SYSTEMATIC SURVEYS FOR QUASARS WITH THE SLITLESS SPECTRUM TECHNIQUE

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ABSTRACT

Recent results with the slitless spectrum technique are reviewed and the total surface densities from five independent surveys are compared. The observational base for extending the technique to search for quasars with $z > 3.5$ is now large enough that either the apparent cutoff at $z = 3.5$ will be confirmed in new surveys or quasars with $z > 3.5$ will be found.

I. SCOPE

In the previous talk Schmidt has reviewed the distribution in depth of quasars as determined from radio-selected samples and from optical surveys with the ultraviolet excess technique. Here I discuss recent results from the slitless spectrum technique. This technique, which is best suited for redshifts larger than 1.8, is a natural complement to the ultraviolet excess method, which is best suited for redshifts between 0 and 2.3.

The excellent review by Smith (1978) describes in detail the slitless spectrum technique, its application to various problems in quasar research, and the results up to May, 1978. Therefore I shall limit myself to events occurring subsequent to Smith's article. In particular I shall discuss the question of where are the redshift four quasars. The statistical base for investigating the question is now solid enough for a feasible program either to find quasars with $z > 3.5$ or show that their space density is indeed low. Although the recent results have implications for the emission-line and absorption-line problems in quasars, time does not allow them to be discussed here.

II. DEFINITION OF THE SLITLESS SPECTRUM TECHNIQUE

The problem in carrying out optical surveys for quasars is how to distinguish them from the myriad star images. For example, there may be 100,000 stars on an exposure with the UK Schmidt that contains

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100-200 quasars (Smith 1978). The slitless spectrum technique is based on the fact that quasar emission lines can be seen directly on objective prism or grating-prism spectrograms. The strongest emission line in quasar spectra, $L\alpha$, is the one normally detected, and the technique is color independent. As used at Cerro Tololo, the technique is based on spectra of about 1500 Å mm^{-1} dispersion, a value which I believe is nearly optimum. At higher dispersion the limiting magnitude suffers; at lower dispersion weaker-lined objects are missed. The UK Schmidt spectra (2500 Å mm^{-1} at $H\gamma$) mark the low end of the usable range (see discussion by Smith 1978). Additional requirements are a large telescope aperture and/or large field of view, good seeing conditions, dark sky, and fine grain emulsions. The Curtis Schmidt telescope, with a 60 cm aperture and 25 deg^2 field, turns up about 8 quasars per 25 deg^2 field; for most programs it represents the smallest telescope one would want to use. The 4-m telescopes are suitable because of their great light gathering power; about 4 quasars are found per exposure in a 1/3 deg^2 field. The UK Schmidt, with medium aperture and large field, is the most efficient instrument in terms of discovery rate per exposure: 100-200 quasars (Smith 1978).

The detailed characteristics of the technique are described by Osmer and Smith (1980) and Osmer (1980). In brief, 90% of the candidates are confirmed to be quasars and 80% of the confirmed quasars have $z \gtrsim 1.8$. The technique is indeed efficient for discovering large redshift quasars.

Perhaps the main technical problem remaining with the survey technique concerns the calibration of and correction for inhomogeneities in the plate material. It is known that bad seeing degrades the resolution of the slitless spectra and thereby reduces the detectability of the quasar emission lines. Whether seeing effects are behind the broad magnitude distribution in the technique remains to be seen. Certainly the seeing effects must be considered in any analysis of the plate-to-plate variation in the number of quasars and before any statement can be made about their spatial uniformity. It is likely that the application of automated measuring and identification techniques to the plate material will lead to progress in both areas. With such techniques quantitative information on the detection threshold of the emission lines and on the spectral resolution of the plates will be available, so that well defined limits of completeness can be established.

III. THE MAJOR SURVEYS

The principal surveys for new quasars with the slitless spectrum technique have been carried out at Cerro Tololo with the Curtis Schmidt and 4-m telescopes, at Kitt Peak with the 4-m telescope, and with the UK Schmidt telescope. A brief bibliography of the surveys is given in Table 1.

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TABLE 1

Major Surveys[1]

CTIO Curtis Schmidt	CTIO 4-m
MacAlpine and Lewis (1978)	Hoag and Smith (1977)
Osmer and Smith (1980)	Bohuski and Weedman (1979)
KPNO 4-m	**UK Schmidt**
Hoag, Burbidge and Smith (1977)	Bolton and Savage (1978)
Sramek and Weedman (1978)	Smith (1978)

[1] By author according to last published reference, which in turn is a source for earlier work.

By now several hundred quasars have been discovered. Of these, more than 250 have follow up observations with slit spectroscopy. Lewis, MacAlpine and Weedman (1979) describe observations of 76 candidates from the Michigan-Tololo survey. Osmer and Smith (1980) present complete data, including a spectral atlas, for a sample of 120 candidates from the Curtis Schmidt survey and Osmer (1980) has carried out an analysis in similar format of the 71 independently discovered quasars in the Hoag-Smith (1977) 4 m sample.

With these recent results it is possible to intercompare the different surveys and check their consistency. The best measure for this purpose is the total surface density of quasars in each survey. Not all surveys have complete photometry and the magnitude scales are not homogeneous, so a more detailed comparison is not yet possible. It can be seen from Table 2 that the results are entirely consistent. Both surveys with the Curtis Schmidt give practically the same surface densities, as do the 4-m surveys, albeit at much larger values. The UK Schmidt result is intermediate between the other two.

