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How relevant are intrinsic magnetic fields in planetary atmosphere evolution?

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Abstract

The escape of atmospheric constituents from a planetary atmosphere is strongly connected to the evolution of the radiation and particle environment of the host star. At Earth, the most efficient heating processes in the early planetary thermospheres are the collisions between electrons (fast and thermal) and ions that are created by photoionization of atmospheric neutrals. For this reason the most important wavelength range relevant for heating is the EUV radiation at wavelengths less than 100 nm which ionizes CO_2, CO, N_2, and O. Based on a large number of X-ray, SXR, EUV, FUV, and UV observations of a sample of single nearby G0V main sequence stars with well-known rotation periods, physical properties, luminosities and ages between 100 Ma to 8.5 Ga, the time evolution of the Sun's activity in the wavelength range between 0.1 – 120 nm can be estimated [e.g., 1]. From these multi-wavelength observations and studies of solar proxies one can conclude that the solar integrated flux over 0.1 - 120 nm (EUV) was higher by a factor of six about 3.5 Ga ago, and about 20 times higher 4.2 Ga ago compared to the present solar value. During the first 100 million years after the Sun arrived at the zero-age main-sequence (ZAMS), the integrated EUV flux could have been even up to 100 times more intense than today [1]. Furthermore, stellar mass loss observations and modelling results of [2, 3] suggest that Sun-like stars after arriving at the ZAMS will have a significantly higher plasma outflow than the present sun. The region of the atmosphere where the main part of the EUV radiation is absorbed and a substantial fraction of its energy is transformed into heat extends from about 100 to 210 km in the CO2-rich atmospheres of present Mars and Venus, and from about 90 to 500 km in the nitrogen-rich atmosphere of present Earth. Recent aeronomical studies [4, 6, 7, 8] indicate that enhanced stellar X-ray and EUV radiation and plasma outflows can result in permanent forcing of the upper atmospheres of terrestrial planets, which can ionize, heat, expand, chemically modify, and erode it during the early phase of a planetary lifetime. In case the upper atmosphere expands beyond a protecting magnetopause, the planet can thus be in danger of being stripped of its whole gaseous envelope. Under these extreme conditions, the exobase might have expanded above the magnetopause and the magnetosphere had not been able to protect the upper atmosphere against strong non-thermal erosion by the solar wind. We present model results which show how the solar wind induced plasma erosion may have affected the atmospheres of early Earth and Mars, and discuss under which atmospheric conditions a magnetosphere could have acted as a protection against atmospheric erosion. Moreover, we discuss the possibility for the observation of thermosphere-magnetosphere environments under extreme stellar/(young Sun conditions) by using ENA-cloud/corona production in the surrounding of exoplanets as a proxy for example early Earth.

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