polar wander curve for South America, possibly because of tectonic affects of the Andean orogeny, there is clear evidence of mixed polarity. The NRM has been thermally cleaned[16]. Stratigraphically, the Mitu formation is placed in the Permian and, furthermore, recent K–Ar age determinations on associated igneous bodies by Rocha-Campos and Amaral[17] yield ages of 260 m.y.

Thus the normal magnetization recorded in the Mitu formation may also correspond to the normal event recorded by the basalts of the Porphyritic Series from Mendoza Province, Argentina.

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1 Irving, E., and Parry, L. G., *Geophys. J.*, **7**, 395 (1963).
2 Khramov, A. N., *Izv. Akad. Nauk. SSR, Earth Physics Series*, **86** (1967).
3 McElhinny, M. W., *Special Pubs. Geol. Soc. Austral.*, **2**, 61 (1969).
4 Graham, J., *J. Geophys. Res.*, **60**, 329 (1955).
5 Burek, P., *Bull. Amer. Assoc. Petroleum Geol.*, **54**, 1120 (1970).
6 Guicherit, R., *Geologica Ultraiectina*, **14**, 1 (1964).
7 Groeber, *Direccion Gral. de Minas, Geologia e Hidrologia*, Publicacion No. 58 (1929).
8 Dessanti, R. M., *Descripcion Geologica de la Hoja 27e, Cerro Diamante* (*Prov. de Mendoza*), D. N. de Minas, Bol. 85, Bs. As. (1956).
9 Dessanti, R. N., and Caminos, R., *Rev. Asoc. Geol. Arg.*, **XXII**, No. 2 (1967).
10 Gonzales, Diaz, *Rev. Asoc. Geol. Arg.*, **XIX**, No. 3 (1964).
11 Bonaparte, J. F., *Rev. Asoc. Geol. Arg.*, **XXI**, 1 (1966).
12 Valencio, D. A., *Cuartas. Jornadas Geol. Arg.*, **2**, 375 (1970).
13 Embleton, B. J. J., *Rev. Asoc. Geol. Arg.* (1970).
14 Creer, K. M., *Earth Science Rev.*, **6**, No. 6 (1970).
15 Grasty, R. L., and Miller, J. A., *Nature*, **207**, 1146 (1965).
16 Creer, K. M., *Phil. Trans. Roy. Soc.*, A, **267**, 522 (1970).
17 Rocha-Campos, A. C., and Amaral, G., *K-Ar Ages of Igneous Rocks of the Mitu Group, Huancayo Region, Central Peru* (in the press).

Accurate Radio and Optical Positions of 3C273B

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New measurements have confirmed that 3C273B and the associated quasi-stellar object are coincident.

THE small angular size component (3C273B) of the radio source 3C273 is generally considered to coincide with the associated quasi-stellar object (QSO), and the most accurate published optical and radio positions[1] are consistent with this interpretation. Nevertheless, they do differ by 0.7 arc s, a discrepancy which is just outside the combined estimated errors, and the possibility of a small but significant displacement between the QSO and 3C273B cannot be excluded. In an attempt to reduce this uncertainty we have therefore carried out a new measurement of the position of 3C273B based on occultation observations using the CSIRO 210-foot telescope at Parkes, Australia, and the 1,000-foot telescope at Arecibo, Puerto Rico. We had not previously carried out this analysis because it was not possible to realize the full positional accuracy of which these high signal/noise observations were capable because of uncertainties in the Improved Lunar Ephemeris and in the difference (ΔT) between Ephemeris (ET) and Universal Time (UT). Recently, corrections to the Improved Lunar Ephemeris[2] have been proposed and, with accurate values for ΔT over the period 1963 to 1966 also now available, it seemed possible to reduce the error in the radio position to ≤ 0.2 arc s. As it turned out, our new position measurement only increased the discrepancy between the optical and radio positions. On examining the optical position, however, we found that the usually quoted value was based on observations made by Jefferys[1] for the purpose of proper motion studies and that no accurate optical position had been measured. We therefore carried out new position measurements of the QSO both at the Cambridge Observatories and at the Royal Greenwich Observatory (RGO) to permit an accurate comparison with the new radio position.

