Minimum variance analysis of diverse heliospheric environments: from universal to endemic wave geometries and their relationships to astrophysical phenomena

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Humans have been exploring the solar system since the 1960s, and our understanding of the heliosphere continues to improve as we explore space with unprecedented temporal and spatial resolution. Our data analysis techniques should evolve alongside instrument capabilities in order to achieve a lower uncertainty threshold than our measurements. Unfortunately, the typical method for determining wave propagation direction introduces a non-symmetric 17% uncertainty. This calculation bias can be mitigated by applying appropriate eigenvalue ratio criteria for intermediate to minimum variance ($\lambda_{int/min}$) and maximum to intermediate variance ($\lambda_{max/int}$). We identify minimum variance parameters compatible with 1 sample per minute low-cadence measurements up to 8192+ samples per second high-cadence measurements. Our analysis has a $\lambda_{y/x}$ uncertainty of $\leq 2\%$.

Using a single set of minimum variance parameters, we present examples of wave hodograms and statistical properties for multiple instruments and plasma environments throughout the heliosphere, including the lunar wake, Saturn's magnetic field, the solar poles, and trajectories extending 300 Earth radii to the left and the right of the Earth-Sun line. We compare wave events with and without the in-situ detection of radio, dust, hard X-ray, and gamma-ray signals. The time series intervals correspond to entries in the KONUS instrument solar flare and gamma -ray burst catalogs from the Ioffe Institute and anomalies in the *Wind* interplanetary and interstellar dust database (Malaspina and Wilson III 2016). We compare these observations to *Wind* 25-year solar wind statistics (Wilson III et al. 2018) to better understand the feasibility of detecting extragalactic, extrasolar, or outer solar system emissions near magnetized and unmagnetized bodies.