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SPECTROPHOTOMETRY OF MICHIGAN-TOLOLO QUASARS

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ABSTRACT

The Michigan-Tololo sample of quasars is discussed using observational data for 48% of this sample. Emission-line quasar characteristics are confirmed for 80% of the objects observed, including at least four new quasars with spectral features indicative of "supernova-like" outflow. Approximately 73% of the redshifts predicted from the discovery plates are found accurate with a mean error in z of 0.03, and a large range of z (from about 0.1 to 3.16) is represented in the sample. The observed redshift distribution for quasars is marginally consistent with a constant co-moving quasar density above $z \approx 2.0$. The shape of the redshift distribution may be used as an isotropy probe with a cosmic time resolution of a few times 10^8 years in the early universe; therefore, continued surveys of this sort are important even if accurate magnitudes are not determined.

Subject headings: cosmology - quasars - spectrophotometry

I. INTRODUCTION

Several observers have demonstrated within the past few years that large numbers of quasars can be found in wide-field, low-dispersion spectroscopic surveys. Such surveys discover quasars primarily because of the strong emission lines in their spectra. A thorough review of the techniques used and the results achieved is given by Smith (1978). With such techniques, it is possible to catalog several hundred thousand quasars. A premier question at present is to determine the utility of large quasar samples and to decide the extent to which they should be accumulated. In this paper, we consider the sample of 174 quasar candidates recently published by the Michigan group from observations with the Curtis Schmidt telescope at Cerro Tololo Inter-American Observatory (MacAlpine, Smith and Lewis 1977ab, MacAlpine, Lewis and Smith 1977, MacAlpine and Lewis 1978). As illustrated in Figure 1, this survey covered roughly 392 deg^2 for $23^h.3 \lesssim$ RA $\lesssim 02^h.3$ and $-2^\circ.5 \lesssim$ DEC $\lesssim + 7^\circ.0$. We present and discuss spectroscopic observations for 48% of this sample to determine the statistical properties of these Michigan-Tololo quasars. The 174 quasar candidates were found on only 18 plates with the Curtis Schmidt telescope, and we have over 100 such plates as yet unexamined (See Figure 1). Consequently, we attempt to define those questions that can be addressed by increasing substantially our quasar sample.

II. OBSERVATIONS

The Michigan-Tololo quasar candidates were found on deeply exposed IIIaJ plates using the 1°50' objective prism on the 61-cm Curtis Schmidt telescope. The search technique is similar to that described by Smith (1975, 1978), but the Michigan-Tololo candidates also include some star-like objects with blue continua as well as those with apparent or marginally detectable emission lines. While we would not expect as high a success rate for finding true quasars among blue continuum objects, cataloging them makes possible an estimate of the fraction of all optically discoverable quasars that have conspicuous emission lines. In the discovery lists, the candidates were classified as "probable" or "possible" quasars depending on whether there were two lines adequate for a redshift estimate (probable) or only one line or just a blue continuum (possible). Survey data and follow-up spectrophotometric data for the observed candidates are summarized in Table 1.

In the Michigan-Tololo survey lists, featureless blue stellar objects (24 in all) comprise only 14% of the quasar candidates. Obvious white dwarfs were excluded. Of the 24 catalogued BSOs, two are known quasars and two others (Nos. 329 and 333) show emission in our spectrophotometry; we would expect, therefore, that more of the BSOs will have detectable emission lines if observed at higher resolution than on the discovery plates. However, our new observations indicate that at least two BSOs are blue stars (Nos. 88 and 169). The implication is that there are not relatively many weak-lined quasars and that at least 85 percent of all quasars chosen as candidates only from their colors would also be discoverable as emission-line quasars. Bolton and Savage (1978) have searched both for blue continuum objects (UVX in their terminology) and emission-line quasars using two-color photographs and a thin prism with the SRC 1.2 meter Schmidt telescope. They examined 50 deg^2 (two fields) to a magnitude limit about two magnitudes fainter than the Tololo surveys. After initially searching only for UVX objects, they rediscovered 70% of their candidates by looking for emission-line quasars. Of the total number of quasars found to a blue magnitude limit of 19.5, 80% were discoverable as emission-line objects.

The total numbers of quasars detected is also consistent with this conclusion. Using the magnitude estimates in the Michigan-Tololo survey lists, there are 146 candidates of magnitude 18 or brighter in the survey area of 392 deg^2. These are continuum magnitude estimates at λ4500, so blue magnitudes that include the emission lines would be brighter. Utilizing our conclusion below that approximately 80% of these candidates are real quasars, there are about 0.30 Michigan-Tololo quasars deg^{-2} with blue continuum magnitudes brighter than 18. If we consider only lists II, III, and IV, which were prepared after more experience had been gained in recognizing quasars on the discovery plates, then the above quantity is 0.39 deg^{-2}. This is comparable to the original estimate of Sandage and Luyten (1967) of 0.4 quasars deg^{-2} brighter than broad-band blue magnitude 18.1. Also, Bolton and Savage (1978) found 0.3 quasars deg^{-2} brighter than 18. Because we do not yet have extensive absolute photometry or spectrophotometry for the Michigan-Tololo quasars, we cannot be very confident of results comparing the space density of these quasars to those from other samples. In fact, for candidates confirmed as quasars (table 1), the measured continuum magnitudes at λ4500 are often as much as a magnitude fainter than the discovery plate estimates. A study of a similarly sized sample of unpublished Tololo quasars now in progress by Osmer and Smith (1977) should provide more definitive results on the number of these objects as a function of magnitude.

Demonstrating that emission-line quasars are the major fraction of discoverable quasars is important because the redshift can be determined in many cases directly from the discovery plates. This means, especially in certain redshift intervals, that analyses of the redshift distribution of quasars can be undertaken without having to observe all candidates with large telescopes. In §III below, we carry through such an analysis of the Michigan-Tololo quasars.

Using the 1.3-m telescope at McGraw-Hill Observatory and the 4-m telescope at Cerro Tololo, we have observed 74 of the 174 quasar candidates. At McGraw-Hill, the observations were made with a photon-counting spectrometer utilizing a reticon array (Shectman and Hiltner 1976); at CTIO, the observations were made using the SIT vidicon spectrometer (Atwood et. al. 1979). All observational results are presented in Table 1, and spectra of five particularly interesting quasars with strong, broad absorption features are shown in Figure 2. Of the total of 76 candidates observed by us in conjunction with Nos. 366 and 368 observed by R. Kirshner and/or M. Smith, 61 are high redshift quasars, 7 are blue stars, 6 do not have sufficiently strong spectral features to determine their nature, and 2 are narrow-line objects with $z \approx 0.1$. Details for the candidates not confirmed as high redshift quasars are presented after the notes to Table 1. These observations included an assortment of both probable and possible quasars, and the 80% success rate improves if only probables are considered. Of the 42 probable candidates observed, only 5 were not confirmed as quasars.

Perhaps more significant is the success in estimating redshifts from the discovery plates. Of 45 quasars observed having predicted redshifts, 33 were predicted correctly (this includes 3 objects previously observed by others). In these successful cases, the estimates were gratifyingly accurate, with a mean difference of 0.03 between predicted and observed redshifts. Of the 12 wrong predictions, 7 confused the Lα, C IV λ1549, and C III] λ1909 lines, 1 was predicted to be a high redshift quasar but is found to have z of 0.1, 1 has only a single line, 1 has no identifiable features, and two are blue stars.

There is a further indication that the emission-line quasars discovered in this kind of survey do not have anomalously strong lines. As has been done by Osmer (1977), the equivalent widths of the lines can be compared to those of radio quasars. We make such a comparison in Figure 3, showing the distribution of observed Lα equivalent widths for the Michigan-Tololo quasars in Table 1 compared with those for the radio quasars observed by Osmer (1977) and Baldwin and Netzer (1978). The distributions in Figure 3 show no systematic difference, as was also the case in Osmer's (1977) comparison with the original Tololo quasars. It appears that the Curtis Schmidt technique would not overlook any radio quasars because Lα has insufficient equivalent width. By comparing our measured equivalent widths with the predictions in the candidate lists, we find a well defined lower limit of 50 Å for lines that were detected on the discovery plates. This is more than a factor of three less than the faintest Lα in Figure 3.

