Hidden Broad-line Regions in Seyfert 2 Galaxies:
From the Spectropolarimetric Perspective

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Abstract

The hidden broad-line regions (BLRs) in Seyfert 2 galaxies, which display broad emission lines (BELs) in their polarized spectra, are a key piece of evidence in support of the unified model for active galactic nuclei (AGNs). However, the detailed kinematics and geometry of hidden BLRs are still not fully understood. The virial factor obtained from reverberation mapping of type 1 AGNs may be a useful diagnostic of the nature of hidden BLRs in type 2 objects. In order to understand the hidden BLRs, we compile six type 2 objects from the literature with polarized BELs and dynamical measurements of black hole masses. All of them contain pseudobulges. We estimate their virial factors, and find the average value is 0.60 and the standard deviation is 0.69, which agree well with the value of type 1 AGNs with pseudobulges. This study demonstrates that (1) the geometry and kinematics of BLR are similar in type 1 and type 2 AGNs of the same bulge type (pseudobulges), and (2) the small values of virial factors in Seyfert 2 galaxies suggest that, similar to type 1 AGNs, BLRs tend to be very thick disks in type 2 objects.

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

Supporting material: machine-readable table

1. Introduction

The unified model (Antonucci 1993), which originates from the detection of broad emission lines (BELs) in the spectro-polarimetric data of Seyfert 2 galaxy NGC 1068 (Antonucci & Miller 1985), proposes that the type 1 (showing both BELs and narrow emission lines) and type 2 (showing only narrow emission lines) active galactic nuclei (AGNs) are the same type of object viewed from different angles. The hidden broad-line regions (BLRs) are observed in the polarized spectra of many type 2 AGNs (e.g., Antonucci 1984; Tran et al. 1992; Young et al. 1996; Moran et al. 2000; Ramos Almeida et al. 2016), and are thought to have a scattering of BELs by the regions above the poles of accretion disks (called “polar scatter regions”; Antonucci & Miller 1985; Antonucci 1993). However, the detailed geometry and kinematics of BLRs hidden in the centers of type 2 AGNs remain elusive and are not yet fully understood.

The virial mass of black holes can be obtained by reverberation mapping (RM; e.g., Blandford & McKee 1982; Peterson et al. 1998; Kaspi et al. 2000; Bentz et al. 2009; Du et al. 2014, 2015, 2016). The RM technique provides a key component, the time lag between continuum and BEL response, that provides a sizescale due to the finite speed of light. There is a dilemma in that we are not able to get the black hole (BH) mass without specifying the kinematics and structure of the BLR. Fortunately, we can obtain the black hole mass from galactic dynamics in type 2 AGNs, providing the opportunity to define the virial factor

\[ f_{\text{vir}} = \frac{M_*}{M_{\text{vir}}} = \frac{GM_*}{V^2 R_{\text{BLR}}}, \tag{1} \]

where \( M_* \) is the BH mass determined by galactic dynamics techniques, \( M_{\text{vir}} \) is the virial mass, \( V \) is the width of BEL, \( R_{\text{BLR}} \) is the emissivity-weighted radius of BLR, and \( G \) is the gravitational constant. For type 1 AGNs, \( R_{\text{BLR}} = c \tau \), where \( c \) is the speed of light and \( \tau \) is the time delay between the response of BELs (mainly H\( \beta \)) to the variation of continuum which is normally measured from the peak of cross-correlation functions between the light curves of the continuum and emission lines. The value of the virial factor is determined by the geometry and kinematics of the BLR, and its evaluation leads to an indirect path to understanding the nature of BLRs. When compared statistically with the BH mass–stellar velocity dispersion (\( M_* - \sigma_* \)) relation (e.g., Ferrarese & Merritt 2000; Tremaine et al. 2002), its average value is estimated as the order of unity for type 1 AGNs if the velocity \( V \) is measured from the full-width-half-maximum (FWHM) of broad H\( \beta \) lines (e.g., Onken et al. 2004; Ho & Kim 2014; Woo et al. 2015). However, a more recent work indicates that the virial factor in individual objects probably varies significantly, as demonstrated by reconstructing the geometry and kinematics of BLRs in a small sample using the Markov Chain Monte Carlo method (MCMC; Pancost et al. 2014). This result means that the kinematics of BLRs or the viewing angles are diverse in these objects.