Radio Position

The method of observation and an account of the structural information obtained from an analysis of all the occultation curves have been given elsewhere[3,4]. For the present investigation we selected only those occultation curves for which the signal/noise ratio and the separation of the A and B components permitted a timing accuracy of better than 1 s, corresponding to an error in the location of the Moon's mean limb of ≤ 0.3 arc s. The relevant data relating to these selected curves are listed in Table 1 together with the estimated times of occultation, all of which have been corrected for delays introduced by the output time constants of the receiving equipment. In the case of the grazing occultation the quoted occultation time corresponds to the time of closest approach. For the other occultations the occultation times were determined using the restoration technique described by Scheuer[5], which gives the brightness distribution across the source as seen by a fan beam of arbitrary width. The widths of the restoring beams used ranged from a minimum of 0.18 arc s for the occultation of June 7, 1965, to a maximum of 3.5 arc s for the occultation of September 7, 1964, where the occultation occurred during the day and close to the Sun, and the observa-

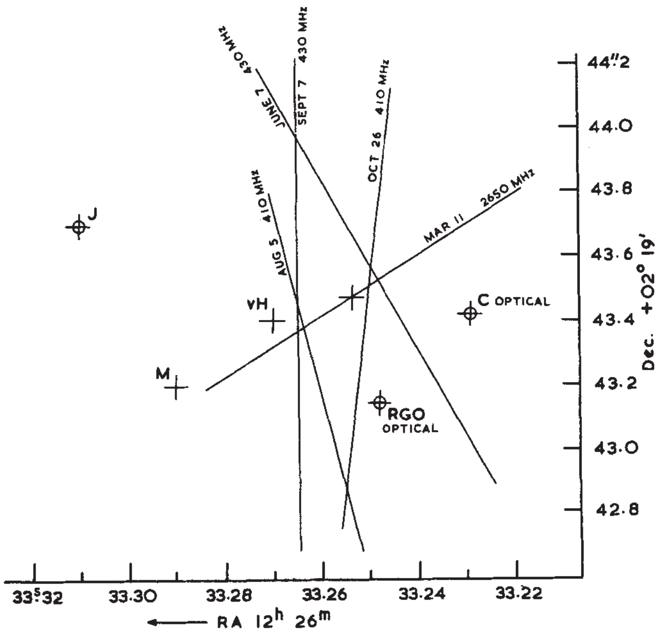

Fig. 1 Corrected lunar limb positions (1950.0) defining lines along which the source 3C273B must lie. (The position for September 7 has been discarded in deriving the final radio position.) The separate optical determinations are denoted by C and RGO (from Table 3). M and vH, The radio positions of Moffer and von Hoerner; J, The optical position given by von Hoerner[1] based on data by Jefferys.

tions were of relatively low quality. For the Parkes occultations the useful width of the restoring beam was limited by the receiver parameters to 0.8 arc s at 430 MHz and 0.5 arc s at 1,420 MHz. In deriving the brightness distributions, the time scale of the restoring functions was adjusted until the restored distribution of the unresolved source 3C273B was symmetrical as described by Hazard *et al.*[4]. This procedure corresponds to taking the best mean slope of the limb at the point of occultation and is necessary when aiming at a timing error of the order of 0.1 arc s.

Each occultation time defines a position of the Moon's limb as viewed from the appropriate observatory and the determination of the source position therefore involves the calculation of these limb positions. The calculations require an accurate lunar ephemeris, parallax corrections for the location of the observatory relative to the centre of the Earth, and corrections for the deviation of the apparent limb of the Moon from a smooth sphere centred on the ephemeris position.

