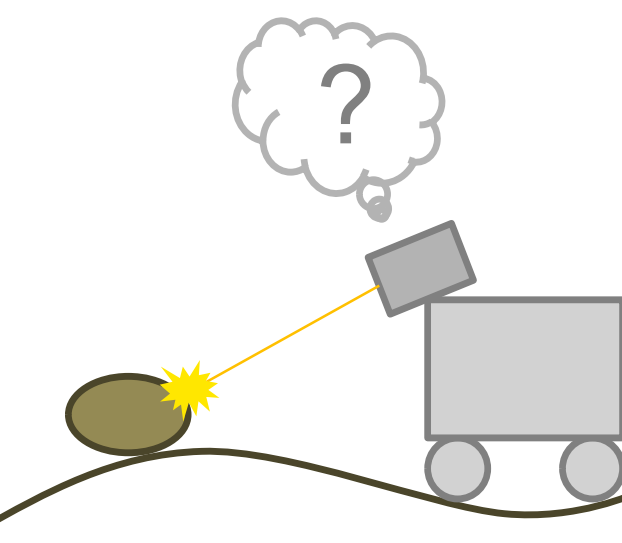


Miniaturized low power LIBS system for in-situ exploration of Solar System bodies without atmosphere

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LIBS for space

LIBS is a very suitable technique for space exploration because of

- its remote capabilities
- the omission of sample preparation
- quick data acquisition times
- reliable detection of major rock-forming elements and many minor and trace elements

LIBS in space

