H2020-INFRAIA-2019-1

Ref. Ares (2020)192262 - 13/01/2020

EPN 2024 RI

EUROPLANET 2024 Research Infrastructure

H2020-INFRAIA-2019-1

Europlanet 2024 RI has received funding from the European Union's Horizon 2020 Research and Innovation Programme under

Grant agreement no: 871149

Deliverable D5.1
Mercury exosphere run on request service

Due date of deliverable:	30/11/2020
Actual submission date:	18/12/2020
Nature:[1]	R
Dissemination level[2]	PU
Work package:	WP5
Lead beneficiary:	INAF-IAPS
Contributing beneficiaries:	CNRS
Document status:	Final

Start date of project: 01 February 2020. Duration: 48 months

Project Co-ordinator: Prof Nigel Mason, University of Kent

1. **Nature:** R = Report, P = Prototype, D = Demonstrator, O = Other
2. **Dissemination level:**

PU	PP	RE	CO
Public	Restricted to other programme participants (including the Commission Service)	Restricted to a group specified by the consortium (including the Commission Services)	Confidential, only for members of the consortium (excluding the Commission Services)

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1. Introduction

The H2020 Europlanet-2020 programme, which ended on Aug 31st, 2019, included an activity called PSWS (Planetary Space Weather Services), which provided 12 services distributed over four different domains (A. Prediction, B. Detection, C. Modelling, D. Alerts) and accessed through the PSWS portal (http://planetaryspaceweather-europlanet.irap.omp.eu/):

A1. 1D MHD Solar Wind Prediction Tool – HELIOPROPA,

A2. Propagation Tool,

A3. Meteor showers,

A4. Cometary tail crossings – TAILCATCHER,

B1. Lunar impacts – ALFIE,

B2. Giant planet fireballs – DeTeCt3.1,

B3. Cometary tails – WINDSOCKS,

C1. Earth, Mars, Venus, Jupiter coupling- TRANSPLANET,

C2. Mars radiation environment – RADMAREE,

C3. Giant planet magnetodiscs – MAGNETODISC,

C4. Jupiter's thermosphere,

D. Alerts.

In the framework of the starting Europlanet-2024 programme, the Virtual Activity (VA) SPIDER (Sun-Planet Interactions Digital Environment on Request) will extend PSWS domains (A. Prediction, C. Modelling, E. Databases) services and give the European planetary scientists, space agencies and industries access to 6 unique, publicly available and sophisticated services in order to model planetary environments and solar wind interactions through the deployment of a dedicated run on request infrastructure and associated databases.

C5. A service for runs on request of models of Jupiter's moon exospheres as well as the exosphere of Mercury,

C6. A service to connect the open-source Spacecraft-Plasma Interaction Software (SPIS) software with models of space environments in order to compute the effect of spacecraft potential on scientific instruments onboard space missions. Pre-configured simulations will be made for Bepi-Colombo and JUICE (JUpiter ICy moon Explorer) missions,

C7. A service for runs on request of particle tracing models in planetary magnetospheres,

E1. A database of the high-energy particle flux proxy at Mars, Venus and comet 67P using background counts observed in the data obtained by the plasma instruments onboard Mars Express (operational from 2003), Venus Express (2006–2014), and Rosetta (2014–2015);

E2. A simulation database for Mercury and Jupiter's moons magnetospheres and link them with prediction of the solar wind parameters from Europlanet-RI H2020 PSWS services.

A1. An extension of the Europlanet-RI H2020 PSWS Heliopropa service in order to ingest new observations from Solar missions like the ESA Solar Orbiter or NASA Solar Parker Probe missions and use them as input parameters for solar wind prediction;

This report the status of the service C5 led by IAPS-INAF, Rome, Italy, made operational at the end of the first year of the project.

2. Exospheric models. Brief description and rationale

Service C5 is devoted to giving public access to a model of the exospheres of Mercury and of some Galilean moons. The first year of project was focused on the prototype of a service for the simulation of the exosphere of Mercury. The generation mechanisms, the compositions and the configuration of the Hermean exosphere will provide crucial insight in the planet status and evolution. The first detection of the exospheric environment have been provided by the Mariner 10 measurements of H, He and O during its fly-bys in 1974-75; later, thanks to ground-based observations, the presence of Na, K and Ca have been discovered. Even if MESSENGER visited Mercury in 2011 and added a consistent amount of data, still the actual knowledge about the morphology of this extremely tenuous atmosphere is anyway very poor and only some speculations can be done before the next BepiColombo measurements; a global description of Mercury's exosphere is still not available. For this reason, it's important to have a modelling tool ready for testing different hypothesis on release mechanism, as well as interpreting observational data. Several processes, such as photon, chemical and ion sputtering, thermal desorption and micro-meteoroids vaporization, has been proposed to be responsible of the formation of such an exosphere, and their relative importance is still discussed. In this frame we propose a MonteCarlo, three-dimensional model of the Hermean exosphere complete with all possible release sources and loss mechanisms, which also include the exo-ionospehere and the SW plasma circulation. Details of the model can be found in the references section.

