Fully self-consistent 3D modeling of spherical Mach-probes in ExB fields

FULLY SELF-CONSISTENT 3D MODELING OF SPHERICAL MACH-PROBES IN ExB FIELDS*

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We carry out 3D particle-in-cell simulations accounting for the full ion distribution function, Boltzmann electrons, and the self-consistent potential profiles in the neighborhood of a sphere in a flowing magnetized plasma. This can be considered as the "spherical Mach-probe" problem, establishing how the ion flux to the surface varies with orientation, and with parallel and perpendicular external velocity. This dependence is required to interpret reliably experimental measurements on several tokamaks.

We use our code SCEPTIC3D, a recent evolution of the particle-in-cell code SCEPTIC[1,2], which includes arbitrary uniform magnetic field, external velocity magnitude and direction, ion temperature and electron Debye length. We compare our results in the strong-field regime with the analytic model which uses an isothermal fluid approximation, within the quasineutral (infinitesimal Debye length) and small Larmor radius limits[3].

Results show that for strongly magnetized plasmas the assumption of isothermal ions gives accurate flux, but can not be justified as the ion Larmor radius becomes finite. We then proceed with an in-depth analysis of how the widely adopted Mach-probe calibration formulas for infinitesimal Debye length, derived from fluid treatments such as Ref.[3], are affected by non-zero Larmor radius effects.

Accounting for finite Debye length changes the potential profiles around the sphere. In particular for conducting probes, a dipole-like field oriented parallel to the convective electric field appears, drastically changing the ion flow in the immediate vicinity of the probe, hence the collected flux.

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3. I. H. Hutchinson, "Oblique ion collection in the drift-approximation: how magnetized Mach-probes really work", *Physics of Plasmas* **15**, 123503 (2008).

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