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## The spectroscopic follow-up of the QUBRICS bright quasar survey

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### ABSTRACT

We present the results of the spectroscopic follow up of the QUBRICS<sup>a)</sup> survey. The selection method is based on a machine learning approach applied to photometric catalogs, covering an area of  $\sim 12,400$  deg<sup>2</sup> in the Southern Hemisphere. The spectroscopic observations started in 2018 and identified 55 new, high-redshift ( $z \geq 2.5$ ), bright ( $i \leq 18$ ) QSOs, with the catalog published in late 2019. Here we report the current status of the survey, bringing the total number of bright QSOs at  $z \geq 2.5$  identified by QUBRICS to 224. The success rate of the QUBRICS selection method, in its most recent training, is estimated to be 68%. The predominant contaminant turns out to be lower- $z$  QSOs at  $z < 2.5$ . This survey provides a unique sample of bright QSOs at high- $z$  available for a number of cosmological investigations. In particular, carrying out the redshift drift measurements (Sandage Test) in the Southern Hemisphere, using the HIRES spectrograph at the 39m ELT, appears to be possible with less than 2500 hours of observations spread over 30 targets in 25 years.

**Keywords:** quasars: general — catalogs — surveys, galaxies: nuclei

### 1. INTRODUCTION

Luminous quasars are the brightest non-transient cosmic beacons in the Universe. The hunt for such bright sources, especially at high redshift, is of paramount importance for a number of extragalactic studies, rang-

ing from the number density of bright quasars at high- $z$  (Schindler et al. 2019a), the theoretical modelling of the early phases of galaxy formation and co-evolution with their central SMBHs (e.g. Valiante et al. 2016; Fontanot et al. 2020), the study and characterisation of their (gas) accretion properties of the super massive black hole (SMBH) population (Wu et al. 2015; Wolf et al. 2018) to the inference on cosmological parameters from time delays of strongly lensed QSOs (Bonvin et al. 2017) and the properties of the dark matter by

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<sup>a)</sup> Acronym for “*QUasars as BRIght beacons for Cosmology in the Southern hemisphere*”, (Calderone et al. 2019).

microlensing statistics in bright quasars (Webster et al. 1991; Bate et al. 2007).

Absorption signatures in the spectra of bright high- $z$  QSOs are one of the most powerful and invaluable tools for studying intergalactic environments, as emerged from the recent Astro2020 Decadal Survey (e.g. Becker et al. 2019). Among the fundamental questions that can be tackled thanks to the study of QSO absorption lines we recall: the measurement of primordial Deuterium abundance (e.g. Cooke & Fumagalli 2018), the temperature evolution of the Cosmic Microwave Background (CMB), the free-streaming of warm dark matter (e.g. Iršič et al. 2017), the variation of the fundamental constants of nature, e.g. the fine structure constant or the proton-to-electron mass ratio (see Leite et al. 2016), the missing baryon problem (e.g. Werk et al. 2014), the production and diffusion of metals in the IGM (e.g. D’Odorico et al. 2016), the Lyman continuum escape fraction of high- $z$  QSOs (e.g. Cristiani et al. 2016; Grazian et al. 2018), the mean free path of ionizing photons (e.g. Prochaska et al. 2009; Worseck et al. 2014; Romano et al. 2019), the reionization epochs of hydrogen and helium, and the sources responsible of these transition phases in cosmic history.

An appealing application of the detailed study of the Lyman forest in Cosmology is the so-called Sandage test (Sandage 1962), which can give fundamental constraints to General Relativity. The detection of the tiny drift due to cosmic expansion in the cosmological redshifts of many absorption lines in the spectra of bright QSOs will allow to measure directly cosmological parameters (e.g.  $\Omega_M$ ,  $\Omega_\Lambda$ ,  $H_0$ ) at  $2 < z < 5$  without the need of any local ladders or intermediate distance indicators. This revolution will be possible only with the brightest QSOs observed by the most powerful and stable high resolution spectrographs which will be available in the future at 20-40m telescopes (Liske et al. 2008).

However, finding the brightest quasars at high- $z$  is not a trivial process. The advent of the SDSS survey (e.g. Fan & SDSS Collaboration 2000) represents a quantum leap in this respect, at least in the Northern hemisphere. At present, the SDSS has delivered more than  $10^6$  spectroscopically confirmed QSOs at  $0 < z < 6.5$ , with a large fraction at absolute magnitudes  $M_{1450} \leq -26$ . Recent studies, however, point out that, at very bright magnitudes, SDSS can suffer from incompleteness due to color selection (see also Fontanot et al. (2007)). For example, Schindler et al. (2019a) find 407 new bright QSOs at  $2.8 < z < 5.0$  in the ELQ survey, showing that the SDSS completeness is  $\sim 60\%$  at bright magnitudes ( $i \leq 18$ ). As a consequence, the hunt for bright quasars, especially at high- $z$  and in the Northern hemi-

sphere, could be biased towards lower numbers due to the adoption of efficient but low completeness selections.

The situation is even more dramatic in the Southern hemisphere, due to the lack of wide multi-wavelength surveys at  $\delta \leq 0^\circ$  in the past. Comparing QSO surface densities, it is statistically evident that high- $z$  objects of bright apparent magnitudes must be present also in the Southern hemisphere: of the 22 known QSOs with  $z > 3$  and  $V < 17$ , only 5 are at  $\delta < 0^\circ$ , and all the 3 QSOs with  $V < 16$  are in the North (Véron-Cetty & Véron 2010).

In Calderone et al. (2019) (hereafter Paper I), we presented the first results of a survey of  $z \geq 2.5$  QSOs at bright  $i$ -band magnitudes ( $i \leq 18.0$ ) in the Southern hemisphere, taking advantage of the recent availability of new multiwavelength public databases. The combination of state-of-the-art databases with innovative techniques for the selection of the best candidates results in an efficient selection, with a success rate in finding high- $z$  QSOs larger than 50% and a completeness in excess of 90%. In the first spectroscopic runs we already identified the intrinsically most luminous QSO at that time, with  $z \geq 3.8$  at  $\delta < 0^\circ$ , QSO J2157-3602, which has been afterwards independently confirmed by Schindler et al. (2019b). In this paper we will present a new  $z > 4$  QSO with apparent magnitude of  $i = 16.886$  (see Section 4) that would be the new record holder in the Southern Hemisphere. In total we present 168 new bright QSOs at  $z \geq 2.5$ , thus quickly completing the identification of the high- $z$  sample of Paper I.

The structure of this paper is the following: in Section 2 we summarize the selection method of our bright QSO candidate sample, in Section 3 and 4 we describe the massive observational campaign carried out at medium size telescopes and the spectroscopic identification of our QSO candidates. The properties of the newly identified high- $z$  QSOs are discussed in Section 5, while Section 6 is devoted to the description of the Golden QSO sample for the Sandage test. Discussions and Conclusions are summarized in Section 7. Unless otherwise stated, apparent magnitudes are in the AB photometric system.

## 2. SELECTION METHOD

In this section we will describe the QUasars as BRiGht beacons for Cosmology in the Southern hemisphere (QUBRICS) survey, first introduced in Paper I. We refer the reader to this work for more details of the method, while here we just recall its main characteristics.

To identify new, high- $z$  QSOs candidates in the remaining sample, a classification algorithm has been applied based on the Canonical Correlation Analysis, (CCA, Anderson 1984). Our candidate list has been

drawn from a multiwavelength catalogue. We used the public databases of: i) Skymapper (DR1.1, Wolf et al. (2018)); ii) Gaia (DR2, Gaia Collaboration et al. (2018)); iii) 2MASS (Skrutskie et al. 2006) and iv) the WISE survey (Wright et al. 2010) to build the initial *main sample* (1014875 sources), covering  $\sim 12400 \text{ deg}^2$ , with *i*-band magnitudes in the range  $14 < m_i \leq 18$ . The sources with secure object-type identification have been used as a training set and the recipe has been applied to the remaining sources in order to predict a likely classification. By using the parallax and proper motion estimates provided by Gaia,  $\sim 83\%$  of the sources were classified as *bona fide* stars. Matching the remaining sources against the following catalogs: SDSS DR14Q (Pâris et al. 2018), Veron-Cetty QSO 13th edition (Véron-Cetty & Véron 2010), and 2dFGRS (Colless et al. 2001), led to reliably identify an object-type classification to 4666 QSOs and 3665 galaxies (in the following, the *original training set*). To discriminate against low- $z$  ( $< 2.5$ ) QSOs, we use the CCA as a regression algorithm to the objects classified as QSOs, in the previous step, to obtain an estimate of their redshift. In Paper I we tested this methodology with a resulting sample of 1476 candidates without spectroscopic confirmation, and our spectroscopic follow-up identified 54 QSOs with  $z \geq 2.5$ .

As the main focus of our work is the identification of the largest possible number of bright high- $z$  QSO in the Southern Hemisphere, we aim at the highest possible success rate of observing runs. Therefore, after each run we update the training set of the algorithm by including the new identifications: this results in an evolving list of QSO candidates. For the statistical purposes of this paper, the list of candidates has been frozen to its current form after the last observing run in Feb. 2020. At this point the list included 1412 sources in total, with 594 secure spectroscopic identifications and 818 candidates yet to be observed. Thanks to the revised training set it has been possible to reduce the number of candidates yet to be observed by  $\sim 25\%$  with respect to the original list of Paper I. Fig. 1 and 2 illustrate the process of classification and redshift estimate, respectively, in the present work. They update the corresponding plots of Paper I.

It should be noted that the selection criteria adopted here and in Paper I could be biased against lensed sources. To reduce the contamination we have adopted relative stringent criteria about the positional coincidence in the various photometric catalogs. While this is not affecting "normal" QSOs, may have the subtle effect of removing lensed sources, forming extended structures like Einstein rings or crosses. Moreover, due to

the choice of the fundamental photometric bands (e.g. GAIA), our selections is probably biased against sources at  $z \gtrsim 4.5$ .

### 3. SPECTROSCOPY

The QUBRICS pilot campaign has been presented in Paper I. Observations have been obtained using various instruments at Las Campanas Observatory (LCO), the TNG telescope, and the ESO-NTT telescope at La Silla. Between August 2019 and February 2020, we have been awarded more nights at these facilities, in order to expand our spectroscopic survey. We discuss here the details of these observations.

#### 3.1. WFCCD at duPont

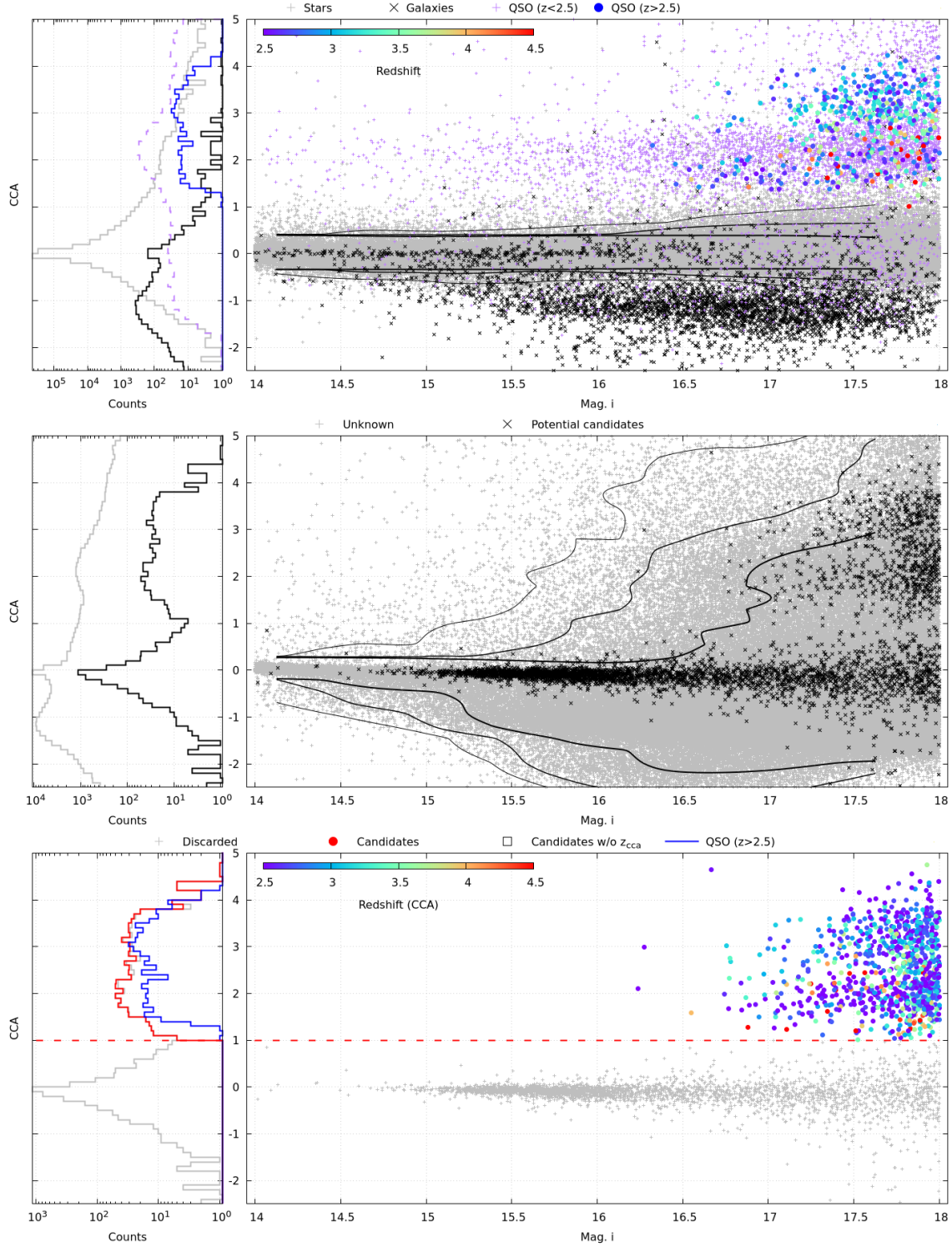
We have been awarded a total of 12 nights with the Wide Field CCD camera at duPont. We used the same configuration as in the pilot study, namely, the blue grism, with the  $1.5''$  long slit, that covers a wavelength range between  $3700 - 8000 \text{ Å}$  giving a  $2 \text{ Å/pixel}$  dispersion. In total we have observed 100 candidates, but only 76 of them have a robust spectroscopic classification (flag=A). Of the securely classified sources, 63 (83%) are QSOs, and 36 of those (57%) are in the desired redshift range ( $z \geq 2.5$ ).