LIBS is a relatively new technique but gets more and more proposed as mission payload. Current and upcoming instruments are:

- ChemCam on MSL (NASA, Mars, since 2012)
- Chandrayaan-2 (ISRO, Moon, scheduled for 2019)
- SuperCam on Mars2020 (NASA Mars, scheduled for 2020)
- MarsCoDe on HX-1 (CNSA, Mars, scheduled for 2020)

Instrument design

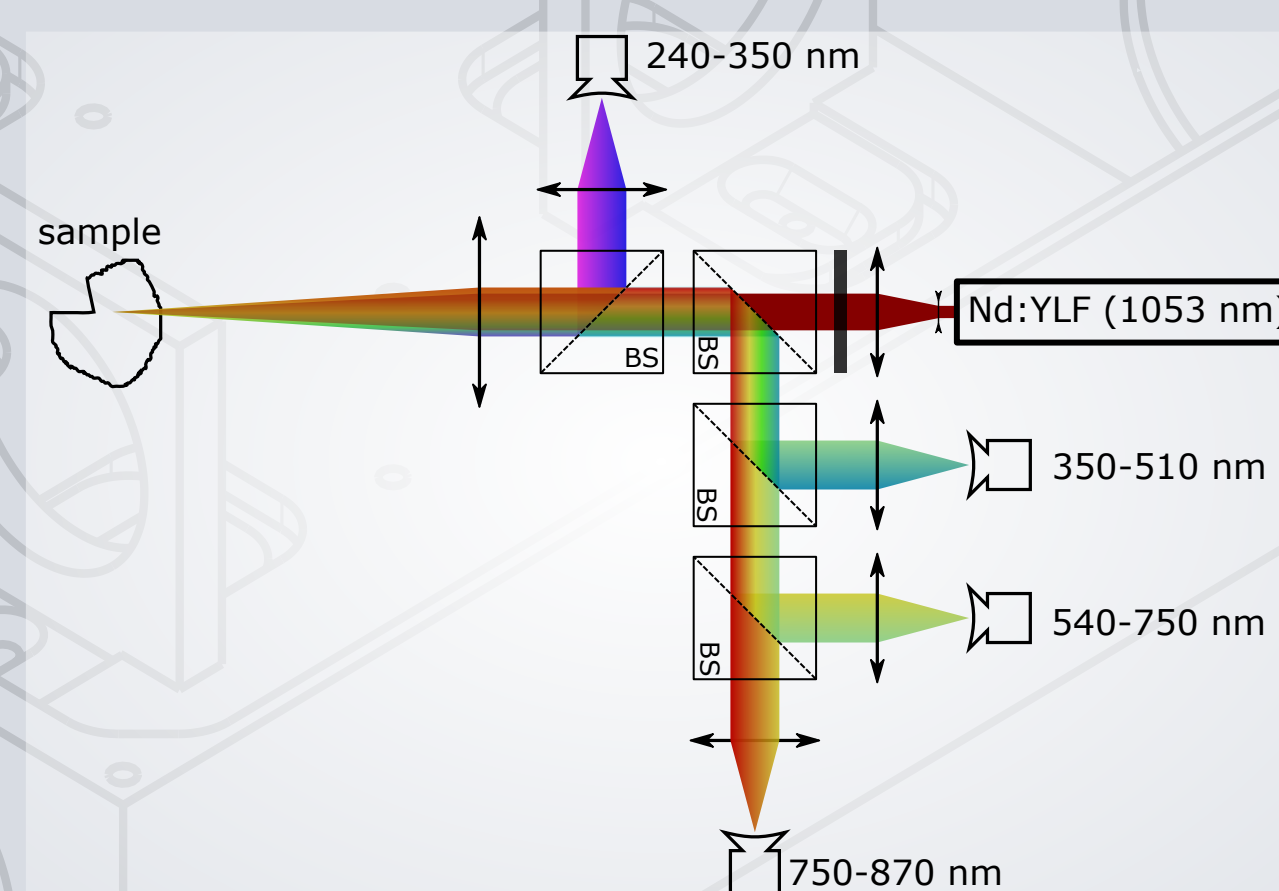
For pioneering missions to small bodies we aim for an especially compact design. This, of course, requires compromises in performance. Nonetheless, we expect the following characteristics:

