frontiers | Frontiers in Astronomy and Space Sciences

TYPE Editorial
PUBLISHED 26 June 2023
DOI 10.3389/fspas.2023.1215526

Editorial: The links between space plasma physics and planetary science

K. Dialynas [1]*†, R. C. Allen [2]*† and E. Roussos [3]*†

[1]Center of Space Research and Technology, Academy of Athens, Athens, Greece, [2]Applied Physics Laboratory, The Johns Hopkins University, Laurel, MD, United States, [3]Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany

KEYWORDS

space plasma, planetary science, magnetospheres of planets, solar wind, space missions

Check for updates

OPEN ACCESS

EDITED AND REVIEWED BY
Qianli Ma,
Boston University, United States

*CORRESPONDENCE
K. Dialynas,
✉ kdialynas@phys.uoa.gr
R. C. Allen,
✉ Robert.Allen@jhuapl.edu
E. Roussos,
✉ roussos@mps.mpg.de

†These authors have contributed equally to this work and share first authorship

RECEIVED 02 May 2023
ACCEPTED 31 May 2023
PUBLISHED 26 June 2023

CITATION
Dialynas K, Allen RC and Roussos E (2023), Editorial: The links between space plasma physics and planetary science.
Front. Astron. Space Sci. 10:1215526.
doi: 10.3389/fspas.2023.1215526

Editorial on the Research Topic
The links between space plasma physics and planetary science

Magnetized plasmas and energetic particles are ubiquitous in our solar system (e.g., Roelof, 2015) and have been observed in planetary magnetospheres (e.g., Paranicas et al., 1996; Krupp et al., 2004; Allen et al., 2018; Allen et al., 2021; Kronberg et al., 2021; Sánchez-Cano et al., 2022; Werner et al., 2022), in the vicinity of planetary moons (e.g., Regoli et al., 2018; Long et al., 2022), asteroids (e.g., Fatemi and Poppe, 2018) and comets (e.g., Goetz et al., 2022), as part of the solar wind within the extended heliosphere (e.g., Roussos et al., 2020; Dialynas et al., 2022; Zirnstein et al., 2022), and even in the Very Local Interstellar Medium (e.g., Krimigis et al., 2019; Dialynas et al., 2021; Gurnett et al., 2021). Their measurement and characterization have greatly advanced our understanding of fundamental electromagnetic and charged particle processes, such as charged particle transport, acceleration, loss and reconnection in both planetary magnetospheres (e.g., Mitchell et al., 2009; Cowley et al., 2015; Yao et al., 2017; Azari et al., 2018; Roussos et al., 2019; Kane et al., 2020) and the heliosphere (e.g., Dialynas et al., 2020; Opher et al., 2021; Kleimann et al., 2022; Richardson et al., 2022; Kornbleuth et al., 2023).

Applications of space plasma measurements via instrument suites from past and ongoing missions sent to planetary magnetosphere [e.g., Voyager, Galileo, Cassini, Mars and Venus Express, Mars Atmosphere and Volatile Evolution (MAVEN), Juno, Messenger, the Lunar Reconnaissance Orbiter, Rosetta, Artemis, Chang'e 4, Chandrayaan-2, and BepiColombo], along with solar wind focused missions utilizing planetary flybys (e.g., Ulysses, Solar Orbiter, and Parker Solar Probe), have extended our capabilities to perform planetary science. This enables studying planetary or moon surfaces, interiors and subsurface oceans, atmospheric escape, and planetary rings (e.g., Iess et al., 2014; Stone et al., 2020; Allen et al., 2021; Hadid et al., 2021; Volwerk et al., 2021; Dimmock et al., 2022; Sulaiman et al., 2022).

Future missions, such as the Jupiter Icy Moons Explorer (launched: 14 April 2023) and Europa Clipper (launch target: October 2024), as well as plans to perform a comprehensive exploration of our solar system, starting from the Earth's moon (e.g., Gateway space station and lander and rover missions enabled by the NASA Commercial Lunar Payload Services, part of the Artemis program) up to the utmost boundaries of our heliosphere (e.g., Interstellar Probe; Brandt et al., 2022; Brandt et al., 2023; McNutt et al., 2022; Dialynas et al., 2023), include a strong planetary science perspective in their science goals through the inclusion of space plasma physics payloads. Further, ESA's Voyage-2050 senior committee recommendations, argued that among the agency's primary future targets, namely, robotic exploration of Jupiter's or Saturn's moons, *"The study of the connection of interior and the near-surface environments [...] in the overall moon-planet system (including the planet's magnetosphere)"* should be addressed.

