Understanding the activity of comets through 67P’s dynamics

Research Domain: Planetary Science

Abstract

Comets, thought to be amongst the most primordial of Solar System objects, are distinguished by their activity, i.e. the insolation driven ejection of gas and dust from their surfaces. The exact mechanisms of the outgassing and dust ejection remain an important open question in planetary science, relating as it does to the structure, composition, and thermophysical properties of the surface material. A directly observable effect of the activity, however, is the resultant non-gravitational force and torque on the cometary nucleus, which can alter its trajectory and rotation state. Understanding the effect of non-gravitational forces on the dynamics of a particular comet therefore gives us a powerful tool to investigate its activity and surface properties.

In this context, the detailed measurements made by ESA’s Rosetta mission at comet 67P/Churyumov-Gerasimenko provide a unique opportunity to discern a ground-truth for models of both non-gravitational acceleration (NGA) and torque (NGT), and outgassing activity. Rosetta collected data at 67P from 2014 to 2016, whilst spacecraft radio tracking combined with optical navigation allowed the comet’s position to be measured with unprecedented precision. Initially, the comet’s trajectory was reconstructed without taking the NGA into account, resulting in discontinuities in the reconstruction and hampering the extraction of the acceleration. Recent work, however, has improved the situation, and it is now possible to extract time-varying curves of the outgassing induced NGA directly from the trajectory. Alongside this, tracking of the nucleus orientation allows a measurement of the outgassing induced torque, while Rosetta’s in-situ instruments have measured the total outgassing rate itself. Together, these data provide significant constraints on both the distribution of activity over 67P’s surface, and the activity mechanism itself. Various comet thermal models are available in the literature, and these produce differing activity curves in space and time that can be directly compared with the combined dataset. 67P, therefore, provides a unique opportunity to constrain thermal-model parameters and near-surface nucleus properties.

This ISSI team will bring together international experts in spacecraft trajectory analysis with those in modelling and observations of cometary activity, in order to better understand the non-gravitational forces present at 67P and their implications for its activity pattern. This usage of the Rosetta data will result in the output of new scientific knowledge regarding cometary activity in general, which will be relevant for the next generation of missions such as Comet Interceptor.

Scientific Rationale

Comets are amongst the most primordial objects orbiting the Sun, having formed directly from the protoplanetary disc and survived unaltered for much of their lifetimes in the outer Solar System. They are therefore vital targets for our understanding of planet formation and early Solar System history.

Upon entering the inner Solar System, comets are heated by the Sun and undergo activity; i.e., the sublimation of volatile ices and the ejection of gas and dust with a resulting reaction force on the nucleus. The physical mechanisms behind this activity are still not fully understood. Open questions remain for example, in how the sublimating ices are distributed, both macroscopically across the cometary surface, and microscopically, within or between the cometary grains; as well as the related questions of exactly how the sublimation happens from beneath a dust mantle, and how the outgassing can overcome intergrain strength and cometary gravity in order to eject the dust. These questions relate to the structure, composition, and thermophysical properties of the cometary material and therefore connect directly to their formation in the early Solar System. Whether comets, and by extension planets, formed from the gravitational collapse of clouds of ~centimetre-sized pebbles (as evidenced in Blum et al. 2017) or by continual collisional growth (Davidsson et al. 2016) has direct implications for the structure and strength (Bischoff et al. 2019) of the near surface material that controls outgassing (Gundlach et al. 2020; Fulle et al. 2019).

In addition to observing the ejected gas and dust, measuring the reaction force's effects in changing comets' trajectories and rotation states provides a useful insight into the activity. Simple non-gravitational acceleration (NGA) models, such as those by Marsden et al. 1973 and Yoemans and Chodas 1989, are often used to fit cometary orbits to ground-based observations, but these provide little insight into the physics of the activity. More complex models (following from Sekanina 1993) relate the observed NGAs to the outgassing via a thermal model and some distribution of ices or active areas across the nucleus surface. If independent measurements of this distribution and/or the outgassing rate can be made, then physical inferences may be drawn. A number of studies (Davidsson and Gutiérrez, 2005; Sosa and Fernandez, 2009; Maquet et al., 2012) have combined ground-based measurements of outgassing and NGAs to better predict the orbits of comets and to infer their masses, densities, and surface activity patterns.

At comet 67P/Churyumov-Gerasimenko our understanding of cometary outgassing can be put to the test, and more detailed deductions about the nucleus structure and properties can be made, thanks to Rosetta. ESA's Rosetta spacecraft measured 67P with in-situ and remote sensing instruments between 2014 and 2016, whilst radio-tracking combined with optical navigation allowed the comet's position to be measured with unprecedented precision. The total outgassing rate and an idea of how it varies across the surface has been constrained by various investigations, such as Hansen et al. 2016, Marshall et al. 2016, 2017, Läuter et al. 2019, 2020; whilst we now understand the importance of seasonal changes in insolation and dust cover across the comet's surface (Keller et al. 2017). As summarised in Mottola et al. 2020, various attempts have been made to fit 67P's non-gravitational trajectory (Kramer et al. 2019, Davidsson et al. 2021), rotation state (Kramer and Läuter 2019), and both in combination with outgassing (Attree et al. 2019).

Several of these efforts have produced a ‘map’ of relative activity over 67P’s surface which can be compared to one-another, while tentative progress has been made in linking the NGA-derived activity with surface morphology (Attree et al. 2020, Attree et al. 2021). Parameters derived from these efforts are highly dependent on the thermal model used to describe the outgassing, however, and these thermal models are complicated and incomplete in their description of the surface material.

There is thus an excellent opportunity to synthesise the results of these various analyses to come to a conclusive view of 67P’s activity distribution, while, at the same time, constraining the thermal model parameters.

