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A STRIP SEARCH FOR QUASARS:

THE CCD/TRANSIT INSTRUMENT (CTI) QUASAR SURVEY

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1.0 INTRODUCTION

Quasars are of great interest to astronomers principally because they are the most intrinsically luminous objects known. They can thus be seen to the greatest distance and can be used in a number of ways as probes of the early universe. The physical characteristics of quasars are, however, sufficiently heterogeneous that an investigation of the quasar phenomenon itself requires an unbiased picture of the various types of quasars and the distribution of quasars with redshift.

Unfortunately, the history of discovery of quasars is riddled with selection effects which have biased this picture. Initially, quasars were radio-loud, starlike objects. Then, quasars became starlike objects, only a fraction of which were radio-loud, but which showed an ultraviolet excess. Next, quasars became emission line objects. More recently, it was known that quasars suffered a "cutoff" in space distribution beyond $z = 3$. Each of these effects is now known to be either only partially true or incomplete, thus there still exists a need for surveys to find representative samples of quasars unbiased with respect to extrinsic selection effects, intrinsic physical differences, or redshift. The CCD/Transit Instrument (CTI) at Steward Observatory has underway such a survey involving multiple survey techniques to be used on the same strip of sky.

2.0 THE STRIP

The survey area is defined as the field-of-view swept out by the CTI in the course of a year. The CTI is a 1.8 m, f/2.2 telescope on Kitt Peak. It does not move, but is fixed in the meridian at a declination of +28 degrees. It utilizes two CCDs aligned east - west in the focal plane to observe the sky in two colors, V and one of (U), B, R or I, depending upon the sky brightness. The CCDs are operated in the "time-delay and integrate" (TDI) mode at the apparent sidereal rate. The resulting image is a strip 8.25 arcmin wide (N-S) with length determined by the length of the night. The CTI surveys about 15 square degrees per night or about 45 square degrees per year to a limiting magnitude of $V = 21$. Each object in the strip thus has (U)BVRI time-averaged colors and a V light curve with a time resolution of one day.

In an effort to both select an unbiased sample of quasars to a faint magnitude limit and to <u>measure</u> selection effects among various techniques, we are conducting independent "blind" surveys using as detection criteria variability and color. An additional survey for radio-loud quasars utilizing the VLA has been initiated.

3.0 THE SEARCH

The CTI quasar survey is multi-purpose by design. In particular, it is designed to find quasars in a manner as unbiased as possible and to monitor the light curves of the discovered quasars. The emphasis of this survey is on precise, continued measurement of quasars. We discuss selection on the basis of color and variability. Each search is conducted independently of all others.

3.1 Selection of Quasar Candidates on the Basis of Color

The principal advantages of selection by color are the depth which can be reached and the relative ease of processing data. The principal disadvantage is that the information content per observation is lower than for objective spectroscopy. We wish to exploit the advantages and minimize the disadvantages of color selection.

Utilizing cluster analysis, selection of quasar candidates on the basis of multiple broadband colors results in a sample chosen relatively independently of redshift. We have investigated the selection of quasar candidates using multiple colors, but on the basis of arbitrary color-color diagrams in an effort to more fully understand the information content of multiple colors, intuitively understand the colors of quasars of different types, discover quasars independent of redshift, and select candidates in a less intensive computational regime. Colors have been fabricated in linear combinations which represent the projection of quasars onto arbitrary planes in color space.

Our approach has been to first try to predict the colors of quasars as a function of redshift and then to search for them, utilizing the arbitrary color-color diagrams for the selection of candidates. The colors we utilize are fabricated by convolving the measured CTI filter bandpasses with the energy distributions of real stars and quasars. Quasar energy distributions were estimated from calibrated IUE and optical spectroscopy. To avoid biases involved in producing an "average" spectrum, we elected to utilized spectra from multiple, independent quasars and to redshift the energy distibution only over the range for which valid data existed. Instrumental colors are calculated by convolving the quasar enery distribution with the filter bandpass, the CCD response, the telescope efficiency and the atmospheric transmission. The result of this analysis should accurately represent the colors of quasars as directly measured by the CTI.

Our analysis includes two hypotheses graphically illustrated here:

* the best discriminant of a quasar is its power law energy distribution, not (necessarily) its emission line spectrum
* arbitrary color-color diagrams can always be constructed to either:
    1) minimize the area occupied by quasars
    2) minimize the area occupied by stars
    3) for a given redshift range, minimize contamination by stars.

The techniques we utilize to select quasar candidates on the basis of color are demonstrated in Figure 1.

In the four diagrams of Figure 1, each expressed in CTI instrumental magnitudes, can be seen the change in color induced by lines entering and leaving bandpasses. The main sequence is marked with letters denoting the spectral type. W and S are used for white dwarfs and subdwarfs, respectively. Colors for power laws are marked with open boxes with indicies noted. The quasar tracks are calculated empirically from selected "typical" emission line quasars with measured optical and uv spectra. Individual quasars are marked by line type over redshift ranges noted at the bottom of each plot. The redshift at integer values is noted where confusion of the tracks allows. In each of these diagrams the details of excursions below z = 2 are not considered significant - only the general locus is of real interest.

