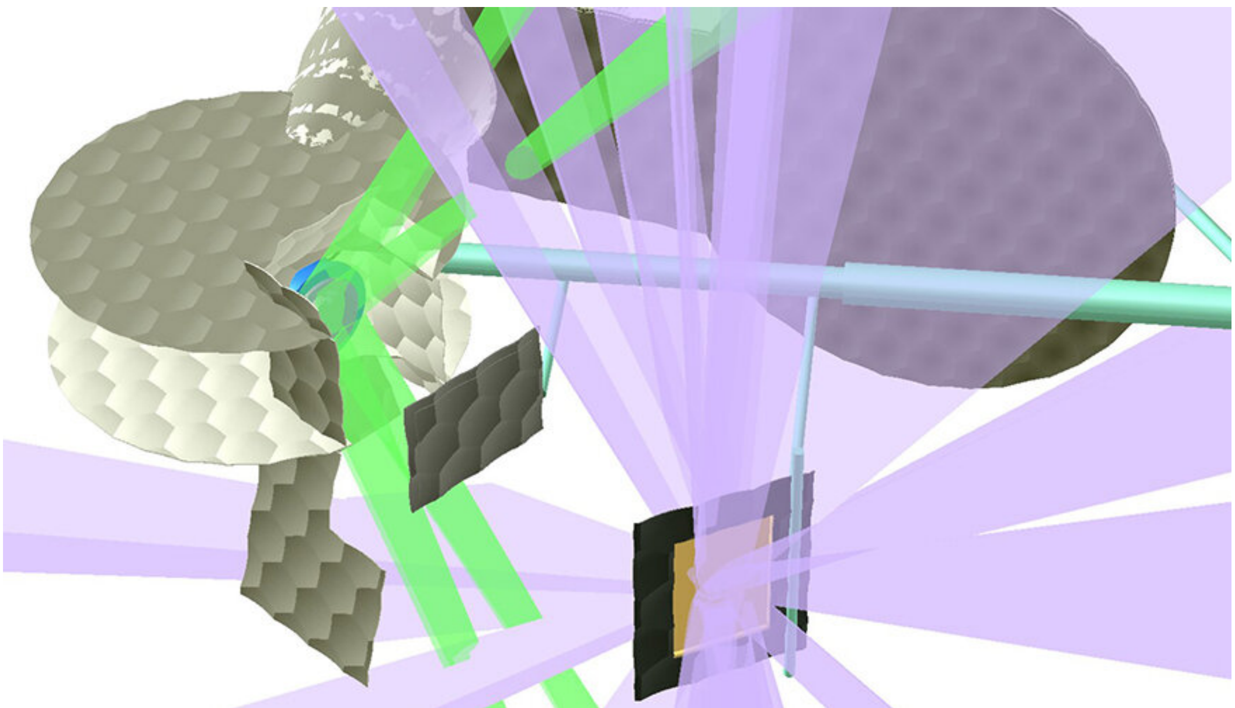
Researchers develop broadband X-ray source needed to perform new measurements at NIF

January 7 2021, by Michael Padilla



This image shows the full EXAFS sample, backlighter and laser configuration at the National Ignition Facility. Credit: Lawrence Livermore National Laboratory

Lawrence Livermore National Laboratory (LLNL) researchers have developed an X-ray source that can diagnose temperature in experiments that probe conditions like those at the very center of planets.

The new source will be used to perform extended X-ray absorption fine structure (EXAFS) experiments at the National Ignition Facility (NIF). The work was published in *Applied Physics Letters* and was featured as an Editor's Pick.

"Over a series of X-ray source development experiments at NIF, we were able to determine that titanium (Ti) foils produce 30 times more continuum X-rays than implosion capsule backlighters in the X-ray spectral range of interest and between two to four times more than gold (Au) foils under identical laser conditions," said Andy Krygier, LLNL physicist and lead author.

Understanding extended X-ray absorption fine structure

"While there are many uses for X-ray sources, the work was primarily focused on making it possible to measure EXAFS of highly compressed materials in the solid state. This is a very difficult regime to operate in and ultimately required a lot of effort and resources to accomplish," Krygier said.

