SDSS J2125-0813: the evidence for the origination of optical FeII emission lines from accretion disk near central black hole

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ABSTRACT
We report on the radio quiet quasar SDSS J2125-0813 which obviously emits optical FeII emission lines and double-peaked broad Balmer emission lines. Using the accretion disk model for double-peaked broad low-ionization emission lines, we reproduce the composite line spectra at the optical band between 4100 Å and 5600 Å. Broad FeII emission lines can be fit simultaneously with the broad Hβ and MgI lines, such that all broad lines have an elliptical disk profile with the same disk parameters. This result indicates that the optical FeII emission lines originate from the accretion disk near the central black hole which produces the double-peaked broad Balmer emission lines. Furthermore, we find that the object has dimensionless accretion rate $\dot{m}\sim0.4-0.6$ which is much larger than accretion rate for ADAF mode, and that the energy budget of the accretion disk is enough to power the double-peaked broad Balmer emission lines.

Key words: Galaxies:Active – Quasars:Emission lines – accretion disk

1 INTRODUCTION
Greenstein & Schmidt (1964) first identified FeII emission lines in the spectra of quasars. FeII emission lines have been observed and studied in Active Galactic Nuclei (AGN) for more than fifty years, and some meaningful results have been found. The ratio FeII4570/Hβ and the equivalent width W(FeII4570) anti-correlate with the line width of Hβ (Boroson et al., 1983; Zheng & O’Brien, 1991; Zheng & Keel, 1993). FeII emission is weak in steep spectrum radio sources (Boroson & Green, 1992). A large value of the ratio FeII4570/Hβ corresponds to a high soft x-ray variability (Moran et al., 1994). A detailed study of the line-related correlations for FeII emission lines can be found in Sulentic, Marziani & Dultzin-Hacyan (2000): for example, the strong anti-correlation between EW(FeII4570)/EW(Hβ) and FWHM(Hβ). These correlations are discussed in the context of the so called Eigenvector 1 parameter space where the authors define a population A (FWHM(Hβ broad)<4000 km s⁻¹), and a population B (FWHM(Hβ broad)>4000 km s⁻¹), which turns out to be a cleaner distinction for objects with FeII emission lines than Radio-loud vs. Radio-quiet objects.

It is widely accepted that there are two main kinds of models which can reproduce the observed shape and equivalent width of FeII emission lines: Photoionization models with microturbulence (Korista et al., 1997; Bottorff et al., 2004; Netzer, 1985; Baldwin et al., 2004) in the context of LOC model (Baldwin, 1995) and collisionally excited models (Grandi, 1981; 1982; Kwan et al., 1995; Dumont et al., 1998; Baldwin et al., 2004). Due to the large amount of FeII emission lines, it is hard to discriminate between photoionization and collisional excitation. There are two ways to estimate the intensities of FeII emission lines, theoretical line ratios predicted from a model, as is done in this paper, and empirical measurements from FeII templates adapted from I Zwicky 1 (PG 0050+124) (Philips, 1978; Oke & Lauer, 1979; Borson & Green, 1992; Laor et al., 1997; Marziani et al., 2003).

