Reports

Earth as an Intense Planetary Radio Source: Similarities to Jupiter and Saturn

Abstract. *Observations from spacecraft have revealed naturally occurring radio emission emanating from two regions near Earth. The characteristics of these two sources suggest a correlation with areas of known electron precipitation. The possibility of a similar production mechanism for observed nonthermal radio emissions from other planetary magnetospheres permits the polar magnetic field strengths of Jupiter and Saturn to be predicted.*

A radio astronomer observing our solar system from some remote point would describe Earth, in addition to Jupiter and Saturn, as an intense and fascinating planet. Warwick (*1*) predicted, over a decade ago, that Earth should be a radio source "after the fashion of Jupiter, but at broadcast frequencies." We on Earth are not generally aware of the intense noise produced in our magnetosphere because the ionosphere reflects this noise back out into space. However, radio astronomy experiments in orbit above this reflecting layer have shown that Earth is a very impressive and complex astronomical object.

The purpose of this report is twofold: first, to describe Earth's magnetospheric radio emission and discuss its possible relationship with known regions of electron precipitation in the auroral zones and, second, to illustrate similarities between the radio emission of Earth and Jupiter. These similarities may be helpful in understanding some of the processes occurring in the Jovian magnetosphere. With the announcement by Brown (*2*) of similar low-frequency emission from Saturn, a pattern may be emerging and an understanding of Earth as a radio source becomes even more important.

The first observations of intense propagating noise from Earth made with a space probe were reported by Benediktov *et al.* (*3*) and subsequently by Dunckel *et al.* (*4*). Stone (*5*) suggested that intense noise from Earth was composed of at least two components. Gurnett (*6*) correlated his observations of intense, sporadic noise with the occurrence of discrete auroral arcs near local midnight.

Figure 1A shows two examples of the observed power flux as a function of observing frequency; the overall background spectrum of the sky (*7*) is shown in both panels for comparison. The spectral feature in the 200- to 400-khz region is the subject of this report. The upper panel in Fig. 1A shows a low-level event with a peak frequency of 185 khz, and the lower panel shows an event orders of magnitude more powerful with a peak frequency near 500 khz. The total radiated power in the event in the lower panel is estimated to be about 10 Mw; even more powerful events are common, making Earth comparable to Jupiter in intensity [see Warwick (*8*)]. Normal amplitude-modulation radio reception would not be possible if these events could propagate to Earth's surface.

Without information on the source location, these observations can be associated with magnetospheric processes only indirectly. However, the radio experiment of IMP-6 (Interplanetary Monitoring Platform) of the Goddard Space Flight Center was capable of making directional measurements with a spinning dipole antenna. By this method, as described by Fainberg *et al.* (*9*), it is possible to determine the one-dimensional direction of arrival of a radio signal, that is, the plane of arrival. Triangulation from various positions in the IMP-6 orbit determines the magnetospheric radio source locations projected onto the ecliptic plane. The height of the source above the ecliptic cannot be determined unambiguously by this method. The results of averaging 500 days of observations at 130 khz are illustrated in Fig. 1B, which is a view from the ecliptic pole with the plane of the figure as the ecliptic plane and the approximate magnetic local time (MLT) indicated. The contours in Fig. 1B show relative occurrence probability and

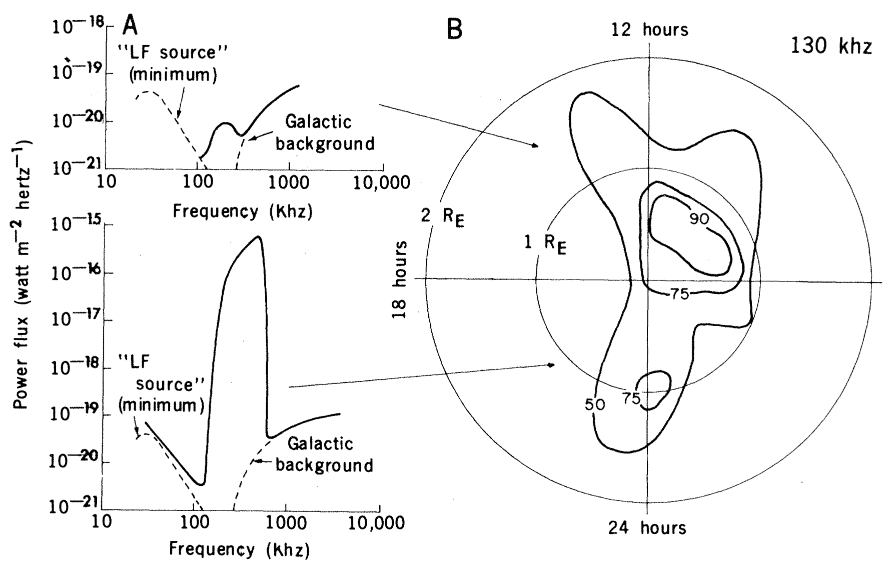

Fig. 1. (A) Spectra of terrestrial radio emission between 100 and 1000 khz from the dayside (upper panel) and nightside (lower panel) sources. The additional low-frequency feature (labeled "LF source") currently under investigation, is an omnipresent component of radio noise also observed from spacecraft. (B) Relative occurrence probability diagram for terrestrial noise at 130 khz projected onto the ecliptic plane. Approximate MLT values and radial distances in Earth radii (R_E) are indicated.

