The Rosetta 3dtool — a web-based trajectory planning and visualization application

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The Rosetta 3dtool was developed in order to provide an overview over the spatial and temporal evolution of Rosetta trajectories. The application supports science planning of the Rosetta mission and shares operational ideas with a broader science community and spacecraft operation engineers. The 3dtool is a web-based application. Therefore, there is a very low threshold for the user to take advantage of it.

I. Introduction

Rosetta is a mission of the European Space Agency (ESA).[1,2] It is the first mission going into orbit around and land on a comet. The spacecraft arrived at the comet on 6 August 2014 following a 10-year journey through the Solar System. On 12 November 2014, Rosetta's lander Philae was deployed to the surface. The trajectory and operations of the mission are particularly complex, have many free parameters and are novel to the community. To support science planning, communicate operational ideas and disseminate operational scenarios to the scientific community, ESA's Rosetta Science Ground Segment (RSGS) makes use of web-based visualization technologies.

Several requirements were crucial for the development of the Rosetta 3dtool: The tool should provide an intuitive and interactive visualization of Rosetta orbiter trajectories and instrument views. It should provide timeline information and additional file products such as plots of relevant parameters and coverage maps. In addition, relevant input data which have been used for generating these visualizations and plots should be made available for the user. Another requirement was to bring 3D visualizations directly to the user's browser by using the recently approved WebGL[a] standard, which turned out to be a convenient way to display a 3D scene.

II. Software design

Figure 1 shows the entire work-flow of the 3dtool framework. The light-blue elements are input data and the blue squares symbolize output data provided to the user. The elements illustrated as circles are software routines transforming input to output data. These are a Python script named `3dtool.py` and its subroutines (red) and external programs (light-red). The execution of `3dtool.py` initiates the overall process chain ending up with the final visualization products. Before executing this script, input data have to be

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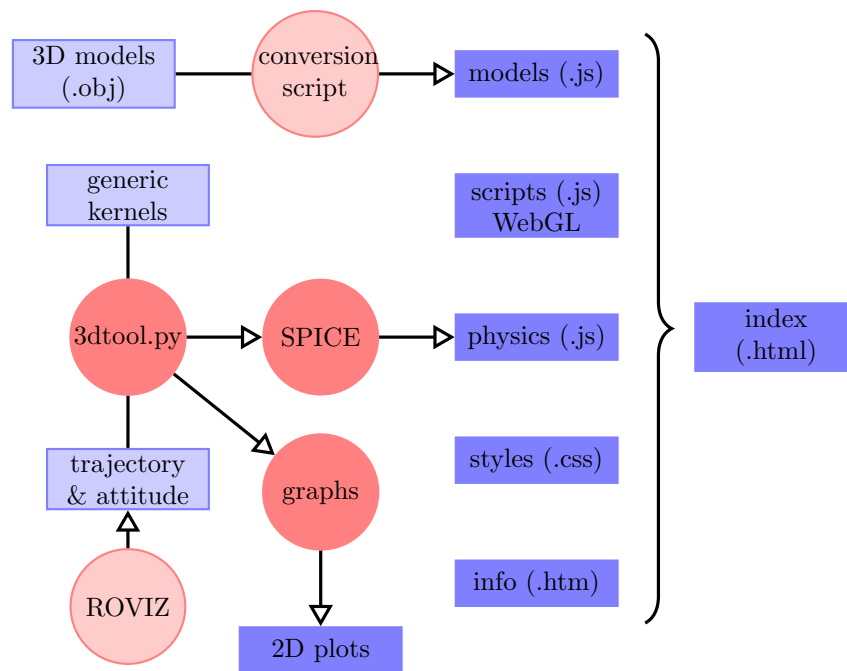American Institute of Aeronautics and Astronautics

Figure 1: Schema of 3dtool software elements. Color code: light-red = external program, red = program, light-blue = input data, blue = output data.

generated beforehand. These are the trajectory and the attitude of the Rosetta orbiter, generic data and additional parameters such as start and end time. Trajectory, attitude and generic data have to be provided in a SPICE kernel format.[b3]

