

Research Paper

OzDES Reverberation Mapping of Active Galactic Nuclei: Final Data Release, Black-Hole Mass Results, & Scaling Relations

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Abstract

Over the last decade, the Australian Dark Energy (OzDES) collaboration has used Reverberation Mapping to measure the masses of high redshift supermassive black holes. Here we present the final review and analysis of this OzDES reverberation mapping campaign. These observations use 6 – 7 years of photometric and spectroscopic observations of 735 Active Galactic Nuclei (AGN) in the redshift range $z \in [0.13, 3.85]$ and bolometric luminosity range $\log_{10}(L_{\text{bol}}) \in [44.3, 47.5]$ erg/s. Both photometry and spectra are observed in visible wavelengths, allowing for the physical scale of the AGN broad line region to be estimated from reverberations of the H β , MgII and CIV emission lines. We successfully use reverberation mapping to constrain the masses of 62 super-massive black holes, and combine with existing data to fit a power law to the lag-luminosity relation for the H β and MgII lines with a scatter of ~ 0.25 dex, the tightest and most robust fit yet identified. We fit a similarly constrained relation for CIV, resolving a tension with the low luminosity literature AGN by accounting for selection effects. We also examine the impact of emission line width and luminosity (related to accretion rate) in reducing the scatter of these scaling relationships and find no significant improvement over the lag-only approach for any of the three lines. Using these relations, we further estimate the masses and accretion rates of 246 AGN. We also use these relations to estimate the relative sizes of the H β , MgII and CIV emitting regions, and find evidence that the MgII emission may occur further out than H β . In short, we provide a comprehensive benchmark of high redshift AGN reverberation mapping at the close of this most recent generation of surveys, including light curves, time-delays, and the most reliable radius-luminosity relations to date.

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1. Introduction

Every massive galaxy is thought to host a super-massive black hole (SMBH) at its core, with these objects believed to play an important role in galaxy evolution (Kormendy & Ho 2013). Despite their ubiquity, these objects remain poorly understood, with the exact mechanisms of their formation and growth within their host galaxies remaining as open questions (e.g. Volonteri et al. 2021). Measuring the mass of these SMBHs over cosmic time is then of

great interest, as it offers us insight into the history and evolution of these important objects.

As dark and compact objects, our ability to observe SMBHs by electromagnetic means relies on observations of their environment, and that ability drops rapidly with distance. This obstacle would frustrate our attempts to observe them into the cosmic past were it not for Active Galactic Nuclei (AGN), extremely luminous SMBHs with bright accretion disks that can easily outshine their entire host galaxy. Under the standard model (Urry & Padovani 1995), these AGN consist of a central black hole / accretion disk ‘engine’ and a complex surrounding structure, including the fast orbiting material in the broad line region (BLR). As the luminosity, kinematics and structure of the AGN are all powered by the driving gravitational force of the central black hole, many of the AGN’s

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physical properties offer means of inferring the mass of the black hole.

AGN in the local universe can have their masses constrained by the kinematics of their surrounding stars, either directly tracking orbits (e.g. Schödel et al. 2002) or the bulk stellar velocity dispersion (i.e. the ‘ $M - \sigma$ relation’ Ferrarese & Merritt 2000; Gebhardt et al. 2000), but such techniques become challenging at larger distances where entire galaxies appear as AGN-dominated point sources. The previous decade has also seen considerable progress in imaging two of the nearest SMBHs with interferometry at millimetre wavelengths (e.g. Akiyama et al. 2019), and in using Very Large Telescope interferometry to potentially access finer angular resolutions (Gravity+ Collaboration et al. 2022). At higher redshifts, the limits on angular resolutions can also be surpassed with reverberation mapping (RM), a technique in which a long temporal baseline can substitute for a lack of spatial information (Blandford & McKee 1982; Peterson 1993).

Conceptually, reverberation mapping is straightforward: stochastic variations in the brightness of the AGN’s central engine drive variations in the brightness of gas in the surrounding broad-line region, but do so with a time delay associated with light travel time between the central engine and the BLR. Where we can distinguish signals from different regions, we can characterise the scale of this time delay and so infer the physical scale of the AGN (see Fig. 1 for a sketch of this process with simplified geometry). Knowledge of this geometric scale, coupled with a measure of the velocity and assumptions about kinematics, provides a means of constraining the mass of the SMBH. As such, reverberation mapping of AGN has become the primary means of constraining SMBH masses at any appreciable redshift, dominating over all other methods beyond $z \approx 0.1$ (Cackett et al. 2021).

For most of the history of reverberation mapping, data have been limited to studies of a hand-full of AGN at a time, predominantly at low redshift (e.g. Peterson et al. 1999, 2005; Denney et al. 2006), limited by the difficulty of continuous photometric and spectroscopic observations over the required time scales. This has changed with the advent of the first generation of ‘industrial scale surveys’, in which reverberation mapping is performed on hundreds of AGN at redshifts probing into the deep cosmological past. Over the last decade, surveys like the Australian Dark Energy Survey (OzDES; King 2015) and the Sloan Digital Sky Survey (SDSS; Shen et al. 2015) have made regular photometric and spectroscopic measurements of well over 1000 AGN in the redshift range $0 < z \lesssim 4.5$, dramatically increasing the number of distant AGN observations with RM data to a statistically significant sample, and pushing our constraints on SMBH masses well into the high redshift domain.

Reverberation mapping is observationally expensive, requiring many epochs of observation. However, black hole masses can be derived with single epoch spectral observations through an empirically observed power-law relationship between luminosity and reverberation timescale (or lag) for each line, the so-called ‘ $R - L$ Relationship’. The parameters of these relationships are calibrated using RM and they are reasonably well defined at low redshift, but the paucity of measurements of more distant AGN means that there has been difficulty constraining $R - L$ relations for high redshift AGN. One of the aims of OzDES has been to fill that observational gap. Here we present the complete OzDES RM sample and also make a comprehensive collation and comparison of contemporary reverberation mapping surveys, and create a catalogue of the SMBH masses derived from reverberation mapping.

The paper is organised as follows. We discuss the physical principles of reverberation mapping in Section 2, including methods

and limitations. In Section 3 we introduce the OzDES and external data sets used in this paper, and then in Section 4 we introduce the methodology used by OzDES, including lag measurement procedures and quality cuts, used to define this data set. We then present the full suite of recovered lags, SMBH masses and other results from the OzDES RM program in Section 5. In Section 6.1 we compare the $R - L$ relationship constraints of OzDES against those of SDSS and a wide range of other surveys for the H β , MgII and CIV lines, identifying where they agree or are in tension, and use a combined data set to tightly constrain the $R - L$ slope, offset and scatter for all three lines. In Section 6.2 we confirm an absence of systematic biases from emission-line width or accretion rate. In Section 7 we derive a *bolometric* $R - L$ relation and use the different lag predictions for H β , MgII and CIV as a probe of the relative scales of their emission regions. We then apply the updated $R - L$ relationships in Section 8 to derive single-epoch SMBH masses for 246 AGN, and finally discuss the results of this paper, examining possible implications about the evolution of SMBH populations via our single epoch mass estimates, in Section 9.

2. Technique and limitations

2.1. Reverberation Mapping

The core of AGN reverberation mapping is based on arguments of the virialized orbit of the broad line region about the black hole, with the SMBH mass being correlated with the estimated radius of the BLR, R_{BLR} , and its velocity dispersion $\langle \sigma_v^2 \rangle$ as in equation 1. The complexities of the BLR’s unresolved geometry are captured in the broad uncertainties of the dimensionless ‘virial factor’, $\langle f \rangle$:^a

$$M_{\text{BH}} = \frac{\langle f \rangle R_{\text{BLR}} \langle \sigma_v^2 \rangle}{G}. \quad (1)$$

Though conceptually simple, each term in the numerator of equation 1 is non-trivial to measure for any given source. One hurdle is that the kinematics at play are dependent on the shape and dynamics of the BLR, the nature of which is as yet unresolved (Pancoast et al. 2014a,b). This uncertainty is quantified by calibrating $\langle f \rangle$ as a loosely constrained value from population analysis of nearby AGN, the masses of which are estimated through use of the $M - \sigma$ relation (Woo et al. 2015; Grier et al. 2013a). Measurements of $\langle \sigma_v^2 \rangle$ are made from the spectroscopic broadening of the reverberating emission lines, either by their full-width half-maximum (FWHM), or their dispersion (i.e. the second moment of the line profile about its peak), with different virial factors being tuned for each (see Section 3.3 for examples of RM papers using either technique).

High redshift AGN are beyond the distances at which we have been able to angularly resolve R_{BLR} , and so RM instead uses the timescale at which light propagates through the AGN geometry to measure this size by proxy (see Figure 1). Variations in broad band photometric luminosity are dominated by the light emanating directly from the accretion disk ‘engine’, with these variations being echoed in the driven response in the emission lines of the BLR after some delay, Δt , typically of order days to months. The BLR spectrum exhibits atomic recombination lines that can be easily distinguished from the broad AGN continuum emission, allowing us to identify this echo through spectroscopic observations even where our photometric observations are dominated by light from the accretion disk. With sufficiently tight cadence of photometric and spectroscopic observations, the delay (or lag) between driving

^aMejía-Restrepo et al. (2018) finds that virial factor may be anti-correlated with line width. In this work, we treat $\langle f \rangle$ as being independent.

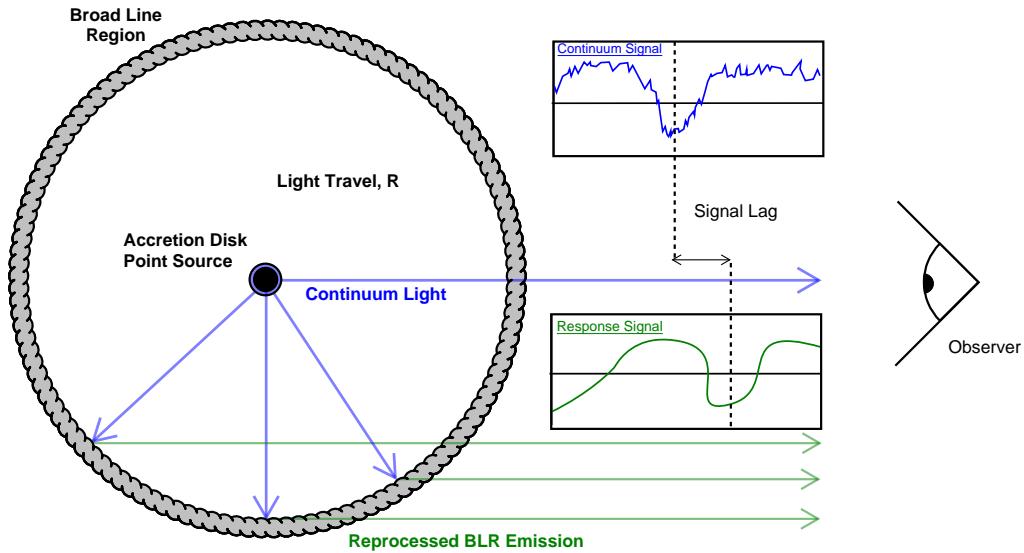


Figure 1: Simplified model of reverberation mapping, showing the different light travel paths for direct and re-processed light. In its simplest ‘single lag’ form, RM relies on the assumption that the accretion disk and BLR are homogeneous, that the accretion disk be reasonably small compared to their angular separation, and the kinematics of the BLR be reasonably well characterised by a single radius (Shakura & Sunyaev 1973; Cackett et al. 2021). Additional geometric complexity is characterised by the virial factor (f) defined in equation 1.

continuum and driven emission line response, Δt can be observed, allowing temporal resolution of observations to substitute for the lack of spatial resolution:

$$R_{\text{BLR}} = c\Delta t. \quad (2)$$

To perform reverberation mapping, a source must provide a clearly identifiable reverberating emission line from the BLR. At cosmological scales, the emission from different emission lines redshift in and out of typical spectroscopic wavelength ranges, and so different atomic emission lines are visible at near, moderate, and high redshift ranges.

For the nearest AGN ($z \lesssim 0.6$), RM is performed with H α at 6562Å and H β at 4861Å (e.g. Bentz et al. 2014). Beyond measuring the mean lag, some studies have even gone as far as using high signal to noise (SNR) measurements of hydrogen recombination lines to constrain the BLR structure and kinematics in further detail. In this “velocity resolved reverberation mapping” (e.g. Denney et al. 2009; Grier et al. 2013b), the reverberating line is treated as being affected by varying degrees of Doppler broadening from different velocities at different radii within the BLR, resulting in different parts of the line profile reverberating at different times.

At higher redshifts ($0.6 \lesssim z \lesssim 1.8$), RM is performed with the MgII line at 2798Å (e.g. Metzroth et al. 2006). RM masses derived from MgII are complicated by iron contamination from the adjacent FeII emission lines, which can distort estimates of the line width unless accounted for (discussed in detail in Section 4).

At high redshift ($z \gtrsim 1.8$), RM is performed with the CIV line at 1549Å. CIV lag measurements have also been made by observing this line in the observer-frame UV range for low redshift and low luminosity sources (e.g. Rosa et al. 2015; Peterson et al. 2005; Metzroth et al. 2006).

The $R - L$ relationship (Kaspi et al. 2000), an empirically observed correlation between the luminosity of an AGN and its physical scale as recovered from RM, is parameterised as a

power-law expressed as:

$$\log_{10}(\Delta t) = \alpha \log_{10}(\lambda L_\lambda) + \beta, \quad (3)$$

where Δt is the rest-frame lag and λL_λ is the monochromatic luminosity of the AGN at a line-specific wavelength: typically 5100Å for H β , 3000Å for MgII, and 1350Å for CIV. Though the $R - L$ relationship for H β is well constrained and found to have small scatter ($\approx 0.1 - 0.2$ dex; Bentz et al. 2013), recent surveys have suggested this scatter may be higher (e.g. Du et al. 2016, 2018). The historical $R - L$ relations for MgII and CIV are found to have higher scatter than H β (Zajaček et al. 2020; Kaspi et al. 2007).

The strong dependence of AGN lags on luminosity has given rise to the technique of stacking (Fine et al. 2012, 2013), in which sources of poor signal to noise but similar luminosity have their lag measurements combined. Through stacking, lag measurements can be made up in aggregate over many sources that would otherwise give poorly constrained results, such as done for the OzDES data in Malik et al. (2024a).

There have been attempts to explain the diversity of lags through more expressive $R - L$ relationships, reducing the intrinsic scatter by adding predictive variables or dividing the AGN population into sub-groups based on the spectral properties (e.g. Mejía-Restrepo et al. 2018, 2016). There is, for example, some evidence that lags are lower for highly accreting sources, above some critical threshold. (Du et al. 2016, 2018). This is described by the dimensionless accretion rate, \dot{M} , given by equation 4, based on the thin-disk model of Shakura & Sunyaev (1973).

$$\dot{M} = 20.1 \left(\frac{L_{5100\text{\AA}}/10^{44}\text{erg/s}}{\cos(i)} \right)^{\frac{3}{2}} \left(\frac{M}{10^7 M_\odot} \right)^{-2}. \quad (4)$$

Here, $\cos(i)$ is the cosine of the inclination of the AGN, taken to be 0.75 as an average value for the quasar inclinations in which the BLR and accretion disk are both visible (Seyfert - 1 type AGN), while $L_{5100\text{\AA}}$ is the bolometric luminosity at 5100Å in units of 10^{44}erg/s and M is the RM-derived SMBH mass in units of 10^7

solar masses. The Super-Eddington Accreting Mass Black Hole (SEAMBH) collaboration use $\dot{M} > 3$ as a benchmark for the separation between low accretion "sub-Eddington" sources and the highly accreting "super-Eddington" sources (Du et al. 2015, 2016).

2.2. The Aliasing Problem

Though the uncertainties in M_{BH} within a single source are dominated by the $\approx 25\%$ population variability in $\langle f \rangle$, lag-recovery presents significant issues with bias and contamination of mass estimates. Cosmological time-dilation means that distant AGN have longer timescales of variability (Lewis & Brewer 2023), meaning that RM requires such sources to be observed over a baseline of multiple years to adequately capture variations in their light curves. For the ground-based observations of most distant RM-campaigns, such multi-year observations are necessarily impacted by a seasonal windowing function that imposes ~ 6 -month gaps in observations. These seasonal gaps give rise to the problem of 'aliasing' (see Fig. 2), which can yield spurious lag recoveries at $n + 1/2$ yearly gaps (180 days, 420 days, etc.; Penton et al. 2021; Malik et al. 2022).

The dangers posed by aliasing are twofold; firstly, it degrades our ability to detect true lags that fall within seasonal gaps, and more dangerously it can lead to false positives arising within these same gaps (Malik et al. 2022). A common approach is to adopt weighting methods in combination with stringent selection criteria to remove sources with spurious lags. Such approaches reduce contamination from false positives, but at the cost of a drastically reduced sample, with typical acceptance ratios being of order $\approx 10\%$ in the OzDES sample. OzDES selections are based on agreement between competing methods (e.g. JAVELIN and ICCF; discussed in Section 4), the emergence of a single well constrained lag, and arguments about the physical reasonability of the overall lag posterior distribution (e.g. whether negative lags are properly excluded). More involved approaches rely on characterising the false positive rate (FPR) through simulation of sources (e.g. Yu et al. 2023; Penton et al. 2025).^b

3. Data

3.1. OzDES

The OzDES project (Yuan et al. 2015; Childress et al. 2017; Lidman et al. 2020) was a parallel project of the Dark Energy Survey (DES), providing spectroscopic follow-up of sources imaged photometrically by DES. DES itself performed a 6-year imaging survey on the CTIO Blanco 4-metre Telescope in Chile. In addition to a wide-field survey, DES repeatedly imaged ten fields to search for supernovae (field coordinates given in Table 2 of Smith et al. 2020). These supernova fields had weekly imaging (during each 6 month season) for 5 years from 2013-2018 and a sixth year with lower cadence in 2019 (for details see Lidman et al. 2020), using DECam in g , r , i and z bands (Flaugher et al. 2015). Primarily, these fields were used to obtain supernova light curves, but they also provide an extensive data set for monitoring the variability of other sources, such as AGN. For ease of access we provide the photometry relevant for AGN reverberation mapping with this paper [link to be provided upon

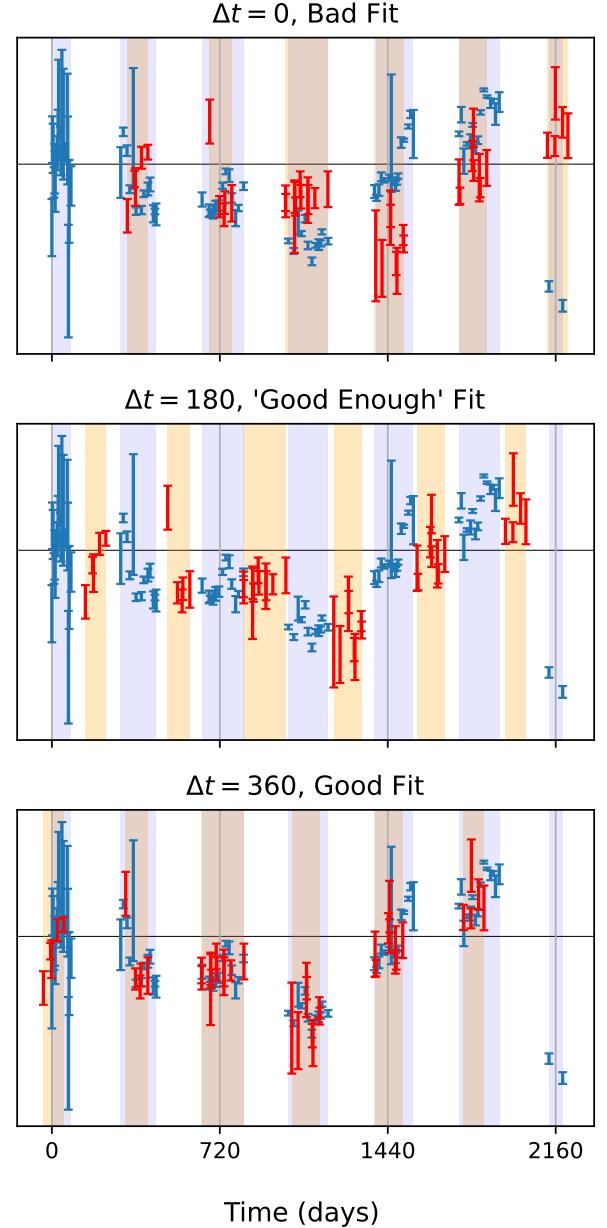


Figure 2: Demonstration of the source of the aliasing problem for mock RM light curves generated with a true lag of 360d, with shaded bands to demonstrate the overlap / gaps in the observations. When observational seasons of our windowing function are of similar or smaller size to the gaps, lags that give no overlap cannot be easily identified as bad fits. This creates local optima in many fitting procedures, inducing 'aliasing peaks' in lag recovery distributions every ≈ 180 d which can obscure the true lag.

acceptance]. The raw images and catalogues from the whole DES survey are available at <https://des.ncsa.illinois.edu/releases/dr2>.

To complement the DES photometry, OzDES obtained monthly spectroscopy using the AAOmega spectrograph fed by the 2dF fibre positioner (Lewis et al. 2002) on the Anglo-Australian Telescope (AAT; for details see Lidman et al. 2020). The 2dF instrument has ~ 400 optical fibres that can be positioned on targets within a 2-degree diameter field of view, and about a quarter of those

^bRecently, a new lag recovery code has been presented in the form of LITMUS (McDougall et al. 2025) which identifies false positives in a fully Bayesian way, but this method has not been used for any lag recoveries used in this paper.

were placed on AGN in each exposure. Using a spectral resolution of $R = 1400$ to 1700 and a wavelength range of 3700\AA to 8800\AA OzDES monitored a total of 735 AGN over six years, gathering between 18 and 25 epochs on each AGN. OzDES typically observed for five months between August and January, perforce leaving large seasonal gaps in the time series data while the fields passed near to the sun. The spectra are publicly available from <https://docs.datacentral.org.au/ozdes/overview/dr2/>.

3.2. Light Curve & Spectral Calibration

For reliable reverberation mapping, a multi-stage calibration procedure of the photometric and spectroscopic measurement is necessary. In OzDES, we make use of the calibration procedures outlined in Hoormann et al. (2019), with the exception of line flux and width measurements for the MgII line for which we use the procedure of Yu et al. (2023). In this section we briefly review this calibration pipeline, but direct the reader to the original papers for more detail.

DECam measurements provide fluxes at an irregular but approximately weekly cadence in the g , r , i , z filters, though in OzDES RM we make use of only those in the g , r and i bands. In the Hoormann et al. (2019) pipeline, spectroscopic epochs are discarded if they are of low quality (require quality flag 4 or greater, see Yuan et al. 2015) or lack a co-temporal calibrating magnitude. Epochs are then discarded as outliers if they differ by more than 0.2 magnitudes from the source's mean in the same year and same band pass, with the remaining measurements being averaged if they occur on the same night. An additional filter-dependent calibration uncertainty is also added to the variance as per Burke et al. (2017).

Each spectral epoch is calibrated, both converting from photon counts to flux values and correcting for systematic distortions of the spectrum, by comparing the spectra to the g , r and i photometric measurements. Synthetic photometric measurements are made by integrating over the product of the spectrum and band-pass, and a ratio taken between synthetic and measured brightness. Describing this factor as a function of wavelength, a quadratic is fit across the three measured ratios, acting as a measure of the relative throughput. The entire spectrum was warped to remove this bias (e.g. Fig. 3). After warping, spectra are co-added if they share the same night.

