# Modelling the Solar Axion Spectrum with Self-Consistent PIC–MC Plasma Simulations

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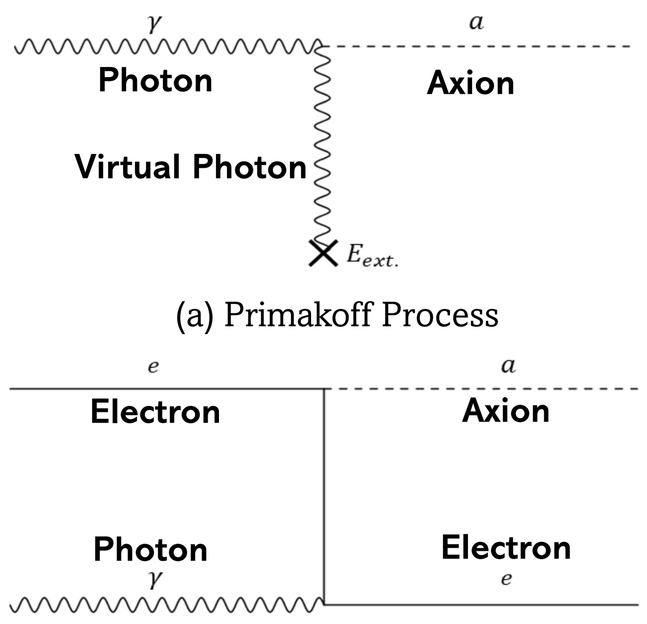
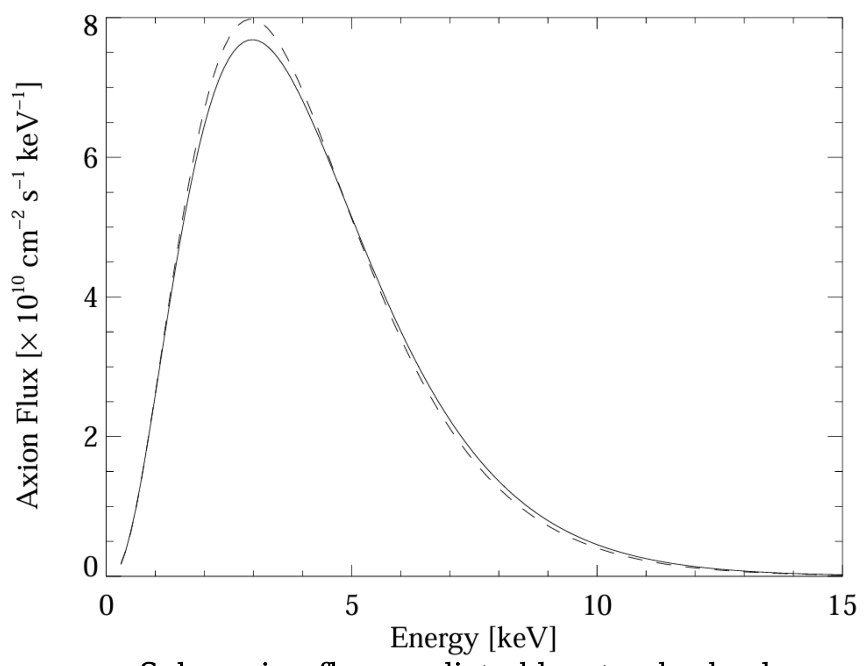
## 1 Introduction

Axions are dark matter candidates that can be produced in stellar plasmas through the Primakoff and Compton processes. Accurate predictions of axion spectra are essential for axion searches. We extend the OSIRIS Particle-in-Cell (PIC) code to model axion dynamics in plasmas, laying the foundation for self-consistent axion modelling in PIC frameworks.



