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Determining the kappa distributions of space plasmas from observations in a limited energy range

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Space plasmas are often in stationary states out of thermal equilibrium with their particle velocities described by kappa distributions. The kappa index, which labels and governs these distributions, is an important thermodynamic parameter that needs to be determined for an accurate description of the plasma. One of the main characteristics of the kappa distribution is the high-energy tail which follows a power law. In spacecraft measurements, there are cases when the high-energy tail is observed with significant uncertainty - or even not observed at all - due to instrument limitations. Here we show that even in these cases we can still estimate the parameters of the kappa distribution without taking into account the high-energy tail. More specifically, we present a novel and reliable method that derives the kappa index and temperature of space plasmas by analyzing the observed distribution function in a narrow energy range around the energy associated with the bulk. To demonstrate the new method, we developed a model of data expected from the SWA/PAS instrument on board Solar Orbiter which is designed to study the energy spectra of the solar wind protons and alpha particles. Our model generates pseudo observations of solar wind protons for given plasma distributions and parameters. The pseudo observations are then analyzed by applying our techniques and for each set of input plasma parameters we derive the kappa index and temperature of the solar wind plasma. We quantify our method through comparison between the input and the derived parameters for a range of the input parameters. We finally present an application of the method to examples of 3D plasma distributions obtained from currently operating missions.