Non-monotonic Distributions of Excited Atoms in the Positive Column of Pulsed Helium Discharges: Dynamic Plasma Regime

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Non-monotonic radial distributions of excited helium atoms have been experimentally observed in a positive column (PC) of pulsed helium discharges using planar laser induced fluorescence. The observed effect is attributed to the peculiarities of electron impact population-depopulation of the excited states under "dynamic discharge" conditions with strong modulations of the electric field maintaining the plasma [1].

Paradoxical non-monotonic radial distributions of excitation rates in the steady-state PC of rare gases (with the exception of helium) at elevated pressures have been previously predicted in simulations and explained by non-local kinetic effects [2]. Nonmonotonic radial distributions of metastables have been recently observed in simulations of pulsed xenon discharges [3] and ascribed to gas heating. However, no experimental observation of this effect was reported. Measured and simulated radial distributions of excited atoms are shown in Fig. 1 for various pressures and various times during the current pulse. For all pressures, the excited species are initially center peaked and monotonic. For the lowest pressure, the distribution of the excited atoms undergoes some degree of flattening during the current pulse but remains monotonic. For the higher pressures, non-monotonic radial distributions of the excited atoms appear during the current pulse. Similar non-monotonic profiles are also observed in simulations using fluid model with simple chemistry of helium plasma. The observed phenomena are attributed in [1] to a "dynamic regime" of discharge operation, making is possible to manipulate electron kinetics and control the electron energy distribution function (EEDF) due to strong modulation of the electric field maintaining the plasma. Low duration, high intensity, and low repetition current pulses can eliminate plasma constriction and stratification, reduce gas heating, and improve discharge stability.

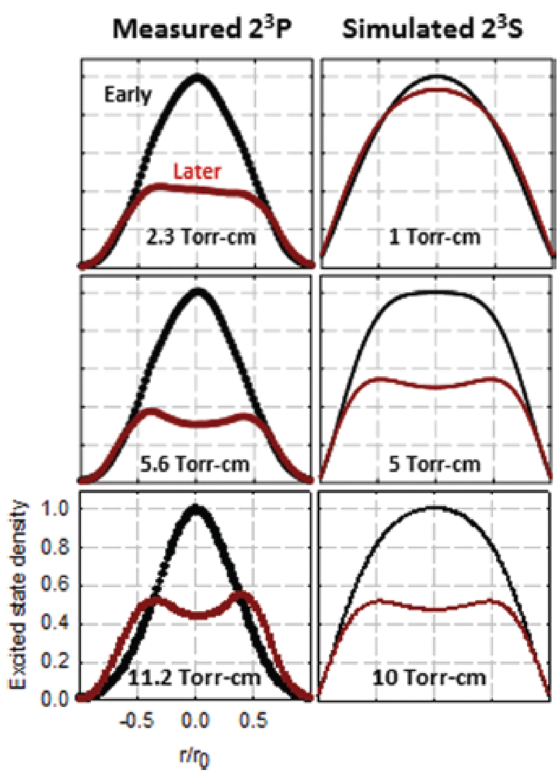

Figure 1 – Radial distribution of excited atoms.

References

[1] E.V. Barnat and V.I. Kolobov, Appl. Phys. Lett. **102**, 034104 (2013).

[2] L. D. Tsendin, E. A. Bogdanov, and A. A. Kudryavtsev, Phys. Rev. Lett. **94**, 15001 (2005).

[3] M. Gnybida, D. Uhrlandt, and D. Loffhagen, J. Phys. D **45**, 195203 (2012).

