NARROW GAP ELECTRONEGATIVE CAPACITIVE DISCHARGES AND STOCHASTIC HEATING

M.A. Lieberman

Department of Electrical Engineering and Computer Sciences
University of California
Berkeley, CA 94720

Collaborators:
E. Kawamura, D.B. Graves, and A.J. Lichtenberg, UC Berkeley
C. Lazzaroni and P. Chabert, Ecole Polytechnique, France
J. Gudmundsson, Shanghai Jiao Tong U; Science Institute, U. Iceland

Motivation: widely used for thin film etch and deposition

Download this talk:

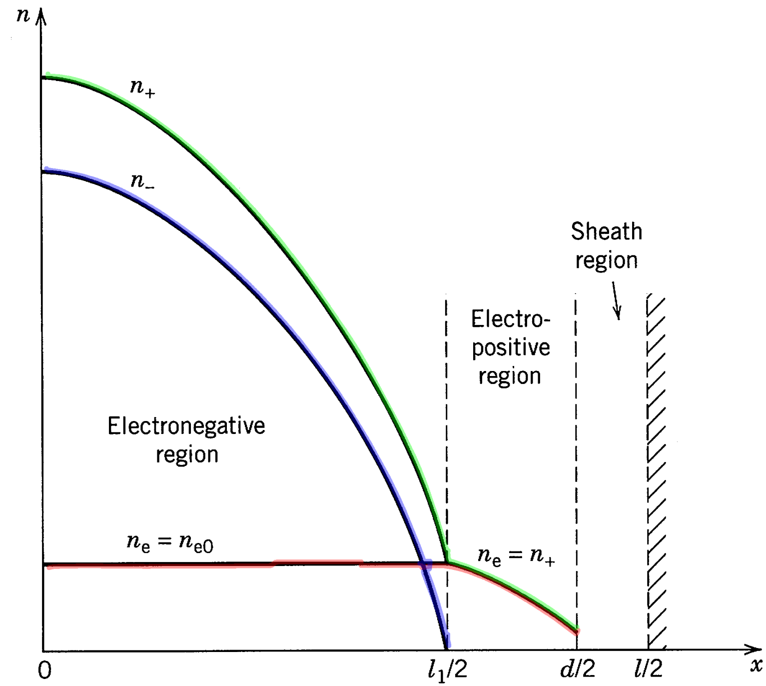
http://www.eecs.berkeley.edu/∼lieber

OUTLINE

- PIC simulations of narrow gap oxygen discharges
- Equilibrium discharge model
- Stochastic (collisionless) heating

DISCHARGE CONFIGURATION

- Oxygen at 10–100 mTorr, $V_{\text{rf}} = 500$–2000 V
- 1D plane-parallel geometry ($\sim$1–10 cm gap length L)
- Usual model is stratified discharge with electronegative (EN) core and electropositive (EP) edge

