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Paper for Keenan course in Astrophysics

LONG WAVE RADIATION OF EXTRATERRESTRIAL ORIGIN

by
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The Work of K. G. Jansky

During the summer of 1931 K. G. Jansky of the Bell Telephone Laboratories constructed equipment for the investigation of the direction of arrival of static. This apparatus[1,2] operated at a wavelength of 14.6 meters. It consisted of a directive antenna two wavelengths long by one quarter wavelength high with an acceptance pattern as shown in fig. 1. feeding energy into a receiver with amplifier and then into a recorder. The double lines give the plane of the antenna.

horizontal vertical

Figure 1.

The horizontal pattern is given in reference 1. The vertic~~le~~ pattern was computed[3,4] by means of the following equation

$$\rho = \frac{1 - \cos\left[\pi/2(1+\cos\delta)\right]}{2}\cos\delta \qquad (1)$$

where δ is angle above horizon and modified[5,6] to include ground reflection. The dotted lines are drawn along $\rho = \frac{\sqrt{2}}{2}\rho$ max and represent fairly accurately the equivalent acceptance angles, θ & ϕ. This directional antenna was rotated in a horizontal plane once every 20 minutes. When no terrestrial static was present small residuals appeared[7,8]. The two fundamental forms are shown in fig. 2.

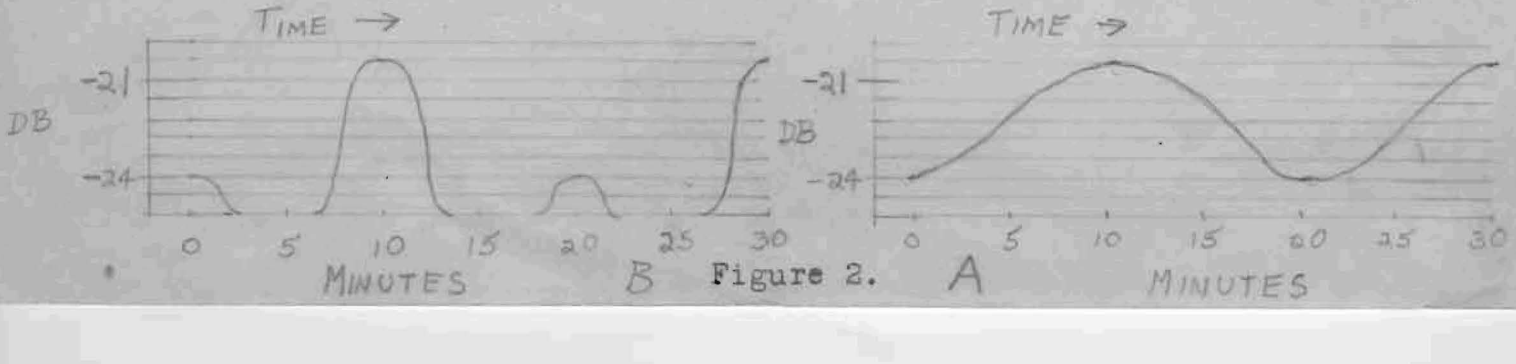

Figure 2.

Fig. 2a occurs when the antenna sweeps along the plane of the milky way, fig. 2b occurs when it sweeps across the plane of the galactic system. In the latter case the major maximum occurs when pointing toward the region of Sagittarius R.A. 18hrs 10 min and Declination -10 degrees. The minor maximum occurs when pointing toward the galactic rim; The two minimums occur when receiving from the galactic poles. These types of curves appear approximately 6 hours a~~p~~part and gradually merge into one another between. The ordinates of fig. 2 are in DB above 1 microvolt/meter/kilocycle band width. This radiation appears as a steady hissing sound in the headphones. Its nature being much the same as that of the familiar thermal agitation noise of charges in a conductor. The work was conducted at Holmdel, N.J. Lat. 40°22' N, Long. 74°10' W during 1932.

Possible Origin of the Radiation

Since the data unmistakeably points to the milky way as the source of this disturbance one immediately wonders if it is not connected with the great aggregation of stars composing our galactic system. If this were so, very intense radiation would be expected from the sun which is an average star and by far the closest. This must be ruled out because no such effect is known. The possibility that the radiation in question is a secondary generated in the earths atmosphere due to a primary from the sun must be ruled out also. The above reasoning seems to eliminate radiation from all hot bodies and requires a substance which radiates selectively at 14.6 meters far more energy than in the heat and light part of the spectrum. With these ideas in mind Greenstein and Whipple[9] investigated various astronomical possibilities.

Jansky states the maximum intensity is 0.39 microvolts/meter/ kilocycle band width. This may be converted to ergs/cm^2/sec/kc.bd.

by using Maxwells equation for energy density in an electromagnetic field[10]

$$U = \frac{1}{8\pi}(kE^2 + uH^2) \text{ ergs/cm}^3 \qquad (2)$$

where E is electric field in statvolts/cm.
H is magnetic field in equivalent statvolts/cm
k is dielectric constant
u is permeability

In space $k = 1$, $u = 1$, and H will equal E since it is due to motion of E with the velocity of light C. Multiplying eqn.(2) by C to obtain intensity this reduces to

$$I = \frac{C}{4\pi}E^2 = 4.0 \times 10^{-13} \text{ ergs/cm}^2\text{/sec/kc band.} \qquad (3)$$

for the data in question.

Greenstein considers the first hypothesis of the central galactic mass containing 1.3×10^{11} solar masses of average luminosity equal to the sun at a distance of tenthousand parsecs. He also assumes 0.5 magnitudes obscuring effect due to absorbing matter at approximately 10°K. From these he computes 4.4×10^{-20} ergs/sec/cm^2/kc band should be arriving from the galactic center and only 5% as much from the rest of the galaxy within the acceptance cone of the antenna. Appearantly black body radiation fails by nearly 10^7 to account for Janskys results.

The second hypothesis assumes a great cloud of small particles approximately 10^{-2} cm in diameter. This would be very opaque to stellar radiation shorter than 10^{-1}cm and produce an increase in the energy density of the central mass with resultant increase in temperature. The low opacity for radio waves would permit the selective escape of these lower frequencies.

The wavelength 14.6 meters is equal to 2.05×10^7 vibrations per second. The smallest particle that can maintain a standing wave of this frequency has a diameter equal to the velocity of sound divided by the frequency. For meteoric material this becomes

$2a = 1.5 \times 10^{-2}$cm. The absorption per unit mass is $\frac{3}{4}$ a d where "d" is the density. The dark mass is taken as one fifth the total mass of the galactic nucleus and is assumed to be contained in a sphere 1500 parsecs radius. From these he computed 6.6×10^{-18} ergs/sec/cm^2/kc.bd. should be arriving from the dark material of the galactic nucleus. Therefore even under the most optimum conditions black body radiation fails by nearly 10^5 to account for Janskys results.

