PLASMA WAVES AT MARS: MAVEN OBSERVATIONS

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We present recent plasma wave observations made by the Mars Atmosphere and Volatile EvolutioN (MAVEN) spacecraft. Five main types of waves have been observed by MAVEN to date: 1. upstream proton cyclotron waves, 2. upstream Alfvén waves, 3. Kelvin-Helmholtz waves at the magnetic pileup boundary, 4. whistler mode waves in the magnetic pileup and the tail regions, and 5. magnetotail waves traveling along the tail current sheet. Proton cyclotron waves, that have frequencies near the local proton gyrofrequency, are found in the upstream region (upstream of the bow shock) of Mars. These waves show seasonal variations which correspond to the seasonal variation of Mars' extended hydrogen exosphere. This seasonal exospheric variation is a consequence of the varying solar UV flux at Mars that arises due to the varying Mars-Sun distance. This indicates that these waves are excited by pickup ions created in the extended hydrogen exosphere. We, in particular, find that two sources are primarily responsible for the excitation of these waves: newly born pickup ions and pickup ions that are reflected from the bow shock. The upstream Alfvén waves that are of solar wind origin, which typically have frequencies below the local proton gyrofrequency, are found to provide a variable energy input to the Martian system. This variability is believed to arise due to heliocentric and solar cycle effects. At the magnetic pileup boundary, we find Kelvin-Helmholtz (KH) waves that are in their linear stage of development. These KH waves arise due to the velocity shear that is present between the plasma flows in the magnetic pileup region and the magnetosheath. The low growth rate and the small system size of Mars preclude the KH waves from becoming nonlinear closer to the planet, unlike at Earth. Narrowband whistler mode waves, with frequencies between the electron cyclotron frequency and the lower hybrid frequency, are observed in the magnetic pileup and the tail regions. These waves are excited by the cyclotron resonance with anisotropic electrons and can play a key role in the electron precipitation at Mars. In Mars' magnetotail, we find waves with frequencies less than the local proton gyrofrequency that propagate along the tail current sheet. The majority of these waves are found to propagate in the opposite direction to the upstream solar wind electric field direction, unlike at Earth and Venus.