Highway to Space: the Direct Connection between the Lower and the Upper Atmosphere of Mars sheds a New Light on the History of Water. F. Montmessin[1], F. Lefèvre[1], O. Korablev[2,3], A. Fedorova[2,3], J.-L. Bertaux[1], J.-Y. Chaufray[1], M. Chaffin[3], N. Schneider[3], L. Maltagliati[1], A. Määttänen[1], A.V. Trokhimovsky[2,3], [1]CNRS LATMOS, 11 bd d'Alembert, 78280 Guyancourt, France, [2]IKI, Space Science Institute, Moscow, Russia, [3]MIPT, Dolgoprudnyi, Russia, [4]LASP, Boulder, Colorado.

Introduction: The SPICAM experiment onboard Mars Express has accumulated over the last decade a wealth of observations that has permitted a detailed characterization of the atmospheric composition and activity from the near-surface to above the exosphere. Here, we present a synthesis of the observations collected to date in order to assemble a single, coherent picture of the Martian atmosphere specifically adressing the issue of water decomposition into its lighter component (hydrogen) that can escape to space. In doing so, we propose a different angle for the long-term evolution of water and hydrogen on Mars.

Observations Modes: SPICAM is dual ultraviolet (110 to 320 nm)-infrared (1 to 1.7 μm) spectrometer specifically designed to retrieve the major and minor species abundances of the Martian atmosphere [1]. SPICAM has the distinct capability of observing with a variety of geometrical configurations; monitoring the column-integrated abundances of ozone, water vapor as well as aerosols in a nadir-looking mode (Figure 1), characterizing their vertical distribution in either stellar or solar occultation modes so as to constrain their presence above typically 10 km up to 140 km of altitude (for CO_2) [2,3,4]. In a dedicated limb staring mode, SPICAM can infer the density of hydrogen atoms from 200 up to 10 000 km of altitude while using the resonantly scattered solar photons at the Lyman-alpha emission line of Hydrogen [5,6]

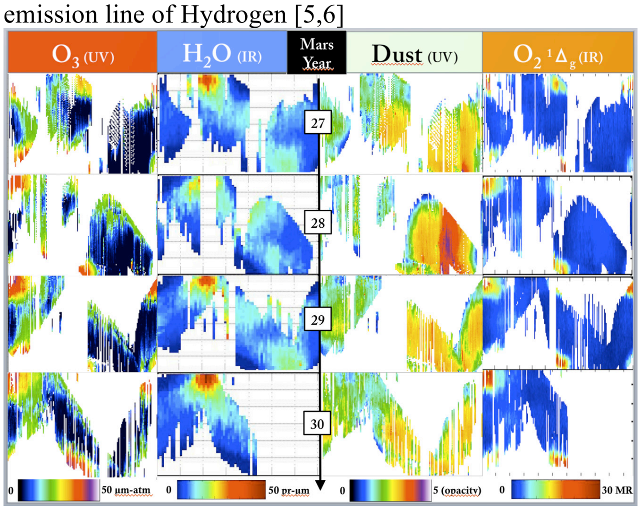

Figure 1: The multi-annual monitoring made by SPICAM for ozone, water vapeur, aerosols and molecular oxygen emission from nadir observations.

Datasets: Since the beginning of its operations at Mars, SPICAM has performed several thousands of stellar and solar occultations and has provided a multi-annual tracking in nadir mode (Figure 1). The study presented here focuses solely on the datasets characterizing the vertical distribution of the species of interest.

Water vapor profiles. The study presented in [7] follows for the first time the evolution of water vapor profiles during a full martian year. 120 profiles, obtained by SPICAM were retrieved that cover the northern spring-summer season and the southern spring of Mars Year (MY) 29. The seasonal evolution of water vapor mixing ratio vertical distribution reveals a strong dynamism, especially during southern spring, that is not predicted by models. The measured profiles exhibit often abrupt temporal variations and a great variety of shapes, with the frequent presence of detached layers (Figure 2). The water vapor vertical distribution is more reactive than expected to regional perturbations, which can propagate rapidly through the atmosphere, create abrupt water vapor and aerosol upsurges and influence the large-scale vertical evolution of these two constituents. This phenomenon has been observed several times during MY29.

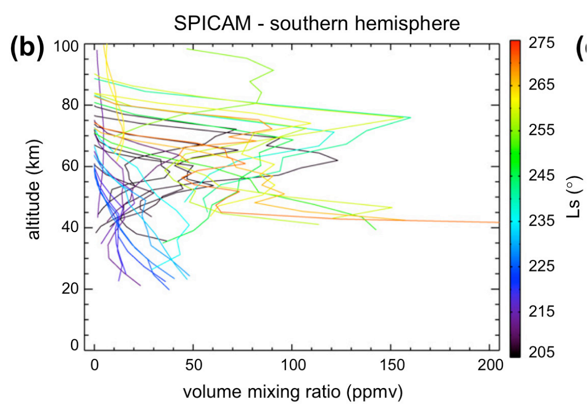

Figure 2: (from [7]). A collection of water vapor profiles obtained by SPICAM during MY29 showing the prominent presence of detached layers up to 80km.

