Astronomical and Astrophysical Transactions (*AApTr*), 2017, Vol. 30, Issue 2, pp. 261–270,
ISSN 1055-6796, Photocopying permitted by license only, ©Cambridge Scientific Publishers

WISE Detections of SBS QSOs

Lidia K. Erastova*, Areg M. Mickaelian

V.A. Ambartsumian Byurakan Astrophysical Observatory, National Academy of Sciences of the Republic of Armenia, Byurakan 0213, Aragatzotn Province, Armenia

Received 1 March, 2017

The Second Byurakan Survey (SBS) General Catalogue (GC) was published in 2005. However the Survey was not finished and its aims were not achieved up to now. Some 450 stellar and diffuse objects are "unobserved" or "unclassified" ones. They do not have activity types. Our work is aimed at using multiwavelength data, mostly WISE infrared photometry, to determine the physical nature of SBS GC unidentified objects. We carried out cross-correlation of all SBS stellar objects with WISE data. We constructed color–color plots for different types of known SBS objects. A simple color–color and color–magnitude selection criterion with WISE 3.4, 4.6, 12 and 22 μm bands is used to distinguish QSOs from stars in the SBS lists. The diagram (W2–W3) vs. (W3–W4) is used as color–color criterion. We determined the primary regions of each type of objects. 32 "unobserved" or "unclassified" SBS stellar objects are located in the region of QSOs. We checked them in SDSS DR12. 12 of these have slit spectra and really are QSOs. None from the objects of other types was found among them. We claim that all these objects are QSOs or BLL. The upgraded SBS survey contains 612 QSOs. The reasons for individual QSOs falling in the region of stars location and vice versa are discussed.

Keywords: Astronomical surveys, active galactic nuclei, quasars, color–color diagrams

1 Introduction

Up to now the search for active extragalactic objects from UV excess continuum in optical range of spectra is the most powerful. This was shown in two basic papers of the past century: search for galaxies with excess in UV continuum in their spectra – Markarian (Markarian 1967) galaxies, and the first QSO sample in the BQS (Schmidt & Green 1983) survey. The second paper attracted attention because its authors discovered the QSOs evolution. Discussion about this result and the sample's completeness continue up to now. The great number of papers published on the study of this sample still has not decreased. In 2005 the survey authors studied the sample by its comparison with the SDSS data and they did not find systematic significant incompleteness when comparing the BQS data with the SDSS quasar sample (Jester et al. 2005).

*Email: lidaerastova8@gmail.com

However this method leads to the fact that in addition to QSOs we at the same time find a great majority of degenerative stars at high galactic latitudes having strong UV continuum. So in BQS only 10% of stellar objects turned out to be QSOs (Green et al. 1986). It is also true for other surveys of this type. Some spectral surveys up to now are not finished: for many objects slit spectra are not received. The same is true for the SBS survey.

At present other ranges of electromagnetic spectrum became available.

Apparently the most successful result for hunting QSOs is the IR range, namely WISE survey, working in the range 4.6–22 μm (version AllWISE; Cutri et al. 2013).

Note that the data from WISE survey currently are widely used in the search for different types of rare objects (Bridge et al. 2013), such as high-z QSOs and other search works (Assef et al. 2013). There are also works on selection of AGN based on WISE colors (e.g. Jarrett et al. 2011; Stern et al. 2012).

2 The Second Byurakan Survey (SBS)

SBS survey is the continuation of the First Byurakan Survey (FBS) to weaker limiting magnitudes. It could be achieved by using new fine-grained astronomical emulsions and the improved techniques of observations. The SBS survey was in fact the first survey, which at the same time extracted either stellar or diffuse objects on the same survey plates. Systematic observations were started in 1978. A total area of 991 deg^2 of the Northern sky was covered. This area is a region between 07^h40^m<RA<17^h15^m and +49°<Dec<+61°. It was conducted with the same 1 m Schmidt telescope of Byurakan Astrophysical Observatory as FBS using the new small-grained (higher resolution) emulsions Kodak IIIaJ, IIIaF and its modifications with the combination of 1.5° objective prism as a basic one and 3° and 4° objective prisms as the additional ones in combination with corresponding filters.