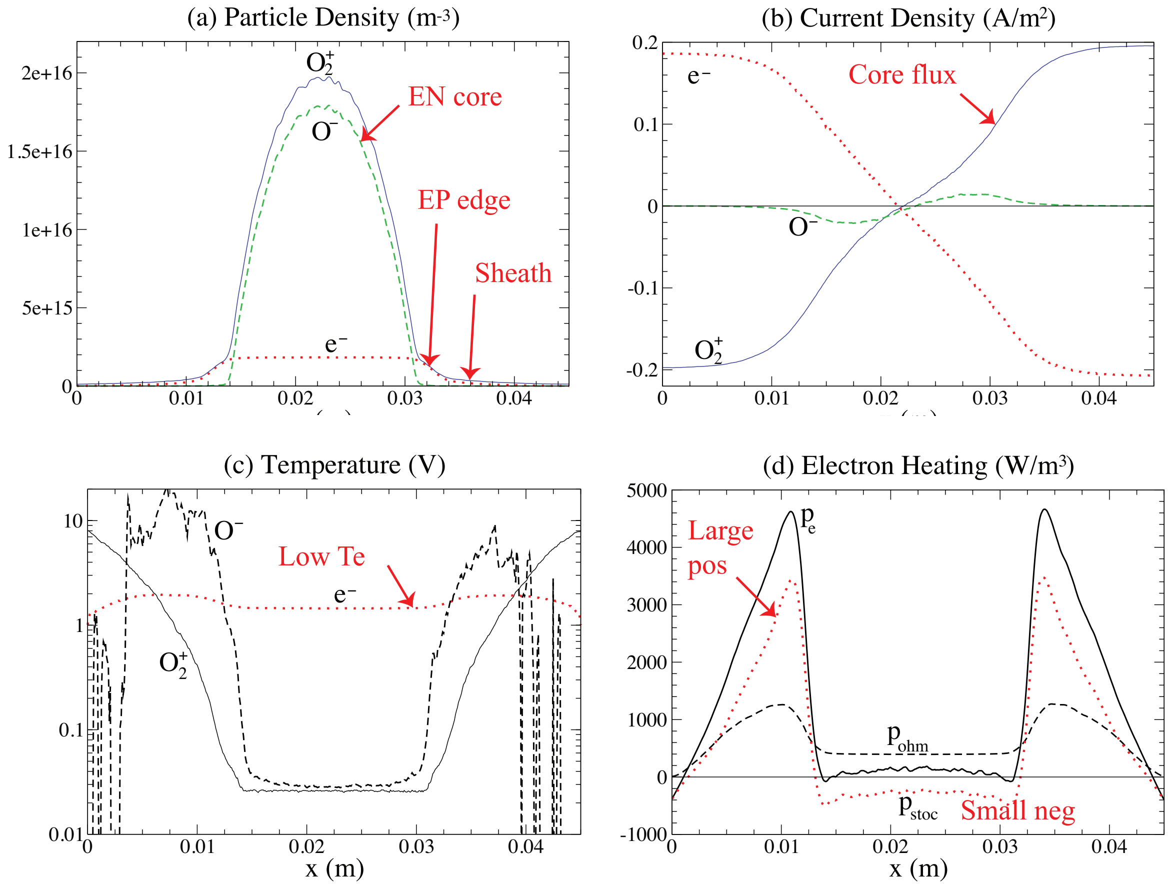


- As L is decreased, the EP edge can disappear and new interesting