EMPIRICAL CONVERSIONS OF BROAD-BAND OPTICAL AND INFRARED MAGNITUDES TO MONOCHROMATIC CONTINUUM LUMINOSITIES FOR ACTIVE GALACTIC NUCLEI

SYZMON KOZLOWSKI

1. INTRODUCTION

Active galactic nuclei (AGNs) owe their tremendous brightness to accretion disks forming around supermassive black holes at their centers. It is presumed that the disk temperature \( T \) falls off with the disk radius \( R \) as \( T \propto R^{-3/4} \) (e.g. Shakura & Sunyaev 1973), giving rise to a wide range of photon energies at a continuous range of wavelengths – a feature known as the "continuum" in observed AGN spectra. This continuum can be described either at particular wavelengths (monochromatic luminosities) or in standard broad band filters (broad band luminosities).

Continuum photons, either monochromatic, broadband, or bolometric, may provide key diagnostics in understanding AGN physics, as they respond to the hard UV ionizing photons. A fraction of these UV photons is partially absorbed by the dust-gas clouds away from the disk, in the broad line region (BLR), and re-emitted in a form of broad emission lines at wavelengths corresponding to certain differences between energy levels in atoms and molecules. The typical distance to the clouds is \( r = c\tau \), so they reverberate any luminosity changes with time-lags \( \tau \) that are strongly correlated with the continuum luminosity \( L \) as \( \tau \sim r \propto L^{1/2} \). This is commonly known as the BLR radius–luminosity relation (e.g., Kaspi et al. 2000, 2007; Bentz et al. 2009). The implications of this relation are essential in determination of the central black hole mass \( M_{BH} \) via the virial theorem \( M_{BH} \propto L^{1/2} v^2 \), where \( v \) is the velocity of the BLR gas-dust clouds (e.g. Vestergaard & Peterson 2006). Their velocity is routinely measured from AGN spectra as either full width (of the broad emission line) at its half maximum (FWHM) or dispersion (\( \sigma \)).

To measure the delay between the continuum and line luminosity variations, it is a common practice in reverberation mapping studies to measure the monochromatic continuum fluxes in the vicinity of the reverberating lines. For the \( H\beta \) line it is the luminosity at 5100\,Å, for the Mg II line at 3000\,Å, and for the C IV line at 1350\,Å. Knowing these luminosities and a BLR radius–luminosity relation (Kaspi et al. 2000, 2007; Bentz et al. 2009), one can estimate the expected BLR radius and hence the central black hole mass.

Monochromatic luminosities can be turned into estimated time-lags for these lines, and may, for example, help in designing a spectroscopic experiment to observe them via spectroscopic (e.g., Peterson 1993; Denney et al. 2010; Shen et al. 2011) or photometric (e.g., Chelouche & Daniel 2012; Zu et al. 2013) reverberation mapping. Inverting the problem, once a time-lag between a continuum flux and a reverberating line flux is measured, the absolute luminosity of an AGN is known, making it a "standardizable candle" (e.g., Watson et al. 2011; Czerny et al. 2013).

Our main motivation here is to estimate the empirical monochromatic luminosities at these three rest-frame wavelengths (5100\,Å, 3000\,Å, 1350\,Å) from the broad-band AGN magnitudes, when we lack flux-calibrated spectra or they are too noisy. We simply take the ~ 100000 AGNs with spectroscopically measured monochromatic luminosities, black hole masses, emission lines, spectral slopes (Shen et al. 2011) and estimate the monochromatic fluxes based on the wealth of broad-band optical–IR magnitudes that are available

(Schneider et al. 2010).

2. DATA

To measure the monochromatic fluxes from the broad-band filters, we have downloaded the data for 105783 quasars from Data Release 7 of SDSS from Schneider et al. (2010) and Shen et al. 2011. All of them are brighter than \( M_i < -22 \) mag and have at least one broad emission line with a FWHM larger than 1000 km s\(^{-1}\) or interesting absorption features.