The first stage of the project will be to simply compare the non-gravitational accelerations extracted from the comet’s trajectory by various methods. The initial ESA-ESOC orbit solution for 67P was reconstructed (from radio-ranging data to the spacecraft combined with optical navigation of the comet-spacecraft position) without taking NGAs into account, leaving large discontinuities of up to several hundred kilometres in heliocentric position (Attree et al. 2019). A recent reanalysis of Rosetta’s radiometric data, combined with ground-based astrometric observations (Farnocchia et al. 2020) shows that a smooth trajectory reconstruction can be achieved using a simple rotating jet model (Chesley et al. 2004). An independent reconstruction has also been undertaken by Lasagni Manghi et al. 2022, which makes use of the whole set of range and ΔDOR measurements collected during the Rosetta mission. These complementary efforts, along with an earlier effort by Kramer et al. 2019, explicitly extract non-gravitational forces, in the form of time-varying NGA curves. These can then be directly compared to each other and with the accelerations produced by Marsden- and rotating jet-style models, in order to assess the ground-truth of their usefulness and accuracy in predicting comet positions (Kramer and Läuter, 2021).

The NGAs as a function of time will then be compared with the outputs of more physical thermal models (e.g. Keller et al. 2015; Attree et al. 2019, Fulle et al. 2019) and inferences made about the distribution of active areas. It is here that the combination of acceleration data with rotation changes will be vital in breaking the degeneracy that otherwise exists when reconstructing the spatial activity distribution (Marschall et al. 2020). Non-gravitational torques are very sensitive to the exact position of the outgassing on the irregularly shaped nucleus, meaning areas of relatively high and low activity can be identified. Relative activity maps, or variations in thermal parameters, will be compared to nucleus surface morphology, as well as with the maps derived from other Rosetta datasets. At the same time, the overall outgassing is constrained by the NGA and gas measurements, meaning a simultaneous fit of the various unknown parameters appearing in the above thermal models can be attempted. Several thermal models will be run so that different parameters such as dust depth, grain sizes (Blum et al 2017, Gundlach et al 2020), gas diffusivity, and gas-nucleus coupling (Davidsson et al. 2021) can be constrained, and the overall fit of each can be assessed.

Finally, the implications for comet material properties and formation models will be discussed and interpreted by the team. At this stage, it will be vital for the experts in trajectory analysis and cometary thermal modelling to be in close contact to enable full interaction of the various models and interpretation of the results; hence the added value of an ISSI collaboration.

As an additional input, the results of laboratory experiments could also be integrated. Several of the team members are participants in the CoPhyLab comet physics laboratory project, also based at the TU Braunschweig, and collaboration here could provide additional constraints on the thermal models. In particular, CoPhyLab experiments in the `large' chamber will be conducted throughout 2022 and should help calibrate quantities such as the sublimation rate and gas diffusivity in real materials as analogues of cometary pebbles.

This project will address longstanding questions in cometary activity relating to volatile distribution and material properties, as well as drawing together all the evidence on a specific Rosetta question: where is comet 67P active? Fully understanding 67P's non-gravitational trajectory and rotation will, alongside other Rosetta measurements, allow us to constrain some of the many unknown parameters in cometary activity and NGA models. The quantities derived can then be applied to other comets, observed from the ground or by future missions such as Comet Interceptor. With the complete Rosetta dataset archived and processed, it is timely to reassess the trajectory and rotation data in comparison with the other measurements and to place the entire mission in context. Leveraging the NGAs will allow new knowledge of cometary activity to be uncovered, which should result in the publication of several papers.

Team Members

The international team consists of experts in several fields (spacecraft trajectory reconstruction/radio-ranging analysis, comet thermophysical modelling and imaging), a range of geographic locations (nine institutions, five countries; all ESA member states), and career stages, and a reasonable gender balance (particularly among the early career scientists to be confirmed). Several participants were Rosetta instrument team members and, in addition, the project will be in contact with other comet scientists through the CoPhyLab project, as well as external experts including Michael Küppers (ESAC) and Björn Davidsson (JPL).

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Proposed Schedule

We propose to use the two week-long meetings of the full team in Bern: in late 2022 and mid-to-late 2023. The schedule will have to remain somewhat flexible to take account of the ongoing pandemic situation. Both meetings will be hybrid to allow for remote attendance.

In principle, the first meeting will bring the team together and discuss the output of various trajectory models, including the new Bologna model that should be published by then. We will then begin analysing the solutions in terms of surface activity, and discuss how to proceed with more physical models. The second meeting will summarise the results of these analyses, discussing the implications for cometary science in general, as well as the progress of the papers to be published. Teleconferences will be used in-between to maintain good communication between team members.

ISSI Added Value

We request the standard ISSI facilities and financial support, plus 2-3 early career researchers to be added, depending on funding, availability, and timing.

ISSI will be vital in providing a venue for the collaboration between team members who are otherwise geographically spread. Trajectory analysis and activity modelling work is ongoing in several groups, but would be significantly enhanced in an ISSI team by physically bringing the group together for in-depth discussions and analysis.

Expected Outputs

At least two papers should be published: one comparing the various activity maps and accelerations extracted from 67P's trajectory, including a comparison with ground-based models; and a second on modelling activity constrained by the NGAs. This second part will approach the problem in different ways; i.e. with different thermal models and the possibility of embedding a thermal model in the trajectory fit, and may be split into several papers.

In addition to the published papers, the new, smooth 67P trajectory will be made available for the community in the form of SPICE kernels covering the period between July 2014 and September 2016, corresponding to Rosetta's proximity phase.

