RADIATION TRAPPING IN ELECTRODELESS LAMPS: COMPLEX GEOMETRIES AND OPERATING CONDITIONS*

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AGENDA

- Radiation transport
- Base case parameters
- Consequences of operating conditions –
  - Effect of cold spot
  - Effect of ICP frequency
  - Effect of ICP power
  - Effect of low powers
- Consequences of change in plasma cavity shape.
- Conclusions

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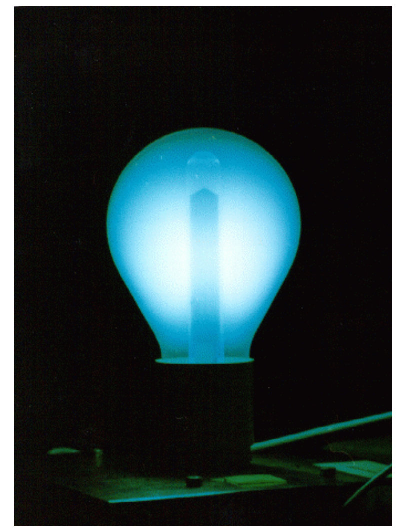
RADIATION TRANSPORT

- **Electrodeless gas discharges are attractive as light sources due to their extended lifetime.**

- **Resonance radiation from the Hg (6^3P_1) (254 nm) and Hg (6^1P_1) (185 nm) excites phosphors which generate visible light.**

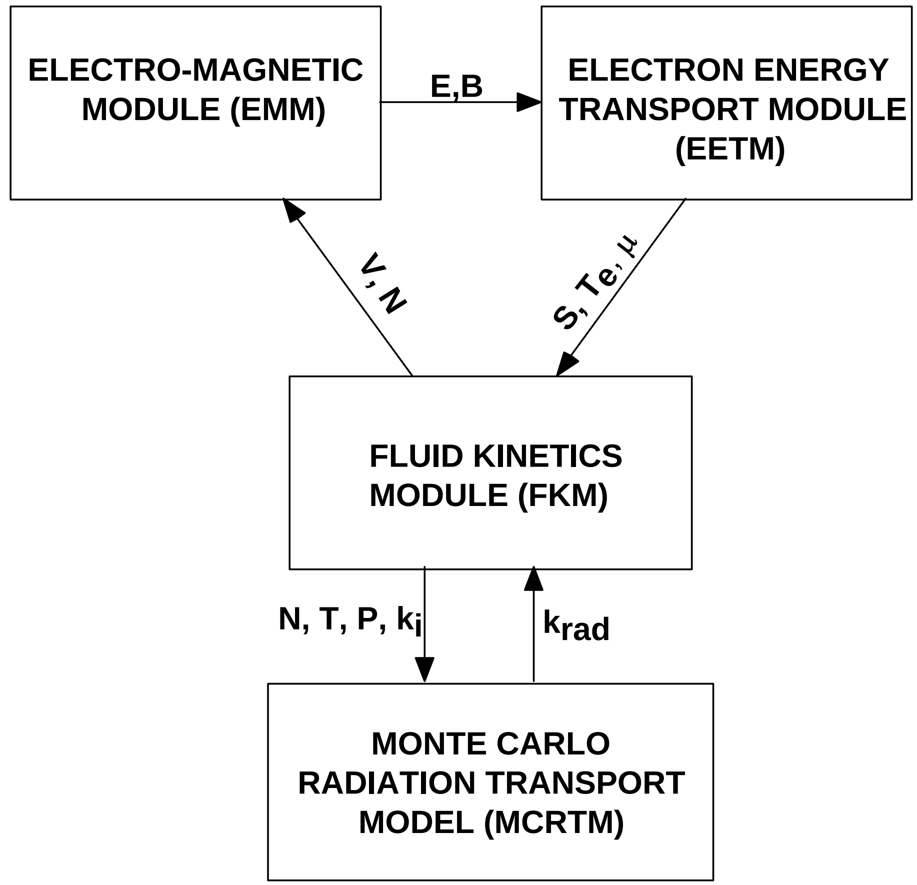
- **This radiation may be absorbed and re-emitted many times prior to striking the phosphor (radiation trapping).**



- **We have modeled the radiation transport using a Monte Carlo module which is interfaced with a hybrid plasma equipment model to realistically simulate the gas discharge.**

HYBRID PLASMA EQUIPMENT MODEL (HPEM)

- **A modular simulator for low pressure plasmas.**
- **EMM: electromagnetic fields and magneto-static fields**
- **EETM: electron temperature, electron impact sources, and transport coefficients**
- **FKM: densities, momenta, and temperatures of charged and neutral plasma species; and electrostatic potentials**



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MONTE CARLO RADIATION TRANSPORT MODULE

- Monte Carlo photon pseudo-particles are launched from locations proportional to Hg* density.
- Trajectories are tracked accounting for absorption/emission based on Voight profile.
- Null cross section techniques account for variations in absorber and perturber densities, collision frequency and gas temperature.
- Partial frequency redistribution of emitted photons.
- Isotope shifts and fine structure splitting.
- Effective lifetimes (residence times) of photons in plasma and exit spectra are calculated.

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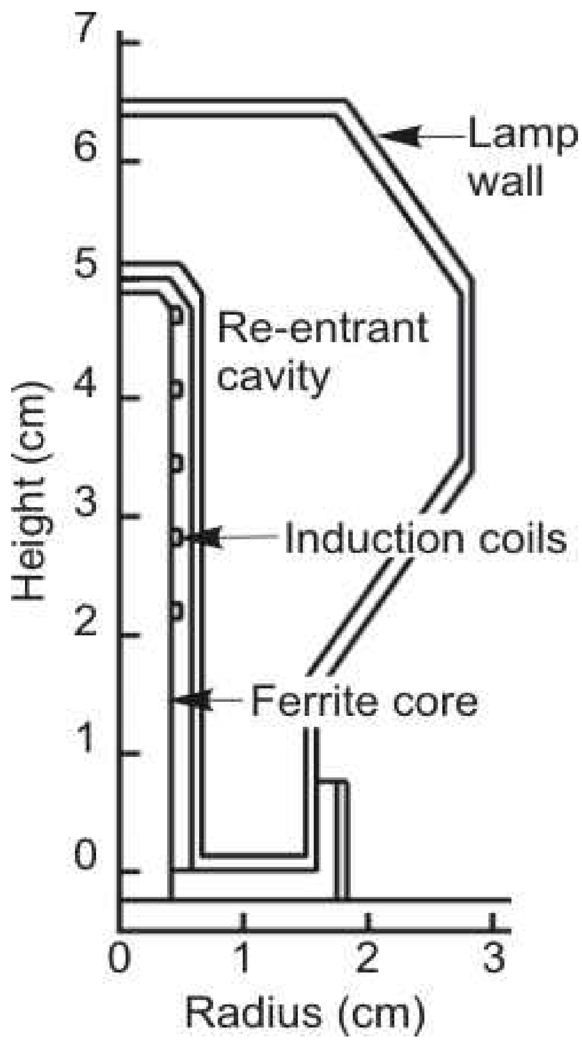
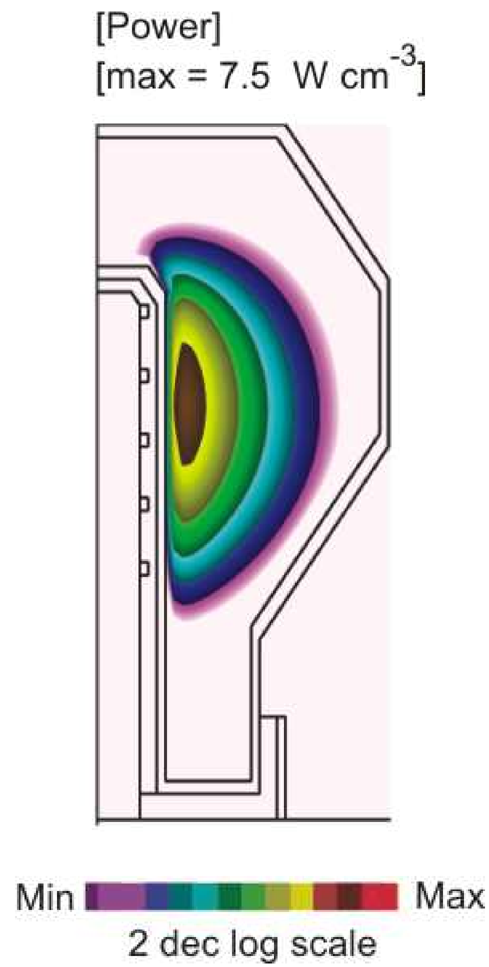
BASE CASE – PHILIPS QL-LIKE

