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The high surface density of bright ultraviolet-excess quasars

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SUMMARY
We have measured the surface density of bright ($B \leq 16.5$) UVX quasars in the recently completed Edinburgh quasar survey, and have found a higher density, by a factor of 3.4, than has previously been measured. The surface density of quasars brighter than $B = 16.50$ is 0.024 deg^{-2} in this survey, and the gradient of the differential log(number)–magnitude relation for quasars brighter than $B = 17.7$ has decreased from 0.98 to 0.78. Future work is expected to show that new models of the optical luminosity function for luminous quasars will need a smaller amount of cosmological evolution, more comparable to that seen at radio wavelengths.

Key words: quasars: general – cosmology: observations.

1 INTRODUCTION

Samples of ultraviolet-excess (UVX) quasars have a very steep number–magnitude relation, which is important evidence for cosmological evolution of the quasar population. The main evidence for the steep relation comes from the Anglo-Australian Telescope (AAT) survey of Boyle *et al.* (1990) at $B > 18.0$ and the low surface density of quasars in the Palomar–Green (hereafter PG) quasar survey (Schmidt & Green 1983; Green, Schmidt & Liebert 1986, hereafter GSL) at $B < 16.17$. The PG survey has been the most important source of bright, optically selected quasars for almost a decade, and has been vitally important in quantifying the luminosity function and evolution of quasars.

However, it has long been suspected that the PG quasar survey may be incomplete because of large errors in the measured magnitudes and colours of the objects (Wampler & Ponz 1985). Until now, this incompleteness has been difficult to quantify due to a lack of other complete samples in this magnitude range. This paper reports on the first results based on a UVX sample generated from the Edinburgh multicolour survey, which has previously been used to select luminous quasars at high redshifts (Mitchell, Miller & Boyle 1990). Full details of the construction and calibration of the survey and selection of the UVX candidates, with a list of the complete catalogue and identification of the objects selected, will be published in the near future. A brief summary is given by Goldschmidt *et al.* (1991). In this paper we present details of the bright quasars found and discuss their surface density.

2 THE EDINBURGH QUASAR SURVEY

The survey is based on 130 UK Schmidt telescope (UKST) plates taken in 13 contiguous fields at high Galactic latitude covering 330 deg^2. The plates' field centres are 5° apart and correspond to standard UKST fields. The coordinates of the field centres range from 12^h40^m to 14^h20^m (equinox 1950) in RA at Dec. $-5°$ (fields 789 to 794) and from 12^h40^m to 14^h40^m at Dec. 0° (fields 861 to 867). Two plates were taken in each field in each of the photographic wavebands corresponding to U (III-aJ emulsion and UG1 filter), B (III-aJ and GG395), commonly known as B(J), V (IIaD and GG495), R (IIIaF and OG590) and I (IV-N and RG715). These photographic bands will be referred to as u, b, v, r and i hereafter. The photographic b magnitudes in this quasar sample have been converted to the B system for the purposes of comparing the quasars in this survey to those in other surveys, by adding a constant offset of 0.05 [derived assuming a mean quasar colour of $b - v = 0.18$ with the colour equation for stars of Blair & Gilmore (1982)]. The plates in each field were taken close together in time so that incompleteness and contamination due to variability should be insignificant. The plates were scanned and measured on the COSMOS machine (MacGillivray & Stobie 1984) and the resulting catalogue of objects was calibrated with photoelectric and CCD sequences in every waveband in every UKST field (Mitchell 1989), obtained at the ESO–Danish 1.5-m, University of Hawaii 88-inch, Steward Observatory 60- and 90-inch and Jacobus Kapteyn (JKT) 1-m telescopes. The error in the mean measured magnitude was determined from a comparison of the two plates in each waveband, and is <0.05.

The prime selection criterion for the UVX quasar sample was $u-b$ colour, requiring quasar candidates to have $u-b<-0.30$. A further criterion of $b-r\geq 0$ was imposed to eliminate hot blue stars. The other wavebands were not used in generating the UVX sample. A morphological criterion was also imposed to exclude any candidates which appeared extended on the UKST U plates. Spectroscopic confirmation of all the candidates with $b<17.5$ has been carried out at the Isaac Newton (INT) 2.5-m, the ESO 1.5- and 2.2-m telescopes and the UKST, the latter using the FLAIR multi-object spectrograph, and spectroscopic confirmation is also complete to $b\leq 17.7$ in seven fields and to $b\leq 18$ in four fields. We expect the resulting quasar sample to be complete in the ranges $15\leq b\leq 18$ and $0.3\leq z\leq 2.2$. The lower redshift limit arises because low-redshift quasars may have host galaxies that are visible and hence appear extended, or they may have redder colours due to the underlying host galaxy. The PG quasar survey contains large numbers of low-redshift Seyfert galaxies, in contrast to the Edinburgh survey, because of the different morphological constraints imposed. The completeness of the Edinburgh survey compared with the PG survey is discussed below.