Once the spectrum is calibrated, line fluxes and widths are calculated by isolating a window of rest-frame wavelengths in which the reverberating line occurs. By linearly interpolating between the flux at the window boundaries, the local continuum is subtracted and the total flux, line dispersion and line width estimated. Uncertainties in this value are found by Monte Carlo variation of the window boundaries and the flux measurements within bounds of uncertainty.

For the MgII sources we add an additional step to account for the iron emission lines that flank and coincide with the MgII emission line, which, if not accounted for, can contaminate measurements of line width. In their analysis of the OzDES MgII lags, Yu et al. (2023) account for this by fitting iron spectral templates (Tsuzuki et al. 2006; Salviander et al. 2007; Vestergaard & Wilkes 2001) in a Bayesian fashion using the python MCMC package emcee. Spectral fits for the emission lines were visually inspected and poorly fitted epochs were removed before lag-fitting with JAVELIN.

Following the line width pipeline of Hoormann et al. (2019), the measurements presented here are made using the spectrum averaged over all epochs and use line dispersion as a measure of the line width. All fluxes are converted to luminosities assuming a Λ CDM

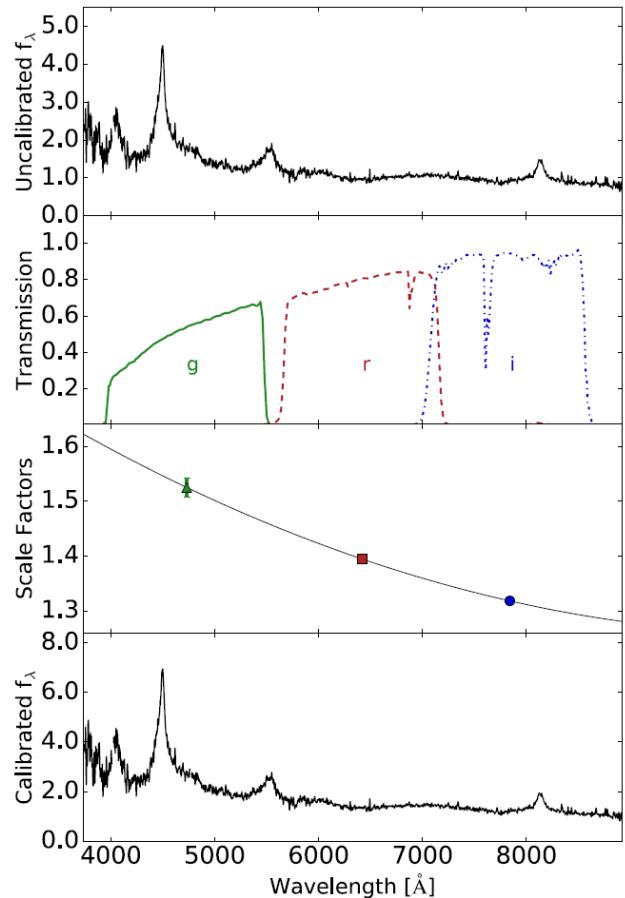


Figure 3: Demonstration of the spectral warping procedure from Hoormann et al. (2019). The top panel shows a smoothed version of the spectrum of AGN DES J022828.19-040044.30. The second panel shows the gri filter transmission functions, while the third shows the wavelength-dependent transmission coefficients, found by integrating the spectrum with these filters, and the quadratic fit between them, each in units of $10^{-16}\text{erg s}^{-1}\text{cm}^{-2}\text{\AA}^{-1}\text{counts}^{-1}$. The bottom panel shows the spectrum after correcting by these scale factors to produce a fully calibrated spectrum in units of $10^{-16}\text{erg s}^{-1}\text{cm}^{-2}\text{\AA}^{-1}$.

cosmology with parameters $H_0 = 70 \text{ km s}^{-1}\text{Mpc}^{-1}$, $\Omega_m = 0.3$ and $\Omega_\Lambda = 0.7$.

3.3. External data sets

In addition to presenting our recovered lags, we make use of a number of sources from the literature, both for comparison and to improve the constraining power of the $R - L$ relationship. A summary of these sources are listed in Table 1. The bulk of these lags are those recovered from the Sloan Digital Sky Survey (Shen et al. 2023), a contemporary to OzDES at a similar ‘industrial scale’ and redshift range. In Section 4.2.4, we describe how the SDSS lags use dissimilar selection criteria to OzDES, including the use of different software as their primary detection method. For the sake of homogeneity in this paper, we adopt the JAVELIN lags for SDSS and apply an analogue of our own selection criteria.

For low redshift lags associated with the H β line, we also supplement our data with the external lags utilised in the analysis of Malik et al. (2023). These include lags from: the Lick AGN Monitoring

H β Sources		
Source	No. AGN	Redshift Range
OzDES	8	0.127 – 0.332
SDSS	26	0.289 – 1.003
Bentz Collection	48	0.002 – 0.292
SEAMBH	40	0.017 – 0.400
LAMP	16	0.029 – 0.078
Misc	6	0.017 – 0.327
MgII Sources		
Source	No. AGN	Redshift Range
OzDES	25	0.840 – 1.860
SDSS	25	0.360 – 2.149
Zajacek	6	0.003 – 1.890
CIV Sources		
Source	No. AGN	Redshift Range
OzDES	29	1.922 – 3.451
SDSS	15	1.675 – 2.453
Kaspi	17	0.001 – 3.368

Table 1.: A summary of the number of sources and redshift ranges for the OzDES, SDSS and other literature data used for constraining $R - L$ relationships in this work. Note that the number of sources here is the number used, and not the total number of published lags from that reference.

Project (LAMP) (U et al. 2022), a low redshift ($z < 0.08$) study of statistically diverse AGN; the SEAMBH survey, which targets high luminosity sources known to produce lower reverberation lags (Du et al. 2016, 2018; Hu et al. 2021); and a collection of low redshift sources collated by Bentz et al. (2013), coupled with similar sources from Fausnaugh et al. (2017); Bentz et al. (2009, 2013, 2014, 2016a,b) and Bentz et al. (2023). Also included are a number of additional sources from Zhang et al. (2019); Li et al. (2021); Lu et al. (2016); Pei et al. (2014); Rakshit et al. (2019). Sources prior to 2019 and not associated with the SDSS collaboration are drawn from a convenient collation by Martínez-Aldama et al. (2019).

The combination of a larger sample size and good signal-to-noise yields a larger set of lags associated with the MgII line in the OzDES intermediate redshift sample than are recovered in the low redshift H β sample (Yu et al. 2021, 2023). In total, 25 OzDES MgII lags are available, which we supplement and contrast with the set of SDSS MgII lags, a smaller set of lags from Zajacek et al. (2021) and a wider collection of literature sources presented by Zajacek et al. (2020). This collection is comprised of lags collated from Lira et al. (2018); Metzroth et al. (2006); Czerny et al. (2019) and earlier SDSS lags from Shen et al. (2016, 2019). We use the entire set of lags as listed by Zajacek et al. (2020) when analysing the collection by itself, but when using these data in combination with other surveys we defer to the SDSS measurements when the same source has been reported twice.

For the CIV lags, we compare the OzDES results presented in Penton et al. (2025) with the latest SDSS CIV lags from Shen et al. (2023) and a diverse collection of earlier literature sources, which we label as as ‘The Kaspi Collection’. It is worth noting that the Kaspi Collection includes SDSS lags from Grier et al. (2017);

Grier et al. (2019); Shen et al. (2019), as well as earlier OzDES lags from Hoormann et al. (2019). As we already analyse more recent and complete SDSS results independently, we do not include these sources in our analysis of the Kaspi Collection.

The sources of the Kaspi Collection can be broadly separated into two groups: high redshift, high luminosity AGN with the CIV line measured in the optical band by Lira et al. (2018) and Kaspi et al. (2021), and a number of nearby low luminosity sources from Peterson et al. (2005), Metzroth et al. (2006) and Rosa et al. (2015) in which the CIV line is observed in the observer-frame UV. We separate these two groups and label them as ‘Kaspi High-Z’ and ‘Kaspi Low-Z’. As we discuss further in Section 6.1.3, these two sub-samples have different statistical properties, and treating them as a single group runs afoul of tensions when constraining the $R - L$ relationship.

When considering the velocity in equation 1, there are two decisions about how this is interpreted from the quasar spectra: whether to use the dispersion / variance of the line profile (disp) or its full-width half maximum (FWHM), and whether to make these measurements from the spectrum as time-averaged over all epochs (mean-spec) or by its root-mean-squared over all epochs (RMS-spec). Different papers in the literature occupy all four quadrants of this decision tree. Note that the disp/FWHM decision represents a different choice of physical measurement, and so leads to a correspondingly different virial factor, while the mean-spec/rms-spec decision is purely about which gives the clearer measurement.

The dispersion approach tends to be the preferred approach in more modern surveys (e.g. Shen et al. 2023; Rakshit et al. 2019; Zhang et al. 2019), while both mean-spec (e.g. Li et al. 2021) and RMS-spec (e.g. Lu et al. 2019) approaches are still in active use. The RMS spectrum is preferred for high SNR sources to isolate the time-varying component of the signals (e.g. Bentz et al. 2014; Pei et al. 2014), but many surveys will measure line widths in all, or at least multiple, ways (e.g. Shen et al. 2023; Fausnaugh et al. 2017).

In this work, as with past OzDES RM papers, we use the dispersion-based definition of line width as our measure of velocity rather than the FWHM, and default to this measurement for literature measurements where available in the source paper. In making the decision between mean-spec and RMS-spec, we defer to the preferred method of the source paper, e.g. mean spectrum for sources from Bentz et al. (2013), RMS spectra for sources from Shen et al. (2023) etc. For source-papers in which only the FWHM line widths are provided, we follow the lead of Kaspi et al. (2021) and use $\text{disp} = \text{FWHM}/2.35$ based on an assumption of a Gaussian line profile.

4. Methods

4.1. Lag Recovery

The central element of reverberation mapping is identifying and constraining the delay between two light curves, a task that is complicated by the stochastic variability in the underlying signal, and a host of obstacles arising from the windowing function. These issues have led to a wide range of competing techniques and software for computing the lag in AGN-RM. These can be broadly sorted into two categories: the first containing non-parametric techniques that assume no underlying statistical behaviour and fit to only the light curves, and the second being those that model the AGN variability as a Gaussian process.

Modelling the AGN light curve as a Gaussian process is physically motivated, as they are known to show consistent patterns in

their variability (MacLeod et al. 2010; Zu et al. 2013; Kozłowski 2016), but the associated fitting procedures are computationally expensive and fraught with numerical and statistical obstacles (Penton et al. 2021; Malik et al. 2022; Read et al. 2019). As a result, non-parametric methods like PyCCF (Sun et al. 2018) and PyROA (Donnan 2021) are still in use as more robust, if less precise, alternatives to full Bayesian modelling. The SDSS team uses PyROA for their ‘primary’ lag recovery method, while OzDES use a combination of the GP-based JAVELIN and the non-parametric PyCCF for validation and source selection cuts. For the interested reader, in Appendix A we provide an introduction to these fitting methods, their statistical basis, and numerical shortfalls.

4.2. Post-Recovery Quality Cuts

The stochastic nature of AGN light curves means that non-physical false positive lags are a possibility even in the presence of arbitrarily good measurements. Coupled with matters of measurement noise, calibration error and, in multi-year surveys such as OzDES, the impacts of aliasing from the seasonal windowing function, the contamination rate from such false positives can outstrip physically meaningful lag recoveries by near to an order of magnitude if unaccounted for.

Bespoke analysis can be used to assess reliability of a handful of sources at a time, but this approach is untenable in industrial-scale studies like OzDES. Instead, it is necessary to use a general, widely applicable criteria for selecting and post-processing the lag recoveries of the sample sources at large to remove spurious results (Penton et al. 2021; Malik et al. 2022).

The methods for suppressing the impacts of aliasing through quality cuts varies significantly between different studies. In this section we outline the quality cuts used in each of the previous OzDES RM papers as well their underlying motivation, and present also a set of selection criteria to apply to the SDSS RM sample of Shen et al. (2023) aimed at drawing from their data a set of sources with selection effects analogous to those of OzDES.

4.2.1. Quality Cuts for H β Lags

OzDES tracked 78 AGN sources in the redshift range for H β line visibility, with only 5 sources passing the quality cuts outlined in Malik et al. (2023). The low luminosities for these sources give lags in the 20 – 200 day range, meaning only a small fraction of the brightest sources are expected to be heavily impacted by aliasing, which becomes more severe when the true lag is ‘off season’, i.e. at $\Delta t \approx 180$ d, 540d etc. (Malik et al. 2022). The OzDES quality cuts for H β are that each source must have:

1. Uncertainties from the JAVELIN recovered lag are less than $\max(30\text{d}, \Delta t_{\text{JAV}})$,
2. Lags from PyCCF and JAVELIN agree to within 2σ of the JAVELIN uncertainties,
3. The maximum correlation from PyCCF (r in equation 12) gives $r_{\text{max}} > 0.6$, and
4. The PyCCF false positive rate (p-value) is < 0.05 .

The first cut selects only well constrained lags, the second leverages the robustness of the ICCF to account for spuriously constrained JAVELIN false positives, and the last two cuts ensure that we keep only lags that do not favour the null hypothesis of there being no relation between the two light curves.

4.2.2. Quality Cuts for MgII Lags

The majority of OzDES AGN sources are observed in the redshift range that allow for visibility of the MgII line, with 453 of its 753 target AGN being in the $z \in [0.65, 1.92]$ redshift range where the MgII line is visible in range of OzDES data. These MgII sources exist over a wide redshift range, and the range of observed lags significantly overlaps with the $n + 1/2$ year ‘danger-zones’ for aliasing effects. These high redshift AGN lags require strict and principled quality cuts to avoid contamination of the $R - L$ relationship. To this end, Yu et al. (2023) applies two distinct sets of selection criteria, one based on the posterior distribution weighting approach of Grier et al. (2019), and another based on the simulation based false positive rate estimation of Penton et al. (2021).

In the SDSS approach, the marginalized lag posterior distribution $P(\Delta t)$, as recovered by PyROA, JAVELIN or PyCCF, is attenuated by a weighting function that down-weights lags that correspond to the poorly constrained seasonal gaps. This weighting function is the convolution of two components. The first term, based on the fraction of observations that overlap between the two light curves after shifting by some lag, down-weights ‘off-season’ lags in seasonal gaps where this overlap is small. The second term is the auto-correlation function of the continuum signal (ACF_{Cont}), which smooths and widens the ‘on-season’ peaks of the weighting function to account for the continuous nature of the light curve. The entire posterior is then convolved with Gaussian smoothing kernel of width 15 days (equation 5):

$$P'(\Delta t) = \left(P(\Delta t) \times \left[\left(\frac{N(\Delta t)}{N(0)} \right)^2 \circledast \text{ACF}_{\text{Cont}}(\Delta t) \right] \right) \circledast \mathcal{N} \left(\frac{\Delta t}{15\text{d}} \right), \quad (5)$$

where \circledast represents the convolution operator. The square bracketed terms represent the weighting function while the convolved normal distribution represents the final smoothing.

This ad-hoc approach suppresses lags that are in danger of being the result of aliasing, retaining only those that give an extremely high likelihood. Different quality cuts have been used in past analysis based on this weighting, including discarding sources in which the weighting reduces the posterior evidence by too large of a fraction (e.g. Grier et al. 2019).

In Yu et al. (2023), the OzDES analysis reports lags from the un-weighted distribution as produced by JAVELIN, but uses the weighted distribution to identify the ‘primary’ peak as being the highest likelihood mode in the weighted-distribution $P'(\Delta t)$. Sources are retained only if the unweighted distribution has:

1. More than 60 % of its evidence (posterior distribution integral) contained within the primary peak,
2. The width of this peak, as measured between the 16th and 84th percentiles, be less than 110 days, and
3. This peak be in agreement with the unweighted PyCCF distribution to within 2σ .

Yu et al. (2023) also includes quality cuts modelled after the more rigorous simulation-work of Penton et al. (2021), in which simulations of mock DRW signals are used to characterize false positive rates, and quality cuts tuned to remove suspicious sources. These cuts, designed specifically for unweighted JAVELIN posterior distributions and OzDES-like observations, require:

1. That the standard deviation of the JAVELIN posterior distribution be less than 110 days,

2. That the separation of the JAVELIN median lag & peak likelihood lag be within 110 days of one another, and
3. That the lags from PyCCF and JAVELIN agree to within 110 days.

Of the 453 available MgII sources, 25 pass both sets of quality cuts and produce reliable lags, $\approx 5.5\%$ of the initial sample, with an estimated false-positive rate in this post-cut sample of $\approx 4\%$ (i.e. 1 false positive out of the 25).

4.2.3. Quality Cuts for CIV Lags

OzDES tracked 305 high redshift AGN with CIV lines visible for reverberation mapping. These distant sources represent the earliest and most luminous AGN in the OzDES RM sample, and, owing to the anti-correlation of AGN luminosity and optical variability (MacLeod et al. 2010), the sources with the weakest AGN variability. These sources are also observed with the shortest rest-frame time window due to higher time dilation at these higher redshifts. In combination, lag recovery for the CIV sample is a difficult process with an outsized risk of false positives if approached naively. For CIV RM of the OzDES sample, Penton et al. (2021) provide a series of quality cuts to maximize the reliability of $R - L$ constraints and minimize the rate of false positives, tuned on mock simulations of OzDES-like data. Under these cuts, sources are sorted into quality levels of ‘bronze’, ‘silver’, ‘gold’, or are rejected completely based on the properties of their marginalized lag posterior distribution and the lag recovery results from the ICCF method. These cuts are:

1. That the JAVELIN posterior rule out $\Delta t = 0$ to within 3σ ,
2. That the lag of JAVELIN and ICCF lags agree to within 100d,
3. That the JAVELIN lag posterior median and maximum posterior value be similar (within 110d for bronze quality, 80d for silver and 65d for gold),
4. That the JAVELIN posterior is strongly constrained to a single peak, with a high fraction (33%, 45% and 65% for bronze, silver and gold, respectively) of posterior density / MCMC chain samples falling within a single mode.

After these cuts, Penton et al. (2025) recovered 29 CIV lags, with 6 each at the gold and silver confidence level and 17 at bronze. This analysis included a re-examination of the two CIV lags from Hoormann et al. (2019) with more years of observations.

4.2.4. SDSS Sub-Sampling Criteria

In the final data release for the Sloan Digital Sky Survey’s 7-yr RM campaign, Shen et al. (2023) constrain and select lags in a fundamentally different way to OzDES. Rather than using simulation-based estimates of the false positive rate, SDSS instead allow each source to fit for both positive and negative lags, and then apply the aliasing mitigation weighting strategy outlined in Section 4.2.2. Under the rationale that any lag recovered at $\Delta t < 0$ must necessarily be a false positive, they use this as an estimate of the population level false positive rate, using this to tune their selection criteria. To this end, they make use of only one quality cut: that the ICCF r value (equation 12) must be > 0.4 as evaluated at the lag recovered by their chosen primary lag recovery method PyROA. This is similar to the selection criteria of the OzDES H β analysis of Malik et al. (2023), which requires $r > 0.6$ at the lag as recovered by JAVELIN.

By contrast to SDSS, OzDES restrict our lag search range to only the physically reasonable domain and apply stringent cuts to minimise the effect of aliasing on each individual source. This

produces a more restricted sample with fundamentally different statistical properties, which can be seen in the tension between the SDSS and OzDES $R - L$ constraints. In particular, restricting the SDSS sample to OzDES-like quality cuts significantly lowers scatter about the MgII $R - L$ relationship (discussed in detail in Section 6.1.2). To make joint fits to the $R - L$ relation using both the SDSS and OzDES data sets, we required a set of lags with relatively homogeneous selection properties. To that end, we derive an alternate set of lags from the published SDSS data of Shen et al. (2023) that differ from their sample in two ways: firstly, in that we use the lags as recovered from JAVELIN instead of their choice of PyROA, and secondly that we apply a number of quality cuts to this alternate sample to bring it more in line with the rationale of the OzDES selections.

Our sub-sampling criteria for the SDSS sources are:

1. That recovered lags must be positive, $\Delta t > 0$ at 1σ .
2. That results should be robust across methods, such that JAVELIN, ICCF and PyROA all agree in peak lag to within 2σ of the JAVELIN uncertainty,
3. That the fit should be statistically significant, as measured by setting $r > 0.6$ evaluated at the JAVELIN modal lag,
4. That the anti-aliasing down-weighting weighting scheme must not overly distort the lag probability distribution. We require that the posterior evidence rejected (fraction of MCMC chain samples in their terminology) by the SDSS anti-aliasing weighting must be $< 60\%$.

For step 2, in cases where the JAVELIN lag peak is strongly constrained, we replace the JAVELIN confidence interval in this test with 30 days for H β or 110 days for CIV and MgII, following a similar reasoning to the cuts of Penton et al. (2021). After applying these cuts, we retain a sub-sample with 26 H β lags, 25 MgII lags and 15 CIV lags from the SDSS sample.

This SDSS-JAVELIN subsample is broadly similar to the published SDSS sample for the H β and CIV lags, but prefers a markedly for lower scatter in the MgII $R - L$ relationship. For the MgII lags, these selection criteria drastically reduce the scatter of the lags about their best-fit $R - L$ relationship, and marginally decrease its preferred slope (see Fig. 6 for a comparison).

5. OzDES Reverberation Mapping Results

In this section we summarise the reverberation mapping results across past OzDES papers, including the reverberation lags and the resulting estimated SMBH masses.

5.1. Lag measurements

In total, the OzDES reverberation mapping program has produced 62 high quality AGN lags, consisting of 8 H β lags (Malik et al. 2023), 25 MgII lags (Yu et al. 2021, 2023) and 29 CIV lags (Penton et al. 2025). For each of these sources, we calculate the mass using equation 1 and accretion rate using equation 4, where the 5100Å monochromatic luminosity uses bolometric corrections of Runnoe et al. (2012) (Table 2 in their paper) and we use the virial factor of $\langle f \rangle = 4.31 \pm 1.05$ from Grier et al. (2013a). Rest-frame lags range from $16^{+2.7}_{-2.7}$ d^c to $335^{+2.5}_{-16.0}$ d, sitting within the range of lags recovered by other works. We find that the distribution of lags over redshift is reasonably consistent with existing reverberation mapping results from the literature (Fig. 4, upper left). We note that the

^cd being days, here and elsewhere in the paper.

distribution of lags changes abruptly as one moves between lines, most notably between the MgII and CIV lines, indicating different lags, and thus radii, for different ions. This is quantified in Section 7. These RM results, as well as the redshifts and luminosities for the relevant sources, are listed in Table 1 for our H β sources, Table 2 for MgII sources, and Table 3 for CIV sources.

5.2. Black hole masses from direct RM measurements

In total, we present a compilation of the 62 SMBH masses from OzDES reverberation mapping, ranging from $25.3^{+8.5}_{-6.8} \times 10^6 M_\odot$ to $4.0^{+1.8}_{-1.7} \times 10^9 M_\odot$. The relevant measurements are listed, along with estimates of the corresponding accretion rates, in Tables 1, 2 and 3. Accretion rates are calculated per equation 4, correcting luminosities to the $L_{5100\text{\AA}}$ using the bolometric corrections of Runnoe et al. (2012). The calculation uses full error propagation by varying the lag, luminosity and line width within their respective measurement uncertainties. Results are reported as the media, with uncertainties drawn from the 16th and 84th percentiles.

We broadly see an increase in mass with redshift (Fig. 4 lower left), which is expected, as the AGN at higher redshifts are selected to be more luminous (see, for example, Fig. 1 in Malik et al. 2024a), and this selection effect will dominate any evolutionary effects. We similarly see the expected general increase of more luminous AGN being more massive, but are unable to infer a clear power-law relationship (Fig. 4 lower right).