(Schneider et al. 2010) provides a dataset containing both the observed SDSS ugriz AB magnitudes for these objects as well as matched JHK and WISE magnitudes. We corrected these observed magnitudes for Galactic extinction using the extinction maps of Schlegel et al. (1998). Schneider et al. (2010) already provides \( u \)-band extinction (\( A_u \)) for all sources and we convert \( A_u \) to

\[ A_u = C_u \times A_{V,0} \]

with a correction factor \( C_u \) to match the extinction Determine corrected magnitudes for all five bands. To complete the monochromatic fluxes, we correct for the SDSS filters given a pure monochromatic flux at 1550\,Å. We calculate bolometric fluxes using the Bolometric Luminosity Relationship (Kaspi et al. 2000, 2007; Bentz et al. 2009).
other wavelengths using the $R_V = 3.1$ Galactic extinction curve (Cardelli et al. 1989) with the following values: $A_g/A_u = 0.736$, $A_r/A_u = 0.534$, $A_i/A_u = 0.405$, $A_z/A_u = 0.287$, $A_f/A_u = 1.052$, $A_v/A_u = 0.641$ (unused), $A_R/A_u = 0.520$ (unused), $A_I/A_u = 0.373$ (unused), $A_J/A_u = 0.176$, $A_H/A_u = 0.111$, $A_K/A_u = 0.072$, $A_{W1}/A_u = 0.033$, $A_{W2}/A_u = 0.016$, $A_{W3}/A_u = 0.000$, and $A_{W4}/A_u = 0.000$. The extinctions in $V$, $R$, and $I$ bands were not used as these magnitudes were synthesized directly from the extinction-corrected $ugriz$ magnitudes.

These quasars generally do not have the common Johnson-Cousins $VRI$ magnitudes and we derive them directly from the extinction-corrected $ugriz$ magnitudes. First, we calculate the $r-R$, $r-I$, $i-R$, and $i-I$ synthetic colors as a function of redshift using an average AGN spectrum from Richards et al. (2006a), a simple function of redshift $z$ as

$$z = 0.01 \times (\nu - \nu_0)/\nu_0$$

where $\nu_0 = 514.98$ Hz (FUV), $\nu_0 = 3636$ Hz (NUV), $\nu_0 = 6.972$ Hz ($g$), $\nu_0 = 5.414$ Hz ($r$), $\nu_0 = 4.677$ Hz ($i$), and $\nu_0 = 3.802$ Hz ($z$).

While the NDWFS survey provides the $RI$ magnitudes, it does not provide the $B$-band data. We therefore calculate the $g - V$ synthetic colors as a function of redshift to obtain the $V$-band magnitudes and calibrate them with the observed $V - I$ colors based on 758 quasars from the Magellanic Quasars Survey (Kozlowski et al. 2013), containing $R$ and $I$ magnitudes, and shift the synthetic colors such that the converted $R$ and $I$ magnitudes match the ones observed in the NDWFS (Jannuzi & Dev 1999). We create $R$ and $I$ magnitudes from two sets of colors to verify their correctness (the dispersion is 0.12 mag).

The extinction-corrected monochromatic luminosity at 5100Å, 3000Å and 1350Å were already provided in Shen et al. (2011) for a cosmology $H_0 = 70$ km s$^{-1}$ Mpc$^{-1}$, $\Omega_M = 0.3$ and $\Omega_\Lambda = 0.7$. We adopt the same cosmological parameters, hence our broadband–to–monochromatic luminosity ratios are cosmological model-independent and can be used with any other set of cosmological parameters. One should be careful about using the low-$z$ ratios, as both the broadband filters and the monochromatic luminosity can be affected by AGN host contamination.

3. METHODOLOGY

A broadband luminosity $L_F (\nu L_\nu)$ in a filter $F$ is calculated from

$$L_F = 4\pi D_L^2 \alpha_F \nu F \times 10^{-0.4 \times m_F}$$

(1)

where $L_F$ is in $10^{23}$ erg s$^{-1}$, $\alpha_F$ is the zero-magnitude flux (in Jy) for a given filter $F$ (column 3 in Table 1), $m_F$ is the observed source magnitude, $\nu F$ is the central frequency (in Hz) for that filter (column 4 in Table 1), and $D_L$ is the luminosity distance (in cm). Details of the $D_L$ calculation from a redshift $z$ and cosmological parameters are given in Wright (2006).

