ON THE EFFECT OF THE OBLIQUITY OF MARS TO THE HYDROGEN ESCAPE AND THE FATE OF WATER IN THE LAST MILLIONS OF YEARS.

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Introduction

The climate of a planet depends on its orbital and rotation parameters, and in particular on the obliquity (i.e. inclination of its axis of rotation to its orbit plane). While for the Earth the oscillations of those parameters are small (± 1.3° for obliquity), in the past 250 Myrs Mars's axis inclination covered a large range of variations, between 0 and 66°, with a mean obliquity of about 35° [Laskar et al., 2004]. Different orbital configurations induce significant modifications in fundamental aspects of the Martian climate, mainly due to the differences in the distribution of the insolation, such as the CO_2 cycle (and thus the surface pressure),the dust and water cycle, or the global circulation [Forget et al., 2017]. The north pole insolation is a key parameter controlling the stability of water ice of the northern polar cap. As shown in Figure 1 it could have varied up to 350 W m^{-2} in the past 20 million years.

Mars was not always as dry as it is today, as several geologic and mineralogical observations indicate the evidence for past liquid water: valley networks and lakes are still visible on the surface [Bibring et al., 2004]. Loss to space appears to explain why the Mars atmosphere evolved from an early, warmer climate to the cold, dry climate that we see today. Substantial amounts of water could have escaped into the interplanetary medium in the form of atomic hydrogen [Jakosky et al., 2018]. Furthermore, recent observations indicate that the amount of exosphere hydrogen at Mars has important seasonal variations, with significant increases of both the water abundance in the mesosphere and the H escape rate during dust storms [Chaffin et al., 2014, Clarke et al., 2014]. By analysing observations by SPICAM on board Mars Express and simulations with the LMD Mars General Circulation Model (LMD-MGCM), Chaufray et al. [2021] suggested that episodic dust storm and associated enhancement at high altitude near the perihelion, averaged over one Martian year or longer period, are a major factor in the H escape estimates. Nevertheless, the accumulated water lost at the estimated rate for 4 billion years is much lower than the amount of water needed to form the flow channels observed on Mars. Both the dust content and the water content of the atmosphere are expected to vary with the obliquity of the planet, thus, the loss rate definitely is not expected to have been constant with time and may vary significantly during Martian history.

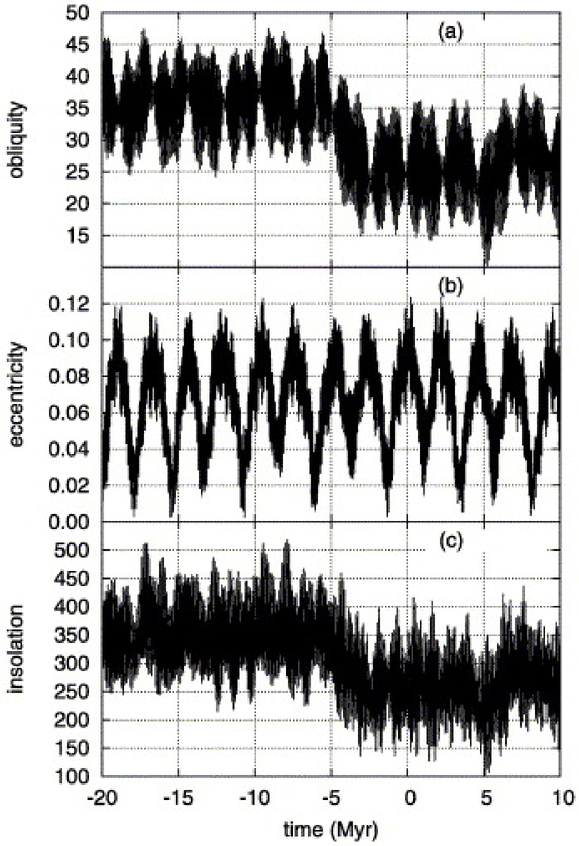

Figure 1: Evolution of the obliquity (a), eccentricity (b) and the north pole insolation (c) at the summer equinox (L_s = 90°) from -20 to +10 million years, provided by Laskar et al. [2004] using the most recent data for the rotational state of Mars, and a new numerical integration of the Solar System)

Previous measurements by different space missions put in evidence the strong coupling between the escape and the water cycle, but many unknowns remain, including the role of the different processes involved in transporting water from the lower to the upper atmosphere and in converting the water molecules into Hydrogen atoms. Also, the relative importance of the different neutral and ionospheric chemical reactions in the production of thermospheric H or the effects of global dust storms compared to the regular seasonal variability have to be taken into account (see abstract by Gonzalez-Galindo et al. 2022, this issue)

A ground-to-exosphere Mars GCM with an update water cycle parameterization

In this study we use an improved version of the ground-to-exosphere Mars General Circulation Model (MGCM) developed at the *Laboratoire de Meteorologie Dynamique* (LMD) with the water cloud microphysics as in Navarro et al. [2014] plus an update photochemical model which includes water-derived ions (H_2O+, H_3O+, $OH+$) as in González-Galindo et al. [2021]

Modeling the water cycle on Mars is challenging because of destabilizing feedback, such as the strong coupling with atmospheric temperature, through clouds and global circulation. The water vapour mixing ratio in the mesosphere also depends on the supersaturation of the upper atmosphere, which is not well known. Furthermore, the effect of the microphysical processes at high altitude depend on model parameters not well constrained by observations [Naar et al., 2021].

