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Resonance Phenomena of Voltage and Current Driven Capacitively Coupled Plasmas

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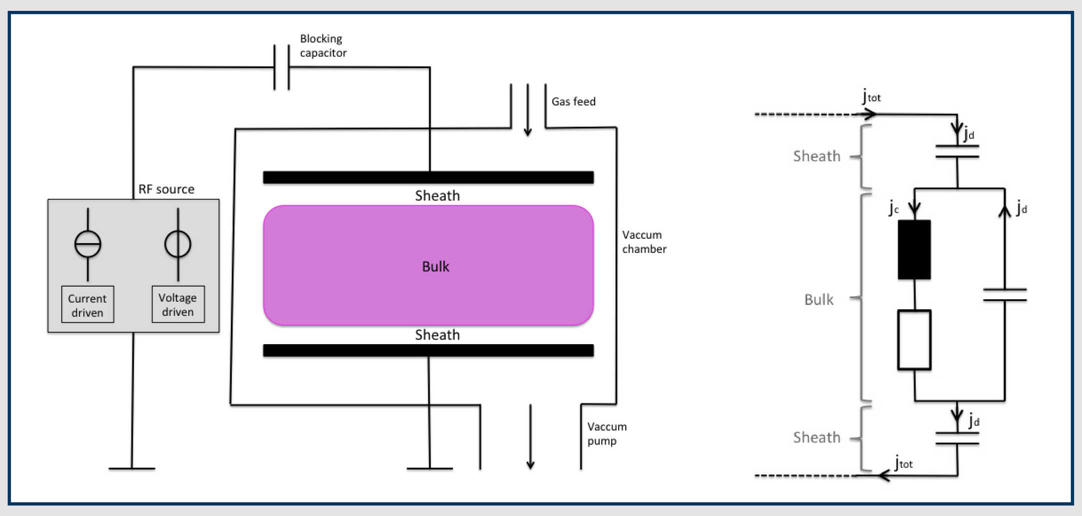
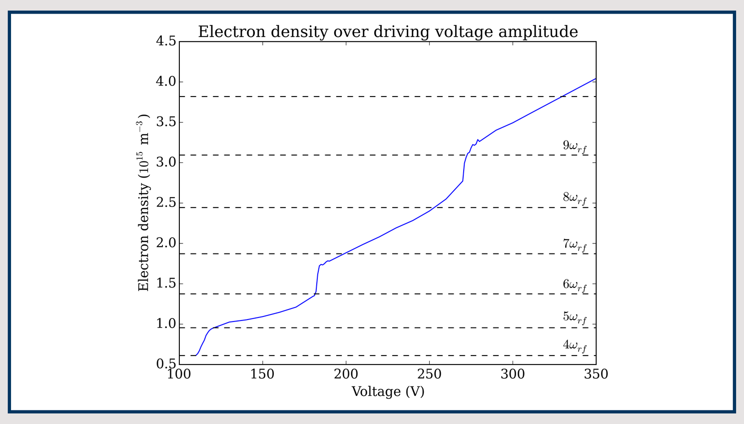
Resonances in CCRF Discharges

- series and parallel resonances [1,2]
- $\omega_{psr} = \omega_{pe}\sqrt{\frac{2s}{L}}$.
- $\omega_{ppr} = \omega_{pe}$
- problem: most global models do not include kinetic effects!
- 1d3v PIC simulation [3] provides a fully kinetic interpretation
- Non-linear Electron Resonance Heating (NERH) [4]

