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Connecting simulation to data analysis in MagLIF fusion experiments

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Abstract

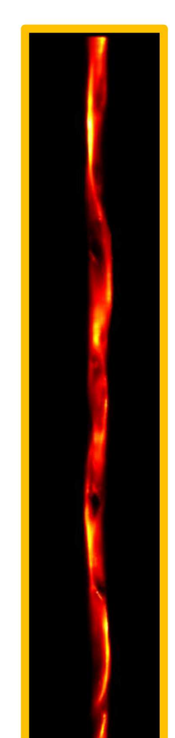
Experimental measurements are used to infer plasma conditions and characterize each MagLIF experiment, but the accuracy of these inferences can depend on assumptions made in analysis. Ideally simulation results of the MagLIF fusion experiment are compared directly with quantities derived from experimental measurements through producing synthetic diagnostics. One such experimental measurement is spectral emission.

Spectral measurements can encode information about plasma conditions, such as temperature and density. Unlike other methods to calculate plasma conditions, it does not require the volume of the plasma, which is often difficult to determine in experiment. SCRAM, an atomic code, is able to simulate spectral emission however it is inefficient to run this code for every temperature and density that may be present in a simulation. Instead, we investigate the use of a lookup table of spectra for specific temperatures and densities and interpolate to produce spectra from a model or simulation. The research presented investigates the various methods and associated errors from interpolation between spectra, and how that effects inference of plasma conditions.

Background

The Magnetized Liner Inertial Fusion (MagLIF) experiments utilize inertial confinement fusion (ICF) concepts to achieve thermonuclear fusion conditions.

- uses a slow (100 ns) cylindrical implosion
- axial magnetic field limits heat loss due to thermal conduction
- Fig.1 depicts the three stages MagLIF utilizes to produce fusion conditions: the applied magnetic field, laser heating of the fuel, and compression of the liner
- Diagnostic tools measure x-ray and neutron emission, to infer ion temperature and plasma density



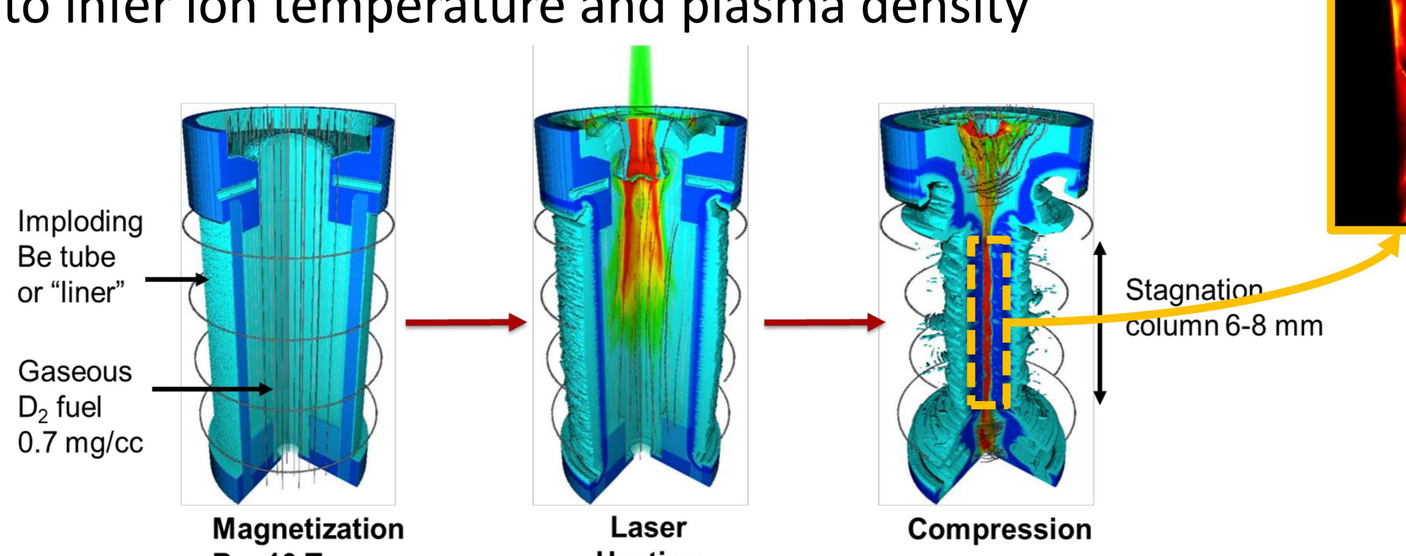


Figure 1: Stages of MagLIF

Synthetic Diagnostics

An existing set of synthetic diagnostic tools will be used to assess the accuracy of experimentally derived quantities

- start simple, with 1D simulation data, assuming cylindrical symmetry
- use this data to calculate X-ray emission, neutron emission, and spectra emission in ways that mimic measurements taken in experiment ("synthetic diagnostics")
- compare conditions inferred from synthetic diagnostic analysis with simulation values to assess how accurate diagnostic inferences can be.

Spectral Emission

The beryllium liner in the experiment is contaminated with a small amount of iron. During stagnation, some of this iron mixes into the fuel and produces a characteristic spectrum. This spectrum varies with temperature and density, providing a measure for plasma characteristics.