The polar scattering regions in type 2 AGNs provide an additional viewing angle, namely from the polar axes, similar to the angle of observation for type 1 AGNs. Considering that the virial factor reflects the geometry and kinematics of BLRs, we can diagnose the hidden BLRs in type 2 AGNs by comparing the virial factors, obtained from their polarized spectra, to those of type 1 AGNs. Therefore, we search for type 2 AGNs with hidden BELs in polarized spectra and directly determined dynamical BH mass measurements, and estimate their \( f_{\text{vir}} \) factors.
2. Virial Factors of Type 2 AGNs

We compile all of the type 2 AGNs that have both polarized BEL detections and direct dynamical BH mass measurements from the published literature in order to check their virial factors. The objects that are definitively identified as low-ionization nuclear emission-line regions (e.g., Ho 2008), or those with uncertain BH mass measurements, have been eliminated. There are a total of six sources in the final sample. The degree of polarization in type 2 AGNs is generally very low (less than several percent); in most cases, only broad Ho lines in the polarized spectra are visible (e.g., Antonucci 1984; Tran et al. 1992; Young et al. 1996; Moran et al. 2000; Ramos Almeida et al. 2016). We assume that broad Hβ and Hα lines have the same widths in the polarized spectrum for each individual object, as has been demonstrated in several objects (Ramos Almeida et al. 2016). Because the poor quality of polarized spectra would influence the measurements of the line dispersions (second momentum of the profile, σ), we only adopt the FWHM of polarized emission lines in the following analysis.

To estimate the radii of BLRs in Equation (1), instead of the RM method employed for type 1 AGNs, we use two approaches: (1) the empirical relation between the time delay and the luminosity of [O III]λ5007 and (2) the empirical relation with the hard X-ray luminosity in 2–10 keV found in the RM samples. For the first approach, we compile the luminosities of [O III] and the time delays of Hβ for all of the type 1 AGNs that have RM observations summarized in Du et al. (2015, 2016). It should be noted that the narrow-line regions (NLRs) in type 1 AGNs suffer local extinction of E(B – V) 0.2–0.3 (e.g., Netzer et al. 2006; Vaona et al. 2012) in addition to the Galactic extinction (Schlafly & Finkbeiner 2011). The line extinction should be corrected for the RM objects. Considering that the Balmer decrements of narrow lines for some RM objects are difficult to determine accurately because of their Lorentzian-like Hα and Hβ profiles (encompassing both narrow and broad components), we adopt the mean E(B – V) of 0.28, which is obtained from the Data Release 7 quasar sample of Sloan Digital Sky Survey (SDSS, Shen et al. 2011), to correct the intrinsic extinction in those RM objects. Using the FITEXY algorithm (Press et al. 1992) for linear regression, the resulting correlation shown in Figure 1 is

$$\log R_{\text{BLR}} = \left(-24.475 \pm 0.684\right) + \left(0.614 \pm 0.016\right) \log L_{\text{[O III]}}$$

where $L_{\text{[O III]}}$ is the extinction-corrected luminosity of [O III]. Equation (2) can be used to estimate the BLR radius. In order to avoid the potential contamination of star formation activities in [O III] fluxes, which would result in uncertainties in $R_{\text{BLR}}$ estimates to some extent, we also adopt the second approach: hard X-ray luminosity in 2–10 keV ($L_{2-10}$, the relation of $L_{2-10}$ versus $R_{\text{BLR}}$ in Kaspi et al. 2005) to deduce $R_{\text{BLR}}$ as a comparison. To calculate the virial factors of the hidden BLRs in type 2 AGN sample, their extinction in narrow emission lines and the absorption in 2–10 keV X-ray luminosities should be also taken into account (see the references in Table 1).

