**New quasars behind the Magellanic Clouds. Spectroscopic confirmation of near-infrared selected candidates**

Valentin D. Ivanov, Maria-Rosa L. Cioni, Kenji Bekki, Richard de Grijs, Jim Emerson, Brad K. Gibson, Devika Kamath, Jacco Th. van Loo, André E. Piat, and Bi-Qing For

European Southern Observatory, Ave. Alonso de Córdova 3107, Vitacura, Santiago, Chile
2 European Southern Observatory, Karl-Schwarzschild-Str. 2, 85748 Garching bei München, Germany
3 Universität Potsdam, Institut für Physik und Astronomie, Karl-Liebknecht-Str. 24/25, D-14476 Potsdam, Germany
4 Leibniz-Institut für Astrophysik Potsdam, An der Sternwarte 16, D-14482 Potsdam, Germany
5 University of Hertfordshire, Physics Astronomy and Mathematics, College Lane, Hatfield AL10 9AB, United Kingdom
6 ICRAR, M468, The University of Western Australia, 35 Stirling Hwy, Crawley 6009, Western Australia, Australia
7 Kavli Institute for Astronomy and Astrophysics, Peking University, Yi He Yuan Lu 5, Hai Dian District, Beijing 100871, China
8 Department of Astronomy, Peking University, Yi He Yuan Lu 5, Hai Dian District, Beijing 100871, China
9 International Space Science Institute–Beijing, 1 Nanertiao, Hai Dian District, Beijing 100190, China
10 School of Physics and Astronomy, Queen Mary University of London, Mile End Road, London E1 4NS, United Kingdom
11 E.A. Milne Centre for Astrophysics, Department of Physics & Mathematics, University of Hull, Hull HU6 7RX
12 Institut voor Sterrenkunde, K. U. Leuven, Celestijnenlaan 200D bus 2401, B-3001 Leuven, Belgium
13 Lennard-Jones Laboratories, Keele University, ST5 5BG, United Kingdom
14 Observatorio Astronómico, Universidad Nacional de Córdoba, Laprida 854, 5000, Córdoba, Argentina
15 Consejo Nacional de Investigaciones Científicas y Técnicas, Av. Rivadavia 1917, C1033AAJ, Buenos Aires, Argentina

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**ABSTRACT**

**Context.** Quasi–stellar objects (quasars) located behind nearby galaxies provide an excellent absolute reference system for astrometric studies, but they are difficult to identify because of fore- and background contamination. Deep wide–field, high angular resolution surveys spanning the entire area of nearby galaxies are needed to obtain a complete census of such quasars.

**Aims.** We embarked on a program to expand the quasar reference system behind the Large and the Small Magellanic Clouds, the Magellanic Bridge, and the Magellanic Stream, connecting the Clouds with the Milky Way.

**Methods.** Hundreds of quasar candidates were selected based on their near–infrared colors and variability properties from the ongoing public ESO VISTA Magellanic Clouds survey. A subset of 49 objects was followed up with optical spectroscopy.

**Results.** We confirmed the quasar nature of 37 objects (34 new identifications), four are low redshift objects, three are probably stars, and the remaining three lack prominent spectral features for a secure classification; bona fide quasars, judging from their broad absorption lines are located, as follows: 10 behind the LMC, 13 behind the SMC, and 14 behind the Bridge. The quasars span a redshift range from $z \sim 0.5$ to $z \sim 4.1$.

**Conclusions.** Upon completion the VMC survey is expected to yield a total of $\sim 1500$ quasars with $Y<19.32$ mag, $J<19.09$ mag, and $K_s<18.04$ mag.

**Key words.** surveys – infrared: galaxies – quasars:general – Magellanic Clouds

1. Introduction

Quasi–stellar objects (quasars) are active nuclei of distant galaxies, undergoing episodes of strong accretion. Typically, the contribution from the host galaxy is negligible, and they appear as point-like objects with strong emission lines. Quasar candidates are often identified by their variability, a method pioneered by Shanks et al. (1991). The recent studies of Gallastegui-Aizpun & Sarajedini (2014), Cartier et al. (2015), and Peters et al. (2015), among others, brought the number of sampled objects up to many thousands. Precise space based photometry was also used (the Kepler mission; Shaya et al. 2015). Gregg et al. (1996) reported a large quasar selection based on their radio properties (see also White et al. 2000; Becker et al. 2001). The radio selection has often been complemented with other wavelength regimes to sample dusty reddened objects (Glikman et al. 2012).