Using the above prescription, we convert the extinction-corrected broad-band $ugriz$, $VRI$ (converted), $JHK$ and WISE magnitudes to the broadband luminosities. We then calculate the empirical ratios $R$ of the broadband–to–monochromatic luminosity and provide their medians along with dispersions and uncertainties in 0.01 redshift bins (Tables 2–4). They are also presented in Figure 1. Note, that the ratios hold independent of the cosmological model.

In addition to the tabular form, we also fit log$_{10}(R)$ as a simple function of redshift $z$ with the formula

$$\log_{10}(R) = a + bz$$

(2)

in redshift ranges where this dependence is nearly linear. Typical dispersions between the best fits and the tabular data are $\sim 0.02$ dex (i.e., lower than the formal uncertainties from the tabular form). The best-fit values for selected redshift ranges are provided in Tables 5–6 and the residuals between the measured median ratios

\[\text{http://www.astro.ucla.edu/~wright/CosmoCalc.html} \]
and the fitted ones are presented in Figure 2.

A desired monochromatic luminosity can be estimated from

\[
\log_{10}(L_{\text{F}}) = \log_{10}(L_{\text{F}}) - \log_{10}(R)
\]

where \(\log_{10}(L_{\text{F}})\) is estimated from Equation 1 and \(\log_{10}(R)\) is provided either in Tables 2 or parametrized form from Equation 2 with the fitted values stored in Tables 3 and 4.

4. A SIMPLE PRESCRIPTION

Imagine a situation when you know your source is an AGN but its spectrum is not flux-calibrated or its signal-to-noise (S/N) is too low to reliably measure the monochromatic luminosities. What you have at hand are just its broad-band common magnitudes and the redshift estimate.

As an example, let assume we are interested in obtaining the monochromatic luminosity for a quasar SDSS J000006.53+003055.2 at (RA, Decl.) = (0.27298, 0.551534) deg at a redshift of \(z = 1.8246\). It is drawn from the sample analyzed in the paper, hence the true spectral monochromatic luminosity is known. Its extinction-corrected magnitudes are \(u = 20.254 \pm 0.065\) mag, \(g = 20.365 \pm 0.034\) mag, \(r = 20.255 \pm 0.038\) mag, \(i = 20.040 \pm 0.041\) mag, \(z = 20.005 \pm 0.121\) mag, \(V = 20.431\) mag (estimated),

### Table 2

| \(F\) | \(z\) | \(\log_{10}(R)\) | \(-\sigma\) | \(-\alpha\) | \(-\text{err}\) | \(-\text{err}\) | \(N_{\text{obj}}\) |
|---|---|---|---|---|---|---|---|
| \(u\) | 0.11 | 0.194 | 0.194 | 0.066 | -0.141 | 0.016 | 17 |
| \(u\) | 0.12 | 0.199 | -0.151 | 0.106 | -0.027 | 0.019 | 32 |
| \(u\) | 0.13 | 0.077 | -0.149 | 0.142 | -0.028 | 0.027 | 28 |
| \(u\) | 0.14 | 0.098 | -0.272 | 0.131 | -0.047 | 0.023 | 33 |
| \(u\) | 0.15 | 0.155 | -0.113 | 0.224 | -0.017 | 0.034 | 44 |

Note. — \(F\) is the broad-band filter, \(z\) is the redshift, \(\log_{10}(R)\) is the base 10 logarithm of the ratio between the band and monochromatic continuum luminosity, \(\sigma\) is the dispersion around the median value, and “err” is the uncertainty of the median ratio. (This table is available in its entirety in a machine-readable form in the online journal. A portion is shown here for guidance regarding its form and content.)

### Table 3

| \(F\) | \(z\) | \(\log_{10}(R)\) | \(-\sigma\) | \(-\alpha\) | \(-\text{err}\) | \(-\text{err}\) | \(N_{\text{obj}}\) |
|---|---|---|---|---|---|---|---|
| \(u\) | 0.35 | 0.071 | -0.085 | 0.125 | -0.006 | 0.009 | 179 |
| \(u\) | 0.36 | 0.056 | -0.089 | 0.256 | -0.005 | 0.036 | 336 |
| \(u\) | 0.37 | 0.078 | -0.101 | 0.104 | -0.006 | 0.006 | 334 |
| \(u\) | 0.38 | 0.094 | -0.123 | 0.103 | -0.007 | 0.006 | 290 |
| \(u\) | 0.39 | 0.068 | -0.096 | 0.117 | -0.005 | 0.006 | 341 |

Note. — \(F\) is the broad-band filter, \(z\) is the redshift, \(\log_{10}(R)\) is the base 10 logarithm of the ratio between the band and monochromatic continuum luminosity, \(\sigma\) is the dispersion around the median value, and “err” is the uncertainty of the median ratio. (This table is available in its entirety in a machine-readable form in the online journal. A portion is shown here for guidance regarding its form and content.)