References

Attree, N., Jorda, L., Groussin, O., et al., 2019. A&A, 630, A18.
Attree, N., Jorda, L., Groussin, O., Marschall, R., EPSC2020-99, Oct 2020
Attree, N., Jorda, L., Groussin, O., Marschall, R., Lasagni Manghi, R, Tortora, P., Zannoni, M., EPSC2020-17, Sep 2021
Blum J., et al., 2017, MNRAS, 459, S755
Bischoff, D., Gundlach, B., Neuhaus, M., Blum, J., 2019. MNRAS, Volume 483, Issue 1, p.1202-1210.
Chesley, S., & Yeomans, D., 2004. Proceedings of the International Astronomical Union, 2004 (IAUC197), 289-302.
Davidsson, B., Gutiérrez, P., 2005. Icarus, Volume 176, Issue 2.
Davidsson, B., et al., 2016, A&A, 592, A63
Davidsson, B., Samarasinha, N., Farnocchia, D., Gutiérrez, P., 2021. MNRAS, Volume 509, Issue 2, p. 3065–3085.
Farnocchia D., Bellerose J., Bhaskaran S., Micheli M., Weryk, R., 2020. Icarus 358, 114276
Fulle, M. Blum, J., Rotundi, A., 2019. ApJ Letters, 879:L8 (3pp).
Gundlach B., Fulle M., Blum J., 2020, MNRAS, 493, 3690.
Hansen, K. C., Altwegg, K., Berthelier, J.-J., et al. 2016, MNRAS, 462, S491
Keller, H., Mottola, S., Davidsson, B., 2015. A&A, Volume 583, id. A34, 16 pp.
Keller, H., Mottola, S., Hviid, S., 2017. MNRAS, Volume 469, Issue 2, p.S357-S371.
Kramer, T., Läuter, M., Hviid, S., 2019. A&A, Volume 630, id.A3, 11 pp.
Kramer, T., Läuter, M., 2019. A&A, Volume 630, id.A4, 6 pp.
Kramer, T., Läuter, M., EPSC2020-337, Sep 2021
Läuter, M., Kramer, T., Rubin, M., Altwegg, K., 2019. MNRAS Volume 483, pp. 852-861
Läuter, M., Kramer, T., Rubin, M., Altwegg, K., 2020. MNRAS Volume 498, pp. 3995-4004
Lasagni Manghi R., Zannoni M., Tortora P., Budnik F., Godard B., 2022, Advances in Space Research (submitted).
Maquet, L., Colas, F., Jorda, L., Crovisier, J., 2012. A&A, Volume 548, id. A81, 8 pp.
Marsden, B. G., Sekanina, Z., & Yeomans, D. K. 1973, AJ, 78, 211
Marschall, R., Su, C. C., Liao, Y., et al. 2016, A&A, 589, A90
Marschall, R., Mottola, S., Su, C. C., et al. 2017, A&A, 605, A112
Marschall, R., Ying, L., Thomas, N., Wu, J-S., 2020. Icarus, Volume 346, id. 113742.
Mottola, S., Attree, N., Jorda, L., 2020. Space Science Reviews, 216, 2
Sekanina, Z. 1993, A&A, 277, 265
Sosa, S., Fernández, J., 2009. MNRAS, Volume 393, Issue 1.
Yeomans, D. K., Chodas, P. W. 1989, AJ, 98, 1083

Appendix: Team Member CVs

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Role in the project: Project lead/ISSI team coordination.
Modelling and interpretation of physical 67P activity models, including analysis of other Rosetta datasets such as rotation.

Current position: Postdoctoral Researcher. Technische Universität Braunschweig

Former Position(s): Postdoctoral Research Fellow
University of Stirling, UK
May 2018 – July 2021
Postdoctoral Research Assistant
Laboratoire d'Astrophysique de Marseille, France
July 2016 – April 2018
Postdoctoral Research Assistant in Astronomy
Queen Mary University of London, School of Physics and Astronomy
June 2015 – December 2015

Education: Ph.D. in Astronomy. Queen Mary University of London
2011 – 2015
MPhys in Physics with Planetary Science. University of Leicester
2007 – 2011

Services in National and/or International Committees (last ones):
Organising committee for Planetary Environments in the Laboratory workshop, University of Stirling, February 2019.
Associate member of InSight HP^3 (NASA), Rosetta OSIRIS (ESA), Cassini ISS (NASA), and Comet Interceptor (ESA) teams.

Honors: Marseille City award for newly arriving researchers. 2016
Ray Duncombe Student Prize supporting travel to the DDA Meeting. 2014
QMUL PG Research Fund award supporting travel to AGU Fall Meeting. 2012
University of Leicester Departmental Prize for Degree results. 2011

Selected Publications:

Journal Publications

Nongravitational Effects of Cometary Activity.
S. Mottola, N. Attree, L. Jorda, H-U. Keller, R. Kokotanekova, D. Marshall, Y. Skorov, 2020, Space Science Reviews, 216: 2

Bilobate comet morphology and internal structure controlled by shear deformation.
C. Matonti, N. Attree, O. Groussin, et al., 2019, Nature Geosciences, a12, pages 157–162

The Thermal, Mechanical, Structural, and Dielectric Properties of Cometary Nuclei After Rosetta.
O. Groussin, N. Attree, Y. Brouet, V. Ciarletti, B. Davidsson, G. Filacchione, H.-H. Fischer, B. Gundlach, M. Knapmeyer, J. Knollenberg, R. Kokotanekova, E. Kührt, C. Leyrat, D. Marshall, I. Pelivan, Y. Skorov, C. Snodgrass, T. Spohn, F. Tosi, 2019, Space Science Reviews, 215: 29

Constraining models of activity on comet 67P/Churyumov-Gerasimenko with Rosetta trajectory, rotation, and water production measurements.
N. Attree, L. Jorda, O. Groussin, et al., 2019, A&A, 630, A18

Thermal fracturing on comets: Applications to 67P/Churyumov-Gerasimenko
N. Attree, O. Groussin, L. Jorda, et al., 2018, A&A, 610, A76

Tensile Strength of 67P/Churyumov-Gerasimenko Nucleus Material from Overhangs
N. Attree, O. Groussin, L. Jorda, et al., 2018, A&A, 611, A33

Conference Proceedings

Activity on different terrain types on comet 67P/Churyumov-Gerasimenko
Talk at the Europlanet Science Congress 2021, held virtually: id. EPSC2021-17
13th - 24th September, 2021

Further constraints on activity models of comet 67P/Churyumov-Gerasimenko with Rosetta data
Poster at the Europlanet Science Congress 2020, held virtually: id. EPSC2020-99
21st September to 9th October, 2020

Thermal and mechanical properties in the near-surface of comet 67P/Churyumov-Gerasimenko from Rosetta
Invited seminar at the Max Planck Institute for Solar System Research, Göttingen, Germany
4th October, 2018

Constraining activity models of comet 67P/Churyumov-Gerasimenko with Rosetta data
Talk at the European Planetary Science Congress, Berlin, Germany
16th to 21st September, 2018

Thermal Fracturing on Comets: Applications to 67P/Churyumov-Gerasimenko
Talk at the European Planetary Science Congress, Riga, Latvia
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MSc in Aerospace Engineering, Alma Mater Studiorum, Università di Bologna (2013-2016)
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Selected Publications:

Journal publications

Lasagni Manghi, R., Zannoni, M., Tortora, P., Budnik, F., Godard, B., (2022), Accurate ephemeris reconstruction for comet 67P/Churyumov-Gerasimenko during Rosetta's proximity phase from radiometric data analysis. Advances in Space Research (submitted).