3. Exospheric models. Implementation and details

The spatial distribution of a neutral exospheric component is obtained by using a Monte-Carlo single-particle model (see references). The particles are accumulated over a 7-dimensional grid (radius r; latitude ϕ; longitude λ , energy $E,$ mass, charge, pitch angle). For a given source process, the surface S where the process occurs is defined. Some (N_{tp}) test-particles are launched from a random starting point P_0 within S; the starting velocity $\mathbf{v}_0$, is also chosen randomly, according to the velocity distribution function of the source. A weight w is associated to the test-particle, which takes into account the number of real particles that it represents. Then, the trajectory of the test particle is computed using classical equation of motion, including gravity force in Mercury reference frame, and radiation pressure, if appropriate (the acceleration due to the non-inertial frame can also be added even if it is negligible in the case of Mercury). The test-particle trajectory ends at the surface of the planet or when it is too far from the planet (in our model, this is a user setting, usually many Mercury radii). Other loss processes do not remove test-particles, but they are taken into account by decreasing w according to τ_i , the lifetime of process i. presently we have included photo-ionisation and charge-exchange. Each time a test-particle crosses a grid cell, a quantity q is added to that cell:

$$q = w(t)\Delta t , \quad \textbf{(1)}$$

where Δt is the time elapsed inside the cell. After all trajectories have been simulated, the density in each grid cell *ijkl* is calculated by dividing Q_{ijkl} by the volume of the cell.

Ion sputtering Ion-sputtering results from the impinging of an ion of mass m_1 onto a surface; if the impact energy (E_i) is high enough, a new particle (m_2) may be extracted. For light ions, ion sputtering is a double-step process: backscattering of the ion over a surface target, and ejection of a second surface atom by the backscattered ion; in most cases, the ejected particle is neutral. The distribution function (f_S) of the ejection energy usually peaks at few eV and can be empirically reproduced by the function in Siegmund, (1969). This is implemented in different ways into the tool: one can simulate the ions precipitating and then simulate the released neutrals, or can just impose an arbitrary plasma flux onto the surface and then simulate just the neutrals.

Photon stimulated desorption. The dayside surface of Mercury is exposed to an intense flux of photons; those of sufficiently high energy (UV or shorten wavelengths) may extract neutral atoms from the planetary surface. Above approximately 250 nm ($h\nu = 5$ eV), photons can extract Na from a SiO_2 surface at 250 K with a cross-section between 1 to 3 10^{-20} cm^{-2}; the cross-section rises with the photon energy. The physical mechanism of the process varies for different adsorbate/substrate systems, and is either a direct or an indirect photon-induced electronic excitation of a surface atom. The process yield at Mercury, in general, should be lower than that founded experimentally, because surface regolith is supposed to be depleted in sodium content by exposure to bombardment, and because of regolith trapping effect. Moreover, the PSD yield is proportional to soil temperature but a soil temperature increase will produce an higher thermal desorption, which acts in concurrency with PSD. The energy distribution of the emitted particles atoms has been extrapolated by laboratory measurements of electron (200 eV) stimulated desorption (ESD) of adsorbed Na from SiO_2 film and from amorphous ice assuming that the electron energy has little impact on the emitted neutral energy, and that PSD and ESD cause desorption of atoms via similar electronic processes. Different velocity distribution models are available in the tool.

Thermal desorption Thermal desorption of sodium atoms from Mercury's surface becomes very efficient as the temperature of the soil becomes greater than 400 K. It has been noted that the sodium production rate should be limited to approximately 10^7 cm-^{2} s^{-1} by the diffusion rate within the soil; in this model however consider an unrestricted sodium flux from the surface. The evaporated particles are in thermal equilibrium with the surface, so that a Maxwellian – Boltzmann flux distribution can be applied. Usually the dayside surface temperature T is reproduced by a cosine function between the sub-solar point temperature T_d and the night-side temperature T_n; T_d varies from 725 K at perihelion to 590 K at aphelion; for other orbital distances, T_d is obtained with a linear interpolation; the night-side temperature T_n is uniform and always equal to 110 K. Alternatively, the tool can use an external surface temperature model.

