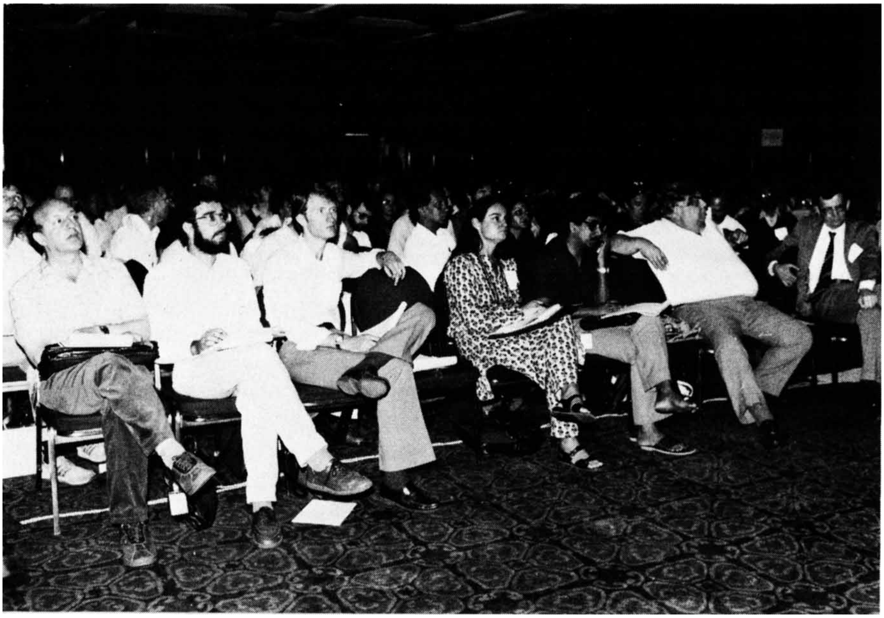
I

SURVEYS

"We must continue this vigorous search for quasars at all wavelengths if we are to gain an understanding of the overall population of quasars and an accurate appreciation of the full range of quasar activity."

- Malcolm Smith (p.28)



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QUASAR SURVEYS

M. G. Smith
United Kingdom Infrared Telescope
Hawaii Headquarters
665 Komohana Street
Hilo, Hawaii, U.S.A.

ABSTRACT. A review is given of progress in surveys for quasars at frequencies from radio to x-ray. Radio results show evidence for a decline in the radio luminosity function for flat-spectrum radio sources at redshifts z > 2. The IRAS survey is uncovering hitherto unknown dusty Seyfert galaxies. Optical surveys, which yield the largest number of QSOs per square degree, may suffer from selection effects which depend on intrinsic luminosity, redshift, and spectral evolution - particularly above redshift 2. Below redshifts of about 2.3, the optical magnitude-redshift plane is being filled in to the point where the evolution of the luminosity function can be seen directly. The statistics of quasar pair separations provide the best evidence so far for quasar clustering.

The existence of many potentially significant selection effects means that a multi-frequency approach to quasar surveys is likely to prove essential to an understanding of the evolutionary behaviour of the quasar population as a whole.

1. INTRODUCTION

In his introductory remarks at this conference, Martin Rees outlined five main research areas being addressed with the products of current surveys for QSOs, viz: (a) the cosmological evolution of QSOs, (b) clustering of QSOs, (c) QSOs as background probes of intervening absorbing material, (d) gravitational lensing and (e) the intrinsic physical properties of QSOs. In this article, I will review progress in surveys for quasars, at frequencies from radio to x-rays, in the 2 years since my review at Liège (Smith 1983); that article (see also Smith 1978; 1981) gives a much more detailed account of the survey methods themselves. In the last two years, work has concentrated more on applying these existing basic survey techniques, rather than developing new ones. The other chapters in this book provide more detailed reviews of the physical properties of quasars.

G. Swarup and V. K. Kapahi (eds.), Quasars, 17–32.

2. RADIO SEARCHES

Following the discovery of PKS2000-330 at z=3.78 using radio search techniques (Peterson et al. 1982), Dunlop et al. (1985) have found that PKS 1351-018 has a redshift of 3.71. Their discovery is important because PKS1351-018 is a member of a complete sample. The lack of objects like it in an "intermediate" flux density sample (S > 0.1 Jy at 2.7GHz - Peacock and Gull (1981)) re-inforces a recent suggestion by Peacock (1985) that the quasar radio luminosity function for flat-spectrum sources declines for redshifts z > 2. Dunlop et al. predict that there should be about 8 quasars in the main Parkes survey with z > 4.