$I_\nu = \frac{\nu^2 kT}{c^2} d\nu \cdot \frac{\pi}{4}\left(\frac{1}{57.3}\right)^2 \Theta \times \phi \cdot = \frac{9\cdot10^{14}\cdot 1.34\cdot10^{-16}\cdot 6\cdot10^{3}}{9\cdot10^{20}} 10^3 \frac{\pi}{4}\left(\frac{1}{57.3}\right)^2 \cdot 25 = 2.14\cdot10^{-20}$
ergs/sec/cm^2/kc bd.

Greenstein also calculates that 4.3×10^{-20} ergs/sec/cm^2/kc bd. should be arriving from the sun at 14.6 meters. This again is far below the available sensitivity of Janskys apparatus.

He uses $I_\nu = \frac{2\nu^2 kT}{c^2} d\nu$

The Work of Feldman and Friis

During 1935 a very large short wave antenna system was constructed at Holmdel, N.J. for use with the transoceanic telephone system.[11] It consisted of 6 rhombic antennas each 200 meters long and 68 meters wide arranged end on. The electrical connections were such that vertical acceptance angle δ could be varied. Its width Θ' varied somewhat depending upon δ and the wavelength. The horizontal[12] and vertical acceptance patterns are shown in fig.3. The antenna was in a horizontal plane about 50' above the ground.

horizontal

vertical

Figure 3.

On several instances when no signals or terrestrial noise was present stellar static could be heard. This data is given in Table I.

Discussion of Friis-Feldman Data

It will be necessary to reduce the data to DB above a 1 microvolt/meter/kc bd level. Since no absolute signal strengths but

Table I

Curve	A		B		C		D		E	
Reference page	397		413		413		413		413	
Date (1935)	9-18		9-19		10-15		10-24		10-24	
G M T	1700		1530		1500		1500		1510	
Date Correction	-16		-12		+130		+206		+206	
Sidereal Time	1147		1021		1133		1209		1219	
Frequency in megacycles/sec.	18.62		18.62		9.51		9.51		9.51	
Static	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
DB above zero	12.0	8.0	8.5			8.0	11,4	5.4	11.0	6.0
δ in Deg.	5	21	5	21	9	30	9	30	9	30
θ' in Deg.	6	3	6	3	7	3	7	3	7	3
ϕ' in Deg.	11		11		16		16		16	

zero DB 12 DB above thermal noise

station time correction + 3 min.

only relative to thermal noise were given the following reasoning had to be used. The thermal noises developed per KC band width in the two receivers were assumed the same. This is reasonable since both receivers were of the same type, namely simple detector-oscillator input circuits feeding an I.F. amplifier. No R.F. stage was used with either one. The fact that the band width of the Friis-Feldman set up was 12kc instead of the 26kc used by Jansky is of no importance because Janskys data is already reduced to a one kc band width and the Friis-Feldman data is only relative to thermal noise which may be taken on a one kc band for this purpose. This assumption is valid since both thermal noise and stellar static are a continuous spectrum (over the few kc in question) and the total noise power present from a band B kc wide of either one will be B times that of a band one kc wide. Hence simply let B equal 1.

The second correction applies to the antenna systems. Jansky used a collector of D square cm. cross section which was at an average angle of $57\frac{1}{2}^{\circ}$ to the oncoming wave front. The effective collecting surface was then D $\sin 57\frac{1}{2}^{\circ}$. Friis & Feldman used a collector of D' sq.cm. which was inclined at an angle δ to the wavefront. The effective area of this being D' $\sin \delta$. Therefore the Friis-Feldman signal data was reduced by $10 \log_{10} \frac{D' \sin \delta}{D \sin 57\frac{1}{2}^{\circ}}$ DB from values published above thermal noise.

Also correction must be made for the difference in size of the cones of acceptance. Since the radiation may be considered to arrive uniformly over the acceptance cones the Friis-Feldman data was increased by $10 \log_{10} \frac{\theta \times \phi}{\theta' \times \phi'}$ DB from the published values. The only assumption made here is that both antennas take an equal percent of the power from the wavefront.

This antenna is used for reception of signals from Daventry

England. It lies therefore along the great circle path which points 49°47' E of N from Holmdel, N.J.

The great circle paths in the sky along which the acceptance cone traveled are plotted in fig. 4. The limits of motion are indicated by cross lines. At Holmdel, the zenith is + 40°22' Dec.; indicated by one end of the lines. The horizon at 49°47' E of N is + 29°20' Dec.; indicated by the other end of the curves. The plane of the milky way is shown by a heavy line across corner of graph.

Table II gives the data of Table I reduced to ergs/sec/cm²/kc bd. The column entitled T is the equivalent temperature of a black body in space necessary to emit the energy indicated. This computation is as follows. Plancks equation for black body radiation is

$$H_v = \frac{h v^3}{C^2}\left(\frac{1}{e^{hv/kT} - 1}\right) \text{ ergs/cm}^2 \qquad (4)$$

where

h is Plancks constant 6.55 x 10^{-27} ergs sec.
v is frequency in cycles per sec.
C is velocity of light 3 x 10^{10} cm/sec.
k is Boltzmanns constant 1.34 x 10^{-16} ergs/deg. K
T is absolute temperature in degrees K

for small values of v/T eqn (4) reduces to

$$H_v = \frac{v^2\ k\ \ T}{C^2} \text{ ergs/cm}^2 \qquad (5)$$

To obtain power multiply by dv and integrate from v_1 to v_2. Let $v_2 - v_1$ be 0.01v or a 1% band width.

$$U_v = \frac{.01v^3kT}{C^2} \text{ ergs/cm}^2\text{/sec} \qquad (6)$$

Adapting this to a spherical system for any band width B

$$U_v = \frac{.01v^3kT}{C^2}\ Q\ \frac{\pi}{4}\left(\frac{1}{57.3}\right)^2 \gamma^2\ B \qquad (7)$$

and solving

$$U_v = 3.57 \times 10^{-43}\ v^3 T Q \gamma^2 B \text{ ergs/sec/cm}^2\text{/deg.K/circular degree}$$

where

Q is area of Receiver in sq. cm.
γ is angular diameter of radiator in degrees
57.3 equal degrees in a radian
B equals band width in percent

