時間変動電場存在下でのプラズマ中固体表面帯電現象の数値モデリング

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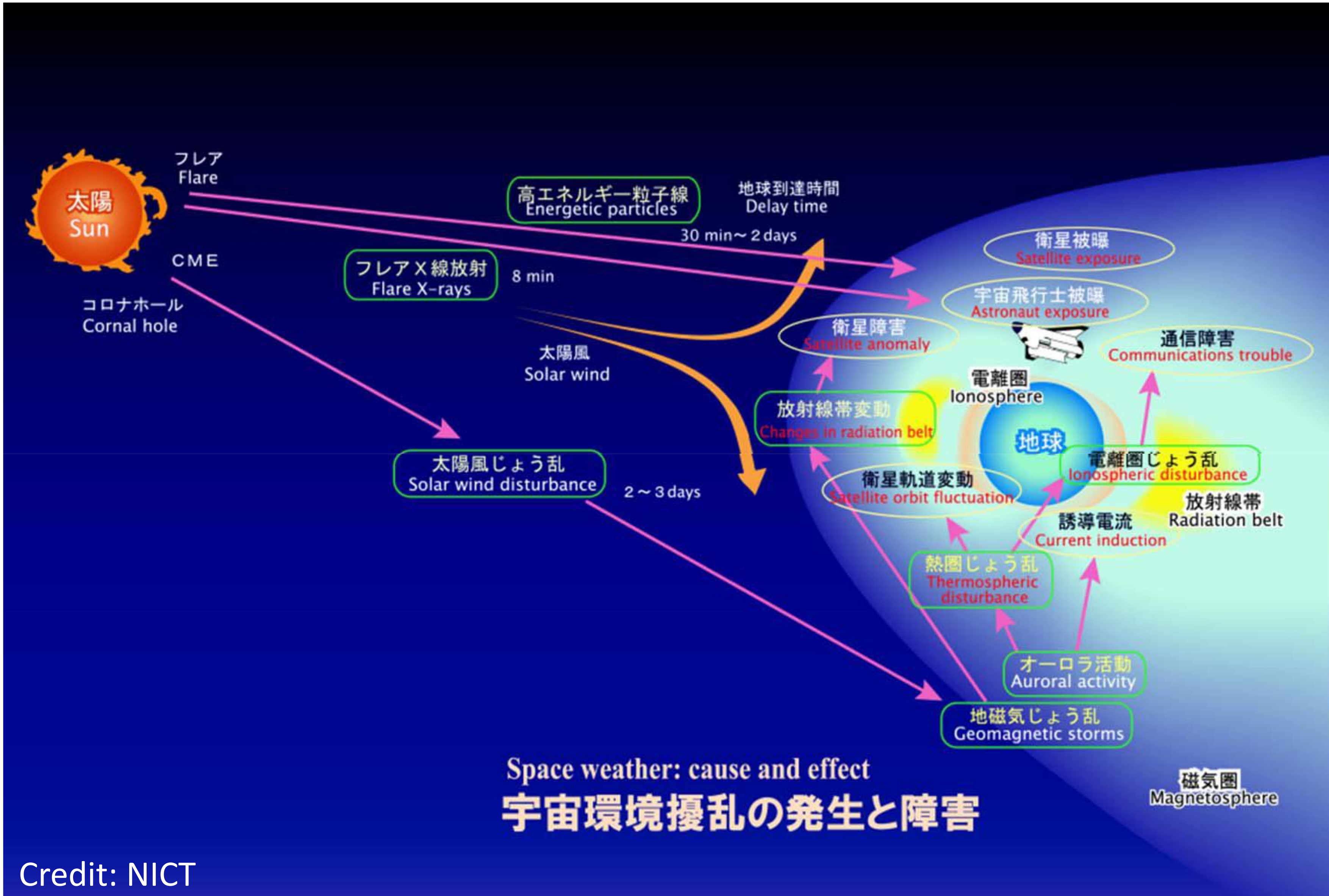
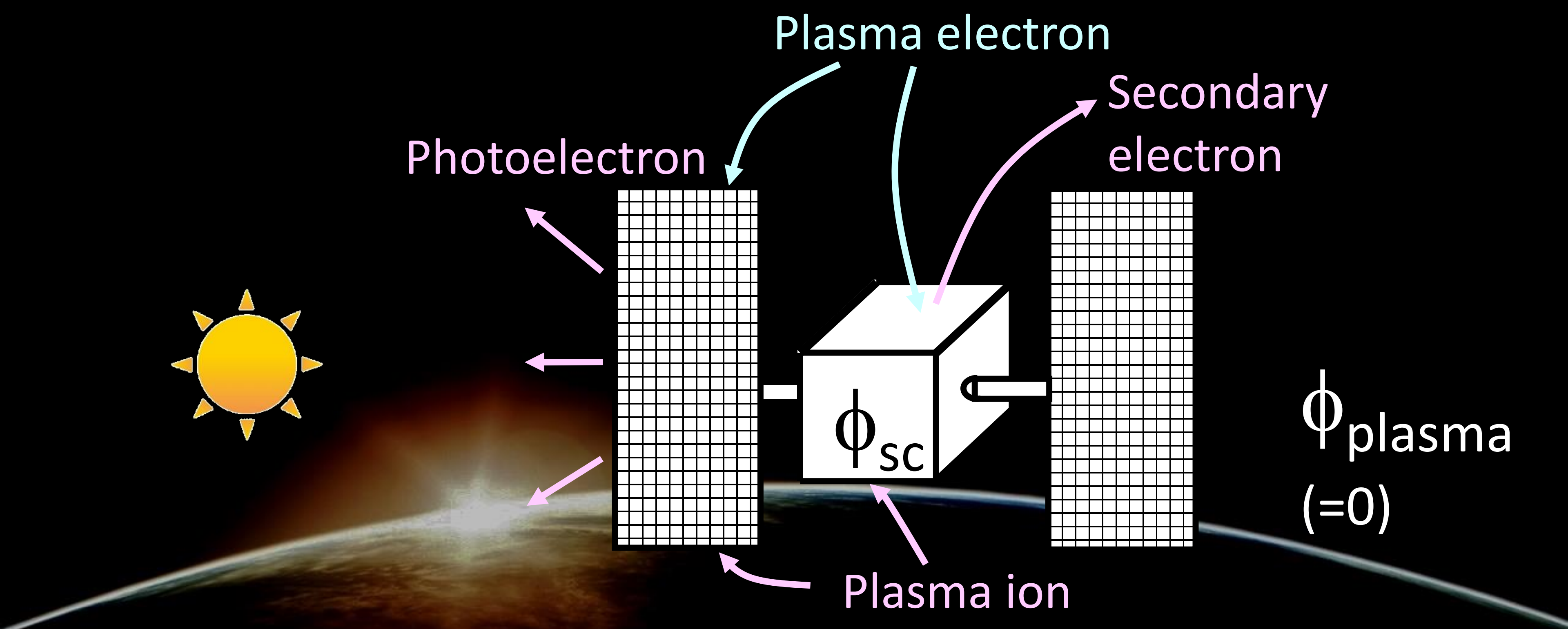
H29年度STEシミュレーション研究会

太陽活動を起点とする宇宙環境変動



Credit: NICT

Spacecraft charging (spacecraft potential)