III. REDSHIFT DISTRIBUTIONS AND QUASAR EVOLUTION

It is possible to measure fairly accurate redshifts for many quasars directly from the discovery plates, while determining accurate magnitudes is considerably more difficult. Hence, we examine the question of whether useful conclusions can be drawn from the redshift distribution alone. In Figure 4 the redshift distribution is shown for: (a) all quasar candidates with predicted redshifts in Michigan-Tololo Survey Lists I-IV; (b) Michigan-Tololo quasars with observed redshifts in Table 1. Examination of Figure 4 leads to several conclusions. The survey detected quasars because of the MgII λ2798 and CIII]λ1909 lines, but associated redshift estimates were not possible. In addition, there is a significant number of quasars showing CIV λ1549 but not Lα ($1.3<z<1.9$). Redshift estimates for these are not always possible but can often be made from the presence of C III]λ1909. The survey is most efficient at picking out quasars with visible Lα ($1.9<z<3.2$), for which redshifts may generally be predicted because of the inclusion of CIV λ1549 or OVI λ1034. For this latter group, we believe that information from the discovery plates alone can be used to consider the quasar redshift distribution without having to obtain individual spectra of all candidates.

From the redshift and flux distributions of both optical and radio quasars, several analyses have shown that the co-moving quasar density was much greater in the past, increasing exponentially with look-back time or as a large power of (1+z) (see Schmidt 1972 or Wills and Lynds 1978). Also, for $z>2.5$ the apparent number of quasars was known to decrease substantially, so there was suspicion that this epoch corresponded to a real cutoff in the quasar phenomenon (e.g. Schmidt 1970). However, Osmer and Smith (1977) have pointed out that the Tololo samples show relatively large numbers of quasars with $z>2.5$, indicating that there may not be a real decrease in the co-moving quasar density beyond this redshift. The discovery of these high redshift quasars has been the most emphasized result of the low-dispersion spectral surveys. Most such quasars would not be found in searches involving blue stellar objects since the strong $L\alpha$ emission can produce a neutral or red color in broad band photometry.

The question of whether there is an identifiable quasar event near $z = 2.5$ in the universe seems to us one of the most important points to be considered with the present sample. Obviously, it is relevant to determining the origin of quasars. Did they actually form at $z \approx 2.5$; did a previously constant co-moving density just begin to decay at that time; or has the co-moving density been decaying exponentially for even longer? Identification of a formation epoch would also lead to interesting results about the isotropy of the universe at that epoch. With the large numbers of potentially discoverable quasars, it is possible to see if the epoch of any quasar event is the same in all directions. Good time resolution is obtainable by studying the quasar redshift distribution at $z \approx 2.5$. For example, for a $q_o=0$ cosmology, the look-back time is $t=z(1+z)^{-1}H_o^{-1}$ so Δz of 0.1 at z=2.5 corresponds to Δt of 1.6×10^8 years for H_o = 50 km s^{-1} Mpc^{-1}.

Observationally, the problem is that which has been discussed by Carswell and Smith (1978); to determine if one can go from the observed redshift distribution of quasars to meaningful statements about quasar evolution in the universe. We now consider this using the Michigan-Tololo sample by comparing the redshift distributions expected for certain assumptions to the observed distribution. From Figure 4, there is certainly a drop in the apparent number of quasars beyond z=2.3, but does this correspond to a real drop in the co-moving density? Carswell and Smith (1978) have emphasized that it may not. For this comparison, we restrict the Michigan-Tololo sample to those quasars with predicted z>2.0, shown in Figure 5. This is because predicted redshifts are most reliable (Table 1) when both Lα and CIV λ1549 are seen on the survey plates.

By using predicted redshifts alone, we avoid any bias that may have entered our selection of the 74 quasars for which follow-up observations were obtained. Also this provides a comparison with the large number of quasars that can have redshifts predicted from our remaining survey plates. Note that quasar redshifts can still be predicted from Lα + OVI λ1034 for z>2.4, when CIV λ1549 becomes redshifted off of the emulsion. However, the error bars in figure 5 allow for all one-line quasars for which the line could conveivably be Lα with z>2.4; this gives an upper limit on the possible number of quasars with z>2.4 compared to those with z<2.4. A statistical correction could also be applied to the sample of predicted redshifts, based on the observations in Table 1. Note that of the 25 redshifts in Table 1 predicted because Lα and CIV were thought to be present (quasars predicted to have $1.89<z<2.45$), 3 of the predictions were wrong because the lines were misidentified. Such a correction would mean that the number of predicted quasars in Figure 5 with $2.0<z<2.4$ is overestimated by up to 10%, so this possibility is incorporated into the error bars shown. Finally, the error bars illustrated also include the statistical uncertainty $N^{0.5}$ for the number of candidates in each bin. The resulting histogram with uncertainty estimates is normalized at $z = 2.1$, and shown as Figure 5. This observed redshift distribution is to be compared with a calculated distribution, described below.

The objective is to calculate the dN/dz expected for emission-line quasars. Obviously, this depends on several cosmological assumptions, each of which could be discussed at length regarding its validity. We proceed by defining and adopting (without defending) those assumptions which seem to us most reasonable.

The luminosity function for quasars seems to be a power-law function, with the number of quasars increasing by about a factor of six per magnitude (e.g. Sandage and Luyten 1969, Braccesi and Formiggini 1969, Usher 1978). Since we are considering quasars discovered by means of their emission-line properties, we adopt the local quasar luminosity function derived by Sramek and Weedman (1978) because it uses the Hβ luminosity as the luminosity indicator. It has the form

$$\log\Phi = \log\Phi_o - 1.87\log(L/L_o), \qquad (1)$$

where Φ is the number of quasars Gpc^{-3} per magnitude interval of luminosity. We assume that a luminosity function in Lα has the same power law as the one determined using Hβ and that this power law is the same at all z. The value of L_o depends on the average Lα/Hβ ratio for quasars. For calculating the relative dN/dz, we do not need to know L_o. Also, we will take dN/dz using only the quasars in the faintest magnitude interval of the survey; integrating to brighter magnitudes will not affect the relative dN/dz for a power-law luminosity function. Then

$$\frac{dN}{dz} \propto \phi\Big|_{L(z)} \frac{dV}{dz} \; \rho(z) \, . \qquad (2)$$

Here L(z) is the faintest observable Lα luminosity for the flux limit of the survey, and ρ(z) is the co-moving quasar density. The co-moving volume element observed is dV, which, like L(z), is cosmology dependent. From Carswell and Smith (1978),

$$\frac{dV}{dz} \propto (1+z) + (1+z)^{-3} \; -2(1+z)^{-1} \quad \text{for } q_o=0$$

and (3)

$$\frac{dV}{dz} \propto z^2(1+z)^{-3}(1+2z)^{-0.5} \quad \text{for } q_o=1.$$

Also,

$$\log L(z) \propto 2 \log[z(1+0.5z)] \quad \text{for } q_o=0$$

and (4)

$$\log L(z) \propto 2 \log z \qquad q_o=1$$

(see Sandage 1961, where total line flux is analogous to bolometric magnitude). Using equations 1 - 4, we have

$$\frac{dN}{dz} \propto [z(1+0.5z)]^{-3.74}[(1+z) + (1+z)^{-3} - 2(1+z)^{-1}]\ \rho(z) \text{ for } q_o=0$$

and (5)

$$\frac{dN}{dz} \propto z^{-1.74}(1+z)^{-3}(1+2z)^{-0.5}\ \rho(z) \quad \text{for } q_o=1.$$

From relations (5) we calculate redshift distributions for the interval $1.9<z<3.3$, all normalized at $z=2.2$, above which the number of discoverable quasars drops dramatically. The distribution is shown in Figure 5 for $\rho \neq \rho(z)$ with $q_o = 0,1$. If we consider the error bars for the redshift distribution, this is in marginal agreement for $z>2.0$ with that predicted for $\rho \neq \rho(z)$. Osmer and Smith (1977) found such a result using V/V_m tests on bright Tololo quasars. However, there is a hint from the error bars in Figure 5 that more quasars than expected from a constant co-moving density suddenly appear in the universe at $z \approx 2.3$. Determining the precise nature of the redshift distribution for $1.9<z<3.2$ is one of the important reasons for continuing surveys of this type. Increasing the number of quasars known in this interval will make it possible to determine if an increase in quasar density actually occurred at $z \approx 2.3$, or whether the smooth curve shown represents the actual distribution. If such an increase is verified, it could be used as an isotropy probe.