4 The Lorentzian profiles of the entire Hα and Hβ emission lines and the too-weak narrow lines for some PG quasars in Kaspi et al. (2000) and most of the AGNs with high accretion rates in Du et al. (2014, 2015, 2016) make it difficult to de-blend the narrow components from the broad components very reliably, and additionally difficult to measure the reddening in their NLRs using Balmer decrements.

5 In fact, in the present sample, only $f_{\text{[O III]}}$ and $f_{2-10}$ of NGC 3393 look different. The relatively anomalous behavior of NGC 3393 could be explained by the very large variation in its X-ray luminosity (see Figure 1 in Fabbiano et al. 2011).
that if we change it to 0.18 or 0.38, the
relation for the RM AGNs. This characteristic correction
Notes.
The Astrophysical Journal Letters, 2011, 6. Gu et al.
there is no evidence that the average
Equation
the mass of a BH in an AGN can be determined using
well as the emission line width, have been measured from RM,
Therefore, the characteristic extinction is reasonable for the present
In order to compare the obtained virial factors in the type 2
samples with the values in type 1 AGNs, we
discrepancy of virial factors in those previous works is mainly
non-barred AGN samples. Park et al.
Furthermore, they accounted for the selection bias caused by
that the virial factor for FWHM is 0.75 (Netzer 1990).
Observationally, the average virial factor for a sample can be
 calibrated by comparing the RM objects with measurements of bulge stellar velocity dispersion with the $M_\star$--$\sigma_\star$ relation of inactive galaxies, if we assume that active and inactive galaxies follow the same $M_\star$--$\sigma_\star$ relation. Based on a sample of 14 AGNs with RM observations, Onken et al. (2004) calibrated $f_{\text{FWHM}}(\text{rms}) = 1.4$ and $f_\sigma(\text{rms}) = 5.5$ through the comparison with the $M_\star$--$\sigma_\star$ relation from Ferrarese & Merritt (2000) and Tremaine et al. (2002). By adding the observations from the Lick AGN Monitoring Project (LAMP, e.g., Bentz et al. 2009), Woo et al. (2010) compiled a sample of 24 RM objects with $\sigma_\star$ measurements and found that $\log f_\sigma(\text{rms}) = 0.72^{+0.09}_{-0.10}$, if adopting the $M_\star$--$\sigma_\star$ relation in Gültekin et al. (2009), which is in good agreement with the value of Onken et al. (2004). Graham et al. (2011) improved the $M_\star$--$\sigma_\star$ relation by including more BH mass measurements of barred galaxies for their sample of 28 AGNs, and derived $f_\sigma(\text{rms}) = 3.8^{+0.7}_{-0.8}$, which is lower than the value in Woo et al. (2010) by a factor of 2. When dividing the sample into barred and non-barred galaxies, they found $f_\sigma(\text{rms})$ would be $2.3^{+0.6}_{-0.5}$ and $7.0^{+1.8}_{-1.4}$, respectively. Furthermore, they accounted for the selection bias caused by the non-detection of intermediate-mass BHs, and gave $f_\sigma(\text{rms}) = 2.8^{+0.7}_{-0.5}$, $2.3^{+0.9}_{-0.6}$ and $5.4^{+1.5}_{-1.2}$ for full, barred, and non-barred AGN samples. Park et al. (2012) claimed that the discrepancy of virial factors in those previous works is mainly caused by the sample selection effect, and preferred to use $\log f_\sigma(\text{rms}) = 0.71 \pm 0.11$. Woo et al. (2013) investigated the assumption that active and inactive galaxies follow the same $M_\star$--$\sigma_\star$ relation, and demonstrated that it is generally reasonable. Grier et al. (2013) updated the RM sample, and added new $\sigma_\star$ measurements of a few highly luminous quasars. They obtained $f_\sigma(\text{rms}) = 4.31 \pm 1.05$, which is slightly lower than Park et al.’s value but larger than that in Graham et al. (2011). Motivated by the fact that galaxies with pseudobulges do not obey the $M_\star$--$\sigma_\star$ relation of classical bulges and ellipticals, Ho & Kim (2014) separated the calibration by bulge types in galaxies and provided calibrated values of $\log f_{\text{FWHM}}(\text{mean})$, $f_\sigma(\text{mean})$, $f_{\text{FWHM}}(\text{rms})$, $f_\sigma(\text{rms}) = [1.3 \pm 0.4$, $5.6 \pm 1.3$, $1.5 \pm 0.4$, $6.3 \pm 1.5]$ for classical bulges and ellipticals, and $[0.5 \pm 0.2$, $1.9 \pm 0.7$, $0.7 \pm 0.2$, $3.2 \pm 0.7]$ for pseudobulges.