The SBS General Catalogue (GC) was published by Stepanian (2005).

Relevant samples of certain types of active extragalactic objects were created to investigate the interconnection of different types of activity. Among stellar objects beside quasars, Seyfert-type galaxies, BCDGs, and BL Lac often occur. Note that most of the other surveys of this type were often devoted to the search for and detection of a single type of objects, for example, QSOs. It is very like the Case Survey, which began later.

SBS, as other surveys of this type, also discovers as a by-product degenerate stars at high galactic latitudes. Among them may be quasars. However, such stars have separate interest.

In this paper we used the sample of SBS stellar objects from the new electronic version of corrected and completed SBS Catalogue (unpublished). All quasar data were checked with the SDSS DR7, DR8 and DR9 data. We removed "false" quasars, which are in fact stars, and on the contrary added quasars from unobserved objects, the physical nature of which was clarified in SDSS survey.

It is interesting to divide stellar objects along their physical types using WISE data. Probably we can establish the nature of these objects, which we have not yet observed, i. e. they do not have slit spectra.

3 The SBS-WISE Sample

The cross correlation of all 1700 stellar objects with the WISE Survey with different radii was done. Objects having associations with WISE were divided into three basic types: stars, quasars, and "unobserved"/"unclassified" objects for further consideration. In the course of the work we added two new individual types – BL Lac and stellar (compact?) galaxies.

The absolute number of associations of QSOs were discovered inside the radius $<1''$ and only 5 QSOs are located between $2''$–$2.3''$.

Note that we found in WISE all our discovered and confirmed SBS QSOs. None of the WISE quasars were found to have more than one SBS counterpart.

Especially we should focus on the problem of cross-correlation of SBS stars. Note, that most of the stars are degenerate ones – white dwarfs and subdwarfs and may have notable proper motions. In Fig. 1 the distribution of proper motions (PM) for all our stars and "unobserved"/"unclassified" objects is given. It is seen that only 2 stars have PM > 1000 mas/yr, 2 have PM between 500–600 and 1 between 400–500 mas/yr (unpublished). The overwhelming majority of stars have PM < 100 mas/yr. For such stars, cross-correlation gives real results. We checked on WISE charts each such star with great PM. After such (preventative) consideration we carried out cross-correlation with $20''$ radius.

At first we do not restrict our objects list along signal-to-noise ratios in WISE. But then we removed all weak and very weak stars usually with W1 and W2 < 16.5–17 and weaker in IR with low signal/noise.

It is clear that our stars often are in double or multiple objects and must be accurately separated especially if there is a nearby bright star.

But our objects present special attention in contact or unresolved with IR objects, which are weak in optical range but bright enough in IR. This may be checked only to review individual objects.

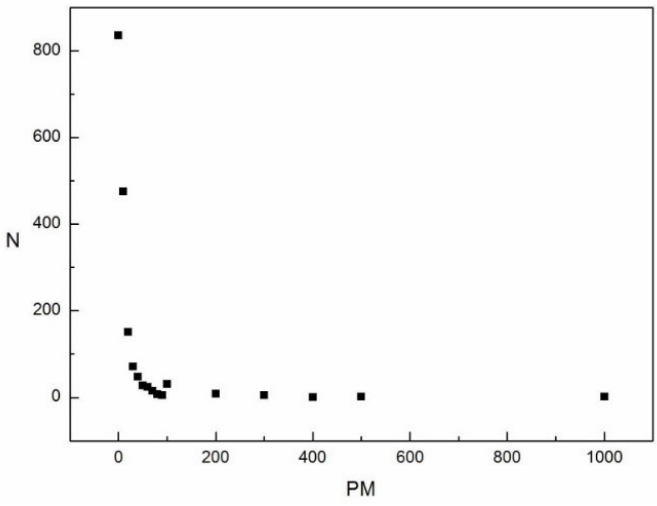


Figure 1 Proper motion distribution of SBS stars.