As determined from previous studies (e.g. Schmidt 1972, Wills and Lynds 1978), the co-moving quasar density must decrease rapidly for $z<2.0$ until the present epoch. Determining at what redshift this decrease begins is also an important problem, but one that requires a sample of optical quasars extending to redshifts substantially below 2.0. The Michigan-Tololo sample contains such quasars, but they cannot be as reliably predicted from the discovery plates as Lα quasars because they have lower emission-line equivalent widths and they often appear as one-line objects. The number of observed quasars in Figure 4 in the range $0.2 < z < 1.2$ suggests that, for some fraction of one-line quasars, the detected line is actually CIII] λ1909 or MgII λ2798. Such objects require precise spectrophotometry for unambiguous redshift measurements. A more promising group of objects is the CIV quasars. With care, redshifts can be determined from survey plates if CIV λ1549 and CIII] λ1909 are present, which is the case for $1.3<z<1.9$. A possible source of confusion is the similarity between such quasars and those for which Lα and CIV λ1549 are visible ($1.9<z<2.4$). For the "CIV window", the wavelength ratio of the two lines is 1.23 compared to 1.27 for the "Lα window". On the low dispersion survey plates, measuring wavelength ratios to such precision is not always possible. Even when follow-up spectrophotometry is required, it is efficient once these two-line candidates are located. Further work is necessary to determine what fraction of quasars in the CIV window show only this line and not CIII] as well. We do not have enough observations of one-line, conceivable CIV quasars to know how often CIII] is also visible on the survey plates.

Observations of only those quasar candidates in the Lα window and CIV window provide a probe for the isotropy of the co-moving density decay process for $z<2.0$. The relative number of quasars in a redshift interval centered at $z=2.1$ ($N_{2.1}$) compared to the number at $z=1.5$ ($N_{1.5}$) is fairly sensitive to the exponent in an exponential decay law. For example, changing from $\rho(z) \propto e^{14\tau}$ to $\rho(z) \propto e^{16\tau}$ increases by a factor of about 1.2 the ratio $N_{2.1}/N_{1.5}$.

This corresponds to a change in the half-life of the quasar phenomenon in co-moving density of 1.2×10^8 years(τ represents look-back time in units of H_o^{-1} and is $z(1+z)^{-1}$ for $q_o=0$.) If we can use large samples of quasars to determine this ratio to such accuracy, we have time resolution in the early universe of approximately 10^8 years.

The apparent changes in quasar numbers as a function of redshift discussed above are all presented in terms of changes only in the co-moving density. However, apparent changes could instead be produced by systematic changes of quasar luminosities as a function of redshift. Even a change only in Lα equivalent widths with redshift could affect number counts. But the question is whether there are traceable changes in _some_ physical property of quasars that occur at well-defined epochs of cosmic time. It would then be possible to determine if these changes occur everywhere in the universe at the same epoch. We think that this can be probed with emission-line quasars from the objective-prism surveys. A problem with such surveys is the great difficulty in achieving homogeneous magnitude limits (e.g. Smith 1978). Because of this, it may not be possible to determine whether the surface density of quasars on the sky is isotropic. This is the curse of a power-law luminosity function; only a small change in the magnitude limit changes drastically the number of quasars detected. But the great blessing of a power-law luminosity function is that _the normalized redshift distribution of quasars is independent of the magnitude limit_, as long as the power-law itself is not a function of redshift. This has been emphasized by Carswell and Smith (1978); if we observe a magnitude fainter into the quasar luminosity function used above, we simply see 5.6 times more quasars in each redshift bin.

Therefore, we feel that surveys for emission-line quasars should be continued with the purpose of determining redshift distributions in different parts of the sky. It is important to determine if the possible feature in the quasar distribution at z=2.3 occurs everywhere at this redshift, and if the ratio of quasars at z=2.1 to those at z=1.5 is the same. This can be done using the Curtis Schmidt technique. To check selection effects, analogous surveys should be carried out with varying methods, using a grating instead of a prism, or a different prismatic dispersion, or a different emulsion. It is also important to observe to different limiting magnitudes in the same fields, as begun by Hoag and Smith (1977). Such observations will provide a check on the assumption that the power-law dependence of the quasar luminosity function is independent of redshift. We note that alternative luminosity functions have been proposed (e.g. Turner 1979).

IV. SUMMARY

Follow-up spectrophotometry of the Michigan-Tololo quasar sample has resulted in confirmation of emission-line quasar characteristics for 80% of the objects observed and roughly 73% confirmation of redshifts predicted directly from the dicovery plates. Within the sample, we found at least four new quasars with spectral features indicative of "supernova-like" outflow (see Figure 2) and also two narrow-line objects with z ≈ 0.1 (see notes on candidates not confirmed as high redshift quasars). The survey technique detects quasars over a large range of redshift, primarily because of the MgII λ2798, CIII]λ1909, CIV λ1549, and Lα lines in emission. For the first three of these cases, it is not always possible to assign a redshift from inspection of the discovery plate; the technique is most accurate and complete in picking out Lα quasars. The redshift distribution for Lα quasars is marginally consistent with a constant co-moving quasar density above $z \approx 2.0$; a continued exponential or power-law increase in co-moving density for $z > 2.0$ appears to be ruled out. Two parameters---the apparent peak in the redshift distribution of Lα quasars, and the ratio of quasars near this peak to those near the peak of CIV quasars---can be measured with a cosmic time resolution of a few times 10^8 years. This allows an all-sky probe of isotropy in the universe with this resolution at a cosmic time of about 1.3×10^{10} years ago. We emphasize that accurate knowledge or repeatability of survey limiting magnitudes is not necessary for comparing redshift distributions, as long as quasars have a power-law luminosity function which is independent of redshift.

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Table 1

DATA FOR OBSERVED MICHIGAN-TOLOLO QUASARS

List No.	Telescope	Redshift Predicted	Redshift Observed	Lα Flux†	Lα E.W.(A)	CIV λ1549 Flux†	CIV λ1549 E.W.(A)	Mag. $(\lambda4500)_{obs.}$
18	MGO	1.89	1.89	29.9:	314:	6.2	70	16.9
30	CTIO	----	2.05	5.3	310	1.7	130	19.1
36*	CTIO	2.06	1.06	----	----	----	----	18.4
42	CTIO	2.30	2.26	8.7	360	2.0	100	18.4
45	CTIO	2.03	1.99	7.4	280	2.4	100	18.4
46	CTIO	2.33	2.31	8.7	560	1.6	120	19.0
81*	MGO	----	?	----	----	----	----	----
86	CTIO(MGO)	1.96	1.96	29.0	480	5.8	90	17.2
87	CTIO	2.36	2.35	15.0	330	3.4	90	17.8
101*	MGO	----	?	----	----	----	----	18.5
104	CTIO	2.35	1.62	----	----	3.0	60	17.8
114*	see notes	----	0.36	----	----	----	----	----
117	CTIO	1.40	1.37	----	----	1.9	150	19.4
118*	see notes	----	0.26	----	----	----	----	----
131	CTIO	1.46	1.42	----	----	2.8	150	18.7
132*	see notes	2.02	1.99	----	----	----	----	----
136	CTIO	2.35	1.60	----	----	3.3	150	18.7
139*	CTIO	2.08	2.03	9.1	480	2.1	110	18.8
141*	CTIO	2.92	2.92:	----	----	----	----	18.6
142	CTIO	1.44	1.39	----	----	3.9	65	17.7
144*	see notes	----	1.91	----	----	----	----	----
145*	see notes	----	0.40	----	----	----	----	----
148	MGO	----	2.99	8.1:	517	1.2:	74	18.8:
153*	MGO	----	0.66?	----	----	----	----	16.9
154	MGO	2.45	2.44	10:	350	2.1:	73	18.2:

Table 1 (continued)

List No.	Telescope	Redshift Predicted	Redshift Observed	Lα Flux†	Lα E.W.(A)	CIV λ1549 Flux†	CIV λ1549 E.W.(A)	Mag. $(\lambda4500)_{obs.}$
164	CTIO	1.94	1.90	85	240	60	240	----
175	CTIO	1.96	1.96	5.9	230	1.6	85	18.6
184*	CTIO	2.96	3.01?	----	----	----	----	19.5
186*	MGO(CTIO)	2.05	0.99	----	----	----	----	17.5
197	CTIO	2.21	2.18	----	180	----	60	----
208	CTIO	2.33	2.31	----	240	----	70	----
211	MGO	2.05	2.00	----	----	3.7:	124:	18.1:
212*	MGO(CTIO)	1.56	1.07?	----	----	----	----	18.4
222	CTIO	----	1.46	----	----	2.0	65	18.4
224	CTIO	2.09	2.09	----	360	----	85	----
232*	MGO	2.18	2.11	6.5	380	2.2	127	18.9
247	MGO	----	2.35	6.7	472	1.4	119	18.9
249	CTIO	----	1.46	----	----	2.2	75	18.6
266*	MGO	1.67	1.68	----	----	7.7	126	17.4
275*	CTIO	2.21	2.13?	----	----	----	----	----
276	CTIO	----	1.59	----	----	4.2	130	18.3
281	MGO	1.33	1.87	----	----	----	----	17.9
287	CTIO	2.32	2.27	----	260	----	100	----
294	MGO	1.97	1.92	----	----	5.3	122	17.7
297*	MGO	2.01	1.95	----	----	3.5	95	17.8
301*	MGO	----	?	----	----	----	----	18.7
305*	see notes	----	0.32	----	----	----	----	----
310	MGO	1.38	1.36	----	----	1.8:	77:	18.4
321*	MGO	----	1.08	----	----	----	----	17.2
324*	CTIO	----	1.44?	----	----	4.4	90	17.8

