portant results, and also for a determination of the parallax of the sun.

c) We shall probably undertake the observation of stellar *radial velocities of faint stars*, in collaboration with other observatories. The latitude of the McDonald Observatory, approximately 31°, will permit us to observe considerably farther to the south than is possible at the Yerkes Observatory or at any other observatory located in the United States.

d) The focal ratio of the mirror will be 1:4, and the instrument will therefore be especially suitable for obtaining *spectrograms of diffuse nebulosities* as well as of *spiral nebulae*. We shall use a quartz spectrograph at the principal focus for this purpose.

e) The McDonald telescope will also be used for other studies which we now have in mind: the positions, brightnesses, and spectra of comets, the extension of our photo-electric work, the determination of photographic and photo-visual magnitudes of faint stars, etc. The large McDonald reflector will be suitable for various proper motion problems, such as the relative motions of bright stars with respect to faint stars or to distant spirals, and the internal motions of clusters and nebulae.

Electrical Phenomena that apparently are of Interstellar Origin

By KARL G. JANSKY*

SUMMARY.

Electromagnetic waves of an unknown origin were detected during a series of experiments on atmospherics of short wave-lengths. Directional records have been taken of these waves for a period of nearly two years. The data obtained from these records show that the azimuth of the direction of arrival changes from hour to hour and from day to day in a manner that is exactly similar to the way in which the azimuth of a star changes. This fact leads to the conclusion that the direction of arrival of these waves is fixed in space; that is to say, that the source of these waves is located in some region that is stationary with respect to the stars.

Although the right ascension of this region can be determined from the data with considerable accuracy, the error not being greater than ±30 minutes of right ascension, the limitations of the apparatus and the errors that might be caused by the ionized layers of the earth's atmosphere and by attenuation of the waves in passing over the surface of the earth are such that the declination of the region can be determined only very approximately. Thus the value obtained from the data may be in error by as much as ±30 degrees.

The data give, for the coördinates of the region from which the waves seem to come, a right ascension of 18 hours and a declination of —20 degrees.

INTRODUCTION.

During the progress of a series of experiments that were being made at Holmdel, New Jersey, on the direction of arrival of atmospherics at high frequencies,[1] records were obtained that showed the presence of very weak but continuous electromagnetic waves of an unknown origin. The first indications of this phenomenon were obtained on records taken during the summer and fall of 1931, and a comprehensive study of it was made during the year 1932. The results of this study are the sub-

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ject of this paper.

The first complete records obtained showed the surprising fact that the azimuth of the direction of arrival of these waves changed nearly 360 degrees in 24 hours and subsequent records showed that each day an azimuth of 0 degrees (south) was reached approximately 4 minutes earlier than on the day before. These facts lead to the conclusion that the direction of arrival of these waves remains fixed in space, that is to say, its right ascension and declination are constant.

Apparatus.

The apparatus used will not be described in detail in this paper. The reader who is interested in that phase of the subject is referred to a former article by the author.[1] There will be given here a description only detailed enough for a complete understanding of the data and the conclusions drawn therefrom.

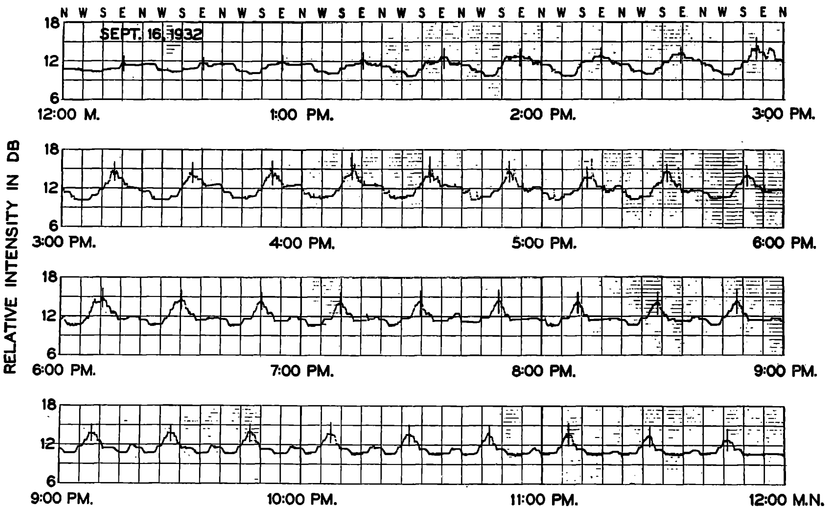

FIGURE 1.
SAMPLE RECORD OF WAVES OF INTERSTELLAR ORIGIN.

