Observation of low-frequency oscillations in a radio frequency-stabilized plasma confined in a Malmberg-Penning trap

B. Paroli[1], M. Ikram[1], G. Maero[1], R. Pozzoli[1], M. Romé[1]

[1] *Dipartimento di Fisica, Università degli Studi di Milano and INFN Sezione di Milano, Milano, Italy*

A Malmberg-Penning trap is a device that confines non-neutral plasmas with electro- and magneto-static fields in ultra high vacuum. In principle an electron plasma can remain stable for many hours, but experimentally the storage is reduced both by collisional and collective processes. Indeed, electron-neutral collisions shorten the confinement time, and the presence of ions and resistive wall dissipation both cause the trapped electrons to drift toward the inner surface of the confinement electrodes [1][2]. All these processes are counteracted applying an external radio-frequency drive by means a rotating-wall technique [3] in dipole and quadrupole configurations. In the quadrupole scheme we observe that the electron column may maintain a stable radial offset even in the presence of a significant resistive dissipation. In this equilibrium the diocotron mode is modulated by the occurrence of low frequency (LF) oscillations of few Hz.

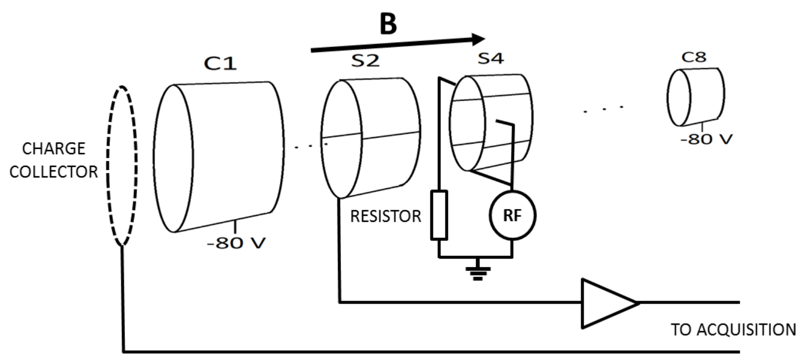

Figure 1: Experimental set-up. The trap is composed by ten OFHC cylinders with two electrodes sectored azimuthally in two and four patches, respectively. Plasma production and stabilization are obtained with a quadrupole RF excitation on S4. The LF oscillations are detected on S2, while an external resistor can be connected on S4. Finally the plasma charge is measured by means of a planar collector beyond the cylinder C1.

The basic experimental scheme is sketched in fig. 1. The device is a cylindrical trap (9 cm diameter, 1m length) operated at a pressure of 10^{-8} - 10^{-9} mbar. Two negative potentials $V_c = -80V$ on C1 and C8 provide axial confinement, while an axial magnetic field up to 0.2 T confines electrons radially. A low-density plasma (10^6 - 10^7 cm^{-3}) is produced by means of a 5 V (peak) radio-frequency applied to an opposite pair of patches of the cylinder S4 triggering a Fermi-like heating mechanism [4]. The quadrupole excitation heats the trapped electrons and the plasma column is produced by the ionization of the residual gas in less than a second. At the equilibrium low frequency oscillations are observed detecting the induced current on a sector of S2.

