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In place of a semi-annual progress report covering all aspects of the work carried out under this grant, we are submitting preprints of two papers concerning two facets of our work. They are entitled "The Maximum Resolution of a Radio Telescope" by W. C. Erickson, and "A Southern Milky Way Survey at 408 Mc/s" by M. M. Komesaroff.

These papers have been submitted for publication in "Radioscience" and in the "Australian Journal of Physics", respectively.

A formal report covering all aspects of our work under this grant will be submitted at the end of the grant year.

THE MAXIMUM RESOLUTION OF A RADIO TELESCOPE

by:

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As radio astronomers plan instruments of ever increasing resolution they are, in some cases, approaching the maximum possible resolution imposed by coronal scattering from the vicinity of the earth's orbit. Coronal scattering has been studied since 1952 and the results have been recently summarized by Hewish and Wyndham (1963), and Erickson (1964). Coronal scattering is multiple small angle scattering which spreads originally parallel rays into a gaussian distribution of angles given by $\exp\left(-\frac{\theta^2}{\varphi_0^2}\right)$. Thus, the details of a brightness distribution whose angular width is smaller than φ_0 should be eradicated.

Previous observations of this scattering have been made beyond 50 $R_\odot$ (Slee, 1961). Interplanetary scintillations which are another manifestation of this phenomena have been observed to about 180 $R_\odot$ (Hewish, Scott, Wills, 1964). All evidence indicates that there is no sharp transition in the corona near the earth's orbit (215 $R_\odot$), and so we may expect the scattering to continue well beyond the orbit of the earth.

It has also been shown that the scattering scales accurately as λ^2 for $2\ m < \lambda < 12\ m$ (Hewish, 1955; Erickson, 1964). Until the frequency approaches the local plasma frequency in the vicinity of the earth's orbit ($\lambda_0 \sim 10^5$ m) we should expect that the scattering will continue to scale proportional to λ^2. The only other parameter which might affect the scaling is the average dimension of the coronal irregularities. This dimension is estimated to be at least 5×10^4 m at 90 $R_\odot$ (Hewish and Wyndham, 1963). The irregularities should be at least a factor of two larger at 215 $R_\odot$. Therefore, scaling the scattering to a wavelength of at least 1000 m should yield reliable results.

The previous results are all reasonably compatible with the formula (Erickson, 1964):

$$\varphi_0 = 50 \frac{\lambda^2}{R^2}$$

where φ_0 is in minutes of arc, λ is the wavelength in meters, and R is the minimum distance of the ray path from the sun in $R_\odot$. This formula neglects the fact that the scattering is anisotropic by a factor of about two, and that the scattering apparently varies with solar activity by a similar factor. The scattering is believed to be caused by a magnetically aligned filamentary irregularities, and we should also expect to observe somewhat greater scattering when making observations nearly parallel to the coronal magnetic field. The scattering may also be a factor of two less when making observations in directions away from the ecliptic plane (Slee, 1961).

With these qualifications, the formula given above should yield a reasonable estimate of the scattering along ray paths within 90° of the earth-sun line. For observations perpendicular to this line one can easily show that

$$\varphi_0 \text{ (Quadrature)} \cong 25 \frac{\lambda^2}{(215)^2}$$

and for observations in the anti-solar direction

$$\varphi_0 \text{ (Opposition)} \cong 12.5 \frac{\lambda^2}{(215)^2}$$

The following table summarizes the order of magnitude of these effects:

λ	φ_0 (Opposition)	Maximum Usable Aperture
3 m	0".14	4300 km
10 m	1".6	1300 km
30 m	14".	430 km
100 m	2'.7	130 km
300 m	24'.	43 km
1000 m	4°.5	13 km

This table gives a reasonably optimistic estimate of the resolution obtainable in the anti-solar direction. For observations in other directions or near solar maximum we might expect 2 to 10 times this amount of scattering.

From the above table it is obvious that coronal scattering opposes no practical limit on the resolution obtainable at meter and decimeter wavelengths. However, this scattering will severely limit the resolution obtainable at long wavelengths from space vehicles above the ionosphere.

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A SOUTHERN MILKY WAY SURVEY AT 408 MC/S

M. M. Komssaroff

ABSTRACT

A survey of the galactic plane emission at 408 Mc/s. has been carried out between $l^{II} = 280^{\circ}$ and 355°, using the C.S.I.R.O. 210 ft. telescope which has a beamwidth of 47.5' arc at this frequency.

It is found that an abrupt increase in the emission which occurs near $l^{II} = 326^{\circ}$ and extends over several degrees of latitude, has a non-thermal spectrum. An estimate of the total radiated power is made, and it is suggested that this feature may be related to the expanding arm of neutral hydrogen whose existence has beem demonstrated by H-line studies.

A SOUTHERN MILKY WAY SURVEY AT 408 Mc/s.

I INTRODUCTION

Before 1962, only two surveys with pencil beam resolution better than 1° had been made of the galactic plane radio emission in the region south of the centre. These were the 85 Mc/s. and 1440 Mc/s. surveys of Hill, Slee and Mills (1958) and Mathewson, Healey and Rome (1962), repectively. By contrast, the region north of the centre had been studied at 85 Mc/s. (Hill, Slee and Mills (1958)), 408 Mc/s. (Large, Mathewson and Haslam (1961)) 960 Mc/s. (Wilson and Bolton (1960)), 1390 Mc/s. (Westerhout (1958)) and 2700 Mc/s. and (Altenhoff, Mezger, Wendker and Westerhout (1960).

It was desirable to have at least one survey of the southern region at an intermediate frequency, both to provide additional spectral data about the discrete sources, and to test the conclusions drawn by Mathewson, Healey and Rome (1962) about the large-scale distribution of the thermal and non-thermal radiation components.

The present observations at 408 Mc/s. were made with the 210 ft. telescope of the Australian National Radio Astronomy Observatory, which at this frequency has a beamwidth of about 48' arc, very similar to the resolution of the earlier surveys. The 408 Mc/s. studies were carried out simultaneously with higher resolution (14' of arc) observations at 1390 Mc/s., Hill (1965). The area covered extends approximately between $b^{II} = \pm 6^{\circ}$ and $l^{II} = 282^{\circ} - 356^{\circ}$.

The present data generally confirm the spectral classification of discrete sources previously made by Mathewson et. al. (1962) though in one or two cases there is evidence of spectral curvature which warrants further investigation.

An interesting result concerns a "step" in the brightness temperature contours near $l^{II} = 326^{\circ}$. The 408 Mc/s. observations show that this contains two components. The first, which was discovered by Mathewson et. al. has a width in latitude of only $1^{\circ} - 2^{\circ}$. and a thermal spectrum. Its longitude is symmetrical with that of a similar thermal "step" north of the galactic centre, first described by Westerhout, (1958) and attributed by him to a ring or disk of ionized hydrogen concentric with the Galaxy.

The second component, which occurs at the same longitude, has a non-thermal spectrum and extends over at least about $\pm 5^{\circ}$ in latitude. The coincidence in longitude and the fact that the non-thermal step represents more than 20% of the total galactic brightness suggests that it ~~too~~ is a large-scale galactic feature. An examination of radio surveys north of the galactic centre indicates that the step at the symmetrical longitude also contains a non-thermal component, although a considerably weaker one.

It is shown that the whole feature may be explained as synchrotron emission from a thin ring containing an approximately tangential magnetic field which is concentric with the galaxy. Section VII of this paper discusses a possible connection with the expanding arm of neutral hydrogen discovered by Rougoor and Oort (1960). It is shown that the power outflows from the two features are of comparable magnitude, and this suggests that they may draw their energy from a common source.

II EQUIPMENT

The observations extended over three periods of one to two weeks in 1962. The receiver, previously described by Mackey, (1964) was a double-sideband crystal mixer with a bandwith of 8 Mc/s., and was electronically switched between the feed dipoles and a low temperature reference load. The feeds consisted of a pair of parallel dipoles and reflector. The aerial beamwidth to half power was measured as 47.5 arc.

III OBSERVING PRODEDURE AND DATA REDUCTION

Because the survey was strongly resolution-limited and in order to minimize non-linearity effects due to the wide range of aerial temperatures, the receiver sensitivity was reduced, the minimum detectable flux being between 5×10^{-26} and 10×10^{-26} $Wm^{-2}(c/s)^{-1}$.