Table 1 (continued)

List No.	Telescope	Redshift Predicted	Redshift Observed	Lα Flux†	Lα E.W.(A)	CIV λ1549 Flux†	CIV λ1549 E.W.(A)	Mag. (λ4500)$_{obs.}$
328*	MGO	----	?	----	----	----	----	17.1
329*	MGO	----	?	----	----	----	----	18.1
331	CTIO	1.42	1.39	----	----	7.2	240	18.6
333*	MGO	----	?	----	----	----	----	17.7
338*	CTIO	----	1.37?	----	----	2.3?	75?	18.5
340*	MGO	----	0.41	----	----	----	----	17.8
341*	MGO	----	0.40	----	----	----	----	17.8
355*	see notes	----	0.26	----	----	----	----	----
357*	MGO	----	0.33	----	----	----	----	17.5
360*	MGO	----	?	----	----	----	----	19.2
366*	see notes	3.19	3.14	9.4	570	2.0	126	18.8
368*	see notes	3.24	3.16	----	----	----	----	----
381*	MGO	0.91	0.91	----	----	----	----	17.3
397*	MGO	----	0.16	----	----	----	----	15.9
400	MGO(CTIO)	1.33	1.89	----	265	2.3	88	18.1
402	MGO	2.83	2.84	1.7	400	3.5	100	17.7
403	CTIO	2.26	2.19	----	310	----	110	----
415	CTIO	----	1.44	----	----	----	80	----

† Units are 10^{-14} erg cm^{-2}s^{-1}.

: Uncertain.

* Notes to Table 1 follow.

36. Spectrum shows CIII] λ1909 with 65 A e.w. and a noisy feature assumed to be MgII λ2798.

81. Noisy spectrum obtained through clouds shows a broad emission feature with roughly 141 A e.w. at λ4260.

Notes to Table 1 (continued).

101. Has a broad emission feature with 114 A e.w. at λ4523.

114. Also PHL 1027. Redshift from Burbidge *et al*. (1977).

118. Also PHL 1033. Redshift from Burbidge *et al*. (1977).

132. Also PHL 1127. Redshift from Burbidge *et al*. (1977).

139. Has strong, broad absorption blueward of Lα, CIV λ1549, and OIV]/SiIV λ1400; spectrum illustrated in Figure 2.

141. Spectrum, illustrated in Figure 2, shows strong, broad emission and absorption features, in agreement with the description from the discovery plate. The redshift was assigned by considering the strongest features to be Lα (strongly absorbed on the blue side), CIV λ1549, and OVI λ1034. For z=2.92, the emission at λ4014 actually corresponds more closely with the position of Lβ. The higher ionization CIV and OVI absorption features appear at a somewhat lower redshift than that for Lα.

144. Also PHL 1222. Redshift from Burbidge *et al*. (1977).

145. Also PHL 1226. Redshift from Burbidge *et al*. (1977).

153. Has one broad emission feature with 50 A e.w., assumed to be MgII λ2798.

184. Has one strong emission line (flux 2×10^{-14} erg $cm^{-2}s^{-1}$, e.w. 140 A) with deep absorption to blue, matching the description from the discovery plate; illustrated in Figure 2. A spectrum obtained by M. G. Smith using the Anglo-Australian telescope appears to show weak OIV]/SiIV λ1400 and CIV λ1549 at z=3.01.

186. Spectrum shows broad emission features at λ3822 and λ5575 (66 A e.w.), assumed to be CIII] λ1909 and MgII λ2798.

212. Noisy spectrum shows two broad emission features at λ3934 (70 A e.w.) and λ5804 (90 A e.w.), assumed to be CIII] λ1909 and MgII λ2798.

Notes to Table 1 (continued).

232. Spectrum, illustrated in Figure 2, shows strong, broad absorption on the blueward side of Lα, CIV λ1549, and OIV]/SiIV λ1400, matching the description from the discovery plate.

266. Also PKS 0038-019.

275. Spectrum, illustrated in Figure 2, shows strong, broad absorption features, in agreement with the description from the discovery plate. The strongest emission feature, with deep central absorption, is assumed to be Lα.

297. Also PHL 938.

301. Noisy spectrum has a broad emission feature with roughly 221 A e.w. at λ3905.

305. Also PKS 0105-008. Redshift from Burbidge et al. (1977).

321. Also PKS 0122-003.

324. Has only one emission feature, assumed to be CIV λ1549 because of observed e.w.

328. Has one emission line with 30 A e.w. at λ5111.

329. Has one emission line with 58 A e.w. at λ4445, possibly with broad absorption on the blueward side.

333. Noisy spectrum shows a weak, broad emission feature at λ4361.

338. Has only one emission feature, assumed to be CIV λ1549 because of observed e.w.

340. Noisy spectrum shows three emission features at λ3958 (roughly 65 A e.w.), λ6121 (roughly 27 A e.w.), and λ6820 (roughly 40 A e.w.). These lines are assumed to be MgII λ2798, Hγ, and Hβ, respectively.

341. Spectrum has three emission features at λ3917 (123 A e.w.), λ6079 (98 A e.w.), and λ6828 (150 A e.w.). These lines are assumed to be MgII λ2798, Hγ, and Hβ, respectively.

Notes to Table 1 (continued).

355. Also PHL 1093. Redshift from Burbidge et al. (1977).

357. Also NAB 0137-010.

360. Very noisy spectrum shows what appears to be a broad emission feature at λ3960.

366. Spectrophotometry obtained by M. G. Smith using the Anglo-Australian telescope and also by R. P. Kirshner using the KPNO Mayall telescope.

368. Redshift obtained by M. G. Smith using the Anglo-Australian telescope.

381. Spectrum shows assumed CIII] λ1909 at λ3613 and MgII λ2798 at λ5391 (60 A e.w.)

397. Also NAB 0205+024 and Mrk 586.

(Follows Notes to Table 1)

Candidates Not Confirmed as High Redshift Quasars

35. Has one possible weak, broad emission feature at λ4104. The continuum is not blue.

66. A low-redshift object (z=0.070) with narrow lines; spectrum shows [OII] λ3727 (e.w. 72 A), Hβ (e.w. 20 A), and [OIII] λλ4959,5007 (e.w. 67 A).

73. Uncertain object; possible, but not obvious emission.

88. Blue star; probably a DA white dwarf.

94. Blue star; probably a DA white dwarf.

100. No obvious spectral features; continuum not blue.

169. Blue star; probably a DB white dwarf.

179. Blue star; probably a DA white dwarf.

228. A low-redshift object (z=0.102) with narrow lines; spectrum shows [OII] λ3727 (e.w. 100 A), Hβ (e.w. 115 A), and [OIII] λλ4959,5007 (e.w. 760 A).

302. Blue star; probably a DB white dwarf.

303. No obvious features; blue continuum.

364. Noisy scan has no obvious features; not very blue.

370. Blue star; probably a DA white dwarf.

383. No obvious emission features; possible absorption at λ3974.

419. Blue star; probably a DA white dwarf.

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FIGURE CAPTIONS

Fig. 1.----Region for which nearly complete objective-prism plate coverage has been obtained with the Curtis Schmidt. The shaded area has been systematically searched, resulting in Michigan-Tololo Lists I-IV of emission-line objects. Each plate covers 5°x5°, and the overlap is about 1/2°.

Fig. 2.----Spectra (flux per unit wavelength interval against observed wavelength) for quasars showing unusually strong, broad absorption features.

Fig. 3.----Comparison between the distributions of observed Lα equivalent widths for the Michigan-Tololo sample (solid histogram border) and radio quasars (dotted histogram).

Fig. 4.----Redshift distribution for redshifts predicted from the survey plates (dotted histogram) compared to those determined from observations in Table 1 (solid histogram), in units of actual number of quasars against redshift.

Fig. 5.----Normalized redshift distributions for redshifts predicted from the survey plates (dotted histogram) compared to those determined from observations in Table 1 (solid histogram). Uncertainty estimates are applied to predicted redshifts with z>2.0 as described in text. Curves represent expected distributions for a constant co-moving quasar density, for q_o=0,1 .