Shanks et al. (1991) demonstrated that the quasars contribute at least a third of the X-ray sky background. The realization that they are powerful X-ray sources led to identification of a large number of faint quasars (e.g. Boyle et al. 1993; Hasinger et al. 1998, and the subsequent papers in these series). Modern X-ray missions continue to contribute to this fields (Loaring et al. 2005; Nandra et al. 2005). More recently, the distinct mid–infrared properties of quasars have come to attention, mainly due to the work of Lacy et al. (2004). These properties have been exploited further by Stern et al. (2012); Assaf et al. (2013), and Ross et al. (2015). Finally, multi-wavelength selections are becoming common (DiPompeo et al. 2015).

Quasars are easily confirmed from optical spectroscopy, aiming to detect broad hydrogen (Ly$\alpha$ 1216 Å, H$\delta$ 4101 Å, Hy 4340 Å, H$\gamma$ 4861 Å, H$\beta$ 6563 Å), magnesium (Mgu 2800 Å), and carbon (Civ 1549 Å, Cm 1909 Å) lines, as well as some narrow
These lines also help to derive the quasar’s redshifts (e.g. Vanden Berk et al. 2001). For distant unmoving objects used to establish an absolute astrometric reference system on the sky, the smaller the measured proper motions (PMs, hereafter) of foreground objects are, the better the match with the actual positions of these objects. The smaller the measured proper motions, the more certain we can be about the location of the VMC counterparts to the spectroscopically confirmed quasars from Kozłowski et al. (2013) (blue). The VMC tiles are shown as contiguous rectangles. The dashed grid shows lines of constant right ascension (spaced by 15°), and constant declination (spaced by 5°). Coordinates are given with respect to ($\alpha_0$, $\delta_0$) = (31°, -69°).

Forbidden lines of oxygen ([O II] 3727 Å, [O III] 4959 Å, 5007 Å) are included among the black dots in regions B and C. These lines also help to derive the quasar’s redshifts (e.g. Vanden Berk et al. 2001).

Quasars are cosmological probes and serve as background “lights” to explore the intervening interstellar medium, but they are also distant unmoving objects used to establish an absolute astrometric reference system on the sky. The smaller the measured proper motions (PMs, hereafter) of foreground objects are, the more useful the quasars become – as is the case for nearby galaxies. Quasars behind these galaxies are hard to identify because of foreground contamination, the additional reddening inside the galaxies themselves (owing to dust), and the galaxies’ relatively large angular areas on the sky, which implies the need to carry out dedicated wide-field surveys, sometimes covering hundreds of square degrees. The Magellanic Clouds system is an extreme case where these obstacles are notably enhanced: the combined area of the two galaxies, the Magellanic Bridge, and the Stream, connecting them with the Milky Way, is at least two hundred square degrees; the significant depth of the Small Magellanic Cloud (SMC) along the line of sight (e.g. de Grijs & Bono 2013) aggravates the contamination and reddening issues.

Cioni et al. (2013) reviewed previous works aiming at discovering quasars behind the Magellanic Clouds. Blanco & Heathcote (1986), Dobrzycki et al. (2002, 2003b, 2005), Geha et al. (2003), Kozłowski & Kochanek (2009, Kozłowski et al. 2012, 2011), and Véron-Cetty & Véron (2010). In this study we add the latest installment of the Magellanic Quasar Survey (MQS) of Kozłowski et al. (2013), who increased the number of spectroscopically confirmed quasars behind the Large Magellanic Cloud (LMC) and SMC to 758, almost an order of magnitude more than before.