### Table 4

| \(F\) | \(z\) | \(\log_{10}(R)\) | \(-\sigma\) | \(-\alpha\) | \(-\text{err}\) | \(-\text{err}\) | \(N_{\text{obj}}\) |
|---|---|---|---|---|---|---|---|
| \(u\) | 1.50 | 0.001 | -0.094 | 0.091 | -0.005 | 0.005 | 353 |
| \(u\) | 1.51 | 0.003 | -0.103 | 0.114 | -0.004 | 0.004 | 644 |
| \(u\) | 1.52 | -0.002 | -0.099 | 0.120 | -0.004 | 0.005 | 574 |
| \(u\) | 1.53 | 0.011 | -0.109 | 0.097 | -0.005 | 0.004 | 511 |
| \(u\) | 1.54 | 0.001 | -0.114 | 0.086 | -0.004 | 0.003 | 717 |

Note. — \(F\) is the broad-band filter, \(z\) is the redshift, \(\log_{10}(R)\) is the base 10 logarithm of the ratio between the band and monochromatic continuum luminosity, \(\sigma\) is the dispersion around the median value, and “err” is the uncertainty of the median ratio. (This table is available in its entirety in a machine-readable form in the online journal. A portion is shown here for guidance regarding its form and content.)
Figure 1. Ratios between the broad-band SDSS ugriz (top-left panel), VRI (top-right), 2MASS JHK (bottom-left), and WISE (bottom-right) and monochromatic luminosity at 5100 Å (blue), 3000 Å (green) and 1350 Å (red). Both broad-band and monochromatic luminosity were derived with the same cosmological model, hence their ratios are model-independent. Having measured any of the magnitudes for an AGN at a redshift \( z \), it is possible to convert that magnitude to either of three monochromatic luminosity with a typical dispersion of \( \sim 0.1 \) dex. This may have profound implications for measurements of BLR radii and/or black hole masses.

\[
R = 20.067 \text{ mag (estimated)}, \quad I = 19.661 \text{ mag (estimated)}, \quad JHK \text{ not measured}, \quad W1 = 16.560 \pm 0.084 \text{ mag}, \quad W2 = 15.094 \pm 0.093 \text{ mag}, \quad W3 = 12.549 \pm 0.539 \text{ mag}, \quad W4 = 8.072 \text{ mag}.
\]

The broad-band luminosities, in units of erg s\(^{-1}\), are then
\[
\log_{10}(L_u) = 45.748 \pm 0.026, \quad \log_{10}(L_g) = 45.583 \pm 0.014, \quad \log_{10}(L_r) = 45.508 \pm 0.015, \quad \log_{10}(L_i) = 45.510 \pm 0.016, \quad \log_{10}(L_v) = 45.447 \pm 0.048, \quad \log_{10}(L_I) = 45.485, \quad \log_{10}(L_R) = 45.495, \quad \log_{10}(L_J) = 45.462, \quad \log_{10}(L_{W1}) = 45.177 \pm 0.034, \quad \log_{10}(L_{W2}) = 45.370 \pm 0.037, \quad \log_{10}(L_{W3}) = 45.271 \pm 0.216, \quad \text{and} \quad \log_{10}(L_{W4}) = 46.185.
\]

From Figure 1 it is clear that at this redshift it is possible to derive both 3000 Å and 1350 Å luminosity from the broad-band filters. Table 7 gives the derived values. In this particular case, the optical bands seem to reproduce the real values better (to within \( \sim 1\sigma \)) than the infrared ones. The overestimate of the luminosity from the infrared filters may be attributed to the host contamination, as galaxies are usually much brighter in infrared than in visible light.

