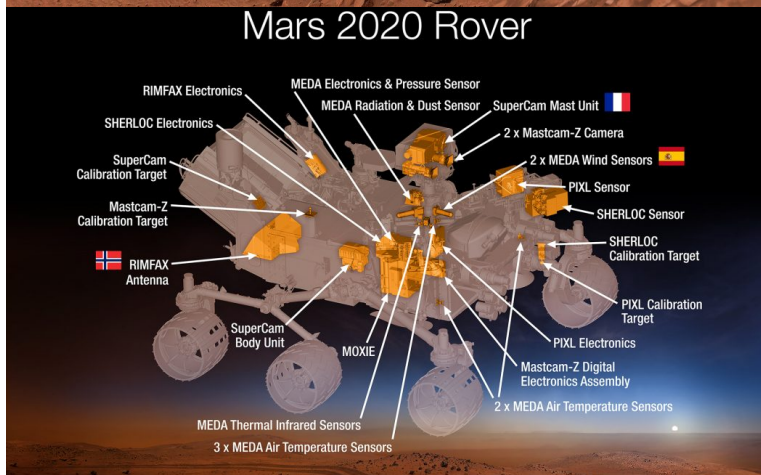
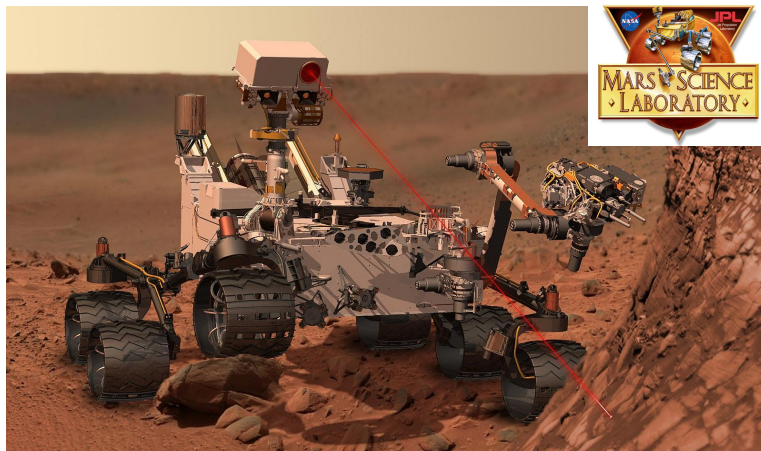




# Science enabled by LIBS exploration of planetary surfaces





<http://www.issibern.ch/teams/caliboflibs/>

## Cross-calibration of Laser-Induced Breakdown Spectroscopy (LIBS) instruments for planetary exploration

ISSI Team led by Jeremie Lasue (FR) & Roger Wiens (USA)

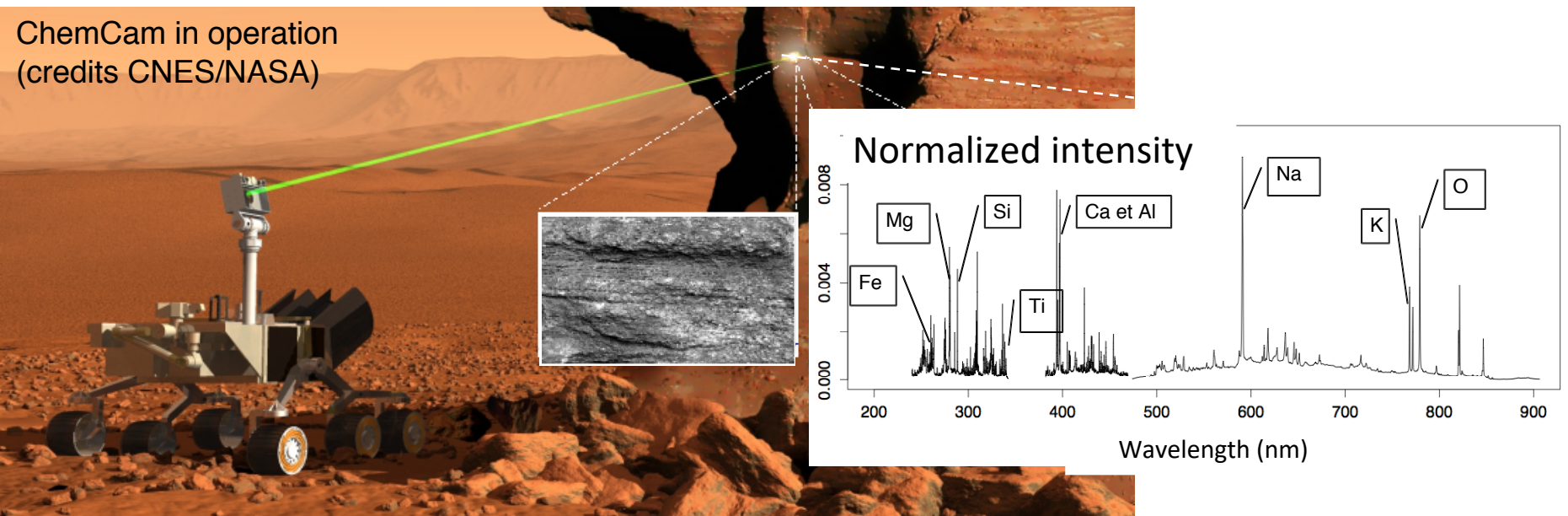


**Jérémie Lasue** (1), Roger C. Wiens (2), Sam M. Clegg (2), Agnès Cousin (1), Shingo Kameda (3), Javier Laserna (4), Zongcheng Ling (5), Sylvestre Maurice (1), Nouredine Melikechi (6), Xin Ren (7), Susanne Schröder (8), Pablo Sobron (9), Xiong Wan (10), Changqing Liu (5), Hongpeng Wang (10)

(1) IRAP-OMP, CNRS-UPS, Toulouse, France ([jlusue@irap.omp.eu](mailto:jlusue@irap.omp.eu)), (2) LANL, NM, USA, (3) Rikkyo University, Japan, (4) Laser Laboratory, Universidad de Malaga, Spain, (5) Institute of Space Sciences, Shandong University, Weihai, China, (6) University of Massachusetts Lowell, MA, USA, (7) National Astronomical Observatories, Chinese Academy of Sciences, China, (8) DLR, Berlin, Germany, (9) SETI Institute, NASA Astrobiology Institute, USA, (10) Shanghai Institute of Technical Physics, Chinese Academy of Sciences, China,



- 1) **No sample preparation**
- 2) Fast analysis (**5-20 min**; rep. rate **1-3 Hz**)
- 3) Measurements at a **distance possible** (up to  $\sim 10\text{m}$ )
- 4) Fine scale analysis ( $\sim 0.5\text{ mm}$ ); smaller if in-situ
- 5) Ablate the surface dust
- 6) Assess composition variation at different depths to  $\sim 1\text{ mm}$
- 7) Sensitive to many chemical elements, notably all **major and the light elements** (H, Li, Be, B, C, N, O, etc.)