The optical surveys can easily miss or misclassify some quasars; near- and mid-infrared surveys are necessary to obtain more complete samples – indeed, ~90% of the MQS quasar candidates were selected from mid-IR Spitzer observations (see also van Loon & Sansom 2015). This motivated us to search for quasars in the VISTA (Visual and Infrared Survey Telescope for Astronomy; Emerson et al. 2006) Survey of the Magellanic Clouds system (VMC; Cioni et al. 2011). The European Southern Observatory’s (ESO) VISTA is a 4.1-m telescope, located on Cerro Paranal, equipped with VIRCAM (VISTA InfraRed CAMera; Dalton et al. 2006), a wide-field near-infrared camera producing ~1×1.5 deg² tiles, working in the 0.9–2.4 µm wavelength range. The VISTA data are processed with the VISTA Data Flow System (VDFS; Irwin et al. 2004; Emerson et al. 2004) pipeline at the Cambridge Astronomical Survey Unit. The data products are available through the ESO archive or the specialized VISTA Science Archive (VSA; Cross et al. 2013).

The VMC is an ESO public survey, covering 184 deg² around the LMC, SMC, the Magellanic Bridge and Stream, down to $K_s=20.3$ mag (S/N~10; Vega system) in three epochs in the $Y$ and $J$ bands, and 12 epochs in the $K_s$ band, spread over at least a year. The main survey goal is to study the star formation history (Kerber et al. 2009, Rubele et al. 2012, 2015; Tatton et al. 2013) and the geometry (Ripepi et al. 2012, 2014, 2015; Tatton et al. 2013; Moretti et al. 2014; Muraveva et al. 2014) of the system. Furthermore, the depth and angular resolution of the VMC survey has the potential to enable detailed studies of the star and cluster populations (Miszalski et al. 2011; Gullieuszik et al. 2012, Li et al. 2014; Piatti et al. 2014, 2015b,a), including PM measurements.

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1. Tiles are contiguous images, combining six pawprints, taken in an offset pattern; pawprint is an individual VIRCAM pointing, generating non-contiguous image of the sky, because of the gaps between the 16 detectors. See Cioni et al. (2011) for details on the VMC’s observing strategy.

2. http://casu.ast.cam.ac.uk/
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SMC 5_2 206g  SMC 5_2 213  SMC 5_2 1003  SMC 5_2 1545  SMC 5_2 241  SMC 5_2 211  SMC 5_2 203

SMC 3_5 82  SMC 3_5 22  SMC 3_5 24  SMC 3_5 15  SMC 3_5 29  SMC 3_5 33  SMC 3_5 18

BRI 3_5 211  BRI 3_5 33  BRI 3_5 127  BRI 3_5 38  BRI 3_5 45  BRI 3_5 137  BRI 3_5 191

BRI 2_8 2  BRI 2_8 136  BRI 2_8 6  BRI 2_8 122  BRI 2_8 16  BRI 2_8 128  BRI 2_8 197

LMC 4_3 95  LMC 4_3 86  LMC 4_3 2050g  LMC 4_3 1029g  LMC 4_3 95g  LMC 4_3 54  LMC 4_3 2423g

LMC 9_3 2414g  LMC 9_3 2639g  LMC 9_3 3107g  LMC 9_3 2375g  LMC 9_3 137  LMC 9_3 2728g  LMC 4_3 3314g

LMC 8_8 376g  LMC 8_8 422g  LMC 8_8 341g  LMC 8_8 655g  LMC 8_8 208g  LMC 8_8 119  LMC 8_8 106

Fig. 3: Finding charts in the $Y$ band for all 49 objects (marked with crosses) with follow up spectroscopy. The images are 1$\times$1 arcmin$^2$. North is at the top and East is to the left.

Cioni et al. (2014) measured the LMC's PM from one $\sim$1.5 deg$^2$ tile, comparing the VISTA and 2MASS (Two Micron All Sky Survey; Skrutskie et al. 2003) data over a time baseline of about ten years and from VMC data alone within a time span of $\sim$1 yr. They used $\sim$40,000 stellar positions and a reference system established by $\sim$8000 background galaxies. Similarly, Cioni
et al. (2015, submitted), measured the SMC’s PM with respect to ~20000 background galaxies. Although numerous, background galaxies are extended sources, and their positions cannot be measured as accurately as the positions of point sources. This motivated us to persist with our search and confirmation of background quasars. The current paper reports spectroscopic follow up of the VMC quasar candidates from a pilot study of only 7 out of the 110 VMC tiles, that were the only ones completely observed at the time of the search. The full scale project intends to select for the first time quasar candidates in the near infrared over the entire Magellanic system.

