SPACEBORNE OBSERVATIONS OF RADIO NOISE FROM 0.7 TO 7.0 MHz AND THEIR DEPENDENCE ON THE TERRESTRIAL ENVIRONMENT

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Résumé. — *On rend compte d'observations du rayonnement hertzien dans l'espace sur des longueurs d'onde supérieures à* 30 *m. On analyse ces résultats en tenant compte de l'environnement terrestre.*

Aux altitudes voisines de 300 *km et sur les fréquences de* 4,0 *et* 7,0 *MHz, on a constaté l'existence de niveaux de bruit très élevés pendant la nuit et dans certains cas pendant le jour. Ces signaux sont au moins* 50 *db au-dessus du bruit cosmique auquel on peut s'attendre et ils sont attribués aux atmosphériques et aux parasites industriels.*

Les mesures à des altitudes comprises entre 3000 *et* 11000 *km fournissent des valeurs du flux sur* 2,2 *MHz voisins des valeurs prévues pour le bruit cosmique alors que sur* 0,7 *MHz le niveau reçu est* 15 *db au-dessus des valeurs prévues. On suggère que le rayonnement cyclotron des ceintures de* Van Allen *et de la ceinture artificielle pourrait expliquer les observations sur* 0.7 *MHz.*

Abstract. — *Observations of long-wavelength* ($\lambda > 30$ *m*) *radio radiation in space are reported and analyzed in the framework of the terrestrial environnement.*

Measurements at low altitudes ($\sim$ 300 *km*) *at the frequencies of* 4.0 *and* 7.0 *MHz have revealed the existence of very high radio noise levels during the night and on certain occasions during the day. These strong signals were at least* 50 *db higher than the expected cosmic background and are attributed to man-made and atmospheric radio noise.*

Measurements at high altitudes (3000-11000 *km*) *at the frequencies of* 2.2 *and* 0.7 *MHz have produced a flux value at* 2.2 *MHz in agreement with the expected cosmic radio background, but the flux value obtained at* 0.7 *MHz is approximately* 15 *db higher than the anticipated flux from cosmic sources. Harmonic gyroradiation from the artificial and the outer* Van Allen *belts might be the cause of the high radio flux observed at* 0.7 *MHz.*

Резюме. — Приведен отчет о наблюдениях герцевого излучения в пространстве на длине волн превосходящих 30 м. Эти результаты проанализированы учитывая окружение Земли.

На высотах около 300 км. и в частотах 4.0 и 7.0 мгц было констатировано существование очень высоких шумовых уровней ночью, а в некоторых случаях-днем. Эти сигналы превышают по крайней мере на 50 бол. гр. космический шум, который можно ожидать, и их приписывают атмосферикам и индустриальным паразитам.

Измерения на высотах заключенных между 3.000 и 11.000 км. дают значения потока в 2,2 мгц близкие к значениям предвиденным для космического шума. Тогда как в 0,7 мгц полученный уровень превышает на 15 бол. гр. предвиденные значения. Выдвинута мысль, что циклотронное излучение поясов Ван Аллена и искусственного пояса смогли-бы объяснить наблюдения в 0,7 мгц.

Introduction

Long-wavelength ($\lambda > 30$ m) observations of extraterrestrial radio radiation are carried out in the vicinity of the Earth from satellites and rocket probes. These observations, therefore, must be analyzed in the context of the terrestrial environment, a fair understanding of which is essential for their correct interpretation.

In general, we can separate the terrestrial radio radiation into radio noise produced below the ionosphere and radio emission produced near and above the F-max. Atmospheric and man-made radio noise are the main sources below the ionosphere. It is important to know how effectively the ionosphere can shield observations conducted above the F-max from this radio interference. Coherent Čerenkov radiation and harmonic gyroradiation can produce significant radio noise levels in the Earth's exosphere with undetermined spectral and spatial distributions.

The Space Radio Project of Harvard University has made observations both at low and high altitudes using, respectively, the 1962 Alpha-Beta satellite and the AP-3 high altitude rocket probe.

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The 1962 Alpha-Beta Satellite

The satellite 1962 Alpha-Beta carried a picka-back scientific payload which contained two radiometers at 4.010 MHz and 6.975 MHz, an antenna impedance probe for the measurement of the local electron density, and a three-axes magnetometer.

The satellite was launched in June 1962 from the Western Test Range in California into a high-inclination (75°) orbit with an apogee of 370 km and a perigee of 200 km. The orbit was considerably lower than anticipated and the satellite decayed in 15 days producing a total of only 25 h 42 m of tape recorded data and 1 h 55 m of real time data. A more detailed description of the instrumentation, the orbits, and the results obtained appears in Huguenin (1963) and in Papagiannis (1964).

