see, e.g., Trager et al. 2000; Davé 2008; van Dokkum 2008; Graves et al. 2009; Treu et al. 2010; van Dokkum & Conroy 2010). In studies on the Ca II triplet at 8500 Å, Saglia et al. (2002) found an anti-correlation between the strength of the Ca II triplet region and the velocity dispersion for elliptical galaxies and concluded that bottom-heavy IMFs are favored (see also Cenarro et al. 2003). Recently, van Dokkum & Conroy (2010) reported the observation of a near-infrared Na I doublet in the spectra of massive early-type galaxies, and claimed that these excesses can be explained by a bottom-heavy IMF (see also van Dokkum & Conroy 2012). This implies that massive early-type galaxies should possess relatively more low-mass stars.

An alternative solution is also possible. It is well known that the Na D feature is sensitive to Na-enhancement ([Na/Fe]). The discovery of non-solar abundance patterns in early-type galaxies was first made by O’Connell (1976) and Peterson (1976). They found extreme enhancement of Mg b and Na D features with respect to calcium and iron peaks and concluded that this was a result of a higher metal abundance.

Worthey (1998) also claimed that strong Na features are caused by an overabundance of [Na/Fe] (see also Worthey et al. 2011). This is a trivial interpretation and thus it is not satisfying unless the origin for the enhancement is given clearly.

Furthermore, the ISM could also increase the Na D line strength. Until the early 1980s it was thought that only late-type galaxies had significant ISM. Advances in X-ray and radio astronomy, however, have demonstrated that many early-type galaxies also have an unignorable amount of ISM. A direct method of measuring hydrogen gas column densities to detect ISM is possible via spectroscopy in the ultraviolet, because observations between 70 and 1000 Å are sensitive to small amounts of hydrogen and helium in the ISM. If it is not easy to obtain such data because of instrumental limitations, an alternative method is to use absorption lines such as K I, Ca II, and Na I in the more accessible optical region of the spectrum. The Na D absorption lines, especially, provide a good probe of cold ISM in the outflow. According to Chen et al. (2010), Na D absorption arises from cool gas in the disk and a blueshifted Na D absorption is frequently detected in star-forming galaxies (see also Heckman et al. 2000).

To understand the origin of the Na D excess, Jeong et al. (2013; J13 hereafter) explored the properties of Na D excess objects (NEOs) from the seventh data release of the Sloan Digital Sky Survey (SDSS; Abazajian et al. 2009), with morphological information obtained through visual inspection of galaxy images. They found that the use of bottom-heavy IMF is not capable of reproducing the observed strength of Na D lines to a large degree but instead found it necessary to evoke an ad hoc enhancement of Na ([Na/Fe] ~ 0.3), just as in Worthey (1998). Their work does not necessarily rule out the possibility of a bottom-heavy IMF, but hints that there is
another missing physics that controls the Na D strengths more importantly (see also Yi & Jeong 2015). Indeed, weak lensing studies (Spiniello et al. 2012, 2015) suggest that a bottom-heavy IMF (similar to the original Salpeter IMF) helps to reproduce the high values of mass derived on lensing galaxies, while the use of Na enhancement was additionally required.

Jeong et al. (2013) also found that little dust extinction seems present in smooth-looking early-type NEOs, quoting the OSSY database (Oh et al. 2011), which supports the interpretation of a stellar (rather than an ISM) origin for the Na strength excess. As a further confirmation test, we hereby present the result of Doppler measurement on the shape of Na D lines for the J13 samples of NEOs. If the Na D excess is related to the ISM, we may detect Doppler components in Na D line shapes due to gaseous outflows in actively star-forming galaxies (Chen et al. 2010) or active galactic nucleus (AGN) galaxies (Davis et al. 2012).

