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Neutral sodium atoms release from the surfaces of the Moon and Mercury induced by meteoroid impacts

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Abstract. In this work we calculate the vapor and neutral Na production rates on the Moon and Mercury, as due to the impacts of meteoroids having an impact probability on the surface that can influence the daily observations of the exosphere: the meteoroids radius range considered for the Moon and Mercury are, respectively, 10^{-8} - 0.15 m and 10^{-8} - 0.10 m. The results of our model are that i) the vapor production rates are 4.752×10^8 g $year^{-1}$ and 2.76×10^7 g $year^{-1}$, for Mercury and Moon, respectively, ii) the Na production rates are 1.5×10^{22} Na s^{-1} and 8.16×10^{19} Na s^{-1}, for Mercury and Moon, respectively.

Key words. Planets: Mercury, Planets: exosphere

1. Introduction

The Moon and Mercury have an extended and tenuous exosphere containing also Na and K (Potter & Morgan 1985, 1986, 1988). The exosphere is the result of dynamical balance between different source and sink mechanisms acting on the planet surface. A good comprehension of the exosphere as a complex system needs to include the different processes involved both in its formation and in its depletion. Among these processes, there is meteoroid impact vaporization, i.e. the vapor production derived from the infalling of small and medium objects present in the Solar System. The present work reports the neutral Na production rate on Mercury and Moon, as due to the impacts of meteoroids having an impact probability on the surface that can influence the daily observations of the exosphere. The meteoroids radius range considered for the Moon and Mercury are, respectively, 10^{-8} - 0.15 m and 10^{-8} - 0.10 m. In order to estimate the total contribution of mass given to the exosphere gases by the meteoroid impacts, we have to take into account the impactors flux on Mercury and Moon, their surface compositions and the way they interact with the exospheres. We have considered a new dynamical model of the flux of meteoroids at the heliocentric distance of Mercury and Moon with radius > 10^{-2} m (Marchi et al. 2005; Cremonese et al. 2005; Bruno et al. 2005), which are not dominated by non-gravitational forces, as

Send offprint requests to: G.Cremonese the Poynting-Robertson effect. Instead, the flux of smaller meteoroids ($< 10^{-2}$ m), dominated by the Poynting-Robertson effect, has been calculated using the distribution adopted by Cintala (1992). We have assumed a meteoroid density (ρ_p) of 2.5 g cm^{-3}, consistent with measurements of the densities of stratospheric cosmic dust particles (Rietmeijer 1998) and with densities data of S-type igneous asteroids (Krasinsky et al. 2002), which are the main constituents of the inner part of the Main Belt.

2. Meteoritic model

The total mass of the vapor produced from the infalling of meteoroids on the surfaces of Mercury and Moon can be obtained by knowing the total number of bodies impacting the surface per unit time Φ, and the volume of the target (regolith) material vaporized by a spherical projectile (Cintala 1992) V_{vap}:

$$\Phi = \int \int \Phi(v, r) dr dv \tag{1}$$

$$V_{vap}(v, r) = \frac{4}{3}\pi r^3 (c + dv + ev^2) \tag{2}$$

where $\Phi(v, r)$ is the differential number of impacts as a function of the meteoroid velocity and radius (Bruno et al. 2005; Cremonese et al. 2005; Marchi et al. 2005), v and r are the projectile's velocity and radius; c, d (km^{-1} s) and e ($km^{-2} s^2$) are constants depending on target temperature and projectile composition (Cintala (1992), Table 3, pag. 952). In our computations we use constant values obtained for a diabase projectile and the target at 400 K for Mercury and 273 K for the Moon.

3. Soil composition model

3.1. Mercury

We assume that the surface mineralogical composition of Mercury is spatially homogeneous and only made up by a regolith (density of 1.8 g cm^{-3}) with anorthositic composition (90% plagioclase and 10% pyroxene, in volume). We consider the plagioclase as a solid solution of the end-members albite (Ab), $NaAlSi_3O_8$, anorthite (An), $CaAl_2Si_2O_8$, and orthoclase (Or), $KAlSi_3O_8$. The pyroxene is considered a solid solution of diopside (Di), $CaMgSi_2O_6$, enstatite (En), $Mg_2Si_2O_6$, and ferrosilite (Fs), $Fe_2Si_2O_6$. Therefore, our model assumes the following compositions for plagioclase (An50 Ab49 Or1) and pyroxene (Di70 En20 Fs10):

$$(Ca_{0.50}Na_{0.49}K_{0.01})(Al_{1.50}Si_{0.50})Si_2O_8$$
$$(Ca_{0.70}Mg_{0.20}Fe_{0.10})(Mg_{0.90}Fe_{0.10})Si_2O_6$$

By considering this plagioclase composition, the ratio of sodium to potassium neutral atoms in the Mercury's soil is 49.

