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AKR SIGNAL INCREASES CAUSED BY TRIGGERING

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Abstract. This paper presents a study of the amplitude increases which accompany the triggering of auroral kilometric radiation (AKR) by Type-III solar radio bursts. IMP-8 data were used to determine the signal increases observed during one-hour periods before and after Type-III bursts at 100 kHz, 178 kHz and 500 kHz and these were compared with similar observations when the Type-III bursts were absent. The results indicate that between 8 to 16% of the Type-III bursts caused statistically significant intensity increases and that infrequent large signal increases of sometimes 20 dB or more tended to characterize the triggered AKR, rather than a large proportion of small increases.

Introduction

Previous studies have indicated that Type-III bursts are capable of triggering AKR onsets [Calvert, 1981; Farrell and Gurnett, 1985], and this observation has become an important factor in determining the exact mechanism of AKR generation. This paper presents a study in which the AKR wave amplitudes before and after Type-III bursts were examined to further characterize the triggered AKR events.

During recent years, the processes which generate Earth's intense auroral kilometric radiation have been the subject of considerable investigation. Although many such processes have been proposed, only the amplification by cyclotron resonance [Ellis, 1965; Melrose, 1976; Wu and Lee, 1979] has achieved much general acceptance. Although cyclotron resonance plays an important role in AKR generation, it is not clear whether amplification alone explains all of the AKR's features. A more comprehensive model has been introduced where a radio wave laser [Calvert, 1982] generates the intense AKR signals. This laser model explains AKR's observed signal intensities, its source location and its spectral fine structure.

The laser model of the AKR generation was spawned by the observation of triggered AKR. Initially, solar Type-III bursts and AKR were perceived to be unrelated phenomena. However, cases were found in which Type-III bursts and AKR were temporally aligned, indicating that stimulation was involved [Calvert, 1981]. The phenomena became known as triggered AKR when it was clear that incoming Type-III bursts were responsible [ibid; Calvert, 1985a, 1985b, 1985c]. Figure 1 shows an ISEE-1 spectrogram with a Type-III bursts and triggered AKR.

Critics of the triggering concept have suggested that the emissions' temporal alignments were accidental [Desch and Kaiser, 1985]. If indeed Type-III bursts are unrelated to AKR, then the probability of detecting AKR before and after Type-III bursts should be equal. In a previous study [Farrell and Gurnett, 1985], a superposed epoch analysis was performed on over 140 Type-III bursts to determine if AKR was triggered by the bursts. In that study, ISEE-3 (at the L-1 Legrange point approximately 200 R_E on the sunward side of the earth) was used to detect isolated Type-III bursts, and IMP-8 (in a relatively close earth orbit) was used to detect the AKR. For each of the Type-III bursts examined in that study, intensities were measured with both satellites in two-hour periods extending from one hour before to one hour after the initial appearance of the Type-III burst. Each of the two-hour event intervals were then analyzed by a two-step process: First, the ISEE-3 measurements for each event were subtracted from the corresponding IMP-8 measurements, effectively subtracting the Type-III burst intensities out of the IMP-8 measurements. Next, the intensities for all the event intervals were averaged as a function of the time with respect to the burst. This analysis was done at three frequencies: 100 kHz, 178 kHz and 500 kHz. The results of this superposed epoch analysis showed statistically significant average intensity increases after Type-III bursts at both 178 kHz and 500 kHz, and thus that the emissions' temporal alignment was not accidental, but a direct result of the Type-III bursts triggering the AKR.

Analysis Procedure

Although the superposed epoch analysis clearly confirmed the AKR triggering, it did not indicate directly the probability of finding triggered AKR events, and a new study was performed to find that probability. This study follows the same basic procedure as the superposed epoch analysis,

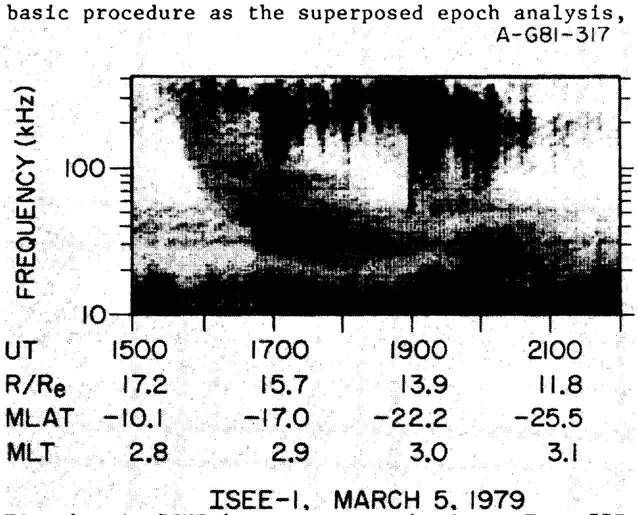

Fig. 1. An ISEE-1 spectrogram showing a Type-III burst which apparently triggered the subsequent AKR.