The observing procedure was determined by the 1390 Mc/s. survey. Declination scans between $b = \pm 6^{\circ}$ were made using a telescope drive rate of 2.5°/ min., the right ascension interval between scans being 1/4 to 1/3 of the 1390 Mc/s. beamwidth (14' arc). This produced a considerable redundancy at 408 Mc/s. An example of such a scan, at R.A. = $14^{h}\ 42^{m}\ 00^{s}$, is shown in fig. 1. The markers appearing on this record are at declination intervals of 10' arc.

Hydra A was adopted as a standard of flux density. Its 408 Mc/s. flux density was taken to be 137×10^{-26} $Wm^{-2}(c/s)^{-1}$(Kellermann 1964). The increment of "full beam brightness temperature" (see Seeger, Westerhout and Vander Hulst (1956)) corresponding to Hydra A is 124° K.

All temperatures were measured relative to the South Celestial Pole To this end two procedures were adopted.

1). Two series of long scans were made through the region to be surveyed, one north and one south of the galactic equator and a few degrees away from it where the gradients are small.

.). Immediately before and after each scan the aerial was pointed at the South Celestial Pole to establish the baseline.

2). The aerial was also pointed at the Pole a number of times during each nights observations.

Taken in conjunction with measured zenith angle effects derived from scans at a number of azimuths, (1) and (2) independently provided "base lines" for the survey scans. In general these agreed to better than half a contour interval.

In constructing the isophotes the contour interval chosen was 25° K aerial temperature, as determined from noise lamp calibrations. This is equivalent to 34.7°K "full beam brightness temperature."

For each night's observations a scale was constructed consisting of parallel lines drawn on transparent paper, the spacing being equal to the deflection corresponding to one contour interval, with allowance made for receiver non-linearities. The scale was laid over the record of each scan in turn, and the declination was noted of each contour level as measured above the previously-determined base line. These declinations were corrected for the two-second receiver time constant and the scanning rate of 2.5°/min. The right ascensions and corrected declinations were then converted, using an I.B.M. 7090 computer, to New Galactic Coordinates, and from the resultant data the isophotes were drawn. These are shown in Fig. 2.

IV: THE DISCRETE SOURCES

a) THE SOURCE LIST

Table I lists the 49 sources which were observed; of these 39 have been catalogued by previous observers. A source was considered to exist if a deflection appeared on at least two adjacent scans with a half power width not greater than 2 aerial beamwidths. It is believed that for the majority of sources the quoted positions are accurate to within $\pm$ 6' arc in each coordinate. Confusion was the major source of position error.

Angular sizes were not estimated, since resolution effects and residual receiver non-linearities could make such estimates quite misleading. Thus the figures quoted in column 6 are "peak" flux densities designated by S'408 (in $10^{-26} Wm^{-2}(c/s)^{-1}$). and represent lower limits to the true flux densities.

Columns 7 and 8 also contain "peak" flux densities for 85 Mc/s. and 1440 Mc/s. The 85 Mc/s. data are quoted directly from the Mills Slee and Hill (1958, 1960, 1961). catalogue, while the 1440 Mc/s. data are derived by multiplying the valued of ΔT_{1440} to Mathewson Healy and Rome (1962) by 15.3.

In calculating the spectral indices α_{85}^{408} and α_{408}^{1440} (columns 9 and 10) the quoted values of S'_{85} and S'_{408} have been divided by 1.2 and 1.1 respectively in order to bring the flux scales at 85 and 1440 Mc/s. into agreement with that of Conway Kellerman and Long (1963). This was done for the sake of uniformity, since the 408 Mc/s. scale was based on C.K.L.

Columns 11, 12 and 13 of Table I. contain source catalogue numbers used by Mills, Slee and Hill, Mathewson, Healey, and Rome, and Wilson and Bolton (1960).

The sources are classed as thermal or non-thermal in column 14, according to their spectral indices, and column 15 repeats identifications previously made by Mathewson Healey and Rome and in the case of source 26, by Mills Slee and Hill. The abbreviations used in Column 15 are:

RCW - Rodgers Campbell and Whiteoak (1960)

G - GUM (1955)

BBW - Bok, Bester and Wade (1955)

NGC - New General Catalogue (Dreyer 1953)

b) ACCURACY OF FLUX DENSITIES AND SPECTRAL INDICIES

The accuracy with which the value of S'_{408} could be estimated was limited mainly by base line uncertainties. For the majority of cases where S'_{408} exceeds 30 flux units it is believed that the error in the quoted value does not exceed about ± 20%. However, sources 1,7, 8, 18, 22, 24, 28, 31, 38 and 39 are situated in highly confused regions and for these the errors may be greater. Assuming that the errors in the other surveys also do not usually exceed ± 20%, the values of α^{408}_{85} and α^{1440}_{408} for the "strong" sources (except those mentioned) are not in error by more than about ± 0.25.

c) SPECTRAL CURVATURE

The only sources therefore, which show an apparently significant and "anomalous" spectral curvature are 4 and 46. The "background level" for 4 is fairly indefinite and may have led to an unexpectedly large error. However, this does not seem to be so in the case of 46, which is quite strong at all three frequencies, but a more careful investigation is required to determine if the spectral curvature is genuine. An exceedingly dense foreground HII region would be required if the effect is due to thermal absorption.

Two other interesting sources are 38 and 39. In neither case is the 408 Mc/s. flux density estimate considered very reliable, but since 38 does not appear at 85 Mc/s., it has been classified as thermal. However, it is the only thermal source of such high flux density not identified with an optical object (unless it is part of R.C.W. 108, whose position, however, is given as $l^{II} = 336.5$, $b^{II} = -1.3$.)

Mathewson et.al. have commented on 39, which, although it seems to have a thermal spectrum, (between 1440 and 85 Mc/s.) is seen in emission at 85 Mc/s. against a background temperature greater than 13,000° K. If it is an HII region with electron temperature of 10^4 °K, and if the non-thermal emissivity of the galaxy is roughly uniformly distributed along the line of sight, the distance of the source must be at least about 4 kpc. In that cse, according to the argument used by Komesaroff and Westerhout (1964), its flux is exceedingly large ----- moretthan ten times greater than that from an HII region excited by an O5 star.

d) THE DISTRIBUTION WITH GALACTIC LATITUDE

(i) THE THERMAL SOURCES:

Fig.3(a) shows the number of sources classified as thermal in Table I. which lie in each half degree interval of b^{II}. The shaded part of the histogram is for $l^{II} > 298°$. For these longitudes the source number density is seen to have a sharply peaked distirubtion, falling by a factor of about 2 within $\frac{1}{4}°$ of the plane.

Taking into account that confusion probably prevents our "seeing" sources beyond a few kpc., this means that the majority of those thermal sources lie within less than 50 pc. of the plane.

For $l^{II} < 298^{\circ}$, (unshaded part of histogram) the thermal sources are generally very intense and all lie south of the plane. Most of them evidently form part of a "local" feature.

(ii) THE NON-THERMAL SOURCES:

Fig.3(b) is a similar histogram for the sources classified as non-thermal. In this case the shaded part of the histogram represents sources with 408 Mc/s. flux densities greater than 20×10^{-26} Wm^{-2} $(c/s)^{-1}$. This separation has been made because the survey of Bolton, Gardner and Mackey (1964) has shown that in high galactic latitudes, where presumably almost all sources are extra galactic, the number density corresponding to flux densities less than this limit and greater than 5 f.u. is about 0.03. per square degree. We, therefore, expect 20 to 30 extra-galactic sources of between 5 and 20 f.u. within the 900 square degrees of our survey.

Because of the smaller number of sources, the interval of latitude is 1° for fig. 3 (b) as compared with $\frac{1}{2}^{\circ}$ for fig. 3 (a). Nevertheless, it is clear on comparing the two figures that the non-thermal sources are more widely dispersed in latitude than the thermal. The non-thermal continuum distribution is similarly broader than the thermal, though of course both continuum distributions are very much broader than either source distribution. Large et.al. (1961) have obtained the same result for the region north of the galactic centre.

V THE " CONTINUUM" RADIATION

(a) THE NON-THERMAL STEP NEAR $l^{II} = 325^{\circ}$

A striking feature of the 408 Mc/s. isophotes is the abrupt increase of brightness at all latitudes near $l^{II} = 325^{\circ}$. This is the longitude at which Mathewson, Healey and Rome (1962) have noted an increase in the thermal component of galactic radiation, symmetrical in longitude with a similar increase observed by Westerhout (1958) north of the galactic centre. However, Westerhout has shown that the thermal emission extends over only about 1.5° of latitude, whereas the 408 Mc/s. step extends over nearly the full range of latitudes covered by our survey.