Figure 1 shows the radio noise data from one of the available orbits together with other pertinent information. The data obtained with the 62 Alpha-Beta satellite led to the following three observations.

1) The radio noise just below the F-max follows the diurnal variations (high during the night, low during the day, steep changes at sunrise and sunset) that are characteristic of the radio noise observed on the surface of the Earth (URSI, 1962). The high intensities recorded at night-time, however, are at least 20 db higher than the corresponding ground-based measurements and at least 50 db higher than the expected cosmic radio background.

2) On four occasions (twice over Western Europe, once north-east of Leningrad and Moscow, and once over the Caribbean) strong radio signals were received during the daytime when, as a rule, the radio noise level was very low. It should be noted that no other daytime passes over the above mentioned areas were available. The daytime pass over the Caribbean is shown in Figure 2.

3) A latitude dependence was observed, characterized by an intensity decrease toward the South Pole. There was also a longitudinal dependence with signals decreasing even further when the southernmost part of the orbit (75 °S) was near the South geomagnetic pole, i. e., at $\sim$ 85° South geomagnetic latitude. The latitude and longitude dependence is in general agreement with available world-wide maps (C. C. I. R. 1957) of ground measured radio noise.

The above observations were not entirely unexpected and can be explained as follows. During the night the conditions for radio wave propagation are more favorable because the absorbing D and E-layers disappear and reflection occurs $\sim$ 100 km higher. As a result, in the dark hemisphere, the satellite receives signals only weakly attenuated from a large part of the planet. During the day, on the other hand, the signals received are strongly attenuated and come from a relatively small part of the Earth because of the critical cone imposed on the radio reception by the daytime high electron density which surrounds the satellite. This cone, centered around the nadir, has a half angle θ_c given approximately by :

$$\cos \theta_c = f_N/f.$$

[For more details, see Papagiannis and Huguenin (1963)].

When the satellite passes during the day over regions with high man-made noise level (e. g., Western Europe) or high thunderstorm activity (e. g., Caribbean), the critical cone sweeps over the high radio noise area and a strong peak is recorded. This explanation is supported by the locations where these noise peaks were observed and by the fact that in the following orbit, when the satellite reached the same latitude but 22° to the West (due to the rotation of the Earth) these peaks were still noticeable but much weaker, especially at 4 MHz.

The latitude dependence arises from the fact that most of the man-made and thunderstorm activity is concentrated at moderate latitudes. The longitudinal variation might be due either to the general noise distribution over the entire planet (e. g., more radio noise over continents than over oceans), or to the fact that part of the radio noise in the polar regions is produced by sources such as the horns of the outer Van Allen belt, the Auroras, etc., which follow the geomagnetic (60-75°) rather than the geographic latitude.

The radio noise levels obtained in the night-time passes near the South Geomagnetic Pole (where the terrestrial interference seemed to be at its minimum and the critical frequency of the F-max was undoubtedly much lower than 7.0 MHz), probably represent the cosmic radio background. The value deduced is :

$$T_b = (1.5^{+1.0}_{-0.5}) \times 10^6 \,^{\circ}\mathrm{K}$$

and is in general agreement (full triangle with error bars in Figure 3) with other existing observations.