It should be noted also that the estimated accretion rates for high redshift CIV sources can be extremely high (Fig. 4 upper right), with most direct RM samples sitting above the $\dot{M} = 3$ threshold used by Du et al. (2015) as the division between low and high accretion sources. In Section 6.1.3 we note an apparent flattening of the CIV $R - L$ curve at high luminosity, and, given that SEAMBH associate high accretion rates with low lags (U et al. 2022), this offers a possible physical explanation. Within the OzDES sample, there is a weak trend for more luminous, higher-redshift sources to accrete more strongly (black data points, Fig. 4 upper right).

6. Comparison of New Results With Past Surveys & Tuning of $R - L$ Relationship

Here we examine the $R - L$ relationship using the full array of lags available at the close of this latest generation RM surveys. In addition to lags from OzDES and the final SDSS release of Shen et al. (2023), we use a wide array of past H β , MgII and CIV lags as outlined in Section 3.3. In Section 6.1, we use a Bayesian approach to constrain the parameters of the $R - L$ relationship for all three reverberating emission lines, and to identify where the results of different surveys are in tension.

We investigate in Section 6.2 the possibility of using line width or accretion rate to reduce scatter in the single epoch model, and finally we use then use the $R - L$ relationship as a probe of the relative sizes of the H β , MgII and CIV emission regions of the BLR in Section 7

6.1. Comparison of $R - L$ Parameter Constraints

In this section we fit the $R - L$ relationship using OzDES data alone and using OzDES data in combination with data from other sources. We note that some surveys are in statistical tension, which indicate unexplored selection effects, and so Table 2 lists the $R - L$

parameters for our chosen ‘primary’ data sets, while the following sub-sections elaborate on alternate $R - L$ relationships with different combinations of literature data and quality cuts.

For consistency, we refit the $R - L$ relationship with the same model for all data, while making use of the published lags and monochromatic luminosities from previous papers.^d We model the $R - L$ relationship as being linear in log-log space, with slope α , offset β , and an intrinsic scatter σ such that the a given luminosity $\lambda L_{\lambda,i}$ predicts a lag $\Delta t_{RL,i}$ by:

$$\log_{10} \Delta t_{RL,i} = \alpha(\log_{10}(\lambda L_{\lambda,i}) - \log_{10}(\lambda L_0)) + \beta \pm \sigma. \quad (6)$$

Here, $\log_{10}(\lambda L_0)$) represents the choice of luminosity units, typically $\lambda L_0 = 10^{44}$ or 10^{45} erg/s, and is chosen to minimize the covariance between offset β and slope α in the posterior distribution. β varies with the choice of time units for the lag, and we here follow the convention of all lags being in days.

The observed RM lag, Δt_{RM} , has an additional scatter from observational uncertainty. We describe this uncertainty in log-space, i.e. $\log_{10}(\Delta t_{RM,i}) = \log_{10}(\Delta t_{RL,i}) \pm E_{\log,i}$. Under this modelling, the resulting likelihood for fit parameters $\theta = \alpha, \beta, \sigma$ is:

$$\mathcal{L} = \prod_i \frac{1}{\sqrt{2\pi(E_{\log,i}^2 + \sigma^2)}} \exp \frac{-(\log_{10} \Delta t_{RM,i} - \log_{10} \Delta t_{RL,i})^2}{2(E_{\log,i}^2 + \sigma^2)}. \quad (7)$$

We approximate the measurement uncertainty, E_{\log} , as an asymmetric ‘split Gaussian’ with uncertainties found from the positive and negative uncertainties of the lag measurement. I.e. if a lag measurement $\Delta t_{RM,i}$ is constrained within upper and lower bounds $\Delta t_{+RM,i}$ and $\Delta t_{-RM,i}$, then the log-space measurement uncertainty is:

$$E_{\log,i} = \begin{cases} \log_{10} \left(\frac{\Delta t_{+RM,i}}{\Delta t_{RM,i}} \right), & \Delta t_{RL,i} > \Delta t_{RM,i} \\ \log_{10} \left(\frac{\Delta t_{RM,i}}{\Delta t_{-RM,i}} \right), & \Delta t_{RL,i} < \Delta t_{RM,i} \end{cases}. \quad (8)$$

For similar consistency reasons, we use the same procedure to re-fit the $R - L$ relation of literature sources and combinations thereof. We treat all published lags and their uncertainties as describing the cumulative summary statistics of the lag posterior distribution (i.e. median and 16th, 84th percentiles).

All fits are performed using the Bayesian analysis tool NumPyro (Phan et al. 2019), specifically its No U-Turn (NUTS) sampler, a Hamiltonian Monte Carlo (HMC) method that is well suited to unimodal distributions. We note that this fitting is relatively insensitive to the choice of sampler, as it is unimodal and produces approximately Gaussian contours (e.g. Fig. 6).

6.1.1. H β $R - L$ Relationship

OzDES is designed primarily for higher redshifts, and so captures only a small number of sources in the H β redshift range. Coupled with the high rejection rate, this yields only 8 high quality lag recoveries for the OzDES H β $R - L$ relationship (Malik et al. 2023). In past OzDES analyses, the limited number of sources has been bolstered by lags from the literature, namely the 5-year SDSS lags (Grier et al. 2017), a wide range of low redshift lags collated by Bentz et al. (2009) as well as later additions to this ‘Bentz Collection’ (Bentz et al. 2013, 2014, 2016a,b; Bentz et al. 2023), lags from the SEAMBH project, lags from the LAMP collaboration (U et al. 2022), and a small number of miscellaneous literature lags (Li et al. 2021; Lu et al. 2016; Zhang et al. 2019; Rakshit et al. 2019). We make use of these same sources, in addition to the final SDSS lags of Shen et al. (2023), but re-fit each data set individually

^dOzDES luminosities differ slightly from previous papers due to recalibration.

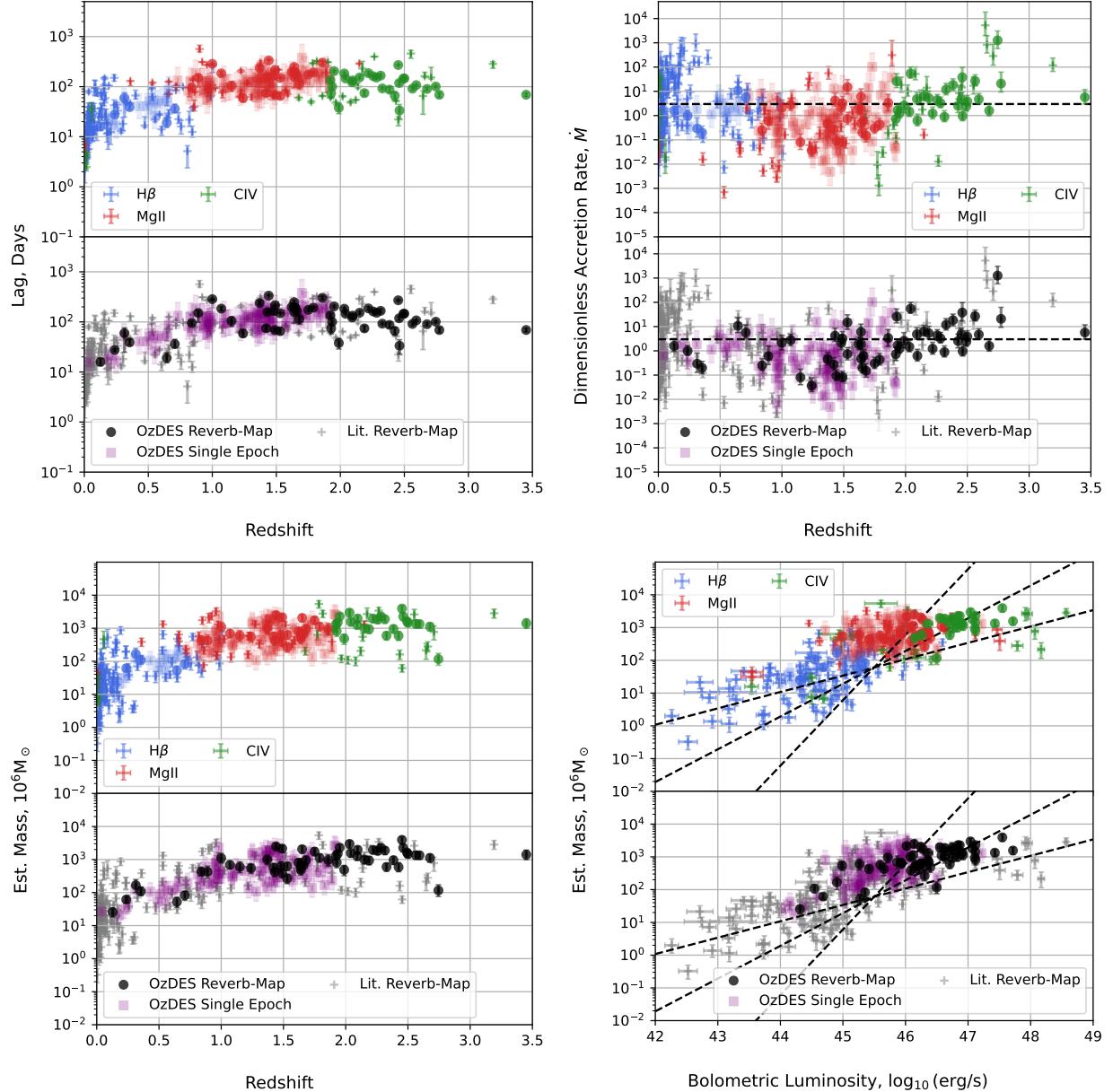


Figure 4: A summary of all OzDES reverberation mapping (circles) and single epoch findings (squares) as well as comparison with literature RM results (plus signs). The top row plots measured and estimated lags (left, estimates from the R-L relationship) and accretion rates (right) against redshift, while the bottom row shows SBMH mass plotted against redshift (left) and bolometric luminosity (right). In each plot, the top panel colours sources by emission line, while the bottom colours by data source. On the mass vs luminosity plot, we also overlay power laws of index 0.5, 1.0 and 2.0 as a way to illustrate the slope of the relation.

Line	Luminosity Unit	Slope (α)	Offset (β)	Scatter (σ)	Slope - Offset Fit Correlation (ϕ)
H β	$\log_{10}(\lambda L_{5100\text{\AA}}) - 44$	$0.44^{+0.04}_{-0.02}$	$1.43^{+0.03}_{-0.02}$	$0.25^{+0.03}_{-0.02}$	0.12
MgII	$\log_{10}(\lambda L_{3000\text{\AA}}) - 45$	$0.34^{+0.04}_{-0.05}$	$2.07^{+0.03}_{-0.03}$	$0.23^{+0.03}_{-0.02}$	-0.13
CIV	$\log_{10}(\lambda L_{1350\text{\AA}}) - 45$	$0.47^{+0.05}_{-0.04}$	$1.65^{+0.05}_{-0.06}$	$0.36^{+0.04}_{-0.06}$	-0.36

$$\log_{10}(\Delta t) = \beta + \alpha \text{Luminosity Unit} \pm \sigma$$

Table 2. : Our final $R - L$ Relationships for H β , MgII and CIV using a combination of multiple data sets for each. Monochromatic luminosities are measured in the rest-frame in units of erg/s, and resulting radii are in units of \log_{10} light-days.

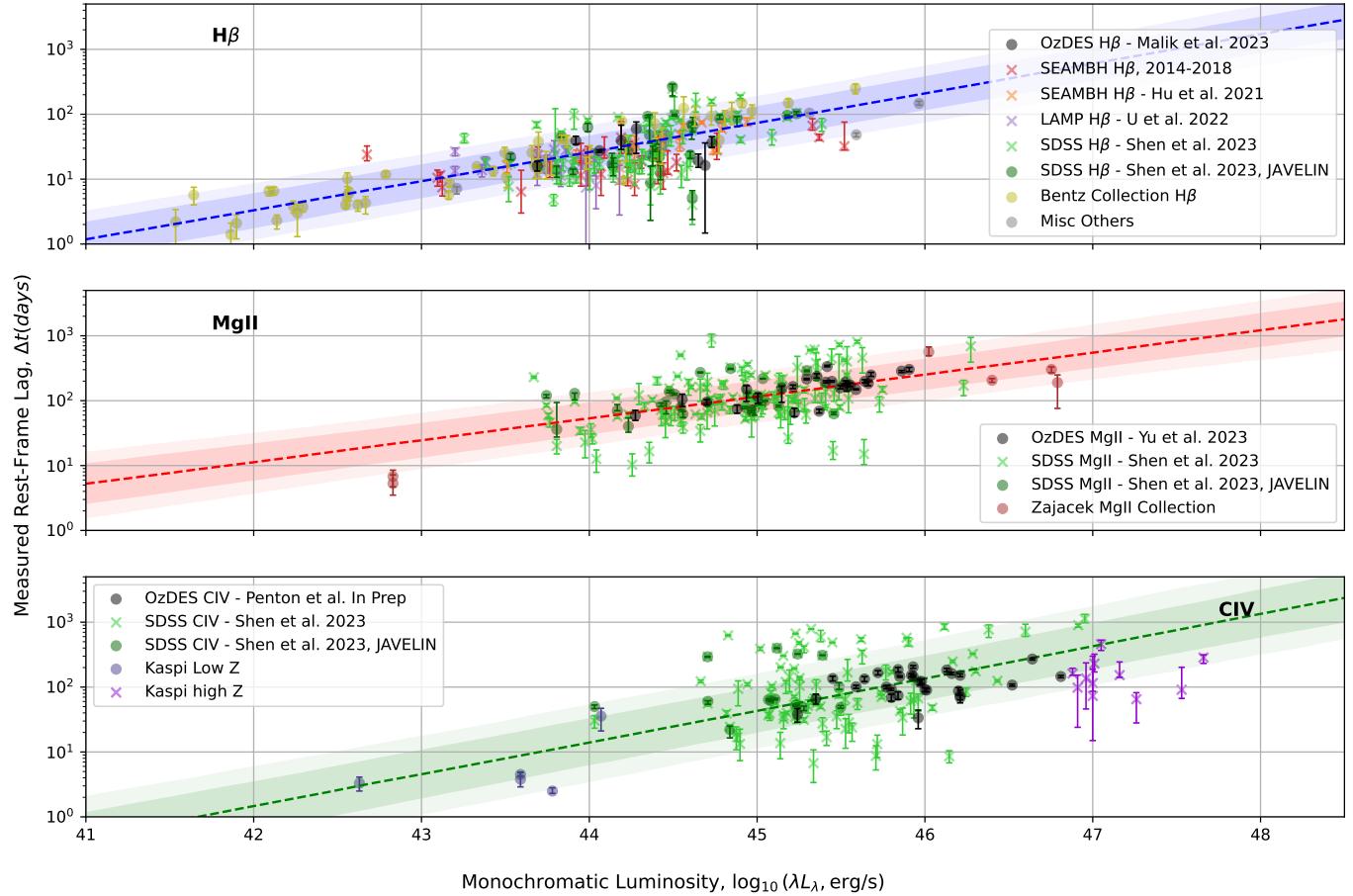


Figure 5: Rest-frame lags and monochromatic luminosities for all data sources from all lines, plotted on a log-log scale to show the linear trend that forms the basis for the $R - L$ relationship. Sources marked with a circle contribute to the constraint of the shown $R - L$ relationship, while sources marked with a cross do not. Sub-plots from top to bottom are for H β , MgII and CIV lags with their ‘best fit’ $R - L$ relationships overlaid (see Table 2). The monochromatic luminosity is measured at 5100Å, 3000Å and 1350Å from top to bottom.

to more fairly measure tensions between them. Considering surveys to be in tension if they differ by more than 2σ , the groups of surveys with mutually consistent constraints are listed in Table 3. In total, 8 OzDES sources and 26 SDSS sources are used.

Fig. 6 (a) shows $R - L$ relationship parameters for data from OzDES, SDSS, the Bentz Collection, the SEAMBH Survey, the LAMP survey, and a number of other miscellaneous sources. Shown also are the contours for SDSS lags as recovered from JAVELIN instead of PyROA, and selected according to the criteria outlined in Section 4.2.4. The constraining power is highest for surveys with a high source-count, like SDSS & SEAMBH, or a wide range of luminosities as in the Bentz Collection.

Due to the low sample count, the OzDES and miscellaneous sources are poorly constrained and are consistent with all other surveys. The largest tension exists between the slope and offset of the Bentz Collection and SEAMBH data, with this tension being the deciding factor about which surveys are mutually consistent. The SEAMBH data are known to produce consistently lower lags from their highly accreting AGN, and this is borne out by the lower values for α and β in collections including SEAMBH sources.

The SDSS results are consistent with these SEAMBH values in slope and scatter, but show systematically higher scatter than any other survey with strong constraints. This lower offset and higher scatter puts the SDSS data in tension with the low redshift

Bentz Collection. Limiting the SDSS lags to only those that pass our cuts in Section 4.2.4 (the SDSS-JAVELIN contour), the constraints become weak enough to overcome this inconsistency, but the preferred values for α , β and σ do not significantly change. The LAMP survey lags sit the lowest of any data set, and their comparatively narrow range of luminosities mean they do not strongly constrain the $R - L$ slope by themselves.

Fig. 6 (b) shows the constraints on $R - L$ relationship parameters when combining all datasets that are not in tension with one another. Four such groups are possible:

1. OzDES combined with the Bentz Collection, miscellaneous sources and the sub-sampled SDSS data,
2. As for 1, but with SEAMBH lags in place of Bentz,
3. As for 2 but using the full SDSS sample,
4. OzDES data combined with miscellaneous sources, the SEAMBH lags and the lags from the LAMP survey.

Where we use a ‘primary’ H β grouping elsewhere in the paper, it refers to the first of these groupings.

6.1.2. MgII $R - L$ Relationship

Until this recent generation of high redshift surveys, the bulk of reverberation mapping lags have been measured using H β , with a

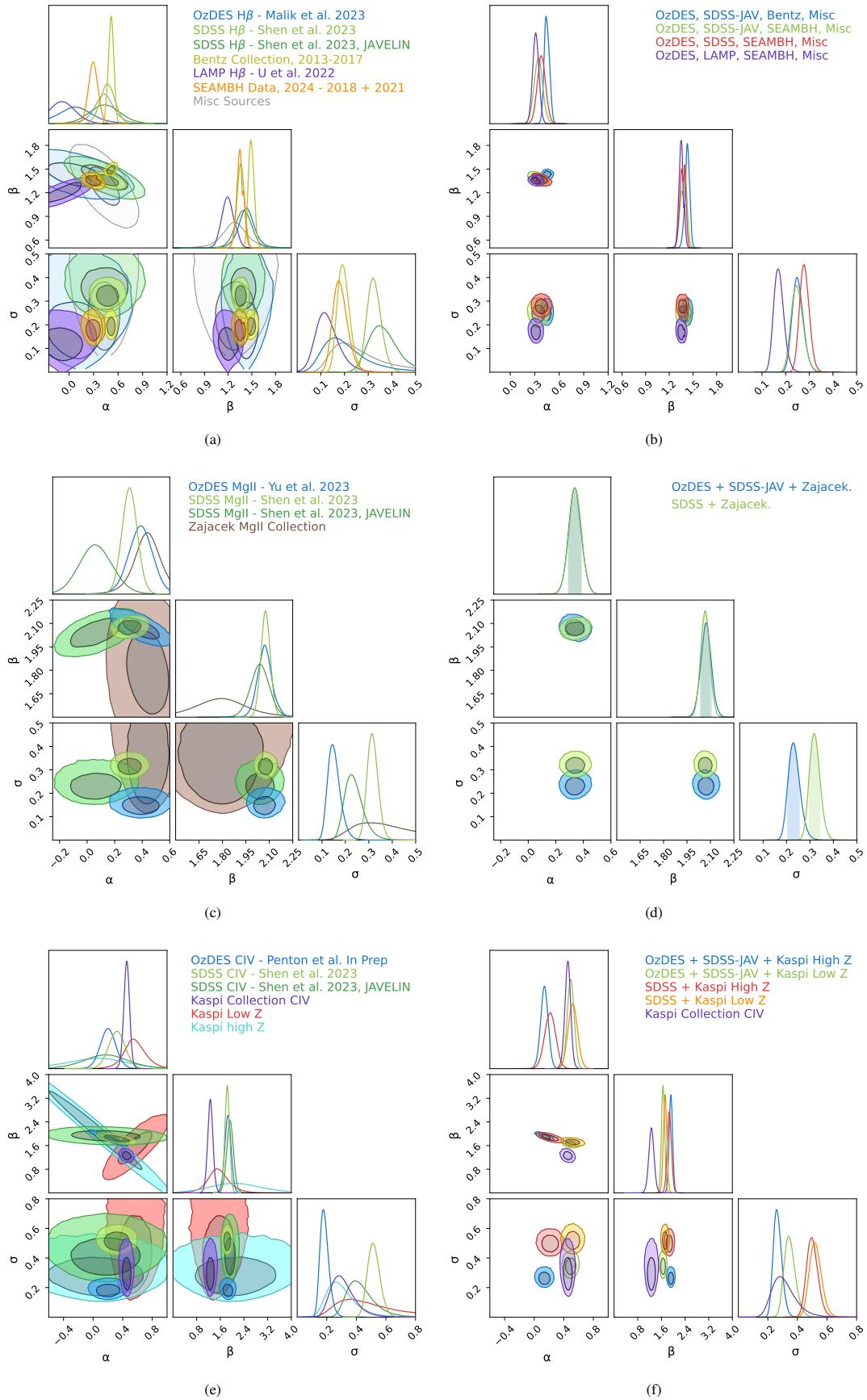


Figure 6: Constraints on $R - L$ relationship parameters for (from top to bottom) H β , MgII and CIV. The left column shows constraints for each individual survey / data source, while the right column shows constraints for mutually consistent data sources, as listed in Table 3. To minimise covariance between α and β , fitting is performed using units of 10^{44} erg/s for H β and units of 10^{45} erg/s in equation 6 for MgII and CIV.

Source	OzDES	SDSS	SDSS-JAV	LAMP	Bentz	SEAMBH	Misc
OzDES	-	T	T	T	T	T	T
SDSS	T	-	-	F	F	T	T
SDSS-JAV	T	-	-	F	T	T	T
LAMP	T	F	F	-	F	T	T
Bentz	T	F	T	F	-	F	T
SEAMBH	T	T	T	T	F	-	T
Misc	T	T	T	T	T	T	-

Table 3.: Consistency between data sources for H β $R - L$ relation parameters. If two data sources are statistically consistent (T), their recovered parameters for slope, offset and scatter are consistent to within 2σ . Otherwise they are visibly in tension (F). No result is listed for the main SDSS results and the sub-sampled JAVELIN SDSS results, as they are drawn from the same survey. These tensions yield four distinct sub-groups of mutually consistent data sources.

far more sparse set of literature lags in MgII. Rather than dividing these few sources by survey, we compare the OzDES and SDSS results to the convenient collection by Zajacek et al. (2020), consisting of 5 lags from Lira et al. (2018), Czerny et al. (2019) and Metzroth et al. (2006), and a recent lag from Zajacek et al. (2021). We exclude the 6 lags from Shen et al. (2016) and Shen et al. (2019), as they are already included in the SDSS results sample. From the OzDES and SDSS data releases we use 25 sources each.

Comparing $R - L$ relationship parameters for SDSS and OzDES, we find that they broadly agree in terms of the slope and offset of the fit, but that SDSS lags exhibit significantly higher scatter by roughly 0.2 dex. The low number of literature sources in the Zajacek Collection means that its fit is poorly constrained, and so is not in tension with OzDES or SDSS. Restricting the SDSS results to the SDSS-JAV sample drastically reduces the number and constraining power, but also decreases the scatter significantly. This decrease in scatter removes the tension with OzDES, allowing these two data sets to be combined.