After that the total stellar objects subsample under consideration consists of 1495 objects.

We plot all possible color–color and color–magnitude diagrams, such as W1–W2 vs. W2–W3, W2–W3 vs. W3–W4 and W1 vs. W2–W3, and restricted the regions of quasars and stars loci, which are well separated from each other in all magnitude ranges in SBS survey. Other combinations of color–color and color–magnitude diagrams also work.

Such diagrams work for all ranges of optical magnitudes and redshifts.

4 Results

In Fig. 2 we give the plot W2–W3 vs. W3–W4. Now a color–color diagram was plotted in WISE color space, showing, where the SBS quasars or stars counterparts lie. The plot is made using W2–W3, which represents magnitude of 4.6–12 μm, on the x axis and W3-W4, which represents magnitude of 12 μm–22 μm, in the y axis.

The region of the most concentration of quasars is restricted by (W2–W3) between 2–4, and (W3–W4), between 1.5–3.

Some part of stars and quasars fall in the strip, dividing these types of objects between (W2–W3) 2.8–3. It is necessary to study each of these cases in detail.

Now as an example we examine only some objects, which are not located in the place where the majority of this type of objects lie. Still we exclude the border strip between stars and quasars from the consideration.

Examples:

- QSOs SBS 0831+557 and SBS 1040+490 are located in the stars region. But it is seen that SBS 0831+557 is not a QSO, but stellar-like galaxy SBN or LINER

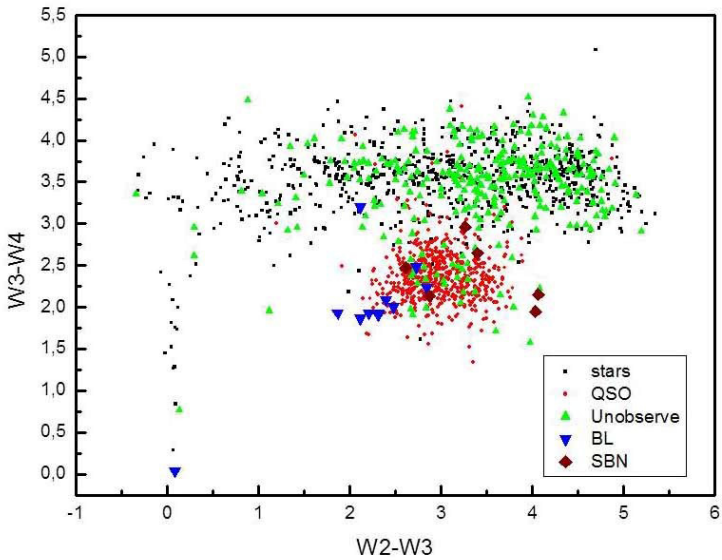


Figure 2 WISE (W2–W3) vs. (W3–W4) diagram for SBS stellar objects.

type.

- SBS 1040+490 QSO is from the list SAO–HS (Ugryumov et al. 1999) and for its physical type see in the AGN catalogue (Veron-Cetty & Veron 2010). Probably, it is an error.
- BLL SBS 1437+527 is located in the star region. Probably it is really a star, not BL Lac type object.
- SBS 0818+608 (sdB) is located in the QSO region. SBS 0818+608 is elongated, i.e. it is probably a binary object.

Thus, using a sample of stellar objects from the SBS, we have identified the regions of the quasars and stars in the infrared WISE space. These objects are well separated from each other at the level of 95%. The majority of quasars have been detected immediately when the cross-correlation with a radius of $<2''$ was done, as well as the most interesting of our "unobserved" stellar objects falling in the region of quasars.

