LIF ion kinetic measurements in a spiral arm ejected from a linear magnetized plasma column

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Abstract

We present an ionic kinetics study by time resolved Laser Induced Fluorescence of radial transport in a linear magnetized plasma device. A spiral arm, extending outside the ionization region, is in constant rotation, with a rotating frequency lower than ion cyclotronic frequency, but ion kinetics exhibits a complex behavior: azimuthal ion velocity is constant and radial velocity growths linearly with respect to the radius. Electric field is also computed and the mean ion velocity does not show a simple $\vec{E} \times \vec{B}$ structure. Flux exhibits a radial transport to conserve the ionizing electron current injected in the bulk plasma.

Experimental conditions

The study of linear magnetized plasmas is of great interest for fusion plasma because similar phenomena can be observed in fully diagnosed, repetitive and upgradable devices such as MIRABELLE[1] in Nancy, KIWI[2] in Kiel. We present ion kinetics observed on the MISTRAL device using temporally (with 10μs resolution), and spatially (with 1cm$\approx \lambda_D$ resolution), resolved Laser Induced Fluorescence (LIF)[3, 4] when a coherent m=1 turbulent mode with rotation frequency $f_0 = 5$kHz is present for a magnetic field $B = 160$G and basic Argon pressure $P = 9.10^{-4}$mbar.

The 1m long, 40 cm diameter linear magnetized plasma column is created by the injection inside a limiter of energetic ionizing electrons called primary electrons. These electrons are created by 32 filaments heated at 16.5V and 4.2A inducing 5A, 57V discharge parameters in the source chamber. The plasma diameter is limited by a 10cm of diameter diaphragm and by two connected plane conducting grids at floating potentials ($\phi_f = -38$V) on both ends, see Fig. 1 for a schematic of the device. The ionization region is completely surrounded by two grounded half-cylinders with 20 cm of diameter.

The injected electronic current cannot be evacuated by the grids at floating potential. Therefore radial plasma ejection occurs to close the current loop and the plasma expands outside the ionization region towards the half-cylinders forming a spiral arm[5] structure, which also extends in the ionization region and rotates with respect to the bulk stationary plasma.

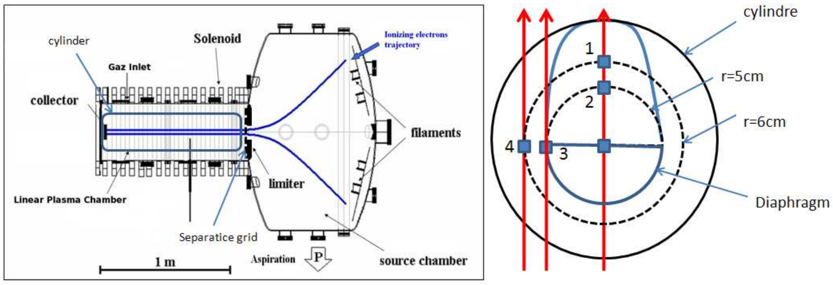

Figure 1: Schematic of the MISTRAL device and measurements positions.

Measurements points and calculations

Fig.1 exhibits some of the measurement points at several radii: $r = 1,2,3$ cm in the ionization region and $r = 5,6$ cm outside this region limited by the diaphragm. It also exhibits the laser beam position for radial and tangential measurements. Because spiral arm are in constant rotation at $f_0 = 5\text{kHz} < f_{ci} = 6\text{kHz}$, fluid velocity measurements at point 3 and 4 are tangential fluid velocity at point 1 and 2 taking into account a $\frac{\pi}{2}$ phase shift. Therefore we can obtain a 2D plot of -radial and azimutal- ion mean velocity and density measured by LIF along the laser beam either in the bulk plasma or in the spiral arm in the shadow of the diaphragm.

A simple fluid model based on continuity equations is used to calculate the 2D electric field which is compared to the electric field computed using energy conservation in the wave reference frame of a fluid particle in a wave.

Radial and tangential fluxes $\Gamma_{r,\theta} = n_{r,\theta} v_{r,\theta}$ are also calculated.

Results

Fig.2 shows radial and tangential fluid velocity with respect to the radius at the time of the maximum density perturbation corresponding to the the spiral arm passage. v_θ is constant and therefore does not correspond to a block rotation of the bulk plasma and this was already observed for a $m = 2$ spiral arms mode. v_r seems to linearly vary with radius and this still remains to be explained. In the bulk plasma outside the spiral arm (minimum of density), ions are not at rest, and the spiral arm appears as a fast perturbation for the bulk central plasma.

Fig.3 shows the radial and azimuthal phase between density and velocity with respect to the radius. Tangentially this phase is quite constant and equal to $\frac{\pi}{4}$ but varies radially from $\frac{\pi}{2}$ to ≈ 0 in the arm outside the ionization region.

The azimuthal flux, averaged over one period, is not null, as for the radial one corresponding to the current transport, see Fig.4.