A similar feature, also extended in latitude, appears at 85 Mc/s., as shown by the observations of Hill, Slee and Mills (1958). In order to determine its spectral index by comparing the two surveys we need to estimate the brightness temperature corresponding to the zero contour of the 408 Mc/s. survey. This has been done by calculating the "expected" temperatures at 408 Mc/s. from the 85 Mc/s. temperature in latitudes $\pm 4^{\circ}$ on the assumption that the spectral index is -0.6. (Komesaroff (1961)). The calculation has been carried out for every 5° of longitude and the results averaged, yielding a mean "base-line" brightness temperature of $16^{\circ} \pm 3^{\circ}$ K, with, however an apparent variation with longitude, which could be the result of spectral changes. The variation may in places be as large as the mean value (i.e. 16° K), but as the temperatures we will be dealing with in the subsequent argument are generally greater than 100° K, this will not effect the validity of our conclusions.

Table II lists "lower envelope brightness temperatures" on each side of the step near $l^{II} = 325^{\circ}$ for $b^{II} = +2^{\circ}$, 0° and -2°, for both 408 Mc/s. and 85 Mc/s. as well as the temperature ratios; in addition it gives

the incremental ratio $\frac{\Delta T_b(85)}{\Delta T_b(408)}$ corresponding to the step. For $b^{II} = +2^\circ$, 0° and -2°, $\frac{\Delta T_b(85)}{\Delta T_b(408)}$ has the approximate values 40, 29 and 36, corresponding to spectral indices of -0.35, -0.15 and -0.28 respectively. For $b^{II} = \pm 2^\circ$, the spectrum of the step is distinctly non-thermal and represents a 30% to 80% increase over the temperature on the low longitude side. For $b^{II} = 0^\circ$ the spectrum of the step is flatter, because of the accompanying rise in the thermal emission. However, the following argument, which is based mainly on the 85 Mc/s. results, and which makes no assumptions about the essentially unobservable spectral index along the galactic equator shows that for this latitude also, there is a very substantial non-thermal increase near $l^{II} = 325^\circ$.

Westerhout (1958) has shown that for a medium which emits non-thermal radiation and also contains ionized hydrogen, a good approximation to the resulting brightness temperature for the frequencies we are interested in is given by

$$T_b = (10^4 + \frac{T_n}{\tau})(1-e^{-\tau}) \qquad (1)$$

Here T_n is the non-thermal brightness temperature which would be observed in the absence of absorption and τ is the optical depth of the ionized hydrogen, the electron temperature of which is assumed to be 10^4 °K.

It can be shown from equation (1) that if $T_b < 10^4$ °K, then T_n must be less than T_b. Now the Hill, Slee and Mills isophotes show that for $l^{II} < 320^\circ$, T_b (85) is always less than 9000° K except on what are obviously discrete sources. It follows that for these longitudes, the "lower envelope" non-thermal brightness temperature is less than 9000°K.

On the other hand, for $l^{II} \geq 330^\circ$, the value of T_b (85) scarcely falls below 14,000°K and in only one region, extended over less than 0.5° in longitude, does it fall as low as 13,000°K. If we accept 13,000°K as the "lower envelope" value of T_b (85) we can set a lower limit to T_n (85) in this region. To do this we refer to the results of Mathewson, Healy and Rome. These show the value of T_b (1440) does not exceed 17.4°K except on discrete sources. Clearly the thermal component alone of brightness temperature at 1440 Mc/s. must be less than this, and this leads to an upper limit of 0.7 for γ(85). From equation (1) we can then show, using 13,000°K as the "lower envelope" value of T_b(85) that T_n(85) is greater than 11,000°K.

Thus between $l^{II} = 320^\circ$ and 330°, T_n (85) increases from less than 9000°K to more than 11,000°K, or by more than 20%. Assuming a non-thermal spectral index of -0.6, the corresponding increase at 408 Mc/s. is greater than 34° K. The variations of T_b(408) at $b^{II} = +2^\circ$ suggest, however, that this is a very conservative lower limit.

(b) THE STEP NEAR $l^{II} = 34^\circ$

Considering the magnitude of the non-thermal step and its coincidence in longitude with the thermal step, it seems that we are dealing with a large-scale feature of the galaxy. Is there a corresponding feature north of the galactic centre?

Fig. (4) is a composite diagram, using data from the present survey and others, showing the variation of brightness temperature with longitude for the three latitudes we have been discussing and for a number of frequencies. The brightness temperature scale is logarithmic and the heights of the scales for the various frequencies have been adjusted to bring the profiles

into approximate coincidence. For $b^{II} = +2^{\circ}$, 0° and -2°, the adjustments of the 408 Mc/s. scale relative to 85 Mc/s. are equivalent to multiplying the 408 Mc/s. temperature by the factors 49, 48 and 45, corresponding to spectral indices of -0.48, -0.46, -0.42 respectively.

The step near $l^{II} = 325^{\circ}$ is obvious at all three longitudes, but its spectrum is clearly flatter at $b^{II} = 0^{\circ}$ than for $b^{II} = \pm 2^{\circ}$.

Near $l^{II} = 34^{\circ}$ there is also a step in the contours, but for $b^{II} = 0^{\circ}$ this only appears at the higher frequencies. (It was from this high frequency increase that Westerhout deduced the sudden enhancement in the thermal component of emission). On the other hand at $b^{II} = \pm 2^{\circ}$ the step appears at both 408 Mc/s. and 85 Mc/s. and the appearance of the profiles suggests the spectrum of the increase is non-thermal. However, the magnitude of the increase is clearly less than for $l^{II} = 325^{\circ}$ and the picture is slightly complicated by the fact that T_b rises between 35° and 30° then falls very slightly and rises again toward the galactic centre.

Table III lists values of $T_b(408)$ and $T_b(85)$ at $l^{II} = 30^{\circ}$ and 33° derived by interpolating between the isophotes of the Large Mathewson and Haslam and Hill, Slee and Mills surveys. The values of $\frac{\Delta T_b(85)}{\Delta T_b(408)}$ and corresponding values of the spectral index are also given. These indicate that for $b^{II} = \pm 2^{\circ}$ the step has a non-thermal spectrum. It is reasonable to suppose that the non-thermal step extends through $b^{II} = 0^{\circ}$ also, but is masked here by the thermal step.

(c) FORM OF THE NON-THERMAL EMITTING REGION

The symmetry in the longitudes of the steps strongly suggests that the non-thermal emitting region, like the thermal, is radially symmetrical about the galactic centre. If the emission is isotropic and confined to a ~~skin~~ thin cylindrical shell, the resulting brightness temperature should be greatest where the line of sight is tangential to the shell, that is the distribution should be " limb-brightened" If, on the other hand, isotropic emission occurs within a disk-like structure, the brightness temperature will increase smoothly to a maximum near longitude zero. In fact, neither model fits the observed distribution shown in figs. 4(a) and 4(b). Between $l^{II} = 310^\circ$ and 325°, T_b remains substantially constant. At $l^{II} = 325^\circ$, T_b rises abruptly to a maximum and then remains close to that level between $l^{II} = 330^\circ$ and 360°. Beyond 360° the distribution is more complicated and shows some evidence of limb-brightening near $l^{II} = 30^\circ$.

We can, however, fit the observations if we take into account the non-isotropic nature of synchrotron radiation. For the case of a uniform magnetic field and an asembly of emitting electrons having an energy spectral ~~index~~ of γ and an isotropic velocity distribution,

$$I(\theta) \propto \sin^{\frac{1+\gamma}{2}}\theta \qquad -(2)$$

(Westfold, 1959)

Here $I(\theta)$ is the intensity emitted in a direction making an angle θ with the magnetic field. The radio frequency spectral index α is related to γ by

$$\alpha = \frac{1-\gamma}{2} \qquad -(3)$$

Fig. 5 represents a thin cylindrical shell of emission viewed edge-on. The magnetic field is assumed to be everywhere tangential to the shell. For such a model it is easily shown that for an observer at O,

$$T_b \propto \frac{I(\theta)}{\sin\theta}.$$

$$\text{or} \quad T_b \propto (\sin\theta)^{|\alpha|}$$

Fig. 6 shows the variation of brightness temperature with longitude l for a shell whose radius subtends an angle of 35° at the observer. The maximum brightness temperature due to the shell is assumed to be 103°K and the shell is superimposed on a uniform background of 120°K. The full curve was computed for = -0.3 and the dashed curve for = -0.6. The crosses indicate observed value of T_b(408) from the present survey for $b^{II} = +2$ and the squares observed values for $b^{II} = -2°$. Clearly both models predict greater rounding of the shoulder of the curve than is actually observed. Good agreement could be secured if we let $\alpha = 0$, but this conflicts with our previous measurements. Increasing the assumed thickness of the shell would only increase the disagreement.