Peacock gives a more detailed account of his statistical studies in a later chapter. Peacock has extended his free-form analysis that he described at Liège (see also Peacock and Gull 1981) and concluded that, for the class of compact flat-spectrum sources, there is a redshift "cutoff". At redshift z=2 the radio luminosity function no longer evolves, and at z=4 it is reduced by a factor > 3 of its peak value. Peacock, Miller and Longair (1985) have concluded that the apparent correlation between the radio and optical fluxes from quasars is an artifact caused by the existence of two classes of quasar with differing host galaxies; radio quiet QSOs exist in spiral galaxies, while radio-loud quasars are found in elliptical galaxies. Miley and de Grijp (1985) also note that "optically selected Seyferts are associated predominately with spirals and radio selected ones occur mainly in elliptical-type galaxies." The evolutionary properties of optically selected QSOs may thus differ from those of radio quasars. We will discuss the "cutoff" for optically selected QSOs in section 4.

3. INFRARED SEARCHES

Infrared observations have, for the first time, been used in a successful search for high-redshift QSOs. Dunlop et al. (1985) used measurements on the United Kingdom Infrared Telescope (UKIRT) to establish the optical-infrared colour of the candidate identification for the z=3.71 QSO PKS1351-018. They found that the "combined properties of (i) compact, flat spectrum radio source, (ii) faint red optical object, and (iii) blue optical-infrared colour ... made 1351-018 a prime candidate for a high redshift quasar and consequently a high priority candidate for spectroscopy." Paul Hewett and I have recently started to make measurements in the infrared of the "peculiar red objects" he has discovered in his generalised pattern recognition approach to IIIaF objective-prism spectra. We shall observe known very high redshift quasars (z>3.5) that fall in his large samples to see if their infrared properties can help distinguish between quasars and other kinds of "peculiar red objects" (see discussion in section 4).

The IRAS point source catalogue was released in its final form at about the time I got on the plane to come to this conference. This IRAS "strong source" survey has a characteristic depth to redshifts of about 0.03 and covers about 96% of the sky to flux levels about 0.5Jy at 12, 25 and 60 microns and to about 1.5 Jy at 100 microns for point sources; it has yielded detections of several hundred previously known active galactic nuclei (AGN). However, there are only about 20 matches with known objects having M(v) brighter than -23, and 9 with M(abs)<-25. None of the classical, luminous QSOs are infra-red selected - all are objects discovered earlier in other wavebands.

The infrared waveband offers an opportunity to combat some of the selection effects which particularly hamper optical searches. It is usually supposed that classical quasars are very luminous active galactic nuclei - AGN. ("Activity" here refers to sources of energy not traceable eventually to nuclear reactions in stars or to their remnants such as supernovae). Surveys identifying low-powered quasar-like activity in the nuclei of nearby galaxies have been highly successful in recent years. In his introductory remarks, Martin Rees compared estimates of the relative co-moving space densities of quasars and galaxies near redshifts of two; activity in the nuclei of a large percentage of nearby galaxies favours models in which frequent cycles of activity occur in any given quasar; luminosity evolution would be a gradual reduction in the mean intensity of the QSO cycles. If black holes are the eventual energy source for the quasar's energy output then, as Rees pointed out, less massive ones are needed to power a series of relatively short outbursts rather than a single gradual dimming maintained through much of the history of the universe. Surveys for low-luminosity quasar activity merit attention similar to that usually afforded the more luminous classical quasars.

Some sort of weak quasar-like activity probably exists in most bright spiral galaxies (see, e.g. Keel, 1983; 1985). At the recent Manchester conference on AGN, I presented a catalogue of composite nuclei, in which the degree of non-thermal activity becomes increasingly obvious (Smith, 1985). Penston and Perez (1984) have suggested that Seyfert 2s are merely "Seyfert 1s" whose central source is temporarily quiescent. Recent IRAS releases support the contention that 30-micron, flat-spectrum, thermal components (a million solar masses of warm dust at 80K from a region 10^2 parsecs across, with luminosities ~ 10^9 to 10^{11}Lo) are widespread, at least in Seyfert 2s. Miley and de Grijp (1985) speculate that these components may, in the spirit of the suggestion of Penston and Perez, be dominant in the "off" phase of Seyfert 1s.

The first active galaxy to be selected on the basis of its far-infrared emission, IRAS0421+040P06, has been discussed by Beichmann et al. (1985). They conclude that the detection of 25-micron radiation may prove to be a key method for selecting AGN from the IRAS sample. Miley and de Grijp (1985) elaborate on this theme and conclude from the IRAS strong source survey that the wide occurence of flat "warm" IR spectra can be used as an indicator of nuclear activity; hence "there should be about 1400 Seyferts present in the strong point-source survey and a factor ~ 4 more could be found if the complete survey data were co-added ... comparing this number of several thousand IR Seyferts in the IRAS survey data base with the 554 known active galaxies and the 2251 known QSOs tabulated by Veron-Cetty and Veron (1984), one can safely predict that within the next few years IRAS will have led to the discovery of a significant fraction of all known AGNs." The IR Seyferts are systematically more distant than the Markarian Seyferts. Some 5% of the IR Seyferts have z>0.1.