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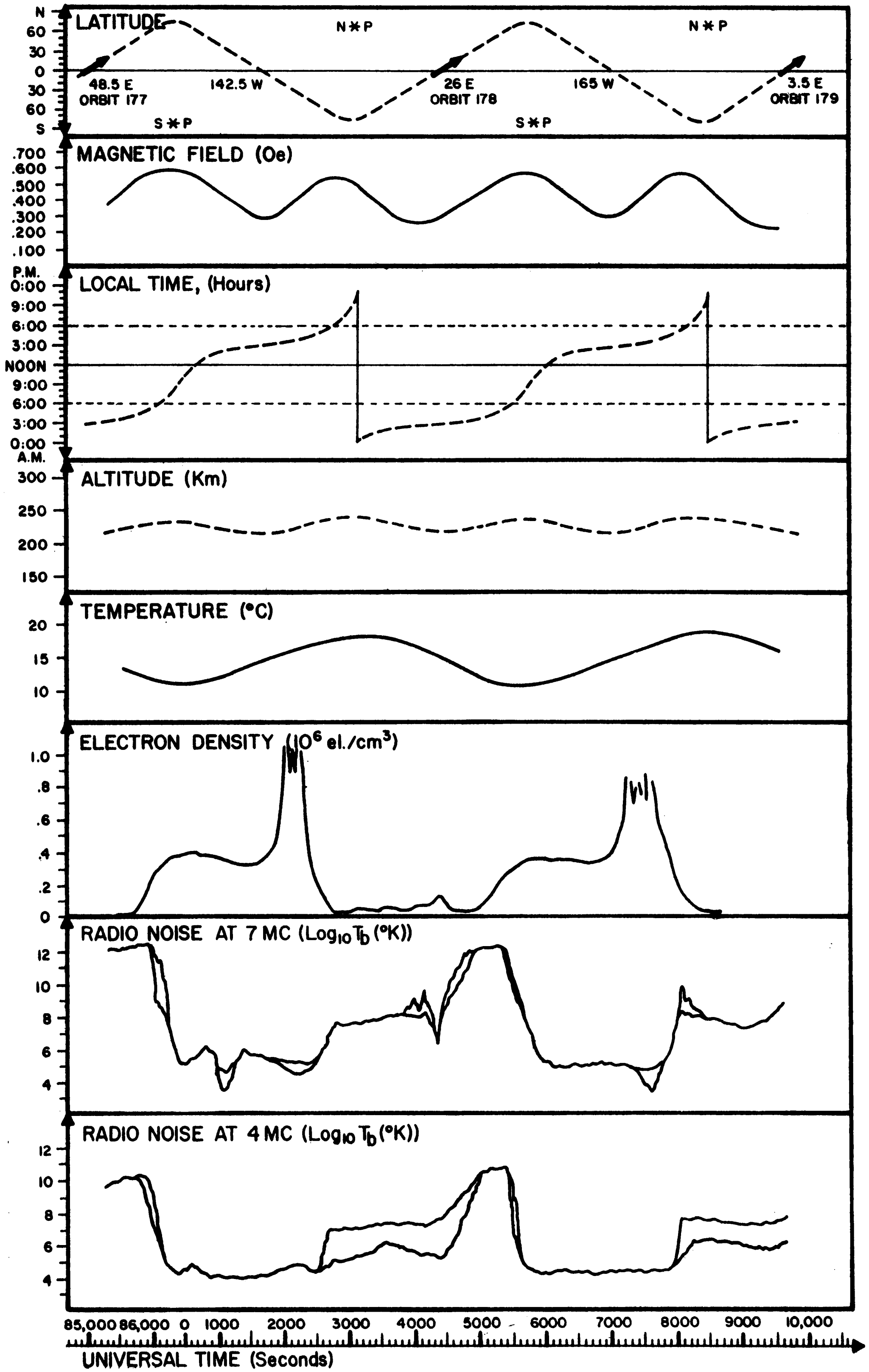

DATA FROM THE 62A-BETA SATELLITE
ON JULY 3-4, 1962

Fig. 1.