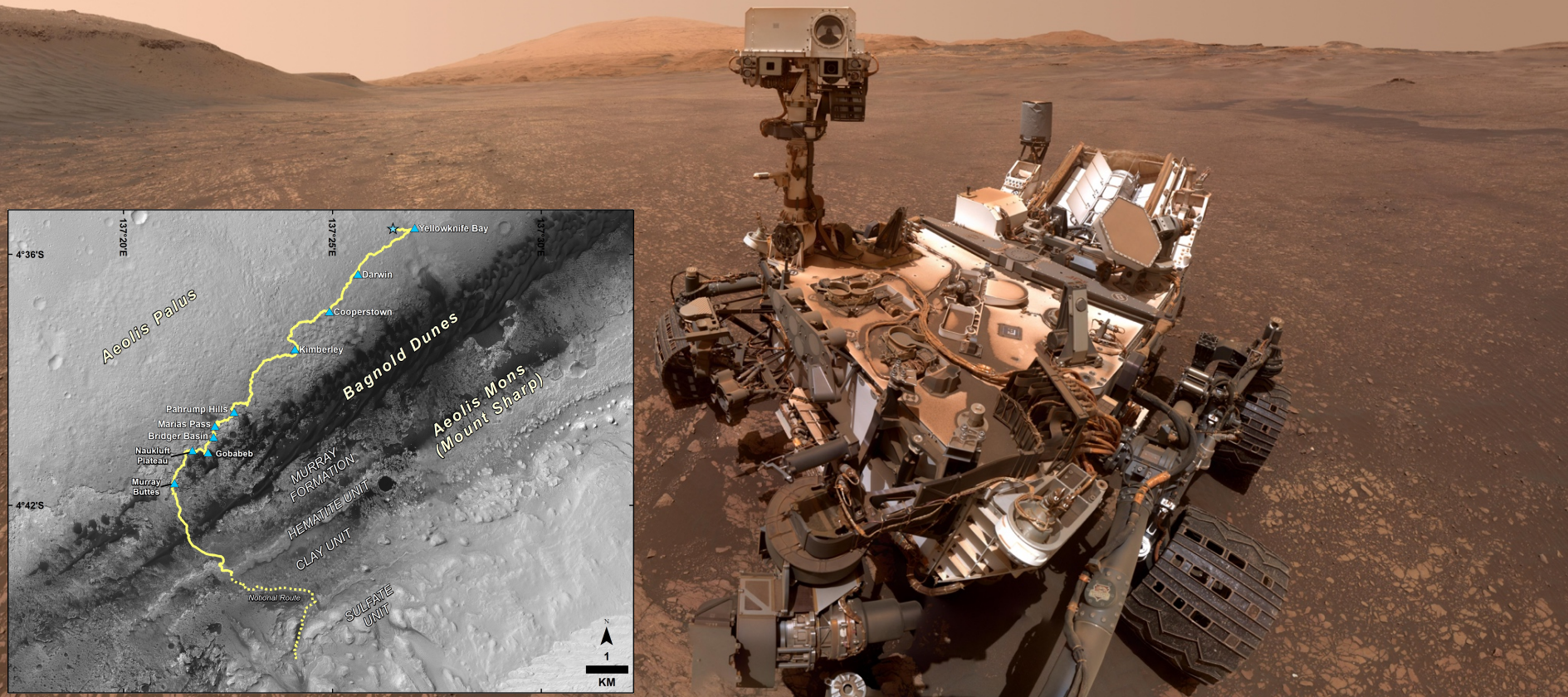


ChemCam on-board MSL has been exploring Gale Crater for the past 7 years, over a 21 km distance (MSL session on Monday).

MSL at the Kilmarie and Aberlady drill site (credit NASA)

Reviews: Wiens et al. Elements 2015; Maurice et al. JAAS 2016

LPSC workshop: [https://pds-geosciences.wustl.edu/workshops/ChemCam\\_Workshop\\_Mar15.htm](https://pds-geosciences.wustl.edu/workshops/ChemCam_Workshop_Mar15.htm)







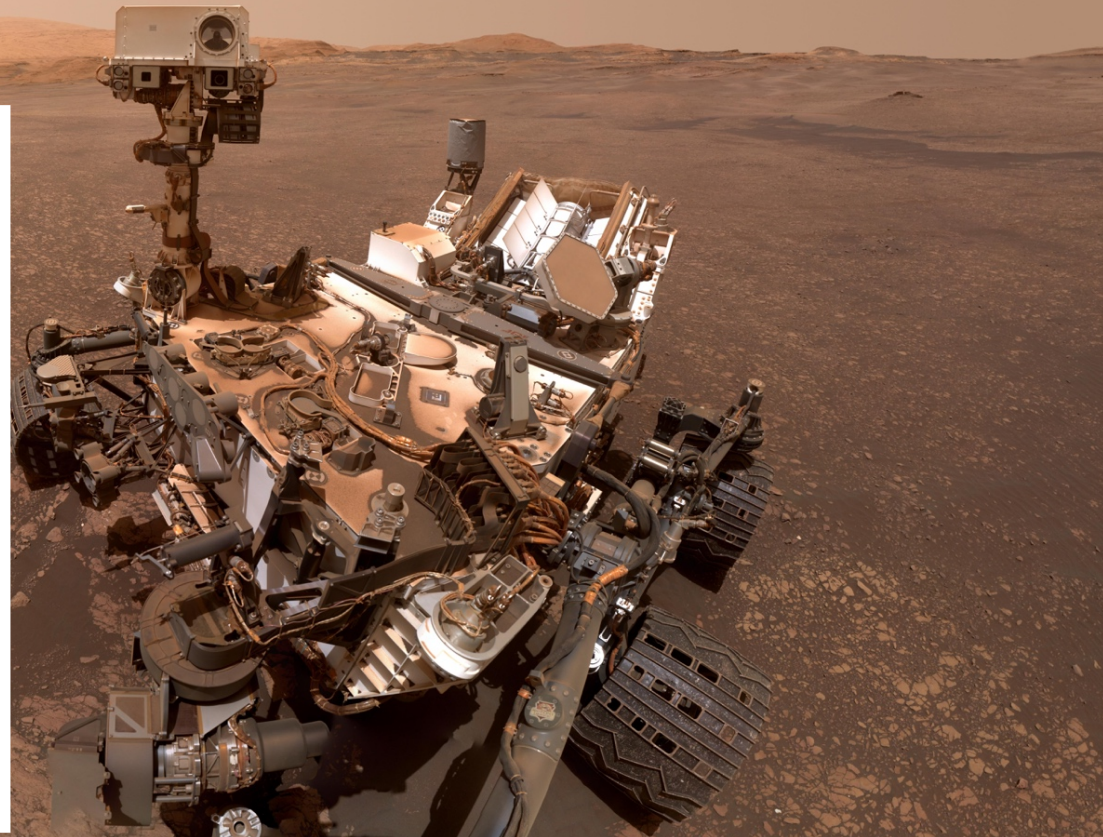
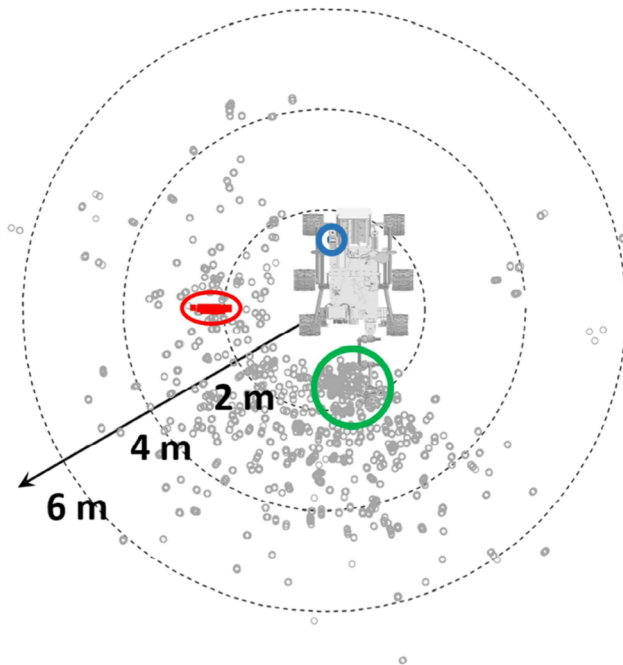
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Distribution of targets around the rover



