High-Energy-Density–Physics Measurements in Implosions Using Bayesian Inference

J. J. Ruby,[1,2] J. A. Gaffney,[3] J. R. Rygg,[1,2,4] Y. Ping,[3] and G. W. Collins[1,2,4]

[1]Department of Physics and Astronomy, University of Rochester
[2]Laboratory for Laser Energetics, University of Rochester
[3]Lawrence Livermore National Laboratory
[4]Department of Mechanical Engineering, University of Rochester

Convergent high-energy-density experimental platforms are used to study matter under some of the most extreme conditions that can be produced on Earth, comparable to the interior of stars. There are many challenges in using these systems for fundamental measurements currently being addressed by new analysis methods, such as the combination of a reduced-physics model and Bayesian inference,[1,2] allowing for a self-consistent inference of physical quantities with a robust error analysis. These methods in combination with simple [as compared to inertial confinement fusion (ICF)] implosion platforms, which can be modified to show sensitivity to different physical mechanisms of interest, can be used to study the physical properties of matter under extreme conditions and analysis.

One example of simplified implosion designs includes shock-dominated systems, such as thin-shelled, gas-filled targets sometimes known as "exploding pushers" and solid-sphere targets, while another includes thick-shelled, gas-filled implosions that create a compressive hot spot much like modern ICF experiments but at lower convergence ratios for high stability. These systems are able to access different regimes where different physical mechanisms are most relevant.

This work discusses these different regimes and gives a detailed example of an experimental design of a thick-shelled implosion informed by Bayesian inference. A reduced-physics model informed by many of the previously published hot-spot models in literature[3,4] is constrained by a suite of synthetic measurements generated from a *LILAC* simulation using Bayesian inference. (*LILAC* is a radiation-hydrodynamics code.)

The reduced model parameterizes the hot spot in terms of the time history of the total internal energy and the trajectory of the outer edge of the hot spot (in this case defined by the fuel–shell interface) while assuming an isobaric hot spot. This parameterization is used in combination with boundary conditions for the temperature profiles, an ideal gas equation of state, and a Spitzer-like conductivity of the form

$$\kappa = \kappa_0 \left(\frac{\rho}{\rho_0}\right)^a \left(\frac{T}{T_0}\right)^b, \tag{1}$$

where κ is the thermal conductivity, κ_0 is a constant factor, ρ is the mass density, T is the temperature, and both a and b are constant exponents that define the conductivity response to temperature and density. Using this conductivity along with conservation relations and the equation of state results in a radial temperature profile that depends on the quantity $(1 + b - a)^{-1}$, meaning that the details of the temperature profile provide information on the thermal conductivity of the hot-spot plasma.

Three key details determine the efficacy of this process: (1) The full-physics model being used (in this case *LILAC*) is able to reasonably represent the experimental system; (2) the reduced-physics model accurately represents quantities of interest from the full-physics model; and (3) the reduced-physics model can be constrained by the available measurements. The (synthetic) measurements used in this work include x-ray framing camera measurements, x-ray temporal histories in different spectral channels, the neutron temporal history, and the neutron spectrum.

Figure 1 shows the inferred profiles informed by all of the above measurements compared to the underlying truth from *LILAC*, showing that the thermodynamic conditions within the hot spot can be reconstructed using readily available measurements, assuming that a 1-D model is appropriate to describe the system, i.e., the system is sufficiently stable that asymmetries are not a significant perturbation on the conditions.

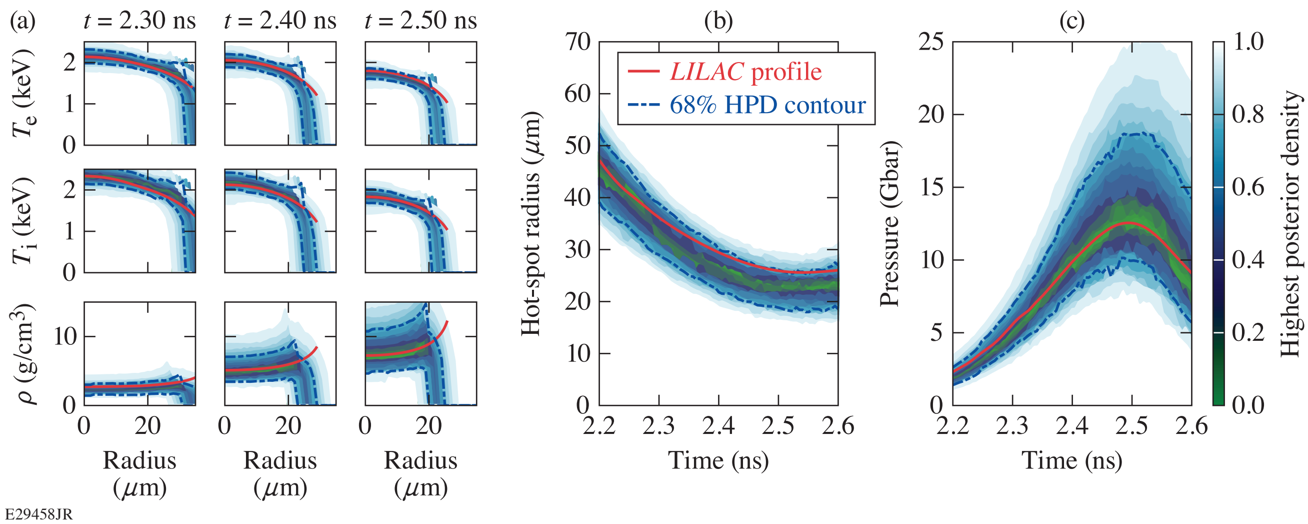

Figure 1
The inferred profiles for (a) the radial distribution of electron temperature, ion temperature, and mass density at three different times around peak emission; (b) the temporal history of the hot-spot radius; and (c) the temporal history of the hot-spot pressure. The color map shows the highest posterior density intervals for the inferred profiles, essentially producing credible intervals where the dashed blue line represents the 68.7% credible interval. The solid red curve shows the profile from the underlying *LILAC* simulation used to generate the synthetic diagnostics. In all cases the profiles are in excellent agreement with the underlying simulation with the exception of the edges of the hot spot where the radius is underpredicted by about 10% at later times, likely due to the fact that there is very little emission coming from the edge of the hot spot and therefore little information about its location. HPD: highest posterior density.

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