Variability-selected quasars behind the Small Magellanic Cloud¹

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ABSTRACT

We present followup spectroscopic observations of quasar candidates in the Small Magellanic Cloud selected by Eyer from the OGLE database. Of twelve observed objects identified as “QSO Candidate”, five are confirmed quasars, with the emission redshifts ranging from 0.28 to 2.16. Two of those quasars were also recently identified independently in the MACHO database by Geha et al. We discuss the prospects of using variability-based selection technique for quasar searches behind other dense stellar fields.

Subject headings: Magellanic Clouds — quasars: individual

1. Introduction

Searches for quasars in dense stellar fields — such as the Magellanic Clouds — were in the past hampered by difficulties in selecting candidates. Optical followup on X-ray selected objects had to deal with large number of candidates in X-ray source error boxes, while variability studies required monitoring of vast number of objects. At the same time, such quasars are of great astrophysical interest, for example as reference points for analysis of proper motions and as background sources for absorption studies. Only a handful of confirmed quasars

¹Based on observations collected at the Magellan Baade 6.5-m telescope.

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behind the LMC and SMC were known (Blanco & Heathcote 1986; Crampton et al. 1997; Tinney et al. 1997; Anguita, Loyola, & Pedreros 2000; see also Kahabka et al. 1999, Haberl et al. 2000 and Kahabka, de Boer, & Brüns 2001). Almost all of those quasars were located behind the outer, sparse parts of the Clouds.

Recent developments — such as the launch of the Chandra X-ray Observatory with its superb spatial resolution in X-rays, and availability of large photometry databases (OGLE, MACHO) — are now making systematic searches for quasars in dense stellar fields possible. Recently, Dobrzycki et al. (2002) found four X-ray quasars among serendipitous sources in four Chandra observations of objects in the LMC coinciding with the OGLE fields. Even more recently, Geha et al. (2002) published a list of forty seven quasars behind the LMC and SMC, selected from the MACHO database.

A characteristic that was often used in quasar surveys was their irregular variability. Several such surveys were performed or are on-going (Hawkins 1983; Meusinger & Brunzendorf 2001; Rengstorf et al. 2001; Geha et al. 2002).

Between 1997 and 2001, large parts of the Magellanic Clouds were monitored for microlensing events by the Optical Gravitational Lensing Experiment (OGLE-II: Udalski, Kubiak & Szymański 1997). Udalski et al. (1998) released photometry and astrometry of 2.2 million objects from the central parts of the SMC. In addition, a large catalog of 68,000 variable objects observed by OGLE-II in both the LMC and the SMC was prepared by Žebruń et al. (2001), based on a version of the image subtraction software (Alard & Lupton 1998) developed by Woźniak (2000).

Eyer (2002) presented an algorithm for selecting quasar candidates from objects in the OGLE database. He searched the database for slowly and irregularly varying blue objects and identified QSO candidates (“QCs”) towards the Magellanic Clouds: 118 QCs towards the LMC and 15 towards the SMC. Eyer also identified several “Unclassified” objects, which had similar light curve characteristics.

In 2002 September, we performed followup observations of twelve brightest “QSO Candidates” from the SMC from the Eyer’s list with the Magellan 6.5-meter Baade telescope. Five of them turned out to be previously unknown quasars; an excellent success rate. We also observed all four of Eyer’s “Unclassified” objects in the direction of the SMC and none of them turned out to be a QSO.

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6Data available from ftp://bulge.princeton.edu/ogle/ogle2/maps/smc/

7Data available from http://bulge.princeton.edu/~ogle/ogle2/dia/
Coincidentally, less then a week after our observations had been completed, the paper by Geha et al. (2002) was posted on astro-ph. In this paper, the authors performed an analysis of the MACHO variable star database. They selected 360 quasar candidates behind the Magellanic Clouds, and completed followup observations of 259 of them. In that way, they identified forty seven quasars: thirty eight behind the LMC and nine behind the SMC. Three of their SMC objects were on the list of Eyer’s candidates: two quasars and a Be star.

In this paper, we present the identifications of the new quasars behind the SMC, and we discuss the prospects for application of Eyer’s method for quasar searches behind other dense stellar fields.

