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# Modeling the impulsive Meteoritic Impact Vaporization in the Hermean Exosphere

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**Abstract.** In the study of the Hermean exosphere, the process of gas production called 'Meteoritic Impact Vaporization' (MIV) has been historically considered less important than the others (thermal desorption, photon stimulated desorption and ion sputtering). Only in the last years it has become evident that, in the nightside, MIVs contribution to the exosphere is probably more substantial, so that it could also account for 30% of gas production (Leblanc & Johnson 2003).
Marchi et al. (2004) showed that the probability of an impact for meteoroids up to 1 meter at Mercury is not negligible.
In this study we evaluate the dynamical evolution of the sodium gas cloud that such an impulsive event would produce, and we discuss this signature in the exosphere in the frame of the possibility to be detected by the SERENA instrumentation onboard the MPO, one of the two probes of the next ESA cornerstone mission BepiColombo to Mercury, planned for the next decade.

**Key words.** Mercury – Meteoritic impact vaporization – Release processes – Sodium Exosphere – Impulsive event

## 1. Introduction

In order to evaluate the vapour produced by a MIV, we consider: a) the sodium concentration (0.53 wt%) on the Hermean surface deduced by Morgan & Killen (1997) via ground-based observation; b)the vapour production law by Cintala (1992).
Thanks to thermodynamic calculations on the shock stress caused on different soils by a meteoritic impact, Cintala (1992) gave an estimation of the vaporized target volume (regolith) as a function of the projectile's velocity $v$, and its radius r:

$$V_{vap} = \frac{4}{3}\pi r^3 (c + dv + ev^2) \qquad (1)$$

where c, d and e are temperature and composition dependent coefficients; here we will

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consider the case of an average surface temperature of 400 K.

By assuming a regolith density of 1.8 $g/cm^3$ (Cintala 1992), the total mass of the vapour cloud can be computed.

## 2. Meteoritic Model

The dynamic model of Marchi et al. (2004) investigates the possibility of meter-sized objects to hit the Hermean surface.

Those meteoroids are ejected from the Main Belt because the 3 : 1 and the $\nu_6$ resonances change their orbital parameters and insert them in the inner Solar System.

In order to model the meteoritic population we need: the size distribution and the velocity distribution of the impacting objects. The size distribution is shown in Fig. 1, giving the number of impacts per year for mass unit on Mercury's surface, as a function of the radius. In particular, it can be computed that the impact of an object with radius of 1.0 ± 0.5 meter may happen twice every year.

The velocity distribution is shown in Fig. 2, showing the impact probability versus the projectile velocity. This distribution shows two peaks at meteoroid velocities of approximately 30 and 40 $km/s$ (their relative magnitude depending from the size of the objects), and that values are mostly distributed in the range 20-70 $km/s$.

For these reasons, in the next we'll show the preliminary results of modeling an impact event with an object of 1 m radius flowing at 30 $km/s$, which is the most probable velocity for a 1 meter-sized object.

## 3. Exospheric Model

The Monte Carlo model by Wurz & Lammer (2003) consists of a simulation of a large number of trajectories of different species following ballistic orbits, and ejected from the surface through the four mentioned different release processes.

This model has been able to reproduce the average density profile of the exospheric particles as a function of altitude.

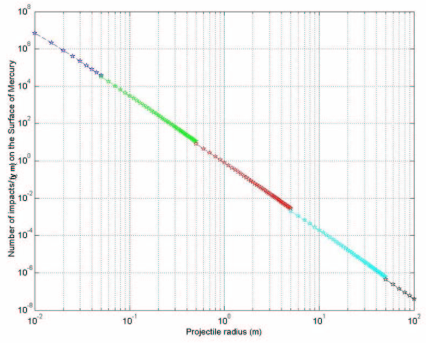

**Fig. 1.** Impact distribution on the Hermean surface, as a function of meteoroid size (number of impacts $\cdot year^{-1} \cdot meter^{-1}$).

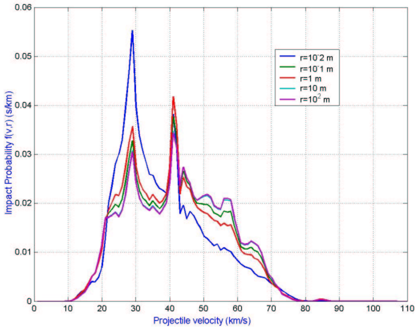

**Fig. 2.** Impact distribution on the Hermean surface, as a function of impact velocity. Note the two peaks and their different magnitude, as a function of the meteoroid size.

In Fig.3 the exospheric density profiles of various species are shown (as derived from this model). In particular, the white sector on the right represents the altitude range to be explored by the BC/MPO/SERENA along its orbit (altitude > 400 $km$). It can be noticed that Na density, at an altitude of 400 $km$, is estimated approximately to be $10^9$ $m^{-3}$.

