# Experimental characterization of instabilities in the linear machine GyM

D. Ricci[a], D. Iraji[a], A. Cremona[a], I. Furno[b], S. Garavaglia[a], G.Granucci[a], M.Lontano[a], V. Mellera[a], D.Minelli[a]

[a] *Istituto di Fisica del Plasma – EURATOM-ENEA-CNR Association, Milan, Italy*

[b] *Polytechnique Fédérale de Lausanne, Centre de Recherches en Physique des Plasmas, Association Euratom-Confédération Suisse, CH-1015 Lausanne, Switzerland*

**Introduction** The experimental characterization of instabilities is one of the main objectives of linear machine GyM operating at IFP-CNR (Milan) [1]. With the present diagnostic setup, based on a movable Langmuir Probe Array (2D-LPA) and on an imaging system for direct visualization of plasma structures, the presence of rotating modes with m=1 has been found and characterized. The mode position and velocity, as detected by direct observation, have been associated to the gradient of main plasma parameters (kinetic pressure and plasma potential). The mode, localized at the gas injection position where the temperature and density peak, rotates at ExB drift at a frequency that depends on ECRH power used to sustain the plasma and the neutral pressure. Statistical and spectral analyses have been performed to study the wavenumber-resolved power spectrum of the density fluctuations and to measure the dispersion relation.

**Experimental setup** GyM is a linear device consisting of a vacuum chamber (dia = 0.25 m, L = 2.11 m) mounted in a solenoid with a field of 0.13 T on the axis (limit in the present configuration). Plasmas are generated and continuously sustained by means of RF power (1.6 kW cw) in the electron cyclotron frequency range (2.45 GHz), injected perpendicularly to the magnetic field lines in O-mode polarization. The resonance at 0.0875 T is located in a single position close to one end of the vessel, opposite to the RF power launcher. GyM plasmas are characterized by electron densities ($n_e$) in the range $10^{16} – 10^{17}$ m$^{-3}$, low electron temperatures ($T_e$) ( 2 - 8eV) and a plasma potentials ranging from 10 to 20 V.

The diagnostic setup is based on a 2D Langmuir Probe Array (2D-LPA) and on a imaging system using, in cooperation with CRPP Lausanne, a fast framing Photron-APX-RS camera and an image intensifier unit for direct visualization of the plasma structures (up to 200 kframe/sec) [2]. The 2D-LPA is based on an array of 6 electrostatic probes (LPA90) separated by ~1 cm and a single probe (LPA45) separated by π/4 counterclockwise. The two probes are installed in the same poloidal cross section (z=1m), and are independently movable in direction perpendicular to the plasma column (LPA90 scan from -4 to 12.5 cm and LPA45 scan from -1 to 10 cm). Both can be used to measure averaged plasma quantities as well as fluctuating ones and the dispersion relation at radial position ranging from 3 to 6 cm from the center.

**Plasma profile** Profiles of plasma parameters $n_e$, $T_e$, $V_{pl}$ and kinetic pressure (calculated as $p_e$=$n_eT_e$) are measured with LP90 in different conditions of working gas pressure (from 1 to 5 $10^{-4}$ mbar) as well as the RF power (from 300 to 1000 W). In Fig. 1 results are shown for 600 and 900 W at 1 $10^{-4}$ mbar. The profile is measured along the vertical direction, with zero on the equatorial plane. The peaks observed in the profiles are in correspondence of the gas injection position at r = -5 cm, z = 0 m in the cylindrical coordinate system of the device. The resulting gradients of kinetic pressure and plasma potential drive instabilities in radial direction. It has to be noted that gradient characteristic lengths are strongly affected by RF power as well as by working pressure, increasing as these experimental parameters decrease.

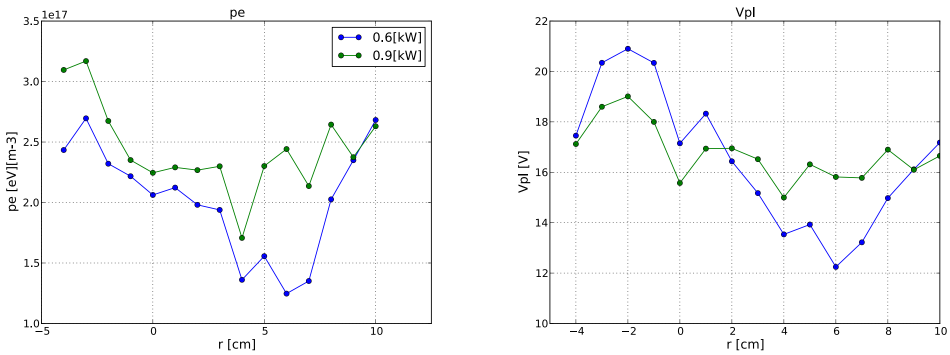


Fig.1 Radial profile of pressure gradient and plasma potential at 1 $10^{-4}$ mbar

Amplitude and direction of electric field has been derived from gradient of plasma potential profile, computed as $V_{pl}= V_{fl}+\mu\, T_e/e$, where $V_{fl}$ is the floating potential. The presence of an inhomogeneous electric field is responsible of the ExB drift inducing the rotation of the mode in the plasma, with a velocity $\mathbf{v}_{ExB}=-\nabla V_P\times\mathbf{B}/B^2$. In the upper part of the plasma section, the maximum of the $\nabla V_P$ is at r=5 cm, where the velocity, estimate from LPA90, is ~1 $10^3$ m/s and turns clockwise in the present magnetic field configuration (reversing the B direction the rotation changes in counterclockwise).

