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Ion velocity in a coherent instability of a linear magnetized plasma

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Abstract

A linear magnetic plasma instability is studied using the spatio-temporal evolution of ion velocity distribution functions (IVDF) using a time resolved laser induced fluorescence (LIF) diagnostic . Langmuir probes measurements indicate a rotation of the plasma column with spiral arms outside the ionization zone. IVDF inside the ionization zone show, in first approximation, a tangential rotation velocity smaller than the spiral arms rotation velocity in spiral arms, and a radial velocity elsewhere.

Introduction

The Argon magnetoplasma produced in the linear constant magnetic field column of Mistral device, see figure 1, displays regular, unstable or turbulent modes. The anomalous radial transport was studied in details during last years with electric probes or ultra-fast camera acquisition [1, 2].

We recently showed that, in the majority of the studied cases, these instabilities occur at frequencies near 15 kHz, higher than the ion cyclotronic frequency of 6 kHz, and consequently cannot be drift waves. The work presented here is based on Laser Induced Fluorescence (LIF) measurements[3] which gives, with a high degree of accuracy , the ion velocity distribution fonctions along the laser beam, temporally and spatially resolved. Temporal resolution is 5 μs compared to the 20 μs duration of the measured structures, and spatial resolution is 1 cm, compared to the 1 cm for a thermal ion Larmor radius ρ_i. The potential of the collector plate placed at the end of the column controls the instability and the flow of the ionizing electrons injected into the column from the source chamber, and therefore the density gradients. Parameters are adjusted to obtain a strongly nonlinear coherent mode with azimuthal number m=2, corresponding to the rotation of 2 spiral arms. From LIF, the temporal and spatial evolution of ion velocity is analyzed and the local electric field deduced from a simple fluid model. We conclude that the rotation of spiral arms is not only an edge phenomenon but is also present in the plasma core. The ion velocity in the arms and in the column is preferentially ruled by rotation and radial ejection out of the arms. The ion rotation velocity in the arms is lower than the arms velocity. In contradiction with Langmuir probes measurements, the plasma column does not exhibit rigid body rotation and ion velocity is fully modulated by the spiral arms.

After a brief description of the experimental device, we will present our results and discuss them.

MISTRAL device

The device is composed of two chambers: a source chamber, where the ionizing energetic electrons are produced starting from 32 filaments and accelerated towards the linear column (second chamber), in which measurements are made, Figure 1.

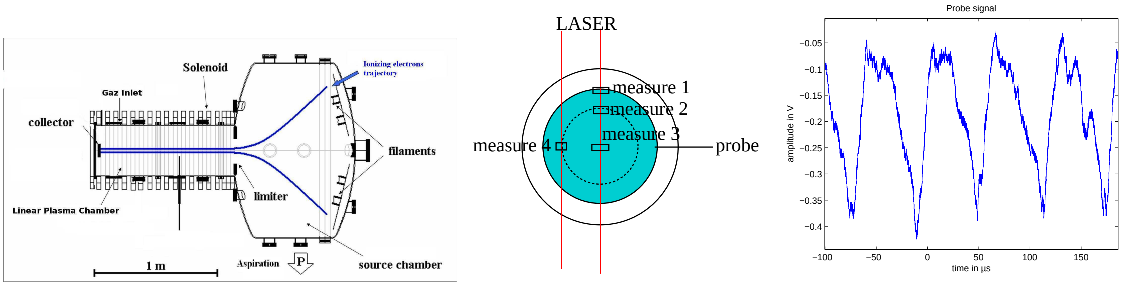

Figure 1: left: sketch of MISTRAL device; middle: measurements points; right: ion density temporal evolution measured by LIF.

A filaments current and voltage of 114A and 16V are used for a discharge voltage of 50V and a discharge current of 7A.

The linear column of MISTRAL has a $1,2$ m length and 40cm diameter. The uniform constant magnetic field is fixed at 16 mT.

The linear column is separated from the source chamber by a 10 cm diameter diaphragm separating grid biased at to 4 V drawing 0.8 A current. At the end of the column a collector biased at 20 V drawing at 1 A current. The Argon pressure is 2.10^{-4} mbar. These conditions trigger a coherent unstable mode with azimuthal mode number m=2.

Measurements and Discussion

Recent work on MISTRAL device with Langmuir probes and imaging, would had to the conclusion whole plasma that the column exhibit uniform rotation with constant velocity.

The density fluctuations at a frequency of $15kHz$ observed by a probe placed at a radius r=5 cm at the edge of the plasma column can be interpreted like a rotation of the plasma column, with spiral arms along the axis, Figure 1 shows one the probe position and Figure 2 a 2D map of the electronic density obtained by an array of probes [2].