The primary motivation of the EXAFS experiments is to determine the temperature of samples at Mbar pressures—conditions like those at the very center of planets (1 Mbar = 1 million times atmospheric pressure). "With this work, we now have the ability to perform EXAFS measurements at NIF over a wide range of materials and conditions that were not previously possible at any facility in the world."

At these conditions, where solids can be compressed by a factor of two or more, the materials can have wildly different properties than at everyday ambient conditions. The X-ray source developed in this work will enable measurements of various higher-Z materials that are of importance for the Lab's mission. This platform also will open up opportunities for scientific discovery in material properties under extreme conditions.

Measuring EXAFS requires detecting signals that are a few percent of the overall signal and is the underlying reason that the team has put so much effort into developing an intense, spectrally smooth backlighter.

Yuan Ping, LLNL physicist and the campaign lead of the work, said the findings conclude a success in the development of backlighter for the EXAFS project. "EXAFS measurements using this backlighter have already started at NIF and the approach is expected to enable future measurements that are a critical part of LLNL's support of NNSA's Stockpile Stewardship Program," she said.

The preferred arrangement of atoms or crystal structure changes with temperature and pressure in many materials and is currently investigated by the TARDIS (target diffraction in situ) platform at NIF. The structure also is one of many things impacting the relationship between pressure and density, which is under investigation by the ramp compression platform at NIF, as well as the strength, which is under investigation by the RT platform at NIF.

"All of these important platforms lack temperature measurements," Krygier said. "It is the goal of the EXAFS platform to test the thermal models underpinning the equation of state models used in hydrodynamics codes as well as complement the other materials platforms."

There has been a lot of effort developing X-ray sources using heated foils by other teams, but these efforts have often focused on different X-ray energies or optimizing line emission (a narrow-in-energy X-ray emission resulting from an atomic transition), Krygier said.

"EXAFS experiments explicitly require a different type of X-ray source than many others at NIF," he said. "Because the EXAFS signal is encoded over a relatively wide, but specific, range of X-ray energies, we needed to optimize the broadband continuum emission in the multi-keV energy range, instead of the line emission, which is far too narrow in energy for EXAFS."

The team has determined that it is possible, by using the very high power density of the NIF lasers, to ionize titanium into its inner shell. "This high degree of ionization enables a continuum X-ray emission process called free-bound to become important and actually dominate the overall continuum X-ray emission," he said.

Krygier said this process leads to a stronger continuum emission in the multi-keV regime from titanium than from silver or gold. "The observation that heating a titanium foil produces stronger continuum emission than with silver or gold was unexpected initially, but after careful data analysis, we determined that free-bound transitions were playing an important role. In the end, the data and model agree nicely." he said.

Elijah Kemp, LLNL physicist, aided in the interpretation of the data with the rad-hydro (HYDRA) and atomic-kinetics (SCRAM) modeling that helped confirm the data interpretation. He said scientists have a tendency to carry around a standard toolbox of generalized scaling laws for various physical phenomena that lead to the assumption that an gold backlighter would outperform silver and titanium. Continuum X-ray emission is generally known to increase with the atomic number, however, heating the sample to the regime where free-bound transitions was important enabled titaniumi, whose atomic number is 22, to outshine silver and gold, whose atomic numbers are 47 and 79, respectively.

"While these ubiquitous scalings can help to quickly guide one's intuition, they also can lead to seemingly paradoxical results," he said. "One of the most important messages from this work is to not naively rely on overgeneralized rules-of-thumb that are so often employed to prematurely narrow down parameter optimization studies."

Team effort

This effort required the team to look beyond typical X-ray emission processes to understand the data from experiments. They relied on experts across a wide range of disciplines including materials science, plasma physics, X-ray spectroscopy and hydrodynamic simulation during planning and analysis.

The team was initially focused on a different approach, using imploding capsules, but eventually determined that it was not going to produce enough X-rays to make EXAFS measurements.

"It's one of the few times where science actually works the way it's portrayed in movies with everyone on the team in a room (back when we could meet in rooms) proposing ideas on a whiteboard," Krygier said. "Results like this are a real testament to the world-class research environment that exists at LLNL."

More information: A. Krygier et al. Optimized continuum x-ray emission from laser-generated plasma, *Applied Physics Letters* (2020). DOI: 10.1063/5.0033629

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