The apparatus consists of a sensitive short-wave radio receiving system to which is connected an automatic signal intensity recorder. The antenna system used is highly directive in the horizontal plane and is rotated continuously about a vertical axis once every twenty minutes so that data obtained with the system, like that obtained with a loop aerial rotated about a vertical axis, give the azimuth of the direction of arrival of signals, but tell nothing directly about its altitude. The recorder motor and the antenna driving motor are both synchronous motors operating from the same power supply so that the records obtained show the azimuth of the direction of arrival of signals directly as well as their intensity.

Figure 1 shows a sample record of the waves in question obtained with this apparatus. Time is given along the horizontal axis as also is the azimuth, (the azimuth is given along the top of the record), and relative intensity values in db..[2] along the vertical axis. The time at which the antenna was pointed in the direction from which the waves come is clearly indicated on the record by the humps in the curve the central points of which are indicated by the short vertical line.

Except where otherwise noted the apparatus was tuned to a wave-length of 14.6 meters.

Results.

If now the azimuth of the direction of arrival for any particular day is plotted against the time of day, a curve similar to one of those of

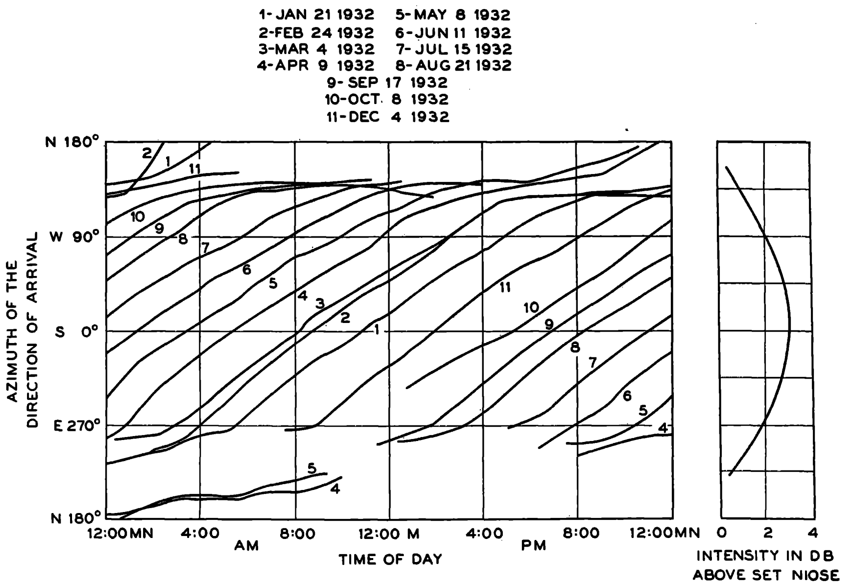

Figure 2.

Azimuth of the Direction of Arrival of Waves of Interstellar Origin Plotted Against Time of Day.

Figure 2 is obtained. Thus data from the record just mentioned constituted part of that from which curve 9 of this figure was obtained. The figure shows curves for eleven different days spaced approximately one month apart during the year 1932. There is no curve for the month of November. These curves were obtained by averaging the data taken over several consecutive days so as to eliminate the effects of the errors made in measuring the records. The day assigned to a given curve is the middle day of the group over which the data for that curve were obtained.

The curve at the right in the figure shows the variation of intensity of the waves plotted against the azimuth of the direction of arrival. It is to be noted that the intensity of the waves is independent of the time of day, but directly dependent upon the hour angle of the direction of arrival. Thus the waves are always at their maximum intensity when this hour angle is zero.