The origin of FeII emission lines is one of the problems which have not been solved completely. Generally, there are two possible origins: the FeII emission lines come from an illuminated (photoionized) region in the accretion disk near central black hole or from shock heated regions in the base of a jet. Both scenarios depend on the inclination of the accretion disk which can give an explanation to the small number of strong FeII emission line objects, and both scenarios provide the high density and high optical depth required for strong FeII emission lines. According to the anti-correlation between EW(FeII)/EW(Hβ) and line width of broad Hβ,
some authors (Zheng & Keel, 1991; Joly, 1985; Wang et al., 1994; Sulentic, Marziani & Dultzin-Hacyan, 2000) predict that the strength of FeII emission lines may be influenced by the inclination angle of accretion disk near central BH and by the luminosity-to mass ratio of active nucleus. Furthermore, FeII emission lines may be one of the important parameters to test different models of AGN (Lipari et al., 1996; Sulentic, Marziani & Dultzin-Hacyan, 2000) predict lines originate from the accretion disk near the central black hole, similarly to the broad lines in a special class of AGN: the double-peak broad low-ionization emission line objects (hereafter, dbp emitters). The double-peak broad low-ionization emission lines are considered to come from the accretion disk near central black hole (Chen & Halpern, 1983; Chen et al., 1989; Chen et al., 1997; Eracleous & Halpern, 1994; Storchi-Bergmann et al., 2003; Chakrabarti & Wiita, 1994; Hartnoll & Blackman, 2002; Karas, Martocchia, & Subr 2001). There are some signs that objects with very broad Balmer lines actually have weak or absent optical FeII emission lines, thus, there are no clues about the properties of optical FeII emission lines for dbp emitters, because the line width of broad Balmer lines is about six times larger than that of normal AGN (Strateva et al., 2001). Here we report on one quasar, SDSS J212501.21-081328.6 at z = 0.623 (hereafter, SDSS J2125-0813, the redshift is provided by SDSS), selected from SDSS, which has both double-peak broad Balmer emission lines, and relatively strong optical and UV FeII emission lines. The structure of the paper is as follows: Section 2 gives the analysis of the observed spectrum and results. Section 3 gives a discussion and conclusions. The cosmological parameters Ω0 = 0.7 and Ωm = 0.3 have been adopted here.

2 OBSERVATION AND RESULTS

The apparent optical PSF magnitudes of SDSS J2125-0813 are 17.78, 17.13, 17.07, 16.96, 17.01 at u, g, r, i and z band respectively. The radio flux at 20cm of SDSS J2125-0813 is 1.59mJy provided by FIRST. The radio-loudness (R = L20cm/L4400Å), 2.95, indicates SDSS J2125-0813 is a radio-quiet quasar. Using the SDSS 2.5m telescope sited at Apache Point Observatory, the reddening corrected (with E(B-V) = 0.068) spectrum of SDSS J2125-0813 with total exposure time 8406 seconds is shown in Figure 1.

Before proceeding further, a careful analysis of the continuum is carried out. From the spectrum, there are obviously double-peak broad Hβ, Hγ and an 3100Å bump which is made up of UV FeII emission lines and Balmer continuum emission (Neugebauer et al., 1987). Thus when we fit the continuum, we avoid these features. We select three wavelength regions, from 2900Å to 3050Å, from 3050Å to 4150Å and from 4140Å to 5600Å to determine the continuum. The fit results with the format $f_\lambda \propto \lambda^{-1.99}$ are shown in Figure 1. SDSS J2125-0813 is a flat-spectrum radio-quiet quasar. We notice that there is a much weaker double-peak broad Hδ around 4100Å. So the level of the continuum might be a little overestimated. The spectrum at optical band after the subtraction of continuum is also shown in Figure 1. Furthermore, we select the wavelength range from ~4950Å to ~5050Å to determine the line parameters of the [OIII] doublet by two gaussian functions adding a background. According to the fit results, the line width of the [OIII] doublet is the same within the error, and the line flux ratio is near to 0.33 within the error. The best fit results for the [OIII] doublet are shown in Figure 1. We notice that the center wavelength of [OIII]$\lambda$5007Å, 5014Å, deviates from the vacuum wavelength (5008.24Å), the same deviation of the center wavelength is found for [OIII]$\lambda$3727Å. Thus, the redshift of SDSS J2125-0813 should be corrected to 0.621.