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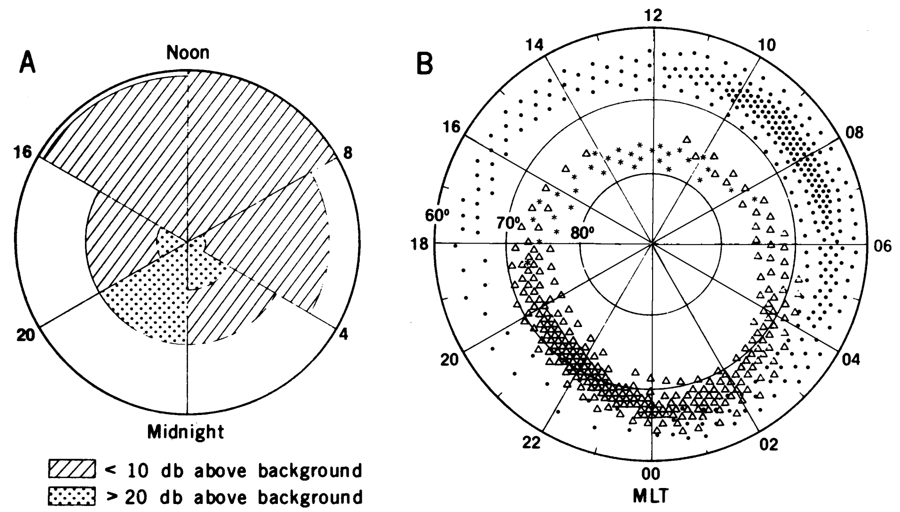

Fig. 2. (A) Relative occurrence rate of 130-khz noise as seen by RAE-2 in lunar orbit. For each 4-hour MLT interval, the percent of the total observed Earth noise is plotted (the outer radius is 20 percent). (B) A plot of MLT versus the invariant latitude distribution of the electron precipitation in the auroral zone: impulsive "splash" type of precipitation (Δ); quasi-stable "drizzle" precipitation (●); and semicontinuous inflow at midday (*). The approximate flux intensity is indicated by the density of symbols [from Hartz (*10*)].

are not a measure of intensity. There are at least two source regions, one situated on the morning and the other on the late-evening side of Earth. The higher occurrence probability for the less intense morning source reflects its quasi-continuous presence, whereas the late-evening source, although usually far more intense, is highly sporadic.

Arrows are drawn from A to B of Fig. 1 to indicate the spectral shape for the two sources. The morning source has a stable structure, always peaking just below 200 khz and nearly always at a flux level no more than ten times the galactic background. The late-evening source ranges over many orders of magnitude in intensity, and has a peak frequency sometimes as low as 130 khz and at other times 500 khz or higher.

Further support for the two-component source model comes from observations of the magnetosphere with the lunar-orbiting Radio Astronomy Explorer-2 (RAE-2) satellite. As the moon circuits Earth every 29.5 days, the distribution of magnetospheric radio noise can be obtained as a function of local time. Figure 2A, based on nearly 1 year of data, shows the relative percentage of radio noise at 130 khz for intensities less than ten times (10 db) the cosmic background and for intensities greater than 100 times (20 db) the background. The less intense noise is seen virtually at all local times with a preference for the mid-morning sector caused by the dayside source region shown in Fig. 1B, which contributes a large portion of the total amount of low-level noise. The intense noise, however, is strongly concentrated in the zone spanning 20 to 24 hours and is essentially absent in the hemisphere from 4 to 16 hours. It is this late-evening source that Gurnett (*6*) has correlated with discrete auroral arcs and thus particle precipitation.

The RAE-2 satellite also provides a means of determining the linear size of the source regions. Every 2 weeks, the moon occults Earth as seen from the spacecraft. Measurements of the rate of disappearance and reappearance of Earth noise during these occultations provide an estimate of the size of the source regions. Preliminary analysis of these data indicates that the intense late-evening noise is most often generated at some point within 12,000 km of the surface of Earth. The dayside emission appears to emanate from a region much closer to the surface, perhaps at an altitude less than 4000 km.