Narrow-emission-line galaxies with luminosities in excess of 10^{12}Lo have been discovered using IRAS. Such objects would be visible as unresolved emission-line objects at redshifts comparable to those of quasars. A comparison between these (red?) IRAS galaxies and the (blue) highly luminous emission-line galaxies discovered by Terlevich on United Kingdom Schmidt Telescope (UKST) objective-prism plates should be made.

Possibly the closest quasar-like activity is invisible at optical wavelengths. The centre of our galaxy suffers about 30 magnitudes of visual extinction. Recent measurements by Geballe et al. (1984) on UKIRT have revealed HI and He I lines with full widths at zero intensity of 1500 km/s within a central region less than 0.1pc across. Serabyn and Lacy (1985) have chosen to interpret these velocities, along with their own measurements further from IRS16, in terms of circular motions, and thus derive a central mass of several million solar masses, all within this tiny volume; they take the measurements of Geballe et al. as excellent evidence for a black hole at the centre of our Galaxy.

Other interpretations of these high velocities are possible. An infrared survey on UKIRT of the Galactic centre region by Gatley et al. (1984) revealed evidence for a possible mass-loss bubble about 4pc across, centred on IRS16. IRS16 was found to have colours distinct from other infrared sources in the immediate vicinity, and a luminosity of several million Lo. A ring of shock-excited molecular hydrogen was found, again centred on IRS16. This suggestion of a powerful outflow source led Geballe et al. to make the crucial infrared line-profile measurements. Whatever IRS16 really is, its concentrated high-luminosity source is unique in our Galaxy.

4. OPTICAL SEARCHES

4.1. Quasar-like activity in nearby galaxies

As mentioned earlier, statistics concerning the incidence of activity in nearby galaxies provide indications of the properties and overall evolution of quasars. Keel (1985) has defined a low-level active nucleus as any nucleus with [NII]6563/Hα greater than 0.7. Elvis and Lawrence have dubbed these objects "microquasars". Such objects may occur in the nuclei of a large fraction of all spiral galaxies (Keel, 1983). Some of these objects have been detected in x-rays (e.g. Elvis and van Speybroeck 1982); perhaps IRS16 is a very low-luminosity object of this type. Moving up in luminosity to what Elvis and Lawrence call "mini-quasars", we come to the Low Excitation Nuclear Emission Line Regions, or LINERS - which are known to occur widely in galaxies (Heckman 1980 a, b, c). Evidence has accumulated from extensive survey work (see, e.g., the review by Keel, 1985) that "many

LINERS are powered by photoionisation from a flat-spectrum radiation source similar to the very luminous ones in conventional active nuclei." Several LINERS are known to be X-ray sources (Halpern and Steiner, 1983). Many, though not all, LINER nuclei may be low-power quasars.

Seyfert galaxies usually have [OIII]5007/Hβ greater than 3; the ratio for LINERS is smaller (see e.g., Baldwin, Phillips and Terlevich 1981). From surveys of nearby galaxies (Stauffer 1982; Keel 1983; Phillips, Charles and Baldwin 1983), 5% of luminous disk systems have been found to contain a Seyfert nucleus, as diagnosed by highly ionised gas (FeVII, NeV) consistent with an ionising continuum extending to at least 100eV.

4.2. The optical luminosity function and the apparent lack of faint, high-redshift quasars

Most of this conference will be dealing with more luminous objects than those seen in the nuclear regions of nearby galaxies. Considerable progress in optical selection of QSOs has been made recently using multicolour techniques. Marshall's (1985) paper on optically selected QSOs with $z<2.2$, and $B<20$ is a particularly important characterisation of the quasars that have been discovered. He concludes that the slope of the luminosity function for optically selected quasars shows no significant relation to redshift (c.f. Veron 1983) and that "a power-law luminosity function that evolves homologously in time describes the data well and suggests that the same mechanism operates in all quasars to supply the gas and produce the light."