This yields two mutually consistent groupings, making use of the full SDSS data set and excluding OzDES or including OzDES but restricting the SDSS data. Owing to the complementary correlations of the data sets, both choices have near identical results for the main properties of the $R - L$ relation, but with a slightly higher scatter for the SDSS-based results (Fig. 6 (c)). We proceed with the OzDES + SDSS-JAVELIN + Zajacek fit as our primary MgII $R - L$ relation, as it has both the lowest scatter and is derived from the most diverse set of sources.

6.1.3. CIV $R - L$ Relationship

Like MgII, there are only a small number of CIV lags outside of large-scale high redshift surveys. For these literature lags, we draw sources from the collation by Kaspi et al. (2021), including 6 low redshift AGN in which the 1350Å CIV line is observed in the observer-frame ultra-violet range from Peterson et al. (2005); Rosa et al. (2015) and Metzroth et al. (2006), as well as 6 high redshift sources from Lira et al. (2018) and 3 high redshift sources new to the Kaspi paper itself. As with the MgII literature collation, we

exclude the Kaspi sources from Grier et al. (2019) and Hoormann et al. (2019) as they are already included in the SDSS and OzDES data.^e We use 29 high quality lags from OzDES and 15 from SDSS.

Unlike the H β and MgII $R - L$ relationship fits, it is much harder to find consistent agreement between different data sources. The literature lags sit systematically lower than the trends set by either OzDES or SDSS, and there is consistently greater scatter than exhibited for either H β or MgII. Some of this discrepancy can be attributed to selection effects (see below); some may be due to CIV being contaminated by a non-virial wind component (Denney 2012). We attempt to account for selection effects in this section, but leave more detailed study of contamination for future work.

The high redshift surveys of SDSS and OzDES are highly consistent with one another except for the markedly higher scatter of the SDSS data, much as is seen for H β and MgII. The OzDES-like SDSS-JAV sample has lower scatter, removing the tension with the OzDES sample, though partially through a loss of constraining power from the reduction in source count.

The literature lags sit noticeably lower than either SDSS or OzDES lags, even at high redshift. Though it is not statistically objectionable to combine both high redshift surveys with either the Kaspi Collection's high redshift lags or its low redshift anchor, this gap means that it is not reasonable to do both at once. This allows for five possible groupings if taking the standard approach to the fitting of the $R - L$ relationship:

1. The high redshift literature lags with the combined OzDES and SDSS-JAV sample,
2. As above but with the low redshift anchor literature sources,
3. As per 1. but with the full SDSS and no OzDES sources,
4. As above but with the low redshift anchor literature sources,
5. The low and high redshift sources of the Kaspi Collection with no new sources.

Though still exhibiting a high scatter, the above groupings that fit for the entire luminosity range (groups 1, 3 and 5) give slopes roughly consistent with those of H β and MgII, while the flattened branch of the high-luminosity only groupings (2 and 4) have flat relationships between reverberation lag and AGN luminosity. This apparent disagreement between sources means we are unable to choose a primary data set for fitting the CIV $R - L$ relationship.

The tension between the slope of the high and low redshift is manifest in an apparent ‘levelling out’ of the $R - L$ relation at high redshift (Fig. 5, bottom panel). This is easiest to see when plotting the residuals against the ‘high- z ’ fit (our ‘grouping 1’). As shown in Fig. 7, high luminosity / redshift sources give unmistakably and consistently higher lags than the lower luminosity / redshift data.

This nonlinear $R - L$ relationship for CIV may have a physical basis, such as distant AGN having higher accretion rates, which have been associated with lower lags (e.g. Du et al. 2015; Hu et al. 2021). A simpler explanation lies in describing this as a selection effect: more luminous AGN have longer rest-frame lags, stretched further at high redshift by time dilation, and are therefore more likely to have lags that exceed the length of the survey. This induces a selection effect in which high redshift / luminosity sources are biased downwards from the true population distribution. CIV sources are often the most distant, and consequently the

^eInterestingly, only one of the two sources from Hoormann et al. (2019) makes it into the final OzDES sample. In that paper we used the down-weighting of seasonal gaps method employed by SDSS (equation 5), however when that is removed, the confidence in those sources drop and only one of them passes (at bronze level) the simulation-based criteria of Penton et al. (2021).

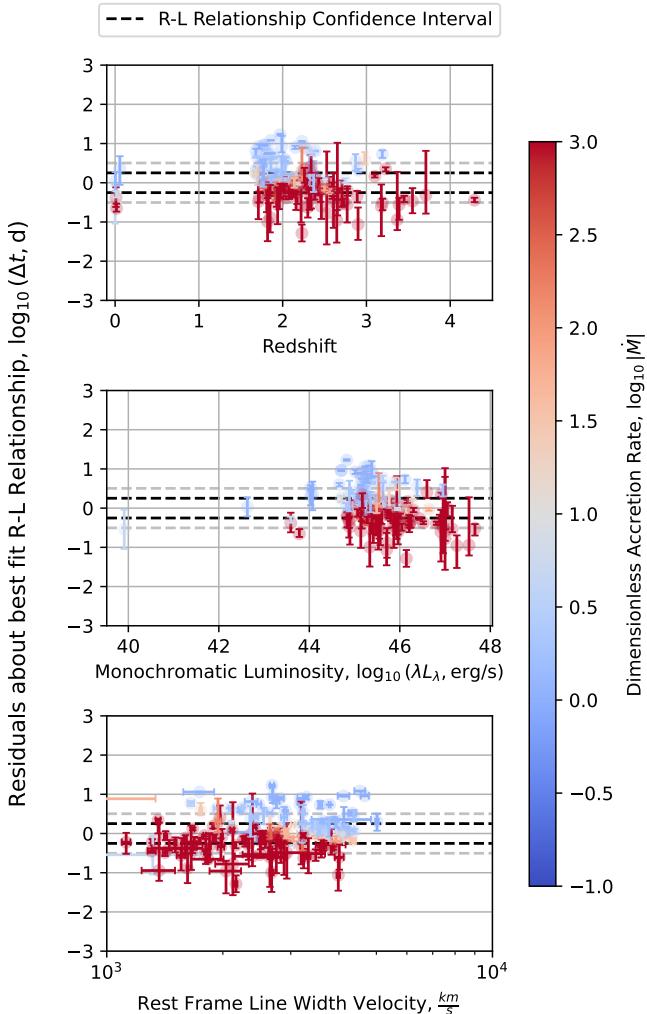


Figure 7: Residuals of CIV lag measurements for all RM sources about the best fit high redshift $R - L$ relationship, coloured by accretion rate $\log_{10}(\dot{M})$. There is a clear trend of the low redshift / luminosity sources, drawn from the Low-Z Kaspi sample, sitting below the fit. Though the high-accretion rate sources sit below the $R - L$ fit, there is no independent correlation with either accretion rate or emission line velocity dispersion (bottom panel, discussed further in Section 6.2).

most luminous, and so their observations are the most likely to be hampered by this effect.

Coupled with recovery rates and quality cuts, the exact effects of this under-sampling of high lag sources is difficult to characterise, as it interacts with the entire observational and analysis pipeline. A complete treatment would require modelling the underlying source population, survey selection, and the entire analysis chain including quality cuts. Though not intractable, this is an involved task, particularly when trying to unify multiple surveys and studies.

Penton et al. (2025) estimates that, for the 6-year baseline of OzDES, a lag-recovery selection effect becomes significant for CIV sources at observer-frame lags of ≈ 1000 d and continues until lags above 1500 d are almost impossible to recover. We make the coarse approximation of treating this 1250 d limit as a hard cutoff, altering our Bayesian model so that that OzDES cannot detect lags above this limit. This is tantamount to altering the normal distribution of

Survey	Highest Observer Frame Lag (days)	Spectroscopic Baseline (yrs)	Nominal Lag Cutoff (days)
OzDES	$934.1^{+31.1}_{-31.1}$	6	1250
SDSS-JAVELIN	$1298.6^{+14.7}_{-12.0}$	7	1460
Kaspi High-Z	$1629.9^{+252.1}_{-326.7}$	9.5	1980

Table 4.: Maximum observer-frame lags for each CIV survey, along with their estimated maximum recoverable lag cutoff.

equation 7 to be a truncated normal distribution with a cutoff at $\Delta t_i = \frac{1250d}{1+z_i}$. To a rough first order approximation, we scale this limit for each survey proportional to the length of their spectroscopic campaign as compared to OzDES, giving nominal lag ‘cutoffs’ in Table 4.

This model significantly relaxes the constraints from each survey, introducing the freedom for an un-observed fraction of sources to exist above the lag cutoff. This relaxes the tension between the surveys, creating a single parameter-space region of overlap between all four data sources (Fig. 8, top panel). The high- z Kaspi lags are dominated by this observational window effect, making this fit match the constraints of the more generic $R - L$ fit achieved when excluding the high- z literature lags all together (Fig. 8, bottom panel). It is this fit, with all CIV data accounted for, that we use as our primary $R - L$ fit for single-epoch mass estimates in Section 8.

6.2. Accretion Rate & Line Width as Predictors of RM Lag

It is matter falling on to the accretion disk circling the SMBH that drives AGN activity, and there is evidence of a separation in behaviour between low and high accretion AGN. Highly accreting ‘super-Eddington’ AGN are associated with lower lags than their ‘sub-Eddington’ counterparts at the same luminosity (Du et al. 2015). It is also evident that high accretion sources tend to sit below our best fit $R - L$ relation (e.g. Fig. 7), while low accretion sources sit above. We are then motivated to see if observations other than luminosity are predictors of AGN lag as a means to reduce the scatter of our single epoch methods, improve the predictive constraints of our single epoch methods and as a probe of the underlying AGN behaviour.

To examine this, we add emission line width as a variable in the $R - L$ relation, i.e. an $R - L - V$ relation:

$$\log_{10}(\Delta t) = \alpha \log_{10}(\lambda L_\lambda) + \gamma \log_{10}(\langle \sigma_v^2 \rangle) + \beta, \quad (9)$$

where γ , the slope of log-lag against log velocity dispersion, represents the predictive power of line-width independent of luminosity.

Our estimates for mass and accretion rate (Equation 1 and Equation 4, respectively) both follow power laws, making them linear for the logarithmic space that we fit our single epoch relations in. In this way, fitting for line width and luminosity also covers the fitting for accretion rate, as it depends entirely on these two other measurements.

Performing this $R - L - V$ fit for all lines, using our primary data groupings from Section 6.1, we find no significant improvement in predictive power (Table 5), and constraints on the lag-velocity dependence are broadly consistent with zero, i.e.

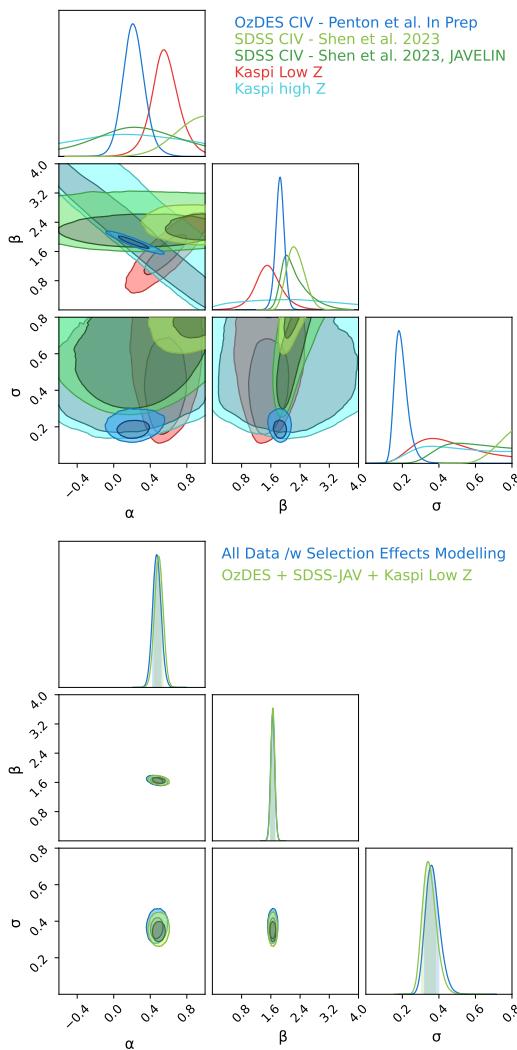


Figure 8: Constraints on the CIV $R - L$ relationship parameters after accounting for a maximum observable lag due to survey lengths. The top panel shows constraints for each individual data set, and the bottom panel compares the combined data. These are based on the same data groupings as used in Fig. 6, but with a model incorporating the cutoffs in Table 4.

no dependence of lag on line width. For MgII we see a slight preference towards $\gamma > 0$, but this is only weakly constrained and there is still no marked decrease in scatter about the model.

The apparent trend between accretion rate and the residuals about our best fit $R - L$ relationships is a projection of the luminosity dependence onto the log-accretion rate axis, rather than an independent axis of variability. For a fixed luminosity, higher than average lags will give higher masses, which will give lower accretion rates, producing an apparent anti-correlation between the two.

There is the possibility that the lack of predictive power comes from a strong correlation between luminosity and velocity dispersion in our sample: if we only probe a narrow band of $L - V$ space, the two parameters become degenerate in our fitting. We can rule this out by examining the correlation between luminosity and velocity (Fig. 9). We find that this correlation is weak, and is not

Line Type	γ	σ for $R - L$	σ for $R - L - V$
H β	$-0.05^{+0.14}_{-0.13}$	$0.25^{+0.02}_{-0.02}$	$0.25^{+0.02}_{-0.02}$
MgII	$0.59^{+0.30}_{-0.23}$	$0.23^{+0.02}_{-0.02}$	$0.22^{+0.03}_{-0.02}$
CIV	$0.04^{+0.38}_{-0.34}$	$0.34^{+0.04}_{-0.03}$	$0.35^{+0.04}_{-0.04}$

Table 5. : Constraints on line-width velocity as a supplementary predictor of lag, and comparison of the scatter about this model compared to the luminosity-only $R - L$ relationship. In all cases we fail to see a reduction in the scatter. Similarly, all lines are consistent with zero log luminosity / velocity ($\gamma = 0$ in equation 9), i.e. no lag-velocity dependence, though with MgII preferring a positive relation.

Line Type	Log-Vel / Log-Lum Slope	Scatter (Dex)
H β	$0.08^{+0.02}_{-0.03}$	$0.22^{+0.02}_{-0.02}$
MgII	$-0.06^{+0.02}_{-0.02}$	$0.12^{+0.01}_{-0.01}$
CIV	$-0.07^{+0.02}_{-0.03}$	$0.14^{+0.02}_{-0.02}$
All Sources	$0.09^{+0.01}_{-0.01}$	$0.19^{+0.01}_{-0.01}$

Table 6. : Constraints on the scaling index and scatter between AGN luminosity and velocity dispersion for all emission lines, per equation 9. Constraints are for sources in our ‘primary’ data sets as outlined in Section 6.1.

consistent between lines. Table 6 notes an extremely shallow scaling index between luminosity and velocity dispersion for all lines, indicating that our sampling of the two parameters is sufficiently uncorrelated.

We note that this lack of predictive power in velocity is in contrast to the findings of the SEAMBH collaboration, (Du et al. 2016, 2018; Hu et al. 2021) who find that higher accretion rates (derived from higher velocities) is associated with lower lags. Our results here do not necessarily contradict their findings: we do not include their data in these fits specifically because their highly accreting sources produce statistically lower H β lags (see Section 6.1.1), nor do we use their critical threshold of accretion rate. Our fit only demonstrates that line width / accretion rate does not serve to explain the residuals about our best fits. It is also worth noting that different data sources have non-uniform approaches to measuring these line widths, and unlike the lag parameter we make no attempt to account for these differences in analysis.

7. Probing BLR Stratification by Comparisons of Bolometric $R - L$ Relations

In cases where there are lags for multiple lines from a single source (e.g. Metzroth et al. 2006; Lira et al. 2018), it has been observed that different RM lines produce different lags, indicating a stratification in the structure of the BLR, with different lines emitted from distinct regions. By comparing these lags, we can probe the relative size and overall geometry of the broad line region. Though a small

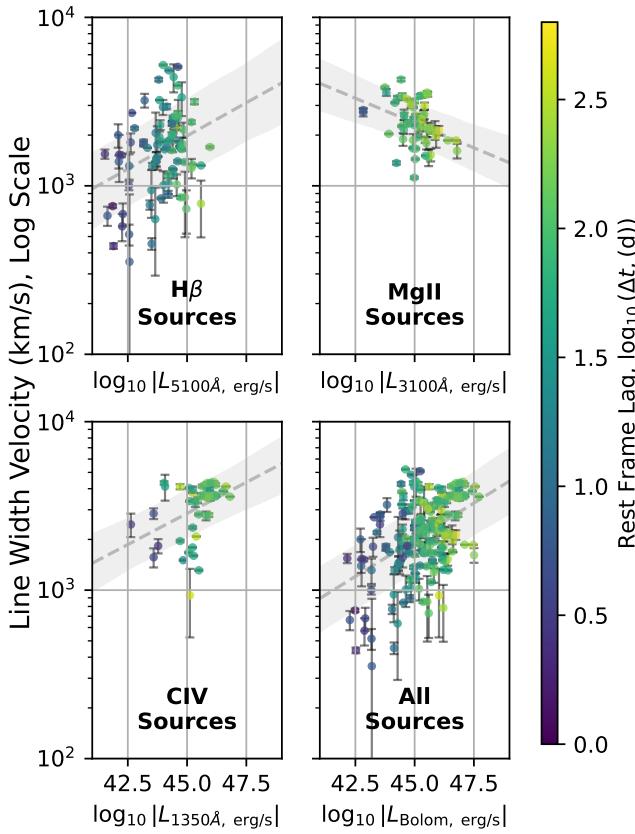


Figure 9: Luminosity / velocity scatter plot for our ‘primary’ data-sets, coloured by rest frame lag. Under-laid are fits for the correlation between lag and velocity, modelled as a power law. The colouring shows how lag evolves strongly over the luminosity axis, demonstrating it is a better predictor of lag compared to velocity.

subset of the OzDES target AGN do exhibit multiple lines in the optical range, these data are of insufficient number and quality to meaningfully measure the BLR stratification. Here we instead leverage the full set of available RM results by making use of the $R - L$ relationships themselves (as fit in Section 6.1) as a probe of the BLR geometry.

For each line, in Section 6.1 we derived $R - L$ relationships relative to the monochromatic luminosity evaluated at a line-specific wavelength conveniently similar to that of the reverberating line itself. Though each line’s $R - L$ relationship refers to a different luminosity, simple bolometric corrections allow us to reposition these relationships onto the same luminosity axis. Doing so allows us to compare the expected lags, and so typical radius of emission, for the different ions that produce reverberating emission lines. Here we use a variation of the $R - L$ relationship fitting in Section 6.1 to examine implications of the radii of the $H\beta$, MgII and CIV emission regions.

In this analysis, we assume a fixed proportionality between monochromatic and bolometric luminosity:

$$L_{\text{bol}} = C_\lambda \times \lambda L_\lambda. \quad (10)$$

We use the bolometric corrections of Runnoe et al. (2012), namely that $C_{5100\text{\AA}} = 4.0 \pm 0.1$, $C_{3000\text{\AA}} = 5.2 \pm 0.2$, and $C_{1450\text{\AA}} = 8.1 \pm 0.4$. We use the correction for 1450\AA for CIV, though note that the

luminosity is defined at 1350\AA . As we take the logarithm of these values, small variations should have little impact.

These corrections result in a horizontal shift of the relations that were derived in Section 6.1 and presented in Table 2. We note that this is the simplest possible bolometric model, applying only a simple translation of the $R - L$ relationship, while more expressive alternatives exist that describe the bolometric correction as a luminosity dependent power law would also impact the relationship’s slope. We note that it is a coarse assumption to treat these corrections as being equally applicable across all redshift ranges, and stress that this is a simplified first pass of this stratification measurement.

By correcting each source to its bolometric luminosity, we can repeat the $R - L$ fitting procedure of Section 6.1 and more meaningfully compare the relations for $H\beta$, MgII and CIV. For all lines, we use the same data sets as the final $R - L$ fits in Table 2, including our treatment of selection effects for CIV as discussed in Section 6.1.3.

Performing this fit with luminosity units of 10^{45}erg/s (Fig. 11 (b)), we find that the MgII and $H\beta$ relations are very similar, though the MgII lags sit at a slightly higher offset and prefer a slightly shallower slope. By contrast, the fit for CIV sits lower, but with a slope and scatter that is broadly similar to $H\beta$. This is in keeping with prior studies of sources with multiple lines visible simultaneously, which found that $H\beta$ and MgII were produced by roughly co-spatial regions of the BLR (i.e. yielded similar lags for the same source, for an example see Shen et al. 2019), while CIV lags tend to be smaller by a factor of 2, though this ratio is poorly constrained. (Lira et al. 2018; Kaspi et al. 2007).

We can constrain these relative radii for the different emission lines by adopting an adjusted $R - L$ relationship with dimensionless scaling factors ‘ S_λ ’ for MgII and CIV (equation 11):

$$\log_{10}(\Delta t_\lambda \times S_\lambda) = \alpha(\log_{10}(L_{\text{bol}}) - \log_{10}(L_0)) + \beta. \quad (11)$$

Here, units for lag and luminosity are as in equation 6. This allows each line’s $R - L$ relation to have a different vertical offset, equivalent to the assumption that the ratio of these lags is the same across different AGN.

By fitting this combined model we arrive at a bolometric $R - L$ relationship with a slope of $\alpha = 0.44^{+0.03}_{-0.02}$. The constraints on this model give two interesting results:

1. Constraints on S_{MgII} suggest MgII produces longer lags than $H\beta$, indicating that it may be emitted from a radius larger than $H\beta$ by a factor of $\approx \frac{1}{0.72} \approx 1.39$. This finding is statistically significant at $\approx 2\sigma$. This is consistent with Malik et al. (2024b) who did a stacked RM analysis (see their Table 1), in which they found that the average MgII lags in the OzDES sample were significantly longer than those for $H\beta$ at comparable luminosities.
2. We find that the CIV radius is significantly smaller than that of $H\beta$ (i.e. $S_{\text{CIV}} > 1$) by a factor of $\approx 1.8 - 3.5$.

The constraints on the $R - L$ relation as well as the relative scaling factors are summarised in Table 7, with a sketch of the implications for the BLR geometry shown in Fig. 10.

It is worth noting that the relative radius of $H\beta$ and MgII are strongly dependent on the assumptions of AGN spectral properties. Bolometric corrections are entirely degenerate with relative radius parameter S_λ , and the corrections of Runnoe et al. (2012) are derived from only low redshift AGN. There is also considerable diversity amongst bolometric corrections from different sources (e.g. Runnoe et al. 2012; Netzer 2019; Richards et al. 2006), though

Data	Slope (α)	Offset (β)	Scatter (σ)	Slope - Offset Fit Correlation (ϕ)	S_{MgII} $\left(\frac{R_{\text{H}\beta}}{R_{\text{MgII}}}\right)$	S_{CIV} $\left(\frac{R_{\text{H}\beta}}{R_{\text{CIV}}}\right)$
H β	$0.44^{+0.04}_{-0.02}$	$1.60^{+0.04}_{-0.03}$	$0.25^{+0.02}_{-0.02}$	0.46	-	-
H β + MgII	$0.42^{+0.02}_{-0.02}$	$1.58^{+0.03}_{-0.03}$	$0.24^{+0.02}_{-0.02}$	0.58	$0.68^{+0.08}_{-0.09}$	-
H β + CIV	$0.47^{+0.02}_{-0.03}$	$1.63^{+0.02}_{-0.05}$	$0.29^{+0.02}_{-0.02}$	0.65	-	$2.32^{+0.43}_{-0.35}$
H β + MgII + CIV	$0.44^{+0.03}_{-0.02}$	$1.60^{+0.04}_{-0.03}$	$0.27^{+0.02}_{-0.01}$	0.56	$0.72^{+0.10}_{-0.09}$	$2.14^{+0.34}_{-0.30}$
$\log_{10}(\Delta t) = \beta + \alpha (\log_{10}(L_{\text{bol}}) - 45) \pm \sigma$						

Table 7. : Parameter constraints for bolometric $R - L$ relationship. All slopes and offsets are fit for equation 11 with units of 10^{45} erg/s.

