Physics 535 – Lecture 33
Physics of Lightning

Arcs & Streameres

4/13/16

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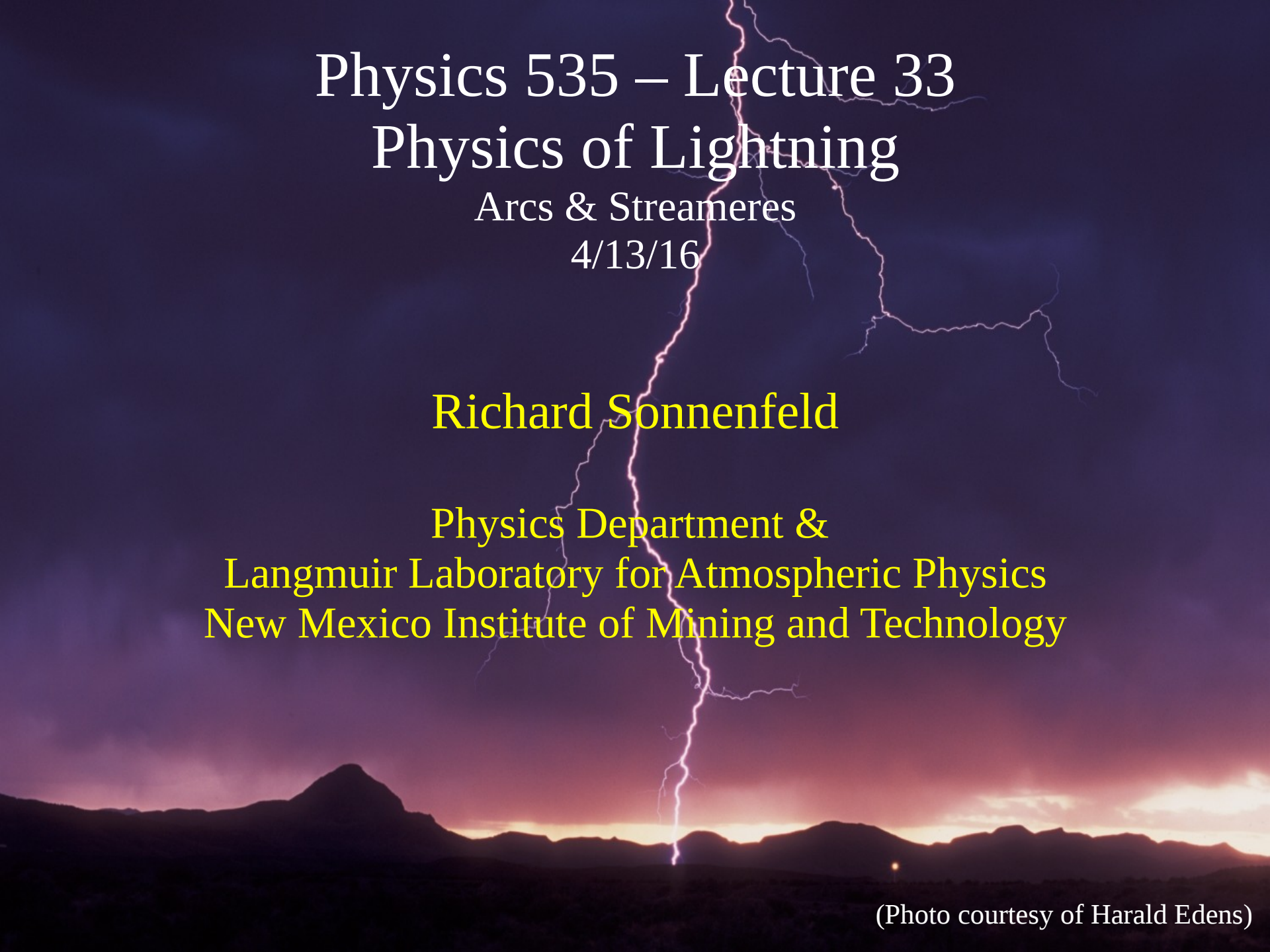

(Photo courtesy of Harald Edens)

Arcs (Ch 2.5-2.8)

Steady state, electron temp. and gas temperature are the same. Ionization is largely thermal. Electrical conductivity is high, E-field is quite low. Negative CVC.