# The ChemCam experience

LIBS use on Mars

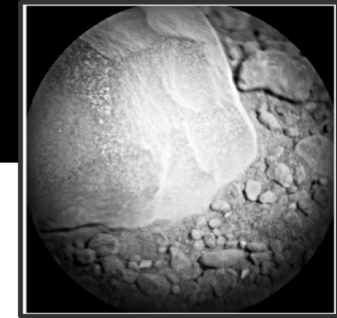
Quantification of the major elements constituting a target (O, Na, Mg, Al, Si, K, Ca, Ti, and Fe);

detection of non-metallic elements especially volatile ones (H, C, O, P, S, Cl);



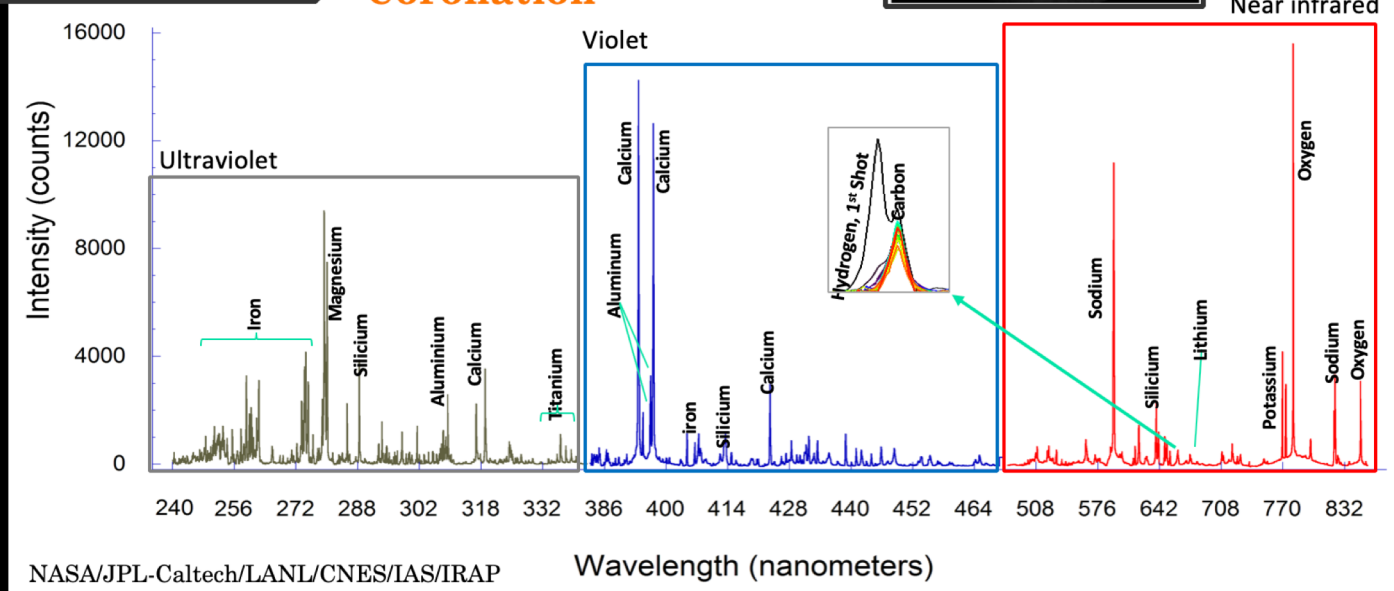
## Sol 13 : ChemCam first shot

RMI: Resolution of 105  $\mu\text{m}$  at 1.2 m



