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Properties of lightning whistlers observed in the topside ionosphere of Jupiter

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Abstract

Short impulsive signals from lightning in Jovian atmosphere are dispersed by their passage through the plasma environment of the planet into the characteristic form of whistlers. Electromagnetic measurements of the Juno Waves instrument allow us to collect the largest existing set of lightning detections and to observe different spectral forms of whistlers at short time scales. Comparison of their observed frequency-time structure with calculations of their frequency dependent group delays allows us to analyze parameters of the low-density plasma in the topside ionosphere of Jupiter.

1. Introduction

Lightning generated electromagnetic waves were discovered in the dense plasma of Io torus by Voyager 1 [1]. They were dispersed by their passage through the plasma medium into the form of whistlers at time scales of several seconds and at frequencies of several kHz.

The unique polar orbit of the Juno spacecraft [2] allows us to observe “rapid” whistlers in the topside ionosphere very close to Jupiter [3]. As their path through the dense plasma is short, the accumulated dispersion is low, and the time scales of these whistlers decrease to only several units to tens of milliseconds.

2. Statistics of detections

The Juno Waves instrument [4] observed 1627 “rapid” whistlers during the initial 8 close approaches to the planet at radial distances below 5 Jovian radii [3]. This outnumbers all previous lightning data sets from Jupiter. Voyager 1 observed 167 whistlers, followed by 434 optical lightning detections from Voyager 1 and 2, Galileo, Cassini, New Horizons, and by 377 Juno MWR “sferics” at 600 MHz [5].

A maximum rate of more than 4 whistlers per second has been observed by Juno. Statistics of whistler rates give us average values of more than 1 whistler/s between +40° and +55° magnetic latitude in the northern hemisphere and more than 0.5 whistler/s between -65° and -50° in the southern hemisphere.

A rough categorization according to the observed dispersion properties provides us with two dispersion classes: Class 1 with a difference of propagation delays at 2 and 5 kHz of less than 5 ms, and Class with larger differences [3]. However, the observed time-frequency spectrograms of Jovian whistlers can be more complex, exhibiting signs similar to terrestrial ion whistlers, as well as sudden “hook” and “flag” signatures in whistler traces.

Analysis of the relative phase and coherency between the electric and magnetic field signals recorded by Juno Waves allows us to determine that these waves propagate outward from the planet.

3. Calculations of the propagation delay

We use the VIP4 magnetic field [6] model recalibrated to the local measurements of the magnetic field strength at Juno, together with the plasma density model from Voyager 2 entry radio occultation [7], extended to higher altitudes using an exponential fit. Our calculations of the accumulated group delay of field aligned and right-hand polarized waves show a good correspondence to the observed Class 2 whistlers [3]. However, we need to decrease the overall density profile by a factor of 10 in order to fit the much steeper Class 1 traces.

The propagation delay can also be influenced by properties of the wave mode structure in the extremely low density plasma close to the Juno altitude. In the situation where the plasma frequency becomes comparable to the ion cyclotron frequency, the wave properties drastically change. An example is given in Figure 1, showing the group velocity as a function of frequency and parametrized by the wave vector angle with respect to the local field line. A hook signature on a whistler trace may be generated by a sudden decrease of the group velocity for inclined wave vectors.

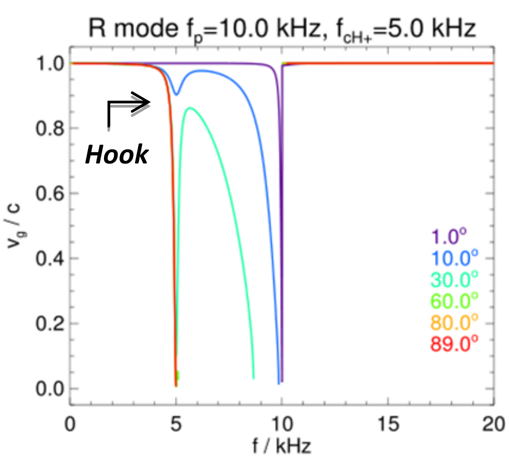

Figure 1: Group velocity of right hand polarized waves for plasma parameters close to Juno orbit.

4. Summary

The Waves instrument onboard Juno collected over sixteen hundred lightning detections, the largest set obtained up to now.

Observed peak occurrence rates of more than 4 whistlers/second in short orbital segments and an average rate of more 1 whistler/second in midlatitudes are similar to thunderstorms at Earth.

Comparison of their frequency-time structure with calculations of their frequency dependent group delay allows us to estimate parameters of the topside ionosphere of Jupiter. Their dispersion properties can be explained by peculiar properties of the mode structure and group velocity for extremely low plasma densities.

Short duration of Class 2 electron whistlers can be explained by dispersion calculations based on existing models of ionospheric plasma and magnetic field. Even shorter duration of Class 1 whistlers might reflect density holes in the ionosphere, not detected by previous radio occultation measurements. Steep frequency-time signatures of class 1 whistlers in the northern hemisphere indicate that the ionospheric plasma may have different properties in the two hemispheres.

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