Space Weathering of the Jovian Icy Moons

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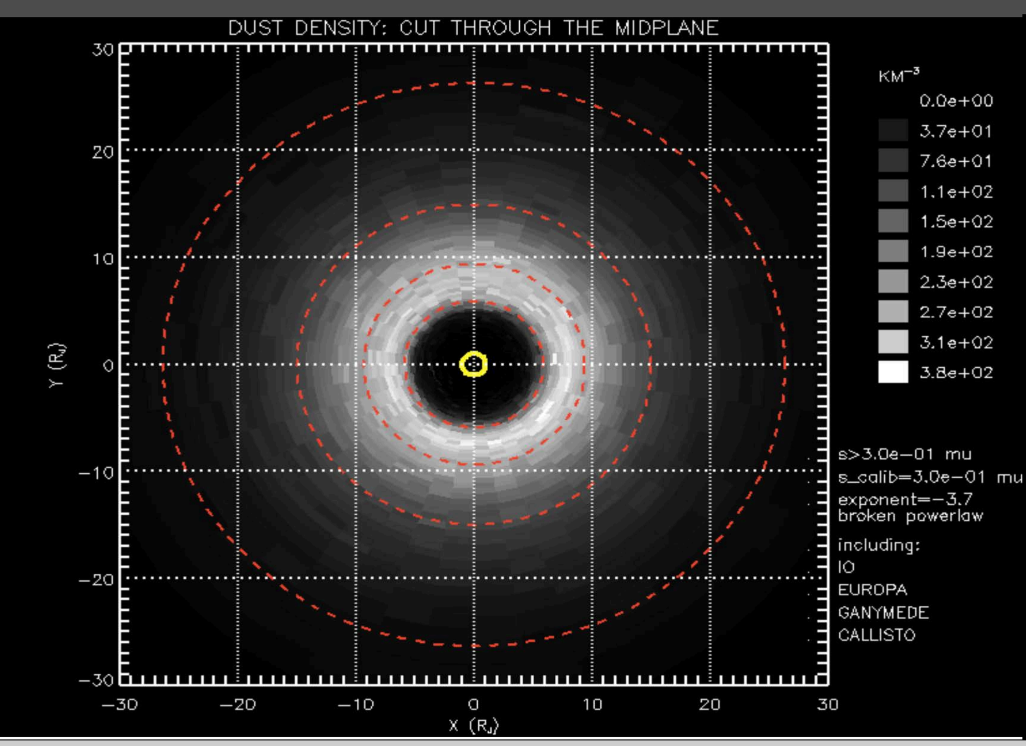
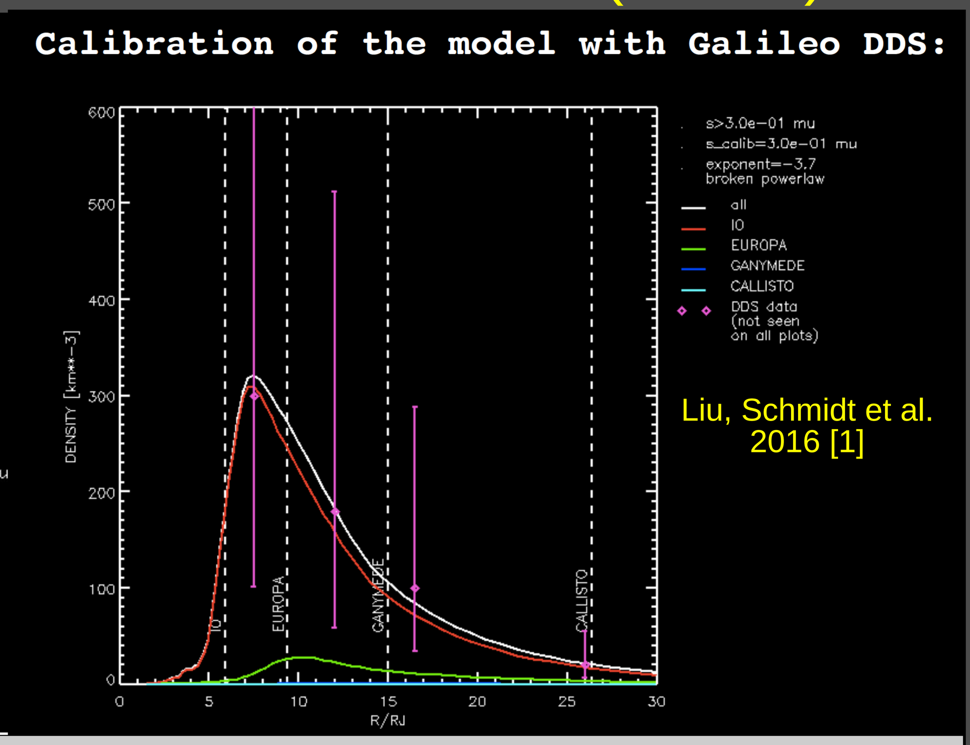
Abstract