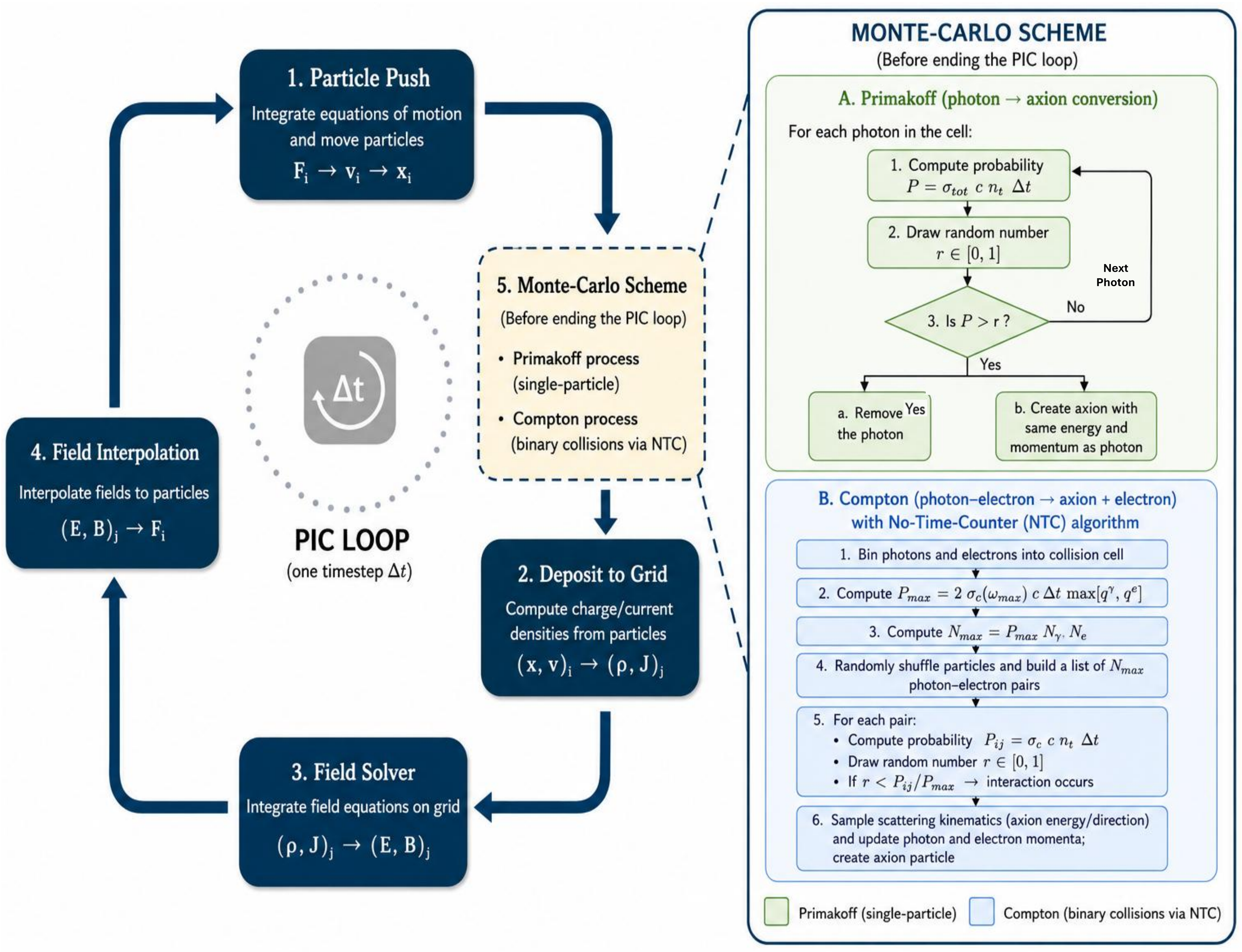

(a) Primakoff Process

(b) Compton Process




Solar axion flux predicted by standard solar models (CAST Collaboration, 2007).