After the subtraction of continuum, we first try to fit the double-peak broad Hβ using the elliptical accretion disk model (Eracleous et al., 1993). But, we notice the presence of obvious FeII and/or MgI and/or FeIII emission lines sitting on the wings of Hβ (The wings of the double-peak broad emission lines depend sensitively on inner radius of accretion disk model). We do not get the complete line profile of double-peak broad Hβ, so we fit all the line spectra between 4100Å and 5600Å. In this range of wavelength, there are Hβ, Hγ, [OIII]$\lambda$4959, 5007Å, FeII emission lines, MgI and/or FeIII emission lines. The [OIII] doublet can be subtracted using the results above. The double-peak line profile of Hβ in velocity space, $f_{\delta H\beta}$, can be reproduced by the elliptical disk model with 8 free parameters. The line profile of the double-peak Hγ in velocity space is estimated by $k_{H\gamma/H\beta} * f_{\delta H\beta}$, i.e., the line profile of Hγ is the same as that of Hβ in velocity space, except for the flux density, where $k_{H\gamma/H\beta}$ is the flux ratio of Hγ to Hβ. Furthermore, we assume that FeII emission lines in SDSS J2125-0813 are also broadened by the orbiting elliptical accretion disk, and have the same double peak line profile as that of Hβ in velocity space. The same assumptions are valid for MgI and FeIII emission lines. The line profiles in velocity space of MgI and optical FeII, FeIII emission lines are estimated using: $k_{MgI/total}/H\beta * f_{\delta H\beta}$, $k_{FeII/total}/H\beta * f_{\delta H\beta}$ and $k_{FeIII/total}/H\beta * f_{\delta H\beta}$

Thus there are 12 free parameters in the fitting procedure.

Theoretical FeII emission line strengths for physical conditions typical of AGN with BLR have been presented by Sigut & Pradhan (2003) who considered the following excitation mechanisms: continuum fluorescence (Phillips, 1976; 1977), collisional excitation (Joly, 1991), self-fluorescence among the FeII transitions and fluorescent excitation by Lyα and Lyβ (Penston, 1982; Sigut & Pradhan, 1996; Verner et al., 1999). We collect all 36 FeII emission lines in the wavelength range from 4100Å to 5600Å from Sigut & Pradhan (2003). In our fitting procedure, the flux ratio of different FeII emission lines is the same as the theoretical value. For MgI emission lines, we select the three strongest lines between 5100Å and 5200Å, MgI$\lambda\lambda$5174, 5168Å, the theoretical line strength ratios are 1.166:4.98. For optical FeIII emission lines, we collect the 26 strongest lines between 5000Å and 5600Å (the optical FeIII emission lines between 4100Å and 5000Å are much weaker). The theoretical line strength ratios are selected from the website of Atomic Line List (http://www.pa.uky.edu/~peter/atomic/).

Using the Levenberg-Marquardt technique and adjusting the 12 free parameters (MPFIT package in IDL), we can get the best results of the 12 parameters for the line spectra after the subtraction of [OIII] doublet and continuum. Last, we accept the flux ratio of Hβ to Hγ as 3.7, which indicates some intrinsic absorption. The flux ratio of Hβ to total optical FeII emission lines is 1.85, and the ratio of Hβ to total MgI emis-
sion lines is 87.51. There is almost no optical FeIII emission lines. The best fit results are not good near 4600 Å, we think this is due to CVI λ4607 Å, NIV λ4608 Å and ArII λ4610 Å emission lines. The last best fit results are shown in Figure 2. The value of the added squared residuals is 1996 with degrees of freedom 1351, \( \chi^2 = 1996/1351 = 1.47 \). The inner radius of the elliptical disk is about 31 \pm 6 R_G, the outer radius is about 339 \pm 40 R_G. The eccentricity of the disk is nearly zero. The slope of emissivity is about \( \beta \approx 1.58 \pm 0.19 \). The inclination angle is about 15.2 \pm 1.6 degrees. The local broadening velocity \( \sigma \) is about 2617 \pm 277 km \cdot s^{-1}. The excellent fit to the FeII emission lines supports the conclusion that the optical FeII emission lines are coming from the same place in the disk as the double-peaked broad Hβ.

We examine the possibility that the FeII emission lines originate from "normal" Broad Line clouds. We try to fit the pure FeII spectrum after subtraction of the Balmer emission, the [OII] doublet, etc. using Gaussian profiles. The result yields a FWHM for each FeII emission line of about 14998 \pm 605 km \cdot s^{-1} with \( \chi^2 \approx 1.68 \). This is an unreasonable value for normal BLR clouds. Furthermore, if we notice that the FWHM of Hβ is also about 14800 km \cdot s^{-1}, the coincidence in velocities indicates that FeII emission lines originate from the same place as the broad Hβ. According to the value of \( \chi^2 \) and the same line width, we think the accretion disk model gives a better fit.

