and the second row those inferred from Draine and Lee's computations. When available, the M(H I) masses calculated by using H I 21 cm data are listed in the fifth column (Bicay and Giovanelli, 1987; Mirabel and Sanders, 1988; Young et al. 1989).

Discussion and Conclusion

The main advantages on the determinations of the dust mass at these wavelengths lie on a better evaluation of $< T_i >$ since at higher frequency the uncertainties in the temperature distribution function may introduce order-of-magnitude errors in $< B_\lambda(T) >$.

Note that the warm dust masses listed in Table 1 can be underestimated also because the IRAS 100 μm measurements do not fully sample the total dust in the galaxy disk.

However, the uncertainties in the grain opacities are larger at long wavelengths even if they do not depend on the details of the size distribution. Gas and dust masses are estimated, then, within a factor of 5 (see Table 1).

The comparison with M(H I) suggests that very likely there is a substantial contribution to the total gas mass due to H_2. But, to draw any firm conclusion on this point we need CO line measurements of these galaxies, which up to now have not been carried out.

Young et al. (1989) found that for a sample of IRAS spirals $M(H_2)$ ranges between 10^8 and $5 \cdot 10^{10}\,M_\odot$ and the ratio $M(H_2)/M(HI)$ is of the order of 1. If this is the case also for the observed sources of our sample, the gas mass values inferred from our measurements would agree with those determined from CO and H I data.

It should be stressed that the approach used here is not claimed to be, up to now, of greater accuracy than other determinations of gas masses (e.g. using the integrated intensity of the ^{12}CO line) but it is important either because it implies a completely independent method based on a different set of assumptions. However, these observations can substantially improve our knowledge on dust opacities at long wavelengths and constrain models of dust grains. This would turn into a better determination of dust and gas masses.

Therefore, we find this approach more promising with respect to that based on CO line intensities since the uncertainties related to this latter are largely connected to the physical conditions of the medium and then more difficult to evaluate.

Further observations will be carried out at SEST in September and they will be helpful in gaining statistical insights into these problems.

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Variability as a Way to Find Quasars: a Complete Sample

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Introduction

To study the cosmological evolution of quasars, it is first necessary to establish a complete sample. This has proved to be particularly difficult, for several reasons. Early work was based on radio surveys, and although this resulted in well defined samples with no obvious bias in redshift, it was inevitably limited to a small subset of quasars (1 or 2 %) which themselves showed a wide variety of radio properties. Most recent results are based on samples obtained by two main methods: the UV excess method (see Véron, 1983, for a review), later generalized to the multicolour method (Koo et al., 1986), and the slitless spectroscopy method (see Véron, 1983, for a review). Although both techniques can produce samples apparently containing a sizeable fraction of the quasar population, they each suffer the drawback that their detection efficiency is strongly dependent upon redshift. To some extent they may be seen as complementary procedures as the UVX method is most efficient in the low redshift regime, while slitless spectroscopy is more sensitive to high redshift objects. However, what is clearly needed is a selection technique which is essentially independent of redshift, and is capable of detecting a substantial fraction of all quasars brighter than a given flux limit.

Most, if not all, quasars are optically variable. Indeed, previous studies have shown that up to 70 % of all quasars have an amplitude of variability larger than 0.43 mag. (Trevese et al., 1989). Van den Bergh et al. (1973) first suggested using this property as a method for finding quasars, and Sanitt (1975) discussed the various types of variable star (RR Lyrae and low-luminosity M-type flare stars) which might contaminate a sample compiled by this method. There are number of advantages in using variability as a search criterion for quasars. There are essentially no instrumental redshift biases, and apart from some constraints set by the passband of the search, there are no colour- or magnitude-dependent biases. Set against this, there is the practical limitation that the timescale of variation for most quasars is several years and so a search must be undertaken over a decade or more to detect a reasonably high fraction of the quasar population.

