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SDSS J0159 as an outlier in the $M_{\rm BH}$–σ space: further clues to support a central tidal disruption event?

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ABSTRACT

In this Letter, properties of black hole (BH) mass are well checked for the interesting object SDSS J0159, a changing-look active galactic nuclei and also a host galaxy of a tidal disruption event (TDE). Through spectral absorption features, the stellar velocity dispersion of SDSS J0159 can be well measured as $\sigma \sim 81\ {\rm km\,s^{-1}}$, leading to SDSS J0159 being an apparent outlier in the $M_{\rm BH}$–σ space, because of the BH mass estimated through the $M_{\rm BH}$–σ relation about two magnitudes lower than the reported virial BH mass of about $10^8\ {\rm M}_{\odot}$. After considerations of contributions of stellar debris from the central TDE to broad line emission clouds, the overestimated virial BH mass could be well explained in SDSS J0159. Therefore, overestimated virial BH masses through broad-line properties in the $M_{\rm BH}$–σ space could be treated as interesting clues to support central TDEs.

Key words: galaxies: active – galaxies: nuclei – quasars: emission lines – galaxies: Seyfert.

1 INTRODUCTION

SDSS J0159 (= SDSS J015957.64+003310.5) is an interesting object, not only due to its being firstly classified as a changing-look QSO in LaMassa et al. (2015) with its apparent type transition from a type 1 quasar in 2000 to a type 1.9 active galactic nuclei (AGN) in 2010, but also due to its long-term variabilities over 10 yr well explained by a tidal disruption event (TDE) in Merloni et al. (2015).

The nature of changing-look AGNs (CLAGNs) is not totally clear so far. More and more evidence strongly indicates that dust obscuration should be not the main reason, but variations of accretion flows should play the key roles as well discussed in LaMassa et al. (2015) and more recently discussed in Yang et al. (2018). Once variations of accretion flows were accepted to CLAGNs, there should be two scenarios.

On the one hand, variations of accretion flows have few effects on dynamical structures of broad emission line regions (BLRs). For this kind of CLAGNs, it should be well confirmed that dynamical properties of broad emission line clouds moving in Keplerian orbits lead to reliable virial BH masses estimated by properties of observed broad emission lines under the virialization assumption (Peterson et al. 2004; Rafiee & Hall 2011) combining with the efficient empirical R–L relation applied to estimate BLRs sizes through continuum/broad line luminosity (Kaspi et al. 2005; Bentz et al. 2013).

On the other hand, variations of accretion flows have apparent effects on dynamical structures of BLRs, such as those cases related to well-known TDEs (Rees 1988; van Velzen et al. 2011; Cenko et al. 2012; Gezari et al. 2012; Guillochon & Ramirez-Ruiz 2013; Guillochon, Manukian & Ramirez-Ruiz 2014; Komossa 2015; Holoien et al. 2016; Wang et al. 2018). Based on the more recent simulated results on TDEs in Guillochon & Ramirez-Ruiz (2013) and Guillochon et al. (2014), accreting fallback debris could provide efficient materials leading to observed broad emission lines, however, there are apparent time-dependent structure evolutions of BLRs from TDE debris. In other words, the empirical R–L relation is not efficient to estimate sizes of the BLRs built by debris from TDEs to some extent, such as the reported abnormal properties of time-dependent variabilities of broad emission lines in the TDE discussed in Holoien et al. (2016). Therefore, due to contributions of TDE debris, more effects should be considered to determine virial BH mass by properties of broad line width and line (or continuum) luminosity.

As a CLAGN and also a TDE candidate for SDSS J0159, it is interesting to check whether are there effects of the probable central TDE on properties of the virial BH mass through broad lines. The main objective of the Letter is trying to find probable clues to support or go against the central TDE in SDSS J0159, after considerations of probable contributions of TDEs to broad emission lines. Section 2 presents our main results on BH mass properties of SDSS J0159, and necessary discussions. Section 3 gives our final conclusions.

