WORKSHOP ON ASTROPHYSICAL OPACITIES

COVER ILLUSTRATION:

The Solar Interior

Natalya Critchley, Caracas, 2017.

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WORKSHOP ON ASTROPHYSICAL OPACITIES

Proceedings of a workshop held at
Fetzer Center, Western Michigan University, Kalamazoo, MI 49008, USA
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IN MEMORIAM

John N. Bahcall (1934–2005)

Arthur N. Cox (1927–2013)

David G. Hummer (1934–2015)

Dimitri M. Mihalas (1939–2013)

Forrest J. Rogers (1938–2013)

Michael J. Seaton (1923–2007)

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Preface

The present volume contains the proceedings of a workshop that took place during the first week of August 2017 in Western Michigan University, Kalamazoo, Michigan, USA, to discuss in extenso the topic of astrophysical opacities and to review new updates in the field.

A previous Workshop on Astrophysical Opacities (WAO) was held at the IBM Venezuela Scientific Center, Caracas, in July 1991 to evaluate the physics and preliminary results of a major revision of the metal opacities by two independent teams: OPAL and the Opacity Project (OP). This revision was required at the time in the face of long-standing discrepancies in stellar pulsation and evolution studies referred to collectively as the *Cepheid mass problem.* It was also the time of the first encounters of the opacity groups (OPAL, OP, and CEA) with helioseismologists, who were making preparations for the launch of the Solar and Heliospheric Observatory (SOHO), the longest-lived and most productive heliophysics probe.

In the present occasion the meeting was motivated by two turning points in astrophysical modeling: the solar abundance problem and the exoplanet explosion.

The solar abundance problem arose in 2005 through a downward correction of the solar metal abundances resulting from three-dimensional hydrodynamic simulations of the solar photosphere, which took into account non-LTE and granulation effects. This new endorsement downgraded the precise reproduction of the helioseismic benchmarks by the Standard Solar Model, thus casting doubts on the reliability of the opacity tables in spite of satisfactory agreement between OPAL and OP. The accuracy of the opacity tables has also been questioned in analyses of recent asteroseismic observations of hybrid B-type pulsators. Both of these cases appear to suggest additional radiative absorption processes not accounted for.

This critical situation has led to extensive comparisons of the bases of opacity computations (accurate and complete atomic datasets, equation of state, line broadening, high-density effects, to name a few), to the emergence of new numerical approaches that handle more efficiently the very large numbers of spectral lines (e.g., *super-transition arrays*); and innovative laboratory experiments (namely, on the Z facility at Sandia National Laboratories). However, the latter has engendered a new and puzzling disagreement between theory and experiment that is still unresolved, and the missing stellar opacity remains elusive. It is worth noting that the importance of opacities in the study of stellar interiors and the need for experimental validation of the computed tables have encouraged the upgrade of large-scale laser facilities, such as the National Ignition Facility (NIF) and Laser MegaJoule (LMJ), to handle plasmas at very high temperatures.

The exoplanet explosion began in the mid 1990s with the discovery of the first planets orbiting other main-sequence stars and with the thousands more detected since then by the space probes *Kepler* and *Corot*. The possibilities of modeling brown-dwarf and exoplanetary atmospheres and protoplanetary disks have hugely escalated the demand for comprehensive molecular opacities, which have been addressed by ambitious projects such as HITRAN and ExoMol. Such studies also require opacities from sources such as aerosols and dust, whose accuracy and scope are far from fulfilling present needs. Moreover, with the discovery of Earth-like exoplanets, determining well-defined atmospheric biosignatures has caught the attention of both producers and users of molecular spectroscopy data due to their inherent complexity and breadth.

The WAO attracted a sizable group of experts who found in the Fetzer Center of Western Michigan University comfortable and cozy surroundings for open discussion on most of the aforementioned topics. Stellar atomic diffusion and the use of stellar observations to test the accuracy of both opacities and atomic databases were also considered, as well as basic atomic processes such as dielectronic recombination and K absorption. Hardly a fortnight after the WAO, the worldwide astronomical community witnessed in awe the binary neutron-star merger GW170817 that gave birth to the new era of multi-messenger astronomy. This type event has been found to produce copious heavy elements (e.g., lanthanides) through rapid neutron capture, whose thick opacities need extensive refinement before the ensuing transient light curve can be properly characterized.

Finally, we would like to dedicate this volume in memoriam to six exceptional scientists—John N. Bahcall, Arthur N. Cox, David G. Hummer, Dimitri M. Mihalas, Forrest J. Rogers, and Michael J. Seaton—who dedicated a great part of their scientific work to the advancement and applications of this important field. Their contributions were seminal, their leadership and legacy shaped indelibly its cutting edge, and their mentoring is well imprinted in the intellectual lucidity of many of us.

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