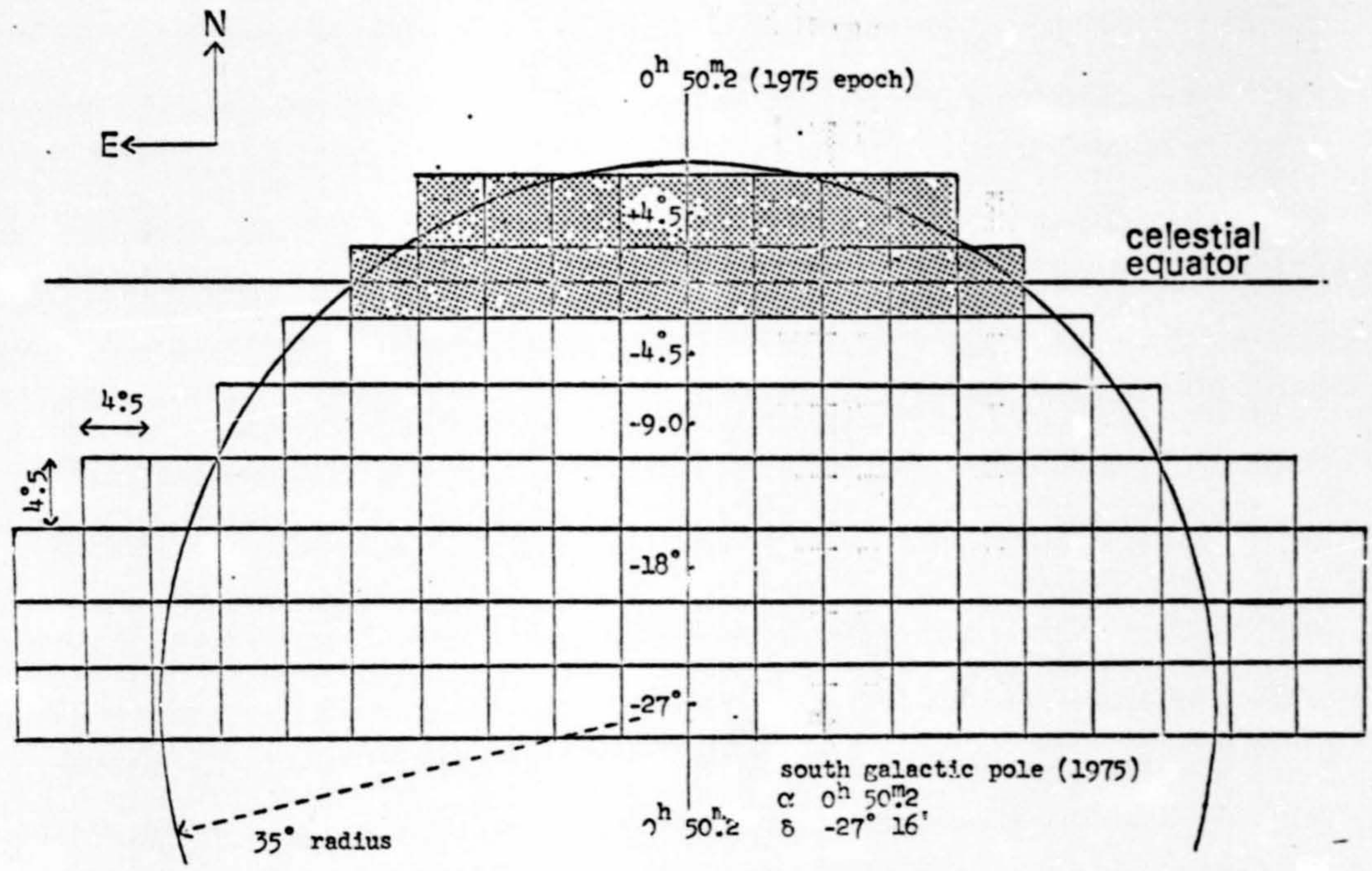

N
E
0h 50m.2 (1975 epoch)
+4.5
celestial equator
-4.5
-9.0
4°5
4°5
-18°
-27°
south galactic pole (1975)
α 0h 50m.2
δ -27° 16'
0h 50m.2
35° radius