Streamers (Ch. 3.1-3.2)

Gas is at ambient temperature but electrons are at > 1 eV. Ionization is by electron impact. Electrical conductivity is low except at the streamer tip. E-field is very high. “Equilibrium” in streamer frame only, contingent on streamer growing at 0.01c.

Set of quantities to self-consistently calculate

$W_1 = 8\pi\lambda T_m^2 / I$ Power

$T_0 = T_m (1 - 2T_m / I)$

$CT_m = \text{sqrt}[(I/k)(W/8\pi\lambda)]$

$\sigma_m = b e^{-I/2T_m}$ Conductivity

$\sigma_0 = b e^{-I/2T_0}$

$r_0 = R e^{-(2\pi\lambda T_0 / W_1)}$ core radius

$E = W_1 / i$ E-field

$i = r_0 \sqrt{\pi \sigma W_1}$ current

$i^2 = \pi r_0^2 \sigma W_1$

Power $= i^2 R$

$R = \rho \frac{l}{A} \rightarrow \frac{1}{R} = A\sigma$

$\frac{\text{length}}{\text{length}}$

$i^2 = \frac{\text{Power}}{R}$

Given σ = average conductivity
r_0 = conducting radius
W_1 = power/unit length
What is i?

$$P = i^2 R \qquad R = \rho \frac{l}{A} = \frac{l}{\sigma A} \qquad \frac{R}{\text{length}} = \frac{1}{\sigma A} \therefore \frac{1}{R} = \sigma A$$

$$i^2 = \frac{P}{R} = \frac{W_1}{R/\text{length}} = \sigma A W_1$$

$$i = \sqrt{\sigma \pi r_0^2 W_1} = r_0 \sqrt{\pi \sigma W_1}$$

Given T_m & λ, what is W_1?

2.42 $$T_m = \sqrt{\frac{I}{8\pi\lambda_m k} W_1}$$

$$T_m^2 = \frac{I}{8\pi\lambda_m k} W_1 \quad \therefore \quad W_1 = \frac{8\pi\lambda_m k T_m^2}{I}$$

Use λ_m = const 1.5 $\frac{\text{Watts}}{\text{m.K}}$

Start w 2.39 What is T_0? (Temp where conductivity goes to 0% e)

$$\ln\left[e = \frac{\sigma_m}{\sigma_0} = \frac{b e^{-I_{eff}/2kT_m}}{b e^{-I_{eff}/2kT_0}} = e^{\left(-\frac{I}{2kT_m} + \frac{I}{2kT_0}\right)}\right]$$

Assume= 2.41

$$1 = \frac{I}{2k}\left[\frac{1}{T_0} - \frac{1}{T_m}\right] = \frac{I}{2k}\left[\frac{T_m - T_0}{T_0 T_m}\right] \rightarrow T_m - T_0 = \frac{2k}{I} T_0 T_m$$

Maximum temperature and thermal conductivity sett the power lost per meter of channel.