However, good agreement between prediction and observation would be achieved if we relaxed the assumed condition that the magnetic field is everywhere strictly tangential to the shell. If instead the magnetic field shows randour fluctuations about this preferred direction, the degree of beaming is reduced, and this has a similar effect to reducing the value of $|\alpha|$. Hanbury-Brown and Hazard (1960) have shown that quite small fluctuation have a marked effect on the observed brightness distribution.

One could explain the difference between the region for which $l^{II} < 360^\circ$ and that for which $l^{II} > 360^\circ$ by assuming that beyond $l^{II} = 10^\circ$ the fluctuations in magnetic field direction increase. This would explain the generally lower values of T_b and also the suggestion of "limb brightening" near $l^{II} = 30^\circ$.

VI THE BAND OF POLARIZED RADIATION

Mathewson and Milne (1964) have shown that at 408 Mc/s., more than 90% of the polarized radiation from the galaxy falls within a fairly narrow band approximately perpendicular to the galactic plane. They attribute this effect to the beaming of synchrotron radiation perpendicular to the magnetic field of the local spiral arm.

As the band of polarized emission is approximately 50° wide and intersects the galactic equator near $l^{II} = 350^{\circ}$, one edge of it must coincide with the non-thermal step on the southern side of the galactic centre, and presumably contributes to it. However, there are two indications that the total contribution is small.

First, the observations of Pauliny-Toth and Shakeshaft (1962) at 404 Mc/s., show that in the vicinity of the anti-centre the step in the brightness contours corresponding to the polarized band is only about 10°K, or an order of magnitude less than the step we find near $l^{II} = 325^{\circ}$. at $b^{II} = +2^{\circ}$.

Secondly, the contribution due to the polarized band vanishes near $l^{II} = 15^{\circ}$, but the 408 Mc/s. isophotes of large Mathewson and Haslam (1961) are quite smooth to within less than 2° of the galactic plane near this longitude.

VII A POSSIBLE ENERGY SOURCE FOR THE NON-THERMAL FEATURE

It has been shown that the enhanced non-thermal radiation extends over $\pm 35^\circ$ of longitude. Taking the sun's distance from the galactic centre as 10 kpc, this corresponds to a radius of 5.7 kpc. The 21-cm observations of Oort and Rougoor (1960) have demonstrated an outwardly-expanding ring of neutral hydrogen at a somewhat smaller distance from the centre. One is tempted to speculate that this may be the energy source for the continuum feature.

Table II shows that near $l^{II} = 325^\circ$ and for $b^{II} = \pm 2^\circ$ the 408 Mc/s. non-thermal brightness temperature increase is between 75° K and 100°K. Near $l^{II} = 30^\circ$ and for the same latitudes the increase is smaller but probably between 20°K and 40°K. For $b^{II} = 0^\circ$, the non-thermal component of the increase is more ~~different~~ difficult to estimate, but it has been shown that for $l^{II} \simeq 325^\circ$ this cannot be less than 34°K. Fig. (2) shows that near $l^{II} = 325^\circ$ the step continues out to about $b^{II} = \pm 5^\circ$ with an amplitude of at least about 30°K. The L.M.H. isophotes show that near $l^{II} = 35^\circ$, the step continues out to ~~b = ±5°~~. $b^{II} = \pm 3^\circ$.

Thus we can set a fairly conservative lower limit to the total power radiated by considering a cylindrical surface having a uniform 408 Mc/s. brightness temperature of 30° K, extending over $\pm 35^\circ$ in longitude and $\pm 4^\circ$ in latitude, corresponding to a radius of 5.7 kpc and a width of 1.4 kpc. Assuming that the spectral index is -0.6, the total power radiated between 0 and 10^4 Mc/s. is about 2×10^{30} watts. If the spectrum extends to light wavelengths (say 5000 A°), this must be increased by a factor of about 80.

Now, according to Oort (1963), the total mass of gas streaming out from the galactic centre in one year is equivalent to one solar mass and the velocity is about 50 km/sec. This corresponds to an outward flow of kinetic energy of 2.5×10^{39} joules per year or 8×10^{31} watts., which is only 40 times larger than ~~over~~ our lower limit on the power radiation from the non-thermal "ring".

Thus it seems that an ~~replanation~~ explanation of the non-thermal feature in terms of a conversion of expansion kinetic energy into synchrotron radiation is ruled out, as this would require an exceedingly efficient conversion process. However, the foregoing does suggest that the expanding arm and the continuum feature may draw their energy from a common source.

v In Section V(c) it was shown that the observed characteristics of the continuum feature can be explained as synchrotron radiation from a thin cylindrical shell containing an approximately tangential magnetic field. If now it is assumed that the radiating electrons, like the neutral hydrogen originate in a source near the galactic centre, whence they are limitted radially outward, three effects will occur when they reach the "tangential field" region.

(1) the electrons will begin to gyrate and emit synchrotron radiation.

(2) As a result of the conversion of translational momentum into rotational, the electrons will accumulate at this distance.

(3) The rate of collisional ~~roinization~~ excitation will increase, leading to increased thermal emission.

Thus the main observational features would be qualitatively ~~explained~~ explained. The validity of our assumption that relativistic electrons and neutral hydrogen originate in a common source could perhaps be tested by a detailed comparison of continuum and 21 cm data.

VIII ACKNOWLEDGEMENTS

These observations were made simultaneously with observations at 1390 Mc/s. Much of the planning and carrying out of the observations was due to Mr.E.A.Hill. The author also wishes to thank Mrs. J. , Mrs. L.Scholem, Miss K.Bdrtels and Miss W. Wolfe for their very considerable help with data reduction. He also expresses his gratitude to the University of Maryland and the National Aeronautics and Space Administration (Grant NSG 615) for the computer time and other help they made available for the completion of this paper.

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NO.	R.A. (EPOCH 1950.0) H M S	DEC. D M	L11 D	B11 D	FLUX DENSITY 10^{-26} W/M^2(C/S) 408	85	1440	SPECT. IND. α_{408}^{85}	α_{408}^{1440}	CAT. NO. MSH	MHR	WB	
1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	10 4 14	-57 2	282.0	-1.3	60	47	110	+0.3	+0.4	10-51	9		Th.
2	10 21 27	-57 31	284.2	-0.4	310	96	350	+0.8	0.	10-54	10		Th.
3	10 42 30	-59 34	287.6	-0.8	610	242	650	+0.7	-0.	10-57	11		Th.
4	10 59 5	-60 34	289.9	-0.8	148	162	100	+0.1	-0.4	11-61	13		Non-Th
5	11 11 49	-61 1	291.5	-0.6	254	42	370	+1.8	+0.3	11-62	14		Th
6	11 22 26	-58 56	292.0	+1.8	19	39	15	-0.4	-0.3	11-54	15		Non-Th
7	11 27 26	-62 03	293.6	-1.0	30		75		+0.7		17		Th.
8	11 36 25	-63 05	294.0	-1.6	95	30	75	+0.7	-0.3	11-65	18		?
9	11 36 26	-67 51	296.2	-6.2	10	34		-0.7		11-64			Non-Th
10	12 9 47	-62 33	298.5	-0.0	166	112	165	+0.4	-0.1	12-61	20		Th
11	12 18 42	-63 46	299.7	-1.4	10								
12	12 28 37	-66 55	301.0	-4.4	15								
13	13 9 44	-62 24	305.4	0.1	230		260		0.		25		Th.
14	13 29 06	-66 56	306.9	-4.6	19								
15	13 43 19	-60 10	309.7	+1.7	242	795	130	-0.6	-0.6	13-62	29		Non-Th
16	13 57 32	-66 36	309.7	-4.9	10								
17	13 59 34	-63 46	310.7	-2.2	26	20		+0.3		13-63			Th.
18	14 06 00	-61 20	312.0	0.0	75	69	140	+0.2	+0.4	14-61	31		Th.
19	13 58 08	-57 46	312.1	+3.6	10	35		-0.7		13-52			Non-Th
20	14 19 31	-64 07	312.7	-3.2	10								
21	14 14 07	-57 21	314.3	+3.4	10		15		+0.2		34		Th.
22	14 38 19	-62 22	315.3	-2.4	45	110	30	-0.5	-0.4	14-63	35		Non-Th
23	14 27 51	-56 57	316.2	+3.1	10								?
24	14 43 10	-59 20	317.1	0.1	132		120		-0.2		37		
25	14 52 31	-61 01	317.4	-1.9	19	84		-0.3		14-61			Non-Th
26	15 11 00	-59 03	320.4	-1.3	90	190		-0.4		15-52			Non-Th
27	15 27 50	-62 47	321.2	-3.9	10	55		-1.0		15-61			Non-Th
28	15 26 44	-53 0	323.0	0.1	53	30	45	+0.2	-0.2	15-54	42		Th
29	15 49 01	-56 01	326.3	-1.0	144	270	130	-0.3	-0.2	15-56	44		Non-Th.
30	15 40 02	-54 14	326.4	+0.4									
31	15 51 03	-53 18	328.2	+0.2	49	146	90	-0.6	+0.4	15-57	48		?
32	15 57 31	-52 13	329.7	+0.3	38	91	30	-0.4	-0.3	15-53	47		Non-Th
33	16 07 48	-51 21	331.3	0.0	75		110		+0.2		49		Th.
34	15 52 06	-48 18	331.6	+3.9	19		15		-0.3		50		?
35	16 05 58	-49 19	332.6	+1.7	53								
36	16 16 13	-50 28	333.0	-0.3	197		260		+0.1		51		Th.
37	16 37 32	-48 35	336.8	-1.6	53		45		-0.2		54		?
38	16 31 22	-47 28	336.9	0.	167		230		+0.2		55	33	Th
39	16 36 31	-46 30	338.2	0.	185	330	230	-0.3	+0.1	16-47	56	34	?
40	16 16 07	-42 58	338.3	+5.1	15								
41	16 24 47	-42 08	340.0	+4.5	15	30		-0.3		16-45			Non-Th
42	16 57 05	-46 12	340.7	-2.5	23	30		-0.1		16-410			?
43	17 04 20	-44 15	343.1	-2.3	45	25		+0.5		17-41			Th.
44	16 45 49	-39 07	344.9	+3.6	26								
45	16 55 08	-40 19	345.1	+1.4	106		110		+0.0		61	35	Th
46	17 11 18	-38 24	348.5	+0.1	196	300	77	-0.2	-0.8	17-33	63	37	Non-Th
47	17 23 44	-38 33	349.8	-2.0	30	75		-0.5		17-35			Non-Th
48	17 16 59	-35 47	351.3	0.7	276		323		0.1		64	39	Th
49	17 22 16	-34 14	353.2	0.7	420		580		0.2		65	40	Th.