Fig 1

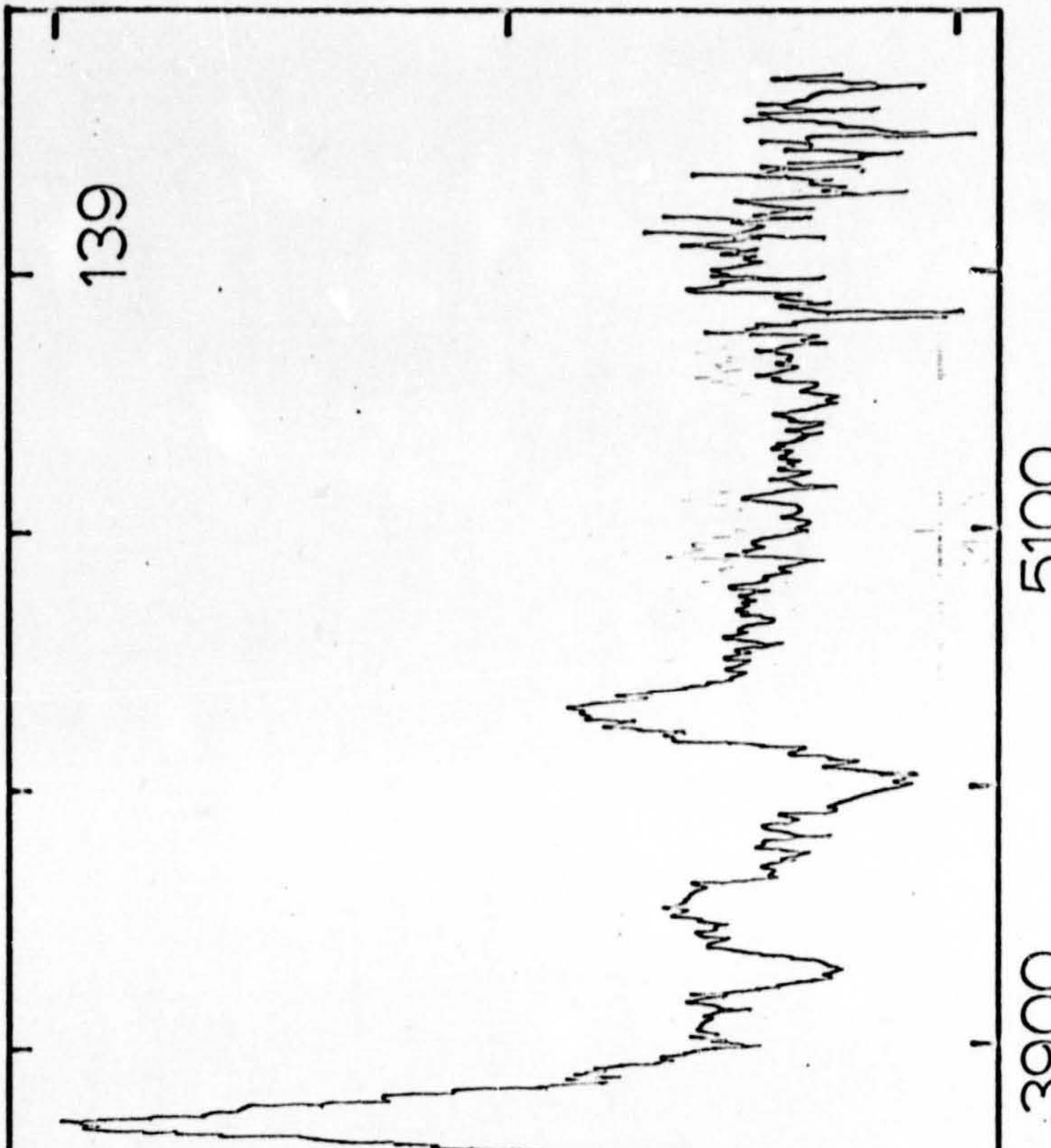


Fig 2a

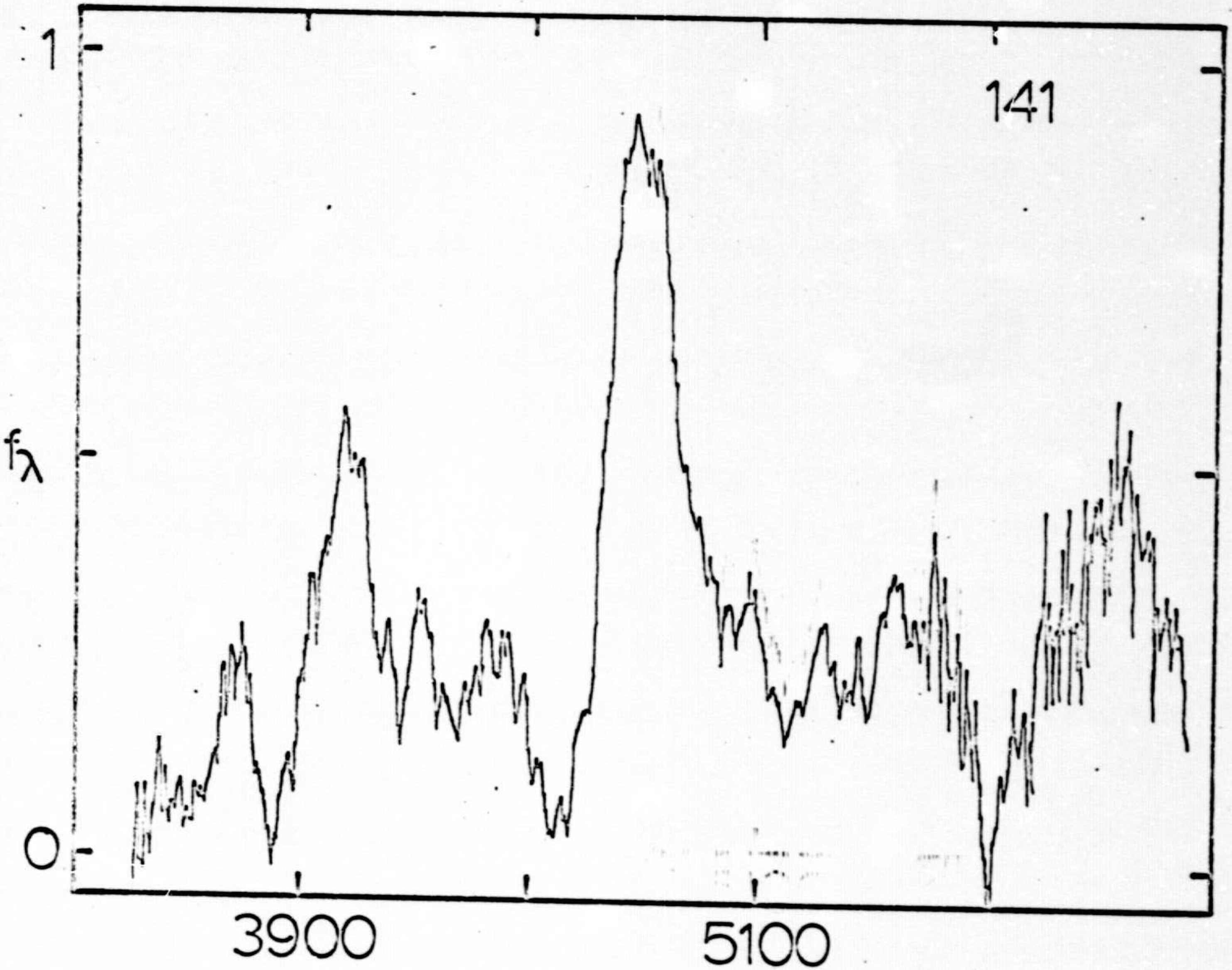


Fig 2b

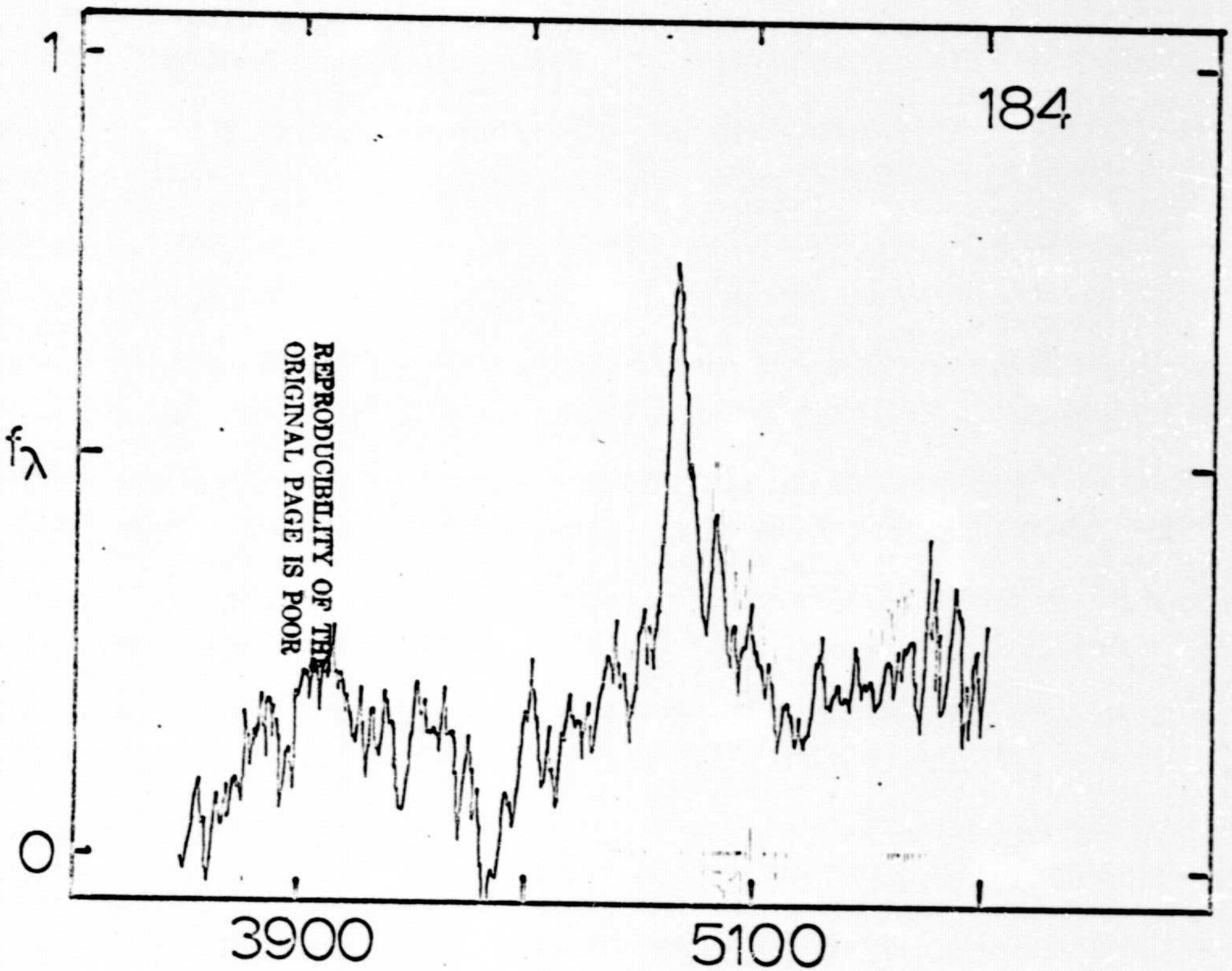


