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Comet.Photos: An Interactive Tool for Rapidly Searching and Displaying Rosetta Mission Images by Spatial Location and Other Properties

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Summary

The European Space Agency's Rosetta mission to Comet 67P/Churyumov-Gerasimenko (hereafter, 67P) provided an unparalleled dataset, which has fundamentally reshaped our understanding of comets. Despite these advances, however, the complexity and volume of Rosetta data, coupled with the lack of efficient tools for comprehensive analyses, have hindered its broader utilization. To address this gap, we developed `Comet.Photos`, an interactive tool for efficiently searching and visualizing images of irregular bodies.

`Comet.Photos` enables fast, intuitive spatial searches across more than 44,000 high-resolution images of 67P, acquired by the Rosetta Optical, Spectroscopic, and Infrared Remote Imaging System (OSIRIS) Narrow Angle Camera (NAC) and Wide Angle Camera (WAC) (Keller et al., 2007) and the Navigation Camera (NavCam) (Geiger et al., 2021). Users can define a region of interest on a 3D model of the comet by painting with a virtual brush (Figure 1). The application then nearly instantly (< 50 ms in this example) returns a time-ordered list of all images containing that region. Results can be further filtered by pixel scale and viewing geometry (emission, incidence, and phase angle), and displayed either in their original 2D form (Figure 2) or projected onto the 3D shape model (Figure 3).

Designed for both professional researchers and the public, `Comet.Photos` can be installed locally for fastest performance, but is also accessible in any modern browser without requiring installation. It combines preprocessed data with real-time, client-side filtering to achieve subsecond search speeds, even across large datasets.

Statement of need

The European Space Agency's (ESA) Rosetta mission to 67P provided the most spatially and temporally comprehensive dataset of any comet to date, enabling a broad range of analyses of its surface. Because each region was imaged multiple times under varying illumination and viewing conditions, studies such as photometric modeling (Fornasier et al., 2023; Oklay et al., 2016), multi-image photoclinometry (Jindal et al., 2024), and surface-change detection (Barrington et al., 2023; Birch et al., 2019; El-Maarry et al., 2017; Fornasier et al., 2017; Groussin et al., 2015; Jindal et al., 2022; Keller et al., 2017) became possible for the first time, substantially advancing our understanding of cometary surface evolution. The sheer number of images, however, makes identifying repeat observations of the same regions a difficult and time-consuming task. This challenge is further compounded by 67P's complex, highly non-spherical shape and Rosetta's variable orbit, which often caused images of the same region to appear dramatically different from one another.

The scale of this difficulty is illustrated by the fact that it took seven years after the end of the Rosetta mission for the first global catalog of surface changes on 67P to be published (Barrington et al., 2023). Compiling this catalog required manually inspecting more than 20,000 OSIRIS NAC images to identify those showing morphological changes—a monumental task that took over a year to complete! This was followed by an additional year for detailed characterization, involving manual map projection of each image with the shapeViewer software (Vincent, 2018) and then mapping changes in ESRI's ArcGIS software. Given the wide range of imaging geometries, errors in co-registration and change detection were unavoidable. Consequently, despite these efforts, the global change catalog—and, by extension, our understanding of 67P's evolution—knowingly remains incomplete, with numerous consequential surface changes still undocumented, as evidenced by Moser et al. (2025).

Efforts have been made to mitigate these challenges—for example, ESA has introduced an image search capability within their Planetary Science Archive (PSA) (ESA, 2024). This tool, however, remains inadequate (at least for Rosetta), as it (a) is slow, (b) frequently returns incorrect or missing data, and (c) lacks user control over filtering searches by image parameters, a crucial feature for assembling a manageable dataset without wasting time removing irrelevant images. Hence, to fully harness the scientific potential of Rosetta's vast dataset and empower researchers to quickly and accurately identify relevant observations for analysis, an efficient and intuitive tool is needed to streamline image retrieval.

`Comet.Photos` has been developed to fill this critical gap, providing a powerful solution for rapid, spatially targeted image searches and facilitating detailed studies of cometary surface properties and evolution. Users can select a region of interest by interactively painting the desired region on a 3D model of 67P. In a fraction of a second, the application searches through over 44,000 NAC, WAC, and NavCam images to identify all observations of the selected region. Results can then be filtered by key parameters such as pixel scale, emission angle, incidence angle, and phase angle, allowing users to tailor datasets for photometric or temporal analyses. Images matching the search criteria can be viewed in 2D or projected onto the 3D shape model, and users can export a list of matching image IDs for further processing with external tools.

