Results from selection of High Redshift Radio-Loud quasars

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Abstract

We present results on reliable selection of Radio Loud Quasars (RLQ) at high redshift (z>3.6), based on the combined use of the surveys FIRST and SDSS.
We explore the redshift range 3.6<z<4.6 by cross matching the FIRST catalogue and the SDSS-DR7 photometric survey. We selected RLQ candidates by using an improved version of the Neural Network machine-learning technique similar to that in Carballo et al. (2008), that were observed and identified spectroscopically at the NOT telescope. Taking into account previous selections, these techniques lead to the identification of 22 new RL quasars out of a total of 48 candidates observed.
The last SDSS quasar catalogue (V), based on SDSS DR7 (Schneider et al. 2010), lists 73 QSO matching our selection criteria. Fifteen of our new high-redshift QSOs are still missing in this catalogue. Therefore, in addition to a good efficiency, our technique leads to a very high completeness (~97%) compared to that of SDSS. This allows to determine the most accurate Luminosity Function up to date for RLQ in this range of high redshift.

Introduction

- The population of radio loud quasars is a significant subset of the entire population of quasars. For the majority of the known quasars, the identifying emission lines fall within the optical region of the spectra, so it is not surprising that the quasar selection criteria exploit large datasets like the SDSS has mostly focused on the analysis of the optical colors.
- The largest homogeneous sample of quasars is the SDSS Quasar Catalog V [Schneider et al, 2010]. This is based on the SDSS Seventh Data Release (DR7) and contains 105,783 spectroscopically confirmed quasars.
- In spite of this remarkable success, the development of new techniques for quasars candidate selection is still of great interest especially when they involve the use of cross matching between surveys in different ranges of the electromagnetic spectrum such as FIRST, SDSS, UKIDSS. By including additional wavebands, it should be possible to discover quasars that are missed by the SDSS quasar selection because their optical colors are too faint and indistinguishable from stars or morphologically misclassified galaxies. These phenomena become more significant as redshift increases since such quasars are rarer, fainter and detected in fewer SDSS wavebands.
- The development of multi-wavelength machine-learning based selection techniques and 'real life' implementation challenges are of interest in themself because can be used also in other contexts that the search for high redshift quasars.
- In particular in this context we are interested to increase the small subset of high redshift Radio Loud Quasars. The use of radio data as pre-selection criteria drastically reduces contamination by foreground stars with optical colors similar to quasars and is unaffected by both intrinsic and extrinsic dust obscuration and reddening.
- The work presented here is the ideal completion and extension of the Carballo et al. (2008) investigation, based on a cross match between FIRST and SDSS DR5 and the use a Neural Network to select a list of RL quasars candidates. With an analogue methodology, we used a new release of the SDSS (the DR7) selecting a list of 22 candidates that were later observed at the NOT telescope in March 2012. Here we present the results of the spectroscopic reduction and the consequent considerations about our selection methodology.

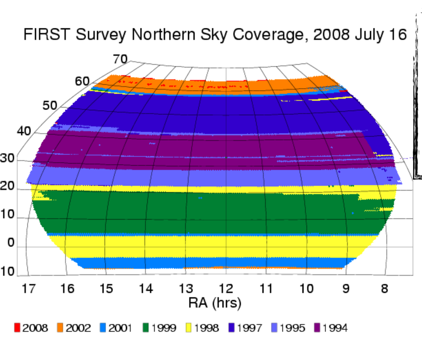
Selection of RL quasars candidates for 3.6<z<4.6

FIRST -SDSS (DR7)

FIRST (2003 release) — Area covered: 9,033 sq. deg; 811,117 sources

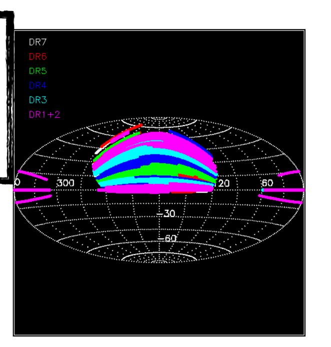
SDSS DR7 — Area covered: 11,663 sq. deg; 357 million distinct objects

OVERLAPPING area: 8,073 sq. deg.