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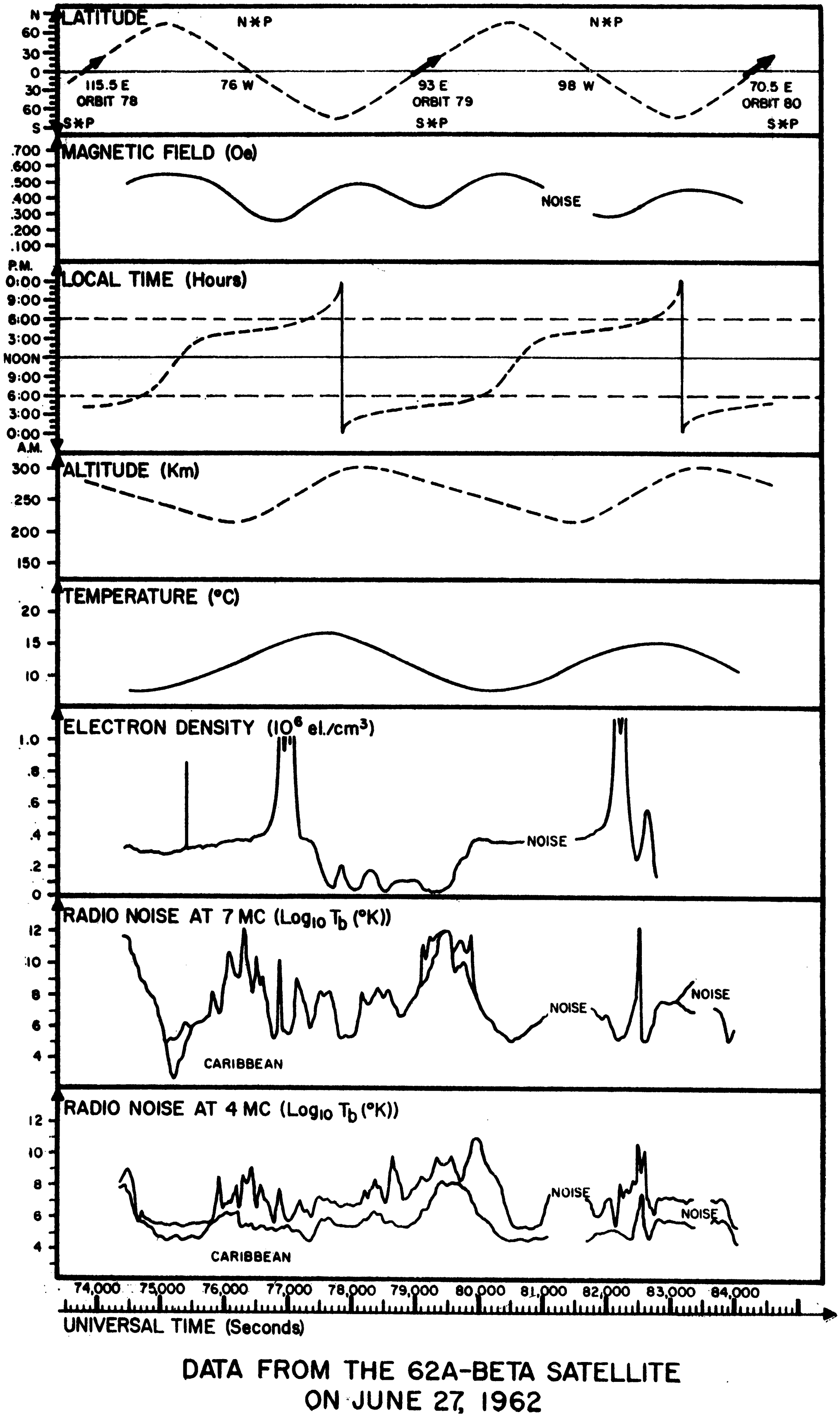
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N*P
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76 W
93 E
ORBIT 79
98 W
70.5 E
ORBIT 80
S*P
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S*P
MAGNETIC FIELD (Oe)
NOISE
LOCAL TIME (Hours)
P.M.
NOON
A.M.
ALTITUDE (Km)
TEMPERATURE (°C)
ELECTRON DENSITY (10^6 el./cm^3)
NOISE
RADIO NOISE AT 7 MC (Log10 Tb (°K))
NOISE
NOISE
CARIBBEAN
RADIO NOISE AT 4 MC (Log10 Tb (°K))
NOISE
NOISE
CARIBBEAN
UNIVERSAL TIME (Seconds)
DATA FROM THE 62A-BETA SATELLITE
ON JUNE 27, 1962

Fig. 2.

