THE POSITION AND PROBABLE IDENTIFICATION OF THE SOURCE OF GALACTIC RADIO-FREQUENCY RADIATION TAURUS–A

By J. G. Bolton* and G. J. Stanley*

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Summary

This paper contains an account of the discovery of, and subsequent work on, one of the minor discrete sources of galactic radio-frequency noise—Taurus–A. Full details are given of observations and calculations leading to the determination of the source's position and its probable identification with the Crab nebula or supernova of A.D. 1054.

I. Introduction

Since Jansky's(1) original discovery of cosmic or galactic radio-frequency noise, considerable information has been accumulated on the intensity distribution of this radiation over the celestial sphere. This distribution roughly follows the optical brightness of the Milky Way, but attempts to account for the intensity and spectrum of the noise in terms of either stellar or interstellar origins have not met with complete success. In 1946 Hey, Parsons, and Phillips(2) found that the noise from the constellation of Cygnus showed short-period variations suggesting that some of the noise from this region was localized in one or several discrete sources. The present writers(3), using an interference technique, showed that these variations originate in an intense discrete source of less than 8′ angular width. Later, in a survey over a limited region of the sky, a number of other discrete sources were found(4). They were designated by the number and year of discovery and by a constellation where a rough position could be estimated. Ryle and Smith(5) have since reported the existence of a further intense source in Cassiopeia as well as a number of smaller sources. They also showed that the radiation from the Cygnus source was unpolarized, making it unlikely that the mechanism of the source is similar to that responsible for enhanced solar radio-frequency radiation.

The subject of the present investigation, the source Taurus–A, was first seen on November 6, 1947, during a search for such objects in the Orion region. The technique employed was to observe a fairly extensive region rising above the horizon with an aerial system situated on a high cliff overlooking the sea. The presence of a discrete source was indicated by a lobe pattern formed by interference between the direct ray and the ray reflected from the sea. In Figure 1A, the record obtained on this occasion, the beginning of the lobe pattern of the suspected source is marked by an arrow. The uneven distribution of the general noise of this region passing through the aerial beam produces a varying base level

* Division of Radiophysics, C.S.I.R.O.

on which the pattern is superimposed. A further series of records obtained in February 1948 showed marked variations on some of the lobes. As the variations always occurred in the same place it was apparent that a second source (8·48) was rising at about the same time as the main source and causing a modulation of the basic lobe pattern. This is illustrated in Figure 1B.

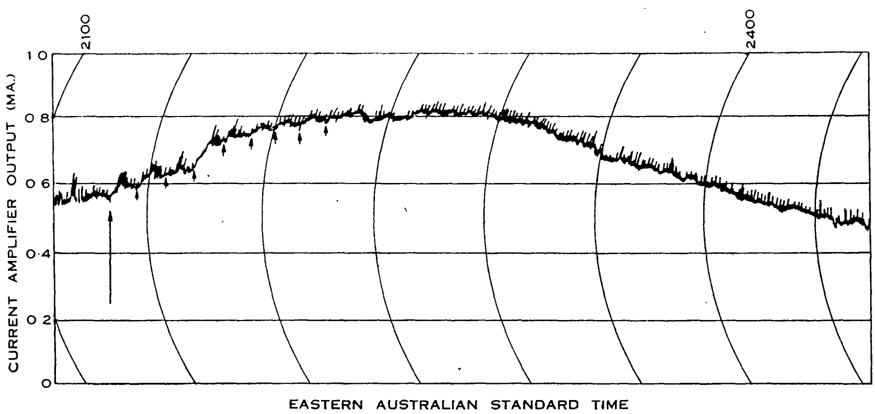

Fig. 1A.—Source Taurus–A as seen from Dover Heights, Sydney, November 6, 1947. Frequency 100 Mc/s. Times, Eastern Australian Standard. Rising point and probable minima are indicated by arrows. Vertical lines on record are due to pick-up from timing mechanism.