3.2. Moon

Lunar surface is made up by pristine highland rocks and mare basalts. The pristine highland rocks make up the lunar highlands (~83% of the lunar surface area). The mare basalts compose the remaining ~17% of the lunar surface, and ~1% of the crustal volume (Head 1976; Head & Wilson 1992). The pristine highland rocks and the mare basalts are completely covered by a regolith layer (also called lunar soil), originated by the exposure of the surface to micrometeoroids impacts and high-energy solar and cosmic charged particles. The soil range in composition from basaltic to anorthositic, and, because of the alkali-depleted nature of the Moon, the Na_2O and K_2O contents are very low. In fact, the wt % Na_2O and wt % K_2O in the soil vary from 0.27 to 0.70 (mean value 0.48) and from 0.027 to 0.55 (mean value 0.29), respectively. We simplify this very complex scenario by assuming that the surface mineralogical composition of the Moon is spatially homogeneous, and made up by a regolith (density of 1.8 g cm^{-3}) with the following mean values of alkali: 0.48 wt % Na_2O and 0.29 wt % K_2O. Therefore, by assuming these alkali values, the ratio of sodium to potassium atoms in the lunar soil results to be 1.5.

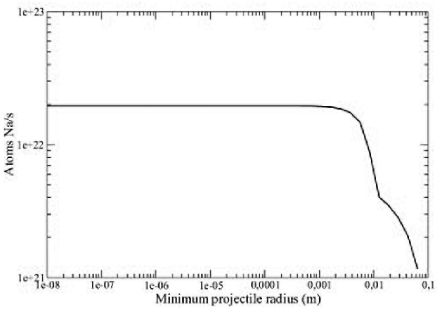

Fig. 1. Cumulative production rate of the neutral sodium atoms for the meteoroid size range 10^{-8} - 0.10 m in the case of Mercury, as a function of the minimum meteoroid radius. Each production rate value is due to all the meteoroids having a size larger than the corresponding radius in the x-axis. The rapid decline in the production rate at larger radius (at about 10^{-3} m) underlines the fact that the main contribution to the sodium production comes from this radius range.

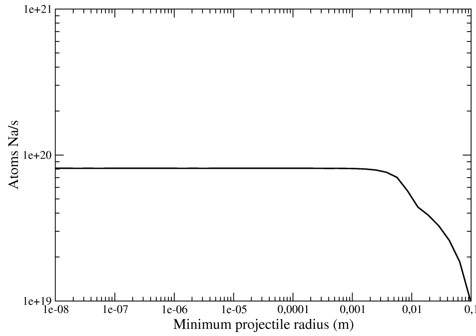

Fig. 2. Cumulative production rate of the neutral sodium atoms for the meteoroid size range 10^{-8} - 0.15 m in the case of the Moon, as a function of the minimum meteoroid radius. The rapid decline in the production rate at the larger radius (at about 2.5×10^{-3} m) underlines the fact that the main contribution to the Na production comes from this radius range.

4. Results

4.1. Mercury

The total mass of vapor produced by the impact of meteoroids in the size range 10^{-8} - 0.10 m, is 4.752×10^{8} g $year^{-1}$. Applying the impact model and the recent surface composition of Mercury we obtained the Na production rate, in the vapor, of 1.5×10^{22} Na s^{-1}. This value is almost in agreement with the values reported in literature: 10^{22} Na s^{-1} (Hunten et al. 1988), $0.15 - 14 \times 10^{23}$ Na s^{-1} (Morgan et al. 1988), and 5×10^{23} Na s^{-1} (Leblanc & Johnson 2003). Following our model we can calculate the Na production rate for any smaller size range within $10^{-8} - 10^{-1}$ m, as reported in Fig. 1. In particular we can see that about 75% of the Na atoms produced is due to meteoroids in the size range of $10^{-3} - 10^{-2}$ m and the remaining 25% in the range of $10^{-2} - 10^{-1}$ m. Therefore, particles smaller than 10^{-3} m do not contribute to the Na production rate.

4.2. Moon

The total mass of vapor produced by the impact of meteoroids in the size range 10^{-8} - 0.15 m, is 2.76×10^{7} g $year^{-1}$ and the production of Na is 8.16×10^{19} Na s^{-1}. The Na production rate obtained is two order of magnitude lower with respect to the estimates of Morgan & Killen (1997) and Smyth & Marconi (1995): $7.59 - 11.4 \times 10^{21}$ Na s^{-1}. Therefore, according to our calculations the contribution of the impact vaporization to the Na exosphere of the Moon is low. In Fig. 2 the Na production rate for the complete meteoroid size range is reported, as a function of the minimum meteoroid radius. This figure clearly shows that the production of neutral Na atoms is mainly due to meteoroids larger than 2.5×10^{-3} m: the 42% of the Na comes from the size range of $2.5-10\times10^{-3}$ m, and the remaining 58% from $1 - 15 \times 10^{-2}$ m.

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