Terrestrial Myriametric Radio Burst Observed by \textit{IMAGE} and \textit{Geotail} Satellites

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Abstract

We report \textit{IMAGE} and \textit{Geotail} simultaneous observations of a terrestrial myriametric radio burst (\textit{TMRB}) detected on August 19, 2001. The \textit{TMRB} was confined in time (0830-1006 UT) and frequency (12-50 kHz), suggesting a fan beam-like emission pattern from a single discrete source. Analysis and comparisons with existing \textit{TMR} radiations strongly suggest that the \textit{TMRB} is a distinct emission perhaps resulting from dayside magnetic reconnection instigated by northward interplanetary field condition.
Introduction

Myriametric radio emissions (with wavelengths of 10-100 km) from Earth's magnetosphere have been known to take on different forms. Most notable forms include the classical non-thermal continuum (NTC) with both escaping and trapped components, continuum enhancement (CE), and auroral myriametric radiation (AMR). Continuum radiation emanating from plasmaspheric notches at the magnetic equator can sometimes extend to higher frequencies (up to ~ 800 kHz) to form the so-called kilometric continuum (KC) radiation. CE has also been known to appear as low-frequency bursts associated with substorm particle injections. This paper presents the simultaneous IMAGE and Geotail observations of a burst of terrestrial myriametric radiation (TMRB) at 8:30-10:06 UT on August 19, 2001. The widely separated satellite observations at 12-50 kHz suggest that the TMRB was a temporal feature. We will compare the TMRB observations to the characteristics of other known TMR components to determine if the TMRB may be consistent with any of the known TMR.

Observations of Terrestrial Myriametric Radio Burst (TMRB)

a) Spacecraft locations

On August 19, 2001, 0830-1006 UT, the IMAGE satellite was near apogee (R ~ 8 Re) over the northern polar region in the afternoon sector while Geotail was at perigee (R ~ 9 Re) located just north of the magnetic equator in the post-midnight/pre-dawn sector. Using the NASA SSCWeb tool (http://sscweb.gsfc.nasa.gov), we show in Figure 1 the IMAGE and Geotail positions in GSM X-Y plane during the times of TMRB observations.
The IMAGE and Geotail GSM coordinates indicate that the two satellites were situated on opposite sides of Earth, nearly along an afternoon-early morning meridian plane. IMAGE, however, was at much-higher geomagnetic latitudes (71.81°-80.46°) than Geotail (7.98°-12.35°). The difference in geomagnetic longitudes shown in Figure 1 means that the two satellites are situated on essentially diametrically opposite field lines. Over this interval, the geomagnetic longitude of IMAGE changed by ~11°, while that of Geotail was ~ -5.3°.

b) IMAGE and Geotail observations

Figure 2 shows the 6-hour dynamic spectrograms for August 19, 2001, recorded by the IMAGE Radio Plasma Imager (RPI, lower panel) [Reinisch et al., 2000] and Geotail Plasma Wave Instrument (PWI, upper panel) [Matsumoto et al., 1994]. The emission feature at 12-50 kHz observed simultaneously by both satellites at 0830-1006 UT (demarcated by the two white lines) is identified here as the terrestrial myriametric radio burst (TMRB). Given the widely separated spacecraft locations, the start and stop of the TMRB being seen simultaneously by both satellites strongly suggest that the TMRB was turning on and off, just like a light bulb.

In view of the differences in spacecraft locations, it is of interest to contrast the wave signatures between the two spectrograms in Figure 2. Firstly, the TMRB observed by both satellites appears as an isolated magnetospheric emission with an enhancement near the center of the burst. The simultaneous observations of the TMRB when IMAGE and Geotail were fortuitously located at different latitudes on diametrically opposite sides of the Earth suggest that the TMRB must at a minimum have a fan-beam radiation pattern that covers the latitude and longitude ranges of both IMAGE and Geotail. Broader
longitudinal beaming is possible in principle, but temporally extended TMRB emission distinct from other TMR components (as discussed later) does not seem to be a common occurrence, implying that TMRB may actually be limited in longitude.