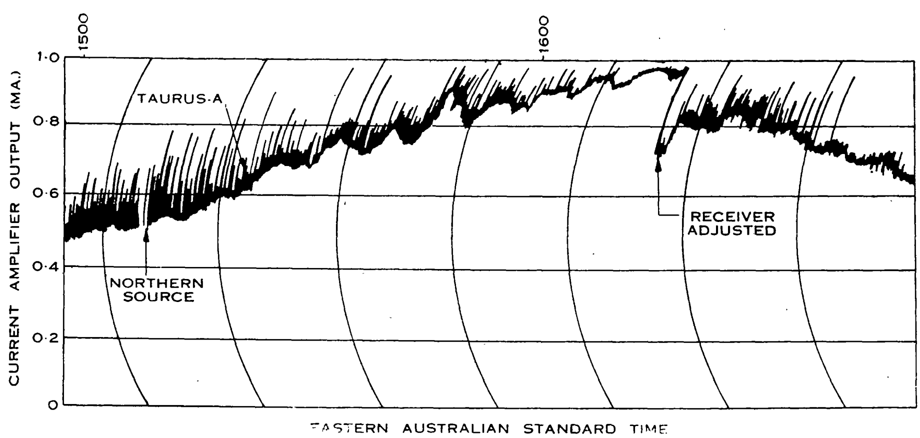

Fig. 1B.—Sources Taurus–A and (8·48) as seen from Dover Heights, Sydney, February 5, 1948. Frequency 100 Mc/s. Times, Eastern Australian Standard. Vertical lines in trace are due to distant atmospherics.

Between June and August 1948 a series of observations was made in New Zealand to determine the exact position of Taurus–A. The sites chosen were Pakiri Hill, near Leigh (on the east coast of the North Auckland peninsula) and a cliff overlooking Piha (on the west coast). Details of sites and equipment used in all observations are given in Table 1. The narrower beamwidth of the aerial system used in New Zealand made it possible to resolve the northern source from Taurus–A. Figure 2 is a record taken at Leigh of the source (8·48) and then Taurus–A rising. It can be seen that after the first four lobes of the Taurus–A

TABLE 1

SITES AND EQUIPMENT USED IN OBSERVATIONS

Site	Dover Heights, Sydney	Leigh, N.Z.	Piha, N.Z.
Latitude	33° 53′	36° 16′ 25″	36° 58′ 10″
Longitude	151° 17′	174° 46′ 25″	174° 27′ 52″
Height above mean sea-level	260 ft.	916 ft.	870 ft.
Frequency	100 Mc/s.	100 Mc/s.	100 Mc/s.
Bandwidth	1·2 Mc/s.	50 kc/s.	50 kc/s.
Noise factor	Nov. 1947—6·0 Feb. 1948—3·7	2·25	2·25
Aerial system	1 Yagi	2 Yagis λ apart in horizontal plane	
Horizontal beamwidth ..	30°	12°	12°
Vertical beamwidth ..	30°	30°	30°
Post detector amplification factor	10	60	20

pattern a modulation effect again occurs, indicating a third discrete source in this small region of the sky. This modulation, in addition to affecting the amplitude of the pattern, displaces the interference minima to a small degree.

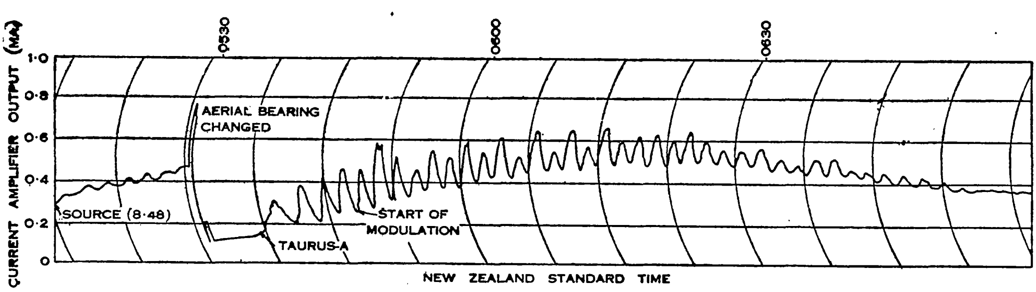

Fig. 2.—Record of sources (8·48) and Taurus–A obtained at Leigh, New Zealand, July 13, 1948. Frequency 100 Mc/s. Times, New Zealand Standard. Note modulation of the Taurus–A interference pattern caused by the third source in this region.

Interference patterns of Taurus–A setting were obtained at Piha but no modulation effect was observed. Owing to solar activity and local interference it was not possible to observe the setting of the two smaller sources.