5. DISCUSSION

AGN are well known as variable sources (see Ulrich et al. 1997 for a review). Their variability is aperiodic and well-modeled by the damped random walk method (e.g., Kelly et al. 2009; Kozłowski et al. 2010a; Zu et al. 2013). A simplified description of their variability is via the structure function – a quantity that measures the average magnitude difference for a time difference between any two epochs (e.g., Schmidt et al...
Figure 2. Residuals after taking out the linear trends (Equation 2) from the measured median ratios for the broad-band SDSS *ugriz* (top-left panel), *VRI* (top-right), 2MASS *JHK* (bottom-left), and WISE (bottom-right) and monochromatic luminosity at 5100Å (blue), 3000Å (green) and 1350Å (red).

It is described by

\[ SF(\tau) = SF_0 \left( \frac{\tau}{\tau_0} \right)^\gamma \]  

where \( SF_0 \) is the structure function at a fixed \( \tau_0 \), \( \tau \) is the time difference between two observations, and \( \gamma \) is the slope of the structure function.

Because both the broad-band optical or infrared observations and the spectra were taken at different epochs, usually a few years apart, a fraction of the scatter in the derived ratios is due to variability itself and not the intrinsic differences between AGNs. Collecting information on the time differences between all observations is beyond the scope of this paper, nevertheless we roughly estimate the imprint of variability contribution to the scatter in the relations.

Most SDSS observations investigated here, both spectroscopic and photometric, were obtained in years 2000–2010, as were the WISE observations. Only the 2MASS data were obtained earlier. For an order of magnitude estimate, we assume that the median difference between any two observations is 5 years, and we know from the sample that the median AGN redshift is \( z \approx 1.5 \). This means that the median rest-frame time difference is 5 years times \((1 + z)^{-1}\), hence 2 years.

\[ \text{Vanden Berk et al. (2004)} \] provides the *gri* structure function parameters for 25000 SDSS quasars with approximately \( \tau_0 = 2 \) years, \( SF_0 = 0.28 \) mag and \( \gamma = 0.30 \). Since our median rest-frame time difference is 2 years and both the broad-band and monochromatic light curves are highly correlated, we can expect the median change in \( \log_{10}(R) \) to be of order of 0.1 dex. This implies that this variability is responsible for a significant fraction of the dispersions reported in this paper.

\[ \text{Kozłowski et al. (2010)} \] analyzes the variability of
Table 6
Best-fit parameters to Equation 4 for infrared bands.

| F'        | λ_cont | z range | a     | σ_a  | b     | σ_b  |
|-----------|--------|---------|-------|------|-------|------|
| J         | 5100Å  | 0.1–0.6 | 0.085 | 0.005 | -0.042 | 0.014 |
| J         | 5100Å  | 0.6–0.8 | -0.313 | 0.051 | 0.063 | 0.073 |
| H         | 5100Å  | 0.1–0.5 | 0.051 | 0.008 | 0.081 | 0.025 |
| H         | 5100Å  | 0.5–0.9 | 0.184 | 0.026 | -0.196 | 0.037 |
| K         | 5100Å  | 0.1–0.7 | 0.128 | 0.006 | 0.071 | 0.015 |
| K         | 5100Å  | 0.7–0.9 | 0.422 | 0.066 | -0.503 | 0.082 |
| W1        | 5100Å  | 0.1–0.25 | 0.191 | 0.042 | -0.655 | 0.232 |
| W2        | 5100Å  | 0.25–0.8 | 0.007 | 0.006 | 0.112 | 0.010 |
| W3        | 5100Å  | 0.1–0.25 | 0.127 | 0.046 | -0.460 | 0.258 |
| W3        | 5100Å  | 0.25–0.8 | -0.040 | 0.006 | 0.217 | 0.012 |
| W3        | 5100Å  | 0.2–0.8 | -0.022 | 0.008 | 0.162 | 0.015 |
| W3        | 5100Å  | 0.2–0.8 | 0.013 | 0.008 | 0.361 | 0.016 |
| W1        | 3000Å  | 0.36–1.4 | 0.045 | 0.003 | -0.295 | 0.094 |
| W1        | 3000Å  | 1.4–2.0 | -0.242 | 0.010 | -0.085 | 0.006 |
| W2        | 3000Å  | 0.4–2.0 | -0.005 | 0.002 | -0.152 | 0.002 |
| W3        | 3000Å  | 0.4–0.8 | -0.030 | 0.012 | -0.146 | 0.020 |
| W3        | 3000Å  | 0.8–2.0 | -0.186 | 0.004 | 0.039 | 0.003 |
| W4        | 3000Å  | 0.4–0.7 | 0.080 | 0.022 | -0.071 | 0.040 |
| W4        | 3000Å  | 0.7–2.2 | -0.058 | 0.006 | 0.100 | 0.003 |
| W1        | 1350Å  | 1.5–2.5 | -0.488 | 0.013 | -0.033 | 0.006 |
| W1        | 1350Å  | 2.5–4.5 | -0.846 | 0.026 | 0.127 | 0.007 |
| W2        | 1350Å  | 1.5–2.5 | -0.131 | 0.011 | -0.174 | 0.005 |
| W2        | 1350Å  | 2.5–4.9 | -0.511 | 0.021 | -0.005 | 0.006 |
| W3        | 1350Å  | 1.5–4.9 | -0.338 | 0.010 | 0.044 | 0.003 |
| W4        | 1350Å  | 1.5–4.9 | -0.274 | 0.014 | 0.146 | 0.005 |

