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MAVEN Observations of Steepened Ultra-Low Frequency Waves in the Upstream Martian Foreshock Region

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In this study, we present the analysis of steepened ultra-low frequency (ULF) waves in the foreshock region upstream of Mars' bow shock observed by the Mars Atmosphere and Volatile EvolutioN (MAVEN) spacecraft at Mars. A survey of MAVEN magnetic field and plasma measurements shows quasi-periodic gradual increases followed by a sharp decrease in the magnetic field magnitude (B_{total}). Higher frequency waves were also commonly, but not always, observed at the trailing edge of the large-amplitude increase in B_{total}. These observations are consistent with the signatures of shocklets observed in the solar wind region upstream of Earth's and planetary bow shocks. Shocklets are believed to be formed as a result of the steepening of fast magnetosonic waves generated by reflected ions in the quasi-parallel foreshock region. We also performed the minimum variance analysis (MVA) and statistical analysis technique to determine the wave properties (e.g. polarization, wave propagation, amplitude and frequency) of the shocklets and higher frequency waves observed in its trailing edge. Our results showed that these shocklets are left-handed polarized in the spacecraft frame, with mean amplitude δB/B of ~3.5 and time separation between adjacent shocklet events of ~40s. We also analyzed measurements (ions and electrons) from MAVEN's plasma instruments to investigate the energization process of the particles during the observations of shocklets. We will discuss the possible generation mechanisms for these steepened ultra-low frequency waves at Mars, and any implications for the martian plasma environment downstream of Mars' bow shock.