2. GALAXY SAMPLE

The parent sample for this study is the NEOs from J13. The J13 sample is drawn from the SDSS DR7 in the redshift range of $0.00 \leq z \leq 0.08$ by applying an absolute r-band magnitude cut-off of $-20.5$ to obtain a volume-limited sample and signal-to-noise ratio (S/N) cut-off of 20 to guarantee high quality spectroscopic data. To find NEOs, J13 defined a new index, $f_{\text{NaD}}$, which quantifies the Na D excess as follows.

$$f_{\text{NaD}} = \frac{\text{Na D (Observed)} - \text{Na D (Model)}}{\text{Na D (Model)}},$$

where Na D (Observed) is the observed Na D line strength and Na D (Model) is the expected model Na D line strength. $f_{\text{NaD}} \geq 0.5$ is used as a criterion for the Na D excess, and $0.0 \leq f_{\text{NaD}} \leq 0.1$ is used to create a control sample. The sample galaxies were then morphologically classified via visual inspection. The NEOs were carefully assigned to four classes: (1) ordinary early-type galaxies (oETGs), (2) peculiar early-type galaxies (pETGs), (3) ordinary late-type galaxies (oLTGs), and (4) peculiar late-type galaxies (pLTGs). We note that galaxies with asymmetric features and dust patches (or lanes) are classified as peculiar types. In the case of control sample galaxies, these are simply divided into two categories: early-type galaxies (cETG) and late-type galaxies (cLTG). The details of the sample are described more fully in Section 2 of J13.

3. FITTING METHODOLOGY

As mentioned in Section 1, we assume that if Na D excess has an ISM origin, the Na D absorption line would be blueshifted by the effect of outflow such as galactic superwind or AGN outflow. It is known that a Na D doublet is a good tracer of cold ISM in the outflow. In order to measure the Doppler component, we tried both Gaussian and Voigt functions to fit each galaxy spectrum near the Na D absorption lines. Note that we fit the Na D line profile with two Gaussian (or Voigt) profiles. A possible criticism is that our fits are mainly mathematical rather than physical. However, it is the simplest method that can be used just to investigate whether NEOs show a blueshift Doppler departure from the bulk of the stellar population or not.

Figure 1 shows the observed stacked spectra (black solid lines) of early-type NEOs (ETG) and early-type control sample galaxies (cETG) in the Na D region. For comparison, we...
stacked their Gaussian fits (red solid lines). The models match the observed spectra well near the two dips, but there is a marked discrepancy in the fit on the sides (wings). One might be tempted to interpret this mismatch as an outflow effect, but if this interpretation is followed, then the same result in the early-type control sample is not explainable.

3.2. Voigt Fitting

Some lines like Ca II H and K, Ca I at 4227 Å, Na D, and Mg b show strong pressure-broadened wings in the spectra of cool stars. It is known that the Voigt profile is particularly well suited to fit the wings of such lines. The Voigt profile is defined by a convolution of the Gaussian and Lorentzian functions:

\[
V(x) = k \tilde{V}(x),
\]

\[
\tilde{V}(x) = \frac{a^2}{\pi} \int_{-\infty}^{\infty} \frac{e^{-(x'-\mu)^2/2a^2}}{(x'-x)^2 + \gamma^2} dx',
\]

where \( k \) is \( a/\tilde{V}_{\text{max}} \), \( a \) and \( \sigma \) denote the depth and width of the Gaussian component, \( \mu \) is the position of the centroid, and \( \gamma \) corresponds to the width of the Lorentzian component. The shape of the Voigt profile is highly sensitive to the value of \( \gamma \), so we defined \( k \) as \( a/\tilde{V}_{\text{max}} \) to restrict the \( \gamma \) contribution to only the width of the wings. We then adopted two Voigt profiles to fit the Na D doublet for each galaxy spectrum, using the following form:

\[
y = V_1(x) + V_2(x).
\]

