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Measuring the opacity of stellar interior matter in terrestrial laboratories

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How does energy propagate from the core to the surface of the Sun, where it emerges to warm the Earth? Nearly a century ago Eddington [1] recognized that the attenuation of radiation by stellar matter controls the internal structure of stars like the sun. Opacities for high energy density (HED) matter are challenging to calculate because accurate and complete descriptions of the energy levels, populations, and plasma effects such as continuum lowering and line broadening are needed for partially ionized atoms. This requires approximations, in part because billions of bound-bound and bound-free electronic transitions can contribute to the opacity. Opacity calculations, however, have never been benchmarked against laboratory measurements at stellar interior conditions. Laboratory opacity measurements were limited in the past by the challenges of creating and diagnosing sufficiently large and uniform samples at the extreme conditions found inside stars. In research conducted over more than 10 years, we developed an experimental platform on the Z facility and measured [2] wavelength-resolved iron opacity at electron temperatures T_e = 156-195 eV and densities $n_e = 0.7 - 4.0 \times 10^{22}$ cm^{-3} - conditions very similar to the radiation/convection boundary zone within the Sun. The wavelength-dependent opacity in the 975 – 1775 eV photon energy range is 30-400% higher than models predict. This raises questions about how well we understand the behavior of atoms in HED plasma. These measurements may also help resolve decade-old discrepancies between solar model predictions and helioseismic observations. This talk will provide an overview of the measurements, investigations of possible errors, and ongoing experiments aimed at testing hypotheses to resolve the model-data discrepancy.

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[1] A.S. Eddington, The Internal Constitution of the Stars (Cambridge Univ. Press, Cambridge, 1926).
[2] J.E. Bailey et al., *Nature* **517**, 56 (2015).