3. Comparison with Virial Factor in Type 1 AGNs

In order to compare the obtained virial factors in the type 2 sample with the values in type 1 AGNs, we first provide some necessary background.

Once the time lag between continuum and emission line, as well as the emission line width, have been measured from RM, the mass of a BH in an AGN can be determined using Equation (1) if the virial factor $f_\sigma$ is known. Due to the fact that the velocity measurement could be either FWHM or $\sigma$, and the velocity could be measured from mean spectra or rms spectra (Peterson et al. 1998), there are four combinations of $f_{\text{vir}}$ estimates ($f_{\text{vir}}$ for FWHM in mean or rms spectra, or for $\sigma$ in mean or rms spectra). For simplicity, we designate them as $f_{\text{FWHM}}(\text{mean})$, $f_{\text{FWHM}}(\text{rms})$, $f_\sigma(\text{mean})$, and $f_\sigma(\text{rms})$.

Assuming the velocity distribution of the BLR is isotropic (which is likely not true), the simplest deduction from theory is

| Object      | FWHM(Hα) (km s$^{-1}$) | Ref. | $M_\star$ ($M_\odot$) | Ref. | $L_{\text{OIII}}$a (erg s$^{-1}$) | Ref. | $f_{\text{OIII}}$ | log $L_{2-10}$ (erg s$^{-1}$) | Ref. | $f_{2-10}$ |
|-------------|------------------------|------|-----------------------|------|-------------------------------|------|----------------|-------------------------------|------|----------------|
| Circinus    | 2300 ± 500             | 1    | $1.14^{+0.20}_{-0.20}$ $\times 10^{6}$ | 2    | 41.17                         | 3    | $0.17^{+0.15}_{-0.15}$       | 41.62 | 4              | $0.20^{+0.16}_{-0.16}$ |
| IC 2560     | 2100 ± 300             | 1    | $2.51^{+0.15}_{-0.15}$ $\times 10^{6}$ | 5    | 40.19                         | 6    | $1.83^{+3.11}_{-1.79}$       | 41.80 | 7              | $1.47^{+3.4}_{-2.45}$ |
| NGC 1068    | 4377 ± 300             | 8    | $8.39^{+0.44}_{-0.44}$ $\times 10^{6}$ | 9    | 42.38                         | 4    | $0.06^{+0.05}_{-0.06}$       | 43.02 | 4              | $0.25^{+0.16}_{-0.16}$ |
| NGC 2273    | 2399 ± 419             | 10b  | 8.61^{+0.04}_{-0.04} $\times 10^{6}$ | 11   | 41.13                         | 4    | $1.28^{+1.02}_{-1.02}$       | 42.73 | 4              | $1.24^{+0.89}_{-0.89}$ |
| NGC 3393    | 5000 ± 600             | 1    | $1.57^{+0.09}_{-0.09}$ $\times 10^{7}$ | 12   | 42.04                         | 3    | $0.15^{+0.14}_{-0.14}$       | 41.60 | 7              | $2.08^{+0.91}_{-0.91}$ |
| NGC 4388    | 4500 ± 1400            | 1    | $7.31^{+0.17}_{-0.18} $ $\times 10^{6}$ | 11   | 41.85                         | 4    | $0.16^{+0.10}_{-0.10}$       | 42.90 | 4              | $0.24^{+0.21}_{-0.21}$ |