Certainly we first of all are interested in extragalactic objects – QSOs, BL Lac, stellar (point-like) galaxies. Among continual objects there are both extragalactic objects and stars. WISE allowed us divide one type of objects from other.

The most interesting objects for us are "unclassified" or "unobserved" objects, which fall in the quasar region. They may be really quasars or BL Lac objects with great probability or very peculiar stars. 209 stellar objects in our sample are "unclassified" or "unobserved" objects. For "unclassified" objects we obtained slit spectra but in most of cases we cannot determine their physical types because of low signal-to-noise. For "unobserved" objects we do not have slit spectra. Now 32 such objects fall in the QSOs region.

In Fig. 3, we give WISE (W2–W3) vs. (W3–W4) diagram for SBS QSOs and "unobserved" or "unclassified" stellar objects, which show by their concentration that most of them are QSOs.

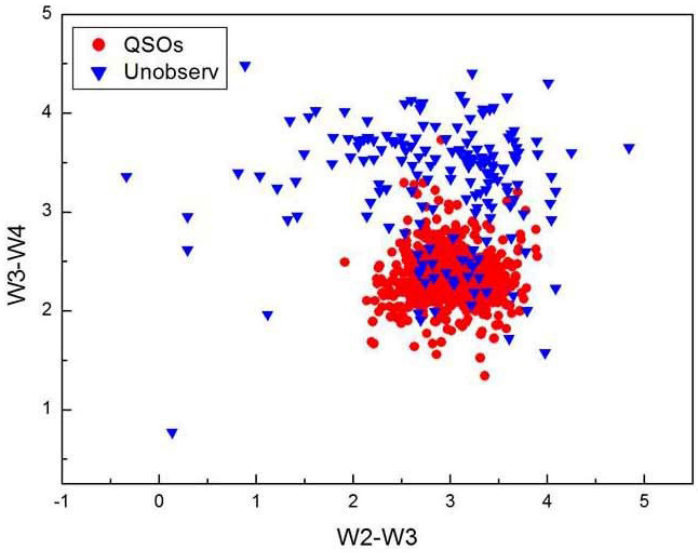


Figure 3 WISE (W2–W3) vs. (W3–W4) diagram for SBS QSOs and "unobserved" objects.

Table 1 New SBS QSO candidates found by WISE colors. 1.