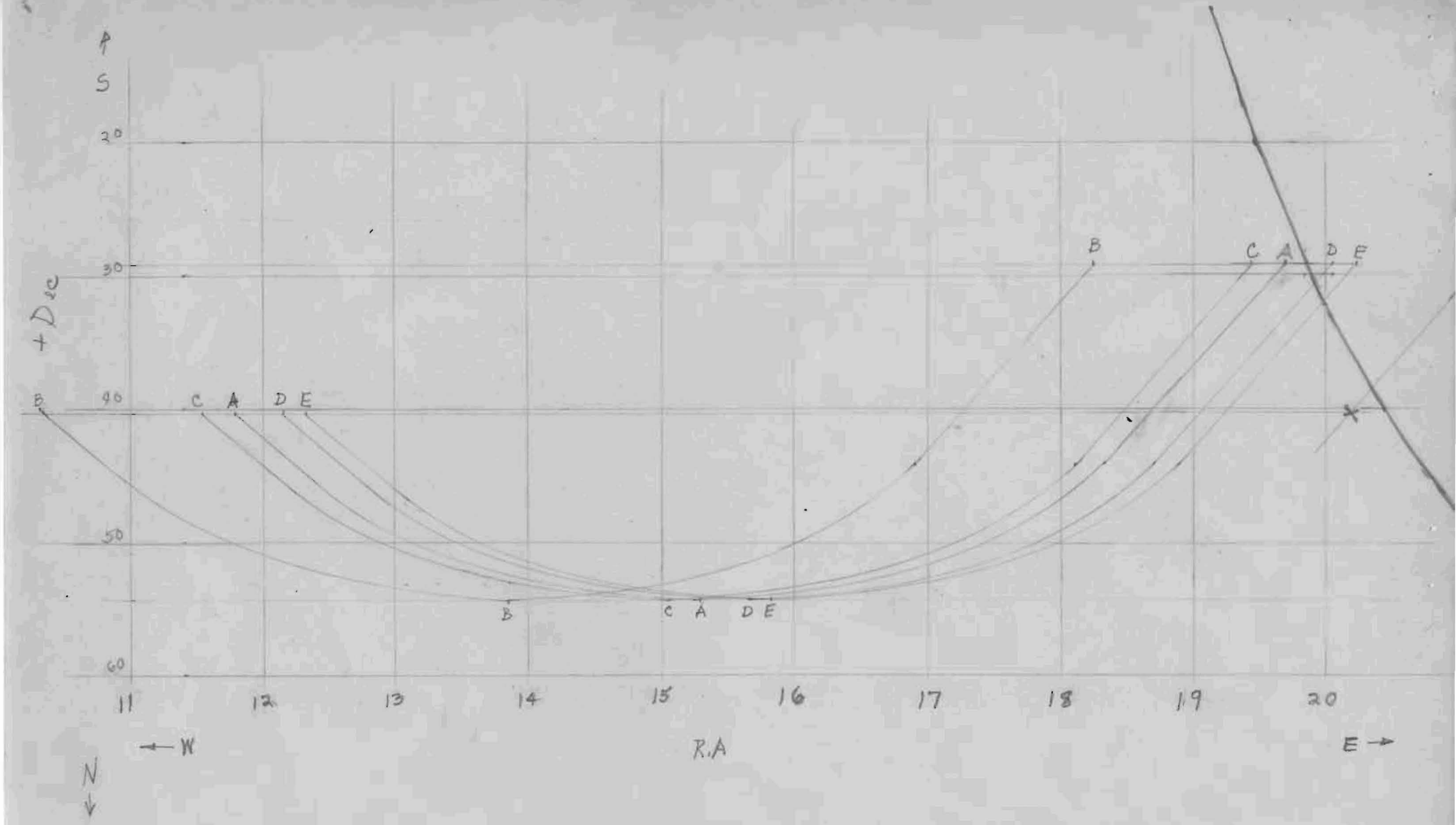

FIGURE 4.

X = point representing curve A fig 4 page 1522 Dec 37 IRE

Table II

Curve	A		B		C		D		E	
Static	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
$\frac{D' \sin \delta}{D \sin 57\frac{1}{2}^\circ}$	79	324	79	324	143	454	143	454	143	454
$\frac{\theta \times \phi}{\theta' \times \phi'}$	17	34	17	34	10	23	10	23	10	23
DB correction	-6.7	-9.8	-6.7	-9.8	-11.6	-13.0	-11.6	-13.0	-11.6	-13.0
DB above noise level	17.3	10.2	13.8	10.7	8.4	7.0	11.8	4.4	11.4	5.0
Static volts E/ meter/kc band $\times 10^{-6}$	.401	.169	.264	.181	.134	.110	.207	.073	.197	.081
U in ergs/cm^2/ sec/kc band $\times 10^{-13}$	4.26	.77	1.85	.87	.48	.32	1.14	.14	1.03	.17
B band width in percent $\times 10^{-3}$	5.38		5.38		10.9		10.9		10.9	
γ^2 in circular degrees	84	42	84	42	143	61	143	61	143	61
T in degrees Kelvin $\times 10^7$	41	14	18	16	12	18	28	8	24	9
Angular degrees from Milky way	6	22	20	36	13	34	7	28	5	26

D = 106.5 sq meters

D' = 81,600 sq meters

$\theta = 37^\circ$

$\phi = 30^\circ$

P in ergs/sec/cm^2/ kcld/circular degree $\times 10^{-18}$	5100	1830	2200	2100	330	530	800	230	720	280

Solving for T and letting Q equal 1.

$$T = \frac{2.8 \times 10^{42} U_v}{v^3 \quad B\, \gamma^2} \text{ degrees Kelvin} \qquad (8)$$

When computing E the zero level was taken from graph on page 1931 Dec. 1932 IRE as 25.2DB below 1 microvolt/meter/kc band. This is equal to .055 microvolt/meter/kc band, the level of thermal noise. The noise and signal voltages will add as the square root of the sum of the squares because while they are both continuous spectra they are derived from different source. Therefore

$$\text{Static} = \text{Noise}\left[\left(\log^{-1}\frac{DB}{20}\right)^2 - 1\right]^{\frac{1}{2}} \text{ volts} \qquad (9)$$

The data of table II applies to the region of Cygnus. About all that can be said is the radiation is most intense near the galactic plane. It does not obey the law of black body radiation in relation to frequency as the 18.62 megacycle readings were consistently high by about 50% in relation to the 9.51 megacycle readings. The exponent of v seems to be nearer 3.5 than 3.0. The relation to temperature seems to have no meaning at all because such temperatures are encountered only in the center of stars. If curve C is excluded as being in error (some doubt is cast upon it in the text) the ratio of energy intensities per circular degree at approximately 6° and 26° from the plane of the galaxy is about 3 to 1. Actually it may fall off much faster than this because of the numerous minor acceptance lobes not shown in fig 3b. These become much more pronounced as δ increases.