#### 3.2. LDSS-3 at Clay

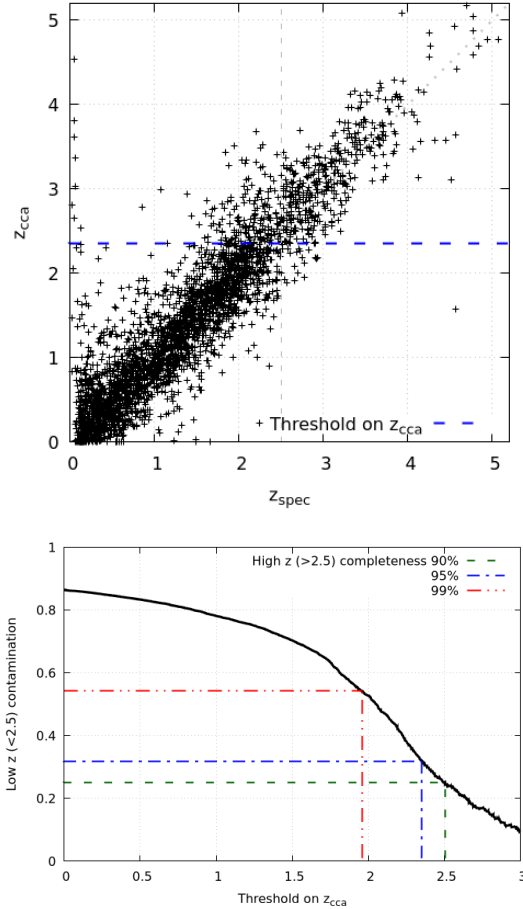
A total of 44 candidates have been observed with LDSS-3 at the Clay telescope. Observations were obtained in several nights during bright time and variable weather conditions. We have used the VPH-all grism with the  $1''$  - central slit and no blocking filter, covering a wavelength range between  $4000 - 10000 \text{ Å}$  with a low resolution of  $R \sim 800$ . Exposure times were ranging between  $800 - 1800 \text{ sec}$ , depending on the candidate magnitude. Out of the observed candidates, 40 have a high quality redshift flag (flag A) and have been securely classified, most of them as QSOs (28 out of 40, 70%) but only 12 (43%) have a redshift above 2.5.

#### 3.3. EFOSC2 at NTT

In September 2019 we were awarded three more nights (PI. A. Grazian, proposal 0103.A-0746) at NTT, to use the EFOSC2 instrument. In order to complete the survey, we obtained 4 additional nights at NTT in January 2020 (PI. A. Grazian, proposal 0104.A-0754). Again, we used grism #13 (wavelength range  $\lambda \sim 3700 - 9300 \text{ Å}$ ), with typical exposure times ranging between 300 and 600 seconds. We observed 217 candidates, obtaining robust identification for 187. Out of these, 161 (86%) were classified as QSOs and 122 have a redshift of  $z \geq 2.5$  (76%). This was one of the most efficient runs in this period.



**Figure 1.** The CCA- $i$  plane for the various subsamples considered in this work. For the statistical meaning of the CCA parameter shown in the y-axis we refer the reader to Paper I. Upper panel: sources in the *main* sample for which a reliable type identification is available. Stars are identified by gray “+” symbols, inactive galaxies by black cross symbols, low- $z$  ( $< 2.5$ ) QSOs with purple “+” symbols, high- $z$  ( $\geq 2.5$ ) QSOs with filled circles. The redshifts for the spectroscopically confirmed QSOs with  $z \geq 2.5$  are shown with the color code shown in the colorbox in the upper left corner. The inset on the left shows the histogram of the CCA coordinate for the stars (gray), galaxies (black), low- $z$  QSOs (purple) and known high- $z$  QSOs (blue). Middle panel: sources in the *main sample* without an object type identification (gray symbols). The same sources after excluding extended and low- $z$  objects are highlighted in black, and represents potential high- $z$  QSO candidates. Lower panel: the *final* sample of high- $z$  QSO candidates, with their redshift  $z_{CCA}$  as in Paper I. The red dashed line represents the cut in the CCA selection. Candidates/observed sources are represented with open and filled circles respectively. The gray histogram represents the potential candidates, while the red and blue ones represent the QSO candidates and the confirmed QSO samples.



**Figure 2.** Upper panel: The  $z_{\text{cca}}-z_{\text{spec}}$  correlation (scatter:  $\sim 0.37$ ). The horizontal blue line is the threshold on  $z_{\text{cca}} = 2.26$ , corresponding to a completeness of 95% and a contamination of 38%. Lower panel: contamination and completeness as a function of the threshold on  $z_{\text{cca}}$ .

The outcome of this new spectroscopic campaign shows that, although our criteria are very efficient at identifying QSOs (84% of robust classifications are QSOs), only 55% are in the targeted redshift range. Anyhow, as discussed in Section 2, by ingesting the new QSOs to the selection algorithm, the efficiency of the selection for future spectroscopy is expected to be as high as 75% in the global sample.

### 3.4. Data Reduction

WFCCD data were reduced using standard IRAF tasks. After subtracting bias and dividing with flat, individual exposures were combined to the final image. We then used the task *apall* to extract the spectra and standard and *sensfunc* to calibrate in flux. The EFOSC2 and LDSS-3 spectra have been reduced with a custom pipeline using MIDAS scripts. The standard pre-reduction (i.e. bias subtraction and flat field nor-

malization) has been adopted, and the wavelength calibration with helium, neon, and argon lamp has been obtained. We also check our wavelength solution on the emission night sky. An rms of  $0.5 \text{ \AA}$  has been obtained from the wavelength calibration process. For WFCCD, EFOSC2 and LDSS-3, we made sure to obtain at least one spectro-photometric standard star per night. Since conditions have not always been photometric, the derived flux calibration is relative. There has been no further attempt to interpolate flux to known broad band magnitudes for absolute flux calibration. Further details can be found in Paper I. Improved data reduction of 3 objects observed in the runs of Paper I allowed us to upgrade their redshift flag to A. They are listed in Tab.4 with an appropriate identification in footnote.

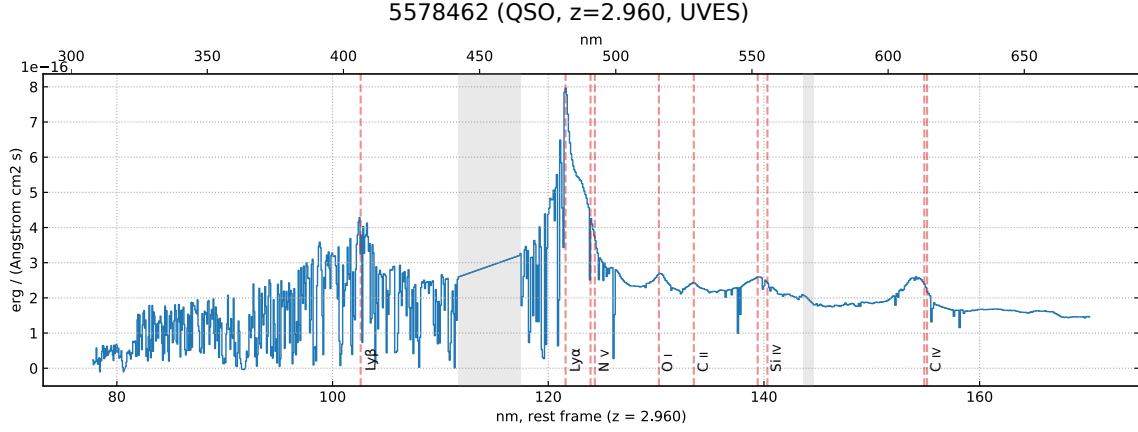
### 3.5. Redshifts from other surveys

We have also searched the databases in the literature for additional reliable spectra of our candidates, finding 24 QSOs (6 with  $z \geq 2.5$ ) and 1 AGN. They are listed in Tab. 1. In particular we found that downloading and analyzing spectra from the 6dF survey (Jones et al. 2009) we could assign a reliable redshift to 22 of our candidates. The candidate with SkyMapper ID 5578462 has spectral data of good quality in the ESO archive (see Fig. 3) that we have reprocessed. For the candidate with ID 10779504 we found a reliable redshift determination in the OzDES survey (Tie et al. 2017).

## 4. RESULTS OF THE SPECTROSCOPY

After 26 observing runs (including those reported in Paper I) we have collected the spectra of 511 sources, and 432 of them have a secure object-type classification. In total we identified 224 new bright QSOs at  $z \geq 2.5$  (of which 15 at  $z > 4$ ), 166 QSOs/AGN at  $z < 2.5$ , 11 inactive galaxies and 31 stars. Among the observed sources, a small fraction has uncertain classification and/or redshift estimate. These sources have been assigned a flagB for a variety of reasons. More precisely 32% have flat spectra without clear emission features that could be either stars or galaxies. Another 68% have a tentative QSOs classification, but it is not possible to robustly estimate the redshift since there is only one emission line or they show broad absorption features that are difficult to interpret. Such sources will be the subject of additional observations in different wavelength ranges aiming to discover additional features that could facilitate classification. An example of such follow-up can be seen in Section 4.3.

The list of the 303 new sources, to be added to those reported in Paper I, and their basic properties are shown in Tab. 4.



**Figure 3.** Composite UVES spectrum of a candidate at  $z=2.960$ , with some AGN emission lines highlighted. The grey bands are gaps in the UVES wavelength coverage, depending on the adopted instrument setup.

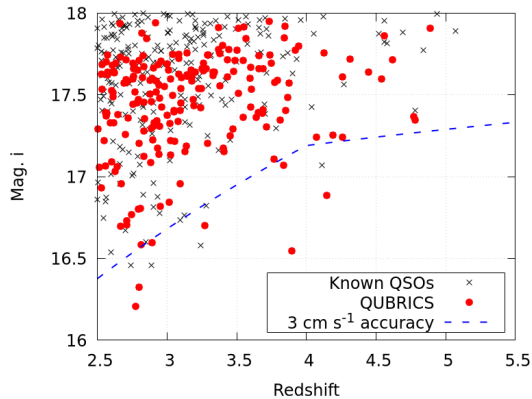
**Table 1.** Additional identifications from the literature.

| Skymapper | R.A. (J2000) | DEC. (J2000) | $m_i$  | $z_{\text{spec}}$ | Class | Survey |
|-----------|--------------|--------------|--------|-------------------|-------|--------|
| ID        |              |              | (mag)  |                   |       |        |
| 8414380   | 00:43:23.42  | -00:15:52.5  | 17.781 | 1.442             | QSO   | 6dF    |
| 8133493   | 00:44:48.56  | -13:39:13.0  | 17.664 | 2.253             | QSO   | 6dF    |
| 7885395   | 00:58:20.54  | -19:04:03.2  | 17.983 | 1.861             | QSO   | 6dF    |
| 9164524   | 02:03:03.20  | -07:06:04.7  | 17.839 | 1.458             | QSO   | 6dF    |
| 8826213   | 02:08:41.52  | -19:44:03.7  | 17.943 | 2.137             | QSO   | 6dF    |
| 8970643   | 02:29:45.41  | -18:17:11.5  | 17.246 | 1.817             | QSO   | 6dF    |
| 315606464 | 03:06:13.56  | -57:51:05.3  | 17.925 | 2.066             | QSO   | 6dF    |
| 318330107 | 03:14:59.84  | -45:45:28.6  | 17.967 | 2.198             | QSO   | 6dF    |
| 10372687  | 03:26:13.41  | -31:00:52.2  | 17.869 | 2.105             | QSO   | 6dF    |
| 10779504  | 03:39:53.34  | -27:00:53.4  | 17.988 | 2.410             | QSO   | DES    |
| 10460382  | 03:40:42.83  | -34:00:44.3  | 17.800 | 1.944             | QSO   | 6dF    |
| 10812487  | 03:47:14.85  | -24:38:08.7  | 17.427 | 3.130             | QSO   | 6dF    |
| 11616376  | 04:22:43.67  | -29:25:29.9  | 17.767 | 2.529             | QSO   | 6dF    |
| 12053071  | 05:05:55.83  | -29:30:38.5  | 17.865 | 1.070             | QSO   | 6dF    |
| 56866269  | 10:18:21.75  | -21:40:07.8  | 17.547 | 2.441             | QSO   | 6dF    |
| 57772960  | 11:18:10.70  | -17:51:59.3  | 15.119 | 0.215             | AGN   | 6dF    |
| 63944442  | 12:12:18.99  | -25:47:26.1  | 17.620 | 2.532             | QSO   | 6dF    |
| 65530384  | 12:28:48.22  | -01:04:14.7  | 17.039 | 2.642             | QSO   | 6dF    |
| 64459508  | 12:31:32.96  | -14:36:30.9  | 16.888 | 2.418             | QSO   | 6dF    |
| 65808873  | 13:25:09.61  | -08:04:48.2  | 17.786 | 2.359             | QSO   | 6dF    |
| 308760834 | 22:21:10.25  | -44:31:57.3  | 17.501 | 2.071             | QSO   | 6dF    |
| 1459087   | 23:06:37.40  | -36:49:26.0  | 17.962 | 2.650             | QSO   | 6dF    |
| 308911502 | 23:21:22.33  | -50:28:17.5  | 17.701 | 2.297             | QSO   | 6dF    |
| 5578462   | 23:21:28.67  | -10:51:22.3  | 17.769 | 2.958             | QSO   | ESO    |

The success rate, defined as the fraction of high- $z$  QSOs among all the sources with a secure classification, as selected by our algorithm (§2), is relatively high (412 / 726 = 57%) for the old Paper I list and 405 / 594  $\sim$  68% for the present work. The main contaminant (in the case of the present work the only one) is represented by low- $z$  ( $z < 2.5$ ) QSOs/AGNs. If we consider only the 1412 selected sources as described in Sect. 2, 266 have

been observed and 199 turned out to be  $z \geq 2.5$  QSOs, corresponding to a success rate of 75%.

In the present work, the success rate could be biased towards higher values, due to the self-learning approach described in Section 2. If we consider the effective success rate, i.e. the global ratio of high- $z$  QSOs identifications carried out by us over all spectroscopic observa-



**Figure 4.** The redshift- $i$  magnitude plane of the QSOs in the area of the present survey. Black crosses: QSOs known before the present observations; Red filled circles: new spectroscopic redshifts obtained in QUBRICS. The dashed blue line shows, in the context of the Sandage Test, the locus of an accuracy of 3 cm/s in radial velocity, reachable allocating 2500 h of observations at the ELT to a single QSO (see Sect. 6 for details).

tions done so far, including empirical attempts on improbable candidates, we still obtain a remarkable 52%.