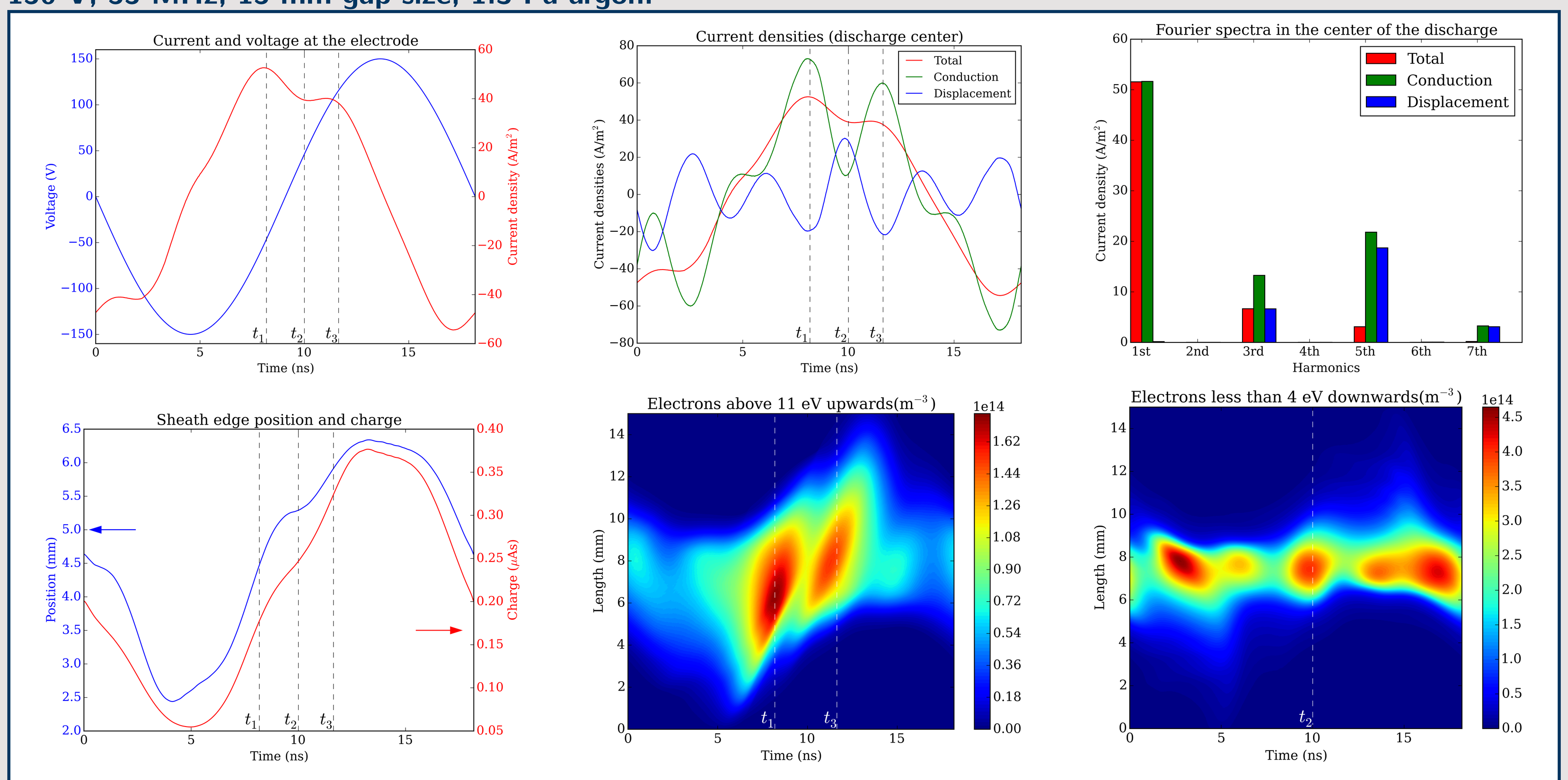


Voltage Source

- setup: 150 ..... 350 V, 55 MHz, 15 mm gap, 1.3 Pa argon
- $\uparrow$ voltage $\Rightarrow \uparrow$ ionization $\Rightarrow \uparrow n_e \Rightarrow \uparrow \omega_{pe} \Rightarrow \downarrow \tau_{pe} = 2\pi/\omega_{pe}$
- electrons respond to local perturbations on faster timescales
- excitation of higher harmonics is possible
- local perturbations by energetic beam electrons
- (bulk) electron-sheath interaction [5]
- sheath edge criterion [6]: $\int_0^{s(t)} n_i(x)dx = \int_{s(t)}^{\infty} (n_i(x) - n_e(x))dx$

