Surrogate modeling of X-Ray emission and Positron production in Laser-Plasma interactions

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In the interaction between a high intensity laser pulse and matter, the extremely strong electromagnetic fields and the electrons accelerated by them can produce bright x-ray sources via non-linear inverse compton scattering (NCS). These highly energetic photons can then go on to produce electron-positron pairs when interacting with the strong electromagnetic fields of either the incoming laser (non-linear Breit-Wheeler process) or of high-Z nuclei (Bethe-Heitler process).[1, 2]
These processes are of great interest when studying strong field Quantum Electrodynamics as well as for laboratory astrophysics experiments for extreme environments similar to those surrounding pulsars and magnetars[3].
Producing and observing these effects in experiments however can be challenging due to the many different parameters that can be tuned in a laser-plasma interaction. Simulations of these interactions are typically done using Particle-In-Cell codes which are computationally expensive and will produce results with some amount of noise. Therefore, using such simulations to explore the many-dimensional parameter spaces involved is itself a challenge.
Here, we cover our work on building surrogate models of these systems. These are a machine learning based approximation of the interaction trained using a sparse sample of simulated interactions. Our methodology uses Gaussian Process Regression[4] and active learning to build the model. The former allows for good handling of noisy data and can interpolate a sparse sampling of a high dimensional parameter space. Active learning involves repeatedly training the model with each new datapoint, and analyzing the result in order to calculate where next to sample in the parameter space in order to best approach the desired outcome; typically either finding an optimum set of parameters or getting a full picture of the parameter space.
We present parameter scans of our model across multiple different output variables and compare how the model performs at predicting the results of new sets of parameters with simulated results as well as theoretical expectations. Figure 1 shows the results of a sample simulation at a reasonably central point in parameter space, such as the resultant number density within the pre-plasma immediately following the peak of the interaction, the emission of NCS photons at this point, the energy spectrum of these photons and the resultant flux of positrons out the back of the target. The latter two plots encapsulate the objective variables we wish for in our model, those being the total NCS photon energy, the mean photon energy, and the peak positron flux.
This methodology presents a novel way of exploring the complicated parameters spaces of laser-plasma interactions and optimizing parameters for desired outcomes. This work is supported by the UK Science and Technologies Facilities Council and by the UK Engineering and Physical Sciences Research Council under EPSRC grant EP/V049461/1.

References
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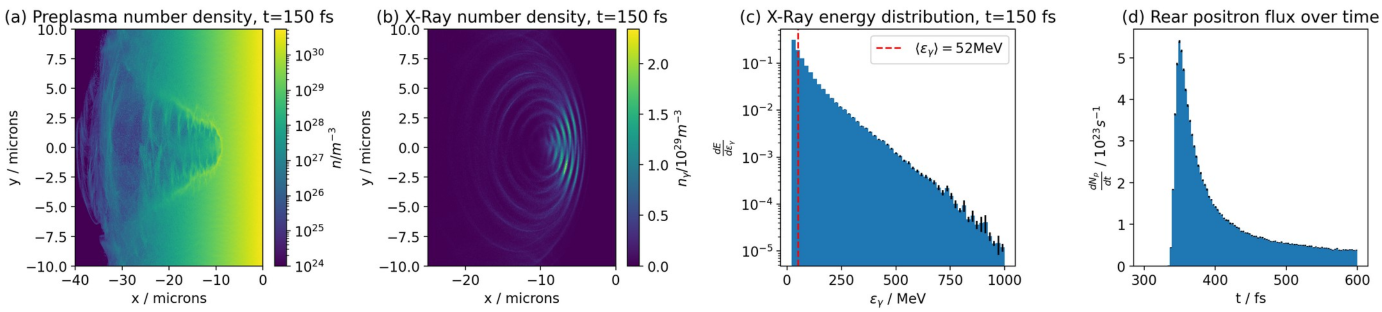

Figure 1: Plots from a simulation of an interaction between a 400J, 10 fs laser pulse (~10^{24} Wcm^{-2}) and a 50 µm gold target with a preplasma of scale length 3 µm. (a) Plot of the number density within the preplasma following the peak intensity. (b) Plot showing the emission of X-rays at this time. (c) Spectrum of the photons shown in (b). (d) Plot of the Positron flux at the rear of the target over the course of the simulation.