All machine learning algorithms are biased by the features of the initial input sample. In this survey, the initial training set has been created based on all known spectroscopically confirmed QSOs from the literature, selected with a wide range of methods. Thus, bias towards specific types of sources should be minimal. However, in order to better assess the properties of our (evolving) selections and achieve a better training, we have carried out observations also of some objects not complying with our initial specifications, for example with no GAIA counterpart within the established radius or not point-like according to our criteria or fainter than 18mag in the  $i$  band ( $i > 18$ ), thus not included in the Main Sample. These objects are also listed in Tab. 4 which contains two columns to show whether the object is a candidate according to the criteria of Paper I or/and selected according to the present work. Sources not included in the Main Sample are indicated with asterisks.

The total number of QSOs with  $z \geq 2.5$  (and  $i \leq 18$ ) in the QUBRICS *main sample* is 428, with 202 discovered by our survey and 226 sources derived from the literature. The machine learning algorithm applied in Paper I was able to identify 412 of the 428  $z \geq 2.5$  known QSOs (96%). Following the self-learning approach, i.e. by re-ingesting all new identifications in the training set, this completeness indicator becomes  $405/428 = 95\%$ .

#### 4.1. QSOs at $z \geq 2.5$

Tab. 4 lists 168 new bright QSOs with spectroscopic redshift  $z \geq 2.5$ , and considering the sources already published in Paper I, the total number of new bright QSOs discovered by our survey amounts to 224.

Fig. 4 shows the updated redshift-magnitude diagram for  $z \geq 2.5$  quasars in the area of the QUBRICS survey. Red points indicate sources published in Paper I or here. Out of the 10 new QSOs at  $z \geq 4.0$  the brightest is 316292063 with a  $z=4.147$  and  $m_i=16.88$ , shown in Fig. 5. As seen in the figure, this QSO has rather narrow lines and this could perhaps indicate a type2 QSO or a lensed source. Additional observations have already been requested and its spectrum will be discussed in detail once our follow-up is completed. Our list includes 5 sources that were already published by Wolf et al. (2020) and were independently selected and classified by our survey.

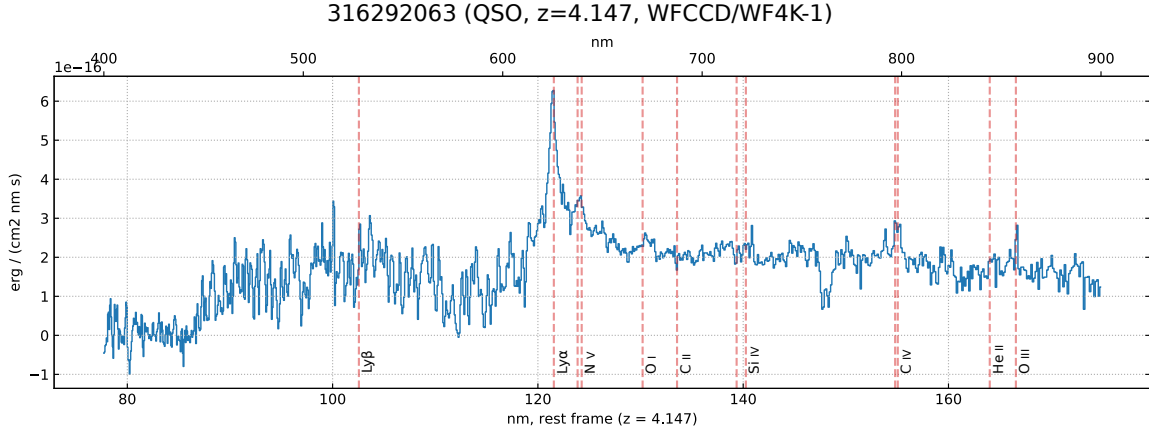
#### 4.2. QSOs at $z < 2.5$

Out of the 121 sources with flag A that are not high- $z$  QSOs, there are 25 with redshift  $z \leq 0.5$  and 78 QSOs at  $0.5 < z < 2.5$ . Thus 85% of the sources (103 out of 121) are active galaxies, but not in our desired redshift range. These relatively bright objects may still turn out to be useful for studies of the evolution of the metal content of the IGM, and of the Lyman forest at low redshift with space observations.

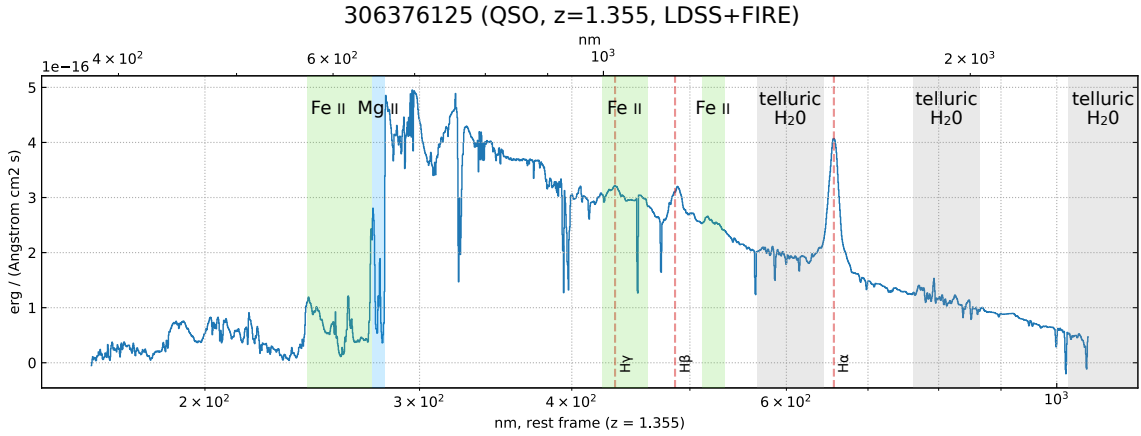
#### 4.3. Notes on BAL QSOs

Both in the pilot and the main campaign, we have encountered sources with pronounced absorption troughs whose classifications, due to the lack of strong emission lines, is not straightforward. A fraction of these sources can in fact be classified as Overlapping Iron Low-ionisation BAL QSOs or OFeLoBAL (Hazard et al. 1987). OFeLoBALs are characterized by extensive systems of low ionization absorption which sometimes appear as broad saturated troughs (e.g. Hall et al. 2002). The troughs may overlap to nearly completely absorb the continuum emission shortward of 2800 Å, effectively mimicking the appearance of the Lyman forest. The estimated fraction of OFeLoBAL QSOs is around 2% (Dai et al. 2012) and their number in our catalogue can be as high as the number of genuine  $z > 4$  QSOs.

The nature of these sources can be confirmed by identifying the Balmer series in the AGN emission, and in particular the H $\alpha$  emission line at 6563 Å rest-frame. For  $z \gtrsim 0.5$  this line is observed in the NIR band. We thus obtained NIR spectroscopic data for some of these sources, using the Folded-port InfraRed EchelleTe (FIRE), at the Baade Magellan telescope, with a long-slit configuration.



**Figure 5.** Spectrum, resampled at 250 km/s, of the brightest  $z \sim 4$  QSO in the sample, with some AGN emission lines



**Figure 6.** Spectrum, resampled at 250 km/s, of a candidate identified as an OFeLoBAL QSO, with some spectral features highlighted. AGN emission lines and metal bands are shown in color, while telluric bands (which have been corrected for in data reduction) are shown in grey.

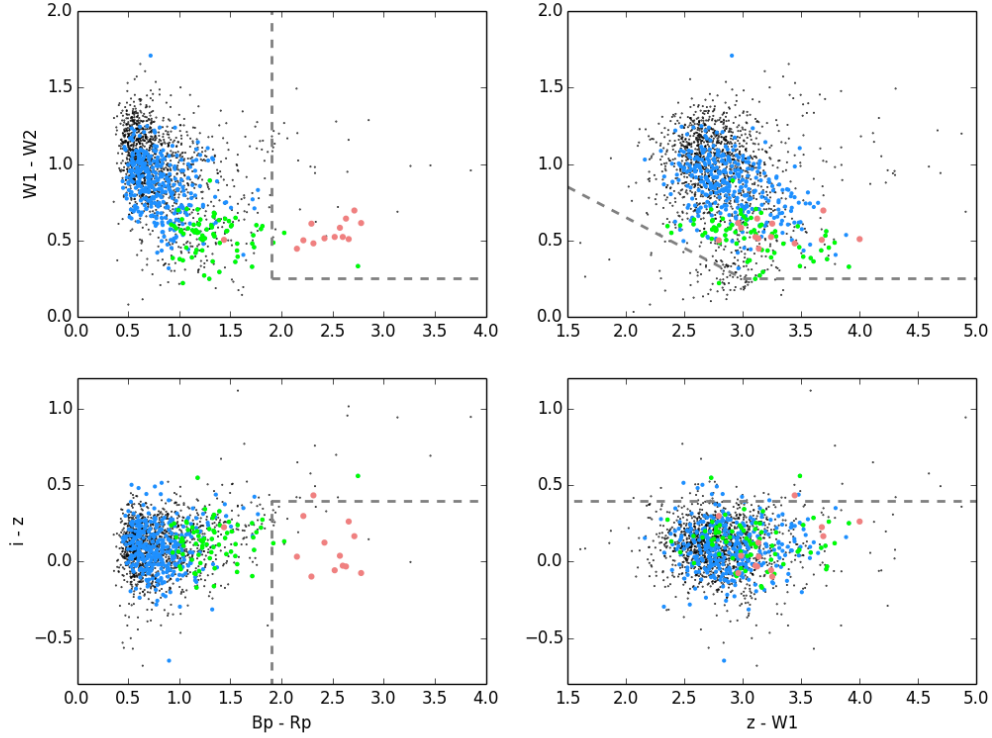
A composite LDSS-3/FIRE spectrum of one such source (Skymapper ID 306376125), flux-calibrated in the visual band using an additional low-resolution spectrum taken by the Magellan Echellette Spectrograph (MagE) at Baade, is shown in figure 6. For this particular object, the  $H\alpha$  and  $H\beta$  line are clearly identified at  $z = 1.355 \pm 0.001$ , with the possible additional detection of  $H\gamma$  blended within a Fe II emission complex. An overlapping Fe II-Mg II absorption complex at the same redshift is also clearly observed around 2600-2800 Å rest-frame, corroborating the identification of the candidate as a OFeLoBAL QSO. A detailed analysis of this object and of other similar sources (currently assigned a flagB classification and not included in Tab.4), is beyond the scope of this work, and will be discussed in a future publication.

## 5. PROPERTIES OF CONFIRMED QSOS

### 5.1. IR colors

Several recent surveys targeting super bright high-redshift QSOS are using WISE colors for the selection (Wolf et al. 2018; Schindler et al. 2019b; Wang et al. 2016). Based on a study by Wu et al. (2012), WISE colors are very good at distinguishing QSOS from late-type stars and more than half of SDSS QSOS have  $W1 - W2 > 0.57$ . Wang et al. (2016) showed that high redshift QSOS,  $z > 4.5$ , are within the  $0 < (W1 - W2) < 1.5$  color range. This has also been confirmed by the survey conducted by Wolf et al. (2018). In Fig.7 we show the distribution of our confirmed QSO candidates in the color space used by Wolf et al. (2018). In that work they were only interested in  $z > 4.5$  QSOS, but in our sample we have a wide range of redshifts going from  $2.5 \leq z < 5.0$ . In order to be able to directly compare our distributions with the aforementioned works in the literature, presented WISE colors are in Vega magnitudes.

As can be seen in our plots, while all our candidates are indeed within the  $W1 - W2[0,2]$  range, based only on



**Figure 7.** Color-color diagrams of all candidates with known redshift. Blue symbols are sources with  $z \geq 2.5$ , green with  $z \geq 3.5$  and red with  $z \geq 4.5$ . The lines correspond to cuts similar to the ones applied by Wolf et al. (2020) to select high redshift bright QSOs ( $z \geq 4.5$ ). The area delimited by the cuts is where the majority of  $z \geq 4.5$  sources are found. WISE magnitudes are in Vega and the rest are in the AB system.

IR colors it is difficult to distinguish between the various redshifts, since all sources are mixed in a small area. Instead, when we include the GAIA ( $B_p - R_p$ ) color, the redshift groups are better separated as seen in the two panels on the left of the figure. Most of our  $z \geq 4.5$  confirmed QSOs have a color of  $B_p - R_p > 1.9$ , in line with the Wolf et al. (2018) selection. In addition, all  $z \geq 2.5$  QSOs have a color  $B_p - R_p > 0.5$ , with the  $z \geq 3.5$  source predominantly being in the area above  $B_p - R_p = 1.0$ . Thus, including bluer colors in the selection, can help to better target higher redshift sources.

### 5.2. Crossmatch to *Galex*

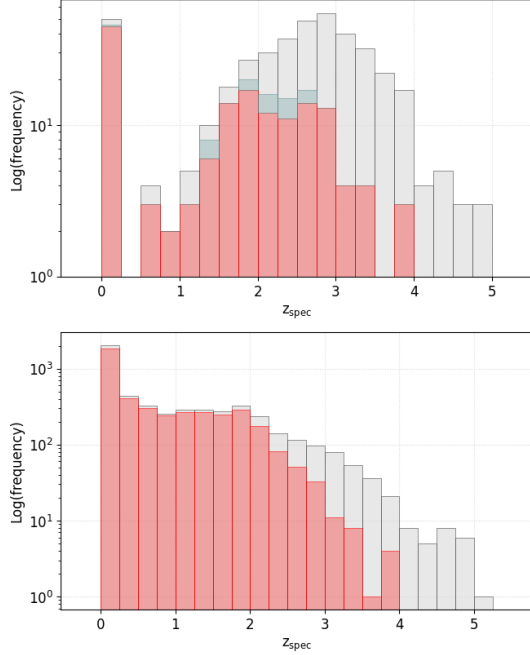
We have cross-matched the QSOs found in QUBRICS with the catalogs of the sources detected by GALEX<sup>1</sup> (Bianchi et al. 2017). Of the 414 QSOs/AGN confirmed in Paper I and II (including those from table 1) we have 161 detections with a confidence level  $> 2\sigma$  in the NUV and 83 detections in the FUV; 75 objects are detected

both in the FUV and NUV. If we consider only QSOs with  $z \geq 2.5$  ( $z \geq 3.5$ ) out of 230 (54) objects 38 (3) have been detected in the NUV, 17 (2) in the FUV and 13 (1) both in the FUV and NUV.

