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Modeling the Upper Atmospheres of Exoplanets: Energy Deposition and Escape

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Abstract

The upper atmospheres of exoplanets are subject to two important energy sources derived form the host star. First, the stellar photon flux in the EUV and XUV ionizes and heats the upper atmosphere, driving atmospheric heating, affecting the conductance, and enhancing atmospheric escape. Second, the stellar wind's interaction with the planet's intrinsic magnetic field transfers energy to the atmosphere through field aligned currents and Poynting flux. That energy is dissipated in the high latitude cusp and auroral regions through Joule heating which can inflate the atmosphere and also enhance the escape rate. This presentation will discuss recent advances in modeling these energy inputs and there consequences for exoplanetary habitability.

1. Introduction

Recent Kepler observations revealed hundreds of terrestrial type exoplanets around G to M dwarfs. Many of the detected exoplanets are located close to their host stars and are exposed to large fluxes of ionizing radiation. How do exoplanetary atmospheres respond to such harsh stellar environments? This presentation discusses modeling the upper atmospheres of exoplanets with a focus on three key parts. Section 1.1 provides an overview of atmospheric escape processes and discusses how enhanced EUV and XUV inputs, typical for close-in exoplanets around active K-M dwarfs, may lead to significant atmospheric loss through the ionospheric outflow process. Section 1.2 presents recent results demonstrating how the extreme stellar wind conditions encountered by many exoplanets leads to enhanced Joule heating of those atmospheres and discusses the role of ionospheric conductivity in modulating the efficiencies of the energy transfer from the wind to the planet. Finally, Section 1.3 discusses new model development to address these interesting problems including new calculations for ionospheric conductivity and upper atmospheric response.

1.1. Atmospheric Escape

Figure 1 presents a schematic summary of the different atmospheric escape processes. Many of these processes are independent of the planet's magnetic field. For example Jeans escape, which considers the portion of the distribution function above escape velocity, and hydrodynamic escape, a strong thermally driven bulk flow, have no terms related to the planet's field. On the other hand, the loss of atmosphere through collisional interaction with the stellar wind, known as sputtering, can be reduced when the planet has a strong field to shield the atmosphere from the influx of stellar wind particles. In contrast, ionospheric outflow can actually be enhanced by planetary magnetic fields as the field can collect and funnel energy from the wind into the planet.

In this presentation we will discuss atmospheric escape and it's implication for atmospheric evolution. In particular, we will focus on recent results demonstrating how EUV and XUV inputs lead to atmospheric loss for close-in exoplanets such as Proxima Cen b [3, 1]. We show the scaling of ionized particle escape rates with XUV input and discuss the importance of thermospheric heating and magnetic field interactions.

1.2. Joule Heating

The habitable zone around faint M-dwarfs is very close to the star. While such conditions are favorable for detection, the extreme conditions encountered by this class of planets is extreme. In the case of TRAPPIST-1, planets e,f, and g are located at less than

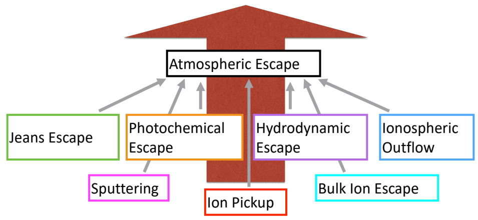

Figure 1: A schematic summary of the myriad of processes involved in atmospheric escape.

0.05 AU and are essentially inside the stellar corona. These stellar wind conditions may lead to heating and evaporation of the planetary atmosphere. Such conditions pose a challenge to whether such planets can truly be considered habitable. We present results from our recent paper examining the limits of the energy transmitted from the intense stellar wind to the upper atmosphere of the TRAPPIST-1 planets using an analytic formalism [2]. We explore the importance of the atmospheric conductivity in modulating the energy transmission and compare the energy transmission to other energy inputs from the star.

1.3. New Model Developments

In addition to the science results of the previous two section, we discuss new developments required for modeling energy input and effects in the upper atmospheres of exoplanets. In particular, we discuss improved approaches for calculating the conductivity and ohmic dissipation for exoplanet applications. We also present initial results of these new model developments.

Acknowledgments

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