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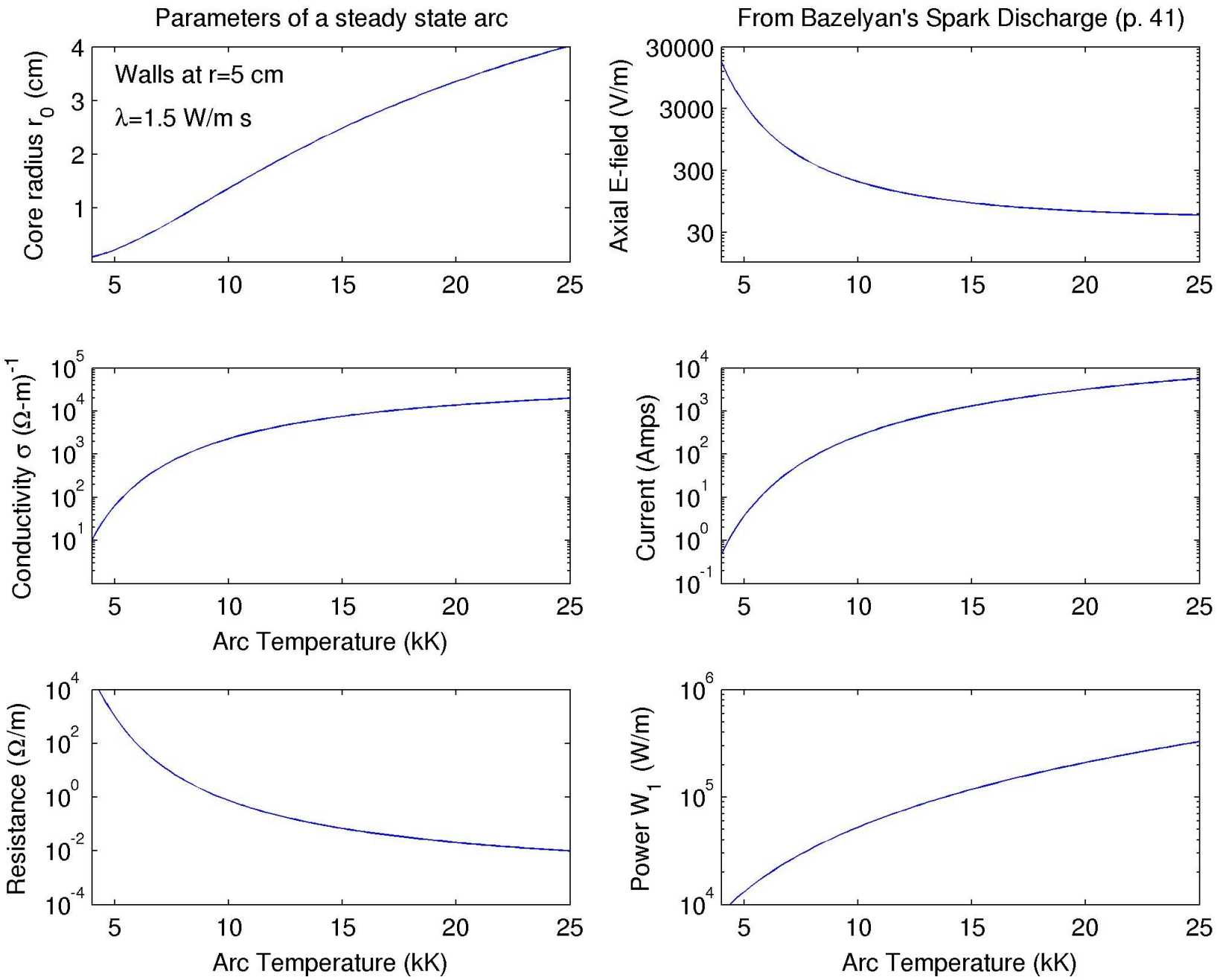
