In the two and a half decades since its inception in the early 1990s, exoplanetary science has evolved into a major research field, and today inspires scientists and the public the world over. It is now possible to directly probe the atmospheres of these extrasolar planets and attempt to understand their diversity. The work presented here in my Ph.D. thesis focuses on modelling the upper atmospheres of some of these other worlds. The upper atmosphere is the interface of the planet with the space environment and in particular is highly influenced by emissions from the planet’s host star. Stellar emissions are very different from star to star, and as such, my work attempts to understand the influence of different types of stars on exoplanetary upper atmospheres, in particular in the case of gas giants, such as Jupiter-like planets or the more extreme Hot Jupiters. The latter are planets that are in extremely close orbits; in many cases, they are found to be over ten times closer to their star than Mercury is to our Sun.

Given this very close proximity to the star, the upper atmospheres of Hot Jupiter planets are subject to extreme radiation conditions that can result in rapid atmospheric escape. It is the high-energy portion of the stellar spectrum that is absorbed in the upper atmosphere and regulates its composition and structure. This stellar emission depends on star type and age, which are thus important factors in understanding the behaviour of exoplanetary atmospheres. The work described in this thesis details the new 1D ionospheric model to describe the upper atmospheres of Extrasolar Giant Planets (EGPs) I developed during my Ph.D. research. The model is time-dependent and includes photo-chemistry and diffusive transport. Electron-impact ionisation processes are taken into account through coupling with a suprathermal electron transport code. Neutral composition and temperature profiles are obtained by using a thermospheric model that incorporates atmospheric escape. Atmospheres composed of H, H₂, He, and their associated ions are considered.

The first chapter of this manuscript presents a detailed introduction to the research field and provides a review of the state of the literature as it stood in early 2015, upon examination of the work.

In Chap. 2, I discuss the efforts that I have made to obtain accurate X-ray and Extreme Ultraviolet (EUV) spectral irradiance of the stars studied. To this effect,
synthetic spectra are used originating from a detailed coronal model for three different low-mass stars of different activity levels: ε Eridani, AD Leonis, and AU Microscopii. A novel method to scale the EUV region of the solar spectrum based upon stellar X-ray emission is developed here.

Chapter 3 focuses on the neutral layer of upper atmosphere known as the thermosphere. I find that in planets irradiated by highly active stars, the critical orbital distance—where atmospheric escape transitions from slow, Jeans escape to rapid, hydrodynamic escape—is larger than in planets orbiting low activity stars (such as the Sun). To correctly estimate the critical orbital distance of this transition, the spectral shape of stellar XUV radiation is important. I find that using the novel scaling method for the stellar spectrum developed in Chap. 1 produces an outcome in terms of the planet’s upper atmosphere and escape regime that is very similar to that obtained using a detailed coronal model of the host star.

Chapter 4 moves on to examine the ionised upper atmosphere—the ionosphere. This work is the first study of the ionosphere of EGPs that takes into account the different spectral energy distribution of low-mass stars. I find that EGP ionospheres at all orbital distances and around all stars studied are dominated by the long-lived H+ ion. In addition, planets in the Jeans escape regime also have a layer in which H³⁺ is the major ion at the base of the ionosphere. For fast-rotating planets, H³⁺ densities undergo significant diurnal variations, their peak value being determined by the stellar X-ray flux. In contrast, H⁺ densities show very little day/night variability and their value is determined by the level of stellar EUV flux. The H³⁺ peak in EGPs in the rapid hydrodynamic escape regime under strong stellar illumination is pushed to altitudes below the homopause, where this ion is likely to be destroyed through reactions with heavy species (C, O, etc.).

Finally, in Chap. 5, a summary of the work can be found, as well as a discussion of future avenues to be explored. Since the end of my Ph.D. in 2015, I have continued to develop some of these lines of research along with my collaborators. Updates to the work produced in each chapter are presented at the beginning of these in a short ‘note from the author’ section.

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May 2017
Modelling the Upper Atmosphere of Gas-Giant Exoplanets Irradiated by Low-Mass Stars
Chadney, J.
2017, XII, 169 p. 85 illus., 70 illus. in color., Hardcover
ISBN: 978-3-319-63350-3