Lasagni Manghi, R., Zannoni, M., Tortora, P., Martellucci, A., De Vicente, J., Villalvilla, J., et al. (2021). Performance characterization of ESA's tropospheric delay calibration system for advanced radio science experiments. Radio Science, 56, e2021RS007330. DOI: https://doi.org/10.1029/2021RS007330

Lasagni Manghi R., Modenini D., Zannoni M., Tortora P., "Preliminary orbital analysis for a CubeSat mission to the Didymos binary asteroid system", Advances in Space Research (2018), Volume 62, Issue 8, Pages 2290 - 2305. DOI: 10.1016/j.asr.2017.12.014

F. Perez, D. Modenini, A. Vázquez, F. Aguado, R. Tubío, G. Dolgos, P. Tortora, A. Gonzalez, R. Lasagni Manghi, M. Zannoni, A. Nazeeruddin, M. Melozzi e I. Carnelli, «DustCube, a nanosatellite mission to binary asteroid 65803 Didymos as part of the ESA AIM mission» Advances in Space Research (2018), Volume 62, Issue 12, Pages 3335 - 3356. DOI: 10.1016/j.asr.2018.06.019

Conference proceedings

R. Lasagni Manghi, M. Zannoni, P. Tortora e D. Modenini, «Measuring the Mass of a Main Belt Comet: PROTEUS Mission». IEEE International Workshop on Metrology for Aerospace, Turin, 2019.

R. Lasagni Manghi, D. Modenini, M. Zannoni e P. Tortora, (2019) «An autonomous optical navigation filter for a CubeSat mission to a binary asteroid system», Paper and presentation for the 69th International Astronautical Congress, 1-5 October 2018, Bremen, Germany

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Services in National and/or International Committees (last ones):
Organising committee of Session B5.3 (Ocean Worlds) at COSPAR 2018, 14-22 July 2018,Pasadena, California.
Honors: 2015 NASA Group Achievement Award to the Enceladus and Titan Gravity Science Team
2009 NASA Group Achievement Award to the Cassini Radio Science Team
2020 AIAA Associate Fellowships

Selected Publications:

Gomez Casajus L.; Zannoni M.; Modenini D.; Tortora P.; Nimmo F.; Van Hoolst T.; Buccino D.; Oudrhiri K., "Updated Europa gravity field and interior structure from a reanalysis of Galileo tracking data", Icarus, 2021, 358,
Zannoni, M., Tommei, G., Modenini, D., Tortora, P., Mackenzie, R., Scoubeau, M., Herfort, U., Carnelli, I., (2018), "Radio science investigations with the Asteroid impact mission", Advances in Space Research, 62 (8), pp. 2273-2289.
Tortora, P., Zannoni, M., Hemingway, D., Nimmo, F., Jacobson. R.A., Iess, L., Parisi, M., (2016) "Rhea gravity field and interior modeling from Cassini data analysis", Icarus 264, pp. 264–273
Iess, L., Stevenson, D.J., Parisi, M., Hemingway, D., Jacobson, R.A., Lunine, J.I., Nimmo, F., Armstrong, J.W., Asmar, S.W., Ducci, M., Tortora, P., (2014), "The gravity field and interior structure of Enceladus", Science, 344 (6179), pp. 78-80.
Iess, L., Jacobson, R.A., Ducci, M., Stevenson, D.J., Lunine, J.I., Armstrong, J.W., Asmar, S.W., Racioppa, P., Rappaport, N.J., Tortora, P., (2012), "The tides of Titan", Science, 337 (6093), pp. 457-459.
Iess, L., Rappaport, N.J., Jacobson, R.A., Racioppa, P., Stevenson, D.J., Tortora, P., Armstrong, J.W., Asmar, S.W., (2010), "Gravity field, shape and moment of inertia of Titan", Science, 327 (5971), pp. 1367-1369.
Tortora, P., Iess, L., Bordi, J.J., Ekelund, J.E., Roth, D.C., "Precise Cassini Navigation During Solar Conjunctions Through Multifrequency Plasma Calibrations", (2004), Journal of Guidance, Control, and Dynamics, 27 (2), pp. 251-257.

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Selected Publications:

Journal Publications

Gomez Casajus L.; Zannoni M.; Modenini D.; Tortora P.; Nimmo F.; Van Hoolst T.; Buccino D.; Oudrhiri K., "Updated Europa gravity field and interior structure from a reanalysis of Galileo tracking data", Icarus, 2021, 358.

Zannoni M., Hemingway D., Gomez Casajus L., Tortora P., "The gravity field and interior structure of Dione", Icarus, 2020, vol. 345, p. 1-14.

Lainey V., Gomez Casajus L., Fuller J., Zannoni M., Tortora P., Cooper N., Murray C., Modenini D., Park R. S., Robert V., Zhang Q., "Resonance locking in giant planets indicated by the rapid orbital expansion of Titan", Nature Astronomy, 2020, vol. 4, p. 1-7.

Iess L., Militzer B., Kaspi Y., Nicholson P., Durante D., Racioppa P., Anabtawi A., Galanti E., Hubbard W., Mariani M.J., Tortora P., Wahl S., Zannoni M., "Measurement and implications of Saturn's gravity field and ring mass", Science, 2019, vol. 364, p. 2965-2979.

Zannoni, M., Tommei, G., Modenini, D., Tortora, P., Mackenzie, R., Scoubeau, M., Herfort, U., Carnelli, I., (2018), "Radio science investigations with the Asteroid impact mission", Advances in Space Research, 62 (8), pp. 2273-2289.

Iess L., et al., "Measurement of Jupiter's asymmetric gravity field", Nature, 2018, vol. 555, p. 220-222.

Lasagni Manghi R., Modenini D., Zannoni M., Tortora P., "Preliminary orbital analysis for a CubeSat mission to the Didymos binary asteroid system", Advances in Space Research, 2018, vol. 62, p. 2290-2305.

