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Joint Heating of Solar Wind Protons by Multi-Wave-Modes via Multi-Resonances

Jiansen He (1), Linghua Wang (1), Chuanyi Tu (1), Eckart Marsch (2), Christopher H. K. Chen (3), Zhongtian Pei (1), Lei Zhang (1), Chadi S. Salem (4), Stuart D. Bale (4,5)

(1) School of Earth and Space Sciences, Peking University, Beijing, 100871, China (jshept@gmail.com), (2) Institute for Experimental and Applied Physics, Christian-Albrechts-Universität zu Kiel, D-24118 Kiel, Germany, (3) Department of Physics, Imperial College London, London SW7 2AZ, UK, (4) Space Sciences Laboratory, University of California, Berkeley, CA 94720, USA, (5) Department of Physics, University of California, Berkeley, CA 94720, USA

How the protons are heated non-adiabatically in the solar wind turbulence is a long-lasting important problem yet to be solved. The simultaneous analysis of the wave modes and proton kinetics may help to unveil part of the puzzle. The bulk parameters of solar wind protons usually behave differently in the fast and slow streams: e.g., weak VS strong density compressibility, distinct large perpendicular temperature VS evident parallel temperature. These differences may be attributed to the different heating processes in these two types of streams, which is the aim of this work. We find there are different wave activities in the fast and slow streams: quasi-parallel ion cyclotron waves and quasi-perpendicular kinetic Alfv\'en waves for the former, oblique Alfv\'en waves and quasi-perpendicular counter-propagating slow magnetosonic waves for the latter. The proton kinetics together with the wave activities reveals the different heating processes for protons in fast and slow streams. For the fast solar wind, proton cores seem to be heated perpendicularly by left-hand polarized ion cyclotron waves, proton beams are heated parallel and perpendicularly by right-hand polarized quasi-perpendicular kinetic Alfv\'en waves. For the slow solar wind, protons seem to be heated parallel and anti-parallel jointly by counter-propagating oblique Alfv\'en waves and quasi-perpendicular slow magnetosonic waves through respective Landau resonances, resulting in asymmetric bi-directional beams. Therefore, it is suggested that the solar wind protons are heated jointly in both parallel and perpendicular directions by multi-types of wave modes via various types of resonances.