Effects of Superflares from Active Stars on Atmospheric Escape: Implications for the Early Earth .

V. S. Airapetian[1], A. Glocer[2], Khazanov[2]

[1]Code 671, NASA/Goddard Space Flight Center (Vladimir.Airapetian@nasa,gov), [2]Code 673, NASA/Goddard Space Flight Center

Introduction: As the number of observed exoplanets skyrockets, the field of exoplanetary science is still searching for a better understanding of whether or when life may have begun on those planets – or how long they could remain viable habitats for life. The stability of water, the major "soilvent of life", is a function of both temperature and pressure, and the effects of pressure have not been esxtensively studied. This includes the effects of atmospheric pressure on the habitability histories of Earth and Mars. Atmospheric pressure is controlled by a variety of physical processes that can contribute to escape, and these properties must be placed in the context of both the host star and the entire planetary atmosphere. Recent reconstructions of the spectral distribution of coronal and chromospheric emission from young and middle-aged K-M stars (1,2] provide a great opportunity to investigate the effects of their radiative output on the outer atmospheres of the early Earth and its twins. Modeling the escape of ions and electrons above the atmospheric exobase presents several challenges not present in neutral atmosphere models. Unlike in the usual Jeans escape scenario, the more mobile electrons would outrun the ions in the absence of a radially directed polarization electric field to trap some of the escaping electrons. Thus, a radially directed electric field self-consistently set up to enforce the quasi-neutrality and zero radial current conditions. For ionospheric ions, the polarization electric field cancels a substantial part of the gravitational potential barrier, greatly enhancing the flux of escaping ions. Another challenge in treating ionospheric escape is that the transition from collision-dominated (local thermodynamic equilibrium) to weakly collisional (non-local transport) physics above the exobase involves a breakdown of the hydrodynamics models often employed to model ionospheric outflow. Modeling these effects requires a kinetic model of the super-thermal electron component.

In this study we focus on the role of the astrophysical drivers, specifically: the effects of X-ray/ EUV/EU emission produced by quiescent corona and energetic eruptive events on atmospheric mass loss [3]. We employ a Fokker-Planck code coupled with the Polar Wind Outflow Model (PWOM) [4] to simulate the effects of atmospheric loss caused by the photoionization of the upper atmosphere of the early Earth due quiescent and flare short-wavelength stellar emission within the range of 0.5 Å -1750 Å. The model calculates the photoionization and photoexcitation processes at all altitudes. The primary photoelectrons are then transported, and the electron impact is computed solving the stationary kinetic Boltzmann equation. This results in the ionization and excitation of the different atmospheric species. The 1D multi-fluid model, PWOM, then solves the equations of continuity, momentum conservation and energy conservation for O^+, H^+ and He^+. The electron density and bulk velocity moments are determined from the quasi-neutrality and current conservation constraints together with an energy equation for the thermal electrons and a kinetic treatment of the super-thermal electron component. The polarization electric field is found from these quantities through the electron momentum equation. A separate energy equation is used to evolve the electron temperature. Neutral N_2, O_2, O and H are treated as a static fixed atmosphere that reacts collisionally and chemically with the ions, including such effects as photoionization and charge exchange.

We calculate the spectra of the population of primary and secondary (cascading) suprathermal (E<600 eV) photoelectrons and then produced mass outflow of hydrogen, oxygen and nitrogen ions in the early atmosphere. Our results suggests that the most intensive loss of water and nitrogen from the Earth's atmosphere occurred in the first 300-400 million years after the formation of Earth. These effects of non-thermal escape were therefore crucial in preventing the habitability of Earth in the first 0.5 Gyr.

References:

[1] Ribas, I., Guinan, E. F., Gudel, M., & Audard, M. 2005, ApJ, 622, 680.

[2] Claire, M. W.; Sheets, J., Cohen, M., Ribas, I., Meadows, V. S., Catling, D. 2012, ApJ, 757, 95.

[3] Airapetian, V. and Khazanov, G. 2014, Proc. of AGU Fall 2014, SM51B-4250.

[4] Glocer, A., Kitamura, N., Toth, G., & Gombosi, T. 2012, *J. of Geoph. Res,*, *117*(A4).doi: 10.1029/ 2011 JA017136.