Generation of Unusually Low Frequency Plasmaspheric Hiss

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Plasmaspheric hiss is an incoherent, broadband electromagnetic whistler-mode emission, preferentially and steadily observed inside high-density plasmasphere and storm-time plasmaspheric plume [1-2]. The frequency of plasmaspheric hiss typically ranges between ~200 Hz and 2 kHz, with peak wave power in a few 100s Hz. It has been recently proposed [3] that the dominant source of this emission is coherent chorus waves generated outside the plasmasphere. Subsequent ray tracing simulations [4] by tracing million rays of chorus waves reproduced a realistically spatial and spectral distribution of plasmaspheric hiss [Figure 1], showing the spatial confinement of plasmaspheric hiss emission within the plasmapause, and the typical frequency range from 200 Hz and 2 kHz with peak intensity around 500-700 Hz. It is worth pointing out that there is little hiss emission below 200 Hz in the simulation, indicating the chorus-as-embryonic-source mechanism does not work for such low frequency because chorus waves at those frequencies cannot propagate inward into the plasmasphere without substantial attenuations.

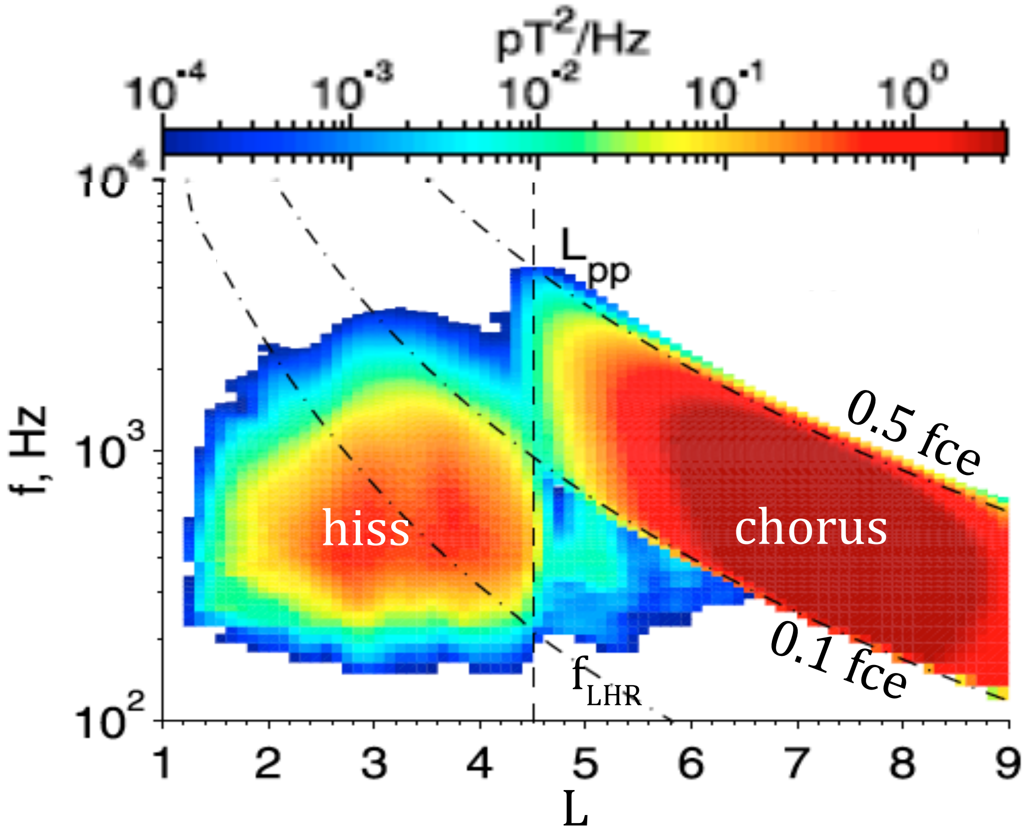

Figure 1. The simulation of spatial and spectral distribution of Plasmaspheric hiss wave magnetic field based on ray tracing of million rays representing chorus waves. Plasmapause location Lpp = 4.5. (Adopted from [4]).