The LMD-MGCM was successfully applied to simulate the past martian climate at different epochs, and for "recent" geological time (million of years ago) simulations showed that higher planetary obliquity conditions produce a significant increase of the water content in the atmosphere and accumulation of ice in the flanks of the prominent martian volcanoes, where geological observations indicated past glacial activity [Forget et al., 2006]. See abstract by Lange et al. (this issue) for simulations of the climate of Mars at low obliquity.
However, those studies are focused on the lower atmosphere and the variability of the escape rate with the past martian obliquity was never explored before.

Simulations of H Escape in "recent" Mars epochs

We aim to provide an estimation of the variation of water escape in past epochs characterized by different orbital parameters. In particular, the sensitivity of the hydrogen escape rate to changes in the obliquity during last 10-20 millions years of Mars history will be presented, and the fate of water will be discussed. As shown in Figure 1 the obliquity varied between 15° and 45° in the past 20 million year, with a mean value around 35°.

Long simulations are needed before the modified water cycle forced by different orbital conditions becomes stable. Furthermore, ground-to-exosphere simulations are particularly computational expensive, and this is one of the main limitation of this work. Figure 2 show simulations after two consecutive martian years, initialized with MGCM outputs after 20 martian years, which simulate stable water cycle conditions in the low atmospheres.

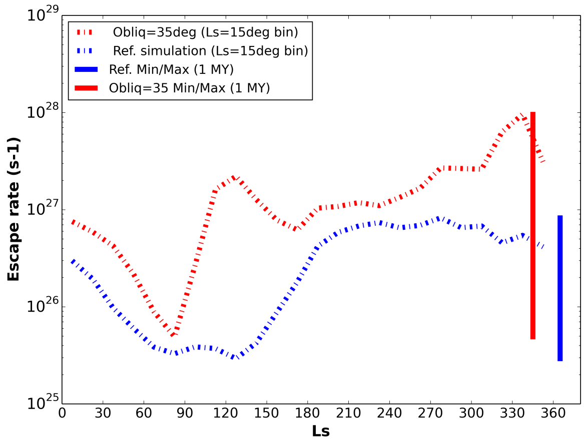

Figure 2: LMD-MGCM Simulated Loss/Escape rate in atoms/s for the reference year (with current martian obliquity = 25°) and with higher obliquity (obliq. = 35°). Model outputs have been averaged binning solar Longitudes L_s every 15° degree. The vertical lines on the right of the panel indicate minimum/maximum values of the loss escape over one Martian Year, for current obliquity (blue) and for higher obliquity (red) simulations.

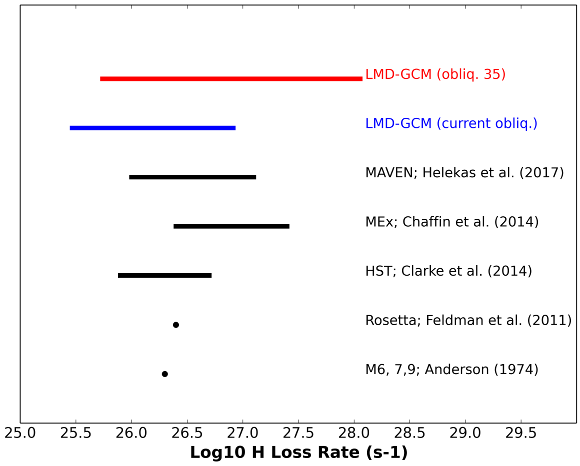

Figure 3: Estimated H loss rate from observations made from different spacecraft, together with simulated H loss rate (min/max values over 1 Martian Year) as shown in Figure 2, for comparison. (Adapted from Jakosky et al. [2018])

Preliminary results and future work

Present-day loss rates of H by Jeans' (i.e. thermal) escape was determined by MAVEN, with values variable during the season between about 1-11· 10^{26} at/s^{-1} [Jakosky et al., 2018]. Similar results was found by observations made from Mariner 6, 7, and 9, Mars Express, Hubble space Telescope and Rosetta flyby of Mars, as shown in Figure 3. Our simulations with the LMD-

MGCM show that, if the martian obliquity was higher than current values (e.g. 35º) the escape rate would have increased up to one order of magnitude (10^{28} atoms/s), especially during dust storm seasons. Preliminary results give 5 times larger time-integrated escape rate than current values. This indicates that a significant H loss could have taken in the past, producing the evaporation of the large reservoir of liquid water potentially present on the surface of Mars in the past million of years.

This theoretical exercise will be performed with other orbital parameters (e.g. eccentricity and time of perihelion) in order to cover a set of past Martian conditions, following the variability range given in Laskar et al. [2004].

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