In the designing phase of the QUBRICS we decided against using GALEX data for the selection of the candidates in order to avoid undesired selection effects relative to the fluctuations in the galactic absorption, which are stronger at UV wavelengths. In fact, we plan to use the QUBRICS sample to study the HeII reionization and the cosmic UV background. In order to fulfill this goal, we need an unbiased sampling of all the possible lines-of-sight in our QSO catalogue and a UV selection may select preferentially less absorbed ones (e.g. Prochaska et al. (2009)), which might bias future results towards shorter mean free paths in the IGM (Romano et al. 2019).

Indeed, one of the QSOs confirmed in Paper I, J045011.37-432429.7, with  $z = 3.95$ , shows a detection in the FUV and a non-detection in the NUV. FUV-loud QSOs are extremely rare at  $z > 3.5$  and precious to study the He II reionization (Worseck et al. 2019).

<sup>1</sup> All the GALEX data used in this section can be found in MAST: <https://doi:10.17909/T9H59D>.



**Figure 8.** Upper panel: redshift distribution of the 414 confirmed QSOs/AGN (grey columns): 169 of those have a corresponding GALEX source in FUV, NUV or both. 152 of them (red columns) were observed by us, while the remaining 17 sources (light blue columns) were found in the literature (§3.5). Lower panel: redshift distribution of QSOs/AGN in the QUBRICS *main sample*. Grey columns show the distribution for all the objects, red columns for those with a GALEX counterpart.

J045011.37-432429.7 is potentially a case of transmission peaks that might indicate an example of patchy reionization of He II at  $z \gtrsim 3.5$ .

As shown in Fig. 8, all of QSOs/AGN with a GALEX counterpart have  $z < 4$ , J045011.37-432429.7 being the object with the highest recorded redshift. Moreover, considering the confirmed QSOs/AGN in paper I and II, 82% of objects below  $z = 2$  have a GALEX counterpart. This number decreases drastically when considering higher redshift intervals: for  $2 < z < 3$  ( $3 < z < 4$ ) 35% (11%) of QSOs have a corresponding GALEX source. Similar results are obtained using all the QSOs/AGN known in the QUBRICS *main sample*, the biggest difference being for  $2 < z < 3$  where a higher percentage (58%) of sources have a GALEX counterpart. In principle, the GALEX detection can be used as a veto criterium to increase the efficiency in the selection of bright QSOs at  $z > 4$ .

## 6. A GOLDEN SAMPLE FOR THE SANDAGE TEST

The redshifts of all cosmologically distant sources are expected to experience a small, systematic drift as a

function of time due to the evolution of the expansion rate of the Universe (Sandage 1962). Liske et al. (2008), using extensive Monte Carlo simulations, determined the accuracy with which the redshift drift can be measured from the Lyman forest (and metal lines),  $\sigma_v$ , as a function of signal-to-noise ratio and redshift:

$$\sigma_v = g \times 1.35 \left( \frac{S/N}{3350} \right)^{-1} \left( \frac{1 + z_{\text{QSO}}}{5} \right)^{-\gamma} \left( \frac{N_{\text{QSO}}}{30} \right)^{-0.5} \text{ cm/s} \quad (1)$$

where the symbol ‘S/N’ refers to the total S/N per 0.0125 Å pixel per object accumulated over all observations,  $N_{\text{QSO}}$  is the number of QSOs in the sample,  $z_{\text{QSO}}$  is the redshift of the QSO, the  $\gamma$  exponent is 1.7 for  $z_{\text{QSO}} \leq 4$  and 0.9 above. The form factor  $g$  is equal to 1 if all the targets are observed twice, at the beginning and at the end of the experiment, and becomes larger if the measurements are distributed in time, reaching 1.7 for a uniform distribution. The S/N per pixel for photon-noise limited observations can be written as:

$$S/N = 650 \left[ \frac{Z_X}{Z_r} 10^{0.4(16-m_X)} \left( \frac{D}{39\text{m}} \right)^2 \frac{t_{\text{int}}}{10\text{h}} \frac{\epsilon}{0.25} \right]^{\frac{1}{2}} \quad (2)$$

where  $D$ ,  $t_{\text{int}}$  and  $\epsilon$  are the telescope diameter, total integration time and total efficiency,  $Z_X$  and  $m_X$  are the zeropoint and apparent magnitude of the source in the  $X$ -band, respectively, and  $Z_r = (8.88 \times 10^{10}) \text{ s}^{-1} \text{ m}^{-2} \mu\text{m}^{-1}$  is the AB zeropoint for an effective wavelength of 6170 Å [corresponding to the Sloan Digital Sky Survey (SDSS)  $r$ -band]. The normalisation of the above equation assumes a pixel size of 0.0125 Å and a central obscuration of the telescope’s primary collecting area of 10 per cent.

Liske et al. (2008) concluded that an ELT-type telescope (at the time planned with a 42m primary mirror) would be capable of unambiguously detecting the redshift drift over a period of  $\sim 20$  yr using 4000 h of observing time. The estimated amount of time would obviously increase assuming the 39m primary mirror of the ELT and considering only the QSOs observable with the ELT, typically those in the Southern hemisphere. We have repeated the estimate of the time requested to carry out the Sandage Test with the 39m ELT, adopting a strategy that maximizes the significance of the detection of a non zero redshift drift (Liske et al. 2008) (i.e. with QSOs in the redshift range  $2.8 \leq z < 5$ ), aiming at a  $3\sigma$  detection and observing 30 targets twice at 25 years distance. Other assumptions are the same as in Liske et al. (2008) except for the spectral slope of the QSO continuum, updated to be  $f_\lambda \propto \lambda^{-1.3}$  (Cristiani et al.

**Table 2.** The golden sample of Southern QSOs for the Sandage Test

| Name                | R.A. (J2000) | DEC. (J2000) | $m_r$  | $m_i$  | $G_{\text{GAIA}}$ | redshift | t(22.5 cm/s) | ID        |
|---------------------|--------------|--------------|--------|--------|-------------------|----------|--------------|-----------|
|                     | (deg)        | (deg)        | (mag)  | (mag)  | (mag)             |          | (h)          | Skymapper |
| J000322.94-260317.9 | 000.845639   | -26.055083   | 17.472 | 17.071 | 17.6019           | 4.111    | 61.2         | 7437380   |
| J000736.55-570151.8 | 001.902387   | -57.031067   | 17.992 | 17.240 | 17.9440           | 4.260    | 70.5         | 317358346 |
| J004131.41-493611.7 | 010.381000   | -49.603247   | 16.736 | 16.580 | 16.7048           | 3.240    | 68.5         | 317850840 |
| J010318.05-130509.9 | 015.825313   | -13.086163   | 17.637 | 17.242 | 17.7349           | 4.072    | 71.9         | 8430815   |
| J015558.26-192848.8 | 028.992816   | -19.480298   | 17.673 | 17.393 | 17.7969           | 3.655    | 96.7         | 8789744   |
| J015644.67-692216.1 | 029.186291   | -69.371155   | 16.637 | 16.325 | 16.5949           | 2.800    | 78.7         | 314938059 |
| J020413.26-325122.8 | 031.055213   | -32.856350   | 17.276 | 17.068 | 17.3900           | 3.835    | 66.2         | 6932623   |
| J030722.89-494548.2 | 046.845395   | -49.763410   | *      | 17.407 | 18.4534           | 4.728    | 78.8         | 318204033 |
| J033015.31-543021.1 | 052.563812   | -54.505886   | 17.203 | 17.174 | 17.2208           | 3.400    | 97.4         | 316834279 |
| J042214.78-384452.9 | 065.561596   | -38.748007   | 16.896 | 16.765 | 16.9504           | 3.123    | 84.2         | 10914737  |
| J054803.19-484813.1 | 087.013348   | -48.803654   | 17.215 | 16.886 | 17.2414           | 4.147    | 51.4         | 316292063 |
| J093542.69-065118.8 | 143.927899   | -06.855260   | 18.008 | 17.424 | 18.1236           | 4.040    | 85.3         | 56483517  |
| J094253.51-110425.9 | 145.722949   | -11.073870   | 16.915 | 16.733 | 16.8174           | 3.093    | 87.0         | 56438607  |
| J101529.36-121314.3 | 153.872359   | -12.220648   | 17.857 | 17.255 | 17.7070           | 4.190    | 72.0         | 57929040  |
| J104856.82-163709.2 | 162.236717   | -16.619244   | 17.194 | 17.164 | 17.2249           | 3.370    | 98.0         | 57339247  |
| J105122.70-065047.8 | 162.844537   | -06.846624   | 17.584 | 17.345 | 17.8003           | 3.765    | 88.1         | 58181076  |
| J105449.68-171107.3 | 163.706991   | -17.185386   | 17.104 | 17.107 | 17.2681           | 3.765    | 70.8         | 57368436  |
| J111054.67-301129.8 | 167.727860   | -30.191652   | *      | 17.346 | 18.5117           | 4.780    | 74.2         | 54680559  |
| J132029.98-052335.1 | 200.124872   | -05.393160   | 17.559 | 17.444 | 17.8589           | 3.700    | 99.4         | 65911949  |
| J144943.17-122717.5 | 222.429861   | -12.454868   | 16.953 | 16.703 | 17.0963           | 3.273    | 82.3         | 66962683  |
| J150527.83-204534.9 | 226.365934   | -20.759752   | 16.966 | 16.955 | 16.9888           | 3.090    | 91.3         | 72002629  |
| J162116.92-004250.8 | 245.320512   | -00.714142   | 17.457 | 17.386 | 17.6713           | 3.703    | 94.1         | 114286192 |
| J195302.67-381548.3 | 298.261202   | -38.263482   | 17.724 | 17.305 | 17.8896           | 3.712    | 87.0         | 135100950 |
| J200324.11-325145.0 | 300.850485   | -32.862537   | 17.470 | 17.296 | 17.6287           | 3.783    | 83.6         | 135386798 |
| J201741.49-281630.0 | 304.422893   | -28.274988   | 17.822 | 17.388 | 17.7996           | 3.685    | 95.0         | 136198132 |
| J212518.38-420547.6 | 321.326583   | -42.096609   | 17.266 | 17.363 | 17.6598           | 3.549    | 98.8         | 307443251 |
| J212540.96-171951.3 | 321.420690   | -17.330947   | 16.644 | 16.548 | 16.8730           | 3.897    | 39.9         | 2379862   |
| J212912.18-153840.9 | 322.300733   | -15.644734   | 17.035 | 16.824 | 17.0243           | 3.280    | 88.4         | 2552049   |
| J215228.21-444603.9 | 328.117538   | -44.767760   | 17.310 | 17.291 | 17.3645           | 3.473    | 94.8         | 307536968 |
| J215728.21-360215.1 | 329.367623   | -36.037557   | *      | 17.367 | 18.2864           | 4.771    | 75.7         | 397340    |

2016). For simplicity we have required that the spectra of all the objects are integrated for a sufficiently long exposure time (different for each target, depending on its magnitude and redshift) to reach the same velocity accuracy (22.8 cm/s) required for a global  $3\sigma$  detection of the drift.

We collect in Tab. 2 our proposed sample of 30 Southern QSOs, most suitable for the Sandage Test. Thanks to the detection of new bright QSOs at high redshift, the total time required to carry out the Sandage Test turns out to be less than 2500 h and each QSO in Tab. 2 needs less than 100h of integration to provide a velocity accuracy of 22.8 cm/s.

## 7. DISCUSSION AND CONCLUSIONS

In this paper, we present spectroscopic identifications of QSO candidates in the QUBRICS sample, using our most updated selection criteria based on the CCA approach, which has been described in Paper I. At present, after 26 observing runs at intermediate and large telescopes (duPont, Magellan, NTT, TNG), we have been

able to approximately double the number of bright QSOs ( $i \leq 18.0$ ) at  $z \geq 2.5$  known in the Southern Hemisphere, bringing it to 428. In this way it has been possible to relieve the persistent lack of bright targets for high resolution spectrographs of Southern observatories.

Using the new spectroscopic sample of bright QSOs from QUBRICS, we are able to further refine our selection criteria, by means of a new CCA training set. The completeness of the selection criterion, evaluated against the presently known bright QSOs at  $z \geq 2.5$ , turns out to be higher than 90%, while the success rate is around 70%. The success of the QUBRICS survey is particularly evident looking at Fig. 4, where among the new identifications we show the two brightest QSOs at  $z \geq 3.8$  in the Southern hemisphere, with an increase of a factor of  $\sim 3$  of the number of QSOs at  $z \geq 3$  and  $i \leq 17.5$ .

The QUBRICS survey also selects rare and peculiar sources, with strong absorption features, e.g. the OFeLoBAL QSO discussed in section 4.3. With the progress of our survey it will be important to quantify

the number densities of these peculiar sources and to compare them with the relative low incidence in the past surveys.

Due to the characteristics of our selection, QUBRICS is expected to be incomplete for QSOs at  $z \gtrsim 4.5$  or with images distorted by lensing. In the future, we will address these issues and try to reduce the biases with improved, less stringent selection criteria.

Surveys similar to QUBRICS have been started recently, based mainly on IR selections of bright high- $z$  QSOs (e.g. Wolf et al. 2020; Schindler et al. 2019b). IR colors from 2MASS and WISE are fundamental to distinguish high- $z$  QSOs from local galaxies or stars, but, taken alone, they are not optimal for a photometric redshift refinement. As discussed in Section 5, the optical colors  $Bp - Rp$  or  $i - z$  are very useful to separate QSOs at  $z \sim 2$  from the ones at  $z \sim 4$ .

Besides, adopting further filters, in particular at short wavelengths (e.g. GALEX), it would be possible to further improve the success rate of the survey at high  $z$ . However, due to the possibility of introducing a bias against clear lines of sight in the intervening IGM, which can mimic the photometry of a lower redshift source (Romano et al. 2019), we chose not to use the GALEX photometry for the selection. In this way, among the newly discovered QSOs at  $z > 2.5$ , we have 29 objects with FUV or NUV detections, potentially important for follow up studies with COS for the HeII reionization (e.g. Worseck et al. 2016, 2019).

The adopted CCA method to compute a photometric redshift, described in Paper I, is based on SEDs extending from the  $u$  band to the WISE bands, and should be less affected by possible biases due to the presence of significant Lyman limit absorbers with short mean free paths, which are evident at  $z \sim 3.5$  on QSO surveys based on  $u - g$  color selections, as shown by Prochaska et al. (2009); Cristiani et al. (2016); Romano et al. (2019). In the future, we will address the effects of optical color selections on the QSO spectral properties and Lyman limit statistics.