Observed stacked spectra (black solid lines) of early-type NEOs (ETG) and early-type control sample galaxies (cETG) with their stacked fits (red solid lines) obtained using two Voigt profiles are shown in Figure 2. Figures 1 and 2 show different numbers of galaxies mainly because they show only the galaxies for which \( r^2 \) was achieved to be better than 3.0 while this cut depends on the fitting method. In addition, we excluded some fits even if the chi squared was small when the fits required the positions of the fitting centroids to be farther than 0.5 Å from the pre-assumed positions of the doublets. Some displacement of centroids was allowed in the fitting procedure because of the limited spectral resolution and the uncertainty in redshift determination. Given that the result based on the Gaussian fitting shows a marked discrepancy in the fit (see Figure 1), the Voigt fitting reproduces the shapes of the Na D lines in a markedly better way, especially for the wings in the spectra. For a sanity check, the mean value of the width (dispersion) in the Gaussian component (\( \sigma \) in Equation (4)) is 150 ± 50 km s\(^{-1}\), which roughly corresponds to the typical value of the velocity dispersion of galaxies.

To compare the Gaussian and Voigt fitting methods, we show the fit residuals of our sample galaxies according to their morphologies in Figure 3. It should be noted that the fit residual based on the Voigt fitting method (solid lines) is below 1% except in the He I region at 5875 Å, while the Gaussian fitting method fails to reproduce the wings of Na D even for the control sample (see cETG and cLTG cases).

4. DISCUSSION

The broadening of absorption lines is difficult to interpret because the physics of the curve of growth is complex. Thus,
we focus instead on the blueshift Doppler departure from the bulk of the stellar population due to outflow caused by either star formation or AGN activity by measuring the centroids of galaxies showing blue or redshift are given. Emission-line classification (based on the BPT diagnostic) is also given in different colors. The gray band shows the range (encompassing 95% of the sample) of Doppler shift exhibited by the control sample in panels (g) and (h). For NEOs, the number and fraction of galaxies showing significantly blueshifted Na D absorption features (below the bands) are shown in the bottom left corner of each panel (from (a) to (f)). Note that the bulk of our sample galaxies shows a systematic redshift by 0.6 Å compared to the prediction from the vacuum experiment. We only focus on the difference between each sample and the control sample.

Figure 4 presents the amount of Na D absorption line shift with respect to the Na D line strength. To investigate the dominant process that causes this outflow component, we use the BPT classification information from J13: star-forming (SF), composite (i.e., hosting both star formation and AGN activity, Co), Seyfert (Se), LINER (Li), or non-emission line galaxies (NE). Furthermore, the Δμ1 distributions of the control sample are shown by gray bands (panels (g) and (h)) for easy comparison. The key point in this investigation is to check whether or not the NEOs are significantly different in the line shift compared with the control sample.

The left panels of Figure 4 show the early-type cases: ordinary (smooth-looking) early-type NEOs (oETG, (a)), peculiar (non-smooth) early-type NEOs (pETG, (c)), early-type NEOs (oETG + pETG, (e)), and early-type control sample (cETG, (g)). A cursory glance at this diagram shows that most early-type NEOs do not seem to show any particular blueshift of the Na D absorption lines. The fraction showing a shift bluer than those of the control counterparts (Δμ1 ≤ −0.6) is roughly 4% (17/412, panel (e)). This result implies that ISM and dust are not likely the main factors causing the increase of the Na D line strength of early-type NEOs.

A possible criticism can be made by asking whether the non-shifted Na D absorption line provides direct evidence of non-ISM. It is known that there should also be a sign of dust extinction to allow neutral sodium to survive in the ISM. This implies that, if the Na D line strength of early-type NEOs is significantly enhanced through ISM effects, these galaxies are more likely to show a correlation between dust extinction and Na D line strength. However, J13 found that there was no correlation between the \( E(B − V) \) values and fNaD. On the contrary, the strongest early-type NEOs were the ones with the lowest dust extinction.