The diagram shown by Koo (1983, Fig. 3) at Liège shows that Marshall's power-law luminosity functions appear to flatten out for fainter quasars. He concluded that quasars were brighter, but possibly less numerous in the past, especially for redshifts greater than 2.5. Koo (1985) has selected candidates from SA57 with $B<22.6$ using 4-metre photographic multicolour photometry, astrometry, variability and CCD spectroscopy; candidates were chosen that had star-like images and colours unlike normal stars. This combination of techniques allowed Koo to filter out white dwarfs, hot subdwarfs and narrow-emission-line galaxies. No quasars with $z>2.54$ were found among the 8 confirmed quasars with $B>21.5$. Koo discusses the possibility that higher-redshift quasars may be hiding in the region of the two-colour plot occupied by most Galactic stars. From his arguments alone, the numbers seem likely to be small. It is important to find them - virtually nothing is known about the luminosity function, spectroscopic properties, or redshift distribution of quasars with $z>3.4$. Knowledge of the space density of such objects, and subsequent detailed studies of the Lyman-alpha absorption systems in the line of sight will provide strong constraints on the energy input to, and the properties of the intergalactic medium at those early epochs (see, e.g., Atwood, Baldwin and Carswell 1985).

Hewett has used plates from the United Kingdom Schmidt Telescope (UKST) and the Automated Plate Measuring (APM) facility to obtain very large numbers of low-resolution optical spectra. Hewett and Irwin (1985) discuss their generalised pattern-recognition techniques for classifying these spectra. An example of this work, as applied to quasar research is given in Figure 1. The cluster of 43 large filled circles at the left of the diagram corresponds to known quasars with redshifts z<2.2. Five known quasars in this field with very high redshifts, are also plotted as large filled circles. They are easily distinguished from most of the known quasars, but are not so easy to separate from the majority of objects found on the plate. Similar stellar colours have been found by Dunlop et al. (1985) for PKS1351-018. It is obvious from diagrams like this that simple colour searches over a restricted wavelength range are very effective at finding QSOs with z<2.2, but are not much good at z>2.9. I am therefore still extremely cautious about claims of "cutoffs" in the range 2.2<z<2.9! The next "cutoff" one hears about comes at around 3.3<z<3.5. IIIaJ, the emulsion which has yielded the most high-redshift QSOs discovered so far, cuts off at 5350A, the wavelength of Lyman-alpha at z=3.4. How did Kodak know?

Schmidt, Schneider and Gunn (1986) report a striking paucity of high-redshift, faint quasars (see also Schneider, Schmidt and Gunn 1984). They have surveyed a total of 0.91 sq. deg. in 113 fields at galactic latitudes above 30 degrees, using a grism technique with the PFUEI at the Palomar 5-metre telescope. They used well-defined selection criteria to pick out a final list of 27 emission-line objects from calibrated spectra for over 9,000 objects in the range 4500-7200A. 17 of these objects are emission-line galaxies with 0.04<z<0.31. The remaining 10 are quasars with 0.91<z<2.66. The luminosity-function models of Schmidt and Green (1983) yielded good agreement with the new survey data over the redshift range 0.7-2.7, but predicted a yield of 40-120 quasars in the range 2.7<z<4.9. From the absence of such detections in their survey, Schmidt, Schneider and Gunn concluded that "quasars with an absolute magnitude of M(B) ~ -25 suffer a redshift cutoff near or below a redshift of 3."

Published systematic searches for objects beyond redshift 3.4 - the IIIaJ emulsion cutoff for Lyman-alpha - have thus proved largely unsuccessful (see, e.g. Koo and Kron, 1980; Osmer 1982; Schneider, Schmidt and Gunn 1984; Koo 1985). These surveys have examined small areas of sky to faint limiting magnitudes, with a strong emphasis on the discovery of objects with clear emission-line features. In contrast, Hazard, McMahon and co-workers have discovered 5 quasars with 3.4<z<3.7 on low-resolution objective-prism plates covering a large area of sky to relatively bright magnitudes m(R)=18 (Hazard et al. 1984; Hazard and McMahon 1985). Three of these objects lie within a single UK Schmidt field, where a z=3.61 object had already been discovered by Shanks et al. (1983). One of these objects does not exhibit strong emission - it is a broad-absorption-line QSO. The highest-redshift optically-selected QSO is 0055-2659, discovered by Hazard and McMahon (1985) at z = 3.68. Dunlop et al. (1985) have suggested, from the radio discoveries of objects like PKS2000-330 (z = 3.78) and PKS 1351-018 (z = 3.71) which have weak emission lines and stellar colours, that it "therefore seems feasible that both