- < 3 kg total weight
- 20-50 cm sampling distance, possibly fixed distance
- ≤ 0.1 nm spectral resolution
- spectral range adjusted to address the mission's scientific questions and maximize scientific return

The current design features:

- 4 spectrometers to study performance and relevance of different spectral ranges
- space design Nd:YLF laser originally developed for ESA's ExoMars mission [1] (1053 nm, < 4 mJ, 2 ns, < 10 Hz)
- atmospheric simulation chamber to simulate low pressure environments

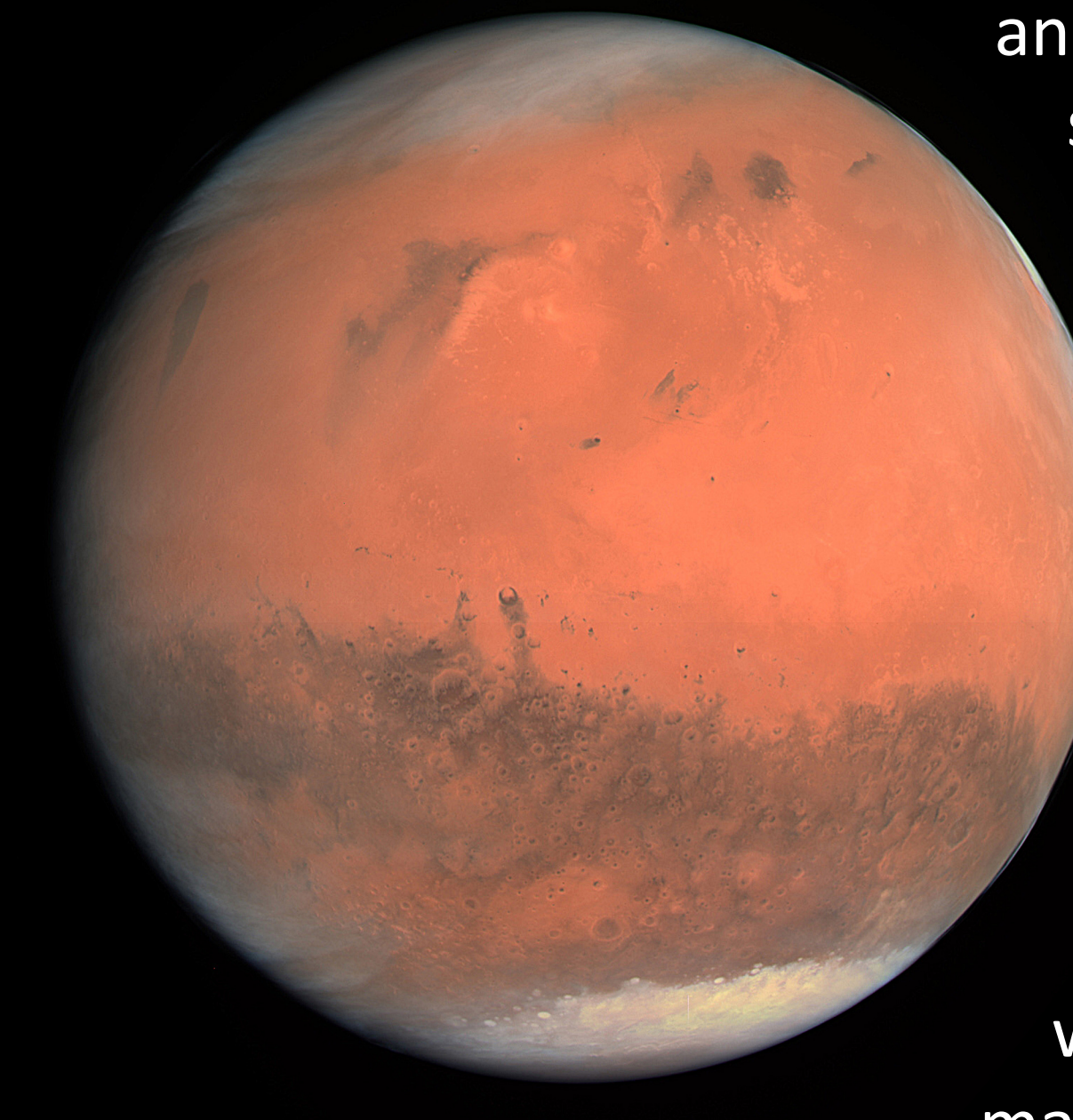
A drawing of the housing of the optical demultiplexer is shown in the background.



Mars

Our neighbouring planet Mars is a terrestrial planet of about half the Earth's diameter. There is evidence for past liquid water on the surface [2, 3], which is one of the essentials for life as we know it. Therefore, space laboratories equipped with LIBS instruments are deployed on the Martian surface to study its geochemistry and mineralogy in order to investigate, amongst others, signatures of water-related minerals.