Although designed primarily for researchers, `Comet.Photos` also provides an accessible interface for educators, students, and the general public to explore Rosetta's imagery of 67P. By making this tool highly efficient, freely available and simple to use, we aim to broaden participation in cometary research and facilitate new scientific insights from this unprecedented dataset. The application can be installed locally for maximum performance, but can also be run in any modern browser without installation, by visiting https://comet.photos.

Notes on the implementation

`Comet.Photos` achieves its speed through extensive preprocessing of image metadata. For each image (Geiger et al., 2020; Sierks & OSIRIS Team, 2020, 2022), the preprocessing pipeline first simulates the spacecraft camera view and its relative position with respect to the comet's 3D shape model, a SHAP7 model (Preusker et al., 2017) with 100,002 vertices. Vertex visibility across all simulated scenes is stored in a lookup table, which enables, at runtime, fast bitwise operations to compute the fraction of the region of interest (painted vertices) visible in any image. Additional precomputed metadata—such as spacecraft position, solar geometry, and image resolution—allow rapid filtering by geometric or photometric criteria with minimal computational overhead.

To support both high-performance local execution and remote web access, `Comet.Photos` adopts a client-server architecture. The client is organized into object-based modules (Filter Engine, 3D Scene Manager, Image Browser, GUI Controller, etc.) that communicate through an event-driven system. The user interface is specified via a declarative schema, fully decoupled from the controller (Filter Engine) and data model. This event-driven runtime architecture provides the basis for a logging system with automated regression testing. The server component is a small, modular Node.js application with components for launching the browser when run locally, loading the platform-specific C library for rapid visibility checks, and distinct modules that separate preprocessing and runtime event handling. The datasets are separate from the code, and are loaded dynamically given a dataset catalog.

We are currently using `Comet.Photos` as part of a broader toolset (Jindal et al., 2025) to discover and map new surface changes on 67P using Rosetta data. With the appropriate preprocessing, the same framework could support other Rosetta instruments, such as VIRTIS (Coradini et al., 2007), MIRO (Gulkis et al., 2007), and ALICE (Stern et al., 2007); it could also be adapted to other small-body missions, including Lucy (Levison et al., 2021), Hera (Michel et al., 2022), OSIRIS-REx (Lauretta et al., 2017), OSIRIS-APEX (DellaGiustina et al., 2023), and Hayabusa2 (Watanabe et al., 2017).

The `Comet.Photos` GitHub repository (Kurlander, 2025) provides the full source code, a detailed user manual, an example workflow, local installation and testing instructions, and documentation on design, architecture, implementation, and performance.

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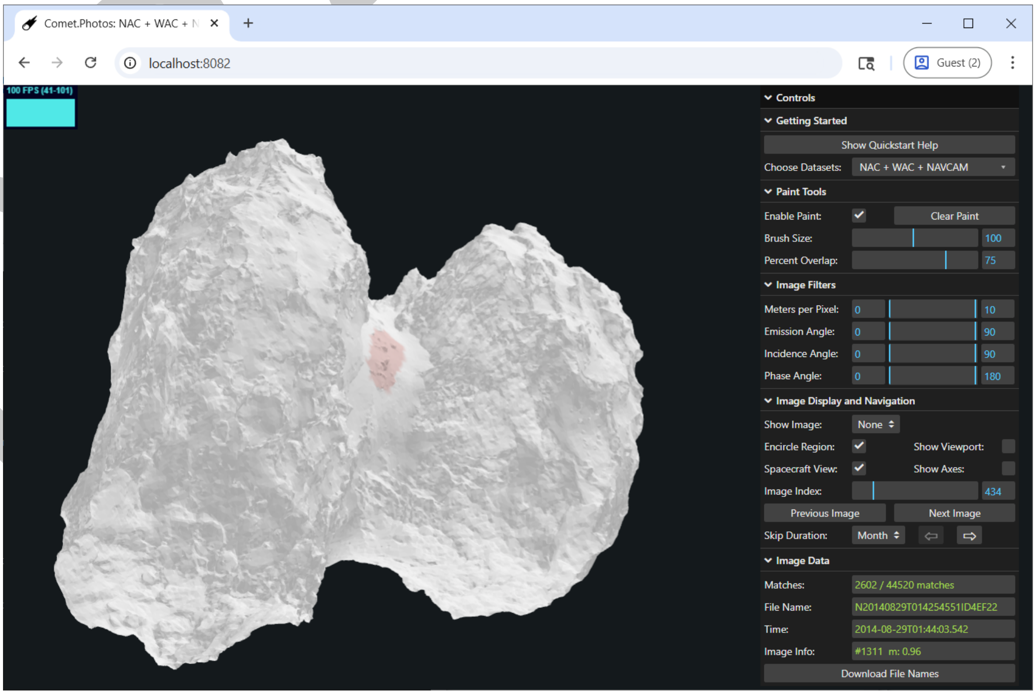