$\phi_{sc} > \phi_{plasma}$: dilute plasma, photoelectron dominant

$\phi_{sc} < \phi_{plasma}$: dense plasma, photoelectron neglected

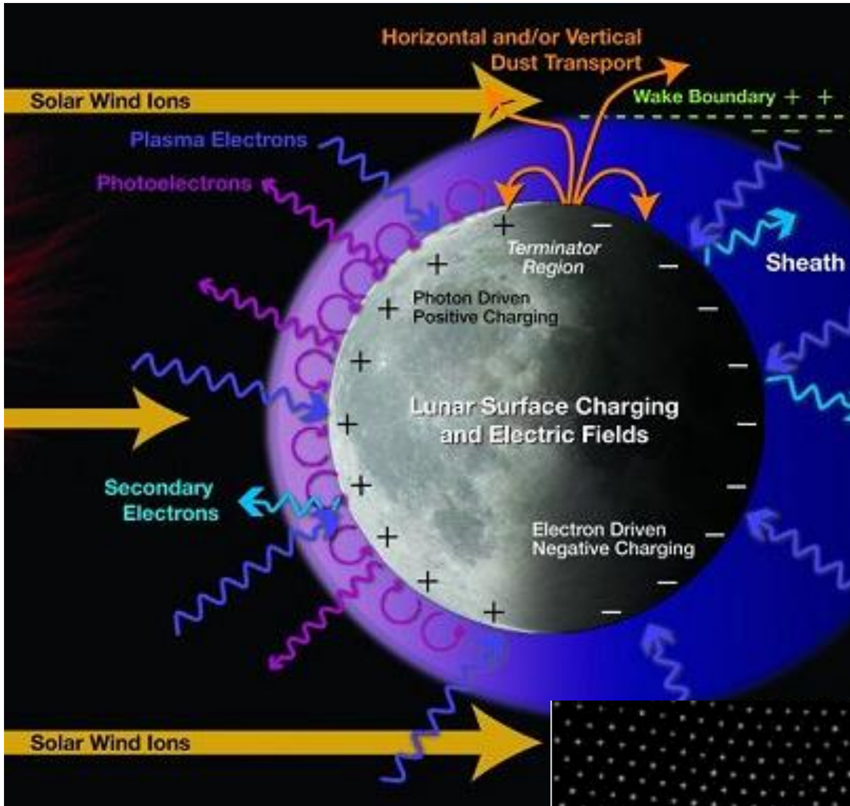
<u>What if plasma environment is NOT stationary in time</u>
<u>e.g., existence of plasma wave (oscillating fields)</u>

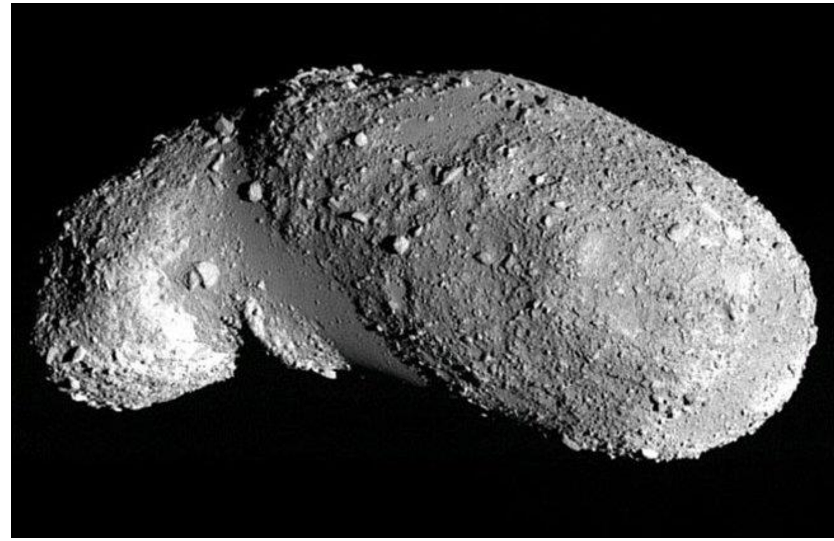
衛星帯電に関わる諸問題

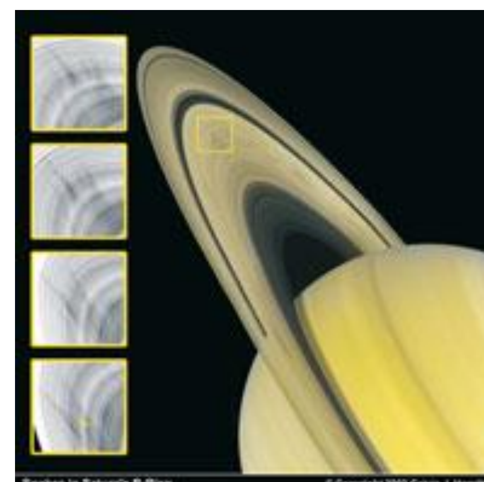
トピックス	キーワード	予測が必要な帯電電圧
衛星障害につながる帯電 工学的	• 日陰環境 • 中/高エネルギー粒子フラックス • 部分帯電(e.g., 太陽電池カバーガラス) • 電気システム(e.g., 電気推進) …etc.	放電につながる降伏電圧: 数100 V～
科学衛星観測への影響: ①粒子計測 理学的	• 中低エネルギー入射粒子の加減速／速度分布変性 • 衛星起源荷電粒子(e.g., 光電子)によるコンタミ	計測対象粒子エネルギーに相当する電圧: 数V
科学衛星観測への影響: ②プローブ電場計測	ダブルプローブ帯電の非対称性 • 光電子 • ウェイク プローブインピーダンス	数 mV

その他のトピックス:デブリ衝突による帯電、固体小型天体の帯電、帯電ダスト

Charging of solar-system small bodies







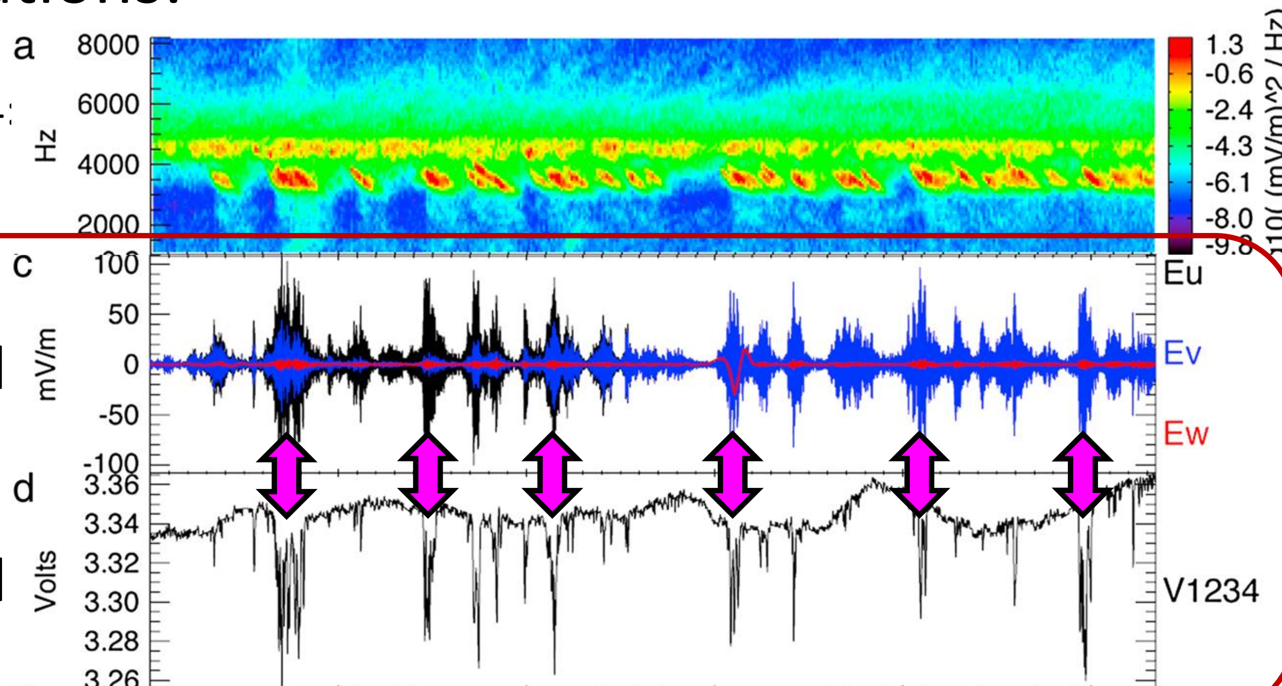
SC potential fluctuations due to chorus waves

- VAP observations:

selected plots from Malaspina et al., 2014: Figure 1.

Wave E-field

SC potential



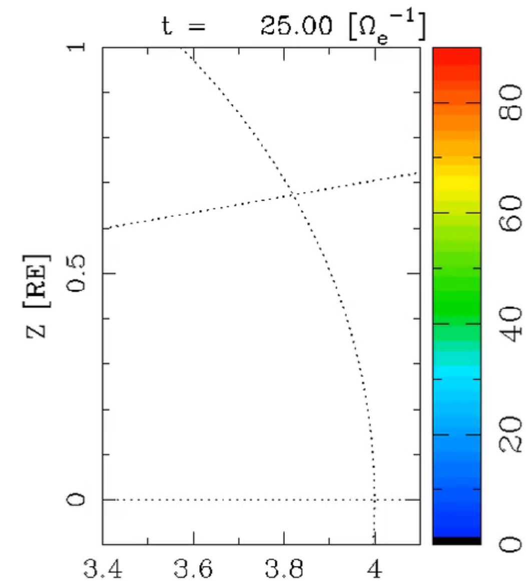
good correlation

On-orbit SC potential data are obtained from a potential difference between SC and E-field probes.