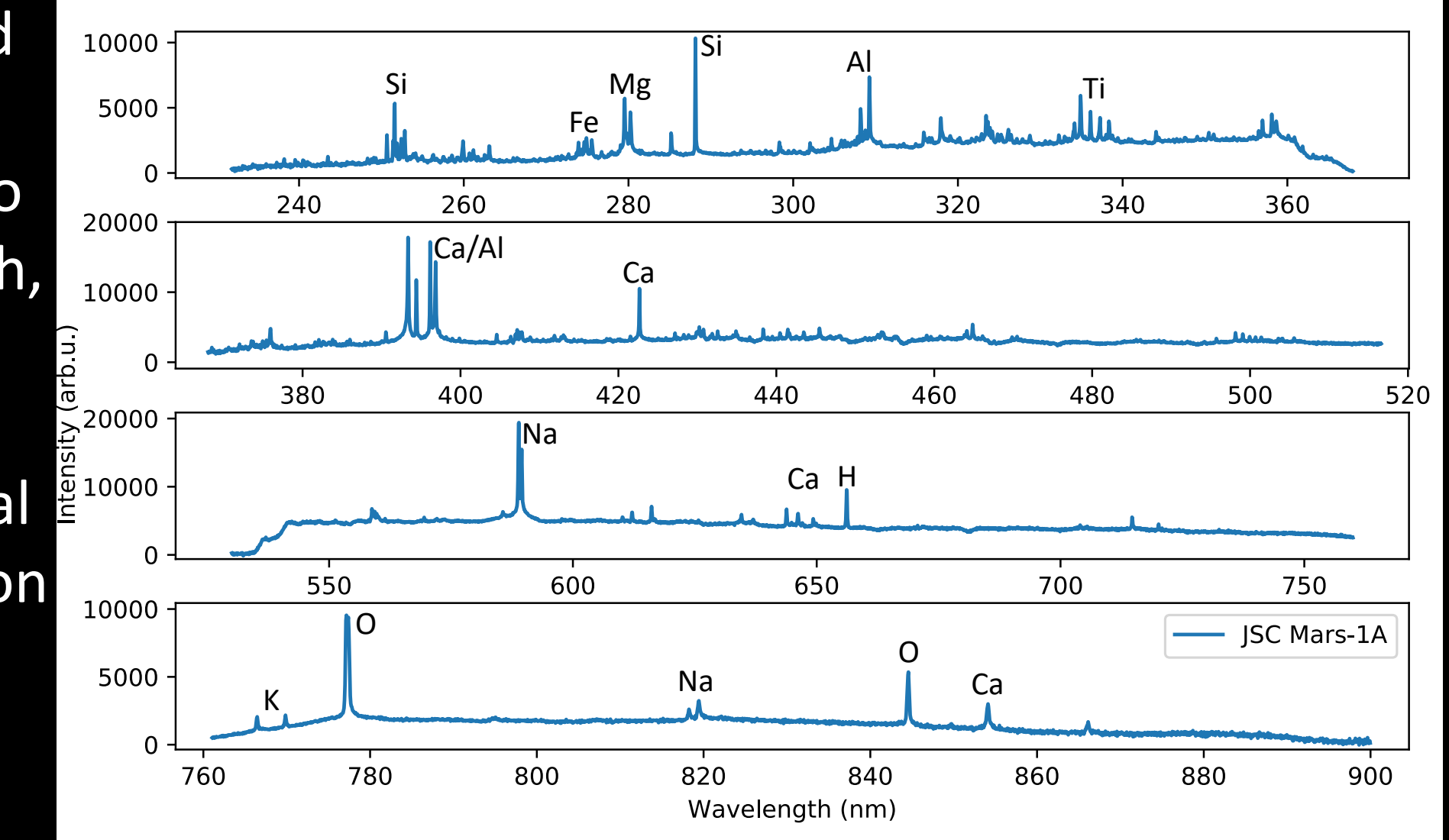
- thin atmosphere (0.5-1.0 kPa, 97 % CO₂)
-> pressure close to ideal for LIBS
- rock and regolith surfaces
- geochemical and mineralogical analysis



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The Johnson Space Center mixed an analogue material [4] to simulate Martian regolith to support scientific research, engineering studies and for educational purposes. The chemical composition is based on XRF and APXS results from the Viking and Pathfinder landers.

