Opacity enhanced by the localization of electrons

Qian-Sheng Zhang^{1,2,3,4*}

¹ Yunnan Observatories, Chinese Academy of Sciences, Kunming 650216, China;

² Center for Astronomical Mega-Science, Chinese Academy of Sciences, Beijing 100012, China;

³ Key Laboratory for the Structure and Evolution of Celestial Objects, Chinese Academy of Sciences, Kunming 650216, China;

⁴ University of Chinese Academy of Sciences, Beijing 100049, China

Received November 24, 2021; accepted December 10, 2021; published online December 23, 2021

Citation: Q.-S. Zhang, Opacity enhanced by the localization of electrons, *Sci. China-Phys. Mech. Astron.* **65**, 233031 (2022), <https://doi.org/10.1007/s11433-021-1832-y>

Plasmas absorbing and scattering photons are often described according to the conception of opacity. The opacity in hot, dense plasmas is crucial in many fields, including astrophysics and controlled nuclear fusion. It is a difficult problem because of many complex mechanisms involving, for instance, excited states, line broadenings, relativistic effects, and two-photon contributions. Studies on opacity, particularly motivated by the advances in stellar physics, have quickly developed since the 1940s. Nevertheless, the current theoretical models of opacity in hot, dense plasmas are inconsistent with the experimental results. For example, Bailey et al.'s experiments [1] of the opacity of iron on the condition of the base of the solar convection zone have shown a significant deviation of more than 30% from the model predictions. The opacity determines the structure of the temperature in the stellar interior. Some of the current issues in stellar physics could be attributed to the defects in the opacity models. One of such issues is the “solar abundance problem”. Based on the 3D hydrodynamic model for the solar atmosphere, Asplund et al. [2] have found that the solar metallicity had been overestimated. The standard solar model with the revised abundance shows significant deviations in several aspects of the helioseismic inferences. It is found that an artificial enhancement of the opacity in the solar interior from 2%-5% to 15%-20% from the solar core to the base of the convection zone could recover the properties

of the standard solar model [3,4]. However, there is no physical justification to support such a significant modification.

In ref. [5], Zeng et al. proposed a new mechanism by which the transient spatial localization of the continuum electrons could enhance opacity. The basic idea is that a photoelectron colliding with a free electron leads to its partial de-phasing and de-coherence, affecting the wave function of the continuum electron and enhancing the probability of the continuum electron around the parent ion. They have shown that, for the solar mixture, the opacity in the solar interior is enhanced by about 20%, which is close to the required modification for the solar model. This study provides a possible solution to the long-standing “solar abundance problem”. Apart from the Sun, such a large revision of opacity should lead to significant variations for all stellar models. Further relevant findings could be expected due to the revision of opacity.

- 1 J. E. Bailey, T. Nagayama, G. P. Loisel, G. A. Rochau, C. Blancard, J. Colgan, P. Cosse, G. Faussurier, C. J. Fontes, F. Gilleron, I. Golovkin, S. B. Hansen, C. A. Iglesias, D. P. Kilcrease, J. J. MacFarlane, R. C. Mancini, S. N. Nahar, C. Orban, J. C. Pain, A. K. Pradhan, M. Sherrill, and B. G. Wilson, *Nature* **517**, 56 (2015).
- 2 M. Asplund, N. Grevesse, A. J. Sauval, and P. Scott, *Annu. Rev. Astron. Astrophys.* **47**, 481 (2009), arXiv: 0909.0948.
- 3 A. M. Serenelli, S. Basu, J. W. Ferguson, and M. Asplund, *Astrophys. J.* **705**, L123 (2009), arXiv: 0909.2668.
- 4 J. Christensen-Dalsgaard, and G. Houdek, *Astrophys. Space Sci.* **328**, 51 (2010), arXiv: 0911.4629.
- 5 J.-L. Zeng, C. Gao, P.-F. Liu, Y.-J. Li, C.-S. Meng, Y. Hou, D.-D. Kang, and J.-M. Yuan, *Sci. China-Phys. Mech. Astron.* **65**, 233011 (2022).

*Corresponding author (email: zqs@ynao.ac.cn)