2 BH MASS OF SDSS J0159

2.1 Virial BH mass

Under the widely accepted virialization assumption for broad emission lines in SDSS J0159, LaMassa et al. (2015) have estimated

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virial BH mass of $(1.7 \pm 0.1) \times 10^8$ and $(1.6 \pm 0.4) \times 10^8$ $M_\odot$ by properties of the single-epoch spectrum in 2000 and 2010, respectively. Meanwhile, Merloni et al. (2015) have reported virial BH mass of 1.3–1.6 $\times 10^8$ $M_\odot$, similar as the values in LaMassa et al. (2015).

Before proceeding further, there is one point we should note. As the results in LaMassa et al. (2015), it is clear that there are strong effects of obscuration on broad Balmer emission lines in 2010, due to the non-detected broad H β but apparent broad H α in the spectrum. As a consequent result, the applied luminosity of broad H α was underestimated in 2010, leading to lower virial BH masses of SDSS J0159 estimated through spectrum observed in 2010. Therefore, values from spectrum in 2000 are mainly considered.

Moreover, besides the formulas discussed in Vestergaard & Peterson (2006), Greene & Ho (2007), Greene, Peng & Ludwig (2010) accepted by LaMassa et al. (2015) and Merloni et al. (2015), based on the spectroscopic features in 2000, the second moment of broad H β (about 2098 km s^{-1}) combining with the BLRs size of about 30 light-days determined by the empirical relation in Bentz et al. (2013) has been applied to estimate the virial BH mass by the formula well discussed in Peterson et al. (2004), $M_{\rm BH} = 5.5 \times \frac{\sigma({\rm H}\,\beta)^2 \times R_{\rm BLRs}}{G} = 1.6 \times 10^8\,{\rm M}_\odot$, well coincident with the ones in Merloni et al. (2015) and in LaMassa et al. (2015). Therefore, $M_{\rm BH} = (1.7 \pm 0.1) \times 10^8\,{\rm M}_\odot$ was safely accepted as the virial BH mass of SDSS J0159 in the letter.

2.2 Stellar velocity dispersion of SDSS J0159

Besides the virialization method, the well-known $M_{\rm BH}$–σ relation can also be well applied to estimate central BH masses of both quiescent galaxies and AGNs. The $M_{\rm BH}$–σ relation was firstly reported by Ferrarese & Merritt (2000) and Gebhardt et al. (2000), based on dynamic measured BH masses and measured stellar velocity dispersions of a small sample of nearby quiescent galaxies. More recent review of the $M_{\rm BH}$–σ relation for galaxies can be found in Kormendy & Ho (2015). McConnell & Ma (2013) and Savorgnan & Graham (2015) have shown more recent and detailed results on the $M_{\rm BH}$–σ relations for large samples of quiescent galaxies with dynamic measured BH masses. Meanwhile, many studies have reported applications of the $M_{\rm BH}$–σ relation from quiescent galaxies to AGNs (Ferrarese et al. 2001; Woo et al. 2006; Gultekin et al. 2009; Ho & Kim 2014; Woo et al. 2015). More recent and detailed discussions on the $M_{\rm BH}$–σ relations to both AGNs and quiescent galaxies can be found in Bennert et al. (2015): the $M_{\rm BH}$–σ relation for broad line AGNs has the same intercept and scatter as that of reverberation mapped AGNs as well as that of quiescent galaxies. Here, in order to estimate BH mass of SDSS J0159 through the well-improved $M_{\rm BH}$–σ relation, the stellar velocity dispersion should be firstly measured.

There are two methods applied to measure the stellar velocity dispersion of SDSS J0159, based on simple stellar population method (SSP method) applied with a bit different techniques in details: the direct SSP method and the STARLIGHT code. Here, due to higher quality of spectral absorption features, the spectrum within rest wavelength from 3750 to 4700 Å observed in 2010 (PLATE-MJD-FIBERID = 3609-55201-0524) rather than in 2010 is mainly considered, because of none-detected absorption features around Mg Iλ5175Å and Ca IIλ8498, 8542, 8662Å triplet. Moreover, due to similar measured stellar velocity dispersions through absorption features in different wavelength regions (Barth, Ho & Sargent 2002; Greene & Ho 2006; Xiao et al. 2011; Woo et al. 2015), there should be no discussions on effects of different wavelength regions on measured stellar velocity dispersions.