Tortora, P., Zannoni, M., Hemingway, D., Nimmo, F., Jacobson. R.A., Iess, L., Parisi, M., (2016) "Rhea gravity field and interior modelling from Cassini data analysis", Icarus 264, pp. 264–273

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Education: Dr. rer. nat. in Theoretical Physics (2003), Technische Universität München, Germany, Dipl. Phys. Theoretical Physics (2000), Technische Universität München, International student (astrophysics), University of Colorado at Boulder (1996/97)
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Selected Publications: Kramer, T, and M Läuter. "Outgassing-Induced Acceleration of Comet 67P/Churyumov-Gerasimenko." *Astronomy & Astrophysics* 630 (2019): A4. https://doi.org/10.1051/0004-6361/201935229.

Kramer, T., M. Läuter, S. Hviid, L. Jorda, H.U. Keller, and E. Kührt. "Comet 67P/Churyumov-Gerasimenko Rotation Changes Derived from Sublimation-Induced Torques." *Astronomy & Astrophysics* 630 (2019): A3. https://doi.org/10.1051/0004-6361/201834349.

Hoang, M., P. Garnier, J. Lasue, H. Rème, M. T. Capria, K. Altwegg, M. Läuter, T. Kramer, and M. Rubin. "Investigating the Rosetta/RTOF Observations of Comet 67P/Churyumov-Gerasimenko Using a Comet Nucleus Model: Influence of Dust Mantle and Trapped CO." *Astronomy & Astrophysics* 638 (2020): A106. https://doi.org/10.1051/0004-6361/201936655.

Kramer, Tobias. "Transient Capture of Electrons in Magnetic Fields, or: Comets in the Restricted Three-Body Problem." *Journal of Physics: Conference Series* 1612 (2020): 012019. https://doi.org/10.1088/1742-6596/1612/1/012019.

Kramer, Tobias, Matthias Läuter, Martin Rubin, and Kathrin Altwegg. "Seasonal Changes of the Volatile Density in the Coma and on the Surface of Comet 67P/Churyumov–Gerasimenko." *Monthly Notices of the Royal Astronomical Society* 469, no. Suppl_2 (2017): S20–28. https://doi.org/10.1093/mnras/stx866.

Kramer, Tobias, and Matthias Noack. "On the Origin of Inner Coma Structures Observed by Rosetta during a Diurnal Rotation of Comet 67P/Churyumov–Gerasimenko." *The Astrophysical Journal Letters* 823, no. 1 (2016): L11. https://doi.org/10.3847/2041-8205/823/1/L11.

Kramer, T, Noack, M., Baum, D., Hege, H-C., and Heller, E. J. "Dust and Gas Emission from Cometary Nuclei: The Case of Comet 67P/Churyumov–Gerasimenko." *Advances in Physics: X* 3, no. 1 (2018): 1404436. https://doi.org/10.1080/23746149.2017.1404436.

Läuter, M., Kramer, T., Rubin, M. and Altwegg, K.. "Surface Localization of Gas Sources on Comet 67P/Churyumov-Gerasimenko Based on DFMS/COPS Data." *Monthly Notices of the Royal Astronomical Society* 483 (2019): 852–61. https://doi.org/10.1093/mnras/sty3103.

NAME, First Name: AGARWAL, Jessica
Affiliation: Technische Universität Braunschweig
Role in the project: Activity distribution across the surface of comet 67P
Current position: Lichtenberg-Professor (tenure-track) at TU Braunschweig
Former Position(s): postdoc and research group leader at MPS Göttingen, postdoc at Potsdam University, postdoc at ESA/ESTEC, Young Graduate Trainee at ESA/ESOC
Education: 2007 PhD in Physics (Heidelberg University), 2002 Diplom in Physics (FU Berlin)
Services in National and/or International Committees (last ones): ESA/SSEWG (2019-21)
Honors: Student and PhD fellowships of the Studienstiftung des deutschen Volkes, ERC Starting Grant (2017), Lichtenberg-Professorship by the Volkswagen Foundation (2020), Agnes-Pockels-Fellowship by TU Braunschweig (2021), Member of the Elisabeth-Schiemann-Kolleg of the Max Planck Society (2018)
Selected Publications:

Kim, et al. (2020), "Coma Anisotropy and the Rotation Pole of Interstellar Comet 2I/Borisov", ApJL 895, L34.

Markkanen & Agarwal (2019), "Scattering, absorption and thermal emission by large cometary dust particles: Synoptic numerical solution", A&A 631, A164

Markkanen, Agarwal et al. (2018), "Interpretation of the Phase Functions Measured by the OSIRIS Instrument for Comet 67P/Churyumov-Gerasimenko", ApJ, 868, L16.

Agarwal et al. (2017), *"Evidence of sub-surface energy storage in comet 67P from the outburst of 2016 July 03"*, MNRAS 469, S606.

Agarwal et al. (2016), "*Acceleration of individual, decimetre-sized aggregates in the lower coma of comet 67P/Churyumov-Gerasimenko*", MNRAS 462, S78.

Agarwal et al. (2010), "*The Dust Trail of Comet 67P/Churyumov-Gerasimenko between 2004 and 2006*", Icarus 207, 992-1012.