2. Sample Selection

Cioni et al. (2013) derived selection criteria to identify candidate quasars based on the locus of 117 known quasars in a $(Y-J)$ versus $(J-K_s)$ color–color diagram, and their $K_s$-band variability behavior. The diagram was based on average magnitudes obtained from deep tile images created by the Wide Field Astronomy Unit (WFAU) as part of the VMC data processing, with version 1.3.0 of the VDFS pipeline. The sample selected for our study is based on these criteria and we refer the reader to Cioni et al. (2013) for details. Table 1 lists the VMC identification (ID) used in the spectroscopic observations.

The sixty eight brightest candidates were selected to sample homogeneously 7 VMC tiles where quasars had not yet been found. The total number of candidates can increase greatly if fainter objects are considered. Forty nine of these were followed up spectroscopically. Some contamination from young stellar objects, brown dwarfs, planetary nebulae, and post–AGB stars is expected. Cioni et al. (2013) estimated total number of quasars, with $Y<19.32\,\text{mag}$, $J<19.09\,\text{mag}$, and $K_s<18.04\,\text{mag}$, is: 1200 behind the LMC, 400 behind the SMC, 200 behind the Bridge and 30 behind the Stream. Figure 1 shows the location of all confirmed quasars from the MOS and our candidates selected for follow up spectroscopy, in the $(Y-J)$ versus $(J-K_s)$ color–color diagram. A sky map showing our program objects is displayed in Figure 2 while Figure 3 depicts $Y$-band finding charts for all. Most of our candidates are located in a sky area external to the OGLE III area studied by Kozłowski et al. (2013).

3. Spectroscopic follow up observations

Follow up spectra of 49 candidates were obtained with FORS2 (Focal Reducer and low dispersion Spectrograph, Appenzeller et al. 1998) on the VLT (Very Large Telescope) in September–November 2013, in long-slit mode, with the 300V+10 grism, GG435+81 order sorting filter, and 1.3 arcsec wide slit, delivering spectra over $\lambda\lambda=445–865$ nm with a spectral resolving power $R=\lambda/\Delta\lambda\sim440$. Two 450 s exposures were taken for most objects, except for some cases when the exposure time was 900 s. Occasionally, spectra were repeated because the weather deteriorated during the observations. We used some of the poor quality data, and a few objects objects ended up with more than two spectra. The starting signal–to–noise ratio varies across the spectra, but typically it is $\sim10–30$ at $\lambda=6000–6200\,\text{Å}$. The observing details, including starting times, exposure times, starting and ending airmasses, and slit position angles for each exposure are listed in Table 2 (available only in the electronic edition). The reduced spectra are shown in Figure 4.

The data reduction was carried out with the ESO pipeline, version 5.0.0. The spectrophotometric calibration was carried out with spectrophotometric standards (Oke 1990, Hamuy et al. 1993, 1994, Moehler et al. 2014) and observed and processed in the same manner as the program spectra. Various IRAF tasks from the onedspec and rv packages were used in the subsequent analysis.

Quasar redshifts were measured in two steps. First, we visually identified the emission lines by comparing our spectra with the SDSS quasar composite spectrum (Vanden Berk et al. 2001). Given our wavelength coverage, if only one feature were visible, it would have to be Mg II at $z=1.1–1.3$ – otherwise another of the more prominent quasar lines would have to fall within the observed spectral range. Then, we measured the wavelengths of the features (mostly emission lines, but also some hydrogen absorption lines visible in the lower redshift objects), fitting them with a Gaussian profile using the IRAF task split. This proved to be an adequate representation, given the low resolution of our spectra. The lines, their observed wavelengths and the derived redshifts are listed in Table 2. Some emission lines were omitted, if they fell near the edge of the wavelength range, or if they were contaminated by sky emission lines, and the sky subtraction left significant residuals. For most line centers the typical formal statistical errors are $\sim1\,\text{Å}$ and they translate into redshift errors less than 0.001. These are optimistic estimates that neglect the wavelength calibration error. We evaluated the latter by measuring the wavelengths of 45 strong and isolated sky lines in five randomly selected spectra from our sample, and found no trends with wavelength, and an r.m.s. of 1.57 Å. This translates into a redshift uncertainty of $\sim0.0002$ for a line at 7000 Å, near the center of our spectral coverage.