Figure 1: In this example, the user paints a region of interest on the 3D comet shape model. Almost immediately, the application finds 2,602 images from the 44,520 images in the dataset that contain the painted region.

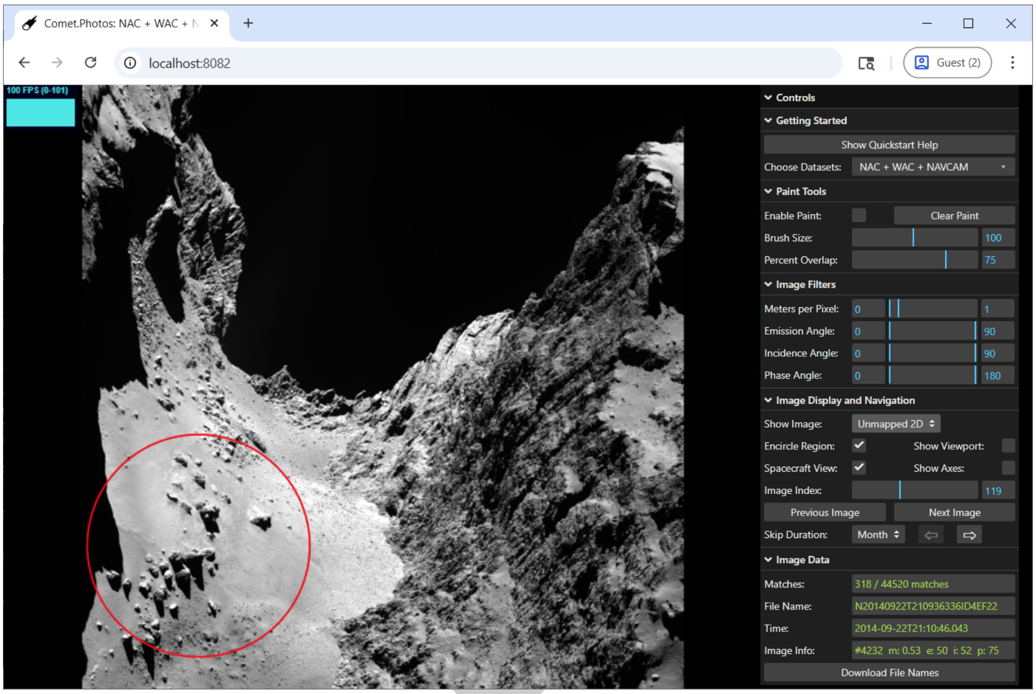

Figure 2: In this example, to find only those images with a high level of surface detail, the user sets the pixel scale slider to a maximum of 1 meter per pixel. This results in 318 image matches, one of which is displayed here in its original 2D form.