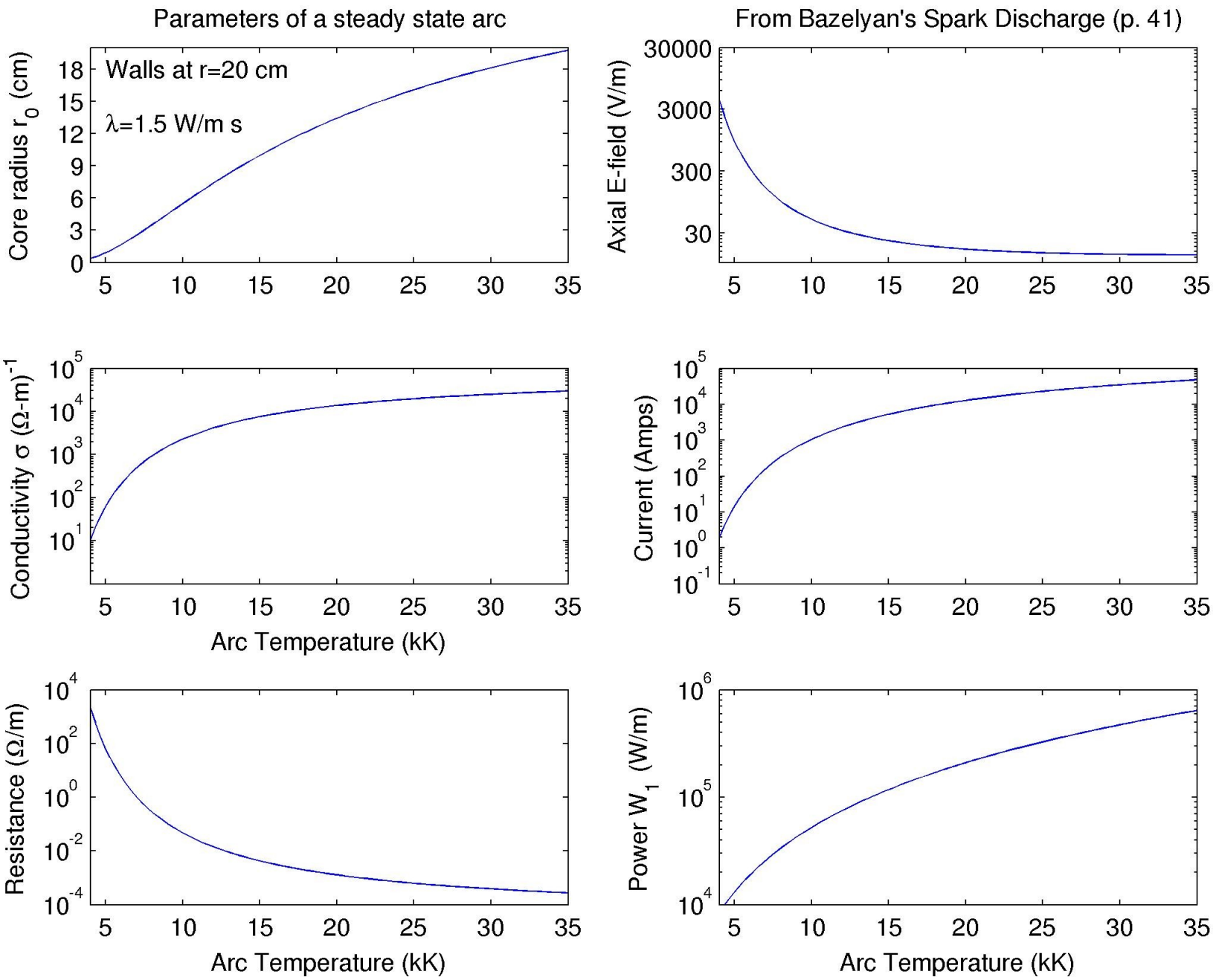
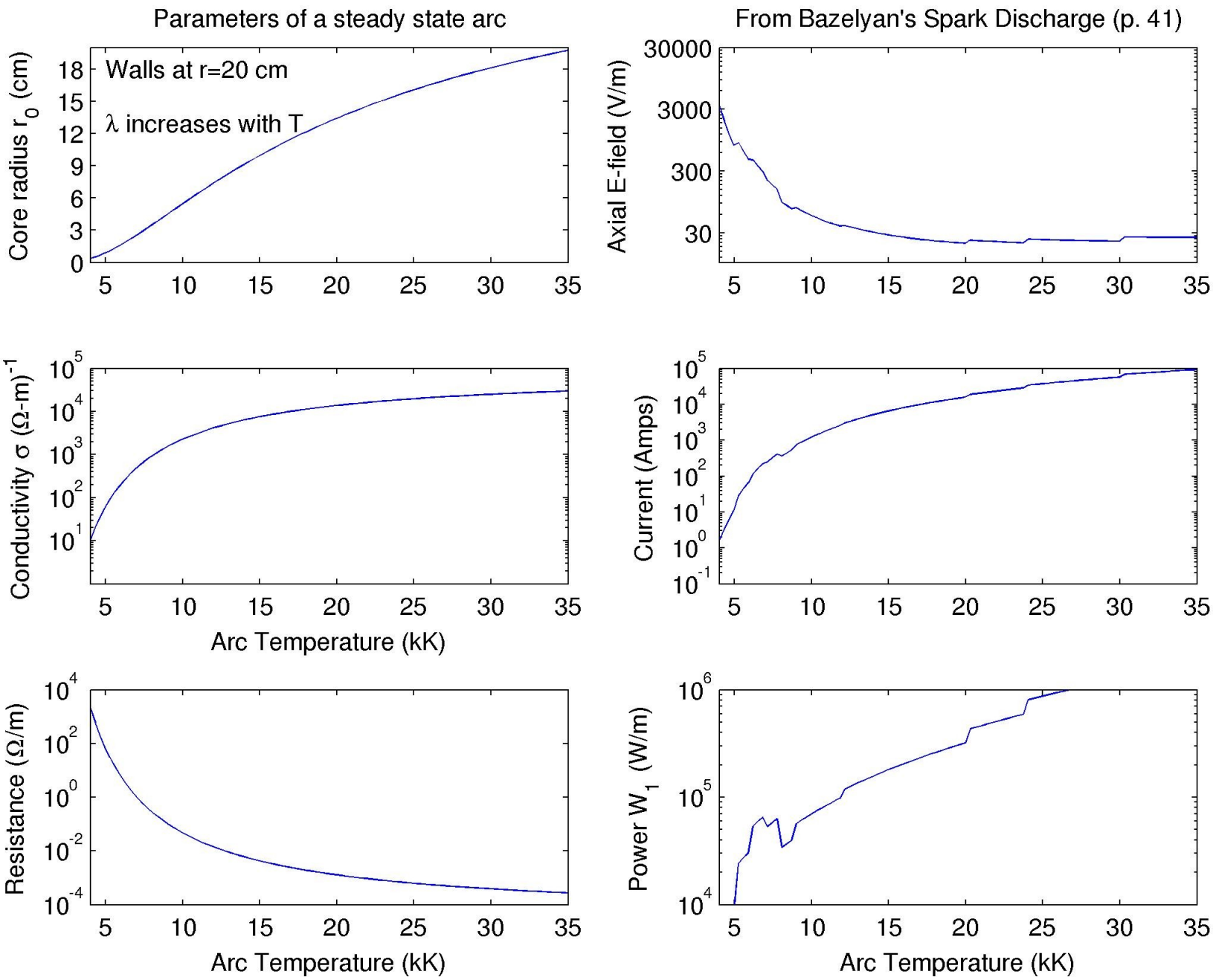

