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Multi-objective spectroscopic analysis of core gradients: Extension from two to three objectives

L.A. Welser[a,*], R.C. Mancini[a], J.A. Koch[b], N. Izumi[b], S.J. Louis[c], I.E. Golovkin[d], T.W. Barbee Jr.[b], S.W. Haan[b], J.A. Delettrez[e], F.J. Marshall[e], S.P. Regan[e], V.A. Smalyuk[e], D.A. Haynes Jr.[f], R.W. Lee[b]

[a]*Department of Physics, University of Nevada, Reno, NV 89557, USA*
[b]*Lawrence Livermore National Laboratory, Livermore, CA 94550, USA*
[c]*Department of Computer Science, University of Nevada, Reno, NV 89557, USA*
[d]*Prism Computational Sciences, Madison, WI 53703, USA*
[e]*Laboratory for Laser Energetics, University of Rochester, Rochester, NY 14623, USA*
[f]*Los Alamos National Laboratory, Los Alamos, NM 87545, USA*

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Abstract

We discuss a three-objective search and reconstruction method for the extraction of spatial structure information from argon-doped implosion cores based on the simultaneous analysis of Heβ and Lyβ X-ray narrow-band images and space-integrated line spectrum data. The search in parameter space is driven by a multi-objective Pareto genetic algorithm. Two alternative implementations of the three objectives are considered. Two- and three-objective analysis of the same set of time-integrated data produce similar temperature profiles but different density profiles.

Keywords: X-ray spectroscopy; Multi-objective search and optimization; Plasma diagnostics

*Corresponding author.
E-mail address: lwelser@physics.unr.edu (L.A. Welser).

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1. Introduction

The diagnosis of temperature and density conditions in inertial confinement fusion (ICF) implosion cores is a vital step in understanding the details of these complex experiments. Spectroscopic analysis of space-integrated line spectra is commonly used to determine core conditions in a spatially averaged level of detail [1–5]. However, it is important to move beyond this approximation and examine the spatially resolved core conditions. Line-based narrow-band X-ray images, which represent a projection of the spatial structure integrated over a narrow range of photon energies about line spectral features, provide critical information towards ultimately pinpointing the spatial structure of density and temperature inside the core.

The X-ray line spectrum and narrow-band X-ray images used in the spectroscopic analysis discussed in this work are the products of experiments conducted at the University of Rochester's Laboratory for Laser Energetics OMEGA laser facility. They consisted of indirectly driven implosions of 512 μm diameter spherical plastic capsules inside 2.5-mm-long gold hohlraums. The targets were filled with 50 atm of deuterium and 0.1 atm of argon, which was used as a tracer element to provide spectroscopic diagnostics. Thirty ultraviolet laser beams, each having energy of 500 J, were used to irradiate the interior walls of the hohlraum. Carefully designed beam-pointing parameters helped achieve stable and low convergence implosions that were useful to test the spectroscopic method [6].

The implosion was viewed through diagnostic holes drilled in the hohlraum walls. The Multi-Monochromatic X-ray Imager (MMI) recorded collections of X-ray narrow-band images in the spectral range of 3000–5000 eV [6,7]. This range includes the Ar emission lines of interest, the Heβ ($1s^2\ {}^1S$–$1s3p\ {}^1P$) and the Lyβ ($1s\ {}^2S$–$3p\ {}^2P$) and their associated Li- and He-like satellite line transitions, respectively. This portion of the Ar K-shell line spectrum was selected because it is sensitive to density and temperature through the density and temperature dependence of the level population kinetics and the density dependence of the Stark-broadened lineshapes [8].

The spectroscopic analysis utilizes a multi-objective Pareto genetic algorithm (PGA) as a search and optimization engine to drive the search for gradients in parameter space that simultaneously and self-consistently provide the best fits to all pieces of data considered in the analysis [9–11]. Two types of data are needed: an X-ray line spectrum, which gives information on spatially averaged electron temperature, T_e, and density, N_e, conditions in the core, and emissivity spatial profiles extracted from narrow-band X-ray images, which are dependent on the spatial distributions of T_e and N_e. The use of a multi-objective PGA is essential for an efficient and practical implementation of this search and reconstruction (SR) method.

This paper will give an overview of recent progress made in developing spectroscopic multi-objective SR analysis. This is motivated in part by the fact that multi-objective SR analysis relies on the strategy of using the largest amount of data with a minimum number of assumptions and has the potential to be applied in a broad range of data analysis problems. Specifically, we will report here on extending the method from two to three objectives and on comparing the results obtained in these two different ways. We have found that the three-objective SR method applied to time-integrated data from OMEGA indirect-drive implosions yields a correlated set of T_e and N_e gradients that fits the spatially integrated X-ray line spectrum and the spatial emissivity profiles of both Heβ and Lyβ lines. On the other hand, two-objective SR analysis of the same data based on the analysis of the X-ray line spectrum and either the Heβ or Lyβ emissivity spatial profile