Long-term planetary evolution: Solar radiation and particle induced effects on the early Martian atmosphere and loss

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The evolution of the Martian atmosphere with regard to its H_2O inventory is influenced by thermal loss and non-thermal atmospheric loss processes of H, H_2, O, N, C, CO, CO_2, H^+, O^+, H_2^+, $N2^+$, CO^+, CO_2^+, and O_2^+ into space, as well as by chemical weathering of the surface soil. The epochs related to escape of the atmosphere and water from Mars over long-term periods can be divided into 3 epochs, the present Mars, the period between the present and 3.5 Gyr ago and the first billion years. The evolution of all escape processes depend on the history of the intensity of the solar X-ray and EUV (XUV)radiation and the solar wind density. Thus, we use actual data from the observation of solar proxies with different ages from the Sun in Time program for reconstructing the Sun's radiation and particle environment from the present to 4.6 Gyr ago. We compare different model investigations for the non-thermal escape processes (ion pick up, sputtering, ionospheric clouds triggered by the Kelvin Helmholtz plasma instability) of the Martian atmosphere over long-time periods and discuss the effect on the total loss to the Martian CO_2 and/or H_2O inventory. We apply a thermospheric model to the CO_2-rich atmosphere of Mars that have been modified to high XUV flux values expected during the Sun's evolution. During the first Gyr after the Sun arrived at the Zero-Age-Main-Sequence high XUV fluxes between 10 - 100 times that of the present Sun were responsible for much higher temperatures in the thermosphere-exosphere environments on both planets. By applying a diffusive-gravitational equilibrium and thermal balance model for investigating radiation impact on the early thermospheres by photodissociation and ionization processes, due to exothermic chemical reactions and cooling by CO_2 IR emission in the 15 μm band we found expanded thermospheres with exobase levels between about 200 (present) to 2000 km (4.5 Gyr ago). Our model results indicate that the high temperature in the thermosphere-exosphere environment on early Mars could reach "blow-off" conditions for H atoms even at high CO_2 mixing ratios of 96 %. Furthermore, we show that lower CO_2 / N_2 or CO_2 mixing ratios in general, or higher contents of H_2O-vapor in the early Martian atmosphere could have had a dramatic impact on the loss of atmosphere and water on early Mars. The duration of this phase of high thermal loss rates essentially depended on the mixing ratios of CO_2, N_2 and H_2O in the early atmosphere. Lower CO_2 mixing ratios on early Mars shortly after its volatile out-gassing could have had a major impact on the thermal loss of the main atomic atmospheric species (O, N, C) combined with impact erosion and loss of O due to dissociative recombination in the dense solar XUV-produced early Martian ionosphere. One should note that thermal and photochemical loss process are independent from an early Martian magnetosphere because these atomic species escape as neutrals. Furthermore, a combination between an expanded thermosphere-exosphere region and a stronger early solar wind could have also enhanced ion pick up loss during the period where the Martian magnetic dynamo decreased.