Both IMAGE and Geotail detected several of the same solar type III bursts. One burst was seen (near 7 UT) by IMAGE to have a low-frequency dispersive tail that extends to the TMRB (Figure 2 lower panel) although no such tail was detected by Geotail (Figure 2 upper panel). The absence of the type III tail at Geotail may be due to its position at the time being deep in the night-side magnetosphere (see Figure 1) and that the low-frequency tail might have been blocked by the dayside plasmasphere. The type III tail seen at IMAGE location, however, means that the solar wind density at the time must have been sufficiently low to allow the tail emission to penetrate the magnetosphere. The solar wind plasma frequencies from OMNI data (white trace in the upper panel of Figure 2) do show a near match of the lower cutoff of the first half of the TMRB, but they quickly exceeded the TMRB lower cutoff throughout the rest of the burst. This behavior essentially rules out the possibility of a solar wind source for the TMRB. In addition, the observations of intensity enhancement near the burst center and distinct upper frequency cutoffs by both IMAGE and Geotail argue strongly that the TMRB is a distinct magnetospheric emission.

The start (0830 UT) and stop (1006 UT) of the TMRB were both observed practically simultaneously at IMAGE and Geotail positions. While both the IMAGE and Geotail observations show the same overall frequency extent (12-50 kHz) of the burst, they also show that the burst has a lower cutoff frequency that decreases toward the center from both the beginning and end of the burst. The frequency bandwidth is also broadest at the
center of the burst where \textit{Geotail} observations seem to extend to slightly lower frequencies. Both sets of observations clearly show no other connecting myriametric radiation, so that the \textit{TMRB} was an isolated emission.

Figure 3 shows an expanded view of the last hour of the \textit{TMRB} in \textit{Geotail} data (see upper panel of Figures 2). The clearly spin-modulated burst signals shown in Figure 3 imply that the \textit{TMRB} radiation was beamed directly from its source, although no such spin-modulation was seen by \textit{IMAGE RPI} due to the much slower satellite spin rate (0.5 RPM) and a longer time (~ 2 min) to complete a frequency scan. The tapered shape of the frequency-time profile toward the end of the burst, particularly the lower cutoff frequencies, is quite evident and consistent with the \textit{IMAGE} observations shown in Figure 2 lower panel. The upper cutoff frequencies, on the other hand, exhibit a number of cycles of undulations, as if the source densities were going through a series of enhancements and depletions.

\textbf{Solar Wind and Magnetospheric Conditions Associated With the TMRB}

A number of terrestrial myriametric radiation components are dependent on geomagnetic activity. It is therefore of interest to see what solar wind and auroral conditions are associated with the \textit{TMRB} emission.

\textit{a) Solar wind conditions}

Figure 4 plots the 5-minute solar wind, interplanetary, and auroral activity data obtained from the \textit{NASA OMNIWeb} (\texttt{http://omniweb.gsfc.nasa.gov}). The top 3 panels in Figure 4 show the interplanetary magnetic field (\textit{IMF}) strength, \textit{IMF Bz} (in GSM) and
solar wind speed, respectively. These parameters show no remarkable IMF activity before and during the entire TMRB interval, with $3 < |B| < 7$ nT and $+1 < B_z < +6$ nT. The solar wind speed in fact decreased rather steadily from $490 \text{ km s}^{-1}$ at 0600 UT to $450 \text{ km s}^{-1}$ at 0900 UT. The positive IMF $B_z$ condition throughout the interval, however, may be of significance because magnetic reconnection can occur over limited region poleward of the cusp [e.g., Kessel et al., 1996] and could potentially provide a high-latitude free energy source to produce the TMRB.

b) *Auroral conditions*

The lower 4 panels in Figure 4 show the $AE$, $AL$, $AU$, and polar cap (PC) indices. Due to the positive IMF $B_z$ condition during this interval, there was also no remarkable substorm activity. Nevertheless auroral kilometric radiation (AKR) was present at the beginning and the second half of the TMRB interval. Referring to the panels in Figure 4 for the $AE$, $AL$, and $PC$ indices, we notice that those indices exhibit peak levels around 0700, 0825, and 0940 UT, consistent with the times of AKR activations shown in Figures 2. On the other hand, Figure 4 shows no apparent auroral activation during the times of TMRB. It would seem then that if an association were to exist between TMRB and AKR (or auroral activity), the two emissions at different frequency ranges are not directly correlated. Figure 2 suggests that TMRB tends to occur after AKR activation.