Detailed descriptions on the direct SSP method can be found in Bruzual & Charlot (2003) and Kauffmann et al. (2003). Based on the 39 broadened SSP template spectra in Bruzual & Charlot (2003) plus one power-law function applied to describe AGN continuum emissions, the observed spectrum of SDSS J0159 can be well described through the Levenberg–Marquardt least-squares minimization technique (the MPFIT package). Certainly, when SSP method applied, emission lines have been masked out with FWZI (full width at zero intensity) about 400 km s^{-1}, which are marked by dark green lines in Fig. 1. Left-hand panels of Fig. 1 show the best-fitting results with $\chi^2/{\rm dof} = 951.3/892 = 1.07$ (total squared residuals divided by degree of freedom) and the corresponding residuals $\frac{y-y_m}{y_e}$ with y, y_e, and y_m represent the observed spectrum, the corresponding errors, and the best-fitting results, respectively. Top-right panel shows the sensitive dependence of $\chi^2/{\rm dof}$ on stellar velocity dispersions, as strong evidence to support reliable measured stellar velocity dispersion and the determined stellar velocity dispersion is about $\sigma = (81.4 \pm 26.7)$ km s^{-1}.

Before proceeding further, there is one point we should note. Through the spectral features in 2010, SDSS J0159 has been classified as a main galaxy in SDSS with a pipeline measured stellar velocity dispersion of $\sigma_{\rm SDSS} \sim 169 \pm 24$ km s^{-1}, much larger than our measured value. The main reason leading to the different stellar velocity dispersions is as follows. In our code of the direct SSP method, there is one additional power-law component, besides the stellar template spectra. Once the additional power-law component was removed from the templates, only the stellar template spectra were applied with the direct SSP method, leading to $\chi_2^2/{\rm dof}_2 = 971.9/894 = 1.09$ and $\sigma = 149.9 \pm 22.8$ km s^{-1} which is similar as the SDSS reported value. The best-fitting results and the corresponding residuals are shown in middle panels of Fig. 1, and the dependence of $\chi_2^2/{\rm dof}_2$ on σ is shown in the bottom-right panel. In other words, there are two models with different applied model functions leading to the different determined stellar velocity dispersions. Therefore, it is necessary to check which model is more appropriate, through the F-test technique applied as follows.

Based on the best-fitting results by the two models, the F-value is firstly calculated as

$$F = \frac{(\chi_2^2 - \chi^2)/({\rm dof}_2 - {\rm dof})}{\chi^2/{\rm dof}} = 9.66, \tag{1}$$

where $\chi_2^2 = 971.9$, ${\rm dof}_2 = 894$, and $\chi^2 = 951.3$, ${\rm dof} = 892$ represent the sum of squared residuals and the corresponding degrees of freedom for the best-fitting results by the model functions without a power-law component considered and with the power-law component considered, respectively. Through the comparison between the calculated F-value $F = 9.66$ and the F-value estimated by the F-distribution with the numerator degrees of freedom of ${\rm dof}_2 - {\rm dof}$ and the denominator degrees of freedom of dof, we can conclude which model is preferred. The F-value by the F-distribution with $p = 0.0001$ is 9.31 [the IDL function f_cvf(0.0001, 2, 892)] based on the numerator and denominator degrees of freedom, which is smaller than $F = 9.66$. The result strongly indicates that it is more preferred to describe the spectral absorption features by the stellar template spectra plus the power-law component, with confidence level higher than 1-p = 99.99 per cent. Meanwhile, the observed broad H α also indicates continuum emissions included in the observed spectrum in 2010, such as the determined power-law continuum emissions in LaMassa et al. (2015). Therefore, we finally accepted $\sigma = (81.4 \pm 26.7)$ km s^{-1} as the best estimate to