The discovery of bright cosmic beacons is especially important for the study of the IGM at high- $z$ . In particular, the QUBRICS survey provides a large sample of bright high- $z$  QSOs for the Sandage Test with future 40 meter class telescopes. We estimate that at present, less than 2500 hours of observations in 25 years are needed with the ELT-HIRES to carry out the redshift drift measurement (Liske et al. 2008) at the precision required to have a  $3\sigma$  detection of the cosmological signal. Before QUBRICS, the targets available in the Southern Hemisphere would have required, in the same metrics, about 4000 hours to accomplish this goal. QUBRICS, in a

sense, contributes to a multi-million saving, considering the projected cost of a night at ELT ( $\gtrsim 50$  MEU or  $\gtrsim 60$  M\$ at the assumed cost of 320 KEU for an ELT observing night and an average of 9 hours per night).

We are continuing the pursuit for the brightest cosmic beacons, exploring other innovative methods, with the main goal of giving a realistic possibility to execute the Sandage test, only dreamed of a few years ago.

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This publication makes use of data products from the Wide-field Infrared Survey Explorer, which is a joint project of the University of California, Los Angeles, and the Jet Propulsion Laboratory/California Institute of Technology, funded by the National Aeronautics and Space Administration.

This paper includes data gathered with the 6.5 meter Magellan Telescopes located at Las Campanas Observatory, Chile.

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*Facilities:* Skymapper, Wise, 2MASS, Gaia, NTT (EFOSC2), Magellan:Baade (IMACS), Magellan:Clay (LDSS-3), Magellan:Baade (FIRE), du Pont (WFCCD), TNG (Dolores)

## APPENDIX

### A. CCA MATRIXES

Our QSO candidate selection procedure relies on a CCA transformation aimed at predicting an object type classification for each source, based on the photometric magnitudes in the bands where these estimates are available. In particular we associate a discrete numeric label to all sources with known object type classification, and search for the transformation matrix to be applied to the available magnitudes which maximizes the correlation with the above mentioned label. Note that the above process identifies the best possible linear transformation while the best performances would likely be obtained with a non-linear one, although the latter can not be obtained analytically. In order to improve our classification algorithm we also included the logarithm of each magnitude estimate in the CCA analysis. It should be noted that the availability of magnitude estimates is not the same for all the sources in our main sample, hence we identified 34 sub-samples with homogeneous availability and repeated the above process for each of them, resulting in 34 different CCA matrices. The largest sub-sample covers 43% of our main sample (438687 sources, with 58581 sources lacking a known object type classification). In Tab. 3 we report the transformation matrix used to calculate the CCA coordinate (i.e., the value displayed on the vertical axis of Fig. 1 in both Paper I and Paper II), for the above mentioned sub-sample.

All magnitudes should be converted to the AB system before applying the transformation, and an offset (last line of Tab. 3) should be added to the resulting label to obtain a classification on the same scale of the training. We can provide the matrices for the remaining sources on request.<sup>2</sup> Further details are available in Paper I.

Note that the presence of strong correlations among the magnitudes in different bands prevents us from drawing any conclusion by just comparing the numbers in the above matrices. The overall performance of each matrix, in terms of success rates and completeness, should thus be estimated by comparing the results with the test dataset, as discussed in §2.

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- <sup>2</sup> Please write to [giorgio.calderone@inaf.it](mailto:giorgio.calderone@inaf.it).

**Table 3.** CCA transformation matrix for the magnitude band combination in the largest sub-sample (covering 43% of the main sample).

| Band              | Paper I | This work |
|-------------------|---------|-----------|
| G (Gaia)          | -9.652  | -10.02    |
| BP (Gaia)         | -4.571  | -3.680    |
| RP (Gaia)         | +10.21  | +9.332    |
| g (Skymapper)     | +2.297  | +2.091    |
| r (Skymapper)     | +4.637  | +4.006    |
| i (Skymapper)     | -2.129  | -1.386    |
| z (Skymapper)     | +3.089  | +3.407    |
| J (2MASS)         | -0.8026 | -0.7531   |
| H (2MASS)         | +3.733  | +3.984    |
| K (2MASS)         | +0.458  | +0.5796   |
| W1 (WISE)         | -8.250  | -7.629    |
| W2 (WISE)         | +0.263  | -0.7174   |
| W3 (WISE)         | +2.348  | +2.326    |
| log G (Gaia)      | +142.9  | +149.4    |
| log BP (Gaia)     | +72.69  | +57.33    |
| log RP (Gaia)     | -138.6  | -125.4    |
| log g (Skymapper) | -40.05  | -36.85    |
| log r (Skymapper) | -71.36  | -61.19    |
| log i (Skymapper) | +33.78  | +22.85    |
| log z (Skymapper) | -45.00  | -49.95    |
| log J (2MASS)     | +14.76  | +13.89    |
| log H (2MASS)     | -50.95  | -53.82    |
| log K (2MASS)     | -8.637  | -10.47    |
| log W1 (WISE)     | +141.7  | +132.2    |
| log W2 (WISE)     | -22.17  | -6.822    |
| log W3 (WISE)     | -41.23  | -40.81    |
| offset            | +10.45  | +5.014    |

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**Table 4.** All observed sources with secure redshift identification

| Skymapper            | R.A. (J2000) | DEC. (J2000) | $m_i$<br>(mag) | $z_{\text{spec}}$ | Class | Candidate | Candidate | Date-Obs | Inst  |
|----------------------|--------------|--------------|----------------|-------------------|-------|-----------|-----------|----------|-------|
| ID                   |              |              |                |                   |       | PaperI    | New       |          |       |
| 107306               | 21:01:34.72  | -30:10:29.75 | 17.616         | 2.761             | QSO   | Y         | Y         | 2019-09  | NTT   |
| 343536               | 21:38:41.84  | -33:49:37.21 | 17.660         | 3.253             | QSO   | Y         | Y         | 2019-09  | NTT   |
| 397340 <sup>a</sup>  | 21:57:28.21  | -36:02:15.11 | 17.367         | 4.771             | QSO   | Y         | Y         | 2019-08  | WFCCD |
| 583628 <sup>b</sup>  | 21:32:25.90  | -28:31:33.24 | 17.605         | 2.821             | QSO   | Y         | Y         | 2019-09  | NTT   |
| 755996               | 21:30:54.92  | -22:46:54.51 | 17.693         | 1.749             | QSO   | Y         | N         | 2019-09  | NTT   |
| 838086               | 21:49:28.24  | -27:47:46.22 | 17.114         | 2.495             | QSO   | Y         | Y         | 2019-09  | NTT   |
| 1316873              | 22:55:26.10  | -36:39:33.80 | 17.531         | 1.148             | QSO   | Y         | N         | 2019-09  | NTT   |
| 1318863              | 22:52:47.11  | -35:42:01.46 | 17.692         | 2.630             | QSO   | Y         | Y         | 2019-09  | NTT   |
| 1826062              | 23:01:39.67  | -28:59:46.08 | 17.062         | 0.000             | STAR  | Y         | N         | 2019-08  | WFCCD |
| 2415223              | 21:05:01.83  | -13:34:40.76 | 17.514         | 2.346             | QSO   | Y         | Y         | 2019-09  | NTT   |
| 2809723              | 21:54:54.84  | -18:06:03.36 | 17.690         | 3.000             | QSO   | Y         | Y         | 2019-09  | NTT   |
| 3310797              | 21:32:17.64  | -06:07:50.64 | 17.732         | 0.000             | STAR  | Y         | N         | 2019-09  | NTT   |
| 3479216              | 21:19:19.03  | -04:56:56.93 | 16.959         | 2.672             | QSO   | Y         | Y         | 2019-09  | NTT   |
| 3709817              | 21:40:53.51  | -05:56:47.09 | 17.582         | 2.001             | QSO   | Y         | Y         | 2019-09  | NTT   |
| 4045023              | 21:55:13.29  | -03:16:05.61 | 17.410         | 3.690             | QSO   | Y         | Y         | 2019-08  | WFCCD |
| 4342067              | 22:57:00.78  | -21:42:09.66 | 17.280         | 2.833             | QSO   | Y         | Y         | 2019-09  | WFCCD |
| 4342686 <sup>b</sup> | 22:59:39.04  | -22:50:34.90 | 17.709         | 3.486             | QSO   | Y         | Y         | 2019-09  | NTT   |
| 4441259              | 22:27:54.04  | -15:49:38.61 | 17.379         | 2.647             | QSO   | Y         | Y         | 2019-09  | NTT   |
| 4538557              | 22:46:46.21  | -16:02:41.71 | 17.547         | 2.259             | QSO   | Y         | Y         | 2019-09  | NTT   |
| 4788903              | 23:56:40.97  | -21:15:56.84 | 16.764         | 1.738             | QSO   | Y         | Y         | 2019-09  | NTT   |
| 4922910              | 23:43:15.99  | -18:21:12.21 | 17.617         | 3.332             | QSO   | Y         | Y         | 2019-09  | NTT   |
| 4924968              | 23:40:28.39  | -17:24:46.12 | 17.609         | 4.257             | QSO   | Y         | Y         | 2019-09  | NTT   |
| 5003358              | 23:59:21.09  | -14:57:22.91 | 17.705         | 2.953             | QSO   | Y         | Y         | 2019-09  | NTT   |
| 5035730              | 22:22:41.07  | -10:27:09.45 | 17.613         | 1.820             | QSO   | Y         | Y         | 2019-09  | NTT   |
| 5081975              | 22:23:13.66  | -08:54:16.34 | 17.593         | 2.706             | QSO   | Y         | Y         | 2019-09  | NTT   |
| 5552633              | 23:15:12.19  | -11:23:43.85 | 17.704         | 2.561             | QSO   | Y         | Y         | 2019-09  | NTT   |
| 5564557              | 23:23:46.94  | -12:15:03.37 | 17.599         | 2.752             | QSO   | Y         | Y         | 2019-09  | NTT   |
| 5931917              | 23:47:49.34  | -04:33:32.60 | 17.679         | 1.880             | QSO   | Y         | N         | 2019-12  | WFCCD |
| 6009251              | 00:01:43.86  | -44:25:35.10 | 17.624         | 2.572             | QSO   | Y         | Y         | 2019-09  | NTT   |
| 6146221              | 00:21:33.83  | -37:40:08.04 | 17.641         | 2.573             | QSO   | Y         | Y         | 2019-09  | NTT   |
| 6232292              | 01:11:58.59  | -40:33:17.64 | 17.611         | 3.432             | QSO   | Y         | Y         | 2019-09  | NTT   |
| 6419289              | 00:00:11.42  | -33:10:50.86 | 17.605         | 3.106             | QSO   | Y         | Y         | 2019-09  | NTT   |
| 6427176              | 00:15:48.69  | -34:03:50.83 | 17.507         | 0.055             | AGN   | Y         | Y         | 2019-09  | NTT   |
| 6810884              | 01:43:22.60  | -25:38:34.27 | 17.748         | 2.307             | QSO   | Y         | Y         | 2019-09  | NTT   |
| 6932623              | 02:04:13.26  | -32:51:22.80 | 17.068         | 3.835             | QSO   | Y         | Y         | 2019-11  | WFCCD |
| 7015154              | 02:39:54.21  | -34:38:36.83 | 17.911         | 0.000             | STAR  | Y         | N         | 2019-09  | NTT   |

**Table 4** *continued*

Table 4 (*continued*)

| Skymapper            | R.A. (J2000) | DEC. (J2000) | $m_i$<br>(mag) | $z_{\text{spec}}$ | Class | Candidate | Candidate | Date-Obs | Inst   |
|----------------------|--------------|--------------|----------------|-------------------|-------|-----------|-----------|----------|--------|
| ID                   |              |              |                |                   |       | PaperI    | New       |          |        |
| 7088896              | 02:49:54.68  | -33:48:35.91 | 16.706         | 2.712             | QSO   | Y         | Y         | 2019-09  | NTT    |
| 7125196              | 02:44:06.47  | -30:07:49.93 | 17.703         | 0.063             | AGN   | Y         | Y         | 2019-09  | NTT    |
| 7134124              | 02:57:16.05  | -31:26:44.44 | 17.671         | 3.599             | QSO   | Y         | Y         | 2019-09  | NTT    |
| 7152915              | 01:51:52.22  | -32:52:38.96 | 17.206         | 0.196             | AGN   | Y         | N         | 2019-08  | WFCCD  |
| 7250804 <sup>b</sup> | 01:50:41.58  | -25:08:46.32 | 17.603         | 3.596             | QSO   | Y         | Y         | 2019-09  | NTT    |
| 7277955              | 02:20:23.13  | -26:12:40.04 | 17.405         | 3.096             | QSO   | Y         | Y         | 2019-11  | LDSS-3 |
| 7292553              | 02:09:46.00  | -24:01:11.19 | 17.679         | 1.370             | QSO   | Y         | N         | 2019-09  | NTT    |
| 7341051              | 02:44:49.14  | -29:04:49.25 | 17.422         | 3.240             | QSO   | Y         | Y         | 2019-11  | WFCCD  |
| 7560979              | 00:32:03.76  | -21:27:29.73 | 17.685         | 1.855             | QSO   | Y         | N         | 2019-12  | WFCCD  |
| 7565232 <sup>c</sup> | 00:39:01.09  | -21:44:28.89 | 17.597         | 3.027             | QSO   | Y         | Y         | 2019-09  | NTT    |
| 7687616              | 00:39:19.11  | -19:06:19.36 | 17.745         | 0.852             | QSO   | Y         | Y         | 2019-09  | NTT    |
| 7751454              | 00:44:18.35  | -15:04:13.35 | 17.442         | 2.755             | QSO   | Y         | Y         | 2019-08  | WFCCD  |
| 7829753              | 01:27:48.47  | -23:34:58.12 | 17.176         | 2.933             | QSO   | Y         | Y         | 2019-08  | WFCCD  |
| 7901686              | 01:10:02.61  | -18:43:20.07 | 17.561         | 2.940             | QSO   | Y         | Y         | 2019-09  | NTT    |
| 7931324              | 01:02:53.62  | -14:15:22.53 | 17.482         | 0.035             | GAL   | Y         | N         | 2019-08  | WFCCD  |
| 7957603              | 01:33:16.52  | -17:39:23.61 | 17.663         | 2.903             | QSO   | Y         | Y         | 2019-09  | NTT    |
| 8145069 <sup>b</sup> | 00:43:46.84  | -11:17:01.77 | 17.510         | 3.510             | QSO   | Y         | Y         | 2019-09  | NTT    |
| 8170168              | 00:32:20.84  | -08:13:00.92 | 17.356         | 2.838             | QSO   | Y         | Y         | 2019-11  | WFCCD  |
| 8430815 <sup>b</sup> | 01:03:18.06  | -13:05:09.89 | 17.242         | 4.072             | QSO   | Y         | Y         | 2019-08  | WFCCD  |
| 8493702 <sup>c</sup> | 01:20:35.95  | -09:46:32.02 | 17.653         | 3.009             | QSO   | Y         | Y         | 2019-09  | NTT    |
| 8513332              | 01:34:10.33  | -12:16:31.76 | 17.072         | 2.010             | QSO   | Y         | N         | 2019-11  | WFCCD  |
| 8529305              | 01:40:41.94  | -12:36:22.39 | 17.587         | 3.178             | QSO   | Y         | Y         | 2019-09  | NTT    |
| 8590857              | 00:58:33.99  | -04:08:23.66 | 17.393         | 0.048             | AGN   | Y         | Y         | 2019-08  | WFCCD  |
| 8619006**            | 01:00:49.23  | -03:19:13.97 | 17.25          | 3.45              | QSO   | Y         | ?         | 2018-10  | IMACS  |
| 8733320              | 01:37:35.48  | -02:46:06.09 | 17.678         | 0.048             | AGN   | Y         | Y         | 2019-09  | NTT    |
| 8789744 <sup>c</sup> | 01:55:58.27  | -19:28:48.98 | 17.393         | 3.655             | QSO   | Y         | Y         | 2019-08  | WFCCD  |
| 8795094              | 02:05:56.09  | -19:53:25.57 | 17.149         | 0.205             | AGN   | Y         | N         | 2019-11  | LDSS-3 |
| 8904188              | 02:16:41.24  | -16:00:18.55 | 17.748         | 3.039             | QSO   | Y         | Y         | 2019-09  | NTT    |
| 8918253              | 02:20:15.17  | -14:53:54.10 | 17.664         | 2.365             | QSO   | Y         | Y         | 2019-12  | LDSS-3 |
| 9089958**            | 02:45:43.76  | -12:06:03.71 | 16.672         | 0.03              | GAL   | N         | ?         | 2018-09  | LDSS-3 |
| 9177858              | 02:08:56.49  | -09:01:06.21 | 17.733         | 2.665             | QSO   | Y         | Y         | 2019-09  | NTT    |
| 9250343 <sup>c</sup> | 01:59:00.68  | -03:27:37.18 | 17.479         | 2.946             | QSO   | Y         | Y         | 2019-08  | WFCCD  |
| 9407358              | 02:52:26.99  | -09:29:18.21 | 17.063         | 2.255             | QSO   | Y         | Y         | 2019-11  | WFCCD  |
| 9892519              | 22:44:25.86  | +02:10:08.30 | 17.015         | 0.060             | GAL   | Y         | N         | 2019-09  | NTT    |
| 10476365             | 03:36:43.14  | -32:20:04.22 | 17.583         | 0.050             | AGN   | Y         | Y         | 2019-09  | NTT    |
| 10531556             | 04:08:12.64  | -34:37:48.67 | 17.659         | 3.279             | QSO   | Y         | Y         | 2020-01  | NTT    |
| 10572165             | 03:16:42.30  | -28:03:45.07 | 17.594         | 2.313             | QSO   | Y         | Y         | 2019-09  | NTT    |
| 10719380             | 03:56:17.49  | -32:08:19.87 | 17.585         | 2.291             | QSO   | Y         | Y         | 2019-09  | NTT    |