### Coronation

Visible  
Near infrared

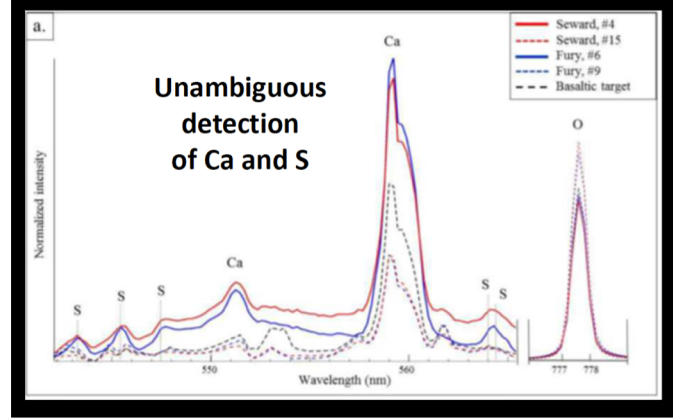
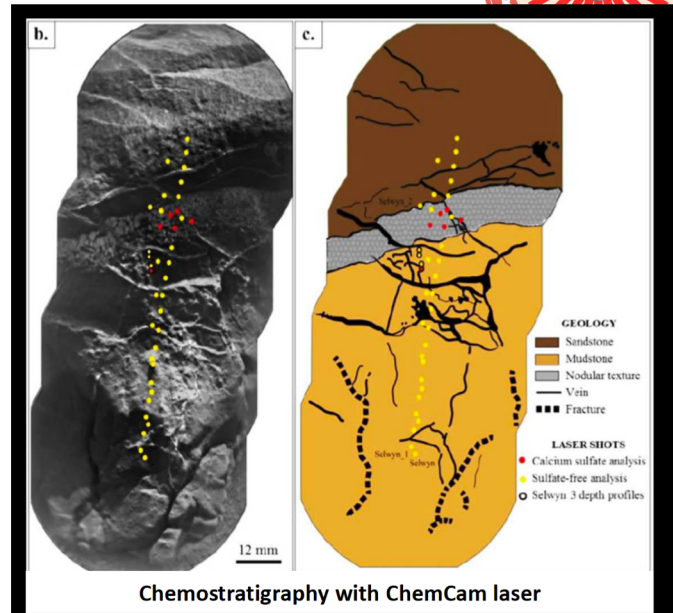
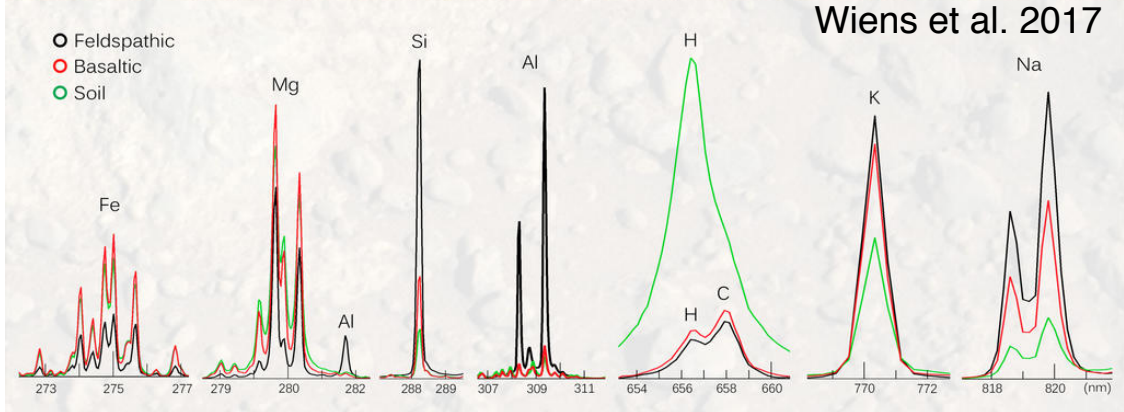






# The ChemCam experience

## ChemCam fine scale analysis of composition variation of Gale crater rocks

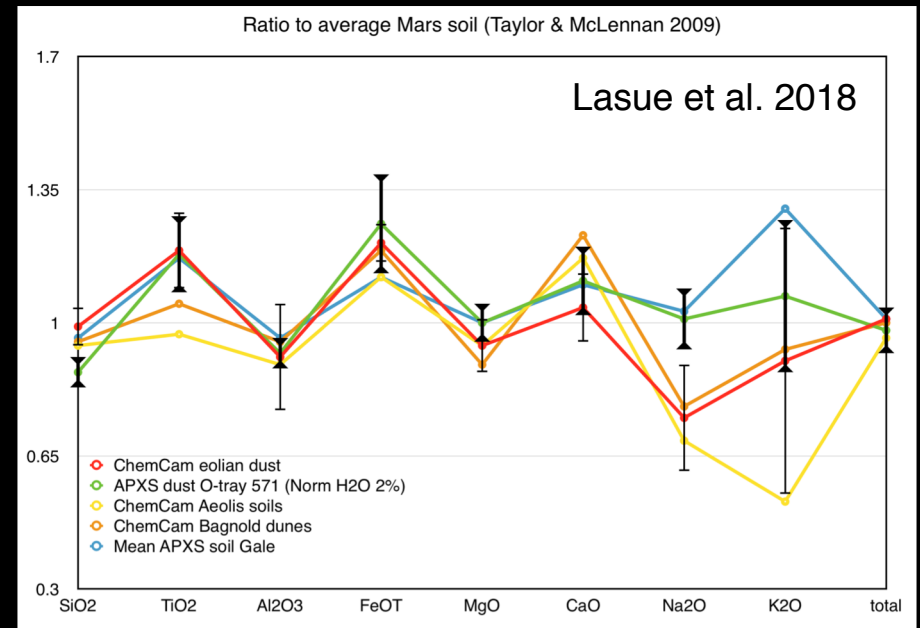
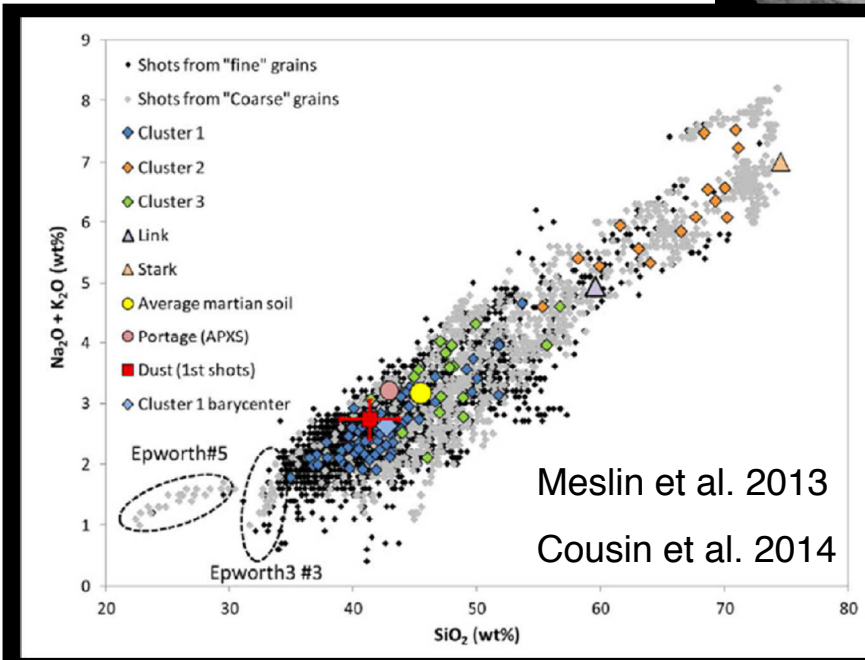
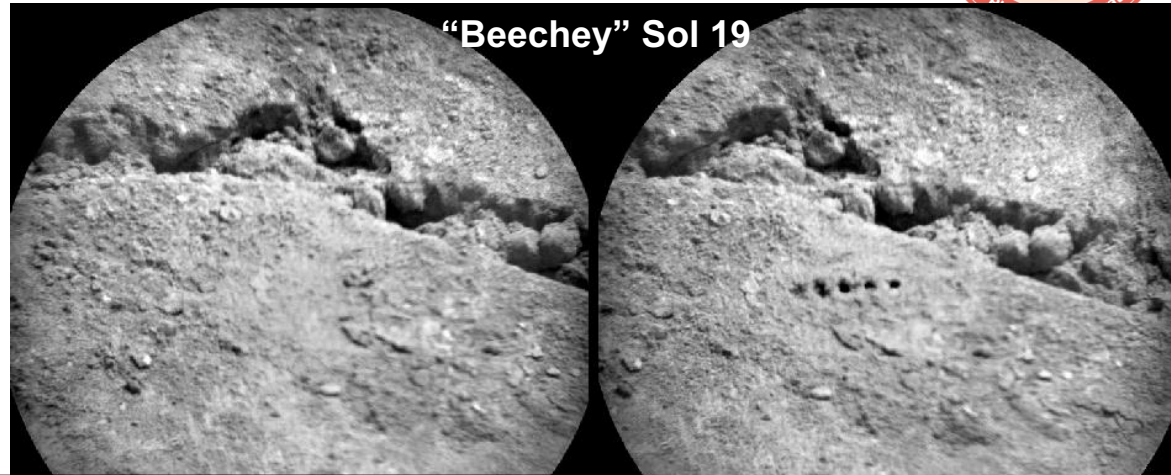


