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Quasar Candidates Multicolor Selection Technique and Quasar Photometric Redshifts.

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Abstract. We present a quasar candidate identification technique based on multicolor photometry, developed for the needs of the VIRMOS spectroscopic survey. The traditional multi-dimensional method (2 × N dimensions, where N is the number of the color-color diagrams) is reduced to a one-dimensional technique, which consists in a standard fitting procedure, where the observed spectral energy distributions are compared to quasar simulated spectra and stellar templates. This method is better suited than the usual multicolor selection techniques to quasar identification, especially for high-redshift quasars, as shown by its application to both simulated and real catalogues. The major advantage of the new method is the estimation of the *photometric* redshift of quasar candidates, enabling, in almost all cases, spectroscopy to be targeted to best suited wavelength ranges.

1. Description of the method

The method presented here is closely related to *hyperz*, a public photometric redshift code developed at the Observatoire Midi-Pyrénées [1]. It is basically a standard SED fitting procedure: the observed photometric SED of a given object, obtained through n filters, is compared to the SED computed for a set of template spectra. The aim is to find the best fit between the observed and the model photometry through a standard χ^2 minimization procedure.

Our template set is made by a series of 213 simulated quasar spectra of redshifts from 0 to 7, the stellar library of Pickles (1998), with 108 spectra of all stellar types, and a series of 22 white dwarf and carbon stars spectra.

When applying the method to a given catalogue, the discrimination between stars and quasars is performed in two steps. A first distinction between stars and quasars is made by identifying as star (quasars) the objects that show a better fit to one of the stellar (quasar) spectra. A further selection on the remaining sample can be made, based on the value of the reduced χ^2, with stars identified as objects excluded as quasars at the 99% confidence levels. When an object is identified as quasar candidate, a photometric redshift estimation is automatically provided.

The quality of the quasar/star discrimination and the photometric redshift estimate depend on the filter combination.

2. Simulations

We define the **efficiency** of a quasar candidate selection technique as follows:

$$\textbf{efficiency} = \textbf{completeness} \times \textbf{confirmation rate},$$

where **completeness**= N_q/N_e and **confirmation rate**= N_q/N_c,
with N_c be the number of quasar candidates, N_q the number of quasars found among the candidates, and N_e the number of expected quasars (estimated from previous surveys).

The method has been first applied on mixed (stars + quasars) simulated catalogues at the magnitude limit of m_b=22.2. They contain ∼100 quasars (according to [4] - HS90), uniformly distributed in redshift, and ∼3000 stars (according to [8] - R95) and correspond to the six Deep Multicolor Survey (DMS) fields.

Photometry in broad-band filters has been simulated, covering the wavelength range between ∼ 3000 Å and ∼ 20000 Å: U, B, V, R, I, H, and K. 40 different filter combinations have been tested in the aim of selecting quasar candidates. Fig. 1 illustrates the **completeness** (solid line), **confirmation rate** (dashed line) and **efficiency** (dash-dotted line) for these 40 combinations (whose order is shown in Table 1), without any χ^2 selection. The filter combinations have been classified by increasing **completeness**.

3. Determination of the Photometric Redshifts

The problem of the quasar photometric redshift (z_{phot}) estimation is at least as the one for galaxies. The filter combination is very important for the accurate determination of the z_{phot}. Figures 2 and 3 show the photometric

Table 1. Filter combinations used in the figure 1a classified by increasing **completeness**

No	filters	No	filters	No	filters	No	filters	No	filters
1	VRI	2	VRH	3	BRH	4	UBV	5	BRI
6	BVRI	7	BVR	8	VIK	9	BVRIH	10	BRIHK
11	VRIHK	12	BRHK	13	BVI	14	BRIK	15	VRIK
16	BVK	17	RIHK	18	BVRIHK	19	UBR	20	UBH
21	BVRIK	22	UBVR	23	UBRI	24	BVIK	25	UBVRI
26	UBVRIK	27	UBVRIH	28	UBRHK	29	UBHK	30	UBVRK
31	UVIK	32	UVRIK	33	UBVRIHK	34	UVK	35	UBRIHK
36	UBVIHK	37	UBVRHK	38	UVIHK	39	UVRIHK	40	UBRIK

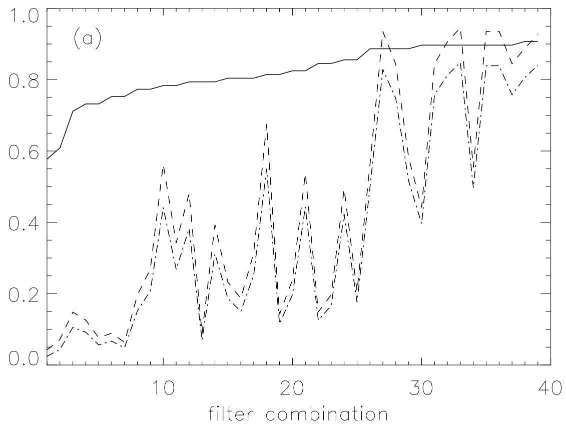

Fig. 1. **completeness**, (solid line) **confirmation rate** (dashed line) and **efficiency** (dash-dotted line) for 40 filter combinations.