To evaluate the real uncertainties we compared the redshifts derived from different lines of the same object (Figure 5 top). The average difference for 35 pairs of lines is effectively zero: $<|z_2-z_1|>=0.006\pm0.007$. For objects with multiple lines we adopted the average difference as redshift error, adding in quadrature the wavelength calibration error of 0.0002. This addition only made a difference for a few low redshift objects. For quasars for which only a single line was available, we conservatively adopted as redshift errors the values 0.005 for objects with $z<1$ and 0.015 for the more distant ones. Finally, as external verification we re–measured in the rest–frame SDSS composite spectrum the redshifts of the same lines that were detected in our spectra, obtaining values below 0.0001, as expected.

3 The Image Reduction and Analysis Facility is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy (AURA) under a cooperative agreement with the National Science Foundation.

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4. Results

The majority of the observed objects are quasars: 37 objects (in the first four panels of Fig. 4) appear to be bona fide quasars at $z \sim 0.47-4.10$, showing some broad emission lines, even though some spectra need smoothing (block averaging, typically by 4–8 resolution bins) for display purposes. The spectra of the three highest redshift quasars show Lyα absorption systems; a few quasars (e.g., SMC 3_5 22, BRI 2_8 197, etc.) show blue-shifted C iv absorption (Fig. 4 panel I), perhaps due to an AGN wind. We defer more detailed study of individual objects until the rest of the sample have been followed up.

These objects are marked in the last column of Table 1 as quasars: 10 are behind the LMC, 13 behind the SMC and 14 behind the Bridge area. The VDFS pipeline classified 28 of the confirmed quasars as point sources, and 9 as extended (recognizable by the “g” in their names). The latter does not necessarily mean that the VISTA data resolved their host galaxies, since the extended sources are uniformly spread over the redshift range — about half of them have $z \sim 1–2$, and random alignment with objects in the Magellanic Clouds can easily affect their appearance. Our success rate is $\sim 76\%$, testifying to the robustness and reliability of our selection criteria. There seem to be relatively more candidates that turned out not to be quasars in region B than in
Table 2: Observing log for the spectroscopic observations. Starting times, exposure times, starting and ending airmasses, and slit position angles for each exposure are listed on separate successive lines.

