Recognising Planetary Rocks and Minerals by Combining a Custom Mineralogical Database with Deep Learning based Multispectral Unmixing

The ESA-PANGAEA Mineralogical Toolkit is a set of data analytics tools aiming to enhance the recognition of planetary minerals. It includes a custom structured database called the PANGAEA Mineralogical Database (MinDB), which contains information on all known minerals found on the Moon, Mars and other planetary bodies [1]. This database then serves as the basis for a set of spectral classification methods using machine learning designed to perform in-situ spectroscopic identification of minerals [2]. Developed and tested together in the context of ESA's astronaut field science training using analogue environments, PANGAEA, the mineral library and recognition software are conceived as a real-time decision support tools for future planetary surface exploration missions.

The Mineralogical Toolkit is composed of:

- PANGAEA Mineralogical Database
- Machine Learning (ML) software for recognition of minerals from multispectral data

I. Drozdovskiy[1], F. Sauro[2], S.J. Payler[1,3], S. Hill[4], P. Jahoda[4], K. Jaruskova[4], F. Venegas[4], A. Angellotti[4], M. Franke[4], P. Lennert[4], G. Ligeza[4], P. Vodnik[4], L. Turchi[1], L. Bessone[1]

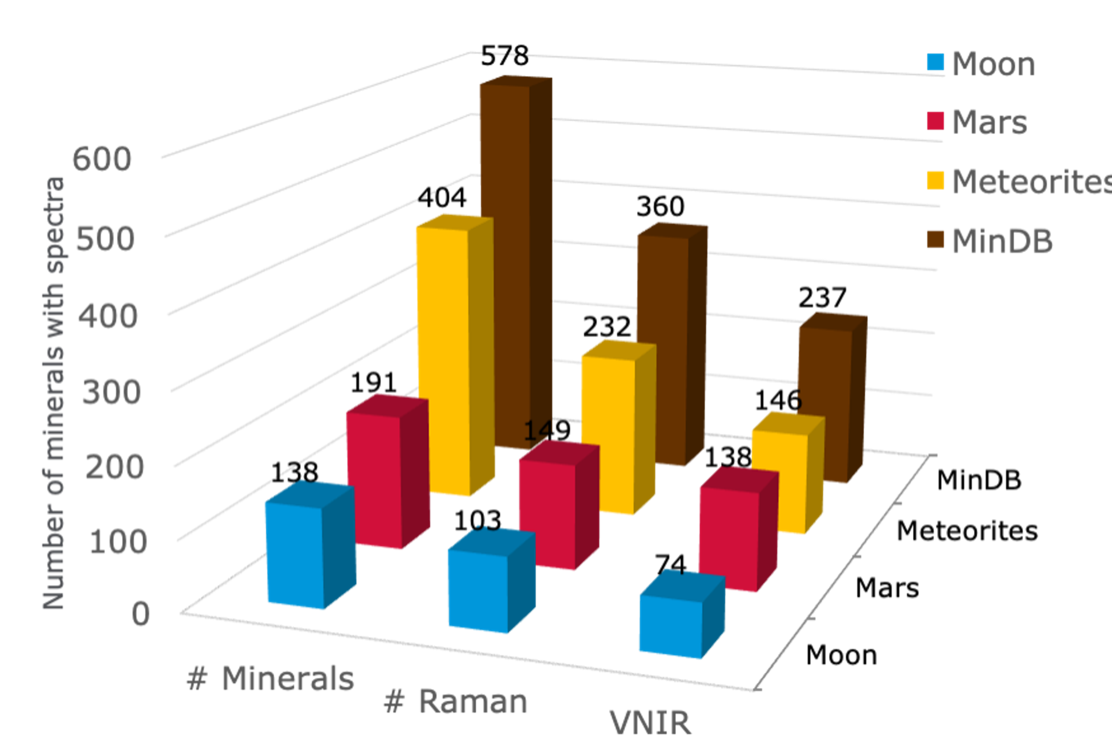
[1]European Astronaut Centre (EAC) - European Space Agency, Cologne, Germany; [2]Geological and Environmental Sciences, Italian Institute of Speleology - Bologna University, [3]Agenzia Spaziale Italiana, Rome, Italy, [4]ESA-EAC, CAVES & PANGAEA intern

PANGAEA Mineralogical Database:

- Catalogue of petrographic information
- Analytical library

The Catalogue consists of petrographic information on all currently known minerals identified on Moon, Mars, and found in meteorites. It provides essential analytical "*in-field*" information for rapid identification and understanding of significance during geological exploration. Each mineral entry includes: IMA recognized name, chemical formula, mineral group, surface abundance on planetary bodies, geological significance in context of planetary exploration, their spectral discoverability and features. The database was compiled through systematic literature research, followed by the careful cross-validation ("out-of-sample" testing) of all characteristic mineral information.