The primary aim of this Research Topic was to expand our understanding in some of the aforementioned science questions, and hosted five articles.

Moon-magnetosphere interactions can result in the formation of Alfvén wings, and can be classified as *local interactions* (considerably controlled by the moon's properties; e.g., atmosphere, surface, etc.) and *far-field interactions* (mainly controlled by the magnetospheric plasma properties). Clark et al. focuses on the far-field interaction of Jupiter's magnetospheric plasma with Io and provides a survey of energetic protons obtained by the Jupiter Energetic Particle Detector Instrument (JEDI) on-board Juno, associated with Io's footprint tail. The analysis builds on previous interpretations claiming that the Juno spacecraft had likely transited Io's main Alfvén wing during its 12th orbit (Clark et al.; Sulaiman et al., 2020), and provides further evidence that precipitating electrons into Jupiter's ionosphere generate ion cyclotron waves, which are responsible for accelerating protons in Io's footprint tail.

Moving closer in our solar system, and in preparation for the upcoming NASA Lunar Vertex mission, Waller et al. simulates the interaction between the solar wind and lunar magnetic anomalies associated with lunar swirl regions. By comparing a surface model of magnetic fields derived from Lunar Prospector in the vicinity of the Reiner Gamma swirl with ultraviolet wavelength datasets, they find that crustal magnetic fields, partially shielding the lunar regolith from particle weathering, are consistent with swirl reflectance. These simulations lay the ground work for the upcoming measurements of Lunar Vertex, which seeks to better understand the relationship between crustal fields and lunar swirl regions.

Future human lunar exploration will require consideration of radiation dosage from sources such as Galactic Cosmic Rays (GCR). To constrain the total flux of GCRs on the lunar surface, Zigong et al. investigates the ratio of primary to secondary albedo protons using a new, detailed calibration of the proton spectra from the Lunar Lander Neutron and Dosimetry Experiment onboard the Chang'E-4 Lander, and compared this dataset with observations from Solar and Heliospheric Observatory/Electron Proton Helium Instrument (SOHO/EPHIN) and the Cosmic Ray Telescope for the Effects of Radiation instrument on the Lunar Reconnaissance Orbiter. A key result is that albedo protons contribute considerably to the total GCR particle flux on the lunar surface, and as such must be considered for future astronaut radiation exposure.

Undoubtedly, our moon provides unique opportunities to study the deep space plasma environment. Starting from mid-2020s NASA will launch the first modules of the Lunar Orbital Platform (Gateway), a crewed platform that is a vital component of the agency's Artemis program. In an extended analysis, Dandouras et al. explores the opportunities for fundamental and applied scientific research over a wide range of topics (e.g., space plasma physics, heliophysics, and space weather) that are provided by future payloads on Gateway. The study presents a model payload conceptual design that provides an efficient approach to obtain space plasma observations and address key multi-disciplinary science questions and objectives.

Obtaining detailed *in situ* charged particle measurements is crucial toward addressing a wide range of questions concerning space plasmas. Nicolaou et al. examines the ability of single electrostatic analyzers to resolve co-moving plasma species with different mass-per-charge ratios, by considering a two-species static plasma of heavy negative ions that is measured by a typical electrostatic analyzer such as the Cassini Plasma Spectrometer. The study takes a detailed modeling approach to study the response of such a top-hat analyzer to incoming plasma and concludes that the mass resolution improves with increasing spacecraft speed and decreasing plasma temperature.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Funding

KD was supported by NASA contracts NAS597271, NNX07AJ69G, and NNN06AA01C (JHU/APL) and by subcontract at the CSRT. RA was supported by NASA grants 80NSSC19K0899, 80NSSC21K0733, 80NSSC22K0993, and 80NSSC19K0270 and by NASA contract NNN06AA01C.

Acknowledgments

We sincerely thank all the authors, reviewers and editors who have participated in this Research Topic.