Nachon et al. 2016



ChemCam analyses the composition of the different fractions of soils and dust.

- Hydrated fraction of eolian dust
- Local alkali enrichment in soils

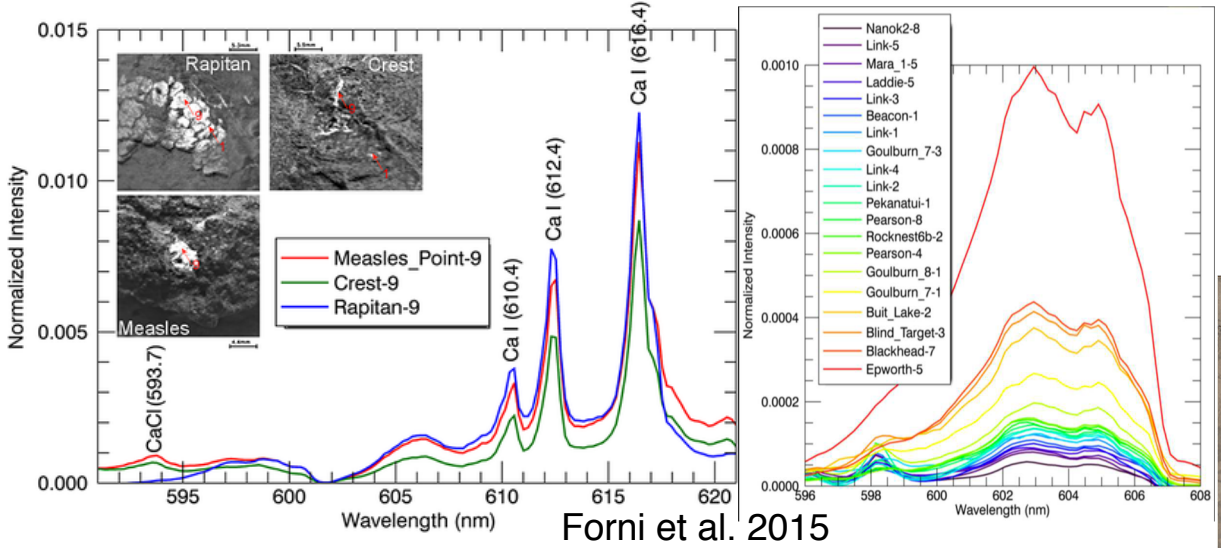




# The ChemCam experience

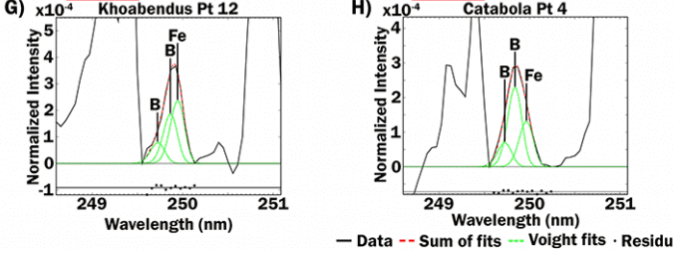
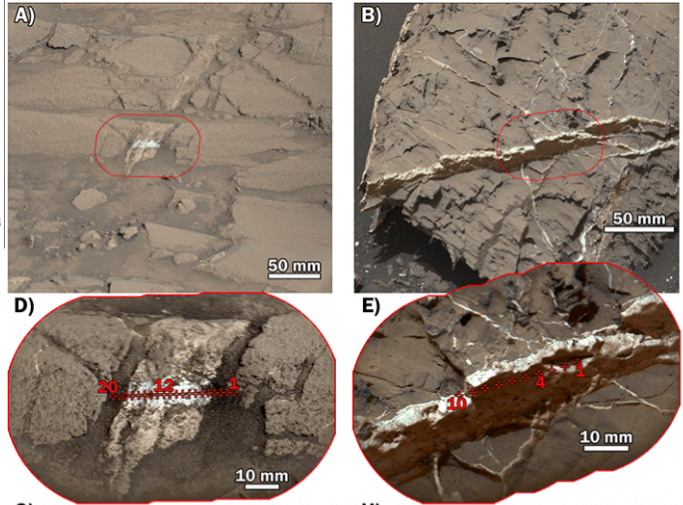
First analyses of F, B, Li, Rb, Sr, and Ba on Mars  
 Detection of Mn, Cu and Zn enriched minerals

(Lanza et al. 2014;  
 Lasue et al. 2016;  
 Payré et al. 2019).