Table 4 (*continued*)

Table 4 (*continued*)

| Skymapper  | R.A. (J2000) | DEC. (J2000) | $m_i$<br>(mag) | $z_{\text{spec}}$ | Class | Candidate | Candidate | Date-Obs | Inst   |
|------------|--------------|--------------|----------------|-------------------|-------|-----------|-----------|----------|--------|
| ID         |              |              |                |                   |       | PaperI    | New       |          |        |
| 10748545   | 03:55:08.17  | -30:11:53.97 | 17.316         | 0.068             | AGN   | Y         | N         | 2019-11  | WFCCD  |
| 10790773   | 03:49:16.29  | -26:55:39.63 | 17.674         | 1.938             | QSO   | Y         | N         | 2019-09  | NTT    |
| 10798423   | 03:36:20.00  | -24:25:47.32 | 17.308         | 0.540             | QSO   | N         | N         | 2019-12  | WFCCD  |
| 10830553   | 03:53:01.84  | -25:48:23.05 | 17.749         | 3.083             | QSO   | Y         | Y         | 2019-09  | NTT    |
| 10875592   | 04:05:48.52  | -24:21:15.18 | 17.449         | 2.785             | QSO   | Y         | Y         | 2019-12  | WFCCD  |
| 11028492   | 04:21:11.68  | -34:34:03.64 | 17.537         | 1.780             | QSO   | Y         | N         | 2019-11  | WFCCD  |
| 11053925*  | 04:40:01.13  | -37:55:34.52 | 18.317         | 3.852             | QSO   | -         | -         | 2020-01  | NTT    |
| 11163743   | 05:12:15.00  | -41:20:13.86 | 17.616         | 3.144             | QSO   | Y         | Y         | 2020-01  | NTT    |
| 11270169*  | 05:04:56.56  | -39:52:45.03 | 18.251         | 3.237             | QSO   | -         | -         | 2020-01  | NTT    |
| 11343829   | 05:31:08.81  | -37:48:20.40 | 17.651         | 3.170             | QSO   | Y         | Y         | 2019-11  | LDSS-3 |
| 11382764   | 05:51:33.62  | -40:56:31.83 | 17.879         | 2.819             | QSO   | Y         | Y         | 2020-01  | NTT    |
| 11477581   | 04:23:33.67  | -32:54:14.19 | 17.463         | 2.270             | QSO   | Y         | Y         | 2019-12  | WFCCD  |
| 11513515   | 04:30:16.02  | -31:57:32.97 | 17.918         | 3.552             | QSO   | Y         | Y         | 2020-01  | NTT    |
| 11530749*  | 04:42:05.78  | -34:46:49.78 | 18.358         | 2.959             | QSO   | -         | -         | 2020-01  | NTT    |
| 11621558*  | 04:14:00.70  | -27:20:58.62 | 18.268         | 3.998             | QSO   | -         | -         | 2020-01  | NTT    |
| 11625837*  | 04:23:28.88  | -27:52:23.74 | 18.166         | 3.016             | QSO   | -         | -         | 2020-01  | NTT    |
| 11639037   | 04:29:37.15  | -28:35:43.10 | 17.389         | 2.569             | QSO   | Y         | Y         | 2019-12  | WFCCD  |
| 11708647   | 04:44:10.65  | -29:13:07.15 | 17.476         | 1.841             | QSO   | Y         | Y         | 2020-01  | NTT    |
| 11797890   | 05:13:04.21  | -35:28:51.50 | 17.397         | 3.050             | QSO   | Y         | Y         | 2019-12  | WFCCD  |
| 11871566*  | 05:19:04.89  | -33:03:27.23 | 18.031         | 3.272             | QSO   | -         | -         | 2020-01  | NTT    |
| 12020560   | 05:50:37.14  | -32:39:11.73 | 17.913         | 3.369             | QSO   | Y         | Y         | 2020-01  | NTT    |
| 12185422   | 05:42:50.82  | -31:03:24.12 | 17.634         | 2.620             | QSO   | Y         | Y         | 2019-11  | WFCCD  |
| 12375861   | 03:06:13.04  | -15:17:46.67 | 17.329         | 2.590             | QSO   | Y         | Y         | 2019-12  | WFCCD  |
| 12411621   | 03:19:01.77  | -17:07:19.05 | 17.626         | 2.526             | QSO   | Y         | Y         | 2019-09  | NTT    |
| 12432405   | 03:07:00.94  | -14:04:56.95 | 17.474         | 1.670             | QSO   | Y         | Y         | 2019-12  | WFCCD  |
| 12455576** | 03:03:54.28  | -10:50:49.01 | 16.35          | 0.04              | GAL   | N         | ?         | 2018-09  | LDSS-3 |
| 12476780*  | 03:19:04.82  | -13:42:00.18 | 18.370         | 2.989             | QSO   | -         | -         | 2020-01  | NTT    |
| 12513469   | 03:29:03.97  | -12:05:42.70 | 17.641         | 2.614             | QSO   | Y         | Y         | 2019-09  | NTT    |
| 12559809   | 03:42:21.23  | -17:55:11.47 | 17.236         | 2.033             | QSO   | Y         | Y         | 2019-11  | LDSS-3 |
| 12668545   | 03:41:38.05  | -11:42:59.46 | 17.205         | 2.800             | QSO   | Y         | Y         | 2019-12  | WFCCD  |
| 12750382   | 04:09:04.91  | -13:37:00.61 | 17.519         | 2.771             | QSO   | Y         | Y         | 2020-01  | NTT    |
| 12817400   | 03:26:45.28  | -08:47:00.54 | 17.365         | 2.348             | QSO   | Y         | Y         | 2019-12  | WFCCD  |
| 12931253   | 03:23:14.75  | -02:29:58.63 | 17.881         | 0.082             | GAL   | Y         | N         | 2019-09  | NTT    |
| 12941812   | 03:25:25.48  | -02:18:04.20 | 17.523         | 2.268             | QSO   | Y         | N         | 2019-12  | LDSS-3 |
| 12957365*  | 03:31:06.08  | -00:32:38.53 | 16.189         | 0.000             | STAR  | -         | -         | 2020-01  | LDSS-3 |
| 12989144   | 03:48:51.22  | -10:15:53.61 | 16.974         | 2.498             | QSO   | Y         | Y         | 2019-12  | WFCCD  |
| 13173703*  | 03:36:34.04  | -00:49:16.40 | 14.678         | 0.002             | GAL   | -         | -         | 2020-01  | NTT    |
| 13291946   | 04:09:34.40  | -02:17:38.04 | 17.640         | 3.202             | QSO   | Y         | Y         | 2020-01  | NTT    |

Table 4 (*continued*)

Table 4 (*continued*)

| Skymapper             | R.A. (J2000) | DEC. (J2000) | $m_i$<br>(mag) | $z_{\text{spec}}$ | Class | Candidate | Candidate | Date-Obs   | Inst       |
|-----------------------|--------------|--------------|----------------|-------------------|-------|-----------|-----------|------------|------------|
| ID                    |              |              |                |                   |       | PaperI    | New       |            |            |
| 13323971              | 04:17:23.77  | -21:47:13.67 | 17.344         | 2.060             | QSO   | Y         | Y         | 2019-12    | WFCCD      |
| 13409036              | 04:37:47.11  | -24:16:23.62 | 17.239         | 1.980             | QSO   | N         | N         | 2019-12    | WFCCD      |
| 13422105              | 04:38:56.76  | -22:56:53.36 | 15.949         | 0.026             | GAL   | N         | N         | 2019-12    | WFCCD      |
| 13479091*             | 04:39:54.55  | -19:43:51.32 | 18.035         | 2.609             | QSO   | -         | -         | 2020-01    | NTT        |
| 13623074              | 04:40:53.44  | -18:43:28.06 | 17.674         | 2.832             | QSO   | Y         | Y         | 2019-11    | LDSS-3     |
| 13754735              | 05:04:50.03  | -24:32:51.42 | 17.488         | 1.789             | QSO   | Y         | Y         | 2019-12    | LDSS-3     |
| 14047570              | 05:37:28.45  | -21:56:10.42 | 17.125         | 2.835             | QSO   | Y         | Y         | 2019-12    | WFCCD      |
| 14148404              | 05:14:11.75  | -19:01:39.46 | 17.681         | 2.609             | QSO   | Y         | Y         | 2019-11    | WFCCD      |
| 14203137              | 05:24:38.81  | -18:16:04.14 | 16.831         | 1.969             | QSO   | Y         | Y         | 2019-12    | WFCCD      |
| 14271415              | 05:25:49.05  | -16:16:12.37 | 17.843         | 3.567             | QSO   | Y         | Y         | 2020-01    | NTT        |
| 14661311              | 04:50:19.69  | -11:18:36.99 | 17.394         | 2.560             | QSO   | Y         | Y         | 2019-12    | WFCCD      |
| 14756860*             | 05:03:29.07  | -09:41:52.22 | 18.389         | 3.307             | QSO   | -         | -         | 2020-01    | NTT        |
| 14797495 <sup>c</sup> | 04:25:03.70  | -05:45:08.94 | 17.498         | 3.040             | QSO   | Y         | Y         | 2019-11    | WFCCD      |
| 14832947              | 04:32:49.02  | -05:41:48.21 | 17.600         | 0.165             | AGN   | Y         | N         | 2019-11    | LDSS-3     |
| 14921486              | 04:32:50.36  | -01:12:53.72 | 16.690         | 1.691             | QSO   | Y         | N         | 2019-09    | NTT        |
| 14930439 <sup>c</sup> | 04:36:23.92  | -00:04:02.89 | 17.404         | 3.852             | QSO   | Y         | Y         | 2020-01    | NTT        |
| 15015396              | 04:58:13.47  | -03:52:51.60 | 17.375         | 3.000             | QSO   | Y         | Y         | 2019-12    | WFCCD      |
| 15040824              | 04:46:17.76  | -02:20:15.64 | 17.687         | 2.533             | QSO   | Y         | Y         | 2019-11    | LDSS-3     |
| 15088950*             | 05:02:54.73  | -03:09:23.73 | 18.089         | 3.689             | QSO   | -         | -         | 2020-01    | NTT        |
| 15248403              | 05:07:32.14  | -06:58:02.27 | 17.427         | 2.960             | QSO   | Y         | Y         | 2019-12    | WFCCD      |
| 16164525*             | 06:01:37.14  | -43:41:43.80 | 18.378         | 3.499             | QSO   | -         | -         | 2020-01    | NTT        |
| 16539422              | 06:02:18.73  | -36:59:24.72 | 17.518         | 2.920             | QSO   | Y         | N         | 2019-11    | WFCCD      |
| 47669241*             | 08:15:45.64  | -01:38:18.59 | 16.261         | 0.000             | STAR  | -         | -         | 2020-01    | LDSS-3     |
| 48196484*             | 08:58:49.38  | -02:34:05.48 | 16.381         | 0.000             | STAR  | -         | -         | 2020-01    | LDSS-3     |
| 48449084*             | 08:44:22.01  | +04:32:44.27 | 18.036         | 3.327             | QSO   | -         | -         | 2020-01    | NTT        |
| 5171811*              | 10:07:03.55  | -23:57:13.36 | 18.287         | 3.347             | QSO   | -         | -         | 2020-01    | NTT        |
| 54192246              | 10:59:56.17  | -30:28:27.95 | 17.487         | 2.610             | QSO   | Y         | Y         | 2020-01/02 | NTT/LDSS-3 |
| 54298405              | 10:58:09.30  | -26:05:42.29 | 17.505         | 2.876             | QSO   | Y         | Y         | 2020-01    | NTT        |
| 54680559 <sup>d</sup> | 11:10:54.68  | -30:11:29.88 | 17.346         | 4.779             | QSO   | Y         | Y         | 2020-01    | NTT        |
| 55462080              | 09:30:53.18  | -12:12:29.67 | 17.007         | 0.000             | STAR  | Y         | N         | 2020-02    | LDSS-3     |
| 55582991              | 09:49:02.92  | -20:07:23.36 | 16.298         | 1.866             | QSO   | N         | N         | 2020-02    | LDSS-3     |
| 55799640              | 09:44:35.17  | -16:16:32.31 | 17.224         | 2.897             | QSO   | Y         | Y         | 2020-02    | LDSS-3     |
| 56003412              | 10:12:57.45  | -14:34:12.40 | 17.540         | 3.229             | QSO   | Y         | Y         | 2020-01    | NTT        |
| 56507631*             | 09:49:34.23  | -08:03:08.77 | 18.086         | 2.333             | QSO   | -         | -         | 2020-01    | NTT        |
| 56610095              | 09:59:20.61  | -06:47:25.66 | 17.189         | 1.797             | QSO   | Y         | Y         | 2020-02    | LDSS-3     |
| 56626491              | 10:04:16.57  | -07:46:34.72 | 17.327         | 0.558             | QSO   | Y         | N         | 2020-01    | NTT        |
| 56648626              | 09:40:52.85  | -05:09:32.44 | 17.144         | 2.370             | QSO   | Y         | Y         | 2020-02    | LDSS-3     |
| 56660065              | 09:41:19.36  | -04:08:12.54 | 16.754         | 0.000             | STAR  | Y         | N         | 2020-01    | LDSS-3     |