The Galilean moons reveal large albedo variations on their surfaces, in particular between their leading and trailing hemispheres. The differences observed are likely the results of a balance between various weathering processes of the surface, determined by the moons' local environment. Chemical and physical alterations occur at the surface, triggered by multiple exogenic energy deposit processes (radiolysis, plasma sputtering, micro-meteoroids impacts, …). The observed variations are probably due to anisotropy in the energy fluxes received on each hemisphere and to a different relative contribution of the weathering agents (plasma, dust…) as function of the distance to Jupiter. We will be testing this hypothesis by estimating quantitatively the kinetic energy flux impacting different part of the surfaces of the Galilean moons using the latest environment models available at the European Space Agency. This work is essential in the context of the future observations performed by the Juice mission, as a proper understanding of the moons' surface history can be achieved only if one is able to constrain the balance between exogenic and endogenic alteration processes. Impacts of dust particles coming from the Galilean moons and evolving dynamically in the Jovian system will be simulated using the Jovian Micrometeoroid Environment Model (JMEM). Primary interplanetary dust impacts are simulated using the prediction of the Interplanetary Micrometeoroid Environment Model (IMEM) computed at Jupiter's Hill radius, taking into account gravitational focusing by the planet while electrons, protons and ions fluxes hitting the moons' surfaces can be estimated using the JOvian Specification Environment model (JOSE). Finally, an ESA-led research proposal has been selected this year to perform laboratory studies of the space weathering effects on icy moons' surfaces: the experiment will consist of bombardment of icy targets (which characteristics are as representative as possible of what we currently know of the various icy moons' surfaces) by micrometeorites and electrons/ions in order to try and better understand how the satellite material in the Jovian environment react to micrometeorites bombardment and charged particles irradiation.

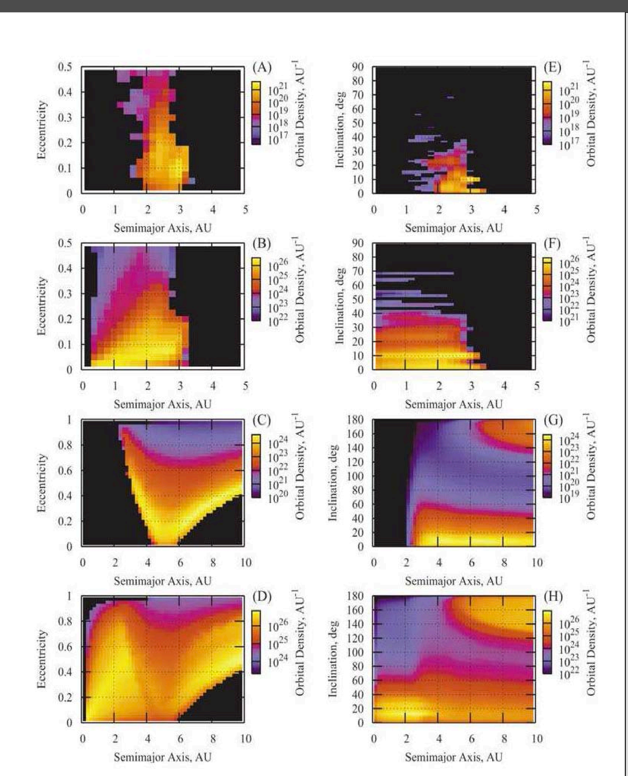
JOVIAN METEOROID ENVIRONEMENT MODEL (JMEM)