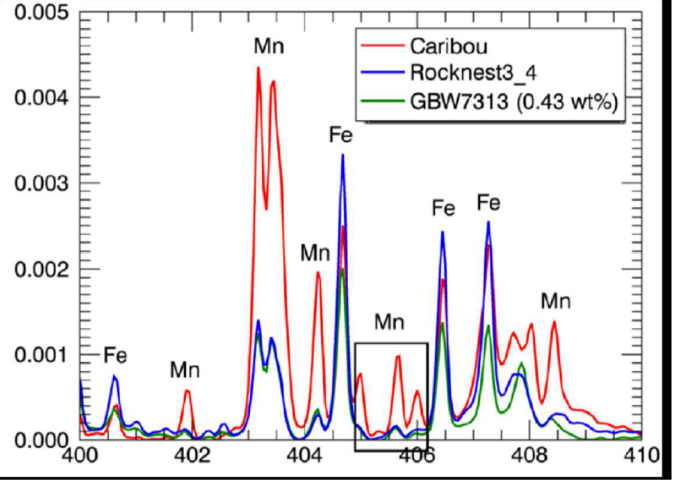


Forni et al. 2015

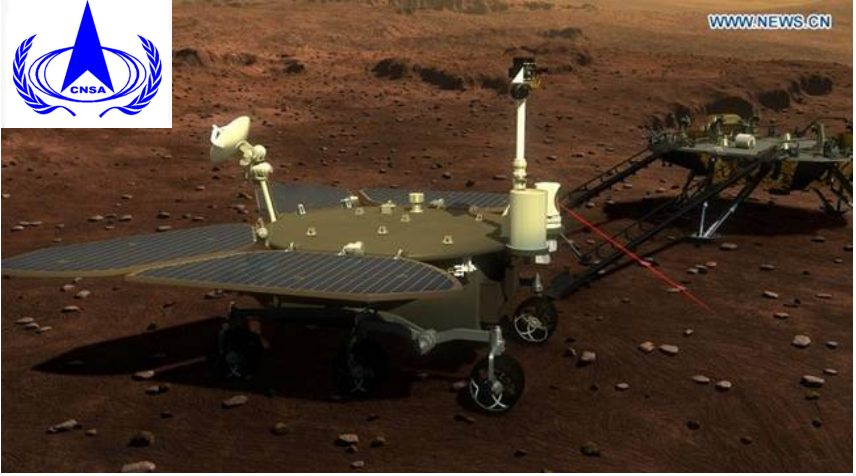
Gasda et al. 2017



Caribou Sandstone with High-Mn Mineral



# The next space missions



MarsCoDE on HX-1 1064nm, 21mJ, 4.5ns, 2-5m distance with adjustable mirror.

SuperCam combines 4 measurement types with LIBS.

Wiens et al. 2017

**SAMPLING MARS**  
In 2020, NASA plans to send a rover to Mars to collect and store tubes of rock and dirt. The plutonium-powered vehicle will have seven instruments and may also carry a helicopter.

- RIMFAX**: A ground-penetrating radar to explore beneath the surface.
- SUPERCAM**: A laser blaster that can investigate chemical compositions of Martian rocks and dirt from a distance.
- HELIICOPTER**: The rover may carry a helicopter that would fly through the thin atmosphere and scout out the path ahead.
- MASTCAM-Z**: A zoomable panoramic camera.
- SHERLOC**: An ultraviolet spectrometer to study mineralogy and chemistry. (Its camera is named WATSON.)
- MEDA**: The rover's weather station, to measure temperature, wind speed and other meteorological factors.
- PIXL**: An X-ray spectrometer for probing the chemical composition of rocks and dirt close up.
- ROBOTIC ARM**: The rover arm can extend outwards to make scientific measurements and gather samples. Its instruments can study, in detail, an area about the size of a postage stamp.
- MOXIE**: An instrument to produce oxygen from carbon dioxide in the Martian atmosphere, as a test for creating resources for future astronauts.

**Analytical techniques**

**Laser-Induced Breakdown Spectroscopy**

**Raman / Fluorescence Spectroscopy**

**Visible - Infrared Spectroscopy**

**Color Remote Micro-Imaging**

LIBS: 2 m Arm workzone  
Raman: 7 m  
VISIR: 12 m  
Imaging: 10 km ∞





## Venera 13 and 14 experience:

- carried x-ray fluorescence experiments, both successful.
- Sources =  $^{238}\text{Pu}$  (50 mCi),  $^{55}\text{Fe}$  (250 mCi)
- Detector energy range = 1.1-8 keV
- MCA = 256 channels
- Mg to Fe detected

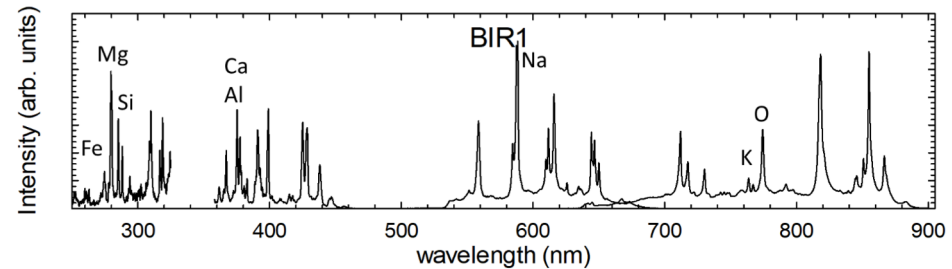
Surkov et al. 1983, 1984



## Advantages of LIBS + Raman

- No need to be in contact with surface.
- Can identify relevant minerals (olivine etc.)
- Most major and some minor elements detected in a 240nm - 900nm range.