The positions of the centre of the Moon and hence the positions of the mean limb were obtained by interpolation of the lunar ephemeris $j=2$ (defined in ref. 6) using values of ΔT, the difference between Ephemeris Time (ET) and Universal Time (UT2), calculated from the expression

$$\Delta T(\mathrm{FK4}) = +30.90 + (\mathrm{AT} - \mathrm{UT2})\ \mathrm{s}$$

The differences between the Atomic Scale (AT) and UT2 were taken from the circulars of the Bureau Internationale de l'Heure, Paris. The interpolated positions were adjusted in ecliptic longitude (λ) and latitude (β) by the addition of the corrections:

$$\Delta\lambda = +0.13 \sin l + 0.17 \cos l \text{ arc s}$$

$$\Delta\beta = -0.05 \sin F - 0.18 \cos F + 0.25 \cos L \text{ arc s}$$

where L is the mean longitude, l is the mean anomaly and F is the mean longitude from the node.

These correcting terms were deduced, with slight modifications, from a recent analysis of occultations of stars by the Moon by Morrison and Sadler[2], who analysed occultations observed between 1960 and 1966. Their results are thus particularly well suited to the reduction of radio occultations observed between 1962 and 1965.

The adopted site coordinates for the Parkes and Arecibo radio telescopes were those given in the 1971 Astronomical Ephemeris. For Arecibo, the latitude was decreased by 9 arc s, the correction to the tabulated astronomical latitude to obtain the required geodetic latitude, and the altitude increased to 496 m. The coordinates used are believed to define geocentric positions to better than 200 m, corresponding to errors in the parallax correction of less than 0.1 arc s.

After calculating the position of the mean limb at each of the occultation times listed in Table 1, corrections were applied to allow for the deviations of the true limb from the idealized profile. These corrections were computed using a digitized version[7] of Watts's charts[8] of the marginal zone of the Moon, and drawn automatically by an on-line graph plotter. It was assumed that the gravitational centre and Watts's optical centre of the Moon were coincident, but corrections of $-0.15 \cos 2(\pi - 153°)$ arc s (the ellipticity corrections) were applied to Watts's heights above the mean limb and $-0°.25$ to Watts's values of the axis angle π (refs. 9, 10). The adopted semi-diameter (932.58 arc s) of the Moon at mean distance is probably accurate to within 0.05 arc s (ref. 9). Except in the case of the grazing occultation, the correction was taken to be the height of the true limb above the mean limb, where the height was averaged over two Fresnel zones on either side of the point of occultation.

In the case of the grazing occultation the required correction is the distance at which the source passes above the mean limb. It was assumed that the observed decrease in the received power was due entirely to the approach of 3C273B to the limb, the A component passing some 20 arc s further from the limb. The flux of 3C273A at 2,650 MHz was calculated from its known flux at 410 MHz assuming a spectral index of -0.66 (ref. 11) while the corresponding flux of the B component was estimated from the measurement of Kellermann[12] at 1,423 MHz and 2,841 MHz. Knowing the flux ratio of 3C273A/3C273B, a comparison of the observed decrease in flux with that expected for a point source then gave the distance at which 3C273B passed from the true limb at the point of closest approach. A comparison of the profiles of the true and mean limbs then gave an estimate (0.09 ± 0.2 arc s) of the distance at which the source passed outside the mean limb.

The positions of the corrected limbs which define lines along which the source must lie are shown in Fig. 1. The scatter of these lines about the mean position is significantly larger if the corrections to the lunar ephemeris are not applied. These corrections, together with the applied limb corrections, are listed in Table 1. It is expected that an ephemeris derived by numerical integration[13] would lead to solutions differing from those in Fig. 1 by 0.1 arc s—due primarily to the effects of planetary perturbations.

In deriving the position of 3C273B from Fig. 1 the occultation of September 7, 1964, was not considered because, although it is in good agreement with the other occultation observations, its estimated timing error is significantly larger. The position with the smallest r.m.s. deviation from the remaining four corrected limbs is given in Table 2 together with other determinations of the radio position, all of which agree within the limits of the experimental errors.