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A recent study [5] from Van Allen Probe observation reported an unusually low frequency plasmaspheric hiss, with intense wave power extending down as low as several 10s Hz and peak intensity ~100 Hz [See Figure 2a]. Such plasmaspheric hiss emission occured during a substorm time at a morning sector and L~5 where injected energetic electrons passed through the expanded region of high-density plasmasphere. The fact that frequency spectrum is well correlation with the enhancement of energetic electrons fluxes [5], the fact that the observed electrons distribution indeed is anisotropic at the time when such low frequency hiss is observed [Figure 2b], and the fact that such low frequency hiss unlikely originates from chorus waves [Figure 1], provide strong evident that plasmaspheric hiss at these unusually low frequencies is likely excited through free energy stored in the anisotropic the energetic electrons. We test such hypothesis using the observed plasma environment to investigate whether the free energy is sufficiently account for the observed unusual hiss.

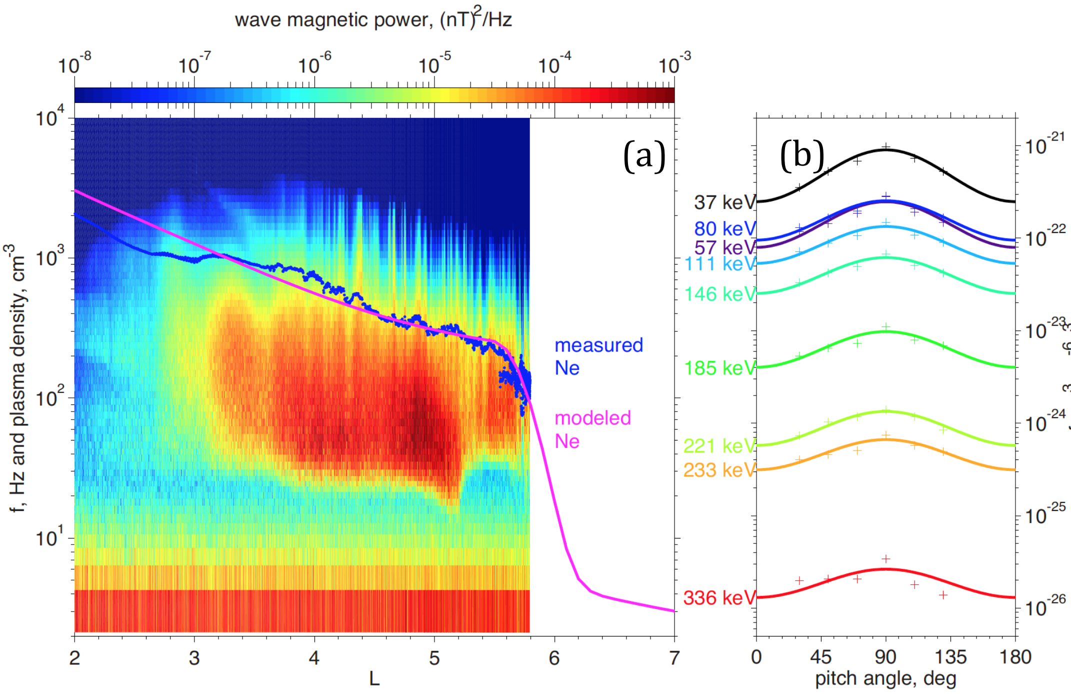

Figure 2. (a) The observed magnetic field spectral density in the WFR channel of EMFISIS instrument on Van Allen Probe A over the time period 14:00-19:30 of 9/30/2012, as a function of *L*-shell. Blue dots represents plasma density measurement inferred from upper hybrid resonant emission line, and magenta line denotes the modeled equatorial profile for ray tracing purpose. (b) The measured and modeled electron phase space density at L=5 as a function of pitch angle over energy channels from 37 keV to 336 keV of Mageis instrument.

We run HOTRAY ray tracing code in the diffusive equilibrium plasma density model with an equatorial density profile (magenta line of Figure 2a) resembling the observed plasma density from the Van Allen Probe (blue dots of Figure 2a), and evaluate relativistic linear growth rates along a ray path based on the observed electron distribution (Figure 2b) and then obtain path-integrated wave gain in dB to represent wave amplification. Figure 3 shows an example of ray tracing for 80 Hz wave launched from L = 5 with initial propagation along the magnetic field line. Interestingly, we find that ray path is cyclic (Figure 3a) in that this ray undergoes the following steps (1) propagating toward the north, (2) bouncing back from the sharp-density-gradient plasmapause, (3) reflecting at high latitude at the northern hemisphere and propagating towards the south, (4) reflecting at the southern hemisphere and propagating towards the north, (5) bouncing back from the plasmapause at the southern hemisphere and then (6) reaching the equator with near field-aligned propagation at L ~ 5, with almost the same configuration as the initial stage. By returning the same configuration it means this ray will repeat the same ray path for subsequent propagation (Figure 3b). We define each of these cyclic ray paths as a cycle, which takes about 20 second to complete for this ray. Wave gain over a cycle is only ~ 7 dB (Figure 3c), which is not sufficient to amplifying the background noise to the observable level, suggesting that amplification due to the observed anisotropic electron distribution through single passage of the equator is rather weak. However, these cyclic ray paths can lead to repeated amplification, yielding more than 40 dB on time scale of 120 seconds inside the plasmasphere and most of amplification occurs during the equatorial crossings closer to the plasmapause location (Figure 3b).