SEE OVER.

SOURCE IDENTIFICATIONS

No. 1	R.C.W. 46
" 2	R.C.W. 49; G29
" 3	Carinae Nebula; RCW 53; NGC 3372
4	NGC 3503
5	RCW 57; G38; NGC 3603
6	
7	RCW 60; IC 2472.
8	RCW 62; IC 2944
9	
10	
11	
12	
13	RCW 74
14	
15	IAV 1356A
16	
17	
18	RCW 83
19	
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21	
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No. 26	B. W 28802
27	
28	
29	
30	
31	
32	
33	
34	
35	
36	BCW 196
37	BCW 108; NGC 6193
38	
39	
40	
41	
42	
43	
44	
45	
46	
47	
48	BCW 127; NGC 6334
49	BCW 151; NGC 6357.

TABLE II

"LOWER ENVELOPE" BRIGHTNESS TEMPERATURES

	$II_b = +2^\circ$			$II_b = 0^\circ$			$II_b = -2^\circ$		
II_l	$T_b(85)$	$T_b(408)$	$\frac{T_b(85)}{T_b(408)}$	$T_b(85)$	$T_b(408)$	$\frac{T_b(85)}{T_b(408)}$	$T_b(85)$	$T_b(408)$	$\frac{T_b(85)}{T_b(508)}$
$310^\circ - 320^\circ$	6000	120	50	8500	200	43	6000	120	50
$330^\circ - 340^\circ$	10000	220	455	14,000	390	36	8000	175	45.7
$\frac{\Delta T_b(85)}{\Delta T_b(408)}$		40			29			36	

TABLE III

l^{II}	$b^{II} = +2^\circ$		$b^{II} = -2^\circ$	
	T_b (85)	T_b(408)	T_b(85)	T_b(408)
30°	8300°	94°	5500°	86°
33°	6200°	43°	6500°	60°
$\frac{T_b(85)}{T_b(408)}$	41		77	
α_{85}^{408}	-0.46		-0.77	

LEGENDS TO FIGURES

Fig. (1) A typical scan in declination at right ascension $14^h42^m00^s$.

Fig. (2) 408 Mc/s isophotes. The contour interval is 25°K aerial temperature, or 34.7°K "full beam brightness temperature".

Fig. (3) a Number of thermal sources in each half degree interval of galactic latitude. The shaded and unshaded areas refer to sources for which $298° - l^{II} - 355°$, and $282° - l^{II} - 298°$, respectively.

Fig. (3) b Number of non-thermal sources in each one degree interval of galactic latitude. The shaded area represents sources with flux densities greater than 20×10^{-26} Wm^{-2} $(c/s)^{-1}$.

Fig. (4) Variation of brightness temperature with l^{II} for three values of b^{II} and for a number of frequencies. Identical logarithmic scales of brightness temperature have been used for all frequencies, but their relative heights have been adjusted (see Section V). Where the results of other surveys are used, the curves have been derived from the published isophotes.

408 Mc/s ━━━━ Present Survey

408 Mc/s ——— Large et al (1961)

- - - - - - - - - - - - - - - - 85 Mc/s Hill, Slee, and Mills (1958)

1440 Mc/s . . . . . Mathewson, et al (1962)

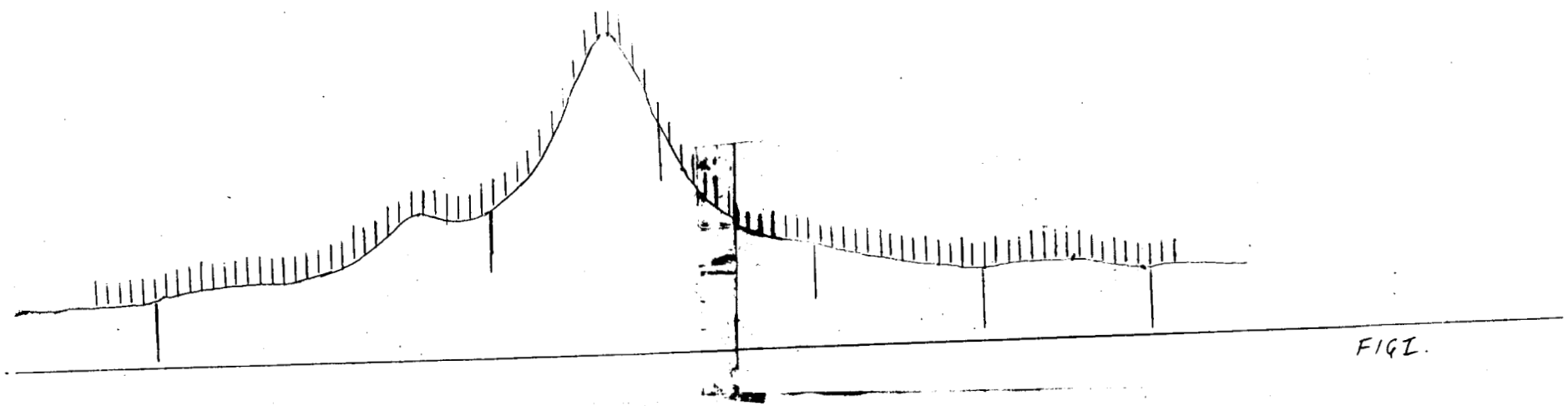
1390 Mc/s — . — . — Westerhout (1958)

(a) $b^{II} = +2°$
(b) $b^{II} = +0°$
(c) $b^{II} = -2°$

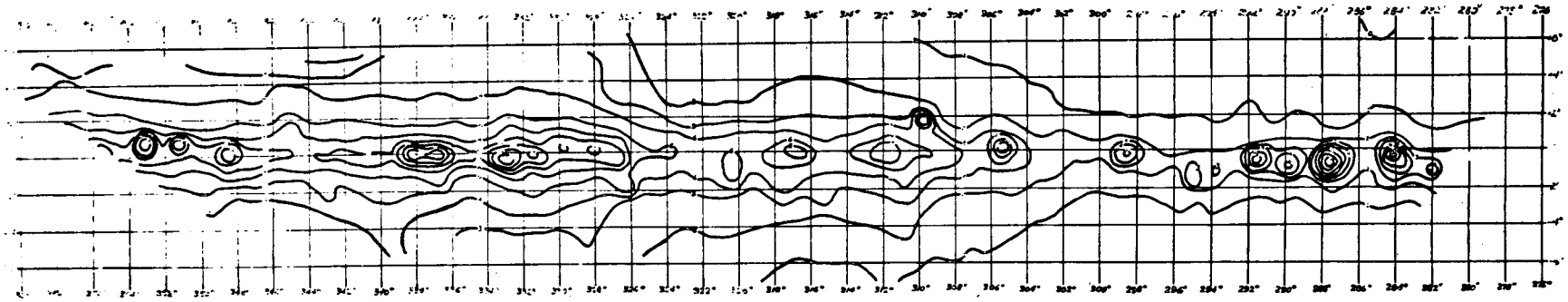
Fig. (5) A thin cylindrical shell seen edge on by an observer at O. The assumed direction of the magnetic field is indicated by an arrow.