Notes.
a The Galactic and local extinction has been corrected.
b We measure the FWHM from the polarized spectrum in Ref. 10. We do not list the uncertainties of $L_{\text{OIII}}$ and $L_{2-10}$ here, because we only use the dispersion of the empirical relationship to deduce the uncertainties of $f_{\text{OIII}}$ and $f_{2-10}$ (see Section 2).

References. 1. Ramos Almeida et al. (2016), 2. Greenhill et al. (2003), Kormendy & Ho (2013), 3. Bassani et al. (1999), 4. Marisucci et al. (2012), 5. Läsker et al. (2016), 6. Gu et al. (2006), 7. Tilak et al. (2008), 8. Inglis et al. (1995), 9. Lodato & Bertin (2003), Kormendy & Ho (2013), 10. Moran et al. (2000), 11. Kuo et al. (2011), Kormendy & Ho (2013), 12. Kondratko et al. (2008), Kormendy & Ho (2013).
It should be noted that, in addition to the inclination angle, the thickness of the BLR and some other dynamical parameters also influence the virial factor. Also, Pancoast et al. (2014) reported that four of the five objects show very thick BLRs, and only the BLR of Mrk 1310 is relatively thin.

1 galaxies, and found \( \log f_{\text{FWHM}}(\text{mean}) = 0.05 \pm 0.12 \) and \( \log f_\nu(\text{mean}) = 0.65 \pm 0.12 \).

Based on another technology, Pancoast et al. (2014) carried out MCMC to reconstruct kinematics models of BLRs in five Seyfert 1 galaxies. It does not rely on the \( M_\ast - \sigma_\ast \) relation, but uses RM data only and can provide \( f_{\text{vir}} \) estimates for individual objects. Adopting this as an independent method, Pancoast et al. (2014) derived the averages \( f_{\text{vir}} \) for the five objects to be \( \approx 0.85 \) and \( \approx 4.74 \), corresponding for FWHM and \( \sigma \), respectively. However, the values in individual objects are very different (by an order of magnitude). They also showed that \( f_{\text{vir}} \) strongly depends on the inclination angle of the BLR and is much larger in more face-on objects (from \( \approx 0.2 \) for the viewing angle of \( 50^\circ \) to \( \approx 6 \) for \( 10^\circ \)).

For the present Seyfert 2 sample, it is difficult to measure the \( \sigma \) of emission lines accurately in their polarized spectra given the poor signal-to-noise ratio (\( \sigma \) depends on accurate measurement of the wings of emission lines). However, FWHMs are more robustly measured. We only estimate the virial factors based on FWHM. The average value of \( f_{\text{vir}} \) in those Seyfert 2 galaxies is 0.60, and the dispersion is 0.69. Considering that all of the objects in the sample are galaxies with pseudobulges (Kormendy & Ho 2013), this number is in good agreement with the \( f_{\text{FWHM}}(\text{mean}) \) and \( f_{\text{FWHM}}(\text{rms}) \) for Seyfert 1 galaxies with pseudobulges in Ho & Kim (2014). Therefore, we can draw a preliminary conclusion, based on the present type 2 sample of limited size, that the virial factors in type 2 AGNs are consistent with the values in type 1 AGNs of the same bulge type (pseudobulge).