Discussion of Jansky data

The graph on page 1931 Dec. 32 IRE gives thermal noise at 25.2DB below 1 microvolt/meter/kc band. This figure is checked fairly close by graph on page 1924 and amounts to 0.055 microvolt/

Review of Table VIII page 913 July 37 BTJ shows that on all measures of star static light QRM was present. This will tend to raise the measured values of static and in part account for the high values of P obtained from Friis-Feldman data. The maximum possible to subtract from this cause is 10 DB or a power ratio of 10 to 1. Since a 100 to 1 reduction is necessary to bring this data into line with Janskys at least 10 to 1 error must be found else where, 2 or 3 to one can be attributed to minor acceptance lobes of the antenna.

If data of table III are increased by ratio of $\left(\frac{.39}{.078}\right)^2$ to agree with Janskys max and values of " II " decreased " " " 10/1 " correct for QRM then two sets of data agree fairly well at 18-20 mc. The measured intensity being $3.6 \cdot 10^{-16}$ ergs/sec/cm^2/circular degree in region of galactic plane.

The 9.51 mc data III and Janskys data of Dec 37 IRE 16.7 mc are low by factors of 5 & 100 respectively.

meter/kc band. Inspection of data given for Feb. 24, 1932 on former above page, data for Sept. 16, 1932 given on page 1388 Oct. 33 IRE and on page 1159 Oct. 35 IRE shows maximum values of major peak 4.8DB and minor peak 1.2DB above thermal noise. These values correspond to .078 and .031 microvolt/meter/kc band respectively. The value of.078 microvolt/meter/kc band is only 20% of maximum value .39microvolt/meter/kc band stated by Jansky on page 1932 Dec. 1932 IRE. Just why this discrepency occurs is not clear. In a letter Jansky suggests that the radiation may be of random polarization. While it is true the antenna is most responsive to horizontal polarized waves it is not sharply so to the extent of 1 to 4. He also suggests attenuation due to the ionosphere and the possibility that some of the energy is reflected away from the earth. No quantitative data is available on either of these questions. Probably the last of these will have the largest effect since all measurments were made on rays arriving at low angles to the horizon where the reflection and dispersion would be the most pronounced.

When Janskys data is reduced by the same method as the Friis-Feldman data Table III is obtained.

The data is in general agreement with that of Friis & Feldman. However there seems to be a constant experimental error of about 10^{-2} between the former and the latter. It might be the cumulative effect of assumptions made. This data tends to show the energy drops off very rapidly from the galactic plane toward the pole which is probably quite reliable since Janskys antenna showed no pronounced minor lobes of acceptance.

Table III

Direction	Towards Galactic Center	Towards Galactic Rim	Towards Galactic Pole
Frequency in megacycles/sec.	20.5	20.5	20.5
DB above noise	4.8	1.2	$<.1$
E in microvolts/meter/kc band	.078	.031	$<.012$
U in ergs/cm^2/sec kc band $\times 10^{-13}$	.16	.03	$<.0004$
γ^2 in circular degrees	1110	1110	1110
B in percent x 10^{-3}	5.0	5.0	5.0
T in degrees Kelvin	10^6	2×10^5	$<3 \times 10^2$
P in ergs/sec/cm^2/Kc bd/circular degree $\times 10^{-18}$	14.3	2.7	$<.04$

Works of Other Investigators

During a conversation with Greenstein he stated Whipple was experimenting in the wavelength range 1-10 meters using parabolic collecting devices and regenerative receivers. No positive results had been obtained yet however.

In the course of correspondence with R.M.Langer of Norman Bridge Laboratory of California Institute of Technology it develops that Potapenko and Folland have checked Janskys results. They are in agreement as to the direction of arrival of the radiation but find it only over a small band of 15 ± 1 meters. It may be that this radiation comes in bands around 15, 30, etc meters since Jansky and Friis-Feldman worked at 20.5 and 18.62, 9.51 megacycles respectively which correspond to 14.6 and 16.1, 31.5 meters.

Langer also suggests that this radiation may be due to "quantum electron jumps in the highly ionized interstellar dust particles." He is carrying out computations but has no positive results yet. This differs from Greensteins idea of obtaining the largest radiating area per unit mass. ~~Just why his particles must vibrate is not clear to the writer as without a charge no electromagnetic waves would be generated by the vibrations.~~ They were charged but q not specified

Conclusions

All evidence points strongly toward the milky way system as the source of this radiation. Nearly all existing data are residuals from other observations. No set of hypothesis based upon other knowledge has been able to explain this phenomena. Before intelligent guesses can be made it is of utmost importance that accurate measurements be made of intensity versus direction and intensity versus spectral distribution.

see over.

adding in Jansky's work of Dec 37 IRE the evidence points toward black body radiation because.

(a) Apparently a continuous spectrum by measurement of $\lambda = 14$ to 36 metr

(b) " v^3 holds by Friis & Feldman.

(c) Energy arriving from all directions in plane of galaxy

Difficulty is that intensity far above what can be accounted for.

On basis of resonance phenomena more energy can be accounted for but still far from enough.

Difficulty is hard to imagine a resonance phenomena producing a continuous spectrum and still unable to account for intensity.

References

1. Directional Studies of Atmospherics by K.G. Jansky page 1920 Dec. 1932 Proc. IRE
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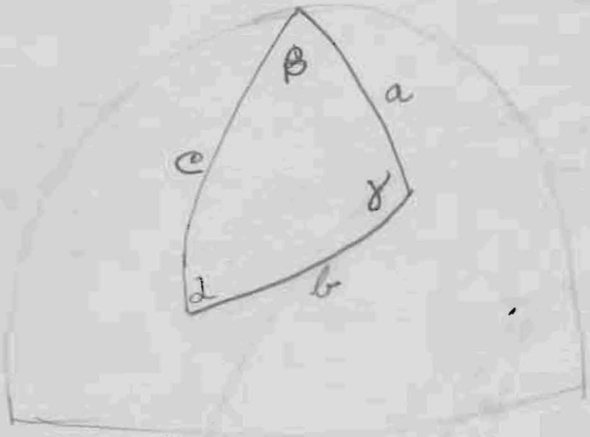
4. $\rho = \cos\delta$ is radiation equation of quarter wave antenna over perfectly conducting earth.
5. The optical Behavior of the ground by C.B. Feldman page 762 June 33, Proc IRE
6. Direction of arrival of Short Radio Waves by Friis, Feldman & Sharpless, page 47 Jan 1934 Proc IRE.
7. Electrical Disturbances of Extraterrestrial origin by K.G.Jansky page 1387, Oct 1933 Proc IRE.
8. Interstellar Interference by K.G.Jansky page 1158 Oct. 1935 Proc. IRE
9. The origin of interstellar radio disturbances by Greenstein and Whipple page 177 March 1937 Proc. National Academy of Sciences.
10. Classical Electricity & Magnetism by Abraham and Becker page 186
11. A multiple unit steerable antenna by H.T.Friis & C.B.Feldman page 337 July 1937 Bell Tech. Journal
12. Horizonal Rhombic Antennas by Bruce, Beck, and Lowry page 24, Jan 35 Proc. IRE