Conflict of interest

The authors declare that the manuscript was prepared in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

Allen, R. C., Cernuda, I., Pacheco, D., Berger, L., Xu, Z. G., Freiherr von Forstner, J. L., et al. (2021). Energetic ions in the venusian system: Insights from the first solar orbiter flyby. *Astronomy Astrophysics* 656, A7. doi:10.1051/0004-6361/202140803

Allen, R. C., Mitchell, D. G., Paranicas, C. P., Hamilton, D. C., Clark, G., Rymer, A. M., et al. (2018). Internal versus external sources of plasma at saturn: Overview from magnetospheric imaging investigation/charge-energy-mass spectrometer data. *J. Geophys. Res. (Space Phys.* 123, 4712–4727. doi:10.1029/2018JA025262

Azari, A. R., Liemohn, M. W., Jia, X., Thomsen, M. F., Mitchell, D. G., Sergis, N., et al. (2018). Interchange injections at saturn: Statistical survey of energetic H^+ sudden flux intensifications. *J. Geophys. Res. (Space Phys.* 123, 4692–4711. doi:10.1029/2018JA025391

Brandt, P. C., Provornikova, E. A., Cocoros, A., Turner, D., DeMajistre, R., Runyon, K., et al. (2022). Interstellar probe: Humanity's exploration of the galaxy begins. *Acta Astronaut.* 199, 364–373. doi:10.1016/j.actaastro.2022.07.011

Brandt, P. C., Provornikova, E., Bale, S. D., Cocoros, A., DeMajistre, R., Dialynas, K., et al. (2023). Future exploration of the outer heliosphere and very local interstellar medium by interstellar probe. *Space Sci. Rev.* 219, 18. doi:10.1007/s11214-022-00943-x

Cowley, S. W. H., Nichols, J. D., and Jackman, C. M. (2015). Down-tail mass loss by plasmoids in jupiter's and saturn's magnetospheres. *J. Geophys. Res. Space Phys.* 120, 6347–6356. doi:10.1002/2015JA021500

Dialynas, K., Galli, A., Dayeh, M. A., Cummings, A. C., Decker, R. B., Fuselier, S. A., et al. (2020). Combined ∼10 eV to ∼344 MeV particle spectra and pressures in the heliosheath along the voyager 2 trajectory. *Astrophysical J. Lett.* 905, L24. doi:10.3847/2041-8213/abcaaa

Dialynas, K., Krimigis, S. M., Decker, R. B., and Hill, M. E. (2021). Ions Measured by Voyager 1 Outside the Heliopause to ∼28 au and Implications Thereof. *Astronomical J.* 917, 42. doi:10.3847/1538-4357/ac071e

Dialynas, K., Krimigis, S. M., Decker, R. B., Hill, M., Mitchell, D. G., Hsieh, K. C., et al. (2022). The structure of the global heliosphere as seen by *in-situ* ions from the voyagers and remotely sensed ENAs from Cassini. *Space Sci. Rev.* 218, 21. doi:10.1007/s11214-022-00889-0

Dialynas, K., Sterken, V. J., Brandt, P. C., Burlaga, L., Berdichevsky, D. B., Decker, R. B., et al. (2023). A future interstellar probe on the dynamic heliosphere and its interaction with the very local interstellar medium: *In-situ* particle and fields measurements and remotely sensed ENAs. *Front. Astronomy Space Sci.* 10, 1061969. doi:10.3389/fspas.2023.1061969

Dimmock, A. P., Khotyaintsev, Y. V., Lalti, A., Yordanova, E., Edberg, N. J. T., Steinvall, K., et al. (2022). Analysis of multiscale structures at the quasi-perpendicular Venus bow shock. Results from Solar Orbiter's first Venus flyby. *Astronomy Astrophysics* 660, A64. doi:10.1051/0004-6361/202140954

Fatemi, S., and Poppe, A. R. (2018). Solar wind plasma interaction with asteroid 16 psyche: Implication for formation theories. *Geophys. Res. Lett.* 45, 39–48. doi:10.1002/2017GL073980

Goetz, C., Behar, E., Beth, A., Bodewits, D., Bromley, S., Burch, J., et al. (2022). The plasma environment of comet 67P/Churyumov-Gerasimenko. *Space Sci. Rev.* 218, 65. doi:10.1007/s11214-022-00931-1