A model of the dust populations in the Jovian System has been built for ESA by J. Schmidt and collaborators of the University of Oulu. The motivation behind this model was to provide an estimate of the micro-meteoroid fluences (integrated flux) of dust impactors on the ESA JUICE spacecraft along its trajectory in the Jovian system. JUICE is the first Large class mission of the Cosmic Vision program, which will study Jupiter and the habitability of its icy moons. The primary source of dust in the Jovian system is the sputtering of the major icy moons by hypervelocity impacts of dust coming from the interplanetary space. As described in [1], the particles that have sufficient velocity to escape the moon's gravity are injected into the Jovian system and their trajectories evolve under the action of various forces: Lorentz forces, radiation pressure including Poyting Robertson drag, solar and moons gravity, plasma drag, and gravitational effects due to Jupiter non-sphericity. The particles dynamical evolution is computed and their distribution of orbital elements is stored, providing a volume number density and velocity of particles across the Jovian System that can be used to compute a flux of impactors on any body which trajectory is given. The plot on the left shows the distribution of the particles for all grain sizes larger than 0.3 micron. The abundance of ejectas produced by each moon has been fitted to the in-situ measurements of the Galileo dust detector (right panel).

INTERPLANETARY METEOROID ENVIRONEMENT MODEL (IMEM)

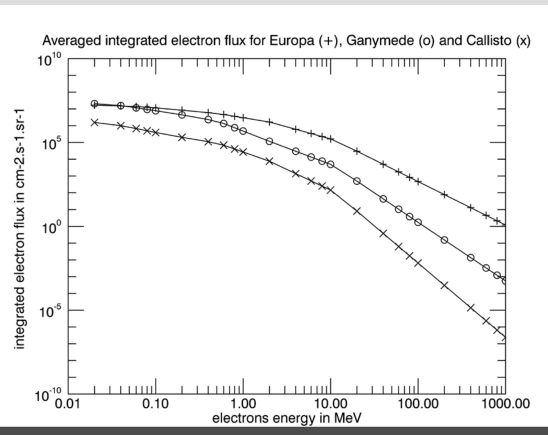


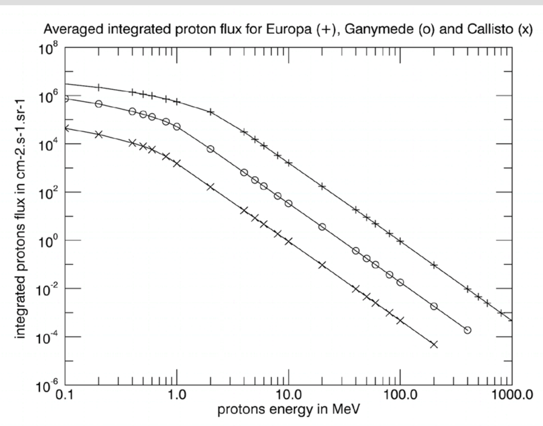
IMEM is a truly (dynamical) evolutionary model built by [2] for ESA. Contrary to all earlier attempts, this model starts from the orbital elements of known sources of interplanetary dust: comets and asteroids. The figure on the left displays the three-dimensional distributions of particle orbits f (a,e,i) of four of the major populations of IMEM. In both mass ranges, the rate of the orbital evolution depends mainly on size, while the topology of particle trajectories is nearly mass-independent, at least on the large scale. Note that IMEM assumes rotational symmetry around ecliptic pole. IMEM states an applicable distance range from 0.1 to 5.0 AU - from Mercury to Jupiter and beyond - and an applicable mass range from 10^{-18} to 1 g. IMEM has no restriction with respect to ecliptic latitudes.

The Figure on the left shows the Orbital distributions of interplanetary dust particles in the ESA meteoroid model [2], calculated for the minimum mass threshold 10^{-12} g. The left column shows the distribution in semimajor axis and eccentricity, the right column shows the distribution in semimajor axis and inclination. Four distinct populations are shown. Plots A and E: the big dust particles (mass $m > 10^{-5}$ g) from asteroids in collisional regime. Plots C and G are the same for comets in Jupiter-crossing orbits. Plots B and F: small dust grains (mass $m < 10^{-5}$ g) from asteroids, spiraling toward the Sun under the Poynting- Robertson effect. Plots D and H are the same for comets.

