Unraveling Particle Distribution Functions: A Novel VDF Reconstruction Method

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Understanding the velocity distribution functions (VDFs) of ions near the Sun is crucial for comprehending the physics of the solar wind. However, measurements from Electrostatic Analyzers (ESA) and Faraday Cups (FC) can have limited temporal and spatial resolutions which lead to an incomplete characterization of the distribution. Using data from any ESA, we can use basis functions to reconstruct VDFs by maximally capitalizing on the available measurements. By virtue of its large thermal velocity, electron distributions have large angular extents about a sphere for each energy shell of the VDF. This makes spherical harmonics (global basis functions on the surface of a sphere,) suitable to decompose electron VDFs. However, ion distributions are localized in phase space, limiting the use of spherical harmonics for reconstructing ion distributions. This work aims to compare spherical harmonics and Slepian functions in their effectiveness for reconstructing missing ion VDF data. Slepian functions are a basis function that are an optimally concentrated orthogonal basis on a partial domain of a sphere. This allows us to account for the localized nature of ions. Using magnetosheath ion VDFs from the MMS spacecraft, we compare the reconstruction capabilities of these two methods. We further expand these tests by restricting the MMS FOV to synthetically mimic the heat shield restriction on the Parker Solar Probe. We found that Slepian functions provide an optimal basis for the reconstruction of ion VDFs. This method will be extended to perform a joint optimization between the ESA and FC on Parker Solar Probe as well as future planned missions such as Helioswarm.