Ionization and transport in partially ionized multi-component plasmas: Plasma model for atmospheres of hot Jupiter

Sandeep Kumar, Anna Julia Poser, Manuel Schöttler, Uwe Kleinschmidt, Martin French, and Ronald Redmer

Institute of Physics, University of Rostock, Rostock, Germany

e-mail: sandeep.kumar@uni-rostock.de or sandeepshukla1112@gmail.com

Partially ionized multicomponent plasmas are composed of molecules, atoms, and ions of various species as well as of free electrons. Profound knowledge of ionization and transport of multicomponent plasmas is important for applications in astrophysics, atmospheric science, and plasma technology. Earth's ionosphere and the atmospheres of hot Jupiters and hot mini-Neptunes can be treated as low density partially ionized multicomponent plasmas.

Interaction of the fierce winds with hot Jupiter planetary magnetic field induces electric currents that can flow deeper into the planet. When efficient enough, the related Ohmic heating transports a sufficient fraction of the stellar irradiation received by the planet to deeper interiors where it could explain the inflation.[1] Electrical conductivity plays a key role in calculation of Ohmic heating in the atmosphere of the planet.

In this study we calculate the ionization degree, the electrical and thermal conductivity, and the Lorenz number for a PIP as a function of temperature and mass density.[2] Mass-action laws (MALs) are used to calculate the composition of the PIP. We assume that the plasma is in thermal and chemical equilibrium so that Saha-like equations for each dissociation and ionization reaction can be derived, from which the partial densities of all species are calculated, i.e., the plasma composition. Furthermore, the electronic transport properties are determined by the electron-ion and electron-neutral transport cross sections.[3] The effect of electron-electron scattering is considered by introducing a correction factor to the electron-ion contribution according to the Spitzer theory. The contributions of the translational motion of neutrals and of the heat of dissociation, ionization, and recombination reactions to the thermal conductivity of PIP is also studied. In the next step we calculate the ionization degree as well as the electrical and the thermal conductivity along typical pressure-temperature (P-T) profiles through the atmosphere of the inflated hot Jupiter HD 209458b, which is shown in Fig. 1. These results are used to assess the Ohmic heating in the planet's atmosphere and to infer whether this effect is efficient enough to explain the inflation in HD 209458b.

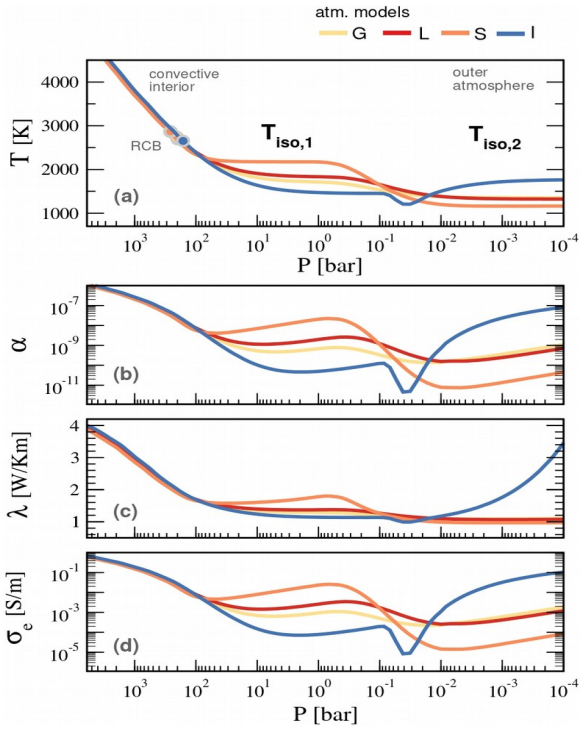

Fig. 1: Temperature T, ionization degree α, thermal conductivity λ, and electrical conductivity σ_e for different planetary interior models along the pressure axis of HD 209458b. Circles in the temperature profile represent the location of the radiative-convective boundary (RCB).

References:

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[3] M. French and R. Redmer, Phys. Plasmas 24, 092306 (2017).