phenomena are found

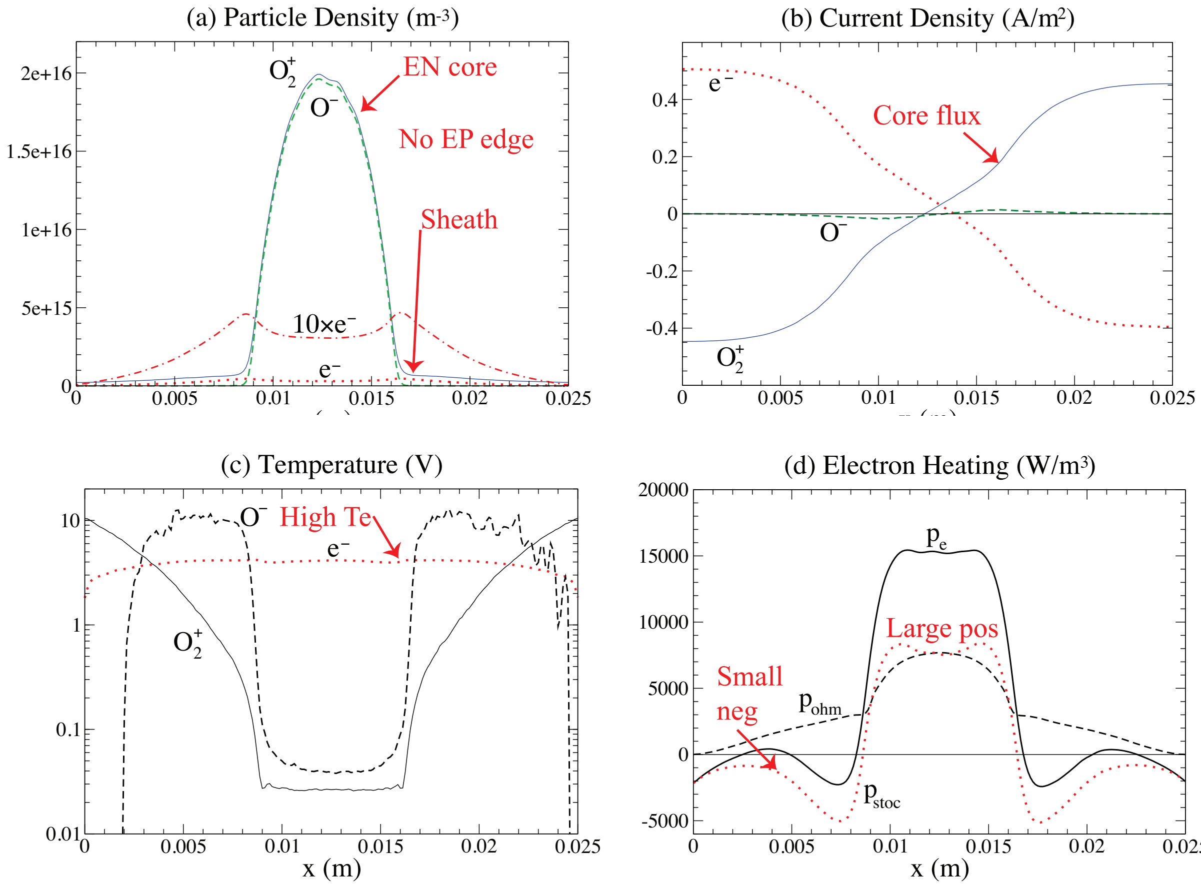
PIC SIMULATIONS AND EQUILIBRIUM MODELING