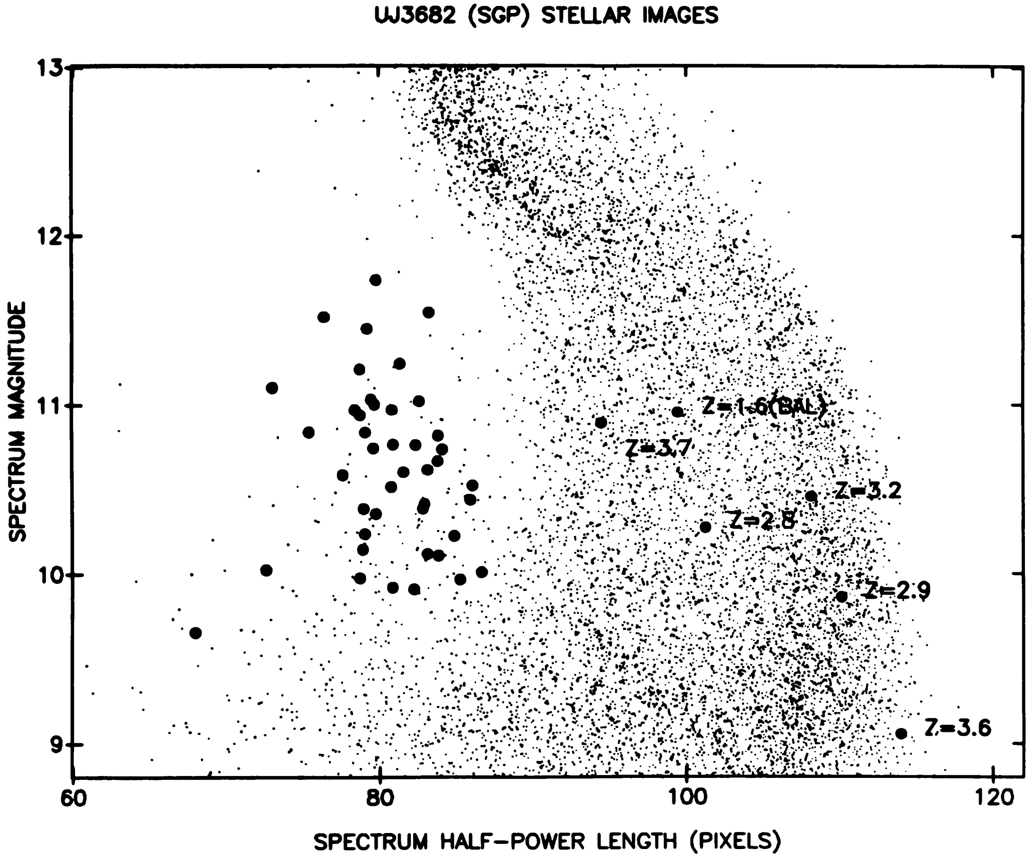

Figure 1. A colour-magnitude for ~10,000 star-like images from a U.K. Schmidt field containing the South Galactic Pole. In this diagram, kindly supplied by Paul Hewett, we see that quasars with redshifts $z<2.2$ (the group of solid circles to the left of the diagram) are bluer than the majority of objects in the field. Quasars of higher redshifts (and at least some broad absorption-line QSOs) do not stand out from galactic stars in diagrams of this type.

The units of magnitude are arbitrary, roughly linear, and cover the range $16<m_B<20$; brighter objects are nearer the top of the diagram. The abscissae measure colour; redder objects are nearer the right of the diagram. The solid circles represent all the known, confirmed, non-overlapped quasars in the central 22 sq. deg. of this field-based on work by Clowes and Savage (1983); Shanks et al. (1983); Boyle et al. (1985); Hazard and McMahon (1985).

prism-plate and colour selection of high-redshift quasar samples may be biased towards bright, strong emission-line objects, in which case it is not unexpected that both techniques should agree on the shape of the quasar luminosity function at high redshift." Concerning the widely-held view that quasars were fewer but brighter in the past Dunlop et al. add that "This conclusion may indeed be correct but at present does not seem fully justified."

4.3. Progress with the automatic measuring machines

Very rapid progress is now being made in the UK with the APM machine in Cambridge and the COSMOS machine in Edinburgh. All the work to be described in this section has appeared since 16 months ago when I was able to state - at a conference on future applications of measuring machines (Smith, 1984) - that "The challenge to the new high-speed measuring machines is obvious. The only significant cosmological results from the studies of optically selected quasars have so far involved neither APM nor COSMOS. Most of the work on clustering of optically selected quasars has been based on visually-selected samples of poor quality. The majority of bright QSOs with z>2 selected for absorption-line studies have been selected by eye. All the BAL QSOs have been found by eye, not by machine. There is no reason for this situation to continue. The hardware is ready for those with the software."