It is also worth noting that almost all of the ordinary early-type NEOs (oETGs, panel (a)) have overall ranges of Δμ1 similar to those of the control sample (cETG, panel (g)). For example, the mean values of Δμ1 for oETG and cETG are 0.87 ± 0.68 and 0.78 ± 0.65, respectively. However, one LINER AGN galaxy below the band is notable. If a galaxy reveals strong emission lines, this galaxy may be a gaseous system. Thus, there is potential for this galaxy to show the Na D excess through ISM effects and to reveal a notable Doppler shift compared with the control sample.

Furthermore, the overall distribution of late-type NEOs (panel (f)) is shifted toward more negative values than the distribution of the control sample (panel (h)). For example, the mean values of Δμ1 for LTG and cLTG are −0.64 ± 1.09 and 0.35 ± 0.68, respectively. This strongly implies that these galaxies have an outflow component.

Figure 4. Amount of Na D absorption line shift with respect to the Na D line strength. In each panel, the number of sample galaxies and the number of galaxies showing blue or redshift are given. Emission-line classification (based on the BPT diagnostic) is also given in different colors. The gray band shows the range (encompassing 95% of the sample) of Doppler shift exhibited by the control sample in panels (g) and (h). For NEOs, the number and fraction of galaxies showing significantly blueshifted Na D absorption features (below the bands) are shown in the bottom left corner of each panel (from (a) to (f)). Note that the bulk of our sample galaxies shows a systematic redshift by 0.6 Å compared to the prediction from the vacuum experiment. We only focus on the difference between each sample and the control sample.

\[
Δμ_1 = μ_1 - 5891.6 \, \text{Å},
\]

where \( μ_1 \) and 5891.6 are the left-dip positions of the best fit for each galaxy and the Na D absorption lines in vacuum, respectively. If the line shows a blueshift Doppler departure from the bulk of the stellar population, \( Δμ_1 \) has a negative value.
We checked the BPT classification for the 78 late-type NEOs with blueshifted Na D lines. Of 78, 41 and 30 galaxies are star-forming (SF) and composite (Co) galaxies, respectively, and only 5 galaxies are AGNs. Such findings suggest that the Na D excess found in these galaxies is related to gaseous outflows caused by star formation (galactic winds), which play an important role in the evolution of galaxies by removing/heating cold gas in galaxies.

We thus conclude that early-type NEOs and late-type NEOs have completely different mechanisms underlying their Na D excess. Many late-type NEOs clearly show blueshift in their Na D lines, which means that their Na D excess is related with ISM. On the other hand, early-type NEOs do not show any significant Doppler component. While this does not necessarily rule out the possibility of an ISM origin, it would be much more natural to conclude that their excessive Na D is of stellar origin. To facilitate follow-up observations of these exciting objects, we provide a catalog of the sample galaxies presented in this paper in Table 1.

H.J. acknowledges support from the Basic Science Research Program through the National Research Foundation of Korea (NRF), funded by the Ministry of Education (NRF-2013R1A6A3A04064993). S.K.Y. acknowledges support from the National Research Foundation of Korea (Doyak 2014003730). This study was performed under the DRC collaboration between Yonsei University and the Korea Astronomy and Space Science Institute.

### Table 1

| SDSS object id | f/NaD | Na D | Morphology | BPT class | A1 | A2 | μ₁ | μ₂ | σ | γ | λ² |
|----------------|-------|------|------------|-----------|----|----|-----|-----|----|----|----|
| 587727179531354122 | 0.53 | 4.65 | oETG | Quiescent | 0.32 | 0.24 | 5892.8 | 5898.5 | 1.0 | 2.3 | 0.9 |
| 588009365862285317 | 0.53 | 4.76 | pETG | LINER | 0.20 | 0.19 | 5891.1 | 5897.3 | 2.7 | 3.0 | 0.8 |
| 587727179528339473 | 0.74 | 4.96 | oLTG | LINER | 0.31 | 0.28 | 5892.3 | 5898.3 | 1.5 | 2.3 | 1.9 |
| 587737827826204741 | 0.94 | 4.04 | pLTG | Star-forming | 0.21 | 0.16 | 5889.0 | 5894.9 | 2.3 | 3.3 | 1.9 |
| 587731186749053163 | 0.03 | 2.97 | cETG | Quiescent | 0.19 | 0.11 | 5892.2 | 5898.6 | 2.7 | 1.5 | 1.4 |
| 58772298278889623 | 0.00 | 2.31 | cLTG | Star-forming | 0.20 | 0.16 | 5891.9 | 5898.0 | 0.8 | 2.2 | 1.0 |