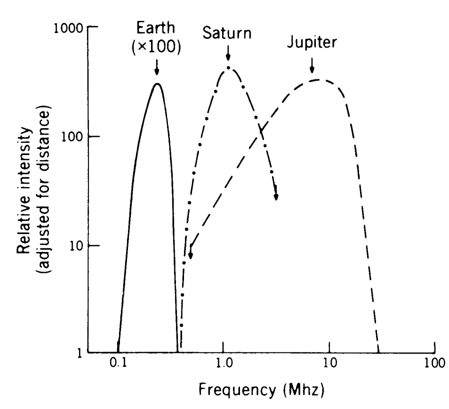

Fig. 3. The relative intensities (corrected for distance) as a function of frequency observed for Jupiter (*13*), Saturn (*2*), and Earth. The Jovian and Saturnian spectra represent the most intense events observed, whereas the Earth spectrum, which has been multiplied by 100, is the most intense event that could be measured by the IMP-6. Even more intense Earth events are common, but they saturate the IMP-6 receiver, making quantitative measurements impossible.

The present picture of the magnetospheric radio source locations and characteristics suggests a correlation with the known high-latitude particle precipitation zones. These zones, synthesized from various data by Hartz (*10*), are shown in Fig. 2B. In comparing Fig. 2, A and B, it should be noted that Fig. 2B shows the several components as a function of MLT, occurrence probability, and latitude, whereas Fig. 2A provides no information on latitude. Nevertheless, the similarity of these two displays is striking.

The intense sporadic night peak of radio emission appears to correspond to Hartz's "splash" zone (Δ). He describes the splash precipitation as highly sporadic and impulsive, strongly localized, and definitely related to magnetospheric disturbances (substorms). This is also the component associated with discrete auroral arcs. The dayside continuous or quasi-continuous component of magnetospheric emission may be associated with either Hartz's "drizzle" population (●) involving the sink for trapped particles or the direct entry of particles into the cusp region (*) or a combination of both. We detect little or no dependence on geomagnetic indices such as K_p or A_p for the dayside source, which agrees with the characteristics of Hartz's midday source (*).

It is fascinating to compare these descriptions of Earth's radio noise and particle precipitation patterns with the decametric wavelength radio noise from Jupiter which has been observed for two decades (*11*), and to the recently announced Saturnian hectometric wavelength noise (*2*). These noise observations are similar to the late-evening Earth noise in at least three general ways: (i) they are sporadic with a detailed time structure, (ii) the overall spectral shapes are comparable (see Fig. 3), and (iii) some radiation beaming is implied for all three planets.

Nothing is known about the source location of the Saturnian emission, and only limited information is available on the source location of the Jovian emission. However, Gruber and Way-Jones (*12*) studied Jovian noise occurrence statistics as a function of viewing geometry and deduced that one component of the Jovian emission emanates from the late-evening sector.

In most theories dealing with the emission mechanisms of Jupiter's noise (and, presumably Saturn's) precipitation of electrons into the Jovian ionosphere is inferred (*11*). In some theories it is also assumed that the frequency of the emission is related to the Jovian magnetic field and is at or near the electron gyrofrequency. If the emission from both planets is related to the gyrofrequency, a rather interesting relationship exists. The frequency at peak intensities is 0.3 Mhz for Earth and 8 Mhz for Jupiter (*13*), and the observed high-frequency cutoff is about 1.7 Mhz for Earth and 40 Mhz for Jupiter (*11*). The frequencies at peak intensity are thus in a ratio of 27 to 1, and the maximum frequencies are in a ratio of 24 to 1. If the magnetic field strengths of the two planets scale like the gyrofrequencies, the Jovian polar field derived by this method would be 15 to 18 gauss. The Pioneer 11 measurements (*14*) indicate a value of 14 to 23 gauss for the Jovian north pole. With Brown's (*2*) spectrum of the Saturn emissions shown in Fig. 3, we would, by the same logic, infer a polar surface field of 2 gauss for that planet. For a dipole field, this would correspond to 1 gauss at the equator, which is the field strength estimated by Scarf (*15*), using various lines of evidence. This prediction will undergo a crucial test in 1979 with the Pioneer 11 flyby of Saturn.

These similarities are circumstantial and speculative at this point, but we feel, nevertheless, that there may well be a pattern in these radio emissions. The Mariner Jupiter-Saturn missions to be launched in 1977 will carry sophisticated radio astronomy experiments as well as magnetic field and particle experiments capable of determining many of the parameters at Jupiter and Saturn. Thus, in the next 5 or 6 years the reality of our proposed pattern will become known.

