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Stellar activity and its influence on planetary atmosphere evolution

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Abstract

The evolution of planetary atmospheres can only be understood if one recognizes the fact that the radiation and particle environment of the Sun or a planet's host star were not always on the same activity level. New insights, the latest observations and research regarding the evolution of the solar radiation, plasma environment and solar/stellar magnetic field from the observations of solar proxies and their impact on planetary atmospheres with different ages will be given. We present also a new innovative idea how hydrogen coronae and energetic neutral atom (ENA) observations around transiting Earth-like exoplanets by space observatories such as the WSO-UV, can be used for testing the addressed atmospheric evolution studies.

1. Introduction

A planet's host star always plays a major role in relations regarding the evolution of planetary atmospheres [1]. During the past decade the study of the history of our Sun and its influence on the evolution of Solar System planets has become an interdisciplinary effort between stellar astronomy, astrophysics of star and planet formation, astrochemistry, solar physics, geophysics, planetology, as well as climatological science. Since the discovery of exoplanets around other stars, the importance in understanding the historical evolution of stars is obvious. Their radiative energy, the plasma outflow, and various forms of transient phenomena such as shockwaves, high-energy particle events during flares, and Coronal Mass Ejections (CMEs) are key factors in the formation and atmospheric evolution including habitability (e.g., [2, 3, 4]). We will discuss the latest research findings in these fields and present a new innovative idea how one can test the atmospheric evolution theories by transit observations of Earth-size exoplanets with space observatories like the WSO-UV, PLATO, etc., which are exposed to higher SXR/EUV fluxes of M-type dwarf stars.

2. From stars to planet atmospheres in time

To understand the impacts of the radiation and particle environment of young stars on early planetary atmospheres one has to consider the following main facts [5, 6]:

- Young stars rotate more rapidly and have an internal magnetic dynamo that is more efficient than that of the present day Sun. This results in stronger surface magnetic fields and/or higher surface magnetic filling factors which induce enhanced "activity" in all its variations, from larger surface spots to a stronger, extended solar wind.
- The optical and infrared emissions of the young star largely control the planetary atmosphere and its related climate. The X-ray, SXR, EUV photons as well as the interaction with high-energy particles and the solar/stellar wind leads to atmospheric

modifications which can be observed by satellites.

We present data from solar and astrophysical observations which indicate strong evidence that the Sun-like main sequence stars underwent very active phases after they arrived at the zero-age-main-sequence. The enhanced activity reveals itself in the form of strong high energy radiation emissions, frequent flares, and a denser and faster stellar wind. Coronal X-ray and EUV emissions of the very young main-sequence Sun were about 1550 and about 80 times stronger than those of the present Sun [5, 6].

3. Observations and model

To understand how planetary atmospheres can overcome the extreme X-ray, SXR and EUV activity of their host stars after they arrived at the ZAMS, one has to combine thermal and non-thermal upper atmosphere processes by developing a self-consistent multi-species ionospheric-thermospheric exosphere model which couples thermal and non-thermal processes, for studying hydrostatic and non-hydrostatic dynamically expanding thermosphere-exosphere regions, including the investigation of the production of hot atoms, their collisional interaction and transport within highly EUV exposed thermosphere-exosphere regions, and their contribution to the thermospheric heat budget.

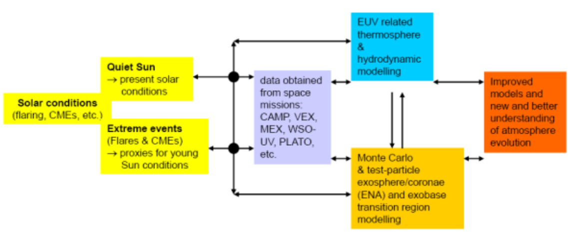

Figure 1: Illustration about the connections between observations, processes and modeling efforts which are important for understanding and characterizing atmospheric evolution aspects for terrestrial planets.

Finally model results should be confirmed by observations. Therefore, we present an idea for testing atmospheric evolution scenarios by UV-transit observations of Earth-like exoplanets around M-stars. Such a detection and investigation of EUV heated, non-hydrostatic thermospheres around terrestrial exoplanets would provide important insights into the interaction of the host stars plasma environment as well as the evolution of Earth-type planets, their atmospheres and possible magnetospheres. We show that extented hydrogen coronae and energetic neutral atoms (ENA) will be produced via charge exchange processes. By observing the size of the extended upper atmospheres and related ENA-clouds and by determining the velocities of the surrounding hydrogen atoms, conclusions can be drawn in respect to the origin of these features [7]. Thus, observations of M-star exoplanets discovered from the ground or in the future by ESA's currently studied PLATO mission [9] together with transit follow-up in the UV-range with space observatories such as the WSO-UV [8] would provide a unique opportunity to shed more light on the early evolution of Earth-like planets, including those of our own Solar System.

6. Summary and Conclusions

We show the impacts of the energy and particle environment to the origin and evolution of terrestrial planets and their atmospheres. Due to the heating of the much higher solar/stellar SXR and EUV flux the planetary thermospheres and exobase levels extend to higher altitudes than for the present time Sun, caused by denser and faster stellar wind. No protection of intrinsic magnetospheres leads to the extent interaction areas between atmosphere and the stellar wind, so that huge hydrogen ENA-clouds are produced and higher non-thermal escape rates are expected. Finally we address the possibility of studying the detection and follow-up observations of atmospheres which are modified by the stellar radiation and plasma environment around exoplanets with near future space observatories such as ESAs PLATO mission in combination with the WSO-UV space telescope. Such observations would enhance our knowledge regarding the interaction of the host stars plasma environment and with Earth-like exoplanets itself, as well as shed light into the evolutionary stage of their atmospheres.

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