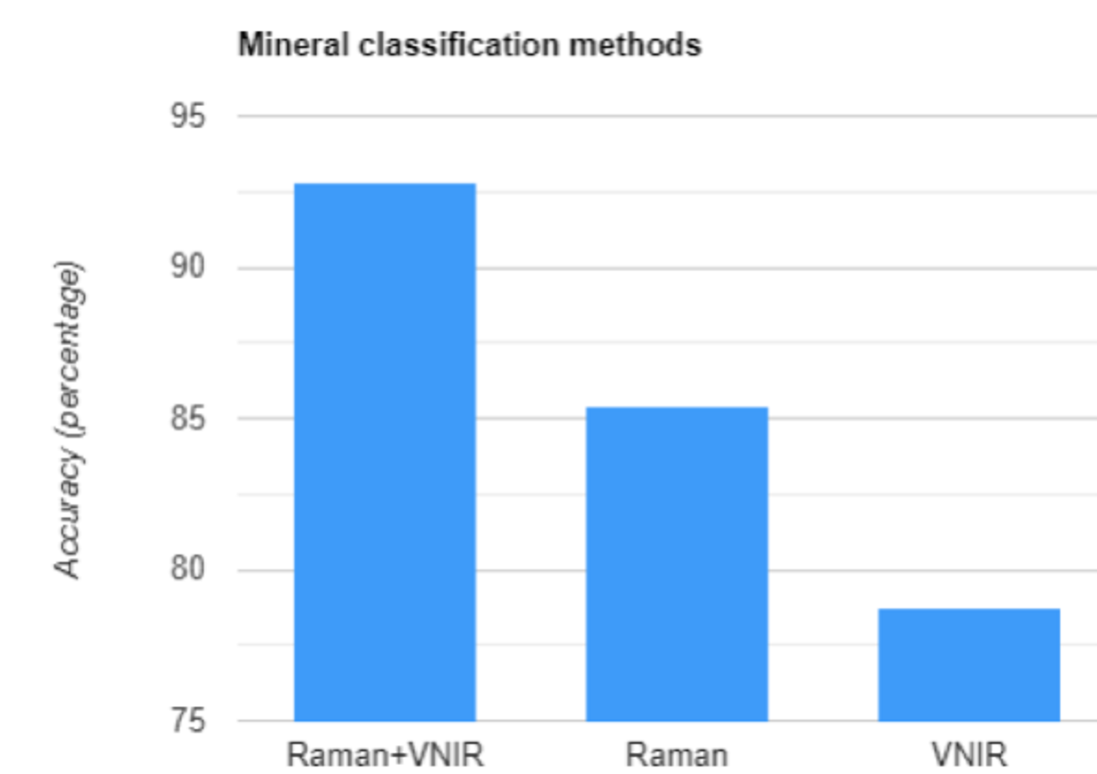
A customized library of analytical data from all known planetary terrestrial analogue minerals. This covers molecular spectroscopy --reflective Visual-to-Near- & Shortwave-Infrared (VNIR) and Raman– and atomic spectroscopy --Laser-Induced-Breakdown (LIBS), and X-Rays Fluorescence (XRF). The library consists of references spectra of planetary analogue minerals collected from available open access catalogues, such as RRUFF (Raman) and USGS, RELAB, ECOSTRESS, and our own collection of spectroscopic measurements of planetary analogue minerals taken by us and from different collections, and synthetic spectral libraries, such as LIBS NIST. The current census of the minerals with available molecular spectra is shown below:



Machine Learning (ML) software for recognition of minerals from multispectral data

To utilize the Mineralogical Database for identifying minerals in the field from the output of analytical tools, we also developed identification methods that combine types of material characteristics, mineral structure (obtained with VNIR and Raman spectra) and its chemical composition (from XRF and LIBS spectra). To achieve this, we evaluated various ML approaches used to identify mineral species from single analytical methods (Raman, VNIR or LIBS), and developed a flexible and modular algorithm that can classify minerals either from one or pair-combined spectroscopic methods.

Our cross-validation tests show that multi-method spectroscopy paired with ML paves the way towards rapid and accurate characterization of minerals (see Figure below). as well improving the quantification of mineral abundances in rocks and soils using ML-based spectral unmixing.



Toolkit for Planetary Surface Exploration:

Combined within the Electronic Fieldbook Tool Suite [3] and various spectral analytical tools, the instrument agnostic nature the Mineralogical Toolkit will enable fast and reliable in-situ recognition of rocks and minerals, thus becoming a crucial decision support tool for future human and robotic planetary surface exploration missions.

References: [1] Drozdovskiy, I. et al. 2020, Data in Brief, 31, 105985. [2] Jahoda, P. et al. 2020, The Analyst, 146(1), pp.184-195. [3] Turchi L. et al. Planetary Space Science, 197, p.105164.