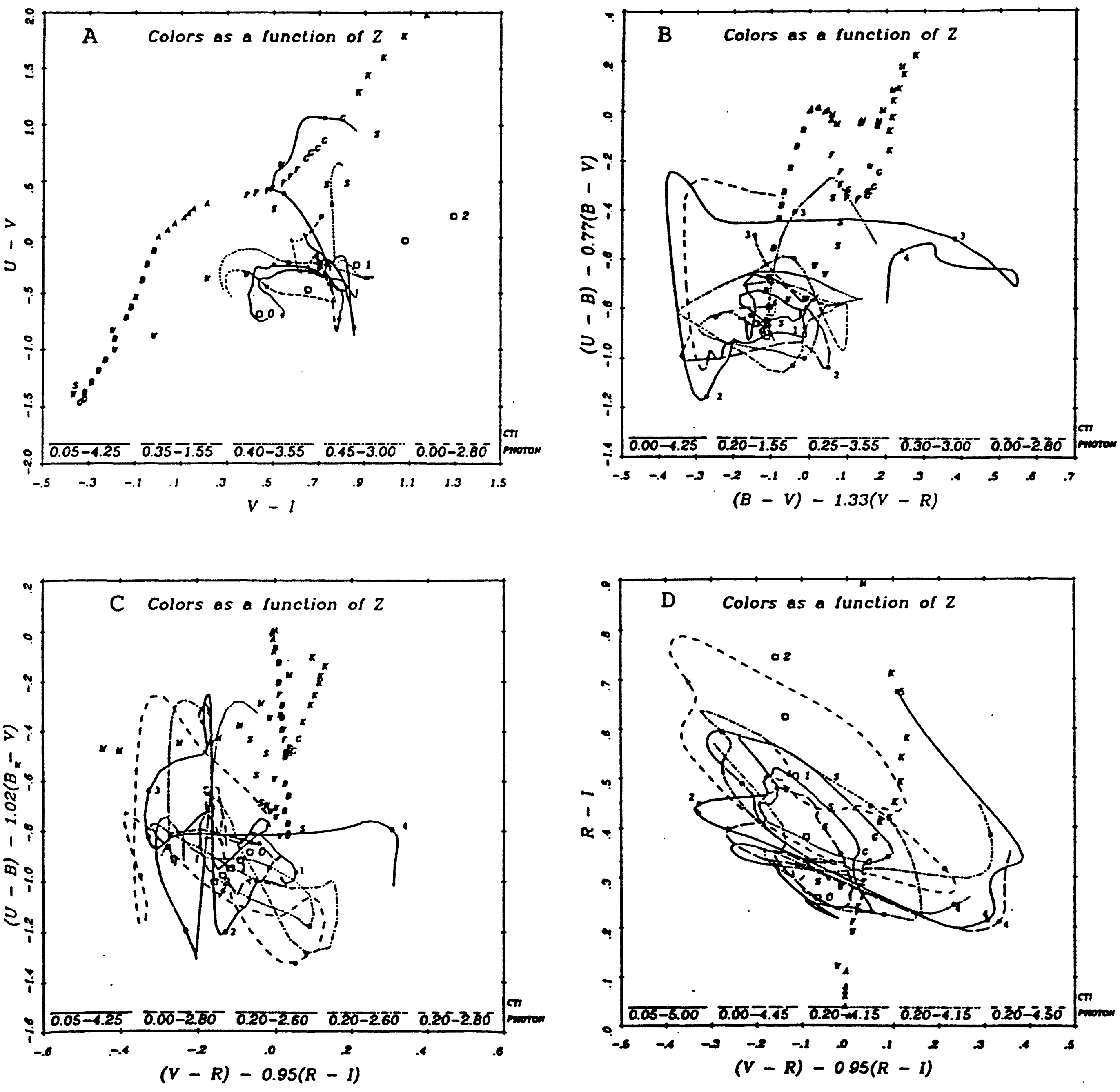


FIGURE 1. Typical excursions of quasars colors with redshift in color-color diagrams.

Figure 1A shows that quasar energy distributions are more like power laws than stars. A wide range in wavelength (U through I) is useful in maximizing the distance of the locus of most (low redshift) quasars from the main sequence.