Gurnett, D. A., Kurth, W. S., Stone, E. C., Cummings, A. C., Heikkila, B., Lal, N., et al. (2021). A foreshock model for interstellar shocks of solar origin: Voyager 1 and 2 observations. *Astronomical J.* 161, 11. doi:10.3847/1538-3881/abc337

Hadid, L. Z., Edberg, N. J. T., Chust, T., Píša, D., Dimmock, A. P., Morooka, M. W., et al. (2021). Solar orbiter's first Venus flyby: Observations from the radio and plasma wave instrument. *Astronomy Astrophysics* 656, A18. doi:10.1051/0004-6361/202140934

Iess, L., Stevenson, D. J., Parisi, M., Hemingway, D., Jacobson, R. A., Lunine, J. I., et al. (2014). The gravity field and interior structure of enceladus. *Science* 344, 78–80. doi:10.1126/science.1250551

Kane, M., Mitchell, D. G., Carbary, J. F., Dialynas, K., Hill, M. E., and Krimigis, S. M. (2020). Convection in the magnetosphere of saturn during the Cassini mission derived from MIMI INCA and CHEMS measurements. *J. Geophys. Res. (Space Phys.* 125, e27534. doi:10.1029/2019JA027534

Kleimann, J., Dialynas, K., Fraternale, F., Galli, A., Heerikhuisen, J., Izmodenov, V., et al. (2022). The structure of the large-scale heliosphere as seen by current models. *Space Sci. Rev.* 218, 36. doi:10.1007/s11214-022-00902-6

Kornbleuth, M., Opher, M., Zank, G. P., Wang, B. B., Giacalone, J., Gkioulidou, M., et al. (2023). An anomalous cosmic-ray mediated termination shock: Implications for energetic neutral atoms. *Astrophysical J. Lett.* 944, L47. doi:10.3847/2041-8213/acb9e0

Krimigis, S. M., Decker, R. B., Roelof, E. C., Hill, M. E., Bostrom, C. O., Dialynas, K., et al. (2019). Energetic charged particle measurements from Voyager 2 at the heliopause and beyond. *Nat. Astron.* 3, 997–1006. doi:10.1038/s41550-019-0927-4

Kronberg, E. A., Daly, P. W., Grigorenko, E. E., Smirnov, A. G., Klecker, B., and Malykhin, A. Y. (2021). Energetic charged particles in the terrestrial magnetosphere: Cluster/RAPID results. *J. Geophys. Res. (Space Phys.* 126, e29273. doi:10.1029/2021JA029273

Krupp, N., Woch, J., Lagg, A., Livi, S., Mitchell, D. G., Krimigis, S. M., et al. (2004). Energetic particle observations in the vicinity of Jupiter: Cassini MIMI/LEMMS results. *J. Geophys. Res. (Space Phys.* 109, A09S10. doi:10.1029/2003JA010111

Long, M., Ni, B., Cao, X., Gu, X., Kollmann, P., Luo, Q., et al. (2022). Losses of radiation belt energetic particles by encounters with four of the inner moons of jupiter. *J. Geophys. Res. (Planets)* 127, e07050. doi:10.1029/2021JE007050

McNutt, R. L., Wimmer-Schweingruber, R. F., Gruntman, M., Krimigis, S. M., Roelof, E. C., Brandt, P. C., et al. (2022). Interstellar probe - destination: Universe. *Acta Astronaut.* 196, 13–28. doi:10.1016/j.actaastro.2022.04.001

Mitchell, D. G., Krimigis, S. M., Paranicas, C., Brandt, P. C., Carbary, J. F., Roelof, E. C., et al. (2009). Recurrent energization of plasma in the midnight-to-dawn quadrant of Saturn's magnetosphere, and its relationship to auroral UV and radio emissions. *Planet. Space Sci.* 57, 1732–1742. doi:10.1016/j.pss.2009.04.002

Opher, M., Drake, J. F., Zank, G., Powell, E., Shelley, W., Kornbleuth, M., et al. (2021). A turbulent heliosheath driven by the Rayleigh-taylor instability. *Astrophysical J.* 922, 181. doi:10.3847/1538-4357/ac2d2e

Paranicas, C., Cheng, A. F., and Mauk, B. H. (1996). Charged particle phase space densities in the magnetospheres of Uranus and Neptune. *J. Geophys. Res.* 101, 10681–10693. doi:10.1029/96JA00077