3 DISCUSSION AND CONCLUSIONS

SDSS J2125-0813 has been mentioned as one of dbp emitters in other papers (Wu & Liu, 2004; Strateva et al., 2003), however, there is no discussion about the mass of the BH. In this case the continuum luminosity and line width of broad Hβ can not be used to estimate the mass of central black hole under the assumption of virialization. The size of broad emission line regions (BLRs) estimated by the empirical relation \( R_{BLR} = L^{0.79}_{5100Å} \) (Wandel et al., 1999; Kaspi et al., 2000; 2005; Peterson et al., 2004), \( R_{BLR} \sim 234.5 \text{light - days} \), is much larger than the size of the accretion disk (for \( M_{BH} \sim 10^8 M_\odot \), 1000R_G \sim 5.6 \text{ light-days} ). We will discuss the difference between the true size of BLRs of dbp emitters and the size of BLRs from the empirical relation in a forthcoming paper. In this case, we estimate the mass of the BH with another method through the line width of the [OIII] emission lines as tracers of the stellar velocity dispersion \( \sigma \) (Tremaine et al., 2002; Gebhardt et al., 2000; Nelson & Whittle, 1996; Boroson, 2003), which yields a value of \( M_{BH} \approx 10^{8.15} \sigma(200) \approx 3.1 \times 10^5 M_\odot \). If the mass of the BH is estimated with from the continuum luminosity (Peterson et al., 2004), \( M_{BH} \propto L^{0.79}_{5100Å} \sim 8.2 L^{1.8}_{5100Å} \), the value is not very different from that estimated by the line width of [OIII]λ5007 Å. The mass of the BH confirms that the size of the accretion disk is much smaller than the radius estimated from the continuum luminosity.

We can also estimate the dimensionless accretion rate, \( \dot{m} = \frac{L_{bol}}{L_{Edd}} \), where \( L_{Edd} \) is the Eddington luminosity given by \( L_{Edd} = 1.26 \times 10^{46} \text{erg} \cdot s^{-1} M_{BH}/10^8 M_\odot \) and \( L_{bol} \) is the bolometric luminosity given by \( L_{bol} \approx 9 \times 13 \times L^{5100Å}_{bol} \) (Wandel et al., 1999; Kaspi et al., 2000). The accretion rate is \( \dot{m} \approx 0.4 \) \sim 0.6, much larger than the mean value of accretion rate 0.01 for the sample of double-peaked emitters in the paper of Wu & Liu (2004). In their paper, the largest value of accretion rate is about 0.12 for SDSS J1710+6521. This is in agreement with the tendency for strong FeII emitters to be found in large accretion rate (population A according to Sulentic, Marziani & Dultzin-Hacyan, 2000) objects. We also find that the optical-X-ray spectral index is \( \alpha_{OX} = 1.2 \) for SDSS J2125-0813 with higher luminosity \( L_{5100Å} \sim 10^{45.36} \text{erg} \cdot s^{-1} \), which is not larger than the mean value for low luminosity double-peaked broad line objects found in nearby galaxies, \( \alpha_{OX} \approx 0.9 - 1.1 \).

We can also estimate the energy budget of the disk by integrating the formula for standard thin accretion disk, \( \dot{W}_{disk}(r_{in}, r_{out}) \approx 2.58 \times 10^{44} \eta^{-1} \text{erg} \cdot s^{-1} \), where \( \eta \) is efficiency of conversion of energy. The luminosity of Hβ is about \( L_{H\beta} \sim 3.14 \times 10^{43} \text{erg} \cdot s^{-1} \). If we accept \( \eta \approx 0.01 - 0.06 \), then the energy budget of the accretion disk could be enough to power the broad double-peaked Balmer line. When the accretion disk model was first proposed for double-peaked broad low-ionization emission line object Arp 102B (Chen et al., 1989), the luminosity of Hα exceeded the power output of the accretion disk. Thus, an ion torus or a hot corona around the inner accretion disk was definitely needed for illumination on the regions which produce double-peaked emission lines from the inner part of the accretion disk. This problem of energy budget is confirmed in other double-peaked objects which are classified as LINERs in the paper of Eracleous & Halpern (1994). If there is an ion torus in the inner part of the accretion disk, the blue bump should be much weaker. However, SDSS J2125-0813 is a normal quasar with an obvious UV bump, thus the ion torus in the inner part of the accretion disk is not necessary. The normal quasar spectra also indicates that the accretion mode is not ADAF which is consistent with the value of dimensionless accretion rate.