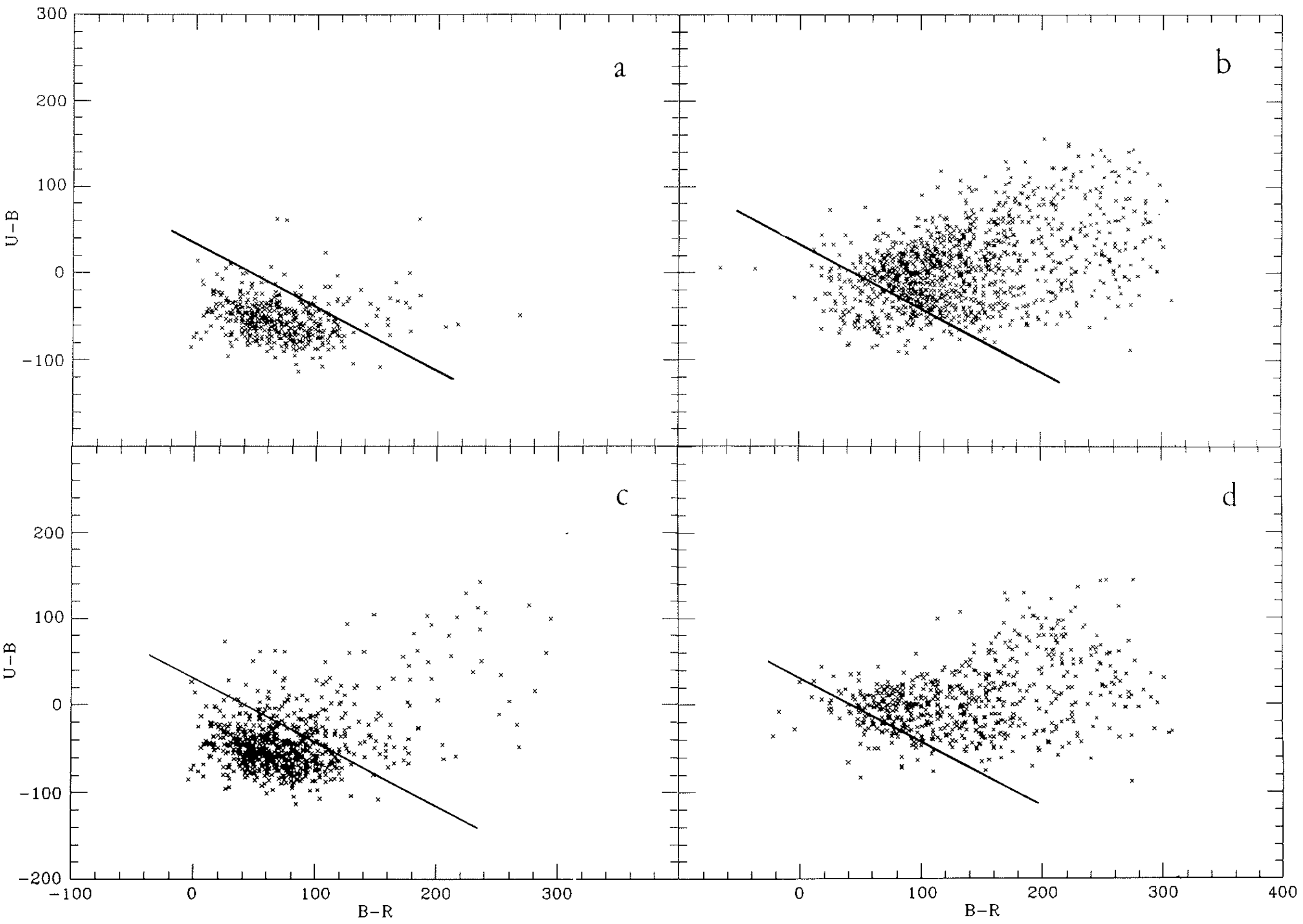

Figure 1: *U-B/B-R diagram (U-B and B-R are in units of 0.01 mag.) for: (a) all variable quasar candidates with $\Delta B \geq 0.45$ mag.; (b) all variable quasar candidates with $0.30 \leq B \leq 0.35$; (c) variable candidates with $\Delta B \geq 0.35$, the objects near a bright star and the extended objects being excluded (809); (d) the extended objects (690).*

Preliminary attempts to discover quasars on a large scale solely on the basis of variability were undertaken by Hawkins (1981, 1983, 1986) using COSMOS measures of a number of IIIa-J plates taken with the UK 1.2-m Schmidt telescope. This early work established that variability was indeed a viable way to find quasars, but dit not cover a long enough time span to detect more than a small percentage of quasars in the field.