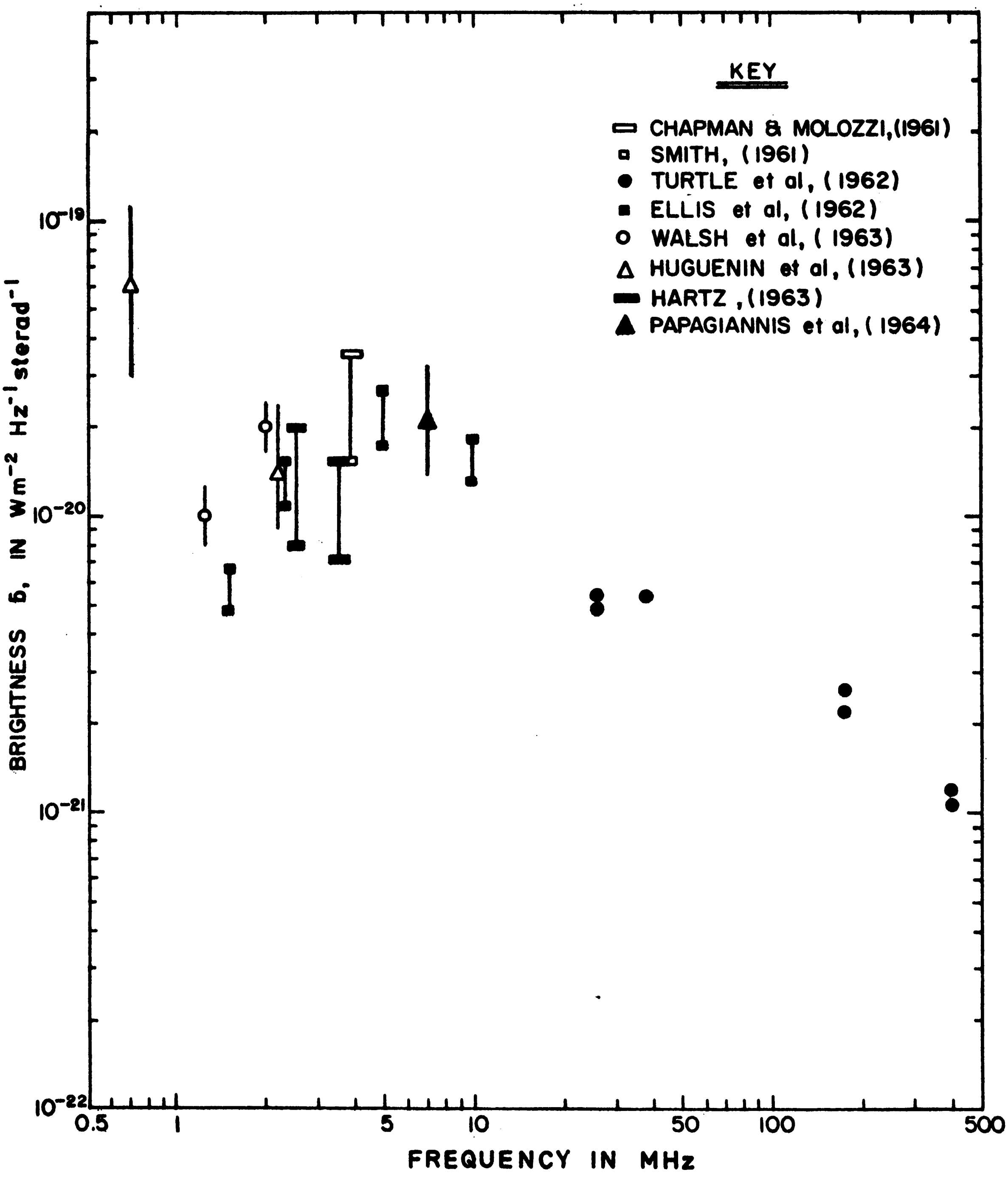

FIG. 3.

In conclusion, the measurements performed with the 1962 Alpha-Beta satellite have shown that at levels below the F-max, the radio noise distribution follows, in general, the same diurnal and world-wide pattern as the one observed from the ground. However, because at satellite altitudes one has a direct view of a much larger ground area, the maxima observed during the night are higher by at least two orders of magnitude. Furthermore, during the quiet daytime conditions, one should expect to encounter high radio intensities whenever passing directly above areas of high radio noise activity.

The composite picture we have obtained for the flux levels in the lower ionosphere suggests that careful planning must precede experiments

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designed to observe the cosmic radio background above the F-max. The low altitude of the orbit did not allow us to evaluate the effectiveness of the ionospheric shielding. However, the available results suggest that at daytime and at frequencies less than half the ionospheric critical frequency, the satellite should be relatively well-shielded except possibly when passing directly above centers of high radio noise activity or anomalous regions of the ionosphere.

The AP-3 High Altitude Rocket Probe

This Blue Scout, Jr. high altitude rocket carried two radiometers for observations at 0.7 and 2.2 MHz. On board the rocket probe were also a single axis magnetometer and an antenna impedance probe. Details of the instrumentation are given in HUGUENIN, LILLEY, McDONOUGH and PAPAGIANNIS, 1964.

The rocket was launched from Cape Kennedy on 30 July 1963 and reached a maximum altitude of 11,100 km. Figure 4 shows the elements of the payload's ballistic trajectory. Unfortunately, the impedance probe did not work properly and thus we were deprived of very useful information on the local electron density.

The objective of this flight was to measure the integrated cosmic radio background at 0.7 and 2.2 MHz, and, at the same time, to look for terrestrial effects as the probe passed through different altitudes, longitudes, and latitudes. Figure 5 shows the results obtained expressed in terms of the total flux [$Wm^{-2}\ Hz^{-1}$] received *vs* flight time. Data were first obtained near 3,900 km (following antenna erection which followed last stage burnout), through the apogee at 11,100 km, until loss of telemetry coverage near 2,500 km.

As seen from Figure 5, the flux received on both frequencies remained nearly constant over the entire trajectory. This allowed us to obtain good flux values at 0.7 MHz and 2.2 MHz and suggests that there was no significant leakage from the ground. (If there were a strong ground component, its intensity would have changed by a factor of 20 from the lowest to the highest altitudes available.) If there were a terrestrial component from radio emission in the exosphere, it did not show up as an altitude or latitude effect. However, because of the nearly symmetric trajectory about the equator, it is possible that the altitude and latitude effects cancelled each other almost completely.