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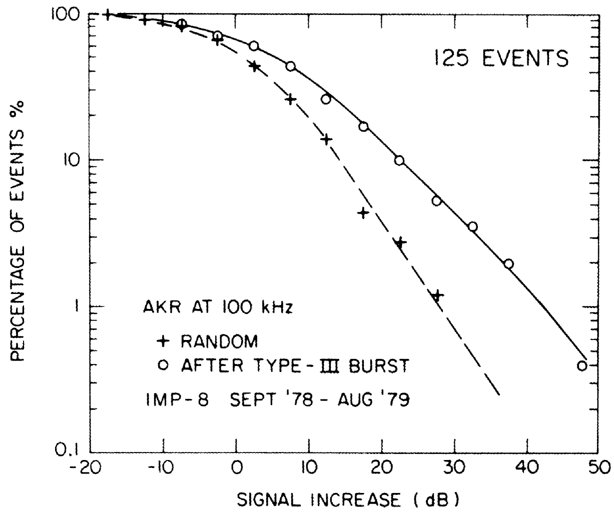

Fig. 2. The cumulative distribution of AKR intensity increases associated with Type-III bursts (circles) compared with comparable randomly-selected intervals (crosses), for consecutive one-hour periods at 100 kHz. Note that consistently more large signal increases (> 20 dB) accompanied the Type-III events, clearly signifying the triggering of the AKR.

where the ISEE-3 and IMP-8 measurements were used to detect Type-III bursts and AKR, respectively. Again, for each event, the ISEE-3 measurements were subtracted from the corresponding IMP-8 measurements. However, rather than averaging the events, as was done in the superposed epoch analysis, a preceeding-hour average and a following-hour average were calculated for each event. The triggering of AKR should then be indicated by changes between these two averages.

In order to determine if triggering had occurred, a control group consisting of randomly selected two-hour intervals was also used. These intervals were analyzed following the same procedure. The intensity changes measured from these intervals were taken to indicate the intensity changes which should have been expected if only randomly occurring AKR were being detected. Consequently, comparing the distribution of these intensity changes to the distribution of intensity changes from the Type-III bursts' data set, the number of triggered AKR events can be estimated.

Results

A comparison of the Type-III and control group intensity change distributions clearly indicates that triggered AKR was being detected. Figures 2, 3 and 4 show the cumulative distributions for both the control group and that with Type-III bursts at 100 kHz, 178 kHz and 500 kHz, respectively. Note that at all three frequencies, the distributions with Type-III bursts had a greater number of events with large signal increases. This result is expected only if the Type-III bursts were consistently triggering the AKR.

At 100 kHz, 13.5% of the events with Type-III bursts had more than a 20 dB signal increase, while only 3.5% of the control group's events were above this same level--almost a factor of four difference. At 178 kHz, 5.4% of the events with Type-III bursts were above a 20 dB signal increase whereas only .45% of the control group's events were above that same level--over a factor of ten difference. At 500 kHz, 6% of the events in the Type-III bursts set were above a 20 dB signal increase, whereas only 1.0% of the control group's events were above that level--a factor of six difference. In all three cases, the number of Type-III events with signal increases larger than about 20 dB was much greater than those of the control group; a result expected of triggered AKR.

Statistical Significance

The results thus show an excess of large signal increases following Type-III bursts, and in order to determine the statistical significance of this result, a count was made of the number of Type-III events exceeding two standard deviations of the control group. This number was then compared to the number of control group events above the same level. A probability for accidentally finding the observed number of Type-III events above two standard deviations was then calculated with Poisson's statistics using the number of control group events above two standard deviations as the expected number of accidental events.

At 100 kHz, 12 events from the Type-III burst set were above two standard deviations (21 dB), while only 4 events from the control group were above that level. The probability of finding this many Type-III events beyond two standard deviations is less than .1%, implying that the 12 events were quite statistically significant. At 178 kHz, 13 events from the Type-III burst set were above two standard deviations (10 db), whereas only 4 events from the control group were above that level. Again, the probability of finding this many Type-III events beyond two standard deviations is quite small (less than .05%) and that indicates that the 13 events were also quite statistically significant. At 500 kHz, 7 events from the Type-III burst set were above two standard deviations (14.6 db) while only 2 events from the control group were above that level. The probability of finding that many Type-III events above two standard deviations is less than .5%. This indicates again that the 7