Daventry, England. 52°16'N, 1°10'W
Holmdel, N.J. 40°21'N, 74°11'W
Zenith angle 49°47' E of N (Direction to Daventry)
Horizon " 41°52' W of N
Freq band Width 12 KC (page 361)
DB zero level equals signal from one rhombus (page 413)
Thermal noise level -12 DB (page 413)
Station time correction +3 min
Horizon R.A 7 hrs 54' later than zenith R.A.
" Dec +29°20'
Zenith R.A = siderial time
" Dec = + 40°21'
Path nearest pole Dec +54°18'
" " " R.A 3 hrs 30' later than zenith R.A.

Curve	A	B	C	D	E
Reference page	397	413	413	413	413
Date (1935)	9-18	9-19	10-15	10-24	10-24
GMT	1700	1530	1500	1500	1510
S.T	1147	1021	1133	1209	1219
Freq.	18,62	18,62	9.51	9.51	9.51
DB max	12	8.5	8.0	11.4	11.0
DB min	8			5.4	6.0



$$\begin{array}{r} 74^\circ\ 11' \\ 1^\circ\ 10' \\ \hline \beta = 73^\circ\ 1' \end{array}$$

$$\begin{array}{r} 90^\circ\ 00' \\ 40^\circ\ 21' \\ \hline c = 49^\circ\ 39' \end{array}$$

$$\begin{array}{r} 60 \\ 55 \\ \hline 115 \end{array}$$

$$\begin{array}{r} 90^\circ\ 00' \\ 52^\circ\ 16' \\ \hline a = 37^\circ\ 44^\circ \end{array}$$

$$\begin{array}{rr} c = & 49'\ \ 39' \\ a = & 37\ \ 44 \\ \hline & 86^\circ\ 83' \end{array}$$

$\frac{1}{2}(c+a) = 43^\circ\ 42'$

11 55

$\frac{1}{2}(c-a) = 5^\circ\ 57^\circ$

$\frac{1}{2}\beta = 36^\circ\ 31'$

$$\tan\tfrac{1}{2}(\gamma-\alpha) = \frac{\sin\frac{1}{2}(c-a)}{\sin\frac{1}{2}(c+a)\ \tan\frac{1}{2}\beta} = \frac{.1039}{.690\cdot.741} = .2032$$

$\frac{1}{2}(\gamma-\alpha) = 11^\circ 49'$, $(\gamma-\alpha) = 23^\circ 38'$, $\gamma = 23^\circ 38' + \alpha$

$$\tan\tfrac{1}{2}(\gamma+\alpha) = \frac{\cos\frac{1}{2}(c-a)}{\cos(c+a)\ \tan\frac{1}{2}\beta} = \frac{.992}{.724\cdot.741} = 1{,}850$$

$\frac{1}{2}(\gamma+\alpha) = 61^\circ 36'$, $(\gamma+\alpha) = 123^\circ 12'$

$$\alpha = \frac{123^\circ 12' - 23^\circ 38'}{2} = \underline{\underline{49^\circ 47'}}$$

$\gamma = 23^\circ 38' + 49^\circ 47' = 73^\circ 25'$

$$\tan\tfrac{1}{2}(\alpha-\beta) = \frac{\sin\frac{1}{3}(a-b)}{\sin\frac{1}{2}(a+b)}\,\frac{1}{\tan\frac{1}{2}\gamma} = \frac{.421}{.909\cdot.368} = 1.260$$

$\frac{1}{2}(\alpha-\beta) = 51^\circ 32'$ $\alpha-\beta = 103^\circ 04'$, $\alpha = 103^\circ 04' + \beta$

$$\tan\tfrac{1}{2}(\alpha+\beta) = \frac{\cos\frac{1}{2}(a-b)}{\cos\frac{1}{2}(a+b)}\,\frac{1}{\tan\frac{1}{2}\gamma} = \frac{.909}{.921\cdot.368} = 5.86$$

$\frac{1}{2}(\alpha+\beta) = 80^\circ 20'$ $\alpha+\beta = 160^\circ 40'$

$$\beta = \frac{160^\circ 40 - 103^\circ 04'}{2} = \underline{28^\circ 48'}$$

$$\alpha = 103\ 04 + 28\ 48 = \underline{131^\circ 52'}$$

$$\tan\tfrac{1}{2}e = \frac{\tan\frac{1}{2}(a-b)\,\sin\frac{1}{2}(\alpha+\beta)}{\sin\frac{1}{2}(\alpha-\beta)} = \frac{.464\cdot.989}{.784} = .585$$

$\frac{1}{2}e = 30\ 20$ $\underline{e = 60^\circ 40'}$

$\theta = \alpha - 90 = 41^\circ 52'$

Horizon = $89^\circ 60' - 60^\circ 40' = +29^\circ 20'$ declination

Zenith = $+40^\circ 21'$ declination.