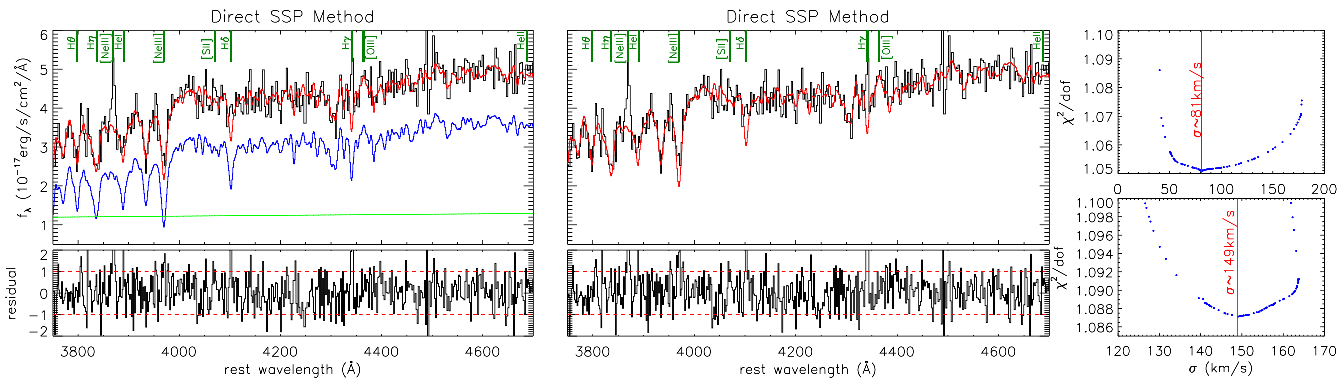

Figure 1. The best-fitting results and the corresponding residuals to the spectral absorption features by the direct SSP method with (left-hand panels) and without (middle panels) considerations of a power-law component. In top left and middle panels, solid lines in black and in red represent the observed spectrum and the best-fitting results, respectively. Thick solid lines in dark green mark the emission lines being masked out when SSP method applied. In top-left panel, solid lines in blue and in green show the determined stellar component and the determined power-law component, respectively. In bottom left and middle panels, solid lines in black show the corresponding residuals, and dashed lines in red show *residual* = ±1. Right-hand panels show the dependence of χ^2/dof on stellar velocity dispersions for model functions with (top right panel) and without (bottom right panel) a power-law component considered.

the stellar velocity dispersion of SDSS J0159 through the direct SSP method, even though the spectrum has lower spectral quality.

Besides the direct SSP method simply applied above, the widely accepted STARLIGHT code has been applied to measure stellar velocity dispersion of SDSS J0159 with more stellar template spectra, in order to ensure our measured stellar velocity dispersion is reliable. The more detailed descriptions on STARLIGHT code can be found in Cid Fernandes et al. (2005). Based on the 159 stellar template spectra created through Bruzual & Charlot (2003), the estimated stellar velocity dispersions are about $\sigma \sim 79$ and $\sigma \sim 151$ km s^{-1} by the STARLIGHT code applied with and without a power-law continuum component considered, respectively. The results are much similar as the ones through the direct SSP method above. And we do not show further results on the best-fitting results to the absorption features in SDSS J0159 by the STARLIGHT code any more, which are totally the same as the ones in Fig. 1. Moreover, after considerations of the power-law component, based on the STARLIGHT code, the calculated total stellar mass is about 7.1×10^{10} M$_\odot$ very similar as the one reported in Merloni et al. (2015). Therefore, with full considerations of existence of the power-law continuum emissions, STARLIGHT code also leads to $\sigma \sim 80$ km s^{-1} of SDSS J0159.

The two different methods lead to the similar stellar velocity dispersion after considerations of the truely existed power-law continuum emissions in the spectrum, indicating the measured value should be reliable to some extent. Certainly, due to lower spectral quality, the velocity dispersion is more likely to be around 81 km s^{-1} as the best estimate, but the larger dispersion may not be absolutely ruled out.

2.3 Properties of SDSS J0159 in the M_{BH}–σ space

Based on the measured stellar velocity dispersion and the reported virial BH mass of SDSS J0159, it is interesting to check properties of SDSS J0159 in the plane of stellar velocity dispersions and BH masses (the M_{BH}–σ space).

Before proceeding further, there are two points we should note. On one hand, after considerations of reliability of BH masses, we only consider the quiescent galaxies with reported BH masses estimated/measured by stellar/gas dynamical techniques and the reverberation mapped AGNs (RM AGNs) with reported BH masses by emission line variability properties from multiepoch spectra. The considered quiescent galaxies and the RM AGNs are listed in Table 1. There are finally 89 quiescent galaxies (including the three galaxies with BH masses larger than $\sim 10^{10}$ M$_\odot$ in McConnell et al. 2011 and in Thomas et al. 2016) and 29 RM AGNs collected from the literature with more reliable BH masses.