Another tool called ROVIZ[4] provides the required trajectory and attitude kernels. ROVIZ stands for *ROsetta trajectory propagation and VIsualiZation system*. When ROVIZ is used to study the evolution of a trajectory from a prescribed starting state, gravity forces of an irregular shaped comet body and of the ephemeris are considered. According to the spacecraft cross-section, additional drag forces are taken into account due to solar wind and emitted comet gases. For calculating the total gas pressures, simulated distributions of gas densities and velocities are provided by the *Inner Coma Environment Simulator* (ICES).[c] Propagation is done by a leap-frog method.[d] In a different application, ROVIZ is used to design trajectories and to create a file with an abstract description as an input for the Flight Dynamics team at the Rosetta Mission Operations Centre (RMOC). Here, preliminary trajectories are computed in Keplerian approximation.[5]

Generic input data are also present as SPICE kernels. In particular, these are files comprising reference frames, instrument geometry, time and clock data, ephemeris data, physical and cartographic data for solar system bodies, such as size, shape and orientation. Additional parameters such as the studied time range and resolution, naming and observation opportunity windows are fed to 3dtool.py as plain text.

For the visual front-end, 3D models of the shown objects have to be converted into a format which can be displayed in web browsers. For that purpose, a UNIX shell script has been written which converts shape models from Wavefront (OBJ) format to JavaScript Object Notation (JSON) format. For comet 67P/Churyumov-Gerasimenko, different shape models based on NAVCAM and OSIRIS instrument data are available for download.[e]

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[b]NASA's Ancillary Data System for Planetary Missions / Navigation and Ancillary Information Facility (NAIF)
[c]ICES - University of Michigan
[d]P. Young: The leapfrog method and other "symplectic" algorithms for integrating Newton's laws of motion
[e]Comet 67P/C-G shape models

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For displaying text and graphical content on the web, all data have to be transfered to suitable file formats such as HTML, JavaScript and Cascading Style Sheets (CSS). Furthermore, WebGL — a HTML5 standard for hardware-accelerated 3D graphics and SceneJS — an application programming interface (API) for WebGL — is used.[f] During execution of `3dtool.py`, template files from a repository are copied to the final output. These files constitute the framework of the Rosetta 3dtool output. Modifiable data, such as trajectory or attitude information are written to dedicated "data" JavaScript files using JSON format.

As shown in figure 1, `3dtool.py` evokes two subroutines. The first subroutine is based on a `C` implementation of SPICE. With the given kernels and further required input, it computes physical data such as trajectory coordinates, velocities and reference frames. Then, the same routine converts these data into appropriate web formats. After completion, a UXIX shell script with integrated gnuplot[6] routines generates a sequence of relevant parameter plots. The web-content can be accessed by the site `index.html` which binds together all parts of the Rosetta 3dtool. It is the starting point for accessing 3D visualizations, 2D plots and parameters which are specific for the studied trajectory.

III. Visual front-end

ESA hosts a web page where studied orbiter trajectories can be found and analyzed using the Rosetta 3dtool. Figure 2 shows a detail of this "homepage". There is a menu on the left-hand side giving quick access to case studies, documentation and further resources. The RSGS classified three different trajectory versions: first the approximate trajectories created by ROVIZ together with a file known as the TRAjectory request at Long term planning (TRAL), second the Long Term Planning (LTP) cycle trajectories provided by the Flight Dynamics team — both these cases were usually sliced by Medium Term Planning (MTP) cycles in the 3dtool — and third the final Very Short Term Planning (VSTP) cycle trajectories, which also comprise the reconstructed trajectory for the past.[7] For each trajectory, there are several products available: the SPICE kernels which have been used to generate the content, a link to 3D visualizations, a link to 2D plots and raw data files containing the computed (time-resolved) parameters.

Figure 2: Screenshot of the Rosetta 3dtool homepage with a list of studied trajectories.

III.A. Layout

After choosing a particular case study from the homepage's list and following the 3D link, the visual front-end of the Rosetta 3dtool opens. The layout of this web page is explained in figure 3. The front-end comprises two 3D visualizations, a link to 2D plots and raw data files, and several control and display panels.