Our 4 points LIF measurements are synchronized with the probe signal placed at the edge of the ionisation zone, at the radial limit of the diaphragm. The amplitude of the measured temporal ion velocity fluctuation increases with respect to the radial position: this is associated to the presence of a structure more pertubative at the edge of plasma than in the center. The velocity fluctuation is also accompanied by a density fluctuation . At 3cm from center the ion density fluctuation is as high as 30%. This suggests that we are not only dealing with an edge phenomenon but rather a fluctuation of the core plasma column.

Axial measurements of IVDF do not exhibit any velocity fluctuation, but only a density fluctuation of about 10% at the same frequency as the spiral arms, $15\,kHz$.

We rebuild the velocity vector evolution in a cross section of the column for a given radius, and we deduce the electric field from a basic fluid model:

$m\frac{d\overrightarrow{v_f}}{dt} = q\overrightarrow{E} + \overrightarrow{v_f} \times \overrightarrow{B}$ where $m = 6.6.10^{-26}\,kg$ is the mass of Argon; $\overrightarrow{v_f}$ the fluid velocity calculated with the IVDF; $\overrightarrow{B} = 150\overrightarrow{z}\,Gauss$ the constant axial magnetic field in the linear column; $q = 1.6.10^{-19}C$ the ion charge; electric field can be deduced.

The ion velocity measurements, along the laser beam, in point 4, corresponds to ion tangential velocity measurement in point 2 because of spiral arms rotation, assuming axial symmetry. Temporal synchronization is carried out by superposing the maxima of ion density perturbation measured at point 2 with the minima at point 4 (m=2 mode).

Figure 2 (left) exhibits temporal evolution of the fluid velocity, at point 2 in hodographic representation. We notice that the ion velocity is essentially either tangential or radial. The density minimum corresponds to the radial velocity whereas density maximum correspond to tangential velocity when spiral arms are present at the measurement point.

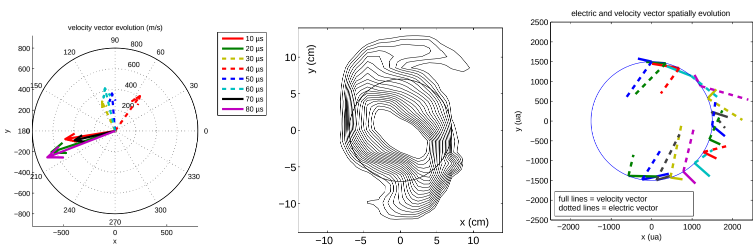

Figure 2: left: ion velocity hodograph; middle: 2D map of the density obtained by probe[2]. The density in the center is higher than the density at the edge. The density is maximum in the arms; right: space reconstruction of ion velocity and electric field. Full lines give the velocity and dotted lines the electric field.

This maximum density in spiral arms can be explained by trapped ions. We must however point out that the rotation velocity of the arms is $1.4\,km/s$ for rotation a frequency of $15\,kHz$, whereas ions have a fluid rotation velocity (tangential velocity) in the arms equal to $700\,m/s$.

Using a constant spiral arms rotation velocity equal to 1.4 km/s, the temporal evolution of $\overrightarrow{E}$ and $\overrightarrow{v_f}$ can be transformed into space evolution: $s = 1.4.10^3 * t$, where s is the curvilinear abscissa along a circle with 3cm radius (point 2), see Figure2 (right).

Electric field is modulated around 18 V/m by spiral arms, with a brutal angle variation corresponding to the front and the end of spiral arms. Note that the time reference for $\overrightarrow{E}$ and $\overrightarrow{v_f}$ (right) and for the 2D map of electronic density (middle) is different in this Figure2.

The angle between vectors $\overrightarrow{E}$ and $\overrightarrow{v_f}$ oscillates around $\pi/2$, which corresponds to the $\overrightarrow{E} \times \overrightarrow{B}$ drift angle.

Conclusion

Our study points out that the image of rigid plasma rotation is wrong. The measured perturbation is not limited to the plasma edge but also occurs in the bulk plasma. The spatial extension of the spiral arms away from the ionization zone delimited by the diaphragm stiel remains to be explained .

The rotation velocity of the measured structure is larger than the ion fluid rotation velocity despite the presence of some trapped ions to explain the density maximum in spiral arms. Apart of the structure, always inside the column, ions have an ejection velocity which is still not explained.

The end and the beginning of the structure is characterized by abrupt fronts observed as well on the electron and ion density as on the ion fluid velocity or deduced electric field.

Work is in progress to measure IVDF inside spiral arms and out of the ionization zone and to study the effect of various plasma parameters on the perturbation.

References

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