Quasistellar Objects: Surveys
Paul Hewett

From
Encyclopedia of Astronomy & Astrophysics
P. Murdin

© IOP Publishing Ltd 2006

ISBN: 0333750888
Quasistellar Objects: Surveys

Since the discovery of quasars in 1963, surveys have been a prerequisite both for investigating models of the central regions of quasars themselves and to provide samples of quasars for use as cosmological probes. The early history of surveys for quasars was determined by our incomplete knowledge of their nature and of their relationship to galaxies. Discovered initially through the campaign to identify the strong radio sources in the Third Cambridge Radio Catalogue (3CR), the optical counterparts were found to be stellar, i.e. unresolved point sources, and to possess blue optical colors. Following the initial spectroscopic identification of 3CR273 as an object with the then unprecedented redshift of \( z = 0.16 \) (see Bright Quasar 3C 273), by Maarten Schmidt, a significant number of quasars were soon found by obtaining optical spectra of unresolved blue objects within the positional error boxes of radio sources. A further major advance was made in 1965 when Allan Sandage showed that there existed a much larger population of unresolved blue sources with very similar properties to ‘quasars’ except that the objects were not detectable as radio sources. Some researchers continue to draw a distinction between quasi-stellar radio sources (quasars) and quasi-stellar objects (QSOs). However, many workers regard the distinction as primarily historical and both ‘quasar’ and ‘QSO’ may be used to refer to objects irrespective of whether they possess significant radio emission.

An enormous observational effort at radio, infrared, optical and x-ray wavelengths in the three decades following the discovery of quasars has resulted in the identification of some 12 000 quasars. Most recently, the ability to undertake sensitive surveys over very large areas of sky has marked the beginning of projects that will produce catalogs of hundreds of thousands of quasars, allowing entirely new scientific investigations to be undertaken.

Identifying quasars

Quasars are rare objects that exhibit a very broad range of intrinsic properties. Normal stars and the majority of galaxies, whose spectral energy distributions are dominated by the radiation from their constituent stars, possess blackbody-like spectral energy distributions that are strongly peaked. The characteristic temperature of the stellar photospheres determines the wavelength at which the bulk of the radiation is emitted. By contrast, the extreme physical conditions in the central regions of quasars lead to the emission of radiation over many decades of wavelength and quasars emit significantly in the x-ray, ultraviolet, optical, infrared and radio portions of the spectrum. With only a few exceptions, surveys for quasars rely on identifying objects whose spectral energy distributions differ from the blackbody-like spectra of normal stars and galaxies.

The majority of known quasars have been identified using data from the optical region of the electromagnetic spectrum. At redshifts \( z \leq 2.2 \) quasars exhibit an excess of near-ultraviolet light compared with common Galactic stars. The ‘ultraviolet-excess’ technique, involving the selection of objects with unusually blue broad-band colors derived from \( B \) and \( U \) band magnitudes, has produced several thousand quasars—figure 1. The technique can be made both more efficient, by reducing the number of contaminating hot stars included, and more complete, by increasing the sensitivity to a larger fraction of the quasar population, by extending the wavelength interval through the use of additional broad-band magnitudes (e.g. one or more of \( V, R, I \)). The so-called ‘multicolor’ technique has proved very effective, allowing the identification of quasars over the redshift range \( 0 < z < 5 \).

The second primary methodology employed in the optical regime relies on the identification of the prominent emission lines, present in most quasars, visible in low-resolution spectra. Slitless spectroscopy, a technique that employs a thin prism (objective prism) or a combination of prism and transmission grating (grism) enables spectra of thousands of objects over large fields to be obtained. Prior to the development of the multicolor selection techniques virtually all quasars with redshifts \( z > 2.2 \) were located through the identification of intrinsic properties.
of the strong hydrogen Lyman-α 121.6 nm and carbon C IV 154.9 nm emission lines which, for redshifts $1.5 < z < 3.5$, appear in the optical portion of the spectrum.

While the basic methodologies of the color, slitless-spectroscopic and other discovery techniques have been established for several decades, there has been a longstanding debate over the relative effectiveness of quasar survey techniques. Advocates of particular methodologies have often claimed to detect a greater fraction of the quasar population compared with other approaches. Originally, the selection of candidate quasars was performed by individual researchers visually inspecting photographic plates through a binocular microscope. In recent years a significant improvement in the agreement between the results of different surveys has come about through the use of digital data and the implementation of automated, computer-based selection procedures. The computer-based selection ensures homogeneity in the candidate selection and, most importantly, allows a precise quantification of the effectiveness of a particular survey (see e.g. SOFTWARE: DIGITAL SKY SURVEYS). A now well-established technique is to simulate the appearance of quasars of given properties—redshift, magnitude and spectral energy distribution—in the data set under examination. The survey selection procedure can then be applied to the simulated objects to establish what fraction of quasars with particular properties can be successfully identified—figure 2. An example of the success of such methodology was the remarkable agreement in the derived space density of HIGH-REDSHIFT QUASARS, $z = 3–4.5$, from two groups, one employing multicolor selection and the other using slitless-spectroscopic techniques.