In this paper we shall discuss primarily quasars with $b<16.5$. Twelve such quasars have been found (Table 1), of which eight have $B<16.5$ and $0.3\leq z\leq 2.2$.

3 THE NUMBER–MAGNITUDE RELATION

Fig. 1 shows the differential log (number)–magnitude relation for this survey and compares it with other surveys. The errors on the points are Poissonian with 68 per cent confidence limits. We only include quasars in the redshift range $0.3\leq z\leq 2.2$.

It can be seen that the surface density of quasars in this survey agrees well with the MBQS survey of Mitchell, Warnock & Usher (1984). Indeed, the brightest point in the MBQS survey, which used to appear anomalous compared to other data, agrees well with the Edinburgh data. It can also be seen that the data from this survey lie above those from the PG survey, implying that the latter survey is incomplete. The gradient of the differential log (number)–magnitude relation for quasars with $B\leq 17.67$ is 0.78 ± 0.12, computed from the Edinburgh survey alone. Calculating the gradient of the differential log (number)–magnitude relation from the PG and the AAT surveys gives a value of 0.98 ± 0.02. This value is different from Braccesi *et al.*'s (1980) canonical value of 0.86 because we exclude from our analysis quasars with $z<0.3$ (see also Boyle, Shanks & Peterson 1988). The integrated surface density of quasars with $B\leq 16.17$ (the nominal limit for the PG survey) in the Edinburgh survey is 0.018 ± 0.009 deg^{-2}.

In order to assess the statistical significance of the disagreement between the surveys, we fitted a power law to the PG and AAT integrated surface densities to find that the expected number of quasars with $B<16.5$ in the Edinburgh survey in this redshift range is 2.75 ± 0.06. Eight quasars brighter than this magnitude limit were detected in the Edinburgh survey; the Poissonian probability of this is 0.73 per cent, implying a significant statistical difference between the surface densities found by the two surveys.

4 COMPLETENESS OF THE SURVEYS

Where does this discrepancy between the two surveys arise? The Edinburgh survey is entirely included within the area of the PG survey, and hence we can make a direct comparison of the number of quasars found by the two surveys. The PG survey found one quasar in the area, PG 1352+011. The Edinburgh survey finds this quasar (and measures its magnitude to be $B=16.75$ compared to its PG magnitude of 16.02) but also finds five *new* quasars brighter than $B=16.07$, the PG survey limit in this area (GSL). Hence the number of quasars found by the PG survey does appear to be significantly incomplete in this area of sky.

5 PHOTOMETRIC ACCURACY OF THE SURVEYS

One possible explanation for the apparent incompleteness is that there exists a systematic difference in the calibration of the two surveys. This can be tested by making a direct

Table 1. Quasars in the Edinburgh survey with $b\leq 16.50$.

R.A. (1950)	Decl.	b	Redshift
12 45 00.4	-03 33 47	16.07	0.379
12 50 46.1	-07 00 38	16.43	0.097
12 52 46.4	02 00 27	15.48	0.345
13 16 48.4	-07 34 43	16.49	0.538
13 26 52.5	-05 16 07	15.59	0.580
13 47 14.1	-00 51 30	16.29	0.600
13 56 44.9	-06 07 44	16.17	0.072
14 04 53.9	-04 55 56	15.79	0.380
14 21 29.8	-00 13 24	16.02	0.151
14 24 24.6	-00 07 30	16.31	0.632
14 30 47.0	-00 41 36	16.17	1.112
14 35 13.1	-01 34 14	15.97	1.310

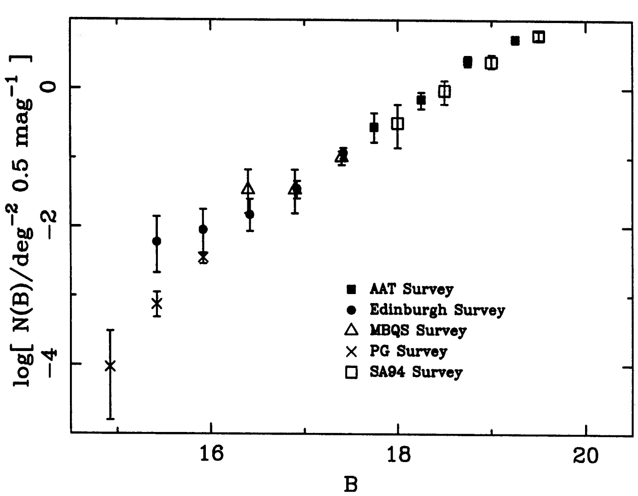

Figure 1. The differential number–magnitude diagram comparing the surface densities found in the Edinburgh survey to those in other surveys in the redshift range $0.3<z<2.2$.