In the *time control* panel, a time slider and several buttons can be used to pick a particular instance in time which is also displayed in Coordinated Universal Time (UTC) at the right of the panel. Below, a

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[f]SceneJS — an open-source WebGL based 3D visualization engine

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panel with several check boxes and named *vectors and landmarks* can be found. By checking a box, the corresponding object appears in the 3D visualizations. The objects are either landmarks on the comet surface or pointing vectors which are useful for orientation. For example, by checking the sun–comet check box, a yellow line from the comet center to the sun is drawn.

On the right of the *vectors and landmarks* panel, there is a button with a star symbol and a slider with a light bulb symbol. The slider controls the comet brightness in the 3D visualizations. This is particularly useful for highlighting features on the night side of the comet or for adapting the apparent brightness to the terminal device (monitor, beamer). The star button toggles the background of the 3D visualizations. It can be either empty (black) or a representation of the brightest stars using the VizieR [g][8,9] star catalogue.

The *information* panel on the lower left part of figure 3 shows relevant information on the current case study such as time range, used kernels and release date. An important focus during development of the Rosetta 3dtool was its modular structure. Whenever possible, data and structural elements were separated. Therefore, the integration of the *information* panel is technically realized by loading a separate file `info.htm` containing the descriptive information (see also diagram in figure 1). The 3dtool web page itself is copied from a template repository without prior modification.

The *instrument control* panel below the upper right 3D visualization allows for changing the visualization's field of view. The field of view of the two OSIRIS cameras (wide and narrow angle) and a custom field of view were implemented. In addition, further optical instruments of the Rosetta orbiter are shown as overlays on top of the actual 3D visualization. Below the *instrument control* panel on the very right part of the 3dtool web page, there is a *graphs* link. By clicking on it, a separate web page with 2D plots opens which is explained in section III.C.

On the lower right, a panel with *online plots* can be found. Graphical representations of two parameters are available: a plot of the distance between orbiter and comet center and a groundtrack plot showing the projected position of the orbiter on the comet surface in longitude and latitude coordinates. The 3dtool was programmed before the particular shape of comet 67P/Churyumov-Gerasimenko was known. Initially, a more uniform shape was assumed. For a complex shape such as the studied comet,[10,11] a unique assignment of surface points to longitude and latitude coordinates is not guaranteed anymore. Notably in the neck-region of the comet, there exist coordinates with more than one singular surface point. However, these coordinates still determine a unique position of the spacecraft with respect to the comet center.

III.B.   3D visualizations

In the 3dtool front-end shown in figure 3, two 3D visualizations can be found. The *inertial view* on the left hand side of the 3dtool comprises a comet shape model, a trajectory and a symbolic representation of the Rosetta orbiter. The orbiter trajectory for the particular case study is shown as a white line. Since comet 67P/Churyumov-Gerasimenko is on an elliptical orbit around the sun, the viewpoint's motion is not strictly "inertial". It refers rather to a viewpoint which is stationary relative to the comet's position. The operational 3dtool uses a comet shape model based on images taken by the ESA NAVCAMs. Before the shape could be derived from Rosetta observations, models based on light-curve measurements were used.[12] Due to operational constraints, the time between Rosetta wake up and the first science planning cycles was very short. Therefore, these preliminary shape models were useful to perform functional tests on the 3dtool.

