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A comparative study: atmospheric sputtering on Mars and Venus

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Abstract

Atmospheric sputtering is well-known process acting on planetary atmospheres in a similar way in which ion-sputtering acts on surfaces of airless bodies: energetic ions impact on the upper regions of planetary atmospheres and may cause significant escape directly or after a series of bouncing, or they may lose velocity and form an atmospheric corona. In particular, a collision cascade below the exobase is expected, and the yield of the process may be very high, allowing a consistent flux outward from the atmosphere.

In this work we study this process due to the energy ions originating from both the solar wind and the exospheric photoions for two different planets of the Solar System: Mars and Venus.

The simulation results show low neutral sputtered flux in the martian system (10^{18}-10^{19} part./s) but a remarkable contribution of atmospheric sputtering for Venus in the case where the solar wind protons impacts on the upper atmosphere (10^{22}-10^{23} part./s).

Further results and comparisons will be shown here

1. Atmospheric sputtering model

Mars and Venus do not possess an intrinsic magnetic field; for this reason, atmospheric sputtering is expected to act more effectively on their atmospheres. To study this process we developed a Montecarlo single-particle model that simulates the cascade process that occurs when the ions impact on the upper atmosphere. For a more realistic approach we try to describe all possible collision processes with the experimental cross section that were derived by an accurate review of the current knowledge. In particular, at the moment, we use the collision-cross sections for: 1) elastic collision; 2) ionization; 3) e-loss; 4) charge exchange. In this ….

1.1 Input parameters

1.1.1 Ion Models

The ion models are a hybrid model developed at the Finnish Meteorological Institute. The basic properties of the hybrid model have been described in Kallio et al. (2010) for Mars and in the Jarvinen et al. (2010) for the Venus case.

Solar Wind model: Mars and Venus

The martian solar wind parameters are chosen to correspond to the input values in the community-wide solar wind–Mars interaction modeling (SWIM) campaign: n_{sw}= 2.5 cm^{-3}, U_{sw}= 487 km/s, B_{sw}=[1.93, -1.6, -2.5]nT, T = $15*10^4$ K, which are the density, the bulk velocity, the IMF and the temperature of the solar wind, respectively.

In the same way the nominal upstream solar wind conditions at Venus are: n_{sw}= 14 cm^{-3}, U_{sw}= 430 km/s, B_{sw}=[-8.09, 5.88, 0]nT, T = 10^4 K.

1.1.2 Exospheric ions: Mars and Venus

Neutral corona profiles from the literature are used to produce photoions from the exosphere. The applied photoionization rates correspond to the minimum solar extreme ultraviolet (EUV) conditions.

1.1.2 Atmospheric/exospheric model

Mars

Our simplified model considers Mars' atmosphere and exosphere as composed by CO_2, O and H. The CO2 atmospheric density profile is derived from the observation of PFS and SPICAM instrument on board Mars Express mission. The O and H neutral profiles are approximated by fig.1 an exponential functions (Krasnopolsky and Gladstone,1996)

Venus

We consider the venusian atmosphere composed by the CO_2, H and O. The model of the neutral gas density used is based on data found in the literature (Krasnopolsky et al.,1996), and has been extrapolated to higher altitudes using a Chamberlain exosphere (Chamberlain and Hunten, 1987).

1.1.3 Cross sections

For a more realistic approach we describe the collision processes between the plasma energetic ions and the exosphere-atmosphere system using different experimental cross sections at 100 eV, 1 keV and 10 keV for elastic collision, ionization, e-loss and charge-exchange (Table 1) taken from the tables described in Rinaldi et al., 2011.