**Comparisons of TMRB with known TMR Components**

The TMRB appeared in the same wavelength band (10-100 km) as other terrestrial myriametric radiation. The most notable ones are the different forms of continuum
radiation [e.g., Green and Fung, 2005; Grimald et al., 2008] and the auroral myriametric radiation [Hashimoto et al., 1998]. We now compare the observed characteristics of TMRB against the known terrestrial emissions to see whether the TMRB might be a distinct emission.

a) Nonthermal continuum (NTC)

Classical nonthermal continuum radiation (NTC) usually appears as banded emission that extends several hours in the post-midnight to afternoon local times [Gurnett, 1975; Gough, 1982; Green and Boardsen, 1999; Menietti et al., 2005]. In addition, trapped NTC at frequencies below the magnetopause plasma frequency (~ 30 kHz) typically appears as a broadband emission due to the radiation having undergone multiple reflections within the magnetosphere [Green and Fung, 2005]. On the other hand, the TMRB beam pattern is compact, limited both in latitude and longitude and/or time (Figures 1, 2, and 3). Spin-modulations of TMRB shown in Figure 4 indicate that the radiation detected by Geotail in the night-side magnetosphere was beamed directly from the source.

Using ray-tracing calculations, Green and Boardsen [1999] showed that NTC is primarily confined to low latitudes, and ray paths reflected off the magnetopause can rarely pass over the polar region at \( Z > 5 \) Re. While these results are consistent with Geotail's position during the TMRB observation, spectral differences from the NTC and the detection of TMRB by IMAGE at high altitude (\( Z > 7 \) Re) over the high-latitude region (see Figure 1) thus make the TMRB likely to be an emission distinct from the classical NTC.
b) Continuum enhancement (CE)

Continuum enhancements are episodic NTC intensity enhancements that can last up to ~ 2 hours [Kasaba et al., 1998]. First identified in GEOS 2 data taken in the geosynchronous region near midnight [Gough, 1982], and then in IMP 6 observations in the magnetotail [Filbert and Kellogg, 1989], CE is characterized by a sudden intensification at 15-30 kHz that is followed by an overall broadening to higher frequencies and separating into discrete frequency bands (see Figure 3 in Gough [1982]).

The band separations also widen with time. The TMRB spectral appearance seems to differ from CE by the lacking of clear frequency bands; but instead the upper cutoff frequencies exhibit some undulations toward the end of the burst (Figure 3).

Onsets of CE are known to temporally correspond to increases in auroral activity (AE, AU, and AL), including AKR [Filbert and Kellogg, 1989; Kasaba et al., 1998]. As shown in Figure 2, AKR and TMRB do not have matching start times. The times of increases in auroral indices in Figure 4 are also inconsistent with the beginning time of the TMRB. Despite the similarity in the compact spectral appearances in the TMRB and the main CE component, the two emissions are not likely to be the same phenomenon.

c) Kilometric continuum (KC)