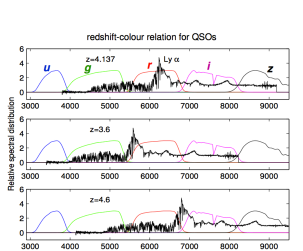


Matching SDSS -DR7 and FIRST Surveys, 1.5 arcsec

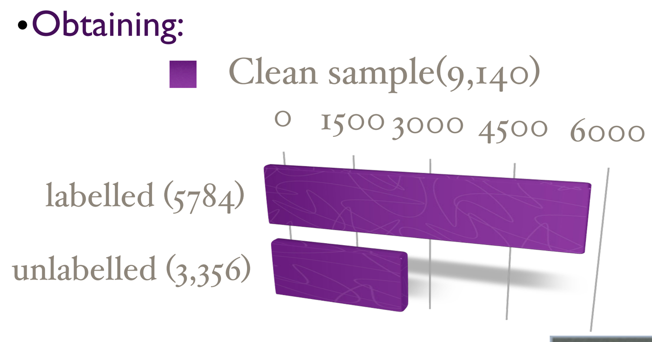
222,517 matched sources



- To create a subsample of **9,140** sources we apply several pre-selection criteria
  - 15<psfMag_r<20.2 (AB mag)
  - Morphological Type =Star
  - Exclusion photometrical FATAL ERRORS: Bright, Saturated, Edge,Blended
  - psfMagError<0.2 at least in one band

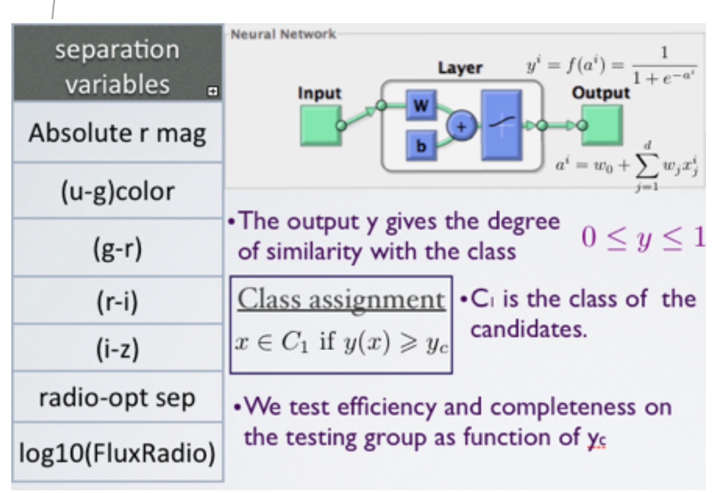


- Obtaining:



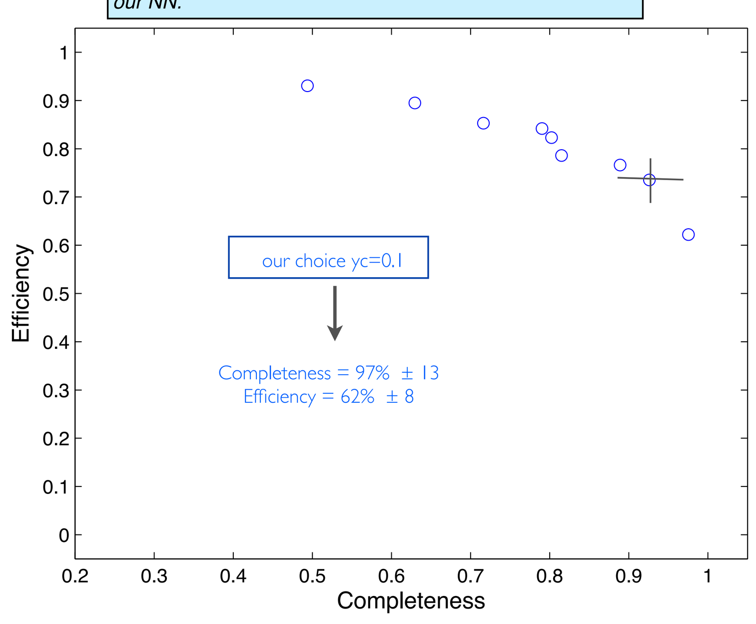
- We call "labelled" sample (machine-learning term) all the sources with spectra and properly classified, otherwise we call the source "unlabelled".

