XII

COSMOLOGY

The Future Utilisation of Schmidt Telescopes
ASP Conference Series, Vol. 84, 1995
J. M. Chapman, R. D. Cannon, S. J. Harrison and B. Hidayat (eds)

Schmidt Telescopes and Quasar Surveys

Paul C. Hewett

Institute of Astronomy, Madingley Road, Cambridge CB3 OHA, UK

Abstract.
Schmidt telescopes have, for some three decades, provided one of the most important sources of data for studies of the quasar population at all wavelengths. In the 1980s the combination of Schmidt telescope plate material and automated scanning machines such as COSMOS and APM allowed a new generation of projects to be undertaken, the results from which are largely responsible for our present understanding of the evolution of the optically–selected quasar population. The digitisation of photographic plates coupled with the computer–based selection of candidate quasars has meant that quantitative calculation of survey selection functions can be accomplished. The first results from surveys with such selection functions are beginning to appear, and progress is being made in constraining the form of the evolution of the quasar luminosity function at high–redshifts, a regime where there has been much disagreement over the nature of evolution. The (still) unique wide–field capability of Schmidt telescopes, coupled with the application of analysis techniques developed using the automated scanning machines, will ensure that Schmidt telescopes continue to make an important contribution to quasar–astronomy over the next ten years.

1. Schmidt Telescopes and Quasar Astronomy

The history of quasar astronomy has been intimately connected with plate material from Schmidt telescopes during the three decades since quasars were first recognised. A comprehensive discussion of the contribution of Schmidt telescopes to the field would fill an article on its own but a few selected examples illustrate the impact of photographic material from Schmidt telescopes. Sandage's (1965) demonstration that there existed a large population of "radio–quiet" ultraviolet–excess sources, far more numerous than the radio–loud quasar population discovered two years earlier, was based on Schmidt plate material. Since the early 1960s the identification of catalogues of radio sources, X–ray sources, and, more recently, far–infrared sources from the IRAS satellite, has been based on the survey material from the Palomar, UK and ESO Schmidt telescopes. The use of very low dispersion objective prisms on Schmidt telescopes by Smith (1975), MacAlpine and others (1977) in the late 1970s led to the generation of the first large samples of what were then "high–redshift" quasars with $z > 2$. The work of Formiggini and collaborators (1980) based on Palomar *UBV* plate material produced one of the first optical samples of relatively faint, $m_B \sim 20$, quasars. Analysis of the Formiggini et al. sample by Marshall et al. (1984) led to the recognition that the evolution of the quasar population for redshifts $z < 2$ could be represented by a very simple parameterisation in which the luminosity function retained its shape but the characteristic luminosity increased at higher redshift; the so–called pure–luminosity–evolution. At the very brightest magnitudes, $m_B < 16$, Schmidt and Green employed the Palomar 18–inch Schmidt to undertake the Palomar–Green ultraviolet excess survey (Green, Schmidt & Leibert 1986), a mammoth undertaking that defined our knowledge of the bright, low–redshift, quasar population for more than a decade.

In the mid–1980's the automated measuring machines, particularly COSMOS and APM, coupled with the availability of improved photometric calibrations to faint limits, enabled entirely new types of projects to be undertaken with Schmidt plate material. The high quality and quantity of direct and objective–prism plate material from the larger Schmidts stimulated the development of automated techniques for identifying quasars (e.g., Clowes, Cooke & Beard 1984, Warren et al. 1991). A rapid improvement in the efficiency of CCD detectors and spectrographs, as well as the commissioning of several wide–field multi–object spectroscopic facilities on 4 m telescopes, also occurred during the 1980s, enabling large numbers of candidate objects to be classified spectroscopically, and thus, for major investigations of apparently faint quasars to become a realistic possibility.