Possible sources of error arise in refraction in the Earth's ionosphere, the solar corona and in a possible lunar ionosphere. It is easy to show that for a refracting region between the Moon and the Earth an angle of refraction Ψ produces a displacement of the apparent source position by $\approx \Psi\ h/D$ where h is the effective height of the refracting medium and D is the Moon's distance. In the case of the ionosphere $h/D < 1/400$ and, because all measurements were made at zenith angles of $<51°$ where the ionospheric refraction at frequencies ≥ 400 MHz is very rarely as large as 10 arc s, the effect of the ionosphere can be ignored.

Coronal refraction produces a displacement of the source position equal to the angle of refraction. At a frequency of 136 MHz it has been shown to be less than 0.3 arc s (ref. 3)

Table 1 Occultation Data

Date	Phase	Observatory	Frequency (MHz)	Occ. time (h)	(m)	(s)	Timing error (s)	(arc s)	Position angle* (degrees)	Zenith angle (degrees)	Angle from the Sun (degrees)	Limb correction† (s)	Ellipticity correction*§ (arc s)	Ephemeris correction¶ (arc s)
August 5, 1962	Immersion	Parkes	410	07	46	25.9	0.3	0.1	104.7	46	53	+0.41	+0.12	−0.23
October 26, 1962	Immersion	Parkes	1,420	02	56	02.0	0.3	0.1	83.2	51	27	−0.62	+0.15	−0.33
March 11, 1963	Grazing	Parkes	2,650	17	30	25	—	—	212.1	47	165	−0.72‡	−0.05	+0.37
September 7, 1964	Immersion	Arecibo	430	18	36	57.0	1.5	0.4	90.2	20	20	−1.38	+0.15	0.00
			195	18	37	02.1	3	0.8						
June 7, 1965	Emersion	Arecibo	430	23	03	56.6	0.2	0.06	298.9	20	108	−0.26	+0.06	−0.22
			195	23	03	56.2	0.5	0.15						

* Position angle of the line from the centre of the Moon to the point of occultation.
† Corrections are in the sense (true-mean) limb measured from the centre of the Moon.
‡ The correction is an average over 30 arc s around the point of occultation. An additional correction was applied for the distance the source passed outside the true limb.
§ In the sense (corrected-mean) limb measured from the centre of the Moon.
¶ Corrections to the position of the limb are in the sense corrected Ephemeris minus $j=2$ Ephemeris measured from the centre of the Moon.

Table 2 Radio Position of 3C273B

	Right ascension		Declination (1950.0)	
Present paper	12 h 26 m 33.253 s	±0.014 s	+2° 19′ 43.47″	±0.3″
Von Hoerner[1]	33.27	±0.02	+2° 19′ 43.4″	±0.4″
Moffet (as quoted by von Hoerner[1])	33.29	±0.01	+2° 19′ 43.2″	±0.2″

for a ray passing within 50° of the Sun and consequently <0.03 arc s for frequencies ≥410 MHz. Only the occultations of October 26 and September 7 occurred closer to the Sun than 50°, at 27° and 20° respectively. The occultation of September 7 has not been used in the analysis whereas that of October 26 was carried out at 1,420 MHz at which frequency coronal refraction is negligible to within 10° of the Sun. Refraction in a possible lunar ionosphere has also been shown to be ≤0.3 arc s at 136 MHz and consequently ≤0.03 arc s for frequencies ≥410 MHz.

Optical Position of 3C273B

The optical positions were determined at both the Royal Greenwich Observatory and at Cambridge. The RGO position was derived from six plates, five with the 26-inch refractor and one with the 13-inch astrograph, and the Cambridge position from two plates with the 17/24-inch Schmidt telescope. Blue sensitive plates were used throughout, unfiltered except for one of the Schmidt plates for which an ultraviolet cutoff filter was used (Schott UG2, thickness 2 mm), reproducing the B photometric system. Reference star positions were taken from AGK 3 updated for proper motion. At least fourteen AGK stars were used for each plate. No attempt has been made to correct for atmospheric dispersion between the QSO and the reference stars.