SBS name	POSS2(2000), RA	POSS2(2000), DEC	in GC	PM, ″/yr	SDSS, DR 7/8/9	SDSS, images
0746+600	07:50:50.49	59:55:28.6	unobs	5.7	no SDSS	
0800+591	08:04:40.60	59:02:35.0	unclas	8.5	no SDSS	
0951+502	09:55:15.31	49:58:55.7	unobs	6.9	no spectrum	grey
1001+585	10:04:52.64	58:18:07.8	unobs	5.3	no spectrum	grey
1150+594	11:53:31.21	59:09:43.9	unobs	2.3	no spectrum	very weak, grey
1156+573	11:58:43.34	57:05:36.4	unobs	12.1	no spectrum	grey, weak
1208+563	12:11:10.30	56:03:48.0	unclas	7.1	no spectrum	grey
1214+523	12:17:04.15	52:02:56.1	unobs	10.8	no spectrum	blue
1222+557	12:25:21.79	55:27:33.1	unobs	37.2	no spectrum	grey, very weak
1234+610	12:36:16.00	60:44:42.0	unclas	6.9	no spectrum	blue
1359+529	14:01:24.17	52:42:26.9	unobs	9.8	no spectrum	grey
1405+513	14:07:14.26	51:05:53.5	unobs	15.3	no spectrum	red galaxy
1416+506	14:18:10.82	50:25:03.5	unobs	20.7	no spectrum	white
1433+536	14:34:59.30	53:27:42.0	unclas	12.7	no spectrum	white
1447+545	14:48:56.61	54:20:37.6	unobs	10.0	no spectrum	white
1531+603	15:32:15.50	60:13:54.3	unobs	14.7	no spectrum	grey
1534+601	15:35:01.50	59:58:45.2	unobs	8.4	no spectrum	grey
1545+585	15:46:26.06	58:21:11.2	unobs	11.5	no spectrum	dbl, blue+red star
1546+522	15:48:05.21	52:06:27.0	unclas	17.7	no spectrum	grey
1606+605	16:07:13.25	60:26:29.1	unobs	8.8	no spectrum	blue
1607+567	16:08:47.06	56:37:02.0	unobs	9.9	no spectrum	grey
1610+495	16:11:28.06	49:25:58.0	unobs	12.3	no spectrum	grey
1611+579	16:12:26.09	57:50:39.5	unobs	18.2	no spectrum	grey
1615+591	16:15:56.39	59:02:09.0	unobs	5.1	no spectrum	white
1616+546	16:17:18.94	54:32:42.8	unobs	8.1	no spectrum	blue
1618+592	16:19:02.60	59:05:27.0	unclas	1.6	no spectrum	galaxy
1620+594	16:21:21.84	59:20:06.4	unobs	3.7	no spectrum	elongated, white
1625+573	16:26:15.46	57:13:44.2	unobs	12.9	no spectrum	blue
1630+563	16:31:39.83	56:17:12.6	unobs	4.5	no spectrum	grey
1634+581	16:35:29.79	58:05:56.0	unobs	9.8	no SDSS	
1634+582	16:35:18.40	58:08:55.0	unclas	3.4	no SDSS	
1641+514	16:42:57.67	51:18:48.8	unobs	10.2	no spectrum	obj+red star

In Tables 1 and 2 we give the list of 32 such objects. Data for 32 "unobserved" and "unclassified" objects in the region of QSOs and BL Lac type objects in the WISE space were collected.