Note: — 2MASS detections are limited to z < 0.8 sources therefore the measurement of conversions to monochromatic luminosities at 3000Å and 1350Å is not feasible.

Table 7
Example of monochromatic luminosity estimates for AGN SDSS J000006.33+063055.2.

| filter | log_{10}(R(105783)) | log_{10}(R(FX)) at 3000Å |
|--------|----------------------|---------------------------|
| u      | 0.30                  | 45.32 ± 0.04              |
| g      | 0.20                  | 45.38 ± 0.09              |
| r      | 0.09                  | 45.42 ± 0.07              |
| i      | 0.11                  | 45.40 ± 0.07              |
| I      | 0.08                  | 45.42 ± 0.07              |
| W1     | -0.40                 | 45.58 ± 0.13              |
| W2     | -0.29                 | 45.66 ± 0.14              |
| W3     | -0.11                 | 45.38 ± 0.16              |
| W4     | 0.14                  | 46.05 ± 0.28              |

~1100 quasars observed by the Spitzer Space Telescope at 3.6 and 4.5μm (bands nearly identical to the W1 and W2 WISE bands, respectively), and finds for the rest-frame τ0 = 2 years S_{F0} = 0.11 mag and γ = 0.56 for 3.6μm and S_{F0} = 0.12 mag and γ = 0.44 for 4.5μm. Again, we estimate the expected median variance between the optical and IR bands in log_{10}(R) is < 0.1 dex.

It is clear that such intrinsic AGN parameters as the black hole mass, emission lines strength and width, spectrum shape, or the host contamination will have impact on the derived ratios. In Figure 3 we inspect the dependence of the derived ratios on the emission line width (top-left panel), its strength (top-right panel), the black hole mass (bottom-left panel), and the spectral slope (bottom-right panel) using the estimates from Shen et al. (2011). As an example, we use the conversion from the r-band to monochromatic luminosity at 3000Å and the Mg II line parameters for the z = 0.4–2.1 quasars. From Figure 3, we see that there is little or no dependence of log_{10}(R) as the Mg II line width and strength or the black hole mass. There is a hint of weak anti-correlations with log_{10}(R) for the latter two observables, but they are most prominent at the redshift extremes, where there are less objects per bin, and the ratios are less precisely determined. There is, as expected, correlation with the continuum slope. Over 91% of AGNs have slopes in the range −2 < slope < 0, while the ratio changes by up to 1σ inside the entire redshift range between −2 < slope < −1 and −1 < slope < 0. The ratios for AGNs with 0 < slope < 2 seem do not follow the ones for the main sample, they, however, constitute only 2% of the sample.

The BLR radius-relation is r ∝ L^{1/2}, so the black hole mass scales as M_{BH} ∝ L^{1/2}ν^2. Keeping the BLR velocity fixed, an 0.1 dex change in luminosity introduces ~12% change in radius and/or black hole mass. These unlucky 2% of AGNs with 0 < slope < 2 will introduce additional biases of that order in the black hole mass or BLR radius estimate.