Table 1. The accepted M_{BH}–σ relations.

Obj	N	α	β	Ref.
QG	89	8.24 ± 0.10	6.34 ± 0.80	Savorgnan & Graham (2015)
QG	72	8.32 ± 0.05	5.64 ± 0.32	McConnell & Ma (2013)
QG	51	8.49 ± 0.05	4.38 ± 0.29	Kormendy & Ho (2015)
RA	29	8.16 ± 0.18	3.97 ± 0.56	Woo et al. (2015)
RAC	16	7.74 ± 0.13	4.35 ± 0.58	Ho & Kim (2014)
RAP	14	7.40 ± 0.19	3.25 ± 0.76	Ho & Kim (2014)
RA	25	8.02 ± 0.15	3.46 ± 0.61	Woo et al. (2013)

Note. The first column shows what objects are used: QG for Quiescent galaxies, RA for reverberation mapped AGNs, RAC for reverberation mapped AGNs with classical bulges, RAP for reverberation mapped AGNs with pseudo-bulges. The second column shows number of the used objects. The fifth column shows the corresponding reference.

On the other hand, through different samples of active and/or quiescent galaxies, there are much different M_{BH}–σ relations

$$\log\left(\frac{M_{BH}}{M_\odot}\right) = \alpha + \beta \times \log\left(\frac{\sigma}{200\ \mathrm{km\ s^{-1}}}\right), \quad (2)$$

reported in the literature, such as the results listed in Table 1. Here, after considerations of uncertainties of both BH masses and stellar velocity dispersions for the collected both quiescent galaxies and RM AGNs with more reliable BH masses, the M_{BH}–σ relation is re-calculated as,

$$\log\left(\frac{M_{BH}}{M_\odot}\right) = (8.22 \pm 0.04) + (4.81 \pm 0.21) \times \log\left(\frac{\sigma}{200\mathrm{km\ s^{-1}}}\right). \quad (3)$$

Here, the least trimmed squares (LTS) regression technique discussed in Cappellari et al. (2013) is applied to find the best-fitting results and the corresponding 68 per cent and 99 per cent confidence bands. The results are shown in Fig. 2

Now, it is interesting to check properties of SDSS J0159 in the M_{BH}–σ space, shown in Fig. 2. It is clear that SDSS J0159 is an

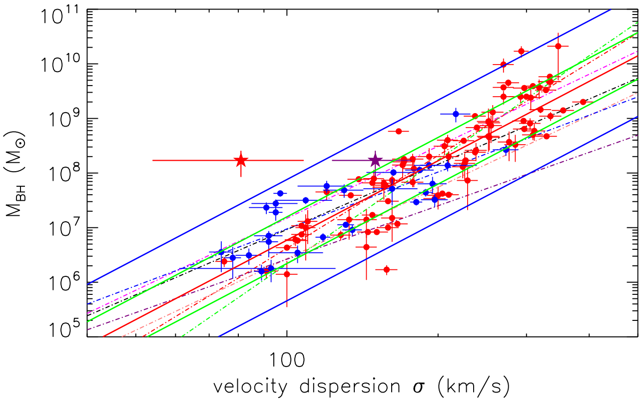

Figure 2. On the correlation between stellar velocity dispersions and BH masses. Solid five-point-star in red shows the values of SDSS J0159 with the best estimate of $\sigma \sim 81\,\mathrm{km\,s^{-1}}$, and solid five-point-star in purple shows the values of SDSS J0159 with $\sigma \sim 150\,\mathrm{km\,s^{-1}}$. Solid circles in red and in blue show the values for the 89 quiescent galaxies and the 29 RM AGNs, respectively. Solid lines in red, in green, and in blue show the best-fitting results and the corresponding 68 per cent and 99 per cent confidence bands, respectively. Dot–dashed lines in green, in red, in magenta, in black, in pink, in purple, and in blue represent the M_{BH}–σ relations listed from top to bottom in Table 1.