The most influential of the automated surveys undertaken at this time was the faint ultraviolet–excess survey of Boyle, Shanks and collaborators (Boyle et al. 1990). This work, which resulted in the detection of 420 quasars to a faint limit of $m_B \sim 21$, has allowed the definition of the behaviour of intrinsically fainter quasars, $-26 \lesssim M_B \lesssim -23$, over the redshift range $0.5 \lesssim z \lesssim 2$. A value of $H_0 = 50\mathrm{kms^{-1}Mpc^{-1}}$ for the Hubble constant, and $q_o = 0.5$ for the deceleration parameter, are used throughout this article. The high surface density, and hence high space density, of objects in the Boyle et al. catalogue also made the sample particularly suitable for studying the spatial clustering of quasars on scales of tens of megaparsecs (Shanks & Boyle 1994). Subsequently, a number of surveys employing objective–prism spectra, ultraviolet excess, multicolour data, photometric variability, and lack of proper motion as discovery techniques have been undertaken. References to original work and summaries of the survey parameters may be found in the recent review by Véron (1994).

2. Evolution of the Quasar Population

The description of the evolution of the quasar population to emerge from the work undertaken in the 1970s and 1980s was very simple in outline. For optically–selected quasars the luminosity function is well–represented by a two power–law form, with a very steep bright end, the number of quasars per unit magnitude per unit volume depending on luminosity as $N \propto L^{-3.9}$. The luminosity function has a characteristic luminosity, L^*, at the point where the rate of increase in number as a function of decreasing luminosity becomes much shallower, $N \propto L^{-1.5}$. Marshall et al. (1984), and later Boyle et al. (1987) using much improved data, showed that the evolution of the quasar luminosity function over the redshift range $0.3 \lesssim z \lesssim 2$ could be represented by a luminosity function whose shape is invariant but whose characteristic luminosity changes with redshift according to the simple power–law form $L^* \propto (1+z)^{3.4}$. Particularly striking features of this result are the simplicity of the representation, and the strength of the evolution; the characteristic luminosity increases by a factor ~ 40 over the redshift range $0 < z < 2$. Boyle (1993) reviews these developments more fully and also discusses the results from samples of quasars defined at radio and X–ray wavelengths. More detailed discussion of the results for radio–selected objects can be found in Dunlop & Peacock (1990), and for X–ray selected samples in Maccacaro et al. (1991) and Boyle et al. (1993). Qualitatively, the form of the luminosity function and the nature of the evolution of quasar samples defined in each of the three wavelength regimes are very similar. While various groups have proposed modifications to, or slightly different forms for, the shape and form of the evolution of the quasar luminosity function, a general consensus concerning the observations of quasars with redshifts $z \lesssim 2$ has been established. The excellent review by Hartwick & Schade (1990) discusses in detail the results from many optically–based surveys.

At higher redshifts, $z > 2$, the nature of the evolution changes, with a departure from the very strong increase in luminosity as a function of redshift. However, while the existence of the change in the nature of the evolution is agreed it has been more difficult to establish any consensus as to the exact nature of the change. The literature contains papers claiming a wide variety of behaviour, from "cutoffs" at various redshifts, constant space densities at all luminosities, through to continued positive evolution at the highest luminosities. Warren & Hewett (1992) review the different discovery techniques for quasars with $z > 2$ and attempt to reconcile the apparent differences in the behaviour claimed by various groups. Quantitative analyses of optically–selected quasar samples are beginning to appear (e.g. Warren, Hewett & Osmer 1994), however, the nature of the evolution at redshifts $z > 2$ remains controversial.

3. Factors Limiting Our Present Knowledge

The size of the most recent Hewitt & Burbidge (1993) catalogue, which contains entries for 7315 quasars, confirms that numbers alone are no longer an important factor limiting our knowledge. However, the rapid growth in the numbers of known quasars has distracted attention from the extremely poor quality of the majority of photometric and spectroscopic data available. Most quasar spectra obtained are barely good enough to obtain a reliable redshift estimate from the strongest emission features visible, and at X–ray and infrared wavelengths the signal–to–noise ratio of fluxes for the majority of quasars detected is also low. Aside from the limited signal–to–noise ratio of much of the data the rest–frame wavelength range for which spectroscopic data is available is usually very limited, particularly for objects at high redshifts.