TMRB appears to be confined in latitude and longitude, similar to KC [Green et al., 2004], but that might be the only similarities between the two emissions. Observed at all local times, KC is generated from deep inside plasmaspheric notches that rotate with the plasmasphere. The narrow latitudinal emission cone of KC (±15° of the magnetic equator) [Green et al., 2004; Hashimoto et al., 2006] can lead to different spectral appearances that depend on the observing satellite orbital characteristics. First identified
in observations by Geotail in a near equatorial orbit [Hashimoto et al., 1999], all the KC discrete frequency bands lasted several hours due to the nearly synchronous changes in the emission cone and spacecraft local times [Green et al., 2002; 2004], see Figure 2.3 in Hashimoto et al. [2006]. On the other hand, the polar-orbiting IMAGE satellite often observed KC upon crossing the magnetic equator as discrete-banded emissions with Christmas-tree patterns (e.g., see Figure 2 in Green and Boardsen, [2006]). With the Christmas-tree center frequencies extending up to ~ 800 kHz, the emission band durations change from several hours at low frequencies (consistent with Geotail observations) to less than an hour at high frequencies, yielding the Christmas-tree spectral pattern. The very similar timing, frequency extents, and spectral shapes of the TMRB observed by Geotail and IMAGE from very different vantage points (Figure 2) mean that the TMRB reported here is distinct from KC.

d) Auroral myriametric radiation (AMR)

The AMR, first discussed by Hashimoto et al. [1994], gets its name because it occurs coincidently with AKR and substorm onsets. This emission is believed to be generated in the L-O mode above the local plasma frequency ($f_{pe}$) in auroral density cavities where the local electron gyrofrequency $f_{ce} > f_{pe}$. The difference in $f_{ce}$ and $f_{pe}$ naturally explains the difference in AKR and AMR frequency ranges [Hashimoto et al., 1998]. Although AMR beaming can potentially account for the nightside TMRB observation by Geotail, it could not easily explain the dayside observation at high latitude by IMAGE. The high temporal correlation between AMR and AKR makes AMR an unlikely candidate for the observed TMRB (Figure 2).
Summary and Conclusions

We report the simultaneous observations of a terrestrial myriametric radio burst, TMRB, by Geotail and IMAGE from very different vantage points (Figure 1). The similarities in timing, frequency extents (12-50 kHz), and spectral characteristics of the TMRB seen by the two spacecraft (Figures 2) imply that the TMRB was a temporal emission with a fan beam radiation pattern emitted from a discrete source. The TMRB upper cutoff frequencies appear to exhibit undulations as shown in Figure 3. Such variability is reminiscent of the density increases and decreases as seen across field-aligned density irregularities (FAI). For L-O mode propagation, the TMRB undulations may suggest the presence of FAI in the TMRB source region.

The TMRB emission seems to occur only after AKR activation as shown in Figures 2 and 4, so its emission process might be a consequence of auroral activity. On the other hand, the positive IMF Bz condition throughout the TMRB interval (Figure 4) suggests that magnetic reconnection occurring over limited longitudinal range poleward of the cusp could provide a transient, high-latitude free energy source at high altitude so that the TMRB can be observed by IMAGE and Geotail from their respective locations (Figure 1). This is consistent with the compactness of the observed TMRB emission pattern.

Comparisons of TMRB characteristics against all other known TMR components reveal that the TMRB was likely a distinct emission, although the emission mechanism might still be the same as those responsible for generating the NTC, CE, KC or AMR. The TMRB may thus be beamed radiation resulting from linear [Jones, 1976; Grimald et al., 2007] or nonlinear mode-conversion mechanisms [e.g., Fung and Papadopoulos, 1987], consistent with the spin-modulations seen by Geotail. We plan to validate this by
performing ray-tracing modeling of the TMRB propagation from potential source regions.

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**References**


Figure 1. GSM and GM Positions of IMAGE (red) and Geotail (yellow) over the interval of TMRB observations on August 19, 2001. The two satellites were at different geomagnetic latitudes on opposite sides of the earth ($LT \sim 14.6$ and $\sim 3.3$, respectively).
Figure 2. A 6-hour data interval showing the start and stop (demarcated by white lines) of the isolated TMRB being observed simultaneously by IMAGE on the dayside at high latitude (lower panel) and Geotail on the night side at low latitude (upper panel).
Figure 3. A 40-minute interval of Geotail observations covering the end of the TMRB at 1006 UT, showing clear spin-modulated emission and undulating upper cutoff of the burst.

Figure 4. Solar wind and interplanetary conditions for August 19, 2001, 0600-1100 UT, covering before, during and after the TMRB interval.