—SC chassis and probe potentials fluctuating differently?

Why SC potential changes?

$$I_{\text{plasma}}(\phi_{\text{sc}}) = env\Gamma(\phi_{\text{sc}})$$



1. Density variations

⇒ Thermal electron evacuation from wave propagation region due to ponderomotive force

⇒ Modified particle flux ⇒ Change in ϕ_{sc}? [Courtesy of Katoh]

2. Modified particle dynamics

⇒ Modulated particle motions due to wave (electric) field

⇒ Modified particle flux ⇒ Change in ϕ_{sc}?

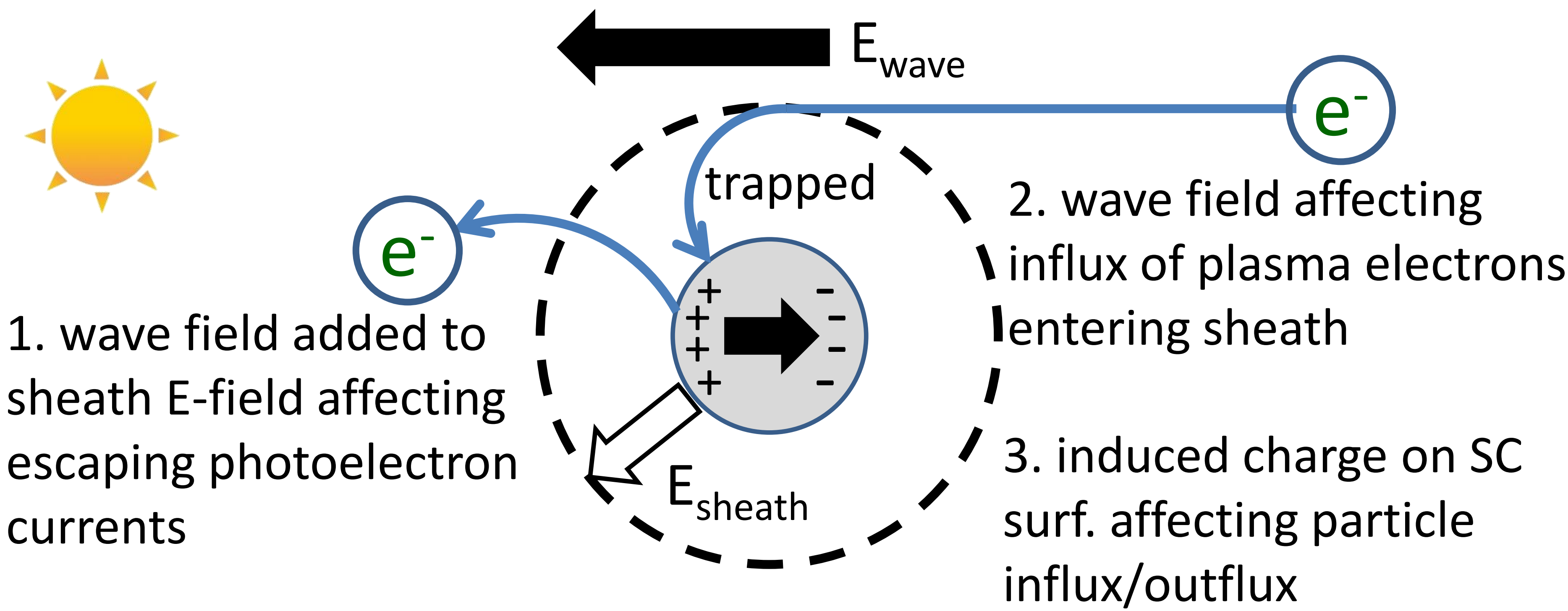
Possible mechanisms

Current balance equation determining SC potential

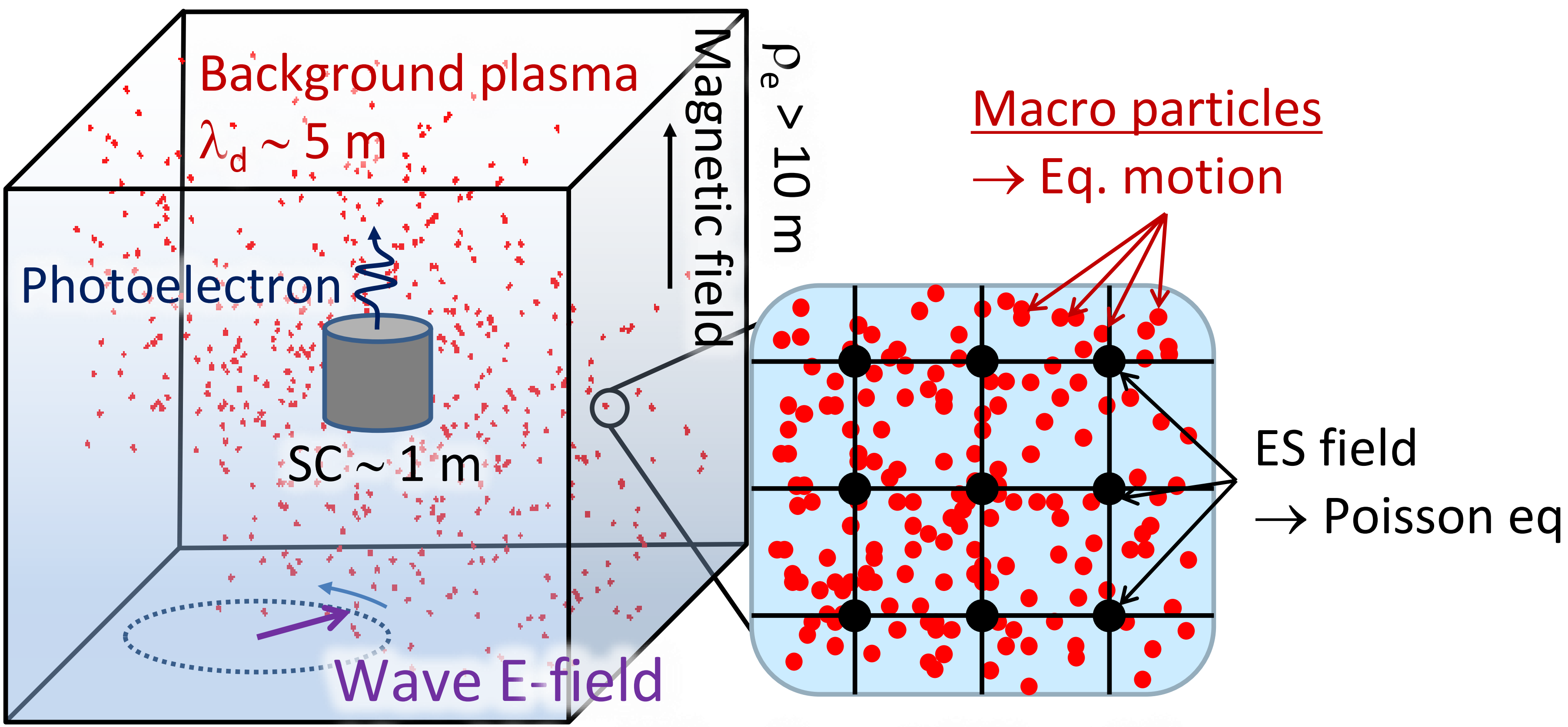
$$I_{\text{total}} = I_{\text{phe}}(\phi_{\text{sc}}) - I_{\text{e}}(\phi_{\text{sc}}) + I_{\text{i}}(\phi_{\text{sc}}) + I_{\text{other}}(\phi_{\text{sc}}) = 0$$

escaping photoelectron

incoming plasma ele.