Parameters of a steady state arc
From Bazelyan's Spark Discharge (p. 41)
Walls at r=5 cm
λ=1.5 W/m s
Core radius r0 (cm)
Axial E-field (V/m)
Conductivity σ (Ω-m)-1
Current (Amps)
Resistance (Ω/m)
Power W1 (W/m)
Arc Temperature (kK)
Arc Temperature (kK)
Arc20160410
R. Sonnenfeld -- As of: 13-Apr-2016


Parameters of a steady state arc
From Bazelyan's Spark Discharge (p. 41)
Core radius r0 (cm)
Walls at r=20 cm
λ=1.5 W/m s
Axial E-field (V/m)
Conductivity σ (Ω-m)-1
Current (Amps)
Arc Temperature (kK)
Resistance (Ω/m)
Power W1 (W/m)
Arc Temperature (kK)
Arc20160413
R. Sonnenfeld -- As of: 13-Apr-2016


Parameters of a steady state arc
From Bazelyan's Spark Discharge (p. 41)
Core radius r0 (cm)
Walls at r=20 cm
λ increases with T
Axial E-field (V/m)
Conductivity σ (Ω-m)-1
Current (Amps)
Arc Temperature (kK)
Resistance (Ω/m)
Power W1 (W/m)
Arc Temperature (kK)
Arc20160413
R. Sonnenfeld -- As of: 13-Apr-2016