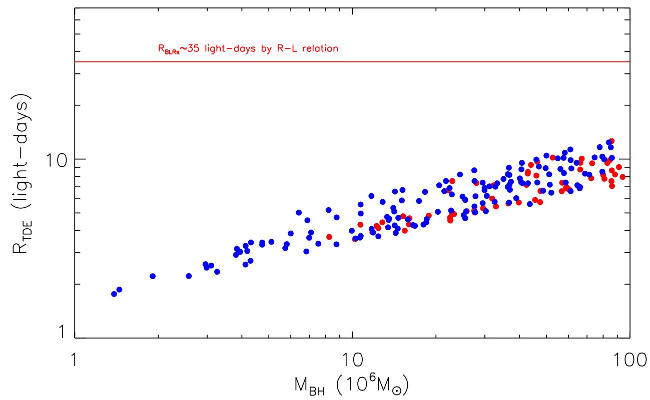

Figure 3. Properties of R_{TDE} at t_{p} calculated through TDE simulations. Circles in red and in blue represent the results for the cases with central tidal disrupted stars with polytropic indices of 4/3 and 5/3, respectively. The horizontal red line shows the position of BLRs sizes $R_{\mathrm{BLRs}} \sim 35$ light-days determined by the R–L relation for SDSS J0159 in 2000.

apparent outlier in the space if the best estimate of $\sigma \sim 81\,\mathrm{km\,s^{-1}}$ accepted, and the virial BH mass is about two magnitudes higher than the value estimated through the M_{BH}–σ relation. Unfortunately, once $\sigma \sim 150\,\mathrm{km\,s^{-1}}$ accepted, SDSS J0159 in the space also deviates from the best description on the M_{BH}–σ relation, but is not an apparent outlier in the space. Here, in the letter, as well discussed results above on the measured stellar velocity dispersions, the following discussions on SDSS J1059 are based on the point that the best estimate of stellar velocity dispersion is about $81\mathrm{km\,s^{-1}}$. And moreover, even accepted the discussed results in Ho & Kim (2014): BH masses of objects with pseudo-bulges could be statistically lower than the values estimated by the M_{BH}–σ relation, it is hard to explain why SDSS J0159 is an outlier in the M_{BH}–σ space, because SDSS J0159 has its virial BH mass higher not lower than the value estimated through the M_{BH}–σ relation. Therefore, properties of pseudo-bulge cannot be applied to explain why is SDSS J0159 an outlier in the M_{BH}–σ space, and no further discussions on properties of bulge of SDSS J0159.

2.4 Outliers in the M_{BH}–σ space could be treated as clues to support central TDEs?

If $\sigma \sim 81\mathrm{km\,s^{-1}}$ is taken as the best estimate for the velocity dispersion, it is now very interesting to consider a question why is SDSS J0159 an outlier in the M_{BH}–σ space? We try to answer the question after considerations of properties of CLAGNs and central TDEs, in order to find further clues on whether outliers in the M_{BH}–σ space could be treated as interesting clues to support central TDEs.

First and foremost, through normal variabilities of accretion flows, similar as accretion variabilities in normal AGNs, applied to explain the observed properties of CLAGN SDSS J0159, there were few effects on dynamical structures of broad emission line clouds. Lower (stronger) ionization emissions lead to smaller (deeper) ionization boundary (smaller BLRs sizes), and then wider (narrower) broad line widths. It is hard to expect significantly overestimated or underestimated virial BH masses. Meanwhile, if combining with dust obscuration which have been applied to partly explain some CLAGNs, continuum (or broad line) luminosity from observed spectrum could be smaller than intrinsic value, leading to a bit smaller BLRs sizes through the R–L empirical relation. Furthermore, if BH mass is small as inferred from $\sigma \sim 81\mathrm{km\,s^{-1}}$ through M_{BH}–σ relation for SDSS J1059 leading to much larger Eddington ratio of about 3.6, the size of BLRs estimated through the R–L relation could be overestimated (Du et al. 2018) by a factor about 2. It is clear that the effects of high Eddington ratio cannot still explain the overestimated virial BH mass in SDSS J0159. Therefore, under the considerations of normal variations of accretion rates for CLAGNs combining with dust obscuration (similar as the cases on accretion variabilities in normal AGNs), not overestimated but underestimated virial BH mass could be expected to some extent. The results are not coincident with the overestimated virial BH mass in SDSS J0159.