(Vary gap length L at p=50 mTorr, $V_{rf} = 500$ V)

L=4.5 cm (EP EDGE EXISTS)

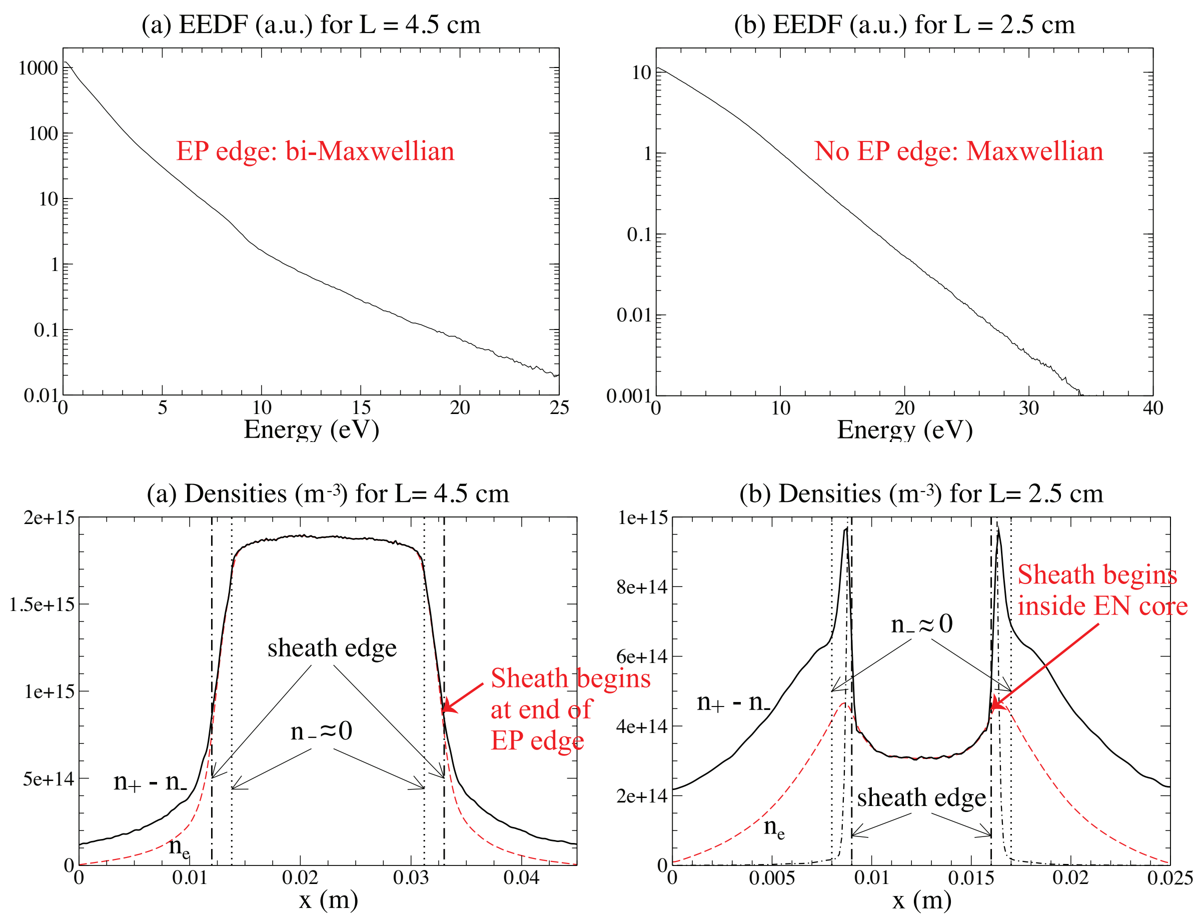


L=2.5 cm (NO EP EDGE)

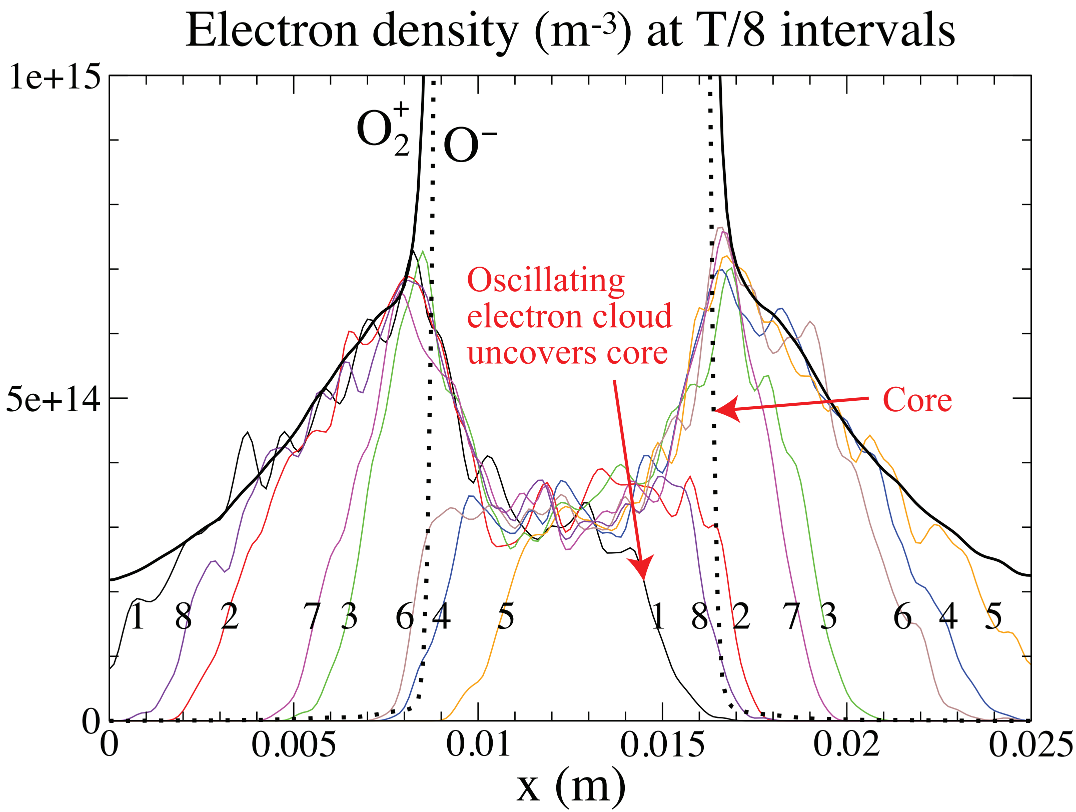


LiebermanPSC13

EEDF'S AND DENSITY DETAILS



TIME-VARYING DENSITY (L=2.5 cm, NO EP EDGE)