Figure 4 shows the path-integrated wave gain for first 8 cycles as a function of wave frequency. Again a simple passage of the equator only provides < 10 dB for frequency less than 100 Hz. To obtain wave gain > 40 dB, it will take 4 cycles of amplification for 100 Hz waves, 8 cycles for 60 Hz, and even more cycles for lower frequency. It would take 40 Hz wave (Figure not shown) to be amplified by 40 dB through ~ 15 minutes (more than 20 cycles), which is typical time scale for duration of sub-storm injection. Therefore we propose that combination of weak instability by anisotropic electrons and cyclic ray path due to the effect of sharp density gradient associated with plasmapause provides accumulative amplification to account for the emission observed at frequency below 200 Hz. It should be noted that the simulated wave gain peaks at just below 200 Hz (Figure 4), while the observed hiss peaks at lower frequency ~ 100 Hz (Figure 2a). This discrepancy might be due to that the lower frequency waves tend to have higher background noise level and therefore need less wave gain to grow to the observable level.

We summarize our principal conclusions as follows. 1) The observed low frequency hiss emission is unstable, but only weakly unstable, due to the observed anisotropic energetic electrons. 2) The cyclic ray paths are found the plasmaspheric hiss emission (< ~ 500 Hz). 3) Repeated amplification due to cyclic ray path is capable of providing sufficient wave gain (> 40 dB) to account for the observed plasmaspheric hiss emission at frequency < 200 Hz. This mechanism will supplement the chorus-as-embryonic-source mechanism, which is favorable for the waves above 200 Hz, to provide a more complete picture on understanding the generation of plasmaspheric hiss.