Fig. (6) Variation of brightness temperature with longitude l for the model of Fig. 5 assuming the parameters given in Section V (c). The full curve is for $\alpha = -0.5$ and the dashed curve is for $\alpha = -0.6$. The crosses indicate observed values of T_b (408) at $b^{II} = +2°$ and the squares observed values at $b^{II} = -2°$.

8A = 1 [illegible] 242 m 00 s.



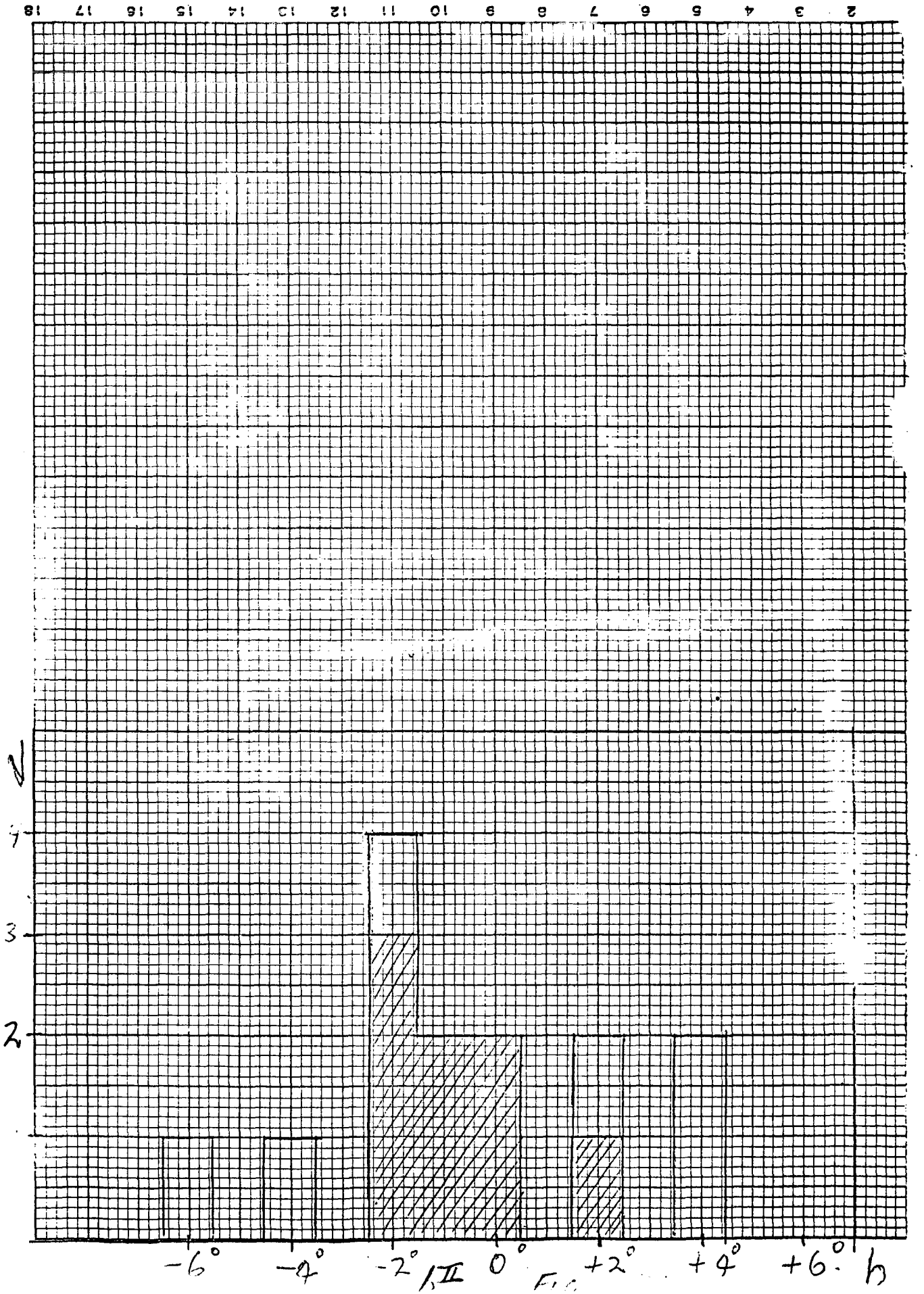
FIGI.



75 CM GALACTIC SURVEY ONE CONTOUR INTERVAL ≈ 30° T_b

Fig. 3

FIG(3a)


2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
N
1
3
2
-6°
-4°
-2°
0°
+2°
+4°
+6°
h

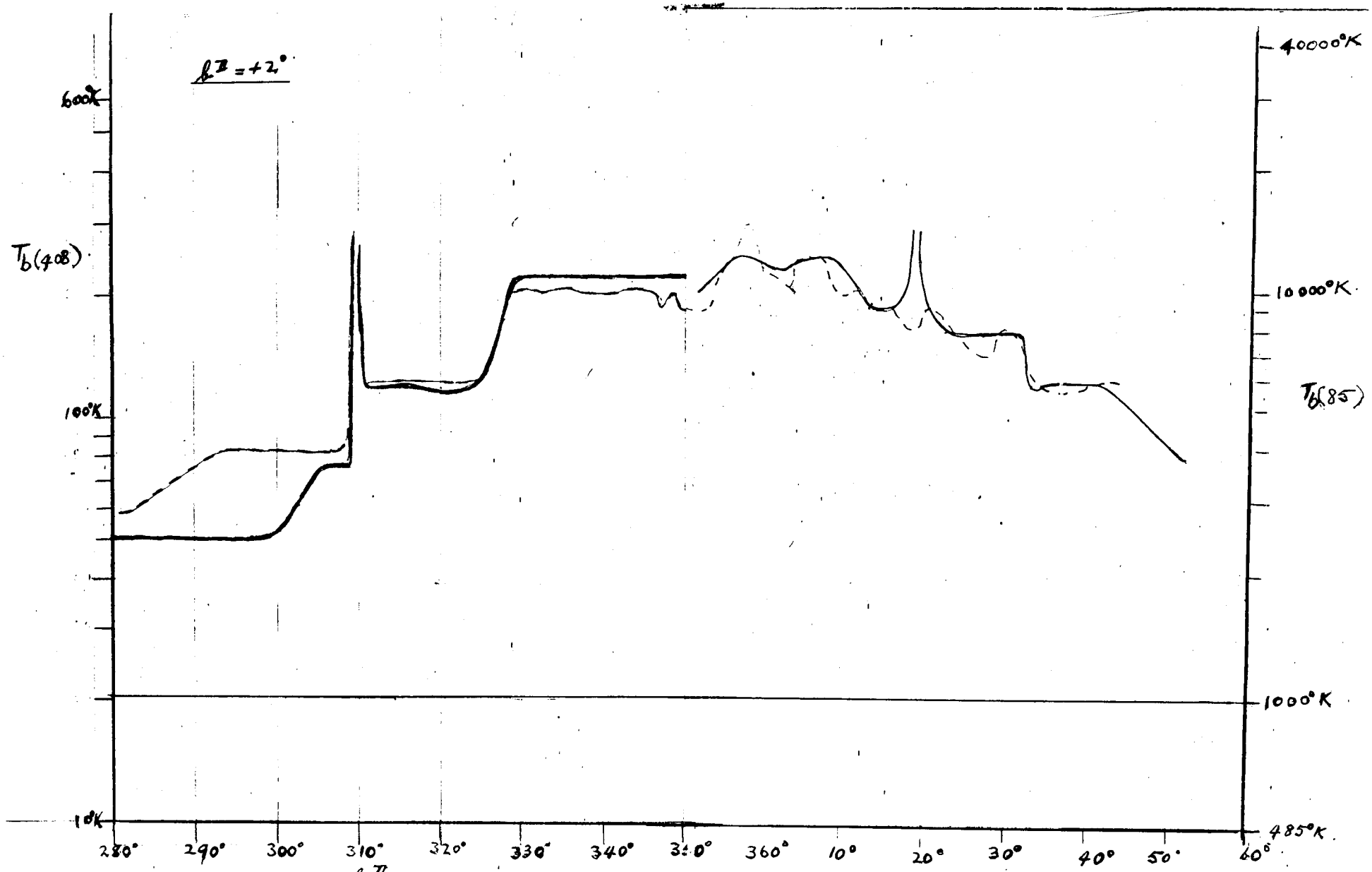

$b^{II} = +2°$
600°K
100°K
10°K
$T_b(408)$
40000°K
10000°K
1000°K
485°K
$T_b(85)$
280°
290°
300°
310°
320°
330°
340°
350°
360°
10°
20°
30°
40°
50°
60°
l^{II}