## 2 Method




## 3 Results and Benchmark

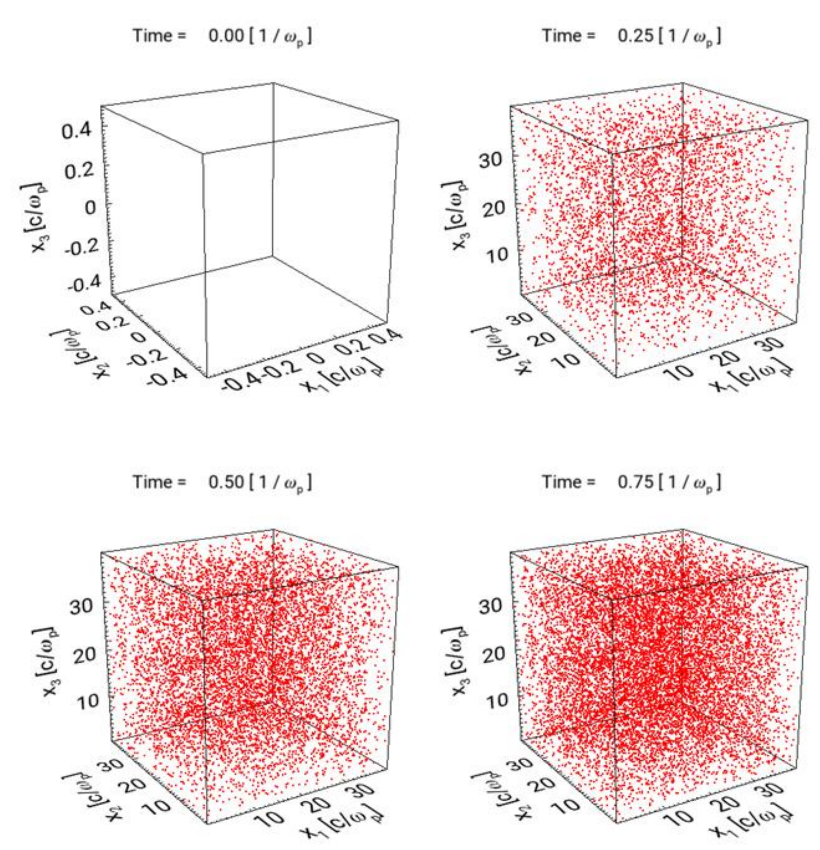
**SIMULATION SETUP**

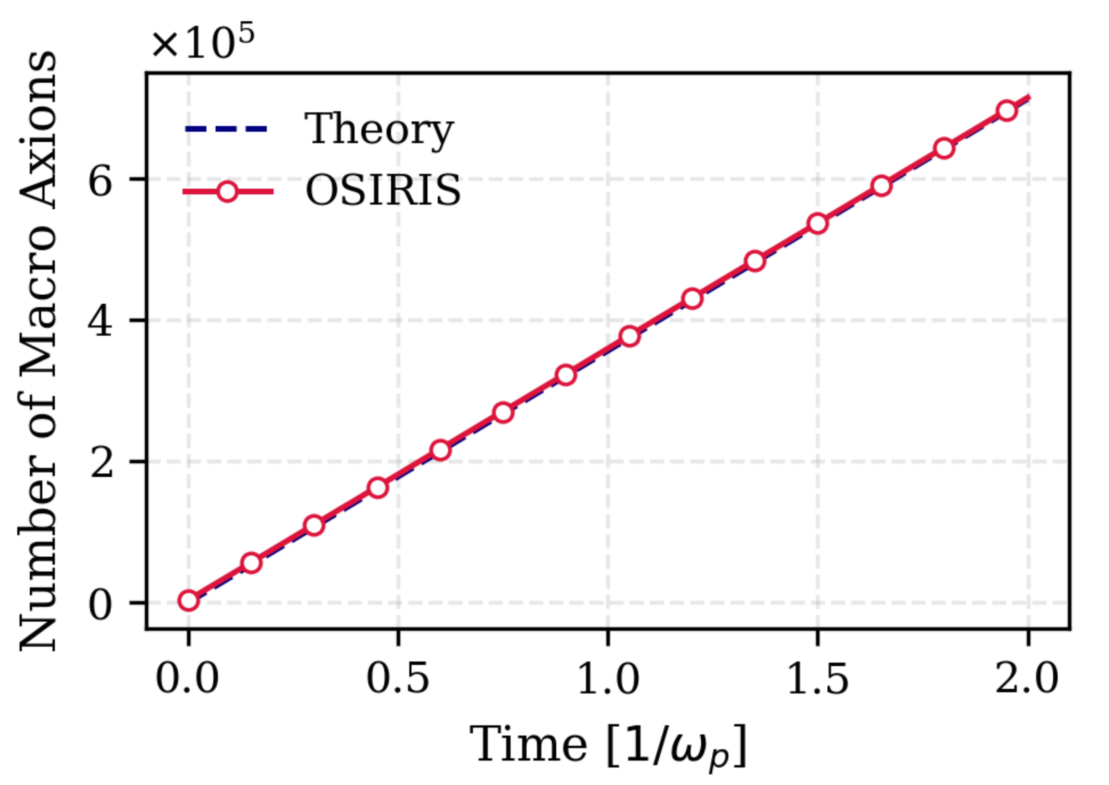
| Simulation Parameters | | Plasma Conditions | |
|---|---|---|---|
| Boundary conditions | Periodic | Temperature | $T = 1.55 \times 10^7\ \mathrm{K} = 1335\ \mathrm{eV}$ |
| Simulation box | $V_{box} = (40\, l_s)^3 = \left(40\, \frac{c}{\omega_p}\right)^3$ | Plasma frequency | $\omega_p = 7.1 \times 10^{17}\ \mathrm{s}^{-1}$ |
| Grid resolution | $10^3$ cells | Electron / ion density | $n_i = n_e = 1.58 \times 10^{32}\ \mathrm{m}^{-3}$ |
| Time step | $dt = 0.01$ | Photon density | $n_\gamma = 2.5 \times 10^{28}\ \mathrm{m}^{-3}$ |