MODELING CONSIDERATIONS

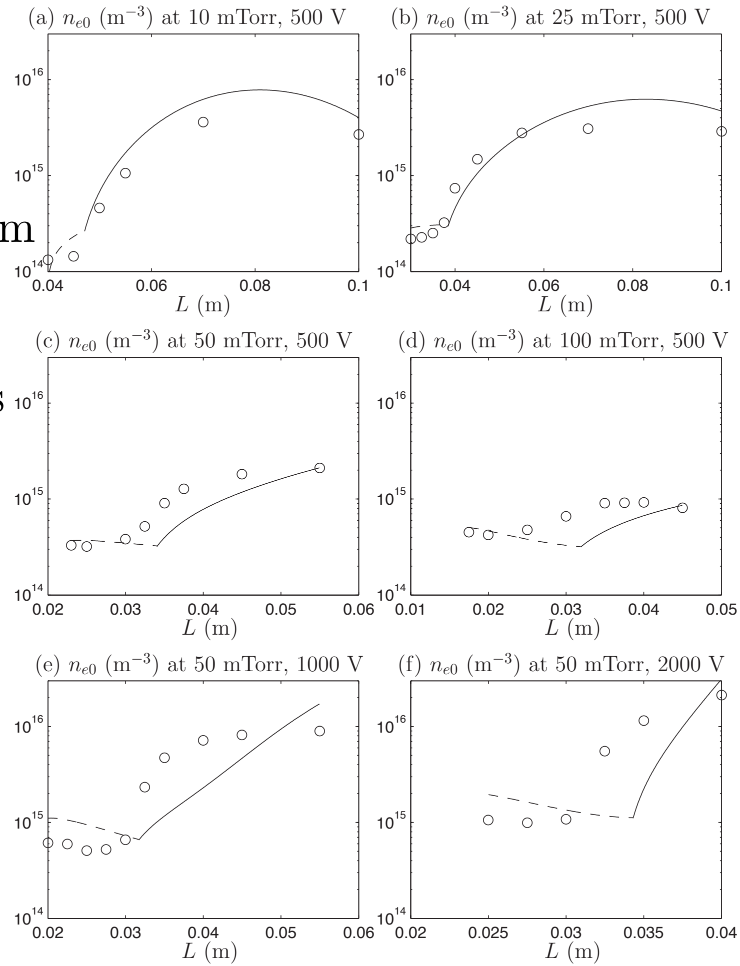
- EP edge exists (larger gap lengths L)
  — Bi-Maxwellian EEDF
  — About half the ion flux generated in sheath/EP edge
  — Usual Child law rf sheath
  — Usual positive collisionless heating in sheath

- No EP edge (smaller gap lengths L)
  — Maxwellian EEDF
  — Over half the ion flux generated in sheath
  — Attachment in sheath is important
  — Unusual rf sheath containing negative ions
  — Negative collisionless heating in sheath, positive in core

- Models developed:
  — model with some inputs from PIC results
  — self-consistent model

MODEL WITH SOME INPUTS FROM PIC

- Rate coefficients and collisional energy losses using PIC EEDF
- Power deposition in core from PIC results
- Solid lines (2-region model with EP edge); Dashed lines (1-region model without EP edge); circles (PIC results)

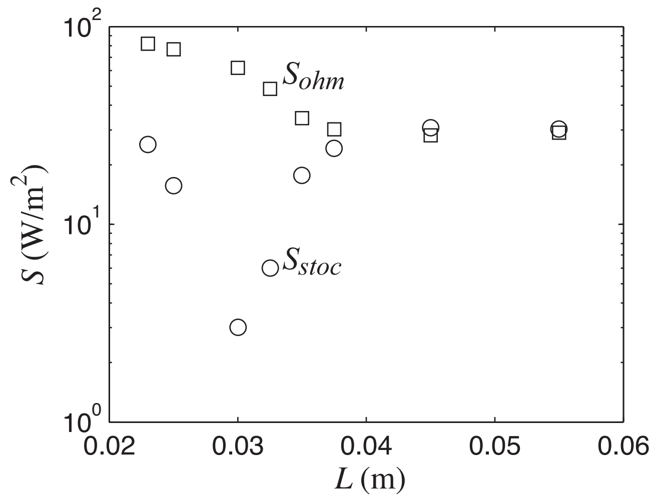


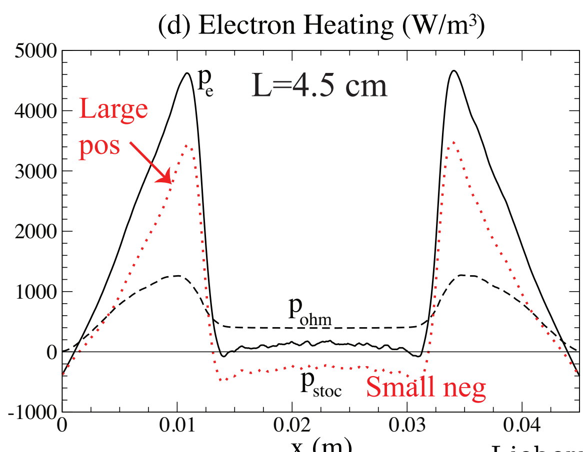
- Reasonable agreement between model and PIC results (submitted to Physics of Plasmas, 2013)