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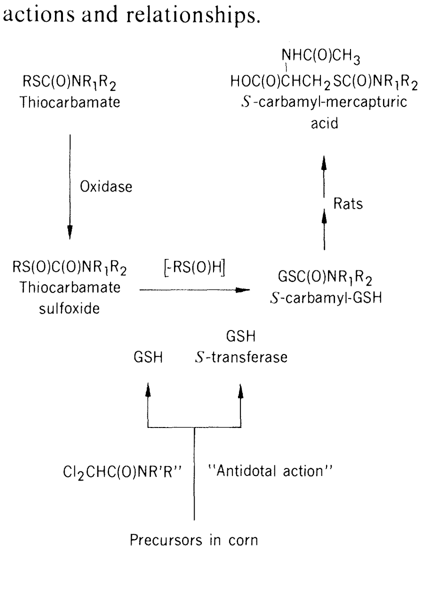
Dichloroacetamide Antidotes for Thiocarbamate Herbicides: Mode of Action

Abstract. *Thiocarbamate sulfoxides formed on metabolic sulfoxidation of thiocarbamate herbicides in plants and mammals are effective carbamoylating agents for glutathione and other tissue thiols. Dichloroacetamides that protect corn from thiocarbamate herbicide injury induce more rapid detoxification of the thiocarbamate sulfoxides by increasing their rate of carbamoylation of glutathione through elevation of the root glutathione level and glutathione* S*-transferase activity.*

Two recent advances provide new chemical probes, thiocarbamate sulfoxides and dichloroacetamides, useful in elucidating the mode of action of thiocarbamates, one of the most important classes of herbicide chemicals. Biological oxidation to form thiocarbamate sulfoxides probably constitutes the first step in a chain of events leading to inhibition of plant growth (*1*). In thiocarbamate-susceptible corn varieties, this chain of events is apparently disrupted by dichloroacetamide "antidotes," which are effective adjuvants in preventing injury due to thiocarbamates (*2*). Three biochemical observations are also relevant. The metabolism of fatty acids is altered by EPTC (*S*-ethyl *N,N*-dipropylthiocarbamate) in some plant species (*3*), suggesting an interference with coenzyme A (CoASH)–mediated reactions. Thiocarbamate sulfoxides are cleaved by glutathione (GSH) *S*-transferase enzymes of mouse liver (*1*). The much greater tolerance of corn than of oat seedlings to thiocarbamates and their sulfoxides (*1*) extends to atrazine herbicide, a chemical which is metabolized by a GSH *S*-transferase of corn but not oat seedlings (*4*).

We now establish that thiocarbamate sulfoxides in vitro readily carbamoylate CoASH and GSH, important enzyme cofactors, and that the antidotes act in corn to elevate the GSH and GSH *S*-transferase levels, resulting in rapid detoxification of the thiocarbamate sulfoxides. The following scheme illustrates a portion of these reactions and relationships.



The studies were made with two thiocarbamates (EPTC and butylate), their sulfoxide derivatives prepared by peracid oxidation (*1*), and two dichloroacetamides (R-25788 and R-29148). These two thiocarbamates are used commercially in combination with the antidote R-25788: Eradicane®, which is EPTC plus antidote, and Sutan +®, which is butylate plus antidote (*5*).

EPTC	$CH_3CH_2SC(O)N(CH_2CH_2CH_3)_2$
Butylate	$CH_3CH_2SC(O)N[CH_2CH(CH_3)_2]_2$
R-25788	$Cl_2CHC(O)N(CH_2CH=CH_2)_2$
R-29148	$Cl_2CHC(O)N-CH_2$ $(CH_3)_2COCHCH_3$

Several initial observations served to focus attention on tissue thiols. The thiocarbamates are converted in mammals and plants to the corresponding sulfoxides, which do not accumulate since they are further metabolized. Thus, EPTC sulfoxide appears as a transient metabolite in the liver of mice 10 minutes after intraperitoneal administration of EPTC at 1.0 mmole/kg (*1*). Further, EPTC sulfoxide is detected in extracts of roots from oat seedlings exposed for 24 hours to [^{14}C]EPTC solutions and of leaves from corn seedlings 24 hours after injection of [^{14}C]EPTC into the stem. The transient nature of the thiocarbamate sulfoxides suggests that they react with tissue constituents such as thiols. This was verified by the finding that CoASH, GSH, and *N*-acetylcysteine are converted to *S*-carbamyl derivatives on reaction with equimolar amounts of either EPTC sulfoxide or butylate sulfoxide in an aqueous medium at *p*H 7.4 (*6*). The alkylsulfenic acids released from the thiocarbamate sulfoxides on carbamoylation of thiols are quite unstable in aqueous medium at physiological *p*H in the presence or absence of biological material, giving predominately the corresponding alkylsulfonic acids (*7*). The thiocarbamate sulfones are even more effective carbamoylating agents than the corresponding sulfoxides, but this observation is probably not relevant to the mode of action of thiocarbamate herbicides since the sulfones are much less effective as herbicides (*1*) and they are not detected as in vivo metabolites of the thiocarbamates in mammals (*1*) or plants.