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# Searching for High Redshift Quasars with S-PLUS, J-PLUS and J-PAS

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**Abstract.** The study of galaxies and the intergalactic medium (IGM) in the early universe remains one of the greatest challenges in astrophysics. Quasars (QSOs) are among the most luminous objects in the universe and their study allows us to understand the formation process of supermassive black holes and their relation to massive galaxy evolution and their environment. Moreover, QSOs at redshifts as high as $z \sim 6-8$ (i.e., within the first Gyr of the Universe) are crucial for assessing the ionization state of the IGM and to determine the role that QSOs played in reionization. The objective of this work is to determine the optimal color selection criteria for finding new QSOs at high redshifts in the ~8500 square degree areas covered by each of the upcoming S-PLUS, J-PLUS and J-PAS optical sky surveys combining them with near-IR data. For this, we are building a large library of synthetic QSO photometry based on QSO spectra previously found in the Sloan Digital Sky Survey. In this contribution, we will present our selection strategy and preliminary results based on the first observations from J-PLUS.

**Resumo.** O estudo das galáxias e do meio intergaláctico (IGM) no universo inicial permanece sendo um dos maiores desafios da astrofísica. Os quasares (QSOs) estão entre os objetos mais luminosos do universo e seu estudo nos permite compreender o processo de formação de buracos negros supermassivos e sua relação com a evolução de galáxias massivas e seus ambientes. Além disso, QSOs em redshifts tão altos quanto $z \sim 6-8$ (isto é, dentro do primeiro Gyr do universo) são cruciais para avaliar o estado de ionização do IGM e determinar o papel que os QSOs desempenharam na reionização. O objetivo desse trabalho é determinar os melhores critérios de seleção de cores para encontrar novos QSOs em alto redshift na área de aproximadamente 8500 deg$^2$ abrangida por cada um dos novos surveys ópticos S-PLUS, J-PLUS e J-PAS combinados com dados de infra-vermelho próximo. Para isso, nós estamos construindo uma grande biblioteca de fotometria sintética baseada em espectros de QSOs anteriormente encontrados no Sloan Digital Sky Survey (SDSS). Nesse trabalho apresentamos os primeiros passos na construção dessa biblioteca, bem como uma comparação entre fotometrias simuladas e fotometrias obtidas para uma amostra de quasares observados no J-PLUS.

**Keywords.** Surveys – Galaxies:active – Black hole physics

## 1. Introduction

Quasars (QSOs) are the most luminous point sources in the Universe. They are powered by active supermassive black holes (SMBHs) that are accreting matter in the center of massive galaxies, and are thus very important tracers of the formation and evolution of SMBHs in relation to their host galaxies (Rees 1984). High redshift QSOs are particularly interesting, as they allow us to investigate the structure of the early Universe. Observations indicate that the epoch at $z \sim 6-8$ marks the end of the cosmic reionization period. Studying QSOs at these high redshifts is also important to infer their overall contribution to the reionization epoch and constrain its duration (e.g. Fan et al. 2006; Carilli et al. 2010; Eilers et al. 2017).

## 2. Searching for quasars at high redshift

The simplest, most common way of finding high redshift QSOs consists of three major steps: (1) building photometric criteria based on previously found objects or templates, (2) matching photometric observations to these criteria, and (3) performing follow-up imaging and spectroscopy to confirm that the objects are genuine QSOs and determine their redshifts. Building the selection criteria demands information about the cosmology, the typical spectral properties of QSOs at a given redshift, and information about the IGM. Even with well defined criteria, the search is problematic because the highest redshift QSOs are very rare and the selection suffers from contamination primarely due to cool stars. However, having the availability of a number of narrow and medium-band filters will increase the level of accuracy of the selection.

## 3. The S-PLUS, J-PLUS and J-PAS surveys

The Javalambre-Photometric Local Universe Survey (J-PLUS; Cenarro et al., in prep., Vilella-Rojo et al. 2015) and the Southern-Photometric Local Universe Survey (S-PLUS; Mendes de Oliveira et al., in prep.) each aim to map a ~8000 deg$^2$ area of the northern and southern sky using new dedicated 0.8m robotic telescopes in Javalambre (Spain) and Cerro Tololo (Chile), respectively. These two surveys use the same set of 12 broad, intermediate and narrow band optical filters. A third survey, the Javalambre Physics of the Accelerating Universe Astrophysical Survey (J-PAS; e.g. Mejía-Narváez et al. 2017) will also cover at least 8000 deg$^2$ using an unprecedented system of 56 narrow band filters in the optical and a wide-field camera mounted on a 2.5m telescope.