Horizon R.A = $90^\circ + \beta = 118^\circ 48' = 7$ hrs $54'$ behind zenith R.A.

at +Dec $41\frac{1}{2}^\circ$ a degree R.A = .75 degree Dec. in scale

Zenith angle = $49^\circ 47'$ E of north

Horizon angle = $41^\circ 52'$ W of north = 92° W. of N

$$\begin{array}{r} 90\ 21 \\ 28\ 48 \\ 131\ 52 \\ \hline 201^\circ 01' \end{array}$$

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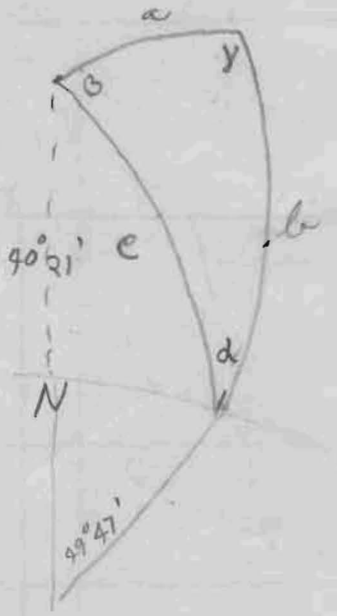


$\alpha = 41°52'$

$\gamma = 90°00'$

$c = 60°40'$

$\frac{1}{2}(\gamma+\alpha) = 65°56'$

$\frac{1}{2}(\gamma-\alpha) = 24°04'$

$\tan 30°20' = .585$

$$\frac{\sin\frac{1}{2}(\gamma-\alpha)}{\sin\frac{1}{2}(\gamma+\alpha)} = \frac{\tan\frac{1}{2}(c-a)}{\tan\frac{1}{2}b} = \frac{.408}{.911} = .4475$$

$$\operatorname{Tan}\tfrac{1}{2}b = \frac{\tan\frac{1}{2}(60°40'-a)}{.4475} = \frac{\tan\frac{1}{2}(60°40'+a)}{2.235}$$

$$\frac{\cos\frac{1}{2}(\gamma-\alpha)}{\cos\frac{1}{2}(\gamma+\alpha)} = \frac{\tan\frac{1}{2}(c+a)}{\tan\frac{1}{2}b} = \frac{.911}{.408} = 2.235$$

$$2.235\tan\left(30°20'-\frac{a}{2}\right) = .4475\tan\left(30°20'+\frac{a}{2}\right)$$

$$2.235\,\frac{\tan 30°20' - \tan\frac{a}{2}}{1+\tan\frac{a}{2}\tan 30°20'} = .4475\,\frac{30°20' + \tan\frac{a}{2}}{1-\tan 30°30'\tan\frac{a}{2}}$$

$$\left(1.308 - 2.235\tan\frac{a}{2}\right)\left(1-.585\tan\frac{a}{2}\right) = \left(.262 + .4475\tan\frac{a}{2}\left(1+.585\tan\frac{a}{2}\right)\right.$$

$$1.308 - .765\tan\frac{a}{2} - 2.235\tan\frac{a}{2} + 1.308\tan^2\frac{a}{2}$$
$$= .262 + .4475\tan a/2 + .1532\tan a/2 + .262\tan^2 a/2$$

$1.046 \tan^2 a/2 - 3,583 \tan a/2 + 1.046 = 0$

$\tan^2 a/2 - 3.430 \tan a/2 + 1 = 0$

$\tan a/2 = \dfrac{3,430 \pm \sqrt{3.430^2 - 4}}{2} = \dfrac{3.430 \pm 2.785}{2} = .322$

$a/2 = 17^\circ 51' \qquad a = 35^\circ 42'$

Nearest path comes to pole is $+ 59^\circ 18'$ Dec.

$\dfrac{\tan \frac{1}{2}(\gamma + \alpha)}{\cot \frac{1}{2}\beta} = \dfrac{\cos \frac{1}{2}(c-a)}{\cos \frac{1}{2}(c+a)}$

$\cot \frac{1}{2}\beta = \dfrac{\tan \frac{1}{2}(\gamma+\alpha) \cos \frac{1}{2}(c+a)}{\cos \frac{1}{2}(c-a)} = \dfrac{1 \cdot .668}{.446 \cdot .976} = 1.533 = \dfrac{1}{.652}$

$c = 60^\circ 40'$

$a = 35^\circ 42'$

$24^\circ 58'$

$\frac{1}{2}(c-a) = 12^\circ 29'$

$\frac{1}{2}(c+a) = 48^\circ 11'$

$\tan \frac{1}{2}\beta = .652, \quad \beta/2 = 33^\circ 09'$

$\beta = 66^\circ 18'$

$178^\circ 48'$

$66^\circ 18'$

$52^\circ 30' =$ 3 hrs 30'.

R.A. of Point nearest pole 3 hrs 30' later than zenith R.A.

Solar day = Sidereal day + Δ

Sidereal time = Solar time + Δ

~~$\tan\frac{1}{2}\beta = \frac{\tan\frac{1}{2}(c+a)\cos\frac{1}{2}(\gamma+\alpha)}{\cos\frac{1}{2}(\gamma-\alpha)}$~~

~~$= \frac{1 \cdot .409}{.894 \cdot .911} = .503$~~

~~$\frac{\beta}{2} = 26^\circ 41'$~~ ~~$\beta = 53^\circ$~~

30
96
126

24
8
32

$\frac{52'\ 2 \times 15}{15} \times 60$

Reference Page.

$48 \times \frac{1}{15} \times 60 = 3'$ min

1700 GMT = 1200 EST
+3 Station correction
1203 Holmdel time
Sept 22 - Sept 18 = 4 days −16
4 × 4 =
11 hrs 47' Sidereal time.

1530 GMT = 1030 EST
3 Station
10 33 Holmdel Time
(Sept 22 - Sept 19) = − 12 time
10 hrs 21 min Sidereal time

1500 10 00 EST
3
10 03
Oct 15 - Sept 22 = +1 30 min
11 33 Sidereal time

1500 = 1000 EST
3
Oct 24 - Sept 22 = 206
1209 Sidereal time

1510 = 1219 " "

Holmdel. Holmdel time correction.
Rugby.

Zenith angle.

Horizon angle.