The object studied in this paper obeys the strong correlation between EW(FeII 4570)/EW(Hβ) and FWHM(Hβ) (Sulentic, Marziani & Dultzin-Hacyan, 2000). The result confirms that Population A/B in PCA Eigenvector 1 space is a cleaner distinction for strong FeII emission lines. Furthermore, for radio loud object, the continuum should consist of two components, one from nucleus, another from jet, which leads to a smaller value of EW(FeII 4570). For radio loud dbp emitters, the contribution of jet is much larger because of inclination angle. Whether the FeII properties of other dbp emitters are the same as that of SDSS J2125-0813 will be studied in a following paper.

The separation of the blue peak (\( \sim 4840Å \)) from the center wavelength of Hβ, \( \sim 20Å \), is much smaller than that of the red peak (\( \sim 4960Å \)), \( \sim 100Å \). This does not obey the correlation between peak separation and dimensionless accretion rate found in Wu & Liu (2004). This is perhaps due to the different way to estimate BH mass which leads to a higher dimensionless accretion rate. The line profile best fit by an elliptical disk model with eccentricity \( e \approx 0 \) could reflect the true physical situation to some extent. The line profile of FeII emission fit by the same profile as Hβ indicates that the FeII emission line regions are the same as those of Hβ in SDSS J2125-0813. There is another model for double-peaked broad emission lines, a double-stream along radio jet model (Zheng, Binet et al., 1990). Their results imply that the blue peak should always be higher than the red peak, the blue peak separation should always be larger than
the red peak separation, if the physical environment is the same for both sides of accretion disk. Furthermore, variability studies of double-peaked emission lines favor the accretion disk model (Newman et al., 1997; Gilbert et al., 1999; Storchi-Bergmann et al., 2003), and reverberation mapping experiments have ruled out a bipolar outflow in the canonical dbp emitter 3C 390.3 (Dietrich et al., 1998).

