RADIATION AND PARTICLE EXPOSURE OF THE MARTIAN PALEOATMOSPHERE: IMPLICATIONS FOR THE LOSS OF WATER


(1) Centro de Astrobiologia (CSIC/INTA), Ctra Ajalvir, km 4, 28850 Torrejón de Ardoz, Madrid, Spain
Email: selsis@observ.ubordeaux.fr
(2) Space Research Institute, Austrian Academy of Sciences, Schmiedlstr. 6, A-8042 Graz, Austria
Phone: +43 316 4120641, Fax: +43 316 4120690, Email: helmut.lammer@oeaw.ac.at
(3) Department of Astronomy and Astrophysics, Villanova University, Villanova, PA 19085, USA
Email: iriba@am.ub.es, guinan@ucis.vill.edu
(4) Departament d’Astrometria i Meteorologia, Universitat de Barcelona, Av. Diagonal 647, 08028 Barcelona, Spain
(5) Instituto de Astrofisica de Andalucía, Camino Bajo de Huétor 24, P. O. Box 3004, 18080 Granada, Spain
Email: lara@iaa.es
(6) Institute for Geophysics, Astrophysics and Meteorology, University of Graz, Universitätsplatz 5, 8010, Graz, Austria
Email: arnold.hanslmeier@kfunigraz.ac.at

ABSTRACT

Multi-wavelength studies of solar like G-type stars at several stages of their main sequence evolution indicate that our Sun may have also undergone a highly active phase in its particle and radiation evolution 3.0-4.5 Gyr ago. Detailed observations of such Sun-like stars by the ROSAT and ASCA X-ray satellites as shown in Fig. 1 indicate that the X-ray luminosity (see Fig. 1) and solar wind density of the early Sun may have been several hundred times higher than today [1]. Studies of isotope anomalies in planetary atmospheres and meteorites suggest also that our early Sun underwent a very active phase after its origin that included continuous flare events and had a particle and energy irradiance several hundred times stronger than today. The early Martian atmosphere proves to be a very efficient shield for X-rays: with the exception of very hard X-rays (1 < 20 Å) which penetrate deeper into the atmosphere, the longer wavelength is absorbed in the atmospheric upper layers. This high altitude absorption results in an energy deposition at low-density levels that further enhance the thermal and nonthermal escape processes already known to be driven by the high EUV radiation and solar wind particle interaction. We discuss also the consequences of hydrodynamic escape of water and pick up ion processes from early Mars.

1. RADIATION AND PARTICLE FLUXES OF SOLAR PROXIES

The amount of absorption in the HI areas surrounding Sun-like stars was used as a diagnostic for their stellar mass loss rates [e.g., 1, 2].

Fig. 1. Complete spectral irradiance (flux at 1 AU vs. wavelength) for EK Dra, the youngest star in the Sun in Time sample. Note the high flux at short wavelengths [1].

The correlation between mass loss and the emitted X-ray flux allows a power law relation, who indicates a solar wind up to 1000 times more massive in the distant past. Mass loss rates of cool main sequence stars depend on activity, stellar wind densities and rotation periods by following a non-linear correlation between mass loss rate and age. Such a dense early solar wind has important implications for the history of planetary atmospheres and evaporation effects on the surface of planetary bodies, like Mercury. Fig. 2 show the evolution of the solar wind density, estimated from the observed stellar winds of solar like stars [1].

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At atmospheric conditions where $X(R)$ is less equal 1.5 the diffusive fractionation according to atomic or molecular mass vanishes, since the level at which atmospheric constituents escape move below the exobase into the bulk atmosphere and results in hydrodynamic escape. By using our solar proxies the evolution of the solar EUV luminosity with time shows that the EUV luminosity is about 3 times and 6 times the present value 2 Gyr and 3.5 Gyr ago and about 100 times at the period of EK Dra (130 My) (Fig. 4).

**Fig. 4.** Escape parameters for H and O at Mars as a function of exospheric temperature. One can see that we get hydrodynamic escape conditions for H on early Mars around time periods, which resemble the solar EUV luminosity close to EK Dra.

**CONCLUSIONS**

By using the solar EUV fluxes obtained from observations of solar like stars our preliminary study shows that the exosphere temperature on Mars should have reached the critical level on Mars of about 1000 K, that hydrodynamic escape conditions could occur after the Martian atmosphere was formed. This results in a strong escape of water from early Mars.

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**REFERENCES**


2. HYDRODYNAMIC ESCAPE CONDITIONS ON EARLY MARS

We use the solar EUV fluxes obtained from five “Sun in Time” stars, for the evolution of the solar EUV luminosity. This model is based on the observation of solar-type stars for guiding us to adjust conditions, which represent the Martian past.

$$X(R) = \frac{G M m_{\text{p}}}{R \sqrt[3]{k T_{\infty}}} \frac{v^2_{\infty}}{u_{\infty}}$$

Eq. 1 shows the escape parameter $X(R)$, the planetary mass $M$, particle mass $m$, gravitational constant $G$, radius $R$, Boltzmann constant $k$ and exosphere temperature $T_{\infty}$.

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**Fig. 2.** The history of the solar wind density with about 2 protons cm$^{-3}$ at present and at 1.5 A.U. for low, average and large solar mass loss rates, estimated with the power law below from solar-like stars.

**Fig. 3.** Shows a strong solar wind interaction and ion pick up fluxes for H+, H$_2^+$ and O+ ions resulting in atmosphere erosion obtained from a test particle model [2] 3.5 Gyr ago.

**Fig. 3.** Simulated flux distribution of escaping H+, H$_2^+$ and O+ ions at Mars 3.5 Gyr ago. The fluxes are shown through a plane perpendicular to the Sun-Mars line at a distance $x = -2$ downstream of Mars (all scales are in Martian radii). The electric field points into the $+y$ direction and causes the north-south asymmetry, while the interplanetary magnetic field is in the $xy$-plane. Since the gyroradius of oxygen ions is relatively large, most of the O+ flux is found in a region with $y > 3$ and therefore not seen in the Figure.

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