Streamers (Ch. 3.1-3.2)

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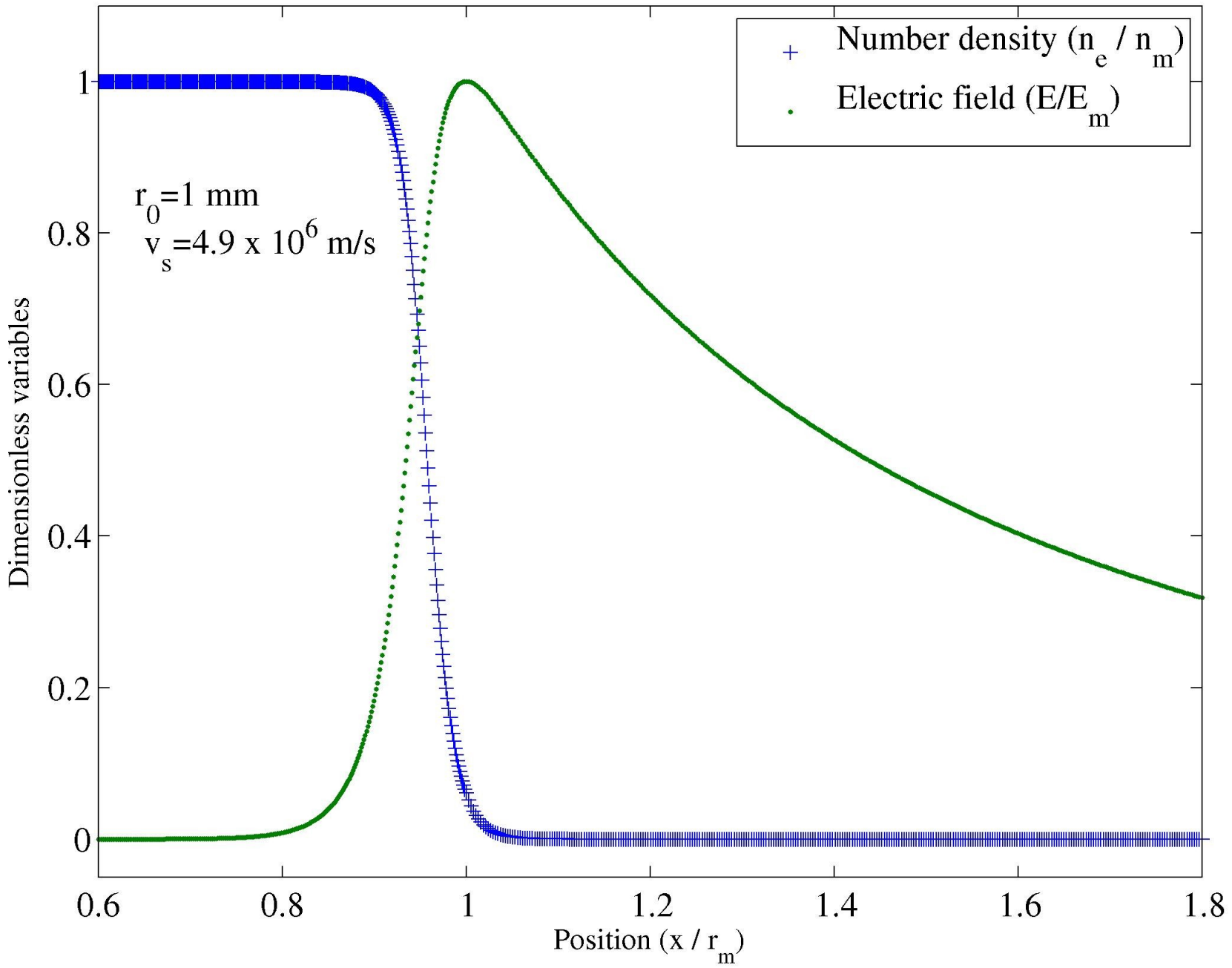