Besides, through a central TDE applied to explain the observed properties of SDSS J0159, the broad emission lines were totally or partly from material clouds related to stellar debris. If the BLRs consist of materials from stellar debris, the BLRs may not be fully virialized. Therefore, virial method should be not so efficient to estimate virial BH mass. Based on the simulated results on TDEs in Guillochon et al. (2014), the length-scale of stellar debris R_{TDE} (the parameter r_o in Guillochon et al. 2014) could be about $r \sim t^{2/3}$; however, the time-dependent accretion luminosity from the central TDE is decreasing after the time of peak accretion (t_{p}). Therefore, L_{TDE} and R_{TDE} cannot follow the empirical R–L relation determined from normal reverberation mapped AGNs.

In order to show much clear results on R_{TDE}, Fig. 3 shows the calculated R_{TDE} at t_{p} from TDEs with central BH masses randomly collected from 10^6 to $10^8\,\mathrm{M_{\odot}}$, central tidal disrupted stars randomly collected with masses from 0.1 to 20 $\mathrm{M_{\odot}}$ and with polytropic indices of 4/3 and 5/3, respectively. Here, the following four criteria have been accepted. The first is that the calculated tidal disruption radius must be larger than event horizon of central BH. The second is that the calculated peak accretion rate from TDEs should be from 0.2 to 0.3 $\mathrm{M_{\odot}\,yr^{-1}}$, leading to peak bolometric luminosity from TDEs around $1.5 \pm 0.2 \times 10^{45}\ \mathrm{erg\,s^{-1}}$ (the value for SDSS J0159 in 2000 with 10–15 as the ratio of bolometric luminosity to optical luminosity). The third is that the calculated t_{p} should be from 0.8 to 2 yr, similar as the case in SDSS J0159 as discussed in Merloni et al. (2015). The forth is the mass–radius relation has been accepted to the main-sequence stars, but with maximum uncertainties of about 50 per cent. For SDSS J0159, the estimated BLRs size in 2000 (around t_p for the TDE in SDSS J0159) is about 35 light-days by the R–L relation, much larger than the calculated R_{TDE} shown in Fig. 3. Therefore, effects of central TDEs should lead to overestimated virial BH masses through properties of single-epoch spectrum observed around t_p due to larger BLRs sizes than intrinsic values, if there were strong contributions of stellar debris to broad line regions.

Last but not the least, we give some further discussions on the case for the central TDE in SDSS J0159. Based on the measured stellar velocity dispersion, the BH mass can be roughly estimated as 2.15×10^6 $M_\odot$ through the M_{BH}–σ relation in equation (3), indicating R_{TDE} about 2 light-days by the results shown in Fig. 3, about 17 times smaller than the luminosity expected BLRs sizes by the R–L relation. Actually, R_{TDE} represents the outer boundaries of materials in disc-like regions in TDEs, the velocity-dependent locations of emission line clouds should be much smaller than R_{TDE}. Thus, the calculated virial BH mass could be several tens of times larger than intrinsic BH mass for SDSS J0159, similar as the results shown in Fig. 2, if accepted that BH mass through the M_{BH}–σ relation reliable enough. In other words, the overestimated virial BH mass leading to SDSS J0159 as an outlier in the M_{BH}–σ space could be treated as a strong evidence to support a central TDE in SDSS J0159.

In brief, after considerations of contributions of stellar debris from central TDEs to broad line clouds, it is inefficient to estimate BLRs sizes by the commonly applied R–L empirical relation, leading to overestimated virial BH masses measured through observed broad line properties of line width and line (and/or continuum) luminosity. Hence, overestimated virial BH masses in the M_{BH}–σ space could be treated as interesting clues to support central TDEs in AGNs.