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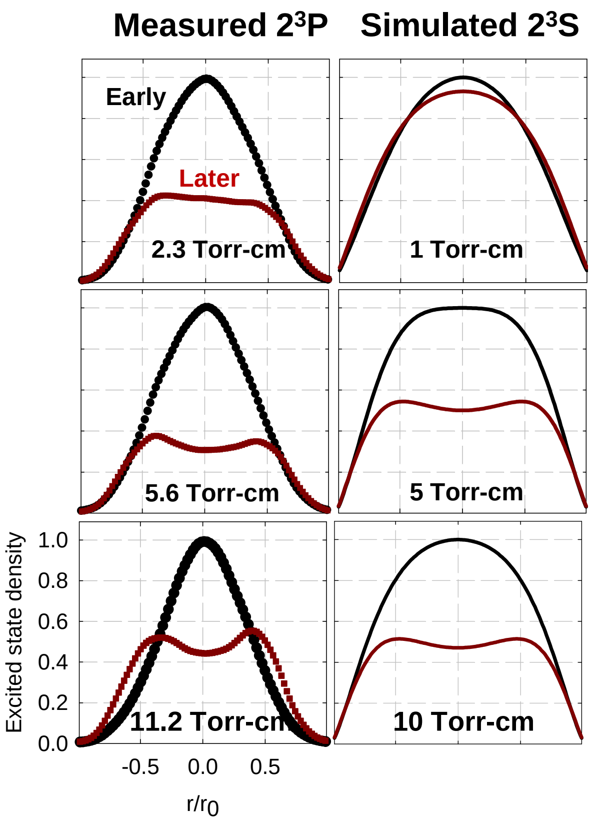
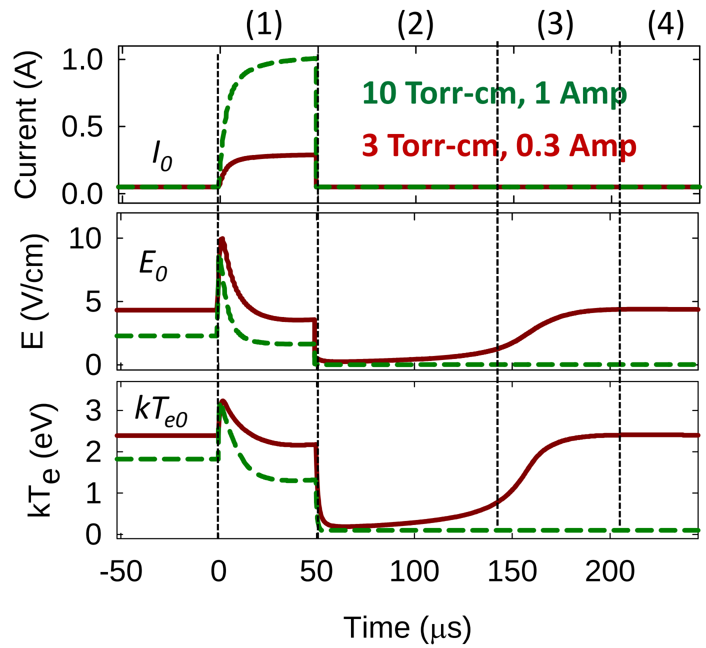


Radial distribution of excited atoms for different pressure and time during the current pulse.



Simulation: Different Stages of Positive Column in Pulsed Current Regimes

- **Nonmonotonic radial distributions of excited helium have been experimentally observed in a pulsed positive column using laser induced fluorescence. Simulations indicate a “dynamic discharge” regime with peculiar properties.**

HIGHLIGHT

Sandia National Laboratories

CFDRC

Center for Predictive Control of Plasma Kinetics: Multi-Phase and Bounded Systems

PSC Department of Energy Plasma Science Center

DOE Plasma Science Center
Control of Plasma Kinetics

Quasi-Periodic Mode Hopping in Competing Ionization Waves

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A neon glow discharge plasma supports multimode oscillation in the form of traveling normal modes of *p*-type ionization waves. The modes compete as coupled spatiotemporal oscillators, each capable of driving the other or being driven. Competition is modulated by resonant laser light chopped *almost* synchronously with the subdominant wave mode, resulting in quasi-periodic mode hopping between neighbor wave modes. This process repeats indefinitely without adjustment of the discharge plasma or chopped laser light parameters. The mode-amplitude normalization of the driving-force term in the governing differential equations, inherent in driven-oscillator phenomena and responsible for quasi-periodic mode hopping, is validated by experimental observations.

Self-organization of striations in glow-discharges exemplifies a laboratory-plasma instability that saturates to become a self oscillator, with behavior common to relaxation oscillators. The *p*-type ionization wave in glow-discharge plasmas is a traveling normal mode of the longitudinally-bounded tube and is an example of a self-oscillating striation. The spatial extent of these self oscillations permit investigation of the system's response to periodically spatial, spatiotemporal, and temporal driving forces. Temporal means localized in space and periodic in time whereas spatial means localized in time and periodic in space. A spatiotemporal means extended and periodic in both time and space, resulting in a driving force with larger effective magnitude.

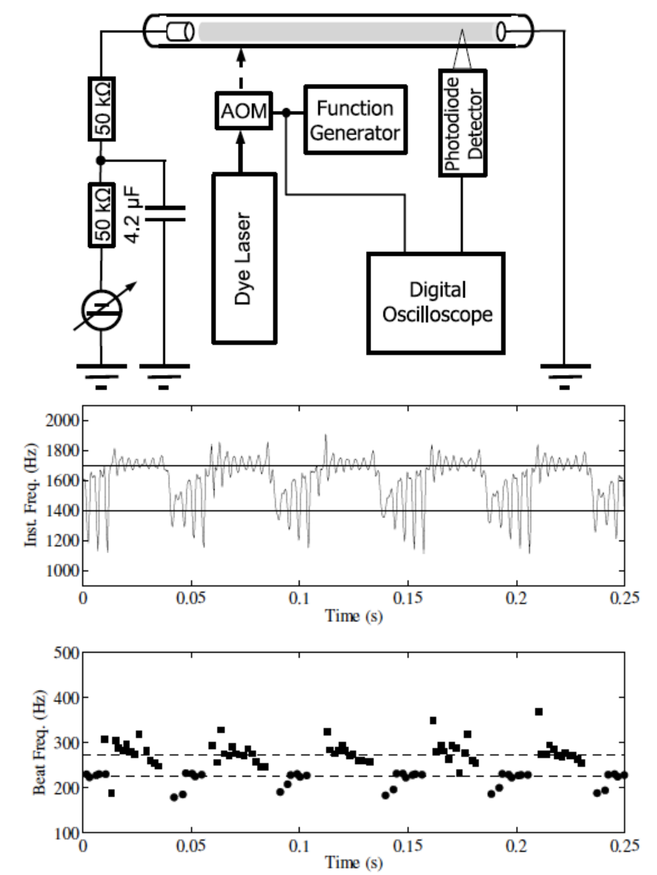
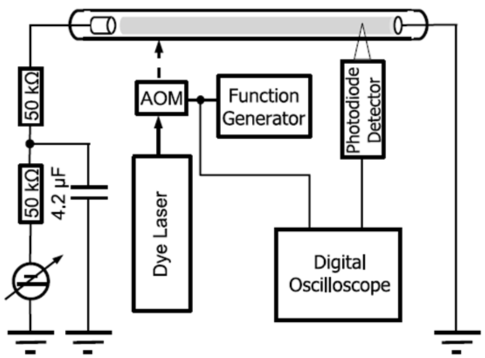