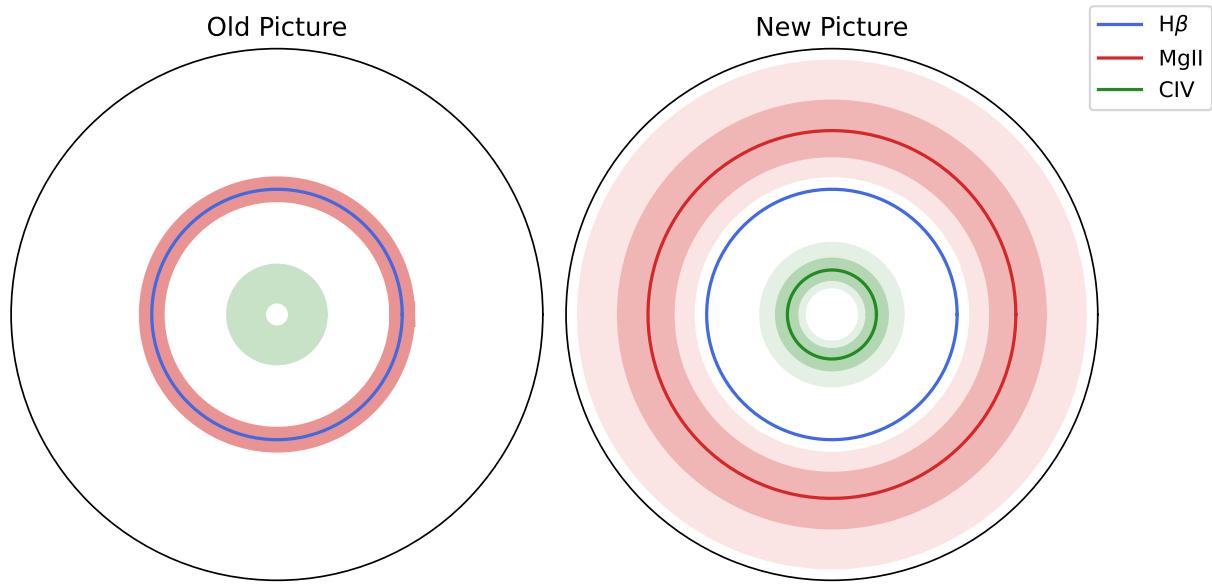


Figure 10: A sketch of the scales of the MgII and CIV emission regions in the BLR relative to H β , comparing the previously understood average stratification (left panel) with the new picture suggested from our relative lag scaling (right panel). For the left panel, the H β and MgII regions are roughly the same size per Shen et al. (2019), while the CIV region is 2 – 4 times smaller per Lira et al. (2018); Kaspi et al. (2007). For the right panel, solid lines represent the nominal values in Table 7 while shaded regions indicate bounds of uncertainty. For the left panel, the shading shows the rough bounds of the scale factors.

there is broad agreement on the relative corrections between H β and MgII, i.e. that $\log_{10}(L_{5100\text{\AA}}/L_{3000\text{\AA}}) \approx 1.25$.

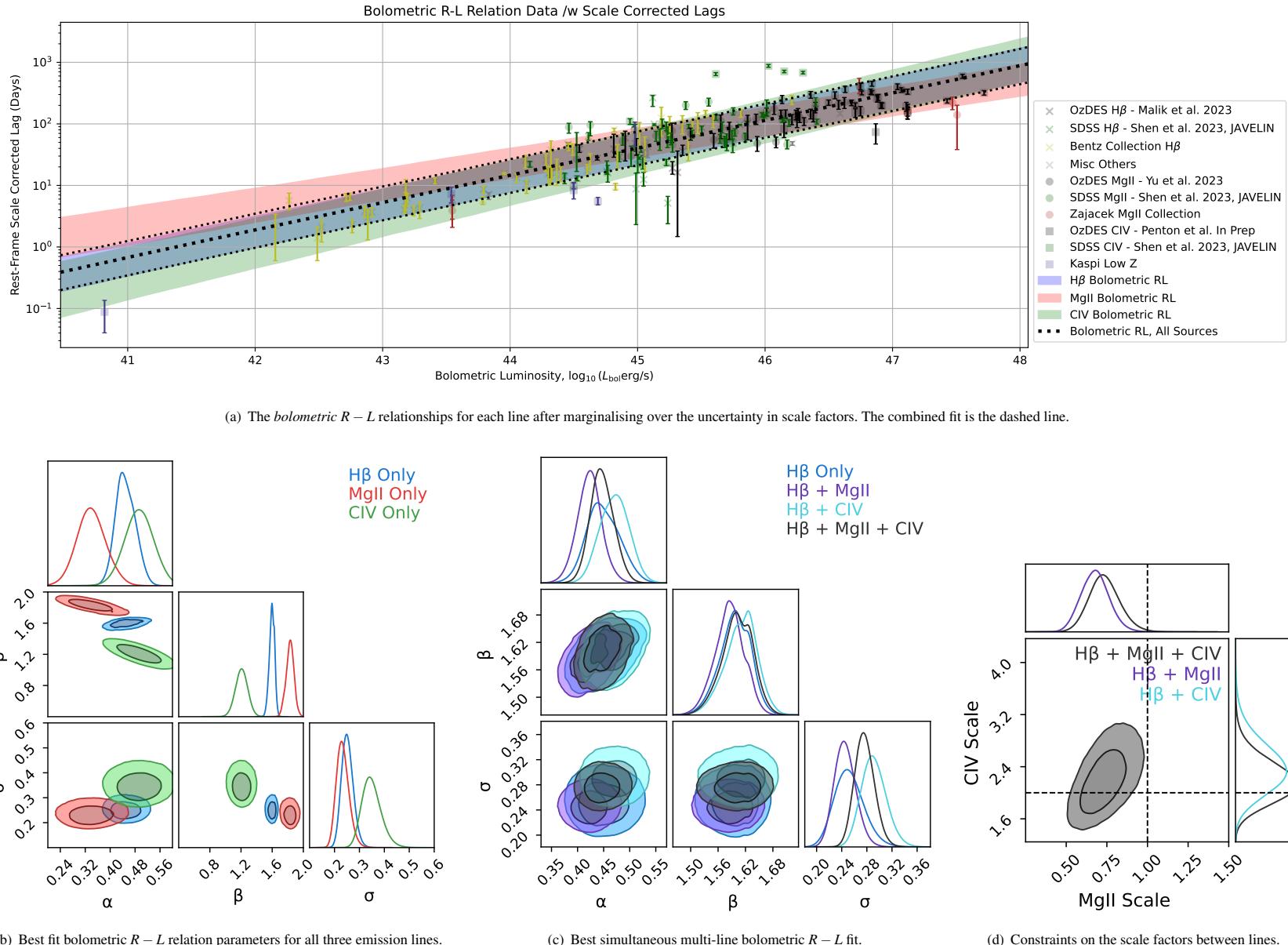


Figure 11: We constrain the relative sizes of the BLR by assuming a single bolometric $R - L$ relation, as shown in panel (a). (b) shows the $R - L$ parameters for the primary data sets from Section 6.1 after converting to bolometric luminosities with the factors of Runnoe et al. (2012). (c) shows the results of simultaneously fitting data from multiple lines to find a single bolometric $R - L$ relation. To achieve this we allow CIV and MgII lags to occur at different radii to the H β lags and combine their data sets, i.e. allow for vertical offset between the $R - L$ relations for different lines. Note that figures (b) and (c) have different axis scaling. Figure (d) shows the best fit scaling needed to bring the lines to a common bolometric $R - L$ relation. Nominal factors of $C_{\text{MgII}} \approx 1$ and $C_{\text{CIV}} \approx 2$ (Kaspi et al. 2007) are marked with dashed lines. A larger scale factor indicates a smaller emission radius relative to the H β region.

8. Black Hole Masses From Single-Epoch Measurements (New Results)

We apply the $R - L$ relationships derived in Section 6.1 and summarised in Table 2, to derive black hole masses for OzDES AGN that do not have time-series spectra. We use the luminosity of the AGN to estimate their lag, and combine that with a measure of the line width at a single epoch to estimate their mass. The results are subject to a set of quality cuts to avoid contamination of poor quality spectra. We require that all single-epoch sources:

1. Have a clearly visible line profile by visual inspection,
2. Have a mass that obeys $M > 0$ at a 2σ level

After these cuts, we derive the masses of an additional 246 OzDES AGN using these single-epoch estimates, consisting of 19 H β sources, 198 MgII sources and 29 CIV sources. This single epoch sample results in masses ranging from $20.1_{-9.9}^{+18.4} \times 10^6 M_\odot$ to $2.9_{-1.7}^{+3.8} \times 10^9 M_\odot$. For the CIV sources, we make use of our ‘selection effect adjusted’ $R - L$ relationship (see Section 6.1 for details).

As with the RM sources in Section 5.2, we also use equation 4 to estimate the accretion rates of these sources, using the bolometric corrections of Runnoe et al. (2012) to convert monochromatic luminosities to the required units. All single epoch sources, including their masses, accretion rates, single epoch radii and measured velocity dispersions, are listed in Table 1. These masses are included, along with the RM and literature measurements, in Fig. 4.

Masses are again calculated by varying all measurements within their uncertainties, with added variation for the single epoch lag within the uncertainties of our $R - L$ parameters. As with all other calculations, values are quoted as the distribution median, and uncertainties quoted using from 16th and 84th percentiles of the marginalised posterior distribution for each parameter. To avoid extrapolating $R - L$ relationships too far, monochromatic log-luminosities must be > 41 erg s $^{-1}$ for H β sources, > 43.5 erg s $^{-1}$ for MgII sources and > 44.5 erg s $^{-1}$ for CIV sources. The luminosity limit is somewhat arbitrary, so we include the single MgII source outside this range in Table 1, marked with a †.

9. Discussion and Conclusions

This work marks the close of the OzDES reverberation mapping program, and, in conjunction with the final RM data release of the Sloan Digital Sky Survey by Shen et al. (2023), the end of the first generation of industrial scale high redshift reverberation mapping. OzDES has measured lags for 62 AGN, including 8, 25 and 29 measurements from the H β , MgII and CIV reverberating lines, respectively, and we have in this work presented an additional 246 SMBH masses from single epoch methods. These 308 SMBH masses represent a significant contribution to the number of high redshift black hole mass measurements. The SMBHs range in mass from $2.3 \times 10^6 M_\odot$ to $4.0 \times 10^9 M_\odot$, putting our most massive measurement at the higher range of presently observed SMBHs.

Supplementing OzDES data with existing lags from the literature, we provide the best and most reliable constraints to date on the radius-luminosity relationship for sub-Eddington H β and MgII lags. We are unable to fit a single relationship for CIV due to a disparity in the trends for low and high redshift sources. For all lines, we do not find a strong impact from accretion rate or emission line broadening as a single epoch lag predictor. Applying our

MgII $R - L$ relationship to ULAS J1120+0641, a particularly distant SMBH observed by JWST at a redshift of $z = 7.09$ (Bañados et al. 2017), we recover a mass of $M = 3.53_{-1.22}^{+1.73} \times 10^8 M_\odot$, slightly lower than Bañados et al. (2017)’s estimate of $8 \times 10^8 M_\odot$.

Our single epoch relations for H β and MgII have a significantly smaller scatter than those of the final SDSS release, ~ 0.25 dex against their ~ 0.45 dex, offering a precise and broadly applicable tool for estimating SMBH masses to higher redshifts. We also offer the best constrained CIV $R - L$ fit at high redshift, but we recommend some caution in extrapolating this relation beyond the luminosity range of the available RM-data (i.e. $L_{1350\text{\AA}} > 10^{47}$ erg/s).

We note that measurements we present are subject to a selection function that depends on interaction between the physical properties of the AGN, the varied analysis pipelines of different surveys and the quality cuts that we apply here. These effects are particularly strong at high redshift where lags abut our upper observational limit of 1000 d observer-frame lags. We make no attempt to model these selection effects, and so defer any interrogation of the black hole population properties to future work.

We note that this ceiling on the AGN SMBH masses has lowered towards more recent times, with no SMBH above $10^9 M_\odot$ nearer than $z = 0.5$ in our results. If we limit ourselves to only the DES single-epoch data of Table 1 we acquire a single homogeneous data set that avoids the observation baseline dependent effects discussed in Section 6.1.3. Even for this data set, we still see a significant evolution of the mass-distribution of sources as a function of redshift (Fig. 13), with nearby sources showing a consistent shift towards lower masses. As OzDES is a magnitude limited survey, some of the lack of distant low-mass observations can be explained by low completeness, dim objects are harder to find at greater distances, but we can still confirm that the high-mass tail of the mass-density distribution, which should be subject only to count-based statistical effects, also decreases for nearby times to a degree that cannot be explained by statistical uncertainty or by a decrease in the number of available sources.

The similarity of the MgII and H β $R - L$ relationship in slope and scatter, even with a statistically significant sample such as we now have access to, supports our understanding of their emission regions as being stratified. Of interest is the systematically larger MgII lags for comparable bolometric luminosity. Simple ionization models that form the basis for the $R - L$ relationship suggest the MgII emission line region should be located closer to the SMBH to the engine, rather than further. We note this with the caveat that our analysis is based on the simplest possible modelling of the spectral-energy distribution of AGN.

Conversely, our fits indicate that CIV is emitted from closer in than either H β or MgII by a factor of 2 – 6, though the challenges in fitting a single $R - L$ relationship for this line make it difficult to constrain this with any certainty.

The strong windowing effects of the CIV $R - L$ trend highlights the need for further study of this emission line,^f either through intensive study of low redshift sources or by extending the luminosity envelope of CIV lag recoveries. Nearby, low luminosity sources can be observed in the observer-frame ultraviolet range, (e.g. Metzroth et al. 2006; Lira et al. 2018), and extending such studies to higher redshift or luminosities would help to clarify the origins of the apparent flattening of the CIV $R - L$ curve. For the same reason, there is also motivation to use infrared spectroscopy to

^fFor example, to investigate whether the CIV line is affected by outflows, which could contaminate the line’s velocity dispersion measurement.

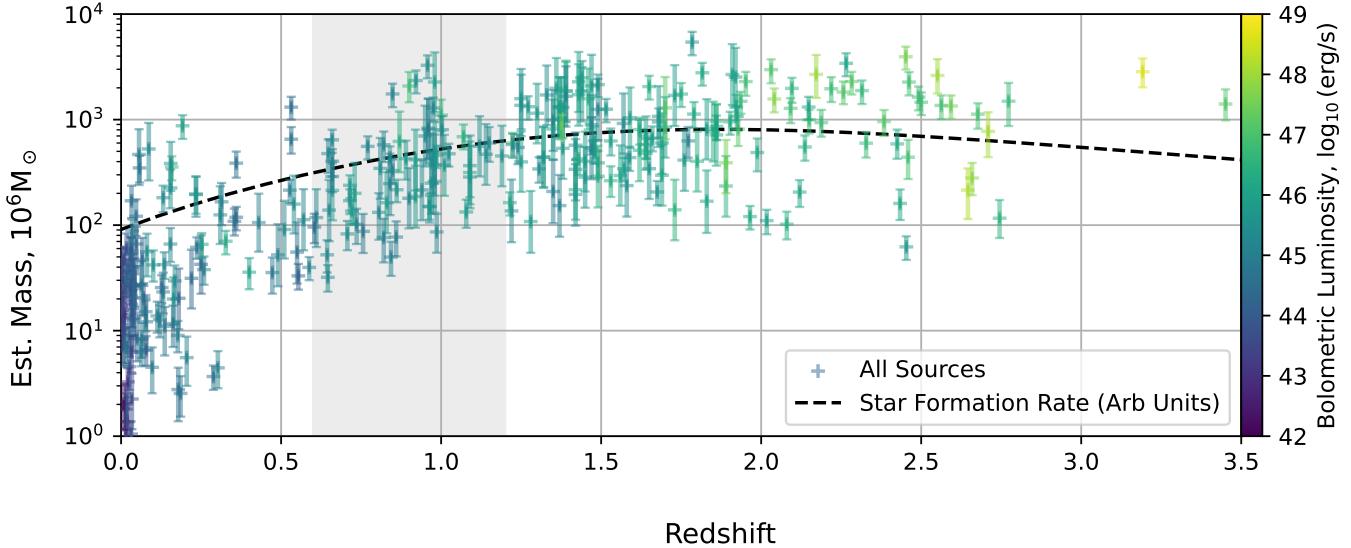


Figure 12: Single epoch masses plotted against redshift for all single epoch sources, with shading showing the limits of the redshift bins in figure 13. Plotted for comparison with a black dotted line is an estimate of star formation rate vs redshift using the functional form and parameters of Madau & Dickinson (2014) (equation 15 in their paper).

observe the high redshift counterparts to the H β and MgII sample to determine if these systems are homogeneous or show evolution over time. Extending these samples to more distant, more luminous sources will allow us to determine whether this ‘levelling out’ of the $R - L$ relationship is physical, a statistical anomaly, or a selection effect. It will also let us probe the evolution of the geometry of such systems over time, and help delineate between accretion and luminosity based effects. In particular, follow up of sources in the low redshift domain, where the lower impact of time dilation means AGN variability is fast and lags are short, will allow direct comparison between CIV lags to H β lags from $z \in [0, 0.8]$ and to MgII lags from $z \in [0.45, 1.25]$. Metzroth et al. (2006) and Lira et al. (2018) already do this for some local AGN, but extending to more distant and luminous sources will help fill the low luminosity branch of the CIV relationship.

Contribution Statement

Project conception and coordination: TMD, CL, PM; Analysis, programming, calculations: HM with input from ZY, UM, AP; Writing: HM; Original figures: HM; Editing: TMD, CL, PM, ZY, RS, GL, BT, BP; Data generation and/or curation: all authors.

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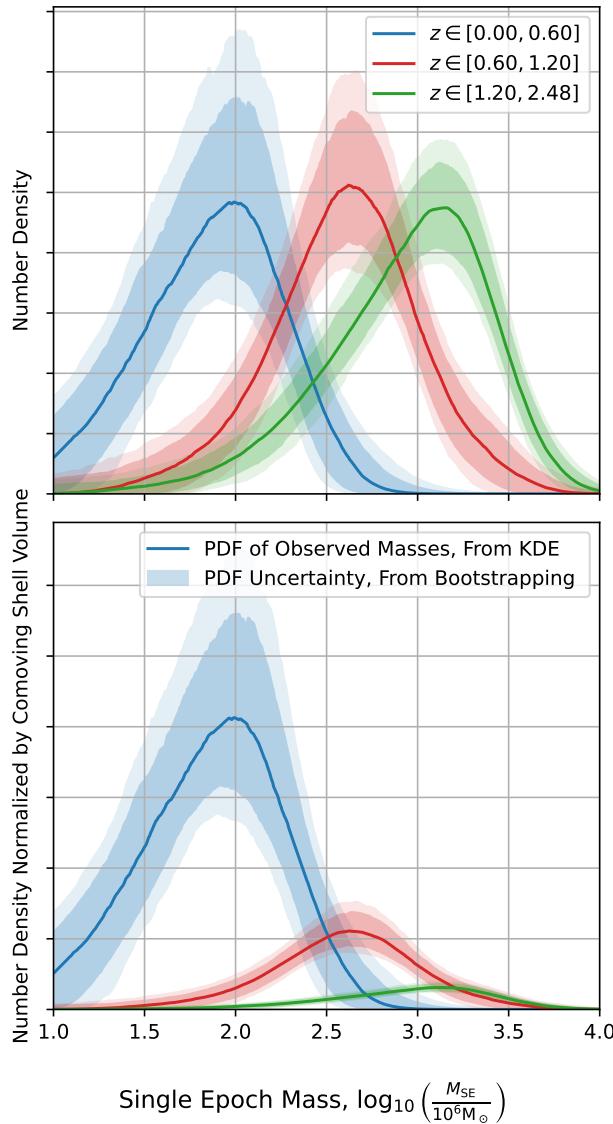


Figure 13: Kernel Density estimates of SMBH mass density at varying redshifts for the single epoch sources in Table 1. The top panel shows the density of observed sources, while the bottom panel have their normalization corrected by a factor of co-moving shell density such that they act as estimates of number-density per co-moving volume. The shaded regions represent uncertainties on the density acquired from bootstrapping and varying the data within measurement uncertainties.

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Calculations were made using python (Van Rossum & Drake 2009) and with the aid of numpy (Harris et al. 2020). Plots and figures were generated with the aid of matplotlib (Hunter 2007) and chainconsumer (Hinton 2016).

We acknowledge and pay respect to the traditional owners of the land on which the University of Queensland and University of Southern Queensland are situated, upon whose unceded, sovereign, ancestral lands we work. We pay respects to their Ancestors and descendants, who continue cultural and spiritual connections to Country.

Based in part on data acquired at the Anglo-Australian Telescope, under program A/2013B/12. We acknowledge the traditional custodians of the land on which the AAT stands, the Gamarlai people, and pay our respects to elders past and present.

Data Availability

With this paper we release a table of the OzDES RM light curves for the full sample, as well as tabulated forms of the RM and single epoch samples listed in Appendix A (Tables 1, 2, 3), and Appendix C (Table 1). This is available at [link to be provided upon acceptance].

The raw images and catalogues from the whole DES survey are available at <https://des.ncsa.illinois.edu/releases/dr2>.

The spectra are publicly available from <https://docs.datacentral.org.au/ozdes/overview/dr2/>.

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Appendix A. Lag recovery methods

The main two lag recovery methods are the interpolated cross-correlation function and Javelin, which we describe here.

A.1. PyCCF

Introduced to the field of reverberation mapping by Gaskell & Peterson (1987), the Interpolated Cross-Correlation Function (ICCF) is a purely non-parametric lag recovery method that relies on the cross-correlation (r) of the two light curves as they are shifted against one another in the time domain. The procedure is to linearly interpolate one (or both) of the light curves between observations and measure the Pearson correlation,

$$r = \frac{\langle y_1, y_2 \rangle}{\sqrt{\langle y_1, y_1 \rangle \langle y_2, y_2 \rangle}}, \quad (12)$$

where y_1 and y_2 represent the sets of photometric and spectroscopic amplitudes respectively, and angled brackets indicate an inner product, approximated by a sum.^g The physical lag is then taken to be the delay that maximises this correlation, while the uncertainties are estimated by ‘bootstrapping’: recovering the peak correlation-lag from many realisations generated by randomly subsampling the observations and then re-sampling these observations within their measurement uncertainties.