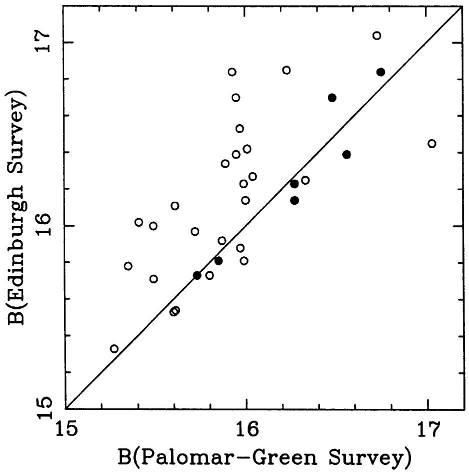

Figure 2. Photometry in the Edinburgh survey plotted against photometry in the Palomar–Green survey for UVX objects found in common with both surveys. The line plotted is the line of perfect agreement. The open circles represent Palomar–Green survey photographic measurements and the filled circles represent Palomar–Green survey photoelectric measurements.

comparison of measured magnitudes of other UVX objects found in common. Most of the objects found in the complete PG survey are hot stars, and GSL provide a list of these with their photographic B_{PG} magnitudes and, in a few cases, photoelectric U, B_{pe} and V magnitudes. In this section, photometry from the Edinburgh survey will be referred to as B_{Edin}. There are 25 stars in common with both surveys in the range $15 < B_{Edin} < 17$. We exclude the quasar, since its magnitude could have varied between measurements. The average offset between the measured photographic magnitudes is $B_{Edin} - B_{PG} = +0.28$. The photographic magnitudes are plotted as open circles in Fig. 2, which shows that this difference exists throughout the magnitude range, and is most likely due to a systematic zero-point error in the PG survey in this region of sky. In contrast, if we only consider the seven objects which have photoelectric photometry in the PG survey, we find an average offset of $B_{Edin} - B_{pe} = -0.01$ (filled circles in Fig. 2), so the Edinburgh photometry agrees well with GSL's photoelectric photometry. The quoted random error in B_{PG} is 0.29, so that with the average value of $d\log(n)/dm = 0.32$ for the UVX objects, we expect a Malmquist bias of 0.03 mag (GSL), which is not a significant contribution to the observed offset in photographic magnitudes. Regardless of the origin of the photographic magnitude offset, the effect should be to *increase* the numbers of objects in the PG survey, and hence the observed *deficit* in numbers of PG quasars cannot be explained by this offset between the two surveys.

This comparison appears to agree with the conclusion of Wampler & Ponz (1985) who carried out photometry of the quasars in the PG survey and also found that the PG photographic magnitudes are systematically too bright, but we should note that the systematic difference between the Edinburgh and PG surveys may not extend to all regions of the PG survey. There is insufficient information currently available to determine the cause of the incompleteness in the PG survey.

6 CONCLUSIONS

The surface density of bright ($B \le 16.5$) UVX quasars measured by this survey is 0.024 deg^{-2}, higher than that measured previously. For quasars with $16.5 < B < 17.7$, the surface densities in this survey agree well with those measured by other surveys and are defined with greater accuracy than before. The gradient of the differential log(number)–magnitude relation has changed from 0.98 to 0.78 for UVX quasars with $B \le 17.7$. The ratio of bright quasars at low redshifts to fainter quasars of the same luminosity at high redshifts has increased, and so the amount of cosmological evolution will decrease from that deduced by Boyle *et al.* (1990) and possibly become more comparable to that measured at radio wavelengths (see e.g. Peacock 1985). There is still a need for a much larger complete sample of bright quasars in order to model the evolution of luminous quasars more accurately since, in order to do this, one needs to model the dependence of the luminosity function on redshift. This requires a significant number of luminous quasars in each narrow redshift bin. It remains to be seen if the 'break' in the luminosity function will still be seen at all redshifts, and if pure luminosity evolution (Boyle *et al.* 1988) is still the best-fitting model to the evolution of the luminosity function.

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