A cube with colored faces symbolizes the Rosetta spacecraft. The cube is not to scale to the comet size. Its apparent size is much bigger. Thus, the 3dtool user can easily localize the spacecraft's position in the 3D viewer even if the distance to the comet is in the order of hundreds of km. No realistic rendering of the spacecraft structure was implemented. This is partly because of saving data volume and enhancing the web browser's performance. However, the user perceives the correct orbiter attitude when looking on the Payload Support Module. This is the spacecraft side where most science instruments are mounted. In the 3dtool, a cube face painted in a different color represents this spacecraft side.
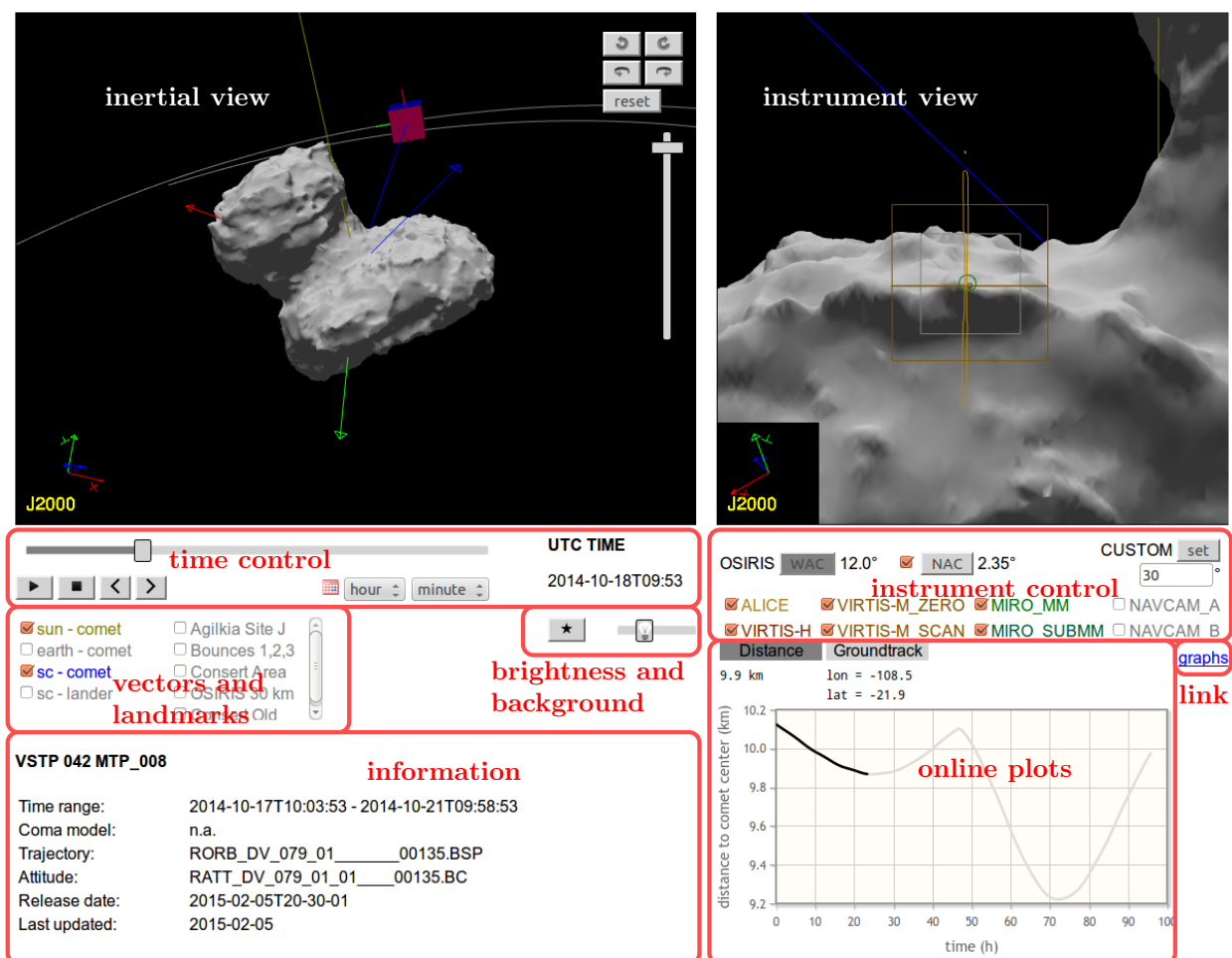
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[g]VizieR bright star catalogue

Figure 3: Layout of visual front-end with the two 3D visualizations and various control and display panels highlighted in red.

The objects in both 3D visualizations are displayed in J2000 coordinates. Small insets of the corresponding coordinate axes are shown in the lower left parts of both 3D visualizations. Furthermore, the body-fixed reference frame of the comet is visualized by a coordinate system spanned by three arrows painted in red, green and blue. The blue arrow points along the rotational comet axis. Finally, several vectors used for orientation purposes and landmarks on the comet surface are shown optionally if the corresponding check boxes are marked. Note that WebGL uses single-precision floating point numbers. To be compatible with features of different scales, the coordinate system had to be chosen carefully to avoid numerical imprecision which would affect the visual presentation by introducing jumps, for example.