- **Ar fill pressure 500 mTorr**
- **Hg pressure 5 mTorr**
- **Power 50 W**
- **Frequency 5 MHz**





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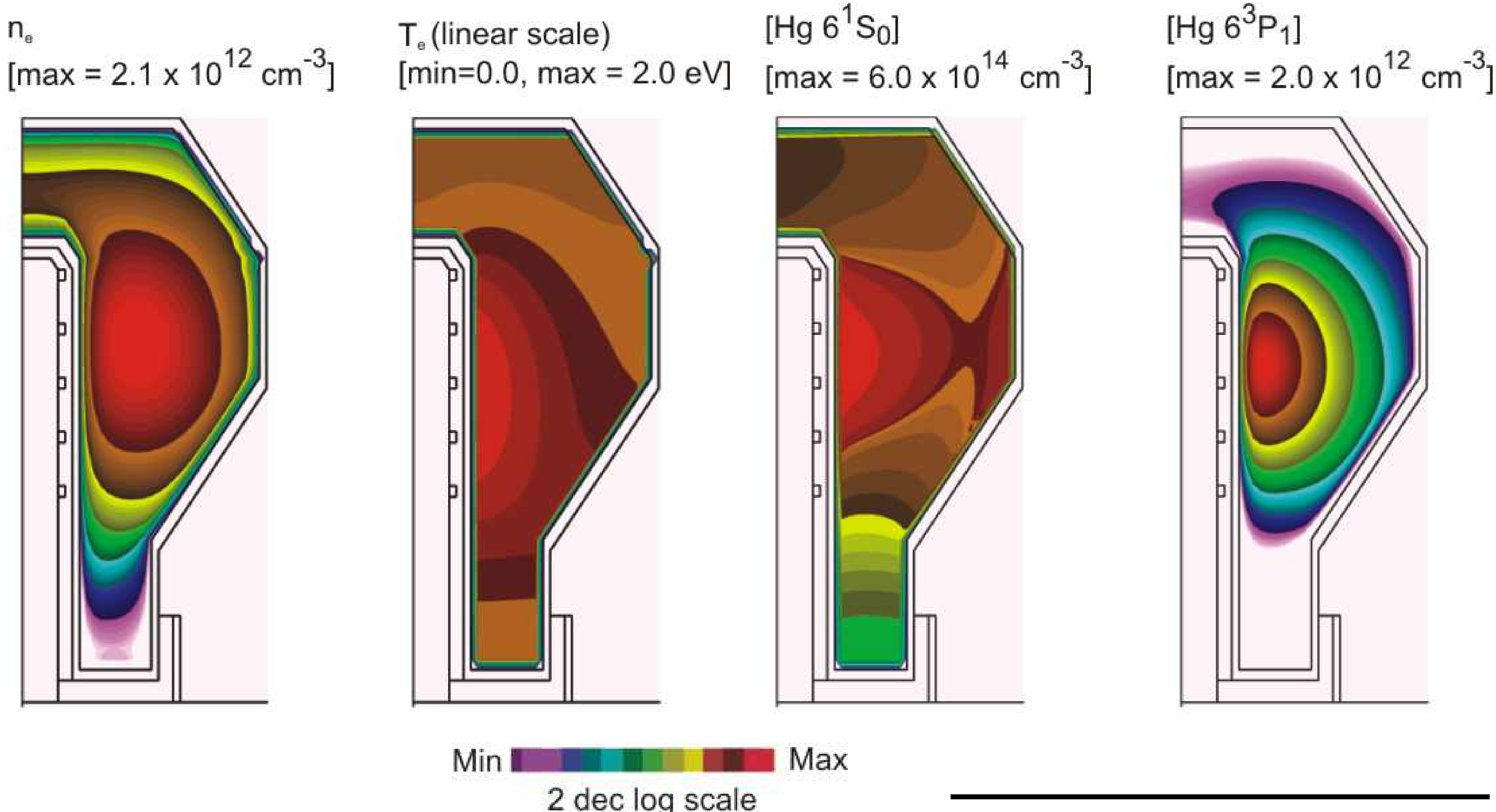
BASE CASE PLASMA PARAMETERS

- **Cataphoresis creates a maximum [Hg] near the walls.**



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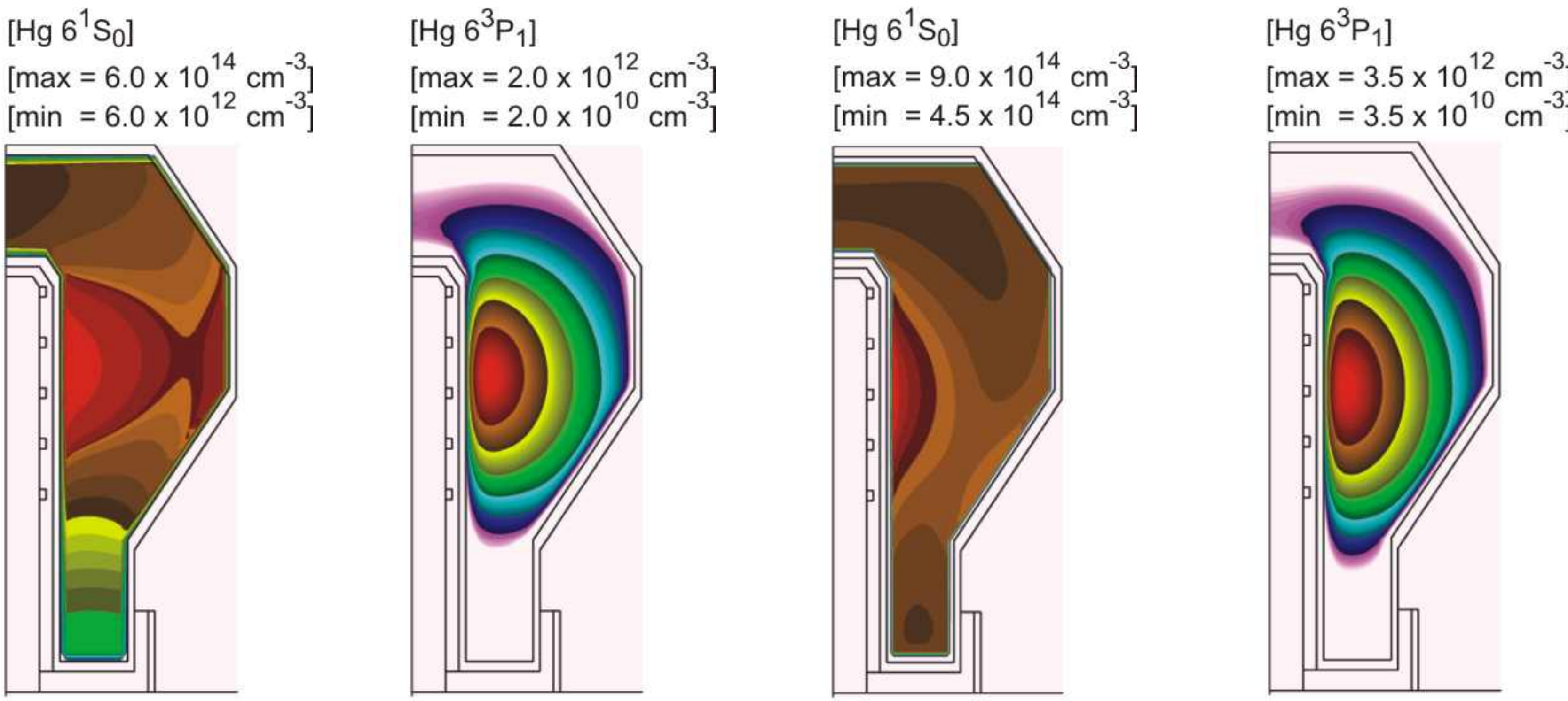
INCREASE IN COLD SPOT