We note that these luminosity conversions are based on a large sample of “average” quasars. There are some residual correlations but they appear to introduce typical shift of 0.1 dex – a minor price to pay if the spectrum for the object does not exist, of low quality, or it is not feasible to determine the continuum slope.

6. SUMMARY

In this paper, we have been interested in empirical conversions of broad-band AGN magnitudes to the monochromatic luminosities that are essential in calculating the bolometric AGN luminosity, central black hole mass via the radius–luminosity relation, or simply the BLR radius. Using the 105783 SDSS DR7 quasars, we calculate the ratios between AGN luminosities as observed in common astronomical filters and their monochromatic luminosity as a function of redshift. We provide a simple prescription for using the broad-band magnitudes to calculate monochromatic luminosity at 5100Å, 3000Å, and 1350Å.

AGNs do have different spectral shapes and different contributions from the emission lines, hence the median values derived and provided in this paper should rather serve as “best estimates” and not as “measurements”. Ratios for low redshift AGNs with z < 0.5 may also be affected by AGN host contamination, and hence are less reliable than the estimates at higher redshifts. Galaxies are brightest in infrared, therefore the infrared estimates (2MASS, WISE) should be used with even higher caution, as shown in the discussed example above. We also study correlations of derived conversions with the black hole mass, emission lines strength and width, and the spectrum slope. Only the latter has a noticeable impact (of up to ~0.1 dex) on the derived conversions, but in the absence of spectrum or when the spectrum is of low quality, this is a low price to pay for a monochromatic luminosity estimate.

Since the majority of observations were taken at signif-
91% of quasars have the slope in a range of continuum slope, and changing with redshift. We note that the black hole mass, the spectral slope (from top to bottom). There is no obvious correlation with the Mg II FWHM (strength, black hole mass, and the spectral slope (from top to bottom). Correlations between the measured median ratios of the Figure 3. -band to 3000˚
light-blue). The AGNs with AGNs with 0
slope < 0 (green–red) do not follow the ones for the main sample, they constitute only 2% of the sample.

The redshift z

\[ \log L_{\text{bol}} = \text{const} \times z \]

The redshift z

\[ L_{\text{bol}} = \text{const} \times z \]

significantly different epochs, we estimate that a fair fraction of the reported uncertainties is not related to the intrinsic AGN properties, but simply due to variability.

Having the broad-band magnitudes converted to any or all the monochromatic luminosities, it is straightforward to estimate the BLR radius using the BLR-radius–luminosity relation (Kaspi et al. 2000; Bentz et al. 2009) or the bolometric luminosities using the prescriptions in (Richards et al. 2006). Transformations provided in this paper may also serve as tools in designing future spectroscopic/photic reverberation mapping campaigns, similar to the one reported in (Shen et al. 2013).

We thank Prof. Christopher C. Kochanek for careful reading of the manuscript and many comments that helped to improve it. We also thank Dr. Kelly Denney for helpful comments on the manuscript. This research has made use of the SIMBAD database, operated at CDS, Strasbourg, France. This research has made use of the NASA/IPAC Extragalactic Database (NED) which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