Other sources. Mercury is exposed to the constant precipitation of particles of small sizes (<100 µm), impacting the surface at a mean velocity of 20 km/s, churning the regolith and vaporizing the surface. Larger objects impact the surface as well, causing local enhancement of the sodium exospheric density, but the contribution by these meteorites to the global Hermean exosphere is considered to be negligible. One can assume different thermal velocity distribution for the ejecta (usually, this is about 2500 K), and whether the precipitating particles are uniformly distributed over the surface or not. Then the tools obtains the simulated densities.

C5 Service Exospheric model - prototype

The model is written in Fortran 90 (~50'000 lines of code, ~300 routines) and run on a dedicated server. The server has a HTPPD interface (Apache 2) that can be reached at http://150.146.134.250 (go to "model" and then to "full model").

The HTTPD server run a Perl script that build a HTML form (see figure). The form "action" is another Perl script that gets the inputs and write a properly formatted input file (input.txt) for the Fortran model. This input.txt is put on a queue. A third Perl script routinely checks for the queue, and select the first input.txt file to be run. If such a simulation already exists in the internal database, with all identical input parameters, then the Fortran model is not run and the results are taken from the database. Otherwise, the simulation starts. At the end, a fourth Perl script collects all the outputs, and send an email to the address that has been indicated by the user.

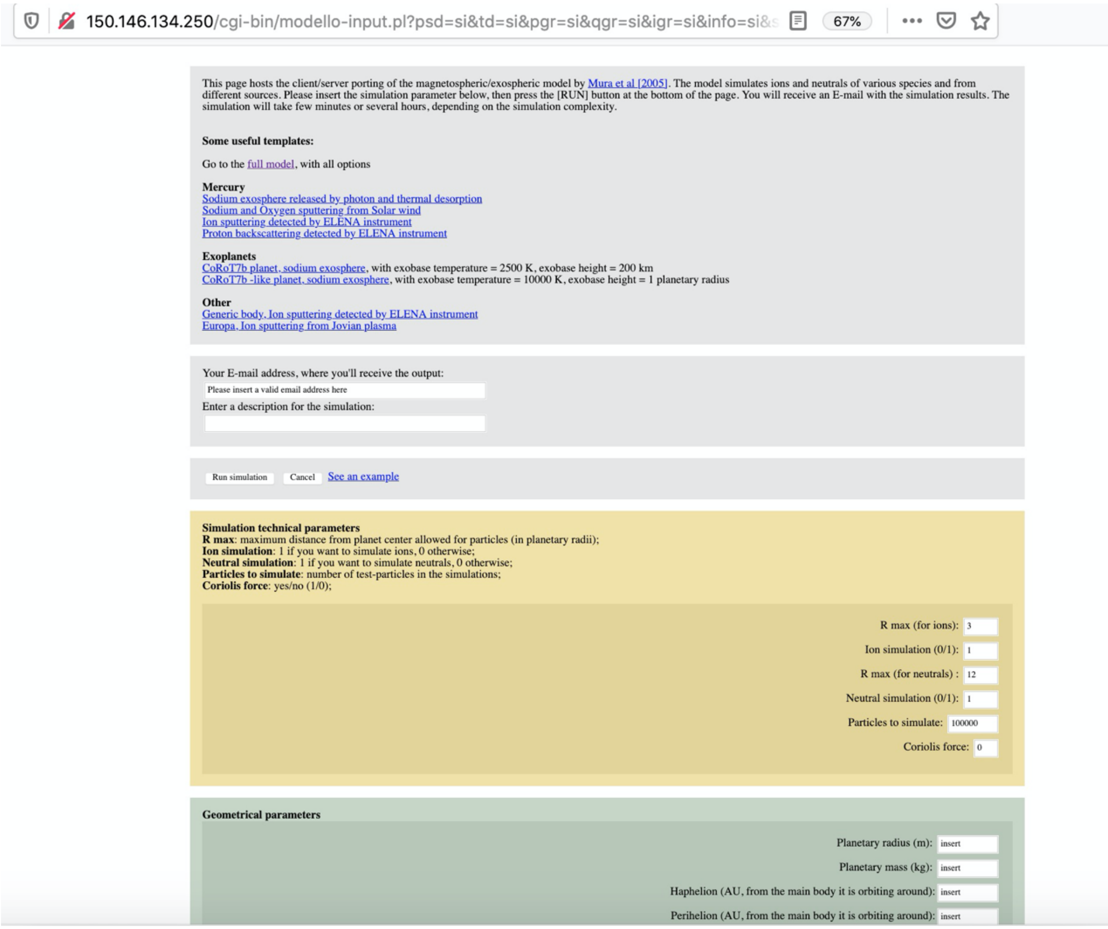
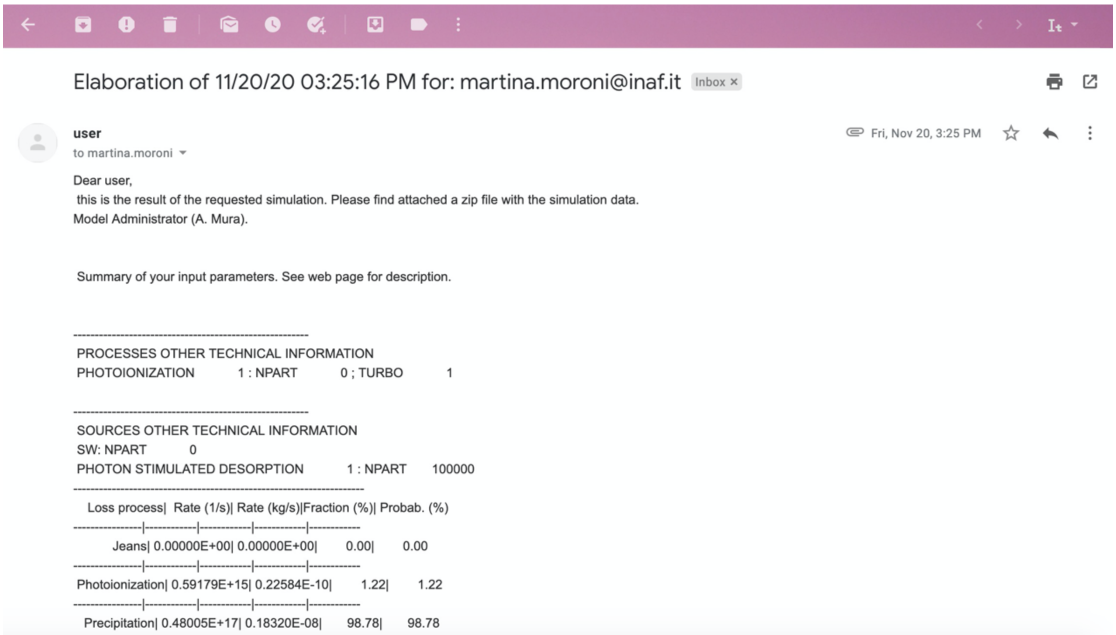