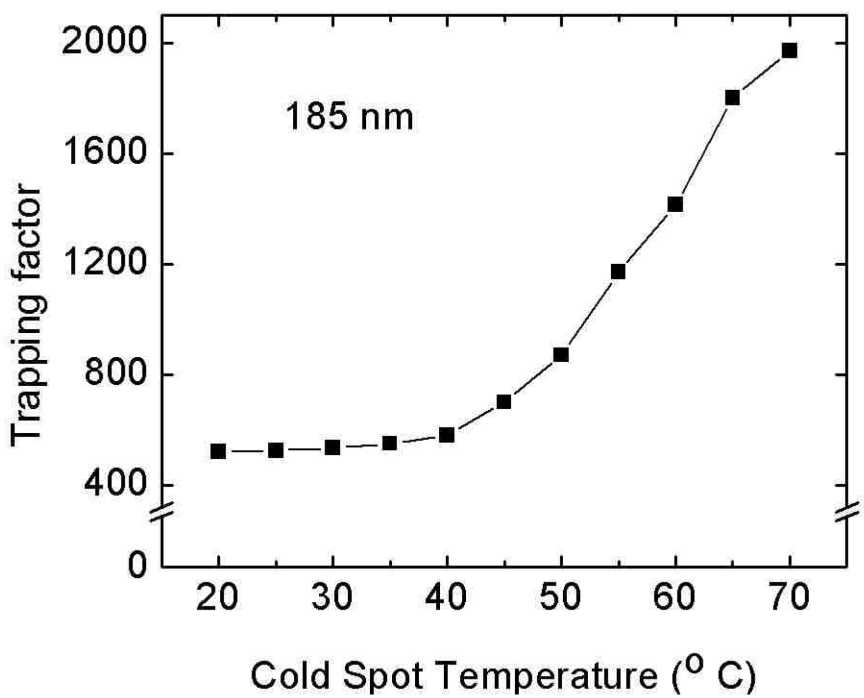
- **With an increase in cold spot, the absolute absorber density goes up much more rapidly than the radiator density, increasing trapping factors.**

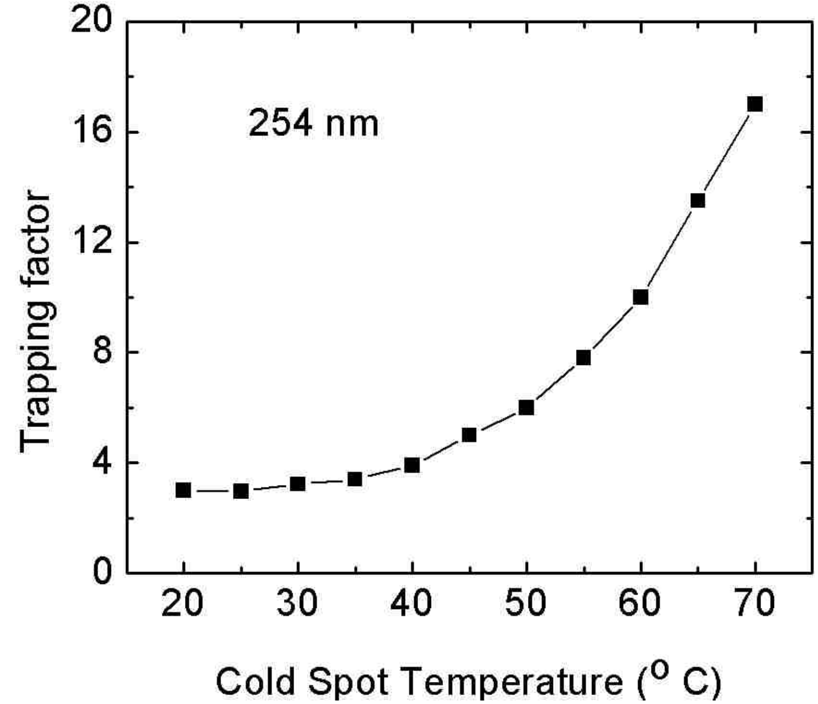


- **T_c = 38 °C (Hg 5 mTorr)**
- **T_c = 56 °C (Hg 20 mTorr)**

INCREASE IN COLD SPOT

- **Vacuum radiative lifetimes are 1.33 ns (185 nm), and 125 ns (254 nm), leading to orders of magnitude difference in trapping factors for the two lines.**





- **Ar 500 mTorr, 5 MHz, 50 W**

EFFECT OF COIL FREQUENCY

- **Coil frequency is an important design parameter for power transfer in ICPs.**
- **Collisional plasma (100s mTorr) implies electron neutral momentum transfer frequency $\nu_m >> \omega$, the applied frequency.**
- $$\delta_c = \left(\frac{2}{\omega \mu_0 \sigma_{dc}} \right)^{1/2} \qquad \sigma_{dc} = \frac{e^2 n_e}{m \nu_m}$$
- **For a max electron density of 10^{12} cm^{-3}, and a minimum collision frequency of 10^7 s^{-1}, $\delta \approx$ 30 cm**
- **As δ is larger than size of the vessel, changes in rf frequencies are unlikely to affect the radiation transport.**