REFERENCES

Bentz, M. C., Peterson, B. M., Netzer, H., Boggs, R. W., & Vestergaard, M. 2009, ApJ, 697, 160
Bessell, M. S. 1979, PASP, 91, 589
Cardelli, J. A., Clayton, G. C., & Mathis, J. S. 1989, ApJ, 345, 245
Che louche, D., & Daniel, E. 2012, ApJ, 747, 62
Cohen, M., Wheaton, W. A., & Megeath, S. T. 2003, AJ, 126, 1090
Czerny, B., Hryniewicz, K., Maity, I., et al. 2013, A&A, 556, A97
Denney, K. D., Peterson, B. M., Pogge, R. W., et al. 2010, ApJ, 721, 715
Fukugita, M., Ichikawa, T., Gunn, J. E., et al. 1996, AJ, 111, 1748
Gordon, K. D., Engelbracht, C. W., Fadda, D., et al. 2007, PASP, 119, 1019
Jannuzi, B. T., & Dey, A. 1999, Photometric Redshifts and the Detection of High Redshift Galaxies, 191, 111
Jarrett, T. H., Cohen, M., Masci, F., et al. 2011, ApJ, 735, 112
Kaspi, S., Smith, P. S., Netzer, H., et al. 2000, ApJ, 535, 631
Kaspi, S., Brandt, W. N., Maoz, D., et al. 2007, ApJ, 659, 997
Kelly, B. C., Bechtold, J., & Sieniginowska, A. 2009, ApJ, 698, 865
Kozłowski, C. S., Eisenstein, D. J., Cool, R. J., et al. 2012, ApJS, 200, 8
Kozłowski, S., Kozłowski, C. S., Udalski, A., et al. 2010a, ApJ, 708, 927
Kozłowski, S., Kozłowski, C. S., Stern, D., et al. 2010b, ApJ, 716, 539
Kozłowski, S., Onken, C. A., Kozłowski, C. S., et al. 2013, ApJ, 775, 92
Morrissey, P., Conrow, T., Barlow, T. A., et al. 2007, ApJS, 173, 682
Oke, J. B., & Gunn, J. E. 1983, ApJ, 266, 713
Peterson, B. M. 1993, PASP, 105, 247
Reach, W. T., Megeath, J. E., Cohen, M., et al. 2005, PASP, 117, 978
Richards, G. T., et al. 2006a, AJ, 131, 2766
Richards, G. T., Lacy, M., Storrie-Lombardi, L. J., et al. 2006b, ApJS, 166, 470
Rieke, G. H., Blaylock, M., Decin, L., et al. 2008, AJ, 135, 2245
Shakura, N. I., & Sunyaev, R. A. 1973, A&A, 24, 337
Schlegel, D. J., Finkbeiner, D. P., & Davis, M. 1998, ApJ, 500, 520
Schmidt, K. B., Marshall, P. J., Rix, H.-W., Jester, S., Hennawi, J. F., & Dokter, G. 2010, ApJ, 714, 1104
Schneider, D. P., Richards, G. T., Hall, P. B., et al. 2010, AJ, 139, 2360
Shen, Y., Richards, G. T., Strauss, M. A., et al. 2011, ApJS, 194, 45
Shen, Y., Brandt, W. N., Dawson, K. S., et al. 2015, ApJS, 216, 4
Stansberry, J. A., Gordon, K. D., Bhattacharya, B., et al. 2007, PASP, 119, 1038
Ulrich, M.-H., Maraschi, L., & Urry, C. M. 1997, ARA&A, 35, 445
Van den Berk, D. E., Wilhite, B. C., Kron, R. G., et al. 2004, ApJ, 601, 692
Vestergaard, M., & Peterson, B. M. 2006, ApJ, 641, 689
Watson, D., Denney, K. D., Vestergaard, M., & Davis, T. M. 2011, ApJ, 740, L149
Wright, E. L. 2006, PASP, 118, 1711
Wright, E. L., Eisenhardt, P. R. M., Mainzer, A. K., et al. 2010, AJ, 140, 1868
Zu, Y., Kochanek, C. S., Kozłowski, S., & Udalski, A. 2013, ApJ, 765, 106
Zu, Y., Kochanek, C. S., Kozłowski, S., & Peterson, B. M. 2013, arXiv:1310.6774

Figure 3. Correlations between the measured median ratios of the r-band to 3000Å luminosity with the Mg II emission line width and strength, black hole mass, and the spectral slope (from top to bottom). There is no obvious correlation with the Mg II FWHM (expressed here in km s\(^{-1}\)), but there is a weak hint of anti-correlation with the Mg II strength (in erg s\(^{-1}\)) and the black hole mass (in M\(_{\odot}\)). There is, however, a strong correlation of the ratios with the continuum slope, and changing with redshift. We note that over 91% of quasars have the slope in a range –2 < slope < 0 (green–light-blue). The AGNs with –2 < slope < –1 and –1 < slope < 0 have ratios different by at most 1σ or 0.1 dex across the entire redshift range. While the ratios for AGNs with 0 < slope < 2 (orange–red) do not follow the ones for the main sample, they constitute only 2% of the sample.