3 CONCLUSIONS

Finally, we give our main conclusions as follows. Based on different methods applied to describe the spectral absorption features, the stellar velocity dispersion can be well measured as $\sigma \sim 81$ km s^{-1} for the interesting object SDSS J0159, a CLAGN, and also a host galaxy of a central TDE. Comparing to the reported virial BH mass of $\sim 10^8$ $M_\odot$ in the literature, the small σ leads SDSS J0159 to be an apparent outlier in the well-known M_{BH}–σ space. After considerations of contributions of TDEs to observed broad line emission clouds, the overestimated virial BH mass can be well expected, due to luminosity dependent BLRs sizes through the R–L relation much larger than the true intrinsic sizes of broad line emission clouds from the central TDE. Therefore, the overestimated virial BH mass estimated through line width and line luminosity in the M_{BH}–σ space could be treated as interesting clues to support central TDEs.

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REFERENCES

Barth A. J., Ho L. C., Sargent W. L. W., 2002, AJ, 124, 2607
Bennert V. N. et al., 2015, ApJ, 809, 20
Bentz M. C. et al., 2013, ApJ, 767, 149
Bruzual G., Charlot S., 2003, MNRAS, 344, 1000
Cappellari M. et al., 2013, MNRAS, 432, 1709
Cenko S. B. et al., 2012, ApJ, 753, 77
Cid Fernandes R., Mateus A., Sodré L., Stasińska G., Gomes J. M., 2005, MNRAS, 358, 363
Du P. et al., 2018, ApJ, 856, 6
Ferrarese F., Merritt D., 2000, ApJ, 539, L9
Ferrarese L., Pogge R. W., Peterson B. M., Merritt D., Wandel A., Joseph C. L., 2001, ApJ, 555, L79
Gebhardt K. et al., 2000, ApJ, 539, L13
Gezari S. et al., 2012, Nature, 485, 217
Greene J. E., Ho L. C., 2006, ApJ, 641, 117
Greene J. E., Ho L. C., 2007, ApJ, 670, 92
Greene J. E., Peng C. Y., Ludwig R. R., 2010, ApJ, 709, 937
Guillochon J., Ramirez-Ruiz E., 2013, ApJ, 767, 25
Guillochon J., Manukian H., Ramirez-Ruiz E., 2014, ApJ, 783, 23
Gultekin K. et al., 2009, ApJ, 698, 198
Ho L. C., Kim M.-J., 2014, ApJ, 789, 17
Holoien T. W.-S. et al., 2016, MNRAS, 455, 2918
Kaspi S., Maoz D., Netzer H., Peterson B. M., Vestergaard M., Jannuzi B. T., 2005, ApJ, 629, 61
Kauffmann G. et al., 2003, MNRAS, 346, 1055
Komossa S., 2015, JHEP, 7, 148
Kormendy J., Ho L. C., 2013, ARA&A, 51, 511
LaMassa S. M. et al., 2015, ApJ, 800, 144
McConnell N. J., Ma C. P., 2013, ApJ, 764, 184
McConnell N. J., Ma C.-P., Gebhardt K., Wright S. A., Murphy J. D., Lauer T. R., Graham J. R., Richstone D. O., 2011, Nature, 480, 215
Merloni A. et al., 2015, MNRAS, 452, 69
Peterson B. M. et al., 2004, ApJ, 613, 682
Rafiee A., Hall P. B., 2011, ApJS, 194, 42
Rees M. J., 1988, Nature, 333, 523
Savorgnan G. A. D., Graham A. W., 2015, MNRAS, 446, 2330
Thomas J., Ma C.-P., McConnell N. J., Greene J. E., Blakeslee J. P., Janish R., 2016, Nature, 532, 340
van Velzen S. et al., 2011, ApJ, 741, 73
Vestergaard M., Peterson B. M., 2006, ApJ, 641, 689
Wang T., Yan L., Dou L., Jiang N., Sheng Z., Yang C., 2018, MNRAS, 477, 2943
Woo J.-H., Treu T., Malkan M. A., Blandford R. D., 2006, ApJ, 645, 900
Woo J.-H., Schulze A., Park D., Kang W.-R., Kim S. C., Riechers D. A., 2013, ApJ, 772, 49
Woo J.-H., Yoon Y., Park S., Park D., Kim S. C., 2015, ApJ, 801, 38
Xiao T., Barth A. J., Greene J. E., Ho L. C., Bentz M. C., Ludwig R. R., Jiang Y., 2011, ApJ, 739, 28
Yang Q. et al., 2018, ApJ, 862, 109

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