| Object ID | UT at start of obs. yyyy-mm-ddThh:mm:ss | Exp. (s) | sec z (deg) | SiltPA (deg) | Object ID | UT at start of obs. yyyy-mm-ddThh:mm:ss | Exp. (s) | sec z (deg) | SiltPA (deg) |
|-----------|------------------------------------------|----------|-------------|--------------|-----------|------------------------------------------|----------|-------------|--------------|
| SMC 5 _2 206g | 2013-09-19T03:07:22.058 450 1.584–1.533 39.480 | 2013-12-09T01:28.759 450 1.570–1.557 28.848 |
| SMC 5 _2 213 | 2013-09-19T03:38:04.857 450 1.518–1.510 28.975 | 2013-12-17T01:40:09.277 450 1.577–1.570 28.516 |
| SMC 5 _2 1003g | 2013-09-19T05:09:22.058 450 1.547–1.548 16.32 | 2013-12-17T01:48:23.554 450 1.571–1.565 28.516 |
| SMC 5 _2 203 | 2013-09-19T05:09:22.058 450 1.547–1.548 16.32 | 2013-12-17T01:48:23.554 450 1.571–1.565 28.516 |
| SMC 5 _3 82 | 2013-09-19T03:38:49.396 450 1.476–1.477 15.682 | 2013-12-16T01:39:56.300 450 1.513–1.505 33.443 |
| SMC 5 _3 24 | 2013-09-19T03:38:49.396 450 1.476–1.477 15.682 | 2013-12-16T01:39:56.300 450 1.513–1.505 33.443 |
| SMC 5 _3 15 | 2013-09-19T03:38:49.396 450 1.476–1.477 15.682 | 2013-12-16T01:39:56.300 450 1.513–1.505 33.443 |
| SMC 5 _3 29 | 2013-09-19T03:38:49.396 450 1.476–1.477 15.682 | 2013-12-16T01:39:56.300 450 1.513–1.505 33.443 |
| SMC 5 _3 33 | 2013-09-19T03:38:49.396 450 1.476–1.477 15.682 | 2013-12-16T01:39:56.300 450 1.513–1.505 33.443 |
| SMC 5 _3 18 | 2013-09-19T03:38:49.396 450 1.476–1.477 15.682 | 2013-12-16T01:39:56.300 450 1.513–1.505 33.443 |
| BRI 3 _5 211 | 2013-10-19T03:40:13.964 450 1.570–1.557 28.516 | 2013-12-17T01:40:09.277 450 1.577–1.570 28.516 |
| BRI 3 _5 33 | 2013-10-19T03:40:13.964 450 1.570–1.557 28.516 | 2013-12-17T01:40:09.277 450 1.577–1.570 28.516 |
| BRI 3 _5 127 | 2013-10-19T03:40:13.964 450 1.570–1.557 28.516 | 2013-12-17T01:40:09.277 450 1.577–1.570 28.516 |
| BRI 3 _5 38 | 2013-10-19T03:40:13.964 450 1.570–1.557 28.516 | 2013-12-17T01:40:09.277 450 1.577–1.570 28.516 |
| BRI 3 _5 45 | 2013-10-19T03:40:13.964 450 1.570–1.557 28.516 | 2013-12-17T01:40:09.277 450 1.577–1.570 28.516 |
| BRI 3 _5 137 | 2013-10-19T03:40:13.964 450 1.570–1.557 28.516 | 2013-12-17T01:40:09.277 450 1.577–1.570 28.516 |
| BRI 3 _5 191 | 2013-10-19T03:40:13.964 450 1.570–1.557 28.516 | 2013-12-17T01:40:09.277 450 1.577–1.570 28.516 |
| BRI 2 _8 | 2013-10-19T03:40:13.964 450 1.570–1.557 28.516 | 2013-12-17T01:40:09.277 450 1.577–1.570 28.516 |
| BRI 2 _8 | 2013-10-19T03:40:13.964 450 1.570–1.557 28.516 | 2013-12-17T01:40:09.277 450 1.577–1.570 28.516 |
| BRI 2 _8 | 2013-10-19T03:40:13.964 450 1.570–1.557 28.516 | 2013-12-17T01:40:09.277 450 1.577–1.570 28.516 |

region A of the color–color diagram (see Fig.1), but for now our statistical basis is small; follow up of more candidates is needed to draw any definitive conclusion.

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Table 3: Derived parameters for the object in this paper. Detected spectral features and their central wavelengths, estimated redshifts, and the object classifications are listed.

