EXTENDED-MIRAS: THE INSTRUMENTAL APPROACH FOR THE SEARCH OF TRACES OF EXTINCT AND EXTANT LIFE ON MARS, INSTRUMENT SETUP

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Abstract

Whether there was or is life on Mars is a question of high interest to man. When looking for evidence of present or ancient life on Mars it might be not sufficient to disclose the chemical composition of the surface or subsurface material. Further information concerning for example the morphology of the sample under investigation or the spatial distribution of the observed chemicals or minerals is of similar relevance. So we need a reliable, automated, robust and miniaturized apparatus capable of resolving all the above mentioned problems in one effort. ***EXTENDED-MIRAS*** is an instrumental approach combining optical microscopy and micro-Raman spectroscopy with additional elementary characterization methods such as LIPS/LIBS (laser induced plasma spectrometry / laser induced breakdown spectrometry) or LMS (laser mass spectrometry).

Introduction

The envisaged future planetary missions require space-born instruments, which are highly miniaturized with respect to volume and mass and which require as less power as possible. Space-born Raman spectrometers fulfilling these characteristics have been studied in the past years in the United States for future Mars missions [1, 3, 6-8], but also in Germany a DLR funded breadboard study has been successfully performed under the leadership of the University of Würzburg and Jena in cooperation with industry (Kayser-Threde GmbH) [2, 4]. The opto-mechanical combination of a Raman spectrometer with a microscope provides two main advantages, first, the illumination optics can be used for both tasks thus minimizing mass and volume and secondly it ensures the spatial correlation between Raman and microscopy.

EXTENDED – MIRAS: Goals

The *EXTENDED-MIRAS* Raman-Microscope combination is the basic system for the proposed planetary research activities. The respective instrument set-up is shown in Figure 1.

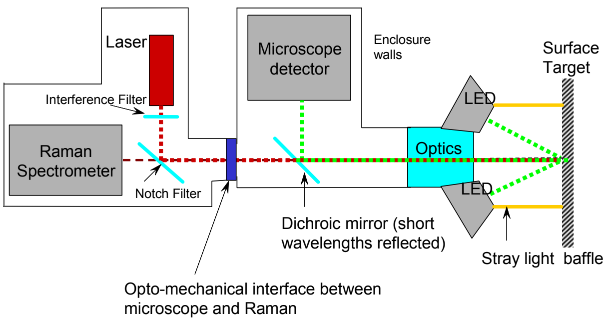

Figure 1. Basic Raman Microscope instrument configuration.

The goal of *EXTENDED-MIRAS* is to provide optical, morphological, as well as spatially resolved chemical, biochemical and mineralogical information of the Martian surface and subsurface material.
The Raman part of the *EXTENDED-MIRAS* instrument is a suitable analytical tool for the characterization and quantification of biological residuals, organic and inorganic molecules as well as for the determination of the associated minerals.
The **Raman microscope** part will address the following issues:

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1. Chemical analysis via determination of the mineral composition.
2. Analysis of organic molecules in the soil.
3. Identification of the principal mineral phases
4. Classification of rocks (igneous, sedimentary, and metamorphic) and definition of Martian petrogenetic processes.
5. Oxidation state of elements of Martian soil, on rock surfaces and inside rocks.
6. Content of volatiles (H_2O, SO_3, CO_2, NO_2) in minerals and glasses.
7. Determination of selected minor and trace-element contents (e.g. rare-earth elements).
8. Measurement of physical properties (e.g. size distribution).
9. Determination of reaction kinetics, i.e. oxidation processes on newly exposed surfaces, and determination of the reaction products.
10. Morphology of organic inclusions (fossils) and minerals on a µm scale.
11. Water and ice on Mars; identification of secondary minerals, clays, state of carbonaceous matter, hydrated crystals.

The **optical microscope** part (Fig. 2) can be used to perform 4 tasks as part of a scientific payload for Martian surface investigations. Firstly, the instrument can be used to study the physical and structural properties of a surface and hence make a geophysical analysis and contribute to the overall geological and mineralogical interpretation of the landing site. Secondly, a microscope can contribute to studies of the atmosphere of Mars. Specifically, dust particles are continuously precipitating out of the dusty atmosphere and hence a microscope can be used to constrain the sizes and shapes of particles for input into atmospheric scattering and radiative transfer models of the Martian atmosphere. Thirdly, the instrument can be used to study the morphology of a potentially biological sample and hence identify structures which are characteristic of past or present biological activity.

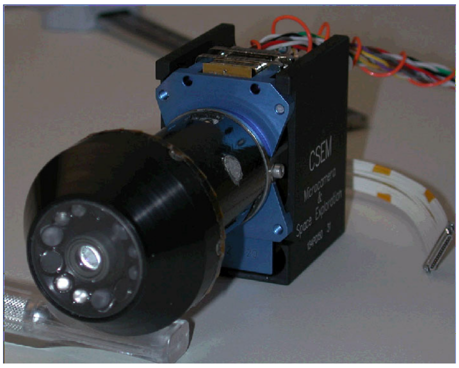

Figure 2. The microscope for Beagle 2 showing the LEDs surrounding the front lens of the optical head. Thedetector and associated read-out electronics is at the rear.

Finally, the instrument can be used to characterize and/or select a sample before it is passed to another analytical instrument. It is used therefore to assist the chemical and mineralogical analysis.
The first 3 objectives have been discussed in detail by Thomas et al. [5]. Because Raman spectroscopy is a point measurement (the laser beam width being a few microns), inhomogeneities might seriously affect the interpretation of the experimental results. A microscope can easily distinguish the inhomogeneity of the samples at resolutions close to the beam width of the Raman laser and can therefore support the interpretation of the received spectra by placing the investigated position in a wider context.