**Note.**
- Redshift and photometry information is also available in the machine-readable table file.
- Observed line strength.
- Optical morphology. o: ordinary, p: peculiar, c: control, ETG: early-type, LTG: late-type.
- Emission line classification by the BPT diagnostic.
- Depth of the left Gaussian component.
- Depth of the right Gaussian component.
- Centroid of the left Gaussian component.
- Centroid of the right Gaussian component.
- Standard deviation of Gaussian component.
- FWHM of Lorentzian component.

(This table is available in its entirety in machine-readable form.)

We checked the BPT classification for the 78 late-type NEOs with blueshifted Na D lines. Of 78, 41 and 30 galaxies are star-forming (SF) and composite (Co) galaxies, respectively, and only 5 galaxies are AGNs. Such findings suggest that the Na D excess found in these galaxies is related to gaseous outflows caused by star formation (galactic winds), which play an important role in the evolution of galaxies by removing/heating cold gas in galaxies.

We thus conclude that early-type NEOs and late-type NEOs have completely different mechanisms underlying their Na D excess. Many late-type NEOs clearly show blueshift in their Na D lines, which means that their Na D excess is related with ISM. On the other hand, early-type NEOs do not show any significant Doppler component. While this does not necessarily rule out the possibility of an ISM origin, it would be much more natural to conclude that their excessive Na D is of stellar origin. To facilitate follow-up observations of these exciting objects, we provide a catalog of the sample galaxies presented in this paper in Table 1.

H.J. acknowledges support from the Basic Science Research Program through the National Research Foundation of Korea (NRF), funded by the Ministry of Education (NRF-2013R1A6A3A04064993). S.K.Y. acknowledges support from the National Research Foundation of Korea (Doyak 2014003730). This study was performed under the DRC collaboration between Yonsei University and the Korea Astronomy and Space Science Institute.

### REFERENCES

Abazajian, K. N., Adelman-McCarthy, J. K., Agüeros, M. A., et al. 2009, ApJS, 182, 543
Cenarro, A. J., Gorgas, J., Wvzekis, A., Cardiel, N., & Peletier, R. F. 2003, MNRAS, 339, L12
Chen, Y., Tremonti, C. A., Heckman, T. M., Kauffmann, G., & Weiner, B. J. 2010, AJ, 140, 445
Davé, R. 2008, MNRAS, 385, 147
Davis, T., Krajnović, D., McDermid, R. M., et al. 2012, MNRAS, 426, 1574
Graves, G. J., Faber, S. M., & Schiavon, R. P. 2009, ApJ, 698, 1590
Heckman, T. M., Lehnert, M. D., Strickland, D. K., & Armus, L. 2000, ApJS, 129, 493
Jeong, H., Yi, S. K., Kyeong, J., et al. 2013, ApJS, 208, 7
O’Connell, R. W. 1976, ApJl, 206, 370
Oh, K., Sarzi, M., Schawinski, K., & Yi, S. K. 2011, ApJS, 195, 13
Peterson, R. C. 1976, ApJL, 210, 123
Saglia, R. P., Maraston, C., Thomas, D., Bender, R., & Colless, M. 2002, ApJl, 579, L13
Spiniello, C., Trager, S. C., & Koopmans, L. V. E. 2015, ApJ, 803, 87
Spiniello, C., Trager, S. C., Koopmans, L. V. E., & Chen, Y. S. K. 2012, ApJL, 753, L32
Trager, S. C., Faber, S. M., Worthey, G., & González, J. I. 2000, AJ, 120, 165
Treu, T., Auger, M. W., Koopmans, L. V. E., et al. 2010, ApJ, 709, 1195
van Dokkum, P. G. 2008, ApJ, 674, 29
van Dokkum, P. G., & Conroy, C. 2010, Natu, 468, 940
van Dokkum, P. G., & Conroy, C. 2012, ApJ, 747, 69
Worthey, G. 1998, PASP, 110, 888
Worthey, G., Faber, S. M., & González, J. I. 1994, ApJ, 94, 687
Worthey, G., Ingermann, B. A., & Serven, J. 2011, ApJ, 729, 148
Yi, S. K., & Jeong, H. 2015, in Proc. IAU Symp. 311, Galaxy Masses as Constraints of Formation Models, ed. M. Cappellari & S. Courteau (Cambridge: Cambridge Univ. Press), 69
Erratum: “Outflows in Sodium Excess Objects” (2015, ApJ, 809, 91)