| Object ID | Spectral features and observed wavelength (Å) | Redshift z | Classification |
|-----------|---------------------------------------------|------------|----------------|
| SMC 5_2 206g | Hy 7030.68±1.31, Hβ 7890.34±0.24, [OIII] 7993.89±0.28, [OII] 8118.30±0.26 | 1.0±0.006 | quasar |
| SMC 5_2 213 | Mgr 6128.54±1.71, Hδ 6094.61±0.06, Hγ 7165.82±0.24 | 1.19±0.015 | quasar |
| SMC 5_2 1003g | Mgr 4731.83±0.05, Hδ 8249.33±0.09 | 1.87±0.007 | quasar |
| SMC 5_2 241 | Sirv 7129.73±1.63, CIV 7887.24±1.61 | 1.86±0.006 | quasar |
| SMC 5_2 211 | Mgr 8011.68±2.19, [OII] 8098.58±2.39, CIV 6200.63±1.10 | 1.59±0.006 | quasar |
| SMC 5_2 203 | CIV 5999.83±1.22, [OIII] 5371.40±2.13, Mgr 7913.45±3.23 | 1.90±0.013 | quasar |
| SMC 3_5 24 | CIV 4839.23±2.87, Mgr 7137.49±2.44 | 1.54±0.015 | quasar |
| SMC 3_5 15 | Hα 6578.83±0.01, Hβ 4863.61±0.67 | 1.00±0.003 | star |
| SMC 3_5 33 | CIV 6200.63±1.10, [OIII] 7913.45±3.23 | 2.24±0.003 | quasar |
| SMC 3_5 22 | Mgr 6262.75±0.99, CIV 5417.57±0.99 | 1.36±0.015 | quasar |
| SMC 3_5 22 | Mgr 5069.65±0.04, Mgr 8256.13±2.15 | 1.94±0.014 | quasar |
| SMC 3_5 33 | CIV 6076.02±2.14, Mgr 7446.36±0.67 | 1.55±0.006 | quasar |
| SMC 3_5 127 | Mgr 8011.68±2.19 | 1.58±0.010 | quasar |
| SMC 3_5 38 | Mgr 7258.02±1.32 | 1.33±0.015 | quasar |
| SMC 3_5 45 | CIV 5417.57±0.99 | 1.97±0.015 | quasar |
| SMC 3_5 137 | Mgr 8256.13±2.15 | 1.94±0.014 | quasar |
| SMC 3_5 191 | CIV 6004.60±1.31, CIV 6651.75±3.87 | 3.29±0.005 | quasar |
| BRI 2_8 2 | Sirv 4877.55±1.46, CIV 5374.87±1.36 | 2.47±0.022 | quasar |
| BRI 3_5 119 | Mgr 6128.07±0.20 | 1.91±0.015 | quasar |
| BRI 3_5 106 | Mgr 5161.42±2.87 | 1.70±0.015 | quasar |

The majority of quasars with redshift z≤1 were classified as extended sources by the VDFS pipeline, supporting our decision to include extended objects in the sample. Four extended objects are contaminating low redshift galaxies: LMC 9_3 2728g, LMC 8_8 655g, and LMC 8_8 208g show hydrogen, some oxygen and nitrogen in emission, but no obvious broad lines, so we interpret these as indicators of ongoing star formation rather than nuclear activity, while LMC 8_8 341g may also show Hβ in absorption. Furthermore, LMC 8_8 341g has a recession velocity of ~300 km s⁻¹, consistent with the uncertainties with LMC membership (V_p=262.2±3.4 km s⁻¹, McCann et al. 2012), making it a possible moderately young LMC cluster. The spectra of all these objects are shown in Fig. 5 panel 5.

Three point–source–like objects are most likely emission line stars: LMC 4_3 95, LMC 4_3 86, and SMC 3_5 29. These spectra are also shown in Fig. 4 panel 5.

The spectra of LMC 8_8 422g, LMC 4_3 3314g, and LMC 9_3 3107g (Fig. 4 panel 5) offer no solid clues as to their nature. Some BL Lacetiae – active galaxies believed to be seen along a relativistic jet coming out of the nucleus – are also featureless, but they usually have bluer continua than the spectra of these three objects (Landoni et al. 2013). A possible test is to search for rapid variability, typical of BL Lacs, but the VMC cadence is not well suited for such an exercise, and the light curves of the three objects show no peculiarities. Finally, the spectra of LMC 4_3 1029g and LMC 8_8 376g (Fig. 4 panel 5) are too noisy for secure classification. The spectra of the five objects with no classification are plotted in the last panel in Fig. 4 at redshifts z=0 to facilitate easier comparison with the sky spectrum shown just below them.