Schmidt plates provide the most efficient means of amassing large samples of quasars; large surface densities are particularly important for studying the large-scale clustering of matter at early epochs. Automated measuring machines do at last, in practice, provide the best means for obtaining large, objective samples of these quasars (Clowes, Cooke and Beard 1984; Hewett et al. 1984; Hewett 1984; Stobie 1984; Boyle et al. 1985; Hawkins 1985). The highest redshift quasar independently discovered using these machines is DHM 0054-284, found at a redshift of z=3.61 by Shanks et al. (1983) using multicolour searches with the COSMOS machine.

Hewett has used APM surveys of UK Schmidt objective-prism plates to identify homogeneous samples of quasar candidates with a broad range of spectral features. His search is not just limited to IIIaJ plates, or to candidates showing strong emission. In one project - to isolate very-high-redshift quasars - he has so far examined a total of 150,000 objects in 75 square degrees to m(R) = 19.25 and has analysed his spectra in the following specific ways: (i) to identify objects having properties similar to those of known high-redshift quasars, (ii) to search for red spectra that can not be classified as normal stars. This subset of "peculiar red objects" has been separated out from the "main sequence" in Figure 1 by a generalised cross-correlation method applied to mean galactic-star templates at different magnitude levels; the subset does contain known very-high-redshift quasars (z>3.4). Hewett's survey produces about 2 good candidates per square degree. As mentioned in section 3, he and I hope to use infrared photometry to help separate out the very high redshift quasars from this subset of peculiar red objects. Hewett is naturally interested to check whether the four z>3.4 quasars in the one "South Galactic Pole" field are part of a statistical fluctuation and whether there is a population of high-redshift quasars with spectra that do not exhibit strong emission. Failure to detect such a population would help to extend Peacock's (1985) conclusions to a much broader class of quasar.

In a later chapter, Shanks et al. present their recent data on an important complete redshift survey of a sample of 200 ultraviolet-excess QSOs obtained from COSMOS measures of U and B plates taken with the UK Schmidt telescope, and present the 2-point correlation function for QSOs over a range of separations up to 500 h^{-1} Mpc. Redshifts for the entire sample were obtained using the AAT fibre-optics spectrograph.

The COSMOS machine at Edinburgh has also been used by Clowes (1985) to locate, automatically, a sample of 56 quasars and to obtain their redshifts. For a subset of objects selected to lie in the redshift range 1.8<z<2.2, apparently significant clustering was observed in two dimensions, which disappeared when the third dimension (redshift) was added. Clowes discusses two possible causes, viz: (i) obscuration, which hides quasars in the directions of dense foreground clusters of galaxies (Shanks et al. 1983) or (ii) a problem with spectral overlaps on objective-prism plates in regions where dense clusters of galaxies occur. Nevertheless, such studies from a single Schmidt field have low statistical significance. It is therefore necessary to use the machines to combine data from more than one field.

Hawkins (1985) has used the COSMOS machine to search two 18 sq. deg. fields, separated by 13 degrees, to look for large-scale fluctuations in QSO surface density. He used variability and ultraviolet excess as selection criteria. With careful calibration, and the use of COSMOS, "it now appears to be feasible to map quasar density" [fluctuations] "at a level of a few percent." He found no differences between the samples at a level of 6%. This is not small enough to be of interest in constraining the fluctuations of the microwave background, but is very much less than the large inhomogeneities being reported by some workers using subjective selection criteria. His conclusions do, however, depend on confirmation of his QSO candidates.

The best evidence so far for quasar clustering is that based on the statistics of quasar pairs, as presented in a later chapter by Shaver.

The APM laser-scanning machine at Cambridge has been used - primarily by Hewett, Hazard and collaborators - to produce very large lists containing hundreds of quasar candidates. Interesting spectra of objects from a number of these lists have been shown at various conferences by Hazard, in which he demonstrates, for example (Hazard 1985) the range of spectra one can encounter at z>2. He has not yet published his sample, nor his magnitude calibration, but reports detection of 36 confirmed QSOs with m(J)<19 in 4.3 sq. deg.; he concludes that "Either QSO densities are still seriously underestimated even for objects brighter than 19 mag., or there is

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evidence here of significant clustering in scales of several degrees." In my view, the most significant results of Hazard's visual searches have been (i) the distinct possibility that the spectral properties of QSOs evolve - see also Wampler and Ponz (1985) - and (ii) his demonstration of the wide range of QSO spectra (see, e.g. Hazard 1984, 1985). As Hewett and Irwin (1986) point out, "It is now believed that the fraction of quasars showing particular features may change significantly with redshift. As a consequence, techniques that only detect certain types of quasar may produce trends in the number density as a function of redshift that are not representative of the quasar population as a whole." In this paper, I am trying to add to this point by stressing the value of multi-wavelength techniques for exploring this diverse and possibly evolving range of QSO properties.