JOvian Specification Environment model (JOSE)

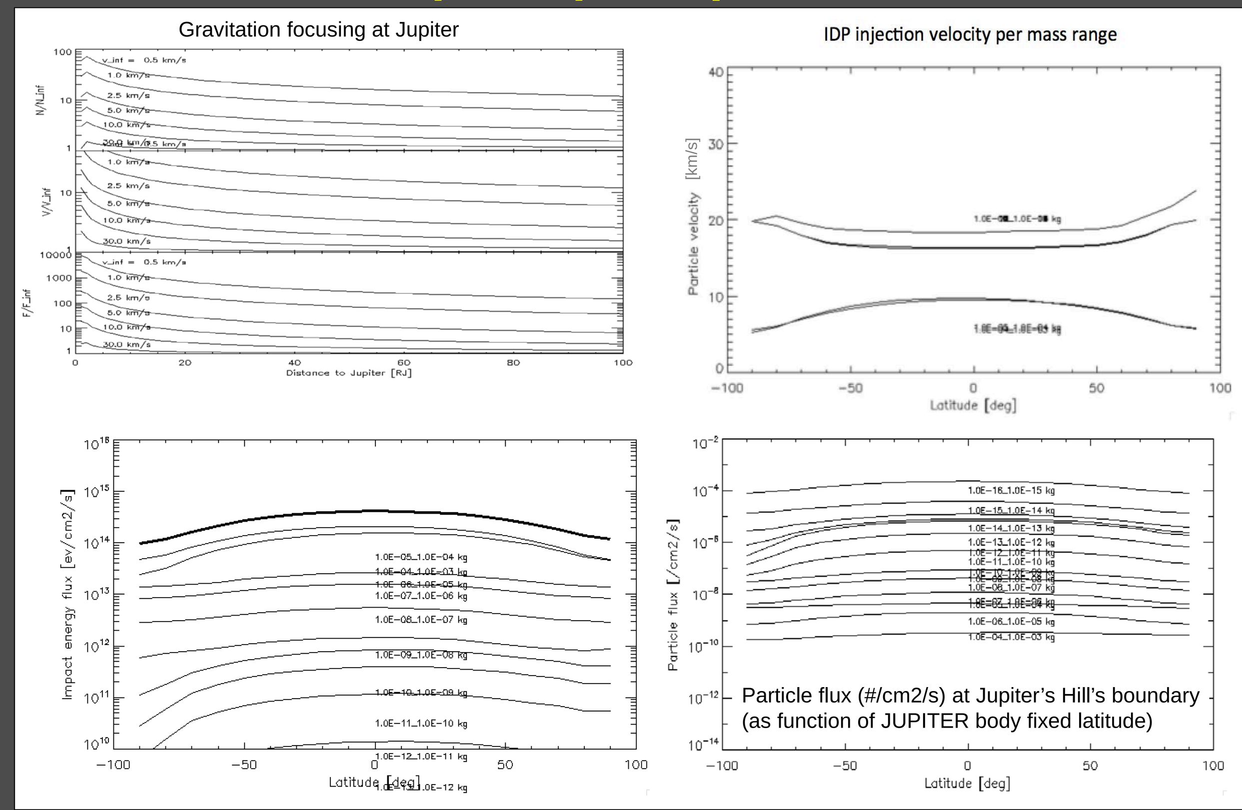
JOSE is an environment model based on Galileo data and validated with all relevant data measured by the missions during their passage in Jupiter's magnetosphere. It was initially developed as en engineering model for Jupiter's environment, and covers protons and electrons from several tens of keV to several hundreds of MeV [3]