Equally, if not more, important is the rudimentary nature of most of the analyses of quasar samples. For example, the quantitative treatment of at least some of: magnitude transformations between different bandpasses, Malmquist and Eddington biases, k–corrections for quasars with different spectral energy distributions, the effects of absorption by intervening clouds of hydrogen on observed spectral energy distributions, intrinsic photometric variability for surveys employing flux estimates from different epochs, and the fraction of candidates remaining unclassified after follow–up spectroscopy, is essential in order to derive quantitative constraints on the behaviour of the quasar population from a catalogue of redshift and flux estimates. In practice these, and other equally important, issues are often ignored in favour of qualitative discussions concerning "completeness" and the relative merits of different selection techniques. Intercomparison of results from surveys employing different selection criteria is prudent and sensible but it is not a substitute for a quantitative understanding of individual surveys. A detailed discussion of the requirements for quantitative analysis of quasar samples is contained in Hewett & Foltz (1994).

If two different experiments (surveys) are performed and the intrinsic behaviour, or make–up, of the quasar population derived, the results should be consistent. If not, either one (or both) of the experiments, or the properties of the quasar population, are not understood. The strength of the evolution of intrinsically bright quasars for redshifts $z \lesssim 2$ is such that taking account of the factors mentioned above only perturbs the basic conclusion concerning the rate of evolution. However, in essentially all other redshift and luminosity regimes, where the behaviour of the population is not as extreme, the lack of quantitative analysis is responsible for the confusion over the behaviour of the quasar population. Real improvements over the qualitative picture now established will only come from well–defined experiments that either produce large numbers of quasars, or, are sensitive to quasars over large volumes, or extended ranges of spectral energy distributions.

4. Future Directions

A critical evaluation of a number of ongoing quasar surveys, not just confined to those involving Schmidt telescope material, would not be altogether encouraging. The requirements, in terms both of the quality of photometric and spectroscopic data as well as the number of quasars and/or area of sky to be studied, to make a significant contribution to our present understanding, involve order of magnitude improvements over many of the surveys undertaken during the last decade. Regrettably, a number of existing projects do not satisfy this criterion and while they involve a substantial investment in resources the results will not make any significant impact on our knowledge. This conclusion echos views expressed by several other speakers at this Colloquium in the context of a variety of stellar and extragalactic research areas. A project producing low signal–to–noise spectra of (say) 100 quasars of intermediate magnitude in a few Schmidt fields is very unlikely to be of great scientific interest. Any associated justification of the investigation that appeals to an improved level of "completeness", compared to other work, should be viewed with great suspicion, unless detailed calculations of the probability of detecting a quasar of specified absolute magnitude, redshift and spectral energy distribution are included.

A significant fraction of the contributions to this Colloquium have discussed the prospects opened up by combining Schmidt telescopes with CCDs as detectors. Given the angular size of fields on the sky accessible to these systems, $\lesssim 1$ square degree, and the poor spatial resolution set by the physical size of CCD pixels, it is difficult to think of projects in the quasar field that could not be tackled as well, if not better, using large CCDs on conventional telescopes with apertures of 2 – 2.5 m. Working to fainter magnitudes than readily achievable using IIIa emulsions or Tech Pan film involves sources with magnitudes at or below the sky brightness. Existing Schmidt telescopes have small apertures and the large pixel size of the present CCDs exacerbates the difficulties. While large numbers of relatively faint quasars can certainly be identified using Schmidts equipped with CCDs I do not foresee the successful completion of forefront quasar research at faint magnitudes using Schmidt telescopes. It would be nice to be proved wrong!

The future contribution that Schmidt telescopes can make in the field of quasar astronomy is considerable. There remain large portions of absolute magnitude *versus* redshift parameter space where the surface density of quasars is such that surveys of steradians of sky are necessary to compile adequate samples of objects. There are at present no CCD–based systems capable of tackling surveys of thousands of square degrees of sky with adequate spatial sampling, although the well–publicised plans for completion of the Sloan digital sky survey (SDSS: Gunn & Knapp 1993) highlight the rapid advances being made. There is a school of thought that suggests the SDSS will "solve" the majority of outstanding problems in survey astronomy and that the future contribution of Schmidt telescopes, whether employing CCDs or photographic emulsions as detectors, is extremely limited. The SDSS project will be highly successful but experience suggests that the likely timescale for completion of the data acquisition and analysis means Schmidt telescopes will have a valuable role for at least a decade. However, to realise their potential it is essential that effort is devoted to accomplishing well–defined science–driven projects that exploit Schmidt telescopes' unique capabilities.