Fig. 2c

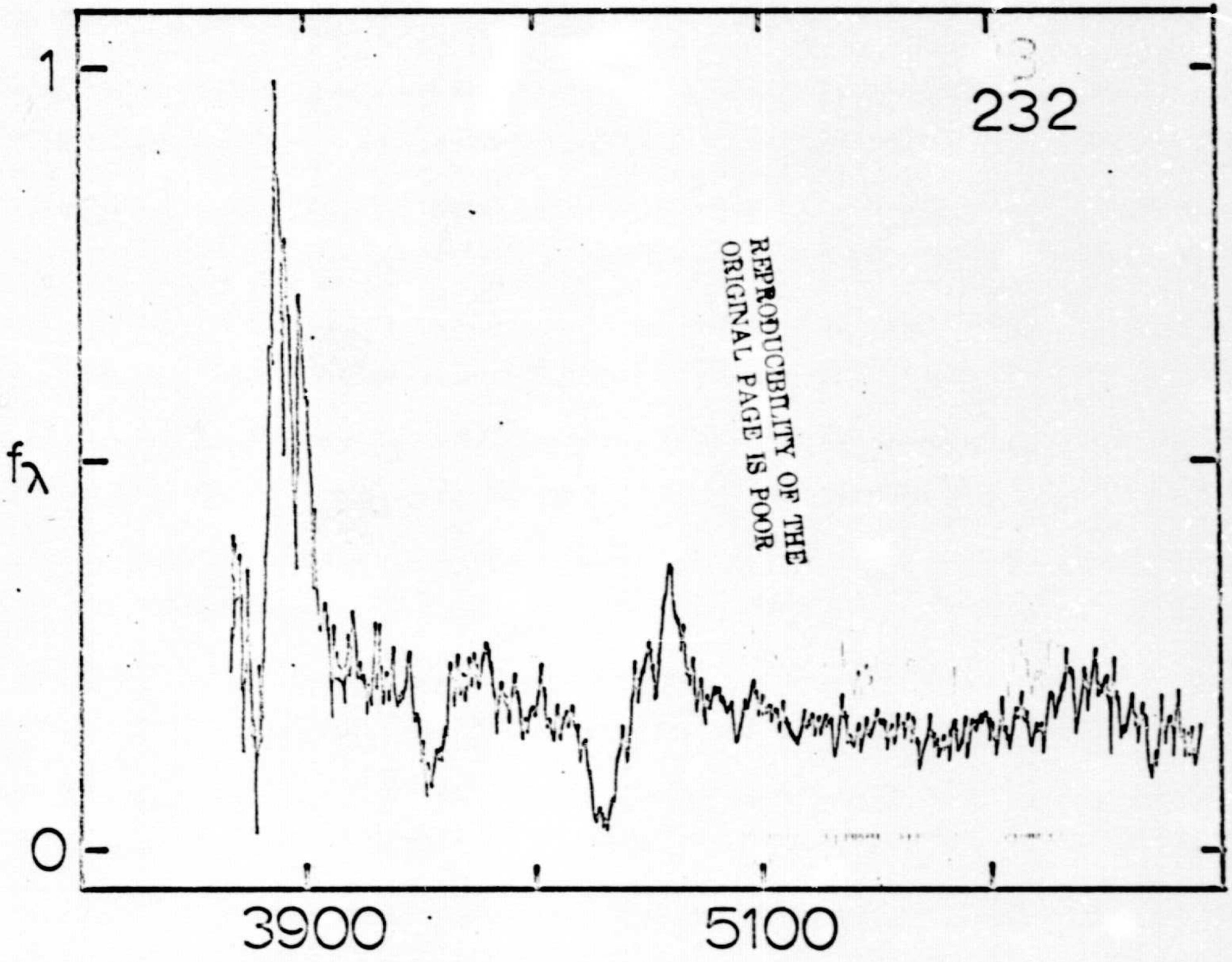


Fig 2d

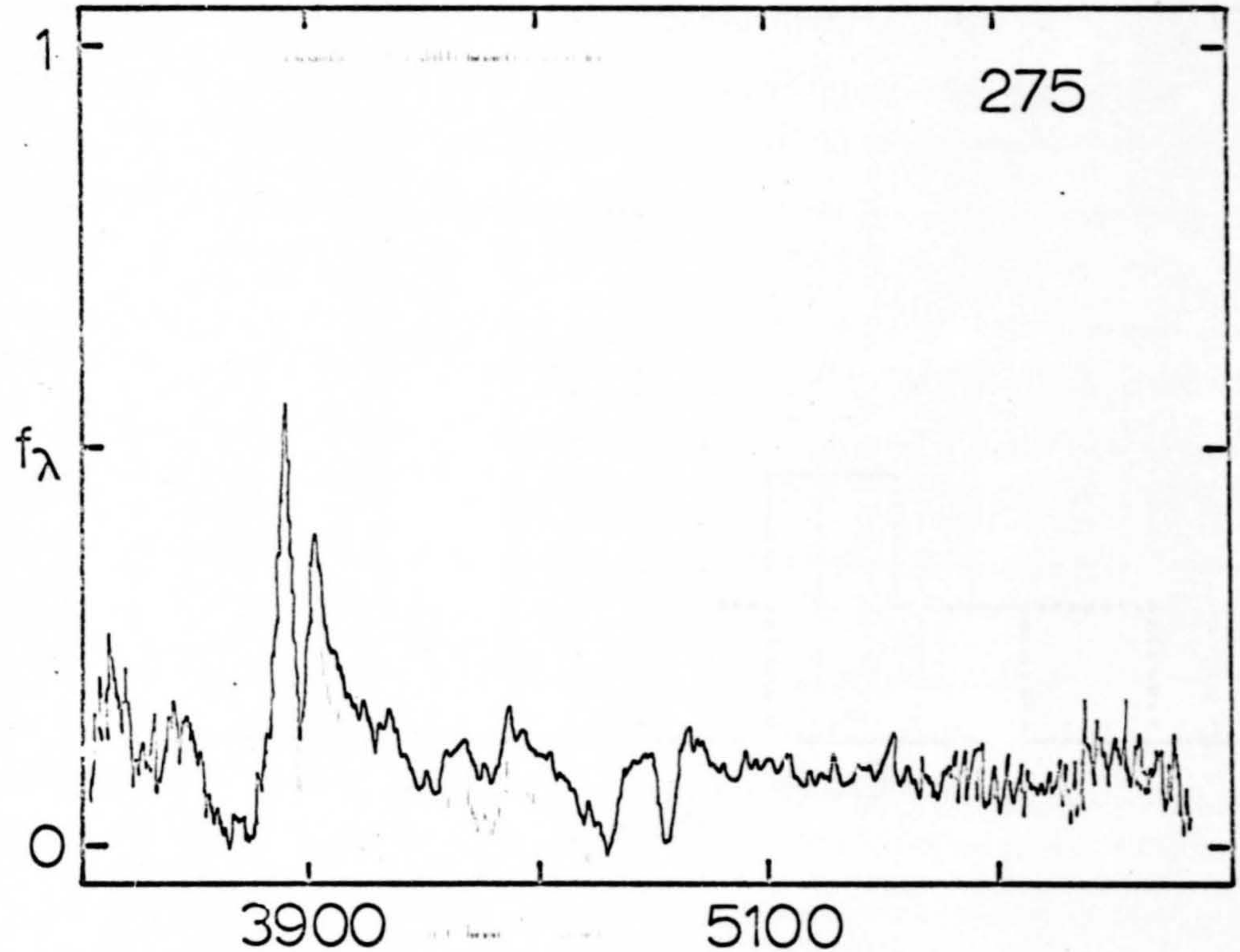


Fig 2c