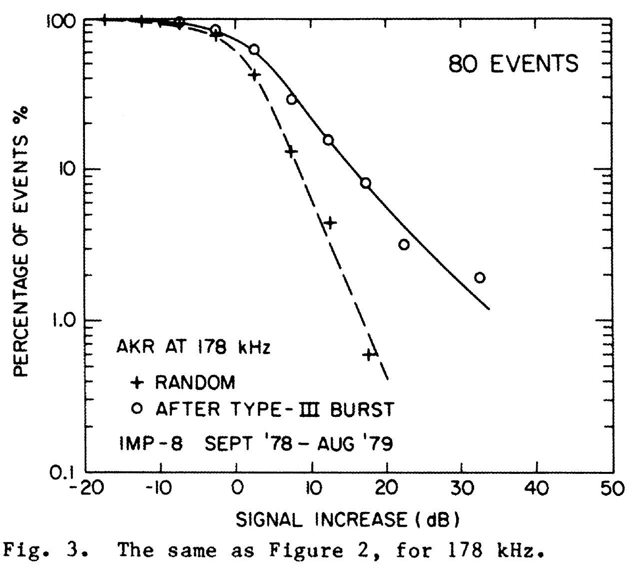

Fig. 3. The same as Figure 2, for 178 kHz.

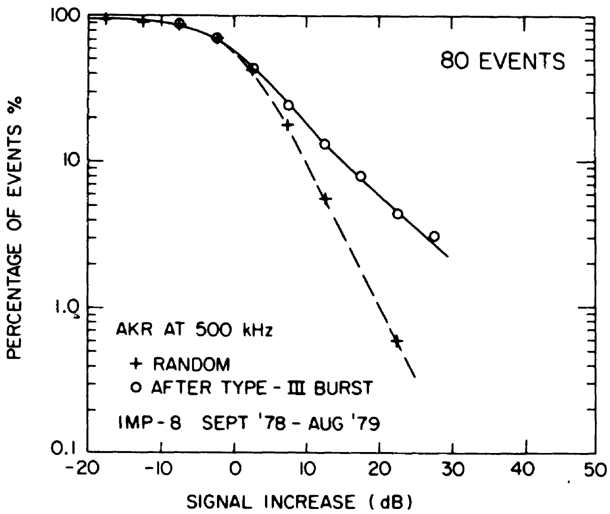

Fig. 4. The same as Figure 2, for 500 kHz.

events also were statistically quite significant. Note that at all three frequencies the number of Type-III events above two standard deviations is statistically significant to a confidence level of at least 99.5%.

Discussion

The superposed epoch analysis previously showed statistically significant intensity increases following Type-III bursts only at 178 kHz and 500 kHz. However, it was not clear from that analysis whether the increases were due to small intensity increases following many Type-III events or large intensity increases following only a few Type-III events. The results of this study show that 9.6%, 16.3% and 8.8% of the Type-III events had intensity increases greater than two standard deviations at 100 kHz, 178 kHz and 500 kHz, respectively, indicating that only a few of Type-III events with large signal increases accounted for the statistically significant intensity increases that were measured in the superposed epoch analysis.

In the superposed epoch analysis, the intensities at particular times from each event were added together, so events with the strongest signals contributed the most to the overall total intensities. In effect, each event in the superposed epoch analysis was weighted by its intensity. The superposed epoch analysis did not show statistically significant intensity increases at 100 kHz presumably because they were drowned out by the more intense random AKR. In the current analysis, however, all events had equal weight, and triggered AKR was relatively easy to detect at all three frequencies.

As previously pointed out [Calvert, 1981; 1982], these observations imply that the generation of AKR involves true lasing rather than open-loop "maser" amplification acting alone. Simply because the triggered AKR continues to persist long after the triggering solar signals have disappeared, they imply states of oscillation within the source which are capable of continuing independently once they have gotten started. Although the exact triggering mechanism remains to be clarified, by analogy with triggerable electronic oscillator circuits like regenerative shortwave radio receivers, this in turn would imply the sort of closed-loop wave feedback oscillations which are the essence of lasing [e.g., see Verdeyen, 1981]. The significance of these measurements, therefore, beyond confirming the remarkable external triggering of planetary radio emissions, is that they also imply radio lasing at the source.

Conclusions

The analysis presented here conclusively confirms the original conclusion that Type-III bursts sometimes trigger onsets of AKR [Calvert, 1981]. It was shown that the AKR intensity changes during Type-III bursts involved a statistically-significant number of events with large signal increases, above about 15 to 20 db. It was concluded that between 8-16% of incoming Type-III bursts trigger AKR onsets.

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