Solar Wind induced waves in the skies of Mars: Ionospheric compression, energization, and escape resulting from the impact of ultra-low frequency magnetosonic waves generated upstream of the Martian bow shock

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Using data from the NASA Mars Atmosphere and Voltatile EvolutioN (MAVEN) and ESA Mars Express spacecraft, we show that transient phenomena in the foreshock and solar wind can directly inject energy into the ionosphere of Mars. We demonstrate that the impact of compressive Ultra-Low Frequency (ULF) waves in the solar wind on the induced magnetospheres drive compressional, linearly polarized, magnetosonic ULF waves in the ionosphere, and a localized electromagnetic "ringing" at the local proton gyrofrequency. The pulsations heat and energize ionospheric plasmas. A preliminary survey of events shows that no special upstream conditions are required in the interplanetary magnetic field or solar wind. Elevated ion densities and temperatures in the solar wind near to Mars are consistent with the presence of an additional population of Martian ions, leading to ion-ion instabilities, associated wave-particle interactions, and heating of the solar wind. The phenomenon was found to be seasonal, occurring when Mars is near perihelion. Finally, we present simultaneous multipoint observations of the phenomenon, with the Mars Express observing the waves upstream, and MAVEN observing the response in the ionosphere. When these new observations are combined with decades of previous studies, they collectively provide strong evidence for a previously undemonstrated atmospheric loss process at unmagnetized planets: ionospheric escape driven by the direct impact of transient phenomena from the foreshock and solar wind.