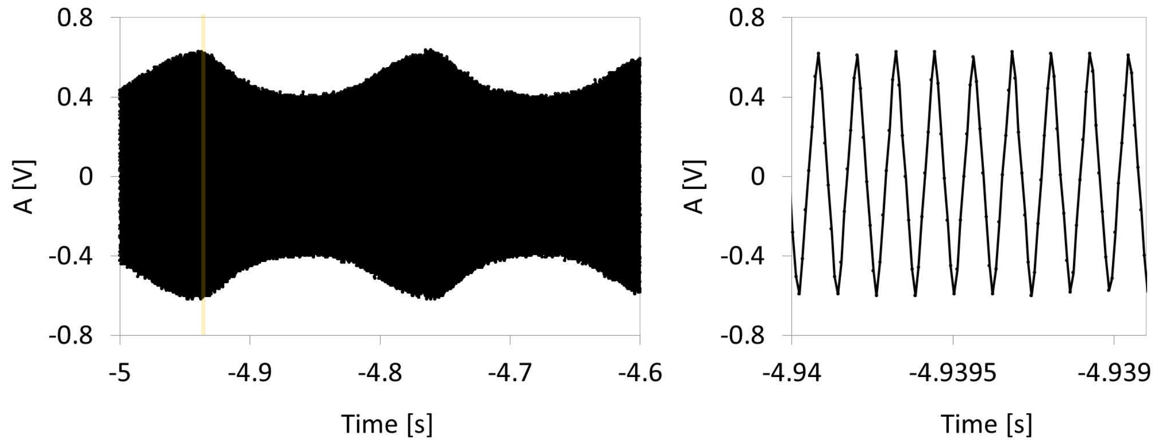

Figure 2: Detected signal on S2. The envelope (left) is a LF modulation of the $m_\theta = 1$ diocotron mode (right). The signal is measured at $B \approx 0.06$ T, $p = 5.1 \cdot 10^{-9}$ mbar and with a load resistor of 0.6 kΩ.

An example of the detected signal on S2, amplified 10^5 times, is shown in fig. 2. The diocotron frequency $\nu_d = 8.3$ kHz is modulated (in amplitude) by an oscillation of $\nu_{LF} = 5.5$ Hz. A quasi-sinusoidal shape of the modulating signal is obtained for lower modulation indexes of the diocotron mode.

The electron column charge was correlated with the phase of the LF oscillation with the following experimental method: the LF oscillation detected on S2 is demodulated and filtered. A gated zero-crossing detector generates a trigger (in phase with the oscillation) shifted by a quantity $\phi = 2\pi\nu_{LF}\Delta t$. Here Δt is a time interval introduced by a delay generator. The output of the delay generator controls a solid-state switch to dump the electron column on the charge collector at the phase ϕ of the LF oscillation.

As shown in fig. 3 the total charge has a relative variation of 0.17 and the charge perturbation is sinusoidal. When the modulation index of the signal on S2 increases, the charge perturbation is strongly distorted but remains in-phase with the LF oscillation observed on S2. This suggests that the charge variation is not always proportional to the amplitude variation of the diocotron mode and a more complex dynamics is involved in this phenomenon.

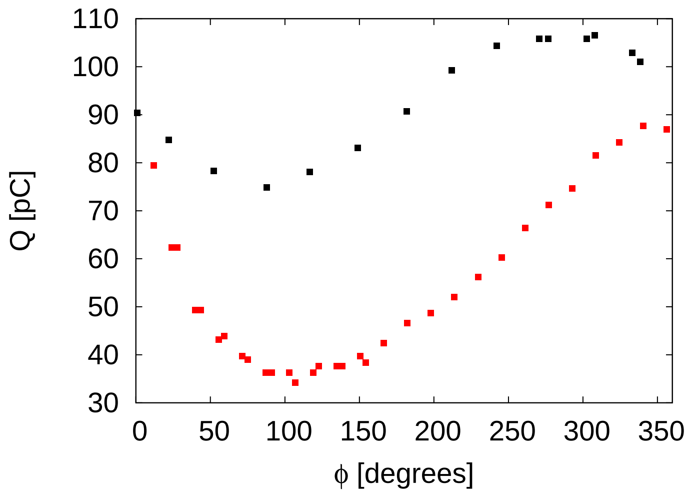

Figure 3: Charge-phase correlation measurement in two different regimes: high modulation index (red) and low modulation index (black). The relative charge variations are ≈ 0.41 and ≈ 0.17, respectively.

We also characterize the frequency response of the electron column around the equilibrium by applying external electric excitations. First we apply a 300 mV (peak) chirped sinusoidal signal on a sector of S4 and detect the response on S2. The amplitude of the modulation resonates at about 7.4 Hz as shown in Fig. 4.