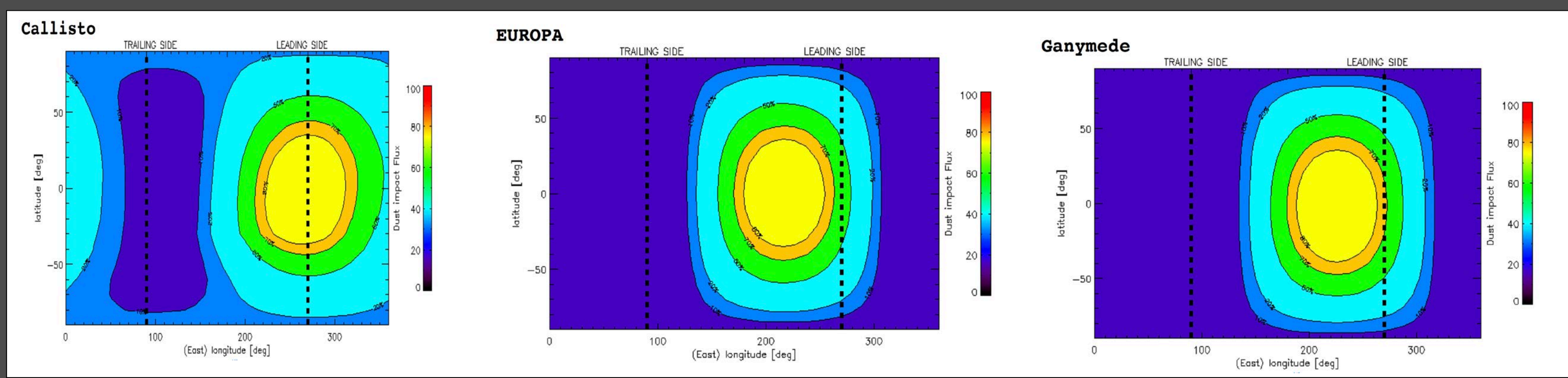
The Figures to the right show the averaged integral flux of protons (left) and electrons (right) on Europa (+), Ganymede (o) and Callisto (x) 's orbits, as computed using the JOSE model

Computing the kinetic energy flux of primary Interplanetary Dust (IDP) impactors at the surface of the icy moons



Using the IMEM model, we computed the flux of interplanetary impactors for all mass ranges above 1e-12 kg, expected at the Hill's radius of Jupiter. The Hill's radius defines the region of influence of Jupiter's gravity field – inside the Hill's radius, we applied a formulation of gravitation focusing as described in [4] in order to estimate the increase in volume number density and speed (resulting in an increase of the flux) of the interplanetary grains as function of the radial distance to Jupiter (top left panel). The injection velocity (top right panel) of the grains refer to the velocity that the grains posses when they reach the Hill's sphere, before the gravitation focusing. On the bottom left plot, we convert the mass distribution, grain speed and the particle flux to infer the kinetic energy flux entering the Jovian system from the interplanetary space. This kinetic energy flux is distributed isotropically on the moons surface, once corrected for the gravitation focusing, and is the primary energy source for producing secondary ejectas.

Computing relative jovian dust impactor (from ejectas) flux anisotropy on the moons surface



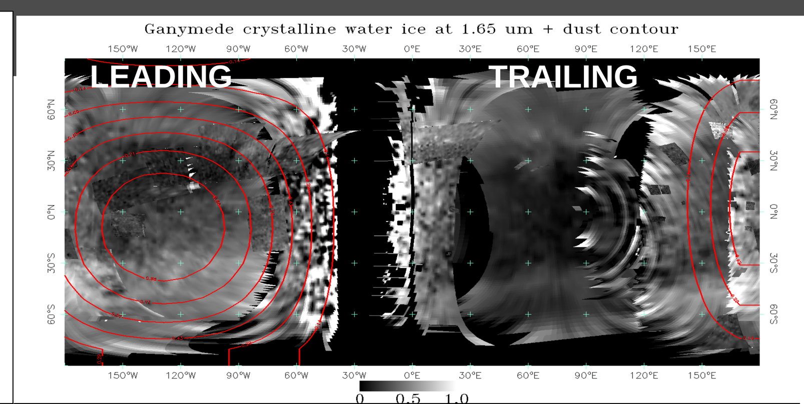


Figure: relative impact flux of dust on the moon's surfaces (Callisto, Europa and Ganymede), as predicted by JMEM. Highest dust impact flux on the leading side of the moon. Almost perfectly aligned on the leading side at Callisto, there is a gradual offset towards the trailing direction the closer the distance to Jupiter. This effect is due to the relative speed of the particles with respect to the moons. Further away from Jupiter, particles on eccentric orbits have velocity with respect to Jupiter lower than Keplerian circular speed – hence, Callisto for example is 'catching up' dust grains, which therefore impact the leading side direction. Closer to Jupiter, dust grains on eccentric orbits have velocities slightly higher than circular – the apparent impact direction on the surface therefore drift away from the leading side direction. The dust impacts are for all moons concentrated at equatorial latitudes, because of the low inclination of jovian dust, resulting in less flux at the poles. Therefore, any alteration effect related to dust impacts will be concentrated on the equatorial regions toward the moon's leading side.