Clegg et al. 2014; Clegg et al. EPSC 2019

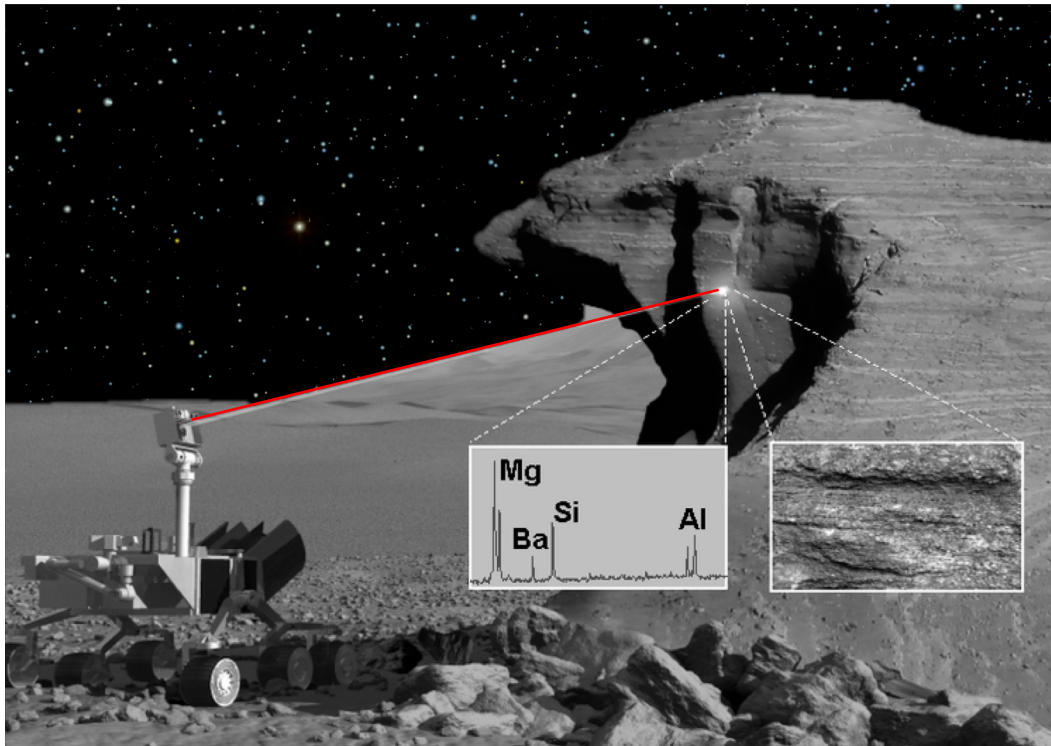




## Validation of a proto-ChemCam instrument for use on airless bodies (Moon, asteroids, comets):

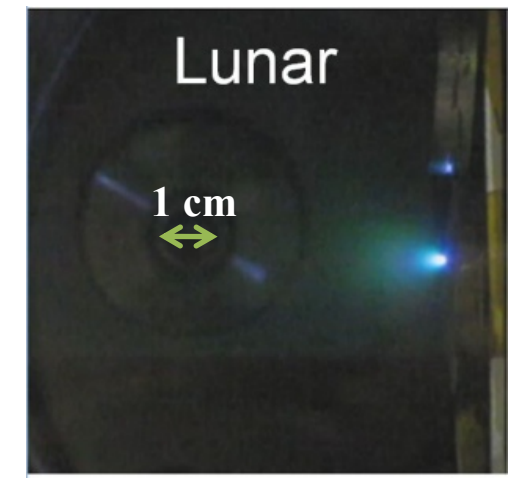
- Nd:Yag laser (17 mJ @ 1064 nm, 10 ns)
- 3 spectrometers [220-835] nm

### LIBS on the Moon



Lasue et al. JGR 2012

~5 Torr



~4e-4 Torr



# LIBS applications for the Moon

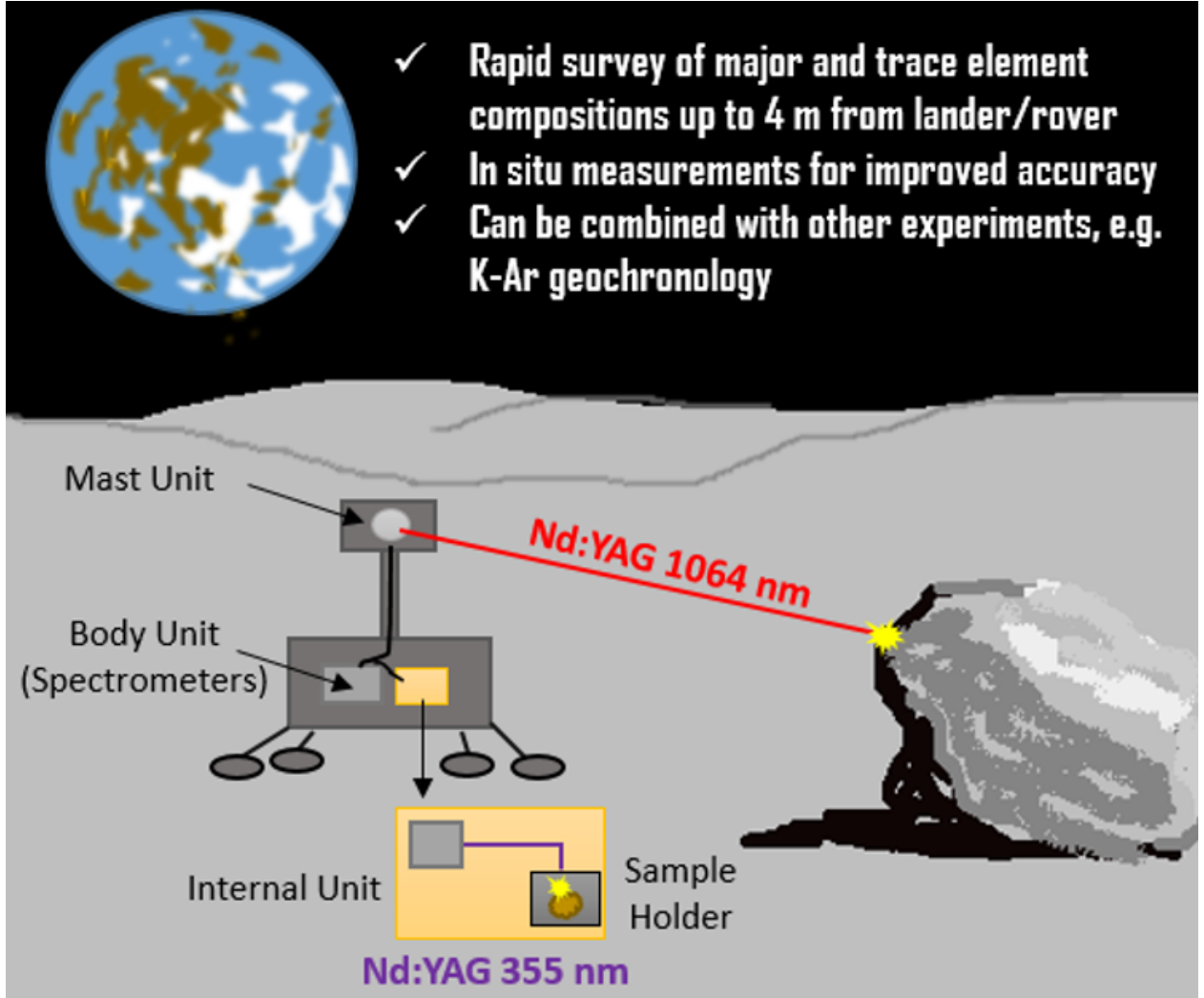
LIBS use on airless bodies

Can separate basalts from feldspatic rocks of lunar highlands (Al, Fe, Ti, Mg).  
 Sensitive to volatile elements

K sensitivity sufficient to detect KREEP. Can be combined with isotopic measurements for age dating.