II. AN UPPER LIMIT OF ANGULAR WIDTH

From the interference patterns it is possible to place a limit on the size of the source in terms of an "equivalent radiating strip". The full theory of this measurement has been described elsewhere(3, 6). Briefly, however, if R is the ratio of the heights of the minima and maxima above the extrapolated cosmic drift level, the width of the equivalent radiating strip W is given by

$$W=\frac{\lambda}{\pi h}\sqrt{3R},$$

where λ=wavelength,

h=height of aerial above sea-level.

In practice, receiver instability and non-linear drift curves place a limit on the resolving power of this method. With the pattern obtained at Leigh of Taurus–A rising, there are two further difficulties: firstly, the modulation effect occurring after the first ten minutes of the lobe pattern, and secondly, "imperfect" minima due to a sea reflection coefficient of less than unity at apparent angles below 1°. This virtually reduced the number of lobes available for the estimate of R to one—the third. From a number of records the mean value of R was less than 0·1, which gives an equivalent radiating strip of less than 6′. From the lobe patterns of the source taken at its setting, a slightly higher upper limit was obtained because recording conditions were unfavourable during daylight. It should be pointed out that measurements made at both setting and rising place an upper limit in the same direction, approximately along the parallel of declination. Further observation will be necessary to ascertain whether this limit has circular symmetry.

III. Determination of Position

The method used to determine the position of the source involved estimating its time of rising at one site and its time of setting at the other. From these times was determined the semi-diurnal arc, which in conjunction with the mean latitude of the two observing sites gave an approximate declination. The Right Ascension was derived from the computed time of culmination on the mean longitude of the two sites. Small corrections were then applied to correct the effect of using a mean value for latitude. The procedure adopted to find the necessary rising and setting times is described in subsequent paragraphs, and calculations for the position of the source may be found in the Appendices.

Each minimum on the records of the source rising or setting represents the time at which the source was at an apparent elevation above the horizon. Above 2° the relation between the angle of elevation (α), the number of the particular minima (n), the wavelength used (λ), and the height of the aerial system above mean sea-level (h) is

$$2h \sin \alpha=n\lambda.$$

Corrections for the effect of earth's curvature(6) are necessary below 2°. The apparent elevations for successive lobes are set out in Tables 2 and 3 together with corrections for atmospheric refraction and derived "true" elevations. Tidal variations which were less than 0·4 per cent. of the heights of the observing sites were neglected and a mean value for the height above sea-level was used.

The times of occurrence of minima on individual days were reduced to a key date for each series by addition or subtraction of the solar-sidereal time correction of 3′ 56″ per day. These times are also presented in Tables 2 and 3.

Apparent tracks, i.e. plots of elevation against time, were then constructed and are shown in Figure 3 as the right-hand curves of the two series. In the

TABLE 2

TIMES AND ELEVATIONS CORRESPONDING TO MINIMA OF FIVE RECORDS OF TAURUS-A RISING AT LEIGH. KEY DATE JULY 15, 1948. VALUES NOT USED ARE SHOWN IN ITALICS. TIMES ARE EXPRESSED IN MINUTES AND FIFTEENTHS OF A MINUTE, NEW ZEALAND STANDARD TIME