Jongwon Park1, Hyunjin Jeong2,3, and Sukyoung K. Yi1

1 Department of Astronomy, Yonsei University, Seoul 120-749, Republic of Korea; jwpark@astro.umd.edu, yi@yonsei.ac.kr
2 Korea Astronomy and Space Science Institute, Daejeon 305-348, Republic of Korea
3 Korea University of Science and Technology, Daejeon 305-350, Republic of Korea

Received 2018 November 8; published 2018 December 13

Supporting material: machine-readable table

In the machine-readable table provided with the published article, the coordinates of some galaxies were wrong. Errors were confined to the coordinates alone, and thus the results of the published article were not affected by them. The revised database is provided in Table 1. We apologize for the inconvenience and thank Marion Schmitz for finding the errors.

Table 1
A Sample of the Catalog of Na D Excess Objects and Control Sample (Critical Columns Only)a

| SDSS Object id | fNaD | Na Dλ | Morphologyc | BPT clased | a1e | a2f | μ1g | μ2h | σi | γj | χ2 |
|----------------|------|-------|-------------|------------|-----|-----|------|------|-----|-----|-----|
| 58772179531354122 | 0.53 | 4.65 | oETG | Quiescent | 0.32 | 0.24 | 5892.8 | 5898.5 | 1.0 | 2.3 | 0.9 |
| 588009365862285317 | 0.53 | 4.76 | pETG | LINER | 0.20 | 0.19 | 5891.1 | 5897.3 | 2.7 | 3.0 | 0.8 |
| 58772179528339473 | 0.74 | 4.96 | oLTG | LINER | 0.31 | 0.28 | 5892.3 | 5898.3 | 1.5 | 2.3 | 1.9 |
| 587737827826204741 | 0.94 | 4.04 | pLTG | Star-forming | 0.21 | 0.16 | 5889.0 | 5894.9 | 2.3 | 3.3 | 1.9 |
| 587731186740953163 | 0.03 | 2.97 | cETG | Quiescent | 0.19 | 0.11 | 5892.2 | 5898.6 | 2.7 | 1.5 | 1.4 |
| 58772298227889623 | 0.00 | 2.31 | cLTG | Star-forming | 0.20 | 0.16 | 5891.9 | 5898.0 | 0.8 | 2.2 | 1.0 |

Notes.
a Redshift and photometry information is also available in the table file.
b Observed line strength.
c Optical morphology. o: ordinary, p: peculiar, c: control, ETG: early-type, LTG: late-type.
d Emission line classification by the BPT diagnostic.
e Depth of the left Gaussian component.
f Depth of the right Gaussian component.
g Centroid of the left Gaussian component.
h Centroid of the right Gaussian component.
i Standard deviation of Gaussian component.
j FWHM of Lorentzian component.

(This table is available in its entirety in machine-readable form.)

ORCID iDs

Sukyoung K. Yi https://orcid.org/0000-0002-4556-2619