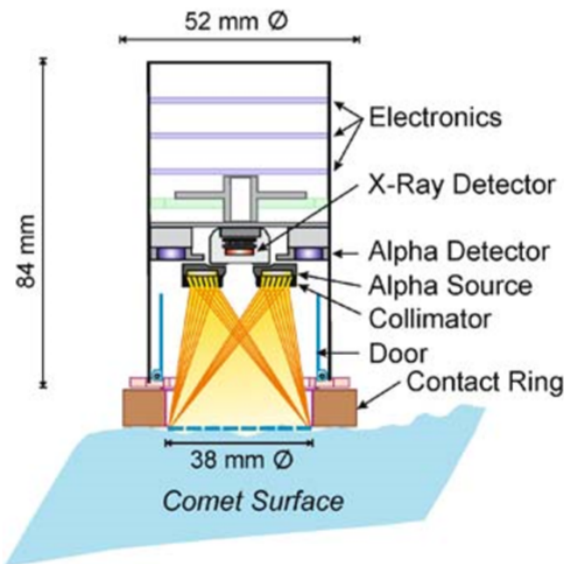
## LunaLIBS

Laser-Induced Breakdown Spectroscopy for Rapid Remote and In-Situ Geochemical and Geochronological Analysis of Lunar Materials

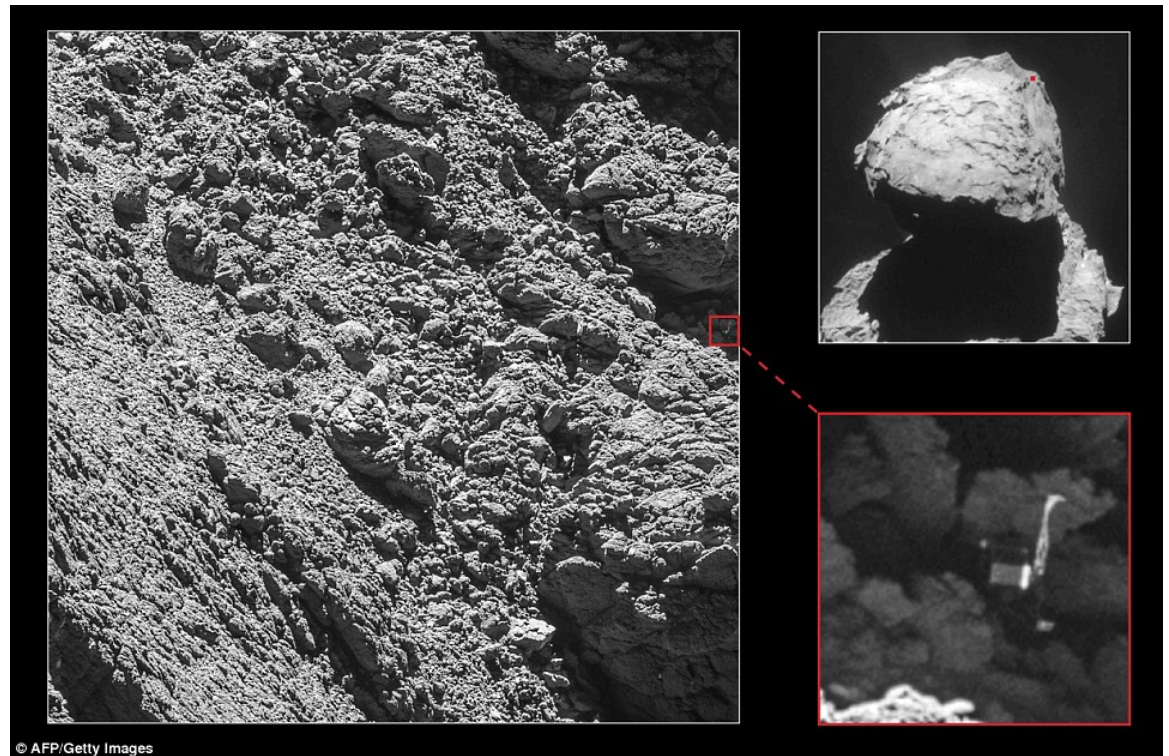


Ollila et al. LPSC 2019

- Avoid the need to be in contact with the surface (unlike Philae's APXS).
- Sensitive to the major elements (O, Na, Mg, Al, Si, K, Ca, Ti, and Fe)
- detection of non-metallic elements especially volatile ones (H, C, O, P, S, Cl)
- Interest in comparison with meteorites collections on Earth (constrain origins).
- Rapid survey of potential sample return areas.



Klingelhöfer et al. 2007



© AFP/Getty Images

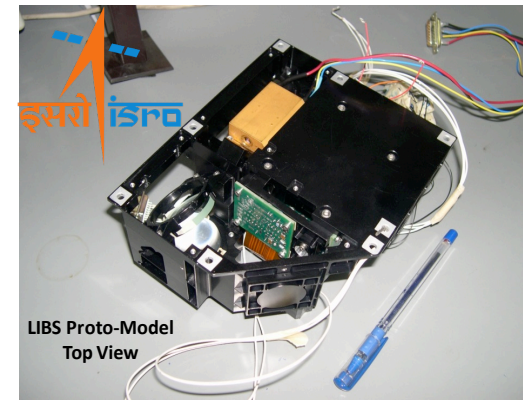




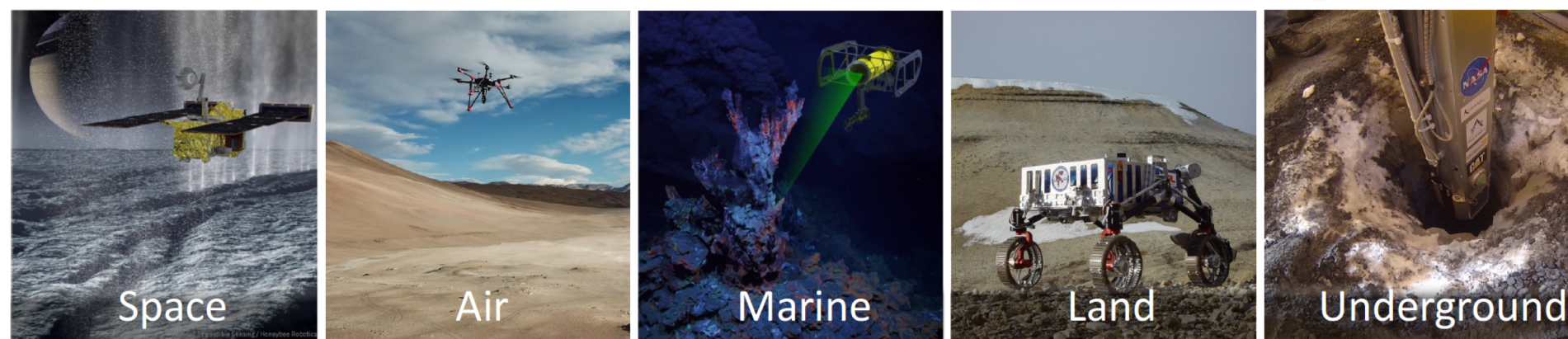
# Chandrayaan 2 rover LIBS

Specification	Value
Volume	180 × 150 × 80 mm
Power	<5 W
Mass	< 1.2 kg

Laxmiprasad et al. 2011; 2013



# Impossible Sensing



e.g. Sobron et al. 2012; 2018



- **Tactical and versatile instrument with many different designs (low to high mass).**
- **Detects most major and volatile chemical elements at distance and with a sub-mm scale**
- **Interesting science for any planetary surface.**