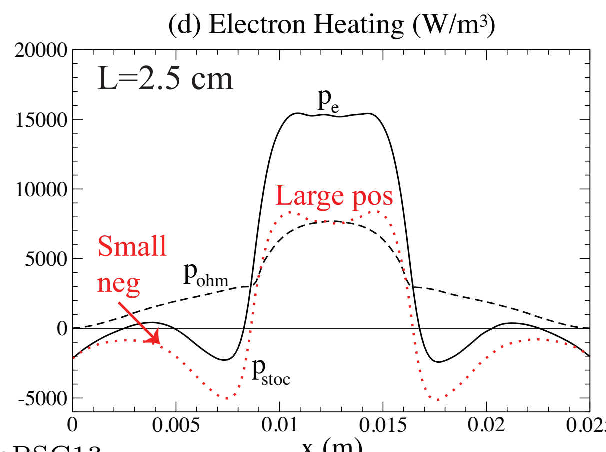
STOCHASTIC (COLLISIONLESS) HEATING

PIC RESULTS FOR VARIOUS GAPS L (50 mT, 500 V)

- Stochastic heating small at transition where EP edge disappears
- EP edge exists ⇒ positive heating in sheath, negative in core
- No EP edge ⇒ negative heating in sheath, positive in core

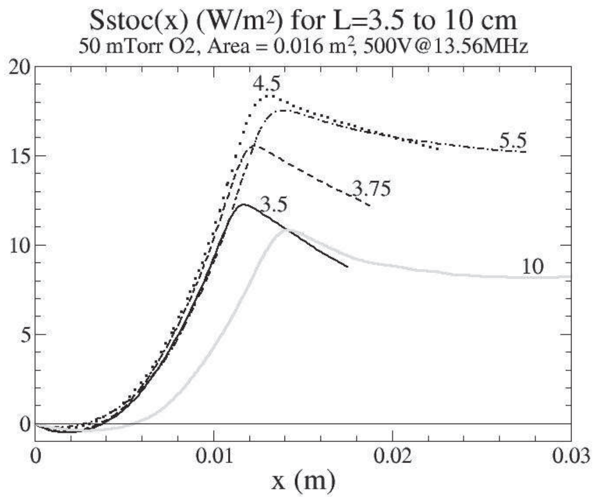


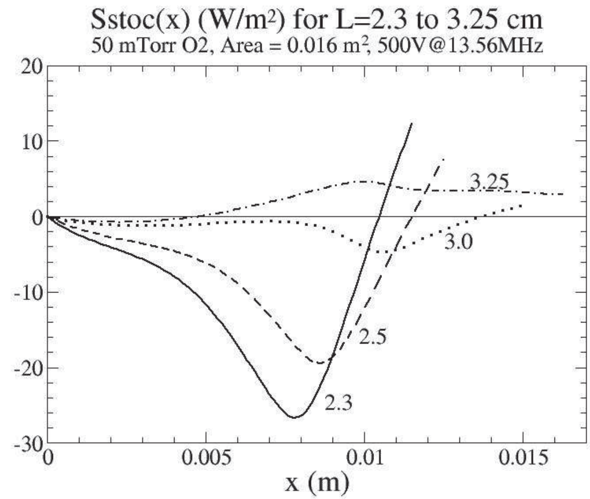




INTEGRATED $S_{stoc}(x)$ FOR VARIOUS GAPS L

- Integrate power density $p_{stoc}(x)$ from electrode toward discharge midplane





- Large $L \Rightarrow n_e(\text{core}) > n_e(\text{sheath})$
  $\Rightarrow$ positive heating in sheath, negative heating in core
- Small $L \Rightarrow n_e(\text{sheath}) > n_e(\text{core})$
  $\Rightarrow$ negative heating in sheath, positive heating in core