The Galileo NIMS data have been re-analysed using the data as provided in the Planetary Data System (PDS) archive. The plot above shows the normalized dust flux on the surface of Ganymede superposed to the Galileo NIMS spectral map at 1.65 µm indicative of crystalline water. How dust impacts alter the phase (crystalline or amorphous) of the surface ice is poorly understood and new laboratory work is needed (see below)

Study icy moons' exosphere formation by sputtering (next steps)

Study the contribution from jovian dust (ejectas) to the exosphere formation:

→ For different longitude-latitude elements on the surface of the icy moons and for different impactors mass ranges, we can estimate the mean velocity of the dust hitting the different parts of the moons surface (using JMEM).

→ For each mass and velocity range, we can adapt the formula used in [5] (numerical modeling of impact processes) to the Jupiter icy moons to get an estimate of the total mass of an impact induced vapor cloud for a single impact as a function of its mass and velocity.

→ The estimated flux of (jovian dust) impactors will be estimated by JMEM to get the total vapor production rate at the moons' surface.

→ We can then analyze the anisotropy at the moons' surface and identify the main contributors (in terms of mass range) to the vapor cloud formation.

Study the contribution from the interplanetary dust population to the exosphere formation

→ Same analysis using IMEM (with estimated flux of Interplanetary dust population also taking into account the gravitational focusing) to compare the contributions of both populations to vapor cloud formation.

Study the effect of plasma sputtering (and the surface anisotropy) at the surface (using JOSE).

The Jovian Icy Moons space weathering experimental studies: an ESA project

<u>**Goal**</u>: better understand how realistically fabricated ices (representative of satellite material in the Jovian environment) react to various weathering agents (micrometeorite and proton/electron) resembling the magnetosphere and the dust environment in the jovian system.

<u>**Steps:**</u>

→ Fabrication of realistic ices and ice-dust mixtures resembling realistically the surface of the various Galilean moons (either within UHV chamber via dust deposition system or by external fabrication of purified water mixed with dust analogs)

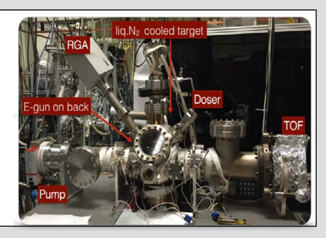
- Flexibility in target make-up: grain size of ice crystals and degree of crystallinity/amorphousness, ice mixture (ice-salts, ice-dust, ice-salt-dust …), uniform vs individually manufactured dust from natural minerals etc...

→ Irradiation of targets by electrons and ions (O, H and potentially S)

- Targets cooled at temperatures typical of Galilean moons, between 70 and 150K
- Observe and record changes within the target and the atmosphere in the chamber (through reflectance spectroscopy, infrared, UV-Vis, and Residual Gas analyzer)

→ Dust bombardment and investigation of ejecta production (species and yield)

<u>**Collaboration**</u>: Univ. of Heidelberg, Georgia Tech, Univ. of Stuttgart, ESAC & ESTEC



Current set-up of UHV-chamber at Georgia Tech

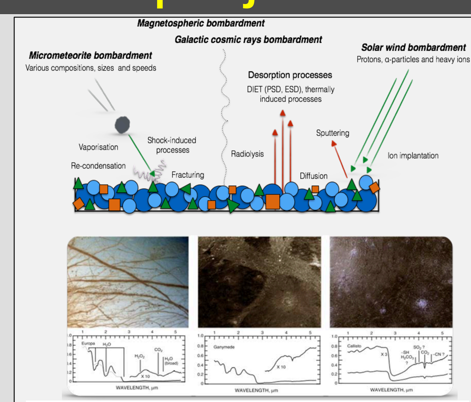


Illustration of the main space weathering agents and the hereby induced effects on surfaces of celestial bodies

References

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[5] Berezhnoy AA, Klumov BA. Impacts as sources of the exosphere on Mercury. Icarus. 2008