0.03 - 10 Hz MAGNETIC FLUCTUATIONS DETECTED BY KAGUYA ON THE DAYSIDE SURFACE OF THE MOON. T. Nakagawa[1], F. Takahashi[2], H. Tsunakawa[2], H. Shibuya[3], H. Shimizu[4], M. Matsushima[2]. [1]Tohoku Institute of Technology, Miyagi 982-8577, Japan (nakagawa@tohtech.ac.jp), [2]Tokyo Institute of Technology, Tokyo 152-8550, Japan, [3]Kumamoto University, Kumamoto 860-8555, Japan, [4]Earthquake Research Institute, University of Tokyo, Tokyo 113-0032, Japan.

Introduction: Absorption of the solar wind particles by the lunar surface leads to the formation of the lunar wake. Recently, it is found that not all the solar wind particles are absorbed but 0.1- 1 % of the solar wind protons are reflected by the lunar surface [1] and that some of the reflected protons can access the center of the near wake due to their large Larmour radius[2]. The solar wind interaction with the moon generates wave activities around the moon. Wind, GEOTAIL, and Lunar Prospector detected monochromatic whistler waves [3,4,5], but they are rarely observed. Instead, most commonly observed around the moon are large-amplitude, low frequency waves with the period around 100 seconds, and non-monochromatic fluctuations whose frequencies range from 0.03 to 10 Hz. In this paper, the properties of the non-monochromatic waves observed mainly on the dayside surface of the moon are presented and their generation mechanism is discussed.

Observation: The magnetic field data used in this study were obtained by MAP-LMAG magnetometer [6,7] onboard Kaguya on its orbit encircling the moon at an altitude of 100 km. Figure 1 shows an example of the orbit of Kaguya on March 8, 2008, when the moon was in the solar wind. The period of the orbital motion was about 118 min at the altitude. The magnetic field vectors were obtained with sampling frequency of 32 Hz. Figure 2 shows an example of the dynamic spectrum of By component. The magnetic fluctuations started at 4:10, before the spacecraft got out of the lunar wake as recognized in Figure 1(c), and persisted until 5:30, when the spacecraft had entered into the lunar wake. That is, the fluctuation was observable in the area where the solar zenith angle was less than about 123°. They were not observed deep in the wake. The frequency extended up to 5 Hz for the period 4:10-5:10, and then up to 10 Hz for 5:10 - 5:27. Although the fluctuations were most intense around 5:20-5:27 when the spacecraft was just behind of an lunar external magnetic enhancement (LEME) observed at 5:10-5:20, for the most part of the time (4:10-5:10), the magnetic fluctuations were observed far from the LEME. Red (blue) bars at the bottom of the spectrum indicate that the spacecraft was magnetically connected with the dayside (nightside) surface of the moon. The spacecraft was not necessarily connected with the lunar surface when the magnetic fluctuations were observed. It would suggest that the wave propagation was not exactly parallel to the magnetic field.

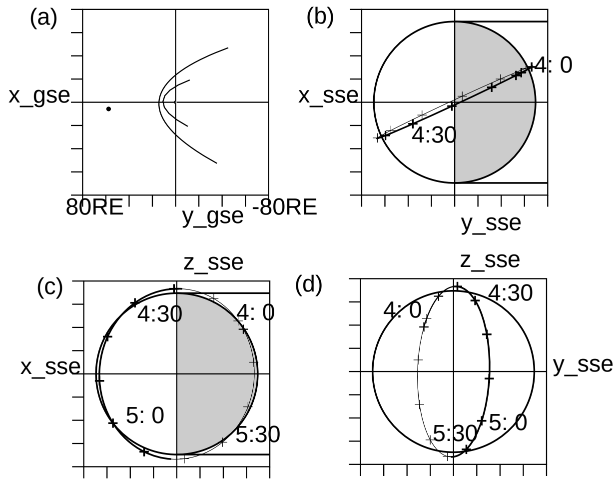

Fig.1 An example of the orbit of Kaguya on March 8, 2008. (a) The position of the moon together with Kaguya, with respect to the Earth and the nominal bow shock in GSE coordinates. (b)(c)(d) The trajectory of Kaguya encircling the moon, projection onto (b) x-y, (c) x-z, and (d) y-z plane of SSE coordinates. Thin curves show that the spacecraft was behind the moon.

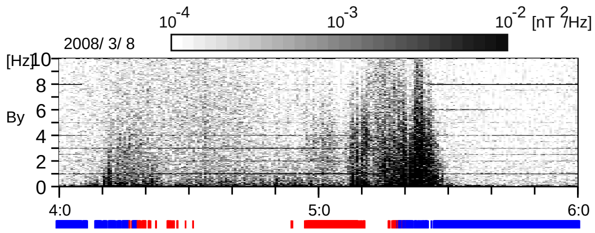

Fig.2 An example of the magnetic fluctuations observed on March 8, 2008 on the orbit shown in Figure 1. The dynamic spectrum of By component obtained at 32 Hz sampling period and Fourier transformed every 32 sec. Red (blue) bars indicate that the spacecraft was magnetically connected with the dayside (nightside) surface of the moon.