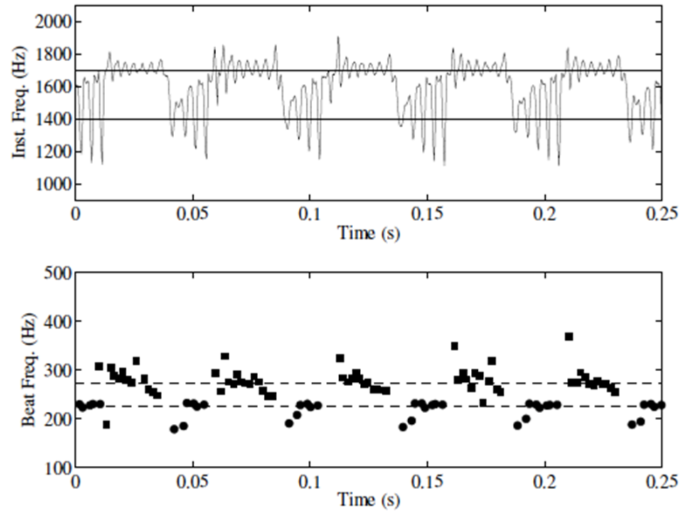
Figure 1 – (top) Schematic of experiment. (bottom) Frequency and beat frequency of ionization modes.

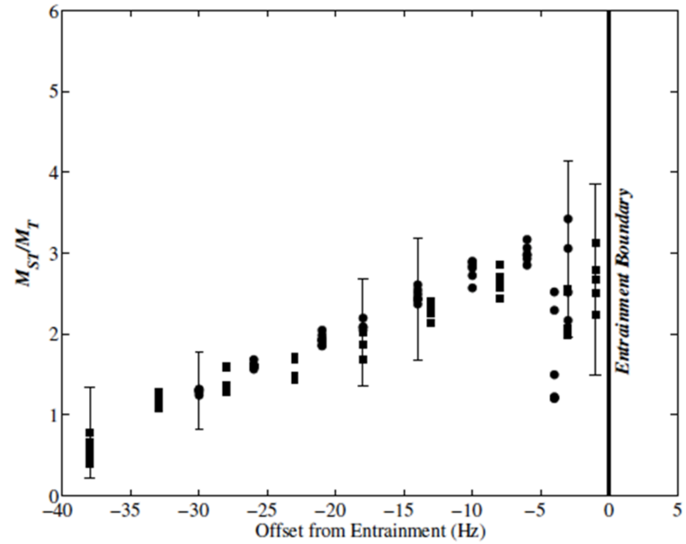
The undriven mode-amplitude normalization of the driving-force term in the forced-van-der-Pol equations is experimentally validated and the time-dependent nature of the normalized driving force, measured here (See Fig. 1) is shown to be responsible for the dynamical-state transition (*i.e.*, modulation). The model [1] provides a method of inferring the time series of normalized driving-force amplitude from measurements. The treatment indicates that an inherent asymmetry between low-frequency and high-frequency manifestation of driving forces may help explain hysteresis in mode transitions caused by spatiotemporal periodic frequency-pulling and wavenumber-pulling between modes.

[1] P. M. Miller, Ph.D. thesis, WVU (2009).

QUASI-PERIODIC MODE HOPPING IN COMPETING IONIZATION WAVES







- **Neon-ionization-wave normal modes compete as coupled spatiotemporal oscillators modulated by resonant laser light chopped *almost* synchronously with the subdominant wave mode resulting in indefinite mode hopping.**
- **The mode-amplitude normalization of the driving term in the differential equations, inherent in driven-oscillator phenomena and responsible for quasi-periodic mode hopping, is validated by experimental observations.**
- **Amount that spatiotemporal driving-force amplitude M_{ST} exceeds temporal driving-force amplitude M_T increases as the spatiotemporal entrainment threshold is approached.**

PLSC_0213 **HIGHLIGHT**

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