Scattering regions in type 2 AGNs are mainly located along the polar axis (e.g., Antonucci 1983; Capetti et al. 1995), and provide a new perspective to BLRs from a pole-on direction (small viewing angles). The similar value of virial factors, which are found from the polarized spectra of type 2 AGNs, as in type 1 objects, indicate that the geometry and kinematics of BLR are similar in type 1 and type 2 AGNs of the same bulge type (pseudobulge). The small virial factors (\( f_{\text{FWHM}} = 0.60 \)) found in the polarized spectra demonstrate that the geometry of BLRs in the present sample tend to be very thick disks (thicker than the results in Pancoast et al. (2014) because of our smaller \( f_{\text{vir}} \)), or are perhaps even isotropic to some extent.

It should be noted that the thermal motion of the free electrons in scattering regions could provide an additional broadening to the polarized emission lines, and further influence the estimates of virial factors to some extent. Miller et al. (1991) showed that, consistent with the conclusion of Antonucci & Miller (1985), thermal electrons dominate the scattering process in NGC 1068 and broaden the polarized emission lines. Unfortunately, similar information is unavailable in other AGNs. On the other hand, lower-temperature dust grains could also contribute to the scattering, and may dominate at least in some objects. In such cases, the additional broadening from the scattering particles is not an issue. The virial factor of NGC 1068 is low compared to the other five objects (Table 1). If the width from the dust scattering were used, it would be more similar. The detailed nature of scattering...
and the corresponding broadening still remain open questions and need to be investigated in the future.

4. Summary

In this work we compile a sample of six Seyfert 2 galaxies with spectropolarimetric observations and dynamical BH mass measurements, and derive their virial factors from the FWHMs of the polarized BELs, in order to investigate the kinematics and geometry of hidden BLRs in type 2 AGNs. Generally, the virial factors estimated in different ways (from the luminosities of [O III] and X-ray) are in agreement. The average of the derived virial factors is 0.60 in the present sample, which is similar to the value of type 1 objects with pseudobulges (Ho & Kim 2014). It implies that (1) the geometry and kinematics of BLRs are similar in type 1 and type 2 AGNs of the same bulge type (pseudobulge) and (2) the geometry of BLRs in type 2 AGNs tends to be a very thick disk or isotropic. In the future, more spectropolarimetric observations would make it possible to explore the properties of hidden BLRs in more detail and investigate the dependency of hidden BLR kinematics and geometry on black hole masses or accretion rates of AGNs.