This is because, in most cases, the standard deviation of the variability is significantly smaller in the case of a short epoch survey (2 yr) than for a long epoch (50 yr) (Angione et al., 1981), although the mean brightness remains essentially constant over 60 to 70 years (Angione, 1973).

The influence of the time dilation due to redshift on surveys of variability depends on the nature of the variability (Gaskell, 1981); however, if the r.m.s. variation increases with time to reach its maximum after two years for quasars at $z \sim 1$, as found by Bonoli et al. (1979), it is clear that the same value will be reached only after four years at $z \sim 3$.

Over the last 12 years we have been undertaking a survey based on COSMOS measures of UK Schmidt plates aimed at detecting almost all quasars in a 19 sqare degree field. Our results to date are described in the following sections.

The Survey for Variable Quasars

The survey for variable quasars has been based on the ESO/SERC field 287 at 21^h25^m, −45°. The first plates of this field were taken in 1975, and since then the field has been extensively photographed in UBVRI. In order to detect variables, several IIIa-J plates (33 altogether) were obtained in each of the years 1977, 1978 and 1983–88. The plates were all sky limited (approx. 60 min exposure) and reached a limiting magnitude of about $B_J = 22.5$.

The photographs were measured using the COSMOS machine at ROE and calibrated with deep CCD sequences obtained at La Silla and with the AAT (Hawkins, 1983). This measurement procedure provides some 20 parameters per image, including position, integrated magnitude and some image structure information. The measures of each plate have produced 33 B magnitudes for each image, as well as extensive additional measures in UVRI.

The actual search for quasars was constructed to detect objects which varied significantly from year to year, but which remained essentially constant within each of the eight measurement epochs. This had the effect of removing essentially all types of variables apart from quasars, as well as most non-varying objects with large photometric errors. It also tended to remove quasars with large variation over short time scales (OVV quasars), but these objects are known to be very rare. The selection algorithm divided the maximum amplitude of variation by the aggregate r.m.s. scatter within each epoch, to give a measure σ of the significance of the variability.

We have first selected all (2450) objects with a variability amplitude larger than $\Delta B = 0.30$ and brighter at minimum than $B = 21.5$; however, we have found that the contamination by non variable objects is very large (~90%) for $\Delta B < 0.35$; we therefore restricted our sample to $\Delta B \geq 0.35$ (1241 objects). Moreover, we have excluded a small area around the 300 brightest stars in the field, total-

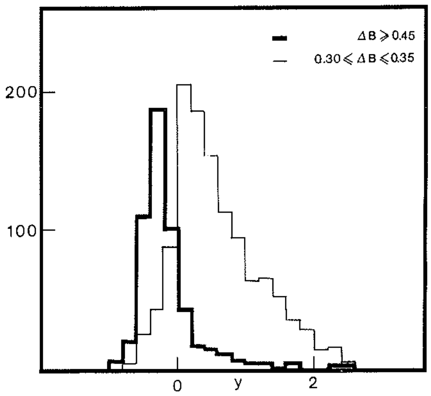

Figure 2: *Histograms of "y" for the objects with $\Delta B \geq 0.45$ mag. and for the objects with $0.30 \leq \Delta B \leq 0.35$.*

ling 3665 mm^2 or 1.28 deg^2, because measurements of weak stars near bright stars are very uncertain. Galaxies were removed from this sample using an algorithm based on maximum density versus image area, using twelve of the plates with the best seeing. The resulting sample contained 809 quasar candidates.

Reliability and Completeness

We have to ask how many of these objects are quasars and how many quasars have been missed.

In a first step, we compare the U-B/B-R diagrams for the highly variable objects ($\Delta B \geq 0.45$ mag) and for the low variability objects ($0.30 \leq \Delta B \leq 0.35$) (Fig. 1); we immediately see that, if we call y = (U-B) + 0.74 (B-R) – 0.32, almost all highly variable candidates have $y < 0$ while very few low variability objects have. Figure 2 shows the histograms of y for the two classes of objects. It clearly shows that most quasars have $y \leq 0$ and that very few low variability objects are quasars.