The azimuthal electric field, E_θ, calculated by a fluid model or by energy conservation, is always directed toward the maximum of density (this can also be seen on v_θ) and is maximum

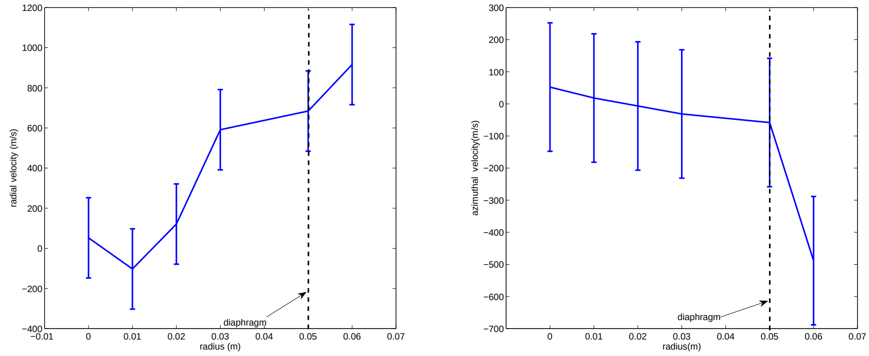

Figure 2: Instantaneous radial and azimuthal ion mean velocity profile for the maximum density.

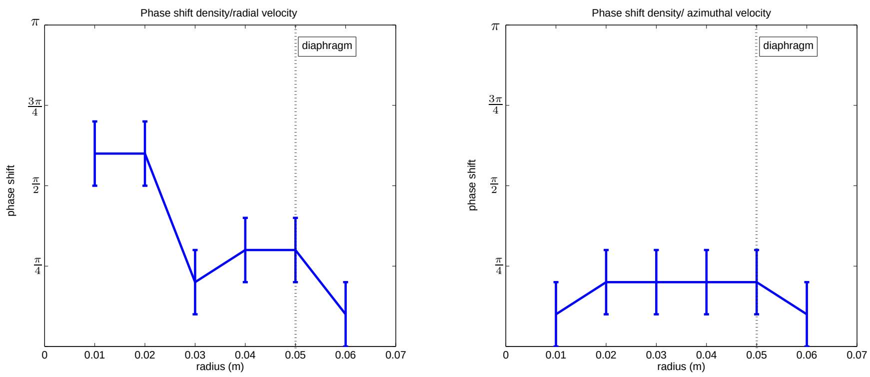

Figure 3: Radial and azimuthal phase shift between velocity and density with respect to radius.

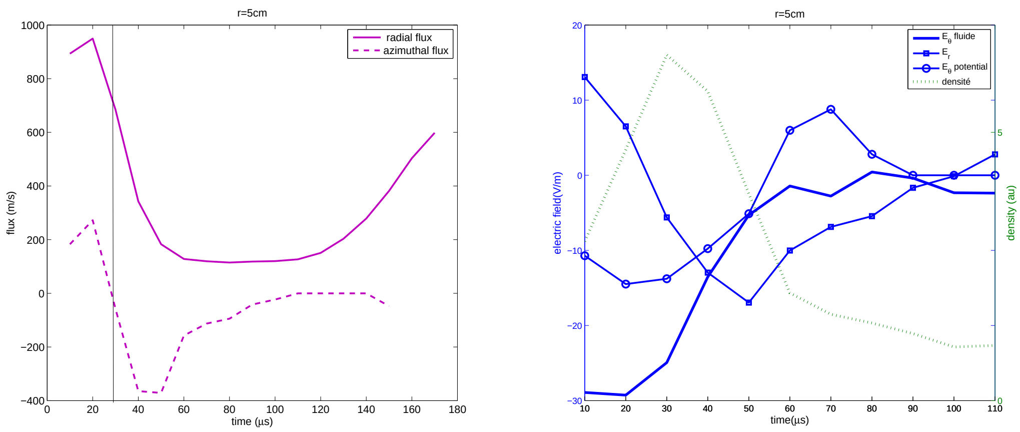

Figure 4: Radial and azimuthal flux and electric field for $r = 5$cm.

at $r = 6$ cm in the shadow of the limiter. The radial electric field E_r increases with r. It seems that the plasma flows toward the center of the arm to be radially ejected.

An axial ion density and velocity perturbation is also present at the spiral arm frequency and can also be seen on the collector floating potential.

Combined with electron current measurements[5], these results shed a new light on the stability of a magnetized plasma column.

Conclusion

As for a previous study of the m=2 spiral arm mode, plasma stability is governed by the ionizing electron current injection. The kinetics is more complex and cannot be seen as a simple $\vec{E} \times \vec{B}$ rotation of the plasma. Radial transport is confirmed and ion velocity is always directed toward the spiral arm's center, inside and outside the ionization region. In the shadow of the limiter, radial velocity is in phase with the density. The current plasma channel associated to the spiral arm acts as a perturbation of the bulk plasma. First results on the ion perturbed distribution function show some trapped ions at the spiral arm rotation velocity. The major differences between $m = 1$ and $m = 2$ mode is the frequency rotation, lower than the ion cyclotronic frequency for the first, and higher for the second, and the presence of an axial ion distribution function perturbation for the $m = 1$ mode.

References

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