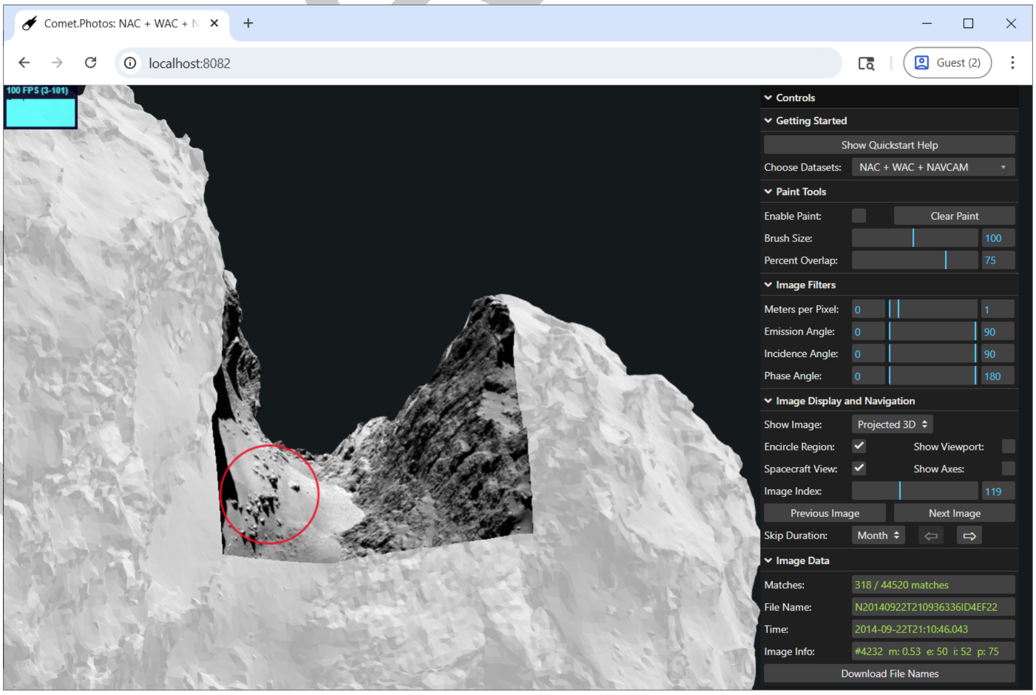

Figure 3: To examine the image from Figure 2 in context, the user projects it onto the 3D model.

References

Barrington, M. N., Birch, S. P. D., Jindal, A., & others. (2023). Quantifying morphological changes and sediment transport pathways on comet 67P/Churyumov-Gerasimenko. *Journal of Geophysical Research: Planets*, *128*. https://doi.org/10.1029/2022JE007723

Birch, S. P. D., Hayes, A. G., Umurhan, O. M., & others. (2019). Migrating scarps as a significant driver for cometary surface evolution. *Geophysical Research Letters*, *46*. https://doi.org/10.1029/2019GL083982

Coradini, A., Capaccioni, F., Drossart, P., & others. (2007). VIRTIS: An imaging spectrometer for the Rosetta mission. *Space Science Reviews*, *128*. https://doi.org/10.1007/s11214-006-9127-5

DellaGiustina, D. N., Nolan, M. C., Polit, A. T., & others. (2023). OSIRIS-APEX: An OSIRIS-REx extended mission to asteroid Apophis. *Planetary Science Journal*, *4*. https://doi.org/10.3847/PSJ/acf75e

El-Maarry, M. R., Groussin, O., Thomas, N., & others. (2017). Surface changes on comet 67P/Churyumov-Gerasimenko suggest a more active past. *Science*, *355*. https://doi.org/10.1126/science.aak9384

ESA. (2024). *Planetary science archive*. https://psa.esa.int/

Fay, B. (2023). Rewarding excellence in open data. *MIT News*. https://news.mit.edu/2023/rewarding-excellence-in-open-data-1116

Fornasier, S., Feller, C., Lee, J.-C., & others. (2017). The highly active Anhur–Bes regions in the 67P/Churyumov–Gerasimenko comet: Results from OSIRIS/ROSETTA observations. *MNRAS*, *469*. https://doi.org/10.1093/mnras/stx1275

Fornasier, S., Hoang, H. V., Fulle, M., & others. (2023). Volatile exposures on the 67P/Churyumov-Gerasimenko nucleus. *Astronomy and Astrophysics*, *672*. https://doi.org/10.1051/0004-6361/202245614

Geiger, B., Andres, R., Fraga, D., & Rosetta NAVCAM Team, the. (2020). *Rosetta-Orbiter 67P NAVCAM Level-3 Calibrated Image Archive, Version 1.0* [Data set]. ESA Planetary Science Archive; NASA Planetary Data System.