Two important facts are disclosed by this figure. First, the azimuth of the direction of arrival changes gradually and uniformly through

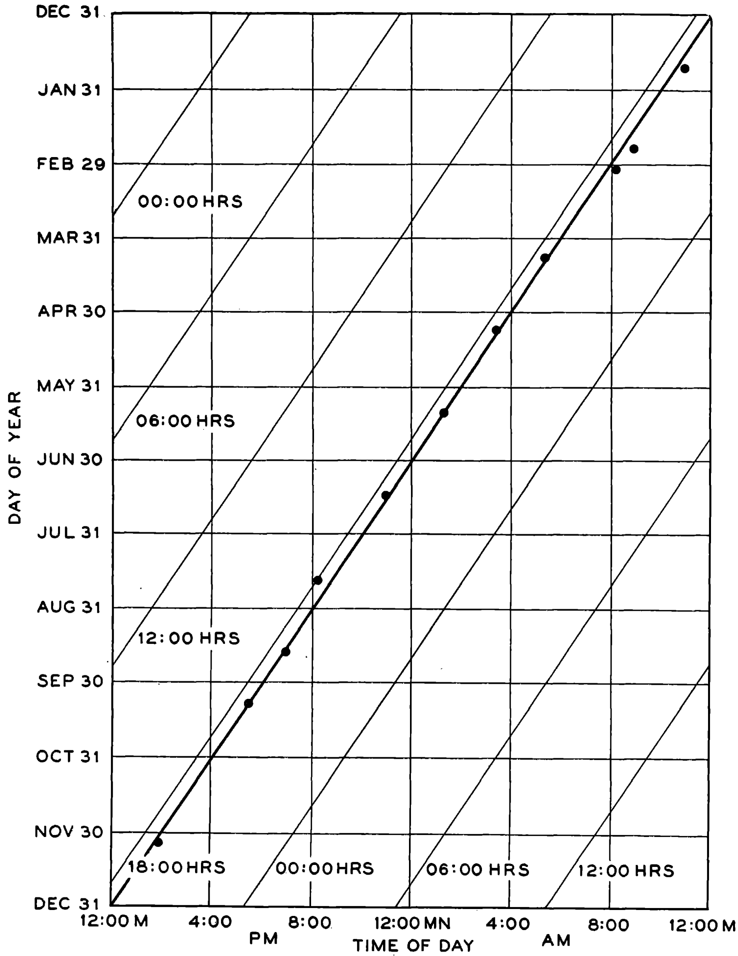

FIGURE 3.

TIME OF TRANSIT OF DIRECTION OF ARRIVAL ACROSS THE MERIDIAN OF THE RECEIVING LOCATION.

nearly 360 degrees during 24 hours. Second, there is a uniformly progressive shift of the curves to the left from month to month which at the end of one sidereal year brings the curve back to its initial position. To one familiar with the manner in which the heavenly bodies change their positions hourly and daily these facts indicate that the direction of arrival is fixed in space.

That the right ascension of this direction of arrival remains constant will be evidenced more clearly by plotting the times of transit of the direction of arrival across the meridian of the receiving location for several days spaced uniformly throughout the year against the day of the year. If the right ascension of the direction of arrival remains constant, the points so obtained should all fall on a straight line[3] having a slope of 1/24 of a sidereal year per hour. Now it will be shown later that the declination of the direction of arrival is less than the latitude of the location of the receiver so that when the transit takes place the azimuth of the direction of arrival is zero. The times at which the curves of Figure 2 have an azimuth of 0 degrees, *i.e.* the times at which they cross the line the ordinate of which is 0 degrees are plotted against the day of year in Figure 3. The correspondence of the points with the heavy line the slope of which is 1/24 of a sidereal year per hour cannot be accidental and indicates that the right ascension of the direction of arrival remains constant.

The position of this heavy line on the graph is determined by the value of the right ascension. Thus the position of the curves corresponding to a right ascension of 0 hours, 6 hours, 12 hours, and 18 hours are shown by the light diagonal lines on the figure. From the relative positions of the heavy line and the light lines it will be seen that the measured direction of arrival occurs at a right ascension of approximately 18 hours, 30 minutes; however, because the recorder mechanism requires a measurable length of time to record the field strength values, the directions measured on the records lag behind the true directions by a value varying fom 4 to 9 degrees. If the measured values are corrected for this error, the right ascension of the direction of arrival becomes approximately 18 hours.[4]

If the declination of the direction of arrival remains constant also, the separate curves of Figure 2 should be similar in shape to one of those of Figure 4. This figure shows theoretical curves of azimuth plotted against time for several different declinations. In this figure time is given not in terms of hours of the day, but in terms of the time interval before and after the time of transit of the direction of arrival. The values of declination used for the different curves are given in the figure. The curves are dotted for that portion of the time that the altitude of the direction of arrival would be negative.