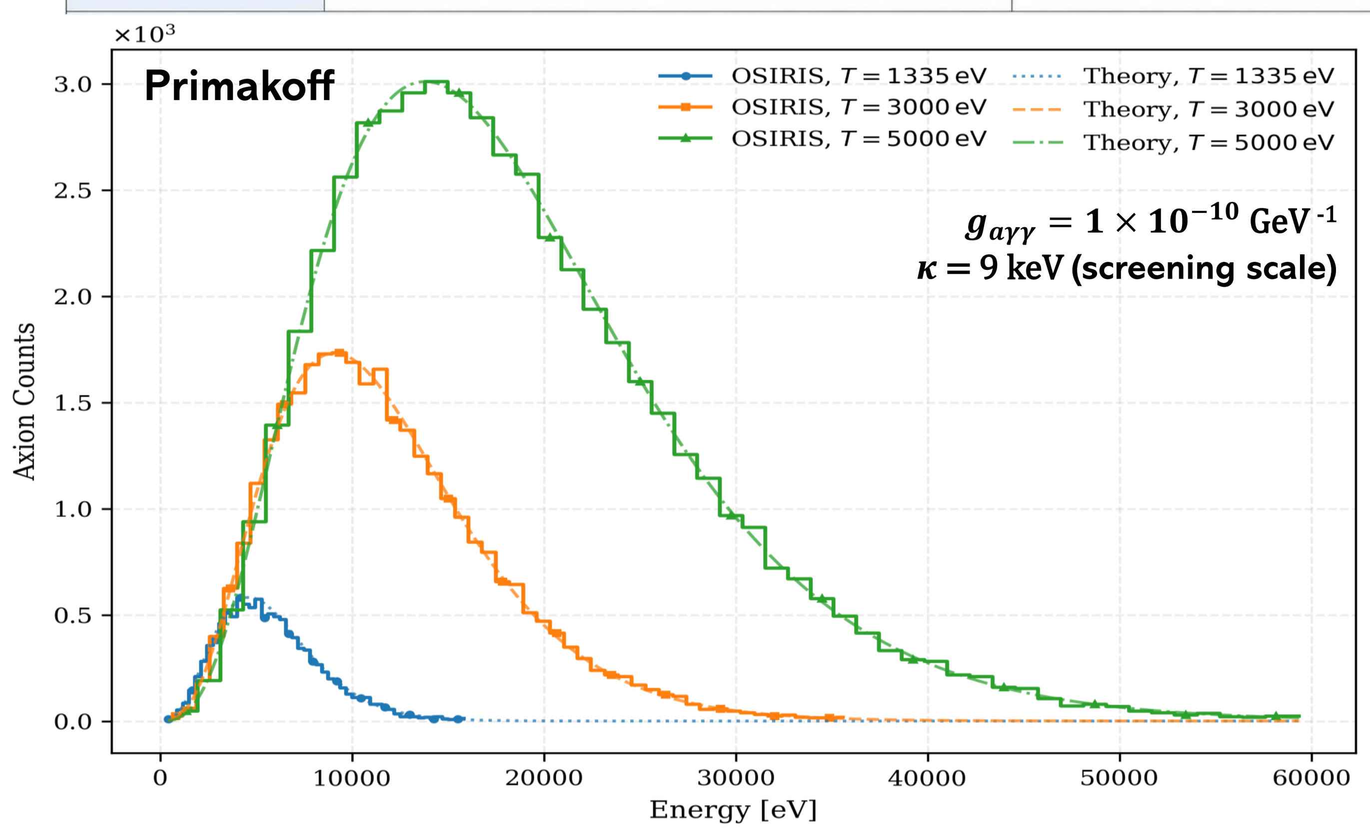
**AXION PRODUCTION PROCESSES AND RELEVANT CROSS SECTIONS**

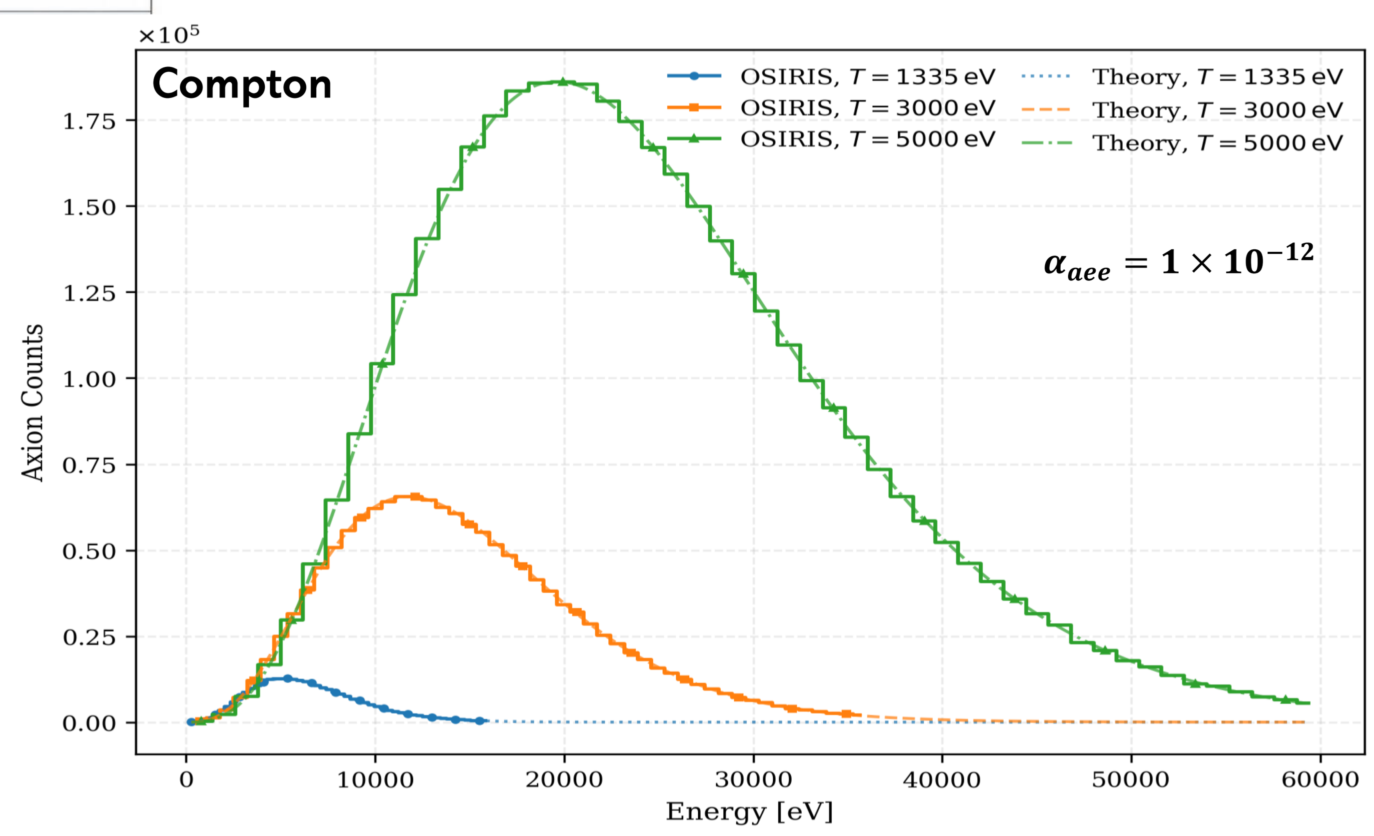
| Process | Cross Section | Definitions of Symbols |
|---|---|---|
| Primakoff cross section | $\sigma_p(\omega) = Z^2 \left(\frac{g_{a\gamma\gamma}}{4\pi}\right)^2 \frac{\pi}{2} \left[\left(1 + \frac{\kappa^2}{4\omega^2}\right) \ln\left(1 + \frac{4\omega^2}{\kappa^2}\right) - 1\right]$ | $Z$ = nuclear charge number<br>$g_{a\gamma\gamma}$ = axion–photon coupling constant<br>$e$ = elementary charge<br>$\omega$ = photon energy<br>$\kappa$ = inverse screening length |
| Compton cross section | $\sigma_c(\omega) = \frac{4\pi}{3} \frac{\alpha\, \alpha_{aee}}{m_e^2} \left(\frac{\omega}{m_e}\right)^2$ | $\alpha$ = fine–structure constant<br>$\alpha_{aee}$ = axion–electron coupling constant<br>$m_e$ = electron mass<br>$\omega$ = photon energy |