Particle-in-Cell (full particle) simulations

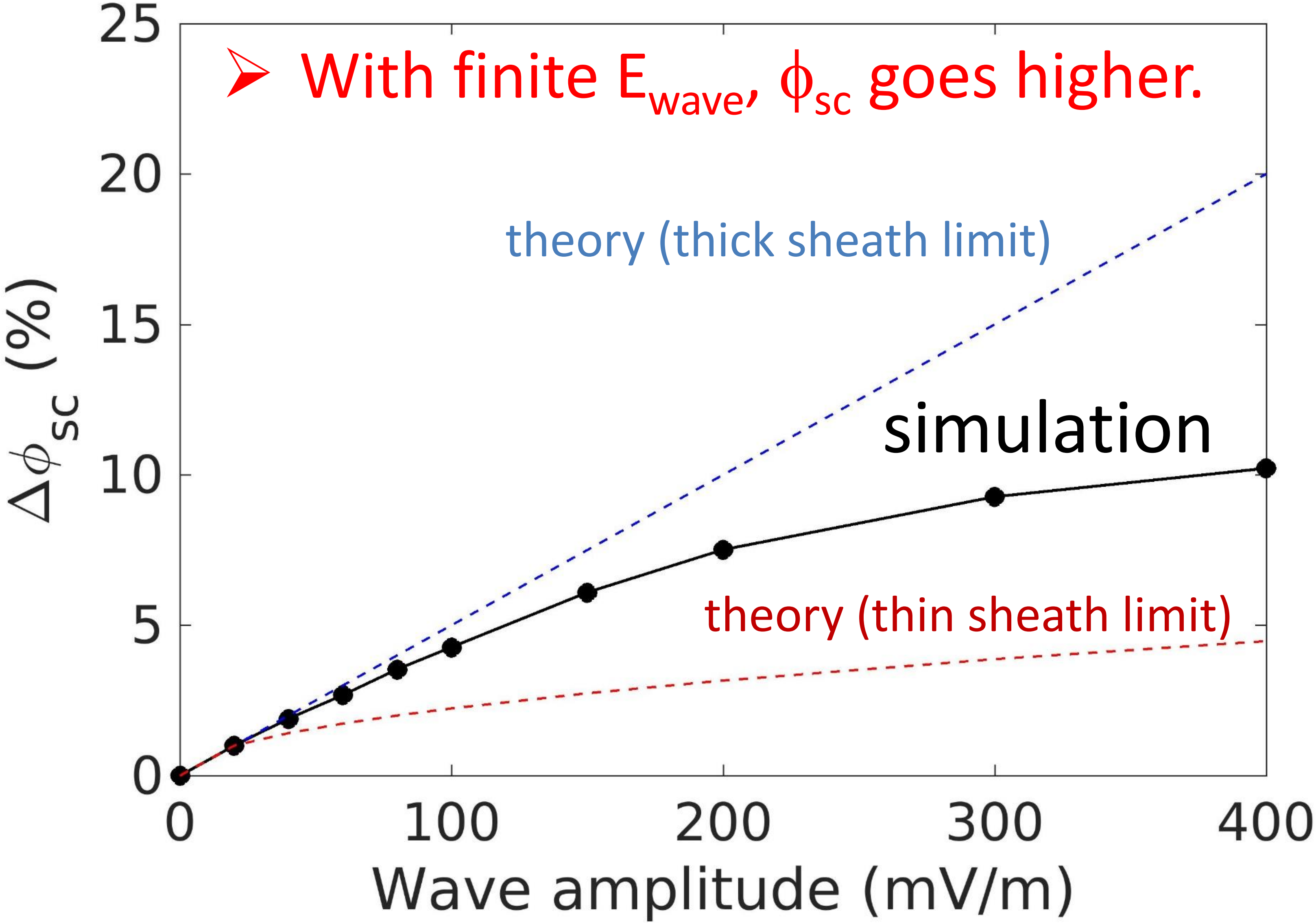


$10 \sim 100$ mV/m, $f_{wave} \sim$ kHz $< 1/\tau_{e\_transit\_in\_sheath}$

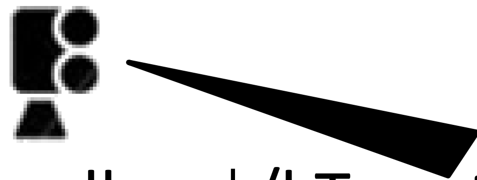
wavelength ≫ spacecraft spatial scale

→ applying spatially-uniform rotating wave E-field

SC potential variation as function of E_{wave}

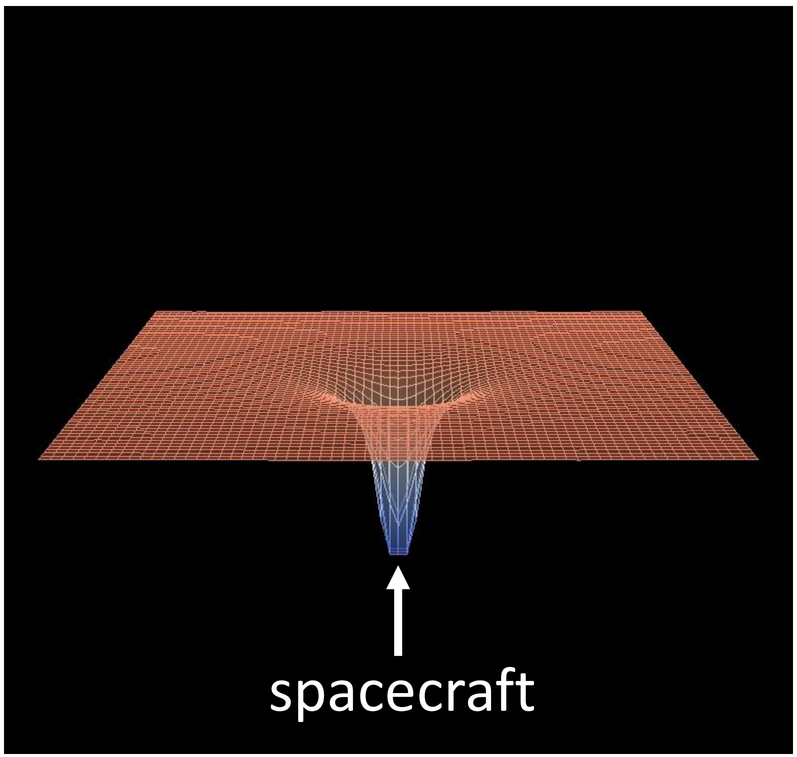


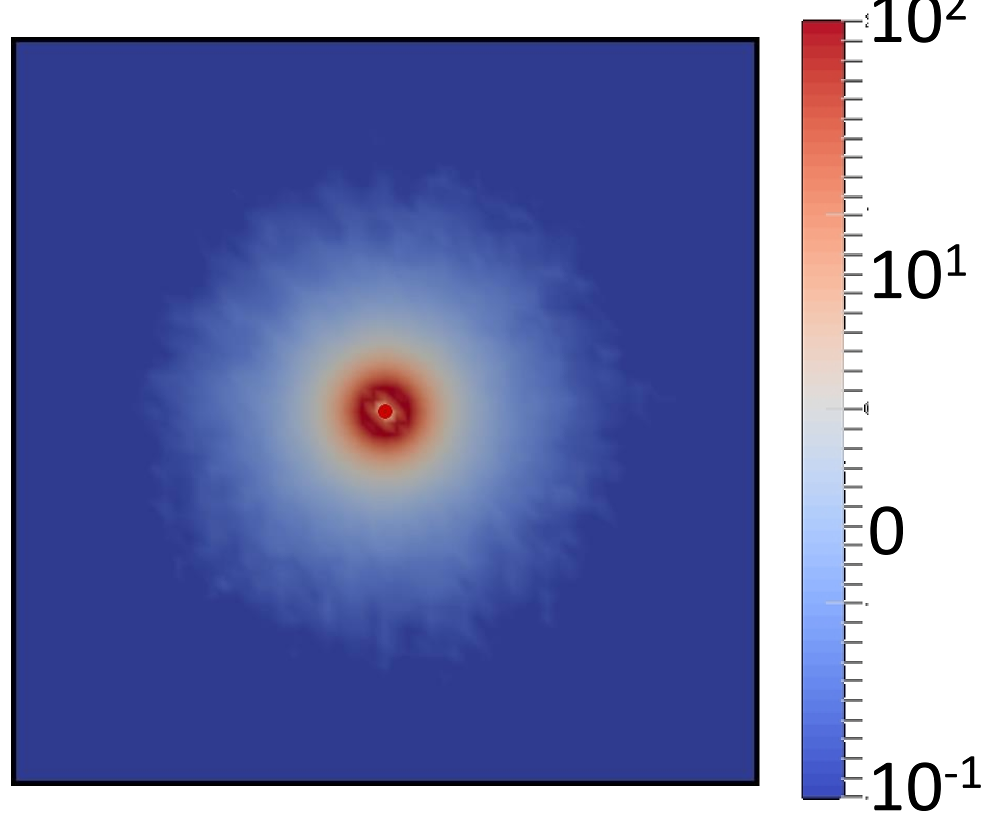
Result: potential & PE structures (w/o waves)