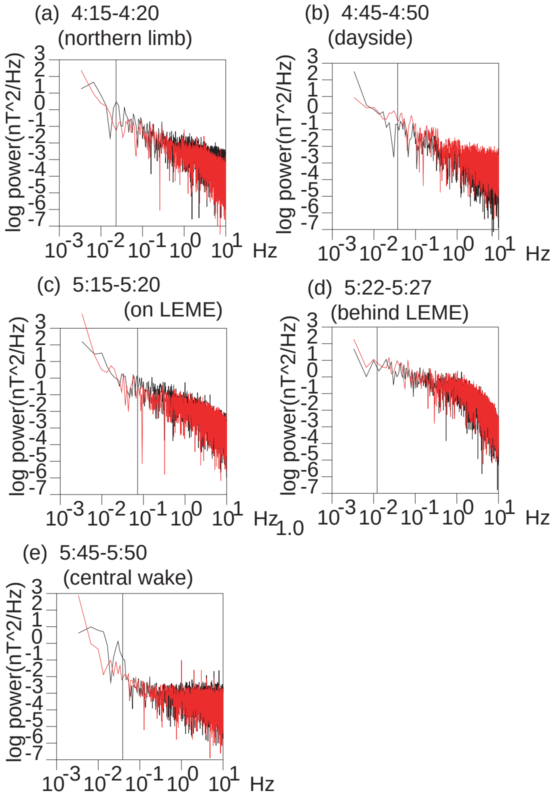

Fig.3 The spectra of the magnetic fluctuations observed on March 8, 2008, for the periods selected from Figure 2. Curves are for the magnetic components of maximum (red) and medium (black) variances, respectively. The vertical lines indicate the proton cyclotron frequency. The level of fluctuations rose over a wide frequency range from 0.03 to 10 Hz at various locations (a) the northern limb, (b) dayside surface, (c) on the LEME near the southern limb, and (e) in the central wake. The position of the spacecraft for each period can be recognized in Figure 1.

Figure 3 shows the spectra of the magnetic fluctuations for 5 different periods selected from Figure 2. Vertical lines indicate local ion cyclotron frequencies (~0.03 Hz for periods (a),(b),(e), 0.06 Hz for (c), or 0.02 Hz for (d)). Compared with the quiet period (e) when Kaguya was in the center of the wake, the level of the fluctuation enhanced over the wide range from 0.03 to 10 Hz at (a) the northern limb, (b) dayside surface, (c) on the LEME near the southern limb, and (d) behind the LEME just nightside of the terminator. The fluctuation level was higher in (d) the weak field region behind the LEME rather than (c) on the LEME. There was no clear peak frequency.

Discussion and Conclusion: The observed frequency 0.03 - 10 Hz is the result of the Doppler shift as Kaguya was in the solar wind flow and observed the waves propagating in the solar wind plasma. The observed frequency higher than the ion cyclotron frequency (0.03 Hz) requires that the frequency must have been much higher than the cyclotron frequency in the solar wind frame of reference, if the waves were propagating upstream Downstream propagating magnetohydrodynamic waves cannot reproduce as such high frequency, either. The only wave that can present in the frequency range is the whistler wave.

It would be natural to think that the waves were associated with the plasma particles reflected by the lunar surface, as the waves were mainly observed on the solar side surface of the moon. If we assume cyclotron resonance as a generation mechanism of the whistler wave, the resonant particles must be protons, because the frequency was too low to match the electron cyclotron frequency.

Comparison of the non-monochromatic waves with the reflected protons detected by MAP-PACE Ion Mass Analyzer (IMA) onboard Kaguya [1] revealed that the period of enhancement of magnetic fluctuations overlapped the period of detection of the reflected ions. The start and end times of the period did not agree with each other. It is partly due to the fact that the waves were convected down by the solar wind stream to the nightside of the moon while the reflected ions were detected only on the dayside.

According to Saito[1], the solar wind protons reflected by the lunar surface were scattered into various directions. It causes a wide range of distribution of the velocity component parallel to the magnetic field. It would account for the wide range of frequency of the non-monochromatic whistler waves generated through cyclotron resonance with the reflected ions, in which the resonant frequency depends on the velocity component parallel to the magnetic field.

References: [1] Saito et al.(2008), *Earth Planets Space*, *60*, 375-385. [2] Nishino et al. (2009), *Geophys. Res.Lett.*, *36*, L16103, doi:10.1029/2009 GL039444.[3] Farrell et al.(1996), *Geophys. Res. Lett.*, *23*, 1271-1274. [4] Nakagawa et al.(2003), *Earth Planets Space*, *55*, 569-580. [5] Halekas et al. (2006), *Geophys. Res. Lett.*, *33*, L22104, doi: 10.1029/2006GL027684. [6] Shimizu et al. (2008) *Earth Planets Space*, *60*, 353-363. [7] Takahashi et al. (2009), *Earth Planets Space, 61*, 1269-1274.