## 4. Predictions for quasar selection

We predict the expected colors and magnitudes of high redshift QSOs based on synthetic photometry derived from QSO spectra

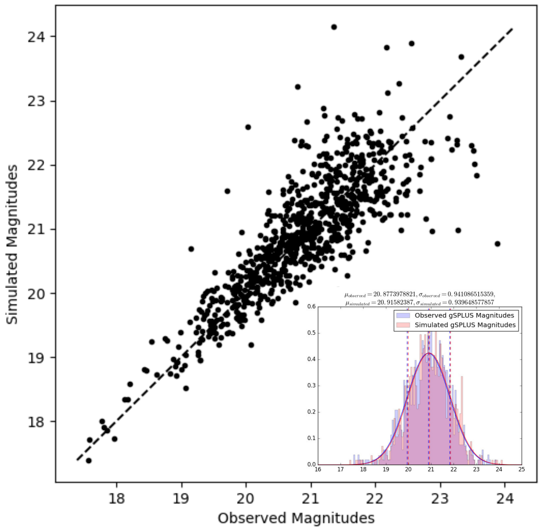


**Figure 1.** Comparison of the synthetic and real photometry in the $g$-band for QSOs detected in SDSS and J-PLUS.

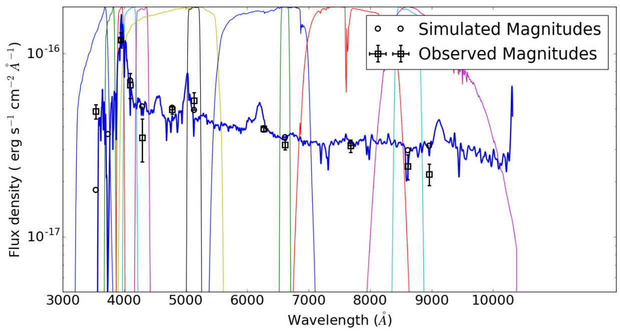


**Figure 2.** SDSS spectrum of a QSO at $z = 2.24$ and the S/J-PLUS filter system. Circles indicate the synthetic photometry for each filter derived from the spectrum, while squares indicate the actual magnitudes taken from the science verification J-PLUS data. The QSO has a strong $Ly\alpha$ emission line that falls into the F0395 filter at this redshift.

convolved with the S-PLUS, J-PLUS and J-PAS filter curves. To test how well our synthetic photometry matches with the actual quality of the data expected, we perform a comparison between our synthetic photometry derived from the spectra of $\sim$ 800 known QSOs in common between the SDSS spectroscopic survey and the first $\sim$ 60 deg$^2$ of data from J-PLUS. The result is shown in Fig. 1 for the synthetic (from SDSS spectra) and observed (from J-PLUS photometry) $g$-band magnitudes of the QSOs.

We also show an example of a QSO that can be identified on the basis of its strong emission lines falling in one or several of the S-PLUS/J-PLUS narrow-band filters for specific redshifts (in this case a QSO at $z \approx 2.2$ observed by both the SDSS and J-PLUS; Fig. 2). The synthetic and real J-PLUS photometry are indicated.

In order to test the feasibility of selecting even higher redshift QSOs, we have constructed a test sample of QSO spectra based on 100 of the brightest QSOs at $3.1 < z < 3.2$ from the Sloan Digital Sky Survey (SDSS) DR12 catalog, and built color-color diagrams as follows: (i) We slide the spectra through the redshift range of $5.0 < z < 7.5$ with steps of 0.1. Because we use

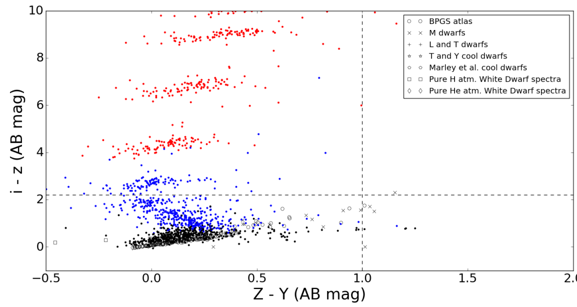


**Figure 3.** The $(z - Y)$ versus $(i - z)$ color-color diagram. Black points indicate QSOs at $z < 5.5$, blue points indicate QSOs at $5.5 < z < 6.0$ and red points indicate QSOs at $6.0 < z < 6.5$.

relatively low redshift QSOs as our model templates, we set any flux below 1216Å to zero, as expected at these high redshifts. (ii) We convolve the redshifted templates with the S-PLUS, J-PLUS, J-PAS and VISTA near-IR filters curves. (iii) We construct color-color diagrams, e.g., $(Y - J)$ versus $(Z - Y)$ for $6 < z < 7.5$ and $(Z - Y)$ versus $(i - z)$ for $5 < z < 6.5$, and identify the typical colors expected as a function of redshift. We also include galactic stars in order to study the contamination. The preliminary results are shown in Fig. 3. As expected, the high redshift QSOs clearly stand out from such a color-color diagram, although it remains to be checked to what depth we can effectively search for such objects.

## 5. Future work

The next steps for this project will be to determine the limiting depths of the photometry in each band expected for the future surveys, and then to obtain reliable criteria for selecting QSOs at the different redshifts. We will also determine the redshifts for which bright emission lines will fall in the narrow band filters, and how to select them from the data. The ultimate goal of this work will be to find new high redshift QSOs in S-PLUS, J-PLUS and J-PAS.

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