Potential well: $-e\phi/kT_{ph}$

Photoelectron density (/cc)



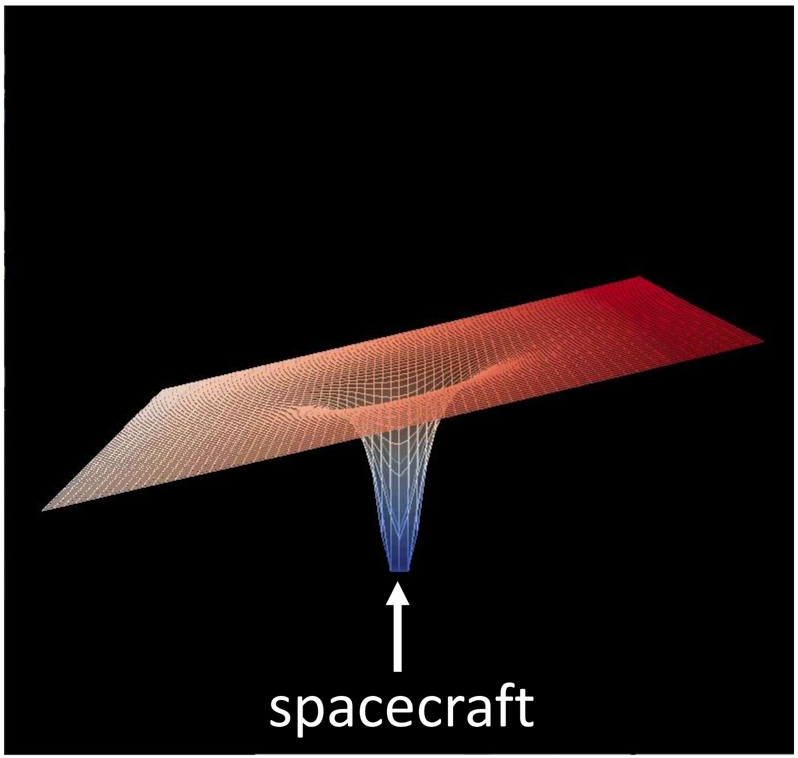


Most of PE trapped by the sheath potential well.

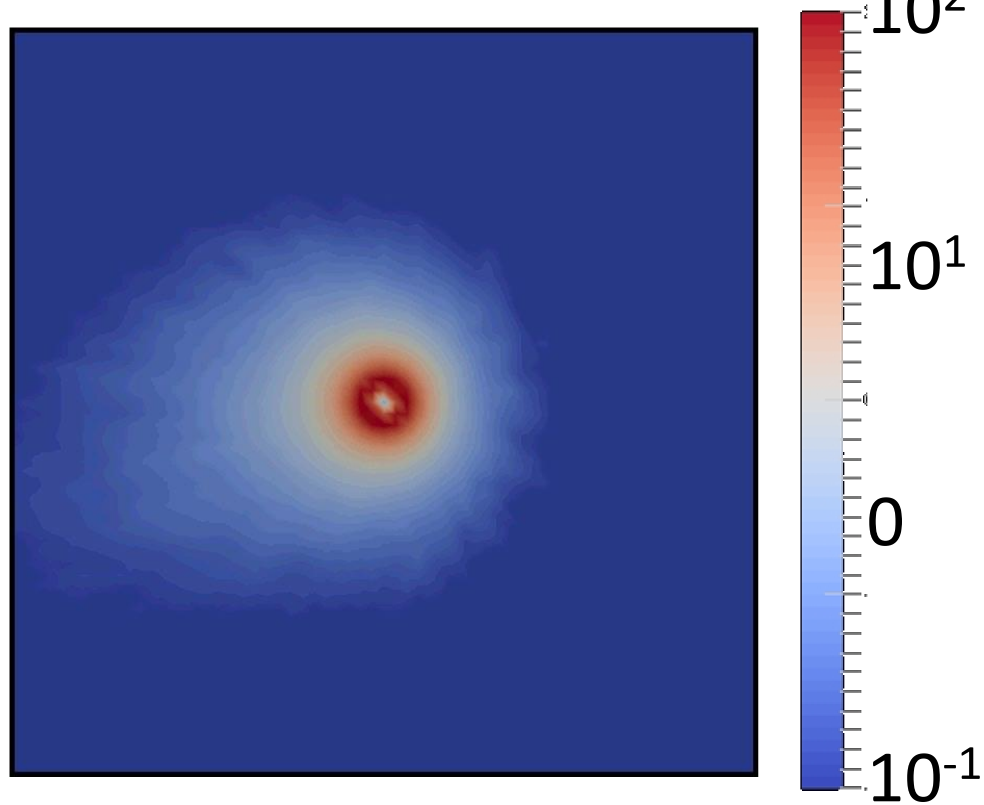
Fraction of PE escaping from the well balances incoming plasma ele.

Result: potential & PE structures (E_{wave}=200 mV/m)

Potential well: $-e\phi/kT_{ph}$



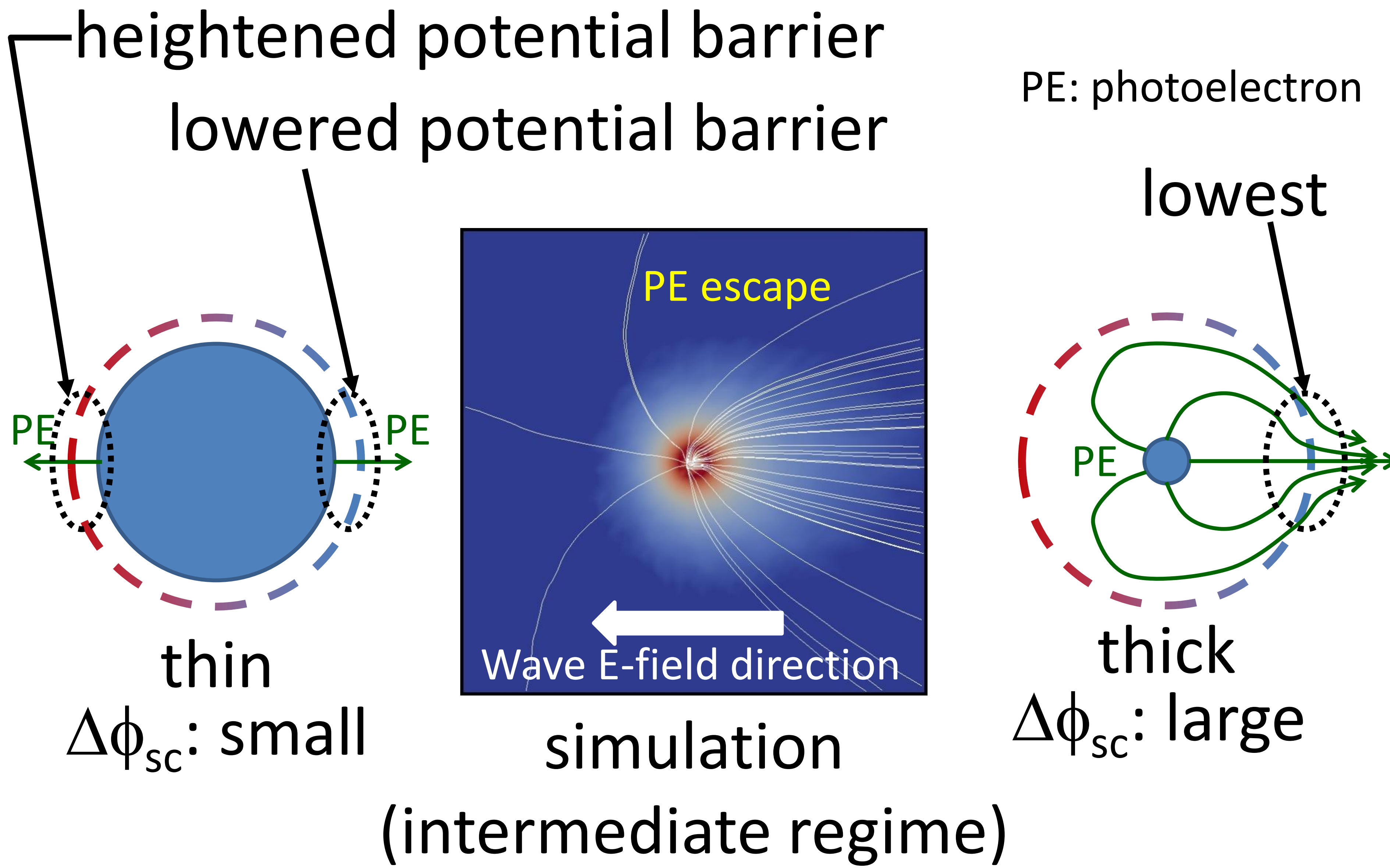
Photoelectron density (/cc)



Potential barrier decreases. → Enhanced PE outflow.