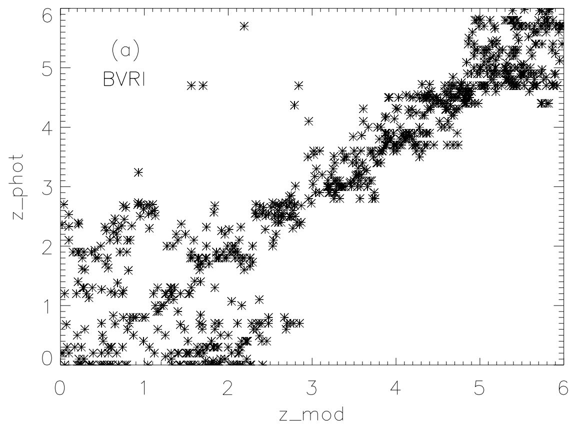

Fig. 2. Photometric redshift versus model redshift for a simulated catalogue of 1540 quasars and the filter combination BVRI.

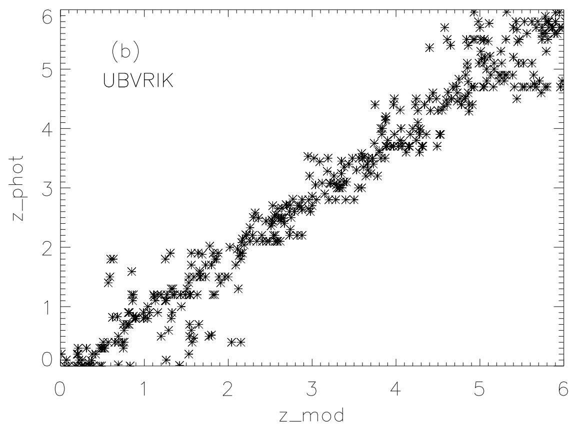

Fig. 3. Same as figure 2 for the filter combinations UBVRIK.

redshift versus the model redshift, for a catalogue of 1540 simulated quasars uniformly distributed over the redshift range [0,6], for the 2 different filter combinations illustrated: BVRI (2) and UBVRIK (3), where we can see the importance of the ultraviolet and infrared filters.

4. The Deep Multicolor Survey

The DMS is an imaging survey covering 6 fields on a total area of 0.83 square degrees on the northern sky at high galactic latitude. 6 filters have been used, covering the wavelength range from 3000 to 10000 Å: U, B, V, R', I75 and I86, and a photometric catalogue of $\sim$ 21000 stellar–like objects has been assembled [6]. 137 stars, 49 CNELGs and 54 quasars with redshifts spanning from 0.3 to 4.3 have already been spectroscopically identified. These objects were the 240 quasar candidates selected according to their position on color-color plots [3].

For our purposes, we cut the catalogue at B=22.3, a limit at which the sample is almost 100% complete and only marginally contaminated ($\sim$ 8%) by galaxies, and we only used objects for which photometry was available in all 6 filters. Hence, 3 of the spectroscopically confirmed quasars were excluded, and we ended up with a catalogue of 3720 stellar-like objects. For the magnitude limit and the area covered by the survey, approximately 106^{+27}_{-22} quasars are expected to be found among the objects of the catalogue (HS90), resulting a **completeness** of at least 80% for the usual multicolor selection techniques (Hall, private communication) and $\sim$88% for our method.

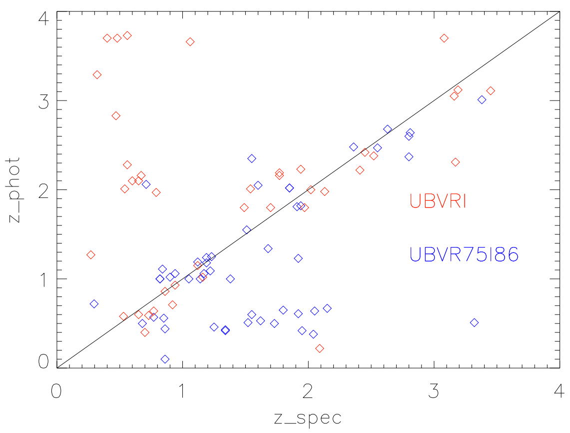

Fig. 4. z_{phot} versus z_{spec} for the 51 DMS quasars (red) and for a new sample of 46 spectroscopically identified quasars (blue) (Hall et al., 2000).

Totally, we identify 3332 out of the 3720 objects as stars and find 388 quasar candidates for 106 actual quasars, with an expected **completeness** of 45/51=0.88 and an expected **confirmation rate** of (106 $\times$ 0.88)/388=0.24, if no χ^2 selection is made. The equivalent values with 99% confidence level selection are 0.88 and 0.27, respectively, for 348 quasar candidates. The usual color-color selection techniques gave a **completeness** of $\sim$ 0.80 and a **confirmation rate** of 0.23.

5. Extension of the method

This software has been developed for the needs of the VIRMOS survey. However, the results and conclusions of this paper apply to all multicolor surveys in general.

This technique can be extended towards different directions. First, it can be adapted to particular objects like very red quasars, by adding the suited templates. It can also be used on spatially resolved objects, like Seyfert galaxies, because by construction, the software is independent of the morphology of the objects. This can be done by adding a stellar component to the AGN simulated spectra already used. Last but not least, it can be extended to very high redshifts (higher than 6), after an appropriate modeling of the intergalactic absorption.

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