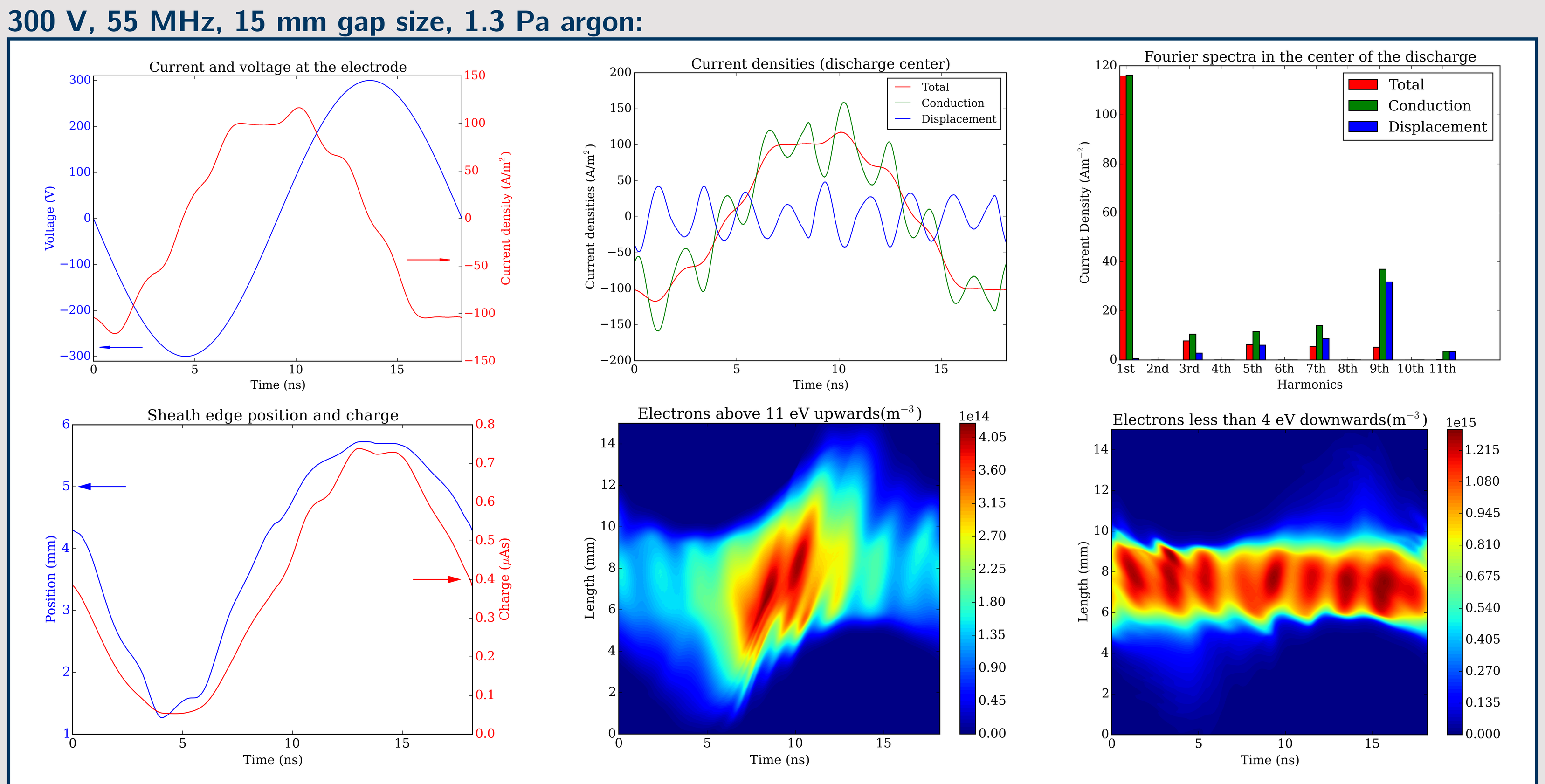


150 V, 55 MHz, 15 mm gap size, 1.3 Pa argon:



- beginning of sheath expansion t_1, generation of first electron beam, increasing conduction current
- beam electrons leave a positive space charge behind, $\Rightarrow$ electric field attracts bulk electrons back t_2
- bulk electrons can only respond on the timescale of the local plasma frequency $\tau \approx 3.5$ ns
- bulk electrons interact with the expanding sheath, second beam is generated t_3, second maximum of the conduction current