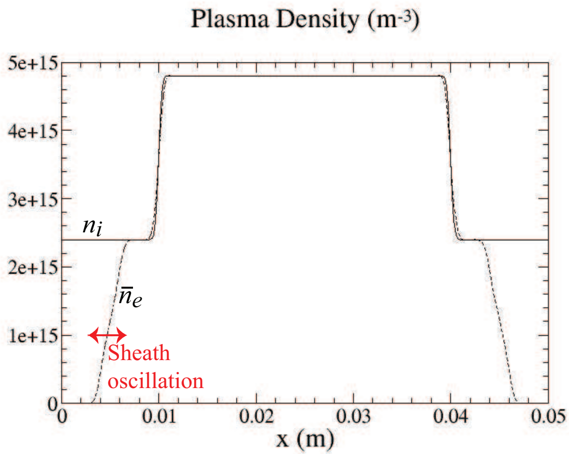
TWO-STEP DENSITY MODEL

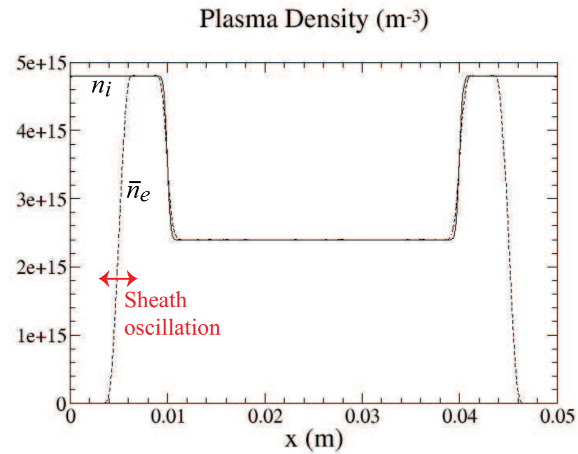
1. I.D. Kaganovich, Phys. Rev. Lett. **89**, 265006 (2002).
2. E. Kawamura, M.A. Lieberman and A.J. Lichtenberg, Phys. Plasmas **13**, 053506 (2006).

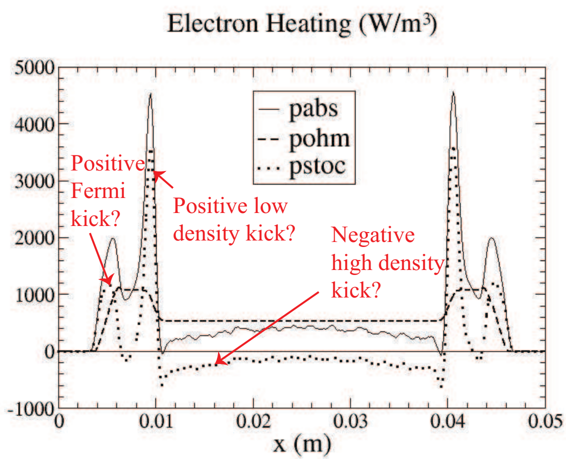
Use to investigate stochastic heating

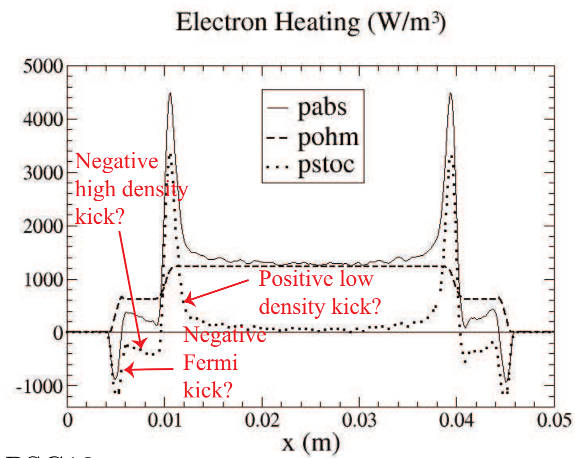
FIXED IONS, PIC ELECTRONS (30 mT Ar, 13.56 MHz)

(Models EN plasma with EP edge) (Models EN plasma with no EP edge)









SUMMARY

- A transition from an EN discharge with an EP edge, to a narrower gap discharge with no EP edge, was investigated with PIC simulations and modeling
- The effects of a bi-Maxwellian EEDF, with an EP edge, and sheath attachment and core uncovering, with no EP edge, need to be taken into account in modeling
- A transition from sheath to internal stochastic heating after the EP edge disappears is observed, and is being studied with a fixed ion, two-step density, PIC simulation