The ICCF method is numerically low cost and robust, and has seen wide use in RM, particularly in low redshift campaigns with high cadence measurements (e.g Barth et al. 2013; Rakshit et al. 2019; Zhang et al. 2019). Through simulations, it has been found to agree with more rigorous models like JAVELIN to within statistical bounds, though with higher reported uncertainties (Yu et al. 2019). The low numerical cost of the ICCF means that it can easily be used as a diagnostic tool for testing the reliability of other more involved methods, as the r test statistic gives a general ‘goodness of fit’ at any lag, and the low cost of evaluation means the entire lag parameter space can be searched exhaustively. OzDES makes use of PyCCF (Sun et al. 2018), a vectorised python-based implementation of ICCF. Malik et al. (2023) estimates a false positive rate

^g $\langle y_1, y_2 \rangle = \sum_{i=1}^N (y_{1,i} - \bar{y}_1)(y_{2,i} - \bar{y}_2)$, where the overline represents the mean.

/ p -value for each lag by shuffling the time ordering of measurements, creating mock observations of signals with the same stationary statistics as the observed light curve. These were then used to tune the quality cuts outlined in Section 4.2.1.

ICCF is robust and ‘light-weight’, but has shortfalls in its lack of precision and its inability to adequately characterise the vague constraints of light curves where large gaps exist between observations, such as the six month seasonal gaps of OzDES and SDSS (Malik et al. 2022). The quality of lag recovery degrades rapidly as measurement cadence or observational season length decrease, as the linear interpolation lends false confidence while failing to capture the stochastic variations that take place between measurements. By contrast, the SDSS team’s preferred lag recovery method, PyROA (Donnan 2021), interpolates the light curves by adopting a ‘rolling average’ of the observations within a window of variable width, giving conservatively broad constraints within seasonal gaps compared to PyCCF’s spuriously tight ones. Non-parametric methods like PyCCF and PyROA allow a certain degree of flexibility to account for their approximate modelling, and so naturally inherit a degree of robustness against outliers or under-estimated errors (Yu et al. 2019).

A.2. JAVELIN

Where non-parametric methods interpolate between observations with as few assumptions about the underlying light curves as possible, the second class of fitting methods leverages our understanding of the underlying stochasticity of AGN variability. Though AGN do not follow a consistent light curve shape like some astrophysical objects (e.g. supernovae, Guy et al. 2005), they do exhibit consistent statistical properties in their signals, namely a set power spectrum for the variations in their brightness. Specifically, these variations are known to follow a ‘damped random walk’ (DRW) (Kelly et al. 2009; Kozłowski et al. 2010; MacLeod et al. 2010), with only small deviations at very long and short timescales of variation (Zu et al. 2013). The DRW is an example of a Gaussian process, specifically a first order continuous auto-regressive process, yielding a red-noise like $1/f^2$ scaling at high frequencies. This Gaussian-process-like structure in the stochastic variations creates statistical correlations within and between light curves, allowing us to interpolate between measurements in a physically principled way. For the DRW specifically, the auto-correlation is encoded in a covariance matrix, whose elements are defined as:

$$C_{ij} = \sigma_i \sigma_j \exp(|t_i - t_j|/\tau_d) + E_i E_j \delta_{ij}, \quad (13)$$

where $\sigma_{i/j}$ are the variabilities of the light curves that measurements i and j belong to, $E_{i/j}$ are their measurement uncertainties, $t_{i/j}$ are their measurement times after the spectroscopic measurements offset by the lag Δt , τ is the timescale of variability in the damped random walk and δ_{ij} is the Kronecker delta.

The predominant Gaussian process modelling program at time of writing is the python-based program JAVELIN (Zu et al. 2010), a DRW-based implementation of the method outlined by Press & Rybicki (1989). This method models the AGN light curves in a Bayesian way, constructing a unified light curve from the photometric and spectroscopic observations by treating the response as a shifted, scaled and smoothed copy of the driving continuum. This approach gives a closed form likelihood function:

$$\mathcal{L} = \frac{1}{\sqrt{\det((2\pi)^N C^{-1})}} \exp\left(-\frac{1}{2}(\vec{y} - \vec{y}_0)^T C^{-1}(\vec{y} - \vec{y}_0)\right), \quad (14)$$

where C is the covariance matrix defined in equation 13 and $\vec{y} - \vec{y}_0$ are the light curve measurements (photometric and spectroscopic) after offsetting by the mean of their respective light curves and N is the total number of observations across all light curves. This likelihood allows the signal parameters, including the lag, to be constrained in a Bayesian framework. This procedure uses all available information simultaneously to constrain the light curve behaviour between measurements, more accurately characterising the uncertainty arising from large seasonal gaps.

Equation 14 requires the inversion of a large matrix of rank N . Though the near-diagonal shape of equation 13 ameliorates this cost somewhat, this is still a computationally expensive process. To reduce the number of evaluations, JAVELIN uses the Monte Carlo Markov Chain (MCMC) approach using the python-based package emcee (Foreman-Mackey et al. 2013), which uses the Affine-Invariant Ensemble Sampler (Goodman & Weare 2010) to direct the

bulk of its samples to high likelihood regions of parameter space. The seasonal windowing function of equatorial surveys, and the resulting aliasing problem (see Section 2.2 for details) can give rise to multi-modal distributions along the lag axis of parameter-space (e.g. Grier et al. 2019), which can result in poor efficiency and inaccurate posterior distributions from `emcee`. Gaussian-process-based modelling is also sensitive to outlier data-points or under-estimated measurement uncertainties, which can spuriously over-constrain the light curve and disrupt the lag recovery results.

Another Gaussian process based lag recovery program similar to JAVELIN is CREAM (Starkey et al. 2015), which broadly adopts the same methodology as JAVELIN but assumes different Gaussian process statistics and parameterises its Bayesian priors in terms of physical properties (e.g. mass, accretion rate etc). CREAM has seen use in earlier SDSS papers, (e.g. Grier et al. 2019), and includes an ‘error scaling’ parameter in its generative model to relax the light curve constraints and side-step the impacts of under-estimated uncertainties. Outlier rejection, for both JAVELIN and CREAM, still relies on ‘by-eye’ identification and removal of suspicious measurements (e.g. Yu et al. 2023).

Appendix B. OzDES Reverberation Mapping Results

Source ID	Redshift	Monochromatic Luminosity $\log_{10}(\lambda L_{5100\text{\AA}} \text{erg/s})$	Rest-Frame Lag (Days)	Velocity Dispersion σ_v (km/s)	Mass ($10^6 M_\odot$)	Dimensionless Accretion Rate \dot{M}
DESJ002802.42 – 424913.52	0.127	43.69 ± 0.01	$16^{+2.7}_{-2.7}$	1385.00 ± 3.00	$25.6^{+7.9}_{-7.4}$	$1.6^{+1.6}_{-0.7}$
DESJ024347.34 – 005354.84	0.237	44.06 ± 0.01	$27.5^{+0.8}_{-1.6}$	1645.00 ± 6.00	62^{+15}_{-14}	$0.99^{+0.68}_{-0.35}$
DESJ034028.46 – 292902.41	0.310	44.69 ± 0.00	16^{+20}_{-15}	1716.00 ± 4.00	37^{+42}_{-38}	20^{+180}_{-20}
DESJ022249.67 – 051453.01	0.314	44.28 ± 0.01	60^{+16}_{-35}	1867.00 ± 5.00	166^{+84}_{-66}	$0.3^{+0.51}_{-0.17}$
DESJ003954.13 – 440509.97	0.332	44.19 ± 0.01	39^{+29}_{-11}	1838.00 ± 9.00	109^{+57}_{-57}	$0.5^{+1.5}_{-0.3}$
DESJ022330.16 – 054758.06	0.354	43.92 ± 0.01	$38.9^{+6.9}_{-4.6}$	1831.00 ± 9.00	109^{+35}_{-29}	$0.2^{+0.17}_{-0.08}$
DESJ002904.43 – 425243.04	0.644	44.65 ± 0.01	$19^{+5.3}_{-3.8}$	1836.00 ± 4.00	52^{+20}_{-17}	11^{+12}_{-5}
DESJ022617.85 – 043108.99	0.707	44.73 ± 0.01	$36^{+9}_{-5.3}$	1671.00 ± 7.00	83^{+27}_{-25}	$5.6^{+6.1}_{-2.4}$

Table 1.: The 8 OzDES results for H β , as listed in Malik et al. (2023). Masses and dimensionless accretion rates are calculated as per equation 1 and 4, with full error propagation.

Source ID	Redshift	Monochromatic Luminosity $\log_{10}(\lambda L_{3000\text{\AA}} \text{erg/s})$	Rest-Frame Lag (Days)	Velocity Dispersion σ_v (km/s)	Mass ($10^6 M_\odot$)	Dimensionless Accretion Rate \dot{M}
DESJ033328.93 – 275641.21	0.840	44.70 ± 0.01	$95.1^{+8.7}_{-9.2}$	2344.2 ± 66.9	430^{+120}_{-110}	$0.25^{+0.23}_{-0.1}$
DESJ024831.08 – 005025.60	0.890	44.94 ± 0.01	151^{+19}_{-54}	1868 ± 163	430^{+210}_{-160}	$0.6^{+0.95}_{-0.33}$
DESJ002933.85 – 435240.69	1.000	45.86 ± 0.01	286^{+7}_{-15}	2147 ± 275	1100^{+440}_{-320}	$2.2^{+2.3}_{-1.1}$
DESJ003710.86 – 444048.11	1.070	45.66 ± 0.00	185^{+16}_{-15}	2121.3 ± 81.9	690^{+210}_{-170}	$2.8^{+2.1}_{-1.1}$
DESJ033836.19 – 295113.50	1.150	44.55 ± 0.02	105^{+21}_{-24}	2644 ± 189	600^{+250}_{-200}	$0.08^{+0.096}_{-0.04}$
DESJ033211.42 – 284323.99	1.240	44.27 ± 0.01	59^{+12}_{-9}	3313.5 ± 95.3	550^{+180}_{-170}	$0.037^{+0.04}_{-0.016}$
DESJ003922.97 – 430230.41	1.370	45.36 ± 0.01	238^{+22}_{-14}	2291 ± 176	1010^{+340}_{-280}	$0.45^{+0.42}_{-0.2}$
DESJ022436.64 – 063255.90	1.420	44.88 ± 0.02	75^{+10}_{-11}	3064 ± 108	570^{+180}_{-160}	$0.27^{+0.25}_{-0.12}$
DESJ003052.76 – 430301.08	1.430	45.50 ± 0.01	158^{+14}_{-6}	1791 ± 148	430^{+130}_{-130}	$4.2^{+4.4}_{-1.7}$
DESJ024340.09 – 001749.40	1.440	45.42 ± 0.01	335^{+16}_{-3}	2977 ± 142	2490^{+650}_{-630}	$0.093^{+0.074}_{-0.034}$
DESJ024944.09 + 003317.50	1.480	45.53 ± 0.00	166^{+13}_{-27}	2157 ± 210	630^{+230}_{-200}	$2.1^{+2.5}_{-1}$
DESJ033213.36 – 283620.99	1.490	45.37 ± 0.01	$68.7^{+5.2}_{-4.4}$	2618 ± 179	390^{+110}_{-110}	$3.2^{+3}_{-1.3}$
DESJ003232.61 – 433302.99	1.490	45.30 ± 0.01	$215.7^{+4.4}_{-5.6}$	3434 ± 109	2150^{+530}_{-510}	$0.083^{+0.062}_{-0.03}$
DESJ024455.45 – 011500.40	1.530	45.22 ± 0.01	65^{+11}_{-8}	3415.1 ± 82.9	630^{+200}_{-170}	$0.74^{+0.64}_{-0.32}$
DESJ003207.44 – 433049.00	1.530	45.59 ± 0.00	148.6^{+4}_{-2}	1472 ± 163	264^{+97}_{-79}	15^{+16}_{-7}

DESJ025225.52 + 003405.90	1.620	45.64 ± 0.01	199_{-10}^{+12}	2218 ± 131	800_{-230}^{+240}	$1.9_{-0.8}^{+1.8}$
DESJ025254.18 – 001119.70	1.640	45.15 ± 0.01	157_{-63}^{+10}	2350 ± 321	690_{-270}^{+380}	$0.47_{-0.28}^{+0.76}$
DESJ022716.52 – 050008.30	1.640	45.45 ± 0.01	$198.5_{-5.3}^{+5.3}$	1877.8 ± 77.6	580_{-150}^{+160}	$1.9_{-0.7}^{+1.6}$
DESJ003234.33 – 431937.81	1.640	45.68 ± 0.00	249_{-12}^{+24}	1527 ± 130	480_{-140}^{+180}	$6.1_{-2.8}^{+6.7}$
DESJ003015.00 – 430333.45	1.650	45.53 ± 0.01	192_{-9}^{+11}	3578.7 ± 73.7	2060_{-510}^{+550}	$0.2_{-0.08}^{+0.15}$
DESJ022208.15 – 065550.50	1.660	45.21 ± 0.01	165_{-12}^{+9}	2200.4 ± 99.1	670_{-170}^{+200}	$0.62_{-0.26}^{+0.5}$
DESJ033903.66 – 293326.50	1.680	45.00 ± 0.01	115_{-25}^{+15}	3185.4 ± 92.9	950_{-280}^{+330}	$0.15_{-0.07}^{+0.15}$
DESJ003206.50 – 425325.22	1.750	45.56 ± 0.01	174_{-10}^{+15}	3486 ± 103	1750_{-430}^{+480}	$0.3_{-0.12}^{+0.23}$
DESJ022751.50 – 044252.70	1.790	45.41 ± 0.02	193_{-5}^{+10}	2656 ± 165	1130_{-290}^{+340}	$0.43_{-0.18}^{+0.36}$
DESJ024723.54 – 002536.50	1.860	45.91 ± 0.02	303_{-23}^{+22}	1972 ± 290	970_{-330}^{+440}	$3.4_{-1.8}^{+4.3}$

Table 2. : The 25 OzDES results for MgII, as listed in Yu et al. (2023). Masses and dimensionless accretion rates are calculated as per equation 1 and 4, with full error propagation, with luminosities being corrected from $\lambda L_{3000\text{\AA}}$ to $\lambda L_{5100\text{\AA}}$ using the bolometric corrections of Runnoe et al. (2012).

Source ID	Redshift	Monochromatic Luminosity $\log_{10}(\lambda L_{1350\text{\AA}} \text{ erg/s})$	Rest-Frame Lag (Days)	Velocity Dispersion σ_v (km/s)	Mass ($10^6 M_\odot$)	Dimensionless Accretion Rate M
DESJ022327.85 – 040119.16	1.922	45.45 ± 0.08	136_{-11}^{+11}	3428 ± 145	1310_{-330}^{+410}	$0.73_{-0.33}^{+0.67}$
DESJ022514.39 – 044700.14	1.928	46.21 ± 0.01	74_{-17}^{+17}	3601.0 ± 27.0	810_{-250}^{+280}	26_{-12}^{+27}
DESJ022537.03 – 050109.34	1.936	45.77 ± 0.02	$100.1_{-5.8}^{+5.8}$	4190.0 ± 40.0	1490_{-350}^{+340}	$1.7_{-0.6}^{+1.3}$
DESJ033401.79 – 265054.28	1.952	45.93 ± 0.02	$204.6_{-9.8}^{+9.8}$	3604.0 ± 67.0	2290_{-610}^{+540}	$1.26_{-0.46}^{+0.98}$
DESJ025159.70 – 005159.89	1.988	45.24 ± 0.05	37.8_{-9}^{+9}	3956 ± 159	490_{-160}^{+180}	$2.6_{-1.3}^{+3.1}$
DESJ032703.62 – 274425.27	2.031	46.13 ± 0.01	183_{-12}^{+12}	4395.0 ± 43.0	2980_{-770}^{+750}	$1.5_{-0.6}^{+1.2}$
DESJ002959.21 – 434835.24	2.041	46.81 ± 0.01	$145.4_{-5.9}^{+5.9}$	3587.0 ± 13.0	1570_{-400}^{+410}	55_{-20}^{+46}
DESJ021921.81 – 043642.21	2.092	45.98 ± 0.02	$122.6_{-9.4}^{+9.4}$	3511 ± 112	1280_{-350}^{+320}	$4.9_{-1.9}^{+4.2}$
DESJ021941.16 – 044100.36	2.096	45.64 ± 0.04	133_{-12}^{+12}	4145.0 ± 75.0	1980_{-530}^{+520}	$0.62_{-0.25}^{+0.54}$
DESJ032829.96 – 274212.23	2.150	45.92 ± 0.01	$152.4_{-8.6}^{+8.6}$	2789.0 ± 67.0	1000_{-260}^{+240}	$6.4_{-2.4}^{+5.1}$
DESJ032939.97 – 284952.40	2.188	45.84 ± 0.01	$74.3_{-9.7}^{+9.7}$	3925 ± 116	940_{-250}^{+300}	$5.3_{-2.2}^{+5}$
DESJ022001.63 – 052216.92	2.219	45.84 ± 0.02	186_{-15}^{+15}	3540.0 ± 77.0	1960_{-490}^{+560}	$1.2_{-0.5}^{+1}$
DESJ003743.89 – 434715.68	2.257	46.16 ± 0.01	$161.8_{-7.1}^{+7.1}$	3664.0 ± 57.0	1820_{-430}^{+470}	$4.4_{-1.7}^{+3.1}$
DESJ033655.83 – 290218.23	2.283	46.21 ± 0.01	$152_{-7.6}^{+7.6}$	4221.0 ± 83.0	2300_{-570}^{+540}	$3.3_{-1.2}^{+2.5}$
DESJ022410.96 – 050653.95	2.315	45.72 ± 0.02	167_{-13}^{+13}	3644.0 ± 64.0	1880_{-480}^{+470}	$0.89_{-0.34}^{+0.71}$
DESJ033843.76 – 294922.54	2.328	45.80 ± 0.02	$92.2_{-3.6}^{+3.6}$	2762 ± 166	600_{-160}^{+170}	$11.9_{-4.7}^{+9.6}$

DESJ004056.56 – 431446.40	2.384	46.20 ± 0.01	87^{+11}_{-11}	3652.0 ± 50.0	960^{+280}_{-260}	18^{+15}_{-8}
DESJ025102.06 – 004142.78	2.425	45.35 ± 0.03	66^{+12}_{-12}	3297 ± 183	590^{+220}_{-160}	$2.5^{+2.3}_{-1.2}$
DESJ022354.81 – 044814.94	2.452	46.64 ± 0.00	270.6^{+9}_{-9}	4121.0 ± 30.0	3940^{+970}_{-960}	$4.9^{+3.7}_{-1.8}$
DESJ025100.64 + 001707.38	2.459	45.97 ± 0.02	118^{+11}_{-11}	-	-	-
DESJ024511.94 – 011317.50	2.462	45.96 ± 0.01	34^{+11}_{-11}	4008 ± 107	440^{+200}_{-170}	38^{+59}_{-21}
DESJ032640.93 – 283206.80	2.492	45.85 ± 0.01	$145.2^{+4.3}_{-4.3}$	4326.0 ± 58.0	2270^{+550}_{-570}	$0.97^{+0.77}_{-0.36}$
DESJ003957.42 – 434107.92	2.500	45.93 ± 0.01	$146.3^{+4.9}_{-4.9}$	3633.0 ± 52.0	1630^{+430}_{-410}	$2.4^{+1.9}_{-0.9}$
DESJ022259.87 – 063326.65	2.563	46.00 ± 0.01	$91.2^{+6.5}_{-6.5}$	4340.0 ± 79.0	1460^{+350}_{-360}	$3.8^{+3}_{-1.3}$
DESJ003352.72 – 425452.55	2.593	46.52 ± 0.01	$107.4^{+3.9}_{-3.9}$	3871.0 ± 21.0	1360^{+330}_{-350}	27^{+21}_{-9}
DESJ022352.19 – 043031.68	2.677	46.01 ± 0.02	$90^{+5.4}_{-5.4}$	4250.0 ± 51.0	1350^{+350}_{-330}	$4.7^{+3.5}_{-1.7}$
DESJ022620.86 – 045946.48	2.745	45.59 ± 0.02	$100.9^{+5.6}_{-5.6}$	3643 ± 116	1130^{+300}_{-310}	$1.6^{+1.4}_{-0.6}$
DESJ024514.93 – 004101.83	2.773	45.80 ± 0.02	$68.9^{+8.2}_{-8.2}$	-	-	-
DESJ025105.13 – 001732.01	3.451	46.21 ± 0.01	$69^{+5.4}_{-5.4}$	1444 ± 213	116^{+57}_{-41}	1300^{+1800}_{-700}

Table 3. : All 29 OzDES results for CIV from Penton et al. (2025). Masses and dimensionless accretion rates are calculated as per equation 1 and 4, using full error propagation, with accretion luminosities being corrected from $\lambda L_{\text{1350}\text{\AA}}$ to $\lambda L_{\text{5100}\text{\AA}}$ using the bolometric corrections of Runnoe et al. (2012).