Table 4 (*continued*)

Table 4 (*continued*)

| Skymapper              | R.A. (J2000) | DEC. (J2000) | $m_i$<br>(mag) | $z_{\text{spec}}$ | Class | Candidate | Candidate | Date-Obs   | Inst       |
|------------------------|--------------|--------------|----------------|-------------------|-------|-----------|-----------|------------|------------|
| ID                     |              |              |                |                   |       | PaperI    | New       |            |            |
| 56681692               | 09:43:51.97  | -03:21:02.73 | 17.464         | 1.701             | QSO   | N         | N         | 2020-02    | LDSS-3     |
| 56699168*              | 09:37:47.61  | -02:01:26.30 | 16.610         | 0.000             | STAR  | -         | -         | 2020-01    | LDSS-3     |
| 56749347               | 09:52:29.66  | -04:08:02.85 | 17.487         | 2.074             | QSO   | Y         | Y         | 2020-01    | LDSS-3     |
| 56791679*              | 09:54:32.83  | -02:07:51.29 | 16.369         | 0.000             | STAR  | -         | -         | 2020-01    | LDSS-3     |
| 56823181*              | 10:12:05.23  | -02:15:24.61 | 16.358         | 0.000             | STAR  | -         | -         | 2020-01    | LDSS-3     |
| 56933068               | 10:25:07.94  | -20:58:19.50 | 17.152         | 2.308             | QSO   | Y         | Y         | 2020-02    | LDSS-3     |
| 57291610*              | 10:32:52.81  | -13:52:04.59 | 18.098         | 2.950             | QSO   | -         | -         | 2020-01    | NTT        |
| 57292353               | 10:35:25.96  | -14:39:47.44 | 17.298         | 2.888             | QSO   | Y         | Y         | 2020-01    | NTT        |
| 57466047               | 11:13:57.01  | -26:04:58.35 | 16.817         | 2.949             | QSO   | Y         | Y         | 2020-01/02 | NTT/LDSS-3 |
| 57669548*              | 11:34:40.56  | -21:03:22.78 | 16.205         | 2.774             | QSO   | -         | -         | 2020-01    | NTT        |
| 58115878*              | 10:54:45.47  | -10:53:29.52 | 18.053         | 0.156             | GAL   | -         | -         | 2020-01    | LDSS-3     |
| 58723356               | 11:13:32.47  | -03:09:13.98 | 17.949         | 3.731             | QSO   | Y         | Y         | 2020-01    | NTT        |
| 58823120*              | 11:57:43.62  | -06:50:04.73 | 18.247         | 2.748             | QSO   | -         | -         | 2020-01    | NTT        |
| 60288193               | 13:04:42.64  | -36:04:27.43 | 17.892         | 0.155             | AGN   | Y         | N         | 2020-01    | NTT        |
| 61068064               | 12:41:46.38  | -29:34:49.05 | 17.404         | 3.048             | QSO   | Y         | Y         | 2020-01    | NTT        |
| 62209153               | 13:55:44.05  | -35:08:15.11 | 17.447         | 0.000             | STAR  | Y         | N         | 2020-01    | NTT        |
| 63230995 <sup>b</sup>  | 14:08:01.83  | -27:58:20.34 | 17.641         | 4.447             | QSO   | Y         | Y         | 2020-01    | NTT        |
| 63285615               | 13:49:40.58  | -26:33:42.92 | 17.222         | 3.023             | QSO   | Y         | Y         | 2020-01    | NTT        |
| 63739700               | 14:32:28.52  | -24:44:35.07 | 17.357         | 2.718             | QSO   | Y         | Y         | 2020-01    | NTT        |
| 63982611               | 12:15:37.66  | -24:53:23.63 | 17.043         | 0.083             | GAL   | N         | N         | 2020-01    | NTT        |
| 64116716               | 12:49:08.53  | -25:32:38.86 | 17.437         | 0.147             | AGN   | N         | N         | 2020-01    | LDSS-3     |
| 65072412               | 12:27:24.77  | -11:33:35.05 | 14.951         | 0.000             | STAR  | N         | N         | 2020-01    | NTT        |
| 65723003*              | 13:20:01.62  | -06:53:21.60 | 18.188         | 1.329             | QSO   | -         | -         | 2020-01    | NTT        |
| 65842041*              | 13:45:17.91  | -08:29:57.17 | 18.254         | 0.472             | AGN   | -         | -         | 2020-01    | NTT        |
| 98859792               | 15:43:22.37  | -19:42:41.10 | 16.004         | 0.177             | AGN   | Y         | N         | 2019-08    | WFCCD      |
| 125383528              | 19:40:12.00  | -41:18:22.33 | 17.642         | 2.618             | QSO   | Y         | Y         | 2019-09    | NTT        |
| 135055221              | 20:06:00.80  | -39:37:32.61 | 17.623         | 1.340             | QSO   | Y         | N         | 2019-09    | NTT        |
| 135169820              | 20:19:01.86  | -38:27:21.89 | 17.387         | 2.070             | QSO   | Y         | N         | 2019-08    | WFCCD      |
| 135210414              | 20:20:27.08  | -36:34:25.79 | 17.214         | 0.086             | AGN   | Y         | N         | 2019-09    | NTT        |
| 135463347              | 20:13:23.96  | -33:47:50.43 | 16.767         | 2.745             | QSO   | Y         | Y         | 2019-09    | NTT        |
| 135639174              | 20:46:44.37  | -33:36:06.31 | 17.725         | 0.132             | AGN   | Y         | N         | 2019-09    | NTT        |
| 135758989              | 20:51:59.18  | -32:28:38.67 | 17.577         | 1.974             | QSO   | Y         | Y         | 2019-09    | NTT        |
| 136204383              | 20:16:19.21  | -27:33:21.66 | 17.458         | 2.062             | QSO   | Y         | N         | 2019-09    | NTT        |
| 136230878              | 20:19:46.01  | -27:40:16.20 | 17.653         | 0.025             | AGN   | Y         | Y         | 2019-09    | NTT        |
| 136588662 <sup>b</sup> | 20:11:58.77  | -26:23:40.86 | 17.662         | 3.657             | QSO   | Y         | Y         | 2019-09    | NTT        |
| 136973888              | 20:55:54.12  | -24:56:25.25 | 17.384         | 0.126             | AGN   | Y         | N         | 2019-09    | NTT        |
| 137044597              | 20:39:21.61  | -24:00:05.00 | 17.942         | 2.916             | QSO   | Y         | Y         | 2019-09    | NTT        |
| 137166249 <sup>b</sup> | 20:48:48.28  | -22:51:52.07 | 17.449         | 3.100             | QSO   | Y         | Y         | 2019-08    | WFCCD      |

Table 4 (*continued*)

Table 4 (*continued*)

| Skymapper  | R.A. (J2000) | DEC. (J2000) | $m_i$<br>(mag) | $z_{\text{spec}}$ | Class | Candidate<br>PaperI | Candidate<br>New | Date-Obs | Inst       |
|------------|--------------|--------------|----------------|-------------------|-------|---------------------|------------------|----------|------------|
| ID         |              |              |                |                   |       |                     |                  |          |            |
| 137203486  | 20:49:49.03  | -21:46:33.63 | 17.299         | 0.038             | AGN   | Y                   | N                | 2019-09  | NTT        |
| 171528002  | 20:19:31.38  | -16:34:40.04 | 17.328         | 2.619             | QSO   | Y                   | Y                | 2019-09  | NTT        |
| 172129292  | 20:40:43.96  | -15:26:26.78 | 17.666         | 0.119             | AGN   | Y                   | N                | 2019-09  | NTT        |
| 175467261  | 20:44:24.99  | -01:48:55.56 | 17.335         | 2.304             | QSO   | Y                   | Y                | 2019-09  | NTT        |
| 288304909  | 06:56:21.64  | -74:21:02.00 | 17.359         | 2.116             | QSO   | Y                   | Y                | 2019-12  | WFCCD      |
| 288408065  | 06:53:54.47  | -75:07:56.30 | 17.339         | 3.081             | QSO   | Y                   | Y                | 2020-01  | NTT/LDSS-3 |
| 288742885  | 06:45:57.00  | -67:53:09.09 | 17.720         | 4.314             | QSO   | Y                   | Y                | 2020-01  | NTT        |
| 293711383* | 06:20:07.34  | -61:55:57.93 | 18.021         | 3.320             | QSO   | -                   | -                | 2020-01  | NTT        |
| 293925557  | 06:12:19.16  | -55:44:21.29 | 17.298         | 2.285             | QSO   | Y                   | Y                | 2019-12  | WFCCD      |
| 293946915* | 06:18:13.16  | -55:19:46.12 | 18.049         | 3.117             | QSO   | -                   | -                | 2020-01  | NTT        |
| 293970104* | 06:06:20.93  | -54:19:38.59 | 18.210         | 3.343             | QSO   | -                   | -                | 2020-01  | NTT        |
| 294463461  | 06:18:46.36  | -51:08:16.66 | 17.173         | 2.050             | QSO   | Y                   | Y                | 2019-12  | WFCCD      |
| 300818220  | 19:18:53.50  | -52:50:11.91 | 17.311         | 2.022             | QSO   | Y                   | Y                | 2019-08  | WFCCD      |
| 301296617  | 20:07:39.92  | -58:10:37.65 | 17.744         | 3.289             | QSO   | Y                   | Y                | 2019-09  | NTT        |
| 301508731  | 20:18:27.87  | -51:51:00.35 | 17.060         | 2.639             | QSO   | Y                   | Y                | 2019-09  | NTT        |
| 301643566  | 20:24:13.87  | -53:12:13.87 | 16.962         | 2.208             | QSO   | Y                   | Y                | 2019-09  | NTT        |
| 301677762  | 20:35:33.65  | -52:53:29.14 | 17.746         | 2.572             | QSO   | Y                   | Y                | 2019-09  | NTT        |
| 302676587  | 18:59:46.16  | -74:34:32.82 | 17.310         | 0.142             | AGN   | Y                   | N                | 2019-09  | NTT        |
| 303302739  | 20:12:29.32  | -67:32:16.66 | 17.056         | 2.512             | QSO   | Y                   | N                | 2019-09  | NTT        |
| 303604203  | 18:55:09.84  | -81:38:28.84 | 17.456         | 1.746             | QSO   | Y                   | N                | 2019-09  | NTT        |
| 304156429  | 20:25:23.01  | -73:01:18.98 | 16.695         | 0.097             | AGN   | Y                   | N                | 2019-08  | WFCCD      |
| 304169254  | 20:35:30.89  | -75:38:11.99 | 17.705         | 2.195             | QSO   | Y                   | Y                | 2019-09  | NTT        |
| 304191239  | 20:36:26.11  | -78:16:34.13 | 17.031         | 2.627             | QSO   | Y                   | Y                | 2019-09  | NTT        |
| 304867318  | 20:35:17.07  | -62:37:01.82 | 16.730         | 2.709             | QSO   | Y                   | N                | 2019-09  | NTT        |
| 305094211  | 21:10:38.23  | -66:38:43.85 | 17.369         | 0.124             | AGN   | Y                   | Y                | 2019-09  | NTT        |
| 305139405  | 21:32:46.07  | -65:20:42.57 | 17.233         | 2.206             | QSO   | Y                   | Y                | 2019-08  | WFCCD      |
| 305149856  | 20:36:41.07  | -58:37:01.26 | 17.620         | 1.701             | QSO   | Y                   | Y                | 2019-09  | NTT        |
| 305336573  | 21:08:17.67  | -62:17:57.53 | 17.589         | 3.794             | QSO   | Y                   | Y                | 2019-09  | NTT        |
| 305446236  | 21:40:40.86  | -58:51:21.57 | 17.325         | 3.021             | QSO   | Y                   | Y                | 2019-09  | NTT        |
| 305565087  | 21:57:46.57  | -72:31:14.44 | 17.329         | 2.908             | QSO   | Y                   | Y                | 2019-09  | NTT        |
| 305588367  | 21:58:49.70  | -70:35:52.25 | 17.121         | 0.218             | AGN   | Y                   | N                | 2019-08  | WFCCD      |
| 305669171  | 22:20:57.18  | -69:59:23.17 | 17.432         | 2.221             | QSO   | Y                   | Y                | 2019-09  | NTT        |
| 305744092  | 22:54:00.77  | -72:07:48.71 | 17.584         | 2.922             | QSO   | Y                   | Y                | 2019-09  | NTT        |
| 305772027  | 23:21:14.00  | -73:26:02.07 | 17.103         | 0.143             | AGN   | Y                   | N                | 2019-08  | WFCCD      |
| 305790724  | 22:34:32.52  | -71:22:42.90 | 17.319         | 1.932             | QSO   | Y                   | N                | 2019-12  | WFCCD      |
| 305817005  | 22:53:01.59  | -69:38:13.41 | 17.725         | 3.082             | QSO   | Y                   | Y                | 2019-09  | NTT        |
| 306048062  | 22:58:05.07  | -65:59:07.40 | 17.712         | 2.796             | QSO   | Y                   | Y                | 2019-09  | NTT        |
| 306142589  | 23:56:05.44  | -66:09:49.56 | 17.622         | 3.143             | QSO   | Y                   | Y                | 2019-09  | NTT        |