6 Spectral library: [http://archive.oapd.inaf.it/zblac](http://archive.oapd.inaf.it/zblac)
After target selection we realized that three of our candidates were previously confirmed quasars, and two more were suspected to be quasars. Tinney et al. (1997) selected SMC 5_2 203 (their designation [TDZ97] QJ0035−7201 or SMC-X1-R-4; our spectrum is plotted in Fig. 4, panel 4) from unpublished ROSAT SMC observations. They confirmed it spectroscopically, and estimated a redshift of $z=0.666 \pm 0.001$, in excellent agreement with our value $z=0.667 \pm 0.015$. Kozłowski et al. (2013) identified SMC 3_5 24 and SMC 3_5 15 (Fig. 4, panels 2 and 3, respectively), and reported spectroscopic confirmation of their quasar nature, measuring redshifts of $z=1.821 \pm 0.013$ and $z=1.543 \pm 0.015$, respectively. LMC 9_3 137 and LMC 4_3 395a were listed as AGN candidates by Kozłowski & Kochanek (2009): [KK2009] J050434.46−641844.4 and [KK2009] J045709.93−713231.0, respectively, based on their mid-infrared colors (Fig. 4 panels 2 and 3, respectively).

The ROSAT all-sky survey (Voigt et al. 1999) reported an X-ray source at a separation of 7″ from our estimated position of the confirmed quasar LMC 8_8 119 (Fig. 4 panel 4). Flesch (2010) associated the X-ray source with a faint object on the Palomar Observatory Sky Survey, but estimated 50% probability...
that this is a random alignment, and only 17% that the X-ray emission originates from a quasar.

Many of our quasars are present in the GALEX (Galaxy Evolution Explorer; Morrissey et al. 2007) source catalog, and in the SAGE–SMC (Surveying the Agents of Galaxy Evolution – Small Magellanic Cloud; Gordon et al. 2011) source catalog. The confirmed quasar SMC 5_2 241 (Fig. 4, panel 1) stands out – in addition to the GALEX and SAGE detections, it has a candidate radio counterpart: SUMSS J002956−714640 at 2.8 arcsec separation from the 843 MHz Sydney University Molonglo Sky Survey (Bock et al. 1999; Mauch et al. 2003).

We revised the light curves of our observed objects because a larger number of \( K \) band measurements have become available since the target selection in Cioni et al. (2013), allowing us to investigate further the near–infrared variability properties of the quasars. Light curves based on all individual pawprint measurements, from all processed data at CASU as of March 2015, for all our objects are shown in Fig. 5 (available only in electronic form). We applied the same variability parameterization with the slope of a linear fit to the light curve, as in Cioni et al. (2013). The distribution of absolute slope values (i.e., slope variation) shows a dip corresponding to flat light curves which corresponds to our criterion to select variable sources with slope variation >0.0001 mag day\(^{-1}\) (Fig. 7). The additional data have moved some of the selected quasars into the low–variation zone.

Cioni et al. (2013) estimated that the VMC survey will find in total about 1830 quasars. The success rate of 76% reached in this paper brings this number down to about 1390. The spectra of the candidates in seven tiles, out of the 110 tiles that comprise the entire VMC survey, yielded on average \( \sim 5.3 \) quasars per tile. Scaling this number up to the full survey area yields \( \sim 80 \) quasars. This is a lower limit, because only the brightest candidates in the seven tiles were followed up, so the larger number is still a viable prediction.

5. Summary

We report spectroscopic follow up observations of 49 quasar candidates selected based on their colors and variability. They are located behind the LMC, SMC, and the Bridge area connecting the Clouds: 37 of these objects are bona fide quasars of which 34 are new discoveries. Therefore, the success rate of our quasar search is \( \sim 76 \% \). The project is still at an early stage, but once the spectroscopic confirmation has been obtained, the identified quasars will provide an excellent reference system for detailed astrometric studies of the Magellanic Cloud system. Furthermore, the homogeneous multi–epoch observations of the VMC survey, together with the large quasar sample, open up the possibility to investigate in detail the mechanisms that drive quasar variability, for example, with structure functions in the near–infrared, following the example of the SDSS quasar variability studies (e.g. Vanden Berk et al. 2004).

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Fig. 6: Light curves of the observed targets with their measurement errors as function of the time since the first available VMC observation. The lines show linear fits to the light curve, following Cioni et al. (2013).
Fig. 7: Histograms of the slope variations (top; the vertical dashed line shows the slope variation limit of 0.0001 mag day$^{-1}$, adopted in our quasar selection) and the slope uncertainties (bottom) for linear fits to the light curves of the objects in our sample.