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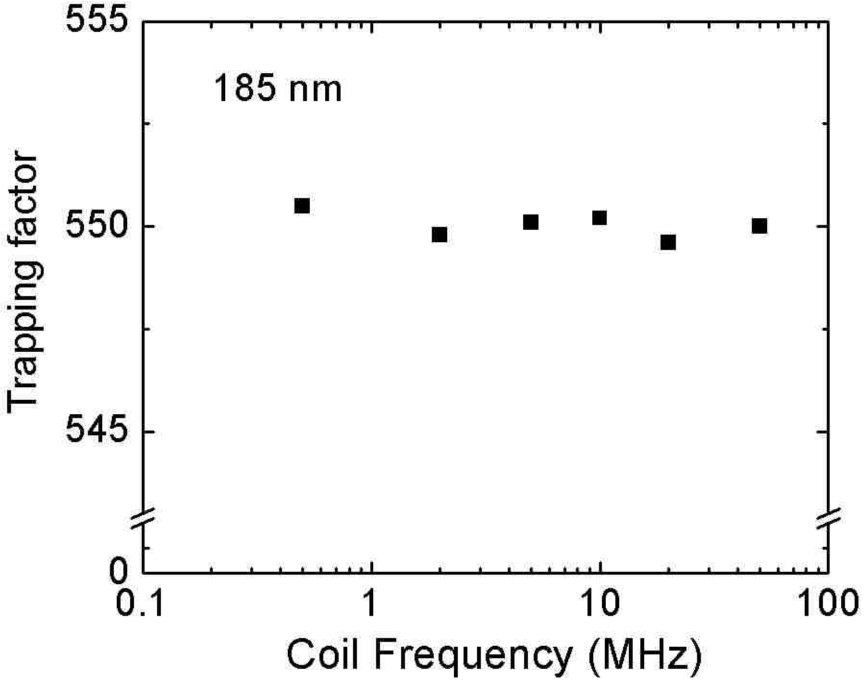
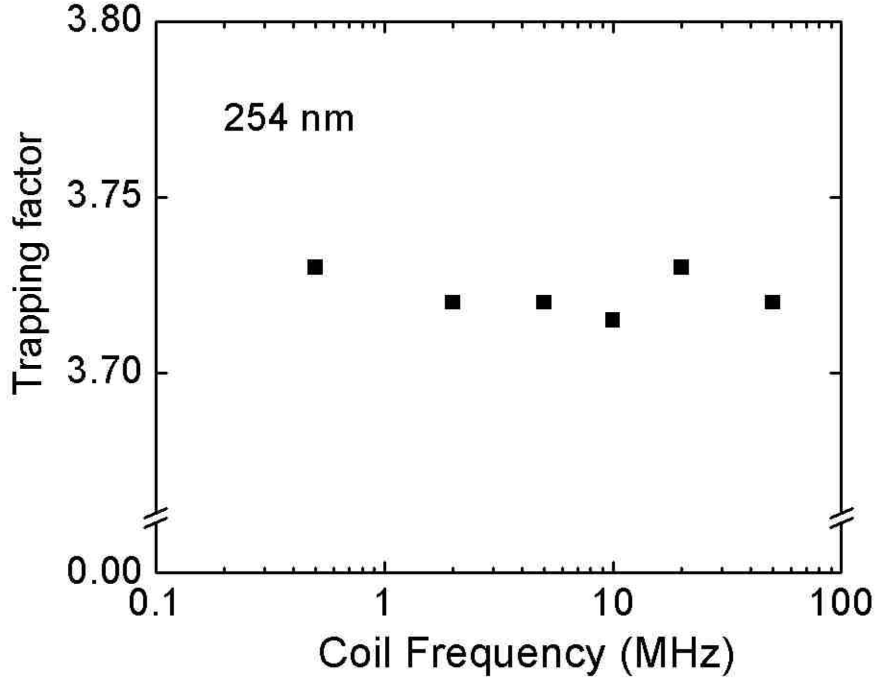
EFFECT OF COIL FREQUENCY (contd.)

- As a result, coil frequency is seen not to affect the trapping factors.





- Ar 500 mTorr, Hg 5 mTorr, 50 W

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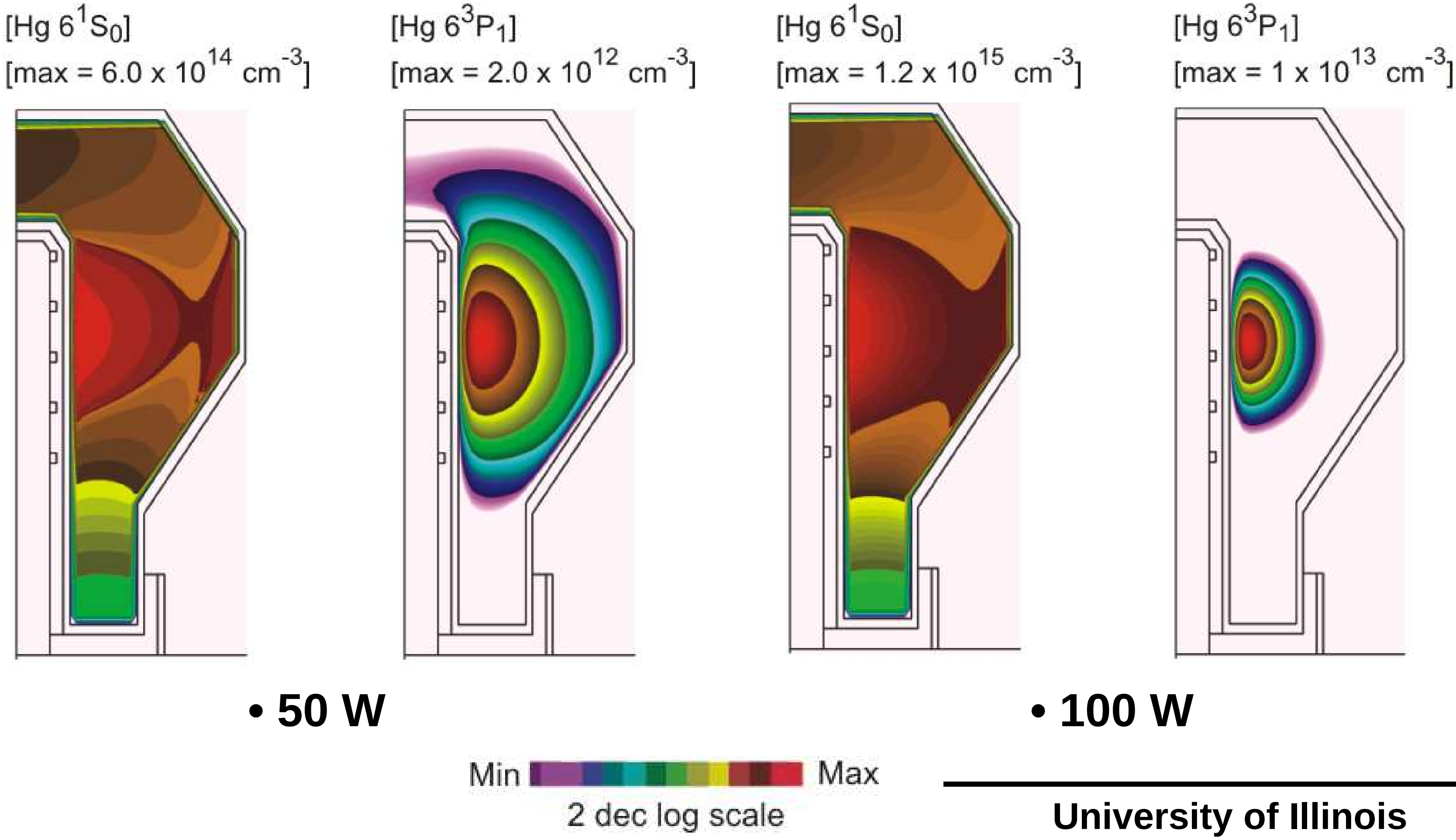
EFFECT OF POWER

- **In sealed systems, increase in power raises ionization and temperature but not total gas density, leading to redistribution of absorbers.**