Sidereal Noise −17 DB (page

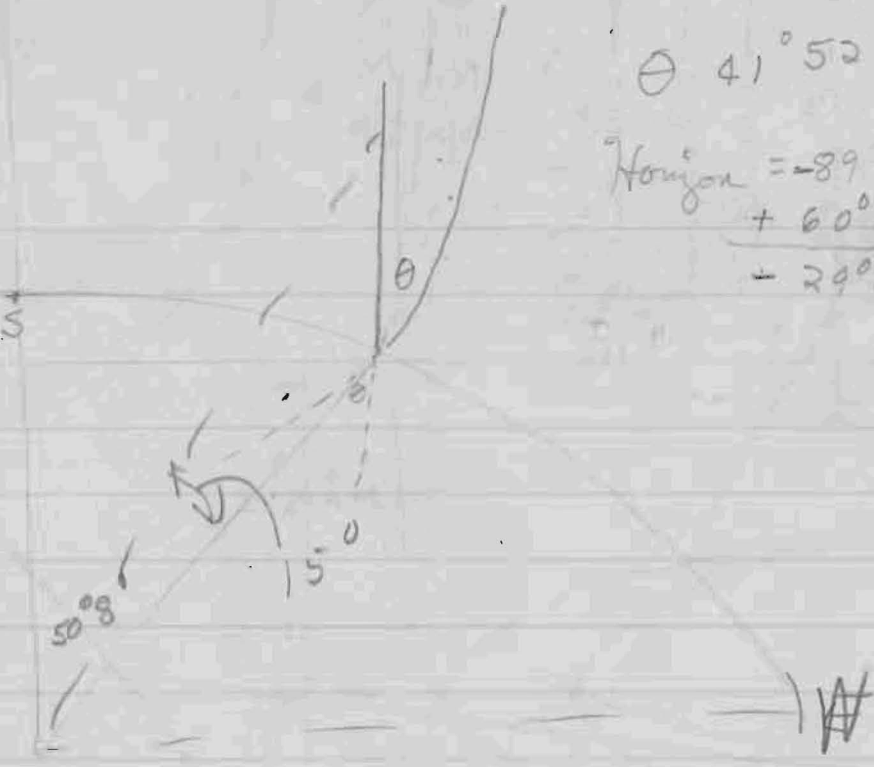
DB zero level one rhombus. (Page

Band 12 KC (page)

Also direction of Rugby from Holmdel.

Date GMT. Sidereal Time Freq. DB max DB min. Max angle.

average Pitch acceptance angle.
" Width "
reference.



θ 41°52'

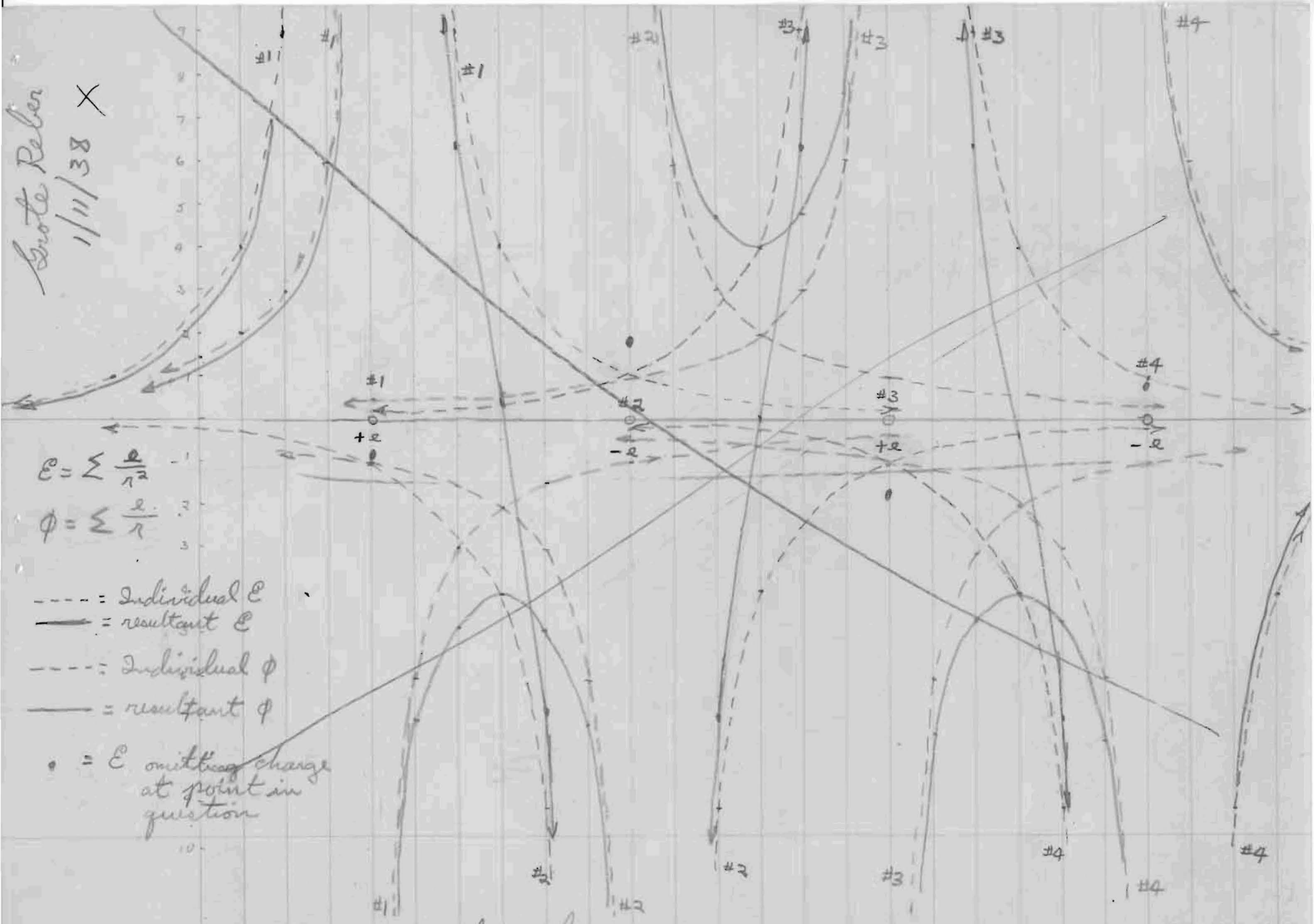
Horizon = -89°60'
+ 60°40'
- 29°20' declination

Horizon R.A = (90 - B) ahead of zenith R.A
= 8960 - 28°48' = 61°12'
61°12' = 4 hrs. 5' ahead of zenith R.A.

Bruce + Beck show major lobe of rhombic antenna to be about 15° above horizon

6:15 EST Jan 4
03 Station correction
6:18 Holmdel Time
date + 6:53 = Jan 4 - Sept 22 = 105 days × 3'56" = 413'
13:11 Siderial Time, of Zenith R.A.
7:54 N.E. horizon ahead zenith.
21:05 R.A. of horizon = point (X) = curve A.
= 31.5 DB below 10^{-12} watt.
-8:30
29:35
24:00
5:35 R.A. of horizon for other point at + 29°30' dec.