From the total of 809 variable candidates, 587 have $y \leq 0$. Figure 3 shows the fraction of candidates with $y \leq 0$ in various ranges of variability amplitude. For $\Delta B \geq 0.50$, this fraction is constant and equal to ~90%; it rapidly drops for lower values of ΔB, being only 42% for $0.35 \leq \Delta B < 0.40$. Among the 39 objects with $\Delta B \geq 0.50$ and $y > 0$, 18 are confirmed Seyfert 1 galaxies or quasars (and 9 have $z > 2.7$), 7 are either stars or galaxies while we have no spectra for 15 of them.

On the other hand, all 73 objects with $\Delta B \geq 0.50$ and $y \leq 0$ for which we have a spectrum are confirmed quasars except one which is a dwarf nova, therefore at least 94% of all highly variable objects are quasars.

To find out how many quasars we have missed because they have a variability amplitude smaller than 0.35, we have extracted all objects in the field with U-B ≤ -0.40, $y < 0$, and $B_{min} \leq 21.0$, irrespective of their variability.

We have found 602 such objects. 325 of them have an amplitude of variability $\Delta B \geq 0.35$. This suggests a completeness level of 54%. However, 45 objects have B-R < 0, only two of them with $\Delta B \geq 0.35$; they are most probably hot stars; this brings the statistic to 323 variable quasar candidates for a total of 557, or 58%.

Comparison of the histograms of the U-B colour index for the highly variable objects ($\Delta B > 0.50$) and the low variability objects ($\Delta B < 0.30$ and B-R > 0) suggests that only half of those are quasars; the other half could possibly be the weak blue galaxies found by Gallagher and Hamilton (1988) and Koo (1986). If this is the case, 90 of the low variability objects would not be quasars and therefore the variable quasars (323) would constitue 69% of the total.

Spectroscopy

In the course of several observing runs with the AAT and the ESO 3.6-m telescope, we have made spectroscopic observations of 176 variable objects. 140 of them turned out to be quasars, 48 having $z > 2.2$, the largest redshift being z = 3.58 (# 695); there is a bias against redshifts larger than this value in a survey based on IIIa-J plates because for larger redshifts, a large k correction applies due to Lyα leaving the bandpass. Three additional objects are Seyfert 1 galaxies (# 23, 211 and 746); two more (# 7 and 24) show a continuous spectrum and have a strong polarization as shown by measurements made at La Silla with a Wollaston prism; they are most probably BL Lac objects. Two objects (# 19 and 668) are dwarf novae; the others are galaxies (3), stars or objects of unknown nature due to a poor signal-to-noise spectrum. Of those objects, all have a positive y except for the two dwarf novae and two objects of unknown nature (# 10 and 24); this confirms that most objects with a negative y are quasars.

Conclusions

This paper is a first step to addressing the problem of obtaining unbiassed samples of quasars, especially with regard to redshift, for the purpose of studying the evolution of the luminosity function. We have reasons to believe that the strong redshift biases associated with other methods of finding quasars are not relevant to selection by variability. With a well sampled search period of some 11 years, we have shown that our sample, in a regime

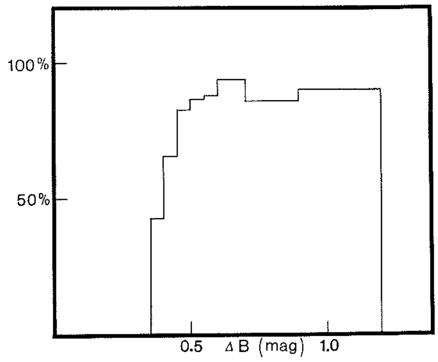

Figure 3: *Fractions of the variable quasar candidates (galaxies and objects near a bright star excluded) with $y < 0$ in various bins of variability amplitude.*

where contamination from non-variables is not significant, is about 70% complete. So far, most work has been done from searches based on blue passband plates, but we now have a baseline of 9 years for red passband plates, which should provide an excellent basis for searching for quasars in the redshift range 3.5 to 5.

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