FIG 4

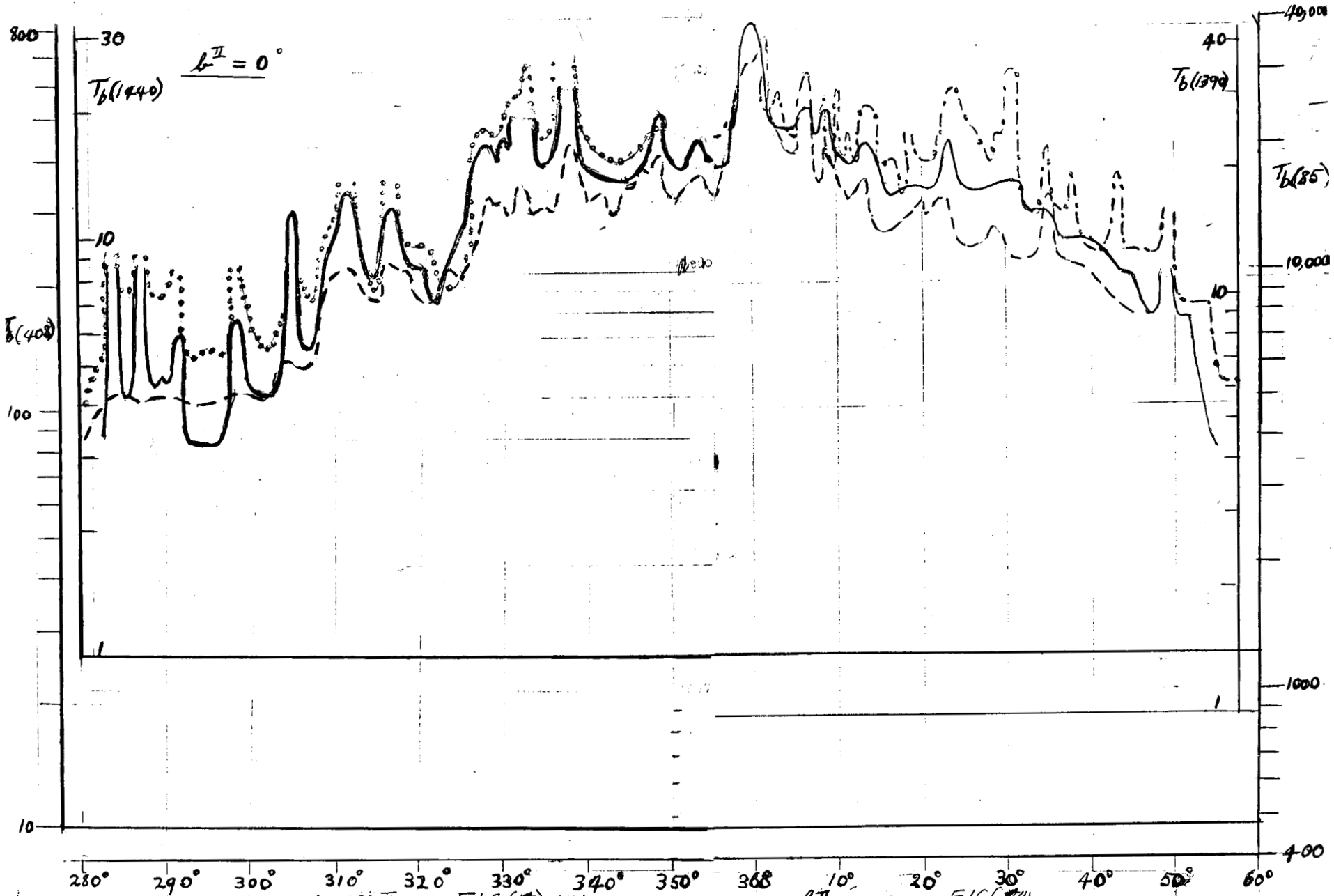

$b^{II} = 0°$
$T_b(1440)$
$T_b(408)$
$T_b(1379)$
$T_b(85)$
800
100
10
30
10
40
10
40,000
10,000
1000
400
280°
290°
300°
310°
320°
330°
340°
350°
360
10°
20°
30°
40°
50°
60°
ℓ^{II}

FIG (4)

FIG (4)

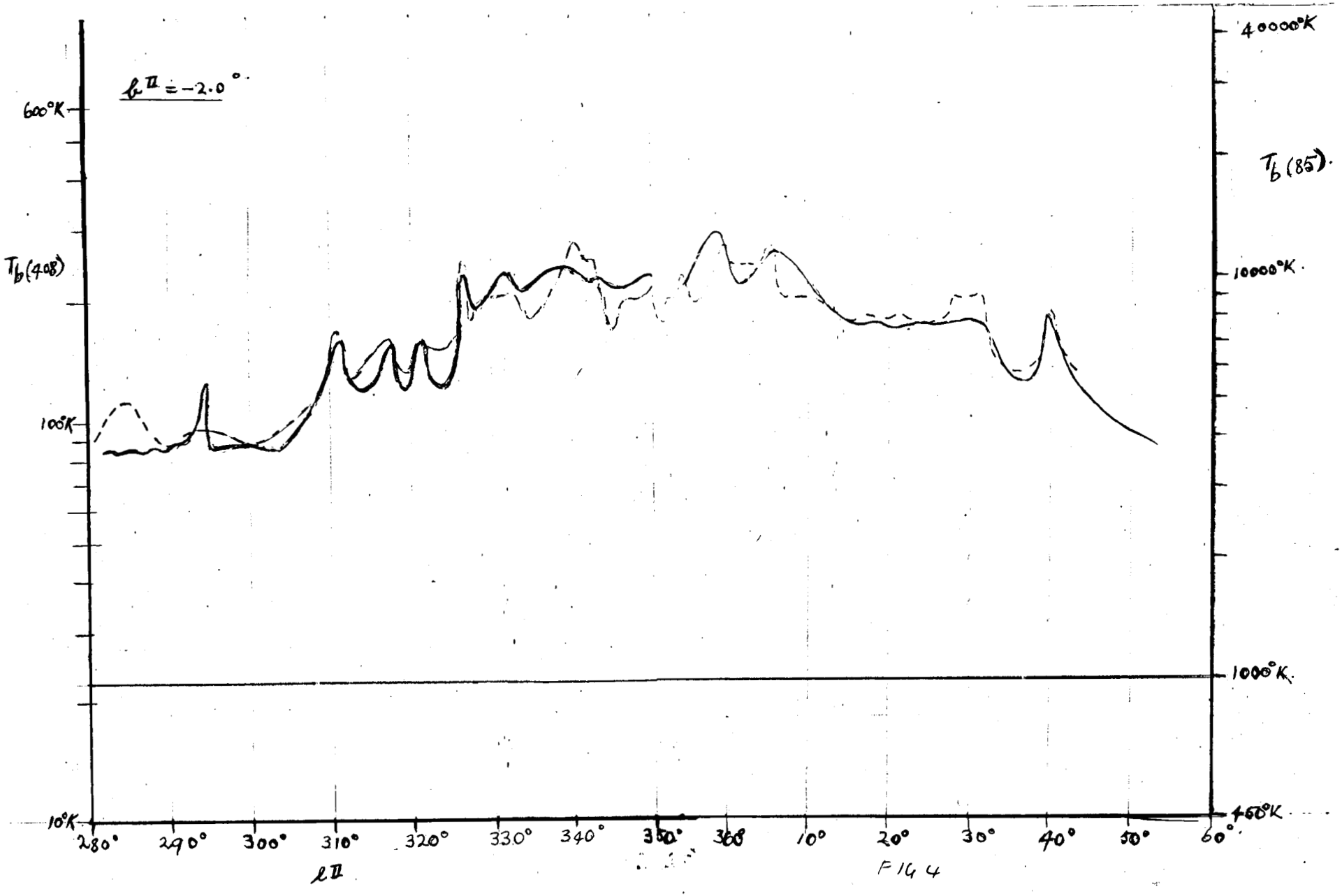

$b^{II} = -2.0°$
600°K
$T_b(408)$
100°K
10°K
40000°K
$T_b(85)$
10000°K
1000°K
450°K
280°
290°
300°
310°
320°
330°
340°
350°
360
10°
20°
30°
40°
50°
60°
l^{II}