4.1. Very Large Area Surveys

A number of projects where the surface density of the target population is $\lesssim 0.01$ per square degree and samples of order 100 objects are necessary to achieve the scientific goals are high–priority areas. The Palomar–Green survey in the northern sky (Schmidt & Green 1983, Green, Schmidt & Leibert 1986) remains as the only published work providing a significant number of apparently bright quasars. Recently Goldschmidt et al. (1993) have concluded that the Palomar–Green survey suffers from a greater degree of incompleteness than previously believed. There is a need for a better defined, very wide area optically–based survey at magnitudes $m_B \lesssim 16.5$ and two groups are engaged on such projects. The Edinburgh–Cape UBV survey of the southern sky, described by Stobie in these proceedings, employs COSMOS measures of direct plates from the UK Schmidt telescope to define a sample of ultraviolet excess objects in the southern sky. More than 100 bright, $m_B \lesssim 16.5$, quasars and active galactic nuclei have been discovered to date, with the prospect of at least as many to follow. In a project with similar aims Demers et al. (1986) are using APM scans of plate material from the Curtis Schmidt to perform an ultraviolet excess survey of the high–latitude southern sky. Acquisition of the plate material and the machine scanning is essentially complete but the spectroscopic follow–up lags well behind that of the Edinburgh–Cape project. Once the associated photometric calibrations are available both surveys offer the prospect of generating well-defined catalogues of apparently bright quasars that will enable a much improved determination of the low-redshift, $z \lesssim 1$, high-luminosity portion of the quasar luminosity function.

In addition to studies aimed at a better understanding of quasars themselves, there are a number of areas where quasars may be used as probes of other physical phenomena. Detection of more bright, $m_R \lesssim 18.5$, quasars with redshifts $z > 3$ will provide much improved statistics concerning the evolution of the intervening high column density hydrogen absorbers that give rise to the familiar Lyman-limit and damped Lyman-alpha absorbers seen in the spectra of high-redshift quasars (e.g. Wolfe 1990). These absorbing systems, with column densities of $N(HI) \sim 10^{17} - 10^{22}\mathrm{cm}^{-2}$, are the best candidates for the progenitors of massive spiral galaxies. Establishing the physical conditions within the systems and how they evolve with look-back time offers a direct insight into the early stages of galaxy evolution. The incidence of high-column density absorbers is less than one system per unit redshift interval, per line of sight, and large numbers of quasars must be identified, and hence very large areas of sky covered, to gather adequate statistics. Objective-prism searches, an example of which is described by Sealey et al. in these proceedings, or multicolour techniques both offer viable methods for identifying such samples of quasars with $z > 2.5$. For statistical studies of the incidence of the absorbers it will be important to ensure that any increase (or decrease) in the probability of selecting a quasar caused by the presence of an intervening absorber is taken into account when interpreting the statistical properties of the absorbers. The objective-prism survey underway at Hamburg (Engels et al. 1988) has already produced examples of very bright, high-redshift quasars that are proving very important for detailed follow-up studies (Wisotzki et al. 1993).

One of the best prospects for learning about dark matter on large scales is through the statistical analysis of a large sample of gravitationally lensed quasars. However, the incidence of multiple images among even the brightest quasars is low, $\lesssim 1\%$, and the number of systems discovered remains very small (Kochanek 1993). Increasing dramatically the numbers of known quasars with redshifts $z \gtrsim 1$ and apparent magnitudes $m_B \lesssim 18.5$ would enable samples of several tens of multiply imaged systems to be studied in the manner described by Kochanek (1993). For image separations $\lesssim 3$ arcsec Schmidt plate material is not a viable method for identifying lenses and high-resolution imaging of the quasars would be necessary. For larger angular separations the Schmidt material could contribute directly to the identification of the lenses. However, close pairs of stellar objects often appear to the image analysis packages employed by the automated scanning machines as "non-stellar". A quantitative determination of the probability of selecting lensed quasars from among the plethora of galaxies and stars is then required. Identification of the several thousand quasars required to generate a sample of ~ 20 new lenses would be a major task, although the methodology is established (e.g. Webster, Hewett & Irwin 1988).

