MAVEN CHARACTERIZATION OF LOW-FREQUENCY PLASMA WAVES IN THE MARTIAN MAGNETOSPHERE. S. Ruhunusiri[1], J. S. Halekas[1], J. E. P. Connerney[2], J. Espley[2], D. Larson[3], D. L. Mitchell[3], [1]Department of Physics and Astronomy, The University of Iowa, Iowa City, IA 52242 (suranga-ruhunusiri@uiowa.edu), [2]NASA Goddard Space Flight Center, Greenbelt, MD 20771, [3]Space Sciences Laboratory, University of California, Berkeley, CA 94720.

Introduction: The goal of this investigation is to characterize low-frequency waves in the induced magnetosphere of Mars using the particle and field instruments aboard the MAVEN spacecraft. Due to the interaction of the solar wind with the magnetosphere and the exosphere of Mars, various plasma waves are excited, with the highest wave power near and below the proton gyrofrequency. Studying these waves is important, because they play an important role in the momentum and energy transfer in Mars's magnetosphere. In order to characterize the magnetospheric waves, we use ion moment (density and velocity) fluctuations and magnetic field fluctuations. For this purpose, we use measurements from the MAVEN Solar Wind Ion Analyzer (SWIA) and the magnetometer (MAG) instruments.

Previous wave investigations: Magnetospheric waves have been previously characterized for Mars primarily using electric or magnetic field measurements [1-7]. In these studies, the waves have been characterized using the following aspects: wave mode, energy source for the instability, and occurrence in different regions within the magnetosphere, for example upstream of bow shock (BS), magnetosheath (MS), and in the magnetic pile up boundary (MPB). Using Phobos 2 electric field measurements, Grard et al. [1, 2] made the first observations of plasma waves at Mars. The authors reported observations of sporadic electron plasma oscillations upstream of the bow shock and broadband electrostatic waves near the bow shock and in the magnetosheath. All this wave activity had a large frequency range, up to tens of kilohertz; however the wave power was mainly concentrated at lower frequencies. The authors suggested that the upstream electron plasma oscillations arise from superthermal electrons accelerated at the bow shock, whereas the waves near the bow shock and in the magnetosheath arise from ion beams formed by specularly reflected protons at the bow shock or by solar wind pick up ions. Phobos 2 also detected broadband waves with frequencies up to a few kilohertz in the night side of Mars that coincided with observations of high-density cold electrons [3]. Using the Mars Global Surveyor (MGS) magnetometer, Brain et al. [4] observed waves near the local proton gyrofrequency upstream of the bow shock. They concluded that these waves arise from instabilities due to solar wind pickup of Martian exospheric protons. Espley et al. [5] performed a statistical analysis using MGS magnetometer measurements to identify low-frequency wave modes in the various regions of the Martian magnetosphere using data from over 400 orbits. They concluded that the dayside is dominated by mirror mode waves, whereas the night side is dominated by right-hand or left-hand resonant instabilities. Using the MGS magnetometer and the electron reflectometer, Bertucci et al. [8] studied low frequency waves on the upstream and downstream sides of the MPB. They observed electron density fluctuations that correlate with magnetic field fluctuations. The authors concluded that the observed waves are mirror mode waves in the upstream side and quasi-monochromatic fast magnetosonic waves in the downstream side.

Low frequency wave identification: Here, we restrict ourselves to an investigation of low frequency waves, i.e. frequencies near and below the local proton gyrofrequency, because the waves have a much higher power in that range. MHD theory predicts three normal modes for plasma waves with frequencies below the local proton gyrofrequency: fast, Alfvén (intermediate), and slow. A fourth mode, the mirror mode, exists when temperature anisotropy is taken in to account. The primary difference between the mirror mode and the other three modes is that it has zero phase velocity in the plasma frame [9].

To identify a wave mode, one needs to measure the wavelength and frequency of a wave and compare them with a theoretical dispersion relation. However, the frequency of the wave is often Doppler shifted due to the streaming solar wind. The wavelength measurement, meanwhile, requires not one but two spacecrafts. Thus, wave mode identification using a single spacecraft requires other methods.

One method of wave identification is based on magnetic field measurements alone. This method requires calculation of wave parameters, for example, the polarization, ellipticity, and wave propagation angle which are then compared with theoretically expected values. Another method uses measurements of both particles and fields. Gary et al. [10] introduced this method of wave identification by computing transport ratios, which are essentially ratios or correlation coefficients among particle moment fluctuations and field fluctuations. Extending this method, Song et al. [9] and Denton et al. [11] developed techniques to identify amongst the four MHD wave modes and they applied these techniques for wave identification in the earth magnetosheath.