## 4. MIV Dynamic Model

We used a Monte Carlo model that followed the ballistic trajectories of $10^6$ test particles in a spherical shell around the planet. They are supposed to be ejected from the surface after

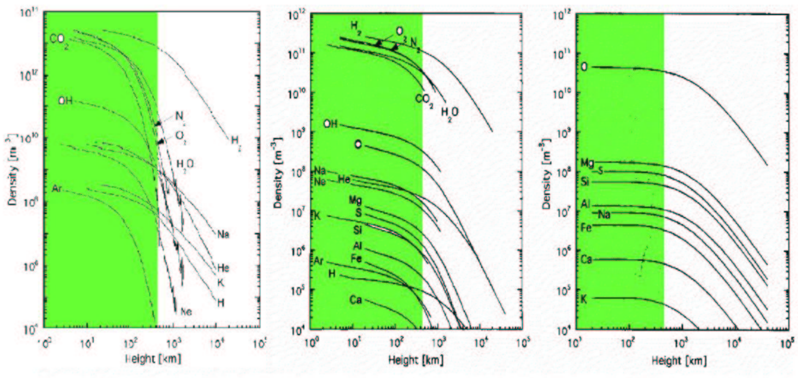

**Fig. 3.** Exospheric profiles for different species, as derived with the Wurz and Lammer model, for different emission processes: on the left panel, dayside thermal emission + photon stimulated desorption for Na and K; middle panel, micro-meteoritic impact vaporization, and ion sputtering on the right side.

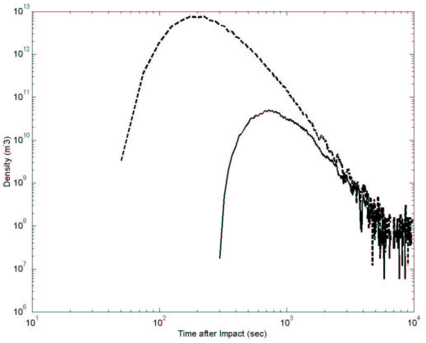

**Fig. 4.** Sodium density profiles with time,at 400 km altitude (dashed line) and at 1500 *km* (solid line). Note that after 2000 sec the two profiles converge to a common value, decreasing gradually. The duration of the density peak is almost 2500 seconds at 400 *km*, and ~ 6000 seconds at 1500 *km*.

the impact of 1 meter-sized meteorite falling at 30 $km/s$ velocity, having ballistic trajectories under the influence of the gravitational field.

The impact studies by Eichhorn (1978) gave a vapour temperature in the range of 2500-5000 K; hence, we choose a Maxwellian energy distribution with characteristic temperature of 4000 K (the same used by Wurz & Lammer (2003) in their model, for the meteoritic contribution to average exosphere).

Here below are discussed our results for Na emission.

The evolution of the vapour cloud with time, and hence the enhancement of the density ($atoms/m^3$) with respect to the exospheric average value of the same species, can be derived. In particular, we have focused our analysis on two peculiar altitude values: 400 and 1500 *km*, that is, the peri- and apoherm of the BepiColombo/MPO probe.

From Fig.4 we can follow the enhancement of sodium in these two cases: at 400 *km*, the density increase can be observed after almost 60 seconds from the beginning of the expansion, and it grows with time to a maximum value of $10^{13}$ $m^{-3}$, more than 3 orders higher than the average exosphere density at this altitude, as computed with the Wurz & Lammer model (2003); after that, the expansion in space will drop the density down to average values (after ~ 2500 sec). At 1500 *km*, instead, the flux of Na atoms is expected to be observed after 300 seconds, it will reach its highest value (even here 3 orders of magnitude higher than average density at this altitude; see the Na profile on the first panel of Fig.3) at ~ 725 sec, and then it will begin to decrease. Note that there is an obvious shift and decrease of the density plot for the case of 1500 km with respect to the other: it depends on the time the cloud takes to expands from 400 to 1500 *km* of altitude. This