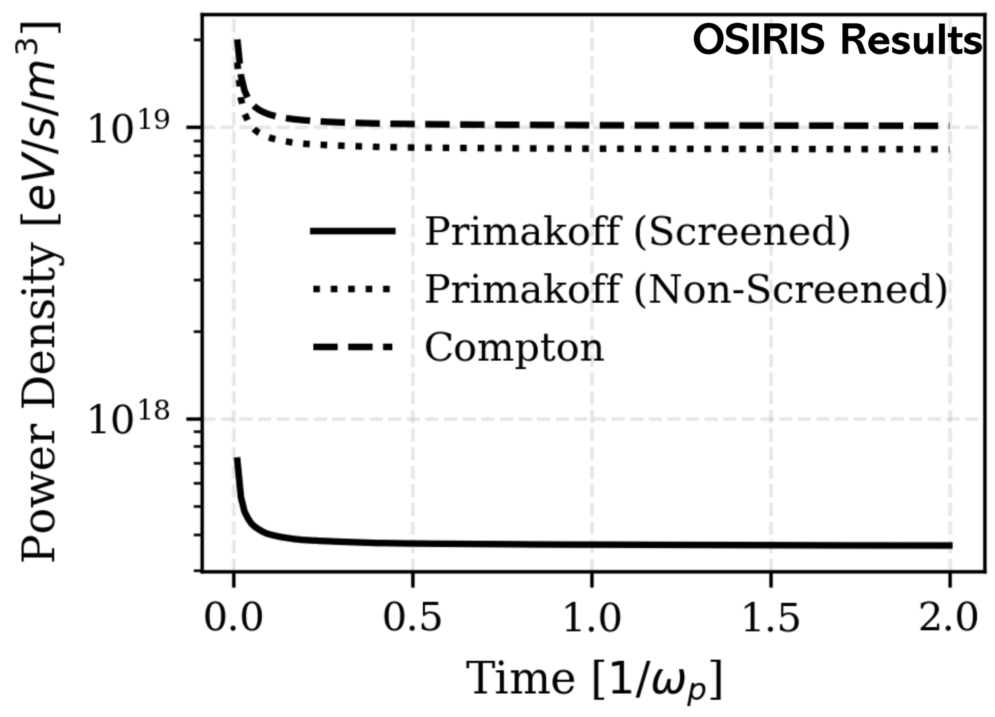
**Axion Production**



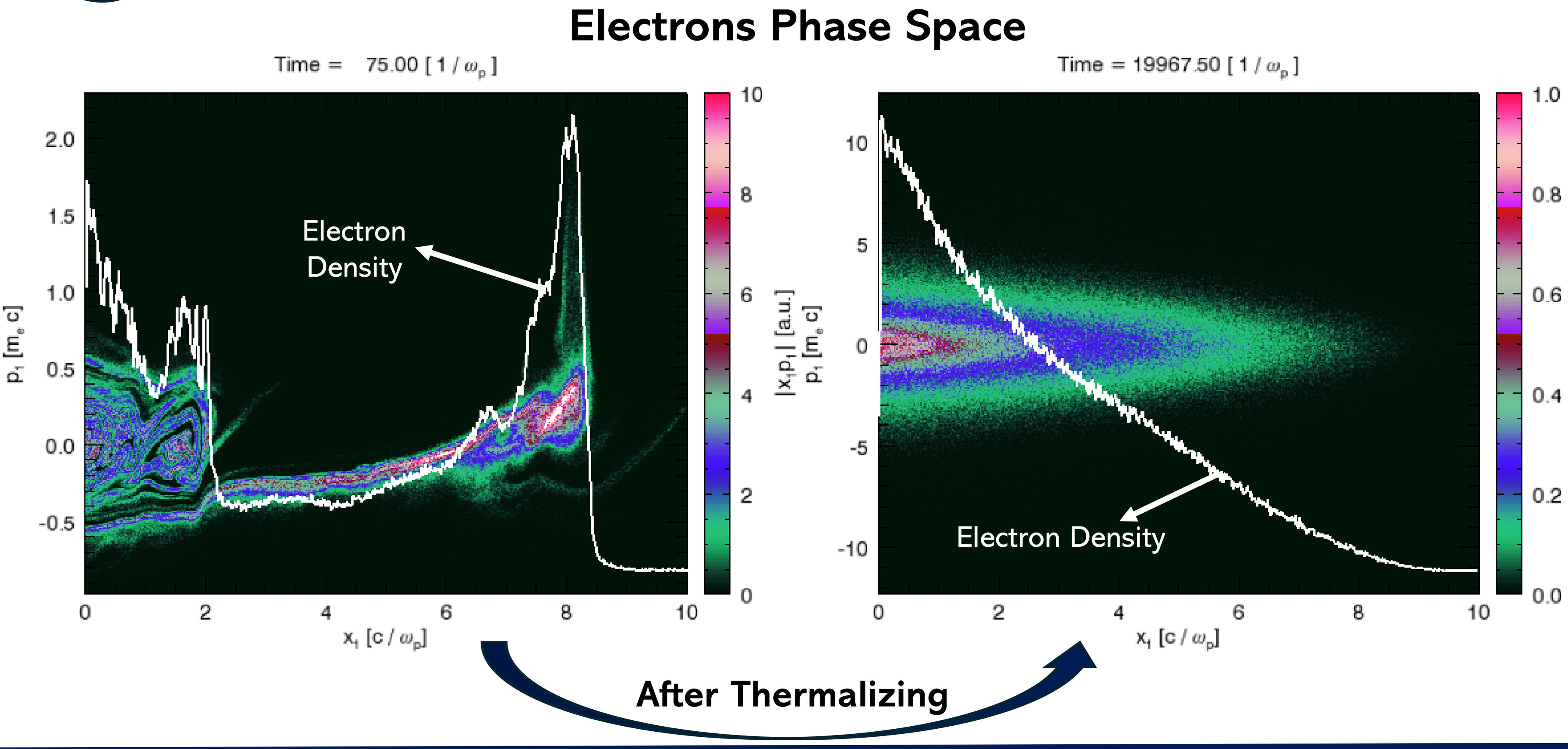




**Implementation Agrees with Analytical Predictions**

## 4 Future Work

**Electrons Phase Space**




## 5 Conclusion

- First PIC-MC implementation of solar axion production.
- Primakoff and Compton production channels integrated into OSIRIS.
- Axion spectra reproduced in excellent agreement with analytical predictions.
- Solar-core axion energy-loss rates computed self-consistently.
- Framework readily extensible to relativistic and unstable plasmas, opening the way to future axion studies in laboratory and astrophysical environments.

## References:

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- (In progress) Ahmed Alsulami, et. al. Modelling the Solar Axion Spectrum with Self-Consistent PIC–MC Plasma Simulations.