NAME, First Name: KELLER, Horst Uwe
Affiliation: 1. Guest scientist IGEP, TU Braunschweig, 2. Guest scientist DLR Institut für Planetenforschung, Asteroiden und Kometen, Berlin
Role in the project: Modelling support
Current position: 1. Guest scientist IGEP, TU Braunschweig, 2. Guest scientist DLR Institut für Planetenforschung, Asteroiden und Kometen, Berlin
Former Position(s): 1971 - 1972 Scientific employee MPI für Physik und Astrophysik, München
1972 - 1975 Postdoc LASP, U. of Colorado, Boulder, Colorado, USA
1975 - 1976 Scientific employee MPI für Physik und Astrophysik, München
1976 - 1987 Scientific employee Max-Planck-Institut für Aeronomie, Katlenburg-Lindau
1987 - 2010 Leader of Planetenforschungsgruppe MPAe, now MPI für Sonnensystemforschung
2008 – 2010 after formal retirement: continuation on honorarium basis MPS
2010 - Guest scientist IGEP, TU Braunschweig
2014 - Guest scientist DLR Institut für Planetenforschung, Asteroiden und Kometen, Berlin
Education: 1953 - 1960 Oberschule in Hamburg
1960 - 1963 Study of physics at Universität Hamburg, Vordiplom
1963 - 1967 Study of physics at Universität München, Diploma
1967 - 1971 PhD at Max-Planck-Institut für Physik und Astrophysik
1977 Habilitation in Astronomy und Astrophysics at Universität Göttingen
Services in National and/or International Committees (last ones): Halley Multicolour Camera (Giotto mission). SIR Infrared Spectrometer for SMART 1. OSIRIS Science Imagers (Rosetta mission). Framing Camera (Dawn mission)
Honors: Stern Gerlach Preis der Deutschen Physikalischen Gesellschaft am 14 März 1990, Publication Award des Naval Research Laboratory, Washington 1992 Deutscher TV Preis „Der Goldene Löwe“ am 3. Oktober 1997, Christiaan Huygens Medal of the European Geophysical Union 2008. Several awards from NASA and ESA
Selected Publications:
H. U. Keller, L. Jorda, M. Küppers, P. J. Gutierrez, S. F. Hviid, J. Knollenberg, L.-M. Lara, H. Sierks, C. Barbieri, P. Lamy, H. Rickman, and R. Rodrigo, Deep Impact Observations by OSIRIS Onboard the Rosetta Spacecraft, Science, 310, 281–283, doi:10.1126/science.1119020, 2005
N. Thomas, C. Alexander, and H. U. Keller, Loss of the Surface Layers of Comet Nuclei, in: Origin and Early Evolution of Comet Nuclei (edited by H. Balsiger, K. Altwegg, W. Huebner, T. Owen, and R. Schulz), vol. 28 of ISSI, pp. 165–177, Springer, New York, USA, 2009, doi:10.1007/978-0-387-85455-7_10.
Keller, H. U. and the OSIRIS Team, 2010. E-Type Asteroid (2867) Steins as Imaged by OSIRIS on Board Rosetta. Science, 327, 190.
Keller, H. U., Mottola, S., Skorov, Y. & Jorda, L. The changing rotation period of comet 67P/Churyumov-Gerasimenko controlled by its activity. A&A 579, L5 (2015).
Keller, H. U. et al. Insolation, erosion, and morphology of comet 67P/Churyumov-Gerasimenko. A&A 583, A34 (2015).
Keller, H. U. et al. Seasonal mass transfer on the nucleus of comet 67P/Chuyumov-Gerasimenko. MNRAS 69, S357–S371 (2017).
Keller, H. U. and Kührt, E. Cometary Nuclei – from Giotto to Rosetta. Space Science Reviews accepted (2019)

NAME, First Name: GROUSSIN, Olivier
Affiliation: Aix Marseille Univ, CNRS, CNES, LAM, Marseille, France
Role in the project: Modelling support and results interpretation
Current position: 2007 – now Astronomer
Former Position(s): 2006 – 2007 Postdoc, LAM, Marseille, France
2004 – 2006 Postdoc, Univ. Maryland, College Park, USA
2002 – 2004 Postdoc, DLR Institute, Berlin, Germany
Education: 1999 – 2002 PhD in Astronomy, France
1997 – 1999 Master in Physics, France
1994 – 1997 Licence in Physics, France

Services in National and/or International Committees (last ones):
2020 – now Associated Scientist on Comet Interceptor (ESA)
2019 – now Co-I on the rover of MMX (JAXA)
2018 – now Co-I on the MERTIS instrument of Bepi-Colombo (ESA)
2012 – now Co-I on the JANUS camera of Juice (ESA)
2012 – 2014 PI of the THERMAP instrument of MarcoPolo-R (ESA, not selected after phase A)
2010 – now Co-I on the Herschel *key program* « TNOs are cool »
2007 – now Co-I on the OSIRIS camera of Rosetta (ESA)
2006 – now Co-I on the BELA instrument of Bepi-Colombo (ESA)
2006 – 2010 Co-I on Stardust-NExT (NASA)
2004 – 2010 Associated scientist on EPOXI (NASA) and Deep Impact (NASA)

Honors:
2017 – French Research and Doctoral Supervisor Grant
2017 – « ESA award » for outstanding contribution to the ESA Rosetta mission
2011 – « NASA group achievement award » for the science team of Stardust-NExT
2011 – « NASA group achievement award » for the science team of EPOXI
2009 – « NASA group achievement award » for the project EPOXI

5 Selected Publications:
- Groussin, O., P. L. Lamy, M. S. P. Kelley, and 4 colleagues 2019. Spitzer Space Telescope observations of bilobate comet 8P/Tuttle, Astronomy and Astrophysics 632, A10
- Groussin, O., N. Attree, Y. Brouet, and 16 colleagues 2019. The thermal, mechanical, structural, and dielectric properties of cometary nuclei after Rosetta, Space Science Reviews 215, 29
- Groussin, O., J. Licandro, J. Helbert, and 28 colleagues 2016. THERMAP: a mid-infrared spectro-imager for space missions to small bodies in the inner solar system, Exp. Astronomy 41, 95
- Groussin, O., H. Sierks, C. Barbieri, and 45 colleagues 2015. Temporal morphological changes in the Imhotep region of comet 67P/Churyumov-Gerasimenko, Astronomy & Astrophysics 583, A36
- Groussin, O., J. M. Sunshine, L. M. Feaga, and 13 colleagues 2013. The temperature, thermal inertia, roughness and color of the nuclei of Comets 103P/Hartley 2 and 9P/Tempel 1, Icarus 222, 580

NAME, First Name: JORDA, Laurent
Affiliation: Aix Marseille Univ, CNRS, CNES, LAM, Marseille, France
Role in the project: Data modeling and interpretation
Current position: Assistant Astronomer / LAM Deputy Director
Former Position(s): 1996-2000: Postdoc (Max-Planck Institute for Solar System Research)
Education: 1992-1995: PhD in Astrophysics (Université Paris 7 Jussieu)
1991-1992: Coopérant at ESO La Silla
Services in National and/or International Committees (last ones):
2002-2010: Scientific Council of the French “National Planetology Programme” (National Planetary Science Committee)
2002-2010: Steering Committee of the Corot consortium
2012-2016: Steering Committee of the Rosetta/OSIRIS consortium
2012-2015: Elected member of the “Comité National des Astronomes et Physiciens” (National Committee)
Honors:
Selected Publications:

- Vernazza, P., Jorda, L. and 45 colleagues, A basin-free spherical shape as an outcome of a giant impact on asteroid Hygiea, Nature Astron. 4, 136-141, 2020.
- Jorda, L., and 47 colleagues, The Global Shape, Density and Rotation of Comet 67P/Churyumov-Gerasimenko from Pre–Perihelion Rosetta/OSIRIS Observations, Icarus 277, 257-278, 2016.
- Jorda, L., Lamy, P., Gaskell, R., Kaasalainen, M., Groussin, O., and Besse, S., Asteroid (2867) Steins: Shape, Topography and Global Physical Properties from OSIRIS observations, Icarus 221 1089-1100, 2012.
- Jorda, L., Lamy, P. L., Faury, G., Weissman, P., Barucci, A. M., Fornasier, S., Lowry, S., Toth, I., and Küppers, M., Asteroid Steins. I. Photometric properties from OSIRIS Rosetta and ground-based visible observations, Astron. Astrophys. 487, 1171-1178, 2008.
- Keller, H.U., Jorda, L., and 10 colleagues, Deep Impact Observations by OSIRIS Onboard the Rosetta Spacecraft, Science 310, 281-283, 2005.

NAME, First Name: MARSCHALL, Raphael
Affiliation: CNRS, Laboratoire J.-L. Lagrange, Observatoire de la Côte d'Azur, Nice, France
Role in the project: Gas and dust source distribution, gas and dust dynamics
Current position: Postdoc at OCA (2022-)
Former Position(s): Postdoc at SwRI (2019-2021), Postdoc at ISSI (2017-2019), PhD student at University of Bern (2013-2017)
Education: PhD in Physics (2017, University of Bern), MSc in Physics (2012, University of Bern), BSc in Physics (2011, University of Bern)
Selected Publications:
Marschall, R., J. Markkanen, S.-B. Gerig, O. Pinzon-Rodriguez, N. Thomas, and J.-S. Wu (2020). The dust-to-gas ratio, size distribution, and dust fall-back fraction of comet 67p/Churyumov-Gerasimenko: Inferences from linking the optical and dynamical properties of the inner comae. Frontiers in Physics, 8, 227. DOI: 10.3389/fphy.2020.00227

Marschall, R., Y. Liao, N. Thomas, and J.-S. Wu (2020). Limitations in the determination of surface emission distributions on comets through modelling of observational data - A case study based on Rosetta observations. Icarus, 346, 113742. DOI: 10.1016/j.icarus.2020.113742

Marschall, R., L. Rezac, D. Kappel, C. C. Su, S. B. Gerig, M. Rubin, O. Pinzon-Rodriguez, D. Marshall, Y. Liao,C. Herny, G. Arnold, C. Christou, S. K. Dadzie, O. Groussin, P. Hartogh, L. Jorda, E. Kührt, S. Mottola, O. Mousis, F. Preusker, F. Scholten, P. Theologou, J. S. Wu, K. Altwegg, R. Rodrigo, and N. Thomas (2019). A comparison of multiple Rosetta data sets and 3D model calculations of 67P/Churyumov-Gerasimenko coma around equinox (May 2015). Icarus, 328, 104–126. DOI: 10.1016/j.icarus.2019.02.008

Marschall, R., S. Mottola, C. C. Su, Y. Liao, M. Rubin, J. S. Wu, N. Thomas, K. Altwegg, H. Sierks, W. H.Ip, H. U. Keller, J. Knollenberg, E. Kührt, I. L. Lai, Y. Skorov, L. Jorda, F. Preusker, F. Scholten, J. B. Vincent, Osiris Team, and Rosina Team (2017). Cliffs versus plains: Can ROSINA/COPS and OSIRIS data of comet 67P /Churyumov-Gerasimenko in autumn 2014 constrain inhomogeneous outgassing?, A&A, 605, A112. DOI: 10.1051/0004-6361/201730849\\

Marschall, R., C. C. Su, Y. Liao, N. Thomas, K. Altwegg, H. Sierks, W.-H. Ip, H. U. Keller, J. Knollenberg,E. Kührt, I. L. Lai, M. Rubin, Y. Skorov, J. S. Wu, L. Jorda, F. Preusker, F. Scholten, A. Gracia-Bern\´a,A. Gicquel, G. Naletto, X. Shi, and J.-B. Vincent (2016). Modelling observations of the inner gas and dust coma of comet 67P/Churyumov-Gerasimenko using ROSINA/COPS and OSIRIS data: First results. A&A, 589, A90. DOI: 10.1051/0004-6361/201628085

NAME, First Name: MAQUET, Lucie
Affiliation: IMCCE/Observatoire de Paris, CNRS
77 avenue Denfert Rochereau
75014 PARIS
Role in the project: Cometary activity model, cometary orbit determination
Current position: Assistant Astronomer
Former Position(s):
2014-2015 : ESA Fellowship
2012-2014 : Postdoc (LESIA/Observatoire de Paris)
Education:
2008-2012 : PhD in Astronomy and Astrophysics (Observatoire de Paris)
2006-2008 : Master degree in Astronomy and Fundamental physics (Lille University and Observatoire de Paris)
2003-2006 : Bachelor degree in Fundamental Physics (Lille University)
Services in National and/or International Committees (last ones):
2015-Now : Co-I Fripon project
Honors:
Selected Publications:

The recent dynamical history of comet 67P/Churyumov-Gerasimenko
Maquet, L., Astronomy & Astrophysics, 2015, Volume 579, id.A78, 5 pp.
Open access : https://www.aanda.org/articles/aa/pdf/2015/07/aa25461-14.pdf

Coupling the nongravitational forces and modified Newton dynamics for cometary orbits
Maquet, L. ; Pierret, F., Physical Review D, 2015, Volume 91, Issue 8, id.084015
Open access : https://arxiv.org/pdf/1411.6146.pdf