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References

Antonucci, R. 1993, ARA&A, 31, 473
Antonucci, R. R. J. 1983, Natur, 303, 158
Antonucci, R. R. J. 1984, ApJ, 278, 499
Antonucci, R. R. J., & Miller, J. S. 1985, ApJ, 297, 621
Bassani, L., Dadina, M., Maiolino, R., et al. 1999, ApJS, 121, 473
Bentz, M. C., Walsh, J. L., Barth, A. J., et al. 2009, ApJ, 705, 199
Blandford, R. D., & McKee, C. F. 1982, ApJ, 255, 419
Capetti, A., Axon, D. J., Macchetto, F., Sparks, W. B., & Boksenberg, A. 1995, ApJ, 446, 155
Du, P., Hu, C., Lu, K.-X., et al. [SEAMBH Collaboration] 2014, ApJ, 782, 45
Du, P., Hu, C., Lu, K.-X., et al. [SEAMBH Collaboration] 2015, ApJ, 806, 22
Du, P., Lu, K.-X., Zhang, Z.-X., et al. [SEAMBH Collaboration] 2016, ApJ, 825, 126
Fabbiano, G., Wang, J., Elvis, M., & Risaliti, G. 2011, Natur, 477, 431
Ferrarese, L., & Merritt, D. 2000, ApJL, 539, L9
Graham, A. W., Onken, C. A., Athanassoula, E., & Combes, F. 2011, MNRAS, 412, 2211
Greenhill, L. J., Booth, R. S., Ellingsen, S. P., et al. 2003, ApJ, 590, 162
Grier, C. J., Martini, P., Watson, L. C., et al. 2013, ApJ, 773, 90
Gu, Q., Melnick, J., Cid Fernandes, R., et al. 2006, MNRAS, 366, 480
Gültekin, K., Richstone, D. O., Gebhardt, K., et al. 2009, ApJ, 698, 198
Heard, C. Z. P., & Gaskell, C. M. 2016, MNRAS, 461, 4227
Ho, L. C. 2008, ARA&A, 46, 475
Ho, L. C., & Kim, M. 2014, ApJ, 789, 17
Inglis, M. D., Young, S., Hough, J. H., et al. 1995, MNRAS, 275, 398
Kaspi, S., Maoz, D., Netzer, H., et al. 2005, ApJ, 629, 61
Kaspi, S., Smith, P. S., Netzer, H., et al. 2000, ApJ, 533, 631
Kondratko, P. T., Greenhill, L. J., & Moran, J. M. 2008, ApJ, 678, 87
Kormendy, J., & Ho, L. C. 2013, ARA&A, 51, 511
Kuo, C. Y., Braatz, J. A., Condon, J. J., et al. 2011, ApJ, 727, 20
Läsker, R., Greene, J. E., Seth, A., et al. 2016, ApJ, 825, 3
Lodato, G., & Bertin, G. 2003, A&A, 398, 517
Marinucci, A., Bianchi, S., Nicastro, F., Matt, G., & Goulding, A. D. 2012, ApJ, 748, 130
Miller, J. S., Goodrich, R. W., & Mathews, W. G. 1991, ApJ, 378, 47
Moran, E. C., Barth, A. J., Kay, L. E., & Filippenko, A. V. 2000, ApJL, 540, L73
Netzer, H. 1990, Active Galactic Nuclei, 57
Netzer, H., Mainieri, V., Rosati, P., & Trakhtenbrot, B. 2006, A&A, 453, 525
Onken, C. A., Ferrarese, L., Merritt, D., et al. 2004, ApJ, 615, 645
Pancoast, A., Brewer, B. J., Treu, T., et al. 2014, MNRAS, 445, 3073
Park, D., Kelly, B. C., Woo, J.-H., & Treu, T. 2012, ApJS, 203, 6
Peterson, B. M., Wanders, I., Bertram, R., et al. 1998, ApJ, 501, 82
Press, W. H., Teukolsky, S. A., Vetterling, W. T., & Flannery, B. P. 1992, Numerical recipes in FORTRAN. The art of scientific computing (2nd ed.; Cambridge: Cambridge Univ. Press)
Ramos Almeida, C., Martínez González, M. J., Asensio Ramos, A., et al. 2016, MNRAS, 461, 1387
Schlafly, E. F., & Finkbeiner, D. P. 2011, ApJ, 737, 103
Shen, Y., Richards, G. T., Strauss, M. A., et al. 2011, ApJS, 194, 45
Tilak, A., Greenhill, L. J., Done, C., & Madejski, G. 2008, ApJ, 678, 701
Tran, H. D., Miller, J. S., & Kay, L. E. 1992, ApJ, 397, 452
Tremaine, S., Gebhardt, K., Bender, R., et al. 2002, ApJ, 574, 740
Vaona, L., Ciotti, S., Di Mille, F., et al. 2012, MNRAS, 427, 1266
Woo, J.-H., Schulze, A., Park, D., et al. 2013, ApJ, 772, 49
Woo, J.-H., Treu, T., Barth, A. J., et al. 2010, ApJ, 716, 269
Woo, J.-H., Yoon, Y., Park, S., Park, D., & Kim, S. C. 2015, ApJ, 801, 38
Young, S., Hough, J. H., Efstathiou, A., et al. 1996, MNRAS, 281, 1206