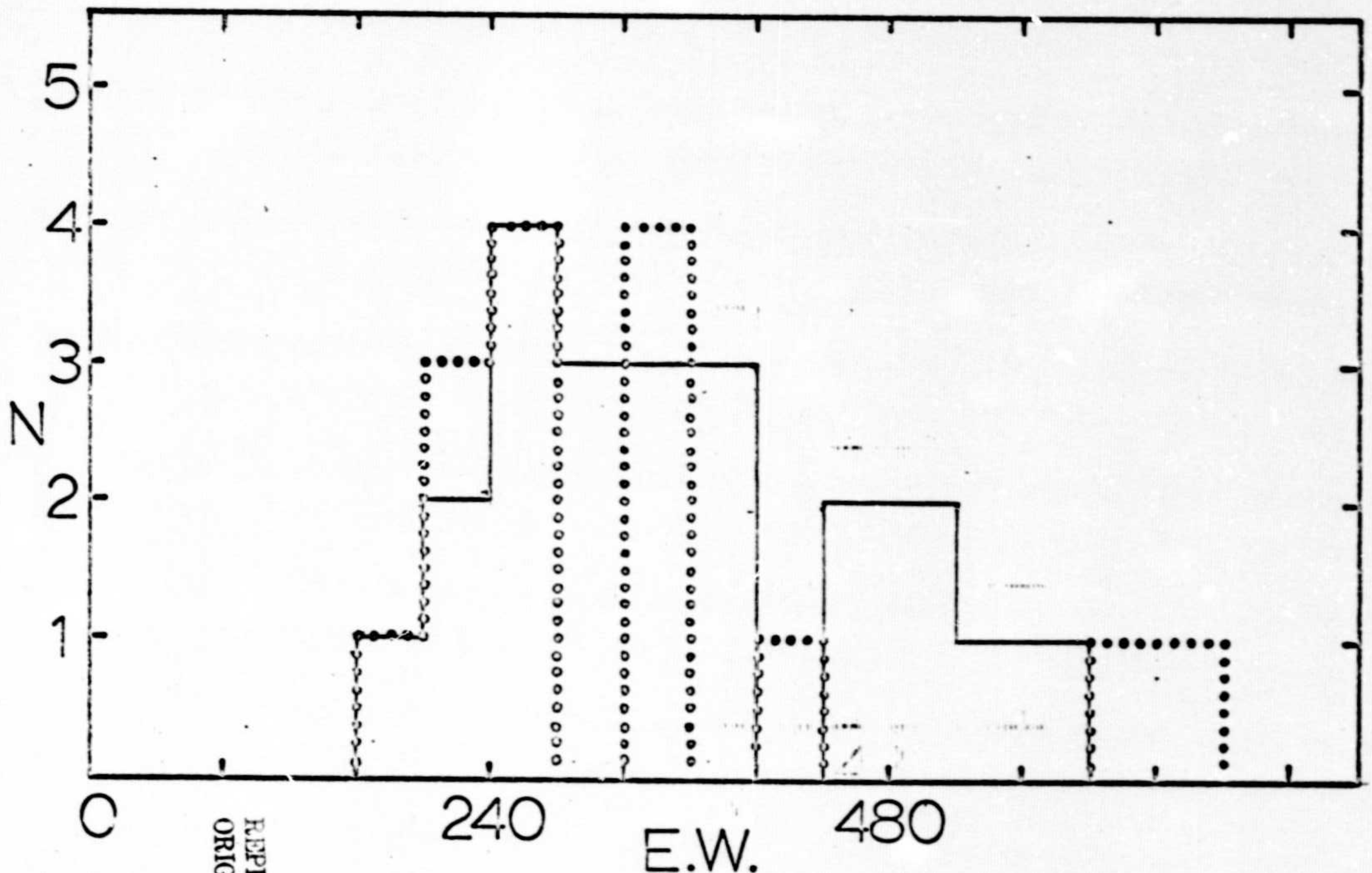
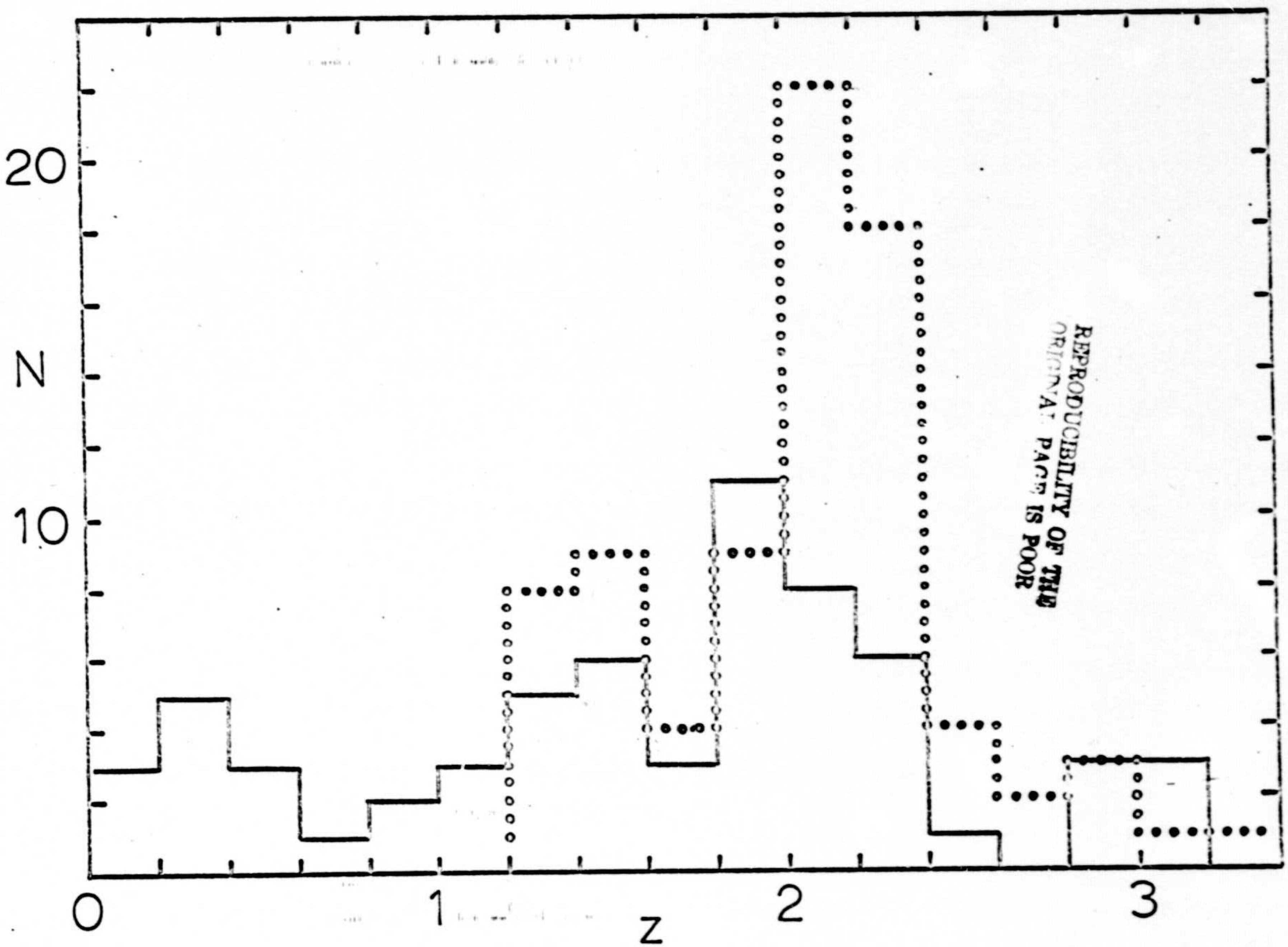


Fig. 3


20
10
N
0
1
2
3
z

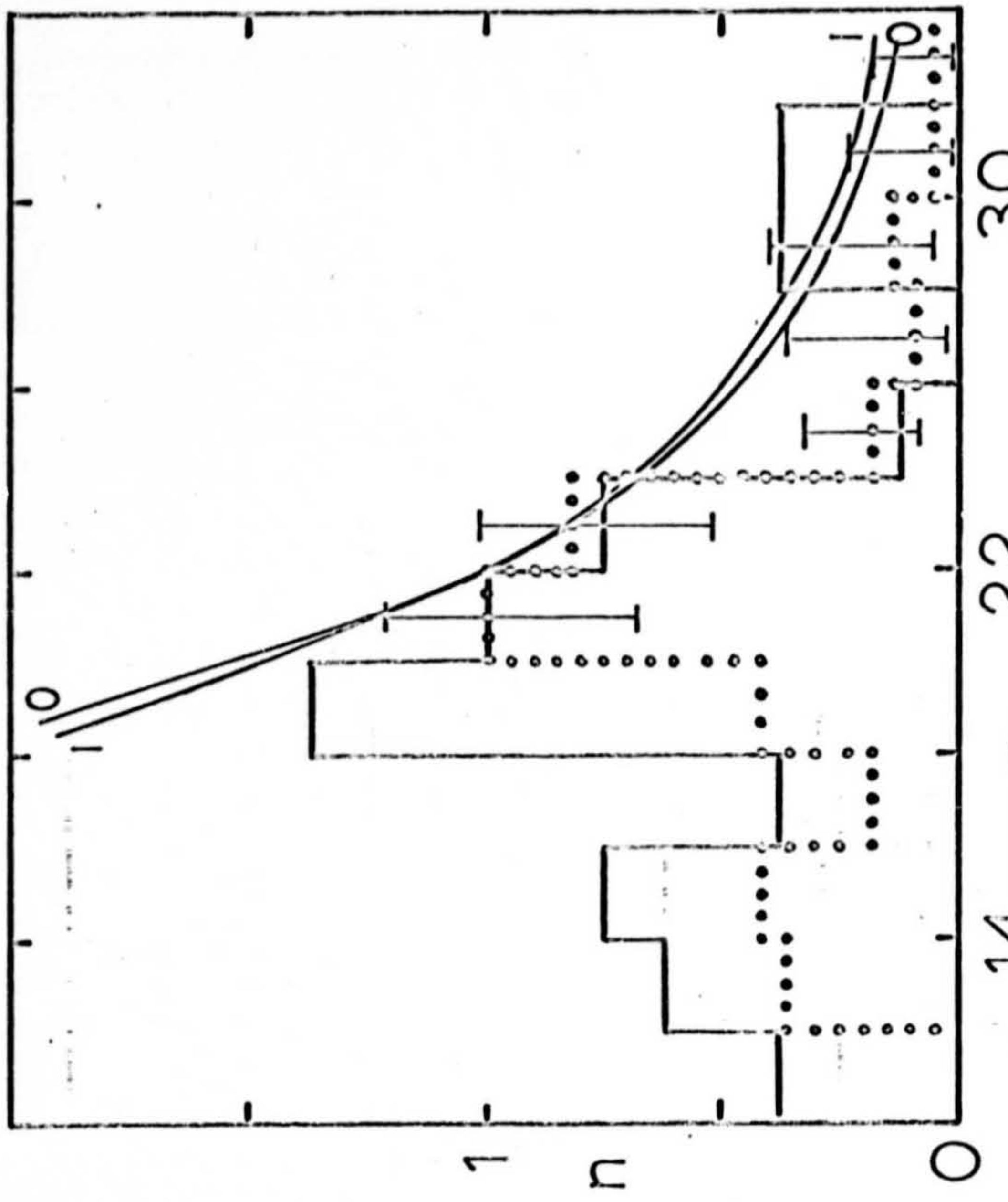


Fig 5