A MULTI-COLOUR SURVEY FOR HIGH-REDSHIFT QUASARS

S.J. Warren, P.C. Hewett and M.J. Irwin
Institute of Astronomy
Madingley Road
Cambridge CB3 OHA
United Kingdom

ABSTRACT. We describe how the application of techniques which utilise all the information contained in multi-colour surveys of stellar-like objects can be employed to detect quasars over an extended redshift range. The method is particularly effective for the identification of quasars with redshifts $z>2.2$ where the application of the ultra-violet excess criterion breaks down. Spectroscopy of a small sample of objects from the first survey field has resulted in the detection of two new faint quasars with redshifts $z=3.42$ and $z=4.01$ (ref. 1).

1. INTRODUCTION.

The identification of intrinsically bright, high-redshift quasars by Hazard and coworkers (ref. 2), contrasts with the apparent lack of large numbers of intrinsically faint high-redshift quasars established by Koo and others (ref. 3-5). The space density and luminosity function of quasars at high redshift remains of considerable cosmological interest, and there is a need for a wide angle, relatively deep survey to explore the absolute magnitude range between those covered by Hazard and Koo.

The study of broad-band optical colours offers the potential for identifying many types of quasar with a large range of redshift owing to the wide wavelength coverage 3300-8500Å. The combination of Automated Plate Measuring Facility (APM) measures of United Kingdom Schmidt Telescope (UKST) plates is ideally suited for such a survey. Each plate covers a useable area of 30 square degrees, a factor 100 larger than the area of the very deep 4-metre surveys, while the magnitude limit extends some one and a half magnitudes fainter than the objective-prism surveys of Hazard et al. The use of direct plates results in simpler selection effects compared to slitless spectroscopic techniques.

A. Hewitt et al. (eds.), Observational Cosmology, 661–664.

2. THE MULTI-COLOUR SURVEY.

Object magnitudes in the U,J,V,R and I photometric bands are derived from APM measures of UKST direct plates. Previous quasar searches have proceeded by identifying objects lying away from the well defined stellar sequence evident in colour-colour diagrams. Substantial improvements in the effectiveness of the quasar search can be realised by using the full four-dimensional (4D) colour space rather than the conventional two-dimensional (2D) colour-colour projections.

The location of each object in the five dimensional magnitude space can be represented by a five component vector. If the apparent brightness of an object is not to be incorporated as a parameter in the search for quasars - i.e. two objects with the same colours but with different apparent magnitudes are regarded as identical -, one of the five dimensions becomes redundant. The most familiar representation of the resultant 4D space is in terms of the colours U-J,J-V,V-R and R-I.

The use of the U-J,J-V,V-R and R-I colours as axes describing the 4D space is not ideal because of the high degree of correlation between the axes. The optimal representation of the 4D space is one where the axes are normalised and mutually orthogonal. In the case of the familiar 2D parameter space employing U,B and V data it is easy to show that the axes $(U-V)*\sqrt{3}/2$ and $B-(U+V)/2$ satisfy these criteria. It may be noted that Koo (ref. 6), using an astrophysical argument, arrives at a similar conclusion concerning the representation of two-colour data: nevertheless his axes, (U-V) and B-(U+V)/2, whereas they are orthogonal, have not been normalised.

The procedure is readily extended to three and four (or higher) dimensions. Figure 1 shows a three dimensional plot of the J,V,R,I multi-colour space, where the axes $x=(R-V)*\sqrt{2}/\sqrt{3}$, $y=(I+J-V-R)/\sqrt{3}$ and $z=(I-J)*\sqrt{2}/\sqrt{3}$ are normalised and mutually orthogonal, together with a 2D projection of the same data. The positions of 14000 stellar objects in a field at the South Galactic Pole field at 0h 53m, -28 03' are plotted. In addition, the locations of some 35 known quasars in the field are shown, including three previously identified quasars with redshifts z>3.3 and 0046-293, the recently discovered z=4 quasar.

