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EDITED AND REVIEWED BY
Jack J. W. A. Van Loon,
VU Amsterdam, Netherlands

*CORRESPONDENCE
Florian Kehl,
florian.kehl@uzh.ch

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# Editorial: Technologies for handling, preparation, and liquid-based analysis of fluidic samples in space

Florian Kehl[1,2,3,4]*, Kathryn Bywaters[5], Alberto G. Fairén[6,7], Timothy Granata[4], Antonio J. Ricco[8] and Luis Zea[9]

[1]NASA Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, United States, [2]Innovation Cluster Space and Aviation (UZH Space Hub), Air Force Center, University of Zurich, Dübendorf, Switzerland, [3]Institute of Anatomy, Faculty of Medicine, University of Zurich, Zurich, Switzerland, [4]Institute of Medical Engineering, Space Biology Group, Lucerne University of Applied Sciences and Arts, Hergiswil, Switzerland, [5]Honeybee Robotics Spacecraft Mechanisms Corp., Altadena, CA, United States, [6]Centro de Astrobiología (CSIC-INTA), Madrid, Spain, [7]Department of Astronomy, Cornell University, Ithaca, NY, United States, [8]NASA Ames Research Center, Moffett Field, CA, United States, [9]BioServe Space Technologies, Department of Aerospace Engineering Sciences, University of Colorado Boulder, Boulder, CO, United States

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Editorial on the Research Topic
Technologies for handling, preparation, and liquid-based analysis of fluidic samples in space

Over recent decades, gas-phase-based measurements (such as GC-MS) have often been the gold standard for *in-situ* measurements of acquired samples on planetary exploration missions. However, liquid-based analyses are essential for the future of space exploration, especially with the growing interest in Ocean Worlds (such as Europa and Enceladus) with their potential to support life, and confirmed water (ice) on both the Moon and Mars. Liquid-based methods are essential due to their orders-of-magnitude higher sensitivity compared to gas-phase-based measurements and because many water-soluble, (putative) biomolecules are targets for upcoming astrobiology missions. Hence, in the search for non-terrestrial life in our solar system, extant or extinct, it is a logical step to directly manipulate and analyze these molecules in their natural, liquid environment instead of bringing them into the gas phase, e.g., by pyrolysis or chemical derivatization, which can compromise or even destroy fragile organics. To enable liquid-based analyses on future planetary missions (e.g., for a Europa lander, Enceladus plume sampler, Titan buoy, comet lander, etc.), new technologies for sample acquisition, manipulation, and preparation need to be developed.

Liquid handling and water analysis will also be critical for future long-duration missions to the Moon (e.g., Lunar Gateway) or on the journey to Mars. Monitoring water quality continuously and in real-time will be essential for the health and survival of future astronauts. The same applies to *in-situ* resource utilization (ISRU) for crewed and robotic missions. The resource (water) will need to be manipulated, potentially treated, and analyzed before consumption or further processing. In addition, microorganisms cultivated in aqueous-phase bioreactors could play an essential role for ISRU by sequestering exhaled carbon dioxide and producing oxygen, biopolymers, biofuels, and food, and by recycling nutrients in closed systems. Systems capable of manipulating fluids under reduced gravity will also be essential to efficiently irrigate plants in future greenhouses to grow plant-based food on long-duration spaceflight missions. These platforms require liquid handling and increasingly complex fluidic operations and analysis methods that function well in the extreme environments of space exploration.

The space environment imposes unique constraints and considerations in using and designing fluidic systems. Besides reduced gravity and ionizing radiation, there are practical limitations for mass, volume, power, data, packaging, materials, and containment of hazardous reagents. Additionally, the platforms often require partial or full autonomy, redundancy, and autonomous fault recovery, due to limited availability of a human crew.

This Research Topic "*Technologies for handling, preparation, and liquid-based analysis of fluidic samples in space*" touches on several of the abovementioned key challenges for future space missions dealing with liquid samples.

The challenges of manipulating and processing acquired liquids via acoustics are discussed in "*Acoustic Processing of Fluidic Samples for Planetary Exploration*" by Sherrit et al. This article discusses a class of compact sample-processing instruments based on solid-state mechanisms that use acoustic waves to process samples prior to delivery to the downstream system, e.g., for sample analysis. Sherrit et al. review various transducer types and how to build network models of said piezoelectric transducers; they discuss several systems developed for sample handling on planetary bodies like Mars and the Ocean Worlds Enceladus and Europa.

Addressing liquid handling on the International Space Station (ISS), Nijhuis et al. provide a comprehensive overview in their review article "*Microfluidics and Macrofluidics in Space: ISS-Proven Fluidic Transport and Handling Concepts*". Understanding and mastering surface tension in microgravity are key to successfully manipulating liquids; Nijhuis et al. report on several concepts for handling liquids *via* surface tension. These include using capillary flow, thermocapillary Marangoni forces, and electrolytic gas evolution techniques. Their review paper also touches on applications of these theories, such as passive gas bubble removal techniques, drinking in microgravity, and biosensors for water monitoring.

One particular instance of such hardware to mitigate the influence of microgravity on liquid geometry is presented by Nicholson et al. in "*Design and Validation of a Device for Mitigating Fluid Microgravity Effects in Biological Research in Canister Spaceflight Hardware*." Nicholson et al. have designed and validated an insert to replace the standard 60-mm Petri dish in BRIC (Biological Research in Canisters) sample compartments so that liquid cultures adopt a disk-like configuration regardless of gravitational conditions. A prototype was built and verified by drop-tower testing and biocompatibility studies using *Bacillus subtilis* and *Staphylococcus aureus* bacteria.

Besides the ISS, small satellites known as CubeSats have become an increasingly popular platform for studying the effects of the space environment on biological organisms. Harandi et al. provide in their perspective article "*Fluidic-Based Instruments for Space Biology Research in CubeSats*" an overview of the past 15 years of instruments and their biological support subsystems for space biology studies in low Earth orbit. Harandi et al. also discuss improvements for the upcoming *BioSentinel* mission, a CubeSat that will launch as a secondary payload on Artemis 1 and will investigate the biological effects of the radiation environment beyond the protection of Earth's magnetosphere while proving the technological capability to support biological research in deep space.

In their original research article "*Micro-Bioreactors in Space: Case Study of a Yeast (Saccharomyces cerevisiae) Bioreactor with a Non-Invasive Monitoring Method*," Granata et al. discuss the use of bioreactors as space-based microbial factories, and present novel methods to manipulate, monitor, and aerate continuous yeast cultures. In addition, Granata et al. discuss in their study how microbial bioreactors could be utilized to produce biomaterials, including carbon fiber, bioplastics, bioconcrete, food, and supplements, as well as how they could play a key role in a sustainable materials concept supporting waste management and life-support systems for space stations.

In summary, the articles in this Research Topic provide an overview of issues related to the challenges of handling and manipulating liquid samples in space. While a solid foundation has been established in the past years with simulations, miniaturization of fluidic components, and experiments on the ISS and CubeSat platforms, many key challenges related to handling liquid samples in space remain to be solved. Moreover, especially for long-duration missions to the outer solar system, storing liquids and solutions for several years while exposed to radiation, temperature fluctuations, and hydrolysis might pose additional challenges for fluids and liquid handling systems in space. Mastering liquid manipulation beyond Earth will play a key role in the successful, continued astrobiological, space biological, and human exploration of the solar system.

## Author contributions

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

## Conflict of interest

Author KB was employed by Honeybee Robotics Spacecraft Mechanisms Corp.

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

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