In addition to the various cosmological studies, the high-speed measuring machines should answer the top requirement for future work on broad-absorption-line (BAL) QSOs suggested by Weymann, Turnshek and Christiansen (1985; see also Smith 1984; Hazard et al. 1984). They state "We need a much larger sample of Broad Absorption Line QSOs to study.....We think that this will require a machine-selection procedure, partly to ensure some objective and quantifiable set of selection criteria, but also just because of the sheer amount of plate material that must be examined. A study over a large area of sky, yielding objects bright enough (e.g. 18-18.5) to be studied with good signal-to-noise without huge investments of telescope time, is strongly to be preferred over studies going much fainter over smaller areas of sky." They, with Hewett, are currently undergoing a survey using APM measures of Curtis Schmidt plates from Chile.

Another application of the automatic machines to absorption-line studies in QSOs is given in a poster paper by He et al. based on a sample of objects selected by APM from a UK Schmidt field in Virgo (see also He et al. 1984). Here the intention is to seek background light sources to probe the halo regions of different kinds of galaxy in Virgo. Virgo was chosen, as the whole field is covered by the anticipated absorption cross-sections of Virgo galaxies. It is important, however to cover a large area of sky - i.e. several Schmidt fields - in order to be able to find quasars bright enough to allow the absorption features to be studied at high spectral resolution with the Hubble Space Telescope.

A significant spin-off of Clowes' survey work with COSMOS has been the discovery of 3 more close pairs of QSOs. These pairs are being incorporated into the lists being used (see, e.g., Shaver and Robertson 1984) to study absorptions in QSO halo regions.

A large automated survey searching 150 square degrees of sky for gravitational lenses has recently been completed by Webster, Hewett and Irwin (1986); they used the APM facility to examine a sample of 3000 quasar candidates with $17<m(b)<20$ for distorted image structures indicative of gravitational lenses. They have explored the separation range $1''<\theta<1°$ in order to derive the probability of detecting a lens of specified magnitude, component magnitude difference and component separation. They find a remarkable lack of pairs with small separations, contrary to the predictions of most existing lensing models (see also the paper by Shaver later in this book).

5. SEARCHES AT X-RAY WAVELENGTHS

Elvis and Lawrence (1985) claim that "the intense output of x-rays is the only property shared by all 'active' objects." Many hundreds of quasars and active galactic nuclei (AGN) have now been discovered at x-ray wavelengths. Many of these discoveries have been made in the medium-sensitivity survey with the IPC on the Einstein (HEAO-2) satellite in the 0.1 - 4.5keV energy band. Later articles by, Gianni Zamorani and Tomasso Maccacaro provide more detailed results from the x-ray satellites, in particular from the medium sensitivity survey. I shall therefore not deal here with the soft x-ray surveys themselves.

For those quasars selected at harder x-ray wavelengths, and having 2-10 keV luminosities greater than 10^{44} erg/sec, the typical X-ray spectrum is a single power law $F(\nu) \propto \nu^{\alpha}$ of energy index $\alpha = -0.7$ over the range 0.1 - 120 keV, with very little low-energy absorption (e.g. Mushotsky et al. 1980; Mushotsky and Marshall 1980; Mushotsky 1982; Rothschild et al. 1983; Petre et al. 1984; Reichert et al. 1985). However, exceptions are known to exist. Furthermore, selection effects are almost always underestimated by workers in a new waveband. X-ray astronomers are not the first to believe that most quasars have spectra with the 'canonical' slope of -0.7!

Only fairly recently has stress been laid on the diversity in soft X-ray spectral slope - (Elvis and Lawrence 1985; Elvis, Wilkes and Tananbaum 1985). Indeed, they and Branduardi-Raymont et al. (1985) have raised the possibility of a 'break' in the soft X-ray spectrum of AGN below energies of about 0.5keV; the x-ray energy spectrum at higher energies has slope -0.7, whereas below 0.5 keV, the x-ray spectrum steepens to meet the short-UV upturn.

Although the tight relation found at energies above 0.5keV for x-ray selected quasars holds over 4 decades of luminosity, it does not apply so strikingly to quasars selected outside the x-ray window. Martin Elvis will show us a number of illustrations of the X-ray to IR continua of optically-selected quasars, which should help to illustrate this point; optically selected QSOs have a mean X-ray power-law index near 1.2. This revision of our ideas away from the idea of a "Universal" X-ray spectrum lead to consideration of different X-ray production mechanisms; indeed, it is quite possible that the x-ray production mechanism in most radio and x-ray selected quasars differs from that in most optically selected QSOs.