The vast majority of stellar objects are stars within our own galaxy which exhibit a very restricted range of properties, and hence are confined to a small region of the multi-colour space. Quasars, by contrast, are widely dispersed and may be recognised by their locations in low-density regions of the multi-colour space. By surveying all objects in low-density portions of the parameter space all quasars except those that mimic closely the properties of common stars can be identified. The advantage of performing such a search in 4D rather than in 2D lies in the observation that the fraction of the total volume of a parameter space occupied by common stars becomes smaller with the addition of each independent dimension. The fraction of the 4D colour space (which is more difficult to illustrate) occupied by stars is even smaller than that in the 3D colour space shown in Figure 1.

In a project to determine much improved limits on the space density of high-redshift z>3 quasars we have started a survey of three UKST fields, a total of 100 square degrees to limiting magnitudes

https://doi.org/10.1017/S0074180900159716 Published online by Cambridge University Press

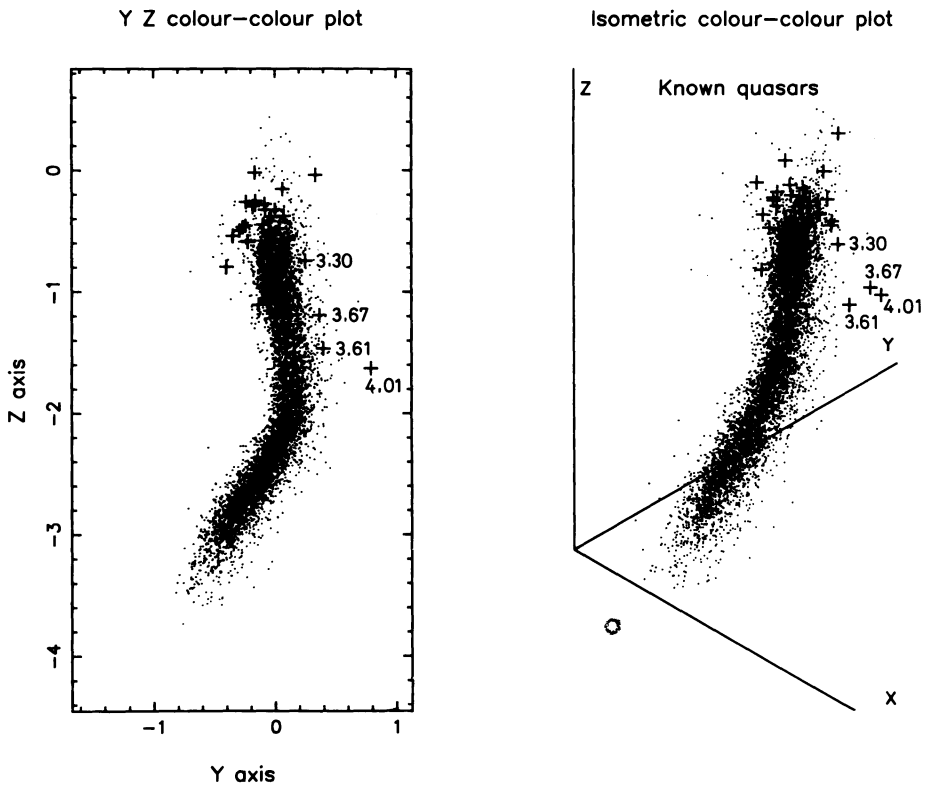

Figure 1. 2D and 3D representations of the multi-colour data, showing the locations of known quasars in the SGP field.

m_J=21.5, m_R=20.0. Observations of 12 candidates from our first survey field resulted in the discovery of a redshift z=3.42 quasar, with broad-band magnitudes J=20.7, V=19.4, R=19.7 and I>19.3, together with a redshift z=4.01 quasar with broad-band magnitudes J=21.0, V=19.5, R=19.2 and I=19.0. The discovery of these two quasars demonstrates that faint high-redshift quasars do exist, but reliable limits on the space density of such objects will have to await the completion of the survey.

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https://doi.org/10.1017/S0074180900159716 Published online by Cambridge University Press

DISCUSSION

AUDOUZE: What is the maximum redshift you can anticipate detecting with your technique?

HEWETT: The detection of quasars with redshifts $z > 4.5$ will be difficult as the objects will be red in all the optical colours. In principle, however, any object with a detectable flux in the optical, and which does not closely mimic a star, could be identified.

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