The "memory" of the Oort cloud
Fouchard, M.; Higuchi, A.; Ito, T.; Maquet, L.
Astronomy & Astrophysics, 2018, Volume 620, id.A45, 13 pp.
Open Access : https://www.aanda.org/articles/aa/pdf/2018/12/aa33435-18.pdf

Meteor hurricane at Mars on 2014 October 19 from comet C/2013 A1
Vaubaillon, J.; Maquet, L.; Soja, R.
MNRAS, 2014, Volume 439, Issue 4, p.3294-3299
Open access :
https://ui.adsabs.harvard.edu/link_gateway/2014MNRAS.439.3294V/PUB_PDF

CONGO, model of cometary non-gravitational forces combining astrometric and production rate data. Application to comet 19P/Borrelly
Maquet, L.; Colas, F.; Jorda, L.; Crovisier, J.
Astronomy & Astrophysics, 2012, Volume 548, id.A81, 8 pp.
Open access : https://www.aanda.org/articles/aa/pdf/2012/12/aa20198-12.pdf

NAME, First Name: LÄUTER, Matthias
Affiliation:
Zuse Institute Berlin
Takustraße 7, 14195 Berlin, Germany
Role in the project:
Orbit determination for 67P including modified rotating jet models
Analysis of ROSINA data for cometary activity
Current position:
Since 2010: Senior researcher and high performance consultant
Former Position(s):
2004-2010: Postdoc at Alfred Wegener Institute for Polar and Marine Research
Education:
2001-2004: Dr. rer. nat. in Physics, Universität Potsdam, Germany
1994-2000: Dipl.-Math. Humboldt-Universität Berlin, Germany
Services in National and/or International Committees (last ones):
Honors:
Selected Publications:
Läuter, M., T. Kramer, M. Rubin, and K. Altwegg. "The gas production of 14 species from comet 67P/Churyumov-Gerasimenko based on DFMS/COPS data from 2014-2016." *Monthly Notices of the Royal Astronomical Society*, 498 (2020): 3995-4004, https://doi.org/10.1093/mnras/staa2643.
Hoang, M., P. Garnier, J. Lasue, H. Rème, M. T. Capria, K. Altwegg, M. Läuter, T. Kramer, and M. Rubin. "Investigating the Rosetta/RTOF Observations of Comet 67P/Churyumov-Gerasimenko Using a Comet Nucleus Model: Influence of Dust Mantle and Trapped CO." *Astronomy & Astrophysics* 638 (2020): A106, https://doi.org/10.1051/0004-6361/201936655.
Läuter, M., T. Kramer, M. Rubin, and K. Altwegg. "Surface localization of gas sources on comet 67P/Churyumov-Gerasimenko based on DFMS/COPS data." *Monthly Notices of the Royal Astronomical Society* 483 (2019): 852-861, https://doi.org/10.1093/mnras/sty3103.
Kramer, T., and M. Läuter. "Outgassing-Induced Acceleration of Comet 67P/Churyumov-Gerasimenko." *Astronomy & Astrophysics* 630 (2019): A4. https://doi.org/10.1051/0004-6361/201935229.
Kramer, T., M. Läuter, S. Hviid, L. Jorda, H.U. Keller, and E. Kührt. "Comet 67P/Churyumov-Gerasimenko Rotation Changes Derived from Sublimation-Induced Torques." *Astronomy & Astrophysics* 630 (2019): A3. https://doi.org/10.1051/0004-6361/201834349.
Orgis, T., M. Läuter, D. Handorf, and K. Dethloff. "Baroclinic waves on the β plane using low-order Discontinuous Galerkin discretisation." *Journal of Computational Physics* 339 (2017): 461-481, https://doi.org/10.1016/j.jcp.2017.03.029.
Kramer, T., M. Läuter, M. Rubin, and K. Altwegg. "Seasonal Changes of the Volatile Density in the Coma and on the Surface of Comet 67P/Churyumov–Gerasimenko." *Monthly Notices of the Royal Astronomical Society* 469, no. Suppl_2 (2017): S20–28. https://doi.org/10.1093/mnras/stx866.

NAME, First Name: GUTIERREZ, Pedro

Affiliation: Instituto de Astrofísica de Andalucía-CSIC, Granada, Spain.

Role in the project: Data modeling and interpretation

Current position: Research staff at IAA-CSIC

Former Position(s): 2007-2008. Ramón y Cajal researcher (postdoc). IAA-CSIC
2005-2006. Juan de la Cierva researcher (postdoc). IAA-CSIC
2003-2004. ESA research fellowship. LAM, Marseille, France.

Education: 2001: PhD in Physics (Granada University, Spain)
1996: Bachelor degree in Physics (Granada University, Spain)

Services in National and/or International Committees (last ones):

2020 – Associated Scientist on Comet Interceptor (ESA)
2010-2014. Coordinator of the Calar Alto obs. TAC for Spanish granted time.
2007 – Co-I on the OSIRIS camera of Rosetta (ESA)
2009 -- External evaluator for funding agencies NASA/SSW, NASA/OPRP, FWF (Austria), ANR (France), ANEP (Spain)

Honors:

Selected Publications:

- Davidsson, B. J.R., Samarasinha, N.; Farnocchia, D.; Gutiérrez, P. Modelling the water and carbon dioxide production rates of Comet 67P/Churyumov-Gerasimenko. Monthly Notices of the Royal Astronomical Society, Volume 509, Issue 2, pp.3065-3085, 2022
- Gutiérrez, P. et al. Possible interpretation of the precession of comet 67P/Churyumov-Gerasimenko. A&A, 590, A46, 2016
- Davidsson, B. J.R., Gutiérrez, P.J. et al. Orbital elements of the material surrounding comet 67P/Churyumov-Gerasimenko, A&A, 583, A16, 2015
- González, M., Gutiérrez, P.J., et al., Thermophysical simulations of comet Hale-Bopp. A&A, 563, A98, 2014
- Gutiérrez P.J. et al., Non-gravitational modelling of Comet 81P/Wild 2. Rotational evolution. Icarus, 191, 651-664, 2007