→ Need higher ϕ_{SC} to recover current balance.

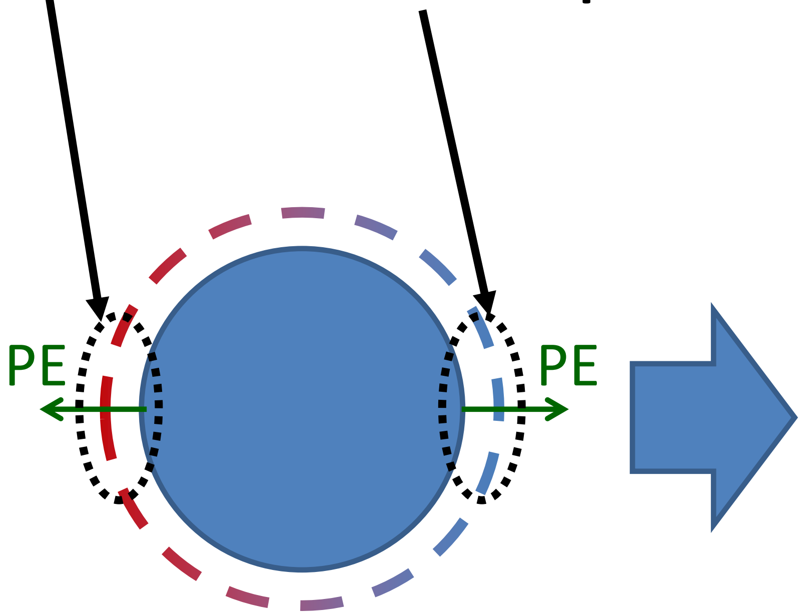
Thin- vs thick- sheath limits



Asymmetry in PE current modification

heightened potential barrier: $\phi_{\mathrm{sc}0} + \Delta\phi$

lowered potential barrier: $\phi_{\mathrm{sc}0} - \Delta\phi$



$\Delta\phi_{sc} = 0$?

or

$\Delta\phi_{sc} \neq 0$?

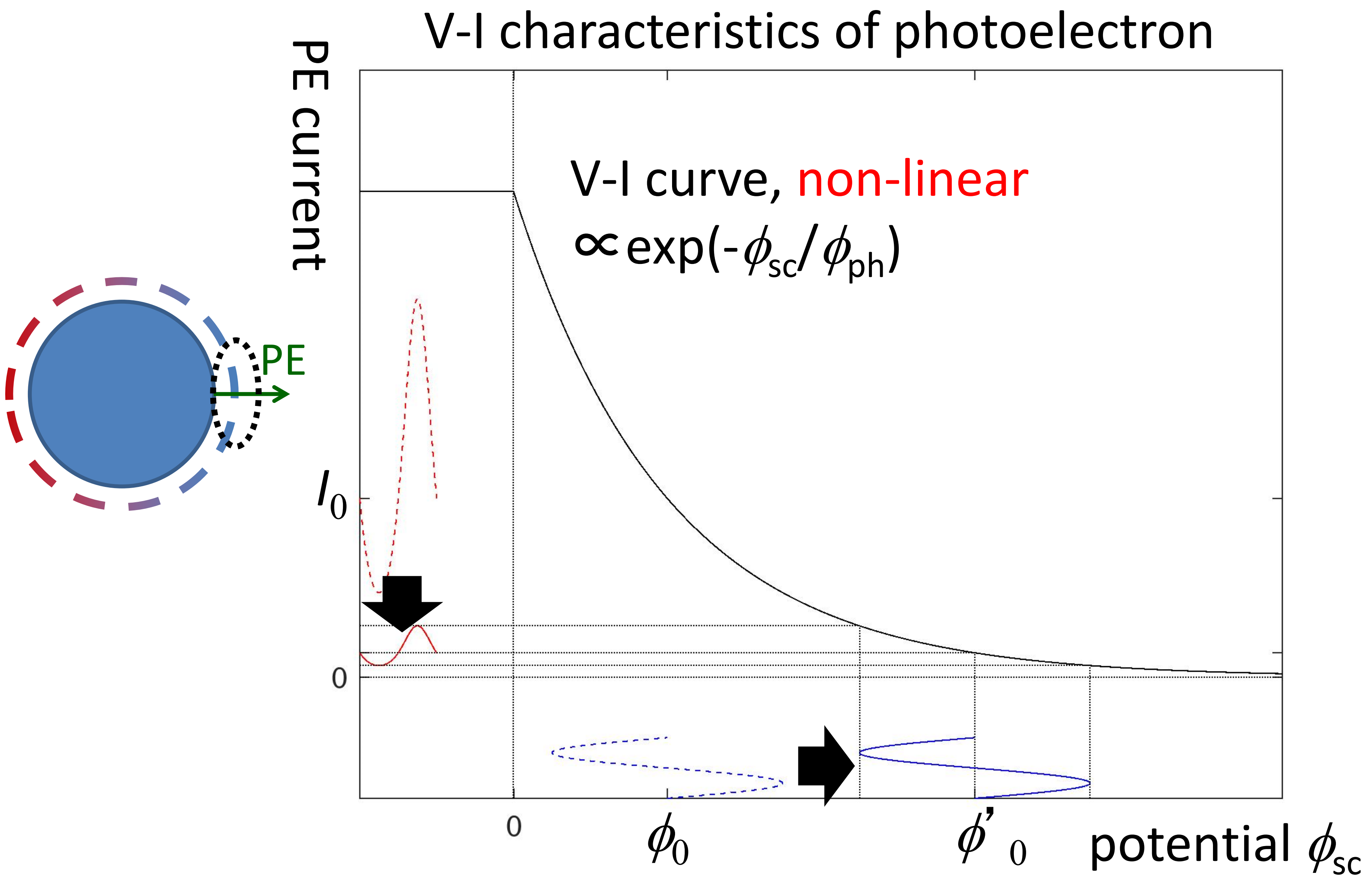
Q:

PE current modifications canceled out with each other?