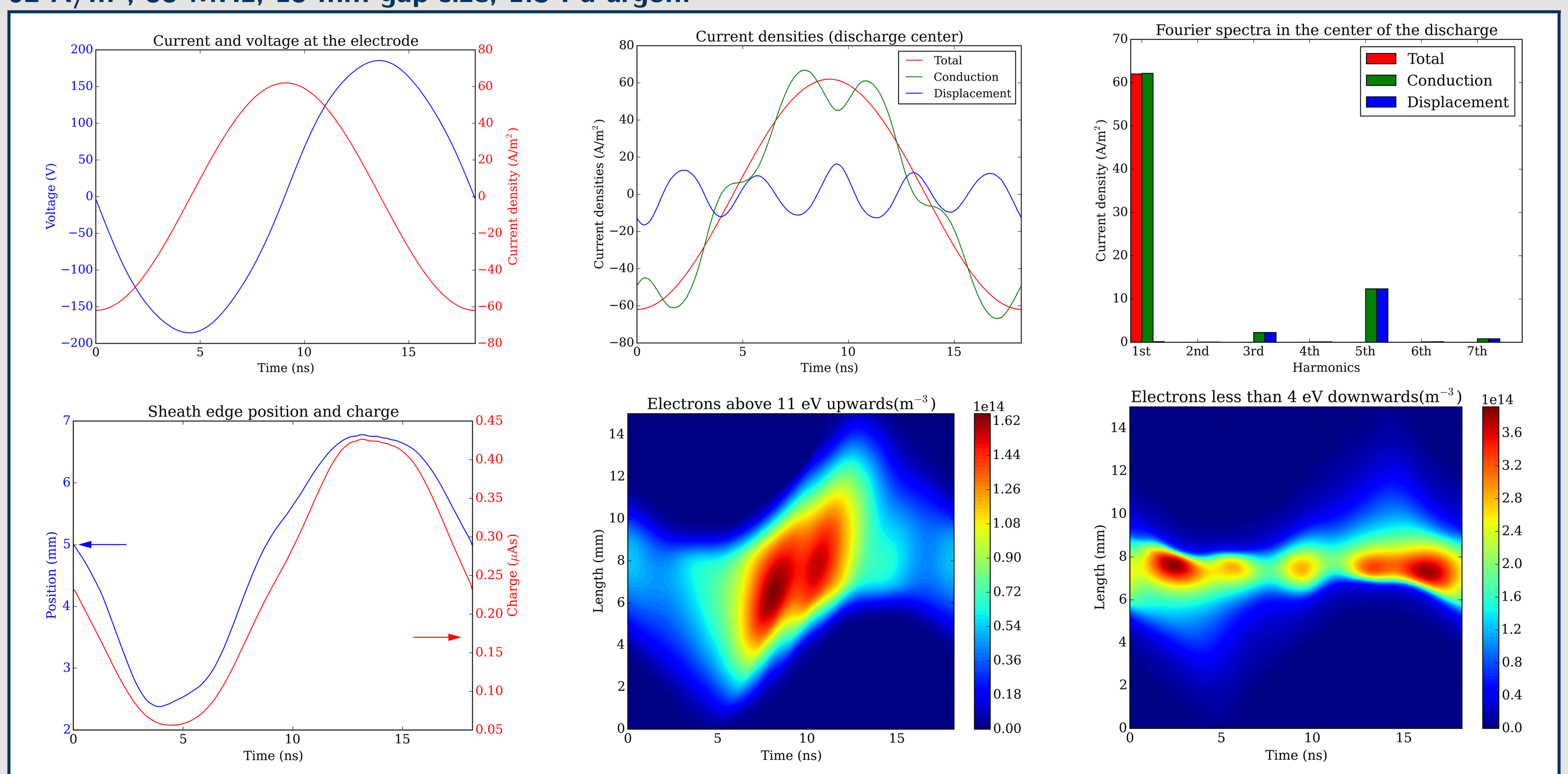
300 V, 55 MHz, 15 mm gap size, 1.3 Pa argon:



- $\uparrow V_{rf} \Rightarrow \uparrow \omega_{pe} \Longrightarrow$ bulk electrons respond on a shorter timescale ($\tau \approx 2$ ns), multiple beam accelerations

