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Statistical study of the ripples and reformation in the collisionless shocks using MMS observation

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Collisionless shocks are ubiquitous throughout the universe in near-Earth and astrophysical plasma environments. The behavior of collisionless shocks in terms of their structure and energy dissipation has been the subject of extensive research over many decades, but many open questions remain. Recent studies have demonstrated that the Earth's bow shock can exhibit ripples that propagate along the shock surface. However, their occurrence, dependence on shock parameters, and their role in shock dynamics is still under investigation. One signature of rippling is the presence of phase space holes in reduced ion distribution (integrated along the tangential plane of the shock). Such ion phase space holes are also observed in association with the shock reformation. It is unclear at what part of the parametric space these ion phase space holes are expected. In this study, we have focused on characterizing ion phase space holes at the Earth's bow shock using MMS observations. We analyze more than 500 shock crossings observed by the MMS spacecraft and establish a systematic procedure to find the shocks exhibiting phase space holes. We investigate the key shock physical processes responsible for the existence of these phase space holes (e.g. ripples and reformation) and study the association to shock parameters such as Mach number and geometry. We present the first statistical study of this nature, and these results are important to understanding the non-stationary behavior of collisionless shocks.