Over the entire trajectory, four events were recorded during which the fluxes deviated largely from their otherwise constant values. These events are marked with the letters A, B, C, and D in Figures 4 and 5, and the conditions under which they occurred are given in Table I.

In event A, an increase in flux was observed on both frequencies. It should be mentioned that no solar or Jovian bursts of any significance were recorded by ground stations during the flight of the AP-3 high altitude probe. In event B, a flux increase was observed at 0.7 MHz which was not accompanied by any detectable variation at 2.2 MHz. In event C, a sudden, short-duration decrease in the flux at 0.7 MHz was directly reciprocated by a similar increase at 2.2 MHz. This phenomenon suggests that the payload was probably passing through a layer or a cloud of increased electron density ($f_N > 0.7$ MHz) which, as a plasma instability, was also producing radio noise (LEPECHINSKY and ROLLAND, 1964) possibly strong enough to explain the observed increase at 2.2 MHz. From the duration of the event, this irregularity must have had a thickness along the trajectory of approximately 250 km.

In event D, the flux at 0.7 MHz was increased by more than two orders of magnitude whereas the flux at 2.2 MHz showed no significant change. One could say that event D was a magnified version of event B. Event D is difficult to explain, especially without having electron density data and observations at corresponding altitudes from the ascending leg of the trajectory. A possible explanation is that the probe had enterred the region $f_N^2 \leqslant f^2 \leqslant f_N^2 + f_H^2$ and was experiencing plasma resonances. However, the large altitude range over which event D extended and the small value of f_H do not favor such an explanation. Another possibility is that the probe had entered the region which is illuminated by the focused beam of harmonic gyroradiation produced in the southern horn of the artificial VAN ALLEN belt. Event B in this case could be a weak reflection from the northern horn of the belt.

These four events indicate the existence of significant effects in the terrestrial exosphere which need further investigation.

The measured fluxes and their estimated errors are :

$$S(0.7\ \mathrm{MHz}) = (8^{+6}_{-4}) \times 10^{-19}\ \mathrm{W\ m^{-2}\ Hz^{-1}}.$$
$$S(2.2\ \mathrm{MHz}) = (1.8^{+1.0}_{-0.5} \times 10^{-19}\ \mathrm{W\ m^{-2}\ Hz^{-1}}.$$

If we assume an isotropic distribution of the measured flux over 4π steradians the corres-