In the upper right part of the *inertial view*, there are several view control buttons: Four buttons rotate the 3D scene in 90° increments, a vertical slider zooms the scene in and out. The view can be restored to the default settings by pressing on "reset". Most conveniently, the scene can be rotated and zoomed by a left mouse button hold and drag and by using the mouse scroll wheel, respectively. Additionally, the view can be shifted sidewards by a left mouse button hold and drag while keeping the shift button pressed.

The observer's orientation and position in the *inertial view* can be changed by taking advantage of the control options described above. However, from a scientific and planning standpoint, the predetermined view seen from onboard instruments is typically the most useful. It allows to compare directly precomputed instrument views with actual measurements. Therefore, a *instrument view* has been implemented on the upper right part of 3dtool. This view includes the OSIRIS Wide Angle Camera (WAC), Narrow Angle Cam-

era (NAC) and a virtual camera with customizable field of view. In the center of the corresponding camera view, several colored overlays can be found. These are the field of view frames of the orbiter instruments ALICE, VIRTIS and MIRO.[13] In addition to these instruments, the field of view frames of the two ESA NAVCAMs can be displayed.

III.C.   2D plots

In terms of parameter plots, the 3dtool web page is limited to a distance and groundtrack plot of the Rosetta orbiter. For users interested in further graphical data representations, a dedicated web page with 2D plots has been created. This site can be accessed by the *graphs* link on each case study. There, plots in the image formats Portable Network Graphics (PNG) and Encapsulated PostScript (EPS) are available. In addition, raw data of these parameters can be downloaded in American Standard Code for Information Interchange (ASCII) format.

A selection of 2D plots is shown in figure 4. Figure 4(a) is an overview of comet and earth orbits during the studied time range. This plot is useful for estimating the distances from the comet to sun and earth. In figure 4(b) the orbiter trajectory around comet 67P/Churyumov-Gerasimenko is visualized. Figure 4(c) shows an example coverage map. There, the cumulative coverage of sun illuminated and visible facets of the comet shape are plotted in color-coded representation and projected on longitude and latitude coordinates (Mollweide projection).

Figure 4(d) is a histogram showing the distribution of spacecraft off-nadir angles for the entire trajectory history. In this definition, nadir is a spacecraft orientation to the comet center. Figure 4(e) is a combined phase angle and local time plot. It shows the time-resolved phase angle, i.e. the angle between the connecting lines sun–comet and spacecraft–comet. Simultaneously, the local time on the comet determined by the position of the sun is plotted in a color code on the phase angle curve.

IV.   Conclusion

The main purpose of the Rosetta 3dtool is supporting mission planning which requires numerous interactions between RSGS and the scientific community and between RSGS and RMOC. Due to a web-based approach, 3dtool users are not required to install additional software packages on their computers. Furthermore, maintenance and updates are centralized on a server infrastructure. Thus, new features and case studies are made available to all users at the same time. In contrast to locally installed software with comparable functionality, much shorter turn-around times are achieved. Ultimately, these advantages lead to a very low threshold for the user.

Strengths and priorities of the 3dtool are visualization and trajectory planning. Due to its modularity and web-based technology, it can easily be integrated in the overall planning process and combined with other software, for instance scheduling, mapping and payload resource tools. Furthermore, the 3dtool provides contextual information for orbiter instruments which do not acquire images. A unique URL is given to each case study which can be extended by a hashtag followed by a timestamp. In a particular case study, this allows to link specific events which then can be shared easily within the Rosetta community. In addition, the timestamp functionality allows to generate simulated images in a batch process for certain time instances or ranges.

Limitations of web-based tools are related to the data volume which has to be transferred over a network link and kept in a web browser environment. Therefore, careful design and reduction of data is required. The 3dtool user sees only the visual front-end. For the implementation of new case studies, execution of 3dtool routines and server uploads are required. Due to an increasing variety of terminal devices, the accurate adaptation of visualizations to devices with various screen resolutions is a challenge.