Appendix C. OzDES Single Epoch Results

Source ID	Redshift	Line	Monochromatic Luminosity $\log_{10}(\lambda L_{\lambda} \text{erg/s})$	Single Epoch Lag (Days)	Velocity Dispersion σ_v (km/s)	Single Epoch Mass ($10^6 M_{\odot}$)	Dimensionless Accretion Rate \dot{M}
DES15E1arx	0.040	H β	43.45 ± 0.01	15^{+12}_{-7}	1444.0 ± 27.0	27^{+23}_{-13}	$0.7^{+1.7}_{-0.5}$
DES14S2aog	0.180	H β	43.59 ± 0.04	18^{+14}_{-8}	1182 ± 130	20^{+19}_{-10}	$1.8^{+5.3}_{-1.3}$
OzDES – DR2_04692	0.220	H β	43.76 ± 0.02	21^{+17}_{-9}	1346.0 ± 70.0	31^{+27}_{-15}	$1.4^{+3.8}_{-1}$
OzDES – DR2_03800	0.250	H β	43.53 ± 0.05	17^{+13}_{-7}	1767.0 ± 52.0	43^{+38}_{-20}	$0.34^{+0.88}_{-0.24}$
SVA1_COADD – 2939653045	0.310	H β	44.65 ± 0.01	52^{+42}_{-23}	1710.00 ± 4.00	130^{+110}_{-60}	$1.9^{+4.8}_{-1.3}$
OzDES – DR2_04665	0.430	H β	44.41 ± 0.08	41^{+32}_{-18}	1786.0 ± 40.0	106^{+93}_{-50}	$1.1^{+2.9}_{-0.8}$
OzDES – DR2_04637	0.490	H β	44.41 ± 0.08	41^{+31}_{-18}	1258 ± 155	52^{+50}_{-26}	5^{+14}_{-3}
OzDES – DR2_03529	0.510	H β	44.63 ± 0.02	51^{+40}_{-22}	1482.0 ± 24.0	91^{+79}_{-43}	$3.3^{+8.4}_{-2.4}$
DES15X2eh	0.540	H β	44.69 ± 0.05	55^{+42}_{-24}	1884.0 ± 43.0	160^{+140}_{-70}	$1.4^{+3.5}_{-1}$
SVA1_COADD – 2940377880	0.550	H β	43.97 ± 0.12	26^{+21}_{-12}	1618 ± 165	55^{+51}_{-28}	$0.9^{+2.7}_{-0.7}$
DES15S2jm	0.570	H β	44.55 ± 0.13	47^{+37}_{-21}	1725 ± 178	110^{+110}_{-60}	$1.6^{+4.6}_{-1.2}$
OzDES – DR2_03499	0.590	H β	44.51 ± 0.06	45^{+36}_{-20}	1166 ± 315	48^{+61}_{-29}	8^{+38}_{-6}
OzDES – DR2_03501	0.610	H β	44.65 ± 0.04	52^{+41}_{-23}	1658.0 ± 28.0	120^{+100}_{-60}	$2.1^{+5.5}_{-1.5}$

OzDES – DR2_04680	0.620	H β	44.50 ± 0.04	45^{+35}_{-19}	1174 ± 159	50^{+48}_{-25}	7^{+22}_{-5}
DES14S2qh	0.640	H β	44.79 ± 0.17	60^{+50}_{-27}	1875 ± 395	170^{+200}_{-90}	$1.7^{+6.7}_{-1.3}$
SVA1_COADD – 2970737963	0.650	H β	44.65 ± 0.07	52^{+41}_{-23}	1815 ± 173	140^{+130}_{-70}	$1.5^{+4.4}_{-1.1}$
SVA1_COADD – 2970614761	0.660	H β	45.17 ± 0.06	88^{+70}_{-39}	1718.0 ± 43.0	210^{+190}_{-100}	4^{+10}_{-3}
OzDES – DR2_03551	0.670	H β	44.42 ± 0.17	41^{+34}_{-18}	1167 ± 285	44^{+55}_{-25}	7^{+30}_{-5}
SVA1_COADD – 2943201524	0.670	H β	44.73 ± 0.08	57^{+45}_{-25}	1480 ± 377	100^{+120}_{-60}	4^{+19}_{-3}
SVA1_COADD – 2970520148	0.710	MgII	43.66 ± 0.11	41^{+35}_{-19}	2211 ± 545	160^{+200}_{-90}	$0.05^{+0.27}_{-0.04}$
OzDES – DR2_03818	0.720	MgII	44.28 ± 0.03	67^{+55}_{-30}	1041 ± 318	56^{+79}_{-35}	4^{+22}_{-3}
SVA1_COADD – 2940389965	0.720	MgII	43.83 ± 0.03	47^{+39}_{-21}	1154 ± 363	49^{+71}_{-31}	$1.0^{+6.7}_{-0.8}$
DES15C3kc	0.730	MgII	44.64 ± 0.01	89^{+73}_{-40}	2337 ± 321	390^{+400}_{-200}	$0.26^{+0.81}_{-0.19}$
DES15S2is	0.730	MgII	44.60 ± 0.03	85^{+69}_{-38}	1477 ± 206	150^{+160}_{-80}	$1.5^{+5}_{-1.1}$
OzDES – DR2_03832	0.730	MgII	45.16 ± 0.01	130^{+110}_{-60}	1358.9 ± 87.2	200^{+190}_{-100}	6^{+17}_{-4}
OzDES – DR2_04247	0.760	MgII	45.36 ± 0.01	160^{+130}_{-70}	1140 ± 170	160^{+170}_{-90}	17^{+57}_{-13}
DES14C1csb	0.770	MgII	44.13 ± 0.06	60^{+50}_{-27}	3870 ± 562	710^{+740}_{-370}	$0.013^{+0.045}_{-0.01}$
SVA1_COADD – 2939696843	0.790	MgII	44.32 ± 0.02	69^{+56}_{-31}	1394 ± 502	100^{+160}_{-70}	$1.2^{+9.7}_{-1}$
SVA1_COADD – 2971010547	0.790	MgII	43.95 ± 0.02	52^{+44}_{-24}	1313 ± 182	72^{+73}_{-37}	$0.7^{+2.2}_{-0.5}$
DES15S2aqw	0.800	MgII	44.45 ± 0.03	76^{+63}_{-35}	933 ± 367	50^{+85}_{-35}	8^{+78}_{-7}
OzDES – DR2_03540	0.810	MgII	44.55 ± 0.03	82^{+68}_{-37}	2261.1 ± 68.0	350^{+330}_{-170}	$0.24^{+0.66}_{-0.18}$
OzDES – DR2_04657	0.820	MgII	44.51 ± 0.02	80^{+65}_{-36}	1478 ± 519	130^{+200}_{-90}	1^{+10}_{-1}
SVA1_COADD – 2925769537	0.830	MgII	45.14 ± 0.01	130^{+100}_{-60}	1239.0 ± 87.4	160^{+150}_{-80}	8^{+23}_{-6}
OzDES – DR2_03561	0.840	MgII	44.20 ± 0.04	63^{+52}_{-28}	2190 ± 142	250^{+230}_{-120}	$0.14^{+0.41}_{-0.1}$
DES14C3ni	0.860	MgII	44.46 ± 0.03	77^{+63}_{-35}	3239 ± 713	640^{+760}_{-360}	$0.05^{+0.22}_{-0.04}$
SVA1_COADD – 2939643434	0.860	MgII	44.33 ± 0.02	69^{+59}_{-31}	782 ± 230	33^{+45}_{-20}	12^{+69}_{-10}
OzDES – DR2_03531	0.870	MgII	45.58 ± 0.01	180^{+150}_{-80}	2025.8 ± 66.8	620^{+570}_{-300}	$2.6^{+7.3}_{-1.9}$
SVA1_COADD – 2971021290	0.880	MgII	43.64 ± 0.08	41^{+34}_{-19}	1373 ± 378	60^{+80}_{-36}	$0.3^{+1.9}_{-0.3}$
SVA1_COADD – 2970720523	0.890	MgII	44.25 ± 0.04	65^{+54}_{-30}	1582 ± 465	130^{+180}_{-80}	$0.6^{+3.5}_{-0.5}$
SVA1_COADD – 2970373462	0.900	MgII	44.04 ± 0.02	55^{+47}_{-25}	1271 ± 141	73^{+72}_{-37}	$0.9^{+3}_{-0.7}$
SVA1_COADD – 2971149575	0.900	MgII	44.44 ± 0.02	76^{+63}_{-34}	1721 ± 103	180^{+170}_{-90}	$0.6^{+1.7}_{-0.4}$
DES15S1cs	0.910	MgII	44.95 ± 0.01	112^{+91}_{-50}	1871 ± 247	320^{+330}_{-160}	$1.1^{+3.4}_{-0.8}$
SVA1_COADD – 2970951747	0.910	MgII	43.68 ± 0.07	42^{+35}_{-19}	1798 ± 235	110^{+120}_{-60}	$0.12^{+0.39}_{-0.09}$
OzDES – DR2_04643	0.920	MgII	45.12 ± 0.01	130^{+100}_{-60}	1988 ± 126	420^{+390}_{-200}	$1.2^{+3.3}_{-0.9}$
SVA1_COADD – 2939031576	0.920	MgII	45.10 ± 0.00	130^{+100}_{-60}	1345 ± 107	190^{+180}_{-90}	5^{+16}_{-4}
DES15X1aw	0.930	MgII	44.83 ± 0.01	103^{+83}_{-46}	2464 ± 436	490^{+540}_{-260}	$0.3^{+1.1}_{-0.2}$

SVA1_COADD – 2925577636	0.930	MgII	44.43 ± 0.02	76^{+60}_{-34}	1804 ± 499	190^{+250}_{-110}	$0.5^{+2.7}_{-0.4}$
OzDES – DR2_03542	0.940	MgII	44.53 ± 0.02	81^{+66}_{-37}	1803.9 ± 64.6	220^{+200}_{-100}	$0.6^{+1.6}_{-0.4}$
OzDES – DR2_04645	0.940	MgII	42.43 ± 0.31	16^{+16}_{-8}	4180 ± 261	220^{+250}_{-120}	$0.0004^{+0.0014}_{-0.0003}$
SVA1_COADD – 2940222883	0.940	MgII	44.82 ± 0.01	101^{+83}_{-45}	2524 ± 455	510^{+550}_{-280}	$0.3^{+1}_{-0.2}$
SVA1_COADD – 2970787873	0.940	MgII	44.43 ± 0.01	75^{+62}_{-34}	1949 ± 528	220^{+290}_{-130}	$0.4^{+1.9}_{-0.3}$
OzDES – DR2_03678	0.950	MgII	44.61 ± 0.02	87^{+70}_{-39}	3148 ± 173	700^{+660}_{-340}	$0.07^{+0.2}_{-0.05}$
SVA1_COADD – 2925526498	0.950	MgII	44.97 ± 0.01	114^{+95}_{-52}	3008 ± 342	830^{+820}_{-420}	$0.18^{+0.52}_{-0.13}$
SVA1_COADD – 2940004848	0.950	MgII	43.36 ± 0.11	33^{+28}_{-15}	1234 ± 261	39^{+47}_{-22}	$0.3^{+1.3}_{-0.2}$
OzDES – DR2_04696	0.960	MgII	45.01 ± 0.03	119^{+98}_{-54}	2932.4 ± 71.1	830^{+760}_{-400}	$0.20^{+0.56}_{-0.15}$
SVA1_COADD – 2925846729	0.960	MgII	44.88 ± 0.01	107^{+89}_{-48}	851 ± 308	60^{+90}_{-40}	20^{+200}_{-20}
SVA1_COADD – 2937702952	0.960	MgII	43.97 ± 0.07	52^{+44}_{-24}	1476 ± 411	90^{+120}_{-50}	$0.5^{+2.7}_{-0.4}$
SVA1_COADD – 2939008600	0.960	MgII	44.00 ± 0.00	54^{+45}_{-25}	4291.8 ± 64.8	810^{+760}_{-390}	$0.007^{+0.018}_{-0.005}$
SVA1_COADD – 2940448274	0.960	MgII	44.56 ± 0.04	84^{+69}_{-38}	2662 ± 359	470^{+480}_{-240}	$0.13^{+0.42}_{-0.1}$
SVA1_COADD – 2970595083	0.960	MgII	43.82 ± 0.03	47^{+40}_{-21}	2334 ± 623	200^{+260}_{-120}	$0.06^{+0.3}_{-0.05}$
OzDES – DR2_04702	0.970	MgII	44.80 ± 0.03	101^{+81}_{-46}	1743.6 ± 75.5	250^{+230}_{-120}	$1.1^{+3}_{-0.8}$
SVA1_COADD – 2940882201	0.970	MgII	44.46 ± 0.02	77^{+63}_{-35}	2891 ± 453	520^{+530}_{-270}	$0.08^{+0.27}_{-0.06}$
SVA1_COADD – 2970605450	0.970	MgII	44.57 ± 0.02	84^{+70}_{-38}	1436 ± 194	140^{+140}_{-70}	$1.6^{+4.9}_{-1.2}$
SVA1_COADD – 2970668428	0.970	MgII	44.65 ± 0.01	90^{+74}_{-40}	2312.8 ± 96.9	390^{+360}_{-190}	$0.26^{+0.72}_{-0.19}$
DES17X1gg	0.980	MgII	44.87 ± 0.01	106^{+87}_{-47}	1285 ± 190	140^{+140}_{-70}	4^{+14}_{-3}
OzDES – DR2_03509	0.980	MgII	45.13 ± 0.02	130^{+110}_{-60}	4626 ± 243	2300^{+2100}_{-1100}	$0.04^{+0.11}_{-0.03}$
OzDES – DR2_04670	0.980	MgII	44.82 ± 0.06	102^{+86}_{-46}	2423 ± 170	490^{+450}_{-240}	$0.30^{+0.88}_{-0.22}$
SVA1_COADD – 2925533510	0.980	MgII	44.39 ± 0.04	73^{+61}_{-33}	2499.0 ± 87.7	370^{+350}_{-180}	$0.12^{+0.33}_{-0.09}$
SVA1_COADD – 2925646449	0.980	MgII	44.66 ± 0.03	90^{+75}_{-41}	1880 ± 123	260^{+250}_{-130}	$0.6^{+1.8}_{-0.5}$
SVA1_COADD – 2925445574	0.990	MgII	45.00 ± 0.01	116^{+95}_{-52}	1604 ± 413	240^{+300}_{-140}	2^{+12}_{-2}
SVA1_COADD – 2937572662	0.990	MgII	44.21 ± 0.02	63^{+53}_{-29}	3342 ± 369	570^{+570}_{-290}	$0.027^{+0.083}_{-0.02}$
SVA1_COADD – 2940043569	1.010	MgII	45.04 ± 0.01	121^{+97}_{-54}	1935 ± 145	370^{+350}_{-180}	$1.1^{+3.2}_{-0.8}$
SVA1_COADD – 2940700344	1.010	MgII	44.25 ± 0.04	65^{+54}_{-30}	2563 ± 524	340^{+380}_{-190}	$0.09^{+0.35}_{-0.07}$
SVA1_COADD – 2925602086	1.020	MgII	44.59 ± 0.01	85^{+69}_{-38}	1532 ± 313	160^{+180}_{-90}	$1.3^{+5.2}_{-1}$
SVA1_COADD – 2970955917	1.050	MgII	44.55 ± 0.03	82^{+67}_{-37}	774 ± 285	38^{+59}_{-26}	20^{+160}_{-20}
SVA1_COADD – 2940552037	1.070	MgII	44.80 ± 0.02	100^{+80}_{-45}	861 ± 251	57^{+79}_{-35}	20^{+110}_{-20}
DES14X3cce	1.080	MgII	44.63 ± 0.03	88^{+70}_{-39}	3252 ± 309	760^{+730}_{-380}	$0.07^{+0.2}_{-0.05}$
DES16C2nn	1.090	MgII	44.39 ± 0.02	73^{+59}_{-33}	3196 ± 494	600^{+620}_{-310}	$0.05^{+0.16}_{-0.03}$
SVA1_COADD – 2925812345	1.090	MgII	44.20 ± 0.05	63^{+52}_{-29}	1400 ± 366	100^{+120}_{-60}	$0.9^{+4.3}_{-0.7}$

SVA1_COADD – 2938397188	1.090	MgII	44.67 ± 0.01	92^{+72}_{-42}	1969 ± 154	290^{+280}_{-140}	$0.5^{+1.5}_{-0.4}$
SVA1_COADD – 2938631157	1.090	MgII	44.72 ± 0.02	93^{+77}_{-42}	2176 ± 191	370^{+340}_{-180}	$0.4^{+1.1}_{-0.3}$
SVA1_COADD – 2939525110	1.090	MgII	45.23 ± 0.00	140^{+120}_{-60}	1663 ± 175	320^{+310}_{-160}	$3.0^{+9}_{-2.2}$
SVA1_COADD – 2939864039	1.090	MgII	43.77 ± 0.05	45^{+38}_{-21}	1840 ± 972	110^{+240}_{-90}	$0.1^{+3.5}_{-0.1}$
SVA1_COADD – 2925464457	1.110	MgII	44.39 ± 0.02	73^{+60}_{-33}	1619 ± 180	150^{+150}_{-80}	$0.7^{+2.1}_{-0.5}$
SVA1_COADD – 2938234013	1.110	MgII	45.12 ± 0.01	130^{+100}_{-60}	2304 ± 623	530^{+690}_{-320}	$0.7^{+3.6}_{-0.6}$
SVA1_COADD – 2940224019	1.120	MgII	44.75 ± 0.01	97^{+80}_{-44}	2664 ± 156	560^{+520}_{-270}	$0.18^{+0.5}_{-0.13}$
SVA1_COADD – 2937854650	1.130	MgII	44.89 ± 0.02	107^{+87}_{-48}	1253 ± 167	140^{+140}_{-70}	5^{+16}_{-4}
SVA1_COADD – 2939029256	1.140	MgII	44.77 ± 0.01	99^{+80}_{-45}	2432 ± 181	470^{+440}_{-230}	$0.28^{+0.77}_{-0.2}$
SVA1_COADD – 2939283340	1.160	MgII	44.36 ± 0.03	71^{+58}_{-32}	1309 ± 465	90^{+140}_{-60}	2^{+13}_{-1}
SVA1_COADD – 2939828380	1.160	MgII	44.12 ± 0.02	59^{+49}_{-27}	1299 ± 316	78^{+96}_{-45}	$1.1^{+5.1}_{-0.9}$
SVA1_COADD – 2970364664	1.160	MgII	43.76 ± 0.16	45^{+39}_{-21}	4056 ± 545	590^{+630}_{-310}	$0.005^{+0.019}_{-0.004}$
DES16X1jr	1.170	MgII	44.54 ± 0.03	82^{+67}_{-38}	1289 ± 464	100^{+160}_{-70}	3^{+20}_{-2}
OzDES – DR2_04250	1.170	MgII	44.89 ± 0.02	108^{+88}_{-49}	3555 ± 539	1100^{+1100}_{-600}	$0.08^{+0.26}_{-0.06}$
OzDES – DR2_03498	1.180	MgII	44.98 ± 0.01	116^{+95}_{-52}	2518 ± 429	590^{+640}_{-310}	$0.4^{+1.3}_{-0.3}$
SVA1_COADD – 2938984610	1.190	MgII	44.82 ± 0.01	102^{+83}_{-46}	2203 ± 342	400^{+420}_{-210}	$0.5^{+1.5}_{-0.3}$
SVA1_COADD – 2971072668	1.190	MgII	44.88 ± 0.01	108^{+87}_{-48}	2272 ± 123	450^{+420}_{-220}	$0.4^{+1.2}_{-0.3}$
OzDES – DR2_04713	1.200	MgII	45.21 ± 0.01	140^{+110}_{-60}	1004 ± 181	110^{+120}_{-60}	22^{+78}_{-17}
SVA1_COADD – 2925799454	1.200	MgII	45.02 ± 0.01	120^{+97}_{-54}	676 ± 273	42^{+69}_{-29}	80^{+880}_{-70}
SVA1_COADD – 2970419657	1.200	MgII	44.05 ± 0.04	56^{+46}_{-26}	931 ± 343	37^{+58}_{-25}	4^{+30}_{-3}
SVA1_COADD – 2925671794	1.210	MgII	44.45 ± 0.01	76^{+64}_{-35}	1429 ± 500	120^{+180}_{-80}	1^{+10}_{-1}
SVA1_COADD – 2970404878	1.220	MgII	44.15 ± 0.03	60^{+50}_{-27}	3161 ± 619	480^{+550}_{-260}	$0.03^{+0.12}_{-0.02}$
SVA1_COADD – 2971250820	1.220	MgII	44.45 ± 0.02	76^{+63}_{-35}	1487 ± 166	140^{+130}_{-70}	$1.1^{+3.2}_{-0.8}$
OzDES – DR2_04535	1.230	MgII	45.71 ± 0.01	200^{+170}_{-90}	1111 ± 173	200^{+210}_{-100}	40^{+130}_{-30}
SVA1_COADD – 2925446646	1.230	MgII	44.08 ± 0.06	57^{+47}_{-26}	2252 ± 677	230^{+320}_{-140}	$0.11^{+0.68}_{-0.09}$
SVA1_COADD – 2970737546	1.230	MgII	44.90 ± 0.01	107^{+88}_{-48}	2010 ± 551	340^{+450}_{-200}	$0.8^{+4.1}_{-0.7}$
OzDES – DR2_03506	1.240	MgII	45.11 ± 0.01	130^{+110}_{-60}	825 ± 273	68^{+96}_{-44}	40^{+300}_{-40}
OzDES – DR2_03511	1.240	MgII	45.61 ± 0.00	190^{+160}_{-90}	854 ± 263	110^{+150}_{-70}	100^{+610}_{-80}
DES13X1cps	1.250	MgII	44.71 ± 0.04	94^{+77}_{-42}	4224 ± 359	1400^{+1300}_{-700}	$0.027^{+0.074}_{-0.02}$
OzDES – DR2_04648	1.250	MgII	45.18 ± 0.01	140^{+110}_{-60}	1903.0 ± 95.0	400^{+380}_{-190}	$1.6^{+4.3}_{-1.2}$
SVA1_COADD – 2925397940	1.250	MgII	44.95 ± 0.01	112^{+94}_{-51}	1472 ± 243	190^{+200}_{-100}	3^{+10}_{-2}
SVA1_COADD – 2970795406	1.250	MgII	44.87 ± 0.01	105^{+87}_{-46}	4256.2 ± 84.1	1600^{+1400}_{-800}	$0.034^{+0.097}_{-0.025}$
SVA1_COADD – 2937430058	1.260	MgII	44.45 ± 0.01	76^{+61}_{-35}	1844 ± 347	210^{+230}_{-110}	$0.5^{+1.8}_{-0.4}$

SVA1_COADD – 2925423969	1.270	MgII	43.69 ± 0.08	42^{+36}_{-19}	1935 ± 598	120^{+180}_{-80}	$0.10^{+0.59}_{-0.08}$
SVA1_COADD – 2925519095	1.280	MgII	44.48 ± 0.01	78^{+64}_{-36}	1058 ± 354	68^{+100}_{-44}	5^{+34}_{-4}
SVA1_COADD – 2938013449	1.280	MgII	45.09 ± 0.01	130^{+100}_{-60}	1025.0 ± 89.9	110^{+100}_{-50}	16^{+46}_{-12}
OzDES – DR2_03518	1.290	MgII	45.19 ± 0.01	140^{+110}_{-60}	1290 ± 157	180^{+180}_{-90}	8^{+24}_{-6}
SVA1_COADD – 2925393331	1.290	MgII	44.75 ± 0.01	96^{+76}_{-44}	3318 ± 355	860^{+840}_{-430}	$0.08^{+0.23}_{-0.06}$
SVA1_COADD – 2925472971	1.300	MgII	45.05 ± 0.01	122^{+98}_{-56}	3388 ± 137	1100^{+1000}_{-600}	$0.12^{+0.33}_{-0.09}$
SVA1_COADD – 2970421037	1.300	MgII	44.77 ± 0.02	98^{+81}_{-44}	2453 ± 254	480^{+460}_{-240}	$0.26^{+0.82}_{-0.19}$
DES17S1auo	1.320	MgII	45.21 ± 0.01	140^{+110}_{-60}	1989 ± 138	440^{+420}_{-210}	$1.4^{+3.9}_{-1}$
SVA1_COADD – 2938942051	1.320	MgII	45.06 ± 0.00	123^{+98}_{-55}	2096 ± 148	440^{+410}_{-210}	$0.9^{+2.4}_{-0.6}$
SVA1_COADD – 2925362897	1.330	MgII	44.64 ± 0.01	89^{+73}_{-39}	4848 ± 168	1700^{+1500}_{-800}	$0.013^{+0.037}_{-0.01}$
SVA1_COADD – 2938622100	1.340	MgII	44.64 ± 0.03	89^{+73}_{-39}	2252 ± 223	370^{+350}_{-180}	$0.29^{+0.87}_{-0.21}$
SVA1_COADD – 2971175628	1.340	MgII	44.37 ± 0.01	72^{+59}_{-33}	1601 ± 372	150^{+170}_{-80}	$0.7^{+3.3}_{-0.6}$
OzDES – DR2_03552	1.350	MgII	45.36 ± 0.00	160^{+130}_{-70}	2526.2 ± 70.9	810^{+730}_{-400}	$0.7^{+2}_{-0.5}$
SVA1_COADD – 2925794296	1.350	MgII	44.37 ± 0.01	71^{+59}_{-33}	4105 ± 266	990^{+920}_{-480}	$0.016^{+0.045}_{-0.011}$
SVA1_COADD – 2940401289	1.350	MgII	44.16 ± 0.05	60^{+52}_{-27}	2066 ± 206	210^{+210}_{-100}	$0.17^{+0.51}_{-0.13}$
OzDES – DR2_03513	1.360	MgII	45.33 ± 0.01	150^{+120}_{-70}	4002 ± 137	2000^{+1900}_{-1000}	$0.11^{+0.3}_{-0.08}$
SVA1_COADD – 2940203561	1.360	MgII	44.62 ± 0.02	87^{+72}_{-39}	4049 ± 400	1200^{+1100}_{-600}	$0.028^{+0.081}_{-0.02}$
OzDES – DR2_03524	1.370	MgII	45.02 ± 0.01	120^{+99}_{-54}	3655 ± 280	1300^{+1200}_{-600}	$0.09^{+0.25}_{-0.06}$
OzDES – DR2_03557	1.370	MgII	45.22 ± 0.01	140^{+120}_{-60}	3410 ± 121	1300^{+1200}_{-600}	$0.17^{+0.45}_{-0.12}$
SVA1_COADD – 2925607376	1.370	MgII	43.47 ± 0.15	36^{+31}_{-17}	1488 ± 284	62^{+72}_{-34}	$0.17^{+0.72}_{-0.14}$
SVA1_COADD – 2940028186	1.370	MgII	44.28 ± 0.04	66^{+57}_{-30}	1679 ± 134	150^{+150}_{-80}	$0.5^{+1.4}_{-0.4}$
SVA1_COADD – 2939668317	1.380	MgII	45.24 ± 0.01	140^{+120}_{-60}	3345 ± 184	1300^{+1200}_{-600}	$0.18^{+0.5}_{-0.13}$
SVA1_COADD – 2940942159	1.380	MgII	45.00 ± 0.02	115^{+97}_{-50}	2372 ± 149	530^{+510}_{-260}	$0.5^{+1.3}_{-0.3}$
OzDES – DR2_03517	1.390	MgII	45.84 ± 0.01	230^{+190}_{-100}	3143 ± 125	1800^{+1700}_{-900}	$0.7^{+2}_{-0.5}$
OzDES – DR2_04694	1.390	MgII	45.50 ± 0.01	170^{+140}_{-80}	3651 ± 127	1900^{+1700}_{-900}	$0.22^{+0.6}_{-0.16}$
SVA1_COADD – 2939487586	1.390	MgII	44.90 ± 0.01	109^{+88}_{-49}	1454 ± 213	180^{+190}_{-90}	$2.8^{+9.2}_{-2.1}$
SVA1_COADD – 2940256946	1.390	MgII	44.28 ± 0.03	67^{+56}_{-30}	1930 ± 353	200^{+230}_{-110}	$0.3^{+1}_{-0.2}$
SVA1_COADD – 2970977864	1.390	MgII	44.33 ± 0.03	70^{+57}_{-32}	5405 ± 114	1700^{+1500}_{-800}	$0.005^{+0.014}_{-0.004}$
SVA1_COADD – 2938037633	1.400	MgII	44.80 ± 0.03	101^{+83}_{-45}	2027 ± 417	330^{+380}_{-180}	$0.6^{+2.4}_{-0.5}$
SVA1_COADD – 2940277059	1.400	MgII	44.40 ± 0.01	74^{+60}_{-34}	1277 ± 306	90^{+120}_{-60}	$1.9^{+8.8}_{-1.5}$
OzDES – DR2_03537	1.420	MgII	45.01 ± 0.01	119^{+97}_{-55}	1873 ± 159	340^{+320}_{-170}	$1.2^{+3.5}_{-0.9}$
SVA1_COADD – 2937586747	1.420	MgII	44.30 ± 0.05	68^{+56}_{-31}	1127 ± 254	68^{+80}_{-39}	3^{+12}_{-2}
SVA1_COADD – 2939390597	1.420	MgII	44.57 ± 0.01	85^{+67}_{-39}	1686 ± 105	200^{+180}_{-100}	$0.8^{+2.3}_{-0.6}$