The polar ozone dichotomy. At low-to-mid latitudes, martian ozone is distributed vertically in two main layers, a near-surface layer and a layer at an altitude between 30 and 60 km. In [8] evidence is reported for the existence of a previously overlooked ozone layer that emerges in the southern polar night at 40–60 km in altitude, with no counterpart observed at the north pole (Figure 3). Comparisons with global climate simulations for Mars indicate that this layer forms as a result of the large-scale transport of oxygen-rich air from sunlit latitudes to the poles, where the oxygen atoms recombine to form ozone during the polar night. However, transport-driven ozone formation is counteracted by the destruction of ozone by reactions with hydrogen radicals, whose concentrations vary seasonally on Mars, reflecting seasonal variations of water vapour. The observed dichotomy between the ozone layers of the two poles, with a significantly richer layer in the southern hemisphere, can be explained by the interplay of these mechanisms.

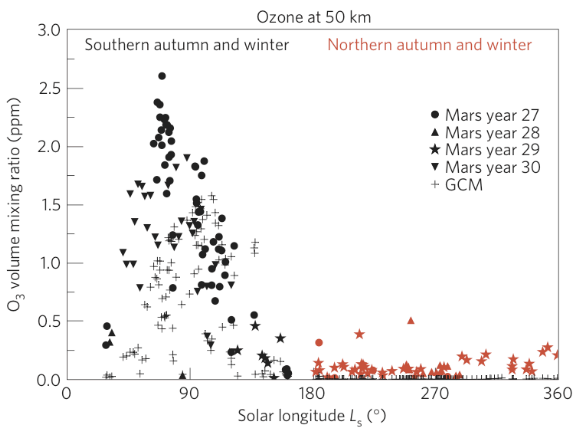

Figure 3: (from [8]) Seasonal evolution of the polar ozone mixing ratio at 50 km. The figure shows the autumn and winter variation of the O_3 layer measured by SPICAM for MY27 to MY30. Black symbols correspond to all locations poleward of 60°S whereas the red symbols refer to latitudes poleward of 60° N.

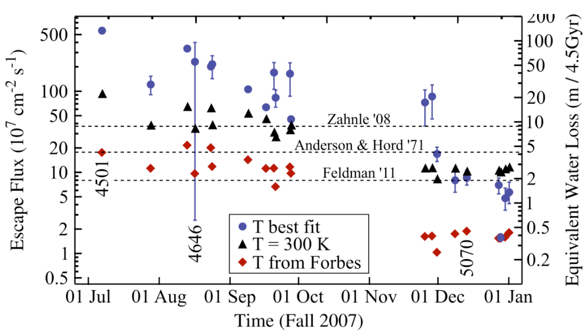

Figure 4: (from [6]) Derived H escape flux and potential explanatory parameters across Fall 2007. (bottom panel) H escape flux for three temperature assumptions: blue circles, temperature as a free parameter over the range 100–1600 K; black triangles, temperature fixed at 300 K; red diamonds, temperature from an empirical thermosphere model.

Variability of hydrogen. An order-of-magnitude change in the Martian hydrogen escape rate in 2007 (Figure 4), inconsistent with established models for the source of escaping hydrogen was reported in [6]. This result was obtained from the analysis of 121.6 nm (hydrogen Lyman-α) airglow observations by SPICAM over the second half of 2007. The enhanced escape rates that were observed may be due to lower atmospheric heating and overturn during the 2007 (Mars Year 28) global dust storm, suggesting that hydrogen escape from Mars during dust storms may dominate loss of the planet's water inventory.

Discussion: The contribution of SPICAM can be summarized as follows:

- The joint monitoring of H_2O and O_3 total abundances has confirmed the suspected role of OH and H as oxidants;
- The characterization of H_2O vertical distribution revealed unexpected amounts of water above 30 km where it can be is photodissociated into H and OH;
- The detection of ozone as discrete layers lying above the pole provides a nearly-direct evidence of the deep (up to 100 km) transport of H atoms;
- The seasonal evolution of H above the exobase, as retrieved from limb staring modes, has revealed a behavior of H contradicting the canonical view of a upper reservoir of H seasonally disconnected from its precursor, water vapor in the lower atmosphere: the H corona shows similar seasonal variability as H_2O in the lower layers, suggesting a tighter connection between the two.

Based on the ensemble of these evidences, the following scenario unfolds: the communication between the well-mixed lower atmosphere and the outer layers where atoms (H in particular) can freely escape is more direct and much faster than anticipated. Escape processes for water need to be reevaluated in light of this consideration. The Martian atmosphere appears as one single coherent system which is able to react on short timescales and may therefore have been dominated throughout its history by seasonal events / peaks.

References: [1] Bertaux, J.-L., et al., (2006), JGR 111, E10S90 [2] Forget, F., et al., (2009), JGR, 114, E01004. [3] Lebonnois, S., et al., (2006), JGR, 111, E09S05. [4] Montmessin, F., et al., (2006), JGR, 111, E09S09. [5] Chaufray, J.-Y., et al., (2008), Icarus, 195, pp. 598-613. [6] Chafin, M. S., et al., (2014), GRL, 41, doi:10.1002/2013GL058578. [7] Maltagliati, L., et al. (2013), Icarus, 223, pp. 942-962. [8] Montmessin, F., and F. Lefèvre, (2013), Nat. Geo., 6(11), pp. 930-933.