FIG 4

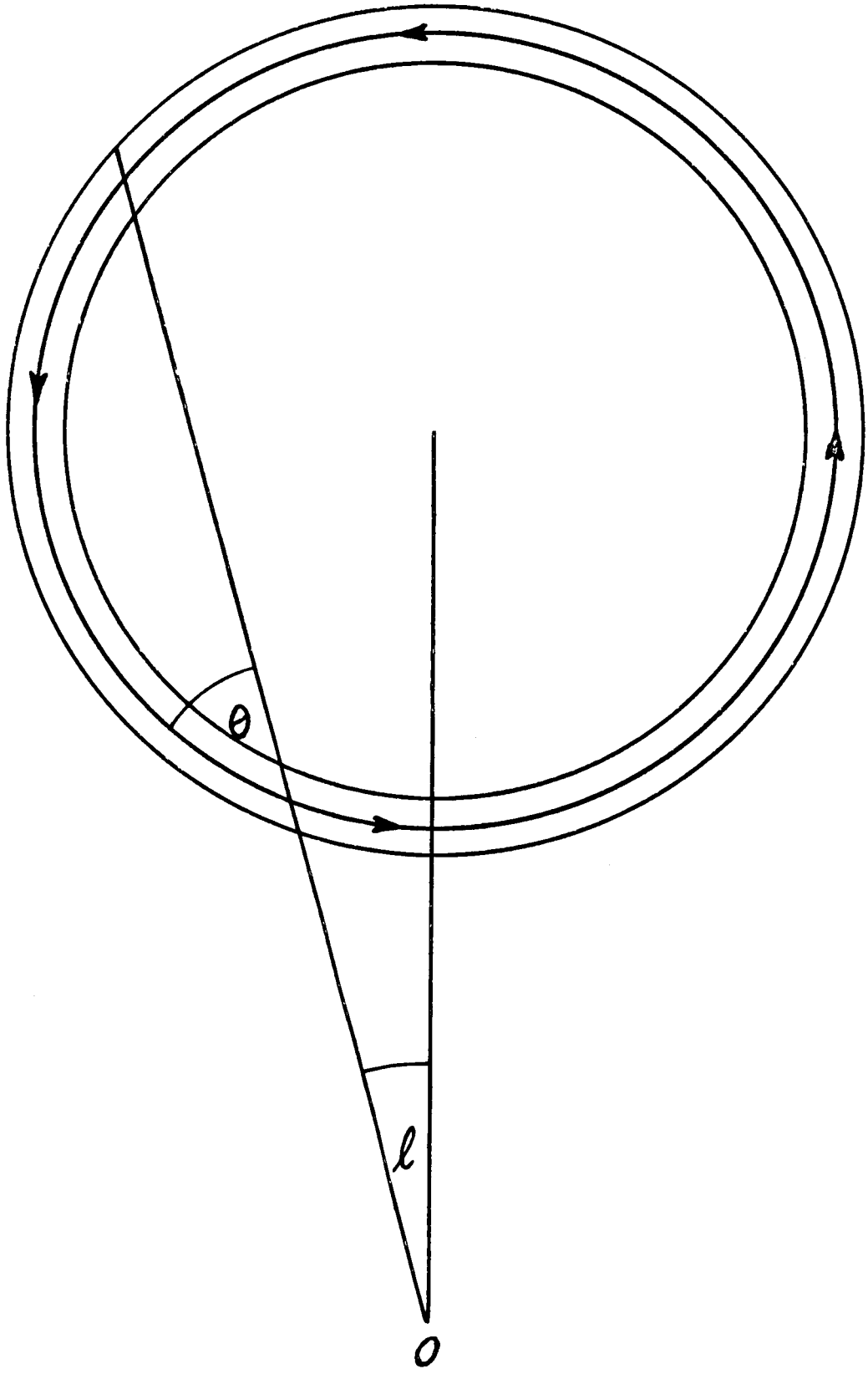


Fig. 5

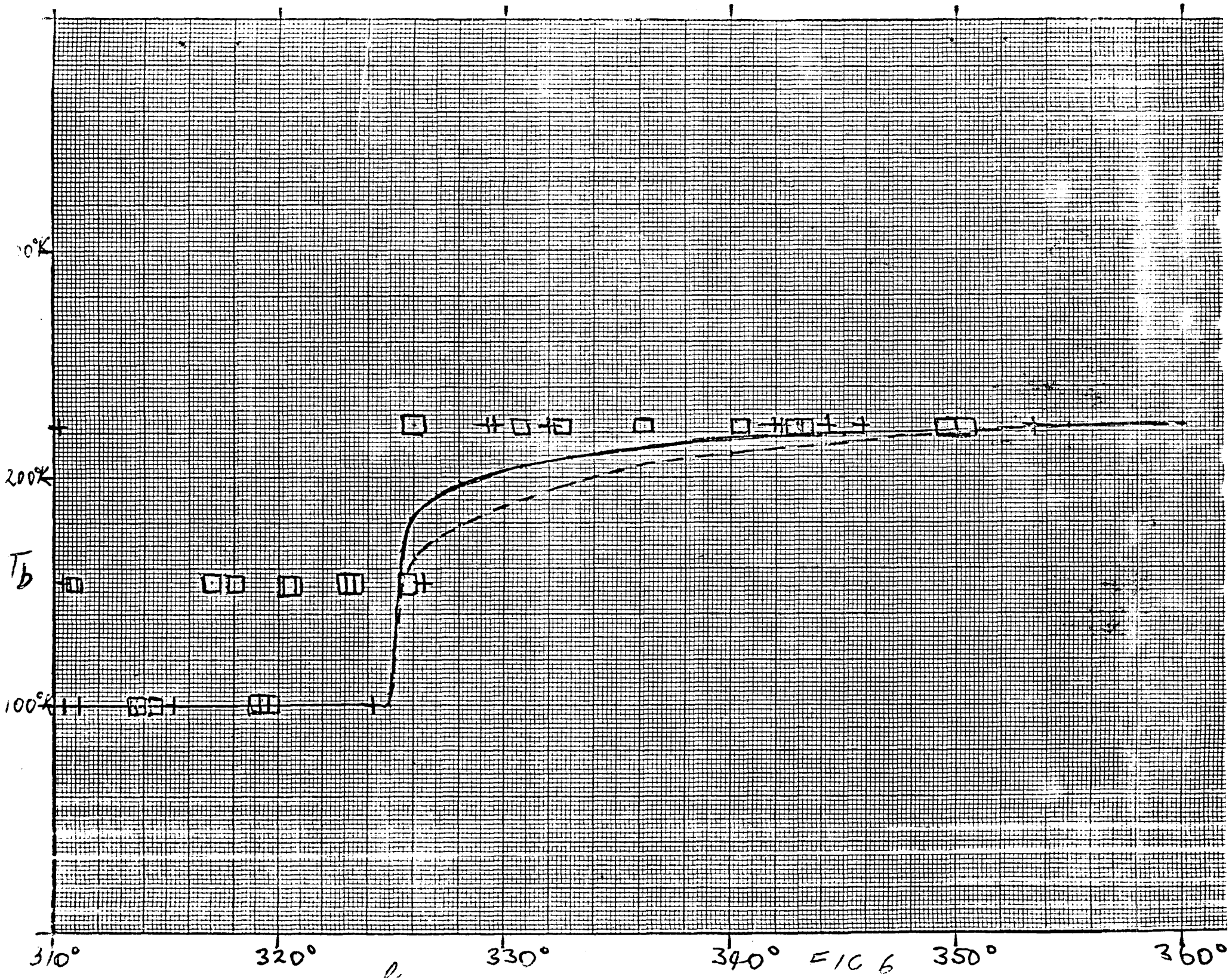


FIG 6