SVA1_COADD – 2940435471	1.420	MgII	45.44 ± 0.01	170^{+130}_{-70}	1268.3 ± 79.0	220^{+200}_{-100}	13^{+35}_{-10}
DES16X3bdi	1.430	MgII	45.35 ± 0.01	150^{+120}_{-70}	3703 ± 294	1700^{+1600}_{-800}	$0.15^{+0.44}_{-0.11}$
OzDES – DR2_03508	1.430	MgII	45.29 ± 0.02	150^{+120}_{-70}	4352 ± 202	2300^{+2100}_{-1100}	$0.07^{+0.2}_{-0.05}$
SVA1_COADD – 2970855768	1.430	MgII	44.56 ± 0.03	83^{+70}_{-38}	1754 ± 204	210^{+200}_{-100}	$0.7^{+2.1}_{-0.5}$
SVA1_COADD – 2937695256	1.440	MgII	44.97 ± 0.01	115^{+92}_{-51}	4461 ± 194	1900^{+1700}_{-900}	$0.035^{+0.097}_{-0.025}$
OzDES – DR2_03753	1.450	MgII	44.82 ± 0.02	101^{+84}_{-45}	1857 ± 111	290^{+260}_{-140}	$0.9^{+2.5}_{-0.6}$
SVA1_COADD – 2925471674	1.450	MgII	44.46 ± 0.04	77^{+63}_{-35}	1731 ± 382	180^{+210}_{-100}	$0.6^{+2.7}_{-0.5}$
SVA1_COADD – 2938539882	1.450	MgII	45.10 ± 0.01	130^{+100}_{-60}	1974 ± 107	400^{+370}_{-190}	$1.2^{+3.2}_{-0.9}$
OzDES – DR2_03546	1.460	MgII	45.65 ± 0.01	200^{+160}_{-90}	3144 ± 173	1600^{+1500}_{-800}	$0.5^{+1.4}_{-0.4}$
SVA1_COADD – 2938336035	1.460	MgII	44.41 ± 0.02	73^{+62}_{-33}	1662 ± 650	160^{+260}_{-110}	$0.7^{+6.6}_{-0.6}$
SVA1_COADD – 2970670047	1.460	MgII	43.77 ± 0.00	45^{+38}_{-21}	2301 ± 710	180^{+250}_{-110}	$0.06^{+0.34}_{-0.05}$
OzDES – DR2_03504	1.470	MgII	45.01 ± 0.03	118^{+97}_{-52}	4650 ± 411	2100^{+2000}_{-1000}	$0.032^{+0.093}_{-0.024}$
OzDES – DR2_03730	1.470	MgII	44.73 ± 0.02	96^{+77}_{-44}	3395.5 ± 93.5	890^{+820}_{-430}	$0.07^{+0.18}_{-0.05}$
OzDES – DR2_04703	1.470	MgII	45.33 ± 0.01	150^{+130}_{-70}	3330 ± 368	1400^{+1400}_{-700}	$0.23^{+0.7}_{-0.17}$
SVA1_COADD – 2940244768	1.470	MgII	44.27 ± 0.03	67^{+55}_{-30}	3146 ± 193	540^{+510}_{-270}	$0.04^{+0.11}_{-0.03}$
OzDES – DR2_03538	1.480	MgII	45.36 ± 0.02	160^{+130}_{-70}	2625 ± 347	880^{+890}_{-450}	$0.6^{+2}_{-0.5}$
OzDES – DR2_03521	1.490	MgII	45.57 ± 0.00	180^{+150}_{-80}	1383 ± 115	290^{+280}_{-140}	11^{+33}_{-8}
SVA1_COADD – 2939280573	1.490	MgII	45.36 ± 0.01	160^{+130}_{-70}	828 ± 304	80^{+130}_{-60}	70^{+560}_{-60}
SVA1_COADD – 2940331968	1.490	MgII	44.22 ± 0.08	64^{+53}_{-29}	998 ± 117	52^{+53}_{-26}	3^{+11}_{-3}
SVA1_COADD – 2970328630	1.490	MgII	44.74 ± 0.03	96^{+81}_{-43}	1100 ± 395	90^{+140}_{-60}	7^{+54}_{-6}
SVA1_COADD – 2970978434	1.490	MgII	44.51 ± 0.02	81^{+65}_{-36}	4368 ± 350	1200^{+1200}_{-600}	$0.016^{+0.045}_{-0.012}$
DES17X3bqv	1.500	MgII	44.67 ± 0.03	91^{+76}_{-41}	2734 ± 433	540^{+580}_{-280}	$0.15^{+0.5}_{-0.11}$
SVA1_COADD – 2971092076	1.500	MgII	44.45 ± 0.04	76^{+63}_{-35}	854 ± 300	43^{+64}_{-29}	11^{+85}_{-9}
OzDES – DR2_03525	1.530	MgII	45.14 ± 0.01	130^{+110}_{-60}	1563 ± 212	260^{+270}_{-130}	3^{+11}_{-3}
SVA1_COADD – 2925739931	1.530	MgII	44.51 ± 0.02	81^{+67}_{-37}	2139 ± 532	290^{+360}_{-170}	$0.3^{+1.4}_{-0.2}$
SVA1_COADD – 2940270267	1.530	MgII	44.19 ± 0.05	63^{+52}_{-29}	2986 ± 503	440^{+490}_{-240}	$0.04^{+0.15}_{-0.03}$
SVA1_COADD – 2925643975	1.540	MgII	45.38 ± 0.00	160^{+130}_{-70}	970 ± 214	120^{+140}_{-70}	40^{+150}_{-30}
OzDES – DR2_03544	1.550	MgII	45.43 ± 0.01	160^{+130}_{-70}	3469 ± 686	1600^{+1800}_{-800}	$0.25^{+0.95}_{-0.19}$
SVA1_COADD – 2939368309	1.550	MgII	44.20 ± 0.09	63^{+52}_{-29}	1607 ± 161	130^{+130}_{-70}	$0.5^{+1.5}_{-0.4}$
SVA1_COADD – 2939231059	1.560	MgII	45.37 ± 0.01	160^{+130}_{-70}	1515.4 ± 71.7	290^{+280}_{-140}	6^{+15}_{-4}
SVA1_COADD – 2971079430	1.560	MgII	44.78 ± 0.03	100^{+81}_{-45}	1584 ± 237	200^{+200}_{-100}	$1.6^{+5.5}_{-1.2}$
OzDES – DR2_03690	1.570	MgII	44.57 ± 0.00	84^{+70}_{-38}	3647.2 ± 80.5	920^{+850}_{-440}	$0.036^{+0.098}_{-0.026}$
OzDES – DR2_03813	1.580	MgII	44.73 ± 0.03	94^{+79}_{-42}	1755 ± 147	240^{+230}_{-120}	$0.9^{+2.7}_{-0.7}$

OzDES – DR2_03734	1.590	MgII	45.24 ± 0.01	140^{+120}_{-60}	3010 ± 194	1040^{+980}_{-500}	$0.29^{+0.78}_{-0.21}$
OzDES – DR2_03839	1.590	MgII	45.09 ± 0.02	130^{+100}_{-60}	1154 ± 200	130^{+140}_{-70}	10^{+37}_{-8}
OzDES – DR2_03802	1.600	MgII	45.76 ± 0.01	210^{+180}_{-90}	1505 ± 355	390^{+460}_{-220}	12^{+54}_{-10}
SVA1_COADD – 2938485719	1.600	MgII	45.23 ± 0.01	140^{+120}_{-60}	1633 ± 172	300^{+300}_{-150}	$3.2^{+9.7}_{-2.4}$
OzDES – DR2_03833	1.610	MgII	45.20 ± 0.01	140^{+110}_{-60}	1614 ± 387	280^{+340}_{-160}	3^{+15}_{-3}
SVA1_COADD – 2937733023	1.610	MgII	45.27 ± 0.01	150^{+120}_{-70}	1444 ± 325	240^{+290}_{-140}	6^{+26}_{-5}
OzDES – DR2_03819	1.620	MgII	45.09 ± 0.02	130^{+100}_{-60}	1822 ± 373	330^{+370}_{-180}	$1.7^{+6.7}_{-1.3}$
OzDES – DR2_03836	1.620	MgII	45.51 ± 0.01	180^{+140}_{-80}	1899 ± 154	510^{+480}_{-250}	$3.0^{+8.6}_{-2.2}$
OzDES – DR2_03805	1.630	MgII	45.33 ± 0.01	150^{+120}_{-70}	3018 ± 488	1100^{+1200}_{-600}	$0.3^{+1.2}_{-0.3}$
SVA1_COADD – 2970728579	1.640	MgII	44.44 ± 0.05	76^{+62}_{-35}	2636 ± 285	430^{+420}_{-220}	$0.11^{+0.34}_{-0.08}$
SVA1_COADD – 2939055397	1.650	MgII	44.95 ± 0.02	112^{+93}_{-50}	1874 ± 535	310^{+410}_{-190}	$1.2^{+6.3}_{-1}$
SVA1_COADD – 2971085043	1.650	MgII	44.90 ± 0.01	109^{+90}_{-49}	1963.0 ± 87.5	340^{+320}_{-170}	$0.8^{+2.2}_{-0.6}$
OzDES – DR2_03826	1.680	MgII	45.12 ± 0.03	130^{+100}_{-60}	1272 ± 297	170^{+200}_{-90}	7^{+32}_{-6}
OzDES – DR2_03827	1.680	MgII	44.90 ± 0.02	108^{+89}_{-48}	2087 ± 691	370^{+520}_{-230}	$0.7^{+4.7}_{-0.6}$
SVA1_COADD – 2925756435	1.680	MgII	45.31 ± 0.02	150^{+120}_{-70}	1162 ± 308	160^{+210}_{-100}	15^{+78}_{-12}
SVA1_COADD – 2939644652	1.680	MgII	45.01 ± 0.01	118^{+97}_{-52}	3335 ± 181	1100^{+1000}_{-500}	$0.12^{+0.34}_{-0.09}$
OzDES – DR2_03835	1.690	MgII	45.42 ± 0.01	160^{+130}_{-70}	2122.4 ± 66.7	600^{+550}_{-290}	$1.6^{+4.5}_{-1.2}$
SVA1_COADD – 2925407044	1.690	MgII	45.13 ± 0.03	130^{+110}_{-60}	2574 ± 733	670^{+900}_{-400}	$0.5^{+2.5}_{-0.4}$
SVA1_COADD – 2971108787	1.690	MgII	45.35 ± 0.01	150^{+130}_{-70}	1544.7 ± 58.1	300^{+280}_{-140}	5^{+14}_{-4}
OzDES – DR2_03846	1.700	MgII	45.23 ± 0.02	140^{+110}_{-60}	2728 ± 165	850^{+790}_{-410}	$0.4^{+1.2}_{-0.3}$
OzDES – DR2_04451	1.700	MgII	46.50 ± 0.00	380^{+320}_{-170}	2042.7 ± 97.3	1300^{+1200}_{-600}	14^{+42}_{-11}
SVA1_COADD – 2938001160	1.710	MgII	44.42 ± 0.05	75^{+62}_{-34}	1737 ± 567	170^{+250}_{-110}	$0.6^{+4}_{-0.5}$
OzDES – DR2_03679	1.720	MgII	44.69 ± 0.02	91^{+75}_{-41}	1528 ± 322	170^{+200}_{-90}	$1.6^{+6.4}_{-1.3}$
OzDES – DR2_03799	1.730	MgII	45.17 ± 0.02	140^{+110}_{-60}	3929 ± 229	1700^{+1600}_{-800}	$0.08^{+0.24}_{-0.06}$
OzDES – DR2_03814	1.730	MgII	45.78 ± 0.01	220^{+180}_{-100}	887.7 ± 54.2	140^{+130}_{-70}	100^{+290}_{-70}
SVA1_COADD – 2940670625	1.750	MgII	45.56 ± 0.01	180^{+150}_{-80}	1355 ± 179	270^{+270}_{-140}	13^{+42}_{-9}
OzDES – DR2_03666	1.760	MgII	45.03 ± 0.01	119^{+97}_{-53}	2050 ± 119	410^{+380}_{-200}	$0.9^{+2.5}_{-0.6}$
OzDES – DR2_03825	1.800	MgII	45.62 ± 0.01	190^{+150}_{-90}	1607.2 ± 58.8	400^{+370}_{-190}	7^{+19}_{-5}
OzDES – DR2_03825	1.800	CIV	45.59 ± 0.73	80^{+170}_{-60}	3754 ± 492	400^{+370}_{-190}	7^{+19}_{-5}
OzDES – DR2_03820	1.830	MgII	45.46 ± 0.02	170^{+140}_{-80}	1621 ± 304	350^{+390}_{-190}	5^{+20}_{-4}
OzDES – DR2_03820	1.830	CIV	45.91 ± 0.13	120^{+150}_{-70}	3767 ± 588	350^{+390}_{-190}	5^{+20}_{-4}
OzDES – DR2_03828	1.830	MgII	45.36 ± 0.02	160^{+130}_{-70}	1154 ± 108	170^{+160}_{-80}	17^{+49}_{-12}
OzDES – DR2_03828	1.830	CIV	45.97 ± 0.14	130^{+160}_{-70}	4857 ± 382	170^{+160}_{-80}	17^{+49}_{-12}

SVA1_COADD – 2939076089	1.830	MgII	45.21 ± 0.01	140^{+110}_{-60}	2672 ± 106	810^{+750}_{-390}	$0.4^{+1.2}_{-0.3}$
SVA1_COADD – 2939076089	1.830	CIV	45.61 ± 0.29	90^{+120}_{-50}	3900 ± 797	810^{+750}_{-390}	$0.4^{+1.2}_{-0.3}$
OzDES – DR2_03841	1.850	MgII	45.63 ± 0.01	190^{+160}_{-90}	2219.1 ± 77.1	770^{+710}_{-370}	$2.0^{+5.4}_{-1.5}$
OzDES – DR2_03841	1.850	CIV	45.42 ± 0.83	70^{+170}_{-50}	3040 ± 1050	770^{+710}_{-370}	$2.0^{+5.4}_{-1.5}$
OzDES – DR2_03837	1.860	MgII	45.55 ± 0.02	180^{+140}_{-80}	2197 ± 153	720^{+670}_{-350}	$1.8^{+5}_{-1.3}$
OzDES – DR2_03815	1.870	MgII	45.51 ± 0.01	180^{+140}_{-80}	920 ± 221	120^{+140}_{-70}	60^{+260}_{-50}
OzDES – DR2_03815	1.870	CIV	45.72 ± 0.14	100^{+120}_{-50}	1192 ± 704	120^{+140}_{-70}	60^{+260}_{-50}
SVA1_COADD – 2938397530	1.880	MgII	44.98 ± 0.04	115^{+96}_{-52}	1066.8 ± 87.4	110^{+100}_{-50}	11^{+34}_{-8}
OzDES – DR2_03816	1.890	MgII	45.79 ± 0.01	220^{+180}_{-100}	1148.7 ± 44.7	230^{+220}_{-110}	40^{+110}_{-30}
OzDES – DR2_03816	1.890	CIV	45.41 ± 1.25	70^{+270}_{-50}	1905 ± 839	230^{+220}_{-110}	40^{+110}_{-30}
OzDES – DR2_03519	1.900	MgII	45.26 ± 0.02	140^{+110}_{-60}	2810 ± 543	900^{+1000}_{-500}	$0.4^{+1.5}_{-0.3}$
OzDES – DR2_03519	1.900	CIV	45.68 ± 0.26	90^{+120}_{-50}	4840 ± 1020	900^{+1000}_{-500}	$0.4^{+1.5}_{-0.3}$
SVA1_COADD – 2938502367	1.910	MgII	45.31 ± 0.01	150^{+120}_{-70}	4703 ± 189	2700^{+2500}_{-1300}	$0.06^{+0.15}_{-0.04}$
SVA1_COADD – 2938498296	1.920	CIV	45.53 ± 0.08	79^{+94}_{-42}	3518 ± 155	800^{+1100}_{-500}	$1.0^{+4.6}_{-0.8}$
SVA1_COADD – 2970554739	1.920	MgII	45.21 ± 0.03	140^{+110}_{-60}	4716.3 ± 79.0	2500^{+2300}_{-1200}	$0.04^{+0.12}_{-0.03}$
OzDES – DR2_03806	1.930	CIV	46.46 ± 0.06	220^{+270}_{-120}	1365 ± 467	310^{+600}_{-220}	200^{+1700}_{-100}
OzDES – DR2_03834	1.970	CIV	45.47 ± 0.16	75^{+92}_{-41}	3972 ± 629	900^{+1500}_{-600}	$0.6^{+3.3}_{-0.5}$
SVA1_COADD – 2970476623	1.990	CIV	45.87 ± 0.08	120^{+140}_{-60}	2632 ± 330	640^{+940}_{-390}	5^{+26}_{-4}
DES13X2esw	2.030	CIV	45.10 ± 0.87	50^{+120}_{-40}	3939 ± 418	600^{+1700}_{-500}	$0.4^{+2.6}_{-0.3}$
OzDES – DR2_03823	2.060	CIV	45.67 ± 0.08	90^{+120}_{-50}	3832 ± 427	1100^{+1500}_{-600}	$0.9^{+4.3}_{-0.7}$
OzDES – DR2_03822	2.070	CIV	46.74 ± 0.02	310^{+380}_{-170}	2234 ± 357	1200^{+1800}_{-700}	30^{+160}_{-20}
OzDES – DR2_03515	2.080	CIV	45.51 ± 0.28	80^{+110}_{-40}	3871 ± 525	900^{+1500}_{-600}	$0.6^{+3.6}_{-0.5}$
SVA1_COADD – 2940803438	2.100	CIV	45.97 ± 0.17	130^{+160}_{-70}	2116 ± 991	400^{+1000}_{-300}	20^{+330}_{-10}
OzDES – DR2_03842	2.110	CIV	45.38 ± 0.28	68^{+89}_{-38}	4601 ± 441	1200^{+1700}_{-700}	$0.3^{+1.4}_{-0.2}$
SVA1_COADD – 2940953293	2.200	CIV	45.73 ± 0.11	100^{+120}_{-60}	5183 ± 274	2200^{+3100}_{-1300}	$0.3^{+1.3}_{-0.2}$
OzDES – DR2_03554	2.220	CIV	45.93 ± 0.06	120^{+150}_{-70}	4308 ± 527	1800^{+2700}_{-1100}	$0.7^{+3.8}_{-0.6}$
OzDES – DR2_03520	2.230	CIV	45.89 ± 0.06	120^{+150}_{-60}	2790 ± 704	700^{+1300}_{-500}	4^{+29}_{-4}
OzDES – DR2_03547	2.240	CIV	45.79 ± 0.07	110^{+130}_{-60}	3444 ± 732	1000^{+1600}_{-600}	$1.6^{+9.5}_{-1.3}$
OzDES – DR2_04714	2.250	CIV	46.22 ± 0.04	170^{+210}_{-90}	4410 ± 672	2600^{+3900}_{-1600}	$1.0^{+5.2}_{-0.8}$
SVA1_COADD – 2970350730	2.250	CIV	45.78 ± 0.02	110^{+120}_{-60}	3235 ± 116	900^{+1200}_{-500}	$1.8^{+8.8}_{-1.5}$
OzDES – DR2_03817	2.260	CIV	46.07 ± 0.06	140^{+170}_{-80}	3651 ± 518	1500^{+2300}_{-900}	$1.7^{+9}_{-1.4}$
OzDES – DR2_03512	2.290	CIV	46.61 ± 0.01	260^{+310}_{-140}	3684 ± 183	2800^{+4000}_{-1600}	3^{+15}_{-3}
OzDES – DR2_03514	2.390	CIV	45.88 ± 0.06	120^{+140}_{-60}	3016 ± 341	900^{+1200}_{-500}	3^{+14}_{-2}

SVA1_COADD – 2939090222	2.440	CIV	45.31 ± 0.88	60^{+150}_{-40}	3720 ± 1770	600^{+2300}_{-500}	1^{+19}_{-1}
OzDES – DR2_03528	2.480	CIV	45.76 ± 0.06	100^{+120}_{-60}	4585 ± 276	1700^{+2400}_{-1000}	$0.4^{+2.2}_{-0.4}$

Table 1. : All single epoch mass estimates from OzDES with BLR radii estimated using the $R - L$ relationships as listed in Table 2. These are new sources from DES and OzDES data, not published in prior OzDES RM works. For H β and MgII estimates, luminosities and line widths are estimated using the pipelines of Hoormann et al. (2019), while MgII sources use the pipeline of Yu et al. (2021). Masses and accretion rates are estimated with equations 1 and 4. Listed monochromatic luminosities are measured at 5100Å, 3000Å and 1350Å in the rest-frame for the H β , MgII and CIV sources respectively, and corrected to 5100Å equivalent using bolometric corrections of Runnoe et al. (2012) in accretion rate estimates and the virial factor of Grier et al. (2013a).

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