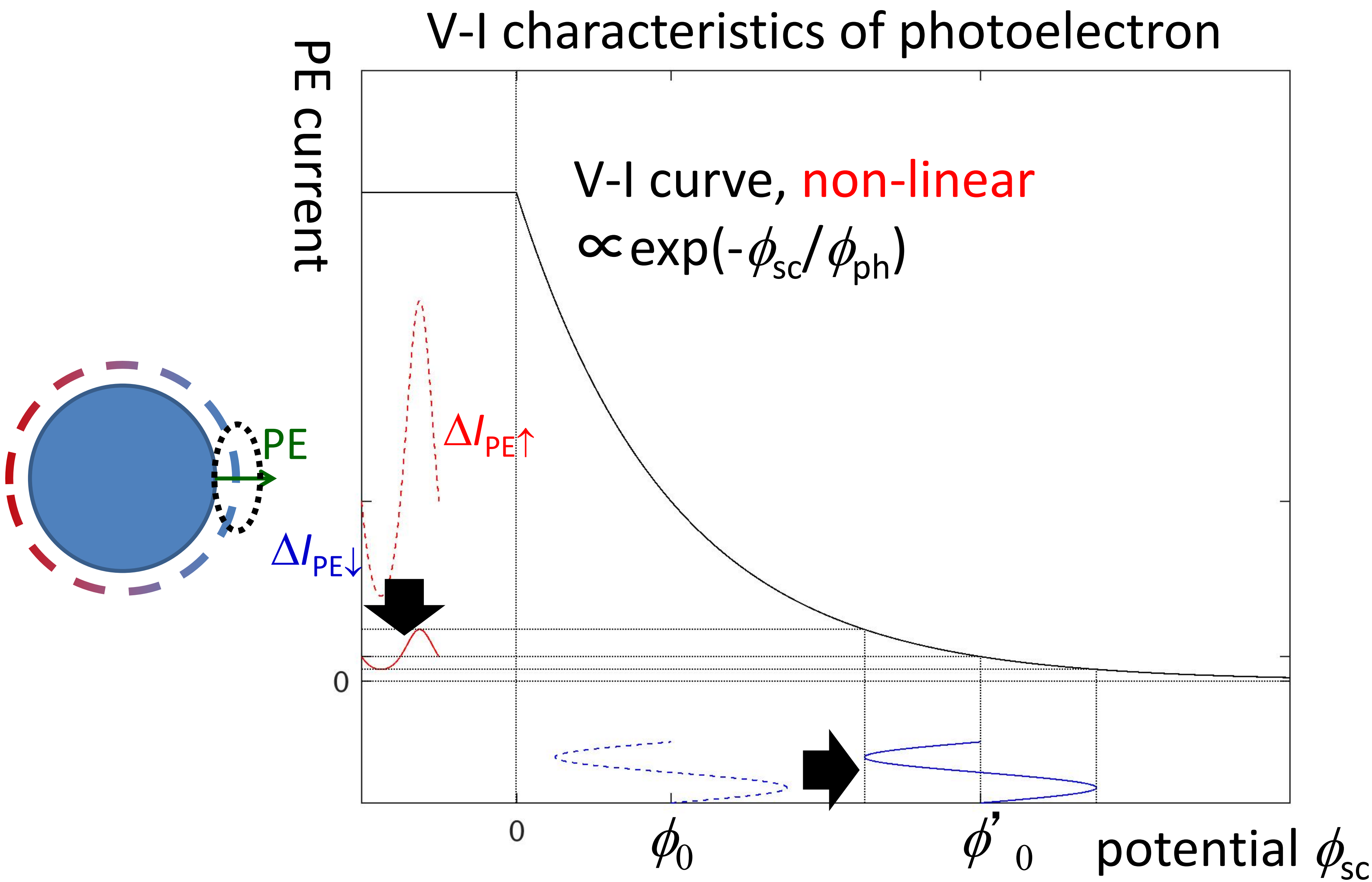
A:

NO

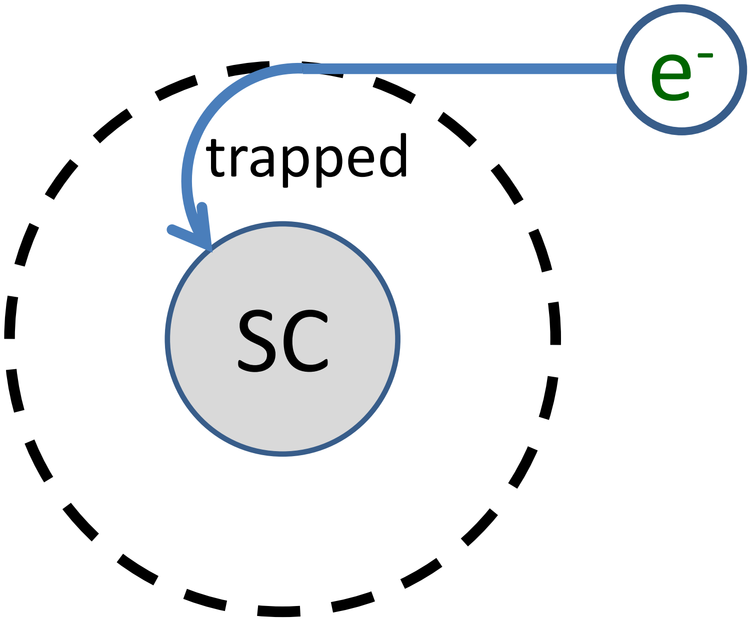
Asymmetry in PE current modification



Asymmetry in PE current modification

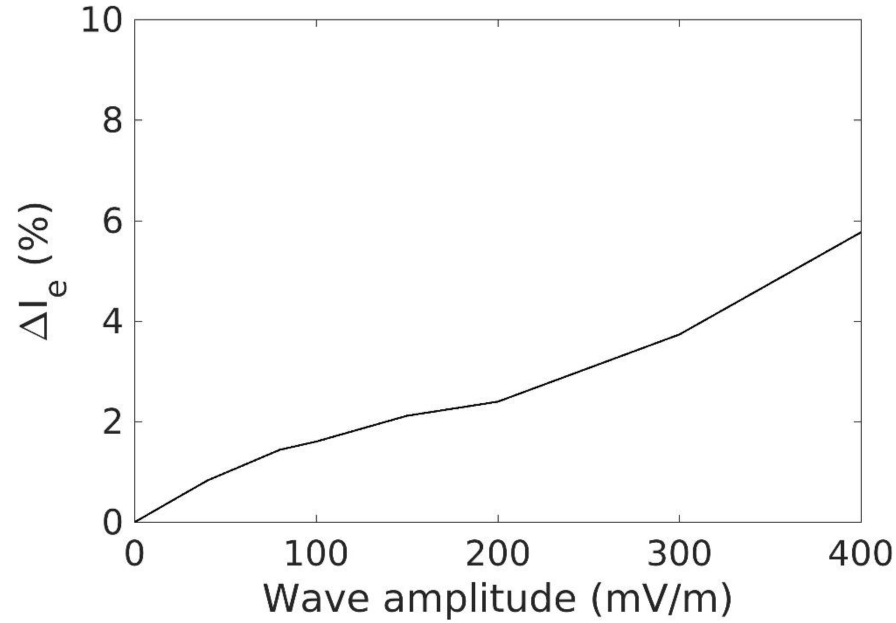


Wave E-field effects on incoming plasma electrons



sheath = trapping region

Simulation result



- influx of plasma electrons rotating with E_{wave}

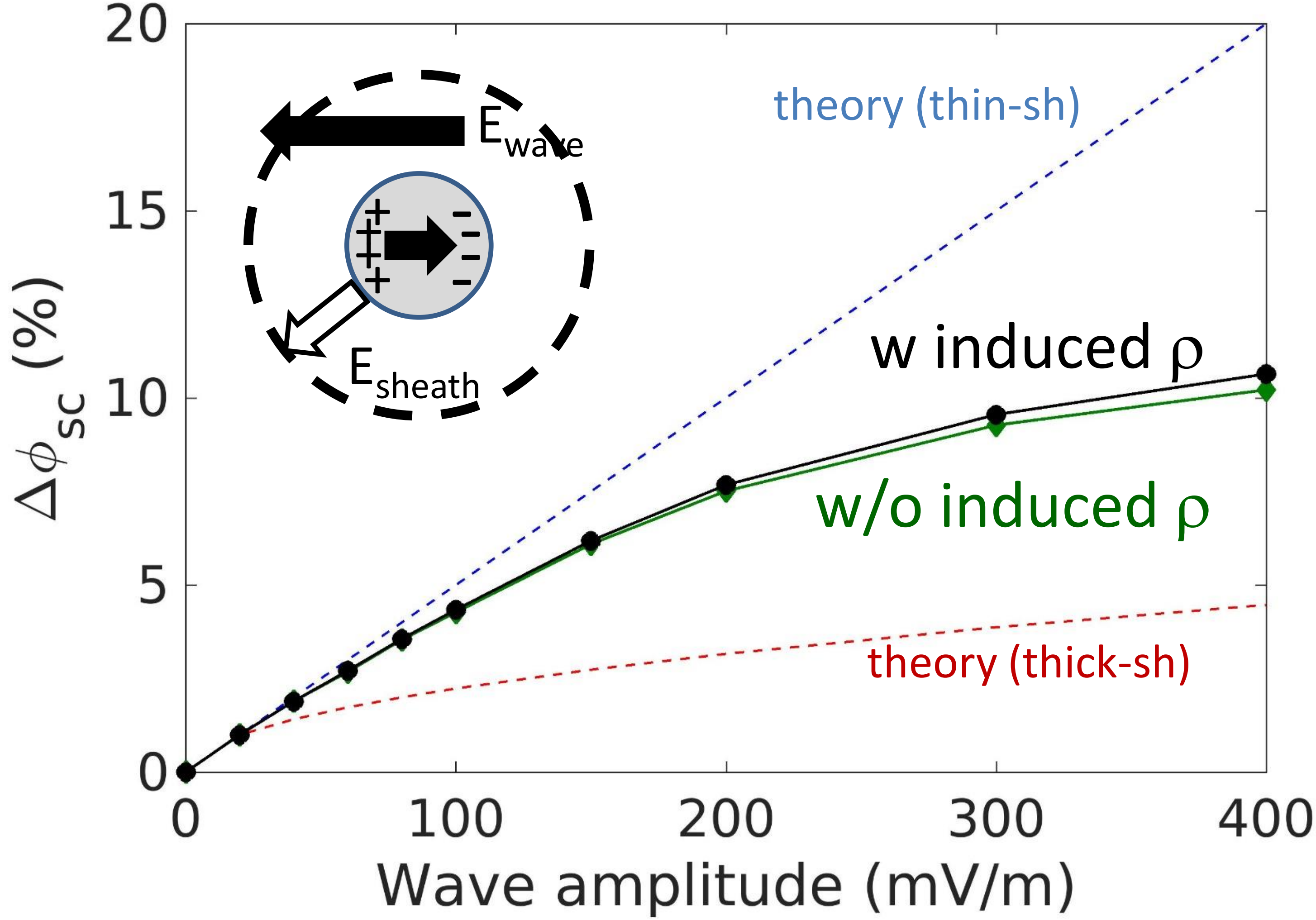
$$v_{x,y} = \pm \frac{q}{m}\frac{\Omega}{\Omega^2-\omega^2}E_{y,x} - \mathrm{i}\frac{q}{m}\frac{\omega}{\Omega^2-\omega^2}E_{x,y},$$