Lobe No.	Times of Minima					Apparent Elevation	Refraction Correction	"True" Elevation (First Approximation)
	July 11	July 12	July 15	July 16	July 18			
	05	05	05	05	05			
0	25/9	23/10	24/7	23/5	25/0	—32′	—	—
1	28/12	28/7	28/2	27/5	28/7	+11′	—51′	—40′
2	31/7	31/7	30/9	30/6	31/3	34′	—44′	—10′
3	33/5	33/8	32/13	32/12	33/8	52′	—39·5′	+12·5′
4	35/9	35/10	35/1	35/4	35/9	1° 11·5′	—35·5′	36′
5	37/13	37/8	36/14	37/5	37/4	1° 31′	—31·5′	59·5′
6	40/3	39/11	*39/1*	39/11	39/10	1° 50·5′	—28·5′	1° 22′
7	42/2	41/9	*41/0*	41/12	41/8	2° 10·5′	—26′	1° 44·5′
8	43/8	43/9	*42/13*	43/13	43/8	2° 29′	—24′	2° 05′
9	45/5	45/8	*44/10*	45/11	45/7	2° 47·5′	—22′	2° 27·5′
10	47/0	47/5	*46/7*	47/6	47/3	3° 06·5′	—20·5′	2° 46′
11	49/5	49/3	*48/9*	49/7	49/4	3° 24′	—19′	3° 05′
12	51/3	51/1	*50/3*	51/3	51/0	3° 43·5′	—17·5′	3° 26′
13	53/1	53/0	*52/9*	53/6	53/2	4° 01′	—16·5′	3° 44·5′
14	55/1	54/13	*53/13*	53/13	54/13	4° 20′	—15·5′	4° 04·5′
15	56/14	56/14	*56/2*	56/12	56/10	4° 38·5′	—14·5′	4° 24′
	06	06		06	06			
17	00/13	00/10	*59/2*	00/11	00/7	5° 16′	—13′	5° 03′
			06					
20	06/3	06/00	*05/10*	06/3	06/1	6° 12·5′	—11′	6° 01·5′
22	10/2	10/3	*09/8*	10/5	09/13	6° 49′	—10′	6° 39′
25	15/10	15/0	15/7	16/1	15/10	7° 44′	—9′	7° 35′
27	19/1	19/9	19/4	19/12	19/6	8° 21·5′	—8·5′	8° 13′
30		25/0	24/13	25/2	25/6	9° 18·5′	—8′	9° 10·5′
32		29/9	28/13	29/7	29/6	9° 50′	—7·5′	9° 42·5′
35		34/10	34/10	34/2	34/5	10° 53·5′	—7′	10° 46·5′
37		39/4	39/0	39/9	39/4	11° 32′	—6·5′	11° 25·5′
40			44/12	43/13	45/9	12° 28·5′	—6′	12° 22·5′

track of the source at its rising, individual points at each elevation are plotted to illustrate the scatter of the results, but only mean points are plotted for the setting track.

As a first approximation in deriving the true elevations, refraction corrections calculated from the Pearcey formula(6) and based on a mean value for the modified refractive index were applied. The resultant corrected tracks are plotted as the second continuous lines in the two series of Figure 3. From the times at which these corrected tracks cut the abscissa for zero elevation an approximate declination of the source was computed. This approximate value was used to construct theoretical rising and setting tracks for the two sites. These are shown as the dotted curves in Figure 3, plotted in positions convenient for comparison with the "corrected" curves (i.e. slightly displaced). The actual shape of these curves would vary by a negligible amount if the approximate

TABLE 3

TIMES AND ELEVATIONS CORRESPONDING TO MINIMA OF FOUR RECORDS OF TAURUS-A SETTING AT PIHA. KEY DATE AUGUST 4, 1948. VALUES NOT USED ARE SHOWN IN ITALICS. TIMES ARE EXPRESSED IN MINUTES AND FIFTEENTHS OF A MINUTE, NEW ZEALAND STANDARD TIME

Lobe No.	Time of Minima				Apparent Elevation	Refraction Correction	"True" Elevation (First Approximation)
	Aug. 4	Aug. 2	Aug. 3	July 31			
	14	14	14	14			
0	02/3	02/8	*00/1*	01/11	—30′	—	—
	13	13	13	13			
1	57/0	*58/0*	55/8	54/11	+11′	—51′	—40′
2	54/0	*55/5*	51/9	51/11	33′	—44′	—11′
3	51/7	*53/0*	50/1	49/9	53′	—40′	+13′
4	49/3	*50/9*	48/1	47/11	1° 14′	—35′	39′
5	46/10	*47/8*	45/14	45/7	1° 35′	—31′	1° 04′
6	44/14	*45/1*	43/9	43/11	1° 55′	—28′	1° 27′
7	*43/1*	*42/11*	41/13	41/10	2° 16′	—25′	1° 51′
8	*41/2*	*41/0*	39/13	39/11	2° 35′	—22·5′	2° 12·5′
9	*39/6*	*38/12*	38/1	37/12	2° 55′	—21′	2° 34′
10	*37/7*	*37/2*	35/10	35/10	3° 14′	—20′	2° 53′
11	*35/12*	34/9	33/8	33/14	3° 34′	—19′	3° 15′
12	*33/13*	32/11	31/8	32/0	3° 54′	—17·5′	3° 36·5′
13	*31/14*	30/12	29/8		4° 15′	—16′	3° 59′
14	*30/0*	28/13	27/7		4° 32′	—15′	4° 17′
15		26/9	25/10		4° 51′	—14′	4° 37′
17			21/8		5° 30′	—12·5′	5° 18′
20	16/0		15/7		6° 28′	—10·5′	6° 18′
22			11/9		7° 8′	—10′	6° 58′
25	06/7		06/1		8° 05′	—8′	7° 57′