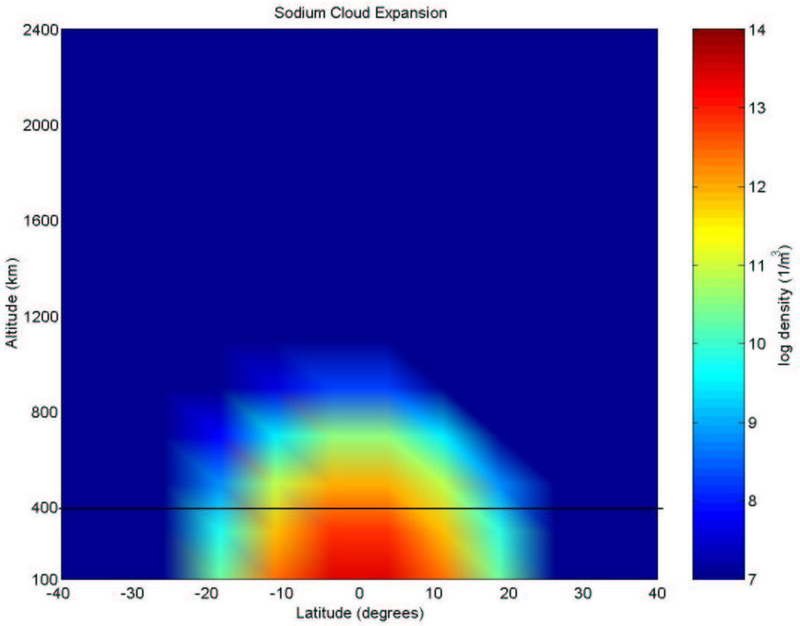

**Fig. 5.** Sodium cloud expansion at 175 sec from the impact, when the cloud density reaches its maximum at an altitude of 400 *km*.

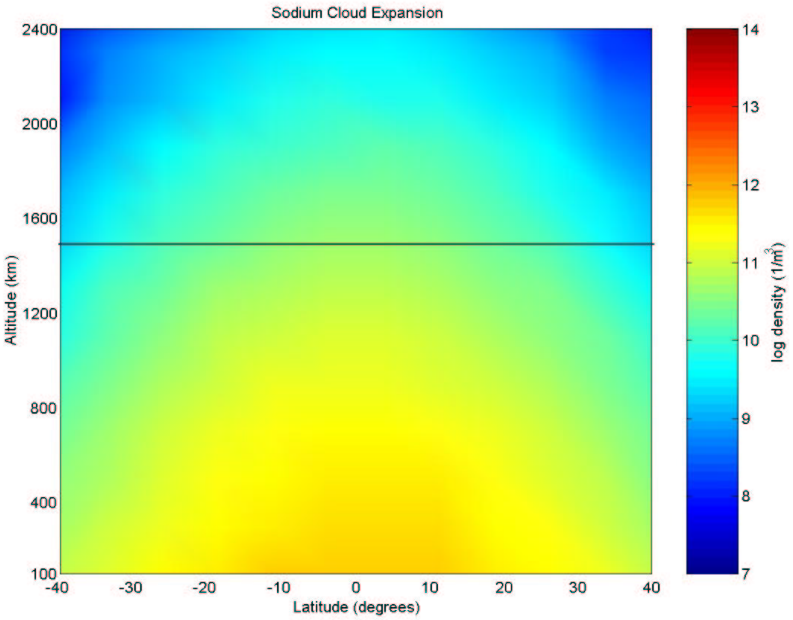

**Fig. 6.** Sodium cloud expansion at 725 sec from the impact, when the cloud density reaches its maximum at an altitude of 1500 *km*.

can be noted also in Figs. 5 and 6 where the cloud expansion in space for the two cases are shown, at the times of their maxima.

Moreover, these simulations allow us to make a rough prediction on the real probability that, if an impulsive event is occurring on the Hermean surface, it can also be observed by the SERENA detectors. The time needed from the MPO to complete one orbit is approximately 150 minutes (hence 9000 seconds), which has to be compared to the typical lifetime of the expanding vapour cloud: $\sim$ 2500 seconds at 400 km altitude, and $\sim$ 6000 at 1500 $km$. The amplitude of the vapour clouds at the two reference altitudes, are 40 and 80 degrees, respectively (see Figs. 5 and 6). As typical dimension on the whole orbit we choose then 60 degrees, and a duration of 4000 seconds. Then an impulsive event will last the $4/9$ of the orbit; this means that, even if the probe will be 160 degrees behind it, it will arrive in time to detect the cloud. Hence, the total coverage of the event on the orbit is $220/360$, that is $3/5$.

A factor of $1/3$ will take into account for the probability to cover the involved zone in longitude, and if we consider that an impulsive event has a frequency of 2 events/year, and that the planned mission lifetime is two years, the probability for such an event to be detected is: $1 - (4 \times (3/5 \times 1/3))^4$, hence $\sim$ 60%.

## 5. Conclusions

This preliminary study is meant to verify the possibility for the particle detector included in the SERENA package to be able to analyse such impulsive events, and hence to improve our actual knowledge of the MIV process acting on the Hermean surface and its real relevance.

We have estimated that the produced sodium density could reach $10^{13} m^{-3}$, at the MPO periherm, with a spatial extension of tens degrees and a duration of tens minutes. A rough estimation of the detectability of this event in the frame of the BC/MPO mission is 60%.

Further studies will include the analysis of other species, other meteoroid sizes and velocities. Furthermore, as suggested by Killen (2003), it is likely that MIV produces the release of molecules like CaO, that are subsequentely dissociated in the exosphere. Such a dynamical feature could also be added to our model.

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