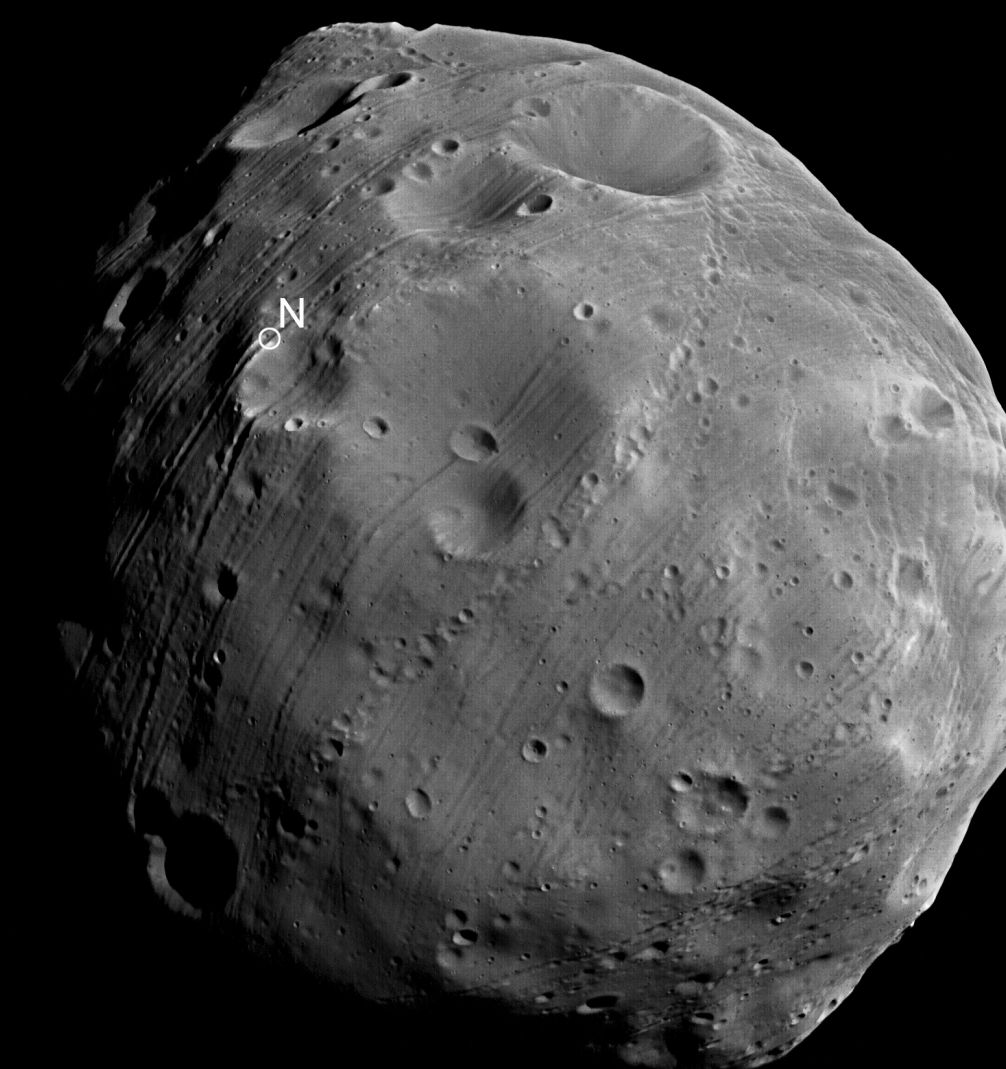
Example spectra of JSC Mars-1A in low pressure environment (≤ 1 Pa) detected with our miniaturized prototype instrument are shown in the figure above. The major rock forming elements as well as H and O have been detected.



Phobos

Phobos and Deimos are the two Martian moons. Like our Moon, they have a tidally locked rotation suggesting to be former pieces of Mars itself. Another theory states that the Martian moons were asteroids, which have been captured by Mars' gravitational field. Obtaining the chemical compositions would allow conclusions about their origins and provide more insight into the formation of the Solar System. However, in-situ science is challenging out there...