Piccinotti et al. (1982) showed that Seyfert galaxies contribute about 20% to the diffuse x-ray background. On the most commonly invoked cosmological models (e.g. Schmidt and Green 1983), quasars were more luminous and perhaps more numerous in the past, so their contribution to the x-ray background is likely to be substantial. Indeed, about the time of the launch of the "Einstein" satellite, many were expecting that the x-ray background would provide good, quantitative upper limits to the evolution of quasars (see, e.g.,

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Setti and Woltjer 1979). Unfortunately, it proved hard to detect the very numerous high-redshift optically selected QSOs with the Einstein satellite (see e.g. Khembhavi and Fabian 1982; Margon, Chanan and Downes 1982). Furthermore, since then, the exact relation between the optical and x-ray properties of quasars has become less clear.

The parameter $\alpha(ox)$ generally used to predict X-ray luminosity functions from optical ones (Tananbaum et al. 1979) depends on measurement of $f(\nu)$ at 2500A; this is in the region of the 'big bump' discussed by Malkan (1983) and by Malkan and Sargent (1983), which they attribute to black-body radiation from an accretion disk at a range of temperatures. QSOs can dominate the x-ray background if certain relations between $\langle\alpha(ox)\rangle$ and optical luminosity and/or redshift are found to hold. Kriss and Canizares (1985) find that the dependence of $\langle\alpha(ox)\rangle$ on redshift "is small and may be null"; they go on to suggest that the CfA Medium Survey data need to be corrected for the effects of low-luminosity, partially reddened and X-ray absorbed objects. In his PhD thesis, Anderson (1985) concludes that "the typical contributor to the X-ray background may well be a moderate-redshift object, with moderate to low optical luminosity: the high-redshift QSOs apparently have too low a surface density, and because they are more optically luminous, have lower x-ray fluxes for a given apparent magnitude as well. Nearby QSOs ($z<0.5$) are simply not abundant enough to make a substantial contribution." In the context of luminosity evolution, the X-ray luminosity evolves less than the optical luminosity (see also Avni and Tananbaum 1982).

Immediately to either side of the x-ray band we have no survey data. Although most of a quasar's luminosity could appear in the MeV gamma-ray region (Bezler et al. 1984), the first trickle of data from AGN in this waveband is not expected until after the launch of the Gamma Ray Observatory in 1988. Few survey data for quasars are expected from the X-ray Ultraviolet Explorer (XUVE) - also due for launch in 1988 - as few quasars will be detectable through the local interstellar medium in the 100A-1000A wavelength range of XUVE. IUE has done magnificent work on studying individual AGN and bright quasars, but has not resulted in the discovery of large samples of quasars useable for statistical studies.

6. CONCLUSIONS

We must continue this vigorous search for quasars at all wavelengths if we are to gain an understanding of the overall population of quasars and an accurate appreciation of the full range of quasar activity. Ever since the announcement of a redshift "cutoff" at $z>2.5$ by Sandage (1972) and Schmidt (1972) and the subsequent discovery of many objects at redshifts $z>3$ (e.g. Smith, 1975), there has been considerable controversy as to the actual form of the evolution functions at $z>2$. I have repeatedly stressed the sensitivity of our conclusions to selection effects and the consequent importance of understanding quantitatively the nature of any selection effects involved. For example, there may be problems with optical surveys

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which could hide a population of very high redshift quasars. Evolution of the optical spectrum is possible, indeed likely. Optical surveys for quasars use methods of selection which probably vary with intrinsic luminosity and with redshift! Though often forgotten, it is obviously necessary to deal with these effects quantitatively before making any quantitative statements concerning the form of the luminosity evolution, particularly at redshifts z>2.5. It also appears likely that the radio and optical properties of quasars are uncorrelated; a demonstration of a redshift cutoff for radio sources is therefore not a sufficient measure of the switch-on time for all quasars because the radio-loud quasars exist mainly in elliptical galaxies whose evolutionary properties could quite easily differ substantially from those of spirals.

Much of the above assumes a Friedmann cosmology and that redshifts are a reliable indicator of distance - assumptions which are not proven, as Profs. Burbidge and Segal often reminded us during the conference.

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DISCUSSION

Burbidge : You suggested that perhaps the spectra of the QSOs changed systematically with redshift. I want to point out that the work on 3CR radio galaxies by Spinrad and others shows that for these objects the spectra systematically change as one goes to higher z.

Petrosian : It appears both from your review and Martin Ree's introductory lecture that the question of redshift cutoff will be discussed extensively in this Symposium. I would like to point out that in addition to the observational selection effects you mentioned and the environmental effects by Rees at high redshifts where the cutoff may or may not be present the cosmological model becomes important, even if one is limited to the Friedman-Lemaitre models of General Relativity.

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