The column designations are understood without explanations. The contents of the tables are as follows: SBS Name, Coordinates for 2000.0, object type in GC, PM (proper motions), object type according to SDSS DR7, DR8 and DR9, pseudo color for SDSS DR7, DR8 and DR9 (our estimate), g-magnitudes, g–r colors, our magnitudes from GC, notes, name in other catalogues, object in SDSS DR12, and z. Proper motions are measured by us (unpublished).

Table 2 New SBS QSO candidates found by WISE colors. 2.

SBS name	SDSS, g	SDSS, g–r	GC, m	Notes	Other names	SDSS12, z	Result
0746+600			19.0			no12	
0800+591			18.0			no12	
0951+502	18.58	0.31	19.0		2MASS	2.73856	QSO!
1001+585	17.82	0.24	18.0			no12	
1150+594	19.90	-0.13	19.0	EmLS >30000 0.495 PHOT		0.55547	QSO!
1156+573	19.62	0.41	19.0	EmLS >30000 1.065 PHOT		1.11952	QSO!
1208+563	19.44	-0.08	19.0	EmLS >30000 2.025 PHOT		2.11580	QSO!
1214+523	18.34	-0.50	18.5	WD candidate, Girven		no12	
1222+557	20.06	0.11	19.5	EmLS >30000 1.615 PHOT		1.54982	QSO!
1234+610	17.90	0.11	17.0	EmLS >30000 0.925 PHOT		0.99735	QSO!
1359+529	18.26	0.09	18.0		2MASS	2.76991	QSO!
1405+513	19.89	1.26	18.0			no12	
1416+506	18.34	0.26	18.5		GALEX	no12	
1433+536	18.05	0.09	17.5, 18.23	EmLS >30000 2.155 PHOT		no12	
1447+545	18.21	0.21	18.0		2MASS	2.33744	QSO!
1531+603	18.76	0.11	19.5	EmLS >30000 1.625 PHOT		1.63333	QSO!
1534+601	19.52	0.17	19.5	EmLS >30000 1.465 PHOT	GALEX, QSO	no12	
1545+585	18.60	0.27	18.5	* >30000 1.055 PHOT		no12	
1546+522	18.94	-0.12	18.5	EmLS >30000 0.525 PHOT	1RX	no12	
1606+605	17.56	0.18	18.5	* >30000 1.155 PHOT		no12	
1607+567	18.47	-0.12	18.0	EmLS >30000 0.585 PHOT	X-ray	0.59572	QSO!
1610+495	19.61	-0.12	18.0	EmLS >30000 0.575 PHOT		0.59318	QSO!
1611+579	18.06	0.05	18.5	EmLS >30000 1.625 PHOT	2MASS	1.68523	QSO!
1615+591	18.45	0.49	18.5	EmLS >30000 1.035 PHOT	2MASS	no12	
1616+546	17.04	-0.09	18.0	EmLS >30000 0.645 PHOT	GALEX	no12	
1618+592	17.52	0.52	18.5	On N blue object	2MASS	no12	
1620+594	17.52	0.23	18.5	EmLS >30000 1.105 PHOT		no12	
1625+573	18.00	0.11	18.5	EmLS >30000 1.965 PHOT		no12	
1630+563	17.42	0.03	18.0	EmLS >30000 1.845 PHOT		no12	
1634+581			18.0			no12	
1634+582			18.5			no12	
1641+514	18.70	0.11	17.0	EmLS >30000 1.915 PHOT		no12	