rising and setting times were in error by as much as one minute, which is unlikely. It will be seen that the theoretical and corrected tracks are closely parallel for relatively high elevations but there is some divergence between them below about 4°, particularly with the rising tracks. It is unlikely that there are serious errors in the corrected tracks at higher angles where the refraction corrections are small. The difference between the theoretical and corrected tracks at high angles was used to adjust the previous values of rising and setting times. The final estimates of these times are shown as the centre of the two blocks on the time axis of Figure 3. The length of the blocks represents the mean scatter of readings and was used in determining the limits in position of the source.

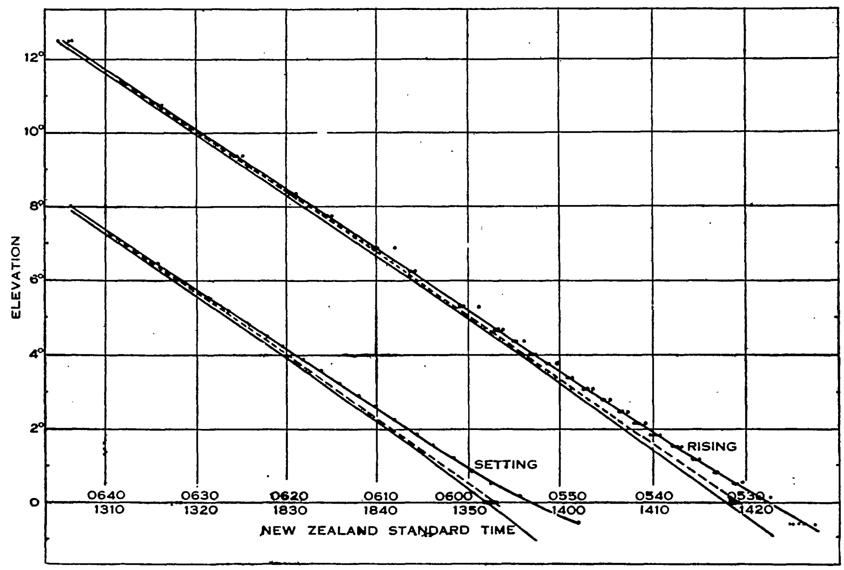

Fig. 3.—Time-elevation curves for the source Taurus–A rising at Leigh (at right) and setting at Piha. From right to left in the two sets the curves are (1) apparent, (2) theoretical, and (3) corrected for refraction following the Pearcey formula. Time runs from right to left for the rising series and left to right for the setting series.

The position of the source Taurus–A as found by this method is:

Right Ascension	5 hr. 31 min. 20 sec.	±30 sec.
Declination	22° 02′	± 8′

IV. Identification of the Source

The limits in the position of the source enclose NGC 1952, otherwise known as the Crab nebula. According to Baade(7) this nebula is the remains of the supernova of A.D. 1054 observed by Chinese astronomers. The angular dimensions of the nebula are 4′ by 6′ and the angular rate of expansion 0·13″ per year. Doppler shift measurements show an expansion velocity of 1300 km./sec. which with the angular rate gives a distance of 4200 light years.

The colour temperature of the supposed central star is between 7000 and 8000 °K. but a number of factors show that the actual temperature must be much higher:

(1) The continuous emission spectrum of the photosphere.

(2) A much greater colour gradient towards the red end of the spectrum than can be explained by interstellar reddening at the known distance of the nebula.

(3) The total light from the nebula is some seven magnitudes (×600) greater than that from the central star.

Minkowski(8) considers that most of the radiation from the central star is in the ultraviolet region and the continuous emission from the photosphere is due to bound-free transitions. He estimates a surface temperature of 500,000 °K. and suggests 50,000 °K. for the nebulosity. He explains a low ratio of H_α to [NII] emission by assuming a deficiency of hydrogen in the nebula. This ratio, however, could also be explained by a much higher temperature, which in turn would result in a greater electron density.

The measurements on 100 Mc/s. give an effective temperature of two million degrees, assuming a source size of 5′ for Taurus–A. From the present values of temperature and density in the Crab nebula it would be difficult to explain this result in terms of strictly thermal processes. However, it is not unlikely that non-thermal components would arise from differential expansion within the nebula and the general expansion into interstellar matter. In view of this and the close agreement between the positions of the Crab nebula and the source Taurus–A, it is suggested that the Crab nebula is a strong source of radio-frequency radiation.