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REFERENCES

Baldwin, J. A., Ferland, G. F., Korista & Vernber, D., 1995, ApJ, 455, L119
Baldwin, J. A., Ferland, G. F., Korista, K. T., et al., astro-ph/0407404
Boroson, T. A., Persson, S. E. & Oke, J. B., 1985, ApJ, 293, 120
Boroson, T. A., 2003, ApJ, 585, 647
Bottorff, M., Ferland, G., Baldwin, J. & Korista, K., 2000, ApJ, 542, 644
Chakrabarti, S. K. & Wiita, P. J. 1994, ApJ, 434, 518
Chen, Kaiyou & Halpern, J., 1999, ApJ, 145, 199
Chen, Kaiyou, Halpern, J. P. & Filippenko, A. V., 1989, ApJ, 339, 742
Chen, Kaiyou, Halpern, J. P. & Titarchuk, L. G., 1997, ApJ, 483, 194
Dietrich, M., et al., 1998, ApJS, 115, 815
Dumant, A. M., Collin-Souffrin, S. & Nazaiova, L., 1998, A&A, 331, 11
Eracleous, M. & Halpern, J. P., 1994, ApJS, 90, 1
Eracleous, M., Livio, M., Halpern, J. P. & Storchi-Bergmann, T., 1995, ApJ, 438, 610
Gebhardt, K., Bender, R., Bower, G., et al., 2000, ApJ, 539, L13
Gilbert, A. M., Eracleous, M., Filippenko, A. V. & Halpern, J. P., 1999, ASPC, 175, 189
Grandi, S. A., 1981, ApJ, 251, 451
Grandi, S. A., 1982, ApJ, 255, 25
Greenstein, J. L. & Schmidt, M., 1964, ApJ, 140, 1
Hartnoll, S. A. & Blackman, E. G. 2002, MNRAS, 332, L1
Karas, V., Martocchia, A. & Subr, L. 2001, PASJ, 53, 189
Joly, M., 1987, A&A, 184, 33
Joly, M., 1991, A&A, 242, 49
Kaspi, S., Smith, P. S., Netzer, H., et al., 2000, ApJ, 533, 631
Kaspi, S., Maoz, D., Netzer, H. & Peterson, B. M., 2005, ApJ, 629, 1
Korista, K., Baldwin, J., Ferland, G. & Verner, D., 1997, ApJS, 108, 401
Kwan, J., Cheng, F-Z., Fang, L-Z., Zheng, Wei & Ge, J., 1995, ApJ, 440, 628
Laor, A., Jannuzi, B. T., Green, R. F. & Boroson, T. A., 1997, ApJ, 489, 656
Lipari, S., Terlevich, R. & Macchetto, F., 1993, ApJ, 406, 451
Marziani, P., Sulentic, J. W., Zamanov, R., Calvani, M., Dulitzin-Hycan, D., Bachev, R., Zwitter, T., 2003, ApJS, 145, 199
Moran, E. C., Halpern, J. P. & Helfand, D. J., 1996, ApJS, 106, 341
Nelson, C. H. & Whittle, M., 1996, ApJ, 465, 96
Netzer, H., 1985, ApJ, 289, 451
Netzer, H. & Peterson, B. M., in Astronomical Time Series, ed. Maoz, D., Sternberg, A. & Leibowitz, E., 85
Neugebauer, G., Green, R. F. & Boroson, T. A., 1985, ApJ, 289, 451
Newmank, J. A., Eracleous, M., Filippenko, A. V. & Halpern, J. P., 1997, ApJ, 485, 570
Oke, J. B. & Lauer, T. R., 1979, ApJ, 230, 360
Penston, M. V., 1988, MNRAS, 233, 601
Peterson, B. M., 1993, PASP, 105, 247
Peterson, B. M., Ferrarese, L., Gilbert, K. M., et al., 2004, ApJ, 613, 682
Phillips, M. M., 1978, ApJ, 226, 736
Phillips, M. M., 1979, ApJS, 39, 377
Sigut, T. A. A. & Pradhan, A. K., 1998, ApJL, 499, 139
Sigut, T. A. A. & Pradhan, A. K., 2003, ApJS, 145, 15
Storchi-Bergmann, T., Nemmen da Silva, R., Eracleous, M., et al., 2003, ApJ, 598, 956
Strateva, Iskra V., Strauss, M. A., Hao L, et al., 2003, AJ, 126, 1720
Sulentic, J. W., Marziani, P. & Dultzin-Hacyan, D., 2000, ARA&A, 38, 521
Tremaine, S., Gebhard, K., Bender, R., ET AL., 2002, ApJ, 574, 740
Verner, E. M., Verner, D. A., Korista, K. T., et al., 1999, ApJ, 120, 101
Wandel, A., Peterson, B. M. & Malkan, M. A., 1999, ApJ, 526, 579
Wang, T-G., Zhou, Y-Y. & Gao, A-S., 1996, ApJ, 457, 111
Wu, X-B & Liu, F-K, 2004, ApJ, 614, 91
Zheng, Wei, Binetie, L. & Sulentic, J. W., 1990, ApJ, 365, 115
Zheng Wei & O’Brien, P. T., 1990, ApJ, 353, 433
Zheng Wei & Keel, W. C., 1991, ApJ, 382, 121
Figure 1. The spectrum of SDSS J2125-0813 in rest wavelength is shown in upper panel. The continuum is shown in the figure as solid line. The spectrum between 4100Å and 5600Å is shown in the upper-right panel. The bottom panel shows the fit results of [OIII] doublet. The fit parameters are listed in the figure.

Figure 2. The best fit results for spectra smoothed by 6 points between 4100Å and 5600Å are shown in the figure. The dotted line represents the observed spectra. The dashed line represents the best fit results. The solid line represents the profile of Hβ. The dash dot line represents the [OIII] doublet.