It is seen that in most cases PMs are small and do not exceed the errors of measurements (Mickaelian & Sinamyan 2010).

From 20 objects having photometric redshifts according to SDSS DR6 data (Richards et al. 2009), two are WD candidates.

We checked in SDSS DR12 all objects from the tables, where we found that 12 objects already have spectroscopic redshifts, which nearly coincide with photometric data. All objects without exception are weak QSOs.

Probably for all bright survey objects we have got slit spectra.

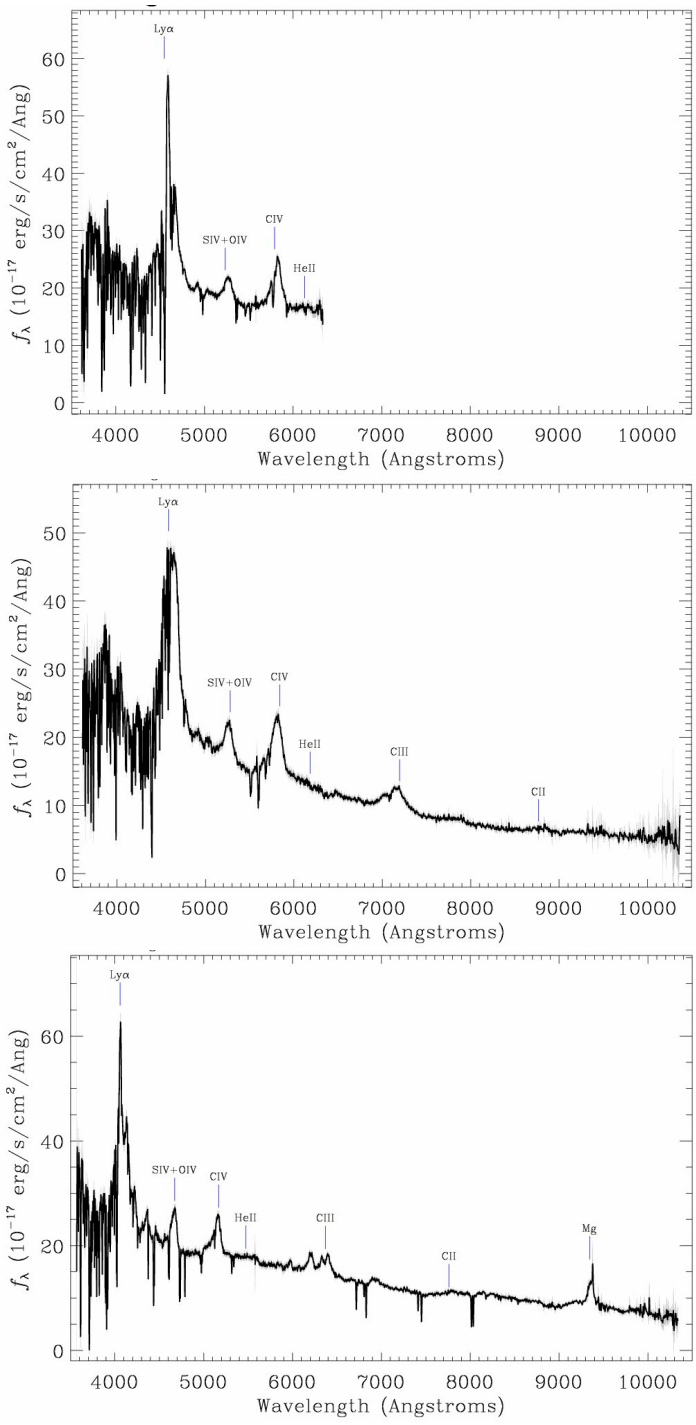


Figure 4 SDSS DR12 spectra of SBS 0951+502, SBS 1359+529 and SBS 1447+545.

5 Discussion

Using multiwavelength data, especially WISE allow us to study the physical nature of active objects found in optical surveys but not having slit spectra.

In this paper we studied the stellar objects of SBS.

We constructed the color–color diagrams for our QSO, BL Lacs, stars from SBS Survey, having WISE data, we determined the region of location for QSOs, BLLs, and stars. Then we marked "unclassified" and "unobserved" objects on these diagrams. Most of all give a peak in stars region. Only 32 objects are located in the QSO region.

We checked these objects in SDSS DR12 and 12 of them show slit spectra and are QSOs with z between 0.5 and 2.7, i.e. in all optical range.

Now in the new version of SBS Catalogue there are 612 QSOs.

We continue the study of unobserved SBS objects to construct the samples of different types of SBS objects.

We suggest that the rest of these objects are QSOs or BL Lac objects as well.

This method can be used to search for QSOs in optical surveys, where many active objects were found, but slit spectra were not obtained, for example KUV, Case, UM and others.

This way the missed bright QSOs may be found. The problem of their lacking is actual so far.

At the end we give in Fig. 4 SDSS DR12 spectra for 3 SBS objects turned to be QSOs.

References

Assef, R. J.; Stern, D.; Kochanek, C. S.; et al. 2013, ApJ 772, 26
Bridge, C. R.; Blain, A.; Borys, C. J. K.; et al. 2013, ApJ 769, 91
Cutri, R. M.; et al. 2013, All WISE Data Release, IPAC/Caltech, Vizier online catalog II/328
Green, R. F.; Schmidt, M.; Liebert, J. 1986, ApJS 61, 305
Jarrett, T. H.; Cohen, M.; Masci, F.; et al. 2011, ApJ. 735, Aid. 112
Jester, S.; Schneider, D. P.; Richards, G. T.; Green, R. F.; Schmidt, M.; et al., 2005, AJ, 130, 873
Markarian, B. E. 1967, Astrofizika 3, 55
Mickaelian, A. M.; Sinamyan, P. K. 2010, MNRAS 407, 681
Richards, G. T.; Myers, A. D.; Gray, A.G.; et al. 2009, ApJS 180, 67
Schmidt, M.; Green R. F. 1983, ApJ 269, 352
Stepanian, J. A. 2005, RMxAA 41, 155
Stern, D.; Assef, R. J.; Benford, D. J.; et al. 2012, ApJ 753, Aid. 30
Ugryumov, A. V.; Engels, D.; Lipovetsky, V. A.; et al. 1999, A&AS 135, 511
Véron-Cetty, M.-P.; Véron, P. 2010, A&A 518, 10