Thus the internal agreement of the surveys is excellent. The main questions (Osmer 1980) concern the steepness of the increase from the Curtis Schmidt value, 0.34 deg^{-2} on the average, to the 4 m value of 13 deg^{-2} and the lack of agreement between the two surveys at magnitude 18, where they might be expected to give similar results. Until the systematic effects involved in different telescopes are understood better, considerable caution is required for any attempt to combine the results.

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TABLE 2

Total Surface Densities
Number deg^{-2}

CTIO Curtis Schmidt		
Osmer and Smith (1980)	Lewis, MacAlpine, and Weedman (1979)	
0.32	0.36	
UK Schmidt	**CTIO and KPNO 4-m**	
Smith (1978)	Hoag and Smith (1977)	Hoag (1979)
~5	13	~13

IV. WHERE ARE THE QUASARS WITH $z > 3.5$?

The Lα emission line in quasars should be visible on slitless spectrum plates taken on IIIa-F emulsion to redshifts as large as 4.7. Nonetheless, the largest redshift yet found in the slitless spectrum surveys is 3.45, still second to the $z = 3.53$ value for OQ 172. Carswell and Smith (1978) have nicely shown how the absence of quasars with $z > 3.5$ in the Hoag-Smith 4-m sample can be accounted for by the properties of the IIIa-F emulsion, the ultraviolet blaze of the grating, and the steep luminosity function of quasars. According to their calculations the data are not inconsistent with a constant space density for $2.1 < z < 4.7$ or a $e^{10\tau}$ form for the evolution, although a $(1 + z)^6$ form is ruled out.

However, the absence of presence is not the same as the presence of absence; that is, the definitive test for the existence or absence of the $z > 3.5$ quasars with the slitless spectrum technique still needs to be done. Both Osmer (1977) and Carswell and Smith (1978) realized that in the case of the grating-prism surveys at the 4-m telescopes, the use of a red-blazed grating should be significantly more sensitive for the detection of quasars with $3.5 < z < 4.7$. Now that the spectroscopy for the Hoag-Smith sample is complete (Osmer 1980), it is possible to make a refined estimate of the expected numbers of quasars with $3.5 < z < 4.7$ that should be detectable on 4-m plates optimized for the red.

Although there are several ways to make the estimate, let me describe the simplest one here. Slit spectra (Osmer 1980) confirm that the Hoag-Smith sample contains a total of 7 quasars with $2.5 < z < 3.5$ in an area of 5.1 deg^2. Carswell and Smith (1978) have made a

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numerical estimate that the Hoag-Smith sample (IIIa-F emulsion with a grating blazed at λ3550) should detect the same number of quasars with $2.5 < z < 3.3$ as a new survey with IIIa-F emulsion and a grating blazed at λ5700 would for $3.3 < z < 4.7$. This estimate assumes constant density; if there is evolution of the type described by Schmidt in the previous article, there would be more quasars with $3.3 < z < 4.7$. If we scale this estimate to the redshift bins $2.5 < z < 3.5$ and $3.3 < z < 4.7$, we find that if an area of 5.1 deg^2 is surveyed with the red-blazed grating, it should contain 2/3 as many quasars with $3.5 < z < 4.7$ as the Hoag-Smith sample did for $2.5 < z < 3.5$, namely 4.7 as opposed to 7. If there is density evolution of the form $e^{10\tau}$, 8 quasars are expected, and if the form is $e^{15\tau}$, 10.5 quasars are expected. I believe it is possible to do even better than the Carswell-Smith estimates by filtering out the sky shortward of 5700 Å, for a fainter limiting magnitude can be obtained.

The point is that a feasible survey optimized for the λλ5700-6700 region should contain at least several quasars with $z > 3.5$. This prediction is based on the simplest possible extrapolation of a known number of quasars in the redshift range immediately below 3.5. If such a survey fails to find quasars with $z > 3.5$, it will provide convincing evidence that the space density of luminous quasars turns down near $z = 3.5$. The motto for the survey might be "Redshift four or bust".

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DISCUSSION

G. Burbidge: Is it not the case that Arp has looked at the distribution of bright galaxies and your clumps of QSOs and has found that they are correlated?

Osmer: Arp has looked at the correlation between the brightest galaxies and the quasars with $z > 2.5$ in the Curtis Schmidt survey. I have been looking athe distribution of quasars in the much smaller areas of the Hoag-Smith 4-m survey. I have done a simple check of Arp's results which shows the excess of quasars near the galaxies is about 1.5 σ above the expected value. However, I do not pretend that the check is definitive and I am unable to comment further on the statistical significance of his result.

Turner: Why is there such a small difference in the predicted number of $z \approx 4$ quasars between your "no evolution" and strong density evolution cases?

Osmer: The difference is small because the extrapolation is from $z = 3.0$ to $z = 4.1$. The evolutionary effects are relatively small over such an interval in z.

Abell: Clumping of quasars on a scale of 0.5° to 1° or so would be expected, would it not, if quasars, like everything else, are within superclusters of size ~ 100 Mpc?

Osmer: Yes, exactly. In fact, I have been looking for them. There certainly are groups of quasars with these dimensions in the Hoag-Smith sample, but it is not yet clear if the grouping exceeds the expectations for random fluctuations.

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