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The Saturnian Environment as a Unique Laboratory for Collisionless Shock Waves

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Collisionless shock waves are ubiquitous in the universe and fundamental to understanding the nature of collisionless plasmas. The interplay between particles (ions and electrons) and fields (electromagnetic) introduces a variety of both physical and geometrical parameters such as Mach numbers (e.g. M_A, M_f), β, and θ_{Bn}. These vary drastically from terrestrial to astrophysical regimes resulting in radically different characteristics of shocks. This poses two complexities. Firstly, separating the influences of these parameters on physical mechanisms such as energy dissipation. Secondly, correlating observations of shock waves over a wide range of each parameter, enough to span across different regimes. Investigating the latter has been restricted since the majority of studies on shocks at exotic regimes (such as supernova remnants) have been achieved either remotely or via simulations, but rarely by means of in-situ observations. It is not clear what happens in the higher M_A regime. Here we show the parameter space of M_A for all bow shock crossings from 2004-2012 as measured by the Cassini spacecraft. We found that the Saturnian bow shock exhibits characteristics akin to both terrestrial and astrophysical regimes (M_A of order 100), which is principally controlled by the upstream magnetic field strength. Moreover, we estimated the θ_{bn} of each crossing and were able to further constrain the sample into categories of similar features. Our results demonstrate how M_A plays a central role in controlling the onset of physical mechanisms in collisionless shocks, particularly reformation. While ongoing studies have investigated this process extensively both theoretically and via simulations, their observations remain few and far between. We show conclusive evidence for cyclic reformation controlled by specular ion reflection occurring at the predicted timescale of $\sim$0.3 τ_c, where τ_c is the ion gyroperiod. In addition, we experimentally underpin the relationship between reformation and M_A and focus on the magnetic structure of such shocks to further show that for the same M_A, a reforming shock exhibits stronger magnetic field amplification than a shock that is not reforming. We anticipate our comprehensive assessment to give deeper insight to high M_A collisionless shocks and provide a broader scope for understanding the structures and mechanisms of collisionless shocks. This can potentially bridge the gap between more modest M_A observed in near-Earth space and more exotic astrophysical regimes where shock processes play central roles.