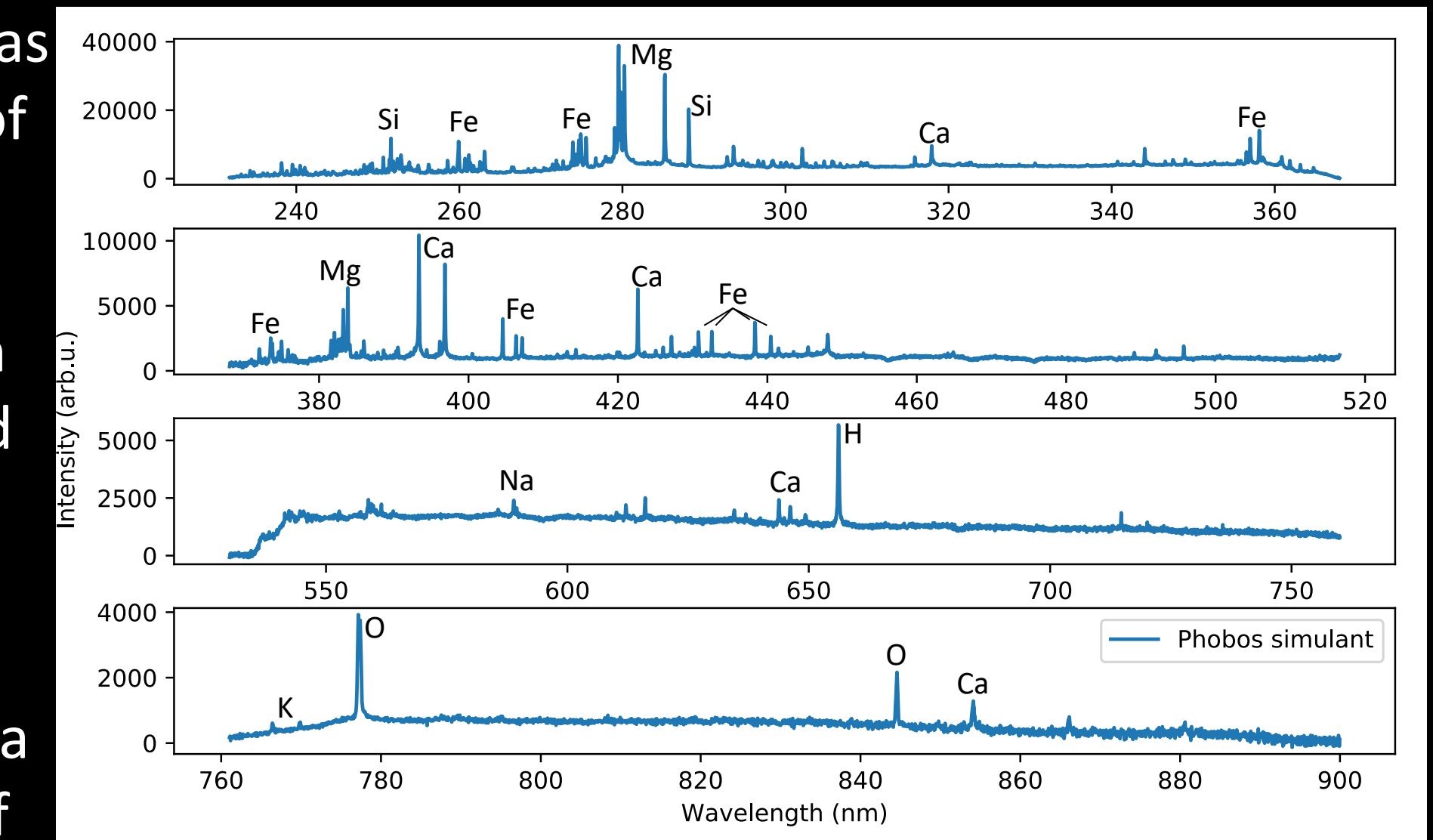
- no atmosphere ($< 10^{-5}$ Pa)
-> small and short-living plasma
- very low gravity
-> landing is difficult, stronger mass constraints
-> ablated material might not settle again



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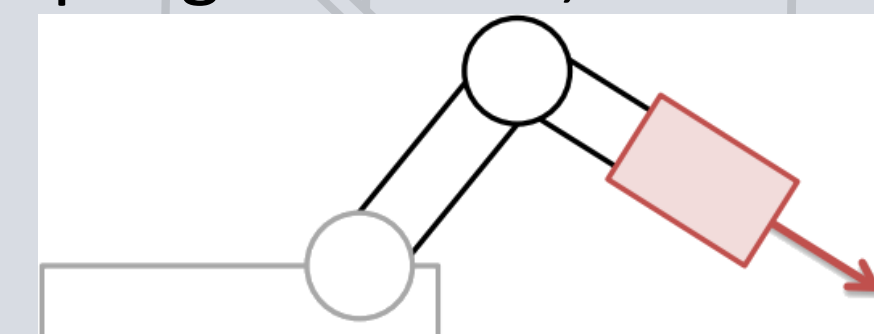
Analogue material for Phobos was developed by the University of Tokyo [5]. Lacking in-situ investigation, its composition is based on reflectance spectra and the low albedo as detected with orbiting spacecrafts. The data has been compared to a database of hundreds of

asteroids and meteorites, leading to a mixture of Mg-rich phyllosilicates and olivine, Magnetite, Fe-Ca-Mg carbonates and Fe-Ni sulfides, together with carbon nanoparticles and organic polymer compounds. The figure shows sample spectra taken with our instrument under low pressure (≤ 1 Pa).