Grote Reber
1/11/38 X



$\mathcal{E} = \Sigma \frac{e}{r^2}$

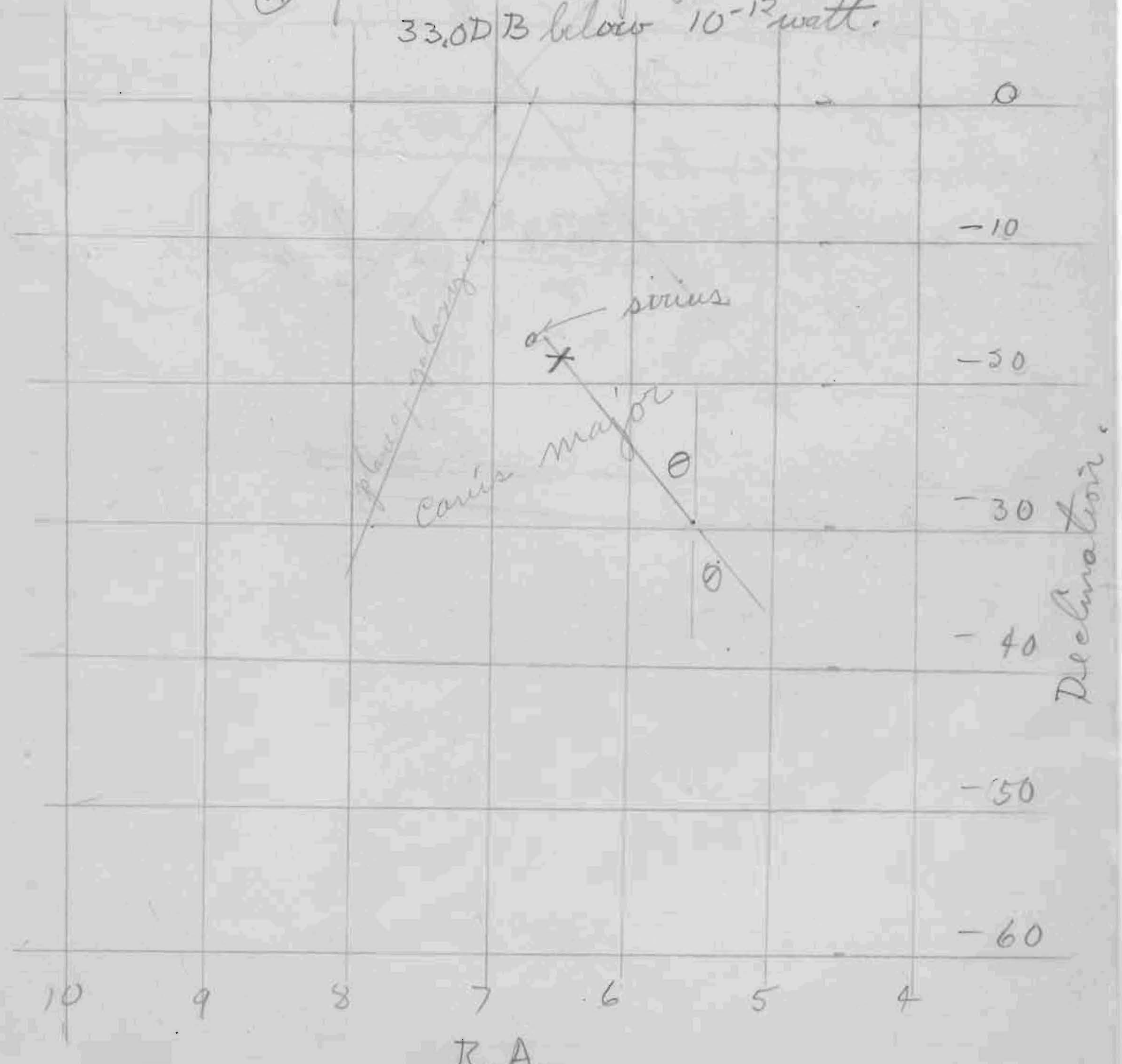
$\phi = \Sigma \frac{e}{r}$

---- = Individual ℰ
—— = resultant ℰ
---- = Individual φ
—— = resultant φ
• = ℰ omitting charge at point in question

This drawing is wrong

4:05 EST Jan 4 $\theta = 91^\circ 52'$
.03 Station correction
4:08 Holmdel Time
6:53 Jan 4 - Sept 22 105 days.
11:01 Sidereal Time of zenith
4.05 S.W. Horizon behind zenith R.A.
6:56 R.A. of S.W. Horizon.

(X)= point curve B page 1522 Dec 37 IRE,
33.0 DB below 10^{-12} watt.



$\lambda = 25$ meters

$P = 28.8$ DB below 10^{-12} watt $= 1.3 \cdot 10^{-15}$ watt

$E = 27.8$ DB below 10^{-6} volts/meter $= 4.1 \cdot 10^{-8}$ volt/meter.

$$P = k E^2 \lambda^2, \quad k = \frac{1.3 \cdot 10^{-15}}{17 \cdot 10^{-16} (25)^2} = \frac{1.3 \cdot 10^{-15}}{1.1 \cdot 10^{-12}} = 1.2 \cdot 10^{-3}$$

If rhombic has gain of 12 DB over 1/2 wave then

$P = 43.5$ DB $(31.5 + 12)$ DB below 10^{-12} watt.

$$P = \frac{10^{-12}}{2.2 \cdot 10^{9}} = 4.5 \cdot 10^{-17} \text{ watt.}$$

$$E = \sqrt{\frac{P}{k \lambda^2}} = \sqrt{\frac{4.5 \cdot 10^{-17}}{1.2 \cdot (16.7)^2 \cdot 10^{3^2}}} = \sqrt{\frac{4.5 \cdot 10^{-17}}{.33}} = 1.2 \cdot 10^{-8} \text{ volts/meter}$$

$= .012\ \mu v$/meter

$= 1.2 \cdot 10^{-10}$ volts/cm.

$$I = \frac{c E^2}{4\pi (300^2)} = \frac{3 \cdot 10^{10} (1.2)^2 \cdot 10^{-20}}{4\pi \cdot 9 \cdot 10^4} = 3.8 \cdot 10^{-16} \text{ ergs/sec/cm}^2$$

$$\frac{3.8 \cdot 10^{-16}}{1.58} = 2.4 \cdot 10^{-16} \text{ ergs/sec/cm}^2\text{/kc bd.} = U_v$$

$$B = \frac{1}{17900} \times 100 = .0056$$

$\theta'' = 10^\circ$, $\phi'' = 11^\circ$, $f = c/\lambda =$

$$T = \frac{2.8 \cdot 10^{42} \cdot 2.4 \cdot 10^{-16}}{(1.79)^3 \cdot 10^{21} \cdot 5.6 \cdot 10^{-3} \cdot 110 \cdot 10^2} = \frac{6.74 \cdot 10^{26}}{3.5 \cdot 10^{21}} = 2 \cdot 10^5 \text{ Deg.}$$

$P = 2.2 \cdot 10^{-18}$ ergs/sec/cm²/Kc bd/circular degree