Method: Here, we use the wave identification scheme developed by Song et al. [9] for low frequency wave identification in the Martian magnetosphere. For this, we first compute four transport ratios: transverse ratio, compressional ratio, phase (partition) ratio, and Doppler ratio (defined in Eqs. 1, 3, 4, and 6 of [9]). Then, a hierarchical scheme shown in Fig. 1 of [9] is used to identify amongst the four MHD wave modes. Calculation of these transport ratios requires magnetic field fluctuations and ion density and velocity fluctuations. We use the MAG and SWIA instruments aboard MAVEN to obtain these measurements, respectively.

We compute the average transport ratios for MAVEN orbits spanning October 7 to December 27 of 2014 and we plot them in MSO coordinates. Figure 1 depicts two of the four transport ratios: transverse ratio and compressional ratio. The transverse ratio, Fig. 1(a), is the ratio between the perpendicular and parallel magnetic field fluctuations. The compressional ratio, Fig. 1(b), on the other hand, is the ratio between the fractional fluctuations of the ion density and those of the magnetic field.

Observations: We find that the magnetic field fluctuations are transverse throughout the magnetosphere, Fig. 1(a). Upstream of the bow shock, we find that the magnetic field fluctuations are generally more dominant, Fig. 1(b). In the magnetosheath, on the other hand, the ion density fluctuations are generally more dominant, and they are more enhanced downstream of the MPB, Fig. 1(b).

According to the Song et al. [9] technique, when the transverse ratio is greater than one (as in our results), waves can be uniquely identified based on the compressional ratio alone. When the compressional ratio is less than one, the waves are either Alfvénic or quasi-parallel slow, whereas when the compressional ratio is greater than one the waves are quasi-parallel fast.

We find that upstream of the bow shock waves are Alfvénic or quasi-parallel slow type. Fluctuations in the magnetosheath consist of a mixture of quasi-parallel fast and Alfvénic or quasi-parallel slow waves. Downstream of the MPB, the quasi-parallel fast waves become the dominant wave mode.

Conclusions: We used the MAVEN SWIA and MAG measurements for characterizing the low frequency magnetospheric waves at Mars. We intend to use the MAVEN orbits in the upcoming year to improve upon our statistical study. One caveat of the Song et al. [9] technique is that it assumes a high beta plasma. The plasma beta value in the Martian magnetosphere is generally less than 5 and in low plasma beta regions (especially inside the MPB), this identification scheme may not be applicable. Thus, accurate wave identification requires knowledge of the transport ratios as well as the ambient plasma conditions. In our future work, we will theoretically calculate the transport ratios as done in the wave identification scheme by Denton et al. [11]. For this, we will use a Vlasov simulation code (WHAMP) using the magnetospheric plasma parameters obtained by SWIA and MAG as inputs. Comparison of the theoretical transport ratios with the measured ones will allow us to be confident on our wave identification.

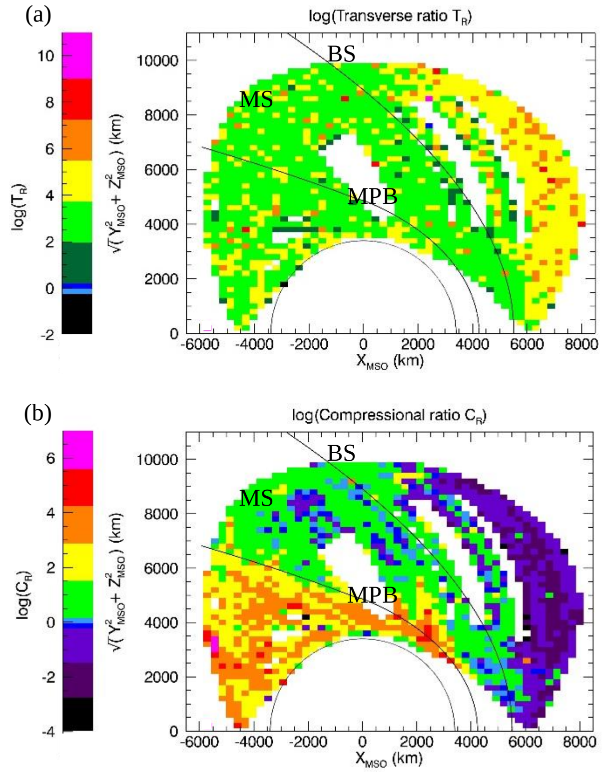

Figure 1: Orbit plots of transport ratios: transverse ratio (a) and compressional ratio (b).

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