**Statistical and spectral properties** The mode is localized along the radius (for r > 0) using density fluctuation profiles as obtained from the time trace of the ion saturation current measured by LPA90 and LPA45 (fig. 2 left column). The fluctuation profile has a maximum at 5 cm above the horizontal plane, in agreement with the observed maximum in pressure gradient. The power spectrum of density fluctuations has been calculated in different radial positions and RF power and reported in fig 2 (right column).

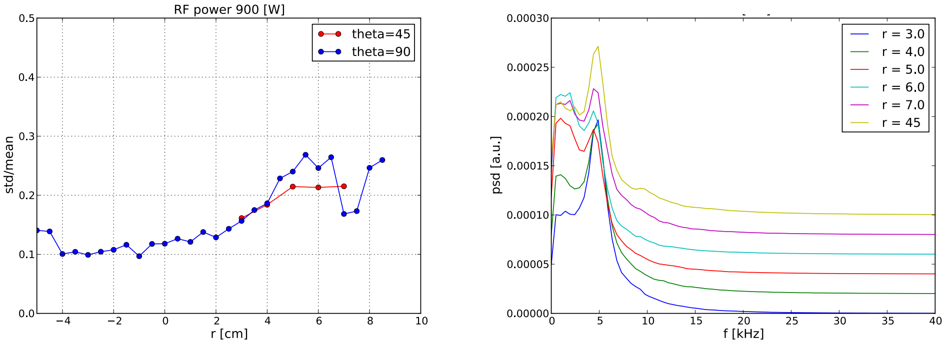


Fig.2 (left) Radial profile of the density fluctuations are deduced from the time trace of the ion saturation current. measurements by 2D-LPA (Hydrogen pressure of 1e-4 mbar and power ranging from 900 W) (right) Power spectrum (a.u.) of density fluctuations in different radial positions and RF power.

The main contribution to the spectral power comes from fluctuations below 10 kHz, in all considered radial positions although with different intensity. The analysis reveals the presence of a mode at ~ 4 kHz with an extension of ~3 cm around r = 5 cm. Spectral characteristics are affected by RF power: the mode frequency increases from 3.6 to 5 kHz with increasing power. Spectra at different poloidal positions (90° e 45°) are coherent allowing the application of a two-point correlation technique to calculate the wavenumber-resolved power spectrum of the density fluctuations in order to determine a poloidal k of the order of ~ 30 $m^{-1}$. This means that the wave propagates with a velocity v = 1 $10^3$ m/s, consistent with the $v_{ExB}$, obtained from profiles.

**Image analysis** The fast camera reconstructed emissivity profiles has been used as an independent technique to measure and characterize fluctuating structures [3]. It is clearly observed that these structures rotate for the presence a radial electric field (ExB drift), at the same frequency measured with LPA90 and with similar radial extension**.** The speed of the rotation deduced by means of Conditional Sampling Average (CAS) analysis is $v_{ExB}$=1.5 $10^3$ m/s at r=5cm.

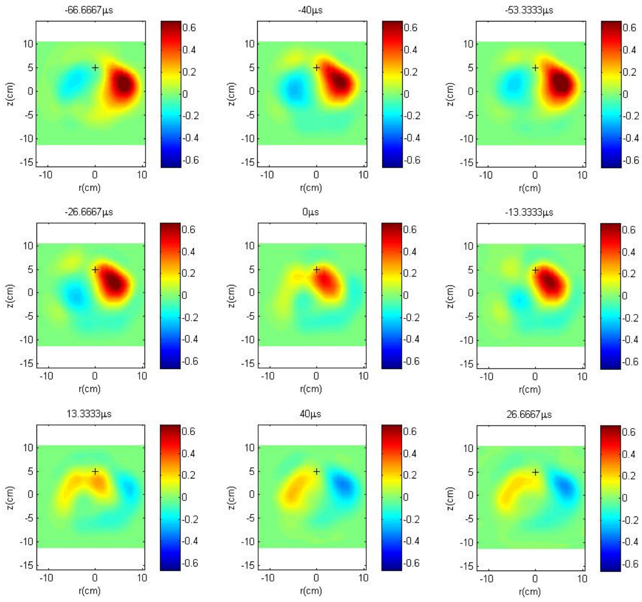


Fig 4 Nine consecutive frames of the CASed reconstructed emissivity profile

**Conclusions** Gradients in the density and plasma potential have been obtained on linear device GyM. The experimental evidence suggests that such gradients could drive instabilities in radial direction characterized by a mode at 5 kHz with a $k_{poloidal} \sim 30\ m^{-1}$ and a frequency depending on RF power, as a consequence of resulting different kinetic pressure gradients. The mode is located at r=5 cm, where radial pressure gradient has a maximum, and rotates with a velocity ~$1.5\ 10^3$ m/s for effect of ExB drift. The $v_{ExB}$, calculated from plasma potential profile, is of the same order of that evaluated from poloidal k deduced using a two-point correlation technique. Independent and consistent evaluation of rotation velocity is also obtain by fast camera image analysis, giving v = $1.5\ 10^3$ m/s. Further studies will include the control of fluctuations dynamics by imposing spatial gradients of main quantities (density and electric field). A full 2D probe array with 52 tips is under construction and will allow simultaneous detection of the turbulent structure throughout the section of the plasma column.

## References

[1] G.Granucci et al. *36th EPS, ECA*, **33**E, P-4.148 (2009).

[2] D.Iraji et al.,Phys. Plasmas **17**, 122 304 (2010).

[3]D.Iraji et al.,7th workshop on Fusion Data Processing Validation and Analysis, Frascati, Roma, Italy (2012).