Table 4 (*continued*)

Table 4 (*continued*)

| Skymapper              | R.A. (J2000) | DEC. (J2000) | $m_i$<br>(mag) | $z_{\text{spec}}$ | Class | Candidate | Candidate | Date-Obs | Inst        |
|------------------------|--------------|--------------|----------------|-------------------|-------|-----------|-----------|----------|-------------|
| ID                     |              |              |                |                   |       | PaperI    | New       |          |             |
| 306255584              | 20:02:54.69  | -42:14:21.06 | 17.516         | 2.612             | QSO   | Y         | Y         | 2019-09  | NTT         |
| 306376125**            | 20:18:47.29  | -45:46:48.42 | 16.462         | 1.355             | QSO   | Y         | N         | 2019-06  | LDSS-3/FIRE |
| 306578934              | 20:40:01.98  | -44:36:33.59 | 17.571         | 2.691             | QSO   | Y         | Y         | 2019-09  | NTT         |
| 306624073              | 20:46:36.95  | -43:11:40.92 | 16.303         | 2.169             | QSO   | Y         | Y         | 2019-09  | NTT         |
| 306630517              | 20:46:33.08  | -42:39:02.11 | 17.692         | 3.260             | QSO   | Y         | Y         | 2019-09  | NTT         |
| 306874313              | 21:01:47.82  | -48:46:23.52 | 17.527         | 2.601             | QSO   | Y         | Y         | 2019-09  | NTT         |
| 307049678              | 21:18:23.60  | -49:21:16.77 | 17.735         | 1.214             | QSO   | Y         | N         | 2019-09  | NTT         |
| 307108556              | 21:37:31.37  | -47:38:03.44 | 16.769         | 2.448             | QSO   | Y         | Y         | 2019-09  | NTT         |
| 307443251              | 21:25:18.39  | -42:05:47.62 | 17.363         | 3.549             | QSO   | Y         | Y         | 2019-09  | NTT         |
| 307536920              | 21:51:37.44  | -44:36:44.17 | 17.363         | 3.638             | QSO   | Y         | Y         | 2019-09  | WFCCD       |
| 307772847              | 21:20:11.80  | -53:04:07.41 | 17.556         | 2.245             | QSO   | Y         | Y         | 2019-09  | NTT         |
| 308002829              | 21:41:07.72  | -52:30:39.28 | 17.287         | 2.334             | QSO   | Y         | Y         | 2019-09  | NTT         |
| 308038519              | 21:49:56.64  | -50:31:28.72 | 17.743         | 3.296             | QSO   | Y         | Y         | 2019-09  | NTT         |
| 308280154              | 23:03:18.38  | -59:15:33.20 | 17.554         | 1.408             | QSO   | Y         | N         | 2019-12  | LDSS-3      |
| 308304837              | 23:17:51.93  | -61:45:57.30 | 17.136         | 2.940             | QSO   | Y         | Y         | 2019-08  | WFCCD       |
| 308375290 <sup>a</sup> | 23:35:05.86  | -59:01:03.33 | 17.599         | 4.540             | QSO   | Y         | Y         | 2019-09  | NTT         |
| 308396429              | 23:44:05.92  | -57:57:14.73 | 17.609         | 3.177             | QSO   | Y         | Y         | 2019-09  | NTT         |
| 308690703              | 22:41:31.39  | -49:40:56.67 | 17.672         | 2.764             | QSO   | Y         | Y         | 2019-09  | NTT         |
| 308973148              | 23:44:57.76  | -50:14:42.87 | 17.433         | 2.343             | QSO   | Y         | Y         | 2019-12  | LDSS-3      |
| 308998359              | 22:58:55.77  | -46:41:44.62 | 17.660         | 1.899             | QSO   | Y         | N         | 2019-11  | LDSS-3      |
| 309030850              | 23:04:14.36  | -44:23:17.76 | 17.679         | 2.283             | QSO   | Y         | Y         | 2019-09  | NTT         |
| 309431269              | 05:01:14.50  | -80:19:03.28 | 17.936         | 2.663             | QSO   | Y         | Y         | 2020-01  | NTT         |
| 309455748              | 05:35:46.75  | -78:15:08.61 | 17.685         | 2.939             | QSO   | Y         | Y         | 2019-11  | LDSS-3      |
| 309656787              | 01:08:40.41  | -82:17:47.76 | 17.579         | 2.707             | QSO   | Y         | Y         | 2019-09  | NTT         |
| 309939096              | 03:54:32.05  | -74:03:44.86 | 17.510         | 0.000             | STAR  | Y         | N         | 2019-09  | NTT         |
| 309972073              | 02:18:10.04  | -75:39:43.01 | 17.699         | 0.000             | STAR  | Y         | N         | 2019-09  | NTT         |
| 310047722              | 02:50:56.99  | -72:04:58.62 | 17.602         | 2.892             | QSO   | Y         | Y         | 2019-09  | NTT         |
| 310206031              | 05:09:43.13  | -74:09:47.89 | 17.575         | 3.773             | QSO   | Y         | Y         | 2020-01  | NTT         |
| 311228175              | 04:31:45.85  | -74:51:26.83 | 17.189         | 3.140             | QSO   | Y         | Y         | 2019-12  | WFCCD       |
| 312716357              | 05:34:58.75  | -64:49:36.83 | 17.541         | 3.247             | QSO   | Y         | Y         | 2020-01  | NTT         |
| 313912389              | 04:39:23.74  | -65:36:22.83 | 17.805         | 3.399             | QSO   | Y         | Y         | 2020-01  | NTT         |
| 313928581              | 04:20:32.51  | -66:09:30.84 | 17.260         | 2.700             | QSO   | Y         | Y         | 2019-12  | WFCCD       |
| 314899504              | 02:24:11.35  | -70:36:38.67 | 17.739         | 2.829             | QSO   | Y         | Y         | 2019-09  | NTT         |
| 315156166              | 01:24:25.20  | -66:08:13.38 | 17.554         | 2.365             | QSO   | Y         | N         | 2019-12  | LDSS-3      |
| 315316671              | 02:43:04.74  | -66:23:11.69 | 17.649         | 2.055             | QSO   | Y         | Y         | 2019-09  | NTT         |
| 315435952              | 03:12:32.49  | -62:38:59.70 | 16.845         | 3.016             | QSO   | Y         | Y         | 2019-09  | NTT         |
| 315483506              | 02:24:56.71  | -63:31:04.98 | 17.716         | 2.706             | QSO   | Y         | Y         | 2019-09  | NTT         |
| 315552288              | 02:37:48.15  | -59:59:51.14 | 17.695         | 2.756             | QSO   | Y         | Y         | 2019-09  | NTT         |

Table 4 (*continued*)

Table 4 (*continued*)

| Skymapper              | R.A. (J2000) | DEC. (J2000) | $m_i$<br>(mag) | $z_{\text{spec}}$ | Class | Candidate | Candidate | Date-Obs | Inst   |
|------------------------|--------------|--------------|----------------|-------------------|-------|-----------|-----------|----------|--------|
| ID                     |              |              |                |                   |       | PaperI    | New       |          |        |
| 315607762              | 03:17:24.89  | -57:36:19.01 | 17.922         | 3.844             | QSO   | Y         | Y         | 2020-01  | NTT    |
| 315783093              | 05:47:55.85  | -58:40:37.81 | 17.430         | 0.000             | STAR  | N         | N         | 2019-12  | WFCCD  |
| 315809832              | 05:27:04.37  | -61:54:57.45 | 16.949         | 1.879             | QSO   | Y         | Y         | 2019-12  | WFCCD  |
| 315974502              | 05:34:49.40  | -57:47:26.92 | 17.085         | 2.880             | QSO   | Y         | Y         | 2019-12  | WFCCD  |
| 316155633              | 05:08:24.66  | -55:44:40.37 | 17.979         | 2.466             | QSO   | Y         | Y         | 2020-01  | NTT    |
| 316186672              | 05:01:00.45  | -54:26:49.97 | 17.093         | 2.600             | QSO   | Y         | Y         | 2019-12  | WFCCD  |
| 316292063              | 05:48:03.20  | -48:48:13.19 | 16.886         | 4.147             | QSO   | Y         | Y         | 2019-12  | WFCCD  |
| 316293416              | 05:45:02.05  | -49:24:47.35 | 17.344         | 2.928             | QSO   | Y         | Y         | 2020-02  | LDSS-3 |
| 316383429              | 05:55:08.16  | -45:58:23.61 | 17.649         | 3.262             | QSO   | Y         | Y         | 2020-01  | NTT    |
| 316434053              | 05:39:21.91  | -45:16:58.03 | 17.064         | 2.556             | QSO   | Y         | Y         | 2019-12  | WFCCD  |
| 316563116*             | 05:20:23.95  | -47:52:12.06 | 18.362         | 3.825             | QSO   | -         | -         | 2020-01  | NTT    |
| 316567405*             | 05:24:10.76  | -47:15:28.25 | 18.052         | 2.399             | QSO   | -         | -         | 2020-01  | NTT    |
| 316591563              | 05:29:14.28  | -45:08:07.03 | 17.661         | 3.690             | QSO   | Y         | Y         | 2020-01  | NTT    |
| 316663640              | 04:30:07.62  | -56:47:36.38 | 17.154         | 3.130             | QSO   | Y         | Y         | 2019-12  | WFCCD  |
| 316757721              | 04:33:26.90  | -52:07:58.20 | 17.777         | 3.442             | QSO   | Y         | Y         | 2020-01  | NTT    |
| 316769552              | 04:18:15.82  | -52:58:14.21 | 15.171         | 0.000             | STAR  | N         | N         | 2019-12  | WFCCD  |
| 316788893              | 04:25:40.68  | -50:43:15.05 | 17.528         | 0.047             | AGN   | Y         | Y         | 2019-11  | WFCCD  |
| 316791881              | 04:11:46.66  | -52:12:07.74 | 17.605         | 2.022             | QSO   | Y         | Y         | 2019-11  | LDSS-3 |
| 316933237              | 03:45:05.36  | -49:35:14.61 | 17.656         | 0.000             | STAR  | Y         | N         | 2019-09  | NTT    |
| 317020875              | 04:45:18.99  | -46:00:49.84 | 17.423         | 2.184             | QSO   | Y         | Y         | 2019-12  | WFCCD  |
| 317068530              | 04:14:59.70  | -49:07:56.59 | 17.652         | 2.790             | QSO   | Y         | Y         | 2019-11  | LDSS-3 |
| 317105305              | 03:56:39.60  | -47:08:34.05 | 17.407         | 2.110             | QSO   | Y         | Y         | 2019-12  | WFCCD  |
| 317138695              | 04:30:48.53  | -43:28:35.18 | 17.660         | 2.757             | QSO   | Y         | Y         | 2020-01  | NTT    |
| 317201391              | 00:42:44.49  | -62:41:09.29 | 17.464         | 2.055             | QSO   | Y         | N         | 2019-12  | LDSS-3 |
| 317253125              | 00:48:05.34  | -59:29:09.44 | 17.536         | 3.607             | QSO   | Y         | Y         | 2019-09  | NTT    |
| 317343050              | 01:27:16.87  | -58:02:47.28 | 17.772         | 3.918             | QSO   | Y         | Y         | 2020-01  | NTT    |
| 317358346 <sup>a</sup> | 00:07:36.56  | -57:01:51.73 | 17.240         | 4.260             | QSO   | Y         | Y         | 2019-08  | WFCCD  |
| 317411112              | 00:18:30.46  | -53:35:35.20 | 17.744         | 3.738             | QSO   | Y         | Y         | 2019-09  | NTT    |
| 317506585              | 01:42:17.55  | -59:37:00.86 | 17.717         | 3.432             | QSO   | Y         | Y         | 2019-09  | NTT    |
| 317647507              | 01:40:04.35  | -54:23:15.53 | 17.623         | 2.458             | QSO   | Y         | Y         | 2019-09  | NTT    |
| 317802750 <sup>a</sup> | 00:12:24.99  | -48:48:29.86 | 17.715         | 4.621             | QSO   | Y         | Y         | 2019-09  | NTT    |
| 318357314              | 03:45:42.68  | -47:36:31.41 | 17.590         | 2.878             | QSO   | Y         | Y         | 2019-09  | NTT    |
| 318395533              | 03:45:07.90  | -44:32:44.08 | 17.192         | 2.140             | QSO   | Y         | N         | 2019-12  | WFCCD  |
| 318397429              | 03:43:30.07  | -43:44:29.86 | 17.121         | 1.777             | QSO   | Y         | Y         | 2019-12  | WFCCD  |
| 318432798              | 03:54:35.83  | -42:16:30.70 | 16.737         | 1.983             | QSO   | Y         | N         | 2019-12  | WFCCD  |
| 318446298              | 03:23:24.22  | -44:03:46.17 | 17.473         | 2.074             | QSO   | Y         | Y         | 2020-01  | NTT    |
| 318479392              | 03:18:24.60  | -41:32:40.30 | 17.647         | 2.495             | QSO   | Y         | Y         | 2019-11  | WFCCD  |
| 318495154              | 03:38:35.49  | -40:30:41.39 | 17.309         | 2.900             | QSO   | Y         | Y         | 2019-12  | WFCCD  |

Table 4 (*continued*)

**Table 4** (*continued*)

| Skymapper | R.A. (J2000) | DEC. (J2000) | $m_i$<br>(mag) | $z_{\text{spec}}$ | Class | Candidate<br>PaperI | Candidate<br>New | Date-Obs | Inst  |
|-----------|--------------|--------------|----------------|-------------------|-------|---------------------|------------------|----------|-------|
| ID        |              |              |                |                   |       |                     |                  |          |       |
| 318699655 | 03:21:50.82  | -39:53:14.75 | 17.471         | 2.794             | QSO   | Y                   | Y                | 2019-12  | WFCCD |

NOTE—

<sup>a</sup>Independently discovered also by [Wolf et al. \(2020\)](#)<sup>b</sup>Included also in [Schindler et al. \(2019b\)](#)<sup>c</sup>Included also in [Schindler et al. \(2019a\)](#)

\* Not part of the Main Sample

\*\* after updated reduction of PaperI observed sources