Regoli, L. H., Roussos, E., Dialynas, K., Luhmann, J. G., Sergis, N., Jia, X., et al. (2018). Statistical study of the energetic proton environment at titan's orbit from the Cassini spacecraft. *J. Geophys. Res. (Space Phys.* 123, 4820–4834. doi:10.1029/2018JA025442

Richardson, J. D., Burlaga, L. F., Elliott, H., Kurth, W. S., Liu, Y. D., and von Steiger, R. (2022). Observations of the outer heliosphere, heliosheath, and interstellar medium. *Space Sci. Rev.* 218, 35. doi:10.1007/s11214-022-00899-y

Roelof, E. C. (2015). Charged particle energization and transport in reservoirs throughout the heliosphere: 1. Solar energetic particles. *J. Phys. Conf. Ser.* 642, 012023. doi:10.1088/1742-6596/642/1/012023

Roussos, E., Dialynas, K., Krupp, N., Kollmann, P., Paranicas, C., Roelof, E. C., et al. (2020). Long- and Short-term Variability of Galactic Cosmic-Ray Radial Intensity Gradients between 1 and 9.5 au: Observations by Cassini, BESS, BESS-Polar, PAMELA, and AMS-02. *Astrophsysical J.* 904, 165. doi:10.3847/1538-4357/abc346

Roussos, E., Kollmann, P., Krupp, N., Paranicas, C., Dialynas, K., Jones, G. H., et al. (2019). Sources, sinks, and transport of energetic electrons near saturn's main rings. *Geophys. Res. Lett.* 46, 3590–3598. doi:10.1029/2018GL078097

Sánchez-Cano, B., Lester, M., Andrews, D. J., Opgenoorth, H., Lillis, R., Leblanc, F., et al. (2022). Mars' plasma system. Scientific potential of coordinated multipoint missions: "The next generation". *Exp. Astron.* 54, 641–676. doi:10.1007/s10686-021-09790-0

Stone, S. W., Yelle, R. V., Benna, M., Lo, D. Y., Elrod, M. K., and Mahaffy, P. R. (2020). Hydrogen escape from Mars is driven by seasonal and dust storm transport of water. *Science* 370, 824–831. doi:10.1126/science.aba5229

Sulaiman, A. H., Achilleos, N., Bertucci, C., Coates, A., Dougherty, M., Hadid, L., et al. (2022). Enceladus and titan: Emerging worlds of the solar system. *Exp. Astron.* 54, 849–876. doi:10.1007/s10686-021-09810-z

Sulaiman, A. H., Hospodarsky, G. B., Elliott, S. S., Kurth, W. S., Gurnett, D. A., Imai, M., et al. (2020). Wave-particle interactions associated with Io's auroral footprint: Evidence of Alfvén, ion cyclotron, and whistler modes. *Geophys. Res. Lett.* 47, e88432. doi:10.1029/2020GL088432

Volwerk, M., Horbury, T. S., Woodham, L. D., Bale, S. D., Simon Wedlund, C., Schmid, D., et al. (2021). Solar Orbiter's first Venus flyby. MAG observations of structures and waves associated with the induced Venusian magnetosphere. *Astronomy Astrophysics* 656, A11. doi:10.1051/0004-6361/202140910

Werner, A. L. E., Aizawa, S., Leblanc, F., Chaufray, J. Y., Modolo, R., Raines, J. M., et al. (2022). Ion density and phase space density distribution of planetary ions Na^+, O^+ and He^+ in Mercury's magnetosphere. *Icarus* 372, 114734. doi:10.1016 /j.icarus.2021.114734

Yao, Z. H., Coates, A. J., Ray, L. C., Rae, I. J., Grodent, D., Jones, G. H., et al. (2017). Corotating magnetic reconnection site in saturn's magnetosphere. *Astrophysical J. Lett.* 846, L25. doi:10.3847/2041-8213 /aa88af

Zirnstein, E. J., Möbius, E., Zhang, M., Bower, J., Elliott, H. A., McComas, D. J., et al. (2022). *In situ* Observations of Interstellar Pickup Ions from 1 au to the Outer Heliosphere. *Space Sci. Rev.* 218, 28. doi:10.1007/s11214-022-00895-2