The extreme luminosities and very extended spectral energy distributions of quasars mean that many of the apparently brightest sources of radiation at x-ray, infrared and radio wavelengths are quasars. Employing the very-large-wavelength baseline between, for example, the optical and x-ray portions of the electromagnetic spectrum should provide a highly efficient technique for identifying quasars; given a sample of quasars and stars of similar optical brightness, the quasars will appear unusually ‘x-ray bright’. Relatively small numbers of quasars have been identified through investigation of radio, infrared and x-ray catalogs and these samples have proved particularly important for studies of the physics of the central energy source of quasars. However, the sensitivity of telescopes and their associated detectors at wavelengths away from the optical is, in a relative sense, poor. Thus, only a small fraction of the quasars detectable via optical techniques have been accessible to observations made at the extremes of the electromagnetic spectrum.

Figure 2. Many modern surveys aim to detect quasars with a variety of spectral energy distributions over a large range in redshift. Simulations of the appearance of a quasar in a particular survey, incorporating a detailed model of the effects of intervening absorption and the properties of the survey itself, allow the probability that a quasar of given brightness, redshift and spectrum will be detected to be calculated. The figure shows a two-color diagram with the colors of 980 of the total of ~30 000 objects in the survey area (●). The larger symbols show the predicted colors of a quasar with redshift $z = 3.33$ derived from such a simulation. ○s indicate occasions when the quasar would not have been identified, while ×s represent occasions when the quasar was successfully picked out. The simulation shows that the probability of detecting a quasar of the specified type is $P = 0.78$. Symbols with downward pointing arrows correspond to occasions when the simulated $U$ magnitude was below the survey detection limit and the quasar lies somewhere below the plotted symbol, with a larger $U − B$ color.

Notwithstanding a general convergence in the results from, and understanding of the differences between, various survey techniques, some researchers continue to believe that a significant fraction of the quasar population remains to be identified. Two alternative techniques, based on lack of proper motion and the presence of photometric variability, have been proposed to address this question. Over timescales of decades essentially every star in our own Galaxy exhibits a small, but detectable, motion on the sky and surveys for quasars employing so-called PROPER MOTIONS focus on objects...
that do not appear to move. Photometric variability, with a wide range of amplitudes, was recognized soon after the discovery of quasars as a distinctive feature of many objects. The cause in the majority of quasars is believed to be variations in the rate at which material is accreted by the central massive object. The statistical properties of photometric variability are not well determined but, if monitored at approximately monthly intervals over a period of one or two decades, virtually all quasars exhibit brightness changes of at least 10%. Variability surveys thus treat any object showing evidence of variability, not explicable as a variable or binary star, as a quasar candidate. Recent results from both techniques agree well with those derived from other surveys.

**Present status**

Impressive progress has been made over the last 15 years in compiling samples of quasars from x-ray to radio wavelengths. As a result, the general behavior of the quasar luminosity function over the redshift range $0 < z < 5$ is fairly well established. Significant constraints on models of the central regions of quasars have been derived from the spectroscopic and other properties of quasars in existing surveys. However, the popular unified scheme models for quasars and ACTIVE GALACTIC NUCLEI predict that the population should exhibit a very large spread in luminosity and spectral energy distribution. Similarly, quasars viewed along a line of sight that passes through an intervening galaxy containing dust may be dimmed by very large factors. Virtually all current surveys, independent of wavelength, are sensitive to objects with only a narrow range in luminosity at fixed redshift (see also GALAXY REDSHIFT SURVEYS). As a consequence, existing surveys do not in general provide strong tests of a number of different theoretical models. While the total number of quasars known, $\sim 12,000$, may seem large, for many investigations, including those that exploit quasars as cosmological probes, very large numbers of objects are required. Progress in areas where the signal sought is weak, such as defining the clustering behavior of quasars as a function of redshift, are still limited by the lack of surveys containing many thousands or tens of thousands of quasars.

**Future surveys**

Undertaking surveys for many thousands of quasars has in practice been impossible because of the lack of an instrument capable of obtaining spectroscopic observations of hundreds of faint candidate objects over areas of at least a square degree on the sky. Recent developments in instrumentation have overcome this practical restriction and two major surveys now in progress will produce samples of tens of thousands of quasars within the next five years.