- To train the Neural Network (NN) we use the labelled sample, divided in the two subsamples as "**target**" and "**not target**". To the "target" sample belong the RLQs with 3.6<z<4.6



Completeness= (candidates above yc that are QSOs)/(total number of QSOs)	Efficiency= (candidates above yc that are QSOs)/(total number of candidates)

A classifier is good *if completeness increases as efficiency decrease. This is the feature that we obtain for our NN.*



Due to the disparity in size of the training sample, we use the "leave one out method" to train the NN, method suited to these cases. That is: train with the {labelled sample} minus the xi element, testing with the xi element. Then repeat the training ∑(i) =5784 times, for all the xi elements of the {labelled sample}

- The NN that we used as classifier is a simply supervised Feed Forward comprised of one hidden and one outer layer.

- **Keep in mind** that of the 3,356 unlabelled sources selected into the DR7 SDSS, **3,106** belongs also to the **DR5** (the release used in Carballo et al. (2008).

- We made **two independent selections**, and then we collected a **unique list** of candidates **identified spectroscopically** at the NOT telescope **in March 2012**

- We **trained a first time** the NN using all the sources matching our criteria and classified as quasars into the V Quasar Catalog (Schneider et al. 2010). Only **73** of the 5784 sources belong to the target sample. We didn't include the QSO identified by Carballo et al. (2008), as a test for the modified NN

Obtaining a total list of **32 candidates**

-> **16** also selected in Carballo et al.(2008) and spectroscopically identified in that work(9/16 QSO with 3.6<z<4.4)

-> **14** also selected in Carballo et al.(2008) and spectroscopy identified in this work (4/15 QSO with 3.6<z<4.4)

-> **2** belonging to SDSS DR7 and not to DR5 (1/2 QSO with 3.6<z<4.4)

- We **trained a second time** the NN using the 73 sources from the the V Quasar Catalog (Schneider et al. 2010), **and 8** sources spectroscopically identified in Carballo et al. (2008) and still missed from the SDSS quasar catalog. For a **total of 81** quasars as target sample

Obtaining a list of **18 candidates**

-> **14** also selected in Carballo et al.(2008) and spectroscopy identified in this work (5/14 QSO with 3.6<z<4.4)

-> **4** belonging to SDSS DR7 and not to DR5 (2/4 QSO with 3.6<z<4.4)

Using more candidates the efficiency of the NN improves

- **List of Candidates observed at the NOT telescope in March 2012**

Object name	RA (J2000)	DEC (J2000)	SDSS r	FIRST flux(mJy)	y(x), NN Output
J081555+4653	08:15:55.01	+46:53:21.4	20.01	2.97	0.13
J83316+2922	08:33:16.91	+29:22:28.2	20.19	12.63	0.34
J084323+1656	08:43:23.70	+16:56:56.1	19.67	1.93	0.27
J084818+3938	08:48:18.88	+39:38:06.0	20.21	1.28	0.18
J085724+1105	08:57:24.33	+11:05:49.2	19.67	1.91	0.96
J090953+4749	09:09:53.84	+47:49:43.0	19.92	373.29	0.21
J091436+5038	09:14:36.23	+50:38:48.5	20.22	47.98	0.18
J091505+1310	09:15:04.54	+13:10:50.8	19.86	9.04	0.28
J092640-0230	09:26:40.29	-02:30:41.5	19.88	1.9	0.1
J100933+2559	10:09:33.23	+25:59:01.2	20.20	3.48	0.27
J102940+1004	10:29:40.93	+10:04:10.9	19.59	2.81	0.24
J103420+4149	10:34:20.43	+41:49:37.5	20.16	2.17	0.37
J105807+0330	10:58:07.47	+03:30:59.6	20.03	4.18	0.13
J113300-0412	11:33:00.71	-04:11:58.5	20.16	9.64	0.18
J115107+5015	11:51:07.43	+50:15:58.6	20.14	1.69	0.42
J120407+4845	12:04:07.83	+48:45:48.2	20.03	3.96	0.15
J120531+2901	12:05:31.74	+29:01:49.2	20.21	1.51	0.39
J121329-0327	12:13:29.43	-03:27:25.7	19.59	23.37	0.5
J122819+4740	12:28:19.97	+47:40:30.4	19.36	2.24	0.41
J124433+0609	12:44:43.07	+06:09:34.6	19.84	1.29	0.2
J131004+0634	13:10:04.28	+06:34:27.0	19.70	1.18	0.12
J154336+1656	15:43:36.59	+16:56:21.8	19.07	10.85	0.13

