Estimation of spatial structure of whistler mode wave packets in Earth's bow shock by multiple spacecraft analysis

*Chika Umegaki[1], Takanobu Amano[1], Naritoshi Kitamura[1]

1. The university of tokyo

There have been a lot of unresolved issues in the generation mechanism of nonthermal charged particles observed ubiquitously in space plasmas. The Fermi acceleration at a shock wave is one of the leading mechanisms for the nonthermal particle acceleration. In this mechanism, it is necessary to confine charged particles in the vicinity of the shock wave while charged particles are being accelerated, which requires pitch angle scattering due to wave-particle interactions. In the case of electrons, whistler mode waves are considered to play a major role in the pitch angle scattering. Whistler mode waves are electromagnetic waves that are right-hand circularly polarized with respect to the background magnetic field. They are thought to contribute to the scattering of electrons by interacting with counter-streaming electrons. In fact, there have been reports of coherent whistler mode waves propagating parallel to the magnetic field in the vicinity of the shock wave (Hull et al., 2012). Recently, it was found that such whistler mode waves are indeed resonantly interacting with suprathermal electrons (Oka et al., 2017). However, it has been known that the acceleration of electrons at the shock is rare, and the relation between whistler mode waves and electron scattering (or acceleration) efficiency has not yet been clarified. The applicability of the standard quasi-linear theory for the electron scattering efficiency by coherent whistler mode waves seen in the shock transition region is not understood very well. For this purpose, one has to identify the spatio-temporal scale of coherent whistler wave packets.

In this study, we aim to estimate the spatial scale of the coherent whistler mode waves around bow shock. For instance, by estimating the scale size of whistler mode wave packets in the direction perpendicular to the magnetic field, we may impose a limit for the energy of electrons being scattered by the wave. This is because gyroradii of electrons must be sufficiently smaller than the perpendicular size of wave packets otherwise the conventional cyclotron resonance theory should not be applicable. For this purpose, simultaneous observations by multiple spacecraft are necessary. In this study, we performed an analysis for high-frequency (~100 Hz) electromagnetic waves observed during bow shock crossings with enhanced energetic electron flux observed by NASA's MMS (Magnetospheric MultiScale) spacecraft.

In particular, we report results for the following two bow shock crossing events: 11:44 UT on October 7, 2015 (Event 1), and 10:29 UT on December 6, 2016 (Event 2). The spacecraft separation was 20 km and 7 km for the Event 1 and Event 2, and comparison between the two may enable us to estimate the scale size of whistler mode wave packets. We applied a band pass filter with for the frequency range 100-250 Hz (fce > 1 kHz) for Event 1, and 50-150 Hz (fce ~ 300 Hz) for Event 2 where prominent peaks were observed in the magnetic field power spectra. We confirmed that whistler mode waves appeared sporadically as wave packets with a short duration (50 - 100 ms). We used MVA (Minimum Variance Analysis) for determining the wave propagation direction. Note that we eliminated the 180-degree ambiguity by referring the Poynting vector direction. Also, we estimated the wavelength from the wave electric-to-magnetic field amplitude ratio using Faraday's law. The obtained wavelengths of the whistler mode waves were roughly 10 km. This indicates that the spacecraft separations were larger (smaller) than the wavelength for the Event 1 (2). By doing the same analysis for each spacecraft, we found that wave packets observed during Event 1 were almost always uncorrelated. On the other hand, both correlated and uncorrelated wave packets were found for Event 2. This suggests that the whistler mode wave packets have spatial scale of a few km. In this report, we will estimate the spatial scale sizes of wave packets in parallel and perpendicular to the magnetic field direction.

Keywords: whistler wave, MMS spacecraft