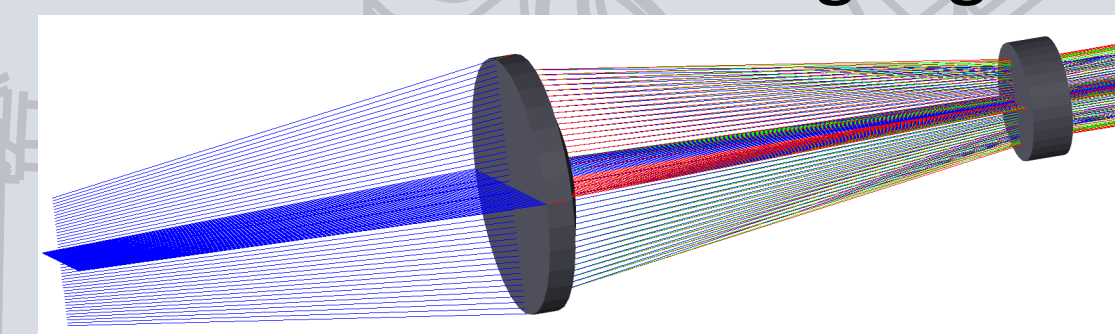
Options for focus mechanisms

Depending on the final mission scenario, especially with respect to mass constraints and desired sampling distances, different options for laser focus and light gathering can be considered:



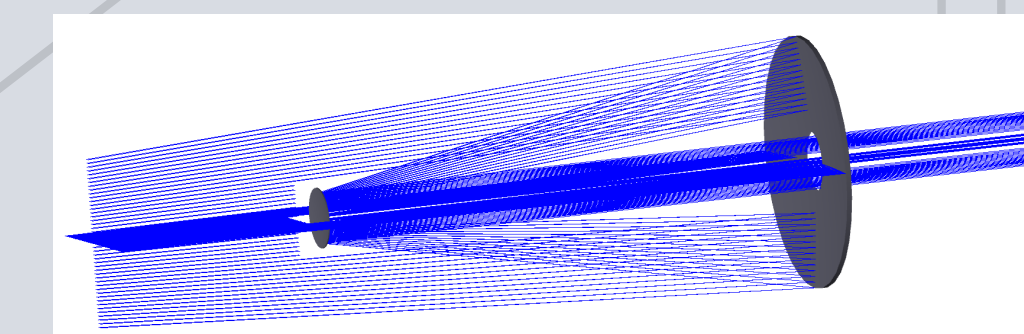
Robotic arm

Moving parts are always critical in space instruments and should be avoided wherever possible. Setting up an optical system for a fixed sampling distance and using platform capabilities to provide this distance to the sample allows the most compact design.



Galileian telescope

Invented 400 years ago, it is a well known technique, simple and robust. Focus capability is provided by translation of the diverting lens or lens group. It has limits in the spectral range, especially when it is used for focusing and detecting at the same time.



Cassegrain telescope

Using reflective optics only, it overcomes the Galileian's spectral limitations. On the other hand, the obscuration due to the secondary mirror demands a larger aperture and also shock-induced misalignment from launch can have a higher impact.

Summary

LIBS is a very suitable technique for in-situ space exploration aboard landers and rovers. Mars and its moons are in the focus of recent mission proposals but also other small and atmosphereless bodies are targeted. For missions to smaller bodies and new destinations constraints on mass, size and power strongly limit the technology that can be applied. We are currently developing a simplified miniaturized and low power instrument and evaluating its performance on different materials under vacuum conditions. With our instrument we were able to detect major rock-forming elements as well as volatiles such as Cl, F, H and O.

- [1] I. Rauschenbach et al., *Spectrochim. Acta B*, vol. 65, p. 758 (2010); [2] M.H. Carr, *Phil. Trans. R. Soc. A*, vol. 370, p. 2193 (2012); [3] J.P. Grotzinger et al., *Science*, vol. 343, no. 6169 (2014); [4] C.C. Allen et al., *LPSC98*, 1690 (1998); [5] H. Miyamoto et al., *LPSC18*, 1882 (2018)