-> It's remarkable to notice that a total of 18 candidates were not observed in Carballo et al. (2008). Considering the weighted efficiency of the NN, Carballo et al.(2008) predicted that **~7** of these 18 candidates had to be RL quasars. In the work here presented **15** of them were observed and 3 have spectra in SDSS DR7. In perfect accordance with what predicted, results that **6** of these objects are RLQ with z>3.6

--> From these observations we identified a total of **7** new RL quasars in the redshift range 3.6<z<4.6

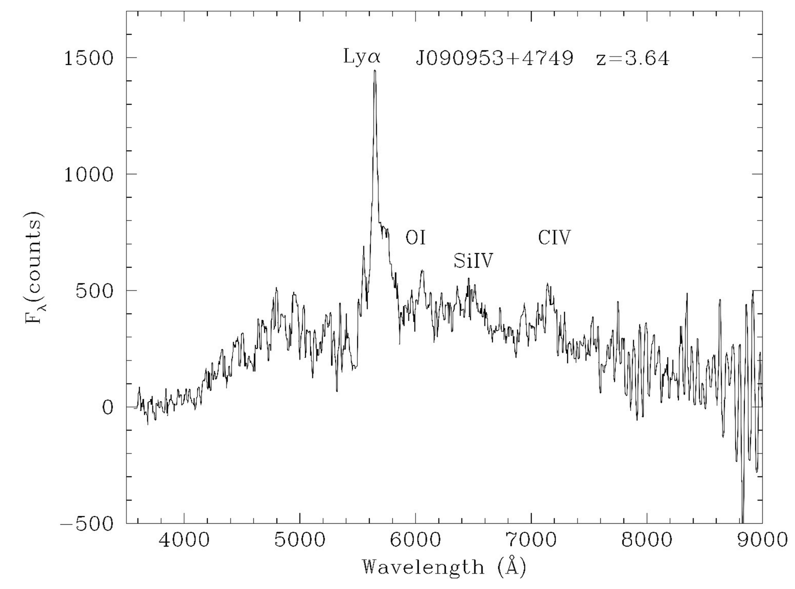
The efficiency of the selection is a function of the NN output y(x). It is ~22% for y(x) <0.55 and ***~91%*** *for y(x) >0.55*