The regions of the other two supernovae of recent years (Tycho's and Kepler's) have been investigated without result, but there is no visible remnant of the former and very little of the latter.

V. Acknowledgment

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VI. References

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Appendix I

Calculation of Approximate Declination

	Hr.	Min.	Sec.	
Approximate time of rising at Leigh, July 15, 1948 (N.Z.S.T.)	05	32	—	(*A*)
Approximate time of setting at Piha, August 4, 1948 (N.Z.S.T.)	13	52	—	(*B*)
Sidereal correction for 20 days	01	18	38	(*C*)
Time equivalent of difference in longitudes of two sites		01	14	(*D*)
Twice semi-diurnal arc for mean latitude in solar time ($B+C-A-D$)	09	37	24	(*E*)

	Hr.	Min.	Sec.	
Solar-sidereal conversion factor		1	36	(*F*)
Semi-diurnal arc for mean latitude $[\frac{1}{2}(E+F)]$	04	49	30	
Equivalent hour angle (θ)		72	23	
Latitude of site at Leigh	36°	16′	25″	
Latitude of site at Piha	36°	58′	10″	
Mean latitude (*l*)	36°	37′	18″	

If δ is the declination,

$$\tan \delta = \cos \theta / \tan l$$
$$= \cos 72° 23' / \tan 36° 37'$$
$$\delta \approx 22°.$$

Appendix II

Right Ascension and Declination using Mean Latitude and Longitude

The final estimated times of rising and setting of the source are:

	Hr.	Min.	Sec.	
At Leigh, rising time July 15, 1948 (N.Z.S.T.)	05	21	20±20	
At Piha, setting time August 4, 1948 (N.Z.S.T.)	13	52	20±40	
Reducing times to July 15				
Rising time, Leigh	05	31	20±20	(*G*)
Setting time, Piha	15	10	58±40	(*H*)
Longitude correction	00	01	14	(*J*)
Twice semi-diurnal arc in solar time (*H*—*G*—*J*)	09	38	24±60	(*K*)
Solar-sidereal time conversion factor	00	01	36	(*L*)
Semi-diurnal arc for mean latitude $[\frac{1}{2}(K+L)]$	04	50	00±30	
Equivalent hour angle (θ) ..	72°	30′	±7′	
Mean latitude (*l*)	36°	37′	18″	
Declination of source (δ)	22°	02′	±8′	

From (*G*) and (*H*) the time of culmination on the mean longitude is 10 hr. 21 min. 09 sec.±30 sec. for July 15, 1948 (N.Z.S.T.)

Longitude of site at Leigh	174°	46′	25″	
Longitude of site at Piha	174°	27′	52″	
Mean longitude	174°	37′	09″	
Time equivalent of mean longitude	11 hr.	38 min.	29 sec.	
Time of culmination July 15, 1948 (N.Z.S.T.)	10 hr.	21 min.	09 sec.±30	(*M*)
Equivalent G.M.T. July 14	22	21	09	(*N*)
Previous transit of Aries (G.M.T.) ..	04	32	11	(*P*)
Difference in solar time (*N*—*P*) ..	17	48	58	(*Q*)
Solar sidereal conversion factor	00	02	58	(*R*)
Right Ascension on Greenwich meridian when source culminates on mean longitude (*Q*+*R*)	17	51	56	(*S*)
Time equivalent of mean longitude ..	11	38	29	(*T*)
Right Ascension of source (*S*+*T*) ..	05	30	25±30	

Appendix III

Corrections for Using Mean Latitude

	Hr.	Min.	Sec.	
Semi-diurnal arc used	04	50	00	
Semi-diurnal arc for Declination 22° 02′ and latitude of site at Leigh ..	04	50	56	(X)
Semi-diurnal arc for Declination 22° 02′ and latitude of site at Piha	04	49	06	(Y)
Semi-sum of (X) and (Y)	04	50	01	
Semi-difference of (X) and (Y)	00	00	55	

Thus the use of a mean latitude involves a negligible correction for the source's Declination but 55 seconds must be added to the value for the Right Ascension.

Final Position

Right Ascension .. .. .. 05 hr. 31 min. 20 sec. ±30 sec.

Declination .. .. 22° 02′ ± 8′