Geiger, B., Andres, R., & Statella, T. (2021). Radiometric calibration of the Rosetta navigation camera. *Journal of Astronomical Instrumentation*, *10*. https://doi.org/10.1142/S2251171721500045

Groussin, O., Sierks, H., Barbieri, C., & others. (2015). Temporal morphological changes in the Imhotep region of comet 67P/Churyumov-Gerasimenko. *Astronomy and Astrophysics*, *583*. https://doi.org/10.1051/0004-6361/201527020

Gulkis, S., Frerking, M., Crovisier, J., & others. (2007). MIRO: Microwave instrument for Rosetta orbiter. *Space Science Reviews*, *128*. https://doi.org/10.1007/s11214-006-9032-y

Jindal, A. S., Birch, S. P. D., Hayes, A. G., & others. (2022). Topographically influenced evolution of large-scale changes in comet 67P/Churyumov-Gerasimenko's Imhotep region. *The Planetary Science Journal*, *3*. https://doi.org/10.3847/PSJ/ac7e48

Jindal, A. S., Birch, S. P. D., Hayes, A. G., & others. (2024). Measuring erosional and depositional patterns across comet 67P's Imhotep region. *JGR Planets*, *129*. https://doi.org/10.1029/2023JE008089

Jindal, A. S., Kurlander, D., Soderblom, J., & others. (2025). *RoSCo: A new tool to navigate Rosetta's dataset*. EPSC Abstracts Vol. 18, EPSC-DPS2025-838. https://doi.org/10.5194/epsc-dps2025-838

Keller, H. U., Barbieri, C., Lamy, P., & others. (2007). OSIRIS – the scientific camera system onboard Rosetta. *Space Science Reviews*, *128*. https://doi.org/10.1007/s11214-006-9128-4

Keller, H. U., Mottola, S., Hviid, S. F., & others. (2017). Seasonal mass transfer on the nucleus of comet 67P/Churyumov–Gerasimenko. *MNRAS*, *469*. https://doi.org/10.1093/mnras/stx1726

Kurlander, D. (2025). Comet.Photos — fast spatial search of comet images from the Rosetta mission. October 2025 (version 3.0.0). In *GitHub repository*. GitHub. https://github.com/comet-dot-photos/comet-dot-photos

Lauretta, D. S., Balram-Knutson, S. S., Beshore, E., & others. (2017). OSIRIS-REx: Sample return from asteroid (101955) Bennu. *Space Science Reviews*, *212*. https://doi.org/10.1007/s11214-017-0405-1

Levison, H. F., Olkin, C. B., Noll, K. S., & others. (2021). Lucy mission to the Trojan asteroids: Science goals. *Planetary Science Journal*, *2*. https://doi.org/10.3847/PSJ/abf840

Michel, P., Küppers, M., Bagatin, A. C., & others. (2022). The ESA Hera mission: Detailed characterization of the DART impact outcome and of the binary asteroid (65803) Didymos. *Planetary Science Journal*, *3*. https://doi.org/10.3847/PSJ/ac6f52

Moser, M., Jindal, A., Birch, S., & others. (2025). *Kaboom: Surface manifestations of cometary outbursts*. EPSC Abstracts, Vol. 18, EPSC-DPS2025-868. https://doi.org/10.5194/epsc-dps2025-868

Oklay, N., Vincent, J.-B., Fornasier, S., & others. (2016). Variegation of comet 67P Churyumov-Gerasimenko in regions showing activity. *Astronomy and Astrophysics*, *586*. https://doi.org/10.1051/0004-6361/201527369

Preusker, F., F., S., Matz, K.-D., & others. (2017). The global meter-level shape model of Comet 67P/Churyumov-Gerasimenko. *Astronomy and Astrophysics*, *607*. https://doi.org/10.1051/0004-6361/201731798

Sierks, H., & OSIRIS Team. (2020). *Rosetta-Orbiter 67P OSINAC Level-4 INFLDSTR Calibrated Image Archive, Version 1.0* [Data set]. ESA Planetary Science Archive; NASA Planetary Data System.

Sierks, H., & OSIRIS Team. (2022). *Rosetta-Orbiter 67P OSIWAC Level-4 INFLDSTR Calibrated Image Archive, Version 2.0* [Data set]. ESA Planetary Science Archive; NASA Planetary Data System.

Stern, S. A., Slater, D. C., Scherrer, J., & others. (2007). ALICE: The Rosetta ultraviolet imaging spectrograph. *Space Science Reviews*, *128*. https://doi.org/10.1007/s11214-006-9035-8

Vincent, J.-B. (2018). shapeViewer, a software for the scientific mapping and morphological analysis of small bodies. *LPSC*.

Watanabe, S., Tsuda, Y., Yoshikawa, M., & others. (2017). Hayabusa2 mission overview. *Space Science Reviews*, *208*. https://doi.org/10.1007/s11214-017-0377-1