- **50 W**
- **100 W**

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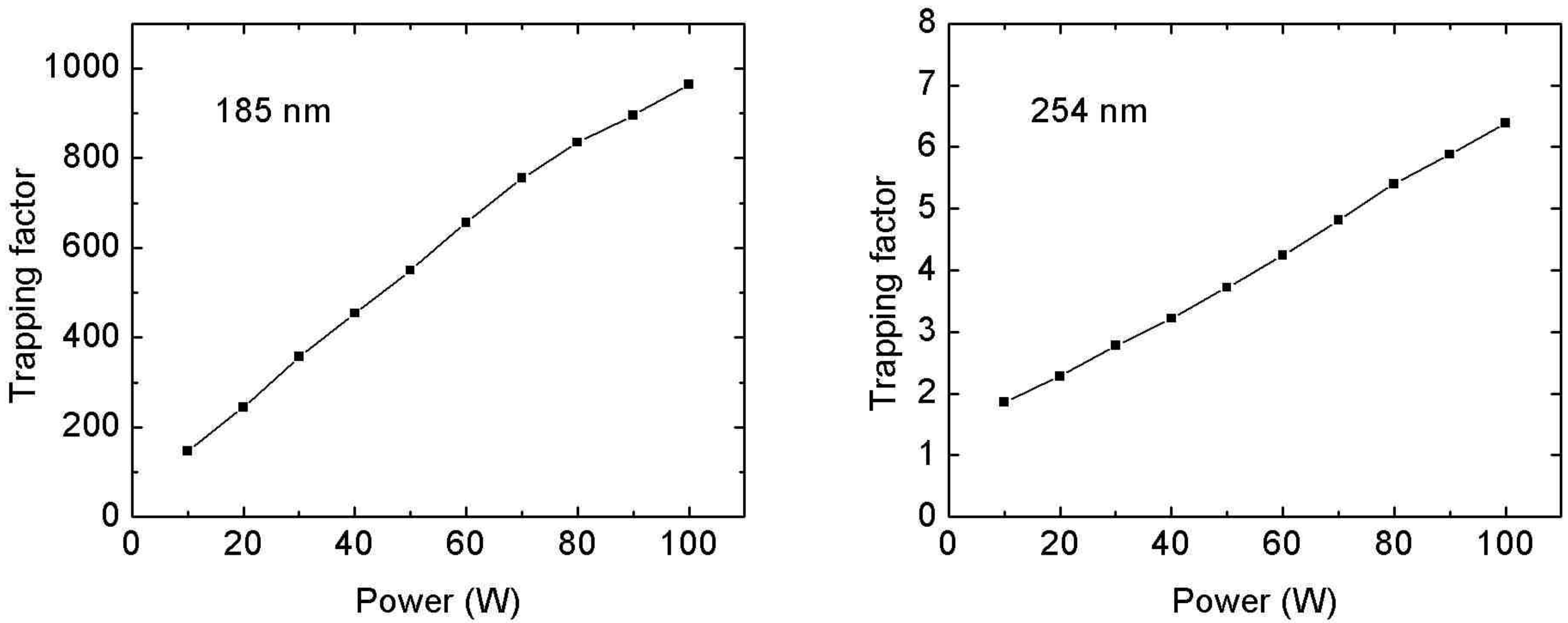
EFFECT OF APPLIED POWER

- **Trapping factors are seen to rise linearly with power.**



- **(Ar 500 mTorr, Hg 5 mTorr, Freq 5 MHz)**

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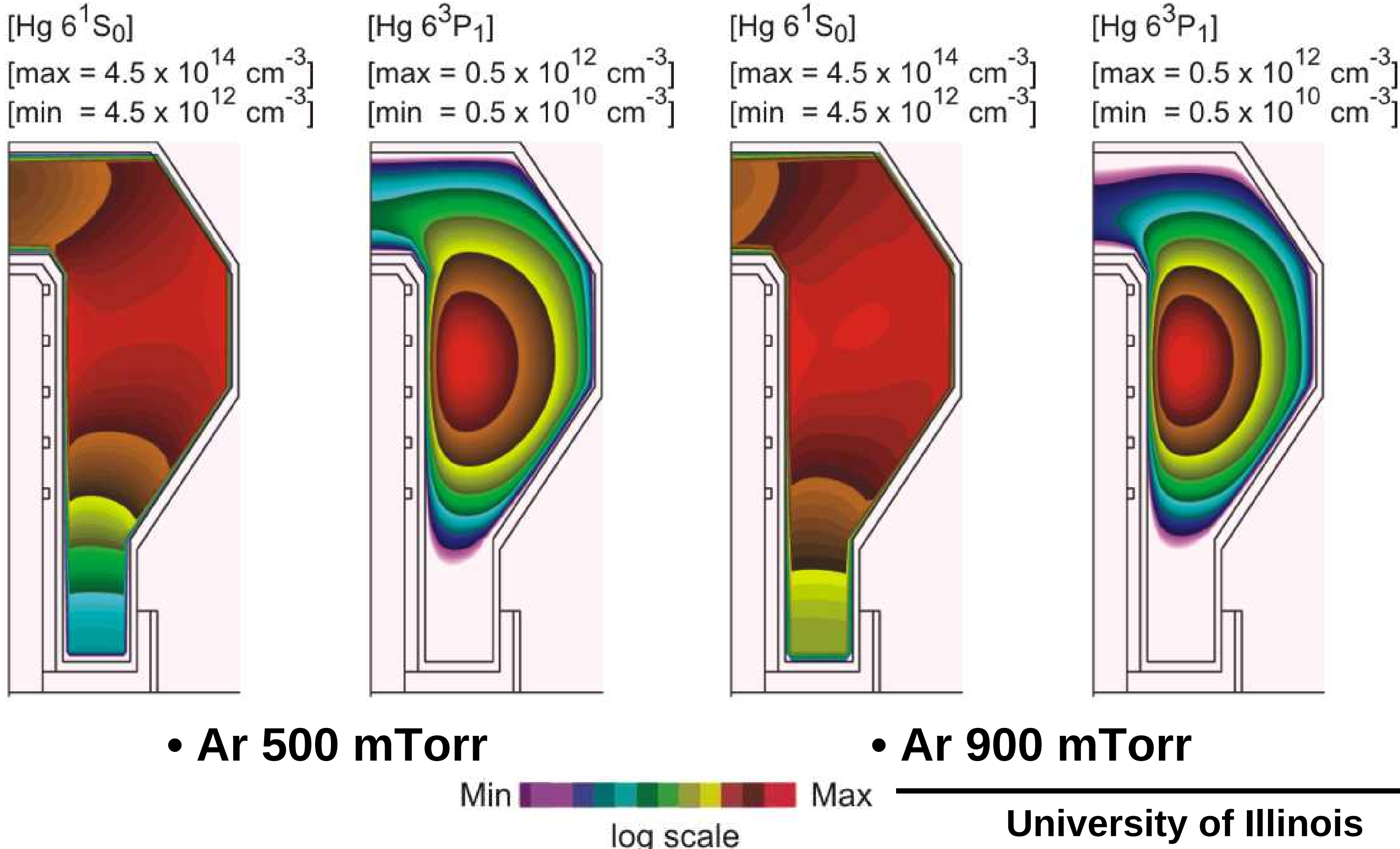
LOW POWER CONSIDERATIONS (Hg 5 mTorr, 10 W)

- **Electron collisions may quench the quanta which are emitted in the interior of the plasma, and these quanta contribute most to the trapping factors.**