$$I_\mathrm{e} = n_\mathrm{e}e\left|v_{xy}\right| \propto E_\mathrm{wave}$$

Plasma electron current also increases slightly.

Effects of induced charge on SC surface

In the simulation, we can artificially exclude that effect.



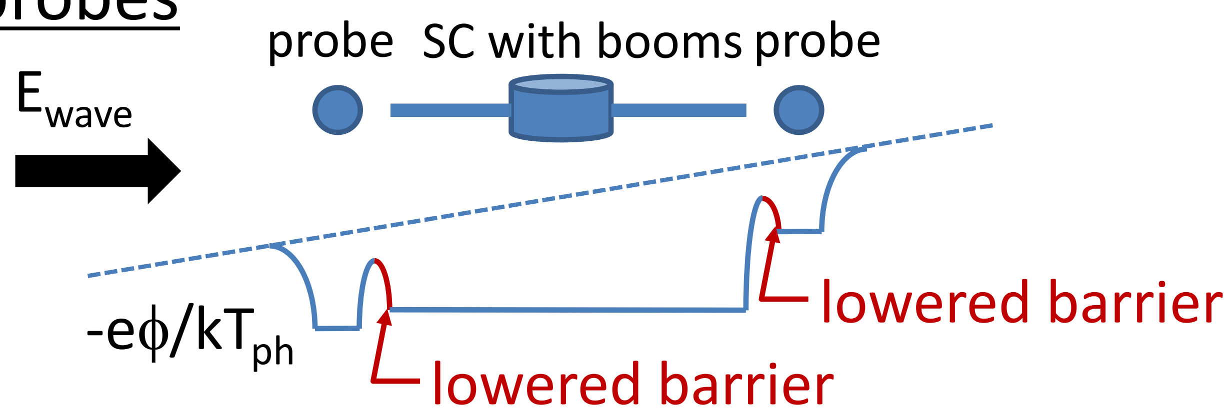
It turned out that it is a minor effect in our case.

In very thin sheath limit (large SC size case), it may contribute to $\Delta\phi_{sc}$…

Further complicating factors… (future works)

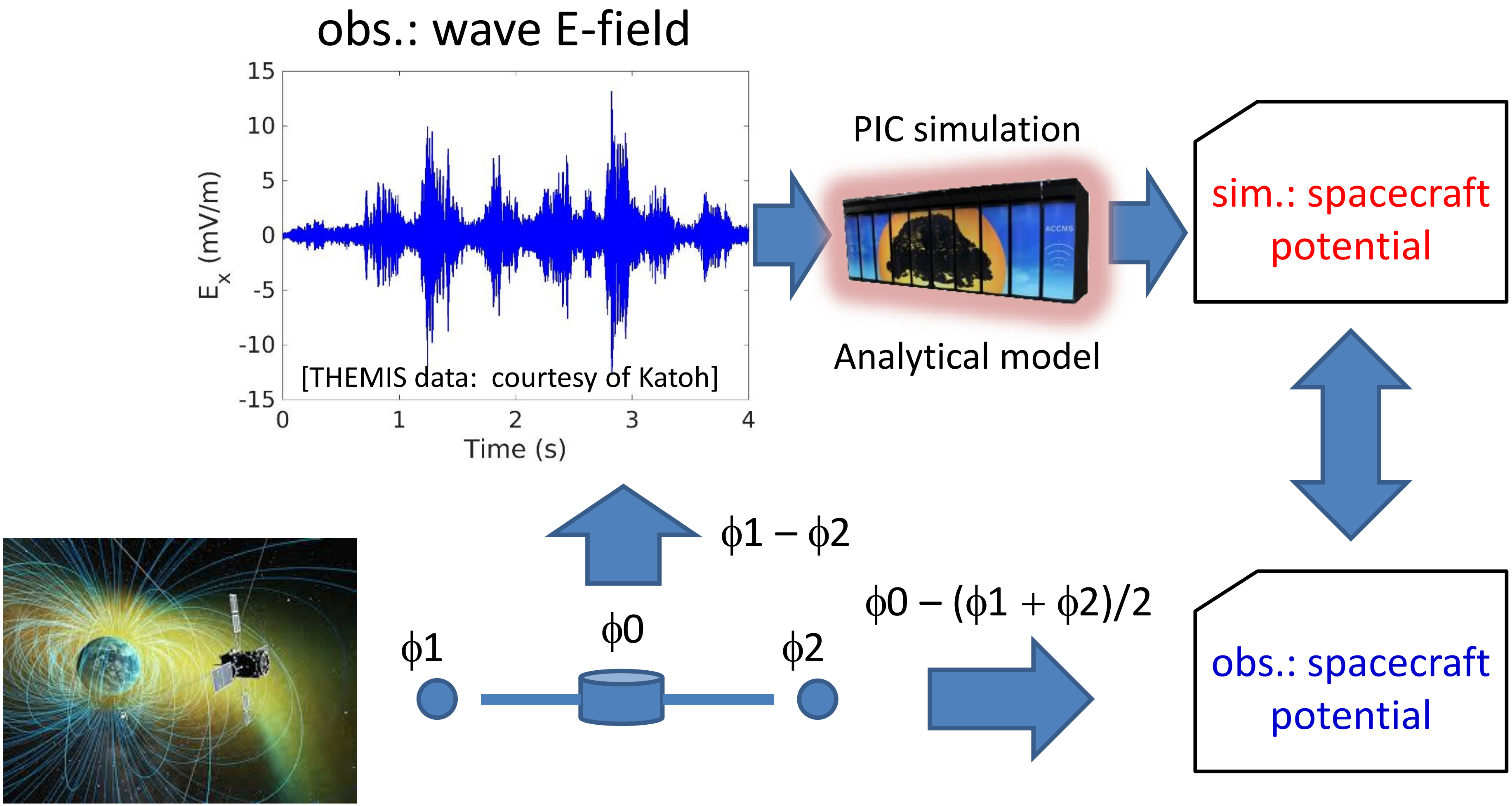
1. Multiple conductor system
   - multiple satellite components will change photoelectron escaping rate

ex) SC with probes



2. Angle between wave E-field & static B-field
   - PE escape enhanced in more parallel E&B orientations (e.g., in case of oblique-whistler mode, electrostatic mode…)

Ongoing work...



Summary and conclusions

PIC modeling of SC potential fluctuations in the presence of plasma wave (time-varying) electric field

Increase in SC potential
- change in height of potential barrier
- increase in escaping photoelectron current

  some basic properties confirmed in the simulations
  - thin-/thick- sheath regime, - induction charge

To be studied:
- Practical cases of multiple conductor system
- Effects of oblique/parallel angles between wave E-field and static B-field