Figure 1: Model input page (part).



Elaboration of 11/20/20 03:25:16 PM for: martina.moroni@inaf.it Inbox ×

user
to martina.moroni

Fri, Nov 20, 3:25 PM

Dear user,
this is the result of the requested simulation. Please find attached a zip file with the simulation data.
Model Administrator (A. Mura).

Summary of your input parameters. See web page for description.

PROCESSES OTHER TECHNICAL INFORMATION
PHOTOIONIZATION 1 : NPART 0 ; TURBO 1

SOURCES OTHER TECHNICAL INFORMATION
SW: NPART 0
PHOTON STIMULATED DESORPTION 1 : NPART 100000

Loss process	Rate (1/s)	Rate (kg/s)	Fraction (%)	Probab. (%)
Jeans	0.00000E+00	0.00000E+00	0.00	0.00
Photoionization	0.59179E+15	0.22584E-10	1.22	1.22
Precipitation	0.48005E+17	0.18320E-08	98.78	98.78

Figure 2: example of email from the tool, with results (attached).

Dataset example

We show some examples of Na exosphere as simulated by the numerical model for specific surface processes and received via email (see above). Figure 3 shows a PSD exosphere simulated using different assumptions on the energy spectrum (Panel B and C) and a TD exosphere (panel C), assuming a uniform distribution of the ejected species. These depend on the parameters as temperature T= 1000 K, cross section= 2 x 10^{-24} cm^2, sodium relative composition c = 0.53%; regolith density N = 7.5 x 10^{14} cm^{-2}; binding energy U= 1.85 eV; vibrational frequency v =10^{13} s^{-1}.