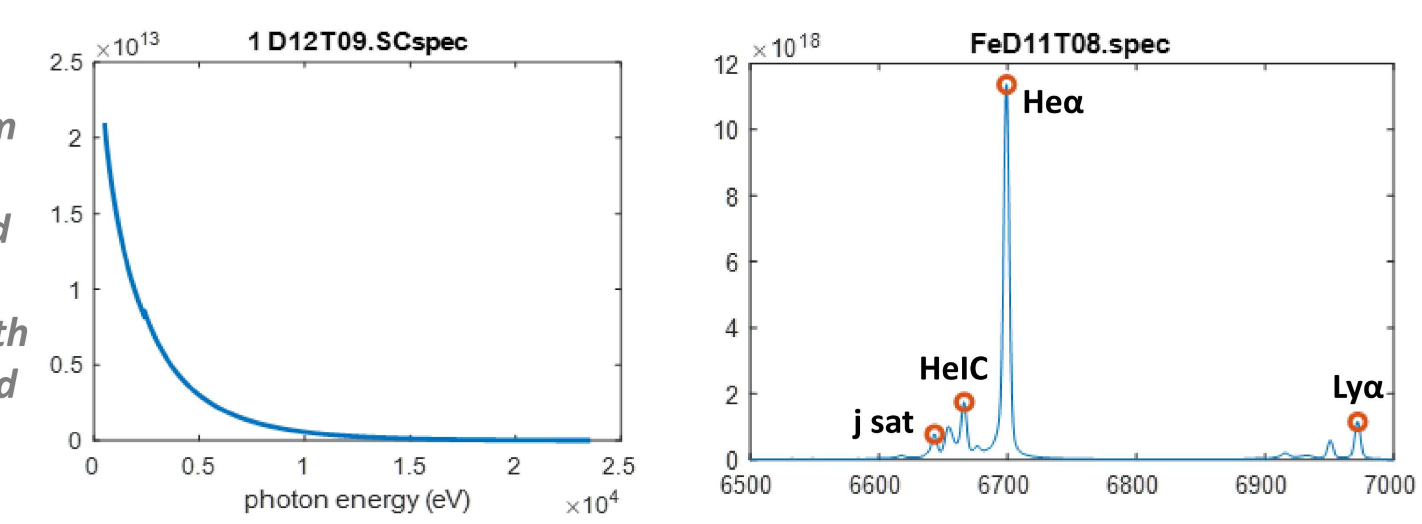
SCRAM is an atomic code which generates spectra under a given set of conditions. It outputs a spectrum for each element in the experiment, at a specified temperature and density. In experiment, we measure a single time integrated emission spectrum.

Iron (Fe) and Deuterium (H) spectra are used to extract the plasma electron temperature and ion density

- process Fe spectra from measured spectral emission
- fit H spectrum to an exponential to extract temperature info
- interpolate on lookup table to extract temperature and density info

By applying these steps to simulation data, we can understand the errors incurred through each process

Figure 2: Deuterium fuel emission spectrum (left) and iron emission spectrum (right) with marked and labeled spectral lines



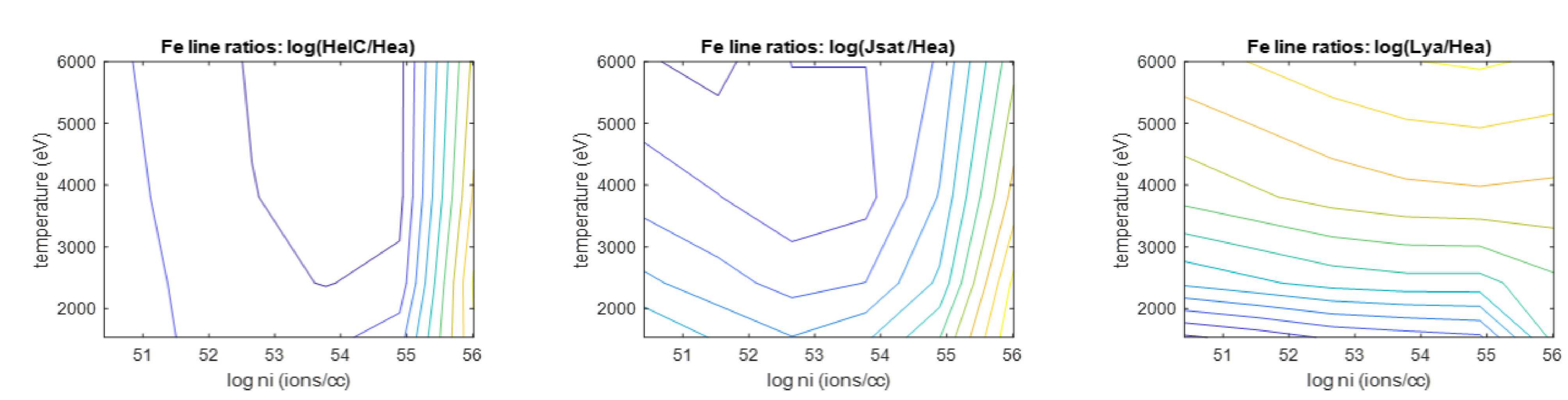


Figure 3: Spectral line ratios as a function of temperature and density.

Pressure

Using one synthetic diagnostic, we can calculate the pressure at many times, and compare these calculations with the single value an experiment would infer to see how time-dependence affects the accuracy of our pressure determination. Synthetic diagnostic tools will test a broad range of simulations, with varying input parameters.

- One pressure calculation requires several diagnostics:
  - *Synthetic PCD yield:* Power and burn duration calculated using X-ray emission intensity
  - *Synthetic volume:* Using intensity calculations, approximate volume of column
  - *Synthetic neutron emission* (also gives burn weighted temperature)
- Another method uses temperature and density characterized from the spectra

The synthetic diagnostic will explore the different dependencies and uncertainties associated with the two methods of calculating pressure. We can compare these values with actual simulation data.

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