4. Tables

Table 1: Collision processes used in our model

Collision process		Reference
Projectile	Target	
Elastic collision		
H	H	linear fit from Newman et al. 1986
H	O	linear fit from Newman et al. 1986
H	CO_2	linear fit from Newman et al 1986
H+	O	linear fit from Newman et al 1986
H+	CO_2	linear fit from Newman et al 1986
O^+	H	Noel and Prolss 1993
O^+	O	Noel and Prolss 1993
O^+	CO_2	linear fit from Noel and Prolss 1993
O	H	linear fit from Newman et al 1986
O	O	Noel and Prolss 1993
O	CO_2	Lyndsay et al. 2005
CO_2	CO_2	linear fit from Newman et al 1986
CO_2^+	CO_2	linear fit from Newman et al 1986
Ionization		
H	O	McNeal and Birely 1973
H	CO_2	Van Zyl et al. 1978
H^+	O	McNeal and Birely 1973
H^+	CO_2	Van Zyl et al. 1978
e-loss		
H	CO_2	Van Zyl et al. 1978
H	O	McNeal and Birely 1973
H	O	McNeal and Birely 1973
H	CO_2	Van Zyl et al. 1978
Charge – exchange		
H+	H	Noel and Prolss 1993
H^+	O	McNeal and Birely 1973
H^+	CO2	Rees 1989
O^+	H	Noel and Prolss 1993
O^+	O	Noel and Prolss 1993
O^+	CO2	Noel and Prolss 1993

Table 2: Total sputtered flux in the energy range 1-10^4 eV

Mars	
Atmospheric sputtered flux due to SW H^+	
Sputtered H Flux	$1.4*10^{19}$ part./s
Sputtered O Flux	$2.4*10^{18}$ part./s
Sputtered CO_2 Flux	$1.3*10^{19}$ part./s
Atmospheric sputtered flux due to the exospheric H photoions	
Sputtered H Flux	$4.1*10^{18}$ part./s
Sputtered O Flux	$3.9*10^{17}$ part./s
Sputtered CO_2 Flux	$1.2*10^{18}$ part./s
Venus	
Atmospheric sputtered flux due to SW H^+	
Sputtered H Flux	$1.3*10^{23}$ part./s
Sputtered O Flux	10^{22}part./s
Sputtered CO_2 Flux	$2*10^{22}$ part./s
Atmospheric sputtered flux due to the exospheric H photoions	
Sputtered H Flux	$7.5*10^{20}$ part./s
Sputtered O Flux	$4.6*10^{19}$ part./s
Sputtered CO_2 Flux	$1.6*10^{20}$ part./s
Atmospheric sputtered flux due to the exospheric O photoions	
Sputtered H Flux	$1.3*10^{21}$ part./s
Sputtered O Flux	$9.2*10^{19}$ part./s
Sputtered CO_2 Flux	$7.0*10^{19}$ part./s

6. Discussion and Conclusions

This work is intended to develop a model able to predict the behavior of particle escape through atmospheric sputtering. The basic idea is to have a more realistic approach involving all possible collision processes occurring in the cascade. At the moment we consider: the elastic collision, charge exchange, ionization and electron stripping processes.

In the Table 2, we report the total sputtered flux for the venusian and martian atmospheric neutral components in the energy range between 1 eV to 10 keV. In both planets, the Solar Wind protons ions are more efficiently respect to the photoions.

In the Mars case the results show a low contribution of atmospheric sputtering (10^{17}-10^{19} part./s) due to both protons originating from the solar wind and exospheric photoions. This means that the atmospheric sputtering due to the ions considered in this work don't produce a remarkable loss and then it is necessary to consider other kind of ions (pick-up ions) impacting below the exobase. In the literature we can found a value for the atmospheric sputtering due to the pick-up ions about 10^{23} part./s (Luhmann et al., 1992)

Whereas in the Venus case the solar wind protons produce a remarkable contribution for the sputtered neutral particles (10^{22}-10^{23} part./s). In general, in the litterature the atmospheric sputtering loss due to the pick-up ions is 10^{24} part./s (Lammer et al., 2008),. This value is not far from these ones found in this work. This means that in the venus environment, the impacting solar wind protons are a considerable sink for the atmospheric neutral particles escape.

Further results about the energy distribution of the sputtered neutral particles will be shown here for Mars and Venus.

The model will be improved using other collision processes (dissociation, etc) and using other energetic ion models (pick-up ions)

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