Figure3_2

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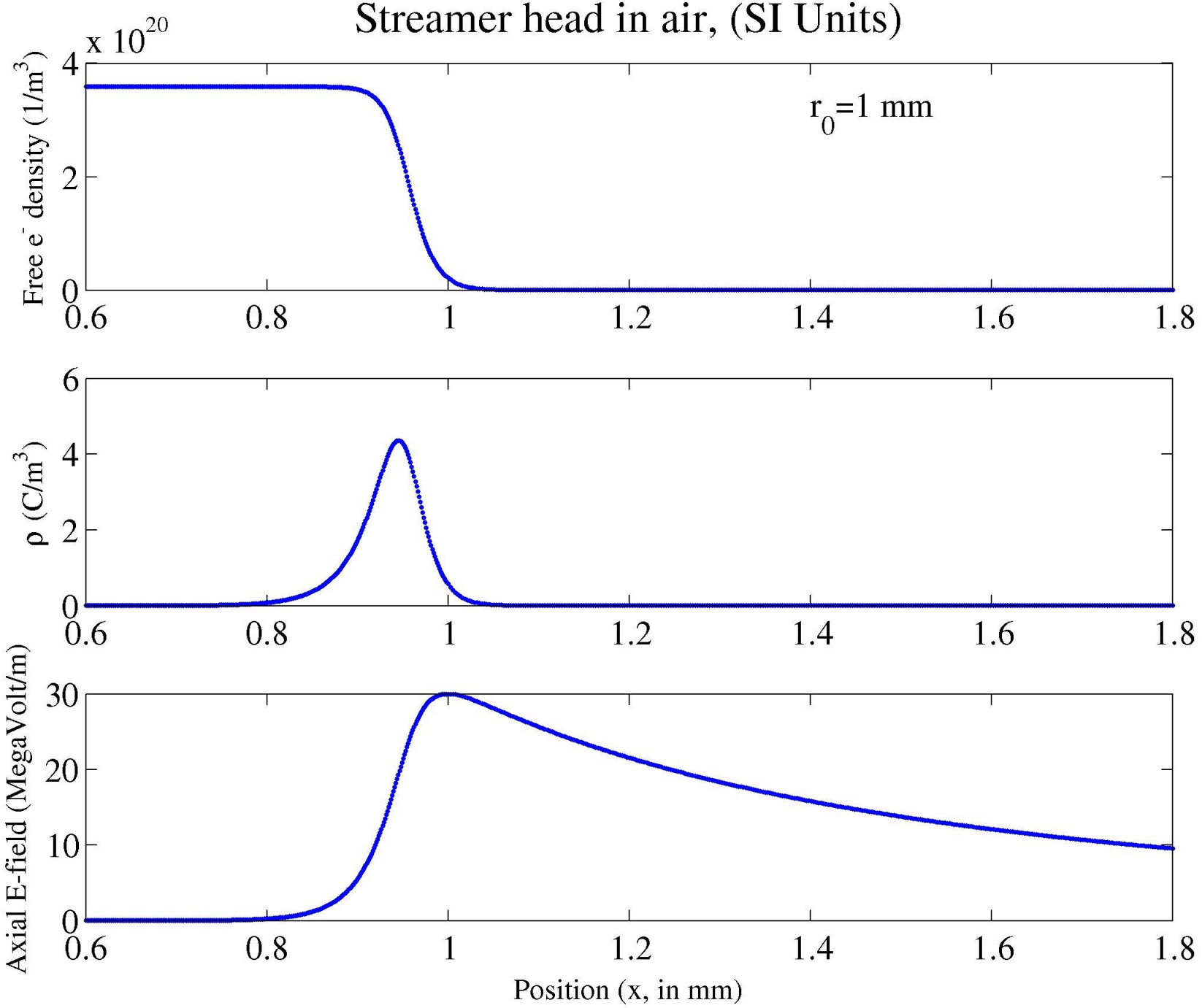

Figure3 2

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