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On the role of the doubly charged ions on the Mars atmospheric escape

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Abstract

Several mechanisms have been invoked in the past to explain the Mars atmospheric escape, ranging from thermal to non-thermal. Most of them rely on the solar energy inputs through solar wind and EUV emission variations. In the present paper, we propose a new mechanism also linked to the solar EUV flux. This additional source of atmospheric escape is from the doubly charged molecular ions. We show that this source can account to 8 to 15% of the total escape and may trigger other mechanisms.

1. Introduction

A thorough review of the existing theories of atmospheric escape has been discussed in Chassefière and Leblanc (2004). This review paper includes an introduction describing the general context of Mars escape studies, describes the theory of thermal escape (of both Jeans and hydrodynamic types) as well as of nonthermal escape (photochemical escape, ion sputtering, ion escape and ionospheric outflow). (Chassefière et al., 2007) provides a revised view on the problem, with a proposition for space exploration. Therefore, it is unnecessary to repeat these conclusions. The main point is that three mechanisms are at work: Photochemical escape, or dissociative recombination, Ion escape and Ion sputtering. It is clear that the Mars escape has a strong connexion to the solar activity: EUV flux creates ions that can diffuse through the atmosphere and are taken away in the solar wind. An additional phenomenon increases the escape rate: the ions are sensitive to the Interplanetary Magnetic Field (IMF) and gyrate around the magnetic field lines. They can re-enter the atmosphere, create a secondary ionization and secondary escape, called "the ions sputtering"
Although abundantly referred in the paper cited above, two main authors made a dedicated contribution to this field of investigations: Dr. Fox (1993) and Dr. Luhman (1997), who set the basis for the understanding of the planetary atmospheric escapes, including the Mars' case. Recently, it has been proposed that volcanism could be at the origin of the atmospheric escape, which would constitute an additional source (Gillmann et al. (2009)).
The existence of stable molecular dications in the Mars ionosphere has been predicted and published in Witasse *et al*. (2003). Part of these ions recombines with electrons, part collides with CO_2 and exchanges an electron and part dissociates spontaneously. However, the production of the stable dications represents only 10% of the total production. 90% is produces in different states, which immediately dissociate into 2 pairs of ions. Each state has a potential barrier in energy. This internal energy is released to the fragments as a function of their respective masses because of the conservation of momentum: For example, 28/44 of the energy goes to O^+ and 16/44 to CO^+. It has been measured that the internal energy is of the order of 10 eV (Slattery et al., 2005), i.e. well above the energy necessary to escape the planet. The main point is that this energy is released as kinetic energy, i.e. velocity.

2. Model

We use a kinetic transport model described in Gronoff et al. (2007). Two main changes have been performed. First, the energy transferred to the atmospheric targets now takes into account the part released to the molecule / atom. Secondly, a complete review of the cross sections has been made to account for the double ionization. We neglect the creation of C^{++} and O^{++} from CO_2 because their thresholds are 80 eV. The production of dications is far of being negligible, and the ratio between the double ionization and the total absorption cross is equal to 7.7 % (Masuoka,1994). The photoionization and the electron collision impacts produce two kinds of CO_2^{++} ions. The ground state $X3_g$ is 37.4 eV above the ground neutral state with a lifetime of 4.2 s (Mathur, 1995). The other states are unstable. Their lifetime is in the range of microseconds (Field and Elan,1993). We compute the production of all the CO_2^{++} states due to EUV photoionization. Their dissociation produces fast ions. We follow these ions from the creation layer to the top of the exosphere solving a Beer-Lambert law. However, the collision cross section between fast ions and ambient CO_2 is not known. Therefore, we varied this parameter from a Van der Walls sphere to zero. Zero corresponds to the assumption that the fast ions are too energetic to interact with the thermal gaz. The model accounts for the variation of the solar EUV flux since the Noachian (Ribas et al., 2005) by using wavelength / time dependant correction factors on the actual solar flux (Torr and Torr, 1985) for average conditions (F10.7 = 145). We run it from -3.5 billion year to today with a time step of 100 000 years.

3. Results

The preliminary results are shown in figure 1. From this first analysis, the proposed mechanism decreases the ground pressure by a rate ranging from 8% to 15%. This is very comparable to several other mechanisms proposed in the literature.