2. Observations and identifications

The optical spectra were obtained on 2002 September 16-18 with the Magellan Baade 6.5 meter telescope. We used the LDSS-2 imaging spectrograph, with a 2048×2048 SITe#1 CCD with a scale of 0.38 arcsec/pixel, a gain of 1 $e^-$/ADU, and a readout noise of $7e^-$. The slit width was 1.03 arcsec and the grism setting was 300 l/mm, yielding a nominal resolution of 13.3 Å. Exposure times ranged from 120 to 600 seconds. All observations were carried out with the slit oriented in the east-west direction. Additionally, we observed two spectrophotometric standards, LTT 1788 and LTT 7379 (Hamuy et al. 1992). Following each observation, a He-Ne arc lamp spectrum was acquired for wavelength calibration purposes. Spectra were reduced in the standard way using IRAF.

Figure 1 shows the spectra of twelve of Eyer’s QC objects. There are five confirmed quasars among them, and we show their spectra on the left panel, while on the right panel one can find spectra of objects that turned out to be stars. We summarize the object properties in Table 1. We also observed all four of Eyer’s “Unclassified” objects, which all turned out to be stars; for completeness, we include this information in Table 1.

The spectra of all five quasars show at least two emission lines, enabling unambiguous determination of emission redshifts. As mentioned earlier, two of those quasars (QSO J010234.69–725424.1 and QSO J010721.61–724845.5) were independently identified by Geha et al. (2002).

On Figure 2 we show the OGLE light curves of the QC objects. This plot is arranged similarly to Fig. 1. Qualitatively, we do not see any obvious trends or differences between the light curves of quasars and stars.
Fig. 1.— Magellan spectra of twelve brightest "Quasar Candidates" from Eyer (2002). Left panel shows identified quasars, right panel shows objects that turned out to be stars.
Fig. 2.— OGLE (Żebruń et al. 2001) light curves for objects from Figure 1, arranged in a similar way.
Table 1. Object identifications.

<table>
<thead>
<tr>
<th>OGLE ID(^a)</th>
<th>V [mag]</th>
<th>Eyre ID</th>
<th>Identification</th>
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<tr>
<th>Quasar Candidates</th>
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<tr>
<td>003850.79–731053.1</td>
<td>17.683</td>
<td>S1</td>
<td>QSO, (z_{em} = 0.28)</td>
</tr>
<tr>
<td>004743.68–731630.1</td>
<td>17.532</td>
<td>S3</td>
<td>F star</td>
</tr>
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<td>004818.25–731242.8</td>
<td>17.446</td>
<td>S4</td>
<td>A star</td>
</tr>
<tr>
<td>004905.87–730257.5</td>
<td>17.973</td>
<td>S5</td>
<td>B star</td>
</tr>
<tr>
<td>005136.59–732016.5</td>
<td>18.036</td>
<td>S6</td>
<td>Be star</td>
</tr>
<tr>
<td>005316.80–724219.9</td>
<td>19.263</td>
<td>S7</td>
<td>G star</td>
</tr>
<tr>
<td>005418.96–723737.7(^b)</td>
<td>18.137</td>
<td>S8</td>
<td>Be star</td>
</tr>
<tr>
<td>005448.97–722544.6</td>
<td>19.001</td>
<td>S9</td>
<td>QSO, (z_{em} = 1.79)</td>
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<tr>
<td>010127.64–722422.6</td>
<td>19.058</td>
<td>S13</td>
<td>F star</td>
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<tr>
<td>010234.69–725424.1(^b),(^c)</td>
<td>18.346</td>
<td>S12</td>
<td>QSO, (z_{em} = 2.12)</td>
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<td>010244.89–721521.7</td>
<td>18.892</td>
<td>S11</td>
<td>QSO, (z_{em} = 1.06)</td>
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<tr>
<td>010721.61–724845.5(^b),(^d)</td>
<td>18.970</td>
<td>S15</td>
<td>QSO, (z_{em} = 2.16)</td>
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<td>004504.34–724449.9</td>
<td>17.906</td>
<td>S22</td>
<td>F star</td>
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<tr>
<td>004702.90–730800.7</td>
<td>18.036</td>
<td>S23</td>
<td>F star</td>
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<tr>
<td>005039.12–724154.3</td>
<td>18.871</td>
<td>S24</td>
<td>F star</td>
</tr>
<tr>
<td>005137.19–731429.2</td>
<td>17.221</td>
<td>S25</td>
<td>Be star</td>
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</table>

\(^a\)OGLE ID contains J2000.0 equatorial coordinates.

