MAVEN OBSERVATIONS OF MAGNETOSONIC LIKE WAVES UPSTREAM OF MARS. S. Ruhunusiri1, J. S. Halekas1, J. E. P. Connerney2, J. Espley2, D. Larson3, D. L. Mitchell3, D. A. Brain4, 1Department of Physics and Astronomy, The University of Iowa, Iowa City, IA 52242 (suranga-ruhunusiri@uiowa.edu), 2NASA Goddard Space Flight Center, Greenbelt, MD 20771, 3Space Sciences Laboratory, University of California, Berkeley, CA 94720, 4Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO 80303.

Introduction: We observe left-hand elliptically polarized waves with a frequency near the proton cyclotron frequency, with large fluctuations in the ion density and in the magnetic field upstream of Mars. These observations are made possible by the solar wind ion analyzer (SWIA) and the magnetometer (MAG) instruments on board the MAVEN spacecraft. Based on our preliminary analysis, we conclude that the observed waves are magnetosonic waves, but not Alfvenic ion cyclotron waves. The instability sources for the Alfvenic ion cyclotron waves and magnetosonic waves are different and identification of these waves in principal allows us to understand the underlying physics operating upstream of Mars. Additionally, the study of waves with frequencies near the proton cyclotron frequency are of interest, because they can be used to assess Mars’s exospheric structure and its loss rate.

Waves near the proton cyclotron frequency: According to the Vlasov theory, there can be two distinct wave modes near the proton cyclotron frequency: left-hand polarized Alfvenic ion cyclotron wave and the right-hand polarized magnetosonic wave [1,2]. Both these wave modes are transverse; the perpendicular magnetic field fluctuations (with respect to an ambient magnetic field) exceed that of the parallel fluctuations. The RH magnetosonic waves have correlated fluctuations between the ion density and magnetic field and their fractional fluctuations are comparable. The LH Alfvenic ion cyclotron waves, however, should have extremely small or no ion density fluctuations that correlate with the magnetic field fluctuations.

Another difference between the two wave modes are their sources of instability. The LH Alfvenic ion cyclotron waves can be driven by an ion/ion left hand resonance instability, whereas, the RH magnetosonic waves can be driven by either a nonresonant ion firehose instability or an ion/ion right hand resonance instability [3].

In the spacecraft frame, these waves can be observed as either RH or LH waves due to a Doppler shift, depending on whether the waves are propagating toward or away from the sun [2]. For example, suppose a RH wave in the solar wind frame is propagating toward the sun. Because the solar wind speed is generally larger than the wave phase velocity, the wave appears to move toward a spacecraft orbiting a planet; consequently the wave appears as a LH wave in the spacecraft frame. Similarly, a RH wave appears with the same polarization if it propagates away from the sun. Thus, the polarization of the wave in the spacecraft frame alone is not a suitable criterion to distinguish the two types of waves.

Previous observations: Left hand circularly-polarized proton cyclotron waves have been observed upstream of Mars’s bow shock by a number of investigators with the aid of magnetometers on board the Phobos 2 and Mars Global Surveyor (MGS) spacecrafts [4-9]. These waves were first observed by Russell et al. [4] by using the Phobos 2 magnetometer. The authors concluded that these waves are made unstable by the solar wind pick up of exospheric protons and that the strength of these waves is an indirect measure of the loss rate of the exospheric hydrogen. Brain et al.

Figure 1: Observations of magnetosonic like waves upstream of Mars. The first panel and the third panel depict the ion density and the energy spectra, respectively, which are based on SWIA measurements. The second panel shows the magnetic field in MSO coordinates. The last panel shows the spacecraft altitude.
[5] studied proton cyclotron waves using the MGS magnetometer and they characterized the spatial distribution of the wave power. Bertucci et al. [6] reported observations of highly coherent waves near the proton cyclotron frequency that have correlated fluctuations in the magnetic field and the electron flux. Based on the quasineutrality assumption, the authors hypothesized that there should be a corresponding ion density fluctuation as well.

To our knowledge, right-hand polarized magneto-sonic waves have not been reported at Mars. However, these waves have been observed upstream of Earth [10]. Now with MAVEN, which is equipped with both SWIA and MAG, we have the capability to detect these waves and distinguish them from the Alfvénic proton cyclotron waves.

MAVEN observations: We observe waves upstream of Mars, which have large fluctuations in both the ion density and in the magnetic field components, Fig. 1 (panels 1 and 2). The wave signature is also visible in the SWIA energy spectra (panel 3 of Fig. 1).

To identify the waves, we compute the average spectra for the ion density and magnetic field fluctuations, from 1430 hrs. to 1440 hrs. The dominant magnetic field fluctuation occurs at a frequency (f) below the local proton cyclotron frequency (fpc) with f/fpc ~ 0.5, Fig. 2(a). Moreover, the transverse magnetic field fluctuations (δB⊥) for the dominant mode is higher than that of the parallel fluctuations (δB||). The density fluctuations has the highest power at the same frequency as that of the transverse magnetic field fluctuations, Fig. 2(b). We find that, for the dominant mode, the fractional fluctuation of the ion density, (δn/n0), is as high as the fractional fluctuation of the magnetic field, (δB/Bo), with (δn/n0)/(δB/Bo) ~ 0.9.

In order to further characterize the waves, we use minimum variance method [11] to compute wave parameters such as the ellipticity and wave vector angle. We find that the dominant wave mode is left-hand elliptically polarized (with respect to the ambient magnetic field) and that it is propagating nearly parallel or antiparallel to the ambient magnetic field in the spacecraft frame.

Conclusions: The observed waves have two characteristics that suggest that these are magneto-sonic type waves: the wave has correlated ion and magnetic field fluctuations and their fractional fluctuations are comparable. Thus, we conclude that the observed waves are magneto-sonic type, but not the Alfvénic ion cyclotron type. The observed left-hand polarization of the wave in the spacecraft frame, meanwhile, can be a consequence of the Doppler shift. Another important aspect to note here is that during the time interval where these waves are observed, the interplanetary magnetic field was mainly in the MSO-x direction.

This enables the reflected protons to easily access an extended region upstream of Mars’s magnetosphere. Thus, the observed waves could have been made unstable by the reflected protons. In our future work, we will attempt to statistically characterize these waves. We will also find the nature of ion distribution functions and the plasma parameters that are responsible for generation of these type of waves.