- **Ar 500 mTorr**
- **Ar 900 mTorr**

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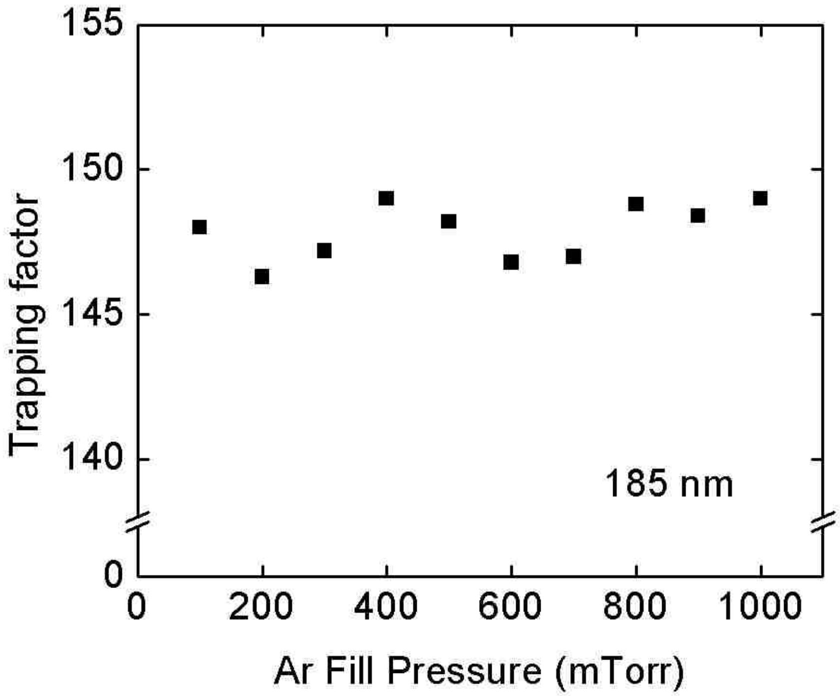
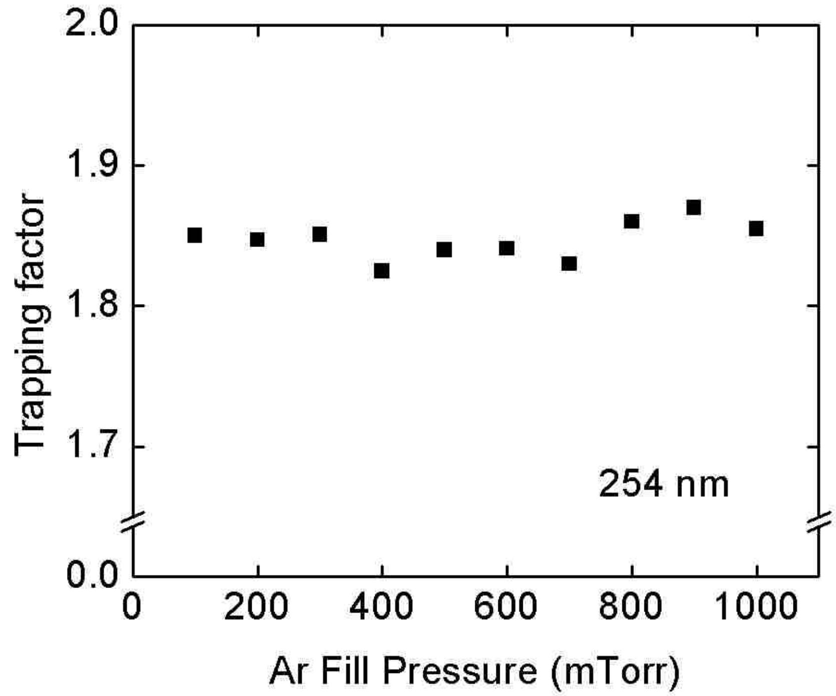
LOW POWER CONSIDERATIONS

- **As pressure increases, the electron collisions increase, but there is little observed effect on the trapping factors.**





- **Hg 5 mTorr, 10 W, 5 MHz**

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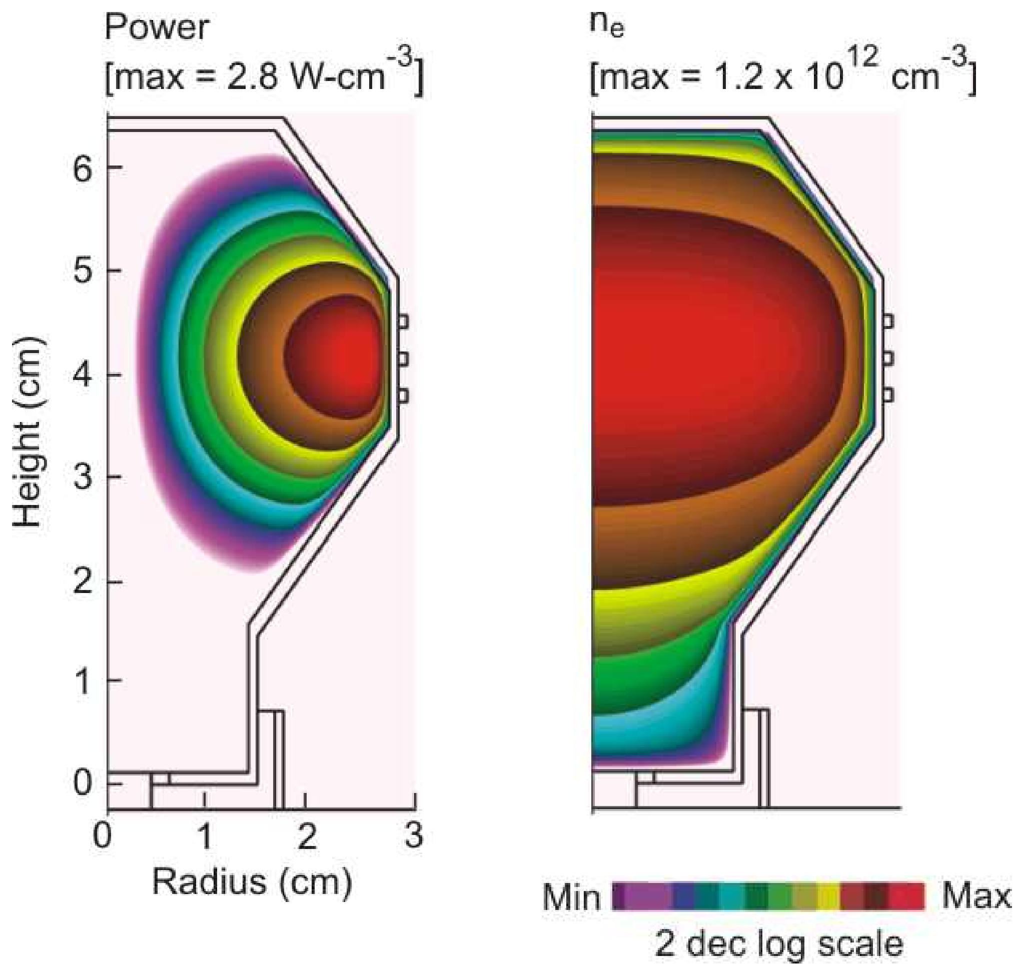
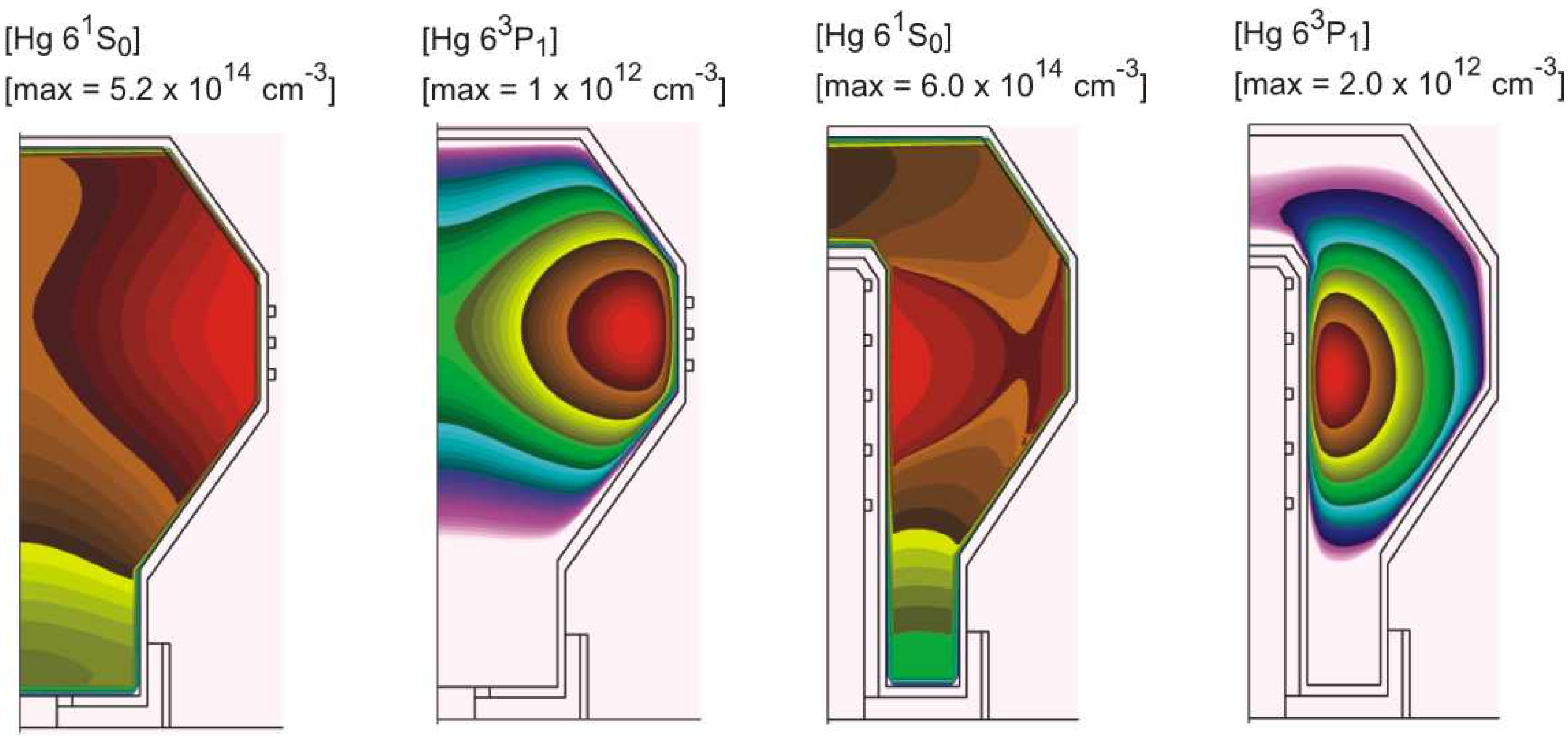
EVERLIGHT GEOMETRY AND BASE CASE