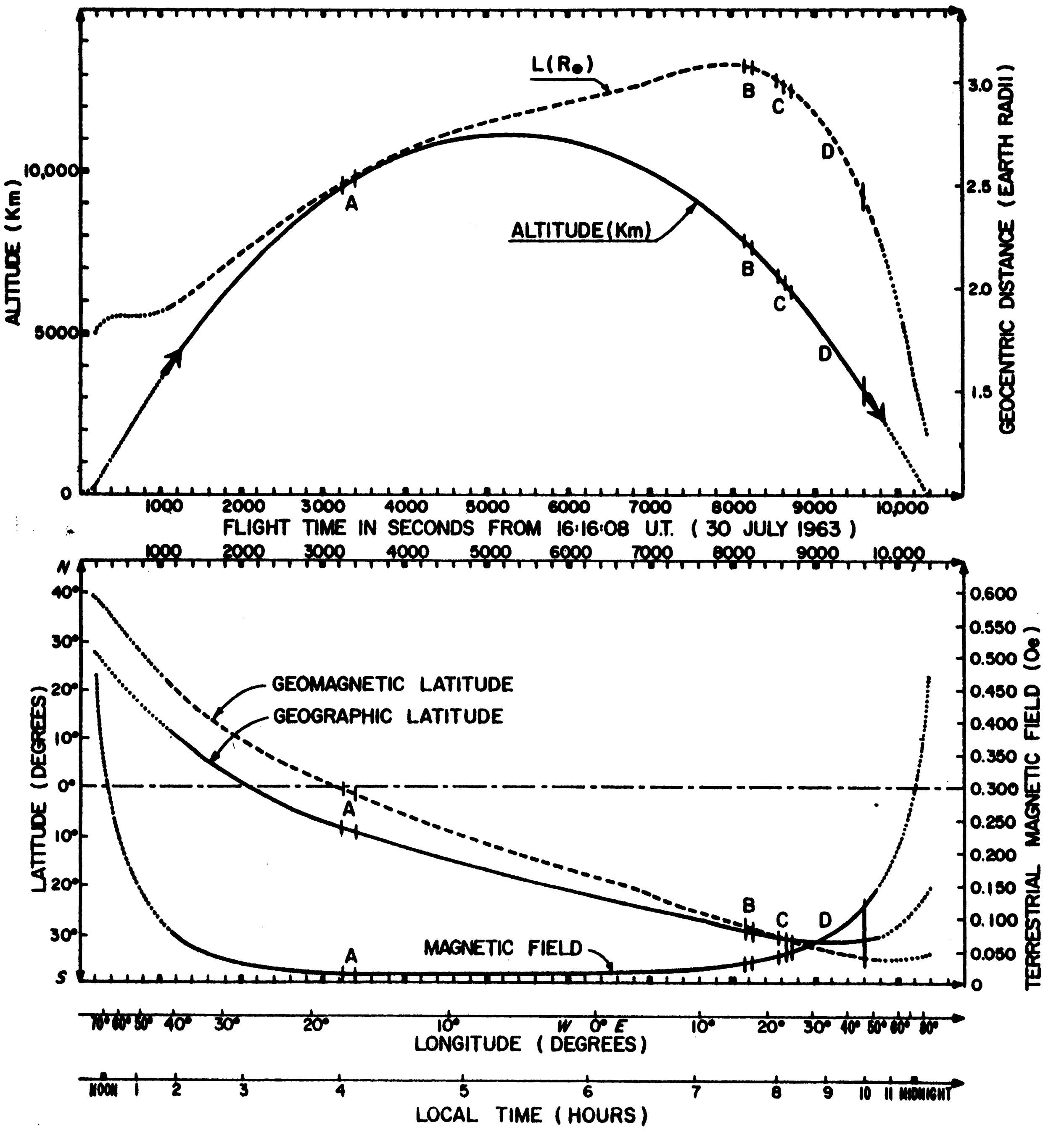

FIG. 4.

ponding values of sky brightness are shown (triangles with error bars) in Figure 3 along with other available observations at nearby frequencies. From this diagram it is clear that the sky brightness obtained at 2.2 MHz is in general agreement with the other existing results. The sky brightness, though, observed at 0.7 MHz is perhaps ~ 15 db higher than expected from the trend of the spectrum and relevant theoretical computations. It should be noted, however, that existing values for frequencies below 2 MHz were deduced from ground-based observations and observations from low altitude rockets and satellites. It is possible therefore that both low and high altitude observations are correct and that the difference is due to strong radio emission in the terrestrial