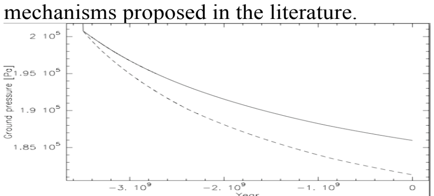

Figure 1: Ground pressure variation due to the double ionization process. Lower curve: collision between Van der Walls spheres. Upper curve: collision cross section set to 0.

4. Discussion and conclusion

The proposed mechanism cannot per se explain the totality of the Mars atmospheric escape. However, it is undoubtedly an important contributor. The fact that the energy released to CO_2^{++} is of the order of 10 eV is important: each fragment receives an energy which may allow the atmospheric escape. However, the same energy is not sufficient to escape Venus or the Earth: this mechanism may explain partly why Mars lost its atmosphere and not the two sister planets. Additional mechanisms may increase the efficiency of the doubly-charged ion escape source. The main one is the fact that this source is permanent. Although tiny, it may create a friction that drives part of the ambient atmosphere to escape altitudes. Finally, the presence of electric field or pile up magnetic field can although create an amplification of this source.

References

[1] E. Chassefière and F. Leblanc, Mars atmospheric escape and evolution; interaction with the solar wind, Planetary and Space Science, Volume 52, Issue 11, p. 1039-1058, 10.1016/j.pss.2004.07.002

[2] E. Chassefière, F. Leblanc, and F. Langlais, The combined effects of escape and magnetic field histories at Mars, Planetary and Space Science, Volume 55, Issue 3, p. 343-357, 10.1016/j.pss.2006.02.003

[3] Fox, J.L., On the escape of oxygen and hydrogen from Mars. Geophys. Res. Lett. 20, 1847–1850, 1993.

[4] Luhmann, J.G.,. Correction to ‘‘The ancient oxygen exosphere of Mars: implications for atmospheric evolution’’. J. Geophys. Res. 102, 1637, 1997

[5] C. Gillmann, E. Chassefière, P. Lognonné, A consistent picture of early hydrodynamic escape of Venus atmosphere explaining present Ne and Ar isotopic ratios and low oxygen atmospheric content, Earth and Planetary Science Letters, Volume 286, Issue 3-4, p. 503-513, 10.1016/j.epsl.2009.07.016

[6] Witasse, O., Dutuit, O., Lilensten, J., Thissen, R., Zabka, J., Alcaraz, C., Blelly, P.-L., Bougher, S. W., Engel, S., Andersen, L. H., and Seiersen, K., Correction to “Prediction of a CO2+2 layer in the atmosphere of Mars”, Geophys. Res. Lett., 30, 070 000–1, doi:10.1029/2003GL017007, 2003.

[7] Slattery A.E., T.A. Field, M. Ahmad, R.I. Hall, J. Lambourne, F. Penent, P. Lablanquie and J.H.D. Eland, Spectroscopy and metastability of CO2++ molecular ions, J. Chem. Phys., 122, 084317, 2005

[8] Gronoff, G., Lilensten, J., Simon, C., Witasse, O., Thissen, R., Dutuit, O., and Alcaraz, C., Modelling dications in the diurnal ionosphère of Venus, A&A, 465, 641–645, doi:10.1051/0004-6361: 20065991, 2007.

[9] Masuoka, T.: Single- and double-photoionization cross sections of carbon dioxide (CO2) and ionic fragmentation of CO+2 and CO22+, Physical Review, 50, 3886–3902, doi:10.1086/427977, 1994.

[10] Mathur, D., Long-lived, doubly charged diatomic and triatomic molecular ions, J. Phys. B:At. Mol. Opt. Phys., 28, 3415–+, 1995.

[11] Field, T. and Elan, J. H. D.: Lifetimes of metastable molecular doubly charged ions, Chemical Physics Letters, 211, 436–+, 1993.

[12] Ribas, I., Guinan, E. F., G¨udel, M., and Audard, M.: Evolution of the Solar Activity over Time and Effects on Planetary Atmospheres. I. High-Energy Irradiances (1-1700 A°), ApJ, 622, 680–694, doi:10.1086/427977, 2005.

[13] Torr, M. R. and Torr, D. J.: Ionization Frequencies for Solar Cycle 21: Revised, J. Geoph. Res., 90, 6675–6678, 1985.