- **To investigate the effect of geometry, the Everlight lamp was considered.**



LAMP COMPARISONS (Ar 500 mTorr, Hg 5 mTorr)

- **Cataphoresis is significant but similar in both lamps.**



- **Tr. Factor – 570 (185 nm)**
  3.7 (254 nm)

- **560 (185 nm)**
  3.7 (254 nm)

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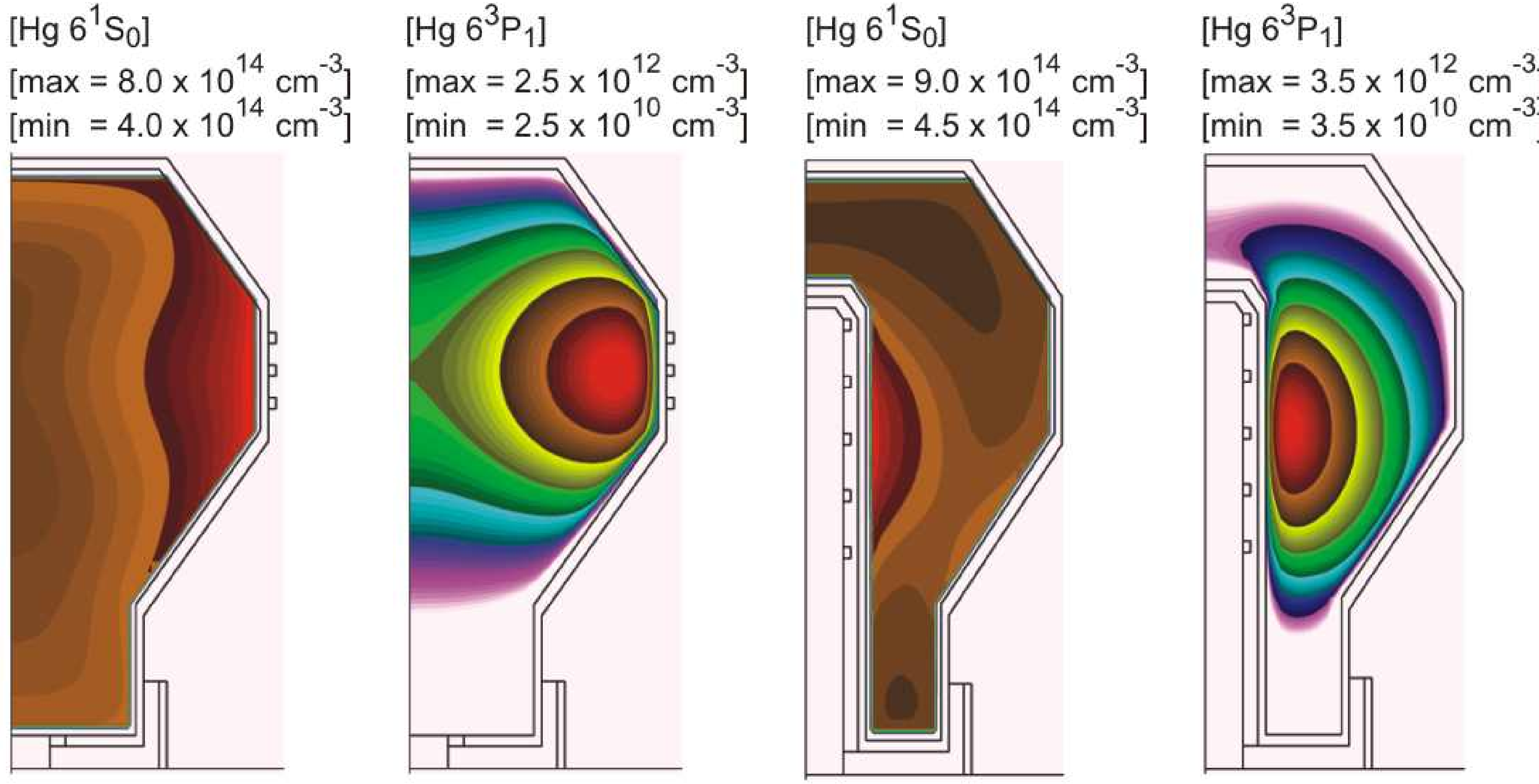
LAMP COMPARISONS (Ar 500 mTorr, Hg 20 mTorr)

- **Due to further cylindrical axis for Everlight, cataphoresis results in isodistributed ground state density, increasing trapping factors.**