4.2. Surveys In Other Wavelength Bands

As stressed by Savage and Canon elsewhere in these proceedings, Schmidt telescopes have played a crucial role in the identification of sources identified at other wavelengths, notably catalogues defined at radio, X–ray and far–infrared wavelengths. Until recently the methodology of quasar surveys undertaken at non–optical wavelengths was very different to those undertaken in the optical. In the optical regime source counts are dominated by stars in our own Galaxy and at fainter flux levels increasingly by other galaxies. The identification of quasars requires the winnowing out of a very small percentage of sources (the quasars) through the use of some characteristic property of the optical spectral energy distribution of quasars. Away from the optical regime source catalogues were limited to bright flux levels, the number of sources was relatively small, and the contribution of normal stars and galaxies to the counts was greatly reduced compared to the optical regime. Identification of quasars proceeded simply by obtaining spectra of the optical counterparts of essentially the entire catalogue. Over the last decade the situation has changed dramatically with all–sky catalogues to much fainter flux levels becoming available, e.g., those from the IRAS and ROSAT satellites. At these fainter flux levels new populations of objects dominate the source counts and the traditional method of proceeding, spectroscopic identification of entire catalogues or large subsets thereof, is no longer viable. Indeed, the problem has become very similar to that in the optical and additional information is necessary to target the populations of quasars and active galactic nuclei.

The wide–area optical catalogues from COSMOS, APM and Space Telescope scans of Schmidt sky surveys have provided the means to proceed. The non–thermal nature of the spectral energy distributions of quasars means that the distribution of flux ratios over large frequency intervals, e.g., X–ray/Optical or Radio/Optical, are significantly different those of the majority of stars and galaxies. Large programmes to match source lists from X–ray (e.g., ROSAT), infrared (IRAS) and radio catalogues (e.g., MIT/Greenbank) to Schmidt–based optical catalogues have been undertaken recently. The accuracy of source position in many modern radio catalogues is such that identification of the optical counterpart is unambiguous. In the X–ray and infrared regimes however, positional uncertainty can still be large and considerable care must be taken to ensure that spurious identifications are avoided and that new populations of objects present only in small numbers, which may have optical counterparts with apparently "normal" properties, or not be visible on the optical plate material, are not overlooked.

In many cases the target population is not visible on the Schmidt plate material, examples include distant, $z \sim 1$, clusters of galaxies and very high–redshift, $z \gtrsim 6$, radio–loud quasars. However, the automated pairing with a Schmidt–based optical catalogue can result in the identification of a population that may then be examined using CCD observations on larger telescopes. Establishing that a population of objects is not present on the Schmidt telescope plate material can be as effective as identifying a population that is visible! The use of Schmidt telescope plate material as the first phase in a more extended identification process will become increasingly important. A highly successful example of this type of work is the recent identification of a sample of $z > 3$ quasars from a large radio survey by McMahon (1991) and Hooke (1994).

4.3. Spatial Clustering on Large Scales

Discriminating between the competing models describing the origin and growth of large scale structure in the universe is limited largely by the lack of observational data. This is particularly true at early epochs. A key goal is to probe the growth of structure on scales of tens of megaparsecs, where the power–spectrum of initial fluctuations is expected to be positive but one is away from the complex non–linear region at smaller scales. Quasars can be seen at sufficiently large look–back times and exist with a space density that makes an experiment of this type possible. Shanks & Boyle (1994) and Andreani & Cristiani (1992) have employed the ~ 1000 quasars that exist in samples at high enough space density in current homogeneous catalogues to make an estimate of the strength of their spatial clustering. A positive detection of clustering is established but the samples are not adequate to trace the evolution of the clustering amplitude with redshift – the key goal. The 2dF multifibre spectrograph on the AAT with a field in excess of 3 square degrees and 400 fibres will make the spectroscopic identification of a sample both deep enough and large enough to measure the clustering amplitude as a function of redshift a real possibility. The UK Schmidt Telescope is now acquiring the source material, large numbers of U and B_J plate pairs, for several groups in the United Kingdom. Selection of candidates according to magnitude and $U-B$ colour should be straightforward and a limiting blue magnitude in the range 21.0 – 21.5 achievable. The surface density of quasars with redshifts $z < 2.2$ at these magnitudes is ~ 50 per square degree, or ~ 150 quasars in the field of the 2dF, ideally matched to the capability of the 2dF. The acquisition of a sample of $10,000 - 20,000$ quasars is viable if the project is supported by the telescope time assignment committees.