\(^b\)Object identified in MACHO database by Geha et al. 2002.

\(^c\)Near object 171 in Kahabka et al. 1999 and object 182 in Haberl et al. 2000.

\(^d\)Near object 203 in Kahabka et al. 1999 and object 338 in Haberl et al. 2000.
3. Discussion

We have identified five variability-selected quasars among twelve brightest Quasar Candidates identified by Eyer (2002) based on the characteristics of their light curves in the OGLE database. The method is very efficient. As expected, the contaminants in the list of candidates were predominantly early type stars in the SMC.

As mentioned earlier, until very recently only a handful of confirmed quasars were known in the general direction of the SMC (Crampton et al. 1997; Tinney et al. 1997). All those quasars are located in fairly sparse stellar fields away from the center of the SMC, which limits their applicability to studies of SMC proper motion or investigations of absorption properties of the SMC. Quasars presented in the present paper and objects from Geha et al. (2002) lie behind the dense parts of the SMC. Note that those quasars — extremely interesting and useful objects in their own right — are in reality byproducts of monitoring surveys, unrelated to the original scientific goals of the surveys. It is an excellent example that such projects can lead to unexpected, yet very valuable results.

Geha et al. (2002) independently identified two of our quasars. We note that those two objects are the largest redshift quasars among our five, but this most likely is just a coincidence, not a result of the difference in the methods applied by Geha et al. and Eyer. Geha et al.’s quasar redshifts span a large redshift range. We note, however, that two methods, which, after all, are based on a similar concept, apparently have a rather small intersection in the final candidate lists: there are only ten objects in common in both the SMC and LMC. We interpret this fact as an indication that those two methods should be considered as complementing one another, not as competing.

We also note that the same two quasars lie relatively close to Rosat X-ray sources listed in Kahabka et al. (1999) and Haberl et al. (2000), although neither one of the X-ray sources was classified as a probable AGN.

One of the quasars identified in this paper, QSO J003850.79–731053.1 (\(z_{\text{em}} = 0.28\), \(V = 17.7\)) is a very promising candidate for studies of absorption in the SMC. Its brightness should enable good spectroscopy with the Cosmic Origin Spectrograph aboard the Hubble Space Telescope. The other four quasars and quasars from Geha et al. (2002) are very well positioned to be reference points for SMC proper motion studies. We add here that we also identified six other X-ray selected quasars behind the dense parts of the SMC; we will present them in the forthcoming paper (Dobrzycki et al. 2003, in preparation).

We were somewhat surprised to find a G-type star among Eyer’s QC objects, especially since he did utilize color selection in constructing the list of candidates. However, it was also the faintest of the observed objects, for which the photometry is likely rather uncertain.
Excellent efficiency of the variability-based method bodes well for searches of quasars behind other dense stellar fields for which monitoring photometry databases are available. A first successful search has already been published by Geha et al. (2002), who found 38 QSOs behind the LMC in the MACHO database. The paper by Eyer (2002) contains a list of 155 QSO candidates behind the LMC. Geha et al. identified two of them as quasars and five as Be stars.

Another extremely interesting region to search for quasars where the method could be applied is the Galactic Bulge. To our knowledge, no quasars have been identified so far in the vicinity of the Galactic center. There are, however, several regions where interstellar extinction is quite low ($A_V < 3$) and where one could, in principle, see quasars. The best known such area is Baade’s Window (e.g. Stanek 1996), but there are several other.

Identifying quasars behind the Galactic Bulge would be very valuable. Recently, Sumi, Eyer, & Woźniak (2002) have shown that there is a statistically significant difference between proper motions of faint versus bright red clump stars in one of the OGLE bulge fields. Finding fixed reference points for this study, which quasars could provide, would be an extremely interesting result.

On one hand, the search toward the Galactic bulge will be made easier by the fact that there will be few early type stars, which in the Magellanic Clouds are the primary contaminants in the candidate lists. On the other hand, the quasars will be considerably reddened even in the low extinction windows, making them less conspicuous as blue objects. Also, the surface density of objects that need to be analyzed will be very large, and as a result there will likely be a sizeable number of artifacts, etc., which will contaminate the candidate lists.

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