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New Observation of Wave Excitation and Inverse Cascade in the Foreshock Region

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Foreshock with nascent plasma turbulence is regarded as a fascinating region to understand the basic plasma physical processes, e.g., wave-particle interactions as well as wave-wave couplings. Although there have been a bunch of intensive studies on this topic, some key clues about the chain of the physical processes still lacks from observations, e.g., the co-existence of upstream energetic particles as the free energy source, excited pump waves as the wave seed, inverse cascaded daughter waves, and scattered energetic particles as the end of nonlinear processes. A relatively comprehensive case study with some new observations is presented in this work. In our case, upstream energetic protons drifting at tens of Alfvén speed with respect to the background plasma protons is observed from 3DP/PESA-High onboard the WIND spacecraft. When looking at the wave magnetic activities, we are surprised to find the co-existence of high-frequency (0.1-0.5 Hz) large-amplitude right-hand polarized (RHP) waves and low-frequency (0.02-0.1 Hz) small-amplitude left-hand polarized (LHP) waves in the spacecraft (SC) frame. The anti-correlation between magnetic and velocity fluctuations along with the sunward magnetic field direction indicates the low-frequency LHP waves in the SC frame is in fact the sunward upstream RHP waves in the solar wind frame. This new observation lays solid foundation for the applicability of plasma non-resonance instability theory and inverse cascade theory to the foreshock region, in which the downstream high-frequency RHP pump waves are excited by the upstream reflected energetic protons through non-resonance instability and low-frequency RHP daughter waves are generated by the pump waves due to nonlinear parametric decay. The weak signal of alpha particle flux in the foreshock region concerned is also favorable to the occurrence of nonlinear decay process. Furthermore, enhanced downstream energetic proton fluxes are found and inferred to be scattered by the nascent turbulent fluctuations. Therefore, some key clues about the newborn turbulence in the foreshock are supplemented in this work. Nevertheless, the more complete scenario about the fundamental plasma physical processes in the foreshock is left for the newly launched MMS project and the proposed THOR mission.