4.4. Other Possibilities

Hawkins, in these proceedings, describes the process of digital coaddition of many photographic plates to increase the depth achieved using Schmidt plate material. This has proved possible in the UK Schmidt field 287 where there is a unique collection of plate material that has formed the basis for Hawkins' long–term project to select quasars using their photometric variability (Hawkins & Veron 1993). The Field 287 plate database is now a major resource and exciting results can be expected from its exploitation. However, the plate collection represents a major investment in telescope time and the enthusiasm with which the prospect of digital plate coaddition has been expounded by some should be tempered by a realistic assessment of the telescope time required to obtain the material. Obtaining sets of high–quality $\sim 5 - 8$ Tech Pan films in similar atmospheric conditions may become a standard way to push the magnitude limit of existing plate material a magnitude deeper. For quasar surveys the reduction in the magnitude errors for objects with magnitudes $m_B = 21 - 22$ or $m_R = 20 - 21$ is probably more important than the ability to simply detect very faint objects at low signal–to–noise ratio.

5. Conclusions

Quasar surveys are entering a new phase where great improvements in the design, scope and quantitative analysis are necessary in order to generate real advances in our knowledge. Notwithstanding the developments in the area of wide–field CCD surveys there remain substantial areas in quasar astronomy where ambitious wide–field surveys using Schmidt telescopes can make highly significant contributions. There is no reason why the strong link between Schmidt telescope plate material and our growing knowledge of the quasar population should not continue over the next decade.

Acknowledgments

I am grateful to Brian Boyle, Craig Foltz, Margaret Harding, Richard McMahon and Stephen Warren for providing advice and ideas, and to NATO for the award of a Collaborative Research Grant in support of my work on quasar surveys and gravitational lensing at the Institute of Astronomy.

References

Andreani P. & Cristiani S., 1992, ApJ, 398, L13

Boyle B. J., 1993, in *The Evolution of Galaxies and their Environment*, 3rd Teton Summer School, H. Thronson & J.M. Shull, eds, (Kluwer, Dordrecht), p. 433

Boyle B. J., Fong R., Shanks T. & Peterson B. A., 1987, MNRAS, 227, 717

Boyle B. J., Fong R., Shanks T. & Peterson B. A., 1990, MNRAS, 243, 1

Boyle B. J., Griffiths R. E., Shanks T., Stewart G. C. & Georgantopoulos I., 1993, MNRAS, 260, 49

Clowes R. G., Cooke J. A. & Beard S. M., 1984, MNRAS, 207,99

Demers S., Kibblewhite E. J., Irwin M. J., Nithakorn D. S., Béland S., Fontaine G. & Wesemael F., 1986, AJ, 92, 878

Dunlop J. S. & Peacock J. A., 1990, MNRAS, 247, 19

Engels D., Groote D., Hagen H. -J. & Reimers D., 1988, in *Workshop on Optical Surveys for Quasars*, ASP Conf. Ser. 2, P.S. Osmer, A.C. Porter, R. F. Green, & C.B. Foltz, eds, p. 143

Formiggini L., Zitelli V., Bonoli F. & Braccesi A., 1980, A&AS, 39, 129

Goldschmidt P., Miller L., La Franca F. & Cristiani S., 1992, MNRAS, 256, 65P

Green R. F., Schmidt M. & Leibert J., 1986, ApJS, 61, 305

Gunn J. E. & Knapp G. R., 1993 in *Sky Surveys: Protostars to Protogalaxies*, ASP Conf. Ser. 43, B.T. Soifer, ed., p. 267