EXTENDED-MIRAS: Instrument Setup

The basic instrument set-up is shown in Figure 1.
In the recently investigated MIRAS breadboard set-up [2] a diode laser in a Litrow configuration operating at 785nm has been used. The laser output power is about 80mW at 785nm. The available laser power influences the achievable SNR and the required measurement time. According to our actual experience a further reduction of the laser output power seams feasible. For EXTENDED-MIRAS the baseline is to use a laser wavelength of 680 nm. A proposal to perform a trade-off study to establish whether a wavelength of 395 nm can be used is considered. This has the advantage that the Raman scattering efficiency will be much larger. However fluorescence effects have to be taken into account.
For the optical part of the instrument, the use of a single objective lens for the Raman spectrometer and the Microscope ensures that the position of the laser spot on the sample is known. This allows one to place the Raman spectrum into context with the visible image. An illumination spot size on the sample surface of a few µm is achievable with a high quality compound lens. This size is comparable to the resolution of the microscope. The basic design for the focusing lens will be taken from the beagle 2 microscope concept with some modification to adapt the lens to the specific needs of the microscope detector subunit as well as the Raman spectrometer. It should be noted that an alternative approach is possible, making use of fiber-optic cables to connect the Raman spectrometer and the laser to the microscope body. This has the advantage of separating the lightweight instrument head (which has to be translated for focus and scanning purposes) from the heavier instrument parts
For the spectrometer and detection part a Hadamard transform spectral sensor with double-array-architecture which uses a switched entrance slit matrix to increase the spectral resolution on one side as well as transmission on the other side is considered. The achievable spectrometer performance is based on the results from a MIRAS development study

(DLR:50OW0103). An alternative approach using an acousto optical tunable filter (AOTF) as the wavelength selecting and deflecting element has been tested also in the MIRAS breadboard study (ref DLR study 50OW0103) [2].
In order to retrieve spectra from various sample points of interest or even to scan a larger part of a rock or a regolith grain, a scanning device is incorporated into the overall design. This scanning mechanism can be achieved either by moving the entire sensor head or by moving the Raman excitation laser beam over the optics of the microscope.
The concept for the microscope is a development of the device provided for the Beagle 2 mission. This instrument [5] weighs around 160 g, is 11.5 x 6 x 6 cm 3 in volume, has a working distance of 12 mm, and a spatial image scale of 4 micron/px (resolution about 6 microns). The device carries an illumination system. The wavelengths used may be optimised for improved scientific return. The basic design of the microscope optics is a modified Cook triplet with a sapphire protective window and a UV filter (used for a fluorescence experiment).
For positioning the measurement head relative to the sample the simplest approach is to move the entire Raman/microscope combination to produce a good focus. However, the size of the instrument may make this difficult. In this case, the use of fibre-optic cables or motion of the microscope optics alone needs to be considered.
EXTENDED-MIRAS can be complemented with other elementary characterization methods such as LIPS/LIBS (laser induced plasma spectrometry / laser induced breakdown spectrometry) or LMS (laser mass spectrometry) depending on the scientific gain and technical feasibility.
EXTENDED-MIRAS follows a modular concept. Therefore the accommodation is very flexible. The temperature and electrical sensitive parts such as laser and spectrometer for Raman could be installed on the main facility (rover or main platform) whereas the sensor head with the optical microscope can be accommodated elsewhere via fibre optics (e.g. on a robotic arm).

Measuring Scenario

A measuring cycle will start by generating the depth profile for the whole microscope field of view. Images taken at different focus positions of the microscope will be combined in order to get the real morphology of the investigated surface.
An autonomous selection of points of interests for Raman measurements (by morphology and color; algorithms) will follow. This step can also be controlled by a human operator if the datalink budget is large enough. After the points of interest are chosen the device switches to the Raman pre-scanning mode which involves a sequence of Raman measurements of selected points of interest. For each measurement an automatic Raman data analysis procedure (quality check, background fitting, peak position & line width analysis for distinct wavelength ranges, identification of chemical and mineralogical composition according to a Raman database) will be performed. Based on the result of this analysis, further Raman point measurement or scans are performed. A few measurement scenarios are described in the following:
If an unknown mineral compound is found then an enlarged area scan around this point of interest is started.
If a mineral, chemical or biochemical compound of interest is found an enlarged area scan around this point of interest will be started;
If the Raman data are of no use then a new microscope image will be acquired at a different position and the cycle will be repeated.

The instrument will provide coordinates for the selected points of interest for further LIBS/LMS measurements
The microscope and focusing system requires a significant amount of onboard processing memory and power. For building the depth profile at least 60 images are required to scan through the focus for a rough (typically +-3 mm) surface. This implies that sufficient RAM needs to be made available to allow calculation of the focus for each position in the field and dynamic storage of the final 2-D focused frame plus the depth map for all 3 colours. The estimated memory requirement for this step is at least 16 MByte (preferably 32 MB) of volatile RAM. This is likely to be a system driver.
The system will also need to provide sufficient computing power to perform the computation of the correctly focussed image and the depth map and also the control of the microscope stepper motor position. Compression of the data (e.g. via wavelet transform compression) to optimize the data return (compression factors of 6-8 are possibly with limited loss in fidelity) is also to be considered as a processing load. An average data volume of 5.5 MByte per day is available for the microscope/Raman system. A 3-colour uncompressed image in the microscope requires around 3 to 6 MByte (depending upon the number of digitization levels for each pixel). Hence, data compression of a factor of 6 should get the total data volume for selected sites down into an acceptable range.

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