Currently, further fields of application for the 3dtool technology are investigated. Hardware-accelerated

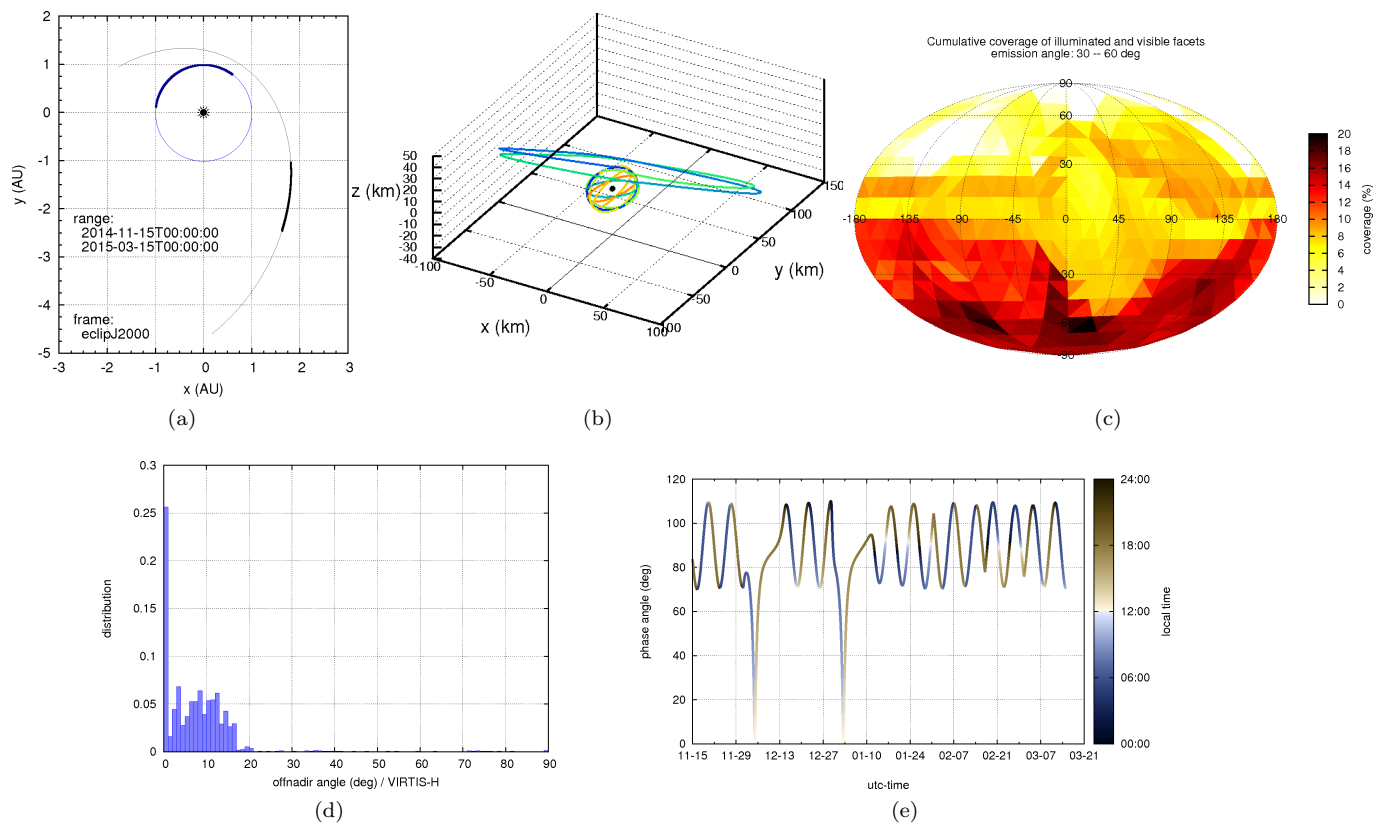American Institute of Aeronautics and Astronautics

Figure 4: Selection of 2D plots available on a separate *graphs* web page.

3D graphics allows for real-time visualizations with fast update rates. For instance, these techniques can be used to monitor the attitude of sounding rockets. For this purpose, telemetry data have to be fed into the web front-end which dynamically updates the view on a 3D rocket model. In addition to state-of-the-art on-flight monitoring, an intuitive and real-time 3D visualization of the rocket attitude might decrease response times for ground station activities during operation and improve post-flight analysis.