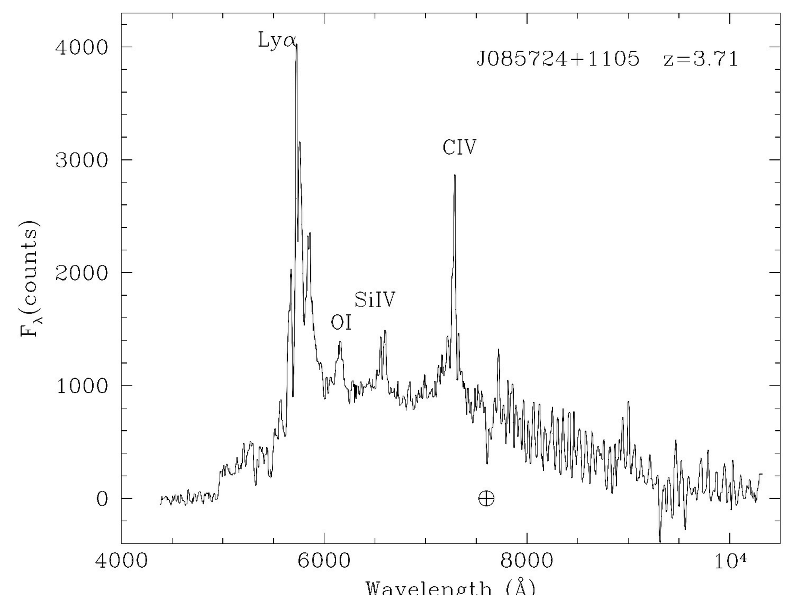
In Green RLQ with 3.6<z<4.2

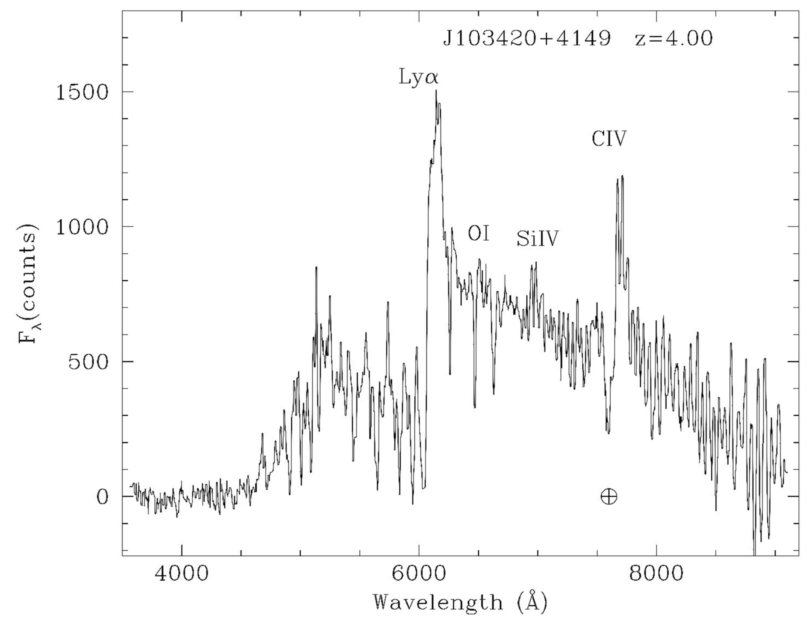
In Purple RLQ with 3<z<3.6

Results from the observations

- Spectra of **3** (out of a total of **7**) of the RL QSO observed at the NOT telescope.







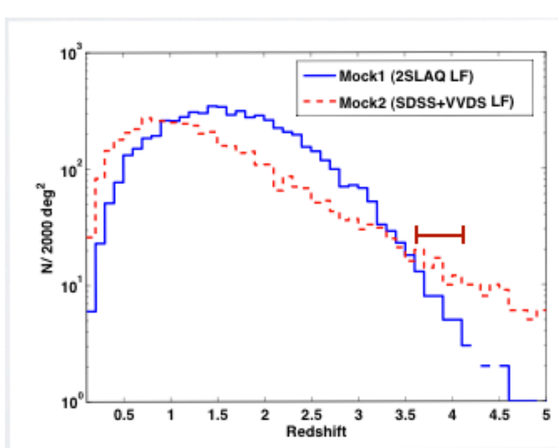
- **81 RLQs** (only 73 with clear photometry and therefore used for the NN training) are present in the V quasar catalog (Schneider et al. 2010) with 3.6<z<4.6 and r<20.2. McGreer et al (2009) found other **5** RLQs, discarded from our analysis due to photometrical errors . Adding up to this sample these 5 sources and thr total of 8+7=**15** sources observed in Carballo et al. (2008) and in our new investigation, we reach o total of **101 RLQ.**

This implies an incompleteness of the ***~20%*** *for the V SDSS quasar catalog*

- In this range of redshift and magnitude the V quasar catalog counts a total of 1,935 quasars.

The fraction of RLQ in the QSO population is **~4%**

Conclusions



Redshift distribution of radio-loud quasars at i < 21.3 over 2000 deg^2 for two mock catalogues generated using the SDSS+VVDS luminosity function (Bongiorno et al. 2007) and the 2SLAQ luminosity function (Croom et al. 2009). The former LF produces more radio-loud quasars at high redshifts. (Bins size 0.1).

The red bar represents the number density derived in this work. This result indicates that there are more QSOs at z~4 that predicted by current LFs.

. Having corrected our sample for all the sources of incompleteness, the next step in our investigation is to use the sample to calculate a luminosity function for radio-loud quasars at 3.5 < z < 4.6. We will derive this function in terms of the optical luminosity in order to compare with results from SDSS. Considering the high completeness of our methodology, our sample should give the most accurate measure of LF for such class of objects.

References

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-Croom et al. , 2009, MNRAS, 399,1755
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