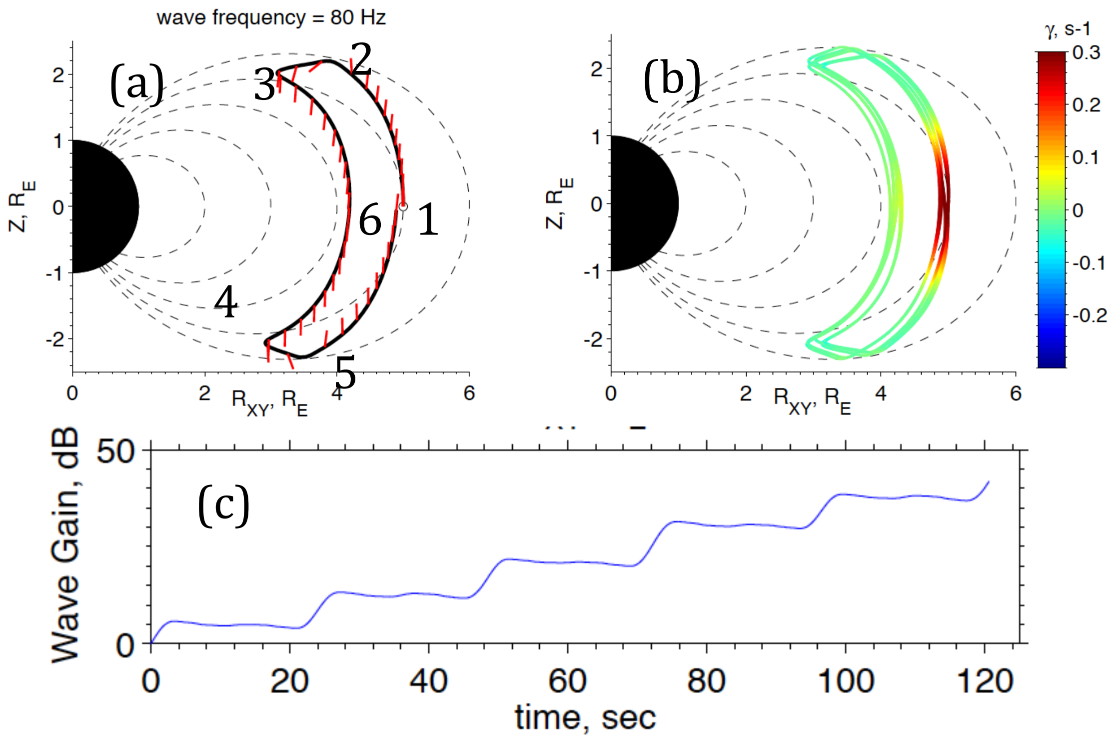

Figure 3. (a) The ray path of 80 Hz wave over one cycle. Short red segments represent the instantaneous wave normal directions along the ray path. (b) The ray path of the wave over the first 5 cycles with color-coded local temporal growth rate along the ray path. (c) Path-integrated wave gain as a function of propagation time. The dashed lines in panels a and b represent dipole magnetic field of L=2, 3, 4, 5, and 6.

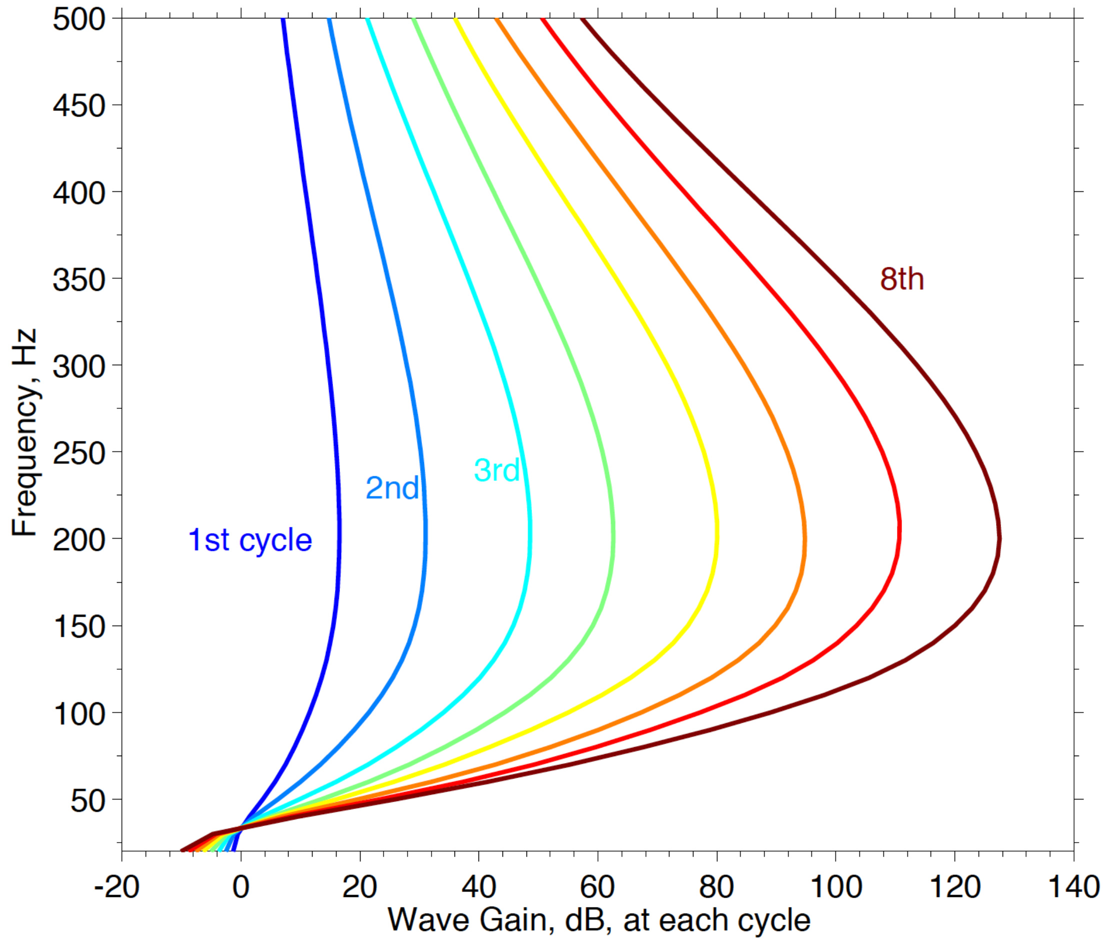

Figure 4. The path-integrated wave gain as a function of wave frequency at the end of each cycle for the first 8 cycles. A cycle is defined when a ray crosses the equator from south to north.

References

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