Hartwick F. D. A. & Schade D., 1990, ARA&A, 28, 437

Hawkins M. R. S. & Véron P. 1993, MNRAS, 260, 202

Hewett P. C. & Foltz C. B., 1994, PASP, 106,113

Hewitt D. A. & Burbidge G., 1993, ApJS, 87,451

Hooke I. M., 1994, Ph.D. Thesis, University of Cambridge

Kochanek C. S., 1993, ApJ, 419, 12

MacAlpine G. M., Smith S. B. & Lewis D. W., 1977, ApJS

McMahon R. G., 1991, in *The Space Distribution of Quasars*, ASP Conf. Ser. 21, D. Crampton, ed., p. 129

Maccacaro T., Cella R. D., Gioia I. M., Morris S. L., Stocke J. T. & Wolter A., 1991, ApJ, 374, 117

Marshall H. L., Avni Y., Braccesi A., Huchra J. P., Tananbaum H., Zamorani G. & Zitelli V., 1984, ApJ, 283, 50

Sandage A., 1965, ApJ, 141, 1560

Schmidt M. & Green R. F., 1983, ApJ, 269, 352

Shanks T. & Boyle B. J., 1994 MNRAS, in press

Smith M. G., 1975, ApJ, 202,591

Véron P., 1994, in *Gravitational Lenses in the Universe*, Proc. of the 31st Liège International Astrophysical Colloquium, S. Surdej, D. Fraipont–Caro, E. Gosset, S. Refsdal & M. Remy, eds, (Univ. Liège, Liège), p. 237

Warren S. J. & Hewett P. C., 1992, in *Observational Astrophysics*, R. E. White, ed., (IOP, Bristol), p. 243

Warren S. J., Hewett P. C. & Osmer P. S., 1994, ApJ, 421, 412

Warren S. J., Hewett P. C., Osmer P. S. & Irwin M. J., 1991, ApJS, 76, 1

Webster R. L., Hewett P. C. & Irwin M. J., 1988, AJ, 95, 19

Wisotzki L., Kohler T., Kayser R. & Reimers D., 1993, A&A, 278, 215

Wolfe A. M., 1990, in *The Interstellar Medium in Galaxies*, H. A. Thronson & J. M. Shull, eds, (Kluwer, Dordrecht), p. 387

Discussion

Malin: My question is really a comment and a caution. Speaking as someone not intimately involved in the field, your talk was an excellent overview of a complex topic. My caution concerns the use of Tech Pan in the U band, or with objective–prism/filter combinations that expose the U band, where the filter red leak may give a spurious signal.

Hewett: I agree entirely that use of Tech Pan in the U band to produce broadband colour should be viewed with caution. The existence of a red leak, coupled with the very red spectral energy distributions of late M-stars, could produce undesirable results. I understand that the UKST team is investigating the amplitude of the leak, so that its importance (or otherwise) can be determined. The use of Tech Pan in the objective–prism field is much less of a problem. For the existing surveys that have produced results, there is no attempt to perform any absolute calibration of the spectra. The machine searches work because the quasar is 'different' from the tens of thousands of stars on the plate. For example, consider a quasar with Lyman α emission at a redshift such that the line coincides with the wavelength of a dip in emulsion sensitivity. One simply looks for objects without 'dips' at that wavelength, rather than an object with an emission line.

Moody: The ability to use machines to find QSOs that you have shown is very impressive. As QSO redshifts increase, the Lyman α line gets more and more eaten away by intervening matter; hence imaging surveys are used to find high z QSOs from colour instead of objective–prism surveys. Do you think that the technique you have presented can be used to find QSOs with $z > 4$?

Hewett: In principle, using a relatively high–dispersion objective prism and restricting the bandpass to focus on the red wavelengths of interest would work. However, the surface density of $z > 4$ objects at bright magnitudes is small, of order 0.01 per square degree for $R < 18$. To compete with the highly successful surveys like that of Irwin and McMahon, which have produced ~ 30 $z > 4$ quasars over $\sim$ 2000–3000 square degrees from $B - R$ colours, would involve a massive undertaking.