- **1289 (185 nm), 9.1 (254 nm)**
- **1214 (185 nm), 8.2 (254 nm)**

Min Max
log scale

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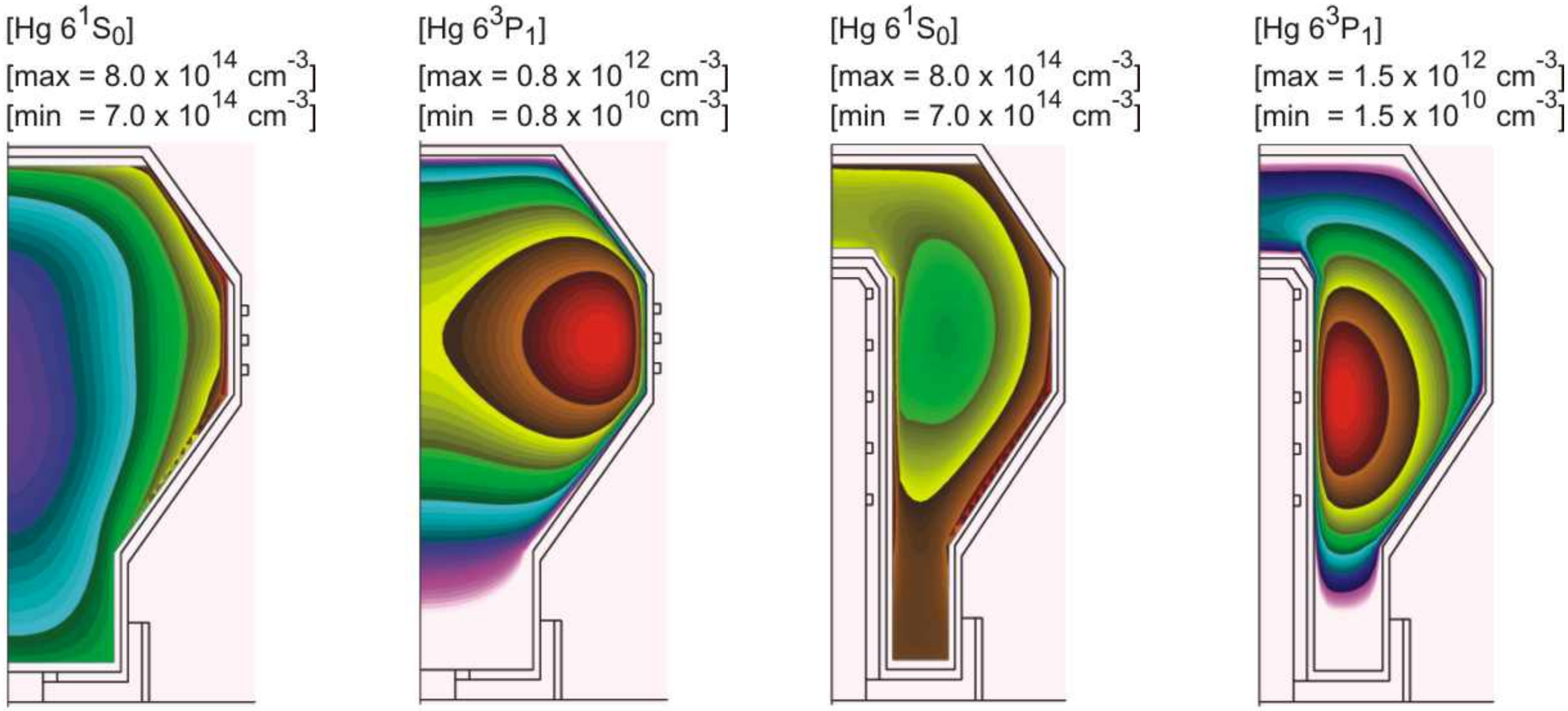
LAMP COMPARISONS (Ar 100 mTorr, Hg 20 mTorr)

- **A lower fill gas pressure allows more ambipolar diffusion and enhanced cataphoresis, and volume effects differentiate the two geometries.**



- **1592 (185 nm), 9.5 (254 nm)**
- **1791 (185 nm), 10 (254 nm)**

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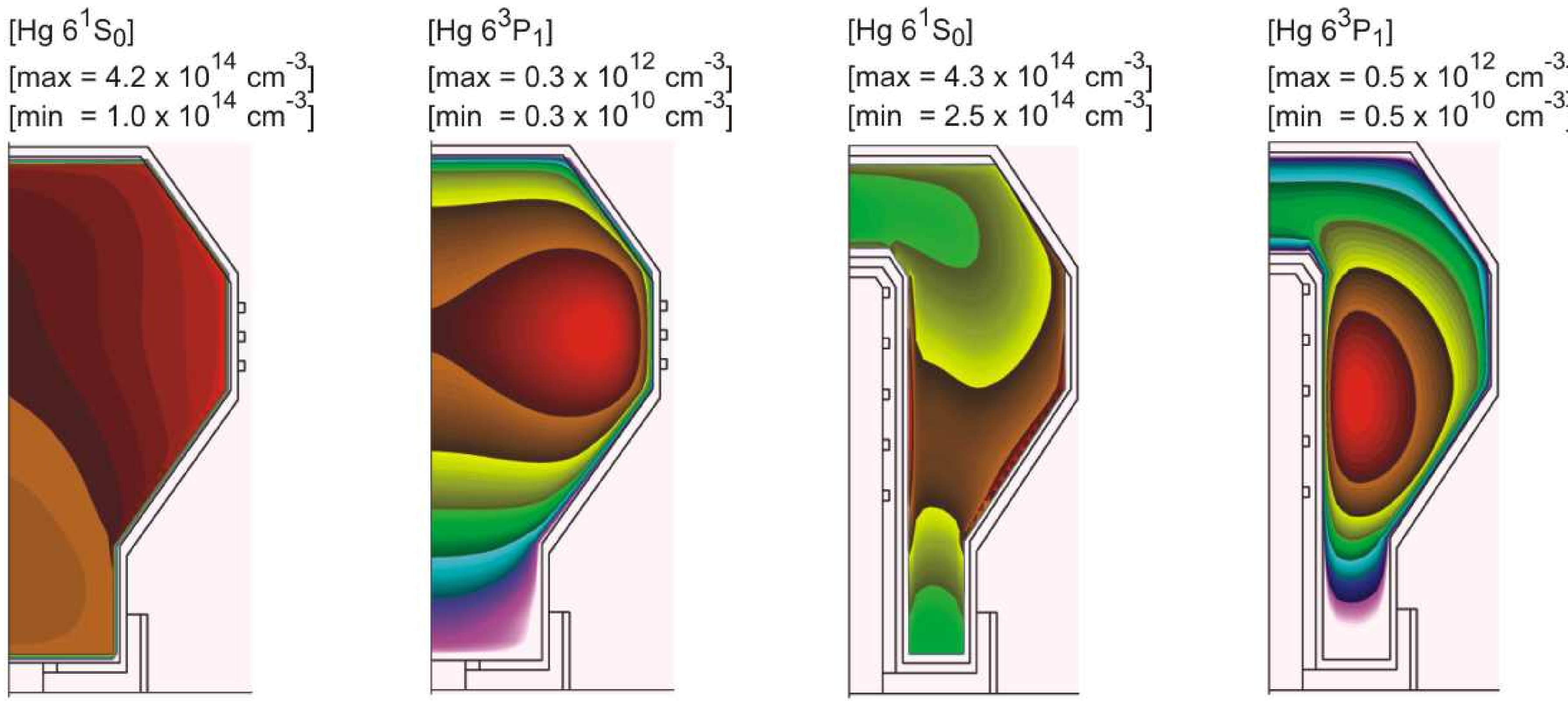
LAMP COMPARISONS (Ar 100 mTorr, Hg 5 mTorr)

- **Lower Hg density results in less defined cataphoresis.**



- **559 (185 nm), 3.7 (254 nm)**
- **629 (185 nm), 4.7 (254 nm)**

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CONCLUSIONS

- A Monte Carlo radiation transport model has been developed and interfaced with a plasma equipment model to model electrodeless lamps.
- The applied frequency does not affect the radiation transport, however increase in power increases radiation trapping factors.
- Low power studies have shown that electron collisional quenching is not important at operating conditions of interest.
- The shape of the plasma cavity affects radiation transport, due to the volume differences in ionization and cataphoresis.

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