Acknowledgments

References

[1] Glassmeier, K.-H., Boehnhardt, H., Koschny, D., Kührt, E., and Richter, I., "The Rosetta mission: flying towards the origin of the solar system," *Space Science Reviews*, Vol. 128, No. 1-4, 2007, pp. 1–21.

[2] Schulz, R., Alexander, C., Boehnhardt, H., and Glassmeier, K.-H., *Rosetta-ESA's Mission to the Origin of the Solar System*, Springer Press, 2009.

[3] Acton, C. H., "Planning and processing space science observations using NASA's SPICE system," *Aerospace Conference Proceedings, 2000 IEEE*, Vol. 2, IEEE, 2000, pp. 305–310.

[4] Grieger, B., Altobelli, N., Küppers, M., Schmidt, A., and Völk, S., "Modelling the trajectories of cm to meter sized chunks in the vicinity of comet 67P/Churyumov-Gerasimenko," *EPSC-DPS Joint Meeting 2011*, Vol. 1, 2011, p. 1056.

[5] Vallat, C., Altobelli, N., Geiger, B., Grieger, B., Küppers, M., Crego, C. M., Moissl, R., Taylor, M. G. G. T., Alexander, C., Buratti, B., and Choukroun, M., "The Science Planning Process on the Rosetta Mission," *Acta Astronautica*, 2016, submitted for publication.

[6] Racine, J., "gnuplot 4.0: a portable interactive plotting utility," *Journal of Applied Econometrics*, Vol. 21, No. 1, 2006, pp. 133–141.

[7] Ashman, M., Barthlmy, M., ORourke, L., Almeida, M., Altobelli, N., Sitj, M. C., Beteta, J. J. G., Geiger, B., Grieger, B., Heather, D., Hoofs, R., Kppers, M., Martin, P., Moissl, R., Crego, C. M., Prez-Aycar, M., Suarez, E. S., Taylor, M., and Vallat, C., "Rosetta science operations in support of the Philae mission," *Acta Astronautica*, 2016, pp. –, submitted for publication.

[8]Zacharias, N., Finch, C., Girard, T., Henden, A., Bartlett, J., Monet, D., and Zacharias, M., "VizieR Online Data Catalog: UCAC4 Catalogue (Zacharias+, 2012)," *VizieR Online Data Catalog*, Vol. 1322, 2012, pp. 0.

[9]Ochsenbein, F., Bauer, P., and Marcout, J., "The VizieR database of astronomical catalogues," *Astronomy and Astrophysics Supplement Series*, Vol. 143, No. 1, 2000, pp. 23–32.

[10]Sierks, H., Barbieri, C., Lamy, P. L., Rodrigo, R., Koschny, D., Rickman, H., Keller, H. U., Agarwal, J., Ahearn, M. F., Angrilli, F., et al., "On the nucleus structure and activity of comet 67P/Churyumov-Gerasimenko," *Science*, Vol. 347, No. 6220, 2015, pp. aaa1044.

[11]Preusker, F., Scholten, F., Matz, K.-D., Roatsch, T., Willner, K., Hviid, S., Knollenberg, J., Jorda, L., Gutiérrez, P. J., Kührt, E., et al., "Shape model, reference system definition, and cartographic mapping standards for comet 67P/Churyumov-Gerasimenko–Stereo-photogrammetric analysis of Rosetta/OSIRIS image data," *Astronomy & Astrophysics*, Vol. 583, 2015, pp. A33.

[12]Lamy, P. L., Toth, I., Davidsson, B. J., Groussin, O., Gutiérrez, P., Jorda, L., Kaasalainen, M., and Lowry, S. C., "A portrait of the nucleus of comet 67P/Churyumov-Gerasimenko," *Space science reviews*, Vol. 128, No. 1-4, 2007, pp. 23–66.

[13]Gulkis, S. and Alexander, C., "Composition measurements of a comet from the Rosetta orbiter spacecraft," *Space Science Reviews*, Vol. 138, No. 1-4, 2008, pp. 259–274.

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