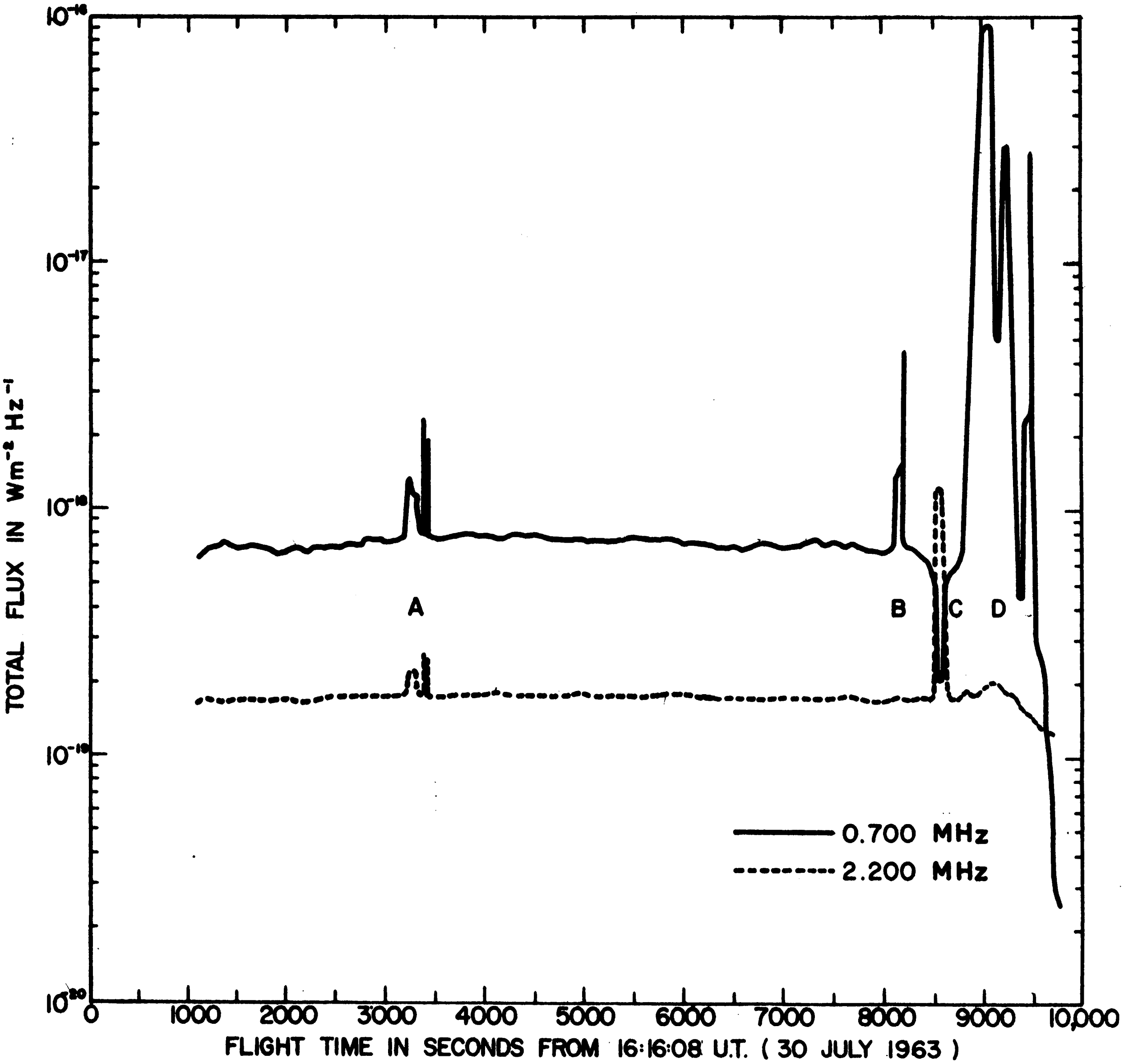

FIG. 5.

exosphere. A potential radio source of this type is the harmonic gyroradiation from the outer VAN ALLEN belt, or the artificial belt which was created by the high altitude nuclear detonations and was still quite hot. The fact that no substantial increase was observed at 2.2 MHz is not entirely surprising because if 0.7 MHz corresponds to the second harmonic, then 2.2 MHz would correspond to the much weaker 6 th or 7 th harmonic. Furthermore, the fact that no substantial changes in the flux were observed during the entire flight is also not very surprising, given the symmetry of the trajectory about the equator.

Summarizing our observations at low and high altitudes, we think it is useful to divide the long wavelength measurements of the cosmic radio background into three groups.

1) $f > 4$ MHz. These measurements can, in principle, be performed from altitudes around 500 km on up. It is advisable, however, to perform them at much higher altitudes and, if possible, during the day in order to avoid strong interference from the ground.

2) 1 MHz $< f <$ 4 MHz. This is the best range for observations because it is relatively safe from ground interference and relatively free from

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TABLE I

Event	A	B	C	D
Onset time in seconds from 16 : 16 : 08.6 UT 30 July 1963	3,258	8,158	8,536	8,731
Onset time in UT	17 : 10 : 26	18 : 32 : 06	18 : 38 : 24	18 : 41 9 :
Duration (seconds)	160	80	90	800
Altitude at onset (km)	9,500	8,200	6,850	6,300
Altitude at end (km)	9,700	8,000	6,600	3,200
Geographic longitude	16 °W	15 °E	20 °E	27 °E-47 °E
Geographic latitude	8 °S	29 °S	30 °S	31 °S
Geomagnetic latitude	1 °S	28° S	30 °S	31 °S-35 °S
L in Earth radii	2.55	3.05	3.00	2.95-2.45
Magnetic field (Gauss)	.015	.035	.045	.050-.120
$Y = \omega_H/\omega$(0.700 MHz)	0.06	0.14	0.18	0.20-0.48
Flux [Wm^{-2} Hz^{-1}] from event at 0.700 MHz	1.5×10^{-18}	3.8×10^{-18}	Drops to 1.8×10^{-19}	8×10^{-17}
Flux [ωm^{-2} Hz^{-1}] from event at 2.200 MHz	1.2×10^{-19}	0	1.3×10^{-18}	0

the terrestrial exospheric component. These measurements can be performed from ~ 1,000 km on up.

3) $f < 1$ MHz. These observations must be performed at much higher altitudes so that $f_N < f < 1$ MHz. However, the radiometers at these altitudes and these frequencies will unavoidably be exposed to the strong harmonic gyroradiation from the Earth's Van Allen belts, which will make these measurements difficult to interpret.

Further experimental and theoretical work is needed, especially at low frequencies and high altitudes, in order to understand clearly the terrestrial radio environment and thus correctly interpret the measurements of cosmic radio radiation from satellites and high altitude probes.

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