For the purpose of making a comparison between these curves and those of Figure 2, an average of the curves of Figure 2 is shown in the figure by the broken line. It will be seen that for the greater part of the time during which the direction of arrival is above the horizon it lies between the curves for a declination of 0 degrees and —20 degrees, but the remaining portions of the curve are not at all similar in shape to any of the theoretical curves. However, as the time interval before or after the time of transit of the direction of arrival is increased, the waves must travel through an increasing thickness of the earth's atmosphere so that any distortion of the direction of propagation of the waves by the ionized layers would increase also and when the altitude of the direction of arrival is less than 0 this distortion might be excessive and coupled with the attenuation of the waves suffered during their passage through the atmosphere might be the cause of the difference between the theoretical and actual curves noted.

It should be emphasized here that at the time of transit of the direction of arrival, this bending is confined to the plane determined by the meridian of the receiving location and will therefore cause no error in the measurement of the right ascension if it is made in the manner de-

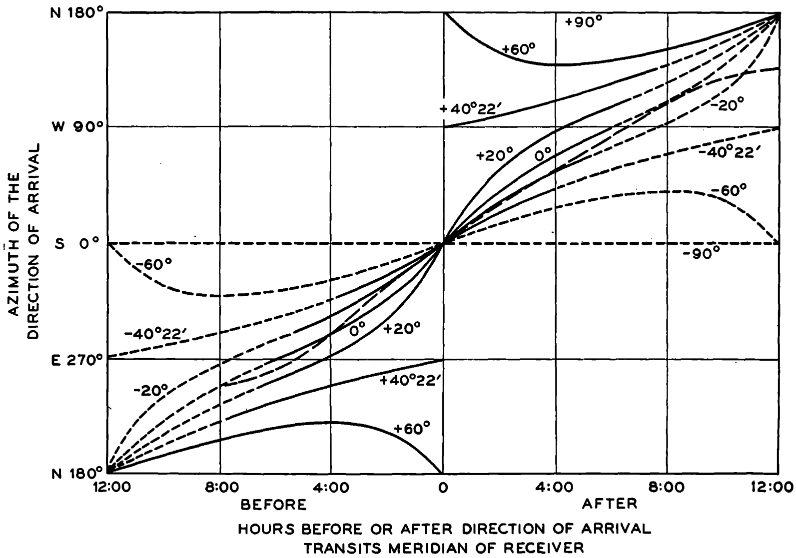

FIGURE 4.

COMPARISON BETWEEN ACTUAL AND THEORETICAL CURVES OF THE AZIMUTH OF THE DIRECTION OF ARRIVAL FOR DIFFERENT DECLINATIONS.

scribed above. Also at this time, since the direction of arrival is more nearly perpendicular to the earth's surface than at any other time, the bending, even in the plane of the meridian, will be less than at any other time so that the value of the declination obtained from the curves for this time will be more nearly accurate that that obtained at any other time. At this time the average curve coincides with the theoretical curve for a declination of —20 degrees and that is the value taken for the declination of the direction of arrival of the waves in question.[5]

At all other times, whatever bending the waves suffer will cause errors in both measurements. However, from a consideration of the data and the method of interpretation, it is believed that in spite of the possible errors mentioned, the declination of the source, or center of activity if there is more than one source, as measured would be accurate within an error not greater than ±30 degrees.

Discussion.

The above data all seem to point to a single source fixed in space with the electromagnetic waves traveling in more or less straight lines from the source with some of them ultimately reaching the receiver. There are, however, other phenomena perfectly conceivable and none the less fascinating that would give similar results.

For example: it may be that the electromagnetic waves that reach the receiver actually do originate in the earth's atmosphere. In that case the data would seem to demand that these waves are secondary radiations sent out from the points of impact with the earth's atmosphere of some primary rays of unknown character and which come from a source or sources fixed in space. If this is the case, then the disturbance measured by the receiver is probably the summation of very many waves of various intensities coming from secondary sources in the earth's atmosphere that are scattered over a considerable area, and the coördinates obtained are those of the source of the primary rays or, if there is more than one source, of the center of activity of these sources providing they are uniformly distributed over a given area.

