The role of sheath and acceptance angle in front of a retarding field energy analyzer for plasma flow analysis.

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Abstract

Measurements of plasma flow are of key interest in a number of plasma environments and applications. In laboratory magnetized plasmas, the directional Langmuir or Mach probe is a well-proven 'in-situ' diagnostic tool to obtain the flow velocity. However, in non-magnetized or weakly magnetized plasmas, this method does not readily yield reliable velocity measurements, as it has been shown by numerical and experimental studies that the collection of upstream ions to the rearward probe surface can be significant. In this study, we utilize the analysis of data from 3D PIC simulations of ion velocity distributions in the vicinity of a negatively biased object embedded in a collision-less, source-free plasma with and without flow. The simulations allow us to study how the grounded probe housing of a retarding field ion energy analyzer (RFEA) affects the distribution of ions and their collection at different angles with a flowing, electropositive plasma. Comparisons are carried out with RFEA measurements in an inductively coupled helicon plasma.

1. Introduction

Plasma flows are known to create plasma instabilities like e.g. two-stream instabilities, and they can lower the threshold for other instabilities. Satellites in orbit interact with the plasma flowing past it and create wake fields that can influence in situ satellite measurements. Hence, measurement of plasma flow is of key interest in a number of plasma environments. In laboratory magnetized plasmas, the directional Langmuir or Mach probe is a well-proven 'in-situ' diagnostic tool to obtain the flow velocity [1, 2]. However, in non-magnetized or weakly magnetized plasmas, this method does not readily yield reliable velocity measurements, as it has been shown by numerical and experimental studies [3, 4] that the collection of upstream ions to the rearward probe surface can be significant.

On the other hand, with retarding field energy analyzers, the energy distributions of ions entering at a limited entrance angle through a small aperture in the probe head are obtained. The aperture (acceptance angle) provides directionality depending on the actual size of the aperture and the distance from the aperture plate to the collector. The grounded probe head can be rotated in a plane parallel to the plasma flow at arbitrary direction with respect to the flow. In this study, we have utilized the analysis of data from 3D PIC simulations of ion velocity distributions in the vicinity of a negatively biased object embedded in a collision-less, source-free plasma with and without flow. The simulations allow us to study how the grounded probe housing of a retarding field ion energy analyzer (RFEA) affects the distribution of ions and their collection at different angles with flowing plasma. The aim of this study is to verify to which extent a direct measurement of subsonic flow velocity in weakly magnetized and unmagnetized plasmas.

2. Importance of acceptance angle

We have investigated the role of the acceptance angle defined by the orifice on the ion energy distribution reaching the probe interior. The shape of the ion distribution reaching the probe (IDF) at lower energies, as well as the strength of the signal, changes with acceptance angle. Wide acceptance angles give stronger signals at the expense of developing a low energy tail in the IDF, while for very small angles, the shape of IDF when the probe is facing the flow and when it is pointing rearward of the flow [5,6]. becomes similar to the ion energy distribution function.

The low energy tails are due to ions entering the aperture at large inclination angles, so that a significant part of their momentum is in the tangential component of the velocity. With decreasing acceptance angle, the low energy tail in the

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IDF diminishes. This confirms that the low energy tail is an artefact due to the acceptance angle θ, which should be
accounted for in the analysis of experimental data. The effect of μ is more pronounced for flowing plasmas.
The wake formation and bending of ion trajectories by electric fields in the sheath, often referred to as ion focusing [7], can lead to large tangential velocity component for particles reaching the rear of the analyzer. Thus, a wide acceptance angle of the analyzer facing downstream can result in an enhanced IDF at low energies. On the upstream side, due to the flow the maximum in the IDF is shifted towards higher energies, and the effect of the acceptance angle is less visible.

3. Effects of sheath on the ion velocity distribution

The ion dynamics leads to radial velocity distributions in the presheath that are similar to results from one-dimensional models with ion sources. Different potentials of the object, and ion temperatures have been considered [8]. Distortion of the ion velocity distribution (ivdf) through the sheath was found. Distortions in the radial ivdfs are found to due to ions that entered the presheath but missed the object, and ions with a small radial velocity component in the sheath. Ions with large impact parameters can miss the sphere, contributing to the low velocity part in the radial ivdf. This process is more pronounced for colder ions, and hence we find larger distortions for larger T_e/T_i ratio.
It is also found that the shape in the radial ivdf close to the object surface for is more distorted for larger spatial averaging in the radial direction, due to a large velocity gradient. The spatial averaging can be equivalent to temporal averaging, for the ivdf measured by the object with the plasma potential Φ varied in time. Recent measurements of the ivdfs in the RF sheath [9] showed that large variations in velocities can occur within one RF cycle. Thus, ion diagnostic tools in RF devices such as Njord [10] will also be sensitive to these variations. At the conference, we will present further results from analysis and comparisons with RFEA measurements, for the specific task of obtaining ion temperatures and flow in the bulk plasma.

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4. References

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