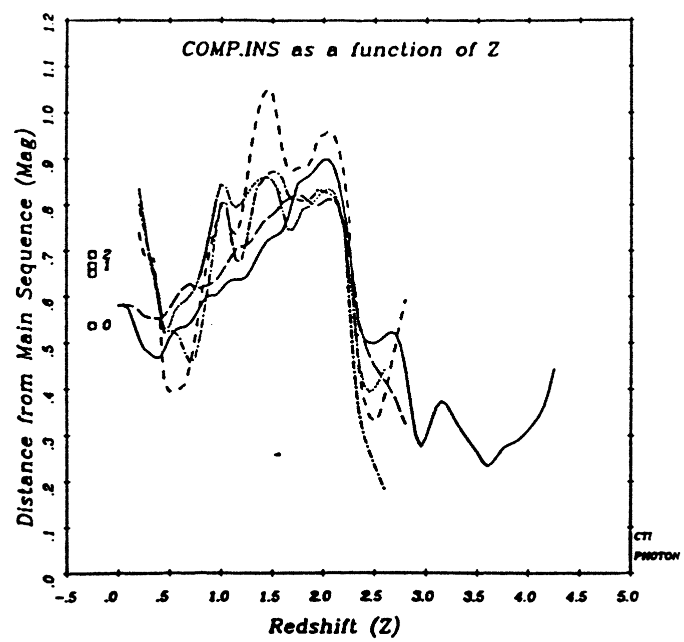
Figure 1B shows a color projection which minimizes the area of the locus of quasars by requiring all power law colors to be identical. In this diagram the locus of quasars remains centered about the colors for power laws with principal contamination from white dwarfs and subdwarfs.

Figure 1C minimizes the locus of stars, with less stellar contamination, in general.

Figure 1D utilizes easily measured colors and indicates that, in this diagram, $z = 4$ quasars are (typically) separated from the main sequence by more than 0.2 magnitude. It is a pity all quasars are not "typical"!

Analysis of the geometrical distance in color space (as a function of redshift) a quasar falls from the main sequence gives a measure of the probability of detection. This is shown in Figure 2. Assuming a uniform distribution of quasars with redshift to $z > 5$, it can be seen that the redshift region $3 < z < 4$ has the lowest detection probability on the basis of color. This effect is a likely contributor to the deficiency of quasars in this redshift range. Overcoming this selection effect is dependent upon:

* multiple broadband colors spanning the optical wavelength range,
* precise measurement of colors, and
* survey depth.



<u>FIGURE 2</u>. The absolute distance of quasar colors from the main sequence colors as a function of redshift. The quasar colors are those used in the above color-color diagrams. We hypothesize that the (former) paucity of quasars with $z > 2.5$ was contributed to by this effect. Photometric precision better than 0.1 magnitude will help investigate the redshift domain $2.5 < z < 4.0$.

3.2 Selection of Quasar Candidates on the Basis of Variability

Because the history of quasar research is a chronicle of attempts to overcome selection effects, we make the hypothesis that stochastic varibility on timescales of days to years is the most unbiased discriminant of a quasar. The CTI is designed to remain fixed for a period of years, observing the same strip of sky and thus amassing light curves sampled more frequently, to fainter limiting magnitude and with greater precision than previously applied to quasar surveys. Though this survey is being carried out "blind" relative to the color survey, we predict that when results are compared, the sample selected on the basis of variability will be a superset of those selected by color (or any other means). In addition, the light curves can be used for correlation among color and radio and x-ray brightness. Figure 3 shows measured V light curves of quasar candidates.

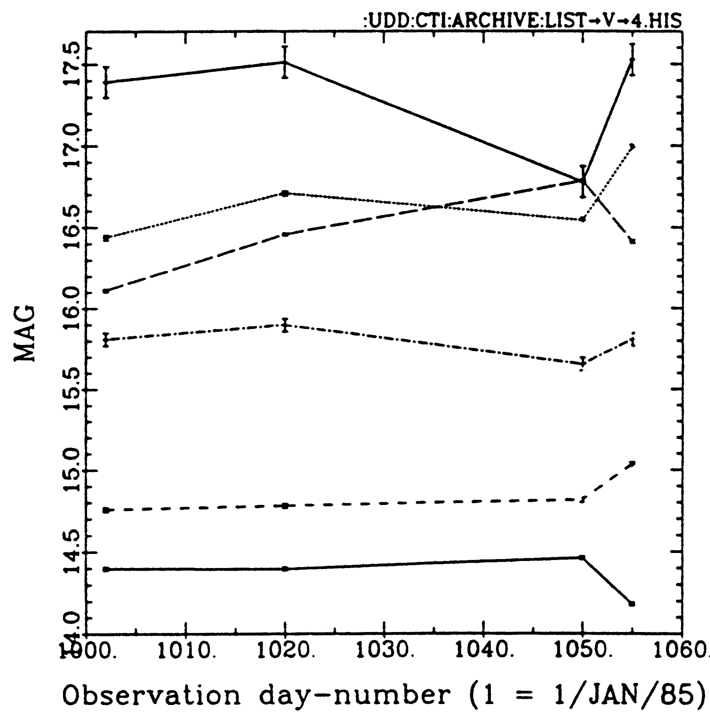


FIGURE 3. Light curves of five quasar candidates. Error bars are one-sigma uncertainties evaluated from the shot noise in the object, the night sky and the CCD readout noise.

The staus of this survey is that the CTI telescope is operational, acquiring B, V, R, I data every clear night. These data are reduced by a pipeline system which is also fully operational. Spectroscopic followup of candidates will begin shortly.

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