If the waves that reach the receiver are such secondary radiations then the question of the character of the primary rays is immediately raised. The possibility of such rays being composed of high speed particles, charged or neutral, should be mentioned. In fact such a possibility has just recently been given added importance by a publication[6] of Gunn showing the probability of just such high speed particles being present in interstellar space. If the particles are charged, *i.e.* if they are positive or negative ions, they must excite the secondary radiations before they are appreciably deflected from their original paths by the earth's magnetic field otherwise the waves would not reach their maximum intensity when the azimuth of the direction of arrival is 0 degree as is shown by the curve to the right in Figure 2.

The possibility of a group of sources not being uniformly distributed over a given area with respect to the earth presents the most fascinating explanation of the data, for after a brief consideration of the curves given in Figure 2 it will be evident that a disk-like distribution of the sources around the earth like the distribution of the stars in the Milky Way would give a very similar curve. This possible explanation proves even more interesting when it is discovered that the coördinates given by the data are very nearly the same as those for the center of the Milky Way, the coördinates of which point are approximately right ascension 17 hours, 30 minutes, declination —30 degrees (in the Milky Way in the direction of Sagittarius)[7] well within the limit of error of the data; and also because the records show a small hump between the main humps in certain sections of the record just as would be expected if the Milky Way were the source of the waves.

Considerable data will have to be taken and thoroughly analyzed, however, before such a theory or for that matter before any theory relative to the source of these waves can be accepted.

Although all the data presented so far in this paper were taken on a wave-length of 14.6 meters, a few runs were made on wave-lengths ranging from 15 meters to 13 meters with no apparent change in the intensity of the waves. Due to the fact that the antenna system loses its directivity outside of the wave-length range, no data have been taken on other wave-lengths.

At no time did the intensity of the waves reach a value in excess of 0.39 microvolts per meter for a receiver with a 1.0 kilocycle band width.

Conclusion.

In conclusion, data have been presented which show the existence of electromagnetic waves in the earth's atmosphere which apparently come from a direction fixed in space. The data give for the coördinates of this direction a right ascension of 18 hours and a declination of —20 degrees.

The experiments which are the subject of this paper were performed during the year 1932 at the Holmdel Radio Laboratories of Bell Telephone Laboratories, Inc., which have a north latitude of 40 degrees 20 minutes and a west longitude of 74 degrees 10 minutes.

References.

[1] Karl G. Jansky, "Directional Studies of Atmospherics at High Frequencies," *Proc. I.R.E.*, Vol. 20, p. 1920, December, 1932. The disturbances that are the subject of this paper are the same as the third group of static of the above paper.

[2] The db.. or decibel is a term used in communication work to express the logarithm of the ratio between two powers or frequently, as in this case, between two voltages. Thus:

$$\text{Voltage ratio in decibels (db..)} = 20 \log_{10} (V_1)/(V_2)$$

For a more complete description of the decibel and its uses see: W. H. Martin, "Decibel—The Name for the Transmission Unit," The Bell System Technical Journal, Vol. VIII, p. 1, January, 1929, and R. V. L. Hartley, "The Transmission Unit," Electrical Communication, Vol. 3, p. 34, July, 1924.

[3] Strictly speaking the line should not be exactly straight. Of the many reasons why this is so the most important is that the earth's motion in its orbit is not uniform. However, the effects are all so small that the greatest deviation would be scarcely perceptible on the curve so they will not be considered in this discussion.

[4] The limit of error has not been exactly determined, but it certainly is not greater than ±30 minutes of right ascension.

[5] In a former paper by the author, "Electrical Disturbances Apparently of Extraterrestrial Origin," *Proc. I.R.E.*, Vol. 20, October, 1933, the value —10 degrees was given for the value of the declination, but for the reasons given above the value —20 degrees is now believed to be more nearly accurate.

[6] Ross Gunn, "Possible Stellar Origin of High-Speed Ions," *Terrestrial Magnetism and Atmospheric Electricity,* September, 1933, p. 247.

[7] H. Spencer Jones, "General Astronomy," pp. 358, 359. Forest Ray Moulton, "Astronomy," pp. 479, 504-509.

Little Silver, New Jersey, September 14, 1933.