Table 3 Mean Optical Positions of 3C273B, Standard Errors of Means, and Numbers of Plates

	Right ascension	Declination (1950.0)	No. of plates
RGO	12 h 26 m 33.248 s	+2° 19′ 43.14″	6
Cambridge	12 h 26 m 33.229 s	+2° 19′ 43.42″	2
Unweighted Mean	12 h 26 m 33.239 s ±0.010 s	+2° 19′ 43.28″ ±0.15″	

The results are set out in Table 3. The standard error for a single plate position, determined from the internal scatter between plates, is about ±0.1 arc s in each coordinate for each observatory, but the means given in Table 3 for the two observatories differ significantly by about 3 standard errors. This will not be discussed here. In the last line of Table 3 we have given the mean from the two observatories, together with standard errors calculated from the difference between the two. A component of ±0.05 arc s in each coordinate has been added to the standard error to allow for the uncertainty of fit to AGK. No allowance has been made for a possible discrepancy between AGK 3 and FK4.

The mean optical position and the new radio position are in excellent agreement and support the generally accepted idea that 3C273B and the associated QSO are coincident. Although a small displacement between the optical and radio positions cannot be excluded, any such discrepancy is ≤0.3 arc s, well within the limits of experimental error. The most reliable of the occultation observations, that of June 7, 1965, passes exactly through the mean optical position. Exact agreement between the optical and radio positions should not be expected because of the different reference systems. Although both are based on FK4, the occultation observations use corrections which are derived from occultations of stars over the whole ecliptic. The optical position, however, is based on reference stars in the region of 3C273B and this local reference system may deviate significantly from the average. We see no reason to prefer either the radio or optical positions and suggest that until better measurements become available the position of 3C273B should be taken as their average, namely,

R.A., 12 h 26 m 33.246 s ± 0.01 s,
declination + 02° 19′ 43.38″ ± 0.1″ (1950.0)

Finally, we note that the close agreement of the optical and radio positions confirms the accuracy of each group's positional measurements and shows not only that the RGO and Cambridge Observatory optical positions can be taken as accurate to 0.2 arc s, but also that using the occultation technique radio positions reliable to 0.2 arc s can be obtained even from a limited number of occultation curves provided corrections are applied for the limb profile and to the lunar ephemeris $j=2$ is adopted.

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1. von Hoerner, S., *Astrophys. J.*, **144**, 483 (1966).
2. Morrison, L. V., and Sadler, F. M., *Mon. Not. Roy. Astron. Soc.*, **144**, 129 (1969).
3. Hazard, C., Mackey, M. B., and Shimmins, A. J., *Nature*, **197**, 1037 (1963).
4. Hazard, C., Gulkis, S., and Bray, A. D., *Nature*, **210**, 888 (1966).
5. Scheuer, P. A. G., *Austral. J. Phys.*, **15**, 333 (1962).
6. *Trans. Internat. Astron. Union*, **13B**, 49 (1967).
7. Morrison, L. V., and Martin, R. J., *The Moon* (in the press).
8. Watts, C. B., *Astron. Papers American Ephemeris*, **XVII** (1963).
9. van Flandern, T. C., thesis, Yale Univ. (1969).
10. Morrison, L. V., *Mon. Not. Roy. Astron. Soc.*, **149**, 81 (1970).
11. Hazard, C., Gulkis, S., and Bray, A. D., *Nature*, **212**, 461 (1966).
12. Kellermann, K. I., *Astron. J.*, **69**, 205 (1964).
13. Garthwaite, K., Holdbridge, D. B., and Mulholland, J. D., *Astron. J.*, **75**, 1133 (1970).