In-situ chemical analysis of surface material: From in-situ resource utilization to basic lunar science

A Whitepaper for the Artemis Mission

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Since the very successful Apollo program, we have with the Artemis mission the opportunity to have two Astronauts on-site that can conduct various in-situ work, ranging from e.g., sample collection to in-situ chemical analysis of lunar rocks. Compared to those instruments used back then in the Apollo program we have now highly developed measurement tools with much extended measurement capabilities. The Artemis mission is targeting the Lunars South Pole, however, its exact landing site is yet not defined but shall be within six degrees from the pole.

This whitepaper is intended to demonstrate the necessity to conduct in-situ analysis of the chemical composition of solids addressing element and mineral composition, contents of volatiles, and isotope studies. Volatiles may be located in the minerals itself (e.g. implanted hydrogen and helium) or as frozen phase mixed with the rocky material. In-situ measurement shall support a better understanding of the evolution of the binary Earth-Moon system through radio-isotope geochronology of lunar rocks, and will be highly beneficial for future in-situ resource utilization. The scientific importance of these two topics is addressed in the following in more detail. References are provided for further detail.

In-situ chemical analysis for a better understanding of in-situ resource utilization

For humans to stay permanently on the lunar surface local resources have to be exploited. For such an endeavor, various resources will be identified, ranging e.g., from fuel burried in the regolith to building materials for habitat structures. The interest is high to produce as much as possible of these resources in-situ, without the continuous and expensive transport from Earth to the lunar surface.

Currently, various space agencies, companies and scientific groups are designing, testing and validating 3D printing technologies that shall be applied in-situ to print structures that are required to build habitats with Lunar regolith as printing material [see e.g., 1-3]. In-situ chemical analysis of lunar regolith shall help to identify which material is most appropriate for the 3D printing, e.g., the composition shall be within required boundaries to ensure in-situ the sufficient quality of the material for the printing.

Another example is the in-situ production of rocket propellant [see e.g., 4] from volatiles extracted from the surface. E.g., the fraction of 10^{-3} of implanted hydrogen in the lunar regolith corresponds to 0.2 bar (STP) of H_2 if fully extracted. Its production on-site would have many benefits, as it could be used to produce energy on-site but as well as to fill the spacecraft tanks without the necessity to fly back to Earth. In-situ analysis of the chemical composition of solids allows the identification of locations that contain samples with high abundance of hydrogen. Subsequently, the hydrogen can be used e.g., to extract oxygen from oxygen containing minerals. And again, locations of such minerals could be identified with in-situ chemical analysis.

To enhance the knowledge for the on-site production of such resources we encourage strongly to test and validate various technologies that allows the in-situ determination of the chemical composition of solids. The instrumentation shall have the capability to provide the chemical composition at major and minor element abundances, down to the ppm level. Moreover, for the identification of appropriate samples that contain specific minerals, instruments providing spatially resolved analysis shall be tested [see e.g., 5-7].

Chemical analysis for in-situ dating of rocks

The chemical composition (elements and their isotopes) of lunar rocks collected during the Apollo mission were intensively analyzed in earth-based laboratories. The measured element and isotope abundances allowed amongst others, radio-isotope geochronology of the material, e.g., via Pb/Pb dating. However, only material from a limited range of locations on the lunar surface near the equator was collected in the course of the previous missions. Moreover, the astronauts picked samples based on their geological training without support by suitable in-situ composition instrumentation. This will be different in the upcoming Artemis mission.

The chemical analysis of samples will allow age dating of lunar rocks which is of considerable scientific interest, as the accurate knowledge of the age will allow for a better understanding on how and when the moon was formed. This information on the other hand will provide a deepened understanding on the formation of the binary Earth-Moon system, which is an important puzzle piece for the understanding of the entire Solar system. Currently it is known that the Artemis mission is going to land within around six degrees from the South Pole within the South Pole Aitken basin, the oldest basin on the Moon. The basin is of high interest because the analysis of the collected samples at these spots have shown a strong enrichment of Pb (ppm range and higher, KREEP material [e.g., 8-9]). In-situ chemical analysis will allow the identification of KREEP material, which shall be measured in a second step with highly sensitive instrumentation in regards of their Pb isotopes abundances. Moreover, the in-situ chemical analysis will enable a pre-screening of the material, which allows a proper selection of the most precious material that shall be sent back to Earth for the more sensitive lab-based isotope analysis [e.g., 9]. A typical pre-scanning procedure could be conducted as following: a spectroscopic technique could be applied to localize KREEP material, and the typically more sensitive mass spectrometric techniques could be used for the subsequent in-situ isotope analysis.

In summary in-situ chemical analysis of solids will have many advantages, ranging from resource utilization in-situ to basic lunar science. Therefore, we propose to operate instrumentation in-situ that have the measurement capabilities required to address the above-mentioned topics.

References

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