Current Source

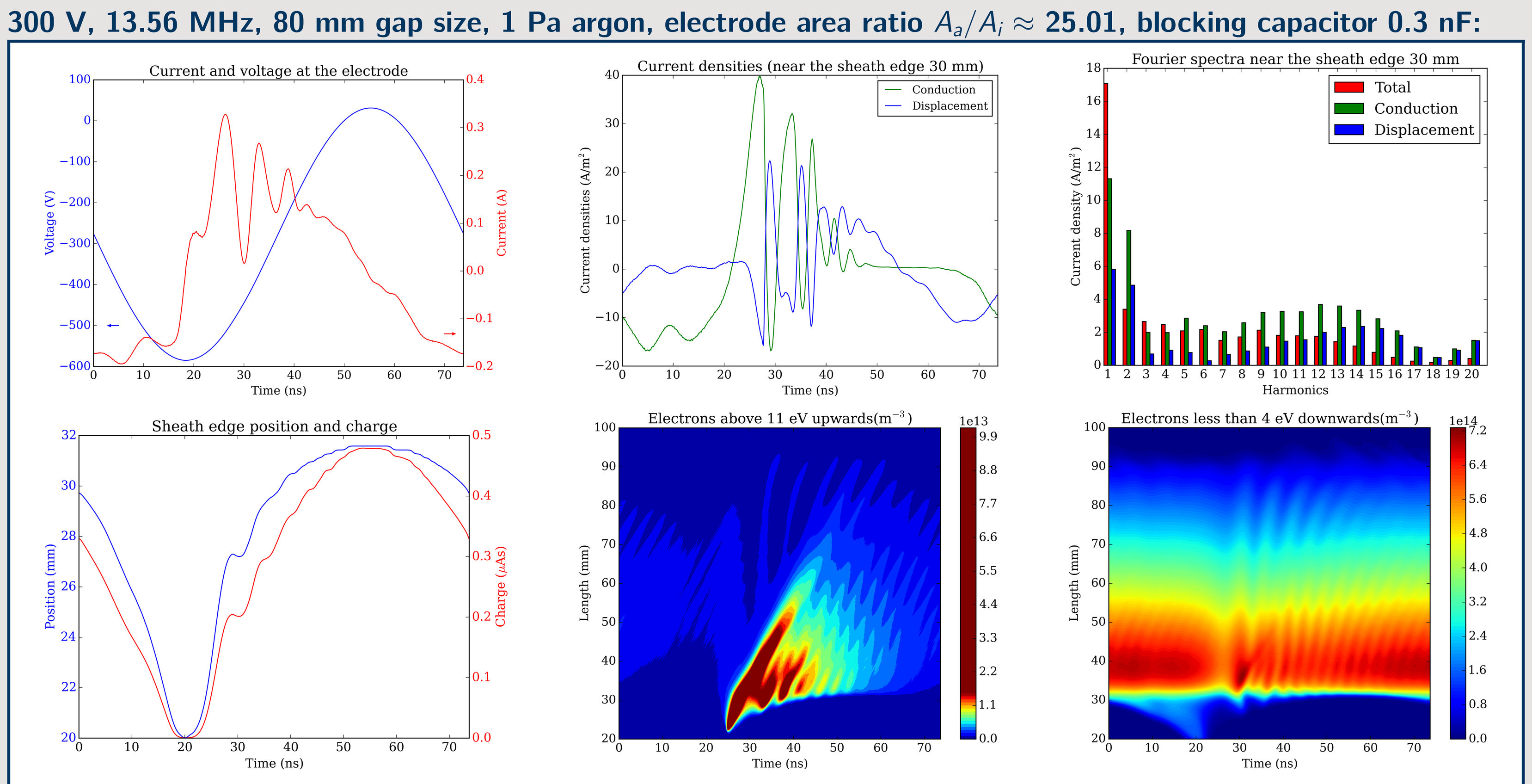
62 A/m^2, 55 MHz, 15 mm gap size, 1.3 Pa argon:



- bulk parallel resonances triggered $\Rightarrow$ same kinetic mechanism of bulk electron modulation
- sinusoidal current waveform $\Rightarrow$ plasma sheaths lose their nonlinear characteristic
- no non-linear interaction of bulk electrons with the expanding sheath, harmonics are fully compensated
- no self-excitation of the plasma series resonance

Asymmetric Discharge

300 V, 13.56 MHz, 80 mm gap size, 1 Pa argon, electrode area ratio $A_a/A_i \approx 25.01$, blocking capacitor 0.3 nF:



- complex harmonic oscillations can be understood, even in asymmetric discharges
- different electrode areas lead to a dc self-bias, major part of the rf voltage drops across one sheath (lower electrode 20 mm)
- complex Fourier spectra indicate series and local (near the plasma sheath) parallel resonances

Conclusion

- kinetic analysis is required in order to understand local kinetic phenomena which lead to resonance effects
- interplay of electron beams (accelerated by the expanding sheath) and bulk electrons (modulated by the local plasma frequency)
- compensation of conduction and displacement current leads to local parallel resonances (even in current driven systems)
- only in voltage driven systems, the non-linear interaction of bulk electrons with the plasma sheaths leads to harmonics in the total current and therefore to the self-excitation of the plasma series resonance

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