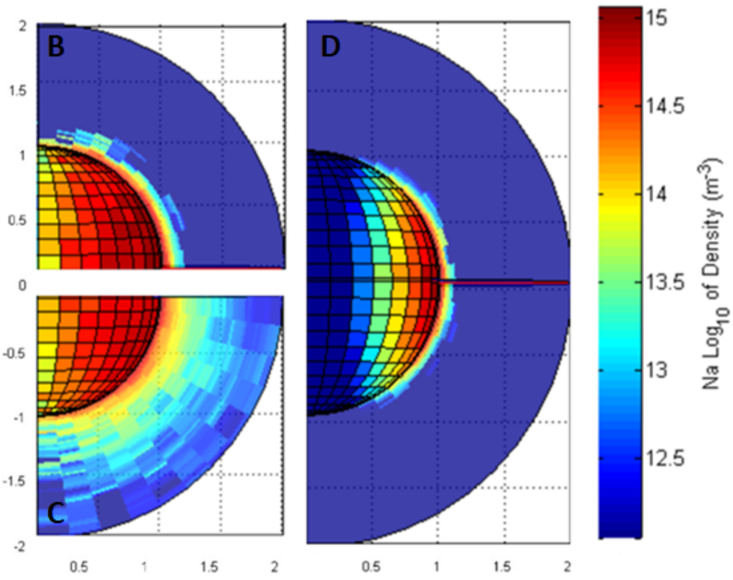


Figure 3: Sodium density is simulated by the numerical model for different processes: photo-stimulated desorption (Panel B and C); thermal desorption (Panel D).

Future perspectives

1. The next steps in the full implementation of the model are:
2. Debugging of fortran code (avoiding unwanted stops of the simulation)
3. Debugging of the HTTP/Perl interface, testing
4. Development of a user manual
5. Development of a list of templates of simulations (with only few parameters that can be changed, to cover most used cases).
6. Implementation of a check of physical coherence of the input parameters, to avoid unfeasible simulation runs.

We will study how to publish the outputs of the model in the VESPA portal and, if possible, we will pass the code in the OPUS platform installed on VESPA before the end of the project.

References

1. A. Mura, S. Orsini, A. Milillo, D. Delcourt, S. Massetti, E. De Angelis; 2005; Dayside H⁺ circulation at Mercury and neutral particle emission; Icarus; volume 175, issue 2; doi: 10.1016/j.icarus.2004.12.010 (file:Icarus 175 (2005) 305–319.pdf)
2. A. Mura, S. Orsini, A. Milillo, A.M. Di Lellis, E. De Angelis; 2006; Neutral atom imaging at Mercury; Planetary and Space Science; volume 54, issue 2; doi: 10.1016/j.pss.2005.02.009 (file:Planetary and Space Science 54 (2006) 144–152.pdf)
3. V. Mangano, A. Milillo, A. Mura, S. Orsini, E. De Angelis, A.M. Di Lellis, P. Wurz; 2007; The contribution of impulsive meteoritic impact vapourization to the Hermean exosphere; Planetary and Space Science; volume 55, issue 11; doi: 10.1016/j.pss.2006.10.008 (file:Planetary and Space Science 55 (2007) 1541–1556.pdf)

4. S. Massetti, S. Orsini, A. Milillo, A. Mura; 2007; Modelling Mercury's magnetosphere and plasma entry through the dayside magnetopause; Planetary and Space Science; volume 55, issue 11; doi: 10.1016/j.pss.2006.12.008 (file:Planetary and Space Science 55 (2007) 1557–1568.pdf)
5. A. Mura, A. Milillo, S. Orsini, S. Massetti; 2007; Numerical and analytical model of Mercury's exosphere: Dependence on surface and external conditions; Planetary and Space Science; volume 55, issue 11; doi: 10.1016/j.pss.2006.11.028 (file:Planetary and Space Science 55 (2007) 1569–1583.pdf)
6. A. Mura, P. Wurz, H.I.M. Lichtenegger, H. Schleicher, H. Lammer, D. Delcourt, A. Milillo, S. Orsini, S. Massetti, M.L. Khodachenko; 2009; The sodium exosphere of Mercury: Comparison between observations during Mercury's transit and model results; Icarus; volume 200, issue 1; doi: 10.1016/j.icarus.2008.11.014 (file:Icarus 200 (2009) 1–11.pdf)
7. C. Plainaki, A. Milillo, A. Mura, S. Orsini, T. Cassidy; 2010; Neutral particle release from Europa's surface; Icarus; volume 210, issue 1; doi: 10.1016/j.icarus.2010.06.041 (file:Icarus 210 (2010) 385–395.pdf)