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Powerful X-rays Experiments Investigate the Inner Workings of Stars

The transparency of iron ions found in stellar interiors is determined using the most energetic X-ray source on Earth to heat iron to 1.8 million degrees.

DALLAS, Texas—Astrophysicists seeking to understand stellar structure face a dilemma: no direct probes can survive a star's 1 to 10 million degree temperatures. Thus, scientists are limited to physical models based on observations made from great distances. A key ingredient of those models is how the energy initially created by fusion reactions in the core is transported to the outside, where it appears as starlight in the night sky or as sunlight that warms the earth.

Recently the first *opacity* experiments at temperatures high enough to produce the ionic charge states that exist in stars were performed using the world's most energetic X-ray source: the Z facility at Sandia National Laboratories. *Opacity* quantifies how transparent or opaque matter is and it dictates energy transport inside stars. The Z experiments [J.E. Bailey *et.al.*, Physical Review Letters, **99**, 265002 (2007)] measured the opacity of iron plasma heated to 1.8 million degrees Celsius.

Iron is a critical component of the stellar mixture. The high temperatures achieved in the Z experiments strips electrons from iron atoms, producing ions with almost the same charge states as those in a star's interior. Physicists must create enough of these charged ions on Earth to permit detailed measurements and test models of their properties.

By measuring the transmission as a function of photon energy, the Sandia scientists probe the detailed quantum mechanical structure of the iron ions that exist in stars, providing much-needed information to test theoretical models. An exact reproduction of stellar matter is still not possible, as the density in the Sandia experiments was about 10 times too low. Nevertheless, the Sandia scientists are working with colleagues from Lawrence Livermore and Los Alamos National laboratories, the French *Commissariat a l'Energie Atomique*, and Ohio State University to test opacity models used by astrophysicists. New experiments planned at Z are aimed at reaching higher densities and should help refine scientific knowledge of high energy density matter and the stars that are made from it.

What makes this challenging – and interesting – is that both stars and inertial fusion plasmas are composed of high energy density matter, a collection of atoms, ions, and electrons at pressures exceeding 1 million atmospheres. The properties of this exotic matter are difficult to study in the laboratory and theoretical models are therefore rarely tested.

Scientists in the U.S., Britain and France began making opacity measurements in the 1980s and have made steady improvements in the complex techniques. Simultaneously, theoretical models have also improved, as have the computers needed to calculate the model predictions. But, until now, the temperatures reached in experiments were too low to help unravel the structure of stars.

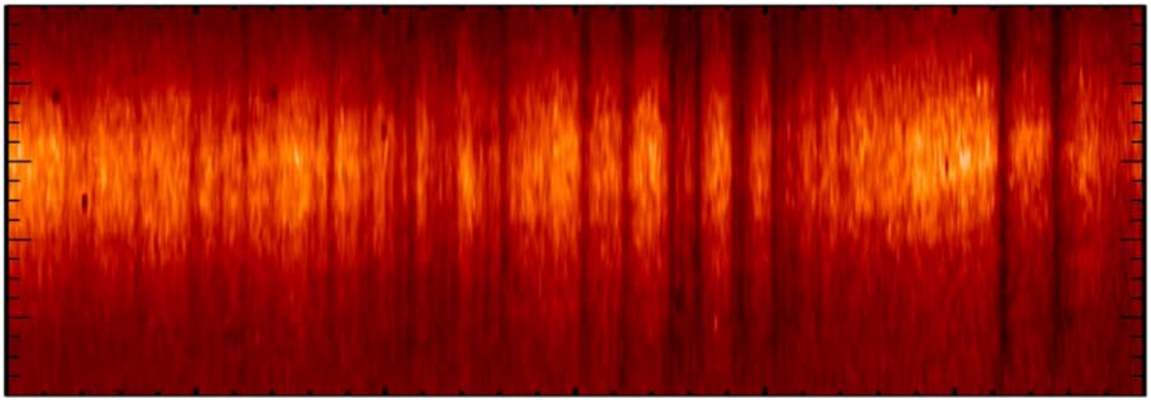

Figure: Transmission through iron heated to 1.8 million degrees. The brighter parts of the image correspond to photon energies with higher transmission, or lower opacity. The dark lines are absorption by the discrete transitions prescribed by quantum mechanics.

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Abstract: PT2.0001

Experimental investigation of opacity models for stellar interiors, inertial fusion, and high energy density plasmas

Invited Session PT2: Tutorial: Experimental Investigation of Opacity Models for Steller Interiors, Inertial Fusion, and High Energy Density Plasmas
2:00PM–3:00PM, Wednesday, November 19, 2008
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