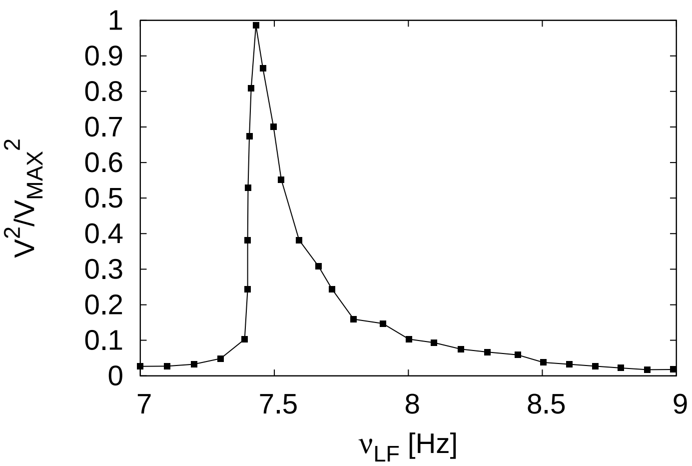

Figure 4: Response of the LF oscillation to an external sweep by varying the drive frequency from 7 Hz to 9 Hz. An asymmetric resonance is observed at $\nu_{LF} = 7.4$ Hz.

Second the existence of characteristic oscillation frequency of the system is also esperimentally confirmed using a pulsed excitation. An external disturbance is applied to the plasma by varying the RF frequency from 15 to 16 MHz for 0.5 s. The initial equilibrium is restored in several seconds after an underdamped oscillation of few Hz.

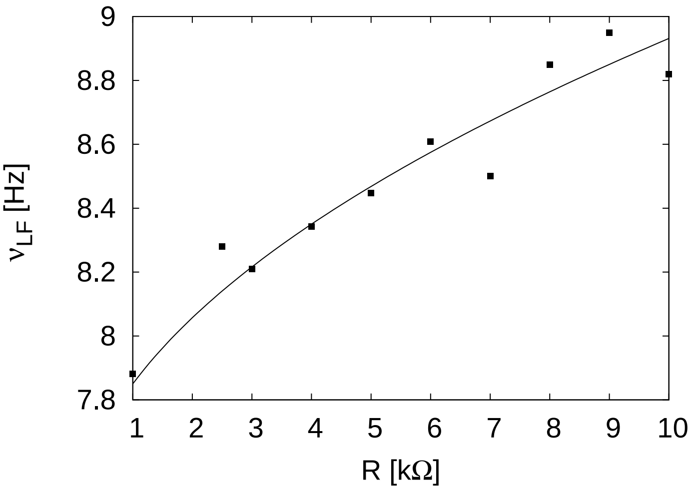

Figure 5: LF oscillation frequency versus destabilization resistance. The perturbed $m_\theta = 1$ mode frequency oscillates at a frequency ν_{LF}. The solid line is a power-law fit with exponent 0.5 of ν_{LF} versus the applied destabilization load R.

With a 15 MHz RF drive (5 V_{pp}) and a magnetic field strength of 0.08 T, we observe an underdamped oscillation whose frequency increases by increasing the external resistor value connected to a sector of S4, from 1 to 10 $k\Omega$. The external resistor introduces dissipation perturbing the initial equilibrium. We find a power law $\nu_{LF} = a + bR^x$ with $a = 7.35$, $b = 0.5$, $x = 0.5$ as shown in fig.5.

Our observations show the existence of a regime where the dynamics of the plasma column and its equilibrium are determined by the interplay between the collective instabilities and the generation and loss of charge resulting from a continuous injection of RF power. To our knowledge this particular regime has not been studied yet. The interpretation of these phenomena will be presented in a forthcoming paper.

References

[1] G. Bettega, F. Cavaliere, M. Cavenago, A. Illiberi, R. Pozzoli and M. Romé, Plasma Phys. Control. Fusion **47**, 1697 (2005)

[2] W. D. White, J. H. Malmberg, C. F. Driscoll, Phys. Rev. Lett. **49**, 1822 (1982)

[3] E. M. Hollmann, F. Anderegg, and C. F. Driscoll, Phys. of Plasmas **7**, (2000)

[4] B. Paroli, F. De Luca, G. Maero R. Pozzoli and M. Romé, Plasma Sources Sci. Technol. **19**, 045013 (2010)