In Australia, at the 3.9 m Anglo-Australian Telescope, a multiobject fiber spectrograph with 400 fibers and a 2º diameter field of view, the so-called ‘2 degree field’ (2dF), has been commissioned (see also SPECTROGRAPHS: FIBER-FED SPECTROGRAPHS). Simultaneous spectroscopy of quasar candidates to $B = 21$ over an area of three square degrees is relatively straightforward and the ‘2dF Quasar Survey’, with a target of 25,000 quasars, is a key program. The survey area consists of two long strips on the sky, $75^\circ \times 5^\circ$ in extent, with the selection of the targets based on a three-color (UBR) technique that is sensitive to quasars over the redshift range $0.2 < z < 3.0$. The magnitude limit of the survey and the geometry of the survey regions have been chosen to optimize the quasar sample for investigation of spatial clustering properties as a function of redshift. The quasars act as probes of large-scale structure and the extended redshift range over which quasars are detected will provide an order of magnitude improvement in the determination of the development of large-scale clustering with redshift, providing an important new constraint on theories of structure formation.

A still more ambitious program involves the SLOAN DIGITAL SKY SURVEY (SDSS) which has recently begun to acquire imaging in five broad optical passbands $(u,g,r,i,z)$ with the aim of covering 10,000 square degrees of the sky at high Galactic latitude. The second element of the project is to obtain spectra of the brighter galaxies and quasar candidates identified from the broad-band imaging data. Although the study of some 1,000 000 galaxies is the principal motivation for the SDSS some 150,000 quasar candidates will be observed using the dedicated multifiber spectrograph mounted on a 2.5 m telescope at Apache Point in New Mexico. The broad-band filters employed in the SDSS extend from the near-ultraviolet through to a ‘z’-band at the far-red extreme of the optical atmospheric window. The $u$ and $g$ colors allow the detection of low-redshift quasars via the ultraviolet-excess technique with additional information from the redder filters, while sensitivity to radiation with wavelengths as red as 1000 nm means the SDSS is sensitive to quasars with redshifts as high as $z = 6$ (see below). The primary, 10,000 square degree, survey will identify relatively bright quasars, $B \leq 20$, and the number of very-high-redshift objects is not expected to be large. However, a smaller area of 100 square degrees will be surveyed to much fainter limits. It will also be possible to select subsets of potentially rare quasar candidates to rather fainter limits that may be followed up using telescopes of larger aperture. The first results from such a strategy are already encouraging, with a number of high-redshift quasar candidates observed in late 1998 producing the first quasar to be found with a redshift $z = 5$. More recently, a group of astronomers in California discovered a quasar with $z = 5.50$, and in April 2000 a group from Chicago reported a quasar with $z = 5.8$. In June 2001, two quasars with redshifts of 6.0 and 6.2, the
most distant objects ever observed in the universe, were identified in the Sloan Digital Sky Survey.

The use of the FIRST (FAR-INFRARED AND SUBMILLIMETRE TELESCOPE) radio source catalog to identify optically bright quasars has proved highly successful, with an initial catalog of more than 650 objects. The origin of the very large range in radio luminosity at fixed optical luminosity among the quasar population has been an outstanding question for several decades. The FIRST sample and future extensions to fainter optical magnitudes will make a significant contribution in this and a number of other areas. Similarly, the quasar samples to be defined from the CHANDRA and XMM x-ray satellites will be well suited to addressing key questions such as the contribution of quasars to the x-ray background and testing the predictions of unified schemes for quasars and active galactic nuclei.

The capabilities of optical telescopes with apertures of 8–10 m will allow fainter quasars at redshifts \( z \approx 2–3 \) to be investigated, helping to extend the dynamic range of the surveys. Probably of even greater significance will be the ability to conduct surveys for quasars at near-infrared wavelengths to relatively faint magnitudes over many hundreds of square degrees of sky. Extinction of radiation by dust is greatly reduced at wavelengths of \( \sim 2000 \) nm compared with optical wavelengths and quasars at very high redshifts, with very faint optical colors owing to the presence of intervening hydrogen clouds, should also be detectable in the near-infrared. Such infrared surveys will be possible early in the millennium and a resolution to the ongoing debate concerning whether a significant proportion of the quasar population has eluded detection owing to extinction by dust and gas, either associated with the quasars themselves or present in intervening systems, should result.

**Bibliography**

A general introduction to quasars and active galactic nuclei, including the principles behind surveys is

Peterson B M 1997 *An Introduction to Active Galactic Nuclei*  
(Cambridge: Cambridge University Press)

A more specific review of quasar surveys

Hewett P C and Foltz C B 1994 Quasar surveys *Publ. Astron. Soc. Pac.* **106** 113

Results from the FIRST Bright Quasar Survey can be found in


The potential of the Sloan Digital Sky Survey for detecting quasars is demonstrated by the description of the discovery of a number of high-redshift quasars by the SDSS Collaboration;

Fan X et al 2000 *Astron. J.* **119** 1

Initial results from the Anglo-Australian Observatory 2dF quasar survey are described in


Paul Hewett